Climate 101:

How the Climate Works

OSHR 1609

Scott Denning, CSU

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Introductions

Course Outline

Climate 101

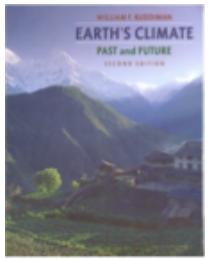
- 2/7 Introduction: The Earth System
- 2/14 Energy, Radiation, & Temperature
- 2/21 Winds, Currents, and Water
- 2/28 Climates of the Past
- 3/7 Modern Climate Change

Course Outline

Climate 201

- 1) Climate Change in a Nutshell
- 2) Forcing, Feedback, & Sensitivity
- 3) Future Climate Changes
- 4) Vulnerabilities & Impacts
- 5) Adaptation & Mitigation

Optional Books



- Excellent but Expensive!
- Archer's book especially useful for **Climate 201** (Modern Climate Change)
- Available on Amazon for $58

Reader's Cove in Fort Collins and ***Anthology Book Co.*** in Loveland offer 20% discounts to Osher members.

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?

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!*

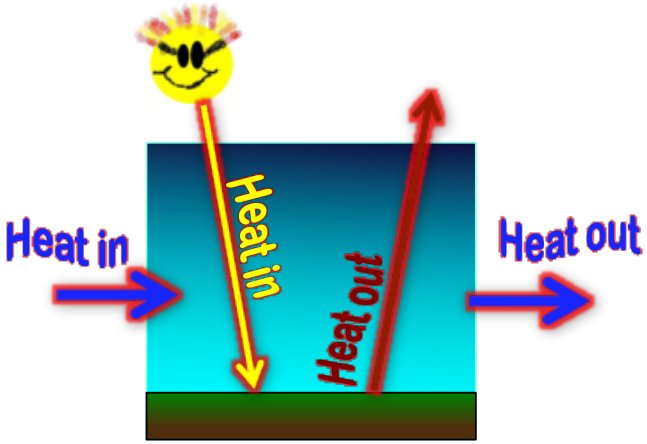
- Day is warmer than night
- Summer is warmer than winter
- Phoenix is warmer than Fargo

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

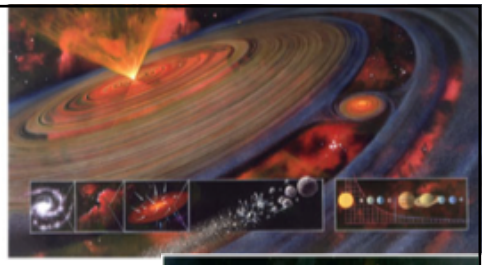
The Earth System

The Earth System

The Earth's climate results from the interaction of many properties and processes

- Solar radiation and orbital geometry
- The size, gravitational force, and rotation rate of the planet
- The composition, structure, and internal dynamics of the planet
- The geography of continents, glaciers, mountain ranges, and oceans
- Ocean properties and circulation
- Atmospheric constituents, their chemical interactions, circulation, and the hydrologic cycle
- The living ecosystems that inhabit the planet, and the biogeochemical transformations they conduct

Origins



- Earth formed by gravitational accretion ~ 4.7 billion years ago
- Solar "constant" was ~ 30% less than today
- Impact heating kept surface hot and sterile
- Giant collision separated the Moon and helped differentiate chemical layers

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

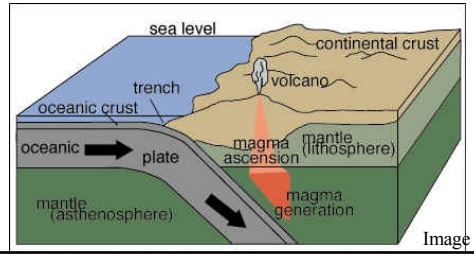
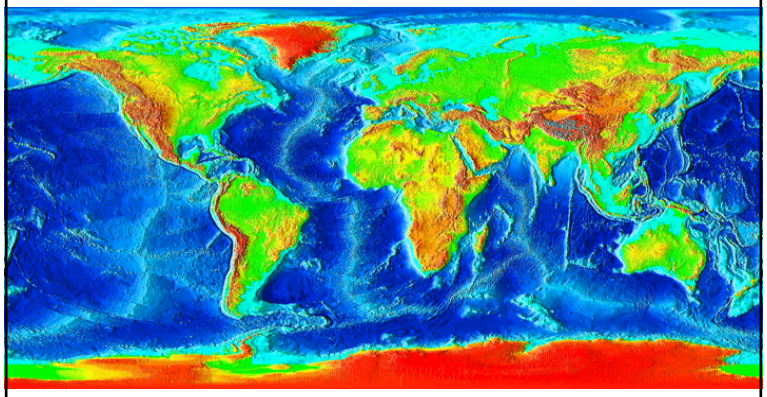


Image Courtesy USGS

Land and Ocean



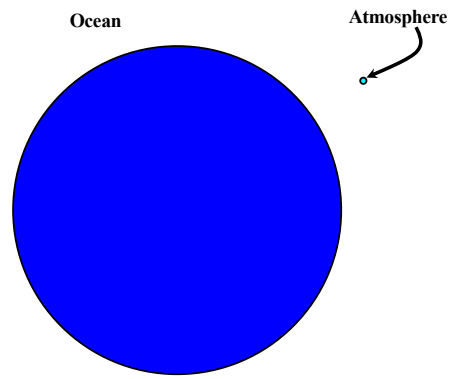
Topography (elevations) on land and under the oceans

Water on Earth

Water reservoir	Depth if spread over the entire surface of Earth (m)	Percent of total
Oceans	2650	97
Icecaps and glaciers	60	2.2
Groundwater[a]	20	0.7
Lakes and streams[a]	0.35	0.013
Soil moisture[a]	0.12	0.013
Atmosphere	0.025	0.0009
Total	2730	100

- Should be called "Planet Water"
- Atmosphere is a bit player in storage of water
- Very dynamic cycling

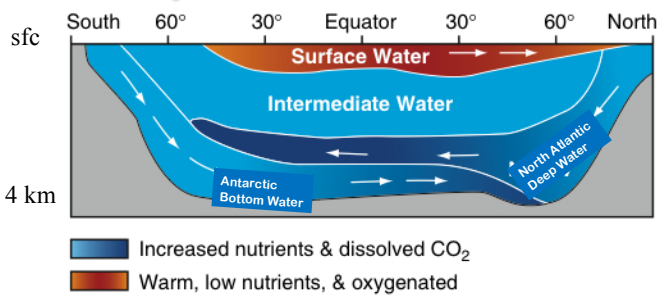
Energy Reservoirs



- 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!

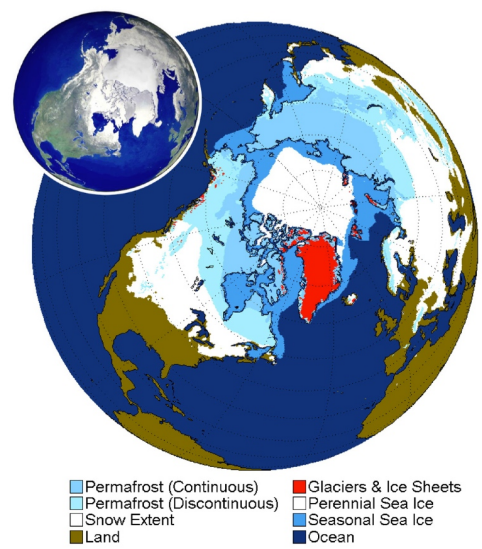
When the ocean says "jump," the atmosphere asks "how high?"

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!

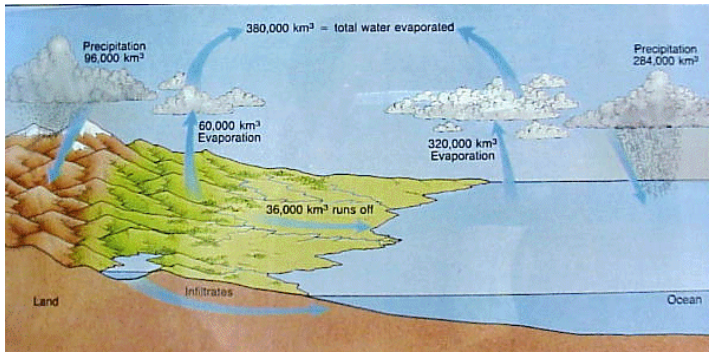
Ice and Snow

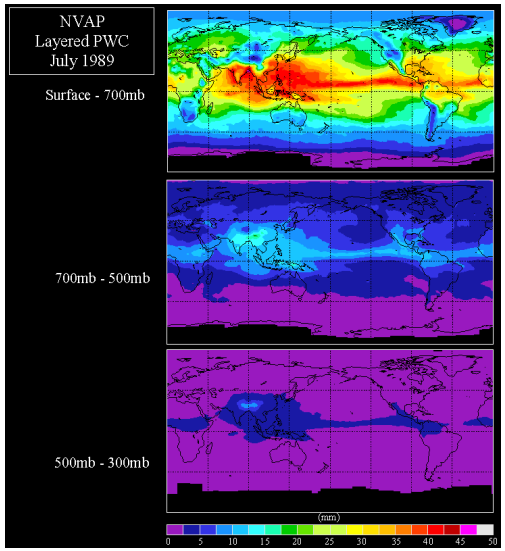


Land and Sea Ice

- Greenland is covered with ice to depths of several kilometers
- Sea ice cover further north overlies an isolated ocean basin

Water Cycle

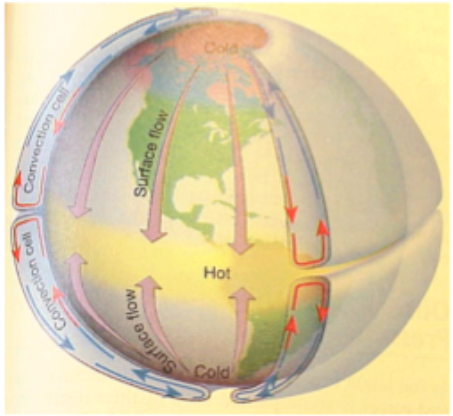




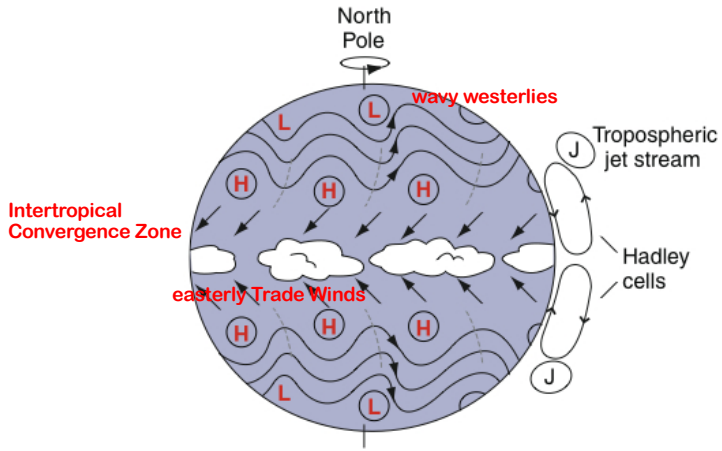
Water in the Air

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



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

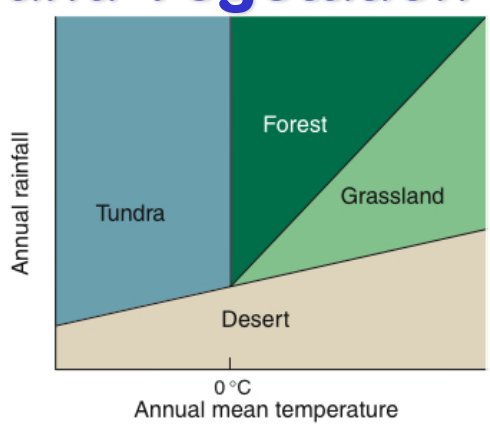
Climates of the World

- **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

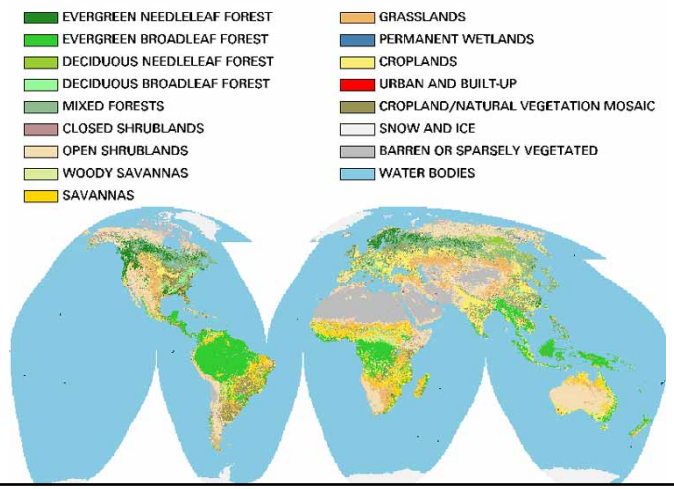
Other Influences:

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

Patterns of Climate and Vegetation

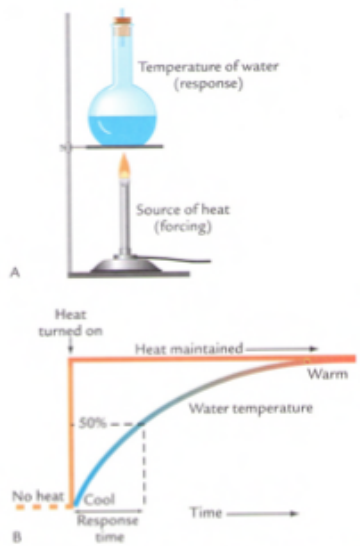


Climate & Vegetation



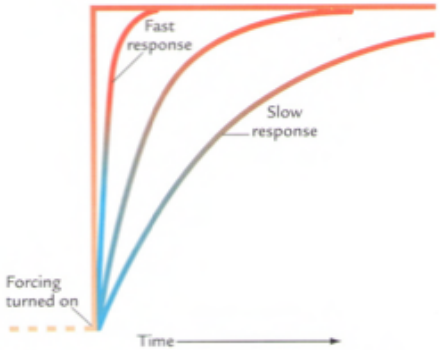
Cause and Effect

- 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



Response Times

Component	Response time (range)	Example
	Fast responses	
Atmosphere	Hours to weeks	Daily heating and cooling Gradual buildup of heat wave
Land surface	Hours to months	Daily heating of upper ground surface Midwinter freezing and thawing
Ocean surface	Days to months	Afternoon heating of upper few feet Warmest beach temperatures late in summer
Vegetation	Hours to decades/centuries	Sudden leaf kill by frost Slow growth of trees to maturity
Sea ice	Weeks to years	Late-winter maximum extent Historical changes near Iceland
	Slow responses	
Mountain glaciers	10–100 years	Widespread glacier retreat in 20th century
Deep ocean	100–1500 years	Time to replace world's deep water
Ice sheets	100–10,000 years	Advances/retreats of ice sheet margins Growth/decay of entire ice sheet

Responses to forcing can be fast, slow, or both!