Solar Radiation

Lecture-3

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Radiation

- Radiation is a process where energy emitted by one body travels in a straight line through a medium or through space.
- Radiation comes from the sun, nuclear reactors, microwave ovens, radio antennas, X-ray machines, and power lines etc...
  - ✓ Everything continually emits radiation and transfers energy in waves.
- Waves are both electrical and magnetic properties and known as electromagnetic radiation.

Cont. . .

- Radiation can be classified or labeled based on the capability of
  - ✓Its ionizing atoms,
  - ✓Its source,
  - ✓Its proper name, and
  - ✓Its wave length
- Based on their ionizing property radiation can be classified as either ionizing or nonionizing.

Cont. . .

- Non-ionizing radiation is lower energy radiation that comes from the lower part of the electromagnetic spectrum.
    - ✓It is called non-ionizing because it does not have enough energy to completely remove an electron from an atom or molecule.
        - ☞Examples:- visible light, infrared light, microwave radiation, radio waves, and long wave (low frequency) radiation.

Cont. . .

- Ionizing radiation has enough energy to detach electrons from atoms or molecules - the process of ionization.
- It comes from both subatomic particles and the shorter wavelength portion of the electromagnetic spectrum.
  - ✓Examples:- Ultraviolet, X-rays, and gamma rays from the electromagnetic spectrum and
  - ✓Subatomic particles such as alpha particles, beta particles, and neutrons.
- Subatomic particles are usually emitted as an atom decays and loses protons, neutrons, electrons, or their antiparticles.

Cont. . .

❖Based on its source radiation can be classified as:

1) Solar radiation which is originating from the Sun.
2) Terrestrial radiation which is originating from the Earth.

❖Based on its proper name:

1) Visible Radiation: It is the spectral range of the standard observer.
   - ✓Most of the visible radiation lies between 400 nm and 730 nm.

Cont. . .

2) Ultraviolet Radiation: It is the radiation with wavelengths in the range 100 to 400 nm.

   ✓It is subdivided into three ranges: UVA is 315-400 nm, UVB is 280-315 nm, and UVC is 100- 280 nm.

3) Infrared Radiation: It is the radiation with wavelengths longer than 730 nm etc…

Solar radiation

invisible Range		visible Range						invisible Range	
	UV	Violet	Blue	Green	Yellow	Orange	Red	Infrared	

100 400 425 490 575 585 650 700 14000

Wave length(nm)

Cont. . .

- Radiation can be classified based on its wavelength (λ) as
  - ✓Short wave radiation (λ< 4 micrometers) and
  - ✓Long wave radiation (λ> 4 micrometers).

Radiation Quantities

Incoming Shortwave Radiation

- Solar radiation that encounters matter, whether solid, liquid, or gas, is called incident radiation.
- Interactions with matter can change the following properties of incident radiation: intensity, direction, wavelength, polarization, and phase.
- Radiation intercepted by the earth is absorbed and used in energy-driven processes or is returned to space by scattering and reflection.

Cont. . .

- In mathematical terms, this disposal of solar radiation is given by the equation.

$$Qs = Cr + Ar + Ca + Aa + (Q + q)(1 - a) + (Q + q)\,a$$

- Where
  - Qs is the incident solar radiation at the top of the atmosphere;
  - Cr is reflection and scattering back to space by clouds;
  - Ar is reflection and scattering back by air, dust, and water vapors;
  - Ca is absorption by clouds;
  - Aa is absorption by air, dust, and water vapors;
  - (Q + q) a is reflection by the earth;
  - (Q + q)(1 – a) is absorption by the earth's surface, where Q and q are, respectively, direct beam and diffused solar radiation incident on the earth and a is albedo.

The global disposal of shortwave radiation (W m−2 per year)

Solar energy	W m–2
Incident on the top of the atmosphere	342
Reflected from the earth	30
Reflected by clouds, aerosols, and atmosphere	77
Total reflected	107
Absorbed by the atmosphere	67
Absorbed by the earth	168
Total absorbed by earth-atmosphere system	235

Cont. . .

- About a quarter of the solar radiation is reflected back to space by clouds.
- A small portion of the incident radiation is scattered back to space by the constituents of the atmosphere, mainly air molecules, dust particles, and water vapors.
- About 30% of the radiation is scattered downward.

Cont. . .

- Atmospheric scattering results from multiple interactions between light rays and the gases and particles of the atmosphere.
- What happens to short wave radiation incident at the top of the atmosphere?
  - ✓It can be absorbed by the atmosphere
  - ✓It can be reflected by clouds, particles and air molecules back to space
  - ✓It can be transmitted to the surface

Cont. . .

- The incoming net shortwave radiation (Rns), a result of the balance between incoming and reflected solar radiation is given by a formula,

$$Rns = (1 - \alpha)\, Rs$$

- Where
  - ☞ α= albedo or canopy reflection coefficient (0.23 for a grass reference crop surface) and
  - ☞ Rs = total incoming solar radiation (MJm-2 d-1).
- ***Example***:- *Calculate the net incoming radiation if the total incoming solar radiation is 310 MJ/m2d and the canopy reflection coefficient is 0.24.*

Outgoing Long wave Radiation

- The surface of the earth after being heated by the absorption of solar radiation becomes a source of radiation itself.
- Because the average temperature of the earth's surface is about 285 K,
  - ✓ 99% of the radiation is emitted in the infrared range from 4 to 120 μm,
- This is long wave radiation and is also known as terrestrial radiation.

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Cont. . .

- The average annual global disposal of infrared radiation is represented by the following equations

$$I(e) = Ia + Is$$

$$I(a) = I + I(a)s$$

$$I = I(e) - I\downarrow$$

- Where
  - ✓ I(e) is infrared radiation emitted by the earth's surface;
  - ✓ Ia is infrared radiation from the earth's surface absorbed by the atmosphere;
  - ✓ Is is infrared radiation from the earth lost to space;
  - ✓ I(a) is infrared radiation from the atmosphere;
  - ✓ I↓ is counter radiation;
  - ✓ I(a)s is infrared radiation from the atmosphere lost in space; and
  - ✓ I is the effective outgoing radiation from the earth.

Cont. . .

- The earth's atmosphere absorbs about 90% of the outgoing radiation from the earth's surface.
- Water vapors absorb in wavelengths of 5.3 to7.7 μm and beyond 20 μm;
  - ✓Ozone in wavelengths of 9.4 to 9.8 μm;
  - ✓Carbon dioxide in wavelengths of 13.1 to 16.9 μm; and
  - ✓Clouds in all wavelengths.

Cont. . .

- Long wave radiation escapes to space between 8.5 and 11.0 μm, known as the atmospheric window.
- A large part of the radiation absorbed by the atmosphere is sent back to the earth's surface as **counter radiation.**
- This counter radiation prevents the earth's surface from excessive cooling at night.
- The rate of outgoing net long wave radiation Rnl is proportional to the absolute temperature of the surface raised to the fourth power.

Cont. . .

➢This relation is expressed quantitatively as

$$Rnl = \sigma\left(\frac{T^4 max,k + \ T^4 min,k}{2}\right)\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\ \frac{Rs}{Rso} - 0.35\right)$$

➢ Where

- ✓ σ= Stefan-Boltzmann constant (4.903*10-9 MJ K-4m-2 d-1);
- ✓ Tmax,K= daily maximum absolute temperature (°K = °C+273);
- ✓ Tmin,K = daily minimum absolute temperature (°K=°C+273);
- ✓ ea=actual air vapor pressure (kPa); and
- ✓ Rso = clear sky solar radiation (MJm-2 d-1).

Cont. . .

- The actual vapor pressure ea (kpa) is calculated as

$$e_a = 0.6108 \exp\left(\frac{17.27\text{Tdew}}{\text{Tdew}+273.3}\right)$$

- Where
  - ✓ Tdew= dew point temperature (°C).
  - ✓ Depending on the availability of the data, ea can be calculated using relative humidity (RH) and/or minimum air temperature (Tmin).

Cont. . .

- Doorenbos and Pruitt (1977) developed an equation to calculate daily values of clear sky solar radiation Rso as a function of
  - ✓Station elevation z (m), and
  - ✓The extraterrestrial radiation Ra (MJm-2 d-1).

$$Rso = (0.75 + 2x10^{-5}Z)Ra$$

Cont. . .

- Ra can be calculated on a daily basis as a function of day of the year, solar constant, solar declination, and latitude as

$$Ra = \left(\frac{1,440}{\pi}\right) Gscdr\ (\omega s \sin(\varphi) \sin(\delta) + \cos(\varphi) \cos(\delta) \sin(\omega s))$$

- Where
  - ✓Gsc= solar constant (0.0820 MJm-2 min-1);
  - ✓dr=inverse relative distance from Earth to sun;
  - ✓ws =sunset hour angle (rad);
  - ✓φ =latitude (rad); and
  - ✓δ =solar declination (rad).

Cont. . .

- For the above equation, the daily values of φ, dr ,δ, and ωs are given by the following equations:

$$\text{Rad}= \left(\frac{\pi}{180}\right)(\text{decimal degrees})$$

$$dr=1+ 0.033 \cos\left(\frac{2\pi}{365} JD\right)$$

$$\delta = 0.409 \sin\left(\frac{2\pi}{365} JD - 1.39\right)$$

$$\omega s = \text{arcos}(-\tan(\varphi)\tan(\delta))$$

- Where JD = day of the year.

Cont. . .

- ***Example**:- If the incoming solar radiation is 320MJ/m2d the maximum and minimum temperature of 27^{o}c and 18^{o}c respectively with dew temperature of 10^{o}c and the extraterrestrial radiation 110 MJ/ m2d, what will be net out going radiation at altitude (elevation) of 10km?*

Net Radiation (RN)

- The global annual mean energy budget is determined by the net radiation flow of energy through the top of the atmosphere and at the earth's surface.
- Net radiation (Rn) is a key variable for computing reference evapotranspiration (ETo) and is a driving force in many other physical processes.
- At the top of the atmosphere, the net energy output is determined by the incident shortwave radiation from the sun minus the reflected shortwave radiation.
  - ✓ This difference determines the net shortwave radiation flux at the top of the atmosphere.

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Cont. . .

- ✓ To balance this inflow of shortwave energy, the earth atmosphere system emits long wave radiation to space.

➢ This quantity of energy is available to drive the processes of

- ✓ Evaporation,
- ✓ Evapotranspiration,
- ✓ Air, and soil fluxes as well as other, smaller energy-consuming processes such as photosynthesis.

➢ ETo predictions are being made continuously for real-time irrigation scheduling, agricultural water management, and other engineering/agronomic applications.

Cont. . .

- Most of the Rn equations predict daily or longer-term Rn values from measured Rs.
  - ✓However, the major difficulty in these equations is that if the Rs term is not measured consistently.
- Rn is normally positive during the daytime and negative during the nighttime.
  - ✓The total daily value for Rn is almost always positive except in extreme conditions at high latitudes.

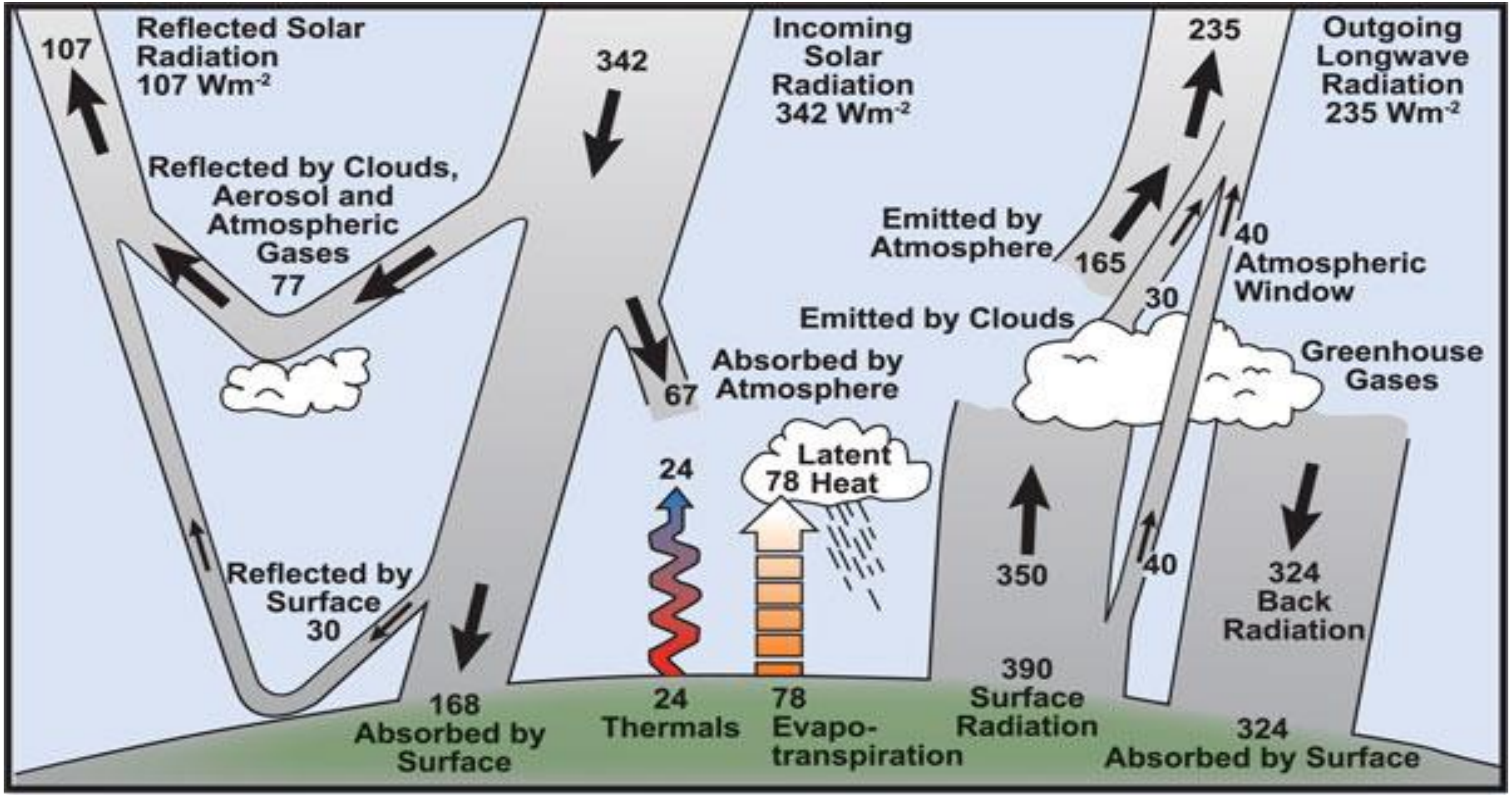
Cont. . .

- The International Commission for Irrigation and Drainage and the Food and Agriculture Organization of the United Nations (FAO) Expert Consultation on Revision of FAO Methodologies for Crop Water Requirements has recommended that
  - ✓The FAO56-Penman-Monteinth (FAO56-PM) method be used as the standard method to estimate ETo.
  - ✓This widely used method requires Rn values.
- The Rn calculation procedures outlined in FAO Paper No. 56 have also been recommended for estimating ETo in the FAO56-PM method.

Cont. . .

- How to change earth's surface temperature:
  - Change energy coming in from the sun (increase reflectance).
  - Change amount of greenhouse gasses (emission T stays the same, but surface T is increased.

Cont. . .


107
Reflected Solar Radiation 107 Wm-2
342
Incoming Solar Radiation 342 Wm-2
235
Outgoing Longwave Radiation 235 Wm-2
Reflected by Clouds, Aerosol and Atmospheric Gases
77
Emitted by Atmosphere
165
40
Atmospheric Window
30
Emitted by Clouds
Absorbed by Atmosphere
67
Greenhouse Gases
Latent Heat
78
24
Reflected by Surface
30
350
40
324
Back Radiation
168
Absorbed by Surface
24
Thermals
78
Evapo-transpiration
390
Surface Radiation
324
Absorbed by Surface

Cont. . .

- These Rn calculations procedures are as follows:

$$Rn = Rns - Rnl$$

- Where
  - ✓Rn= net radiation (MJm-2 d-1);
  - ✓Rns= incoming net shortwave radiation (MJm-2 d-1); and
  - ✓Rnl=outgoing net long wave radiation (MJm-2 d-1).

Cont. . .

- ***Example***:- *If the total incoming solar radiation is 300MJ/m2d and the maximum and minimum temperature of 28^{o}c and 18^{o}c respectively with an actual vapour pressure of 1.6 kpa; if the canopy reflection coefficient is 0.23, and extraterrestrial radiation 120 MJ/m2d, what will be net radiation at altitude (elevation) of 5 km?*

Factors of Solar Radiation

- Life depends substantially on solar radiation,
    - ✓Because all physical and biological processes taking place on the earth's surface or in the atmosphere involve some form of energy transfer.
- Solar radiation is also a major requirement for other processes related to water, land, soil, vegetation and animals.

Cont. . .

- The sun provides over 99% of the heat energy required for the physical processes taking place in the earth – the atmospheric system.
- As the sun radiates its energy, the amount received at the outer boundary of the earth's atmosphere,
  - ✓ At normal incidence and at mean distance between the earth and the sun is known as the ***solar constant***.

Solar Input

- The solar constant, which is the basic amount of solar input, is a major factor of solar radiation received by the earth's surface, outside the atmosphere.
- In general the amount of solar radiation received outside the atmosphere also depends on a number of other factors, which include
  - ✓ Solar altitude and
  - ✓ Duration of solar energy (length of day).

Solar Altitude

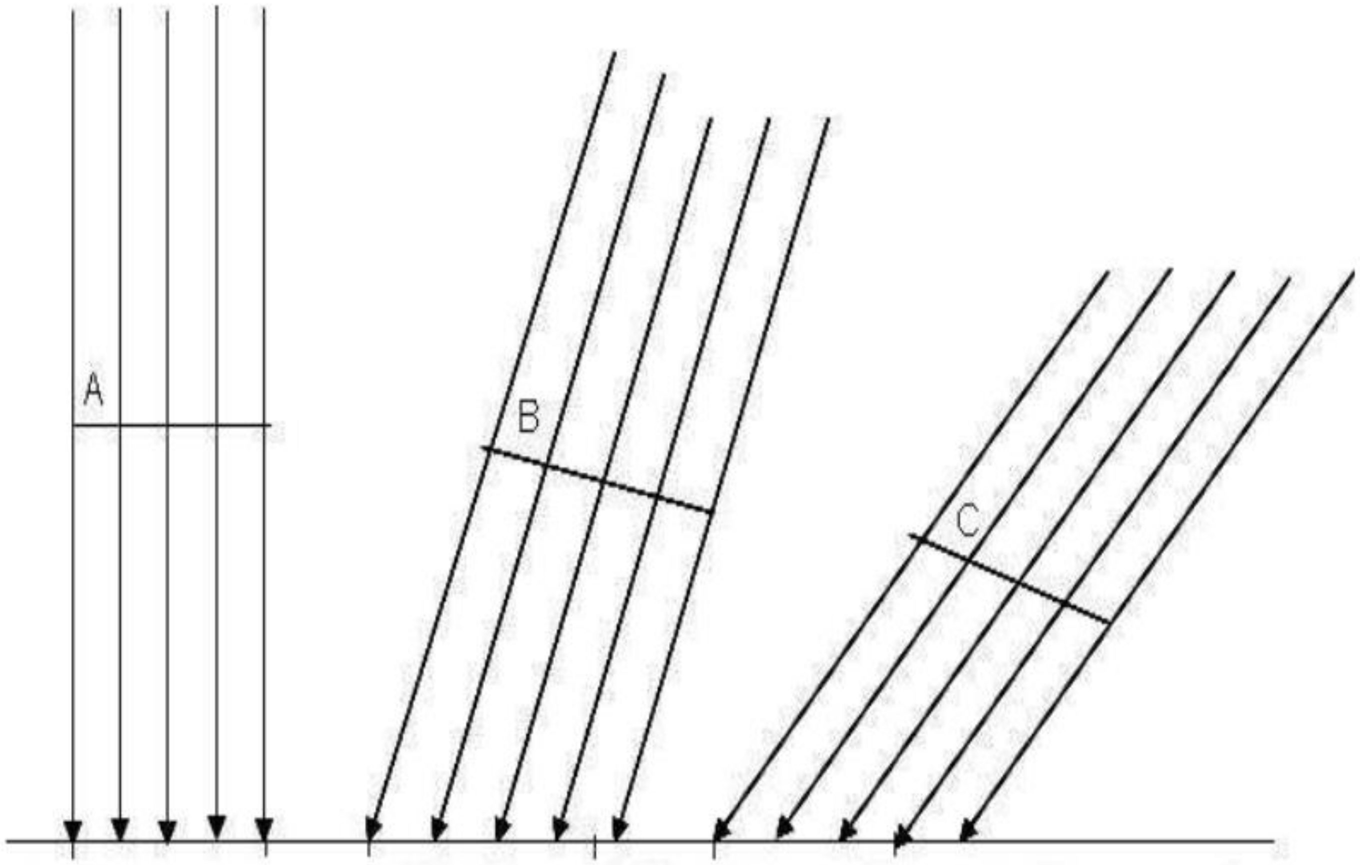
- The altitude of the sun (angle between the rays of the sun and at tangent to the earth's surface at a point of observation) is an important factor which affects the amount of insolation received at the earth's surface.
- It depends on the time of the day, the latitude of the location and the time of the year (session).
- When the sun's altitude is great, the solar radiation intensity per unit area is highly concentrated at the earth's surface.

Cont. . .

- ✓ For example at noon, the intensity of insolation is greatest, but in the morning and evening hours when the sun is at a low angle, the amount of insolation is small.

- ➢The same principle has a broader application with respect to latitude and the seasons.
- ➢In winter and at high latitudes even the noon sun’s angle is low.
- ➢In summer and at low latitudes, it is more nearly vertical

Cont. . .



- The oblique rays of the low angle sun are spread over a greater surface than are vertical rays, thus less heating per unit areas is produced by the low-angle sun.

The Length of Day

- The longer the time of day during the sun shine,
    - The greater the quantity of radiation which a given portion of the earth will be able to receive.
- Below table shows the latitudinal variations of sunshine hours during the solstices and the equinoxes.

Cont. . .

- ➢Note that there are shorter days during winter solstice of every latitude to the north or south of the equator.
  - ✓During equinoxes the length of days and nights are equal for all latitudes.
- ➢Also note that there are six months of daylight hours during the summer solstice at the pole and
  - ✓Zero hours of daylight hours (six months of darkness) during the winter solstice.

Latitudinal variations of sunshine hours

Latitude	Winter Solstice	Vernal or Autumal Equinox	Summer Solstice
90°	0	12 hours 0 min	6 months
80°	0	12 hours 0 min	4 months
70°	0	12 hours 0 min	2 months
60°	5 hours 33 min	12 hours 0 min	18 hours 27 min
50°	7 hours 42 min	12 hours 0 min	16 hours 18 min
40°	9 hours 8 min	12 hours 0 min	14 hours 52 min
30°	10 hours 4 min	12 hours 0 min	13 hours 56 min
20°	10 hours 48 min	12 hours 0 min	13 hours 12 min
10°	11 hours 25 min	12 hours 0 min	12 hours 38 min
0°	12 hours 0 min	12 hours 0 min	12 hours o min

Cont. . .

- ➢The variation in the length of day is as a result of the
  - ✓Revolution of the earth around the sun and
    - ❖Whereas its orbit round the sun explains the seasons.
    - ❖A complete revolution takes 365 ¼ days at a variable speed which averages about 26km per second.
  - ✓Its rotation on its axis.
    - ❖The earth’s rotation on its own axis causes day and night.
    - ❖A complete rotation takes 24 hours resulting in the alternation of day and night.

Cont. . .

- The effect of the atmosphere slightly affects the radiation received on the earth's surface.
  - ✓ The atmosphere absorbs, reflects, scatters and reradiates solar energy.
    - ❖ Among the atmospheric constituents involved in the absorption are water vapour, liquid water carbon dioxide and ozone.
    - ❖ Part of the incoming solar radiation is also scattered or reflected back to space.
    - ❖ About 80% of the incoming solar radiations are reflected by clouds; clouds are powerful reflectors of shortwave radiation.

Solar Radiation and Crop Plants

- Solar radiation is the energy source that sustains organic life on earth.
  - ✓Crop production is in fact an exploitation of solar radiation.
- The three broad spectra of solar energy described in this section are significant to plant life.
  - ✓The shorter-than-visible wavelength radiation segment in the solar spectrum is chemically very active.
    - ❖When plants are exposed to excessive amounts of this radiation, the effects are harmful.

Cont. . .

- ✓Solar radiation in the higher-than-visible wavelength segment, referred to as infrared radiation, has thermal effects on plants.
  - ❖In the presence of water vapors, this radiation does not harm plants; rather, it supplies the necessary thermal energy to the plant environment.
- ✓The third spectrum, lying between the ultraviolet and infrared, is the visible part of solar radiation and is referred as light.
  - ❖This segment of solar radiation plays an important part in
  - ❖Plant growth and development through the processes of chlorophyll synthesis and photosynthesis and
  - ❖Through photosensitive regulatory mechanisms such as phototropism and photoperiodic activity.

Cont. . .

- ➢Light of the correct intensity, quality, and duration is essential for normal plant development.
  - ✓Poor light availability is frequently responsible for plant abnormalities and disorders.
- ➢Almost all plant parts are directly or indirectly influenced by visible part of the spectrum.
  - ✓It affects the production of tillers; the stability, strength, and
  - ✓Also it affects length of the culms; the yield and total weight of plant structures; and the size of leaves and root development.

Cont. . .

- The length of day or the duration of the light period determines flowering and has a profound effect on the content of soluble carbohydrates present.
  - ✓ The majority of plants flower only when exposed to certain specific photoperiods.
  - ✓ It is on the basis of this response that the plants have been classified as short-day plants, long-day plants, and day neutral plants.
- When other environmental factors are not limiting it, photosynthesis increases with longer duration of the light period.

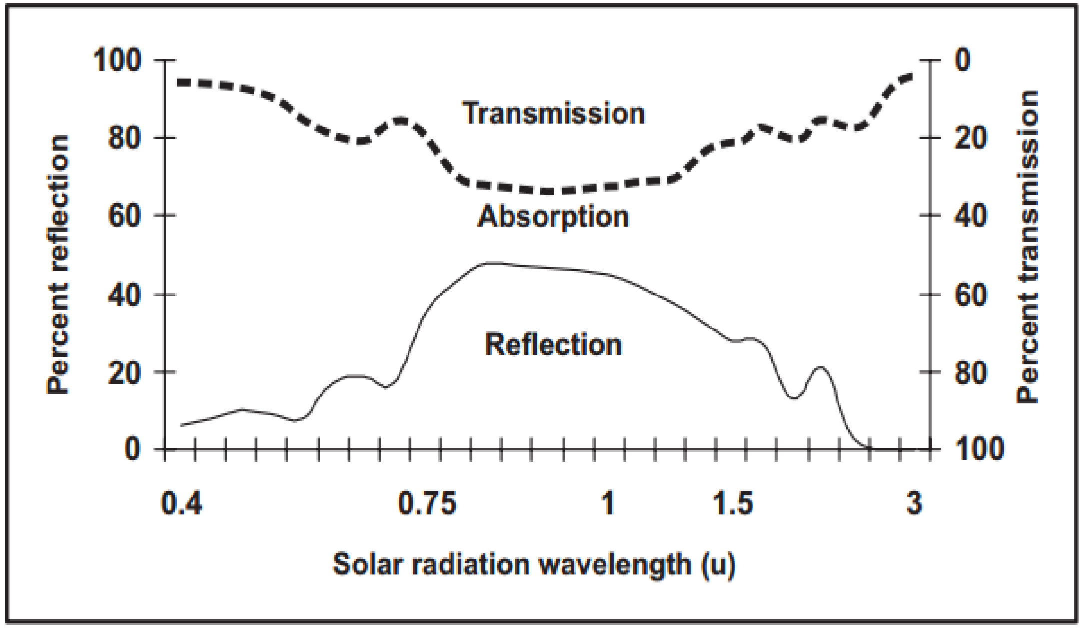
Reflection, Transmission, and Absorption

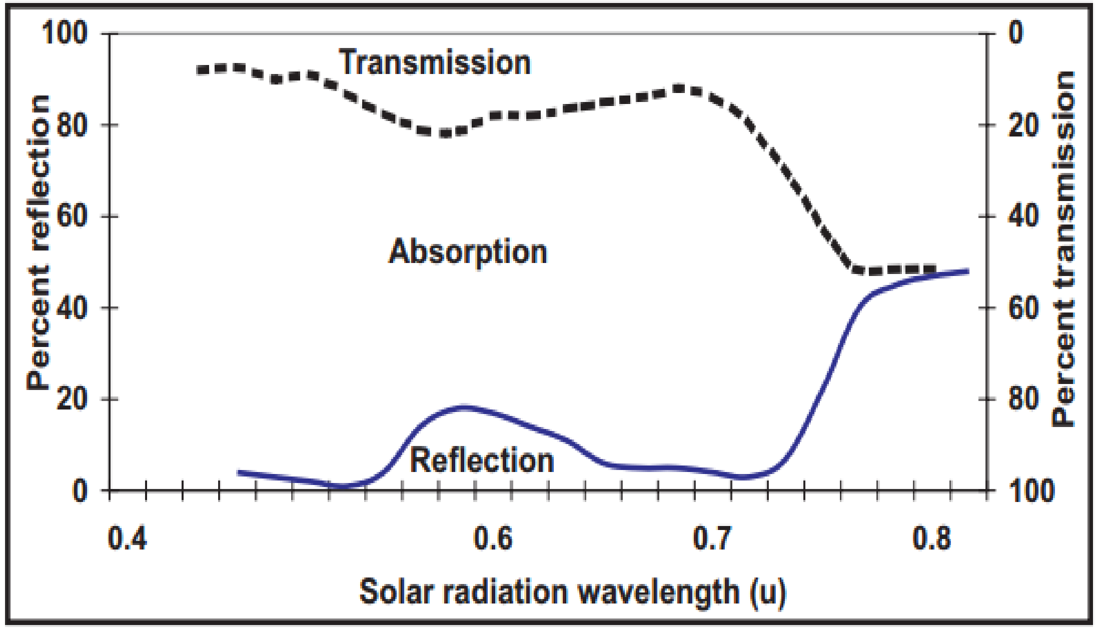
- ➢Reflection and transmission from the leaves have similar spectral distributions.
  - ✓The maxima for both are in the green light as well as in the infrared region.
- ➢The impression of the green color of the plants depends on the high reflectivity,
  - ✓The relatively high intensity of solar radiation, and
  - ✓The greater sensitivity of the human eye for green light.

Cont. . .

- The strong infrared reflection from plants is an important natural device for protection of plant life against damage due to overheating.
- On average, the plant canopy absorbs about 75% of the incident radiation, with about 15% reflected and 10% transmitted.
- Due to their chemical components or physical structures, plants absorb selectively in discrete wavelengths (See figure below).

A generalized pattern of reflection, absorption, and transmission of solar radiation through a green leaf





Cont. . .

- ➢The transparent epidermis allows the incident sunlight to penetrate into the mesophyll, which consists of two layers:
  - ☞The palisade parenchyma of closely spaced cylindrical cells and
  - ☞The spongy parenchyma of irregular cells with abundant interstices filled with air.
- ➢Both types of mesophyll cells contain chlorophyll, which reflects part of the incident green wavelengths and absorbs all the blue and red energy for photosynthesis.

Cont. . .

- The solar spectrum can be divided into the following eight broad bands on the basis of the physiological response of plants:

1. Wavelength greater than 1.00 µm: Most of this radiation absorbed by plants is transformed into heat without interfering with the biochemical processes.
2. Wavelength 1.00 to 0.70 µm: Elongation effects on plants.
3. Wavelength 0.70 to 0.61 µm: Very strong absorption by chlorophyll, the strongest photosynthetic activity, and in many cases strong photoperiodic activity.

Cont. . .

4. Wavelength 0.61 to 0.51 µm: Low photosynthetic effectiveness in the green segment and weak formative activity.
5. Wavelength 0.51 to 0.40 µm: Strong chlorophyll absorption, strong photosynthetic activity, and strong formative effects.
6. Wavelength 0.40 to 0.315 µm: Produces fluorescence in plants and a strong response by photographic emulsions.

Cont. . .

7. Wavelength 0.315 to 0.280 µm: Significant germicidal action.

   ✓Practically no solar radiation of wavelengths shorter than 0.29 µm reaches the earth's surface.

8. Wavelength shorter than 0.280 µm: Very strong germicidal action.

   ✓It is injurious to eyesight and when below 0.26 µm can kill some plants. No such radiation reaches the earth's surface.

SOLAR RADIATION INTERCEPTION BY PLANTS

- Three aspects of solar radiation are biologically significant.
  - The first is the intensity of radiation, the amount of radiant energy falling on a unit of surface area in a unit of time.
  - The second is the spectral distribution of radiation that governs the photochemical process of photosynthesis.
  - The third aspect is the radiation distribution in time, which is important for photoperiodic phenomenon.

Cont. . .

- Quantification of intensity and spectral distribution of radiation within crop canopies is important
  - ✓ Because of its control of the photosynthetic process and the microclimate of the plant community.
- The rate of photosynthesis is dependent on the availability of photo-synthetically active radiation intercepted by the leaves.

Cont. . .

- The rate of transpiration taking place from the plant canopy is also controlled to a great extent by the radiation energy.
  - ✓ Thus, knowledge of radiation transmission through the elements of a plant community is necessary to know the quality and quantity of incident radiation used by the plants.

Factors Affecting the Distribution of Solar Radiation Within the Plant Community

- The distribution of radiation in a plant canopy is determined by several factors, such as
  - ✓The transmissibility of the leaf,
  - ✓Leaf arrangement and inclination,
  - ✓Plant density,
  - ✓Plant height, and
  - ✓The angle of the sun.

Cont. . .

- Transmissibility varies slightly with the age of the leaf.
  - The transmissibility of a young leaf is relatively high.
  - With the maturing of the leaf, it declines but then rises again as the leaf turns yellow.
- The transmissibility of a leaf is indirectly related to its chlorophyll content.
  - The logarithm of transmissibility decreases linearly with an increase in the chlorophyll content.