Sea Ice and Density-Driven Ocean Circulation

Density and Water Masses

Thermohaline Circulation

Readings:

Ch 6: 6.6-6.10, 6.16-6.19

Ch 9: 9.16-9.21

Top graphic: Mother polar bear and cub explore a pressure ridge in the Arctic Ice (Photo by J. Ortiz)

Bottom Graphic: USCGC Roger Healy beset in a multiyear iceflow in the Chuckchi Sea, Arctic Ocean (Photo by J. Ortiz).

What Influences Ocean Circulation?

- **Wind**
- **Earth Rotation**
- **Heating, Cooling**
- **Gravity**
- **Geography**
- **Precipitation (i.e., rain) and Evaporation**

Graphic: Sea surface temperature measured by satellite for October 1999. Courtesy of NOAA.

Types of Ocean Circulation

<u>Wind-driven circulation</u>

- **driven by wind; influenced by the Coriolis effect and gravity**
- **confined to upper part of the ocean (top 400-1000m)**
- **occurs in "gyres" confined to individual ocean basins**
- **fast currents (up to 2 meters per second)**

<u>Density-driven circulation</u>

- **forced by heating/cooling/precipitation/evaporation and gravity**
- **occurs over the full depth of the oceans**
- **circulation connects all of the ocean basins**
- **slow currents (typically 1-2 meters per day)**

Wind-Driven Circulation

Subtropical gyres – driven by Trades and westerlies in both the northern and southern hemispheres

Western boundary currents=strong poleward flows on the west side of ocean (along the east side of a continent)

Difference in western and eastern boundary current strength – occurs due to rotation of the Earth

Wind-Driven Ocean Circulation

3 Parts: 1=Subtropical gyres

Graphic: Garrison, Fig. 9.8b.

Wind-Driven Ocean Circulation

3 Parts: 1=Subtropical gyres, 2=Subarctic gyres (northern hem only)

Graphic: Garrison, Fig. 9.8b.

Wind-Driven Ocean Circulation

3 Parts: 1=Subtropical gyres, 2=Subarctic gyres (northern hem only)

3=Antarctic Circumpolar Current

Graphic: Garrison, Fig. 9.8b.

Ice and Climate

Polar ice is an important part of the Earth's climate system

Ice is much "brighter" than land or water and reflects the sun's energy back to space very efficiently

A world with less ice would absorb more solar energy

Graphic: View of Earth as seen by the Apollo 17 crew travelling toward the moon, Dec. 7, 1972. Photo courtesy of NASA.

The "Ice-Albedo" Feedback
Climate and Ice - North and South
Ice in the Arctic

The Arctic has "permanent" (multi-year) ice and ice that persists only until summer

Graphic: Sea ice cover in the Artic in February (left) and September (right). Courtesy of National Snow and Ice Data Center.

Climate Change and the Arctic

Many climate models predict that the Arctic will warm significantly due to increases in atmospheric CO2

Graphic: Surface air temperature change at the time of CO2 doubling (colors) predicted by an ensemble of climate models with CO2 increasing 1% per year. From the Intergovernmental Panel on Climate Change (IPCC).

Land-Based Observations Support Climate Model Predictions

Graphic: The Grinnell Glacier in Glacier National Park, Montana. Left: 1938, Right: 1981. Courtesy of USGS.

Sea Ice Draft: 1950's-1970's vs 1990's

Measurements of sea ice draft (amount of ice below the water line) indicate less ice in the Arctic recently compared with the 1950's through 1970's

Graphic: Decrease in Arctic sea ice draft. Graph derived from Rothrock et al., 1999, courtesy of National Snow and Ice Data Center.

Density-Driven Circulation

Heating, cooling, precipitation and evaporation change the density of seawater

The density driven circulation is the motion that arises as dense water sinks below light water under the influence of gravity

Graphic: Ross Ice Shelf, Antarctica. M.Van Woert, photographer, courtesy of NOAA.

Density of Fresh Water

The density of fresh water depends on temperature

Fresh water reaches maximum density at about 4^{o}C

Ice is less dense than fresh water

Graphic: (top) Pinet Fig. 5.5b, see Garrison, Fig. 6.3, (bottom) icebergs near Antarctica, M.VanWoert, photographer, courtesy of NOAA.

Density of Seawater

Seawater density depends on temperature and salinity

Cold salty water is more dense than warm fresh water

Two samples of water at different temperatures and salinities can have the same density

Graphic: Density as a function of temperature and salinity. The curved lines are lines of constant density. See Garrison, Fig. 6.9

What Happens as Sea Water Freezes?

As the ocean cools and freezes, sea ice forms

The "salt" in the sea is not incorporated into the ice, it is left behind in the water

Net result:

- "fresh" ice

- very cold, very salty water

- heat moves from the ocean to the atmosphere

Graphic: The midnight sun illuminates multiyear ice in the Arctic during June, 2005 (Photo by J. Ortiz)

Sea Ice and Bottom Water*

Bottom water:

Very cold winds blow over the ocean, forming sea ice

The seawater that is not incorporated into the ice is very cold and salty and sinks as "bottom water“

Deep water:

Winds cool water enough for it to sink, but not enough to form sea ice

Evaporation and Mediterranean Sea Water

Not all dense water is produced near the poles...

Evaporation creates very salty warm water in the Mediterranean Sea

This spills over the Gibralter sill and sinks in the central North Atlantic

Graphic: Garrison, 4th Ed., Fig. 9.21, pg. 227, 5th Ed., Fig. 9.23, pg 219.

Graphics: Top, Salinty in September Salinity at 1000 m, Bottom, North Atlantic Salinity section at 35.5N. [Data from the World Ocean Atlas viewed with the IRI data viewer.]

Intermediate Water Production at Convergence Zones

(arrows indicate direction of water motion)

Where <u>ocean currents converge, dense water can sink under lighter water</u> leading to a new class of water masses (Intermediate Water)

Convergence zones occur due to winds

Regions Where Dense Water Forms

Deep & Bottom Water

- form due to

atmospheric cooling

Med Sea Water

- forms due to

evaporation

Intermediate water

- forms due to

convergence of

ocean currents

Graphic: See Garrison, Fig. 9.26.

Water Masses

Water masses - bodies of water identifiable by their salinity and temperature (i.e., density) or other unique properties

Water mass	Approximate depth range
Less dense	
Surface	0-200 m
Central	200m -bottom of thermocline (depths depend on latitude)
Intermediate	bottom of thermocline to about 1500 m
Deep	1500-4000 m
More dense	
Bottom	In contact with the sea floor

Water Mass Layering (Atlantic)

Antarctic Intermediate Water - flows northward

North Atlantic Deep Water - flows southward at mid-depths

Antarctic Bottom Water -flows northward along the bottom

Others: Mediterranean Sea water, Central water, Surface water

Graphic: Garrison, Fig. 9.29.

Themohaline Circulation - The Concept

Thermo = temperature

Haline = salt

<u>Themohaline = Temperature and salinity (i.e., density) driven circulation</u>

Cold, salty (dense) water sinks in the poles

Warm, fresh (less dense) water floats in the tropics

Graphic: Garrison, Fig. 9.28.

Themohaline Circulation - Linking the Global Ocean

1. Sinking at poles in Atlantic

2. Deep flow of cold, salty water into Indian and Pacific

3. Upwelling in Pacific

4. Return flow at surface via Indonesean Passages

Graphic: Pinet, Fig. 6.16b, see Garrison, Fig. 9.26.

Climate Change - Life in the Greenhouse

Natural Climate Change

What is the Greenhouse Effect?

Climate Change and the Future

Ch 9: 9.10-9.13, 9.15

Graphic: See Garrison, Fig. 18.27.