Lecture 31. Introduction to climate and climate change. Part 1.

Objectives:
1. Weather and climate.
2. Earth's radiation budget.
3. Clouds and radiation field.

Readings: Turco: p. 320-349; Brimblecombe: 184-188.

1. Weather and climate.

Weather is the meteorological state of the atmosphere that we experience instantaneously at our particular location.

Climate is the average weather over some appropriate averaging time in a specific location.

- Note that the definition of climate is flexible for the period of averaging. A traditional averaging time for defining climate is 30 years.

Climate system is an extremely complex system of energy reservoirs joined together (coupled) by energy transfer processes.

- **Sun** is the only energy source of our climate system. Sun emits electromagnetic radiation in a range of wavelengths from 200 nm to about 5000 nm, with the maximum at about 550 nm. The amount of solar radiation varies (will be discussed in Lecture 32).

NOTE: electromagnetic radiation and solar spectrum were discussed in Lecture 5.

Major energy reservoirs of the climate system:

(i) Atmosphere (gases, aerosols, and clouds);

(ii) Ocean;

(iii) Land (including biosphere)

Major energy transfer processes of the climate system:

Sun radiative energy is transformed by numerous processes to other form of energy (such as kinetic, potential, etc.) and distributed between the major energy reservoirs.

- The amount of energy in a reservoir is determined by its size and its heat capacity.

Table 31.1 Earth's energy reservoirs (Turco, 1997).

Reservoir	**Approximate volume (km^3)**	**Mass (Gt)**	**Tempe-rature (K)**	**Heat capacity ($J\ g^{-1}\ K^{-1}$)**	**Energy content (J)**
Atmosphere (taken as 10 km thick)	**$5.0x10^9$**	**$5.0x10^6$**	**260**	**1.0**	**$1.3x10^{24}$**
Land surface (taken as 4 cm thick)	**$5.0x10^3$**	**$1.0x10^4$**	**290**	**4.0**	**$1.2x10^{22}$**
Land subsurface (taken as 80 cm thick)	**$1.0x10^5$**	**$2.0x10^5$**	**280**	**4.0**	**$2.2x10^{23}$**
Surface oceans (taken as 100 m deep)	**$3.8x10^7$**	**$3.8x10^7$**	**280**	**4.0**	**$4.3x10^{25}$**
Deep oceans (taken as 4 km deep)	**$1.4x10^9$**	**$1.4x10^9$**	**275**	**4.0**	**$1.5x10^{27}$**

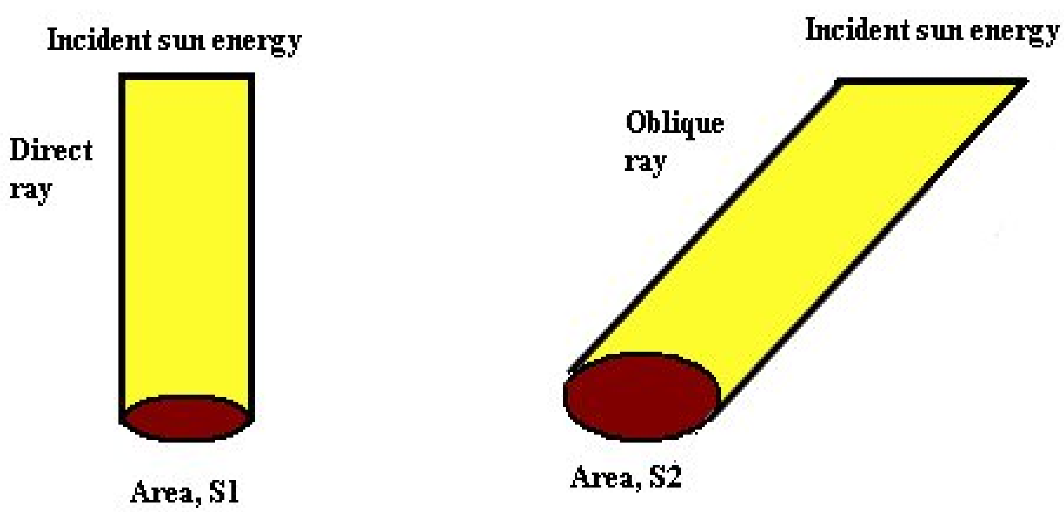
- **The most fundamental climate parameter is the planetary (global) average temperature.**

NOTE: Global mean surface temperature is the most stable climate parameter, which varies less than a few tenths of a degree over centuries. The atmosphere, land and ocean have an enormous capacity to store heat. Therefore they maintain the stable average temperature despite fluctuations in the global heat balance.

2. Earth's radiation budget.

The balance of the absorption of sunlight and the emission of the thermal radiation determines the average temperature of the Earth.

- Most surfaces are not perpendicular to the Sun, and the energy they receive depends on the solar elevation angle (90^{o} for the overhead Sun). This angle changes systematically with latitude, the time of year, and the time of day: the more direct the ray is, the greater the energy per unit area of surface will be.



Because S1 < S2

Incident sun energy /S1 > Incident sun energy /S2

- Although the temperature has inertia against cooling (because of heat contained in the ground, sensible heat, and the heat of condensation of water vapor, latent heat), the angle of the sun is a key factor determining regional climate and climate variations. The changing seasons are a manifestation of variations in the sun's angle.

Let's develop a simple climate model to estimate the average temperature of the Earth.

Sun energy reaching the Earth:

$$F_s = F_{s0} (D_{es0}/D_{es})^2$$

where

F_{s0} is the **solar constant** (about 1365 W/m^2) at the average distance of the Earth from the sun, D_{es0};

F_s is the total sun energy flux (in W/m^2) reaching the Earth when the distance from the Earth to sun is D_{es}.

Thus, F_s depend on the distance D_{es}.

Sun energy reflected or scattered back to space:

Planetary albedo, α_e, shows a fraction of the total radiative energy flux impinging on the planet that is reflected back to space.

NOTE: the average planetary albedo of the Earth is about 0.33.

Thus the total energy (in W) absorbed by the earth-atmosphere system is:

$$Q_{in} = F_s (1 - \alpha_e) (\pi R_e^2)$$

where R_e is the radius of the Earth (6.37x10^6 m), and πR_e^2 is the cross-section area of the Earth.

Emission of thermal radiation:

assuming that the Earth is a blackbody with temperature T, we have:

$$F_b = \sigma_B \; T^4$$

where σ_B is the Stefan-Boltzmann constant.

Thus the total energy (in W) emitted to space is:

$$Q_{out} = \sigma_B \; T^4 (4\pi R_e^2)$$

where $4\pi R_e^2$ is the total surface area of the Earth, because the emission of thermal radiation occurs from the entire surface of the planet.

From the balance of incoming and outgoing energy, the 'effective temperature' of the Earth is:

$$Q_{in} = Q_{out}$$

$$F_s (1 - \alpha_e) (\pi R_e^2) = \sigma_B \, T_e^4 (4\pi R_e^2)$$

$$T_e^4 = F_s (1 - \alpha_e) / 4 \sigma_B$$

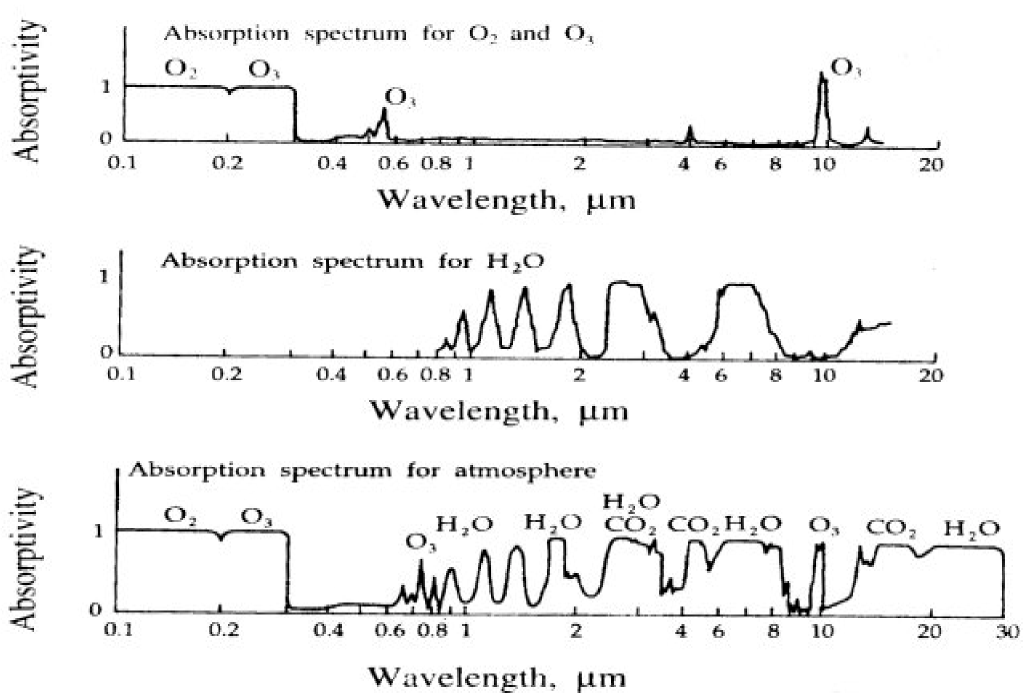
$$T_e = 255 \text{ K} = -18^0\text{C is very low!!!}$$

Why? : because we didn't include the greenhouse effect.

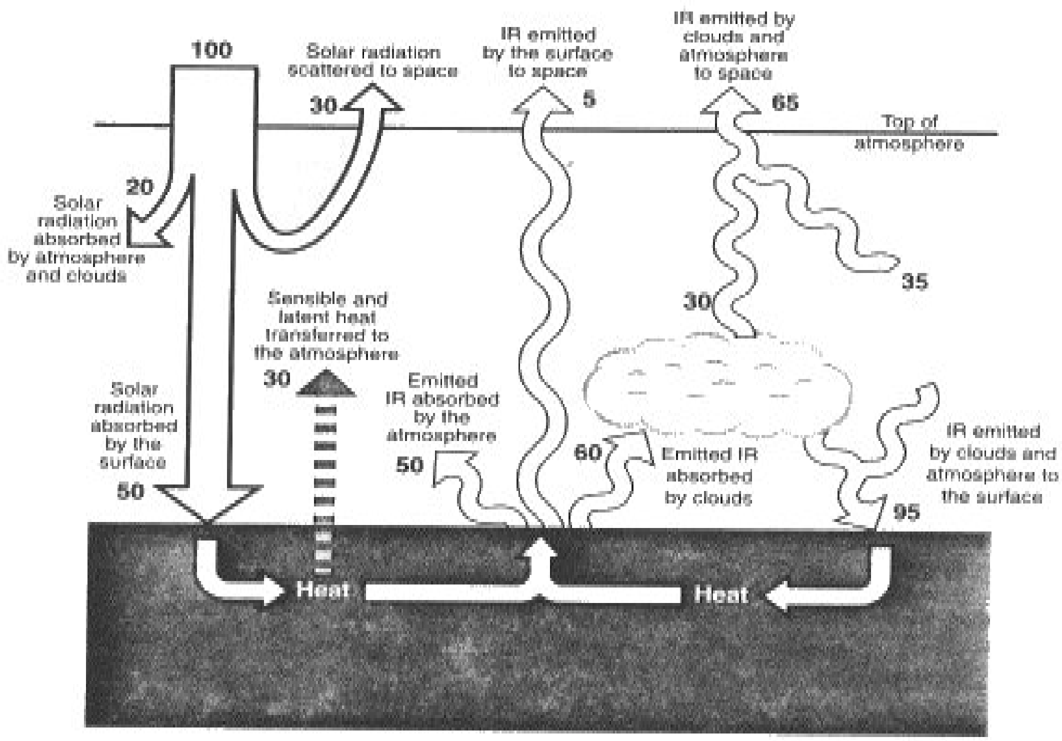
Greenhouse effect is a trapping of the earth's thermal radiation by the clouds and greenhouse gases (such as H_2O, CO_2, O_3, CH_4, etc.) and re-emitting it back to the surface.

NOTE: greenhouse gases are the gases, which absorb at the infrared (thermal) wavelengths (detailed discussion will be given in Lectures 33-34).

Figure 31.1 Absorption spectra for molecular oxygen, water vapor, and the atmosphere.



The radiative and physical processes that control the overall energy balance and climate of the Earth.



NOTE: for detailed description of the above figure see Turco (1997), Figure 11.14).

- Latitudinally, it has been found that much more solar radiation is absorbed at low latitudes than at high latitudes. On the other hand, thermal emission does not show nearly as strong a dependence on latitude, so that the planetary radiation budget decreases systematically from the Equator to the poles. It changes from being positive to negative at a latitude of about 40. The atmosphere and oceans, through their general circulation, act as vast heat engines, compensating for this imbalance by providing non-radiative mechanisms for the transfer of heat from the Equator to the poles.

3. Clouds and radiation field.

NOTE: clouds, cloud types, major cloud characteristics were discussed in Lecture13.

- **Clouds** are a major factor in the Earth's radiation budget, reflecting sunlight back to space or blanking the lower atmosphere and trapping infrared radiation emitted by the Earth's surface.

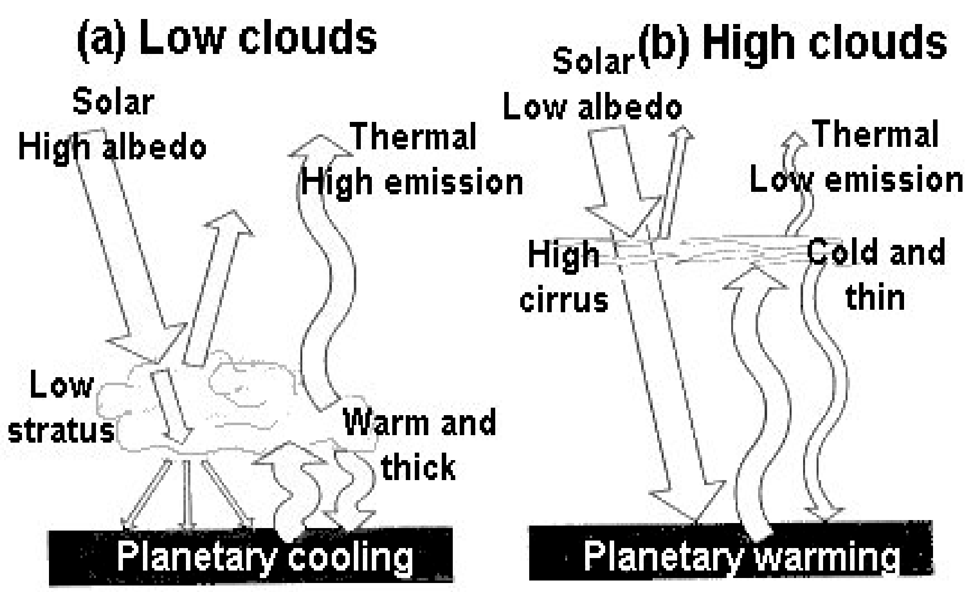
Effects of clouds on the atmospheric radiation field:

(i) Clouds reflect, absorb and transmit solar radiation.

(ii) Clouds reflect and transmit the infrared (thermal) radiation emitted by the earth's surface and the atmosphere, and, at the same time, emit infrared radiation according to the their temperature.

- Scattering and absorption properties of cloud are determined by particle size distribution and particle number concentration.
- Low clouds, 4 km and less above the surface, and high clouds, about 8 km above the surface have the dramatically different effects on the radiation field.

Figure 31.2 The effects of clouds on the flow of radiation and energy in the lower atmosphere and surface (Turco, 1997).



- If cloud amount changes, the global albedo will change, and hence the global mean temperature can be altered.
- Aerosols can alter cloud particle size distribution and cloud particle concentration and, hence, cloud albedo and the global mean temperature (known as indirect effect of aerosols on climate, see Lecture 39).