Global Heat Fluxes

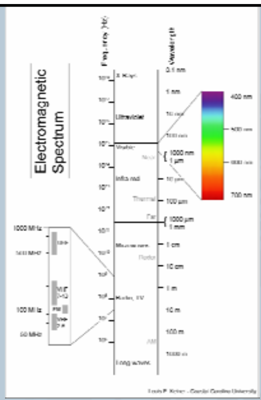
MSCI 301
Physical Oceanography
Coastal Carolina University

Outline

- Motivations
- Electromagnetic Spectrum
- Solar Radiation
- Back Ratiation
- Evaporation
- Conduction
- Advection
- Heat Balance

Electromagnetic Radiation

$$c = \lambda f$$



Wavelength

What is the frequency of your favorite radio station?

Calculate the wavelength of its waves.

Emissions:

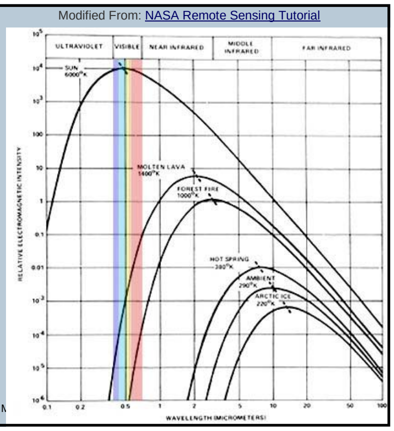
- Wien's Displacement Law:

$$\lambda(\mu m) = \frac{2897.8\mu m}{T(^{\circ}K)}$$

If the sun has a surface temperature of 5900K,
What is its wavelength of maximum radiation?
What kind of radiation is this?

Modified From: NASA Remote Sensing Tutorial

'Blackbody' Spectra



Power from the Sun

The sun's Power output is roughly 3.825×10^{26} Watts. (J/s)

If the earth is 1.496×10^{11}m from the sun, how many Watts of power hit every m^2 at the surface of the earth's atmosphere?

"Q_s"

Variations

- Earth's elliptical orbit:
  - Equinox precession – 22,000 year period
  - Eccentricity variations – 100,000 year period
- Earth's tilt:
  - 23.5° now
  - Varies from 22° to 24.5° - 41,000 year period

Seasonal Changes in Earth's Orbit

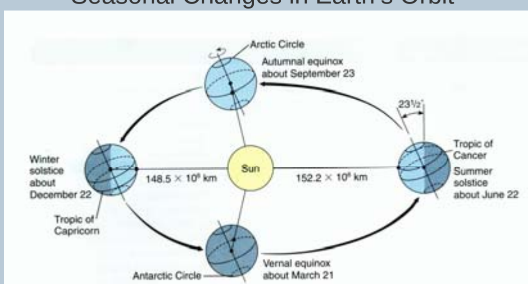
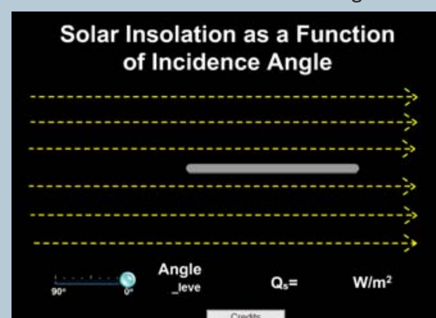


Figure 1.5 So why do we have seasons?

(Duxbury)

Heat Flux and Incident Angle



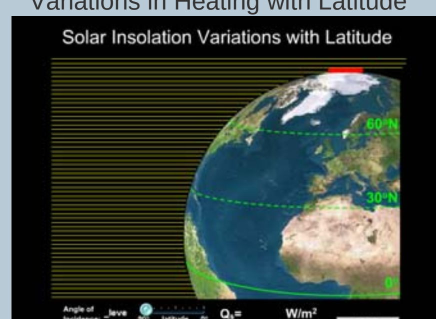
Online Animation Version

Sun Incidence Angle

(Duxbury)

- Results in unequal amounts of solar radiation incident on the atmosphere at different latitudes
- Tropics receive more heat than higher latitudes

Variations in Heating with Latitude



Online Animation Version

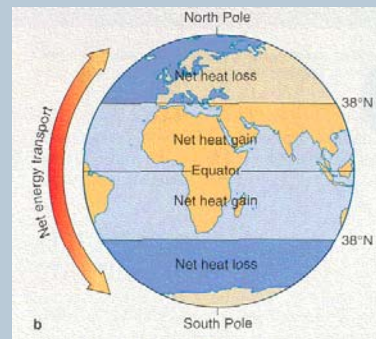
Incident Angle Problem

What is the solar power that hits the surface of the atmosphere above us (33° latitude) at the Summer and Winter Solstices?

Remember the solar constant is 1360 W/m^2 and the earth's tilt is 23.5°.

Now do the same for the North Pole.

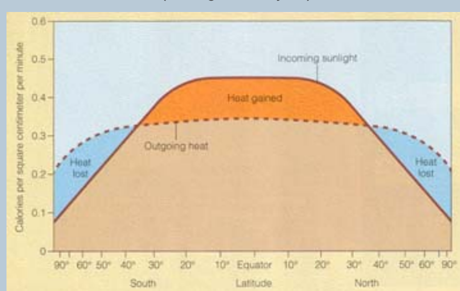
Global Average Heat Flux



(Garrison)

Unequal Heating

(Average over a year)



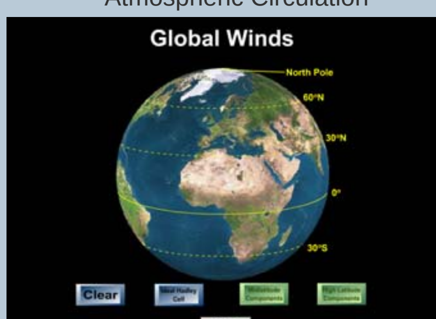
(Garrison)

Atmospheric Convection

Assuming no Coriolis Effect!

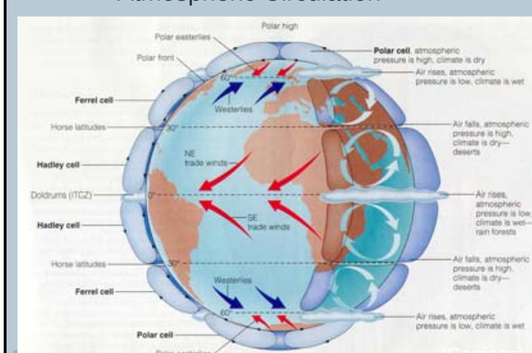
(Garrison)

Atmospheric Circulation



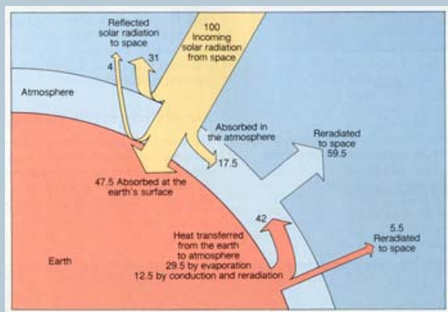
Online Animation Version

Atmospheric Circulation



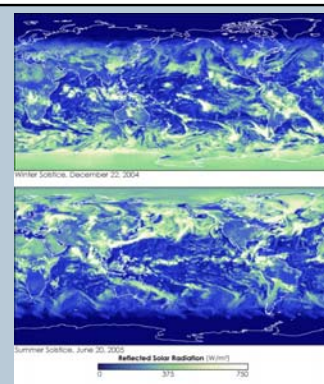
(Garrison)

Earth's Heat Budget



(Duxbury)

Albedo



Solar Heating Problem

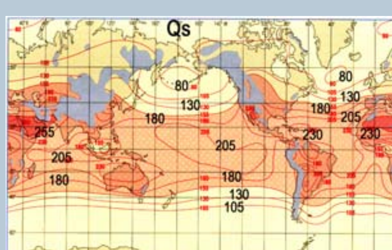
You are measuring the heat fluxes in the ocean off of SC (33° latitude). You calculate that of the total incoming solar radiation, 25% is reflected by clouds and 20% is absorbed in the atmosphere. What is the solar power that hits a m^2 of sea (in W/m^2) on June 21 and Dec 21?

Water Heating Problem

If all of the incoming power is efficiently converted into heat, how many degrees will the ocean warm over the course of a day? (Approximate a summer day as 9 hours of constant sunlight and a winter day as 6 hours.)

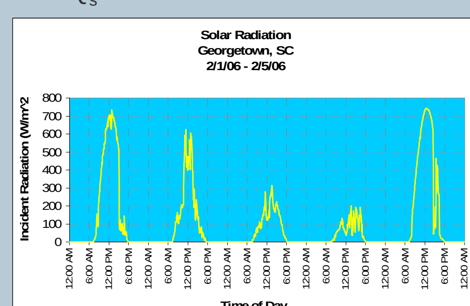
We'll assume c_{water} = 4186 J/kg°C
Use a density of 1028 kg/m^3.

Global Solar Heating (Q_s)



Why are these values generally smaller than the heating you just calculated at the same latitude?

Real Q_s



Heat Balance Equation (preview)

$$Q_t = Q_s - Q_b - Q_e - Q_h \pm Q_v$$

$$Q_t > 0 \Rightarrow \text{ water is heating up}$$
$$Q_t < 0 \Rightarrow \text{ water is cooling down}$$

Generally calculated per second and per m^2. (W/m^2)

Oceanographers often still use Q for this heat *flux*.

Back Radiation

Since the Earth's temperature is above absolute zero, it radiates energy. The *wavelength* of maximum radiation was given by Wien's Law:

$$\lambda(\mu m) = \frac{2897.8\mu m}{T(^\circ K)}$$

What we are concerned with now is the amount of heat energy that leaves the surface of the Earth.

Stefan-Boltzmann Law

The power (heat energy per time) per area radiated from the surface of an object is given by:

$$P/A = c_{sb}\, T(K)^4$$

$$c_{sb} = 5.67 \times 10^{-8}\ W/m^2K^4$$

Back Radiation Problem

How much power is radiated from an average m^2 of the ocean surface?

(In other words, how much heat energy is lost every second by a m^2 of the ocean?)

$$P/A = c_{sb}\, T(K)^4$$
$$P/A = \left(5.67 \times 10^{-8}\ W/m^2K^4\right)(292\,K)^4$$
$$P/A = 412\ W/m^2$$

So the average m^2 of ocean loses about 400 J of heat energy every second from back radiation.

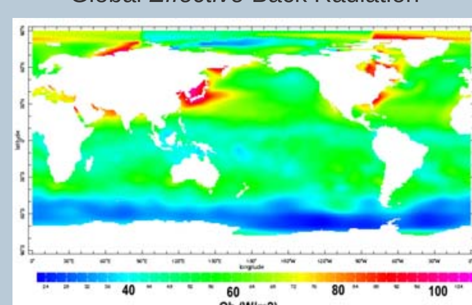
Effective Back Radiation

Most of the heat energy that is back radiated never escapes into space. It is reflrctsd back to the ocean by clouds or absorbed by the atmosphere and eventually re-radiated back to the ocean.

The part that does escape (the *effective* back radiation Q_b) is usually only about 50-75 W/m^2.

(Think about what the temperature does on cloudy nights as opposed to clear nights)

Global *Effective* Back Radiation



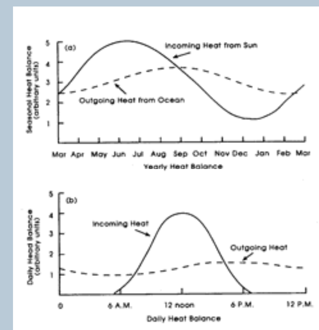
Heat Balance Problem

Draw a graph showing Q_s and Q_b for a certain spot over a 24 hour period.

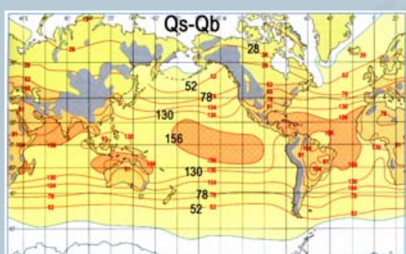
Draw a graph showing Q_s and Q_b for a certain spot in the ocean over an entire year.

Heat Balance

$$Q_T = Q_s - Q_b$$



Global Q_s - Q_b



Evaporative Heat Loss (Latent Heat Flux)

It takes energy to evaporate seawater, roughly 2400 J/g. When water is evaporated, this energy is lost from the ocean.

Yes, that's 2,400,000 J/kg.

Latent Heat Loss Variables

Evaporation depends *mainly* on two variables:

- *Wind Speed*
- Difference in Humidity of the air layer just above the water and the humidity of the air above.

Q_e

$$Q_e = c_e\,(e_w - e_a)\,W$$

c_e is a constant
e_w is the *specific* humidity at the water's surface
e_a is the *specific* humidity of the air above the water
W is the wind speed

This is a very simplified and approximate equation. It's main use is to show you which variables are important in evaporative heat loss.

Digression on Humidity

Specific Humidity

$$\frac{\text{mass of water in the air}}{\text{total mass of air}}$$

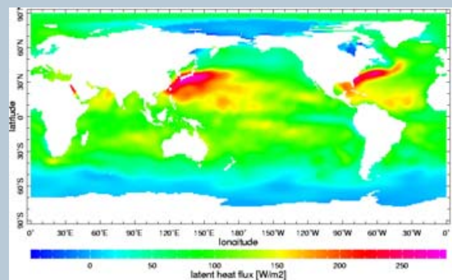
Relative Humidity

$$\frac{\text{amount of water in the air}}{\text{amount of water the air can hold}}$$

Dew Point

temperature at which condensation occurs

Global Latent Heat Flux



Latent Heat Problem

If a certain spot in the ocean loses 0.5 cm of water a day to evaporation, how much heat energy is lost per day per m^2?

How much energy is lost per second? (W/m^2)

Conductive Heat Loss (Sensible Heat Flux)

From the Zeroth Law of Thermodynamics, heat will flow from an object with a higher temperature to an object with a lower temperature. This conductive heat loss happens when the ocean is warmer than the air.

Water / Air heating questions

What happens when the air just above the water is warmed?

What happens when the air is warmer than the water? Why don't we care about that case?

Sensible Heat Loss Variables

Conduction depends *mainly* on two variables:

- Wind Speed
- Difference between the air and water temperatures

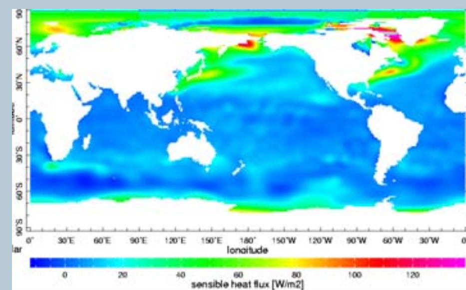
Q_h

$$Q_h = c_s\,(T_w - T_a)\,W$$

c_h is a constant
T_w is the temperature at the water's surface
T_a is the temperature of the air above the water
W is the wind speed

This is a very simplified and approximate equation. It's main purpose is to show you which variables are important in sensible heat loss.

Global Sensible Heat Flux



Bowen's Ratio

$$R = {Q_h}/{Q_e}$$

The ratio of sensible heat loss to latent heat loss in a certain spot in the ocean.

Heat Advection (Q_v)

Heat can also be transported by the movement (advection) of water.

The subtropical gyre systems move huge amounts of heat from low latitudes to high latitudes.

Heat Balance Equation

$$Q_t = Q_s - Q_b - Q_e - Q_h \pm Q_v$$

$$Q_t > 0 \Rightarrow \text{water is heating up}$$
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Q_t