# *Lecture 2:* Global Energy Cycle

- Planetary energy balance
- Greenhouse Effect
- Selective absorption
- Vertical energy balance

# Solar Flux and Flux Density

- Solar Luminosity (***L***)

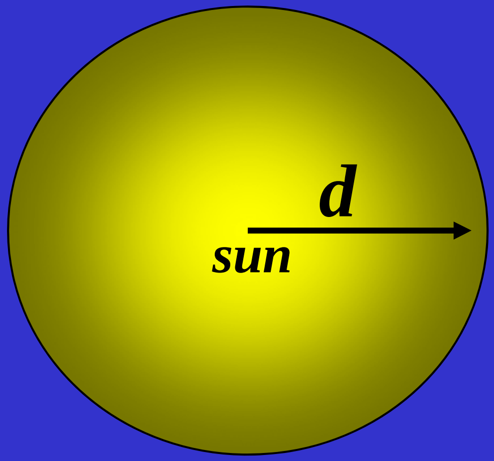
  the constant flux of energy put out by the sun

$$L = 3.9 \times 10^{26} \quad W$$

- Solar Flux Density ($S_d$)

  the amount of solar energy per unit area on a sphere centered at the Sun with a distance ***d***

$$S_d = L / (4 \pi d^2) \quad W/m^2$$



# Solar Flux Density Reaching Earth

- Solar Constant (***S***)

  The solar energy density at the mean distance of Earth from the sun ($1.5 \times 10^{11}$ m)

$$S = L / (4 \pi d^2)$$

$$= (3.9 \times 10^{26}\ \mathrm{W}) / [4 \times 3.14 \times (1.5 \times 10^{11}\ \mathrm{m})^2]$$

$$= 1370\ \mathrm{W/m^2}$$

# Solar Energy Incident On the Earth

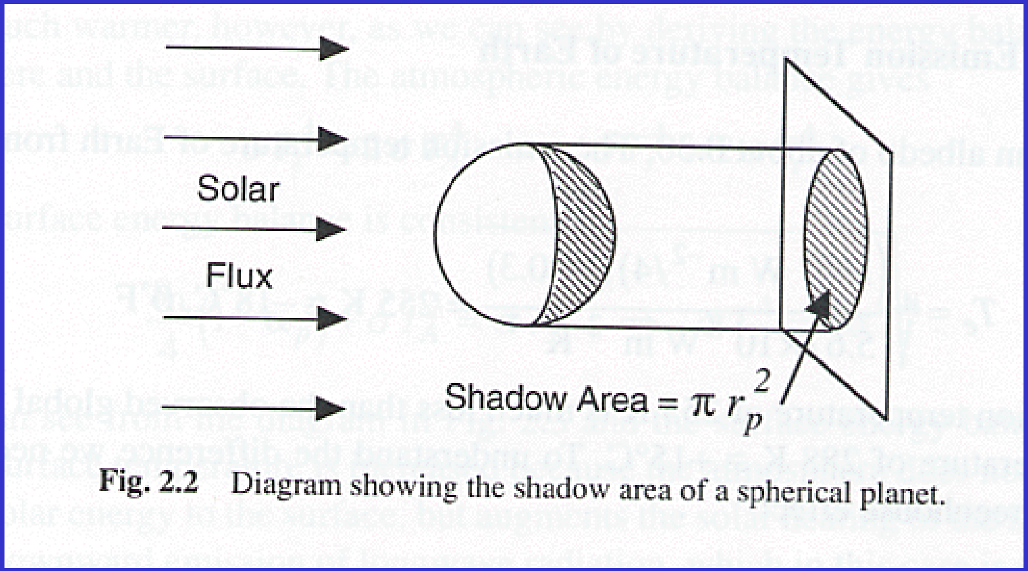
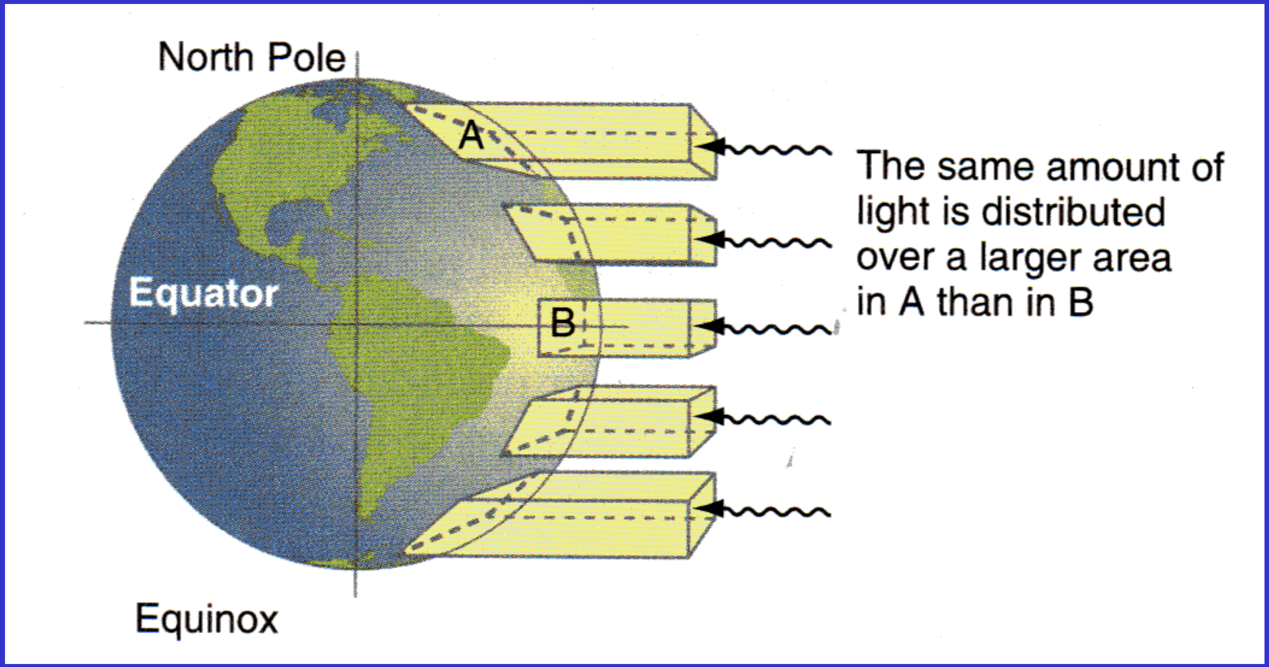


**Fig. 2.2** Diagram showing the shadow area of a spherical planet.

- Solar energy incident on the Earth
  = total amount of solar energy **can be** absorbed by Earth
  = (Solar constant) x (Shadow Area)
  = $S \times \pi R^2_{Earth}$

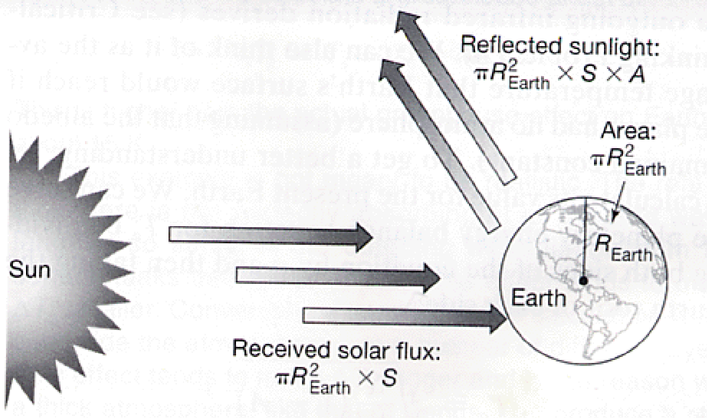
# Zenith Angle and Insolation




(from *Meteorology: Understanding the Atmosphere*)

- The larger the solar zenith angle, the weaker the insolation, because the same amount of sunlight has to be spread over a larger area.

# Solar Energy Absorbed by Earth




**BOX FIGURE 3-1**
The amount of sunlight received by and reflected by Earth.

(from *The Earth System*)

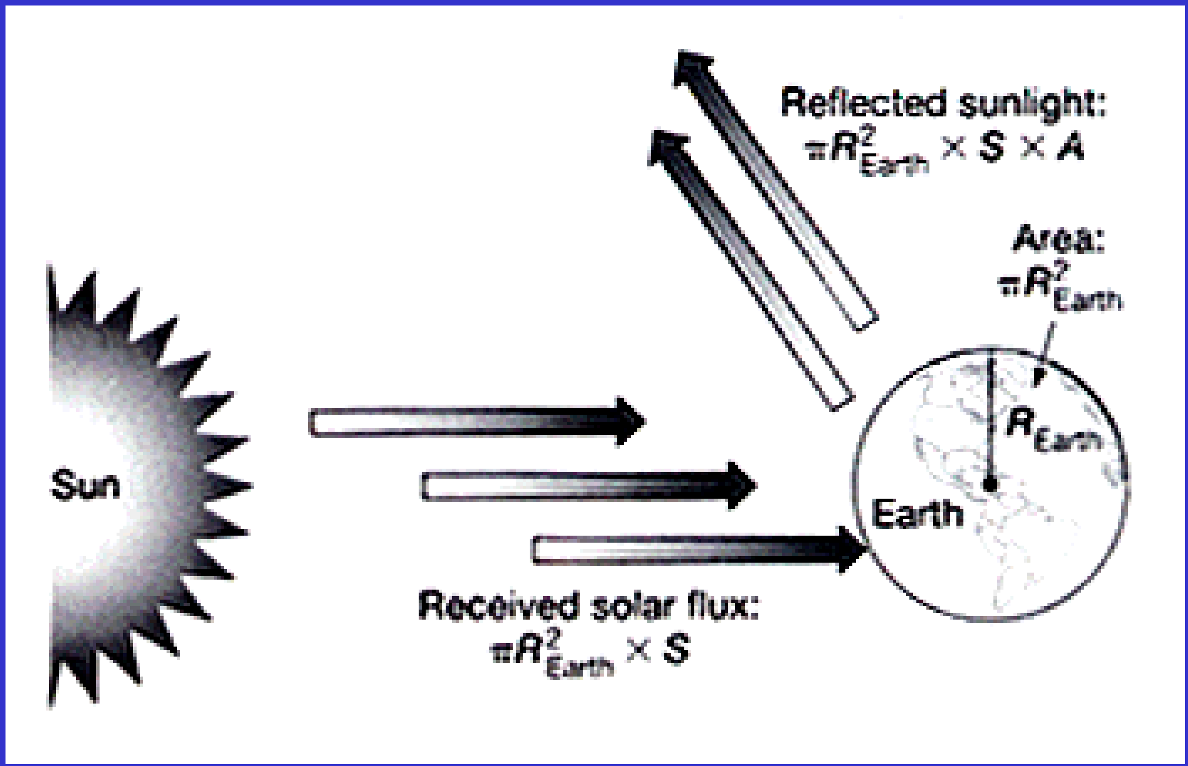
- **Solar Constant (S)**
  = solar flux density reaching the Earth
  = 1370 $W/m^2$

- **Solar energy incident on the Earth**
  = S x the "flat" area of the Earth
  = $S \times \pi R^2_{Earth}$

- **Solar energy absorbed by the Earth**
  = (received solar flux) – (reflected solar flux)
  = $S \pi R^2_{Earth} - S \pi R^2_{Earth} \times A$
  = $\mathbf{S \pi R^2_{Earth} \times (1-A)}$

**A** is the *planetary albedo* of the Earth, which is about 0.3.

# Albedo = [Reflected] / [Incoming] Sunlight




Albedo is the percentage of the sunlight that is reflected back to the space by the planet.

# What Happens After the Earth Absorbs Solar Energy?

- The Earth warms up and has to emit radiative energy back to the space to reach a equilibrium condition.

- The radiation emitted by the Earth is called "terrestrial radiation" which is assumed to be like blackbody radiation.

# Blackbody Radiation

- Blackbody

  A blackbody is something that emits (or absorbs) electromagnetic radiation with 100% efficiency at all wavelength.

- Blackbody Radiation

  The amount of the radiation emitted by a blackbody depends on the absolute temperature of the blackbody.

# Stefan-Boltzmann Law

$$E = \sigma T^4$$

E = radiation emitted in W/m$^2$

$\sigma$= 5.67 x 10$^{-8}$ W/m$^2$ * K *sec

T = temperate (K ← ***Kelvin degree***)

- ❑ The single factor that determine how much energy is emitted by a blackbody is its temperature.
- ❑ The intensity of energy radiated by a blackbody increases according to the fourth power of its absolute temperature.
- ❑ This relationship is called the Stefan-Boltzmann Law.

# Apply Stefan-Boltzmann Law To Sun and Earth

- **Sun**

  $E_s = (5.67 \times 10^{-8}\ W/m^2\ K^4) * (6000K)^4$

  $= 73{,}483{,}200\ W/m^2$

- **Earth**

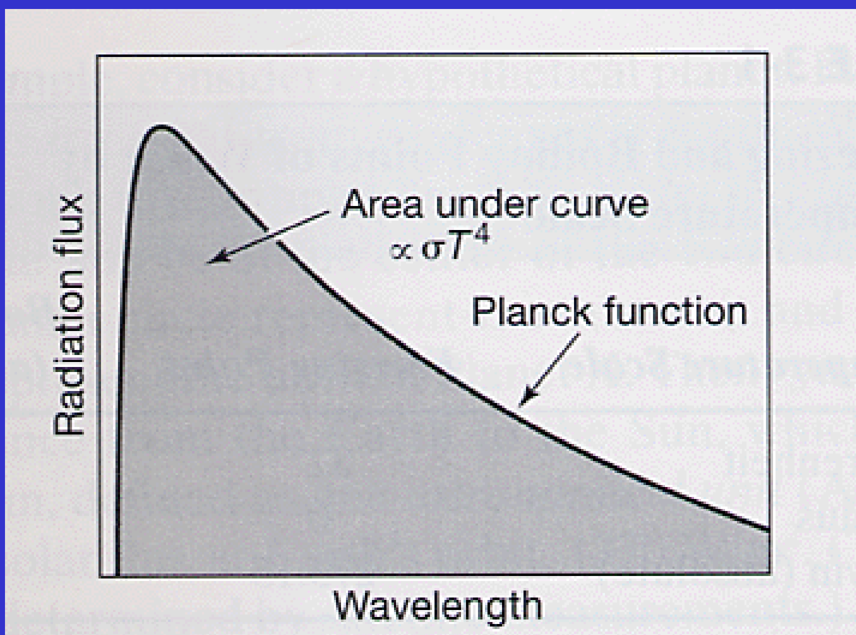
  $E_e = (5.67 \times 10^{-8}\ W/m^2\ K^4) * (300K)^4$

  $= 459\ W/m^2$

- Sun emits about 160,000 times more radiation per unit area than the Earth because Sun's temperature is about 20 times higher than Earth's temperature.

  ➔ $20^4 = 160{,}000$

# Energy Emitted from Earth




(from *The Earth System*)

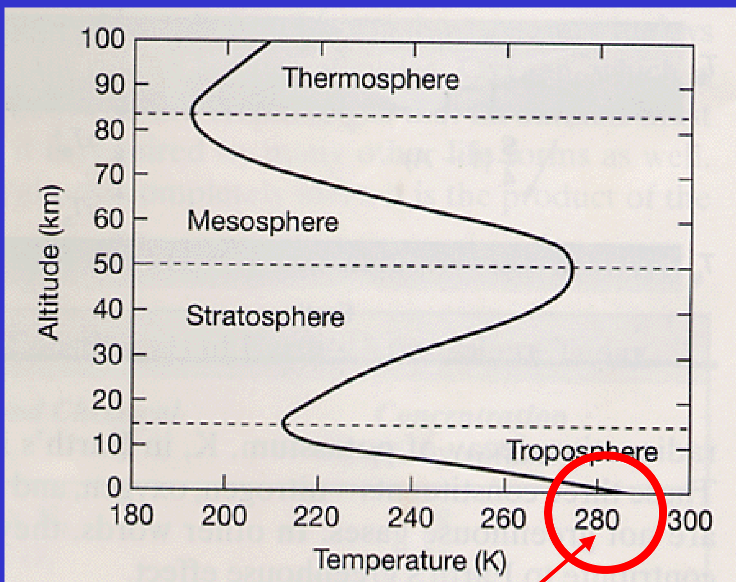
- **The Stefan-Boltzmann Law**

  The energy flux emitted by a blackbody is related to the fourth power of the body's absolute temperature

  $\mathbf{F = \sigma T^4}$ where $\sigma$ is $5.67 \times 10^{-8}$ W/m$^2$/K

- **Energy emitted from the Earth**
  = (blackbody emission) x (total area of Earth)
  = $(\sigma T_e^4)$ x $(4\pi R^2_{Earth})$

# Planetary Energy Balance




(from *Global Physical Climatology*)

- **Energy emitted by Earth = Energy absorbed by Earth**

$$\sigma T_e^4 \ \text{x} \ (4\pi R^2_{Earth}) = S \pi R^2_{Earth} \ \text{x} \ (1\text{-}A)$$

$$\sigma T_e^4 = S/4 * (1\text{-}A)$$

$$= 1370/4 \ W/m^2 * (1\text{-}A)$$

$$= 342.5 \ W/m^2 * (1\text{-}A)$$

$$= 240 \ W/m^2$$

- **Earth's *blackbody* temperature**

**$T_e$ = 255 K (-18C)**

**Earth's *surface* temperature**

**$T_S$ = 288 K (15C)**

***greenhouse effect (33C) !!***

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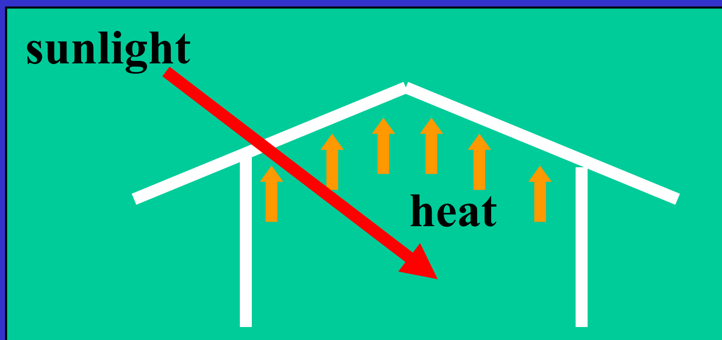
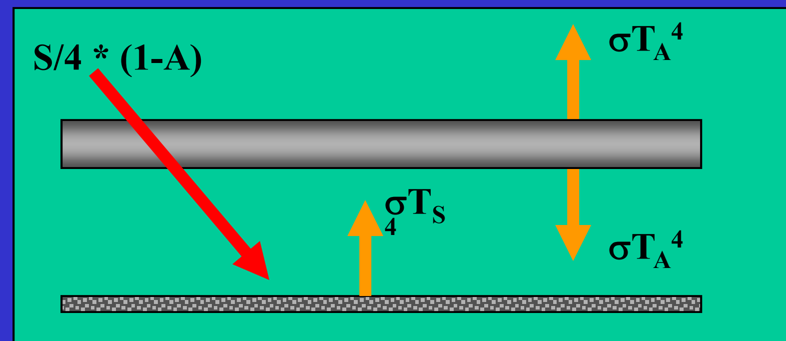
# Greenhouse Effect

## Greenhouse




- allow sunlight to come in
- trap heat inside the house

## Atmosphere




- For Earth's surface:

  $S/4*(1\text{-}A) + \sigma T_A^4 = \sigma T_S^4$

- For the atmosphere:

  $\sigma T_S^4 = 2\sigma T_A^4$

➔ $T_A = T_e =$ **255K**

➔ **$T_s = 2^{1/4}\, T_A = 303K$**

# Greenhouse Gases

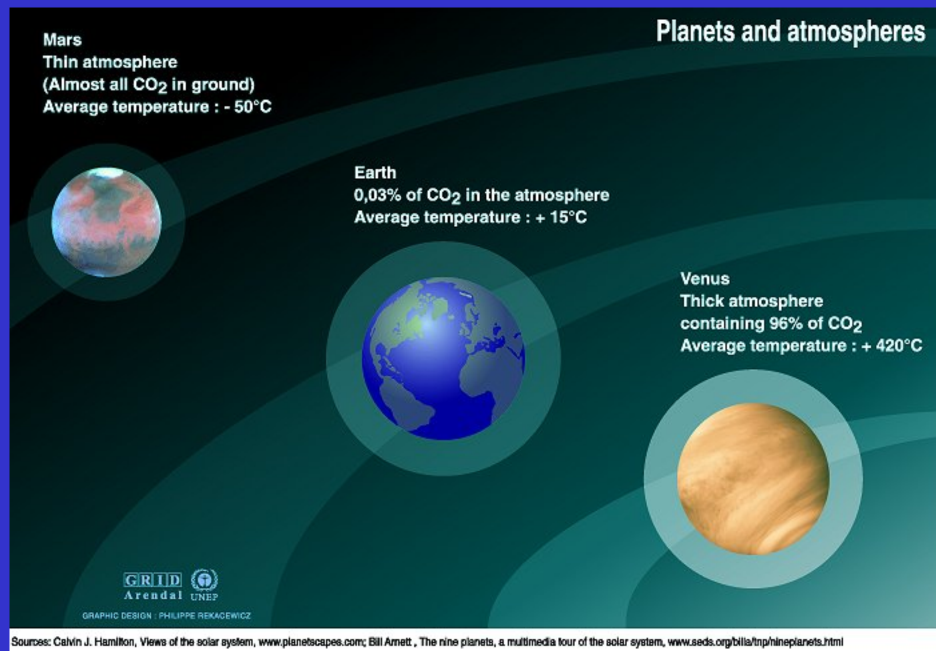
**Important Atmospheric Greenhouse Gases**

| *Name and Chemical Symbol* | *Concentration (ppm by volume)* |
|---|---|
| Water vapor, $H_2O$ | 0.1 (South Pole)–40,000 (tropics) |
| Carbon dioxide, $CO_2$ | 360 |
| Methane, $CH_4$ | 1.7 |
| Nitrous oxide, $N_2O$ | 0.3 |
| Ozone, $O_3$ | 0.01 (at the surface) |
| Freon-11, $CCl_3F$ | 0.00026 |
| Freon-12, $CCl_2F_2$ | 0.00047 |

# Factors Determine Planet Temperature

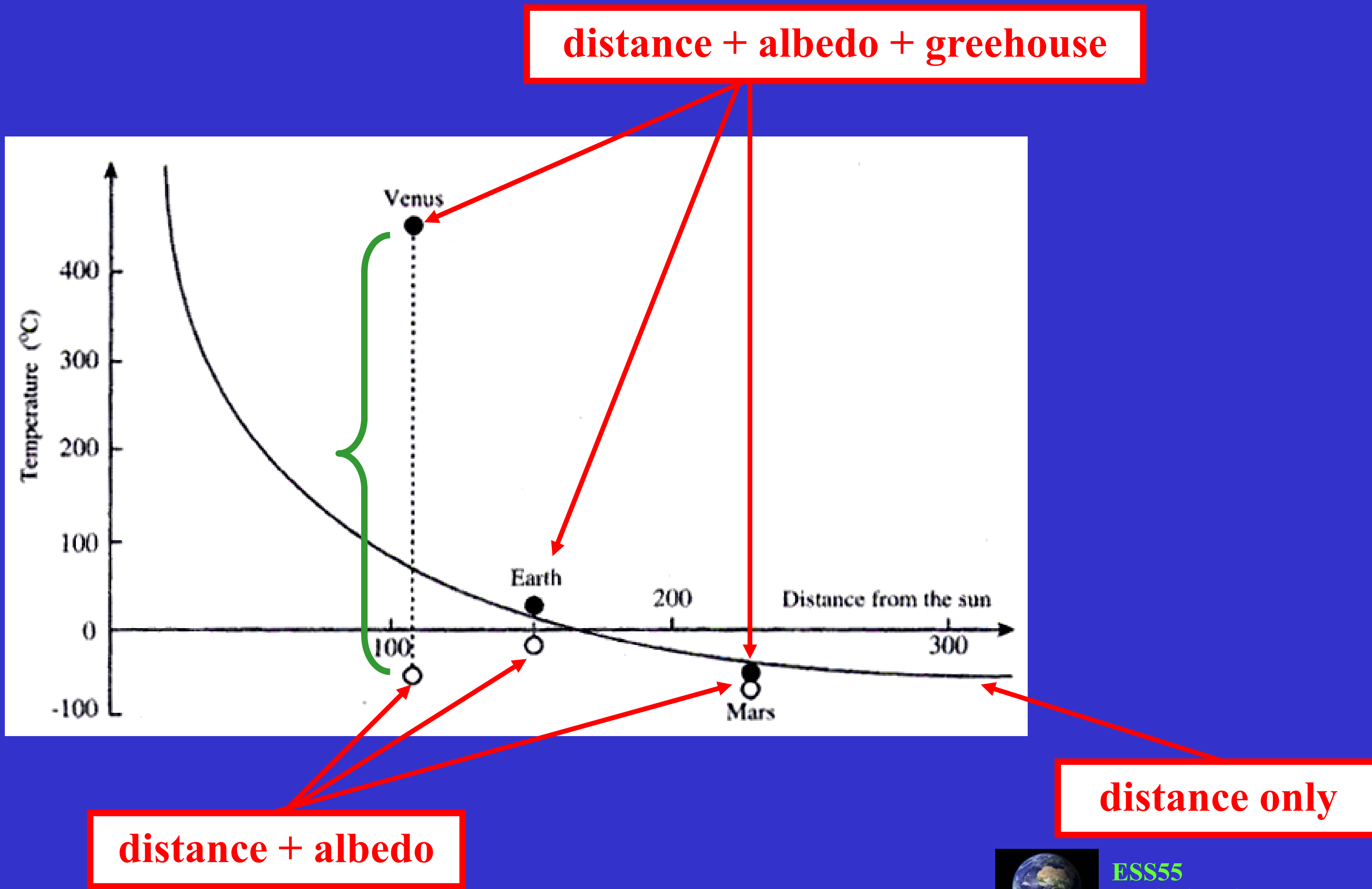
- ❑ Distance from the Sun
- ❑ Albedo
- ❑ Greenhouse effect

# Mars, Earth, and Venus




| Planet | Distance to the Sun | Radius | Planetary Albedo | Mean Surface Temperature |
|---|---|---|---|---|
| Venus | 0.72 AU | 6,052 km | 0.80 | 730°K |
| Earth | 1.00 AU | 6,370 km | 0.30 | 288°K |
| Mars | 1.52 AU | 3,397 km | 0.22 | 218°K |

# Global Temperature

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# Greenhouse Effects

- ❑ On Venus → 510°K (very large!!)
- ❑ On Earth → 33°K
- ❑ On Mars → 6°K (very small)

# Why Large Greenhouse Effect On Venus?

- **Venus is very close to the Sun**

➔ Venus temperature is very high

➔ Very difficult for Venus's atmosphere to get saturated in water vapor

➔ Evaporation keep on bringing water vapor into Venus's atmosphere

➔ Greenhouse effect is very large

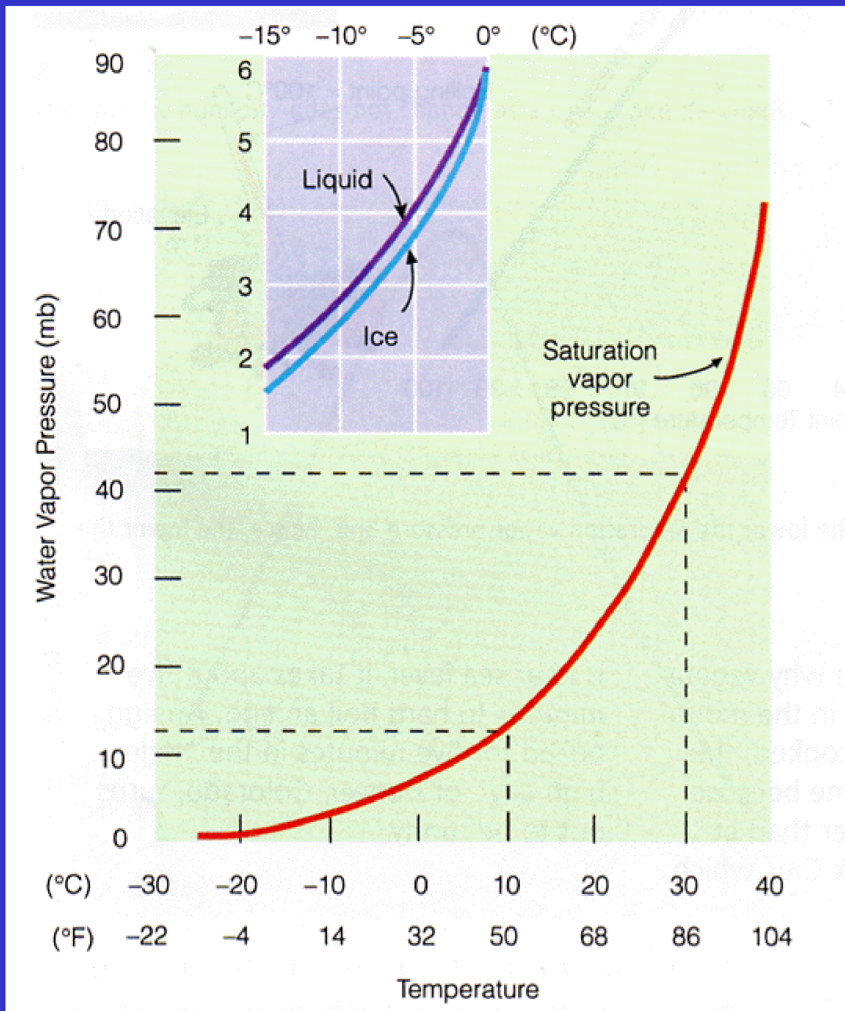
➔ A "run away" greenhouse happened on Venus

➔ Water vapor is dissociated into hydrogen and oxygen

➔ Hydrogen then escaped to space and oxygen reacted with carbon to form carbon dioxide

➔ **No liquid water left on Venus**

# Saturation Vapor Pressure




- Saturation vapor pressure describes how much water vapor is needed to make the air saturated at any given temperature.
- Saturation vapor pressure depends primarily on the air temperature in the following way:

$$\frac{de_s}{dT} = \frac{L}{T(\alpha_v - \alpha_l)}$$

**The Clausius-Clapeyron Equation**

➔ $$e_s \cong 6.11 \bullet \exp\left\{\frac{L}{R_v}\left(\frac{1}{273} - \frac{1}{T}\right)\right\}$$

- Saturation pressure increases exponentially with air temperature.

L: latent heat of evaporation; α: specific volume of vapor and liquid

# Why Small Greenhouse Effect on Mars?

- ❑ **Mars is too small in size**

➔ Mars had no large internal heat

➔ Mars lost all the internal heat quickly

➔ No tectonic activity on Mars

➔ Carbon can not be injected back to the atmosphere

➔ Little greenhouse effect

➔ **A very cold Mars!!**

# Two Key Reasons for the Greenhouse Effect

- Solar and terrestrial radiations are emitted at very different wavelengths.

- The greenhouse gases selectively absorb certain frequencies of radiation.

# Stefan-Boltzmann Law

$$E = \sigma T^4$$

E = radiation emitted in $W/m^2$

$\sigma$= 5.67 x $10^{-8}$ $W/m^2$ * K *sec

T = temperate (K ← ***Kelvin degree***)

- The single factor that determine how much energy is emitted by a blackbody is its temperature.
- The intensity of energy radiated by a blackbody increases according to the fourth power of its absolute temperature.
- This relationship is called the Stefan-Boltzmann Law.

# Wien's Law

$$\lambda_{max} = w/T$$

$\lambda_{max}$ = wavelength (micrometers)

W = 2897 μm K

T = temperate (K)

- Wien's law relates an objective's maximum emitted wavelength of radiation to the objective's temperature.
- It states that the wavelength of the maximum emitted radiation by an object is inversely proportional to the objective's absolute temperature.

# Micrometer (μm)

**1 micrometer (μm) = $10^{-6}$ meter (m)**

# Apply Wien's Law To Sun and Earth

- **Sun**

  $\lambda_{max} = 2898\ \mu m\ K\ /\ 6000K$

  $= 0.483\ \mu m$

- **Earth**

  $\lambda_{max} = 2898\ \mu m\ K\ /\ 300K$

  $= 9.66\ \mu m$

- Sun radiates its maximum energy within the visible portion of the radiation spectrum, while Earth radiates its maximum energy in the infrared portion of the spectrum.

# Spectrum of Radiation

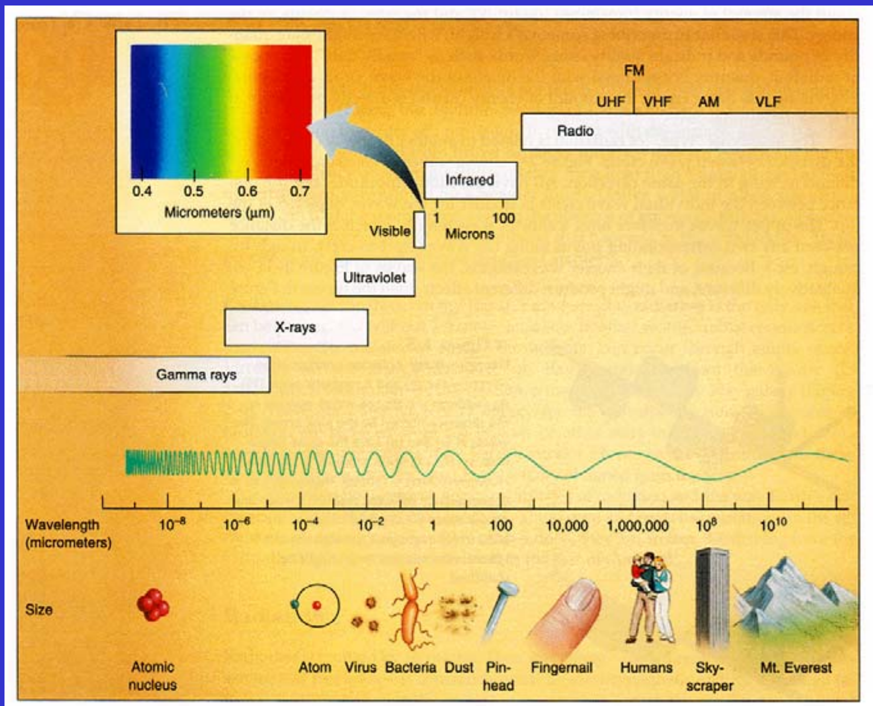


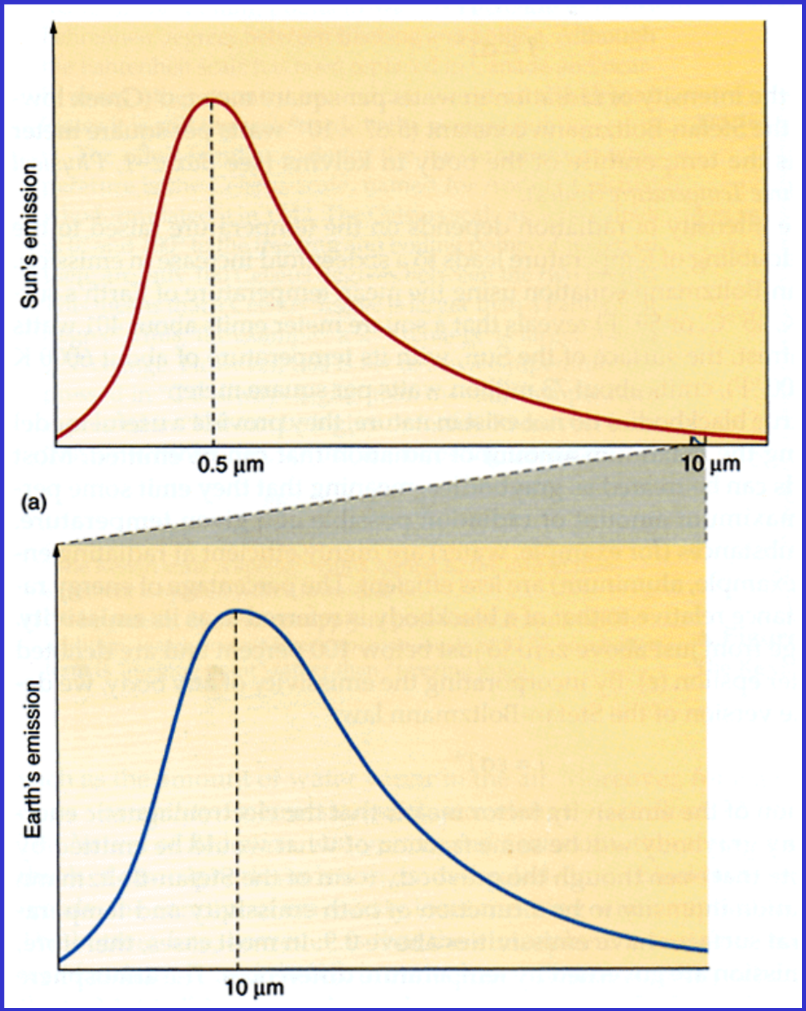

**Table 2–1 Wavelength Categorizations**

| Type of Energy | Wavelength (micrometers) |
|---|---|
| Gamma | <0.0001 |
| X ray | 0.0001 to 0.01 |
| Ultraviolet | 0.01 to 0.4 |
| Visible | 0.4 to 0.7 |
| Near Infrared (NIR) | 0.7 to 4.0 |
| Thermal Infrared | 4 to 100 |
| Microwave | 100 to 1,000,000 (1 meter) |
| Radio | >1,000,000 (1 meter) |

(from *Understanding Weather & Climate*)

- ❑ Radiation energy comes in an infinite number of wavelengths.
- ❑ We can divide these wavelengths into a few bands.

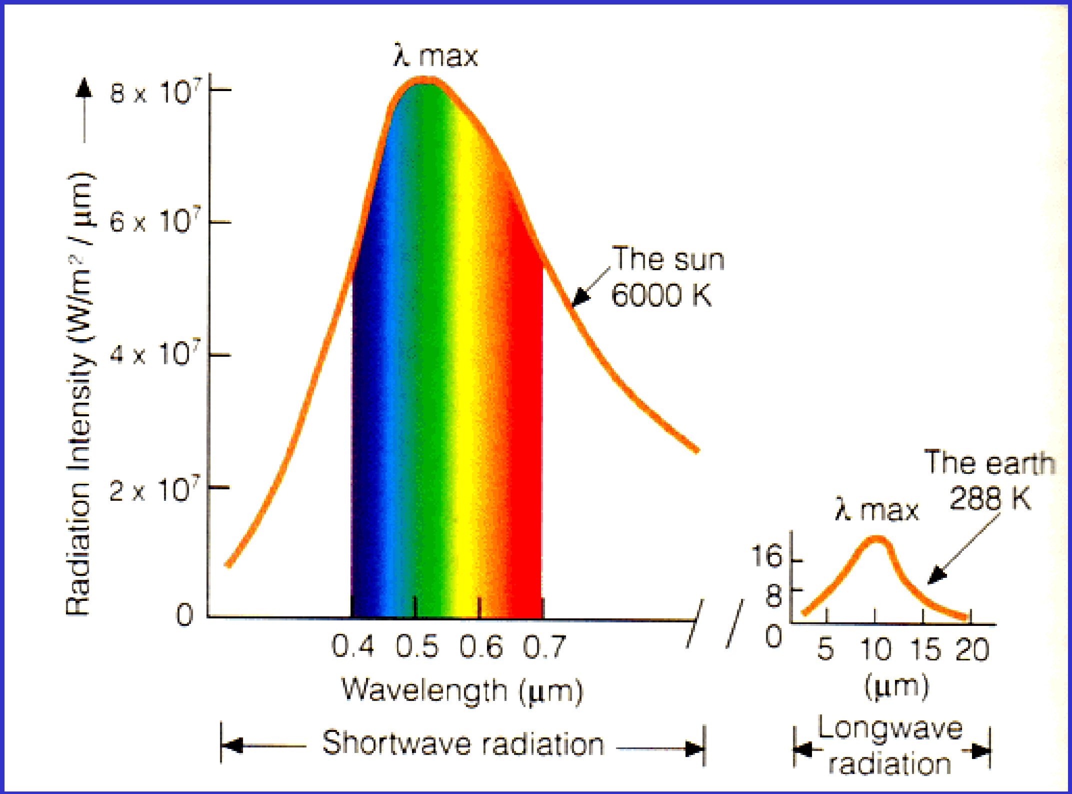
# Solar and Terrestrial Radiation




(from *Understanding Weather & Climate*)

- All objectives radiate energy, not merely at one single wavelength but over a wide range of different wavelengths.
- The sun radiates more energy than the Earth.
- The greatest intensity of solar energy is radiated at a wavelength much shorter than that of the greatest energy emitted by the Earth.

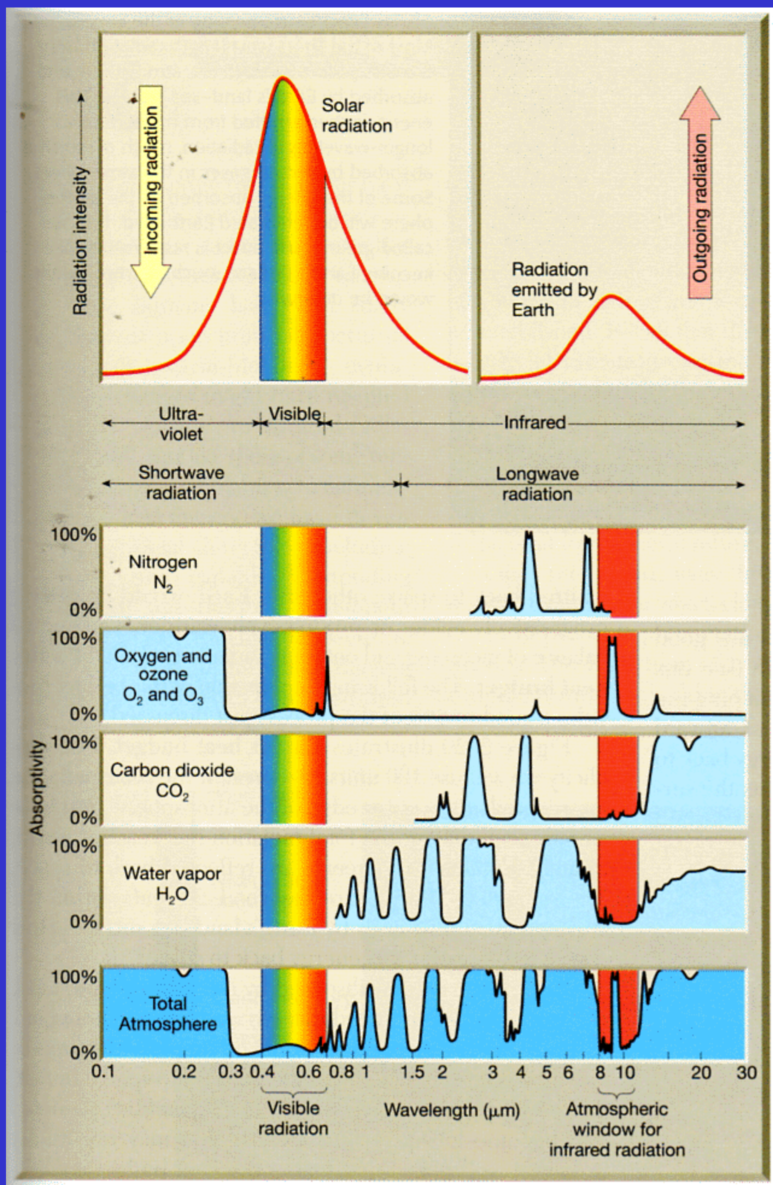
# Shortwave and Longwave Radiations




(from *Meteorology: Understanding the Atmosphere*)

- Solar radiation is often referred to as "shortwave radiation".
- Terrestrial radiation is referred to as "longwave radiation".

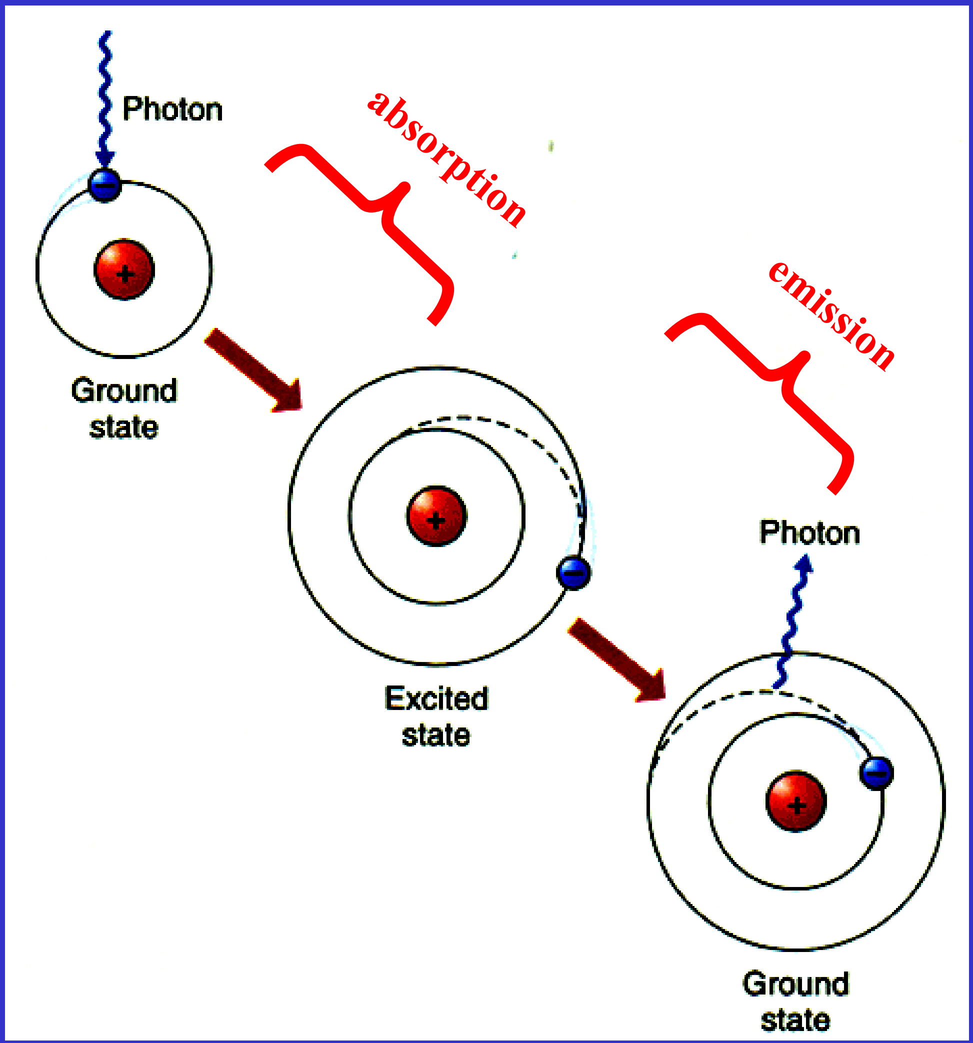
# Selective Absorption and Emission




- The atmosphere is not a perfect blackbody, it absorbs some wavelength of radiation and is transparent to others (such as solar radiation). ➔ Greenhouse effect.
- Objective that selectively absorbs radiation usually selectively emit radiation at the same wavelength.
- For example, water vapor and CO2 are strong absorbers of infrared radiation and poor absorbers of visible solar radiation.

(from *The Atmosphere*)

# Why Selective Absorption/Emission?

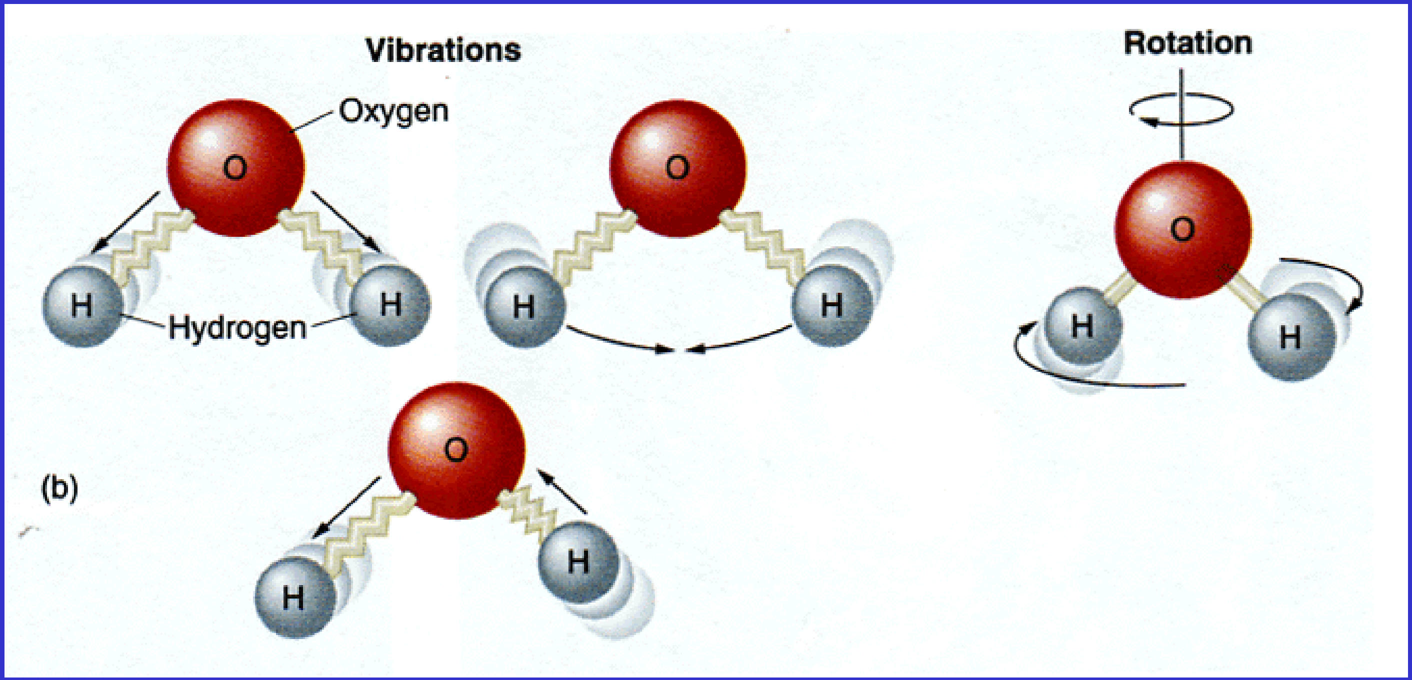



(from *Understanding Weather & Climate*)

- Radiation energy is absorbed or emitted to change the energy levels of atoms or molecular.
- The energy levels of atoms and molecular are discrete but not continuous.
- Therefore, atoms and molecular can absorb or emit certain amounts of energy that correspond to the differences between the differences of their energy levels.

➔ Absorb or emit at selective frequencies.

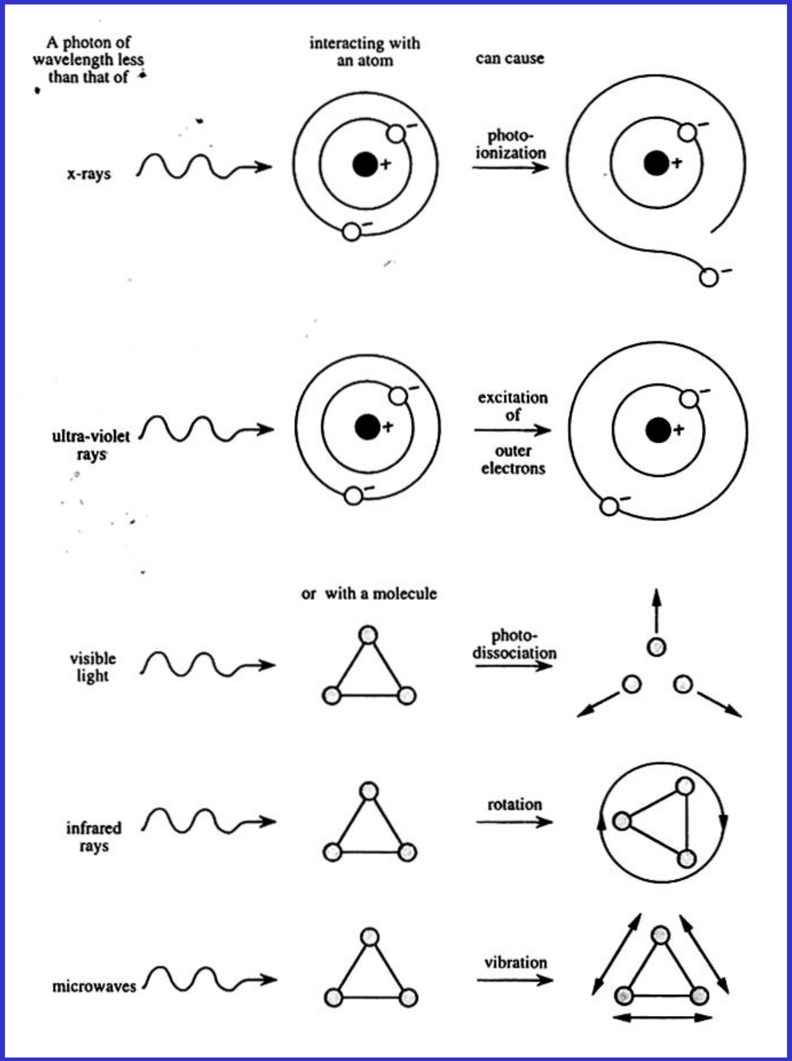
# Different Forms of Energy Levels




(from *Understanding Weather & Climate*)

- The energy of a molecule can be stored in (1) translational (the gross movement of molecules or atoms through space), (2) vibrational, (3) rotational, and (4) electronic (energy related to the orbit) forms.

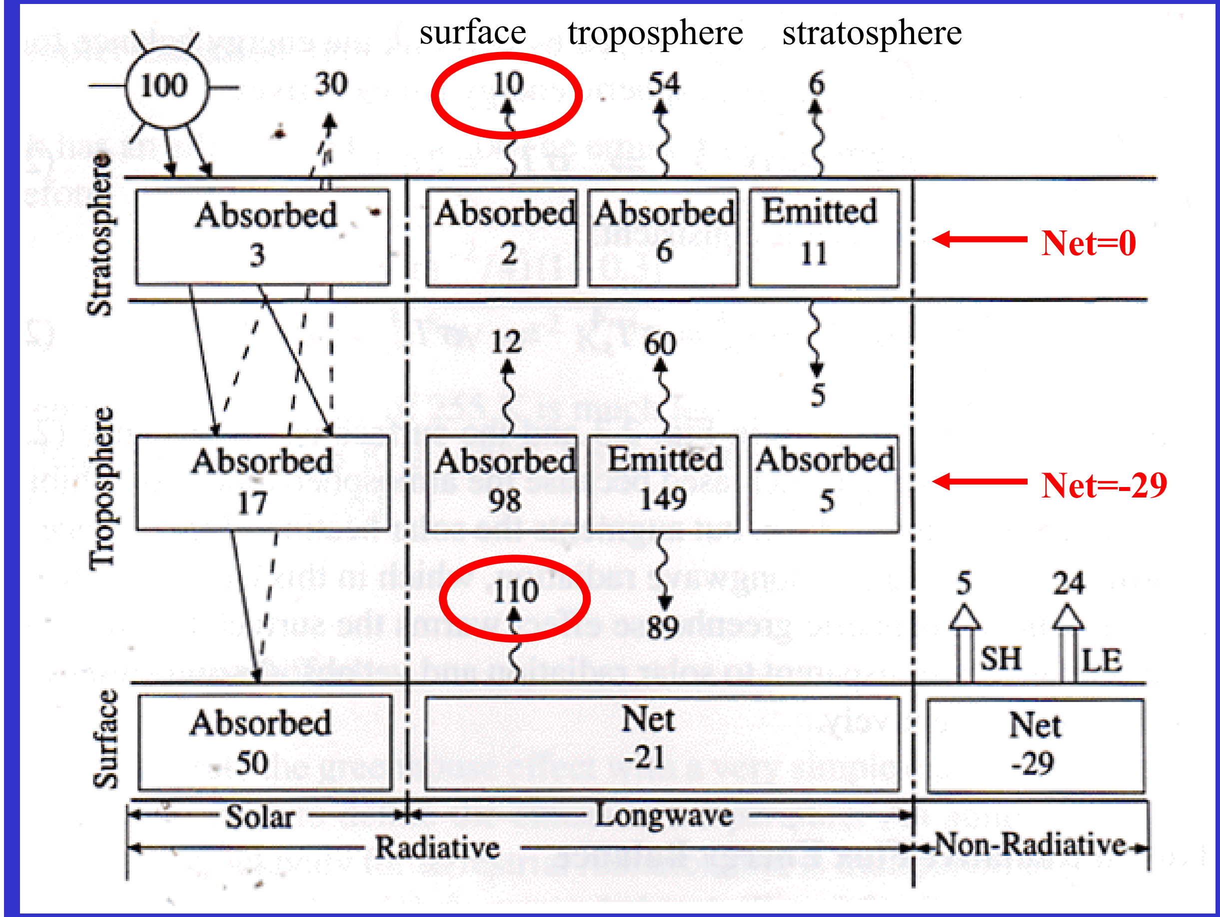
# Energy Required to Change the Levels




- ❑ The most energetic photons (with shortest wavelength) are at the top of the figure, toward the bottom, energy level decreases, and wavelengths increase.

(from *Is The Temperature Rising?*)

# Vertical Distribution of Energy




(from *Global Physical Climatology*)

**Incoming solar energy (100)**

- 70% absorbed

  50% by Earth's surface

  20% by atmosphere

  3% in stratosphere (by ozone and $O_2$)

  17% in troposphere (water vapor & cloud)

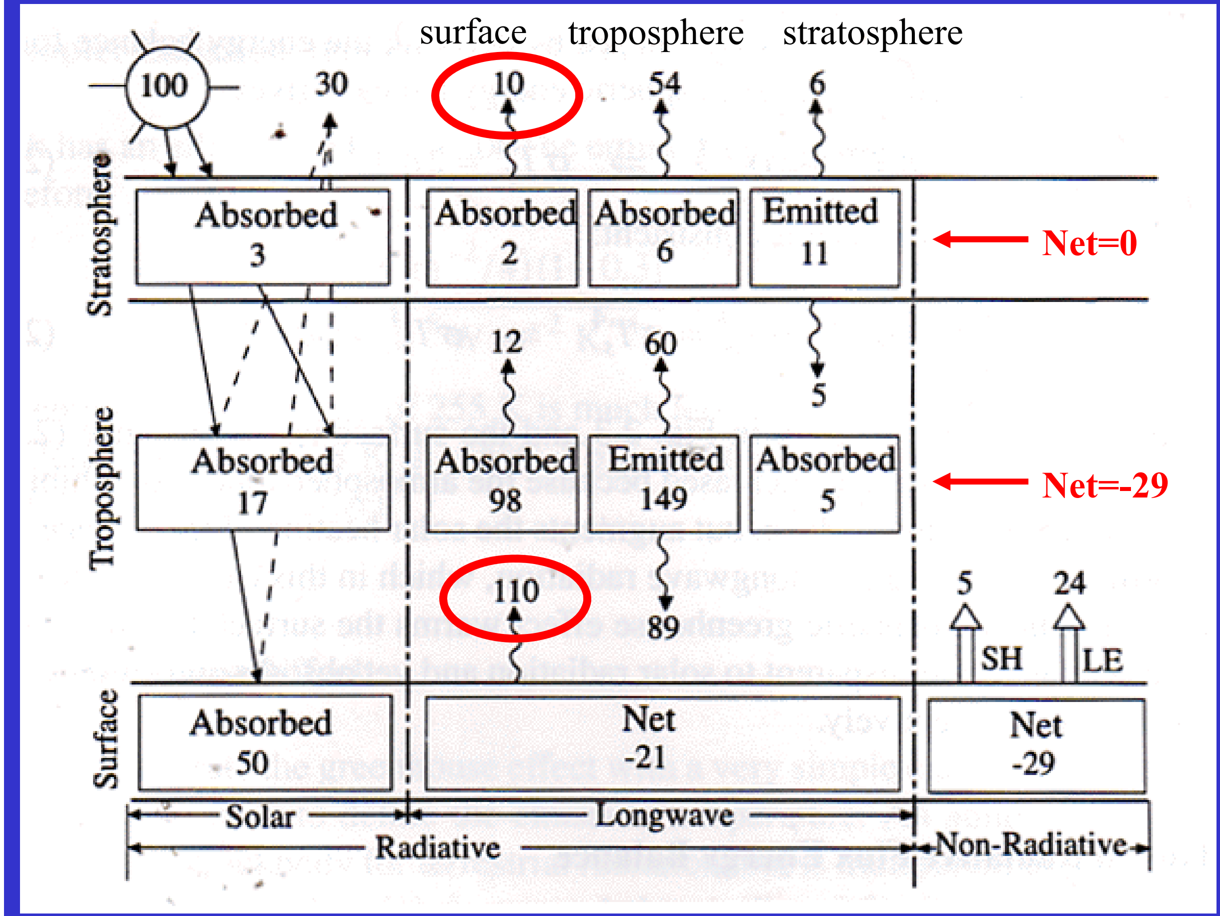
- 30% reflected/scattered back

  20% by clouds

  6% by the atmosphere

  4% by surface

# Vertical Distribution of Energy




(from *Global Physical Climatology*)

**Outgoing radiation (70 units)**

- 10 units by the surface
- 60 units by the atmosphere

  54 units by troposphere

  6 units by stratosphere

- Greenhouse effect (89 units) from the atmosphere back to the surface

- Water vapor and cloud provide 80% of the greenhouse effect

# Greenhouse Effect and Diurnal Cycle

- The very strong downward emission of terrestrial radiation from the atmosphere is crucial to maintain the relatively small diurnal variation of surface temperature.
- If this large downward radiation is not larger than solar heating of the surface, the surface temperature would warm rapidly during the day and cool rapidly at the night.

  → a large diurnal variation of surface temperature.
- The greenhouse effect not only keeps Earth's surface warm but also limit the amplitude of the diurnal temperature variation at the surface.

# Important Roles of Clouds In Global Climate

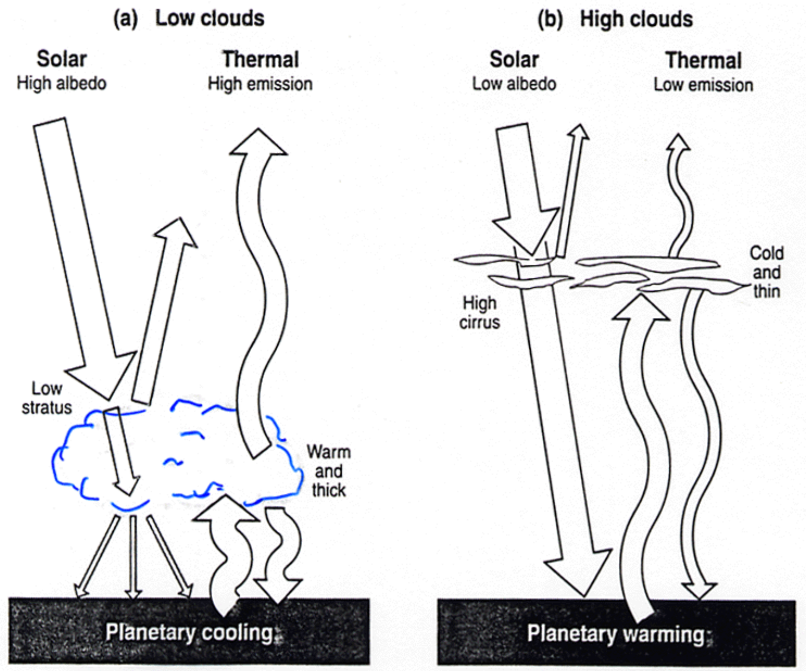
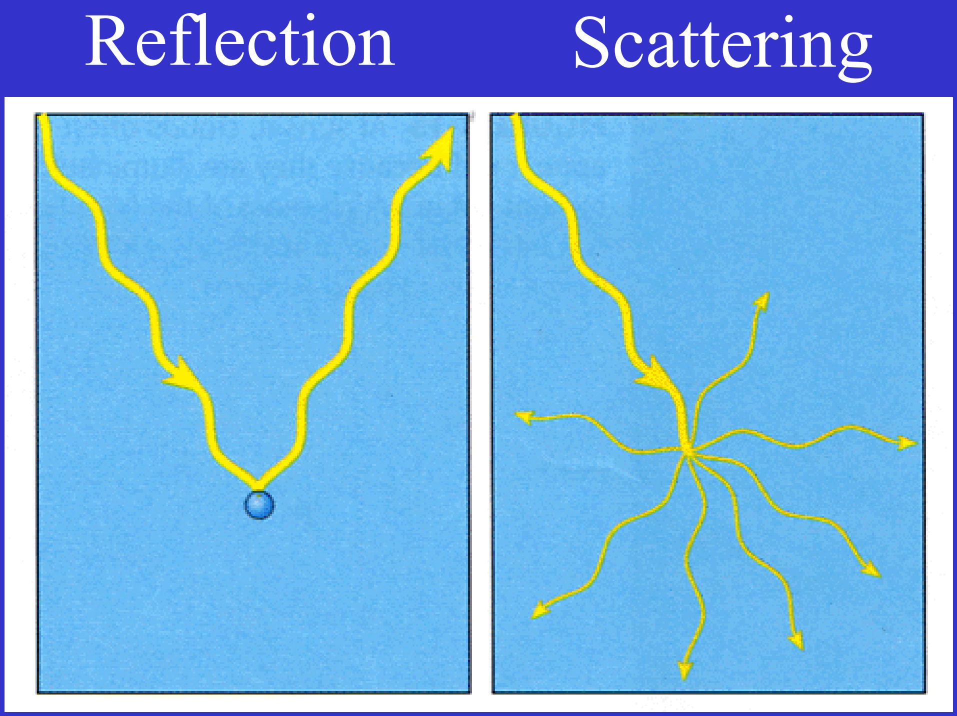



Figure 11.13 The effects of clouds on the flow of radiation and energy in the lower atmosphere and at the surface. Two cases are shown: (a) low clouds, with a high solar albedo and high thermal emission temperature; and (b) high clouds, with a low solar albedo and low thermal emission temperature. The solar components are shown as straight arrows, and the infrared components, as curved arrows. The relative thicknesses of the arrows indicate the relative radiation intensities. The expected impact on surface temperature in each situation is noted along the bottom strip.

# Atmospheric Influences on Insolation

- Absorption
  - convert insolation to heat the atmosphere
- Reflection / Scattering
  - change the direction and intensity of insolation
- Transmission
  - no change on the direction and intensity of insolation

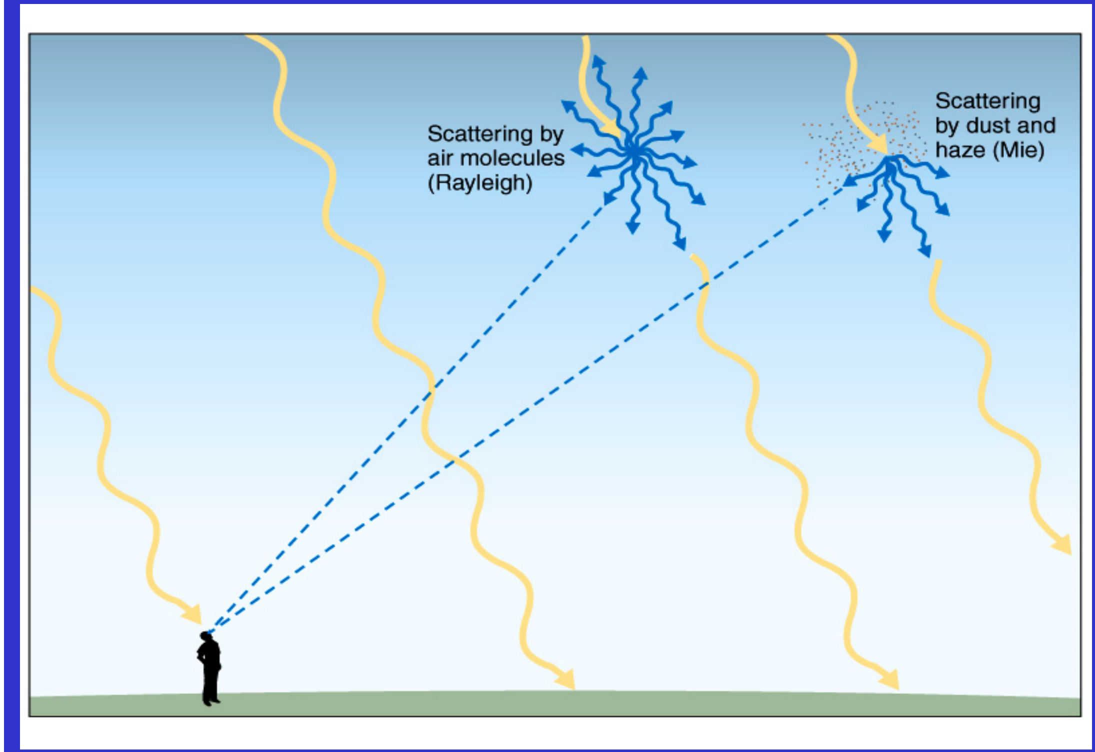
# Reflection and Scattering




(from *The Atmosphere*)

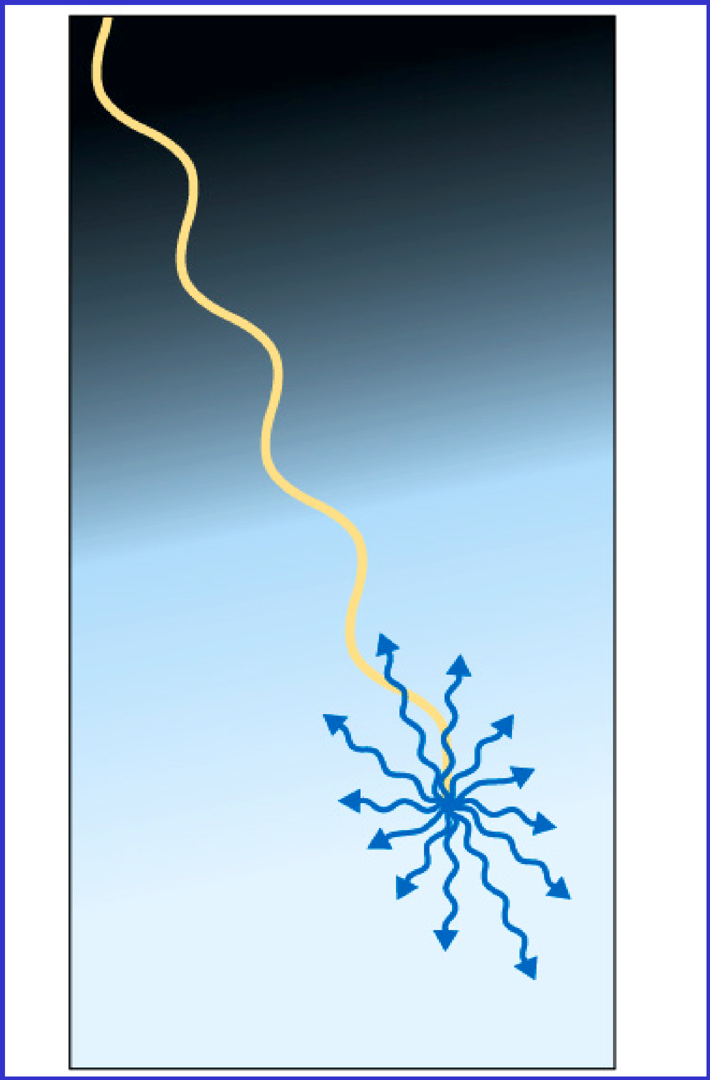
- Reflection: light bounces back from an objective at the same angle at which it encounters a surface and with the same intensity.
- Scattering: light is split into a larger number of rays, traveling in different directions.
- Although scattering disperses light both forward and backward (backscattering), more energy is dispersed in the forward direction.

# Scattering



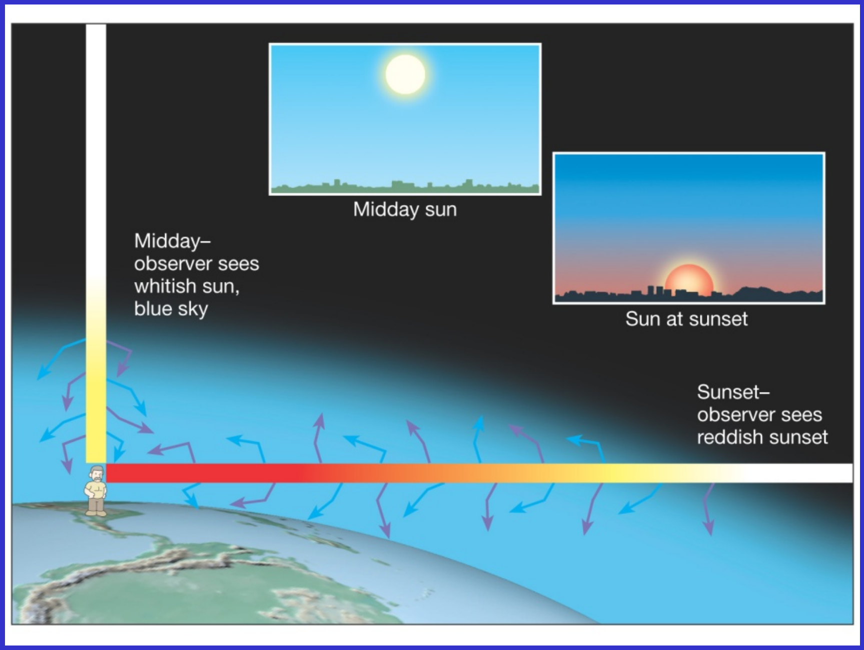

- ❑ Scattering is a process whereby a beam of radiation is broken down into many weaker rays redirected in other direction.
- ❑ Gases in the atmosphere effectively scatter radiation.
- ❑ Characteristics of scattering are dependent upon the size of the scattering agents: (1) Rayleigh Scattering, (2) Mie Scattering, (3) nonselective Scattering.

# Rayleigh Scattering (Gas Molecules)



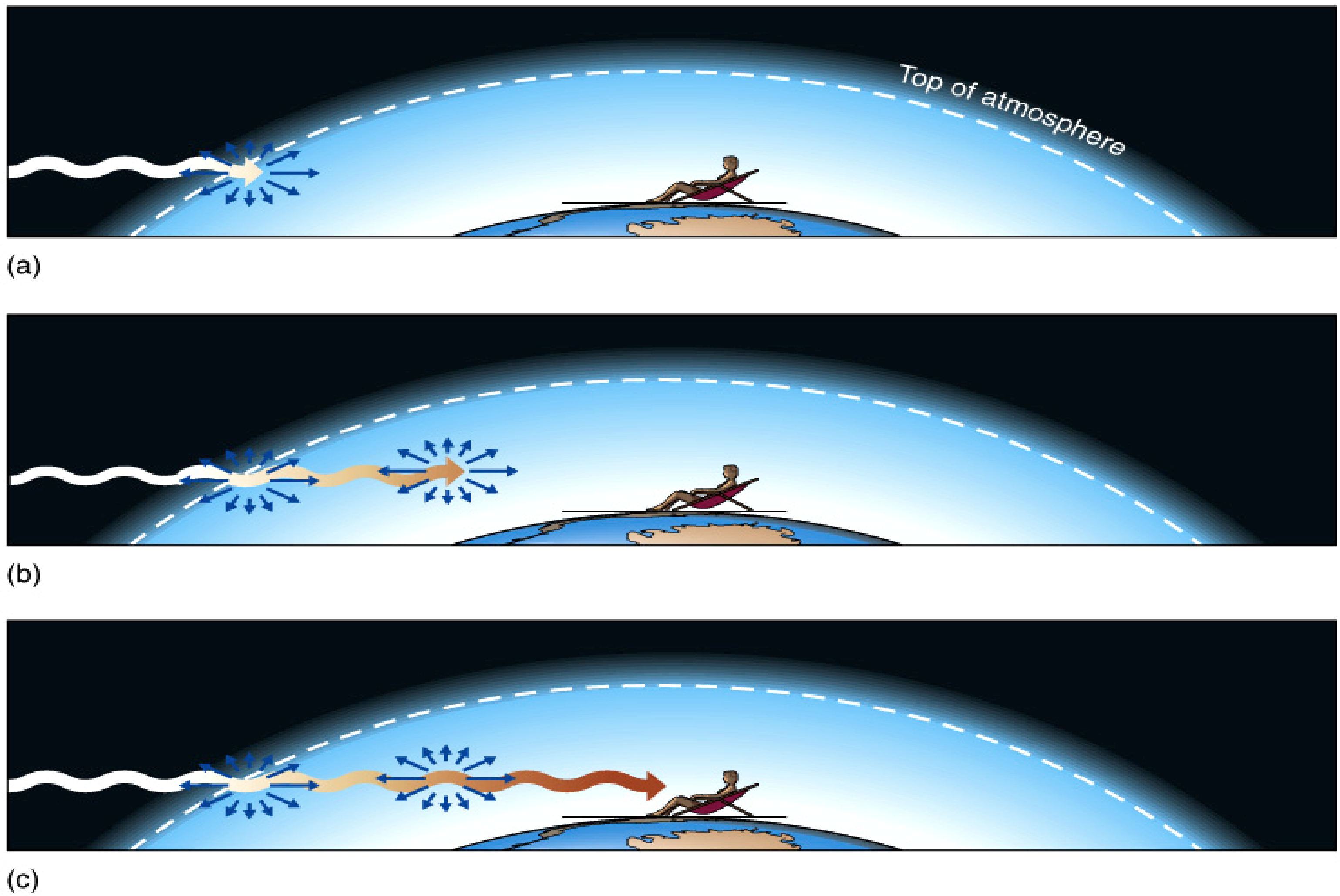
- Involves gases, or other scattering agents that are smaller than the energy wavelengths.
- Scatter energy forward and backward.
- Violet and blue are scattered the most, up to 16 times more than red light.
- Responsible for (1) blue sky in clear days, (2) blue tint of the atmosphere when viewed from space, (3) why sunsets/sunrises are often yellow, orange, and red.

# Scattering and Colors

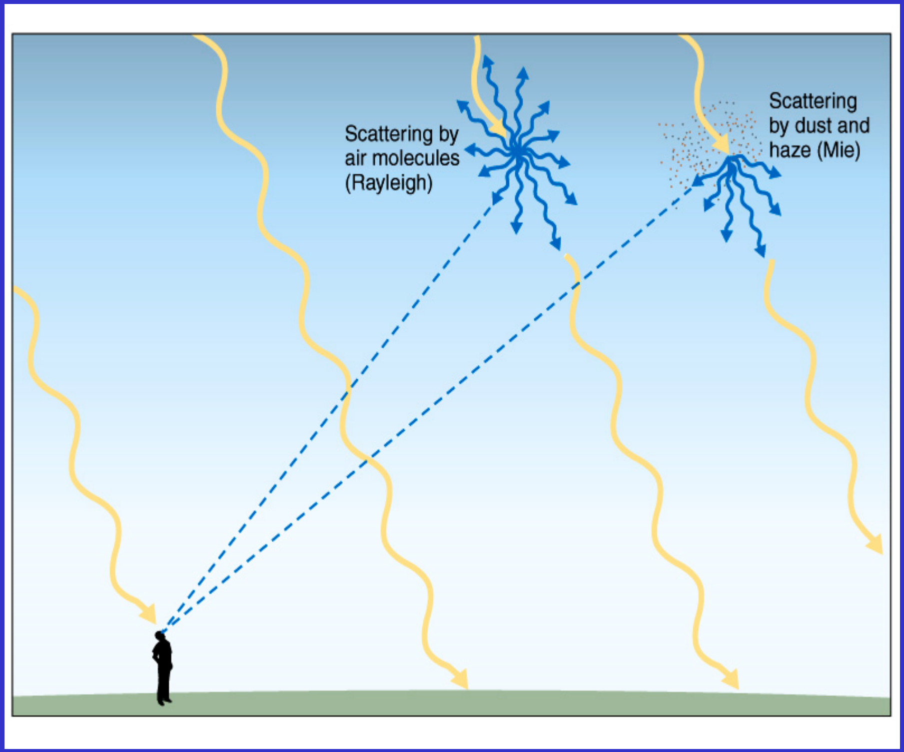



- Short wavelengths (blue and violet) of visible light are scattered more effectively than longer wavelengths (red, orange). Therefore, when the Sun is overhead, an observer can look in any direction and see predominantly blue light that was selectively scattered by the gases in the atmosphere.
- At sunset, the path of light must take through the atmosphere is much longer. Most of the blue light is scattered before it reaches an observer. Thus the Sun appears reddish in color.

# Rayleigh Scattering Causes the redness of sunsets and sunrises



# Mie Scattering (Aerosols)




- ❑ Larger scattering agents, such as suspended aerosols, scatter energy only in a ***forward*** manner.
- ❑ Larger particles interact with wavelengths across the visible spectrum (instead of just interacting with short/blue colors).
- ❑ Produces hazy or grayish skies.

- ❑ When the atmosphere becomes loaded with particles (aerosols) during sunset/sunrise, only the longest red wavelengths are able to penetrate the atmosphere, and we see a red sun.
- ❑ Enhances longer wavelengths during sunrises and sunsets, indicative of a rather aerosol laden atmosphere.

# Nonselective Scattering (Clouds)

- Water droplets in clouds, typically larger than energy wavelengths, equally scatter wavelengths along the visible portion of the spectrum.
- Produces a white or gray appearance.
- No wavelength is especially affected.

# *Lecture 3: Temperature*

- Heat and Temperature
- Seasonal Cycle
- Latitudinal Variations
- Diurnal Cycle
- Measurements of Temperature

# Seasonal and Latitudinal Variations

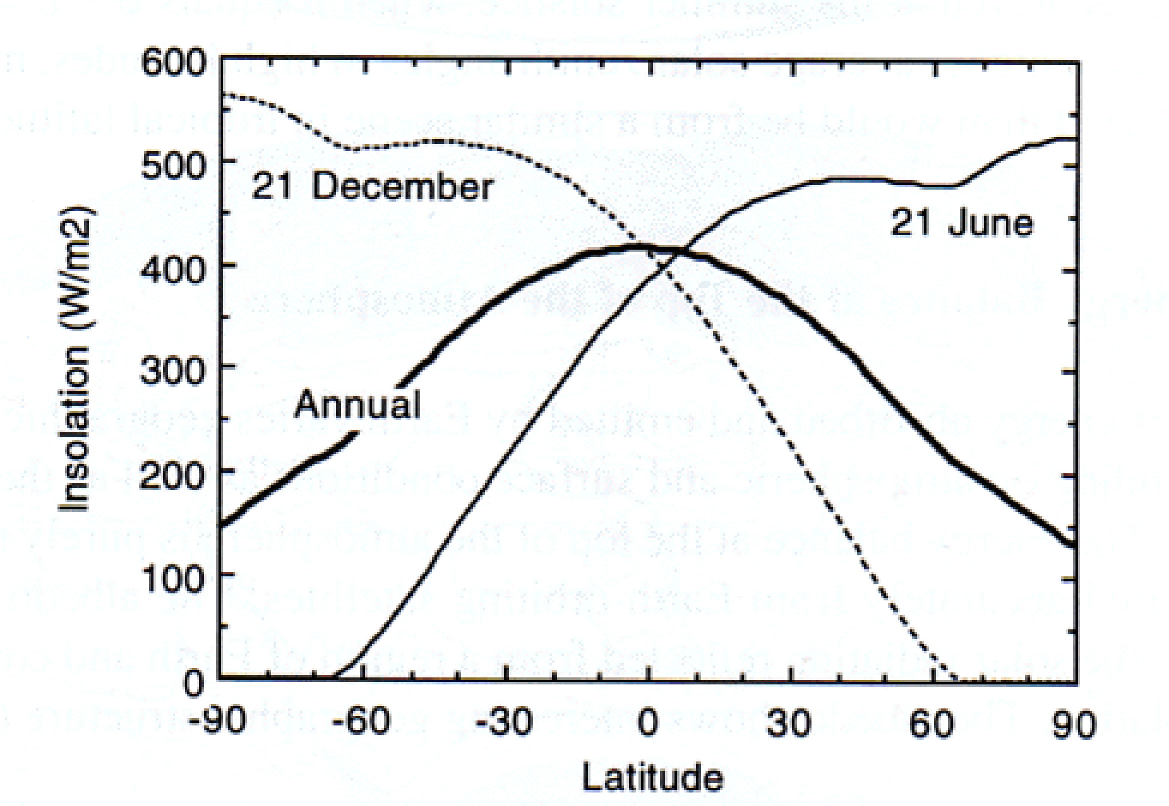
- The amount of energy absorbed and emitted by Earth changes geographically and seasonally.

- **Seasonal variations:** the angle of inclination is responsible for the seasonal variation in the amount of solar energy distributed at the top of the atmosphere.

- **Latitudinal variations:** the variations of solar energy in latitude is caused by changes in:

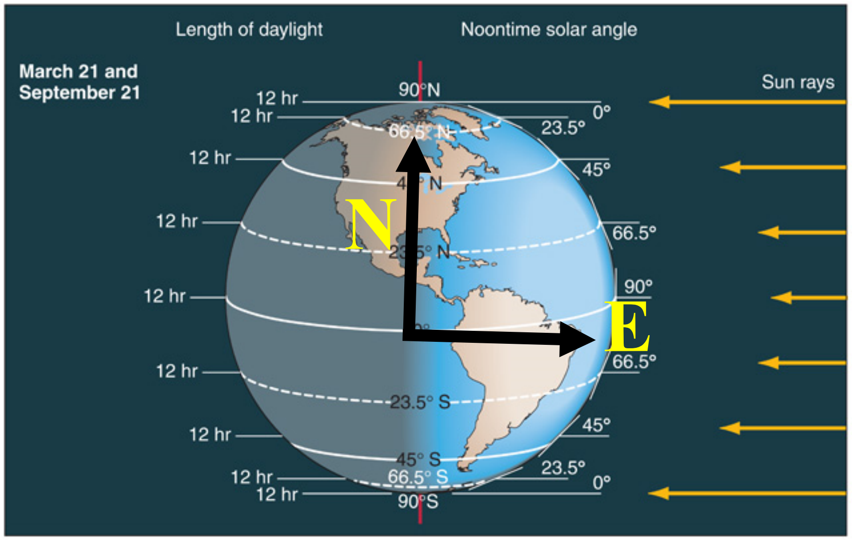
  (a) the angle the sun hits Earth's surface = solar zenith angle
  (b) the number of day light hours
  (c) albedo

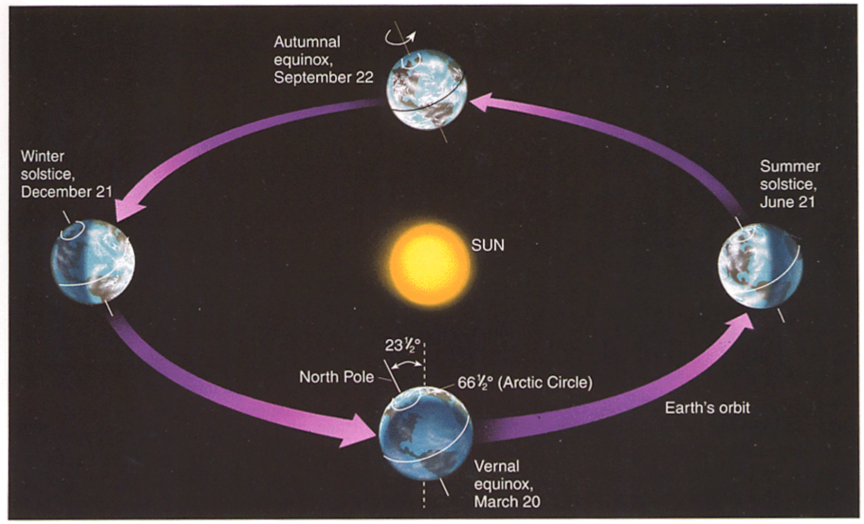
# Insolation at Top of Atmosphere

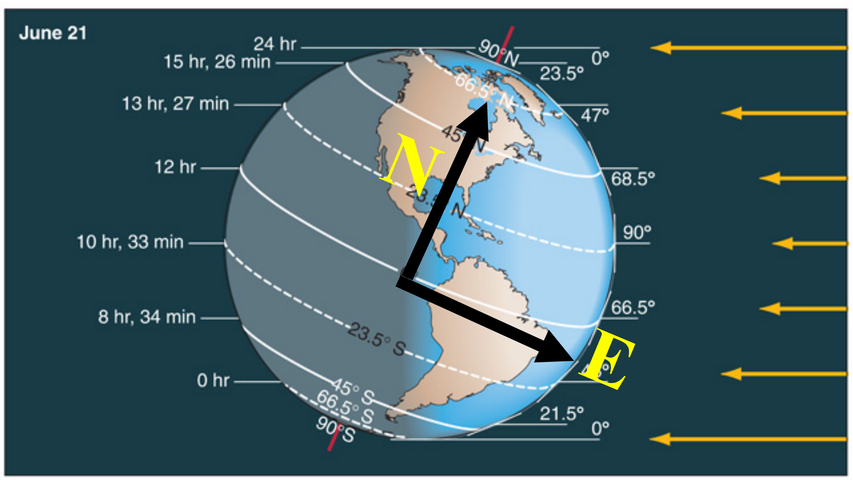


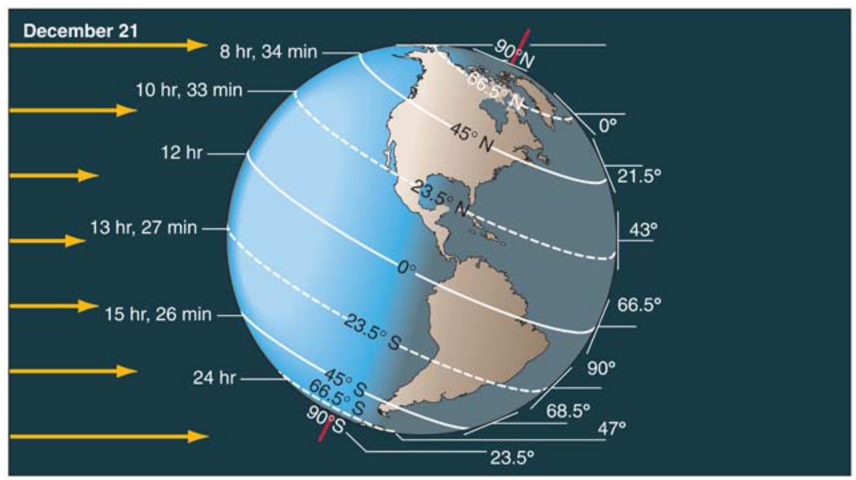

(from *Global Physical Climatology*)

# Length of Day



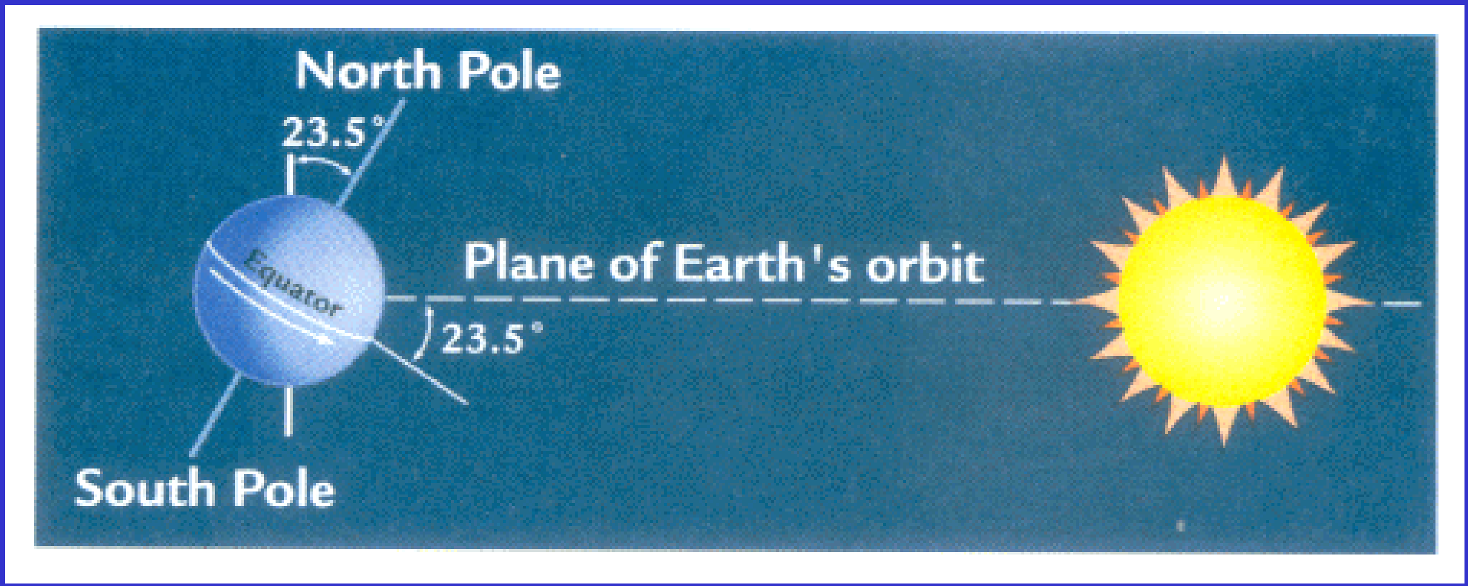




(from *Understanding Weather & Climate* and *Meteorology Today*)

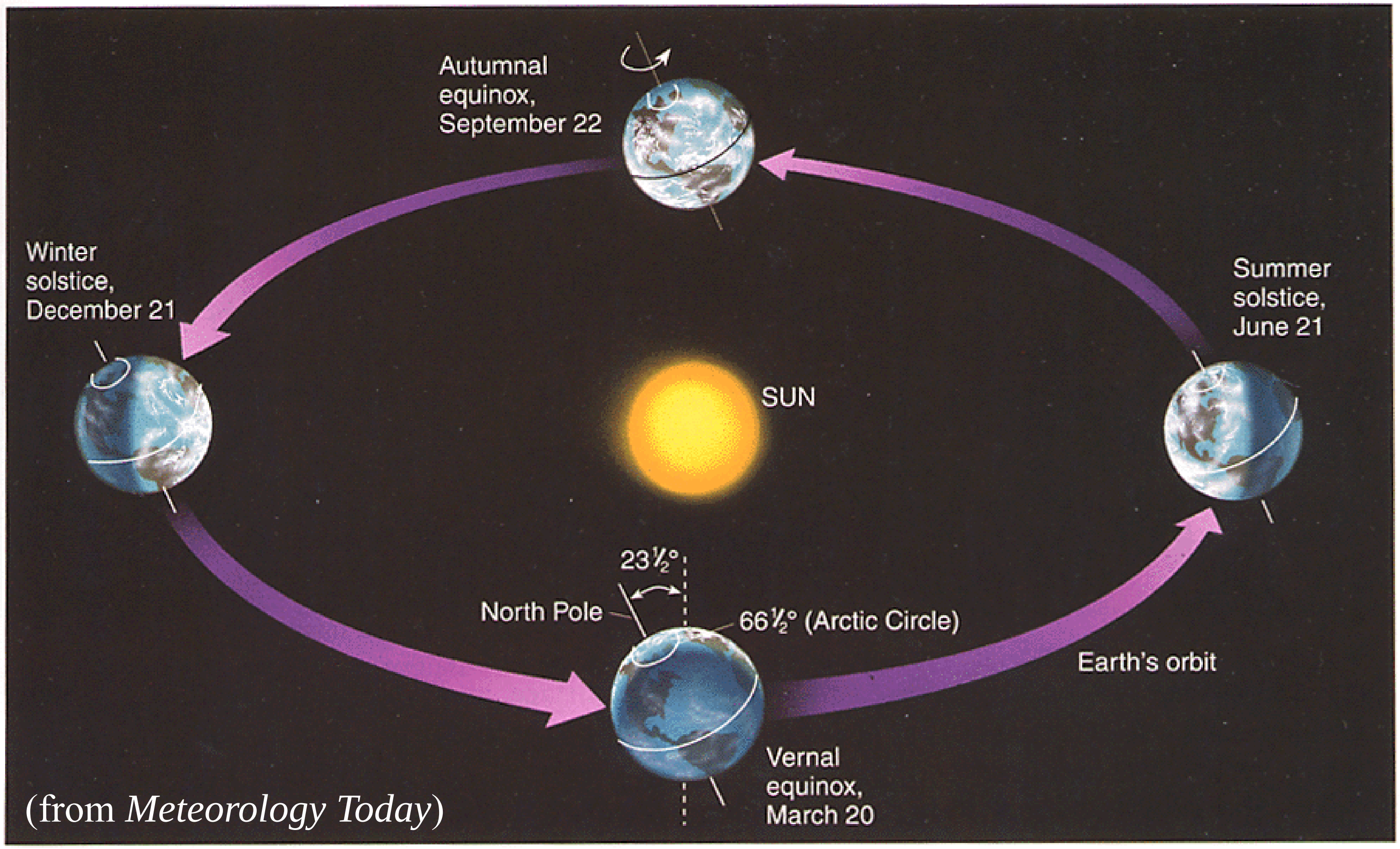
# Angle of Inclination = the Tilt




(from *Earth's Climate: Past and Future*)

- At present-day, the axis is tilted at an angle of 23.5°, referred to as Earth's "obliquity", or "tilt".
- The Sun moves back and forth through the year between 23.5°N and 23.5°S.
- Earth's 23.5° tilt also defines the 66.5° latitude of the Artic and Antarctic circles. No sunlight reaches latitudes higher than this in winter day.
- The tilt produces ***seasons***!!

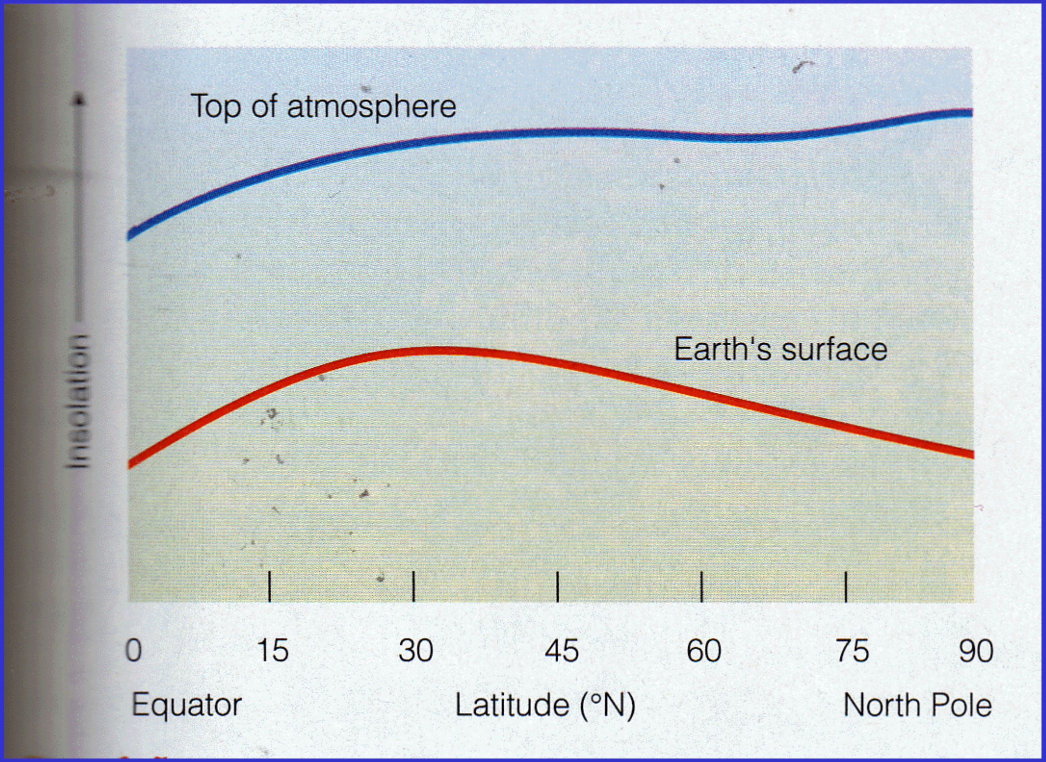
# Seasons and the Elliptical Orbit




(from *Meteorology Today*)

- Solstices: mark the longest and shortest days of the years (June 21 and December 21 in the northern hemisphere, the reverse in the southern hemisphere)
- Equinoxes: the length of night and day become equal in each hemisphere.

# Insolation in Summer Solstice



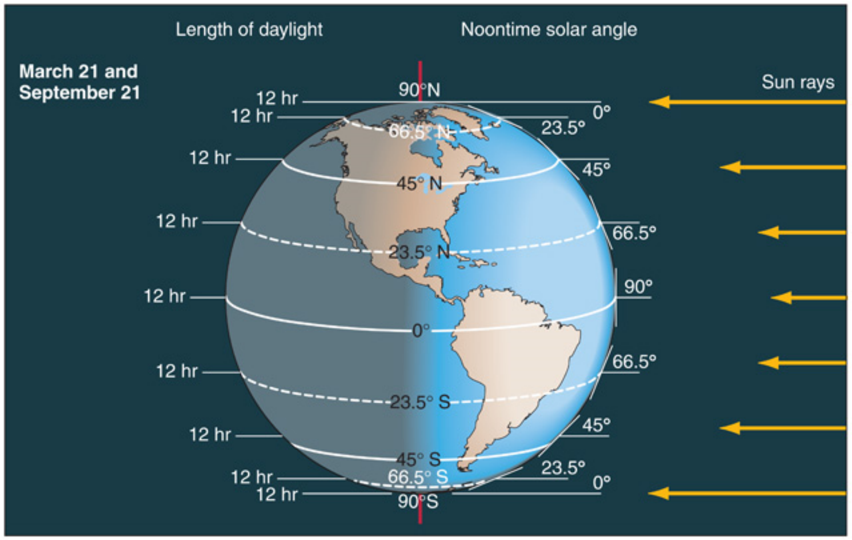

(from *Meteorology Today*)

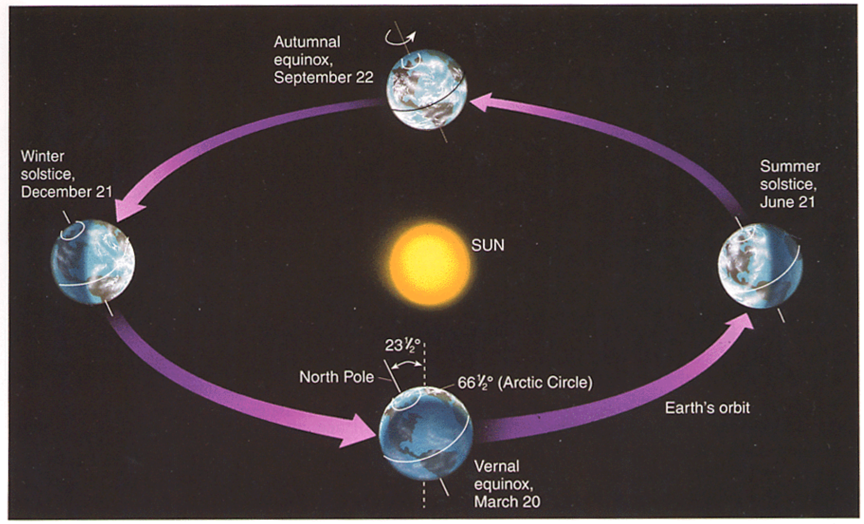
# Latitudinal Variations

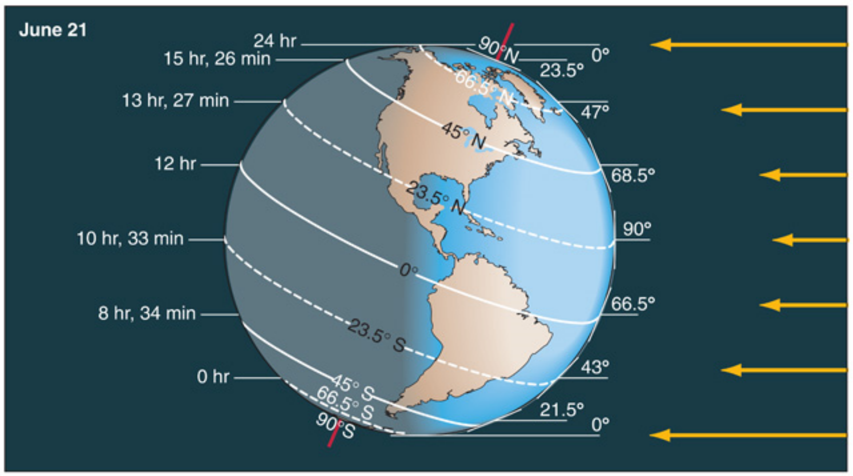
- **Latitudinal variations:** the variations of solar energy in latitude is caused by changes in:

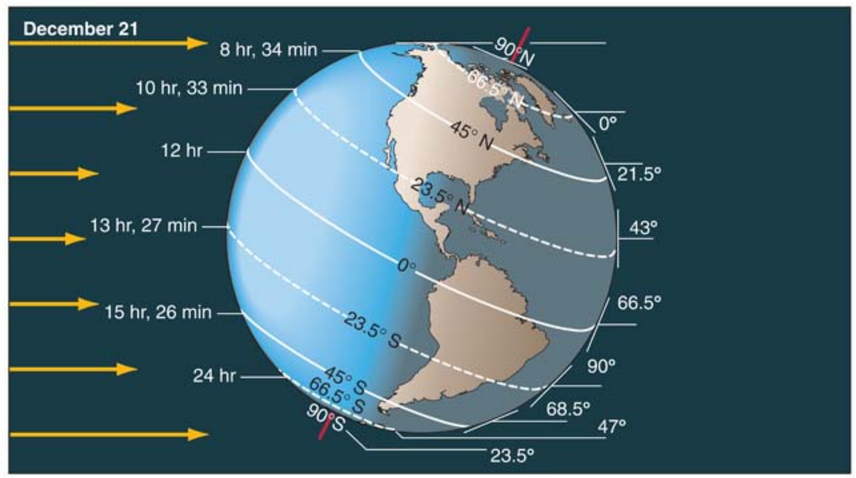
  (a) the number of day light hours
  (b) the angle the sun hits Earth's surface = solar zenith angle
  (c) albedo

# Length of Day




(from *Understanding Weather & Climate* and *Meteorology Today*)

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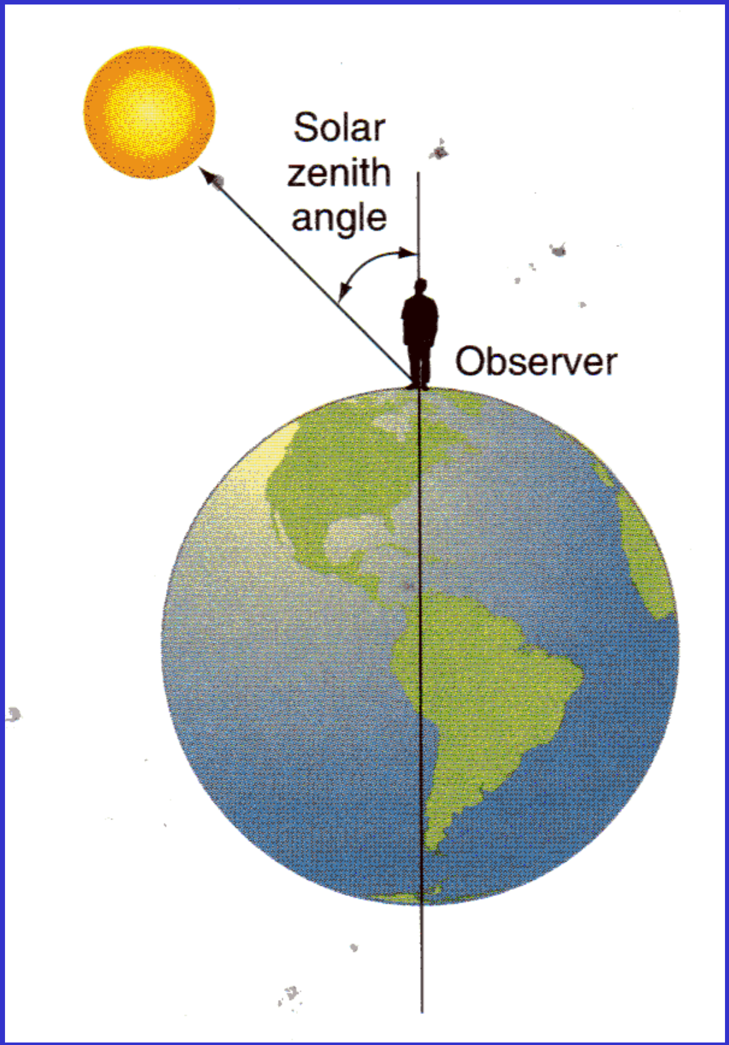
# Solar Zenith Angle

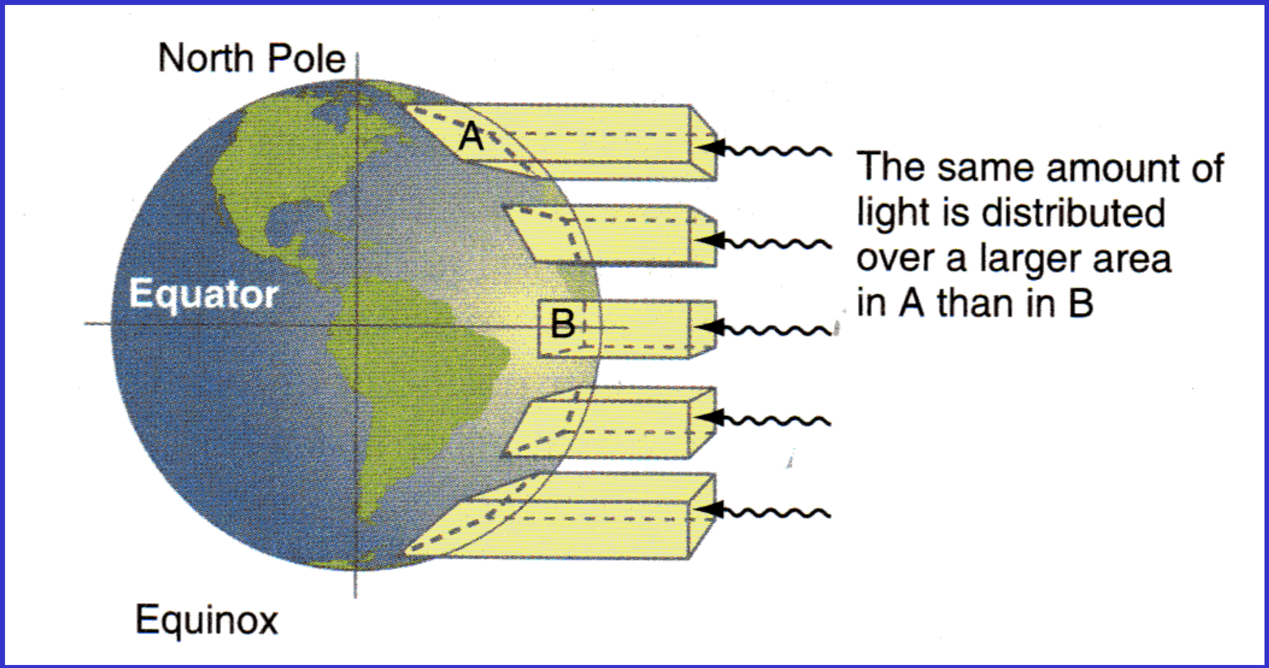



(from *Meteorology: Understanding the Atmosphere*)

- Solar zenith angle is the angle at which the sunlight strikes a particular location on Earth.

- This angle is 0° when the sun is directly overhead and increase as sun sets and reaches 90 ° when the sun is on the horizon.

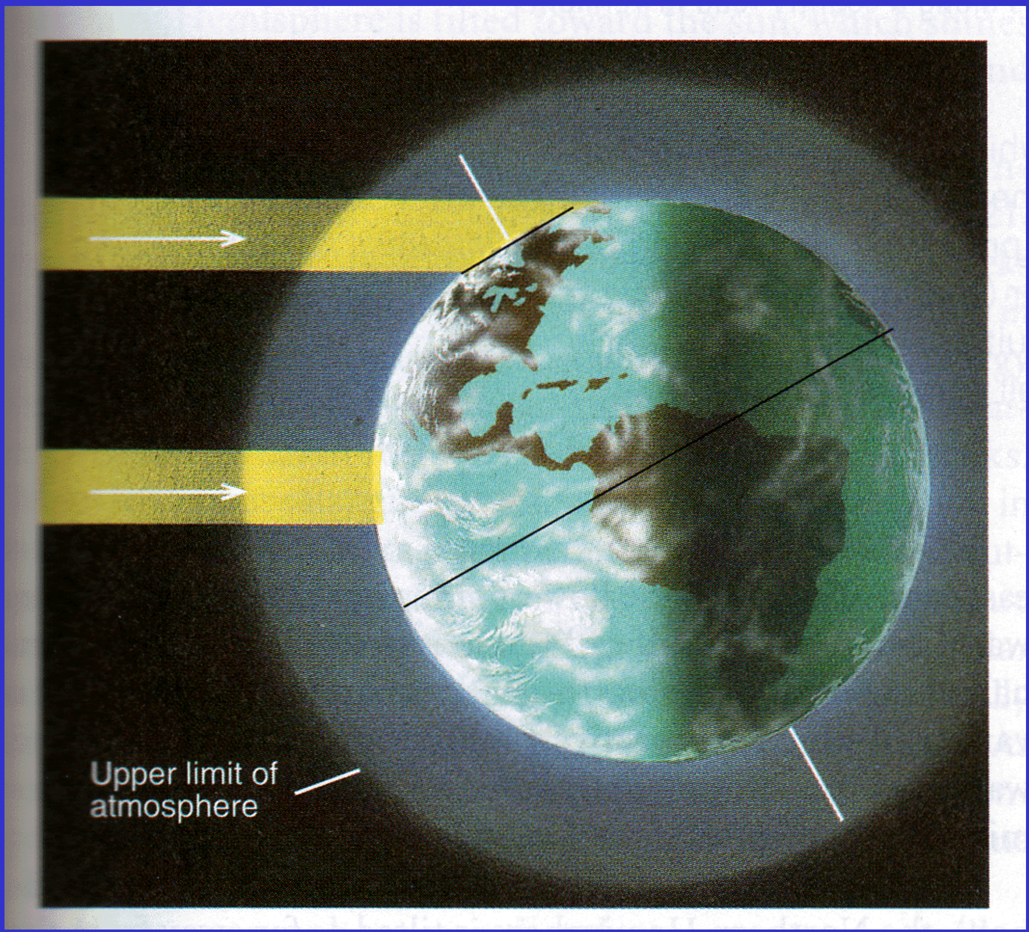
# Zenith Angle and Insolation




(from *Meteorology: Understanding the Atmosphere*)

- The larger the solar zenith angle, the weaker the insolation, because the same amount of sunlight has to be spread over a larger area.

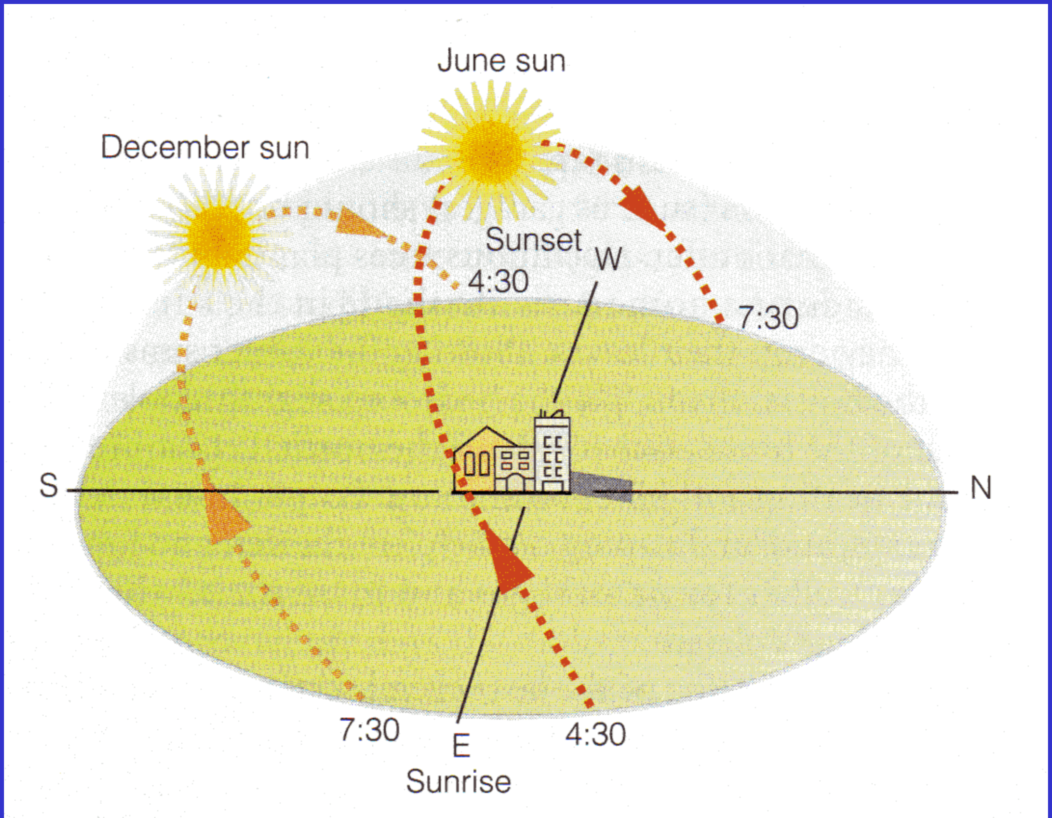
# Solar Zenith Angle Affects Albedo




(from *Meteorology Today*)

- The larger the solar zenith angle, the larger the albedo.
- When the zenith angle is large, sunlight has to pass through a thicker layer of the atmosphere before it reaches the surface.
- The thinker the atmospheric layer, more sunlight can be reflected or scattered back to the space.

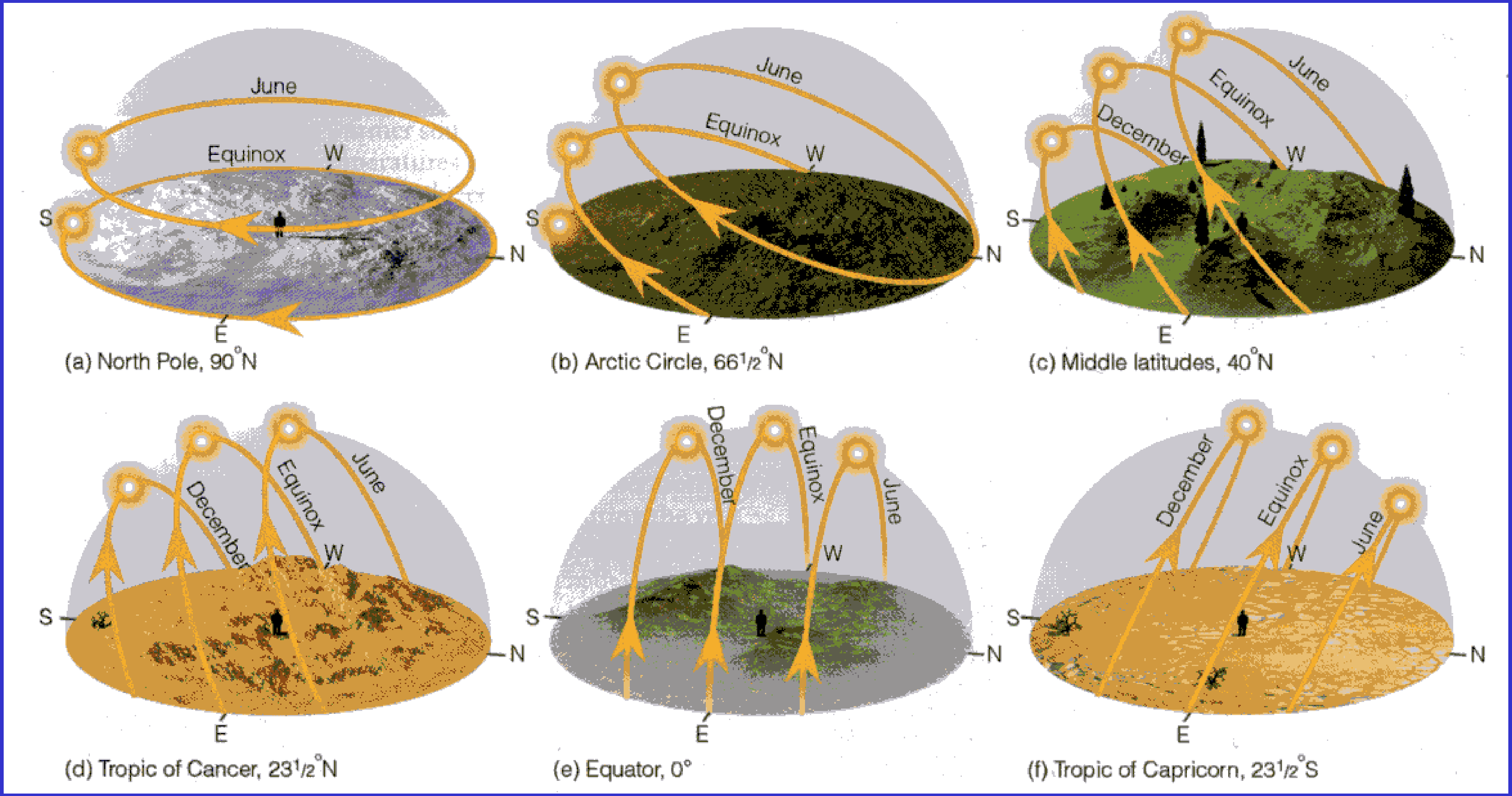
# What Determine Zenith Angle?




(from *Meteorology Today*)

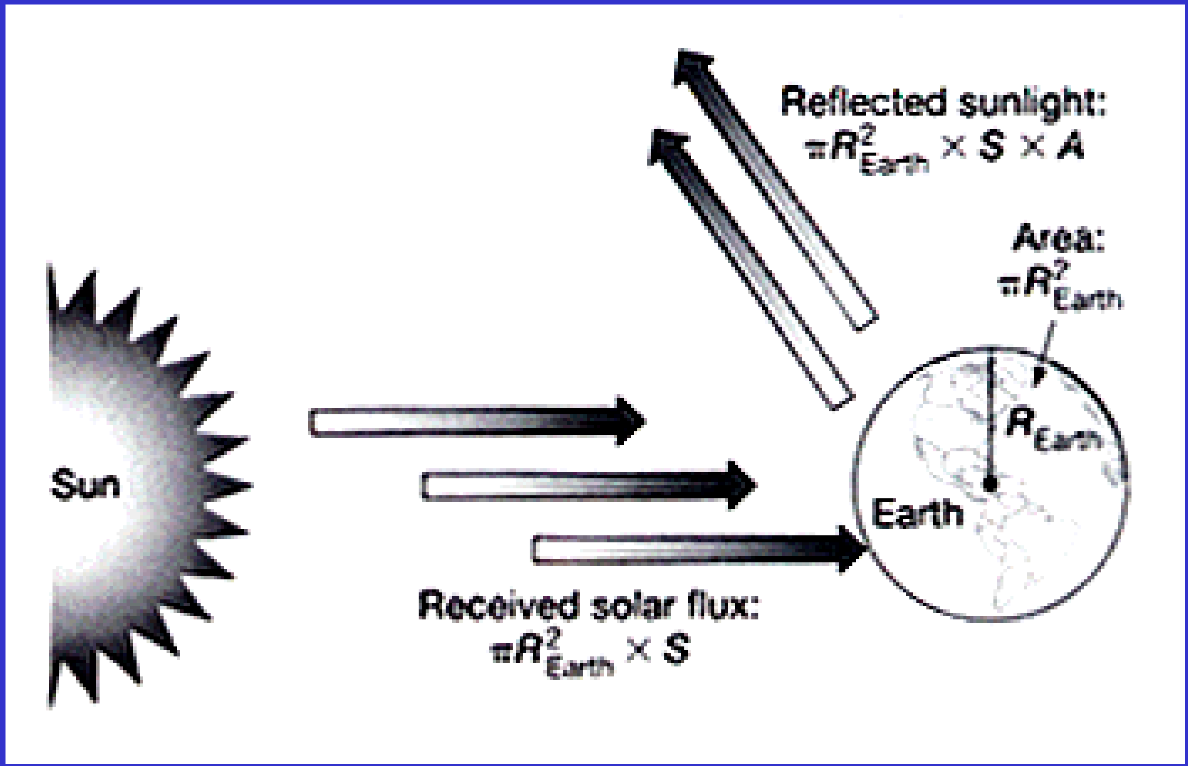
- The solar zenith angle is a function of time of day, time of year, and latitude.

# Sun in the Sky




(from *Meteorology Today*)

# Albedo = [Reflected] / [Incoming] Sunlight




Albedo is the percentage of the sunlight that is reflected back to the space by the planet.

# Surface Types Affect Albedo

**TABLE 2-1 Average Albedo Range of Earth's Surfaces**

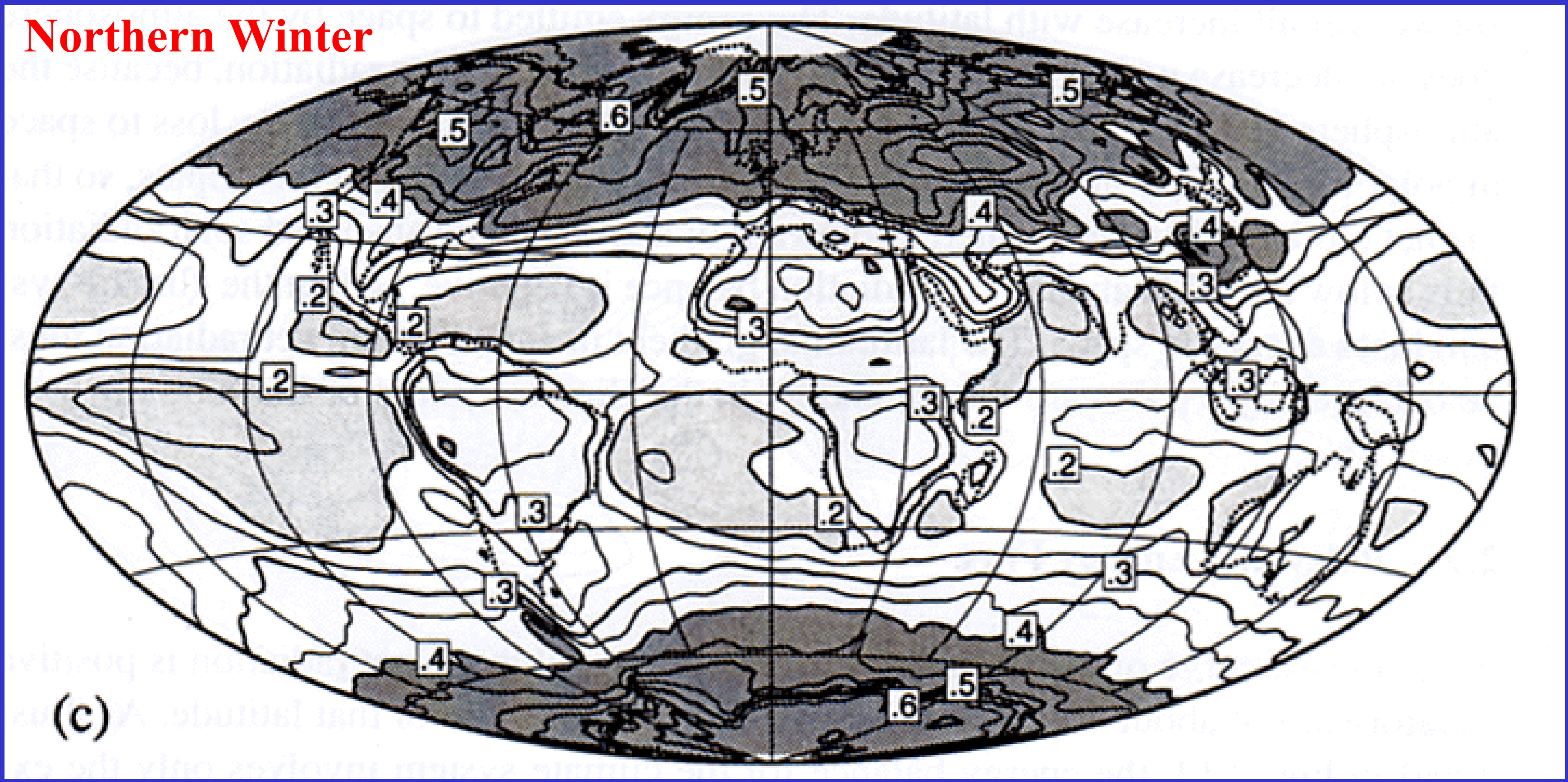
| Surface | Albedo range (percent) |
|---|---|
| Fresh snow or ice | 60–90% |
| Old, melting snow | 40–70 |
| Clouds | 40–90 |
| Desert sand | 30–50 |
| Soil | 5–30 |
| Tundra | 15–35 |
| Grasslands | 18–25 |
| Forest | 5–20 |
| Water | 5–10 |

*Adapted from W. D. Sellers,* Physical Climatology *(Chicago: University of Chicago Press, 1965), and from R. G. Barry and R. J. Chorley,* Atmosphere, Weather, and Climate, *4th ed. (New York: Methuen, 1982).*

(from *Earth's Climate: Past and Future*)

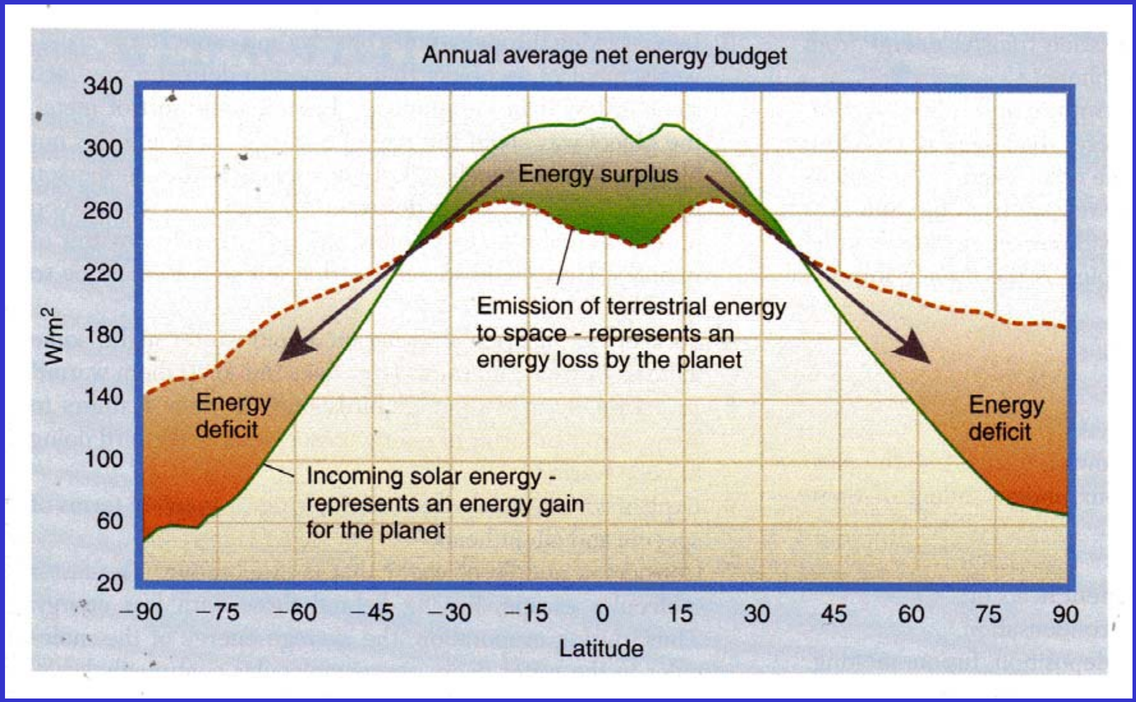
The brighter a color, the more it reflects sunlight.

# Global Distribution of Albedo




(from *Global Physical Climatology*)

# Latitudinal Variations of Net Energy

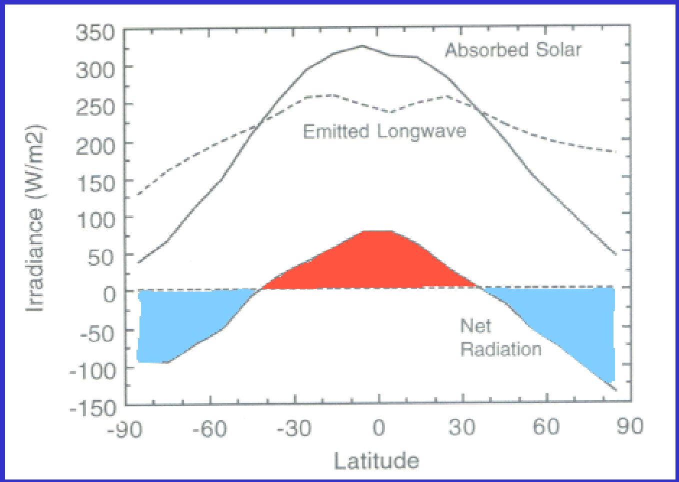



(from *Meteorology: Understanding the Atmosphere*)

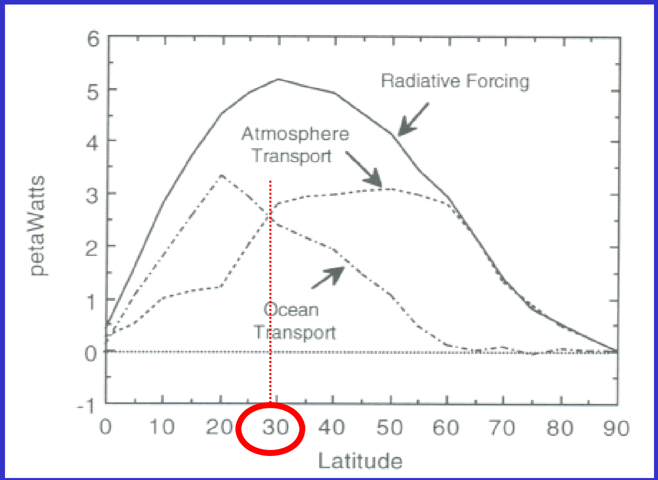
- Polarward heat flux is needed to transport radiation energy from the tropics to higher latitudes.

# Polarward Energy Transport

**Annual-Mean Radiative Energy**




**Polarward Heat Flux**




Polarward heat flux is needed to transport radiative energy from the tropics to higher latitudes

The atmosphere dominates the polarward heat transport at middle and high latitudes. The ocean dominates the transport at lower latitudes.

(figures from *Global Physical Climatology*)

**(1 petaWatts = $10^{15}$ W)**

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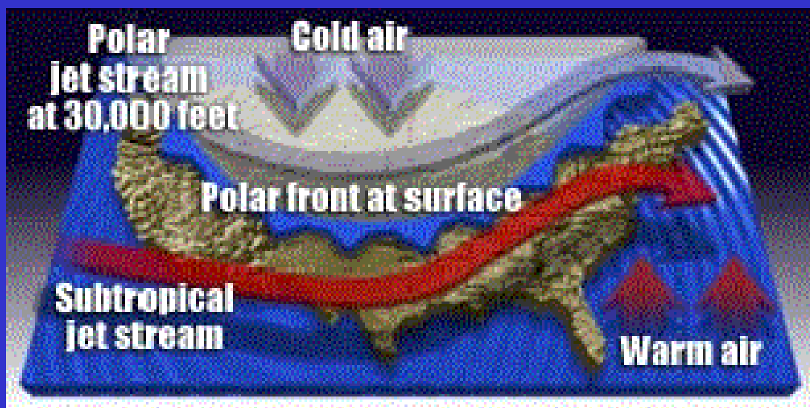
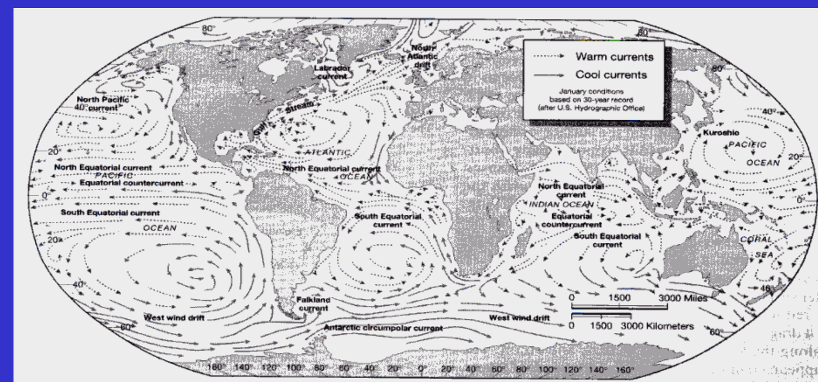
# How Do Atmosphere and Ocean Transport Heat?

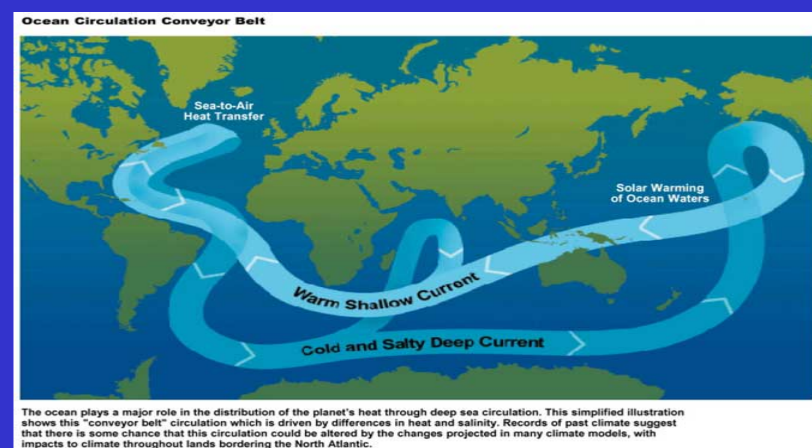
## Atmospheric Circulation



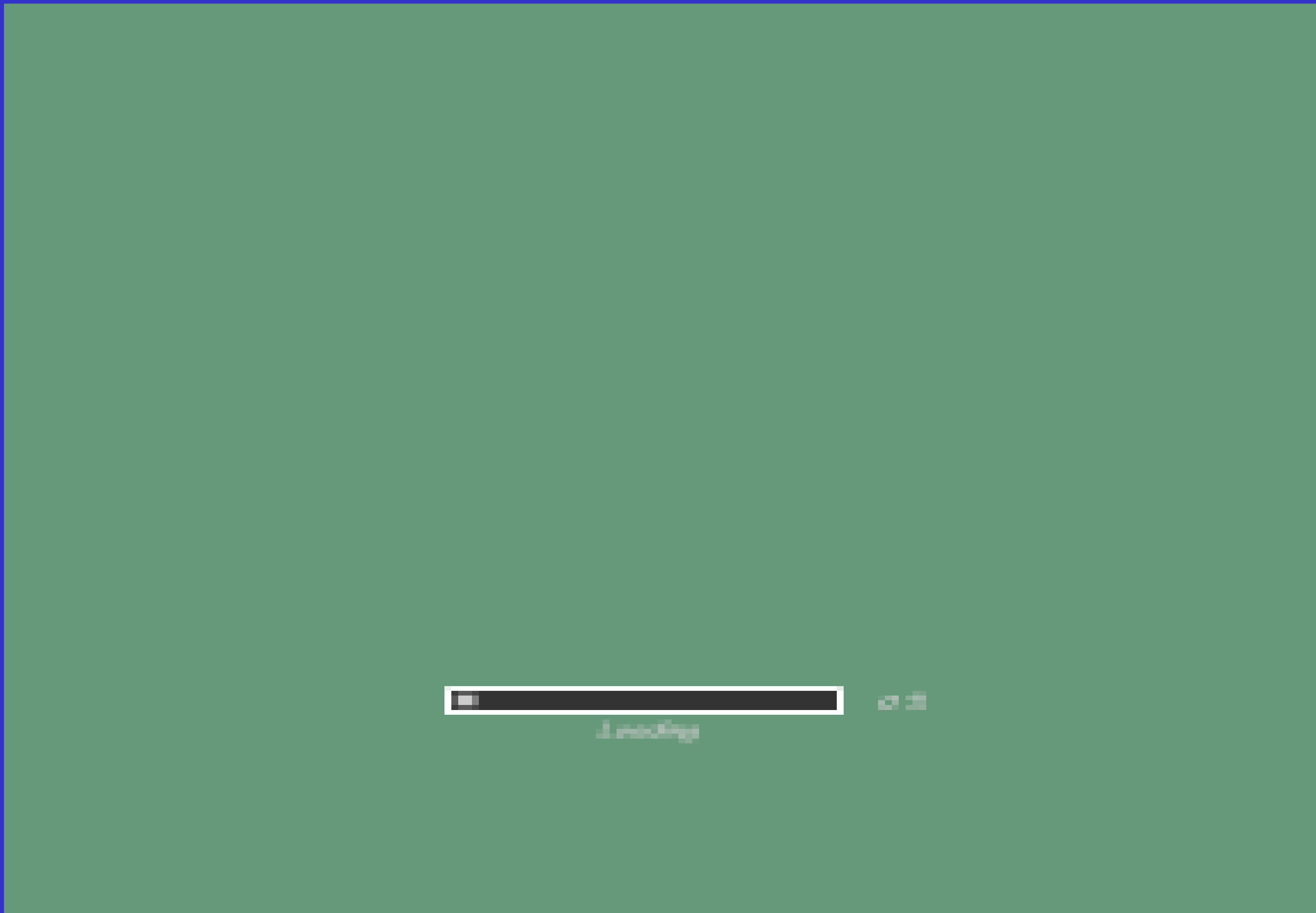

(from USA Today)

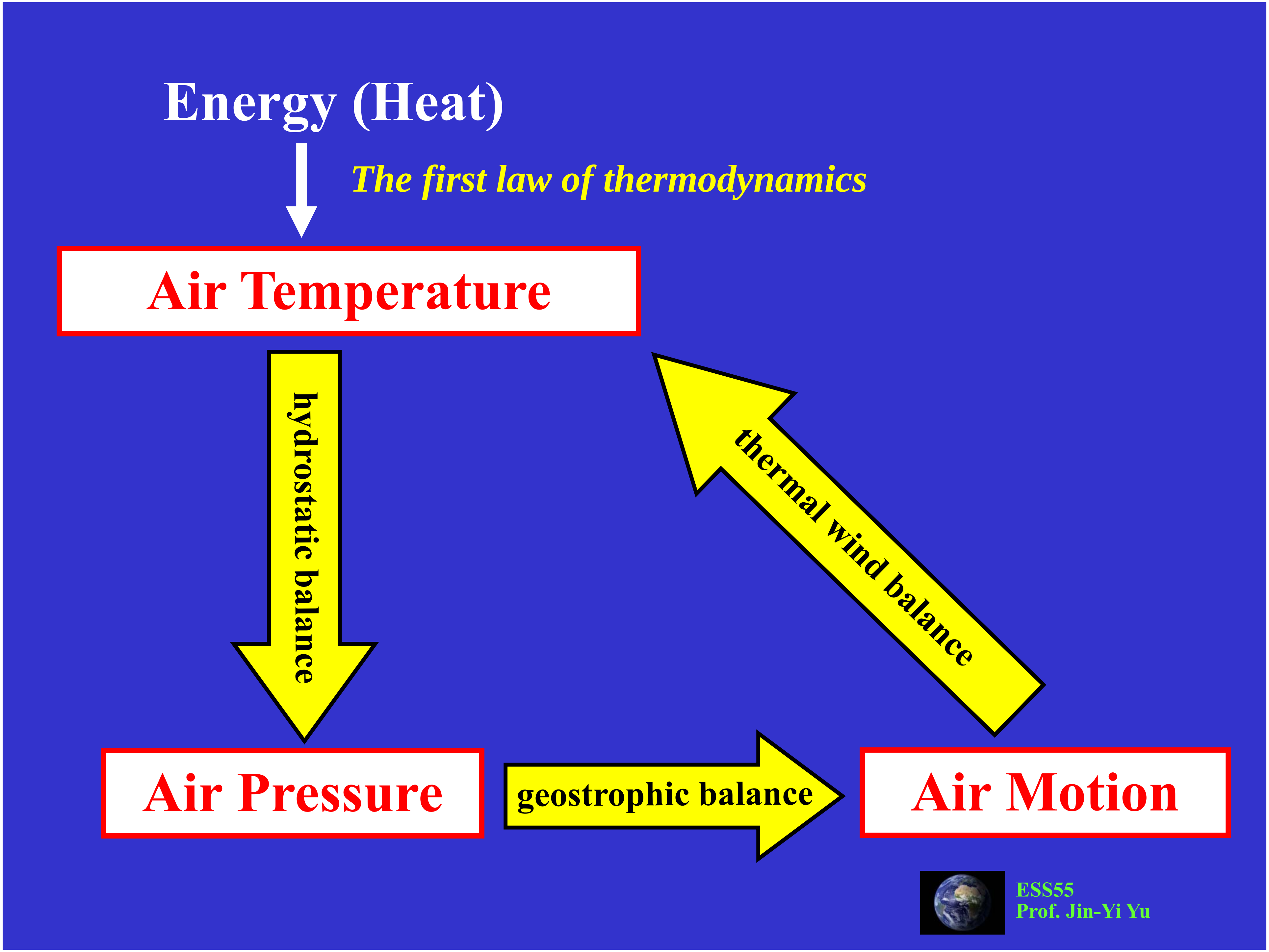
## Ocean Circulation




(top from *The Earth System*)
(bottom from USGCRP)





Energy (Heat)
The first law of thermodynamics
Air Temperature
hydrostatic balance
Air Pressure
geostrophic balance
Air Motion
thermal wind balance
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# The First Law of Thermodynamics

- This law states that (1) heat is a form of energy that (2) its conversion into other forms of energy is such that total energy is conserved.

- The change in the internal energy of a system is equal to the heat added to the system minus the work down by the system:

$$\Delta U = Q - W$$

change in internal energy (related to temperature)

Heat added to the system

Work done by the system

# Heat and Temperature

- Heat and temperature are both related to the internal kinetic energy of air molecules, and therefore can be related to each other in the following way:

$$Q = c*m*\Delta T$$

**Heat added** (Q)

**Mass** (m)

**Temperature changed** (ΔT)

**Specific heat** (c) **= the amount of heat per unit mass required to raise the temperature by one degree Celsius**

# Specific Heat

**TABLE 2.1** The Specific Heat of a Substance is the Amount of Heat Required to Increase the Temperature of One Gram of the Substance 1° C

| | *Specific Heat* | |
|---|---|---|
| *Substance* | *(cal/g/°C)* | *(J/kg/°C)* |
| Water | 1.0 | 4186 |
| Ice | 0.50 | 2093 |
| Air | 0.24 | 1005 |
| Sand | 0.19 | 795 |

(from *Meteorology: Understanding the Atmosphere*)

# How to Change Air Temperature?

- **Add (remove) heat to (from) the air parcel (diabatic processes)**

  (1) Conduction: requires touching

  (2) Convection: Hot air rises

  (3) Advection: horizontal movement of air

  (4) Radiation: exchanging heat with space

  (5) Latent heating: changing the phase of water

- **Without adding (removing) heat to (from) the air parcel**

  (1) Adiabatic Process: Expanding and compressing air

# The First Law of Thermodynamics

- This law states that (1) heat is a form of energy that (2) its conversion into other forms of energy is such that total energy is conserved.

- The change in the internal energy of a system is equal to the heat added to the system minus the work down by the system:

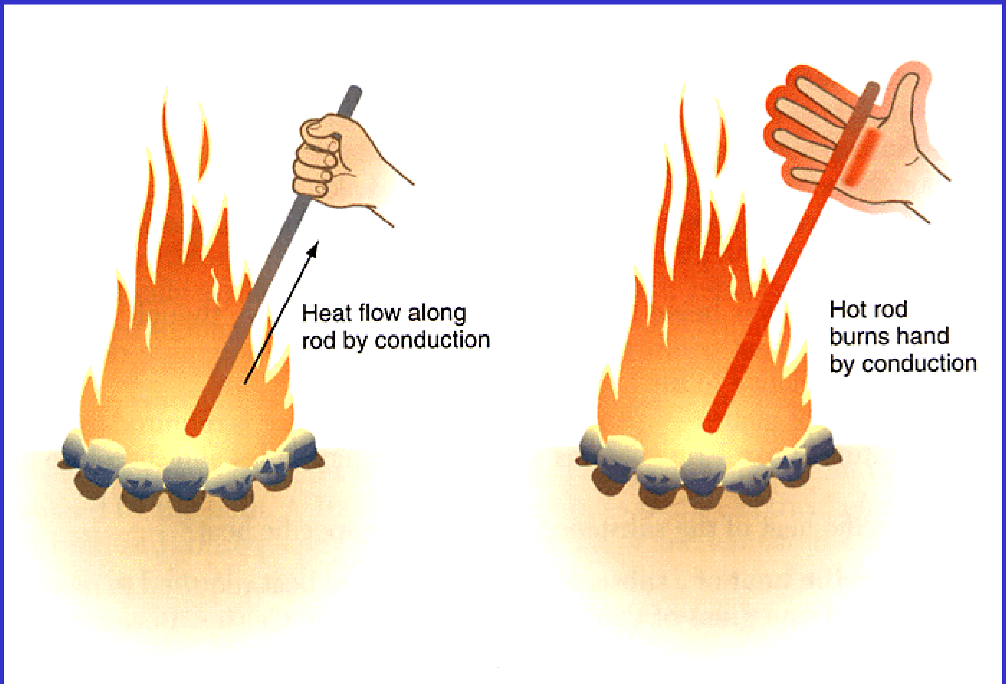
$$\Delta U = Q - W$$

change in internal energy (related to temperature)

Heat added to the system

Work done by the system

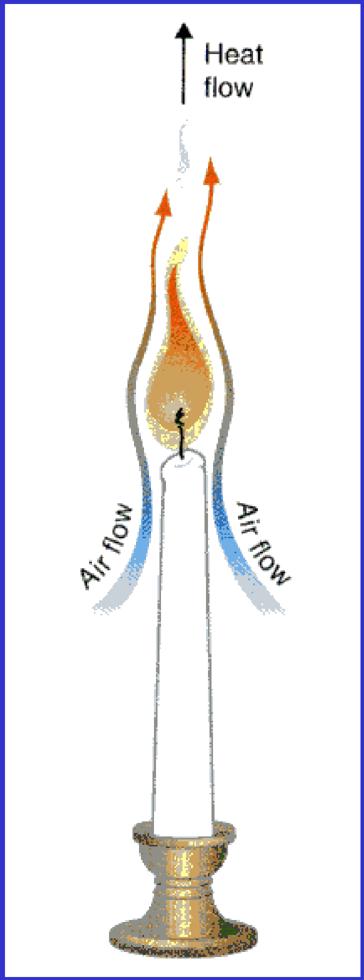
# Conduction




(from *Meteorology: Understanding the Atmosphere*)

- Conduction is the process of heat transfer from molecule to molecule.
- This energy transfer process requires contact.
- Air is a poor conductor. (with low thermal conductivity)
- Conduction is not an efficient mechanisms to transfer heat in the atmosphere on large spatial scales.

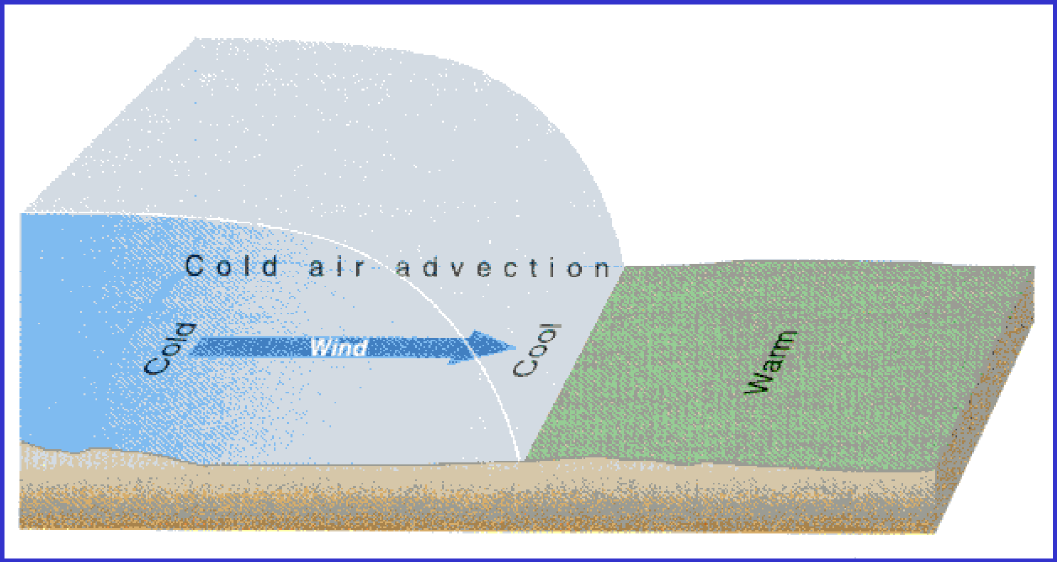
# Convection




- Convection is heat transfer by mass motion of a fluid (such as air or water).
- Convection is produced when the heated fluid moves away from the heat source and carries energy with it.
- Convection is an efficient mechanism of heat transfer for the atmosphere in some regions (such as the tropics) but is an inefficient mechanism in other regions (such as the polar regions).

(from *Meteorology: Understanding the Atmosphere*)

# Advection




(from *Meteorology: Understanding the Atmosphere*)

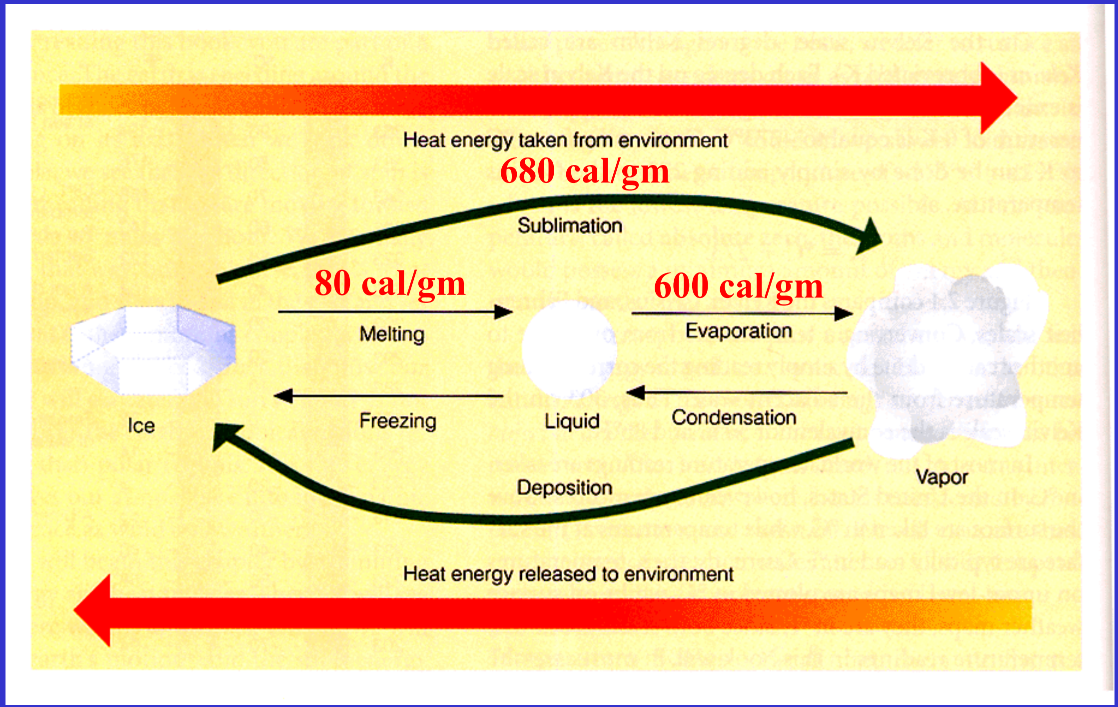
- Advection is referred to the horizontal transport of heat in the atmosphere.
- Warm air advection occurs when warm air replaces cold air. Cold air advection is the other way around.
- This process is similar to the convection which relies on the mass motion to carry heat from one region to the other.
- Advection can be considered as one form of convection.

# Radiation

- Radiation is heat transfer by the emission of electromagnetic waves which carry energy away from the emitting object.

- The solar energy moves through empty space from the Sun to the Earth and is the original energy source for Earth’s weather and climate.

# Latent Heating




(from *Meteorology: Understanding the Atmosphere*)

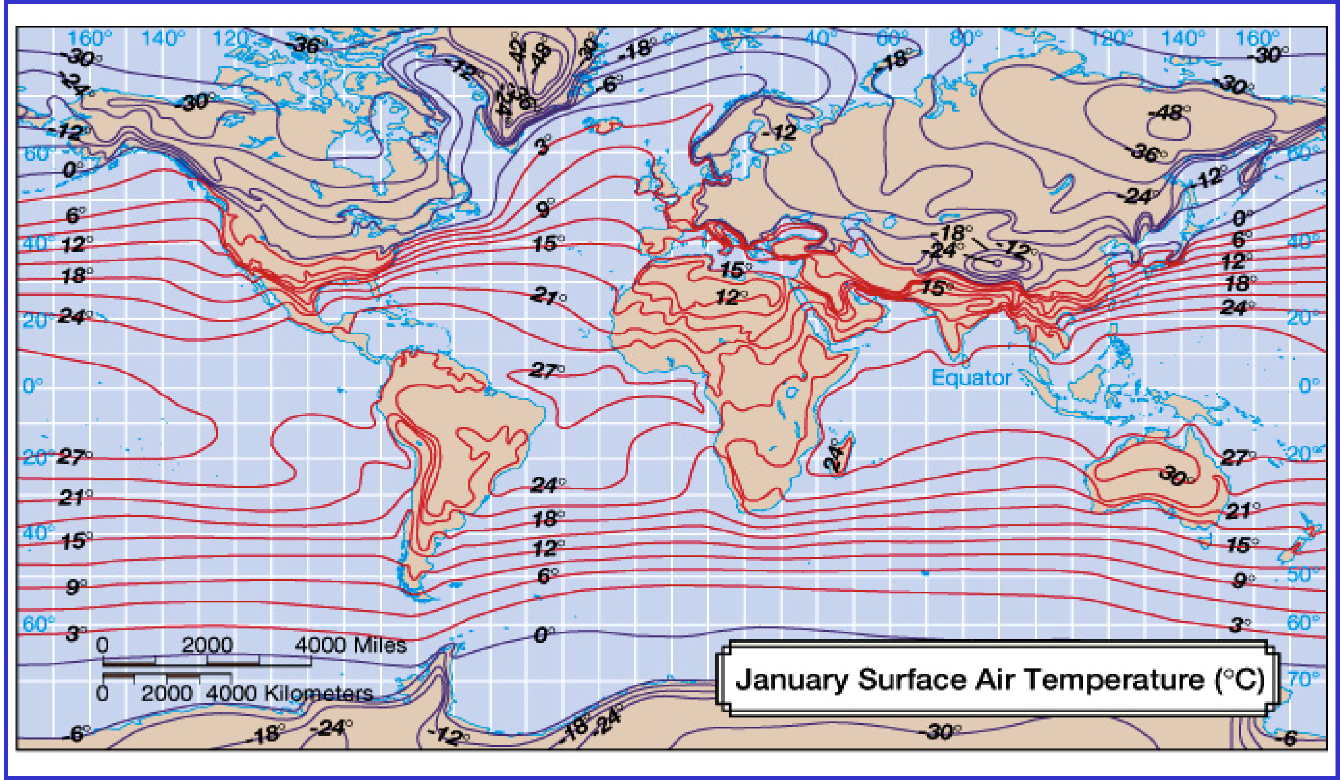
- Latent heat is the heat released or absorbed per unit mass when water changes phase.
- Latent heating is an efficient way of transferring energy globally and is an important energy source for Earth's weather and climate.

# Latent Heat of Evaporation

- The latent heat of evaporation is a function of water temperature, ranging from 540 cal per gram of water at 100°C to 600 cal per gram at 0°C.

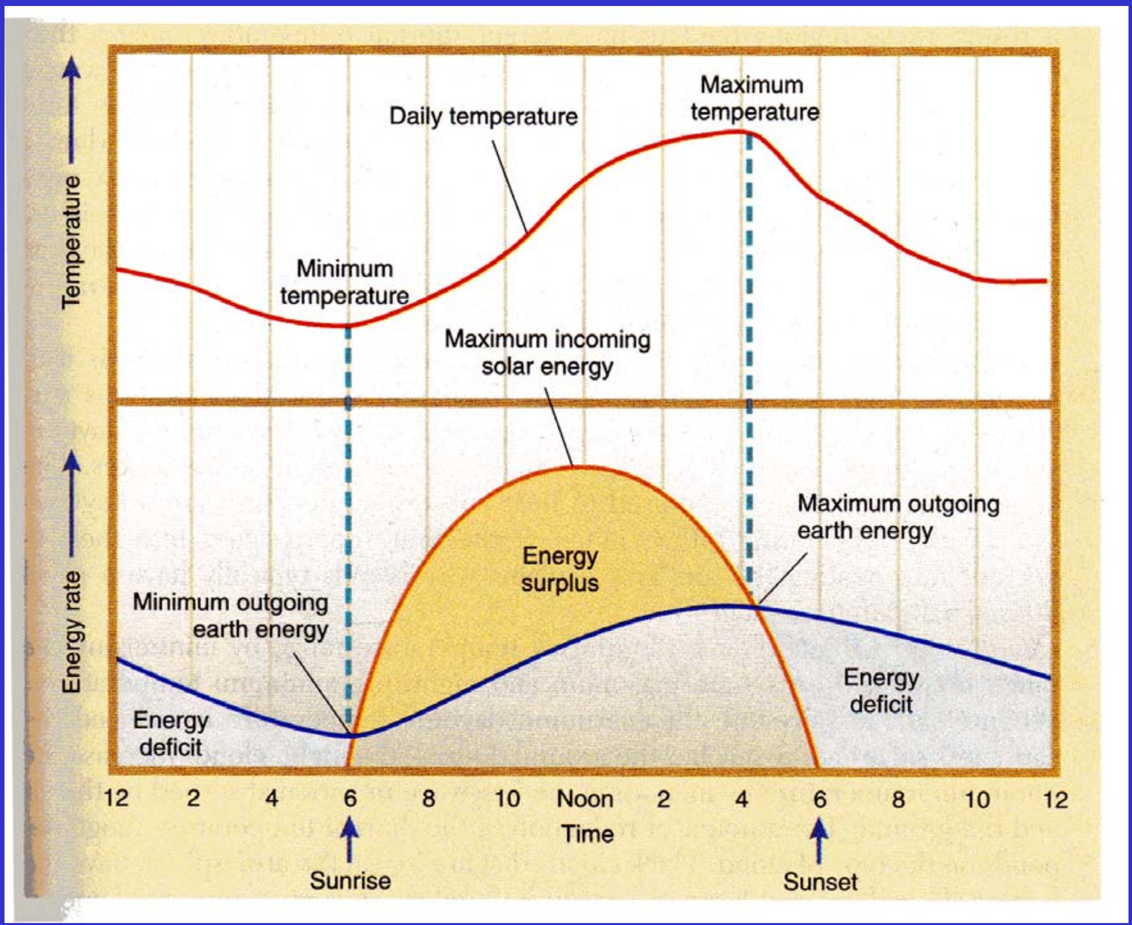
- It takes more energy to evaporate cold water than evaporate the same amount of warmer water.

# The controls of Temperature




- Latitude
- Sea/land distribution
- Ocean currents
- Elevation

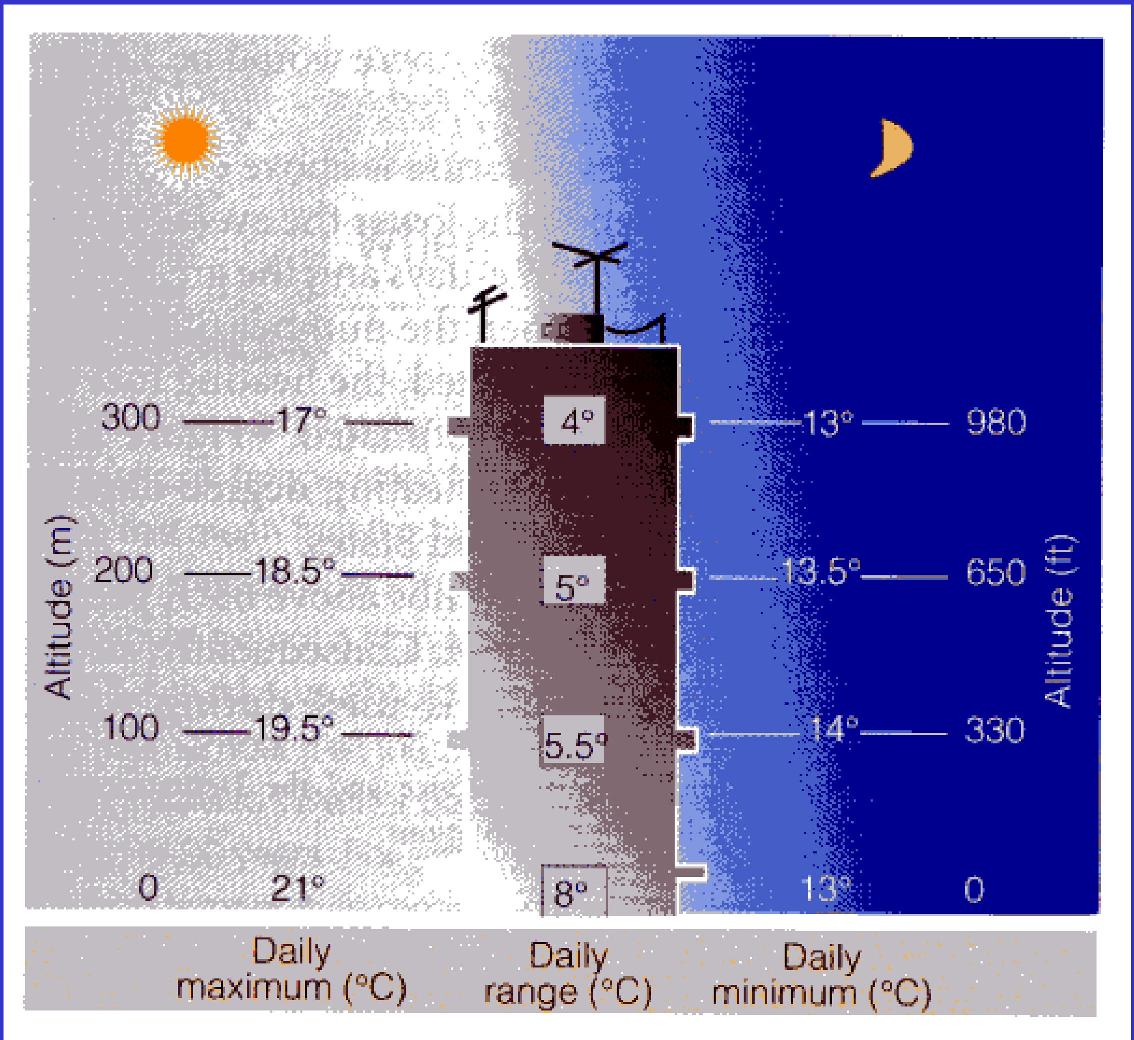
# Diurnal Temperature Variations




(from *Meteorology: Understanding the Atmosphere*)

- The difference between the daily maximum and minimum temperature is called the daily (or diurnal) range of temperature.

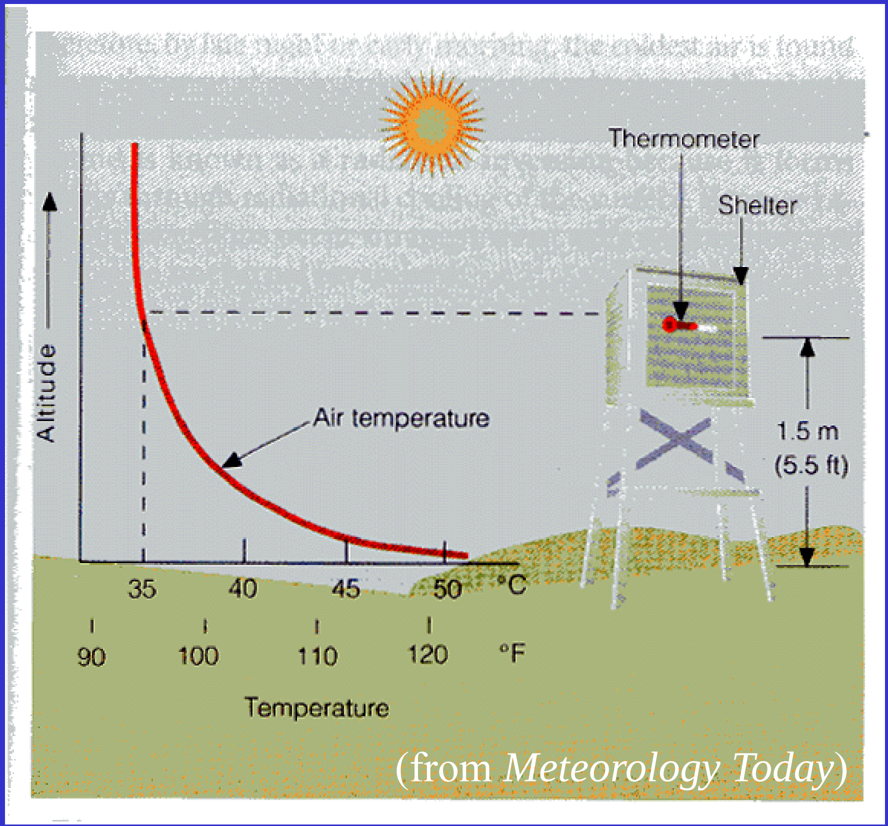
# Diurnal Cycle Changes with Altitude



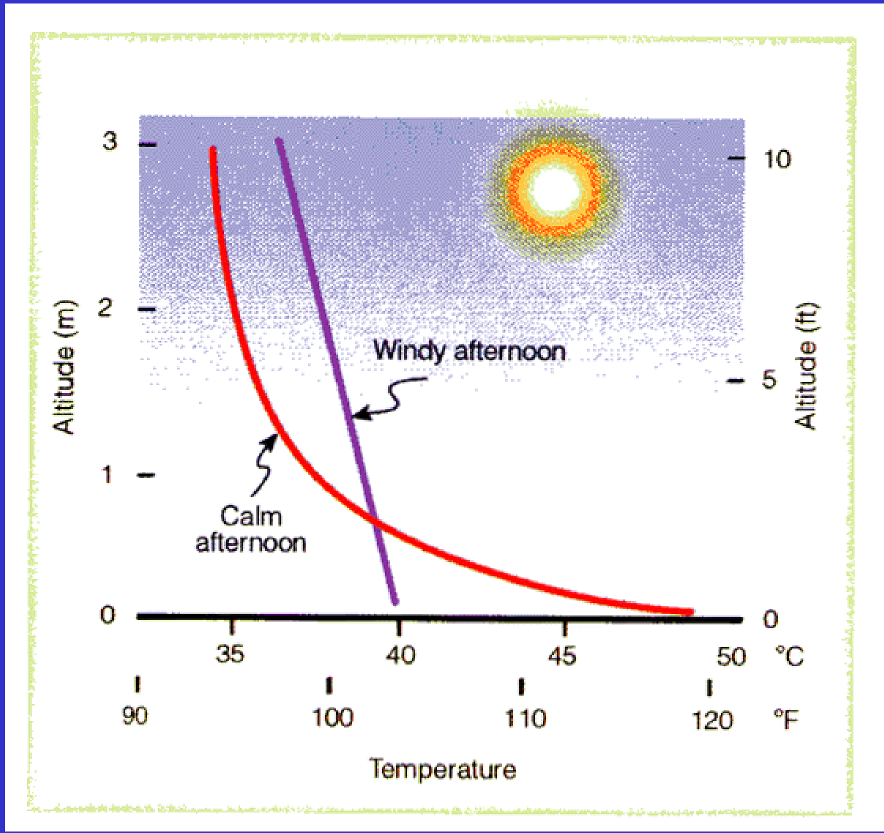

(from *Meteorology Today*)

- The diurnal cycle (the daily range of temperature) is greatest next to the ground and becomes progressively small as we move away from the surface.
- The diurnal cycle is also much larger on clear day than on cloudy ones.

# Daytime Warming

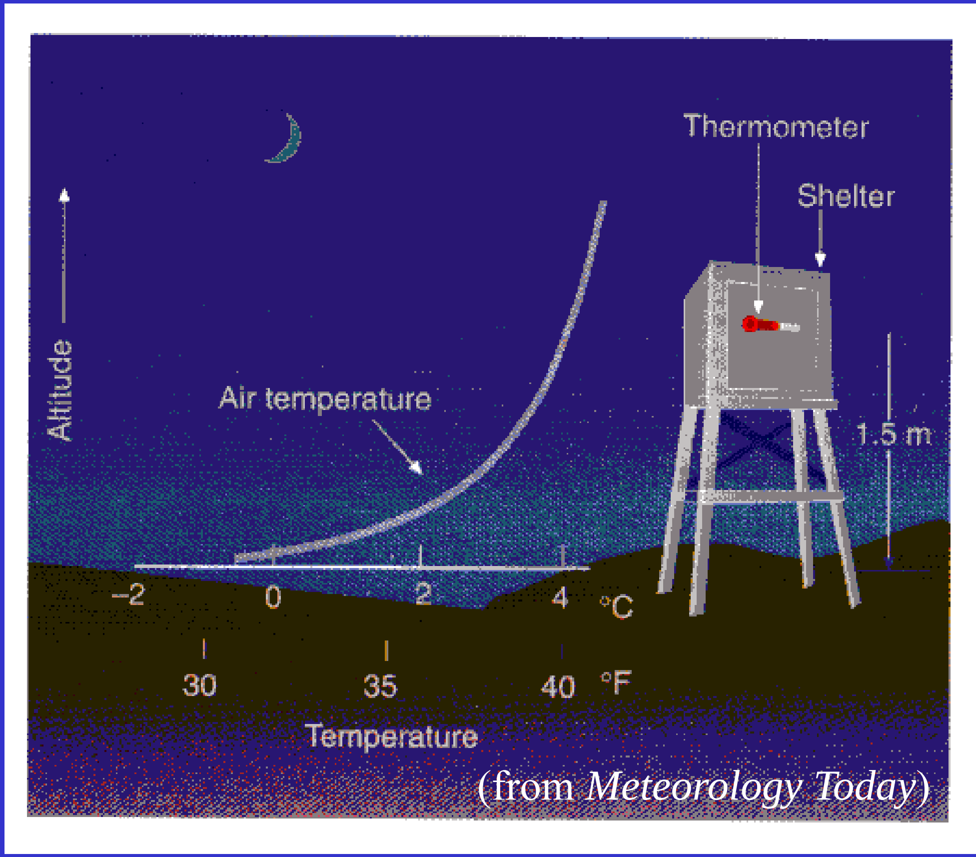


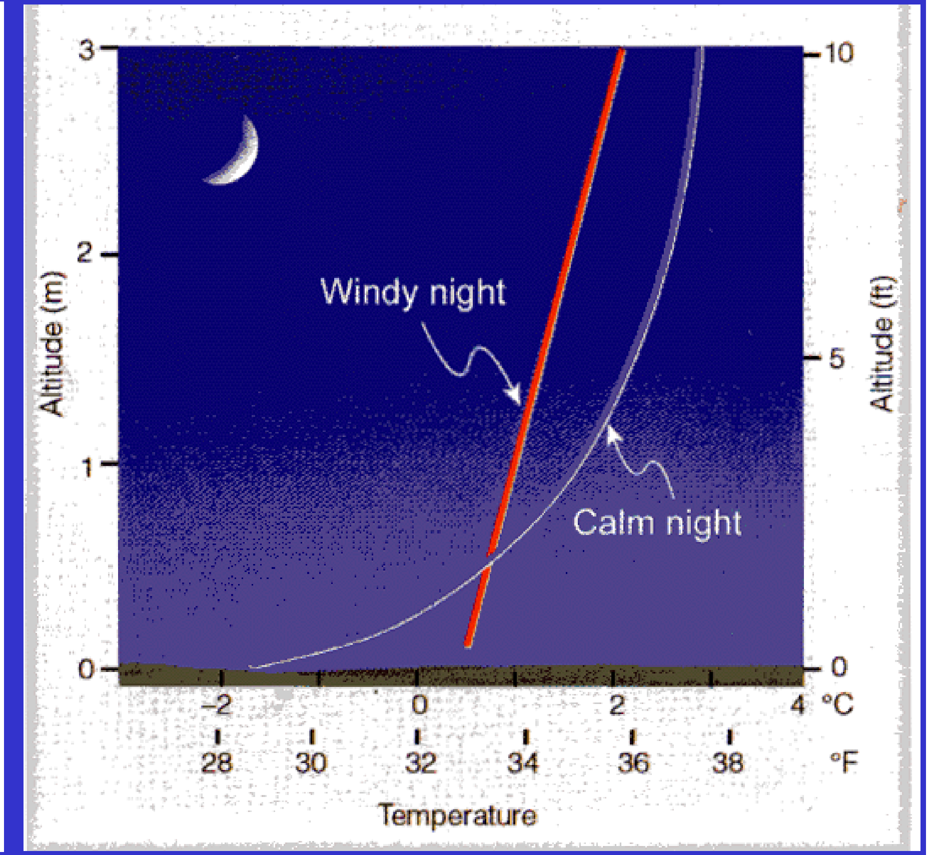
(from *Meteorology Today*)




- Sunlight warms the ground and the air in contact with the ground by conduction.
- Air is a poor heat conductor, so this heating is limited to a layer near the surface. Air temperatures above this layer are cooler.
- Wind stirring can reduce this vertical difference in air temperatures.

# Nighttime Cooling



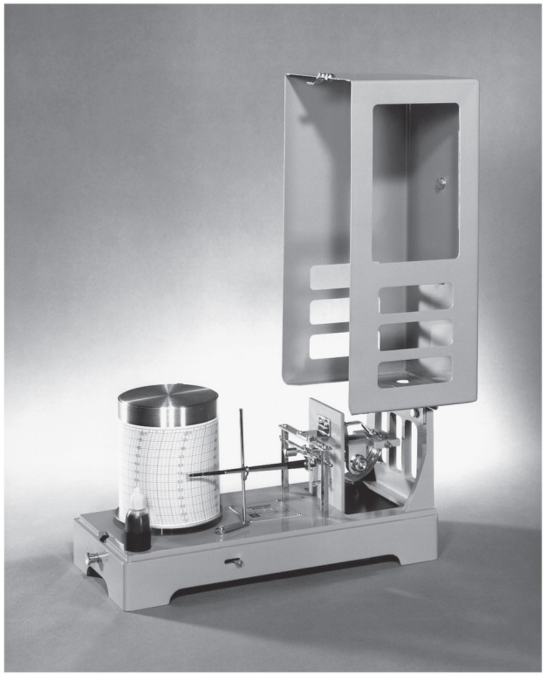

- Both the ground and air above cool by radiating infrared energy, a process called radiational cooling.
- The ground, being a much better radiator than air, is able to cool more quickly.
- Shortly after sunset, the earth's surface is cooler than the air directly above.


● FIGURE 3.17
Orchard heaters circulate the air by setting up convection currents.

(from *Meteorology Today*)

# How to Measure Temperature







thermograph

- The thermometer has to be mounted 1.52m (5 ft) above the ground.
- The door of the instrument shelter has to face north in Northern Hemisphere.