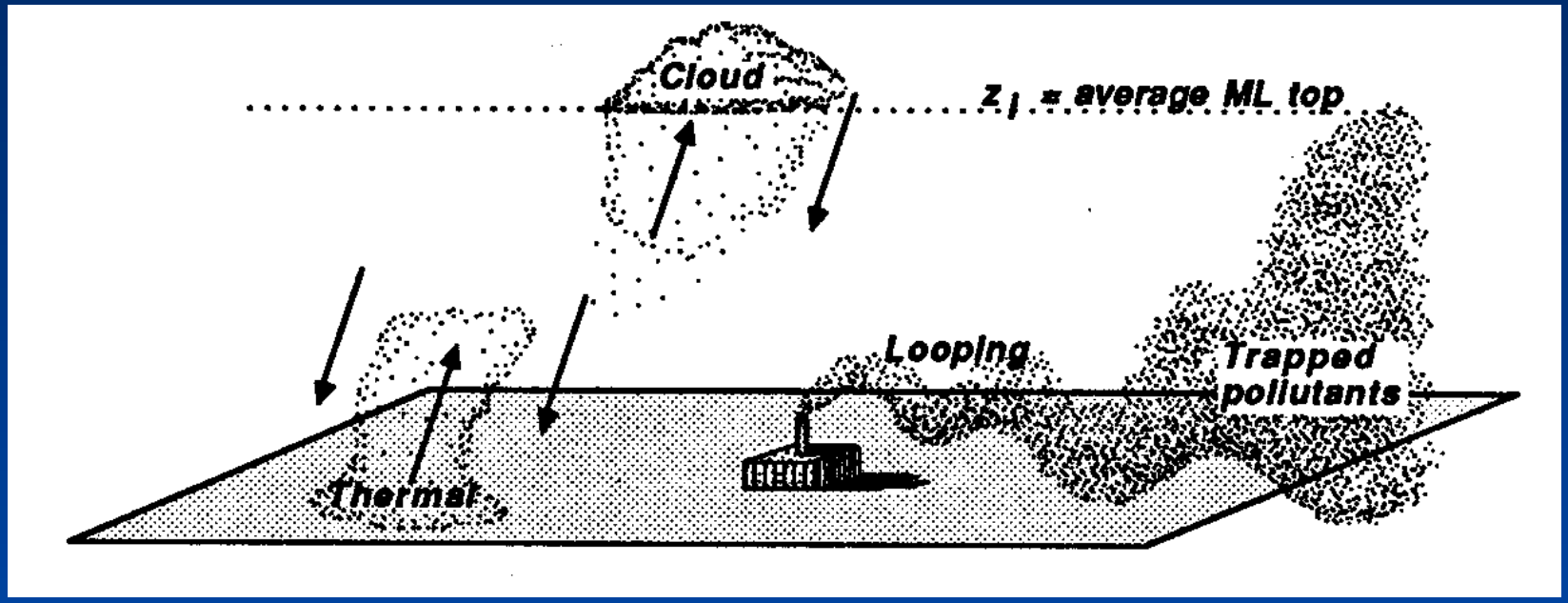
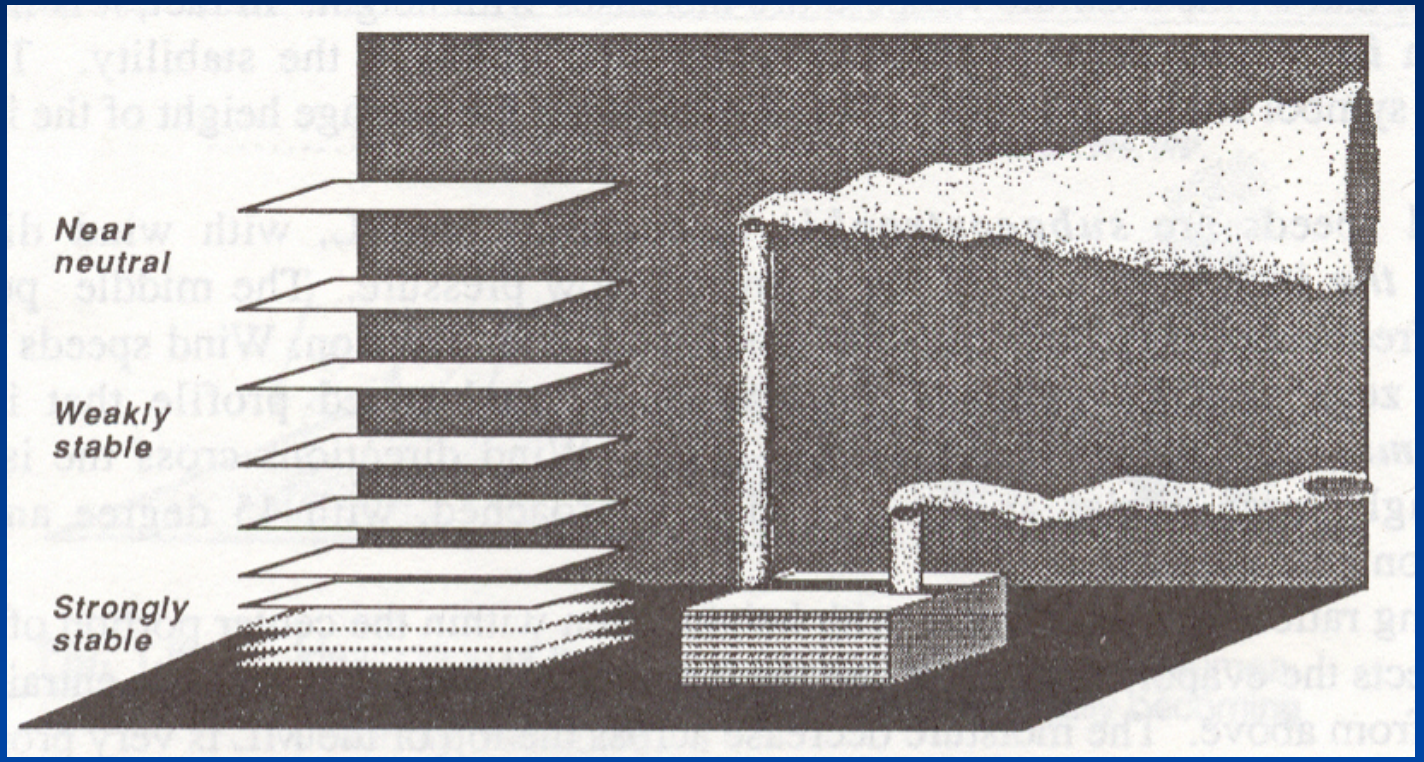
Dispersion in the convective BL



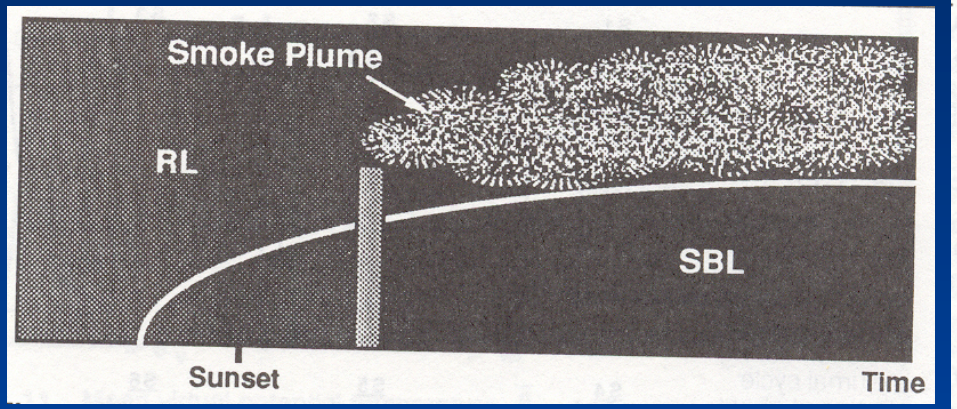
- The ML is characterized by intense mixing in an unstable situation where thermals of warm air rise from the ground
- The ML reaches its max depth in late afternoon and grows by entraining or mixing down into it.
- Pollutants exhibit a characteristic **looping** behavior

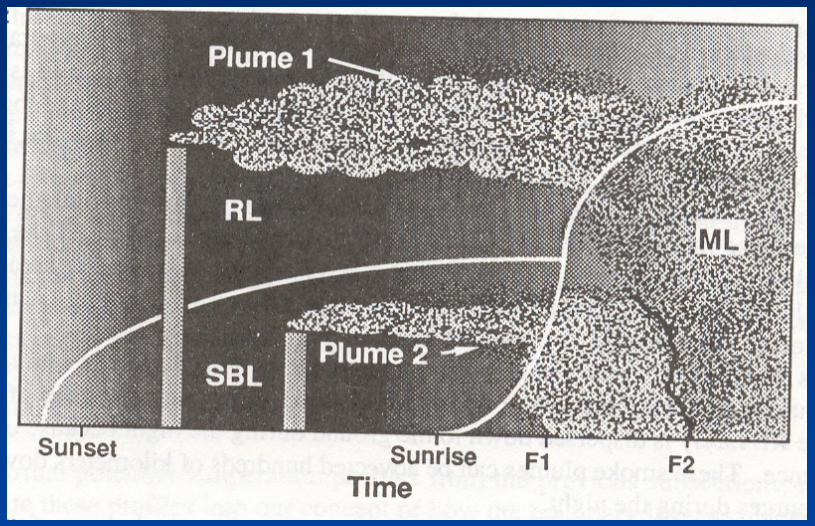
Dispersion in the nocturnal BL



- Smoke emissions into the stable SL fan out (**fanning**) in the horizontal with little vertical dispersion other than wavelike oscillations
- Smoke emissions into the neutral RL spread with an almost equal rate in the vertical and horizontal, cone like shape (**conning**)

Dispersion in the transitional zones





- Smoke plumes in the RL may disperse to the point where the bottom of the plume hits top of the SBL. The strong stability reduces downward mixing, (**lofting**)
- After sunrise a new ML begins to grow, eventually reaching the height of the elevated plume from the previous night (**fumigation**)

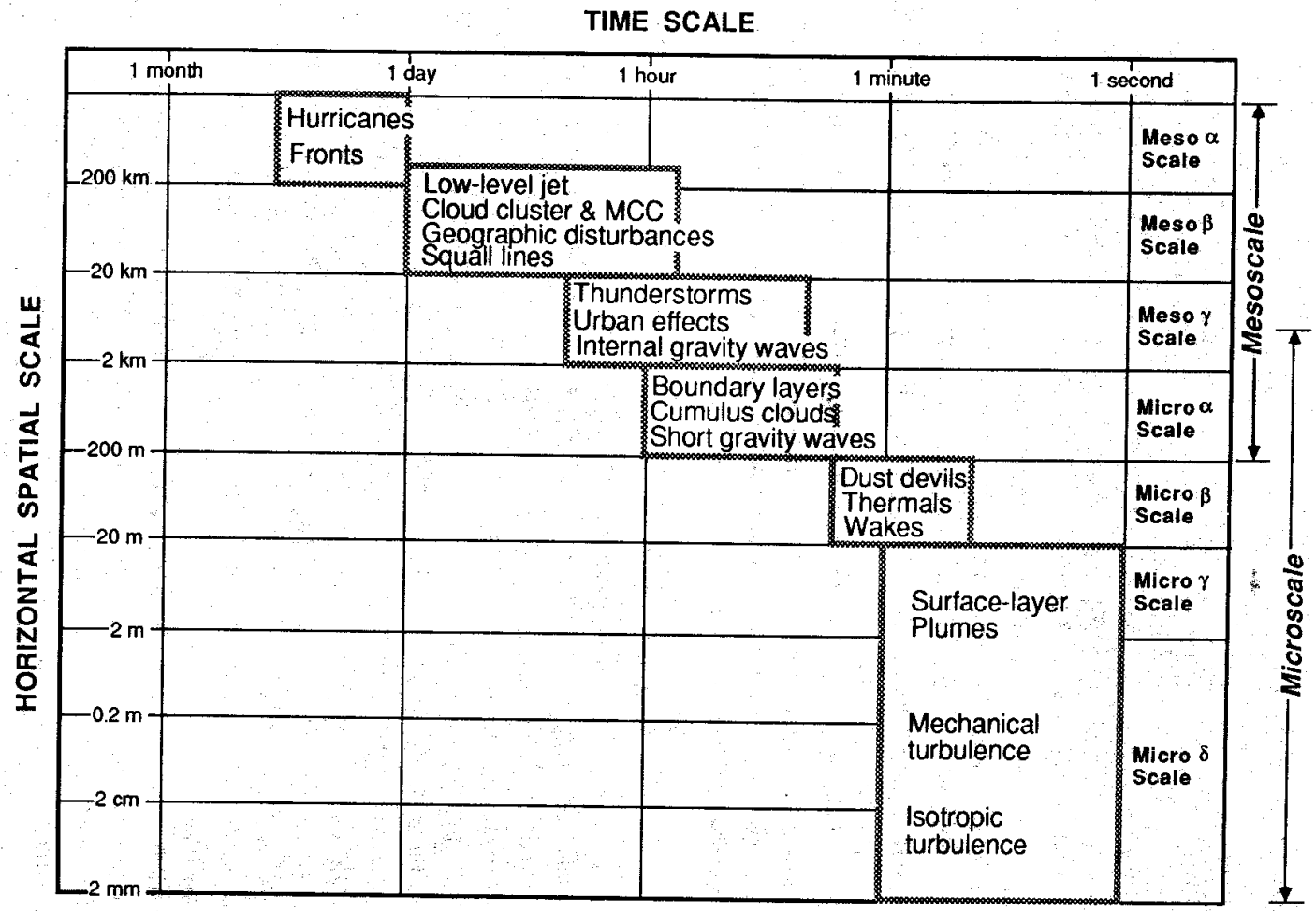


Fig. 1.15 Typical time and space orders-of-magnitude for micro and mesoscales. (After Orlanski, 1975.)

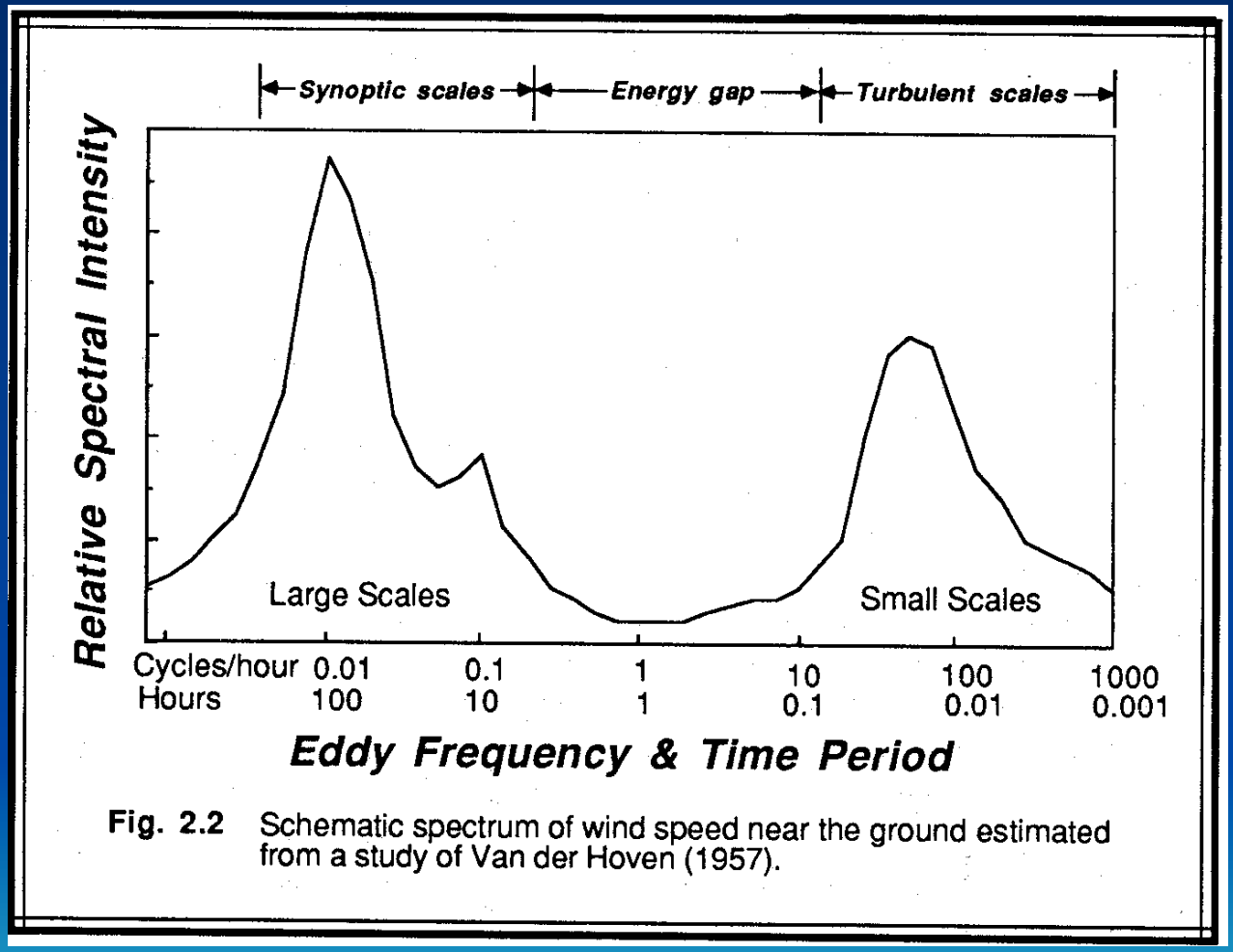


Fig. 2.2 Schematic spectrum of wind speed near the ground estimated from a study of Van der Hoven (1957).

Significance of the boundary layer

- People spend most of their lives in the PBL
- Dew, frost and max min temperature forecasts are BL forecast
- Pollution is trapped in the BL
- Fog occurs within the BL
- Virtually most of the atmospheric moisture is in the BL
- Thunderstorm and hurricane evolution are tied to the inflow of moist BL air
- SL is the most important momentum sink in the atm.
- About 50% of the atmosphere's kinetic energy is dissipated in the BL
- About 90% of the net radiation absorbed by oceans causes evaporation. The latent heat stored in water vapor accounts for 80% of the fuel that drives atmospheric motions.
- Crops are grown in the BL. Pollen distributed by BL circulations



Property	Boundary Layer	Free Atmosphere
Turbulence	• Almost continuously turbulent over its whole depth.	• Turbulence in convective clouds, and sporadic CAT in thin layers of large horizontal extent.
Friction	• Strong drag against the earth's surface. Large energy dissipation.	• Small viscous dissipation.
Dispersion	• Rapid turbulent mixing in the vertical and horizontal.	• Small molecular diffusion. Often rapid horizontal transport by mean wind.
Winds	• Near logarithmic wind speed profile in the surface layer. Subgeostrophic, cross-isobaric flow common.	• Winds nearly geostrophic.
Vertical Transport	• Turbulence dominates.	• Mean wind and cumulus-scale dominate
Thickness	• Varies between 100 m to 3 km in time and space. Diurnal oscillations over land.	• Less variable. 8-18 km. Slow time variations.

Turbulent Flux Profiles

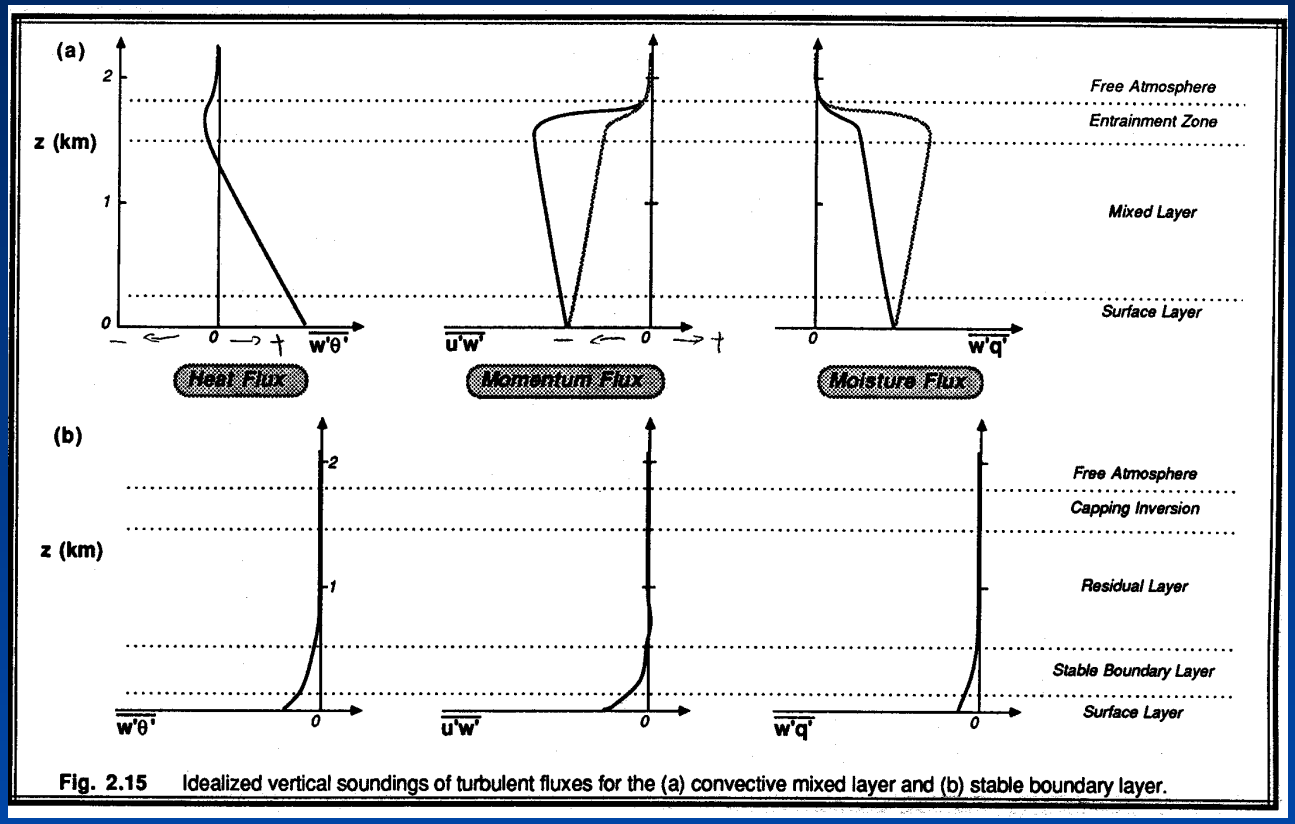


Fig. 2.15 Idealized vertical soundings of turbulent fluxes for the (a) convective mixed layer and (b) stable boundary layer.

- Turbulent heat, momentum, and moisture fluxes for both the daytime and nighttime PBLs
- During the daytime, the fluxes are large, and usually change linearly with height over the ML
- At night, the fluxes are much weaker

Energy Budget Near the Surface

- We will be concerned with fluxes of the various forms of heat energy at or near the surface for an ideal surface
- The ideal surface considered here is relatively smooth, horizontal, homogeneous, and extensive
- There are 4 types of energy fluxes at an ideal surface
  - 1) The net radiation to or from the surface (R_N)
  - 2) The sensible (direct) heat flux to or from the surface (H)
  - 3) The latent (indirect) heat fluxes to or from the surface (H_S)
  - 4) The heat flux into or out of the sub-medium (soil or water) (H_G)



Energy Budget Near the Surface

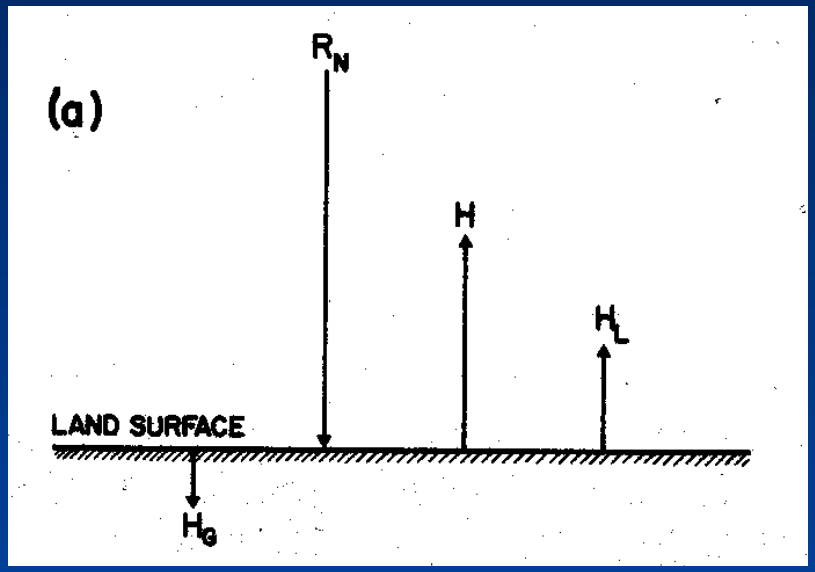
- The heat exchange through the ground medium is primarily due to conduction if the medium is soil, rock, or concrete
- At distances beyond a few millimeters from the interface, however, the primary mode of heat exchange becomes convection through mean and turbulent motions in the air.
- Through water heat is transferred in the same way as it is through air
- The depth of the sub-medium, which responds to and is affected by changes in the energy fluxes at the surface on a diurnal basis, is typically less than a meter for land surfaces and several tens of meters for large lakes and oceans

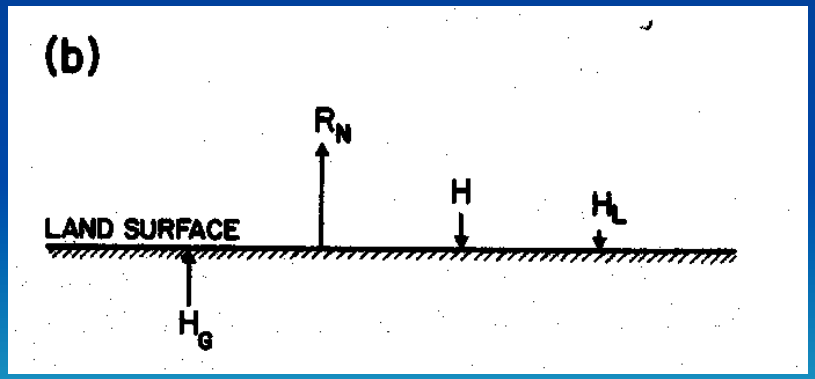
Energy Balance Equation

- Energy balance at an ideal surface
  - $R_N = H + H_L + H_G$
- Assumptions
  - The surface to be a very thin interface between the two media
  - Having no mass and heat capacity
  - The energy fluxes would flow in and out of such a surface without any loss or gain due to the surface
- Here we use the sign convention that all the radiative fluxes directed toward the surface are positive, while other (non-radiative) energy fluxes directed away from the surface are positive



Energy Balance Equation





Actual magnitudes depend on

- Type of surface and its characteristics (soil moisture, texture, vegetation, etc).
- For example, when irrigating a field, H and/or H_G may become negative during day time and H_L may exceed the net radiation received at the surface
- Geographical location
- Month or season
- Time of the day
- And weather

Magnitudes are generally much smaller than the magnitudes of the daytime fluxes, except for H_G

Energy Balance Equation

- What happens over large lakes, seas, and oceans?
- The energy budgets of extensive water surfaces differ from those of land surfaces in several ways
- Over water surfaces
  - $H << H_L$, $R_N = H_L + H_G$
- Water has a huge heat capacity. Therefore H and H_L do not undergo large diurnal variations
- Solar radiation penetrates to depths of tens of meters
- Therefore, the surface energy budget may not be very useful or even appropriate to consider over water surfaces



Radiation balance near the surface

- The transfer of energy by rapid oscillations of electromagnetic fields is called radiative transfer or simply radiation
- These ossillations are traveling waves characterized by their wavelength or wave frequency
- All electromagnetic waves travel at the speed of light with an enormous range of spectrum of frequencies
- Here we are primarily interested in the approximate range 0.1-100 micrometer, in which significant contributions to the radiation balance of the atmosphere or the earth's surface occur



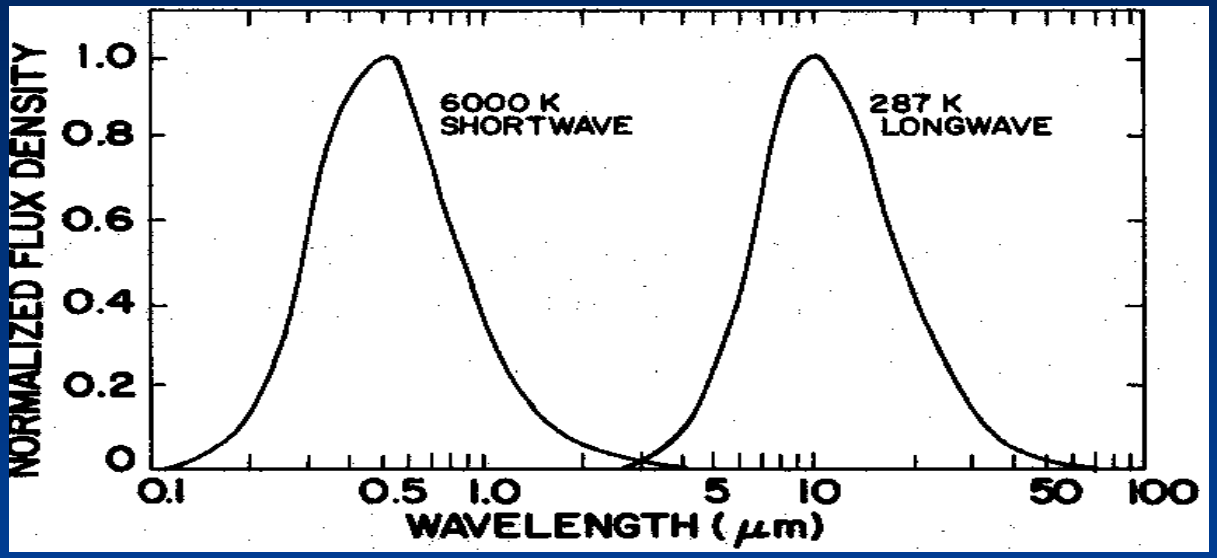
Blackbody radiation Laws

- Any body having a temperature above absolute zero emits radiation
- If a body at a given temperature emits the maximum possible radiation per unit area of its given surface, per unit time, at all wavelengths, it is a perfect radiator or "**blackbody**"
- The flux of radiation (R) emitted by such a body given b y the ***Stefan-Boltzmann Law***

$$R = \sigma T^4 \qquad \lambda_{\max} = 2897 / T$$

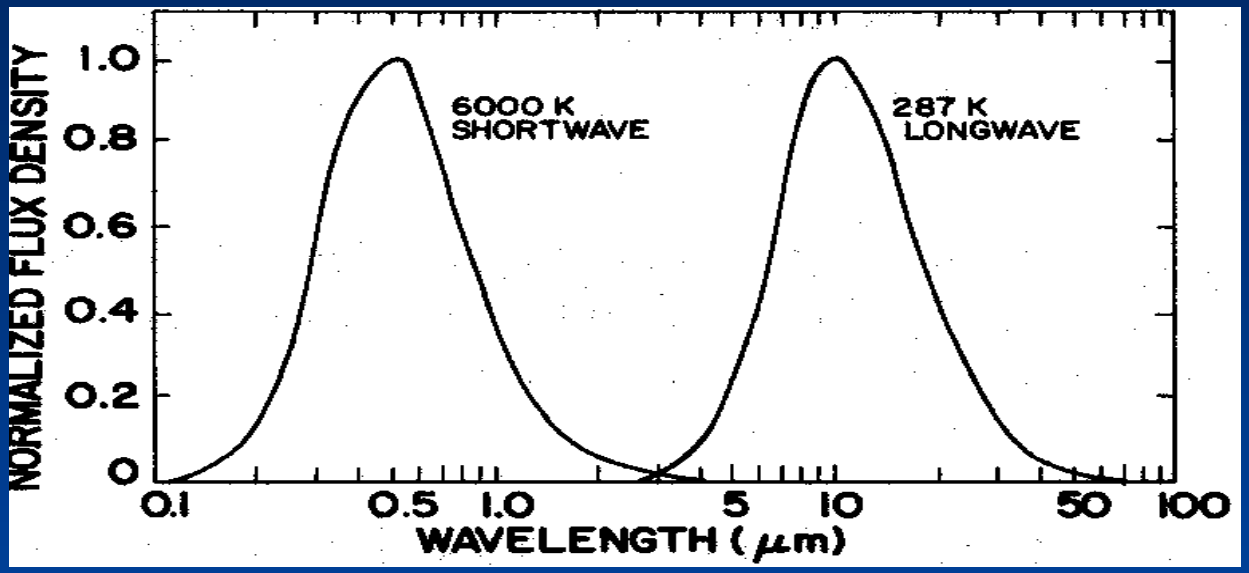
- Where σ is the Stefan-Boltzmann constant = 5.67X10^{-8} W m^{-2} K$^{-4,}$
- and T is the surface temperature of the body in absolute (K) units
- The wavelenght at which R is max turns out to be inversely proportional to the absolute temperature
- From the above laws, it is clear that radiative flux emitted by a blackbody varies in proportion to the fourth power of its surface temperature, while the wavelenghts making the most contribution to the flux change inversely proportional to T

Shortwave and Longwave Radiations



- Calculated blackbody spectra of solar and terrestrial radiation, both normalized by their peak flux density
- The spectrum of solar radiation received at the top of the atmosphere is well approximated by the spectrum of a blackbody having a surface temperature of about 6000 K
- Thus, sun may be considered as a blackbody with an equivalent surface temperature of about 6000 K and

Shortwave and Longwave Radiations



- Spectra of solar (6000 K) and terrestrial (287 K) radiation shows that there is a clear separation in between them
- All the solar energy flux is confined to the wavelength range of 0.15-4.0 (micrometer), while the terrestrial radiation is mostly confined to the range of 3-100 (micrometer)
- There is a little overlap between the two spectra
- In meteorology, the above two ranges of wavelengths are characterized as **shortwave** and **longwave** radiations, respectively

Radiative properties of natural surfaces

- Natural surfaces are not perfect radiators or blackbodies, but are, in general, gray bodies. They are generally characterized by several different radiative properties, which are defined as follows
- **Emissivity (ε)** is defined as the ratio of the energy flux emitted by the surface at a given wavelength and temperature to that emitted by a blackbody at the same wavelength and temperature
- **Absoptivity (α)**is defined as the ratio of the amount of radiant energy absorbed by the surface material to the total amount of energy incident on the surface
- **Reflectivity (r)** is defined as the ratio of the amount of radiation reflected to the total amount incident upon the surface
- **Transmissivity (t)** is defined as the ratio of the radiation transmitted to the subsurface medium to the total amount incident upon the surface

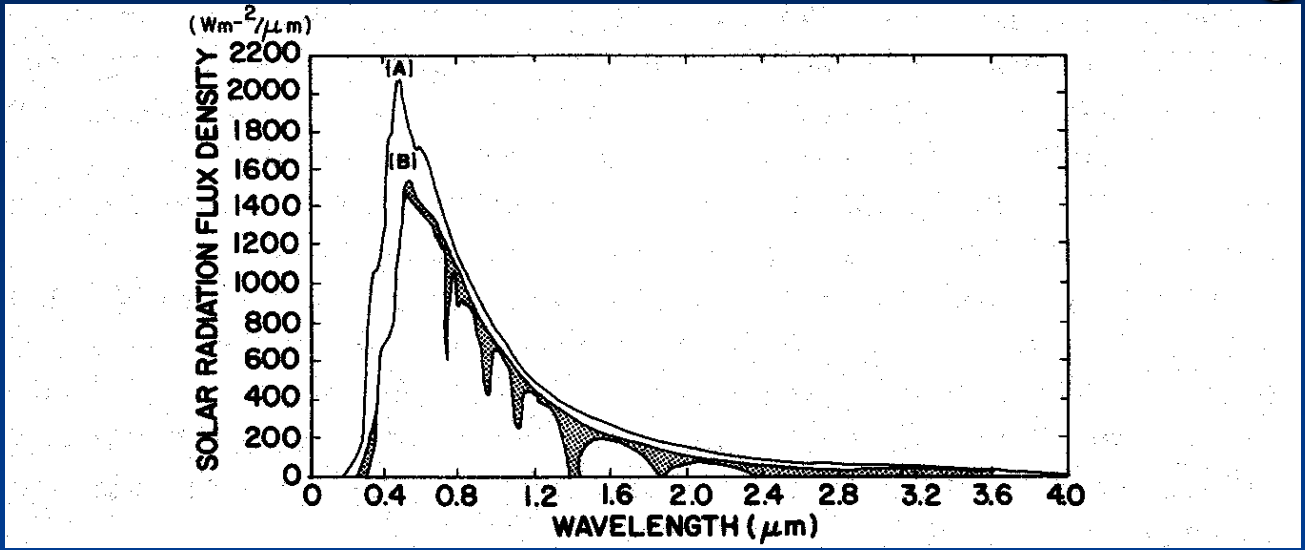


Radiative properties of natural surfaces

- In studying the radiation balance near the surface, we are interested in the radiative fluxes integrated over all the wavelengths of interest
- For this an integrated emissivity and reflectivity, pertaining to radiation in certain range of wavelengths, are used to characterized the surface
- E.g., the term "**albedo**" is used to represent the integrated reflectivity of the surface for shortwave (0.15-4 micrometer) radiation
- The term "**emissivity**" refers primarily to the longwave (3-100 micrometer) radiation
- For natural surfaces, the emission of shortwave radiation is usually neglected, and the emission of longwave radiative flux is given by the modified Stefan-Boltzmann Law

$$R_L = -\varepsilon \sigma T^4$$

Shortwave Radiation (R_s)



- The ultimate source of all **shortwave radiation (R_s)** received at or mear the earth's surface is the sun
- As a measure of the intensity of solar radiation, **the solar constant** (**S**) is defined as the flux of solar radiation falling on a surface normal to the solar beam at the outer edge of the atmosphere, when the earth is at its mean distance from the sun
- The best estimate solar constant is 1368 Wm^{-2}
- The solar flux density received at the surface of the earth is smaller than their values at the top of atmosphere, because of the depletion of solar radiation in passing through the atmosphere

Longwave Radiation (R_L)

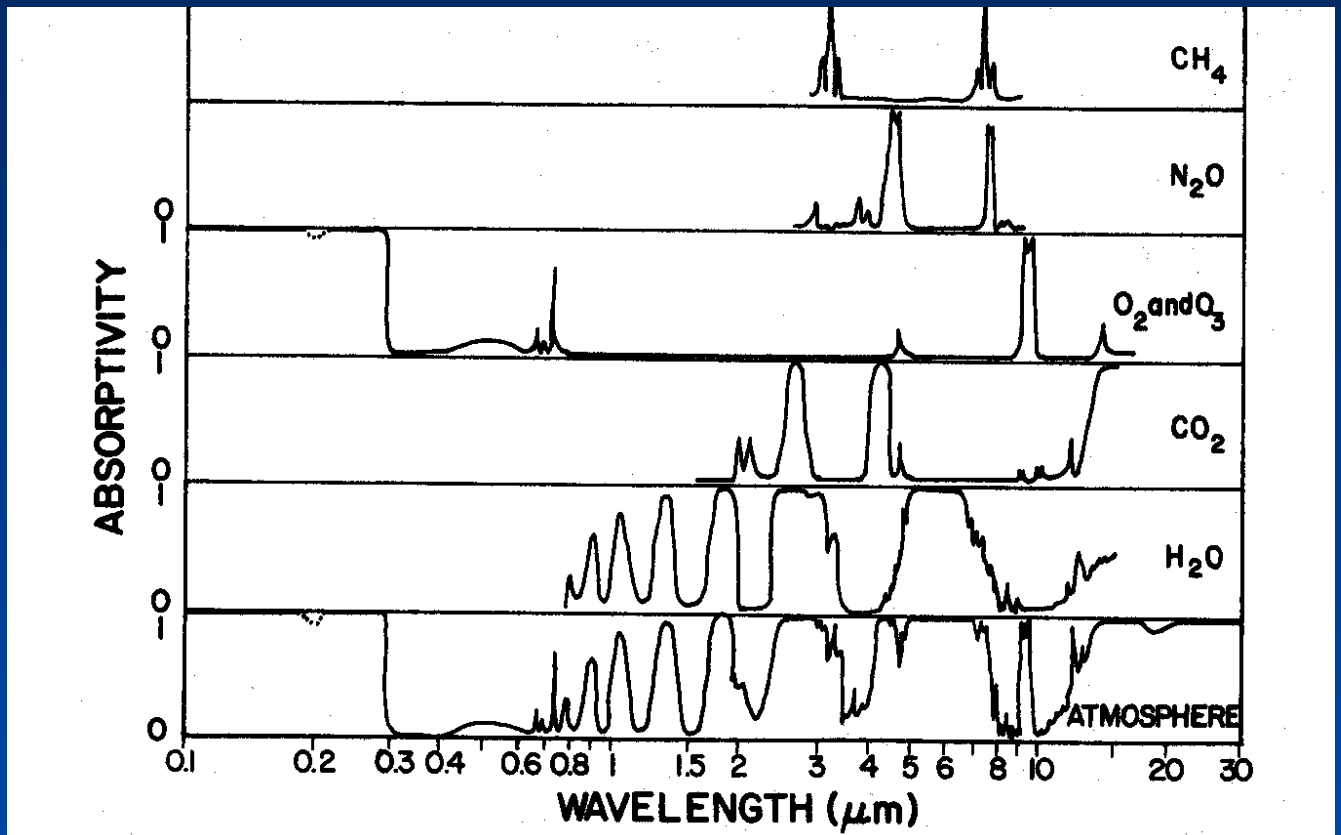
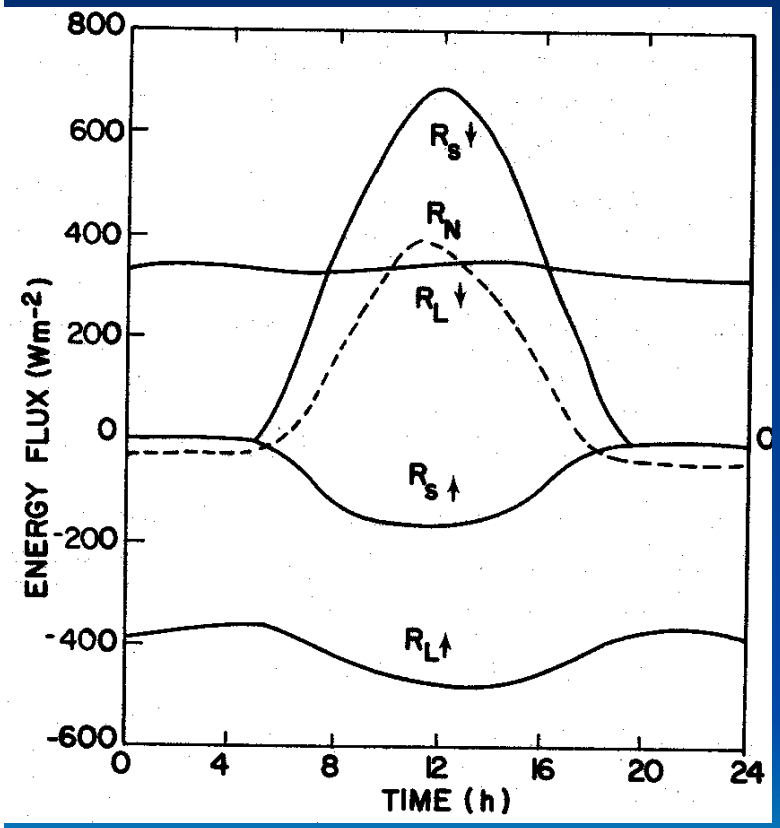


Fig. 3.3 Absorption spectra of water vapor, carbon dioxide, oxygen and ozone, nitrogen oxide, methane, and the atmosphere. [From Fleagle and Businger (1980).]

- It is clear that the atmosphere absorbs much of the longwave terrestrial radiation and a significant part of the solar radiation
- Therefore, Longwave radiation has a downward component

Radiation balance near the surface



- $R_N=R_S+R_L$

$$R_N = R_{S\uparrow} + R_{S\downarrow} + R_{L_\uparrow} + R_{L\downarrow}$$

$$R_{S\uparrow} = -aR_{S\downarrow}$$

- where a is albedo
- The net shortwave radiation

$$R_S = (1-a)R_{S\downarrow}$$

- The net longwave radiation

$$R_L = R_{L\downarrow} + R_{L\uparrow}$$

$$R_N = (1-a)R_{S\downarrow} + R_{L\downarrow} + R_{L\uparrow}$$

Soil temperature and heat transfer

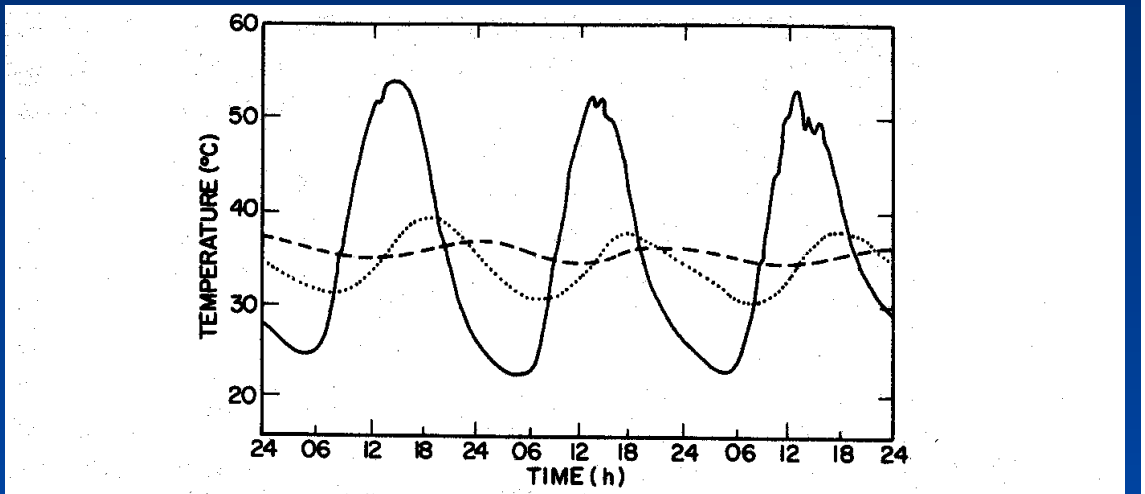


Fig. 4.1 Observed diurnal course of subsurface soil temperatures at various depths in a sandy loam with bare surface. ——, 2.5 cm; ·····, 15 cm; ---, 30 cm. [From Deacon (1969); after West (1952).]

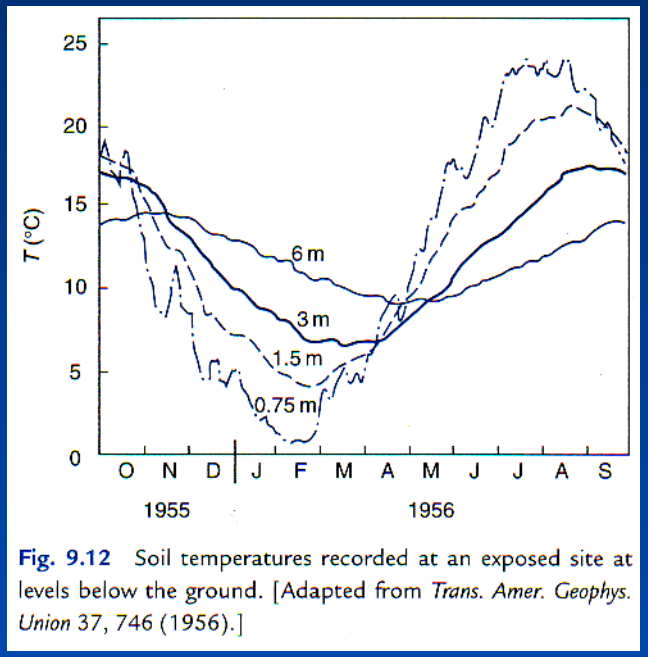


Fig. 9.12 Soil temperatures recorded at an exposed site at levels below the ground. [Adapted from *Trans. Amer. Geophys. Union* 37, 746 (1956).]

- Deep soil temperature becomes insignificant at a depth of the order of 1 m or less