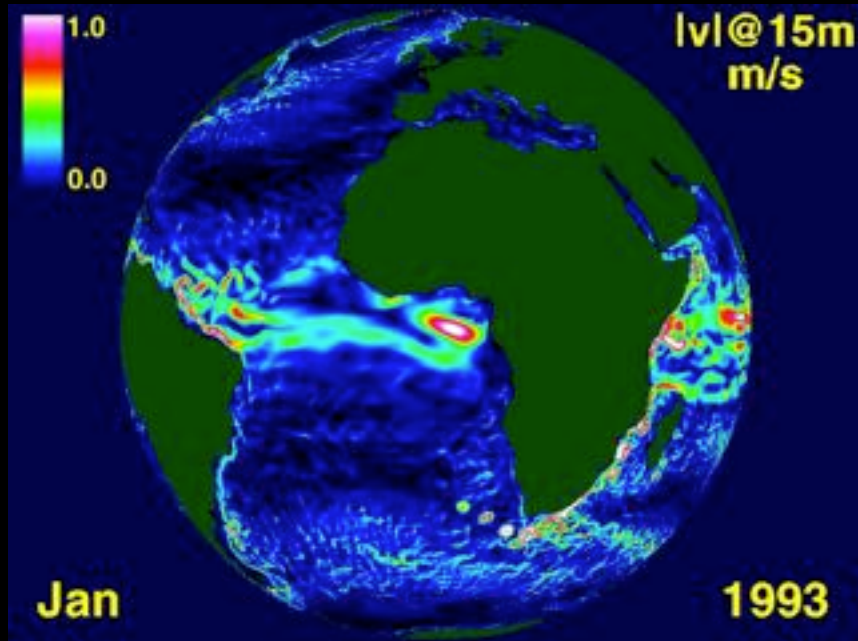


Introduction to Oceanography Lecture 18, Current 2



Surface Ocean Currents. Video by Chris Henze, NASA Ames, Public Domain

Midterm 2: Nov. 20 (Monday)

Review Session & Video Screenings TBA

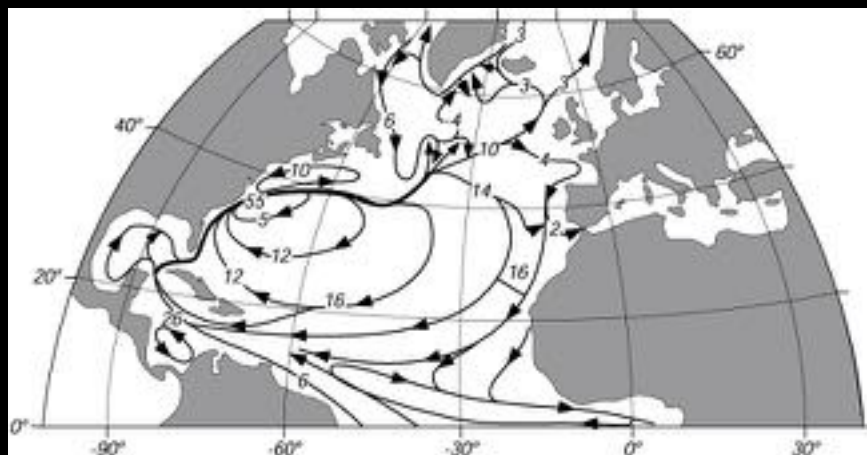
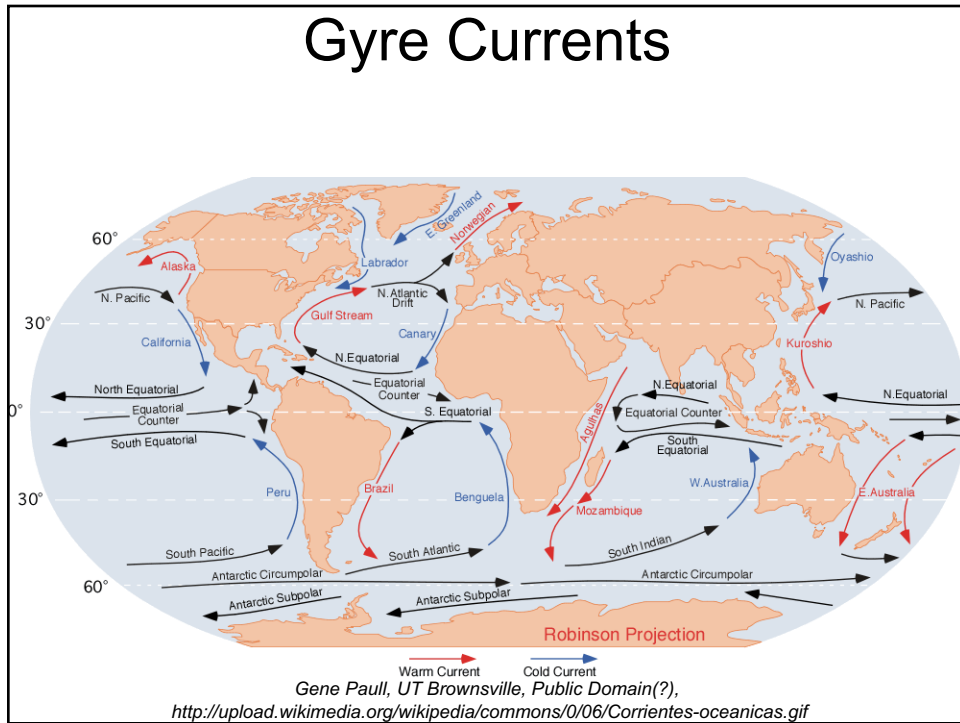
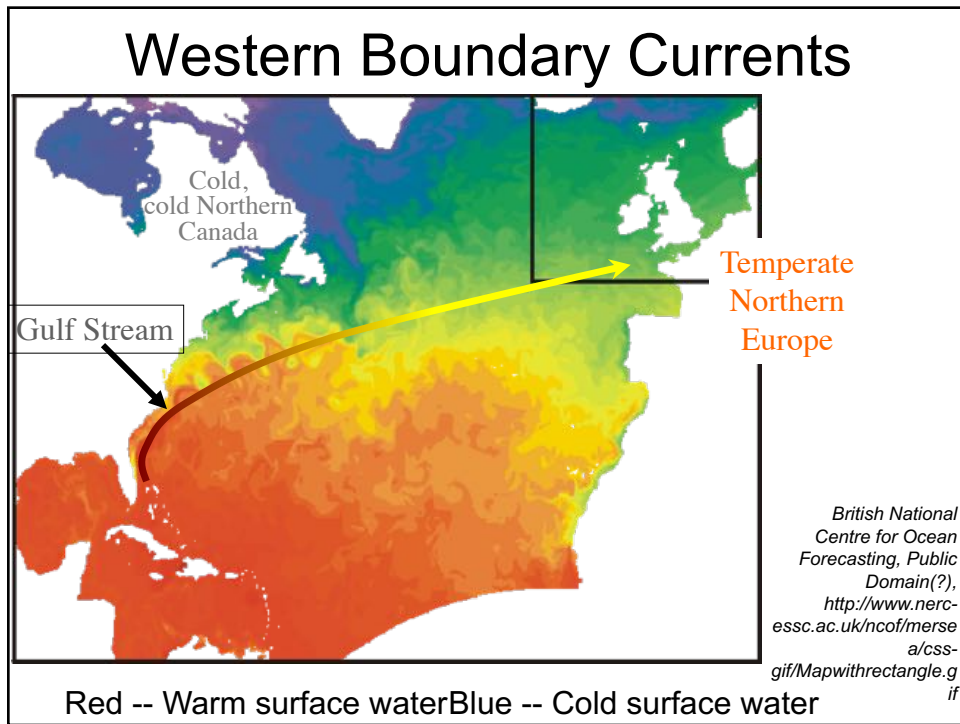


Image from Sverdrup, Johnson, and Fleming, Sverdrup H.U., Johnson M.W., Fleming R.H. *The Oceans.. their physics, chemistry, and general biology* (1942), http://oceanworld.tamu.edu/resources/ocng_textbook/chapter11/Images/Fig11-7.htm

Gyre Currents

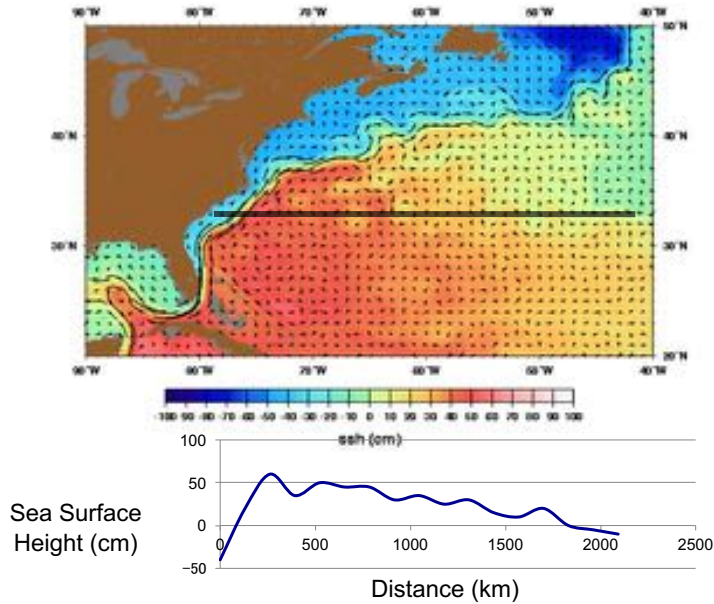


Western Boundary Currents



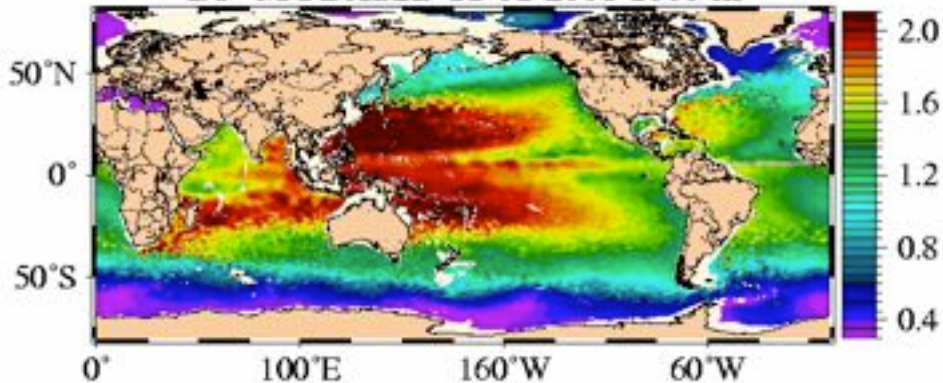
North Atlantic Gyre Boundary Currents

January



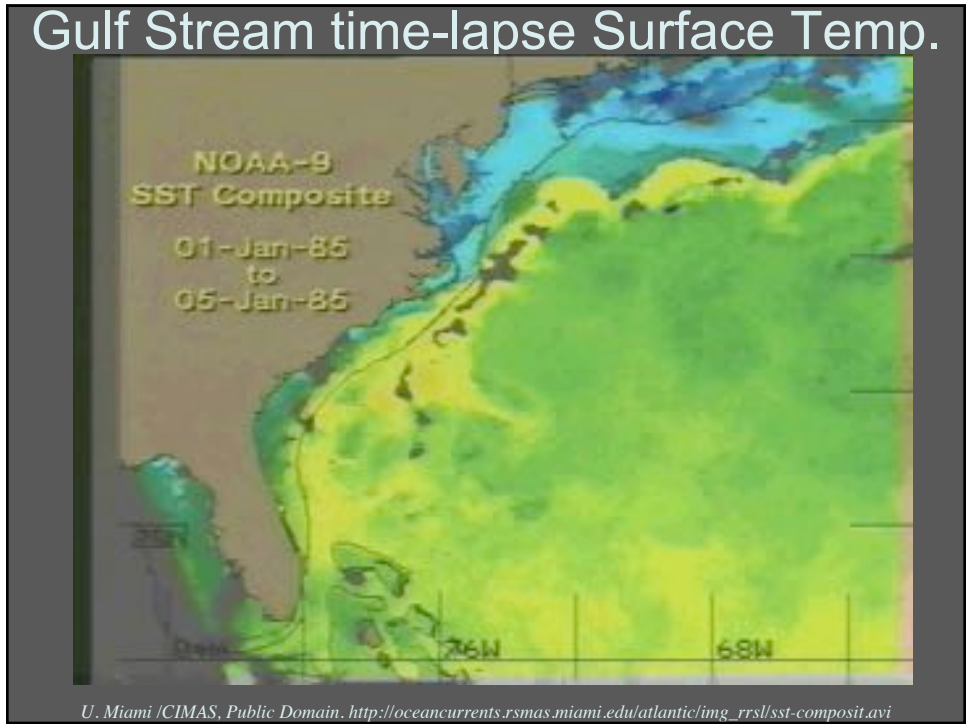
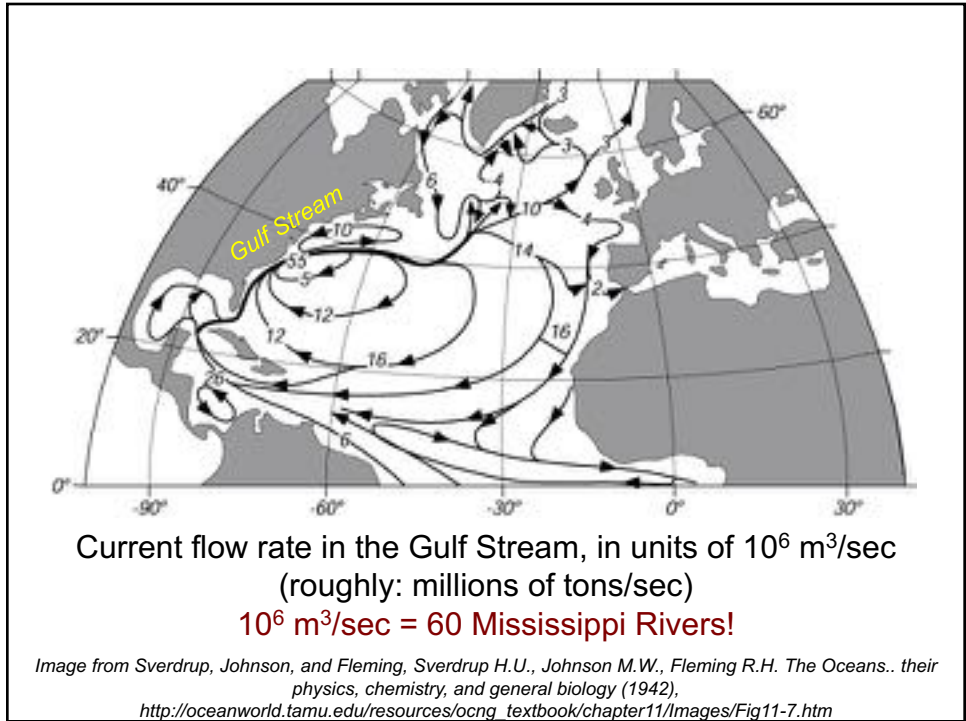
Coriolis “Geostrophic” Response

Altimeter OI: Steric Height Anomaly (m)
1/8° MODAS2D 11-01-2008 1000 m



Centers of gyre “hills”: Sargasso Sea, W. Pacific, Madagascar, etc.

Animation from the Naval Research Laboratory, Public Domain,
http://www7320.nrlssc.navy.mil/modas2d/animations/gbl/httot_gbl_12mon.fli



Western Boundary Currents

- Fastest, deepest gyre currents
 - Equatorial currents are deflected to high latitudes by continents
 - Transport warm water to high latitudes
- **Gulf Stream** (N. Atlantic); **Kuroshio Current** (N. Pacific); **Brazil Current** (S. Atlantic); **Agulhas Current** (Indian); **East Australian Current** (S. Pacific)
- **Gulf Stream** is king of them all!
 - 2 m/s \approx 200 km/day
 - $55 \times 10^6 \text{ m}^3/\text{sec} = 55 \text{ Sverdrups}$ transported
 - > 3000 Mississippi Rivers!

Eastern Boundary Currents

- Shallow, broad, slow currents
 - Return flow to low latitudes
 - Transport cold water to the equator
 - Roughly 1/10 the speed of WBCs
- **Canary Current** (N. Atlantic); **California Current** (N. Pacific); **Benguela Current** (S. Atlantic); **West Australian Current** (Indian); **Peru Current** (S. Pacific)

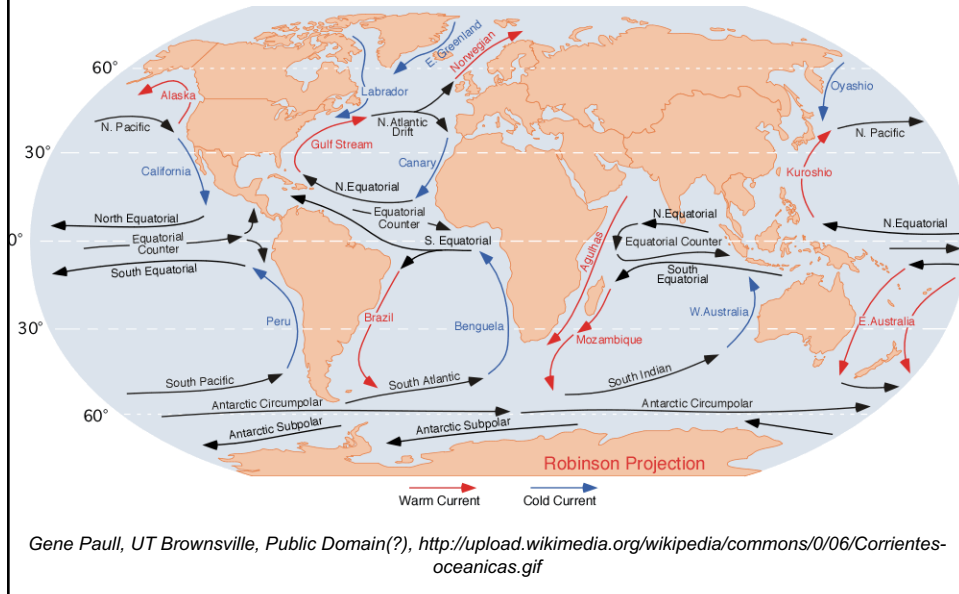
Boundary Currents

Current	Width (km)	Depth (km)	Flow Rate (km/day)
Western Boundary	< 100 km	1-2 km	~ 100 km/day
Eastern Boundary	> 1000 km	< 0.5 km	~ 10 km/day

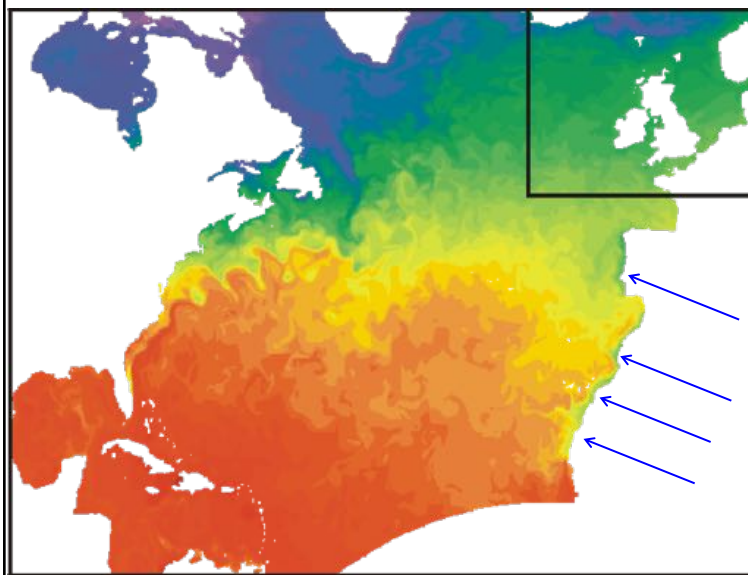
Important non-gyre currents: Equatorial **Counter** Currents

- Right between the two Equatorial currents
- No Coriolis at equator: only wind stress vs. pressure
- Response of water to constantly being pushed / piled up on the west side of the basin (up to 50 cm high)
- Tends to flow back towards East.

QUESTIONS?



Upwelling of Deep Water



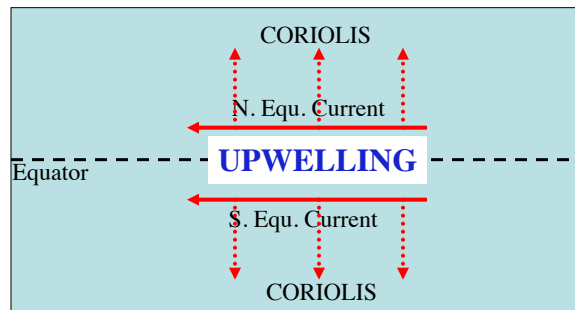
British National
Centre for Ocean
Forecasting, Public
Domain(?),
<http://www.nerc-essc.ac.uk/ncof/mersea/css-gif/Mapwithrectangle.gif>

Red -- Warm surface water

Blue -- Cold surface water

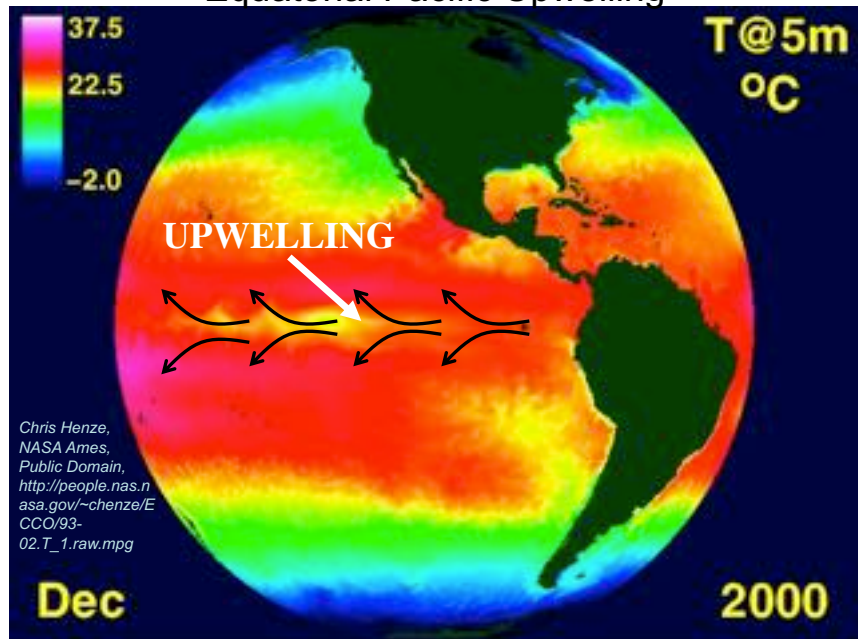
Sites & Causes of Upwelling

- Equatorial Divergence: Opposite Coriolis bending on each side of the equator causes pull surface water away. Cold deep water rises to replace it.



Figures, UCLA

Equatorial Pacific Upwelling



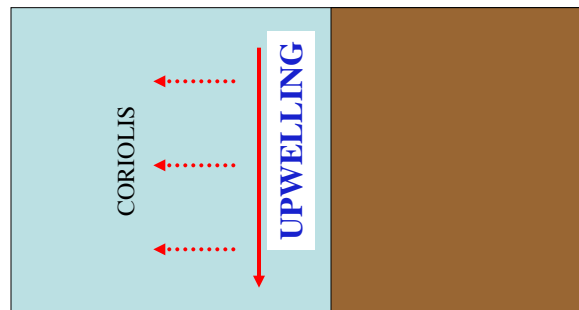
Blue-Yellow - Cold water

Red-Magenta - Warm water

Chris Henze,
NASA Ames,
Public Domain,
http://people.nasa.gov/~chenze/ECCO/93-02.T_1.raw.mpg

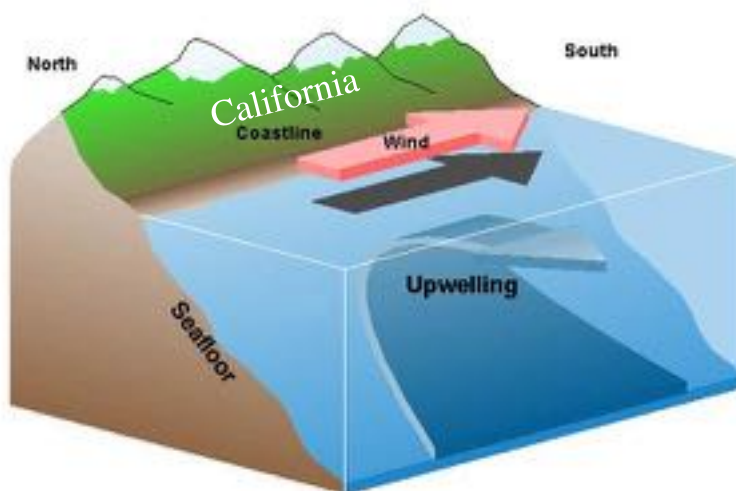
Coastal Upwelling

- Coastal Upwellings: Ekman transport away from shoreline forces upwellings



Figures, UCLA

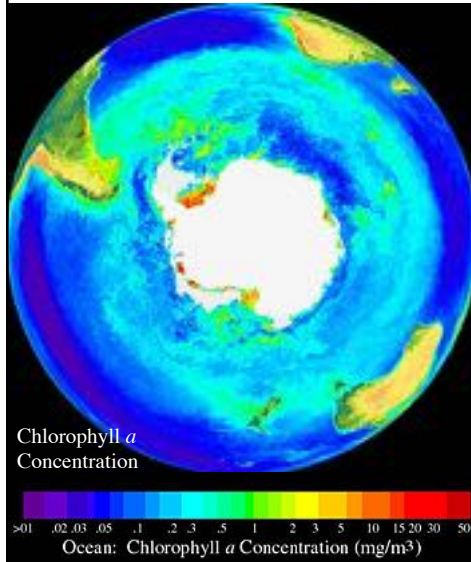
Coastal upwelling, California



NOAA image, Public Domain,
http://oceanexplorer.noaa.gov/explorations/02quest/background/upwelling/media/fig1_cartoon.html

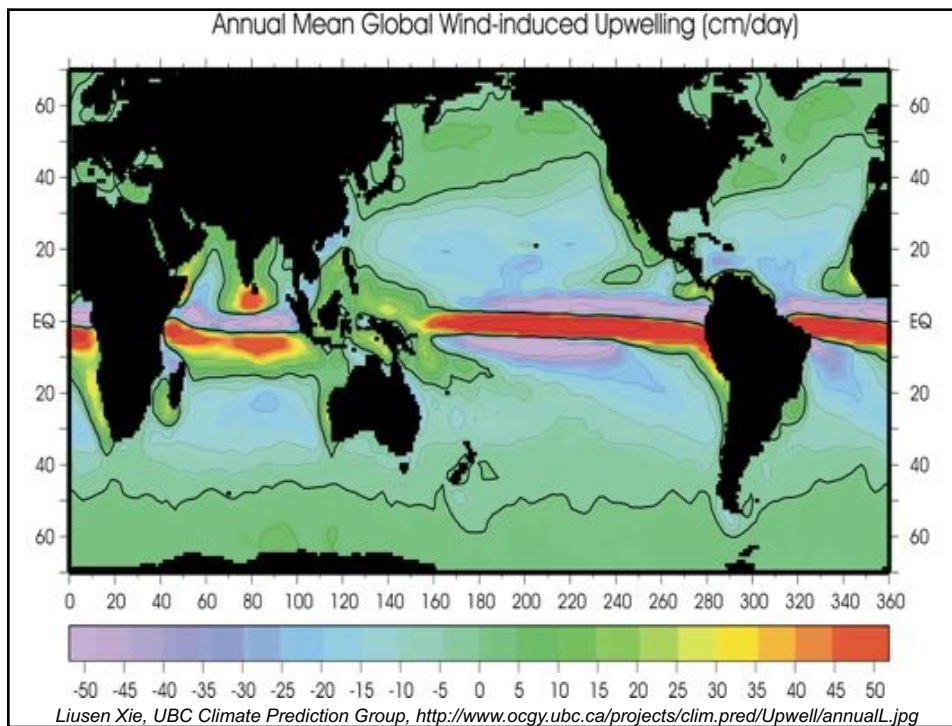
Upwelling and Downwelling Flows

- Antarctic Divergence:

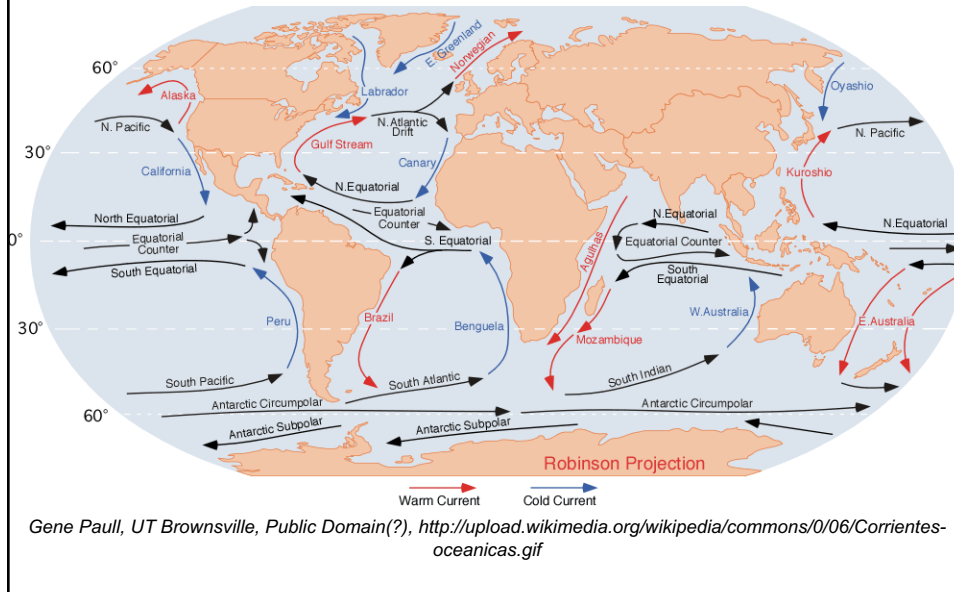


- **Two causes:** Dense sinking waters (vertical mixing) and **Ekman transport** (upwelling) away from Antarctic Circumpolar Current
- Results in intense upwelling around Antarctica
- Very high biological productivity

NASA image, Public Domain,
<http://earthobservatory.nasa.gov/Study/Polynyas/>

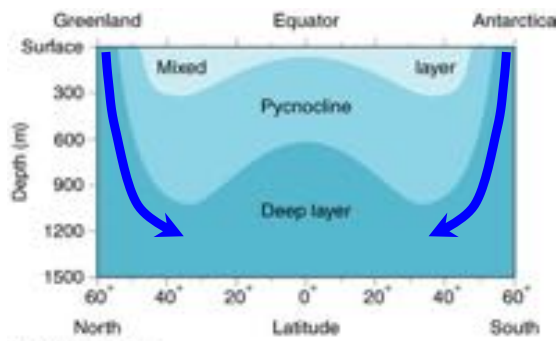


QUESTIONS?

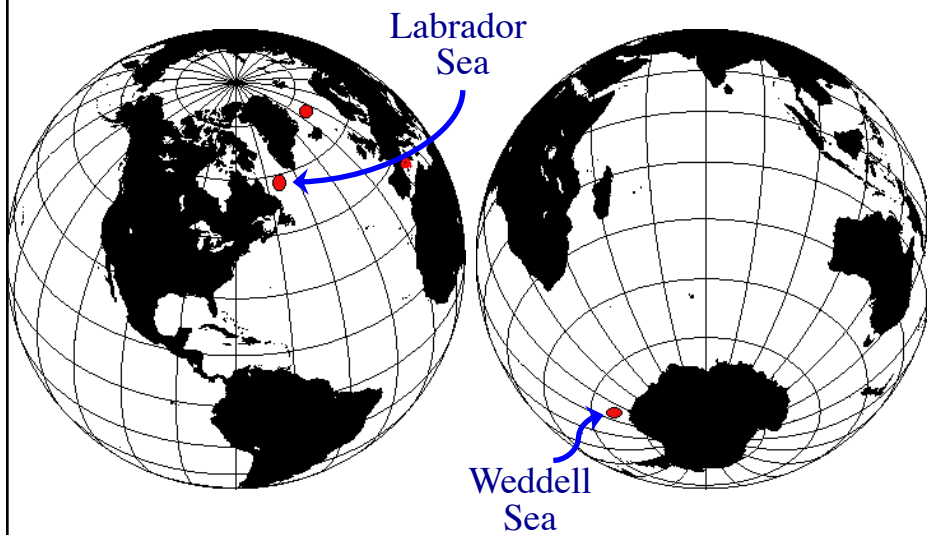


Deep Currents in the Ocean

- Two Types
 - Surface Currents
 - Mixed layer (0-300 m), most surface currents here
 - Pycnocline (to 1000m)
 - Sub-surface (deep) Currents
 - Deep water

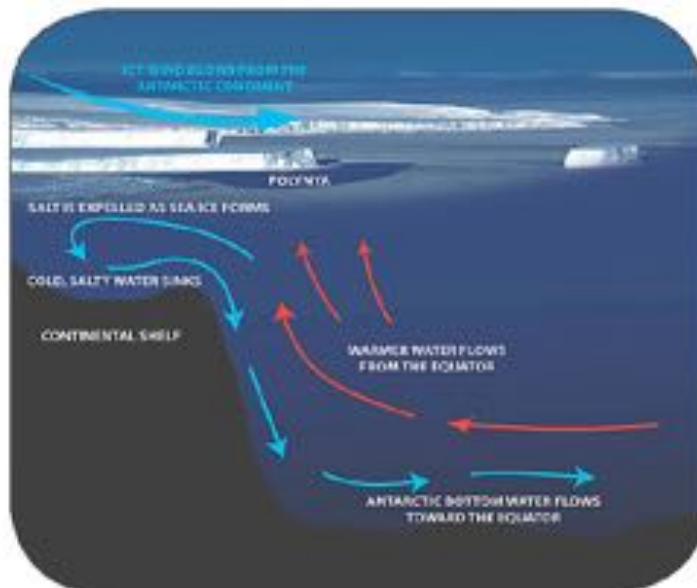


Where does deep water come from?



Adapted from figure by Helen Hill(?), MIT, <http://puddle.mit.edu/~helen/>

Deep Water Formation



Deep currents – sinking of dense water near the poles

Figure from Matthew England, Climate Change Research Centre (CCRC) University of New South Wales, http://web.maths.unsw.edu.au/~matthew/southern_ocean_variability.htm

Water Mass Classifications

- Deep Waters:
 - North Atlantic Deep Water (NADW)
 - Vertical mixing & incorporation of salty N. Atlantic waters near Greenland
- Bottom Waters:
 - Antarctic Bottom Water (AABW)
 - Forms dominantly in Weddell Sea in regions of active sea ice formation (polynyas)
 - Cold, saline sinking water
 - Densest water mass in the oceans

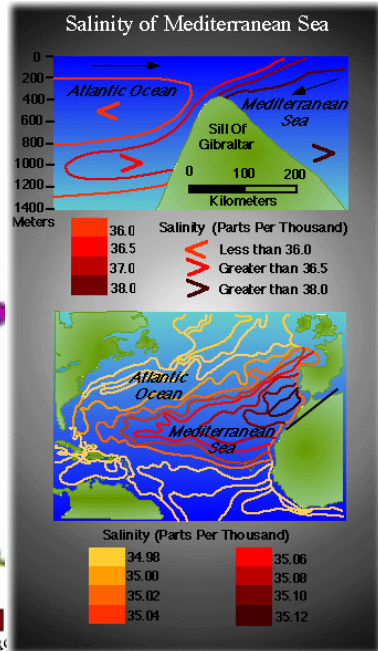
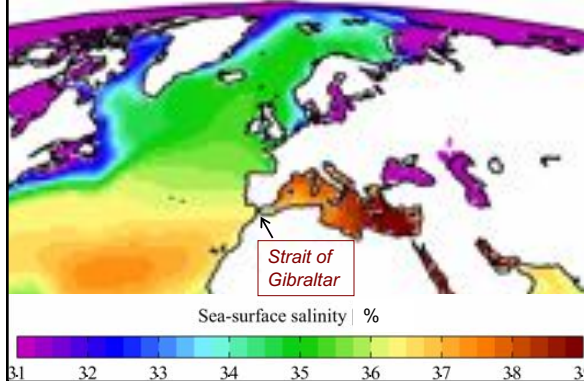
Water Mass Classifications

Intermediate Waters: Water between cold, deep polar water and surface

Example: Mediterranean outflow:
Warm and highly saline at ~1000 m

*Med. outflow figure by G. P. King,
<http://www.eng.warwick.ac.uk/staff/gpk/Teaching-undergrad/es427/rice.glacier.edu-oceans/GLACIER%20Oceans-%20-%20Densitydriven.htm>*

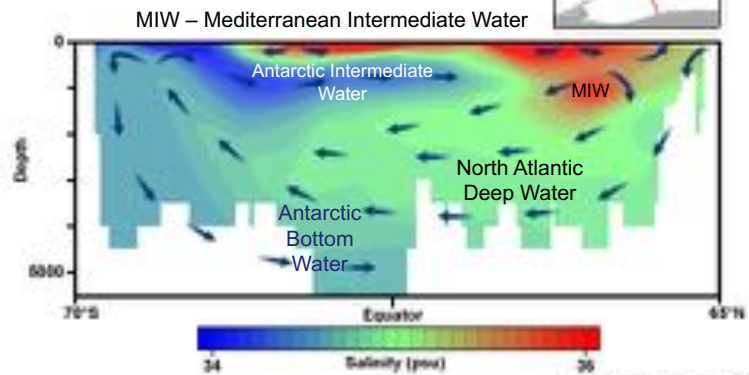
*Sea-surface salinity map by Rosarinagazos, Creative Commons A S-A 3.0,
http://commons.wikimedia.org/wiki/File:Wiki_plot_04.png*



Atlantic Deep Circulation

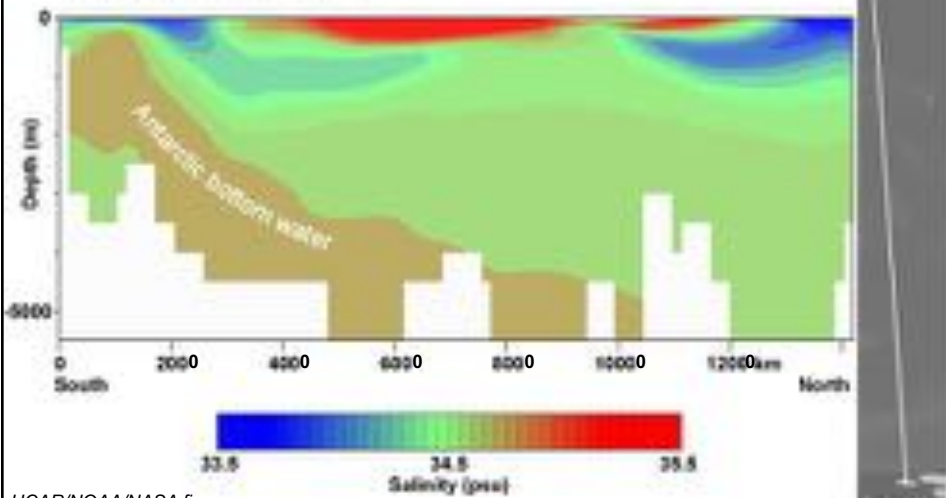
UCAR/NOAA/NASA,
Public Domain,
http://www.meted.ucar.edu/tropical/met_topics/media/graphics/moc_atlantic_salinity.jpg

Cross Section of Salinity in the Atlantic Ocean with Meridional Overturning Circulation



Pacific

Cross Section of Mean Annual Salinity, World Ocean Atlas 2005

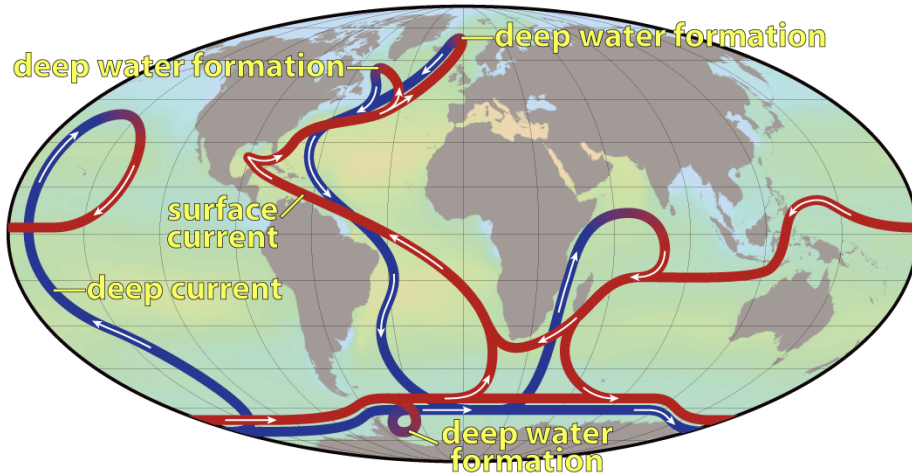


UCAR/NOAA/NASA figure,
Public Domain,
http://www.meted.ucar.edu/oceans/currents/media/graphics/pacific_s

NOAA / NODC / The COMET Program

Global deep water 'conveyor'

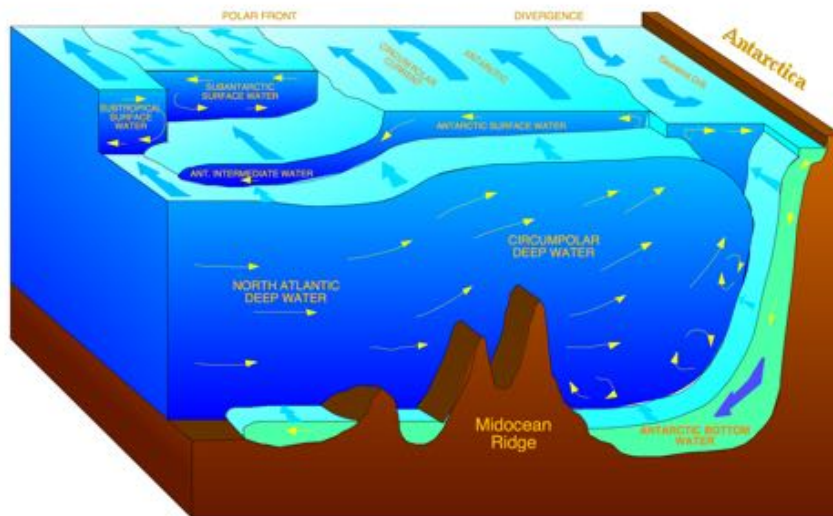
Thermohaline Circulation



32 34 36 38 Salinity (PSS)

Robert Simmon/Robert Rohde, NASA/Wikimedia, Public Domain,
http://en.wikipedia.org/wiki/File:Thermohaline_Circulation_2.png

Hannes Grobe, Wikimedia Commons, Creative Commons A S-A 2.5,
http://upload.wikimedia.org/wikipedia/commons/2/2c/Antarctic_bottom_water_hg.png



QUESTIONS?