Earth System Overview

Climate 101:
How the Climate Works

OSHR 1609
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Introductions

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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

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, in Fort Collins and 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?

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

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**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!

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**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**

- Heat in
- Heat out
- Heat out

**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**

- Air
- Water
- Land
- Life
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

Land and Ocean

Topography (elevations) on land and under the oceans

Image Courtesy USGS
**Water on Earth**

<table>
<thead>
<tr>
<th>Water reservoir</th>
<th>Depth if spread over the entire surface of Earth (m)</th>
<th>Percent of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceans</td>
<td>2650</td>
<td>97</td>
</tr>
<tr>
<td>Icecaps and glaciers</td>
<td>60</td>
<td>2.2</td>
</tr>
<tr>
<td>Groundwater</td>
<td>20</td>
<td>0.7</td>
</tr>
<tr>
<td>Lakes and streams</td>
<td>0.35</td>
<td>0.013</td>
</tr>
<tr>
<td>Soil moisture</td>
<td>0.12</td>
<td>0.013</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>0.025</td>
<td>0.0009</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2730</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

- 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!
• Greenland is covered with ice to depths of several kilometers

• Sea ice cover further north overlies an isolated ocean basin

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**Land and Sea Ice**

**Continental Ice**

**Sea Ice**
**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**
- Intertropical Convergence Zone
- Tropospheric jet stream
- Hadley cells
- Eastern Trade Winds
- Slow westerlies
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, “continentiality,” vegetation, mountain ranges (altitude and orographic precipitation)

Patterns of Climate and Vegetation

![Patterns of Climate and Vegetation](image)

Climate & Vegetation

![Climate & Vegetation](image)
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

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