Highways in the Sea

(Chapter 9)

Surface Currents

Deep Currents

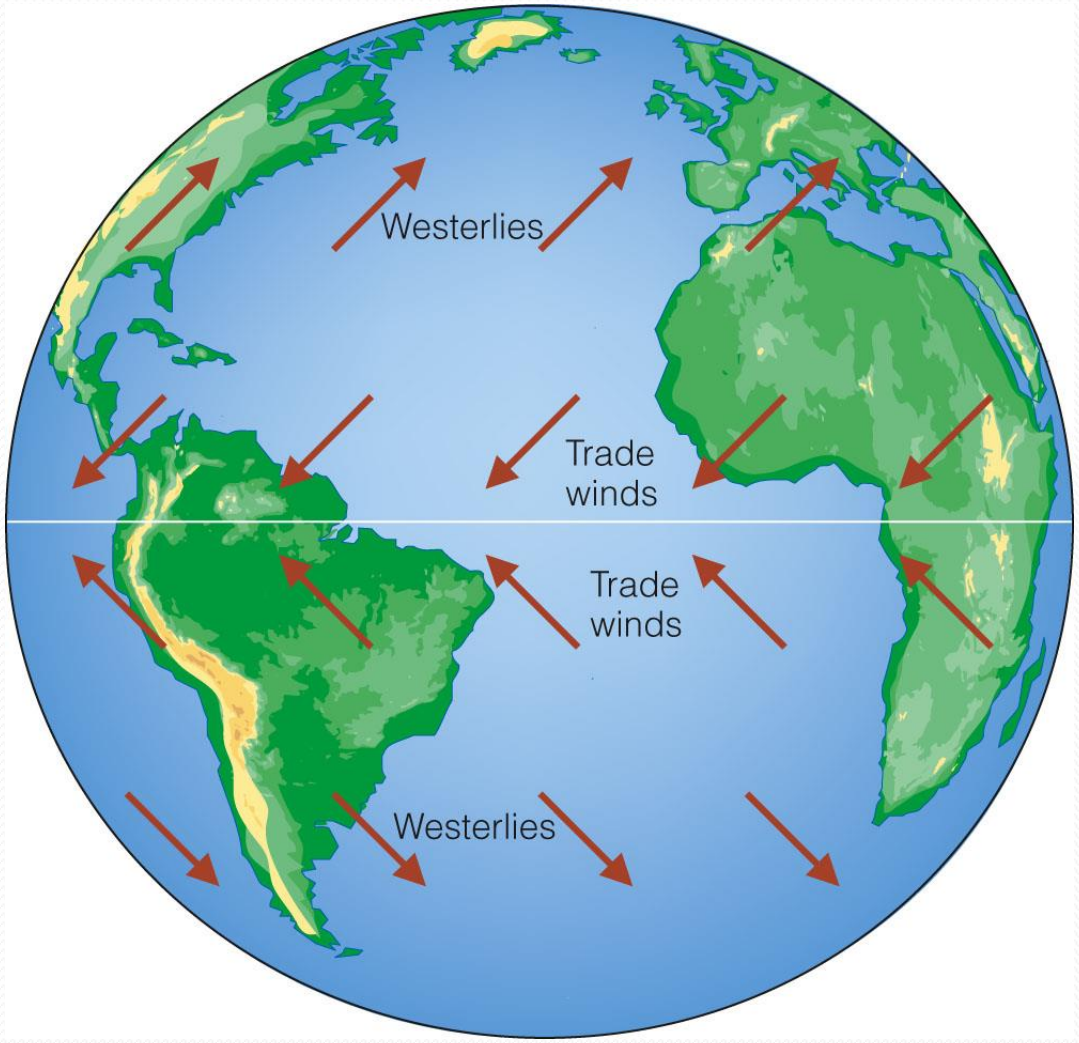
Studying Ocean Currents

What causes currents?

- **Wind** causes surface currents (and waves)
  - Frictional force transfers energy from air to water
- Changes in sea level across distance causes surface currents
  - Pressure gradient (water wants to be level due to force of gravity)
  - Coriolis effect deflects current direction (so does land)
- Changes in water density causes surface and deep currents (dense water sinks, gravity again)

Wind and currents

Surface Currents Are Driven by the Winds



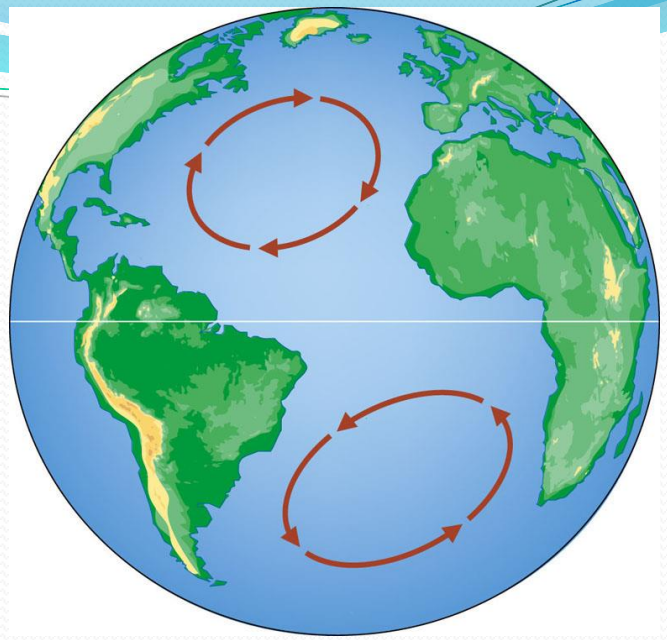
Surface currents: composed of water flowing horizontally in the uppermost 400 meters (1,300 feet) of the ocean's surface, driven mainly by wind friction.

Winds, driven by **uneven solar heating** and **Earth's spin**, drive the movement of the ocean's surface currents. The prime movers are the powerful westerlies and the persistent trade winds (easterlies).

What are some effects of ocean currents?

- Transfer heat from tropical to polar regions
- Influence weather and climate
- Distribute nutrients and scatter organisms

Global Surface Gyres

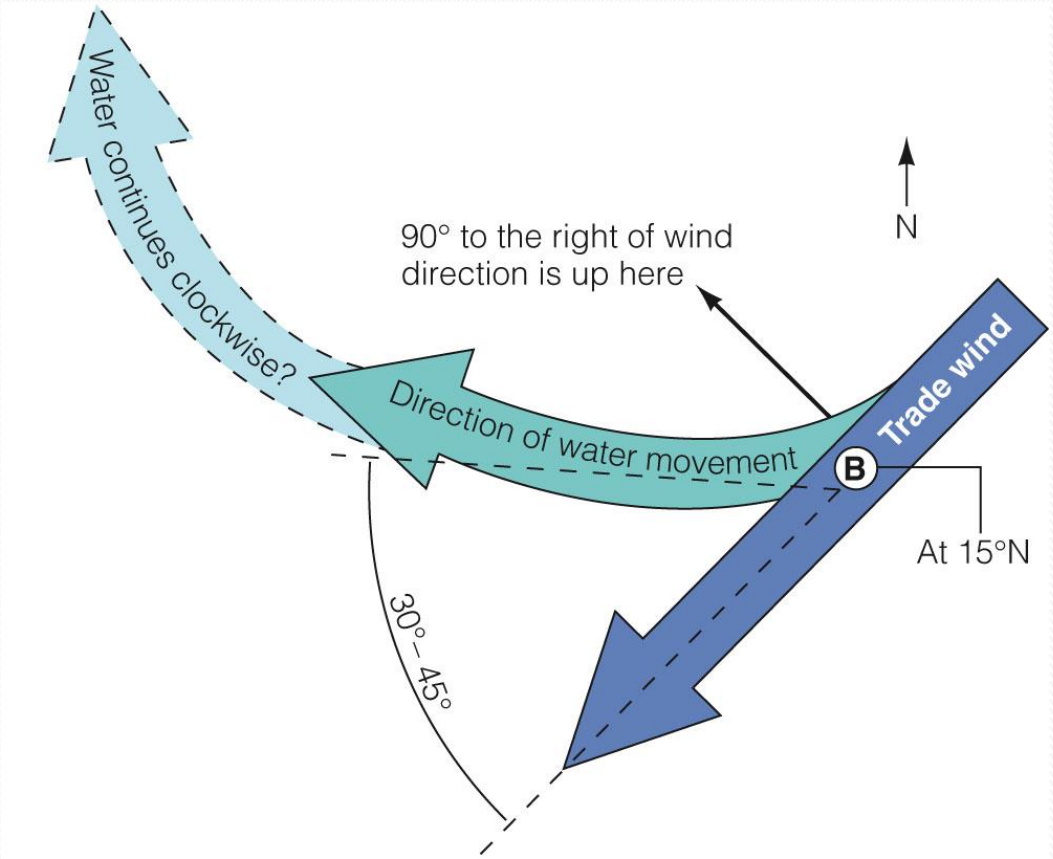


A combination of four forces: 1. surface winds

2. the sun's heat
3. the Coriolis effect
4. gravity

Creates circulation of the ocean surface to rotate clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere, forming **gyres**.

Surface Currents Flow around the Periphery of Ocean Basins

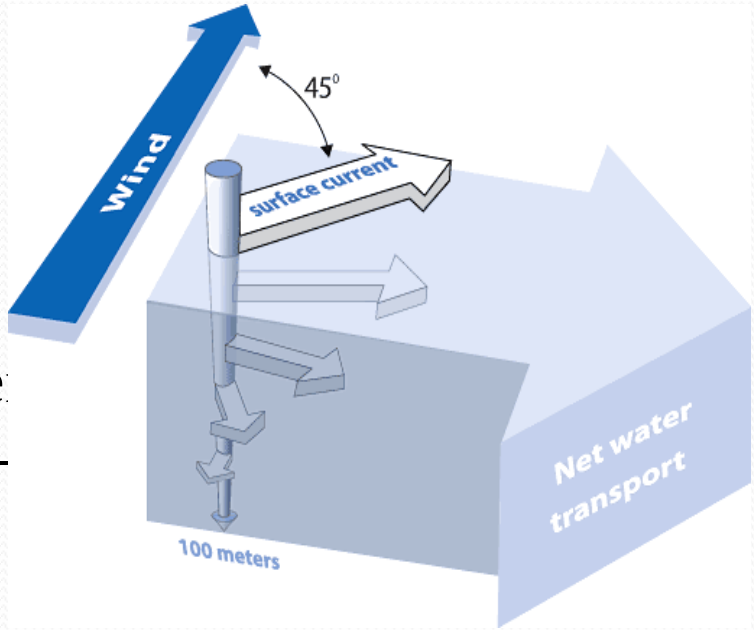


The effect of **Ekman spiraling** and the Coriolis effect cause the water within a gyre to move in a circular pattern.

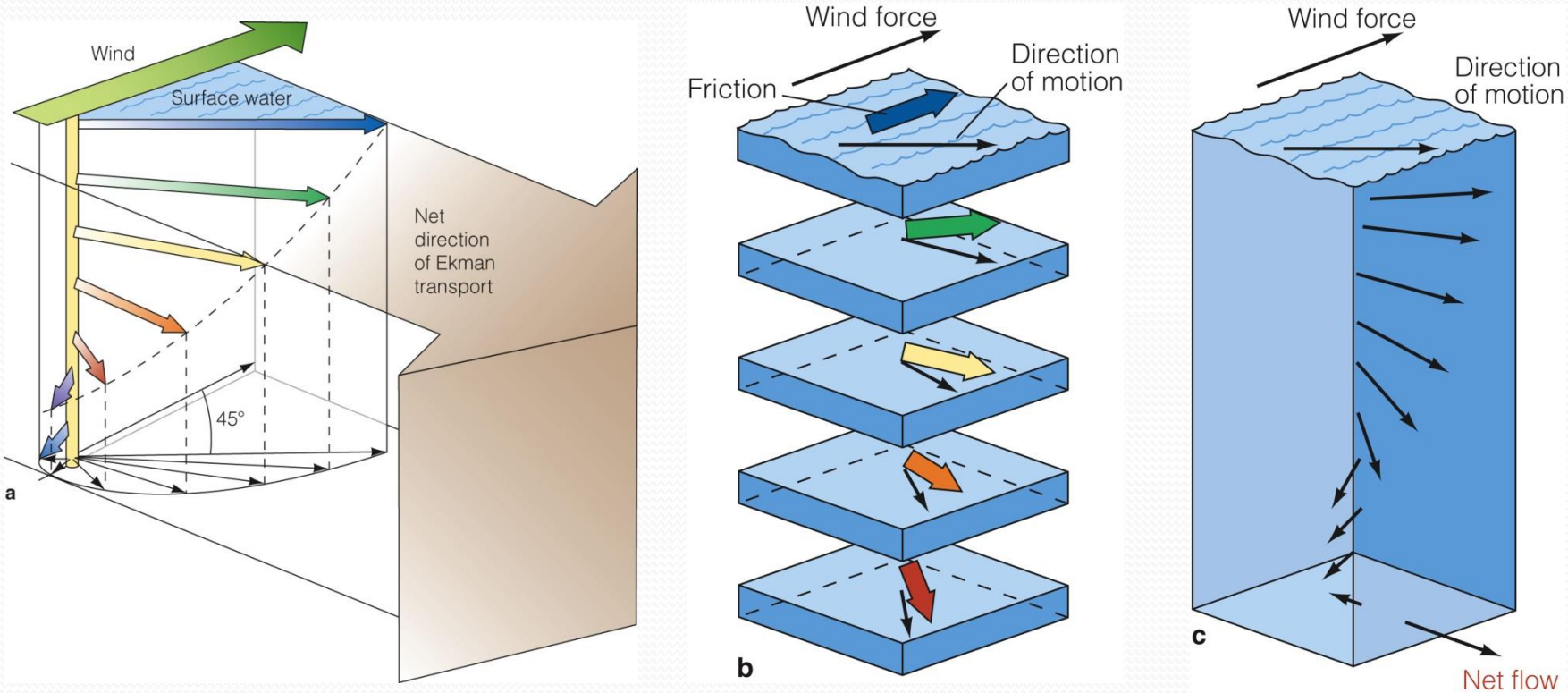
The movement of water away from point B is influenced by the rightward tendency of the Coriolis effect and the gravity-powered movement of water down the pressure gradient.

Ekman Spiral

- Occurs as a consequence of the Coriolis effect.
  - When surface water molecules are moved by the wind, they **drag deeper layers** of water molecules below them.
  - Like surface water, the deeper wate is deflected by the Coriolis effect—to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.
  - As a result, each successively deeper layer of water moves more slowly to the right or left, creating a spiral effect.



Surface Currents Flow is driven by Ekman Spiral and Coriolis

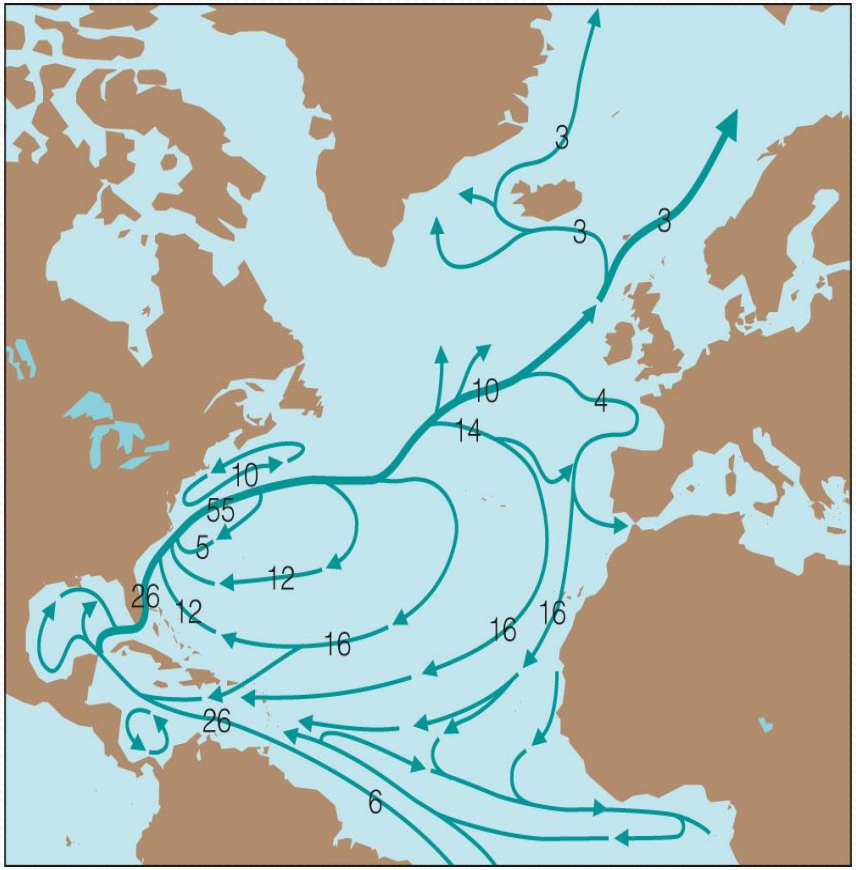


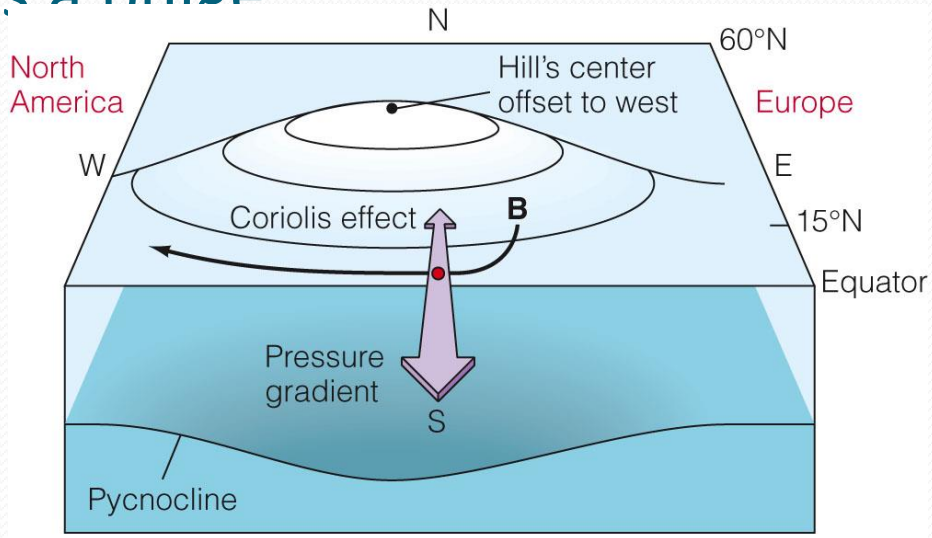
The Ekman spiral and the mechanism by which it operates. The length of the arrows in the diagrams is proportional to the speed of the current in each layer. (a) The Ekman spiral model. (b) A body of water can be thought of as a set of layers. The top layer is driven forward by the wind, and each layer below is moved by friction. Each succeeding layer moves with a slower speed and at an angle to the layer immediately above it – to the right in the Northern Hemisphere, to the left in the Southern Hemisphere – until water motion becomes negligible. (c) Though the direction of movement varies for each layer in the stack, the theoretical net flow of water in the Northern Hemisphere is 90° to the right of the prevailing wind force.

Seawater Flows in Six Great Surface Circuits around the periphery of ocean basins

These **Geostrophic gyres** are formed by ocean boundary current flow in a balance between the pressure gradient and the Coriolis effect. Of the six great currents in the world's ocean, **five** are geostrophic gyres. (The sixth current, the **Antarctic circumpolar current** is not shown)

A **geostrophic gyre** is comprised of individual ocean currents that balance flow at the periphery of ocean basins. Water is pushed to the center and forms a bulge





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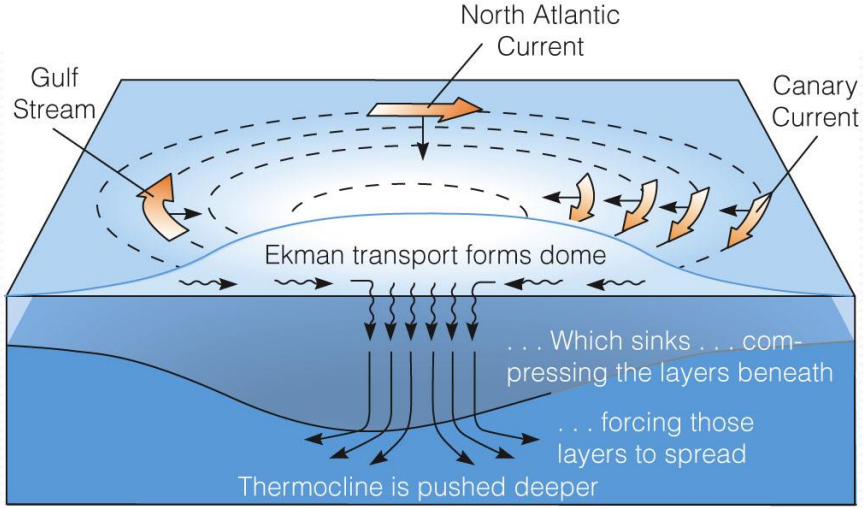

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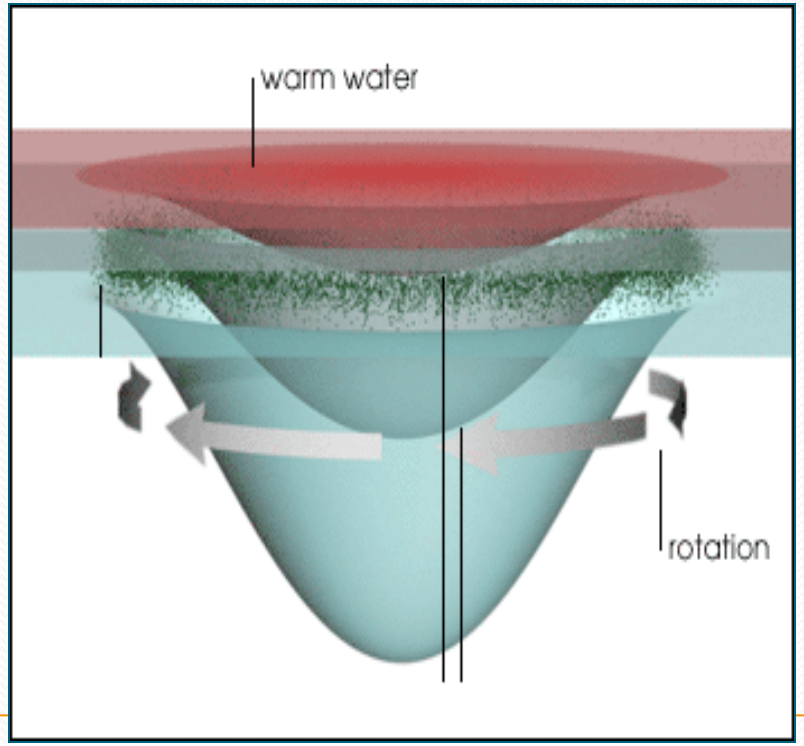
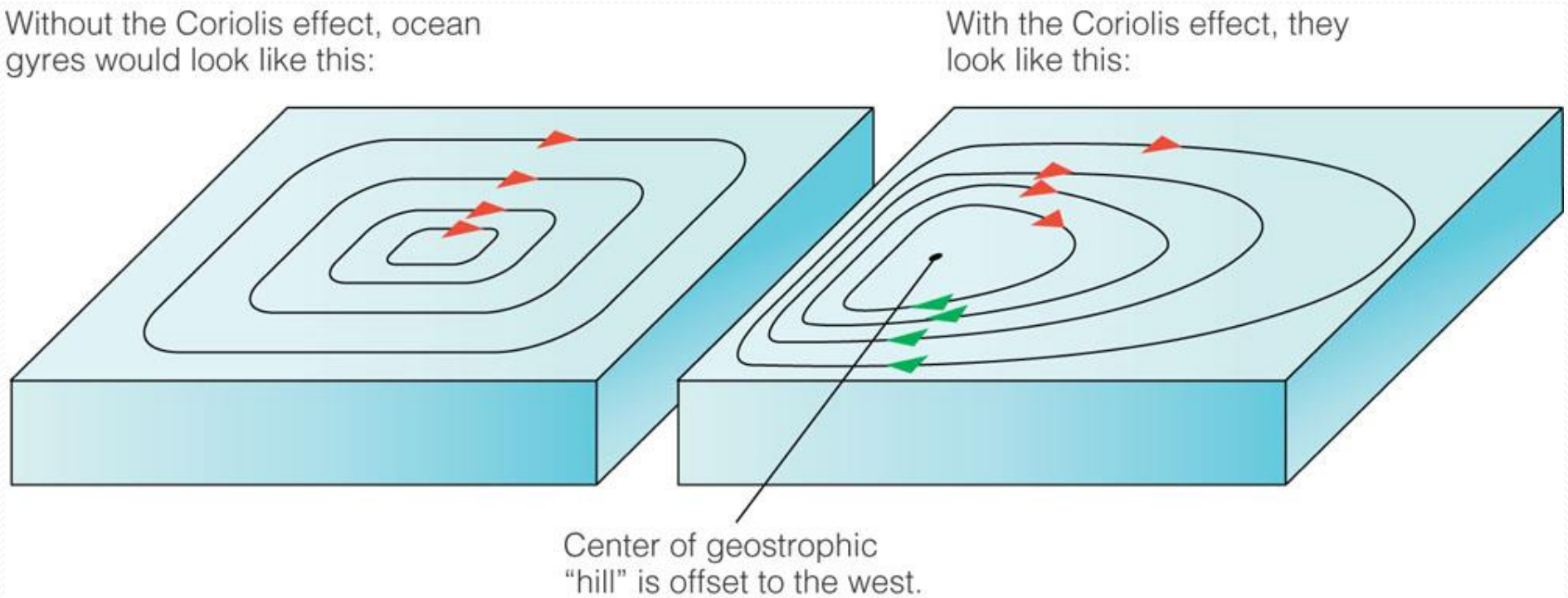
The Understanding

Special features



- **Geostrophic balance exists in the N. Atlantic as the Coriolis effect piles water into a bulge (Sargasso Sea) that gravity carries downhill**

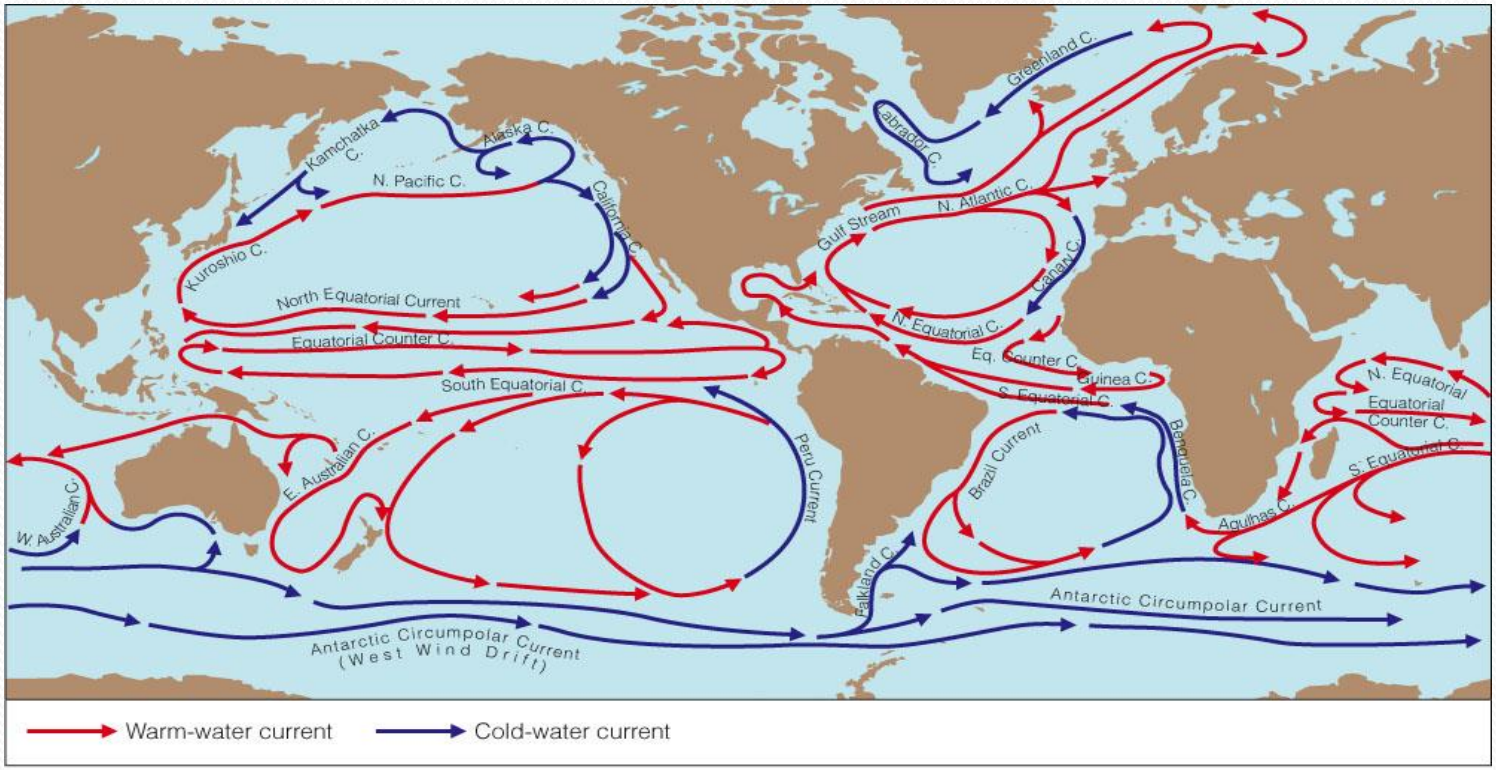
Boundary Currents Have Different Characteristics



The Coriolis effect is stronger in the latitudes of the westerlies than in the latitudes of the trade winds, which causes an uneven ocean-surface slope. The result is the western side is more intense.

Water flow in the Gulf Stream and the Canary Current, parts of the North Atlantic gyre.

- **What currents are found within geostrophic gyres?**
- **Western boundary currents** – Intense, narrow, deep, fast currents found at the western boundaries of ocean basins.
  - The Gulf Stream; East Australian Current, Kuroshio Current
- **Eastern boundary currents** – These currents are cold, shallow and broad, and their boundaries are not well defined.
  - The Canary Current; West Australian Current; California Current



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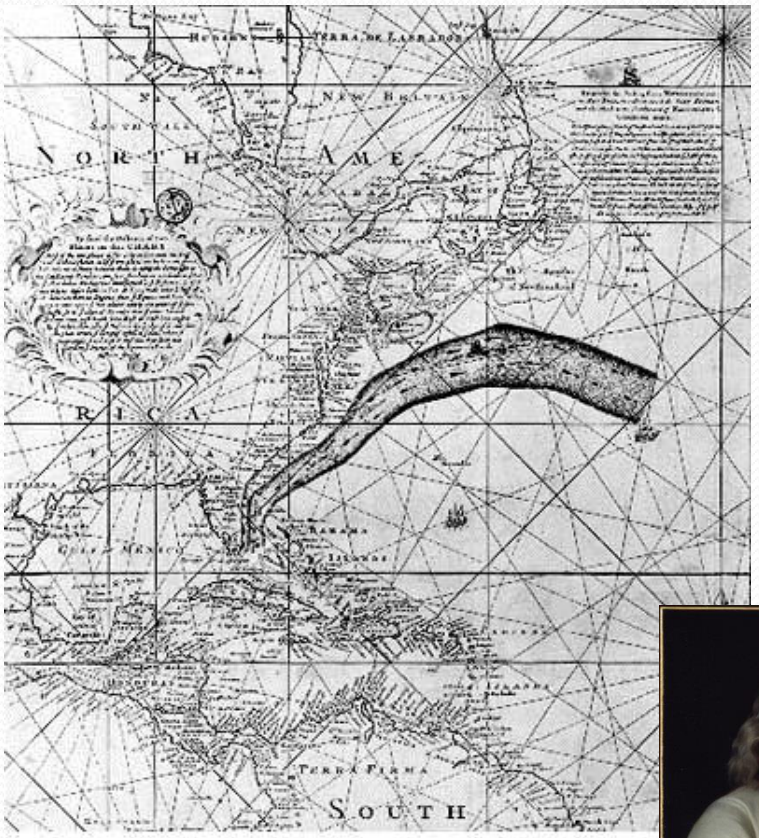
“Highway Gulfstream”

- **The Florida Current and the Gulfstream moderate the sea and air temperatures in the North Atlantic**
- **AND transport plankton and fish from the Florida Straits to the North Atlantic**

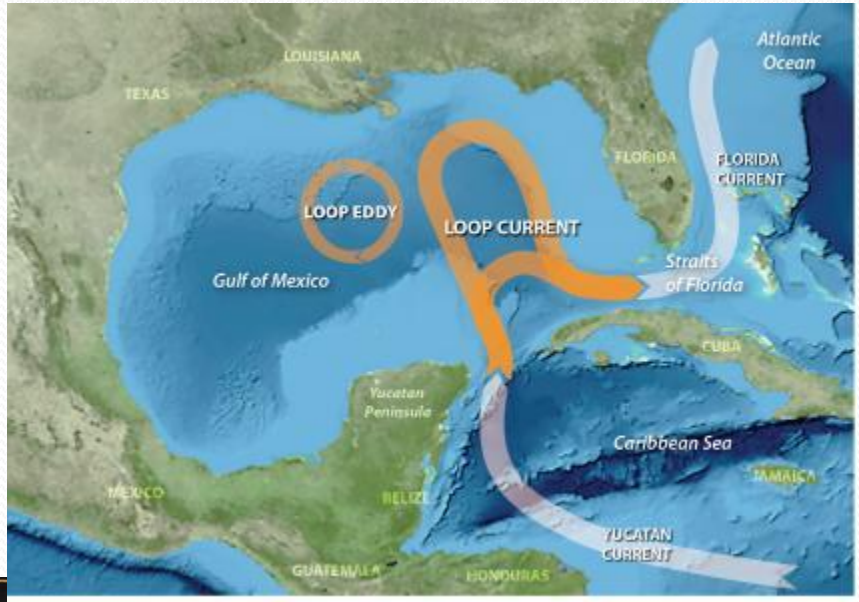
(National Geographic Video clip)

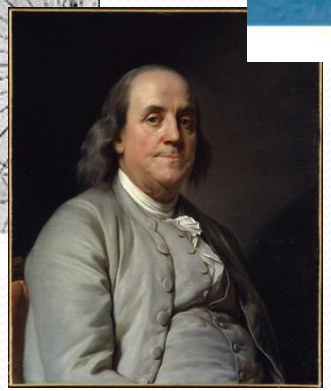
The Florida Current/Gulf Stream

(moves average 55,000,000 cubic meters/second!)



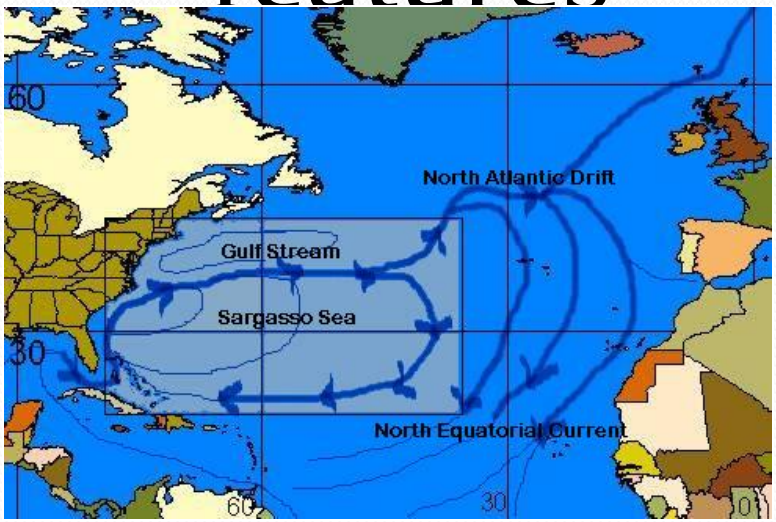
Franklin's chart of the Gulf stream published in 1769





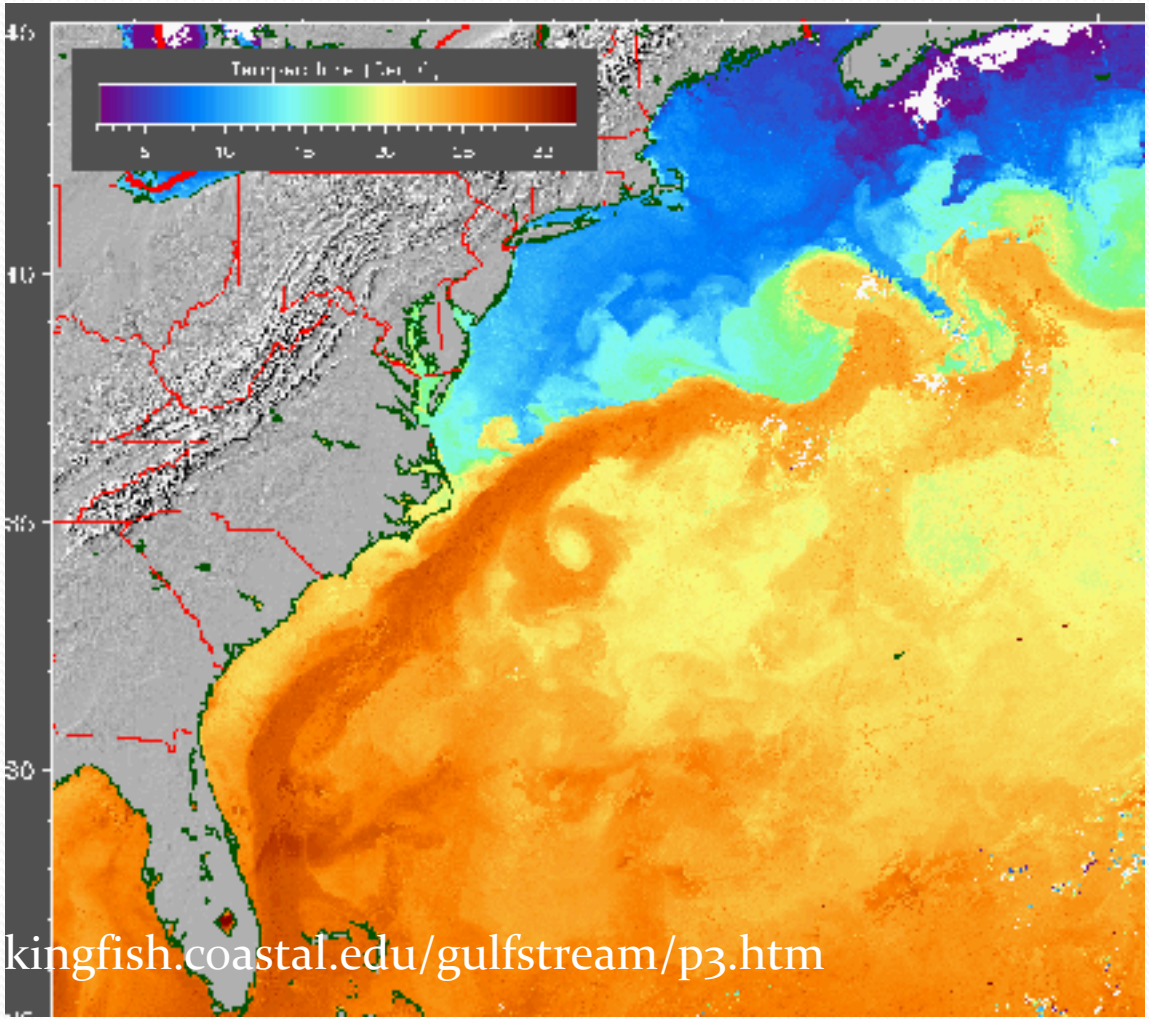
The Understanding

Special features



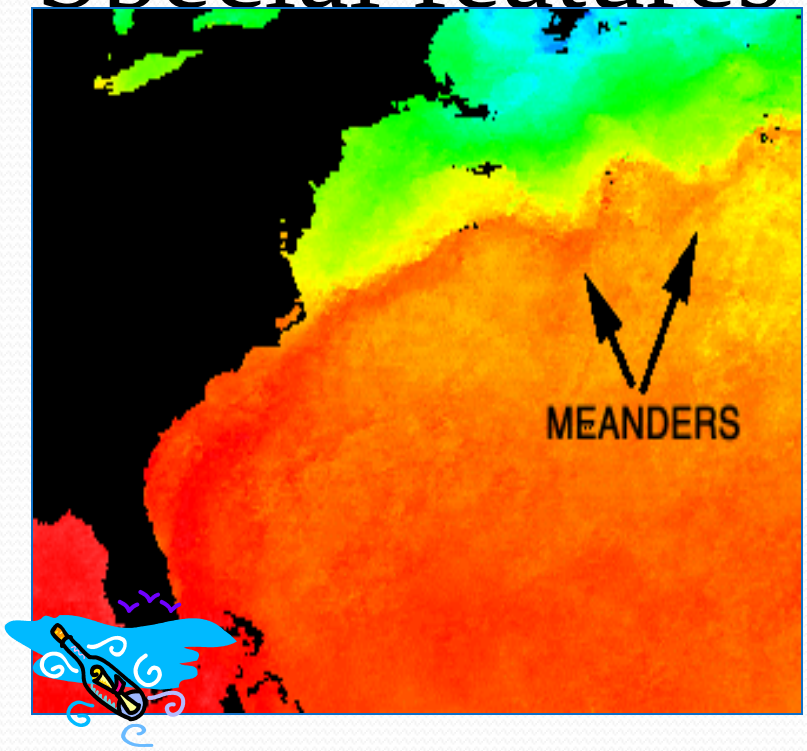
- **Carries heat energy toward the continent of Europe**
- **Some surface water becomes cooler, more saline and sinks near Norway**

Satellite Image of SST



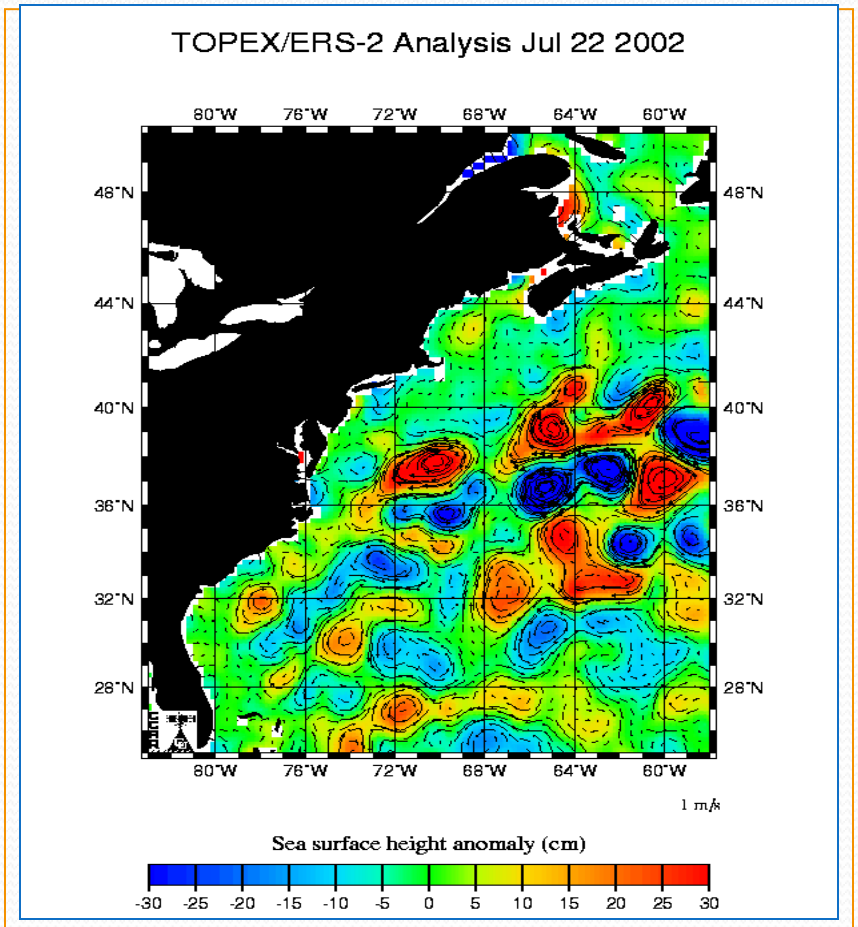
The Understanding

Special features



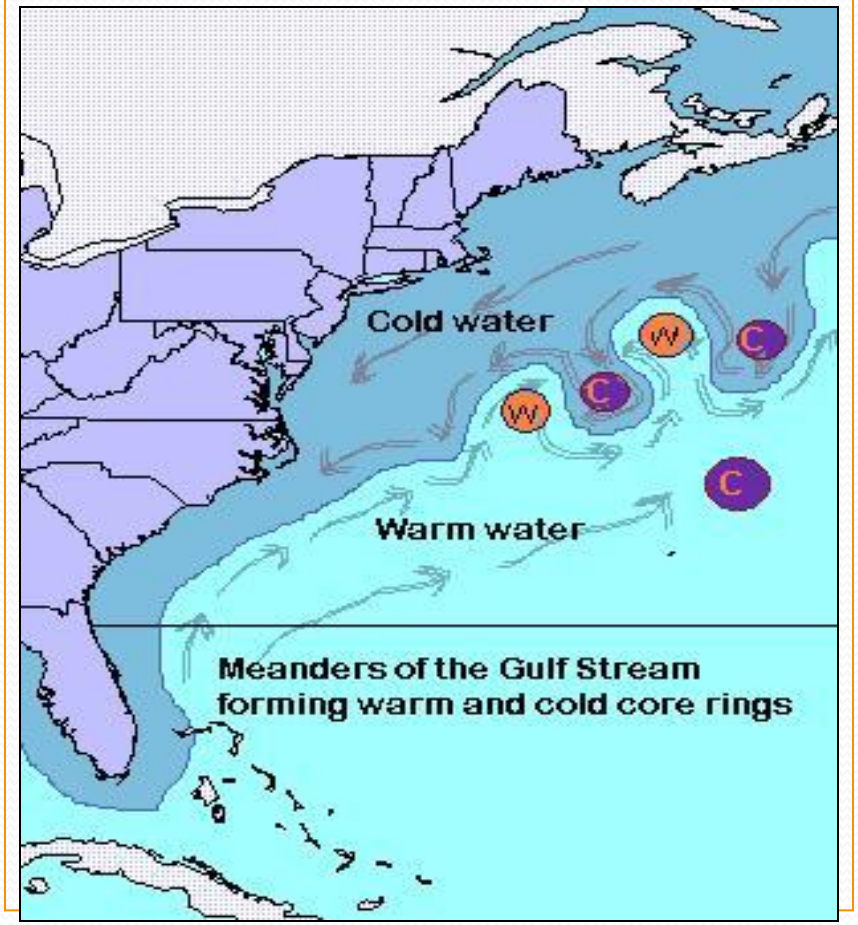
- **Gulf Stream water temperatures are substantially warmer than the waters to the North**
- **Act as a barrier between Sargasso Sea and North Labrador current**

The Understanding



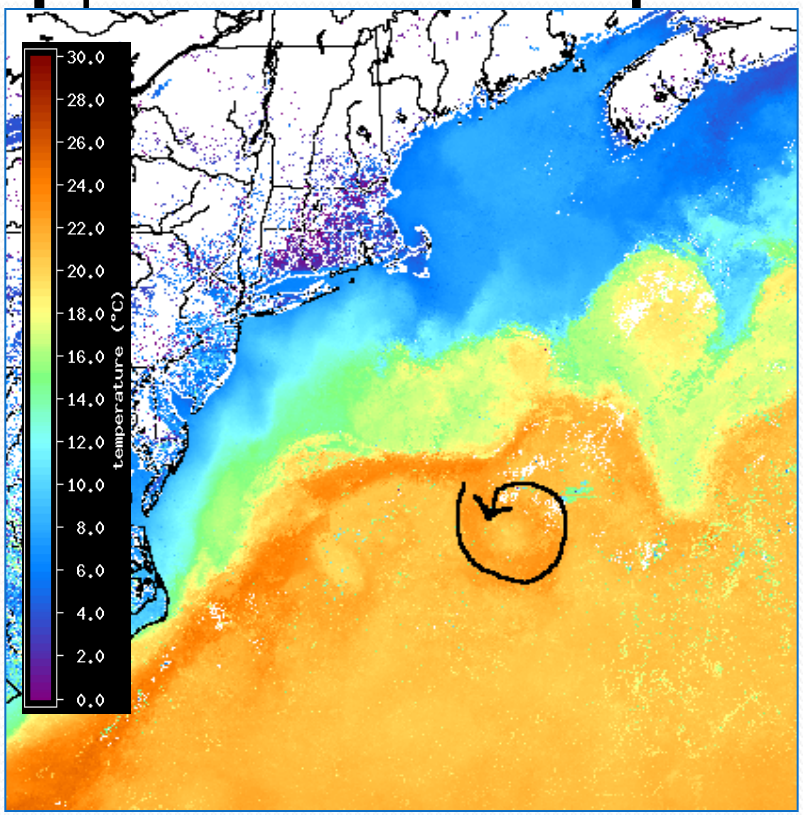
- **Differences in sea height are seen with satellite altimetry**
- **Pockets of warm or cold water may be trapped**

The Science Twist



- **Warm- core eddies are found usually to the north of the north wall**
- **Spin clockwise**
- **WCR = Warm core rings**

The Science Twist

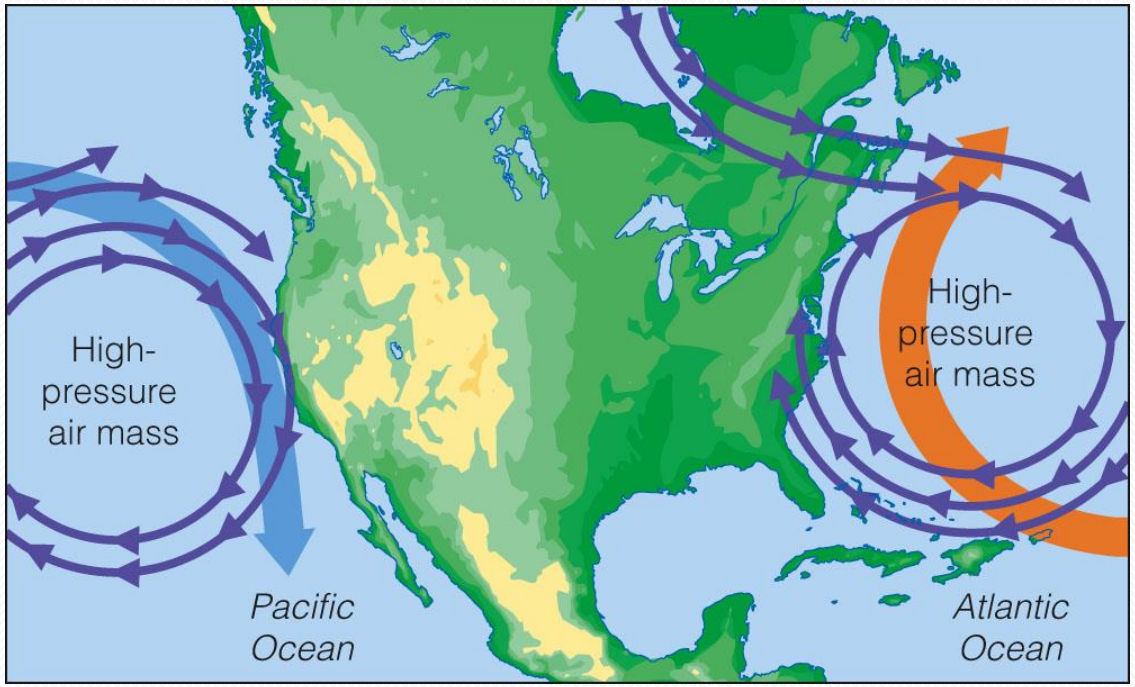


- **Cold- core eddies are found to the south of the Gulf Stream**
- **Spin counterclockwise**
- **Migrate into the Sargasso Sea**

Heat Transport and Climate

- **Currents play a critical role by transporting heat from warm areas to cool areas and affects climate by moderating temperatures**. Without currents moving heat, the world's **climates would be more extreme**.

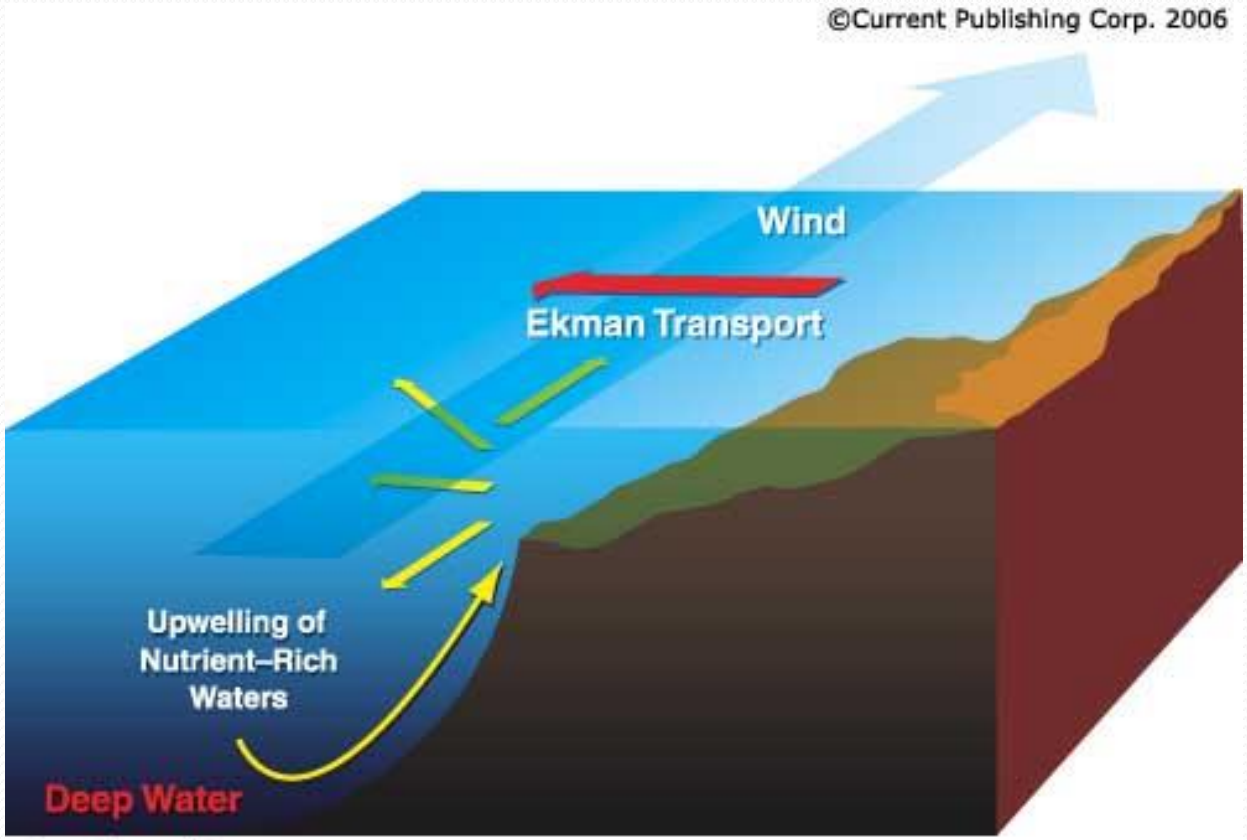
Surface Currents Affect Weather and Climate



General summer air circulation patterns of the east and west coasts of the United States. Warm ocean currents are shown in red; cold currents, in blue. Air is chilled as it approaches the west coast and warmed as it approaches the east coast.

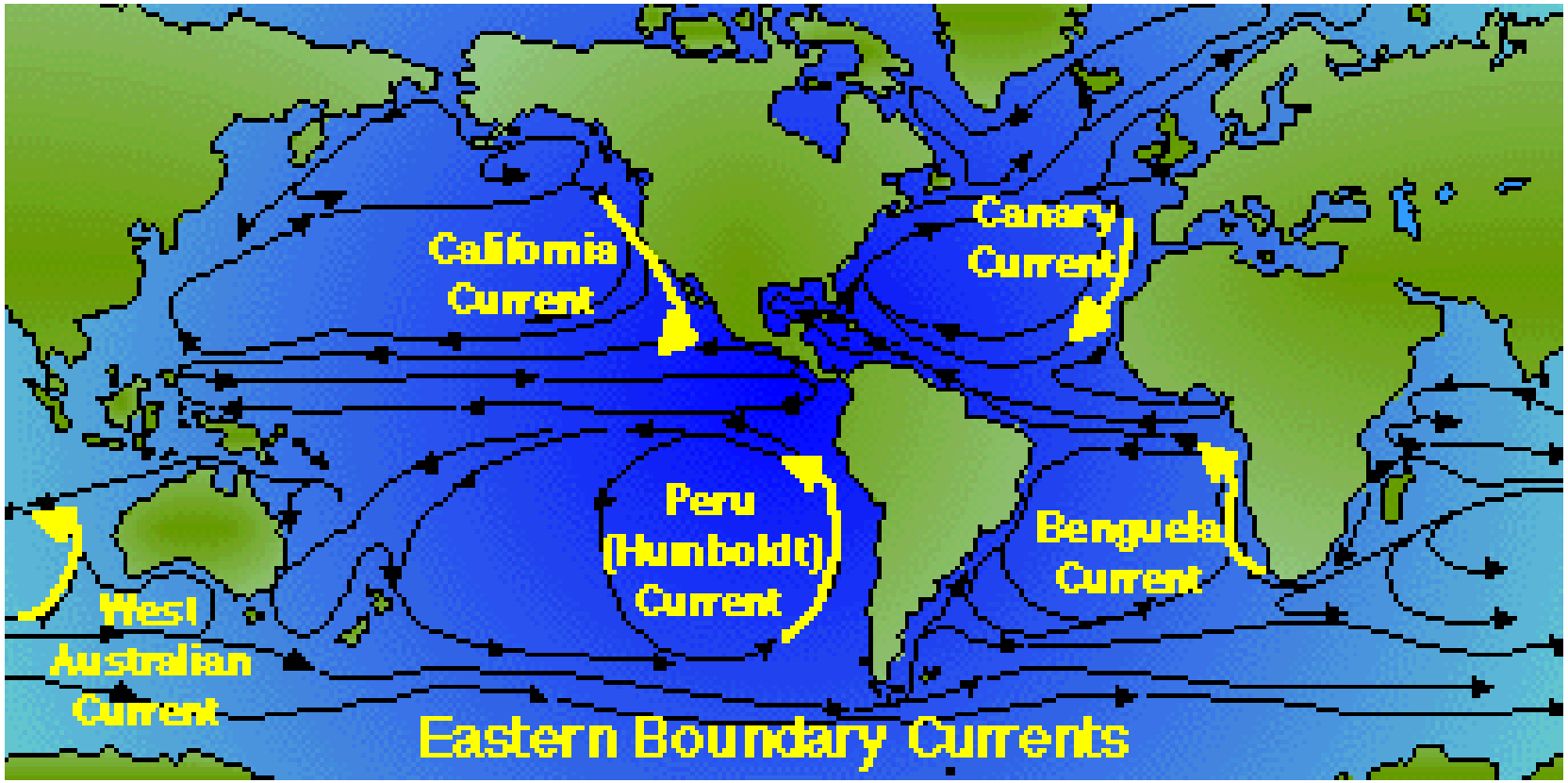
Vertically flowing currents

- **Upwelling** - upward flow of deep water to surface (brings nutrients to the euphotic zone)
- **Downwelling** - downward flow of surface water towards bottom. It supplies the deeper ocean with dissolved gases.

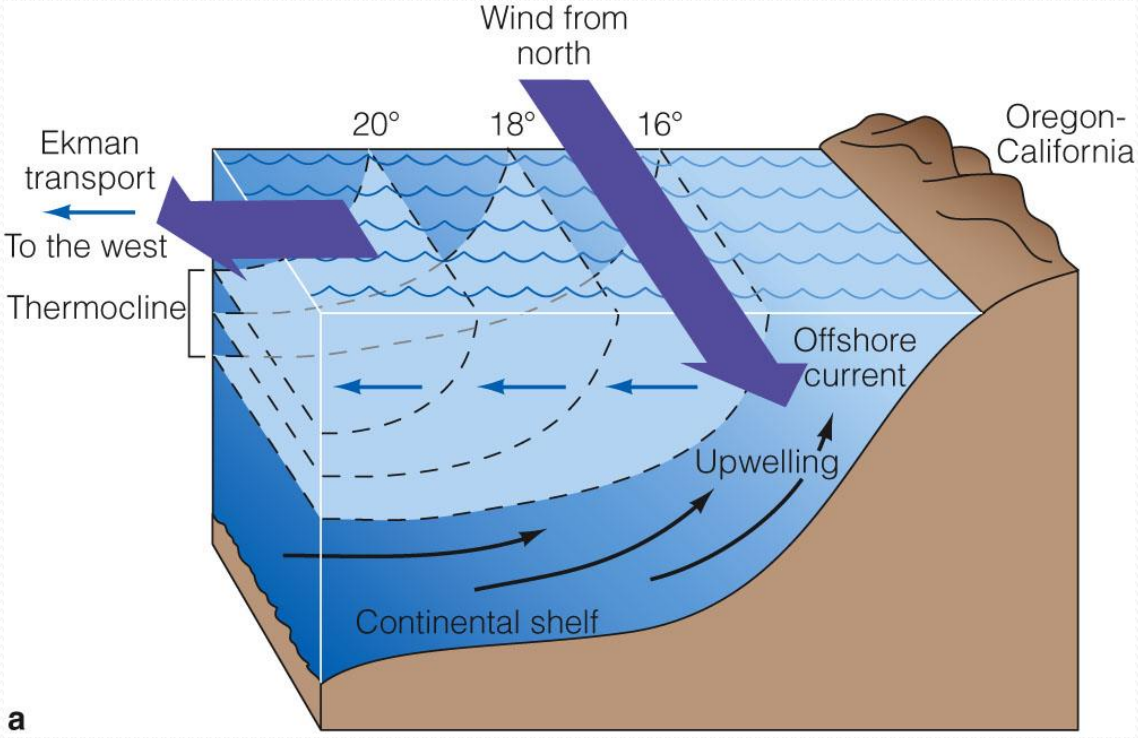


Coastal upwelling

Upwelling ocurrs at Eastern Ocean Basin Boundaries



Wind Can Induce Upwelling near Coasts

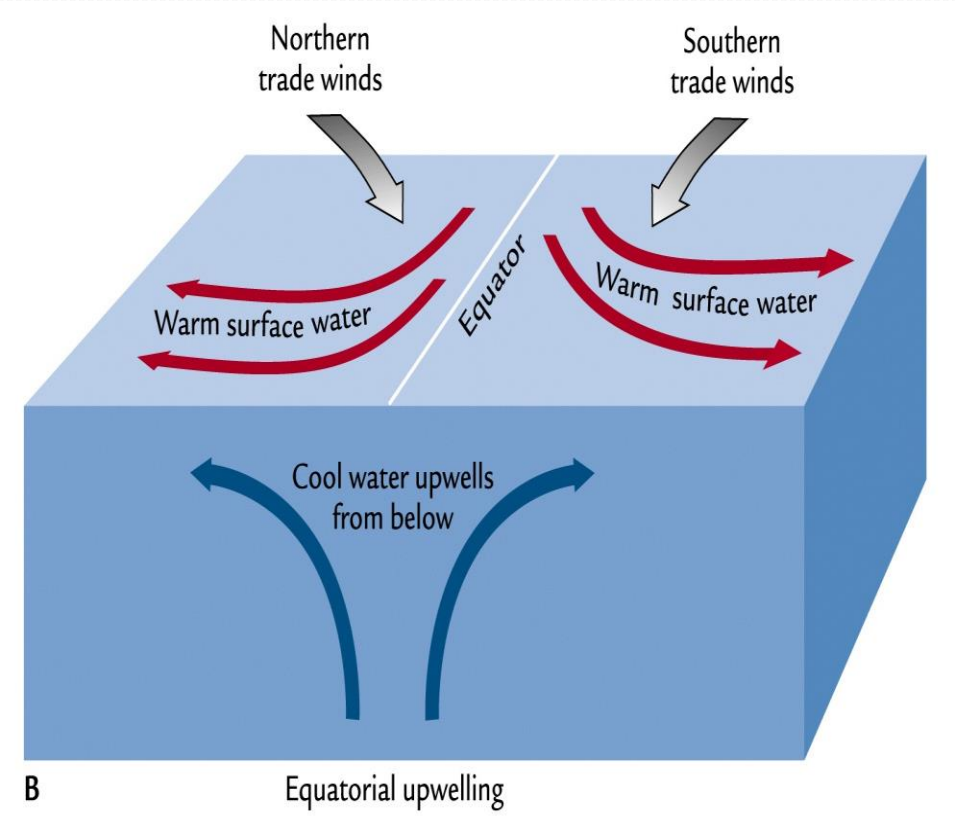


<u>Coastal upwelling</u>

In the Northern Hemisphere, coastal upwelling can be caused by winds from the north blowing along the west coast of a continent. Water moved offshore by **Ekman transpor**t is replaced by cold, deep, nutrient-rich water.

High Biological Productivity

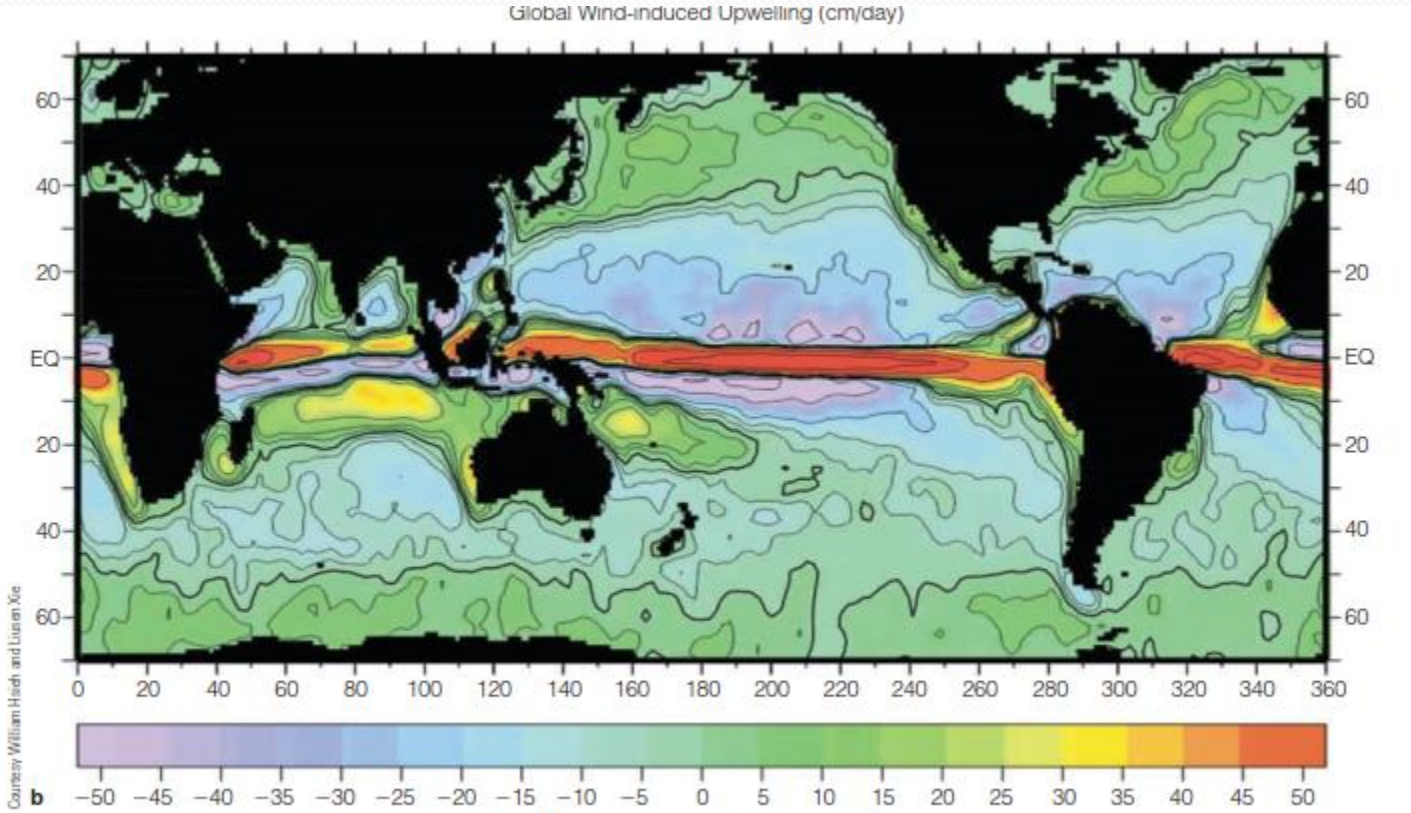
Nutrient-Rich Water Rises near the Equator



Equatorial upwelling.

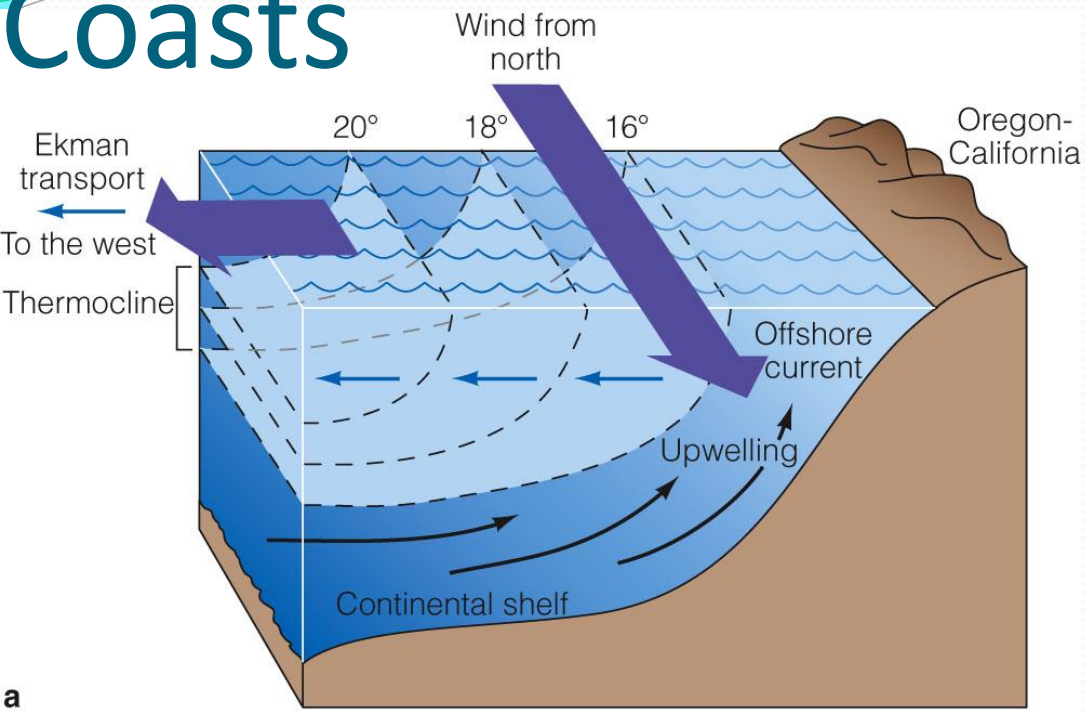
The South Equatorial Current, especially in the Pacific, straddles the geographical equator. Water north of the equator veers to the right (northward), and water to the south veers to the left (southward). Surface water therefore diverges, causing upwelling. Most of the upwelled water comes from the area above the equatorial undercurrent, at depths of 100 meters or less.

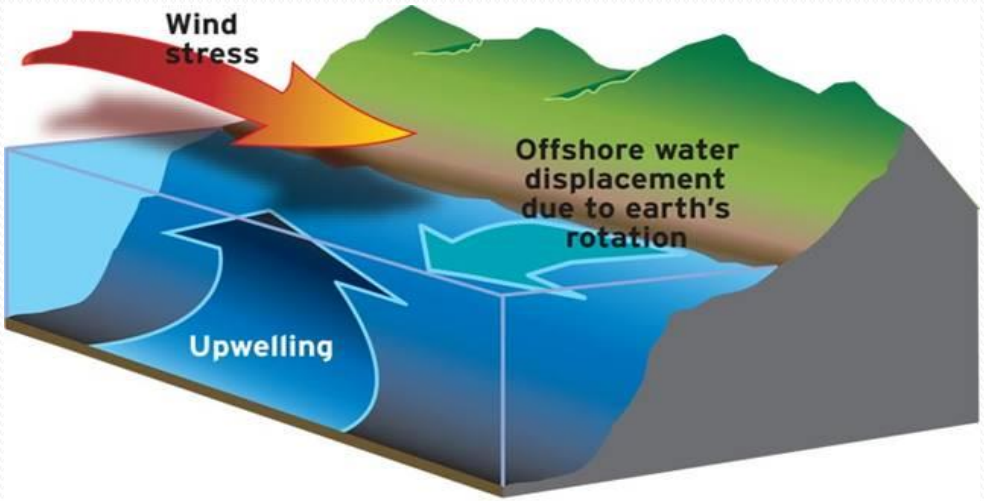
Wind-Induced Equatorial upwelling indicted by nutrients



The phenomenon of equatorial upwelling is worldwide but most pronounced in the Pacific. The red, orange, and yellow colors mark the areas of greatest upwelling as determined by biological productivity.

Wind Can Induce Upwelling near Coasts

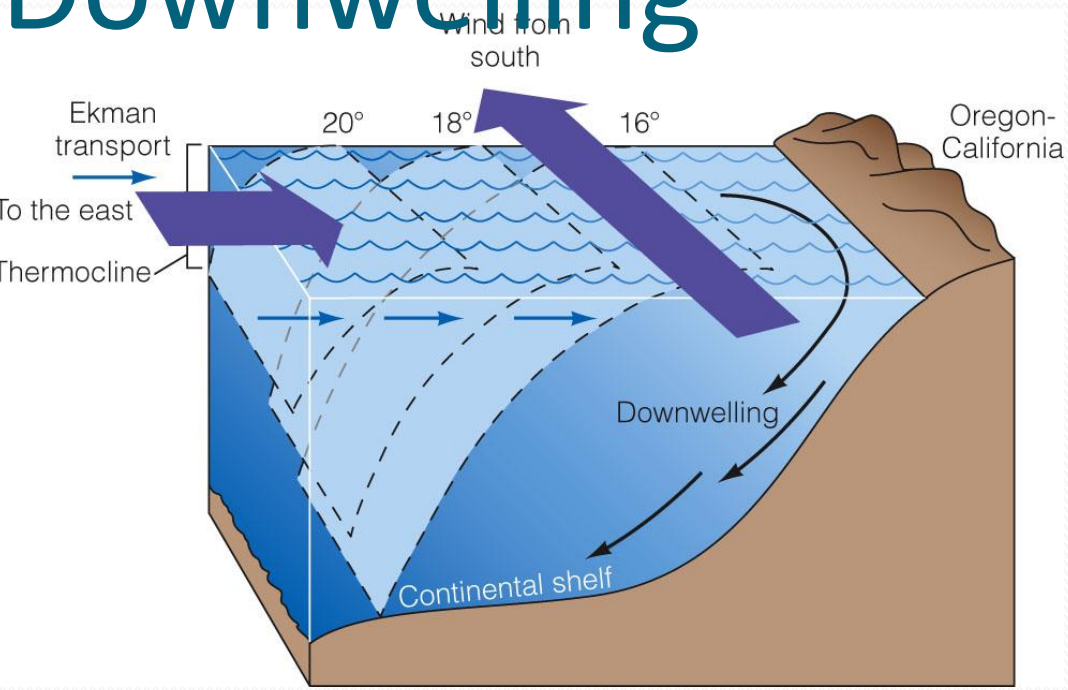


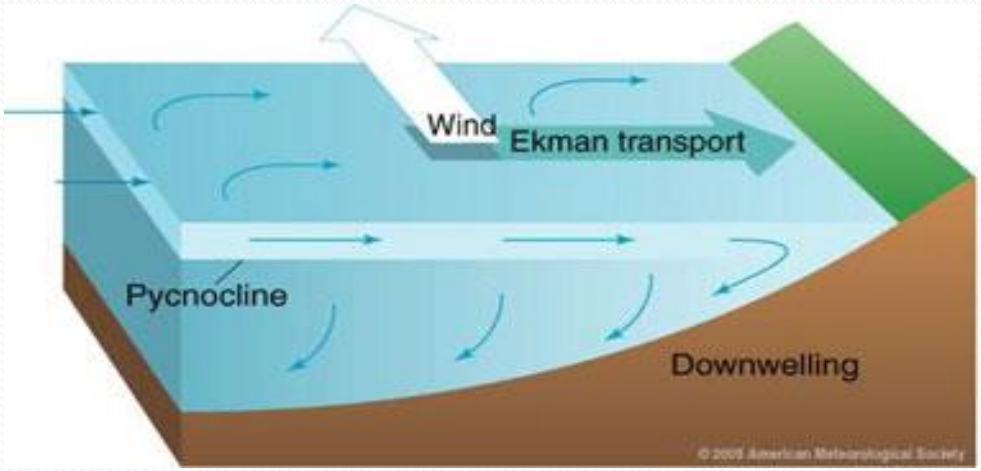


Coastal upwelling.

In the Northern Hemisphere, coastal upwelling can be caused by winds from the north blowing along the west coast of a continent. Water moved offshore by Ekman transport is replaced by cold, deep, nutrient-laden water. In this diagram, temperature of the ocean surface is shown in degrees Celsius.

Wind Can Also Induce Coastal Downwelling

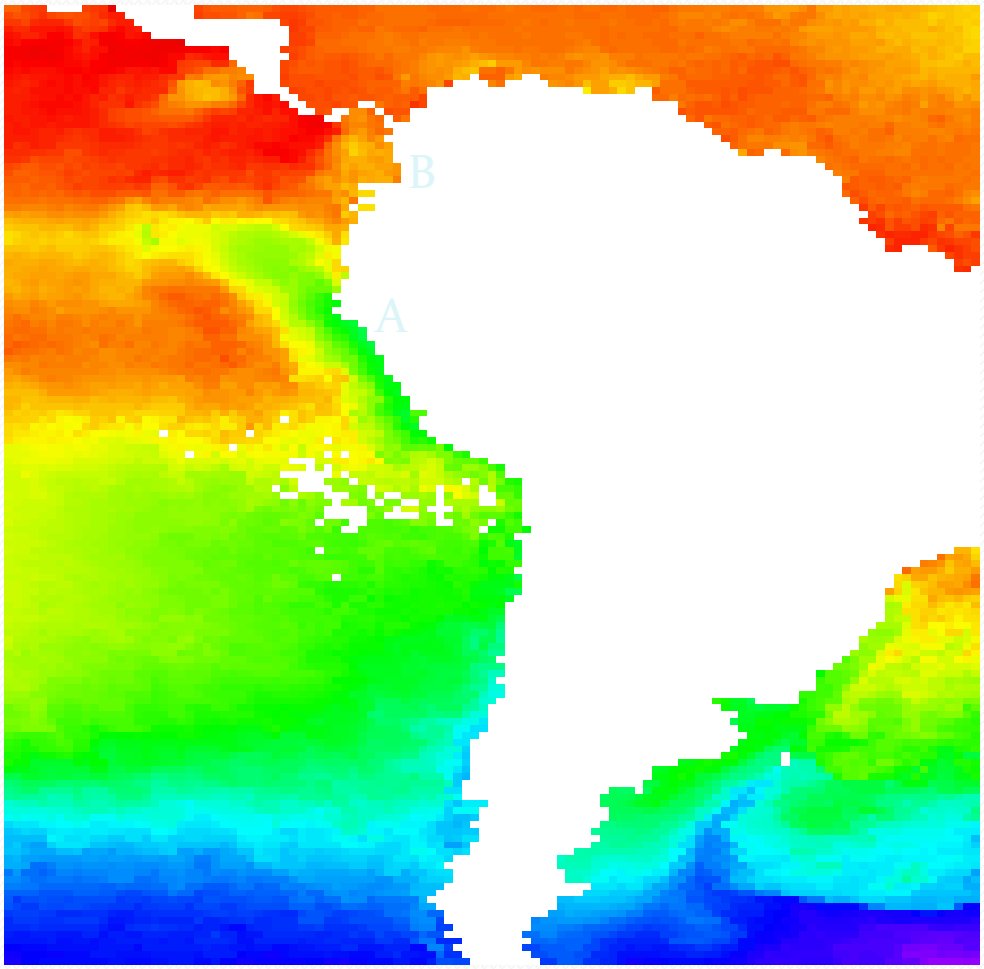




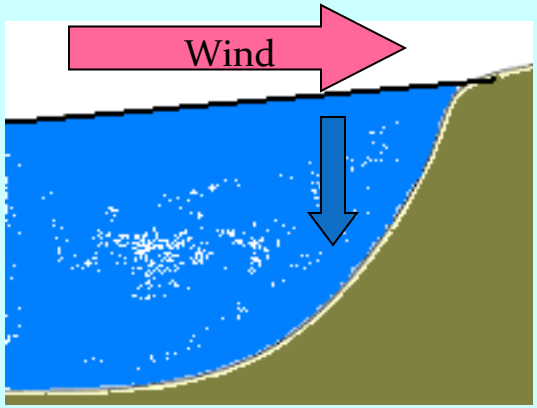
Coastal downwelling.

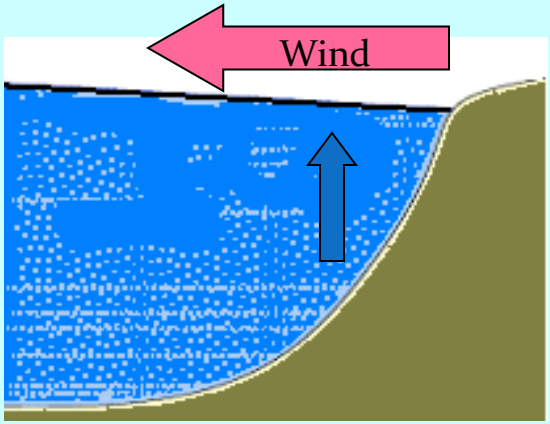
Wind blowing from the south along a Northern Hemisphere west coast for a prolonged period can result in downwelling. Areas of downwelling are often low in nutrients and therefore relatively low in biological productivity.

What’s the difference between Peru(A) and Columbia (B)?



Seasonal upwelling

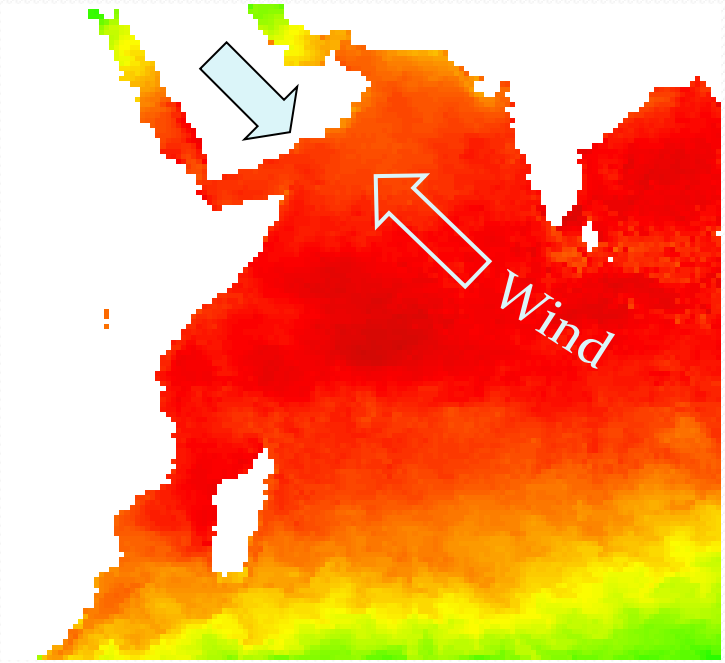




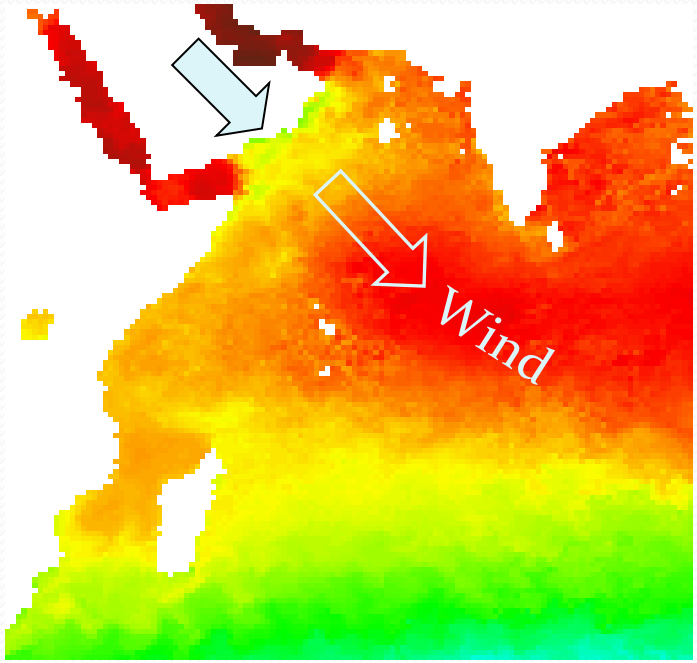
Onshore winds pile water up on shore, thus surface water will be forced downward. This is 'downwelling'.

Offshore winds take water away from shore, thus water from depth will upwell to the surface.

The Monsoonal wind shifts in Oman create very different conditions.



April, 1999
Onshore winds: Downwelling

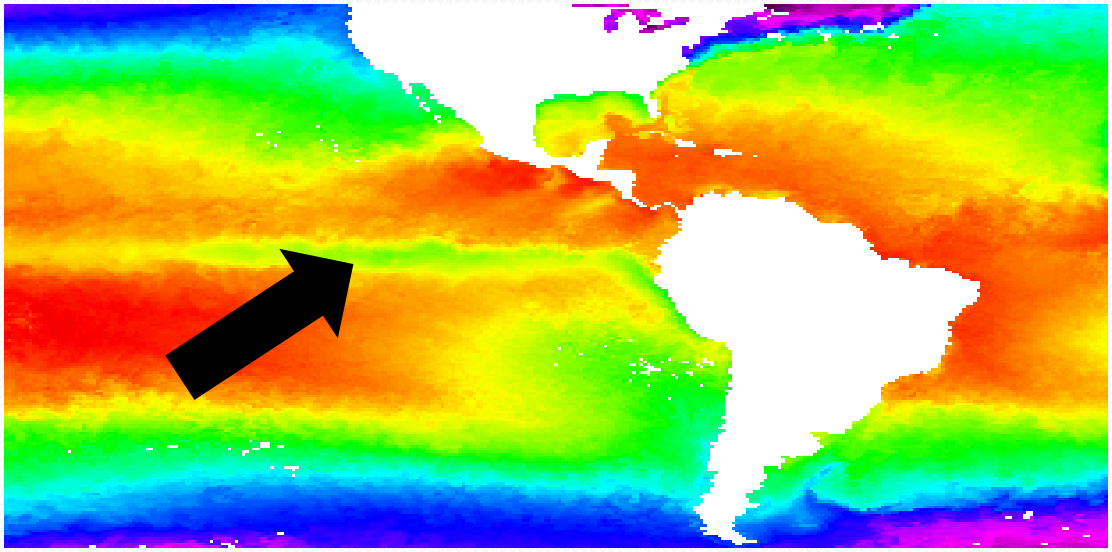


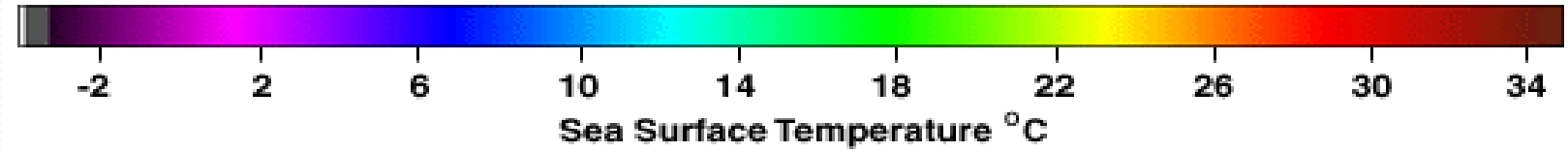
August, 1999
Offshore winds: Upwelling

Identifying upwelling on satellite-derived maps

- Sea Surface Temperature
- Ocean Color

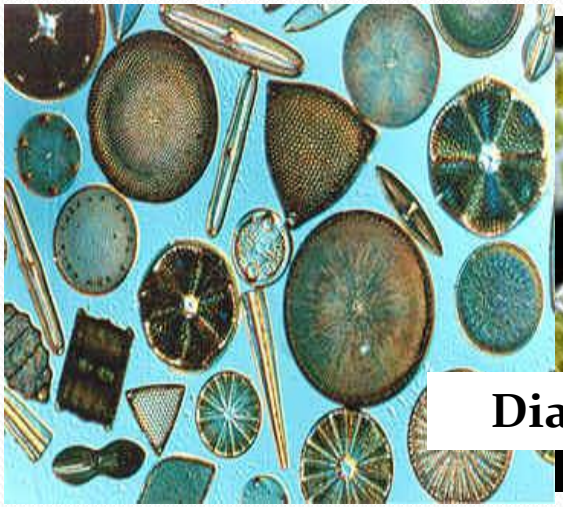
The deep water that surfaces in upwelling is cold; by looking at Sea Surface Temperature maps we can identify cool upwelled water versus hotter surface water.

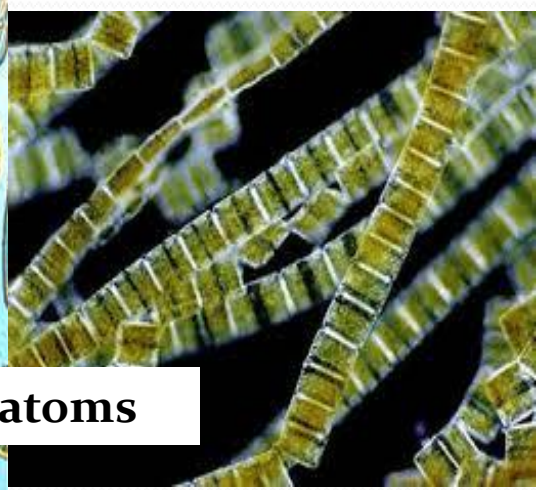




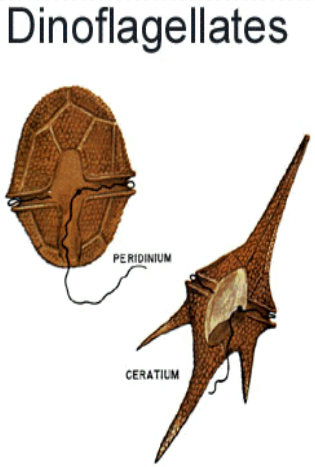
Upwelled water also contains nutrients (nitrate, phosphate, silicate) that are not utilized at depth because of a lack of sunlight.

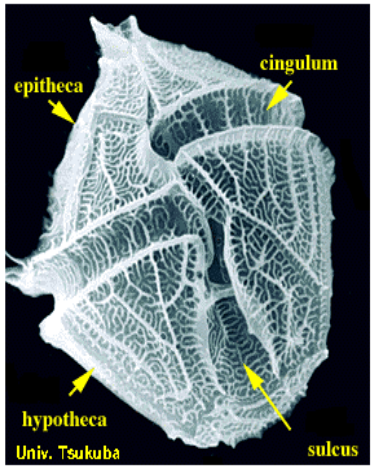
Now on the surface, these nutrients help to fuel photosynthesis by small algae called phytoplankton.



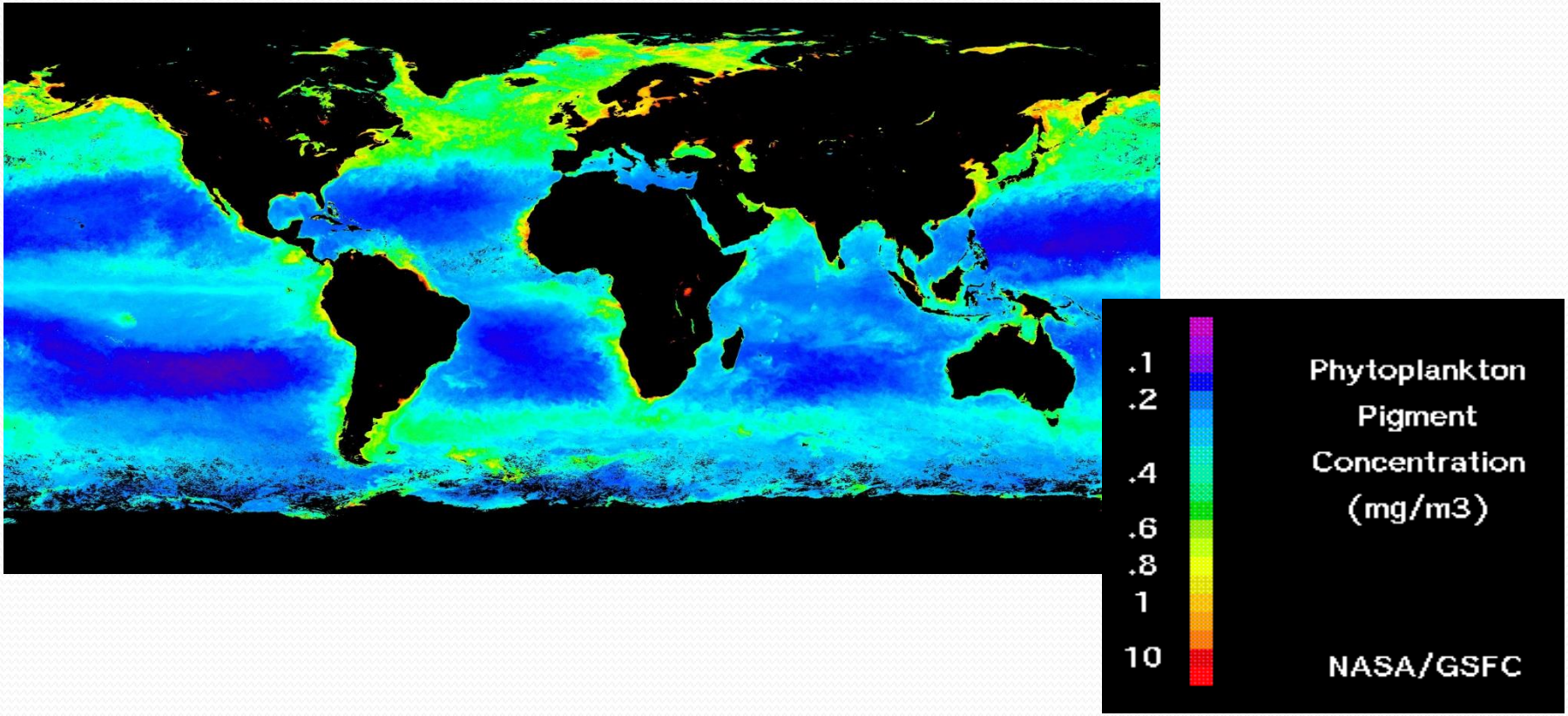


Diatoms





Phytoplankton photosynthesize using specialized color pigments called chlorophyll. Thus, “Ocean Color” maps are another way to identify areas of upwelling. Where on this ocean color map are high phytoplankton concentrations?

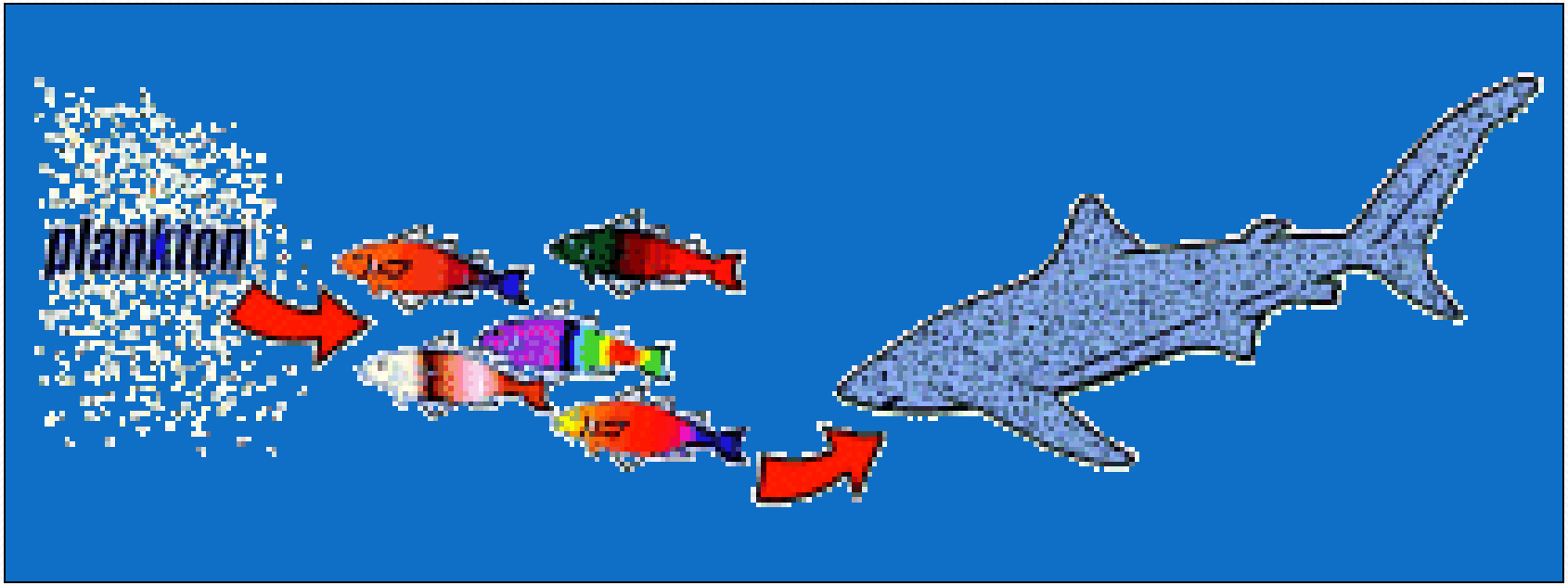


Ecological and Economic effects of upwelling:

- Upwelling leads to more phytoplankton
- More phytoplankton leads to more fish
- More fish lead to commercial fishing jobs and to more seafood

Even though upwelling areas account for only 1% of the ocean surface, they support 50% of the worlds fisheries.

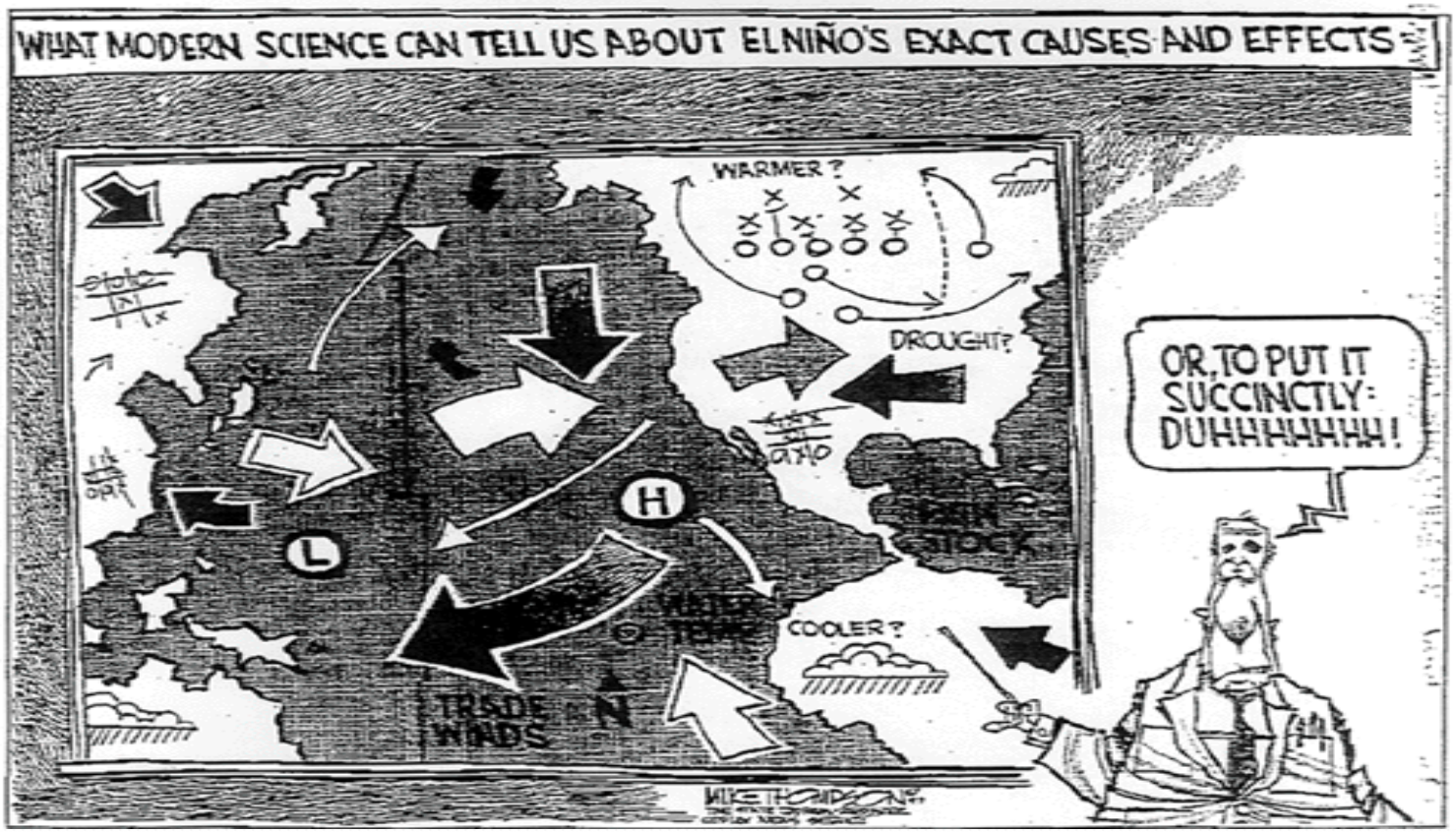
Phytoplankton come in many shapes and forms. Collectively they form the base of oceanic food webs.



Without upwelling many of the world's fisheries would not thrive.

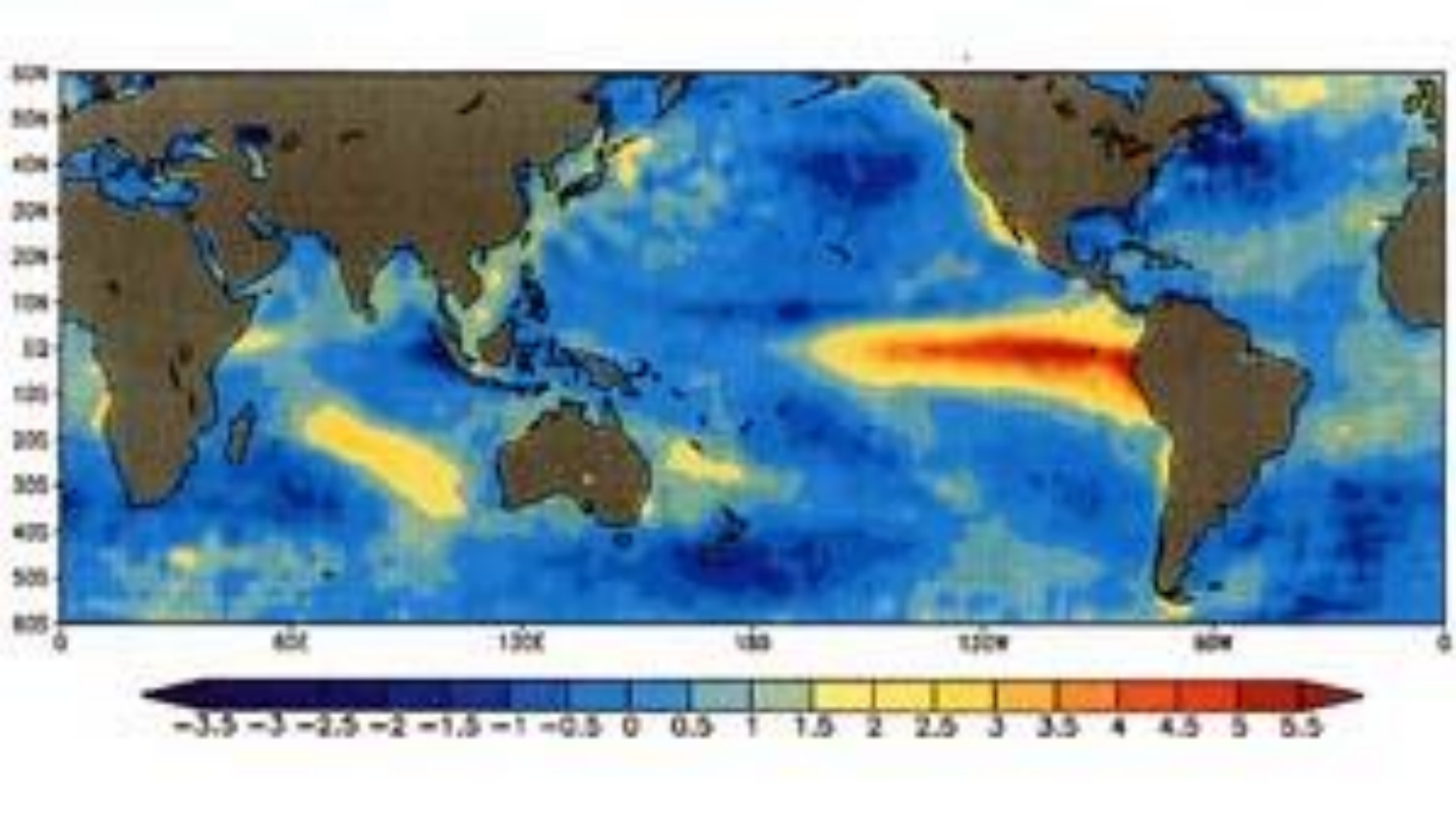
Some climatic events can reduce upwellings.

Along Peru's coast, an El Nino event decreases the coastal winds. Thus the upwelling from below is slowed.



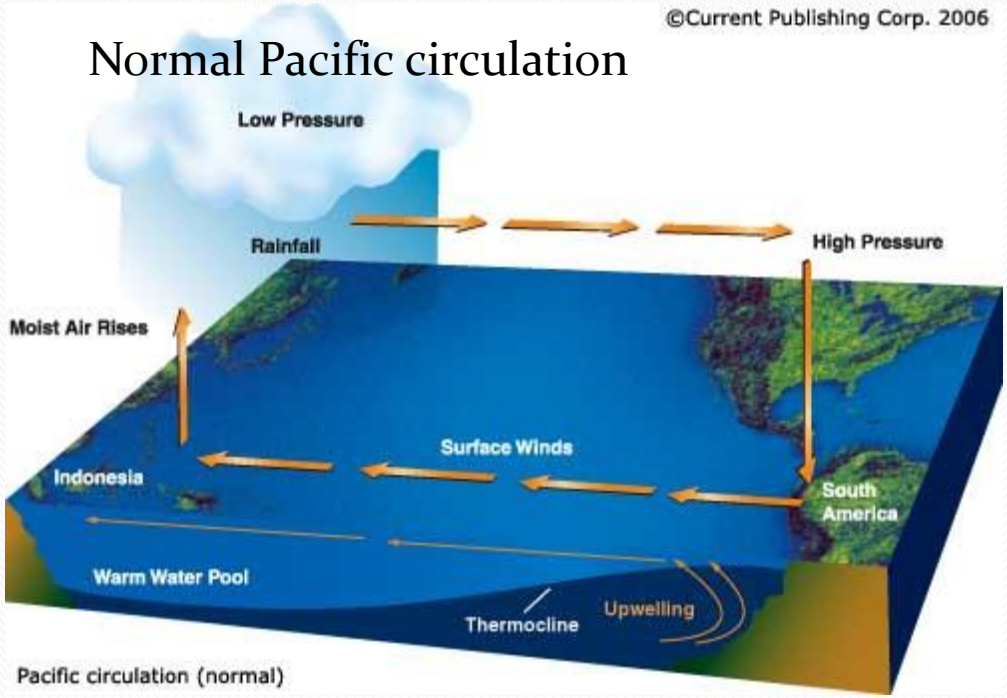
An El Nino condition results from weakened trade winds in the western Pacific Ocean near Indonesia, allowing piled-up warm water to flow toward South America.

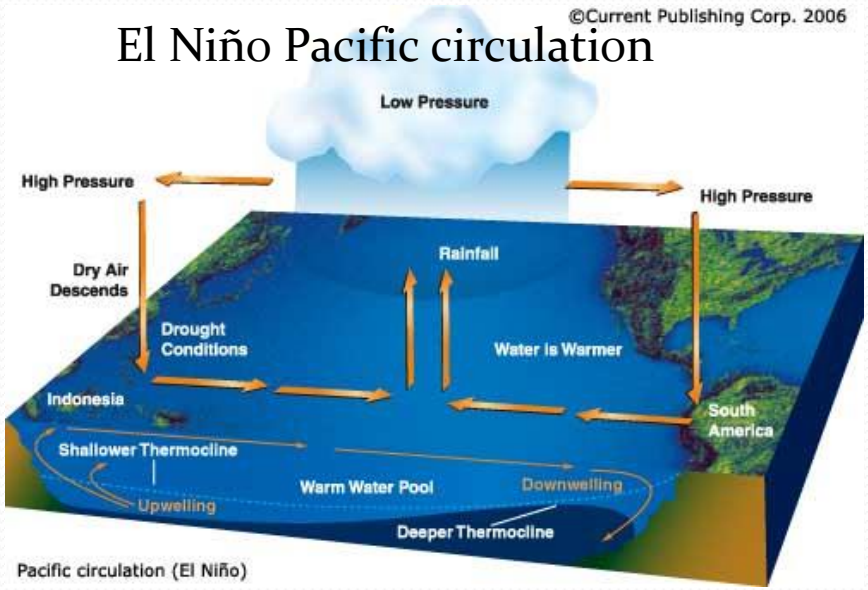
El Nino warm water flow shuts d0wn upwelling making affected regions less biologically productive.



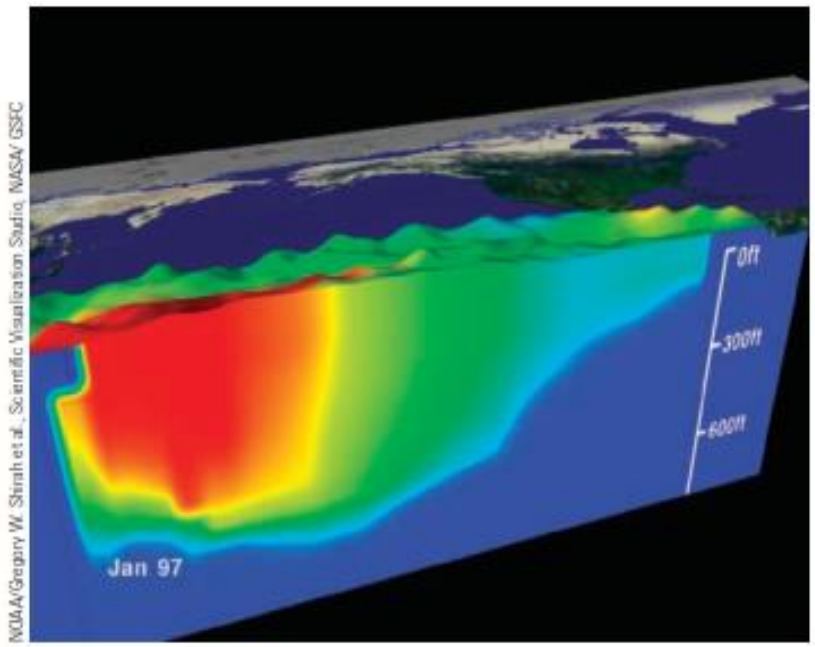
El Niño Southern Oscillation (ENSO)

- El Niño is a buildup of warm water in the Central and Eastern Equatorial Pacific.





Off the coast of Peru, cold water upwelling normally occurs. El Nino events coincide with a reversal of this cool water with warm water that lacks nutrients.



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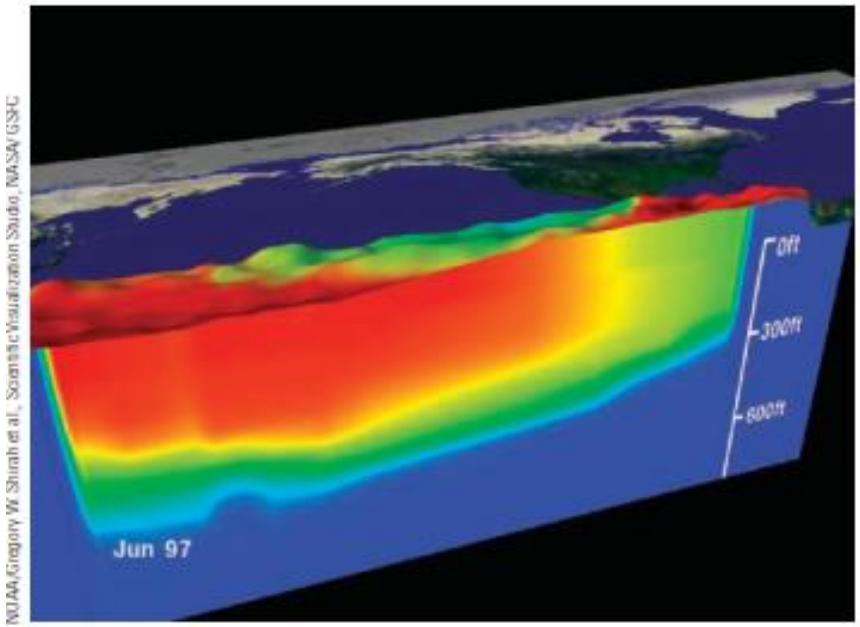

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Peruvian fisheries decline during El Nino years due to less productive waters from a lack of upwelled nutrients

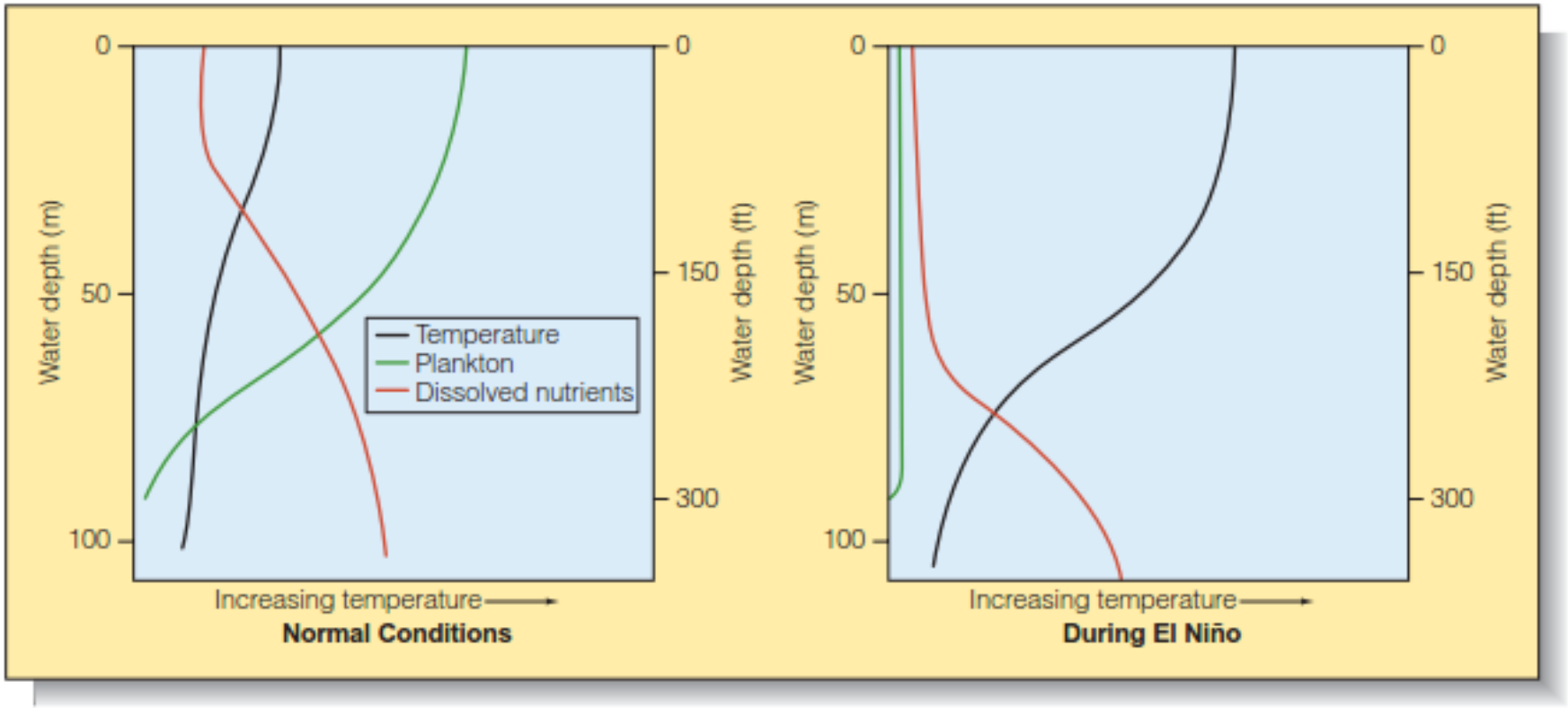
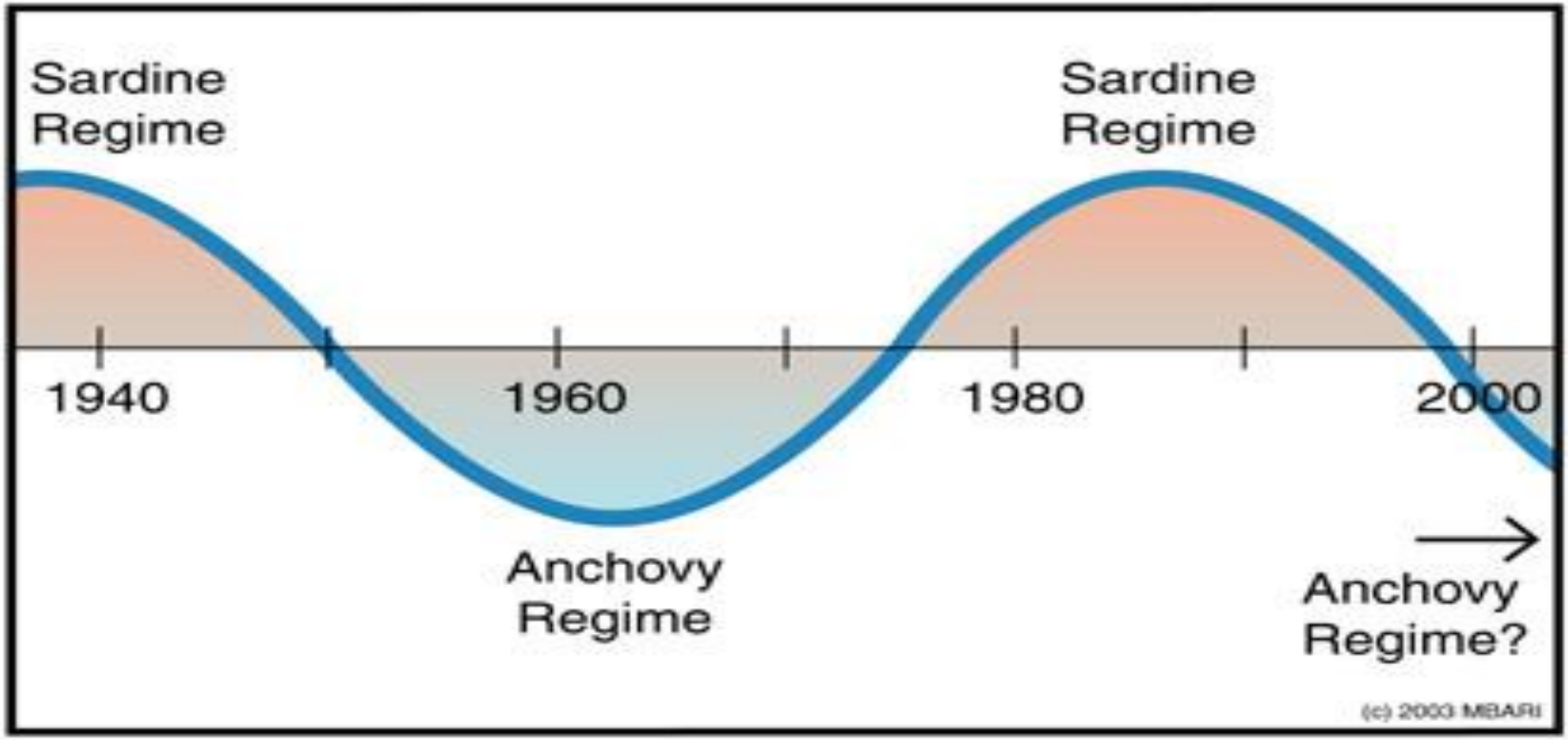
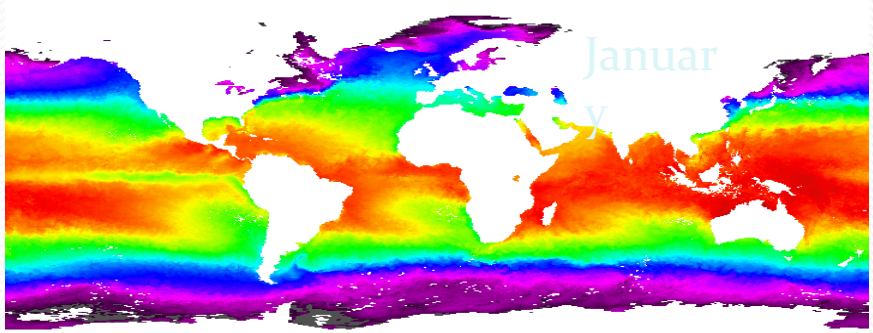


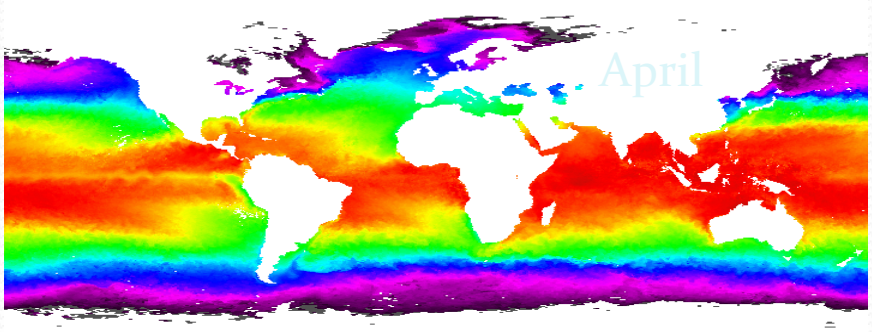
Figure 9.21 Peruvian fisheries decline or collapse during El Niño years. Small drifting animals and plantlike organisms called plankton form the base of the food chain on which commercial fish depend. When the normal northward flow of the cold Peru Current is interrupted, nutrient upwelling fails, plankton cannot prosper, and fish starve.

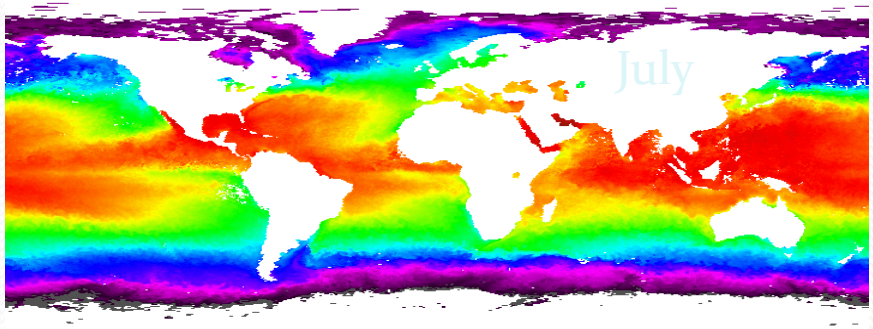
El Nino Regime Changes in Fisheries

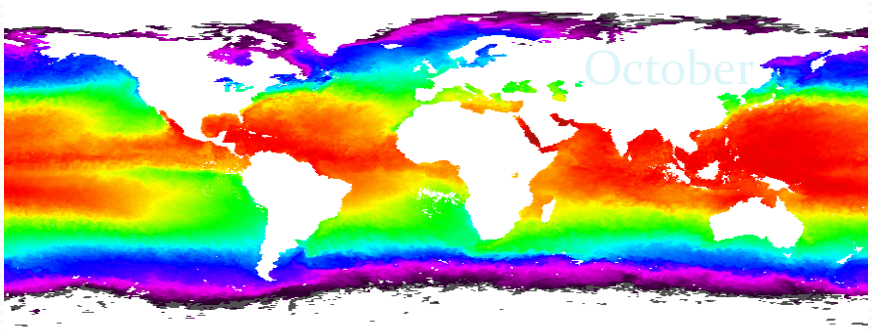


Upwelling and Fisheries









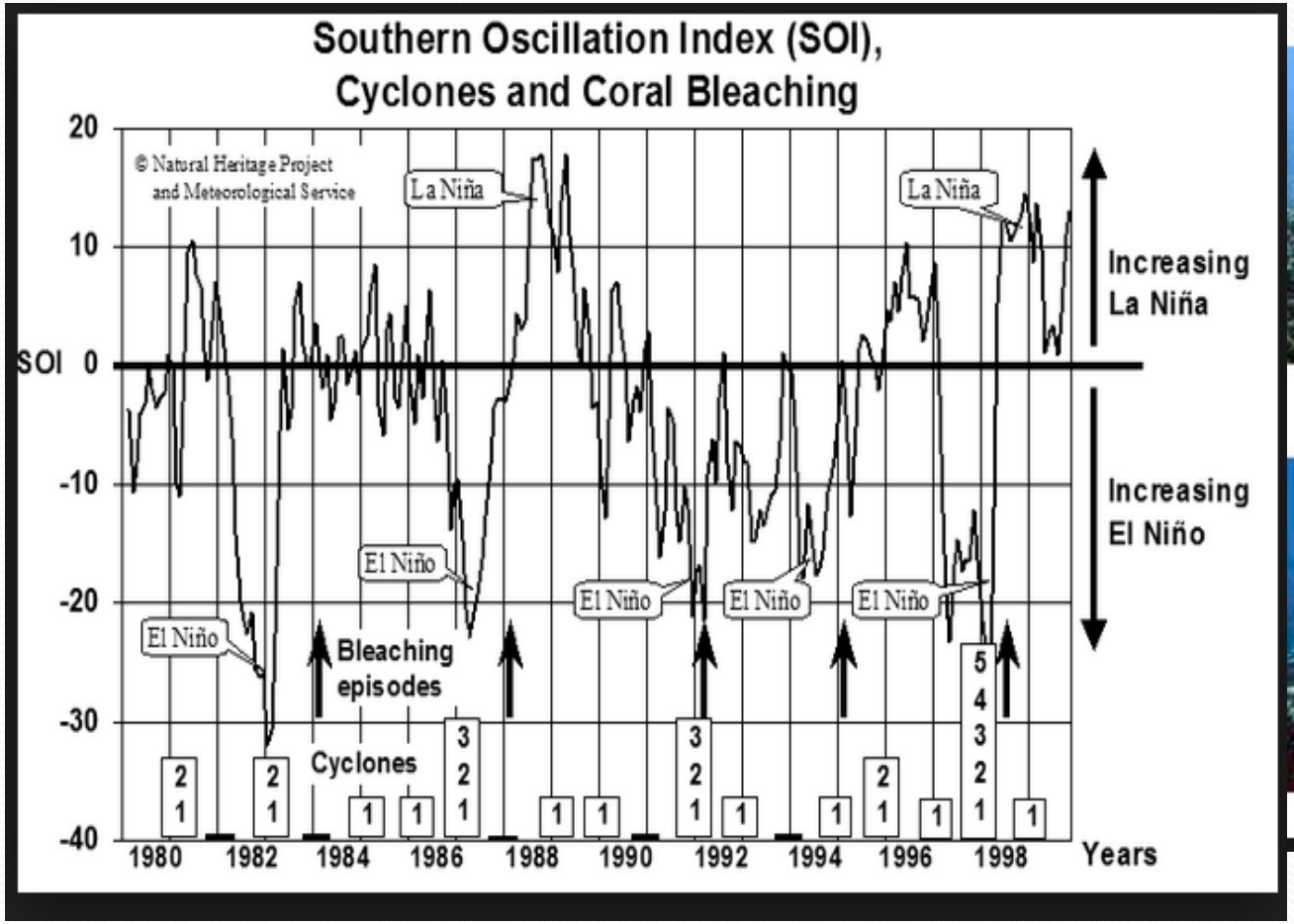
Using this series of Sea Surface Temperature Maps from 1999, can you determine areas/times for possible fisheries?

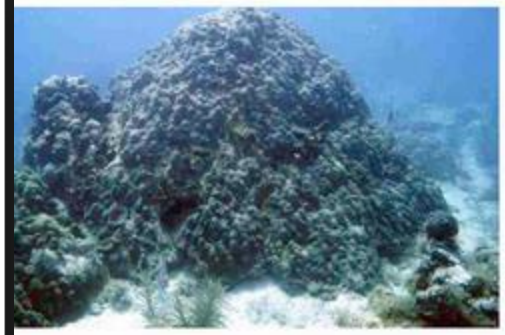
(Hint: Look at Peru's coast in January and April. Look at the northwestern tip of Africa in July and October.)

ENSO effect on Atlantic hurricanes?

- El Niño conditions are associated with less active hurricane seasons due to wind shear.
- La Niña conditions are associated with more active hurricane seasons.

Mass Coral Bleaching Events follow strong El Nino events





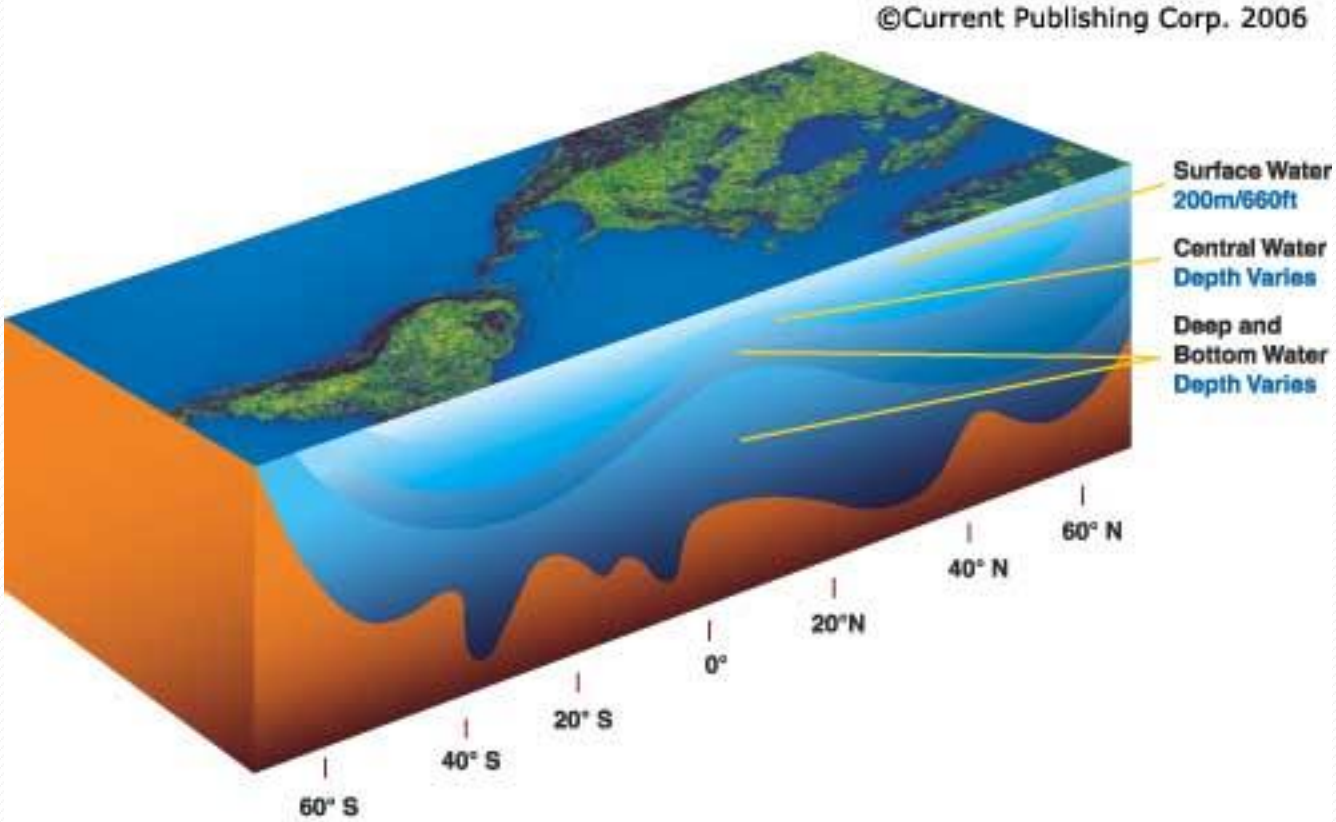
June 3rd 1996

Oct 2nd 1997

Thermohaline Circulation Affects All the Ocean's Water

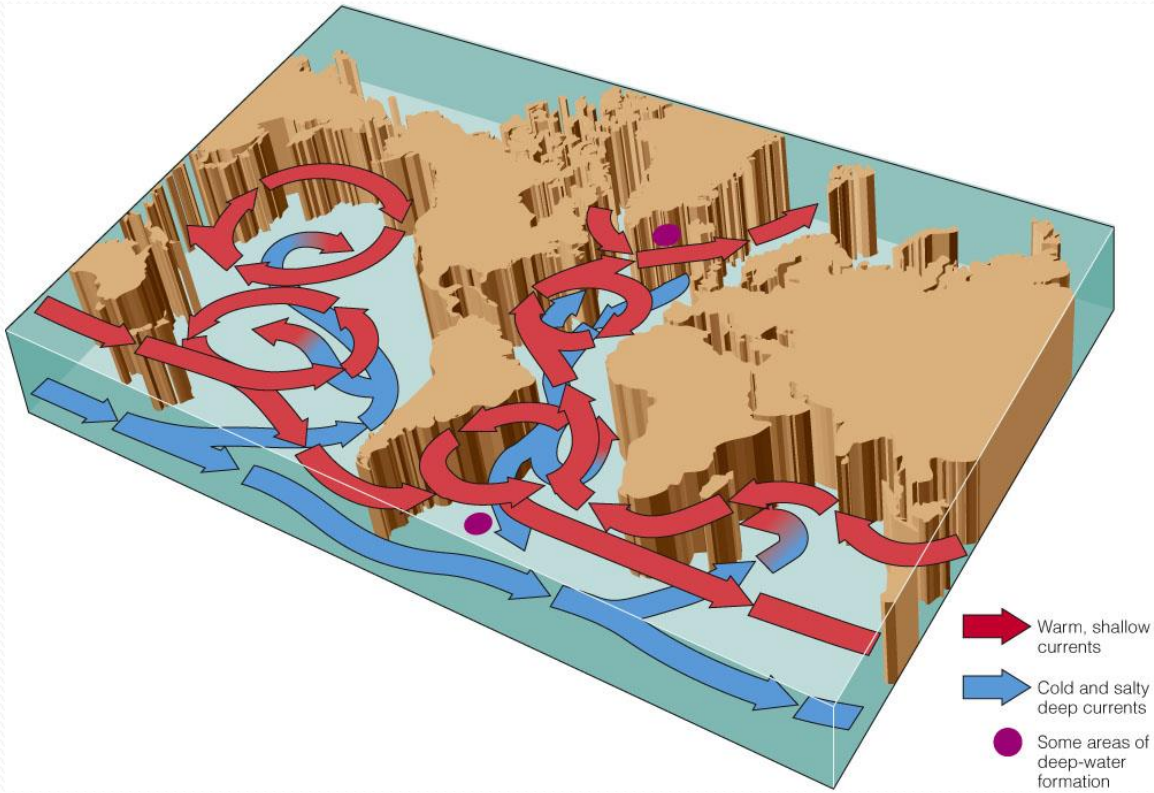
- The movement of water due to different densities is **thermohaline circulation.**
- Because the ocean is density stratified, the densest (heaviest) water is at the bottom.
- There are five common water masses:
  - Surface water
  - Central water
  - Intermediate water
  - Deep water
  - Bottom water

Density layers



Layers in the sea

Thermohaline Flow and Surface Flow: The Global Heat Connection



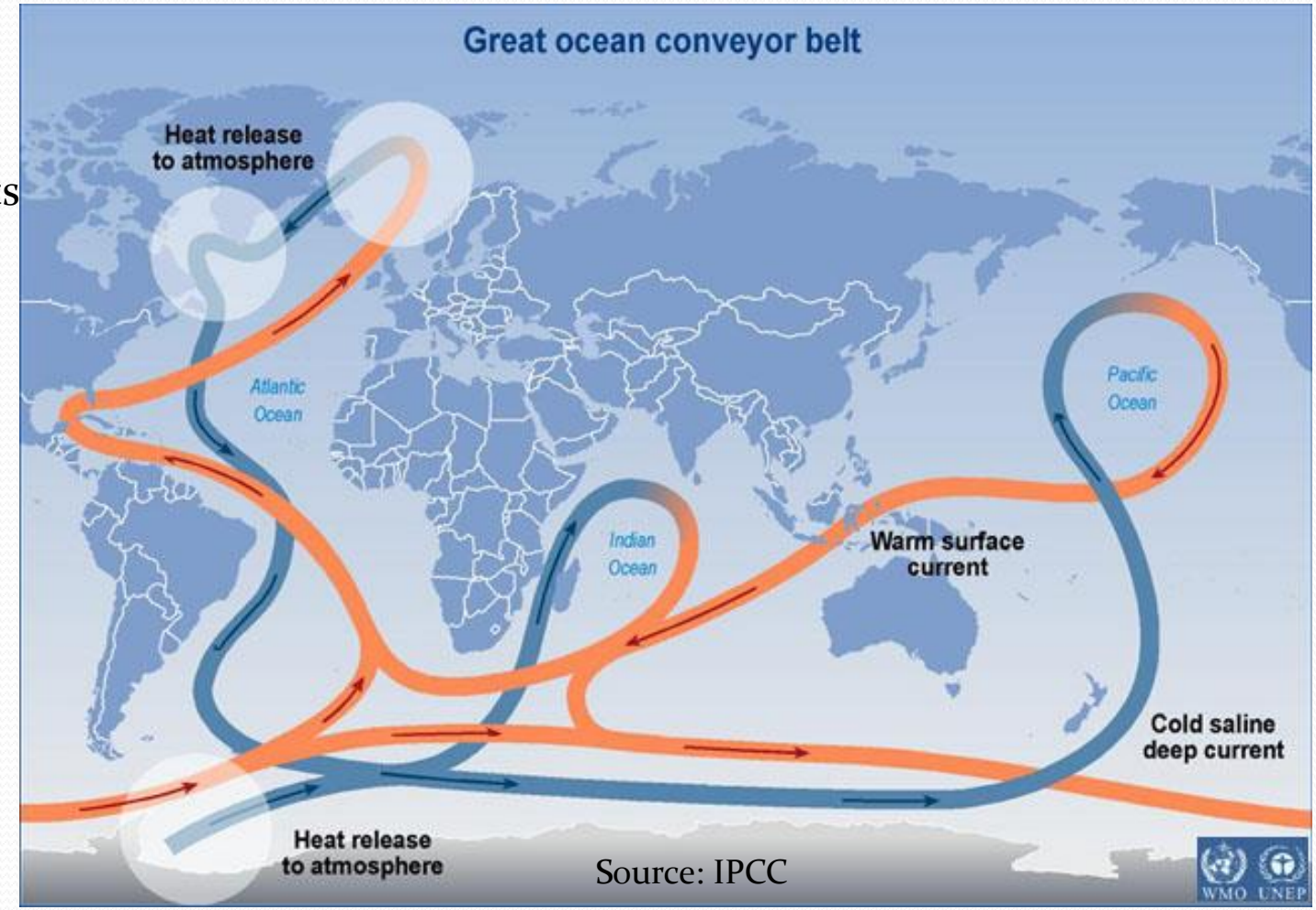
The global pattern of deep circulation resembles a vast "conveyor belt" that carries surface water to the depths and back again. The slow-moving system is important in transporting water and heat.

Deep Currents

- How does thermohaline circulation differ from wind driven circulation?
- Remember *thermohaline circulation* (from the Greek *thermo* meaning heat and *hales* meaning salt) is water motion caused by differing water densities.
- More dense water sinks, displacing less dense water…

Great Ocean Conveyor

Earth's "air conditioning system" transports heat away from equator and circulates cold water to warm regions.



Source: IPCC

Cold, salt

H.C. Berann www.berann.com

The flow of Atlantic Deep Water

Current measurements

- How do we know current speed and direction?
- Two methods:
- ***Lagrangian* method** (aka *float method*): current is studied by following a drifting object, or drifting objects.
- ***Eulerian* method** (aka *flow method*): current direction and velocity measured from stationary location.

Acoustic Doppler Current Profiler (ADCP)

Using Dopplers in the sea

St. Croix, USVI

- Studying the environment and health of coral reefs

Coral bleaching: