Climate 201:

Modern Climate Change

OSHR 1623

Scott Denning, CSU

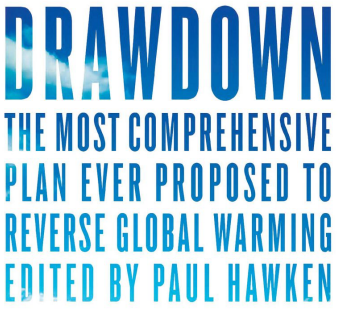
Introductions

Course Outline

Climate 201

- 3/21 Climate in a Nutshell
- 3/28 Forcing, Feedback & Sensitivity
- 4/4 What's the Future Look Like?
- 4/11 Impacts of Climate Change
- 4/18 Solutions!

Optional Book



- Excellent & inexpensive!
- Available on Amazon for $15
- Fantastic FREE website:

www.drawdown.org

Class Web Site

http://climate201.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!*

- Day is warmer than night
- Summer is warmer than winter
- Phoenix is warmer than Fargo

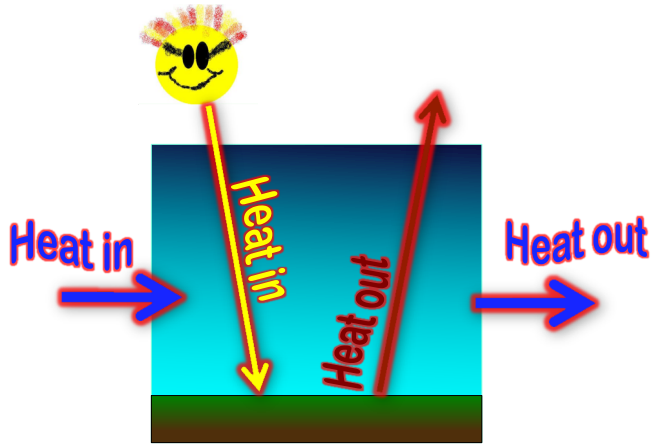
Climate is Place

Location! Location! Location!

- Depends on where you live:
  - Latitude!
  - Altitude (mountains vs valley)
  - What's upwind (ocean vs land)
- Changes very slowly
- Very predictable

- We can *predict that Phoenix is warmer than Fargo* for precisely the same reasons that we can predict a warmer future!

Heat Budgets



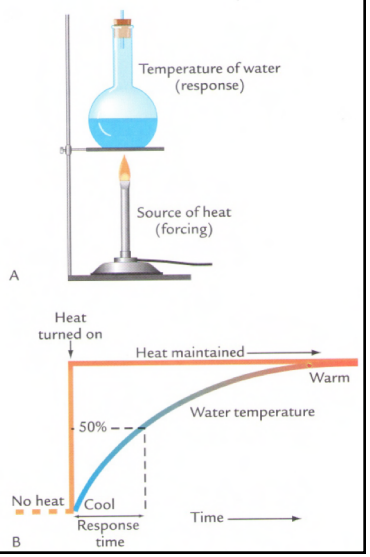
Climate vs. Weather

"Climate is what you expect … weather is what you get!"

- Climate is an "envelope of possibilities" within which the weather bounces around
- Climate is determined by the properties of the Earth system itself (the boundary conditions), whereas weather depends very sensitively on the evolution of the system from one moment to the next

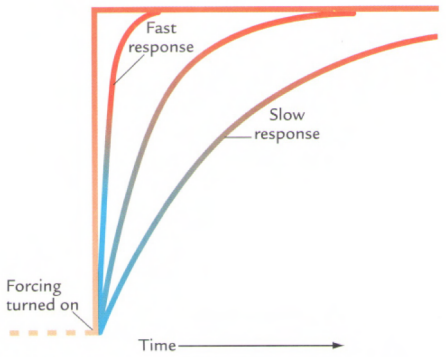
Cause and Effect

- Heat in minus heat out equals change of heat
- Forcing causes a response
- Strength of response to unit forcing is called "sensitivity"

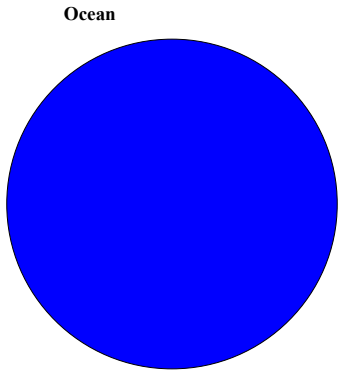


Response Times

- Response to climate forcing can be fast, slow or in between
- Persistent forcing produces a range of responses on different time scales
- Eventual equilibration to



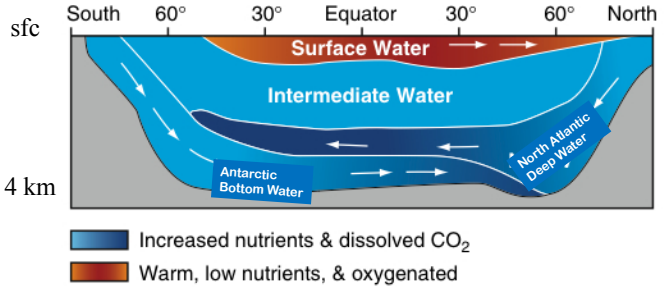
Energy Reservoirs



- 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!

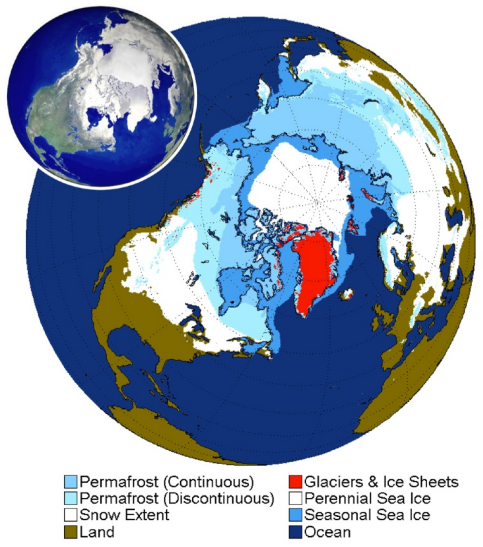
When the ocean says "jump," the atmosphere asks "how high?"

Deep, Dark, and Cold



- Warm buoyant "raft" floats at surface
- Cold deep water is only "formed" at high latitudes
- Very stable, hard to mix, takes ~ 1000 years!
- Icy cold, inky black, most of the ocean doesn't know we're here yet!

Ice and Snow



Heat Transfer

Conduction is by hot molecules colliding with neighbors
Convection is by hot stuff moving in bulk from place to place

Electromagnetic Radiation

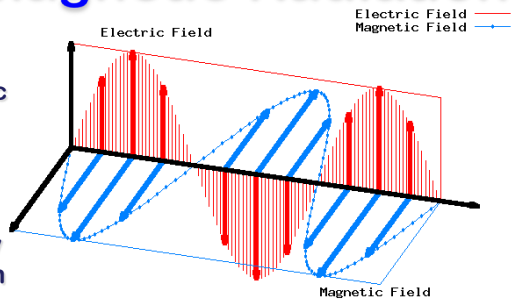
Changing electric fields create changing magnetic fields …

and vice versa!

This makes energy move even through empty space

We can see it, feel it

Plants harvest it directly, and we harvest them!



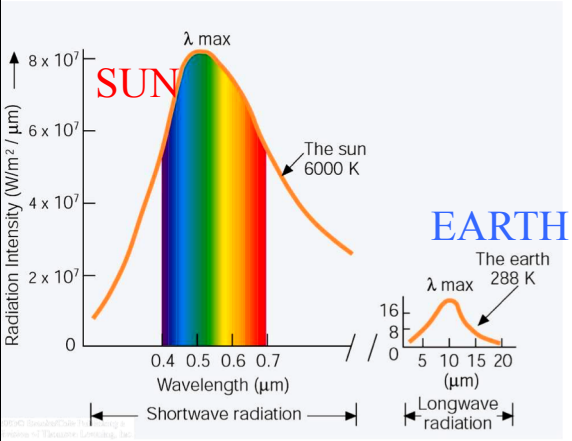
Travels at 3×10^8 m/s = 186,000 miles / sec !

Distance it goes in one cycle is called the wavelength

Thermal Radiation

"Everything emits heat"

Thermal Emission



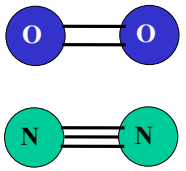
Both are almost perfect blackbodies!

The hot sun radiates at shorter (visible) wavelengths that carry more energy

Energy absorbed by the cooler earth is then re-radiated at longer (thermal infrared) wavelengths

Dancing Molecules & 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

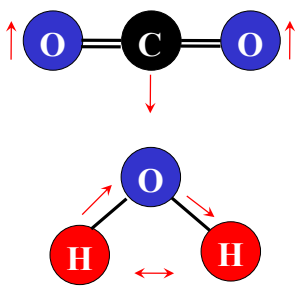


- Infrared (heat) energy radiated up from the surface can be absorbed by these molecules, but not very well

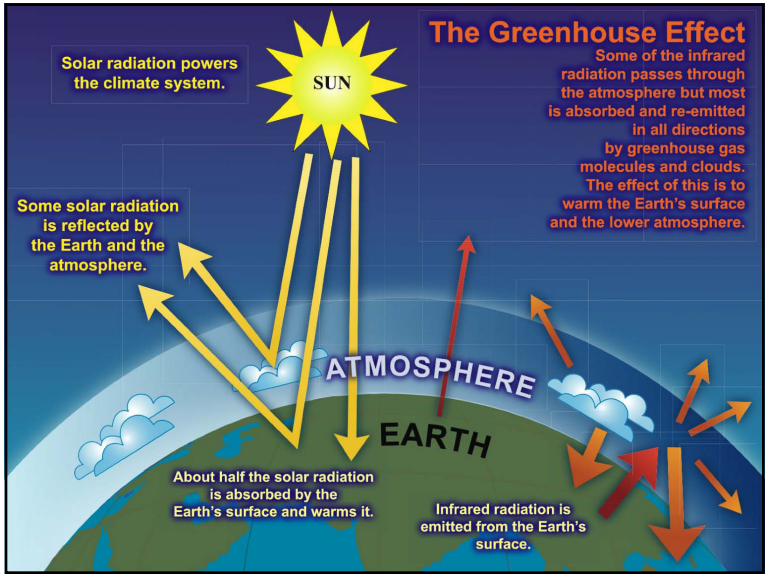
Diatomic molecules can vibrate back and forth like balls on a spring, but the ends are identical

Dancing Molecules & Heat Rays!

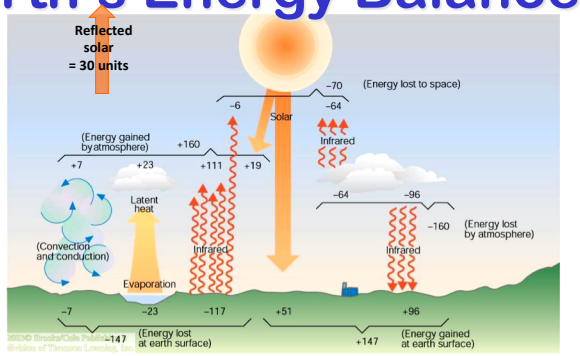
- Carbon dioxide (CO_2) and water vapor (H_2O) are different!
- They have many more ways to vibrate and rotate, so they are very good at absorbing and emitting infrared (heat) radiation



Molecules that have many ways to wiggle are called "Greenhouse" molecules



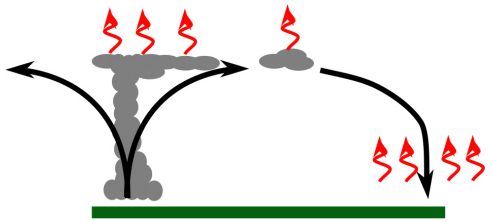
Earth's Energy Balance(s)



- Surface absorbs 51 units of sunshine, plus 96 units of thermal IR! (total = 147 units, 47% more than incoming solar!)
- Surface emits only 117 units, gives the rest back by evaporating water (23 units) and convection (7 units)

The Job of the Atmosphere

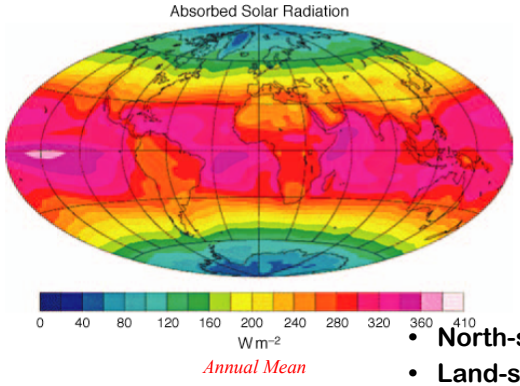
is to let the energy out!



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

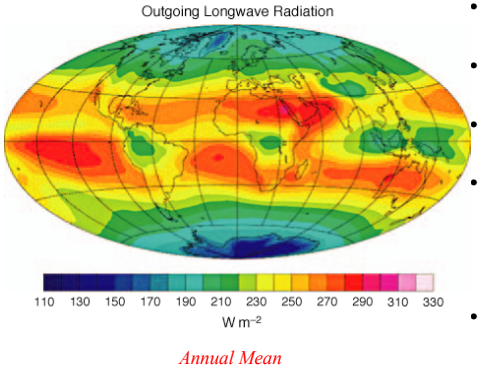
The movement of the air (and oceans) allows energy to be transported to its "escape zones!"

Energy In



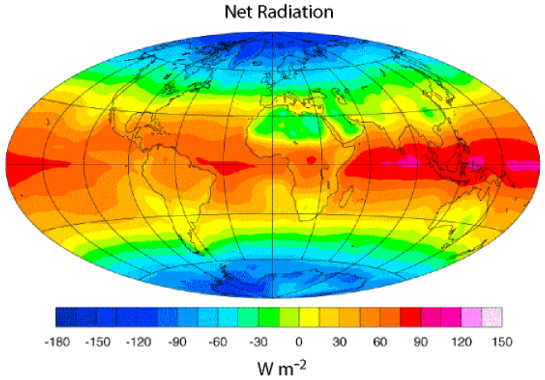
- North-south contrast
- Land-sea contrast
- Ice and snow
- Deserts vs forests

Energy Out



- Given by $\varepsilon\sigma T^4$ (which T?)
- Combined surface and atmosphere effects
- Decreases with latitude
- Maxima over subtropical highs (clear air neither absorbs or emits much)
- Minima over tropical continents (cold high clouds)
- Very strong maxima over deserts (hot surface,

Energy In minus Energy Out

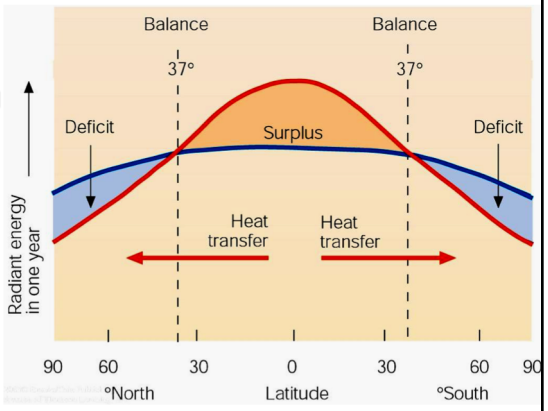


- Incoming solar minus outgoing longwave
- Must be balanced by horizontal transport of energy by atmosphere and oceans!

Earth's Energy Balance

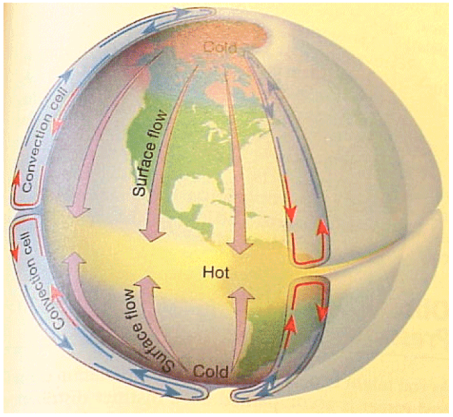
Earth's annual energy balance between solar insolation and terrestrial infrared radiation is global but not local

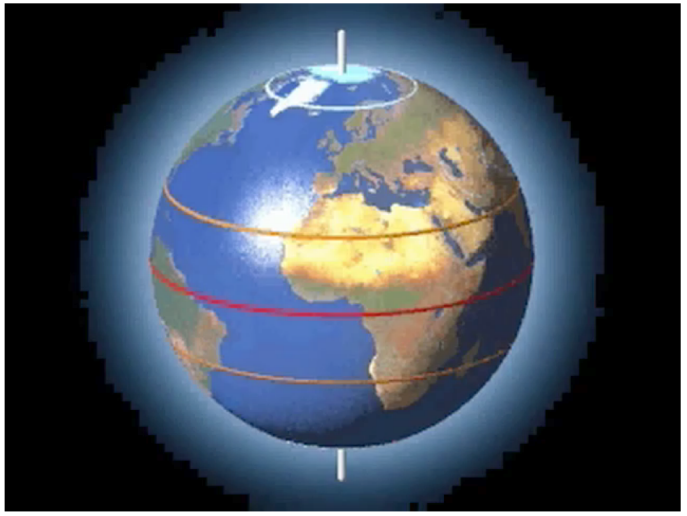
The global balance is maintained by transferring excess heat from the equatorial region toward the poles



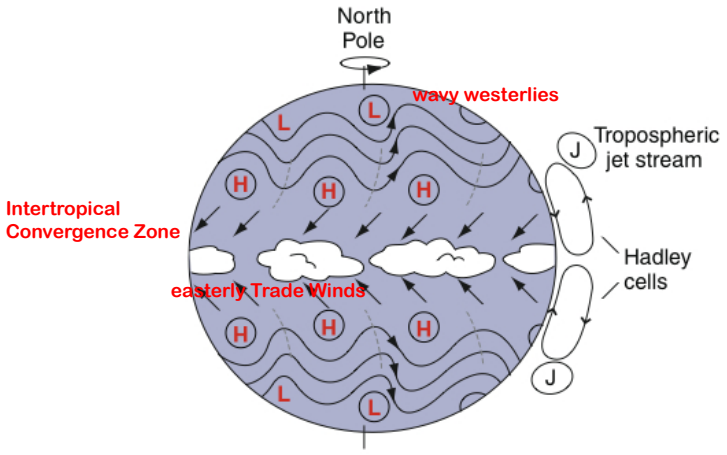
If Earth Didn't Rotate

- Thermal convection leads to formation of convection cell in each hemisphere
- Energy transported from equator toward poles
- Does prevailing surface wind look like this? What about Colorado?
- What about rotation?





Winds on a Rotating Earth



Planetary Waves and Poleward Energy Transport

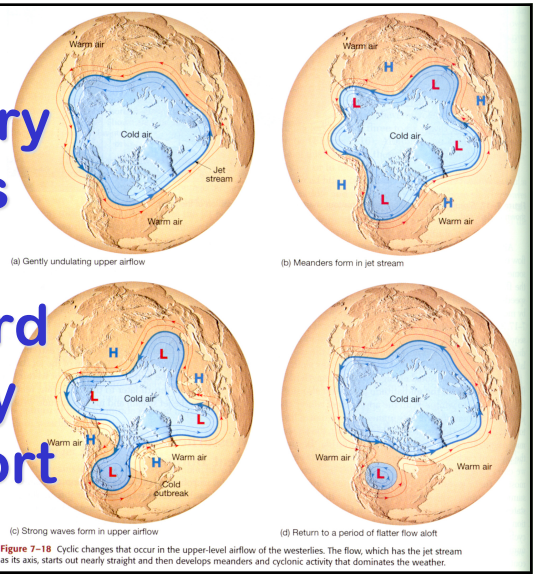


Figure 7–18 Cyclic changes that occur in the upper-level airflow of the westerlies. The flow, which has the jet stream as its axis, starts out nearly straight and then develops meanders and cyclonic activity that dominates the weather.

Atmospheric Circulation
in a nutshell

- Hot air rises (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

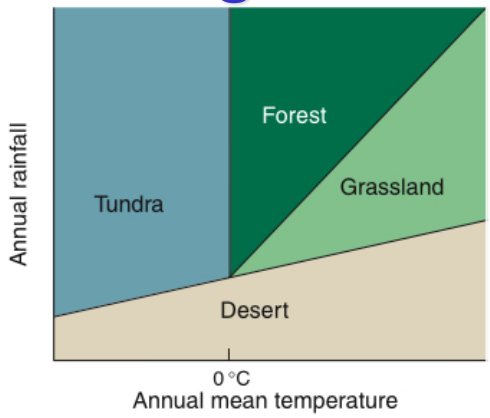
Climates of the World

- Deep Tropics: hot and wet, with little seasonal variation
- Seasonal tropics: hot, with "summer" rain and "winter" dry (monsoon)
- Subtropics: dry and sunny, deserts and savannas, often with a well-defined rainy season
- Midlatitude temperate zone: warm summers, cold winters, moisture varies by location but often comes in episodes throughout the year
- Polar regions: very cold, generally very dry, dark in the winter

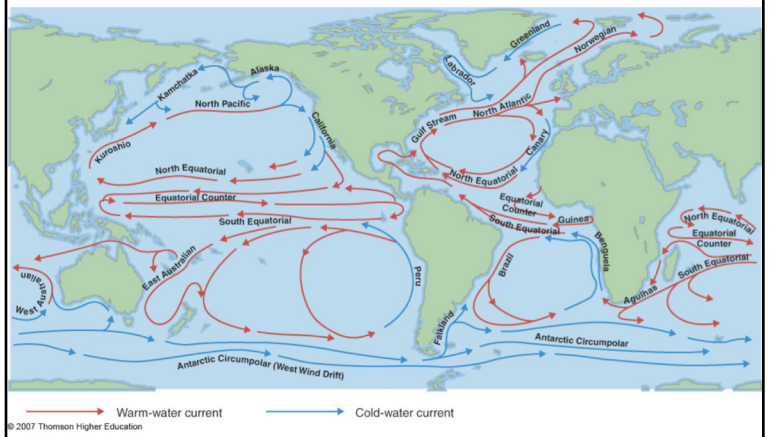
Other Influences:

Ocean currents, "continentality," vegetation, mountain ranges (altitude and orographic precipitation)

Patterns of Climate and Vegetation



Ocean Surface Currents



Warm flows toward poles, cold toward equator

Plate Tectonics

- Continental plates are lighter (buoyant) and rise in collisions, whereas oceanic plates subduct
- Continents can "bunch up" due to collisions, forming *supercontinents* ("Pangea," "Gondwana")
- Continental drift can radically alter the geometry of ocean basins, with corresponding dramatic changes in ocean circulation and poleward heat transport

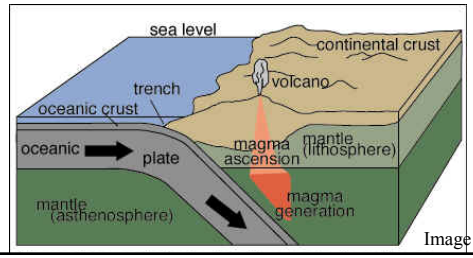
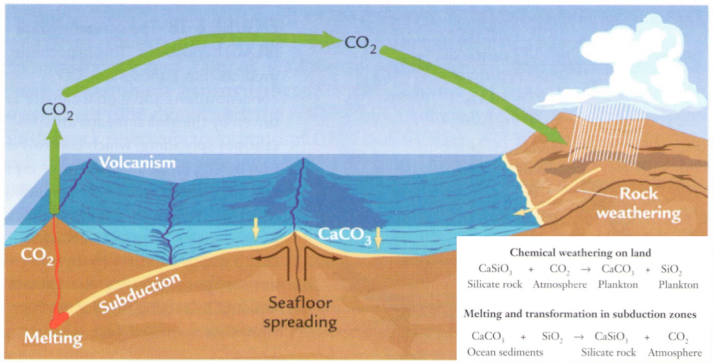


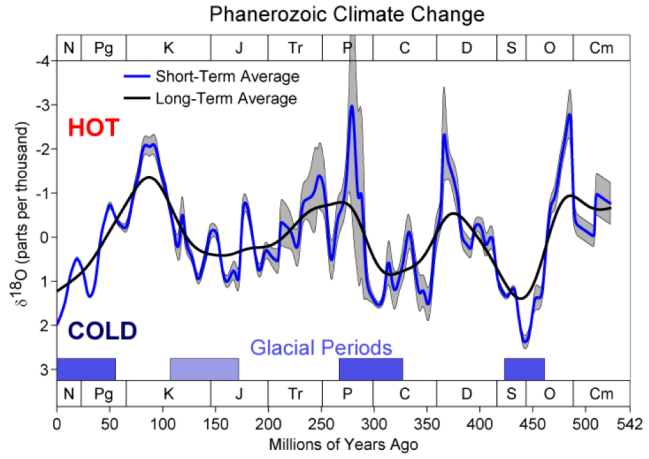
Image Courtesy USGS

Plate Tectonics and CO_2



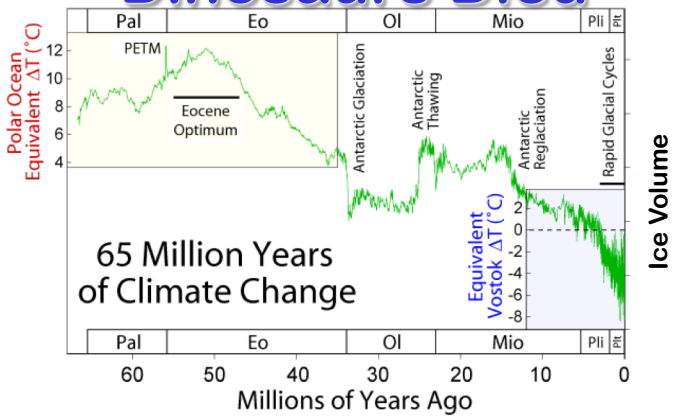
- Seafloor spreading -> volcanism releases CO2
- Mountain building enhances chemical weathering consumes CO2

Half a Billion Years



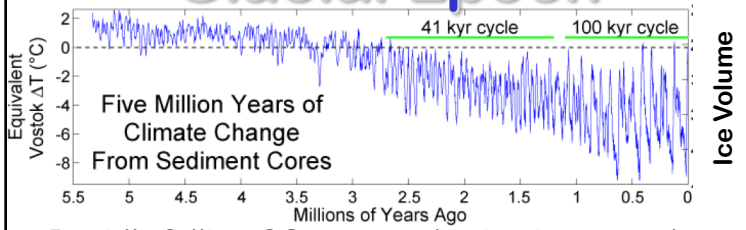
http://commons.wikimedia.org/wiki/File:Phanerozoic_Climate_Change.png

Since the Dinosaurs Died



https://en.wikipedia.org/wiki/Paleocene–Eocene_Thermal_Maximum#/media/File:65_Myr_Climate_Change.png

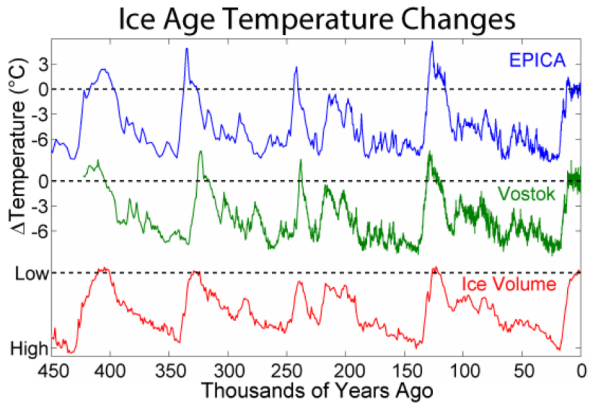
Slow Descent into a Glacial Epoch



- Rapidly falling CO_2 as weathering increased
- Antarctic ice sheet reduced Earth's albedo
- Northern ice sheets began to grow and collapse in a cycle of ice ages ~ 3 Ma

http://commons.wikimedia.org/wiki/File:Five_Myr_Climate_Change.png

Reconstructions from Ice Cores



http://commons.wikimedia.org/wiki/File:Ice_Age_Temperature.png

Orbital Cycles

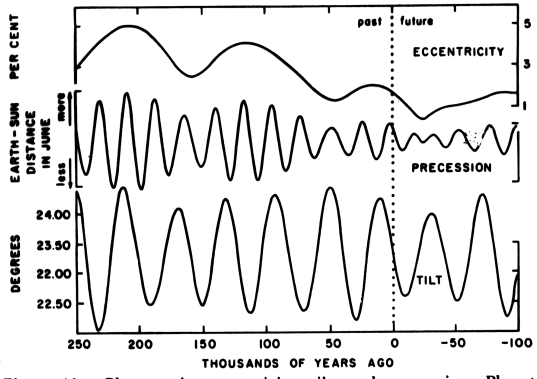
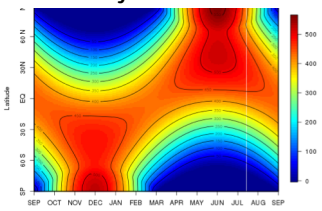


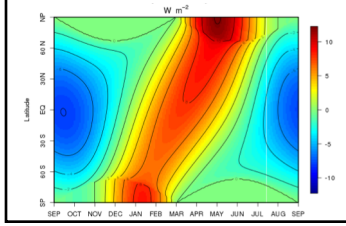
Figure 41. Changes in eccentricity, tilt, and precession. Planetary movements give rise to variations in the gravitational field, which in turn cause changes in the geometry of the earth's orbit. These changes can be calculated for past and future times. (Data from A. Berger.)

Orbit Affects Sunshine

Present Day Solar Radiation



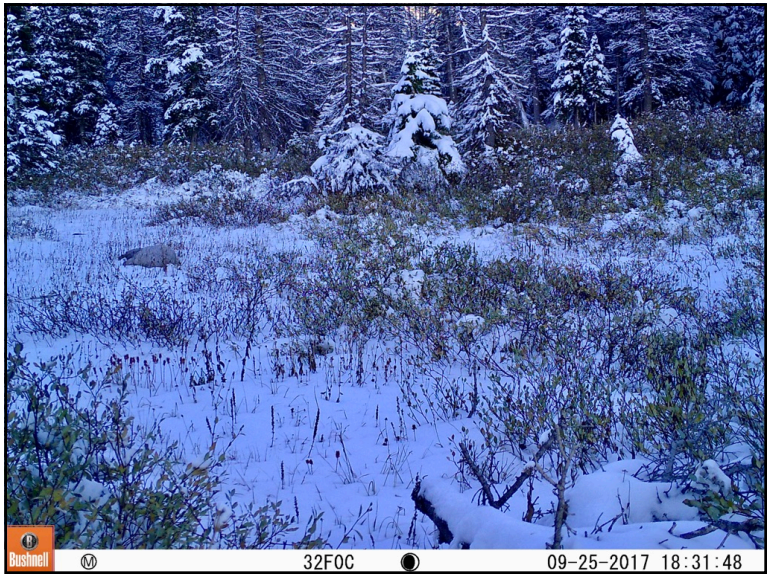
Present Minus 20 k yr ago



- Total amount of solar radiation received by planet in a year hardly changes at all, but …
- Combined tilt, precession, and obliquity effects change Boreal summer sunshine by as much as 20%
- Modulates energy available to melt snow!
- When Boreal summer is cold, ice sheets grow


June 26, 2011


Late July
2017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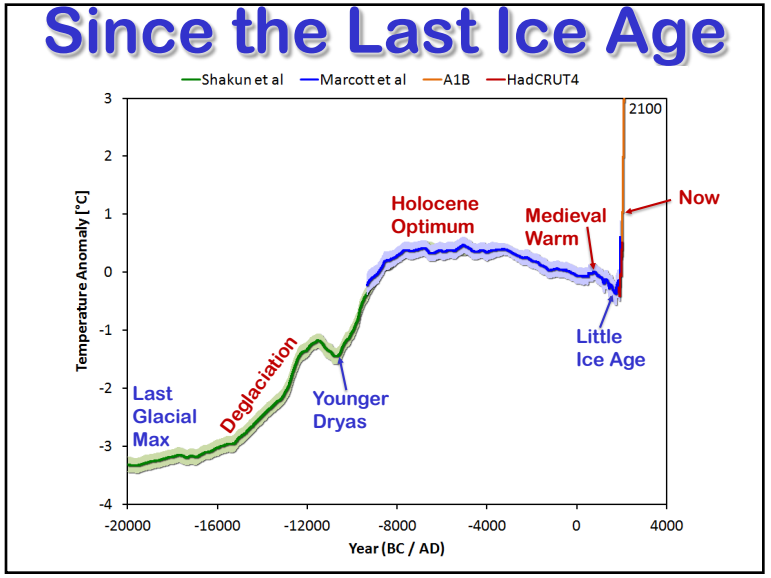
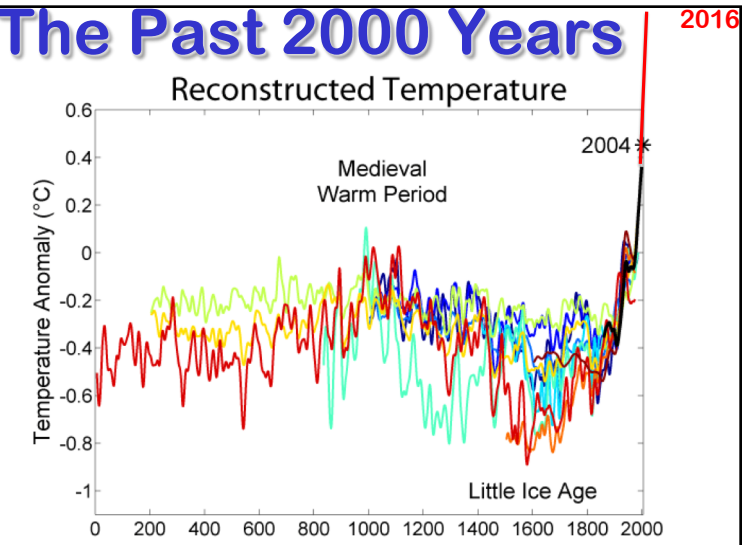
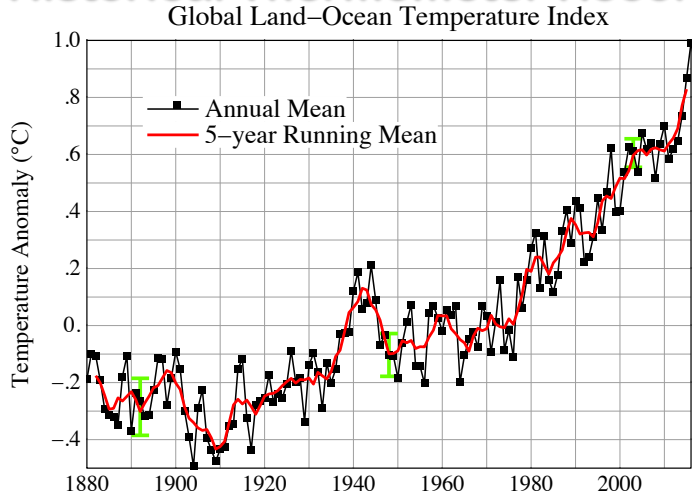

Since the Last Ice Age
Shakun et al
Marcott et al
A1B
HadCRUT4
Temperature Anomaly [°C]
Year (BC / AD)
2100
Now
Holocene Optimum
Medieval Warm
Little Ice Age
Younger Dryas
Deglaciation
Last Glacial Max

The Past 2000 Years



http://commons.wikimedia.org/wiki/File:2000_Year_Temperature_Comparison.png

Historical Thermometer Record



https://data.giss.nasa.gov/gistemp

Remember!

- Heat in minus heat out equals change of heat = climate change
- All heat exchange between Earth & the universe is through EM radiation
- Heat out depends on albedo, atmospheric gases (greenhouse effect)
- Heat transport by winds & currents balance spatial & seasonal radiation
- Past climate changes:
  - Millions of years – plate tectonics -> CO2
  - Thousands of years – orbital changes

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