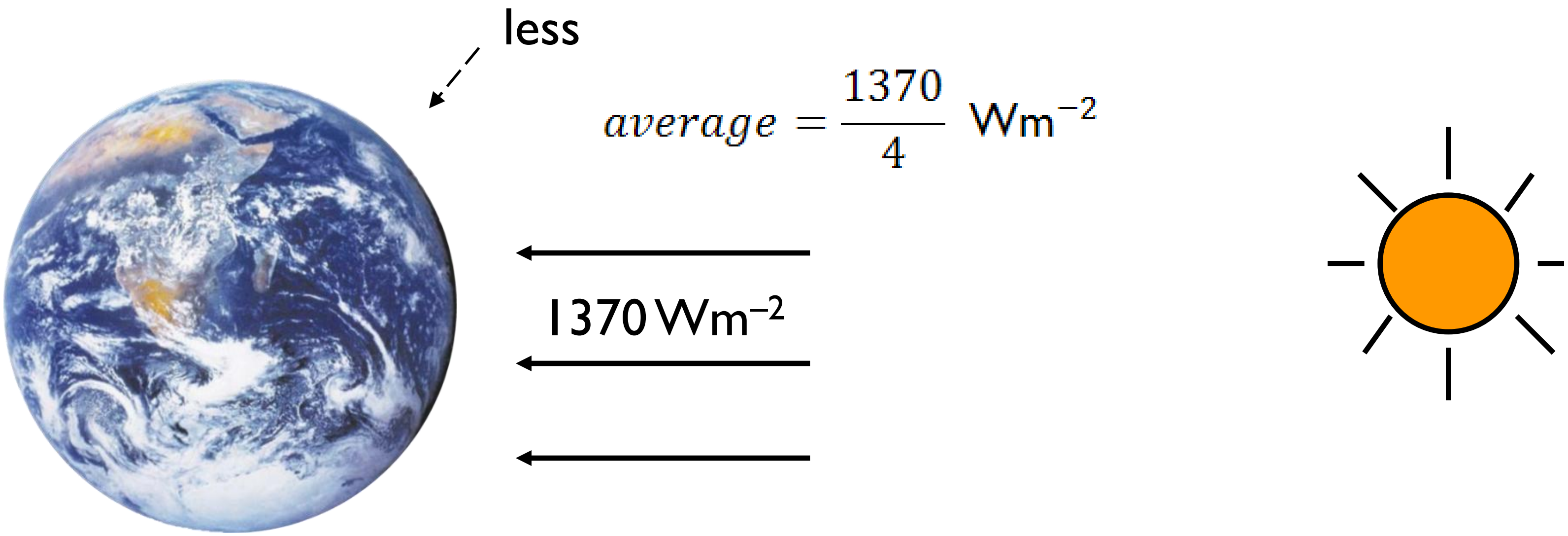
Forest Hydrology: Lect. 2

Contents

- The energy balance
- Climate and climate disturbance
- Global patterns of precipitation

How Earth operates (simplified)

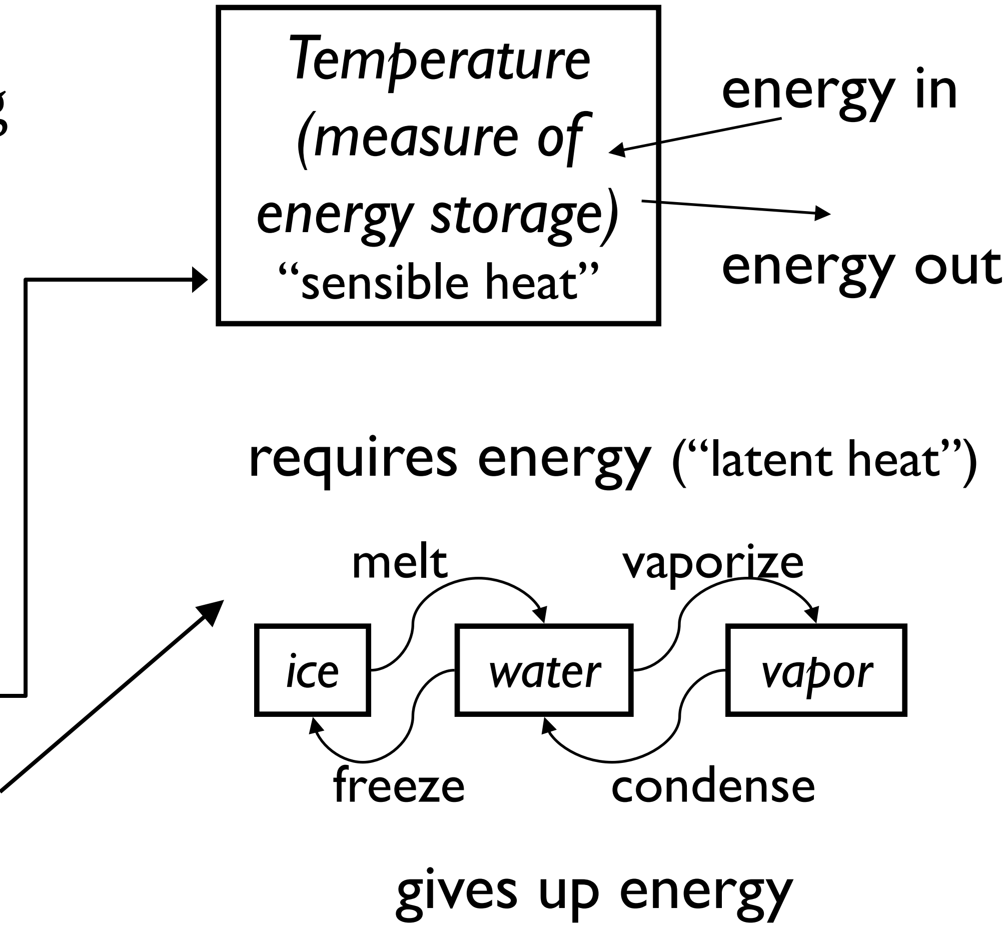


- Some fraction (20-30%) is *reflected* by atmosphere and surface
- Remainder (70-80%) is *absorbed* and emitted at longer wavelengths
  - Some emitted radiation is absorbed in atmosphere
- Imbalance between Equator and Poles causes circulation of atmosphere and ocean
- Heated surface transfers energy to atmosphere
- Water at surface evaporates and moves into atmosphere
  - … and condenses to fall back to surface as precipitation

} and the energy also moves

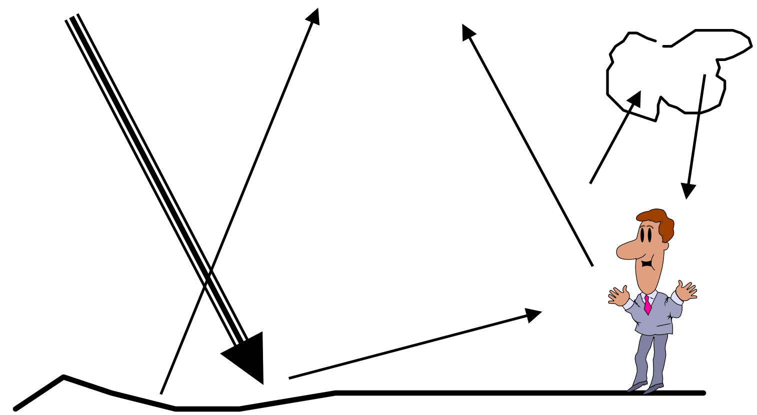
Energy balance principles

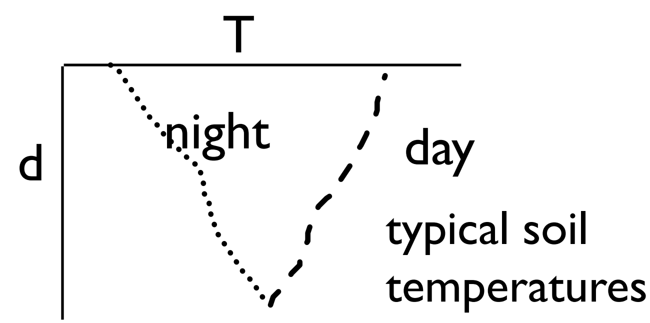
- Energy is the capacity for doing work (i.e. motivating some change in a system)
- "Energy" and "heat" are equivalent
- Energy in – energy out = Δ energy storage
- Δ energy storage ≡ either
  - Δ temperature
  - Δ "phase" of water (solid, liquid, gas)

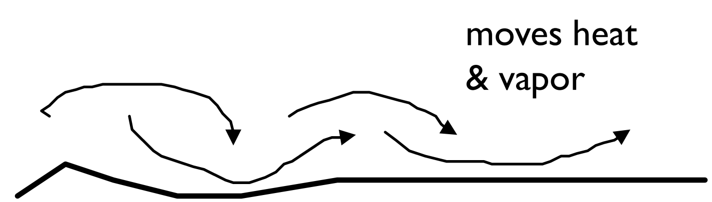


Methods of energy transfer

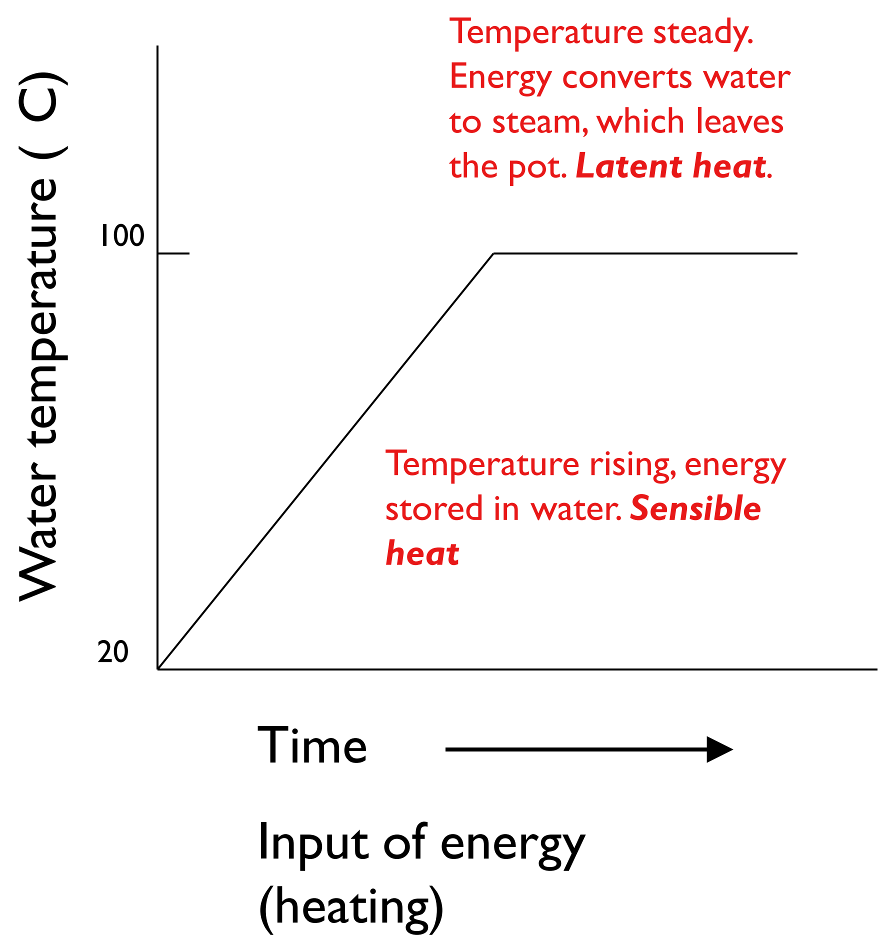
- ***Radiation:*** electromagnetic waves propagate through space
  - all bodies radiate, warmer bodies more
  - interactions depend on wavelength
- ***Conduction:*** molecule-to-molecule
  - hot to cold temperature
- ***Convection:*** mixing in air or water enhances transfer
  - sensible: temperature difference between warmer and colder fluid
  - latent: change of phase of water during mixing







Sensible and latent heat



Radiation

- A body radiates energy when electrons in its atoms receive or generate so much energy that they release a small packet of energy (photon)
- If the atoms are receiving or generating a lot of energy (i.e. they are hot) they emit photons in large numbers and frequently. Thus, both the intensity (energy per unit time) and the frequency of emission are high.
- Since energy (*E*) travels through a vacuum at a constant speed (*c*, the speed of light), if the frequency (*v*) of particle (wave) emission is high, the wavelength (λ) is short: $\nu = c/\lambda$
- Planck's law: energy per photon$= h\nu = h/\lambda$

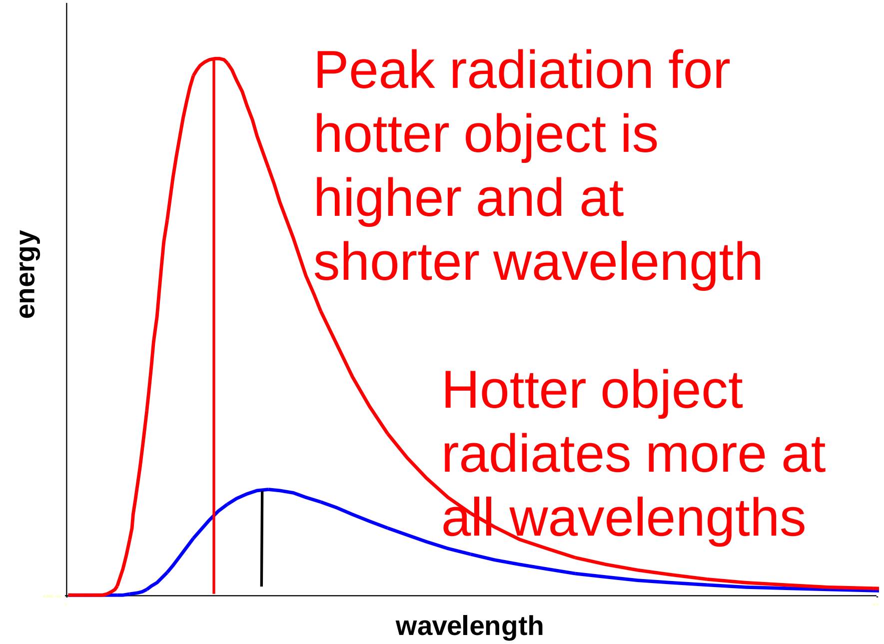
h is Planck's constant

Two rules describing radiation:

- ***1. Planck's equation***

$$L_\lambda = \frac{2hc^2}{\lambda^5 \left(e^x - 1\right)}, \text{ where } x = \frac{hc}{k\lambda T}$$

  - At a given temperature a body emits a spectrum of wavelengths and the intensity of radiation varies with the wavelength



c = speed of light = 3.0 x 10^8 ms^{-1}

h = Planck's constant = 6.63 x 10^{-34} Js

k = Boltzmann's constant = 1.38 x 10^{-23} JK^{-1}

Integration over all wavelengths (derived from Planck's equation)

- ***2. Stefan-Boltzmann equation***

$$E = \pi \int_0^{\infty} L_\lambda d\lambda = \varepsilon \sigma T^4$$

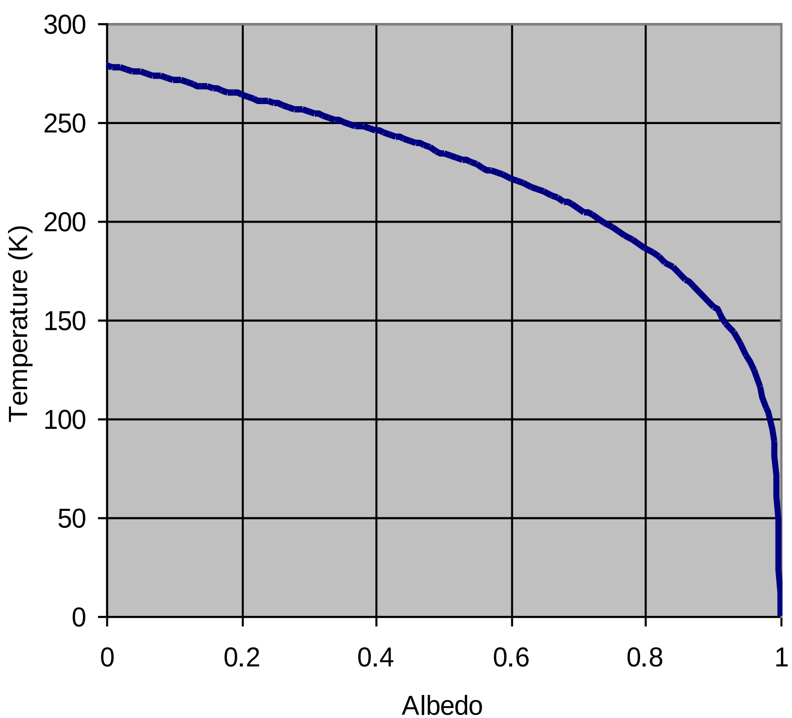
  - E = energy emitted (W m^{-2})
  - T = temperature (K)
  - σ = Stefan-Boltzmann constant = 5.67 x 10^{-8} W m^{-2} deg^{-4}
  - ε = emissivity (ratio of radiation from the material to that from an ideal 'blackbody' at same temperature). 0.9-0.99 for most natural materials, but 0.01-0.05 for aluminum foil, for example.

- Energy from the Sun (T = 5800 K) = 6.4 x 10^{7} W m^{-2}
- Energy from Earth (T = 288 K) = 390 Wm^{-2}

The simplest climate model—energy balance with a non-absorbing atmosphere

- Solar radiation absorbed by whole Earth = infrared radiation emitted by whole planet
  - *i.e., net all-wave radiation = 0*

- S_0 = solar radiation
- α = planetary average albedo
- $F_{\uparrow}$ = infrared radiation
- T = planetary surface temperature



$$\frac{S_o}{4}(1-\alpha) = F_{\uparrow} = \varepsilon\sigma T^4$$

$$so, T = \left[\frac{S_0}{4\varepsilon\sigma}(1-\alpha)\right]^{1/4}$$

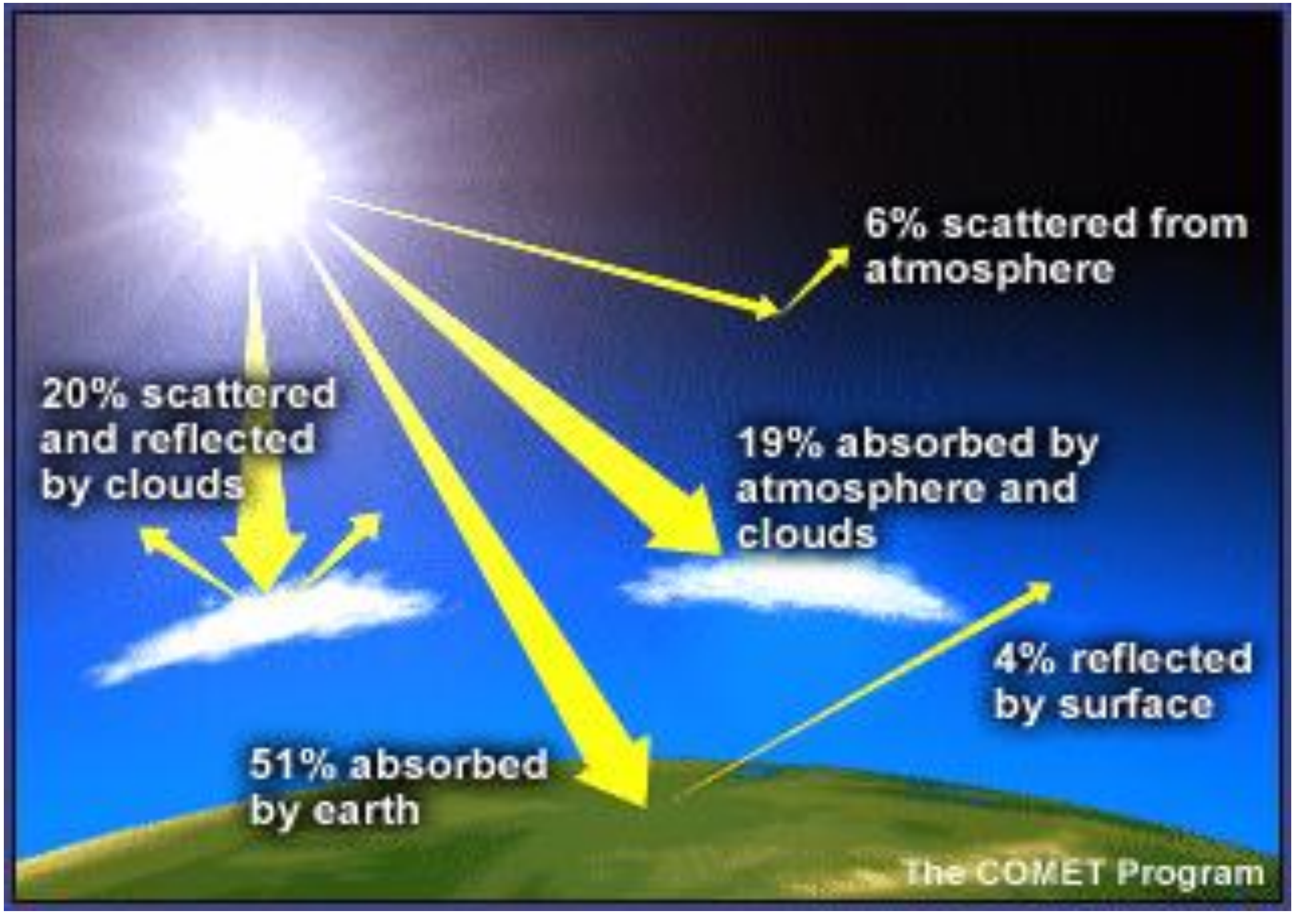
- ε ≈ 0.90-0.95, σ = 5.67 10^{-8}

- S_0 = 1370 W m^{-2} normal to Sun
  - Divide by 4 to average over Earth, 342.5 Wm^{-2}
- Albedo ≈ 0.27-0.33 (see Charlson)
- Thus T ≈ 255 K = –18 C

Interpretation

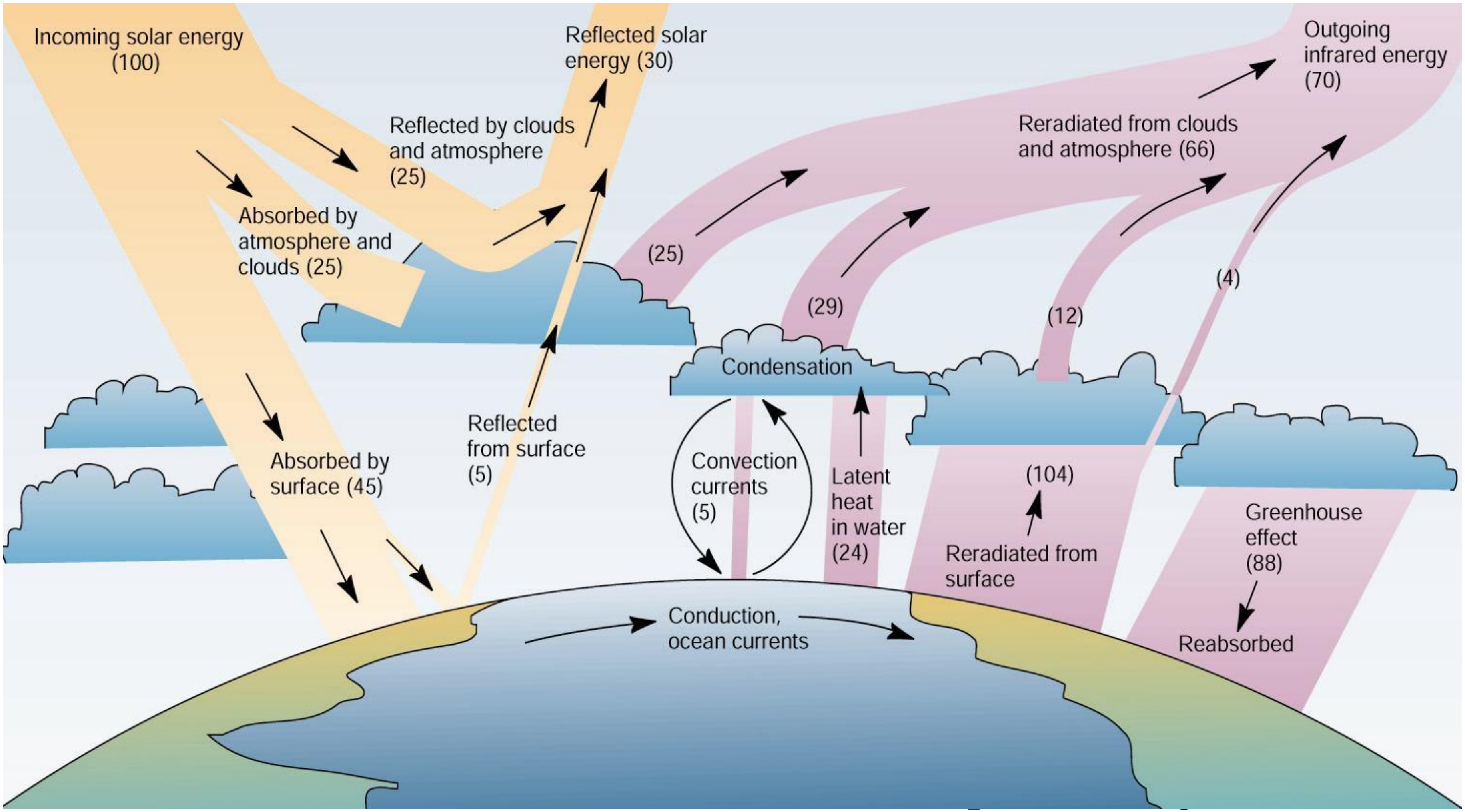
- If the atmosphere didn’t absorb radiation, the global average temperature should be about –18 C.
- Near the surface, average air temperature is measured to be about 16 C.
- The discrepancy must be due to the role of the atmosphere in absorbing energy and storing it near the surface.
- This interaction between solar radiation and the atmosphere begins the processes of energy transfer that create climate

Radiation balance - 1

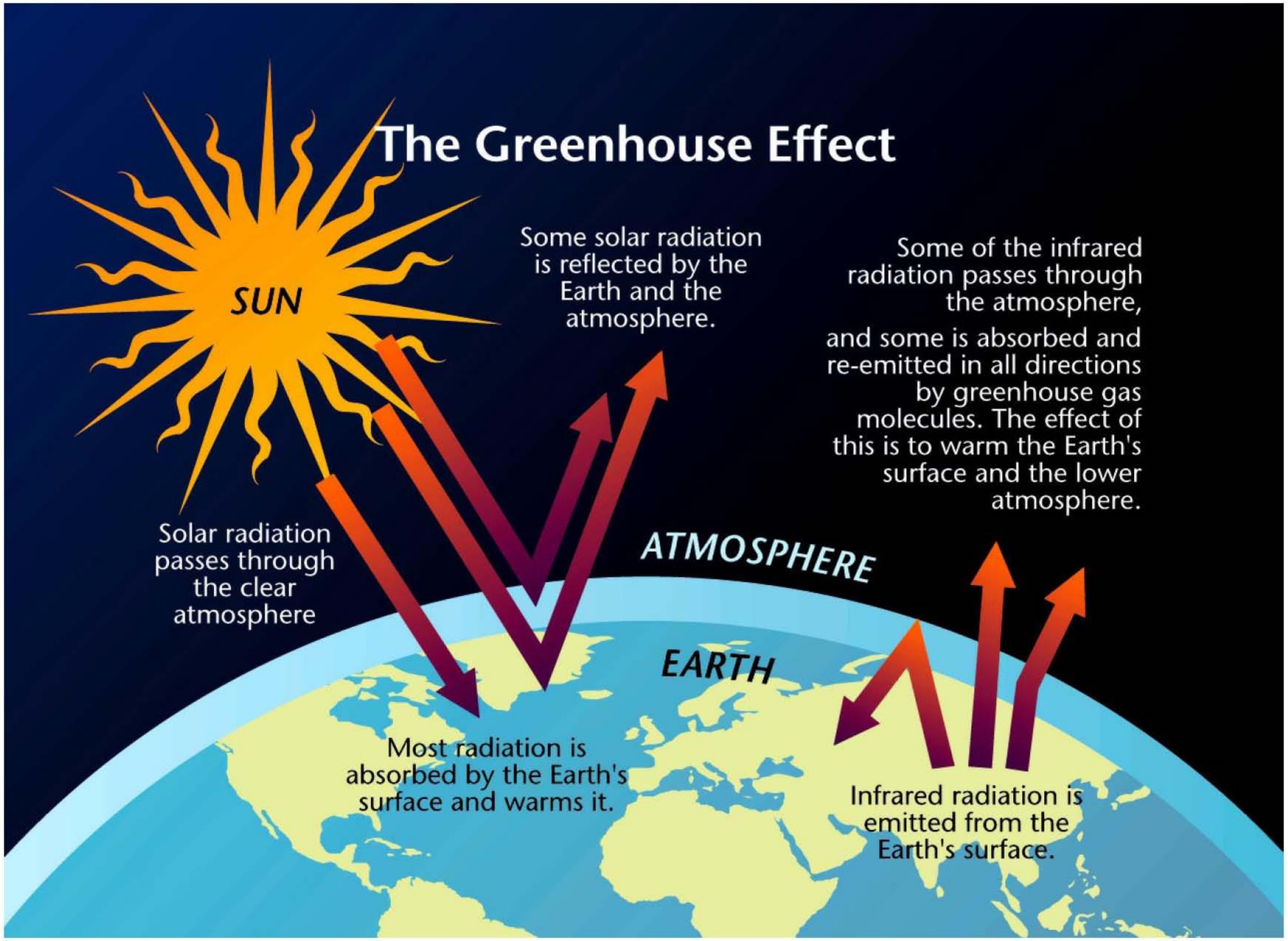


www.windows.ucar.edu/earth/Atmosphere/images/...

Radiation balance - 2



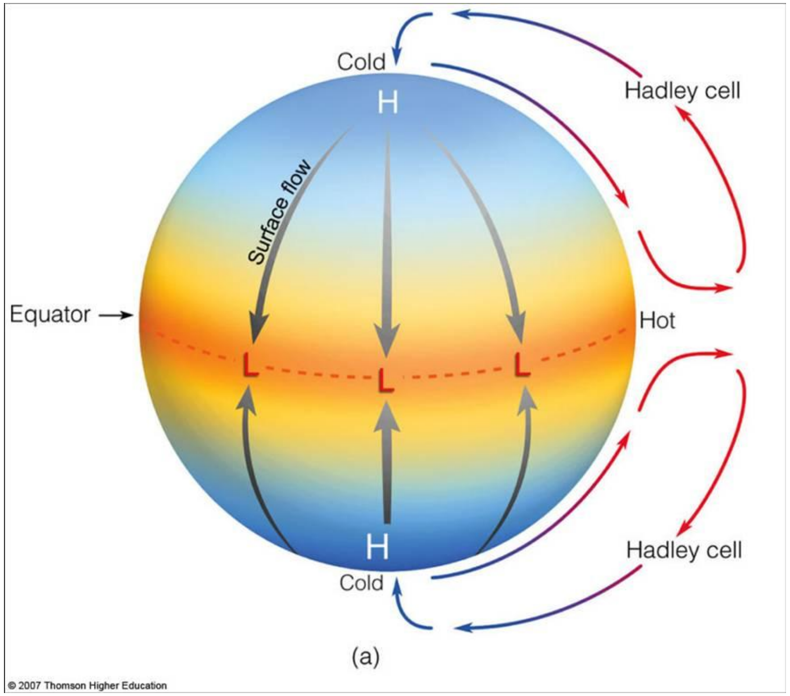
Radiation balance – The greenhouse effect



Wind and circulation patterns - 1

The major driving force of atmospheric circulation is solar heating, which on average is largest near the equator and smallest at the poles.

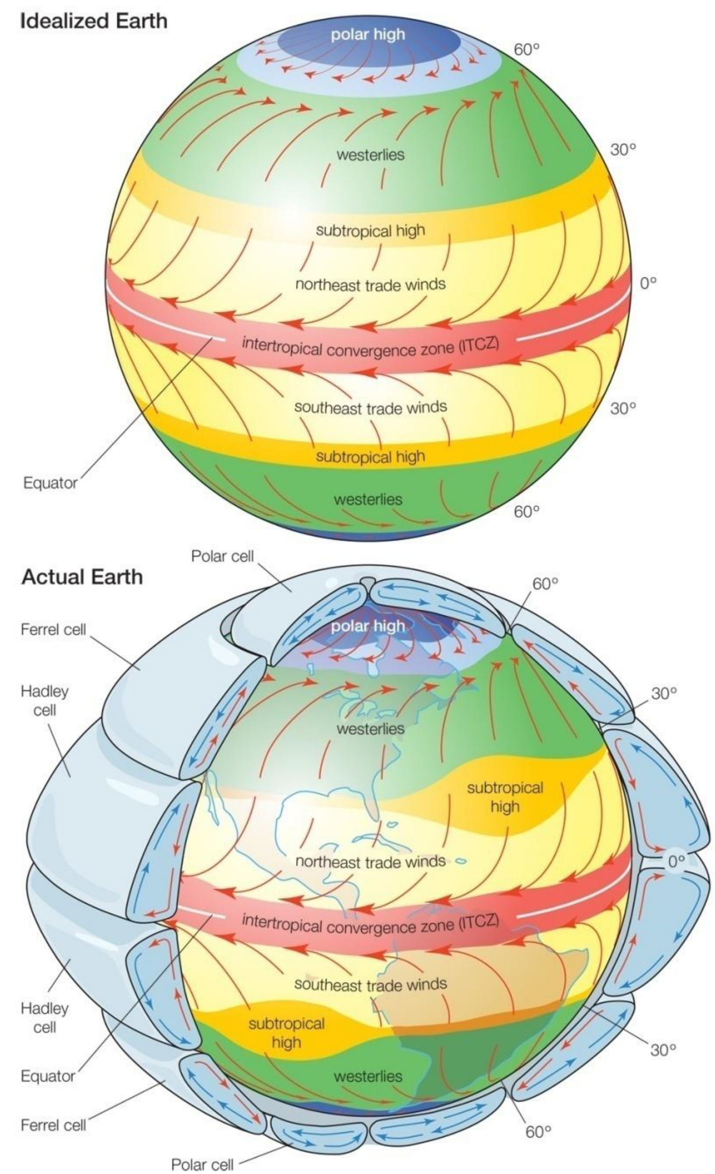
The atmospheric circulation transports energy polewards, thus reducing the resulting equator-to-pole temperature gradient. The mechanisms by which this is accomplished differ in tropical and extratropical latitudes.



Wind and circulation patterns - 2

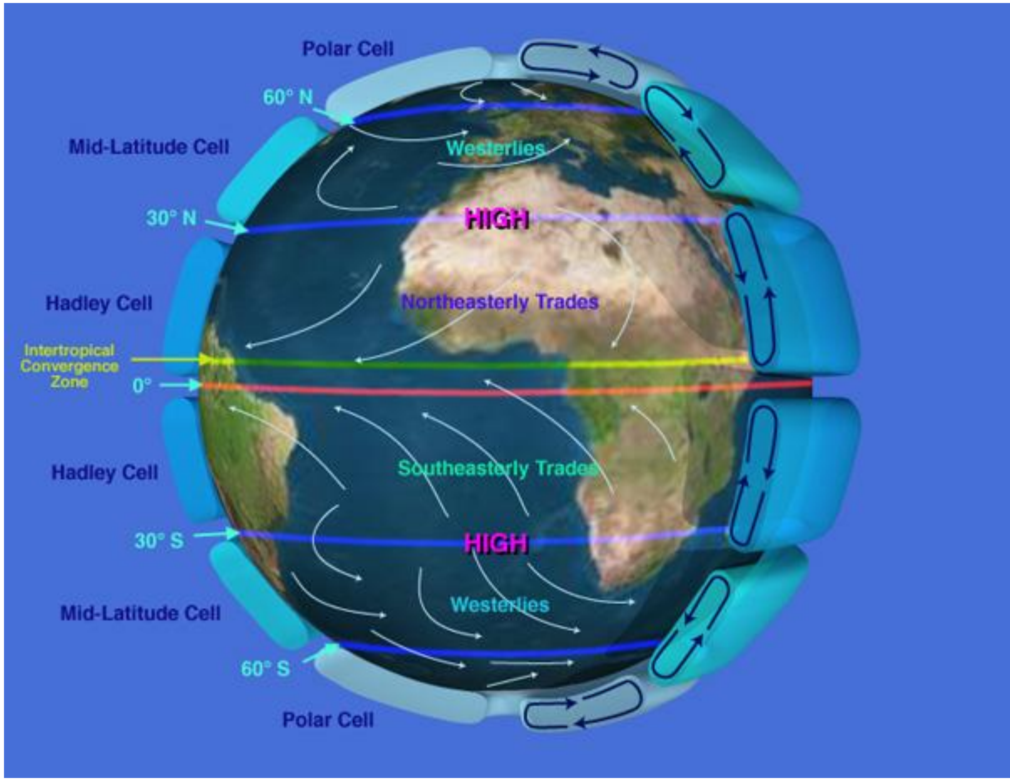
Between 30°N and 30°S latitude, this energy transport is accomplished by a relatively simple overturning circulation, with rising motion near the equator, poleward motion near the tropopause, sinking motion in the subtropics, and an equatorward return flow near the surface. In higher latitudes, the energy transport is instead accomplished by cyclones and anticyclones that cause relatively warm air to move polewards and cold air to move equatorwards in the same horizontal plane. The tropical overturning cell is referred to as the Hadley cell. Questions as to why it extends only to 30 degrees latitude and what determines its strength are at the heart of modern dynamical

meteorology..



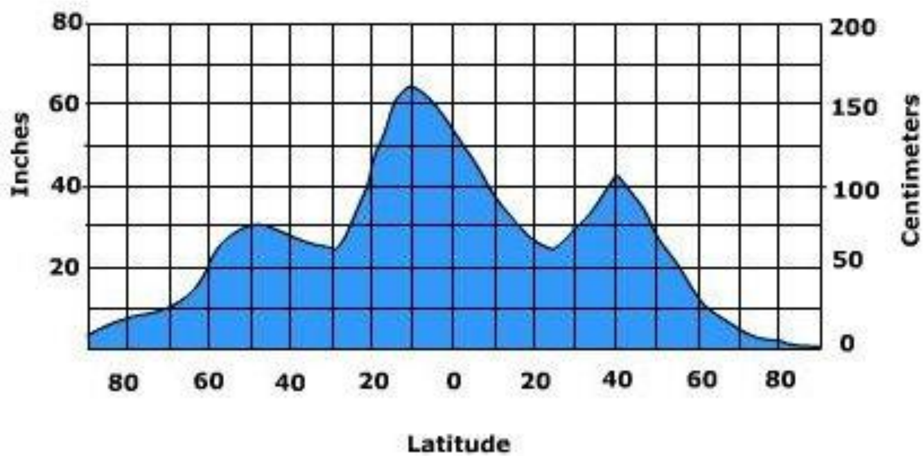
Wind and circulation patterns - 3

The region in which the equatorward moving surface flows converge and rise is known as the intertropical convergence zone, or ITCZ, a high-precipitation band of thunderstorms. Having lost most of its water vapor to condensation and rain in the upward branch of the circulation, the descending air is dry. Low relative humidities are produced as the air is adiabaticalley warmed due to compression as it descends into a region of higher pressure. The subtropics are relatively free of the convection, or thunderstorms, that are common in the equatorial belt of rising motion. Many of the world's deserts are located in these subtropical latitudes.

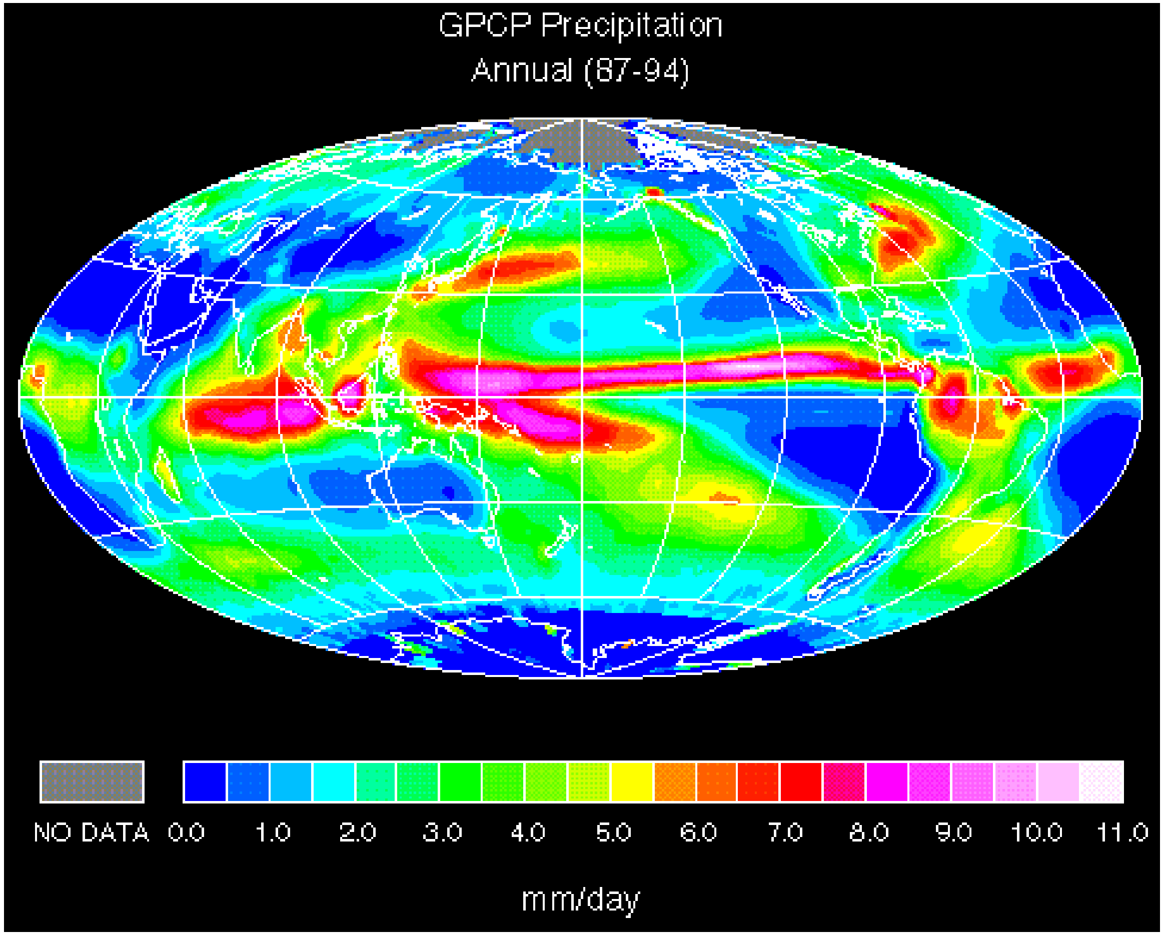


Latitudinal distribution of precipitation

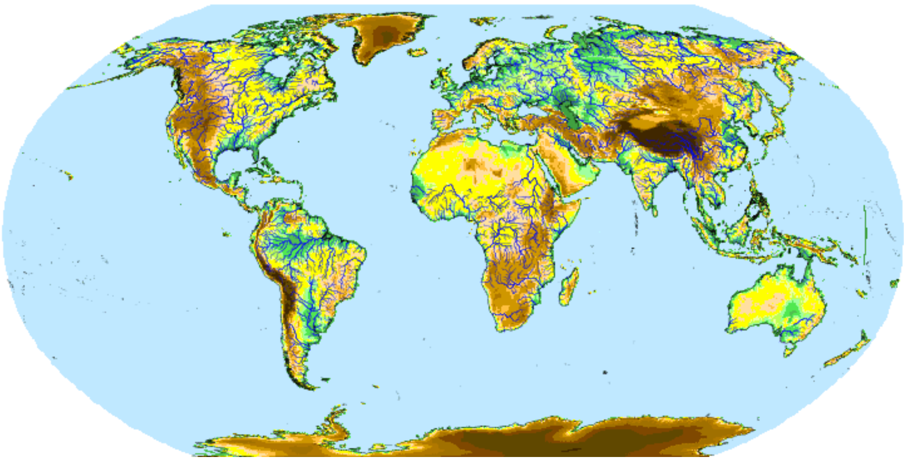
Precipitation near the equator is high due in part to the influence of the Intertropical Convergence Zone. Here, convection and low pressure dominate and provide lift for the air throughout much of the year. At about 30° north and south latitude precipitation decreases due to the presence of the subtropical high pressure systems. Precipitation increases in the midlatitudes where vastly contrasting air masses collide along weather fronts to cause precipitation. As one approaches the poles, precipitation decreases on account of the cold temperature and its associated low saturation point.



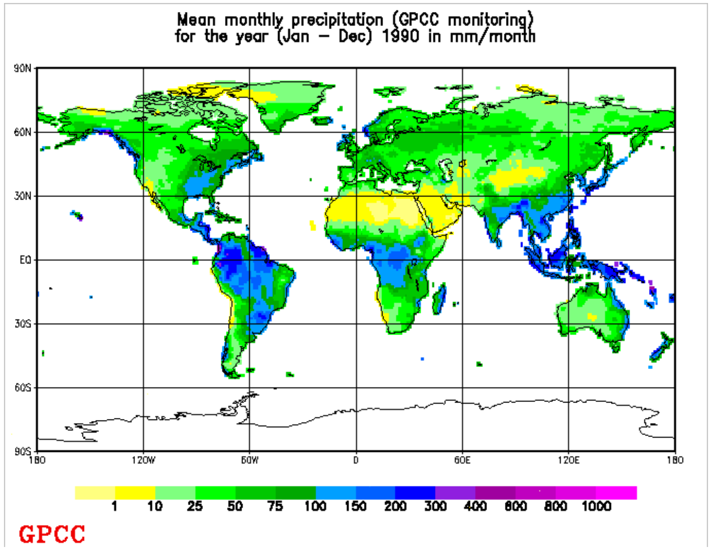
Spatial distribution of precipitation (from satellites)

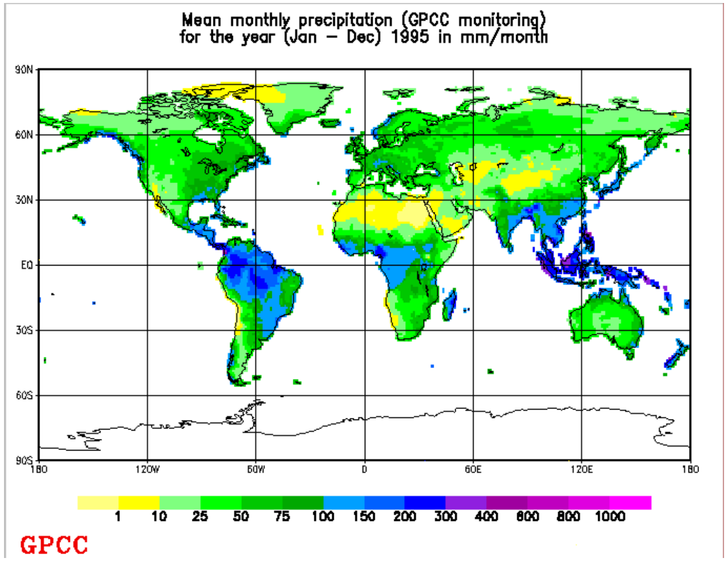


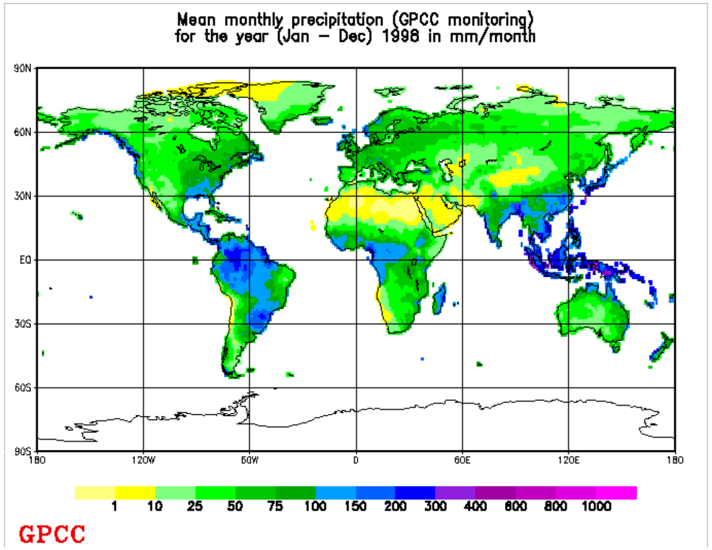
Spatial distribution of precipitation (from raingauges)



Global altimetry







NEXT: Climate and vegetation