Sailing the Seas: Wind Driven Ocean Circulation

Ocean Gyres

Ocean Currents

What Happens at the Coast?

Readings:

Ch 9: 9.2-9.6, 9.8-9.13

Graphic: America's Cup sailboat race off Newport, Rhode Island. J. Bortniak, photographer, courtesy of NOAA.

Global Atmospheric Circulation

1. Warm air rises, cold air sinks

2. Three circulation cells – where they meet, air moves the same direction

3. Coriolis – deflects motion to the right (in the northern hemisphere)

4. Weak winds where cells meet

5. Rising air – moistens – forests sinking air – dries – deserts

Blue Planet, Fig. 13.12. See Garrison, Fig. 8.13.

Deserts and Rainforests

Polar Regions:

- sinking air (cold and dry)

Midlatitudes:

- rising air (mild and wet)

Subtropics:

- sinking air (hot and dry)

Equatorial region:

- rising air at ITCZ
- intense thunderstorms
- very hot and wet

Graphic: False color view of ocean and land color, courtesy of the SeaWiFS Project, NASA/Goddard Space Flight Center, and ORBIMAGE.

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

Wind-driven circulation

- 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)

Density-driven circulation

- 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 and Ocean Currents

Wind-driven currents flow perpendicular to the wind due to how the frictional force of the wind is translated downward into the water

Flow direction:

90^o to the right of the wind in the northern hemisphere

90^o to the left of the wind in the southern hemisphere

Graphic: Garrison, Fig. 9.5b,c.

Ocean Gyres

Large-scale winds set up basin-scale ocean currents called gyres

The Trade winds and Westerlies drive subtropical gyres (the largest of the ocean gyres)

Graphics: Garrison, Figs. 9.1, 9.2.

Subtropical and Subarctic Gyres

Subtropical gyres occur at midlatitudes and rotate clockwise in the northern hemisphere

Subarctic gyres occur at high latitudes and rotate counterclockwise in the northern hemipshere

Gyre rotation is in the opposite sense in the southern hemisphere

Graphic: After Garrison, Fig. 9.8b.

Trash or Treasure?
Using Floating Debris to Measure Gyre Circulation

Graphic: Containership at the Port of Charleston, SC. Capt. A.E. Theberge, photographer, courtesy of NOAA, Insets: Daily Herald, Everett WA.

Making Use of Gyre Circulation

The North Atlantic subtropical gyre flows clockwise

Ships traveling west to east follow the north side of the gyre

Graphic: Start of the 2002-2003 Around Alone Race, copyright Billy Black, PPL. (right) the 2002-2003 Around Alone Race route.

Ocean Gyres and Ocean Currents

Gyres consist of ocean currents with distinct properties

Example: North Atlantic gyre

Western boundary current:

Gulf Stream - narrow, fast, warm

Eastern boundary current:

Canary Current - broad, slower, cold

These are connected by the North Atlantic and North Equatorial Currents

Graphic: Garrison, Fig. 9.3.

Wind-Driven Ocean Circulation

Graphic: Garrison, Fig. 9.8b.

Wind-Driven Boundary Currents

Type of Current	Features	Speed	Transport
Western boundary currents (WBC)	narrow (<100 km) deep (to 2 km) warm	fast	large (50 Sv) toward poles
Eastern boundary currents (EBC)	broad (~1000 km) shallow (< 500 m) cold	slow	small (10-15 Sv) toward equator

Graphic: Garrison, Fig. 9.13b.

Sailing Subtropical Gyres and Equatorial Doldrums

Winds and currents provide good sailing in the subtropical gyres, but...

Winds are weak and unpredictable in the equatorial doldrums

Graphic: (top) Team Assa Abloy under sail. (bottom) Team SEB struggling near the equator.

Photos by R.Tomlinson.

Perils in the Antarctic Circumpolar Current

The Antarctic Circumpolar Current is the only wind-driven flow that connects all of the major ocean basins

Graphics: (top left) SEB approaching Chile after losing her mast, (bottom left) icebergs sited during leg 4, (top right) jury-rigging after extensive rudder and tiller damage in the Southern Ocean.

Real Ocean Currents Observed by Satellite

The real ocean flows in complex patterns due to turbulence

<u>Example: North Atlantic</u>

The warm, turbulent flow of the Gulf Stream carries 70 million cubic meters of water per second northward along the eastern seaboard (3500 times more than the Mississippi River)

Red=warm

Purple/blue=cold

Graphic: North Atlantic sea surface temperatures measured by satellite. Image courtesy of NOAA.

Ocean Eddies

Strong currents like the Gulf Stream develop loops which can detach to form isolated rings ("eddies")

<u>Cold core eddies</u> - cold masses of water that drift into warmer regions

<u>Warm core eddies</u> - warm masses of water that drift into colder regions

Red=warm

Purple/blue=cold

Graphic: North Atlantic sea surface temperatures measured by satellite. Image courtesy of NOAA, See Garrison, Fig. 9.11.

Ocean Eddies and Biology

Eddies are biologically and chemically isolated and can persist for several years

Red=high productivity

Blue=low productivity

Graphics: (top) False-color image of the biological productivity off the eastern seaboard of the U.S. (blue=low productivity, red=high productivity), (bottom) schematic of warm and cold core ocean eddies. Both courtesy of NASA Goddard Space Flight Center.

What Happens at the Coast?

Ocean currents flow perpendicular to the wind, but if a coastline blocks the current, the water must move vertically

Upwelling – water moves upward

Downwelling – water moves downward

Graphic: Garrison, Fig. 9.5b,c.

Upwelling

Wind blowing along the coast moves water away from the coast

This water is "replaced" by water that moves vertically

West coasts in the northern hemisphere:

- Winds from the north drive offshore currents

- "upwelling" brings water up from below

Graphic: Garrison, Fig. 9.16.

Upwelling and Biology

Water from below is cool and rich in nutrients, which support plant growth and sustain animal communities

High productivity **Upwelling zones are regions of abundant plant and animal life and some of the world's best fishing grounds**

Red=high productivity

Blue=low productivity

Graphic: Upwelling off Cape Town South Africa, February 21, 2000 (red=high productivity). In this southern hemisphere case, the wind blows along the coast from south to north and the water flows offshore. Image Provided by the SeaWiFS Project, NASA/GSFC and ORBIMAGE.

Next Lecture: Sea Ice and Density-Driven Ocean Circulation

Ice and Climate

Density and Water Masses

Thermohaline Circulation

Readings:

Ch 6: 6.6-6.10, 6.16-6.19

Ch 9: 9.16-9.21

Graphic: Gerlache Strait, Rear Adm. H.D.Nygren, photographer, courtesy of NOAA.