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S. Schneiderbauer · G. Zeug
(Eds.)

Remote Sensing from Space

Supporting International Peace and Security

Springer

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Remote Sensing from Space

Supporting International Peace and Security

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Preface

David Stevens

Space-based information, which includes earth observation data, is increasingly becoming an integral part of our lives. We have been relying for decades on data obtained from meteorological satellites for updates on the weather and to monitor weather-related natural disasters such as hurricanes. We now count on our personal satellite-based navigation systems to guide us to the nearest Starbucks Coffee and use web-based applications such as Google Earth and Microsoft Virtual Earth to study the area of places we will or would like to visit.

At the same time, satellite-based technologies have experienced impressive growth in recent years with an increase in the number of available sensors, an increase in spatial, temporal and spectral resolutions, an increase in the availability of radar satellites such as Terrasar-X and ALOS, and the launching of specific constellations such as the Disaster Monitoring Constellation (DMC), COSMO-SkyMed (COnstellation of small Satellites for the Mediterranean basin Observation) and RapidEye. Even more recent are the initiatives being set-up to ensure that space-based information is being accessed and used by decision makers, such as Sentinel Asia for the Asia and Pacific region and SERVIR for the Latin America and Caribbean region.

There has been an increase in the access and use of space-based information to support response activities for natural and technological disasters but the same cannot be said on the use of earth observation data within the security arena. Many of the initiatives that could facilitate access to space-based information to help humanitarian teams have strict guidelines with regard to making the imagery available to support complex emergencies, such as the civil conflict in Darfur.

The September 11 attacks stunned the world and brought forward the new security challenges we are all facing regardless of where we live and what we do. We are now all potential observers and targets. With the increase in space-based information and solutions one must ask how could space-based technologies effectively contribute to security issues, such as terrorism as well as regional conflicts, complex emergencies and organised crime (including the piracy activity off the coast of Somalia).

The Global Monitoring for Stability and Security (GMOSS) Project set out to understand exactly this. And this landmark book brings together the results of this project. For the first time a group of scientists and practitioners worked together to understand how earth observation could provide support to several security-related activities such as treaty monitoring, early warning, population data, border monitoring and natural and man-made disasters. The GMOSS Network of Excellence brought together the leading European institutions that carry out civil security research that include the use of space-based earth observation. Together they identified key research areas that are central to security applications, such as, feature recognition techniques, change detection, data integration, advanced data visualisation, rapid mapping and damage assessment and GRID computing.

The GMOSS Project also pointed to areas where further research was still needed and also identified key additional areas where earth observation could play a major role. Importantly though was the conclusion put forward by the editors of the book that in order “to realise fully the utility of earth observation within the security area, there is still a need to bridge the communication gap between scientists and policy makers.” For sure this book is a first step towards bridging this gap.

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About the Editors

Bhupendra Jasani

Bhupendra Jasani is a Visiting Professor in the Department of War Studies, King's College London, where he heads a programme on military uses of outer space and arms control verification from space. He joined the Department in 1990. Between 1958 and 1972, he worked for the British Medical Research Council at the University College Hospital Medical School, London and acquired a Ph.D. in nuclear physics and nuclear medicine. He joined the Stockholm International Peace Research Institute (SIPRI) in Sweden in 1972 before joining the Royal United Services Institute for Defence Studies, London, in 1987 as a Rockwell International Fellow. He has completed a project as part of the support programmes of the British, German, the Canadian and the US Governments for the International Atomic Energy Agency (IAEA) on the use of commercial satellite imagery as part of the IAEA's safeguards procedures. This resulted in the IAEA and the United Nations Monitoring, Verification and Inspection Commission (UNMOVIC) using satellite data for their tasks. He has written a preliminary report demonstrating the usefulness of commercial remote sensing satellite data the verification of the Chemical Weapons Convention under a grant from the UK Foreign and Common Office. Under the European Union's Framework 6 programme, it was proposed to organise a Network of Excellence within Europe. This programme, called the Global Monitoring for Security and Stability (GMOSS), was established in early 2004. Bhupendra Jasani is coordinating two projects, treaty monitoring and early warning using commercial remote sensing satellites. For the past few years he has been giving lectures each year at the International Space University, Strasbourg, France on various space issues. Recently he has been appointed to chair the Technical Commission VIII, Working Group VIII.5 Policies, Treaties and Data Access. Apart from a number of scientific publications, he has published some 157 papers on nuclear and space arms control issues. His books include Outer Space – Battlefield of the Future? (Taylor & Francis for SIPRI 1978), Satellites for Arms Control and Crisis Monitoring (ed. with T Sakata) (Oxford University Press for SIPRI 1987); Space Weapons and International Security (ed.) (Oxford University Press for SIPRI 1987); Outer Space: A Source of Conflict or Co-operation? (ed.) (Tokyo: The United Nations University Press and in co-operation with SIPRI 1991); Peaceful and Non-Peaceful Uses of Space (ed.) (London: Taylor and Francis for UNIDIR-United Nations Institute for Disarmament Research 1991); and Commercial Satellite Imagery – A tactic in nuclear weapon deterrence (ed. with Gotthard Stein) (Springer/Praxis 2002).

Martino Pesaresi
Graduate in Town and Regional Planning (IUA Venice 1991–1992) with an overall first class mark of 110/110. In 1993 he followed a specialization course on Digital Photogrammetry at the CISM (International Centre for Mechanical Sciences) in Udine (Italy). Since 1998 visiting professor of Spatial Statistics at the University of Venice (IUAV CdSIT, Corso di Laurea in Sistemi Informativi Territoriali). Mr. Pesaresi pursued research activities involving the use of remotely sensed data in urban analysis with the CAMS (Centre d'Analyse et de Mathématique Sociales) of the EHESS (École des Hautes Etudes en Sciences Sociales) in 1991–1992 and with the LIA (Laboratoire d'Informatique Appliquée) of the ORSTOM (France) in 1992–1993. He has worked as a research assistant with the DAEST (Dipartimento di Analisi Economica e Sociale) and the DU (Dipartimento di Urbanistica) of the University of Venice (IUAV) during 1992–1995 and with the DAU (Dipartimento di Architettura e Urbanistica) of the University of Pescara in 1996–1997. In 1992–1997 he has also been working as consultant expert on remote sensing and GIS data analysis for many public and private companies as well for professionals involved in town and regional planning activities. From 1997 to the end of 2000 he has been working with a research contract at the EC JRC Space Applications Institute/EGEO, Advanced Methods Sector. From February of 2001 to December 2004 he is working at the INFORM srl, Padova, Italy, leading the group of Geographical Information System and Remote Sensing applications. Since January 2004 he is working at the European Commission, Joint Research Centre, Institute for the Protection and Security of the Citizen (IPSC) in the Global Security and Crisis Management Unit, contributing to the Global Monitoring for Environment and Security program with various activities, and specifically he is the scientific coordinator of the Global Monitoring for Security and Stability (GMOSS) Network of Excellence in the aeronautics and space priority of the 6th FP. Since September 2007, he is the chief of the Geo-Spatial Information Analysis for Global Security and Stability (ISFEREA) team of the same JRC Institute, focused on application of remote sensing data analysis for human security (more info available at the http://isferea.jrc.ec.europa.eu). The main scientific publications of M. Pesaresi are related to automatic satellite image understanding, multi-scale image decomposition by derivative of the morphological profile, automatic recognition and analysis of human settlements, and applications to automatic damage and reconstruction assessment using very-high-resolution satellite data.

Stefan Schneiderbauer
After having obtained a M.Sc. in Geography from the University of Cologne in 1993 Stefan Schneiderbauer joined the University for Applied Sciences in Berlin as an expert for remote sensing image analysis and GIS applications (1994–1995). In the scope of this position he carried out several expeditions to the Darfur Region/Rep of Sudan for mapping and ground truth work for the German Research Foundation.

Following he worked from 1996–2001 as international consultant focusing on the application of Earth Observation and GIS technology for natural resource management in particular in Africa and Europe. In this context he developed and implemented various training courses dealing with Environmental Monitoring and Environmental Management. During this period he also lectured at the University for Applied Sciences and the Humboldt University in Berlin. From 2001 on he worked at the Joint Research Centre (JRC) of the European Commission in Ispra/Italy. First as consultant within the Global Vegetation Monitoring Unit, following as scientific staff member of the Global Security and Crisis Management Unit of the Institute for the Protection and Security of the Citizen (IPSC). In this position he carried out research on population density estimations, people's vulnerabilities and indicators for risk determination. At the same time he supported the scientific management of GMOSS and was responsible for the project's work package 'Public Outreach'. In April 2007 he completed his doctoral thesis about populations' risk and vulnerability to natural disasters at the Free University in Berlin/Germany. Currently Stefan Schneiderbauer holds a position as researcher at the European Academy in Bolzano/South Tyrol within the institute for Applied Remote Sensing.

Gunter Zeug
After studies in geography, geology, remote sensing and prehistory in Regensburg and Munich, Gunter Zeug graduated as geographer from Ludwig-Maximilians University Munich in 2000. In 2001 he joined GAF AG, an internationally renowned consulting company for remote sensing and geoinformation, as technical expert. There he was mainly involved in the design and implementation of agricultural GIS tools (IACS) and Land Parcel Identification Systems (LPIS) within several German Ministries of Agriculture. In September 2006 Gunter joined the IPSC-GLOBESEC Unit of the Joint Research Centre (JRC) of the European Commission in Ispra/Italy as geomatics and remote sensing specialist. His main focus is on urban hazard risk assessment and more general challenges of urbanization in the developing world including population growth, environmental impact and hazard risk. In GMOSS he supported the scientific management of the network and took over responsibility of the work package 'Public Outreach' in 2006.

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List of Acronyms

ALICE	Absolutely Local Index of Change of Environment
AVHRR	Advanced Very High Resolution Radiometer
BCP	Border Crossing Point
BNSC	British National Space Centre
BWR	Boiling Water Reactor
CARABAS	Coherent All Radio Band Sensing
CBW	Convention on the Prohibition of the Development, Production, Stockpiling of Bacteriological and Toxin Weapons and on their Destruction
CCD	Coherent Change Detection
CEN	European Committee for Standardisation
CEOS	Committee on Earth Observation Satellites
CERN	European Organisation for Nuclear Research
CFAR	Constant False Alarm Rate
CFE	Treaty on Conventional Armed Forces in Europe
CFSP	Common Foreign and Security Policy
CNES	Centre Nationale d'Etudes Spatiales
CNSA	China National Space Administration
CONAE	Comision Nacional de Actividades Espaciales
COP	Common Operational Picture
CS/W	Catalogue Service for Web
CSA	Canadian Space Centre
CTBT	Comprehensive Nuclear Test Ban Treaty
CTBTO	Comprehensive Test Ban Treaty Organisation
CWC	Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on their Destruction
DEM	Digital Elevation Models
DGIWG	Defence Geographic Information Working Group
DLR	German Aerospace Centre

DMC	Disaster Monitoring Constellation
DMSP	Defence Meteorological Satellite Programme
DRK	German Red Cross
DSM	Digital Surface Models
EC	European Commission
ECHO	European Commission Humanitarian Office
ECR	European Crisis Response
ECVision	European Research Network on Cognitive Vision Systems
EEC	European Economic Community
EMS	European Macroseismic Scale
ENTC	Esfahan Nuclear Technology Centre
EO	Earth Observation
EPC	European Political Cooperation
ESA	European Space Agency
ESDP	European Security and Defence Policy
ESS	European Security Strategy
EU	European Union
EUMS	European Union Military Staff
EUSC	European Union Satellite Centre
FGDC	Federal Geographic Data Committee
FMT	Fourier-Mellin Transform
FOI	Swedish Defence Research Agency
GAERC	General Affairs and External Relations Council
GATT	General Agreement on Tariffs and Trade
GEO	Group on Earth Observation
GEOSS	Global Earth Observation Systems of Systems
GIS	Geographic Information System
GMES	Global Monitoring of Environment and Security
GMOSS	Global Monitoring for Security and Stability
GNEX	GMOSS Near real-time Exercise
GOES	Geostationary Operational Environmental Satellites
GPS	Global Positioning System
HAU	Human Activity Units
HRV	High Resolution Visible
IAEA	International Atomic Energy Agency
ICISS	International Commission on Intervention and State Sovereignty
IDP	Internally Displaced Person
IMS	International Monitoring System
INF	Intermediate-range Nuclear Forces Treaty
InSAR	SAR Interferometry

INSPIRE	Infrastructure for Spatial Information in Europe
ISO	International Organisation for Standardisation
ISRO	Indian Space Research Organisation
JAXA	Japanese Aerospace Exploration Agency
JRC	Joint Research Centre
JSC	Joint Situation Centre
LHC	Large Hadron Collider
LiDAR	Light Detection and Ranging
LIST	Landscape Interpretation Support Tool
MAD	Multivariate Alteration Detection
MGCP	Multinational Geospatial Coproduction Programme
MIC	Monitoring and Information Centre
MIR	Medium Infra-Red
MNF	Minimum Noise Fraction
MODIS	Moderate Resolution Imaging Spectroradiometer
MSG	Meteosat Second Generation
MTM	Multinational Technical Means
MTMF	Mixture Tune Matched Filtering
NATO	North Atlantic Treaty Organisation
NDVI	Normalised Difference Vegetation Index
NFRPC	Nuclear Fuel Research and Production Centre
NGI	National Geographic Institute of Belgium
NOAA	National Oceanic and Atmospheric Administration
NoE	Network of Excellence
NPT	Treaty on the Non-Proliferation of Nuclear Weapons
NRT	Near Real Time
NTM	National Technical Means
NTS	Nuclear Test Site
OECD	Organisation for Economic Cooperation and Development
OGC	Open Geospatial Consortium
OLS	Operational Linescan System
OSCE	Organisation for Security and Cooperation in Europe
PRESENSE	Pipeline Remote Sensing for Safety and the Environment
PSC	Political and Security Committee
PWR	Pressure Water Reactor
ROC	Receiver Operating Characteristics
RST	Robust Satellite Technique
SALT	Strategic Arms Limitation Talk
SAR	Synthetic Aperture Radar

SEaTH	Separability and Thresholds
SEVIRI	Spinning Enhanced Visible and InfraRed Imager
SIC	Signal and Image Centre
SPIDER	United Nations Platform for Space-Based Information for Disaster Management and Emergency Response
START	Strategic Arms Reduction Treaty
SVM	Support Vector Machine
THW	German Federal Agency for Technical Relief
TIR	Thermal Infra-Red
UGS	Unattended Ground Sensor
UML	Unified Modelling Language
UN	United Nations
UNDP	United Nations Development Programme
UNGA	United Nations General Assembly
UNHCR	UN High Commissioner for Refugees
UNITAR	United Nations Institute for Training and Research
UN-OCHA	United Nations Office for the Coordination of Humanitarian Affairs
UNODC	United Nations Office on Drugs and Crime
UNOOSA	United Nations Office for Outer Space Affairs
UNOSAT	United Nations Operational Satellite Applications Programme
UNSC	United Nations Security Council
USGS	United States Geological Survey
VHSR	Very High Spatial Resolution
WFP	World Food Programme
WMD	Weapons of Mass Destruction
WTO	World Trade Organisation
XML	Extensible Mark-up Language
ZKI	Center for Satellite Based Crisis Information

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Alexander Almer studied Geodetic Engineering – emphasis on Photogrammetry and Remote Sensing – at the Technical University of Graz. He is senior scientist and project manager at the Institute of Digital Image Processing at JOANNEUM RESEARCH and he has contributed (and managed some) to several national, ESA and EU research projects and is also involved in some of the EU-Projects. He has more than 30 publications in the field of Remote Sensing and Data Visualisation. At present Alexander Almer is head of the group "Multimedia and Visualisation" and his research interests concentrate on the field of geometric treatment of remote sensing data and the field of data visualisation, mobile solutions, CD-Rom and internet development.

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Delilah Al Khudhairy, born in 1962, and graduated with a first class honours B.Sc. (Eng.) and Ph.D. degrees in Materials Science Engineering from London University. She was employed at British Gas before joining the Joint Research Centre in 1990. Her research areas have covered X-ray and electron scattering (scanning and transmission) experimental techniques, X-ray diffraction analysis, numerical modelling, and remote sensing.

In 2004, she was appointed as the head of the Support to External Security unit in the JRC's Institute for the Protection and Security of the Citizen which today specialises in Web and information technologies, remote sensing and statistics. The unit, recently renamed into Global Security and Crisis Management Unit, provides scientific and technical support to European Commission Directorates General with responsibilities related to the implementation and monitoring of EU policies concerning External Assistance and Relations, combating terrorism and financial fraud, and crisis management. She has developed together with the former director of her institute, JM Cadiou and contributions from JRC colleagues, the JRC's strategy for Security during FP7.

Furthermore, Delilah Al Khudhairy established in early 2000 together with other JRC colleagues the JRC Women and Science network. She served as the chairperson of the Women Science Network of the Joint Research Centre and the secretary of the Scientific Committee in the Institute for the Security and Protection of the Citizen until her appointment as head of unit.

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He has joined UNOPS in October 2002, as UNOSAT Humanitarian Task Manager. Since 1999, he was Specialist in satellite image applications and geographic information management within the United Nations High Commissioner for Refugees (UNHCR) Geographic Information and Mapping Unit. He developed policies, guidelines and wrote articles on use of space-based tools such as satellite imagery, GPS and tele-communication devices for disaster and environmental management for a range of users. He initiated, developed and managed projects related to space-based tools for disaster management and environmental assessments, including the ReliefSat project and the Environmental Monitoring of Refugee Camps Using High Resolution Satellite Images (ENVIREF) project, that the first to assess how very high resolution satellites can be used to support UN refugee operations. Terra Orbit Ltd Manager, from 1998 to 1999, in charge of applied environmental information management using satellite imagery for national and international customer, he has assisted with input to tele-education for distance learning of space-sciences and developed and managed a fax-on-demand service for satellite-derived ice condition maps for low-bandwidth connections to fishing vessels operating close to the ice edge in the Arctic. He also provided guidance to development of a tele-monitoring product called "SpaceTrack" for monitoring physical conditions (temperature, humidity, stability, etc.) of remote sites/objects and transmitting this information via satellite and the Internet to end-users. He has a Masters Degree (1995) and a Ph.D. (1999) in Geophysics and Applied Remote Sensing, from the University of Bergen, Norway

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Thomas is currently deputy director of Z_GIS and leader of the LARG research group. He holds an M.Sc. in Geography (Applied Geographic Information Systems Technology) of Salzburg University and a Ph.D. in Geography at Salzburg University. For his dissertation the author received two scientific awards. From 2001 to 2003 he was professor at the University of Tübingen, Germany. He acts as a research manager of at Z_GIS and contributes to or leads several research projects. He is author of 170+ publications and author or editor of eight books.

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Ph.D. Astrophysics, University of Amsterdam, 1990 on far-infrared observations of starburst galaxies. Since 1991 he is working as research scientist in the Radar Remote Sensing group at TNO-FEL, the Hague (Currently the Radar Concepts and Signal Processing group of the Observation Systems division). The activities concern microwave image interpretation of primarily land. Key words for his work are: land use classification, radar modelling, radar polarimetry, synergy of microwave/optical imaging, calibration of SAR images, military surveillance and target acquisition with SAR. For the WEU satellite centre near Torrejon (Madrid) he prepared and gave a course on the interpretation of SAR images and studied the combination of SPOT and ERS-1 imagery. Currently he is responsible for several projects comprising studies of the applicability of SAR imagery for military surveillance and target acquisition. Within this context he participates in the NATO

SET030/TG14 working group on ‘Advanced Millimetre Wave Techniques for Ground Target Acquisition’.

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Born 1962 in Kassel/Germany and diploma degree in political science. Post graduate studies and research in social/political science as well as European and international affairs from 1988–1991 at the Free University of Brussels (ULB) and for the European Foundation for the Improvement of Working and Living Conditions (Dublin). He joined the European Commission in 1991, from 1996–2004 at DG External Relations (Western Balkans, CFSP, Middle East, Asia, terrorism, WMD). From 11/2004 Dirk Buda was employed at the JRC/IPSC (unit support to external security), responsible for the issue areas conflict in third countries and migration. Currently he is working as Counsellor for Political and Economic Affairs with the Delegation of the European Commission to Afghanistan.

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After completing degrees in Media Studies/English at Strathclyde University and Computational Linguistics at University of Manchester Institute of Science and Technology (UMIST), Clementine Burnley worked at UMIST, first on an electronic dictionary project for OKI Corporation and then on developing a concept dictionary for Matsushita. Before coming to the Joint Research Centre she taught Digital Media development and Comparative Literature at Luton University. She is a consultant to the Bimbia-Bonadikombo Community Forest Project, a forest conservation and community welfare project in Cameroon. She is working on the “early warnings” work package in GMOSS, JRC’s “science and governance” and GMES activities.

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Morton John Canty (Ph.D. Nuclear Physics 1969, University of Manitoba, Canada) is a research scientist in the Department of Systems Analysis and Technology Evaluation at the Juelich Research Center in Germany. He has authored many papers and monographs on the subjects of low energy nuclear physics, nuclear safeguards, applied game theory and remote sensing. He has served on numerous advisory bodies to the German Federal Government and to the International Atomic Energy Agency.

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Adriana holds a Ph.D. in Geographic Information Science and Geodesy, University of Technology Vienna, and is the International Programme Coordinator for UNIGIS since 09/2005. She works in the area of spatial information theory, particularly hierarchical spatial reasoning. She is interested in hierarchy as method of efficient selection of spatial data, as well as formal descriptions of spatial inferences using hierarchies (e.g., the conceptual model of hierarchical way finding and its formal specification). Dr. Car published her research in journals, books and conference proceedings and participated in several workshops. In addition, she investigates application possibilities of the hierarchical spatial reasoning in other areas such as conceptual modelling and design of spatial databases. Presently Adrijana manages Erasmus–Mundus study programs and coordinates the CEEPUS exchange project "Applied Geoinformation" (CEE-GIS).

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Daniele was born in Pompei (NA) on January 1, 1977. He obtained a degree in Environmental Science at the University of Naples "Parthenope" on February 9, 2004. He worked on the development and refinement of a change detection technique, based on the use of satellite data, for oil spill detection and monitoring. At the present, as DIFA-Unibas Ph.D. student, he's continuing to work in this field, by using geo-stationary satellite observations.

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Simon focuses on image processing and feature extraction research, testing and developing processes and algorithms using IDL and image processing software (such as ERDAS Imagine and ENVI) with high resolution optical and SAR data. He is also a member of a team that provides an operational service for ship detection using SAR imagery, and he has contributed to ongoing research in vessel detection and classification from space. He has also worked on the design, data up-load and demonstration of a GIS using ESRI's ArcGIS, and provides GIS consultancy to other QinetiQ projects. Simon has an M.Sc. in Remote Sensing from University College London.

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Anthony Cragg was educated at Oxford University. He is an Associate Fellow of the Royal United Services Institution and a Senior Associate Research Fellow of King's College, London. He is also a graduate of the Royal College of Defence Studies. His career has been spent in the field of security policy in the UK Ministry of Defence and Foreign and Commonwealth Office and also as Assistant Secretary General for Defence Policy and Operations in the International Staff of NATO. He has extensive practical experience of top-level strategic analysis, the formulation of national and international defence programmes, resource management and the planning and conduct of major national and international negotiations up to the level of Summits of Heads of State and Government. He participated directly in the management of the crises in Bosnia, Kosovo, Afghanistan and Iraq. He has chaired or participated in a wide range of high-level national and international seminars on security policy and defence planning. He is the author of many articles and papers on these subjects and led the international team responsible for drafting NATO's Strategic Concept.

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Has a Ph.D. in Geology (Madrid University) and a Masters Gegree in Marin Geology and Geophysics (University of Cape town, South Africa). As Operations Manager at the EUSC since 1996 he has been involved in a wide range of operational tasks with the "State of the Art" imagery and collateral data, being of interest for the GMOSS Network, crisis management, peace keeping, arms control, marine surveillance, humanitarian and environmental assessment. He has been Evaluator for several EC Information Societies Technology projects (MINEO, RAPSODI), proposer and coordinator of the OILWATCH project, team leader of the Environmental Group in the TACIS programme, and lecturer of Global change at Saint Louis University (Madrid). He has long term practical experience in remote sensing applications for the exploration of oil-minerals in several countries of Africa and the Middle East.

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Ola Dahlman has been President of OD Science Applications SA, from 2000 to the present. Previously he was Deputy Director General at the Defense Research Institute (FOA), Sweden. From 1994–200 he was Director of the Laboratory for Weapon Systems and from 1987 to 1994 he was Director of Laboratory for Information Technology Between 1985 and 1987 he was head of multidisciplinary project on Anti-submarine warfare 85–87 and head of Verification division in 1980. He has been Chairman of Working Group on verification within the Preparatory Commission of the CTBT since 1996 and Chairman of the Group of Scientific Experts at the Conference on Disarmament 1982–1996.

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Rob received the B.Sc. degree in electrical engineering from the Hogeschool Rotterdam and the M.Sc. degree in geographical information systems from the Vrije Universiteit Amsterdam. Since 1991 he has been with the TNO Physics and Electronics Laboratory (now TNO Defence, Security and Safety) in The Hague where he has worked on Synthetic Aperture Radar (SAR) signal and image processing, polarimetry, calibration, a variety of remote sensing projects and automatic target detection and recognition. His current interests include remote sensing image analysis, urban monitoring and geographical information systems. He participates in the NATO SET 053 working group on ground target automatic recognition by SAR. He is a member of ASPRS (US), RSPSoc (UK) and GIN (the Netherlands).

Daniele Ehrlich ♂, Joint Research Centre (JRC),
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Daniele Ehrlich holds a BS in Forestry from University of Padua, Italy (1984) and a Master (1989) and PHD (1992) in Geography from University of California, at Santa Barbara, USA. He worked as a Post doc at the USGS Sioux Falls GRID and as remote sensing consultant in southern California. In 1994 he joined the Joint Research Centre (JRC) as a post doc with the Monitoring Tropical Vegetation Unit and was subsequently awarded a position as a Scientific Technical Officer with the Centre for Earth Observation at the JRC where in 1999 he started the activity on geo-spatial data in support of the humanitarian community. He is now permanent staff of the JRC with the Global Security and Crisis Management Unit where from 2002 to 2007 he co-led the Isferea team. In his scientific and professional career he has used optical Earth Observation data for crop area estimations, tropical deforestation assessments, land cover change mapping at continental scales, population estimations and more recently for disaster risk and human security applications.

Carolina Filizzola ♀, Instituto di metodologie per l'Analisis Ambientale (IMAA), I-85050 Tito Scalo (PZ), Italy
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She was born on July 4, 1974. She attained the degree in Geological Science at the University of Basilicata (Potenza, Italy) and after 3 years she took her Ph.D. degree in "Methods and technologies for environmental monitoring". Since 1999 her research activity has been focused on the development of advanced change-detection techniques in the field of natural hazards monitoring and mitigation by satellite remote sensing. She has been co-investigator in several national and international projects and since 2 years she is a researcher at the Institute of Methodologies for Environmental Analysis (IMAA) within the National Research Council (CNR).

Richard Göbel ♂, Hochschule Hof – University of Applied Sciences,
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Professor Dr. Richard Göbel holds a diploma in Computer Science (1982) and a doctoral degree (Dr. rer. nat.) in Computer Science/Artificial Intelligence (1988). His work experience includes employments at the University Kaiserslautern, a software house and the German Aerospace Research Center (DLR) as a scientist and project manager in the fields Software Engineering, Artificial Intelligence and Information Systems. Since 1997 Dr. Göbel is Professor at the University of Applied Sciences in Hof. Here he participated in different national and European projects in information systems and security. During his sabbatical semester 2001/2002 Dr. Göbel was working for the JRC Institute for the Protection and the Security of the Citizens. During this semester he contributed to the development of a system supporting the European Commission Humanitarian Aid Office ECHO. In his sabbatical semester in 2006 Dr. Göbel visited several times the European Union Satellite Centre. A major result of these visits was the definition of a spatial search engine for security applications and the implementation of a first prototype by different students during their thesis work.

Klaus Granica ♂, Joanneum Research (JR),
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Klaus Granica is senior scientist and project manager at Joanneum Research, Institute of Digital Image Processing and has 15 years of experience in remote sensing. He has a degree in geography and history from the Karl-Franzens University in Graz. He has got a Scholarship at the Technical University of Dresden (D) within the HCM-Project: Landslides and Mudflows, Development of Operational Remote Sensing Tools for Mapping, Monitoring, and Mitigation of Mass Movements. He is mainly working in the fields of environmental monitoring, disaster management and forest mapping, and has also experience in aerial photo interpretation. He managed several projects and was project manager for the JOANNEUM part in the DG XII SEMEFOR project.

Karlheinz Gutjahr ♂, Joanneum Research (JR),
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Karlheinz Gutjahr has a background in Geodetic Engineering, and received the diploma degree in 1997 and a Ph.D. on interferometric bundle block adjustment techniques in 2002, both at the University of Technology, Graz. He is senior scientist at the Institute of Digital Image Processing at JOANNEUM RESEARCH, where he is member of the working group on geometric processing of remote sensing data. His main working fields are related to geometric, geodetic and photogrammetric aspects of optical and SAR remote sensing data. These cover mathematical sensor modelling, geocoding, stereo mapping from space borne and airborne imagery (optical sensors and SAR), SAR interferometry, differential SAR interferometry and polarimetric SAR interferometry.

Andre Husson ♂, Centre National d'Etudes Spatiales (CNES),
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Andre was born in Valence, France, in 1948. He received a M.Sc. in physical geography in 1971 at Strasbourg University and a Ph.D. in applied remote sensing at Strasbourg University/CNES in 1974. For 3 years, he made research studies (forest fires detection with remote sensing) at 'Ecole Supérieure des Mines de Paris' in Sophia Antipolis. Thereafter, he worked as engineer with the remote sensing centre of Thomson/Sodeteg. From 1987 to 2004, he worked as consultant, project manager and head of Development Department at SCOT, a subsidiary of CNES. Since October 2004, he is with the Directorate for Strategy and Programmes of CNES, in charge of GMES, in connection with the European Commission.

Jordi Inglada ♂, Centre National d’Etudes Spatiales (CNES),
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Jordi Inglada was born in 1973. He received the Engineering diploma degree in Telecommunication.

Engineering from both the “Ecole Nationale Supérieure des Télécommunications de Bretagne”, France, and the “Escola Tècnica Superior d’Enginyeria de Telecomunicacions”, UPC, Barcelona, Spain, in 1997, and the Ph.D. degree on Signal Processing and Remote Sensing at Rennes 1 University, France in 2000. There since he has been working at CNES, at the “Image Products and Analysis” Office, in the field of information extraction from remote sensing images mainly on the following topics: multi-sensor image registration, change detection and object recognition. He has been involved in the International Charter “Space and major disasters” as a Project Manager for several activations.

Bhupendra Jasani ♂, King’s College London (KCL),
Department of War Studies, King’s College London, Strand,
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Professor Bhupendra Jasani is a Visiting Professor in the Department of War Studies, King’s College London, leading a programme on military uses of outer space and arms control verification from space. He has completed a project for the IAEA on behalf of the UK, German and the Canadian Governments on the use of commercial satellite imagery to monitor nuclear fuel cycle and recently wrote a preliminary report for the UK Foreign and Common Office on the verification of the CWC.

Erland R.A. Jungert ♂, Swedish Defence Research Agency (SDRA),
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Born in 1942, Dr. Jungert obtained a B.Sc. in electrical Engineering Göteborgs Lärarhögskola, Sweden, 1969 and a Ph.D. (Computer Science) University of Linköping, October 1980. Dr Jungert has been a Docent of Computer Science at the University of Linköping, Sweden since November 1988. Adjunct Professor, Department of computer and information science, Linköping University, from the fall 1998 and Director of Research (Computer Science) at the National Defence Research Inst. (FOI), Linköping, Sweden, from 1987. Research interest; Query Languages for Multimedia Search and Spatial/Temporal Query Processing for Information Fusion Applications. Data Fusion Concept for a Query Language for Multiple Data sources, Qualitative motion of point-like objects and Spatial Query Language for Multiple Data Sources in a Heterogeneous Information System Environment.

Thomas Kemper ♂, Joint Research Centre (JRC),
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Thomas Kemper, born in Wickede, Germany (1969), has a degree in physical geography (1997). In 2003 he received a Ph.D. from the University of Trier (Germany) for his work on quantification of heavy metals in soils using reflectance spectroscopy. From 1998 to 2004 he was working at the Institute for Environment and Sustainability of the Joint Research Centre in the context soil degradation and desertification. From 2004 to 2007 he was working for the German Aerospace Center (DLR), where he helped to develop the Center for satellite based crisis information (ZKI) providing rapid mapping information after natural disasters. Since 2007 he is permanent staff of the EC JRC IPSC, Support to External Security Unit being responsible the analysis of settlements, in particular informal settlements, and the production management.

Ralph Kiefl ♂, Deutsches Zentrum für Luft- und Raumfahrt (DLR),
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Ralph Kiefl, born in Mainz, Germany in 1973, studied Physical Geography, Geology and Botany at the Johannes Gutenberg University in Mainz and received his diploma in 2002. He is an expert in GIS and remote sensing. In the field of optical remote sensing his main focus is on classification of land cover and land use. He is also engaged in GIS development and analysis and in the integration of remote sensing data in GIS. During his freelance employment fort he Institute for Regional Planning ifp in 1999 he was involved in projects on land use and vegetation mapping MURBANDY Munich and the components BIOTOPE and WATER of Prosmart. Since 2002 he is employed as a scientific assistant at the German Remote Sensing Data Center DFD of DLR, working for the EC project CORINE Land Cover 2000.

Donna Kodz ♀, QinetiQ, Farnborough, Hampshire, GU14 0LX, UK, (QINETIQ)
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Over 10 years of directly relevant experience in the geospatial information field ranging from image processing and GIS through to database technologies. Knowledge of current and emerging standards from key standards bodies such as ISO TC211 and the Open Geospatial Consortium (OGC).

Considerable experience in the design, development and implementation of a wide range of GIS applications, based on Commercial-Of-The-Shelf (COTS) products. Extensive experience of open and proprietary geospatial data formats.

Claudia Künzer ♀, Deutsches Zentrum für Luft- und Raumfahrt (DLR),
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Claudia, born in Berlin/Germany (1975), studied physical geography, remote sensing and soil science at the University of Trier, specializing in remote sensing change detection of land surfaces and GIS. Within her master thesis she analysed time series of Landsat-5 TM and Landsat-7 ETM+ data as well as water quality data to investigate land cover changes within the watershed of Luxemburg's most important drinking water reservoir. From 1997 to 1998 she received a scholarship to study Environmental Science with a strong focus on Remote Sensing and GIS at ‘Huxley College of Environmental Science’ of Western Washington University, USA. At the University of Trier she also tutored basic GIS and remote sensing classes for the Remote Sensing department until receiving her diploma in 2001. Since July 2001 she has been working at the German Remote Sensing Data Center (DFD) of DLR within a project on remote sensing analysis of coal seam fires in China.

Teodosio Lacava ♂, Instituto di metodologie per l’Analisis Ambientale (IMAA),
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He was born on April 24, 1972 and he attained the degree in Geological Science at the University of Basilicata (Potenza, Italy). In 2004 he obtained a Ph.D. in “Methods and technologies for environmental monitoring” at the University of Basilicata.

At the present, he is a researcher of the CNR Institute of Methodologies for Environmental Analysis (IMAA). Since 1999 his research activity has been focused on the development of advanced satellite techniques for natural hazards monitoring and mitigation. He has taken part as co-investigator in several projects in the framework of ASI activities.

Vinciane Lacroix ♀, Royal Military Academy – Signal and Image Centre
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Vinciane obtained her Ph.D. degree from the ENST, Paris, France, a M.Sc. degree from Computer and System Engineering department of Rensselaer Polytechnic Institute, Troy, NY, USA and a “Licence en Physique” from the ULB, Belgium. From 1985 to 1992 she has been a researcher at the PHILIPS Research Laboratory Belgium. She joined the Signal and Image Centre of the RMA in 1994 to work on feature extraction in Remote Sensing. Today, her fields of interest include computer vision, pattern recognition, image processing for remote sensing, and humanitarian de-mining.

Giovanni Laneve ♂, Centro di Ricerca Progetto San Marco – Università di
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Giovanni Laneve is assistant professor at the School of Aerospace Engineering of the University of Rome “La Sapienza”. Since 1998 he has taught *Aerospace System for Remote Sensing*. Sixteen years of research activity in the field of aeronomy, remote sensing (algorithms development for applications of remotely sensed data, integration of remotely sensed data and “in situ” measurements, acquisition and processing of satellite images) and orbit dynamics for remote sensing applications.

Stefan Lang ♂, Centre for GeoInformatics – Salzburg University (Z_GIS),
Zentrum für Geoinformatik, Universität Salzburg, A-5020 Salzburg, Austria
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Stefan Lang, a senior researcher at Z_GIS, completed his academic qualifications (Master of Science (Mag. rer. nat.) and Ph.D. (Dr. rer. nat.) in Geography) at the Salzburg University, Austria. He is a specialist in GIS science and remote sensing for urban applications, nature conservation, landscape analysis and land use/land cover mapping. Involved in a range of research projects, he is an active member of the Z_GIS GMOSS group and has been working in various educational projects and capacity building projects for GIS and remote sensing in Africa and Asia (India, Bhutan). He has gained significant teaching experience over the last 5 years through giving university courses and commercial seminars.

Manfred Lehner ♂, Deutsches Zentrum für Luft- und Raumfahrt (DLR),
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Manfred Lehner, born 1943 in Straubing/Germany earned a diploma degree in mathematics. He is enrolled at the Remote Sensing Technology Institute (IMF) of the German Aerospace Centre (DLR). He is working since 1980 in the field of image processing, specializing in image matching and stereo image processing since 1983. Large scale application of the developed software systems were later applied to derive 3D models from the data of the German MOMS mission, a stereo camera mounted onto the Russian space station Mir from 1996–1999. Right now he is concentrating on adapting these software packages to processing of very high resolution imagery.

Iris Lingenfelder ♀, Definiens AG, D-80339 München, Germany
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Iris Lingenfelder studied Geography at Ludwig–Maximilians University in Munich and Geoinformatics at University of Salzburg and conducted research in physical geography. She participated in the creation of a geographical multi-media atlas and is experienced in ecological research and forest management based on remote sensing data. Since 2000 at Definiens, Iris is an application specialist in feature recognition and involved in space based pipeline monitoring and other innovative monitoring projects. Iris is a GIS-specialist; she is fluent in English, French and basic Spanish.

Hans-Joachim Lotz-Iwen ♂, Deutsches Zentrum für Luft- und Raumfahrt (DLR), DLR Oberpfaffenhofen, D-82230 Wessling, Germany
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Hans-Joachim Lotz-Iwen, born in 1950, received M.S. and Ph.D. degrees in physics at the University of Göttingen (Germany) and joined DLR in 1983. Until 1992 he set up the image processing lab at the German Remote Sensing Data Centre DFD and worked on different application projects. In the mid 90th he was head of the project ISIS, establishing on-line access to distributed image archives and catalogue interoperability among DLR, ESA and NASA, and coordinator of a working group on environmental data management within the Helmholtz-Community of German Research Centres (HGF). He was engaged in international education programmes and projects (GLOBE, EURISY, CASTLE, CNES-DCE), and manager of the project “E-Business in DLR”. Recently he is information manager of the Institute Cluster on Applied Remote Sensing (CAF) and coordinator of public outreach and educational activities.

Raphaële Magoni ♀, Joint Research Centre (JRC),
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With a background in public international law and conflict analysis, Raphaële Magoni has been active in the field of migration and human rights. After working as a refugee co-ordinator with Amnesty International in Brussels, she became a researcher for the Migration Policy Group, contributing to a number of projects relating to policy development in the field of migration at European level. She is currently conducting research on migration issues for the Institute for the Protection and Security of the Citizen of the European Commission Joint Research Centre.

Robert Meisner ♂, European Space Agency (ESA-ESRIN),
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Robert Meisner, born in 1962 in Bayreuth Germany, holds a Master's degree in geography, geology and remote sensing. In 1999 he received his Ph.D. from the University of Berlin and worked in remote sensing at Stanford University and University College London before joining DLR in late 1991. For the past 12 years he has worked on different research projects mainly in optical remote sensing and was also concerned with database design and system administration. Since 1996 he has mainly worked in the field of scientific visualization and computer animation, heading the "Value Adding and Visualization" group at DFD. In May 2000 he became head of the "Marketing & Media" unit at DLR's Remote Sensing Data Center.

Karin Mertens ♀, Royal Military Academy – Signal and Image Centre
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Karin obtained her M.Sc. in Geography and a postgraduate in Computer Science from the University of Ghent, Belgium. In 2002 she worked on a de-mining project at the Signal and Image Centre of the RMA. In 2003 she started working on a disaster management project that is based on GIS software.

Allan Aasbjerg Nielsen ♂, Technical University of Denmark (DTU),
Technical University of Denmark, Informatics and Mathematical Modelling,
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Associate Professor Nilsen, M.Sc., Ph.D. has worked on several national and international projects on development, implementation and application of statistical methods and remote sensing on spatial, multi-/hyperspectral and multi-temporal data in mineral exploration, mapping, geology, environment, oceanography, geodesy and agriculture funded by industry, the European Union, Danida (the Danish International Development Agency), and the Danish National Research Councils.

Irmgard Niemeyer ♀, Technische Universität Bergakademie Freiberg (TUBAF), Institut für Markscheidewesen und Geodäsie, D-09599 Freiberg, Germany
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Since December 2008 Dr. Niemeyer is leading the working group on Geomonitoring at the Institute for Mine-Surveying and Geodesy of the Freiberg University of Mining and Technology. Before she was working as a junior professor for Photogrammetry and Geomonitoring at the same institute. She received her Diploma (1996) and Ph.D. (2000) in Geography from the University of Bonn and did her dissertation at the Research Center Juelich (FZJ) on multispectral satellite imagery analysis for nuclear verification. Since 2000 she has been a consultant in the German Support Programme for the International Atomic Energy Agency for satellite imagery analysis and geo-information. She has authored many papers and reports on monitoring nuclear facilities using satellite imagery analysis.

Albert Nieuwenhuis ♂, The Netherlands Organisation for Applied Scientific Research (TNO), NL-2597 AK The Hague, The Netherlands
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Albert Nieuwenhuis has been working for 4 years in projects concerning identifying critical infrastructure protection in the Netherlands, where he was mainly concerned with the development and application of methods and tools. In these projects, the criticality of infrastructures, considering chain-effects due to interdependency of infrastructures in Holland have been examined, first on very high levels, later on lower levels. On these lower levels, a general method for vulnerability analysis was developed and applied. Also, Albert is active in an EC project on critical infrastructures (VITA), where he is involved with the work package concerning methods and tools.

Sven Nussbaum ♂, Forschungszentrum Jülich GmbH (FZJ),
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Sven Nußbaum, born December 20, 1975 in Cologne, Germany graduated in 1995 from the Staatliches Wiedtal-Gymnasium Neustadt/Wied. Following his Military-Ersatz service he enrolled in the University of Bonn for a Diploma in Geography. His auxiliary subjects were Agrarian and Environmental Economics and City Planning. He has successfully completed his Diploma examinations (final mark "very good"). He is employed at the Forschungszentrum Juelich since January 1, 2004, under a project entitled "Institutional and technological improvement of international nuclear material control" financed by the German Federal Ministry of Economics and Labour.

Nicola Pergola ♂, Instituto di metodologie per l'Analisis Ambientale (IMAA),
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Born on 05/01/1968 in Potenza (Italy). Degree in Physics at the University of Rome "La Sapienza" on May 1993. Since 1998 he is research scientist at the Institute of Methodologies for Environmental Analysis of the National Research

Council. Since 2003 he is the person in charge of the IMAA Satellite Remote Sensing Laboratory – "Geohazards" Unit.

He is member of the "core team" Geohazards within the IGOS (Integrated Global Observing Strategy) project, contributing to define the new global observational strategies for geohazards mitigation. He was scientific coordinator of different ASI (Italian Space Agency) and CNR (National Research Council) projects and co-investigator of several EU Projects. Currently, he is involved in EU Projects in the framework of GMES (Global Monitoring of Environment and Security), like the Network of Excellence GMOSS (Global Monitoring for Security and Stability) and the STREP GRIDCC (Grid-Enabled remote Instrumentation with Distributed Control and Computation). At University of Basilicata he holds (since 2003) the course of "Earth Observation Information Technology Lab" at the Faculty of Engineering. His main interests are in the field of satellite data analysis for environmental research, especially concerning AVHRR (Advanced Very High Resolution Radiometer) and MSG-SEVIRI (Spinning Enhanced Visible and Infra-Red Imager). His research activity is mainly focused to the development of robust satellite techniques for natural hazards investigation from space and on multi-temporal satellite data analysis in the space–time domain. Currently, he is the scientific responsible of the IMAA Research Unit within the relevant project "Etna" jointly funded by INGV and Department of Civil protection. He is author or co-author of more than 80 papers mostly on books and journals with international distribution.

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Graduate in Town and Regional Planning (IUA Venice 1991–1992) with an overall first class mark of 110/110. In 1993 he followed a specialization course on Digital Photogrammetry at the CISM (International Centre for Mechanical Sciences) in Udine (Italy). Since 1998 visiting professor of Spatial Statistics at the University of Venice (IUAV CdSIT, Corso di Laurea in Sistemi Informativi Territoriali).

Mr. Pesaresi pursued research activities involving the use of remotely sensed data in urban analysis with the CAMS (Centre d'Analyse et de Mathématique Sociales) of the EHESS (École des Hautes Etudes en Sciences Sociales) in 1991–1992 and with the LIA (Laboratoire d'Informatique Appliquée) of the ORSTOM (France) in 1992–1993. He has worked as a research assistant with the DAEST (Dipartimento di Analisi Economica e Sociale) and the DU (Dipartimento di Urbanistica) of the University of Venice (IUAV) during 1992–1995 and with the DAU (Dipartimento di Architettura e Urbanistica) of the University of Pescara in 1996–1997. In 1992–1997 he has also been working as consultant expert on remote sensing and GIS data analysis for many public and private companies as well for professionals involved in town and regional planning activities. From 1997 to the end of 2000 he has been working with a research contract at the EC JRC Space Applications Institute/EGEO, Advanced Methods Sector. From February of 2001 to December 2004 he is working at the INFORM srl, Padova, Italy, leading the group of Geographical Information System and Remote Sensing applications. Since January 2004 he is working at the

European Commission, Joint Research Centre, Institute for the Protection and Security of the Citizen (IPSC) in the Global Security and Crisis Management Unit, contributing to the Global Monitoring for Environment and Security program with various activities, and specifically he is the scientific coordinator of the Global Monitoring for Security and Stability (GMOSS) Network of Excellence in the aeronautics and space priority of the 6th FP. Since September 2007, he is the chief of the Geo-Spatial Information Analysis for Global Security and Stability (ISFEREA) team of the same JRC Institute, focused on application of remote sensing data analysis for human security (more info available at the http://isferea.jrc.ec.europa.eu). The main scientific publications of M.Pesaresi are related to automatic satellite image understanding, multi-scale image decomposition by derivative of the morphological profile, automatic recognition and analysis of human settlements, and applications to automatic damage and reconstruction assessment using very-high-resolution satellite data.

Peter Reinartz ♂, Deutsches Zentrum für Luft- und Raumfahrt (DLR),
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Peter Reinartz, born 1958 in Cologne/Germany, is project manager and team leader at the German Aerospace Center, DLR, in the Remote Sensing Technology Institute (IMF). He has 17 years of experience in image processing and remote sensing. In 1985 he began work at the Institute of Optoelectronics of DLR (one of the predecessors of the IMF) in the optical remote sensing group. In 1983 he received a diploma degree in theoretical physics and in 1989 he received a Ph.D. degree in photogrammetry from the University of Hannover. He has more than 60 publications in the field of image processing and remote sensing. Since 1989 he has been project engineer of several application projects for airborne remote sensing. For the last 6 years he has been supervising the pre-processing and calibration group for the German M0MS-02/M0MS-2P camera. In the recently-founded IMF, he is in the "Image Science" unit and works in the field of digital terrain models from optical data and high resolution optical data, further, he leads the team on space photogrammetry.

Alain Retière ♂, UN Development Programme,
Brest, France
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In 2008 Alain Retiere has been called upon by UNDP as special advisor in charge of mainstreaming satellite applications to fight climate change at local/regional level in the context of a new trend within the "territorial approach to development". He was the former Director of UNOSAT. He is a Member of the Scientific Advisory Committee of the Euro-Mediterranean Center on Major Risks established within the University of Corsica, France. He joined UNOPS in 1992 and since 1998 he works as senior advisor at the UNOPS Consulting Services Group, in charge of remote sensing and geographic Information systems, hearth resources mapping and sustainable management, natural disaster prevention and post-disaster recovery (water-related hazards), decentralized development planning and evaluation, local governance (multi-stakeholder management) and local economic development. He represents UNOPS at the United Nations Geographic Information Working Group established since 2000. He is UNOPS representative at the Global Network in Conflict Prevention and Post-Conflict Rehabilitation (CPR) where all OECD member countries bilateral cooperation agencies and UN multilateral organizations involved in conflict prevention, crisis management and post-conflict recovery coordinate joint operations. He has an extensive experience of managing complex humanitarian and development operations in local and international NGOs as well as United Nations. Since 1984, he has carried out short, medium and long term technical assistance missions and managed development projects in Mexico, Madagascar, Guatemala, Belize, Honduras, El Salvador, Nicaragua, Costa Rica, Cambodia, Lebanon, Burundi, DR Congo, Georgia, Kosovo, Albania, Former Yugoslav Republic of Macedonia, Mozambique, Ivory Coast, Tajikistan, North Korea, Peru, Palestine, Bosnia and Herzegovina, Croatia, Haiti, Tunisia, Papua New Guinea, Solomon Islands and Fiji. He has a Masters Degree in Tropical Ecology from University Pierre et Marie Curie PARIS VI (1991) and an Agriculture Engineering degree (1986), Agricultural High School, Angers.

Torsten Riedlinger ♂, Deutsches Zentrum für Luft- und Raumfahrt (DLR),
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Torsten Riedlinger, born in Überlingen/Germany (1973), studied physical geography, climatology and soil science at the University of Trier, specializing in glaciology, permafrost, GIS modelling and remote sensing. Subsequently he wrote his master's thesis on the occurrence of high and low altitude permafrost in the Swiss Alps using geophysics, temperature logger and aerial photo interpretation. From 2000 to 2003 he had a Ph.D. scholarship on analyzing and modelling the landscape evolution of a semi-arid watershed in southeast Spain. Additionally, he taught several basic and advanced GIS courses at the University of Trier. Since spring 2003 he has been working in the crisis response team at the German Remote Sensing Data Center (DFD) of the DLR, including remote sensing and GIS analysis, as well as national and international coordination, related to man-made and natural disasters, humanitarian relief and civil security. Furthermore he is responsible for DLR's Project Management within the International Charter "Space and Major Disasters".

Jörg Schlittenhardt ♂, Bundesanstalt für Geowissenschaften und Rohstoffe
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http://www.seismologie.bgr.de

With a Diploma in Geophysics from Karlsruhe University, Germany and a Ph.D. in Geophysics from University of Frankfurt a.M., Germany, Dr. Schlittenhardt is a research scientist in the Department of Geophysics of the Federal Institute for Geosciences and Natural Resources in Hannover, Germany. He has authored papers on global and array seismology, explosion source phenomenology and yield estimation, seismic discrimination of earthquakes and nuclear explosions and on regional seismic wave propagation. He has more than 15 years of experience in various aspects of seismic verification of nuclear test ban treaties, including participation in international CTBTO-related workshops on evaluation and OSI-(On-Site Inspection) techniques.

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After having obtained a M.Sc. in Geography from the University of Cologne in 1993 Stefan Schneiderbauer joined the University for Applied Sciences in Berlin as an expert for remote sensing image analysis and GIS applications (1994–1995). Following he worked from 1996–2001 as international consultant focusing on the application of Earth Observation and GIS technology for natural resource management. In this context he developed and implemented various training courses dealing with Environmental Monitoring and Environmental Management. During this period he also lectured at the University for Applied Sciences and the Humboldt University in Berlin. From 2001 on he worked at the Joint Research Centre (JRC) of the European Commission in Ispra/Italy, first within the Global Vegetation Monitoring Unit, following as member of the Support to External Security Unit of the Institute for the Protection and Security of the Citizen (IPSC). In this position he carried out research on population density estimations, people's vulnerabilities and indicators for risk determination. At the same time he supported the scientific management of GMOSS and was responsible for the project's work package 'Public Outreach'. In April 2007 he completed his doctoral thesis about populations' risk and vulnerability to natural disasters at the Free University in Berlin/Germany. Currently Stefan Schneiderbauer holds a position as researcher at the European Academy in Bolzano/South Tyrol within the institute for Applied Remote Sensing.

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http://www.imm.dtu.dk, http://www.oersted.dtu.dk

Associate Professor Skriver's main interest are retrieval of sea ice parameters from synthetic aperture radar data, including SAR data from ERS-1 and different aspects of land applications, such as forestry in the MAESTRO-1 project, agriculture, environmental and topographic mapping applications using both satellite SAR data and data from the Danish air-borne polarimeter SAR, EMISAR.

Interests also include various methods of processing SAR data such as image simulation, image filtering, speckle statistics, texture analysis, segmentation, calibration, and polarimetric analysis. He is recently project manager of an international study of ESA concerning the use of polarimetric SAR data for agriculture, forestry and sea ice.

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Nils Sparwasser was born in 1972 in Mainz Germany, holds a Master's degree in geography, zoology and botany. In 1999 he joined DLR working for the "Value Adding and Visualization" group at DFD which team-leader he became in 2001.

For the past 6 years he has worked on different projects in the field of scientific visualization of remote sensing data.

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Nathalie Stephenne obtained a degree in Geography followed by a Master degree in Development Studies in 1995 from the University of Louvain-la-Neuve (UCL), Belgium. After an experience as teaching assistant at UCL, she had a contract in the private I-mage consult company (database management and mapping on an EU project). She presented her Ph.D. thesis untitled dynamic simulation model to understand land-use change processes in the Sudano-sahelian region (SALU – Sahelian Land Use) in 2002, supervised by Pr E. Lambin. Laureate of ARSOM in 2000, this foundation published her Ph.D. thesis in 2003. In collaboration with the CEH Wallingford, UK, the integration of SALU results in GCM simulations estimated the impact of these changes on climate. She joined the IGEAT, University of Brussels, on a Belgian Science Policy funded and user-oriented project that compared classical and object-oriented classifications of very-high-resolution satellite imagery. Engaged at the JRC IPSC in 2005 with a post-doctoral research position, she is currently involved in the JRC institutional research activity related to modeling of EU Border Permeability and EU Neighbourhood Stability.

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Dirk Tiede graduated in 2002 at the department of Geography at the University of Tübingen, Germany, with a diploma thesis on storm damages in forests of Southern Germany. In April 2003 he started working at the Landscape Analysis and Resource Management Research Group (LARG), University of Salzburg. Currently involved in GIS application development and tree crown mapping using LIDAR data and object-oriented methodologies. He is currently undertaking Ph.D.-research in the field of bridging remote sensing and GIS.

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Born 28/12/57, graduated in Physics at the University "La Sapienza " of Rome. Since 1993 he is Researcher at the University of Basilicata where, since 1997, holds official courses on Remote Sensing Geology and Remote Sensing of Environmental Resources. Since 1991 he has been visiting scientist in the main international centres involved in the Earth's observation by satellite and has taken part as PI or co-investigator in several national and international projects as well as in international scientific groups (in the framework of EU, ESA, ASI, EUMETSAT, NASA, NASDA EO, IGOS activities). His research activity has been focused on the development of new satellite sensors and techniques in the field of natural, environmental and industrial hazards monitoring and mitigation by satellite remote sensing. On this topic he has authored more than 80 scientific papers (mostly in international journal and conferences), has been referee for international journals (like International Journal of Remote Sensing, Natural Hazards, Annals of Geophysics, etc.) and project proposals, has been invited as chairman or co-chairman at several International Conferences and Workshops. He is the proposer of the generalized *change-detection* RAT approach which (at present) has been successfully applied to several natural, industrial and environmental hazards (fires, volcanoes, earthquakes, floods, air, soil and water pollution, sand-storms, oil spills, etc.).

He participated in the activity of the CEOS/DMSG and in the international core team in charge to formulate a proposal for a new IGOS Theme on Geo-Hazards.

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Andreas Wimmer is an expert in software development and C and C++ programming. Since 1998 he is working at JOANNEUM Research, Institute of Digital Image Processing. He is responsible for the development of the IMPACT software, and image analyses software. Furthermore he is project manager of several national and international projects. His special field is the establishment of processing lines for land use and land cover classifications, algorithms for image calibration, change detection, segmentation and texture analyses.

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Peter Zeil holds a degree in geophysics and has worked for over 20 years in international projects and programmes for environmental monitoring and natural resources management. He is Visiting Professor at the Department for Geography and Applied Geoinformatics, University of Salzburg, Austria, member of management team for the UNIGIS M.Sc. distant learning programme; author and tutor of the UNIGIS optional module 'Remote Sensing'; project coordinator of the Center for Geographic Information Processing Salzburg ZGIS. He has extensive experience in institutional assessment, strategic planning, project management and technical implementation in the field of remote sensing and GIS.

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After studies in geography, geology, remote sensing and pre- and ancient history in Regensburg and Munich, Gunter Zeug graduated as geographer from Ludwig-Maximilians University Munich in 2000. In 2001 he joined GAF AG, an internationally active consulting company for remote sensing and geoinformation, as technical expert. Since 2002 he was mainly involved in the design and implementation of IACS-GIS tools and Land Parcel Identification Systems (LPIS) within several German Ministries of Agriculture. In September 2006 Gunter joined the IPSC-GlobeSec Unit (formerly IPSC/SES) of the Joint Research Centre (JRC) of the European Commission in Ispra/Italy as geomatics and remote sensing specialist. His main focus is on urban hazard risk assessment and more general challenges of urbanization in the developing world including population growth, environmental impact and hazard risk. In GMOSS he supported the scientific management of the network and took over responsibility of the work package 'Public Outreach' in 2006.

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Introduction

Bhupendra Jasani, Martino Pesaresi, Stefan Schneiderbauer, and Gunter Zeug

Changing Security Perception and Definition

During the past half a decade or so, perceptions of regional and international security have changed dramatically as reflected in a number of studies published since 2003. Two notable examples are the December 2003 European Union report[1] and the 2004 report written by a group of experts on behalf of the United Nations Secretary General.[2] Between them they identified poverty, infectious disease, terrorism, trans-national organised crime, state failure and proliferation of weapons of mass destruction (WMD) as some of the threats to national and international security. A state is secured when it is free from these threats. On the other hand, two other studies, the 2005 Human Security[3] and the 2006 Human Development Report[4] concluded that conflicts within states make up for more than 95% of armed conflicts resulting in a huge number of casualties and death. Moreover, some 1.8 million children die as a result of unclean water in conflict stricken states. It is hard to believe that although large-scale devastation can result from, for example, acts of terrorism and conventional warfare fought with conventional weapons, states appear to be concerned about WMD only. Thus, together with WMD, conventional weapons should also be considered. Human security is concerned with risks to the survival of people, their livelihood and dignity. For example, internal conflicts have become more important than interstate wars as the major threat to international peace and security. Human security is also inseparable from development and poverty. Many poor people have to depend on their local environment for their survival.

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[1] "A secure Europe in a better world", Document proposed by Javier Solana and adopted by the Heads of State and Government at the European Council in Brussels on 12 December 2003 (The European Union Institute for Security Studies, Paris, France, 2003).

[2] "A more secure world: Our shared responsibility", Report of the Secretary-General's High-level Panel on Threats, Challenges and Change (United Nations, 2004).

[3] "Human Security Report 2005. War and Peace in the 21st Century", Human Security Centre, The University of British Columbia, Canada, http://www.humansecurityreport.info/

[4] "Human Development Report 2006. Beyond scarcity: Power, poverty and the global water crisis", UNDP, http://hdr.undp.org/hdr2006/pdfs/report/HDR06

Particularly for those who live in rural areas, economic security, and sometimes sheer subsistence, is intimately connected with the natural environment. Daily safety and survival need to be assured from natural hazards and environmental degradation; the issues related to climate change are increasingly relevant for human security. This has been developed both in the 2005 Human Security Report by the Human Security Centre and the 2007/2008 Human Development Report of UNDP entitled "Fighting climate change: Human solidarity in a divided world".[5]

The GMES Policy Context

The European Commission together with the European Space Agency initiated the Global Monitoring for Environment and Security (GMES) project (for a detailed account of GMES, see Chapter 1). The GMES was initiated in 1998 and was placed on the Ministerial Agenda of the EU during 2001. Its purpose is to provide information needed to address some of the security related concerns. In summary, it was established to support the following:

1. Europe's environmental commitments, within the EU and globally by contributing to the formulation, implementation and verification of the EC environmental policies, national regulations and international conventions
2. Other policy areas, such as agriculture, regional development, fisheries and transport are also considered
3. Common Foreign and Security Policy (CFSP), including European Security and Defense Policy (ESDP) and
4. Policies relevant to European citizens' security at EC and national levels (e.g. border surveillance)

These aims were to be achieved with the following general principles:

(a) The production and dissemination of information in support of EU policies for Environment and Security
(b) The mechanisms needed to ensure a permanent dialogue between all stakeholders and in particular between providers and users and
(c) The legal, financial, organisational and institutional frame to ensure the functioning of the system and its evolution

The aim of the GMOSS Network of Excellence (NoE) was to identify and integrate, in Europe, civil security research that is based on earth observation from outer space. This allowed the acquisition and nourishment of the knowledge and expertise that was needed to be developed to maintain an effective capacity for global monitoring in support of its external aid and security policies.

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[5] "Human Development Report 2007/2008. Fighting climate change: Human solidarity in a divided world", UNDP, http://hdr.undp.org/en/reports/global/hdr2007-2008

Thus, in order to address the problems related specifically to security (for details on what is meant by security, see Chapter 1), the European Commission established GMOSS in 2003 under which several specific studies were carried out. These are summarised in Fig. 1. The science and technology encompassed within the Network included:

1. The generic methods, algorithms and software needed for the automatic interpretation and visualisation of imagery including feature recognition and change detection
2. The specific science and technology needed to provide, for example:
    a. Effective monitoring of international treaties preventing the proliferation of weapons of mass destruction. As a first step the focus was on the 1970 Treaty

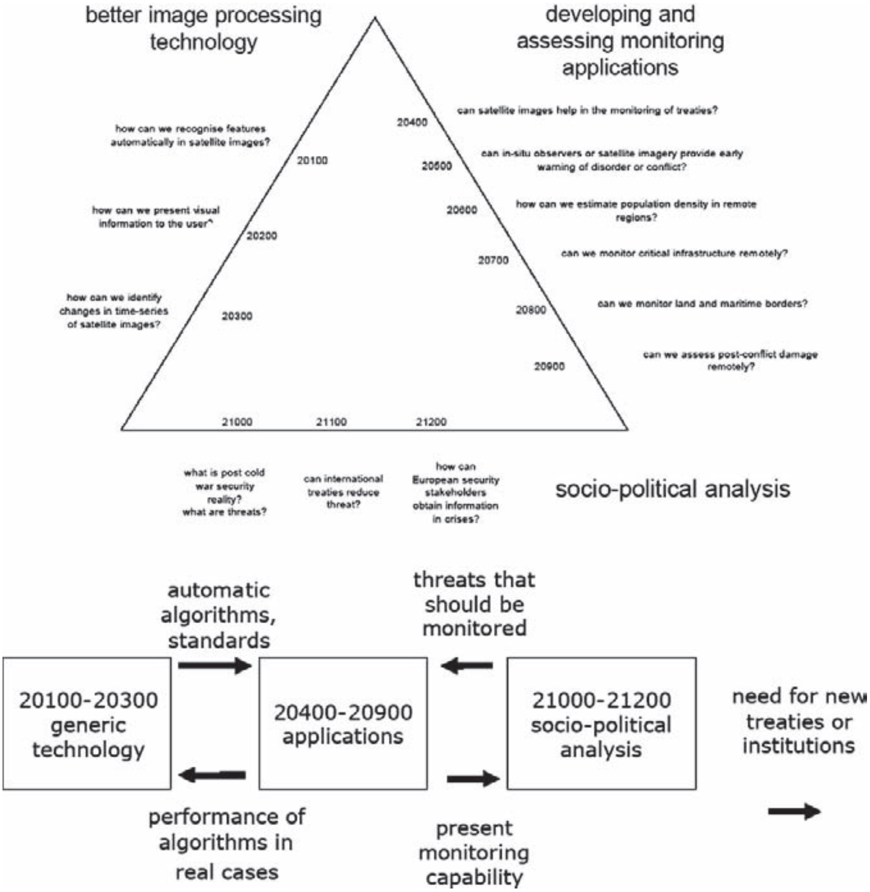

Fig. 1 The GMOSS concept

   on the Non-proliferation of Nuclear Weapons (NPT); in this context, most of the elements of the civil nuclear fuel cycle were characterised and a "key" was developed for effective interpretation of satellite imageries (see Chapter 12)
   b. The generic methods, algorithms and software needed for the automatic interpretation (combined with the "key") and visualisation of imagery including feature recognition and change detection (see Chapters 8 and 9)
   c. Development of tools for early warning (see Chapter 13)
   d. Better estimates of static and dynamic populations on a global scale (see Chapter 14)
   e. Better monitoring of infrastructure and borders (see Chapter 15)
   f. Rapid remote assessments of damage (see Chapter 16)

3. Investigations of present and future threats to security and the needs for exchange of information between stakeholders during crises (see Chapters 2 and 3)

Integration between the consortium organisations was achieved through participation in the joint research programmes and to dedicated activities such as joint events (see Chapters 4 and 6), data and infrastructure sharing, and standardisation (see Chapter 7). The aim of the network to spread excellence was achieved through training sessions, workshops and an enhanced web site.

There is a common agreement among scientists and policy-makers on a strong need for further research and development (R&D) to address the complex nature of the new threats and challenges mentioned above, which also call for a range of measures and actors (including civil protection, intelligence, law enforcement, judicial, economic, diplomatic, and technological) in order to address them effectively. In the EC's fifth and sixth framework programmes, European R&D activities contributed towards defining potential elements of research related to security. However, for the first time in its seventh framework programme, European R&D activities relevant to European security policies and issues are being conducted with clear aims and direction within new thematic priorities, entitled Space and Security. The European security research is designed to respond to societal demands in the face of new security challenges and to enhance competitiveness of the European Security Industry, thus contributing to the implementation of the Lisbon strategy. It is also considered to be an essential building block in supporting EU policies (namely Common Foreign and Security Policy, conflict prevention, crisis management, border management, protection of critical infrastructure, transport, civil protection, and energy) as well as in attaining a high level of security within an EU-wide area of justice, freedom and security. The space research theme under the seventh framework programme is intimately linked with security related policies. In addition, there are several themes for research that will deal with other elements of security, which are not necessarily linked to space: amongst them, health (for example, security and safety of food and drinking water) under the theme "Food, Agriculture and Biotechnology". Moreover, security is also a key component in several priorities under the theme "Information and Communication Technologies"; challenges to security of food supply and climate change as well as the security of smart energy networks under the "Energy" theme, and the "Transport" theme.

In the seventh framework programme, the key security research linked with space is being conducted within the GMES initiative. The results of the Network of Excellence, GMOSS, funded by the EC during the previous framework programme, contribute to the definition of the security dimension of the GMES. At the forefront of research in GMES, GMOSS is identifying research gaps and user needs to institutions, industry and the scientific community at large.

New Challenges for the Remote Sensing Technology

It is difficult to argue against the fact that new technologies play a crucial role in the changing of collective threats and security strategies: emerging techniques make the scenario more and more complex and are an accelerator of change. Since the early 1990s, civilian satellite remote sensing technologies have reached the sophistication necessary for having an impact on security issues. The spatial, radiometric, and temporal resolution of the data obtained by new satellite platforms and sensors have improved the impact on our security and safety by monitoring more and more detailed information in a multi-scale and synoptic way.

The latest generation of very-high spatial resolution data are challenging the available technology and software regarding the access and interpretation of such imageries. As a result, new image data storing, access, visualisation and Internet streaming paradigms have been successfully developed in recent years, and the world-wide success of systems like Google Earth or Microsoft Virtual Earth demonstrate the technological possibility to access and distribute to a shared world-wide central database of very high resolution images.

While it is technologically possible to visually access detailed, world-wide imageries, the same level of reliability is not available yet for automatic image understanding and image information mining tasks. In fact, the operational image interpretation of latest generation satellite data is done largely by visual inspection and reporting: this methodology is sustainable only for limited areas and a limited number of targets to be detected in the image data. It is difficult particularly when applied to large areas where there is a need to have rapid and reliable assessments.

The availability of improved data has resulted in a dramatic increase in data complexity, increased statistical variability of the signals detected and increased geometrical complexity of the image as a result of the presence of parallax and panoramic distortion. All these factors have added to the computational complexity and the instability of the inferential models used for automatic image understanding. Paradoxically (and contrary to the expectations of the remote sensing scientific community), the improved details in the available satellite images seems to decrease our capacity to interpret using automatic inferential systems.

Beside these scientific and technical challenges related to the nature of the new data source to be managed, some others are related to the nature of the applications explored in the contributions presented in this volume. Some of the constraints and challenges related to the use of remotely-sensed data in security applications are:

(i) The need for multi-temporal analysis as in assessment of before and after an event, trends and detection of anomalies
(ii) The need for rapid assessment of sometime large areas (hours, days)
(iii) The need to integrate heterogeneous geo-information sources often of unknown quality
(iv) The fact that often basic information is missing because the areas under analysis are inaccessible for security reasons (e.g. regarding data geo-coding, interpretation keys, validation)
(v) The fact that the output of the assessment is often highly controversial, as in the case of presence of conflict or politically or economically sensitive topics, so the need to show a shared and convincing inferential model
(vi) The problem of misunderstanding and misinformation can be overcome via the use of the satellites of the various states
(vii) The possible existence of camouflage in the observed scene, consequently the necessity to handle a possible intelligent strategy of the observed entities

All these issues are characteristics of the use of satellite data in security applications and they are challenging the traditional methodologies for image data processing, automatic image data understanding and output validation developed by the scientific remote sensing community. In particular the first four characteristics that are listed above force the design of robust systems able to handle more consistently semantic and spatial information with less certainty, while the last three characteristics force the scientist to abandon the classical paradigm of natural science (largely dominant in the remote sensing scientific community) postulating complete dichotomy between the observer and the observed external reality eventually directly accessible as truth.

When dealing with security issues, often the observer and the observed are the same, humans, so that political and ethical questions are inevitably intermingled with technical discussions. Furthermore, the observed can try and influence the map maker or a remote sensing expert to comply with his wishes.

If the above were true, then in order to avoid the risk of naïveté and irrelevance, or worse still, of uncontrolled exploitation of scientific work for unclear political strategy, it is important that the new generation of remote sensing specialists are trained with new conceptual tools able to effectively support complex decision-making processes. As a consequence, it is necessary to evolve from the strict traditional "problem-solving" paradigm within the remote sensing community, to conceptual tools supporting, for example, the problem framing and problem setting during the decision making process.[6]

This book is regarded as a first but important step forward towards defining the possibilities and limitations of a rapidly changing technology used for a very new application.

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[6] Herbert Simon, Reason in Human Affairs, Stanford University Press; 1 edition (July 1, 1990). Herbert Simon, The Sciences of the Artificial, the MIT Press; 3 edition (October 1, 1996).

Contents of the Book

In this book, the activities and achievements of the GMOSS network on the use of remote sensing to support international peace and security are reported. The latest scientific and technological research in the field of remote sensing satellite imagery analysis is presented. The book is divided into four parts.

In Part I, considerations are given to general concepts of security and crisis, EU security policies and the role of earth observation in support of European crisis response. In the first chapter, theoretical concepts and definitions of security are discussed. Furthermore, geospatial concepts and geospatial technology are introduced in an attempt to link the security policy makers and social science researchers to the science and technology researchers by proposing definitions of security and applying these definitions via the use of geo-spatial tools. In the second chapter, an analysis of the European Security Strategy and other major EU policy documents in this field is given in order to provide a summary account of the strategic challenges facing the EU. The role that earth observation technologies can play in the European Union's strategy for responding to these challenges with particular reference to the wide range of potential customers for the EO product within EU structures and the contribution which can be made to crisis management is also considered.

A critical review of the current state of development of European capabilities in the applications of satellite based information for civil crisis response in Europe and worldwide is discussed in the third chapter. Various initiatives and projects exist today, which work towards the building-up of European satellite analysis capacities for civil security purposes. Although the first elements of a European civil security "intelligence" infrastructure are materializing, further efforts and coordination mechanisms are necessary to build respective operational and fully analytical and coherently acting capacities within Europe.

The contributions of GMOSS in the context of GMES and security are highlighted in Part II. A theoretical background is given that investigates and illustrates security issues and research within GMES. GMOSS and its specific role within the GMES is also discussed. Under the GMOSS, the European security concept and several of the challenges identified within the European Security Strategy and other subsequent EC policy papers and communications are considered. With its overall goal of bringing together and advancing Europe's civil security research in order to contribute to the development and maintenance of an effective European capacity for global monitoring for security, GMOSS played a fundamental role as a "Think Tank" for the development and benchmarking of new tools and methodologies for the application of EO technology in the security area.

The second chapter of Part II introduces a novel training approach that has been developed and tested within GMOSS, which aims at integrating technology, natural sciences and social sciences in order to enhance the monitoring capability in the cross-cutting emerging field of security research. With the aim of increasing European competitiveness and cooperation and to build a critical mass of expertise, the newly developed research training agenda encompasses remote sensing technologies, social and political science research, the exchange of information between stakeholders, and the evaluation of existing or new organizational structures.

Games and scenario analysis are tools that bring together people of varying expertise and backgrounds in order to improve the common understanding of an issue. GMOSS as a network to promote cross discipline contacts among experts from different fields is a good example of how gaming and scenario analysis can create a common ground for addressing a monitoring problem from different perspectives. An introduction to gaming and scenario analysis in the context of the GMOSS network both as an analytical tool and as a means of promoting training is considered in Chapter 6.

In conclusion, the importance of using common infrastructures and standards to enable parties from different disciplines to effectively collaborate, share data and assure high quality is considered in Chapter 7. The use of standards improves efficiency and reduces the chance of semantic confusion and misinformation in all situations. In this chapter, analysis of available metadata standards is given with a focus on security and attention is drawn to the gaps in current definitions. In the chapter, it is also demonstrated the implementation and use of standards in GMOSS are also demonstrated (e.g. through the definition of a feature catalogue and through ISO compliant metadata).

Research and development of image processing methods and tools for security applications are dealt within the various chapters in Part III of the book. For example an insight into the development of feature recognition techniques which provide important capabilities to exploit the full potential of remotely sensed images is provided. Today almost all applications in security relevant areas take advantage of high quality feature recognition products. Another example is the progress in the earth observation methodologies for detecting changes in a scene. Different multi-spectral classification and change detection methodologies (including 3D), applied to optical as well as radar images are analysed, compared, and discussed on a variety of data with different spatial resolution, and within the different application themes of GMOSS. As one of the main open issues the accuracy and timeliness of using automatic change detection methods in comparison to visual interpretation of changes is highlighted.

Today the provision and use of maps for the purpose of decision making during crisis and effective disaster management is well accepted. Disaster response based on satellite data and GIS-information rapidly offers reliable information with a high degree of automation and consistency. Nevertheless there is a need for effective data integration and advanced data visualisation. The key aspects of crisis-related visualisation strategies comprising of methods and models such as predefined landscape models, and tools including 2D and 3D web viewers and globe viewers are highlighted in Chapter 10. An overview of visualisation tools used in the GMOSS context is also given.

Within Chapter 11, the implementation of the UNOSAT Grid is described which will, when fully operational, constitute a unique mechanism for using space based tools without worrying about computing power and storage capacity. This would be particularly relevant to actors involved in humanitarian assistance, early recovery and development.

In Part IV of the book, various applications relevant to national and international security implemented by the GMOSS network partners are considered. Until today a number of multi-lateral arms control treaties, conventions and export control regimes have been concluded in order to reduce the proliferation of weapons of mass destruction. Remote sensing data plays an important role in the verification process of some of these treaties. In Chapter 12 ‘Treaty monitoring’, a description of image processing techniques and tools developed for monitoring the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) as well as the Comprehensive Nuclear Test Ban Treaty (CTBTO) are given. Algorithms to automatically detect nuclear facilities in a satellite image are a first step towards the efficient verification of information provided by a Member State, thus reducing onsite inspections. Use of multi-spectral and synthetic aperture radar is another method for change detection to investigate changes in the built-up area and infrastructure within an area of interest. The analysis of hyper-spectral imagery is a way to detect for example uranium mine waste. Although satellite imagery analysis is not an element of the International Monitoring System for CTBT, it can provide, especially in combination with seismology, important information for the verification regime foreseen in the treaty.

Timely information is required to prevent or mitigate the risk posed to the civilian population by events either man-made or natural that affect their security. Different satellite observation techniques can be utilised, depending on the temporal dynamics of the event to be monitored. In Chapter 13 on ‘Early warnings and alerts’ the utility of low spatial and high temporal resolution meteorological image data is considered.

Human security means the security of individuals, households, societies or nations. Today there is still a tremendous need for population data for many regions of the world. Information on where and under what conditions people live remains limited especially for developing countries. During an emergency response, population information is used to estimate quickly the number of potentially affected people and their ability to cope with disasters in order to save both lives and to take care of the survivors. Information on population and on built-up infrastructure is also needed in order to plan the reconstruction process. A further contribution summarises state of the art and current work conducted within GMOSS regarding the use of earth observation and geospatial data to derive indicators for the presence of populations and their characteristics.

Effective border management and monitoring is a very important issue on the EU agenda. Issues relevant to this are described in Chapter 14. The modelling of border permeability according to environmental conditions is exemplified on the EU-25 terrestrial border and the Horn of Africa. The activities resulted in the definition of a border permeability index. In spite of the difficulties in obtaining ground truth information for validation of the analysis, the permeability maps illustrate the high potential of those spatial modelling approaches.

The usefulness of rapid mapping and damage assessment is discussed in Chapter 16. Fast and standardized techniques and algorithms are needed to assess accurately damages in the aftermath of disasters. In this chapter, a broad range of approaches for assessing damage using satellite imagery is presented. The research on the use of low- and middle-resolution, high-temporal optical, infrared and radar imagery for rapidly obtaining overviews of damaged areas, as well as how to use very high-resolution optical and radar imagery are discussed. The outcome of the research contributes to and supports Europe's capability to respond effectively to crises.

In the final chapter of the book, the editors have concluded that to realise fully the utility of earth observation within the security area, there is still a need to bridge the communication gap between scientists and policy makers. The aim of the book is an attempt to bridge this gap. Also by providing an initial introduction to the numerous capabilities that exist in Europe, it is hoped to enhance the European security.

Chapter 1
Definitions, Concepts and Geospatial Dimensions of Security

Clementine Burnley, Nathalie Stephenne, Dirk Buda, and Daniele Ehrlich

Abstract Several EU policy papers on security research have called for improved dialogue between security policymakers, social science researchers and science and technology researchers working in the area of security. In this paper, geospatial concepts and geospatial technology are introduced into this dialogue in order to improve the efficacy of communication. The explanatory power of these concepts has already been described theoretically. Their quantitative application using GIS and spatial statistical techniques poses challenges. Several technical issues still have to be addressed through a three-way dialogue in order to assist in monitoring European security policy. Generally, increases in the scientific knowledge base and in technology, are seen as enhancing state capabilities and political coordination.

Keywords Security concepts • security policy • geospatial concepts

1.1 Introduction

Several important policy papers on security research have called for an improvement in dialogue between security policymakers, social science researchers and science and technology researchers working in the area of security. This three-way dialogue is envisaged to enable timely research responses to global security challenges, which in themselves lead to the modification of security research policy. Within such a dialogue, the geospatial concepts have to be translated into technologies to address policy makers' needs and to test scenarios of political changes (Fig. 1.1). The geopolitical component of security policies addressed by technological tools is introduced in order to improve the efficiency of the communication.

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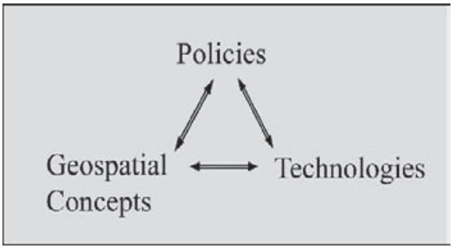
Fig. 1.1 Bringing geospatial concepts into the flow of spatial information between technologies and policies in order to improve the collaborative responses to global threats from the scientific and policy communities



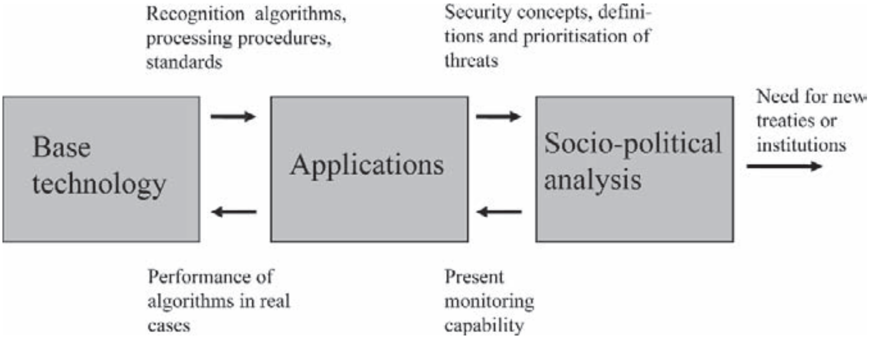


Fig. 1.2 Workflow between technological and socio-political work packages within GMOSS

One important task of this paper is to reconcile the demand for information from socio-political analysts with that supplied by geospatial technology including earth observation. The process can be handled by a workflow between socio-political analysts and earth observation experts (Fig. 1.2). This paper attempts to link these two communities by proposing definitions of security and the application of these definitions to spatial tools.

Section 1.1 will discuss the theoretical concepts surrounding the definitions of security and the historical evolution of the two main security definitions. We highlight the different focus of each security definition on risk to the state or to the individual and mention the consequences for scientific and policy responses. Section 1.2 describes the historical evolution of security policies at the regional level, focusing on the legal, institutional and political aspects of the European Economic Community (EEC), and later European Union (EU). This section illustrates the complexities of formulating security policies above the level of the state, in a changing global context and mentions some consequences for security research. Section 1.3 considers the use of technologies like earth observation, navigation and geographical information systems (GIS) in the context of the different security definitions, drawing on specific examples of both research and operational products. We pay particular attention to newly developing capabilities of remote sensing research to analyse and address the geospatial component in security problems.

1.2 Security Definitions

A wide body of literature has developed around the concept of security. It has commonly been defined in relative terms, by reference to an object at risk, threats to that object and measures which may be taken to safeguard the object. Therefore, security definitions, are context-dependent and non-absolute; denoting several, shifting and disputed understandings of risk, threats, objects at risk and safeguard measures (Booth 1990; Wolfers 1962; Garnett 1996; Buzan et al. 1998). Security has been described negatively as the absence of threats and the perception of threats to survival, or positively as the modelling of human needs, aspirations and potential (Wolfers 1962; Garnett 1996; Sen 1999). Defining an issue as a threat to survival is seen by some as a political strategy used by both states and groups (Ullman 1983). However, defining issues as survival threats carries certain dangers; one is to limit the range of response options to purely military (in the case the danger is to state survival), the other is to overstretch the security concept, emptying it of meaning by applying it to non-immediate dangers (Baldwin 1997). Security strategists usually define and prioritise threats on the basis of analyses from the scientific, security research and intelligence communities. The challenge for all involved is also to analyse associated probabilities and design preventive or mitigating strategies.

1.2.1 Theoretical Frameworks for Security Concepts

The two main schools of thought in international relations, realism, later followed by neorealism, and critical security studies, can be distinguished by the weight given to states, groups and individuals as both actors and objects at risk, and the importance placed on cooperation within the international system (Table 1.1).

1.2.2 Realist Definition: State Security

After World War II, security concepts were framed by the Cold War. The object at risk was automatically the state, which was the primary international actor. In an anarchic international environment the exclusive and primary responsibility of the state was the protection by military means of state borders, territory and

Table 1.1 Multilevel concepts of security (Buzan et al. 1998; Rothschild 1995; Möller 2003)

Whose security	Individual	Group/	State	International System	Planet
Which security	Economic	Political	Military	Social	Environmental
Whose responsibility	Regional Government	INGO's	States	Local Government	NGO's/ Civil society

citizens. The main threat to states was interstate conflict, thought to be inevitable given the essentially selfish, aggressive human nature (Hobbes 1651). Realist assumptions about security as a finite good achieved at the expense of other states compelled countries to take unilateral steps, often using military means, to protect their national interests. State sovereignty gave the state exclusive jurisdiction over internal matters and the interests of states were presumed to be the interests of the individuals and communities they contained. Maximisation of power was seen as the best defence for states against the "other" beyond the state border (Morgenthau 1948; Lynn-Jones and Miller 1995). This perspective conflates state survival with individual security, a position which ignores the problem of insecure states as sources of danger to their populations (Ayoob 1995). Postmodernist and poststructuralist theorists have challenged the realist view of violent conflict as natural and inevitable, seeing interdependence and international collaboration as both needed and actual (Buzan 1991).

1.2.3 Changes in Definition: Human Security

The Post-Cold War era has witnessed a shift in focus from the security of the state, conceived in terms of power, autonomy, territorial integrity and sovereignty to one which relies on the concepts of universal, indivisible, interdependent human rights, recognised and protected by international law enforced by states and international institutions. In particular, threat definitions have expanded from immediate threats to state power, borders and territory requiring military responses, to longer term, indirect threats requiring international political cooperation. The nuclear stalemate, the increasing weight of shared threats to states and to the global environment, as well as the increased focus on people and their needs have led to a shift towards conceptualisation of security as multiscale, inter-dependent and requiring a multilevel response not only by states, but by international institutions like the United Nations (UN) and regional organisations like the EU, North Atlantic Treaty Organisation (NATO) and Organisation for Security and Cooperation in Europe (OSCE).

The UN definition of human security is a rights-based definition, addressing the wellbeing of people at multiple levels of analysis from the individual, the community, the state, the region, or the entire global ecosystem (UNDP 1994). According to the United Nations Development Programme (UNDP), human security translates into "…freedom from fear, wars and pervasive threats to people's right, safety and lives…" (UNDP 1994). This human security definition takes into account the causes of fears and conflicts and focuses on the reality of individuals' actual situations rather than on state security. Human security is seen as complementary, but not identical to state security.

The human security concept is based on a normative perspective and is wide in scope. It has specific aims for global human wellbeing in multiple dimensions such as economic, environmental, food, personal, health, community, education, political, employment, and cultural. This definition is mainstreamed at international level in the United Nation organizations and is finding broad acceptance within the security policymaking community.

Within the human security concept, while states remain the primary international actors with primary responsibility for security, civil society is establishing a stronger role in supporting human security. Civil society here is taken to include the scientific community and non state-institutional actors. In this view, state security capabilities are seen to have increased through improvements in the scientific knowledge base, technology, and political coordination. Ecosystem protection agreements like the Kyoto protocol are an example of collaborative responses to global threats from the scientific and policy communities.

1.2.4 Criticisms of the Human Security Concept

The human security concept addresses economic, environmental, food, personal, health, community, education, political, employment, and cultural rights of individuals. This very broad scope and normative perspective has led to criticism due to potential difficulties in making it operational. In order to create the institutional mechanisms to safeguard human security, policy makers need to define and rank which needs, aspirations and capabilities can be realistically and systematically provided with available resources. This constraint leads to interpretations of human security which can narrow policy responses to immediate and direct threats such as violent conflict or natural disasters. Within an international security framework largely designed with the needs of states in mind, there are practical difficulties in designing international responses without the extension of current organisational mandates and without agreement from some insecure states concerned. These constraints do not, however alter the scientific task which remains to provide evidence-based theories, models and qualitative and quantitative data on causes, linkages and effective responses to security threats.

1.2.5 Gender Perspective in Security

Within the realist security concept, since the object at risk is the state and the interests of individuals are collapsed into those of the state, gender issues are ostensibly irrelevant. The difference in interests and situations of women and men is broadly assumed to be insignificant. Power and autonomy are the guarantee of personal, group and state security. The human security concept, with individuals as its focus, identifies civilians, particularly women and children as extremely vulnerable to all types of security threats and thus eligible for special protective measures. The human security definition takes into account individual rights, where gender can be specifically identified to play a part in determining different levels and types of security. Gender discrimination and gender equity are well recognised dimensions of human security. This approach is still deemed insufficient by some feminist theorists who nevertheless continue to advance a normative and multilevel view of security.

The gender perspective argues the importance of inclusion of both women and men in political decision making processes, policy decision making and economic activities (Tickner 1992). Empowerment and security for women are seen as indivisible, with the elimination of inequality for women requiring access to societal power and resources. While gender mainstreaming in security is a well known concept after the Beijing Platform for Action and adoption of UN Security Council 1325 on Women, Peace and Security, in practice, implementation is uneven, especially outside the countries of the Organisation for Economic Cooperation and Development (OECD).

The gender perspective on security describes a specific, gendered experience, with particular security needs of women and men which are different due to their different cultural, political and social influence. For example, people's vulnerability to environmental stresses and to natural disasters is affected by differential access to resources (food, healthcare, information, markets). A gender perspective in scientific analysis can distinguish any vulnerabilities specifically attributable to gender. The gender perspective on security also questions arbitrary divisions between public and private life which mean that physical security concerns for women (such as domestic violence) are relegated to the domestic sphere.

1.3 On Course for a European Security Concept?

1.3.1 Historical Development of EU Security Policy

European integration after World War II was driven by economic and political interests. These political interests included considerable security considerations which were initially, 'control by integration' of Germany and fortification of Western Europe as the Cold War developed and intensified. The 1970s saw major changes in the international system: superpower détente, the end of the Bretton Woods monetary system, conflict in the Middle East and an increasing divergence of interests between the US and Europe. The European project nevertheless continued, with political stabilization and integration of former Mediterranean dictatorships and most recently with the ambitious attempt at stabilization of the whole of Europe.

During this time there was an almost complete monopoly on security policy in all EEC Member States by NATO and national bodies. EEC Member States continued to deal with foreign affairs such as sovereign states within NATO and increasingly, in multilateral frames such as UN or OSCE without a notable political will to develop a common European security policy. Thus, all Member States followed in fact a 'realist' or 'neo-realist' security concept outside any EEC mandate. This fitted within the Cold War period state security paradigm described in Section 1.1, in the Cold War period where state power, autonomy and control of territory was paramount. Nevertheless, some Community policies that are relevant in terms of external action and security continued to emerge in the form of development cooperation policies, consolidated through the establishment of a Euro-Mediterranean dialogue a Community mechanism (later called office) for humanitarian aid Commission and a strong role of the EEC represented by the Commission in international trade business (within GATT).

Although important documents had advocated already at an early stage for more European political cooperation, including cooperation in the area of external policy and security, the structural economic crisis triggered initially by the 1970s OPEC oil boycott had aborted such plans and put institutional progress on hold. European Political Cooperation (EPC) emerged in 1971 as a first forum to discuss issues of foreign policy and security, although the word "security" was purposefully omitted. Even after its integration into the EEC Treaty in 1987, EPC never had any relevance at all in the area of security and foreign policy. However, a shift in threat perception occurred in Europe after the end of the Cold War, which also had some consequences for the pace of European integration. Existing transboundary challenges such as globalisation and environmental problems were brought to greater attention within the emerging human security concept. In the 1990s the fall of the Berlin Wall, the collapse of the Soviet Union and the violent break-up of Yugoslavia, exposed the extent of European vulnerability. All this finally paved the way for a Common Foreign and Security Policy (CFSP) under the Maastricht Treaty (consolidated subsequently by the Amsterdam and Nice treaties).

In recent years, there has been a growing consensus that the EU must address issues of political, economic and humanitarian security, internally and externally. On this basis, notable elements of European security relevant policy have been developed in the last 15 years, all EU treaty 'pillars' combined:

- Enhanced cooperation and assistance first, followed by association and integration of the countries of Central and Eastern Europe, association and stabilisation efforts in the Western Balkans and major cooperation and assistance to republics emerging from the former Soviet Union, more recently put in the context of a stronger comprehensive European Neighbourhood policy for both (new) Eastern and (old) Southern Neighbours, not to forget the increased development and humanitarian efforts worldwide (first pillar)
- Development of a more action orientated CFSP including a European Security and Defence Policy (ESDP), in particular through the establishment of the post of a High Representative held currently by J. Solana, Joint Actions and European security and crisis management missions, both military and civilian (second pillar)
- The development of a European policy for Freedom, Security and Justice (first and third pillar)
- The ever increasing role of the EU global trade and competitiveness policy within the World Trade Organisation (first pillar)
- The increasing role of external and security relevant aspects of Community sectoral policies such as environment, energy, transport, agriculture, fisheries, etc. (first pillar)

1.3.2 Legal, Institutional and Political Aspects Hampering the Development of a Coherent EU Security Concept

Despite these achievements, the formulation of a European Security Strategy (ESS) and a decade and a half of EU actions in foreign affairs and security, a clearly identifiable concept is still pending. Legal, institutional and, in fine, political factors have continued to hamper the development of a genuine comprehensive and coherent European, security policy based on a common security concept. The ESS itself contains important but only minimal programmatic elements of such a concept.

As regards security in a strict sense (external: military, defence; internal: police), despite the developments in CFSP/ESDP, Home Affairs and the recent 'solidarity clause', Member States are reluctant to delegate a main role to the EU. ESDP can still only be considered as complementary to NATO, other international coalition or national action. CFSP is clearly not a single Foreign and Security Policy for Europe, but only a common one that is being built up in addition to (and partially in competition with) the remaining national ones. There are several security relevant policies, not one common (or single) policy. The Nice Treaty (also the Draft Constitution) clearly indicate the continuous co-existence of national and EU Foreign and Security Policy

This, at first sight, impressive list of elements of EU security relevant policy highlights in fact the complexity of the institutional framework of the EU itself. The institutional dualism and dichotomy between Commission and Council combines with the different decision making processes and voting systems foreseen by the Treaty: qualified majority vote under the first pillar and almost exclusively unanimous votes under the second and third pillars The Commission is in the driving seat for the first pillar, but is also fully associated to CFSP; the Council is the main actor in the second and third pillar on the basis of intergovernmental rules, giving the EU Member States a decisive role. From an institutional point of view, Commission and Council are both responsible for 'overall coherence' but due to competition and also legal and institutional hurdles of the current treaties – these efforts are suboptimal.

The issue of the establishment of European capabilities relevant to security is certainly also important. Indeed, how can a coherent security concept or policy be developed without the necessary technical, administrative and financial means? In recent years, there has been a strong focus on the creation of the European Crisis Response capabilities, both for military and civilian purposes, complemented also by efforts to establish a coherent security research strategy. On the other hand, such tools and instruments can only effectively be used in a more coherent and streamlined EU institutional context. But also more general doubts are permitted that the 'capabilities' versus 'expectations' issue would be the real problem preventing a more coherent and effective European security policy.

Unsurprisingly, there are underlying political problems. There seems to be a lack of a political consensus among main EU Member States as to 'what extent' and 'how' the EU should address European internal and external security issues because the concepts and ideas of EU Member States naturally differ. But existing national concepts and policies of EU Member States may also be somewhat deficient when confronted with important questions and challenges prevailing today, such as: a role for NATO after the end of the Cold War, 'national security' challenges especially for the smaller EU Member States (and/or for those outside NATO), effective multilateralism, shadow aspects of globalization and their negative impact on sustainable development and security and finally, the choice of a comprehensive human security concept or a rather more selective approach, with specific EU economic and/or geopolitical motivations (as done by the US based on its interests).

The views of EU Member States about these challenges may differ significantly, but some of the Member States do not even see a clear need to address such challenges on their own (or via the EU). As a result, the political discussion between Commission, Council and EU Member States remains underdeveloped, hampering the formulation of a genuine EU security concept, which could also guide security research.

From a programmatic point of view, the EU seems to pursue a human security concept, in particular in multilateral fora. This is confirmed by relevant UN voting, in particular at United Nations General Assembly (UNGA) and Human Rights Committees (leaving aside special cases like Iraq etc.). In practice, however, EU policy is marked by a more eclectic and often incoherent approach, characterised by the co-existence of several security relevant policies as set out above, on the one hand, and missing important elements of core security policy (internal and external), on the other.

The Constitution in its current proposed form would not automatically reverse this. An organised process, with focus both on conceptual and operational elements of EU security policy and involving all relevant institutions at EU and EU Member States level would be needed in order to ensure the development of a more coherent EU security concept and its implementation in practice. A Common Service for External Relations would be necessary but only represent a point of departure for such process. Following lessons from European history one may conclude that the situation may well remain unchanged until the next major crisis. Europe seems to most, pre-disposed to changes and advances in integration as a response to major crises.

1.4 Spatial Component of Security

Spatial studies have historically addressed security in two different ways; to support diplomacy and external relations and to conceptualize and explain causes and development of conflicts. Firstly, geographers have been involved in "international relations" where geographical knowledge has been used to support military expansion, to foster peace and provide advice to policy makers (Mamadouh 2005). The most notable example is the use of "geopolitics" in the Darwinian theories largely exploited by colonial powers to rationalize the foreign policy of imperialism expansion before and during World War II (Foster 2006). In the second half of the twentieth century geographers have started to conceptualize and analyse the causes and developments of conflict and peace processes in political geography, international relations and geopolitics (Megoran 2004). Concepts used to address security like territory, power, borders, population distribution, competition for resources and distribution of ethno/linguistic groups have a strong geospatial component.

1.4.1 Spatial Concepts Related to State and Human Security Definitions

The spatial dimension of security issues (territory and border) has been theoretically addressed in socio-political studies whether security is defined as realist, state security or as human security.

The concept of "territory" is intrinsically linked to "power" and "sovereignty" of authority within a political community (Paasi 2003). Territory can be defined as the portion of space claimed by individuals, social groups or institutions. The definition of territories is a socio-political-cultural construction of space referring to identity and the difference between "us" and "others" (Schack 2000). Until recently, the "nation/state" was the only holder of territorial power in controlling its citizens. Since the recent changes in the geopolitical order, state territoriality has been unbundled by agreements and alliances between various territorial and non territorial actors. State territoriality is challenged by numerous actors that question the boundaries of formal state territories.

The human security definition is used to question the primacy of state sovereignty over individual well-being in international relations. The International Commission on Intervention and State Sovereignty (ICISS) pointed to a measure for abrogation of state sovereignty as "large scale loss of life, actual or apprehended, with genocidal intent or not, which is the product of either deliberate state action, or state neglect or inability to act, or a collapsed state situation; or large scale 'ethnic cleansing', actual or apprehended, whether carried out by killing, force expulsion, acts of terror or rape" (ICISS 2001). In the recent past, for example in Bosnia, Kosovo and Macedonia, state sovereignty was judged less important than the well-being of individuals and communities inside state borders, resulting in multilaterally organised armed interventions by some nations. The response of the international community is no longer to automatically support state sovereignty over individual interests. On the other hand, the human security concept can be co-opted to reinforce a classic state security concept if the intervention is purely to increase the security of the intervening state (Jolly and Ray 2006).

The demarcation of boundaries is fundamental to the spatial organization of people and social groups. The drawing of these lines is then an ongoing social and dynamic construction of territory (D'Arcus 2003). In the state security definition, boundary refers to the line separating two states while the border is the area surrounding a boundary (Pace and Setter 2003). In the globalization and regionalization processes, state boundaries are becoming more and more permeable to trans-boundary collaboration, borderland initiatives, and openness (Blake 2000).

But opening borders has not solely been seen as a positive development; anxieties and even fears have accompanied the process. The vast literature on “border drawing” and “territory disputes” illustrates the scientific interest in better understanding and mapping these geospatial concepts.

Once the scale of the analysis is changed, the safeguard measures required to provide security may be quite different; groups and individuals may achieve security in different ways to states. A group response to violence may be to challenge the state, often with the help of external parties. The individual response is often to abandon the territory. When such movement takes place across international borders other international challenges are triggered. Migration may result from the movement of groups of people who feel unsafe in their state because of armed conflicts or large-scale natural disasters. Mobility is one of the most crucial elements of globalisation, conceived in terms of free movement of information and capital. Border crossing is a somewhat different matter, as it impinges on state concepts of border security; as a result of this and for other reasons refugees end up being highly insecure (Giles and Hyndman 2006). Spatial patterns of exclusion can be shown in many places around the world and the long term displaced are the most insecure part of the world population.

1.4.2 Spatial and Quantitative Analysis of Security

While of high political interest, the spatial dimension of security concepts – so common in political and social sciences has been seldom addressed in quantitative studies (Starr and Most 1976). Moreover, the change in the security paradigm from state to human security brings environmental and demographic components that increase the interest of subnational studies but also the spatial quantitative methods already used by geographical and environmental disciplines.

Two different ways of quantitatively studying the spatial dimension in security issues can be distinguished in the literature of the last decades. Until recently, the spatial concepts seen as relevant causes in global studies of interstate conflicts have been state territory and proximity (distance between capital, centroids or shared borders) introduced as categorical variables in regression models using countries as the unit of analysis. While military security is usually discussed at the state level, control of territory – such as that enforced by police forces has to be effective at the sub-national level, including ethnic conflict, resources monitoring and security of people. A second body of literature calling for a larger use of georeferenced data in intra-state security research is beginning to emerge. As contemporary wars are, by and large, civil conflicts, any statistical study of wars that applies country-level statistics is therefore “potentially flawed” (Buhaug and Rod 2005). A growing number of studies use GIS-layers generated from physical and socio-economic data to define the determinants of violence that occur at local level including the illegal mining of gemstones, the illegal cultivation of illicit crops or other natural resources such as oil or forest that are used to finance antigovernment force. In fact, there is new consensus among researchers that conflicts or structural indicator data at subnational level – corresponding to the limits of districts or provinces – would improve statistical models by increasing the number of observation units. But for most of the important themes related to security the data sets still need to be generated.

1.4.3 Geospatial Technologies for Security

The quantitative analysis of security issues benefits from geospatial technologies. Earth observation and navigation provide high precision measures of spatial entities and events. Geographical information systems (GIS) allow quantitatively to process geospatial information. The cartographical representation of these spatial measures remains a fundamental discipline for the dissemination of information.

1.4.3.1 Cartography

Geopolitical and political geography rely on maps to display features of high relevance to security (Hay 2003). In paper or digital format, maps act as a powerful visual communication tool that helps the interpretation of data and strengthens the message delivered through text (Denisov et al. 2005). Maps are also used interactively in political consultation processes (Rekacewicz 2006). A number of scientific challenges need to be addressed in this participatory use of maps. For example, the cartographic representation of international boundaries in addressing disputed areas between two countries is critical. The historical change in territory and borders requires a precise representation of historical maps that are now available at different scales, in different projections and with different semantics. This lack of standardization makes quantitative analysis very difficult.

1.4.3.2 Earth Observation

The production of security information in the form of images is still shaping politics (Edwards 2000) even if not as evidently as during the second war. Earth observation data has progressively become a source of updated geospatial data that when combined with field information (see Section 1.4.3.3) can be used as a visual tool for decision makers in negotiations (Starr 2002). For example, satellite imagery and digital elevation models (DEM) were used operationally during the negotiations for the delineation of the international border between Bosnia and Herzegovina and Serbia (Wood and Smith 1997). Satellite imagery is also widely used to assess damage in the aftermath of a conflict in support of needs assessments for reconstruction purposes (Ehrlich et al. 2000; Pesaresi et al. 2007).

Satellite imagery is sometimes used for visualization purposes in the decision making process (Moshe 2000) but is more extensively integrated in creating grid-based/raster data sets of spatial socio-environmental indicators. Data sets of physical factors that relate to security like topography, elevation, land cover, natural resources and population can be built or improved using these remote data. The new generation of globally available digital elevation models allows more realistic representation of landscapes, a feature that can be used also in addressing security issues. The frequent revisit time of Earth observation satellites can be used to monitor security issues including illegal crops in crisis countries as reported by the United Nations Office on Drugs and Crime (UNODC for Colombia, Afghanistan and Burma) or illegal timber harvesting that can provide insights in revenues that fuel civil war and insurgencies. On a more general level remote sensing is providing geospatial features – often from archive data sets that are incorporated in a number of geospatial products used in security research that include natural land resource assessment and population density estimations.

1.4.3.3 Navigation

Navigation technology enables the retrieval of precise geographical information on events or processes measured on the ground. Field data can be collected using hand held equipment and classified based on a standardized damage reporting template (Ehrlich et al. 2006). Digital cameras would provide evidence on the assessment from the field reporting officer, GPS receivers would provide geographical standardization. Hand held imaging devices are increasingly used for field data collection. The current trend is to connect them to GPS receivers in order to provide field data that are geo-referenced and that can be included in GIS's. The information from field data can then be used to improve the analysis. The information from a number of field pictures can then be extrapolated to different grids within the grid based reporting.

1.4.3.4 GIS

GIS offers three invaluable opportunities in the analysis of geospatial data: (i) improved cartographic output capability for visualization, (ii) efficient tools and techniques to integrate different data sources, and (iii) ability to quantitatively analyse geospatial data.

The cartographic functions of GIS's can be used to make decision-making more transparent, to analyse options more thoroughly and to present results more convincingly especially for security issues (Wood and Milefsy 2002). However, to harness the potential of GIS, the issues of data completeness and data quality need to be addressed. For example, data sets need to have associated appropriate geographical information that allows them to be geo-referenced. Often, even if available, sub-national geospatial data are not as complete as country-level information. This includes not only military expenditures that are typically computed at national level but also political or economic data that should be available at sub-national level.

GIS tools possibly combined with satellite imagery can provide a continuous spatial representation of variables such as road density; population density, distribution or ethnicity; land cover or natural resources, among different layers. The GIS tools built to support humanitarian aid include road and river network information to precisely locate the civil population needs (Wood and Smith 1997) or the accessibility of damaged regions (Ehrlich et al. 2000). Digital elevation models (DEM) derived from radar, laser or optical imagery can be used to derive slopes aspect and elevation that for example can provide physical characteristics along borders or over large areas. Gridded data sets of rainfall, as well as other environmental variables such as land cover or extraction of natural resources are built using remote sensing data and can be used as spatial indicators in a geospatial model of security. Rainfall also prevents conflict in regions where a rainy season effectively hinders road transportation and therefore the ability to carry out warfare. Gridded global population data sets in which latitude/longitude quadrilaterals are used as the units of observation have been developed to address environmental issues (Tobler et al. 1995). These GIS tools using raster data can also propose some solutions to the overlapping issue of some of these data, as the fuzzy and situational character of ethnicity (Fearon 2003). These georeferenced data sets could be a basis database that has to be increased in its spatial and time extensions to geographically model the instability of these regions.

GIS tools not only provide the structure to build grid based data set but also some tools to integrate and overlay the different data sets and to provide spatial indicators such as proximity, shape, size, buffering, accessibility, vulnerability or border permeability. The GIS allows modelling of different spatial characteristics in a whole system based on the conceptual interactions existing between these characteristics. The model is a tool to predict and simulate "What if" scenarios that help to better understand the system. Accessibility measures integrating land use and transport information are used in environmental and economic applications (Ritsema van Eck and de Jong 1999). Border permeability models the sustainability of border crossings for illegal migrants (Stephenne and Pesaresi 2006). This permeability is calculated using a multi-criteria fuzzy decision support system integrating spatial data sets including remotely-sensed satellite data, and information on land use, land cover, DEM, weather and environmental conditions, presence of population, infrastructures, and physical obstacles, and the presence of controlling border police. Modelling spatial and temporal alternatives of the security issues is an important challenge in the overall goal of the political geography, geopolitics and international relations.

1.5 Conclusions: Geospatial Concepts and Tools to Support EU Security Policy

The preceding sections have sketched out interactions between security concepts, security policies and scientific research. Generally, increases in the scientific knowledge base and in technology, are seen as enhancing state capabilities and political coordination. At the level of the EU Member States, but also the enlarged EU as a whole, the relationships with neighbouring countries were modified, creating a need for more active EU security policies (internal and external). European vulnerability at the fall of the Berlin Wall, especially its exposure to armed conflict in the Balkans, paved the way for a Common Foreign and Security Policy (see Section 1.3.1). The creation of European Crisis Response capabilities, both for militarian and civilian purposes, contributed to developing a security strategy. At the level of research, ongoing changes to the map of Europe also caused changes to the European security research strategy. A specific geospatial security research strategy is part of the next Framework Programme (FP7, see Chapter 2). All this should also contribute to a more coherent definition by the EU of its security interests, of a coherent EU security concept and of instruments to implement such a concept.

This document further maintains that geospatial technology and geospatial concepts can help in monitoring European security policy. In fact, the cartographic representation and threat scenarios produced by geospatial scientists are requested by political scientists to improve the information delivered to the decision makers. Earth observation and complementary geospatial technologies that include navigation and geospatial information systems can be used to complement the current information flow to decision makers. Researchers have the responsibility both to use geospatial concepts and methods and to communicate these concepts and the results of the analysis in a suitable way to negotiators (Wood and Milefsky 2002) and decision makers. This would require coordination and better communication between technologists and political scientists. The use of GIS with its user friendly interface and tools to provide information products in the form of maps can help in this coordination process.

Several existing links between security policies and geospatial analysis have been highlighted in this chapter. The emerging concept of human security requires geospatial variables to be quantified. This chapter has also addressed the capacity of geospatial technologies to deal with evolving security definitions. In fact, a number of geospatial concepts have been used in security research. The emerging technologies could help researchers to apply such geospatial concepts to obtain spatial quantitative indicators. The explanatory power of these concepts has been described theoretically and can now be applied in a quantitative manner using GIS and spatial statistical techniques. For example, borders can be seen as a discontinuity in processes (demographic, economic, etc.) that can provide insights on future disputes. These spatial and dynamic aspects of borders can be quantified using fuzzy analysis techniques within a GIS.

Evidence-based theories that explain security threats would require models and qualitative and quantitative data on their causes. A number of challenges are posed to the research community. Geospatial indicators quantifying threats have to take into account their historical evolution. Current spatial statistical techniques that are static in nature will have to include also the time dimension. The lack of GIS maps for the temporal span of the conflict data needs to be addressed for effective security modelling (Buhaug 2003). Conflict data sets will need to be disaggregated or made available with information at local level. For example, gridded conflict event data sets could be developed. These in turn could be combined with structural indicators in a dynamic approach that is a promising but challenging geospatial research avenue. Integrating the precise representation of spatial entities, location changes and system dynamics remains an important future research orientation (O'Loughlin 2003).

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Chapter 2
European Security Policy and Earth Observation

Anthony Cragg, Dirk Buda, and Albert Nieuwenhuijs

Abstract This paper gives an account of the activities of the GMOSS Working Group studying issues and priorities for European security. It draws on the European Security Strategy (ESS) and other major policy documents to provide a summary account for the general reader of the strategic challenges facing the EU and its response. It then considers the role which EO can play in the Union's strategy for responding to these contingencies with particular reference to the wide range of potential customers for imagery within the EU structures and the contribution which EO can make to crisis management.

Keyword EU security strategy

2.1 A New Security Landscape

There has been a radical change in European security priorities since the establishment of governments in Central and Eastern Europe in 1989, committed to democratic principles and to membership of NATO and the EU. With the dissolution of the Warsaw Pact in 1991 and the gradual emergence of the EU as a significant player in international security, the focus of European security has moved from the confrontation of massed forces on the inner German border and in the North Atlantic to a commitment to a broadly-based concept of international security within and beyond Europe allied to a spectrum of potential crisis response options ranging from diplomatic and humanitarian intervention to military action.

New philosophies and strategies have been developed which reflect this fundamental shift in European and wider international security priorities. These include,

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in particular, the UN's Agenda for Peace (1992, 1995); NATO's Strategic Concept (1999); and the European Security Strategy (2003). All acknowledge new threats and risks and see crisis management and peacekeeping as a key security challenge to which international organisations must rise.

At present, the UN, it is running about 20 peace operations and thus contributes greatly towards the maintenance of stability and in the regions in which it is currently engaged. NATO also played a significant part in bringing the civil war in former Yugoslavia to an end and learned much from the crises in Bosnia–Herzegovina, Kosovo and Afghanistan in terms of strategic political direction, the conduct of operations and post-conflict peace-building. This was reflected in decisions of the Madrid (1997), Washington (1999) and Prague (2002) Summits aimed at improving crisis management mechanisms and bringing greater flexibility to the Alliance's forces.

For its part, the EU is committed to being able by 2010 to act with rapid and decisive action applying a fully coherent approach to the whole spectrum of crisis management operations covered by the Treaty on European Union. A range of instruments is at its disposal, ranging from political and diplomatic initiatives through measures such as trade, aid and humanitarian relief to the possibility of military intervention within the framework of the Petersburg Tasks set out in Article 17 of the Treaty. These are an integral part of the Common Foreign and Security Policy (CFSP) and European Security and Defence Policy (ESDP), and range from humanitarian and rescue operations to crisis management including peacemaking. Joint disarmament operations, support for third countries in combating terrorism and security sector reform are also seen as potential tasks.

The EU has had limited practical experience of military operations to date. They comprise the short-term operations: Artemis (DRC – 2003); Concordia (FYROM – 2003); and the longer-lasting and potentially more demanding Operation Althea, which saw the takeover of responsibility from NATO in Bosnia–Herzegovina towards the end of 2004. It has broad experience, however, of the use of 'soft power', including in particular, police and other rule of law missions, including border monitoring and security sector reform aimed at contributing to stability and security. Indeed, of the 13 operations in train at the beginning of 2009, 10 were of this nature rather than military.

2.2 Major Threats and Risks

The principal security challenges faced today by the EU were set out in the ESS approved by Heads of State and Government in December 2003. These are:

- Terrorism
- Proliferation of weapons of mass destruction (WMD)
- Regional Conflicts
- State Failure
- Organised Crime

The ESS also recognises that poverty, disease and economic failure can lead to the breakdown of societies and that competition for natural resources is likely to lead to instability, with energy dependence a special concern for Europe.

2.3 Strategic Objectives and Policy Implications

Against this background, the ESS identifies three main strategic objectives:

- To tackle these key threats by means of a mix of military, political, economic and other instruments, including humanitarian intervention and law enforcement. The EU is particularly well equipped to respond to crises in a multi-faceted way.
- To build security in the EU's neighbourhood by promoting a ring of well governed states to the east of the Union and on the borders of the Mediterranean. The stability of the Balkans region and a resolution of the Arab/Israeli conflict are strategic priorities for Europe.
- To support the development of an effective system of international security based on a strong United Nations and other international bodies, flourishing transatlantic relationship and commitment to upholding and developing international law.

To achieve these objectives, the ESS sets out a broad policy framework which envisages that the EU should:

- Become more active in pursuing strategic objectives by developing a culture which fosters early, rapid and, where necessary, robust intervention, including a willingness to act preventatively
- Enhance its military and diplomatic capability, including by means of common threat assessments, the pooling or sharing of military assets and a greater capacity to bring the necessary civilian resources to bear in crisis and post-crisis situations
- Improve coordination and coherence among EU policy instruments, including the military and civilian capabilities of member states, diplomatic efforts, development, trade and environmental policies, and assistance programmes
- Foster multilateral cooperation in international organisations and seeking strategic partnerships with nations and regional groupings which share the EU's goals and values

2.4 The Information Requirement

An up to the minute, clear and all-embracing information picture is an essential requirement to enable the EU to conduct the full spectrum of its security policy from situation monitoring to crisis management. Earth observation from radar, infra-red and optical means of acquisition, is an essential contributor to this picture and complements other information ranging from open source data to classified material such as confidential political reporting and secret intelligence.

Information support to policy makers in the conduct of CFSP/ESDP and of security-oriented business managed by the Commission will need to be fast, precise and flexible. For example:

- A broadly based approach is required. This is needed in order to manage today's security issues as compared with the military 'bean counting' of the Cold War. A consolidated analysis of a wide range of factors – whether humanitarian or military – is required, drawing on information provided from many sources, including earth observation.
- ESS also makes it clear that the EU must be ready to act before a crisis occurs by pre-emptive engagement to prevent a situation from deteriorating. This will require flexibility in responding to demands for information by policy makers. Practical experience demonstrates that a stream of information in near real time is required by policy makers exercising strategic political control over an operation.
- Peacekeeping operations demand precisely focused information to help define and support the minimum force required to secure an operational objective. The successful handling of a humanitarian crisis also demands similarly precise and focussed information to support the delivery of aid as rapidly and effectively as possible.

2.5 Customers

The EU Satellite Centre (EUSC) is the focal point for the acquisition and analysis of satellite imagery to support the operations and missions of the EU and memeber states including, for example, military operations, police missions and security monitoring tasks. Given the complex institutional framework of EU security policy, the range of potential customers for this imagery is considerable and includes:

- The General Affairs and External Relations Council (GAERC). This is the senior ministerial body which is ultimately responsible for the EU's external relations and strategic issues.
- The Political and Security Committee (PSC). This meets at ambassadorial level and is the central body for the conduct of CFSP/ESDP. It provides political control and strategic direction for the EU's response to crises.
- The High Representative. The principal adviser of the PSC and in day to day charge of foreign and security policy on behalf of the Council.
- The Policy Unit. Its role includes monitoring and advising on developments relevant to the CFSP (including early warning of potential crises) and policy advice on crisis management.
- The Situation Centre. Supports the High Representative, the Policy Unit and the EUMS in the task of monitoring developments, providing early warning

of potential crises and support for crisis management, including, in particular, provision of the integrated information picture for policy makers.
- The Military Committee. The senior body responsible for providing military advice to the PSC.
- The EU Military Staff (EUMS). This is responsible for the day to day management of military aspects of the ESS under the guidance of the Military Committee.
- The Civilian Planning and Conduct Capability (CCPC). Plans and conducts civilian crisis management operations
- The European Commission. A key contributor to CFSP and responsible for the implementation of a wide range of EU policies relevant to security, whether external with respect to third countries (humanitarian, development assistance, trade, sanctions, etc.), or internal (justice and home affairs, energy/transport, public health, environment, etc.).

2.6 Earth Observation and Crisis Management

Much practical experience of the gathering, processing and dissemination of information in a crisis management situation is available from recent operations. Against this background, the following broad approach to the principal demands for earth observation support can be envisaged:

- *Pre-crisis*: broadly-based routine observation in the context of the ESS, counter-terrorism and counter-proliferation policies to support the Situation Centre and other bodies as required. Other useful areas for pre-crisis or conflict prevention include the monitoring of resources in developing countries which are potential focal points for crises (including, for example, diamonds, timber and water) as well as applications for humanitarian purposes such as the monitoring of crops for food security.
- *Developing crisis*: flexibility to facilitate rapid focus on emerging problem and crisis management planning. This might include on the one hand assessing the impact of natural disasters or of indicators of potential crises, such as movements of troops and refugees and on the other supporting the preparation of humanitarian or military operations.
- *Crisis situation*: contribution to political management of crisis including humanitarian interventions and any military or police involvement in crisis management. All will require high quality information in near real time
- *Post-crisis*: contribution to management of post-crisis phase will require flexibility, accuracy and precision. This will include supporting damage assessment and tracking post-crisis humanitarian aid, recovery and reconstruction programmes, the monitoring of military disengagement, including disarmament and demobilisation and possibly specific observation tasks linked to the implementation of peace building agreements, such as the monitoring of large-scale

movements of displaced persons and refugees, borders or other disputed areas, critical infrastructure etc.

2.7 Targets for Earth Observation

It is possible to identify from the ESS and other key EU policy statements – notably the Declaration on Combating Terrorism and the Strategy against the Proliferation of WMD – a range of priority targets. These include:

Regional Problems: EU Neighbourhood, including the Wider Middle East and the Western Balkans; the Great Lakes; Kashmir; the Korean Peninsula.

State Failure: Somalia

Terrorism: security of transport systems; protection of key points; essential services (e.g. water, energy, communications); consequence management. Many of these requirements will, of course, be national responsibilities but it is possible to envisage a coordinated international response under some circumstances.

WMD Proliferation: treaty verification; monitoring of export controls; interdiction of illegal procurement; security of procurement-sensitive items (e.g. spent nuclear fuels); illegal trafficking; cooperative threat reduction; monitoring regional instability and state proliferators.

Organised Crime: heroin trafficking from Afghanistan via Balkans criminal networks; trafficking of women; illegal migration; maritime piracy; illegal weapons trading.

Humanitarian Relief: the extent and impact of natural disasters and humanitarian crises.

2.8 Recent Work

2.8.1 Earth Observation in the Overall Information Picture

The GMOSS research programme concentrates on a range of applications of potential value to the conduct of EU security policy. This includes treaty monitoring, early warning, damage assessment, and population, infrastructure and border monitoring. In order to support this programme and as part of the overall objective of developing advice and operational guidelines on EU priority security issues for the GMOSS research community, a range of examples have been identified in which earth observation might be able to contribute to managing the major threats and risks faced by the EU. These include the following:

(a) Regional conflicts or potential conflict (including failed states). Earth observation is likely to be able to contribute significantly to the monitoring and managing of such situations. This includes border monitoring, change detection, monitoring of longer term infrastructure developments in military facilities or important infrastructure of civilian nature and the provisions of early warning of troop movements, particularly in border areas. This may also include the identification of ecological changes and/or disputes about natural resources (for example water, oil and other minerals, etc.) that can lead or contribute to regional instability.

(b) Counter-terrorism. Earth observation might be able to assist in the identification of training camps in states supporting terrorism or the movement of personnel and weapons and perhaps contribute to the monitoring of key points for security purposes.

(c) WMD proliferation. Nuclear facilities appear to be suitable for monitoring. Chemical and biological capabilities are likely to be more problematic both to identify and monitor and biological the most difficult. Earth observation also has the potential to help in sustaining the basic policy building blocks of counter-proliferation policy, notably: multilateral agreements; the promotion of a stable international environment; close cooperation with key partners; and political action against state proliferators.

(d) Organised crime. There is potential for using earth observation to detect poppy, coca or other illicit crops and the illegal exploitation of natural resources such as logging or mining. On the maritime front, the space-based detection of vessels might be used in order to support action against maritime piracy and organised trafficking of persons, arms or other illicit items.

(e) Humanitarian relief. Earth observation could be used for the identification of useable infrastructure such as ports, roads, railways and airstrips; checking possible locations for establishing relief facilities such as refugee camps and temporary hospitals; and obtaining information on the extent and impact of natural disasters.

2.8.1.1 Prioritisation

Work has also been undertaken with the aim of helping to prioritise the GMOSS scientific, technical and training programmes, This entailed conducting an evaluation of the current implementation of EU security policy by means of a detailed review of:

(a) The EU's overall security policy orientation, as set out in particular in the ESS, and

(b) The practical application to third countries of the EU's main instruments and tools for addressing global security

While the existing global threats, risks and priority targets are identified by the ESS and other main policy documents, any assessment must also take into account the EU's practical capacity to address these threats or security challenges (mostly in close co-operation with the international community, UN, NATO, etc.). In turn, this capacity is defined by both the EU's political will (and interests) and the existence of necessary instruments and means to address these threats or security challenges. In both respects, the EU's capacity varies considerably, depending on the country (or region) concerned.

The evaluation of the current geographic priorities of EU security policy has been based on a balanced analysis of issues and parameters, including:

- Threats and security challenges identified in the ESS (regional instability, international terrorism and WMD proliferation)
- General policy orientations as deriving from ESS and other main EU policy documents (preventive engagement, effective multilateralism, transatlantic partnership and other strategic partnerships)
- ESDP action (EU police or military missions)
- CFSP (Joint Actions and Common Positions)
- Presence of EU Special Representatives
- EU Common Strategies
- EU sanctions based on UN Security Council Resolutions and other restrictive measures (arms embargo, freeze of funds, visa restrictions, etc.)
- EU Official Development Assistance

Cumulative points, or in specific cases, weighted points (for example for EU Official Development Assistance) were attributed to the countries concerned. The resulting overall scores and classification, ranked from 'low' to 'very high' priority mainly confirm the geographical priorities as set out in the ESS. The resulting picture can be considered as the (current) areas of particular EU interest:

- The Western Balkans and the European neighbourhood (almost all countries classified 'very high' to 'medium'), with extension to several countries of the wider Middle East and adjacent Asian countries (including Afghanistan, Pakistan and countries of Central Asia)
- Great Lakes Region in Africa and some other selected developing countries in Africa and Asia

In summary, prominent countries of conflict or post-conflict such as Iraq, Afghanistan, Serbia and Montenegro/Kosovo or Bosnia and Herzegovina are ranked 'very high' or 'high'. Latin America seems to have overall 'low' priority while the ranking of nations in Africa and Asia appears to depend on regional instability concerns.

A frequent common factor is the contemporaneous involvement of both the EU and other multilateral actors (UN, OSCE, etc.). In practice, the EU is almost always present in or supporting countries when multilateral action (based on UN Security Council resolutions) is being taken. The EU often uses the full range of EU policy instruments from a security presence to development aid. Thus, apart from being a programmatic objective set out in the ESS, effective multilateralism is a principle that is already being applied in practice in the implementation of EU security policy and therefore can be seen as an important criterion in the conduct of security policy and for the use of satellite monitoring.

2.8.2 Emerging Crises

Given the high priority of conflict prevention and crisis management within security policy, a potentially fruitful field of study is the scope for assessing the likelihood for instability of countries (or regions) and their respective ability to cope with conflict. Work is therefore in train on:

(a) Longer term indicators of socio-economic performance (for example, human development, demographic stress, governance, etc.) with the aim of creating a relative index of conflict risk
(b) The use of short-term, news-based country monitoring to identify emerging crises

As a first step, two different means of generating event data for use in early warning of country instability have been considered. The approach adopted was to compare machine coded news from Reuters with news produced by field reporters in a local information network in Pakistan. An assessment of the performance of the two approaches over the period 2000–2004 concluded that both provided dynamic data to supplement structural data for early warning purposes. Both approaches also generated sufficient numbers of events relevant to country stability for the construction of event-based early warning country stability indicators. The second step of the study will coordinate structural rankings and event data with the aim of developing a comprehensive picture of global instability risk in order to help decisions about areas on which to focus EO effort.

2.8.3 Classification of EO Data

In order to help policy makers assess the extent to which earth observation can contribute to the information required for managing individual crises, work has started on devising a means of relating the requirements of customers to the technical product offered by earth observation satellites. Terminology has been developed for the customer to use in order to specify his requirements in non-technological terms which in turn can be translated into technical requirements by earth observation specialists, thereby enabling the feasibility of each requirement to be assessed. This should enable a rapid assessment to be made of the extent to which earth observation can respond to customers' demands.

Within the GMOSS project, this methodology could be used:

- To identify new applications for existing earth observation platforms and techniques
- To provide a clear common frame of reference

The main use of this methodology beyond the GMOSS community would be to determine objective criteria for assessing at an early stage in the emergence of a crisis the extent to which earth observation is likely to contribute to the overall information picture. Such issues as the type, size and complexity of the target, whether it is dynamic or static and whether there is repetition are examples of factors likely to be of significance in reaching conclusions about the utility of earth observation in monitoring individual cases of natural disasters or crises driven by political or economic factors. This is intended to assist in the commitment of earth observation resources towards creating the required information picture.

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http://www.consilium.europa.eu/cms3_applications/applications/newsRoom/loadBook.asp?BID=80&LANG=1&cmsid=978
http://www.weu.int/documents/920619peten.pdf
EU External Relations (General and CFSP)
http://ec.europa.eu/comm/external_relations/index.htm
http://ec.europa.eu/comm/external_relations/cfsp/intro/index.htm
NATO (on-line library)
http://www.nato.int/docu/home.htm

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UN (peace and security issues)
http://www.un.org/peace/
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http://www.weu.int

Chapter 3
Satellite Based Information to Support European Crisis Response

Stefan Voigt, Jiri Trnka, Thomas Kemper, Torsten Riedlinger, and André Husson

Abstract This chapter presents a critical review of current state of development of European capacities in the domain of satellite based information for civil crisis response in Europe and worldwide. New global security challenges require new technological solutions to answer the civilian security monitoring tasks of an enlarged European Community, acting in a more globalised world. Different crisis types and patterns require different analysis and response capacities. Various initiatives and projects exist today, which work towards European satellite analysis capacities for civil security issues. Mechanisms like the International Charter 'Space and Major Disasters', the EC initiative on Global Monitoring for Environment and Security (GMES) or the Group on Earth Observation Systems of Systems (GEOSS) provide a basis for forging and expanding such capacities. Today, especially the scientific community and research initiatives provide substantial information support and analytical capacities to member states and the bodies of the European Community. One very interesting and promising tool to further develop satellite intelligence for civil security issues through the conduct of coordinated analytical exercises in distributed research networks and thus to test strengths and weaknesses of the current state of the art technology and methods available. It can be concluded that the first elements of a European civil security analysis infrastructure are materializing; however, further efforts and coordination mechanisms are necessary to build respective operational and fully analytical and coherently acting capacities within Europe.

Keywords satellite • crisis • disaster management • response • exercise

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3.1 Introduction

Present development of globalisation and societies – industrialization, urbanization and most prominent: computerization – has lead to a closer interconnection among all levels of human activities as well as an increasing complexity of the technological systems. This increasing complexity, together with the instability in some regions of the world, contributes to an unpredictable nature of present and future crises with the risk of catastrophic losses. It is impossible to say whether crisis situations will occur more frequently in the future; however, it is certain that they will have more complex consequences than today. Thus Europe, just as much as the rest of the World, faces new security challenges.

Future crisis management capacities have to adapt to these global developments and dimensions. Many of these security threats do not stop at state borders and hence have an international and increasingly global dimension. Furthermore, the linkage between environmental and security related aspects have been recognized for several years now. There is growing evidence that environmental threats most often have international implications of relevance at much wider scope than, lets say, the plain ecological aspect of it. In other words, the threats to the European security are no longer a mass army of ‘blue’ or ‘yellow’ tanks, however, it is more an increasing number of complex issues including food security, shortage of natural resources (among which water is playing an increasing role), natural or man-made hazards, public health, cross border trafficking, energy supply, deliberate marine pollution as well as terrorism or clandestine nuclear activities. A long list of examples could be given for such security issues and this would go far beyond the current geopolitical crisis situations in the Middle East, the attempts to contain terrorist activities or the large ethnic and failing state issues in Africa.

In the European dimension, this means that policies as well as interventions may have to more often address other parts of the World in order to prevent the escalation of crisis situations at early stages, before they have a negative impact on Europe or other parts of the World. This also means that awareness and interventions are required around the World in order to ensure security and safety for the European citizen. In other words, Europe needs to move closer together and to cooperate more efficiently in order to respond to the current and future crisis situations in a more proactive and successful way.

One can already observe shifts away from the traditional, national security concepts (state-centred view of security) to more global security perception (collective security). The work towards a Common Foreign and Security Policy (CFSP) in Europe and the beginning of setting up the required common response mechanisms are examples for how Europe is developing its joint capabilities and thus answering to the increasing responsibilities. Developing and exercising these joint capabilities is, however, becoming an increasingly challenging task. This is especially the case in light of an increasing number of the European Union member states. In order to maintain a high security level for citizens of Europe as well as to contribute to a better and safer world, an active contribution of all members and sectors of the entire EU is required. Information and communication technologies are one of the key pillars helping to achieve this goal. Many of the increasing challenges to facilitate more effective crisis management in the future will rely on fast and reliable situation assessment, building on new technologies. Thanks to its strategic and multi-purpose nature, space technology can support such a comprehensive approach to global security issues. In this context, the use of satellite imagery and satellite derived geospatial information can facilitate more accurate crisis response decision making. This chapter reviews crisis response patterns in order to assess the operational capabilities and performances of current and future satellite based observation and monitoring systems with regard to the increasing demand for space-derived information linked to security issues. The work shall contribute to an improved flow of reliable information from the satellite data analysis experts to the decision making and policy support actors in Europe.

3.2 Crisis Patterns Relevant for Europe

The effective handling of a crisis is central not only to the EU's security responsibilities. It requires an exact understanding of the different crisis situations, their possible impacts, mechanisms and actors.

There are in general four broad classes of crisis:

- Technological crisis types refer mainly to the breakdown of utility networks (electricity, water, gas, oil, etc.) and communication networks (telephone, Internet), which include also technical process failures and accidents that lead to large scale contamination and endangerment of the population.
- Natural crisis situations include all types of fast onset natural disasters like earthquakes and tsunamis, floods, storms, or large scale fires. Additionally, also slow onset crisis like droughts and effects of global warming are summarised in this category.
- The term "complex crisis" describes the often interrelated conglomerate of riots and civil commotion, terrorism, civil wars and coupes d'état, which may be induced by strong demographic changes or supply shortages.
- Economic, financial crises, which cover stock exchange crashes, resource shortages, market failures or bankruptcies.

Damages and impacts caused in the context of such events are not necessarily a crisis or a disaster. They may be grouped into emergency, crisis or disaster, based on their impact and the existing coping capacity (Fig. 3.1). A harmful event with a low impact and a high coping capacity is defined as an emergency; for example a common car accident in a European country has a small impact (despite the effects on the people directly involved) and usually a high coping capacity is available, because emergency services will be available with sufficient capacity and at short notice. A crisis is defined as an event/situation with a medium to high impact and a low to medium coping capacity available. In a country with a high coping capacity

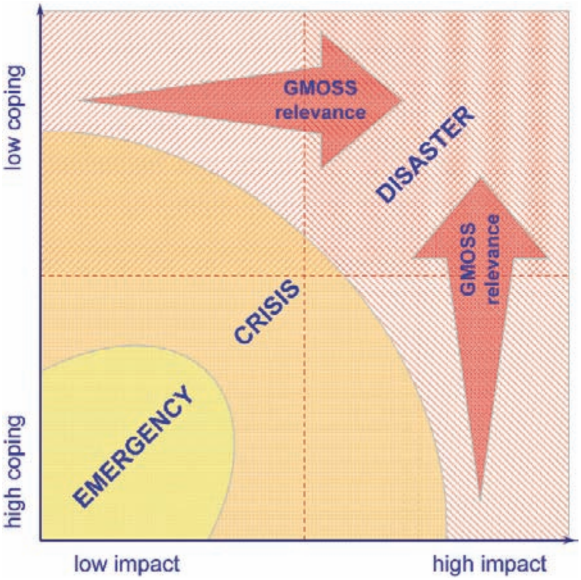

Fig. 3.1 Crisis patterns and relevance for matters of Global Monitoring for Stability and Security (indicated by arrows and hatching)

an event reaches crisis character once a certain impact is reached. In a country with less developed coping mechanisms already relatively small impacts are sufficient to provoke a crisis. If eventually a harmful event has reached a certain threshold – even in countries with a high coping capacity – it may be of disastrous nature. For the GMOSS Network of Excellence, the main study focus is on methods to analyse and monitor crisis and disaster events as indicated with the arrows Fig. 3.1 highlights.

3.3 Satellite Imagery in European Crisis Management

In the domain of civil security management already today satellite imagery provide a fair amount of decision support information in member states and at the European scale. Various research centres, e.g. the Joint Research Centre of the European Commission (JRC) or the German Aerospace Center (DLR), provide policy and decision support information derived from satellite data on an ad-hoc basis. Most of these activities are based on individual initiatives and mostly institutional funding sources. The only pan European organisation providing satellite intelligence analysis across several member states is the European Union Satellite Centre, an agency of the Council of the European Union and operating in support of the European Union's Security and Defence policy. Coordinated efforts to support decision making and international policies in the more civilian security domain by means of satellite intelligence are not yet operational. In the following section various initiatives, mechanisms and precursor activities, which may lead to such a coordinated mechanism are described.

3.3.1 Charter on Space and Major Disasters

The International Charter "Space and Major Disasters" specifically addresses the response phase in the domain of natural and man-made disasters. It services the entire world in case of major disaster situations. Cooperation between the nine space agencies, all members of the Charter (CNES France, ESA Europe, CSA Canada, ISRO India, NOAA/USGS USA, CONAE Argentina, JAXA Japan, BNSC/DMC UK and CNSA China) is based on voluntary basis and it is working with no exchange of funds.

The members of the Charter answer to data requests by its authorized users on a best effort basis and do not guarantee that the data and products will meet the intended purpose and accept no liability for the use of the data and products provided by them. Nevertheless, the Charter represents an excellent example of international integration for rapid satellite imagery and information provision. The seven years of activity of the Charter lead to a significant improvement of accessibility to satellite data and the recognition of the usefulness of space products in case of major disasters worldwide.

The great success of the Charter has improved the usage of space based imagery in the domain of civil security and disaster relief. Along with this, expectations towards optimisation of the mechanism have also risen. The Charter remains, in its present form, limited in scope (response phase plus anticipation, although this opportunity has been very rarely used so far) and continues to deliver information products (however outside the formal Charter commitment) using the financing capabilities of its members. The space agencies member to the Charter are essentially R&D agencies and the provision of operational services to the Charter quite often does not fit their primary mandates.

It is expected that the future GMES services (see below) in support of civilian crisis management focus on a European "rapid mapping service" in support of emergency response and humanitarian relief, which will also take into consideration activities linked to preparedness, early warning, as well as rehabilitation and reconstruction after crisis events. The EU has to further extend the contact with the International Charter and develop a partnership for future operational interfaces or set up similar mechanisms available operationally for its European users. A first helpful step in this direction is the coordination provided by the Monitoring and Information Centre (MIC) of the DG Environment in the domain of natural or man-made disasters. In any case, the experience and worldwide recognition of the efficiency of the Charter as a precursor mechanism should be taken into account for discussion in the GMES rapid mapping and security related services implementation. The exact scope of the services provided before and after emergencies has to be clearly identified with the European end users (the civil protection, security authorities, the humanitarian and the international relief community of the EU).

3.3.2 Global Monitoring for Environment and Security: GMES

The primary objective of GMES is to provide, in a sustainable way, timely information related to environmental and security issues in support of European policies. Space observation, linked with in situ information, can contribute to a more efficient crisis management and a reduction of security threats in Europe and in the world.

Commission authorities managing agriculture, forest fires, border control, coastal areas, illegal trafficking, marine pollution, environment, illegal immigration, air quality, foreign policy, etc. all are likely to use GMES services. The question of whether or not security/defence matters should be included in the 'S' of GMES, has not been answered yet. The scope of the first initiative defined in the Baveno Manifest as a Global Monitoring for Environmental Security was extended to the current Global Monitoring for Environment and Security. What is still missing today, as mentioned in the course of the eighth European Interparliamentary Space Conference held in June 2006, is the direct and active involvement of the EC and the high level representatives of the EU on the Common Foreign and Security Policy (CFSP) in order to support the management of the GMES' security element.

In any case, the challenge in the next few years will be the transformation of the many challenging and ambitious R&D projects in the safety/security and humanitarian domain (e.g. Preview, Respond, LIMES and Risk-EOS) into long term operational services responding to user needs and sustained by operational budget lines. When declared operational, GMES will be an important asset to maintain an autonomous European capacity for political independence in decision making in various environmental and security related domains. Today GMES services in the civil security domain are still at R&D level (e.g. GMOSS Network of Excellence, Preview, LIMES), consolidation and implementation level (Respond/RISK-EOS) or in the preparatory phase like the emergency response core service and the security pilot services. All these project activities provide a major base of experience, for service providers, R&D institutions and civil security actors to jointly build a future operational global satellite information service for civil security and crisis response capacities in Europe.

3.3.3 Group on Earth Observation: GEO

GEO (Group on Earth Observation), which was established in 2005, is an international cooperation framework for Earth observation. The mission of GEO is to build the Global Earth Observation System of Systems (GEOSS) in order to "realize a future wherein decisions and actions for the benefit of human kind are informed via coordinated, comprehensive, and sustained Earth observations…". It is important to recall that the GEOSS aims to create a world-scale synergy of Earth observation, while GMES consists of European services essentially to support EU policies.

Building on the 2002 World Summit resolution "to work expeditiously towards the establishment of a worldwide early warning system for all natural hazards with regional nodes, building on existing national and regional capacity…", GEO activities regarding the first (of the nine) societal benefit area will focus on expanding the use of Earth Observations for disaster prevention and mitigation and developing a multi-hazard approach to early warning and crisis management. In this context, GEOSS implementation will provide a helpful contribution to the monitoring, prediction, early warning and mitigation of hazards occurring at local, regional and global levels. GMES is the contribution of the European Union to GEO.

3.3.4 Satellite Imagery as It Is Applied Today

The following three examples show how satellite imagery can help to derive information and can serve as valuable input to support decision making in crisis management. This is the case in many fields of civil security, spanning from complex humanitarian crisis situations, international treaty monitoring, situation analysis, etc.

Assessment of an Explosion of Old Ammunition in the Ukraine

On May 6, 2004 a military arms dump close to the village of Novobogdanovka in southern Ukraine exploded. According to press statements 10,000 people in the surrounding villages had to be evacuated and a major highway and railway line connecting the cities of Melitopol and Zaporizhzhya had to be blocked. The satellite image of May 8, 2004 shows that the arm dump was completely destroyed and that large amounts of debris were hurled hundreds of meters and even kilometers into the neighboring villages and agricultural land (Fig. 3.2). The satellite imagery shows that some fires are still burning in the explosion area. The imagery and analysis helped to verify ground based reports of the situation as well as helped to give an overview on the local situation.

Base and Crisis Mapping of the Al Fashir and Al Junaynah Region, Darfur/Sudan

Because of the continuing refugee/IDP situation and the onset of the rainy season in western Sudan, the humanitarian aid organizations working there during 2004 were in urgent need of up-to-date, detailed maps. In consultation with UN-OCHA, Germany's disaster relief organization (THW) and the German Red Cross (DRK), the crisis regions around the cities of Al Fashir and Al Junaynah were mapped by means of satellite imagery to support humanitarian relief operations. The focus was on ascertaining the road network, its condition, and the traversability of possibly flooded wadis and river valleys. Furthermore settlements and the current size of internally displaced people (IDP) camps were mapped with the help of very high resolution satellite imagery (Fig. 3.3).

Fig. 3.2 Explosion accident in conventional arms deposit Novobokdanovka, Ukraine. The IKONONS BW-image shows the destroyed arms dump and some debris in the surrounding fields (visible as black or white spots on the agricultural land)

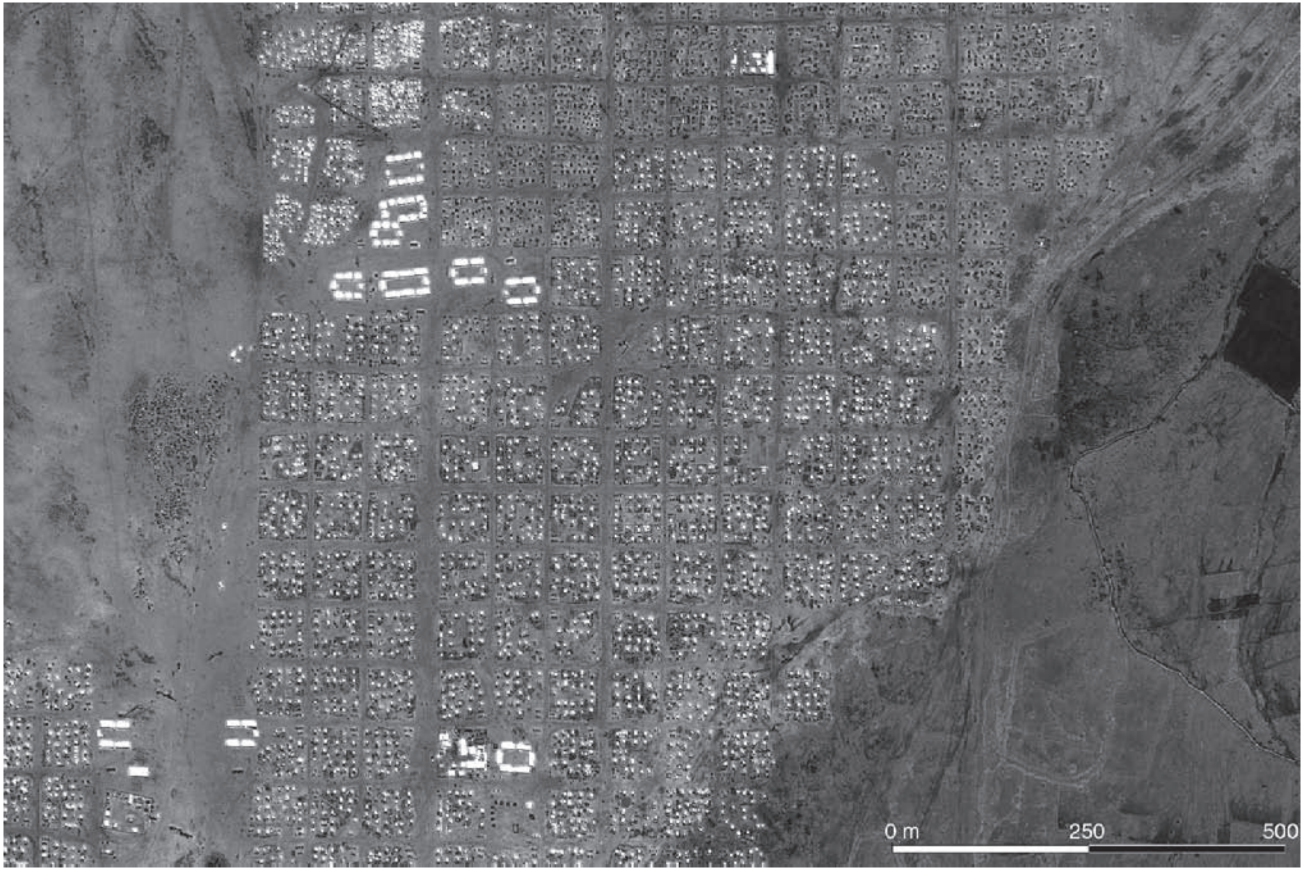

Fig. 3.3 IDP camp in Darfur, Sudan. Very high resolution satellite imagery allows identification of single tents and resources (e.g. firewood) for camp management

Verifying Nuclear Non-Proliferation Treaties

Compliance verification of international treaties is a task where satellite imagery analysis can contribute significantly. The images document the construction and operation activities at nuclear facilities such as the Isfahan site in Iran (Fig. 3.4). Bringing building heights, ground movements, transportation activities, exhaust temperatures (etc.) into the context of the declared site use and operation can verify or falsify these declarations and can provide indications of diverging activities.

3.4 Involving the Scientific Community

Since the use of satellite derived geospatial information in the context of civil security is relatively new, there is no 'settled' community or coherent service in Europe, yet. The initiatives were uncoordinated and performed by single entities for example, coming from national research centres, which provided on occasion, services to decision makers, or the Joint Research Centre of the EC that started to support DG RELEX with security related geo-information and satellite imagery analysis. The Network of Excellence "GMOSS" is the first European initiative in this context has pooled European science experts from different backgrounds in the field of remote sensing and security and integrated the critical mass of resources and expertise needed to strengthen scientific and technological excellence.

3.4.1 Simulations and Exercises

Exercises – as a type of simulation – can be seen as training events but also as methodological tools of research evaluation. In the context of the Network of Excellence GMOSS, exercises were used as a method to assess the use of state-of-the-art geospatial technologies in collaborative team structures as well as to study and discuss policy measures to make this technology available for possible operational deployment. The objective of the exercises was to confront the research community with operational needs and deployment of future space technologies. In other words, the interest laid in an understanding of if, how and why the exercise participants – as prospective users – are able to use various geospatial technologies in complex and dynamic situations and whether this had positive effects. These exercises were also recognized as GMOSS Near real-time Exercises, shortly GNEX.

GNEX exercises were real-time, scenario-based exercises combined with thorough data collection and analysis tasks. The design of GNEX settings was steered so that various situations and procedures could be simulated. Realistic shape of the exercise content was an essential factor in designing the scenarios, in order to achieve a high qualtity of the simulations. Therefore, scenarios were developed in collaboration with relevant user groups. The approach in the GNEX exercises

Fig. 3.4 Satellite image of the nuclear site in Isfahan, Iran

provided a possibility to investigate the actual work and interaction of the teams during the collaborative processes of using/deploying advanced scientific spatial technologies during crisis responses in relatively controlled settings. Moreover, the approach made it possible to collectively test and try out research results on complex technologies under advanced realistic scenarios.

The GMOSS network carried out two exercises – GNEX'06 and GNEX‘07 – focusing on the application of satellite imagery and other geospatial technologies in different crisis scenarios. In the GNEX‘06, which took place in October 2006, the partner and associated organizations from GMOSS were acting in three separate analytical teams supporting crisis response efforts in a 33 h long simulation. The scenario focussed around a nuclear accident with limited release and deposition of radioactivity. The main interest was to test and analyze the actual team work and performance, as well as the comparison between the different teams and their results. The analysis of the results revealed that all teams were able to respond to the scenario and produced not only the requested information in time, but also a lot of additional information products. The exercise revealed also some problems caused by the distributed teamwork like communication issues leading to problems in task handover, contingency planning and missing standardization. The GNEX‘07 of October 2007 had a different focus. The scientists from the Network of Excellence GMOSS acted as one analytical team simulating the assistance to the EU crisis management decision bodies and emergency response personnel of DG RELEX and DG Environment in a complex crisis situation. The attention was given to the interaction between actors in the analytical team and the decision-makers during an 82 h long simulation. Although many of the scientists participating in the simulations were not used to near real time analysis tasks in their every day working environment, they were able to respond to the scenario in an adequate way. The collaboration effort under severe time pressure provided an excellent test bed for the methods developed in the GMOSS network. It helped to test out how such methods and technologies may be used synergistically in more operational environments of crisis analysis and response in the future. As such they provide valuable information beyond the GMOSS network for the development of operational services in GMES.

3.5 Conclusion and Outlook

The experiences gained through the various projects, initiatives and pre-operational activities in Europe, though still incomplete and heterogeneous in character, show that analytical crisis response capacities for all types of crisis can be significantly improved by enhanced integrated satellite observation and analysis efforts. Timely acquisition, processing, careful analysis, combination with additional thematic data and dissemination of the resulting information to relevant authorities are key elements of this information chain. The setting up of operational, reliable and available satellite observation capacities for civil security monitoring purposes in Europe and worldwide is considered a challenging key task. In addition, the growing concern on security threats brought by environmental stress, climate change and the likelihood of seeing global events increasingly affecting the world and particularly the European Community, calls for an increased involvement of European actors in a coordinated mechanism to support the synergistic use of satellite observation and analysis capacities for decision making support in all fields of civil security as well as for environmental stability. This point indicates that human and environmental security often can not be separated and are in many points strongly interrelated. The monitoring demands for environmental legislation and treaties such as the Kyoto or the Montreal protocols in conjunction with the increasing importance of the Common Foreign and Security Policy identify the need for developing efficient 'environmental security intelligence' in order to response to future crisis situations in Europe and world wide.

It can be concluded that first mechanisms to set up such monitoring capacities in a coordinated way for Europe are available in the various R&D activities mentioned. It is now that these existing precursor services and networks have to be built up operationally and institutionally. In addition, policy stakeholders have to clearly engage and set in place the formal and financial basis for such European satellite monitoring capacities. These involve actors from all three fields of civil human security: disaster management and prevention, humanitarian relief and rehabilitation as well as civilian threat mitigation.

Exercises exposing skilled teams of scientists to realistic crisis scenarios proved to be an interesting and powerful tool to study and develop crisis monitoring and response capacities in Europe. It is important to note that such light and agile R&D networks like GMOSS may serve as a powerful support mechanism to more engineering and operationally oriented service development frameworks. It is strongly recommended that substantial efforts are taken in Europe to coordinate current and future civil security satellite monitoring capacities and initiatives. This could happen through well structured distributed networks of dedicated centres and sub-centres. By doing this, national, regional and global analysis needs can be met and the best use of existing capacities and infrastructure in Europe can be achieved at the same time.

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Chapter 4
The Security Dimension of GMES

Network of Excellence GMOSS: A European Think Tank for EO Technologies in Support of Security Issues

Delilah Al-Khudhairy, Stefan Schneiderbauer, and Hans-Joachim Lotz-Iwen

Abstract The European research landscape has evolved in the 7th framework programme (FWP) to reflect new challenges to human security both at the European and global levels. Today, European security research is designed to address societal demands in the face of these new security challenges, and to enhance the competitiveness of European security industry.

The Global Monitoring and Environment and Security (GMES) initiative has particularly evolved in the 7th FWP to reflect the increasing importance space technology can play in developing solutions to address the requirements of several European Union (EU) policies with a global dimension such as border monitoring and crisis management.

Research though is still an essential element in the European security research programme. GMOSS is a network of excellence that has developed into a European think-tank focusing on research on earth observation (EO) technologies for security. The greatest achievement of GMOSS has been to bring together fragmented civil security research from around Europe, to build the foundation for a security research community focusing on EO technologies for civil security applications.

Keywords GMES • space and security • Space and Security focused European think tank • EO technologies • civil security research

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4.1 Introduction

Since the end of the cold war, the concept of European security has evolved from the traditional political concept of protecting the state and its borders from military threats or external aggressive acts to new dimensions that include human security and protection of essential societal functions (including health, economy, food, transport, and energy sectors). Moreover, new threats varying in origin and complexity include natural hazards, unintentional (e.g. industrial accidents) and intentional (e.g. terrorism and illegal activities including organized crime and fraud) acts, as well as geo-political factors originating elsewhere outside of Europe. Today, the European security concept has also evolved to include global challenges, such as poverty, disease, conflict and climate change, all of which can affect European security both directly and indirectly (see Chapter 1).

There is a common agreement among scientists and politicians on a strong need for further research and development (R&D) to address the complex nature of the new variety of threats and challenges mentioned above, which also calls for a range of measures and actors (including civil protection, intelligence, law enforcement, judicial, economic, diplomatic, and technological) in order to effectively address them. In the EC's fifth and sixth framework programs, European R&D activities contributed towards defining potential security research elements. However, in the European Commission's seventh framework program, European R&D activities relevant to European security policies and issues are being conducted clearly and with direction for the first time within new thematic priorities, entitled Space and Security. European security research within the new European Security Research Program is designed to respond to societal demands in the face of new security challenges and to enhance competitiveness of the European Security Industry, thus contributing to the implementation of the Lisbon strategy (European Commission 2005a). It is also considered to be an essential building block in supporting EU policies (namely Common Foreign and Security Policy, conflict prevention, crisis management, border management, protection of critical infrastructure, transport, civil protection, and energy) as well as in attaining a high level of security within an EU-wide area of justice, freedom and security. The space research theme under the European Commission's seventh framework program is intimately linked with security related policies. In addition, there are several themes in the seventh Framework Program for Research that will deal with other elements of security, which are not necessarily linked to space: amongst them, Health (for example, security and safety of food and drinking water) under the theme "Food, Agriculture and Biotechnology"; security is also a key component in several priorities under the theme "Information and Communication Technologies"; challenges of the security of supply and climate change as well as the security of smart energy networks under the "Energy" theme, and the "Transport" theme.

In the seventh framework program, the key security research linked with space is being conducted within the GMES (Global Monitoring for Environment and Security) initiative. The results of the Network of Excellence, GMOSS, funded by the EC, contribute to the definition of the security dimension of the GMES. At the forefront of research in GMES, GMOSS is communicating research gaps and user needs to institutions, industry and the scientific community at large.

4.2 Security Issues Within GMES

The GMES is an EU-led program initiated as a joint activity by the EC and ESA in order to develop an independent European capacity for the timely and reliable provision of operational services for global monitoring of environmental and security issues (European Commission 2004, 2005b). Besides the support to European policies, the potential of GMES as a European contribution to the global 10-year implementation plan for a Global Earth Observation System of Systems (GEOSS) was recognised later on in the GMES process. The objective of GMES is to provide sustainable, reliable, and timely services in support of European Union (EU) environmental and security policies. GMES activities are wide in range spanning from research to operational services, and from technical to institutional developments (see Fig. 4.1). For promoting the achievement of GMES objectives, the European Commission (EC) and the European Space Agency (ESA) have been financing numerous projects and instruments varying in the number of partners, duration, and available funds.

The GMES initiative was launched in 1998 and was adopted by the EU council and ESA in 2001. Following the Gothenburg EU Council Summit of 2001, the political mandate of GMES has been to envisage operational and autonomous GMES services from 2008. With the end of an exploratory initial period in 2003, the program entered into its development and implementation phase.

In order to advance the work with regard to the security dimension of GMES, a special working group was created by the GMES steering committee in 2002, which was composed of experts from a variety of public institutions and private companies representing the Member States, the Council, ESA and the Commission services. One of the main tasks of the working group was to define the scope of security within GMES. The group distinguished the security aspects from those of the environment by emphasizing the focus of concern on the protection of the individual; “Thus, they relate to information services to prevent, mitigate and

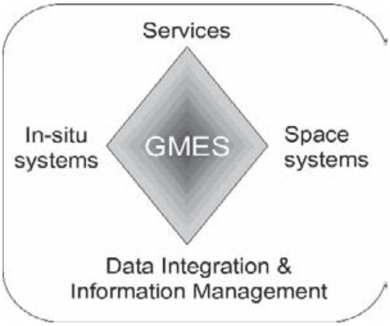

Fig. 4.1 The ‘GMES Diamond’ (European Commission 2004)

manage dramatic or catastrophic events that threaten human life and property" (GMES WG 5 2003, p. 3). Protection of the population and their property, of vital and vulnerable infrastructure (e.g. transport and communication) and of resources (e.g. food) is thereby explicitly included under security. The working group also identified the main security missions that should be tackled within GMES in order to support European policies, namely:

- Civil Protection
- Humanitarian Aid
- Conflict Prevention
- The Common Foreign and Security Policy (CFSP), including the European Security and Defence Policy (ESDP)
- Other policies relevant to European citizens' security at Community and national levels, in particular those addressed by Justice and Home Affairs and Customs, such as integrated border management

The military–civil workshop on Security and Space entitled "GMES: The Security Dimension", organized by the Commission and Council, held on 16 March 2006 in Paris, identified additional issues that should be addressed within the security dimension of GMES: maritime surveillance, critical infrastructure protection, and support to Community activities in the context of external action (e.g. conflict prevention and crisis management support).

The main bottlenecks regarding the successful implementation of the user-required end-to-end GMES systems were identified and reported in GMES forums and other meetings including the GMES workshop 'The Users' Perspective' in Stockholm/ March 2001. Some relevant key challenges were highlighted (see Liljelund 2001), and which are particularly crucial to achieving an independent European capacity for global monitoring for security:

- Establishment of end-to-end systems that ensure: availability of the right earth observation data at the right time; guaranteed, reliable and easily accessible data supply.
- GMES should make full use of relevant, existing, systems and data supply chains as well as institutions and mechanisms.
- Enhanced inter-action between the users in the civilian security and military domains, and the scientific community in order to develop the necessary end-to-end systems.
- GMES action plan should highlight meetings and institutions that are involved in the GMES process in order to avoid unnecessary duplication.
- Steps should be taken to ensure citizen awareness of the GMES program: objectives and benefits.

It is clear that the space infrastructure plays an essential role in the development of an independent European capacity for the provision of the information needed to support European security policies and issues. Space and airborne systems designed for this purpose would ideally have the means to identify and monitor objects and areas of interest worldwide, day and night, and in all weather and other conditions. However, in reality a number of constraints still hamper today appropriate data acquisition or, if available, its timely access and distribution. This makes the contribution of the EU's military actors, by means of making available data that can be widely shared with civil security users, essential to availability of an apt European space infra-structure that can support the "S" in GMES.

4.3 Security Research Within GMES

GMES-related projects undertaken in the fifth and sixth EC Research Framework programs (FP) and ESA's GMES Service Element (GSE) program have contributed to the definition of the key security research elements that are relevant to achieving the objectives of the GMES initiative. Both the EC and ESA have been carrying out their programs in parallel. However, from 2008 onwards, it has been agreed by the EC and ESA that the latter will be responsible for the space segment, whereas the EC will cover all applications including research, services, strategy, user relations, etc.

In the fifth FP, the key focus of GMES related research was to deliver user-driven information products relevant to environmental and security issues, improve knowledge, methods and algorithms needed for information gathering, production and distribution, and related challenges and lessons learned. In the sixth EC FP, GMES was addressed within the "Aeronautics and Space" Thematic Area and its focus evolved to cover the development of pre-operational capabilities by means of integrating:

- Existing research results acquired through former initiatives of EC, ESA and national entities; and
- Planned research and technological development results, as they become available, within the other relevant FP6 thematic priorities, ESA and national entities.

In addition, space and security were also addressed within the sixth FP's preparatory action for security research (PASR) and the "Information Society" thematic area. In parallel the ESA's GSE evolved to cover the development of European, regional and global services closely linked to users' needs. The various GSE focus upon the delivery of these policy-relevant services to end-users, primarily (but not exclusively) from EO sources. In ESA's GSE, the end-users are involved in 'closing the loop' between the operational results obtained from the present generation of EO satellites and the definition of future systems. The communication flows between operational service driven ESA funded GSE and research oriented European Commission funded Network of Excellence (NoE) is visualized in Fig. 4.2.

In the sixth EC FP and the ESA's GSE, a number of security relevant projects were funded to further advance technologies and systems in order to enhance:

Fig. 4.2 Coordination between EC NoE projects and GSE (Science Systems (Space) Limited 2005)

- Civilian crisis management capabilities
- Projects: OASIS, RESPOND, RISK-EOS
- Tasks: e.g. support response and rescue operations, including humanitarian assistance, in large scale emergencies; enhance mechanisms for fast and reliable information exchange between relevant actors; risk management
- Delivery of humanitarian aid
- Projects: GMFS – global monitoring for food security; RESPOND; LIMES
- Maritime security focusing on maritime border surveillance
- Projects: MARISS, LIMES
- International treaty monitoring
- Projects: LIMES
- Security missions and capabilities
- Projects: ASTRO +

In the seventh FP, GMES is addressed within the Space theme. Since the fifth FP, the GMES initiative has evolved notably to focus in FP7 on developing and validating a number of pilot operational services, based on related research and development projects and activities. In this respect, three services have been selected for fast track, one of which that is relevant to security is the Emergency Response fast track. These fast track services are expected to enter the validation phase by 2008. In 2007, the first calls for proposal were launched in the first half of 2007, focusing primarily on the development of the three 'fast track' services based on their respective Terms of Reference.

4.4 GMOSS and its Role within GMES

4.4.1 Introduction

The Network of Excellence GMOSS is financed by the Directorate General for Enterprise and Industry within the Aeronautics and Space Priority of the sixth FP for Research and Technical Development of the EU. GMOSS was established to foster the European civil security research capacity, to identify and fill research gaps, and to pinpoint future fields of research and development activities. GMOSS builds upon the European Security concept and addressed several of the challenges identified within the European Security Strategy and other subsequent EC policy papers and communications as being pertinent to European and global security including non-proliferation, regional conflicts and humanitarian disasters. Examples of practical applications are presented in this book dealing with applications and tools relevant to monitoring of security issues. Alongside these hands-on results, GMOSS is at the forefront of a wide range of projects and instruments employed by EC and ESA to advance GMES objectives.

The overall goal of GMOSS is to bring together and advance Europe's civil security research in order to contribute to the development and maintenance of an effective European capacity for global monitoring for security using satellite earth observation technologies. Thus the purpose of GMOSS is to establish a research platform for integrating European civil security research and development activities. Hence, GMOSS' main tasks include: (1) integrating research and know-how between the GMOSS partner institutions and applying it to security related applications and (2) the exchange of information, new knowledge and products of scientific research with the external research community and GMES clients dealing with security issues (see Fig. 4.3).

GMOSS therefore plays a fundamental role as a "Think Tank" for the development and benchmarking of new tools and methodologies for the application of EO technology in the security domain. Though GMOSS' main task is the integration of ongoing research activities, there are emerging focus-areas within the project that have been determined as a result of the interaction within the research community and with potential users/costumers of research results achieved by the GMOSS partners. GMOSS users within the GMES community are predominantly

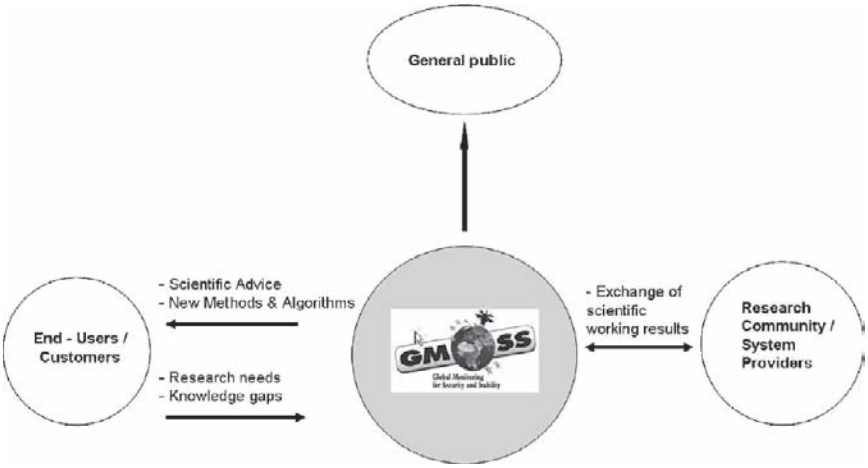

Fig. 4.3 GMOSS relations with the 'external world' (authors)

institutions and project consortia involved in the development of (pre-) operational services including GSEs or GMES FTS; e.g. RESPOND, Astro + , LIMES and BOSS4GMES. Potential end-users of GMOSS research and networking results include:

- Commission services e.g. DGs ECHO, RELEX, AIDCO, JLS, Civil Protection Unit of the DG Environment
- Community and EU agencies; EUSC, FRONTEX, EMSA, EDA
- National civil protection authorities
- National ministries of interior, foreign affairs
- International institutions, in particular relevant UN agencies (e.g. UNOCHA, UNHCR, UNDPKO, IAEA, WFP)
- Research institutions
- Industry

For a fruitful and extended communication with its users, GMOSS has been organising regularly integration meetings of varying scientific foci, which involve the engagement of external experts and users.

4.4.2 GMOSS Structure and Work Packages

The results of the GMOSS activities have contributed in particular to the following two strategic objectives pursued within the scope of GMES:

- Developing the right tools, in space, in the air, in the oceans and on the ground, for collecting the required information
- Designing the appropriate data integration and information management infrastructures that will allow users to easily access and share the information

Exceeding the horizon of "classical" remote-sensing-focused projects, GMOSS is characterized by the end-to-end integration of political/socio-political aspects of security with the assessment of remote sensing capabilities and end-users support opportunities. The work breakdown structure of the GMOSS research reflects this approach (see Fig. 4.4)

Fig. 4.4 GMOSS work breakdown structure

The work packages of the Security concept domain deal with:

- The analysis of European security needs and concepts and the identification of security-relevant areas and information requirements
- The analysis of security threats in order to incorporate information from EO for increased preparedness and effective crises management and prevention
- The design of a catalogue of early warning indicators
- Development of scenarios

The work packages of the Application Domain concentrate on best practises concerning the specific science and technology for:

- Effective monitoring of international treaties protecting against proliferation of weapons of mass destruction
- Better estimates of static and dynamic populations on a global scale
- Better monitoring of infrastructure and borders
- Rapid remote assessments of damage

The Generic Tools Domain work packages focus on the assessment and benchmarking of present and future generic methods, algorithms and software needed for the automatic interpretation and visualization of imagery for security applications, including feature recognition, change detection and data fusion techniques.

Having pointed out the main activities in the field of research conducted within GMOSS it should be emphasised again that GMOSS' purpose as a 'Network of Excellence' is first and foremost the integration of the existing research capabilities and the dissemination of its excellence beyond the boundaries of its partnership. This integration and dissemination of GMOSS expertise across these domains is promoted by training workshops and summer schools, which are open also to external participants. Near-real-time exercises and scenario analysis are performed to analyse and improve the information flow in between the components of possible emergency response systems.

By accomplishing this wide range of tasks and by representing the only security focused 'Network of Excellence' financed by the EC, GMOSS plays a strategic role as a linchpin and node for other GMES research activities and identified as well as potential future GMES service users.

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Chapter 5
A Novel Approach to Capacity Building for Security Applications

Peter Zeil

Abstract In the context of the European Commission's Network of Excellence GMOSS (Global Monitoring for Security and Stability) a training approach has been developed and tested with the aim to integrate technology, natural sciences and social sciences in order to enhance the monitoring capability in the cross-cutting emerging field of security research. The training measure contributes to the establishment of a platform for experienced researchers who will make their impact felt by feeding research results into the security community and are themselves prepared to act on an implementation level. The alumni are social and political scientists with a sound understanding of monitoring capabilities as well as natural scientists and remote sensing experts with a sensitivity to political concepts, structures and processes in different security relevant fields. These objectives are accomplished by the following results: (a) A research agenda is developed which encompasses studies on social and political science research, facilitates the exchange of information between stakeholders, and activates existing organizational structures or stimulates the establishment of new ones. (b) Presentations and practical sessions are organized to inform on the state-of-the-art techniques in:

- Effective monitoring of international treaties for environmental protection and the development of tools for early warning
- Better estimates of populations on a global scale and the rapid remote damage assessment
- Generic methods, algorithms and software needed for the automated interpretation and visualisation of imagery, including feature recognition and change detection

(c) The specific training measures stimulate the integration of research, incorporate the know-how of external experts and provide required soft-skills for future career options in science, technology and policy implementation for security.

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The key questions to be dealt with are: how can we cope with a certain hazard/threat and what can we do to reduce the susceptibility to a probable risk? The response to both aspects requires fast decision making (disaster management) or taking preventive measures (risk reduction) long before an event. To test capabilities of first responders, the commonly practiced methodology in disaster management is contingency exercises. In the context of our training approach we explore the wide experience provided by military research organizations with scenario analysis, situation awareness and gaming. The participants of the training course have to act in given scenarios reflecting possible risks, make decisions on interventions and gather experience about the specification and relevance of information needed. The outcome of the games are analyzed in considerable detail and discussed with experts working for relevant organizations. First results from Summer Schools in 2005 and 2006 indicate that participants highly value the approach and organizations dealing with disaster risk reduction or security are greatly interested to be involved in the exercise.

Keywords Capacity building for security applications • interdisciplinary setting • integration • games • scenarios • feedback

5.1 Security and Threat

‘I wonder why terrorism ranks so high on your agenda, while we struggle with diseases, hunger and poverty affecting millions of people’ (statement by an African participant during the GMOSS Summer School 2006).

What is security? And what is felt as a threat? Engaging in exchange and sharing of experience – as such describing the main processes in training and capacity building – we can and should not simply resort to official versions or the state of the scientific debate.

Security as “freedom from fear and want” is a basic social value of humankind. According to a classic definition by Wolfers (1962) ‘Security, in an objective sense, measures the absence of threats to acquired values, in a subjective sense, the absence of fear that such values will be attacked.’ The perception of security threats, challenges, vulnerabilities and risks depends on the worldviews or traditions of the analyst and on the mind-set of policy-makers and their advisers. Security has also been a key concept of two competing schools of (a) war, military, strategic or security studies, (b) of peace and conflict research that has focused on war prevention. Security issues are addressed by several EU Community policies in areas such as sustainable development and climate change, civil protection, humanitarian aid, and safety research.

Security is one of the basic needs of mankind, both individually and collectively. It is an important prerequisite for economic growth, investments and job creation as well as a powerful driving force for human ingenuity. With the end of the Cold War, Europe and the rest of the world faced new security challenges. The attack of September 11, 2001 added a perception of new vulnerabilities of industrialised countries. The distinction between hard military and soft non-military dangers, activities and priorities is blurred. The same applies to the traditional difference between internal and external security. Economic globalisation has been challenged by transnational terrorism and international crime, and both created new security problems in the early twenty-first century. The sciences' traditional deep division into military research, isolated pockets of technological research, and the social and political sciences is coming into question. Terrorism and international crime have not only led to the globalisation of our security dependence, but also to emerging fields concerned with non-military security research, the redefinition of threats, and society's response options. A further area of concern is the increasing vulnerability of people as a result of the increased intensity and number of natural disasters that are striking areas that have so far generally been considered safe.

There is a growing recognition that past and present global environmental change, environmental degradation and environmental conflicts affect the lives of millions of people across the world. This interplay results in significant lost opportunities in terms of human and economic development, and imperils the process of building democracy, establishing peaceful international relations, as well as reducing lawlessness and human insecurity. At a fundamental level, environmental insecurity originates from environmental degradation and/or threats, and from the coping and adaptive capacities of individuals and societies exposed to the threats. Development and security are closely linked.

Once the focus of considerable scepticism, both global environmental change and the concept of environmental security have moved squarely into the mainstream. Not only has public awareness of climate change seemingly reached a tipping point, but the likely security repercussions of the unsettling changes to our planet's climate are now increasingly acknowledged and analyzed. Recent reports such as the latest assessment by the Intergovernmental Panel on Climate Change (2007a, b) and the Stern Review report (2006) on the economics of climate change have quickened the pace of the debate, as have events like the ongoing conflict in Darfur, Sudan, made worse by drought and desertification.

There is perhaps no better sign of this new realization than the recent decision of the United Nations Security Council (2007) to discuss, for the first time, the impacts of climate change on peace and security. The discussion came at the initiative of the British government, which circulated a concept paper calling attention to a range of security implications of climate change, including border disputes, migration, societal stress, humanitarian crises, and shortages of energy, water, arable land, and fish stocks.

What is felt as a threat not only depends on the sectorial standpoint (military, civil society), the school-of-thought (defence, peace research), or social, political and cultural factors but also on geo-location (Fig. 5.1). Building capacity to use spatial information for monitoring in the field of security therefore requires firstly to embark on consensus building about problem definition and possible interventions. A pre-requisite for using information technology effectively is that a consensus exists within society on the nature of these threats to human and environmental security, as well as the political will and the means to put preventive activities and mitigation into place prevails.

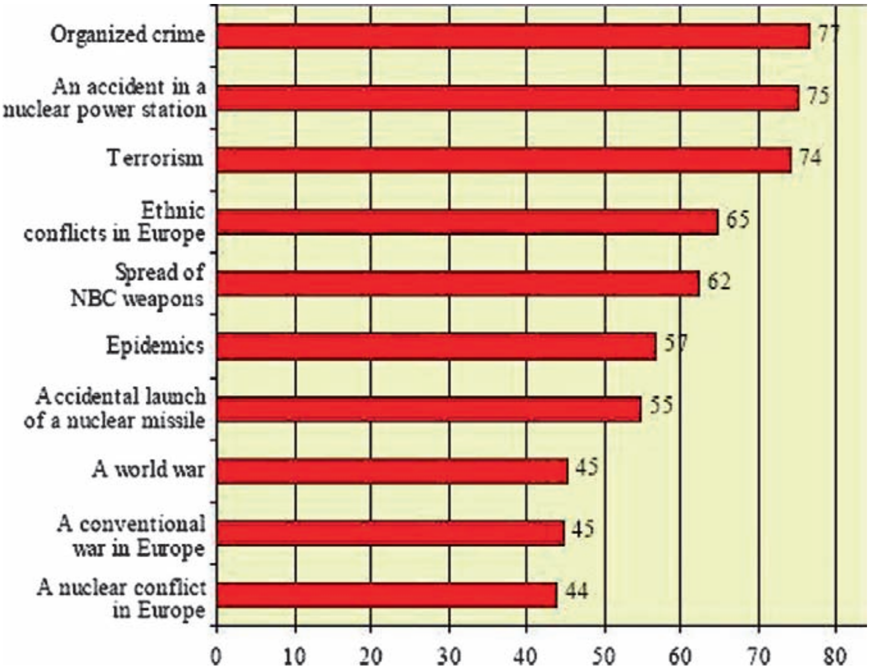


Fig. 5.1 Fears of Europeans from different threats (Eurobarometer 2001–2009) http://ec.europa.eu/public_opinion). A similar compilation for Africa or Asia unfortunately was not found

5.2 Concept for Capacity Building

Responding to the overall objective of GMOSS

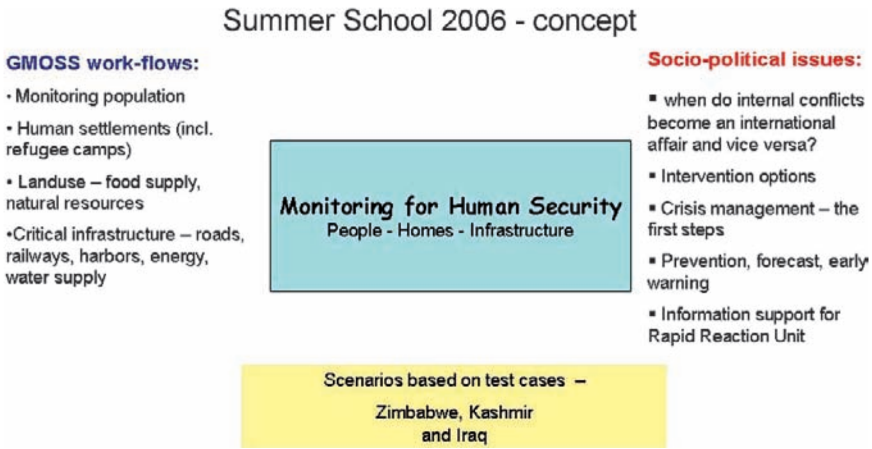
- To evaluate the capability of remote sensing for human security applications, and
- To identify existing gaps that have to be addressed and bridged by future research programmes of the European Union, as well as
- To integrate European research on the usability of remotely sensed data for civil security application

The capacity building concept requires the dissemination of research results, strengthening the integration of research efforts within, and to facilitate the exchange with actors outside of the Network. With the aim to increase European competitiveness, to benefit from synergy effects and to build a critical mass of expertise, a newly developed research training agenda encompasses, in addition to remote sensing technologies, social and political science research, the exchange of information between stakeholders, and the evaluation of existing or recommendations for new organizational structures. The concept was implemented in the form of summer schools (duration: 8 days) by exploring the broad expertise of the GMOSS partnership and inviting experts contributing specific aspects not covered by the network partners. The core sessions of the schools covering technical aspects regarding the processing of EO data for effective monitoring were framed by exploration of the socio-political context. The structure of the schools had to provide for technical presentations, practical exercises, as well as group work and feedback sessions with policy actors. To create an enabling environment for sharing experience and problem awareness in a relatively short period, games based on theme-specific scenarios were selected as an appropriate methodology (see Chapter 6).

5.3 GMOSS Summer Schools

At present two Summer Schools have been implemented according to this concept and one is being planned. The first school was held in September 2005 in Salzburg on the topic: Rapid information generation for security applications and decision support, with presentations and practical sessions exploring the potential of rapid mapping using earth observation data for crisis management. The respective expertise of the GMOSS consortium was demonstrated in presenting workflows for early warning, better population estimates and rapid remote damage assessment as well as generic methods, algorithms and software needed for the automated interpretation and visualisation of imagery, including feature recognition and change detection. A scenario based on a terrorist attack targeting the Festival Hall in Salzburg was developed for the game. Acting in the roles of local, provincial and national authorities and first responders, the participants had to plan for evacuation, emergency management and counteraction. The principal problems targeted were the timeliness and accuracy of information, the availability of auxiliary data, the line-of-command and the exchange of information for common situation awareness. Feedback was provided during a final panel discussion with experts representing the national government (Austria), the EU, NATO and the UN (UN Office for Outer Space Affairs).

The next school in 2006 (also Salzburg) focused on Monitoring for Human Security – People, Homes and Infrastructure (Fig. 5.2). The capabilities to monitor population – settlements and migrations – in urban and rural areas, for damage assessment and infrastructure monitoring were presented. During hands-on exercises, the participants were guided through case studies on landcover changes in rural areas and damage assessment in urban areas of Zimbabwe, and pipeline monitoring in Iraq. Work in progress on the GMOSS Test Cases (Zimbabwe, Iraq, Kashmir, and Iran) formed the basis for technical sessions, practical exercises and policy analysis. Against this background, scenarios were developed for intervention options in Zimbabwe, and planning for humanitarian action in the case of the earthquake in Pakistan in 2006. The latter provided the context for a rapid mapping exercise (gaming environment) at the Center for Crisis Information, German Space Agency, DLR. Local knowledge for the Zimbabwe and Kashmir test cases was contributed by an invited remote sensing expert from Harare and an employee of the Pakistan Civil Protection Agency as participant. The potential and limitations of remote sensing information for monitoring human security and stability



Summer School 2006 - concept

GMOSS work-flows:

- Monitoring population
- Human settlements (incl. refugee camps)
- Landuse – food supply, natural resources
- Critical infrastructure – roads, railways, harbors, energy, water supply

Monitoring for Human Security
People - Homes - Infrastructure

Socio-political issues:

- when do internal conflicts become an international affair and vice versa?
- Intervention options
- Crisis management – the first steps
- Prevention, forecast, early warning
- Information support for Rapid Reaction Unit

Scenarios based on test cases –
Zimbabwe, Kashmir
and Iraq

Fig. 5.2 Example: GMOSS Summer School 2006 – concept

factors was discussed with representatives from NGOs (conflict research), NATO (crisis response) and UN (United Nations Platform for Space-based Information for Disaster Management and Emergency Response (SPIDER)).

The 2007 Summer School was held in Madrid, Spain (Fig. 5.3), organised by the Universidad Pontificia de Salamanca (associated partner of GMOSS) and the European Satellite Centre (EUSC). Following the same layout of the program, Early Warning and Monitoring of Agreements were selected as the central theme.

5.4 Achievements and Challenges

After two successfully completed training events, the concept developed for the Network of Excellence GMOSS still offers opportunities for improvement. The participants using questionnaires and group feedback evaluated each of the schools. In addition, the review team of GMOSS has continuously assessed the impact.

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Fig. 5.3 Example: GMOSS Summer School 2006 – program. GMOSS partners: Center for Geoinformatics Salzburg University (AT) Z_GIS, EC Joint Research Centre (IT) JRC, Kings College London (UK) KCL, Centro di Ricerca Progetto San Marco (IT) CRPSM, OD Science Applications (SE) OD, The Netherlands Organisation for Applied Scientific Research (NL) TNO, Technische Universität Bergakademie Freiberg (DE) TUBAF, Università della Basilicata (IT) UNIBAS, European Satellite Centre (ES) EUSC, Swedish Defence Research Agency (SE) FOI, Swisspeace (CH), Deutsches Zentrum für Luft- und Raumfahrt (DE) DLR, Royal Military Academy (BE) RMA.
Associated partners: Threat Analyses and Solutions (AT) TAAS, Università degli studi di Pavia (IT) Pavia, Bonn International Center for Conversion (DE) BICC, UN Office for Outer Space Affairs (UN) UNOOSA.
Invited: Forestry Commission of Zimbabwe (ZW) FCZ, Research Studio iSpace (AT)

Introduction

GMOSS – Progress until now *Zeil/Pesaresi Z_GIS/JRC*
Case Studies – Kashmir, Iraq, Zimbabwe *Lang/Rama Z_GIS/KCL*
Spatial and temporal resolution requirements of single and multiple (constellations) satellites for human security related applications *Laneve CRPSM*
Getting to know about security scenarios *Dahlmann OD*
Threat and Risk Assessment *Steinhäusler TAAS*
Zimbabwe Case Study *Kwesha/Zeil FCZ/Z_GIS*
Geo-Annotation Tool *Schmidt iSpace*

Themes & methodologies

Population Monitoring *Lang, Ehrlich, Stephenne Z_GIS/JRC*
Data integration, scientific 3D visualisation, spatio-temporal population dynamics *Lang, Tiede Z_GIS*
Damage assessment by radar change detection *Dekker TNO*
Disaster damage assessment *Gamba Pavia*
Monitoring of critical infrastructures *Dekker TNO*
Object-oriented image analysis for security applications: from data to information to knowledge *Niemeyer TUBAF*

Applications

Team building exercise
Robust satellite techniques for human security applications *Tramutoli UNIBAS*
Rapid damage assessment indicators: Kashmir earthquake and the Israel-Lebanon crisis *de la Cruz EUSC*
Zimbabwe LULC change detection *Schöpfer, Tiede, Lang Z_GIS*
Iraq Test Case GIS *de la Cruz & team EUSC*
Scenario analysis *Andersson, Asvärn FOI*
FAST International – Early Warning Program *Krummenacher Swisspeace*

Applications

Rapid Mapping Exercise – Kashmir Earthquake *Kemper & team DLR*
(all day)

Environment and Human Security

Indicators for Security and Stability *Katakyre JRC*
Water and Conflict *Wirkus BICC*
Examples of the use of Remote Sensing and GIS for Humanitarian Demining *Lacroix RMA*
United Nations Platform for Space-based Information for Disaster Management and Emergency Response (SPIDER) *Stevens UNOSSA*

Situation room - group work

Impact & relevance

Situation Room Group work – preparation of panel (statements, questions)
Expert panel
Peter Croll, BICC
David Stevens, UNOSSA
Anthony Cragg, KCL
Followed by graduation *Strobl, Pesaresi, Zeil Z_GIS/JRC*
Evaluation & Feedback

In pursuing its set objectives and implementing the developed concept, the training team of GMOSS managed to ascertain the optimal dissemination of the GMOSS expertise under the selected theme and, by this, strengthened the integration among the consortium members. Already during the first Summer School, invited experts immediately applied for associated membership to GMOSS at the end of the training event, a persisting trend which helped constantly increase the GMOSS partnership. Capacity building has to be understood as an important outreach activity. The announcement of GMOSS Summer Schools has attracted between 60–70 applications every year; due to financial and infrastructural constraints however, only 25 participants could be accepted, with two-third of the attendees from EU and the remainder coming from Asia, Africa and Latin America. The gender balance has been maintained at an above 40% participation of female experts. Capacities were built and partnerships facilitated. As one example among many: during extreme floods in Somalia in the early months of 2007, one summer school alumni from Africa contacted one of the lecturers at the 2006 Summer School for assistance with satellite data; the request led within a day to a call to the International Charter Space and Major Disasters which provided the required raw data. During the summer schools, ideas for joint projects are tabled and – in some cases – were pursued as submitted proposals. As a crucial element, games facilitated the building of consensus on threats and policy intervention options, as well as served as the integration mechanism between different nationalities, sectors and disciplines. To foster the alliance with the alumni of the schools, an e-Learning platform has been developed by the Center for Geoinformatics Salzburg. Presentations and material used during the event are prepared on the platform as a continuous accessible source of information (Fig. 5.4a–d).

Fig. 5.4 a–d GMOSS Summer School 2005 – participants during gaming (scenario: terrorist attack on Salzburg Festival Hall)

Fig. 5.4 a–d (continued)

How to respond to the request for extending the practical exercises and games poses one of the major remaining challenges. Organisational and infrastructural complications aside, it would be desirable to develop for the training measures a similar framework as GNEX (see Chapter 7). In the future, gaming and a lead

Fig. 5.4 a–d (continued)

scenario need to figure more centrally within the concept. This may also attract more participants from social and political sciences (until now in low numbers) and improve the integration between sectors and disciplines.

5.5 Conclusions

Interdisciplinary, intersectorial and coordinated research is of critical importance to generate both the technologies and the understanding that we need to strengthen our security monitoring capability. The definition and perception of security threats, challenges, vulnerabilities and risks is a socio-political process resulting from a complex policy assessment in EU partner countries by governments, societal groups, research institutions and the media. Information derived from remote sensors can contribute to an early recognition and warning of such threats and can enable policy makers to prevent the emergence of conflicts and to reduce their impact. Technology itself, however, cannot guarantee security, but security will be greatly enhanced by technological support. Space technology and geo-data provide context information on security problems and contribute to strengthen preparedness. Using technology effectively may enable policy-makers to enhance the coping capacities of states and by that foster stability. To this end, the GMOSS Training Concept has been developed, implemented in Summer Schools and evaluated by participants and users of space based information for security applications. By maintaining the achievements and improving on the challenges, the presented concept can serve as a role model for training in other GMES applications and services.

Acknowledgements The training activities were supported by funds from the unallocated budget of GMOSS provided by the EC. This essential contribution is highly acknowledged.

The evolution of the training concept involved many colleagues from the GMOSS Network and represents a true team effort. When reflecting on the implementation and without diminishing the effort made by several GMOSS partners, there is one champion to be mentioned: Antonio de la Cruz from the European Satellite Centre. The Summer Schools so far would have been impossible to be organized without the invaluable contributions in time and content by Stefan Lang, Hermann Klug, Dirk Tiede, Elisabeth Schöpfer, Florian Albrecht, a.o. from our Center.

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Chapter 6
Games and Scenarios in the Context of GMOSS

Adrijana Car, Ola Dahlman, Bengt Andersson, and Peter Zeil

Abstract In this paper gaming and scenario analysis in the context of the GMOSS network are introduced both as an analytical tool and as a means of promoting training. Such analysis can create a common frame for addressing a monitoring problem from different perspectives whereby answering "What if" questions is its most essential feature. This kind of approach is expected to bring together the community working in scientific research, technological developments, and engineering on one side, and analysts, decision and policy makers on the other, which is specifically true for the GMOSS community.

6.1 Introduction

Games and scenario analysis are tools to build bridges between people with different expertise and background and to increase the common understanding of an issue. It is also a good way to assess, at an early stage, new ideas and the consequences of new knowledge, new systems and methods or organizations. Scenarios have for many years proved to be useful in analyzing issues related to military security it could, and should, be used also to address issues related to non-military security and stability.

GMOSS is a network to promote cross discipline contacts on global monitoring among experts from different fields. Gaming and scenario analysis can create a common frame for addressing a monitoring problem from different perspectives. It can bring together the community working in scientific research, technological developments, and engineering on one side, and analysts, decision and policy

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makers on the other. Scenarios and games can be used at any system level. A most essential feature is the simple “What if” questions giving anyone a reason to reflect on the consequences and applications of her or his work or expertise.

This paper gives an introduction to gaming and scenario analysis in the context of the GMOSS network both as an analytical tool and as a means of promoting training.

6.2 Gaming as a Tool for Analysis and Training

GMOSS is a network aimed at promoting contact and interaction among experts on monitoring techniques and thereby explores how generic technologies such as remote sensing and GIS can support decision-making in the EU. In a large network like GMOSS all participants have their views on what our common task is all about. Gaming and scenario analysis could help create a common understanding of key issues and a framework of reference. It could further address which complementary capabilities are required in order to take maximum advantage of remote sensing data. GMOSS should also increase the understanding among technical experts on the security tasks facing the EU and how global monitoring might support decision-making in the EU.

To address monitoring applications you need to analyse the technical system or maybe rather system of systems, ranging from sensors via processing to presentation, plus the human interface and the situation of the decision makers. This will require an interactive analysis of an interagency character that has to do with the relation between and the behaviour of different actors and systems/functions. Games are generally a highly suitable tool to increase the depth and width of analysis of such complex issues. Games are also an acknowledged method for problem-based learning and training. In other words, games can be utilized both as a means of training/learning within the GMOSS network and for understanding the consequences of research and development.

Gaming would give the participants an opportunity to see and reflect on problems from another perspective than their own and to put them in the position of those who will use the future applications. This might help everyone identify the key questions that decision-makers should seek answers to. As a final point it is worth noting that games in themselves generate interaction, which in turn enhances integration and creates engagement.

6.2.1 What Is a Game?

A review of the literature on games and gaming indicates that there seems to be no commonly accepted and precise definition of the term *game*. And neither does this paper intend to make one. The idea is instead to describe various aspects/dimensions of games and thereby, hopefully, give the reader an idea of what the authors mean by the term *game*. Numerous instructive publications on gaming are available (Chapman 1992; Greenblat 1988; Shubik 1975a, b; Ståhl 1989).

Over the decades the Swedish Defence Research Agency (FOI) has produced a number of publications about games and gaming and how this tool has been used in military and civil defence planning. In the following sections some key aspects from these publications are outlined for the needs of GMOSS.

In (Agrell 1987, p. 9) a game is defined as

- A concrete framework for various activities
- An interactive group activity to highlight and deal with questions that have to do with the relation between and the behaviour of different actors/systems/functions

As a prerequisite a game has a scenario and a set of rules, which govern the game.

To be a little more concrete, we generally think of a *game as a structured tabletop discussion/exercise during which the players/participants act against an opponent or against a scenario as it develops*.

A key virtue of games is that they create a common framework of reference for all the participants. This would seem highly essential in the case of GMOSS where a large portion of the research is distributed and the researchers are physically separated. Games are specifically apt at making clear the objectives of the whole organisation and examining the environmental conditions in which the applications will function. Games are also likely to elucidate the technical specifications/demands on generic technologies or the need to develop new technologies to satisfy the needs of future applications.

By having a game framework in which generic technologies are explicitly coupled to applications, as seen by the security stakeholders, one creates a common overall picture for all participants of the direction in which GMOSS should be developing. An example of how a game is played is described in the following section and a hypothetical scenario is given in Appendix 1. Generally games can be a useful tool for learning, teaching, assessment, research, testing, etc.

6.2.2 How to Run a Game? Theory About Practice

In the setup for a GMOSS game there would typically be a game management, several players (i.e. mixed WG groups) representing both the (political) demand side and the (technical) supply side, two groups for analysis and documentation, a group of independent observers and, perhaps, some additional functions (Fig. 6.1):

By presenting different events in a time sequence the scenario will unfold. The player groups will respond to the developments and take the necessary action. The technologies and applications groups will interact with the decision-making level. For the sake of manageability the groups would be physically separated. The interaction between the decision-makers' group and the technologies/applications groups would take place in plenary sittings. The analysis group would listen in on this dialogue and draw conclusions both about the construction of the game (evaluation for future needs) and from the results of the played developments. A separate group would have the responsibility for documenting the games.

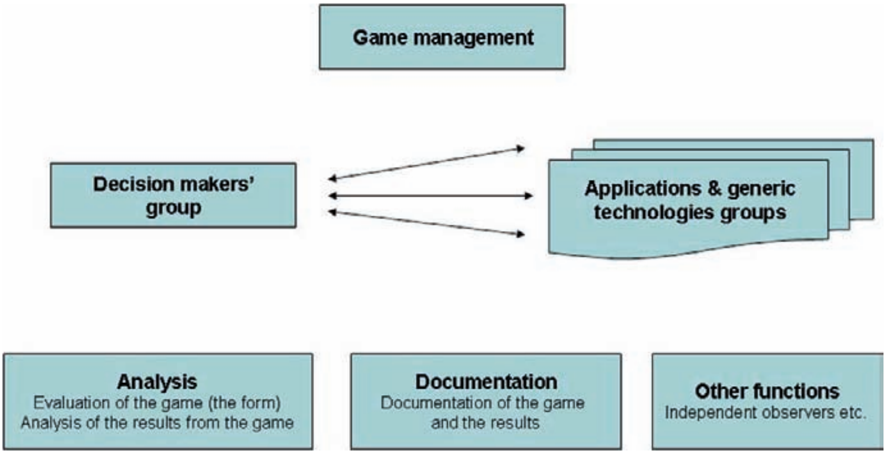

Fig. 6.1 Principal organisation of a game

A typical move in the scenario could be as follows. The management group presents an event, i.e. a large-scale terrorist attack. The players withdraw to confer about the specifics of their domain, i.e. rapid urban damage assessment, infrastructure monitoring and population monitoring. After deliberations they return and present their capabilities/applications, options for political action, technical constraints (etc.) to the decision-makers. The decision-makers' group then convenes and works out some kind of a crisis management response that will generate further action and so on.

A game typically involves preparation, gaming and post-gaming documentation and analysis. The second game performed in the context of GMOSS took place during the first international Summer School in September 2005. To assess the potential of rapid information extraction and the use of such information for decision making (prevention, first response, crisis management), the participants where exposed to an imminent terrorist attack on the Salzburg Festival Hall. Three groups of actors were selected: counter-measures (prevention), first responders (evacuation), and crisis management headed by the city mayor. The game management added new information during the course of the game (e.g. type of device used for attack: (at start) nuclear/chemical; (midway) nuclear).

6.2.3 Typology of Games: The Aim and Construction of a Game

Games are a complex activity and they can be described, characterized and categorized from many aspects using different typologies. Some typologies are descriptive, whereas others are normative (prescriptive). Some well-renowned researchers within the field of games and gaming are Martin Shubik, Ingolf Ståhl and Ken Bowen. See especially (Dreborg 2004, paper 1 "Learning by Gaming"), and the references given therein.

Dreborg (2004) proposes two typologies assuming three aspects/dimensions. His typologies are a refinement of Ken Bowen's typologies, in which Bowen couples the aim of the game to the degree of control, to get the players to behave in a desired way. The dimensions are:

- The overall aim of the game; for *education* or *investigation*
- The function of the game; to *transmit* or *generate knowledge*
- The degree of complexity of the game; *simple* or *complex*

The relation between the aim, the function and the complexity of a game can be described as follows.

Typology 1 is presented in Table 6.1. In game type A1 the game designer possesses specific knowledge he wants to convey to a group of players/pupils. Pure teaching games seem to be relatively rare. In B1 games the players are supposed to learn by making their own experiences. The game provides an opportunity for the players to get acquainted with the task, a set of problems and an institutional context.

A2 games are used to elicit more or less tacit knowledge from a group of experts. The idea is that they share their knowledge, which is difficult to state explicitly, by their actions and choices in the game. B2 is a broad category of games for organisational development purposes. The common denominator is that the game designer is the one to learn and that the purpose is to gain new knowledge. Games intended for the identification of new problems and questions and for the generation of new ideas are also examples of B2 (Dreborg 2004, p. 10–11).

Typology 2 is presented in Table 6.2. E1 games are suited to let the players/pupils try and apply principles, which they can already express verbally. These games will give the players a deeper understanding of how these principles work. K1 games provide a rich environment with many actors and relations, institutional conditions and procedural rules. Also, the problem area to be handled may be more or less complex. The main purpose is learning, i.e. the players will not be taught anything in particular, but are supposed to gain experience from being in the complex interactive game situation. An understanding of the institutional

Table 6.1 Typology 1. Game typology describing the relation between the aim of a game and its function (Dreborg 2004, paper 1, p. 10)

Function Purpose	A. Transmit knowledge	B. Generate knowledge
1. Game as a method for *education*	A1. Teaching	B1. Learning
2. Game as a method for *investigation*	A2. Expert games	B2. Testing; evaluation; problem identification

Table 6.2 Typology 2. Game typology describing the relation between the aim of a game and its degree of complexity (Dreborg 2004, p. 11)

Type of game Purpose	E. Simple and idealized	K. Complex and realistic
1. Game as a method for *education*	E1. Teach principles	K1. Give understanding of social context
2. Game as a method for *investigation*	E2. Research (Controlled experiment)	K2. Case study (Test the whole system)

environment and rules for interaction, communication and decision-making is also an important benefit from this kind of games.

In E2 games, the game designer wants to gain insights into a specified problem pertaining to a few factors or a few variables. Other factors are kept constant or are assumed not to affect the relationship studied. Research games designed as an experiment belong in this category. In K2 games the game designer wants to explore a complex problem area, which is not yet well understood. The purpose is not to elaborate on a few variables or to test some well defined principles. No general relationships can be isolated at the time the game is being developed. Instead, the game will provide a case, rich in detail and aspects. The purpose may be to get a deeper understanding of the whole situation and to generate hypotheses concerning relationships (Dreborg 2004, p. 11–12).

Typologies 1 and 2 are complementary. They are not exhaustive. The typologies express the fact that when designing a game different methods will have to be applied based on the main purpose of the game. In reality, a game, which mainly belongs to one category, may have some features of games in one or more of the other categories. It is the experience of the authors that a series a games is preferable when dealing with large and complex problems involving a large number of actors and players. Initially it would be advisable to perform a test game to explore the more precise construction of the future games. As a second stage a so-called overview-game could be carried out for learning as well as teaching purposes and to test the chosen construction. After that the players are ready for in-depth games aimed specifically at reaching the main goal of the investigation/study/analysis.

6.2.4 Open or Closed Games?

Another aspect of games is their character regarding the amount of information available to the players. In open games the players have the same information about each other and about the scenario developing.

In closed games the players are separated. All information about the opponent or the scenario developments is provided by the game management either on request or as a result of own activities (i.e. remote sensing collection). Decisions on how the player acts and uses her or his resources are relayed to the game management, who subsequently confronts them with the actions of the opponent or with the scenario developments. The subsequent step in the game is then decided upon by the management.

In a rough generalization one could say that closed games are best suited for training and education, whereas open games are better suited for assessment, planning and studies. In general, open games are preferable in studies when you want to assess the effect of a new capability, organisation, subsystem etc. on the overall output of a system. Closed games, on the other hand, are advisable when one wants to analyze and assess decision-making and command and control.

6.2.5 GMOSS Games for Various Purposes

An idea would be to perform gaming activities with various purposes and in several steps. One could envisage the following scheme during the existence of GMOSS:

- Games for internal GMOSS education (mutual teaching) and learning how to proceed with gaming (e.g. game performed at GMOSS Meeting 2004, Brussels; see Appendix 1)
- Games for investigative purposes to develop the desired GMOSS applications and to address the effects and values for the overall performance of a system of a particular development in technology and analysis methods
- Games for transferring knowledge about the applications to EU decision-makers and staff and others that will be using them (external education); (e.g. game performed during the GMOSS Summer School 2005)

The first step would be to play a game with the aim of mutual education among the network participants (B1). Such a game would also have an A1 feature since the game designer would want to convey knowledge to the players about what a game is and how one plays such a game. This game should be simple and idealized with the aim of teaching principles (E1).

Games and scenario techniques are important tools in the newly developed philosophy of ‘problem-based learning’ in scientific education (see e.g. Car 2004). In essence the methodology proposed under this scheme comes back to the observation that learning is best set in motion when one has to find solutions to a problem without being presented with predefined options. As an example, please consider the game described in Appendix 1.

From the experience made so far we observe that some experts – being confronted with a game setting for the first time – show a certain uneasiness to act in a role during the game. While this can lead to a total refusal to participate, it prevents the objectives of the game to transpire. To the contrary, the game as a ‘mind-opener’ was well received during the training environment of the Summer School.

6.3 Scenario Design

6.3.1 General Considerations

A scenario (‘the scenery’ in Italian,) is a brief description of an event. A scenario is also an account or synopsis of a projected course of action, events or situations. A number of issues have to be considered when developing a scenario. The following key issues are taken from a more comprehensive presentation in Wikipedia (Scenario 2007).

- Decide on the key question to be answered by the analysis.
- Set the time and scope of the analysis.
- Identify major stakeholders.

- Map basic trends and driving forces.
- Find key uncertainties.

A well developed and documented scenario development process is presented in (ScenariosWorkingGroup 2005): Below we illustrate the development of a comprehensive and complex scenario. We, however, want to stress that many most useful scenarios can be quite simple and contain few components.

6.3.2 Scenario Design for GMOSS

Within WP 21100 a number of sessions took place to conceptualise a process of a scenario design, such that it is applicable within the GMOSS network. To do so, a number of existing scenarios were analysed and discussed and common denominators were derived (Tunberger et al. 2006). This lead to a formal description of the scenario design process.

We distinguish two main tasks in the process of a scenario design (Fig. 6.2). To design the *Environment* (i.e. solve problems), including all the external factors that influence the game, and the *Monitoring system*, giving tentative parameter of a system to analysed.

The process of designing an environment requires a specification of the following components (Fig. 6.3):

1. Choice of a topic (i.e. hypothesis) and the supporting assumptions.
2. This choice needs to be made in a political, military, economic, societal (etc.) context.
3. Selection of indicators.
4. A set of indicators must then be determined such that they support the assumptions. Again, the pool of possible indicators is context-driven, and can be e.g. geographical (local, regional or national extent), economic (wealth distribution), etc. We distinguish between static and dynamic indicators.
5. Development and running of experiments.

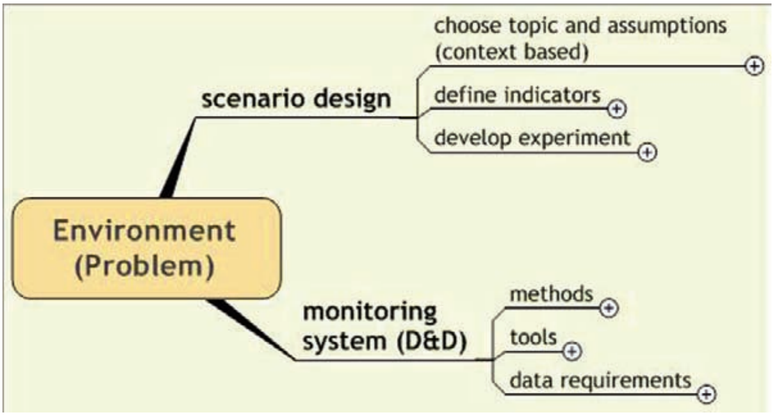

Fig. 6.2 Scenario design approach: two main tasks

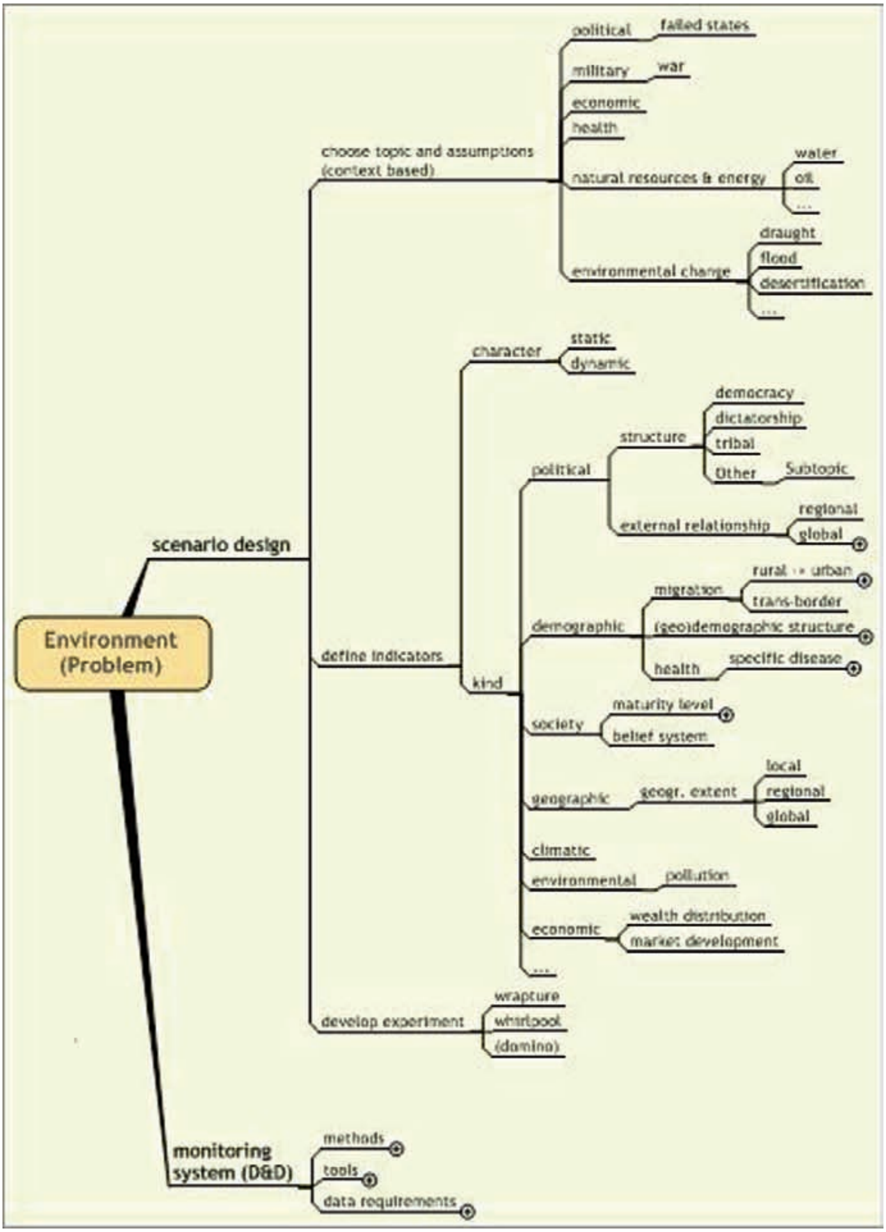

Fig. 6.3 Components of the Task 1 – Scenario design

6. One or more experiments are then designed and run to prove the posited assumptions and selected indicators.

The selection of indicators and the development of experiments has a direct influence on the design and development of a respective monitoring system as explained below.

We understand a *monitoring system* as a system that can measure/collect/gather data associated with indicators specified in a scenario, evaluate them, and determine how much such a model of reality deviates from the respective scenario.

Design and development of a monitoring system comprise the following elements (Fig. 6.4):

- Methods
- Tools
- Data requirements

From the technological point of view, a monitoring system may contain a database management system, a geographic information system, or a spatial decision support system. The latter will influence the choice tools to be used, in particular software and applications. The choice of these methods is further influenced by the intended use or purpose of the monitoring system, such as early warning, preparedness or contingency planning.

Data is an important aspect of a monitoring system. What will be measured and evaluated should be stated within the scenario. This could include; *data selection* such as usability, availability and accessibility; *data sources* such as primary and secondary sources; and *data type* specification such as statistical, demographic or geodata (e.g. images, maps).

A complete representation of a scenario design and monitoring system for the GMOSS environment is given in Appendix 2.

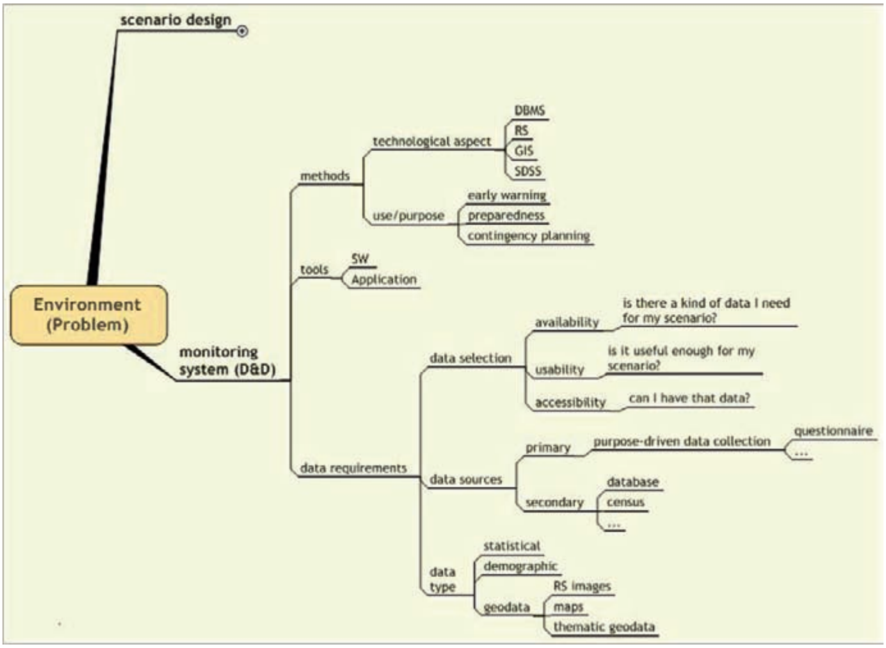

Fig. 6.4 Components of the Task 2 – Design and development of a monitoring system

6.4 Summary of Gaming and Scenario Experiences in GMOSS

Scenario analysis and gaming have long proved to be useful to analyse events and processes related to security and stability. The GMOSS network, having participants from a number of scientific and technological fields relevant to remote sensing and GIS, could also have benefited from the use of these tools. They could have been used at a technical level to analyse the integration of different technologies. At a higher system level it could have brought scientists, system analysis and decision and policy makers together to address the way different monitoring systems might provide data to support decision making at a European level. It will bring scientific research, technological developments, and engineering achievements on one side, and analysts, decision and policy makers from various GMOSS relevant fields on the other, to work together

For different reasons this did not happen within GMOSS. Few scenario analyses or games were conducted and for future projects it might be interesting to discuss why. GMOSS members are, as most scientists, unfamiliar with scenario analysis and gaming. The first game conducted early during GMOSS (Appendix 1) was a high level game. Most GMOSS members found the game far away from their experience and interest. This enhanced the hesitation to engage in further games or scenario exercises. An important lesson is to create scenarios and games at a level where participants feel attached. The game during the GMOSS Summer School 2005 was on the other hand well received by the students, illustrating that games can play an important role in training.

Acknowledgments This paper is based on the position paper “Gaming as a tool for analysis and training”, 2004, GMOSS, authored by Ola Dahlman (WG 10500 Games and scenarios), Wilhelm Unge and Peter Zeil (WG 21100 Reducing Threats), Hans Günter Brauch (WG 21000 Security Concepts and Threats), and Harald Mehl (WG 21200 Responding to Crises). The final version of this paper was compiled and authored by Adrijana Car, Ola Dahlman, Bengt Andersson and Peter Zeil.

Appendix 1 GMOSS Game at the Annual Workshop in Brussels, November 8, 2004

1 Background Scenarios

Europe Faces Increased Threat from Terrorism and Organized Crime

Over the last year the number of terrorist attacks in Europe has increased significantly and so has the cross-boundary criminal activities. The aim of the terrorist activities has not only been to create fear generally among the European citizen but also to an increasing extent target commercial activities. A number of large scale explosions have taken place, one of them releasing a limited amount of radioactive fall-out. Several explosions have hit offices, industries and communications. An unexplained outbreak of smallpox occurred last months in central Europe.

Efforts by the European States to prevent terrorist activities have by and large been unsuccessful. The resources available to counteract terrorist attacks differ significantly among the European States and cooperation and coordination among the States are limited. The present role of the Commission is limited and few joint resources are available to the EU. The need for increased coordination, cooperation and joint resources is most pronounced in the field of intelligence gathering and analyzes.

Following this increased terrorist activities on European soil and worldwide, EU has decided to increase its joint actions to counteract such attacks. It has just established, within the EU Commission, a Homeland Security Commissioner with overall responsibility at an EU level for counter-terrorist activities and for cooperation with and support to corresponding national authorities. EU has also decided to create a European Surveillance Agency, subordinated to the Homeland Security Commissioner.

Homeland Security Commissioner: Tasks and Mandate

To increase the efficiency and coordination within the EU in counteracting the growing threat to Europe from terrorism and international crime, the EU leaders have decided to establish a Homeland Security Commissioner within the EU Commission. The tasks and mandate of the Homeland Security Commissioner can be summarized as follows.

The Commissioner shall:

- Coordinate the cooperation among the European Union States in counteracting terrorism an organized international crime.
- Prepare the necessary legal frames to facilitate a close cooperation among the European Union States in combating terrorism and international crime.
- Facilitate the exchange of intelligence information among EU States related to terrorism and international crime.
- Be responsible for EU Commission support to individual States to improve their counter terrorism capability.
- Be responsible for agencies establish by the EU Commission and other actions taken by the Commission to assist EU States to combat terrorism and organized crime. Among those agencies is the European Surveillance Agency.

More specifically the Commissioner shall in the field of intelligence gathering, analysis and information distribution:

- Establish a mechanism and necessary secure information systems to facilitate the rapid exchange among the EU States of information related to terrorism and international crime.
- Provide coordination among the national agencies in EU States working with counter-terrorism intelligence.

- Support individual States in the development of their intelligence capability related to terrorism and international crime.
- Direct, oversee and finance the operation of the European Surveillance Agency and make sure that the Agency has the necessary technical tools and procedures in place to provide EU States valuable intelligence data.
- Provide direction on how to focus the EU Research Program on Security.

The European Surveillance Agency

EU has decided to create a European Surveillance Agency, subordinated to the Homeland Security Commissioner. The task of the Agency is to provide surveillance and intelligence information at a European level and to coordinate with and support corresponding national institutions. The Agency will get its direction, oversight and financing from the EU Commission and more specifically its Homeland Security Commissioner.

The overall tasks and responsibilities of the European Surveillance Agency are:

- To support EU States with intelligence data by establishing and operating surveillance systems that would be most suitably operated at a European level
- To collect and analyze intelligence information related to terrorism and international crime from such systems and distribute the information to EU States
- To support EU States in establishing their national surveillance systems
- To support EU States in their analyzes of intelligence data
- To provide training to personal from EU States working on the collection and analyzes of intelligence data

2 *Issues to Be Considered During the Game*

Part 1 Defining the Tasks of the European Surveillance Agency

At the time of the first part of the game the European Surveillance Agency is just about to be established. The task of the players is to deal with the following issues and to find a proper balance between the responsibilities of the EU Commission, the Agency and the EU States. The task is to:

- Define the tasks of the Agency in relation to the Homeland Security Commissioner and to national intelligence authorities and institutions.
- Define the interaction between the European Surveillance Agency and the national authorities.
- Define the products to be delivered by the Agency.
- Identify the surveillance systems that are to be operated by the Agency.
- Define the data analysis to be carried out at the Agency.

- Identify the method of work of the Agency and the resources needed.
- Identify the presently available knowledge that could go into the establishment of the Agency and with areas would most urgently need further research.

Part 2 Identify the Way the European Surveillance Agency Would Handle a Threat Scenario

The European Surveillance Agency has now been established and given the tasks and modus of operation as defined in Part 1.The Agency, the Homeland Commissioner and national authorities are now facing the following scenarios. (We can choose two of the three scenarios below and the two groups could play different scenarios.)

The prime task is to address the way the new Agency can respond and support possible actions by EU States and by the Commission, in particular by providing intelligence information.

Scenario 2a

1. Unconfirmed intelligence reports claim that a large-scale terror attack is to be expected that might involve also WMD. It is expected that the terrorists will use ships to transport the explosives and other materials to European targets – mainly harbours. The ships are reported to have departed from an unspecified West African country.
2. There are unconfirmed reports coming in of a large explosion at see in the waters south of the Canary Islands. (To be introduced into the game a bit later.)

Scenario 2b

1. Reports are coming in that a large number of refugees are gathering in North African Mediterranean ports. There is widespread fear that these people, in large numbers, soon will be transported across the sea to countries in southern Europe. The situation is, however, quite unclear.
2. There are unconfirmed reports coming in that one or more ships, carrying large number of refugees, are in emergency situations in hard weather west of Malta.

Appendix 2 Scenario Design Approach for GMOSS

In Fig. 6.5 a detailed representation of the scenario design approach for GMOSS is given.

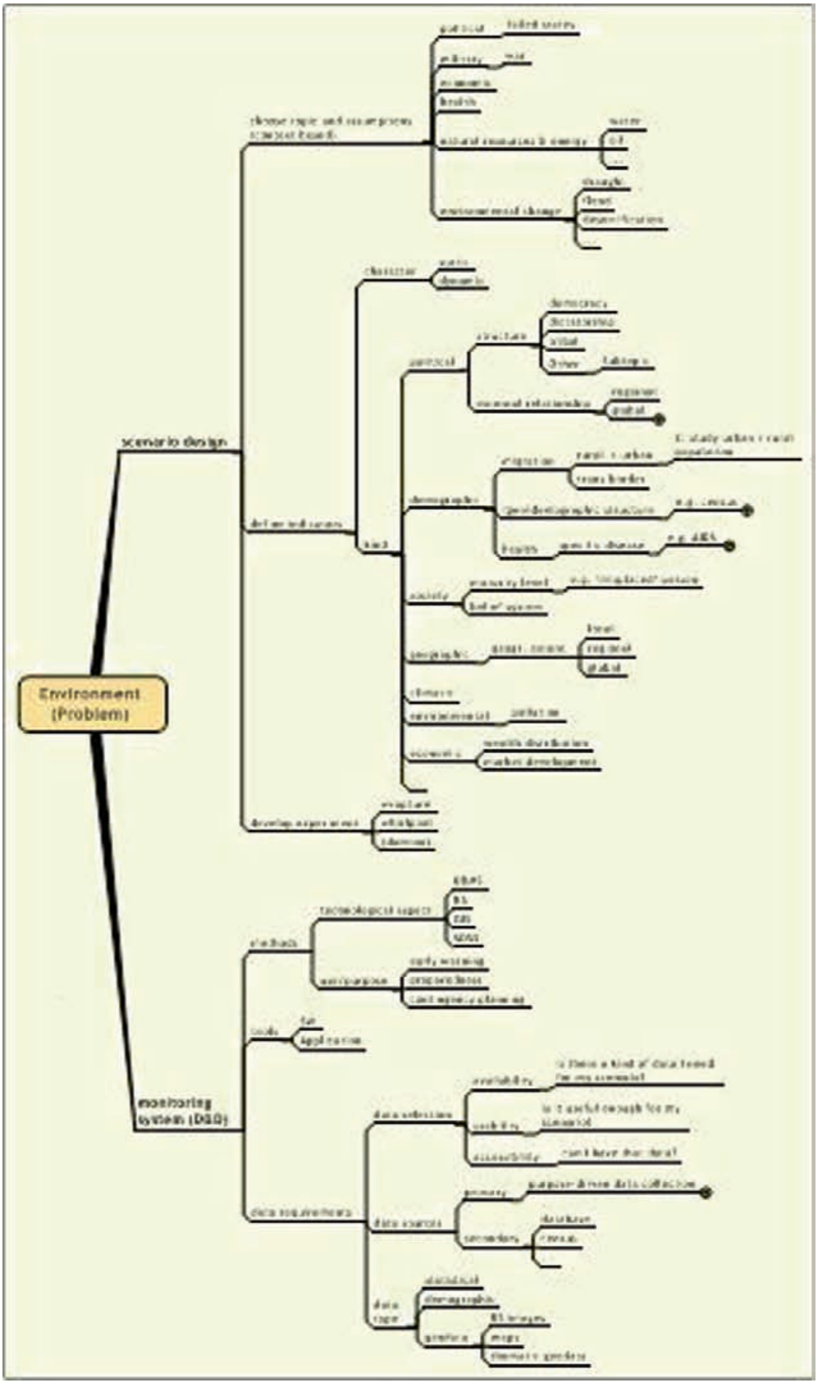

Fig. 6.5 Scenario design approach for GMOSS at a glance

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Chapter 7
GMOSS: Infrastructure and Standards

Donna Kodz and Joseph Jobbings

Abstract This chapter discusses the importance of standards to aid collaborative working within the GMOSS Network of Excellence (NoE). The focus is on facilitating the various elements of security and sustainability research towards potential delivery operational services in the future. One area in which the use of standards has been demonstrated, is through the provision of a web catalogue to enable sharing and discovery of common resources across the disparate organisations of the NoE.

Keywords standards • infrastructure • data catalogue

7.1 Introduction

7.1.1 Why Are Standards Important?

Standards have importance to the security and safety domain for a number of reasons. In this discussion, we shall focus on the key concepts, which are:

- *Collaboration* – data sharing, knowledge sharing, common semantics
- *Interoperability* – systems, processes and procedures
- *Quality assurance* – fitness for purpose

To enable security and safety organisations from different geographies, as well as different scientific or socio-political disciplines to effectively collaborate, common interoperable systems need to be in place. Less effort is then needed for management, allowing resources to be properly focused on the security and safety activities. The seriousness and weight attached to decisions made in a security or sustainability context means that any capability (such as those for monitoring or estimating) *must* be fit for purpose. Quality assurance provides the necessary checks in the task of ensuring 'fitness for purpose'.

D. Kodz (✉) and J. Jobbings
QinetiQ, Farnborough, Hampshire, GU14 0LX, UK

B. Jasani et al. (eds.), *Remote Sensing from Space: Supporting International Peace and Security*,

Beyond the lifespan of GMOSS, the research undertaken will aid the security and sustainability user-base by contributing to security-oriented operational services under the GMES[1] framework. Implementing appropriate standards ahead of this eventuality will enhance the preparedness of GMOSS outputs for integration into the security and sustainability domains.

The research activities undertaken by the GMOSS programme will use existing technologies and standardised infrastructure elements. Within commerce and industry this is everyday practise. The manufacture and successful operation of a domestic electrical appliance, for example, is dependent on standards: a standardised power supply and standards in electrical engineering. In fact, in the absence of standards, it is hard to imagine such an appliance functioning with any success. The security and safety domain, however, should not only exploit existing standards but build on them to develop security specific, vertical applications of known standards that can apply across multiple domains. GMOSS provides an ideal context for such work on standards and a strong foundation for any services or systems that might evolve around them at a later date. Section 7.2 touches on groups and organisations that have published standards in technological areas, while Sections 6.3 and 6.4 consider the NoE itself and the relevance and use of standards in a GMOSS context. The achievements of standards bodies to date present opportunities for exploitation and further domain specific development. The geospatial specifications published by the Open Geospatial Consortium,[2] is one such example of work on standards for building on by GMOSS, as is the Dublin Core Metadata initiative.[3]

For the GMOSS NoE, standards present an opportunity to improve the efficiency involved in data sharing and product workflow. More importantly however, standards are a way for the network to preserve the value inherent in its data and knowledge-base. The data and knowledge-base accumulated by GMOSS will outlive not only the sensors that originally captured it but also the systems used to process, analyse and visualise it. Provided data is correctly described (using appropriate metadata standards to describe its provenance and content), holding that data in a standardised manner means it can be de-coupled from the systems it is reliant on for processing or display. ‘De-coupling’ systems and data preserves the value of data and avoids its redundancy once those systems become obsolete. The importance of this effort is notable for GMOSS activities such as change detection where scientists want to know the temporal value of data, as well as how and where data was collected. Standardisation is one way to ensure longevity is built into the work of GMOSS and its outputs.

Standards help the interaction of GMOSS partners to be done more consistently and for scientists to perform related activities with greater ease. Production or creation of products to be shared is more cost-effective where fewer disparate systems are in use. Fewer systems leads to savings on licensing and maintenance costs and time spent transferring data between different formats and systems. Common

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[1] Global Monitoring for Environment and Security, http://www.gmes.info/

[2] Open Geospatial Consortium, http://www.opengeospatial.org

[3] Dublin Core Metadata initiative, http://dublincore.org/

interfaces, particularly those based on open standards, increase the ease with which systems can interoperate, even where disparate systems are in place. It is notable that in the absence of recognised standards many systems would have little success at all in interacting with others (without the development of bespoke interfaces, which can be expensive to maintain).

7.1.2 Types of Standards

Although standards afford similar benefits through their use, types of standards vary according to their provenance or purpose. The standards mentioned in this chapter are often described as either '*de jure*' or '*de facto*'. This distinction implies the manner of adoption of a standard as well as its origin and might arguably be an indicator of the ease of use or scope of a standard. A *de facto* standard often originates as a solution to a problem or requirement and becomes an industry standard through its ease of use and resulting wide-scale adoption, often in the absence of any other suitable standard.[4] *De jure* standards are those that are agreed and developed, usually by an expert body[5] that has the interest and the required specialist knowledge to publish standards for use in a known context. These standards are then adopted by the user community, on a voluntary basis.

Both *de facto* and *de jure* standards have relevance for GMOSS. However, notwithstanding the different terminology, it is notable that standards that help to 'unlock' the value of information (and the ability to access it) are more often the standards adopted with the most enthusiasm. In the case of the World Wide Web, adherence to *de jure* standards (such as html mark-up language and http protocol), used to publish and transfer data via the Internet, has been significant. The potential size of the Internet 'audience' makes it an ideal channel for communication, commerce, and knowledge distribution. It is the use of standards however, that enables commonplace computer and telecommunications networks to be adapted and exploited as a means to deliver content to users. The difficulty inherent in different technologies on different platforms trying to share data over the web is overcome through standards implementation.

7.1.3 Who Are Standards Important To?

Standards in a GMOSS context impact a variety of different actors. Figure 7.1 shows those actors involved in GMOSS activities and perceived end users. Scientists are described in Fig. 7.1 as being the initial contributors and recipients of the NoE.

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[4] A commonly cited example of a *de facto* standard is the ESRI shape file format for storing geospatial data.

[5] Examples of these 'expert bodies' on standards are the European Committee for Standardization (CEN) and the International Organization for Standardization (ISO).

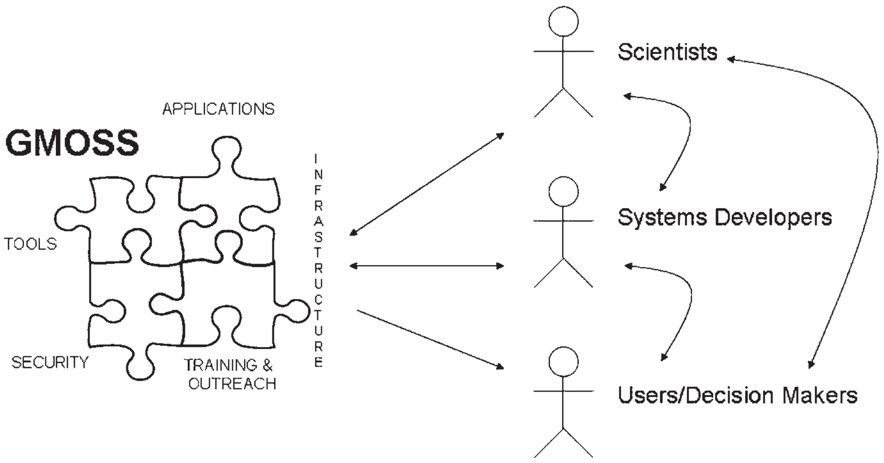

Fig. 7.1 Showing GMOSS ‘actors’ and the inter-relation between them

Scientists might be described as the structural ‘nodes’ of the network – that includes academics involved in remote sensing and socio-political studies. Their work provides the core knowledge and applications for inclusion by developers and data suppliers in systems for security and sustainability monitoring. Where core tools produced ‘at source’ by the scientific and socio-political actors embrace standards, systems developers can design and develop better systems using these core tools as building blocks. The third ‘actor’ is seen as the user or decision maker, who may be functioning at a regional or international level, in a governmental or non-governmental context but who is able to benefit from the NoE’s ‘effective capacity for global monitoring’ in an operational context.

Geospatial data from remote sensing can be processed, stored and retrieved in different ways. This presents opportunities to standardise on data models, data formats, data content and the interfaces used to access the operations handling processing, product generation and product storage. Figure 7.2 shows examples of these areas and some associated, commonly used standards.

The following discusses the enumerated elements illustrated in Fig. 7.2. Standardised interfaces allow development of connected systems. For the NoE this means that future GMOSS services built on such interfaces will be achieved with less overhead. Standardised interfaces enabled the proliferation of ‘plug and play’ devices commonplace in computer hardware. Similarly, systems that offer services, such as a web map server, implement standardised interfaces, meaning they can be easily integrated into larger systems without the need for re-engineering or duplication of effort.

1. Data can be formatted in a number of different standards and encodings to suit requirements. Some formats, such as html and XML aid the delivery of remote sensed data with less associated effort, by exploiting cross-platform technologies like the internet. Encodings such as Unicode increase language support, enabling information to be meaningful to users on a global scale, regardless of geographic or cultural context.

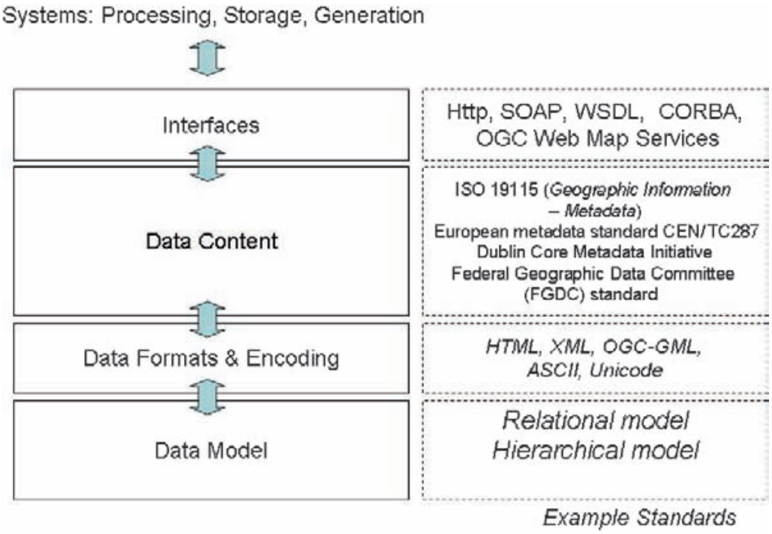

Fig. 7.2 Elements presenting opportunities for standardisation and some common examples

2. The different actors involved in GMOSS and its eventual outputs will collect, store and share data with greater ease where its content is described according to explicit standards. To access the information users need, they must be able to perform an effective search of large volumes of data. Metadata standards ensure data is adequately described so that it can be retrieved as need arises but also ensures that its origin and content are correctly defined. This is an important point in regard to products resulting from remotely sensed data, which may incorporate resolution information and geographic extents. Standardised content definition benefits system development by enabling systems to interact with less reliance on human intervention. For example, metadata termed ‘navigational’ can tell other systems where to access the data they are looking for, by passing a URL indicating the location hosting the data of interest.
3. Data models are commonplace in data structures and data management, enabling support for physical data models and effective storage and management of large amounts of complex data. UML is a particularly useful modelling language as it is extensible (if a concept is not present in UML base language it can be introduced by defining a stereotype) and is incorporated into various commercial development tools allowing modelling and code generation to be done more efficiently.
4. Data quality is essential to the application of data in GMOSS and any resulting tools to aid the decision making process in a security monitoring environment. The ‘trustworthiness’ and ‘completeness’ of data can only be assessed by a quality indicator. The ISO 19113 and 19114 standards present quality principles and quality evaluation procedures respectively, for geographic information. Such standards can be applied to give users, scientists and decision makers a means to assess the suitability of data for scientific analysis or situational analysis.

5. Security has relevance in some degree to all the technical areas of GMOSS, due in no small part to the sensitive nature of the programme's mission of global monitoring. Standards exist to implement security at system, network, data storage, interface and metadata levels. Effective security measures incorporate some or all of the following in a manner commensurate to the value of the data requiring protection:

   - Hardware and software for network and communications management
   - Security software
   - Security policy
   - User processes
   - User management
   - Data encryption

The overarching principle in the decomposition of elements in Fig. 7.2 is the separation of data content and its encoding. This provides the benefit of reducing reliance on specific formats and systems and allows data to be held in a 'product-neutral' way. For example, XML can be used by a system despite that system not explicitly knowing the data's structure in advance. Data is also described more efficiently, enabling significant gains when searching for information or packaging data for distribution.

7.1.4 Scope of GMOSS

The GMOSS aim of investigating "present and future threats to security and the need for exchange of information between stakeholders during crises"[6] is of particular importance to standards in the security domain. Crisis situations can involve complex logistical operations and coordination of significant numbers of people – both those affected by a crisis and those involved in recovery efforts. In the case of, for example, humanitarian relief, available resources of time and expertise are usually limited. In all situations, the use of standards can improve efficiency and reduce the chance of semantic confusion and misinformation. In a practical sense, the use of standards would ensure data used to plan disaster recovery was to a known level of quality and in a standard format usable by supporting systems: workers in different organisations or different geographical areas collaborate most effectively where information is referenced in a common way.

GMOSS follow-on activity is likely to be guided by the aims of GMES[7]: creating the building blocks for security oriented operational services. The GMOSS network will need to ensure harmonisation with external projects such as GMES and is aiming to achieve this by implementation of a GMES profile for metadata (see Section 7.4.4).

The test case activities being conducted under the GMOSS programme are a positive but initial step towards the services envisaged by GMES. The test cases

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[6] GMOSS Mission Statement, http://gmoss.jrc.it/?page=mission

[7] Global Monitoring for Environment and Security, http://www.gmes.info/

will examine the work, analytical approach and algorithms under development within GMOSS. The performance of these algorithms and techniques against real world data will demonstrate their value to the civil security community. Test cases will need cross-working between the different GMOSS activities and the ensuing collaboration will present an opportunity to examine the effectiveness of standards in facilitating data sharing and execution of tasks using a shared infrastructure.

7.2 Standards Bodies and Initiatives

7.2.1 Security and Remote Sensing

Standards bodies exist at national, international and domain levels, with varying remits and license. These organisations are largely made up of industry authorities and experts with significant support from public and private bodies with a vested interest in establishing standards in key areas. Geographic Information Systems, analysis and presentation software and networking technologies are often integrated into adjoining infrastructures to exploit remotely sensed imagery stores. There are a considerable number of relevant standards and guidance materials which relate to these areas, that GMOSS can draw on to the network's advantage.

National standards bodies pursue publication of standards from a domestic perspective. Additionally, these domestic standards groups often have the important role of input to international and multinational organisations whose publications may take precedence over national standards.

The European Committee for Standardization (CEN), founded in 1961, provides voluntary technical standards to the European Union and European Economic Area. The CEN Technical Committee 287 on Geographic Information has seen periods of inactivity, as its role was absorbed by the work of the International Organization for Standardization (ISO)'s Technical Committee 211. It is currently revived, however and is looking at ways to adopt and implement in Europe[8] the standards being published by ISO TC 211. ISO TC 211 consists of working groups with responsibility for various areas including geospatial services, imagery and information management. Based in Geneva, ISO is formed from (non-governmental) national institutes of 156 countries, on the basis of one member per country. ISO's well established 9000 series on Quality Management and the work of ISO TC 211 are just two examples among hundreds of areas covered by ISO.

The Open Geospatial Consortium (OGC) provides geospatial standards and other location-based standards, with an emphasis on 'open and extensible' and specifications free for public use. OGC also benefits from a class 'A' liaison with ISO, meaning that their specifications may be offered to ISO to become an international standard. OGC is addressing remote sensing and security in working groups such

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[8] Draft Business Plan of CEN/TC 287 – 'Geographic Information', 2004-07-06, Revised Draft.

as the Risk and Crisis Management Working Group,[9] Decision Support Working Group,[10] Coverages Working Group[11] and Security Working Group.

Other organisations and initiatives are working with or through the OGC and ISO bodies to improve the interoperability of remote sensing systems: the Committee on Earth Observing Satellites (CEOS) has as part of its mission the goal of improving interoperability in systems used for earth observation and receipt of such data.[12] The OGC itself organises test beds, "…designed to encourage rapid development, testing, validation and adoption of open, consensus based standards specification."[13]

GMOSS can monitor and maintain a 'watching brief' over the activities and publications of many of these bodies to ensure the network is aware of current developments and the achievements of practical exercises like test beds and prototyping activities. Developments of particular relevance or use for the NoE can then be incorporated in an appropriate manner.

7.3 Standards for GMOSS

The practical implications of standards for GMOSS are more easily understood when the work packages are considered in more detail. Examining how standards affect the different threads of GMOSS also gives an indication of where standards do not fully address the domain requirements. At the time of writing, for example, it is our understanding that ISO 19115 for metadata does not define security-specific metadata. Additional constraints are inherent in a security context, further questioning whether existing standards adequately meet requirements. To ensure confidentiality and integrity of sensitive data, for example, the level at which metadata is stored may become an issue for debate.

7.3.1 Generic Tools

The GMOSS area of most immediate relevance to standards is the 'Generic Tools' group of GMOSS work packages.

The semantics and description around features, integration of different imagery and the ability to detect change all benefit from standardisation. This is implicit in feature extraction and change detection, where fundamental principles require a known reference for comparison or identification of features and changes. However, to effectively use the *outputs* from these work packages, or to even co-ordinate the work within them, requires standardisation on certain basic fundamentals:

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[9] http://www.opengeospatial.org/groups/?iid=163

[10] http://www.opengeospatial.org/groups/?iid=44

[11] http://www.opengeospatial.org/groups/?iid=49

[12] http://www.ceos.org/pdfs/CEOS_Annual_Report_2004.pdf

[13] http://www.opengeospatial.org/initiatives/?iid=199

processing, geo-referencing, resolution, feature characteristics and nomenclature. Feature extraction can benefit from a standard approach to naming and describing features, through use of a data dictionary. A data dictionary is ideally created on a domain-specific basis, with mappings implemented between data dictionaries describing different domains. GMOSS has had success in establishing a data dictionary and initiating its creation and use among GMOSS packages. Once semantic resolution has been achieved between different domains, a further valuable contribution would be to establish a multi-lingual data dictionary that establishes not only common semantics but also ensures that semantic coherence is not lost in translation. The following example illustrates this point: a semantic data dictionary can reconcile meaning across different domains, for instance a 'track' and an 'un-adopted road' may be shown to have a common meaning by reference to a data dictionary. However, a linguistic dictionary might translate the French word 'autoroute' into 'motorway' in English but this could prove to be an erroneous translation for the purposes of remote sensing, where the former's characteristics typically describe a two-lane road and the latter's a three-lane road. This example demonstrates the importance of semantic convergence, information for use within security and sustainability must be not only accurate but meaningful to its end user. This is one of the areas where GMOSS can combine its pan-European makeup and the collective expertise of its partners to provide value to decision makers.

The image format used for displaying end products from exercises like feature extraction is another example of where standards can facilitate GMOSS activities. A common output encoding means integration of data from one system can be done with more ease and furthermore will benefit workflow, as NoE activities involve effort spanning different work package groups. In sharing data (see Section 7.4), a standard approach to describing data and its content (such as a metadata standard for geospatial data) and a standard approach to accessing it (such as through a standards-based catalogue) consolidates and increases the value of data that has been captured and processed, by making sure it is accessible and fit for purpose, at the point of use.

7.3.2 Applications and Security Concepts

The 'Applications' group of work packages compliments work carried out within the 'Generic Tools' group, by applying techniques to real world situations with security implications, in conjunction with aspects and requirements of the area under investigation. Many areas of the applications group of work packages involve qualitative and quantitative assessments, such as timeliness, image resolution and nomenclature. Standards are imperative to establish consistency across these activities. The semantic convergence described above in Generic Tools, is one factor that can aid European collaboration on security and sustainability monitoring. The INSPIRE (Infrastructure for Spatial Information in Europe[14]) proposal for a European directive has this idea (and others) at its core in its mission to

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[14] Infrastructure for Spatial Information in Europe, http://inspire.jrc.it/

integrate Spatial Data Infrastructures across European Member States. INSPIRE places specific emphasis on environmental policies and impact, and is providing architecture and implementation rules for geospatial specific standards. GMOSS can learn from these standards and make positive contributions to their on-going development. Environmental disasters within the last decade stress the need for such collaborative action between member states. For example, flooding of the Morava and Odra river basin and the East Bohemia region of the Czech Republic in 1997 resulted in an estimated 1.9 billion euros of damage with 538 cities and municipalities being affected in 34 districts.[15] In this example, the cause of damage and subsequent relief efforts involved cross border coordination. Analysis has suggested that the INSPIRE programme placed in context alongside GMES could offer cost savings to European states in excess of 1 billion euros.[16]

Security policy is traditionally an area that is difficult to define concisely, hence the verbose nature of many policy documents. However, domain specific information may be informed indirectly by policy: impacting on feature catalogues, data dictionaries and metadata. Conversely decision making is dependent on the quality of information and fitness for purpose of products.

7.4 Data Sharing: An Example of Implementation in GMOSS

Within the context of the preceding discussion on standards, this section looks at the sharing of data in GMOSS as a specific example of how compliance to standards facilitates enhanced collaborative working between organisations and project work packages.

7.4.1 Data

The ability to share data within the GMOSS NoE is a fundamental requirement for achieving integrated working between the various partner organisations and the GMOSS work packages. Within the programme, satellite imagery is key to much of the research being undertaken to derive information about activities relating to security and stability. Satellite imagery and associated derived products form the focus of these discussions. A derived product is typically created from a satellite image by applying a user defined algorithm – for example the application of a change detection algorithm to temporally different images of the same area, to determine areas of change.

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[15] NEDIES series of EUR Reports, Lessons Learnt from Flood Disasters, Alessandro Colombo and Lisa Vetere Arellano, EUR 20261.

[16] Xtended Impact Assessment of INSPIRE, Massimo Craglia, 2006 http://sdi.jrc.it/ws/costbenefit2006/presentations/craglia_xia.pdf (http://sdi.jrc.it/ws/costbenefit2006/)

Proprietary data formats can impede data sharing as they typically require use of specific software which must be obtained, or developed to ingest or convert the source data into an alternative proprietary or standard format. There are a number of software tools in the market place that support conversion between numerous formats; however conversion often suffers from issues such as:

- Cost – the assumption that the user has access to and a licence for a suitable conversion tool
- Potential data loss – particularly during data compression or where multiple conversions are performed using lossy conversion algorithms
- Time consuming – an issue when timeliness of data is critical

These issues can largely be addressed through widespread use of standard ‘open’ formats for the exchange of satellite imagery. Examples of international open standards include GeoTIFF and JPEG2000 formats. GeoTIFF has the support of a wide range of applications and remains a core file format in the geo-information community purely on the basis of its compatibility and familiarity. However, important information about source, accuracy and image data sensor information are missing in GeoTIFF. JPEG2000 has been designed with new technologies that are well suited to the handling of satellite imagery. The JPEG2000 format has no licensing restrictions and is increasingly being used as a key distribution format by data providers. It is widely supported by software vendors. A key advantage is the ability to create a lossless image with the application of ‘region of interest compression’ – essentially compression according to the level of detail in an image, thus reducing file size. In January 2006 the Open Geospatial Consortium issued the Geography Markup Language (GML) in JPEG 2000 specification, which specifies the encoding and packaging rules for GML use in JPEG 2000. It also allows an XML encoding of the metadata describing the image to be held within the JPEG 2000 data file.

The GMOSS NoE will aim to adopt open exchange format(s) such as GeoTIFF or JPEG2000 for imagery, taking into consideration potential future creation of operational services. Open exchange formats will enable greater interoperability between systems and avoid need for time consuming format conversion, which may be critical in operational scenarios.

7.4.2 Digital Rights Management (DRM)

Satellite imagery within GMOSS is primarily obtained from commercial sources and is typically subject to a single or a multi-user license. Such a license places restrictions on the reproduction of the original image and on the number of copies which can be held and distributed both internally within an organisation and externally. In most cases license restrictions apply unless products have been derived that cannot be reverse engineered to the original image. For example a land use classification would be based on the original radiance values for each pixel within the image but are not retained in the output image. The algorithms to create these products may also be subject to intellectual property rights or licensing agreements.

The OGC, the GeoData Alliance and the Federal Geographic Data Committee (FGDC) issued a report on a cooperative agreement in the area of GeoDRM[17] in March 2006. The report discusses the importance of DRM in protecting information and helping to develop means to trade that information. It also describes the need for a shared model of GeoDRM, general enough to fit numerous contexts. OGC currently has a working group assigned to 'GeoDRM', with efforts being focussed on, "…standards, technologies, and practices which enable interoperable trading of geospatial content…".[18]

Within the scope of the licensing agreements, data specifically purchased through GMOSS budgets and data held by partner organisations has been made available for use by all partners of the NoE. At an early stage in the programme dialogues were undertaken with the various imagery suppliers to negotiate uplifted license rates to enable use by the twenty plus partners in the NoE. These licenses were achieved for a number of suppliers under the condition that imagery is being used for research and not commercial gain. The images purchased via GMOSS are available on a password protected FTP site for remote access and download within the NoE. Other data sources are currently retained and made available by individual data custodians, however prior to sharing with the NoE, licenses for existing data needs negotiation with the original supplier.

7.4.3 Metadata

Metadata is data describing other data including how, when, by whom a particular set of data was collected and its intended use. Metadata can be used at different levels and within different contexts.

For satellite imagery, metadata is typically provided either as a separate file or as part of the image file itself. This metadata supplies the technical specifications of the imagery which for example enables precise geo-rectification. The Committee on Earth Observation Satellites (CEOS) format has been adopted for use by many satellite providers however there are a significant number of variations, even among CEOS formats belonging to the same nominal sensor. As a result, CEOS readers provided with most commercial remote sensing software are typically specific to certain sensors, and often specific to the receiving stations for those sensors.

In a web enabled environment metadata provides the means for discovering published data resources using remote catalogue services. Data is discovered by performing searches against information contained for the various metadata elements, for example keyword searches or a search on a date range of data acquisition. These searches are only possible where the elements contained within the metadata are conformant to a standard.

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[17] http://www.geoall.net/GeoDRM_Final_Report_March_2006.pdf

[18] http://www.opengeospatial.org/initiatives/?iid=199#geodrm

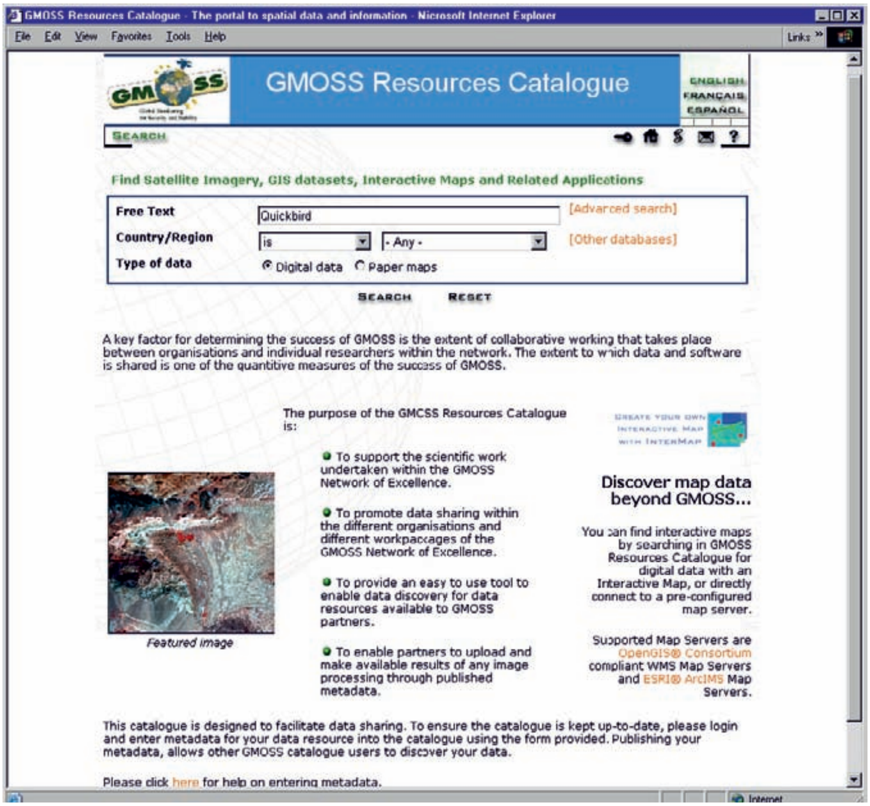
A number of different metadata standards are available for specific domains and the description of different data types. The ISO TC/211 committee have developed the metadata schema ISO 19115 specifically for the geospatial domain. There are two parts to the ISO 19115 standard: the first for describing vector data and the second provides extensions specific to raster data and imagery. The standards outline the various mandatory and optional metadata elements that can be used to describe the data along with their definition, together with the standard means of extending the schema for specific domain metadata. The ISO 19115 standard is specified as an abstract standard that can be applied to a multitude of implementations. The standard contains no information on how the metadata records should be built and formatted. For a particular implementation the metadata standard should be profiled i.e. tailored. Profiling involves a process of selection of optional metadata elements and can be extended to include additional elements as appropriate. All elements specified within the standard as mandatory are core elements and must be included within all profiles. Several profiles of ISO 19115 currently exist such as the Multinational Geospatial Coproduction Programme (MGCP) contribution to the Defence Geographic Information Working Group (DGIWG) and the NATO core geographic services metadata profile.

In a web based scenario XML is typically used as a standard encoding for information interchange. The ISO 19139 standard specifies an XML schema that prescribes the format of the metadata record implementation and may be used to describe, validate, and exchange geospatial metadata prepared in XML.

7.4.4 Data Catalogues

The advancement of web based technologies, i.e. services oriented architectures, has enabled remote discovery and use of data resources. Data discovery can be undertaken through catalogue services based on published metadata. Published metadata can reference data held in one or multiple repositories in both local and distributed systems. The Open Geospatial Consortium has defined an abstract standard for a catalogue service for discovery of geospatial data i.e. the Catalogue Service for Web (CS/W) specification. The CS/W specification may be implemented to use of one of three standard protocols for binding the service i.e. HTTP, Z39.50 or CORBA. The catalogue specification enables the publishing, query and harvesting of metadata, provided metadata is conformant to a profile of a recognised standard such as the profile of the FGDC.

To exploit these advancements in web based technologies and to ensure all participants in GMOSS can easily discover and access data across the network, a resources catalogue for GMOSS has been implemented based on the open source software project ‘GeoNetwork’. A snapshot of the catalogue is provided in Figs. 7.3 and 7.4 showing the results of a user query. The software was developed by the Food and Agriculture Organization of the United Nations, the World Food Programme and the United Nations Environment Programme.



Find Satellite Imagery, GIS datasets, Interactive Maps and Related Applications

Free Text: Quickbird [Advanced search]
Country/Region: is - Any - [Other databases]
Type of data: ● Digital data ○ Paper maps

A key factor for determining the success of GMOSS is the extent of collaborative working that takes place between organisations and individual researchers within the network. The extent to which data and software is shared is one of the quantitive measures of the success of GMOSS.

The purpose of the GMCSS Resources Catalogue is:

- To support the scientific work undertaken within the GMOSS Network of Excellence.
- To promote data sharing within the different organisations and different workpackages of the GMOSS Network of Excellence.
- To provide an easy to use tool to enable data discovery for data resources available to GMOSS partners.
- To enable partners to upload and make available results of any image processing through published metadata.

Discover map data beyond GMOSS...

You can find interactive maps by searching in GMOSS Resources Catalogue for digital data with an Interactive Map, or directly connect to a pre-configured map server.

Supported Map Servers are OpenGIS® Consortium compliant WMS Map Servers and ESRI® ArcIMS Map Servers.

This catalogue is designed to facilitate data sharing. To ensure the catalogue is kept up-to-date, please login and enter metadata for your data resource into the catalogue using the form provided. Publishing your metadata, allows other GMOSS catalogue users to discover your data.

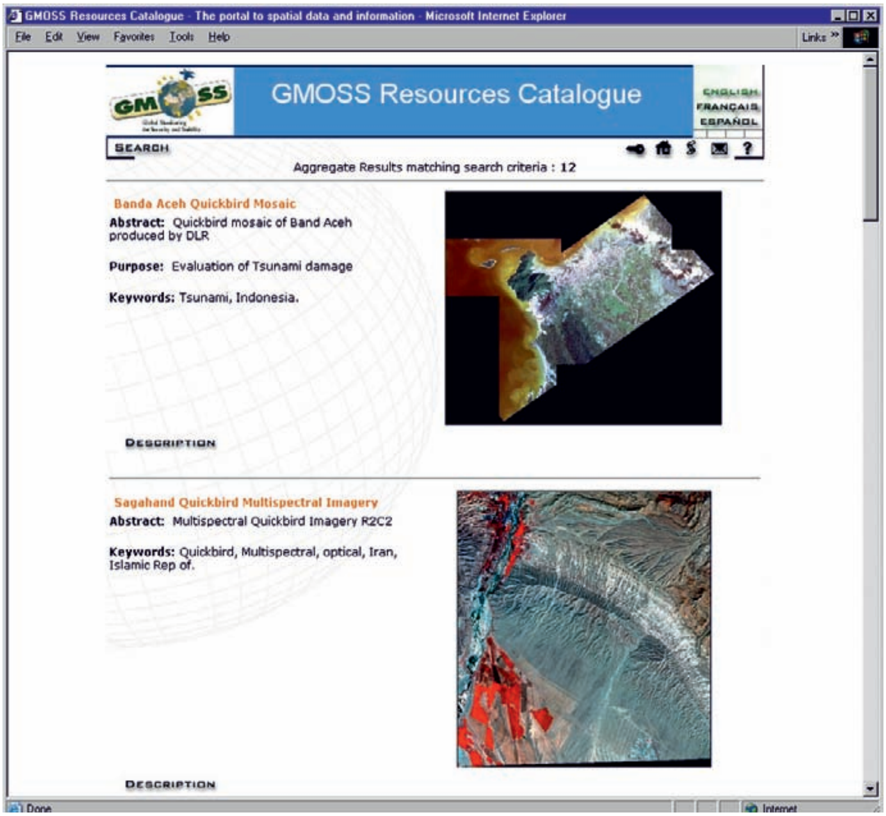
Please click here for help on entering metadata.

Fig. 7.3 Snapshots from the GMOSS Resources Catalogue

The GeoNetwork open source architecture is based on International and Open Standards for services and protocols such as those of ISO/TC211 and OGC. The architecture has been designed according to the Geospatial Portal Reference Architecture, which is the OGC Guide to implementation of a standardised geospatial portal, a catalogue service and data services. The intention of the open source project is to further integrate the catalogue with open source map services such as InterMap or MapServer.

The GMOSS resources catalogue has been designed to generate ISO 19115 compliant metadata from input into a user friendly form. Once created, metadata can be uploaded and viewed in a standard web-browser and if required, individual metadata records can be exported in XML.

A default metadata profile provided through the GeoNetwork project however to facilitate future services, a longer term vision for GMOSS is the definition of a metadata profile as discussed in section *Metadata* above. For example a GMOSS profile may provide a dictionary of keywords from which the catalogue user can form catalogue queries. The keywords may then be used to populate a pick list on the query web page. The profile adopted will ideally be in line with other GMES



Aggregate Results matching search criteria : 12

Banda Aceh Quickbird Mosaic

Abstract: Quickbird mosaic of Band Aceh produced by DLR

Purpose: Evaluation of Tsunami damage

Keywords: Tsunami, Indonesia.

Sagahand Quickbird Multispectral Imagery

Abstract: Multispectral Quickbird Imagery R2C2

Keywords: Quickbird, Multispectral, optical, Iran, Islamic Rep of.

Fig. 7.4 GMOSS Resources Catalogue 'Results' Web Page

projects such as RESPOND,[19] where the defined list of common keywords would form part of an overarching GMES profile.

Currently the catalogue has few fully populated metadata entries, particularly for data held by individual organisations. A key reason for this is that comprehensive metadata creation typically tends to be an onerous, time consuming and low priority task. Within programmes such as GMOSS, metadata should be recognised as a fundamental requirement for data discovery and for enabling better collaborative working, particularly where participants are remotely located from each other. The GMOSS metadata profile needs to recognise this overhead and therefore ensure the lightest profile is defined that is fit for purpose.

Imagery suppliers are largely yet to supply metadata in a standard format such as ISO 19115. Some metadata is present within the header files of satellite imagery

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[19] RESPOND, GMES Services Supporting Humanitarian Relief, Disaster Reduction and Reconstruction, http://www.respond-int.org/Respond/

however each provider presents this information in different formats. Under GMOSS the intention is to investigate possibilities for creation of tools to extract this metadata from the header files and automatically populate the metadata profile. Although such tools will help alleviate some of the metadata creation overhead, manual input will still be required for many metadata fields where human interpretation is required e.g. an abstract description of the data.

The catalogue is an efficient mechanism to promote data sharing to geographically distributed members of the GMOSS NoE, by enabling remote discovery of available data resources and associated contact details for obtaining the data. The catalogue effectively provides a front end to the data repository published on an FTP site as users can view the metadata and a thumbnail of the image prior to download of a large image file. The success of the catalogue however is ultimately reliant on data owners publishing metadata for their holdings to promote greater data sharing.

7.4.5 Future Direction

When considering the successes of GMOSS with regards to standards and efforts to date, the areas of metadata and semantics best demonstrate its achievements. GMOSS is already demonstrating the importance of standards through the definition of a feature catalogue and through ISO compliant metadata in GMOSS resources catalogue. Data dictionaries specific to the security and sustainability domains have been initiated within the ‘Generic Tools’ group of work packages, showing that the semantic convergence crucial to informed decision making is underway.

The future direction and role for standards in the GMOSS NoE will concern the further identification, adoption or development of appropriate standards that carry benefits to the NoE, the wider scientific and remote sensing community and security and safety domain. Planned GMOSS initiatives and exercises, such as the Test Cases and the 48-h scenario, will offer opportunities to assess such benefits and establish guidelines for subsequent standards introduction.

The identification of appropriate standards can be achieved by reference to publications by bodies such as ISO, with their strong steer on salient areas for standards introduction. This will help GMOSS to focus its efforts. As well as the lead from authoritative standards bodies, GMOSS can look to European initiatives like INSPIRE for guidance on best practise for standards in geospatial technology.

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Chapter 8
Feature Recognition Techniques

Andreas Wimmer, Iris Lingenfelder, Charles Beumier, Jordi Inglada, and Simon J. Caseley

Abstract: Almost all applications of remotely sensed imagery require generic algorithms for image feature extraction and classification to gain the required information. Therefore the GMOSS project defined a work package Feature recognition to serve the application work packages in their need to derive information for their tasks. For this purpose an important task is the definition of terms, nomenclature and the creation of a feature catalogue which describes significant features as well as the ability and means to detect these features. The work performed in this work package covers a very wide area and reaches from basic image processing algorithms used in pre-processing steps to highly sophisticated automated, object-based classification and detection methods and its evaluation regarding to performance and robustness. In principle two basic operations will be covered by the feature recognition work package. Classification should provide good and robust background knowledge of the basic land-cover within a certain area whereas object detection techniques are specialized on finding one specific feature or object in a defined area.

Keywords: Feature recognition • Object detection • Classification • Pre-processing • Feature extraction

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8.1 Introduction

Feature recognition is one of the basic techniques in Earth Observation (EO) needed to gain information about the situation within remotely sensed imagery. Within GMOSS it is one of the three generic work packages used to provide the basic information necessary for the individual applications and socio-political working groups to perform their tasks. An important task is the definition of terms, nomenclature and the creation of a feature catalogue, which describes significant features as well as the ability and means to detect these features. Other important topics concentrate on the comparison and evaluation of methods and algorithms for the detection of such features. The variety of tools available is relatively large and ranges from basic image processing algorithms used in pre-processing steps to highly sophisticated and automated, object-based classification and detection methods. One of the most important issues is the evaluation of the robustness of automated methods compared with the visual delineation of features. The two basic operations for feature recognition are classification and detection. Where classification should provide good and robust background knowledge of the basic land cover within a certain area, object detection techniques specialize in finding one specific feature or object in a defined area.

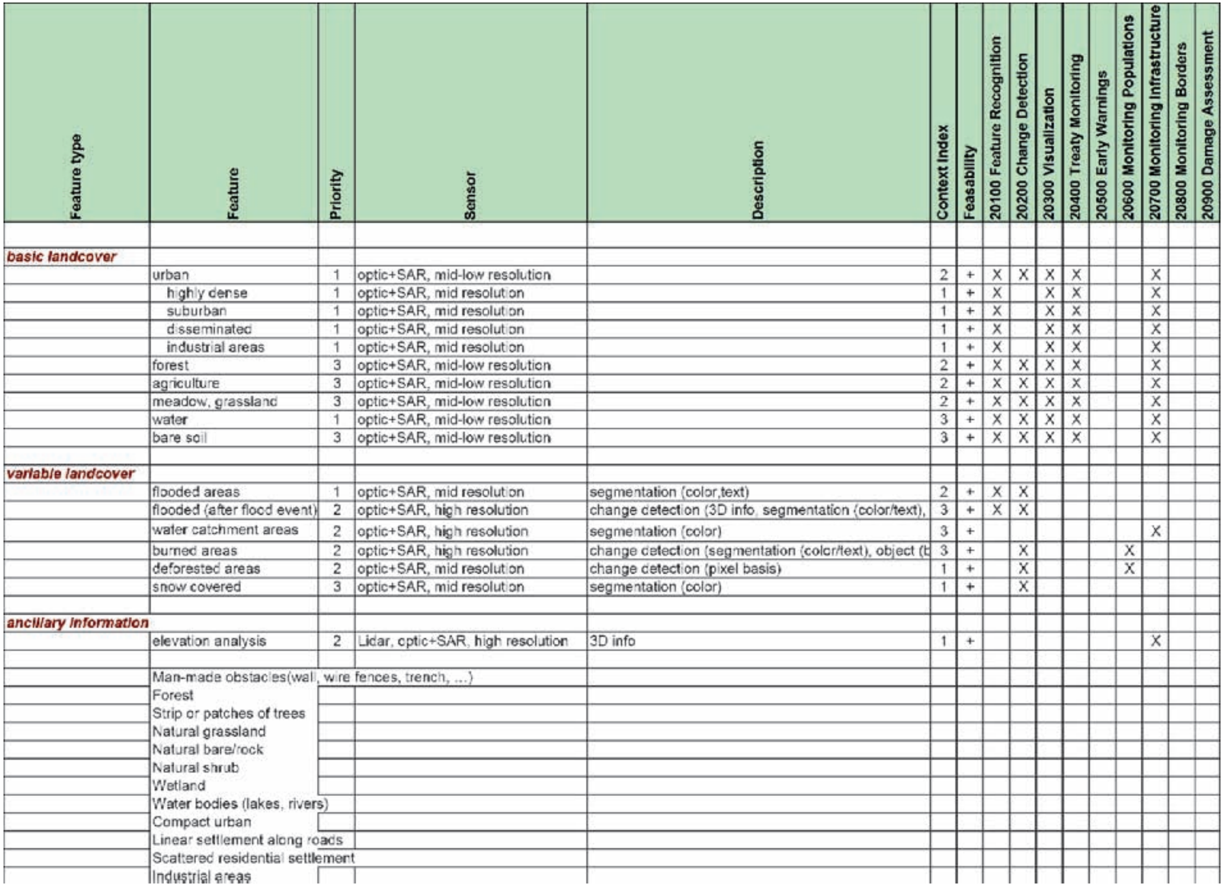
The first section of this chapter defines a framework which guides the way through the wide field of user needs for feature recognition tasks and introduces a basic procedure to optimize the information content of satellite image data. The second section provides an introduction into the wide field of land cover/land use classification systems. In the third part, certain applications in the domain of object detection/object recognition are presented to highlight the current developments in this area.

8.2 Feature Catalogue and Image Pre-processing

One of the first GMOSS activities of Joanneum Research was to initiate a so-called “feature catalogue”, which aimed to list features of relevance for security applications in the context of the GMOSS network. For each feature the relevance was evaluated and assessed by users. The task of the Feature Recognition working group was to devise a strategy and methodology to extract these features. For these features the expected quality of the methodology was evaluated and the necessary input data listed.

The catalogue (see Fig. 8.1) was targeted at the application work-packages in order to support their needs and provide them a standard database to solve their feature recognition tasks. Hence, the feature catalogue was passed to the “Standards” work-package for further evaluation.

Joanneum Research developed a number of pre-processing techniques to deal with the increased need for accurate image datasets for security applications (Raggam et al. 1999). This need results from the current mainstream methods for change detection (comparison of pre- and post-event imagery) as well as the need for the highest possible level of detail required in certain other fields of security



Feature type	Feature	Priority	Sensor	Description	Context Index	Feasability	20100 Feature Recognition	20200 Change Detection	20300 Visualization	20400 Treaty Monitoring	20500 Early Warnings	20600 Monitoring Populations	20700 Monitoring Infrastructure	20800 Monitoring Borders	20900 Damage Assessment
basic landcover															
	urban	1	optic+SAR, mid-low resolution		2	+	X	X	X	X			X		
	highly dense	1	optic+SAR, mid resolution		1	+	X		X	X			X		
	suburban	1	optic+SAR, mid resolution		1	+	X		X	X			X		
	disseminated	1	optic+SAR, mid resolution		1	+	X		X	X			X		
	industrial areas	1	optic+SAR, mid resolution		1	+	X		X	X			X		
	forest	3	optic+SAR, mid-low resolution		2	+	X	X	X	X			X		
	agriculture	3	optic+SAR, mid-low resolution		2	+	X	X	X	X			X		
	meadow, grassland	3	optic+SAR, mid-low resolution		2	+	X	X	X	X			X		
	water	1	optic+SAR, mid-low resolution		3	+	X	X	X	X			X		
	bare soil	3	optic+SAR, mid-low resolution		3	+	X	X	X	X			X		
variable landcover															
	flooded areas	1	optic+SAR, mid resolution	segmentation (color,text)	2	+	X	X							
	flooded (after flood event)	2	optic+SAR, high resolution	change detection (3D info, segmentation (color/text),	3	+	X	X							
	water catchment areas	2	optic+SAR, high resolution	segmentation (color)	3	+							X		
	burned areas	2	optic+SAR, high resolution	change detection (segmentation (color/text), object (b	3	+		X				X			
	deforested areas	2	optic+SAR, mid resolution	change detection (pixel basis)	1	+		X				X			
	snow covered	3	optic+SAR, mid resolution	segmentation (color)	1	+		X							
ancillary information															
	elevation analysis	2	Lidar, optic+SAR, high resolution	3D info	1	+							X		
	Man-made obstacles(wall, wire fences, trench, ...)														
	Forest														
	Strip or patches of trees														
	Natural grassland														
	Natural bare/rock														
	Natural shrub														
	Wetland														
	Water bodies (lakes, rivers)														
	Compact urban														
	Linear settlement along roads														
	Scattered residential settlement														
	Industrial areas														

Fig. 8.1 Example from the feature catalogue

relevant applications. Since the Feature Recognition work-package is an important source for algorithms and methods used to obtain such highly accurate image datasets, different techniques have been developed and validated to achieve this objective.

A long known technique to increase the spatial accuracy of remotely sensed image data-sets is the fusion of a high spatial/low spectral resolution dataset with a low spatial/high spectral resolution dataset into a high spatial/high spectral resolution image. The main application of such techniques is the fusion of the panchromatic and the multi-spectral dataset available from a number of satellite image providers. Therefore, the technique is sometimes referred to as pan-sharpening.

Simple methods such as the IHS-based fusion-methods produce only partially usable results for visual image interpretation; hence improved methods are required to overcome these limitations.

Many different methods have been proposed in the literature such as improved colour transformations, PCA based methods or wavelet based algorithms to name but a few. Although the techniques may be different, the criteria to assess their quality are simple, yet difficult to measure. A good image fusion method leaves areas without high spatial content (i.e. large homogenous areas such as fields, streets, etc.) untouched and changes only areas where high spatial content is actually available in the high spatial resolution data source. It is also important that the spectral properties of the original multi-spectral dataset are preserved in a way to allow for example the application of a classification system. An appropriate and simple solution for the case of QuickBird imagery has been developed and tested for a number of different test sites (see Fig. 8.2). The method to obtain this result is based on four steps:

Fig. 8.2 Result of an optimized data fusion process

1. Colour space transformation using a Brovey transformation (Phol 1999)
2. Histogram matching in order to adjust the pan channel to the first component of the colour transform
3. Replace the first component with the adjusted pan channel
4. Inverse colour transformation to obtain the fused result

This relatively simple method proved to produce good results in the case of the QuickBird and Ikonos datasets, as well as acceptable results for Spot V imagery.

8.3 Land-Cover Classification Systems

Methods and technologies for feature recognition and automated image analysis are as manifold as images and the information to be gathered. Nevertheless, some methods have been established as "Best Practice" since they are useful in several application fields. As a comprehensive goal, all methods and research activities for image analysis aim at extracting information from images in an automated way and with the same quality as humans would do, or even better. In order to have a common understanding of automated image analysis and feature recognition we describe it as a circular process of information extraction from images (see Fig. 8.3). The process can be subdivided into the four main steps: pre-processing, image optimization, image segmentation, image classification and object detection, which are circular dependent that is, the results of later steps might be used to improve the results of previous steps.

Pre-processing steps such as radiometric calibration or de-striping are not considered in this context since they are assumed to have been carried out by the image data distributors. Moreover, registering and geo-coding methods are more important, especially when working on multi-temporal imagery. Thereby, precision arises especially in high resolution and complex imagery when using additional data such

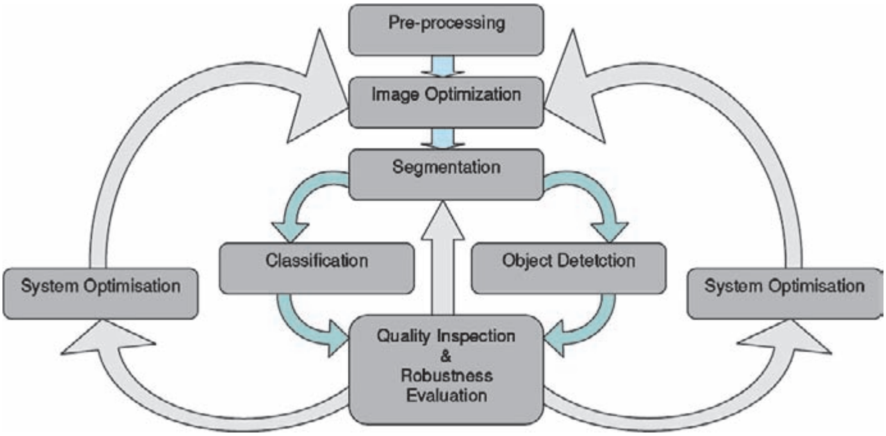


Fig. 8.3 Circular process of information extraction from images

as surface models. Using vegetation covers as well as building information might be necessary to detect and identify occlusion areas in vegetated or built-up areas. Registration methods operate on reference points from imagery and/or ground measurement, and can be applied for image-to-image and image-to-ground registering.

Methods of image optimization intend to manipulate the original image so that the information extraction is better feasible. These can either be methods of image enhancement, such as filters or feature space transformations to de-correlate the original pixel values of the channels (e.g. PCA-transformation). In some cases also the creation and consideration of arithmetic image derivatives, such as the NDVI are understood as image optimization, since they emphasize the properties of the objects of interest on pixel level. Image segmentation methods intend to create image regions, which delineate objects to detect. There are several methods available; for many applications Definiens' multi-resolution segmentation (Benz et al. 2004) is a suitable and commonly used method.

Classification methods are manifold. In general there are two types: supervised and unsupervised. Unsupervised methods are data driven and create classes according to image statistics or the statistics of image objects. They can also be used for the purpose of pre-classification to serve as input for supervised classifications or image segmentations. Supervised methods are class driven. The user determines and describes the classes and simultaneously generates a knowledge base containing rules in the probabilistic and/or fuzzy manner. Methods for object detection mostly optimize single stage feed-forward processing from the image to object hypotheses, using feature extraction for characterising colour, shape, texture, or 3D information cues. Recent object detection methods are self-organizing networks and rule based interpretation of local semantic information. A trend in template correlation for object detection is to apply hierarchically organized template databases. In general, context can play a useful role in object detection and classification: it can facilitate object identification when the local intrinsic information about object structure is insufficient. And it can simplify the object discrimination by cutting down on the number of object categories, scales and positions that need to be considered. Recently, cascaded classifiers have been proposed for object detection to decompose the mapping into a set of classifiers that operate on a specific level of abstraction and focus on a restricted classification problem. This allows for example, to subdivide the task of classifying a satellite image into several land-cover classes in a specialized algorithm for forest classes and another one specialized in urban areas.

System optimization concerns system architectures for control and data flows that aim at (i) optimizing the task based quality of service, (ii) learning structures and thresholds in order to adjust parameterization to the purpose of the system, (iii) evaluating intermediate and high feature values with the goal of feeding back into earlier processing modules so as to optimize the overall system performance, and, finally, (iv) estimating strategies to provide optimal control and exploitation of expected rewards to the system. The initiative of the European Research Network on Cognitive Vision Systems, ECVision, understands a cognitive vision system *as "… being capable of categorizing and identifying, learning structure and parameterization, of autonomous reasoning on past and future events, being capableof exploiting knowledge, of recognizing states of quality and of reacting* *correspondingly, and of acting appropriately to the task at hand"*.[1] Knowledge based interpretation of remote sensing imagery becomes mandatory if the complexity of the interpretation makes single-pass classification unfeasible. Input is also coming from cognitive psychology, which has discovered that attention mechanisms play a key role in object recognition and scene interpretation. Modelling human perception leads to computational attention mechanisms that focus on highly informative, i.e., discriminative regions of interest. These methods might play an innovative role in future remote sensing image analysis.

8.4 Object Detection Systems

In this section we present image processing chains for the detection of man-made objects in high resolution remote sensing images. Detection is understood as finding the smallest rectangular area in the image containing the object. These algorithms are based on learning methods and on example data bases which contain examples for classes of objects (isolated buildings, bridges, crossings, roundabouts, and several types of roads, etc.).

8.4.1 Man-Made Object Recognition

Little work has been done in the field of object detection and recognition on remote sensing images. One particular aspect of high resolution remote sensing imagery is that most of the information is located in the geometry. Furthermore, working on the image geometry only makes the system weakly dependent on the spectral band of the sensor used. Therefore, our system will carry the following steps:

1. Image geometry extraction
2. Geometric characterization
3. Classification by comparison to object class models

Therefore, we need tools for each of these steps. The first step, the image geometry extraction, will use a simple Canny operator (Canny 1986). The geometry characterization will be performed with the descriptors introduced in Section 8.4.2.1. The model for each object class will be obtained by supervised learning over an example data base.

8.4.1.1 Example Database

The example data base has been built by CNES photo-interpreters using SPOT5 THR images (panchromatic band with 2.5 m pixel sampling). We have defined

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[1] Taken from the Website ECVision, European Research Network on Cognitive Vision, http://www.eucognition.org/ecvision/home/Home.htm < viewed 2006 >.

ten object classes: isolated buildings (IB), paths and tracks (PT), crossroads (CR), bridges (BR), wide roads (WR), highways (HW), roundabouts (RA), narrow roads (NR), railways (RW), suburbs (SB). For each class, more than 150 examples have been entered into the database. Each example is a *100* × *100* pixels image patch with the object in the centre of the image. Figure 8.4 shows two examples of the images in the database. The object classes we are interested in are IB, BR and RA. The other classes are used in order to better characterize objects with high geometric information content. We have also created a supplementary class called OT (other) in order to take into account the possible landscapes.

8.4.1.2 Geometrical Characterization of Objects

Complex Geometric Moments

Using the algebraic moment theory H. Ming-Kuel obtained a family of seven invariants with respect to planar transformations called Hu invariants (Hu 1962). These invariants can be seen as nonlinear combinations of complex geometric moments:

$$\mu_{pq} = \int\int (x - iy)^p (x - iy)^q f(x, y) dxdy$$

where x and y are the coordinates of the image $f(x,y)$, i is the imaginary unit and $max(p,q)$ is the order of μ_{pq}. The geometric moments are particularly useful in the case of scale changes. Hu invariants have been very much used in object recognition during the last 30 years, since they are invariant to rotation, scaling and translation. They have been modified and improved by several authors (Flusser 2000; Flusser and Suk 1994).

Fig. 8.4 Examples of images from the database

The Fourier–Mellin Transform

Let *f(r)* be a causal function (*r > 0*), the Fourier–Mellin transform, FMT, of *f*, if it exists, is written as:

$$\forall(k,v) \in ZxR, M_f(k,v) = \frac{1}{2\pi}\int_0^{\infty}\int_0^{2\pi} f(r,\theta)r^{-iv}e^{-ik\theta}d\theta\frac{dr}{r}$$

The FMT [4] can be seen as the Fourier transform over the group of planar similarities (rotations, translations, and dilations). It is a unique representation of the function *f*. It has several properties which makes it very useful for grey level image analysis (Flusser 2000). The most important aspect will be that the modulus of the FMT coefficients is invariant to rotation and scaling.

8.4.1.3 Learning and Classification

Given the low number of available examples and the high dimensionality of the feature space (we typically use ten geometric moments and several hundreds of FMT coefficients), it is not possible to use neural networks or Bayesian learning. Kernel based learning methods in general, and the Support Vector Machine (SVM) in particular are able to deal with large feature spaces and have been introduced in the last few years to learning theory for classification and regression tasks (Vapnik 1998). SVM classification systems have been successfully applied to text categorization (Joachims 1997) and face recognition (Osuna et al. 1997). Simply stated, the approach consists of searching for the separating surface between two classes, by the determination of the subset of training samples which best describes the boundary between the two classes. These samples are called support vectors and completely define the classification system. In the case where the two classes are non-linearly separable, the method uses kernels in order to make projections of the feature space onto higher dimensionality spaces where the separation of the classes is linear. The classification procedure consists of, (i) taking the images of the test set, (ii) computing the feature vector and then (iii) applying the set of pre-computed support vectors in order to take the decision for the class.

8.4.1.4 Results and Discussion

The results obtained by the system will be shown in this section. Two kinds of analysis will be performed. First, we study the two-class separability problem, that is, we compute the classification ratio (percentage of objects correctly classified with respect to the total number of objects in the class) for our interest classes (IB, BR, RA, OT) with respect to each of the other classes. This ratio gives us the quality of the classification given by each particular SVM. The results are shown in Figs. 8.5–8.8. As one can see, IB (better than 84%), RA

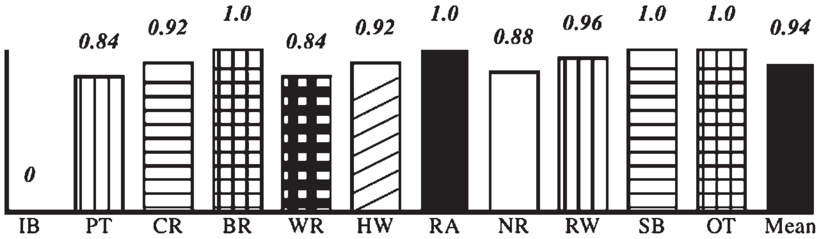

Fig. 8.5 Separability for class IB

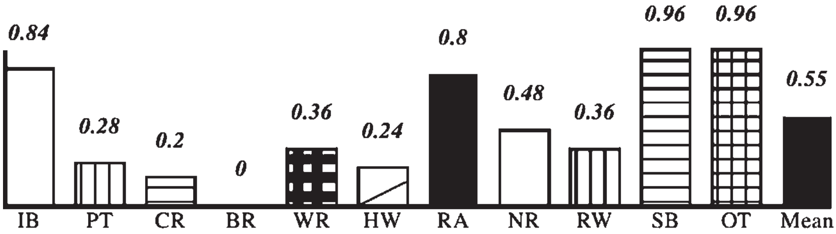

Fig. 8.6 Separability for class BR

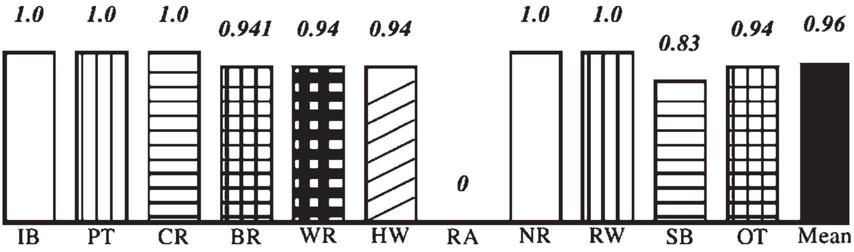

Fig. 8.7 Separability for class RA

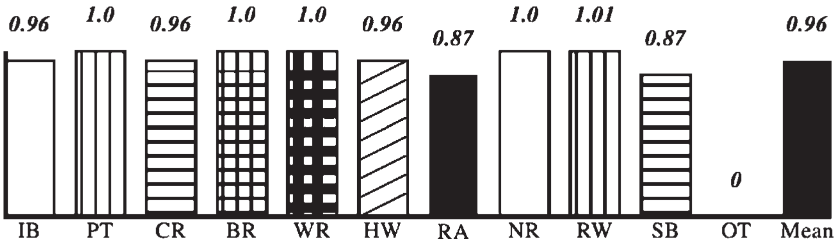

Fig. 8.8 Separability for class OT

(better than 83%) and OT (better than 87%) are very well separated from other classes. The results for BR are lower, but they are well separated from IB, RA, SB and OT (better than 83%).

The second kind of analysis we perform is the one of overall system performances, that is, the classification rate for each class and how each of the classes is classified with respect to the other. The results are shown as a confusion matrix (Table 8.1), where each row *i* corresponds to the class of the test image, each column *j* corresponds to the class decided by the system, and each cell in the table gives the percentage rate of one object of class *i* being classified as class *j*. MD stands for miss-detection and FA stands for false alarm. We see that our classes of interest (IB and RA), except for BR, are detected at 87% and 66% respectively. We also note that most of miss-classified bridges are labelled as crossroads, which is logical. Also, 34% of PT is classified as being NR and the different types of roads are miss-classified as other types of roads, something that was expected since our characterizations are scale invariant.

The overall performances of the system can be evaluated by using the kappa coefficient (Congalton 1991) which equals to 99.330 for this case.

8.4.1.5 Conclusions

We have shown with a very simple approach that it is possible to recognize a number of complex objects in high-resolution remote sensing images without explicit model construction. Recent developments on more complete descriptions of the objects using higher level geometry (lines, closed curves, etc.) have shown significant improvements on the recognition performances (Inglada 2005). Finally, we emphasize that the approach presented here is independent from the kind of object we want to recognize and that no a priori knowledge was introduced into the system.

Table 8.1 Confusion matrix for the recognition system

	IB	***PT***	***CR***	***BR***	***WR***	***HW***	***RA***	***NR***	***RW***	***SB***	***OT***	***MD***
IB	***87.0***	2.0	0.0	0.0	0.0	3.0	1.0	2.0	0.0	3.0	2.0	13.0
PT	10.0	***32.0***	12.0	4.0	4.0	12.0	2.0	20.0	4.0	0.0	0.0	68.0
CR	0.0	6.0	***17.0***	20.0	6.0	13.0	15.0	11.0	3.0	6.0	3.0	83.0
BR	0.0	10.0	13.0	***30.0***	9.0	12.0	14.0	2.0	5.0	4.0	10.0	70.0
WR	3.0	21.0	6.0	12.0	***12.0***	13.0	2.0	18.0	8.0	5.0	0.0	88.0
HW	1.0	13.0	9.0	20.0	9.0	***11.0***	4.0	6.0	10.0	6.0	2.0	89.0
RA	1.0	5.0	3.0	1.0	2.0	9.0	***66.0***	1.0	3.0	9.0	1.0	34.0
NR	7.0	34	6.0	6.0	17.0	2.0	2.0	***19.0***	7.0	0.0	0.0	81.0
RW	0.0	18.0	0.0	7.0	23.0	17.0	6.0	2.0	***20.0***	2.0	6.0	80.0
SB	0.0	0.0	1.0	0.0	0.0	3.0	26.0	1.0	1.0	***56.0***	12.0	44.0
OT	0.0	2.0	0.0	0.0	0.0	0.0	2.0	0.0	4.0	36.0	***56.0***	44.0
PFA	3.0	11.0	5.0	9.0	7.0	7.0	8.0	6.0	4.0	6.0	3.0	

8.4.2 Automatic Linear Feature Extraction

In the context of feature recognition, QinetiQ has been developing and testing various techniques to extract feature information from various EO sources; including high resolution SAR, optical and aerial datasets. These methods include a technique based on the use of a spatial object-oriented database system to develop methods for automatically extracting linear features. Most algorithms work at the pixel scale, but widening the approach to an object scale, supporting contextual information will increase the available information. These features can be represented in a hierarchical structure using an object oriented database. Rules and behaviours can be associated directly with objects allowing these objects to exhibit self-awareness. Using a set of object rules and behaviours, techniques have been developed to automatically differentiate between linear features. This approach was tested and applied to a combination of optical and SAR data with good results. It has been shown to be able to automatically detect, with high accuracy, specific linear features such as road and rail links and airport runway details (Fig. 8.9).

8.4.3 Automatic Verification of Man Made Structures

The RMA/SIC (Signal and Image Centre) department has been tackling the problem of man-made structure detection mainly in the area of change detection. Current satellites such as Quickbird and Ikonos deliver very high resolution images with geometrical and radiometric information pertinent to man-made structures. On the one hand, the geometrical resolution of about 1 m allows for the detection of straight segments, which is characteristic of man-made objects but rather absent from natural scenes. On the other hand, the spectral information contained in the

Fig. 8.9 Linear feature extraction results

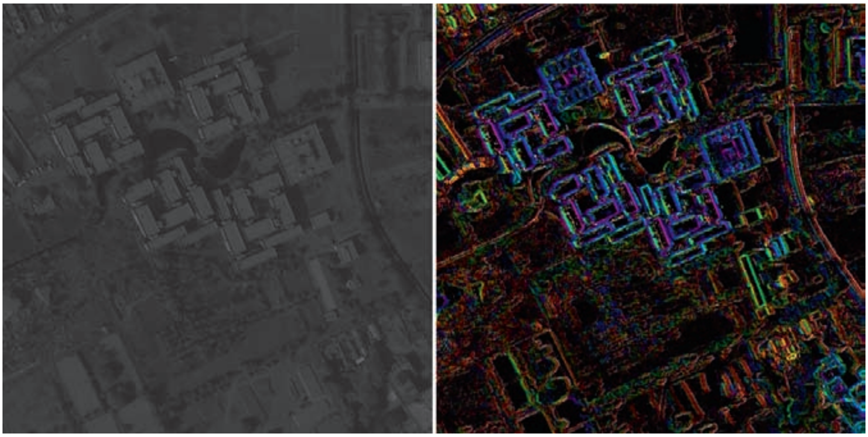

Fig. 8.10 Chromo-disparity map of Ikonos stereo pair for building detection

four bands (red, green, blue and infrared channels) leads to an easy classification of the terrain into natural (vegetation) or man-made classes thanks to the colour or vegetation index (NDVI).

RMA/SIC has been working on the detection of roads, bridges and buildings by combining geometrical and radiometric clues. In the publication of Beumier and Lacroix (2006), RMA/SIC reported its participation to the EuroSDR contest about road extraction. Roads were extracted thanks to edge detection and linking, introducing a straightness constraint (implemented by inertia moment [Beumier 2006]) and vegetation constraint (based on NDVI). For the damage assessment of bridges after the Tsunami of 2004 (Banda Aceh, Sumatra), linear segments have been detected and further supported by the presence in the vicinity of dark areas corresponding to water. In the GMOSS test case about Bagdad, Iraq, RMA/SIC detected large buildings (Beumier 2007) for risk assessment thanks to elevation estimated by the disparity of an Ikonos stereo pair (see Fig. 8.10).

8.5 Summary and Conclusions

Feature recognition and its basic pre-processing forerunners are very important steps in order to exploit the full potential of remotely sensed images. Almost all applications in security relevant areas take advantage of high quality feature recognition products. Such applications may be seen as a pyramid where the top represents the final user product, but the basis for this final product is built upon the foundation represented by feature recognition services. The insights and examples given above present an overview of the possibilities and the current research activities in their respective areas. They provide a starting point and are intended to clearly show the potential and their usefulness to security relevant applications.

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Chapter 9
Change Detection Tools

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Abstract In this chapter a wide range of change detection tools is addressed. They are grouped into methods suitable for optical and multispectral data, synthetic aperture radar (SAR) images, and 3D data. Optical and multispectral methods include unsupervised approaches, supervised and knowledge-based approaches, pixel-based and object-oriented approaches, multivariate alteration detection, hyperspectral approaches, and approaches that deal with changes between optical images and existing vector data. Radar methods include constant false-alarm rate detection, adaptive filtering, multi-channel segmentation (an object-oriented approach), hybrid methods, and coherent change detection. 3D methods focus on tools that are able to deal with 3D information from ground based laser-ranging systems, LiDAR, and elevation models obtained from air/space borne optical and SAR data. Highlighted applications are landcover change, which is often one of the basic types of information to build analysis on, monitoring of nuclear safeguards, third-party interference close to infrastructures (or borders), and 3D analysis. What method to use is dependent on the sensor, the size of the changes in comparison

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with the resolution, their shape, textural properties, spectral properties, and behaviour in time, and the type of application. All these issues are discussed to be able to determine the right method, with references for further reading.

Keywords Change detection • Earth observation • Multispectral imagery • Synthetic aperture radar • 3D analysis

9.1 Introduction

Change detection is one of the key Earth Observation (EO) techniques in security research. Within GMOSS it is one of the three generic tools that are used to gain information on the threats that are identified by the socio-political working groups. The main focus of the work package on change detection is to analyse and compare different methods using a variety of data (optical and radar) with different spatial resolutions, and to test methods depending on the applications that are studied. The first success was the establishment of a change detection catalogue, which links the type of sensor with the application and the possible methods (see Appendix). One of the main open issues is the accuracy and timeliness of using automatic change detection methods in comparison to visual interpretation of changes, which is still the method used in several operational applications of remote sensing. Therefore, the new developed methods have to prove their usefulness and accuracy. For the successful establishment of automatic methods a very high level of co-registration of the space borne image is an absolutely necessary prerequisite. For this reason, studies concerning the necessary pre-processing steps were also carried out. One result is that for automatic change detection the geometric co-registration should be better than the pixel size of the images. This condition is not always met by the satellite data providers so that additional work for co-registration is often necessary before starting the automatic change detection processes.

9.2 Change Detection Using Optical and Multispectral Images

Kuenzer (2005) reviewed and tested several classification and change detection methodologies concerning their applicability for thematic questions and applications. Classification and feature extraction methods reviewed include:

1. Unsupervised approaches
2. Supervised and knowledge based approaches
3. Object oriented approaches
4. Hyperspectral approaches (applied to multispectral data)

Unsupervised approaches, where a classifier algorithm subdivides the image into several pixel clusters according to distance measures (e.g. Euclidean distance) of the mean cluster vectors are only favourable, when clearly distinguishable spectral objects shall be separated from each other. For example, unsupervised classification yields good results when a fast extraction of deep clear water surrounded by vegetation or soil and bedrock components is needed. Unsupervised classification can also support rough land cover investigations. Results are usually not sufficient for tasks like settlement or road extraction, the classification of high spatial resolution data or the extraction of specific classes only present in small quantities within the scene. Within GMOSS, scenarios for the application of these algorithms could be: rapid water mapping, rapid forest/non forest mapping, rapid mapping of bare versus vegetated areas, rapid non quantitative mapping of water pollution, rough land cover mapping, classified temperature maps (etc.), based on low to medium resolution data (Modis, Meris, Landsat, Aster, etc.).

Supervised and knowledge based approaches yield good feature extraction results for most classes. In combination with filters and threshold-based decision rules, nearly every surface feature can be extracted – however, the setup of such systems and the need for extensive training data stands hampers the fast classification and extraction of objects, as it might be needed in the context of GMOSS. Within GMOSS scenarios for the application of supervised and knowledge based methods, all products that are not demanded within near real time are considered. This can be detailed land cover classifications, settlement extraction, water quality maps, time series analysis of vegetation, land cover, settlement, or geology mainly based on medium resolution data (Landsat, Aster, etc.). An example of using a supervised maximum-likelihood approach is shown in Fig. 9.1.

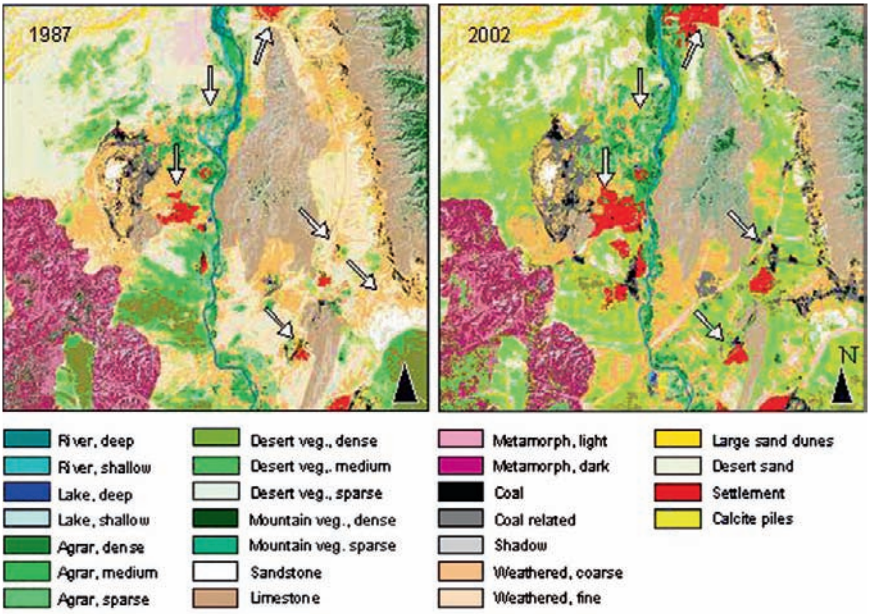

Fig. 9.1 Example of land-cover change detection in the region of Wuda (North China) using a supervised maximum-likelihood approach

Object oriented approaches combine the advantages of the combination of spectral and textural feature recognition. Segmentation and fuzzy classification allow for very high classification accuracies, especially for high spatial resolution data. However, object oriented approaches are also time consuming to implement and near real time products can not yet be generated. Furthermore, the class hierarchies and decision rules set up for one satellite data set are hardly ever transferable to other regions. Within the context of GMOSS, object oriented approaches are assumed to be applied for high resolution data (Ikonos, Quickbird, Spot, etc.) mainly. Tasks to handle, if no real time processing is desired, include the extraction of roads, railway tracks, single buildings, settlement extraction, detailed border monitoring, and vehicle detection amongst others.

Hyperspectral approaches applied to multispectral data as for example, spectral mixture analysis, spectral feature fitting or, spectral angle mapping are very positive approaches under the precondition that the data are radiometrically pre-processed. Without the supervised or object oriented approaches analyst interpretation or influence is minimized. Partial unmixing is considered especially as a good quantitative and transferable method to extract the subpixel fractions of a certain surface of interest. These approaches are assumed to be applied for water pollution assessment, mine waste or comparable accidents, quantitative mapping of individual surface classes or time series analysis.

A combination of pixel-based change detection and object-based change analysis procedures were also introduced against the background of nuclear safeguards applications (Niemeyer and Nussbaum 2006). A two-step attempt for change detection and analysis was thus developed. Beginning with the wide-area monitoring on the basis of medium-resolution satellite data for the pre-scanning of significant changes within the nuclear-related locations, the areas of interest could then be explicitly analysed using high-resolution satellite data.

For the detection of change in pixels, several statistical techniques exist, calculating e.g. the spectral or texture pixel values, estimating the change of transformed pixel values or identifying the change of class memberships of the pixels. In regard to the specific application of nuclear monitoring the most satisfactory results were carried out with the so-called Multivariate Alteration Detection (MAD) transformation (Nielsen et al. 1998). The MAD procedure is based on a classical statistical transformation referred to as canonical correlation analysis to enhance the change information in the difference images and is briefly described as follows: if multispectral images of a scene acquired at times t1 and t2 are represented by random vectors X and Y, which are assumed to be multivariate normally distributed, the difference D between the images is calculated by:

$$D = a^T X - b^T Y$$

Analogously to the principal component transformation, the vectors a and b are sought subject to the condition that the variance of D is maximized and subject to the constraints that $\mathrm{var}(a^T X) = \mathrm{var}(b^T Y) = 1$. As a consequence, the difference image D contains the maximum spread in its pixel intensities and – provided that this spread is due to real changes between t1 and t2 – therefore maximum change information. Determining the vectors a and b that way is a standard statistical procedure which amounts to the so called generalised eigenvalue problem. For a given number of bands N, the procedure returns N eigenvalues, N pairs of eigenvectors and N orthogonal (uncorrelated) difference images, referred to as to the MAD variates. Since relevant changes of man-made structures will generally be uncorrelated with seasonal vegetation changes or statistic image noise, they expectedly concentrate in the higher order components (if sorted according to the increasing variance). Furthermore, the calculations involved are invariant under affine transformation of the original image data.

The decision thresholds for the change pixels could be defined in terms of standard deviations for each MAD component. Regarding automation, a probability mixture model was applied to the MAD variates based on an EM algorithm to determine automatically the density functions for the change and no-change pixels and thence the optimal decision thresholds for discriminating change and no-change pixels (Bruzzone and Prieto 2002).

The application and expressiveness of the proposed change detection technique for monitoring nuclear facilities depends (among other things) on the spatial resolution of the imagery. When a change signal within nuclear sites is very significant in terms of radiance changes, it can mostly be detected by the pixel-based analysis of mid-resolution multispectral image data. But when adopted to off-nadir high-resolution imagery, the results of the MAD transformation pixel-based algorithms are in general very complex.

Processing satellite image data in an object-based way generally extends the possibilities to detect and analyse changes between two or more dates by taking into account the changes of the mean object features (spectral colour, form, etc.), the modified relations among neighbouring, sub- and super-objects or changes regarding the object class memberships. Moreover, specific knowledge can also be easily included into the procedure. Previous studies implying a combination of pixel- and object-based techniques have already demonstrated the advantages of firstly pinpointing the significant change pixels by statistical change detection and subsequently post-classifying the changes by means of a semantic model of change-related object features. According to the results the analysis and interpretation of changes within nuclear plants can be more precise and reliable if the change detection procedure makes use of the characteristic features of facility objects and changes (e.g. compared to other industrial sites) (Niemeyer et al. 2005).

The procedure works for both medium-resolution and for high-resolution imagery. Figure 9.2 displays the results of the change analysis for the Esfahan Nuclear Technology Centre (ENTC) using high-resolution imagery. Here, a MAD transformation was carried out based on two QUICKBIRD images acquired in July 2002 and July 2003 (Fig. 9.2a). The four MAD components (according to the number of input channels) contain the degree of change for each pixel (Fig. 9.2b). The change pixels were then subjected to a post-classification within the software eCognition (Benz et al. 2004). Based on the Quickbird data of 2003, image objects were extracted. A classification model distinguishing between two types of

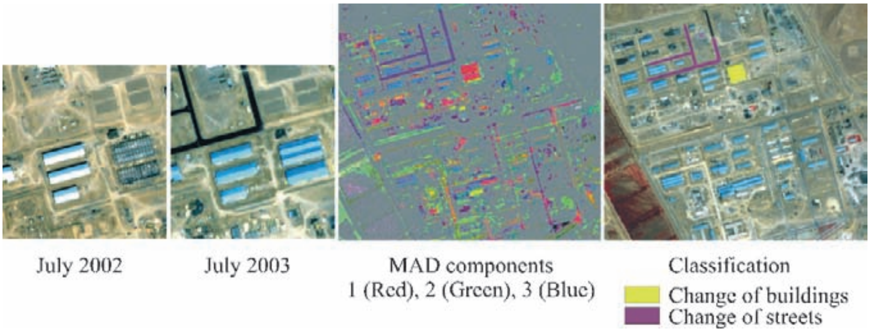

Fig. 9.2 Object-oriented change analysis of the Esfahan Nuclear Technology Centre (ENTC) using high-resolution images with respect to buildings (yellow) and roads (purple)

man-made structure changes was defined using different object features and class-related features. Figure 9.2c therefore shows the most significant changes between July 2002 and 2003: the completion of buildings (yellow) and the partial asphalting of the previous gravel roads (purple). See also Chapter 12 Treaty Monitoring for more analysis on the Esfahan site.

Lacroix et al. (2006) proposed a change detection method to detect coarse changes between a SPOT5 image and a vector database for the National Geographic Institute of Belgium (NGI). Only the built up areas and the road network have been considered as objects of interest, as this may be the case in the majority of security problems.

The project started with a literature study on methods dealing with changes between an image and a geographic database, something which is often considered as a feature extraction problem. In Vosselman and de Gunst (1997), knowledge is used for updating road maps; the old road position is compared to the image using intensity profiles. If change is observed, a hypothesis of the changes is made. While the incorporation of knowledge about possible lane widths and exit angles improves the interpretation of results, many changes are in fact, false alarms because of disturbing objects like shadows, trees and cars. In Busch (1998), a method is proposed to perform the revision of built-up area in a GIS using satellite imagery and GIS data. The satellite images are SPOT and IRS-1C with a ground resolution of 10 and 5.8 m respectively. The built-up area is detected on the basis of short edge densities. A threshold obtained from training on GIS data is used to separate the built-up area. The changes are then observed comparing the classified zones with the GIS data. Klang (1998) proposed an automatic detection of changes in road database using satellite imagery. The considered satellite data are Landsat, SPOT, IRS-1C, all re-sampled to 10 m resolution. The projected road vector database is matched to detected roads. Statistics over the latter are used to find a threshold which serves at extracting seed points of potential new roads where a line tracking is started. Finally, the changes with the road database are extracted.

Baltsavias (2002), provides the state of the art technique in object extraction and revision by image analysis using existing geospatial data and knowledge. The paper mainly focuses on multi looking aerial images or satellite images of 1 m resolution. As far as the detection of man-made objects in satellite images is concerned, some researchers have also used NDVI and edges in the form of a complexity index (Sakamoto et al. 2004).

The strategy that has been developed is described as follows. Changes in the built up areas and in the road network are located by comparing a mask generated by the database projected on to the image, to the output of a classifier extracting the man-made structures class. It is assumed that the built-up area and communication network generate structures and texture in the panchromatic image. Therefore, changes inside the “old” database extent and changes in attribute such as the road width will probably not be noticeable. On the other hand, the system should detect as change, places where the database indicates roads or buildings while they do not exist. NGI’s vector database and SPOT 5 images are the input of the system. NGI’s vector database and SPOT 5 images are the input of the system. NGI filters the database to produce vector layers containing only the built-up area, the road network, and the hydrography. The road network and the built-up area are used to produce the “Old Mask”, representing the old extent of the man-made class. The images are registered with the vector database using a data registration process. Then the registered panchromatic image is analyzed by a “Texture and Structure algorithm” that separates textured from non-textured areas. The latter makes use of simplified Gabor filters which produce an energy measure at each pixel depending on the local texture. The best filter parameters are estimated using ROC (Receiver Operating Characteristics) analysis. ROC curves show the relation between true and false detections (i.e. the probability of detection versus the probability of false alarm) of a detector as a function of the threshold. The energy threshold, which separates the man-made class from the rest, is found by assuming a mixture of two γ distributions. The NDVI (Normalized Difference Vegetation Index) computed from the multi-spectral images, provides another two-classes separation: vegetation and non vegetation areas. The fusion of both classifications from which the hydrological network is removed, is compared with the “Old mask” to generate a “Change Map”. Figure 9.3 shows a result of the change detection strategy of St. Niklaas in Belgium.

The system was then tested and evaluated on 10 zones selected from SPOT5 5 and 2.5 m resolution images in order to include sub-urban and rural areas. The results were compared to the results of visibility tests performed by an experimented photo-interpreter. The analysis shows that the number of elements missed by the automated system compared to the photo-interpretation are of the same order (10%) in half of the experiments, independently of the landscape type or image resolution, while it is of approximately 20% in the other cases. In all cases, the automated system is presenting many more false alarms, which could probably be reduced by a post-processing step. It is not clear whether adding multi-spectral images (i.e. NDVI) has an advantage over using panchromatic images only.

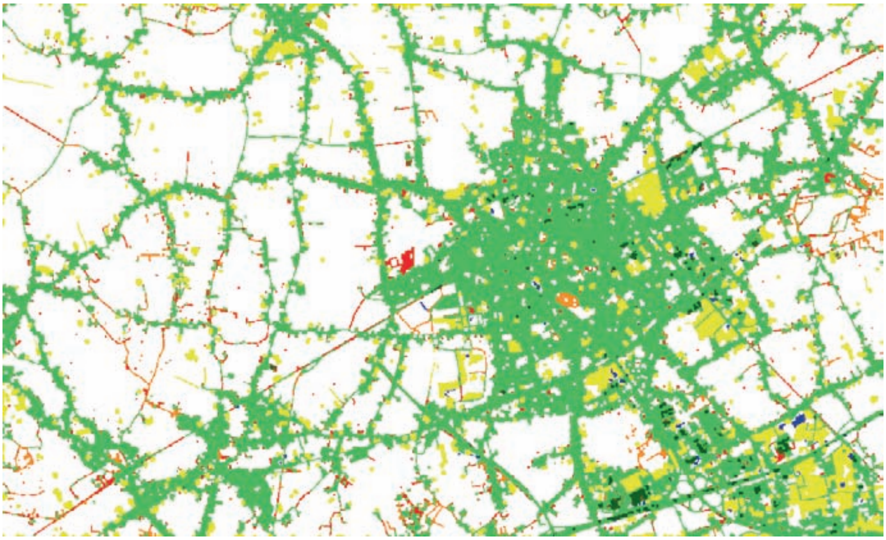

Fig. 9.3 RMA change map of St. Niklaas (Belgium) using NDVI and texture detection. Bright green: no change (NDVI + texture); dark green: no change (NDVI only); red: missed objects or database errors (NDVI + texture); orange: missed objects in forest (NDVI + texture); yellow: changes or false alarms (NDVI + texture); blue: false alarm or changes detected (NDVI only); white: no change (NDVI + texture)

Schöpfer (2005) presents a technique that can track spatial and temporal changes of objects. Several techniques for digital change detection have been presented and used for different applications, but unfortunately, few spatial change detection techniques to highlight pattern-related changes in the landscape are available. Since nature is various, a method should be capable of detecting both quantitative changes of landscape elements and changes in the patterns (object transition). First approaches to characterize changes by investigating the topological relationships among corresponding patches are discussed by Raza and Kainz (2001) and Blaschke (2005). Spatial representations are discussed in light of the geographical information science available since several decades; important studies were done by Mark (1999) and Hornsby and Egenhofer (2000). A typology of object geometry changes may include four basic categories, namely existence-related, size and shape-related and location-related changes. However, in reality a combination of all of these basic types of geometric changes must be handled. The use of the concept of spatial relations to detect change dynamics of image objects and their changing spatial properties provide a good conceptual base for the spatial change detection.

A tool called LIST (Landscape Interpretation Support Tool) was developed and programmed as an extension for ESRI's ArcView 3 and ArcGIS 9 by Z_GIS (Lang et al. 2008). The tool performs object quantification, supports manual interpretation and includes a method for object-based change analysis and object-based accuracy assessment. Following the concept of 'parent-and-child', two vector layers represent the specific ‘fate’ of corresponding objects (the term was introduced by Lang et al. 2008). Object fate may reflect different time slices of data capturing (change analysis) or different methods for object generation (i.e. different segmentation algorithms, heterogeneous data material, visual vs. machine-based interpretation, reference data sets, etc.).

LIST implements a straight-forward method for investigating spatial relationships for three different states of transition using a ‘virtual overlay’. At this stage is has to be assumed that t0 (*before*) objects are larger than t1 (*after*). Therefore object fate can be expressed by three special types of object transition:

1. ‘Good (t1-)objects’: (n_{good}) The object is entirely contained within the buffered outline of the t0 object;
2. ‘Expanding (t1-)objects’: (n_{exp}) The object exceeds its original boundary, but its centroid is within the t0 boundary;
3. ‘Invading (t1-)objects’: (n_{inv}) The object’s centroid lays outside of t0 boundary, but a certain part, which can be specified in percent, of the object lays within the t0 object

This concept is a simple way to characterize the development of each t0-object (‘parent object’) and additionally enables unique categorization of every ‘child object’. To characterise object fate of an entire data set, two indices were introduced. The first index, ‘offspring loyalty’ (*OL*), is calculated by:

$$OL = \frac{n_{good}}{n_{good} + n_{exp}}$$

Here n_{good} = number of good objects and n_{exp} = number of expanding objects. A value of 1 indicates that no expanding objects are among the t0 object. The second index, ‘interference’ is defined by:

$$I = \frac{n_{inv}}{n_{all}}$$

Here n_{inv} = number of invading objects and n_{all} = number of all intersecting t1 objects. The closer the value of *I* is to zero, the smaller the number of invading objects that interfere with the t0 object (Schöpfer and Lang 2006).

The developed tool supports the detection of spatially related objects. Until now three different spatial relationships of object transition are implemented that are adequate for solving temporal and spatial complexities. With LIST an object’s fate can be analysed using these three simple spatial relationships. This object-specific methodology successfully examines spatial changes of the t0 objects by investigating the topological relationships between objects through time and thus provides an improved assessment of the changes. The approach demonstrated on first attempt (Lang et al. 2008) that the interpretation of changes overcomes the limitations of a mere comparison of percentages. However, it is necessary to implement additional and more complex spatial representations to cover different object fate scenarios (Schöpfer 2005).

9.3 Change Detection Using Synthetic Aperture Radar Images

Dekker (2005) studied and developed several radar change detection methods especially for security applications. The advantage of radar, also known as SAR (Synthetic Aperture Radar), is that it can provide imagery during cloudy skies, day and night. Because radar sensors illuminate the earth's surface themselves using a microwave (generally in the range of centimetre wavelengths) transmitter, it is independent of illumination by the sun. The following methods are discussed:

1. Constant False Alarm Rate (CFAR) detection
2. Adaptive filtering
3. Multi-channel segmentation
4. Hybrid methods

All are pre-classification methods, meaning that changes are detected before classification. Post-classification techniques are only reliable when the classification accuracy of the SAR images that are compared is sufficient. The first and the second method are based on the ratio image, which is obtained by dividing the after image by the before image. Dividing images is preferred above differencing, in which the images are subtracted (Rignot and van Zyl 1993). The third method is based on segmentation techniques. A disadvantage of pre-classification change detection is that the changes still have to be classified.

CFAR detection is based on a two-dimensional moving-kernel detector (Novak and Hesse 1991). Within the kernel the pixel-value of the central pixel is compared with its surrounding background pixels (i.e. clutter). In the case of change detection the CFAR detector is applied to the ratio image. In the CFAR detector, for every pixel background, statistics are computed. Based on these statistics, it is decided whether this pixel is (part of) a target or not. Change detection by CFAR detection is generally applied when the changes are small compared to the resolution, i.e. when changes cover a few pixels.

The second method is based on an adaptive filter that is applied to reduce the speckle-noise in the ratio image (Dekker 1998). Because filters introduce errors in estimating the underlying radar cross-section, it is more effective to apply a filter once to the ratio image, than twice to the original SAR images. The work flow is as follows:

- Create ratio image
- Logarithmic scaling to make the multiplicative speckle-noise additive
- Adaptive filtering
- Thresholding

Logarithmic scaling is applied because additive noise is easier to filter than multiplicative noise, as in the original SAR and ratio images. The filter preserves edges, lines and point-targets. The point-target detector is a kind of CFAR detector, but with a different kernel. The threshold is global, for the whole ratio image, while in CFAR detection the threshold is local, for every kernel. An advantage of applying the adaptive filter, compared to the CFAR detector, is that it can be used to detect distributed changes as well. The method has been successfully implemented in PCI Geomatica (Wouters et al. 1996) and ERDAS Imagine (e.g. Dekker 2006). Figure 9.4 shows a result of the method on two Radarsat 1 images (resolution 10 m) of new dwellings under construction.

The third method of pre-classification change detection is based on multi-channel segmentation (Caves and Quegan 1995). Segmentation is the process of grouping adjacent pixels into multi-pixel homogeneous objects that can be further processed as one entity. The advantage of this method is that, in case of not too

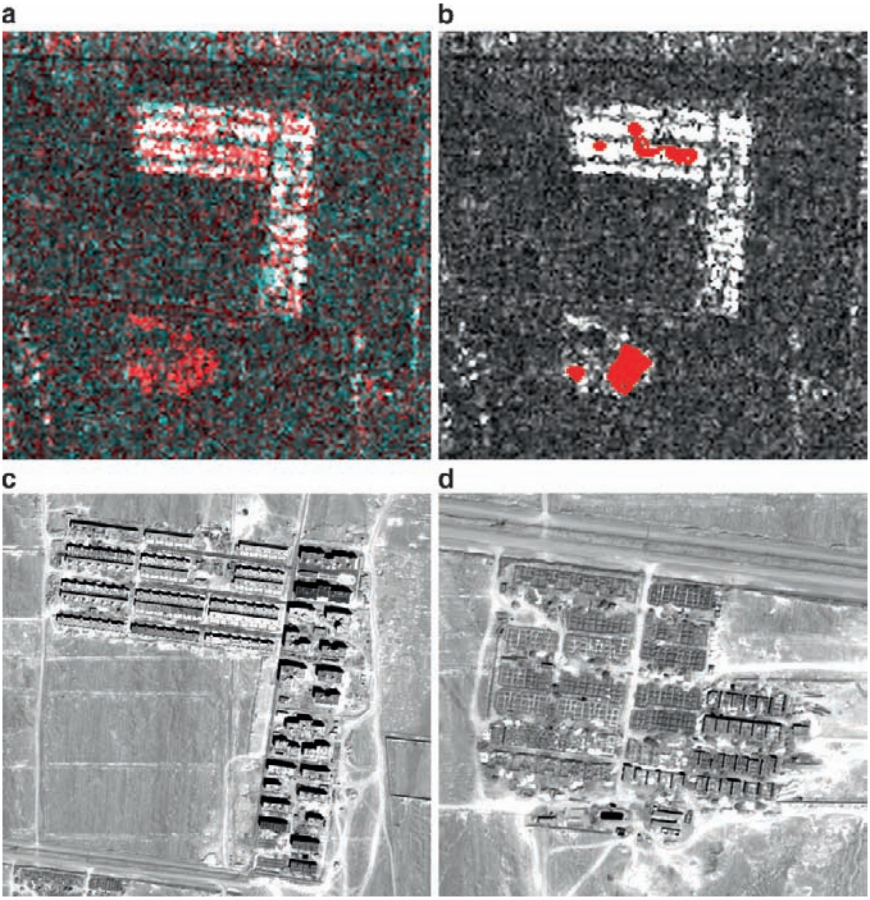

Fig. 9.4 Results of change detection by adaptive filtering applied to two Radarsat-1 images of new dwellings under construction, south of Esfahan, Iran (29 July 2003 = red; 20 September 2002 = cyan). (a) Shows the colour composite, (b) the detected changes. (c) and (d) the corresponding Quickbird images of 19 September 2003 of the upper dwellings respectively the lower dwellings

much speckle noise (about more than three looks), it reduces the remaining speckle. In case of multi-channel segmentation, the grouping process is applied to two or more images instead of one. Compared to adaptive filtering, the number of changed objects is often lower, and smaller objects tend to disappear. On the other hand, the shape of the changed objects is often better reproduced.

Hybrid methods can be applied to improve the change detection capabilities of one method, for example multi-channel segmentation. This method can be improved by (1) adding an adaptive filter to reduce speckle-noise for segmentation of distributed changes and (2) by adding a CFAR detector to detect smaller changes such as vehicles (Dekker et al. 2004). Here the speckle-filtered ratio and the results of CFAR detection are both input to the segmentation and thresholding process. The output is a set of polygons representing the changed objects. In case the georeferencing of the original SAR images is not accurate enough, they can be co-registered automatically using a FFT-based correlation procedure. The method was developed for the EU 5th framework project PRESENSE (Pipeline Remote Sensing for Safety and the Environment, http://www.presense.net/). In this project the detectability of digging machinery (i.e. draglines, shovels, tractors) in the neighbourhood of gas pipelines was studied. Figure 9.5, shows the test site of Borculo in the Netherlands, where in less than 2 h several machines were relocated. The detected changes are projected on the original SAR image.

Summarising, CFAR detection is only suitable when the changes are small compared to the resolution (i.e. when changes cover a few pixels). Adaptive filtering is able to deal with distributed changes as well. A disadvantage of this method is that the shapes of changes are not always well reproduced. Multi-channel segmentation is a method that reproduces the shape of changes generally better for multi-look

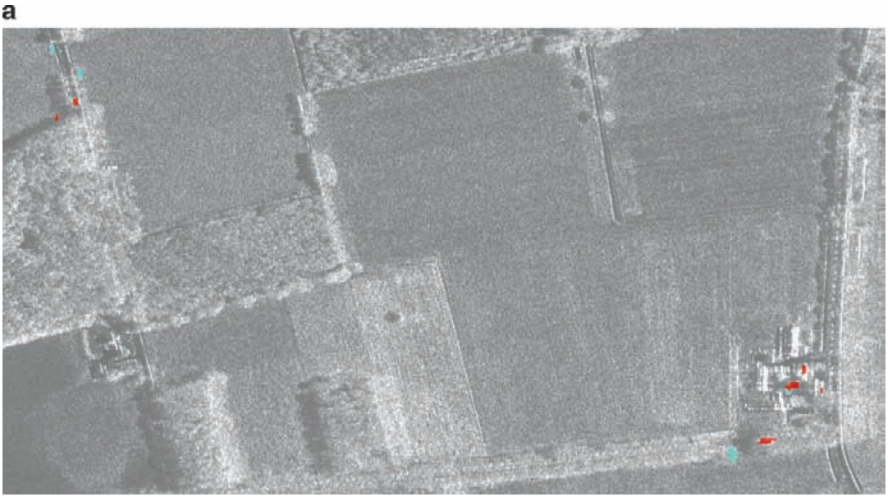

Fig. 9.5 (a) Changes in Intermap AeS-1 SAR images of Borculo (The Netherlands), detected using a hybrid change detection method. Detected are relocated machines and a water tank

Fig. 9.5 (continued) (b) (upper left), and relocated machines and farm activities (c) (lower right)

images, but lacks in the detection of small changes. Hybrid methods are a combination of CFAR detection, adaptive filtering and multi-channel segmentation. These methods combine the appropriate detection of distributed and small changes, even for noisy SAR images. As a result, there is a preference for the last three methods, but the choice of method to be used is also dependent on the application.

So far only non-coherent SAR change detection methods have been discussed. SAR interferometry (InSAR) enables coherent change detection (CCD) in which the decorrelation of the phase between two consecutive acquisitions is determined. One of the first references on CCD, referred to as surface change detection, is from Werner et al. (1992). The decorrelation can be caused by thermal noise (thermal decorrelation), the baseline between the platform tracks (baseline or spatial decorrelation) and temporal effects (temporal decorrelation) (Zebker and Villasenor 1992). The maximum baseline for which the spatial correlation is zero is called the critical baseline. Temporal decorrelation follows from physical changes of the surface over a certain period of time due to the weather, soil motion or human activities. The latter are the most interesting to detect in case of security applications. Examples of human activities that disturb the surface are mining, tillage, building activities, damage, and vehicle tracks.

9.4 Three-dimensional Change Detection

Sequeira et al. (2004) developed JRC Reconstructor® and JRC Verificator®, respectively to build and process 3D models of large areas. In particular, JRC Verificator® performs automatic scene change detection by comparing the 3D points of a reference 3D model with the newly acquired 3D data. Even when the newly acquired data is only in 2D (like an optical image), it is anyway possible to overlap the image on to the 3D model and visually find inconsistencies (e.g. a new building in a flat area).

JRC Reconstructor® builds 3D models by using different data:

- Data acquired from the ground with JRC acquisition system (Sequeira et al. 2005): optical images and range data
- Data acquired from airborne acquisition system (LiDAR): optical and range data
- Data acquired from satellite: optical/SAR images and Digital elevation models

Typically, data acquired from the ground has good accuracy (less than 1 cm) whereas the precision of models obtained by solely satellite data is from several meters, depending on the quality of the source data. Whenever possible it is recommended that a 3D model of a very large area is built using satellite data and then the areas of interest refined using airborne data, thus allowing coverage of quite a large area with few decimetre accuracy. The JRC Verificator® has been tested to perform 3D scene change detection using high accuracy models of JRC premises at Ispra in Italy that were obtained with data acquired from the ground.

Three-dimensional change detection has been tested by considering as a reference an area covering 300 by 530 m of the Ispra model described earlier. The model of the considered area has been improved with 3D data previously acquired with the ground vehicle borne acquisition system. The best accuracy of the reference model is 1 cm. In the test area, houses, warehouses as well as some trees are present. Focus was put on the detection of changes associated to presence/absence of objects like vehicles. This assumption is important in order to set the appropriate detection threshold. Indeed, the 3D change detection algorithm computes the differences between two different 3D data sets of the same area and changes are detected when this difference is higher than a threshold. The threshold depends on the accuracy of the available 3D data and on the 3D size of changes. The 3D accuracy ranges from 1 to 15 cm.

A verification scan, that is to say, 3D data to be compared with the reference model for change detection purposes, was acquired with the ground vehicle borne range scanner during a normal working day. This resulted in some distinct differences, basically due to the presence and absence of parked cars. A zoom-in of the warehouse entrance for both the Reference Model and Verification Scan is shown in Fig. 9.6 (top). A change detection of the limited area outside the warehouse was performed with a change detection threshold of 0.5 m. This parameter can be interactively configured. In the current experiment, aiming the detection of objects like cars, this threshold level is justified. The result from the change detection is

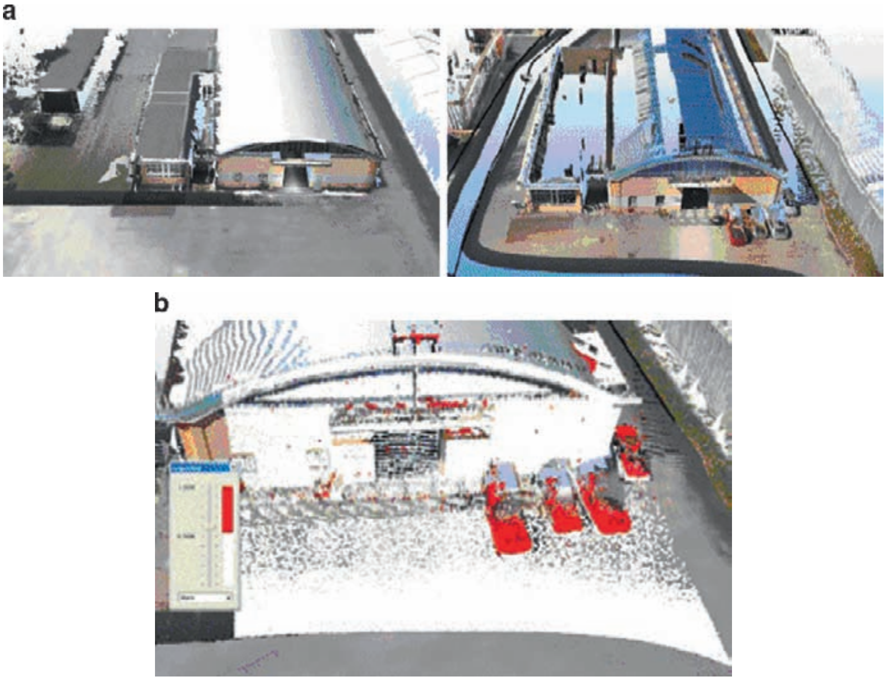

Fig. 9.6 The 3D reference model (upper left) and the model to be verified (upper right). Both are acquired using a ground based laser range data. Below the 3D change model (white = 0–0.5 m; red > 0.5 m)

visualised in Fig. 9.6 (bottom). Cars not present in the reference model have been correctly and accurately detected with our system.

Reinartz et al. (2006) studied 3D change detection using digital surface models (DSM) obtained from stereo images. For this purpose a sufficiently good representation of individual buildings is necessary. The automatic derivation of a DSM from 2004 Quickbird bi-temporal stereo images of the Esfahan nuclear facility via stereo evaluation software was tried by DLR (with DLR software) and by other institutions.

This automatic derivation of a DSM did not succeed in built-up areas for three reasons:

1. Too homogeneous radiometry of soil and buildings
2. Large stereo angle of 59.9°
3. Multi-fold bi-temporal radiometric differences

Thus, no 3D representation and therefore no heights could be extracted for most of the buildings. In order to achieve an overview on building heights manual tie point extraction was used:

- Tie points are measured manually for each building: a nearby ground point and several levels of the building
- Rational polynomial functions provided along with the imagery are used to calculate the object space coordinates of these tie points, and thus height differences of ground point and roof points are derived (results for points on the same level of a building show a standard deviation below 1 m).

This method was applied to the Esfahan facility and 2004 QuickBird images. A classification of the buildings on the basis of the maximum height is shown in Fig. 9.7.

On November 27, 2005 an along-track QuickBird stereo pair of the Esfahan region was taken. Unfortunately, it was not possible to choose a smaller stereo angle (this time 60.8°). Thus, the two first hindrances for automatic DSM derivation mentioned above are also valid for this stereo pair. Additionally, strong reflections appear from the roofs.

The automatically derived DSM still shows no 3D representations of buildings. Because roof edges cannot be matched automatically, tie lines have been introduced into the measurement software. About 800 tie lines have been measured for the central area of the Esfahan nuclear facility. After converting to a series of tie points (e.g. 14,000 for point distance 2 pixel on lines) and forward intersection based on RPC, provided in auxiliary data, the resulting object space coordinates are merged with the automatically derived point set. DSM interpolation now shows the 3D structure of the buildings. Automatic location of such stereo lines will be tried next via epipolarly resampled stereo images in order to compensate the radiometric problems mentioned above – software for epipolar projection of high resolution stereo imagery (e.g. provided by QuickBird, Ikonos-2) based on a sparse set of tie points derived by automatic matching and on RPC has already been developed. The changes of buildings (new or different height) between the two image pairs can be derived from these data.

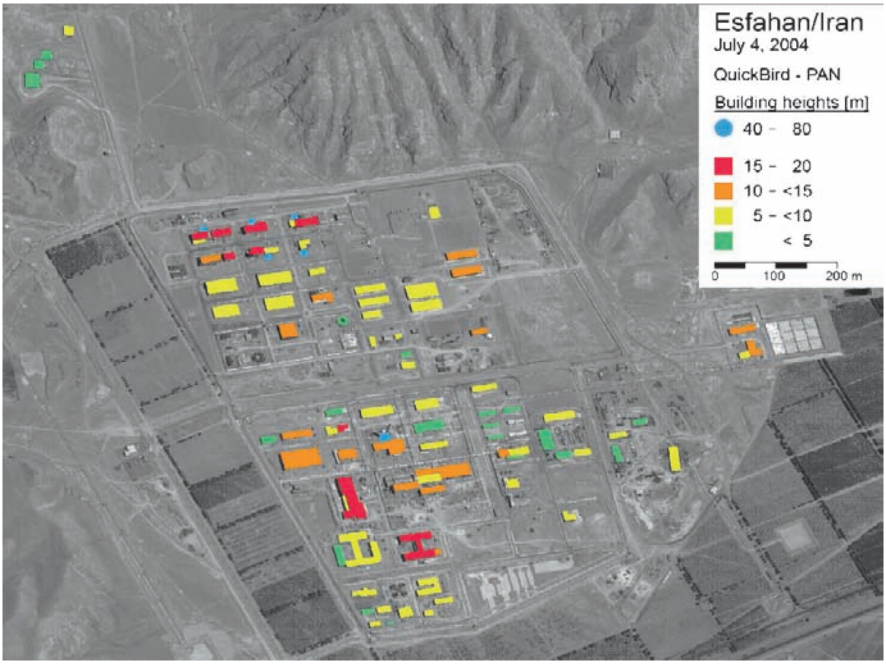

Fig. 9.7 Building heights for Esfahan nuclear power plant in four height categories and heights of chimneys, the absolute height accuracy for single Buildings is in the order of 1–2 m

9.5 Summary and Conclusions

In this chapter a wide range of change detection tools have been discussed, grouped into methods suitable for optical (multi spectral), radar (SAR) and 3D data. The first section on optical methods review unsupervised approaches, supervised and knowledge-based approaches, pixel-based and object-oriented approaches, multivariate alteration detection, hyperspectral approaches, and approaches that deal with changes between optical images and existing vector data. The second section on radar methods reviews constant false-alarm rate detection, adaptive filtering, multi-channel segmentation (an object-oriented approach), hybrid methods, and coherent change detection. The third section on 3D methods discusses systems that are able to deal with 3D information from ground based laser-ranging systems, LiDAR and elevation models obtained from air/space borne optical and SAR data.

This chapter also discusses several security applications. Among them are land-cover change which is often one of the basic types of information to build analysis on, monitoring of nuclear safeguards, third-party interference close to infrastructures (or borders), and 3D analysis. What method to use for which application is not easy to determine, it is for instance dependent on the size of the changes, shape, textural properties, spectral properties, and their behaviour in time. For example, the detection of third party interference requires a method that is able to detect small objects that relocate in short periods of time. Population monitoring and land-cover analysis require methods that are also able to deal with larger objects over longer periods of time.

What method to use is also dependent on the sensor. In general, radar data is less dependent on atmospheric and illumination conditions (cloudy skies, day and night) than optical. On the other hand, interpretation is often more difficult due to the physical mechanisms affecting microwave backscattering so optical information, even if not available at the appropriate time, is necessary in most analysis. The orbit and tasking properties of the different platforms play an important role too. A trend in satellite observation is to deploy systems that consist of a number of satellites (i.e. satellite constellations) to reduce revisit times. Examples are the German optical system RapidEye and the French–Italian optical and radar system Pleiades-Cosmo/SkyMed. Another important parameter is the resolution of the sensor. Optical satellites with a resolution up to 0.6 m (Quickbird) are operational and accessible. In case of radar satellites the best resolution is 1–3 m (TerraSAR X and Radarsat 2).

Appendix Catalogue on Change Detection Applications, Data and Methods for the Application Work Packages 20400–20900

Table 9.1 Definition of spatial image resolution

Very high resolution (VHR)	≤1 m
High resolution	≤10 m
Medium resolution	≤50 m
Low resolution	≤250 m
Very low resolution	≥250 m

Table 9.2 20400 Treaty monitoring

Application	Optimal data	Available data sets	Method
Nuclear facilities	Very high resolution, radar	Isfahan, Iran VHR optical and radar data	Visual (2D and 3D), stereo evaluation, semi-automatic height derivation
Industrial facilities, plants	VHR, radar		Visual (2D and 3D), Stereo evaluation, coherent and non-coherent change detection
Chemical/ biological weapons	VHR, radar		Visual
Disarmament	VHR and medium Res, radar		Visual
Convention monitoring	Low resolution data (~250 m) and very low resolution data		

Table 9.3 20500 early warning

Application	Data	Available data sets	Method
Water resources (desertification)	Medium res. (<30 m) and low res. for large areas		Time series, veg index, soil moisture
Pollution	VHR, hyperspectral , very low resolution	Meteosat data for large fires (pipelines)	Visual
Land cover, drought	Medium res. (<30 m) and low res. for large areas		Time series, veg index, soil moisture
Movement of troops	VHR, high resolution (10 m)	SPOT data Kuwait	Visual
Earthquakes	Radar		Differential interferometry

Table 9.4 20600 monitoring population

Application	Data	Available data sets	Method
Megacities	Medium res. (<30 m) (e.g. Landsat Aster, Radarsat, Envisat) Census data		Time series, veg index, population estimation
Refugee camps	VHR, radar	Goz Amer camp, Mile camp (Chad)	Visual, coherent/ non-coherent automatic tent counting
Analyse night time imagery	Very low resolution (~500 m)	OLS (DMSP)	Measuring of amount of light
Track movement of refugees and finding mobile populations	VHR, medium res. (<30 m)	Aster images over Africa	Visual, Measuring of amount of light
Land cover changes as indicator	Medium res. (<30 m) and low res. for large areas	Aster images over Africa	Time series, veg index
Population density	VHR, medium res. (<30 m), radar	availability radar data of Goz Amer and Abidjan is being investigated	CFAR, change detection, automatic counting of dwellings, other methods

Table 9.5 20700 Monitoring infrastructure (EU critical infrastructures)

Application	Data	Available data sets	Method
Pipelines	VHR, radar	Data from PRESENSE project (Airborne VHR and radar)	SAR interferometry Object-based recognition and CD, non-coherent change detection
Energy installations, production and storage	VHR, radar		Change detection
Transportation network	VHR and medium res. (<30 m)		Visual
Airports, harbours	VHR, radar		Change detection
Communications and ICT (telecom, broadcast, etc.)	VHR, radar		Change detection
Health care	VHR, radar		Change detection
Food	VHR, radar		Land cover classification
Water	VHR and medium res. (<30 m)		Multispectral analysis, change detection
Critical services (government, banking, etc.)	VHR, radar		change detection

Table 9.6 20800 Monitoring borders

Application	Data	Available data sets	Method
Ships, beaches	VHR and medium res. (<30 m), radar	Radarsat, eros and spot data from Street of Gibraltar	Ship detection
Borders	VHR and medium res. (<30 m)	Aster data Iraq/Saudi-Arabia	Visual
Tracks	VHR and medium res. (<30 m), radar	Aster data Iraq/Saudi-Arabia	Visual, vehicle detection, coherent change detection

Table 9.7 20900 damage assessment
Comment: pre-damage imagery is necessary

Application	Data	Available data sets	Method
Buildings, houses	VHR, radar and DEM		Visual, 3D analysis
Industrial facilities	VHR and medium res. (<30 m), radar	Quickbird (Ryongchon, Korea), Bagdad data	Visual, 3D analysis, non-coherent and coherent CD
Timescale: catastrophe (war, earthquake)	VHR, radar		Coherent and non-coherent change detection
Timescale: slow changes (subsidence, drought, etc.)	Radar, medium res.		Differential SAR-interferometrie, "permanent scatterers"

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Chapter 10
Data Integration and Visualization for Crisis Applications

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Abstract Satellite data play an increasingly important role in supporting decision making in disaster management. Rapid data integration and visualization are essential to make data accessible and convey the results in an easier to perceive way. Especially when presenting information to a non-expert audience, visualization of the data and its content improves the understanding of the situation at hand. The paper gives an overview of the current status of data integration and visualisation technologies including an analysis of the advantages and disadvantages of the technologies available. It also highlights several aspects of visualisation strategies using technologies such as predefined landscape models, and tools including 2D and 3D web viewers and globe viewers, and discusses the inextricable link between data integration and visualization.

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Keywords Sensor integration • ground sensor network • COP • crisis-related visualization techniques • near-realistic landscape visualization • real-time vs. pre-processed visualization • automatic scene generation • information extraction • object libraries • online mapping services • globe viewers

10.1 Introduction

In most crisis situations, rapid yet reliable information provision is highly supportive – if not crucial – for crisis-related decision making and effective disaster management. Disaster response based on satellite data and geospatial information, pushed and challenged by a series of events in the recent past, moves ahead in providing maps and other information products more rapidly and at a higher degree of automation and consistency. In order to fulfil this demand, there is a need for effective data integration and advanced data visualisation. These two topics may appear distinct at first glimpse, yet from an operational point of view they are strongly interlinked and of mutual interdependence. In this section we highlight key aspects of crisis-related visualisation strategies comprising methods and models such as predefined landscape models, and tools including 2D and 3D web viewers and globe viewers, and we discuss their inextricable linkage with data integration. We also include a section on rapid scene generation based on an integrated workflow for including information extraction, analysis and delivery. The chapter closes with an overview of visualisation tools used in the GMOSS context. The tools are grouped genetically, whether they are coming from a "Geographical Information Systems (GIS) environment or from computer graphics. Irrespective of the history of the tools being used, the development of a sound methodology and predefined workflows for providing visualisations on demand rely on thorough, yet effective data integration. This comprises several technical challenges, such as:

- The need for a widely applicable model and workflow from data capture to visualisation.
- The use of various visualisation approaches currently not exchangeable.
- The generation of 3D visualisations from GIS databases and the use of various techniques revealing detected or potential changes.
- The definition of methods to enhance speed and quality for the generation of three dimensional, realistic landscape models.

Whereas a few years ago GIS relied on external technologies for representing reality, today, near-realistic landscape visualisations are generated from GIS databases directly. The growing accessibility of this technique is pushed forward by ever increasing cost-efficiency, capability and availability of computer hardware, visualisation software, and GIS data layers. Within the last 20 years, great achievements were made concerning the level of detail, the level of realism and the overall visual quality of computer visualisations (Sheppard 2000, 2001; Almer et al. 2004). Utilizing these increased capabilities are able to tackle the above mentioned challenges induced by the time constraints of 'near-real time applications' as imposed in any kind of crises management. Still, with those capabilities at hand we also need to be cautious, with a sense of responsibility. Current visualisation technology has to be carefully evaluated concerning its usability for responders and decision makers. More specifically, it requires a common understanding, a common language between GIS scientists and visualisation specialists and a common set of objectives. By creating and agreeing on a common operational picture (COP, see Chapter 23), we may achieve this common understanding of (1) the situation as such, (2) the data needed to represent it and (3) the information packages required and exchanged.

10.2 Requirements for Security Applications

10.2.1 Speed, Real-Time Delivery and Realism

Scenario techniques and photorealistic visualisations of scenarios have proven to be useful in the context of planning and participatory decisions in general (e.g. Tress and Tress 2003). Tied into a spatial referencing system as realised in GIS-based landscape visualisation, they become a powerful means for producing true representations of status-quo and future situations, thus being of great use for various consultation exercises (Appleton and Lovet 2003). GIS-technology enables integrating datasets such as fine-scale baseline maps, digital elevation models (DEM) for terrain representation, and any other auxiliary GIS layers on e.g. critical infrastructure or population. For deriving and updating GIS data, remote sensing imagery is a virtually unlimited, yet not fully exploited source (see Blaschke et al. 2006; Tiede and Blaschke 2005). However, detecting smaller or narrower features such as power lines or single buildings requires imagery with a sufficient spatial resolution (around 1 m or less), coupled with appropriate analysis techniques. Whereas time constraints and high accuracy requirements in certain situations do not allow for new developments, in other situations, automated techniques built on established algorithms may significantly improve the entire process, overcoming labour intensive visual interpretation. A general limitation of remote sensing data is that certain classes of critical features such as administrative boundaries or no-go zones may be ‘invisible’ and therefore hard to detect, unless they coincide with specific land-use patterns.

Visualisation in this context means representing reality. More specifically, the effort, the proposed method and the quality of the visualisation largely depend on an agreed ‘sufficient’ level of realism for a particular application. Whereas not any kind of visualisation technique would necessarily require a ‘realistic representation’ – for example a baseline map showing the important features at a disaster site with conventional symbology may be considered a highly efficient means of communication – the techniques discussed here share a common demand for realistic depictions. Technically, computer models are capable of rendering a high degree of (pseudo)realism, a fact impressively proven by the computer games industry. In terms of the effort required, the degree of realism negatively corresponds with the preparation work. Likewise, the degree of automation and

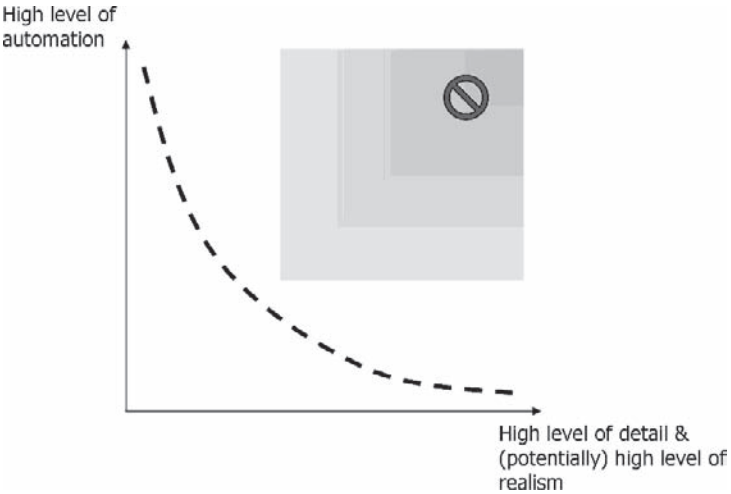

Fig. 10.1 Conflicting goals for the purpose of visualisation. At present, a high level of automation and a high level of detail still exclude each other

the flexibility in terms of adapting it to a changing situation will not allow a high degree of realism (see Fig. 10.1).

Crises management has to find a trade-off between what may be possible and what is feasible. It is necessary to critically examine which level of detail and which degree of realism is really required in the very situation.

10.2.2 Detection and Ground Sensor Network

Today, a wide variety of different sensors is available. Space-borne and in-situ based sensors need to be incorporated and data produced by these sensors need to be integrated. A sensor network is commonly understood as a "computer network of many spatially distributed devices using sensors to monitor conditions at different locations" (see wikipedia, http://en.wikipedia.org/wiki/Sensor_network). In non-technical terms we may view a sensor network as serving the goal of "bringing together and coordinating all necessary knowledge and response information quickly and effectively" (see http://www.sensornet.gov). The following section exemplifies this by illustrating the use of a rather unusual radar sensor and a ground sensor net designed for both vehicle detection and tracking.

10.2.2.1 CARABAS

CARABAS (Ulander 2003) is a synthetic aperture radar (SAR) sensor carried by an air plane, flying at a distance of 12 km and at an altitude of about 6,000 m.

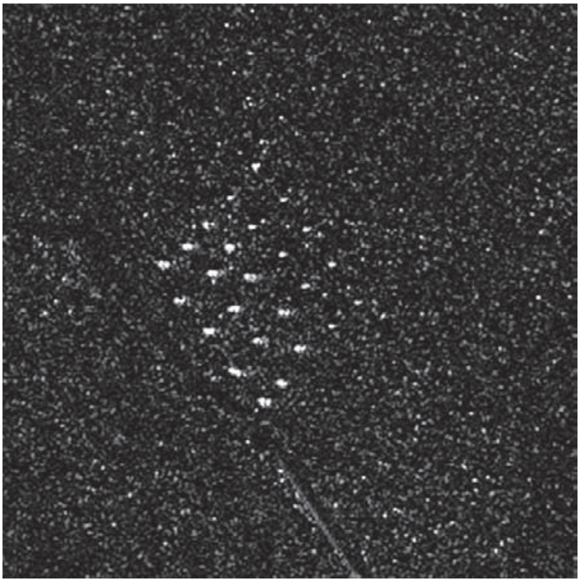

Fig. 10.2 Objects (here: cars) hidden under canopy in a forest seen by CARABAS

Compared to traditional radars, CARABAS uses a very long wavelength, typically ranging between 3 and 15 m unlike the much more common microwave SAR that uses wavelengths in the size of centimetres. Objects that are much smaller than the wavelength do not significantly affect the result of the radar. The effect of this is that CARABAS penetrates vegetation, meaning that tree trunks and branches in a forest do not prevent the radar for seeing what is on the ground. Objects, arranged in a pattern, hidden in a forest are in spite of that detected by CARABAS, which can bee seen in Fig. 10.2.

10.2.2.2 Ground Sensor Network

Complementary, a sensor network for ground surveillance can be used for detection, tracking and classification of vehicles. The network can be made up by arrays of either acoustic or seismic sensors (i.e. microphones and geophones). Signal processing takes place in each of the sensor nodes. All sensors know their position and orientation. In a multi-hop radio network they can communicate with the other nodes and thus association and fusion of combined data can be performed. The unattended ground sensor network (UGS) used here (Brännström 2004) has not been put into practice commercially yet, but it exists as a simulation connected to MOSART (Tyskeng 2003). The simulation though is verified using data from real microphones and geophones (see Fig. 10.3).

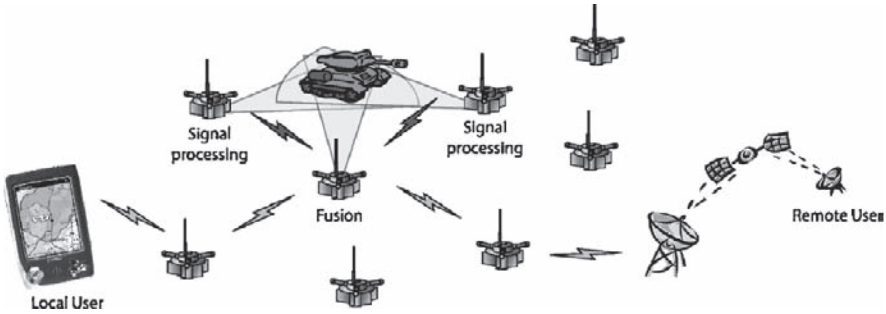

Fig. 10.3 Principle of an unattended ground sensor network

10.2.3 Common Operational Picture (COP)

The main purpose of a common operational picture (COP) is to present information regarding relevant processes that may take place over longer or shorter periods of time. One objective, among others, is to build an environment for coordination and monitoring of emergency or crisis situations where situational awareness should be determined, refined, compared and shared among users to enable a common operational understanding. To bring such events to their ends will require information often coming from a large number of different sources. Consequently, all data generated by these different sources have to be merged or gathered into a general overview of the situation and this has to be done in real time or at least near real time. Such requirements may be hard to fulfil. However, in many cases the users are willing to accept some delay if the information can be presented in a way that will increase the users trust in the information. This will also make it simpler for the users to make adequate and correct decisions.

From a user's perspective, the COP is a highly dynamic interface environment in which data can be distributed and exchanged. As a result of this a consistent information database is developed where each user can contribute, process and add value to this database according to the processing needs within any specific emergency situation or task. In general, users can be considered experts in different fields and have different information requirements due to different responsibilities. According to that users may interpret the information residing in the COP in different ways depending on background, knowledge and other aspects of individual attitude. For this reason, a COP should be consistent among all users, meaning a picture with respect to the actual information, should coincide with the operational pictures of all other users. Otherwise, inconsistency of information may cause an obvious risk where users may form different perceptions of the crisis and consequently draw diverging conclusions when interpreting the given situation. Hence, crisis management or other similar activities will become difficult without a common operational picture, due to the lack of consistent information and insufficient situational awareness. Basically, this is the main intention of a COP. That is, to give the users an

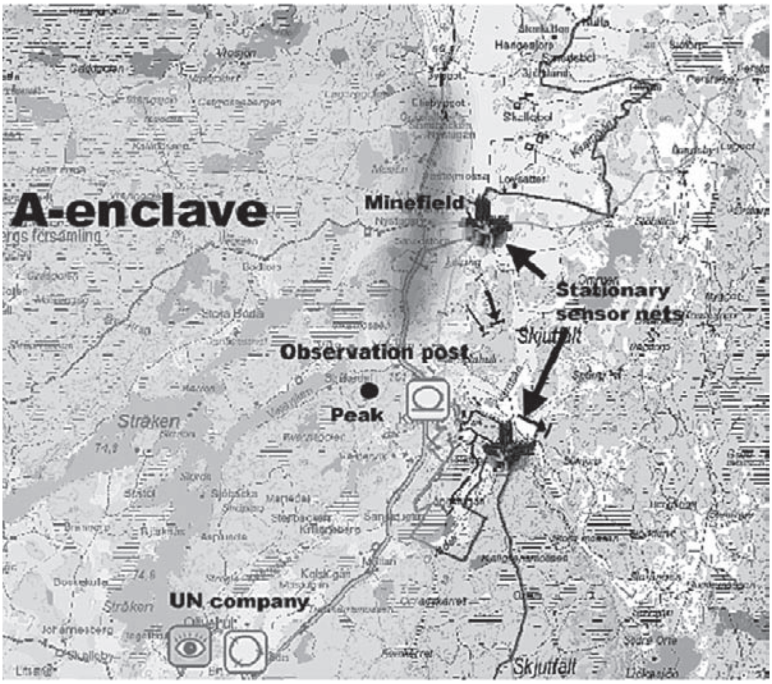

Fig. 10.4 An illustration of a mapped common operational picture (see text for further explanations)

awareness of the current situation in the ongoing process (i.e. the crisis). To provide means for delivering incoming information to the users, visualization techniques are required as well. A system for the support of a COP presentation must include capabilities for selection, analysis and visualization of relevant information to, if needed, give the users a high degree of situation awareness of the ongoing process. From a service perspective the COP-system can be regarded as part of a service architecture to which various services can be attached. Such an approach will make it possible to see the COP-system as a decision support tool as well.

Summarizing, the COP aims at providing all the necessary tools to assure that the decision makers have received correct situation awareness. In order to accomplish this, the COP-System must be able to manage the very diverse incoming information, to fuse this information whenever necessary, and to present it in a well-organized manner to the decision makers. Furthermore, the users must also be able to share this information to maintain the overall situation awareness.

A simple example of a COP can be seen in Fig. 10.4. In this example, the objects that occur are represented with symbols. The text in the figure is given just for explaining the types of objects, though it is generally not present in a COP-system unless the user requests this. The example is taken from a scenario simulated in a simulation framework developed at FOI (Silvervarg and Jungert 2006). The scenario is run in the simulator to demonstrate how the different services can be used for building up an actual COP. Likewise it illustrates how the dynamic processes that are carried out in the scenario reflect the changes that occur over time. The selected objects in the COP are mainly generated from a query language for multiple sensor data sources and correspond to the result of different queries.

10.3 Data Integration, Visualisation and Dissemination

Three-dimensional (3D) visualisation of virtual landscapes has undergone quantum leaps over the last years concerning performance and quality. This is particularly true for real-time processing. This development today allows for integrating huge data sets such as very high spatial resolution (VHSR) satellite imagery and DEMs into 3D landscape models that reveal a very high degree of spatial detail. Even specific landscape elements like single trees, buildings, ground patterns, or infrastructure items can be integrated into these kinds of models. These elements significantly increase the degree of realism and the quality of visualisation. Visualisation techniques in general can be used to convey a (pseudo-) realistic impression of the setting under concern or a part of it, without actually being in place. This may be of critical advantage during crisis situations, because relief units can familiarise themselves with the situation of a particular location before going there. For this purpose we can also freely adapt the visualised situation, as soon as new data becomes available. Finally, we are able to simulate situations, which might occur.

The following Section 10.3.1 briefly describes the relevant steps of a workflow which comprises both the processing and the visualisation of geo-information. This workflow is considered a production chain for the visualisation process, by which the products of mapping and subsequent analyses are delivered adequately and in time. Section 10.3.2 shows possibilities for web-based visualizations for information dissemination, including online map presentations and real-time 3D visualizations. In Section 10.3.3 we provide a tabular summary of 3D visualisation tools as being tested and used within the GMOSS network. Specifications are given in bullet form.

10.3.1 Fast and Automatic Scene Generation: Rapid Visualization

Fast generation of realistic landscape models and scenes is the key to the usability of simulation techniques and remotely sensed data in security applications. Since traditional methods for generating realistic models are likewise time and work intensive, a way for an automated generation of fine-scaled landscape models is presented here. It includes data integration, object-based information extraction, establishing object libraries and visualisation. The workflow as developed by

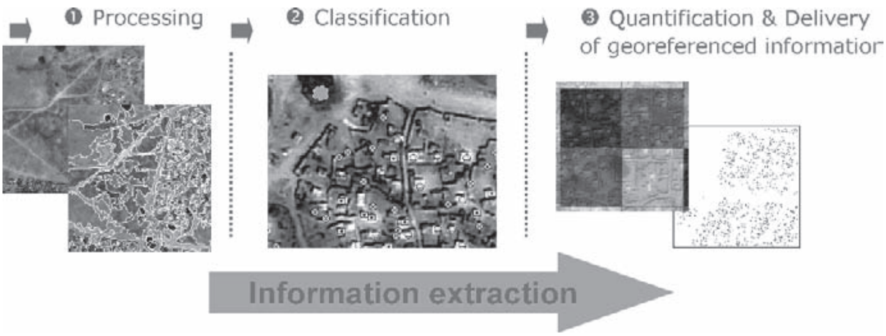

Fig. 10.5 Object-based information extraction. The process includes processing, classifying and quantifying imaged data

Z_GIS has been applied on QuickBird data (acquired 12/2004) of the Sudanese refugee camp Goz Amer in Eastern Chad (cf. Lang et al. 2006).

10.3.1.1 Matching and Integration of Various Source Data

The integration of data originating from different sources (like satellite data, DEM, auxiliary vector data) requires detailed documentation about data format and quality (spatial and thematic accuracy, timeliness and scale), map projection, history and the like. When working in operational mode, the capacity of the particular software package needs to be taken into consideration, including issues of data format compatibility. Matching geo-data from different sources requires means for geo-referencing or geometrical co-registration in general, for ortho-rectification of aerial photographs and very high resolution satellite imagery, and for transformation or (re-)projection on-the-fly. Services exist to provide co-registered data in a high accurate mode, but often the importance of this profound step is neglected when rapid action is required.

10.3.1.2 Object-Based Information Extraction

Automated object-based information extraction starts with pre-processing steps like pan-sharpening and edge-enhancement required for improving image content in general. In this workflow, established by Z_GIS, classifiable units are provided by segmentation (see Fig. 10.5), but depending on the approach, these units can also be derived by other techniques (e.g. mathematical morphology analysis). The classification itself is performed by establishing rule-sets or using other classifiers suitable for knowledge-based classification of multispectral, optical data. Additional GIS layers, like a DEM or road network can be included in the classification process as a source for external information. Quantification aggregates and refines the classification results. Finally, delivery of geo-referenced information is the main objective of the analytical chain of information extraction.

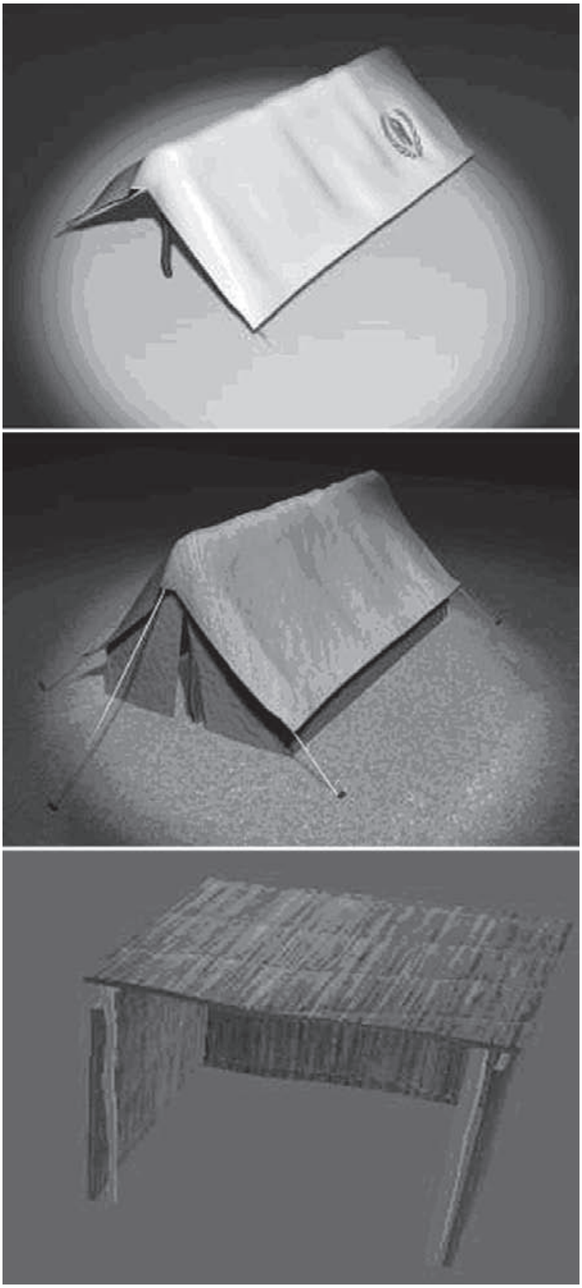

Fig. 10.6 Three-dimensional objects of an object library, in this case two different types of tents and a shelter in a refugee camp. (Courtesy of Z_GIS)

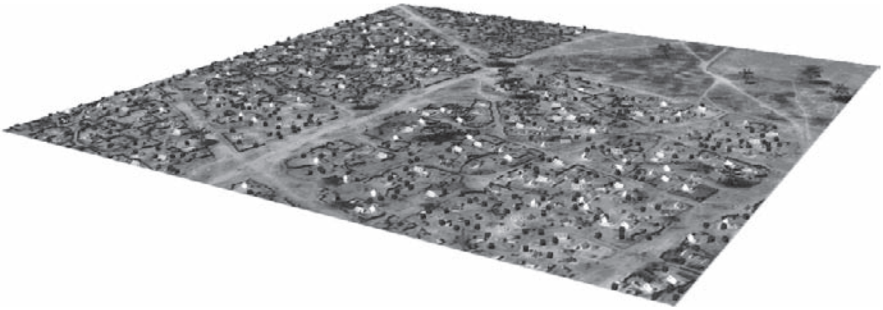

Fig. 10.7 Three-dimensional objects visualisation of a refugee camp (Goz Amer, Chad) applying a workflow for information extraction and visualisation using 3D objects (Courtesy of Z_GIS)

10.3.1.3 Object Libraries

Object libraries may contain all kinds of object categories for the respective situation including for instance tree species or vegetation types, building types and ground cover, land use and land cover types, dams, etc. Establishing pseudo-realistic object libraries (see Fig. 10.6) is time-consuming, but otherwise supports the creation of realistic 3D visualisations, virtual flights or walks. The time effort pays off in cases and in certain areas, where object libraries do already exist. Changes or modifications in the depicted landscape can be visualised in an automated and rapid way. The object library, if organised in a database, allows for combining single objects into artificial, mimicked ecosystems for representing certain patterns or patch mosaics. True 3D objects, or 2D picture representations can be used as input data. The latter, since saving time for rendering, are useful for simulating vegetation types.

10.3.1.4 Visualisation

The object-based approach for information extraction supports a direct export of the extracted features as geo-referenced GIS layers. Their attributes may contain information about the assigned class and additional information. Visualisation of these objects is enabled by using 3D GIS applications, but also external visualisation software provided that automatic import of the datasets is supported. A pseudo-realistic visualisation is realised by linking 3D symbols to the footprints of the extracted features, respectively. The quality of the visualisation is dependent on the quality of the available object library. The same applies to the extraction process: assuming a high quality of feature extraction we can derive additional information from the image data, like the size of the objects and orientation. Using this data, objects can be placed as in reality (see Fig. 10.7). It should be noted that the object library needs to be tailored to the possibilities of the feature extraction. We can only visualise rapidly what is extracted from the image data. Existing libraries implemented as presets in visualisation software are often not specific enough.

With respect to the time span required to deliver the demanded visualisation product from the very point when the demand was raised, we can distinguish between:

- Real-time visualisation, which allows for producing geometries and rendering 3D scenes in (near) real-time and
- Pre-processed visualisation, which supports producing highly detailed 3D models; the production phase and presentation are time wise separated

In general, there is no factual difference between the workflow of real-time visualisation on the one hand and pre-processed visualisation on the other hand. However, if it comes to rendering there may be significant differences in quality. The pre-processed approach implies higher quality in terms of level of spatial detail and the amount of displayable objects. And it allows interaction of the operator who can highlight specific phenomena and control the conveyed content. End-user interaction (e.g. free navigation), however, is limited.

10.3.2 Web-Based Visualization for Information Dissemination

As stated above, visualisation of geo-data plays a crucial role in information dissemination and the online availability of maps and landscape models is important for planning and decision tasks. In this section, implementations for online 2D- and 3D-geo-data presentations are described in detail.

Google Earth, widely used in both the private and public domains, provides the means for fusing imagery, terrain and collateral data for quick access and distribution to relevant users for enhanced visualisation and analysing geospatial interrelationships. This supports data exchange and collaboration by security teams by sharing common perspectives in a fast and efficient, yet familiar way. A user-friendly interface allows concentrating on the specific task without the usual restraints of software processing. Still, Google Earth as developed out of the keyhole software is only a solution, and one that is centrally owned by one company. So in certain situations access restrictions may apply, which makes it less suitable for crisis applications. Furthermore, the database of Google is available in very high resolution the images are of different origin and represent different time periods. This may lead to confusion if data is outdated without being marked as “old”. Additionally, it requires a well established Internet connection, which may not always be available in crisis situations. However in the context of the GMOSS project, the mosaic of IKONOS data for the Zimbabwe test case was published in the Google Earth server of EUSC and the data was accessed by the partners of the project in a remote location via the Internet. In addition, this server also provides the standard imagery and data that is available with the free version of Google Earth such as the topographic data from SRTM. This EUSC server could be used again for the other test cases explored as part of the GMOSS project. To provide additional views on the applications of visualisation some complementary approaches are discussed in this chapter.

Fig. 10.8 WebGIS client for the test case Zimbabwe showing the city of Harare. Background: Quickbird image, pan-sharpened image with 0.6m ground resolution (Courtesy of JR)

10.3.2.1 Online Map Presentation

For online visualisation of geo-data a WebGIS client based on the open source software UMN MapServer has been applied. UMN MapServer is compiled according to the following principles:

- The user requests data from the server.
- The web server handles the request; if geo-data are requested, the request will be forwarded to the MapServer.
- The MapServer accesses the geo-data base including raster and vector data and processes them according to the request.
- A raster image is sent back via the Web sever and presented at client side.

Requests for maps like web map service (WMS) and web feature service (WFS) conform to OGC (Open Geospatial Consortium) specifications. The following figure (Fig. 10.8) shows a WebGIS client as been established by Joanneum Research for the GMOSS test case, Zimbabwe.

The client is based on HTML and Javascript and thus can be used with standard Internet browsers. It offers an intuitive graphical user interface allowing the presentation of maps and additional data as well as basic GIS functionalities like distance measuring and buffering.

A commercial counterpart of the UMN MapServer ESRI's ArcIMS Webserver has been applied by RMA in the GMOSS test case Iraq, as shown in Fig. 10.9. The

Fig. 10.9 ArcIMS Viewer showing QuickBird imagery from Bagdad, Iraq (Courtesy of RMA)"

principles and functionalities are similar, but ArcIMS uses its own communication protocol. In order to still be interoperable an OGC WMS Connector has been made available. In the following figure an HTML ArcIMS Viewer with an image of the Iraq test area is shown.

In general the 2D map presentation offers a very fast and geographic oriented access to up-to-date information, which is very important in the context of crisis management. Geo-referenced satellite and also aerial images as well as vector information can be visualised and allow direct access to crucial information to support decision processes. The 2D visualisation offers a high quality presentation of spatial information but can not provide a real spatial impression. For specific interpretations the visualisation of the third dimension is essential. The generation of 3D-models allows us to realise a real-time 3D-visualisation which will be described in the next paragraphs.

10.3.2.2 Real-Time 3D-Visualisation

For the 3D-presentation of geo-data a client using Macromedia Shockwave 3D has been implemented. Macromedia Director, as the development environment for Shockwave, enables easy programming of the user interface and offers DirectX and OpenGL support. Combining digital elevation models and textures generated from high resolution remote sensing data, 3D-models are created and can be

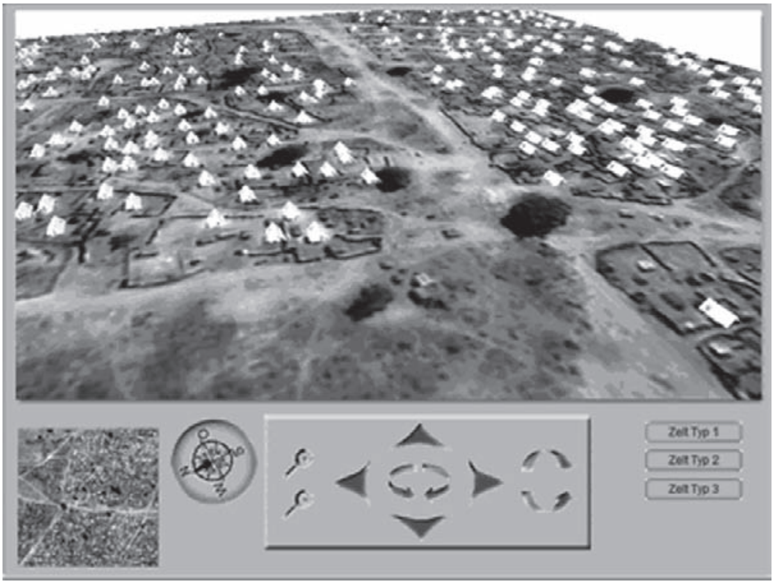

Fig. 10.10 Real-time 3D-presentation of Goz Amer based on a Quickbird satellite image (Courtesy of JR)

viewed in real-time. In comparison to the 2D visualisation a satisfying real-time 3D-visualisation requires more processing power which is provided by specific graphic cards. The following figure shows the 3D-viewer with a model of the above mentioned refugee camp Goz Amer.

Additional to the 3D-landscape model also 3D-objects for the visualisation of infrastructure are included. In this example, different models for tents are used and placed into the model based on image classification results. The 3D-model can be navigated very easily using functions for panning, zooming, camera tilting and rotating (see Fig. 10.10).

The integration of an overview map and a compass enables user friendly and easy orientation. Additional information to the presented objects is made available via tooltips and hyperlinks.

10.3.3 Overview of 3D Tools

This section provides a summarizing characterisation of 3D visualisation tools that have been tested and used within the GMOSS network. Whereas many other categorizations could have been applied (e.g. commercial vs. non-commercial) we differentiate between (1) 2D/3D visualization tools emerging from GIS technology including globe viewers, and (2) virtual landscapes visualisation tools originating from computer graphics. Distinction of both groups is not sharp; there is a transition in terms of spatial reference and spatial analysis. Thus, the latter group is ordered in such a way, that tools offering widest GIS interoperability are listed first. The "+" symbol indicates strengths; the "–" symbol indicates weaknesses of the respective tool (as being judged from a disaster management operational view.)

10.3.3.1 Two-Dimensional/Three-Dimensional Visualization Tools Emerged from GIS Technology Including Globe Viewers

ArcReader (2D Viewer and 3D Globe Viewer)

+ Freely available
+ 3D visualization possibility
+ Integration of projects from ArcGlobe including: 3D globe view, animation files, spatial bookmarking
+ Possibility to equip data with added value, e.g. meaningful legend, spatial bookmarks, notations
    - External data integration is limited
    - Limited baseline data available

ArcGlobe (ESRI 3D Analyst Extension)

+ Commercial product
+ Ability to handle large datasets (pyramid files, intelligent data caching)
+ Support projection "on the fly" for automatically integrate data sets with different projections
+ GIS analysis capabilities e.g. watershed calculation, surface analysis, area/length calculations
+ Various data integration possibilities such as vector data (2D/3D, e.g. KML, shapefiles, 3D objects); raster data (2D/2.5D, satellite data/scanned maps); various formats (ESRI grids for analysis purpose, tabular data, DEMs in different resolutions)
+ Animation/video capabilities
    - Not a web tool
    - Limited baseline data available

ArcScene (ESRI 3D Analyst Extension)

+ Commercial product
+ 3D perspective tool, but no globe view
+ Support projection "on the fly" for automatically integrate data sets with different projections
+ Full GIS analysis capabilities
+ Various data integration possibilities such as vector data (2D/3D) e.g. kml/kmz, shapefiles, 3D objects; raster data (2D/2.5D, satellite data/scanned maps); various formats; ESRI grids; tabular data; DEMs in different resolutions

- \+ Animation/Video capabilities
  - Not a web tool
  - Limited baseline data available

ArcGIS Explorer (ESRI Globe Viewer)

- \+ Freely available
- \+ GIS analysis capabilities to be supported through ArcGIS Server connection
- \+ Support projection "on the fly" for automatically integrating data sets with different projections
- \+ Integration of WMS and ArcIMS Services
- \+ Various data integration possibilities such as vector data (2D/3D) e.g. kml/kmz, shapefiles, 3D objects; raster data (2D/2.5D, satellite data/scanned maps); various formats: ESRI grids; tabular data; DEMs
- \+ Web integration
- \+ Different base data sets available, user can choose between "subjects", e.g. satellite data, thematic maps, historic maps, etc.
  - Limited VHSR baseline data outside of the USA

Google Earth (Version 4)

- \+ Freely available (basic version)
- \+ Data integration possibilities
- \+ vector data (2D/3D) e.g. kml/kmz, 3D models via Google Sketchup (free CAD sketch software)
- \+ WMS incorporation via kml
- \+ Georeferenced raster data limited in free version
- \+ Animations via time stamps
- \+ A lot of recent baseline data sets available, especially very high spatial resolution imagery
  - No projection "on the fly" supported
  - No GIS analysis capabilities

10.3.3.2 Three-Dimensional Visualization Tools Originating from Computer Graphics

Leica Virtual Explorer

- \+ Commercial product
- \+ Real-time 3D visualization tool with GIS functionality
- \+ Fast handling of very large datasets (pyramid files, intelligent data caching)
- \+ Concurrent use/edit of scenes by distributed groups (requires advanced client, additional costs)
- \+ "On the fly"-projection
- \+ GIS Analysis capabilities e.g. watershed calculation, surface analysis, area/length calculations

- \+ Various data integration possibilities: vector data (2D/3D) e.g. shapefiles, 3D objects; raster data (2D/2.5D, satellite data/scanned maps); various formats; Integration of DEMs in different resolutions
- \+ Animation/Video capabilities
- \+ Free Web Client available (Active-X, limited to MS Internet Explorer)
- \+ Support for VirtualGIS Projects and Flight Paths
- \+ Multi-resolution morphing
  - Limited baseline data available

Three-Dimensional Studio Max

- \+ Commercial product
- \+ 3D Visualization software for advertising, game design and film industry
- \+ Photorealistic high-quality renderings
- \+ Highly adaptable via Scripts and Plug-ins
- \+ Export of real-time formats via plug-ins (additional costs)
- \+ Distributed rendering
  - No direct geo-data support (projections, GIS, DEM)
  - Focus on pre-rendered animations
  - Large data support only with plug-ins
  - Very complex
  - Integration of geo-data cumbersome
  - Not a web tool

Shockwave 3D (with Macromedia Director)

- \+ Shockwave 3D is a 3D Engine free of license costs
- \+ Macromedia Director is used as powerful authoring system
- \+ Production of 3D animations for on- and offline applications
- \+ Integration of different 3D content using the 3D Xtra (from Intel)
- \+ Script language Lingo for development
- \+ Integration of 3D content from 3ds Max, Cinema 4D, Maya or Lightwave 3D using theW3D-format
  - No direct geo-data support (projections, GIS, DEM)
  - Limited LOD functionalities

Visual Nature Studio 2

- \+ Commercial product
- \+ 3D terrain visualization software with strong capabilities in ecosystem depiction and pre-rendered photorealistic animations
- \+ Specialized on pre-rendered animations
- \+ Export of various real-time formats possible
- \+ Provides proprietary real-time format and free real-time viewer
- \+ Wide range of level of detail: from close-up views on single plants to global views
- \+ "on the fly" projection support

\+ Support of large datasets (e.g. pyramid layering, tiling, wavelet compression support)
\+ Broad range of data integration possibilities including GIS data (2D/3D); 3D Objects (3Ds, DXF); broad range of image data (various bit depths and formats); broad range of DEM formats
\+ Seamless integration into professional visualization (e.g. 3D Studio Max)
\+ Distributed rendering

- No GIS Analysis capabilities
- Focus on pre-rendered animations, therefore real-time performance still limited
- Focus on high-quality visualization
- No WMS/WFS support
- Long render times
- Limited batch integration functionalities
- No web distribution functionality

10.4 Conclusions

The argumentation followed in this article leads to the conclusion that visualisation within the context of crises management or, in other words, for Global Monitoring of Security and Stability is not an end in itself. It is, and is going to be, demand driven and thus it strongly builds upon GIS as a central, integrative tool. From a technical point of view, high performance and speed is decisive for the usability of visualisation technologies in crisis situations. Similarly the availability of very high resolution satellite imagery along with digital elevation models and other geodata is a crucial prerequisite for establishing a fundamental information basis. By means of information extraction and quantification of classification results imaged information will be transformed and we arrive at an aggregated information level relevant for decision support. Considering usability one needs to be aware that any subsequent automated analysis builds upon the quality of the data pre-processing and the accuracy of the classification. Effort needs to be put into an optimization strategy of the entire workflow. Transferability and repeatability on the other hand are fostered by establishing rule bases which hold the knowledge base for a range of similar situations. The described approach is considered a common interface between processing and 3D visualisation of geo-information. Finally, in any kind of operations related to crisis management, it is of great importance to share a common understanding and to have an overview of the complete situation in order to make correct decisions and to secure a good common progress. It is important to see the relations between all those entities and to understand what is actually happening. This will then contribute to improved situation awareness.

The visualisation process can be automated, meaning that appealing results can be generated on demand almost without human interaction. It is important to emphasize that once the basic elements for the visualisation have been prepared, any reported change can be considered and depicted. By this, disaster management is given a valuable tool for assessing and characterising the current situation.

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Chapter 11
UNOSAT Grid

Einar Bjorgo and Alain Retiere

Abbreviations CASTOR: CERN Advanced STORage manager; CERN: European Organization for Nuclear Research; UNOSAT: United Nations Institute for Training and Research Operational Satellite Applications Programme

11.1 Introduction

A humanitarian field worker based in Freetown, Sierra Leone, is on a field assessment to assess possible locations for a new school and the road network that exists in the area of interest. The terrain is unfamiliar. She has not been to this part of the country before, although there are several cities close by. “If I only had a map it would make this assessment so much easier”, she thinks. Fortunately, she carries her mobile phone and immediately requests a map over her current location using the UNOSAT developed mobile phone Grid interface. After a short time she receives a satellite map onto her mobile phone and by zooming and panning on this she gets a much better understanding of the terrain and its suitability for locating a school. In her office, there is already an e-mail waiting for her with a link to download the same satellite map from the UNOSAT Grid and allowing a more detailed assessment now that she also knows the terrain from the field.

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B. Jasani et al. (eds.), *Remote Sensing from Space: Supporting International Peace and Security*,

11.2 From Science–Fiction to Reality

This scenario may seem like science–fiction, but the reality is that through GMOSS, UNOSAT, in close collaboration with CERN, is currently developing such a tool. The Grid, or the Data Grid – named after the electrical power grid due to structural similarities, consists of a number of computers linked together providing unprecedented computing power and storage space accessible to a wide audience. This next generation World-Wide-Web (the WWW was in fact invented at CERN), could bring radical changes to the way computer processing and data storage is undertaken. It was created based on the need at CERN to handle the data storage and processing challenge that will come with the Large Hadron Collider (LHC), currently in construction in the area bordering France and Switzerland on the outskirts of Geneva. The LHC will be used to perform experiments on nuclear science, recreating the conditions a fraction after the creation of the universe based on the big bang theory. Annually a storage capacity of 15 Petabytes will be needed – that is a tower of 20 km height, twice the altitude where commercial aircrafts operate, if one puts the data on CDs and rack these on top of each other. In addition there is a processing need of 100,000 of today's PCs. The Grid is exactly designed to tackle this problem.

Although still at a different scale, similar challenges of processing power and data storage is experienced by the Earth Observation (EO) community, including United Nations organization and their diverse applications of remote sensing imagery (Bjorgo 2002), as more and more satellites come into orbit, making data available at very high spatial and spectral resolutions. How to store and process these data is already a problem, in particular for developing countries. As a program of the United Nations Institute for Training and Research (UNITAR), UNOSAT is contributing to bridge the digital divide by developing solutions for using EO data in developing countries with slow Internet capacity, low processing power and scarce data storage.

The ongoing development of a Grid infrastructure and acceptance as a Virtual Organization, the Grid nomenclature for an accredited player allowed to submit jobs to the Grid, permits UNOSAT, with the assistance of the GMOSS NoE, to provide EO solutions to developing countries (Moran and Mendez Lorenzo 2005).

The UNOSAT Grid currently consists of 3.5 Terrabytes of allocated storage space for testing on the CASTOR storage system and applications such as image upload, download, compression and database search is implemented (Mendez Lorenzo 2006; Sandoval 2006). Currently, UNOSAT is populating the Grid domain with various types of EO data collected during the 2004 Indian Ocean Tsunami aftermath and over 100 Landsat7 scenes covering Eastern Chad. In addition, UNOSAT plans to upload the GMOSS test case data and have GMOSS partners test the system prior to using it in developing countries also.

As an add-on to the existing UNOSAT Grid, the mobile phone easy map access SMS application, as described in the introduction, is well under development using Grid-block Java applications for accessing the Grid via portable devices. The current system allows for Global Positioning System (GPS) wireless Bluetooth

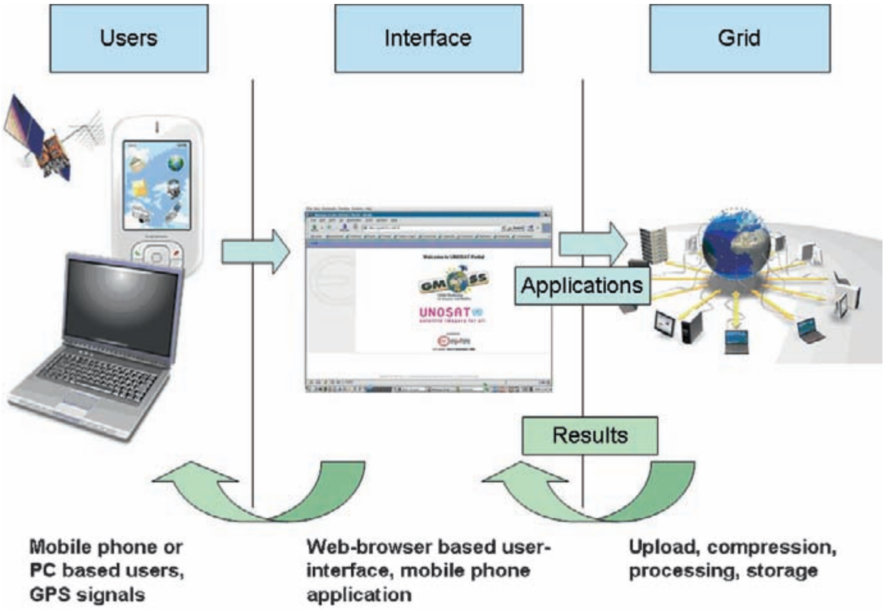

Fig. 11.1 UNOSAT Grid structure

location recording and automatic transfer to the mobile phone Grid application, which sends the collected metadata to the UNOSAT Grid, where database queries are handled and the resulting satellite maps are passed back to the users in ECW compressed image formats. Users will be ensured rapid access to information on the Grid through the Short Deadline Job (SDJ) setup to reduce latency, see Fig. 11.1 for schematics of the UNOSAT Grid structure.

When the UNOSAT Grid is fully operational, it will constitute a unique mechanism for actors involved in humanitarian assistance, early recovery and development, including local governments. There are currently no other Grid applications targeting this group of users. Hence, the humanitarian relief worker in Freetown will be provided with a user friendly (SMS) way of accessing EO based information without any background knowledge of EO database searches. More importantly, an infrastructure and service is being developed to allow developing nations to take more advantage of the use of space based tools for their own needs without worrying about computing power and storage capacity.

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Chapter 12
Treaty Monitoring

Mort Canty, Bhupendra Jasani, Iris Lingenfelder, Allan A. Nielsen, Irmgard Niemeyer, Sven Nussbaum, Jörg Schlittenhardt, Michal Shimoni, and Henning Skriver

Abstract This paper introduces several unique image processing and interpretation techniques that can be used to monitor and verify arms control treaties. It is argued in the paper that not only has there been great improvement in the spatial and temporal resolution of commercial satellite imagery providing the international community with the means to monitor arms control treaties, but also, unlike aerial observations, it is non-intrusive. The paper first looks at the development of a "key" that describes research and power reactors and conventional power plants. Secondly, with the aid of this and digital image processing, it is shown how the verification and monitoring of the NPT could be carried out. One of the image processing techniques, the multivariate alteration detection (MAD) concept is introduced, which has been developed for the purposes of multi-spectral change detection. This is then followed by descriptions of several other imaging techniques, including: detection of changes using synthetic aperture radar (SAR) images; automated object-based image analysis; and analysis of hyper-spectral imagery. Finally, the potential use of commercial satellite

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based digital images and advanced image processing techniques could be used for monitoring and verifying the Comprehensive Nuclear Test Ban Treaty (CTBT).

Keywords Treaty Monitoring • satellite imagery analysis • multivariate alteration detection (MAD) • change detection • verification • NPT • CTBT • hyperspectral imagery • digital image processing

12.1 Introduction

While more advanced satellites are being used under the aegis of National Technical Means (NTM) by some states in order to monitor bilateral and multilateral arms control treaties, information thus acquired is not generally available to the international community. Herein lies one advantage of commercial satellites. The second advantage is that not only has there been a great improvement in spatial resolution but also an improvement in the temporal resolution because of the number of countries that are now launching and operating their own satellites. The third advantage is that observations made by satellites are non-intrusive, unlike aerial observations used under the 1992 Open Skies Treaty that followed the 1990 Treaty on Conventional Armed Forces in Europe (the CFE).

The 1978 United Nations report on the Implications of the Establishment of an International Satellite Monitoring Agency stated that the minimum spatial resolution required for monitoring most multilateral arms control treaties is 0.5 m (UN 1981). Currently the best resolution of commercial remote sensing satellites is 0.5 m. With the launch of the SPOT-1 satellite (10 m resolution) many such developments were anticipated and therefore, in 1989 it was suggested that observations from space be used to monitor and study global changes in the natural environment (Jasani 1989; Aschbacher 2002). Furthermore, in 1990, it was recommended that the International Atomic Energy Agency (IAEA), use satellites to support its safeguards activities (Jasani 1990).

While remote sensing satellites hold considerable promise, there are limitations. For example, at present space-based multi- and hyper-spectral sensors are either not sufficiently developed or they are only few in number. It is often argued that data from satellites are costly. However, costs can be minimised if the acquisition of such data is rationalised. It would be more appropriate if data that cover large areas at a lower resolution were used initially to identify areas of interest before acquiring more costly higher resolution images. Moreover, as more and more countries make data available, the cost of imageries is bound to decrease. There is also the issue of shutter control that may limit the acquisition of data when required. This problem may cease to exist, as more and more states launch and operate their own satellites; it is highly unlikely that all will exercise shutter control simultaneously. Finally, there is the problem of collecting ground truth to validate image interpretation. To some extent this problem is alleviated for most treaties as now the tendency is for states to give more information to the verification agencies.

12.2 Arms Control Treaties

A number of multilateral arms control treaties, conventions and export control regimes have been concluded in order to reduce the proliferation of weapons of mass destruction (WMD). Among these are the 1970 Treaty on the Non-Proliferation of Nuclear Weapons (NPT), the 1972 Convention on the Prohibition of the Development, Production and Stockpiling of Bacteriological (Biological) and Toxin Weapons and on their Destruction (CBW), and the 1997 Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on Their Destruction (CWC). Then there are regional treaties, for example: the 1959 Antarctic Treaty, the 1967 Treaty for the Prohibition of Nuclear Weapons in Latin America (the Tlatelolco), agreements on other nuclear free zones and the 1990 CFE treaty. Moreover, there have been a number of bilateral agreements such as the 1987 Intermediate-range Nuclear Forces (INF) Treaty and the 1972 and 1979 Strategic Arms Limitation Talk Agreements (SALT), the 1991, 1993 Strategic Arms Reduction (START) Treaties and the subsequent 2002 Treaty on Strategic Offensive Reductions (Poucet 2006). Furthermore there are treaties that have been signed but are not in force yet. An example of this is the 1996 Comprehensive Nuclear Test Ban Treaty (CTBT).

Remote sensing data plays an important role in the verification process of some of the above-mentioned treaties as NTM and commercial satellite imagery in particular as the Multinational Technical Means (MTM). The use of satellite imagery as an essential part of the nuclear safeguards system of the International Atomic Energy Agency (IAEA) is a good example of MTM.

12.3 The 1970 NPT

The purpose of the NPT is to prevent the spread of nuclear weapons and weapons technology. Furthermore, the NPT supports the peaceful uses of nuclear energy under international safeguards. The treaty commits the five nuclear weapons states to achieve nuclear disarmament. A total of 189 countries are parties to the treaty, including the five nuclear-weapon states. With this number, more countries have ratified the NPT than any other arms limitation and disarmament agreement. The NPT establishes a safeguards system under the responsibility of the IAEA, which is then used to verify compliance with the NPT through inspections conducted by the IAEA.

The Integrated Safeguards Approach provides the IAEA with improved access to all aspects of a non-nuclear weapon state's nuclear programme, even where nuclear material is not involved. In order to strengthen nuclear safeguards, new verification technologies, such as the non-intrusive satellite-based commercial remote sensing are needed to gain more detailed information on the member state's nuclear programme (Cooley 2006).

Over the last few years, the usefulness of commercial satellite imagery for strengthening IAEA safeguards has been successfully demonstrated in a number of case studies that examined panchromatic, multispectral, hyperspectral and radar images (Jasani and Stein 2002). In general, the IAEA not only uses satellite image data to verify states' declarations but also in planning for on site inspections.

12.4 Digital Image Processing for Verification of Monitoring the NPT

12.4.1 Key for Research and Power Reactors and Conventional Power Plants

Figure 12.1 shows various elements of the civil and military nuclear fuel cycle. The NPT related activities can essentially be broken down into three phases:

1. Operation
2. Shut-down
3. De-commission

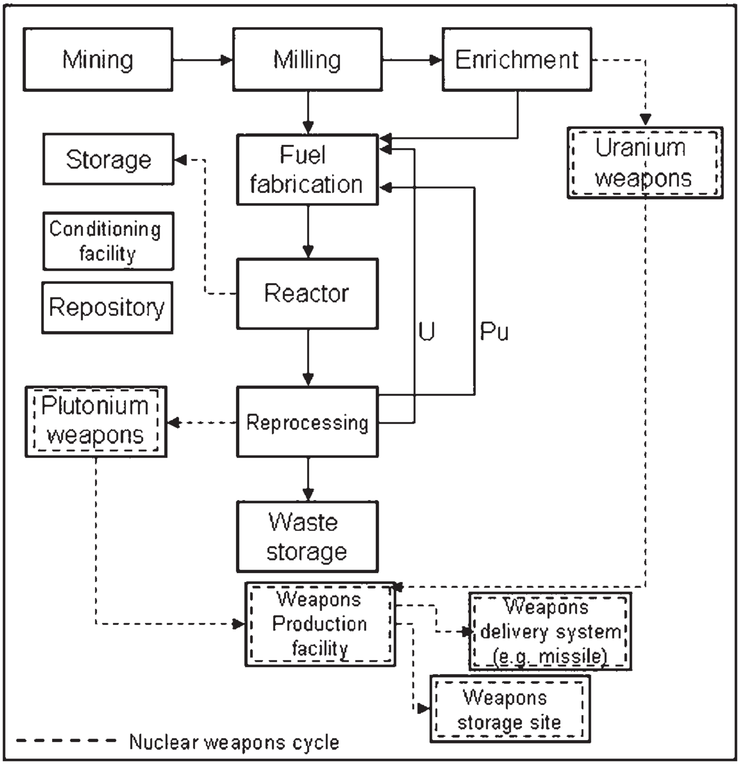

Fig. 12.1 The various elements of the civil and military nuclear fuel cycle

It would be advantageous if in the early stage, that is, at the mining phase, minerals associated with uranium could be detected so as to improve the efficiency and mode of the verification procedures. This would be made possible by using multi- and hyper-spectral sensors on board satellites. While the current state of the hyper-spectral technology may not allow the direct detection of uranium in a mining process, it may be possible to detect the type of compound being mined thus, via a process of elimination, would provide the IAEA with some form of an early warning system for their verification procedures.

For the second and third phases of the NPT, the use of a thermal sensor (in addition to the hyper-spectral sensor) would provide the agency with the means of confirming the 'shut-down' and 'de-commission' phases of the nuclear facility. This would be done by checking for thermal signatures around the facility, therefore informing the inspector about its status of operation.

12.4.2 Research Reactors

Initially within the GMOSS programme, nuclear research and power reactors and conventional power plants were examined in order to determine whether any identifiable common features are shared between them. These features could then be used as follows:

- In algorithms, developed to automatically detect facilities in a satellite image
- To see if within different types of power reactors, common features could be identified
- To efficiently verify the information provided by a Member State, thus reducing onsite inspections
- To build, for example, databases on facilities in States where on site inspections are not possible because they have not signed the NPT and/or the IAEA's safeguards agreements. This capability is important if further proliferation of nuclear weapons is to be minimised

Such reactors are used for research and training, materials testing, as neutron generators and for production of radioisotopes for medical and industrial applications. Many such systems are located within universities and research centre campuses. Typically a research reactor produces power in the range between 10 MW (th) and 100 MW (th) compared with the 3,000 MW (th) (or 1,000 MW(e)) generally produced in a nuclear power plant.

The following key features for neutron production research reactors could be concluded:

- They are rectangular measuring about 40 × 40 m.
- If the reactor is a PWR, then the building is cylindrical with a dome-shaped roof of about 10 m diameter that is much smaller than that used for a PWR power reactor.

- Contiguous to the reactor is a long neutron guide hall measuring 30 × 50 m.
- The reactor also has mechanical draft cooling towers measuring approximately 30 × 30 m.
- An exhaust stack is associated with research reactors.
- They have a perimeter fence; and
- A research reactor that is used for training purposes and to investigate materials does not have a large, long hall to accommodate neutron-related experiments.
- These features are confirmed in an image acquired by the US QuickBird satellite over the Iranian reactor in Tehran, located at 35° 44’21”N, 51° 23’19.4” E. The image is shown in Fig. 12.2.

Although, the key features for research reactors were identified earlier, it is important to be aware that it is still possible for the diameters of the reactors to vary. This is demonstrated in Fig. 12.2, where the diameter of the 5 MW research reactor is 30 m rather than the expected 10 m. All research reactors that were analysed during this study were located in Germany. Therefore, if there is a discrepancy in terms

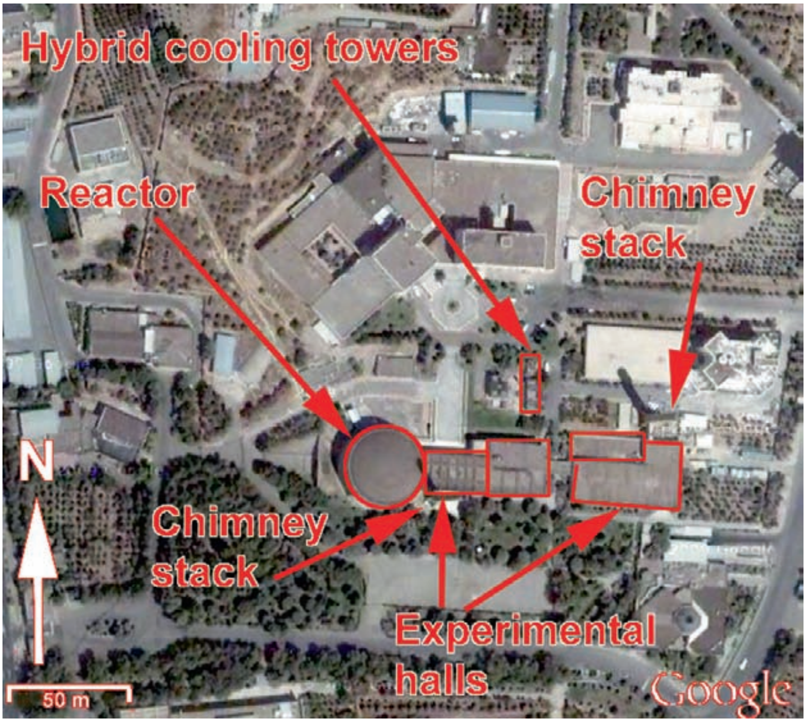

Fig. 12.2 Close up Digital Globe image identifying key signatures of the Tehran research reactor. The diameter of the 5 MW reactor is about 30 m and the sizes of the experimental halls are about 50 × 30 m (middle hall) and about 40 × 30 m (the end hall) (Digital Globe/Google Earth)

of the diameter of the reactor, this is due to the different levels of advancement of the technology itself. Specifically, when looking at Fig. 12.2, the 30 m-diameter reactor displayed within the image provides 5 MW of power, compared to the 10–100 MW (th) range of power provided by the 10 m diameter German reactors. Therefore, the technology of the research reactor in Iran is not as advanced as that currently present in Germany. By keeping this particular limitation in mind, the key provides an efficient and beneficial means of monitoring the NPT via the use of commercial observation satellites.

12.4.3 Power Reactors

The study of power reactors found the following key features that were identified for a PWR:

- The reactor core, pressurised-water, primary coolant system and the steam generator are housed in a cylindrical containment building, the top of which is a hemispherical dome
- The diameter of the dome and hence the cylindrical containment building is about 60 m
- Close to the reactor are a number of rectangular buildings housing, for example, the reactor control system, spent fuel storage pool and the turbine generator system
- The size of, for example, turbine and electricity generator building is about 50 x 90 m
- Excess heat is carried away to the environment by either high (~150 m) cooling towers (base diameter of 120 m) or by very short cylindrical ones (base diameter 160 m and diameter of the top of the short tower 70 m) or rectangular (190 x 30 m) cooling towers
- Reactors are generally located either closer to a sea, river or lake; and
- The civil PWRs examined did not have fuel-reprocessing plants in the reactor complex

These features are confirmed in Fig. 12.3, which was acquired by the US QuickBird satellite over the German Emsland nuclear pressure water reactor (PWR) power plant.

From the study of a number of images of boiling water reactors (BWRs) the following important characteristics could be identified:

- The reactor core, primary coolant system and the steam generator are housed in two rectangular containment buildings
- The size of the outer containment building, on average, is 35 × 45 m
- As in the case of the PWRs, close to the BWRs is the reactor control system, spent fuel storage pool and the turbine generator system all of which are housed in rectangular buildings

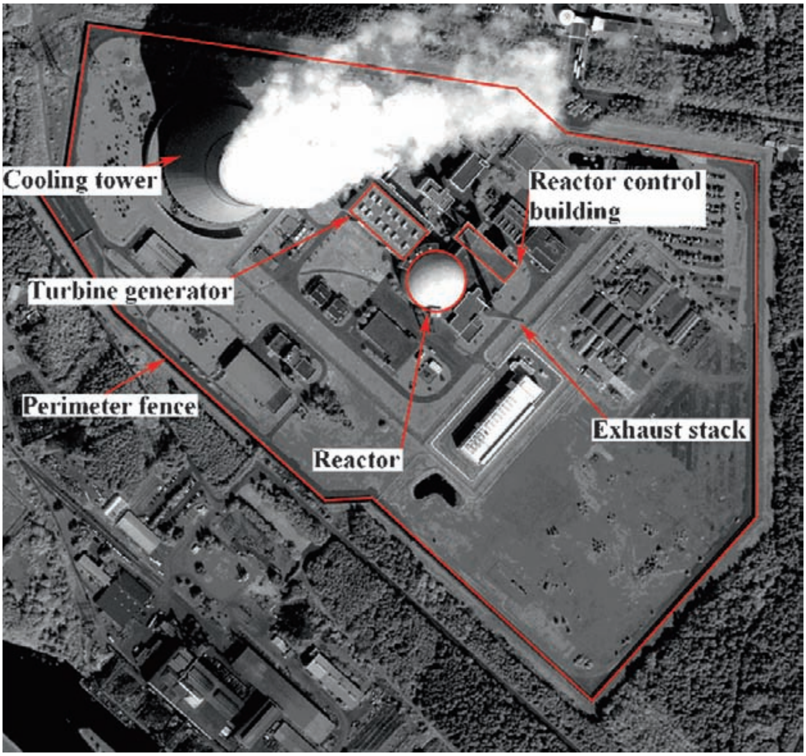

Fig. 12.3 Emsland PWR with some of the features identified. Scale 1:6,900 (Digital Globe)

- The size of, for example, turbine and electricity generator building is about 40 × 75 m
- Excess heat is carried away to the environment by discharging warm water into either a sea, lake or a river generally located near the reactor complex or via cooling towers and
- Civil BWRs examined also did not have fuel-reprocessing plants in the reactor complex

12.4.4 Conventional Power Station

Some of the following characteristics can be summarised:

- Fossil fuel is stored outside at the site of a plant as heaps of coal or gas and oil cylindrical (about 60 m diameter) containers
- Gas cylinders can vary in height depending on the amount of gas present
- Unlike in the case of nuclear reactors, gas and oil containers are well separated from the power generator buildings

- Coal fuel plants have extensive conveyor belt systems and railway lines to transport coal to the power plants and
- Exhaust stacks are either built on top of the generator buildings or near them as in the case of nuclear reactors

These features are confirmed in an image in Fig. 12.4 acquired by the US QuickBird satellite over the German Emsland conventional fossil fuel plant.

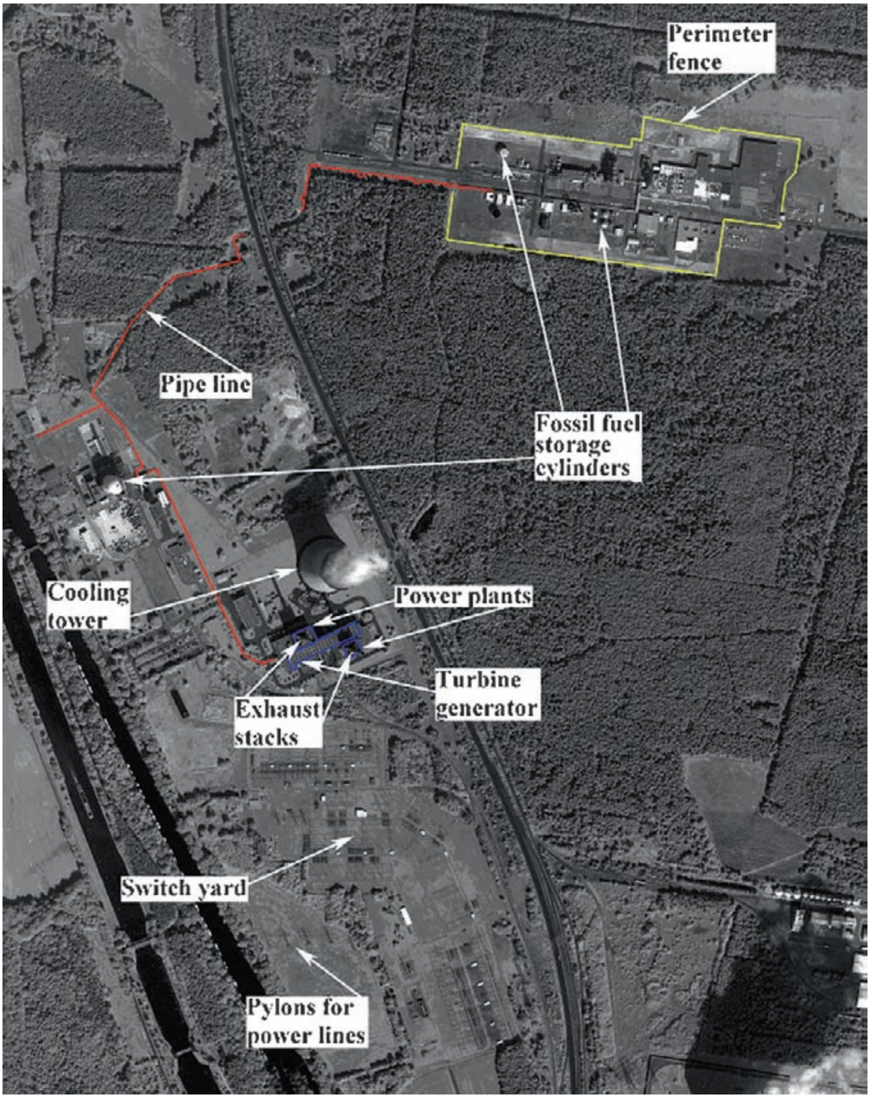

Fig. 12.4 The Emsland conventional power plant near Lingen photographed by the US QuickBird satellite (resolution 0.61 m) on 26 June 2003. Several fuel tanks can be seen in the top right of image. Other features such as the pylons are also identified in the satellite image. Scale 1:11,500 (Digital Globe)

The above key was then used to test the ability of eCognition technology to automatically recognise objects in a satellite image. The current limitation is that image objects that result from one segmentation level do not always represent objects of interest especially of different scales. Here an automated approach for iterative segmentation is currently tested and looks very promising.

12.4.5 Multispectral Change Detection

Much of the emphasis within GMOSS has been upon development and improvement of change detection methods for visible/infrared multispectral satellite imagery. For intermediate resolution platforms such as LANDSAT TM, ASTER or SPOT, a pixel-based approach to change detection has proven to be advantageous.

The basis for change detection is the multivariate alteration detection (MAD) transformation developed by Nielsen et al. (1998), and Nielsen (2007). After matching images of a scene taken at two different times and correcting for atmospheric distortions, a simple and commonly applied procedure to see changes is to subtract one from the other component-by-component. Large positive or negative differences in pixel intensities indicate changes in ground reflectance. However, there is a better way to proceed.

Suppose we make a linear combination of the intensities for all spectral channels in the first image, that is to say, we create a single image whose pixel intensities are the weighted sums of the pixel intensities in the individual components. We do the same with the image components for the later time and the look at the difference between these two images.

The advantage of this procedure is that it combines all the information into a single image, and one is free to choose the weight coefficients in any suitable way. The choice adopted in our investigation was first suggested by Nielsen et al. (1998). The coefficients are chosen so that the statistical correlation between the combined images is minimized, subject to the condition that both combined images have equal variances. This means, in effect, that the resulting differenced image will show maximum spread in its pixel intensities. If we assume that the spread is primarily due to actual changes that have taken place in the scene over the time interval between image acquisitions, then this method will enhance those changes as much as possible. The method will be sensitive to any changes in the reflectance of the earth's surface on the scale of the spatial resolution that occur within the range of wavelengths spanned.

Minimizing the mutual correlation between two digital images is a standard statistical procedure, which in fact returns not just a single set of appropriate weight coefficients but as many sets as there are original spectral channels, each corresponding to a unique differenced image.

The first difference has, as already mentioned, maximum spread in its pixel intensities and, ideally, maximum change information. However, depending on the type of change one is looking for, the other differenced images may also be relevant. The second image has maximum spread subject to the condition that the pixel intensities are statistically uncorrelated with those in the first image, and so on. Since interesting man-made changes will generally not be related to dominating seasonal vegetation changes or stochastic image noise, it is quite common that such changes will be concentrated in higher order differences. This in fact is one of the nicest aspects of the method: It sorts different categories of change into different pictures. As an example, Fig. 12.5 shows a change image for the Saghand uranium mining area in the Iranian highlands.

An additional advantage of the MAD procedure stems from the fact that the calculations involved are invariant under linear transformations of the original pixel intensities. This implies that the method is quite insensitive to differences in atmospheric conditions or sensor calibrations at the two acquisition times (Nielsen et al. 1998) and indeed, can be used for automatic relative radiometric normalization of multitemporal images (Canty et al. 2004).

The MAD algorithm, including a recent iterative extension to make the method even more powerful, has been integrated into the COTS environment ENVI, which is widely used within the remote sensing community, see Canty (2006).

MatLab routines are also available (http://www2.imm.dtu.dk/~aa/software.html). Pre-processing algorithms for fusion and panchromatic sharpening involving

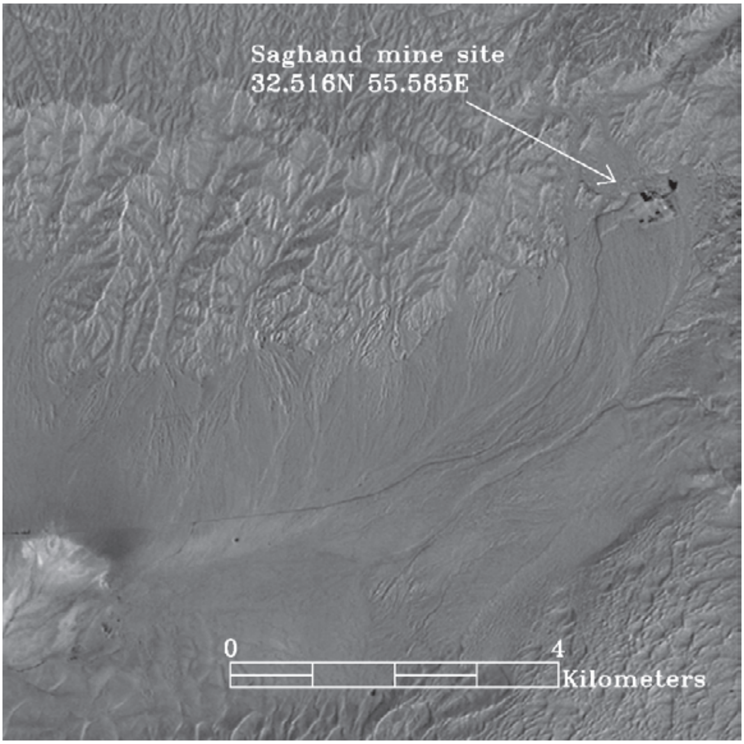

Fig. 12.5 MAD change detection result using ASTER imagery over the Saghand uranium mining area in Iran

various flavours of the discrete wavelet transformation, as well as feature matching procedures for automatic image registration have been taken from the recent literature and implemented in easy-to-use program modules. In addition a method for unsupervised classification of the MAD change images based upon the Expectation Maximization algorithm (Redner and Walker 1984) and multiresolution analysis (Mallat 1989) has been developed to facilitate interpretation of significant changes (Canty and Nielsen 2006).

These modules, together with post-processing routines for change interpretation, also extend the ENVI environment and constitute one of the GMOSS deliverables (Canty 2006).

12.4.6 Detection of Changes Using Synthetic Aperture Radar (SAR) Images

The imaging technique used by a synthetic aperture radar (SAR) is fundamentally different from the acquisition techniques used by the optical and infrared passive sensors discussed previously. First of all, the SAR uses an active technique. That is to say, it transmits an electromagnetic wave, and receives reflected signals from objects on the ground. Secondly, the microwave part of the electromagnetic spectrum is used. Finally, a slanting geometry is employed for the acquisition. This results in radar images that are sensitive to man-made targets, like buildings, poles, and fences, but also to moisture in soil and vegetation. The background for using SAR images in connection with the Treaty on the Non-Proliferation of Nuclear Weapons is the ability to detect changes in man-made structures, and they are hence expected to be able to monitor sensitive areas to detect changes independent of cloud cover and daylight.

An example of such change detection is shown in Fig. 12.6, where two Radarsat images from 2002 and 2003, respectively, over the nuclear test facility in Esfahan have been used to detect changes. One Radarsat image over the test facility is shown in Fig. 12.6a. A special type of inherent noise, called speckle noise, corrupts SAR images and hence a special change detection technique is required. Filtering must first reduce the speckle, and afterwards a ratio of the filtered SAR images is formed. Here the ratio is used instead of the difference, due to the statistics of the speckle noise. In Fig. 12.6d a thresholded ratio image is shown, where a threshold has been selected that only allows very strong changes. The changes marked A and B in Fig. 12.6d correspond to the changes illustrated by the pairs of QuickBird images shown in Figs. 12.6b and 12.6c and Figs. 12.6e and 12.6f, respectively. It is clear that dramatic changes have taken place, and that these changes have been detected by the SAR. However, a number of other changes have also been detected as seen in Fig. 12.6d where no changes can be identified in the corresponding QuickBird images. It is clear that further research is needed to verify the change detection capabilities of satellite SARs for this application, and the future polarimetric SARs may help in the process.

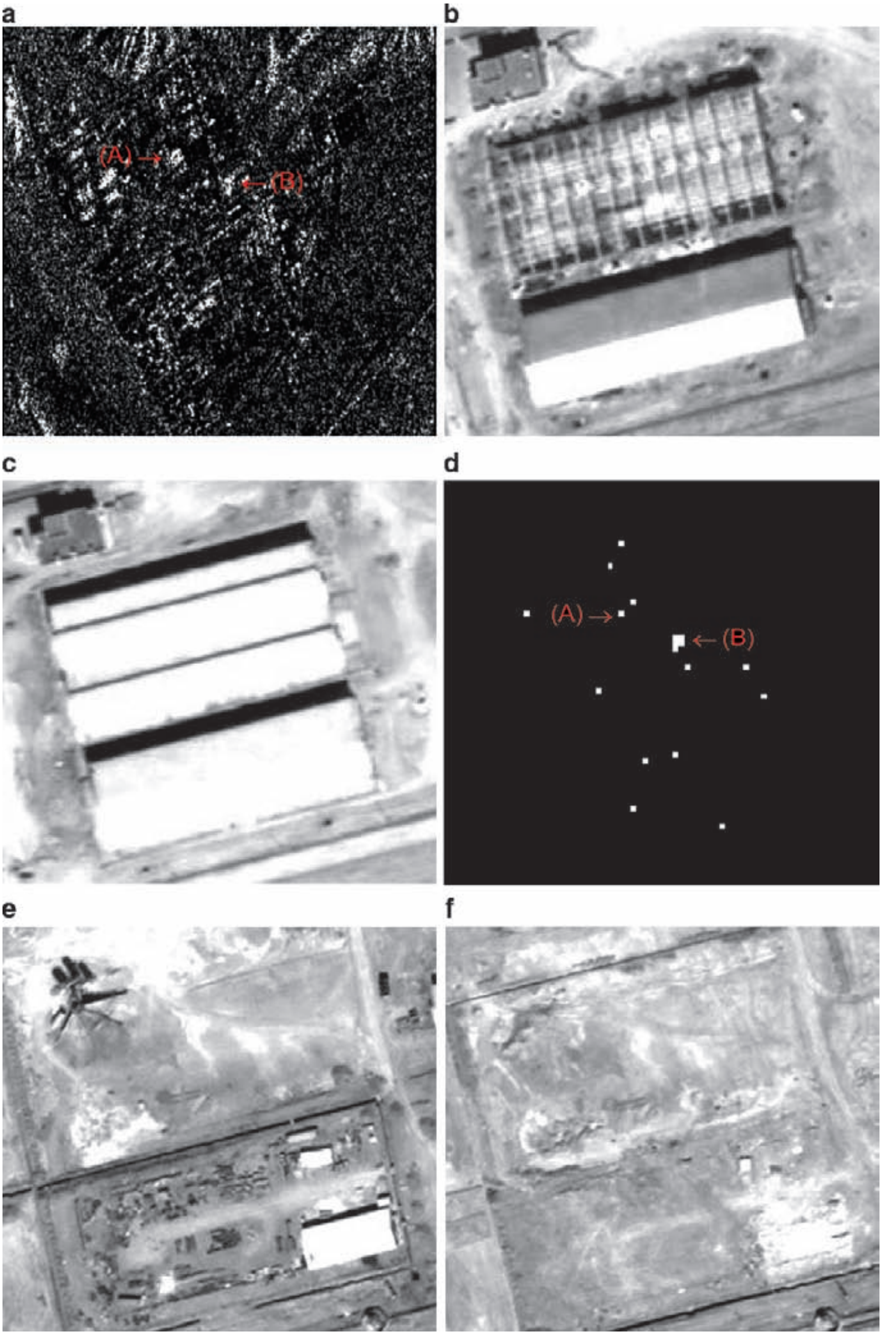

Fig. 12.6 Change detection by SAR: (a) Radarsat image over the Esfahan nuclear site, (d) changes detected between two acquisitions in 2002 and 2003, respectively, (b) and (c) changes observed in QuickBird images from 2002 and 2003 corresponding to A in (d), and (e) and (f) changes observed in QuickBird images from 2002 and 2003 corresponding to B in (d)

12.4.7 Automated Object-Based Image Analysis

When adapted to high-resolution imagery, the traditional pixel-based image processing algorithms are sometimes limited. Especially if small structural objects are to be detected, object-based procedures have promises. In comparison to the purely spectral-based features used within the pixel-based approaches, the inclusion of features such as the size or orientation of an object, its shape or texture and its relations to other objects on the same or at different scales, considerably extends the possibilities for image analysis. Computer driven, object-based image analysis is in a first approximation comparable to visual perception. An image interpreter recognizes, along with the colour of an image, also the shapes, textures and coherent regions present within it, and associates meaningful objects and their contextual relations. A similar goal is striven toward in object-based image analysis, although the complexity and effectiveness of human perception is of course, still far from being achieved. The extraction of the objects is carried out by segmenting the pre-processed images and the resulting object primitives should ideally represent the real world objects.

The object's feature analysis provides the basis for the preparation of a rule-based classification model. Generally, a semantic class can be described by its characteristic features and their distribution in the feature space. Using an object-based approach to analyse an image, there are many possible features to take into consideration in order to describe the object classes of interest. Therefore it is necessary to determine the prominent features for each object class for the succeeding image analysis. The feature analysing tool SEaTH (*SEparability* and *THresholds*), introduced by Nussbaum et al. (2005), identifies these characteristic features with a statistical approach based on training objects. These training objects represent a small subset of the total amount of image objects and should be representative objects for each object class. The statistical measure for determining the representative features for each object class is the pair wise separability of the object classes among each other. Subsequently, SEaTH calculates the threshold, which allows for the maximum separability in the chosen features.

A QuickBird scene acquired over the Esfahan Nuclear Fuel Research and Production Centre (NFRPC) in July 2002 provided the basis for automatic feature extraction for the classification model. After extracting the object primitives by the so-called Multi-resolution Segmentation provided with the eCognition software, the optimal object features and the range of their membership functions were automatically determined by the SEaTH procedure for the classes "building development", "walls", "shadows", "streets" and "vegetation". An overall accuracy of approximate 90% was achieved, depending on the respective segmentation level (Fig. 12.7, left).

In order to check the temporal transferability the 2002 classification model was then applied to another image acquired over the Esfahan Nuclear Fuel Research and Production Centre (NFRPC) in July 2003. After minor changes of the 2002 model in reference to one single feature, an overall accuracy of approximate 88% was obtained (Fig. 12.7, right).

Finally, the possibilities to automate change detection and analysis procedures using high-resolution image data were examined. For this purpose a combination of pixel-based techniques for the detection of change pixels and object-oriented pro-

Fig. 12.7 Object-oriented classification of the 2002 (left) and 2003 (right) QuickBird images over Esfahan Nuclear Fuel Research and Production Centre (NFRPC)

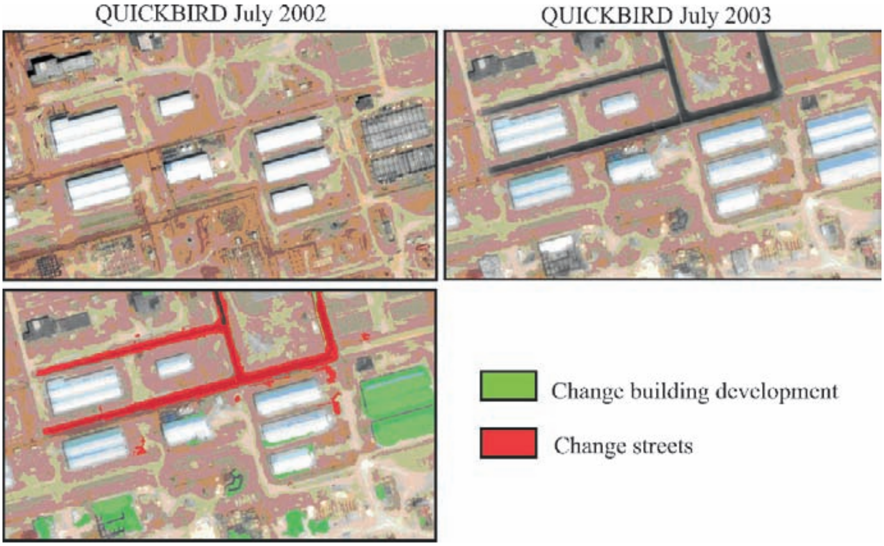

Fig. 12.8 Change analysis 2002–2003 for parts of the Esfahan Nuclear Fuel Research and Production Centre (NFRPC) with respect to two types of man-made structure changes

cedures for post-classifying the change pixels was proposed. Given a subset of the 2002 and 2003 QuickBird images over the Esfahan NFRPC, the MAD transformation explained previously, was carried out in order to find the change degree for each pixel. The change information was then included as part of the semantic classification model in the eCognition software, along with other object and class features and the correlation between MAD components and original image data. Figure 12.8

shows the result of a classification for two types of man-made structure changes between July 2002 and 2003: the completion of buildings and roads.

12.4.8 Analysis of Hyperspectral Satellite Imagery

Mine wastes are difficult to hide, especially when mining low-grade ore, as is often the case with uranium mining where the amount of waste is large compared to the amount of economic mineral extracted.

The radiological activity emanating from uranium mine tailings can be best assessed using airborne gamma ray spectrometry. However, it is not feasible to use these sensors on board a satellite platform due to the strong atmospheric absorption of the gamma radiation. A study is currently being carried out to identify spectral signatures, in the 400–2,500 nm range, of mineral compounds in the mine tailings that are associated with uranium mining. It is thought that the surface mineralogy of exposed uranium tailings can be determined using hyperspectral remote sensing, which provides many contiguous narrow spectral bands that allow spectral discrimination and identification of various minerals (Neville et al. 2001). The objective of this study is to investigate the potential of EO-1 Hyperion data for the identification of uranium mine tailings and distinguish them from other types of mine tailings. More specifically, the objective is to determine if uranium mine tailings include spectrally distinct mineral compounds that could help distinguish them from mine tailings of other sources.

At the second level of consideration, the hyperspectral satellite image should provide better understanding of the uranium core activities: type of ore, industrial activities in the area (e.g. purifying and/or separation of uranium or copper) and ore volume.

Processing of the Hyperion data includes atmospheric corrections, end-member extraction and identification, constrained linear spectral unmixing, mixture tune matched filtering (MTMF) and the production of an abundance map of each end member.

Ideally, imaging spectrometer data should be calibrated to absolute reflectance using onboard calibration. Onboard calibration however, is difficult and typically not available. The atmospheric correction of the Hyperion data was realized using ATCOR code, and its efficacy was initially assessed through successful recognition of green vegetation spectral signatures along creeks (Fig. 12.10). The overall shape, including the characteristic NIR plateau between 700 and 1,300 nm, as well as absorption bands related to chlorophyll (675 nm) and leaf water (980, 1190, 1450 nm) are clearly evident in the reduced Hyperion data.

At the present the stage of the image processing of the research work is as follows:

- Atmospheric corrected Hyperion
- Suppression of noise and reduction of dimensionality of the data cube using the Minimum Noise Fraction (MNF) transformation

Fig. 12.9 Hyperion scene Saghand uranium mine, Iran (04-02-2003)

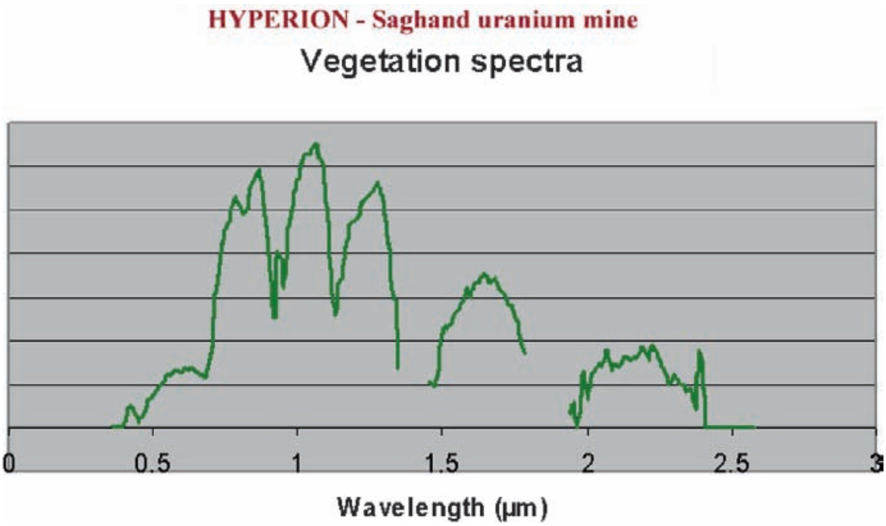

Fig. 12.10 Hyperion vegetation spectra after atmospheric correction

- Selection of the significant bands
- Selection of significant spectra

Future work will be focused on the:

- Identification of end member spectra using visual inspection, automated identification, and spectral library comparisons
- Production of mineral maps using a variety of mapping methods

12.5 Comprehensive Nuclear Test Ban Treaty (CTBT)

The Comprehensive Nuclear Test Ban Treaty has the objective to prevent any nuclear weapon test explosion and thus to constrain the development and qualitative improvement of nuclear weapons. Today, 180 of the 194 States have signed the treaty and 148 have also ratified it (Februry 2009). However, the Treaty will only enter into force after it has been ratified by the 44 Member States listed in its Annex 2: up to now, only 41 have signed and 35 have ratified. Once the treaty has become effective, the Comprehensive Test Ban Treaty Organisation (CTBTO) will become operational. The global verification regime consists of an International Monitoring System (IMS), Consultation and Clarification between Members, On-Site Inspections and Confidence Building Measures.

Though satellite imagery is not explicitly listed as a monitoring technique, it can nevertheless provide essential information, such as the location of underground nuclear explosions. Not only this, but satellites can also provide information on whether a state party is preparing for a nuclear test (Jasani 1994). This capability is extremely important if, by persuasion, a state party could be prevented from carrying out a test thus avoiding the proliferation of nuclear weapons (For example, the potential nuclear test that could have taken place in the Kalahari Desert, South Africa in 1977).

12.6 Digital Image Processing for CTBTO Monitoring

The protocol to the CTBT describes altogether four monitoring techniques (seismological, radionuclide, hydroacoustic and infrasound networks) that comprise the International Monitoring System (IMS). Although satellite imagery analysis is not an element of the IMS it can provide, especially in combination with seismology, important information for the verification regime foreseen in the treaty (see Canty and Schlittenhardt 2001). The request for an on-site inspection, which according to the treaty is within the responsibility of state parties, shall be based on information collected by the IMS or on any relevant technical information obtained by national technical means of verification. Hence, alone or in combination with the techniques established in the treaty, satellite image analysis is a valid means to supplement the CTBT verification regime. For GMOSS, with the aid of test cases, different possibilities of using digital satellite image analysis techniques in combination with seismic detection and localization are investigated for their use in supplementing verification measures provided by the IMS. Up to now, mainly multispectral data (Landsat, Aster) of underground nuclear tests in India and on the United States' test site in Nevada (NTS) were investigated using the MAD change detection procedure (Canty et al. 2005). Figure 12.11, shows a change image for the Pahute Mesa area of the Nevada Nuclear Test Site determined from LANDSAT TM images acquired on May 6, 1984 and May 26, 1991. (The horizontal feature in the centre of the image is due to an instrument error in the 1984 data).

All underground tests which took place after the first acquisition are indicated and are seen to be associated with change signals arising from surface preparation activities.

A comparison of the change detection signals computed from satellite image data over the NTS of historical underground explosions with seismic data (origin time, location, yield and depth of burial) and associated phenomenological data of the explosions (e.g. crater depth and diameter) were carried out. It turned out that the detection of changes corresponding to subsidence crater formation at the Pahute Mesa sub-test site were possible, in general (with one exception) but difficult at the 30 m ground resolution. In contrast, changes associated with test site preparations at ground zero are easily discriminated and well-correlated with the seismic reference data. Hence, the discovery of suspicious preparation activities may give evidence for planned future tests and, in connection with a recorded seismic signal generated by the explosion, may contribute to its identification and improved localization. This result underlines the value of the synergy effects of interlinked satellite based

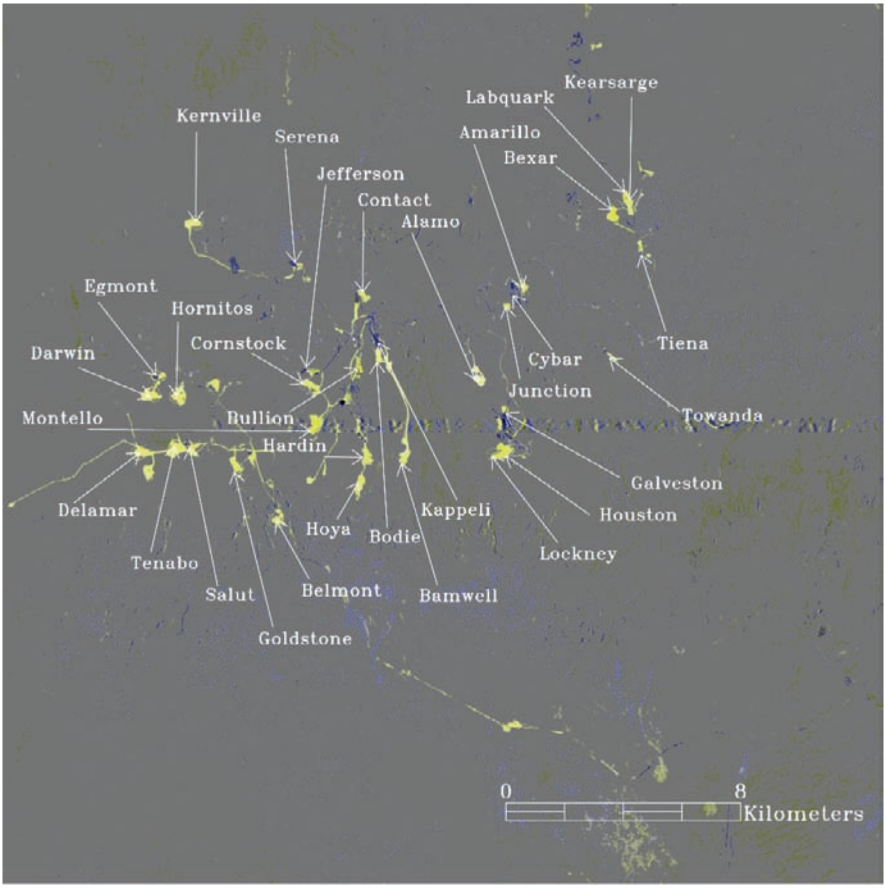

Fig. 12.11 Change image for the Pahute Mesa area of the Nevada Nuclear Test Site determined from LANDSAT TM images acquired on May 6, 1984 and May 26, 1991

and seismic analysis for the initiation and direction of on-site inspections for further investigations at the test site by the CTBTO.

12.7 Conclusions and Outlook

The six consortium institutions grouped under GMOSS WP 20400 have been cooperating extremely intensively with each other throughout the present lifetime of the GMOSS network. Their achievements in the application of remote sensing to the problems of monitoring for international security, and especially treaty monitoring, have been documented in a large number of publications covering work completed in that period and many of these have been outlined above. The most recent methods and tools developed have been explained at a summer school for students and at a training seminar to image analysts.

Interesting continuations of the work, for example the use of INSAR for underground test detection, hyperspectral data for monitoring uranium mining activities, or polarimetric radar data for statistical change detection are now appearing and will involve integration with institutions from work packages within the Consortium.

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Chapter 13
Early Warnings and Alerts

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Abstract Several satellite observations, mainly made in the optical part of the electromagnetic spectrum and with different spatial/temporal resolutions, have proved to be useful for providing early indications or rapid alerts about events (e.g. conflict, unrest) that might pose a risk not only to civilian populations but also to regional security. In particular, meteorological satellites, which have a low spatial resolution but a high (up to 6 hours for NOAA-AVHRR) or very high (up to 15 minutes for MSG-SEVIRI) time repetition rate, have shown new potentials in the field of security-related applications as soon as suitable algorithms (like the Robust Satellite Technique - RST) are applied to the observations they provide in the optical range. RST demonstrated indeed both robustness (minimizing the proliferation of false alarms) and sensitivity (detecting even low intensity changes of the observed signal) in the identification of thermal anomalies related to potentially dangerous events.

In the context of early warnings, the detection capabilities of SEVIRI channels were successfully tested, for example, in the case of numerous terrorist attacks to Iraqi pipelines and to other, rapidly evolving phenomena, related to security issues, such as terrorist bombings of buildings or oil spills caused by pipeline sabotages. The timely detection of such thermal anomalies may be used to give an early/rapid warning of possible accidents, providing a support to the decision-makers. Integration with observations at a medium (Landsat) or high (Quickbird) spatial resolution (when achievable) could surely help in order to better define the exact nature of events timely detected (but not very precisely located) by meteorological

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satellites. Even if the very long revisiting time of high spatial resolution sensors prevents them from capturing dangerous events which are characterized by rapid temporal dynamics, they turn out to be very useful in detecting less rapidly evolving (but not less important for security related purposes) events (like troop-build-ups and/or population movements at borders) as well as other long term signs of impending conflict related to MDW accumulation or new nuclear plants installations.

Keywords Robust satellite techniques • early warning • sabotage • pipelines • oil spills • nuclear plants • MDW

13.1 Introduction

Generally, by "security" it is meant that a group of people or a State is secure from either man-made disasters (such as conflicts) and/or natural disasters such as earthquakes, floods or fires. If such events could be predicted, or even detected early, increased stability within a State and in international relations could be achieved and maintained. Commercial remote sensing satellites could play an important role in this process.

Timely information is required in order to prevent or mitigate the risk posed to the civilian population by the occurrence of events that affect their security. Depending on the temporal dynamics of the event to be monitored different satellite observational techniques can be used. As such events develop over a period of months or even years, a timely detection can be achieved by using satellites that, despite their long (from weeks to months) revisiting cycle, can offer very detailed (spatial resolution of 0.61 m) information. Unexpected or rapidly (from few minutes to few days) developing events could also be detected in time (but with low spatial resolution) using meteorological satellites. It is important to note that meteorological satellites are the only ones offering a suitable time-repetition (from few hours to few minutes).

Together with their obvious advantages, both choices have limitations, which can be partly overcome provided that suitable data analysis techniques are used. Spatial resolution from 1 to 3 km offered by meteorological satellites packages, like NOAA/AVHRR, EOS/MODIS (on polar platforms) or MSG/SEVIRI and GOES (geostationary), do not prevent the detection of interesting events over small ($<100\,\mathrm{m}^2$) portions of the Earth's surface. In some cases (e.g. detection of hot spots related to events like explosions, fires, etc., with temperatures above 800°C, using MIR observations) a low spatial resolution is itself an advantage limiting the probability of sensor saturation. On the other hand, the possibility of temporarily increasing the revisiting cycle of very high spatial resolution (VHSR) satellite packages, by remotely operating a change in their optical axe, can fruitfully integrate products achieved by meteorological satellites (by giving details on the area previously identified as affected by a security event) provided that suitable methods are used to manage and compare images which are collected out of the usual view angles. Most of the required data analysis methods are already available as they are already being used in applications for environmental, natural and technological hazard monitoring and mitigation. The GMOSS context poses new challenges and requirements, which solicit algorithm improvements and full exploitation of data integration.

In this chapter the potential of the above mentioned techniques will be discussed giving specific examples on their application to security events that have occurred in the past, and also more recently in Iraq, Kuwait and Egypt. At this stage, the potential employment of VHSR satellite techniques to provide early warning of relatively slowly developing security risks will be described in parallel with the use of one of the meteorological satellites for early/rapid alert of security events. Information on integration issues will be described in the second volume of this book.

13.2 Early/Rapid Alert for Security

During humanitarian crises – whether they involve rescuing people trapped in rubble or providing food to refugees – speed is essential. As a rule of thumb, relief has to be provided within 72 h. In recognition of this, the European Union's Humanitarian Office, ECHO, is used to speed up the decision-making procedures (primary emergency decisions) that enable it to fund projects within 24–72 h after a sudden disaster. The procedure was formally adopted in June 2001 and has been successfully implemented in many countries affected by conflicts and/or disasters, both natural and man-made, all over the World: the Peru earthquake, the Algeria flooding, the cyclone in Belize, the recent Afghanistan crises, the SE Asian tsunami and the Pakistan earthquake are only a few examples of the disasters where ECHO has intervened. Within the framework of early warnings, there are two main requirements for systems:

1. Abrupt changes of Earth's thermal emission, related to nuclear experiment, accident in nuclear plants, oil well fires, refugee bonfires, terrorist explosions, etc., could be observed by satellites that have very short revisiting times. However, it is essential that the methodologies, which are employed to detect these changes, are robust enough to avoid false alarms. For example, a natural occasional warming (e.g. due to a particular meteorological condition) gives thermal signal variations as intense as some man-made events.
2. A rapid detection of dramatic (both natural and man-made) events can be decisive to produce a rapid (and more effective) rescue operation of citizen protection organizations. In other cases, a rapid alert that something has happened can represent an early warning for impending events when a first event can entail a consequent action in the short term (e.g. sabotage of infrastructures can incite an immediate counter-offensive) or in the long-term (e.g. a natural disaster can initiate mass movements of, for example, people, towards neighbouring countries where instability can slowly rise).

Integration with other information sources (that are dynamically updated such as meteorological analyses and forecast, or more static such as population density) could help to better evaluate the origin, dimension and possible impact of the observed event. It is clear that confidence in the occurrence of an event improves as we move closer towards it. However, it is also obvious that we cannot wait to discover the exact scale of a disaster before taking action. Resources must be put on stand-by or mobilized. Therefore, it is important that the accuracy of the warnings improve as well as the speed with which information on the ground can reach those responsible for mounting relief operations, whilst keeping the false alarm rate under control.

13.3 Short/Medium Term Early Warnings of Security Events

Many examples can be found with regards to improve the security of populations relating to both natural and man-made events. A common example is represented by a flood warning system where the combined study of different parameters (meteorological, geomorphologic, hydro-geological, etc.), computed by integrating satellite information and in-situ observations, can provide the indication of a possible risk to the local population. For instance, after a long rainy period which determines soil saturation, a downstream flood becomes inevitable if intense rain is foreseen (Lacava et al. 2005a, b). Concerning man-made events, the capability of surveillance by satellites enhances the possibility of conflict prevention by keeping a close watch on potential threats and identifying humanitarian crises in their early stages. For example, build-up of weapons on a country's border or violent demonstrations in the streets might be an indication of an impending conflict.

13.4 Satellites Observations for Early Warnings and Alerts Within GMOSS

A number of different satellite-based observation techniques (mainly passive optical, with different spatial and temporal resolutions) have been proved to be useful for providing early indications or rapid alerts of events (e.g. conflict, unrest) that might pose a risk not only to civilian populations but also to regional security. Two main levels of observations may be considered in order to satisfy the above-mentioned requirements:

- Low spatial resolution and high or very high temporal resolution to give an early/rapid warning and/or a real-time monitoring of events potentially dangerous for the civilian population in order to give support to the decision-makers that are devoted to mitigating the resultant effects
- Use of high or very high spatial resolution imagery, but relatively low time repetition to detect troop-build-ups and/or population movements at borders as well as other signs of impending conflict

13.5 Satellite Observations at High (NOAA-AVHRR Data) or Very High (MSG-SEVIRI Data) Temporal Resolution: the RST Approach

High temporal resolution satellites that are usually employed for meteorological/climatological purposes, have demonstrated a new potential. Besides the traditional (well known and widely used) satellite sensors like AVHRR, aboard polar NOAA platforms, new generation instruments like SEVIRI (Spinning Enhanced Visible and Infrared Imager), the imager on the Meteosat Second Generation (MSG) platform, are finding unexpected applications in areas such as security-related issues.

Within the GMOSS project, the high repetition rates of MSG-SEVIRI have shown their potential in acquiring near real-time information on acts such as terrorist attacks on different kinds of infrastructure (e.g. residential buildings, pipelines, etc.). In the context of early/first warning applications, the detection capability of Visible (HRV, High Resolution Visible), Medium Infra-Red, MIR (3.9 µm), and Thermal Infra-Red, TIR (10.8 µm), channels of SEVIRI was clearly demonstrated, for example, during the numerous terrorist attacks on Iraq's pipelines. Figure 13.1 shows SEVIRI images acquired in the visible, MIR and TIR of the electromagnetic spectrum, respectively. They show that a pipeline blast occurred on 4 July 2004. It is evident that in spite of its relatively coarse (1 km VIS, 3 km MIR-TIR) spatial resolution, signal variations due to the presence of oil fire and smoke (Lat = 35° 4′ 48″ N, Long = 43° 32′ 23″ E) are clearly detectable. Moreover, it is worth noting that some SEVIRI channels permit us to monitor the plume only (see Fig. 13.1a and Fig. 13.1c), while other channels allow us to detect the "hot spot" which generates the plume (brighter pixels within the zoom in Fig. 13.1b).

In any case, SEVIRI not only enables the immediate detection of the event, but also allows one to follow the evolution of the fire/smoke at 15 min intervals. The SEVIRI image sequence that is presented in Fig. 13.2, using a 3.9 µm channel, shows a burst pipeline. The first indications and concerns were raised in connection to a sabotage episode along a known pipeline near Bayji on 22 June 2005. Even without any particular satellite image processing, the hotspot (corresponding to the oil fire) and the smoke are clearly evident. The same sequence allows us to appreciate the time persistence of the fire as well as the growing extension of the smoke cloud.

In other circumstances, SEVIRI high temporal resolution needs to be coupled with a robust data analysis system in order to guarantee the detection of anomalous TIR signal transients (related to man-made actions) in satellite images. The use of the RST, proposed by Tramutoli (1998, 2005), permits us to identify anomalous space–time signal transients related to actual hazardous events automatically, distinguishing them from signal occurrences of similar intensity but originated by the natural space–time variability of land coverage and/or atmospheric conditions (see, for instance, the circle in Fig. 13.1c).

The RST technique is based on a preliminary multi-temporal analysis technique performed over several years (4–10 years depending on the availability of a homogeneous historical data-set {T}) of satellite records, which is devoted to

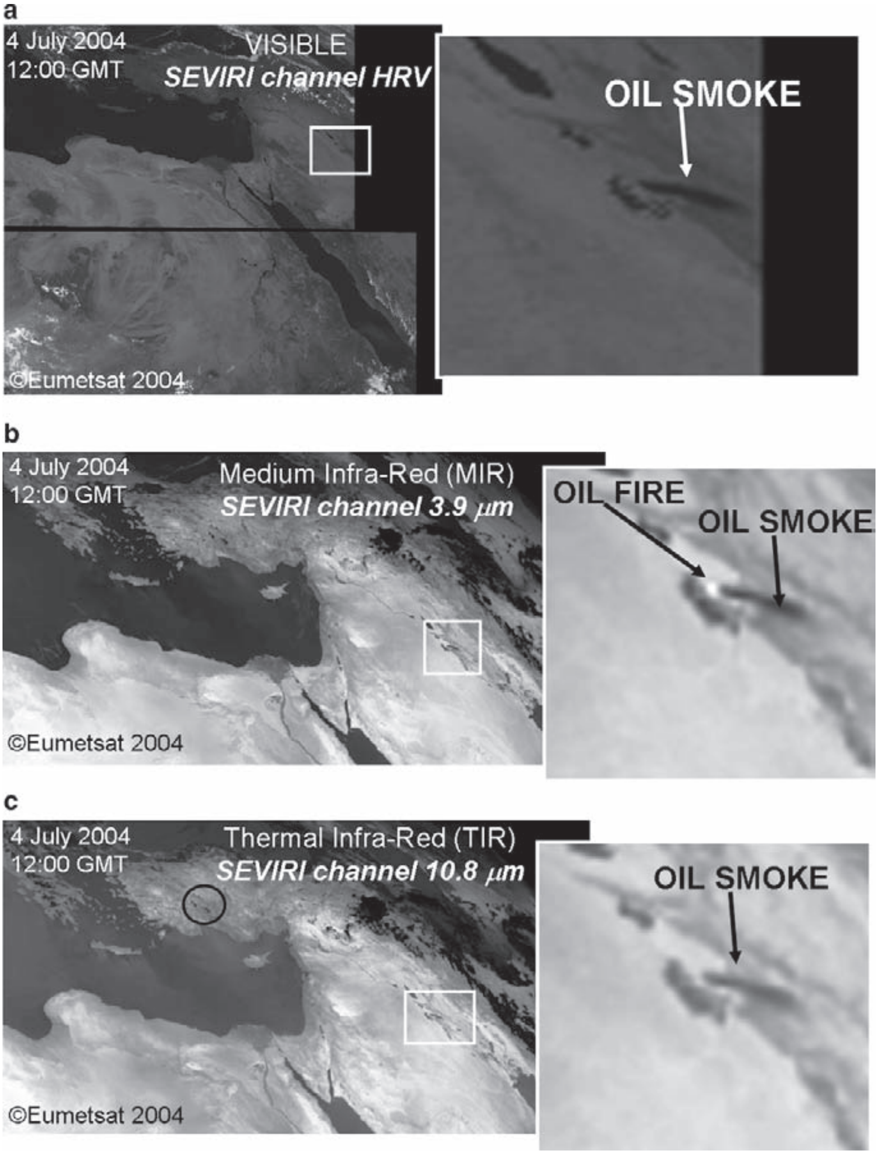

Fig. 13.1 SEVIRI channels for rapid detection of pipeline sabotages: (a) High Resolution Visible channel for oil smoke detection; (b) MIR channel for oil smoke and fire detection; (c) TIR channel for oil smoke detection

characterize the signal (in terms of its expected value and variation range) for each pixel of the satellite image to be processed. On this basis, anomalous signal patterns are identified by using a local change detection index, named ALICE (Absolutely Local Index of Change of Environment) (Tramutoli 1998, 2005), so defined:

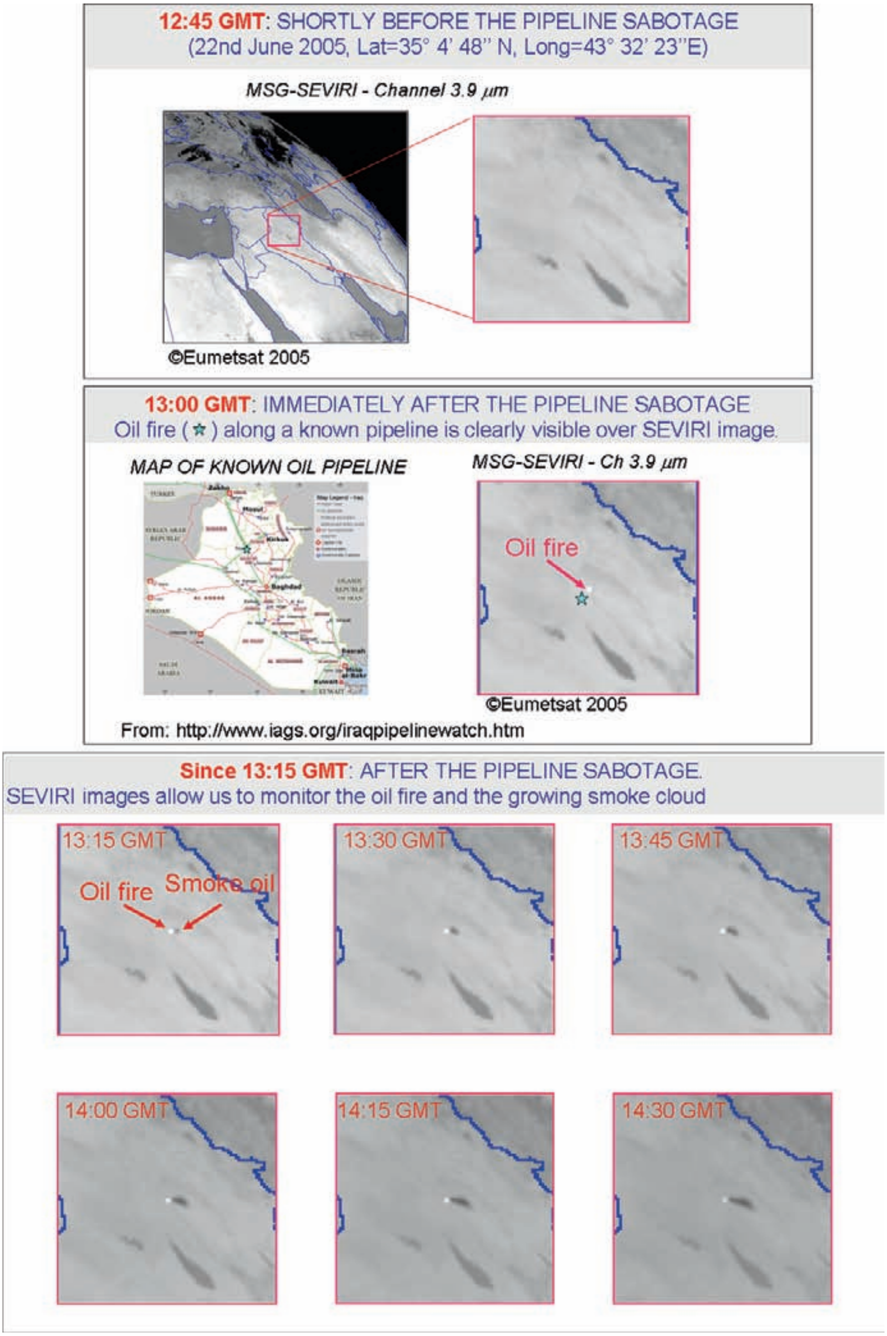

Fig. 13.2 SEVIRI image sequence: rapid detection of a pipeline sabotage

$$\otimes_V(\mathbf{r},t') \equiv \frac{\lfloor V(\mathbf{r},t') - V_{ref}(\mathbf{r}) \rfloor}{\sigma_V(\mathbf{r})}$$

Here, $V(\boldsymbol{r},t)$ is the signal to be analyzed (e.g. TIR, MIR, VIS), $\mathbf{r} \equiv (x,y)$ represents the geographic coordinates of the image pixel centre; t' is the time of acquisition of the satellite image at hand; $V_{ref}(\boldsymbol{r})$ and $\sigma_V(\boldsymbol{r})$ are, respectively, a reference field for signal $V(\boldsymbol{r},t)$ (e.g. minimum, maximum, mean, etc.) and its standard deviation computed on the pre-selected homogeneous data-set {T} of cloud-free satellite records, collected at location $\boldsymbol{r}$ in the same time-slot (hour of the day) and period (e.g. month) of the year of the image at hand ($t' \in \{T\}$). By construction, reference images ($V_{ref}(\boldsymbol{r})$ and $\sigma_V(\boldsymbol{r})$) describe for each location $\boldsymbol{r}$ (i.e. for each image pixel) and observation time $t \in \{T\}$, the normal behaviour of the signal and its range of variability in observational conditions as similar as possible to the ones of the image at hand. The local excess $V(\boldsymbol{r}, t) - V_{ref}(\boldsymbol{r})$ represents the Signal (S) to be investigated for its possible relation with man-made events. It is always evaluated by comparison with the corresponding natural/observational Noise (N), represented by $\sigma_V(\boldsymbol{r})$ which describes the overall (local) variability of S including all (natural and observational, known and unknown) sources of its variability as historically observed at the same site in similar observational conditions. In this way, the relative importance of measured signal (or the intensity of anomalous signal transients) can naturally be evaluated in terms of S/N ratio by the $\otimes_V(\boldsymbol{r}, t)$. Moreover, the larger $\sigma_V(\boldsymbol{r})$ is, the lower $\otimes_V(\boldsymbol{r}, t)$ will be, so that the ALICE index results are intrinsically protected against false alarm proliferation (*robustness*).

The ALICE index is expected to be independent from (or to strongly reduce the effects of) the known sources of natural/observational noise described in Tramutoli et al. (2005) as it is based on the comparison of homogeneous measurements performed at the same ground pixel in the same observational period (month) and daytime (hour of the day). For instance, the independence of the ALICE index from elevation a.s.l. and vegetation coverage has been demonstrated in Tramutoli et al. (2001).

By construction, the RST approach is not only applicable to different instrumental packages, but also completely exportable over every geographical region. Thanks to these characteristics, RST originally applied to data acquired by polar platforms (e.g. NOAA-AVHRR), has been easily exported to a geo-stationary satellite (e.g. Meteosat First Generation and Meteosat Second Generation), as demonstrated in Filizzola et al. (2004), Tramutoli et al. (2000) and Cuomo et al. (2004).

Concerning the fields of application, RST was initially applied to the prediction and NRT (Near Real Time) monitoring of major natural and environmental hazards: seismically active areas (Filizzola et al. 2004; Corrado et al. 2005; Tramutoli et al. 2005; Genzano et al. 2007), volcanic activity (Bonfiglio et al. 2005; Pergola et al. 2004a, b), hydrological risk (Lacava et al. 2005a, b) as well as forest fires (Cuomo et al. 2001) and oil spills (Casciello 2004) are the main fields of RST application. In all cases, the technique demonstrated how meteorological satellites, which presently offer the most frequent time repetition (from a few hours to a few minutes), despite their low spatial resolution, can be used to detect events of interest that cover relatively small areas (<100 m^2) of the Earth's surface.

In the framework of GMOSS, the RST algorithm has been applied for the first time to new (and sometimes, unforeseen) applications that affect the security of a state, such as terrorist attacks and pipeline sabotages. All test cases considered up to now, confirmed and consolidated results already achieved by the RST satellite technique.

The high detection capabilities that can be achieved by applying RST also allowed the successful detection of events of small intensities such as the Hotel Hilton explosion, which occurred in Taba (Egypt) at 22:00 LT and 19:00 GMT on October 7, 2004. The visual comparison between SEVIRI images acquired just before and after the explosion does not give any apparent sign of changes (see Fig. 13.3a and 13.3b) which are indeed revealed after a more careful analysis.

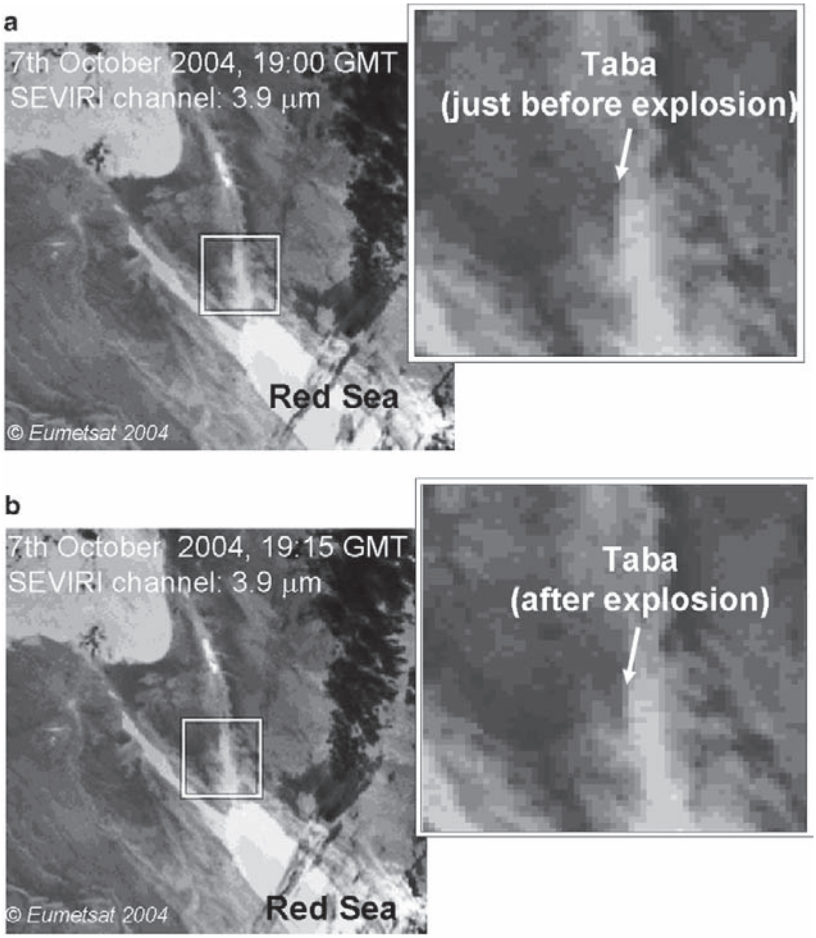

Fig. 13.3 (a) SEVIRI image acquired just before Taba's explosion; (b) SEVIRI image acquired just after Taba's explosion. No change can be revealed, as far as the eye can see, between the two images (MSG data – acquired at University of Basilicata MSG-HRIT station)

As Fig. 13.4 clearly shows, the high temporal resolution of SEVIRI allows us to identify unambiguously the quick (it involves a 15-min time slot) slope inversion, due to the explosion, along the naturally decreasing curve of MIR brightness temperature for the SEVIRI image pixel covering Taba. Clearer evidence of such an inversion trend is well-represented in Fig. 13.5, where the robust ALICE index (emphasizing signal differences between successive time slots) is plotted some hours before and after the time of the explosion.

In the field of rapid alert for infrastructure monitoring, the potential of the RST technique has been evaluated when it is applied to satellite sensors such as NOAA/AVHRR with high temporal resolution (6-h) and a better spatial resolution than SEVIRI (1 km). Figure 13.6 shows the oil spill that was successfully detected by RST, when it is applied to AVHRR data. The test case concerns the timely detection of sea water contamination due to the large oil spill, which formed along the Kuwait coastline during the Gulf War, as a consequence of the military action of Iraqi forces that opened valves at the Sea Island oil terminal near Kuwait City. The RST potential in oil spill detection could be successfully employed also to identify natural oil seepage, resulting from submarine (possibly unknown) pipeline failures.

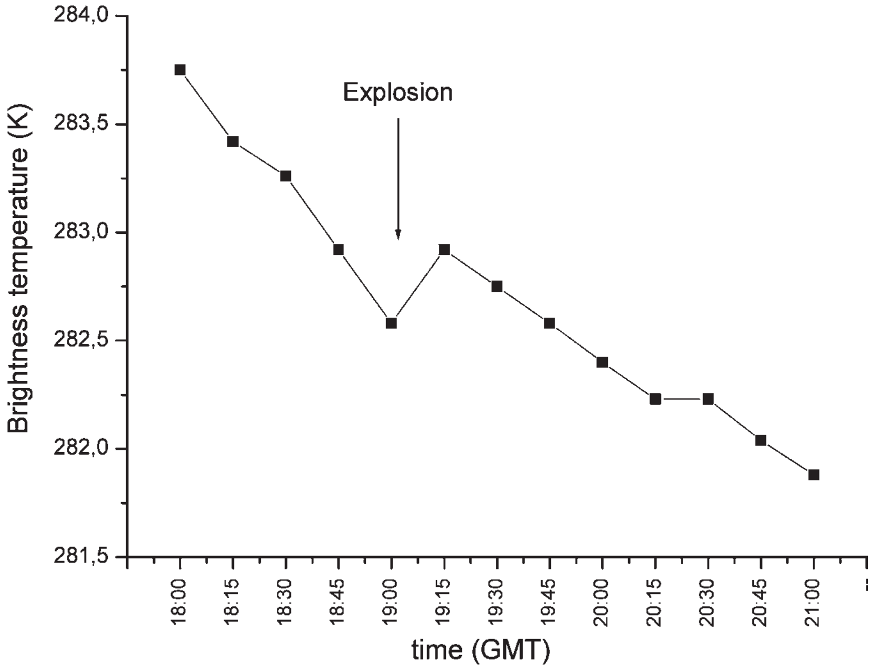

Fig. 13.4 Brightness temperature vs time (GMT) for SEVIRI image pixel containing Taba

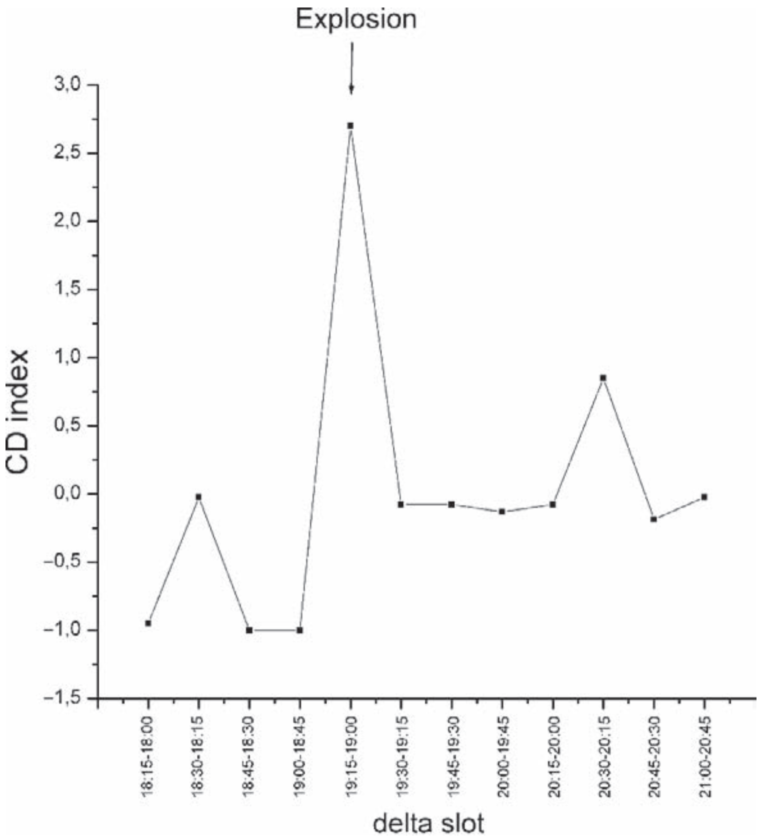

Fig. 13.5 ALICE index vs time slot difference (GMT) for SEVIRI pixel containing Taba

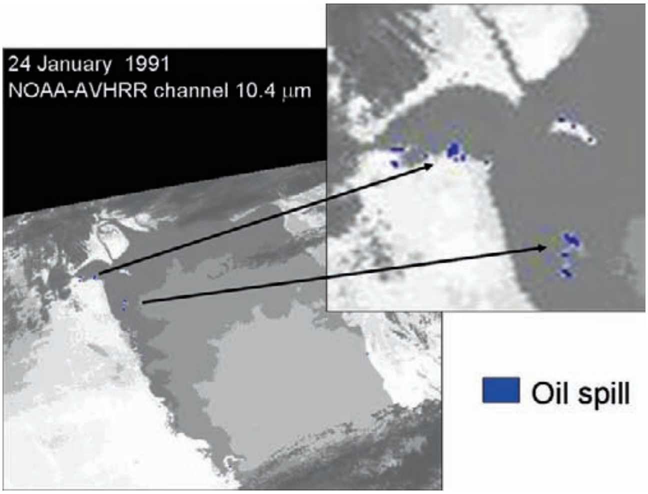

Fig. 13.6 AVHRR image: oil spill detected by RCDT near Kuwait-Saudi Arabia coasts

13.6 Satellite Observations with High Spatial Resolution

It has been successfully demonstrated in the foregoing discussion that very low spatial but high temporal resolution sensors on board certain types of satellites can provide very useful early warning information on man-made and natural disasters. While in an example above it was possible to detect an oil fire using such images, clearly it is not possible to determine the nature of the fire without prior knowledge of the surrounding circumstances. However, a high spatial resolution commercial sensor could give added information. In this section, some medium (30 m) to high spatial resolution (between 1 and 2 m) images were acquired over the Internet from Google Earth to show the extent of details that can be seen from such images. It should be pointed out that, while it was possible to download the images available on the Google Earth software, the dates and several image characteristics were not available at this source. Moreover, the coverage is not global and the areas of interest are not always available. However, an advantage is that such images are cost free and they have been very useful for the purpose of this study.

13.6.1 *Some Oil Wells Observed*

The images used for this study are based on those acquired from two Google Earth sites over the Internet: http://www.google.co.uk/ and http://maps.google.com/maps. In Fig. 13.7, a wide area image with low resolution, presumably a Landsat image

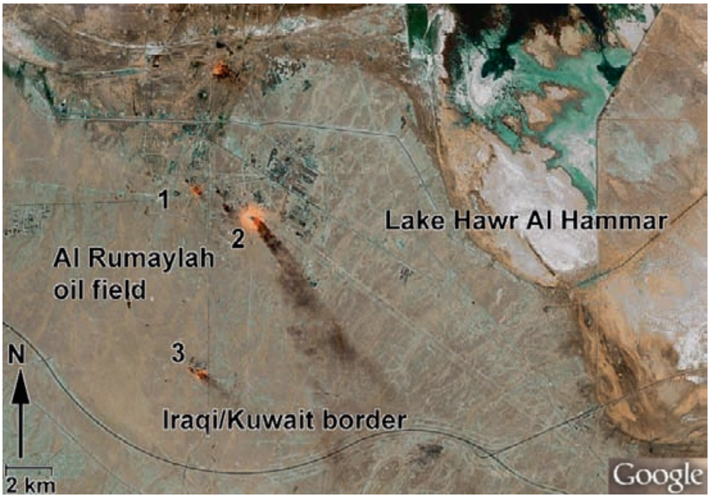

Fig. 13.7 This a low resolution (30 m) image acquired over the Internet from the Google Earth site. Three fires can be detected from the smoke plumes caused by burning excess oil from the oil wells (http://www.google.co.uk/ and http://maps.google.com/maps)

(30 m), is analyzed. Three smoke plumes can be detected. These probably originate from oil wells that are burning excess oil causing smoke or they may have been deliberately damaged. The oil wells are located at Al Rumaylah oil field, just south of Hawr Al Hammar Lake in Iraq. The details over the oil rigs can not be resolved. The northern border of Kuwait and the Hawr Al Hammar Lake can be seen in the inset at the bottom right hand corner of Fig. 13.7. The area covered by the image is shown in the inset in the blue rectangular area.

The areas over the two oil rigs at **1** and **2** in Fig. 13.7 are enlarged in Fig. 13.8, a higher resolution (about 2 m) multi-spectral image. It can be seen that at **1** there are three oil wells and at **2** only one. There are no indications that the oil wells have been damaged. The smoke appears to be due to the burning of excess oil. Here lies the advantage of the higher resolution images.

It should be noted that while very high temporal resolution cannot be achieved by Landsat or other higher resolution satellites on their own, there are a number of other similar spacecraft in orbit that have been launched and operated by other states. If these satellites are placed in orbit via the coordination and cooperation of the various states, utilising the tilting capabilities, the temporal resolution could be improved. Thus, it may be effective if very high spatial resolution satellites are used together with those with high temporal resolution spacecraft.

13.6.2 Some Oil Leaks Observed

An enlarged section of area **3** from Fig. 13.7 is shown in Fig. 13.9. Five more oil rigs are identified; one at **A** and four at **B**. At **A**, there may have been an explosion as indicated by the radial nature of the charred earth surface.

Fig. 13.8 This shows an enlarged section of oil fields at **1** and **2** from Fig. 13.12. Three oil wells are clearly resolved at **1**. This image has a 2 m resolution (http://www.google.co.uk/ and http://maps.google.com/maps)

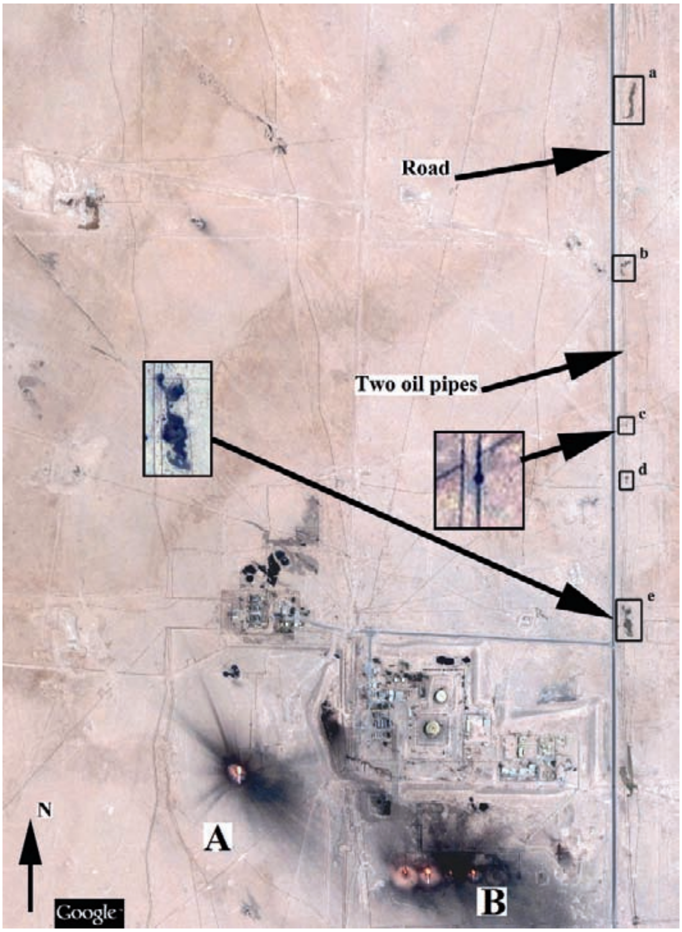

Fig. 13.9 An enlarged section of oil field at **3** from Fig. 13.7 shows one oil well at **A** and four at **B** indicated by the bright red color. North of these are a number of oil leaks at **a, b, c, d** and **e** along the oil pipe. The sizes of the leaks vary from 2.5 m diameter for the smallest at **c** to a much larger one at **e**. The road and two pipes along it are identified. Five oil rigs can also be identified. The image resolution is 2 m (http://www.google.co.uk/ and http://maps.google.com/maps)

In Fig. 13.9, parallel to the road, two pipelines were identified. A number of oil leaks of different sizes were detected along these pipelines. Some of these are indicated in Fig. 13.9 at **a, b, c, d** and **e**. Two spills, the smallest at **c** and the largest one at **e**, are enlarged and are shown within the insets displayed in Fig. 13.9. From such an image it is possible to detect and locate oil leaks along the pipelines; it may also be possible to determine whether the leaks have been caused due to faulty pipes or sabotage. The latter could be identified by tracks in the sand around the leak areas and/or other activities in the vicinity. The size of the spill at **c** has a diameter of 2.5 m. If in time this increases, initial detection of even a smaller size spill could give an early warning.

13.6.3 Observation Along the India–Pakistan Border

A satellite (see Fig. 13.10) image along the international border between India and Pakistan was acquired using the Google Earth sites. The Indo/Pak border, including the Line of Control, is marked on the image. The areas containing rectangular strips indicate the locations where high-resolution (2.4 m and 0.61 m – if purchased) images are available. It can be seen that only a limited number of high-resolution

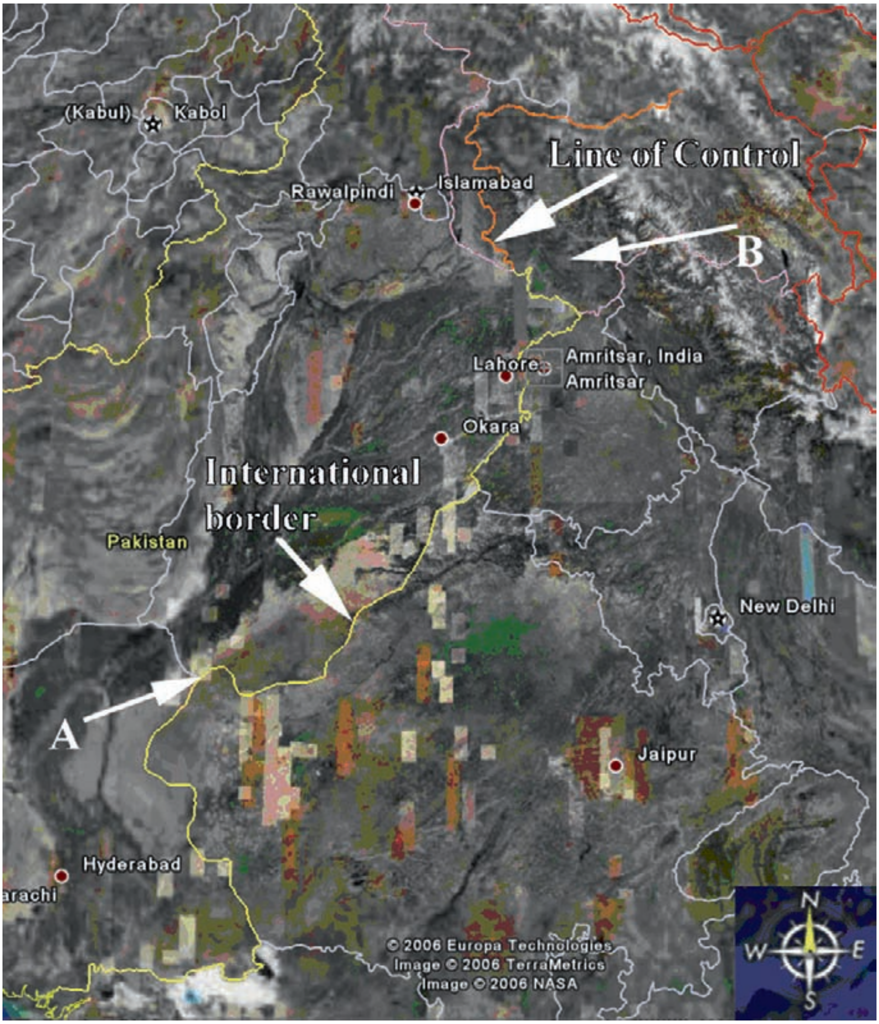

Fig. 13.10 This is an overview of a satellite image along the international border between India and Pakistan. The position of the Line of Control is also indicated. The striped areas are where high resolution (2 m) images are available. Areas investigated are at **A** and at **B** (http://www.google.co.uk/ and http://maps.google.com/maps)

images are available along the border and Line of Control. A good example of an early warning of a conflict was just before Iraq's invasion of Kuwait (Jasani 1993; Jasani and Rathmell 1998).

Two areas at **A** and **B** in Fig. 13.10 have been investigated. An enlarged area at **A** in Fig. 13.10 shows the India–Pakistan border and three lookout posts near Tanot (a small Indian village) in the Rajasthan desert (Fig. 13.11). The three lookout posts from Fig. 13.11 are enlarged in Fig. 13.12 showing such details as perimeter fences, railway tracks and the associated level crossing. These images do not show any unusual activities at or near the border and lookout posts, suggesting that the images may have been acquired much before or after the December 2003 attack on the Indian Parliament by a group of terrorists. It was reported that the tension between India and Pakistan heightened resulting in both sides mobilizing their troops along the international border and Line of Control.

Such activities could be detected by images at 2 m resolution, as shown in Fig. 13.14. Figure 13.13 is an overview of the border area between Amritsar (India) and Lahor (Pakistan). At Lahor, a large garrison is located near the civil airport. An enlarged image over the garrison is shown in Fig. 13.14. It is divided into two areas, to the left of the image 24 barracks are situated and to the right a large number of

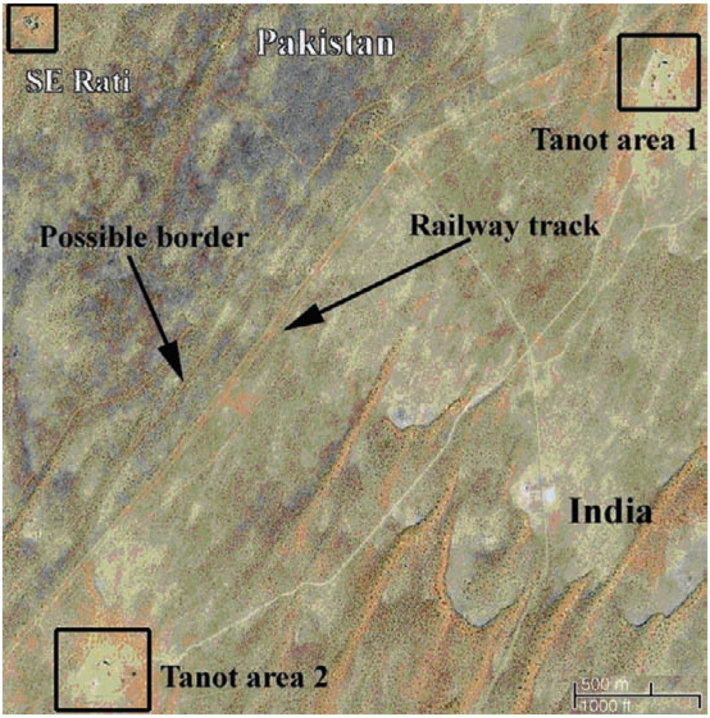

Fig. 13.11 An enlarged area at **A** in Fig. 13.10 showing the India–Pakistan border and three look out posts near Tanot (a small Indian village) in the Rajasthan desert (http://www.google.co.uk/ and http://maps.google.com/maps)

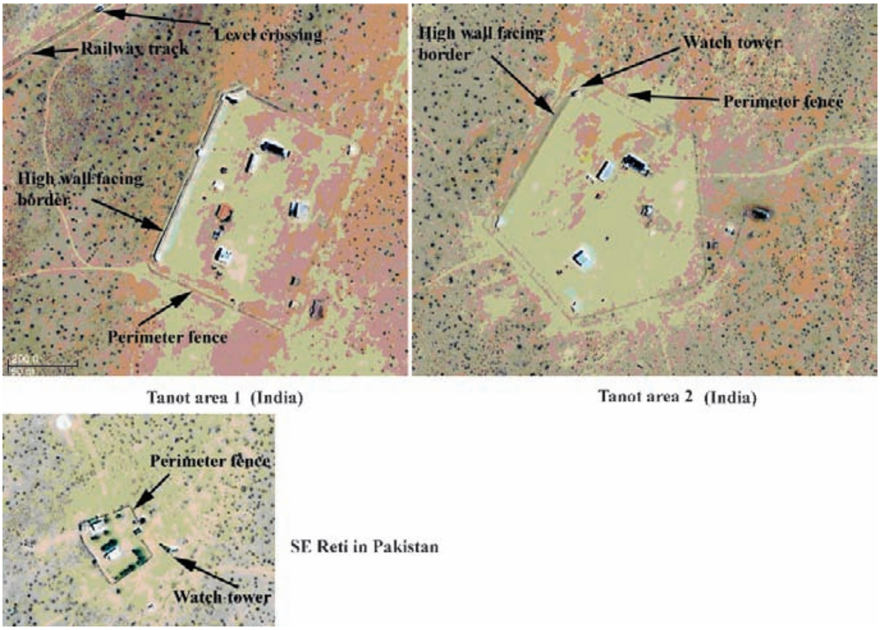

Fig. 13.12 Three lookout posts from Fig. 13.11 are enlarged in this image showing such details as perimeter fences, railway tracks and associated level crossing

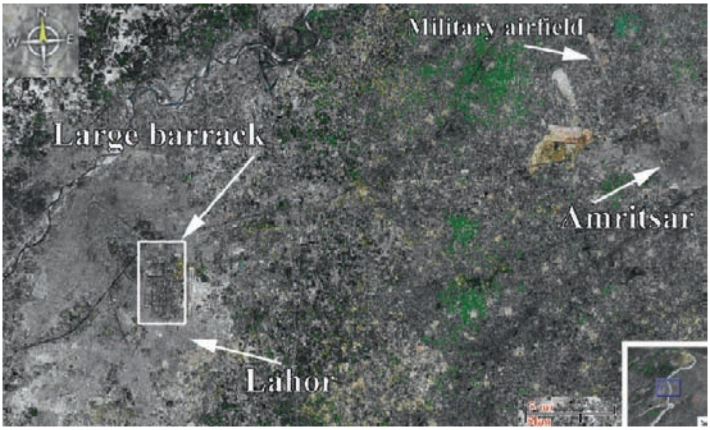

Fig. 13.13 This is an overview of a low resolution (30 m) image Lahor (Pakistan) and Amritsar (India). As can be seen from the inset the international border runs between the two cities

vehicles are deployed. The images acquired from the Google Earth website always provide the longitude and latitude of the selected location. This information can then be used in coordination with Google Maps, which provides the scale. Thus, by determining the size of each barrack (approximately 2,420 m^2), and assuming

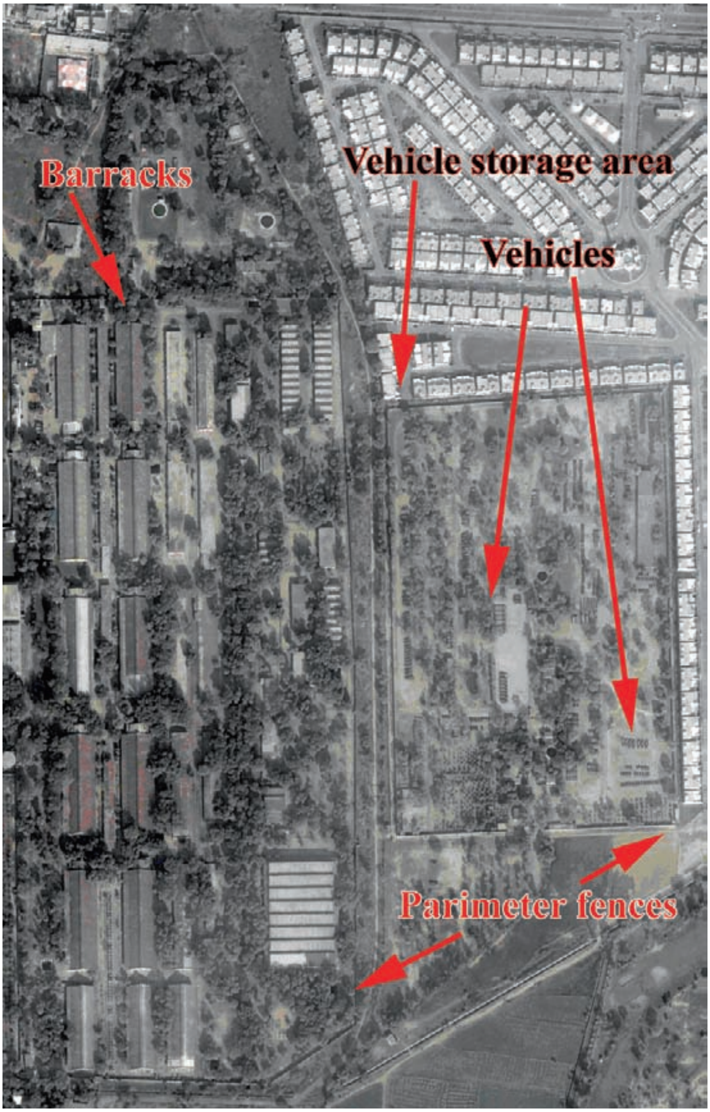

Fig. 13.14 This is an enlarged section over the barracks near the Lahor civil airport (see Fig. 13.13)

that each soldier might occupy an area of 9 m^2 (one bed, a small side table and a locker), the number of soldiers residing in each barrack can be estimated. It has been calculated that within one barrack, approximately 270 soldiers could be present. Subsequently, it is possible to estimate the total number of soldiers residing within the garrison. As there are 24 barracks, it is estimated that around 6,500 soldiers could be present in total.

Within the vehicle deployment area, while it is not possible to describe the types of vehicles that are deployed, it is possible to detect the presence of 6 very large, 15 somewhat smaller, 24 medium size and about 15 small vehicles parked in the open. There may be more under cover in the sheds. It is suggested that if the numbers change, this could give an early warning of either an imminent conflict or just a move for an exercise.

13.6.4 Some Preliminary Conclusions

The above preliminary study demonstrates that very low spatial resolution images provide high temporal resolution enabling one to get an early warning of an event on the Earth's surface. It may not be possible to know the exact nature of the events unless one has some prior knowledge of them. However, medium spatial resolution (30 m) and high resolution (at least 2 m) can contribute in resolving this dilemma. There are a number of countries that launch and operate medium to low resolution satellites. In order to improve (to some extent), their temporal resolution, this can only be achieved via cooperation in the way these satellites are orbited. It is urged that such cooperation be implemented. Moreover, in such cooperation, if the very low spatial resolution images are included then remote sensing from space could become an effective tool for early warning activities.

13.7 Open Issues, Challenges and Future Perspectives

In the context of early warnings, the first phase of the GMOSS project has been characterized by the identification of new fields of application for old meteorological sensors and new potentials for next generation satellite instruments. Moreover, preliminary results allowed us to make a sensitivity analysis of the thermally detectable events of different intensity. Within this context, work will continue in attempting to identify weaker and weaker signals associated with man-made activities. Moreover, the next goal of the Early Warning working group will be to try and extend the application field to new security-related issues in order to support, for example, population/border-monitoring systems. Therefore, a short term challenge, which links two such purposes (low intensity signal detection and support for population monitoring), is the possibility of increasing the RST sensitivity in order to achieve rapid detection of very low intensity TIR signals connected to "anomalous" population presence (e.g. bonfires in refugee camps). This should always be achieved by coupling the high time-repetition rate offered by meteorological satellites and the use of the RST approach.

Looking at a possible application in an operational context, a long term challenge is the possibility of implementing a completely automatic processing chain which will respond to the criteria of rapidity of information transfer, reliability of satellite-based information (no false alarms) and virtual system independence (no or few interface operators). In this context the integration with other satellites (not only at VHSR but also, for instance, from DMSP/OLS offering every day night-lights variation maps) and open source products will not only permit the full validation of new (or improved) algorithms but also the added value that their combined use can offer to an integrated observational system for security.

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Chapter 14
Can Earth Observation Help to Improve Information on Population?

Indirect Population Estimations from EO Derived Geo-Spatial Data: Contribution from GMOSS

Daniele Ehrlich, Stefan Lang, Giovanni Laneve, Sarah Mubareka, Stefan Schneiderbauer, and Dirk Tiede

Abstract The objective of this document is to summarize the current work conducted within GMOSS regarding the use of Earth Observation (EO) and geospatial data to derive indicators for the presence of populations and their characteristics. The objective of this paper is to create a link between the Earth Observation products generated and the demand for information at the policy level.

Keywords Population • Remote sensing, • Earth Observation

14.1 Introduction

Security – in its broadest sense – refers to the ‘well-being’ of a population. Whether at an individual, household, society or national scale, the population is the subject of study within any context and at any scale within the matter of security. For example, energy security addresses the threats to the supply of energy with global implications; territorial security relates to protecting the geographical space in which a

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nation functions; food security focuses on the availability of food at the community or country level as well as accessibility at household level; psychological security is related to fear or danger at the individual level. Human security in its broad definition, addressed herein, relates to the protection of the individual from natural hazards or acts of violence and crosses all societal hierarchical levels (see Chapter 1 'Definitions, concepts and geo-spatial dimensions of security').

The threat to human security for civilian population is particularly high in the aftermath of natural disasters and complex emergencies. In these situations, the livelihood balance is disrupted to such a degree that outside help is needed to return the society to a functional status again. In post disaster situations, physical security is particularly low in those countries that do not have enough internal resources that can be mobilized to help themselves. Large scale disasters and post-conflict situations in low income countries are addressed with the support of the international community as short to medium term emergency aid and longer term development programs.

International emergency aid programs aim to save lives and support survivors. Development programs aim to get society functioning again by improving the well-being of populations through the investment in structural components of the society. In emergency aid processes, population information is used to quickly estimate those potentially affected and their ability to cope with disasters in order to both save lives and to take care of the survivors. Information on population and on built-up infrastructure is then needed to plan the reconstruction process that aims to re-build the society. The effective and efficient sizing, planning, and delivering of both emergency aid and development programs rely heavily on information regarding the population and their characteristics.

Against common belief, information on where and under what conditions people live remains limited, especially for developing countries. Worldwide population data are available from international organizations that collate census data provided by national government in aggregated form at sub national level. Censuses are conducted every 10 years and often the results are released with significant delays, making census data obsolete especially in countries with rapid population growth and/or migration. This is of particular relevance in regions that have experienced prolonged conflicts and population displacement for which reliable data are lacking completely. In fact, food aid or development programs often rely on ad hoc surveys used to assess the population in need. Field surveys however, may not be publicly available and are limited by their geographical scope and specificity.

The research community is addressing these population data shortages using geo-spatial information and Earth Observation to indirectly assess population. Geographical indicators of population includes built-up areas, transport infrastructure and land use while other uses of land completely exclude the presence of population such as water bodies, high elevation places or ice caps. Earth Observation can provide information on many geographical features and often is the only source for the current status of such information (Harvey 2002). EO also covers large areas and provides a synoptic view that is critical in situation and damage assessments. It is also non intrusive and relatively inexpensive considering the wide coverage. EO tools can collect information from regions for which data would not otherwise be available. These characteristics make it effective when addressing the population information needs for emergency aid, for which timeliness is very critical.

Remote sensing data has been used as the input layer for population density models at fine resolution. Recently they have been tested for alerting the occurrence of a disaster based on the pattern of night-time lights. Satellite data may be used in the future more effectively to estimate the extent of built-up areas. Also post-conflict change detection techniques are used to estimate the damage to buildings and indirectly the affected populations (Pesaresi and Pagot 2007).

Within development programs remote sensing is used to estimate the growth of population in urban areas in order to assess the increased demand for domestic water use, services and infrastructure. In rural areas, and in particular in those areas most at risk of crop failure, remote sensing is used to assess rural population density to provide estimates on food demand (based on the number of people) and access (determined by the household resources and cost of food).

This paper reviews and provides results from research in four different areas conducted within the framework of GMOSS. These four areas illustrate the range of information requirements demanded by policy and decision makers focusing, by and large, on the post disaster emergency response and development community.

14.2 Population Data in Emergency Response

Disasters unfold when natural hazards strike populated areas or ensue from man made actions (e.g. conflicts). Civil society – national civil protection agencies or international humanitarian institutions – are set up to respond to disasters in order to bring relief and aid to the affected population. These institutions require population information to gauge the level of aid that is needed and subsequently, to carry out the associated operation. The humanitarian community intervenes in disasters in order to: (1) save lives; (2) take care of survivors that are unable to cope; (3) assist with reconstruction and development programs that restore the functions of society.

The number of people and their needs is pre-requisite information to tailor any humanitarian aid program. In post disaster situations the needs vary according to the phase of the disaster (Fig. 14.1). Immediately after the occurrence of a fast onset disaster event such as an earthquake or a tsunami, civil society requires information on whether anyone lives in the affected areas and existing transport infrastructure. The pre-requisite for alerting is thus information on the population distribution with sufficient detail to provide assessments on the people affected by the disaster. General atlases and map products, and more recently digitally available global population density datasets, are commonly used for this purpose.

The emergency response phase requires information on the number of survivors and injured who need assistance and health care. Furthermore, information about the degree of damage to transport and infrastructure is needed. This information is usually provided by a combination of the population totals and their coping capacity. This phase thus requires detailed information on population that may come from local authorities. Estimates on the casualties can be inferred from this information. International aid organizations have at their disposal the census information

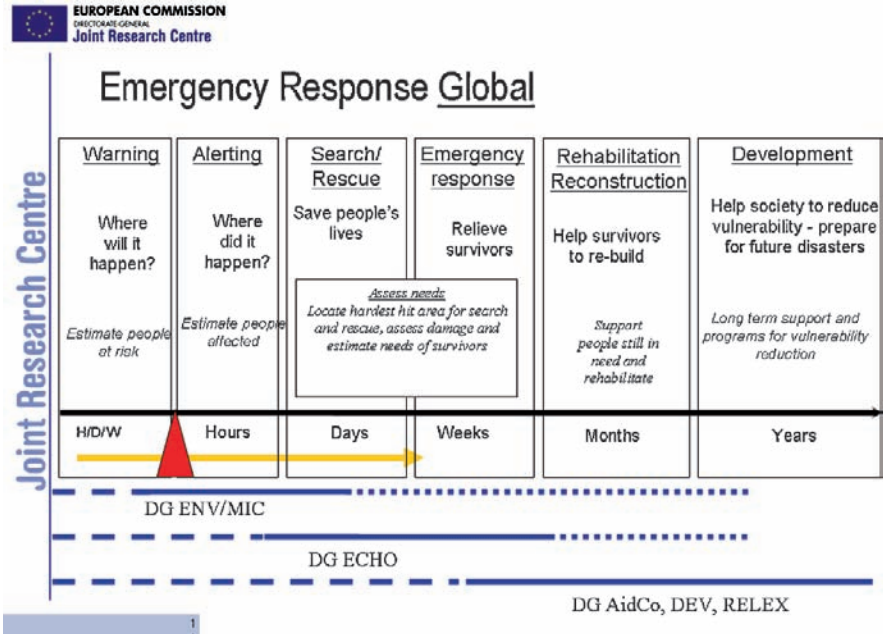

Fig. 14.1 The phases of a crisis (underlined) and the time scale as referred to in the disaster literature. The red triangle indicates the occurrence of a fast onset security event, the orange arrow that of a slow onset security event. Underneath the phases names we can find the need of information as formulated by decision makers and the specific information related to population for that specific crisis phase

available through UN agencies that include the UN Population division and FAO and WFP that maintain population districts.

Survivors, especially in the aftermath of conflict related crises, are often concentrated in safe areas or refugee camps. Refugees and Internally Displaced People (IDPs) represent one of the most vulnerable groups of people and often rely heavily on the support of the international community. Assessing their numbers is essential to tailor the aid operations that aim to allow the people to recover from the disaster and reconstruct their lives.

The recovery and rehabilitation phases require information on how many people need prolonged assistance. This includes people that cannot provide the basic needs for themselves or their household. Recovery and rehabilitation are often part of more general development programs that are put in place to reconstruct or rehabilitate infrastructure at a household (dwelling units) or societal (i.e. hospitals, roads) level.

14.2.1 Alerting

When a hazard strikes the priority is to understand whether there are any people in the affected area. Satellite data in combination with other geographical information layers are used to identify built-up areas and transport infrastructure that are indicative of human presence. Population density, derived in part from Earth Observation data as described in Section 14.2.3, combined with the location of the occurrences of fast onset natural hazards are a common feature of current disaster alert systems that aim to assess the amount of affected people within hours of the occurrence (De Groeve et al. 2006).

The night time images collected by the Operational Linescan System (OLS) on board of the Defense Meteorological Satellite Program (DMSP) have been used to indirectly detect the presence of population. The satellite was first used for the identification of inhabited areas by measuring the amount of energy emitted from built-up areas (Sutton et al. 2003). The data are used also to identify transient phenomena such as wild fires or other transient energy outburst such as gas flares. Due to the coarse resolution and geometric accuracy, DMSP-OLS requires significant pre-processing in order to get stable lights. This consists in averaging the signal over longer time periods. Transient events are identified by measuring light signals in those areas for which usually no lights are recorded. Research within GMOSS tested the use of night time data to provide an alert on the occurrence of a disaster by (1) identifying changes in light intensity over inhabited areas and in (2) locating lights in areas that do not record this information and that would be the indication of the presence of population.

Alerting on a disaster through changes in light intensity recording was tested in the aftermath of the Kashmir disaster. The disaster, which struck on October 8, 2005, was caused by an earthquake and its aftershocks registering seven on the Richter scale. Figure 14.2a shows part of the affected area around the epicenters and shows the hardest hit cities, Balakot and Muzzafarabad and the reduced intensity in night light – as measured from DMSP/OLS – on 9th and 10th of October 2005. The lights recorded in the aftermath of the earthquake were compared with an average of the recordings made on 4th, 5th, and 6th of October 2005 and made available to

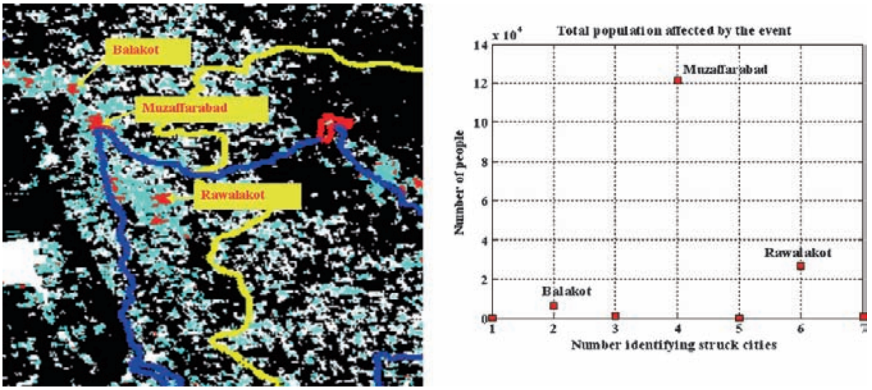

Fig. 14.2 Testing of DMSP/OLS light for disaster alerting. The left figure (14.2a) shows in red the potentially disaster affected areas, in blue the main road network and light blue the number of potentially affected people. The right figure (14.2b) shows the total population affected in earthquake struck cities

the GMOSS researchers through the European Union Satellite Centre (EUSC). The areas that showed a signal decrease of 30% (over the total) were labeled as probable affected areas (red in the Fig. 14.2a). These areas were used to derive potential affected people using the Landscan dataset as shown in Fig. 14.2b. The population estimates derived from the analysis coincide, by and large, to population estimates available from open source and from the humanitarian community.

The use of night lights is also tested to locate displaced people. Figure 14.3 shows night time imagery in otherwise uninhabited areas in eastern Chad. The hypothesis is that night time flying sensors can detect lights from bonfires lit in refugee camps. The test was made on the DMSP/OLS and the High Sensitive Camera made available by CONAE the Argentinean Space Agency that operates the SAC-C satellite (Colomb et al. 2001). HSTC is a highly sensitive intermediate resolution (about 300 m) camera, designed to operate during the night in the 0.4–0.9 μm range of the electromagnetic spectrum, for observing light from the Earth's surface that includes fires or lightning, even if the latter event has low probability to be recorded. The image acquired on 15 February 2005 over South-Eastern Chad provides evidence of the usefulness for detecting night light sources (Fig. 14.3).

The presence of fires from the HSTC camera was confirmed by visual analysis conducted on the thermal channel of the MODIS sensor, which was recording in the 4 μm part of the EMR spectrum. Based on current testing it is foreseeable that two or more fire camps will provide a sufficiently strong signal to be recorded on the HSTC sensor. The hypothesis is currently verified by the authors over the Kakuma refugee camp in Northern Kenya. Both the OLS/DMSP sensor and the HSTC/CONAE sensor will be used in an exercise of sensor benchmarking.

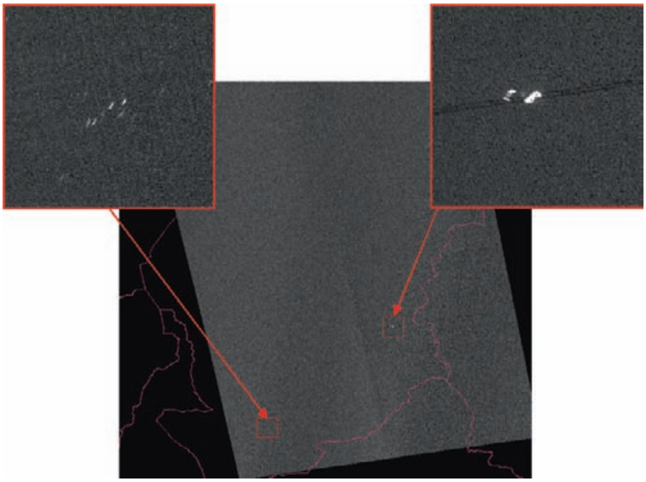

Fig. 14.3 High Sensitivity Camera (HSTC) image collected on 15 February 2005. The main image covers an area of 700 × 700 km The red lines identify the borders with Central African Republic to the South, Chad to the West and Sudan to the East

14.2.1.1 Future Direction

Remote sensing data have just started to be tested for disaster alerts. The newly available night-time recording sensors are likely to provide improved signals that may prove to be very effective to detect changes in energy emissions associated with reduced societal functions. Other sensors that fly with very high repetition cycle are the ones that may provide the highest potential for this phase of the crisis.

The alerting process will also benefit from improved population density and population characteristics datasets that will be generated using higher resolution satellite imagery and other geo-spatial information at finer resolution. Improvements in producing such datasets through the use of data produced by new EO sensors are welcome and will make the resulting analysis more effective as discussed in Section 14.2.4.

14.2.2 Local Population Estimates in Informal Settlements

Displaced people in the aftermath of a conflict or a large natural disaster concentrate in informal settlements such as refugee or IDP camps. These camps may remain in existence for years and often decades and can host different waves of refugees. VHR satellite imagery is used as source for an overview on camps, their growth in time, and for an estimation of the number of people hosted – a number that is often difficult to obtain through other means – and for the management of the camp by providing camp maps. Satellite imagery has also proven effective in communicating to decision makers the magnitude of the humanitarian issues related to refugee camps (Giada et al. 2003a).

The availability of VHR imagery from the year 2000 allowed for the first time an enumeration based on dwelling units (Bjorgo 2000; Giada et al. 2003b). The spatial resolution of VHR satellite imagery allows identifying single dwelling units and thus, based on average household occupancy, the total number of dwellers. Enumeration of dwelling units, the critical factor, is being performed through manual interpretation, assisted through sampling techniques, as well as automatic techniques (Giada et al. 2003a). This is best summarized in estimation of the Goz Amer refugee camp in Eastern Chad (Fig. 14.4).

The image was processed for visual inspection and quantitative analysis. For visual inspection it was enhanced using pan-sharpening and sobel-filtering techniques that bring into evidence the dwelling structures in the image. The quantitative analysis consisted in segmenting the image and using rule-based classification and fuzzy operators to classify the segments according to different dwelling types and the features present in the image, including fences/walls, bare soil/sand, single trees, and vegetation. The accuracy of the classification was assessed using a visually interpreted reference layer, focusing on tents only, which resulted in a producer's accuracy of 80% (Fig. 14.5). The classification result was used to enumerate the total number of tents: 2,236. An average family size of 7.5% – obtained from

Fig. 14.4 Goz Amer refugee camp (Eastern Chad). The camp hosts refugees fleeing from the neighboring Darfur region (Sudan). The image was collected on 27 December 2004

open source information – was then used to estimate the total number of refugees summing up to 16,770. The estimated number of people living in the Goz Amer camp comes close to the figure of 18,341 published by UNHCR (2004).

Challenges arise when trying to use the number of extracted dwelling types as proxies for estimating the number of camp dwellers. A metric for calculating the number of camp inhabitants should take into account uncertainties in tent detection. In fact, the 20% error in the enumeration of tents may account for the underestimation when compared to UNHCR figures – should those proven to be correct. Improved image processing algorithms such as those proposed by Laneve et al. (2007) and Lang et al. (2006) are promising but need to be benchmarked against other datasets and algorithms. The estimation of refugees from very high resolution satellite imagery relies on one important variable – the average household occupancy or family size – that can be made available only from field surveys.

14.2.2.1 Future Direction

Refugee camps are dynamic places. Often these camps host different waves of refugees. These dynamics can be monitored using optical Earth Observation acquired and analyzed at various intervals of time. The need for rapid assessment of people in refugee camps in complex emergencies has also been addressed using aerial samples (Brown et al. 2001). Automated and transferable procedures such as those

Fig. 14.5 Dwelling and population densities in a 50 × 50 m grid cell (Modified from Lang et al. 2006)

proposed by Lang et al. (2006) can be used. In fact, integrating change detection techniques and rapid multi-temporal analysis within a work flow as illustrated in Fig. 14.6 that allows the provision of information customized for decision making is one of the research avenues that will be followed (Blaschke et al. 2006).

14.2.3 Population Density Estimations

Global population density datasets are one of the most widely used population data within the humanitarian aid and development community. The first global population density datasets, the gridded Population of the World (GPW) (Tobler et al. 1995), was developed to address environmental issues in the developing world (Deichmann 1996). The pioneers in the population density studies were Deichmann and Eklundh (1991), whose heuristic approach to assigning probability weights to pixels was based on land cover and land use in order to map the population density in Africa. Two other population densities were derived: a gridded density for urban areas derived from night time imagery (Sutton 1997), and the Landscan global population database (Dobson et al. 2000) which has since been revised and improved several times. The global raster maps have also been used to forecast urban and rural population into the future (Balk et al. 2006).

Population densities are developed to improve our understanding of the geographic distribution of population. The population density datasets are generated from a number of geographical information available from maps and remotely sensed data and from a primary source population data (Fig. 14.7). The population data are available from maps and from censuses. Data from maps are difficult to use and have very low spatial accuracy. Census data are the most accurate population

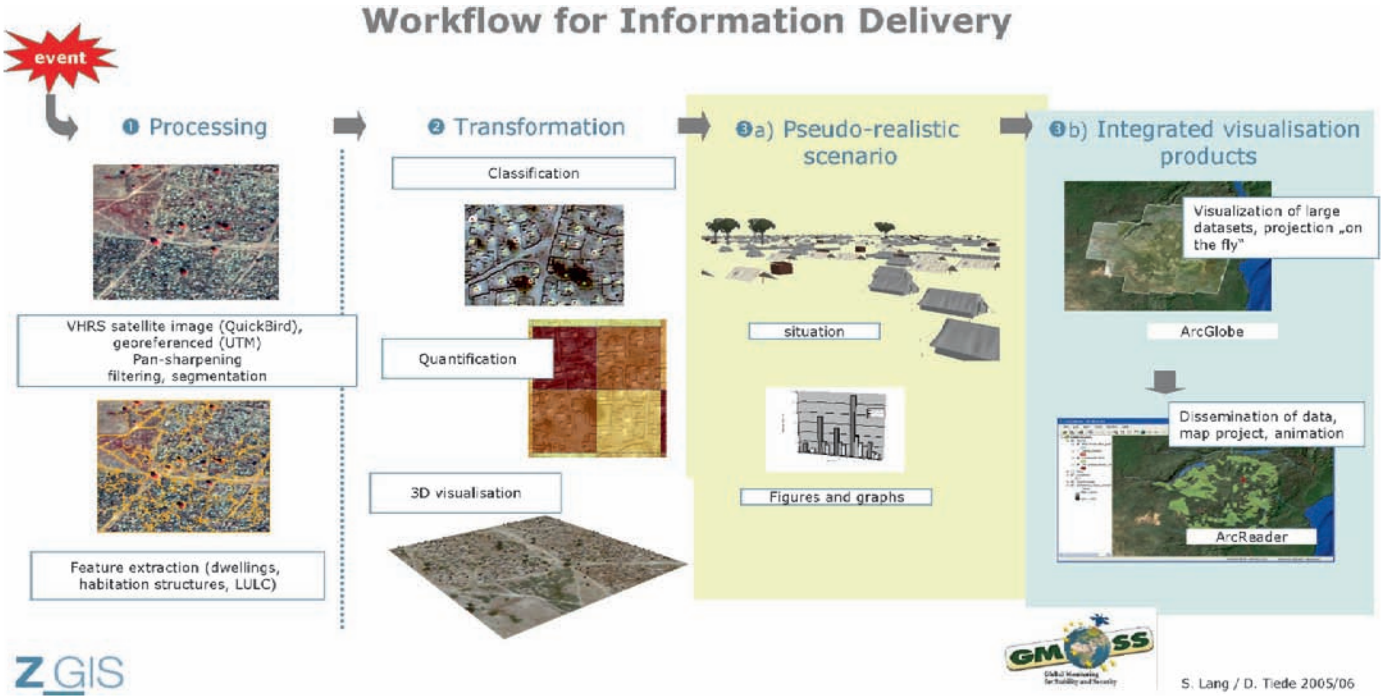

Fig. 14.6 Example of processing flow that uses satellite imagery and provides information products in the form of maps, statistics and web products (Modified from Lang et al. 2006)

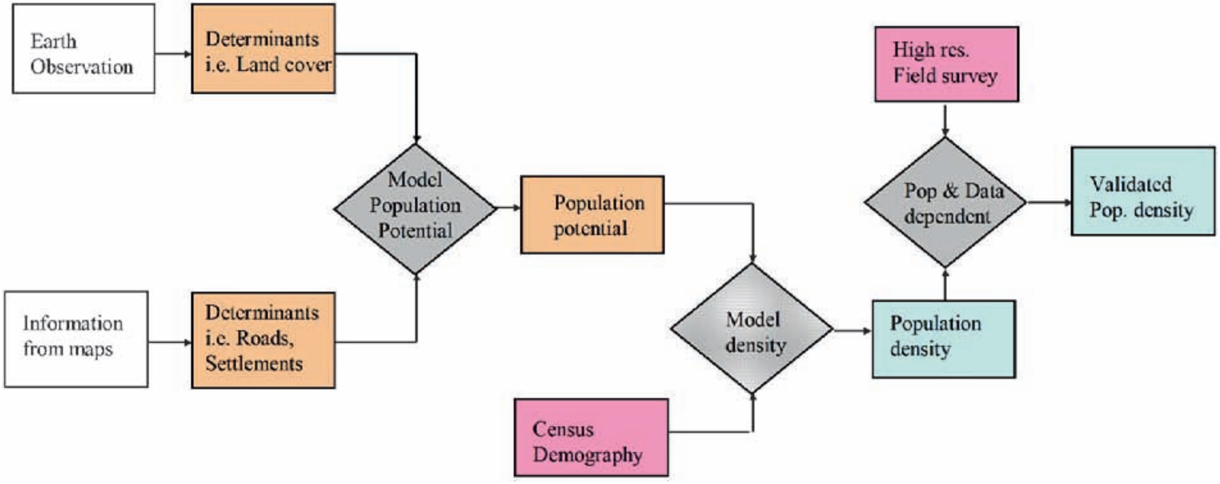

Fig. 14.7 Conceptualized information flow for population density estimations based on geo-spatial information layers. The figure shows geographical information sources (white boxes), processed information layers (pink), population data (purple), the main processing steps (diamonds) and resulting information products (light blue)

data since these are attached to a well defined geographical entity. For privacy reasons, most statistics on population derived from census are disclosed to the public in large areal units, typically at third hierarchical administrative level. District population data are thus the result of averages over areas that may include regions with very different density especially when urban areas are present. Population data from censuses are often inadequate to address population estimation such as those required in disaster areas.

Geographical data extracted from maps or EO are used as population determinants and are combined to come up with a "population potential" that is a set of weights attached to a certain land use that represent an indication of the likelihood to find people. One method to combine population potential with population data is the surface modeling approach. Surface modeling refers to allocating population or attributes of population that is available at aerial units (from censuses or field surveys) to a regularly spaced fine scale grid. The grid provides the surface based population commonly referred to as population density. Each pixel is assigned a weight according to the relative probability of population numbers living within the area of the pixel. These weights are the determining factor for the population number assigned to the pixel. The absolute numbers assigned to each pixel is the result of the total district population divided by the total amount of pixels representing this district and multiplied by the probability factor.

A population density dataset is useful in a number of ways. It allows for population data aggregation to nearly any desired aerial unit. It allows for analysis with other grid based datasets, it overcomes the arbitrary nature of the aerial unit partitioning that may influence the results of the spatial data analysis.

Continental population density databases with improved resolution and accuracy are also produced. The European dataset for example (Gallego and Pedell 2001) aims to improve the spatial resolution of the grid cells for more precise estimates, and to provide an uniform coverage of population from administrative units that can be very different in size, and with accuracy assessment provided from detailed municipality datasets. Security applications require even more precise population information to be produced. Both humanitarian and development programs require finer population datasets that should be developed at national or sub-national level.

14.2.3.1 National and Sub-national Population Density Estimations

National and sub-national population density estimations can be computed with a higher precision and better accuracy than global or continental population densities due to a number of reasons: (1) primary population data such as censuses are homogeneous across the country, (2) demography of a population and population distribution determinants are country specific and related to culture and history of a given country; (3) the geo-spatial datasets used to produce population potentials, the layer used in combination to primary population data to produce population density, are also uniformly derived and produced at finer scales than the ones available globally.

Two sub-national studies are reported below, one for Zimbabwe and one for Northern Iraq. Both studies incorporate a rapid, easily implemented and inexpensive methodology. The case study in Zimbabwe is based on an extensive knowledge base that is available for the country, whereas with Northern Iraq the knowledge base is not as extensive and therefore, little is known about its population distribution. There are inevitable differences in the level of field knowledge and data availability, as well as differences in social, economic, political, historical and biophysical features of the two study sites. The procedure used in both cases however, follows the same logic but was customized to each case based on the availability of data.

14.2.3.2 Zimbabwe Case Study

The Zimbabwe case study was initiated to provide a background population dataset in support of food aid activities following a frequency of droughts and the increasingly unstable political situation in the country causing shortages of food (Schneiderbauer and Ehrlich 2005). It also aimed to provide a background to assess the impact that the re-settlement programs have on the country. The population density available from existing global datasets was deemed not to be appropriate because (1) the spatial resolution is too coarse and (2) the methodology applied did not take into account important country specific population determinants which are historical, physical or socio-economic in nature.

The Zimbabwe case study covers an area in the centre of the country including the capital Harare accounting for approximately 25% of the overall Zimbabwean population. The density is computed for a 150 × 150 m size grid (Schneiderbauer and Ehrlich 2005). The geo-spatial data layers used in the exercise included: elevation, and slope calculated from the digital elevation model derived from the Shuttle Radar Topography Mission (SRTM); land cover derived from Landsat imagery (30 m resolution), secondary data layers such as the woody cover map (1: 1,000,000), the map of protected areas (1:1,000,000), road network, and settlement locations derived from scanned topographic maps available at 1:250,000 scale.

These information layers were used first to mask the regions which are uninhabitable (i.e. protected areas, water bodies) and then used to apply a weight regarding the conduciveness of settlement locations for each land cover type. The allocation of weights to each pixel for the computation of the population potential is based on a number of decision rules. These rules include the respective pixel's land cover/use class allocation, its terrain characteristics and its distance to settlements and the road network. The selection of weighting factors in the modeling process is based on extensive field experience and expert knowledge available for Zimbabwe. The resulting map shows the estimated population densities in a resolution appropriate for activities at district level.

14.2.3.3 The Iraq Study Site

The second population density estimation focuses on northern Iraq (Fig. 14.8). The dataset is part of a more comprehensive study that aims to assess baseline population characteristics as described in Section 14.2.4. This case study benefits

Fig. 14.8 Study area in Northern Iraq

from a settlement location and population number dataset derived from the Rapid Assessment Program (RAP) database. The RAP is part of a situation assessment taken after the second Gulf War in 2003 under the supervision of the United Nations Joint Humanitarian Information Center (JHIC) for Iraq, headquartered in Erbil (JHIC 2006). In order to obtain a population density, the field data are subdivided into two randomly divided halves: the first to calibrate the model and the second to validate it.

The geo-spatial input variables to the population density model for northern Iraq are derived from the Landsat Enhanced Thematic Mapper sensor data and the SRTM dataset. The first dataset is used to derive the land cover heterogeneity, water bodies and to identify built-up areas. The second dataset is used to pre-process the Landsat imagery, correcting spectral errors due to topography, as well as to derive the likely passage of roads. The input grids are normalized for settlement distribution based on the calibrated dataset, they are then incorporated into a linear regression model to test the impact of each on population numbers. A probability weight is assigned to each pixel according to the various input variables using the smart interpolation approach (Mubareka et al. 2008). Figure 14.9 shows the output for the model for both an urban and a rural area, and compares the results to the global scale Landscan product. The population density layer derived from this process is used as one component of the model that aims to characterize population in Iraq through time as the result of the various conflicts in the country since 1974.

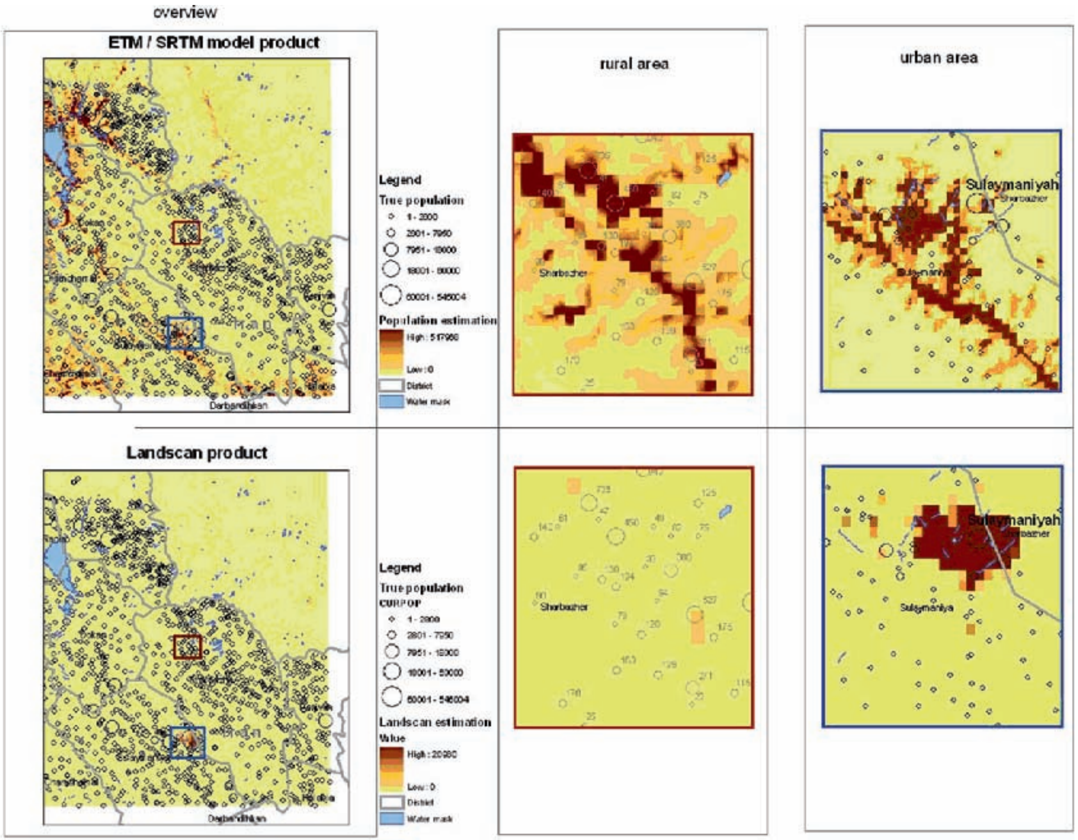

Fig. 14.9 Comparison of the output from global grid databases and finer scale grid produced within this study

14.2.3.4 Future Direction

The scale (resolution) of population densities depends on the geo-spatial information layers used to develop the population potential and from the granularity of the census or field data. Inevitably, the accuracy of the population dataset will depend on the assumption of the determinants of population distribution that are region and country specific. An important step towards the establishment of future population density datasets will be the systematic verification of the resulting population datasets using field survey on population. Methods of verification and accuracy assessment need further research.

14.2.4 The Spatial Component of Population Vulnerability

The characteristics (often referred to as "attributes") of populations are typically recorded in country censuses (Bigman and Deichmann 2000a). As is true for any census data, population characteristics data are usually available at district level. Often neither the scale nor the format is appropriate for fine-scale analysis. For this reason, similar to population density estimations, the characteristics of population can be investigated by disaggregating information using land cover and land use, proximity to roads and infrastructure and other ancillary information.

Population characteristics may change rapidly in time, especially in the aftermath of crisis or natural disasters. The hardship conditions are captured through field surveys that are commissioned to assess needs. Field data is precise and usually of high quality, but expensive to gather and to keep up-to-date. Furthermore it may not always be available thus forcing researchers to rely upon global, extrapolated, and inferred indicators. These surveys may address very specific characteristics, food security, accessibility, nutrition or more general well-being of population that may be captured under the more general term poverty (Henninger and Snel 2002). Within the disaster response community the characteristics of people are often captured using the term vulnerability and its changes over time.

Vulnerability is used widely by both the physical and social sciences and there is no unique definition. Thywissen (2006) compiled a state-of-the art overview of the different terms and in parallel scientific discussions for different methodologies is carried out at operational level (e.g. FAO, WFP, IFRC, etc.) to assess the vulnerability of a system at different scales. For Cutter (2003), vulnerability science helps us to understand those circumstances that put people and places at risk and those conditions that reduce the ability of people and places to respond to environmental threats. Vulnerability science should thus provide a basis for risk, hazard, and disaster reduction policies (Cutter 2003). Additionally, vulnerability can also be defined as a human condition or process resulting from physical, social, economic and environmental factors, which determine the likelihood and scale of damage from the impact of a given hazard (UNDP 2004).

Many aspects of vulnerability have a spatial dimension and can also be measured through Earth Observation. For example, accessibility to services can be measured as the Euclidean distance from households to services and may be used as a contribution to defining the baseline characteristics (Bigman and Deichmann 2000b). Also, risk factors that modify the baseline characteristics of population are geographic specific. These have been referred to as aggravating force or stressor (Cicone et al. 2003; Turner et al. 2003), and also as ‘exposure factors’, ‘hazards’, and ‘root causes’ (Lambin 1994). Land cover or land use and especially changes in these, may provide additional indications measures of vulnerability.

14.2.4.1 The Iraq Study Site

The objective of the case study is to assess the usefulness of EO data in characterising population after a conflict and for assessing its changes during the conflict Indicators based on biophysical features seen with EO tools are used to infer spatially specific population vulnerabilities.

In the first part of the study, field data from Iraq corresponding to information relative to the population prior to the Gulf war (pre-war indicators) are assessed for their links to population vulnerability. A model is simulated using this field data through a stepwise regression process and is validated using the information about the population after the war (post-war indicators). Both pre-war and post-war indicators are available from the RAP database.

Once the significant pre-war indicators derived from the field data are identified, they are sought using remote sensing data. These indicators are modeled and validated using the same post-war population indicator as the field data model. The satellite-driven model is then applied to the study site in northern Iraq for a different conflict situation, the Anfal Campaigns consisting of repeated chemical bombings of the region, occurring 2 decades prior to the Gulf War. The model output is compared to land cover changes which are quantified using Landsat data.

The output consists of three 90 × 90 m resolution grids corresponding to three dates: 1987, 1989 and 2001 (selected based on satellite image availability). The pixel values of the grids correspond to a geographically based vulnerability measure. The data for the year 2001 are taken as a reference because of the availability of ground data. Open source information about the stressors which may have caused changes in the population characteristics for the region, are used to analyze the results.

The results of this study show that the characteristics of population depend on three main variables which can be inferred from EO tools: population density, remoteness, and economic diversity. The population density is a compounded calculation which is discussed separately in Section 14.2.3. Accessibility to services, or remoteness, is another compound calculation which takes into consideration the true distance of grid cells to built up areas, topography and other physical barriers. The third parameter, economic diversity, is estimated by counting the “patchiness” of land cover, inferred as land use heterogeneity. The land cover classification of the Landsat imagery is used for this purpose. A moving filter corresponding to 500 m^2 is passed and land cover types are counted within the filter and assigned to the grid cells. In order to compare the land cover classifications between the different years, seasons and sensors, the images were normalized by applying atmospheric and topographic corrections. A robust feature-based classification method by segmentation is then applied. Using spatial, spectral and thermal information as input to this classification method, important indicators such as dried-up rivers and small towns are identified.

Since the changes in population vulnerability are due to the level of exposure to external agents – the stressors, these factors are quantified within this study and are weighted to evaluate the relative contribution of each. The four factors considered for this study include violence, infectious disease outbreaks, abnormalities in climate and the absence of humanitarian aid. Each stressor is quantified in a method described in detail in Mubareka et al. (2005) and a time line corresponding to the period of study is traced. The variations in the levels of the stressors are compared to the changes in population vulnerability levels measured for the three time periods.

It is observed that the type of change occurring in land cover and land use is linked to the type of stressor affecting the population. For Jafati Valley, the main short-term changes are linked to the abandonment of cropland (due to chemical bombings) and the subsequent transformation of agricultural fields to grassland. Also, evident is a small patch of deforestation in the mountainous areas, indicating displacement of people to those marginal areas. Long term observation of the territory shows reclamation of agricultural fields.

The main stressor for this area is conflict and the areas most affected are indeed those predicted by the spatial population vulnerability model. In another region further North, where the Anfal campaigns were less numerous, the short term changes in land use are negligible but long term changes in land cover show a transformation from vegetation to bare soil. This corresponds to meteorological abnormalities. For this study site, the model was unable to predict the most vulnerable areas.

The main conclusions drawn from this vulnerability study over northern Iraq is that. (1) The more remote populated places in the study site are the less affected by the conflict. This is likely to have been caused by two factors: inaccessibility of the enemy and the ability to survive with few outside resources, even under normal circumstances. (2) The population density is inversely proportional to its level of vulnerability except when in proximity to an urban centre. Sparse populations near urban centers are in fact the most vulnerable population. This output corresponds to the first finding: These marginal areas are highly accessible but do not benefit from the resources available in city centers. (3) Economic diversity is inversely proportional to vulnerability. Villages relying on more than two economic activities are less affected than those with less than two economic activities.

14.2.4.2 Future Direction

Modeling the population characteristics remains one of the biggest and least explored research topics in geo-demography (Deichmann 1996). Estimating population characteristics is as important as estimating population totals or densities. Progress in this area is in high demand and remote sensing just started to be used to address these needs. It is the opinion of the authors that the availability of very high resolution imagery provides the remote sensing community addressing security a new and challenging area of investigation.

14.3 Discussion

Remote sensing information derived from a variety of sensors is used in population estimations. Table 14.1 briefly summarizes a range of Earth Observation data, which have been used to produce information products for population studies referenced herein together with others that may be used for future studies. The table is sorted based on the spatial resolution, which is one of the most important image characteristics as illustrated in Fig. 14.10. While coarse and medium resolution are important for land cover characterization it is the spatial resolution below $10 \times 10\,\text{m}$ that provides improved measurements of built-up objects that can be directly used to estimate population and its characteristics.

The potential for coarse, medium and high resolution imagery for population studies has been largely explored. Coarse and medium resolution data have been used by and large to derive land cover that is used to infer land use and thus the population potential. High and very high resolution data have been used to provide information within built-up areas and thus, subsequently derive population potential and characteristics. These data also enable the identification of transport infrastructure and the determination of the volume of buildings when stereo satellite data are available. All these data layers can be used as a measure for population totals and characteristics.

The detail of the new high resolution imagery provides a set of new challenges to the remote sensing community. Optical imagery at the (sub)meter resolution is extremely voluminous. The voluminous datasets require very efficient algorithms to process them. The image processing of very high resolution optical data is based on new interpretation models where both spectral and spatial components play an important part. Even pre-processing techniques like the ortho-rectification become a challenging task largely due to the multiple viewing angles and variation in flight parameters. Techniques used in the analysis of aerial photography such as automatic matching techniques and/or the use of field data for the rectification process need to be considered. The biggest challenge and opportunity comes from the new radar sensors for which the sensor benchmarking and the development of image analysis algorithm leaves opportunities for the research community. Field data is critical for the transformation from a geo-spatial information layer possibly derived from remote sensing data into a product useful in security since it enables an extrapolation to larger areas.

The opportunities of the new sensors will allow analysts to better address the information needs of the disaster response community and also those of the developing aid community. The most pressing are the need for estimations of population totals at regional and/or country level as well as, their changes over

Table 14.1 Satellites/sensors currently available and those planned to be launched before 2010

Satellite	Spatial res.	Spectral bands/SAR freq.	Lifetime	Best possible revisit rate	EO derived information layer used in population estimations
SPOT/Vegetation	1,000 m	VIS NIR	2000–2008	1–2 days	Land cover and change
DMSP/OLS	1,000	VIS	1973 –>	1 day	Energy use and thus inhabited areas
MODIS	250 m	VIS-NIR-SWIR-TIR	Terra: 1999 – >2006 Aqua: 2002–2008	1–2 days	Land cover, change in LC
Envisat MERIS	300 m (FR)	VIS-NIR	2002–2008	3 days	Land cover and change
Landsat	30–28.5 m	VIS-NIR-SWIR	L.-5: 1984–2006 L.-7: 1999–2004	16 days	Land cover and change
DMC	~32 m	VIR-NIR	2003 onwards	Daily (with 5 sat. constellation)	Land cover and change
ASTER	15–30–90 m	VIS-NIR-SWIR-TIR	Terra: 1999 – >2006	4–16 days	Land cover and change
Formosat	2 m (pan)	VIS-NIR, pan	F. -2: 5/2005–2010		
	8 m (ms)		F. -3: 4/2006–2008/ exp.2011	Daily	Land cover and change
Kompsat	6.6 m (nadir)	VIS-NIR, pan	12/1999–12/ 2004	2–3 days	Land cover and change, built-up density
Rapid Eye	6.5 m (nadir)	VIS-NIR, pan	2007–2014	Daily (with all sats.)	Not yet available
IRS	5, 23.5, 70.5, 188 m	VIR-NIR-SWIR	P4 (Oceansat) 5/ 1999–2004 P5 (Cartosat) 5/ 2005–2011 P6 (Resorcesat-1) 10/2003– late 2008	5 days	Land cover and change, built-up area, density

SPOT	2.5–20 m	VIS-NIR-SWIR	2 and 4 5 until late 2007	1–3 days	Built-up area and density, infrastructure, buildings typology
IKONOS	1 m	VIR-NIR, pan	1999–2008	1–2 days	Built-up area and density, infrastructure, buildings typology
OrbView	1 m	VIR-NIR, pan	3: 2003–2010 5: 2007–2011	<3 days	Built-up area and density, infrastructure, buildings typology
QuickBird	0.6 m	VIR-NIR, pan	2001–2009	1–5 days	Built-up area and density, infrastructure, buildings typology
Pleiades	0.7 – 2.8 m	VIS-NIR, pan	2008–2013	4 days	Ortho-imagery on regional scale
ERS-1 ERS-2	30 m	C band	1991–2000 1995 ->	35	Elevation
Radarsat	12.5 m	C-band	1: 1995–2006 2: 2006->	1–2 days	Land cover and change, Elevation
Envisat ASAR	12.5 m (image mode)	C-band	2002–2008	3 days	Land cover and change, Elevation
Cosmo-Skymed	<1–30 m (flexible mode)	X-band		<8 h in Europe (with 4 sat.)	Built-up area and density, infrastructure, buildings typology
TerraSAR-X	1–16 m (flexible mode)	X-band	2006–2013	2 days (flexible mode)	Built-up area and density, infrastructure, buildings typology
ALOS	2.5 m (optical) 10 m (optical and radar)	VIR-NIR, L-band	2006–2009	2 days (46 normal repeat)	Built-up area and density, infrastructure, buildings typology

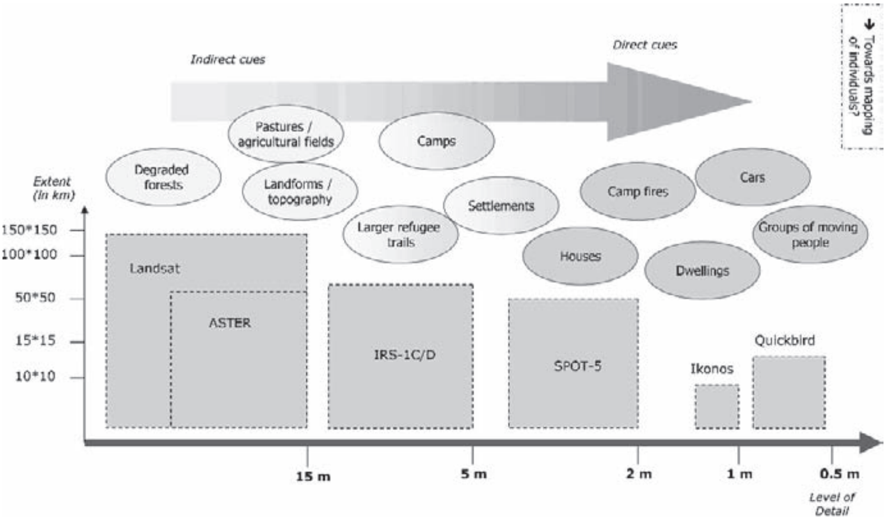

Fig. 14.10 The figure illustrates the relationship between sensor spatial resolution and detectable features on the ground. The latter represent indicators or proxies for human presence (graphic: S. Lang)

time and their characteristics in urban and rural environment. The assessment of the accuracy of the information and the visualization are also important topics to be addressed.

There are a number of regions of the world for which no up-to-date population data exist. For example, in a number of countries in central Africa the planned decadal nation wide censuses have been skipped. This is largely due to conflict situations. These countries are those that experience forced population displacement which makes enumeration and characterization of the population even more important. Earth observation in combination with other geo-spatial data can be used to derive population potential to optimize the location for field surveys by establishing strata that can also be used to extrapolate population figures.

An emerging need is also to be able to provide information about populations within the urban regions of the developing world. These often develop very rapidly and the availability of very high resolution imagery provides a unique opportunity to monitor their growth. VHR imagery not only allows for the monitoring of urban sprawl, but also built up densities and built-up volume. This in turn can be used to enumerate people.

Growth of the area occupied by cities is an indication of in-migration and changes in the use of the land in rural area may be associated with out-migration. Earth observation can be used to monitor changes in land use that can be associated to changing economic activity or out-migration. This also in view of the controversial issue of conflict over land resources – decreasing arable land per capita due to population growth – that is heralded as one of the causes of inter-ethnic violence occurring in the Great Lakes region of Africa.

Country and regional population density and attribute mapping may benefit from a larger number of datasets than those available at global level. Some regions of the world are better censed and have better geographical datasets at their disposal. When deemed necessary and upon requests, ad hoc current and future population densities could be produced for these regions. Satellite imagery, especially the very high resolution imagery could provide information on population counts and densities and identify pockets of underdevelopment even within large metropolitan areas. The methodologies developed should be geographically adaptable to different regions of the world.

14.3.1 Spatial Temporal Characteristics of Population

The need to improve the ability to analyze the characteristics of a population has been stressed before. There are new techniques that should be used including the analysis of the temporal changes in vulnerability. For example, the fine-scale population dynamics in urban environments can be addressed. There are techniques developed that identify human activity units (HAUs) that are fine-scale land-use units, with a given size and object definition (Lang and Tiede 2006). These are used as basic reference units for human presence, the latter being modeled for each specified object category. Every object category gets assigned a graph showing its respective daily pattern of occupancy (DPO). DPO graphs can be weighted and overlaid with additional patterns representing annual population dynamics including tourism or more episodic events such as concerts or football games. These techniques would be particularly suitable to characterize the vulnerability of very dynamic environments such as cities to outside anthropogenic threats.

Scientific visualization is considered of particular importance for communication purposes. In general, 3D rendering could be used for informing both the public as well as specific funding agencies about the severity of a particular crisis, the number of refugees and their humanitarian needs. For example in the case of the refugee camps, showing the different types and specific arrangements of dwelling units may indicate how the camp is organized and socially structured. 3D representations convey a better picture of the overall situation, and as a complement to 2D map products this kind of visualization may be easier to interpret and more familiar to rescue teams and locals. Products can be posted on a browser, which is shaped as a globe, in order to provide the required 3D context on several scales and enable a better understanding of the overall situation (Lang et al. 2006).

The accuracy of population figures generated through modeling is dependent on the quality of the input geo-spatial data layers of the existing census population data and the size of the administrative unit the population data is attached to. In fact, the accuracy of the population data relates to the data collection methodologies, which also varies according to funding availability for the training of surveyors and response from people. Shifts in census tracks and administrative boundaries from one census to the other may create historical inconsistencies. Administrative boundaries are often only vaguely drawn on maps that are often the cause of border disputes. Hopefully, new technologies such as GPS and satellite imagery will help in consolidating administrative subdivisions.

There may be inconsistencies between the application and the population datasets used for the application. For example, the distinction between ambient and resident populations has recently been coined to address the population whereabouts during working hours and at night in their residence (Sutton et al. 2003). Clearly, damages and casualties resulting from an earthquake may vary according to whether it occurred during the day or at night. Therefore, this should be properly reflected in the datasets used.

14.4 Conclusions

By and large, physical and human security addresses population and infrastructure. Within this study we have addressed the need for population data during crisis response and the contribution of remote sensing to address those needs. The review shows that information derived from earth observation has been used and is increasingly being used to derive information on a population and its characteristics that can assist in all crisis response phases. During the alerting process, night time imagery is used to monitor changes in radiance as indicators of a decreased societal functioning. In emergency response, the satellite images often act as surrogates for maps which are unavailable, allowing for the identification of populated areas. During the rehabilitation phase, earth observation-derived damage assessment maps can provide information on the vulnerability of the population and help to assess their humanitarian needs. The availability of more sensors with increased spatial resolution, more frequent repetition cycle and the ability to operate in all weather conditions can only increase the use of these data.

The principal advantage of earth observation over other measuring systems is its global coverage. The global availability of images of the surface of the Earth are assured by satellites and an open sky policy that allows the commercialization of such products and which allows for the visiting and re-visiting of every corner of the Earth, limited only by the life span of satellites. The synoptic capability provides the opportunity to cover large areas with single acquisition providing insight and context. Satellite data provides a standardized datum, although not always easily useable, it provides information on the surface of the Earth. This information can be used to provide up-to-date standardized quantitative information on infrastructure that would also be of use for population estimations.

Despite the potential to generate useful information for population assessments, the EO technology remains by and large under-utilized. Large stocks of data sit in the archives unused. Even when data are made available to researchers as is the case of Landsat, the information products derived provide little added value. A number of initiatives such as the Global Monitoring for Environment and Security (GMES) funded by the European Commission, which addresses rapid response, will hopefully provide the means to enhance the value added to the basic satellite images. This data preparation will be conducted as one of the crisis preparedness activities. Information will thus be at the disposal of the relevant communities, to address future crises more effectively and efficiently. Part of this preparedness will have to deal with population densities and characteristics.

The demand for information on population is increasing. The budget spent by civil society to address humanitarian crises approximates to 2 billion euros (in 2005). The requests to respond to crises in the future will increase for at least two reasons:

1. The Earth's population continues to grow with a large proportion of this growth occurring in those societies that have the fewest resources to make society more resilient to disasters.
2. Populations tend to concentrate in large agglomerations and are often located in hazardous prone regions. Donor fatigue is not new and humanitarian and development funds will need to be stretched to their full extent.

Therefore, we must ask, can we afford to be ineffective or inefficient because of a lack of information on populations?

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Chapter 15
From Real Time Border Monitoring to a Permeability Model

Nathalie Stephenne, Raphaële Magoni, and Giovanni Laneve

Abstract International migration has risen to the top of the global policy agenda (GCIM 2005). This paper assesses the potential use of satellite imagery to monitor flows of people across borders. The objective of this "border monitoring" assessment is to contribute to the development of scenarios on potential future migration through land borders and to develop recommendations for border management. This study begins with an assessment of statistical and earth observation information datasets to monitor border crossing in real time. Due to the unavailability of relevant data, this study evolved towards an indirect definition of migrants' likelihood to cross the border (the border permeability). The permeability model combines earth observation and geo-spatial technologies with formal decision theory to assess the likelihood that a border area may be crossed by an illegal migrant, based on a presumed cost/opportunity behavioural strategy. Two preliminary permeability models were developed on two different areas, the EU-25 land border and the Central African region. The resulting permeability maps help in the overall understanding of illegal migration patterns. In the border monitoring process, they help to identify high permeability areas where change detection analysis can be carried out using medium resolution satellite imagery.

Keywords Illegal migration • statistics • remote sensing • geographical information system • multi-criteria model

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15.1 Introduction

International migration has risen to the top of the global policy agenda (GCIM 2005). The economic, social and cultural benefits and disadvantages of international migration and cross-border movement must be more effectively understood. With globalisation, growing disparities in the standards of living have resulted in an increase in the scale and scope of international migration. Today, one human being out of 35 is an international migrant. According to the United Nations' Population Division, the number of people who have settled down in a country other than their own is estimated at 175 million worldwide (approximately 3% of the world population). It is more than twice the figure recorded in 1980, only 25 years ago. Nearly all countries are concerned by the issue of international migration, whether as sending, transit, or receiving countries, or as a combination of these. States exercising their sovereign right to determine who enters and remains on their territory, have to fulfil their responsibility and obligation to protect the rights of migrants. In controlling illegal migration, states should actively cooperate with one another without jeopardizing human rights (GCIM 2005).

The control of national borders is a key element in sovereignty and national security. In classical realist security studies, border security is usually seen as an issue of power and military order (Ackleson 2003). Sovereignty is the internationally recognized authority of a government over the territory and people it claims to control (Wood and Milefsky 2002). Boundaries have often been understood as neutral lines that are located between power structures (Paasi 2003) or lines that enclose state territories (Newman 2003). But, in fact, the definition of demarcation lines is a physical and social construction of identity (Ackleson 2003). Boundaries are fundamental to the spatial identity of people and social groups by separating "us" from "others" (Berg and Saima 2000), and by creating exclusive spatial entities (Diehl 1999). Moreover, the drawing of these lines is an ongoing social and dynamic construction of the territory (Falah and Newman 1995; D'Arcus 2003).

Borders do not only separate but also mediate contacts between states and localities (Berg 2000). Borders have to integrate the notion of shared territories and permeability (Newman 2000). Permeability is however, most often used as convenient shorthand for trans-boundary collaboration, borderland initiatives, and open-ness (Blake 2000). "Permeability" is a term borrowed from the physical sciences where it is a measurable process. Permeability is a magnetic or geological property that measures the ease with which a flux goes into a material. By analogy, boundary permeability is the product of the barrier characteristics of the boundary (the outcome of legal, geographical, historical and social factors) and the pressures on the boundary from people, goods, capital, ideas, and so on.

The huge amount of "border drawing" or "territory disputes" studies illustrates the scientific interest to better understand these border lines. Blake (2000) studied 309 land boundaries and pointed out that 52 among them illustrate territory disputes. Scientists have a responsibility to better define, and measure these highly politically sensitive dimensions of borders (Paasi 2003) especially in light of new opportunities offered by measurement instruments like Earth Observation (EO) that have recently been providing unthinkable precision and processing tools like geographical information systems (GIS). The availability of these new GIS technologies provides a new opportunity to address border issues in a quantitative way. Starr (2000) identified advantages of using GIS such as, georeferenced dataset and spatial analysis tools in investigating the permeability of borders in the Israeli dyads or militarized confrontations. This study is the first systematic use of spatial and localized information on the nature of the borders extracted from vector and raster datasets. Starr and Thomas (2001) used this technology to define three variables called (i) ease of interaction, (ii) salience and (iii) border vitalness, in addition to two new concepts of opportunity and willingness.

The challenge of these border studies lies in the support to political decision makers and in the effort to politically manage the threats to the general security paradigm. Resulting from the GMOSS border monitoring working group, this paper addresses the potential use of satellite imagery to monitor flows of people across national borders. The objective of this "border monitoring" assessment is to contribute to the development of scenarios on potential future migration through land borders and to develop recommendations. This study begins with an assessment of statistical and EO information datasets to monitor border crossing in real time (Section 15.3). Due to the unavailability of relevant data, this study evolved towards an indirect definition of the migrants' susceptibility to cross the border: the border permeability.

The flow of people crossing a particular border is proportional to the geographical permeability of the type of border area, but also to the driving force defined by people's willingness to cross this border. The spatial models presented in this paper refer only to the first part of this flow – the geographical border permeability. These models could be used to test different assumptions on geographical driving forces of migratory flows in political scenario analyses. The permeability model integrates earth observation and geo-spatial technologies with formal decision theory to assess the likelihood that a border area may be crossed by an illegal migrant, based on a presumed cost/opportunity behavioural strategy. Two preliminary permeability models were developed on two different areas, the EU-25 land border and the Central African region. Scales, resolutions, hypotheses and methods differ when their decision support goals are similar. These spatial support decision tools are built either to optimize EU investments in the field of migration policies, or to implement stability measures in less accessible areas.

15.2 Areas of Study

Permeability border assessments were built in two thematically and technically different contexts: (i) the European, and (ii) the Central African level. The permeability assessment for the enlarged EU border, has been carried out to identify potential future hot spots for migration inside the EU, scenarios of changes in border crossings linked to political decisions as well as potential trafficking routes. The Central African case study focused on six countries: Kenya, Uganda, Tanzania,

Table 15.1 Legal border crossings to selected Central and Eastern European Member States (thousands) in 2004 (Adapted from ICMPD 2005)

Country	No. of entries
Czech Republic	131,691
Hungary	54,193
Estonia	8,195
Latvia	5,500
Lithuania	6,199
Poland	98,330
Slovakia	46,482
Slovenia	94,073

Table 15.2 Refugees in selected African countries (UNHCR 2004)

Country	No. of refugees
Kenya	239,835
Uganda	250,482
Rwanda	50,221
Burundi	48,808
DRC	199,323

Rwanda, Burundi and the Democratic Republic of Congo. The permeability assessment illustrates data issues as in some rather inaccessible places, satellite imagery is usually the only provider of quantitative and homogeneous information.

The research began with collecting reliable data on legal (Table 15.1) or illegal migration and border crossings (ICMPD 2005). To this end, the quality of existing EU datasets on migration has been assessed (Magoni and Pesaresi 2004). According to the United Nations High Commissioner for Refugees (UNHCR 2004), Africa has over 4.2 million refugees (Table 15.2.). Due to the magnitude of these refugee flows on the African continent and the difficulty to find reliable statistics on legal and illegal migration in Africa, the Central African analysis dealt more specifically with refugee movements, rather than examining migration flows in general.

15.3 Data Analysis

15.3.1 Statistical Databases

Data on migration and asylum were collected from a wide range of sources, including international organisations such as the OECD, UNHCR, NGOs (Migration Policy Institute) and European agencies like Eurostat (New Cronos database). A distinction was made between primary and secondary sources of migration statistics. Primary sources were defined as entities which collect and gather firsthand information, for example by carrying out censuses and surveys. There are few primary sources of information in the field of migration, the main ones being governments and the UNHCR. Secondary sources include entities which bring together and use data provided by primary sources of information. These organisations usually provide interpretation and primary analysis of the data (e.g. Eurostat, OECD).

Reliable and comparable data on migration can be difficult to find for the following reasons:

- Migration flows fluctuate rapidly
- Information on migrants is often derived from sources with other objectives (e.g. population registers), therefore, the data is often inaccurate
- It is impossible to determine precisely the number of illegal immigrants entering a country
- Countries have a different definition of the term "immigrant" (based on nationality, country of birth, duration of stay, etc.)
- Not all countries consider asylum seekers as immigrants

These data cover topics such as stocks and flows of migrants, asylum applications, acquisition of citizenship (etc.) in the old and new EU Member States as well as in other countries. The databases detail as variables, the countries and years covered. They have been described and qualitatively assessed according to the following criteria: geographical range, time range, comprehensiveness (i.e. "internal quality") and coverage of the EU countries (Magoni and Pesaresi 2004). The analysis also evaluated the extent to which the data was kept up-to-date. A score was subsequently granted to each database ("overall quality") (Fig.15.1).

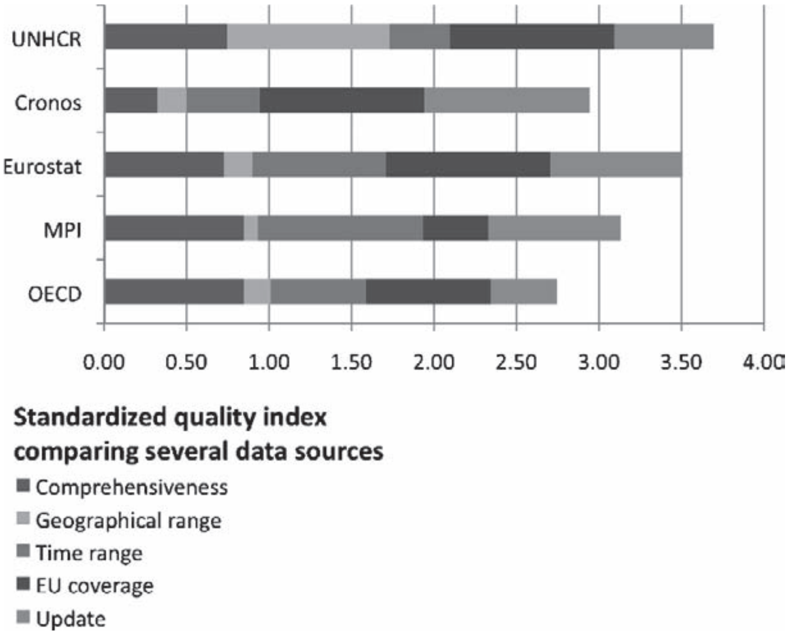


Fig. 15.1 Quality scores of statistical databases

The assessment of these five major data sources concluded that current statistical data on migration are rather unsatisfactory. The information required to carry out a border permeability assessment could not be readily extracted from these sources. Official migration statistics lacked comprehensiveness and did not provide a complete picture of migration trends. Furthermore, the differences in data sources and migration definitions at national level lead to problems of comparability. Quality problems also emerged, which included a lack of suitable documentation to assist in the correct usage of the statistics, incomplete or missing data, errors and inconsistencies. These elements prevented a thorough analysis of migration patterns and trends, as well as the identification of the causes, and the projection of future potential movements.

15.3.2 Survey

In order to carry out an improved border permeability assessment and to evaluate the level of illegal flows across the border, additional information has been gathered through a survey. A questionnaire (Annex) was sent to the border control authorities, mainly the CIREFI Contact Points, of the new Member States of Central and Eastern Europe: Estonia, Latvia, Lithuania, Poland, Slovakia, Hungary and Slovenia. All countries except Estonia replied to the questionnaire. The quality of the answers received varied greatly among the different countries, but in some cases, they included statistical data and even detailed maps of the country. When suitable information was not available from the answers provided, the data presented was extracted from a publication of the International Centre for Migration Policy Development (ICMPD 2005).

The questionnaire collected information regarding the various entry points into the EU territory, the way in which they are guarded, and the numbers of border crossings (goods and people). Information on the level of illegal flows across the border and the means used for crossing is generally not available from open sources, and when it is, it is usually out-of-date. The questionnaire was therefore, a means to obtain first-hand, updated information to gain a better understanding of the situation regarding migration to, and through, the new Member States. Unfortunately, the data provided by the different Member States was often incomplete or inconsistent, which made comparisons between countries difficult.

The total length of the EU-25 eastern land border is over 6,000 km. The 20 countries of this area are represented by 18 segments of sharing borders (two different neighbours).The border situation of the countries examined is very diverse: it ranges from Poland, which has an external border of 1,140 km with three different countries: Belarus, Ukraine and Russia (Kaliningrad Oblast); to Slovakia, which has a relatively small external border with Ukraine (less than 100 km); or Hungary, which shares a border with four non-EU countries, namely: Ukraine, Romania, Serbia, and Croatia (more than 1,100 km in total). Consequently, the number of external entry points, and more generally, the vulnerability of the external land border, varies greatly from country to country.

The number of entry points also depends on the existing transport infrastructure network in the border region. Border Crossing Points (BCPs) at the land border are classified as road BCPs or railway BCPs (Table 15.3). In addition, the countries examined have airport BCPs and some of them also have sea BCPs and pedestrian BCPs. Since the main direction of migration is from East to West, it can be assumed that all border sections are submitted to a certain amount of "pressure" from states outside the EU.

The evidence gathered by the survey suggested that border controls at the Eastern land border influence the number of border crossings, although it is clear that their effects are not uniform across countries. In particular, undocumented or illegal migration eludes statistical accounting and, when information is available, it is usually scarce. The statistics provided by this survey belong to different aspects of illegal migration (e.g. apprehended migrants, trafficking in human beings, forged documents, removal of migrants). If the lack of data prevents direct comparison between

Table 15.3 Number of guards and BCP points based on JRC survey

Country (total number of border guards)	Official BCPs
Latvia	Not available
Lithuania (490)	Kena-Gudagojjs BCP (rail)
	Medininkai-Kamenyj Log BCP
	Raigardas-Privalka BCP
	Šalčininkai-Benekainys BCP
	Kybartai-Černyševskoje BCP
	Kybartai-Nesterov BCP (rail)
	Nida-Morskoje BCP
	Panemunė-Sovetsk BCP
	Pilies BCP
	Molo BCP
	Malkų BCP
	Vilnius Airport BCP
	Kaunas Airport BCP
	Palanga Airport BCP
	Zokniai Airport BCP
Poland (933)	Bezledy-Bagriatonowsk
	Kuznica Bialostocka-Bruzgi
	Terespol-Brzesc (road and rail)
	Hrebenne-Rawa Ruska
	Medyka-Szeginie
Slovakia (300)	Not available
Hungary	Not available
The total number of guards on duty at one BCP depends on the season, the time of the day and the features of the terrain	
Slovenia (609)	3 BCPs at outflow of river Dragonja
	5 BCPs around Starod
	8 BCPs near Obrežje
	9 BCPs between Gibina and Središče ob Dravi

countries, the countries surveyed have one common point. The vast majority of illegal crossings take place at the border sections between the crossing points (the so-called "green border"), and are therefore discovered there. In Slovenia, approximately 90% of illegal entries occur at the green border. This element gives argument to assess the permeability of the EU external land border, and to combine existing information (in particular, physical aspects of the border) in order to develop a deeper understanding of the local characteristics and potential vulnerability of the green border.

This survey also identified corridors of migration that can be compared to the spatial permeability maps. The "Balkan Route", which runs through Slovenia, is the avenue via which migrants look for a better life in Western Europe. The majority of illegal migrants enter Slovenia from Croatia in the Ormož and Ljutomer regions with the intention of going to another country, primarily Italy. They are usually smuggled across Slovenia through the green border, or through official BCPs with the use of forged documents. The survey explained some of these routes with geographical driving forces. Slovakia is one of the smugglers' favourite routes due to its geography: the heavily forested and mountainous border is difficult to control and, once across, smugglers only have a short journey to the Austrian or Czech borders.

15.3.3 Earth Observation Information

A border monitoring system requires (i) detection of people and vehicles approaching the border, (ii) identification of exact figures of people and vehicles, and definition of a suitable response, and (iii) support to the security forces' response with adequate data and communications. Time is the most crucial parameter of these monitoring systems. The system must detect potential crossings in advance to provide the adequate response and to set up the sequence between detection, identification, and reaction. The actual distance between the border and the detected object varies according to the object's velocity and the type of terrain. An ideal sensor system would detect approaching objects and identify them at the same time. A variety of standard sensor technologies can be used to detect different types of objects (Table 15.4). But the identification (ID) of a target requires much higher resolution than just detection of said target (Table 15.5).

Table 15.4 Objects to be detected and potential useful sensors

Objects	Sensor
People	Cameras, radar, thermal imagers, barrier sensors, seismic, acoustic, chemical sensors, weight sensors, dogs, infrared (IR) break beams
Vehicles	Cameras, radar, thermal imagers, barrier sensors, seismic, acoustic, chemical sensors, weight sensors, dogs, magnetic sensors, IR break beams
Aircraft	Aircraft radar, cameras, thermal imagers, acoustic sensors
Boats	Boats radar, cameras, thermal imagers, acoustic sensors, barrier sensors
Tunnels	Tunnels active or passive acoustic sensors, barrier sensors, magnetic sensors, electromagnetic sensors, ground penetrating radar, gravimeters

Table 15.5 Typical requirements for resolution (in meters)

Target	Detection	General ID	Precise ID
Aircraft	4.5	1.5	1
Surface ships	7.5–15.0	4.5	0.6
Vehicles	1.5	0.6	0.3

Satellite images can be used to monitor changes in infrastructures such as roads, large buildings or facilities, vegetation patterns and trails in border areas. But the operational use of these synoptic and repetitive aerial images to detect marks or traces left by possible intruders is a completely different target. This study has specifically assessed the use of these data in the objective of near-real time monitoring of land border crossing by migrants at the Iraq-Saudi Arabia border. Although Very High Resolution (VHR) resolution (from 1 to 0.6 m) sensors are potentially useful for the identification of people crossing, the limited swath (around 10 km) of the satellite sensors (IKONOS, QuickBird, EROS, etc.) are unsuitable for the monitoring of long borders like the 6,000 km EU25 land border. Because of the time that is necessary to repeat the observation at the same location (i.e. the "revisit time"), which ranges from 12 h to several days, these images cannot provide an exhaustive coverage of a wide area over a range of dates. Moreover, for those sensors whose revisit time is within an acceptable time frame, such as the very high-resolution satellite IKONOS (1.5 days), the delivery of the requested images is 60 days. Because of these reasons, medium resolution sensors have been seen as alternatives to VHR in this border monitoring assessment.

Gupta and Harris (1999) detected changes in human trails and apparition of military encampments on two panchromatic SPOT images (10-m resolution) during the 1991 Gulf War at the Iraq-Saudi Arabia border. Numerous trails attributed to the civilian traffic of Bedouin Arabs can be identified near the town of Ash Shubah on the first 1990 image (Fig. 15.2). On the second image, taken on the 29 January 1991 (i.e. almost 2 weeks after the beginning of Operation "Desert Storm"), nearly all of the Bedouin trails have disappeared and new camps can been detected along the Tapline road up to the border (Fig. 15.3). Two new unpaved roads can be identified leaving the Tapline Road towards the border. These roads can be seen as corridors of transit through the border. These results of a well localised area cannot be applied easily to detect potential crossings on thousands of kilometers of borders. However, this study tested the potential use of ASTER images (15-m resolution) to detect and monitor roads and tracks in a potential route of migrants at the Iraq-Saudi Arabia border.

Comparison of the same two images (2000/2001) illustrates differences in trails crossing the Iraq-Saudi Arabia border (Fig. 15.4a and b). In particular, the so-called "secondary tracks" in the first image (Fig. 15.4a), either disappear or become much fainter in the more recent image (Fig. 15.4b). This can be interpreted as a reduction in the use of these paths to cross the border during the 2-year span. Since the main track crossing the border also appears less marked (while the other main track is more evident), it could be assumed that the traffic across the border has moved to other routes during the considered period of time. As in this case, satellite images of

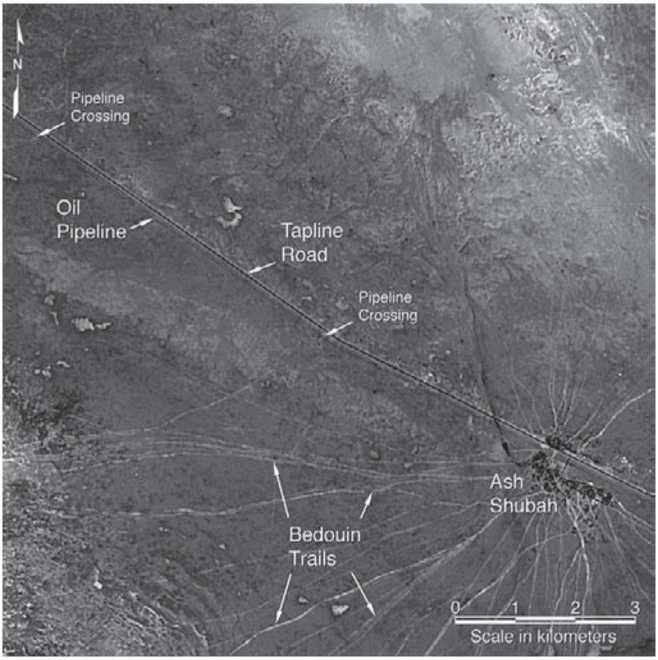


Fig. 15.2 SPOT Satellite view of Ash Shubah Area (Gupta and Harris 1999)

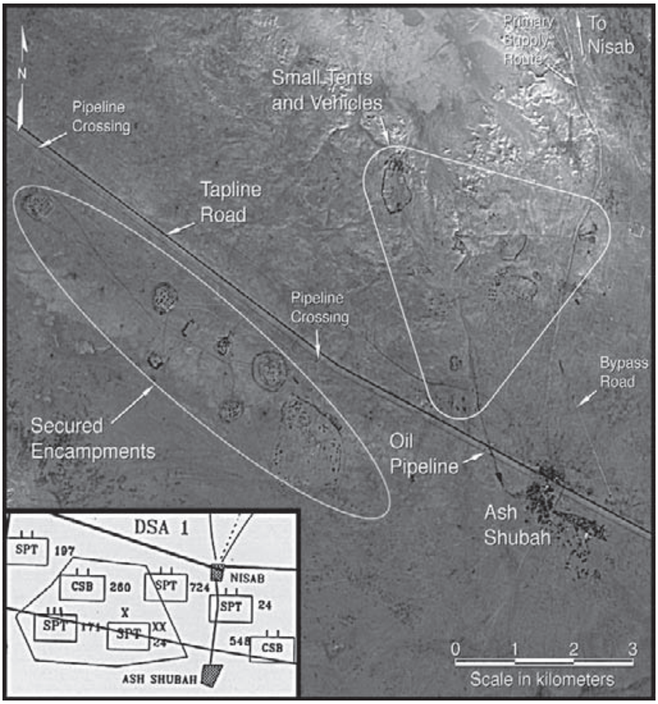


Fig. 15.3 29 January 1991 SPOT image around Ash Shubah (Gupta and Harris 1999)

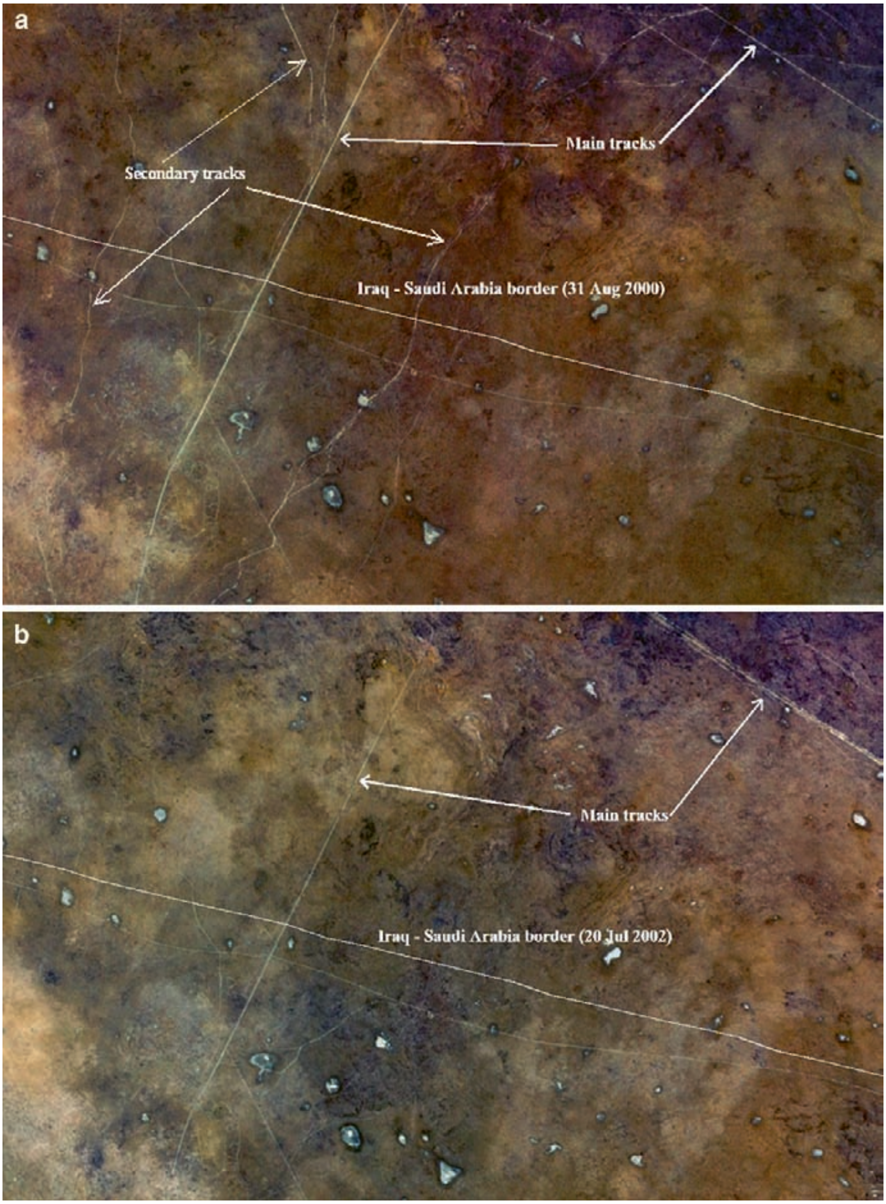


Fig. 15.4 (a and b) Comparison between two TERRA/ASTER images (15 m spatial resolution) covering a portion of the Iraq – Saudi Arabia border 2 years apart

specific border areas could then be periodically evaluated to see if smugglers have changed their preferred routes. An evaluation would be particularly useful after storms have changed the surface of the ground. This information can be useful for security forces in order to adapt their operations to the threat.

From this assessment, current revisit and acquisition time of satellite imagery is not yet suitable for an overall real-time monitoring of all the borders around the world. However as seen in this study, in specific cases where the potential migration routes have already been defined, imagery comparison can be used to detect and analyse the changes in migration patterns. From the example of borders in desert areas scrutinized with satellite images at medium resolution (SPOT: 10 m, ASTER: 15 m), remote sensing imagery allows the detection, and in some cases the recognition, of vehicles and people. These data can then assist in the planning and operation of a security system by confirming or denying the location of trafficking routes.

15.4 Permeability Models for the Two Study Areas

If data provided by satellite imagery cannot be used directly during real-time monitoring of wide areas, these data can nevertheless be used indirectly in the analysis of the potential flow of people at the borders, via their integration into a spatial conceptual model of border permeability. Our modeling experience is based on the hypothesis that the flow of people across a border in a particular location is proportional to the geographical permeability of the crossing point. Knowing that migration is also driven by people's willingness to cross, the spatial quantitative simulation model of permeability represents only the geographical driving forces of migration. It is important to note that a model is always a theory based on assumptions, which represents reality for some purpose (Spedding 1988). The objective of building a simulation model is to use this tool to generate "what-if" scenarios to explore hypotheses on the relative roles of geographical driving forces of migratory flows, optimize EU investments in the field of migration, or to improve the implementation of stability measures in less accessible areas such as in the Central African context. Defined with the same objectives, the two modelling approaches differ in method. While the EU-25 model is based on a multi-criteria approach with the adoption of fuzzy logic rules for the formalisation of the criteria, the Central African model refers to the classical Boolean choices (i.e. 1 or 0/true or false), taking into account slope, soil type, land cover and total population.

15.4.1 The EU-25 Border Permeability Model

The EU-25 border permeability model built by the JRC is based on fuzzy multi-criteria geo-spatial data integration. With the present release the model uses as input more than 20 spatial datasets ranging from satellite remotely-sensed data, land cover (Bartholomé et al. 2002), GTopo30 digital terrain model (Verdin and Greenlee 1996), ERA-40 weather conditions forecast (Simmons and Gibson 2000), LandScan population (Dobson et al. 2000), infrastructures and water bodies – Gisco (2006), Esri Basemap (ESRI 1999), Global Discovery (Europa Technologies 2006) – and presence of border points (adapted from JRC survey results). Based on the locations of the Border Control Points (BCP) provided by the survey, this dataset has been completed using the main crossing points on the roads and railways vector datasets. The Geographical Information System technology is used to integrate and combine different types of data into a common system. Standardization methods used are the unambiguous spatial reference (LAEA/ETR89), the aggregation at the same resolution of 1 km, rasterization of the vector dataset based on the density of features in neighbouring grid cells (Fig. 15.5). The European Terrestrial Reference System ETRS89 has been accepted by the National Mapping Agencies (NMAs) and the scientific community as the most appropriate European geodetic datum for continental spatial referring tasks (Ihde et al. 2000).

The model focuses on the permeability related to a standard adult person crossing the land border illegally on foot. The basic criteria implemented in the current release are built around three concepts: the walking speed allowed by the terrain and the weather conditions (walk), the possibility to be hidden by the physical environment (hide), and the probability to be stopped by a border police agent (secure). The three concepts refer to three criteria derived from GIS layers. The general friction combines the three in the multicriteria analysis using a buffer zone as a constraint. The simplest choice of equal weights for each criterion, is used as a pilot test in order to increase the understanding of the basic rules of the model. However, other weighted combination defined by a pair wise comparison matrix can be used to build spatial analysis scenarios.

In the present release, the model quantifies border permeability in cells of 1 × 1 km, along 6,000 km of border between Norway in the North and Greece in the South. It allows calculating permeability statistics related to specific spatial contexts around the border lines (from 1 to 50 km) aggregated at the national and sub-national levels between different countries. Interesting results came out of the regional analysis of frictions calculated for each border segments in three buffer zones: (i) 50 km, the "geographical friction" that represents 1 day of walk from the border, (ii) 5 km, the "vicinity friction", the last hour of walk for the migrant, and (iii) 1 km, the real difficulty at the "border line". For each segment of land border, the mean friction is calculated in the three buffer zones.

The three types of friction according to the buffer size always increase from the geographical context to the border line. In that pattern, the model works logically as it considers that it is easier for a migrant to move in the area around, than in the 5–1 km on each side of the border line. The increasing trend of the accessibility friction and the decreasing trend of the secure friction have a compensative effect. No clear trend can be identified in the mean frictions for the countries ranked from the South to the North (Fig. 15.6). From these values, there is no big difference in permeability between the 18 boundary segments, but the existing differences illustrate some specific patterns of security concern. For each border segment, the three friction values differ from each other by about 10 scores, except in four cases: Greece–Turkey, Ukraine–Hungary, Latvia and Russian Federation–Norway. For these segments, the major difference is between the geographical context and the two other buffer sizes. The border line friction is also a bit higher than the friction

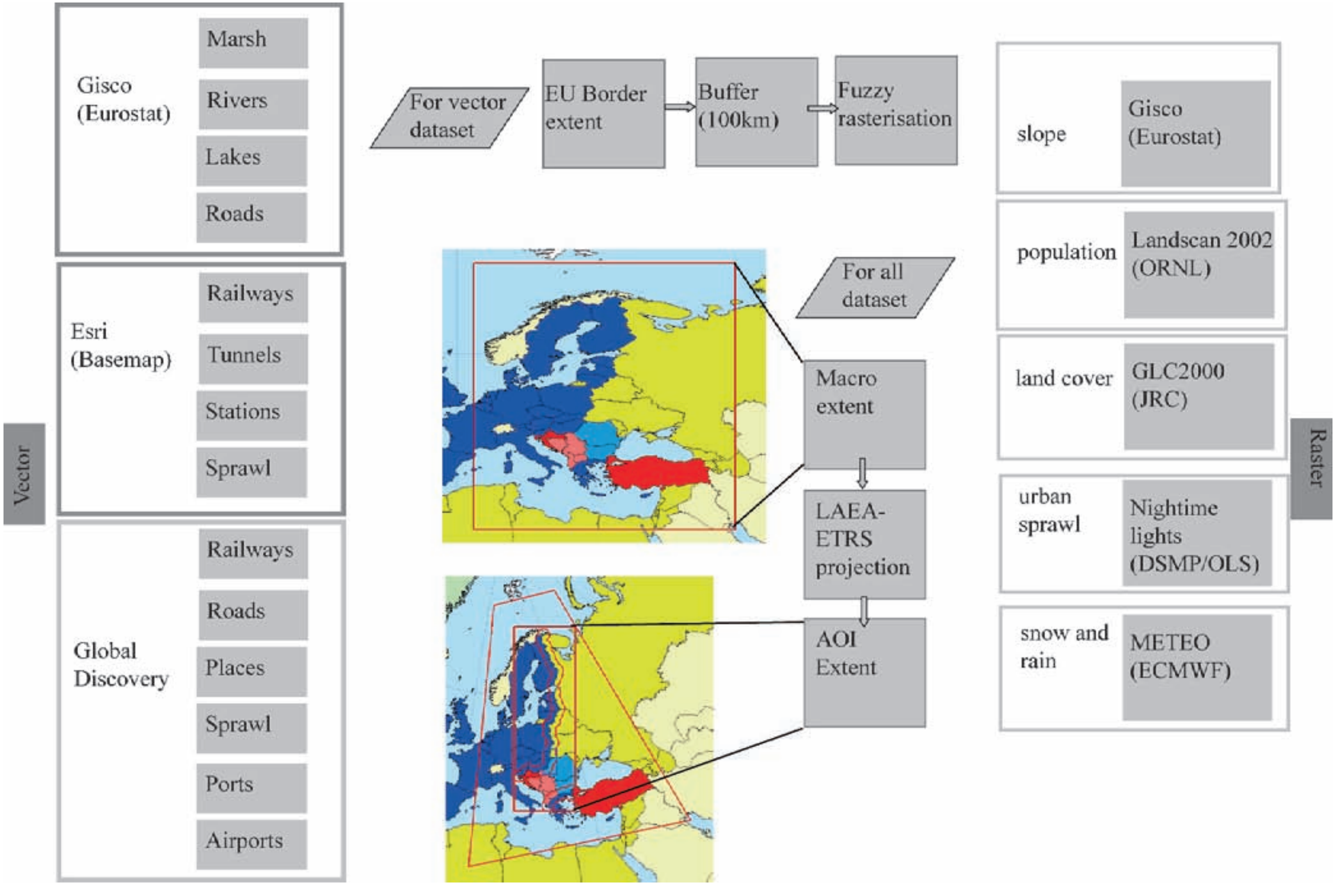
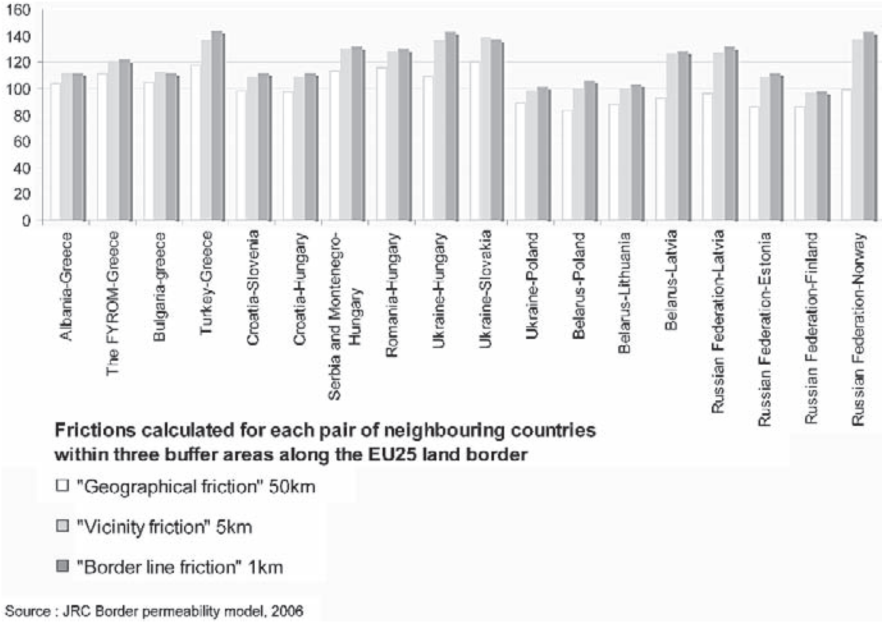


Fig. 15.5 Dataset standardization in the EU-25 BP model



Source : JRC Border permeability model, 2006

Fig. 15.6 Average friction values (inverse of permeability) for the 18 border segments along the EU-25 permeability model in the three buffer zones (1, 5, 50 km)

in the vicinity of the 5 km. For these four segments, the protection at the border line seems adequate. As these boundaries have been illustrated in the third criteria, it is mainly the number of border points that creates this level of protection. A scenario analysis based on the number of border points or the quality of the policing capacity could be a way to understand these specific patterns better.

The lowest level of friction is calculated for the Finnish border, mainly for the friction in the geographical context. The specific case of the Russian Federation–Finland border is a complementary explanation of the three criteria. This border can be seen as permeable for the migrants that can escape easily from the low number of border control points. The natural protection of the border shown by the high values in the accessibility friction is overwhelmed in the general friction. The highest values can be seen in four segments and these patterns are very interesting to scrutinize (Fig. 15.7). The Ukraine border sections with Slovakia and Hungary present high levels of friction for potential migrants. The Ukrainian border has been seen as one of the major entry routes into Europe. The northern border of the EU-25 line is the corridor of Norway that is an important crossing point because Norway does not belong to the Schengen area but is located in Europe, and entering through Norway can be seen as an easy option. This is not true according to the results of the model. With a high friction in accessibility and a low level of hide friction, the resulting overall friction for the migrant remains high for this border segment. This border seems to be well protected. This cluster of high level friction

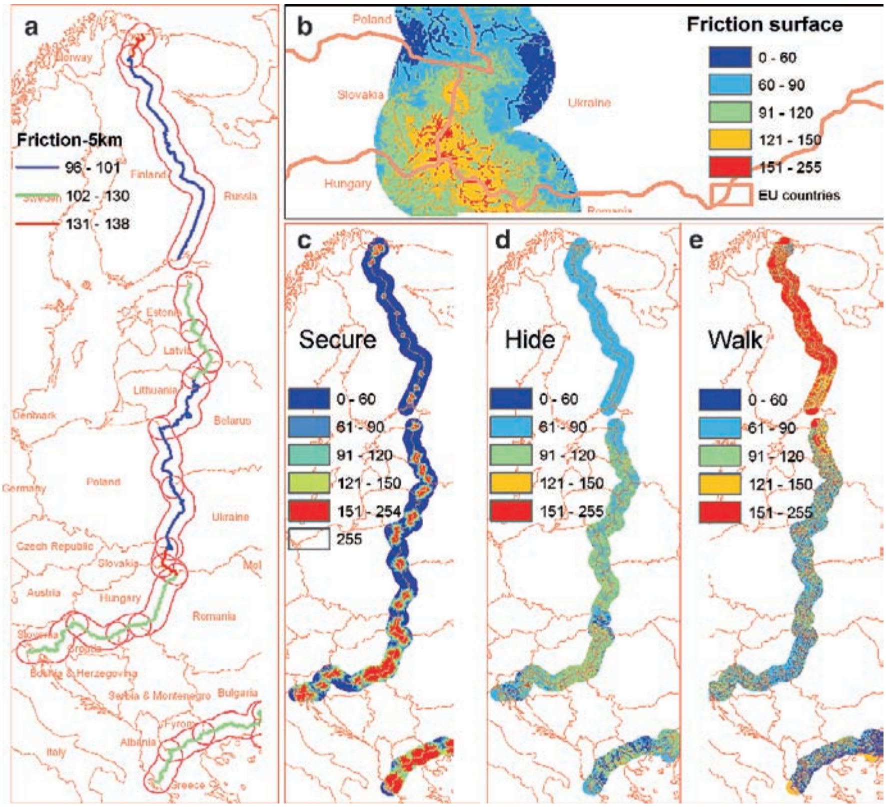


Fig. 15.7 (a, b, c, d, e) Border friction of the EU-25 (a) the vicinity friction – 5 km buffer, (b) friction surface at the Slovakia–Ukraine segment, (c) "secure" friction (max = 255 at the border points), (d) "hide" friction, (e) "walk" friction

results mainly from their pattern in the third criteria that is clearly linked to the number of border control points and then the attention of the border authorities on these particular segments. High levels of friction are detected at the Turkish section of the Greek border where the border line friction is particularly important. This is also a potential corridor of migration.

15.4.2 The Central African Permeability Model

The Central African model defined border permeability on the basis of the ease with which a border can be crossed in a study site limited to the areas stretching 100 km inside and outside each country border. Border permeability is spatially defined in two steps; firstly, by characterising the observable areas (i.e. those that can be seen from remote sensors such as satellites) and secondly, by selecting among these zones the accessible ones (i.e. appropriate areas for border crossing on foot). The final permeability reflects the ease with which the border can be crossed by an illegal migrant, taking into account slope, soil type, land cover and total population (Fig. 15.8). Three main datasets were used in the analysis, all of which are either direct products of remote sensing (RS), or derived from elements of RS: the Landsat based FAO/AFRICOVER land cover dataset, the radar derived NASA SRTM DEMs and Landscan 2002 gridded world population from Oak Ridge National Laboratory (ORNL).

Each dataset was reclassified to take into account the walking choices of a migrant. The 50 AFRICOVER land cover classes were weighted according to the difficulty to walk (from one-difficult to five-very easy). Roads are extracted from this land cover dataset and incorporated in border permeability with a buffer of 10 km to define the relatively more accessible areas. The percentage (%) of slope, defined as "Rise/Run * 100", is extracted from the SRTM DEMs. For the whole study site, values in the slope dataset ranged from 0–64%. For slope reclassification considering accessibility, the following values were assigned: 0–5% as very easy, 6–10% as easy, 11–15% as moderate, 16–35% as difficult and 36–64% as very difficult. For border crossing, populated areas and urbanisation were assumed to be a hindrance (detection) to illegal crossings. The Landscan gridded population (people per kilometer) has been reclassified by assigning the following weights: 0–5 as

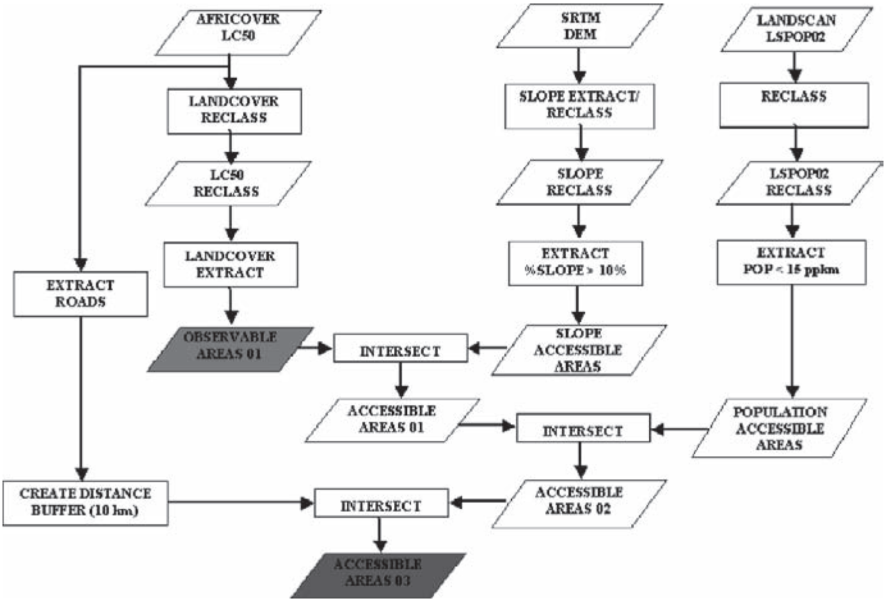


Fig. 15.8 Spatial data processing in CRPSM border permeability model

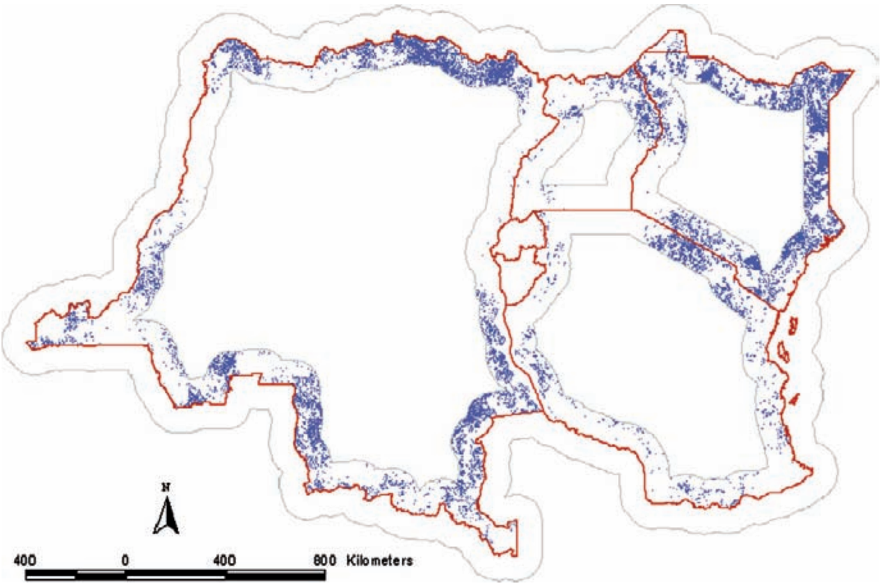


Fig. 15.9 Border permeability in Central Africa taking into account: slope (SRTM), land cover (Africover) and population density (Landscan)

Very Easy, 6–15 as Easy, 16–50 as Moderate, 51–100 as Difficult, 101-highest as Very Difficult. The accessibility maps (Fig. 15.9) resulting from this assessment illustrate the potential of these spatial modeling analyses. This classical Boolean overlay of reclassified dataset provides clues to target more interesting areas that can be studied with satellite images.

15.5 Discussions

Model and theory building cannot be extensively validated but they can be thoroughly tested by comparing the sensibility of the results in different contexts and simulations (Toxopeus 1996). The application of the same border permeability theory in two distinct frameworks has already illustrated the interest of this approach in the overall understanding of migration patterns. The tests of robustness carried out in this study are mainly based on the logic of the models behaviour, a more complete robustness assessment by scenario analysis can be carried out as a follow up to this activity. As illustrated in the data analysis, it is impossible to obtain real ground truth information to check the validity of the index of border permeability. However, some of the results of our two permeability indices have been corroborated by the information available. The permeability of EU border segments identified illegal migration corridors reported in statistical studies. At the Kenya-Somalia border, high permeability values have been calculated in areas where changes have been detected on ASTER images.

Two models have been built using different processes, from the complex fuzzy definition of the EU-25 permeability using 20 datasets, to the Boolean approach of the Central African region using only 3 datasets. Comparison of advantages and disadvantages of these two complementary assessments has to be further investigated, for example in an application on the same region. Multiple resolution analysis and remote sensing or field studies can help in the validation and comparison of these models.

Models are always based on simplifications. Building a model implies making choices, and any use of this tool requires a real awareness about all the assumptions. The current version of the permeability models quantifies the friction in cells of 1 × 1 km on the average capacity of an adult person walking across the green border. The qualitative survey analysis brings some clues that the illegal walking pattern through the green border is an actual behaviour. The migration patterns revealed at the 1 km square resolution can only represent a spatial abstraction taking into account a variety of geographical driving forces. No real figures on the number of migrants crossing the border can be extracted from this study, this paper only proposed spatial differences in border segments permeability.

Because of its modular and multi-criteria approach, the EU-25 model has an open logical frame that can be extended (with additional work) covering other basic options like different types of people using different moving strategies or deciding to cross the sea border. If they could be provided by official sources, additional data input, like the presence of special control devices along the border (fences, electric sensors), or the legal constraints related to border crossing could be integrated as additional criteria contributing to refine the overall model. In close collaboration with border management decision makers, future work could be dedicated to the improvement of the model. This understanding can further be used to build some “what-if” scenarios about the assessment of the impact of EU development or migration policies.

15.6 Conclusions

The core idea of developing a border permeability model for a synoptic view of border characteristics has been suggested to overcome the unavailability of relevant statistical and remote sensing information in monitoring long borders. The concept of “Border Permeability” was defined in strict cooperation in the two distinct study areas. The permeability maps which resulted from these assessments, illustrate the high potential of these spatial modeling analyses in two objectives. Firstly, the continuous map of permeability values allows a comparison of border segments and a regional analysis of the geographical driving forces of illegal migration. This product helps in the overall understanding of illegal migration flows. Secondly, permeability maps can be seen as a first step in the border monitoring process. In identifying high permeability areas, this method identifies areas where the change detection analysis can be done with satellite imagery.

Annex: Questionnaire

1. Where are the main external (i.e. from outside the EU) entry points located? Please provide names of places and if possible geographic coordinates.
2. Are these entry points guarded? If so, how many guards are there?
3. Are any special devices (walls, electric fence, radar alarm devices, etc.) used along the external border? If possible, please provide a map of them.
4. Is there any form of co-operation with guards/authorities of the neighbouring third country? In cases where there is a border with another Member State or with more than one third country, is there co-operation with guards/authorities of that other Member State and of the third countries concerned?
5. Based on your experience of co-operation with guards/authorities of the neighbouring third country, how would you assess their efficiency: A – inefficient or mostly inefficient; B – partly inefficient; C – globally efficient; D – efficient; E – very efficient?
6. Are you aware of the existence of organised trafficking of (1) arms, (2) human beings, (3) drugs, (4) goods? If so, do you consider that trafficking occurs: A – constantly, B – often, C – occasionally, D – seldomly, E – never? (please provide an answer for each type of trafficking).
7. What are the most used illegal entry points? Please provide statistics regarding entry of goods/persons, including nationality and means of transport, if available, otherwise qualitative description.
8. What are the most used illegal border areas (green lines)? Please provide statistics regarding crossing of goods/persons, including nationality, if available, otherwise qualitative description.
9. How many people are sent back from the most used legal entry points to their country of origin? Please provide statistics including nationality and ground for refusal, if available.
10. What are the most used legal entry points? Please provide statistics regarding entry of goods/persons if available, otherwise qualitative description.
11. What are the most used means of transport at legal entry points (rail, road, car, bus, boat, etc.)?

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Chapter 16
Rapid Mapping and Damage Assessment

Bert van den Broek, Ralph Kiefl, Torsten Riedlinger, Klaas Scholte, Klaus Granica, Karlheinz Gutjahr, Nathalie Stephenne, Renaud Binet, and Antonio de la Cruz

Abstract This chapter covers two main topics. The first deals with rapid mapping of damages for generating an overview, while the second deals with detailed assessment of damages. For the topic rapid mapping, fast procedures and methods for obtaining overview maps and information from satellite imagery are the main focus. For the second topic, production of accurate and detailed information from satellite imagery is more of an issue. The chapter is based on the activities of the various partners that have contributed to the GMOSS work package handling this subject. These activities comprise both security issues as well as natural disasters.

Keywords Rapid mapping • Damage assessment

16.1 Introduction

After the occurrence of a disaster or at the beginning of a crisis, a rapid overview of the damage caused is often more important than a detailed description of the damages. Therefore, for rapid mapping, satellites with short revisit times are the most

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B. Jasani et al. (eds.), *Remote Sensing from Space: Supporting International Peace and Security*,

important. These satellites usually have low to medium spatial resolution. For rapid mapping of damage information should be obtained within hours (or, up to a few days for larger areas) and should provide an overview rather than a detailed assessment of the damage that has occurred.

An accurate inventory of damages is required at a later stage when the area has to be cleared and reconstruction becomes the issue. In this case, high-resolution images are required, such as images from Ikonos, Quickbird, Radarsat and TerraSAR-X (scheduled launch mid 2007), which usually cover a smaller area and are often only available several days after the event has taken place. Users of maps showing damaged areas are relief organizations for natural disasters, local authorities in case of flooding and forest fires, and intelligence organizations for conflicts and crises.

GMOSS brings together working methods and expertise in the EU on global monitoring using satellite imagery. Identifying user needs and developing a common approach for responding to future demands for information about damage is a main issue. This is done in close cooperation with other activities within the GMOSS network such as technical, application and socio-political orientated work.

Within GMOSS, studies have been carried out on damage caused by natural disasters as well as human induced damages. Examples are earthquakes in Kashmir and Iran and the tsunami in Sumatra. Human induced damages observed with satellites are studied from the military operation in Iraq, the Ryongchon explosion in Korea, the conflict in Darfur, and the politically unstable Zimbabwe. Also the risk assessment of the damage caused, for example in the Alpine regions, is one of the topics.

Several institutes are contributing to the work with their relevant expertise. CEA is contributing with several case studies on infrastructural damages. Detection and analysis of changes for finding and assessing damage is addressed by work from TNO as well DLR. DLR also covers the rapid mapping aspect on the basis of their activity in the Crisis Information Center (ZKI). QinetiQ and Joanneum Research study three-dimensional changes, which is important in determining the collapse of buildings from satellite imagery. Joanneum Research also contributes to work on probability assessment of damage risk in elevated areas. The European Union Satellite Centre (EUSC) is using nightlight data with low spatial resolution to detect the reduction of permanent lights in urban areas related to damage, while JRC is focusing on protocols for reporting damages.

A detailed overview of user requirements and activities of the GMOSS partners is given at the end of the chapter. The chapters comprise two main sections: the first section handles the rapid mapping aspect for provision of an overview of damages, while the second section focuses on detailed damage assessment.

16.2 Rapid Mapping and Overview of Damages

In this section rapid mapping using satellites with a short revisit time is described first. The use of multi-spectral imagery for finding changes in vegetation due to natural disasters is discussed by JRC, while the use of night light imaging for finding damaged areas is discussed by the EUSC. Secondly, a service for producing rapid mapping of damages is described by DLR. JRC describes a standardized way of reporting for such a service.

16.2.1 Rapid Overview of Damaged Areas Using Satellites with a Short Revisit Time

Rapid overview of damaged areas using multi-spectral imagery – The tsunami of 26 December 2004 is used here as an example of how to use multi-spectral satellite image data for rapid mapping of damaged areas. Timely and reliable information was needed on areas of severe damage to land resources and on areas which were not affected. To support the European Commission's services, as part of the international relief effort, the JRC and its partners, created a web site (http://tsunami.jrc.it/), which provided information such as damage estimate reports and maps. Maps of damage to urban infrastructure and land resources became available in the second week after the disaster using the high temporal revisit capabilities of low (1 km) and medium (250 m) resolution satellite imaging systems.

The first rapid assessment of land cover change used automated image differencing applied to 1 km resolution data from the Vegetation 2 sensor on board the SPOT 5 satellite (VEGETATION 2002). The tsunami-driven land cover changes being reported from the ground included destruction of standing crops, removal of top-soil, uprooting and snapping of trees and complete leveling of the land. So we hypothesized that the difference in the standard VEGETATION Normalized Difference Vegetation Index (NDVI) products from immediately before and after December 26 could be a good "early" indicator of changes in land cover. Areas within 5 km of the coastline and with an altitude less than 20 m were identified and extracted from the pre and post disaster maximum value composites. This buffer was obtained by combining the Shuttle Radar Topography Mission 3 arc second database (http://www2.jpl.nasa.gov/srtm/cbanddataproducts.html) with the "Coastline and International Boundaries of the World" from the FAO Geo Network (FAO 2002) mapped at a 1:1 million scale. NDVI values from the two periods were compared and drops in values of more than 10% were assigned to a potential major land cover change class. We arrived at the 10% threshold from empirical testing over Sumatra, where the first reports in the general media had already highlighted profound changes. The visual comparison with selected high and very high resolution images from Quickbird, SPOT and Landsat satellites confirmed the damaged areas located in Sumatra and Thailand, but highlighted over estimation in the central part of the Andaman Islands and along the Myanmar coast, partly explained by the lack of accurate and internationally accepted coastline vector file but also by the spectral confusion in the 1 km resolution data.

This first approximation was then refined using MODIS sensors on NASA's Terra and Aqua satellites. These systems provide daily observations at a resolution of 250 × 250 m in two spectral channels (red and near-infrared). Cloud free MODIS imagery mosaic before-and-after the event could be assembled. After the geometric corrections and improvement of the contrast between land and water, the areas of visible impact on land cover were manually delineated. Two interpreters analyzed all pairs of images of 11,000 km of coastline and identified major changes to land cover along 1,200 km of coast. A third independent interpretation was made with MERIS data, which were not available for all regions. A statistical analysis was then led on the four major categories of land cover. Landsat Thematic Mapper images from 2000 were used to estimate land cover types affected. Almost 70% of the affected area was rural land (a mixture of villages, cropland, orchards and some grazing/fodder), 14% was previously forest and 11% could be identified as urban. The study highlights the role satellite imagery can play in international emergency rescue and humanitarian relief operations following natural disasters such as the tsunami and emphasizes the importance of standardised methods of impact assessment, rapid access to pre and post-disaster processed imagery and to standardised geographical information layers such as coastlines.

Night time data for indication of damage – Night-time satellite imagery from the OLS-DMSP provided by NOAA-NGDC has been used to evaluate the reduction of permanent lights after the Kashmir earthquake (Elvidge et al. 1999, see also Fig. 16.1). This reduction is a significant indication of damaged areas due to collapsed houses and affected electrical infrastructure, thus indicating where damage is located. On the contrary, new ephemeral lights appeared after the earthquake indicating the relocation of the people affected due to the lighting of bond fires. A preliminary analysis has been made by monitoring the changes in the permanent and ephemeral lights provided by the OLS sensor before and after the recent earthquake in Kashmir. Comparison with available maps from the first responders in the field suggests a good correlation. While the reduction of permanent lights is an indicator of damage, the increase and distribution of ephemeral lights after the earthquake reflects the population dynamics (the affected population lived outside their houses due to fear of aftershocks and lighted bonfires for cooking and keeping warm). Further monitoring of the ephemeral lights, after the panic situation of the first days, could indicate the relocation of displaced persons as well as the population groups that could have been isolated in distant areas by damaged infrastructure and were in need of urgent aid.

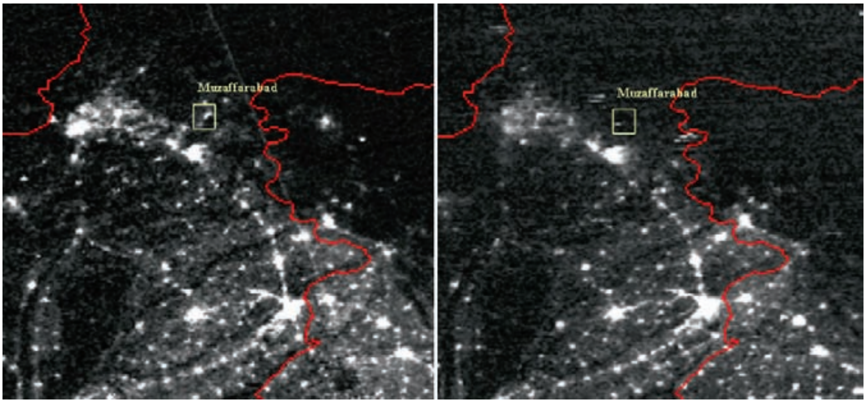

Fig. 16.1 F16 Satellite/DMSP-OLS, 1 day before the earthquake (left, 7 October 2005) and a few hour after the earthquake (right, 8 October 2005)

The increase of ephemeral lights after the earthquake has important applications for humanitarian response. The nightlight data is collected by the OLS sensor aboard a constellation of NOAA satellites at several times in the day. Therefore, these data could be available just after a disaster event, providing a quick indication of the geospatial location of damage and the distribution of the population in need of urgent assistance. This information could be available when it is mostly needed, i.e. during the period just after a disaster that is characterized by general confusion caused by the lack of relevant information.

The validity of the proposed methodology still has been tested operationally. One of the goals within the GMOSS network of excellence, after further testing, is to disseminate and propose this methodology to first responders, so that it could be applied in areas affected by natural disasters in the future to quickly provide information about:

- A first indication of damages
- Geospatial distribution of population dynamics for humanitarian response
- A first guide for the acquisition of high resolution imagery, in the relevant affected areas, thus saving time and money

16.2.2 Rapid Mapping Service for Satellite Based Crisis Information

Due to the increasing occurrence worldwide of natural disasters, humanitarian emergency situations and civil endangerment, there is a growing need for timely information on rapidly evolving events. The experience of the past few years shows expanding demands for comprehensive, near real-time, earth observation data covering wide areas, for a broad spectrum of civilian crisis situations. The reasons for this development are manifold and can be seen in the increasing vulnerability of societies and infrastructure and population growth (Murlidharan 2003). Furthermore, weather patterns most probably have been shifted to more extreme conditions. Additionally, regional and global cooperation of relief actors have been extended strongly. Satellite imagery can serve as a source of information in emergency, crisis or disaster situation.

Having recognized the aforementioned need, the German Remote Sensing Data Center (DFD) of the German Aerospace Center (DLR) established a service called "Center for Satellite Based Crisis Information" (ZKI) for linking its comprehensive operational remote sensing data handling and analysis capacities with national and international civil protection and humanitarian relief actors as well as with political decision makers. ZKI's function is the rapid acquisition, processing and analysis of satellite data and the provision of satellite-based information products on natural and environmental disasters, for humanitarian relief activities, as well as in the context of civil security. The analyses are tailored to meet the specific requirements of national and international political bodies as well as humanitarian relief organizations.

In order to provide up-to date and relevant satellite based cartographic information and situation analysis, it is necessary to establish efficient and operational data flow lines between satellite operators, receiving stations and distribution networks on the one hand and the decision makers and relief workers on the other. Service lines and feedback loops have been established to allow best possible data and information provision as well as optimized decision support. Besides response and assessment activities, focus is given on deriving geo-information for use in medium term rehabilitation, reconstruction and crisis prevention activities. ZKI operates in national, European and international contexts, closely networking with German public authorities at national and state levels (crisis centers, civil security, environmental protection), nongovernmental organizations (humanitarian relief), satellite operators and space agencies. The current and long-term goals can be described as follows:

- Developing and establishing methods to generate customized information products and services for disaster management, humanitarian relief and civil security
- Designing appropriate information technologies and infrastructure
- Providing advice on establishing crisis information centers
- Combining existing technical and scientific resources and expertise for effective and coordinated crisis management, particularly with DLR's Remote Sensing Technology Institute (IMF)
- Developing and setting up distributed European and international networks for satellite-based civil crisis information

Rapid mapping service – After the occurrence of a natural or man-made disaster the necessity of fast and reliable spatial information is important not only for situation centers but also for relief organizations and rescue teams. Civil protection authorities have to meet the demand for adequate crisis information in order to ensure an appropriate decision process and an effective crisis management. Therefore all possibilities obtaining spatial crisis information have to be taken into account, particularly earth observation data proved to provide significant information input. In order to cover these user requests in crisis situations, DLR set up a rapid mapping service (Fig. 16.2) to ensure fast access to available, reliable and affordable crisis information worldwide. After the mandatory decision process whether satellite analysis is appropriate for the respective crisis, the area of interest has to be defined and cross checked to avoid false geo location. Following this iterative process, it has to be assured that all applicable satellites are programmed for data acquisition.

This can either be coordinated within the International Charter "Space and Major Disaster" by the responsible project manager or through commercial satellite tasking. Furthermore an enquiry for corresponding archive imagery has to be set up for later change detection analysis. Along with the procurement of satellite data it is necessary to check and prepare supplementing geo-data like population and infrastructure data, road network, contour lines and administrative boundaries. The experience of several activations and the user feedback shows that additional geoinformation increases the satellite data analysis significantly. This includes place

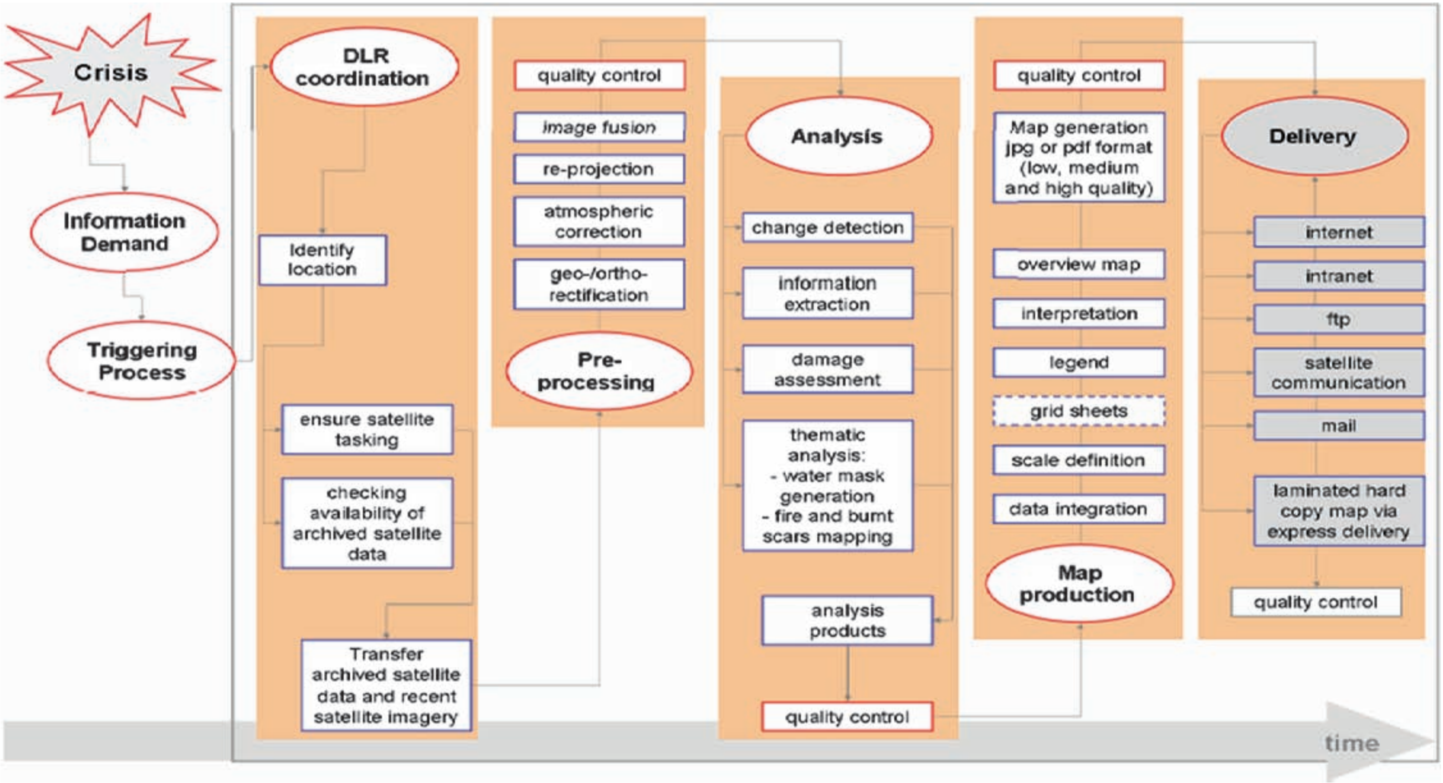

Fig. 16.2 DLR Rapid Mapping Service – processing chain

names, critical infrastructure, transportation network or further detailed specifications. After receiving the archived and recently recorded satellite imagery, essential pre-processing has to be done. This includes geo- and ortho-rectification as well as atmospheric corrections (using ATCOR – Richter 1996) and data format conversions. Data re-projection is necessary due to varying demands and standards. In the majority of cases a Universal Transverse Mercator Projection is used due to global applicability and following international standards. Dependent on user needs, crisis type and extent, different analysis process chains have to be applied. The derivation of water surfaces or general damage assessment is dependent on input data type, scale and possible availability of archived satellite imagery. Before and after image comparison allows the quantification of affected areas. This change detection method can either be applied for optical or radar imagery in order to derive areas where significant change can be stated. The following two Ikonos images from the Bandah Aceh region illustrate this approach for the severe Tsunami disaster in December 2004 (see Fig. 16.3).

In order to translate complex satellite information into a readable and coherent format, situation and damage maps are generated. Following this map compilation an adapted map generation process is applied. Before publishing the information products a settled quality control process takes place. The map delivery is accomplished via Internet, Intranet, ftp, e-mail or satellite communication.

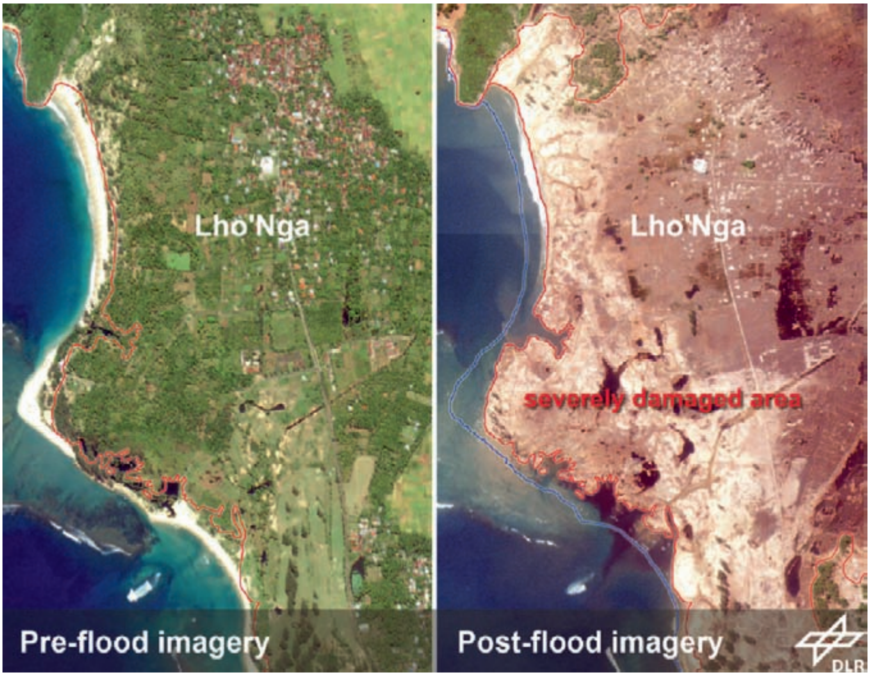

Fig. 16.3 Change detection for Lho'Nga after Tsunami hit the area on December 26, 2004; Ikonos imagery of January 29, 2003 (left) and December 29, 2004 (right); blue line indicate former shoreline, red lines represent recent shoreline and damaged area

Furthermore, printed and laminated maps are sent via express delivery on request. Besides the quality control during the processing steps, it has proved to be important to insert user feedback from field units. This means that map updating after having new and improved data available or implementing knowledgeable feedback is an important issue even though the maps are published and delivered. During the past years it has also been shown that training and consulting of decision makers and field workers plays a key role in the proper understanding and accepting of space based information products as one of the information sources for decision making or mission planning.

Standardized damage assessment – The JRC has set up a grid based image analysis for assessing the stock of built-up and the damage that may occur in the aftermath of the disaster based on satellite image and field data. This was based on the experience gained by analyzing satellite imagery in support of emergency response in the aftermath of the Indian tsunami and the Kashmir earthquake. The procedure was tested on the city of Muzzafarabad and on the tsunami affected area in Bandah Ace (see Fig. 16.4). Grid based analysis aims to provide two attributes, the area occupied by built-up and, from post disaster imagery, a quantitative assessment of the damage. Grid based analysis aims to be used in assisting emergency response, rehabilitation and reconstruction and/or development activities. It is particularly suited for quickly providing information to the emergency response teams that are dispatched to the disaster affected areas, for which usually little information is available. The procedure includes also the use of information collected from hand held equipment, GPS receivers and digital cameras/video cameras, by personnel in the field to report on damage. The grid based image analysis is designed to be used on imagery with at spatial resolution of 2.5 × 2.5 m or finer. It is best used on imagery of 1 × 1 m commonly referred to as Very High Resolution imagery. The salient characteristics of VHR imagery is that single buildings and transport infrastructure that make up the built-up class be clearly delineated and their area measured. This provides a new opportunity to estimate stocks of built-up to be used for development emergency and recovery anywhere in the world. VHR imagery that has first become commercially available in 2000 can now be obtained in archived form or as newly collected imagery for a large part of the world. The advantage of the procedure is that it can produce assessments on built up and on damage very rapidly and it complements the information derived from the field. The procedure is also robust and provides standardized results that can be used to compare damages occurring in two or more geographically different areas that have occurred at different times; therefore it is useful for providing assessments at different scales.

16.3 Detailed Assessment of Damages

Methods for detailed analysis of damaged areas are presented by CEA and JRC, while the use of three-dimensional data for determining the collapse of buildings is discussed by Joanneum Research. A method for the assessment of the amount of damage in urban areas by visual interpretation is discussed by DLR.

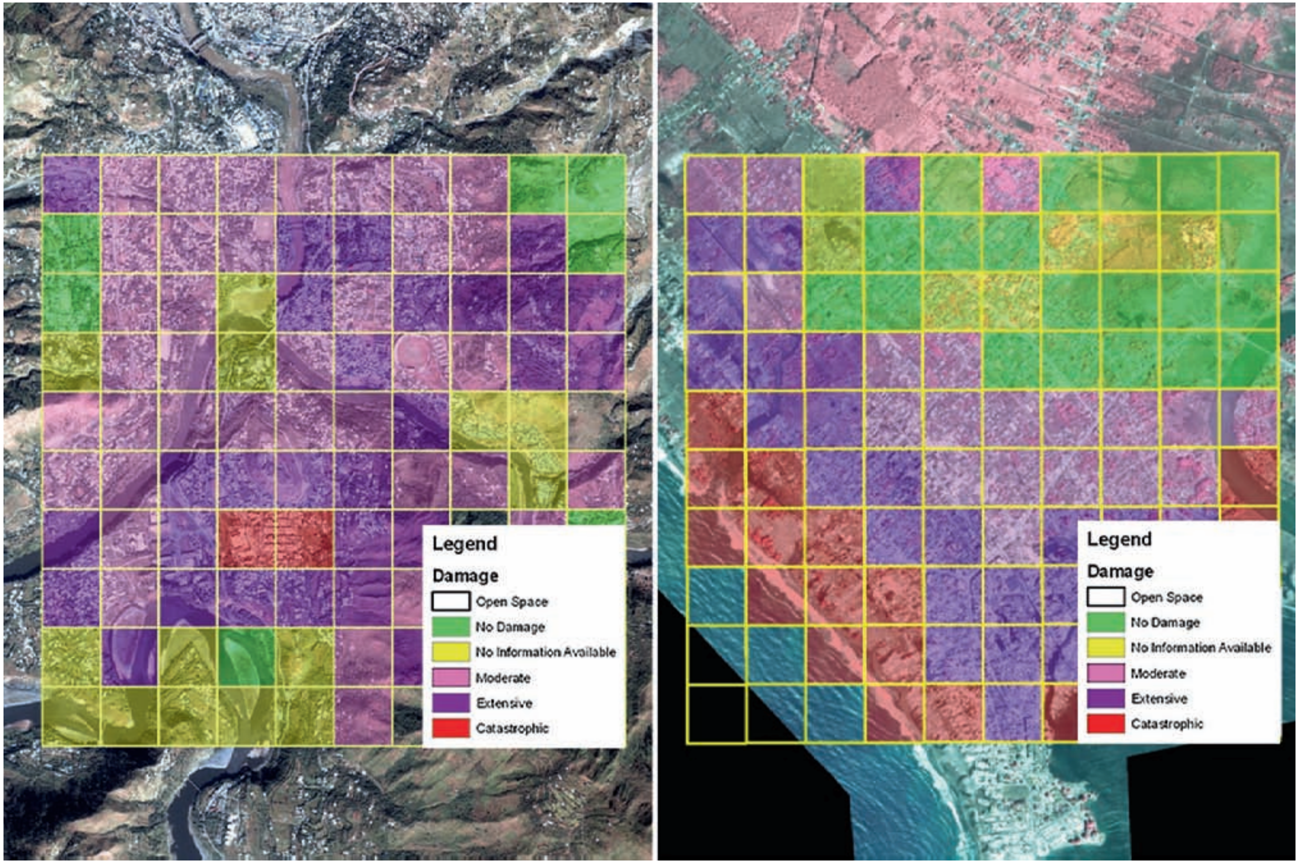

Fig. 16.4 Standardized damage assessment and reporting. The colours indicate the relative amount of damage, where the colour range (from green to red) corresponds to increasing damage. An example is given for the earthquake affected Muzaffarabad (left) and Bandah Aceh (right)

The use of radar imagery to find damaged areas and buildings is presented by TNO. Joanneum Research describes the use of satellite imagery for finding and predicting damages due to alpine hazards.

16.3.1 Detailed Analysis of Damages Using High-Resolution Satellite Imagery

CEA is working on building damage assessments in dense urban areas following a natural disaster such as an earthquake. Very High Resolution (VHR) images offer a strong potential to achieve this evaluation because it allows identification of changes in buildings and therefore, increases the reliability of the assessment. However, this assessment is time-consuming because of the large number of objects that have to be analysed. An automated or semi-automated data processing technique can assist in speeding up the assessment.

Pixel based methods for change detection have been proposed for damage assessment involving medium resolution images. However they may not allow distinguishing damage from other changes, hereinafter called natural changes. The assessment of the performances of methods is hardly addressed. The outcomes of a method should be compared in a quantitative way to the reality. However, ground surveys reporting the exact extent of the disaster are rare and it is hard to assess visually the damage on buildings using medium resolution images in a reliable manner. Some methods based on VHR images face new difficulties. The natural changes are more numerous as the resolution increases, leading to new difficulties: shadow changes, apparitions and disappearances of multiple objects due to the human activity (e.g. cars, refugee's tents). In addition, the relative influence of errors of registration of building roofs increases because the building height is often unknown. However, VHR images help in better quantifying the performances of a method because visual damage assessment is more reliable.

A way to ride out most of these problems is to estimate the pertinent changes only on the roofs of the buildings. Though the aspect of the buildings is highly dependent on the viewing angle, the roofs are less affected by this phenomenon. Moreover, they are visible by means of remote sensing and it is expected that they are less concerned with natural changes. One should take advantage of a preliminary segmentation of the roofs, in order to conduct an object-based analysis of the changes on the roof footprints. The building extraction can be done by segmentation techniques of building footprints or via the means of a Geographic Information System (GIS). A priori knowledge of the building footprints on a reference image is therefore assumed.

A standard image registration does not allow for registration of objects of unknown heights (ground, roofs) when the off-nadir viewing angles differ from one image to another. Thus the building roofs have to be registered prior to the change analysis. The proposed method is divided into four steps. Firstly, the building roofs are segmented. The roofs on the two images are then registered by a sub-pixel correlation method. Third, pixel-based and object-based tools for change detection are used to assess the damage leading to, the classification of the buildings in the fourth step.

This method has been applied to the 2003 case of the Bam (Iran) earthquake. The images used were panchromatic images from the QuickBird satellite acquired before and after the earthquake. A database has been built and is used as a reference for registration of roofs (second step), training (fourth step) and assessment of the performance of the method. The evaluation of its performance is made by comparison to a reference damage database made visually (Fig. 16.5). We point out that in order to compare the algorithm performances, the final damage classification should be related to a standard damage scale. The European Macroseismic Scale (EMS) is well suited for a building damage assessment.

The changes used in the Bam case are based on a similarity measure (correlation) and on the similarity of four texture features (Gabor wavelet). It was established that a supervised classification based on neural net is able to classify two degrees of damage (EMS grade <3 vs. grade ≥3) with 90% of confidence. Of course, these results are worsened when more than two damage levels are classified. Figure 16.6 shows the confusion matrix of a classification based on four damage degrees. The overall performance is 73% of good classification, most of the errors being close to the real damage grade. Confusion between grade 3 and grade <3 might be partly due to a visual misinterpretation of the damage on the database. The best classification performance is reached for a training of 200 buildings, but note that this performance is reached at 90% with only 30 buildings.

Following these encouraging results, further work will involve more test cases, in order to try to generalise our method. The use of two different VHR sensors will also be an interesting and more realistic case.

Fig. 16.5 Reference damage database used for roof segmentation and performance evaluation

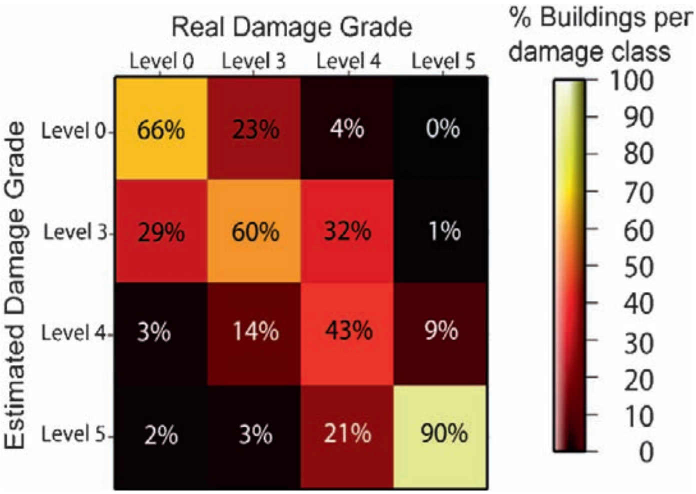

Fig. 16.6 Confusion matrix for a classification with four damage grades

Detailed damage assessment carried out at the JRC is a general methodology for post-tsunami damage assessment and an automatic procedure able to discriminate different kind of damage on built-up structures at local scale, ranging from 1:10,000 to 1:25,000 nominal scales (Pesaresi et al. 2007). The information extracted at this level is crucial for (i) the calibration and estimation of the reliability of the low and medium-resolution assessment, (ii) for planning the logistic of relief actions in the field immediately after the event, and (iii) for planning the resources needed for first recovery and reconstruction. Using very high resolution (VHR) satellite data, the operational methodology for extraction of the information is based on manual photo-interpretation of the satellite data which are processed on the screen by the photo-interpreter as any other aerial imagery. Huge processing time is in conflict with the necessity of rapid damage estimation. The proposed solution to this problem is based on an integrated semi-automatic methodology. The methodology uses as input multi-scale and multi-sensor remotely-sensed data, with a multi-temporal approach related to pre and post event comparison. It involves the manual photo-interpretation of basic image features of reference, and the subsequent automatic mapping of damaged built-up structures for different degrees of damage. The discrimination of different relevant features is based on textural, morphological and radiometric characteristics of image data, while the automatic image understanding phase is based on a fuzzy rule-based inferential engine. Any built-up structure placed between the tsunami impact line and the before-event coast line is defined as “damaged built-up structure”. The purpose of the proposed multi-criteria system is to automatically evaluate the likelihood of different morphological class of damage occurred. The set of criteria quantified the level of biomass, the flooded areas, presence of debris, presence of shadows. The test reported here is related to the study area of Meulaboh, Indonesia which has a surface of around 16 × 6 km and was heavily affected by the tsunami wave. A extensive photo-interpretation exercise was carried out by EC JRC in support of the post-tsunami damage assessment and recovering process, and part of these data have been used as input for the validation of the automatic damage recognition system. The proposed procedure shows good performances with an overall accuracy estimated by the validation procedure equal to 93.97%. The best performances are estimated in the discrimination between non-flooded and flooded built-up structures and in the recognition of collapsed built-up structures with debris in place. Problems of omission error have been detected in the recognition of collapsed built-up structures without debris in place as in the case of completely erased built-up structures placed close to the shoreline.

16.3.2 Use of 3D Data to Determine Damages of Buildings

To obtain more detailed information on the level of damage, a more complex methodology has to be applied. Currently one of the most powerful tools is the use of 3D information from remote sensing data in combination with classification results. The drawback of this 3D change detection is the lack of 3D stereo data, especially for the a priori images. Some investigations have still to be performed on this new technology, but the first results are promising (see Chapter 7 on Infrastructure Monitoring).

Alternatively image matching techniques can be applied to a pre- and post-event image (Paar and Pölzleitner 1992). Investigations on a Quickbird dataset of the Bam earthquake show that the so-called backmatching distance is a very useful measure for the detection of damaged buildings for example, see Fig. 16.7. To make this technique more robust GIS information or the delineation of the buildings in the pre-event images is required.

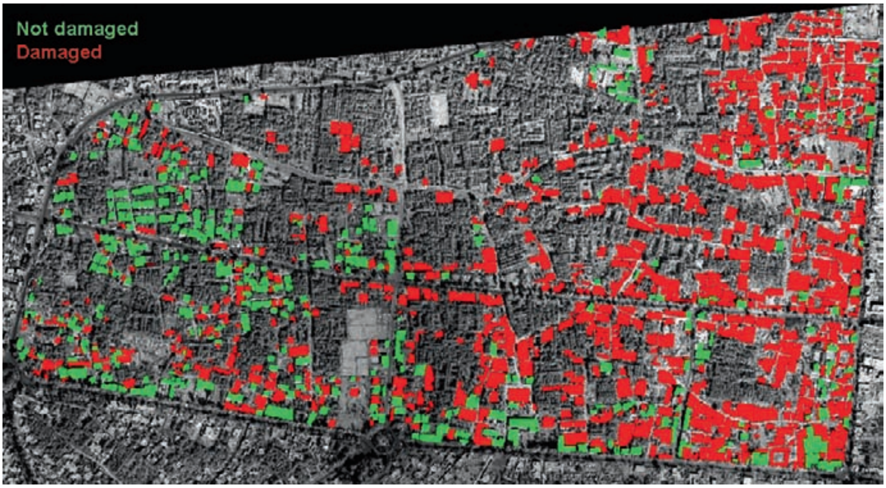

Fig. 16.7 Example of damaged building detection using backmatching distance

However, damage assessment is a very complex task involving many decision levels. To be able to assess the damage more precisely the integration of as many different data layers as possible is needed, e.g. pre- and post-event satellite data, ancillary data and, optionally, information from field or LIDAR data.

16.3.3 Detailed Damage Assessment Based on Visual Inspection of Using High-Resolution Satellite Imagery

Within the framework of rapid mapping services, damage assessment is an important task and there are almost unlimited applications of change analysis (Pesaresi et al. 2007) using pre- and post-disaster imagery. Prior to automatic or interactive damage assessment a number of pre-processing steps are applied on the imagery, such as atmospheric corrections, orthorectification, pansharpening, filtering, and contrast enhancements. Standard change analyses by means of object based classification methods is a very time demanding task which takes up to 30 h or more in some cases, and therefore other methods are needed on behalf of rapid change detection services. One method to visualize damages is to delineate core damage areas using a red line signature derived from visual comparison of co-registered pre- and post disaster images. In the ideal case the results are combined with data from the field of sufficient quality. However such a rapid mapping damage assessment service is an intuitive job, and experienced remote sensing scientists use about 3–6 h after data pre-processing.

Another approach is to visualize change analysis through colour coding by means of the pre image in green and the post image in red. Hence an image combination by superimposing the different colours (colour additive mixing process) will then reveal unchanged properties in yellow. It is important to note that this method requires very accurate image co-registration. For the Pakistan earthquake in October 2005 damage assessment, the European Joint Research Centre proposed a new method to the team working on the satellite based disaster response efforts. This method is a first step to come to a more standardised and harmonised way to assess damages, i.e. the method should be applicable for different regions and different types of disaster. A visual interpretation was performed of pre- and post disaster images using 250 × 250 m grid cells in case of the Pakistan earthquake. For each grid cell damage of housing and infrastructure is interpreted separately by means of UN housing damage classification to be of more direct operational support and review for map users. The UN housing damage classification distinguishes the following classes:

- No damage visible
- Moderately damage (<33%)
- Severely damage (33–66%)
- Completely destroyed (>66%)

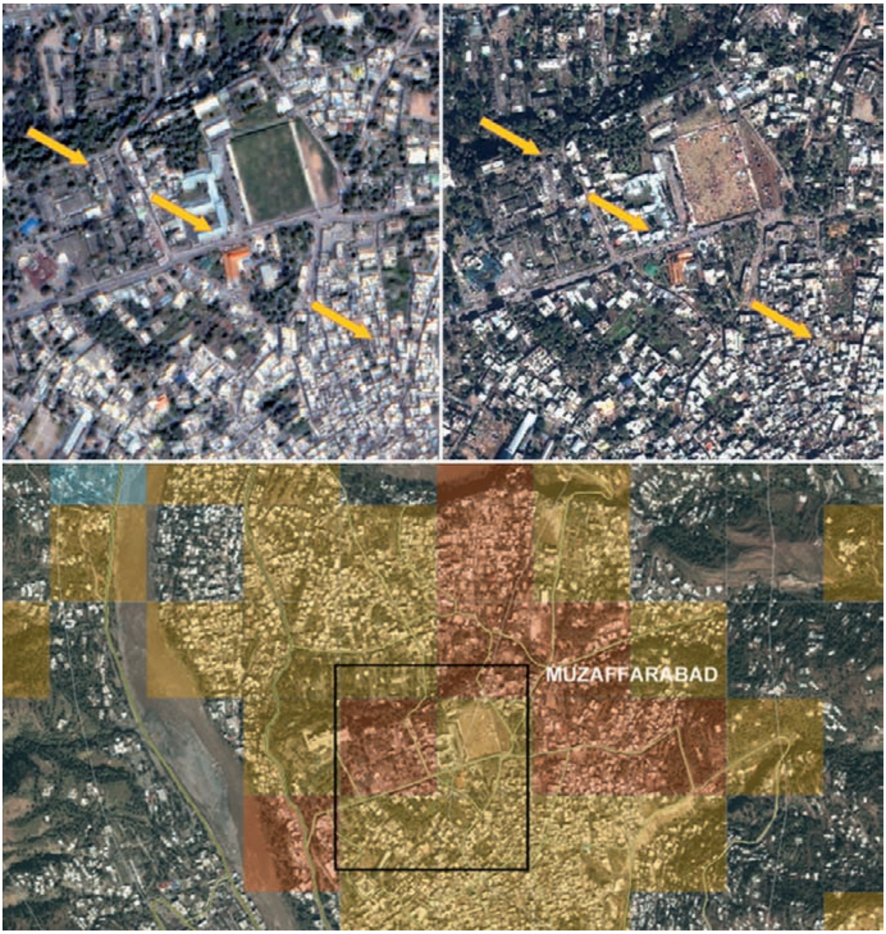

Fig. 16.8 Overview of the visual damage assessment procedure

Figure 16.8 shows an example of the interpretation process. The upper two images show detailed pre (left) and post (right) subsets of the city centre of Muzaffarabad, where arrows indicate areas with visible damages. The lower image overviews the final resulting damage assessment map using transparent colour map overlay.

Note that depending on the type of building structure, the quality of damage assessment based only on satellite imagery may vary and can differ from field observations. For production of the final maps the damage assessment should typically be combined with critical infrastructure information such as bridges, airports, tunnels, ports, hospitals, clinics, and schools.

Although the described methodology needs further enhancement such as validation of the results, the example shows that harmonized and/or standardised products can be derived within a short production time which is a vital pre-requisite for the humanitarian relief community.

16.3.4 Damage Assessment Using Radar Satellite Images

One of the techniques to find damages is to use change detection with radar images (Dekker 1998). Radar data are ensured during cloud cover and at night when the appropriate satellite infrastructure exits. Detection of a change is not enough since also the changes need to be characterized as damage. For this purpose higher resolution is beneficial, but even with high-resolution SAR imaging recognition and identification of objects in the image is a difficult task. This is due to the backscatter mechanisms for microwaves, which give rise to peculiar phenomena in the image, such as speckle noise and specular reflections.

At TNO a concept for the characterization of changes was developed (van den Broek et al. 2005), and is summarized here (see Fig. 16.9). The first step is to only select significant changes by removing irrelevant changes and so-called false alarms. This step reduces the number of changes to be considered and involves knowledge (features) about the *objects* that are to be monitored, knowledge about the *sensor*, and combination with geographical information of the *scene*.

During the second step the changes are positively selected and identified from the reduced set of changes, where *context* information (maps and optical images), information from earlier monitoring (*time series*) and preferences of the *user* are used. In the following figure we give an overview of the workflow.

False alarm reduction – Changes in imagery can be due to several causes other than a real change on the surface. For example, a change in specular reflection, or change in shadow due to little differences in aspect and incidence angles, can

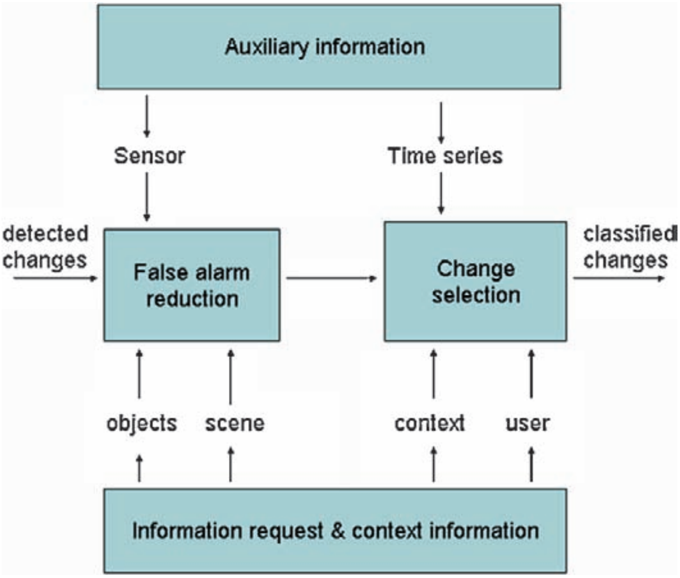

Fig. 16.9 Workflow for change classification

cause change detection. These kind of detected changes are typically related to the sensor and the sensor geometry and can clearly be discarded. If we know what we are looking for (for example, an object with specific dimensions and specific radar signatures) we can discriminate such a change from changes with other dimensions and signatures. Another way to reduce the number of changes is knowledge about the scene, when it contains areas where changes are not important. For example, in the case of maritime surveillance only changes on water surfaces need to be considered. This kind of reduction, which uses information from the sensor, object, and scene, can be performed mostly automatically. It involves feature extraction and criteria for these features, radar characteristics of objects, and geographical analysis of the scene. The criteria are quite objective and are not very susceptible to change once an optimal working procedure is obtained.

Change selection – A second less automatic step for classification is selection by an interpreter. Selection of changes can be performed by using *context* information, such as pipeline corridors or certain areas with a specific ethnic population. Context information may also be derived from interpretation of a high resolution optical image. In the case of regular monitoring of a certain area, which is often the case for surveillance, a comparison can be made with detections from earlier monitoring cycles, so that analysis of *time series* is possible. This also helps to select changes. An example is given by repetitive changes due to regular parking of vehicles, which may not be interesting for the goal of the monitoring. Another reduction is the choice of the interpreter not to consider certain changes, since he assesses that these changes will not be of interest for the *user*. For example, the user only wants to know about military activity and is not interested in changes due to civil activities.

In the following we present a case study of Baghdad monitored with Radarsat during Operation Iraqi Freedom in 2003 following the workflow described above. The acquisition dates are January 17, March 30 and April 23, 2003. All images are obtained in the so-called 1f1 mode, a fine beam mode with a resolution of 10 m, the highest resolution possible with Radarsat I. Since the same track is used, the imaging geometry is the same for all three recordings.

Using data from maps and optical satellites, detected changes can be identified as belonging to a number of categories such as infrastructure, economic, military, environment, agriculture, and damage. For example, height information retrieved from high resolution optical stereo data can be used to characterize the changes (van den Broek et al. 2007). We discuss here an example of areas with damage which are characterized using particular radar backscattering features for buildings and debris. During the war, around the end of March/beginning of April, several barracks, which were probably used as storage for military equipment, were blown-up when coalition forces arrived. These changes can easily be detected by Radarsat. Before the destruction the buildings reflect microwaves mainly by double bounce scattering between walls and the ground, which implies that only part of the outline of the buildings are seen in the image. After destruction, the debris scatters the microwaves in all directions so that the whole site of the destructed barracks is seen in the image. In Fig. 16.10, we show two Radarsat images before the war (17 January 2003) and immediately after the war (23 April 2003) in two complementary colour channels (cyan and red, respectively). In Fig. 16.10 large

Fig. 16.10 Top-left: radarsat colour composite. Top-right: corresponding map with changes (red) in overlay. Bottom-right: Quickbird before destruction. Bottom-left: Quickbird after destruction

red spots are visible due to the backscatter from the debris in the colour composite. For comparison, we show detected changes in overlay on a map and for validation we also show Quickbird imagery before and after destruction of the complex that is present in the right-lower corner of the Radarsat composite. Change detection of such destructed objects can easily be performed automatically using information about the *object* and appropriate criteria for size and backscatter intensity.

16.3.5 Damage Assessment and Risk Assessment of Damages in Alpine Regions Using Satellite Images

Natural disasters are an age-old problem that occur regularly in the alpine regions, posing a major threat to the safety of settlements and transport routes, as it is impossible to predict exactly when and where a disaster will occur. Not all natural disasters are triggered by local events. Many are caused by developments in regions that are remote from the site of the catastrophe. Frequently they are the result of human activities that have a negative impact on the environment, such as the felling of protection forests, the construction of new roads and tracks, changes in the density of stocking, the rerouting of rivers and streams, and pollution originating in industrial areas which adversely affects alpine vegetation. They can have a significant impact on the population and lead to consequential economical losses, if for example, transport routes are disrupted or tourist resorts are disconnected from outside. Avalanches, landslides or torrents are a permanent threat to traffic routes across the Alps causing damage to infrastructure, and/or buildings and even disaster victims. This fact was confirmed by the flooding in August 2005, where the railway track along the East–West connection over the Arlberg route was disrupted for more than 3 months. Conventional means for the risk assessment could not satisfy the security needs of the responsible administration. Therefore, new methods have been researched to support the existing disaster management cycle (see Fig. 16.11).

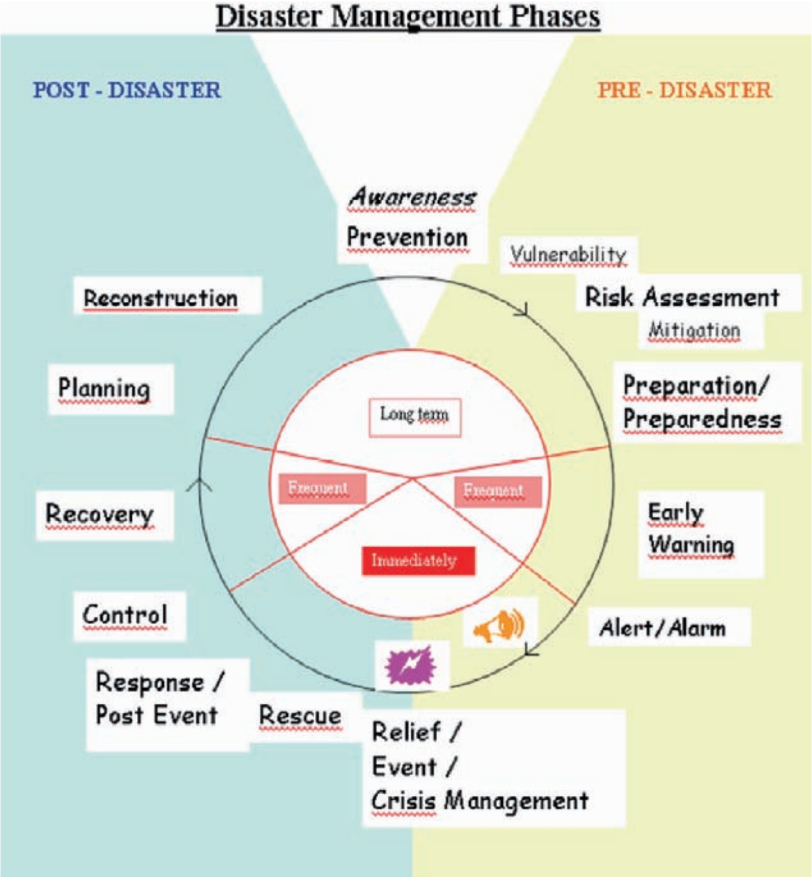

Fig. 16.11 Disaster management cycle

In close co-operation with experts many of the most relevant indicators for such processes as landslides, flooding or avalanches can be identified by means of remote sensing imagery. The data base for the analysis of Earth observation data included radar satellite systems and optical satellites such as Landsat, SPOT and Quickbird. Furthermore, aerial photography still plays a major role in the investigation of security relevant topics and is often used for analysis.

Complex analysis algorithms have been applied to extract the required information on the Earth's surface from remote sensing data, which can be integrated into a decision support system based on GIS (Geographical Information System). Methods for interferometric processing of radar data have been optimised and used for the derivation of digital elevation models and the detection of changes within the landscape.

Land cover and forest parameters (see Figs. 16.12 and 16.13) which are relevant for the assessment of potential threats can be derived by classification of satellite data, and be integrated into a decision support system (Granica et al. 2004). Specific methods based on multi-temporal satellite data allowed for the analysis of temporal changes within the vegetation cover, for example, to detect windfall areas.

For damage assessment purposes several approaches have been applied using remote sensing imagery. One of the most common and easy to handle is the change detection method (Granica et al. 2005). This was proven after the recent events of the 2004 Tsunami in the Indian Ocean or the 2005 Earthquake in Kashmir/Pakistan by the International Charter. The prerequisite of this approach is an image "before" and an image "after" the event. Using the software package "*IMPACT*" an automatic change detection method can be performed on these images. For instance, a so-called "2D change detection" was applied on a windfall event in November 2002 in Salzburg/Austria (see Fig. 16.14). The detection of changes within these two time periods allowed the assessment of the location and the extension of indicators of possible damage. It is a possibility to get quick information on the landscape over large regions.

16.4 Conclusion

For response to crises, fast and standardized techniques and algorithms are needed to accurately assess the damage and present this information in the form of adequate maps. In this chapter a broad range of approaches for assessing damage using satellite imagery from the contributing partners has been presented. The described research focuses on techniques how to use low- and middle-resolution high-temporal optical, infrared and radar imagery for rapidly obtaining overview of damaged areas, as well as how to use very high-resolution optical and radar imagery for obtaining detailed assessment of the damage caused. Also, approaches and services for operationally using such techniques are reported.

The research to develop and improve these techniques and algorithms will be going on, where the GMOSS network of excellence brings together the various working methods and expertise from the various partners by focusing on common

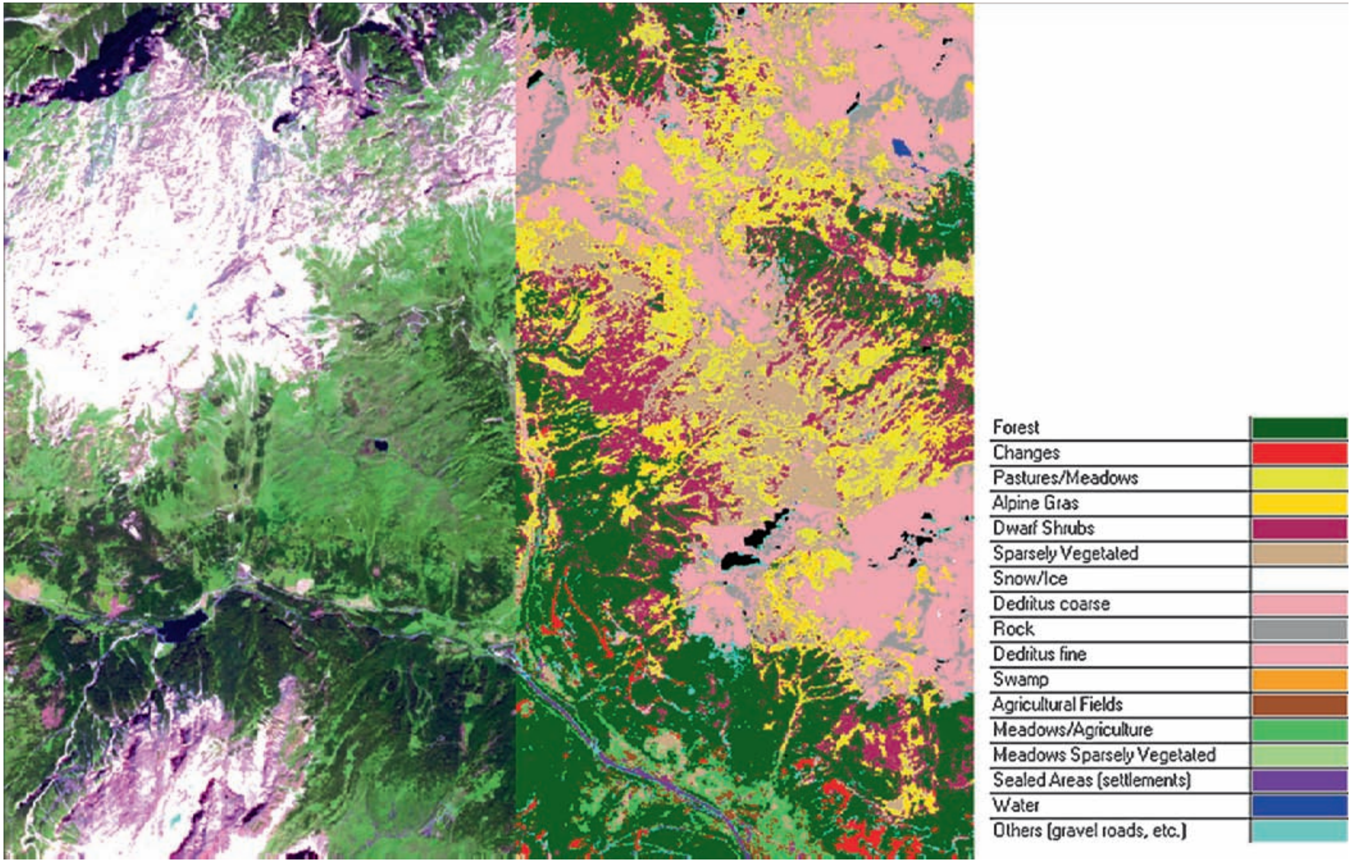

Fig. 16.12 Result of a land cover classification using SPOT5 satellite data

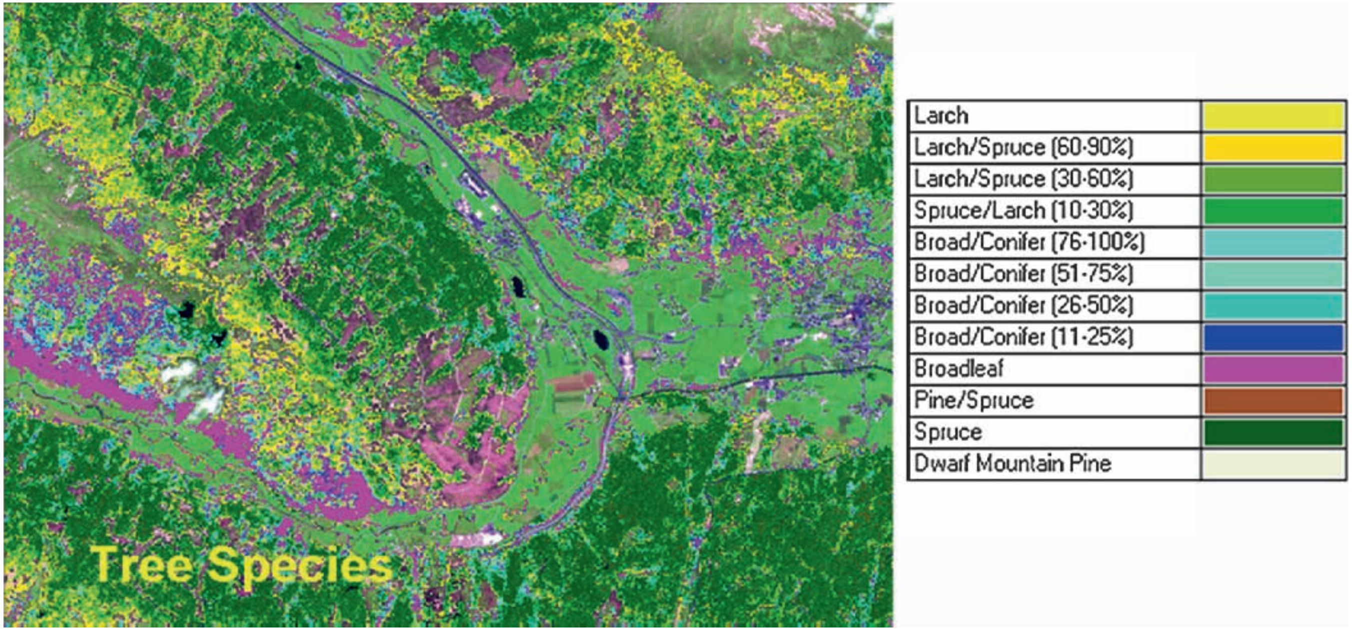

Fig. 16.13 Result of a forest classification using SPOT5 satellite data

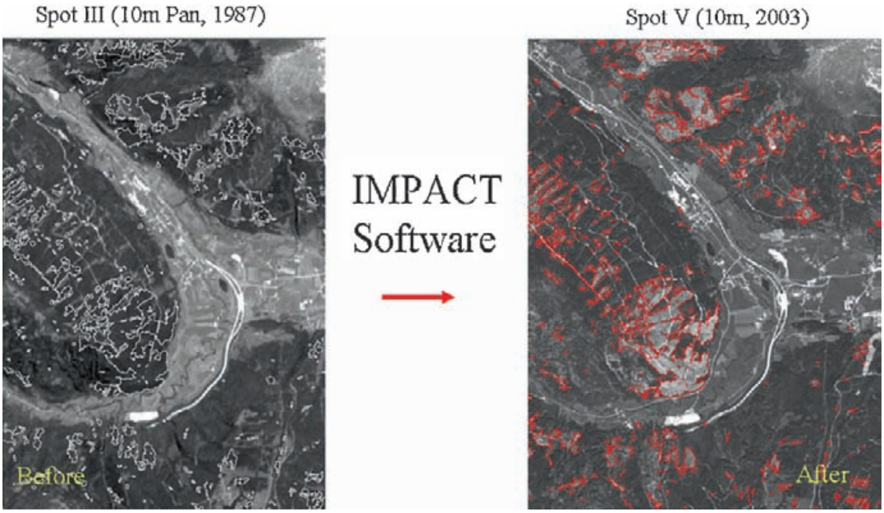

Fig. 16.14 Two-dimensional change detection after a windfall event using SPOT satellite data

scenarios and cases. A roadmap for combined and coherent future research is obtained by elaborating on questions of how the various technologies can be used operationally and which information should be produced to satisfy the requirements and needs of the user. The outcome of this combined research on damage assessment and rapid mapping contributes to and supports Europe's capability to effectively respond to crises.

Overview of User Requirements and Activities of GMOSS Partners on Rapid Mapping and Damage Assessment

Table 16.1 and Table 16.2 summarize the involvement of the partners in several cases with respect to security and natural disasters, respectively. Users, requirements and satellite data used are also indicated.

Table 16.1 Overview of involvement of GMOSS partners in several cases for security

Case	Users	User requirements	GMOSS partners	Satellite data
Conflict (Baghdad)	Intelligence agencies	Detailed analysis of infrastructure	TNO, JRC	Radarsat, Quickbird
Explosion (North Korea)	Intelligence agencies	Detailed analysis of infrastructure	CEA	Quickbird
Destabilization and internal conflict (Gaza, Darfur)	Intelligence agencies	Detailed analysis of infrastructure	TNO, DLR	Ikonos, Quickbird
Conflict (Iraq)	Intelligence agencies	Distribution of pipeline sabotages (GIS)	EUSC	Landsat 7 Spot 4 Terra, Aqua Quickbird

Table 16. 2 Overview of involvement of GMOSS partners in several cases for natural disasters

Case	Users	User requirements	GMOSS partners	Satellite data
Tsunami (Sumatra)	Relief organizations, local authorities	Overview of coastal erosion and infrastructure	DLR, TNO, JRC	Landsat, Ikonos, Quickbird
Earthquake (Kashmir)	Relief organizations, local authorities	Damage indication and affected population	EUSC	DMSP-OLS
Earthquake (Bam, Kashmir)	Relief organizations, local authorities	Detailed analysis of infrastructure, planning of refugee camps	CEA, DLR, JR, JRC	Quickbird, ERS, Ikonos
Forest fire (Portugal)	Local authorities, EU Monitoring and Information Center (MIC)	Overview of smoke and hot spots	DLR	Bird, Modis, AVHHR
Forest damage (Alpine region)	Local authorities	Overview of forest status	JR	Landsat, Spot, IRS, Aster, QB
Flooding (Alpine region)	Local authorities	Overview of damaged infrastructure	JR	Aerial photographs, Quickbird

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Summary and Outlook

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Summary

Earth observation data has an important role to play within the security arena. In order to fully realise the utility of such information however, there is a need to bridge the communication gap between scientists and policy makers. The aim of this book has been to provide an initial introduction to the numerous capabilities that exist in Europe to enhance and analyse imagery for the strengthening of European security.

Earth observation can provide vital and timely intelligence in many areas, including: treaty monitoring, early warnings, population data, border monitoring and natural and man-made disasters. The advanced feature recognition, change detection and data integration techniques developed under the umbrella of the GMOSS project proved that the application of these techniques would ensure that countries are complying with international treaties such as the NPT. Furthermore, the analysis of earth observation data offers a cost efficient and accurate method of monitoring activities that affect the security within and along the borders of particular states.

The 2003 European Security Strategy outlined five key threats facing Europe in today's international environment: terrorism, the proliferation of weapons of mass destruction, regional conflicts, state failure and organised crime. It has been realised that the techniques developed by GMOSS would improve the EU's ability to deal with these identified threats. For example, regional conflict often results in the mass movement of populations from one region to another. This movement can be monitored via the use of earth observation data. The long-running political situation in Zimbabwe has resulted in the destruction of many homes and social infrastructure. The analysis of earth observation data over Zimbabwe demonstrated the extent of damage that has occurred over this time period. The devastating earthquake in Pakistan created the urgent need to deliver aid and relief to the multitude of people affected by this disaster. The generation of two-dimensional and three-dimensional images using a combination of earth observation and GIS data assisted in the identification of affected areas so that aid and relief could be delivered quickly and efficiently. The attack on and damage of oil pipelines in Iraq has been a major cause for concern in the area of energy security. By using earth observation data, it has been demonstrated that oil pipelines can be watched, and leaks or deliberate damage can be identified so as to take appropriate action in order to ensure their fortification. Of course, these are just a few examples of the application of the techniques developed under GMOSS.

The experience gained in the GMOSS network, which is largely reported in this book showed that there are specific constraints and challenges that have to be faced by remote sensing experts. These challenges are both related to the technical nature of the earlier generation satellite data as well as the complexity of the environment in which the information will be used, an example of which is the decision-making process dealing with national and international security.

These challenges need to be addressed by specific technical and conceptual tools to be developed. Examples of these are: the automatic recognition and analysis of key security targets (and their temporal evolution) using latest-generation satellite data, the validation protocol of the extracted information.

The needed research effort is enormous, and it is clear that the material presented in this volume is only a first step. The future work will have to taken into account the rapid evolution of the technical capabilities and the collective perception of the security as well.

It is therefore important to mention in the conclusions of this volume that the GMOSS experience has demonstrated the vitality of a new research community, has highlighted specific area of expertise involving some innovative methodological solutions, fostering a more precise and shared identity of this community. Moreover, it is evident that there is a strong need to continue research in this new field.

Outlook

As a result of the GMOSS project, other areas in need of further research were highlighted. For example, treaty monitoring played an important role as it drew on other aspects of research such as the development of sensitive change detection techniques, automatic accurate image registration methods, and the use of different types of images (optical and radar). The focus of this work during the project was on the monitoring of the NPT. However, other areas still need to be explored, such as the detection of the preparations and execution of a nuclear test (Comprehensive Test Ban Treaty), using optical and radar imageries.

The EU could also benefit if the exploitation of space-based remote sensing technologies were applied in other security related areas, such as:

- Monitoring of national defence capabilities
- Future fissile material cut-off agreement
- The 1993 Chemical Weapons Convention

- 1990 Conventional Arms Forces in Europe Treaty (CFE)
- Confidence Building Measures (CBMs)
- Monitoring of inter-border conflict
- Monitoring of the location of terrorist camps
- Monitoring of natural hazards and related disasters
- Monitoring degree and speed of environmental degradation / depletion of natural resources as important triggers for migration and conflict

It is therefore necessary for GMOSS to move into its second phase in order to continue the work that has been carried out so far. As has been demonstrated within this book, there are number of areas within which, earth observation could play a crucial role. However, in order for this capability to be used to full effect it is necessary to have close collaboration between the policy-makers (who identify the issues/threats) and scientists (who develop the applications to combat these issues/threats). However, before this technology can be applied in a meaningful manner, it is essential to understand what the concept of 'security' means to the EU.

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