Advanced Agro-Hydro- Meteorology

A MSc course for students of Atmospheric Sciences

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Lecture 5: Agrometeorology and the solar radiation

5.1 Agrometeorology

- Agriculture meteorology or Agrometeorology is a branch of applied meteorology which investigates the physical conditions of the environment of growing plants or animal organisms. It deals with the relationship between weather/climatic conditions and agricultural production. The aim of agricultural meteorology is to make use of the science of meteorology in the interest of food production.
- Agriculture deals with three most complex entities viz., soil, plant and atmosphere and their interactions. Among these three, atmosphere is the most complex entity over the other two.
- The dangers to the crops and livestock that have a meteorological component include pollution; soil erosion from wind or water; the effects of drought; the frost; the dangers of forest fires. Agrometeorology offers practical solutions for harnessing climate potential and for protection against or avoidance of climate-related risks.
- The role of Agrometeorology is both strategic and tactical. The strategic role is involved in the assessment of long-term utilization of natural resources in the development of crop diversity. The tactical role is more concerned with the short-term and field-scale decisions that directly influence crop growth and development.
- Of the total annual crop losses in world agriculture, a large percentage is due to direct weather effects such as drought, flash floods, untimely rains, frost, hail, and storms. Losses in harvest and storage, as well as those due to parasites, insects, and plant diseases, are highly influenced by the weather.

5.2 The solar energy reaching the earth's surface

- The solar constant is the flux of radiation at the outer boundary of the atmosphere, received on a surface held perpendicular to the sun's direction at the mean distance between the sun and the earth. The value of the solar constant is 1,370 W m^{-2}
- Of this energy, approximately 31 % is scattered back to space, 43 % is absorbed by the earth's surface, and the atmosphere absorbs 26 %. The ratio of outward to inward flux of solar radiation from the entire earth's surface (termed *albedo*) is about 0.31, leaving an average around 225 W m^{-2} (range 220 to 235 W m^{-2}) that is available for heating, directly and indirectly, the earth-atmosphere system. The irradiation amount at the earth's surface is not uniform, and the annual value at the equator is 2.4 times that near the poles. The solar energy incident upon a surface depends on the geographic location, orientation of the surface, time of the day, time of the year, and atmospheric conditions.

5.3 Nature and laws of radiation

- The behavior of electromagnetic radiation may be summed up in the following simplified statements:
  - Every item of matter with a temperature above absolute zero emits radiation.
  - Substances that emit the maximum amount of radiation in all wavelengths are known as black bodies. Such bodies will absorb all radiation incident upon them. A black body is thus a perfect radiator and absorber.
  - Substances absorb radiation of wavelengths, which they can emit.
  - The wavelengths at which energy is emitted by substances depend on their temperature- the higher the temperature, the shorter the wavelength.
  - Gases emit and absorb radiation only in certain wavelengths.
  - The amount of radiation absorbed by a gas is proportional to the number of molecules of the gas and the intensity of radiation of that wavelength.
- ***Wavelength***

The wavelength of electromagnetic radiation λ is given by the equation

$$\lambda = \frac{c}{v} \qquad (5.1)$$

Where c is the constant equal to the velocity of light; and v is the frequency.

- ***Planck's Law***

Electromagnetic radiation consists of the flow of quanta or particles, and the energy content (E) of each quantum is proportional to the frequency

$$E = hv \qquad (5.2)$$

where h is Planck's constant (having a value of 6.625×10^{-34} J s). The equation indicates that the greater the frequency, the greater is the energy of the quantum.

- ***Kirchoff's Law***

This law states that the absorptivity a of an object for radiation of a specific wavelength is equal to its emissivity e for the same wavelength. The equation of the law is

$$a(\lambda) = e(\lambda) \qquad (5.3)$$

- ***Stefan-Boltzmann Law***

It states that the intensity of radiation emitted by a radiating body is proportional to the fourth power of the absolute temperature of that body:

$$Flux = \sigma T_a \qquad (5.4)$$

where σ is the Stefan-Boltzmann constant (5.67×10^{-8} W m^{-2} K^{-4}) and T_a is the absolute temperature of the body.

- ***Wein's Law***

The wavelength of maximum intensity of emission from a black body is inversely proportional to the absolute temperature (T) of the body. Thus,

$$Wavelength\ of\ maximum\ intensity\ (\mu m) = \frac{2897}{T} \qquad (5.5)$$

For the sun, λ_{max} is near 0.5 μm and is in the visible spectrum.

- ***Beer and Lambert's Laws***

Beer law states that concentration and absorbance are directly proportional to each other. Lambert law states that absorbance and path length are directly proportional.

The intensity according Beer-Lambert law equation

$$I = I_o\, e^{-\mu d} \qquad (5.6)$$

where I_o represents initial intensity (here the solar constant) , μ is the absorbance coefficient, and d represents distance of the air transversed.

5.4 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* (see Figure 5.1).

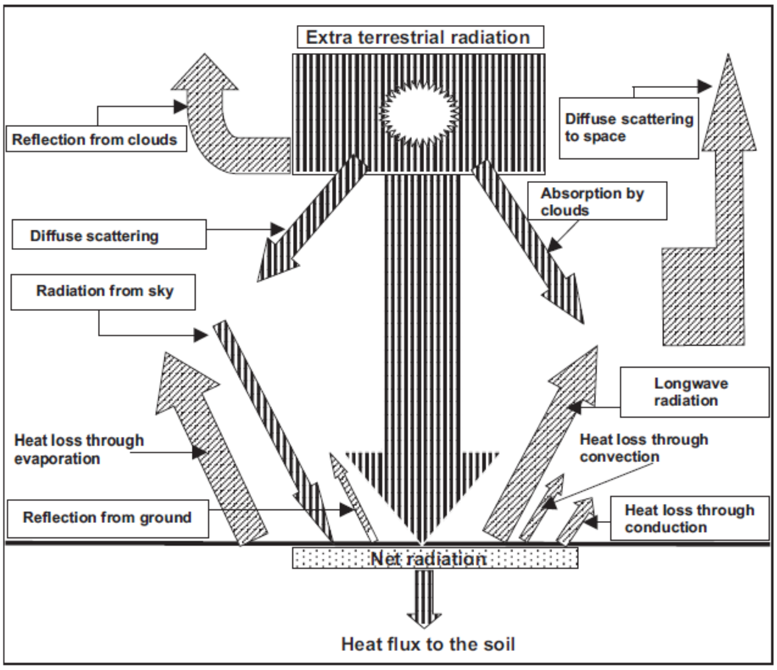

Figure (5.1) Daytime radiation balance over the earth's surface

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

$$Qs = Cr + Ar + Ca + Aa + (Q + q)(1 - a) + (Q + q)\,a \qquad (5.7)$$

where *Qs* is the incident solar radiation at the top of the atmosphere (*342 W m*$^{-2}$); *Cr* is reflection and scattering back to space by clouds; *Ar* is reflection and scattering back by air, dust, and water vapors (*Cr + Ar=77 W m*$^{-2}$). *Ca* is absorption by clouds; *Aa* is absorption by air, dust, and water vapors (*Ca + Aa=67 W m*$^{-2}$). *(Q + q)a* is reflection by the earth (*30 W m*$^{-2}$); *(Q + q) (1 – a)* is absorption by the earth's surface (*168 W m*$^{-2}$), where Q and q are, respectively, direct beam and diffused solar radiation incident on the earth and a is albedo.

- The atmosphere absorbs about 20 % of the solar radiation. The constituents of the atmosphere that absorb the solar radiation significantly are oxygen, ozone, carbon dioxide, and water vapors.
  - Oxygen and ozone: Solar radiation in the wavelengths <0.3 μm is absorbed in the upper atmosphere. Energy of 0.1 μm is highly absorbed by the atomic and molecular oxygen and also by nitrogen in the ionosphere. Energy of 0.1 to 0.3 μm is absorbed efficiently by ozone in the ozonosphere (in the stratosphere).
  - Carbon dioxide: This gas is of chief significance in the lower part of the atmosphere. It has a very strong absorption band around 15 μm.
  - Water vapor: Water vapors absorb the largest amount of solar radiation. Several weak absorption bands occur below 0.7 μm, while important broad bands of varying intensity exist between 0.7 and 0.8 μm. The strongest water absorption is around 6 μm, where almost 100 % of longwave radiation may be absorbed if the atmosphere is sufficiently moist.
- About 6 % of the solar radiation that reaches the earth is reflected back to outer space. This is known as albedo which is defined as the fraction of incoming shortwave radiation that is reflected by the earth's surface. The albedo varies with the color and composition of the earth's surface, the season, and the angle of the sun's rays.

5.5 Outgoing longwave radiation

The surface of the earth after being heated by the absorption of solar radiation becomes a source of radiation itself (Figure 5.2). 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, with a peak near 10 μm, as indicated by Wein's displacement law. This is longwave radiation and is also known as *terrestrial radiation*. The average annual global disposal of infrared radiation is represented by equations 2.9, 2.10, and 2.11.

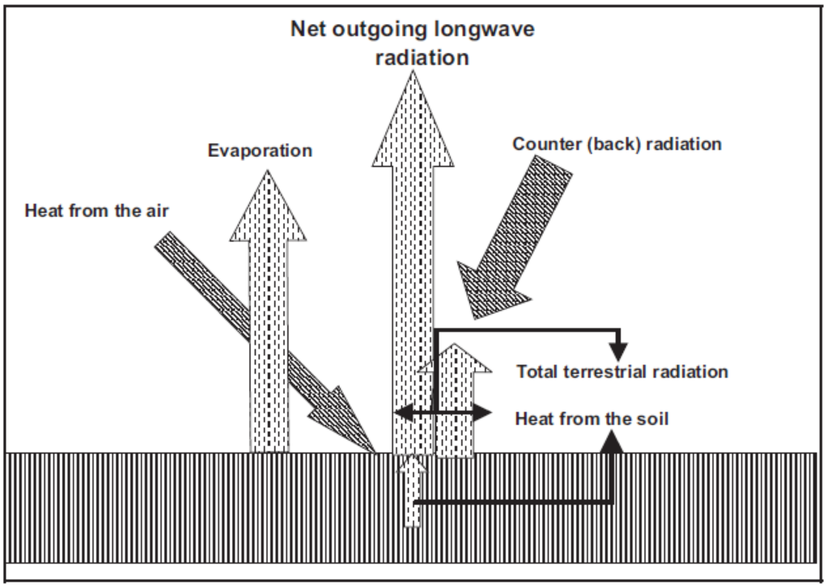

Figure (5.2) Outgoing longwave radiation balance at night

$$I(e) = Ia + Is \qquad (5.8)$$

$$I(a) = I\downarrow + I(a)s \qquad (5.9)$$

$$I = I(e) - I\downarrow \qquad (5.10)$$

where *I(e)* is infrared radiation emitted by the earth's surface (390 $W\,m^{-2}$) ; *Ia* is infrared radiation from the earth absorbed by the atmosphere (350 $W\,m^{-2}$); *Is* is infrared radiation from the earth lost to space (40 $W\,m^{-2}$); *I(a)* is infrared radiation from the atmosphere; $I\downarrow$ is counter radiation (324 $W\,m^{-2}$); *I(a)s* is infrared radiation from the atmosphere lost in space (195 $W\,m^{-2}$) ; and I is the effective outgoing radiation from the earth.

- The earth's atmosphere absorbs about 90 % of the outgoing radiation from the earth's surface. Water vapors absorb in wavelengths of 5.3 to 7.7 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. Longwave 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.

5.6 Solar radiation and crop plants

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 and be detrimental if it is excessive. The atmosphere prevents most of this type of solar radiation from reaching earth. The ultraviolet radiation of this segment reaching the earth's surface is very low and is normally tolerated by plants.

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 visible part (light) 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. 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. It affects the production of tillers; the stability, strength, and length of the culms; the yield and total weight of plant structures; and the size of leaves and root development. 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.

5.7 Reflection, Transmission, and Absorption

Reflection and transmission from the leaves have similar spectral distributions as shown in Figures 5.3 and 5.4. 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. 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.

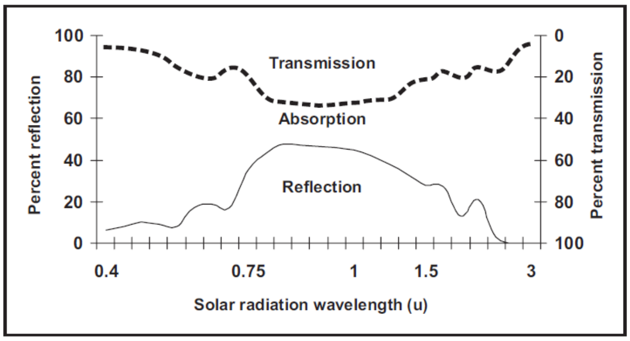

Fig. 5.3 A generalized pattern of reflection, absorption, and transmission of solar radiation through a green leaf

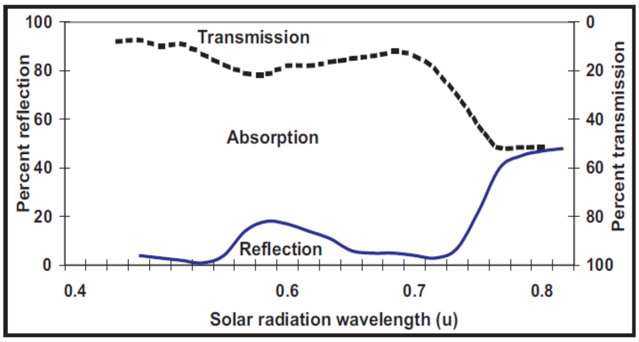

Fig. 5.4 A generalized pattern of reflection, absorption, and transmission of light through a green leaf

Due to their chemical components or physical structures, plants absorb selectively in discrete wavelengths (Figure 5.5). The transparent epidermis allows the incident sunlight to penetrate into the mesophyll, which consists of two layers: (1) the palisade parenchyma of closely spaced cylindrical cells and (2) the spongy parenchyma of irregular cells with abundant interstices filled with air. Both types of mesophyll cells contain chlorophyll, blue and red energy for photosynthesis. Chlorophyll absorption is maximum in the blue (0.45 μm) and in the red (0.65 μm) regions. The longer wavelengths of photographic IR energy penetrate into the spongy parenchyma, where the energy is strongly scattered and reflected by the boundaries between the cell walls and air spaces. The high near-infrared reflectance of leaves is caused by the internal cell structure. Near the border of visible light, absorption by the plant decreases but then increases again in the infrared. Infrared radiation greater than 3 μm is completely absorbed by the plants.

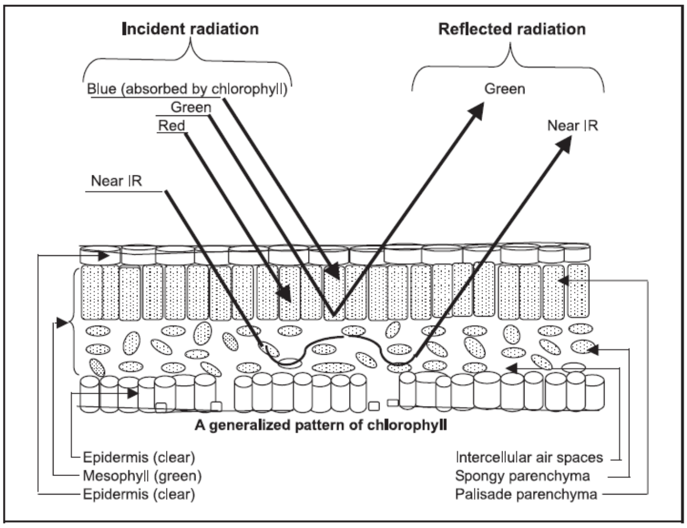

Figure (5.5) Interactions of incident solar radiation in a leaf cross section

It can be summed up that the plant leaf strongly absorbs blue and red wavelengths, less strongly absorbs the green, very weakly absorbs the near infrared, and strongly absorbs in the far-infrared wavelengths. Because the absorption of the near-infrared wavelengths by the leaf is limited, by discarding this energy it prevents the internal temperature from becoming lethal. At the infrared wavelengths, the plant leaf is an efficient absorber, but in these wavelengths the energy at the surface is small, with the result that the plant is a good absorber in the far-infrared. It is an equally a good radiator at these wavelengths. The quality of radiation affects flowering, germination, and elongation.

The visible part of the spectrum also influences the orientation of shoots, phenomenon known as phototropism. When shoots turn toward the light, the phenomenon is known as positive phototropism. With increasing intensity of light, positive phototropism turns into negative phototropism. The strongest influence on phototropism is by the blue part of the spectrum (0.5 μm) and the weakest influence is by red rays. Very little of ultraviolet part of the spectrum reaches the earth’s surface but it has biological effects. This type of rays may kill microorganisms, disinfect the soil, and eradicate diseases. Ultraviolet rays also influence the germination and quality of seeds. Ultraviolet radiation leads to a strong inhibition of photosynthesis and metabolism.