Lecture 10

Global Circulation and El Nino
Global Circulation

Sea Surface Temperature

Global Clouds
Energy Balance

Annual Average

Radiation Flux Density (W/m²)

-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90

Latitude

Energy Surplus
Energy Deficit

Emission of terrestrial energy to space - represents an energy loss by the planet

Incoming solar energy - represents an energy gain for the planet
The global energy balance also varies with longitude, primarily due to the differences of land, water and elevation.
Heat Transport

• Because there is an excess of heat at the equator and a deficit of heat at the poles, transport of heat from the tropics to the polar regions must occur
  – Atmospheric heat transport through the general circulation
  – Ocean heat transport through ocean currents
Global Atmospheric Circulation

• To transport heat we might imagine a meridional (north-south) circulation with cold air flowing from the pole to the equator at the surface and vise versa aloft:

But such a circulation can not exist because Coriolis prevents it!
Rotation produces banding of the General Circulation
6 Celled Circulation
East West Circulations (Caused by Continents and Topography)
East West Circulations  
(Caused by Continents and Topography)

The Walker circulation involves a westward flow of surface air over the equatorial Pacific and a return flow in the upper troposphere.
Ocean Currents

• What causes them?
  – Wind drag. Friction with the wind drags the ocean surface to produce a current. The semi-permanent position of the subtropical high over the north and south Pacific and the north and south Atlantic help drive the anticyclonic gyre of water in each basin.
  – Thermohaline circulation. Density variations in water arise from differences in temperature (warmer=>$less dense) and salinity (more salty=>$more dense). More dense water tends to sink relative to less dense water, giving rise to vertical circulations known as thermohaline circulations.
  – Interactions of ocean currents with bottom topography and lateral boundaries
  – Other ocean “weather”, i.e. ocean waves, vorticies, etc.
How do ocean currents affect weather and climate?

- Oceans store and transport heat. The high heat capacity of water makes it an excellent mechanism to store the sun’s energy and transport it from one place to another.
- Oceans store liquid water and pump vapor into the air as a key link in the global water and energy cycle.
- Ocean storage and release of heat is a key forcing mechanism for weather.
- Oceans absorb (release) atmospheric gases, such as oxygen and CO2.
  - Absorption of CO2 by oceans is the most important sink of CO2 from the atmosphere.
  - Amount of CO2 that the oceans can hold is inversely proportional to temperature, i.e. colder water holds more CO2 and warmer water (think global warming here) holds less.
  - Oceans are a major source of oxygen for the atmosphere due to photosynthesis of microscopic plants in the ocean.
Basic Ocean Circulations
More complete Depiction of Ocean Circulation
Ocean “Weather”

Ocean eddies in tropical Pacific

Gulf Stream induced ocean “weather”
Arctic Currents
Thermohaline Circulation

Generalized model of thermohaline circulation: "Global Conveyor Belt"

- High salinity water cools & sinks in the North Atlantic
- Deep water returns to surface in Indian & Pacific Oceans through the process of upwelling
- Warm shallow current
- Cold & deep high salinity current
Global Warming and Thermohaline circulation

- Gulf Stream transports warm water from tropics to North Atlantic
  - This keeps Europe warm for its latitude:
    - London at same latitude as Hudson Bay
    - Sweden at same latitude as Greenland
- Gulf Stream driven by:
  - Wind stress from the North Atlantic Gyre
  - Thermohaline circulation...subduction (sinking of high density water under lower density water) of cold salty water from Arctic, draws up Gulf Stream to replace the water mass lost.
  - Subduction driven by:
    - Very cold water produced by long winter nights
    - Increased water density due to increased salinity of water in contact with the forming Arctic ice. Freezing of ice cap, forces salt out of the ice thereby increasing salinity (saltiness) of water in contact with the developing ice
Consequences of Global Warming to Thermohaline Circulation

- Ice cap melts creating an excess of floating fresh water in the Arctic Ocean
- Permafrost and glaciers, particularly in Siberia, melt, causing huge flux of warm fresh water into Arctic Ocean via northward draining rivers.
- Low density water inhibits subduction and supply of deep water to the cold conveyor belt
- Gulf Stream slows, and turns east at much lower latitude because it is no longer being driven northward
- Cessation of northward heat transport causes Europe, and northeast North America to become colder
A Local Thermohaline Circulation in Mediterranean

Global Cell, Upper Branch

Red arrows indicate the lower branch

TH circulation driven by relationship between evaporation, precipitation, runoff and heating that all affect water density
Feedback between Ocean Currents and Climate

• Since atmospheric winds produce currents, variations in climatological winds can affect ocean currents, that can affect the transfer of thermal energy and vapor into the atmosphere, that can affect weather and climate, that can affect wind that affects currents and so on.

• The feedback between climate variability and ocean current variability help to “lock in” certain climate regimes.
Climate Variability

• Diurnal variability (minor in most oceans)
• Annual variability (strongest of the variabilities)
• Interannual variability
  – Southern Oscillation
    • Pressure in Thaiti-Pressure in Darwin
• Interdecadal variability
  – North Atlantic Oscillation
    • Pressure at Iceland- pressure of Azores
  – Pacific Decadal Oscillation
    • Mean Sea Surface Temperature of North Pacific
El Nino

• Original definition: Annual warming of water off of the Coast of Peru around Christmas. “El Nino” referred to the Christ child.

• Since early 1980’s new definition: Warm water occurring off of the Peru and reaching out to the dateline that tends to occur periodically every 2-5 years.
El Nino

Sea Surface Temperature Anomaly

Courtesy of the U.S. Navy Fleet Numerical Meteorology and Oceanography Center
Southern Oscillation

- Reversal of difference of pressure anomalies between Darwin, Australia and Tahiti. Measures the relative strength of the Walker circulation.

**Southern Oscillation Index (SOI)** = \( SOI = P_{\text{Darwin}}' - P_{\text{Tahiti}}' \)

where \( P' = \text{Pressure} - \text{Normal Pressure} \)

- \( SOI > 0 \) - Weak Walker Circulation
- \( SOI < 0 \) - Strong Walker Circulation
ENSOS

• Since El Nino’s are associated with the SO, the combined ocean Atmospheric oscillation is called the ENSO

• Since the SOI is positive now, we are in a positive phase of the ENSO
La Nina

• New term coined recently to refer to the opposite of an El Nino when the Equatorial Pacific is colder than normal and the SOI is negative
Normal Pressure pattern

January mean SLP (1971-2000)
Cross-section showing change in ocean temperatures for 1997 El Nino development.

Courtesy of NOAA/Pacific Marine Environmental Laboratory.
A: Low wind shear (Non-El Niño Year)

Storm’s latent heat is focused over small volume

B: High wind shear (El Niño Year)

Storm’s latent heat is spread over larger volume

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• El Nino today
• http://www.ngdc.noaa.gov/paleo/ctl/clisci.html