Overview: Follow the Energy

Energy flows downhill from hot to cold

Earth's energy budget

Weather and Climate involve Earth's energy flowing from warm places to cold places

Defining Energy is Hard!

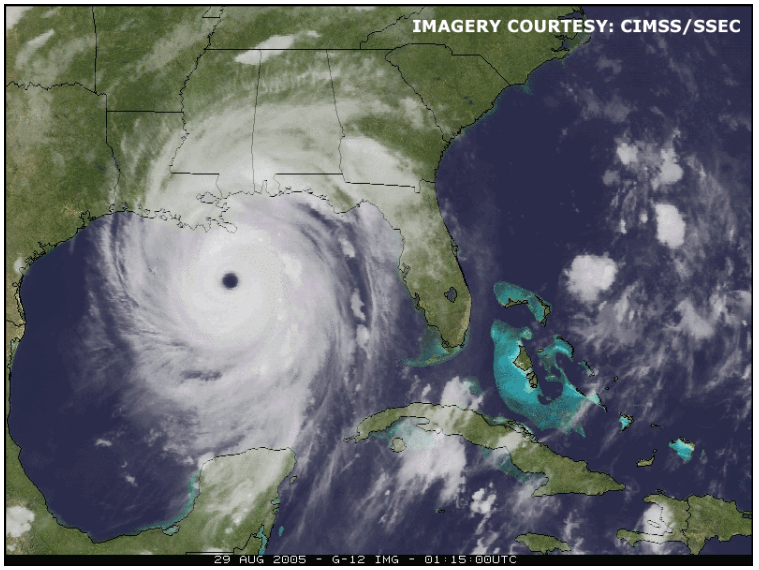
- "Energy is the capacity to perform work"
  - (but physicists have a special definition for "work," too!)
- Part of the trouble is that scientists have "appropriated" common English words and given them special meanings
- But part of the trouble is that the concept of energy is absolutely central to understanding the physical world, yet is very hard to define precisely

"Energy Changes Make Things Happen"

Dave Watson, http://www.ftexploring.com

- Energy is a property or characteristic of matter that makes things happen, or, in the case of stored or potential energy, has the "potential" to make things happen.
- Without energy, nothing would ever change, nothing would ever happen. You might say energy is the ultimate agent of change, the mother of all change agents.

Hurricane Andrew Devastation in Homestead, Florida
August 24, 1992



Conservation of Energy

- Energy can be stored
- Energy can move from one piece of matter to another piece of matter
- Energy can be transformed from one type of energy to another type of energy

- **The First Law of Thermodynamics:**
  - **During all this moving and transforming the total amount of energy never changes.**

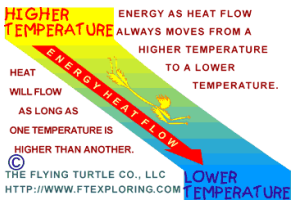
Kinds of Energy

- Radiant Energy -- light
- Kinetic Energy -- motion
- Gravitational Potential Energy -- height
- "Internal Energy"
  - Temperature, Pressure -- hot air
  - Chemical energy
  - Nuclear energy

- Conversions among different kinds of energy power all that happens in the weather and climate!

If Energy is Conserved …
then why do we need to "conserve energy?"

- Total energy is conserved (First Law), but not its usefulness!
- Second Law of Thermodynamics: Energy **flows "downhill"** from highly concentrated (hot) forms to very dilute (cold) forms



- Gasoline burned in your car (hot) makes it move
- Turbulence and friction of tires on road dissipated as heat
- Heat radiated to space (cold)

It all starts with the Sun

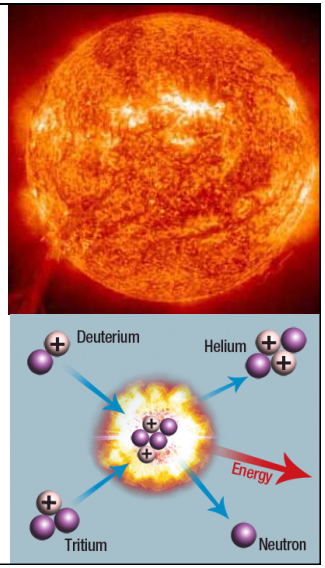
- Nuclear fusion in the Sun powers all changes on the Earth!
- Solar energy heats the air, lifts it, blows it around, evaporates water, makes snowstorms
- Conversion of solar energy and downhill dissipation as heat energy drive all weather and climate phenomena
- Energy comes in hot, and goes out cold, at 342 W m^{-2}

Only Four Forces in the Universe!

- Gravity
- Electromagnetism
- "Strong" nuclear force
- "Weak" nuclear force

How the Sun Works!

- The immense pressure and a temperature of 16 million degrees C force atomic nuclei to fuse and liberate energy
- About four million tons of matter is converted into sunlight every second



What is Temperature?

- Temperature is a measure of the kinetic (motion) energy of air molecules
  - K.E. = $\frac{1}{2}$ mv^2 m = mass, v = velocity
  - So…temperature is a measure of air molecule speed

(show web applet)
VideoStuff/Molecular_Motion.webarchive

- The sensation of warmth is created by air molecules striking and bouncing off your skin surface
  - The warmer it is, the faster molecules move in a random fashion and the more collisions with your skin per unit time

Energy Transfer Processes

- *Conduction* - molecules transfer energy by colliding with one another
- *Convection* - fluid moves from one place to another, carrying its heat energy with it.
  - In atmospheric science, convection is usually associated with vertical movement of the fluid (air or water).
  - Advection is the horizontal component of the classical meaning of convection.
- *Radiation* - The transfer of heat by radiation does not require contact between the bodies exchanging heat, nor does it require a fluid between them.

Conduction - Heat Transfer

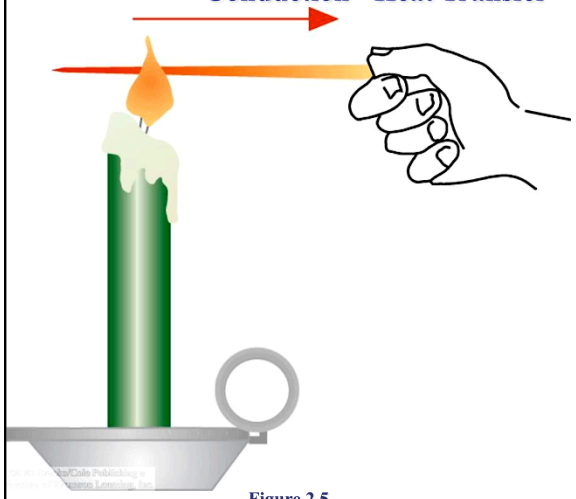
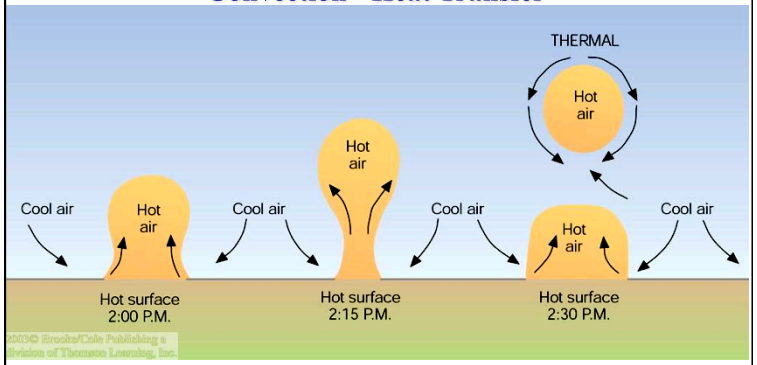


Figure 2.5

Conduction of heat energy occurs as warmer molecules transmit vibration, and hence heat, to adjacent cooler molecules.

Warm ground surfaces heat overlying air by conduction.

Convection - Heat Transfer



Convection is heat energy moving as a fluid from hotter to cooler areas.

Warm air at the ground surface rises as a thermal bubble, expends energy to expand, and hence cools.

Electromagnetic Radiation

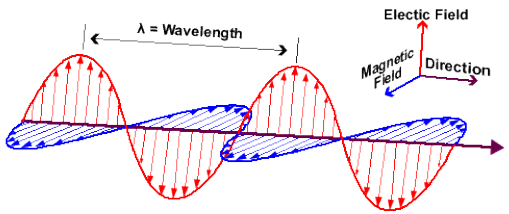
Changing electric fields create changing magnetic fields …

and vice versa!

This makes energy move through space

We can see it, feel it

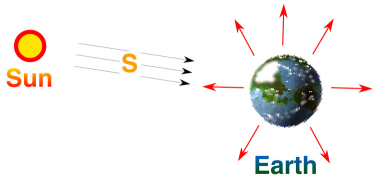
Plants harvest it directly, and we harvest them!



Travels at 3×10^8 m/s
= 186,000 miles / sec !

Distance it goes in one cycle is called the wavelength

Planetary Energy Balance



Energy In = Energy Out

$$S(1-\alpha)\pi R^2 = 4\pi R^2 \sigma T^4$$

$$T \approx -18^{\circ}\mathrm{C}$$

But the observed T_s is about 15° C

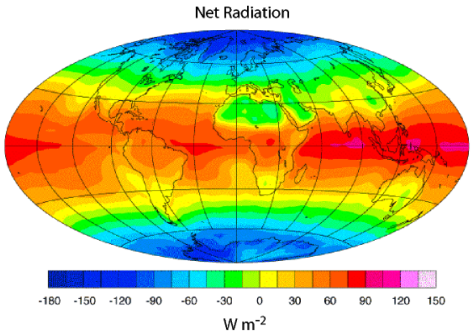
What's Missing
from the 0-D energy balance model?

- Vertical structure
  The "greenhouse effect"
- Energy storage and transport
  The "general circulation" of the atmosphere and oceans

Vertical Structure is Crucial

- The world is a big place, but the atmosphere is very thin, and most of it is close to the ground
  - About 15% of the atmosphere is below our feet
  - At the top of Long's Peak, the figure is 40%
  - You are closer to outer space than you are to Colorado Springs!
- Changes in atmospheric temperature with height are responsible for the "Greenhouse Effect," which keeps us from freezing to death

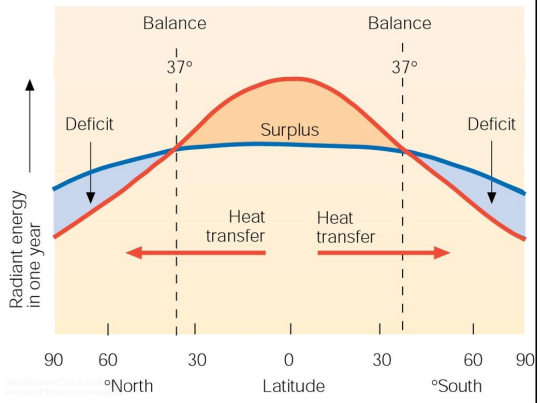
Net Accumulation of Energy



- Incoming (solar) minus outgoing energy
- Must be balanced by horizontal transport of energy by atmosphere and oceans!

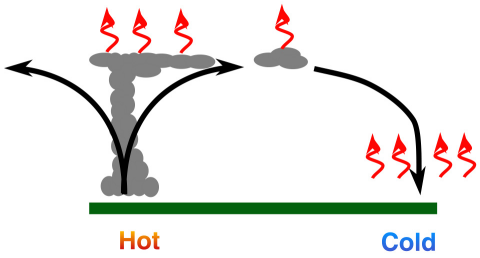
Earth's Energy Balance

A global balance is maintained by transferring excess heat from the equatorial region toward the poles



The Job of the Atmosphere

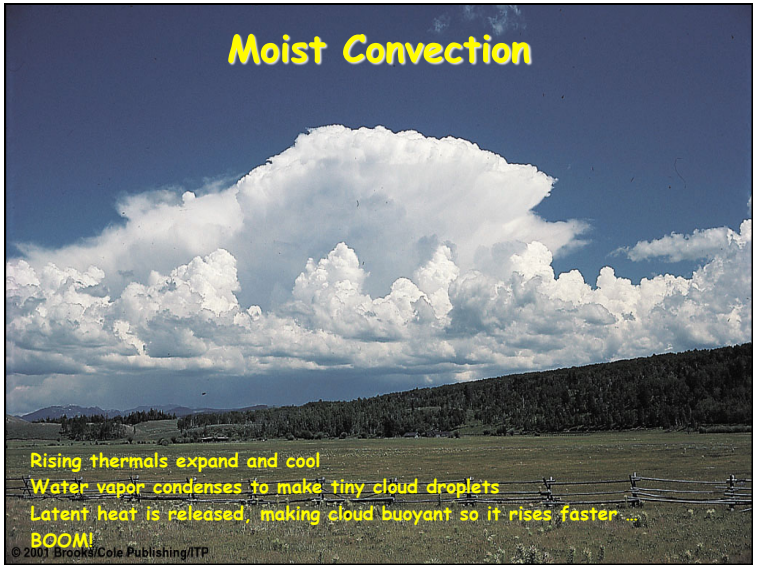
is to let the energy out!



"Piles up" in tropics "Escapes" near poles and aloft

The movement of the air (and oceans) allows energy to be transported to its "escape zones!"

Moist Convection



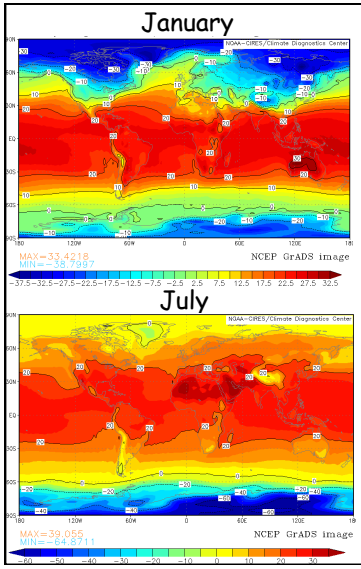
Convective clouds

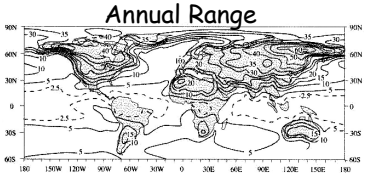
As seen from space, even the tallest clouds are quite shallow … but they move a lot of energy

Atmospheric Circulation
in a nutshell

- Hot air rises (it rains a lot) in the tropics
- Air cools and sinks in the subtropics (deserts)
- Poleward-flow is deflected by the *Coriolis* force into westerly jet streams in the temperate zone
- *Jet streams* are unstable to small perturbations, leading to huge eddies (storms and fronts) that finish the job

Mean Temperatures



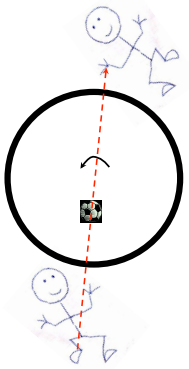


- Latitude dependence
- Seasonality
- Continentality
- Ocean currents

The Coriolis Barf Machine

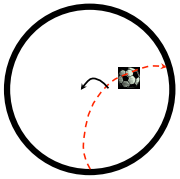
Remember these things?

Earth is Like a Barf Machine Too

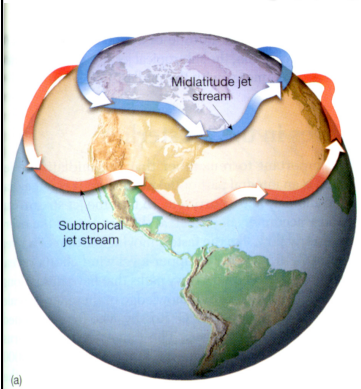


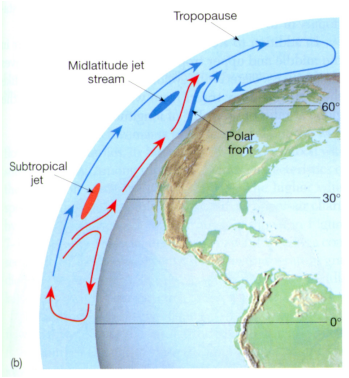
From the kids point of view, the ball goes in a straight line …

but from the point of view of the barf machine, the ball curves to the right as it passes over



Jet Streams





Planetary Waves and Poleward Energy Transport

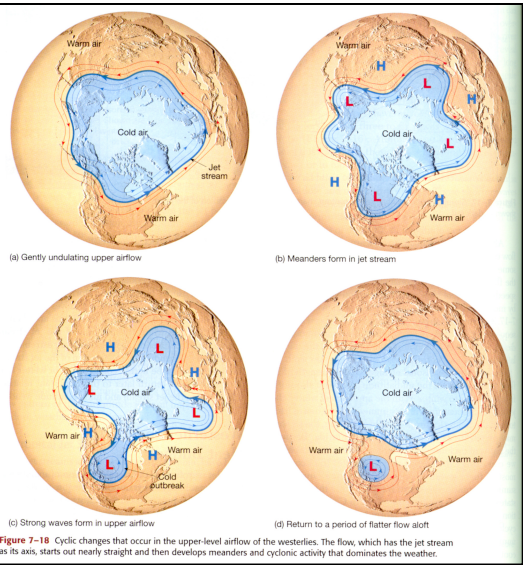
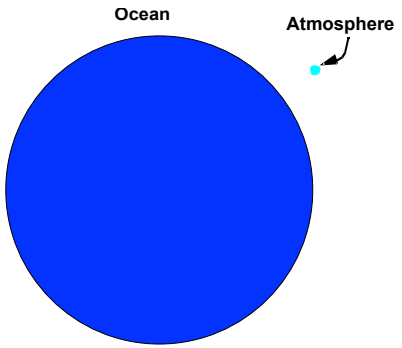


Figure 7–18 Cyclic changes that occur in the upper-level airflow of the westerlies. The flow, which has the jet stream as its axis, starts out nearly straight and then develops meanders and cyclonic activity that dominates the weather.

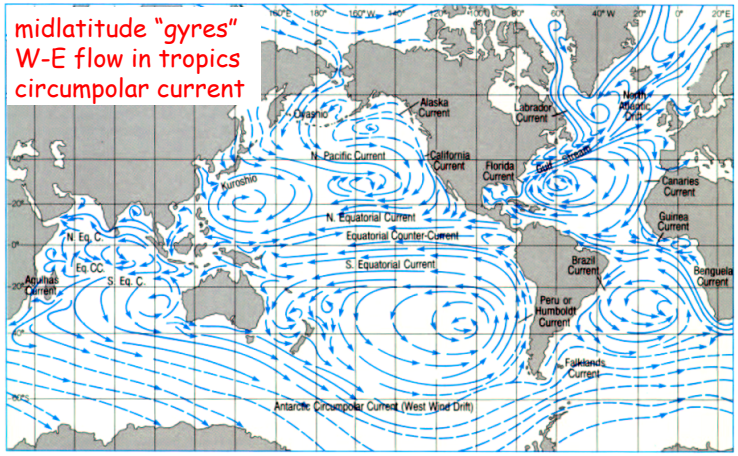
Energy Reservoirs



- The oceans are about 4000 m deep
- The top 10 m equal the mass of the atmosphere
- The top 3 m equal the heat capacity of the atmosphere!

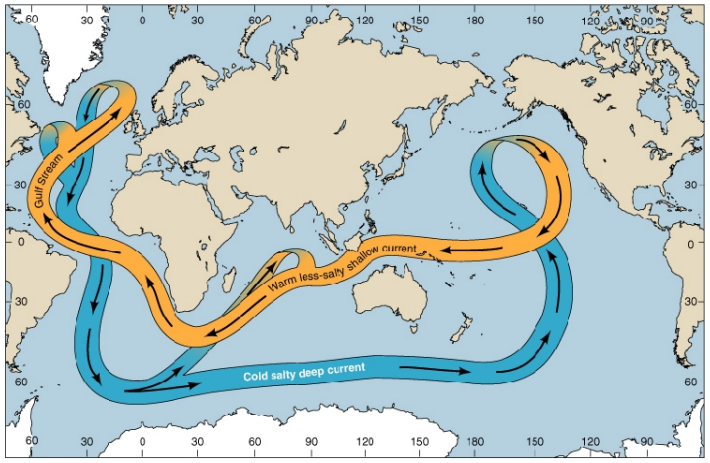
The state of the oceans determines the climate on time scales of thousands to millions of years!

Ocean Currents



How are these known? Effects on poleward energy transport?

Thermohaline Circulation



Things to Remember

- Energy is "conserved," but it can be converted from one type to another and it can move around from place to place
- Energy flows from hot places to cold places
- Earth's weather and climate are powered by the flow of energy from the Sun to the Earth and back out to space
- Solar energy accumulates in the tropics, and the "job" of the atmosphere and oceans is to move it poleward and upward
- Energy is radiated back to space from the top of the air and from the poles