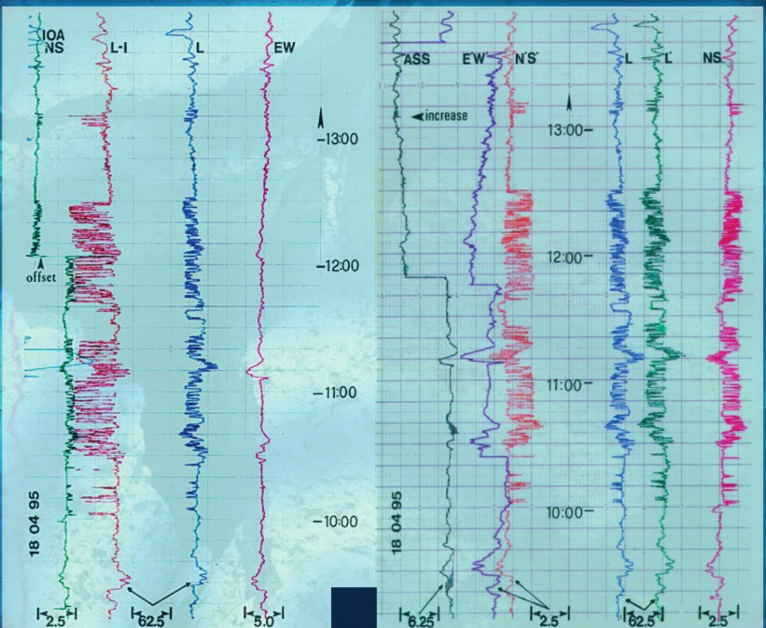
EARTHQUAKE PREDICTION BY SEISMIC ELECTRIC SIGNALS

The success of the VAN method over thirty years



It is bad to fail, but much worse never to have tried
(Ancient Greeks)

Mary S. Lazaridou-Varotsos

Springer

PRAXIS

Earthquake Prediction by Seismic Electric Signals

The Success of the VAN Method over Thirty Years

Mary S. Lazaridou-Varotsos

Earthquake Prediction by Seismic Electric Signals

The Success of the VAN Method over Thirty Years

Springer

Published in association with
Praxis Publishing
Chichester, UK

PRAXIS

Dr Mary S. Lazaridou-Varotsos
Solid Earth Physics Institute
Department of Physics
University of Athens
Greece

SPRINGER-PRAXIS BOOKS IN GEOPHYSICAL SCIENCES
SUBJECT *ADVISORY EDITOR*: Philippe Blondel, C.Geol., FGS., Ph.D.,
M.Sc., F.I.O.A., Senior Scientist, Department of Physics, University of Bath, UK

ISBN 978-3-642-24405-6 ISBN 978-3-642-24406-3 (eBook)
DOI 10.1007/978-3-642-24406-3
Springer Heidelberg New York Dordrecht London

Library of Congress Control Number: 2011943629

Cover design: Jim Wilkie
Project copy editor: Rachael Wilkie
Typesetting: David Peduzzi

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Contents

List of figures

List of acronyms

ASS	VAN station close to Thessaloniki
EPL	*Europhysics Letters*
EPPO	Earthquake Planning and Protection Organization (in Greek: OASP)
EQ	Earthquake
GI-NOA	Geodynamic Institute National Observatory of Athens
GMT	Greenwich Mean Time
GOR	VAN station at Gorgopotamos
JMA	Japan Meteorological Agency
ICSU	International Council of Scientific Unions
IDNDR	International Decade for Natural Disasters Reduction
IOA	VAN station close to Ioannina town
KER	VAN station at Keratea close to Athens
LT	Local Time
PAT	VAN station close to Patras
PIR	VAN station close to Pirgos town at Elia
SC-IDNDR	Special Committee of ICSU for International Decade for Natural Disasters Reduction
SES	Seismic Electric Signal(s)
USGS	United States Geological Survey
UT	Universal Time
VAN	Acronym of Varotsos, Alexopoulos, Nomicos
VOL	VAN station close to Volos

List of symbols

ΔV	Potential difference change between two points (Section 3.1)
$\Delta V/L$	The amplitude (intensity) of Seismic Electric Signal(s) (Section 3.1)
$\varkappa_1$	Variance of natural time weighted by the normalized energy released at each event (Section A.1)
L	The distance between two points (electrodes)
M	Earthquake magnitude
μ	Average value (Section A.3)
M_w	Moment magnitude of an earthquake
S	Entropy in natural time (Section 18.2)
σ	Standard deviation (Section A.3)
σ/μ	Variability of the variance $\varkappa_1$ of natural time (Section A.3)
χ	Natural time (Sections 18.2 and A.1)
$<\chi>$	Mean value of natural time weighted by the normalized energy released at each event (Section A.1)

Preface

This book follows the adventures of a research team, which began 30 years ago, is still continuing its efforts, and hopes to complete the investigation. This is a research effort for earthquake prediction, the study of changes in the Earth's electromagnetic field, known as the **VAN method** after the initials of Varotsos, Alexopoulos and Nomicos, who began this investigation in 1981 following the disastrous earthquake at Alkyonides Corinth in Greece. (Although I belonged to the team and participated in the experiments from the beginning, it was my decision not to include my name in the logo.)

From the start, there was cooperation between our team and Dr Elizabeth Dologlou, currently Assistant Professor in the Department of Physics, University of Athens, and her experience as a seismologist greatly helped our team. Over the course of the years, Alexopoulos was no longer able to participate in the experiments because of his age (he passed away in 2010 at the age of 101; to the end he watched our efforts with great interest as we met together every Sunday to give him our news). Mr Nomikos left us in 1986. In 1995, two young scientists joined our team: Nicholas Sarlis, physicist, Associate Professor in the Department of Physics, University of Athens, and the mathematician Dr Efthimios Skordas, currently Assistant Professor in the Department of Physics, University of Athens. Since then we have continued with strong will and hard work.

The group includes three graduates of higher technical education: Basil Dimitropoulos, Spyros Tzigkos and George Lampithianakis. The first two have helped install several VAN field stations and have the custody and care of the proper functioning of the field stations and the central station of the telemetric network in Glyfada, Athens. Obviously, just as a living organism needs constant care, so the network needs constant supervision and maintenance to keep it in good working order. There are frequent operational problems, especially in the field stations, due to external factors (lightning, violent weather changes, cable wear by various factors, etc.). The third member (Lampithianakis) of our technicians' group collects digital data from the field stations through dialup once a day in the University of Athens. Finally, working with us is Anastasia Philippopoulou who, amongst other things, is focusing on archiving all the recordings.

The entire team is committed to continue as we have been doing and as forces allow. We all knew from the beginning that the road of this research effort would be very long and difficult. However, we believe that we are going in the correct direction and we are all determined to continue with it, whatever the cost to our personal lives.

I wrote this book for two main reasons.

Firstly, I wanted to explain that the investigation did not start in 1981 out of nowhere. In the 1970s, Varotsos and Alexopoulos published numerous scientific articles in international journals, and wrote a monograph called *Thermodynamics of Point Defects* in Solid State Physic*s*. The monograph was completed and submitted for scientific evaluation in 1980 and eventually published by the international publisher North Holland in 1986 (Figure 2.1). The VAN experimental measurements are just an application of this theoretical work, as I explain in Section 2.1.

Our odyssey of 30 years trying to resolve a problem like earthquake prediction, previously considered unsolvable, splits into three major periods.

The first period, in the 1980s, includes experiments in various regions of Greece and the installation of a network comprising 18 stations whose data we could obtain telemetrically, in real time, at the central station in Glyfada, a suburb of Athens. (The procedure to carry out the measurements is described briefly in Chapter 3.) From these experiments, we found that there were indeed preseismic electric signals, termed **Seismic Electric Signals (SES)**, whose physical properties – found empirically from the continuous measurements (and summarized in Chapter 3) – allowed us to determine the epicenter and magnitude of a forthcoming earthquake.

The second period, in the 1990s, was devoted to achieving a deeper understanding of the SES properties, which were so “strange” and new in the literature when announced in the 1980s and which immediately gave rise to the logical question, “Why is nature working in such a way?” After theoretical work and additional measurements, we have now reached the point where we know “why”, and the explanation is provided in simple terms in Chapter 3 by avoiding the use of complex mathematical formulae. Detailed mathematical proofs can be found in Varotsos’ (2005) monograph, *The Physics of Seismic Electric Signals* (TerraPub, Tokyo, Japan). How these properties were applied to predict large earthquakes, for example in the central Aegean Sea in 1986, in Kyllini–Vartholomio in 1988, in Pirgos in 1993, and the three major earthquakes of 1995 in Chalkidiki, Grevena-Kozani and Eratini-Egion, is described in Chapters 5, 6, 9, 13, 14 and 15.

During the third period, the 2000s, all our efforts were focused on how we could determine more precisely the time window for an upcoming earthquake after we had learned from the SES signals that an important earthquake would soon occur. In that decade, we published several articles on the subject in international journals, which are summarized in Varotsos, Sarlis and Skordas’ (2011) , under the title *Natural Time Analysis: The New View of Time* (sub-titled *Precursory Seismic Electric Signals, Earthquakes and other Complex Time Series;* Springer-Verlag). The main result was that the perception we had regarding *time* should be changed to another way of thinking, called **natural time**, which is explained in simple terms in Chapter 18. This new view of time is of particular use when determining the time of an impending earthquake. As examples, I explain in Chapters 19, 21 and 22 how we were able to identify the timing for three major earthquakes that occurred in Greece after 2000; namely the northern Aegean Sea earthquake in 2001 and the large earthquakes in southwestern Greece and western Peloponnesus in 2008. In Chapter

23, I summarize the current stage of the VAN research in other countries, including Japan, the USA, China, Russia, France, Italy and Mexico.

Note that I do not use any mathematical formulae throughout the 23 chapters of the main body of the book. However, the Appendix at the end of the book gives the necessary mathematical background to undertake calculations in natural time. In this Appendix, I also discuss the case of the super-giant earthquake of magnitude 9.0 in Japan on 11 March 2011, which devastated the Pacific side of northeastern Honshu with a huge tsunami causing serious nuclear plant disasters. This is so placed because the understanding of what happened before that earthquake requires knowledge of the mathematics explained in the first two sections of the Appendix.

All evaluations to date of the VAN method from international committees and conferences have been positive. In the following chapters I describe six of them, namely two international conferences in Athens in 1984 and 1990 (Chapters 4 and 8), two international conferences in California in 1992 and 1995 (Chapter 10), the Special Scientific Committee of the United Nations for Natural Disaster Reduction in 1994 (Chapter 11) and the Royal Society of London in 1995 (Chapter 12).

My second reason for writing this book is, by describing the research which began 30 years ago and continues to this day, to highlight the enormous difficulties that can be met by a research effort. I am addressing mainly young researchers here – those who dream of achieving something in life, those who dare to follow unfamiliar and difficult paths, to those who make targets to resolve some of the unsolved problems of Science. I am addressing them. I want to inform them of what they might encounter in their path and to pass on this message: They must know that the path of their effort is long and difficult, and mostly impassable. It will hurt; it will deprive many of their personal lives. They will be pressed, perhaps even by those around them, to leave. Many will be disappointed and, if they do not have enough strength, will stop. In the long history of humankind, there are countless such examples. If, however, they have faith in that research and the strength to continue, then the adventure is exciting, even magical, and it will bring a sense to their lives. They should be prepared for any eventuality. If they succeed, they will feel complete satisfaction, because they have achieved their purpose. However, despite their long and arduous efforts, they may fail. Nevertheless, believe me, they will feel complete because they tried with all their might. The conclusions of their efforts will be useful, even in that situation. In addition, always remember the maxim of our ancient Greek ancestors: **It is bad to fail, but it's much worse never to have tried**.

Since the beginning of our efforts, we have always presented our results at the Academy of Athens. Some seismologists, however, criticized this by claiming that we did not publish in international journals. Therefore, at the end of this book (and in particular in the References) is a list of more than 140 research articles solely related to this subject that we published in well-known international journals through the reviewing process. This is in addition to the aforementioned three monographs and numerous papers in the proceedings of international conferences.

Furthermore, I would like to mention that almost all the well-known and widely distributed scientific journals, like *Nature, Science, Physics Today*, *EOS* (Transactions of the American Geophysical Union), *La Recherche*, *NewScientist, Physics World*, have repeatedly devoted specific articles and/or commented on our research results. Such articles have also appeared in well-known newspapers in Europe and USA such as *Le Monde, Le Figaro*, *Libération, The Times, Los Angeles Times*, etc., as well as in Japan, for example, *Asahi Shimbun* and *Mainichi Shimbun*.

In the following pages, I have drawn many pieces of information from the press archives and every time I cite the source. Keeping chronological order, I have gradually recorded the course of this research effort.

Finally, it should be remembered that the attacks made on us from time to time were never answered in a similar style. I was always angry, especially when I thought that the attacks were unfair but we did not answer back. The cooler-headed Alexopoulos and Varotsos said to me: "Calm down, Mary, always remember that **one day these people will not feel good about what they have said, while we will be proud of what we have not said**."

I would like to express my sincere thanks to my husband (P.Varotsos) as well as to Mrs Pauline Lovell, who carefully went through the English version of this book and suggested several very helpful improvements

Mary Lazaridou-Varotsos, PhD
Athens, October 2011

1 Earthquakes, seismology and the VAN earthquake prediction method

1.1 Earthquakes: General background and history

An earthquake is a natural phenomenon that causes awe, terror and insecurity. It is characterized by a sudden release of energy which travels via waves from the Earth's interior. The wave nature of the phenomenon was understood in the late 18th century, but the development of research in the field of seismology only started in the second half of the 19th century, with the construction of the first "modern" seismographs achieved shortly before the start of the 20th century. We feel the earthquakes from the sudden movement of soil and perhaps from the breaking of rocks as a result of this energy. If the earthquake is fierce, large areas are affected and the consequences are frightening, resulting in both property damage and, frequently, loss of human life. Over the past five centuries, earthquakes have killed more than seven million people.

Major earthquakes have affected and even destroyed many ancient civilizations. Several historical reports of large earthquakes in Greece and their disastrous consequences were written by Epicurus, Herodotus, Thucydides, Xenophon, Pausanias, Plutarch, Strabo, etc. Let me mention a few examples: powerful earthquakes occurred in 1650 BC when a volcanic eruption destroyed the island of Santorini (sinking the centre of the island and forming a caldera); the destruction of Sparta in 463–464 BC; the destruction of old Corinth in 426 BC; a devastating earthquake at Helice in 373 BC; a very strong earthquake in Rhodes in 227 BC, which caused the collapse of the Colossus of Rhodes (one of the seven wonders of the ancient world); a very strong earthquake which destroyed the Olympia and caused the collapse of the temple of Zeus in 385 AD.

When Charles Darwin, known for his theory on the evolution of species, saw the devastating effects of the earthquake in Chile in 1835, he lamented: "How bitter and humiliating a thing for man to see his works, for which he struggled so badly, destroyed in mil-

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_1,

liseconds." This cry of sorrow and distress is the confession of the inability of humans to withstand such disasters.

Earthquakes have attracted attention from very early times. Throughout history, there are many references to them, mostly characterized by supernatural phenomena associated with the superstitions and prejudices of each place. In Greek mythology, the causes of earthquakes are as follows.

In one version, when the sea god Poseidon (Kosmoseistis, Gaiokratis, Seisichthon), is angry he fixes the trident and the Earth shakes. In Homer's epic *The Iliad*, we have the first description of a large earthquake. The poet wanted to highlight the severity of the Trojan war, in which the gods also participated, and compared it with the massive earthquake that occurred during this time and which shook a great area from Ida (Ossa, a mountain close to Olympus) to Troy (see Rhapsody Y, lines 56–66). The shaking was so strong that, according to the poet, Hades became afraid that the Earth would break open and his palace would emerge covered with cobwebs.

According to another version, the giant Enceladus caused earthquakes. He was the son of Heaven (or Tartarus) and Gaia (Earth), whom the goddess Athena – during the **gigantomachy** (war of giants)[1] – struck with a spear or with the quadriga chariot, threw him to Tartarus and crushed him with a whole mountain (Ossa), or an island (Sicily). Since then, every time the submerged giant stretches, the mountains shake (earthquakes), or when he gets angry he exhales and smoke and fire leave the Earth (volcanoes). This battle between Enceladus and Athena has been immortalized by many artists (for example, in the Parthenon at the Acropolis and the Temple of Apollo at Delphi), as well as on the veil of Athena at the Panathenaic festival[2] wandering through the city.

The first step in understanding the earthquake as a natural (rather than supernatural) phenomenon was made by the great Greek philosophers of antiquity (for example, Pythagoras, Diagoras, Parmenides, Anaxagoras, Thales, Anaximander, Anaximenes, Epicurus, Callisthenes, Democritus Aristotle, etc.). They understood that people could not stop natural phenomena and so they tried to study them. Aristotle was the first to identify the different types of earthquake and the first to note the connection of earthquakes with volcanic activity. He was also among the first who noted that earthquakes mostly occur in the same regions. So his famous saying, "**where the Earth shook once, it will shake again**", is timeless.

1 There is the view that the ancient Greeks characterized the gigantomachy as the perpetual struggle of humans against the natural disasters that threaten their extinction.

2 Panathenaea, a religious festival of the goddess Athena (protector of the city of Athens), was held every year in Athens. Every fourth year, when the Panathenaic Games were also held, the festival was known as the Great Panathenaia and lasted 10 days. During the Great Panathenaia, a special robe (the *peplos*) was made by the women of Athens for the statue of Athena, which was carried to the Parthenon (at the Acropolis) as part of the procession. There was also a sacrifice made to Athena. Award ceremonies included the giving of *Panathenaic amphorae,* which were large ceramic vessels containing the oil given as prizes.

1.2 Seismology in general: The theory of plate tectonics

Seismology is the science of studying earthquakes and the structure of the Earth's interior (it also deals with the detection of nuclear explosions). The scientific study of earthquakes is a new discipline of the past 120 years. In attempting to explain the causes of the occurrence of earthquakes in some regions, seismologists record the seismic waves and study the structure and dynamics of the Earth's interior. A **seismograph** is an instrument that records earthquakes after their occurrence. The record is called a **seismogram** and, after appropriate analysis, the **magnitude** of the earthquake is determined as a measure of the amount of seismic energy released during its occurrence. For the measurement of the magnitude, the 10-unit Richter scale is used. The magnitude of an earthquake is practically the same from any region measured. However, for the same earthquake, the seismological institutes announce different magnitudes that vary considerably (see an example in Chapter 19 for a major earthquake in 2001 in the northern Aegean Sea). These differences occur because individual seismological institutes might follow different definitions of earthquake magnitude and/or have different ways of measuring it. The **focus** of the earthquake is called the "spot", the place inside the Earth where the rupture starts along a fault and thus begins the release of energy. The vertical distance from the focus to the Earth's surface is the **depth** of the earthquake. The **epicenter** of the earthquake is the point on the Earth's surface located directly above the focus of the earthquake. In order to determine the position of the epicenter to the maximum possible accuracy, ideally a dense seismographic network should be installed. (However, beware: the epicenter is an *ideal mathematical point*, as explained in detail in Section 3.6). The **intensity**, namely the severity, of the earthquake is determined by the devastating effects it has on a particular site. Therefore, for the same earthquake, we have different intensities in different regions. The intensity of an earthquake in a region depends on its magnitude, the distance from the epicenter, the depth of the earthquake, the quality of soil in the region, and by the geological structure between the region and the focus of the earthquake. To measure the intensity, the **12-unit Mercalli scale** is widely used.

According to the theory of **plate tectonics** (the idea was originally proposed by Wegener in 1912; for more details see Section 7.2), the upper portion of the Earth, the **litho sphere**, is rigid (solid). Beneath this approximately 100-kilometer-thick rigid surface layer lies the **asthenosphere**, which consists of rocks that are softer (i.e., almost in a state of flux) because of the high temperatures that prevail there. The lithosphere consists of ten or so blocks, termed (**tectonic**) **plates**, which "float" on the asthenosphere and move at speeds of between 2–16 centimeters per year. The stress is caused by the jostle and slip between plates. Large stresses build up at plate boundaries. When these stresses exceed the tensile strength of the rocks, the rocks break along the most sensitive part of the plate (surface **fault**) and thus an earthquake occurs. The world's earthquakes occur chiefly in the boundary zones of the plates, and their devastating effects are due to the generation of elastic waves caused by the sudden rupture (or slip) of the faults in the lithosphere.

The earthquakes described above are termed **tectonic** earthquakes. This description can be applied to almost all (around 90%) earthquakes. There are also, but on a smaller scale, the **volcanic** earthquakes associated with processes that cause volcanic eruptions, and the

collapse earthquakes that are small earthquakes in underground caverns. Finally, there is a class of earthquake caused by **human activity**, for example the construction of dams, industrial or military explosions, underground nuclear explosions, etc.

Depending on their depth, we characterize earthquakes as: (a) **surface** earthquakes that have a depth of up to 60 kilometers (over 90% of earthquakes belong to this class); (b) earthquakes of intermediate **depth**, that occur at depths of between 61 and 160 km; and (c) **deep** earthquakes that have much greater depths.

As already mentioned, most earthquakes occur at the boundaries of tectonic plates. Greece, which lies just on the boundary of the converging African and Eurasian plates, is one of the most earthquake-prone countries – in terms of seismicity it holds the first place in Europe and the sixth in the world. From antiquity to the present, large earthquakes in Greece have caused not only loss of human life but also the partial or total destruction of cultural monuments, as mentioned above.

We call the areas located within the plates **aseismic** because they usually have low seismicity. However, major earthquakes can occur inside the plates as well; an example is a terrible earthquake in Lisbon in 1755 that resulted in the deaths of about 60,000 people and destroyed most of the city from the earthquake itself and from the fires and tsunami that followed. A second example is the 6.6 magnitude earthquake that occurred in Grevena-Kozani in northern Greece on 13 May 1995, in an area previously considered aseismic (see Chapter 14). A third example is the 6.1 magnitude earthquake that occurred on 29 March 1986 in the central Aegean sea, which is discussed in Section 5.1.

1.2.1 Seiya Uyeda

In the further development and foundation of the theory of plate tectonics, which today is established worldwide, Professor Seiya Uyeda has played a key role. His book (Figure 1.1) entitled *The New View of the Earth* (1971) is a classic in this field. As far as the content of this book is concerned, the review by the famous Sir Edward Bullard says it all:

> ...Until the late 1960s most scientists thought of the earth as a rigid body with fixed continents and permanent ocean basins. Now most scientists believe the earth's surface is brittle, in constant motion, and composed of large plates. These plates repeatedly collide, break apart, and collide again. The results of these movements are new ocean basins, mountains, earthquakes, volcanoes and other dramatic features and events. This scientific revolution is called global tectonics, more commonly known as continental drift and it is the central topic of this book ...
>
> ... This book gives an account of the ideas about the earth and about the nature of geological change that have developed over the past 25 years… Uyeda has a topic that is worth treating in the way he has treated it. The development of Geology since 1950 has been a real revolution in ideas ...

Seiya Uyeda served in the University of Tokyo (Japan) as professor of geophysics until his retirement in 1990, and then served in the University of Tokai as a distinguished professor until 2008. During this period, he was a visiting scientist or professor at the universities of Cambridge, Oxford, Stanford, California, Columbia, Pierre et Marie Curie and Texas A&M, and Massachusetts (MIT) and California (Caltech) Institutes of Technology. He is a member of the Japanese Academy of Scientists, and a foreign member of the American

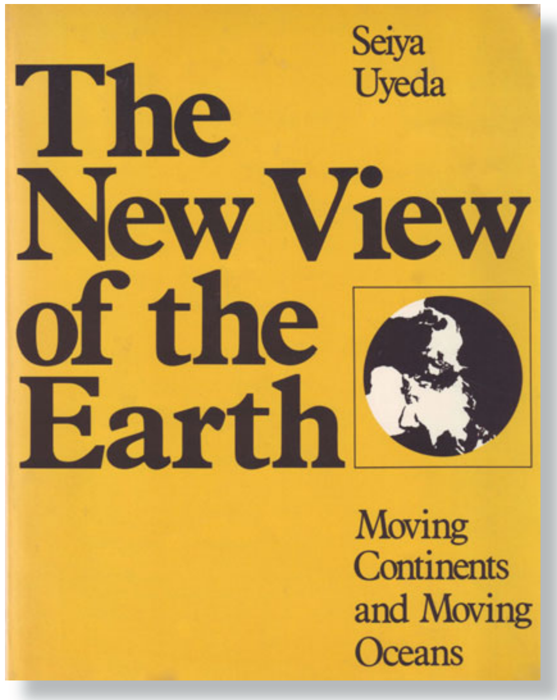


Figure 1.1 The cover of the English version of the classic book *The New View of the Earth: Moving continents and moving oceans* by the eminent Japanese professor Seiya Uyeda, first published in Japan in 1971 and translated into English in 1979.

Academy of Arts and Sciences, the Russian Academy of Sciences, and the U.S. National Academy of Sciences.

In his long and distinguished scientific career, Professor Uyeda has made outstanding contributions to research in many fields of geophysics, including, in addition to plate tectonics mentioned above, rock magnetism, geodynamics, heat flow and earthquakes' generation processes. His scientific optimism is readily apparent in his favourite piece of advice for young scientists: At the end of the 19th century, it was commonly said "a flying machine heavier than air is impossible" (as, for example, stated by Lord Kelvin in 1895), but a decade later, airplanes flew.

1.2.2 Seiya Uyeda and the VAN method

Professor Uyeda, who is highly respected in the international scientific community, visited Greece for the first time in 1984 following an invitation from the Greek Ministry of Public Works to participate in the first international evaluation of VAN. He made a detailed study of the VAN method and, since then, has devoted his time to this area of research. He follows very closely the developments and advances in the field, visiting Greece almost every year to study in situ (Figure 1.2). He has led the research efforts for the implementation of the VAN method in Japan, and in addition played a role of paramount importance in the development of VAN research efforts worldwide, as explained in other chapters of the book (see, for example, Sections 4.2, 4.3, 12.1, 21.5, 22.3, 23.1 and A.4).

1.3 Earthquake forecast: The VAN method

The Earth is a living planet and as long as it remains alive, all natural phenomena in it, including earthquakes, will continue to occur. Earthquakes, therefore, cannot be prevented. Because almost half the Earth's population live in areas affected by earthquakes, from antiquity until today people have tried and are still trying to find precursory phenomena of earthquakes; that is, to predict the earthquakes in order to warn the population and to avoid as much as possible the consequent loss of life.

Let me give a few examples: In the Achaia writings, the traveller Pausanias described various phenomena which preceded the terrible earthquake in Helice in 373 BC (which caused its disappearance). Furthermore, in his texts from On The Animals, Aelian described the change in the behaviour of some animals five days before this earthquake.[3] Cicero reported that Anaximander, a student of Thales of Miletus, happened to be in Sparta in 550 BC when he saw a water source dry up suddenly. He warned the residents of Sparta about an upcoming earthquake, which actually occurred and destroyed Sparta (and now we believe that a change in water level may be indicative of an impending earthquake). Ferekides of Syros, a student of Pythagoras, predicted an earthquake by observing a change in the taste of the water he drank from a well, the earthquake finally occurring two days later (and now we believe that the release of gases, such as radon, from wells may be due to impending seismic activity).

Over the decades, earthquake prediction began to take on a more scientific character. Many scientists in various countries have employed various methods to succeed. In particular, success means to determine the **magnitude**, the **epicentral area** and the **occurrence time** of an impending earthquake. If the assessment refers to the next days, weeks or several months, we talk about **short-term** earthquake prediction. If the estimate is for the next 5–10 years, it is termed **medium-term** prediction, while for a few decades we talk about **long-term** prediction.

3 Some animals have sensitive sensors that capture anomalous electrical signals, or they hear microcracks from rocks before their total rupture.

Figure 1.2 Professor Seiya Uyeda (with the author) visiting Santorini Island in the 1980s in order to study the area for a tentative installation of a VAN measuring station.

VAN constitutes a **short-term earthquake prediction** method. It is an instrumental method: by using electrodes buried into the earth, the VAN method involves taking measurements to detect and interpret precursory electrical signals (see Chapter 2). In the literature, these signals are termed **seismic electric signals (SES)**, and come from the future focal area of an earthquake. These signals are essentially transient changes in the Earth's electric field before the earthquake. On the basis of these signals, VAN achieves the determination of the three parameters: magnitude, epicentral area and time of an impending earthquake. Section 3.6 explains in general terms the desired accuracy of a prediction method, because there is often (unjustified) criticism of the VAN method that it contains "errors" or "ambiguities".

Laboratory measurements carried out at the Solid State Physics Section of the University of Athens confirmed the existence of these signals. In particular, by measuring various types of rocks, it has been found that upon gradually increasing either the uniaxial stress or the hydrostatic pressure, electric signals are emitted well before the breakdown of the measured material – as in the case of earthquakes – in accordance with the theoretical aspects developed by Varotsos and Alexopoulos in the 1970s (see Section 2.1).

2 The development of the VAN research on earthquake prediction

2.1 How and why the VAN research started

On 24 February 1981, at 22:53, a very strong earthquake shook Athens and power cuts in several areas reinforced the panic. The terrified residents rushed out of their homes and tried to understand what was happening. They switched on radios and waited to hear something relevant. Unprepared for such an event, they did not know what to do. They had had no preparation or training on how to react in this situation. Many took to their cars and left, without knowing where they should go. Many people went to coastal areas believing the beaches would provide safety, not realizing the potential risks from tidal waves (tsunami) which are sometimes generated after a major earthquake. They were not aware that the safest places are the open spaces (squares) away from buildings and beaches. Other people remained calmly in their homes, apparently not aware that more earthquakes of greater or lesser intensity could follow over the next few hours, and that these earthquakes, even if smaller, were more dangerous because of the risk of collapse of houses already affected by the first earthquake. Those who remained outside their homes gathered wood and lit fires to keep warm, because of the bitter cold.

Having recovered from the shock, people relied on the radio to learn about the epicenter of the earthquake, the magnitude, and to get advice on what to do. After some time, information became available. The earthquake recorded a magnitude 6.8 and its epicenter was in the Halcyon (Alcyonides) Islands in the Corinthian Gulf close to Corinth. Initially the consequences were unknown. Recommendations were made that people "stay out of homes that had suffered damage, but to return to homes that had not been harmed". In my opinion, this recommendation was wrong. It was midnight and who could, and with what experience, check the houses?

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_2,

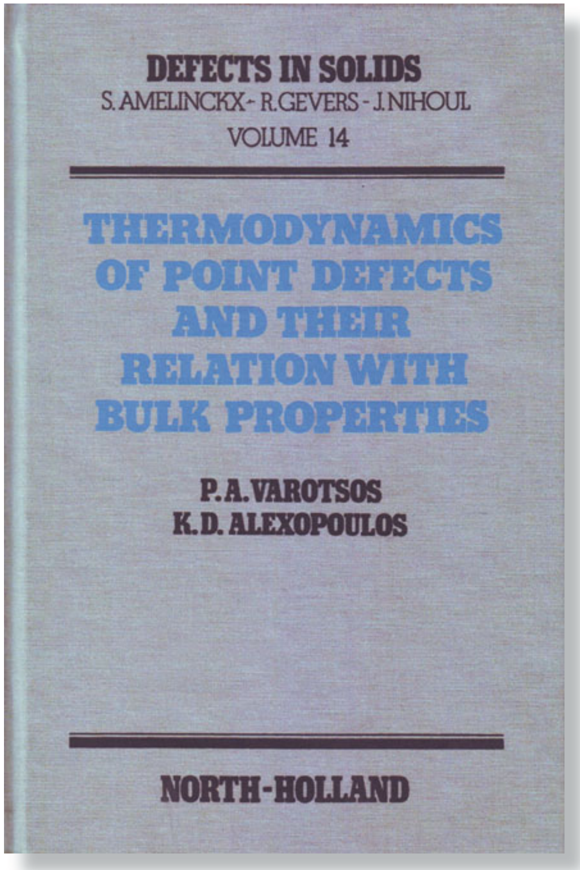


Figure 2.1 The cover of the research monograph by P. Varotsos and K. Alexopoulos, entitled *Thermodynamics of Point Defects and Their Relation with Bulk Properties*, submitted for publication in 1980 and finally published in 1986 by the international publisher North-Holland (Amsterdam, Oxford, New York, and Tokyo).

Time passed, people were cold and tired, and many returned to their homes. Others preferred to stay in their cars, where they tried to keep warm and sleep a little. Many who returned to their homes were unable to sleep and watched television broadcasts until the early hours. Suddenly, at around 04:35 am, a second very strong earthquake occurred. In a panic, everyone now left their homes and stayed outside until morning. Many people gathered around the fires they had lit and endlessly discussed events. Some criticized either the authorities, who had not prepared the population for such an event, or the scientists, who had not informed people about what was going to follow. Others criticized the civil engineers who had not built sturdy houses. Many remembered the tragedy of Thessaloniki in 1978, where a block of flats collapsed, burying 49 people under the rubble. (An earthquake of magnitude 6.8, which followed smaller earthquakes, came after the residents had returned home after assurances from the authorities “that the danger had passed”.)

Experts visited the affected areas and recorded the damage. There were several dead, many people had been injured, and many houses had collapsed. Many houses had suffered severe damage and were uninhabitable without repair. This monitoring extended to the regions, where there was found to have been large losses (Corinth, Perachora, Loutraki Kaparelli, Domvraina, etc.). In these areas, residents were housed in tents for a long time. In Athens, the earthquake had been felt strongly, but the losses were relatively small and had occurred mainly in areas with loose soil, and over the following few days, people gradually returned to their homes.

Our house, then a newly-constructed building, was located in the Ano Glyfada foothills around Hymettus. Built on rocky subsoil, it had withstood the earthquake, showing only minimal surface cracks in the plaster. During the days that followed, Varotsos was almost silent and watched the walls inside the building and out. He was absorbed in his thoughts. One day he decided to speak: “Look, for an earthquake to be generated the rocks inside the earth are brought under high stresses and when the stress exceeds the strength limit, the rocks break. Before breaking, however ...”. At some length, he explained his thoughts to me.

In the 1970s, Varotsos and Alexopoulos, investigating lattice defects in solids, published more than 100 scientific articles in prestigious international journals of solid-state physics. Their theory, verified by laboratory experiments, can be found in their book (see Figure 2.1) *Thermodynamics of Point Defects and Their Relation with Bulk Properties*, which contains all the main results of the articles co-authored by Varotsos and Alexopoulos from 1970 to 1980. In simple words this theory states the following: “When the pressure on a solid gradually increases and reaches a **critical** value, the existing electric dipoles (due to lattice defects) acquire the same orientation, which leads to the emission of a transient low-intensity electric signal, before the fracture. So the solids before the fracture emit an electric signal, which ‘alerts’ the upcoming fracture. How much time elapses between the signal and failure depends on many factors, such as pressure, temperature, physical properties of the solid, etc…”

In the light of this theory (see Figure 2.2), the rocks – which are solids – should at high stress, emit a “warning” electrical signal before the fracture. The question was whether we could record this weak electrical signal, and so we decided to investigate it by undertaking relevant measurements in the area where the aftershocks were going to continue for some time.

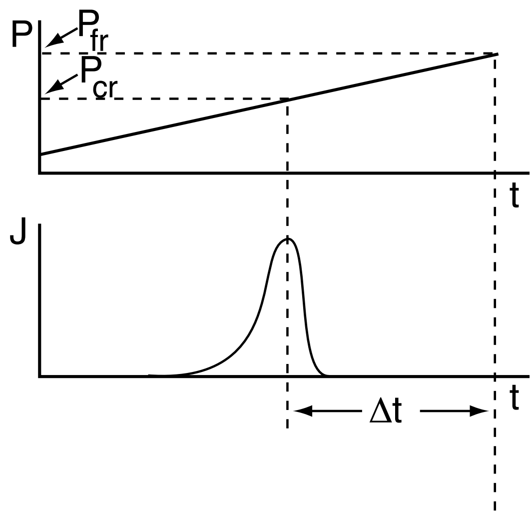


Figure 2.2 Schematic diagram of Varotsos and Alexopoulos' theory, which shows that before the fracture an electrical signal is emitted. The upper figure shows that the pressure (stress) (P) exerted on a solid gradually increases versus time (t) and when it reaches a critical value (P_{cr}) then a transient electrical signal of intensity J is emitted, shown in the figure below. The figure also shows that the fracture (fr) of the material occurs after some time Δt, i.e., when the pressure (stress) reaches a value P_{fr} that is greater than the critical pressure P_{cr}. At low pressure, the electric dipoles have random orientations, and just when all dipoles acquire the same orientation, the solid emits a warning signal, which constitutes the SES. Taken from Varotsos and Alexopoulos (1986).

After a few days, Varotsos invited Professor Alexopoulos to come to the house. When Alexopoulos came, Varotsos, after showing him the cracks, explained his thoughts. The Professor listened very carefully. Extensive discussion followed for 2–3 days and they finally decided to tackle the issue. There was no doubt about the existence of the precursory signal, since the laws of physics are not violated. The question was whether recording would be possible. In other words, this weak electrical signal could be covered (shaded), by electrical noise. (As we all know, in our homes and industries, there are electrical apparatus and installations that are "grounded", so any "parasitic" current goes to earth, thus producing "man-made" electrical signals which could shade the preseismic weak electrical signal emitted by a natural source, such as an earthquake). We could check this by undertaking measurements in the active area where, as mentioned, we expected that earthquakes would continue for some time. Then Varotsos and Alexopoulos called Dr Nomicos, a student of Alexopoulos, who is an expert in electronics, to make the equipment for this experimental work. Nomicos eagerly accepted.

We decided to conduct the experiment at Perachora village, near Corinth, an area very close to the epicenter where the damage suffered was very large. Preparations were made quickly. We prepared electrodes and took a recorder from the university as well as purchasing cables and tools. A few days later, everything was ready for the first experiment.

It was 9 March 1981 when we started, 13 days after the 6.8 earthquake. Our small team (Varotsos, Alexopoulos, Nomicos and myself) arrived in the morning at Perachora. When we saw a military vehicle handing out flatbread to the residents, we realized that it was Shrove Monday. Jokingly, Professor Alexopoulos said, “If we fail in our measurements, we can say that we came to celebrate Shrove Monday out in the country.” We tried to find a suitable home which could provide the electricity we needed. It is worth noting that 80% of the houses at Perachora suffered damage from the earthquake to some extent. Mr Petrou, the owner of a house at the foot of the Gerania mountain (which was why it was not damaged), gladly gave us his home. He and his family lived in a tent in the courtyard of their house.

We put the instruments onto a large table and went out to work, which involved digging holes to place the electrodes, arranging the cables, and making a proper connection with the recorder, etc. Mr Petrou and the surrounding residents were very willing to help and we thank them once again for this. After a few hours, everything was ready and the measuring began. We were trying to see whether there were visible changes in the electric field of the earth before any event. There were some small and some larger earthquakes. However, we did not have a seismograph and very small earthquakes are not easily monitored. Therefore, we hung an object on a tightrope, hoping to see any small oscillations which would result from an earthquake. With such meagre and primitive instruments, we began to investigate the existence of the precursory signal and the possibility of recording it (Figure 2.3). Early indications were quite encouraging and we decided to stay there and continue throughout the night. Small earthquakes continued and this helped us a lot.

(Note: As a first step, we were trying to see if an electrical signal of very short duration, i.e., milliseconds, was recorded a few minutes before each earthquake. If this was the case, Varotsos and Alexopoulos’ theory predicted that there would be another signal of longer duration, but weaker, and much earlier, at several hours, days, or even months before the earthquake; this was the SES.)

At around 9pm, Nomikos left for Athens and the three of us were left to continue. After midnight, Alexopoulos said, “We must continue but take shifts.” After discussion, we convinced him to go to sleep in his car, which was in front of the house. He accepted on condition that we woke him at four in the morning for a shift change. After a few hours, at approximately 3:50am, we felt a strong earthquake, followed by a muffled roar. You would think that the mountain had been plucked and had tumbled to pieces in the nearby ravine. Terrified, we left the house by jumping over the railings of the balcony. This was our first instinctive movement. However, immediately after, Varotsos turned back the way we had come to see whether the instrument had fallen from the table and any measurement had been lost. Logically, his action was erroneous because the earthquake threatened the collapse of the building but Varotsos, excited by the experiment, was afraid of losing information from the event. I found myself in the yard, and heard Mrs Petrou’s shouting, like an experienced seismologist, “Lady Mary, that was 4.5 Richter”. They already had experience of the continuous aftershocks and their estimates were almost accurate. Alexopoulos

Figure 2.3 This photograph was taken in March 1981, when the first measurements were conducted in Perachora village, in the region of Corinth. The picture shows Alexopoulos (left), Varotsos (right) and me (kneeling, watching the records), and a few residents of Perachora.

described the scene with humour: "I was lying in the back seat of the car sleeping, when suddenly I felt a strong shaking. I awoke and looked in fear at the house, because I thought it might be falling down. Then I saw Varotsos and his wife jump over the railings of the balcony and then, immediately after that, Varotsos turning back. So I went outside to see what had happened.". Of course, after this, we forgot the previous agreement to sleep in shifts since nobody had an inclination for sleep. Brewing coffee, we passed the rest of the night together.

The next day, Mrs Dologlou arrived from the Seismology Department, University of Athens. She had learned about the presence of our team at Perachora. She said she had installed a portable seismograph in a nearby home and watched the evolution of the aftershock sequence. We asked her to inform us of any seismic event and she gladly promised. The information she gave us helped us to see if there was a correlation between electrical signals and earthquakes.

Alexopoulos and Varotsos continued taking the measurements and later I did a walk through the city. I had heard about the devastation on the radio, and wanted to see the extent of the damage. I had no previous experience of the fury and power of Enceladus, never seen a city devastated by an earthquake. The images I saw were terrifying. Most of the houses were partially damaged or completely destroyed, the church had suffered major damage, and the tower collapsed. The inhabitants lived in tents installed in open spaces within or outside the village or, where possible, in the courtyards of their homes. Outside a café, which had withstood the fury of the earthquake, many residents sat and talked about the situation. I sat down to drink coffee, and started to strike up a conversation with them. They began to say different things: "We suspected that something strange was about to happen because the animals were very restless with dogs barking and screaming, the donkey bray was of a particular nocturne, and hens cackled uncomfortably", etc. And then the report: "Many homes were completely destroyed, others were uninhabitable, there were injured and dead. Mr… together with his daughter came out of the ruins without suffering any injury because of the protective wooden roof which fell onto their bed, Mr… was very lucky because they pulled him out alive from under the rubble." Endless stories, everyone had something to say. Shocking was the description of the lighthouse keeper who was found with his dog on a wooden boat in the sea. He nearly went mad from fear thinking that the end of the world had come. Before the earthquake, his dog had been panting to get out, but of course he had not understood.

To continue our study in other areas near the epicenter, we needed a seismograph. When we returned to Athens, Varotsos and Alexopoulos visited the Seismological Institute and asked for a seismograph, explaining why they needed it. The then director of the Institute willingly gave them one.

Now equipped with the necessary instruments, Varotsos and I undertook similar measurements in other places around the epicenter (Corinth, Loutraki, Plataea, Thisbe, Kaparelli, Vilia, Thebes, Domvraina), where there were many aftershocks. We made our experimental measurements by installing our recorder either in homes willingly lent by their owner, or in the countryside using batteries. I remember in Domvraina the landlord gave us his kitchen and all we needed, namely a large table and electricity, and he remained all night next to us dozing in his chair and refusing categorically to go to sleep and take a rest, despite our recommendations.

After careful study of the recordings, our first results were announced at the Academy of Athens by the Academician K. Alexopoulos on 21 May 1981 (*Proceedings of Athens Academy*, Volume 56, pages 277–286). Its content, very briefly, was: "During the current period of aftershock activity following the 6.8 earthquake of February 24, 1981, we observed before the earthquakes electrical pulses of very short duration of the order of a few milliseconds. We studied more than 400 earthquakes and found that this electrical pulse precedes the earthquake by 30 seconds to several minutes."

The next day, the press ran enthusiastic articles about the optimism of scientists to predict earthquakes in the future and the global importance of this effort.

The fact that very short pulses precede earthquakes, by a lead time of between half and some minutes, in practical terms is not very useful, but from a theoretical perspective it was for us extremely important. That something happened, even very shortly before an earthquake, showed us that the theory was applicable. This meant that other, weaker electrical signals should exist, which would last longer and appear much earlier before the earthquake. So we modified our experimental apparatus and the measurements continued.

Indeed, we observed that for the aftershocks of the Corinthian gulf, there were electric field changes prior to several hours (about seven on average) before each earthquake. This was announced by Varotsos at the 4th International Conference on Basement Tectonics and Earthquakes, held in Oslo from 9 to 12 August 1981. The announcement had a great impact and was reported internationally by the electronic and printed press. The international news agencies reported instantly to every corner of the world that: “At an International Conference held in Oslo, Norway, a group of scientists from Greece announced that they have recorded electrical signals several hours before the onset of an earthquake...” Unsurprisingly, the Greek news agency took this story and made it the first news item in practically all media in Greece. On the 9.00pm and midnight television news, there was a telephone interview broadcast by Varotsos, who was still in Oslo. The next day, Alexopoulos and Nomicos gave a press conference in Athens. In the evening the public TV channel ERT on its news interview show transmitted the telephone response of Varotsos from Norway.

On his return from Norway, Varotsos said to journalists who were waiting at the airport: “I believe that if a dense network of recording stations is installed in Greece, the prediction of earthquakes may be achieved ...” He asked for the first experimental phase, a network comprising 3–4 stations in different areas.

On 14 August 1981, the then Prime Minister called Alexopoulos and Varotsos and, after congratulating them, promised that the State would provide the necessary assistance to the research group.

But a few days later, things changed dramatically. On 18 August 1981, almost all the press wrote about the previous day’s press conference by a professor of seismology, who expressed reservations about the VAN results. He said:

> The research team comprises very good scientists with extensive research work, but all of them are physicists, so their way of thinking is that of a physicist and not of a seismologist. Their theory can be applied in the laboratory, but this is not necessarily true in seismology, where the influencing factors are complex and indistinguishable.

Varotsos was informed by reporters about the aforementioned interview and, concerning the reservations, answered as follows:

> I’m sure that what we announced is real, and despite any difficulties, we will proceed in our research project. Our theory is experimentally documented. For our experiment, the recordings constitute the evidence. Of course, with the single station that we currently have, we do not pretend to forecast earthquakes, but I insist that this is possible if we have a reasonable number of stations. Anyone who doubts the existence of the signal before the earthquake can do the experiment, or can come with us as an observer to see how and what we measure.

Then Alexopoulos commented with humour: “The seismologists want to convince us with words that we do not see what we see. They will not conduct a similar experiment because they are afraid the result will confirm we are right.”

On 20 August 1981, the newspaper *Mesimvrini* published the results of interviews with 10 scientists and writers who commented on the scientific controversy about VAN. Mr G. Doxas, a literary man, said: “It has created a very bad impression that a Greek scientist invited reporters to express his objections on the work of colleagues. He said he has doubts, but did not substantiate his scientific objections. These vague words were just another show of the particular professor.”

Another professor of seismology had a long meeting with Alexopoulos and Varotsos, at Alexopoulos's home. He was informed about the theory and the views of the VAN team, and they also exchanged views on the implementation of the method and the difficulties to be faced to get the final result. On leaving, he told reporters waiting outside:

> With the information I have, as well as reading the texts of the papers they have given me, I conclude that this is a remarkable research effort. It appears that the team is well on the way to identifying one of the parameters that defines the prediction of earthquakes. It identifies the existence of the electrical signal and the time-correlation between signals and earthquakes. However, there are difficulties that arise in determining the magnitude and the epicentral location of the earthquake. [Excerpt from newspapers, 19 August 1981.]

He stressed, however, that: "It is a serious effort by scientists, and should continue to be supported by the State and seismologists."

On 20 August 1981, the newspaper *Ta Nea* carried a statement by a seismology professor who, among other things, said: "In earthquake prediction efforts should always be made to involve scientists from a range of different backgrounds and expertise, because pre-earthquake phenomena are more physical and geophysical and less seismological." (Later, however, he repeatedly claimed that "the VAN research team comprised physicists, who did not understand seismology".)

Almost all the press commented on the strong reactions of the seismologists. For example, the article in the newspaper *Kathimerini* of 20 August 1981 entitled "The right to hope" read:

> The thirst to know our world and its laws guides eternal humanity in the endless path of progress. It was born with the first man and will disappear when the last man dies. It is natural, then, to excite interest in every event, which leads along this laborious path to progress. And this means so much more to us when the event happens in our country (such as the announcement of the three scientists of the earthquake prediction method they invented), and is associated with the risk to a large part of humanity (earthquakes) in which our involvement is very important, and even linked indirectly to a science (seismology), which explores an object which is as unknown as the sky, because it cannot even come close to reproducing in the laboratory the phenomenon or the environmental conditions. ...
>
> Like so many other things, so it is with scientific research – because research objects are all these – which cannot live outside its area. And its space is the laboratory. In science there are no swords, but dialogues – which is the essence of science – to discuss the different opinions to crystallize views and this is the way to promote science. And let's leave the columns of newspapers for other swords and other dialogues. ...
>
> It will certainly not disappoint this time, as previously mentioned, to undertake the defence of the scientific method and apparatus proposed by the three scientists and to predict that the future will justify them. It will be said now – where it is needed and in the proper format – by the scientists and will be judged in the future. Nor will it attempt comparisons with scientific discoveries or inventions, which determined the evolution of science, but were reviled with contempt when raised for the first time. ...
>
> But we have to defend scientific research indicating almost anecdotal moments from its history [cf. then several examples are reported here, ranging from antiquity.]

Again, to exclude any misunderstanding, we did not mention all these giants of science for nothing else but to highlight the examples of how the facts of science have each their own positions, its path and its future. Thus the scientific research – and that is science – has its own rights. And first among them is the right to try and hope. And above all else we have only the right to hope…

2.2 The first experimental VAN network

On 21 August 1981, Alexopoulos and Varotsos delivered a memorandum to the Prime Minister detailing the first network of stations that the team wanted to install. The Prime Minister promised financial help and said that the army would help both in the transportation of instruments to the countryside and in the installation. The Prime Minister instructed the Office of Scientific Research and Technology to finance the purchase of instruments. From the outset, the scientists made it clear that they did not want a salary and/or any form of payment for their work or generally any involvement with economic issues, and this is why they asked for the purchases to be made directly by the authorities.

Bureaucracy delayed the funding of the first phase promised by the Prime Minister. The group threatened to close the only operating VAN station, because from a single station we could only estimate that an earthquake was coming. This had restricted practical importance (see Sections 3.5 and 3.6), because if there was no network of stations we could not determine the magnitude and the epicentral area. The press pushed hard and finally, after two weeks, 530,000 drachmas[1] were made available for the purchase of instruments for four experimental stations.

At a meeting held on 17 September 1981 at the Ministry of Coordination, attended by the VAN team and seismologists, it was decided to start the first phase of the programme by identifying suitable sites where the four stations would be installed and to operate an experimental week. Also, the Deputy Prime Minister, who was at the same time Minister of Defence, approved the use of the army to help the team. (This was widely reported the following day.)

So the first phase of the experiment began (see, for example, the newspaper *Eleftherotypia*, 26 September 1981) with the help of the army. There were four military vehicles (one for each station), equipped with the necessary instruments and communication systems (radios) and 3–4 soldiers in each vehicle. A temporary network comprising four stations was installed to operate 24 hours a day for approximately one week. Our goal was to see if there was a simultaneous recording of preseismic electric signals at stations of different locations and distances.

The central station of the network was in the house where I stayed. Every four hours, I communicated with the four stations through the Army Signal Centre. There was a full report and a description of local records (I kept a record of all these telephone communications).

1 One US dollar was approximately 300 drachmas.

We spent a period of nearly two months analyzing the records of this one-week experiment and the results were presented in two communications to the Academy of Athens by Professor K. Alexopoulos on 26 November 1981.

The first communication (*Proceedings of Athens Academy*, Volume 56, pages 417–433) refers to the detection of electric signals that precede the earthquakes by about seven hours. These are the Seismic Electric Signals (**SES**), already mentioned. We gave examples of these signals and a histogram of their lead times compared to the time of the earthquakes. The relationship between the logarithm of the amplitude (intensity) of these signals and the magnitude of the earthquakes is approximately linear (as explained in detail in Section 3.5).

The second communication (*Proceedings of Athens Academy*, Volume 56, pages 434–446) discusses how to determine the epicenter of the earthquake on the basis of the preseismic signals recorded. It was observed that the relationship between signal strength and epicentral distance is approximately inversely proportional. In the light of this relationship, the epicenter of an earthquake can be determined by the intensity (amplitude) of the signal that has been previously recorded at a minimum of three stations.

In the UNESCO Balkan Conference in Thessaloniki (23–26 November 1981), the VAN group was invited to talk about their method. There was protest from almost all the Greek seismologists and a stormy debate followed. The professors of seismology claimed that VAN was not a new discovery and that such measurements had been made in other countries by various researchers (however, these allegations were subsequently denied by all the relevant foreign researchers).

This matter occupied the press over the next few days. For example, an article in the newspaper *Kathimerini* on 29 November 1981, entitled “In Greece, the end of ’81”, said:

> You have probably watched how objectively the two known professors of seismology, at the international conference in Thessaloniki, threw the VAN device into the fire of Inquisition. With national pride, they announced, in front of foreign scientists, that this device, which was made a myth in Greece, is not an invention, because such devices exist in all the geophysical laboratories of the world ...
>
> After that, it is considered certain that the fabulous sum of 530,000 drachmas, which was adopted for the VAN experiments by the corrupt government of the Right, will not be granted to the three researchers by the government of socialist change. At some point we stop the squandering of public money.
>
> The financial support of scientific research requires special programming. An example is the great American project of tens of millions of dollars that will be applied internationally, if I remember correctly, by UNESCO with the participation of scientists from various countries, including Greek seismologists. And that programme aims at studying earthquake prediction...
>
> So proper investigations are made without five hundred thousand drachmas of Greek inflation mint. Anyway, I do not think that the implementation of this major project, already underway, with huge amounts of spending on scientific equipment has anything to do with the systematic discouragement of the three Greek researchers VAN. It is coincidence obviously…

On Christmas Eve 1981, the BBC devoted a special laudatory broadcast about VAN. Having referred to the current stage of research, it highlighted the controversy of the Greek seismologists (see the newspaper *Mesimvrini*, 29 December 1981).

At the end of 1981, therefore, we find the VAN team insisting that earthquake prediction is possible if the appropriate network of stations exists, while the seismologists insist that *it is impossible to predict earthquakes*. But the vast majority of the Greek people agree that the State should assist the VAN research in order to install such a network and to be held to account if the allegations are incorrect. The then Minister of Environment promised to do better. “We appreciate the VAN team *as a scientific endeavour*,” he said, “and will help.”

3 The procedure for the measurements: The telemetric VAN network and how the epicenter and magnitude are predicted

3.1 The methodology of measurements

The experimental procedure to measure a preseismic VAN signal, or SES, is simply the following: Two electrodes are driven into the earth, to a depth of, for example, two meters. Each electrode is connected to one end of an insulated cable and then the potential difference is measured between the two free ends of the wires with a voltmeter (which in practice is a differential amplifier). So basically we measure the potential difference between two points A and B on the Earth's surface and this is called a (**measuring**) **electric dipole,** hereafter termed simply **dipole**. When the SES is detected, the potential difference between the two points changes by ΔV, dividing this value by the distance L between the two electrodes, for example 100 meters, is the ratio of ΔV/L, which tells you the change of the electric field of the Earth *in the direction AB*. To find the total change of the electric field of the Earth, however, we must also simultaneously measure in a second direction, for example the one that is perpendicular to AB. In principle, we can make measurements in the two directions, east−west (EW) and north−south (NS), which means that we measure the electric field with two dipoles that are oriented to the NS and EW directions and add the two vector results.

So at least two measuring dipoles are needed, thus placing four electrodes in the earth. In practice, however, many more dipoles are necessary in order to be able to distinguish signals coming from natural sources (and in particular the SES emitted from natural sources, such as the focal areas of future earthquakes) from the signals coming from "artificial" sources, for example, the grounding of electrical installations from nearby industrial sites or the electrochemical changes of the electrodes due to rain. To achieve this distinction, therefore, for each direction many measuring dipoles of different lengths are used, for ex-

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_3,

ample 100 meters, 200 meters, 1 km, and 10 km. The dipoles with lengths of up to a few hundred meters are called **short** dipoles and those with lengths greater than one kilometer are called **long** dipoles. When a signal is recorded, each direction is checked and note taken if the ΔV values measured are proportional to the corresponding lengths. This means that *if* the ratio $\Delta V/L$ is constant for all dipoles of *each* direction (short and long), this indicates that the signal cannot be attributed to an "artificial" source at a distance of up to several kilometers.

Our first measurements were made by installing at least eight measuring dipoles, that is, four dipoles with different lengths in each of the two directions, but nowadays we use many more, from 16 to 48, for reasons I will explain below. Furthermore, at several of our stations we also installed **magnetometers** in order to measure the change of the Earth's magnetic field accompanying the preseismic electric signals, SES.

3.2 The installation and operation of the telemetric network

In order to send real-time data from a remote station, for example, Ioannina (northwestern Greece) to Athens, the measurements of the eight (measuring) dipoles are first amplified (because the SES measurements are weak, typically in the range of a few tenths of a thousandth of V for a dipole length of 100m) and then digitized and collected by a (small) computer at the field station. These data are transmitted through MODEM and a telephone line to the central station at Athens, where they are converted from digital to analogue and recorded on recording machines (recorders), each one of which has 6 to 32 pens. Because a preseismic signal could last for a while, for example, 10 minutes, and then *not* appear again until the earthquake, the records must be continuous, that is 24 hours per day. In this way, we monitor how the electric field of the Earth changes in the different regions of Greece where we have installed (measuring) stations. The selection of these stations is difficult because, beyond that they should be areas of low "artificial" electrical noise, they must be sufficiently "sensitive" to record SES, as explained below.

Let us now see how the installation and operation of the telemetric network has been developed over time.[1] The construction of the network started in 1982 and it took about two years, 1982 and 1983, to install 18 stations, the locations of which are shown in Figure 3.1 (Varotsos and Alexopoulos published this map in 1984 in the first of their two articles in the scientific journal *Tectonophysics*, Volume 110, pages 73–98). The network functioned with minor modifications, explained in the next section, until November 1989 and then stopped as a result of the interruption of telephone lines caused by the EPPO (Earthquake Planning and Protection Organization).

The interruption of the telemetric network occurred not long after we had gathered enough information on the physical properties of the precursory signals SES, which ena-

1 It would be remiss not to mention that the design of the telemetric VAN network was made by a group of Greek scientists led by the physicist Dr P. Hatzidiakos. It was the first time that Greek scientists had constructed electronic microprocessors, adapted to the needs of such a network.

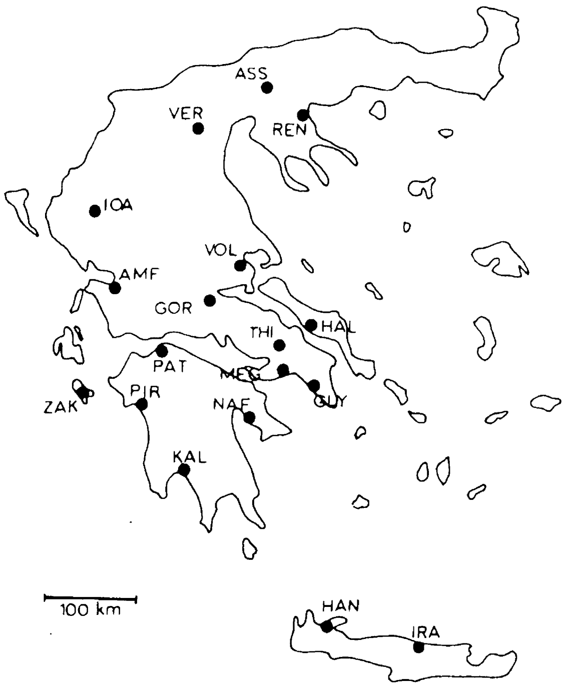


Figure 3.1 Solid circles show the locations of the 18 stations of the VAN telemetric network in late 1983. The stations labelled Chania (HAN) and Heraklion (IRA) were not telemetrically connected to the central station marked here with GLY, because it is located in Glyfada, a suburb of Athens. Taken from Varotsos and Alexopoulos (1984a).

bled the determination of the epicentral area and the magnitude (see Section 3.5) of an impending earthquake and so we proceeded in 1988 to the prediction of the destructive earthquakes in the Killini-Vartholomio area (see Chapter 6). Some months after that prediction, the funding from EPPO stopped completely, and soon after EPPO also interrupted the network's telephone lines.

During the subsequent period 1989–1995 we ran only four out of 18 stations, without the help of the State. These were: a station in Keratea (KER) close to Athens, one in western Greece in Pirgos (PIR), one in northwestern Greece in Ioannina (IOA), and finally one in northern Greece, in Assiros (ASS) close to Thessaloniki. Note that during this six-year period the following powerful earthquakes occurred: Pirgos in 1993, and three large earthquakes in 1995, i.e., at Chalkidiki, Grevena-Kozani and Egio-Eratini (described in detail in Chapters 9, 13, 14 and 15). Thus, we tried to identify the parameters of the impending earthquakes from the very incomplete network of only four stations, which further had inadequate maintenance. To understand the difficulties we faced, I mention, simply for the sake of comparison, that Greek seismological institutes have a total of several tens of stations to measure the magnitude and the epicenter of an earthquake that has, of course, already occurred.

Finally, in late 1995 and early 1996, the then newly-established University Research Institute of the Physics of Solid Earth – following the official recommendation of the United Nations Special Scientific Committee for Natural Disaster Reduction (see Chapter 11) – began reopening some of the stations that had been discontinued in 1989. Today the VAN network comprises nine stations as shown in Figure 3.2. These are the stations that provided the data on which we relied on in order to predict the subsequent earthquakes. In particular, during that period, the predictions of the following major earthquakes with magnitudes 6.5 or greater were documented, amongst others: 26 July 2001 in the North Aegean Sea, 14 February 2008 in southwestern Greece in the area of Methoni, 8 June 2008 in the western Peloponnese between Patras and Pirgos in the Andravida area. These are described in detail in Chapters 19, 21 and 22.

3.3 Sensitive and nonsensitive sites

Let us now proceed to the following important question: *Can we install a station for recording preseismic signals SES in* ***any*** *area*? The answer is categorically **no**. Recall that, in principle, a candidate region must have very low "electrical" noise, which means that it should lie at a considerable distance from "artificial" electrical sources (for example, electrical installations in homes, factories, etc.) which, through their electrical power grounding, as explained above, emit electrical disturbances that can exceed and hence "shade" the preseismic electric signals (SES). But suppose we have indeed identified (after in situ measurements lasting a few weeks), such a "quiet" area that has very low "artificial" electrical noise. It may be that this site is *not* ultimately appropriate to install a permanent station to capture SES. This is due to the following reason.

We found experimentally, but we also understand it from the theory (as explained below) that **not all sites of the Earth's surface are sufficiently sensitive to capture SES**. For this reason, we first install a considerable number of temporary stations (usually 10 to 20) in a region and operate them for a significant period (usually 1–2 years). If during that time there have been some earthquakes, even in the magnitude range 4.0 to 4.5, we can decide whether one (or a few) of these stations have actually recorded SES. If we have no SES record from any of them, we move everything away and settle it in new locations, repeating the previous process until we find a suitable site which is sensitive to capturing SES. For example, the tedious procedure through which we found a suitable sensitive site for the Ioannina station was described in an extensive paper by three Japanese researchers (Kondo, Uyeda and Nagao, 2002, *Journal of Geodynamics*, Volume 33, pages 433–461). They reiterated and confirmed the procedure we followed, and published their own conclu-

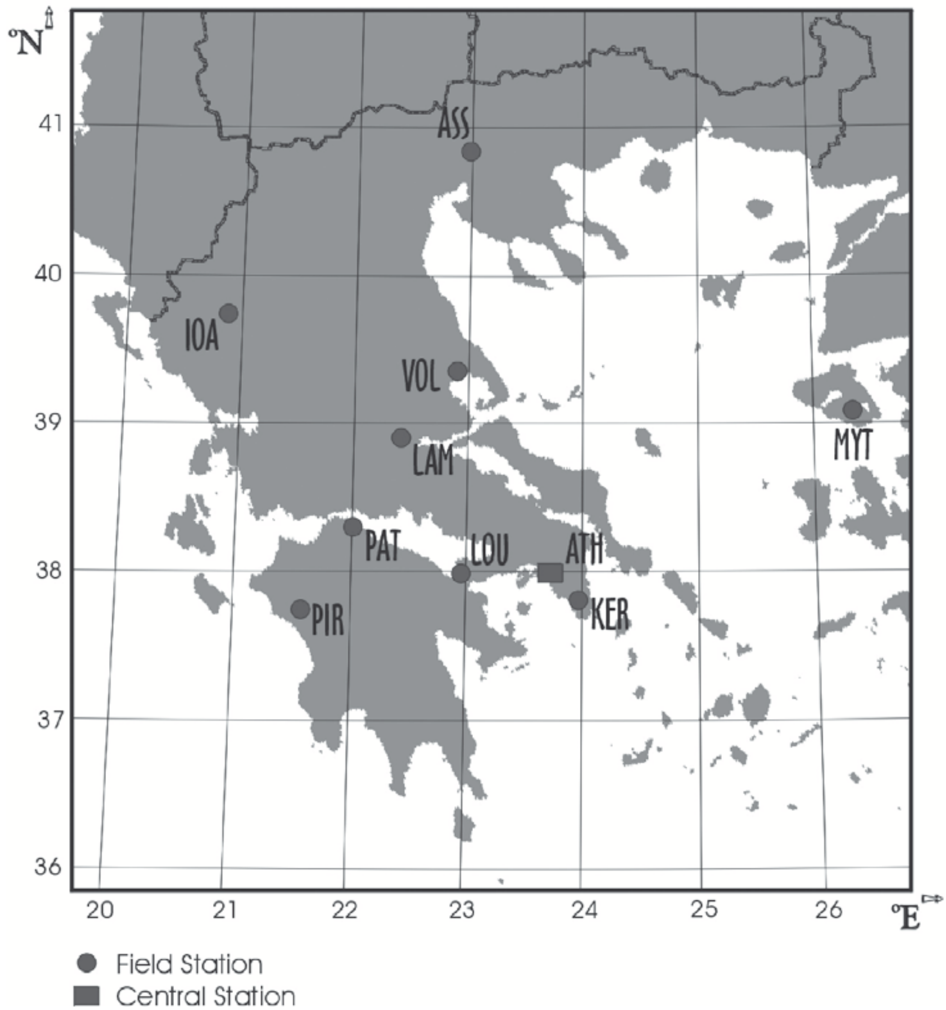
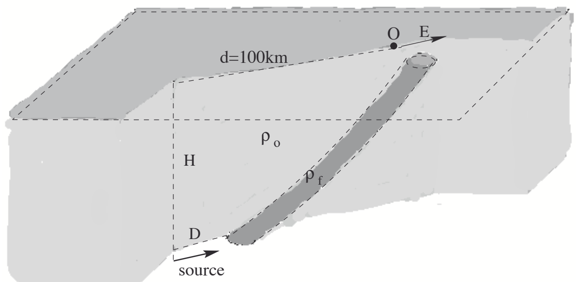


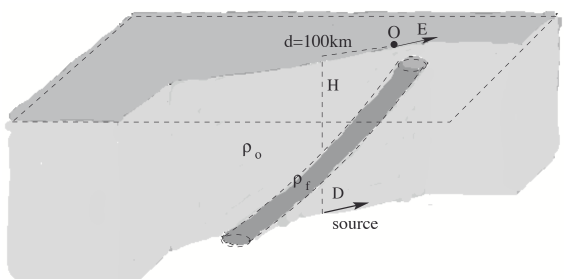
Figure 3.2 The solid circles mark the nine stations operating today: Keratea (KER), Corinth-Loutraki (LOU), Patras (PAT), Pirgos (PIR), Lamia (LAM), Volos (VOL), Ioannina (IOA), Assiros (ASS), and Mytilene-Lesvos (MYT). All these stations are currently connected to the central telemetric station at Athens (ATH) marked by a square. The central station lies in the suburb of Glyfada (GLY), as also shown in Figure 3.1. Taken from Varotsos (2005). Copyright (2005), with permission from *TerraPub*.

sions in order to let other researchers, both in Japan and other countries, know the steps to be followed for finding a sensitive SES station.

Why are only a few points on the surface of the Earth sufficiently sensitive to record SES while others are not? This has been explained by Varotsos and Alexopoulos as follows: Earthquakes occur when one "side" of a preexisting fault is "sliding" on the other. But these faults, which can be very long, typically 100km or so (note, however, that faults exist that have a total length of several hundred kilometers, or more), are regions of the Earth's crust where the electrical conductivity is much higher, for example 100 times or even 1000 times, than the average conductivity of the Earth's crust. This was suggested by Varotsos and Alexopoulos in the early 1980s and has since been verified by independent research groups in various parts of the world, such as the USA (California), Japan, China, Russia, etc. So when an electric signal is emitted from a future focal area, most of the current



A



B

Figure 3.3 Schematic explanation of why a station located at site "O" on the Earth's surface is "sensitive" to record SES. The future focal area of the earthquake, located at depth h, is the source from which the SES is emitted, as indicated by the arrow, and lies near a fault that is very shaded.

"prefers" to take the most conductive path, that is, to follow the "conductive corridor" that has been created by the pre-existing fault. See, for example, Figure 3.3, where the arrow shows the focal area, at depth h from the surface of the Earth, which emitted the preseismic signal SES. Most of the current follows the adjacent rift designed with a bright shady "tube" (which is a conductive corridor) and ends at the top just below the Earth's surface. When the current reaches that end, in neighbouring sites of the Earth's surface, for example the site "O" indicated in Figure 3.3, a strong electric field is created. (When we are close to the "*edges*" of a conductive surface, as here, we know from physics that strong electric fields are created. This is the phenomenon on which the "lightning rod" is based, where the current has been "concentrated" from the lightning, and then passed on to the Earth). However, in sites of the Earth's surface located far from the upper end of that conductor, the SES electric field is very much smaller, about 100 to 1000 times smaller than that in point "O", and therefore does not exceed the electrical noise caused by man-made "artificial" power sources. In other words, if the station for the SES measurement is installed at a point similar to the "O" in Figure 3.3, it will be (sufficiently) sensitive to record the SES. So this explains why the vast majority of points on the Earth's surface are *not suitable* (or are *non-sensitive*) for installing SES stations, and only about 10% (or less) is SES sensitive.

The sites shown in Figure 3.2 indicate stations currently operating which are SES *sensitive*, and have repeatedly recorded SES during their operation over nearly three decades.

3.4 The selectivity of a sensitive station

A very important property of these sensitive stations is their **selectivity**, which means that *a sensitive station does **not** record SES from **all** seismic areas, but only from some of them* (this phenomenon will be discussed, together with others, in Section 3.5). For example, Figure 3.4 shows the VAN stations at the end of 1988 (note this map is slightly different from that of Figure 3.1, which shows the locations of VAN stations at the end of 1983, when they were established for the first time. Since then, we began looking for more sensitive stations, which meant our network was gradually improved). In this figure, the slightly shaded area to the west of the country shows that earthquakes occurring in this region until 1988, gave SES recorded at Ioannina (IOA) station. This area is called the **selectivity map** of IOA station.

Figure 3.4 also shows the heavily shaded regions "a", "b" and "c", which show that earthquakes in these regions emitted SES recorded at the Assiros (ASS) station, near Thessaloniki. In other words, the **selectivity map** of the ASS station is the large area which includes these three highly shaded regions. So far, we have built such selectivity maps for each of the stations currently in operation (shown in Figure 3.2), bringing together all the SES information collected before the major earthquakes in the last three decades. Obviously, when a station is new, its selectivity map is unknown. It is gradually constructed over time by accumulating the collected information, that is which seismic regions emitted SES that have been recorded by the station under discussion. Knowing the selectivity map of a station is very important (Section 3.5).

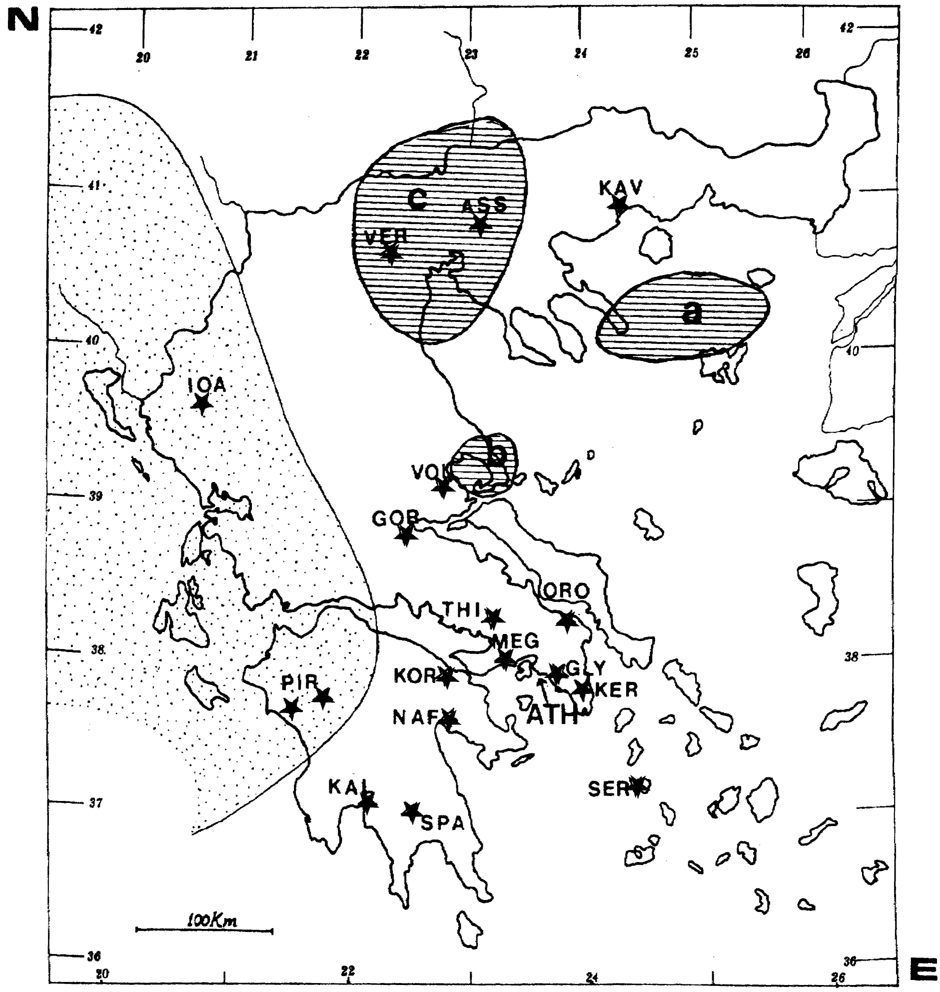


Figure 3.4 Selectivity maps for two stations: Ioannina (IOA) and Assiros (ASS). For IOA the selectivity map is the slightly shaded area in the west, and for ASS the area resulting from the combination of the heavily shaded regions a, b and c. These maps were compiled from the relevant information gathered from these stations by the end of 1988. Taken from Varotsos (2005). Copyright (2005), with permission from *TerraPub*.

3.5 How the magnitude, epicenter and time of an expected earthquake is predicted

To understand how the parameters of an impending earthquake are determined based on the physical properties of the preseismic signals SES, I summarize below these properties, beyond the "sensitivity" and "selectivity" I mentioned in the previous two sections, along with the likely explanation. (One can find the detailed mathematical explanations in Varotsos (2005).

An SES may last for half a minute to several hours, but in some cases can last for a few days (such as the SES before the 6.5 earthquake in Peloponnese on 8 June 2008, discussed in Chapter 22). It has been found experimentally that there is *no correlation between the duration of preseismic signals SES and the magnitude of the subsequent earthquake*. This is a very important point because it is completely distinct from other precursory phenomena proposed in the past, in which it had been suggested that the longer the duration of precursory phenomena, the greater the magnitude of the expected earthquake.

The time (Δt), which elapses between the recording of SES and the subsequent earthquake, generally ranges from several hours to several months (Chapter 18 describes a significant improvement in recent years concerning the determination of the occurrence

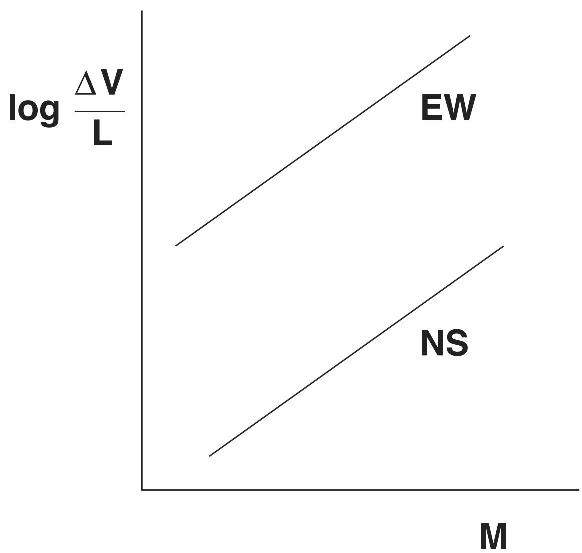


Figure 3.5 How the SES amplitude (intensity), as measured by the ratio ΔV/L, recorded at two directions EW and NS, increases with the increasing earthquake magnitude.

time of the impending earthquake, the accuracy of which is now of the order of some days). Approximately, but very generally, we can say that usually (but not always) if we record a **single** SES (that is, a single transient change of the electric field of the Earth), it is followed by an earthquake within 11 days. If, however, several electric signals are recorded within a short period of time, say within 1−2 hours, which we call **SES activity**, then that activity is followed by several earthquakes. The strongest of these earthquakes occurs *after three weeks, during the fourth week after the recording of the SES activity, or 2−3 weeks later*. There are several such cases, such as the Killini-Vartholomio earthquakes in 1988 (Chapter 6), the Pirgos earthquakes in 1993 (Chapter 9), the Chalkidiki earthquake in 1995 (Chapter 13), the Kozani-Grevena earthquake in 1995 (Chapter 14), the earthquake at Eratini-Egion in 1995 (Chapter 15), etc. But I stress again that there is no correlation between the precursory time Δt and the magnitude of the forthcoming earthquake.

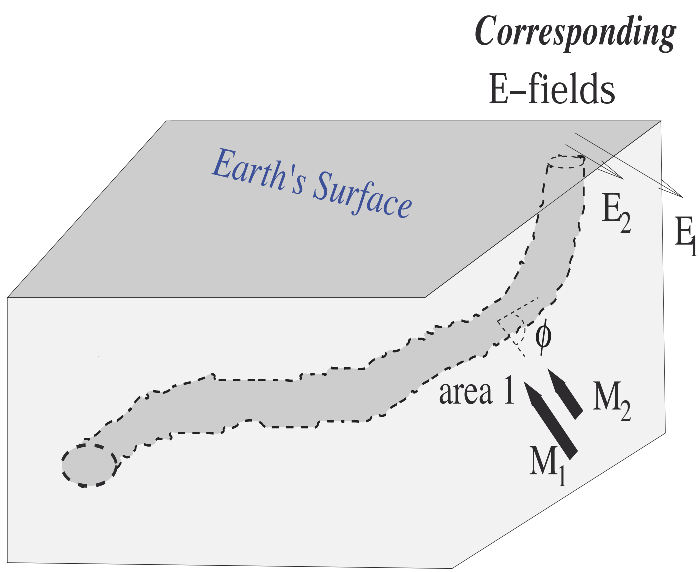


Figure 3.6 Let us consider two earthquakes of magnitude M_1 (larger) and M_2 (lower) that occurred in the same area ("area 1", in the figure). The corresponding SES are recorded in the same sensitive station located on the Earth's surface (near the upper end of the "conductive corridor" shown in the figure by a strongly shaded tube) and have the same direction but different amplitudes (intensities) E_1 and E_2. Taken from Varotsos (2005). Copyright (2005), with permission from *TerraPub*.

What governs the magnitude of the impending earthquake is the SES amplitude (that is, its intensity), calculated by the ratio $\Delta V/L$ as explained in Section 3.1. The exact law, found experimentally by Varotsos and Alexopoulos in 1984 (see their two articles in *Tectonophysics*, 1984, volume 110, pages 73–98 and 99–125) is shown in Figure 3.5 and tells us that the logarithm (log) of the quantity $\Delta V/L$ increases linearly with the increasing magnitude M of the earthquake (this holds for both components of the SES along the directions EW and NS, in which we usually make the measurements) with a slope that is stable, indeed equal to about 0.3 (to 0.4).

Let us now see what slope 0.3 means in simple words. If we compare SES signals recorded at the same station (for example, the Pirgos station) to earthquakes of different magnitude but from the same seismic region (say, for example, from Kefalonia), if the earthquake magnitude increases by 1 unit, then the corresponding SES amplitude is approximately double. This is very important and what happens is shown in Figure 3.6.

In Figure 3.6, the thick arrows indicate two earthquakes with magnitudes M_1 (larger) and M_2 (lower) that occurred in approximately the same area (designated "area 1" in the figure). The SES of these two earthquakes (recorded when the current reached the upper end of the "conductive corridor" close to a sensitive station had been installed in the Earth's surface, as explained in Figure 3.3) *have the same direction but different amplitudes*, labelled with the two arrows E_1 and E_2, that is, the lengths of the arrows are the corresponding values of $\Delta V/L$ for these two signals.

In other words, this means that if in the past we have actually recorded an SES with an amplitude E_2 corresponding to an earthquake of magnitude M_2 (this is called "calibration" of the station in respect to the seismic area 1) and we now record a new SES with an amplitude E_1 approximately two times higher (compared to E_2), we expect that the imminent earthquake must have a magnitude M_1 larger by one unit compared to M_2 (note that if the amplitude of the new SES is four times higher, then the new earthquake magnitude will be larger by two units, and so on). I also clarify that when we say the directions of E_1 and E_2 are the same, this is judged from the experiment as follows: When we record an SES, as explained in Section 3.1, we measure a component $\Delta V/L$ in the EW direction and another in the NS direction. *The ratio of these two components determines the SES direction*. So when we say in Figure 3.6 that E_2 and E_1 have the same direction, we mean that the ratio of the two components in the one SES is almost identical to the corresponding ratio of the two components measured in the other SES.

Let us now suppose that in a sensitive station on the Earth's surface, shown in Figure 3.7, we record two SES from earthquakes occurring in two different areas labelled as "area 1" and "area 2", respectively. We find experimentally, but it is also theoretically proven (Varotsos, 2005), that (regardless of the magnitude of the expected earthquakes) *these two SES have different directions*, that is, the ratio of the components in the EW and NS directions of the one SES differs from the ratio of the components in the other SES. If indeed our measurements in the past have already "calibrated" the station both in respect to the seismic "area 1" as well as to the seismic "area 2", we can estimate the magnitude of each earthquake expected in those areas.

Taking into account the above-mentioned properties, we can now summarize how we determine the epicenter and the magnitude of an impending earthquake relying solely on the properties of SES (as long as the selectivity map is available from previous measurements). Suppose, for example, that we recorded one SES at the station Ioannina (IOA). The first and most important step is to immediately consult this station's selectivity map to see that the impending earthquake will occur in the slightly shaded area to the west (Figure 3.4). As a second step, we find the direction of the SES by calculating the ratio of the two components, namely the values of $\Delta V/L$ at the directions EW and NS. From this ratio (remember how we made the distinction of seismic areas 1 and area 2 in Figure 3.7) we understand which part (that is, which region) of the light shaded area in Figure 3.4 is the *most probable epicentral area for the forthcoming earthquake*. Figure 3.8 shows *three SES in different directions*, recorded at the same station on the Earth's surface, which are indicated with the thin arrows 1, 2 and 3. These three SES correspond to three different seismic regions, marked by the thick arrows 1, 2 and 3, respectively. As a third step – which should be carried out *only* after the determination of the candidate epicentral area in the second step – we consult the calibration of the station that recorded the SES, in respect

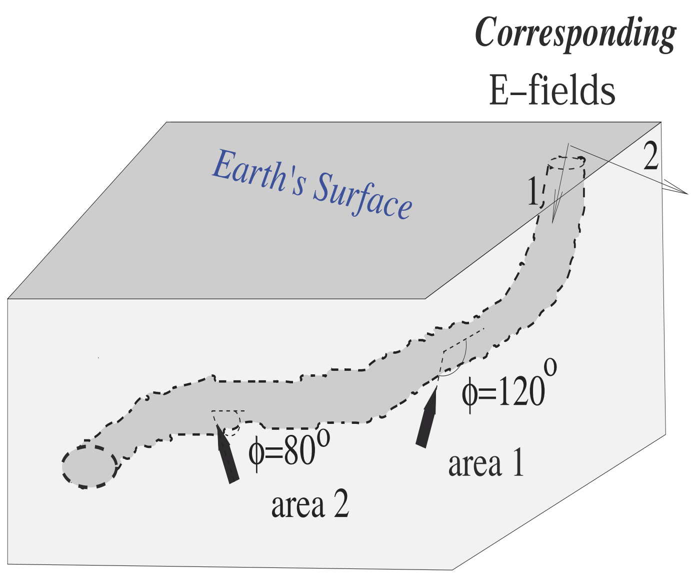


Figure 3.7 The two thick arrows indicate two earthquakes that have occurred in two different areas: "area 1" and "area 2". If the corresponding preseismic SES are recorded in the same sensitive station on the surface of the Earth, their **directions**, as shown by the arrows E_1 and E_2, are **different**. Taken from Varotsos (2005). Copyright (2005), with permission from *TerraPub*.

to the candidate epicentral area, as explained in the discussion of Figure 3.6. This means that we compare the amplitude of the current SES with the amplitude of an earlier SES (registered at the same station) that corresponds to a past earthquake which had occurred in the same area, taking into account the rule stated above which means that *if the current SES amplitude is twice the amplitude of the past SES, the magnitude of the expected earthquake will exceed the past earthquake magnitude by one unit*.

The above methodology is applied if there is a very sparse network of stations, such as ours in Greece where there is on average only one station for every 100–150 km, so the preseismic SES is usually recorded at only one of the stations (while the frequent electric field variations – called magnetotelluric disturbances – induced on the Earth's surface by the magnetic field variations due to sources lying outside of the Earth, e.g., to particles from the Sun, are simultaneously recorded at all the stations).

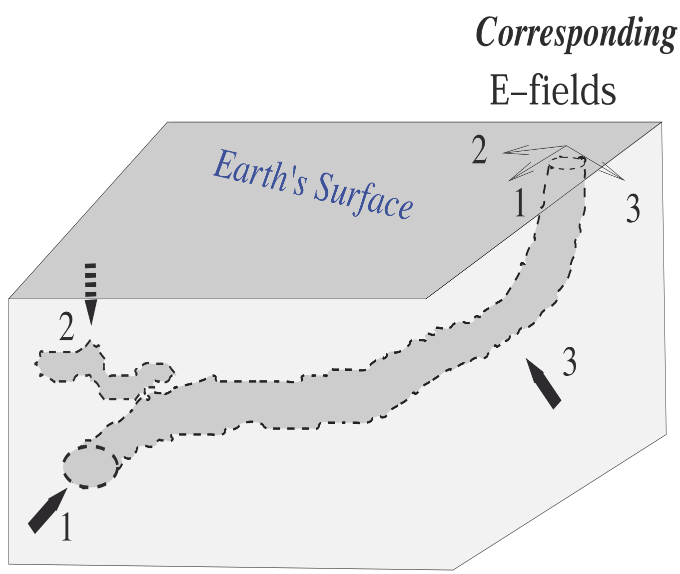


Figure 3.8 Three different seismic regions – marked with the thick arrows 1, 2 and 3 – that emitted three preseismic SES recorded *in different directions* at the same station on the Earth's surface, which are marked with the thin arrows 1, 2 and 3, respectively. These three seismic regions are certainly in the selectivity map of this station and are distinguished (on experimental grounds) by means of the *different SES directions* indicated from the different ratios of the components of the SES recorded. Taken from Varotsos (2005). Copyright (2005), with permission from *TerraPub*.

On the other hand, if the network is dense, Varotsos and Alexopoulos showed (*Tectonophysics*, 1984) that the epicenter and magnitude of the expected earthquake can be easily determined when the SES happens to be almost simultaneously recorded, for example at three to four stations.

I would like to emphasize the following point concerning the above-mentioned methodology applied to a very sparse network of stations. Let us assume that we actually record an SES at a station for which we know neither the selectivity map nor the calibration of the different epicentral areas. In this case, we **cannot identify the epicenter and the magnitude** of the impending earthquake. In other words, when an SES is recorded at such a station, all we learn is that an earthquake is coming and can only estimate, for example, that *if* the epicenter is located 100 kilometers from the station the earthquake magnitude will be, say about 5 units, but *if* it is located 200 kilometers away the magnitude will be about 6.0 (recall that the *signal strength decreases approximately inversely with the epicentral distance*). Of course, even this incomplete information is very useful in the case of a very strong earthquake (compared with the fact that we had no information before and did not even know that a powerful earthquake would occur), but it is certainly not enough to take precautionary measures to a particular region when the earthquake is for example, of magnitude 6.0 (see also the next section on this point).

3.6 The desired accuracy in a prediction

Now the important question is raised about the necessary precision of the information obtained from the SES in order for it to be of practical use. Here we will see that there is unintentional misunderstanding if we accept the good faith assumption that there is ignorance as to the true extent of the natural phenomenon.

Let us start with the so-called **epicenter**, described in simple words in Section 1.2. This is an "ideal" (fictitious) mathematical point on the Earth's surface directly above the earthquake **focus** (again an ideal point) from which we assume that the fracture (or slip) initiates and then propagates over long distances within a very short time, because the corresponding speed is a few kilometers per second. For example, for earthquakes with magnitudes of about 7.0 to 7.5, the length over which the rupture actually propagates is of the order of 100 kilometers; for magnitudes of about 8.0 it is 200 to 300 kilometers (for example, the ruptured length of the magnitude 8.0 earthquake in China in 2008 was around 300 kilometers, see Section 23.3); and for earthquakes of around 9.2, as in Sumatra in 2004, it is approximately 1000 kilometers. Moreover, we now know that major damage may occur at distances over 200–400 kilometers away from the epicenter, as happened, for example, in the devastating earthquake in Mexico in 1985 (cited by Varotsos in his speech when receiving the International Prize of the Onassis Foundation (1995), see Chapter 16 and Section 23.5). In other words, to "enclose" in advance (forecast) a future area of a (linear) dimension of about 100 kilometers, it is necessary to indicate a square with (linear) dimensions about twice as much, that is 200 kilometers (if, of course, you take into account the so-called "experimental error" when you make measurements). Hence, you must indicate in advance a “square” area 200kilometers × 200kilometers for an expected earthquake of a magnitude in the range 7.0 to 7.5. If indeed the expected earthquake magnitude is 8.0 to 8.5, this area will be approximately 500kilometers × 500kilometers or larger. For the sake of comparison, the largest earthquake in Greece since 1983 (that is, after the installation of the VAN telemetric network), occurred in southwestern Peloponnese on 14 February 2008 with a magnitude close to 7.0. In this case, we had indicated about two weeks before (see Chapter 21), an almost square area measuring approximately 220kilometers × 250kilometers. The criticism we often hear is that the VAN method does not identify the epicenter with enough precision. This is totally unjustified and incomprehensible, because it is like predicting that a certain house is going to collapse, but then one is required to say which specific crack and what column in the house will begin to collapse. Whoever raises the question is ignorant of the actual dimensions of the phenomenon, that is, is unaware that the epicenter is only of theoretical or academic interest, and what matters in practice is how long the eventual reach of the "slip" (or “break”) at the activated fault will be. So much for the accuracy of the epicenter.

Now, regarding the accuracy of the prediction of the magnitude, as will be explained in later chapters, it is well known that even after a particular earthquake, the figures announced by various seismological institutes differ significantly. For example (see Chapter 19), for the earthquake that occurred in the Aegean Sea (close to Skyros Island) on 26 July 2001, the Geodynamical Institute of the Athens Observatory initially said the magnitude was 5.5 but later that it was 5.7, while the official announcement of the U.S. Geological Survey was 6.5. (Note that the predicted magnitude by the VAN group was 6.5.) Therefore, the critics cannot require from the VAN team “accuracy” in the prediction of the magnitude while ex post (that is, after the earthquake) there is not even agreement among the seismological institutes about the actual magnitude of an earthquake. In summary, I would say that a difference of around 0.5 to 0.7 between the predicted magnitude and the average figures reported after an earthquake occurrence by reliable institutes would in principle be admissible in view of the expected experimental errors.

4 First international evaluation of VAN, 1984

4.1 The first unsuccessful attempts to evaluate VAN (late 1983–early 1984)

The first substantial scientific evaluation of VAN research results was made at the November 1984 International Workshop in Athens (see Section 4.2). It was preceded by other unsuccessful attempts, briefly described in this section.

At the end of 1983 and in early 1984, the Earthquake Planning and Protection Organisation (EPPO) and the Ministry of Public Works appointed two committees (i.e., a scientific panel of experts and a second committee comprising representatives from scientific associations) to evaluate VAN. What eventually happened was described much later by the newspaper *Kathimerini* on 10 March 1985:

> ... It should be noted that the conference in November [1984] held, pursuant to a decision of the Ministry of Public Works took place on December 15 1983. An earlier meeting at that time had never taken place. Instead, a scientific meeting (January 13, 1984) of Greek professors took place…in which it was decided to make a proposal to the state general aid VAN programme and to organize an international conference on the electrical methods for the prediction of earthquakes. This was followed by another attempt to set up a committee of scientific associations to evaluate the method. Again, however, there was no specific (and commonly accepted) result for this committee, because the Academy of Athens and the Hellenic Association of Physicists had already left…

Indeed, at this committee of scientific associations, which met on 19 March 1984, the Hellenic Association of Physicists (HAP) stepped down. At a press conference, an HAP board member explained the reasons. The next day (20 March 1984) the newspapers reported. First, the newspaper *Kathimerini*:

> In the first meeting of the associations – it was announced yesterday by the participating representative of HAP – "we discovered that the scientific committee of experts ... could not

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_4,

complete its work or draw conclusions". The minutes make it clear that not only had the composition not been secured according to the Ministerial Decision (from six foreign experts announced to participate, only one, the Swedish seismologist Dr Kulhanek was present), but there were serious organizational weaknesses, as evidenced by the protests made by committee members. Greek specialists were not informed in time and the foreigners were not informed at all. The EPPO had not sent data to both sides, before the meeting. After this, the absence of any conclusion from the scientific committee is not surprising but should be expected.

Second, the newspaper *Eleftherotypia* wrote:

The Hellenic Association of Physicists (HAP) has withdrawn from the EPPO meeting with the accusation that the associations involved in it and convened to decide the practical use of the VAN method, give an impression that precludes any positive aspect of the method, before even examining first whether there may be or may not be practical exploitation. After the Athens Academy, the HAP withdrawal from the EPPO creates serious problems for its continued operation.

And it then continues in a similar vein to the *Kathimerini* article quoted above. The newspaper *Eidiseis* wrote that the representative of the HAP explained that:

... We were under the impression that the associations were invited just to decide that there was no practical value in exploiting VAN and not to examine whether or not VAN could actually make predictions.

In the same newspaper, an article read: "Representatives of seismological organizations and of the Association of Geologists who participated in the committee were assistants of one professor of seismology."

Finally, the newspaper *Vradini* wrote:

The withdrawal of the HAP is due to the fact that the coalition [of the associations] and EPPO attempted to go above and beyond any scientific ethics by deciding to vote upon the practical use of the VAN method without first reaching a scientific conclusion on whether or not the VAN method achieves prediction and with what accuracy…

4.2 International Scientific Meeting, Athens, November 1984

Finally, the first scientific evaluation of the VAN research was made in November 1984 by an International Scientific Advisory Committee. Specifically, from 20 to 23 November, a scientific meeting of top international scientists was held in Athens, following a decision by the Ministry of Public Works to assess the up-to-date research results of the VAN method. Ten prestigious researchers attended from seven countries: USA, Japan, China, Germany, Great Britain, Sweden and Poland. Their names are given below (in the order they signed the relevant five-page conclusions of the meeting).

Dr S. Crampin, The British Geological Survey, Chairman of the Commission on Wave Propagation in Real Media of the International Association of Seismology and Physics of the Earth's Interior.

Professor Ota Kulhanek, Professor of Seismology, Director of the Seismological Institute, Uppsala, Sweden.

Professor D. Lazarus, Editor-in-Chief of the American Physical Society, Professor of Physics, University of Illinois, Urbana, USA.

Professor Lü Dajiong, Chinese Academy of Sciences, Beijing, Director of Chinese Institute of Developing New Technology, Chairman of the Council of Chinese Society of Frontier Science.

Professor W. Ludwig, Professor of Physics, Director of the Institute for Theoretical Solid State Physics, University of Münster, West Germany [coworker of Max Born].

K. Meyer, seismologist, Seismological Institute, Uppsala, Sweden.

Professor L. Slifkin, Distinguished Professor of Physics, University of North Carolina, Chapel Hill, USA.

Professor R. Teisseyre, Professor of Geophysics-Seismology, Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland.

Professor S. Uyeda, Editor-in-Chief of the journal *Tectonophysics*, Professor of Geophysics-Seismology, Earthquake Research Institute, University of Tokyo.

Professor J. Zschau, Director of the Institute of Geophysics, Kiel, West Germany.

The conclusions of this international scientific meeting were delivered to the Ministry of Public Works and EPPO on 23 November 1984 .They were never officially made public. After about 14 weeks, a brief summary of these conclusions was published in the newspaper *Kathimerini* on 10 March 1985 and six months later, on 28 April 1985, a detailed summary appeared in the newspaper *Ta Nea*.

I first refer to the article (by J. Vlastaris) in the newspaper *Kathimerini* on 10 March 1985, under the headline "The VAN method predicts earthquakes with high reliability" and subtitled "The opinion of ten eminent seismologists and geophysicists":

> Four years after the devastating earthquake of Corinth, and while distant Chile still counts the victims of the recent shock, the Greek VAN method to predict earthquakes is coming again in the international news in the most impressive way: Ten leading seismologists and geophysicists (who have been invited from seven countries with the sole aim to study the results of the experiments to date) advise that the VAN method predicts large earthquakes over 4.5 on Richter scale with high reliability!
>
> According to confirmed information of *Kathimerini* a special scientific meeting on the effectiveness of the VAN method was held during 20–23 November 1984 in Athens. This took place secretly in a beachfront hotel with the participation of world-class researchers. These are ...

Here followed the names of the top 10 researchers already presented at the beginning of this section. And the article continued:

> The international meeting was initiated by the Ministry of Public Works (which issued a decision on its establishment) and the final outcome was kept secret until now. Information, however, indicates that it contains five paragraphs that give a new dimension to the VAN issue:

> **1**. The ten scientists state that the rare large earthquakes (considered to be larger than 4.5 on the Richter scale) are predicted by the VAN method with high reliability.
>
> **2.** They conclude that the Greek method gives great promise for the development, in the future, of a practical early warning system that offers a method through which the residents will be alerted that a preseismic electrical signal has been detected.
>
> **3**. They are convinced that the reported events (data on the hitherto effectiveness of the method) are real and significant.
>
> **4**. They consider it necessary to grant greater assistance to the researchers Alexopoulos, Varotsos and Nomicos, by way of both technical equipment and scientific personnel.
>
> **5.** They suggest finally that a special public laboratory to continue the essential scientific programme should be established. (As is known, the central station of the telemetric VAN network had operated for four years in the livingroom of Professor P. Varotsos).

I now refer to the subsequent publication by the newspaper *Ta Nea* on 28 April 1985, which gives extensive excerpts from the conclusions and recommendations contained in the report prepared by the researchers after their aforementioned meeting in Athens.

The newspaper article was titled "A 'secret' report by seismologists" and subtitled "10 scientists invited by the ministry approved it" [the VAN method]. Its content is as follows (note: bold type indicates text highlighted by the newspaper):

> In November 1984, the Ministry of Public Works invited 10 prestigious scientists (seismologists and physicists) to consider the VAN case and to decide on the method.
>
> Today, *Ta Nea* of Sunday, secured this report, which is unanimous and signed by 10 scientists from abroad who are [here, the newspaper gives the names of the scientists already noted at the beginning of the section and continued]: As is evident, the Committee comprises seven seismologists and three physicists, and the report is dated November 23, 1984.
>
> The title of this report is: "**Conclusions and recommendations of the Consultative Group**".
>
> **Summary**: Our group has examined the findings of the Varotsos-Alexopoulos-Nomicos programme, regarding the detection and the presence of seismic electric signals, as precursors to earthquakes in Greece.
>
> **We are convinced that the effects reported are real and significant and that this technique provides a potentially very powerful tool for earthquake prediction**.
>
> We feel that considerably increased support should be provided to permit an expansion of technical and scientific staff, the creation of a proper dedicated publically accessible laboratory and a major improvement in the detection and data processing equipment.

Subsequently, the newspaper referred to the text of the report, which read as follows:

> At the invitation of the Greek Ministry of Public Works, we met for a four-day period, November 20–23, 1984, to review in detail the findings of Profs Varotsos, Alexopoulos and Nomicos (VAN), regarding the detection of seismic electric signals (SES) as precursors to earthquakes...

> SES are a natural, detectable phenomenon which are precursors to earthquakes. **Compared to other current techniques this method appears to be a potentially very powerful tool for the prediction of earthquakes within significant small error limits of time, magnitude and location**.
>
> Our review has also pointed out the necessity for a major research effort involving, in particular, improved methods for signal detection and data processing, to enhance both the practical utility of the method and to clarify the fundamental geophysical processes involved in the creation, propagation and detection of the SES.
>
> **Part of the credibility of the method derives from our conclusion that electrical signals of sufficient magnitude** can be generated by stress-induced processes which can occur in natural rocks. Various possible atomistic mechanisms were discussed.

Then the report mentioned in detail theoretical considerations and the frequency range at which VAN operated. It also suggested that:

> …much more research is needed to elucidate the fundamental character of SES. This will involve analysis of signals using much larger frequency bandwidths by means of much more sophisticated digital data processing apparatus…
>
> Examination of the records of the documented earthquake predictions of the VAN network for 1983 and 1984, together with the actual recorded earthquake locations and magnitudes for the same period, shows immediately a very high degree of correlation between predictions and actual events, which is far beyond any possible chance correlation. At the same time it is presently impossible to do a truly detailed statistical analysis of the VAN results because of inherent limitations in the measurements. The following problems, in particular, require considerable elucidation either through improved physical understanding or improved instrumentation:
>
> **1**) The predictive time "window" following the detection of the SES varies from a few hours to five days. In a region like Greece with a high degree of seismic activity of low-level events, it is thus very difficult to find a precise measurement of "success" and "failure" of a prediction for small earthquakes typical of the region. **The very occasional large earthquakes are predicted with high reliability**.
>
> **2**) The present bandwidth limitations and simple analogue recording devices used in the VAN network disclose SES of highly variable shapes, and these have required subjective evaluation by trained observers to select "signals" from "noise". It has not thus far been possible to construct a simple algorithm to define a valid signal which would permit automatic detection. **The use of more sophisticated digital processing techniques required in any case if the current 16 station network is ever to be expanded, might permit cross-correlation methods which could well be automated reliably.**
>
> **3**) The detection of signals at various stations in the network appears to be highly dependent on local conditions which are not at all understood.

Then the report referred to technical issues and finally proceeded to Recommendations:

> Recommendations
>
> **We recommend strongly that this project be continued with increased funding to provide a major enhancement of the research aspects of the program**. This should provide for an

> increase in laboratory studies and, in the field, development of more sophisticated signal detection, transmission, and data processing techniques to address the problems detailed above. In addition to the need for major improvements in the apparatus, there is a very real and urgent need for more technical and scientific personnel and for creation of a publically accessible laboratory dedicated to this program. The program to date has been carried out largely on the basis of extraordinary personal commitments by several of the investigators. These efforts must be reinforced by substantial additional support.
>
> We believe that the VAN approach has a great promise for future development of a practical earthquake warning system and strongly recommend its continued support.

4.3 The impact of the international meeting, November 1984

Returning to their countries, the participants of the Athens International Scientific Meeting carried the impressions they had gained from on-site monitoring of the functioning of the VAN telemetric network and the VAN results and published relevant articles in the journals of their countries. For example, almost all the press highlighted on 21 April 1985 a very laudatory article on VAN written by Professor Seiya Uyeda in the Japanese magazine *Kagaku (Science)*, issue of March 1985. For example, see the newspaper *Ta Nea* titled: “Anthem for VAN from the Japanese”.

There was now support from abroad from the high profile Seiya Uyeda, who was one of the 10 experts who attended the international meeting in November 1984 in Athens. Before coming to Greece, however, Professor Uyeda was already aware of the ongoing VAN research to predict earthquakes, since he was Editor-in-Chief of the prestigious journal *Tectonophysics* in which Varotsos and Alexopoulos had submitted for publication their early VAN results, described in two articles almost three years previously (27 January 1982). The scientific evaluation and screening of these two articles continued until June 1984 when the editor decided to accept them for publication (they finally appeared in the December 1984 issue, Volume 110, pages 73–125). The long review period was due to the fact that the experts selected by the Journal as referees to check both the originality and the correctness of the work had many questions (cf. Note that the procedure for the evaluation of a manuscript submitted for publication in scientific journals is explained in detail in Chapter 20). So Professor Uyeda was fully aware of the repeated questions by the referees and of the relevant responses from the authors. In other words, on coming to Greece in November 1984, Professor Uyeda found in situ the experimental details which had been explained through correspondence by the Greek researchers to the referees of the Journal and so he formed his own picture of how this research effort had run and evolved.

On 21 April 1985, the newspaper *Kathimerini* summarized the aforementioned article of Seiya Uyeda in the journal *Kagaku* (*Science*). Entitled “The Japanese seismologists believe that the VAN predictions are secured”, and subtitled “After evaluating the Greek method”, the article (by J. Vlastaris) proceeded as follows:

> It is really wonderful! Where, else in the world, could this be achieved? Of course nowhere! This characteristic expression refers to the predictability of earthquakes using the Greek meth-

od of VAN which acquires special importance as it is written by the leading Professor of Seismology, S. Uyeda of the Earthquake Research Institute of Japan.

The full scientific view of this Japanese expert on the validity of the VAN method was published in the well known journal KAGAKU (Science) in the March issue and occupies five pages. There are also mentioned all the conclusions of a secret international meeting of seismologists and physicists organized in Athens (as KATHIMERINI wrote on March 11, 1985). In particular, Professor Uyeda states that:

• After the Greek discovery the up-to-date claim of seismologists that earthquake prediction is impossible, is unrealistic.

• He personally, like other colleagues, attended the prediction process to identify the epicenter in the cases of four earthquakes that occurred during his stay in Greece.

• The effectiveness of the Greek method is not comparable, even with that of previous efforts at earthquake prediction, since the VAN method ensures not only the prediction of time, but also the exact determination of the magnitude and the epicentral area. In addition, it is a completely new discovery.

• The theoretical basis of the Greek method is recognised internationally and has been published in the most prestigious scientific journals.

• Many foreign countries (China, Japan, and the Soviet Union) are interested in the effective use of VAN, despite the relative indifference it receives in Greece.

• The method is based on observations, experiments and theoretical conclusions based on physics (and is thus difficult to fully understand by ordinary seismologists). It is wrong for seismologists to fight the method, because the inventors are scientists of another specialty.

According to reports, the Greek embassy in Tokyo had been informed of this article by the leading scientist of the Japan Earthquake Research Institute and immediately sent a copy to the Ministry of Foreign Affairs. It is not yet known if the Ministry of Public Works, which is concerned with the matter, has expressed any interest. Our newspaper (KATHIMERINI) now presents most of the article (omitting the specific technical details given by Professor Uyeda) having the opinion that it is a real document.

The usual scientific publications by seismologists on earthquake prediction – says Mr. Uyeda – are usually treated with inertia by the seismological community. This inertia is normal since today it is considered impossible to succeed in earthquake prediction with "orthodox" methods. However, at the end of November 1984, I had the chance to meet with and study the research of some physicists in Greece. I came to the conclusion that the claim "that today earthquake prediction is impossible" now is not true. The purpose of this publication is to draw the attention of scientists in my country to this very spot.

It is true that the work of Mr Varotsos and Alexopoulos has been occupied with endless debates for about three years with the editorial committee of the prestigious journal of seismology "*Tectonophysics*" as to whether it should be published. There were various criticisms and questions which, however, were clarified by the Greek scientists and it was finally decided to accept their work for publication. It was actually published in this journal in December 1984.

> In November 1984, I was invited by the Greek Ministry of Public Works to take part in an international scientific meeting in Athens on the effectiveness of the VAN method. I accepted the invitation with great scientific interest, but feeling at the same time a very great responsibility that the information of the international scientific community rested on my opinion. In this conference other scientists from England, Poland, Germany, Sweden, USA and China participated.
>
> I found that the Seismology Department of the University of Uppsala, led by Professor Kulhanek, had shown great interest in the VAN method and had been collaborating with the Greek physicists for three years...
>
> In Athens I had the opportunity to be a witness to the prediction of earthquakes using the VAN method: Four electrical (preseismic) signals were recorded. Mr Varotsos showed us these signals and told us that based on his previous experience, the earthquakes would occur at 4.0–4.5 Richter scale... The earthquakes occurred, in fact, while we were still in Athens.

And the newspaper *Kathimerini* continued the article by Professor Uyeda as follows, with the subtitle "The Russians are also interested":

> It is really wonderful! Where else in the world could this be achieved? Certainly nowhere ... This is so because, as all seismologists know, even an earthquake of magnitude 7.0 is considered "too small" to give enough information to predict its occurrence. It should be emphasized that the few "famous" predictions made so far in China, would have been considered unsuccessful when compared with the VAN method, because they had larger errors in predictions compared to the accuracy of the VAN method.
>
> Personally I arrived in Athens full of doubts and attended all the meetings full of questions. Leaving, however, I was much surprised and excited by what I had seen and learned.
>
> And now I will tell you a sad truth: The central station of the VAN telemetric stations, which collects information from 18 stations in Greece, is in the living room of Professor Varotsos!...
>
> The biggest problem for us is that seismologists cannot identify and understand the physical mechanism for the generation of electrical preseismic signals. If you consider, though, that rocks (from which the pressure stimulated current of VAN is generated) contain ionic crystals, not pure but with lattice defects, then it is not so difficult to prove that electrical signals are emitted before the earthquake. These views were presented at the conference by Varotsos and Alexopoulos and were accepted by the attending American physicists.
>
> Here I must mention that Greek scientists have published dozens of articles in various journals in physics (such as *Physical Review*) and they are internationally recognized scientists with expertise in the electrical properties of crystals. The fact that established scientists such as the Editor of the prestigious journal *Reviews of Modern Physics*, i.e., the American physicist Lazarus who participated in the conference, agreed with their views does not allow me to disagree with the theory. I think it is wrong that some seismologists do not accept the VAN method because it happened that Varotsos and Alexopoulos are not seismologists. This situation must not continue …
>
> Mr Uyeda closed his article, noting that shortly after the Athens meeting, he visited Moscow where he discussed the Greek method with Professor Shebalin. "I have been informed," he wrote, "that the next day the Earthquake Prediction Committee of the Soviet Union convened

> and decided to send expert scientists to Greece to examine the VAN method, **and this is so despite the fact that Soviet Union is considered to be one of the most 'bureaucratic countries'".**
>
> And the Japanese expert concluded with the following characteristic view: **It is necessary to trust VAN, because I believe that the dream can become reality**!

We also learned from several reports in the Greek press that just a few weeks after the scientific meeting, letters arrived at the Ministry of Public Works from various countries seeking to send their scientific groups to Greece to study VAN methodology. For example, on 28 April 1985, the newspaper *Ta Nea* ran the headline "Strongly Trust VAN" with the subtitle "Scientists from four countries want to come and study the method". The newspaper began by summarizing the above article of Professor Uyeda published in the journal *Kagaku* (*Science*), as follows (note: bold type indicates text highlighted by the newspaper):

> WHAT IS GOING ON WITH THE VAN METHOD? Where are the research efforts of the Greek scientists? What is the State doing about the method? What do the foreign scientists say?
>
> Recently (a few days ago) the newspaper TA NEA reported the view of the Japanese Professor of Seismology, Mr. S. Uyeda, who, in the well-known journal of his country KAGAKU (Science), wrote that
>
> "**It is necessary – as far as Japan is concerned – to trust VAN strongly, because I believe that the dream can become reality**".
>
> The Japanese professor wrote that it "**is something wonderful and no-one so far, either in Japan or in the world has done anything similar. The accuracy of the VAN method is far better than the few famous predictions made so far in China**…"
>
> "**There are many studies to date, which have tried to achieve earthquake prediction, but these methods are nothing compared with that measured by the VAN method.**"
>
> Subsequently, the newspaper writes: These warm words come from a Japanese Professor at the Earthquake Research Institute in his country … and are a response to all the questions that have appeared until now about the VAN method in the press of our country by seismologists or assistant seismologists.
>
> It is not only the Japanese professor who advocates the VAN method. **Since December, four letters have reached the Ministry of Public Works from an equal number of scientific institutions of foreign countries seeking to send their scientific groups to our country, to study the VAN methodology…**

These letters have been sent from China, Poland, Sweden and the Soviet Union and, after noting that the proposals come from countries advanced in seismology, the newspaper explains in detail the content of each of these letters. For example, here are excerpts – as published by the newspaper – from the first one, that of China:

> The first proposal came from China. Chinese scientists have been asking to send a group to our country for almost two years. The team leader was to be the Director of Research in China, who came to Athens in November at the invitation of the Ministry of Public Works to comment on the VAN method, along with some colleagues ...

> The Chinese wrote in their letter: "*We are increasingly interested in the method, and we wanted to be the first to join the Greek team.*" They went on to say: "*We want to work in Athens, near the VAN team for two, maybe more, years. We emphasize that this cooperation will be useful for the development of earthquake prediction in both our countries and around the world…*".

And the newspaper, subtitled "The Chinese", continued:

> So, apart from the article of the Japanese Professor Uyeda mentioned above, the Chinese scientists in the journal *Recent Developments in World Seismology*, Volume 12, No. 60, page 27, entitled "Greek physicists predict earthquakes", write: The data we gathered from the VAN team show that their forecasts are good, within an error of half a unit of the Richter scale…. Previous literature does not mention even a single case where a definite relationship between the electrical signal from the electric field, and the earthquake parameters, that is, the epicentral area, the time and the magnitude, has been found. Against this background, the efforts made by the three Greek physicists, represent, no doubt, an original work… From the studies so far, there is a correlation of 1 to 1 between the electrical signal and a successful prediction. The results so far, leave little room for doubt about the direct correlation between earthquakes and electrical recordings. The error is around 50 km in epicentral distance and 0.5 Richter in magnitude and the above method does not need costly installations… It is therefore easy for mass production in order to lessen the effects of future earthquakes.

The following was written in another article from the newspaper *Ta Nea*, subtitled "In Germany":

> In February 1985, the Professor of Seismology in Zurich wrote in the scientific page of the newspaper *Frankfurther Allgemeine Zeitung*: The seismic focus radiates electrical signals some hours or days before an earthquake. This is what was discovered in the early 1980s by Greek scientists. The reasons, despite extensive investigations, have not yet been revealed. Nevertheless, it has been possible to develop a method for warning about upcoming earthquakes." And then the Professor continued: "Only in 1981 did the Greek scientists detect electrical precur sory signals which they called 'seismic electric signals'. The accurate analysis of seismic electric signals will give significantly better understanding of earthquakes, with the benefit of warning the population about upcoming earthquakes. ... It is necessary to continue extensive collection of such empirical data to provide secure earthquake prediction from electrical signals"...

5 Two powerful earthquakes, 1986

5.1 The 6.1 earthquake in an aseismic region in the central Aegean Sea

On Monday 31 March 1986 nearly every Greek newspaper referred to the great earthquake that occurred in the central Aegean Sea on the evening of Saturday 29 March, at 20:37. For example, the newspaper *Mesimvrini* (31 March 1986) entitled “Panic due to 6.1 Richter” and subtitled “Shaken areas from Thessalonica to the Peloponnese”, carried this article:

> The violent earthquake of 6.1 on the Richter scale panicked half of Greece on Saturday evening. From Thessalonica to the Peloponnese, the shaking was strongly felt and momentarily brought into memory the days of Alkyonides in February 1981. [Here the newspaper refers to the magnitude 6.8 earthquake on 24 February 1981 with an epicenter in the Alkyonides Islands close to Corinth, see Section 2.1.]
>
> As announced by the Institute of Geodynamics of the National Observatory of Athens and the Geophysical Laboratory of Aristotelian University of Thessaloniki, “The earthquake was strong and its epicenter was located at a distance of 140 km from Athens, specifically in the Aegean sea area between Euboea and Chios. In the same area a 5.7 earthquake on the Richter scale occurred last week which ultimately proved to be a foreshock.

What had happened before the earthquake was published by Varotsos, Alexopoulos, Nomicos and Lazaridou in the scientific journal *Nature* (1986, Volume 322, page 120). In order for the reader to understand better what happened, I should first describe a significant improvement made to the telemetric VAN network about two months before this earthquake. Specifically, in mid-January there had been fault activation in the Oropos area – in the vicinity of Athens – with an earthquake magnitude of 4.4 and multitudes of smaller earthquakes.

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_5,

Because the existing telemetric VAN network did not include stations near Athens, the State approved an emergency installation of four VAN stations in the activated Oropos region. One week later, the newspaper *Ethnos* (23 January 1986) wrote: "The State has decided to settle a VAN network in Oropos. After the seismic activation in recent days … four VAN stations have been placed in Oropos, near Athens, since for this region, as is known, there has so far been no network coverage for earthquake prediction."

These four new stations were in operation when, on 24 March 1986, an earthquake of magnitude 5.7 occurred in the central Aegean Sea, about 140 km east-northeast of Athens, between Euboea and Chios. Note that this region was considered aseismic, because in the past there had not been a major earthquake. Remember that, as described in Section 3.5 (see Figure 3.6), if in the past we had recorded an SES related to an earthquake of small magnitude M_2, we could calibrate this station for the specific seismic area, and thus be able to estimate a larger magnitude M_1 of an upcoming earthquake in that area if at any time in the future an SES of larger intensity was recorded. This was indeed the case, since the next day (25 March) we recorded a new SES of stronger intensity. We immediately issued a telegram to inform the State that we expected a larger earthquake of magnitude 6.1, 130 km east of Athens, which is in about the same area. And this was despite the seismic history of the region since the available data indicated that such an earthquake had never happened in the past in this part of the country.

But the facts ultimately showed that we were right because, four days later on 29 March, an earthquake of magnitude 6.1 actually occurred there, which "panicked half of Greece on Saturday evening (*Mesimvrini*, 31 March). As usual, the new earthquake caused great concern to residents, especially in Athens where it was strongly felt, perhaps as it might result in an even stronger earthquake than the one that had previously occurred. Then, at midnight, Varotsos had to appear on the public television channel ERT to inform the population of not only what had happened, but primarily to reassure them that this time a stronger earthquake was not expected. The whole of the conversation between Varotsos and the journalist was reported extensively by all of the press on Monday 31 March (this is because the Sunday newspapers had already been released). For example, the newspaper *Eleftheros Typos* reported the conversation on 31 March 1986 under the headline: "The Varotsos interview in ERT: I took responsibility and because the expected epicenter was at sea, we did not notify the residents".

Now let us see how those events were described in the press and the comments that followed. In an article from *The Times* (London, 31 March 1986) under the heading "The Aegean quake was predicted", the following was written:

> A powerful earthquake measuring 6.1 on the Richter scale shook the central Aegean Sea on Saturday night, and a physicist revealed that he had predicted the shock to the Government four days before ...

An additional article by the newspaper *Mesimvrini* appeared the same day, entitled "The VAN predicted". It read (note, the bold text is that used by the newspaper):

> In the five years "war" between VAN and seismologists, the earthquake prediction system of P. Varotsos, K. Alexopoulos, and K. Nomicos has won another battle, which it seems will determine the final outcome of the war ... in the vindication of VAN.

> The reason for the recent "show-down" were the two earthquakes of March 24 and March 29 with magnitudes of 5.7 and 6.1 respectively, which were in the sea area between Euboea and Chios, 140 km east northeast of Athens.
>
> The seismologists, after the occurrence of the earthquake on March 24, in a statement reassuring the public, argued that the region was aseismic and that **according to the parameters resulting from the historical background to the phenomena of the region, would not result in another earthquake**.
>
> VAN, however, held the opposite view. The next day (March 25) Mr. Varotsos sent a telegram to, and on March 26, had a personal communication with, the Deputy Minister of Public Works, Mr. Geitonas, informing him that according to the SES recordings he had, there would be a 6.1 earthquake in the sea area 130 km east of Athens, in the same area that had experienced an earthquake of magnitude 5.7 on March 24.
>
> Mr. Geitonas showed interest and asked Mr. Varotsos whether he should alert the population. The answer was that there would be no damage because the expected epicenter was in the sea and that it would be inappropriate to create panic among citizens.
>
> On Saturday, March 29 there was indeed an earthquake of magnitude 6.1 at a distance of 140 km east of Athens in perfect agreement with the VAN prediction.
>
> Regarding the agonising question of advising the population whether a greater earthquake would follow, Mr. Varotsos answered on television that until 11 pm Saturday there was no such evidence in the recordings ...

The newspaper *Eleftherotypia* (31 March 1986), ran the story on the front page. Entitled "Triumph of VAN with the 6.1", it wrote: "For the first time in the world earthquake prediction is officially certified. This was achieved by the VAN team last Tuesday after an earthquake of magnitude 6.1 that shook Athens on Saturday. For extensive reportage see pages 24 and 25."

In addition, the same newspaper ran two articles that day. The first (by G. P. Massavetas) entitled "The VAN" said:

> It is difficult to go forward without facing the smallmindedness in this country. We are usually ready to admire the achievements and discoveries of the human mind, when they come from abroad. And we are primarily ready to deride, to wither, and to reject, when a great achievement comes from our patriots. See how many years the inventors of the VAN method battled to get recognition of the value of their invention. ... With the presence of Professor Varotsos on television, no longer as a controversial person who devised a controversial method, but as the renowned scientist who offered the whole world, and particularly earthquake prone Greece, an extremely important method for the prediction of earthquakes. What makes us very sad, however, is the fact of the war waged against the researchers ...

The second commentary, entitled "A bravo", says:

> A good time for the news at ERT-1 was of course at midnight, when it aired the interview with the VAN inventor Mr. Varotsos. Those who felt panic must have been reassured by the fact that, according to VAN, no other shocks were going to occur that night. This is the way we want [the public TV channel] ERT-1: to stand by us.

In the main commentary of the newspaper *Ethnos*, again published on 31 March 1986, entitled "Harnessing an earthquake from a box ..." the following was written:

> Suddenly, at midnight Saturday the day before yesterday – those who were shaken by the 6.1 Richter in the central Aegean, and those who did not realize it, saw something shocking on the television channel ERT-1.
>
> They saw a Greek scientist, researcher, inventor, and activist – Mr. Varotsos – coming out modestly on the small screen and explain to the stunned nation…:
>
> "You know, we expected this evening's earthquake of magnitude 6.1. By means of our measurements – the VAN system – we had predicted it on March 25, 1986.
>
> Look at the relevant telegram we sent to the Government, which identifies an impending tremor of magnitude 6.1, originating from a distance of 130 km east of Athens.
>
> Yes, we contacted government officials by telephone, but we expressed the view that the population should not be alerted and not panicked, because we knew the earthquake would happen in the central Aegean Sea which is a non-residential area.
>
> We apologize to all citizens, but we believe that this was the best course of action. Besides, once we had alerted the authorities, the State had the final say of whether or not to alert the population..."
>
> Despite the fact that Mr. Varotsos appeared on television at midnight, his presence and what he said immobilized hundreds of thousands of spectators in their seats.
>
> Is there a Greek who has not once felt awe when the ground trembles beneath his feet? Who has not shivered at the feeling of shaking? Who is not frightened by this infernal beast, and ghost?
>
> FOR THIS was amazing the presence of Mr. Varotsos on television and all of Greece hung on his words, and our phone broke down yesterday with the hundreds of "bravos" for the inventor ...

The main commentaries in the press continued the next day, 1 April 1986. I mention two of them, from the newspapers *Apogeymatini* (entitled "Well done to the inventors"), and *Vradini* (entitled "After the prediction, the problem ..."). The first commentary from *Apogeymatini* read:

> ... Many of us saw Mr. Varotsos on television last Saturday to explain the miracle of how the VAN had predicted Saturday's earthquake on Wednesday, March 25! ... We want to congratulate those inventors who offer courage to those living in earthquake-prone areas around the world from the shivering experience of earthquakes. And also to unite our voices to those of others who believe in the high level of achievement of Greek scientists, who in this research area can provide much, provided they have the means and the full support of the State. And above all who should not have to suffer the ... rivalry and undermining of mediocrities!

The second commentary from *Vradini*, said:

> ... As stated officially, the inventors of this revolutionary method had accurately predicted the most recent strong earthquake of magnitude 6.1 that occurred on Saturday ... Recently, Professor Varotsos resigned – and rightly so – from the Committee of the Earthquake Planning and

> Protection Organization (EPPO) because he could no longer tolerate an outrageous situation. As he said during his appearance at midnight on Saturday, on the television channel ERT-1 – in which he was occasionally invited to speak in view of the concern of the population due to the new earthquake. On this occasion there was interest and the decision of the State to take responsibility. It was time...
>
> But the international recognition of VAN had already been made earlier in many foreign countries, which had adopted the method ... If anything justifies the delay of the Greek Government, it is indeed the maximum difficulty of warning the population on the basis of an alarming earthquake prediction…

The next day, 2 April 1986, the newspaper *Kathimerini*, in an article entitled “The State supports the development of the VAN method across the country” and subtitled “After a sequence of correct predictions and international recognition” wrote:

> The leadership of the Ministry (Secretariat of Public Works) acknowledged fully yesterday the VAN earthquake prediction system and said at a press conference that the research efforts of the inventors Varotsos, Alexopoulos and Nomicos will be further supported. The Ministry acknowledged that there was a misunderstanding on the issue and noted that it was multidimensional and of major importance because of the high seismicity in the country, so the contribution of the VAN method was seen as important.
>
> The fact is, said Mr. Geitonas, Secretary, that the State had been influenced by the persistence of researchers who had already shown remarkable and effective progress. The effort, he added, is multidisciplinary and requires the cooperation of many disciplines. So far we have established a Committee of representatives of scientific organizations as well as a group of ten experts from abroad who have compiled a report [this is the report of the 10 foreign researchers mentioned in Section 4.2] on the basis of which we go on to assess the achievements of VAN ...

In addition, the commentary in *Kathimerini* entitled “Recognition after five years ...” continues:

> KATHIMERINI feels very happy for even a five-year delay in the official recognition by the State of the VAN earthquake prediction system. Academician Mr. Caesar Alexopoulos and the physicists Varotsos and Nomicos have suffered a major test; they met not only with indifference and opposition but with the denigration of their scientific discovery, from the Professors of Seismology. They persisted, however, with their great scientific effort and eventually succeeded. It is characteristic – and features “Modern Greece” ... – that the recognition of the method first came from abroad, by scientists, seismological institutes and governments, and after five long and hard years they gained recognition from the Greek State!
>
> KATHIMERINI, from the first moment, supported the research effort of the three VAN physicists and hopes that there will be no further complications to the full development of the system.

On 3 April 1986, Varotsos informed the State about two forthcoming earthquakes and also reassured the Ministry that there should be no concern that a larger earthquake would follow. Two earthquakes with magnitudes 5.3 and 4.7 occurred on 4 April 1986 and the epicenter was on the same site as the 6.1 earthquake of 29 March. Again, naturally, people worried whether a bigger earthquake was imminent. The next day, 5 April 1986, almost all the press published an official announcement from the Ministry that Varotsos had indeed informed it about the upcoming earthquakes. *Kathimerini*'s article was entitled “The VAN system predicted yesterday's earthquake” and subtitled “The Minister knew of this since the day before yesterday”. As a second example, I cite the article written for *Ta Nea* entitled “Yes, VAN ‘spoke’” and subtitled “The Ministry for Public Works has acknowledged this for the first time”:

> For the first time yesterday, the Ministry of Environment - Planning and Public Works admitted in a written statement that the VAN system predicted the two earthquakes that took place yesterday in the morning, with epicenters in the sea area between Euboea and Chios.
>
> More specifically, the announcement of the Ministry stated:
>
> On the night-time earthquakes ... it is clarified that at noon on April 3, 1986 Mr. Varotsos ... informed the Minister and the Secretary of Environment that an earthquake was expected from the same area but it would be smaller than the earthquake of March 29, 1986. **Also the Ministry gave publicity to the two VAN telegrams which showed that the earthquakes on March 29, 1986 and yesterday had been predicted.**
>
> The ministry also announced that there was no reason for concern ... and that it was not expected that the earthquake would be greater than that which occurred on March 29 with a magnitude 6.1. All the scientists, who took part in yesterday's meeting at the Ministry, agreed with this.

The next day, after the issue of this official statement by the Ministry, almost all the press commentators, on the one hand, agreed with the action of the Ministry to certify the facts for the prediction of the earthquakes of 29 March and 4 April and, on the other, recalled what the VAN team had suffered over time from both seismologists and the State. The main article in the newspaper *Kathimerini* on Sunday 6 April 1986, entitled “Meritocracy” (by D. Papanayiotou) read:

> MERITOCRACY
>
> BECAUSE there are civilized countries in the world, there are still some things done correctly. The worthy are encouraged, for example, their values are recognized and not deemed unworthy. It seems strange, but there it is. We have stored meritocracy in dictionaries and bring it to the surface (as a word) usually at election time. In a civilized country, then, say governmental officials had evidence of a historically new and useful scientific discovery which was of benefit to humankind, what will they do?
>
> Allow me to answer my naive question: a) encourage scientists to continue with their work, b) fund research to arrive promptly on direct application, c) claim a Nobel Prize because there are rewards, which still give importance to great endeavours.
>
> Let us not add more to the answer and let us return to Greece immediately. Here, then, obviously tired of giving over three thousand years of the lights of civilization to others, we settled in our civilized darkness (even in twilight periods) and what do we do?
>
> I answer this very naïve question: a) we immediately not only discouraged the scientists but also exposed them to the public as irrelevant dreamers. (What relationship can three physicists

have with seismology for example?), b) we began as a State to give some money to research a thousand demands after having seen that foreign scientists recognized it as a unique discovery, c) After five years of continuous scientific – and very fundamental – confirmations, we finally officially recognized it as worthy of State sponsorship and made a plan to develop its application. (To claim the Nobel Prize, of course, not a word has been heard from any of the officials and especially the mainstream.)

No need to add more in the answer, and the story, of course refers to VAN. The VAN and three physicists, the Academician Mr. Alexopoulos and the Professors Varotsos and Nomicos, who dared to achieve accurate predictions of earthquakes ... without being seismologists!

Their audacity and their error (by being serious scientists in the wrong discipline) were repaid with incredible suffering. As previously mentioned, despite our three thousand years of civilization, there are some countries which became civilized much later, where achievements were immediately recognized, while we the meritocracy...

But here I must correct a big mistake that I made in my initial naiveté, writing about meritocracy, the meaning of which we have stored in dictionaries. Well, you may not believe it but it is not there in the dictionaries! I looked at two major encyclopedias, a 1963 issue and an issue in 1978; I searched two dictionaries for an interpretation, a 1980 issue and an issue of 1983, and did not find it. The word MERITOCRACY is not there in Greek encyclopedias and dictionaries of the Greek language, neither the entry nor any derivative! I found it only in a small monotonic spelling dictionary so at least I had not made a mistake in writing the word...

I did not search other books. After all, I am not a linguist.

... ...

Varotsos, Alexopoulos, Nomicos: VAN.

One day it will get into dictionaries. From the dictionary point of view a good place might be just before the entries: brutal, vandalism, vandal…

5.2 The 6.2 earthquake in Kalamata, 13 September 1986

At 20:24 local time on 13 September 1986, a 6.2 magnitude earthquake occurred in southern Greece with an epicenter 10 km north of the city of Kalamata, causing the loss of 20 lives. We now describe the events that preceded this earthquake.

In early May 1986, an experimental VAN station was installed in the Keratea area approximately 30 km east of Athens. The new station began to record a preseismic signal SES at 23:10 on 8 September 1986 which lasted until approximately 08:30 am on 9 September. Due to the long duration of the signal, and to see it clearly, the continuous recording is presented in two parts: from 17:52 on 8 September to 01:52 on 9 September 1986 (Figure 5.1), and from 01:52 to 9:52 on 9 September (Figure 5.2). (I point out that the time in our records is always written in Greenwich Mean Time, GMT, preceded by 3 hours (this season) from the local time). In the upper part of Figure 5.1, we see that the SES starts, since the level of the signal drops, at 20:10 GMT (that is 23:13 local time), and in the upper part

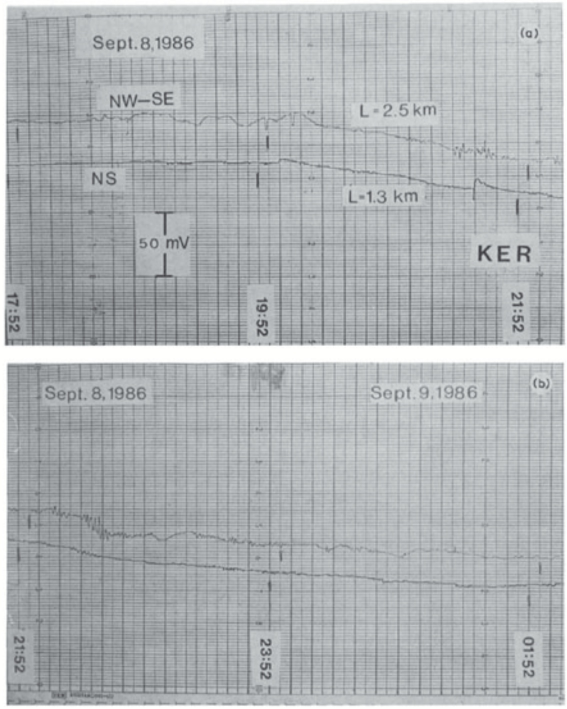


Figure 5.1 The recordings at the station Keratea (KER). Part (a) shows the recordings from 17:52 to 21:52 on 8 September and part (b) from 21:52 on 8 September until 01:52 on 9 September. Note that the preseismic signal SES starts at about 20:10 GMT on 8 September. Taken from Varotsos and Alexopoulos (*Tectonophysics*, Volume 136, pages 335–339, 1987).

of Figure 5.2 the SES ends, as the signal returns to normal levels, at 05:30 GMT (08:30 local time) on 9 September.

This was the first time that a preseismic signal SES had been recorded at the KER station, because the station had been operating for just four months. As explained in Section 3.5, in order to calibrate a station it must have experienced at least one earthquake of magnitude of about 4.0 or larger from the future focal region, and so the KER station had not yet been calibrated. Moreover, we had not yet made the selectivity map for this station (see Section 3.4), that is, the map showing the seismic areas of which preseismic SES have been recorded at that station. In other words, due to lack of experimental data, we could not apply the methodology explained in Section 3.5 to determine the future epicentral area and

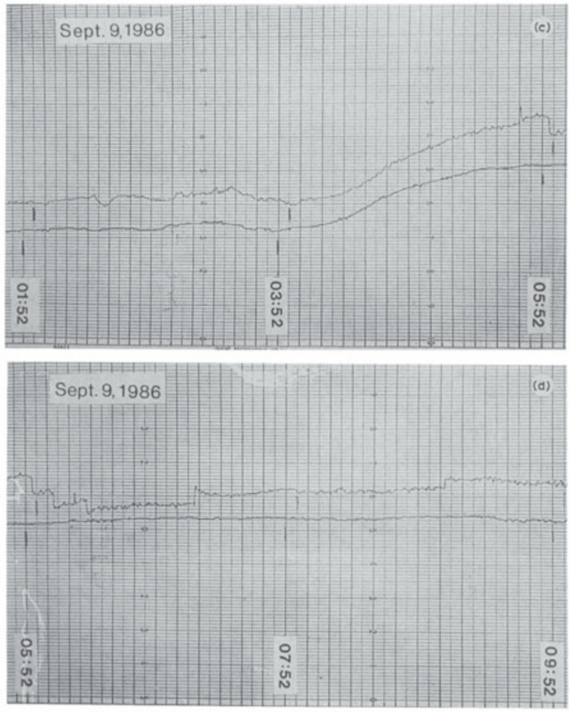


Figure 5.2 The continuation of the recordings at the KER station on 9 September 1986, (c) from 01:52 to 05:52GMT and (d) from 05:52 to 09:52GMT. The signal ends at 05:30 GMT on 9 September 1986 as can be seen from (a). Taken from Varotsos and Alexopoulos (*Tectonophysics*, Volume 136, pages 335–339, 1987).

magnitude of a forthcoming earthquake. But the recording of such a strong and evident signal did not leave us in any doubt that a major earthquake was going to occur, so we thought it would be useful to convey this information to the State to enable it to prepare properly, if it so decided. Indeed, after having dedicated many hours to making sure that the signal recorded was a preseismic SES and not noise from artificial sources, late after midnight on the same day (that is, from 9 to 10 September, 1986) Varotsos contacted the Inter-Ministerial Committee (IMC) at the Ministry of Defence and reported the SES recording. He was then asked whether the upcoming earthquake threatened the wider region of Athens. The answer was no, because Varotsos knew that the VAN stations installed in the Oropos region near Athens in early 1986 (see Section 5.1) had not shown any significant preseismic SES.

The latter experimental fact led us to estimate that if the earthquake were to occur at a distance of 100 km from Athens its magnitude would be about 4.5.

The conversation between Varotsos and the IMC was revealed many years later. In 1993, seismologists published a criticism against VAN in the journal *Tectonophysics* (Volume 224, page 224). This criticism was answered by Varotsos, Alexopoulos and Lazaridou in the same journal (*Tectonophysics*, Volume 224, page 239). Below, I explain a little about the exact content of that criticism, and the reply.

Nearly 24 hours after the conversation between Varotsos and the IMC, a second very important SES signal was recorded at the KER station, which lasted from 20:28 on the evening of 10 September until late in the morning of 11 September. This led the VAN team to send a telegram, which read as follows: "*A new* [preseismic] *signal was recorded at 20:28 on September 10, 1986 from distance 200 km from [Athens] with magnitude 5.5, or from 100 km with magnitude 4.5*." To understand the content of this telegram, remember that, as I explained in Section 3.5, the signal decreases approximately inversely proportional with distance. This means that if the signal had been emitted from a focal area located 100 km away from the KER station it would correspond to an earthquake of magnitude 4.5, but if the epicentral distance had been twice that at 200 km then the magnitude of the earthquake would be larger by one unit, around 5.5. In other words, the telegram indicates that if the focus of the expected earthquake lay in an area more than 200 km from the station at Keratea, then the expected magnitude of the earthquake would be greater than 5.5. Indeed, the earthquake that followed on 13 September 1986, had a magnitude of 6.2 according to the Geodynamic Institute of Athens, and 5.8 (mb) in accordance with the United States Geological Survey (USGS). A second earthquake (aftershock) occurred on 15 September which had a magnitude of 5.6, thereby verifying the fact that the KER station had recorded two important preseismic SES.

The newspaper *Eleftherotypia* on Monday 15 September 1986 (note the earthquake had occurred late on Saturday 13 September) ran an article with the headline "DISASTER-ALARM" and "An operation [like] lightning for help", beginning on page 15 as follows: "**There was a prediction for the earthquake with no specific time limit. This was implied by the representative officer** [spokesman] **of the Inter-Ministerial Committee, when he was asked about it last night**", and continued: "Mr. Varotsos was called, and went yesterday morning to the Pentagon to work with members of the IMC. The IMC spokesman said: "Mr. Varotsos was invited to the meeting, because on these occasions we call on the people who can help and we fully exploit the available scientific knowledge."

I now present a translation (verbatim) of the criticism by seismologists (mentioned above):

> On September 10, 1986 at 03:45 local time (that is, 00:45 GMT), Professor Varotsos sent a telegram to the Inter-Ministerial Committee (IMC) of the Greek Government announcing an SES arrival time at 01:55 local time on September 10, 1986 (that is, 22:55 GMT on September 9, 1986). Expected earthquake magnitude 4.5. Probability of occurrence 60%. Expected epicenter at distance of 100 km from Athens.
>
> Immediately after the receipt of this telegram the IMC forwarded an official form to the Minister and to the General Secretary of the Ministry of Public Works as well as the Director of the EPPO (Earthquake Planning and Protection Organization). This procedure was followed in all cases...

The response of the VAN team, is as follows:

> We clarify that all the relative SES data have been already published…: One of the two largest SES in this series can be found in the paper by Varotsos and Alexopoulos in volume 136 of the journal *Tectonophysics*, pages 335–339, 1987 ... The reason why these SES did not allow a unique and precise prediction of the epicenter was extensively discussed in the Conference (in Athens in February 1990 [see the relevant reply by Professor H. Tazieff in Section 8.3]. This was mainly due to the fact that the station Keratea was installed in May 1986 which was only a few months before the Kalamata earthquake of September 13, 1986 so that the selectivity of this station had not yet been mapped... The only estimate that we could make at the time was that if the epicentral distance was 100km from Athens (ATH), the earthquake magnitude would be around 4.5, whereas if the epicentral distance was 200 km from ATH, the earthquake magnitude would be 1 unit larger... They [the critics] admit that we recognized the preseismic signal SES well before the occurrence of the earthquake but they wonder why we did not inform the IMC officer that the impending earthquake would be destructive ... What our critics present in their figure is not a telegram but refers to a telephone conversation between the first author [Varotsos], and an officer of the National Defence after the detection of the first significant SES. The officer's question was "will the impending earthquake be destructive?" (note that, as is obvious from the text, his question was referring only to the case of an earthquake located 100 km from Athens and hence to the ATH area) and the answer was negative ... Apart from this conversation, a telegram was issued at 08:45 local time on September 11 (that is, after the second of the significant SES the arrival time of which … [Here follows the text of the telegram mentioned above].

By summarizing, the case of the Kalamata earthquake in 1986, we can say that the VAN team recognized well in advance the preseismic SES and forwarded this information to the Inter-Ministerial Committee (IMC). Nobody questions this fact. Recalling also that preseismic information is sent to the IMC only for major earthquakes, it is very likely that this greatly helped the State to act immediately after the earthquake. Accurate determination of the magnitude and the epicenter – as achieved in the case of the magnitude 6.1 earthquake that occurred on 29 March 1986 in the central Aegean and described in Section 5.1 – could not be achieved for that earthquake, because the KER station that recorded the preseismic SES was installed just a few months before and therefore its calibration was not possible; neither was its selectivity map known (note that these two pieces of information are necessary to determine the epicenter and the magnitude of the expected earthquake, as explained in Sections 3.4 and 3.5)

6 Disastrous earthquakes in Killini–Vartholomio, 1988

6.1 Introduction

On 22 September and 16 October 1988, two earthquakes occurred with magnitudes of 5.6 and 6.0 in the Killini-Vartholomio area (western Peloponnese) and caused extensive damage. Thousands of homes were reduced to rubble**, but** there was no loss of life. This is because the "beast" did not appear suddenly, since, as explained below, the population had been informed from the beginning of September that large earthquakes would occur in this region in the next time period and on their own initiative people took elementary precautions. This is not my own opinion, but a crucial finding of specific studies by Japanese scientists who had followed the events closely. Specifically, they visited the region and distributed questionnaires to the residents and, having carefully studied the responses, they published the conclusions, in scientific journals and in Proceedings of International Conferences specific to the subject, as described below.

In particular, three articles were published by the Japanese team, led by Professor Hiroaki Yoshii from the University of Bunkyo. The first can be found in the *Proceedings of the 2nd Japan–US Conference on Urban Earthquakes Hazards Reduction* (1989) under the title "Social impact of earthquake warnings"; the second appeared in 1990 in the international journal *Disaster Management* (Volume 3, pages 3–7); and the third, that summarizes all the findings, was published in 1993 in the journal *Tectonophysics* (Volume 224, pages 251–255). The latter two articles have the common title "The Social Impact of Earthquake Prediction in Greece".

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_6,

6.2 What happened before the earthquakes

What happened, then? We will recall the events, not by setting out my own opinion, but rather by following closely the description of Professor Yoshii, as summarized in his 1993 paper. I add, as appropriate, quotations from Greek newspapers and telegrams to the Greek Government which corroborate the accuracy of Professor Yoshii's description.

Professor Yoshii's 1993 article began with the following description:

> The VAN group recorded four preseismic electric signals (SES) on August 31, 1988 and sent their prediction the next day, on September 1, 1988, by telegrams, to the Greek Government and to Dr. Tazieff, a French scientist, as well as to a Japanese researcher [Prof. S. Uyeda]. The text described the prediction of two alternative possibilities for the epicenter [Figure 6.1].
>
> One solution suggested that an earthquake was imminent 300 km northwest of Athens [Figure 6.1]: "the Corfu area" where the potential magnitude of the upcoming event would be 5.3. The alternative solution was for the region located 240 kilometers west of Athens [the solid circle between Vartholomio and Zakynthos in Figure 6.1] where the expected magnitude of the up-

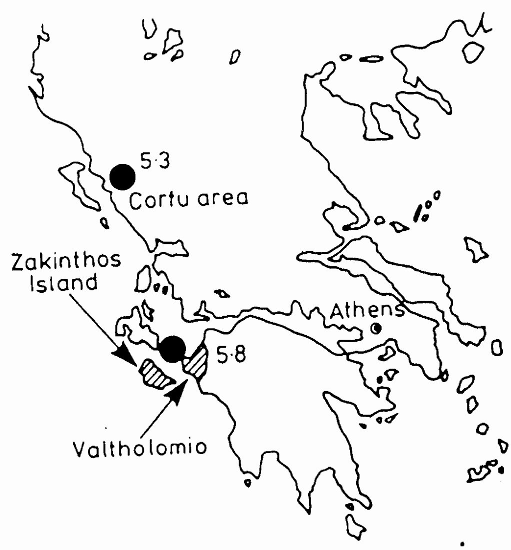


Figure 6.1 (Solid circles) two alternative possible areas for a future epicenter in the VAN prediction issued on 1 September 1988. The shaded regions marked with arrows are Vartholomio and Zakynthos and shown for the convenience of the reader. Taken from Yoshii (1993, *Tectonophysics*).

> coming earthquake would be 5.8. Two days later, Dr. Tazieff, who was convinced of the validity of these forecasts, made the prediction public, suggesting that contingency plans should be made against the consequences of a possible earthquake at this region. The announcement was made in the conviction that the Greek government would fail to respond to such a warning [see also what Professor Haroun Tazieff said during the international conference held in Athens in 1990, and read his relevant answer in Section 8.3].
>
> The mass media in Greece reacted strongly to this warning and published detailed articles describing the opposite opinion of seismologists to these views as well as quoting the VAN group's comments. Almost all the newspapers in early September 1988 referred, with lead stories, to this subject. In an article published on 5 September, Dr. Tazieff says that '**the upcoming danger was very high**'. In addition, the media suggested that it was the **moment of truth** as far as VAN's predictions were concerned, the subject being treated as a serious social issue. The effect was that the VAN forecast had become a kind of public warning, despite the fact that it was not an official announcement.

An article in the newspaper *Vradini* of 3 September 1988 is entitled "Earthquake 5.8 R knocking on our door ..." and "Prediction by a French volcanologist", along with a subtitle referring to strong denials by Greek seismologists. The article continues on an internal page which states that: "According to the French scientist [Professor Tazieff] the VAN method predicts an earthquake located either at a distance of 300 kilometers northwest of Athens or 240 km west of the Greek capital. The first location is in a residential area in southern Corfu and the second is expected in the sea area west of Patras. In Tazieff's opinion **if the earthquake is on the land, the damage could be very serious**."

According to the newspaper *Eleftherotypia* on 3 September 1988, the above announcement was made the previous day by Professor Tazieff in one of the greatest broadcasts in France, "in Antenne 2", and the news of what he had said spread naturally in no time to Greece. Professor Tazieff's statement was transmitted by the AFP and the next day (3 September 1988) was carried in many leading newspapers abroad, even in distant countries. For example *The Pakistan Times*, 3 September 1988, ran an article entitled "Earthquake may hit Greece", in which it was written that "a large earthquake is likely to hit Greece" according to estimates made by Greek scientists, transmitted from Paris the previous day, 2 September 1988.

The front page of the newspaper *24 Hours* on 5 September 1988, was entitled "Shaking from the VAN prediction" and "Tazieff Insists: High Danger".

This article reported the following:

> There has been strong controversy in the scientific world of Europe caused by the statement of the French volcanologist Haroun Tazieff, that a strong earthquake in Greece is imminent...
>
> The French scientist believed that the risk was so high he decided to speak publicly which he knew the VAN team were not in a position to do.

The scientific evidence announced by Professor Tazieff was accurate, as can be seen in Figure 6.2, which depicts the official copy of the telegram addressed to the Secretary General of the Ministry. The text is in English because the same telegram was sent to several scientists in various countries.

ΟΤΕ ΟΡΓΑΝΙΣΜΟΣ ΤΗΛΕΠΙΚΟΙΝΩΝΙΩΝ ΤΗΣ ΕΛΛΑΔΑΣ ΑΕ

ΑΝΤΙΓΡΑΦΟ ΤΗΛΕΓΡΑΦΗΜΑΤΟΣ

ΑΘΗΝΩΝ 155 671031 39 1/9 11.30

ΕΠΕΙΓΟΝ
Κον Ν.ΣΑΡΑΝΤΗ
ΓΕΝΙΚΟ ΓΡΑΜΜΑΤΕΑ ΥΠΕΧΩΔΕ
ΧΑΡ.ΤΡΙΚΟΥΠΗ ΚΑΙ ΛΕΩΦ.ΑΛΕΞΑΝΔΡΑΣ
ΥΠΕΧΩΔΕ ΑΘΗΝΑ

SIGNIFICANT ELECTRICAL ACTIVITY WAS RECORDED AT IOA - STATION
ON AUGUST 31 1988 EPICENTER AT N.W 300 OR W 240 WITH MAGNITUTES
5,3 AND 5,8
PROFESSOR P.VAROTSOS

Ακριβές αντίγραφο
Τηλεγραφήματος του
στην Υπηρεσία μας
Χορηγείται ύστερα από αίτηση
για κάθε νόμιμη χρήση.
Αθήνα 7-9-1988
Ο Βεβαιών

Ν. ΑΝΕΣΤΗΣ ΤΟΜ./Δ
ΠΡΟΪΣΤ. ΤΟΜΕΑ ΕΚΜ/ΣΕΩΣ

Figure 6.2 The urgent telegram for the upcoming earthquake which Varotsos sent to the Secretary General, Mr N. Sarantis of the Ministry of Public Works, at 11:30 am on 1 September 1988.

The telegram states the following: “Significant [preseismic] electrical activity was recorded at Ioannina station on August 31, 1988. The epicenter [will be] northwest 300 or west 240 [kilometers] with magnitudes 5.3 and 5.8. Professor P. Varotsos”.

Above the address and message are written different numbers. The first (155) means that the telegram was sent via telephone, the penultimate (1/9) corresponds to the date and the month, and the last one (11:30) refers to the exact time when the telegram was issued. The seals of the National Telecommunication Organization (OTE) below officially certify the telephone number the telegram was sent from, who the sender was, and when the request to grant the above official copy with the corresponding protocol number was issued. The first sentence in the telegram stating “*Significant electrical activity*”, that is a sequence of preseismic electric signals (SES activity), implies that, as explained in Section 3.5, **significant seismic activity would follow** and hence, not just a single earthquake. In particular, Professor Yoshii says in his work, that “four preseismic electric signals SES were recorded”, shown in Figure 6.3.

Now let us see exactly how Professor Yoshii continues his description of the events:

> On September 22, 1988 the predicted earthquake occurred, at a point 250 km west of Athens with a magnitude of between 5.2 and 5.5. [Later, the Athens Geodynamic Institute revised the final magnitude to 5.6.] However, the reaction of the mass media was muted as damage was slight. Indeed, the effect was insufficient to prove publicly the success of the VAN’s prediction. However, on September 30 and October 3, the VAN group recorded two successive SES events. They again dispatched two telegrams saying that seismic activity would continue in the same area.

I shall now give some additional information on the facts mentioned above by Professor Yoshii:

A story in the newspaper *Eleftheros Typos* (23 September 1988) is entitled “The Killini was broken” and reads: “VAN has hit it [the earthquake]”. It also refers to the damage and shows a photograph of “...The pier of the port of Killini broken in two”.

Secondly, one of the new VAN telegrams mentioned by Professor Yoshii was sent to both the State and to foreign researchers at 13:14 on 30 September 1988 and the next one at 14:13 on 3 October 1988, stating that new SES activities had been recorded which showed that **significant seismic activity would continue in a region located at the most 20–30 km away from the epicenter of the earthquake on 22 September.** What is the explanation for this persistence of ours, namely that we had to send two new telegrams within just 3 days? This was for two reasons: the first, the fact that we recorded two new sequences of preseismic SES and the second, and more important reason, was this: After the occurrence of three earthquakes with magnitudes 3.8, 4.7 and 4.9 on 30 September 1988, some seismologists assured the residents that (see the newspaper *24 Hours* on 1 October 1988) these shocks were “due to usual small activation” and that “In the past the region has repeatedly experienced small consecutive shocks, but following these cases a large earthquake has never occurred in this region. In general, from what we know from similar phenomena, we rarely experience a big earthquake, so there should be little concern”.

Because we completely disagreed with these assertions, we came back with our second telegram on 3 October and, in addition, on 5 October Professor Tazieff proceeded to issue a public warning to highlight the upcoming danger.

6.3 After the 6.0 mainshock

Unfortunately, our fears were verified. On 15 October, an earthquake measuring 5.0, and the next day a much greater one of magnitude 6.0, occurred with an epicenter close to Vartholomio, roughly 10 km away from that of the earthquake of 22 September. This caused extensive damage. The headlines of the newspaper *Apogeymatini* on 17 October 1988 were “DISASTER” and “Vartholomio collapsed”, “The Killini sank”.

On the same day the first page of the newspaper *Mesimvrini* led with a heading “An earthquake that PARALYZED half of Greece”, which aptly began the article as follows: “The earthquake has warned. The day before yesterday an earthquake of magnitude 5.0 on the Richter scale in the maritime area of Zakynthos, was the harbinger of yesterday’s disaster …”

The damage, as I mentioned, was extensive. The first report was of heavy losses (which turned out to be heavier the next day). For example, the first page of the newspaper *Ethnos* on 17 October 1988 reported: “30 injured, 2,070 houses RUINED”. Nevertheless, as I wrote in Section 6.1, **no human life was lost**.

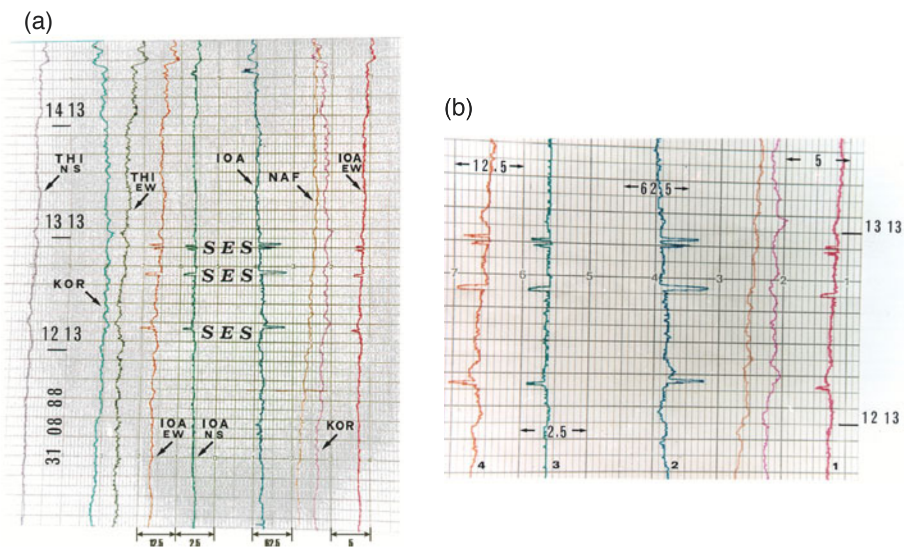
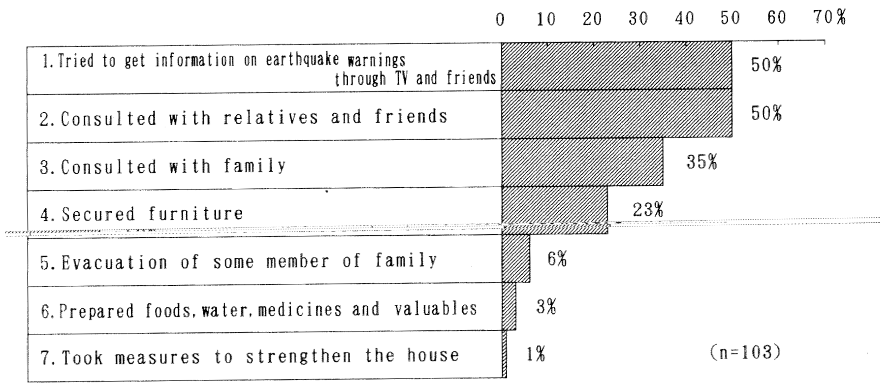
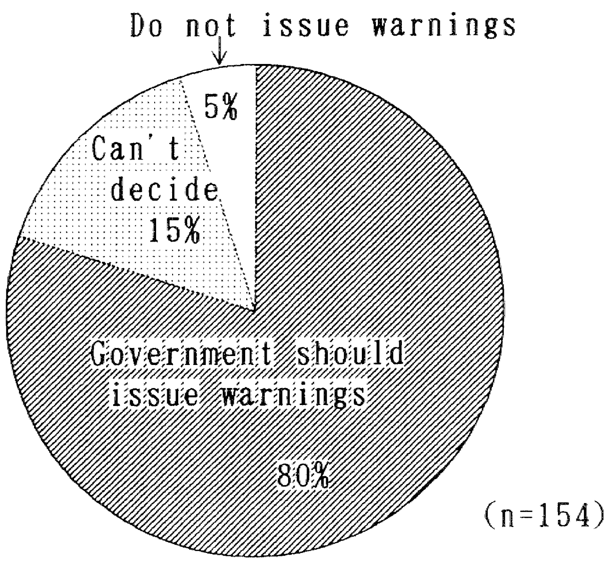


Figure 6.3 The four preseismic electric signals that were recorded in Ioannina station on 31 August 1988. The left part (a) shows a photocopy of the original recording, and the right part (b) shows these electric signals in an expanded scale. Taken from Varotsos (2005). Copyright (2005), with permission from *TerraPub*.



(a)



(b)

Figure 6.4 (a) Professor Yoshii describes the specific countermeasures taken by the residents after the public warning of Professor Tazieff; (b) shows the residents' response to the question of whether or not the Greek government should issue warnings following the VAN forecasts. Taken from Yoshii (*Tectonophysics,* Volume 224, pages 251–255, 1993).

To understand this, let us return to the article by Professor Yoshii, who continues his description as follows:

> What was the reaction of local residents during this period? For example, how many people were aware of the VAN prediction prior to the destructive earthquake on October 16? About two-thirds of those questioned at Vartholomio and Zakynthos (samples 69 and 88, respectively) had received prior warning. Of those who knew the prediction, 80% had read it in the newspapers, whilst 20% had been informed by friends or acquaintances.

Subsequently Professor Yoshii presented detailed tables and figures for the individual precautionary measures taken by the residents, according to their own responses, both in Vartholomio and Zakynthos (see Figure 6.4).

Professor Yoshii continued:

> On October 16, 1988 the predicted destructive earthquake occurred, registering magnitude 6.0. More than 2,000 houses were destroyed or made uninhabitable. After the event, there was widespread acknowledgment in the mass media that the VAN prediction had been valid…
>
> In relation to the level of concern, 80% of the residents expressed the opinion [see Figure 6.4b] that the Greek Government should issue warnings following a prediction by the VAN group.
>
> Professor Yoshii concluded that "Earthquake prediction is therefore an effective countermeasure in the saving of lives", noting especially the following: "Although those in opposition to the release of such warnings have claimed that the results will be panic, such a reaction seldom occurs. This fear falls within the category of the so-called 'disaster myth'."

Summarizing the events that unfolded before and after this destructive earthquake, we can say that indeed "after the event, there was a widespread acknowledgment in the mass media that the VAN prediction had been valid" as concluded by the aforementioned Japanese study. This is understood in the context of what Professor Tazieff had said at the beginning of September 1988 in the public warning by drawing attention to the high risk due to the impending earthquake in this region (remember Figure 6.1 where the shaded regions are Vartholomio and Zakynthos), could now be easily compared with the disaster that finally occurred on 16 October 1988. The only criticism could possibly be that while the original VAN estimate for the earthquake magnitude was 5.8 (see Figure 6.1), the actual earthquake magnitude finally turned out to be 6.0. However, as I explain elsewhere (for example, see Section 3.6 and Chapter 19), such criticism does not stand up because such small differences are within the limits of experimental error, and, after any earthquake, the various seismological institutes also report different magnitudes.

Despite this apparent verification, some people continued to attack the VAN team even after the earthquake. However, for us the important fact is **that no human life was lost** even though "Vartholomio collapsed" and "the Killini sank". Still etched in my memory is the agony of the telephone calls from the President of Vartholomio region, Mr P. Makrydimas, when the mass media revealed the public warning from Professor Tazieff. I told him then that there existed the need to address the situation calmly and that the residents would be wise to take immediate precautions. Note that "90% of the 1200 Vartholomio houses after the earthquake were uninhabitable", as Mr Makrydimas told the newspaper *24 Hours* on 17 October 1988.

7 The FRENCH interest in VAN (1986–1989)

7.1 Professor Haroun Tazieff and the French interest in VAN (1986–1989)

As described in Chapter 6, the destructive earthquakes in the Killini-Vartholomio area in 1988 had been announced by Professor Haroun Tazieff, on the basis of the telegram sent by the VAN team to the Greek Government. A year later, in 1989, Professor Tazieff's book *La Prévision des Séismes* (*Earthquake Prediction*) was released in France by the publisher Hachette (Figure 7.1) in French and it was later translated into other languages, such as English, Chinese, etc. It was also translated into Greek and published in Greece in 1996.

The back cover of the book describes its contents:

> Mexico, Tangshan, most recently Erevan in Armenia. The list of killer earthquakes gets longer every year, and the victims number in millions. Although science can now explain these phenomena, it is only just beginning to predict them, and technology is just starting to mitigate their effects.
>
> Despite the denials and scepticism of a certain number of specialists, three Greek scientists have developed a new method of predicting earthquakes: the VAN method. In this book, Haroun Tazieff expounds its principles, presents its successes and explains its rare failures. Faced with the urgency and increasing seriousness of the danger, confronted with special interests and inertia, the author is outspoken in his accusations: Since an earthquake prediction method exists and has been experimentally confirmed, why is there such delay in using it and in implementing concrete actions that might avert disasters?
>
> Questions of science, politics and morality are all part of this debate.

And the back cover of the book continues, under the title "About the Author" as follows (taken from the English translation in 1992):

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_7,

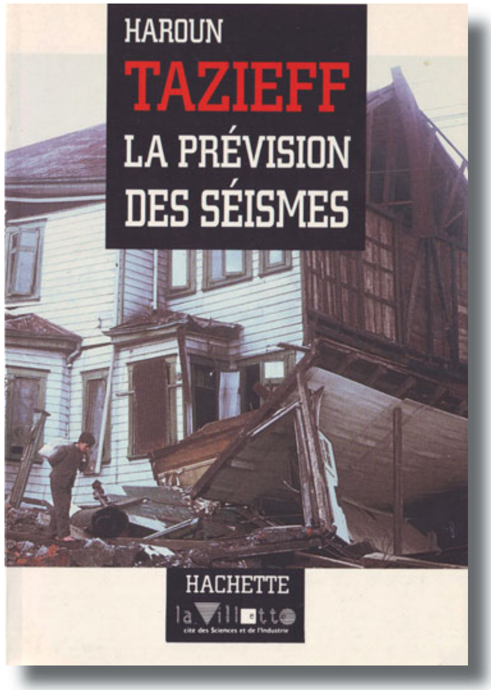


Figure 7.1 The front cover of the second edition of Haroun Tazieff's book, *La Prévision des Séismes (Earthquake Prediction*) (Hachette, 1989).

> Haroun Tazieff, former Director of Research at CNRS [French National Scientific Research Center], has been involved in numerous studies that have focused worldwide attention on volcanology. Now president of the Pilot Program in Isère, France, he has served as Secretary of State for major risks. In addition to more than twenty books and hundreds of scientific articles about volcanic activity, he is the author of 'Quand la Terre Tremble' [When the Earth Trembles] (Fayard, new edition, 1981).

Immediately after the release of this book in France in 1989, which was generally very well received abroad, the Earthquake Planning and Protection Organization (EPPO) and the Ministry of Public Works in Greece announced that they would be stopping any further funding of the VAN research, citing allegations that VAN had not informed them of their research results! They even sent a mandate to the National Telecommunication Organization (OTE), to interrupt the telephone lines carrying measurement data from the VAN stations installed at various locations in Greece to the central station in Athens. These events, especially the way the discontinuation of the VAN network was announced, without ever explaining the real reasons that caused the break, are described in Section 7.2. First, I explain below how Professor Tazieff, who was originally an opponent of any effort to predict earthquakes, on being informed about the scientific details of the VAN method, changed sides and became a fervent supporter of the endeavour.

Shortly after the installation of the telemetric system in Greece (the end of 1983, see Section 3.2), we read in the newspaper *To Vima* (26 February1984) that:

> ... 20 to 30 moderate earthquakes occur almost every year in Greece. Your country is the most seismic country in Europe with problems throughout the country, said the famous French geologist Haroun Tazieff ... who is a technical advisor to President Mitterrand, president of the research center for disaster prevention from natural phenomena and member of the Socialist Party of France ... When he was asked about VAN, the French seismologist felt disinclined even to talk about it.

But, nevertheless, only two years later, on 14 February 1986, with correspondence from Paris published in almost every Greek newspaper, the Greek population was informed that (see, for example, the newspaper *Kathimerini*'s story entitled "VAN system for the prediction of earthquakes will be installed in France" with the leader "At the suggestion of Minister Haroun Tazieff" and subtitled "Praise for the scientific discovery of the three Greek physicists"):

> PARIS (ANA - Reuters). The French Minister for disaster prevention, Mr. Haroun Tazieff, proposed yesterday to install an early warning VAN system for earthquakes in the high-risk area, along the French and Italian Riviera. Mr. Tazieff told reporters that he would propose the idea to the Italian Civil Protection Minister Mr. Zamperloti, during his visit to Rome on Monday.
>
> Mr. Tazieff said the move is made after the great scientific discovery of the three physicists, of the University of Athens, who recently integrated the world's first system to accurately predict the time, epicenter and magnitude of earthquakes.
>
> The process is revolutionary. For the first time there is the possibility of warning and evacuation of up to five days before an earthquake, he said. He will hold talks at the end of the month with the Prime Minister, Laurent Fabius, to install the system throughout France.
>
> The earthquake prediction system is called VAN from the names of the inventors Varotsos, Alexopoulos and Nomicos ... The Greek physicists began the measurements in 1981...
>
> Mr. Tazieff, eminent geologist, said that this relatively simple system used electrodes to measure and analyze transient changes in the electric field of the Earth, which appear before earthquakes ...

The content of the publication of the newspaper *Eleftherotypia* of 14 February 1986, entitled "France - Italy adopt the revolutionary VAN" , coming from a correspondent in Paris, is analogous to that of *Kathimerini*. Also *Eleftherotypia* continues with a separate publication, entitled "Alexopoulos: Greece is Proud", as follows:

> The members of the VAN research team expressed deep emotion for the vindication of their toil when they heard from our newspaper the above news. In particular, Professor Alexopoulos said:

> All the people of Greece should feel vindicated and proud that a system invented and successfully applied here in Greece is slowly expanding into Europe. The great interest of other countries in the VAN system is already known. Today, I received a video from Switzerland showing an hour long programme presented by a television channel in Geneva. Much of the plaudits from the international programme makers and producers reporting on earthquake proofing systems are dedicated to our country which is viewed like a model State as far as protection from impending earthquakes is concerned.

On the following day, 15 February 1986, almost all the Greek press continued with the VAN story, publishing extensive articles and comments. For example, the newspaper *Eleftherotypia* did an extensive publication entitled "9 countries asking for VAN", and the main comment on "A vindication of the VAN method" read:

> The interest of nine developed countries for the adoption of the Greek VAN system for earthquake prediction – some of these countries being highly developed in the area of seismological research, such as Sweden, USA and China – must be met with proportionate action by the Greek State.
>
> First, we congratulate the members of the research group (Varotsos, Alexopoulos, Nomicos), who have shown perseverance and method in their invention of the prototype method.
>
> Beyond that, the State, which admittedly – even with the initial reservations – has helped and continues to assist the VAN team, must implement an initial promise of establishing and running a governmental VAN laboratory for the cooperation of foreign scientific missions with our own researchers. Thus, our country will keep the paternity of the invention and we will become a magnet for foreign researchers.

So what happened between 26 February 1984 when Professor Tazieff had expressed rather derogatory views about the VAN method, and 14 February 1986 when he was fully convinced of its correctness and formally recommended its installation in France? It is useful to see the answers he gives to this question in his 1989 book. Specifically, in the chapter of his book entitled "Solid Sceptism" (pages 50–53), he writes (note that we closely follow here the English version of the book starting from page 58):

> Before 1984 I believed it was impossible to predict earthquakes and I thought it would always be so ... The reasons for my scepticism appeared solid, ranging from the impossibility of conducting on-site research deep inside the Earth, where earthquakes are caused, to the complexity of the natural phenomena involved. A comparison with the difficulties faced by meteorologists trying to forecast the weather merely confirmed my belief. Not only can weather forecasters contemplate a transparent and easily accessible atmosphere – rather than the impenetrable opaque planet that confronts seismologists – but the resources available to them are also incomparably more impressive than those of the geophysicists: from supercomputers to artificial satellites, from weather balloons, meteorological helicopters and airplanes, not to mention thousands of observation points and hundreds of thousands of specialized personnel. The importance of weather prediction for aerial and maritime navigation, for agriculture, for the tourism industry and above all for all the world's armed forces, explains the size of meteorology budgets. Earthquakes, on the other hand, mean nothing to any of these rich and powerful pressure groups. Moreover …

And Professor Tazieff after stating additional arguments continues in the chapter entitled "The VAN Method" as follows (see page 64 of the English edition):

> For many years, therefore, I had stopped believing that it was possible to predict earthquakes. Then [i.e., 1984], on the occasion of an official visit that I was making to Athens in the context of a cooperative Greek–French project that I had initiated – designed to improve the effectiveness of the relief efforts needed after any large scale disaster, by combining the resources of our two countries – I was interviewed by Greek television about the purpose of my visit. I explained the problem of organizing relief work, which today is quite scandalously inadequate all over the world, and mentioned the reforms that I had been trying for two years to have implemented in France.
>
> I was then asked what I thought of earthquake prediction as a preventive measure. I set forth the reasons for my scepticism. The journalist then replied: "What about the VAN method?" "What is the VAN method?" I asked. He explained it to me briefly and my response was that I doubted whether these three Greek scientists, Varotsos, Alexopoulos and Nomicos, whose initials were the acronym designating the method, could have succeeded where the world's most famous seismologists with all the dollars, rubles, yen, and yuan of their respective rich nations behind them had completely failed.
>
> A few days later, after I had returned to Paris, I received a letter from Professor Alexopoulos (the 'A' in VAN). He said he had been informed that I was not familiar with their method (which was absolutely true), and asked if I would please read the two articles he had enclosed with the letter. I groaned silently: my unhappy experience with volcanology treatises sent occasionally to me by many inventors, amateurs and so-called specialists, made me wonder whether these articles would be in a similar vein. But as soon as I took them out of the envelope, I began to take them more seriously: they had been published in *Tectonophysics*, a prestigious international journal.
>
> As every scientist already knows, an article that discusses science can almost never make it into print in a leading journal, without penetrating those formidable barriers called 'referees'. These reviewers are, theoretically, specialists on the subject of the article in question, and are therefore (again theoretically) competent to render an opinion, favorable or otherwise, as to whether it should be published. Theoretically, again, they are honest and their judgment is not affected either by their personal reactions to the author or the hypothesis advocated by the article, or by the effects which it might have on their own work, their personal reputation or credibility. Of course, it does happen that some reviewers do not always adhere to the ethic that is presumed to govern them, but I am still convinced, despite all the disillusionment accumulated over fifty years of experience, that most of them do respect it.
>
> The fact that "Physical Properties of the Variations of the Electric Field of the Earth Preceding Earthquakes" appeared in *Tectonophysics* constituted, once the usual potential reservations had been set aside, a strong presumption that the work was serious and of high quality. This fact ensured that the authors of the articles were probably neither dreamers nor charlatans.
>
> I therefore began reading with interest, and when I had finished, I was rather taken aback: my conviction that it was impossible to predict earthquakes had just been undermined.

After this, Professor Tazieff, having first asked the VAN team for extensive scientific material that he studied by himself, twice sent French research teams consisting of physicists and seismologists to Greece during 1985. These groups stayed with us for several weeks, studying the records of the telemetric VAN network (sometimes visiting some of our stations) and discussing in depth the theoretical background of the method with Varotsos and Alexopoulos. After each of these visits, the French scientists supplied Professor Tazieff with a report detailing the conclusions of their visit to Greece. The last report was submitted to Professor Tazieff in early 1986 by Professors J. Labeyrie and M. Halbwachs.

Based on these reports, which were subsequently discussed in detail in larger committees in France, as the Secretary of State, Professor Tazieff decided to propose to the French Prime Minister the installation of a VAN network in France and publicly announced this in Paris. It is this proposal which, as previously mentioned, was commented on in the press on 14 and 15 February 1986.

After two weeks, Professor Tazieff officially invited the VAN team to Paris accompanied by a representative of the Greek Government. Reporting on what happened there, the newspaper *Kathimerini* on 9 March 1986, entitled “Greek response is expected by France for the VAN system” and subtitled “Paris decides on VAN implementation in France”, wrote:

> Following their proposal to implement the early warning VAN system for earthquakes, the French government expects this week an early and specific response from the Greek government. It would be appropriate for an answer to be given before the French elections next Sunday, before the formation of a new Government.
>
> The French proposal is contained in a letter from the Secretary of State for Prevention of Natural and Great Technological Hazards Mr. Haroun Tazieff to the Minister of Environment, Country Planning and Public Works Kostas Geitonas. The bearer of the letter is Professor of Geology, Mr. Papanikolaou, who participated as a representative of the Greek Government in a meeting last Monday, March 3, in Paris.
>
> At that meeting, the French Secretary of State Professor Tazieff announced to the three members of the VAN team, Academician Mr. Alexopoulos, Associate Professor Varotsos and Dr. Nomicos, that the French Prime Minister Mr. Fabius after cooperating with the Minister of Research Mr. Courien and with Mr. Tazieff, had given instructions for the immediate implementation of the VAN system in France – with the help of Greece – but also for the support of the VAN project in Greece. This decisive role of the French was due to the actions of Mr. Varotsos who had taken the initiative to make known in advance to Mr. Tazieff the details of the prediction of the earthquake [magnitude 5.1] west of Thessaloniki on February 18, 1986.
>
> The French interest in the VAN system had been expressed the previous year. Mr. Tazieff asked the group of three researchers to send him the relevant scientific material. After studying this material for himself – since he is a geologist – he sent a French scientific mission to Greece, which followed the functioning of the system in situ and studied the above mentioned material.
>
> After receiving the report of this mission, Mr. Tazieff referred the matter to a broader committee comprising directors of research institutes, which recommended to the French government the implementation of the VAN system.

After a few days, on 11 March 1986, almost all the press in Greece wrote about the official Communiqué of the French Government on its decision to develop the VAN system in France. For example, the newspaper *Kathimerini* wrote:

> PARIS - The French government has decided to cooperate with Greece for the development and refinement of the early warning VAN system for the prediction of earthquakes and will proceed with the experimental use of this system in a sensitive region of France. These are reported in a Communiqué of the French State Secretariat for the prevention of major natural and technological risks ... The Communiqué emphasized that the VAN system provided promise for seismic prevention and could contribute in the near future to the rescue of thousands of people, if the necessary resources were secured for its development.
>
> At the request of the French State Secretary Haroun Tazieff, the Prime Minister and the Minister of Research decided to start the process of Greek-French cooperation to develop and strengthen the system for the prediction of earthquakes ...

The French Government's proposal for cooperation was officially accepted by the Greek side, as published in the press. For example, on 13 March 1986 the newspaper *Ta Nea* carried an article entitled "Acceptance of the Greek-French cooperation on VAN" which said:

> The Greek Government accepts the cooperation with the French, as far as the VAN method is concerned, and today sent to the French Minister Mr. Tazieff the answer to his recent letter. According to our accurate information, the Greek Deputy Minister Mr. Geitonas, has written the following letter:
>
> "*I am pleased that the French Government considers that the VAN method which operates in Greece is an important step forward for the prediction of earthquakes. Within the overall technical and scientific cooperation between Greece and France, we agree to cooperate on this issue*..."

As part of this cooperation, after a few months the French scientific mission came to Greece to cooperate with the VAN team. On 8 July 1986 almost all of the press reported on an official statement from the French scientists following their visit. For example, the newspaper *Eleftherotypia* wrote the following, entitled "We export the VAN to France":

> Top representatives of the scientific circles of France propose the installation of a VAN network in the Pyrenees before 1987 with the prospect of extending it into southern and eastern France ...
>
> A statement was made yesterday by Jacques Labeyrie (Professor of Geophysics) and Yves Ménéchal (Dr. of Seismology), as representatives of the French Agency for the Prevention and Management of Natural Disasters, in the context of their scientific exchange with the VAN team.
>
> In this statement, the two French scientists point out clearly that any criticism about the effectiveness of the method can only come from scientists who have not undertaken detailed studies of it in situ...
>
> Following the agreement [on the Greek-French collaboration established in March 1986], we came to Greece as official representatives of the French side, to further promote our coopera-

> tion. After a stay of seven days in Greece, and having followed continuously the VAN network monitoring, we would like to disclose the following:
>
> **We studied** in depth the results of the VAN team and saw with pleasure the effectiveness of the method...
>
> **We thank** Prof. Varotsos and his colleagues, who willingly provided us with all the data requested. We have now gained a better knowledge and opinion, both for the effectiveness of the VAN method, and the physical theory on which it relies.
>
> **We shall** propose the installation of a VAN network in the Pyrenees, possibly before the end of 1986. Future network expansion will take place in regions of southern and eastern France, which are seismically hazardous.

The subsequent events up to September and October 1988, when the earthquakes in the Killini–Vartholomio area occurred, are described in Chapter 3 of Professor Tazieff's book. For example, he explains that in the framework of the Greek cooperation with France, he visited Athens in early February 1988, accompanied by two expert geophysicists, Bernard Massinon and Alain Leroy of the French Atomic Energy Commission (CEA). The CEA finally settled VAN stations in the Pyrenees in cooperation with other French institutes (see, for example, the newspaper *Le Monde* on 10 December 1988 under the title "La région Rhône-Alpes va se doter du systéme VAN de détection de séismes").

During the above-mentioned visit, Professor Tazieff and his colleagues were present during the recording and the subsequent analysis (to determine the epicenter and magnitude) of a preseismic signal SES that was followed by an earthquake of magnitude 4.7. Varotsos and I went to France several times in order to select suitable locations for installing VAN stations (where the photo shown in Figure 7.2 was taken).

7.2 The interruption of the VAN network

In chapter 4 of his book, entitled "Protecting Ourselves Against Earthquakes", Professor Tazieff is very critical of governmental officials. See, for example, pages 79 and 80 of the English translation, where he writes:

> Whether elected officials or civil servants, those responsible for the security of these countries are at fault when they do not take all the necessary preventive measures. Such measures range from predicting earthquakes to organizing effective relief, and include enforcement of earthquake-resistant construction regulations and public education. Especially since 1981, when the position of Commissioner for Major Natural Risks was created in the [French] Government, that excuse is no longer valid: today not taking preventive measures is tantamount to refusing assistance to persons in danger… When it comes to trying to predict the occurrence of major tremors, only Greece has been doing so effectively since 1981, and Japan and the Rhône Alpine region are in turn adopting the Greek method. But nowhere in the world has anyone taken the right approach to the difficult problem of effective organizing relief work.

Figure 7.2 Professor Tazieff together with Varotsos, searching for suitable locations in Southeastern France in March 1989.

And in the section under the title "The Role of Government" (pages 116 and 119 of the English version), Professor Tazieff returns to the same issue of protection from earthquakes, writing:

> The Ministers responsible for such mistakes, the gross errors committed both in disaster and prevention and in organising the relief work that follows disasters, have never, in any country, had to give an account of them...
>
> I remember how sickened I was after the terrible earthquake in Chile in 1960 ... At that time I had the impression that a few well-placed politicians, a few high-ranking military officers, a group of business executives and insiders, had gathered up the 'big lumps', the 'lumps' and the 'half lumps' of international aid. And at the very bottom of the social scale, all that was left, was a mere whiff of the 'extra-fines'.
>
> I have relived that experience of 1960; I regret to say, in every country, including our own, where each time the misfortune of the many has fattened a rather repugnant minority. That includes long, large and costly reconstruction programs, and even certain pseudo-scientific or pseudo-humanitarian missions.

Professor Tazieff continues this theme throughout the section entitled "Scientific Controversy and Dishonesty" (pages 125–132), where he also comments on the war against the VAN research efforts. Specifically, he writes:

> Some geophysicists have claimed over the years that Varotsos and his colleagues were not announcing earthquakes before the fact but actually after the fact. Now that the VAN team is sending its predictions to the government by officially dated telegram (date and time), this argument can no longer be used openly, but all too often it is still implied. The most violent enemies of Varotsos are those who, by profession, nationality or place of residence, are closest to him: certain Greek seismologists first of all... sent, on April 4, 1988 ... a three page letter to *Tectonophysics* from which I have extracted only the following sentences:[1]
>
> We also want to draw the attention of the scientific community to the following serious problems. Why do the authors (VAN group) systematically refuse to send their telegrams to the Government or to the seismological institutes before the occurrence of particular earthquakes? They mainly just exchange telegrams between themselves (for example, Mrs. Varotsos-Lazaridou to Professor Alexopoulos) ...
>
> From the reply by Professor Varotsos, dated June 3, 1988, also three pages long, plus two pages of appendices, which appeared in the same issue of *Tectonophysics*, I quote the following lines, concerning the accusation made above:
>
> a) As explained in our previous publication (*Tectonophysics*, volume 152, pages 190–193, 1988), our predictions until March 18, 1986 were discussed (before an earthquake occurrence) during sessions of the official Earthquake Prediction Committee (EPC) of the Ministry of Public Works. ... Mr… [one of the two seismologists who authored the above-mentioned criticism] was a member of this Committee, and there are official minutes proving that he signed our predictions before an earthquake occurrence. [We] have published a detailed list of the predictions made during the EPC sessions.
>
> b) Concerning the magnitude M=6.1 earthquake that occurred on March 29, 1986 [see Section 5.1], the preseismic information was directly transferred to the Ministry (4 days before the earthquake occurrence).
>
> c) After April 1986, the Greek Government decided upon the following procedure: before an earthquake occurrence, the prediction (that is the telegram) should be sent to the Inter-Ministerial Committee (IMC) of the Greek Government. The IMC, immediately after receipt of our telegram, sends a copy to the Organisation for Protection from Earthquakes, hence is officially informed of our predictions before any tremor... (Two characteristic examples are given in the Appendix of this paper).

1 At this point it would be useful to the reader to read also the relevant comments made on that subject by the Chief Editor of *Tectonophysics*, Seiya Uyeda, see Section 8.3.

And Professor Tazieff continues:

> I have gone on at some length about this controversy, because it illustrates the incredible dishonesty that is sometimes exhibited in a profession – science – in which the highest intellectual rigour ought to be an absolute necessity. But that rigour is too often nonexistent among the careerists, who are too numerous, and among certain others who have already "made it", who are also too numerous. This is what I have called the Lysenko syndrome,[2] which corrupts academia and the research community in France and elsewhere...
>
> We may well wonder why certain governmental authorities have not felt the need to give their countries the benefits of the VAN method, although everyone should be able to recognise its amazing effectiveness… Must we wait for the next disaster and then, as usual, do nothing until afterwards? This situation demonstrates the tremendous importance of establishing ethical rules to codify the selection of scientific experts who are called upon to advise political figures. Too many geophysicists and too many professors opposed the VAN method as soon as it was disclosed. They have opposed it without having seriously studied it, and without having discussed it with its creators. They have opposed it **in principle**, the characteristic reflex of every Establishment scientist. Religious or political Establishment thinking is the very antithesis of intelligence. When it comes to religious or political faith, in which rationality is of little or no consequence, such thinking is conceivable if not excusable. But in science...?
>
> Why, you might ask, so much hostility, so much dishonesty, because of this Establishment thinking, if you accept my views? Because in the scientific or academic community, [which exhibits] this "confraternity" or "fraternity", high quality is not very widespread... As far as money is concerned, here, as almost everywhere, it reigns abusively supreme.
>
> The funds committed by the industrialised nations in the search for a method of predicting earthquakes are not negligible. The fact that such a method has now been discovered by someone else, threatens to dry up one of the sources of your own budget...
>
> What matters in this case is not being right or wrong in some umpteenth little scientific squabble: what matters are human lives. How can we reject a method when almost all of its predictions have been borne out? A method whose only and infrequent failures, which are moreover becoming more and more infrequent as experimental data accumulate, consist in not having predicted 10% of [all the earthquakes] that have occurred in more than half a dozen years ...?

These bold statements and questions as Professor Tazieff ends his book confirm what Dominique Lecourt writes on page 18 (of the English version) of the Introduction:

---

2 …the "Lysenko syndrome", [named] after that Russian agronomist, whose intellectual rigour was no match for his intelligence, and whose ambition became evident from his contempt for his colleagues' reputations. Lysenko had managed to gain Stalin's ear and took advantage of his position to see that the best Soviet geneticists – who at that time were among the finest in the world – were stripped of their positions and sent to concentration camps. Today, forty years later, genetics in the [former] USSR has still not recovered from that tragedy (*ibid*, page 33).

> Haroun Tazieff takes up the cause of this theory [that is, the theory behind the VAN method], presenting its principles and demonstrating its successes. He explains the few failures that it has suffered. He refutes the arguments of its opponents, invoking the 'ghost' of Wegener[3]… He suggests incorporating into a prevention system that has been recast in new terms, and denounces the universally and scandalously negligent attitude of public officials in this regard.
>
> Haroun Tazieff does not mince words: **he spares neither the experts nor the politicians**. Based on his experience, as a field researcher all over the world and then as a government official, **he accuses**. And with his much acclaimed ardor and spirit, he proposes solutions. Readers will find here all of his arguments and will be able to judge for themselves. They will see how in our time, on this particularly "hot" issue, certain questions of science are intimately bound up with questions of politics and ethics.

Only a few days after the release of Tazieff's book in France, on 9 October 1989, an official communiqué of the Greek Ministry of Environment, Planning and Public Works was issued, which was published in almost all the press. For example, the newspaper *Ta Nea* in a report entitled "Ministry versus VAN" writes that "... the announcement was that the Ministry and the EPPO stop all assistance to the VAN team. In the same announcement it is stated that the VAN team refuse to give the EPPO the data needed to scientifically assess the method".

The Ministry's claim that we refused to give them the data greatly surprised us because it was obviously incorrect, as Varotsos explained the following day. As reported in the newspaper *Kathimerini* on 11 October 1989, under the headline "P. Varotsos: we have sent the telegrams [predictions]" and subtitled "The problem is whether the competent bodies received them":

> The controversy is not scientific but the problem focuses on the fact of whether the competent agencies received our telegrams or not. This was explained yesterday by Varotsos, a member of the VAN team, at a press conference in response to the Ministry's Communiqué attack the day before yesterday against the VAN system ...
>
> During the press conference, a movie was shown that was released in Japan in early September, in which the director of EPPO states that: 'When there was such a [preseismic electric] signal a process was followed by combining this information with other seismological data we had from the relevant authorities to ascertain the degree of risk'. That statement alone, underlined Varotsos, shows that EPPO did receive the prediction telegrams of VAN ...

A second indication of proof, leaving no doubt that the State had received the VAN warning telegrams, can be seen, for example, in Figure 6.2, where the telegram addressed to

---

3 By 1912 Alfred Wegener had formulated his hypothesis stating that the continents moved with respect to one another and did not occupy today the successive positions that they had occupied in the geological past, or those they would occupy in the future. Despite evidence almost every geologist and geophysicist refused, for half a century, to acknowledge this fact. One of the reasons was that Wegener was talking about continental "drift", which he compared to the movements of icebergs over the surface of the ocean. But another reason, an unstated one, was that Wegener was not a geologist but meteorologist (*ibid*, page 39).

the Secretary of Public Works was issued about three weeks **before** the first devastating earthquake in Killini in 1988.

A third and more recent example, just a month and a half before the Ministry's Communiqué, appeared on the front page of *Eleftherotypia* on 22 August 1989. Referring to the earthquake of magnitude 5.9 which occurred on 20 August 1989 in the sea area off the coast of Elia (Ionian Sea), it said: "*The VAN predicted the earthquake on August 15, said Professor Varotsos, and this was confirmed by the Ministry*". The reportage of this newspaper published on pages 20–21, entitled "I sent a warning" and subtitled "Varotsos says and the Ministry confirms" read:

> The 'E' [our newspaper] contacted yesterday the Secretary of the Ministry ... concerning the VAN prediction of the earthquake the day before yesterday. ... He told us: "Indeed we were informed by Mr. Varotsos of the impending earthquake. We assessed the situation and took the necessary measures. We informed the prefecture, the police chief and other relevant bodies. We acted as we have done in previous years.

How is it possible that on 22 August 1989 the Ministry officially confirmed that they had been alerted by Varotsos of the impending earthquake and "took all the necessary measures" yet a month and a half later claimed that the VAN team refused to send information to the EPPO? In other words, this action confirms what Professor Tazieff castigated in his book where he wrote that Greek seismologists sent letters to journals abroad in which they **falsely** claimed that the VAN team had not sent prediction telegrams to the State before the earthquake occurrences!

In addition to the aforementioned suspension of any assistance and funding, six weeks later, namely in early December 1989, the Ministry and the EPPO interrupted our telephone lines (and later the electricity power, see Section 8.4) through which data was transmitted from the VAN stations sited in the countryside to the central station at Athens. Professor Alexopoulos and Varotsos complained publicly on 5 December 1989 about this incomprehensible action. Almost all the press wrote about that issue, for example the reports of the newspapers *Kathimerini*, *Eleftherotypia*, *Ayriani*, and *Ethnos* on 5 December 1989. For example, the *Kathimerini* story is entitled "They cut the telephone lines of the VAN [network]" and subtitled "Protest of Alexopoulos and Varotsos".

Just one week after the forced interruption of our network, the Greek press reproduced an article from the well-known newspaper *The Washington Post*. See, for example, the newspaper *Eleftheros Typos*, under the headline "The VAN method wins in the U.S.A.", writes (nb. the bold words are the newspaper's) on 13 December 1989 (by D. Rizos):

> I have in my hands a very interesting article of [yesterday's] *Washington Post* which reveals one more success of the VAN earthquake prediction method.
>
> Eleven days before the earthquake in San Francisco on 17 of the last October, **a scientific team from the University of Stanford, recorded preseismic electromagnetic signals**! In other words, they had in their **hands a precursor of the earthquake that shook San Francisco**!
>
> ...
>
> This dramatic confirmation of the effectiveness of the method by the Americans, makes even more **'mad'** the attitude of the Greek State against the VAN team of **Professor Varotsos** ...

I come back to this confirmation by the Stanford researchers in Sections 8.3, 8.5 and 23.2.

8 Second international evaluation of VAN, 1990

8.1 The organization of the International Conference

This international conference, funded solely by the Alexander S. Onassis Public Benefit Foundation was entitled "Measurements and Theoretical Models of the Earth's Electric Field Variations Related to Earthquakes". It took place in Athens, lasted for three days (6–8 February 1990) and its main purpose was "to assess the results so far of the VAN investigation". The conference was organized by the Solid State Section of the Department of Physics of the University of Athens.

The conference was attended by a total of 44 scientists, including 28 researchers from abroad (nine countries) and specifically the USA, USSR (now Russia), Japan, France, Germany, Sweden, Italy, Poland and Bulgaria. The 28 researchers who participated from prestigious universities and research centres abroad were as follows.

The six researchers from the USA were Professors H. Kanamori (California Institute of Technology), T. Fraser-Smith (Stanford University), D. Morgan (Texas A & M University, Massachusetts Institute of Technology), D. Lazarus (Editor-in-Chief of the American Physical Society, University of Illinois at Urbana-Champaign), M. Johnston (United States Geological Survey), L. Slifkin (University of North Carolina).

The four delegates from the Soviet Union (now Russia) were Professors M. Gokhberg (Deputy Director, Academy of Sciences of USSR), G. Sobolev (Deputy Director, Academy of Sciences of USSR), A. Nikolaev (Academy of Sciences of USSR) and Dr N.I. Gershenzon (Institute of Physics of the Earth, Moscow).

The seven Japanese delegates were Professors S. Uyeda (University of Tokyo), H. Utada (University of Tokyo), K. Hamada (National Research Center for Disaster Prevention, Tsukuba), H. Yoshii (Bunkyo University), M. Uyeshima (University of Tokyo), T. Kawase (University of Tokyo), and M. Kinoshita (University of Tokyo).

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_8,

The five French delegates were Professors H. Tazieff (Director of CNRS, Secretary of State for Major Risks in the French Government), J. Labeyrie (Director of CNRS), J. L. Le Mouel (Institut de Physique du Globe de Paris), B. Massinon (Commissariat at l'Energie Atomique) and Dr J. Zlotnicki (Institut de Physique du Globe de Paris).

From Germany came Professor W. Ludwig (Director of the Institute of Theoretical Physics, Westfälische-Wilhelms Universitat, Münster).

Two delegates came from Sweden: Professor Ota Kulhanek (Director of the Seismological Institute of Uppsala University) and Dr R. Arvidsson (Seismological Institute of Uppsala University).

There was one delegate from Poland: Professor R. Teisseyre (Vice Director of the Institute of Geophysics, Polish Academy of Sciences); Italy: Professor G. Martinelli (Regione Emilia Romagna Servizio Informative e Statistica, Bologna); and Bulgaria: Dr T. Ralchovsky (Bulgarian Academy of Sciences).

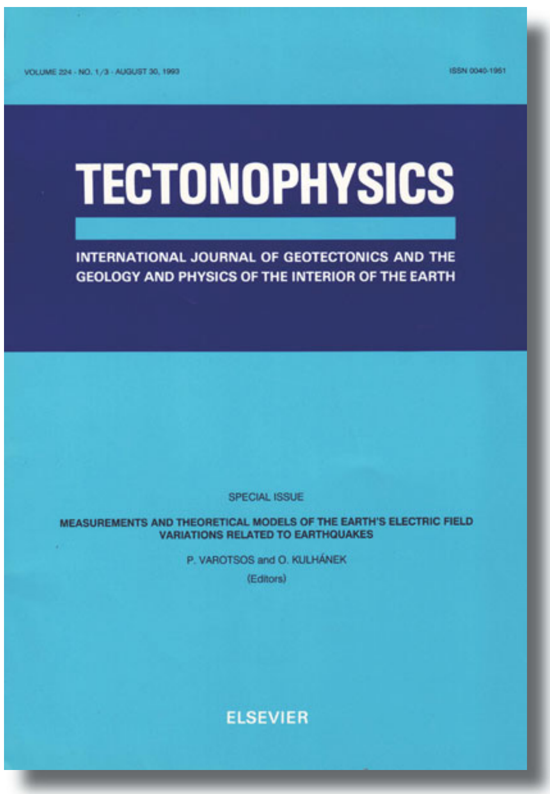


Figure 8.1 The cover page of the special volume published in 1993 by the international journal *Tectonophysics* (Volume 244, pages 1–288), which contains the proceedings of the international conference held in Athens from 6 to 8 February 1990 to evaluate VAN.

The following were participants on the Greek side: Professor Kessar Alexopoulos of the Athens Academy, six members of the faculty of the University of Athens (P. Varotsos, G. I. Papadopoulos, K. Eftaxias, V. Hadjicondis, E. Dologlou and A. Vassilikou-Dova), plus two researchers from Technological Educational Institutes (P. Hatzidiakos and K. Nomicos), Dr M. Lazaridou-Varotsos, member of the VAN team, and a researcher from IGME (Dr K. Thanassoulas). Also invited and attended were the Geological Society (Professor D. Papanikolaou) and the Hellenic Association of Physicists (Mr G. Bouritsas) as well as representatives of the Ministry of Public Works and EPPO. Concerning the Seismological Institutes, only Professor A. Tselentis, head of the Seismological Laboratory of Patras participated, while the Directors of the Seismological Institutes of Athens and Thessaloniki did not, although they were invited. (However, an article co-authored by the two seismologists G. Stavrakakis and J. Drakopoulos, which criticized the VAN method, was submitted and included in the proceedings of the conference).

The conference took place in six sessions, each lasting half a day, and was presided over by the following: Professors S. Uyeda (Japan), G. Sobolev (USSR), H. Tazieff (France), D. Lazarus (USA), M. Gokhberg (USSR), K. Hamada (Japan), O. Kulhanek (Sweden), J. Labeyrie (France), L. Slifkin (USA) and Professor of Physics G. I. Papadopoulos (Director of the Solid State Physics Section). The conference proceedings were published in 1993 in a special volume of the prestigious international journal *Tectonophysics* (volume 244, pages 1–288). Figure 8.1 shows the cover page of this special Volume.

8.2 The conclusion of the Conference

At the end of the conference, late on 8 February 1990, the participants announced a unanimous conclusion. The full text is as follows:

Athens, February 8, 1990

RECOMMENDATIONS OF THE CONFERENCE

ENTITLED*: *"MEASUREMENTS AND THEORETICAL MODELS OF THE EARTH'S ELECTRIC FIELD VARIATIONS RELATED TO EARTHQUAKES"

At the invitation of the Solid State Section of the Department of Physics, University of Athens and the sponsorship of the Alexander S. Onassis Public Benefit Foundation, many scientists from several countries met in Athens for three days, from 6 to 8 February 1990, to review the progress in the continuing study of the transient electrotelluric signals as precursors to earthquakes. This programme developed in Greece by Professors Varotsos, Alexopoulos and Nomicos (VAN), ***has shown great promise for earthquake prediction.***

We wish to thank the Foundation, for providing the opportunity to meet together and to carry on scientific discussions related to this important work.

While research on earthquake prediction in Greece will eventually require the integration of many different geophysical data, the VAN technique shows considerable promise at this point. ***The VAN system has shown that, under certain conditions in precalibrated areas, electrical***

signals can be detected up to several days in advance of major earthquakes. During the past years, several events of magnitude greater than 5 have been predicted with reasonable precision as to magnitude, time and epicenter location. *These successes have prompted some other countries, notably Japan, France, Italy and Bulgaria, to undertake related programmes.*

For the immediate future, it is important that the VAN programme should continue, and be expanded, if possible, to other parts of Greece. We urge the Foundation to use its good offices to encourage the continued development of this programme and, in particular, to ensure that the necessary telephone lines be provided without charge to the VAN group.

The eventual development of a reliable earthquake prediction system will require the best efforts of scientists from all countries.

Following the announcement of this unanimous conclusion, some participants expressed the following additional comments and clarifications:

D. Lazarus (Editor-in-Chief of the American Physical Society, Professor at the University of Illinois):

"I would firstly like to clarify that I came to Greece again in November 1984 with Professor Kulhanek and Professor Slifkin at the invitation of the Greek government to assess the results of VAN. I am happy to announce that from then until now the VAN technique has shown excellent and significant progress and has answered in the meantime a number of important scientific questions. Now we understand more about the physical processes and the VAN technique is a great hope, much more so than we thought five years ago."

L. Slifkin (Professor at the University of North Carolina):

"I am sure that the main interest of most people is that the VAN technique is useful for saving the lives of people. I would like to stress that there is great scientific interest because with the VAN technique we collect such scientific knowledge to help us better understand the physical and geophysical processes related to earthquakes."

S. Uyeda (Professor, University of Tokyo)

"I am from Japan and working at Tokyo University and was among the first great advocates, I may say, of the method. In collaboration with the VAN team we tried to repeat the method in Japan as applied in Greece. Japan is a more active seismic country than Greece. Japan is one of the two largest countries in the world that spends huge amounts each year solely for its earthquake prediction programme, spending approximately 6 billion drachmas annually. Since the VAN method is so new, it is not yet included in the national programme and, therefore, some of my colleagues and I worked to implement it in Japan with, I would say, modest financial means. We started in 1987 installing the first stations and now have 22 VAN stations. Our stations are not as sophisticated as those in Greece, but you should take into account that Japan is a large country and very crowded, so we have electrical noise almost everywhere (mainly due to the high number of electric DC trains and industry). We had great difficulty in finding quiet stations, so that we could read the records. We were finally able to find 2–3 such quiet areas, and during the past 2.5 years we have obtained some encouraging results. I would like to mention a few examples. In July last year, in a peninsula near Tokyo we had a series of earthquakes and observed electrical changes in a VAN station that had been installed on a nearby island. In recent years we have had three cases of seismic activity in this region and indeed observed in all three cases electrical precursory signals. Although I cannot guarantee this, we believe that in a few years we will reach the same level as the VAN scientists. But I must say that today we are far behind in Japan compared with the VAN group."

Ota Kulhanek (Director of Seismological Institute, Uppsala):

"I work at the University of Uppsala in Sweden and I must say that since 1982 we have been working closely with the Greek VAN team. Of course you know that Sweden is a very stable country in terms of tectonics, so despite our great desire to apply the VAN method in Sweden, it would not have immediate practical results. So we started a programme for its implementation this autumn in Ethiopia in the northern part, which is quite active. We used the same technique as the VAN team at two stations south of Addis Ababa. This country has the advantage that it has no high electrical noise (due to the small number of industries) and hopefully we will have excellent electrical signals. I would point out that Ethiopia is one of the developing countries supported by Sweden and thus we have found support from the Swedish Government for a three-year research programme for developing the VAN method until 1992. The prospect for continuing the programme beyond 1992 is very favourable. Because we only started in Ethiopia last autumn, I am not ready yet to give you results, but I really believe that we will have good results."

R. Teisseyre (Professor, Polish Academy of Sciences):

"There are already a number of successful applications of the VAN method in various countries. I would like to add our own results (of the Institute of Geophysics, Polish Academy of Sciences) in Italy in the Friuli region in collaboration with the University of Trieste. We found it difficult in this region of Italy, due to industrial noise. After eliminating the noise, however, we saw really powerful electrical signals that precede earthquakes."

M. Gokhberg (Professor, Deputy Director of the Earth Institute in Moscow, USSR Academy of Sciences):

"I am from the Earth Institute in Moscow, the Soviet Academy of Sciences. I have taken part in several international conferences where the method of the VAN team has been discussed. Now we are developing the electrokinetic theory which may explain the method theoretically. Our model is slightly different, but we agree with the experimental technique and I can say this: In terms of position, that is the epicenter, seismic maps show us clearly future locations of earthquakes. So the main, difficult issue is the prediction of the time of upcoming earthquakes. And we have here in Greece for the first time the opportunity to learn from VAN how to find the time. I can tell you, for example, that in California they had more than 300 ordinary seismic stations and failed completely to predict the time of the forthcoming earthquakes. Therefore, the traditional seismological methods compared with the electrical method are very unlikely to give accurate prediction of an earthquake in terms of information about the time of future earthquakes. I think the VAN research is very important, what is happening in Greece is indeed a unique experiment for the whole world and therefore VAN needs very strong support."

D. Morgan (Professor at the University of Texas A & M and the Massachusetts Institute of Technology):

"I would like to make a few comments that might help the public to understand what is happening. I am a geophysicist and I know very well that many scientists of my scientific community in various countries around the world have been trying for many, many years to achieve the prediction of earthquakes. Unfortunately, scientists in my specialty have for many years been trapped in our own perceptions, we had the expectation of success in predicting earthquakes. If someone from our specialty achieved it, all the rest of the Geophysics Community would feel very pleased. I think the following thing happened: Professor Varotsos and his colleagues come from another field, the field of physics, and being free from bias of our geophysical community, open a new door to real science, even in a scientific field that has the highest and most special interest, such as the prediction of earthquakes. I think that makes the VAN team scientifically so great that the Greeks must feel really proud today. Professor Varotsos and his colleagues should continue the uphill task."

8.3 Scientists' responses to questions from the press

After the completion of the aforementioned comments of the participants from abroad, many questions were submitted by journalists. The responses were published in almost all the press the following day (9 February 1990).

Question: I want to ask the scientists from abroad, especially those of France and Japan, to tell us about the results of VAN and comment on the deviations of the predictions. I would also like to ask the participants to comment on the decision of the Greek EPPO to stop the telephone lines of the VAN network.

H. Tazieff (Professor, former Secretary of State for Major Risks in the French Government): There are a few cases in the history of science where scientists have been able to make a successful prediction, for example the Chinese scientists in 1975. However, the Chinese scientists failed one year later in China to predict the most destructive earthquake in their history (which killed some hundreds of thousands people). With this experience, a few years ago I suggested that earthquake forecasting was impossible. On the other hand, we know that in Greece in recent years the VAN team has accurately predicted all major earthquakes with the exception of the Kalamata earthquake. And we know well why that prediction failed. It was the first earthquake in this region and there was not (even one) calibrated station in respect of the magnitude and the epicentral area. Therefore it was practically impossible to achieve an accurate prediction. But I stress again that all other major earthquakes were predicted with good accuracy. Some were even predicted with great accuracy, for example the earthquakes in Killini–Vartholomio in 1988 that were predicted with amazing accuracy. To think that I said a few years ago that earthquake forecasting was impossible to achieve. In 1984, I was saying these things. Later, when I learned the technique and studied VAN, I became convinced in a few months. I suggested then, as a member of the French Government, its application in France. My experience from observing the method over the last six years fully cemented my belief in the correctness of VAN. I am now more convinced. If in the future a large earthquake should happen in Greece, in a region that has been calibrated in respect to the VAN stations, I am quite sure that VAN would predict it. On the other side of the question, I tell you that I do not understand, I really cannot understand, that some people had the nerve to cut the VAN telephone lines that carry scientific information from regional stations to the central station. Such acts are totally unacceptable from a scientific point of view. It is also unacceptable from a humanitarian perspective, because they hamper research efforts that could save people from upcoming earthquakes.

Question: I would like to ask the participants to estimate how long it will take for VAN to provide definitive results.

Ota Kulhanek (Director of the Seismological Institute of Uppsala, Sweden): But the VAN method has already reached the point where it now gives successful results.

L. Slifkin (Professor at the University of North Carolina, USA): For a few years now the VAN system has been giving final results for the regions of the stations.

Ota Kulhanek: What do you mean by your question "when will VAN provide final results?"

Question: The phrase "final results" means a warning to the population.

Ota Kulhanek: The problem is more complicated than it seems from your query. We are talking here about earthquake prediction. Warning the population is quite another complex matter. Scientists predict earthquakes and transfer information to the State whose relevant agencies are responsible for alerting the population or not. We are not experts in warning the population. There have been special and specific studies in different countries on this issue. It can happen that a warning to the population can lead to more deaths than the earthquake itself. In response to your question, I would answer briefly as follows: For the places where the VAN system has stations, the expectation of prediction of earthquakes has been raised. We recommend that the VAN system must be extended to cover the whole area of Greece.

H. Tazieff: I agree with Professor Kulhanek on the issue of public warnings. For a politician to use scientific information to warn the population is a difficult and very responsible act. But it must be assumed that the politician who has this responsibility will act accordingly, otherwise he should immediately resign in advance. Being responsible for such issues over the last nine years, I can say that when France arrives in 3–4 years to the point of having equally usable information as Greece, I am determined to take such responsibility. But the population should be trained appropriately, for example Japan's population has been trained for many years not to react with panic and everyone knows what to do when the need arises.

Question (addressed to Tazieff): You have received harsh criticism in Greece after you publicly forecasted earthquakes, a few of which did not occur.

H. Tazieff: I regret this very much, but I was criticized because I announced an earthquake in Greece on September 1, 1988 as a representative of Professor Varotsos who had made the prediction in an area which was also announced. But why was the announcement issued? Because for several years, the VAN team had predicted earthquakes, which actually occurred at the epicentral areas identified in advance, but the government did not disclose these forecasts and they remained secret. This time the announcement of the earthquake was significant because its expected magnitude of the earthquake was about 6.0. Caution was needed because it was almost 30 times stronger than the magnitude 5.0. So I decided at that time to announce it, without asking the opinion of Professor Varotsos, who was silent because of his professional obligations. This public warning, for which I was entirely responsible, was made in the French media, and it immediately spread everywhere. The earthquake was right where Professor Varotsos had predicted and the magnitude was comparable to that estimated in advance, 22 days after his prediction.

Question: But are both the epicentral area and the time important?

H. Tazieff: The epicentral area and the magnitude were accurate. As for the time, they cannot say exactly, but the experience they have allows them to say that the majority of earthquakes is between 10 hours and 10 days with a few exceptions, such as a maximum of around three weeks. I agree that the window of time in this case is somewhat long, but it is better to live 23 days in anticipation than to be buried lying in ruins. [Note that, as explained later in Sections 18.3 and A.2, a more accurate determination of the time of an impending earthquake is now possible after the introduction of the new concept of *natural time*.]

M. Gokhberg (Professor, USSR Academy of Sciences): I would also like to add something to what Professors Kulhanek and Tazieff have said. We must deeply understand the scientific value of the prediction and distinguish it from alerting the population, which is purely the responsibility of government. After the recent devastating earthquakes in the Soviet Union we began with a Governmental initiative, a very complex programme for earthquake prediction and I am able to announce that we have included the method of electric potential (that is the VAN method) in this programme. I think in five to seven years from now we will have developed our own prediction network that will collect information in real time. We will develop it with modern telecommunications and computer methods for analyzing and processing data, etc. The system will start to operate independently. We must understand that in such a difficult problem, as the prediction of earthquakes, there will initially be a lot of mistakes until the system is perfected. I think from a scientific point of view that in Greece VAN has achieved for the first time in science a good knowledge of the time of an upcoming earthquake so I think that Greece should immediately start the organization of the authorities for the exploitation of this information on earthquake prediction.

Question: What scientific data were analyzed that led all scientists to a unanimous conclusion?

D. Lazarus (Professor, Editor-in-Chief of the American Physical Society): We analyzed all the data of the last several years. We studied each individual case. We had in our hands all the official prediction telegrams that the VAN team had sent to their Government. We gave special attention to the earthquakes of the last two years with magnitude 5.0

or greater. In each case we studied the preseismic signal SES, since the VAN team gave us the recordings. As an example, we studied in detail the case of the prediction of the earthquakes in Killini-Vartholomio, but we were not piecemeal or selective, and looked at all cases. I would add that our study was not based on a table, but we studied each case from the original recordings of the VAN team. The team hid nothing. They gave us even the slightest trace on the record. The VAN team gave us copies of all these records to take with us to our laboratories. Anything we asked they gave us immediately.

Question: If someone takes into account the high seismicity of Greece, could there have been an accidental success rate in all of these results?

D. Lazarus: We had taken into account this possibility and **excluded** the percentage of hits by chance. Suffice it to say that, especially in cases of earthquake of magnitude 5.0 or greater, the rate of this prediction by chance reaches only 4%, while the success rate of the VAN team reaches about 75%. Coincidental prediction by chance in the VAN results should be ruled out.

L. Slifkin: It should be clear that when the VAN team sends predictions, they do not say that there will be an earthquake in the next two to three weeks somewhere in Greece. The crucial point is that each prediction says there will be an earthquake of this magnitude in a quite specific area, which means in an area that has been identified exactly. And that is the point which convinces me that the method excludes chance.

D. Lazarus: I make it clear that the prediction determines the region within 100 km and the magnitude with a maximum deviation of 0.7 on the Richter scale.

J. Labeyrie (Professor, Director of the Research Centre of France): Keep in mind that there were several VAN predictions to within just 10 and 20 kilometers from the real epicentral region.

Question: Returning to the original wording of your conclusion which says that the VAN team has achieved remarkable progress with substantial accuracy. This means that we are on the right path that will lead to something but what is it that we are still missing? We need more time and more scientific knowledge? A second point that I ask is: Did they predict earthquakes that did not happen?

D. Lazarus: I think we still need to expand our scientific knowledge and accuracy and to explain what I mean by this: the VAN team found and installed its stations in "*sensitive*" regions which only cover approximately 50% of the Greek area. Regarding the second part of your question, the answer is: There has been no case of earthquakes of magnitude larger than 5.0 predicted by the VAN team which have been "false". After each telegram there has always been an earthquake. If I remember correctly, in only one case has the deviation of the prediction exceeded 0.7 units on the magnitude and 120 km when determining the epicenter. Summing up, I underline that there were no "false" (or wrong) predictions, which I think is very important.

H. Tazieff: I would like to add the following to what Professor Lazarus said: Never has any other country in the world achieved anything similar. The achievement of the VAN team is absolutely unique. Other methods have been tested so far but cannot even be compared with the results of the VAN team. The VAN method is superior by several orders of magnitude than all other methods proposed or tested to date in all countries.

D. Morgan (Professor at the University of Texas A & M and the Massachusetts Institute of Technology): I would also like to add something to the question. In science there are, on the one hand, the experimental results, on the other hand, the theoretical model that can explain these results. In this conference we have discussed in detail some theoretical models that can explain satisfactorily the generation of the VAN signals. This has encouraged us immensely.

Question: Apart from the data studied, namely the telegrams and recordings, has the VAN team given to you the certificates that were also sent to EPPO? Because in the past there was disagreement and EPPO said they did not receive them. I would also like to ask how the scientific community is going to respond to these allegations of EPPO, which is a National Agency, to obstructing a research effort that helps people all over the world? Mr Varotsos told us that he sent telegrams, while EPPO is saying the opposite. Would you like to comment on that?

H. Tazieff: The actual telegrams were sent in the official way. We got copies of the official telegrams certifying the time and date that were sent from the VAN team. I should add here that copies of these telegrams were sent before the earthquake to the University of Tokyo (Professor Uyeda), me and other scientists in France, for example Professor Labeyrie and Dr Massinon. Remember that one of these telegrams led to my public announcement on the devastating earthquake in Killini-Vartholomio through the French media [see Chapter 6]. All the participants of the conference now have in their hands the copies of those official telegrams. Allegations by EPPO that they had not received the telegrams are contrary to scientific ethics. And I remind you that the word ethics is Greek word.

M. Gokhberg: Regarding the telegrams I have to register my own experience. Two years ago in Sweden and on the initiative of the six countries, I attended an international conference for the Nuclear Test Ban Verification. Mr Varotsos, who took part in this conference, showed us the telegram he had sent to his Government on an earthquake that would happen in a few days. Some delegates, who were expert in detecting nuclear tests, but not expert in earthquake prediction, did not believe in his prediction and smiled. And yet, two days after this, the earthquake actually took place in Greece, just where Mr Varotsos had announced. This is just one example of many I could mention. This happened in May 1988, where an earthquake of magnitude close to 6.0 occurred in the area of Kefalonia.

D. Lazarus: We had the same experience in November 1984 when we had come to Greece to evaluate the research effort of VAN. Such a fact, as that described by Professor Gokhberg then happened, which convinced those of us who had not been satisfied at that point.

J. Labeyrie: In 1986, together with my colleagues I had come to Greece and stayed for four days to study the VAN system and investigate its applicability in France. There I had the opportunity to study and evaluate hundreds of telegrams that their success rate was about 60%. Later, with increasing experience, the success rate grew. We need to certify: The telegrams actually exist.

Akis Tselentis (Professor of Seismology at the University of Patras): I think it is time to stop this ridiculous controversy between the seismologists in our country and the VAN team and all work together for the good of this country. Because if we all help the VAN team and do not fight it, we are on the stage for a discovery of tremendous importance internationally, for which Greece will be truly proud. Certainly we should not forget that prediction is only a component of antiseismic policy and not build homes inappropriately at incorrect positions. And I will be succinct, closing with a proverb which says that "those who live in glass houses should not throw stones," because I fear that our house is not just glass but also cracked.

Question: I would like to ask the USA delegation the following: It was mentioned earlier that before the earthquake in San Francisco there were about 300 seismic stations. Is the US government willing to introduce the VAN technique?

D. Lazarus: I would like to make it clear that we are not here in the form of a delegation. Each scientist has his own scientific opinion. The scientist who could answer your question is Mr Johnston who is currently in the central VAN laboratory in Glyfada. It is inappropriate for me to answer on his behalf. He is responsible in terms of the government on the subject of earthquakes in California. But if I take into account the recommendations and findings he found for VAN, I guess that would suggest a VAN installation in California. I would not wish to speak on his behalf. Perhaps you can ask him.

Ota Kulhanek: There is a misunderstanding and I would like to clarify something: The 300 stations that existed in California were not VAN stations, they were classical seismological stations which means stations that simply record earthquakes.

D. Lazarus: I would say that during this conference we have heard the following scientific communication of Professor Fraser-Smith from Stanford University, who participated in our conference. Near the epicenter of the recent disastrous earthquake in San Francisco in 1989 he happened to take electrical measurements. He fully recorded a net electrical warning signal in a wide frequency range several days before the earthquake. The station which recorded the signal was not designed for this purpose, but accidentally recorded the characteristics of a strong electrical warning signal.

L. Slifkin: VAN measures voltages while the device at Stanford University was a large spool that was designed to record magnetic changes. In physics, however, we know well that when you record magnetic disturbances they are necessarily accompanied by electrical disturbances. These two disturbances always go together.

Question: How many countries use the VAN technique today?

J. Labeyrie: We said in the conclusion, the following countries (apart from Greece): Japan, France, Bulgaria, and Italy. Ethiopia also was mentioned by Professor Kulhanek, but there are also measurements in Brazil.

M. Gokhberg: As I said earlier, we also now use the VAN method in the Soviet Union. It is included in the official governmental programme and our government has approved funds for this.

Question: I would like to ask what happens now with the VAN network in Greece?

P. Varotsos (Professor of Physics at the University of Athens): I do not want to comment today. I shall speak in a few days after first hearing the opinion of the scientists from abroad.

D. Papanikolaou (Professor of Tectonics at the University of Athens): The VAN network, the telephone lines of which were stopped last November, comprised 18 stations.

J. Labeyrie: I would like to add some additional information on the measurements of the VAN system in Brazil. Initiated by the Director of the Geophysical Institute of Brazil, after a period of unusual seismic activity about three years ago, they settled two VAN portable stations with the help of Dr K. Nomicos. The stations were operating for a time period and found that there were two major earthquakes, before which clear VAN signals were detected. This is important because it shows that the VAN system works well in other geotectonic structures different from those of Greece.

Question: It has been published in scientific journals abroad that some Greek seismologists challenged the results of the VAN team. I would like to ask the opinion of the scientists from abroad about it. And a second question: Can the scientists from abroad know and judge the capabilities of the Greek Earthquake Planning and Protection Organization (EPPO)?

S. Uyeda: You may be referring to an article published by Greek seismologists in the journal *Tectonophysics*, where Greek seismologists have criticized the VAN method. Because I am the Chief Editor of this journal, I know very well the details of that criticism of Greek seismologists, but I know also the reply given by the VAN team. My scientific opinion on the criticism of Greek seismologists is that it is based on incredibly simple arguments, which are scientifically incorrect. So much for the scientific aspect. Now as to what the Greek seismologists claimed for the absence of VAN prediction telegrams and other such excuses, I would say that is completely untrue. The VAN team responded immediately with clear arguments. For anyone who reads these two articles (meaning the publication of the Greek seismologists and the response of the VAN team) the conclusions are obvious. The criticism of Greek seismologists is full of elementary scientific errors, and what they claimed regarding the telegrams of the VAN team is just untrue.

H. Tazieff: I would like to add something regarding the second part of the question. From the years 1981, 1982, 1983 and 1984 to 1986 I was responsible to the French Government on issues of natural disasters. Then I proposed bilateral cooperation between France and Greece, France and Italy and France and Spain. In your country, I suggested direct cooperation at ministerial level between Greece and France, because I do not believe in the effectiveness of multinational cooperation, such as UNESCO, in such matters. After that and since 1981, I came to your country several times for discussions with the Greek Ministry of Public Works and EPPO to deal with such issues. In France we have excellent specialists, for example engineers specialising in earthquake-resistant structures that can be compared with those of Japan and California. So we offered to Greek engineers the opportunity to gain from the knowledge of our specialists. Secondly, I would like to clarify that no country in the world is quite ready to deal with such situations as the aftermath of a devastating earthquake. I had my own opinion and my own ideas for this programme and I came here to meet the leaders of EPPO. I think the way they deal with post-earthquakes is about nine years out of date. I might add that in France we are not sufficiently advanced in this field.

D. Morgan: I would like to return to the criticism made by the Greek seismologists and the reply by the VAN team. I read carefully the two articles and I can confirm absolutely what Professor Uyeda said. I absolutely agree with his answer. It was a very good response.

8.4 The electric power to the VAN network is switched off

Before the conference, as mentioned in Chapter 7, the Earthquake Planning and Protection Organization (EPPO) had already cut the telephone lines carrying the VAN measurements from the field stations to the central station. Shortly before the conference, upon the personal request of Varotsos to the Hellenic Telecommunications Organization (OTE), this organization offered to open the telephone lines for data collection for 15 days, so that the telemetric network was in operation during the conference. Unfortunately, despite the positive conclusions concerning VAN from the conference, we were informed (see the newspaper *Kathimerini* on 15 February 1990) that “on 20 February the Electricity Company now will cut the power after the EPPO decision that it will not undertake the payment of the bills amounting to 49,500 drachmas” (approximately 1500 dollars). On the same day, 15 February 1990, almost all the press referred to this issue; for example, *Eleftherotypia*’s story was entitled “*Switch-off the electric power from VAN*”.

The following day, several newspapers sprang into action. For example, in *Ayriani* (16 February 1990) journalist K. Diakogiannis wrote:

> Cold-blooded murder of a noble scientific endeavour, the famous VAN!
>
> I could not imagine so much unscientific horror, such dense and deep darkness, medieval, unsaturated, such hatred against any attempt to move forward. I would not believe, as I lived, that such actions could have happened against the leading and internationally recognized Greek scientists who discovered and implemented an earthquake prediction system, the VAN, known today throughout the world. Is it possible to operate freely and unhindered amongst the bloodthirsty butchers of knowledge in this country, two steps away from passing the threshold of a new century? What is sacred in human life? The struggle for research and knowledge acquisition, in Greece in 1990 has been hacked to death with a savage brutality above all brutality! The notorious EPPO (Earthquake Protection Agency) after cutting the telephone lines of the VAN research group, which comprises three University professors, they now switch off their

> electric power! Even if the VAN achievement was quite unknown (to the contrary it is internationally recognized) why should the efforts of three researchers be shot because of such immense malice? ...

In a similar spirit, a second article in the same newspaper was written on the same day by another journalist, N. T. Koutsoumis, entitled: "*Who fights the prediction of earthquakes* ..." which ended as follows: "When power flows to the deserted streets of Glyfada for a lantern, it is incomprehensible to cut it from an installation that aims to save our lives from earthquakes ... They should tell us anyway what is hidden behind this story …".

After our intense pleas, the Hellenic Telecommunications Organization (OTE) agreed to temporarily retain four out of the 18 VAN telephone lines until the issue was resolved. But EPPO remained adamant, insisting they stop all the VAN stations, although the press continued with its recurrent theme in newspaper articles. Look, for example, at the main article from *Kathimerini* on 26 June 1990 (by D. Papanayiotou) entitled "The Adventure of VAN", from which we convey here some excerpts.

> Only in Greece in recent years could this happen ... This is the new suffering of the VAN researchers, following the adventures they have undergone all these years since the first announcement of their scientific discovery, since the great earthquake of 1981 – until now!
>
> Now the OTE threatens to cut the last four special [telephone] lines that connect the remaining four field stations with the central laboratory of the VAN network in Glyfada, because they have not paid the relevant accounts! Some time ago something similar happened for the same reason, with the Public Power Company (PPC) in the provision of electricity. However, neither the PPC nor the OTE are responsible for these unacceptable actions. In the dock is placed EPPO, which is the government agency ... earthquake protection [Here the newspaper writes the names of the directors of the EPPO].

A little further down the article continues:

> Last autumn, EPPO, although a body ... of protection, decided to abolish the VAN network, through which the researchers have made successful predictions of the earthquakes that have occurred over the years. So from 18 VAN stations in various regions of the country only four remained, and even for these four stations EPPO denied responsibility for payment although it had paid for the operating expenses for years that is, the payment of the bills for electricity and telephone lines, which was the only State aid to VAN ... And of course, how can the academician Mr. Kessar Alexopoulos and the University Professor Mr. P. Varotsos undertake to pay such accounts themselves from their academic purse?
>
> Last February an international conference to review the VAN method was organized by the University of Athens, with the financial sponsorship of the Onassis Foundation, and included the participation of eminent scientists from all top seismological institutes in the world. The scientists from abroad studied all the evidence, attended the function and specifically recognized the practical value of the VAN scientific research arguing that it should be strengthened and continued because it would lead to a safe prediction of seismic activity.
>
> This from scientists from abroad ... From the Greek scientists, however, all that followed was to cut the telephone lines ... after the decision of the EPPO that it did not support VAN. After requests and representations to the Hellenic Telecommunication Organisation's management, there remained just four telephone lines, as mentioned above. And all this while the VAN

> method gains scientific recognition in European countries such as France, which has applied it in that country, and meanwhile, in Japan, which operates 22 VAN stations and decided to install and operate a full VAN network across the country.

Here the newspaper mentioned the names of the political leadership of the Ministry and the article ended as follows:

> It is desirable, if not imperative, for the political leadership of the Ministry to investigate the whole issue and restore order because it is unacceptable that what is happening exposes us as a country internationally, for the treatment we grant to scientific research. The disagreement among scientists as to the scientific evaluation of the same 'object' is legitimate. What is unacceptable and unfair is when scientists on the dissident side exercise authority and have the power to impose costs on the other side which condemns them to scientific decline. The political leadership of the Ministry must be informed and asked to take responsibility. We await further developments.

Despite the strong intervention of the press, the EPPO kept the majority of the VAN stations out of operation for almost six years. Until toward the end of 1995, 14 out of the 18 stations remained closed and VAN tried to continue the research with only the following four stations: Keratea (close to Athens), Pirgos, Ioannina and Assiros (near Thessaloniki), shown in Figure 3.2 as KER, PIR, IOA and ASS, respectively. Only after the recommendation of the Scientific Committee of the United Nations (see Chapter 11), were some of our stations returned to operation in 1996.

8.5 The impact of the Conference abroad

Whilst the above was going on in Greece, the response of the February conference abroad was significant. In view of the prestige of the participants, their recommendations had a huge impact in scientific circles. For example, researchers in the USA began to prepare a similar conference, which finally took place two years later, in 1992, just outside Los Angeles (see Chapter 10). A year later, in 1993, a similar conference was organized by the Japanese to discuss current advances in the research of precursory electromagnetic signals. So much for the response of the scientific community. Meanwhile, the most prestigious international mass media, especially newspapers in France, Japan and the USA, devoted space to extensive articles. I will mention here, for example, one such article with the central title: "Earth signal – It could portend an earthquake" which was published in the *Los Angeles Times* on 7 October 1990.

This article, written one year after the 7.1 magnitude earthquake of 18 October 1989 in Loma Prieta, California (south of San Francisco), describes how, before that earthquake, in accordance with very interesting work presented at the Athens Conference in February 1990, a strong electromagnetic signal was recorded, similar to that of VAN. The article begins as follows: "Hours before the San Andreas fault ruptured through the hills east of Santa Cruz nearly a year ago, a delicate sensor designed to help the US Navy detect enemy submarines picked up a radio [low frequency] signal that was so strong that it 'broke' (exceeded the capacity) of a computer system."

The article continues on page A44: "The stakes are so high and the results have been so tantalizing that other scientists around the world are looking for 'electromagnetic' evidence of pending earthquakes. Most of the research is based on the fact that the Earth is a giant dynamo, creating electric currents that flow through its crust and emitting various electromagnetic signals from such geophysical events as the crushing of rock buried in fault systems." It goes on to explain that signals such as those recorded before the earthquake in California had been detected over the last few years in Greece, leading Greek scientists [i.e., VAN] to a series of successful predictions, and similar phenomena to that observed in Greece have been verified in China and Japan. The report notes that the researcher who recorded the signal before the Loma Prieta earthquake in California was Professor Fraser-Smith from Stanford University. He was the researcher who participated in the conference of February 1990 in Athens, and signed the unanimous conclusion at the conference about VAN. Remember that, as mentioned in Section 8.3, both Professor Lazarus and Professor Slifkin in their responses to the journalists, referred to the powerful signal that was recorded by Stanford University researchers by an apparatus that was not exactly designed for this purpose, and that this signal was similar to those recorded in the VAN research.

The article in the *Los Angeles Times* continues on to page A46 entitled "Quakes: Scientists Eye [warning] Earth's Signals" and describes many details about VAN and the discussions made during the conference the previous February in Athens as well as the conclusion obtained. In particular, the newspaper wrote: "Of all the scientists working in the field, only one group in Greece has claimed repeated success in predicting earthquakes through electromagnetism. Physicists at the University of Athens have been using what they call 'seismic electric signals' to predict earthquakes since 1981."

The newspaper described in detail how the measurements are made in Greece, explaining their differences from the measurements in California, and then continued:

> Three Athens professors announced in February [at the international conference held in Athens], that they had achieved a 75% success rate in predicting earthquakes there by monitoring changes in the Earth's electric potential just before the quakes.
>
> During the past few years, several quakes measuring more than 5.0 on the Richter scale were predicted with reasonable precision as to the magnitude, the time and the epicenter, the scientists said in a presentation to the international earthquake conference in Athens.

Subsequently, the newspaper wrote:

> One of those present was Caltech's Kanamori, one of the leading earthquake experts in the world. Kanamori has been recognized as a skeptic on the subject of earthquake prediction, but he came away from the Athens conference with mixed feelings. "It's hard to believe it," he said in an interview. "But there seems to be something to this." Kanamori said: "The Greek system depends on a complex 'pattern recognition' by scientists who have studied the data so much that they can recognize subtle changes from sensors scattered around their country. The Greek scientists have built a track record by documenting their prediction through telegrams to various officials in which they have successfully predicted earthquakes…
>
> Most seismologists reject the Greek [VAN] claims because the Athens group has included small quakes in their predictions and anybody can predict small quakes since they happen so often in that region that it would be hard to be wrong. But Kanamori said that if "only predic-

tions of larger quakes, above magnitude 5.0, are considered, the Greek record is impressive. For large events, they seem to have very good data", he said.

Subsequently, Kanamori talks about the possible generation mechanism for the VAN signals when rocks are squeezed and the newspaper notes: "As time goes on, Kanamori believes scientists will be able to narrow their predictions to short-range forecasts".

Kanamori's assessment was indeed prophetic, because over 10 years after the Athens Conference in February 1990, namely in 2001, Varotsos and his colleagues announced their new concept on **natural time** which, as I explain in Sections 18.3 and A.2, achieves this very goal.

The content of the *Los Angeles Times*' article was reprinted in many newspapers in different countries, including Greece. For example, the Greek newspaper *Kathimerini* on 10 October 1990, wrote: "Following the completion of one year after the devastating earthquake in Los Angeles, the newspaper the *Los Angeles Times* on October 7, 1990 published an extensive article on the possibility of earthquake prediction by means of the method of recording electromagnetic signals. Particular reference is made to the VAN method, since as outlined in this article, of all scientists working in the field of electromagnetic signals only one group in Greece has had repeated success in earthquake prediction."

9 Disastrous earthquakes in PIRGOS, 1993: The public warning

9.1 Events prior to the earthquakes

The events leading up to the Pirgos earthquakes in 1993 have some similarities to what happened before the earthquakes that occurred in Killini-Vartholomio in 1988. A summary of the events of 1988, mentioned in Chapter 6, appears in the top time-chart of Figure 9.1 indicated by A. It is in fact Figure 28 from page 346 of the article entitled "Latest aspects on earthquake prediction in Greece, based on Seismic Electric Signals (SES)" (Varotsos and Lazaridou, 1991). This time-chart summarizes the following: On 31 August 1988, we recorded strong preseismic electric signals which were followed on 22 September by a strong earthquake of magnitude 5.6 near Killini. Approximately one week later, on 30 September, there was seismic activity near the island of Zakynthos and after 16 days, on 16 October, a devastating earthquake of magnitude 6.0 destroyed Vartholomio.

Figure 9.2(a) repeats the top time-chart of Figure 9.1, with the addition of arrows on the dates 3 September and 5 October 1988, when Professor Tazieff publicly warned the population through the French media of the upcoming "high risk". The preseismic signals SES are marked with white "columns" in this figure and the solid black "pillars" show the earthquakes. Figure 9.2 (b) shows the facts before the destructive earthquakes in Pirgos on 26 March 1993. In this figure, two public warnings are marked on 23 February and 26 February 1993, which were not issued, upon our request, by Professor Tazieff, as explained below.

Let us now explain what happened in 1993. On 30 January 1993, the VAN group sent a prediction to 22 research institutes abroad (Europe, Japan, USA), with details of a "preseismic series of electrical signals SES [that is SES activity] recorded at the Ioannina (IOA) station.". The first paragraph of this text reports that on 27 January and 29 January 1993 we recorded preseismic electric signals SES at the Ioannina station, and in the attachment

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_9,

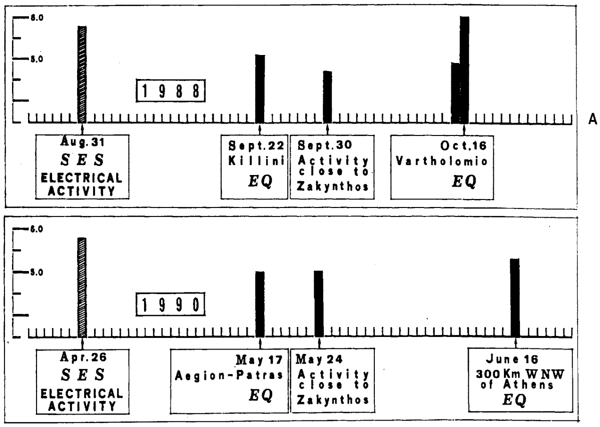


Figure 9.1 The upper part of the figure indicated by (A) is the time-chart in 1988 which shows the data recorded before the destructive earthquakes in Killini-Vartholomio. Taken from Varotsos and Lazaridou (*Tectonophysics*, Volume 188, pages 321–347, 1991).

we give an example of the recording of the signals on 29 January. The second paragraph explains that if we take into account the physical properties of the recorded SES, meaning their polarity, amplitude and direction (see Section 3.5), we estimate that the parameters of the impending seismic activity should follow the same time-chart as the one shown in Figure 28 A of the article by Varotsos and Lazaridou (*Tectonophysics*, Volume 188, pages 321–347, 1991). Recall that Figure 28 A of this article is shown here at the top of Figure 9.1. In other words, we say to the reader of this prediction text that in order to follow the parameters (magnitude, epicentral region and time) of the evolution of the earthquakes in the current phenomenon, it is sufficient to read what was already written in Figure 28 A (that is Figure 9.1 A). This information was sent to the State a few days later for the reasons that will now be explained:

One of the recipients of our prediction was Professor Haroun Tazieff. It was therefore natural to expect that, as this prediction was similar to the one made before the earthquakes in Killini-Vartholomio in 1988 about which he had made public warnings, he would do the same now, because as a specialist he knew very well the upcoming danger. Varotsos contacted him and begged him *not* to do so in order to have enough time to try to persuade the Greek authorities to take countermeasures for the population, after the prediction had been

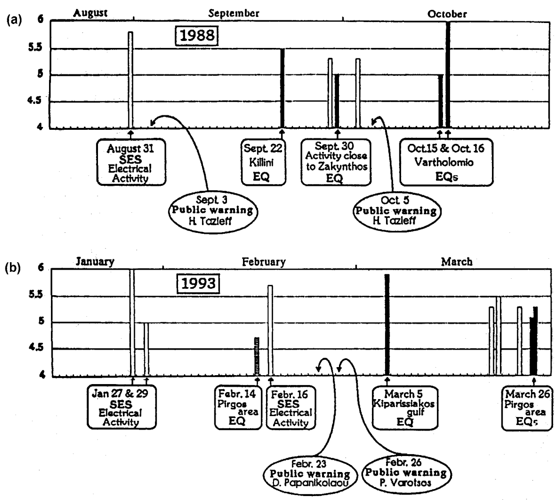


Figure 9.2 (a) The evolution of the facts in 1988; the arrows highlight the dates 3 September and 5 October, when Professor Tazieff issued public warnings. The white "columns" mark the SES and the solid (black) "pillars" the earthquakes. **(b)** Depicts the time-chart of the facts in 1993.

evaluated by a committee of experts. I must say, especially now that he is not alive, that Professor Tazieff explained to Varotsos that his efforts to convince those in charge would fail, both for the reasons he had explained in his book (which had already been released in French and English, see Section 7.2), and from his own experience with politicians when he had served in the French Government as Secretary of the State responsible for Major Risks and Natural Disasters.

It turned out that Professor Tazieff was absolutely right. Although Varotsos persistently tried to persuade the Greek State to set up a committee of experts, he was forced to resign from the committee which had appointed him the Minister of Public Works since the members of the committee were not experts. This is explained in his letter dated 4 February 1993 to the President of the National Committee on Earthquake Prediction, Earthquake Hazard and Earthquake Protection in the first paragraph:

> In repeated letters to the Minister of Public Works and Environment, of which you are not aware, our research team had proposed a committee of experts (both from Greece and abroad) for the prediction of earthquakes with electrical methods. The purpose of the committee would be to express an opinion to the government for taking or not precautionary measures in the event of the recording of significant preseismic electric signals.

The Minister had already appointed a committee to decide on such a serious topic, but none of the members had the scientific expertise to make judgements. In paragraph (b) of his letter Varotsos explains that he encloses all the scientific material "referring to a forthcoming major earthquake activity in Western Greece" that had already been sent on 30 January 1993 to 22 institutes abroad "for an evaluation and then to assess the degree of imminent danger".

After three days, Varotsos received EPPO's response dated 5 February 1993, according to which, in order for the prediction to be submitted to the Committee, Varotsos must send "... the coordinates of the epicenter, the magnitude and the time, along with their uncertainty limits as well as the prediction method and the data to substantiate it".

Varotsos immediately answered on 9 February 1993 stating that "... *all necessary data* ..." of the scientific information were already attached to his letter dated 4 February. In other words, by means of those attached data, Varotsos had already informed the government that the upcoming earthquakes "*may follow the time-chart of Figure 28 A*"; thus anyone seeing that figure (depicted also in the top of Figure 9.1) could read the epicenter, the magnitude and the approximate date when those indicated earthquakes would happen.

After that, Varotsos received no further information from the authorities regarding their decision on whether or not to take countermeasures for the protection of the population. Five days after Varotsos' letter, namely on 14 February, the first moderate earthquakes of magnitude 4.6 to 4.8 Richter occurred in the region of Pirgos. Thus, the time-chart of Figure 9.1A started to be verified, except that the epicenter of these earthquakes was a few tens of kilometers away from the Killini area indicated in the predicted time-chart. So should those responsible, who had received our prediction, act now in view of the expectation of more earthquakes which would eventually (as shown in Figure 9.1A) reach magnitude 6.0, only a few tens of kilometers away. To our great surprise, however, the day after these earthquakes at Pirgos (15 February), the newspaper *Ta Nea* published an article entitled "The Seismologists are not Worried". Similar statements appeared on the same day in many other newspapers, such as *Ethnos*, *Apogeymatini*, *Mesimvrini*. In other words, not only were the fears expressed by Professor Tazieff that "*those responsible will not take precautionary measures to protect the population*" verified, but the situation went in the opposite direction from that envisaged by our time-chart with the seismologists assuring the public that it was just "the usual earthquakes that occur every day and not to be concerned". In addition, we recorded new powerful preseismic signals SES on 16 February. This further confirmed the time-chart of Figure 28 A (that is Figure 9.1A), which we had forwarded to the State, due to the following fact: If we look at Figure 9.2 (a), between the first earthquake of 22 September near Kilini and the second of 30 September, new signals were recorded on September 29. The same had happened here (see Figure 9.2 (b)), because after the earthquake of 14 February, new SES were recorded on 16 February. In view of this situation, Varotsos decided to go to Pirgos, for the following two reasons: first, to inform the population himself, and second to fit one or two VAN stations in the Pirgos area in order to observe more closely, if possible, the evolution of the ongoing phenomenon.

Therefore, on 18 February, we went to Pirgos notifying the Mayor, G. Dimitrakopoulos, of the purpose of our visit. The Mayor organized a press conference for the local media to better inform the population.

Varotsos explained publicly that "*my own view is that the population should know whether there will be an earthquake*", which is the title of an article in the local newspaper *Proini* on 19 February 1993. In order to substantiate this view – since he "*left open the possibility of the occurrence of further earthquakes*", this being distinctly different from the statements of the seismologists – he reminded people what had happened five years previously, before the destructive Killini-Vartholomio earthquakes in 1988 . He said: "*Professor Tazieff had then warned the population about earthquakes based on the VAN predictions. Indeed on September 22, 1988 the first earthquake caused damage to the port of Killini. At that time then a number of people came forward and said that there should be no concern about another big earthquake, in contrast to our team which had alerted the State*" (see newspaper *Patris* on 19 February 1993). This mirrored the current situation, since some seismologists now assured the public "that a destructive earthquake will not occur". Varotsos continued to advise the population as follows: "*On October 16, 1988 our concerns were verified when a devastating earthquake of magnitude 6.0 occurred which flattened several hundreds houses but happily there were no victims. There is no precedent of a magnitude 6.0 earthquake in a densely populated area, where there were no victims. This was* ***because the local population was informed of the expected event and had taken precautionary measures***" (*Proini* on 19 February 1993). And to be more specific about the current case and to avoid panic that could lead people to leave the area, Varotsos said: "*There need be no abandoned areas. But some, who live in dilapidated houses, should go to live in neighbouring houses, as also happened in Vartholomio ... where we did not have to mourn dead people. This is because the population was prepared*" (*Patris* on 19 February 1993).

About a week later, there were intensified fears of an imminent earthquake in Elia (note that Pirgos is the capital of the Elia Prefecture), especially after statements by the then Associate Professor of Tectonics at Athens University, Mr Papanikolaou, who, having in mind the estimate of VAN measurements, expressed the view that impending activity in the region was likely and this could happen before 1 March 1993. See, for example, the newspaper *Eleftherotypia* on 25 February, which reported: "*The VAN team dared yesterday to announce that the new earthquake could reach up to 6 Richter and might cause significant damage... And this time, Mr. Varotsos declined to speak to reporters and the announcement was made by Mr. Papanikolaou, Associate Professor of Geology*." Since by then intense fear had been created that the expected second earthquake would once again occur close to Pirgos, on February 26 (Friday), Varotsos publicly reassured the residents (television news by Terens Kouik on ANT-1) that the expected earthquake would be likely to be located in the sea area and *not near Pirgos*. Actually the following Friday, 5 March, an earthquake of magnitude 5.9 occurred. Its epicenter was initially reported to be close to Oinousses (small islands in the southwestern Peloponnese), giving the impression of a significant deviation from the VAN prediction, but finally it was located in the Kyparissiakos Gulf south of Zakynthos which was pretty much in agreement with the original time-chart of the VAN prediction. This is so, because in Figure 9.1A the second earthquake on 30 September 1988 corresponded to the second earthquake in the ongoing situation shown in Figure 9.2 (b). Almost all of the press dealt with this issue the following day, 6 March 1993.

Over the next two weeks discussions continued in the media. It had become widely known to the population that there was a time-chart of the VAN prediction, as shown in

Figure 9.1A, which was now being gradually verified as indicated in Figure 9.2 (b). But remember that in the time-chart of 1988 there was a continuation of the seismic activity, and 16 days after the second earthquake on 30 September 1988 in the south of the island of Zakynthos, a destructive earthquake occurred in Vartholomio on 16 October 1988. Now in the current situation there had only been two major earthquakes, one on 14 February 1993 near Pirgos and another one on 5 March 1993, in the Kyparissiakos Gulf, as indicated in Figure 9.2 (b).

9.2 Events on the eve of and immediately after the Pirgos main shock

Let us now go back to the original time-chart of Figure 9.1 A and study its details which are better depicted in Figure 9.2 (a). We see that before the third, more destructive, earthquake of 16 October 1988, we had recorded new preseismic signals SES on 3 October, as explained in Chapter 6. Something similar happened in the current case. In particular, on 20, 21 and 24 March 1993, we actually recorded new preseismic signals SES at Ioannina station. Immediately, on 24 March 1993, we addressed a personal letter to the Minister of Public Works and Environment with a copy to the President of the National Earthquake Prediction Committee. On the first page, Varotsos, after recalling the specific time-chart of his letter of 4 February 1993, in which "beyond time, the magnitude and the epicenter of the expected earthquakes were given", explains that this is now verified after the occurrence of the "first significant earthquake of magnitude 4.8 (February 14, 1993) in the Pirgos region" and then "the second earthquake of [about] magnitude 6.0 in the Kyparissiakos Gulf on March 5, 1993".

Subsequently, on the second page, Varotsos writes in the last paragraph: "Our team, Mr. Minister, has again recorded preseismic electric signals (which we analyzed in cooperation with Professor S. Uyeda) for upcoming IMPORTANT [the capitals were in the original letter] seismic activity and therefore the following question is raised: Should we confide our scientific information to the State in accordance with the previous procedure, since it is proven in practice that our information is transmitted to the population CORRUPTED?"

On the same page, Varotsos suggests that the current scientific evidence should be judged by experts who would advise the State on the necessity of taking **specific precautionary measures**. In particular, he wrote:

> We reiterate that we will gladly participate in a panel of experts on preseismic electric signals, which will be able to evaluate appropriately our scientific information (which admittedly has some uncertainty because 14 of the 18 stations of our network are still closed) and to recommend to the State to take specific measures or not. It is therefore obvious that we expect your answer very shortly.

Of course, as always, the VAN team sent the information about the preseismic signals recorded at the Ioannina station on 20, 21 and 24 March to 22 research institutes abroad. The hours passed, but we waited in vain for the Minister's answer, as we shall see below.

To our great surprise, on the morning of 26 March we read in the newspapers that some seismologists did the opposite of what we had expected by reassuring the residents of Pirgos, who had been terrified by successive shocks felt particularly in the town because the epicenter was just below Pirgos, stating "Do not worry, because the phenomenon is usual". See, for example, the articles in the newspapers *Ethnos* and *Ta Nea* of 26 March 1993.

Only a few hours after the release of these newspapers, that is at 13:58 local time on Friday 26 March 1993, the Seismological Institute of the National Observatory of Athens announced the occurrence of a disastrous earthquake of magnitude 5.5 with an epicenter at Pirgos, while the Seismological Institute in Uppsala, Sweden, announced magnitude 5.8. The following day, 27 March 1993, the press all published more or less similar headlines: for example, the front page of the newspaper *Eleftheros Typos* entitled "RAGE and Terror in Pirgos" and subtitled "The residents blame the government, because they took no action" and "1 dead, 20 injured, huge disasters".

On the same day, 27 March, the newspaper *Kathimerini* in a relevant editorial entitled: "State of Emergency in Elia" published the statements of the Director of EPPO who, among other things, said: "*... it had never received any telegram or other notice from the VAN team*", but just above (in the same article) the Professor at the University of Patras, Mr Tselentis, states that "*... on the evening of March 25, I received an official letter from the VAN team, which referred to the fact that the Ioannina station recorded strong signals from the region of Elia*". When the above statement of the Director of EPPO came to Varotsos' attention, he replied with a series of questions to EPPO and to the Ministry of Public Works, as follows (as we read in the same article published in *Kathimerini*):

> Where is the sense of responsibility of EPPO's officials who even today assured ... (for example, see the newspapers *TA NEA* and *ETHNOS*, March 26,1993) the population of Pirgos town "Do not worry, the phenomenon is usual", when they knew since yesterday afternoon (13:53 hours) the content of our urgent and agonising fax and in which our team asked EPPO and the Minister of Public Works to call an urgent meeting of the Committee to evaluate important preseismic VAN signals that were recorded on March 20, 21 and 24 ... The responsibility of the officials is even greater because our fax emphasized that the analysis of these signals for the expected important seismic activity was made in collaboration with the Vice President of the International Union of Geological Sciences, Professor Seiya Uyeda ... It should be recalled that Professor Uyeda just the day before yesterday in his speech (after having studied the signals we recorded on March 20 and 21) at the international conference held in Athens confirmed publicly the accuracy of our predictions.

Following the publication of Varotsos' questions the next day (28 March 1993), EPPO changed its story and the newspaper *Kathimerini* wrote:

> ... Finally, it should be noted that EPPO acknowledged receipt of the warning issued by Professor Panayiotis Varotsos for the Elia Prefecture, despite the fact that on late Friday afternoon they stated that there was no warning.

On the same date *Kathimerini* also published a statement issued by the Seismological Institute of the University of Uppsala, one of the 22 research institutes abroad that had received our prediction. This statement described that "one day before the devastating earthquake, on March 25, the Seismological Institute of Uppsala received the FAX sent by Mr. Varotsos of the University of Athens" and then continued as follows: "This FAX shows that electrical activity was recorded on 20, 21 and 24 March, in the measuring station of Ioannina. Based on these observations Mr. Varotsos predicts a seismic activity, according to his model, which is expected within one to ten days." Subsequently, the statement indicated several additional technical details, and finally concluded: "In our opinion this prediction must be considered successful and very encouraging."

The damage from the earthquake was extensive. For example, in the headline of the newspaper *Eleftherotypia* on 29 March, we read: "Enceladus has not yet calmed in the bowels of Pirgos which now resembles a dead town with 41% of homes judged uninhabitable." The same publication states: "... apart from an 80-year woman, who was killed on Friday afternoon while trying to escape the wrath of the earthquake, there were no other dead people". In other words, *despite the large extent of the damage, human loss was minimal*. Remember that the VAN assessment for the upcoming high risk to Elia reached the local population of Pirgos around mid-February. Subsequently, there was a strong response in the Greek media throughout this period until the occurrence of the devastating earthquake of 26 March, which helped many people to take precautionary measures, thereby minimizing loss of life (see Figure 9.3).

These events attracted the keen interest of foreign media, especially in Japan. Leading newspapers such as *Asahi Shimbun* (which is widely regarded as Japan's most respected daily newspaper with more than 8 million subscribers), devoted extensive articles to these events, and special broadcasts on television made by journalists specializing in science

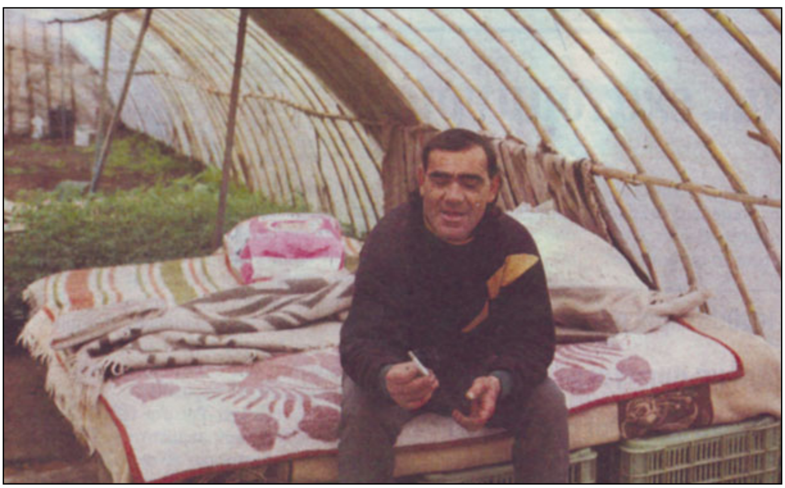


Figure 9.3 Photo from the newspaper *Ta Nea* on 2 March 1993, which shows an example of the precautionary measures taken by the people in Elia. The caption for the photo is: "Waiting for the ... Richter living under glass" and below the photograph, the newspaper writes: "... The farmer is not convinced that there is no risk of a great earthquake and settled in the greenhouse".

10 Third evaluation of VAN, 1992, 1995

The National Research Foundation of the USA (National Science Foundation), as part of its plan to minimize the risk from earthquakes (National Earthquake Hazard Reduction Program) organized an international conference from 14 to 17 June 1992 in Lake Arrowhead, close to Los Angeles, California, entitled "Low-Frequency Electrical Precursors: Fact or Fiction?" Thirty-seven scientists and specialists on the topic were invited to participate. The participants came from different countries (Japan, China, Canada, France, Sweden, Russia, etc., and from Greece Alexopoulos, Varotsos and myself) and from various universities and research institutes in the USA, such as the University of California at Riverside, the University of California at Berkeley, Massachusetts Institute of Technology, University of Texas A & M, NASA, and the U.S. Geological Survey.

In the first paragraph of the recommendations of this conference the following was written:

> Highlights of this workshop included presentation of seismic electric signals from Greece, precursory changes of resistivity in China, a reassessment of the low frequency anomaly at Loma Prieta[1] and identification of geophysical constraints for mechanisms possibly causing precursory signals. Discussions focused on instrumentation, laboratory studies, definition of anomalous signals, mechanisms, and significance of correlations between anomalies and earthquakes.

On the second page of the recommendations it is stated:

> The participants of the workshop identified three regions where supplementary measurements are advisable. It seems that the seismic electric signals observed in Greece are generated in the earth and the apparent correlation with earthquakes is extremely promising. Much discussion was focused on the mechanism causing these signals, however, and the participants concluded that additional measurements were necessary to distinguish between causative mechanisms. The efforts by Varotsos and others to instrument 'sensitive' sites for simultaneous measurements of magnetic field, resistivity, strain, and water level were commended and extension of these methods and others to all of the 'sensitive' sites are strongly encouraged. Most impor-

1 The earthquake on 18 October 1989 south of the San Francisco Bay area in California.

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_10,

> tantly identifying the characteristics of 'sensitive' sites is a critical first step before extending this approach to other regions.

And the recommendations continued as follows:

> The Chinese have clearly recorded a regional decrease in resistivity which is apparently associated with the Tangshan earthquake. Discussion again emphasized that our knowledge of other geophysical phenomena associated with that decrease was very incomplete and supplementary measurements would help us to understand the causative mechanism. Comparison of the resistivity data to other electromagnetic measurements and other geophysical observations at the same sites in China is essential. The participants concluded that additional comparisons of existing data and supplementary measurements at the resistivity sites would be very beneficial to the international community. Extension of the measurements to investigate the depth dependence of the resistivity changes could help identify the cause of the fluctuations.
>
> Finally, the participants concluded that the measurements at Parkfield [an area in California where US scientists have installed a lot of instrumentation for forecasting] should be augmented with monitoring of electric field at ultra low frequencies (ULF) and at extremely low frequencies (ELF) and shallow resistivity using an active system.

The last paragraph identifies the geographic areas where the participants wished to focus their future efforts. The first in importance was recommended to be Greece, the second China and the third the Parkfield experimentation site at the San Andreas Fault.

The findings of this scientific conference in Lake Arrowhead were commented on in several scientific publications in both the USA and Japan.

First, *EOS*, the official journal of the American Geophysical Union, ran an article entitled "Workshop on Low-Frequency Electrical Precursors to Earthquakes" (by St. Park), which explains what was discussed in this conference and what were the conclusions (Vol. 73, No. 46, pages 491–492, November 17, 1992).

The first paragraph of the article summarizes the highlights of the research presented at this conference. The first one refers to the VAN team, namely "*seismic electric signals from Greece*". Also in the first paragraph of the fourth column it was written that "*The participants… concluded that the seismic electric signals observed in Greece are generated in the Earth and the apparent correlation with earthquakes is promising*". Note that it is the *only method* that was described as promising in the outcome of this conference.

Secondly, the issue of the Japanese journal *Kagaku (Science)* of September 1992 carried an article under the title "The Greek method of forecasting earthquakes in the USA" authored by Professor Yukio Fujinawa, who participated in the conference. This two-page article began as follows:

> The electrical phenomena at frequencies lower than 100 kHz is one of the precursory events that are explored in many countries. In particular, the VAN method, based on these phenomena, has successfully predicted earthquakes several times, and has thus attracted the interest of the researchers in this field.
>
> In June this year, a special conference took place in California which focused on these phenomena. Some scientists from Japan attended including Professor Seiya Uyeda and me.
>
> In the USA, where they have conducted a few studies of this kind, they actually detected such

> precursory signals before the Loma Prieta earthquake in California in October 1989. **Almost all the discussions at the Conference were focused on the presentation made by Professor Varotsos on the VAN method**. He was also asked many questions of crucial interest from many researchers who saw the data for the first time, especially from those who have worked in the field of geomagnetism. In response to these questions, Professor Varotsos gave clear explanations for the VAN method, the way in which the "sensitive" locations were selected to record preseismic signals, for the installation of electrodes, and how the relevant useful information is separated from the non-beneficial. The main figures in this research field, namely Professor Ted Madden from MIT, and Professor F. Morrison from the University of California (Berkeley), had completely changed their opinion when the Conference ended, meaning that they had finally formed a positive opinion, compared to the early stages of the Conference when they believed that, whatever had been recorded by the VAN method was merely noise. This fact will have important effects on the applicability of the VAN method in the future.
>
> **The author of this article deepened and enhanced his belief in the reality of the VAN results**, examples of which are shown in the Figures depicted below

Then follow different details, especially on the mechanisms for the generation of the preseismic electric signals.

Three years later, from 10 to 12 October 1995, a conference entitled "Low-frequency Electromagnetic Signals and Resistance Changes Preceding Earthquakes" was held at the University of California, Berkeley.

Instead of describing the events, I present below exact accounts from the experts from the official conclusions of the Conference, most of which were transmitted by a correspondence of the Athens News Agency (Berkeley, USA, 01/11/1995) under the title "Science-Earthquakes":

> A three-day conference was convened at the University of California, Berkeley, between October 10–12 to discuss recent results and assess the strategies of various scientific groups that monitor electromagnetic fields or variations of ground resistivity before earthquakes.
>
> The conference singled out as most promising the results of Professor P. Varotsos and his colleagues in Greece, the work of Professor A. Fraser-Smith and colleagues at Stanford University, and the efforts of a variety of workers in resistivity monitoring.
>
> The Berkeley conference was a follow-up to a larger one held in Lake Arrowhead, California, in 1992, which led to recommendations for complete characterization of measurement system response and noise, including regular checks of system drift and calibration. The Arrowhead conference also recommended the recording of common signals on parallel sensors to differentiate among the normal fluctuations of the natural field, spurious noise and possible precursors. The Berkeley workshop devoted time to a review of the implementation of those recommendations made two years ago.
>
> Among the first issues discussed was the VAN method presented by Varotsos. Questions about the method have centered on the criteria for identifying seismic electric signals (SES) and on the statistical relationship of the SES to a subsequent earthquake. Professor Seiya Uyeda reported on a study of SES signals in the Greek database by a team of Japanese researchers.
>
> Although not intending to address the statistical evaluation of the predictions, both Varotsos

> and Uyeda pointed out that with a database that now included 14 earthquakes with magnitude greater than 5.8 (Athens observatory magnitude), the success rate is considerably higher than had been calculated previously using smaller and far more frequent earthquakes. The most recent results of the VAN method are the 1995 predictions for the magnitude (M6) shock which occurred on May 4 and two disastrous earthquakes on May 13 (M6.6) and June15 (M6.5). The M6.6 occurred in an area where no large earthquakes had occurred in the previous 1000 years. These predictions were a major topic of the workshop review and they have certainly heightened the interest of the U.S. and Japanese monitoring groups.

The conclusions of this Conference at Berkeley were commented on by a number of scientific journals. For instance, the widely-circulated journal *Science* devoted a special article to the VAN method, entitled "Quake prediction tool gains ground," (*Science*, Volume 270, pages 911–912, 1995).

The article is extensive and covers one and a half pages. The first page, depicted in Figure 10.1, presents a map of Greece in which the epicenters of the three major earthquakes in Greece in 1995 predicted by VAN team are shown.

Now I reproduce some excerpts from this article:

> .. Although long disparaged by Greek seismologists, a prediction scheme based on these signals [that means the VAN electrical signals reported in the previous paragraph of the article] is now attracting interest, and some enthusiasm, in Japan and the United States, after the Royal Society of London and the University of California (UC), Berkeley recently held workshops examining it. 'It's bedevilingly intriguing', says Berkeley's Thomas McEvilly ...
>
> Solid-state physicist Panayiotis Varotsos of the University of Athens and his colleagues got into the business in the mid-1980s as a result of laboratory experiments in which they squeezed dry rocks while monitoring their electrical properties. Just before the fracturing, the rock would generate a transient electrical current as crystal imperfections caused a separation of charges. Because earthquakes are much larger versions of rock fractures, Varotsos and his colleagues reasoned they should generate precursory electrical signals in the crust.
>
> Greece has more than its share of earthquakes, making it a good testing ground for the idea. So Varotsos and his physicist colleagues began setting up what amounts to giant voltmeters – wires as long as 3 to 4 kilometers connected to electrodes stuck in the ground – intended to record the changing electrical state of the crust. **And sure enough recorded signals before earthquakes**. Soon, Varotsos (V) and colleagues K. Alexopoulos (A) and K. Nomicos (N) were making public earthquake predictions using the "VAN" method…
>
> 'I can understand why people are complaining about the VAN method,' says seismologist Kanamori of the California Institute of Technology. But when it comes to the rarer, larger quakes, where the odds of succeeding by chance are smaller, Kanamori's 'subjective judgment' is favorable. Because Varotsos has been faxing VAN predictions around the world as they are made, Kanamori has a feel for the correlation between predictions and larger earthquakes. 'In the past, when I received several faxes in a relatively short time', says Kanamori, 'there were almost always large events in Greece. That was the case when a series of three large quakes – magnitude 5.2, 6.5 and 6.4 – struck Greece last May and June'…
>
> 'This year Varotsos sent out three predictions for big earthquakes', notes Stanford's Fraser-Smith, 'and there were three big earthquakes. There have been no predictions since.'…

RESEARCH NEWS

Quake Prediction Tool Gains Ground

Seismologists don't fully understand a controversial Greek prediction scheme, and some think its "successes" are just luck. But it is enticing many researchers

Each time researchers have flirted with a possible scheme for predicting earthquakes, they have ended up regretting it when the scheme failed to live up to expectations. Now they are being tempted again. This time, the attraction is strange electrical signals in the ground that, according to proponents, heralded three large earthquakes in a row this spring in Greece. And, in spite of those past disappointments, some researchers are wondering whether this might be the real thing.

Although long disparaged by Greek seismologists, a prediction scheme based on those signals is now attracting interest, and some enthusiasm, in Japan and the United States, after the Royal Society of London and the University of California (UC), Berkeley, recently held workshops examining it. "It's bedevilingly intriguing," says Berkeley's Thomas McEvilly.

Most seismologists are still skeptical, arguing that the apparently successful predictions are just lucky guesses, aided by the vagueness of the predictions and the abundance of earthquakes in Greece. "But you just keep getting sucked back toward the apparent—though fuzzy—successes, especially those in the last year," says McEvilly. Hiroo Kanamori of the California Institute of Technology, a prominent seismologist and a longtime skeptic of simplistic approaches to earthquake prediction, adds that the statistical criticism "is probably valid. But that doesn't mean the whole thing is invalid," he says. "My feeling is there is something to it."

Geophysicists who study the electromagnetic properties of the crust tend to think so too, in part because they have been working along the same lines. For decades Chinese researchers have been searching for electrical precursors that might signal changes in fluid flow or rock properties leading up to an earthquake. And in the United States, researchers have been looking for magnetic precursors, especially since Antony Fraser-Smith of Stanford University detected a striking burst of magnetic noise just before the Loma Prieta earthquake of 1989 in California (*Science*, 22 December 1989, p. 1562).

Solid-state physicist Panayiotis Varotsos of the University of Athens and his colleagues got into the business in the mid-1980s as a result of laboratory experiments in which they squeezed dry rocks while monitoring their electrical properties. Just before fracturing, the rock would generate a transient electrical current as crystal imperfections caused a separation of charges. Because earthquakes are much larger versions of rock fractures, Varotsos and his colleagues reasoned, they should generate precursory electrical signals in the crust.

Greece has more than its share of earthquakes, making it a good testing ground for the idea. So Varotsos and his physicist colleagues began setting up what amount to giant voltmeters—wires as long as 3 to 4 kilometers connected to electrodes stuck in the ground—intended to record the changing electrical state of the crust. And sure enough, they recorded signals before earthquakes. Soon, Varotsos (V) and colleagues K. Alexopoulos (A) and K. Nomicos (N) were making public earthquake predictions using the "VAN" method.

Threesome foretold? VAN came close to predicting three quakes, including a 15 June event in southern Greece *(photo)*.

Few seismologists were seduced by the VAN group's early claims that they were successfully predicting quakes. "The experiment was not convincing, say 10 years ago, that Varotsos was measuring anything but electrode noise or some other problem with the sensors," says electrical geophysicist Stephen Park of UC Riverside. But since then, say Park and others, Varotsos has altered his equipment to compensate for instrumental noise and the crustal currents induced by fluctuations in Earth's own magnetic field. "Now we're convinced that it is a signal from the Earth," says Park.

That still leaves the question of whether these signals, dubbed "seismic electric signals," or SES, actually have anything to do with earthquakes. Varotsos believes they do, although he notes that the connection isn't simple. He has learned that SES aren't always detected at the location of an impending earthquake but often are recorded at distances of up to 100 kilometers and more. The reason, he says, is that the current has to reach the surface by way of conductive channels in the crust, which may carry it long distances.

Park and other geophysicists think such long-distance transmission is unlikely, because it would require too much energy at the source. And most geophysicists are skeptical of Varotsos's belief that crustal rock on the verge of fracturing generates current. Instead, speculates Kanamori, the signals might be generated as water and gas surge through the crust, triggering electrical changes and other precursors over a wide area and weakening a major fault until it ruptures.

But whatever their genesis, Varotsos converts the signals into a prediction based on the distribution of sites detecting them, the number of signals, and their amplitudes. And the results, Varotsos told *Science*, have been consistently successful. In the past 9 years, he says, 14 earthquakes of magnitude 5.8 or larger have struck Greece, three of which fell outside his network. Of the remaining 11, 10 were predicted weeks in advance, he says; only one prediction failed, and there were one or two false alarms.

Park sees it a little differently. When he and Richard Aceves and statistician David Strauss of UC Riverside include smaller, more abundant quakes in the magnitude range covered by VAN, the picture looks less impressive. "Varotsos has only issued predictions for 10% of the earthquakes that have actually occurred," he says. But of the predictions issued, "he's had a success rate of about 65 to 70%. Our results have shown it's very unlikely this could be produced by random chance. To me, that says that this is a physical phenomenon worth studying."

Seismologist David Jackson of UC Los Angeles disagrees. "I think [VAN] has gotten

SCIENCE • VOL. 270 • 10 NOVEMBER 1995 911

Figure 10.1 The first page of the article in the journal *Science* (Volume 270, pages 911–912, 1995), entitled "Quake prediction tool gains ground" that focuses on the VAN research. On the map of Greece, three solid dots mark the epicentral locations of the three major earthquakes in 1995 for which the VAN team issued successful predictions.

> Fraser-Smith and colleagues in California are now mounting a study of the SES phenomenon there. Likewise, Seiya Uyeda of Tokai University will be expanding his electrical network in Japan, which he and other researchers set up in recent years to emulate the Greek system ...

On 21 October 1995, the magazine *Science News* (Volume 148, page 260), wrote a specific article about the VAN method entitled "Electric signals may herald earthquakes" . Furthermore, the day after Varotsos' presentation on the first day of the Conference at Berkeley, there was widespread publicity from the mass media. For example, on 11 October 1995, the *San Francisco Examiner*, referring to Varotsos' presentation, ran an article entitled "Mysterious signals that precede quakes have scientists listening".

11 The United Nations recommendation on VAN, 1994

In the "International Decade for Natural Disaster Reduction", a World Conference on Natural Disasters Reduction took place in the city of Yokohama, Japan, 23–27 May 1994. It was organized by the United Nations (see Figure 11.1) and nearly 2000 representatives from 150 countries took part.

Note that ultimately the VAN team did not attend this conference, for reasons discussed at the conference and which will become obvious below.

The International Council of Scientific Unions (ICSU) had appointed a Special Committee (SC) for the "International Decade for Natural Disasters Reduction" (IDNDR). This special committee, named by the corresponding initials ***SC-IDNDR***, met at the aforementioned World Conference and prepared an official report

On page 2 of this report, details are given why Varotsos was absent from the conference, as follows:

> The striking reason why Professor Varotsos found it essential to cancel his attendance at the World Conference was his detection of electrical signals, beginning on 3 May, of a type indicated by his experience as making very likely the occurrence of more than one major earthquake in Greece during (or very close to) the week of the Conference. Besides having informed SC-IDNDR on 10 May of this reason for his non-attendance, he issued on 14 May an official warning to the Greek Government and communicated it also to leading institutions active in seismic research (which included, for example, MIT, Caltech and Stanford).
>
> Against that background, the actual incidence of two magnitude 6 earthquakes in Greece on 23 May (at 06:46 GMT) and on 24 May (at 02:05 GMT) must be seen as a sensational (yet not isolated) instance of the method's predictive power. **Accordingly, this was reported on 27 May to the meeting of the United Nations Scientific and Technical Committee, which fully accepted the need to pay increased attention to the potential of Professor Varotsos's methods** (see Part 2 for further details).

The two earthquakes mentioned above in the report were: first, an earthquake of magnitude 6.1 at 09:46 local time on 23 May 1994 centered in the sea north of Crete, between Rethymnon and Heraklion and which was also felt in Athens, Peloponnese, Cyprus, etc;

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_11,

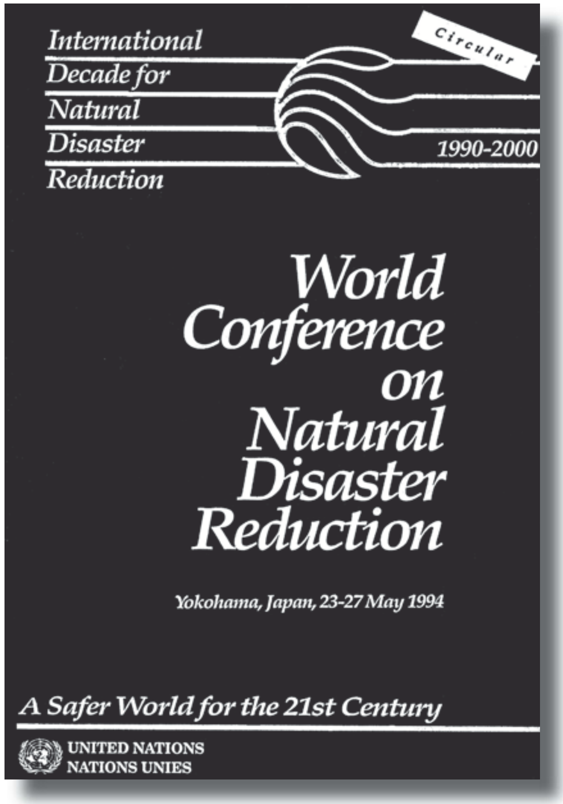


Figure 11.1 The circular for the United Nations World Conference on Natural Disaster Reduction held in Yokohama, Japan, 23–27 May 1994.

second, an earthquake of magnitude 6.1 at 05:05 local time on 24 May 1994 in the Aegean sea between Chios and Lesvos, which was also felt in Athens.

Part 2 of the Report, which constitutes a United Nations recommendation to the member states, refers to the VAN method and begins:

> ... Measurements of the passive type are found valuable for Short Term Prediction (a week to one month ahead); these employ no external power source and are based on determining electric field strengths due to natural processes from measured point-to-point potential differences (but with fields of magnetospheric origin eliminated). This technique was developed in Greece over the past decade; also, Japanese and U.S scientists have recently participated in the de-

> velopments. Very briefly, sudden changes in the electrical field strengths are found to precede major earthquakes in closely related locations by periods of a week to a month.

On page 7 the report states that:

> ... The far more ambitious goal of Short Term Prediction was viewed by the Special Committee at all its early Meetings as an objective which it would be unrealistic to try to achieve during the present decade. The long history of failure of a succession of plausible methods had contributed to form this pessimistic view... Now at last, however, SC-IDNDR recognizes a realistic hope that the natural sciences may make one further vital contribution to IDNDR by developing during the 1990s a practical method of Short Term Prediction of major earthquakes by passive electrical measurements. In such a development, of course, the primary role of the Special Committee itself would be to make known to the international Natural Disaster Reduction community the promise of these methods. At the same time, an important secondary role would be to encourage those responsible for public awareness programmes and emergency response planning to find the optimum ways of using reliable Short Term Prediction data to achieve in a cost-effective manner the greatest mitigation of earthquake disasters.

On page 8 the report states that this approach, "based on passive measurements of electric field strengths was initiated by a group of three Greek scientists – P. Varotsos, K. Alexopoulos and K. Nomicos – which has become known as the VAN group from the initial letters of their surnames". Then the experimental results to date in Greece are described, stating that "practically all earthquakes with magnitude greater than 5.0 occurring in Greece … have been preceded by characteristic, very sudden changes in the electrical field recorded by closely related stations". In addition, the report includes on page 9 the positive results for the VAN method presented at the Conference by the Japanese scientists. Finally, on the same page it is stated that "Inevitably, members of the Special Committee feel a strong compulsion as scientists to enquire about the mechanisms underlying those precursor phenomena which have been identified by the VAN group and their Japanese colleagues… At present, however, it appears that there still exist two alternative possible mechanisms for these effects, between which it remains uncertain which is the dominant one". The report summarizes first the generation mechanism suggested by Varotsos and Alexopoulos (see Section 2.1), and then turns to the alternative mechanism proposed by other workers that could also explain well the generation of these signals.

On the last page of the report (page 10), the UN scientific committee concludes:

> …None of these uncertainties about mechanisms can obscure the clear importance for Natural Disaster Reduction of those discoveries regarding seismic prediction by passive electrical measurements which have been pioneered by the VAN group… One of the Special Committee's functions within the International Decade for Natural Disaster Reduction is to draw the attention of the general IDNDR community towards any new possibility that a specialized scientific development may be in progress which, if taken very widely into consideration, may make a truly significant contribution to Natural Disasters Reduction.
>
> Simply because sound developments in Short Term Prediction of major earthquakes could – if they were powerfully associated with new public-awareness programmes and cost-effective emergency-response plans – assist substantially in mitigation of earthquake disasters, **we view the international work on seismic prediction by passive electrical measurements as now**

> **needing to be massively accelerated** (rather than allowed to proceed at a pace characteristic of normal evaluation processes for scientific developments). **We put forward this recommendation as one which could offer a chance of bringing very real benefits to populations under threat before the end of the decade.**

This United Nations' recommendation attracted a great deal of attention from the mass media, both abroad and in Greece. For example, an article in *Le Figaro* of 24 May 1994 entitled "Earthquake prediction: The VAN method is champion", subtitled "From a Conference in Japan on Natural Disasters", said:

> The prediction of earthquakes with electrical measurements, pioneered by the Greeks, may assist substantially in the mitigation of earthquakes disasters, says an official report of the United Nations Special Committee within the International Decade for Natural Disaster Reduction.

The newspaper carried also a photo and interview with Professor Haroun Tazieff, who for a decade had supported the successful results of the Greek method.

In later reviews and articles, many leading newspapers referred to this fact. For example, in Japan on 6 December 1994 *Asahi Shimbun* with a circulation of 8 million per day published a detailed front-page article by a journalist sent especially to Greece, describing the new developments of the VAN method.

In Greece, the newspaper *Kathimerini* published an article on 11 December 1994, entitled: "The VAN method persuaded the United Nations but not the Greeks" and subtitled "The recommendation of the United Nations has resulted in leading international media turning their attention to Greece, expecting to see the effectiveness of the VAN method during the next major earthquake in our country", Nevertheless, as stated in the article: "*While the international organization* [The United Nations] *recommends that all countries reap the benefits of the system, the National Telecommunications Company keeps closed the telephone lines of the VAN network*".

After the publication of the recommendation of the Special Scientific Committee of the United Nations, in 1995 the Greek Ministry of Education established – from a proposal by the University of Athens – the "Research University Institute on the Physics of Solid Earth". This Research Institute, which is of postgraduate level, is a cooperation between the Physics Departments of the Universities of Athens and Ioannina. Since then, all research activities related to VAN are conducted in this Institute, including the operation of the VAN telemetric network comprising nine field stations (shown in Figure 3.2).

12 VAN evaluations, 1995, 1996

12.1 The International Meeting at the Royal Society of London, 1995

On 11–12 May 1995, an international conference entitled "A Critical Review of VAN – Earthquake Prediction from Seismic Electric Signals" was held in the halls of the Royal Society of London. This conference was organized jointly by the International Council of Scientific Unions (ICSU) and the Royal Society of London. Besides the representatives of these two scientific bodies, 38 scientists from nine different countries were invited and participated. The appointed Chairman of the conference was Sir James Lighthill, in his capacity as Chairman of the Special Committee of the United Nations for the "International Decade for Natural Disaster Reduction 1990–1999" (this special committee is named by the corresponding initials SC-IDNDR, as mentioned in Chapter 11).

The conference concluded on Friday 12 May 1995. The following day, Saturday, 13 May, the largest earthquake of the decade, of magnitude 6.6, occurred in Greece in the Grevena-Kozani region (see Chapter 14). On Monday 15 May, the Chairman of the Conference, in response to questions from journalists of the BBC in London, said:

> In recent years we have had significant results in terms of storms and hurricanes, flooding rivers, droughts and volcanic eruptions. In all these cases it is important to have reliable and valid predictions. Recently we decided that it was important to look at the VAN method of earthquake prediction and after a year of study we felt it was necessary to hold a closed meeting, by invitation only, of experts and supporters of VAN and for people who have doubts about its effectiveness to hear the arguments for and against.

Asked if the meeting resulted in concrete conclusions, the eminent professor replied:

> I am not willing to talk now about the findings. Currently I am writing a report of the conclusions of the meeting in which we also proceed to specific recommendations, but we were all very impressed that this great earthquake in Greece on May 13, a day after the meeting, had been clearly predicted by the VAN team. And this will certainly be significant in terms of the

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_12,

> findings. I know you want a specific answer but you must understand that the President must be neutral and you will appreciate why at the moment my answer is unclear. However, the conclusions of the meeting will be published soon.

The proceedings of this two-day conference were published a few months later (early 1996) by World Scientific. The cover of this volume is shown in Figure 12.1.

In the final article of the proceedings, the Chairman, Professor Sir James Lighthill, writes:

> This, the book's last paper, is partly based on remarks from the chair that concluded the London review meeting of 11–12 May 1995, but it takes into account too all the texts printed above as they were finalized by authors during the ensuing four months. In these texts, of course, the earthquakes occurring after the meeting (on 13 May in northern Greece and on 15 June in Egion, which were the two largest in Greece for over a decade) are carefully related to the

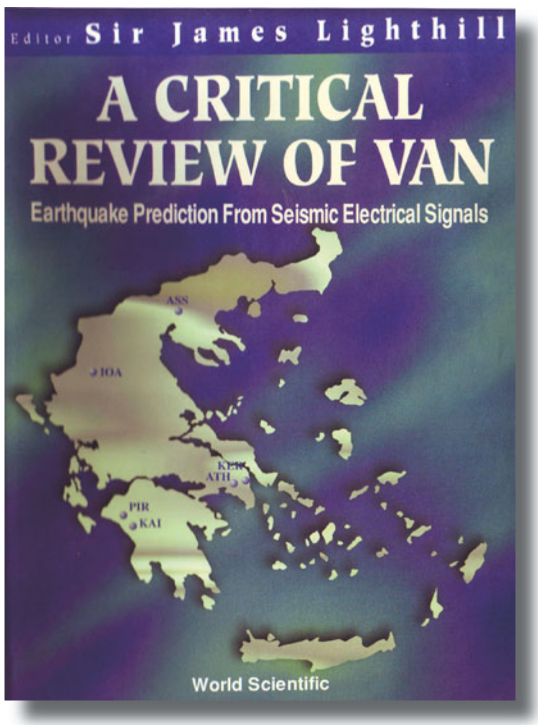


Figure 12.1 The cover of the Proceedings of the Conference at the Royal Society of London in 1995 entitled "A Critical Review of VAN: Earthquake Prediction from Seismic Electric Signals" published by *World Scientific* (Editor: Sir James Lighthill).

corresponding VAN predictions (those received by myself, for example – along with other interested scientists – on 2 May and on 20 May 1995). It is noteworthy that the distinguished seismologist Professor H. Kanamori was influenced partly by these events, as well as by the proceedings of the review meeting (which he had attended in an initially neutral spirit) to give the views he has expressed above in [the preceding article entitled]: "A seismologist's look at VAN"; suggesting that for the larger earthquakes in Greece the VAN group appears to have usefully identified SES precursors.

I return later (in Chapters 13, 14 and 15) to the exact opinions expressed by Professor Kanamori for each of the forecasts for the three large earthquakes in Greece during 1995.

The conference was opened, at the invitation of the President, by the representative of the International Union of Geological Sciences (IUGS), Professor Seiya Uyeda, as follows:

> In the 1970s optimism prevailed in the geoscientific community that successful earthquake prediction was in sight. The gap strategy, Haicheng prediction [see Section 23.3], and the dilatancy model, among others, contributed to that optimism. However, subsequent events yielded only discouraging results, so that the present consensus now appears to be that earthquake prediction, in particular short-term prediction, is still beyond the foreseeable future. Some theoretical seismologists even believe that earthquake prediction would be impossible in principle because of the intrinsic chaotic nature of the fracture process. [At this point two papers by the theoretical seismologists R. Geller are cited to which we will return in Section 12.2]. However, there is an outstanding exception to the general pessimism, which is the success of the VAN method in Greece. The VAN method is unique in that it has been successfully predicting earthquakes for more than a decade. Naturally, the VAN method has been highly controversial. Some of the criticism and confusion, however, seems to be rooted in misunderstandings. It is the intention of this paper to provide a general introduction to the VAN method and try remove misunderstanding.

Then in his article, Professor Uyeda, after first noting that those who claim that "*VAN success can be achieved by chance…, their arguments are not without serious errors*", summarizes his own estimate for all major earthquakes that have occurred in Greece since 1 January 1984 (see Figure 12.2) which leads to the following conclusions:

> ... These results seem to decisively rule out the necessity of any statistical discussion in evaluating the validity of the precursory nature of SES... The precursory nature of SES to earthquakes is best revealed for larger earthquakes of magnitudes larger than 5.5, by high scores without need of any statistical treatment. Since no particular reason is apparent why the method should not work in other parts of the world, it is advisable and urgent that the method be applied to other seismic regions of the world to save as many lives, as possible from seismic hazard …

In the proceedings of this conference, 24 articles were included by various participating research groups. Of these, only three articles (authored by R. Geller, M. Wyss, and F. Mulargia & P. Gasperini) were critical of the VAN method. The remaining 21 articles were authored by eminent researchers from 34 countries across Europe, USA and Japan, among which were: Professors J. Lighthill and S. Uyeda; the Director of the Seismological Laboratory of the California Institute of Technology (CalTech) Professor H. Kanamori; the Director of the Seismological Institute in Uppsala Professor Ota Kulhanek; the well-known

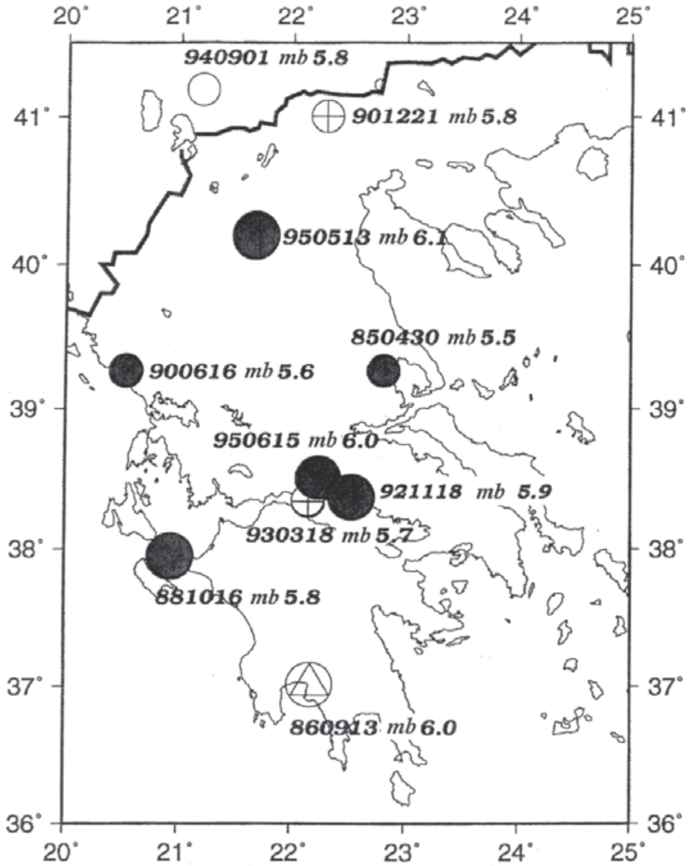


Figure 12.2 The results of the VAN method evaluated by Professor Seiya Uyeda and presented in his introductory speech at the international conference at the Royal Society of London in 1995. All earthquakes occurring with a magnitude greater than 5.5 that occurred during the period 1984–1995 (from the list of the U.S. Geological Service) are shown. Solid circles: earthquakes predicted successfully. Circle with triangle: the earthquake was predicted but not successfully. Empty circle: no forecast was sent because the epicenter was outside Greece. Taken from the proceedings of the conference published by *World Scientific* (Editor: Sir James Lighthill).

Figure 12.3 A photo from the opening of the international conference at the Royal Society of London early in the morning of 11 May 1995: The Chairman, Sir James Lighthill (center), invites Professor Uyeda (right) to deliver his introductory lecture on the VAN method.

Russian Professor Keilis-Borok; etc. A photo from the opening of that conference, and in particular when the Chairman Sir James Lighthill invited Professor Seiya Uyeda to start his introductory talk on VAN, is given in Figure 12.3.

I strongly recommend the reading of Section 14.2. This features statements to the BBC by some of these eminent researchers on 15 May when they were asked if they knew the forecast for the 6.6 earthquake that occurred in Greece on 13 May.

12.2 Special issue of *Geophysical Research Letters* (American Geophysical Union) entitled "Debate on VAN", 1996

Some seismologists claim that the high success (and alarm) rate of the VAN predictions could be attributed to chance. Two of them, the Italians Mulargia and Gasperini, published the allegation in 1992, but soon after, four other research groups (namely the Russians Shnirman and colleagues in 1993, and the Japanese Hamada in 1993, Takayama in 1993, and Nishizawa and colleagues in 1994), showed that this claim was unfounded. For example, the conclusion of the distinguished Professor Hamada, who analyzed about three years' of VAN data, was (see page 208 of *Tectonophysics*, Volume 224, 1993): "... The dramatic increase in success rate from 6.6% to 50% when increasing the magnitude threshold of the earthquakes [that are taken into account in the calculation], from 4.0 to 5.0, suggests the existence of a physical relationship between the SES signal and subsequent earthquakes."

By the same argument, as we saw above in Section 12.1, Professor Uyeda (who studied 15-year VAN data for earthquakes with magnitudes larger than 5.5) in his opening speech at the Royal Society Meeting of London in 1995, as well as Professor H. Kanamori, speaking in the journal *Science* (Chapter 10), ruled out any possibility of attributing the high success rate of VAN to chance.

In 1993, R. Geller, one of the editors of the journal *Geophysical Research Letter*s of the American Geophysical Union, proposed to Varotsos to participate in an open debate on VAN, to answer critics who believed the claim that the success of VAN could be attributed to chance, and this would appear in a special issue, entitled "Debate on VAN" of that prestigious journal. Geller was widely known in the scientific community as a strong opponent of any effort to predict earthquakes since it was his belief that earthquake prediction is impossible, and therefore any success towards this goal should be attributed to chance. Despite the fact that the Editor of the debate would not be neutral, Varotsos accepted the challenge by agreeing in advance that, first, Geller could choose the critics he wished and,

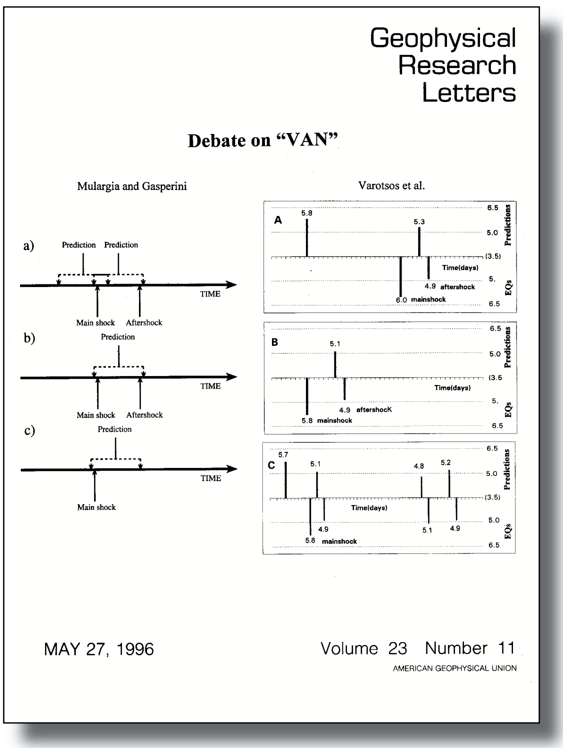


Figure 12.4 The cover of the special issue of the journal *Geophysical Research Letters* (Volume 23, No. 11) of 27 May 1995, entitled "Debate on VAN". Copyright (1999), American Geophysical Union. Reproduced by permission of American Geophysical Union.

second, both the critics' texts and Varotsos' answers should be immediately published as such, meaning without any further modification from either side. Although the duration of this debate was estimated to last for about six months, it finally took almost three years and was published on 27 May 1996 (Volume 23, No. 11; see Figure 12.4).

The long delay in the publication of this issue was due to fact that Geller repeatedly violated the second point of the above-mentioned agreement. In particular, when Geller read Varotsos' answers to the articles submitted by the VAN critics, instead of being immediately sent for publication as expressly agreed, he allowed critics to change their arguments post debate. Then Varotsos had to write **new** responses, since his previous answers were related to arguments in the first texts of the critics, which Geller had allowed them to change. Keep in mind that every "round" of that debate, namely presentation of new claims from critics and thus new responses from VAN, lasted several months. Unfortunately, this was repeated more than four times for some articles. This situation, nearly three years after the start of the debate, forced Varotsos to write an open letter to the members of the Editorial Committees of the Journals of the American Geophysical Union, explaining what was happening and asking them to intervene to stop the tug of war. Only after sending the letter did the tug of war stop, which made it possible for the publication of the debate issue.

To explain a common argument used by critics to attribute the VAN successes to chance, I must first explain in simple words the law of *Gutenberg* and *Richter* in seismology. The law says that upon lowering the magnitude of the earthquakes, their population increases too much. In particular, when the magnitude threshold drops one unit, about 10 times more earthquakes are measured. (This law should not be confused with the fact that when increasing the earthquake magnitude by one unit, the energy of the earthquake increases about 31.6 times.) This law was found experimentally in 1954 by two American professors (Gutenberg and Richter) who could offer no explanation. An explanation was found in 2006, which was published in *Physical Review E*, (Varotsos et al., *Physical Review E* Volume 74, 021123). Specifically, Varotsos and his colleagues, using as a basis a new concept of time termed "natural time" (explained in Chapter 18), showed that the Gutenberg-Richter law could be explained by a fundamental principle of physics, namely the Maximum Entropy Principle.

Let us take a specific example: The Gutenberg-Richter law says that the number of earthquakes with magnitudes above 4.0 is about ten times larger than the number of earthquakes with magnitudes above 5.0. A second example (which we will use below) is that the number of the earthquakes with magnitudes larger than 4.3 is about seven times more than that of the earthquakes with magnitudes above 5.0. Let us see what the VAN group contends and what critics said in the "Debate on VAN".

The VAN group says: "Suppose that our goal is to predict earthquakes with magnitudes of 5.0 or greater. The experimental error in determining the magnitude is at the most 0.7. (For the reader to understand the main source of this "error", remember that even after the earthquake the figures communicated by different seismological institutes do not match. For example, see Section 3.6, and the case of the earthquake that occurred on 26 July 2001 in the Aegean Sea (Chapter 19): the Athens Observatory claimed the magnitude was 5.7, while the U.S. Geological Survey said 6.5). So if the predicted magnitude of an earthquake is equal to 5, and the earthquake actually occurs (exactly in the predicted epicentral region within the expected time) its magnitude will be deemed to be 4.3. This should not be regarded as a failure in view of the above experimental error. Of course, since the objective was earthquakes of magnitudes 5.0 or greater, the percentage of those earthquakes that are successfully predicted – which is termed the alarm rate – will be calculated after dividing how many of these earthquakes predicted in all the earthquakes occurring with a magnitude of 5.0 or greater. However, critics demand that when the VAN aims to predict earthquakes with a magnitude over 5.0, predictions must be provided for all earthquakes above 4.3. Since the number of the latter, as explained above, is seven times higher, this erroneous claim eventually leads to a decrease in the "alarm" rate" from 100% to about 23% or so (and using this claim they attribute the VAN successes to chance).

In short, in the debate Varotsos and his co-workers showed that the claims of VAN critics, in addition to the above false argument, violate five fundamental principles. Moreover, Varotsos and his co-workers proved that the allegations of the VAN critics are wrong by means of the following simple argument: Assume that we have discovered an "ideal" method of earthquake prediction, namely a method that is able to predict **all** earthquakes over a magnitude. Applying then the claims of critics to this "ideal" method, Varotsos and his co-workers showed explicitly that these claims would reject even that "ideal" method!

Example: Let us take an extreme example of an "ideal" method to work out just what the VAN critics say. Assume that it has been agreed in advance to issue predictions **only** if the method estimates that the magnitude of an impending earthquake is equal to 5.0 or greater. Also suppose that, after a considerable time, the method sent a total of 11 predictions which were all successful in all aspects, namely the determination of the epicenter, magnitude and the time of the earthquakes. Of these 11 predictions, let us assume for simplicity that 10 actually correspond to earthquakes with magnitudes of 5.0 or greater, but one of them corresponds to an earthquake where the actual magnitude was lower, for example 4.3 (due to the experimental error mentioned above). To further simplify the problem, suppose that the whole period under study experiences only 10 earthquakes with magnitudes equal to or greater than 5.0. Let us now see how Varotsos and his colleagues evaluate these specific results: "The 11 forecasts we sent were all successful; moreover, since among them are the 10 successful predictions for the 10 earthquakes with magnitudes 5.0 or greater; the "alarm" rate is 10/10, that is 100%. On the other hand, critics claim the following: 'During the study period 10 earthquakes occurred with magnitudes of 5.0 or greater, but the number of the smaller earthquakes with magnitudes 4.3 or greater is seven times higher, namely 70 earthquakes. So of those 70 events, a total of only 11 predictions were issued, therefore the "alarm" rate is 11/70, or approximately 16%, which could be attributed to chance.' This way, they reject even this "ideal" method of forecasting. In other words, in their calculation, the VAN critics 'forget' the prior agreement, which demanded that the method should send predictions **only if** it estimates that the magnitude of the forthcoming earthquake is 5.0 or greater.

In this debate, 22 articles were published by other research groups. Varotsos and his colleagues answered all the claims raised by VAN critics, point by point.

13 Earthquake at Chalkidiki, 1995: The success of the prediction

At 03:34 am on 4 May 1995, an earthquake of magnitude 6.0 occurred in Arnea on the Chalkidiki (Halkidiki) peninsula. It was felt throughout northern Greece and particularly alarmed the residents of Thessaloniki, as reported by the newspapers. Much smaller shocks had started early in the afternoon the previous day, that is 3 May.

Kathimerini on 5 May 1995 wrote: "The shocks had epicenters in the region of Arnea and were felt in Thessaloniki and the surrounding prefectures, causing only material damage, but 'forcing' residents to stay overnight in the countryside ... In Poligiro, Arnea, Olympiad, and Ierissos, and in many villages of the area terrified residents spent the night outdoors or in their cars."

This earthquake attracted the interest of almost all the media. Some newspapers even noted with emphasis the great risk in Chalkidiki, as well as in the surrounding region. For example, in the newspaper *Ethnos* on 5 May 1995, we read: "**A miracle saved Arnea and the surrounding villages in Chalkidiki from total destruction**... The minimal damage is miraculous considering the fact that the seismic activity occurred in a fault only a few dozen meters from residential areas" and then come statements by a renowned professor of seismology, who said: "Such an earthquake devastated Kalamata" (in 1986, see Section 5.2) and then added: "A possible shift in the epicenter either to the great fault Ierissos or to the town of Arnea would be very dangerous, because it could result in a literally devastating earthquake."

A central issue, also in the newspapers, was the recognition by the government that the VAN team had issued an early warning of this earthquake. (Recall that such recognition also happened in the case of the 6.1 Richter earthquake in the central Aegean in 1986, which had particularly alarmed residents of Athens, as described in Section 5.1.) For example, the newspaper *Kathimerini* on 5 May 1995 under the subtitle: "The VAN team had informed the government about the earthquake in Chalkidiki" said: "For the first time the leadership of the Ministry officially recognized the VAN team's prediction about yesterday's earthquakes in Chalkidiki". The Deputy Minister, Mr. Geitonas said yesterday that:

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_13,

> We were informed by Mr. Varotsos of the impending seismic activity in the region in which the phenomenon occurred. Subsequently, the Earthquake Planning and Protection Organization (EPPO) was informed and has taken all the appropriate measures. On April 6, about a month ago, Professor of Physics at the University, Mr. P. Varotsos, informed the Ministry of Public Works and Environment as well as EPPO of the upcoming earthquake in the region of Chalkidiki, of magnitude 5.8.

Another example is the newspaper *Ta Nea* published on 5 May 1995, with a heading "VAN had predicted" and sub-titled "Mr. Geitonas confirmed that on 6 April, Varotsos sent information about the earthquake", and further noted: "*A month ago, namely on April 6, the Ministry knew about yesterday's earthquake in Chalkidiki, since the VAN team had alerted it with a relevant prediction as it was announced yesterday by the Deputy Minister, Mr. Geitonas and by a statement of the EPPO*".

Also, this newspaper emphasized that: "*The Deputy Minister of Public Works and Environment said that the State was on alert because of the warning*."

I now describe the exact details of the prediction. On 6 April 1995, Varotsos sent a letter to the Ministry along with an attached document reproduced in page 59 of the proceedings of the Royal Society meeting (see Figure 12.1) which described the details of the predicted earthquake.

The prediction text is in English, because it was going to be sent the next day (as written in the cover letter to the Ministry) to several institutes in Europe, USA and Japan. (For ethical reasons, we usually first notify the State and then the foreign research institutes, except in special cases such as that before the earthquakes in Pirgos as explained in Section 9.1.) This text describes how the VAN station located near Thessaloniki (meaning the ASS station near Lagada, see Figure 3.2) – which was in fact the only VAN station operating near Thessaloniki – recorded a series of preseismic electrical signals SES (that is, an SES activity).

Based on these SES signals (see Figure 13.1), all the parameters (magnitude, epicentral area and time) of the forthcoming strong seismic activity were assessed as follows: As to the epicentral region and the magnitude, if the earthquake were to occur very near Thessaloniki (i.e., only a few tens of kilometers away from the ASS station), the magnitude Ms (ATH), based on the scale used by the Institute of Seismological Observatory of Athens, would be about 5.2. But at larger epicentral distances (that is in the south, and near to the peninsula of Chalkidiki) the magnitude would be larger, almost 5.8. It was also clarified in the text that a better assessment of the epicenter was not possible, because the other VAN stations near Thessaloniki were still not operating. Regarding the timing of the expected seismic activity, the prediction text referred to two time-charts of our earlier work, namely "Figure 28A of the article by Varotsos and Lazaridou in the journal *Tectonophysics* 1991, volume 188, pages 321–347, or Figure 22 of the article by Varotsos, Alexopoulos and Lazaridou in the journal *Tectonophysics* 1993, volume 224, pages 1–37." According to these time-charts, as explained in Section 3.5, the strongest earthquake happens during the fourth week after the SES recording, or 2–3 weeks later. Indeed, since the SES had been recorded on 6 April 1995, and the strongest earthquake occurred on 4 May, the estimate of the time was satisfactory. Thus, because the epicenter and magnitude were also assessed correctly, there was absolutely no doubt that the prediction was successful on all the three parameters for the impending earthquake.

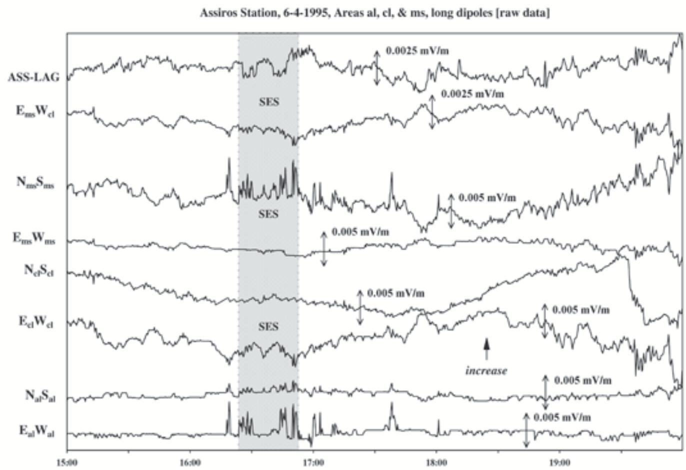


Figure 13.1 The preseismic electrical signals (SES activity) – included in the shaded area – that were recorded at the Assiros (ASS) station on 6 April 1995. Taken from Varotsos (2005). Copyright (2005), with permission from *TerraPub*.

In the newspaper *Ta Nea* of 5 May 1995, we read: "... On last night's television news station ANTENNA, Mr. Varotsos explained how VAN had predicted the earthquake. **He also stressed that the VAN team did not foresee any earthquake of magnitude about 7.0 occurring in the same area**, which suffered great damage from such an earthquake in 1932."

I want to clarify here why public intervention by Varotsos was considered imperative after the earthquake. As explained, people were terrified after the earthquake in the early morning hours (for example, the newspaper *Eleftherotypia* on 4 May 1995 was entitled "Turmoil in northern Greece ... people stay out on the streets") and many were there for the second night, kept out of their homes, fearing a larger earthquake. This fear was intensified for two reasons. First, they were informed by the media about the statements of some seismologists claiming that they "could not rule out an earthquake of about 7.0" and that "a possible shift in focus could result in a devastating earthquake in the area". Second, the public still had fresh memories of what had happened in Thessaloniki before the destructive earthquake of magnitude 6.8 on 20 June 1978 which caused 49 deaths. (That earthquake was preceded by other earthquakes of smaller magnitude of around 6.0.) Beyond these two reasons, however, it is understandable that when an earthquake of magnitude 6.0 occurs, the anxiety in the population peaks if that is the main earthquake and there is widespread fear of a larger follow up. There is therefore a great responsibility to inform the population, on the basis of concrete scientific evidence, about what is going to happen. In this case, we relied on the data at the ASS station. After the electrical signals of 6 April 1995 (see Figure 13.1), which showed that the magnitude of an impending earthquake was near 6.0, no further signals of larger amplitude had been recorded. On the basis of these data, Varotsos took on the heavy responsibility of assuring the public that a larger earthquake would not happen, thus reassuring them. Recall that Varotsos had also taken on such a responsibility after the 6.1 earthquake on 29 March 1986, reassuring the population, especially in Athens, as I explained in Section 5.1.

Finally, I note that the response of scientists from abroad on that successful prediction was very positive. For example Professor Ota Kulhanek, Director of the Seismological Institute in Uppsala (who was one of the recipients of our forecast) sent a FAX to Varotsos on 4 May 1995, just after the earthquake, which read:

> Dear Panayiotis
>
> This morning at 00:38 [The time is GMT, not local time] we recorded in Uppsala, a medium-strong earthquake in the region of Thessaloniki in northern Greece with magnitude M (UPP) = 5.6. **Congratulations**.
>
> Looking forward to see you in London next week
>
> I remain with the best of regards
>
> Ota Kulhanek

I should make clear to the reader that the reference in the penultimate sentence that Professor Kulhanek would meet Varotsos the following week, referred to the upcoming Royal Society Conference in London on 11–12 May, described in Chapter 12. In that conference, the leading seismologist Hiroo Kanamori, Professor at the California Institute of Technology, referring to the VAN prediction issued before the earthquake at Chalkidiki (see page 342 of the Proceedings), said: “Since this area is not a particularly active area, this prediction appears very unique.”

14 Earthquake in Grevena-Kozani, 1995

14.1 What happened before and immediately after the earthquake

As explained in Chapter 12, a conference was held at the Royal Society of London on 11–12 May 1995. The following day, May 13, Varotsos and I were returning to Greece together with the Japanese Professors Uyeda and Nagao. During the flight, a 6.6 earthquake occurred in the area between Grevena and Kozani in northern Greece at 11:47 local time. Our co-workers in Greece were aware of the prediction we had sent and which Varotsos reported during his speech at the London Conference (see Chapter 12). Because our co-workers knew our flight they made a call to the airline, which alerted a flight attendant who brought us a note that "an earthquake of magnitude 6.6 had taken place in the Kozani area in northern Greece". We "rejoiced" to hear of our success, but please do not misunderstand the word "rejoiced"; as researchers we were glad that our prediction was correct, but of course, our minds were on whether the earthquake had tragic consequences. Upon arriving at the airport we immediately called the relevant officials who said that only property damage had been reported, and we were relieved to get this news.

This earthquake was a surprise to seismologists, because the area was classified as aseismic. No comparable earthquakes had occurred for more than 1000 years, and almost all the press wrote on that subject. For example, see the Sunday newspapers *Eleftherotypia* and *Kathimerini* of 14 May.

The first newspaper, *Eleftherotypia*, published a leader entitled "Surprise for the seismologists", and wrote: "The occurrence of the 6.6 earthquake that hit Kozani yesterday was a surprise for the seismological chronicle of that region. It was the shock that literally took us by surprise ... declared yesterday." The same newspaper just below this, with the subtitle "25 injured and hundreds of homes damaged, the worst disaster since the outbreak of the Enceladus in Kozani" continued: "A thousand years after, the Enceladus visited… again ... with a 6.6 earthquake versus 6.0 in Richter in 896 A.D., which was the last time there was a major earthquake in the region."

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_14,

The second newspaper, *Kathimerini*, entitled “Fear and panic of 6.6 Richter scale” and subtitled “Damages in Grevena, Ptolemais, Kozani and Larisa” wrote: “The earthquake yesterday surprised the scientists as the area Kozani was characterized **without a seismic past**. The existing historical evidence suggests that the only earthquake that resulted from this focus occurred in 856 A.D. and had a magnitude of 6 on the Richter scale. Ever since then the earthquake had been silent, and until yesterday Kozani was not recorded on seismic maps.”

VAN had recorded preseismic signals (SES activities) at the Ioannina station (IOA) on 18 and 19 April 1995 (a photocopy of the signals on April 18 is shown in Figure 14.1). Then it was one of only four stations that the VAN team had in the entire country, and the closest to the area devastated by the earthquake.

After studying the signals, on 27 April 1995 Varotsos sent a brief statement to the State (meaning the Minister and the Deputy Minister of Public Works and Environment) and to various institutes abroad. The article related to the assessment of an expected 6.0 class earthquake with two alternative solutions for the epicenter (unknown exactly as a result

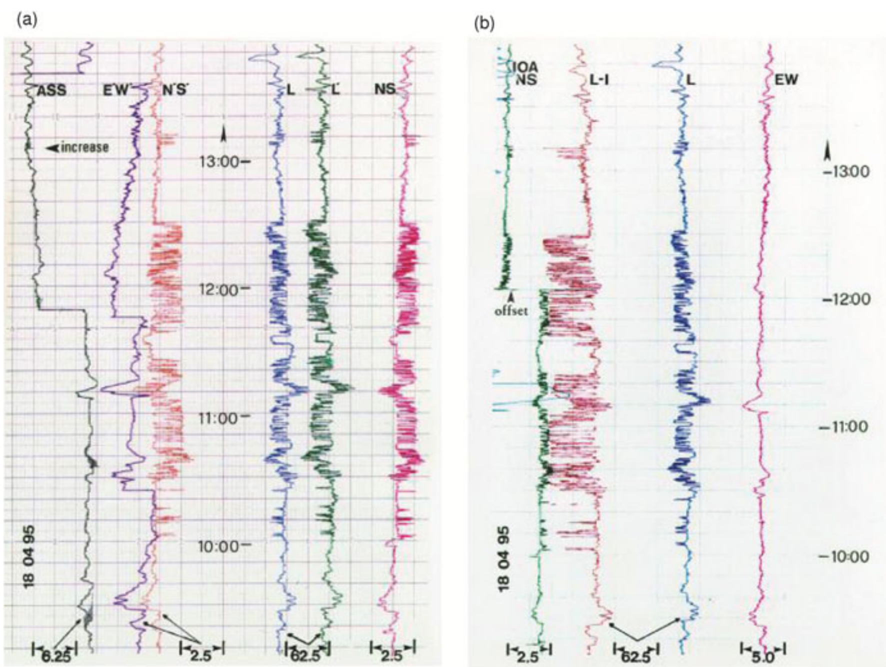
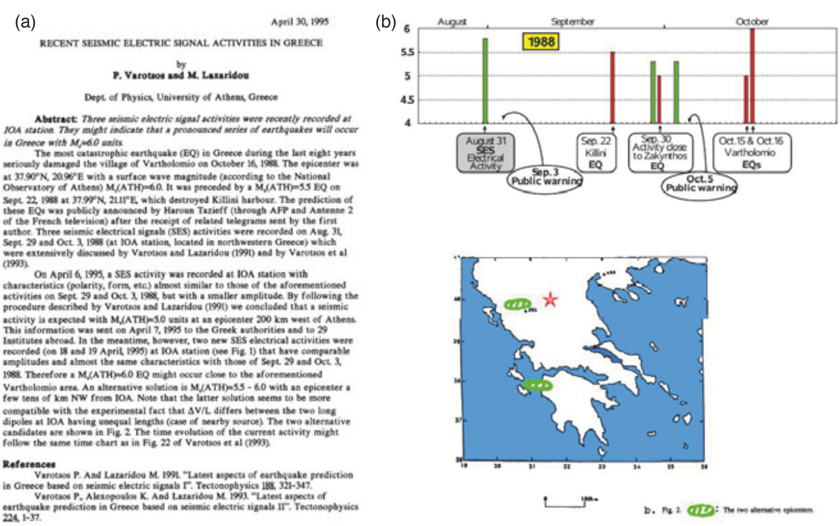


Figure 14.1 The preseismic electric signals (SES activity) at Ioannina station on 18 April 1995, recorded at dipoles of various orientations and lengths L. Taken from Varotsos (2005). Copyright (2005), with permission from *TerraPub*.

of the absence of other stations in the area). One was in western Greece (200 km west of Athens) and the other a few tens of kilometers near Ioannina station. After further study, we **designated the most likely area for the second region, which was a few tens of kilometers from Ioannina** (see the map in Figure 14.2) and sent a second message on 30 April 1995. In addition, a time-chart was attached, indicating what was likely to follow in this case. This time-chart had been constructed on the basis of our experience from the destructive earthquakes at Killini-Vartholomio in 1988 (top right in Figure 14.2) and showed that the first earthquake (near Killini) occurred during the fourth week after the registration of the preseismic SES activity as described in Chapter 6.

The map attached to the prediction showed the two possible epicenters, but I now add – for the reader's convenience – a red asterisk showing the final epicenter of the earthquake that occurred on 13 May 1995 near Kozani. Note that the earthquake actually occurred closer to the possible epicenter that was given in the prediction as being the most likely, namely about 80 to 100 km from it. The magnitude of the earthquake was 6.6, which is larger by 0.6 than that predicted. This is in agreement with the experimental results, show-


(a)

April 30, 1995

RECENT SEISMIC ELECTRIC SIGNAL ACTIVITIES IN GREECE

by

P. Varotsos and M. Lazaridou

Dept. of Physics, University of Athens, Greece

Abstract: *Three seismic electric signal activities were recently recorded at IOA station. They might indicate that a pronounced series of earthquakes will occur in Greece with M_s≈6.0 units.*

The most catastrophic earthquake (EQ) in Greece during the last eight years seriously damaged the village of Vartholomio on October 16, 1988. The epicenter was at 37.90°N, 20.96°E with a surface wave magnitude (according to the National Observatory of Athens) M_s(ATH)=6.0. It was preceded by a M_s(ATH)=5.5 EQ on Sept. 22, 1988 at 37.99°N, 21.11°E, which destroyed Killini harbour. The prediction of these EQs was publicly announced by Haroun Tazieff (through AFP and Antenne 2 of the French television) after the receipt of related telegrams sent by the first author. Three seismic electrical signals (SES) activities were recorded on Aug. 31, Sept. 29 and Oct. 3, 1988 (at IOA station, located in northwestern Greece) which were extensively discussed by Varotsos and Lazaridou (1991) and by Varotsos et al (1993).

On April 6, 1995, a SES activity was recorded at IOA station with characteristics (polarity, form, etc.) almost similar to those of the aforementioned activities on Sept. 29 and Oct. 3, 1988, but with a smaller amplitude. By following the procedure described by Varotsos and Lazaridou (1991) we concluded that a seismic activity is expected with M_s(ATH)≈5.0 units at an epicenter 200 km west of Athens. This information was sent on April 7, 1995 to the Greek authorities and to 29 Institutes abroad. In the meantime, however, two new SES electrical activities were recorded (on 18 and 19 April, 1995) at IOA station (see Fig. 1) that have comparable amplitudes and almost the same characteristics with those of Sept. 29 and Oct. 3, 1988. Therefore a M_s(ATH)≈6.0 EQ might occur close to the aforementioned Vartholomio area. An alternative solution is M_s(ATH)≈5.5 - 6.0 with an epicenter a few tens of km NW from IOA. Note that the latter solution seems to be more compatible with the experimental fact that ΔV/L differs between the two long dipoles at IOA having unequal lengths (case of nearby source). The two alternative candidates are shown in Fig. 2. The time evolution of the current activity might follow the same time chart as in Fig. 22 of Varotsos et al (1993).

References

Varotsos P. And Lazaridou M. 1991. "Latest aspects of earthquake prediction in Greece based on seismic electric signals I". Tectonophysics 188, 321-347.

Varotsos P., Alexopoulos K. And Lazaridou M. 1993. "Latest aspects of earthquake prediction in Greece based on seismic electric signals II". Tectonophysics 224, 1-37.

Figure 14.2 The prediction sent on 30 April 1995 to the State (the Minister and Deputy Minister of Public Works and Environment) as well as to several research institutes abroad. (a) The text of the prediction; (b) the time-chart; and, finally (bottom right), the two green spotlights on the map showed the two possible epicenters (it was clear from the text that the northern was more likely). The prediction had an extra page with copies of the recorded signals (shown in Figure 14.1). Taken from Varotsos (2005). Copyright (2005), with permission from *TerraPub*.

ing that if the actual earthquake lies at a distance somewhat further than that estimated from the recording station, the final magnitude of the earthquake is slightly more than that predicted (as described in Sections 3.5 and 5.2). However, the difference is within the experimental error of 0.7 explained in Sections 3.6 and 12.2. Finally, as far as the earthquake occurrence time is concerned, since the preseismic signals were recorded on 18 and 19 April and the earthquake occurred on 13 May, that is during the fourth week after the recording of the SES activities, and thus it is in good agreement with the predicted time-chart. This is the typical behaviour of what happens after an SES activity as I explained in Section 3.5. In other words, the deviations of the three parameters (magnitude, epicentral region and time) were well within the internationally accepted limits for qualifying it as a successful prediction, especially when taking into account that no such earthquake had occurred in this region for more than 1000 years. This was also pointed out by Professor Kanamori in his article in the Proceedings of the Conference of the Royal Society of London.

Upon its receipt, the Ministry sent the prediction, urgently to the EPPO, as stated in an official letter from the Deputy Minister Mr K. Geitonas to Varotsos on 3 May 1995.

14.2 What the international scientific community said after the earthquake

Recall that, as explained in Section 12.1, the 30 April forecast was also sent to the Chairman of the Conference at the Royal Society of London, Sir James Lighthill, which he describes in the last article of the Proceedings of the Conference. Two days after the 6.6 earthquake of 13 May (and only three days after the Conference ended on 12 May 1995), Sir James Lighthill wrote the following letter to Varotsos:

> Dear Professor Varotsos
>
> I would like emphatically to confirm that I was one of those who received by FAX on 1 May, 1995, the three page paper (dated 30 April 1995) "Recent Seismic Electric Signal Activities in Greece" by P. Varotsos and M. Lazaridou. This was a very striking paper because of the SES [seismic electric signals] activity of large amplitude observed at Ioannina station around 07:00 on 19 April, 1995 (and following earlier bursts as described in the paper).
>
> The discussion in your paper predicted that either one out of a pair of two possible alternative high-magnitude earthquakes was likely to occur in the near future. The second out of this described pair of two possible alternatives (the one near the Ioannina station itself) can be recognized as very close to what actually emerged in the severe earthquake on the morning of 13 May, 1995. Moreover, the paper explicitly recognized this alternative as the one which "seems more compatible with the experimental fact."
>
> Please do not hesitate to use this confirmatory letter in any way that may seem appropriate to you.
>
> With my warmest regards,
> Yours sincerely,
> Sir James Lighthill

The next day (Tuesday, 16 May 1995), the newspaper *Eleftherotypia* published an aticle under the headline "International VAN Shaking: Forecast: Impressed 3 famous seismologists" and subtitled: "But we did not get an alert about Grevena, say government officials." This front page article reported: "A British and a Japanese world-class seismologist as well as Professor of Uppsala Kulhanek, known for the 7 Richter earthquake in 1981, yesterday acknowledged the usefulness of VAN and revealed that they had been informed by Varotsos on April 30 about the 6.6 earthquake. The Ministry denies having been informed about the earthquake at Grevena."

On the same day the newspaper published a two-page article (pages 20 and 21) entitled "International support for Varotsos" with a heading: "Foreign scientists admit that they had been informed of the impending earthquake. Government: We were not advised for the region of Grevena". This article presents the statements of three distinguished professors, namely the British Professor Sir James Lighthill and the Japanese Professor Seiya Uyeda in their response to the BBC in London, and Ota Kulhanek, the Director of the Seismological Institute of Uppsala Professor to the Greek media.

This article began as follows:

> International shaking in seismic things has been caused by VAN research after the statements of Professors from abroad who admit that they received a prediction from Professor Varotsos ... However, the issue tends to have a major dimension, because the Secretary of State for the Environment and the EPPO President say that they never received warning of an imminent earthquake in this region. With the issue now shifting from the prediction to the accuracy of the prediction of the area and the practical effects, the function of VAN becomes of special importance in view also of the statement of Professor Kulhanek who considers that the VAN prediction has been confirmed with the occurrence of the 6.6 earthquake. Positive opinion for the VAN prediction was also expressed by the Japanese Professor Seiya Uyeda who is already in Greece to discuss the prospect of future cooperation.

And the correspondent of the newspaper in London wrote:

> Two prestigious foreign scientists, one British and one from Japan, say that the VAN team had predicted the earthquake of May 13 in northern Greece on April 30 and had informed them. And according to the British Professor, Sir James Lighthill, the international scientific community is close to accepting VAN as a reliable method of forecasting earthquakes….
>
> Sir James Lighthill, Professor at University College London and member of the Royal Society, is the president of the Special Committee of the "*International Decade for Natural Disaster Reduction*". The United Nations described the 1990s as the decade to reduce natural disasters worldwide and the International Council of Scientific Unions (ICSU) appointed the Committee which is chaired by Professor Lighthill. Under his chairmanship a scientific meeting on "A Critical Review of VAN" was held last week – 11 and 12 May – in London.

Speaking on the Greek service of the BBC, Professor Lighthill after stating that "*it greatly impressed us all that the large earthquake in Greece on May 13, a day after the meeting, had been clearly predicted by the VAN team*" [as mentioned in Section 12.1], continued as follows:

> "*Y*es, exactly, I had been informed personally. A scientific article came to my office by FAX dated April 30, written by Mr. Varotsos and Mrs. Lazaridou. I received this very impressive

article the next day on 1 May. It consisted of 3 pages and referred to a series of seismic electric signals that had been recorded at the Ioannina station at 07:00 on April 19. They were preceded by other signals also referred to in the article. Then the article made a specific prediction and said an earthquake of high intensity would take place in the near future an earthquake of high intensity and that there were two alternatives as to where the earthquake would happen. The second alternative referred to the possibility of a major earthquake near Ioannina. **And this prediction is considered to be very close to the earthquake that actually occurred on the morning of May 13**

Professor Lighthill told the BBC that he was satisfied that the forecast was accurate and continued: “It’s very interesting that in this case, the article acknowledged that the second alternative prediction was more likely to be verified. I think **this is a very important prediction** that adds to other predictions that have been published by Varotsos and his colleagues in recent years.”

The journalists then asked Professor Lighthill whether he knew that information had been made available to the Greek Government. He answered: “I cannot tell you this, but I think that it would have been made available to the Government. As far as I know, the VAN team sends all its predictions to the Greek Government. But I cannot prove it. What I can prove is that I personally received the forecast on May 1 and I was one among many scientists who also received it at that time.”

The reporter continued as follows:

“The Japanese Professor of Geophysics at the University of Tokai, Seiya Uyeda, who was present at the closed meeting in London, told the BBC: “At the meeting in London in the same room were supporters and opponents of the VAN method, but also scientists with neutral opinions. I am from the supporters of the method and I am satisfied with the results of the meeting. The neutral participants seemed convinced that the VAN method works.”

Professor Uyeda said the VAN team had informed him about the occurrence of the May 13 earthquake fifteen days before hand.

In the same two-page publication is an article subtitled “Additional confirmation from the Professor at Uppsala”, where it is written:

Professor Kulhanek added another positive opinion for the VAN operation to those presented by other foreign scientists. The famous scientist of the seismological Institute of Uppsala told the television station ‘ANTENNA’ that on April 30 he received a FAX from Varotsos in which reference was made to an expected earthquake measuring around 6.0 on the Richter scale and with an epicenter close to Ioannina, which, according to his opinion, occurred on Saturday [that is May 13].

In the aforementioned interview with the BBC, the two distinguished professors, James Lighthill and Seiya Uyeda, were also asked to answer the following question [I present the translation as given by the newspaper *Eleftherotypia* on 16 May]:

– “If indeed the VAN method is an effective method of forecasting earthquakes, what are the practical consequences? What would one expect Governments to do?” Professor Lighthill replied:

"The first thing is to warn the population who will need special training in how to react to the danger. People should sleep in places where there they will not be in danger if buildings collapse. Industries should also be warned, especially the factories where there is risk of fire and other hazards after an earthquake.

We know very well what to do when there are warnings for hurricanes and storms and we could do the same for earthquakes if we had really reliable estimates. **The example of the VAN prediction for the earthquake of May 13 is encouraging**."

Professor Uyeda replied:

"It is a good question. It is the job of Government to take action when it receives such information and I believe that the Greek Government should have taken countermeasures in this case. They need to warn people close to the expected epicenter in a way that would cause the least possible panic."

15 Disastrous earthquake at Eratini-Egion, June 1995

15.1 The earthquake and its prediction

At 03:14 am on 15 June 1995, a devastating earthquake occurred in Central Greece, in the region of Eratini (almost opposite to the town of Egion, which is why this event is called the Eratini-Egion earthquake), which shook half of Greece and was also strongly felt at Athens. The earthquake, which was eventually announced by the U.S. Geological Survey (USGS) to have a magnitude of Mw = 6.5, caused widespread destruction, as well as the deaths of 25 people due to the collapse of a building and a hotel in the Egion area.

On the following day, Friday 16 June 1995, the international public became aware for the first time that the earthquake had been predicted by the VAN team. The UK broadsheet, *The Times*, ran an article with the leader: "Athens, Physics Professor predicted disaster at Greek resort which killed tourists", and main title: "17 die after warnings of quake are ridiculed". This article began as follows: "An earthquake in Greece, which left at least 17 dead and tens of thousands living outdoors yesterday, was predicted last month by an Athens physics professor who is locked in a bitter dispute with Greek seismologists."

The second paragraph read: "But as rescue workers tore at mounds of rubble in stifling heat to free people trapped in the debris of the quake, it emerged that the warning was relayed to London, because of the hostility from Greek authorities." In particular, the final three paragraphs of the article read:

> The frantic efforts were marked by the revelation that Professor Panayiotis Varotsos, of Athens University, has predicted several earthquakes, including yesterday's. But his work has drawn fury from Greek seismologists, who prefer traditional methods.
>
> Professor Varotsos passed his prediction of yesterday's quake to Sir James Lighthill, the distinguished mathematician and former Provost of University College London. Professor Varotsos

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_15,

> maintains that electrical signals are emitted one to four weeks before an earthquake and he uses them in the predictions.
>
> Yesterday Sir James Lighthill said: "We all knew of this prediction made in May ... There is no doubt that he expected this [the earthquake]."

The next day (17 June 1995) the Greek media referred extensively to the article in *The Times*, as well as to the statements by Sir James Lighthill to the BBC. For example, the headline of the newspaper *Ethnos* of 17 June read: "BEHOLD THE PREDICTION" and the leader "The VAN station at Volos recorded the Egion earthquake".

The newspaper wrote in more detail: "The VAN station at Volos on 19 May captured the electromagnetic signals which led Varotsos' team to the prediction of the earthquake at Egion and particularly with excellent precision as to the date that it occurred. This **shocking documentary** was presented to the *ETHNOS* by the distinguished British professor Sir James Lighthill, who was one of the recipients of the scientific warning from Professor Varotsos."

I now describe what happened before the earthquake. The previous September, an experimental station had been installed in the region of Volos, with the assistance of the Mayor of Nea Ionia-Volos. At that station (VOL, see Figure 3.2) we recorded strong preseismic electric signals on 30 April 1995. The difficulty in analyzing these signals was huge, since the station had not yet been calibrated; that is, we did not have any experience from previous earthquakes to predict the precise magnitude of the upcoming earthquake based on the amplitude of the electric signals which we now recorded at that station. A second major difficulty was that we were not yet aware of the "selectivity map" of this station (see Sections 3.4 and 3.5), which meant from what seismic areas the new station could "capture" preseismic electric signals. Finally, the other stations in the area were still closed (see Sections 3.2 and 7.2). It took over two weeks to overcome some of these difficulties, as will be explained below, and on 19 May we were absolutely convinced that these new preseismic signals SES corresponded to a new impending major earthquake (with a magnitude of about 6.6), which would occur in an area different from that of Grevena-Kozani, where days before (i.e., on 13 May 1995) there had been an earthquake of magnitude 6.6. Our study led to a prediction text dated 19 May 1995 that was sent on 20 May 1995 to the State as well as to several research institutes in Europe, the USA and Japan. It was accompanied by the map shown in Figure 15.1 which was used to estimate the potential epicentral area by means of the procedure described in the text (see below).

I would like to emphasize that a handwritten cover letter was also sent to the State in which Varotsos summarized the content of the prediction and intentionally drew the attention of all the political leadership to "**the criticality of the situation**" and that "**this scientific information indicated a new major earthquake elsewhere**" (meaning in a different area from the Grevena-Kozani region which was seismically active at that time).

Let us now see the additional information which was contained in the text and the map of the prediction. Because the **shape** and **amplitude** of these preseismic electric signals SES were similar to those of the signals recorded at Ioannina (IOA) station before the 6.6 earthquake in Grevena-Kozani region but were being recorded only at VOL, we concluded that the impending earthquake would be of similar magnitude, namely about 6.6, but in an epicentral region different from that of the Grevena-Kozani (shown with an asterisk in Fig-

Selectivity maps of the stations ASS and IOA. The sites of the other Greek stations are also shown. The areas *a*, *b* and *c* correspond to station ASS. The large hatched area is the the selectivity map of station IOA and includes seismic areas from which the SES are collected either at station IOA alone or at station PIR as well.

The asterisk shows the epicentre of 6.6 EQ of May 13, 1995 indicating that the selectivity map of IOA extends up to that area (this epicentre was not activated before).

Figure 15.1 The map on the basis of which we estimated the epicentral region of the impending earthquake. It was attached to the prediction text "(published in page 64 of the proceedings of the Royal Society meeting, see Figure 12.1) that was sent to the State and to several research institutes abroad.

ure 15.1). To assess the potential epicentral area of the impending earthquake, we thought as follows: Remove from the possible area those regions that gave signals to the other stations operating at that time but did not record preseismic signals (recall that apart from the new VOL station, the following four were operating: KER, PIR, ASS and IOA, see Section 3.2 and Figure 3.2). **Thus, we concluded that the impending earthquake would happen in the remaining part of continental Greece after excluding the following areas**:

(i) The region around Volos city (Thessalia) because, although the signals were recorded at VOL, their properties revealed that they originated from a remote source in respect to that station (meaning from a distance greater than 120 km, as explained below).

(ii) The regions in the shaded area to the left of the map in Figure 15.1 (because the preseismic signals were not recorded at IOA and PIR stations).

(iii) The wide area resulting from the combination of regions “a”, “b” and “c” of Figure 15.1 (because the signals were not recorded at the ASS station).

(iv) The region around Athens as well as the Peloponnese (since the preseismic signals were not recorded at KER station).

The text explicitly states that it cannot exclude as a candidate epicentral area, the one that adjoins the station Gorgopotamos (GOR) see Figure 3.1 – which was unfortunately closed because EPPO had cut our telephone lines (see Section 7.2) – and specifically the area south of that station since the area to the north had been excluded in view of argument (i). Indeed, the epicenter of the earthquake of 15 June, as announced by the U.S. Geological Survey, was in the Eratini region which is just 40–50 kilometers to the south of GOR station. In other words, both the magnitude (6.5) and the epicentral region of the earthquake at Eratini-Egion were entirely consistent with our estimates in the prediction text. Finally, for the third aspect of the forecasting – that is, the timing of the impending earthquake – the last line of the prediction text indicates a specific time-chart since it states that “The time evolution might follow the time-chart of Figure 22 of Varotsos and his colleagues’ article in 1993”, which showed the evolution of the earthquakes in the Killini-Vartholomio case in 1988 after the SES recording (see Chapter 6). For the convenience of the reader, this time-chart is shown at the top of Figure 15.2, while at the bottom of figure is shown the evolution of the earthquakes in Eratini-Egion. (Note that the two intermediate time-charts in Figure 15.2 refer to the earthquakes at Chalkidiki of 4 May 1995 and at Grevena-Kozani on 13 May 1995, that I described in Chapters 13 and 14, respectively).

A comparison of the two time-charts reveals a striking similarity between these two cases (note that this behaviour is not followed in all cases, as is explained in Chapter 18). Concerning this similarity, in the FAX sent to Professors Uyeda, Nagao and Sir James Lighthill immediately after the earthquake occurred (at that time it was announced that the magnitude was 6.2, while the final magnitude was 6.5), Varotsos wrote

> Today at 03:15 local time (that is 00:15 GMT) an earthquake of magnitude 6.2 actually occurred a few tens of kilometers south of GOR [Gorgopotamos station]. As I wrote to you yesterday, today was the probable (?) date for its occurrence, according to the time-chart mentioned in the prediction. (There was damage but the authorities reacted immediately as [I think] they were prepared due to our prediction.)

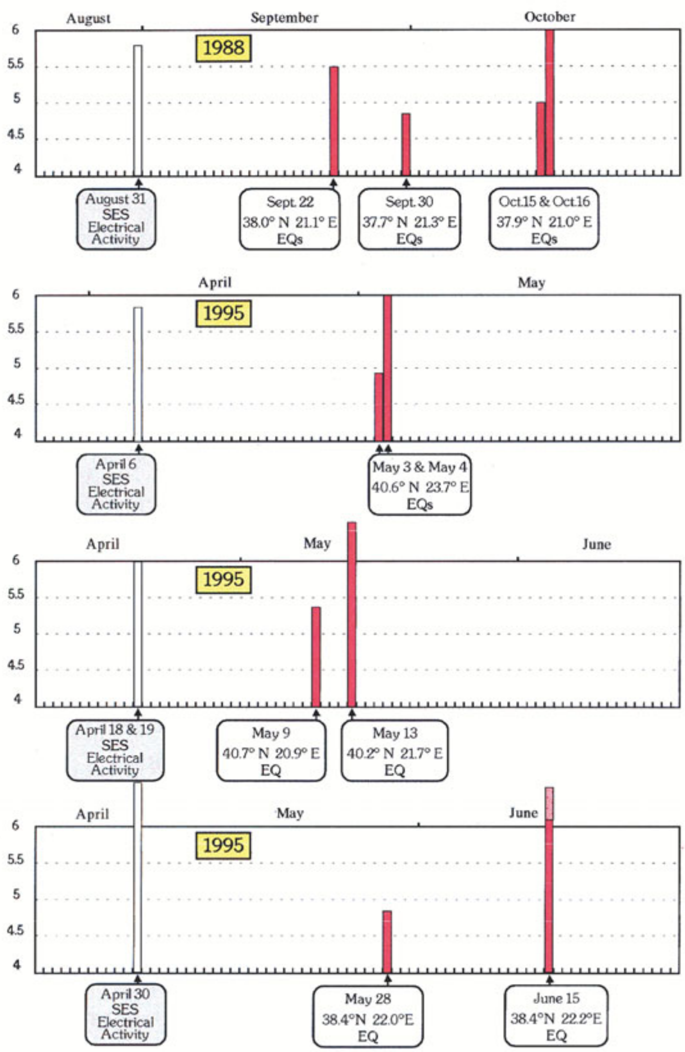


Figure 15.2 (Top) The time-chart of the earthquakes in Killini (22 September 1988) and Vartholomio (15 and 16 October 1988) is shown after the recording of the SES activity on 31 August 1988. (Bottom) The evolution of the earthquakes that occurred in Eratini-Egion (28 May and 15 June 1995) after the recording of the SES activity on 30 April 1995. The similarity of these two time-charts is evident.

> This is the largest earthquake (after that of May 13, 1995) to have occurred in Greece during the last 13 years.
>
> It is not good, is it? **It is really astonishing that again the time-chart of the SES activity worked so well.**
>
> Mary joins me in sending to you our fondest wishes
>
> Panayiotis

As is evident from the above letter, we were following closely the evolution of the time-chart and this is why, one day before the earthquake, we reminded the recipients of our prediction that "Tomorrow is the most probable date". Of course, having received our prediction, the recipients knew the date of the recording of the SES activity and, hence, once they also knew the time-chart of the prediction they could carefully follow for themselves the overall evolution of the phenomenon.

In response to Varotsos' letter, Professor Sir James Lighthill, after a few hours, sent the following letter:

> Dear Professor Varotsos
>
> Thank you very much indeed for your communication about last night's earthquake at Egion, and about its close relationship to the prediction you issued on 19 May after the strong SES activity which was recorded at your relatively new VOL station on 30 April. Once again, I emphatically acknowledge that I was one of those who received the forecast which you issued on 19 May and **that the occurrence of last night's earthquake appears wholly in accord with the terms of that prediction.**
>
> With warmest good wishes
>
> Yours sincerely
>
> Sir James Lighthill

The above letter from the distinguished professor explains how the international media (for example, *The Times* of London, the BBC, etc.) were informed immediately of exactly what had happened regarding the VAN team's prediction. And so the Greek public learned later from these reports from abroad what the Greek authorities had known before the earthquake. Certainly after these reports, the Greek media contacted other international research institutes, which simply confirmed that they had also received the prediction from the VAN team. For example, on 17 June 1995, *Ethnos*, in an article entitled "They knew about the earthquake" (page 13), wrote the following:

> This issue has been addressed by the international press. Indeed, the British newspaper *THE TIMES* characteristically stated that the earthquake had been predicted by Varotsos and added that the hostility from the Greek authorities towards the VAN method had led the Greek scientist to transfer his warning to London. Dr Ronald Arvidsson from the Seismological Institute of Uppsala also confirmed that Mr. Varotsos had sent a prediction about the earthquake.

15.2 What countermeasures did the State take after receiving the prediction?

Regarding the FAX sent to research institutes abroad immediately after the earthquake, (see Section 15.1) Varotsos wrote: "There was damage but the authorities reacted immediately as [I think] they were prepared due to our prediction." (At that moment, as already mentioned, Varotsos did not know that 25 people had died.) You may wonder, therefore, whether the information (about preparedness) was based on some official information from the State or merely his own assessment. The first should be categorically ruled out, because nobody ever influenced him and he would never be pressurized into presenting someone else's views. Moreover, *The Times* of London, a newspaper known for its credibility, one day after the earthquake presented a picture of the Greek authorities' hostility to VAN (see also the newspaper *Ethnos* on 17 June) which is a completely different picture from the one that Varotsos conveyed, in good faith, to the researchers abroad. Of course, in writing this, *The Times* had carefully collected their information. The only certainty is that, despite the critical situation that Varotsos had emphasized in his letter of 20 May to the Minister, a warning to the population about the upcoming earthquake was never transmitted directly from the State. What seems most likely is that the State put the authorities on alert, but in what area is not yet clear from the information available, which I will quote below. So I describe the events of those days.

Just three days after sending the prediction, Varotsos received an urgent request from the Office of the Prime Minister of Japan to participate in a three day forum to be held 1–3 June 1995. Specifically, the invitation reads:

> Dear Professor Varotsos
>
> It is my great pleasure to invite you to participate in the Forum for Earthquake Prediction and Disaster Prevention Technology to be held at Hamamatsu-city in Shizuoka Prefecture, Japan.
>
> *The Forum will run from June 1 to June 3 and consist of a series of discussions that we believe will help to build a better understanding of earthquake prediction and disaster prevention technology. Part of the Forum will include a guided tour of the Institution for Disaster Prevention in Shizuoka Prefecture. This is scheduled for June 1.*[1]
>
> I have attached a detailed schedule of the Forum. Please do not hesitate to let me know if you have any questions or comments.
>
> We look forward to seeing you in Hamamatsu city
>
> Sincerely yours
>
> Kazuki Okimura
>
> Director General
>
> *Research and Development bureau, Science and Technology Agency.*

1 The Japanese scientists are afraid that this area, including that of Tokyo, will be affected by a future large earthquake of magnitude about 8.0 to 8.5.

Varotsos accepted this honorary invitation and we left for Japan on 30 May. We returned to Greece on 8 June, because the discussions with the Japanese scientists lasted longer than the original programme. The results of these discussions appeared in the publication of the prestigious international journal *Nature* on 22 June 1995 (Volume 375, page 617), entitled: “Japan jumps on board the VAN wagon”.

Authoritative information was provided in this publication on the decision by the Ministry of Education, Science and Culture and of the Japan Meteorological Agency to fund the installation of VAN stations, both in Kobe (where on 17 January 1995 a devastating earthquake of magnitude around 7.3 caused several thousand deaths; see also the Appendix and in particular Section A.4) and in other areas of Japan. I take the opportunity to categorically point out here that Varotsos never expected to receive any money for such an installation in Japan.

Let us now go back to what was going on in Greece: During the week which had elapsed from the receipt of our prediction by the State (20 May 1995) until our departure for Japan, EPPO’s officials actually contacted Varotsos, asking for clarification about the prediction. Varotsos insisted on the accuracy of the scientific data and also explained that further details about the forthcoming large earthquake could not be submitted because the vast majority of the VAN stations (i.e., 13 out of 18 stations) were closed during the recording of the preseismic signals SES on 30 April 1995 (due to the shortage of telephone lines for data transmission, see Sections 3.2 and 7.2). But two days before our departure for Japan, specifically on 28 May 1995, the media began to publish “information” that a major earthquake was imminent once again in Greece. We realized that our forecast, sent to the State a few days before (on May 20, 1995), had leaked. We were very surprised, however, because these publications reported that the State was taking countermeasures possibly in the area of Thessalia, which was a region that had been explicitly excluded from our prediction (see point (i) in the prediction text, to which I will return).

An article in the newspaper *Paron* on 28 May 1995 (by M. Kouris) said: “Strong concern about an imminent earthquake in Thessalia prevails among seismologists, as there are **signals** that faults in that area are becoming active. Already, according to reliable information, the government has been told by seismologists (whether belonging to the VAN team or not), of impending action. And subtly the government agencies have been on alert to avoid creating panic in the population. The fears of scientists are based mainly on the fact that due to the activation of the fault in Grevena there is likely to be similar activations in Thessalia.”

The following day, Varotsos contacted the State, giving the addresses of the Japanese services through which Greek officials could reach us, if necessary, during our stay in Japan. Moreover, Varotsos expressed his strong surprise that the information published in the newspapers talked about an impending earthquake in Thessalia and repeated once again his insistence on the accuracy of the information mentioned in the forecast. Specifically, he insisted on point (i) of the prediction text which states verbatim the following: *“(i) The two long dipoles installed at VOL (with lengths 22 kilometers and 5 kilometers) show comparable ΔV / L values, thus indicating a non nearby source (and hence the neighbouring area of VOL should be excluded).*” This meant that the source of the signal (that is, the focal volume of the impending earthquake) **should be distant from the VOL area** – where electric signals were recorded – that is, at a distance five to six times greater than the 22 kilometer length of the longer dipole. Hence, the future epicenter should be placed at a distance greater than about 120 kilometers from VOL. This, coupled with the fact that the area around Grevena (where there had been a previously activated fault) was also expressly excluded from the VAN prediction, meant that in no way could one conclude that the earthquake would be in Thessalia. Varotsos made it very clear to EPPO's officials, but got the impression that the State, after receipt of our own prediction, had also asked the opinions of some seismologists who expressed a different opinion on the most probable area to become active. Unfortunately, this was the case as will become clear from the evidence presented below.

The information mentioned in the newspaper *Paron*, is strikingly similar to a statement made by an official of EPPO **after** the earthquake, reported in the journal *Nature* (1995, Volume 377, page 375). Specifically, this article focused on what happened **before the Eratini-Egion earthquake and after the receipt of the VAN prediction**: "... [The EPPO official] claims that they had taken precautionary measures, which were based **only partly on Varotsos' advice**, and so were ultimately not accurate." In addition, the journal published the following statement of the EPPO official: "After the May earthquake [Grevena], I consulted several colleagues, including Varotsos, and decided to alert emergency services in the Thessalia area in central Greece to prepare for a possible earthquake in June. It is not my fault that the earthquake took place 100 km to the south".

Unfortunately, the EPPO official does not state the precise scientific justification of the "*several [anonymous] colleagues*" who eventually convinced him to take countermeasures in Thessalia, an area which, as explained above, was explicitly excluded from the VAN prediction text on the basis of the electrical measurements, whereas it was written expressly in point (iv) of the VAN prediction that "*GOR immediate vicinity cannot be excluded*", and thus this was likely to be the epicentral area of the impending earthquake. (It should be remembered that, ultimately, the earthquake's epicenter was near Eratini which is only a few tens of kilometers to the south of GOR station). We never officially learned why the State reached such a decision and Varotsos felt very embittered, because as a result there were many dead. That was the main reason why Varotsos spoke to the TV journalist M. Triantafillopoulos on 18 June 1995, three days after the earthquake, where he presented to the public all the information sent to the State, and never spoke again to the media. However, after 2006 and advances in technology, Varotsos decided that, rather than being sent confidentially to the State, all the information gathered by the VAN team on a forthcoming major earthquake should be posted on scientific sites of prestigious international institutions which are freely accessible via the Internet to everyone, including of course the State. This method ensured that what happened before the Eratini-Egion earthquake could never be repeated, namely that in the future a Government official could not take countermeasures in an area that had been ruled out from the prediction text rather than an area designated by it.

16 The International Prize of the Onassis Foundation, 1995

On 7 April 1995, the Alexander S. Onassis Public Benefit Foundation announced its prestigious awards. One out of the four award-winning people was Varotsos. The ceremony was to take place on 11 July on Pnyx Hill.

The next day (8 April 1995), almost all of the press addressed the issue with comprehensive articles. I present here the leaders from some of the newspapers. As an example, I present the newspaper *Kathimerini* with a report entitled "With courage the awards" and subtitled "Support and consideration for International Relations, Culture and the Environment", in which we read:

> There is an invisible thread that connects the people who were honoured this year with Onassis International Prizes. All four still work and are active members of society by promoting basic considerations of humanity. According to Stelios Papadimitriou, the president of the Onassis Foundation, and member of the committee for International Awards, Boutros Boutros Ghali [General Secretary of United Nations], Jacqueline de Romilly, Yorg Imperger and Panayiotis Varotsos, are personalities who unequivocally offer so much to International Relations, Culture and Environment, sectors that make up the essentials of life and thought...

The last paragraph of this publication read:

> "Onassis Prizes should not lag behind," said Mr. Papadimitriou during yesterday's official announcement to the press ..."to reward a posteriori, after the prior "decorations" of other organizations and institutions. They must be innovative and rush to take the risk and responsibility." The selection of the prize winners from 400 proposed candidates was the result of the painstaking and laborious work of the committee comprising fifteen members (among them, Hel. Glykatzi Ahrweiler, N. Goulandris A. Delivorrias, G. Vlachos, G. Babiniotis, John Brademas, etc.) ...

Also on 8 April 1995, *Kathimerini's* "Notebook" column, under the heading "Announcement of the Onassis Awards – for the publicity and the complimentarity of Greece internationally", began as follows:

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_16,

> Aristotle Onassis would have been very happy to know who had been awarded the Onassis International Prizes and why they received them, and especially for the heat of the applause from the representatives of the press and the media on yesterday's announcement … An Egyptian, a French woman, an Australian and a Greek, whose names are already known around the world for what they have given to humanity…

The newspaper *Eleftherotypia* of 8 April 1995 carried statements from the winners. Varotsos' full text is as follows:

> I thank deeply the Committee of International Awards and the Board of the Onassis Foundation for their decision, which honours greatly my country, my colleagues and me.
>
> To believe that man can tame natural forces, such as those caused by earthquakes, constitutes arrogance. The effort, however, at specifying when and where the devastating effects will occur is not an exaggeration, given that these forces must obey the laws of nature. With this knowledge, we can reduce as much as possible, adverse influences on environment and cultural heritage, primarily to safeguard the supreme good, namely human life.
>
> Finally, it is my duty to point out that the Onassis Foundation was the first which supported the scientific evaluation of our research efforts in their most difficult turning point, by organizing an International Conference in 1990, inviting 30 distinguished experts from various countries. Similar initiatives have been taken, but later, by other institutions and international organizations such as the National Science Foundation (NSF) of the USA in 1992, the United Nations Scientific Committee for Natural Disaster Reduction in 1994 and the Royal Society of London in 1995.

The awards ceremony was held on 11 July 1995 on Pnyx Hill in the presence of the President of the Republic, Kostis Stephanopoulos, the Prime Minister Andreas Papandreou and many other dignitaries (Figure 16.1).

The ceremony began in the shadow of the Acropolis (Figure 16.2) with the following address by Stelios Papadimitriou, the President of the Foundation:

> Excellency Mr. President of the Republic
>
> Mr. Prime Minister
>
> Ambassadors of foreign countries
>
> Ladies and Gentlemen
>
> Consistent with the will of its founder, Aristotle Onassis, the Foundation continues for the 15th time the award of the International Onassis Prize for International Understanding and Social Achievement, Culture and Environment, Awards that inextricably link each other.
>
> You accepted with pleasure, Mr. President of the Republic, in continuing the tradition of your predecessors, to personally deliver the awards to the winners. Nevertheless, the biggest prize and the greatest value is the ceremony itself, which is now taking place in the shadow of the Acropolis. In particular in the same location, where for the first time in history met "City Church" and arose "Republic" with all that it implies for freedom, culture, isonomy, social solidarity and humanity and responsibility, but also for sacrifice, meritocracy, yearning for truth and self-esteem, things that are the essence of the Onassis International Prizes.

Figure 16.1 Shortly before the beginning of the Prize Ceremony: The President of the Hellenic Republic, Kostis Stephanopoulos (in the front), has arrived and everything is now ready for the opening. The four recipients of the honour (Boutros Boutros Ghali, Jacqueline de Romilly, Yorg Imperger and Panayiotis Varotsos) are sitting in the second row and behind them are the Mrs Ghali, Imperger and Lazaridou-Varotsos.

Mr. President, allow me now to deliver a short rationale that led the selection committee and the Onassis Foundation to award the Prize to each of the honourees separately and let it be 'the praise of the public and the Sophists, the hard and the priceless well done'.

Here is presented the rationale for the selection of Varotsos, as delivered by the President of the Foundation during this ceremony.

Brief rationale for Prof. Panayiotis Varotsos

The Selection Committee and the Onassis Foundation awards the Prize of Environment to Professor of Physics at the University of Athens, Mr. Panayiotis Varotsos, recognizing his work in finding a scientific method of forecasting earthquakes, known by the name VAN (from the initials of himself, the Professor and Academician Mr. Kessar Alexopoulos and Dr. Constantine Nomicos).

When in the environment in the broadest sense there is tremendous damage from the wrath of the infernal god of Enceladus, the successful prediction of earthquakes contributes decisively to protect human life and material goods. In addition, to protect the cultural heritage of humanity by ensuring the responsible agencies react in time, in this way decreasing the adverse effects of hazardous earthquakes.

Figure 16.2 Varotsos makes his speech during the Prizes Ceremony, in front of a large audience.

> The scientific work of Prof. Panayiotis Varotsos and the practical applications in the prediction of earthquakes were recognized as the most important and pioneering not only by the largest international academic centers in different countries dealing with the prediction of earthquakes, but also by the Scientific and Technical Committee of the United Nations, as 'a realistic hope and vital contribution to Natural Disaster Reduction'.
>
> The Selection Committee and the Foundation, in awarding to Professor Panayiotis Varotsos the Environment Prize, primarily sought to support and actively encourage the good work and his pioneering scientific effort in this area which is so crucial for many countries and especially critical for our own country.

Subsequently, Varotsos' speech followed (Figure 16.2), which mainly focused on VAN. I present this speech below, since its content is useful to the reader. In summary, Varotsos described how, in cooperation with Professor K. Alexopoulos, they had concluded from their study in Solid State Physics that before the fracture of a material a warning signal would be emitted, and how this conclusion was subsequently applied to the VAN method by measuring the electric field of the Earth. He then tackled the question of how much accuracy may be required in practice from a researcher in the prediction of the epicenter of an impending earthquake. Finally, Varotsos clarified that the responsibility of the scientist involved in the prediction is to offer scientific information and data that can be properly used to defend society; it is the responsibility of the State, however, whether to take measures to minimize the effects of an impending disaster. In full, the speech read as follows:

> Mr. President of the Republic,
> Mr. Prime Minister,
> Ladies and Gentlemen,
>
> I wish to express my deep gratitude to the Awards Commission and the Board of Directors of the Alexander S. Onassis Public Benefit Foundation for awarding me the "Onassis International Prize for the Environment" which constitutes a great honour for my country, my collaborators and me.
>
> In previous years, the "Onassis International Prize for the Environment" was termed the" Delphi Prize". This name, in addition to its ancient connotation, was very appropriate for an environmental prize since in ancient Greece the "Oracle of Delphi" was closely associated with the Earth, the prediction of the future and earthquakes.
>
> The Oracle was dedicated to mother Gaia (Earth), whom Aeschylus describes as the "chief seer". Earth gave her place to another daughter, Themis, the goddess of justice, who was succeeded by another of Gaia's children, the Titaness Phoebe from whom Apollo (Phoebus Apollo) finally took over the Oracle. [Apollo is one of the twelve Olympian deities in Greek mythology, god of light and the sun, truth and prophecy, poetry, arts and more]. The most significant event in the history of Delphi, however, was that the Apollo's arrival was not peaceful, but gave rise to a harsh struggle for domination. The people celebrated his arrival with honours. The Oracle collapsed in 373 B.C. after a terrible earthquake and later they rebuilt it. Earthquakes continued to occur in later periods and the recent earthquake of Eratini [Chapter 15], nearby, has tragically confirmed what our ancient ancestors had aptly observed, "**where the Earth has trembled, it shall tremble again**". Not quite by accident, our research on short-term earthquake prediction which has been going on for many years, is linked to these very words (Earth, prediction of the future, the quest for scientific truth, earthquake).
>
> All the members of our VAN research team (which presently numbers more than 20 researchers, including Professor K. Alexopoulos and Dr. C. Nomicos) are physicists who come from a different discipline than that of conventional seismology. During 1970–1980, our research focused on the physics of solid materials. Let us recall at this point that the Earth's crust, where earthquakes occur, is solid. In [crystalline] solids, the atoms (or ions) display a periodic arrangement (that is, like a huge auditorium with parallel rows of seats and a person in each seat). Our specific field of research that is quite new (being just around 40 years old) was the presence of two types of defects in this periodic configuration: point defects and linear defects. We can consider the first type like the few seats in the auditorium, which remain vacant. The others are the half rows of seats placed between the regular rows. The "vacancies" explain why the electric current can flow through an ionic solid, while the additional half rows play a primary role in the breaking of any solid.
>
> After ten years of research, around 1980, we had arrived at the following conclusion (in collaboration with Professor and Academician K. Alexopoulos): when we start compressing a solid gradually, eventually it will break. However, some time before it breaks, because of the defects I mentioned before, it will emit an electric signal. This electric signal will give us early warning of the imminent breaking of the material.

We therefore simply thought that something similar was happening in the case of earthquakes since an earthquake is nothing more than the breaking of rocks in Earth's solid crust. In 1981, we started our field experiments to establish the existence of this electric signal before the earthquake. Since the laws of Physics always hold, there was no doubt in our minds that this precursor electric signal did in fact exist. The question that remained, however, was whether we could measure it, as it is very weak. Furthermore, this signal which precedes the earthquake is mixed with other signals, hundreds or thousands of times stronger, "flowing" on the Earth's surface and caused by extraterrestrial factors (e.g., Sun-emitted particles which constantly influence the Earth's magnetic field) or terrestrial factors (man-made sources). An additional difficulty was that this signal is transient, meaning that although it is emitted several days or weeks before the earthquake, its duration is small, maybe one minute, so you have to measure continuously and if during that critical minute your instruments are not in operation, there is no chance that the precursor will appear again.

Another fact that we have established experimentally is that **not all the points on the Earth's surface are suitable for detecting the preseismic electric signals**; there are only a few "**sensitive**" points that we have to identify, after prolonged experimentation and based on certain criteria. Usually, out of the ten points you are studying only one may turn out to be sensitive. This does not mean, however, that you can record at this point precursor signals from any seismic area, but only from some. In other words, any future focus of an earthquake is "connected" only to a few "sensitive" points of the Earth's surface, which, however, must have been pre-selected to allow the detection of a future warning signal. It is evident that the more pre-selected points you use to record the preseismic signal, the more accurate the determination of the epicenter and magnitude of the forthcoming earthquake is going to be. In any event, earthquake prediction means the ability to estimate beforehand and with relative accuracy the three parameters of the expected earthquake that is **its magnitude and where and when it will occur**.

The question is how much accuracy can we demand from a researcher in predicting the epicenter? I clarify that the epicenter (or more precisely the focus) is an ideal point, which simply indicates where fracturing (and/or sliding) will start which will then spread to a larger area. What is of practical interest however is the total zone undergoing rupture (which emits the preseismic signal, in accordance with the physics of the phenomenon) and not the exact point at which the rupture initiates. When the magnitude of an earthquake is greater, the larger is the finally ruptured zone. For example, **in the case of a magnitude 8.0 earthquake, the ruptured zone will be approximately 200 kilometers long** [or even longer, for example 300 kilometers see in Section 23.3 the magnitude 8.0 earthquake in China in 2008] while damage will extend over an even wider area. In the case of the earthquake in Mexico in 1985, where there were about 10,000 dead, the location of the epicenter was at a distance of 300-500 kilometers away from the city itself. In smaller 6.6–7.5 earthquakes, the length of the rupture zone is about 40-100 kilometers, but destruction can of course extend over a much wider area. Let us recall two examples from Greece: the 6.8 earthquake of 24 February 1981, whose epicenter was at the Alkyonides, also provoked damage in the Athens area that is at a distance of 60–80 kilometers. In the case of the 6.6 earthquake of March 1957, whose epicenter was at the western coast of Pagasitikos bay, only half of the damage occurred in the prefecture of Magnesia and the other half in neighbouring areas.

The above clearly shows that in major earthquakes there is absolutely no sense in demanding maximum accuracy (of say 10 to 30 kilometers) in the determination of the epicenter [or more precisely the focus], that is the "point" where fracturing (and/or sliding) starts. What is of practical value is to know beforehand the area where the ruptured zone of the future earthquake will be located, in order to take measures to achieve disaster reduction. It is therefore certain that almost 100 kilometers accuracy (our present accuracy range) in the determination of the epicenter is sufficient, for practical purposes, in major earthquakes of magnitude of the order of 6.5.

In summary, I would like to say that when we began our research, practically everybody was saying, "earthquake prediction is impossible", while the United Nations Special Committee [that is the Committee SC-IDNDR, see Chapter 11] was insisting that "short-term earthquake prediction is not a realistic target". Now, however, things have drastically changed; almost all experts agree today that such a thing is possible and any criticisms refer only to the need to improve accuracy. This knowledge could minimize the harmful effects for the environment in the wider sense, comprising human life and material and cultural goods.

The fact that earthquakes emit precursor electric signals is by now a scientific truth, which we try to understand and study in even greater depth. We shall be working in future in order to improve accuracy. This, however, does not mean that until we have achieved maximum results, society should remain inactive and fail to put to use any benefits that the present level of accuracy can offer. Consequently, society should gradually begin to adjust to this new situation, as rapidly as possible. This is also the spirit of the recommendation issued by the United Nations Special Scientific Committee for the International Decade for Natural Disaster Reduction (SC-IDNDR Yokohama, Japan, 23–27 May 1994), which recognizes our method as a realistic hope and views the international work on this method as needing to be massively accelerated. In addition, this recommendation "encourages those responsible for public awareness programmes to find the optimum ways of using these reliable short- term prediction data, in order to achieve the greatest possible mitigation of earthquake disasters".

My collaborators and I, in spite of our successes, often feel bitterness and frustration. Every time we predict a destructive earthquake, we feel like the soothsayer Calchas, if you allow me another reference to antiquity, when he had to listen to Agamemnon telling him. "You are a bearer of bad tidings! You have never anything pleasant to say to me. Your mind loves bad omens; you have never done or said anything good in your life![1]" However, like Calchas, we do not enjoy predicting disaster, nor do we do it because some kind of morbid curiosity drives us. Unfortunately, earthquakes, like many other destructive natural phenomena, are a painful reality with which we have to contend. It is our duty as scientists not to ignore it. We prefer to be aware of it and believe that, eventually, our society will adjust to the idea that it is better to know a scientific truth rather than ignore it. With knowledge, we can at least reduce the disastrous effects. There was a time when no one could predict the precise route, intensity and arrival time of destructive typhoons. Thanks to research, we can now predict all these things.

1 Agamemnon, king of Mycenae, was the commander-in-chief of the Greeks in the Trojan War. Calchas prophesied that in order to gain a favourable wind to deploy the Greek ships mustered in Aulis (a port in Boeatia) on their way to Troy, Agamemnon would need to sacrifice his daughter, Iphigeneia. Agamemnon did it.

Society has adjusted to this scientific truth. Today, vast areas are warned about a forthcoming typhoon and measures can be taken to limit the damage, and rescue operations organized if necessary. Tomorrow, science's ability to predict various phenomena including earthquakes, will improve. The aim of scientists who work in this direction and study the environment is to give to humankind the scientific tools that it can use for its protection. There the work of the scientist ends and the work of the State begins. The environment and man in general will benefit in many ways from our close cooperation. It is precisely this kind of cooperation that we have offered and wish to continue to offer to our country with regard to the VAN method. Furthermore, our collaboration with other countries is developing at a fast rate. I am sure that whatever problems may arise will be solved in the end in a spirit of goodwill, just as I am sure that the method will be improved, wherever we are given the appropriate material resources, **with the ultimate aim of protecting the greatest of all goods, human life**.

The Onassis International Prize for the Environment, which is awarded to me today, represents a special honour for my collaborators and me. It brings encouragement to our work, which we shall pursue with the same zeal we have shown until now. May Apollo be our protector and may he ensure that our prognosis, whenever it is made, shall be well received by the Atreides.[2]

On the day after the Onassis Prizes Ceremony, 12 July 1995, almost all the press raised the issue with several leaders, and published excerpts from the speeches of the President of the Onassis Foundation and the four recipients.

2 In Greek mythology, the word Atreides usually refers to one of the two sons, Agamemnon and Menelaus (who became kings of Mycenae and Sparta, respectively, and played a major role in the Trojan War) of Atreus who was a king of Mycenae, but it is sometimes used for his more distant descendants. Here, Varotsos used this word meaning those who occasionally have strength and govern.

17 Disastrous Athens earthquake, 1999

17.1 The preseismic signals recorded

This 5.9 earthquake occurred at 14:56 local time (11:56 Greenwich Mean Time, GMT) on 7 September 1999. Some days before, on 1 and 2 September, two series of preseismic electric signals SES were recorded at Lamia station (LAM). These signals are included in Varotsos et al. (1999) (*Acta Geophysica Polonica*, 1999, Volume 47, issue 4, 435–439.) In the second paragraph, we read that "the selectivity map of this station is still unknown" because this station was new, and therefore (see Sections 3.4 and 3.5) we could not identify the exact epicenter and magnitude of the impending earthquake. The same paragraph continues: "Signals of such amplitude have not been recorded since the installation of the station. A first inspection led to the conclusion that they correspond to an earthquake activity with magnitude M=5.5 (recall that, after an official recommendation since the end of 1995, the prediction is issued only when the expected magnitude is larger than or equal to 6.0)".

In the fourth paragraph of the article the following was written:

> The aforementioned SES activity [Figure 17.1, top left] exhibits the following peculiarity: It lasts several hours, but its last portion has a larger amplitude and also changes polarity. Thus, it could be interpreted as consisting of two separate SES activities, coming from different epicentral areas (these areas may not be far away from each other), if we consider our past experience from the earthquakes at Killini-Vartholomio: The 5.6 earthquake at Killini on September 22, 1988, was followed by the earthquake of magnitude 6.0 on October 16, 1988. In these two earthquakes the SES activities had opposite polarities – see the SES activities on August 31, 1988 and September 29–30, and October 3, 1988, given in the article by Varotsos and co-workers in 1993 – although their epicenters differed only by around 10 kilometers or so...

The above-mentioned article was submitted for publication on 7 September, as shown by the date marked with the left arrow in Figure 17.1.

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_17,

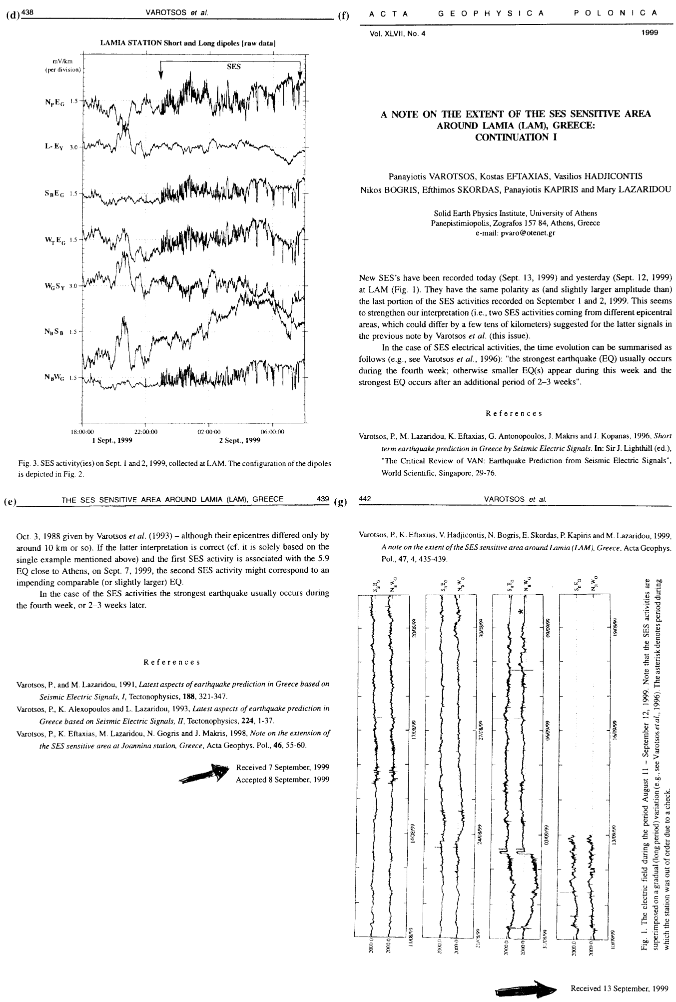


Figure 17.1 (Top left) The preseismic signals recorded on 1 and 2 September 1999. (Bottom left, labelled (e)) The last paragraph of the article submitted for publication to *Acta Geophysica Polonica* on 7 September 1999 (see the date written at the point indicated by the arrow on the left). (Right) The right column shows the second article submitted on 13 September 1999 (see the date indicated by the arrow on the right), on pages 441 (top) and 442 (bottom) of the same issue (*Acta Geophysica Polonica*, Volume 47, No. 4, 1999). Taken from Varotsos (2005). Copyright (2005), with permission from *TerraPub*.

Six days later, on 13 September 1999, a second article was submitted (Figure 17.1, right). The first paragraph reports that new preseismic signals were recorded on 12 and 13 September 1999 (their recordings can be seen at the bottom right part of Figure 17.1). The second paragraph indicates that in such cases the earthquake is expected to occur during the fourth week (after the SES recording) or 2–3 weeks later (as explained in Section 3.5). Finally, a third article was submitted on 26 September 1999, which did not report new preseismic signals, but clarified items mentioned in the two previous articles.

17.2 The earthquakes that followed the preseismic signals

In this section, I will reveal some very important scientific information about the Athens earthquake, which Varotsos writes about on page 111 of his book (Varotsos, 2005). This is the following: The Athens earthquake on 7 September 1999 was not a single event, despite the fact that one earthquake of magnitude 5.9 was officially announced. In 2001, Professor Kikuchi – after making a more careful analysis of this earthquake using a method published in 1991 together with Professor Hiroo Kanamori (*Bulletin of the Seismological Society of America*, volume 81, pages 2335–2350) – made the following important conclusion.

Three and half (3.5) seconds after the main seismic event, a second earthquake of magnitude 5.5 occurred. These two earthquakes came from different faults and, in addition, they had significantly different parameters of focal mechanisms (this means that the faults in these two earthquakes moved differently). The exact parameters of their movement are given in Varotsos (2005; page 111). The fact that actually two different earthquakes occurred essentially agrees with the initial assessment and interpretation given by the VAN team (Varotsos et al., 1999, *Acta Geophysica Polonica*, Volume 47, issue 4, pages 435–439), that the overall feature of the preseismic signals recorded on 1 and 2 September 1999 actually "consisted of two separate SES activities, coming from different epicentral areas…". Recall that the second SES activity had a different polarity from the first one and therefore two, and not one, earthquakes were expected, the epicenters of which "may not be away from each other". (This assessment was sent on 7 September to the Minister of Public Works and Environment. Unfortunately, it was leaked to the press, causing panic among the residents of Athens and the VAN team then received repeated criticism). In other words, the criticism against the VAN team was that, although the electric signals predicted two earthquakes in the region of Athens, the second earthquake had never happened. This was unfair since the earthquake of 7 September, according to the new and more accurate analysis by Professor Kikuchi, undoubtedly consisted of two separate earthquakes. Professor Kikuchi's result was also confirmed by independent satellite observations published in well-known scientific journals.

With respect to the subsequent signals of 12 and 13 September, published in the second article (see Figure 17.1, right), the earthquake was expected to occur probably during the fourth week after the SES recording (but the epicenter determination could not be made, for the reasons explained above). In his 2005 book, Varotsos notes the following: Exactly during the "expected fourth week", an earthquake of magnitude 7.2 occurred on 12 November east of Istanbul, with several hundred victims (a previous earthquake on 17 August 1999, in another area had resulted in about 20,000 dead). Varotsos, however, notes that this relationship cannot be confirmed because such large earthquakes in this region occur very rarely, but neither can it be excluded. Moreover, Varotsos and Alexopoulos had mentioned previously in their articles in the journal *Tectonophysics* (1984) an example where an earthquake of magnitude around 6.5 in the region of the Dardanelles, was preceded by signals recorded on the VAN network.

18 A new concept of time and its applications: Natural time

18.1 The need for a different view on time

As explained in earlier chapters of this book (for example see Section 3.5), the preseismic electric signals of the VAN method (that is, the SES), are detected a few hours to several months before the earthquake. This information is obviously very important if one compares this relatively short time-window with the usual statistical estimates of the seismologists, for example that an earthquake will occur in an area after 30 years plus or minus 10 years, which in practice means that the earthquake might occur after 20 to 40 years. (Note that all these statistical seismologists' estimates are based on the conventional concept of time, that means they count the time in years, days, hours, etc.)

Having thus confirmed the existence of SES after detailed measurements in the countryside in the 1980s, and largely understood the SES physical properties in the 1990s (that is, why one area is sensitive to SES while another is not, or why a sensitive station can record earthquakes from certain seismic areas only, which is the "selectivity" effect), during the next decade of 2000 all our research efforts were focused on the following: whether the above time-window (from a few hours to several months) could be made more precise. In other words, the question is as follows: If you say, for example, the earthquake will happen within the next three months, to avoid agonizing over this whole time period, could we somehow further identify just a few hours to a few days in advance that the earthquake is imminent? This is a very difficult question, because it is not only related to seismology, but is more general: in nature extreme (rare) phenomena occur in many disciplines, and hence the question turns to whether we can know when the occurrence of such a rare phenomenon is approaching. For example, let us mention such an important question in cardiology: while the electrocardiogram gives the doctor a picture of a healthy man, the man may suddenly die. Can we know in advance if this is going to happen? This is the case of the

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_18,

so-called sudden cardiac death, which is a generally intractable problem, but widely known in the science of cardiology. For this reason there are several research groups working on this problem worldwide, and advanced research institutes abroad are exclusively devoted to this research.

In other words, the broader question could be raised as follows: Assume that we observe a complex system (for example, the Earth's crust, the atmosphere, the heart of an individual, etc.) whose function at first glance is "normal" in the sense that our observations on its function show events that more or less occur frequently and maybe periodically. Is it possible from a series of "routine" measurements of such events to extract the information that an extreme (rare) event is going to occur shortly? The answer to this key question constitutes one of the objectives of a specific branch of science called "The Physics of Complex Systems" which has been developed during recent decades.

18.2 What is natural time?

To respond to this broader question, in 2001 Varotsos and his co-workers N. Sarlis and E. Skordas concluded that *time* should be measured in a way that is completely different from the conventional way we use it today. This new way of measuring time is called "natural time", and is symbolized with the letter χ, from the Greek word "χϱόνος", in contrast to conventional time which is usually denoted by t (from the English word "time").

To understand the difference, let us look at Figure 18.1, where the red lines plot what we measure in each one of five consecutive events 1, 2, 3, 4 and 5 observed at different times (as we measure them in the conventional way) marked on the horizontal axis. Consider, for example, that these events are earthquakes (in this case the symbol M in the vertical axis of Figure 18.1(a) stands for the earthquake magnitude) and suppose that earthquake 2 occurs one year after earthquake 1, earthquake 3 three months after earthquake 2, earthquake 4 two months after earthquake 3, and earthquake 5 two and half years after earthquake 4.

The situation in natural time (18.1(b)) is drastically different, since we now "forget" completely the different time intervals between these events. Here, we plot the energies (symbolized by the letter "E" in the vertical axis of Figure 18.1(b)) of the five events at equal distances from each other, because we believe that an observer in natural time is thinking as follows: The sequence (order) of the events is kept in the observer's memory, i.e., which is the first event, which is the second, which is the third, etc., together with the relative energy released by each event compared to the total energy released by all the events (including the last one). In other words, imagine how a primitive man, who is not yet aware of the periodic phenomena that are happening around him (for example, the motion of the Earth around the Sun), remembers extreme events such as major earthquakes, severe storms, etc. The information that the (primitive) observer keeps in his memory are the following **pairs of values**: The first event emitted 40% of the total energy, the second 10%, the third 5%, the fourth 15% and the fifth 30%. (This is equivalent to what is expected to happen in practice: As each new event occurs, the observer compares its energy with that of the previous event or another earlier event which the observer remembers very well.)

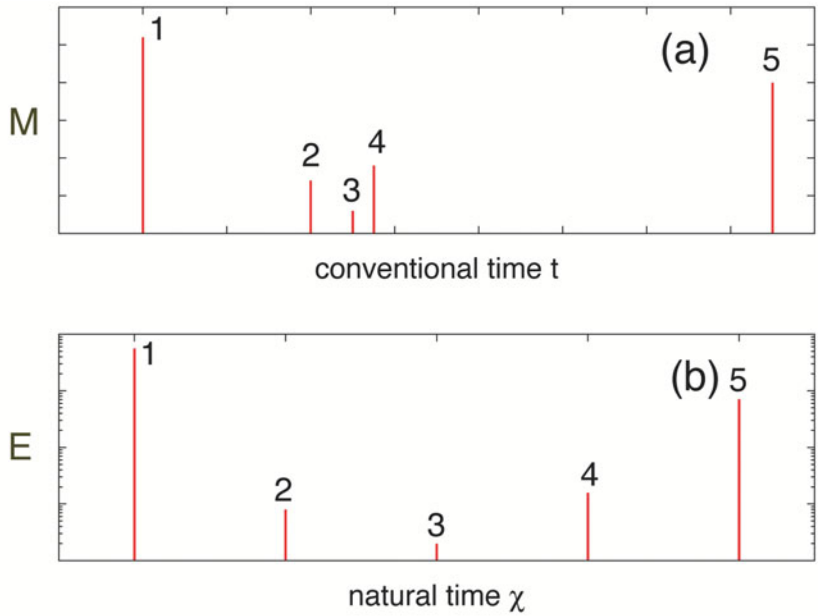


Figure 18.1 (a) How we read in conventional time five events 1, 2, 3, 4, 5, which did not occur at equal time intervals. (b) How these five events are perceived in natural time (note that the distances between them are designed equal, because the observer employs only which event is the first one, which is the second, etc).

Now suppose that an additional event occurs, namely the sixth in a row. Depending on how much stronger or weaker this new event is compared with the ones that have happened in the past, the percentage of the total energy which has been released by each one will change to a greater or lesser degree. In this way, we can "follow" step by step – that is after the occurrence of each new event – what "happens" in the complex system we observe. So for each "step" of the system we can calculate the physical quantities, such as the **entropy S** of the system, which in simple terms is a measure of the "disorder" in the system. If the new event, namely the sixth in our example, is significantly larger than all the previous ones, this implies that the entropy S will change significantly.

Varotsos and his co-workers proposed this new concept of time in 2001 (after demonstrating by fundamental principles of physics that it extracts the maximum "information" possible from the system). They now have the privilege of identifying **when** the system approaches a critical point, which means that in the near future our system will exhibit a **very significant change**: for example, a very strong earthquake in the case of the Earth, or sudden cardiac death in the case of the human body. This work of Varotsos and co-workers was first presented in 2001 at the Academy of Athens (*Athens Academy Proceedings*, Volume 76, 294–321) and was subsequently published in 2002 in the authoritative journal of the American Physical Society (*Physical Review E*, Volume 66, Article No. 011902).

A review of this new methodology, termed "**natural time analysis**", was presented in *Physics of Seismic Electric Signals* (Varotsos, 2005), and explains how in this way the occurrence time of a major earthquake can be determined. (For the reader interested in understanding how the corresponding calculation in natural time is carried out, an Appendix at the end of this book explains it in simple words; in particular see Sections A.1 and A.2.) In order to check the new methodology, this method was first applied in retrospect to large earthquakes that had already occurred in Greece. Subsequently, in several articles that were published in high level journals, mainly in *Physical Review E*, *Physical Review Letters*, and *Applied Physics Letters*, Varotsos and his colleagues showed that the new methodology of natural time applies to other areas of science, such as biology, cardiology, solid state physics (for example, in superconductors), etc. Eight of these articles have been selected by the American Physical Society for inclusion in specific on-line publications (*virtual journals*) which offer researchers quick, convenient access to the latest developments in advanced and frontier research. Of these, I limit myself here to describing briefly the results achieved by natural time analysis when applying it either to determine the time of an impending earthquake (see Section 18.3 and the Appendix) or to an electrocardiogram to identify if there is a danger of imminent "sudden cardiac death" (see Section 18.4).

All the articles that show applications of natural time analysis to different research fields are summarized in the recent book by Varotsos et al. (*Natural Time Analysis: The New View of Time,– Seismic Electric Signals, Earthquakes and Other Complex Time Series*, Springer-Praxis, 2011). Its cover presents excerpts from thoughts related to the meaning of "**time**" expressed by such giants as Aristotle (4th century B.C.), Einstein (in 1921) and Schrödinger (in 1951); note that the latter is one of the founders of quantum mechanics.

18.3 How to determine the time of a forthcoming earthquake

As explained in Section 2.1, the preseismic electric signals SES are emitted when the accumulation of stress in the focal area of the future earthquake reaches a critical value. Then the electric dipoles that exist in this area in any case are oriented all together, resulting in the emission of SES. This "cooperation", or collaborative behaviour, of the electric dipoles marks when the system enters the critical stage and then it starts to gradually approach the "**critical point**" which is the earthquake. Take, for example, the case of the major 6.6 earthquake in the Grevena-Kozani region that occurred on 13 May 1995, in which the preseismic electric signals SES were recorded at IOA station on 18 and 19 April 1995 (Section 14.1). This means that the future focal area – determined from the properties of the SES by the procedure explained in Section 3.5, namely the area described in the prediction text and which appears in the map shown in Figure 14.2 – entered the critical stage from 18 April 1995. So we start from that date and note the (small) seismic events occurring in this area, calculating the respective energy released for each one. Then we analyze these events in natural time, thus designing a plot similar to that shown in Figure 18.1b. In this way, as explained in Section 18.2, we follow step by step (meaning event by event) the evolution of the system by calculating certain physical quantities of this dynamical system upon the occurrence of each new event (the procedure for doing this calculation is explained in the Appendix and in particular in Sections A.1 and A.2). These values of the physical quantities identify whether or not the system has approached the critical point. Thus, we find that when a small earthquake of magnitude 3.4 occurred on the morning of 10 May 1995, the values of the physical quantities revealed that the system was very close to the critical point. The detailed calculations for this case can be found in Varotsos et al. (2005, *Physical Review E*, Volume 72, Article No. 041103). Indeed, three days later, on 13 May 1995, a major earthquake of magnitude 6.6 occurred in the region of Grevena- Kozani in northern Greece.

In other words, the whole prediction process can now be summarized as follows: When we record a series of preseismic signals SES at a station, we analyze their properties (the SES amplitude, the "selectivity map" of the station that recorded the signals, and the ratio of the two SES components along the directions EW and NS, as explained in Section 3.5) and determine the probable epicentral area and the magnitude of the expected earthquake. Thus we learn two of the parameters of the prediction.

Regarding the procedure to specify the occurrence time of the expected earthquake, we distinguish two periods in our research efforts. First, in the period before 2001 (that is **before** the proposal of natural time) we relied on time-charts using events we had noticed on previous occasions (for example, as mentioned in Section 3.5, in some seismic areas the main shock happens at least three weeks after the recording of SES, that is during the fourth week, or 2–3 weeks later). Based on these time-charts we sent the forecasts of the three major earthquakes in 1995 (Chapters 13, 14 and 15).

Second, in the period after 2001 we use the additional analysis in natural time of the successive small seismic events that occur *after* the SES activity in the future epicentral area. So for every small seismic event that happens, we repeat the calculation in the natural time of certain physical quantities. When these quantities reach certain values predicted from the theory of critical phenomena and experimentally verified from earlier cases –hereafter called "**critical values**" – we understand that **the system approaches the critical point**. (For example, the critical value of a quantity labelled $\varkappa_1$, which is termed **variance of natural time**, explained later in Sections A.1 and A.2 of the Appendix, is $\varkappa_1 = 0.070$.) **Then the results show that the main shock occurs after a few days to about a week**. Note that if the accuracy of the recording of the small events is increased, the occurrence time of the forthcoming main shock can be achieved with greater precision. Three such examples for the determination of the occurrence time of the impending main shock are given in Chapters 19, 21 and 22.

18.4 Using natural time to analyze electrocardiograms

In the same way as explained in Figure 18.1, we analyze in natural time electrocardiograms of a few minutes' duration, where the events are the consecutive heartbeats that occur during the recording. To simplify the analysis, we assume that the approximate energy in each pulse is proportional to its duration. Varotsos and his co-workers (2004, *Physical Review E*, Volume 70, Article No. 011106), showed that natural time analysis enables us to distinguish in advance whether there is a possibility of "sudden cardiac death". Moreover, in a later article, Varotsos et al. (2007, *Applied Physics Letters*, Volume 91, Article No. 064106) found that the risk of such a situation happening can be recognized about three hours before its occurrence.

The results of this new approach to analyze electrocardiograms in natural time attracted the keen interest of the international scientific community. For example, the *NewScientist* commented on our approach in its main article in the issue of 3 April 2004 entitled "Clues to sudden death found in heart trace". It also devoted a full-page article (page 10 in this issue) by Duncan Graham-Rowe entitled "Heartbeats warn of sudden cardiac risk" in which it wrote:

> How do you tell a healthy heart from one that could stop without warning? By measuring variations in the length of the heartbeat, according to a team of researchers in Greece...
>
> The findings could provide a way to screen for people at risk of sudden cardiac death. Such people's heartbeat often looks perfectly healthy by conventional criteria. Yet a quarter of million people die each year in the US alone when their heart suddenly stops and, like the soccer player Marc-Vivien Foe, who collapsed and died last year while playing for Cameroon...
>
> Standard approaches to analyzing electrocardiograms tend to focus on the peaks and troughs of the trace. Instead, Panayiotis Varotsos [and colleagues] of the University of Athens have been studying the variation in the length of time it takes for the heart to complete one beat... For Varotsos the crucial test is the variation in the length of each beat, and whether this variation is random. He adapted equations he had previously used to describe physical systems such as earthquakes…
>
> To test the theory, Varotsos and his colleagues analyzed 95 sample electrocardiograms taken from public databases of people with various heart conditions and 10 from healthy patients. He found that the beats of the diseased hearts did indeed vary more randomly and the results are to be published in a future issue of *Physical Review E.*

These results are described in the print issue of *NewScientist* on 3 April 2004, but they were circulated a little earlier, on 1 April 2004, from the journal's website and broadcast and commented upon by many in the international and Greek media.

19 Earthquake in the northern Aegean Sea, 2001

At 03:21 local time on 26 July 2001, a very powerful earthquake occurred in the northern Aegean Sea near Skyros Island, fortunately without casualties. It was felt strongly throughout a large part of Greece. For example, see the front page of the newspaper *Xora* on 27 July 2001 entitled: "Shock. The whole of Greece was shaking" with the headline: "The earthquake struck at dawn on Skyros by 5.7 Richter. Incalculable damage to the island. Terrified, the residents passed the night outside of their homes in squares, due to fear of new earthquakes".

It is interesting to note that the three seismological laboratories in the country (Athens, Patras and Thessaloniki) reported three markedly different magnitudes – that is, 5.7, 6.0 and 6.3 – while the Seismological Institute in Istanbul announced a magnitude of 7.0. The smallest magnitude, 5.7, was reported by the Geodynamic Institute of the Athens Observatory (see also below). This fact was widely quoted in the press.

A second example is the newspaper *Ta Nea* (27 July 2001) which, under the headline "The fight of the seismologists seriously hurts our health" wrote: "Is it 5.7 Richter? No. How can this be? It was 6.0 Richter. But why is it 6.0 and not 6.3? The seismologists were able again to confuse the public with their measurements…".

In the end, the magnitude of this earthquake, as announced by the U.S. Geological Survey, was 6.5 (Mw).

Now let us see what VAN had done in this case. Over four months before the earthquake, that is on 17 March 2001, the station near Volos (VOL) recorded a series of preseismic electric signals (SES activity) lasting about two hours. It took about a week to analyze the signals, and on 25 March 2001, Varotsos and his colleagues Sarlis and Skordas submitted an article to the scientific journal *Acta Geophysica Polonica* (2001, Volume 49, pages 415–421) under the title "A note on the spatial extent of the Volos SES sensitive site". On the last page the date of the receipt of the article is mentioned, i.e., "Note received on March 25, 2001" , while an Appendix informing the reader that the predicted earthquake had just happened, was added on 29 July 2001.

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_19,

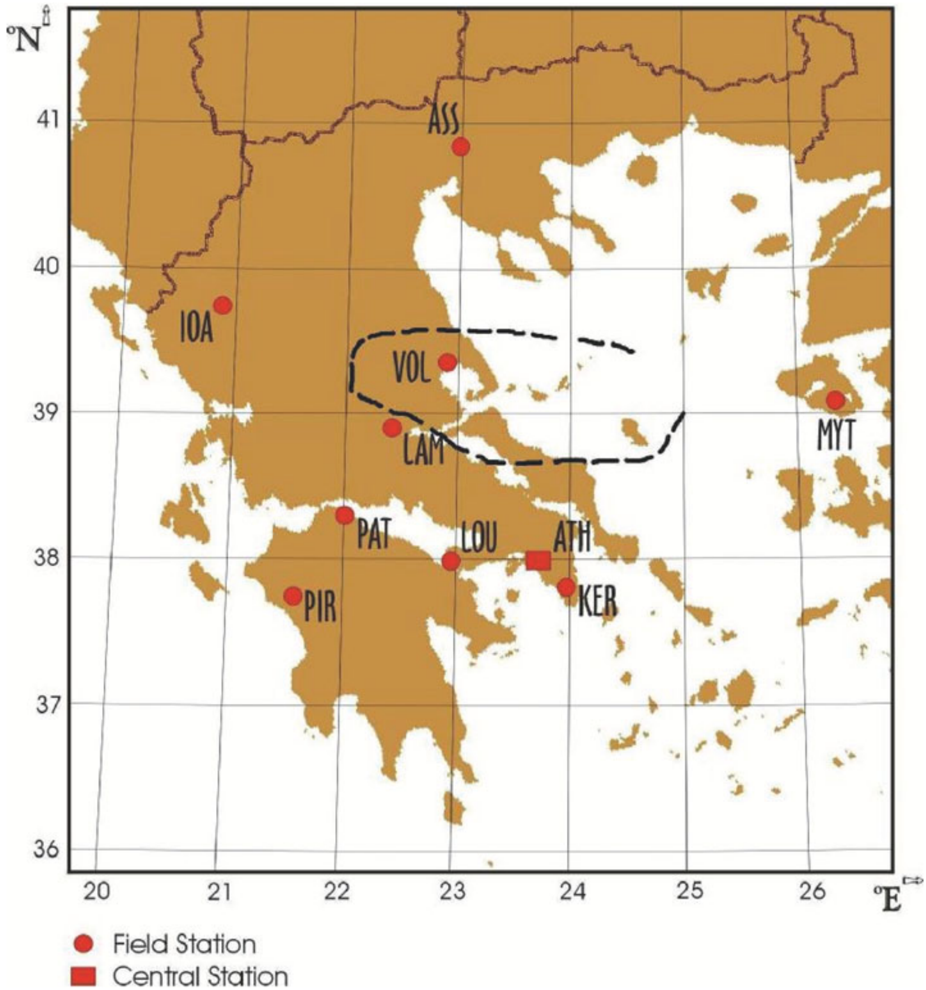


Figure 19.1 The map on the fourth page of the article submitted for publication on 25 March 2001 to *Acta Geophysica Polonica*. The black dashed line around the station VOL indicates the predicted area of the expected earthquake. Taken from Varotsos (2005). Copyright (2005), with permission from *TerraPub*.

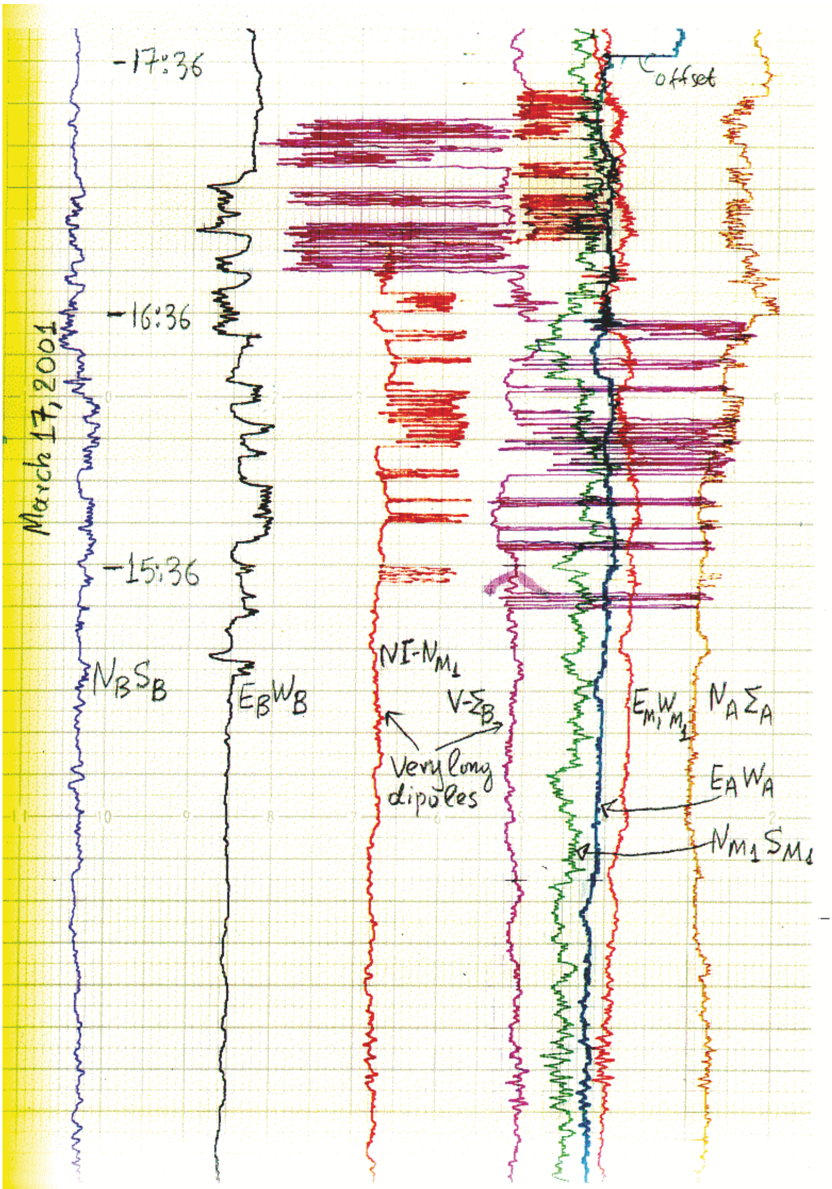


Figure 19.2 The preseismic signals SES as they had been recorded at VOL by the real-time telemetric network on 17 March 2001. They were presented on the third page of the article submitted for publication on 25 March 2001 to *Acta Geophysica Polonica*. Taken from Varotsos (2005). Copyright (2005), with permission from *TerraPub*.

The first two lines of the summary, on the first page of the article, read: "A very strong disturbance, with duration of around two hours, was recorded at the Volos sensitive area on March 17, 2001".

The fourth page of the article included a map, shown in Figure 19.1, where a bold dashed line was designed to show that a very strong earthquake of magnitude 6.5 was expected within this region. (Note that the third page of this article presented the preseismic signals SES, as recorded on 17 March 2001 by the telemetric network; these signals are shown in Figure 19.2.) This line actually encompasses the area near Skyros Island, where the earthquake of magnitude 6.5 occurred.

Let us now focus on the determination of the time of the impending earthquake: The details of this calculation, using the method of natural time analysis (Section 18.3), can be found in Varotsos et al. (*Proceedings of the Academy of Athens*, Volume 76, pages 294–321, 2001). These calculations show that at 19:35 local time on 25 July 2001, **about eight hours before the main shock**, the system approached the "**critical point**", which meant that the main shock was expected at any time from then on.

In summary, on the basis of the preseismic electric signals SES on 17 March 2001 we identified that a magnitude 6.5 earthquake would happen in the area shown in Figure 19.1. In actuality, a major 6.5 earthquake occurred in this area at 03:21 local time on 26 July 2001. Moreover, the analysis in natural time revealed that the earthquake was imminent almost eight hours **before** it occurred.

I finish the description of this case by noting the following: If one relied only on the announcement of the Athens Geodynamic Institute that the magnitude of the earthquake was 5.7, it could in principle "reject" our prediction, which had estimated an expected earthquake magnitude 6.5.This is because the discrepancy between the predicted and the actual magnitude would be 0.8, thus slightly exceeding the "allowed experimental error of 0.7", as mentioned in Section 12.2. But eventually this was not the case because the actual magnitude (Mw) announced by the U.S. Geological Survey was 6.5, that is, equal to the one predicted. But I stress again here that, as explained in Section 3.6, it is unreasonable to require a forecasting method, such as VAN, to predict the magnitude of an earthquake with excellent accuracy when even after an earthquake has occurred the seismological institutes differ so much in their measurements, namely announcing magnitudes ranging from 5.7 to 7.0.

In the case of this earthquake, as already mentioned, there have been many reports in the press. I show here what Mr Akis Tselentis, Professor of Seismology at the University of Patras, said a week after this earthquake, in an interview with the newspaper *Business Consultant* on 3 August 2001:

> "The VAN team does important work at a global scientific level, although lately some seismologists have sought to embrace the method of Professor Varotsos and his colleagues. We have seen that four groups of seismologists claim to have predicted the earthquake of Skyros, but did not send a warning for the impending earthquake." He continued: "The only team that does a serious job is the VAN team, which has been reviled by many seismologists."

20 Publicising predictions: Changes from 2006

From 2006 onwards, the rapid expansion of the internet world-wide gave us the capability of publicizing the VAN forecasts in a timely and, above all, in an authoritative manner, so that everybody (including, of course, all the research institutes worldwide and the State) could be informed about the details of our estimate for an upcoming earthquake almost simultaneously with our submission for publication to a scientific journal. This method was decided upon for the following reasons.

Let us first explain briefly how an article is published in a scientific journal, a process that is always followed by our research group (this has also been described by Professor Haroun Tazieff, as explained in Section 7.1). When authors submit their work for publication, the journal's editorial board selects three scientists, termed Referees, who have expertise in the research field of the submitted work. After carefully studying the work, the Referees, who are not identified to the authors, assess it, usually recording a series of objections or questions on various aspects of the work to send to the editorial board. Then the board invites the authors to answer these Referees' questions point by point, and also to improve the text of their work so that future readers will not have the same queries. If the Referees deem the answers satisfactory, the editorial board decides that the work is accepted for publication, otherwise the paper is rejected. If the work is accepted, it is sent for printing and is published a few months after the decision. But this whole process of scientific evaluation, from the moment the work is submitted until its publication as a scientific article, usually takes 6–8 months or even longer (in some cases it could be as long as 2–3 years as happened with two articles by Varotsos and Alexopoulos published in *Tectonophysics* in 1984, see Section 4.3).

From the above, it is obvious that if the VAN team records significant preseismic electric signals SES and submits them for publication, in view of the fact that the time from the SES recording until the earthquake occurrence is at the most 4–5 months, the scientific community (and the public) will be informed of the content of this scientific work only **after** the earthquake. Thus, neither the State nor the population could take precautionary measures. To overcome the difficulty, therefore, after 2006 the VAN team adopted the following procedure: First we send the work to a specific scientific site, www.arXiv.org in the

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_20,

library of Cornell University in the USA, where, after a rapid examination of its content, it is publicized the next day with a stamp indicating the submission date.

Immediately after, we submit our work to a leading scientific journal which follows the time-consuming evaluation procedure explained above. Of course, we then inform the editorial board of the journal that we have already uploaded the work to the above-mentioned valid scientific website (the work should not be uploaded to any invalid site). Note that *not* all journals allow this procedure. The VAN team chooses to submit to those authoritative scientific journals that allow it. For example, *Physical Review*, highly respected internationally as one of the most prestigious journals in physics, belongs to the American Physical Society which allows (and encourages) this procedure so that the scientists of economically weak countries (which are unable to pay the high fees required by the leading scientific journals) have free access to even the most recent scientific knowledge through this website.

There follows a concrete example, from which it will become apparent why we chose this procedure. On 13 February 2006, we recorded significant preseismic signals SES at the VAN station located near Patras (PAT; see Figure 3.2). After careful analysis, which lasted about 12 days, we concluded that a major earthquake of magnitude around 6.0 would occur west of Patras in the Ionian Sea. We then prepared an article containing the relevant scientific material of this prediction, which was publicized on Cornell University's above-mentioned scientific website on 25 February 2006 (see arXiv:cond-mat/0602603v1). The third line of the summary reads: "... [Here] we analyze **recent** data on Seismic Electric Signals, which support the view that ..."

On the same day (25 February), we submitted this article to *Physical Review E*. After having followed the time-consuming process of the scientific evaluation, explained above, the article was finally published six months after its submission, namely on 23 August 2006 (Volume 74, Article No. 021123).

Nearly six weeks after the SES recording, during the first half of April 2006, there were repeated earthquakes in the region of Zante (Zakynthos) Island, which is in the predicted area, with magnitudes amounting to 6.1 Furthermore, note that during the evaluation process of the paper in *Physical Review E*, by applying the method of natural time analysis, we found that the system approached the **critical point** around midnight of 31 March, about two days before the initiation of intense seismic activity with a strong earthquake of magnitude 5.3 at 02:50 local time on the morning of 3 April 2006.

For example the newspaper *Eleftherotypia* of 13 April 2006 had the headline "Dance of Richter revolutionized again Zakynthos Island and western Greece" and subtitled "5.8 and 5.4 Richter announced the Athens Geodynamic Institute, while 6.1 and 5.6 the University of Patras", also wrote: "The dance of Richter triggers a new round of clashes between seismologists. Yesterday afternoon [12 April], in a meeting at the Ministry, the seismologists expressed cautious optimism that after the triple, strong, occurrence of earthquakes [on 11 April] **the phenomenon rather began to wane**. However, two very strong shocks just before 8 pm [that is, **after** the above meeting] **showed the opposite**. Once again, the seismological institutes of Athens and Thessaloniki gave different magnitudes from those of the Patras [University]..."

However, in this case, the VAN team, having followed the new procedure described above, had already publicized on 25 February 2006 our forecasts on the website of Cornell

University, thus letting everybody know in advance that major earthquakes with magnitudes of around 6.0 were expected to occur in the region (while our article in *Physical Review E* – through the normal process of scientific evaluation – appeared, as I mentioned, a few months after the earthquakes' occurrence).

The following clarification might be useful: Recall that after an official recommendation of the "Special Committee on Earthquake Prediction of the Council of Europe", from 1996 onwards (see Section 17.1) predictions should be issued *only* when the expected magnitude is approximately 6.0 or larger. Accordingly, this is why we publicized our prediction in advance since the amplitude of the recorded signals SES in the above case led us to conclude that the expected magnitude of the upcoming earthquakes would be approximately 6.0.

Let me summarize. The procedure followed for the communication of the forecasts by the VAN team after 2006 consisted of the following two almost simultaneous actions. First, we publicize the prediction on the above-mentioned scientific website of the Cornell University Library. Second, we submit our article – which includes all the information related to the prediction – for publication to an international journal through the usual evaluation process. This way, which is perfectly consistent with scientific ethics, ensures:

(a) The reliable and timely (i.e., long **before** the earthquake) publication of all information about our estimate of **future** seismic activity.

(b) The rigorous scientific evaluation of our research results from internationally distinguished experts (i.e., the Referees appointed by the Editorial Board of the scientific journal), and **not** by a committee chosen by the political leadership of the Ministry of Public Works whose members do not guarantee a reliable scientific evaluation because they do not have expertise on the research topic to be evaluated. (Remember, for example, what happened **before** the destructive earthquakes in Pirgos in 1993, described in Section 9.1.)

(c) We **preclude the false leak** of the prediction information in the media (and from there to the population), as unfortunately happened before the disastrous 6.5 earthquake in Eratini-Egion in 1995, described in Section 15.2.

21 Earthquake in southwestern Greece, 2008

21.1 What happened before this earthquake

At 12:09 local time (10:09 GMT) on 14 February 2008 a big earthquake occurred in southwestern Greece, near Methoni, which – according to the U.S. Geological Survey – had magnitude 6.9 (Mw) and was felt even in neighbouring countries. It was the largest earthquake to occur in Greece since 1983, that is, since the date when the VAN team completed the installation of their telemetric network.

Just over a month before, on 6 January 2008, there had been another major earthquake (Mw = 6.2, according to the U.S. Geological Survey) near Leonidio, in southern Greece, which was felt throughout most of the country. Before this earthquake, on 23 November 2007 the VAN team had publicised on the Cornell University Library website (see Chapter 20) a warning for an impending earthquake of magnitude 6.0, as will be further described below. This earthquake seemed to surprise the media, public opinion, and the State. After that, however, they began to build on our first indications that strong seismic activity would continue elsewhere. The disturbing thought that the next earthquake could cause victims persuaded Varotsos to speak publicly. (Recall that he had stopped speaking to the media after the Eratini-Egion earthquake in 1995, see Section 15.2.) He decided to do so with an open lecture at the University of Athens, under the title: “Preseismic Electric Signals. Analysis in Natural Time: Recent results”, which he gave on 10 January 2008, that is, just four days after the 6.2 earthquake on 6 January 2008.

The newspaper *Eleftherotypia* on Sunday 13 January 2008 reported excepts from this lecture relating to the prediction of the earthquake of 6 January, and published the map that marked the epicenter of the earthquake in Leonido.

Subsequently, the newspaper turned to the new findings reported, that caused strong interest, and wrote: “There is interest on the collected data concerning the existence of **new faults** (hitherto unknown) in the Mediterranean region, the possible behavior of which is currently being investigated. However, P. Varotsos did not want to specify in detail the

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_21,

up to date results of this investigation... There are faults which could give earthquakes of magnitudes around 7.5, and even reach 8.0."

The journalist Mrs Georgia Linardou who wrote the above lines had correctly understood from Varotsos' talk that there was **new data** which was currently being investigated but Varotsos did not proceed at that time to give details. Indeed, Varotsos had in mind that there were **new preseismic signals, indicating strong activity in a new area** (this was the main reason for his finally deciding to speak,), **but their recording still continued**. Actually, the strongest signals until that moment had been recorded just a few hours before Varotsos' speech, as will be seen below.

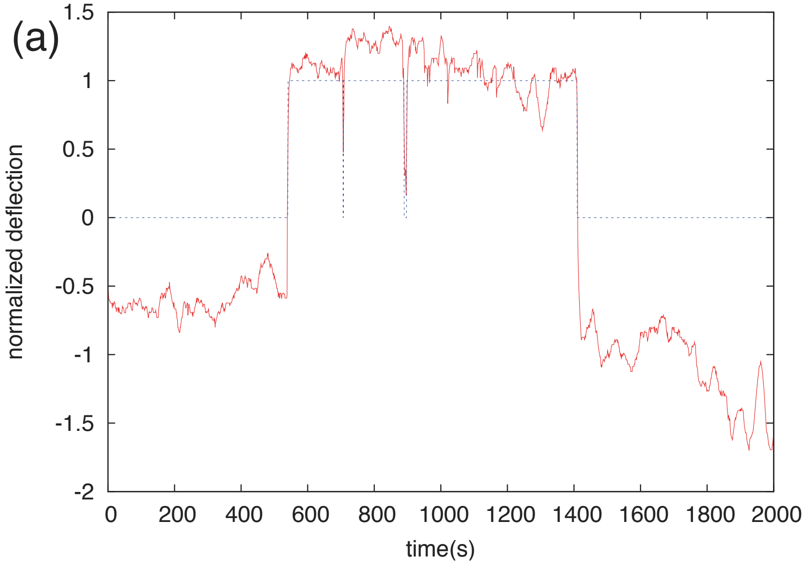
21.2 The preseismic signals and how they were publicized in advance

It is not possible here to describe all the electric signals SES recorded, because there were too many and some of them lasted up to five days. I describe only those that were the strongest and led us to conclude that major earthquake activity was going to occur. (Recall that, as explained in Section 3.5, what governs the magnitude of the impending earthquake is the amplitude or the intensity of the SES and not the duration of the preseismic signals.) These signals were recorded on 10 January 2008 at PAT station as well as on 14 January at Pirgos (PIR) station. Our natural time analysis of the small events after the SES recorded at PAT station showed on 1 February 2008 that strong seismic activity was approaching. Thus, we immediately followed the procedure explained in Chapter 20, and uploaded on 1 February 2008 an article to the scientific website of the Library at Cornell University.

In the upper-left paragraph on page 12 of this article, we read: "... two additional SES activities have been recorded as follows (see Fig. 16 [here Figure 21.1]). One SES activity at PAT station on January 10, 2008 and another one on January 14, 2008 at the PIR station in western Greece... Their subsequent seismicities are currently studied … in the following areas: Concerning the former SES activity at PAT the areas are depicted in Figure 13 [that is the rectangle with black continuous contour in Figure 22.3, but now the section to Rio-Antirio and westwards is indicated], while for the one at PIR on January 14, 2008, the subsequent seismicity is studied in the area B of Figure 9 as well as in the larger area: North (from 36.6º and 38.6º) East (from 20º to 22.5º) [this area is shown in Figure 21.2 with the red rectangle] and the one surrounding the epicenter (North 36º, East 23º)".

21.3 The two 5.5 earthquakes in previously inactive faults near Patras

Indeed, on 4 February 2008, just three days after the appearance of our article, there were two strong earthquakes near Patras. Almost all the press referred to these events the next day, 5 February 2008. For example, the newspaper *Ta Nea* headed the article "The riddle of the Patras seismic Domino" and subtitled it "Richter chain in Western Greece ... was felt particularly in Achaia, Elia and Etoloakarnania" and then wrote: "successive earthquakes



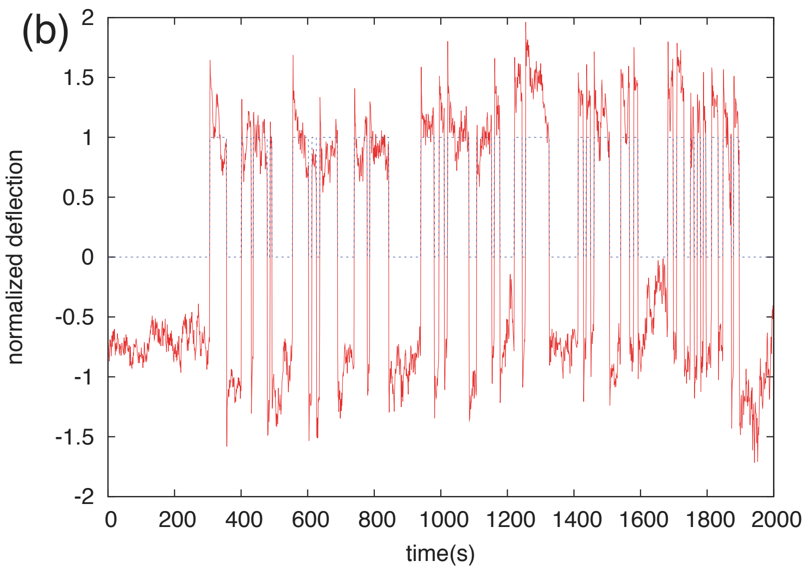


Figure 21.1 The preseismic electric signals (SES activities) recorded at the stations PAT (above, Figure 1(a)] and PIR (below, Figure 1(b)) on 10 and 14 January respectively, as publicised on 1 February 2008, in the article arXiv:0711.3766v3 [cond-mat.stat-mech].

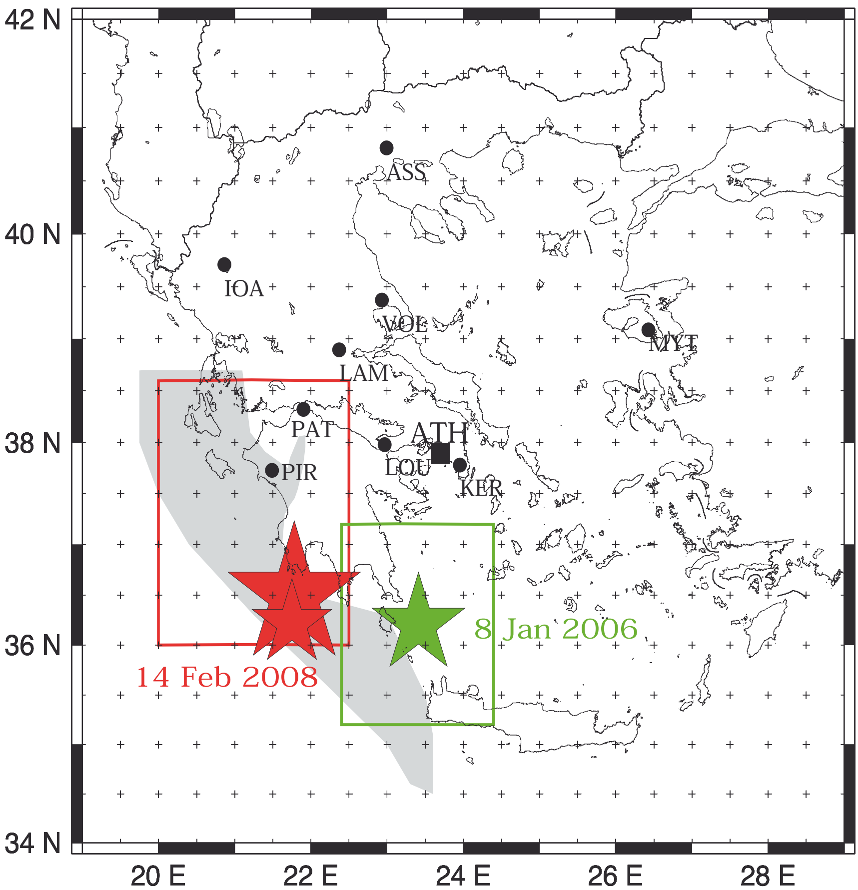


Figure 21.2 The area described on page 12 (see arXiv:0711.3766v3 [cond-mat.stat-mech]) of the article released on 1 February 2008 **as being the most likely for the upcoming earthquake** that would follow the SES activity recorded at the PIR station The area is: North (from 36.0° to 38.6°) East (from 20.0° to 22.5°) shown by the left red rectangle.

yesterday evening shook western Greece. The scientists characterize as a riddle this seismic excitation in the Chalandritsa region of Achaia in the mountain Erimanthos, which resulted in two strong earthquakes of magnitude 5.5 (at 10:25 at night) and 5.5 a quarter after midnight." Under this last report was a piece entitled "The fault" in which the newspaper wrote: "We are dealing with a puzzle," said the Professor of Geology at Athens University ... Mr. E. Lekkas, "based on what we know, these faults were inactive ...".

Remember that almost three weeks earlier, on 13 January 2008, the newspaper *Eleftherotypia* referred to Varotsos' speech of 10 January, and wrote that there was evidence for the activation of new faults, the behaviour of which was currently under investigation.

21.4 The 6.9 and 6.5 earthquakes in southwestern Greece

The two earthquakes near Patras actually occurred in the first region that had been predicted in our article of 1 February on the basis of the SES activity at PAT shown in the upper part of Figure 21.1. But the prediction still remained open for the major earthquake that would happen after the strongest SES activity at PIR station (Figure 21.1, below) and which should have an epicenter in the second area described in Section 21.2 (as shown in Figure 21.2). This is why we continued our natural time analysis in the latter region, which showed that, approaching 10 February, the system was very close to the critical point (that is, close to the occurrence time of the big earthquake in that area).

On Sunday 10 February 2008, the newspaper *Ethnos* had a central article on its front page, entitled "Forecast-mystery for an earthquake of 6 Richter" with the headline "Preseismic vibrations again from the VAN team".

In addition, in an extensive two-page article (by J. Kritikos) on pages 36 and 37 of the same day, *Ethnos* presented much of the detail (that is, a copy of the SES, the expected epicentral area and the magnitude) contained in our 14-page paper posted on the Cornell University website on 1 February 2008. In the second paragraph of that article (page 36), the newspaper wrote: "The scientific conclusion of the two strong preseismic electric signals SES recorded by the VAN network on January 10 at Patras on 14 January at the Pirgos station, is that **a strong earthquake greater than 6.0 Richter is imminent!**"

Anxiety peaked on Monday 11, Tuesday 12 and Wednesday 13 February, with almost all the press referring to the *Ethnos* article.

On Thursday 14 February 2008 at 12:09 local time, a great earthquake occurred, whose magnitude, according to the American Geological Survey and Harvard University was 6.9; according to the Geodynamic Institute of the Athens Observatory it was 6.5. About two hours later, a second earthquake of magnitude 6.5 followed. The epicenters of both earthquakes were inside the predicted area, and are marked in Figure 21.2 with red stars, one large and one smaller.

The next day, Friday 15 February 2008, almost all the press referred to these two major earthquakes by emphasizing the confirmation of the VAN prediction, with extensive publications. The newspaper *Adesmeftos Typos* titled its story "Richter Terror" with the headline: "Within two hours earthquakes 6.5 and 6.4 of Richter scale shook Greece. The epicenter in Methoni” and sub-titled: “THE VAN TEAM HAD PREDICTED THE NEW HIT”.

Also on the same day, the headlines in the newspaper *Eleftherotypia* were: “Southwestern Greece is shaking” and subtitled “Akis Tselentis: Perfect success for Varotsos”.

In the same newspaper that day an article appeared on pages 20 and 45 referring to these earthquakes. In particular, on page 45 under the central title: “New Richter ‘twins’” and subtitled “The Varotsos article at Cornell”, the newspaper presented a photo of Varotsos together with a reproduction of the first page of the article published on the scientific website of the Cornell University Library almost two weeks **before** the earthquakes. It wrote:

> On 1 February 2008, Professor Varotsos anticipated the fierce earthquakes that occurred yesterday south of Methoni with an article that was publicized by the VAN research team at the University of Cornell. This was revealed yesterday in our newspaper by Professor of Seismology at the University of Patras, Akis Tselentis, who also said that “Mr. Varotsos succeeded in this forecast with precision, since on page 12 of his article he had described the coordinates of the expected area for the yesterday’s earthquakes and this was verified … And I, on my own initiative, tried subsequently, with personal letters to the Chairman of the Seismic Hazard Committee, that I also copied to the Director of the Geodynamic Institute of Athens and to the President of EPPO, to draw attention to the point that the region is active and that we should take some measures ... It is fortunate that the earthquake epicenters were in the sea. If the earthquake had been on land we would surely be mourning victims and there would have been tremendous impact and damage ...”.

21.5 The international impact of the prediction

Many international media and scientific journals referred to this VAN prediction, hosting the opinions of foreign scientists who were aware of the 1 February 2008 article by Varotsos et al after its appearance on the scientific website of the Library at Cornell University, and who watched the subsequent events with great interest. All the foreign experts said they were impressed by the great progress that the VAN research had made with such a difficult problem, and proceeded to give flattering comments, noting that all three parameters, namely the epicentral area, the magnitude and the time of the forthcoming intense seismic activity, had been identified successfully.

The journal *EOS*, the official newsletter of the American Geophysical Union, published an article by two Japanese experts in earthquake forecasting, namely Seiya Uyeda, Professor at the Earthquake Prediction Research Center of Tokai University, and Professor Masashi Kamogawa at the Department of Physics of Gakugei University in Tokyo (*EOS*, Volume 89, Number 39, 23 September 2008, in the NEWS column).

The exact content of this article is as follows:

> *EOS*: Vol. 89, No. 39, 23 September 2008.
>
> **NEWS: The Prediction of Two Large Earthquakes in Greece**
>
> The VAN experimental method of short-term earthquake prediction (named after the initials

of three Greek physicists, Panayiotis Varotsos, Kessar Alexopoulos and Konstantine Nomicos) has been used to monitor preseismic electric signals since the 1980s [see Varotsos, 2005]. From observed telluric current signals, called seismic electric signals (SES), the epicentral area, magnitude and the occurrence time of an impending earthquake are estimated. SES are interpreted as having been emitted when the focal region in which the earthquake in question could occur has entered the critical regime (i.e., a stage close to rupture).

The VAN method recently reached the stage of possibly enabling the narrowing of the time window of earthquake prediction to the order of a few days. This narrowing is made possible by the use of a new method called "natural time analysis". This analysis has been developed to identify the time when a dynamic system (i.e., a system evolving with time) exhibits behavior similar to a phase change (Varotsos et al., 2008, and references therein). On the hypothesis that the main shock earthquake is a critical phenomenon, when SES activity is observed, natural time analysis is conducted on the seismicities of small earthquakes in the suspected future epicentral area solely by considering their order of occurrence and the energy emitted by each of them. The term 'natural time analysis' stems from the disregard of the conventional time of the earthquakes occurred. It has been found that such an analysis enables the identification of the time of the main shock usually within a few days before it occurs (see P. Varotsos et al., Seismic electric signals and 1/f 'noise' in natural time, at http : //arxiv.org/abs/0711.3766).

On 14 February 2008, a large earthquake (U.S. Geological Survey reported M=6.9) and its probable aftershock (M=6.5) occurred in the Ionian Sea close to the region of southwestern Peloponnese, in Greece. The paper by P. Varotsos et al.s (http://arxiv.org/abs/0711.3766), which appeared 2 weeks earlier (1 February 2008), reported that new electric signals were registered on 14 January at the Pirgos VAN electrotelluric station in western Greece, the earthquake for which, however, had not yet occurred. The report also indicated that on the basis of the recorded signals amplitude, the magnitude of the impending earthquake had been expected to be more than 6.0 and that the epicenter would be inside the area with coordinates 36 to 38.6 degrees North, 20 to 22.5 degrees East, that is approximately in a 250 $\times$ 260 square kilometer area in the southwestern Peloponnese.

On 10 February 2008 an article in the front page of the Greek newspaper *Ethnos* announced that a magnitude 6.0 earthquake would occur imminently in the predicted area. Four days later, on 14 February, the two earthquakes occurred inside the expected area. The first one, the largest in Greece since 1983, was also felt even in some adjacent countries. This was a case where prediction by the VAN method was documented in a scientific publication as well as in the public media well before the main shock occurrence.

References

1. P. Varotsos (2005), The Physics of Seismic Electric Signals, TerraPub, Tokyo.

2. Varotsos, P. A., Sarlis N.V., Skordas E.S., and Lazaridou M.S. (2008). Fluctuations under time reversal of the natural time and the entropy distinguish similar looking electric signals of different dynamics, Journal of Applied Physics 103, 014906.

22 Earthquake between Patras and Pirgos, 2008

22.1 What happened before the earthquake

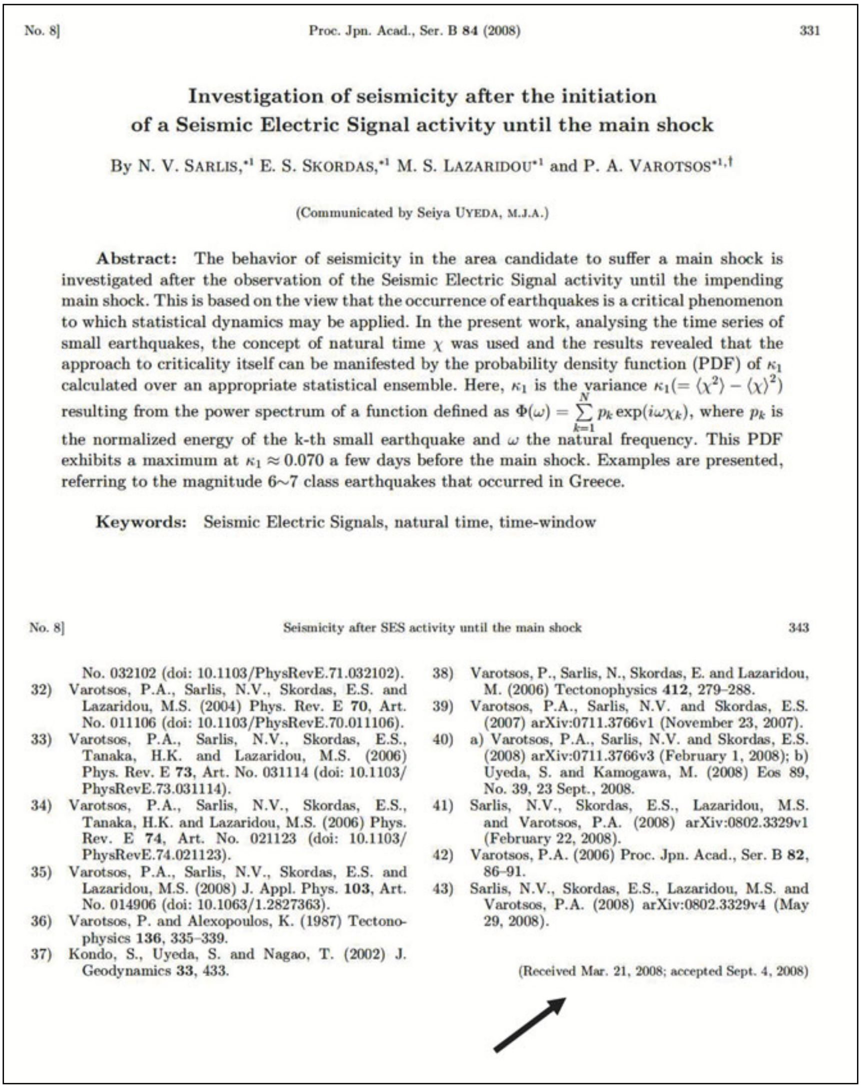
Nearly four months after the 6.9 earthquake (14 February 2008), another very strong earthquake of magnitude 6.5 occurred between Patras and Pirgos in the Andravida-Lechaina region which caused extensive damage.

I now describe what happened before this earthquake. About 10 weeks before the earthquake, namely on 21 March 2008, we submitted for presentation (and publication) to the Japan Academy an article entitled "Investigation of seismicity after the initiation of a Seismic Electric Signals activity until the main shock" authored by N. Sarlis, E. Skordas, M. Lazaridou and P. Varotsos. The first and the last page of this 13-page article appear at the top and bottom respectively of Figure 22.1. This work, explained in more detail below, reports that a new sequence of very strong preseismic signals (SES activity) was recorded at Pirgos (PIR) station from 29 February until 2 March 2008 as well as suggesting a more accurate method to determine the occurrence time of the impending main shock. At the end of the last page the date of the receipt of this work by the Japan Academy, 21 March 2008, is shown by an arrow.

The previous day, 20 March 2008, following the procedure explained in Chapter 20, we publicized the article on the scientific website of the Library at Cornell University (see arXiv:0802.3329v2 [cond-mat.stat-mech]).

In the fourth page of this article, we now indicate the points that require special attention. Two paragraphs before the Conclusion, it is explained that the area with coordinates North (37.5º to 38.6º) East (20.0º to 23.3º) – was studied until the morning of 19 March, but **did not** show critical behaviour. Moving to the next paragraph (i.e., the one before the Conclusion), the text states the following: "The ongoing SES data collection and analysis, however, **revealed similarities between the current case and the one that preceded**

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_22,



No. 8] Proc. Jpn. Acad., Ser. B **84** (2008) 331

Investigation of seismicity after the initiation of a Seismic Electric Signal activity until the main shock

By N. V. SARLIS,[*1] E. S. SKORDAS,[*1] M. S. LAZARIDOU[*1] and P. A. VAROTSOS[*1,†]

(Communicated by Seiya UYEDA, M.J.A.)

Abstract: The behavior of seismicity in the area candidate to suffer a main shock is investigated after the observation of the Seismic Electric Signal activity until the impending main shock. This is based on the view that the occurrence of earthquakes is a critical phenomenon to which statistical dynamics may be applied. In the present work, analysing the time series of small earthquakes, the concept of natural time χ was used and the results revealed that the approach to criticality itself can be manifested by the probability density function (PDF) of κ_1 calculated over an appropriate statistical ensemble. Here, κ_1 is the variance $\kappa_1(= \langle\chi^2\rangle - \langle\chi\rangle^2)$ resulting from the power spectrum of a function defined as $\Phi(\omega) = \sum_{k=1}^{N} p_k \exp(i\omega\chi_k)$, where p_k is the normalized energy of the k-th small earthquake and ω the natural frequency. This PDF exhibits a maximum at $\kappa_1 \approx 0.070$ a few days before the main shock. Examples are presented, referring to the magnitude 6~7 class earthquakes that occurred in Greece.

Keywords: Seismic Electric Signals, natural time, time-window

No. 8] Seismicity after SES activity until the main shock 343

No. 032102 (doi: 10.1103/PhysRevE.71.032102).
32) Varotsos, P.A., Sarlis, N.V., Skordas, E.S. and Lazaridou, M.S. (2004) Phys. Rev. E **70**, Art. No. 011106 (doi: 10.1103/PhysRevE.70.011106).
33) Varotsos, P.A., Sarlis, N.V., Skordas, E.S., Tanaka, H.K. and Lazaridou, M.S. (2006) Phys. Rev. E **73**, Art. No. 031114 (doi: 10.1103/PhysRevE.73.031114).
34) Varotsos, P.A., Sarlis, N.V., Skordas, E.S., Tanaka, H.K. and Lazaridou, M.S. (2006) Phys. Rev. E **74**, Art. No. 021123 (doi: 10.1103/PhysRevE.74.021123).
35) Varotsos, P.A., Sarlis, N.V., Skordas, E.S. and Lazaridou, M.S. (2008) J. Appl. Phys. **103**, Art. No. 014906 (doi: 10.1063/1.2827363).
36) Varotsos, P. and Alexopoulos, K. (1987) Tectonophysics **136**, 335–339.
37) Kondo, S., Uyeda, S. and Nagao, T. (2002) J. Geodynamics **33**, 433.
38) Varotsos, P., Sarlis, N., Skordas, E. and Lazaridou, M. (2006) Tectonophysics **412**, 279–288.
39) Varotsos, P.A., Sarlis, N.V. and Skordas, E.S. (2007) arXiv:0711.3766v1 (November 23, 2007).
40) a) Varotsos, P.A., Sarlis, N.V. and Skordas, E.S. (2008) arXiv:0711.3766v3 (February 1, 2008); b) Uyeda, S. and Kamogawa, M. (2008) Eos 89, No. 39, 23 Sept., 2008.
41) Sarlis, N.V., Skordas, E.S., Lazaridou, M.S. and Varotsos, P.A. (2008) arXiv:0802.3329v1 (February 22, 2008).
42) Varotsos, P.A. (2006) Proc. Jpn. Acad., Ser. B **82**, 86–91.
43) Sarlis, N.V., Skordas, E.S., Lazaridou, M.S. and Varotsos, P.A. (2008) arXiv:0802.3329v4 (May 29, 2008).

(Received Mar. 21, 2008; accepted Sept. 4, 2008)

Figure 22.1 The first (top) and the last (bottom) page of the article by P. Varotsos and his co-workers (*Proceedings of the Japan Academy, Ser. B*, Volume 84, pages 331–343, 2008). The arrow at the foot shows the receipt date of our article by the Academy, 21 March 2008.

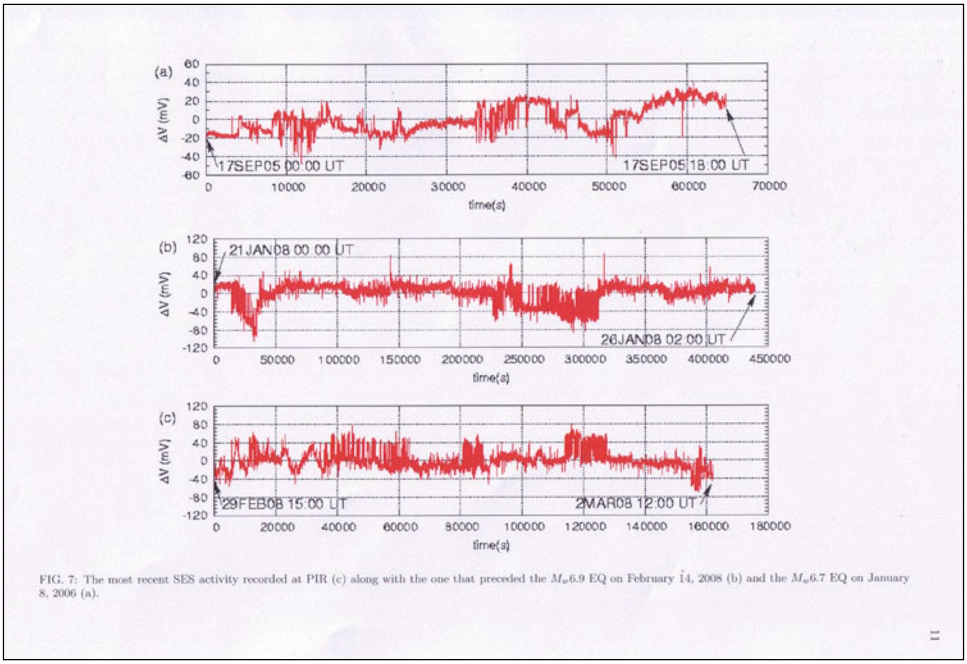


Figure 22.2 Figure 7 of our article, published on 29 May 2008 on the Cornell website (see arXiv:0802.3329v4 [cond-mat.stat-mech]), showing the SES activities of long duration recorded at PIR station before three large earthquakes: (a) the earthquake of magnitude (Mw) 6.7 that occurred at Kythira Island in southern Greece on 8 January 2006; (b) the Mw 6.9 earthquake near Methoni in southwestern Peloponnese that occurred on 14 February 2008; and (c) the SES activity from 29 February to 2 March 2008, recorded in the case under discussion. This figure was also in our article submitted on 21 March 2008 to the Japan Academy.

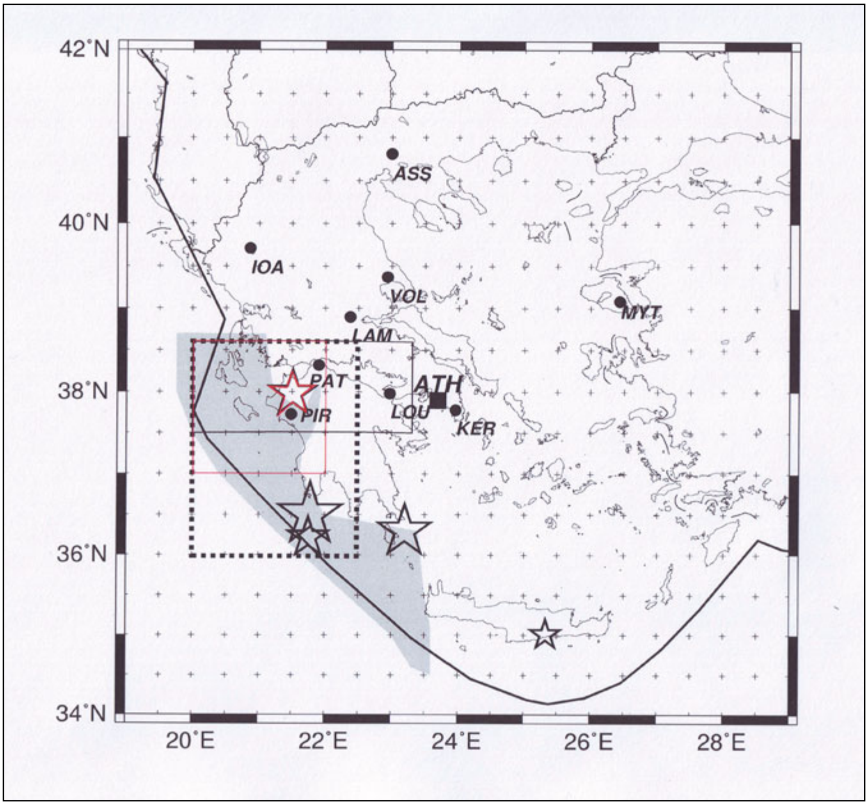


Figure 22.3 Map showing Figure 8 of our article published on 29 May 2008 on the scientific website of Cornell University. The selectivity maps of the PIR station (the shaded area) and of the PAT station (the rectangle with black continuous contour) are shown. Also the broken black line shows the expected area before the major earthquakes that occurred on 14 February 2008 near Methoni. Finally, the red line marks the most likely area for the epicenter of the expected earthquake.

the aforementioned event of February 14, 2008 (details will shortly appear elsewhere)[1]. Thus, the **procedure suggested in this paper is also currently applied to the seismicity in the area North (37.0º to 38.6º) East (20.0º to 22.0º)**".

Notice that this area suggested is a rectangle (outlined in red in Figure 22.3 that will be discussed later), which is a smaller part of the rectangle we had indicated in Figure 21.2 before the great earthquakes of 14 February 2008, because we now exclude the area to the south surrounding the epicenters of these earthquakes, as well as excluding the areas with coordinates East of Patras.

On 15 April 2008, Professor Uyeda, informed us, via e-mail, that "the work was presented at yesterday's Meeting of the Japan Academy and was received very warmly". (Note that the members of the Japan Academy include seven Nobel Laureates.)

A few weeks later, on 29 May 2008, we published detailed drawings on the Cornell website showing that, after having applied the natural time analysis (as described in Section 18.3) and having followed the individual methodology already announced to the Japan Academy, we observed a behaviour that should be obeyed when a complex system is very close to the critical point, meaning that we had approached the time for the expected major earthquake to occur. The last lines of the text on page 6 of the article read:

"Quite interestingly, this [calculation] exhibits magnitude threshold invariance (a behaviour that should be 'obeyed' at the **critical** point). Since a similar maximum appears simultaneously at the value $\varkappa_1 = 0.070$[2] if we take into account seismic events that have occurred until now with larger magnitudes of either 4.0 or 4.1 [or 3.9, as explained above] as can be verified by an inspection of Figs (11) and (12), respectively." (Note that these two figures can be viewed on pages 15 and 16 of this article, while the figure corresponding to magnitudes larger than 3.9 is on page 14).

In addition, the following two important points are explained in this article:

1. The above calculation in natural time takes into account the small seismic events that occurred after 29 February 2008, when the recording of consecutive SES started at PIR station, and lasted until 2 March 2008. This long duration SES activity is shown in Figure 7(c) on page 11 of our article, which is reproduced here in Figure 22.2(c).

In this figure, the current SES activity, from 29 February to 2 March, is *intentionally* compared with the SES activities that had been recorded at PIR station before the 6.7 earthquake at Kythira Island in southern Greece on 8 January 2006 (see Figure 22.2(a)), and before the 6.9 earthquake at Methoni on 14 February 2008 (Figure 22.2(b)). It is this comparison which revealed that the current SES activity has amplitude equal to that of the two SES activities that preceded the large earthquakes 6.7 and 6.9 in 2006 and 2008, respectively. Thus our article concluded that the magnitude of the expected large earthquake would be about the same. (Note that the recording of the SES activity in Figure 22.2(a) was submitted for publication on 22 October 2005 to the journal *Acta Geophysica,* (Volume 54, pages 158–164, 2006) in an article under the title "Recent

1 This refers to the article to be submitted for publication the following day to the Japan Academy.

2 This value of the quantity $\varkappa_1$, which is termed variance of natural time, indicates **approach to the critical point** (see Sections A.1 and A.2 in the Appendix).

Seismic Electric Signals Activities in Greece", estimating that an earthquake with magnitude of the order of 6.5 would probably occur inside the selectivity map of PIR station. Actually, almost two and half months later, the 6.7 earthquake occurred close to Kythira Island on 8 January 2006).

2. The above-mentioned calculation that led us to conclude on 29 May 2008 that we were approaching the occurrence time of the impending earthquake (since we explicitly wrote that the behaviour observed was that close to a **critical point**) was very detailed in view of the following: In the new methodology proposed in our article in the Japan Academy, we took into account all the possible "sub-regions" of the selectivity map of the PIR station, depicted in Figure 22.3 as a shaded area (this appeared in our article as Figure 8). Recall that this selectivity map contains all the epicenters of the past earthquakes that had produced SES recorded at PIR station. In Figure 22.3, I also show with the two largest black stars the epicenters of the past earthquakes near Methoni in 2008 and close to Kythira in 2006, as well as the following three additional areas. First, the selectivity map of PAT station, shown by the rectangle surrounded by the continuous black line. Second, the area inside the thick broken black line was the predicted area for the big earthquakes that occurred near Methoni on 14 February 2008. Finally the area marked in **red indicates the expected region for the impending large earthquake**, as explicitly stated in the fourth page of our article publicised on 20 March 2008 on the Cornell website.

Summarizing the above, I clarify that, after publicizing our article on 29 May 2008 on the scientific website of Cornell University Library, in which we made clear we had approached the occurrence time of the expected major earthquake, we had made publicly available all the scientific material on the basis of which the expected magnitude was identified to be at least 6.5 in the area depicted by the red rectangle in Figure 22.3. Moreover, I note that our article had been positively evaluated by the Referees appointed by the Japan Academy, who characterized it as "an excellent work with extremely interesting results".

22.2 What happened after the earthquake

At 15:25 local time on Sunday 8 June 2008, a powerful earthquake of magnitude 6.5 occurred, "shaking the whole of Greece", as almost all the press wrote the next day. See, for example, the newspaper *Ayriani* of 9 June 2008 with headlines "FEAR AND TERROR for a new earthquake" and "Varotsos team had predicted the 6.5 Richter".

The epicenter was in the area between Patras and Pirgos close to the region of Andravida at a previously unknown fault. For example, the front-page headline of the newspaper *Eleftherotypia* on 9 June reads "Terrified of the unknown fault", subtitled "An energy equivalent to 15 [atomic bombs of] Hiroshima was released" and on page 47 we read: "Felt in a very great area in almost all the Peloponnese, Western Greece, Ioannina, Karditsa, and Attica (Athens). Particularly it was strongly felt in the city of Patras and the surrounding region". Concerning the casualties, some newspapers said that four people had died, and others quoted two, with more than 100 injured, and many left homeless. For more details see Section 22.4.

22.3 The impact of our prediction abroad

This successful prediction had a great impact abroad. Below is given the scientific information sent by Professor Uyeda on 12 June to the "Working Group for the Electromagnetic Studies of Earthquakes and Volcanoes" of the International Union of Geodesy and Geophysics.

> Japan, June 12, 2008
>
> NEWS ON RECENT VAN ACHIEVEMENT – Seiya Uyeda
>
> At the April 2008 Session of Japan Academy, I delivered a paper by Professor P. Varotsos and co-workers entitled 'Investigation of seismicity after the initiation of Seismic Electric Signal (SES) activity until the main shock'. As well known, the VAN team has long been practicing short-term earthquake (EQ hereafter) prediction by monitoring the telluric current in Greece. The main scope of the paper was to introduce a new objective procedure by which the time-window of the occurrence time of the impending main shock can be shortened to the order of one week. The main basic idea of the procedure is that the EQ is a critical phenomenon in the sense of statistical physics. Therefore, its prediction is equivalent to identifying the time when the seismogenic process enters the critical stage. The main shock will occur within a week or so after approaching the critical point. In the proposed procedure to identify criticality approach, the time series of small earthquakes after the initiation of an SES activity is analyzed in the new time frame, called natural time, that has been developed by the same authors since 2002 in a series of papers in *Physical Review Letters* and *Physical Review*.
>
> The recent examples of application of the new procedure reported in the aforementioned paper included the following two electrical activities recorded at Pirgos (PIR) station in western Greece. One is the case of SES activity observed on January 14, 2008, after which approach to the critical point was recognized on February 10 and the Mw 6.9 earthquake (the largest earthquake in Greece in the last twenty years in the Greek area) occurred at 36.50 North, 21.78 East on February 14. The second is the SES activity on February 29 to March 2, 2008. In this case, criticality approach was noted on May 29 and an Mw 6.5 earthquake occurred on June 8, at 37.86 North 21.50 East, causing a loss of four human lives and damage to hundreds of houses. Description on these and others events will be detailed in the paper to be published in the *Proceedings of Japan Academy* and has already been sent to the arXiv database of Cornell University (to view this version just press http://arxiv.org/ PS_cache/arxiv/pdf/0802/0802.3329v4.pdf). Remarkable is that all these cases had been well documented before the events none of them being post-prediction!
>
> In summary, it now appears that **VAN group unambiguously achieved identification of the time-window, the epicentral area and the magnitude of earthquakes in Greece** [my emphasis].

Scientists from around the world study the scientific website at the Library at Cornell University every day. It is natural, therefore, that many researchers had read our work heralding the imminent earthquake. Thus, in the days immediately after the earthquake's occurrence, we got many congratulatory letters from research centers in Europe, Japan, China and the USA, encouraging us to continue our research efforts. Below I give two examples of e-mails received by Professor Uyeda from Chinese researchers after sending his report of 12 June.

In the first e-mail, the researcher Jean Chu writes:

NEWS ON RECENT VAN ACHIEVEMENT:

Dear Seiya,

This news is so great, Seiya! Congratulations to all those working with, using and support the VAN effort. Now, the challenge is, to have this methodology and others available to the people who are at risk, right now. The social acceptance and use of such methods is where we are all headed. Good Luck and Keep up the Great work!

With love, Jean

In the second message, the researcher Xiaoping Zeng writes:

Dear Seiya,

Thank you for e-mailing the news on a paper by Professor P. Varotsos and his co-workers and their recent achievement.

Congratulations!

All the best,

Xiaoping ZENG

22.4 The extent of the destruction caused by the earthquake of 8 June 2008

As mentioned in Section 22.2, despite our warning to the public about the upcoming danger on 29 May 2008, unfortunately there was the loss of a few human lives. However, if one compares the extensive damage with the small number of victims, one can draw one's own conclusions on whether the population had taken effective precautionary measures upon receiving our warning in late May, despite a number of public assurances by some seismologists who claimed that nothing was going to happen.

In order for the reader to realize the extent of damage on the basis of official data, I present for example the newspaper *Eleftherotypia* on Sunday 22 June 2008.

The newspaper article was entitled "Count their losses" and read as follows:

... Heavy reports on serious damage, according to official figures from the Prefectures Elia and Achaia, with hundreds of people having been left homeless...

In the Elia Prefecture the buildings seriously affected by Enceladus run to the thousands. Of the total 7,100 tested in the region, they found significant problems in 2,200 (in need of immediate repair) and 350 of them had to be demolished. Significant losses were found in the schools of Elia. Five were disrupted by the earthquake and were demolished, while 56 reported cracks ... The earthquake hit the basic infrastructure, roads, water supply, public buildings, etc.

> There are more than 20 cases of roads that have been damaged either by subsidence ... Damage from landslides falling into reservoirs has affected water supplies in many municipalities ... The earthquake has also affected dozens of public buildings, municipal offices, fire stations, tax offices, courts, etc. And more than 30 ancient temples... also over 2,000 companies, small and large, sustained serious damage…
>
> [In Achaia] ... 30% of the 11,000 buildings that have been tested were not residential ... Of the 351 public buildings checked, 204 were classified unfit ... 34 schools needed repairs ...

22.5 Has our decision to publicize forecasts changed after the earthquake of 8 June 2008?

The newspaper *Eleftherotypia* on Sunday 22 June 2008 also ran an article entitled "We predicted the epicentral area, time, and magnitude" and subtitled "The responses of Professor P. Varotsos to the Andravida earthquake" which read:

> With an unanswerable letter, very cautious expressions, Professor P. Varotsos breaks his silence to defend his recent study of earthquake prediction in Andravida. Typical recipients are fellow Professors, students and friends. However, in view of the details given for the prediction of the earthquake in the Peloponnese, the basic beneficiaries are many more outside the Department of Physics. His willingness to answer those who question is apparent and he states:
>
> 'It is understandable that a large part of the population now looks forward to our future work on what might happen to it (Andravida) or other areas of the country. To respond to this, my colleagues and I have to continue our research efforts every day, working almost 24 hours to ensure the good operation of our 10 telemetric stations.'
>
> P. Varotsos does not refer fortuitously to the population. Since the web site where Professor publicises his studies became publicly known, there are many who visit it to learn.

The newspaper then lists the sections of Varotsos' letter, referring to the article publicized on the scientific website of Cornell University on 29 May 2008 that identified the parameters (epicenter, time, and magnitude) of the forthcoming earthquake. The newspaper also presented the map from this article on the basis of which the identification of the parameters of the impending earthquake has been achieved (Figure 22.3 explained in Section 22.1).

Varotsos, obviously influenced by the events of the earthquake in the Peloponnese, now wanted the whole of his time, apart from his teaching duties, to be devoted to his research. Taking into account the great extent of the damage mentioned above, imagine if the number of victims had been greater, as had happened in the past in similar earthquakes on the mainland. In view of these facts, we are fully convinced that it was a good decision to publish the seismic information in advance, when we believed that the impact of an upcoming earthquake could be devastating. Fears that when people learn such information, panic will prevail, have been demonstrated in practice to be exaggerated. This is because in both cases of the 2008 major earthquakes, namely the great 6.9 earthquake in Methoni on 14 February 2008 (Chapter 21), and the 6.5 earthquake in Andravida on 8 June 2008 (discussed in this chapter), when predictions were made public, no panic was noticed.

Knowledge is better than ignorance and the people have the maturity to take the necessary precautionary measures.

23 The VAN earthquake prediction method in other countries: Current views

I start this chapter by stating that the "Inter-Association Working Group for Electromagnetic Studies of Earthquakes and Volcanoes" (EMSEV), founded by the International Union of Geodesy and Geophysics in 2001 after an initiative by the eminent Professor Seiya Uyeda, is now composed of more than 250 corresponding members from 14 countries. Unfortunately, due to the limitation of space, it is difficult to describe here the recent VAN developments in all countries. Thus, I have to restrict myself to describing what is happening in only the following seven countries: Japan, the USA, China, Russia, Mexico, Italy, and France.

23.1 Japan

It should be emphasized from the beginning that Professor Seiya Uyeda has played a key role in the development of the VAN research in Japan since the late 1980s. As already mentioned, he is a member of the Japan Academy of Sciences, and a foreign member of the American Academy of Arts and Sciences, the Russian Academy of Sciences, and the U.S. National Academy of Sciences. For his great contributions to scientific research (see section 1.2.1), Professor Uyeda has been conferred – in addition to several international prizes – an Honorary Doctor of Philosophy from the University of Athens (Greece), see Figure 23.1.

The facts associated with the super-giant Tohoku 9.0 earthquake on 11 March 2011 are discussed separately in the Appendix, and in particular in Section A.4. This is because a discussion of the Tohoku case requires some mathematical background in order to understand better the natural time analysis, which is set out in the first two sections of the Appendix. Thus, here we restrict ourselves to the recent advances in Japan until 2010.

Several articles from Japanese scientists focusing on SES investigations have been published. I mention, for example, just four of them in 2009: Two articles by Y. Orihara and

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3_23,

Figure 23.1 A photo from the Honors Ceremony at the University of Athens on 13 September 1996, in which Professor Uyeda (pictured here together with the author) was conferred Honorary Doctor of Philosophy by the University of Athens, Greece.

colleagues appeared in the November and December issues of the *Proceedings of the Japan Academy* (Volume 85B, pages 435–442 and 476–484, respectively). They reported electrical measurements in different regions of Japan, during which electric signals were recorded. Their analysis showed that these signals did not originate from artificial sources (noise), but from natural processes (earthquakes) within the Earth, **thus being SES**. The other two articles were published in international journals of high prestige. One appeared in the journal *Tectonophysics* (Uyeda et al., Volume 470, pages 205–213), and the other in the *Journal of Geophysical Research* (Uyeda et al., Volume 114, article number B02310). I mention below some characteristic excerpts from these two articles.

The first article in *Tectonophysics* was entitled "Short-term earthquake prediction: Current status of seismo-electromagnetics", in the abstract of which the authors wrote the following:

> …Loss of human lives as a result of earthquakes is caused overwhelmingly by the collapse of buildings within less than a few minutes of main shocks. The most urgent countermeasure consists of two key elements: One is strengthening of weak structures and the other is short-term earthquake prediction. Short-term prediction needs precursors... Nonetheless, nationally funded large-scale earthquake prediction programs always emphasize the need to reinforce seismometer networks. They do not take into account the views of those in the science community, who point to the importance of **non-seismic precursors** ...

In the second section of this article under the heading “Short-term earthquake prediction: Impossibility myth” the authors wrote:

> Although much more difficult than the long- and intermediate-term predictions, the short-term prediction is evidently most effective for the purpose of directly saving human life ... We draw attention to the recent work of Varotsos and his group, based on a new time domain called natural time ... It was indeed shown for a number of events that the seismicity entered a critical stage a few days before the catastrophe of the following earthquakes: In the earthquake of magnitude 6.6 Grevena-Kozani in 1995, the 6.5 earthquake at Eratini-Egion in 1995, the 6.4 earthquake at Strofades in 1997, the 6.5 earthquake in the Aegean Sea in 2001, and other major earthquakes. **This suggests a striking possibility to narrow the time window for the prediction of earthquakes to a few days** [my emphasis].

Focusing on the VAN method the authors continue as follows (words in bold are my emphasis):

> ... The VAN method, named after the initials of the founding Greek scientists, monitoring the so-called Seismic Electrical Signals (SES) has conducted actual short-term prediction of earthquakes of magnitudes larger than 5 for well over a couple of decades. The VAN method has been successful in making predictions within the following error range: a few weeks in time, better than 0.7 units in magnitude and better than 100 km in epicentral distance ...
>
> The VAN methodology is based on two major discoveries: One is the so-called *selectivity* stating. 1) There are sites sensitive to SES (sensitive sites), while most randomly chosen sites were insensitive. 2) A sensitive site is sensitive only to SES from some specific focal areas ... The other discovery by the VAN research is the relationship among the epicentral distance, the earthquake magnitude and the observed intensity of the SES. Once the epicentral location is estimated from the *selectivity* map, the magnitude of the impending earthquake can be assessed, since both the intensity and the epicentral distance are known.
>
> The VAN method, however, has been the target of a heated debate. As far as we have critically examined, **VAN successes are convincing** ... **The public impact of VAN’s predictions has been large because lives have actually been saved at some disastrous earthquakes** (see the relevant article in 2000 by S. Uyeda in the journal *EOS*, volume 81, No. 3). In the present authors’ view, **VAN has well survived the test of time.** In Japan, both VAN type monitoring and magnetic monitoring of very low frequency have been implemented during the last two decades. Despite the high level of artificial noise, in particular from DC driven electric trains, **the existence of the VAN type SES has been confirmed**.
>
> ... Pressure stimulated polarization currents (PSPC) proposed by Varotsos and Alexopoulos for SES (and magnetic field) are emitted from a solid containing electric dipoles upon a gradual increase of the pressure (or stress) ... This PSPC model **is unique among other models**, in that SES would be generated spontaneously during the gradual increase of stress [in the focal area] without requiring any sudden change of stress such as micro-fracturing...

I now proceed to the presentation of some excerpts from the second article by Professor Uyeda and co-workers in the *Journal of Geophysical Research* in 2009, mentioned above, entitled “Analysis of electrical activity and seismicity in the natural time domain for the volcanic – seismic swarm activity in 2000 in the Izu Island region, Japan”.

The summary of this article reads:

> The Izu 2000 seismic swarm activity lasted for about 2 months with some 7,000 shocks with magnitude greater than 3 and five earthquakes larger than 6.0 and was preceded by a pronounced electrical activity with innumerable [electric] signals that started two months prior to the swarm onset. It is shown, **first**, that the seismicity subsequent to the electrical activity approaches a critical stage a few days before the occurrence of the first shock with magnitude larger than 6.0 and, **second**, that the electrical signals also have the properties characteristic to the critical stage. Despite the big differences in time scale and numbers of electric signals and earthquakes, these features are similar to those found in Greece. The present results suggest that both in Greece and Japan, the electrical activity as well as the subsequent seismicity may have a self-similar structure and exhibits similar dynamic evolution toward critical stage.

At the end of the paper, the authors conclude (words in bold denote my emphasis):

> Thus, the analysis in the natural time domain of the seismicity, **led to an estimate on the date of the impending large earthquake of July 1, 2000, with a narrow time window of the order of a few days.**
>
> … Finally, it is worthwhile noting that the obtained results should not be misinterpreted as definitely proving that the analysis in the natural time domain of seismic catalogue alone can lead to an estimation of the date of an impending main shock and replace the electrical activity data. In reality, we may need both, because it is the initiation of the SES activity which has so far provided the key information on the time from which the computation of the seismicity should start.

In other words, Japanese scientists confirm that both the registration of SES and the analysis of the subsequent seismicity in the natural time domain are equally important to determine when a forthcoming major earthquake will happen (see Section 18.3).

23.2 The USA

I start by referring to two scientific publications that are indicative of ongoing research in the USA.

The first is an article published in a leading international journal in physics (*Physical Review Letters*, Volume 97, Article No. 238 501, 2006), authored by six researchers (J.R Holliday, J.B Rundle, D.L Turcotte, W. Klein, K.F Tiampo and A. Donellan) who work in well-known universities in the USA and Canada as well as at NASA. In this article, entitled "Space-Time Clustering and Correlations of Major Earthquakes" (which was followed by other works), they cite as a basis for their calculations the idea of natural time proposed by Varotsos and his colleagues. In particular, these researchers wrote: "A **central idea** is that the length of the snapshot window [for the calculations] is not fixed in time; it is instead fixed by earthquake number at each threshold magnitude. Nature appears to measure the 'earthquake time' in numbers of events, rather than in years". (I explained this crucial aspect of natural time in Section 18.2.)

Next, I refer to a very recent article (*Geophysical Journal International*, Volume 184, pages 1214–1222, 2011), authored by three renowned researchers, S. Lennartz, A. Bunde and D.L. Turcotte (the first two from Germany and the third from the USA). This article, entitled "Modelling Seismic Catalogues by Cascade Models: Do We Need Long-term Magnitude Correlations?" is again based on the concept of natural time proposed by the Greek team, and the authors conclude that they "obtain **excellent** agreement between the simulations and the California [seismic] data".

Finally, I mention a book entitled *Predicting the Unpredictable* (Hough, 2010, Princeton University Press, N.J.). Authored by a seismologist at the United States Geological Survey, it recounts the efforts of the scientists, mainly in the USA, for short-term earthquake prediction, which ultimately **have not led to any substantial positive result to date**. The status of the current efforts of American seismologists emerges clearly from Susan Hough's book. For example, on page 3 we read:

> The last great earthquake in California was over one hundred years ago, in 1906 in San Francisco ... In recent years, scientists have developed and deployed increasingly sophisticated instruments to capture signals from the earth, not only earthquake waves [i.e., seismographs] but also minute warping of the crust... Data have been recorded prior to a number of recent moderate earthquakes of magnitude 6–7 in California. And they have revealed no sign of precursory signals… So seismologists are left to wonder what, if anything, the instruments will reveal when the next Big One strikes. Thus when instruments reveal something outside the ordinary, we are left to wonder could this be it?

It seems that seismologists in the United States, relying on the data collected by seismographs and GPS, have tried a few predictions, but all eventually failed. For example, on page 10 of the book we read:

> In the spring of 2004, a team of researchers at the University of California at Los Angeles went public with a prediction that a magnitude 6.4 or greater quake would strike the southern California desert by September 5, 2004. This prediction, based on apparent past patterns of small and moderate earthquakes preceding previous large earthquakes in California and elsewhere, **failed**. Not only did no large earthquake strike the target region during the prediction windows; if anything the region remained unusually quiet throughout 2004. If a person didn't know better, he or she could start to think that the planet is determined to instill humility in scientists who dare to believe they have unlocked her secrets.

On pages 10 and 11, the author sums up as follows: "We know that in a place like California, it isn't a matter of if the next Big One will strike, but only when… For nearly a century scientists and residents in Southern California, have lived under a sword. We know that a very big earthquake will strike the region some day; we don't know but if that day is tomorrow or fifty years from now."

In other words, the message clearly emerges that seismologists in the USA declare **they are completely unable to predict earthquakes**. However, in a typical case when VAN measurements were carried out near an epicenter in the USA, the results were quite different, to which we now turn.

On several pages of this book the author refers to VAN. Here, however, I only reproduce an excerpt related to the 7.1 earthquake that occurred on 18 October 1989 (in local time it was 17 October) near Loma Prieta, in the Santa Cruz Mountains south of San Francisco, with extensive damage to the wider area. About this earthquake, Susan Hough wrote (pages 131–133):

> The researchers continued to explore the age-old idea [recall that VAN was initially proposed in 1981] that earthquakes are preceded by electromagnetic precursors and to develop methods such as VAN. ... In the days prior to the Loma Prieta earthquake south of the San Francisco Bay area, a magnetometer in operation close to the epicenter recorded what appeared to be a highly unusual signal. The instrument had been installed by Stanford University Professor Anthony Fraser-Smith to monitor variations in the earth's ultra-low-frequency, or ULF, magnetic field ...On October 5, 1989, his instrument near the town of Corralitos recorded an increase in ULF intensity [Note that anomalous variations of smaller intensity had started earlier as I will explain later in Section A.3]. On October 17, three hours before the quake, the signal was increased even more dramatically, reaching amplitude thirty times larger than normal. No similar excursion had been recorded during the two years of operation prior to this time. The results were touted in *Science* less than two months after the earthquake, and published in 1990.

For the convenience of the reader, I point out once again that changes in the magnetic field are always accompanied by changes in the electric field and the VAN research records **both** the electric and magnetic field changes. In other words, the signal recorded by Fraser-Smith with a magnetometer should necessarily have been accompanied by an electric signal. This was identical to the SES recordings of the VAN team, as Professor Fraser-Smith explained at the international conference in Athens he attended in 1990 (see Section 8.1).This was also clarified by Professors Lawrence Slifkin and David Lazarus in their responses after that conference (see Section 8.3). In this striking similarity I also refer to the *Los Angeles Times*' article, discussed in Section 8.5, and to the *Washington Post*'s article in Section 7.2.

Concerning the opinion of the scientific community about Hough's book, rather than presenting my own point of view, I find it more useful to cite the book review from the American Physical Society, published in the widely distributed journal *Physics Today* (November 2010, pages 46–47). This review, after noting that this book is "a comprehensive, broadly accessible and readable overview of the ups and (mostly) downs of earthquake prediction over the past 50 years" also states: "My main reservation with the book is that it is rather US-centric, as even the author admits. There is little discussion about the development of earthquake prediction in Japan, China or Russia. Briefly mentioned is Greece's VAN project…, which uses seismic electrical signals [SES] to predict earthquakes. **However, that classic case – it led to a great debate in the 1990s among seismologists about whether earthquakes could be predicted – deserved a more detailed exposition.**"

23.3 China

China has a long tradition of efforts to predict earthquakes. In one case, the Haicheng earthquake of magnitude 7.5 that occurred in North China on 4 February 1975, after combining a number of precursory phenomena (including the abnormal behaviour of animals), the Chinese scientists were successful in warning the population in time. Following this success, however, a lot of doubts have been published as to whether a true prediction actually existed. But apart from this, it is certain that for a similar magnitude 7.5 earthquake that occurred the following year, on 28 July 1976 in Tangshan (about 120 km east of Beijing), the Chinese scientists failed to warn the population and thus hundreds of thousands of lives were lost.

Chinese scientists have expressed strong interest in the VAN research (see Section 4.3), and have also translated into Chinese articles by the VAN team. Since the mid 1980s to date they have published dozens of scientific articles related to VAN. Note that they have also installed 120 stations to perform geoelectric observations according to a recent article (*Science in China Series D: Earth Sciences*, Volume 52, pages 1572–1584, 2009, co-authored by 28 researchers).

I mention here only the most recent articles, and particularly those related to the devastating Sichuan earthquake of magnitude 8.0, which occurred at 14:28 local time on 12 May 2008. This earthquake is also known as the Wenchuan earthquake, the name of the region's epicenter 80 kilometers west-northwest of Chengdu, which is the capital of the Sichuan province of China. The earthquake was also felt in nearby countries and as far away as both Beijing and Shanghai, located at distances of 1500 and 1700 km respectively from the epicenter. Fifteen million people lived in the broader region affected by the earthquake, and the final report on the number of victims was dramatic. Over 87,000 people died, there were more than 374,000 seriously injured, and the homeless numbered more than 4 million. It was the most deadly earthquake since the earthquake in Tangshan in 1976. According to Chinese authorities, the rupture lasted about 120 seconds with the majority of energy released in the first 80 seconds. Upon starting from Wenchuan, the rupture propagated at an average speed of about 3.1 kilometers per second towards the northeast, rupturing a total of about 300 km.

Let us recall here that the earthquake in Mexico in 1985 also caused thousands of deaths in Mexico City, although the city was located about 350 km from the epicenter of the earthquake. These two examples, namely the Wenchuan earthquake in China in 2008 and the earthquake in Mexico in 1985, taught us that those who criticize the VAN team by demanding higher accuracy in predicting the epicenter, are obviously wrong (see Section 3.6). The critics require that the VAN research identify in advance where the fault will start breaking (i.e., the focus). This, however, has only academic interest, because in practice the rupture can propagate in a short time to distances of about several hundred kilometers. If, say, Chinese scientists had succeeded in identifying in advance an area measuring 400 km × 400 kilometers and warn the population, their accuracy would have been excellent. But they failed to do so. However, **they had detected clear preseismic electric signals**, as they wrote in their recent articles, which will be mentioned briefly below.

First, in the 2009 article mentioned above, the following is reported in the conclusion: "Four geoelectric monitoring stations are within 300–600 km from the epicenter of the Wenchuan earthquake and were deployed 3–4 years before the earthquake. Just before the Wenchuan 8.0 earthquake, **we found a significant signal, in the early morning of May 12, 2008, which implied that a very strong earthquake was coming**…"

Second, in an article published in March 2010 (Zhao et al., *Chinese Journal of Geophysics – Chinese Edition*, Volume 53, pages 487–505), the 10 authors report that in the geoelectric observation station in Hongge (the only station that the team had in this region), located 465 km away from the epicenter of the Wenchuan earthquake, they **recorded a significant precursory change around 05:00 am in the morning** of 12 May 2008 (we remind readers that the earthquake occurred early in the afternoon, at 14:28 local time).

Third, in an article published in 2011 (*Journal of Asian Earth Sciences*, Volume 41, pages 421–427) entitled “Retrospective Investigation of Geophysical Data Possibly Associated with the 8.0 Wenchuan Earthquake in Sichuan, China”, the Professor of Geophysics at Beijing University, Qinghua Huang, confirms that geoelectrical precursory signals were observed before the earthquake in Wenchuan. He wrote: “The preliminary analysis of the extremely low frequency data during January–June, 2008 at the Hanwang station (which, at about 300km distance, is the nearest station to the epicenter of the Wenchuan earthquake) showed that the power spectra of electric and magnetic fields during May 1–12, 2008, **enhanced significantly** with respect to the normal background level (see Gao and co-workers in their article in 2010 in the *Chinese Journal of Geophysics*, Volume 53, pages 512–525) ... **These data recorded before the main shock should be reliable**.” Furthermore, in a separate article published in 2010 (*Chinese Journal of Geophysics – Chinese Edition*, Volume 53, pages 535–545) under the title “Numerical Simulation of the Selectivity of Seismic Electric Signals and its Possible Influences”, Huang and Lin presented calculations showing that the selectivity phenomenon of the SES is due to electrical inhomogeneity in the Earth’s crust, thus confirming the views of the VAN team published since the 1980s.

Finally, in an article that was published in December 2010 (*Chinese Journal of Geophysics – Chinese Edition*, Volume 53, pages 2887–2898) under the title “The Electromagnetic Phenomena before the Magnitude 8.0 Wenchuan Earthquake”, Fan et al. also reported “**significant precursory anomalies of the geoelectric and geomagnetic fields**”.

23.4 Russia

In this country, as in China, there is a long tradition of research on earthquake prediction. Since the mid 1980s Russian scientists have expressed strong interest in the VAN research (see Sections 4.3 and 8.3) and published dozens of scientific articles, both with their own independent measurements as well as in collaboration with other researchers (Japanese, American, etc.), **confirming the existence of electromagnetic signals before upcoming earthquakes**.

Beyond these articles, there are several other publications by Russian researchers who first studied the physical basis for the SES generation suggested by Varotsos and Alexopoulos in the 1980s (according to which, as explained in Section 2.1, the SES are emitted when the system enters a **critical phase**), and second examined the applicability of this physical basis to other areas of science where “catastrophic” phenomena have been also observed. A typical example is a series of recent articles by Russian researchers from two renowned research institutes in St Petersburg: the Ioffe Institute of the Russian Academy of Science, and the Institute for Arctic and Antarctic Research. In one of these articles (Chmel et al., *Physica A*, Volume 389, pages 2617–2627, 2010) under the title “Variability of Scaling

Parameters in Non-Conservative Systems: Geophysical Aspect", the authors write in their introduction:

> The interest to the scaling processes in Geophysics was initially stimulated by … [the] predictability of catastrophic tectonic perturbations animated by statistical physicists when the concept of self-organized criticality appeared. The **critical state** of permanently loaded rocks in nature and under laboratory conditions was identified by direct physical methods, such as acoustic emission, **electromagnetic emission, and seismic electric signals (SES)**, and recognized, in general, by the geophysical community.

And they summarized the main conclusions of their article as follows: "Newly obtained data on the critical dynamics of the drifting/fracturing sea ice in the Arctic Ocean were analyzed and compared with published data on the dynamic processes in the Earth's crust. Substantial similarities were found in the scaling behavior of both geophysical systems."

23.5 Mexico

In Mexico City in 1985 (see Chapter 16 as well as Sections 3.5 and 23.3), thousands of lives were lost in an earthquake that occurred 350 km away. So from the beginning of the 1990s, teams of researchers from leading universities, polytechnics and other research centers in Mexico settled several VAN stations around the country. In several articles published in scientific journals between 1996 and 2010, they reported preseismic electric signals recorded before earthquakes of magnitudes larger than 6.0, which **had similar shape and properties to the signals reported by the VAN team in Greece**. For example, in an article published in 2009 Guzman-Vargas et al., *Physica A*, Volume 388, pages 4218–4228), entitled "Correlations and Variability in Electrical Signals Related to Seismic Activity", the four authors wrote in their introduction:

> ... In many seismically active zones around the world, there exist research programs for the study of possible precursory phenomena of earthquakes. In particular, one of the techniques used in the search for earthquake precursors for more than three decades consists of monitoring the so-called electric self-potential field. The main motivation for exploring such signals is that it is expected before the occurrence of an earthquake (see the book by Varotsos, 2005), that stress (pressure) gradually varies in the focal area ... This stress variation may change the relaxation time [that is the time needed for a dipole to change orientation] for the orientation of the electric dipoles formed due to lattice defects. It may happen that when the stress (pressure) reaches a **critical value**, these electric dipoles exhibit a cooperative orientation (collective organisation), thus leading to emission of transient electric signals termed Seismic Electric Signals (see the articles by Varotsos and Alexopoulos in 1984) ...
>
> …We have measured the ground electrical potential (self-potential) at several sites along the Mexican coast near the Middle American trench, which is the border between Cocos and the American tectonic plates. In some previous articles we have reported more detailed descriptions of that region and some studies of possible **precursory electrical phenomena associated with several earthquakes of magnitude larger than six**...

> In this work we are interested in evaluating the changes in the variability and correlations of geoelectric signals during a two-year period from June 1, 1994 to May 31, 1996 at two sites (Acapulco and Coyuca stations) located in southern Mexico. In particular, our study is related to **the magnitude 7.4 earthquake that occurred on September 14, 1995**, with epicentral distances of 110 km from Acapulco and 145 miles from Coyuca, respectively.

Describing how the experimental data were obtained, the authors explain: "The time series presented in this study ... are electric self potential fluctuations between two electrodes buried 2 m into the ground and separated by a distance of 50 meters ... as is indicated by VAN methodology."

Summing up their conclusions, the authors state: "Previous studies have reported… the emergence of correlated dynamics in geoelectric potentials prior to an important earthquake… In this work… **important differences** in scaling exponents and entropy profiles… **are observed… in the vicinity of the magnitude 7.4 earthquake** that occurred on September 14, 1995." (See also Section 23.6, where an additional article by Mexican researchers in collaboration with Italians is mentioned.)

23.6 Italy

Since the late 1980s, many researchers from various Italian universities and research centres have studied theoretically and/or experimentally the VAN method and published several articles on this subject in the 1990s and 2000s. Here, I mention two indicative examples, referring to measurements carried out in Italy with the same methodology as the VAN research

The first example refers to a 2005 article (Telesca et al., *Natural Hazards*, Volume 34, pages 177–198) under the title "Analysis of Extreme Events in Geoelectrical Time Series Measured in a Seismic Area of the Southern Apennine Chain (Italy)". Telesca and his co-workers made measurements at a station located in the Southern Apennine chain, regarded as one of the most seismically active Mediterranean areas where the earthquakes are mainly associated with collision between the African and the Eurasian tectonic plates. In the summary of their work, the authors wrote: "In the present paper we analyze the series of extreme events in geoelectrical signals recorded at the monitoring station Tito located in a seismic area of southern Italy. Applying an objective criterion to estimate the probability of occurrence of extreme events in the time series, **we found a correlation between the geoelectrical anomalies and earthquakes in the area monitored during the period of recording**". Furthermore, in their conclusion the authors stated: "We found correlations between geoelectrical runs and seismic events in almost all cases examined, suggesting the existence of **precursory** geoelectrical patterns preceding earthquakes."

In a later work (Colangelo et al., *Natural Hazards and Earth System Sciences*, Volume 8, pages 1009–1104, 2008), three Italian researchers returned to analyze subsequent measurements during the period January–April 2007 with a network of stations installed in the aforementioned area. In that article, under the title "Study of Self Potential Anomalous Fluctuations in a Seismic Activity Zone of Lucano Apennine (Southern Italy): Recent Results", the new results confirm the main conclusion given in their previous article in 2005, mentioned above.

23.6.1 Collaboration with Mexico

Also, in recent years cooperation between Italian scientists and researchers from Mexico has developed, which has led to the publication of a series of articles describing the recording and/or analysis of VAN precursory signals. In a recent paper (Ramirez-Rojas et al., *Natural Hazards and Earth System Sciences*, Volume 11, pages 219–225, 2011) entitled "Entropy of Geoelectrical Time Series in Natural Time Domain" the three researchers wrote in their summary:

> Seismic electrical signals (SES) have been considered precursors of strong earthquakes and, recently, their dynamics have been investigated within the natural time by Varotsos and his colleagues in 2004. In this paper we apply the natural time approach and the chaotic map signals analysis to two geoelectric time series recorded in a seismically very active area of Mexico, where two strong earthquakes of magnitude 6.6 and 7.4 occurred on October 24, 1993 and September 14, 1995 respectively ... **Our findings point to an increase of the correlation degree of the geoelectrical signals *before* the occurrence of strong earthquakes**. Furthermore, the power spectrum and the entropy in natural time, are in good agreement with the results published in the literature [that is the results reported by Varotsos and co-workers in 2004] ..."

23.7 France

Since the mid 1980s (see Section 7.1), France had expressed strong interest in the VAN research.

The interest of French researchers still continues. Here I only mention an indicative article published by Zlotnicki et al. in the journal *Planetary and Space Science* (Volume 54, pages 541–557, 2006) entitled "Ground-based Electromagnetic Studies Combined with Remote Sensing Based on Demeter Mission: A Way to Monitor Active Faults and Volcanoes", which summarized the results so far of the measurements of the electric and magnetic field for both earthquakes and volcanoes.

In particular, in the introduction to this work, the authors wrote:

> With decades of experience, it is now possible to highlight some key findings. First: On volcanoes ... There are electromagnetic signals that vary from short (few Hz) to very long duration (days to years). Secondly: With regard to active faults, they are difficult to monitor, mainly because the density of the electric, magnetic or electromagnetic observation stations is relatively small taking into account the length of the faults (100 kilometers long or more) ...
>
> In Greece, during recent decades, the VAN group has investigated the existence of very low frequency electric signals, of a few milivolts per kilometer in amplitude, appearing up to a few weeks before earthquakes. These signals were called Seismic Electric Signals (SES) ... A large debate is still active on the existence of preseismic signals of very low frequency. The positive consequence of this debate is that many investigations are now being carried out using diverse

> techniques in different tectonic contexts and **at present there is evidence that some of these electrical and magnetic signals are indeed related to earthquakes. Like volcanoes, slow self-potential, resistivity and/or magnetic changes can appear before the occurrence of an earthquake.**

I point out that the famous volcanologist Haroun Tazieff, in his book *Earthquake Prediction* (Hachette, 1989; published into Greek, 1996), wrote that VAN signals should appear before both volcanic eruptions **and** earthquakes.

Remember also here that, as explained in the Section 23.1, the Japanese researchers Uyeda and co-workers in their article in the *Journal of Geophysical Research* (2009) confirmed that before the volcanic activity in 2000 in Izu Peninsula, Japan, they detected very clear SES. In other words, the current developments in the VAN research confirm the view expressed by Haroun Tazieff since the late 1980s that it was imperative to develop VAN networks in various locations in the world which are active as far as volcanoes and/or earthquakes are concerned.

23.8 Concluding remark

Ending this chapter, I would like to repeat that it is impossible to describe here all the research efforts related to SES that are going on in various countries at the moment. For example, in India very active SES research has been developed and a number of relevant international conferences have been held there. Among these conferences was the three day "International Workshop on Electromagnetic Studies Related to Earthquakes and Volcanoes" organized by the Faculty of Engineering & Technology, R.B.S. College, Agra in November 2007. In that conference, an invited paper under the title "Recent Progress in the VAN Method: Analysis in Natural Time" was presented co-authored by Varotsos, Sarlis, Skordas and Lazaridou.

Appendix

Quantities calculated in natural time analysis. What happened before the Japanese super-giant 9.0 earthquake in 2011

This Appendix comprises four sections as follows: Section A.1 explains how the calculation of the mean value of natural time, weighted by the normalized energy released at each event, is made. In addition, we introduce a quantity, termed variance of natural time (labelled κ_1) again weighted by the normalized energy released at each event, which is of major importance in identifying when a complex system approaches the critical point. The general procedure through which the occurrence time of an impending main shock can be determined by means of κ_1 is explained in Section A.2. Examples of this procedure are put forward in Sections A.3 and A.4 for major earthquakes in California and Japan, respectively. In Section A4, we also describe in detail what happened just before and just after the devastating earthquake of magnitude (M) 9.0 that occurred in Japan on 11 March 2011 as far as the investigation in natural time is concerned.

A.1 Calculation of the mean value and the variance of natural time χ weighted by normalized energy release.

Let us review the example depicted in Figure 18.1, in which we consider the occurrence of five consecutive events (say earthquakes) 1, 2, 3, 4 and 5 and then explain how we read them in both conventional time (Figure 18.1, upper) and in natural time (Figure 18.1, lower). In particular, let us recall that the observer in natural time kept in his memory the following five pairs of values: The first event emitted 40% of the total energy, the second event 10%, the third 5%, the fourth 15% and the fifth 30%. These events occurred at the following values of natural time χ (see Figure 18.1(b)): The first event (out of five) corresponds to the natural time value χ_1=1/5=0.20; the second event to χ_2=2/5=0.40; the third event to χ_3=3/5=0.60; the fourth to χ_4=4/5=0.80; and the fifth event to χ_5=5/5=1.0.

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3,

This way, the values of natural time always lie between 0 and unity. The percentages of the total energy that have been released by each of these five events are: For the first event p_1=40%=0.40; for the second p_2=10%=0.10; for the third p_3=5%=0.05; for the fourth p_4=15%=0.15; and for the fifth p_5=30%=0.30.

The *mean value* $<\chi>$ of natural time weighted by the percentage of the total energy released at each event (hereafter called simply "**mean value of natural time**", for the sake of brevity) is now calculated as follows: $<\chi>= p_1\,\chi_1+ p_2\,\chi_2+ p_3\,\chi_3+ p_4\,\chi_4+ p_5\,\chi_5$ and hence $<\chi>=$ 0.4×0.2 + 0.1×0.4 + 0.05×0.6 + 0.15×0.8 + 0.3×1, thus we find $<\chi>$=0.57. This value cannot be interpreted as telling that the (whole) energy of the system has been released on the average at the value $<\chi>$=0.57 of natural time, in view of the following fact: The calculated mean value $<\chi>$=0.57 is very close to the value χ_3=0.6 at which the *smallest* event (that is the third one) occurred and released *only* 5% of the total energy. Thus, instead of claiming that the energy of the system was released on the average at the value $<\chi>$=0.57 of natural time, we should consider that in reality the emission of the energy was distributed at various instances χ_1, χ_2, χ_3, χ_4 and χ_5 lying ,as mentioned, between zero and unity. Furthermore, we should take into account that each of those instances lie away from the mean value $<\chi>$ by a "distance" which can be estimated by means of the quantity $(\chi-<\chi>)^2$, that means that the "distances" for each of these five events from the mean value are: $(\chi_1-<\chi>)^2$, $(\chi_2-<\chi>)^2$, $(\chi_3-<\chi>)^2$, $(\chi_4-<\chi>)^2$ and $(\chi_5-<\chi>)^2$. It is now preferable to find the *mean value of these five "distances", which is designated by the symbol* $\varkappa_1$. In the present example, this mean value is found to be $\varkappa_1$=0.121. In general, **the quantity $\varkappa_1$, termed variance of natural time weighted by the normalized energy released at each event,** or **simply variance of natural time** for the sake of brevity, denotes the mean value of $(\chi-<\chi>)^2$.

A.2 Usefulness of the variance $\varkappa_1$ of natural time to identify the occurrence time of an impending main shock

The value of the quantity $\varkappa_1$ is of prominent importance in identifying when a dynamic system approaches the critical point. In particular, in the case of earthquakes we do the following: Recall that, as already explained in Section 18.3, after the SES recording (which marks when the system enters the critical stage as indicated by the original SES generation model of Varotsos and Alexopoulos, see Section 2.1), we start the analysis in natural time – in a way depicted in Figure 18.1(b) – of the successive small seismic events that happen in the candidate epicentral area (which has been determined on the basis of SES physical properties, as explained in Section 3.5). Thus, upon the occurrence of every small seismic event we repeat the calculation and compute (among others), the variance $\varkappa_1$. The following has been theoretically found and experimentally verified: If we observe that the $\varkappa_1$ value gradually decreases and reaches the value $\varkappa_1$=0.070 the system approaches the critical point and the main shock occurs after a few days up to 1 week or so. Thus, we need both the SES recording and the natural time analysis of the subsequent small seismic events, in order to be able to determine the occurrence time of the impending main shock within a narrow time window.

The following question of crucial importance is raised: Can we judge whether a major earthquake is going to occur **if no SES measurements are available**? In other words, if **only** the seismic catalogue – from the routine measurements of a seismological institute – is available, *can we do anything*? The answer to this question is in general **yes**, provided that we employ the natural time analysis of the seismic events reported in the seismic catalogue. (In this case we rely on the fluctuations of the $\varkappa_1$ values – as will be explained later in Section A.3 – and *not* on the $\varkappa_1$ value itself used in the previous case, because – due to the lack of SES data – we do not know the starting point to calculate the $\varkappa_1$ value). I emphasize, however, that the latter analysis alone may reveal important information that a major earthquake is upcoming, but ***without being able to specify the future epicentral area and the exact magnitude*** (which demand the knowledge of the SES data; see Section 3.5). I present below examples for both cases – that is, (1) when both SES recording and seismic data are available and (2), when SES data are lacking and hence we know only the seismic catalogue. These examples refer to large earthquakes that occurred in the USA (Section A.3) and Japan (Section A.4).

A.3 Using natural time analysis to identify upcoming earthquakes in the USA

First, let us consider the case of the 7.1 Loma Prieta earthquake that occurred at 00:04:15 GMT on 18 October 1989 in California. This is a typical case in which data equivalent to SES were available. This is so because Professor A. Fraser-Smith from Stanford University had recorded precursory magnetic field variations (Section 23.2), which are obligatorily accompanied by electric field variations, strikingly similar to the magnetic field data simultaneously observed with SES activities in Greece (see also Section 8.3, and in particular the clarifications of Professors Lazarus and Slifkin on this point).

Fraser-Smith and co-workers (*Geophysical Research Letters*, Volume 17, pages 1465–1468, 1990; *Physics of the Earth and Planetary Interiors*, Volume 68, pages 45–63, 1991), report that the recording of the electromagnetic precursory variations started on 12 September 1989, i.e., almost one month before the Loma Prieta earthquake (these variations became clearer on 5 October 1989 and were dramatically enhanced almost three hours before the earthquake, as mentioned in Section 23.2). This means that the area entered into the critical stage on 12 September 1989. Thus, we started the analysis in natural time of the subsequent small seismic events with magnitudes larger than 2.5 inside the area N (36.2° to 38.5°), W (120.7° to 122.7°) surrounding the Loma Prieta earthquake epicenter. The calculations of the variance $\varkappa_1$ of natural time were made in all the possible sub-regions of that area in a similar fashion with the procedure we followed before the 6.5 earthquake in western Peloponnese between Patras and Pirgos explained in Section 22.1. The results of these calculations were published in 2010 (Varotsos et al., *Europhysics Letters*, EPL, Volume 92, Article Number 29002, 2010) and showed the following: At 12:22 GMT on 13 October 13, that is almost four and half days before the Loma Prieta earthquake, the variance $\varkappa_1$ reached the value $\varkappa_1 \approx 0.070$, thus identifying that the system approached the critical point. In other words, after 12:22 GMT on 13 October 1989, the main shock was expected to occur at any time, as actually happened four and half days later, that is at 00:04 GMT on 18 October 1989.

We now turn to two other major earthquakes that occurred in California in 1992 and 1999, for which SES data *were not available*, thus we had to rely on the seismic catalogue alone. These two earthquakes were, first, the Landers earthquake of magnitude 7.3 that occurred at 11:57 GMT on 28 June 1992 (with an epicenter at 34.2° N, 116.4°W) and, second, the Hector Mine earthquake of magnitude 7.1 that occurred at 09:46 GMT on 16 October 1999 (with an epicenter at 34.6° N, 116.3° W). Due to the lack of SES data, we could not apply the procedure followed for the Loma Prieta earthquake, where we started the natural time analysis of the earthquakes that occurred *after* the initiation of the electromagnetic precursors on 12 September 1989 and then repeated the computation of the $\varkappa_1$ value upon the occurrence of every new seismic event. In other words, we did not know, from which small seismic event we should start the natural time analysis in order to compute the $\varkappa_1$ value. We then worked as follows: Let us start from a certain earthquake of the catalogue and consider a small number N – usually between 6 and 40 – of the subsequent earthquakes, say N=40 earthquakes (including the first earthquake from which we start), and compute the $\varkappa_1$ value for this sequence of 40 events. We then repeat the same computation by starting from the next earthquake and considering again N=40 earthquakes, which now leads to a $\varkappa_1$ value different from the previous one. This is repeated for a large number of consecutive earthquakes, say for W=1000 earthquakes. Thus, we have now computed 1000 different $\varkappa_1$ values which fluctuate around an *average value* (μ). As a measure of these fluctuations, we can consider their standard deviation σ (that is, we find the square of the difference of each $\varkappa_1$ value from the mean value, we then sum all these results and divide by the number W=1000; this way we find σ^2 and from there we get σ). Thus, we have the ratio σ/μ which may be considered to provide a measure of *the fluctuations of the $\varkappa_1$ values compared to their mean value* μ. This will hereafter be termed **variability of $\varkappa_1$** and could simply be thought of as telling us the following: *the extent to which the $\varkappa_1$ values vary in an earthquake time series when a length comprising W earthquakes slides step by step through an earthquake catalogue*. In an article entitled: "Order Parameter Fluctuations of Seismicity in Natural Time Before and After Main Shocks" (Sarlis, Skordas and Varotsos, submitted for publication on 27 April 2010; published in *EPL*, Volume 91, Article Number 59001, September 2010), the following striking result was found: When these consecutive W earthquakes gradually approach the occurrence time of a major earthquake, **the fluctuations of the $\varkappa_1$ values** (and, hence, **the variability of $\varkappa_1$) are markedly enhanced, thus identifying the upcoming main shock**. This has been ascertained for several major earthquakes including some major earthquakes in Greece as well as the above mentioned two earthquakes in the USA. This article, appeared on 21 September 2010, that is **almost six months before the super-giant 9.0 earthquake** that occurred in Japan in 2011. We shall return to this point below.

A.4 What happened before the super-giant 9.0 earthquake in Japan in 2011

In Section 23.1, I explained that in the research, carried out in Japan under the leadership of Professor Seiya Uyeda, SES had been observed before the occurrence of several earthquakes. In addition, I mentioned that Professor Uyeda and co-workers recorded an SES activity of long duration before the volcanic–seismic activity in the region around the Izu islands in 2000 and upon analyzing the subsequent seismicity in natural time, they successfully determined the occurrence time of the first strong earthquake (1 July 2000) with an accuracy of the order of a few days.

Here, I focus solely on the description of the facts before the occurrence of the super-giant magnitude M9.0 Tohoku earthquake (officially named Tohoku-chiho Taiheiyo-oki earthquake) on 11 March 2011. This earthquake devastated the Pacific side of northeastern Honshu, with a huge tsunami causing more than 20,000 victims and serious nuclear plant disasters.

A week before the occurrence of this earthquake, specifically on the morning of Friday 4 March 2011, the Japanese researchers Seiya Uyeda and Masashi Kamogawa arrived at Athens (and left on 10 March 2011, just one day before this earthquake's occurrence) to collaborate with Varotsos and co-workers. Varotsos was waiting for them at the airport and, during the drive from the airport to the VAN laboratory at Athens University, Professor Uyeda explained the current situation in Japan. He described that, although the Japanese population believes that the government supports the earthquake prediction research, the real situation is drastically different. Professor Uyeda said that practically all the financial support for earthquake prediction in Japan went to the "New Observation Research Project for Earthquake Prediction" inaugurated in 1999, which strongly emphasizes seismometric observations only (for example, the seismologists have already installed 2,000 seismological stations and 1,000 GPS in Japan). As has always been the practice throughout the long national earthquake prediction programme, encompassing more than half a century, the title of the project carries the words "Earthquake Prediction" but there is no support for short-term prediction research, including Professor Uyeda's team for VAN measurements. And this happens, in spite of the fact that "earthquake prediction is always ranked at the top of urgent problems in all the public opinion polls" (Uyeda, 2011 "What Should We Do? Earthquake Prediction in Japan" *Chuou Kouron* [translated as *The Central Public Opinion*]). This article was published on 10 March 2011, a day before the Tohoku earthquake.

Varotsos, of course, was not surprised by these actions of a seismologist-dominated national project in Japan, having had a more-or-less similar experience in Greece. He then reminded the Japanese scientists of the recent paper in *EPL* by Sarlis, Skordas and Varotsos (see Section A.3) which described that, even when SES data are lacking, the natural time analysis of the seismic data alone can give very useful information for an upcoming major earthquake.

Upon arriving at Athens University, Varotsos and his co-workers Sarlis and Skordas together with the Japanese scientists, jointly proceeded to study the seismic Japanese data. As expected, their efforts were first focused on the study of the previous catastrophic earthquake in Japan, magnitude 7.3 (or 7.1 depending on the type of magnitude used), that occurred at Kobe on 17 January 1995. In particular, their aim was to examine whether the procedure followed by Varotsos and co-workers for the two major earthquakes in California, when applied to the seismicity data collected before the Kobe earthquake, could reveal a similar precursory change. These seismic data from the Japan Meteorological Agency (JMA) earthquake catalogue were already available in Athens, because Dr Haruo Tanaka (a member of Uyeda's team), during his long stay at Athens in 2004–2005 when collaborating with Varotsos and co-workers, had analyzed these data in natural time. They then concluded (Tanaka et al., *Proceedings of the Japan Academy*, Volume B80, pages 283–289,

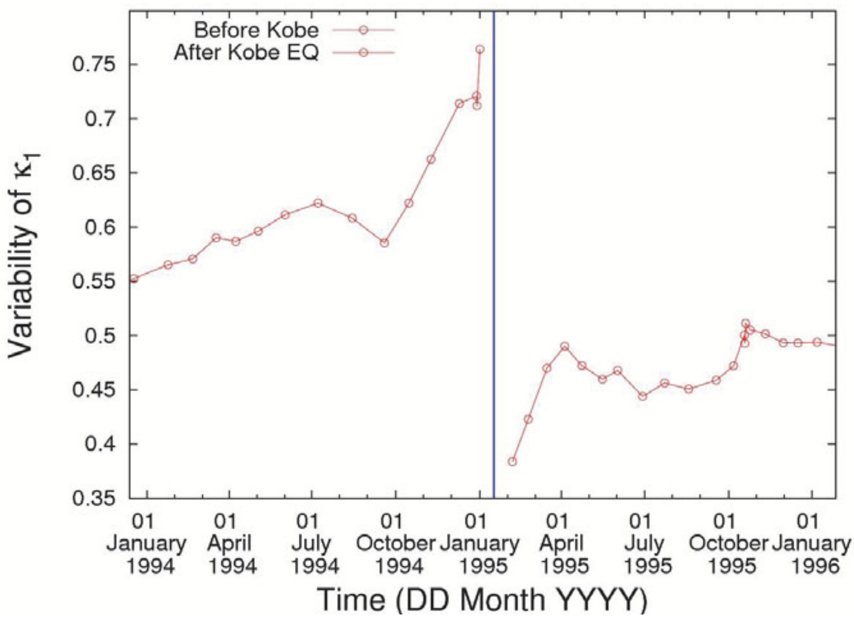


Figure A.1 The values of the variability of κ_1 as a function of time during the period one year before and one year after the Kobe 7.3 earthquake. The points depict the results of the calculations made by using excerpts of the JMA catalogue comprising W earthquakes before or after the earthquake (see Section A.3). The difference between the W values of two consecutive points either to the left or to the right of the vertical line (which shows the occurrence time of the Kobe earthquake) is 100 earthquakes. For the period before the Kobe earthquake, the remotest and closest points to the main shock correspond to W=1700 and 200 seismic events respectively (only events with magnitudes larger than 3.4, as reported in the JMA catalogue, have been considered in this calculation as well as in the other calculations mentioned in this section).Taken from Varotsos et al., *Proceedings of the Japan Academy*, Ser. B, (in press).

2004), that an SES activity could have been recorded almost two and half months before the Kobe earthquake occurrence *if* electrical measurements were carried out in that area. (Unfortunately, this was not the case, since such measurements were decided upon in 1995, after the occurrence of the Kobe earthquake, as written by *Nature*, Section 15.2). I clarify, however, that the present study was focused on a different question, that is, did the Japanese seismic data show **an enhancement of the variability of the quantity $\varkappa_1$** before the Kobe earthquake as found in the article published in *EPL* the previous September?

The results found by the two teams for the Kobe case were striking indeed. Figure A.1 shows the **variability of the quantity $\varkappa_1$** (see Section A.3 for the definition) obtained from the natural time analysis of the seismicity of Japan as a function of time for the two-year period from 1 January 1994 to 1 January 1996, that is, one year before and one year after the Kobe earthquake. The vertical line in the middle of the figure marks the time of the occurrence of the Kobe earthquake (17 January 1995).

To better visualize the results of the approach of the Kobe earthquake, I now take an excerpt of Figure A.1 and show in Figure A.2 only the results after the middle of September 1994.

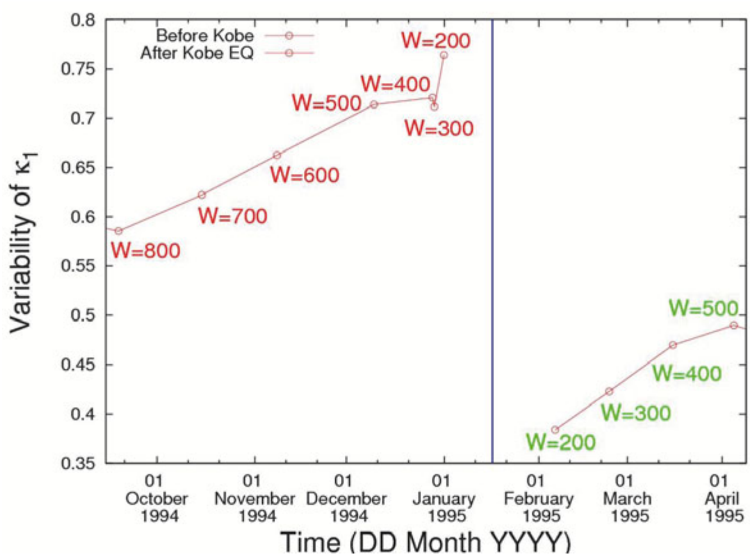


Figure A.2 An excerpt of Figure A.1, showing only the results for the *variability of* $\varkappa_1$ as a function of time for the period after about the middle of September 1994. Taken from P. Varotsos et al., *Proceedings of the Japan Academy, Ser. B,* (in press).

To each of the points to the left of Figure A.2 we now attach the W value in red (but turn to green after the main shock) that means how many earthquakes before the Kobe earthquake have been considered in the calculation of the variability of $\varkappa_1$. An inspection of this figure shows that the variability of $\varkappa_1$ becomes higher towards the main shock, peaking on 1 January 1995 (where W=200), **almost two weeks before the main shock**.

In order to make sure that this increase of the variability of $\varkappa_1$ well before the Kobe earthquake is not due to an artifact, various tests were employed. One example is as follows.

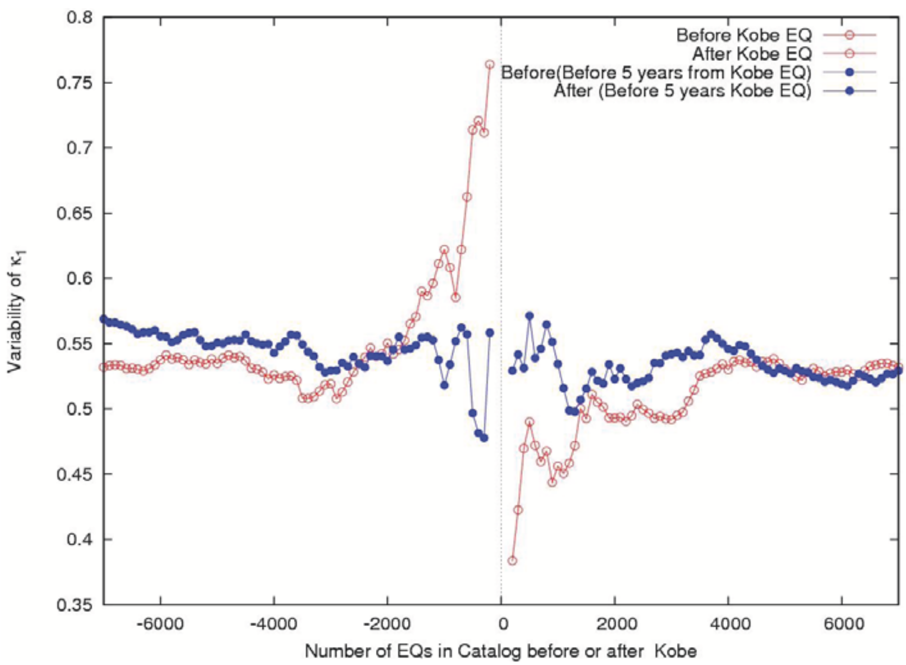


Figure A.3 Values of the variability of $\varkappa_1$ calculated by using excerpts of the JMA catalogue comprising W earthquakes *before* (red circles, with negative W) or *after* (open [red] circles, with positive W) the Kobe earthquake on 17 January 1995.The vertical dotted line, at the zero value of the horizontal axis, marks the occurrence of the Kobe earthquake. The blue solid circles describe the results calculated *before* and *after* a "virtual" Kobe earthquake, that is *if* it had occurred five years before (on 17 January 1990). Taken from P. Varotsos et al., *Proceedings of the Japan Academy, Ser. B,* (in press).

In Figure A.3, the open circles depict in red the results of the variability of $\varkappa_1$ as a function of the number of earthquakes W *before* (negative x semi-axis, that is x=−W) or *after* (positive x semi-axis, that is x=+W) the Kobe earthquake. The vertical dotted line, at the zero value of the horizontal axis, marks the occurrence of the Kobe main shock.

The results extend to 7,000 events before and to 7,000 events after the Kobe earthquake. It is obvious that well before and well after the Kobe earthquake, **the variability of $\varkappa_1$** (red points) exhibits small changes lying more or less on the same level, but it shows **an evident increase when approaching the main shock**. We now repeat the same calculation, but assuming a *virtual* Kobe earthquake, that is, assuming that a *virtual* earthquake had occurred exactly five years before (on 17 January 1990) and using the corresponding seismic data from the same JMA catalogue. These points obtained for the virtual earthquake are depicted in Figure A.3 as blue solid circles do **not** show any evident increase before the virtual earthquake. Such tests are convincing enough to demonstrate that the increase of the variability of $\varkappa_1$ before the actual Kobe earthquake, as can be visualized in Figure A.3 by the open circles approaching the vertical dotted line, is an effect beyond any doubt.

These results, from merely analyzing the seismic data in natural time, clearly opened up a new possibility to warn of upcoming major earthquakes in Japan. At the same time, however, both Varotsos and Professor Uyeda were aware of the fact that the seismologists in Japan had not followed the new developments of the natural time analysis of seismicity so that short-term prediction of the next major earthquake would not be made. Thus, in other words, both Professor Uyeda and Varotsos were afraid that before the next catastrophic earthquake in Japan, this large enhancement of the variability of $\varkappa_1$ would not be recognized in advance by the seismologists. **Unfortunately, this was the case.**

Professor Uyeda suggested to Varotsos that it might be useful to contact the Japanese Ambassador in Athens, since he is the official representative of the Japanese government in Greece. In fact, on 9 March 2011 – that is **only two days before the 9.0 Tohoku earthquake** – Professor Uyeda and Dr Kamogawa, together with Varotsos, visited the Ambassador and had an extensive talk with him. At the start of the discussion, Professor Uyeda gave the Ambassador a copy of an article he was going to publish the following day (10 March 2011) in the widely circulated Japanese journal *Chuou Kouron*, that is *The Central Public Opinion* (mentioned above). At the beginning of the article Professor Uyeda wrote:

> Most readers must naturally be guessing that active research for earthquake prediction is being carried out in Japan. However, it is not actually so… Japan has never succeeded in predicting any earthquake despite having the world's best seismological network. In fact, not even one prediction has been issued even though a national scale project on earthquake prediction has been carried out over several decades. Obviously, this means that something is wrong with the way the project has been carried out. How did this happen? Where is the problem? And, what should we do to solve it? This is the theme of this article…
>
> *…The catalyst for my suddenly realizing that short-term earthquake prediction was possible was my encounter in 1984 with the VAN method… This is perhaps the only one method which has continued to make successful short-term predictions for nearly 30 years.* ***This method is best established both empirically and theoretically in the world****... The present author and colleagues worked like horses and deployed a number of VAN-type observation stations from Hokkaido to Okinawa in Japan. A distinct signal came out suddenly on a certain day at the*

*observation station on the foot of Iwate Mountain, and a magnitude 6.0 earthquake occurred two weeks later. …****There were more of such cases. The VAN method works also in Japan.***

And, after describing the current unhappy situation in Japan, and emphasizing that "However, we are not abandoning the research. Far from it. Active international collaboration is in progress and international conferences are carried out with scarce funds…" the article ended with some concrete suggestions:

> … We are not asking to stop seismic observations as they are important. We are simply asking for the recognition that the main player in short-term earthquake prediction is not seismic observation and devoting a mere one or so percent of the total budget and staff posts to short-term prediction.
>
> … Seismology and earthquake prediction science should be clearly recognized as "**different disciplines**", and it is necessary to concentrate on the education and the research for this new born interdisciplinary short-term prediction science.
>
> … The research and the education there will give birth to the next generation for the establishment of a practical prediction system. It may sound a leisurely story but the driver of research is people and it is education which gives birth to them. Education raises people unexpectedly quickly…

The Ambassador read the manuscript carefully. Varotsos told me later that he saw strong surprise in the Ambassador's face on being informed of the current situation in Japan. Having finished reading the article, he had a lengthy discussion with Professor Uyeda who clarified what in reality happens in Japan, and then explained the reasons for their visit to Athens. Among others, Professor Uyeda described that their close collaboration with the VAN team enabled them to know that actual earthquake prediction is possible today since it is carried out in Greece, as for example happened in the case of the three major earthquakes in Greece during 2008 the predictions of which were extensively commented on in the mass media in Greece. (The Ambassador did not know these facts, because at that time he was not in Athens.) Varotsos was almost silent during the whole discussion which took place mainly in the Japanese language, but at the end said:

> Since, dear Ambassador, you are the official representative of the Japanese government, please let me kindly ask you to convey to your government the following:
>
> *After the catastrophic earthquake at Kobe in 1995, the Prime Minister's office invited me to come to Japan for a 'series of discussions that we believe will help to build a better understanding of earthquake prediction and disaster prevention technology'* [see Section 15.2]. *I gladly accepted this honorary invitation and I came to Japan where I strongly recommended that measurements of the electric and magnetic field of the Earth should be started urgently, as we do here in Greece. Actually, your government accepted this recommendation and provided support to the measurements under the leadership of Professor Uyeda. They led to extremely promising results in the beginning of 2000 that culminated in an international external review which strongly recommended the continuation of the programme. Despite this strong scientific recommendation, Japan stopped providing support for the continuation of this extremely important research effort. The whole budget is now spent to support solely classical seismological procedures, which I am absolutely sure will fail to provide any warning before the next*

catastrophic earthquake in Japan. I kindly urge you to convey my strong conviction to your government that under the current circumstances, your seismological community will be again surprised upon the occurrence of the next catastrophe exactly as they were in the disastrous case of the Kobe earthquake. In the light of current scientific advances, the only way to achieve warning is to continue the electro-magnetic measurements [that is the VAN method] *along with analysis in natural time.*

The next day, 10 March 2011, the Japanese scientists left for Tokyo. One day later, on 11 March 2011, the fears of both Varotsos and Professor Uyeda were unfortunately confirmed. The devastating M9.0 Tohoku earthquake occurred, which surprised the seismologists who did not even imagine that such a large earthquake could happen. However, their seismic data contained very important information on the precursory change.

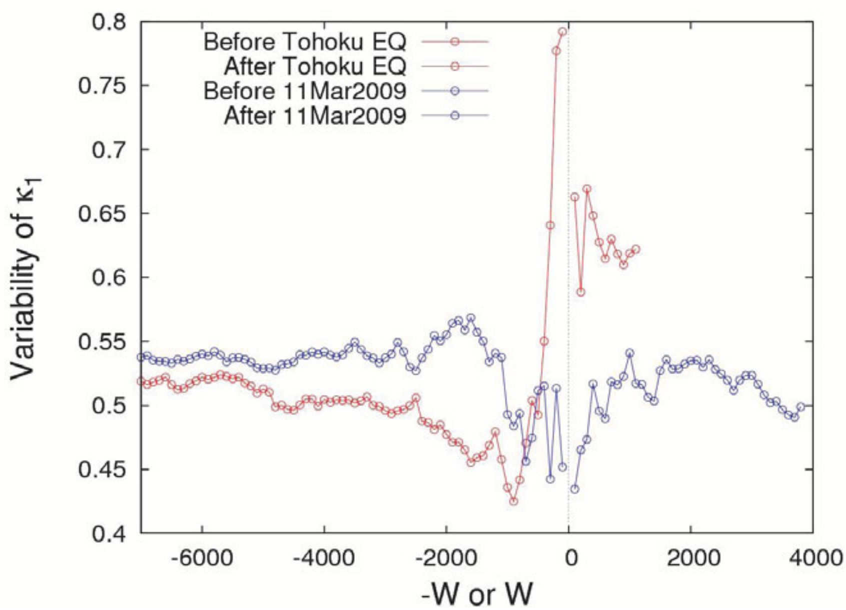


Figure A.4 The values of the variability of $\varkappa_1$ by using W earthquakes before (red, with negative W) or after (open [red], with positive W) the Tohoku M9.0 earthquake on March 11, 2011. The blue circles describe the results calculated before and after a "virtual" Tohoku earthquake, that is if it had occurred two years before (on 11 March 2009). Taken from Varotsos et al. (*Proceedings of the Japan Academy*, Ser. B, (in press)).

Just a few days after the occurrence of this super-giant earthquake, we received the JMA seismicity data from Japan. Thus, we were able to repeat exactly the same analysis that we had already done for the Kobe earthquake and found the following results.

Figure A.4 is similar to Figure A.3, shown for the Kobe earthquake. It depicts with open red circles the values of the variability of $\varkappa_1$ versus the number W of earthquakes and presents what happened *before* (negative W values) and *after* the Tohoku earthquake. An inspection of this figure clearly shows that the variability of $\varkappa_1$ ***shoots up just before the main shock***, thus showing a clear precursory change.

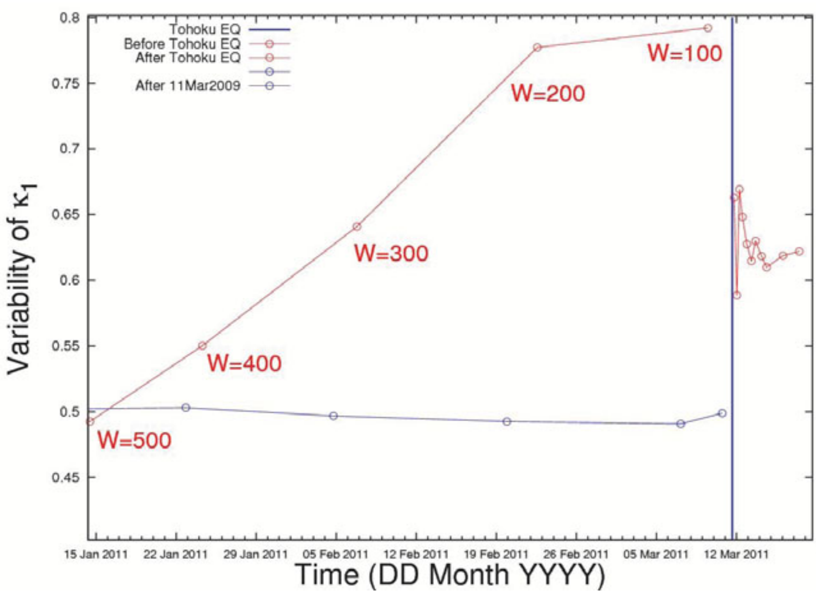


Figure A.5 Part of Figure A.4 in the vicinity of the Tohoku earthquake, but plotted against the conventional time. The results of the variability of $\varkappa_1$ of seismicity as a function of time for the period after around the middle of January of 2011. The vertical line marks the occurrence of the Tohoku M9.0 earthquake on 11 March 2011. The dots for the red circles in the order from the uppermost (closest to the main shock) backwards: 9 March, 22 February, 6 February, 24 January and 14 January 2011.

Note that the results in the case of a "virtual" Tohoku earthquake, shown in blue circles in Figure A.4, did *not* show such an increase, in a similar fashion as found in Figure A.3 during the investigation of a "virtual" Kobe earthquake. Furthermore, note that the open red circles *after* the Tohoku earthquake indicate that the variability of $\varkappa_1$ had not yet reached the background level (as happened in Figure A.3 well after the Kobe earthquake) since the intense aftershock activity was still going on at that time.

Figure A.5 is similar to Figure A.2 of the Kobe case (thus plotted against the conventional time). It is an excerpt of Figure A.4 and in order to show what happened close to the Tohoku earthquake we plot only up to W=500 seismic events before the mainshock.

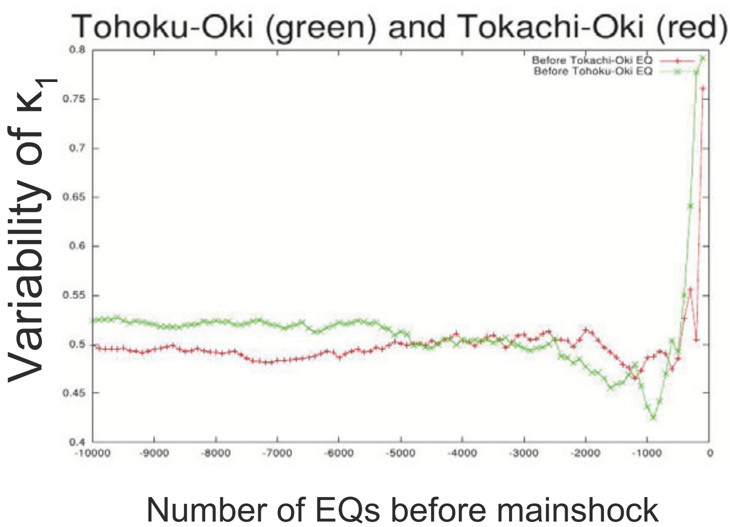


Figure A.6 The green curve shows the results for the variability of $\varkappa_1$ of seismicity during the period before the M9.0 Tohoku earthquake on 11 March 2011. The results are plotted as a function of the number of seismic events before the occurrence of the main shock. The calculation started from 10,000 events before (W=–10.000) and it was made every 100 consecutive events until 100 events before (W=–100) the Tohoku earthquake. The red curve depicted with + shows the corresponding results for the variability of $\varkappa_1$ before the M8.3 Tokachi-oki earthquake on 25 September 2003. Taken from P. Varotsos et al. (*Proceedings of the Japan Academy*, Ser. B, (in press)).

It shows the results of the variability of $\varkappa_1$ as a function of time for the period after around the middle of January 2011. It can be noted that the rise of the variability in $\varkappa_1$ is clear from late January 2011 with W=400, that is about six weeks before the Tohoku earthquake. Remarkably, this rise ***becomes strikingly obvious in late February when W=200, that is about two weeks before this devastating main shock.*** To better visualize the extent of this rise let us look at it at the rightmost part of the [green] curve described with x in Figure A.6.

In this figure the green curve described by x depicts the variability of $\varkappa_1$ of seismicity during the period *before* the occurrence of the Tohoku earthquake versus the number of seismic events before the main shock, from W=−10.000 until W=−100 events. In the same figure, the red curve depicted by + plot, for the sake of comparison, the corresponding results before the magnitude M8.3 Tokachi-oki earthquake that occurred off Hokkaido in northern Japan on 25 September 2003. We again observe a sharp rise of the variability of $\varkappa_1$ when approaching the occurrence of the main shock, which corresponds (for both main shocks) to the rightmost vertical line at the zero value (W=0) of the horizontal axis. The striking similarity between the two curves showing the precursory variations, and in particular the enhancement of the variability of $\varkappa_1$ before these two large earthquakes, is evident.

In other words, there is no doubt that the seismic data in Japan exhibited a remarkable precursory increase of the variability of $\varkappa_1$ before the M9.0 Tohoku earthquake that occurred on 11 March 2011. This, however, can be brought out **only** if these seismic data are analyzed in natural time as introduced by Varotsos and co-workers in 2001. All these results, which include the cases of the M7.3 Kobe earthquake in 1995, the M8.3 Tokachi-oki earthquake and the M9.0 Tohoku earthquake in 2011 have been presented in an article to be published in the *Proceedings of the Japan Academy*, co-authored by both research teams, that is the Greek one (P. Varotsos, N. Sarlis and E Skordas) and the Japanese (S. Uyeda, M. Kamogawa, T. Nagao and H. Tanaka).

Finally, I refer to the Fall Meeting of the American Geophysical Union held in San Francisco on 5–9 December 2011. In this Meeting, which is the largest worldwide (more than 20,000 scientists participating from all over the world), two papers were presented dealing with earthquake prediction in Japan by means of natural time analysis.

The first, which was an invited paper co-authored by Professors S. Uyeda and P. Varotsos under the title "Earthquake Prediction in Japan and Natural Time Analysis of Seismicity" summarized the current situation in Japan as well as what happened before the devastating Tohoku earthquake in 2011. The published abstract of this paper read:

> A M9.0 super-giant earthquake with huge tsunami devastated East Japan on 11 March, causing more than 20,000 casualties and serious damage to the Fukushima nuclear plant. This earthquake was neither predicted for the short-term nor the long-term. Seismologists were shocked because was not even considered possible that it might happen in the East Japan subduction zone. However, this was not the only unpredicted earthquake. In fact, throughout several decades of the National Earthquake Prediction Project, not even a single earthquake was predicted. In reality, practically no effective research has been conducted for the most important short- term prediction. This has happened because the Japanese National Project was devoted to the construction of elaborate seismic networks, which are not the best way to make

short-term prediction. After the Kobe disaster, in order to counter the mounting criticism of their continuing lack of success, they defiantly changed their policy to “stop aiming at short-term prediction because it is impossible and concentrate resources on fundamental research”, which meant obtaining “more funding for non prediction research”. The public were not then, and have never been informed about this change.

Obviously, earthquake prediction is possible only when reliable precursory phenomena are identified and we have insisted this is best done through non-seismic means such as geochemical/hydrological and electromagnetic monitoring….

In this presentation, we show a new possibility of finding remarkable precursory signals, ironically, from ordinary seismological catalogues. In the frame of the new time domain termed natural time, an order parameter of seismicity, κ_1, has been introduced. This is the variance of natural time χ weighted by normalized energy release at χ. In the case that Seismic Electric Signals (SES) data are available as in Greece, the natural time analysis of the seismicity after the initiation of the SES allows the determination of the time window of the impending mainshock through the evolution of the value of κ_1 itself. It was found to work also for the 1989 M7.1 Loma Prieta earthquake. If SES data are not available, we rely solely on the evolution of the fluctuations of κ_1 obtained by computing κ_1 values using a natural time window of certain length sliding through the earthquake catalog. The fluctuations of the order parameter, in terms of variability, i.e., standard deviation divided by average, ***was found to increase dramatically when approaching the 11 March M9 super- giant earthquake****. In fact, such increase was also found for M7.3 Kobe in 1995, M8.3 Tokachi-oki in 2003 and the Landers and Hector-Mines earthquakes in Southern California. It is worth mentioning that such increase is obtained straightforwardly from ordinary earthquake catalogs without any adjustable parameters.*

As is obvious from the content of the above abstract, Professors Uyeda and Varotsos showed the extraordinary results depicted in Figures A.1 to A.6.

The second paper, co-authored by Varotsos, Skordas, Sarlis and Lazaridou-Varotsos, was entitled “Identifying Seismic Electric Signals upon Significant Periodic Data Loss. The Case of Japan”. This is of particular importance for various countries like Japan where at many sites the electrical recordings are contaminated by high noise due to leakage currents from DC driven trains, which makes any attempt to recognize precursory signals SES almost impossible. The noise level, however, becomes very low when nearby trains cease service, which occurs in Japan from 22:00 in the night to around 06:00 next morning; that is, 30% of 24 hours. In this paper we show that, if an SES activity is of long duration, lasting for example a few days to a few weeks or even more (as in the case of the Izu island swarm discussed in Section 23.1), we can identify it by means of natural time analysis upon removing the noisy data segments lasting for the period 06:00 to 22:00 every day. In other words, we can achieve our goal of recognizing an SES activity by solely analyzing the low noise data segments collected during the night hours.

References

List of refereed publications related to the VAN method and/or Natural Time Analysis by P. Varotsos and co-workers

1. P. Varotsos, K. Alexopoulos and K. Nomicos, Comments on the pressure variation of the Gibbs energy for bound and unbound defects, *Physica Status Solidi (b)* **111**, 581–590, 1982.

2. P. Varotsos and K. Alexopoulos, Physical properties of the variations of the electric field of the earth preceding earthquakes, I. *Tectonophysics* **110**, 73–98, 1984a.

3. P. Varotsos and K. Alexopoulos, Physical properties of the variations of the electric field of the earth preceding earthquakes, II. Determination of epicenter and magnitude, *Tectonophysics* **110,** 99–125, 1984b.

4. K. Meyer, P. Varotsos, K. Alexopoulos and K. Nomicos, Efficiency test of earthquake prediction around Thessaloniki from electrotelluric precursors, *Tectonophysics* **120**, 153–161, 1985.

5. E. Dologlou and P. Varotsos, Thermally stimulated currents in rocks, *Journal of Geophysics* **59**, 177–182, 1986.

6. P. Varotsos, K. Alexopoulos, K. Nomicos and M. Lazaridou, Earthquake prediction and electric signals, *Nature* **322**, 120, 1986.

7. P. Varotsos, Earthquake prediction in Greece based on seismic electric signals; Period: January 1, 1984 to March 18, 1986, *ANNO XLV Bolletino di Geodesia e Scienze Affini* **2,** 192–202, 1986.

8. P. Varotsos and K. Alexopoulos, Physical properties of the variations in the electric field of the earth preceding earthquakes, III, *Tectonophysics* **136**, 335–339, 1987.

9. M. Lazaridou-Varotsou and D. Papanikolaou, Tectonoelectric zonation in the Hellenic Arc, *Tectonophysics* **143,** 337–342, 1987.

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3,

10. P. Varotsos, K. Alexopoulos, K. Nomicos and M. Lazaridou, Official earthquake prediction procedure in Greece, *Tectonophysics* **152**, 193–196, 1988.

11. P. Varotsos, and K. Alexopoulos, Physical properties of the variation of the electric field of the earth preceding earthquakes-reply, *Tectonophysics,* **161**, 58–62, 1989.

12. P. Varotsos, Why are Geophysicists sceptical about the VAN method of seismic forecasting – Response, *La Recherche* **21**, 1076, 1990.

13. P. Varotsos and K. Alexopoulos, La Methode VAN, *La Recherche* **22**, 220, 1991.

14. P. Varotsos and M. Lazaridou, Latest aspects of earthquake prediction in Greece based on Seismic Electric Signals. I, *Tectonophysics* **188,** 321–347, 1991.

15. P. Varotsos, K. Alexopoulos and M. Lazaridou, On recent seismic electrical signal activity in nothern Greece, *Tectonophysics* **188**, 403–405, 1991.

16. P. Varotsos, K. Alexopoulos and M. Lazaridou, Results of a recent VAN-prediction on Greek earthquakes announced at a Japanese Meeting, *NewsLetter of the Jap. Seism. Soc***.** **3,** 4, 26–29, 1991.

17. P. Varotsos, N. Bogris and A. Kiritsis 1992, Comments on the depolarization currents stimulated by variations of temperature and pressure, *J. Phys. Chem. Solids***,** **53**, 1007–1011, 1992.

18. P. Varotsos, K. Alexopoulos and M. Lazaridou, Comment on 'Evaluating the statistical validity beyond chance of VAN earthquake precursors' by Francesco Mulargia and Paolo Gasperini, *Geophys. J. Int.* **111**, 1, 1992.

19. P. Varotsos, K. Alexopoulos and M. Lazaridou, Latest aspects of earthquake prediction in Greece based on Seismic Electric Signals II, *Tectonophysics* **224,** 1–37 1993a.

20. P. Varotsos, K. Alexopoulos, M. Lazaridou, and T. Nagao, Earthquake predictions issued in Greece by Seismic Electric Signals since February 6. 1990, *Tectonophysics* **224**, 269–288, 1993.

21. P. Varotsos, K. Alexopoulos and M. Lazaridou, A reply to "evaluation and interpretation of thirteen official VAN telegrams for the period September 10, 1986 to April 28, 1988" by J. Drakopoulos, G.N. Stavrakakis and J. Latoussakis, *Tectonophysics* **224**, 237–250, 1993b.

22. A. Ifantis, G-Akis Tselentis, P. Varotsos and C. Thanassoulas, Long-term variations of the Earth's electric field preceding two earthquakes in Greece, *Acta Geophys. Pol***.,** **41**, 337–350, 1993.

23. P. Varotsos, S. Uyeda, K. Alexopoulos, T. Nagao and M. Lazaridou, Prediction of Recent Destructive Seismic Activities in Greece based on Seismic Electric Signals, in *Electromagnetic Phenomena Related to Earthquake Prediction*, edited by M. Hayakawa and Y. Fujinawa. pp. 13–24 (Terra Scientific Publishing Company, Tokyo, 1994).

24. P. Varotsos, K. Eftaxias, M. Lazaridou, G. Antonopoulos and J. Makris, Recent VAN

results on earthquake prediction in Greece by geoelectric current (in Japanese), *Jishin*, **17**, 18–26, 1994.

25. M. Hayakawa, Y. Fujinawa, F.F. Evison, V.A. Shapiro, P. Varotsos, A.C. Fraser-Smith, O.A. Molchanov, O.A. Pokhotelov, Y. Enomoto and H.H. Schloessin, What is the Future Direction of Investigation on Electromagnetic Phenomena Related to Earthquake Prediction?, in *Electromagnetic Phenomena Related to Earthquake Prediction*, edited by M. Hayakawa and Y. Fujinawa. pp. 667–677 (Terra Scientific Publishing Company, Tokyo, 1994).
26. P. Varotsos, K. Eftaxias, F. Vallianatos and M. Lazaridou, Basic principles for evaluating an earthquake prediction method, *Geophys. Res. Lett.* **23**, 1295–1298, 1996.
27. P. Varotsos, K. Eftaxias, M. Lazaridou, E. Dologlou and V. Hadjicontis, Reply to "Inaccuracies in seismicity and magnitude data used by P. Varotsos and co-workers, by M. Wyss, *Geophys. Res. Lett.* **23**, 1303–1306, 1996.
28. P. Varotsos, K. Eftaxias, M. Lazaridou, E. Dologlou and V. Hadjicontis, Reply to "Probability of chance correlations of earthquakes with predictions in areas of heterogeneous seismicity rate: the VAN case", by M. Wyss and A. Allmann, *Geophys. Res. Lett.* **23**, 1311–1314, 1996.
29. P. Varotsos and M. Lazaridou, Reply to "VAN earthquake predictions – an attempt at statistical evaluation", by Y.Y. Kagan, *Geophys. Res. Lett.* **23**, 1319–1321, 1996.
30. P. Varotsos, K. Eftaxias and M. Lazaridou. Reply I to "VAN: Candidacy and validation with the latest laws of the game" by F. Mulargia and P. Gasperini, and "Precursor candidancy and validation; the VAN case so far" by F. Mulargia and P. Gasperini. *Geophys. Res. Lett.* **23**, 1331–1334, 1996.
31. P. Varotsos, K. Eftaxias and M. Lazaridou. Reply II to "VAN: Candidacy and validation with the latest laws of the game", by F. Mulargia and P. Gasperini, and "Precursor candidancy and validation: the VAN case so far", by F. Mulargia and P. Gasperini. *Geophys. Res. Lett.* **23**, 1335–1338, 1996.
32. P. Varotsos, K. Eftaxias and M. Lazaridou, Reply to "The VAN method: Contradictory and misleading results since 1981", by G. Stavrakakis and J. Drakopoulos, *Geophys. Res. Lett. **23***, 1351–1354, 1996.
33. P. Varotsos, K. Eftaxias and M. Lazaridou, Reply to "A false alarm based on electrical activity recorded at a VAN-station in Northern Greece in December 1990", by J. Drakopoulos and G. Stavrakakis, *Geophys. Res. Lett.* **23**, 1359–1362, 1996.
34. P. Varotsos, M. Lazaridou and V. Hadjicontis, Reply to "Earthquake prediction evaluation standards applied to the VAN method", by D.D. Jackson, *Geophys. Res. Lett.* **23**, 1367–1370, 1996.
35. P. Varotsos and M. Lazaridou, Reply to "The VAN earthquake predictions", by D. A. Rhoades and F. F. Evison, *Geophys. Res. Lett.* **23**, 1375–1378, 1996.

36. P. Varotsos and M. Lazaridou, Reply to "Dicing with earthquakes", by Paul W. Burton, *Geophys. Res. Lett.* **23**, 1383–1386, 1996.

37. P. Varotsos and M. Lazaridou, Reply to "Difficulty of statistical evaluation of an earthquake prediction method", by H. Utada, *Geophys. Res. Lett.* **23**, 1395–1398, 1996.

38. P. Varotsos and M. Lazaridou, Reply to "A few considerations for ascribing statistical significance to earthquake predictions", by P.B. Stark, *Geophys. Res. Lett.* **23**, 1403–1405, 1996.

39. P. Varotsos and M. Lazaridou, Reply to "A note on evaluating VAN earthquake predictions", by G-Akis Tselentis and Nicos S. Melis, *Geophys. Res. Lett.* **23**, 1415–1416, 1996.

40. P. Varotsos and M. Lazaridou, Reply to "Probability of earthquake occurrence in Greece with special reference to the VAN predictions", by Y. Honkura and N. Tanaka, *Geophys. Res. Lett.* **23**, 1421–1423, 1996.

41. P. Varotsos and M. Lazaridou, Reply to "Statistical evaluation of the VAN method using the historic earthquake catalog in Greece", by Richard L. Aceves, Stephen K. Park and David J. Strauss, *Geophys. Res. Lett.* **23**, 1429–1431, 1996.

42. P. Varotsos and M. Lazaridou, Reply to "Statistical tests of VAN earthquake predictions: comments and reflections", by Y.Y. Kagan and D.D. Jackson, *Geophys. Res. Lett.* **23**, 1437–1440, 1996.

43. P. Varotsos, K. Eftaxias, E. Skordas, V. Hadjicontis and M. Lazaridou, Reply to "Rebuttal to Replies I and II by Varotsos et al.", by F. Mulargia, W. Marzocchi and P. Gasperini, *Geophys. Res. Lett.* **23**, 1341–1342, 1996.

44. P. Varotsos, N. Sarlis and M. Lazaridou, Reply to "Rebuttal to reply by Varotsos and Lazaridou: Towards Plainly Successful Prediction", by Paul W. Burton, *Geophys. Res. Lett.* **23**, 1389–1390, 1996.

45. P. Varotsos, V. Hadjicontis, K. Eftaxias, E. Skordas and M. Lazaridou, Reply to "Re-Rebuttal to the Reply of Varotsos et al.", by F. Mulargia, W. Marzocchi, and P. Gasperini, *Geophys. Res. Lett.* **23**, 1345–1346, 1996.

46. P. Varotsos, K. Eftaxias, M. Lazaridou, G. Antonopoulos, J. Makris and J. Poliyiannakis, "Summary of the five principles suggested by P. Varotsos et al. (1996) and the additional questions raised in this debate", *Geophys. Res. Lett.* **23**, 1449–1452, 1996.

47. P. Varotsos, M. Lazaridou, K. Eftaxias, G. Antonopoulos, J. Makris and J. Kopanas, "Short term earthquake prediction in Greece by Seismic Electric Signals" in "A Critical Review of VAN: Earthquake prediction from seismic electric signals", edited by Sir J. Lighthill, *World Scientific*, Singapore, 29–76, 1996.

48. P. Varotsos, K. Eftaxias, M. Lazaridou, K. Nomicos, N. Sarlis, N. Bogris, J. Makris, G. Antonopoulos and J. Kopanas, Recent earthquake prediction results in Greece based

on the observation of seismic electric signals, *Acta Geophys. Pol.*, *Vol.* **44**, 301–327, 1996.

49. P. Varotsos, N. Sarlis, M. Lazaridou and N. Bogris, Statistical evaluation of earthquake prediction results. Comments on the success rate and alarm rate, *Acta Geophys. Pol.,* **44**. 329–347, 1996.

50. P. Varotsos, N. Sarlis, M. Lazaridou, and P. Kapiris, Transmission of stress induced electric signals in dielectric media, *J. Appl. Phys.* **83**, 60–70, 1998.

51. P. Varotsos, N. Sarlis, M. Lazaridou, and P. Kapiris, A possible explanation for detecting Electric Signals at certain sites of the earth's surface, *Studying the Earth from Space,* **1**, 123–129, 1998.

52. P. Varotsos, K. Eftaxias, M. Lazaridou, N. Bogris, and J. Makris, Note on the extension of the SES sensitive area at Ioannina station, Greece, *Acta Geophys. Pol.*, **46**, 55–60, 1998.

53. P. Varotsos, N. Sarlis, and M. Lazaridou, Statistical evaluation of earthquake prediction results. Comments on the success rate and alarm rate, II, *Acta Geophys. Pol.,* **46**,261–271, 1998.

54. P. Varotsos, N. Bogris, K. Eftaxias, V. Hadjicontis, M. Lazaridou, and M. Kefalas, Additional evidence on the extent of the SES sensitive area around Ioannina, *Acta Geophys. Pol.,* **46**, *27*3–275, 1998.

55. P. Varotsos, N. Bogris, K. Eftaxias, V. Hadjicontis, M. Lazaridou, and M. Kefalas, On the extent of the SES sensitive area around Ioannina. Additional evidence II, *Acta Geophys. Pol.,* **46***,* 411–413, 1998.

56. P. Varotsos, N. Sarlis, and M. Lazaridou, Claims of success in using geoelectrical precursors to predict earthquakes are criticized and defended, *Physics Today,* **51**, Issue 6, 96–100 (June 1998). Also published in *Parity* (Japanese translation from *Physics Today*).

57. P. Varotsos, N. Sarlis, N. Bogris, J. Makris, P. Kapiris, and A. Abdulla, A comment on the ΔV/L-criterion for the identification of Seismic Electric Signals, in "Atmospheric and Ionospheric Electromagnetic Phenomena Associated with Earthquakes", edited by M. Hayakawa, pp. 1–45. Terra Scientific Publishing Company (TERRAPUB), Tokyo, 1999, pp.1–45.

58. P. Varotsos, and M. Lazaridou, A review of the VAN method, in "Atmospheric and Ionospheric Electromagnetic Phenomena Associated with Earthquakes", edited by M. Hayakawa, Terra Scientific Publishing Company (TERRAPUB), Tokyo, 1999 pp. 47–51.

59. P. Varotsos, N. Sarlis, M. Lazaridou, N. Bogris, K. Eftaxias and V. Hadjicontis, A Review on the Statistical Significance of VAN Predictions, *Physics and Chemistry of the Earth (A),* **24**, 111–114, 1999.

60. P. Varotsos, N. Sarlis, K. Eftaxias, M. Lazaridou, N. Bogris, J. Makris, A. Abdulla and P. Kapiris, Prediction of the 6.6 Grevena-Kozani earthquake of May 13, 1995, *Physics and Chemistry of the Earth (A),* **24**, 115–121, 1999.

61. P. Varotsos, N. Sarlis, and M. Lazaridou, Interconnection of defect parameters and stress-induced electric signals in ionic crystals, *Phys.Rev. B*. **59**, 24–27, 1999.

62. N. Sarlis, M. Lazaridou, P. Kapiris, and P. Varotsos, Numerical model of the selectivity effect and the ΔV/L criterion, *Geophys. Res. Lett.* **26**, 3245–3248, 1999.

63. P. Varotsos, K. Eftaxias, V. Hadjicontis, N. Bogris, E. Skordas, P. Kapiris, and M. Lazaridou, A note on the extent of the SES sensitive area around Lamia (LAM), Greece, *Acta Geophys. Pol.,* **47***,* 435–439, 1999.

64. P. Varotsos, K. Eftaxias, V. Hadjicontis, N. Bogris, E. Skordas, P. Kapiris, and M. Lazaridou, A note on the extent of the SES sensitive area around Lamia (LAM), Greece. Continuation I, *Acta Geophys. Pol.,* **47***,* 441–442, 1999.

65. P. Varotsos, K. Eftaxias, V. Hadjicontis, N. Bogris, E. Skordas, P. Kapiris, and M. Lazaridou, A note on the extent of the SES sensitive area around Lamia (LAM), Greece. Continuation II, *Acta Geophys. Pol.,* **47**, 443–444, 1999.

66. E. Dologlou and M. Lazaridou, Comments on the predictions of large earthquakes issued by VAN during the last decade, *Acta Geophys. Pol.,* **47***,* 59–75, 1999.

67. K. Eftaxias, J. Kopanas, N. Bogris, P. Kapiris, G. Antonopoulos, and P. Varotsos, Detection of electromagnetic earthquake precursory signals in Greece, *Proc. Japan Acad. Ser. B,* **76**, 45–50, 2000.

68. E. Skordas, P. Kapiris, N. Bogris, and P. Varotsos, Field experimentation on the detectability of co-seismic electric signals, *Proc. Japan Acad., Ser. B,* **76**, 51–56, 2000.

69. P. Varotsos, N. Sarlis, and M. Lazaridou, Transmission of stress induced electric signals in dielectric media, Part II, *Acta Geophys. Pol.,* **48**, 141–177, 2000.

70. P. Varotsos, N. Sarlis, and E. Skordas, Transmission of stress induced electric signals in dielectric media, Part III, *Acta Geophys. Pol.,* **48**, 263–297, 2000.

71. K. Eftaxias, J. Kopanas, N. Bogris, P. Kapiris, G. Antonopoulos, and P. Varotsos, Detection of electromagnetic earthquake precursory signals in Greece, *Proc. Japan. Acad. Ser. B,* **76**, 45–50, 2000.

72. A. Kyritsis, M. Siakantari, A. Vasilikou-Dova, P. Pissis, and P. Varotsos, Dielectric and electrical properties of polycrystalline rocks at various hydration levels, *IEEE,* **7**, 493–497, 2000.

73. A. Kyritsis, M. Siakantari, A. Vasilikou-Dova, P. Pissis, and P. Varotsos, Large low frequency dielectric constant exhibited by hydrated rock materials, *Proc. Japan Acad. Ser. B,* **77***,* 19–23, 2001.

74. P. Varotsos, V. Hadjicontis, and A.S. Nowick, The physical mechanism of Seismic Electric Signals, *Acta Geophys. Pol.* **49***,* 415–421, 2001.

75. P. Varotsos, N. Sarlis, and E. Skordas, A note on the spatial extent of the Volos SES sensitive site, *Acta Geophys. Pol.* **49**,425–435, 2001.

76. P. Varotsos, and M. Lazaridou, Thermodynamic of Point Defects. In "Earthquake Thermodynamics and Phase Transformation in the Earth's Interior" (edited by R. Teisseyre and E. Majewski). *Academic Press*, pp. 231–259, 2001 .

77. P. Varotsos, A review and analysis of electromagnetic precursory phenomena, *Acta Geophys. Pol.* **49**, 1–42, 2001.

78. N. Sarlis, and P. Varotsos, Comments on the transmission of electric signals in dielectric media, *Acta Geophys. Pol.* **49**, 277–285, 2001.

79. P. Varotsos, N. Sarlis, and E. Skordas, Magnetic field variations associated with SES. The instrumentation used for investigating their detectability, *Proc. Japan Acad. Ser. B,* **77***,* 87–92, 2001.

80. P. Varotsos, N. Sarlis, and E. Skordas, Magnetic field variations associated with SES before the 6.6 Grevena-Kozani earhquake, *Proc. Japan Acad. Ser. B,* **77***,* 93–97, 2001.

81. K. Eftaxias, I. Rokityansky, N. Bogris, G. Balasis, and P. Varotsos, Magnetovariatonal and magnetotelluric study of Ioannina region sensitive to Seismic Electric Signals (SES), *J. Atmospheric Electricity*, **22**, 113–137, 2002 .

82. N. Sarlis and P. Varotsos, Magnetic field near the outcrop of an almost horizontal conductive sheet, *J. Geodynamics,* **33**, 463–476, 2002.

83. P. Varotsos, N. Sarlis, and E. Skordas, Seismic electric signals and seismicity: On a tentative interrelation between their spectral content, *Acta Geophys. Pol.* **50**, 337–354, 2002.

84. P. Varotsos, N. Sarlis, E. Skordas, and M. Lazaridou, Note on an important SES activity at Ioannina station (IOA), *Acta Geophys. Pol.* **50**, 355–359, 2002.

85. P.A. Varotsos, N.V. Sarlis, and E.S. Skordas, Long-range correlations in the electric signals that precede rupture, *Phys. Rev. E,* **66**, 011902 (7), 2002.

86. P. Varotsos and N. Sarlis, A review of the recent VAN efforts: the explanation of the SES physical properties, in "Seismo-Electromagnetics: Lithosphere-Atmosphere-Ionosphere coupling", edited by M. Hayakawa and O.A. Molchanov, *TerraPub.*, Tokyo, 131–140, 2002.

87. P.A. Varotsos, N.V Sarlis, and E.S. Skordas, Long-range correlations in the electric signals that precede rupture: Further investigations, *Phys. Rev. E*, **67**, 021109 (13), 2003.

88. P. Varotsos, N. Sarlis, E. Skordas, and M. Lazaridou, Four notes on SES activity at the Ioannina observatory, Greece, *Acta Geophys. Pol.* **51**, 147–153, 2003.

89. P.A. Varotsos, N.V. Sarlis, and E.S. Skordas, Attempt to distinguish electric signals of a dichotomous nature, *Phys. Rev. E.* **68**, 031106 (7), 2003.

90. P.A. Varotsos, N.V. Sarlis, and E.S. Skordas, Electric fields that “arrive” before the time-derivative of the magnetic field prior to major earthquakes, *Phys. Rev. Lett.*, **91**, 148501 (4), 2003.

91. P. Varotsos, N. Sarlis, E. Skordas, and M. Lazaridou, Determination of the epicentral distance of an impending earthquake from the rise time of Seismic Electric Signals, *Studying the Earth from Space* ,**5**, 3–5, 2003.

92. P. Varotsos, N. Sarlis, E. Skordas, and M. Lazaridou, The time-difference between the electric and magnetic field variations of Seismic Electric Signals and the Space Techniques, *Studying the Earth from Space,* **6**, 14–17, 2003.

93. P. Varotsos, N. Sarlis, E. Skordas, and M. Lazaridou, SES activity recorded at Keratea (KER) station on April 12, 2003, *Acta Geophys. Pol.* **52***,* 45–48, 2004.

94. P. Varotsos, Fracture and friction: A review, *Acta Geophys. Pol.*, ***52***, 105–142, 2004.

95. P. Varotsos, N. Sarlis, and E. Skordas, On the difference in the rise times of the two SES electric field components, *Proc. Japan Acad., Ser. B,* **80**, 276–282, 2004.

96. H. Tanaka, P.A. Varotsos, N.V. Sarlis, and E.S. Skordas, A plausible universal behavior of earthquakes in the natural time-domain, *Proc. Japan Acad. Ser. B,* **80**, 283–289, 2004.

97. P.A. Varotsos, N.V. Sarlis, E.S. Skordas, and M.S. Lazaridou, Entropy in the natural time-domain, *Phys. Rev. E,* **70**, 011106(10), 2004.

98. P.A. Varotsos, N.V. Sarlis, E.S. Skordas, and H.K. Tanaka, A plausible explanation of the b-value in the Gutenberg-Richter law from First Principles, *Proc. Japan Acad. Ser. B,* **80**, 429–434, 2004.

99. R. Teisseyre, P. Varotsos, and C. Rozluchi, Electromagnetic excitation and seismicity in the natural time-domain: Stimulations with a theoretical model, *Acta Geophys. Pol.* **52***,* 477–496, 2004.

100. N. Sarlis, E. Skordas, and P. Varotsos, A review of the current understanding of the physical properties of SES, In *Routledge IDNDR volume*, 2004.

101. I. Rokityansky, P. Varotsos, and N. Sarlis, Comment on “Electrical conductivity and crustal structure beneath the central Hellenides around the Gulf of Corinth (Greece) and their relationship with the seismotectonics, Pham et al., 2000, *Geophys. J. Int.* 142, 948–969”, *Geophys. J. Int.* **162**, 332–336, 2005.

102. P.A. Varotsos, N.V. Sarlis, E.S. Skordas, and M.S. Lazaridou, Natural entropy fluctuations discriminate similar looking electric signals emitted from systems of different dynamics, *Phys. Rev. E* **71***,* 011110(11), 2005.

103. P.A. Varotsos, N.V. Sarlis, H.K. Tanaka and E.S. Skordas, Some properties of the entropy in the natural time, *Phys. Rev. E,* **71**, 032102(4), 2005.

104. P.A. Varotsos, N.V. Sarlis, and E.S. Skordas, Time diference between the electric field components prior to major earthquakes, *Appl. Phys. Lett.* **86**, 194101(3), 2005.

105. S. Abe, N.V. Sarlis, E.S. Skordas, H.K. Tanaka and P.A. Varotsos, Origin of the usefullness of the natural time representation of complex time series, *Phys. Rev. Lett.* **94**, 170601(4), 2005.

106. P.A. Varotsos, N.V. Sarlis, E.S. Skordas, H.K. Tanaka, and M.S. Lazaridou, Additional evidence on some relationship between Seismic Electric Signals and earthquake source parameters, *Acta Geophys. Pol.* **53**, 293–298, 2005.

107. P.A. Varotsos, N.V. Sarlis, H.K. Tanaka and E.S. Skordas, Similarity of fluctuations in correlated systems: The case of seismicity, *Phys. Rev. E* **72**, 041103(8), 2005.

108. P. Varotsos, N. Sarlis, E. Skordas, and M. Lazaridou, Additional evidence on some relationship between Seismic Electric Signals (SES) and earthquake focal mechanism, *Tectonophysics* **412**, 279–288, 2006.

109. P. Varotsos, and M. Lazaridou, A Review on Friction. In "Earthquake Source Assymetry, Structural Media and Rotation Effects", edited by R. Teisseyre, M. Takeo and E. Majewski, Springer, Heildelberg, pp. 91–111, 2006

110. P. Varotsos, N. Sarlis, and E. Skordas, On the recent advances in the study of Seismic Electric Signals (VAN method), *Physics and Chemistry of the Earth (A)* **31**, 189–197, 2006 .

111. I. Rokityanski, and P. Varotsos, Magnetotelluric data collection and analysis in the SES sensitive site of Ioannina area, Greece, *Physics and Chemistry of the Earth (A)* **31**, 198–203, 2006.

112. N.V. Sarlis, P.A. Varotsos, and E.S. Skordas, Flux avalances in $YBa_2Cu_3O_{7-x}$ films and rice piles: Natural time domain analysis, *Phys. Rev. B,* **73**, 054504 (7), 2006.

113. P.A. Varotsos, N.V. Sarlis, E.S. Skordas, H.K. Tanaka, and M.S. Lazaridou, Entropy of seismic electric signals: Analysis in natural time under time reversal, *Phys. Rev. E,* **73**, 031114 (8), 2006.

114. P.A. Varotsos, What happened before the last five strong earthquakes in Greece, *Proc. Japan. Acad. Ser. B,* **82**, 86–91, 2006.

115. P.A. Varotsos, Recent Seismic Electric Signals (SES) activities in Greece, *Acta Geophysica* (Springer-Verlag) **54**, 158–164, 2006.

116. P.A. Varotsos, N.V. Sarlis, E.S. Skordas, H.K. Tanaka and M.S. Lazaridou, Attempt to distinguish long-range temporal correlations from the statistics of the increments by natural time analysis, *Phys. Rev. E,* **74**, 021123(12), 2006.

117. P.A. Varotsos, N.V. Sarlis, E.S. Skordas, and M.S. Lazaridou, Electric pulses some minutes before earthquake occurrences, *Appl. Phys. Lett.* **90**, 064104(3), 2007.

118. P. Varotsos, Comparison of models that interconnect point defect parameters in solids with bulk properties, *J. Appl. Phys.* **101,** 123503(8), 2007.

119. P.A. Varotsos, N.V. Sarlis, E.S. Skordas, and M.S. Lazaridou, Identifying sudden cardiac death risk and specifying its occurrence time by analyzing electrocardiograms in natural time, *Appl. Phys. Lett.* **91,** 064106(3), 2007.

120. P.A. Varotsos, N.V. Sarlis, E.S. Skordas, and M.S. Lazaridou, Fluctuations, under time reversal, of the natural time and the entropy distinguish similar looking electric signals of different dynamics, *J. Appl. Phys.* **103***,* 014906 (2008).

121. P. Varotsos and S. Uyeda, Comments on "Seismomagnetic Effects from the Long-Avaited 28 September 2004 M 6.0 Parkfield Earthquake" by M.J.S. Johnston, Y. Sasai, G.D. Egberg, and R.J. Mueller", *Bulletin of the Seismological Society of America* **98**, 2087–2089, 2008.

122. N.V. Sarlis, E.S. Skordas, M.S. Lazaridou, and P.A. Varotsos, Investigation of the seismicity after the initiation of a Seismic Electric Signal activity until the main shock, *Proc. Japan Acad. Ser.B* **84,** 331–343, 2008.

123. P.A. Varotsos, N.V. Sarlis, and E.S. Skordas, Detrended fluctuation analysis of the magnetic and electric field variations that precede rupture, *CHAOS* **19**, 023114(8), 2009.

124. N.V. Sarlis, E.S. Skordas and P.A. Varotsos, Heart rate variability in natural time and 1/f «noise», *EPL* **87**, 18003, 2009.

125. N.V. Sarlis, E.S. Skordas, and P.A. Varotsos, Multiplicative cascades and seismicity in natural time, *Phys. Rev. E* **80**, 022102, 2009.

126. E.S. Skordas, N.V. Sarlis and P.A. Varotsos, Effect of significant data loss on identifying electric signals that precede rupture estimated by detrended fluctuation analysis in natural time, *CHAOS* **20**, 033111, 2010.

127. N.V. Sarlis, E.S. Skordas and P.A. Varotsos, Order parameter fluctuations of seismicity in natural time before and after mainshocks *EPL* **91**, 59001, 2010.

128. N.V. Sarlis, E.S. Skordas and P.A. Varotsos, Nonextensivity and natural time: The case of seismicity, *Phys. Rev. E* **82**, 021110, 2010.

129. P.A. Varotsos, N.V. Sarlis, E.S. Skordas, S. Uyeda and M. Kamogawa, Natural time analysis of critical phenomena: The case of seismicity, *EPL* **92**, 29002, 2010.

130. P.A. Varotsos, N.V. Sarlis and E.S. Skordas, "Identifying long-range correlated signals upon significant periodic data loss", *Tectonophysics* **503,** 189–194, 2011.

131. P. Varotsos, N. Sarlis, E. Skordas, S. Uyeda and M. Komogawa, Natural time analysis of critical phenomena, *Proc. Natl. Acad. Sci. USA*, **108,** 11361–11364, 2011.

132. N.V. Sarlis, E.S. Skordas and P.A. Varotsos, Similarity of fluctuations in systems exhibiting Self-Organized Criticality, *EPL* **96**, 28006, 2011.

133. N.V. Sarlis, E.S. Skordas and P.A. Varotsos, The change of the entropy in natural time under time-reversal in the Olami-Feder-Christensen earthquake model, *Tectonophysics* 513, 49–53 2011.

134. P. Varotsos, N. Sarlis and E. Skordas, Scale-specific order parameter fluctuations of seismicity in natural time before mainshocks, *EPL* **96**, 59002, 2011.

135. P. Varotsos, N. Sarlis, E. Skordas, S. Uyeda, M. Komogawa, T. Nagao and H. Tanaka, Fluctuations of an order parameter for seismicity before the 2011 M9.0 super giant Tohoku earthquake and several other recent large Japanese earthquakes, *Proc. Japan Acad. Ser. B*, (to be published 2012).

Additional publications related to the VAN method and/or natural time analysis by P. Varotsos and co-workers (mainly in *Practica of the Athens Academy*)

136. P. Varotsos, K. Alexopoulos and K. Nomicos, Seismic electric currents, *Practica Athens Academy* **56**, 277–286, 1981.

137. P. Varotsos, K. Alexopoulos and K. Nomicos, Seven hours precursors to earthquake determined from telluric currents, *Practica Athens Academy* **56**, 417–433, 1981.

138. P. Varotsos, K. Alexopoulos, K. Nomicos, G. Papaioannou, M. Lazaridou and E. Dologlou, Determination of the epicenter of impending earthquakes from precursor changes of the telluric current, *Practica Athens Academy* **56**, 434–446, 1981.

139. P. Varotsos, K. Alexopoulos, K. Nomicos, G. Papaioannou, M. Lazaridou and E. Dologlou, Determination of the epicenter of an earthquake, *Practica Athens Academy* **57,** 364–371, 1982.

140. P. Varotsos, K. Alexopoulos and K. Nomicos, Electrotelluric precursors to earthquakes, *Practica Athens Academy* **57**, 341–363, 1982.

141. P. Varotsos, K. Alexopoulos, K. Nomicos, E. Dologlou-Revelioti, and M. Lazaridou-Varotsou, Parameters of the electrotelluric precursors to earthquakes of Kefallinia, *Practica Athens Academy* **58**, 250–257, 1983.

142. P. Varotsos and K. Alexopoulos, Physical properties of the variations of the electric field of the earth preceding earthquakes, *Practica Athens Academy* **59**, 51–116, 1984.

143. P. Varotsos, K. Alexopoulos, K. Nomicos and M. Lazaridou, On the contribution of selectivity to the prediction of earthquake epicenters, *Practica of Athens Academy* **61**, 12, 1986.

144. M. Lazaridou-Varotsou and D. Papanikolaou, Tectonoelectric zonation in the Hellenic Arc, *Practica Athens Academy* **62,** 164–187, 1987.

145. E. Dologlou, K. Eftaxias, V. Hadjikontis, A. Androutsopoulou and P. Varotsos, The installation of a new seismic network in Greece for test ban monitoring, Proceedings of the Conference on Nuclear Test Ban Verification (Linkoping, Sweden, May 17–19, 1988; invited paper).

146. P. Varotsos, Review on Seismic Electric Signals, in "Sono prevedibili, terremoti e le eruzioni vulcaniche", *Protezione Civile Publicazione* **17,** 81–84 1989.

147. P. Varotsos, K. Alexopoulos, K. Nomicos and M. Lazaridou, Earthquake Prediction in Greece from Seismic Electric Signals: Period January 1, 1987–June 30, 1989, *Practica of Athens Academy* **64**, 514–523, 1990.

148. P. Varotsos, K. Alexopoulos and M. Lazaridou, Short term earthquake prediction from measurements of the electric field of the earth, Invited paper in "The Seminaire de Formation Avancee sur les Problemes de l' Interdisciplinarite". Etude de cas: la prevision des seismes (Delphes, 25–27 March 1990). [Publications de la Sorbonne 1996]

149. P. Varotsos and M. Lazaridou, Earthquake Prediction in Greece by VAN-method, in "*International Seminar on Earthquake Prediction and Hazard Mitigation Technology*", Edited by Science and Technology Agency (Tsukuba, Japan) pp. 307–322, 1991 (Invited Paper).

150. P. Varotsos, K. Alexopoulos and M. Lazaridou, Comments on the recent seismic electric signal activity in Greece, in "International Seminar on Earthquake Prediction and Hazard Mitigation Technology", edited by Science and Technology Agency (Tsukuba, Japan) pp. 323–331, 1991 (Invited Paper)

151. P. Varotsos, K. Alexopoulos, K. Nomicos and M. Lazaridou-Varotsou, Prediction of 5.7 Richter earthquake of January 23, 1992, *Practica of Athens Academy* **67**, 213–219, 1992.

152. P. Varotsos, K. Alexopoulos, K. Eftaxias and M. Lazaridou, Basic principles for evaluating an earthquake prediction method, *Practica of Athens Academy* **68**, 306-316, 1993.

153. P. Varotsos and M. Lazaridou, Earthquake prediction in Greece based on Seismic Electric Signals, Invited talk on the workshop on Emergency Management, Ispra (June 23–24, 1992), EUR 14953 EN, 15–32, 1993.

154. J. Kopanas, K. Eftaxias, G. Antonopoulos, J. Makris, M. Lazaridou and P. Varotsos, Short Term Earthquake Prediction in Greece by detecting Seismic Electric Signals, in "Electromagnetic Compatibility", EMC12-16, Poland, 1994.

155. P. Varotsos, N. Sarlis, M. Lazaridou and P. Kapiris, A plausible model for the explanation of the selectivity effect of Seismic Electric Signals, *Practica of Athens Academy* **71**, 283–354, 1996.

156. P. Varotsos, N. Sarlis, M. Lazaridou, and P. Kapiris, Transmission mechanism of Seismic Electric Signals. II, *Practica of Athens Academy* **72**, 270–302, 1997.

157. M. Lazaridou, N. Sarlis, P. Varotsos, and P. Kapiris, On the physical basis of the $\Delta V/L$-criterion for the discrimination of electrical precursors from artificial noise, *EOS 78*, S210, 1997 (Extended abstract).

158. P. Varotsos, N. Sarlis, and E. Skordas, Spatiotemporal complexity aspects on the

interrelation between Seismic Electric Signals and seismicity, *Practica of Athens Academy,* **76**, 294–321, 2001.

159. P. Varotsos, N.Sarlis, E. Skordas, and M. Lazaridou, A real-time application of spatio-temporal complexity aspects to a recent electric disturbance recorded at Ioannina, *Practica of Athens Academy*, **77**, 111–117, 2002.

160. P. Varotsos, N. Sarlis, E. Skordas, and M. Lazaridou, The use of the entropy in the natural time-domain to distinguish electric signals, *Practica of Athens Academy* **78**, 281–298, 2003.

161. S. Abe, U. Tirnakli, and P.A. Varotsos, Complexity of seismicity and nonextensive statistics, *Europhysics news* **36**, *N^r 6*, 206–208, 2005.

162. P.A. Varotsos, N.V. Sarlis, E.S. Skordas, and M.S. Lazaridou, Recent Progress in the VAN Method: Analysis in Natural Time, in "Electromagnetic Phenomena Related to Earthquakes and Volcanoes", edited by Birbal Singh, Narosa Pub. Co., pp. 169–184, New Delhi (2007).

Books related to the VAN method and/or natural time analysis by P. Varotsos and co-workers

1. P. Varotsos and K. Alexopoulos, Thermodynamics of Point Defects and their Relation with the Bulk Properties, *North Holland,* Amsterdam (1986) 474 pages.

2. P. Varotsos. The Physics of Seismic Electric Signals, *TerraPub*, Tokyo (2005) 338 pages.

3. P.A.Varotsos, N.V.Sarlis and E.S.Skordas, Natural Time Analysis: The New View of Time. Precursory Seismic Electric Signals, Earthquakes and other Complex Time-Series, *Springer-Verlag, Berlin,* Heidelberg (2011) 484 pages.

Special Issues related to the VAN method

1. Measurements and Theoretical Models of the Earth's Electric Field Variations Related to Earthquakes, *Tectonophysics* Vol. 224, No 1/3 (1993) 288 pages.

2. A Critical Review of VAN, Earthquake prediction from seismic electric signals, ed. Sir J. Lighthill, *World Scientific*, Singapore (1996) 376 pages.

3. Debate on VAN, *Geophysical Research Letters* Vol. 23, No. 11 (1996) pp1291-1452.

List of publications related to the VAN method and/or Natural Time Analysis by other authors

1. J. Miyakoshi, Anomalous time-variation of the self-potential in the fractured zone of an active fault preceding the earthquake occurrence, *Journal of Geomagnetism and Geoelectricity* 38, 1015-1030, 1986.

2. J.C. Sabroux, The long March of Greek physicists in forecasting earthquakes, *La Recherche* 17, 836-838, June 1986.

3. G. Chouliaras and T.M. Rasmussen, The application of the magnetotelluric impedance tensor to earthquake prediction research in Greece, *Tectonophysics* 152, 119-135, 1988.

4. J. Labeyrie, Un moyen fiable de prévoir les séismes*?* [Is there a reliable way to forecast earthquakes?]*, La Recherche* 19, 1236, October 1988.

5. I.P. Dobrovolsky, N. L. Gershenzon and M.B. Gokhberg, Theory of electrokinetic effect occurring at the final state in the preparation of a tectonic earthquake, *Phys. Earth Planet. Inter.* 57, 144-156, 1989

6. M. Kinoshita, M. Uyeshima and S. Uyeda, Earthquake prediction research by means of telluric potential monitoring, Progress Rep. 1. *Bull. Earthq. Res. Inst.* 64, 255–311, 1989.

7. A.C. Fraser-Smith, A Bernardi, P.R. McGill, M.E. Ladd, R.A. Helliwell and O.G. Villard, Low-frequency magnetic-field measurements near the epicenter of the Ms-7.1 Loma Prieta earthquake. *Geophys. Res. Lett.* **17**, 1465–1468, 1990.

8. A. Sornette and D. Sornette, Earthquake rupture as a critical point: Consequences for telluric precursors. *Tectonophysics* **179**, 327-334, 1990.

9. A. Bernardi, A.C. Fraser-Smith, P.R. McGill, and O.G. Villard, ULF magnetic field measurements near the epicenter of the Ms 7.1 Loma Prieta earthquake. *Phys. Earth Planet Inter.* **68**, 45–63, 1991.

10. M. Kikuchi and H. Kanamori, Inversion of complex body waves-III, *Bull. Seism. Soc. Am*, **81**, 2335-2350, 1991

11. S. Uyeda, Greece; A country where earthquake prediction is in practice, *Zisin* **44**, 391-405, 1991.

12. F. Mulargia and P. Gasperini, Evaluating the statistical validity beyond chance of VAN earthquake precursors, *Geophys. J. Int.* **111**, 32-44, 1992.

13. S. Park, Workshop on Low-Frequency Electrical Precursors to Earthquakes, *EOS Trans. AGU* **73**, 491–492, 1992.

14. C. Maron, G. Baubron, L. Herbreteau and B. Massinon, Experimental study of a VAN network in the French Alps, *Tectonophysics* **224**, 51-81, 1993.

15. T. Kawase, S. Uyeda, M. Uyeshima and M. Kinoshita, Possible correlation between geoelectric potential change in Izu-Oshima Island and the earthquake swarm off the east Izu Peninsula, Japan, *Tectonophysics* **224**, 83-93, 1993.

16. T.M. Ralchovsky and L.N. Komarov, SES activity and the Earth's electric potential, *Tectonophysics* **224**, 95-101, 1993.

17. R. Arvidsson and O. Kulhánek, Enhancement of seismic electric signals using magnetotellurics, *Tectonophysics* **224**, 131-139, 1993.

18. T. Ernst, J. Jankowski, C. Rozłuski and R. Teisseyre, Analysis of the electromagnetic field recorded in the Friuli seismic zone, northeast Italy, *Tectonophysics* **224**, 141-148, 1993

19. L. Slifkin, Seismic electric signals from displacement of charged dislocations, *Tectonophysics* **224**, 149-152, 1993

20. H. Utada, On the physical background of the VAN earthquake prediction method, *Tectonophysics* **224**, 153-160, 1993.

21. J. Labeyrie, Comments on the results obtained in Greece by the VAN method of seismic prediction, *Tectonophysics* **224**, 161-167, 1993.

22. N. Gershenzon and M. Gokhberg, On the origin of electrotelluric disturbances prior to an earthquake in Kalamata, Greece, *Tectonophysics* **224**, 169-174, 1993.

23. K. Hamada, Statistical evaluation of the SES predictions issued in Greece: alarm and success rates, *Tectonophysics* **224**, 203-210, 1993.

24. S. Park, M. Johnston, T. Madden, D. Morgan, and F. Morrison, Electromagnetic precursors to earthquakes in the VLF band: A review of observations and mechanisms, *Rev.Geophys*. **31**, 117-132, 1993.

25. M. Shnirman, S. Schreider and O. Dmitrieva, Statistical evaluation of the VAN predictions issued during the period 1987–1989, *Tectonophysics* **224**, 211-221, 1993.

26. H. Takayama, Comment on "Evaluating the statistical validity beyond chance of VAN earthquake precursors" by Mulargia F. and Gasperini P., *Geophys. J. Int.*, **115**, 1197-1198, 1993

27. H. Yoshii, Social impacts of earthquake prediction in Greece, *Tectonophysics* **224**, 251-255, 1993.

28. Y. Honkura and Y. Kuwata, Estimation of electric fields in the conducting Earth's crust for oscillating electric current dipole sources and implications for anomalous electric fields associated with earthquakes, *Tectonophysics* **224**, 257-263, 1993.

29. D. Lazarus, Note on a possible origin for seismic electrical signals, *Tectonophysics* **224**, 265-267, 1993.

30. O. Nishizawa, X. Lei and T. Nagao, "Point Process analysis of Seismic Electric Signals" in "Electromagnetic Phenomena Related to Earthquake Prediction", edited by M. Hayakawa and Y. Fujinawa, *TerraPub*, Tokyo, 459-474, 1994.

31. Y. Zhao and F. Qian, Geoelectric precursors to strong earthquakes in China, *Tectonophysics* **233**, 99-113, 1994.

32. R.A. Kerr, Quake prediction tool gains ground. *Science* **270**, 911–912, 1995.

33. E. Masood, Greek earthquake stirs controversy over claims for prediction method. *Nature* **375**, 617, 1995.

34. E. Masood, Court charges open split in Greek earthquake experts. *Nature* **377**, 375, 1995.

35. R. Monastersky, Electric signals may herald earthquakes. *Science News* **148**, 260, 1995.

36. D. Swinbanks, Japan jumps on board the VAN wagon, *Nature* **375**, 617, 1995.

37. R.L. Aceves, S.K. Park and D,J, Strauss, Statistical evaluation of the VAN Method using the historic earthquake catalog in Greece, *Geophys. Res. Lett.* **23**, 1425-1428, 1996.

38. P. Bernard, and J.L. Le Mouel, "On electrotelluric signals" in "A Critical Review of VAN: Earthquake Prediction from Seismic Electric Signals" edited by Sir J. Lighthill, *World Scientific*, Singapore, 118-152, 1996.

39. J.J. Chu, X.T. Gui, J.A. Dai, C Marone, M.W. Spiegelman, L. Seeber *et al.*, Geoelectric signals in China and the earthquake generation process, *J. Geophys. Res.-Solid Earth* 101, 13869-13882, 1996.

40. K. Hamada, "Re-examination of statistical evaluation of the SES prediction in Greece" in "A Critical Review of VAN: Earthquake Prediction from Seismic Electric Signals" edited by Sir J. Lighthill, *World Scientific*, Singapore, 286-291, 1996.

41. Y. Honkura and N. Tanaka, Probability of earthquake occurrence in Greece with special reference to the VAN predictions, *Geophys. Res. Lett.* **23**, 1417-1420, 1996.

42. H. Kanamori, "A seismologist's view of VAN" in "A Critical Review of VAN: Earthquake Prediction from Seismic Electric Signals" edited by Sir J. Lighthill, *World Scientific*, Singapore, 339-346, 1996

43. V.I. Keilis-Borok, "Non-seismological fields in earthquake prediction research" in "A Critical Review of VAN: Earthquake Prediction from Seismic Electric Signals" edited by Sir J. Lighthill, *World Scientific*, Singapore, 357-372, 1996

44. O. Kulhanek, "Implementation of VAN technique in Guatemala: Project description" in "A Critical Review of VAN: Earthquake Prediction from Seismic Electric Signals" edited by Sir J. Lighthill, *World Scientific*, Singapore, 332-336, 1996

45. D. Lazarus, “Physical mechanisms for generation and propagation of seismic electrical signals” in “A Critical Review of VAN: Earthquake Prediction from Seismic Electric Signals” edited by Sir J. Lighthill, *World Scientific*, Singapore, 91-96, 1996.

46. J. Lighthill, “A brief look back at the Review Meeting’s Proceedings” in “A Critical Review of VAN: Earthquake Prediction from Seismic Electric Signals” edited by Sir J. Lighthill, *World Scientific*, Singapore, 349–356 1996.

47. J. Lighthill, “A brief look forward to future research needs” in “A Critical Review of VAN: Earthquake Prediction from Seismic Electric Signals” edited by Sir J. Lighthill, *World Scientific*, Singapore, 373–376,1996.

48. Y.F. Moroz, Precursors of strong earthquakes in the Kamchatka low-frequency electromagnetic field, *Fizika Zemli* **5**, 58-62, May 1996.

49. T. Nagao, M. Uyeshima and S. Uyeda, An independent check of VAN’s criteria for signal recognition, *Geophys. Res. Lett.* **23**, 1441-1444, 1996.

50. T. Nagao, S. Uyeda, Y. Asai and Y. Kono, “Anomalous changes in geoelectric potential preceding four earthquakes in Japan” in “A Critical Review of VAN: Earthquake Prediction from Seismic Electric Signals” edited by Sir J. Lighthill, *World Scientific*, Singapore, 292–300, 1996.

51. S.K. Park, D.J. Strauss and R.L. Aceves, “Some observations about the statistical significance and physical mechanisms of the VAN method of earthquake prediction, Greece” in “A Critical Review of VAN: Earthquake Prediction from Seismic Electric Signals” edited by Sir J. Lighthill, *World Scientific*, Singapore, 267–285, 1996.

52. L. Slifkin, “A dislocation model for Seismic Electric Signals” in “A Critical Review of VAN: Earthquake Prediction from Seismic Electric Signals” edited by Sir J. Lighthill, *World Scientific*, Singapore, 97-104, 1996.

53. K. Sudo, “Foreshocks preceding VAN signals (SES)” in ”A Critical Review of VAN: Earthquake Prediction from Seismic Electric Signals” edited by Sir J. Lighthill, *World Scientific*, Singapore, 239-243, 1996.

54. G. Akis Tselentis and A. Ifantis, Geoelectric variations related to earthquakes observed during a 3 year independent investigation, *Geophys. Res. Lett.* **23**, 1445-1448, 1996.

55. G. Akis Tselentis and N.S. Melis, A note on evaluating VAN earthquake predictions, *Geophys. Res. Lett.* **23**, 1411-1414, 1996.

56. S. Uyeda, “Introduction to the VAN method of earthquake prediction” in “A Critical Review of VAN: Earthquake Prediction from Seismic Electric Signals” edited by Sir J. Lighthill, *World Scientific*, Singapore, 3-28, 1996.

57. L. Jouniaux and J.P. Pozzi, Laboratory measurements anomalous 0.1-0.5 Hz streaming potential under geochemical changes: Implications for electrotelluric precursors to earthquakes, *J. Geophys. Res.* **102**, 15335-15343, 1997.

58. J. Wakefield, Electric shockers, *NewScientist* **153**, 34-37, 1 March 1997.

59. O.A. Molchanov and M. Hayakawa, On the generation mechanism of ULF seismogenic electromagnetic emissions, *Phys. Earth Planet Inter.* **105**, 201–210, 1998.

60. S. Uyeda, Earthquakes can be predicted, *Natl. Acad. Sci. Lett.-India* **21**, 221-236, 1998.

61. S. Uyeda, VAN method of short-term earthquake prediction shows promise. *EOS Trans. AGU* **79**, 573–580, 1998.

62. O.A.Molchanov, "Fracturing as underlying mechanisms of seismo-electric signals" in "Atmospheric and Ionospheric Electromagnetic Phenomena Associated with Earthquakes" edited by M. Hayakawa, *TerraPub*, Tokyo, 349-356, 1999.

63. Y.F. Moroz, S.V. Popruzhenko, V.M. Trubnikov, V.P. Kuznetsova, T.A. Moroz *et al.*, Geoelectric current effects preceding earthquakes on the Kamchatka peninsula, *Fizika Zemli* 3-4, 82-88, MAR-APR 1999.

64. I.I. Rokityansky, Anomalous phenomena preceding earthquakes (one more approach to discussion on SES nature and VAN-prediction reliability), *Phys. Chem. of the Earth (A)* **24**, 731-734, 1999.

65. I. Takahashi, T. Nagao and S. Uyeda, On some geoelectric potential changes in Naha, Okinawa, Japan and their possible relationship with nearby earthquakes (in Japanese with English abstract). *Bull. Inst. Oceanic Res. and Develop.* **20**, 31–40, 1999.

66. S. Uyeda and K.S. Al-Damegh, "Evaluation of VAN method" in "Atmospheric and Ionospheric Electromagnetic Phenomena Associated with Earthquakes", edited by M. Hayakawa, *TerraPub*, Tokyo, 53-69, 1999.

67. S. Uyeda, E. Al-Damegh, E. Dologlou, and T. Nagao, Some relationship between VAN Seismic Electric Signals (SES) and earthquake parameters. *Tectonophysics* **304**, 41–55, 1999.

68. W. Kanda, M. Uyeshima, J. Makris, Y. Orihara, H. Hase, T. Nagao, and S. Uyeda, Electric field polarization around Ioannina VAN station, Greece, inferred from a resistivity mapping, *Phys. Earth Planet. Inter.* **119**, 269-283, 2000.

69. Uyeda, S., In defense of VAN's earthquake prediction, *EOS Trans., AGU* **81**, 3, 2000.

70. S. Uyeda, T. Nagao, Y. Orihara, T. Yamaguchi and I. Takahashi, Geoelectric potential changes: Possible precursors to earthquakes in Japan. *Proc. Natl. Acad. Sci. USA* **97**, 4561–4566, 2000.

71. D. Appell, Danger signals: Have we finally found a way to predict earthquakes?, *NewScientist*, page 12, 15 June 2002.

72. S. Kondo, S. Uyeda and T. Nagao, The selectivity of the Ioannina VAN station. *J. Geodynamics* **33**, 433–461, 2002.

73. Y. Orihara, Y. Noda, T. Nagao and S. Uyeda, A possible case of SES selectivity at Kozu-shima island. *J. Geodynamics* **33**, 425–432, 2002.

74. P.M. Reppert and F.D. Morgan, Frequency-Dependent Electroosmosis, *J. Colloid Interf. Sci.* **254**, 372-383, 2002.

75. V.V. Surkov, S. Uyeda, H. Tanaka and M. Hayakawa, Fractal properties of medium and seismoelectric phenomena, *J. Geodynamics* **33**, 477–487, 2002.

76. S. Uyeda, M. Hayakawa, T. Nagao, O. Molchanov, K. Hattori, Y. Orihara, K. Gotoh, Y. Akinaga and H. Tanaka, Electric and magnetic phenomena observed before the volcano-seismic activity in 2000 in the Izu Island Region, Japan. *Proc. Natl. Acad. Sci. USA* **99**, 7352–7355, 2002.

77. D. Graham-Rowe, Heartbeats warn of sudden death risk, *NewScientist*, page10, 3 April 2004

78. A. Ramírez-Rojas, C.G. Pavía-Miller and F. Angulo-Brown, Statistical behavior of the spectral exponent and the correlation time of electric self-potential time series associated to the Ms=7.4 September 14, 1995 earthquake in Mexico, *Phys. Chem. Earth* **29,** 305–312, 2004

79. S. Uyeda and H. Tanaka, Maxwell's equations and earthquakes, *Physics World* **17**, 21-22, 2004.

80. S. Uyeda, T. Nagao and H. Tanaka, A report from the RIKEN international frontier research project on earthquakes. *Terr. Atmos. Ocean. Sci.* **15**, 269–310, 2004.

81. L. Telesca, M. Balasco, G. Colangelo and V. Lapenna, Analysis of Extreme Events in Geoelectrical Time Series Measured in a Seismic Area of Southern Appenine Chain (Italy), *Natural Hazards* **34**, 177-198, 2005

82. J.R. Holliday, J.B. Rundle, D.L. Turcotte, W. Klein, K.F. Tiampo and A Donnellan, Space-time clustering and correlations of major earthquakes. *Phys. Rev. Lett.* **97**, 238501. 2006.

83. J. Zlotnicki, J.L. Le Mouel, R. Kanwar, P. Yvetot, G. Vargemezis, P. Menny *et al.*, Ground-based electromagnetic studies combined with remote sensing based on Demeter mission: A way to monitor active faults and volcanoes, *Planet Space Sci.* **54**, 541-557, 2006.

84. L. Flores-Márquez, J. Márquez-Cruz, A. Ramírez-Rojas, G. Gálvez-Coyt and F. Angulo-Brown, A statistical analysis of electric self-potential time series associated to two 1993 earthquakes in Mexico, *Nat. Hazards Earth Syst. Sci.* **7**, 549-556, 2007

85. M. Uyeshima, EM monitoring of crustal processes including the use of the Network-MT observations, *Surv. Geophys.* **28**, 199-237, 2007

86. G. Colangelo, V. Lapenna and L. Telesca, Study of self potential anomalous fluctuations in a seismic active zone of Lucano Apennine (southern Italy): recent results, *Nat. Hazards Earth Syst. Sci.* **8**, 1099-1104, 2008.

87. A. Ramírez-Rojas, E.L. Flores-Márquez, L. Guzmán-Vargas, G. Gálvez-Coyt, L. Telesca and F. Angulo-Brown, Statistical features of seismoelectric signals prior to M7.4 Guerrero-Oaxaca earthquake (México), *Nat. Hazards Earth Syst. Sci.* **8**, 1001-1007, 2008.

88. S. Uyeda and M. Kamogawa, The prediction of two large earthquakes in Greece. *EOS Trans. AGU* **89**, 363, 2008.

89. L. Guzman-Vargas, A. Ramirez-Rojas, R. Hernandez-Perez and F. Angulo-Brown, Correlations and variability in electrical signals related to earthquake activity, *Physica A* **388**, 4218-4228, 2009

90. Y. Orihara, M. Kamogawa, T. Nagao and S. Uyeda, Independent component analysis of geoelectric field data in the northern Nagano, Japan, *Proc. Jpn. Acad., Ser. B.* **85**, 435-442, 2009

91. Y. Orihara, M. Kamogawa, T. Nagao and S. Uyeda, Heterogeneous electrical structure of Kozu-shima volcanic island, Japan, *Proc. Jpn. Acad., Ser. B* **85**, 476-484, 2009.

92. F.Y. Qian,B.R. Zhao, W. Qian, J. Zhao, S.G. He, H.K. Zhang *et al.*, Impending HRT wave precursors to the Wenchuan Ms8.0 earthquake and methods of earthquake impending prediction by using HRT wave. *Sci China Ser D-Earth Sci* **52**,1572-1584, 2009

93. S. Uyeda, M. Kamogawa and H. Tanaka, Analysis of electrical activity and seismicity in the natural time domain for the volcanic-seismic swarm activity in 2000 in the Izu Island region, Japan. *J. Geophys. Res.* **114**, B02310, 2009.

94. S. Uyeda, T. Nagao and M. Kamogawa, Short-term earthquake prediction: Current status of seismo-electromagnetics, *Tectonophysics* **470,** 205–213, 2009.

95. A Chmel, V. Smirnov, and O. Golovanov, Variability of scaling parameters in non-conservative systems: Geophysical aspect, *Physica A* **389**, 2617-2627, 2010

96. Y.Y. Fan, X.B. Du, J. Zlotnicki, D.C. Tan, J. Liu, Z.H. An *et al.*, The electromagnetic phenomena before the M(s)8.0 Wenchuan earthquake, *Chinese J Geophys-CH* **53**, 2887-2898, 2010

97. Q.H. Huang and Y.F. Lin, Numerical simulation of selectivity of seismic electric signal and its possible influences, *Chinese J Geophys-CH* **53**, 535-543, 2010.

98. S. Uyeda and M. Kamogawa, Reply to a Comment on 'The prediction of two large earthquakes in Greece'. *EOS Trans. AGU* **91**, 163, 2010.

99. Y.L. Zhao, Zhao, BR Zhao, W. Qian, G.Z. Zhao, J. Zhao, S.G. He *et al.*, HRT Precursory wave and its mechanism, *Chinese J Geophys-CH* **53**, 487-505, 2010.

100. Q.H. Huang, Retrospective investigation of geophysical data possibly associated with the M(s)8.0 Wenchuan earthquake in Sichuan, China, *J. Asian Earth Sci.* **41**, 421-427, 2011.

101. Q.H. Huang, Rethinking earthquake-related DC-ULF electromagnetic phenomena: towards a physics-based approach, *Nat. Hazard Earth Sys.* **11**, 2941-2949, 2011

102. S. Lennartz, A. Bunde and D. L. Turcotte, Modelling seismic catalogues by cascade models: Do we need long-term magnitude correlations?, *Geophys. J. Int.* 184, 1214–1222, 2011

103. A. Ramírez-Rojas, L. Telesca and F. Angulo-Brown, Entropy of geoelectrical time series in the natural time domain, *Nat. Hazards Earth Syst. Sci.* **11**, 219-225, 2011.

Index

M.S. Lazaridou-Varotsos, *Earthquake Prediction by Seismic Electric Signals: The Success of the VAN Method over Thirty Years*, Springer Geophysics, DOI 10.1007/978-3-642-24406-3,

C

D

E

F

G

H

I

M

O

P

Q

R

S

T

U

V

W

X

Y

Z