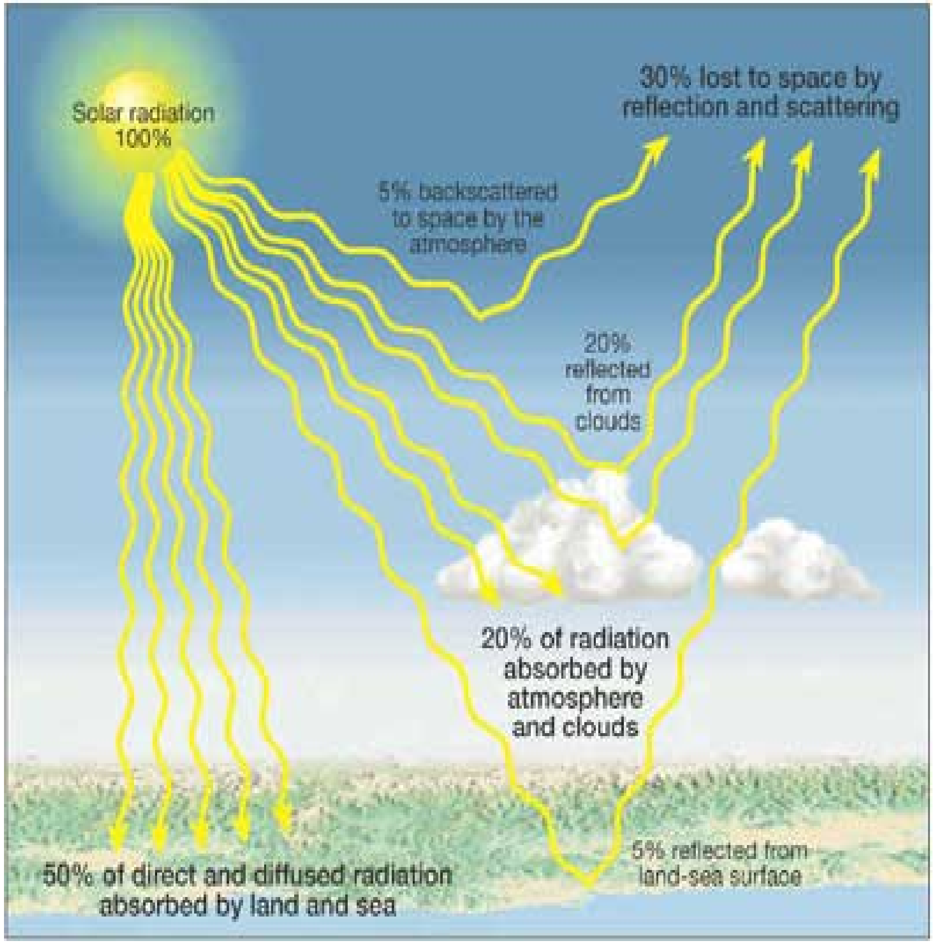
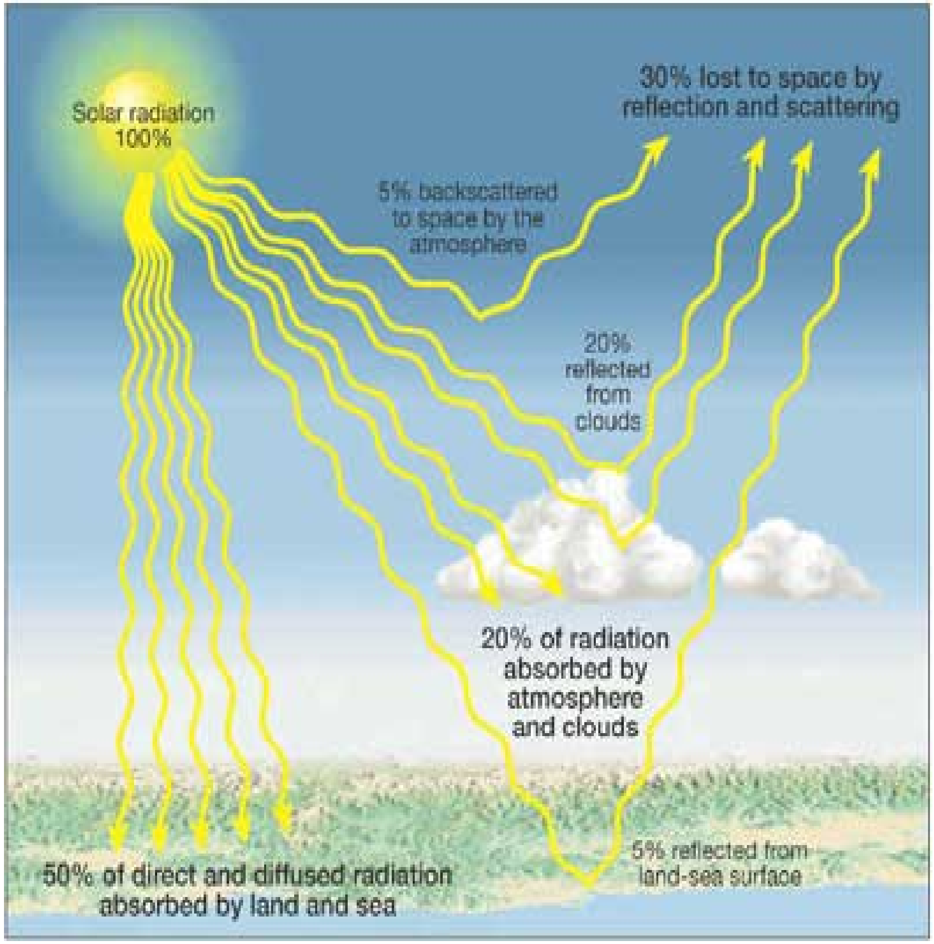
Heat Budget

- Energy transfer processes, including radiation, maintain a balanced heat budget at the earth's surface. They are represented the equation:
- Rs = H+LE+A
- Where, Rs is the surface radiation balance
- H is the net transfer of sensible heat between surface and atmosphere by conduction and turbulent exchange.
- L is the latent heat of vaporization.
- E is the rate of evaporation.
- A is the flux of heat between the surface and lower layers of soil or water.



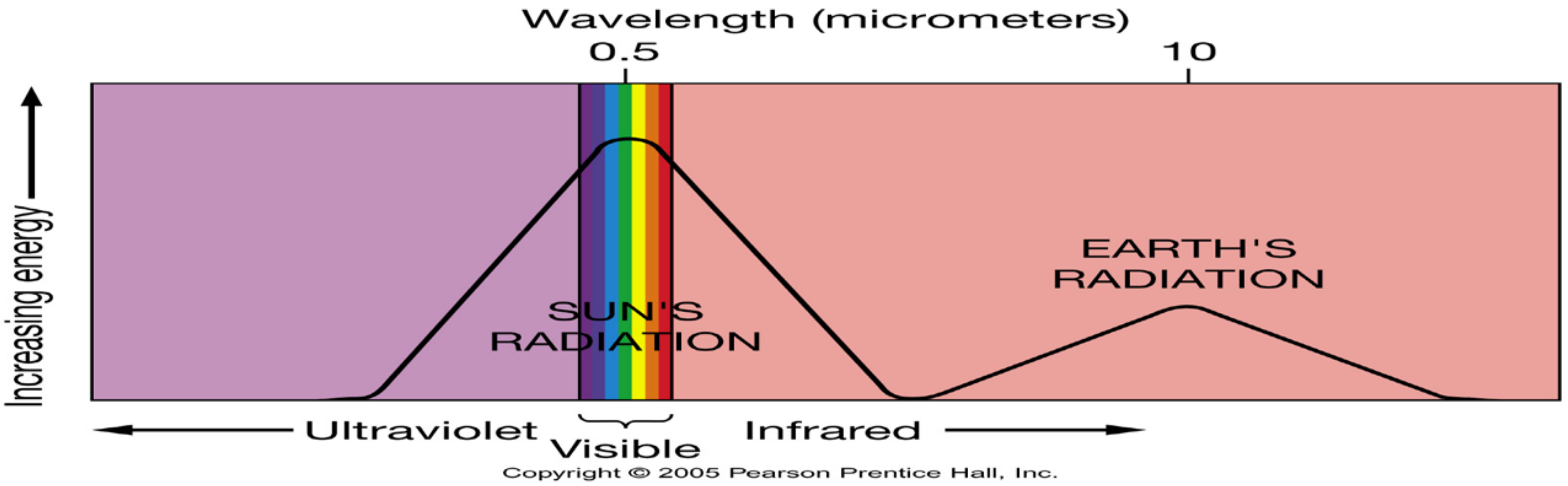
Heat Budget Cont….

- Incoming heat being absorbed by the Earth, and outgoing heat escaping the Earth in the form of radiation are both perfectly balanced. If they were not balanced, then Earth would be getting either progressively warmer, or progressively cooler with each passing year. This balance between incoming and outgoing heat is known as Earth's heat budget. While on average, Earth's heat budget is balanced, the interactions that take place as heat and electromagnetic radiation interact with Earth, and its many objects, oceans, and atmosphere are complex. Over all they balance out, however, some places are hotter, or cooler day in and day out



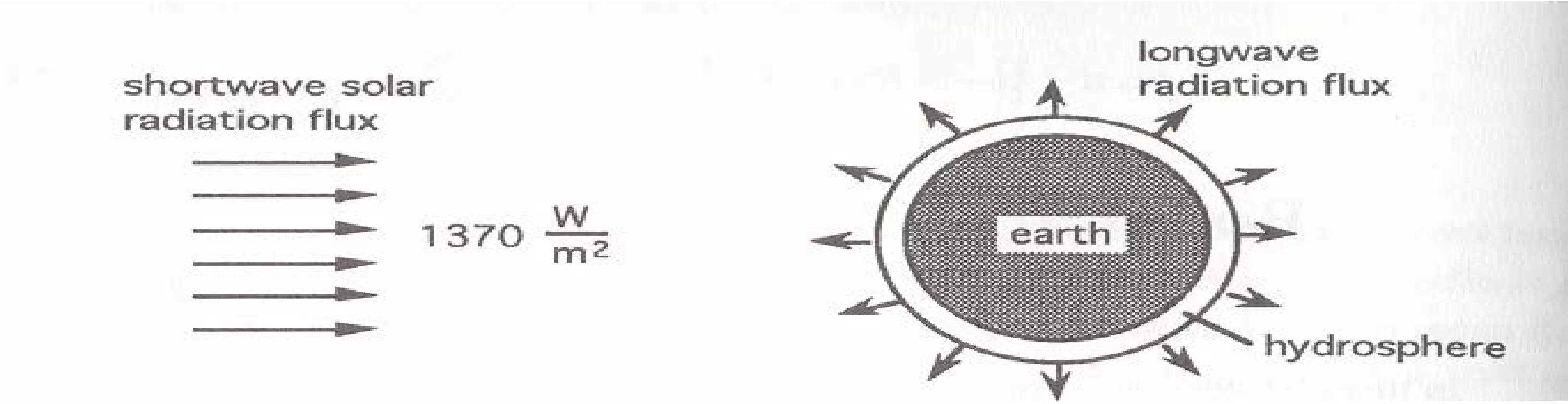
Heat Budget Cont…..

- The Earth effectively receives its energy from the sun
  - At wavelengths between 0.2 and 4.0 μm
  - About 40% in the visible range
    - Between 0.4 and 0.67 μm



Heat Budget

- Solar Constant – Average energy flux from the sun at the mean radius of the Earth
  - ~1368 W m^{-2}
  - Note, as the Earth's orbit is elliptical, not circular, this varies by ±3.5% seasonally



Heat Budget

- Energy seen by the Earth is equivalent to a disk of the same cross-sectional area
  - Thus, the total power hitting the Earth is $P=S_o \pi R_E^2$
  - But this power is distributed over the Earth's entire surface
  - Gives an average solar irradiance of 344 W m^{-2}
- But not all this energy is absorbed
  - A fraction, the albedo α, is reflected or scattered
  - An average albedo for the globe is 0.30 (although it varies greatly by location)
- Thus, actual solar energy received is 238 W m^{-2}

Albedo

High albedo at high latitudes

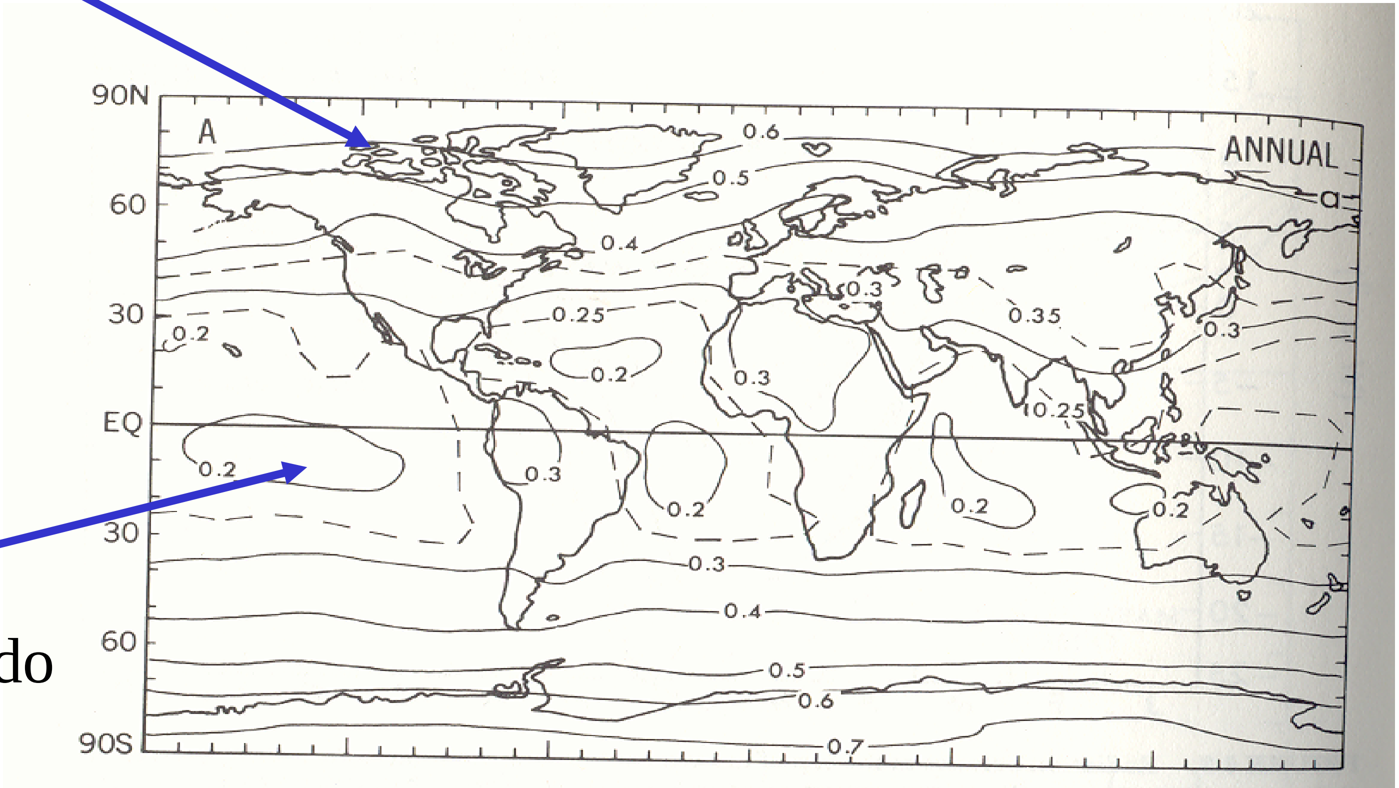


FIGURE 6.10a

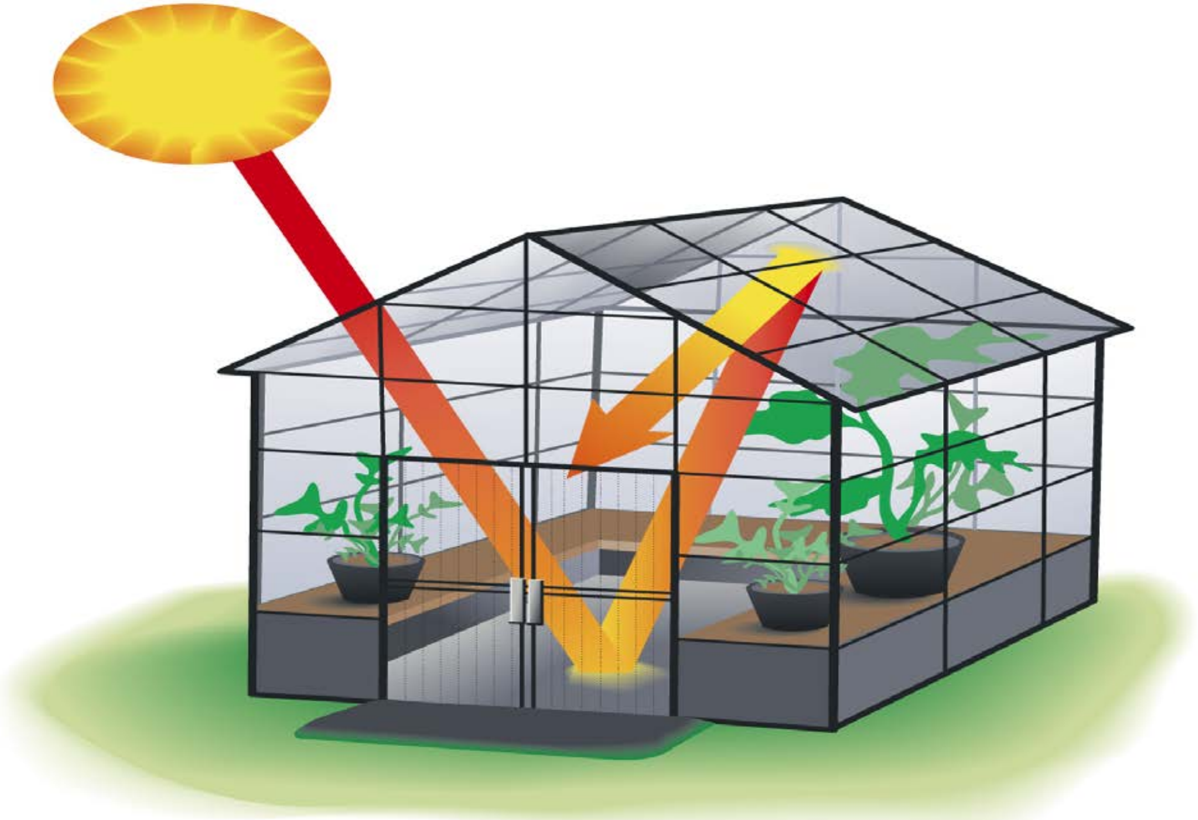
Low albedo in tropics

Peixoto and Oort, 1989

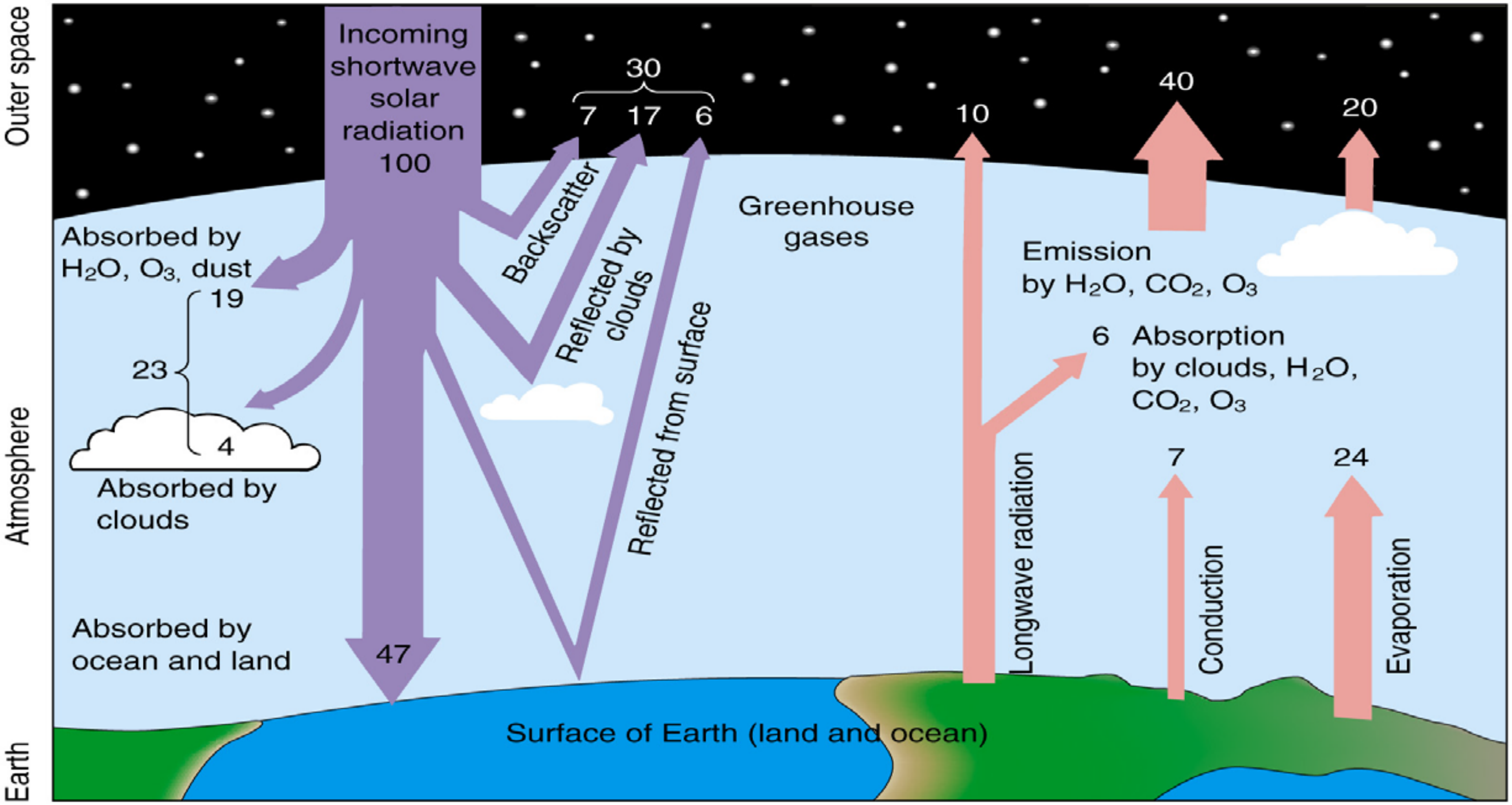
Greenhouse Effect

- Stefan-Boltzmann Law: $I = \sigma T^4$ with $\sigma = 5.670 \times 10^{-8}$ W m^{-2} K^{-4}
  - Thus, the flux density (energy per unit area per unit time) emitted by a black body is proportional to the 4th power of the absolute temperature
  - Using our solar constant calculations, we can find a T_{earth} of 255K or –18C
  - But, we know the average surface temperature is 288K or 15C
  - The difference is caused by radiation absorbed and trapped in the atmosphere
    - Incoming energy is short wave radiation
    - Outgoing radiation is long wave (infrared)
    - This is termed the greenhouse effect
    - The main greenhouse gas is water vapour

Greenhouse Effect



Heat Budget



Outer space
Atmosphere
Earth
Incoming shortwave solar radiation 100
30
7 17 6
Backscatter
Reflected by clouds
Reflected from surface
Absorbed by H_2O, O_3, dust
19
23
4
Absorbed by clouds
Absorbed by ocean and land
47
Greenhouse gases
10
40
20
Emission by H_2O, CO_2, O_3
6 Absorption by clouds, H_2O, CO_2, O_3
7
24
Longwave radiation
Conduction
Evaporation
Surface of Earth (land and ocean)

Heat Fluxes

- Net Heat Flux = SW + LW + Sensible + Latent
- SW – incoming net short wave radiation
- LW – outgoing long wave radiation
- Sensible – Flux of heat due to conduction
  - Direct physical contact between the atmosphere and the ocean leads to energy exchange by conduction
  - Energy is transferred to the cooler (and thus slower) molecules by molecular collisions
  - Thus it depends on the local air-sea (or land) temperature difference and wind-speed

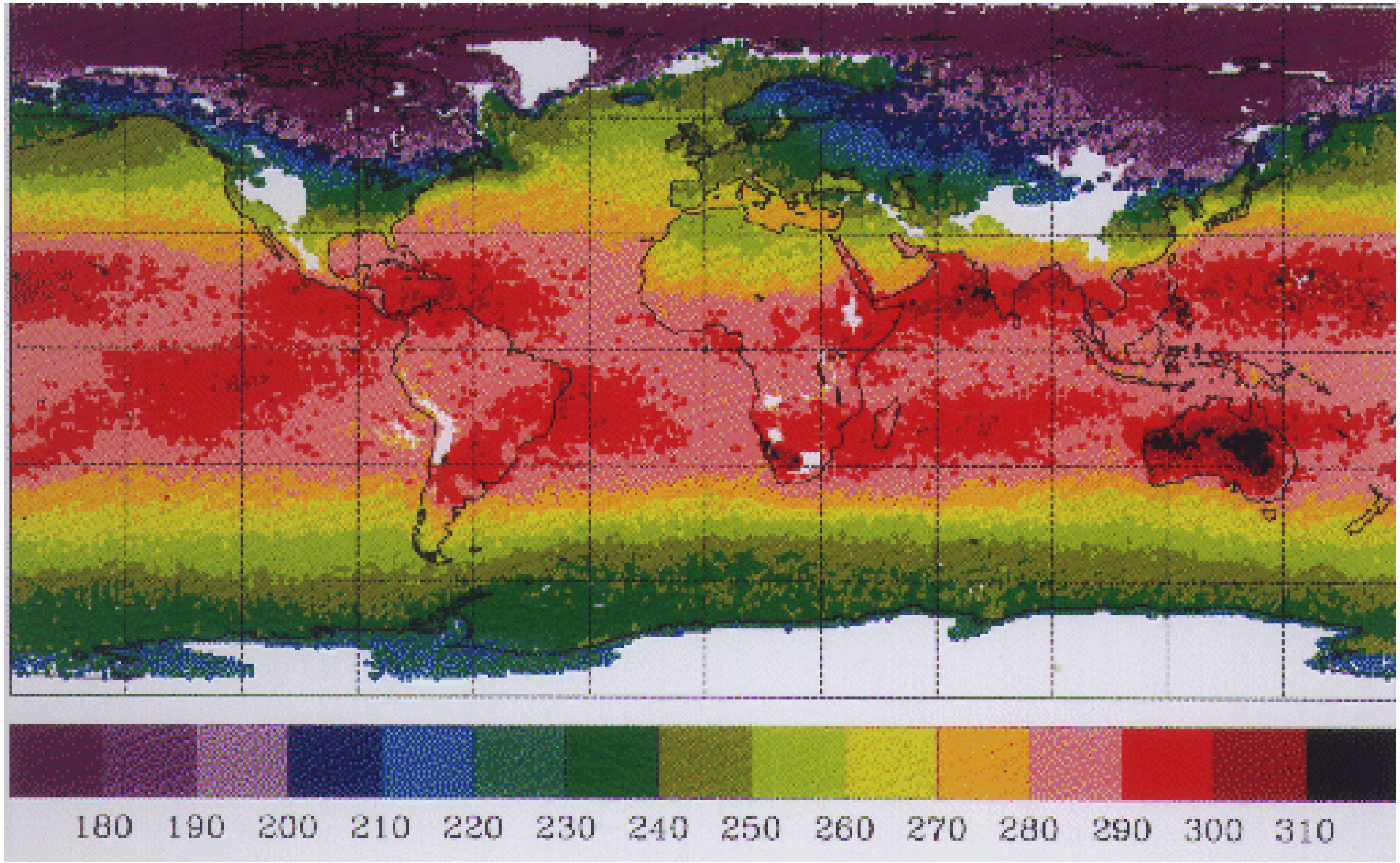
Heat Fluxes

- Latent – latent heat exchange
  - When water is evaporated, energy is supplied to the molecules to free them from the strong bonds in liquid water
  - When the molecules condense to form droplets, usually in clouds, energy is released to heat the surrounding air
  - This process is very temperature dependent
    - The higher the temperature, the more moisture air can hold and therefore the greater potential for latent heat release upon condensation

Heat Properties of Water

- Water's very high heat capacity and latent heat has tremendous impacts on the ocean's storage and transport of heat, as well as climate
- In polar regions, most heat exchange is latent (cooling in winter, warming in summer)
  - This means that the ocean temperatures change very little over the course of the year
- The high latent heat of vapourization is also important for atmospheric heat transport
  - Heat is added in the tropics, which warms the water and leads to evaporation. This heat is then stored in the water vapour molecules, which are blown to higher latitudes, where they condense as rain
  - Thus the heat in those water molecules is released to the atmosphere, warming the higher latitudes

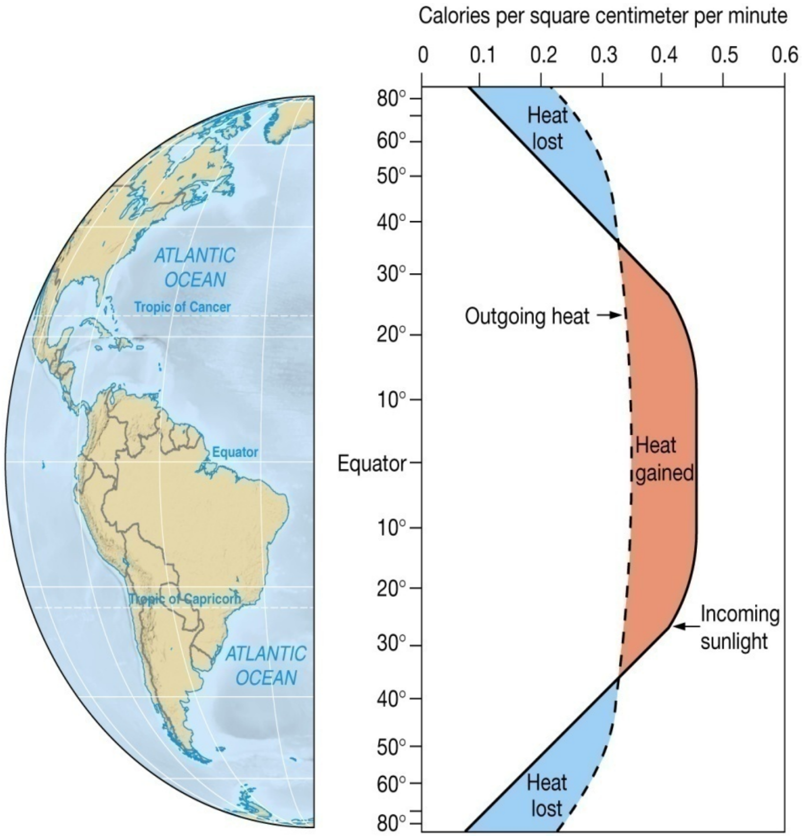
Heat Budget



Net Radiation Received, W m^{-2}

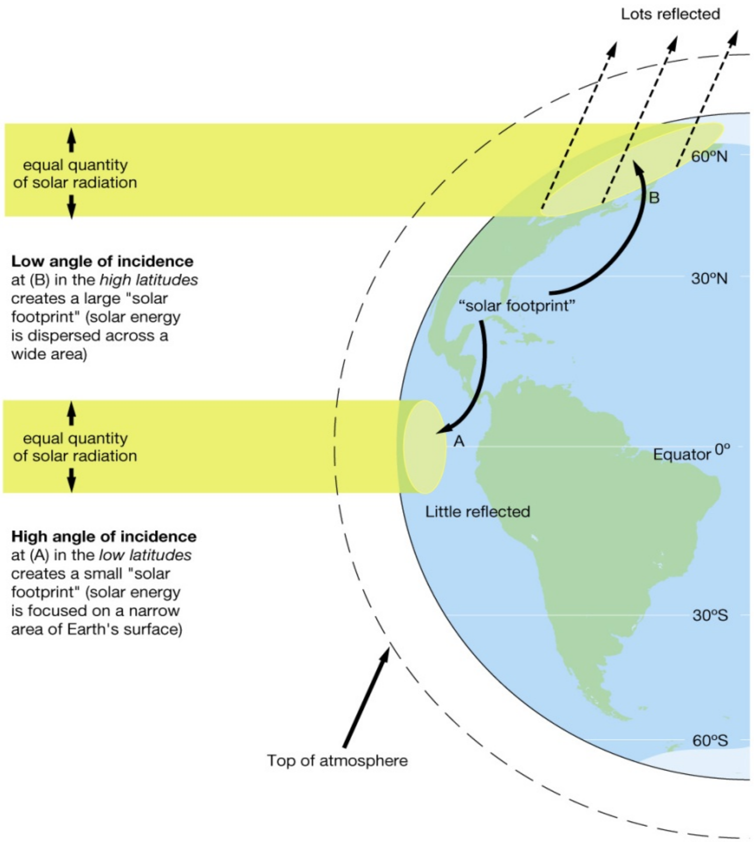
Heat Budget

- Incoming solar radiation is not evenly divided over the earth
- Net surplus of radiation in tropics and deficit at high-latitudes
- This leads to a transport of heat by the oceans and atmosphere from the equatorial regions to the poles
- This need to redistribute heat is the main driving force the oceanic and atmospheric circulation



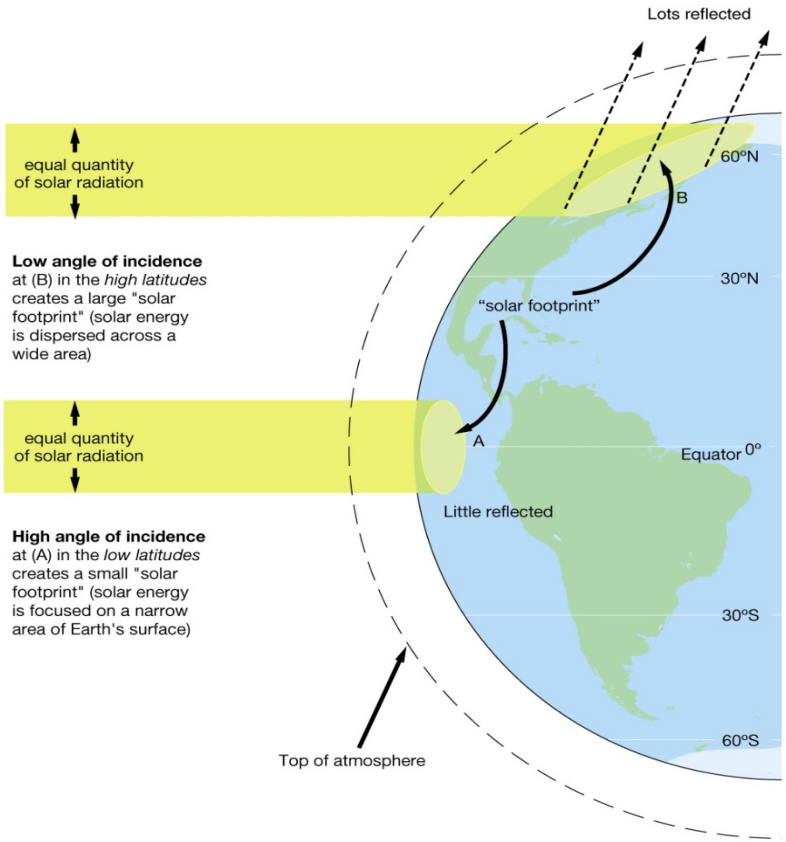
Heat Budget

- Reasons for the distribution of incoming solar radiation:
- 1) Angle of impact of solar radiation



Heat Budget

- 2) Earth's surface area
- 3) Atmospheric path length



Heat Budget

- 4) Albedo
  - This value measures the ratio of reflected incoming radiation

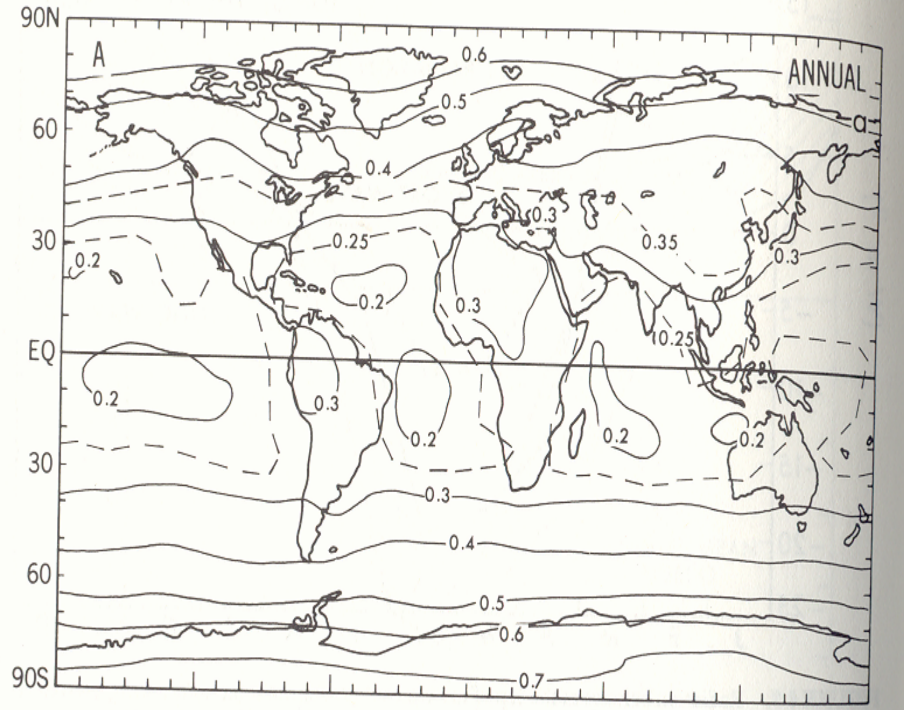
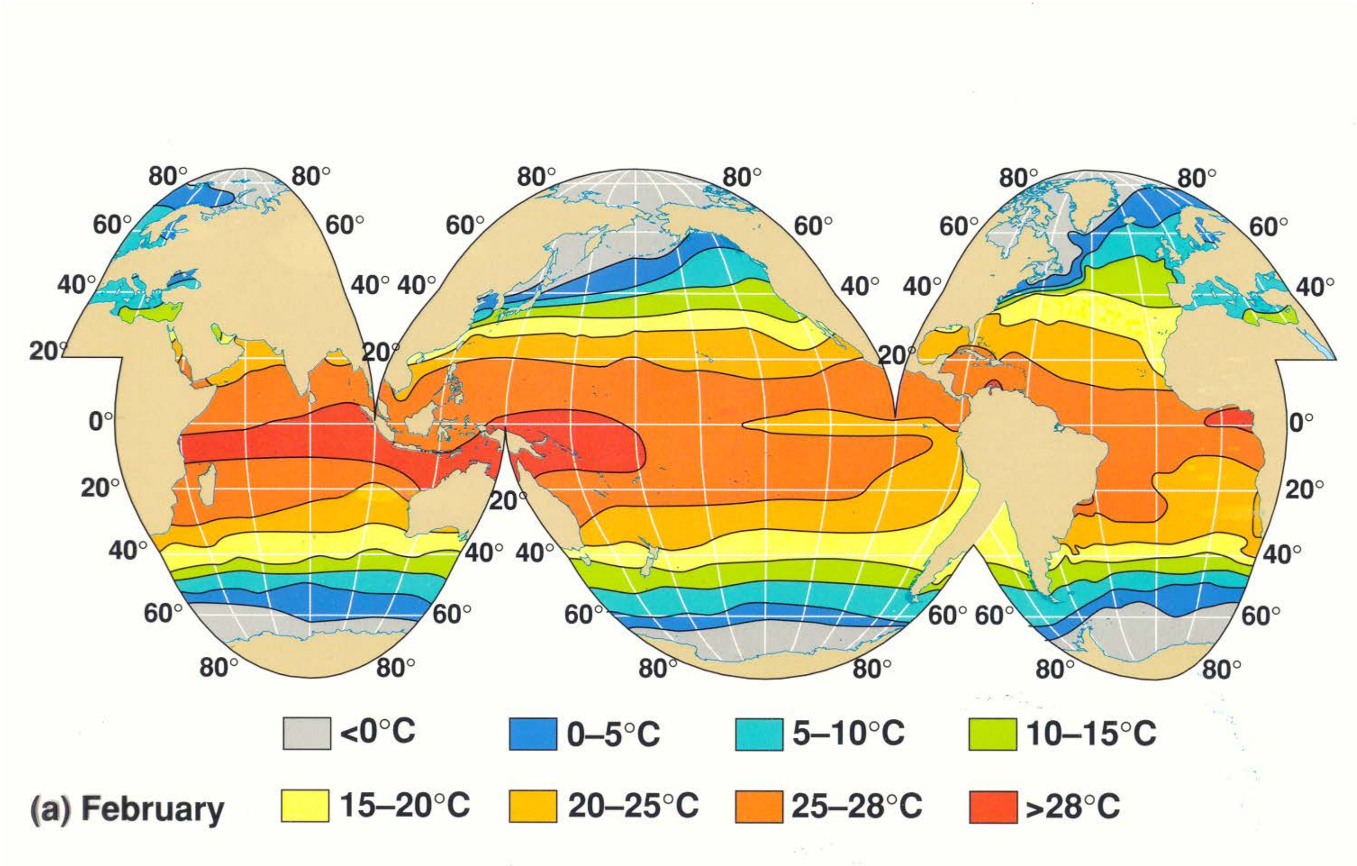


FIGURE 6.10a

Ocean Surface Water Properties

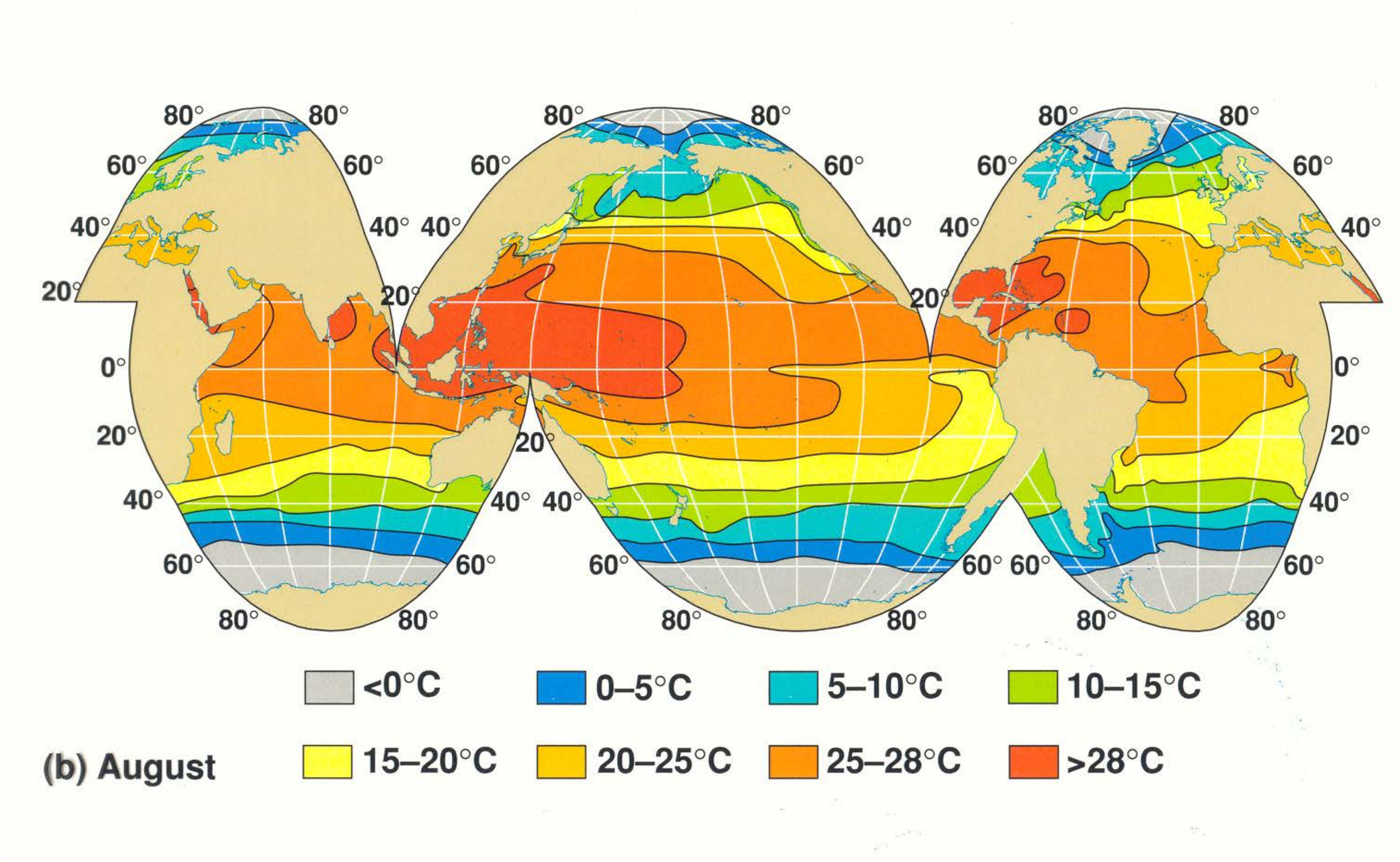
- Mainly controlled by:
  - Solar radiation
  - Transfer of heat and water with the atmosphere
  - Ocean currents
  - Vertical mixing
  - Runoff

February Surface Temperatures



Segar, 2007

August Surface Temperatures



Segar, 2007

Insolation

- incoming solar radiation
  - intensity
    - Langleys
      - FYI: 1 langley = 2 calories per cm^2
  - amt. received at a ground location
    - angle of solar incidence
    - length of day
    - atmospheric obstruction

Insolation

The sun is the primary source energy for the process of change at earth surface and the atmosphere. The amount of energy the earth receive from other celestial bodies is negligible by comparison. Radiation energy from the sun that strikes the earth is called insolation a concentration of “incoming solar radiation.”

Incoming solar radiation is transmitted in various wave length of the solar spectrum, mainly in the ultraviolet, visible and infrared bands.

Variability of Insolation

The amount of insolation received on any date at a place on earth is governed by:

1. Solar radiation reaching the outer limit of the atmosphere, which depends on:

    Energy output of the sun.

    Distance from the earth to the sun.

    Interstellar dust in the solar system.

2. Transparency of the atmosphere.
3. Duration of daily sunlight period.
4. Angle at which the sun's moon rays strike the earth.

Transparency of the atmosphere

1. Transparency of the atmosphere has more important bearing on the amount of insolation which reaches the earth surface.
2. The effect of dust, clouds, water vapor, and certain gases in reflection, scattering absorption was noted.
3. Dense cloudiness or polluted air transmit direct solar radiation less effectively to lower atmospheric layers or earth’s surface.
4. Transparency is also a function of latitude, for at middle and high latitudes the solar beam must penetrate the reflecting-absorbing atmosphere at a lower angle than in tropical latitudes.

Duration of daily sunlight period

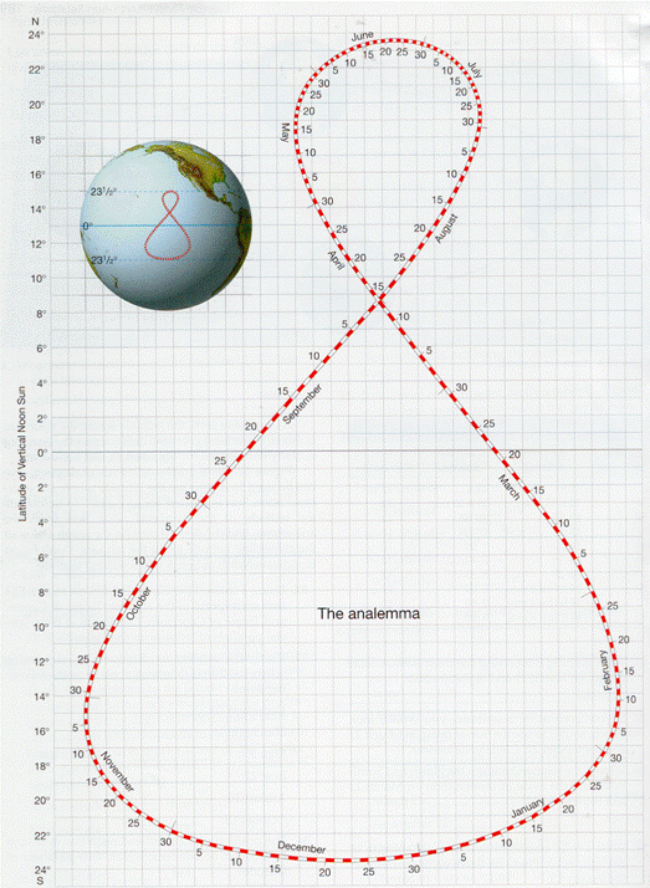
1. The duration of daylight (the photoperiod) also varies with latitude and the seasons, and the longer the photoperiod the greater is the total possible insolation.
2. At the equator day and night are always equal.
3. In the polar regions the daily photoperiod reaches a maximum of 24 hours in summer and minimum of zero hour in winter.
4. A polar area may receive more radiation per 24-hour day than lower latitude, although the net radiation use for heating is reduced because of the high albedo of ice and snow surface.

Angle at which the sun's moon rays strike the earth

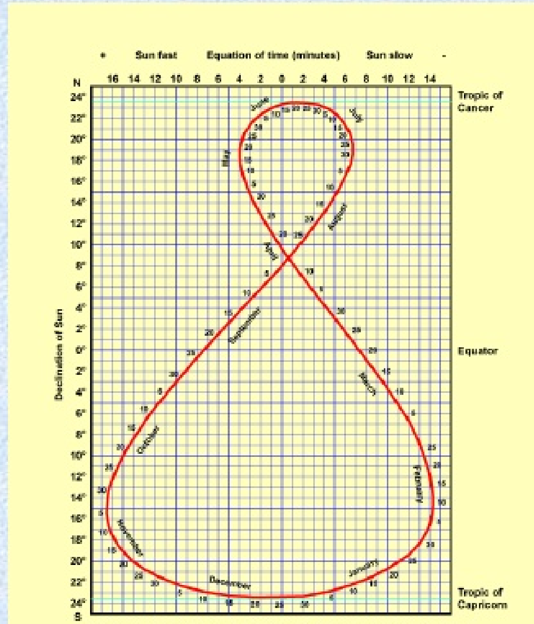
1. The angle at which the solar radiation strike the earth surface also depends on terrain feature.
2. In the Northern Hemisphere southern slopes receive a more direct solar beam, whereas northern slopes may be entirely in shade.
3. The world distribution of possible insolation at the surface is closely related to latitude.
4. At the equator the annual amount is about four times that at either of the pole.
5. The direct solar beam shifts seasonally from one hemisphere to the other, the zone of maximum possible daily insolation move with it.
6. In tropical latitude the amount of possible insolation is constantly great, and there is little variation with the seasons.

Angle of Incidence

- Solar Constant
  - insolation at subsolar point in upper atmosphere
    - 2 Langleys per minute
  - latitude of subsolar point changes daily
    - analemma



Analemma



The analemma (redrawn using data from the U.S. Coast and Geodetic Survey)

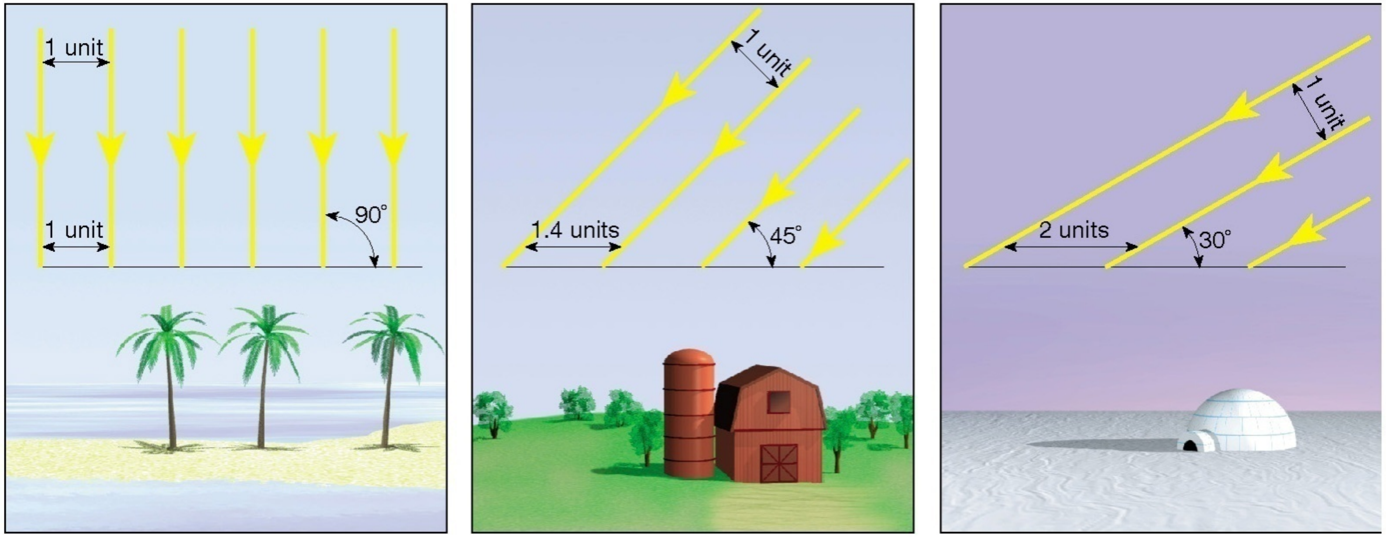
WHAT IS AN ANALEMMA?

An **analemma** is a natural pattern traced out annually in the sky by the Sun.

a plot or graph of the position of the sun in the sky at a certain time of day (such as noon) at one locale measured throughout the year that has the shape of a figure 8 also : a scale (as on a globe or sundial) based on such a plot that shows the sun's position for each day of the year or that allows local mean time

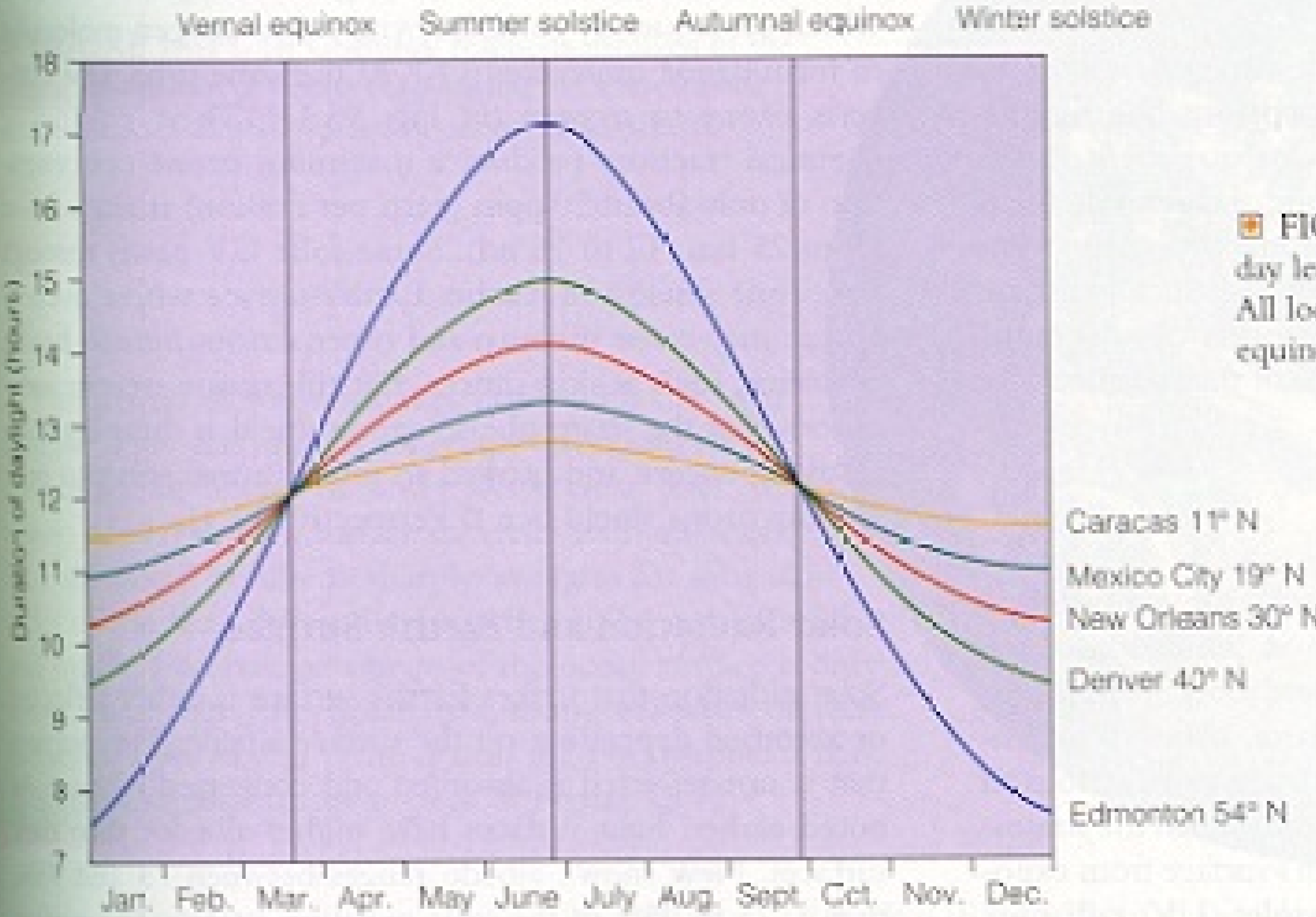
Solar Angle at any Latitude

- For latitude desired
  - know day of year
  - determine subsolar point using analemma
  - 90 degrees - [subsolar point - given latitude]
- As angle decreases from subsolar point
  - intensity decreases



Day Length

- total insolation increases with increasing day length
- equator
  - 12 hrs of daylight & darkness
  - every day of the year
- elsewhere
  - 12 hrs day/dark only during equinoxes
  - maximum variation occurs during solstices
  - annual variation increases poleward

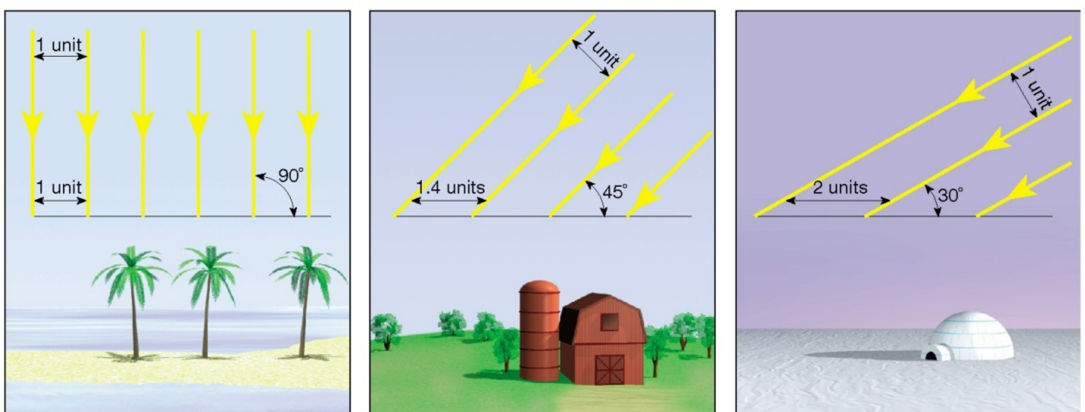


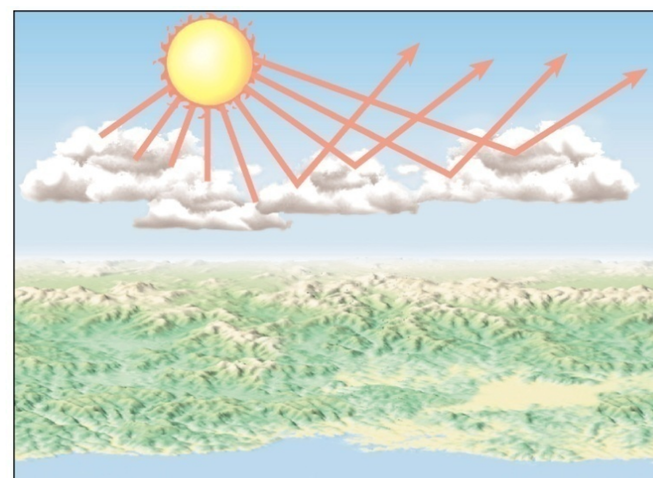
FIGU
day lengt
All locali
equinoxe

Atmospheric Obstruction

- Atmosphere reflects some solar energy back into space
- Percentage reaching surface decreases with decreasing angle of incidence
- Weather/climate
  - cloudiness

SUN ANGLE	PERCENT RADIATION REACHING SURFACE
90	75
70	74
50	69
30	56
20	43
10	20
5	5
0	0





A.

Annual Insolation

– total decreases with increasing latitude
– variation increases with increasing latitude

Table 12.3 Solar radiation at the outer edge of the atmosphere (langleys/day) at various latitudes during select months

Latitude	March	June	September	December
90°N	50	1050	50	0
40°N	700	950	720	325
0°	890	780	880	840

World Latitude Zones

- Defined with respect to insolation

- Equatorial zone 10°N - 10°S
- Tropical zones 10° - 25° N & S
- Subtropical zones 25° - 35° N & S
- Midlatitude zones 35° - 55° N & S
- Subarctic & Subantarctic zones 55° - 60° N & S
- Arctic & Antarctic zones 60° - 75° N & S
- Polar zones 75° - 90° N & S

Heat balance

A heat balance is another name
for an energy balance

The Energy Balance of Earth

- Conduction and convection!!!

    1) Conduction causes heat transfer to air in contact with ground

The Energy Balance of Earth

- Conduction and convection!!!

  1) Conduction causes heat transfer to air in contact with ground

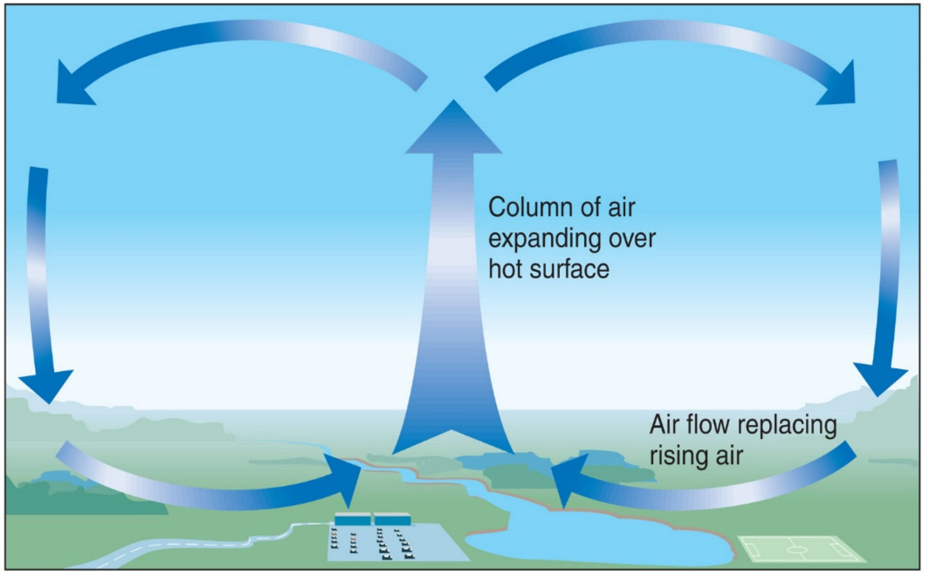
  2) Convection causes this air near the surface to rise like a helium balloon, mixing heat throughout the atmosphere

→ **Sensible heat flux**

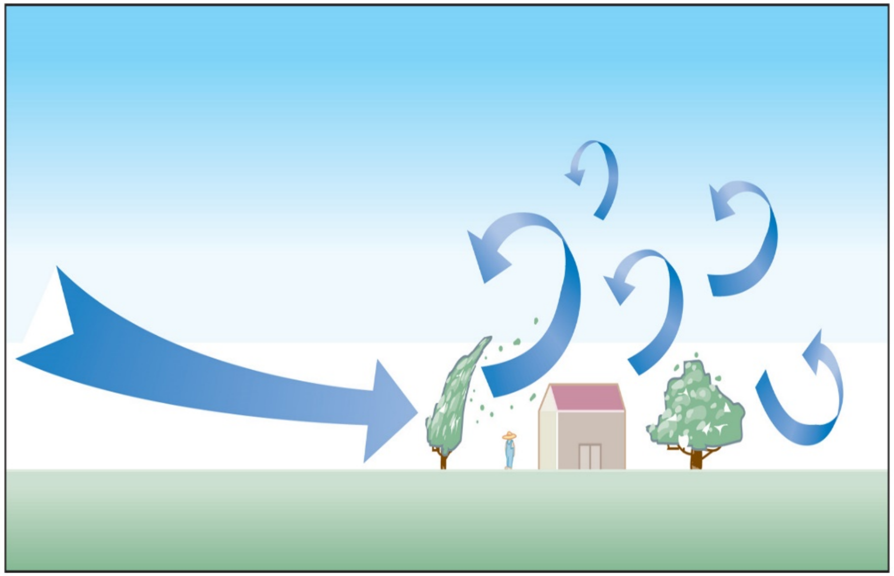
The Energy Balance of Earth

- Conduction and convection!!!

2 types of convection



(a)



Free **Forced**

The Energy Balance of Earth

- One last mechanism of surface/atmosphere heat exchange:

  - **Latent Heat**

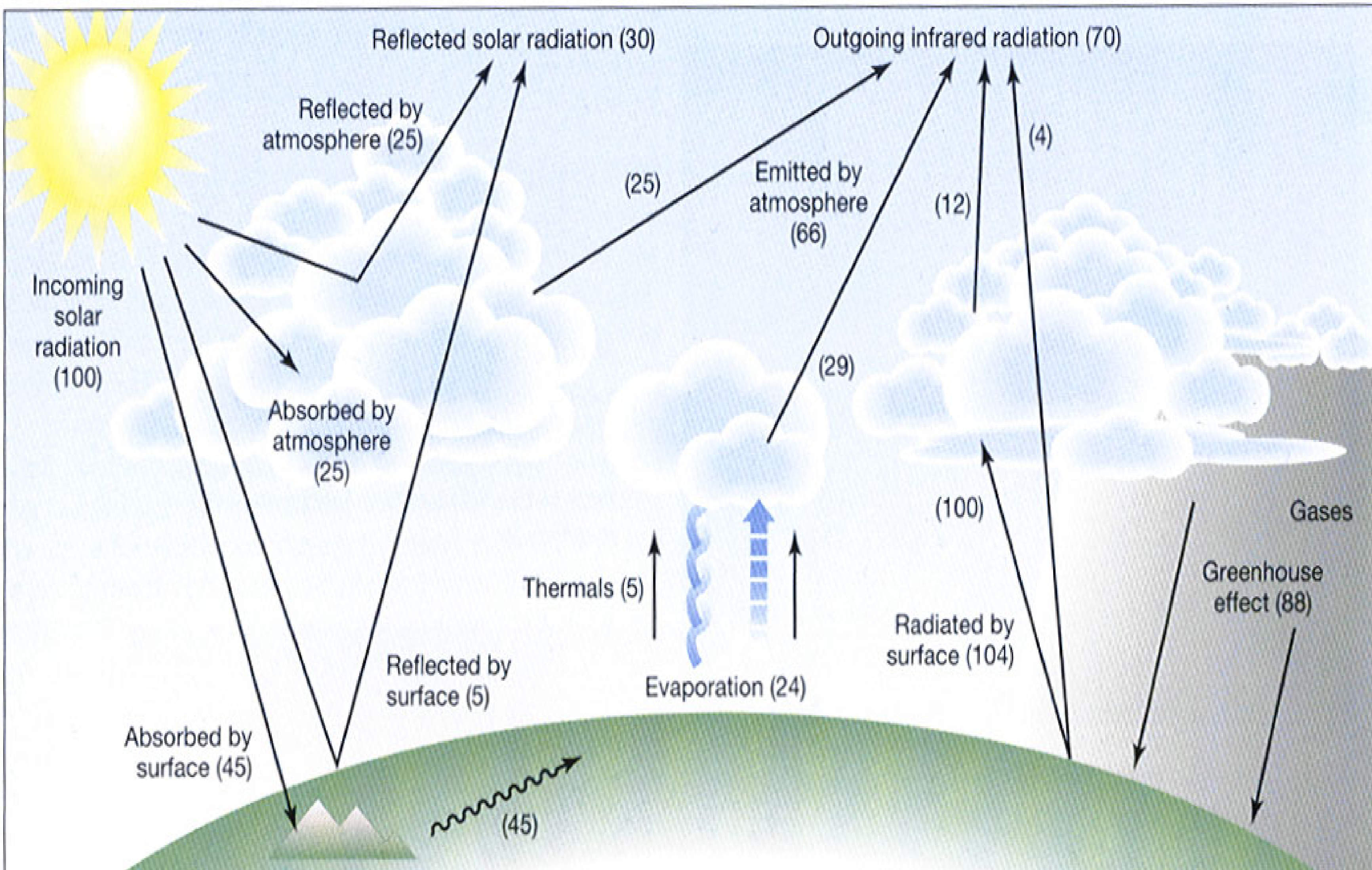
The Energy Balance of Earth

- One last mechanism of surface/atmosphere heat exchange:

  - **Latent Heat**

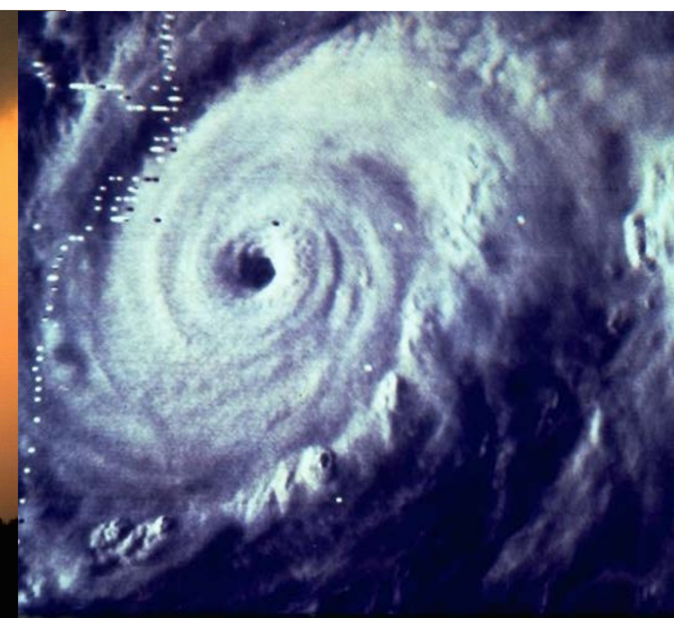
- **Latent heat** is the energy used to change the phase of a substance, and it is transferred in the atmosphere through convection

Typical Energy Balance Diagram



Weather and the Earth’s Heat Balance

- Weather = motion in the atmosphere due to unequal heating
- Over time, the amount of energy lost and received by the atmosphere must be in balance
- But, the atmosphere is not in balance
- Attempt to regain balance → disturbance → weather



Components of Weather

- Temperature & Moisture
- Atmospheric Stability
- Winds
- Masses & Fronts
- Clouds & T-Storms