Course Outline

Climate 101

- 9/20  Introduction: The Earth System
- 9/27  Energy, Radiation, and Temperature
- 10/4   Winds, Currents, and Water
- 10/11  Climates of the Past
- 10/18  Modern Climate Change
Class Web Site

http://climate101.atmos.colostate.edu

- All slides as printable handouts
- Supplemental readings
- Videos
- Links to more resources
Weather vs Climate

what’s the difference?

• If you don’t like the weather:
  - *Wait five minutes!*

• If you don’t like the climate:
  - *Move!*
Heat Budgets
Radiation and the Planetary Energy Balance

- Electromagnetic Radiation
- Solar radiation warms the planet
- Conversion of solar energy at the surface
- Absorption and emission by the atmosphere
- The greenhouse effect
- Planetary energy balance
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.
**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!
Energy is Conserved ... so 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.
Energy Transfer

- **Conduction** - molecules transfer energy by colliding with one another

- **Convection** - fluid moves from one place to another, carrying its heat energy with it

- **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 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 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 therefore 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 \(3 \times 10^8\) m/s

\(= 186,000\) miles / sec!

Distance it goes in one cycle is called the wavelength
Electromagnetic Radiation

Radiation travels as waves or photons.

Waves do not require molecules to propagate.

Shorter waves carry more energy than longer ones.
Electromagnetic Radiation

Radiation travels as waves or photons.

Waves do not require molecules to propagate.

Shorter waves have more energy than longer waves.

<table>
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<th>TYPE OF RADIATION</th>
<th>RELATIVE WAVELENGTH</th>
<th>TYPICAL WAVELENGTH (meters)</th>
<th>ENERGY CARRIED PER WAVE OR PHOTON</th>
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<tr>
<td>X rays</td>
<td>![Wavelength]</td>
<td>$10^{-9}$</td>
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</table>
Electromagnetic Radiation Spectrum

Shorter waves carry more energy than longer waves.

Electromagnetic waves interact with matter at similar scales (sizes) as the waves.
Waves and Photons

Long Waves = small photons

Short Waves = BIG PHOTONS

Is light a wave? YES!

Is light a particle? YES!

All light travels at the same speed

Think of short waves as BIG HEAVY particles

Think of longer waves as small, lightweight particles
Emission of Radiation by the Sun and Earth
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

• 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
Atoms, Molecules, and Photons

- Atmospheric gases are made of molecules
- Molecules are groups of atoms that share electrons (bonds)
- Photons can interact with molecules
- Transitions between one state and another involve specific amounts of energy
Dancing Molecules and Heat Rays!

- Nearly all of the air is made of oxygen ($O_2$) and nitrogen ($N_2$) in which two atoms of the same element share electrons.

- Infrared (heat) energy radiated up from the surface can be absorbed by these molecules, but not very well.

Diatomic molecules can vibrate back and forth like balls on a spring, but the ends are identical.
Dancing Molecules and Heat Rays!

- Carbon dioxide ($CO_2$) and water vapor ($H_2O$) are different!

- They have many more ways to vibrate and rotate, so they are very good at absorbing and emitting infrared (heat) radiation.

Molecules that have many ways to wiggle are called “Greenhouse” molecules.
Atmospheric Absorption

Solar radiation passes rather freely through Earth's atmosphere.

Earth's re-emitted longwave energy either fits through a narrow “window” or is absorbed by greenhouse gases and re-radiated toward earth.

Major LW absorbers:
- Water vapor
- $CO_2$
- $O_3$
- Clouds
Solar radiation powers the climate system.

Some solar radiation is reflected by the Earth and the atmosphere.

About half the solar radiation is absorbed by the Earth’s surface and warms it.

Infrared radiation is emitted from the Earth’s surface.

The Greenhouse Effect
Some of the infrared radiation passes through the atmosphere but most is absorbed and re-emitted in all directions by greenhouse gas molecules and clouds. The effect of this is to warm the Earth’s surface and the lower atmosphere.
Planetary Energy Balance

Energy In = Energy Out

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

\[ T \approx -18^\circ C \]

But the observed \( T_s \) is about \( 15^\circ C \)
Things to Remember

- All energy exchange with Earth is radiation
- Outgoing radiation has longer waves (cooler)
- Longwave radiation is absorbed and re-emitted by molecules in the air (H_{2}O & CO_{2})
- Recycling of energy between air and surface is the “greenhouse effect”
- Changes of angle of incoming sunlight and length of day & night are responsible for seasons and for north-south differences in climate
- Regional energy surpluses and deficits drive the atmosphere and ocean circulations (wind & currents)