Lecture 5: Land Surface and Cryosphere (Outline)

- Land Surface
- Sea Ice
- Land Ice

Earth’s Climate System

Climate Roles of Land Surface

- greenhouse gas emissions
  - affects global energy and biogeochemical cycles
- creation of aerosols
  - affects global energy and water cycles
- surface reflectivity (albedo)
  - affects global energy cycle
- impacts on surface hydrology
  - affect global water cycle

Surface Albedo

<table>
<thead>
<tr>
<th>Surface</th>
<th>Albedo range (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh snow or ice</td>
<td>60-80%</td>
</tr>
<tr>
<td>Old, melting snow</td>
<td>40-70%</td>
</tr>
<tr>
<td>Clouds</td>
<td>40-50%</td>
</tr>
<tr>
<td>Desert sand</td>
<td>30-50%</td>
</tr>
<tr>
<td>Soil</td>
<td>5-30%</td>
</tr>
<tr>
<td>Tundra</td>
<td>17-35%</td>
</tr>
<tr>
<td>Grasslands</td>
<td>18-25%</td>
</tr>
<tr>
<td>Forest</td>
<td>5-20%</td>
</tr>
<tr>
<td>Water</td>
<td>5-30%</td>
</tr>
</tbody>
</table>

Feedback Mechanism: Albedo ➔ Energy Cycle

- Initial change
- Climate cooling
- Greater cooling
- Tundra replaces forest:
- Snow cover replaces vegetation cover

(from Earth’s Climate: Past and Future)

Feedback Mechanism: Transpiration ➔ Water Cycle

- Initial change
- Increased precipitation
- Additional precipitation
- Forest replaces grassland:
- Wet soil replaces dry soil

(from Earth’s Climate: Past and Future)

Cryosphere

Sea Ice
- The cryosphere is referred to all the ice near the surface of Earth, including sea ice and land ice.
- For climate, both the surface and the mass of ice are important.
- At present, year-round ice covers 11% of the land area and 7% of the world ocean.

(from The Blue Planet)

Land Ice

Seasonal Cycle of Antarctic Ice

(figures from Gloersen, P. et al. 1992; animated by D. B. Reush)
One major climate effect of sea ice is to seal off the underlying ocean from interaction with the atmosphere.

Without an sea ice cover, high-latitude oceans transfers large amount of heat to the atmosphere, especially in winter.

With an sea ice cover, the heat flux into the atmosphere is stopped. In addition, the ice surface absorbs little incoming solar radiation. Winter air temperature can cool 30°C or more near a sea-ice cover.

The “Antarctic Dipole” (ADP) is characterized by an out-of-phase relationship between the ice and temperature anomalies in the central/eastern Pacific and Atlantic sectors of the Antarctic.
Pacific South America (PSA) Pattern

What Happened to H₂O?

The atmosphere can only hold small fraction of the mass of water vapor that has been injected into it during volcanic eruption, most of the water vapor was condensed into clouds and rains and gave rise to rivers, lakes, and oceans.

The concentration of water vapor in the atmosphere was substantially reduced.

Ice and Sea Level

- The Antarctic Ice Sheet holds the equivalent in seawater of 66 meters of global sea level.
- The Greenland Ice Sheet holds the equivalent of 6 meters of global seawater.

Land Ice

- Continental Ice Sheets: 100-1000 km in horizontal extend.
  1-4 km in thickness.
  Two larges sheets: Antarctic Ice Sheet and Greenland Ice Sheet.

- Mountain Glaciers: a few kilometers in length and 10-100 meters in width and thickness.

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Table 1.2

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage of mass of atmosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceans</td>
<td>97</td>
</tr>
<tr>
<td>Ice</td>
<td>2.4</td>
</tr>
<tr>
<td>Fresh water (underground)</td>
<td>0.6</td>
</tr>
<tr>
<td>Fresh water in lakes, etc.</td>
<td>0.024</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>0.004</td>
</tr>
</tbody>
</table>

* Total mass = 1.36 × 10^21 kg = 2.66 × 10^9 kg m⁻² over surface of earth.

(From Atmospheric Sciences: An Introductory Survey)
Glacial Ice
(from Earth's Climate: Past and Future)

- Ice cores retrieve climate records extending back thousands of years in small mountain glaciers to as much as hundreds of thousands of years in continental sized ice sheets.
- The antarctic ice sheet has layers that extend back over 400,000 years.
- The Greenland ice sheet has layers that extended back 100,000 years.

Ice and Sea Level
(from Earth's Climate: Past and Future)

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Interactions between Ice and Ocean
(from Earth's Climate: Past and Future)

- This hypothesis argues that millennial oscillations were produced by the internal interactions among various components of the climate system.
- One most likely internal interaction is the one associated with the deep-water formation in the North Atlantic.
- Millennial oscillations can be produced from changes in northward flow of warm, salty surface water along the conveyor belt.
- Stronger conveyor flow releases heat that melts ice and lowers the salinity of the North Atlantic, eventually slowing or stopping the formation of deep water.
- Weaker flow then causes salinity to rise, completing the cycle.

Ice and Sea Level
(from Earth's Climate: Past and Future)

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Global Warming and Sea-Level Change

- Global Warming (2.5°C by 2100)
  - Thermal Expansion (11 inches)
  - Glacier and Ice Caps (6.3 inches)
  - Greenland Ice Sheet (2.4 inches)
- Sea Level Rise (19.3 inches by 2100)

Sea Level Rise vs. Sea Floor Sink

- OCEAN
- Sea floor

After a certain amount of land-supported ice melts, instead of saying the sea level will rise "so much", we should say the oceans will get "so much" deeper. -- (Kivioja 2003; EOS)