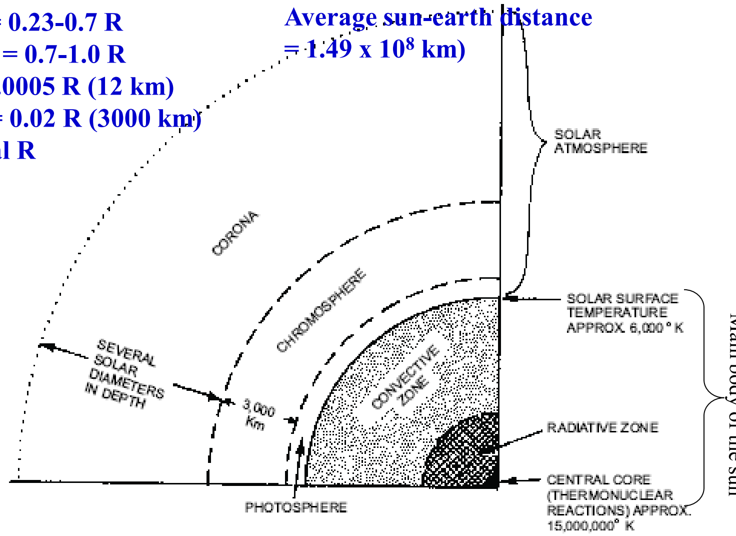
Sun

Sun Diameter = 1.382×10^6 km
Sun Radius = 0.691×10^6 km
Centeral Core = 0.23 R
Radiative zone = 0.23-0.7 R
Convective zone = 0.7-1.0 R
Photosphere = 0.0005 R (12 km)
Chromosphere = 0.02 R (3000 km)
Corona = Several R

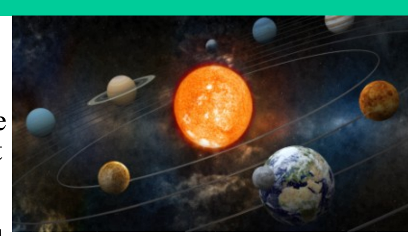
Average Temperature of the sun surface = 5762 °K
Sun Energy = 56×10^{26} cal min^{-1}
Average sun-earth distance = 1.49×10^8 km)



Solar Radiation

SOLAR RADIATION

Radiation is form of energy in terms of *Electromagnetic Spectrum* that is emitted by all objects having temperature above absolute zero. Thus, *Solar Radiation* is the energy that is being emitted by sun.

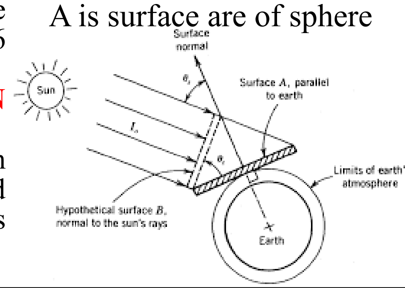


SOLAR CONSTANT (SC)

Solar radiation at the top of the earth atmosphere on a surface perpendicular to the sun rays is called as ***Solar Constant***. The solar constant can varies upto ±3.5 % depending upon the sun-earth distance The mean value of solar constant is 1.96 langely/min.

$$SC = Emitted\ Energy / A$$
$$A = 4\pi r^2$$

A is surface are of sphere



EXTRA TERRESTRIAL RADIATION (ETR)

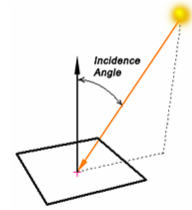
Solar radiation at the top of the earth atmosphere on a horizontal surface is called as ***Extra Terrestrial Radiation***. ETR varies with time and place.

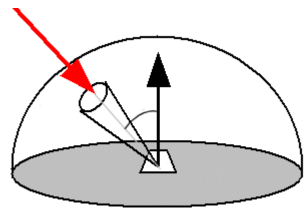
Solar Radiation

INSOLATION
The actual amount of solar radiation received at a horizontal surface per unit area over a specified time is called as ***Insolation***. It depends strongly on the solar zenith angle and the sun-earth distance.

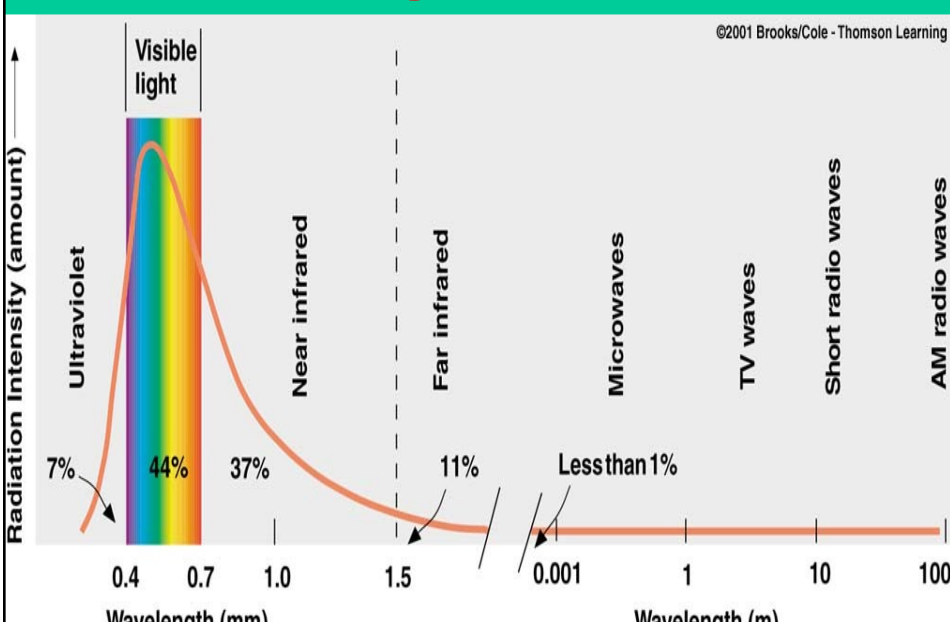
RADIANCE
Radiant flux per unit area (watts per square meter) incoming on solid angle.

IRRADIANCE
Radiant flux per unit area (watts per square meter) incoming on horizontal surface.





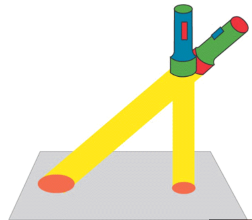
Electromegnetic Radiation

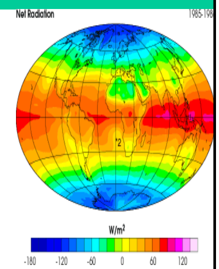


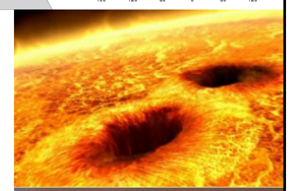
Factors Affecting Solar Radiation

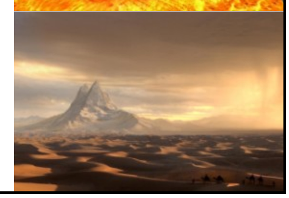
Factors affecting Solar Radiation

1. Latitude
2. Incidence Angle
3. Duration of sunlight (sunshine hours)
4. Sun-earth distance
5. Sunspots
6. Transmissivity (Transparency) of atmosphere)
7. Altitude









Light as Waves

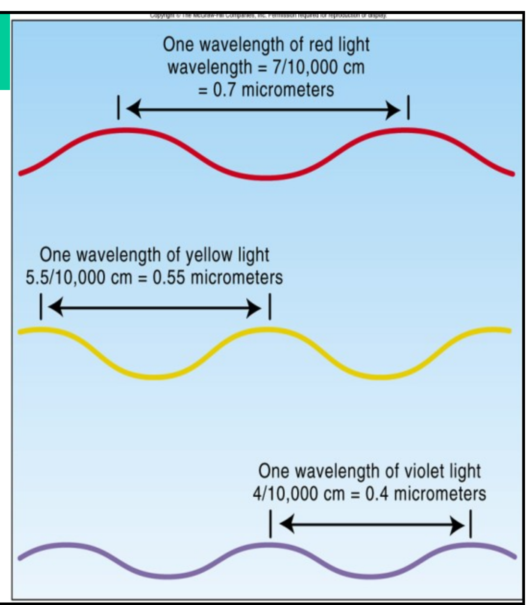
Light as a wave

$$\lambda = \frac{c}{v}$$

λ= Wavelength
C= Speed of light
V= Frequency
Color = different wavelengths

Wavelength
Distance from a given point on one wave to the same point on the next wave
Example – peak to peak

Frequency
Number of vibration or cycle per second



Measured in micrometers for metrology, 1 millionth of a meter symbol is µm or called micron

Ultraviolet, 0.01µm; Violet, 0.4µm; Yellow, 0.55µm; Red light, 0.7µm
Infrared, 10 µm

Planck's Radiation Law

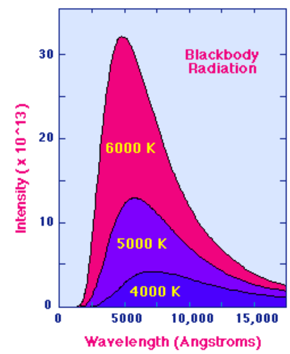
The primary law governing blackbody radiation is the *Planck Radiation Law*, which governs the intensity of radiation emitted by unit surface area into a fixed direction (solid angle) from the blackbody as a function of wavelength for a fixed temperature. The Planck Law can be expressed through the following equation.

$$E(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}$$

$h = 6.625 \times 10^{-27}$ erg-sec (Planck Constant)

$k = 1.38 \times 10^{-16}$ erg/K (Boltzmann Constant)

$c = 3 \times 10^{10}$ cm/sec (Speed of Light)



1 Cal = 4.2 Joule **1 Joule =10^7erg**

The Planck Law gives a distribution that peaks at a certain wavelength, the peak shifts to shorter wavelengths for higher temperatures, and the area under the curve grows rapidly with increasing temperature.

Planck's Law

DISCRETE

Newton and Planck propagated the theory of light as discrete units which travel in straight lines. Planck discovered that light is absorbed and emitted in discrete units called ***QUANTA*** or ***PHOTONS***. The size of each unit (energy content) is directly proportional to the frequency of the energy's radiation.

$$Q = hv$$

where

Q **= Radiant Energy**

v **= Frequency**

h **= Planks constant 6.626x10^{-27} erg-second**

Planck's equation explains the **PHOTOELECTRIC EFFECT**. The impact of quanta upon certain metal surfaces cause the emission of electrons.

KIRCHHOFF’S LAW

KIRCHHOFF'S LAW
The ratio of emitted radiation to absorbed radiation is the same for all blackbodies at the same temperature. This law forms the basis for the definition of emissivity. Emissivity is the ratio between emitted radiation of a body at a specified wavelength and temperature and emitted radiation of blackbody at same wavelength and temperature.

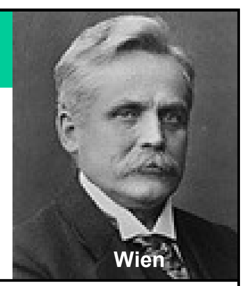
ε= M/Mb
ε = Emissivity
M = Emittance of a given object
Mb = Emittance of a blackbody at the same temperature

The emissivity of a true blackbody is **1** and that of a perfect reflector is **0**
Emissivity = absorptivity at each wavelength for all materials.

$$\varepsilon(\lambda) = \alpha(\lambda)$$

Therefore, a good absorber is also a good emitter of radiation.

Wien’s Law



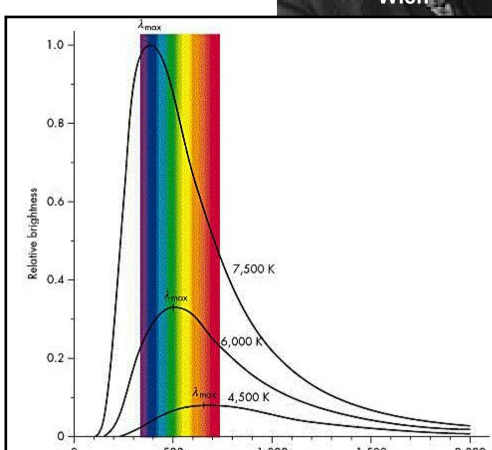
The Wavelength of Maximum Emission From a Continuous Spectrum Is Inversely Proportional to Its Temperature.
λ_{max} **(µm) = 2890 µm °C^{-1} / T(K)**

Example:

Sun: 5780 K, λ_{max} = 2890 / 5780K = 0.5 µm, yellow light

Earth: 15°C = 288K, λ_{max} = 2890 / 288K ≅ 10 µm, infrared

Hotter an object
Higher Temperature – shorter the wavelength

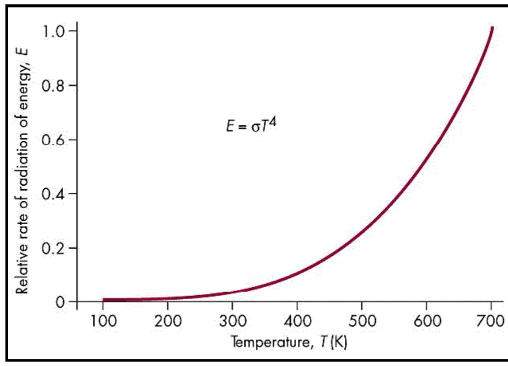


The Stefan-Boltzmann Law

Total Energy Radiated Per unit time Per unit Area is Proportional to the Fourth Power of the Temperature.

$E = \sigma T^4$ (erg per minute)

Stefan-Boltzmann Constant (σ) = $5.6703\ 10^{-8}$ (W/m^2K^4)



Example: An object with 2x T has 16x the Energy

Energy radiated by an Object = Total Energy Emitted

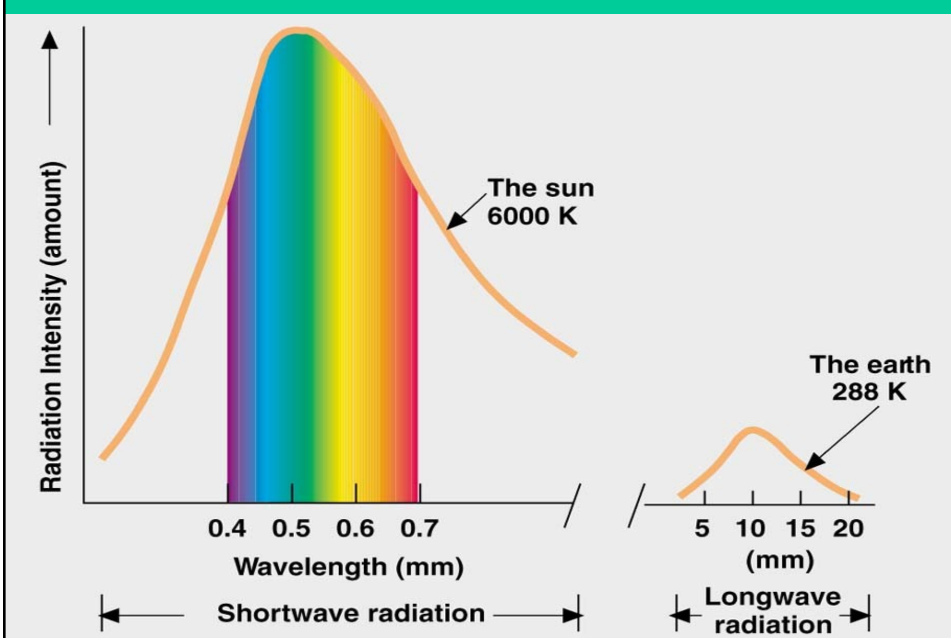
P = (surface area) x E $= A\ \sigma\ T^4$

Example:

An object with 2x T has a Power of

$P = (2)^4 \times (2) = (2 * 2 * 2 * 2)$ = 16x More

Radiation from Sun and Earth



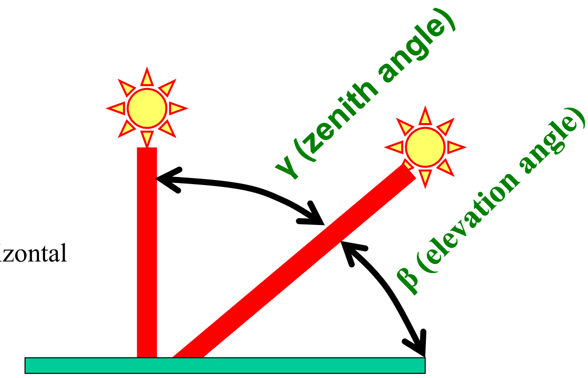
Lambert cosine law

Angle of Incidence: (Lambert cosine law): It states that the radiant intensity (Flux per unit solid angle) emitted in any direction from a unit radiating surface varies as the cosine of the angle between the normal to the surface and the direction of radiation.

$$I = I_0 \text{ Cos } \gamma$$

or

$$I = I_0 \text{ Sin } \beta$$



Where

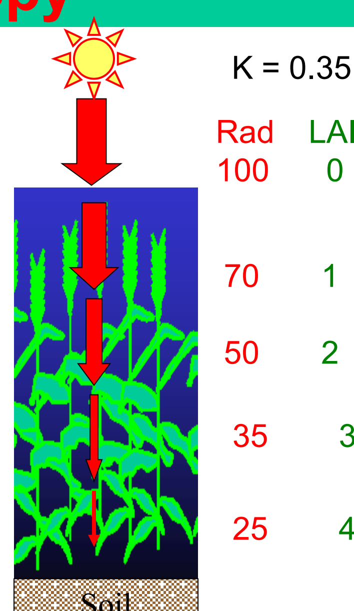
I= Flux density on a unit horizontal surface

I_0= Flux density of the beam received on a unit surface perpenidcular to the source

Distribution of Solar Radiation in Plant Canopy

Beers Bouguer Law:

Beers law describes the distribution of radiation in a transparent medium. According to this law, radiation decreases exponentially with every unit increase in medium. For plant canopy, radiation decreases with every unit increase in LAI.



$$I = Io * \exp^{-kf}$$

Where I = Radiation inside the plant canopy

Io = Radiation at the top of crop canopy

k = Extinction coefficient (depend on leaf characterstics)

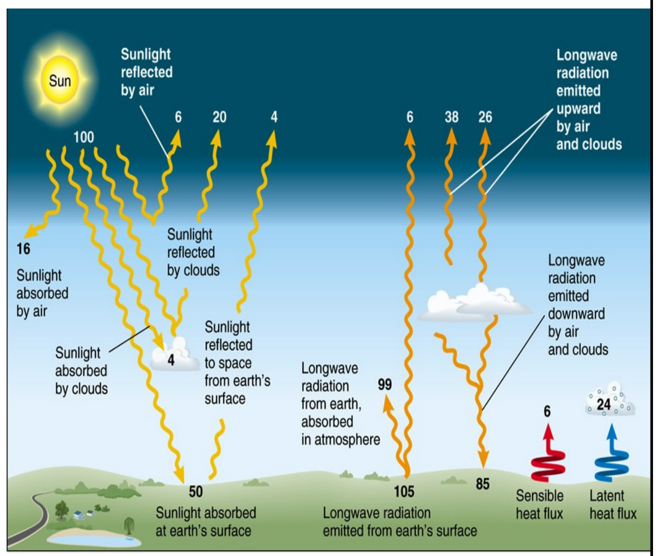
f = Leaf Area Index

The Heat Budget

Atmosphere radiates 85 units downward radiates 64 to space (clouds 26, air molecules 38)

All short and longwave radiation balance in the Earth-atmosphere system

Earth's surface shows a surplus Atmosphere shows a deficit



Net Radiation

Net Radiation (Rn)

The net radiation is the difference between total incoming radition (both shortwave and longwave) and outgoing radiation (both shortwave and longwave) and is a measure of the energy available at the ground surface. Basically it is the difference between radiation received from sun and raidation emitted by the earth surface. It is the energy available at the earth surface to drive the process of air and soil heating, evaporation, photosynthesis and respiration. In general, the net radiation is also positive between an hour after the sunrise and an hour before the sunset with a maximum at midday.

$$Rn = Rs\downarrow + Rl\downarrow - Rs\uparrow - Rl\uparrow$$

Instruments for measuring Radiation

1. Pyranometer (Total; Diffuse & Direct)
2. Pyrheliometer (Only Direct)
3. Shading ring Pyranometer (Only Diffuse)
4. Pyradiometer (Longwave & Shortwave)
5. Albedometer (Reflectance in shortwave)

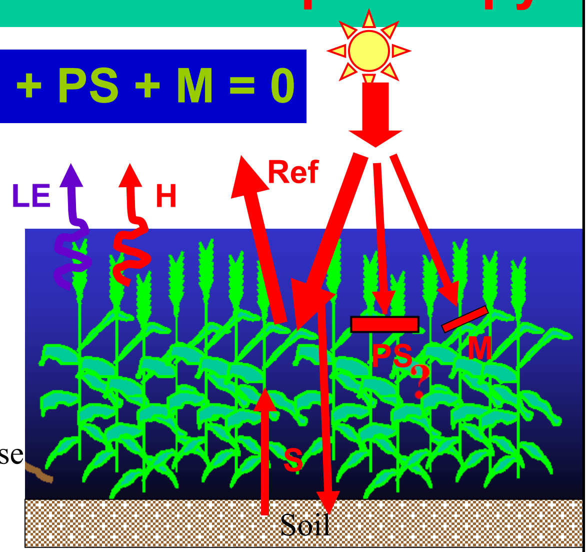
Instruments for mesuring Duration of sunshine

1. Sunshine recorder
2. Marvin Transmitter or Electrical sun-shine recorder

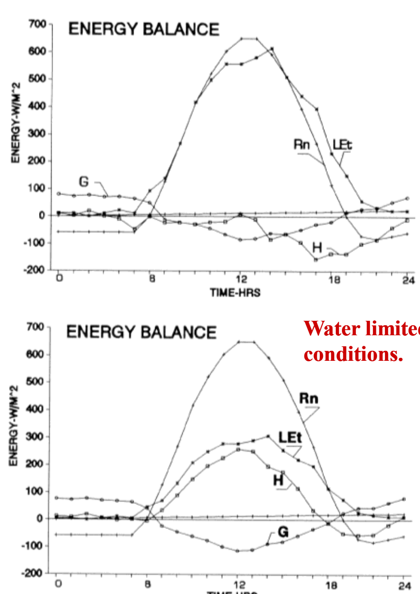
Energy Balance over Crop Canopy

Rn + S + H + LE + PS + M = 0

Rn = Net Radiation
S = Surface soil heat flux
H = Sensible heat flux
LE = Latent heat flux
PS = Energy used in Photosynthesis
M = Energy used in miscellenious purpose such as retained by crop canopy



Daily energy balance for wet and dry surfaces



Water limited conditions.

Energy balance components for an oat field in Logan, UT.

Note that almost all energy input goes to LEt when water is not limiting, due to the great amount of energy (L) required to change water from a liquid to vapor state.

Sensible

Sensible Heat flux: Exchange of heat between the ground surface and air through convective process is called as sensible heat flux. This increases the air temperature, which can be sensed.

$$H = \rho a C p K h \frac{d\theta}{dz}$$

Where
H= Sensible heat flux
pa = air density 1.13 x 10^{-3} gm cm^{-3}
Cp = Specific heat of air 0.24 cal/gm/^{o}C
Kh = Turbulence exchange coefficient
dθ/dz = vertical gradient of potential temperature

Potential Temperature

Potential temperature: It is the temperature of a parcel of air would attains if brought adiabatically from its actual pressure (P) to a standard pressure (generally taken as 100 kpa)

$$\theta = T\left(\frac{100}{P}\right)^{(\gamma-1)/\gamma}$$

$$\theta = T\left(\frac{100}{P}\right)^{0.288}$$

Where T (°K) is temperature at given Pressure (P), γ = Cp/Cv, Where Cp and Cv are specific heats of air at constant pressure and constant volume respectively.

Adiabatic Process: a process, which takes place without addition or withdrawal of heat, is known as adiabatic process. If the pressure of a volume of air changed adiabatically from (P1 to P2) the resulting changes in temperature (from T1 to T2) can be given by

$$\frac{T2}{T1} = \left(\frac{P2}{P1}\right)^{(\gamma-1)/\gamma}$$

Where T1 and T2 are absolute temperature (°K) at Pressure P1 and P2, respectively.

Latent Heat

Latent Heat: It is the flux of latent heat to and from the surface through evaporation of water or condensation. In other words the amount of heat required to change the state of water i.e. Liquid to gaseous form (evaporation) and gaseous to liquid (condensation). The latent heat flux is directly proportional to the rate of evapotranspiration or condensation and can be estimated by converting water loss or gained equivalent to the heat used. Alternatively it can be calculated by:

$$LE = -\left[Rn + S + \rho a C p \frac{(Ta - Ts)}{ra} \right]$$

Where,
LE= Latent heat flux
Rn= Net solar radiation
Ta= Air temperature
Ts= Surface temperature
ra= Boundary layer resistance

Soil Heat Flux

Soil heat flux: It is heat flow into or out of soil and is given by:

$$S = k \frac{dt}{dz}$$

Where,

K = Thermal Conductivity

dt/dz = temperature gradient within the soil.

Thus, the rate of heat flux into a soil is determined by the temperature gradient and thermal conductivity.

All energy fluxes to the surface soil will be considered positive (+) and all away from the soil will be negative (-).

Heat Capacity

Heat capacity: It is the ratio of heat absorbed (or released) to corresponding temperature rise (or fall). It has units of J/^{o}K

Specific Heat :

Mass of Sp. Heat : Amount of heat required to raise the temperature of 1 kg of that substance by 1^{o}C (or $^{\circ}$K). It has units of J/g ^{o}K. It is also defined as Specific heat of soil.

Volume of Sp. Heat: Amount of heat required to raise the temperature of a unit volume of that substance through 1^{o}C (or 1^{o}K). It has units of J cc^{-1} K$^{-1.}$ It is also defined as heat capacity of soil.

The mass and volume sp. Heat are related by

paCs = Cv

pa = Density of a substance

Cs = Mass of Sp. Heat

Cv = Volume of Sp. Heat

Cs of coarse sand = 0.830 J/ g/^{o}C

Thermal Conductivity & diffusivity

Thermal Conductivity (K): It is defined as the quantity of heat flowing in unit time through a unit cross section of soil in response to a temperature gradient of 1°C/cm. Unit: J cm^{-1} s^{-1} ^{o}K^{-1} i.e. W m^{-1} ^{o}K^{-1}

It determines rate of heat transfer. The temperature changes with time experienced by the body as result of heat transfer will vary with its heat capacity.

Thermal Diffusivity(α): It is ratio of thermal conductivity and volume of Specific Heat or heat capacity. It is the change in temperature (°C) that occurs in one second when the temperature gradient is changed by 1°C per cm.

ά = K/Cv = K/paCs cm^{2}/sec.