Earth 50

Lecture 19-Ocean Circulation and Paleoclimate

Ocean circulation

Surface ocean currents are largely wind-driven and therefore follow the flow in the atmosphere

The "***Western Warm Pool***"

Evaporation-Precipitation (E-P)

Temperature

The major layers are:

1. ***Surface water*** (the ***surface mixed layer***)
2. ***Thermocline water***
3. ***Intermediate Water***
4. ***Deep water***
5.

Circulation of the Deep Ocean

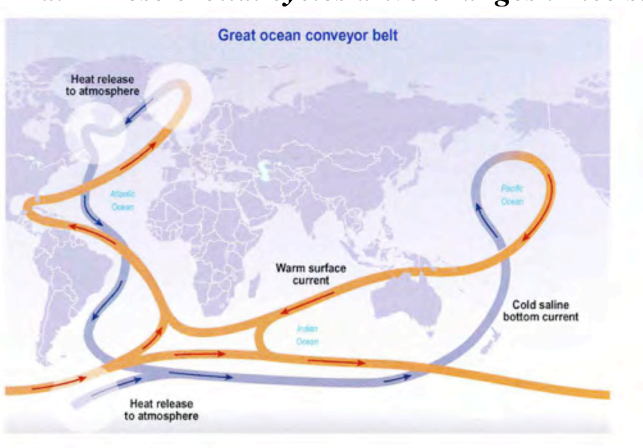
1. = ***Thermohaline circulation.***
2. Two issues in forming deep water—
    a. density difference from other deep water masses and
    b. amount of water that can be formed.

The Great Ocean Conveyor

Deep waters may remain isolated from surface waters for1000-1500 years

The Climate System

1. ***season***
    a. ***Decadal variability***—Includes the ***el Nino*** cycle and ***North Atlantic Oscillation (NAO)***
2. ***Orbital Scale***—21,000 yr (average), 41,000 yr, and 100,000 yr (average) cycles
    a. These orbital cycles drive changes in ice storage on land



Earth 50 **November 6, 2006**

Lecture 19-Ocean Circulation and Paleoclimate

Ocean circulation

Surface ocean currents are largely wind-driven and therefore follow the flow in the atmosphere

1. Like air circulation, major circulation systems move at right angles to surface winds in response to the Coriolis Force.
2. Consequently, the flow of the trades and westerlies induces the formation of clockwise circulation in the Northern Hemisphere and counter-clockwise circulation in the Southern Hemisphere—
3. these circulation systems are called ***gyres***.
4. The gyres are topographic highs and are sites of net ***down-welling***.

In the tropics, the trades push water to the west, piling it up in the "***Western Warm Pool***" removing water from the western coasts of the Americas and Africa.

Offshore removal of water causes the surface water to be replaced with colder deeper water in a process called ***"upwelling".***

1. The piling of water in the Western Warm Pool creates a pressure head
2. displaces water to the "***western boundary current***"
3. as well as to counter currents that flow under and north and south of the tradewind-induced ***Equatorial current***

Evaporation-Precipitation (E-P)

1. The gyres, being in the subtropics, are sites of net evaporation
2. equatorial regions and subtropical convergences are sites of rainfall and therefore net precipitation.
3. Evaporation of gyre water produces moist air masses that travel
   a. toward the equator to feed the ITCZ and
   b. toward the mid latitudes and continents to feed the storm tracks that track the Jet Stream.

Temperature

The ocean is thermally stratified, at least in the tropics and subtropics. This used to be a *significant escape for submarines*—hiding below the thermocline where the temperature and salinity contrast helped reflect sonar pings.
The major layers are:

6. ***Surface water*** (the ***surface mixed layer***)—wind mixed between depths of 10-100 m with uniform temperature (usually between ~5-30°C)
7. ***Thermocline water***—the thermocline is the sharp change in temperature with depth below wind-mixed, solar-heated surface water. The thermocline often falls within the depth of light penetration between 30 m to 1000 m (~3-10°C)

8. ***Intermediate Water***—mostly formed in mid latitudes by sinking of cold waters poleward of the subtropical convergences from depths of 100 m to ~2500 m (~2-5°C)
9. ***Deep water***—formed mostly at high latitudes (today in the Greenland Sea and the Weddell Sea), often under ice cover in winter time (-1 to 2.5°C; can be below freezing owing to its salt content) fills the deep ocean below 2500 m depth

Circulation of the Deep Ocean

3. While the surface circulation is driven mostly by wind, the deep circulation (of intermediate and deep waters) is driven largely by, often small, differences in density
4. Due to temperature and salinity differences.
5. = ***Thermohaline circulation.***
6. Density increases as temperature declines and salinity increases.
7. Two issues in forming deep water—
    a. density difference from other deep water masses and
    b. amount of water that can be formed.

Today, ***Antarctic Bottom Water*** is the densest water mass with temperature of ~1°C and salinity of 34.9‰. ***North Atlantic Deep Water*** has a temperature of ~2.5°C and salinity of ~35.4‰. Both water masses are denser that ***Mediterranean Outflow Water*** which has a temperature of ~13°C and Salinity of ~37‰. Because AABW > NADW > MOW, this is also the order in which these water masses are stratified with AABW deepest and MOW shallowest in the deep sea.

The Great Ocean Conveyor

Maps of deep water age (made by radiometrically dating 14C in dissolved organic carbon in 55 gal of seawater) show that the youngest water is that close to the major sites of deep water formation (Weddell Sea and Greenland-Scotland Sea); passing through the southern Indian Ocean (in the circum-Antarctic Current) and eventually upwelling the oldest water off the Americas and northern Japan. Some of the oldest water is ~2000 yrs.

Stratification of ocean water means that deep waters typically remain isolated from surface waters for1000-1500 years

The longer waters remain isolated from the surface, the more CO2 and acidity they accumulate (owing the decay of sinking organic matter from plankton). "Young" waters recently in contact with the atmosphere are not very acidic, whereas "old" waters are highly acidic.

Deep Sea Sediments

Four major types of deep sea sediment:

1**.Terrigenous sediment**--found mostly along continental margins.

2. **Calcareous ooze**—typical of open oceans in areas where deep water has recently formed and is not yet highly corrosive to carbonates

3. **Siliceous ooze**—typical of ocean environments where abundant nutrients are available to phytoplankton—typical of upwelling systems where nutrients are upwelled to the surface
4. **Red clay**—composed mostly of wind-blown dust; accumulates very slowly in the absence of carbonates or siliceous ooze (both dissolved in "old" acidic deep waters).

Hence, see a progression from mostly carbonates in the Atlantic (where deep waters are young) to red clay in the N. Pacific where deep waters are old.

Also see a change in sediment type with water depth since acidity increases with depth. The tops of undersea mountains typically covered with calcareous ooze whereas the deepest basins are mantled with red clay. Ooze forms a kind of undersea "snowline".

Also means that, as the ocean crust cools and sinks, the crust passes from the depth of carbonate preservation to the depth of red clay deposition. **Get sequence: Basalt-> carbonate ooze-> red clay** as crust subsides from a depth of ~2500 m at the ridge crest to >5000 m at the trenches.

The Climate System
Climate is not static but experiences cycles of variable duration

3. shortest period is the ***season***
4. ***Decadal variability***—Driven by variations in strength of the Hadley and Ferrel Cell circulation
5. In turn, these circulations drive variations in surface pressure (high pressure = descending air masses, low pressure = rising air masses)
6. The differences in pressure drive the winds (weak pressure differences = weak winds, strong pressure differences = strong winds)
7. Includes the ***el Nino*** cycle with 7-11 year cycle
    a. Manifested as a weakening of the trade winds;
    b. Less warm water is pushed off the coast of the Americas; therefore upwelling off the Americas shuts down.
        i. The reduction in upwelling causes collapse of fisheries along the Americas—usually starts near Christmas (hence the el Nino name—"the Child")
    c. The reduction in warm water in the Western Warm Pool, reduces rainfall over Indonesia, Papua New Guinea and Northern Australia
    d. The abundance of warm water off the Americas strengthens evaporation and the westerlies, carrying more moisture and rainfall over western North America—we get floods, mud slides, and massive displays of spring wildflowers
8. Another interdecadal cycle is the ***North Atlantic Oscillation (NAO) with ~20 year cycle***
    a. Controls hurricane intensity by varying the warmth of the tropical oceans. When trade winds are weak, warm water builds up off West Africa
    b. The warm water allows tropical depressions (caused by converging air masses in the tradewind system) to organize into tropical storms.

   c. Hurricanes form when tropical storms pass over warm water which supplies heat and evaporating seawater.
   d. The rising moist air condenses the moisture into clouds giving up more heat to the storm and causing a feedback system driving more evaporation, more rising air, more heat transfer by cloud formation and so on.
9. ***Orbital Scale***—21,000 yr (average), 41,000 yr, and 100,000 yr (average) cycles
   a. These cycles are driven (ultimately) by variations in the gravitational pull of the nearby planets on Earth's orbit. Jupiter, Saturn, Mars and Venus are the most important (the first two because they are very large, the last two because they are close to Earth)
   b. These gravitation effects tweak the shape of Earth's orbit
      i. For example, the 100 kyr cycle reflects a cycle between a very circular Earth orbit and a fairly elliptical one.
      ii. A highly elliptical orbit produces more extreme seasons than a circular orbit.
   c. Orbit changes, in turn, change the amount of solar heating the upper atmosphere receives which then affects the strength of pressure systems and winds
   d. ***The Earth has a "heartbeat" and "breaths" quite literally***. There is a 400 kyr cycle of productivity driven by multiples of the 100 kyr cycle.
      i. probably reflects variations in aridity and hence growth rates and productivity of plants.
      ii. Similar to the seasonal cycle of CO_2 where high CO_2 reflects winter depression of plant growth and low CO_2 reflects summer consumption of CO_2 during active photosynthesis.
   e. These orbital cycles drive changes in ice storage on land
      i. More ice growth during extreme years of very cold winters that can grow more ice than that be melted in the following summer
      ii. In turn, ice growth increases albedo (reflected sunlight) causing the surface to cool more and accumulate more snow—leads to "runaway ice sheet growth"
      iii. More ice stores water on land, removing water from the oceans and causing sea level to drop. During the Pleistocene (last Glacial "Maximum") sea level dropped by ~120 meters!
      iv. Allows people and mastodons to walk from Asia to North America over the Bering "land bridge"

Long Timescale changes in Earth's Climate

1. Over past 500 my Earth has cycled between ***"Greenhouse" and "Icehouse"*** climates with expansion of glaciers during the latter and expansion of tropical vegetation and animals during the former.
   a. Breadfruit trees and crocodiles in Greenland during the "Cretaceous Thermal Maximum"
   b. Ice sheets covering the southern part of Gondwanaland in the Permian
2. In the Precambrian has ***"Snowball Earth"*** episodes

a. Active debate from paleomagentism arguing that ice sheets extended to the equator.
b. "Snowball" episodes at 2.5 Ga, 750 Ma, and 610 Ma—the youngest of these certainly overlaps the evolution of the first multicellular animal life. How did they survive a frozen planet?
c. How do we freeze the planet?—soak up CO_2? CH_4? Extreme orbit?