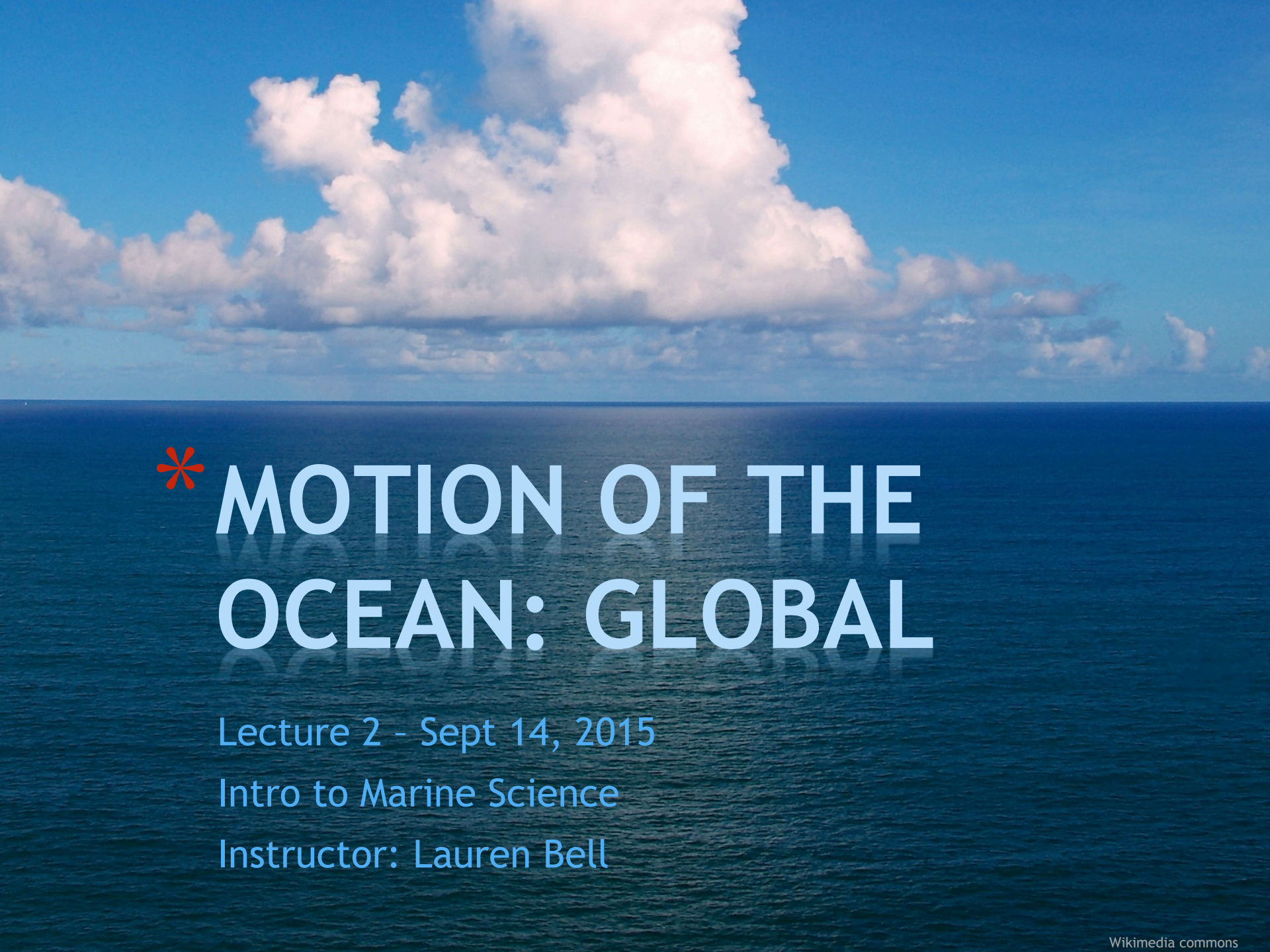


MOTION OF THE OCEAN: GLOBAL

Lecture 2 – Sept 14, 2015

Intro to Marine Science

Instructor: Lauren Bell

Wikimedia commons

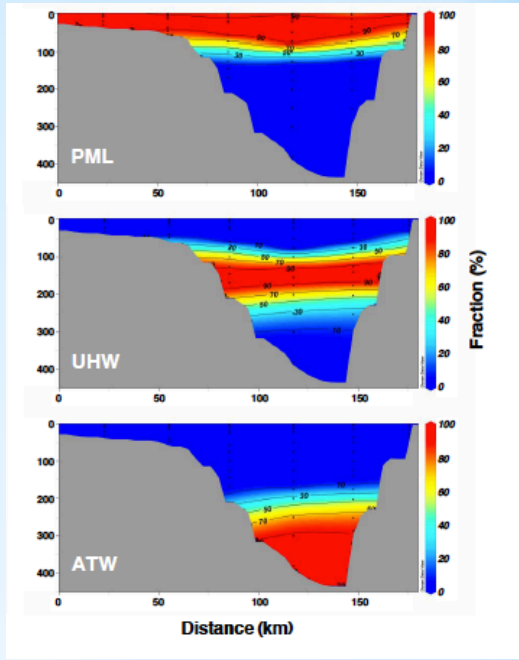
Learning objectives

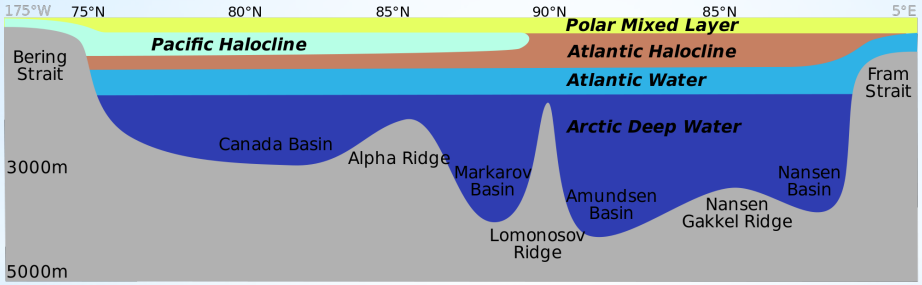
After this lesson, you will be able to:

- Explain and diagram the Coriolis effect and Ekman transport and their relevance to oceanic gyres
- Describe what the “global conveyor belt” is, what drives it, and why it’s important to global climate
- Hypothesize about the general biological characteristics of an region based on its oceanographic features
- Understand the variation measured by the major climate indices (ENSO, PDO, AO) and how these variations affect Alaska’s climate

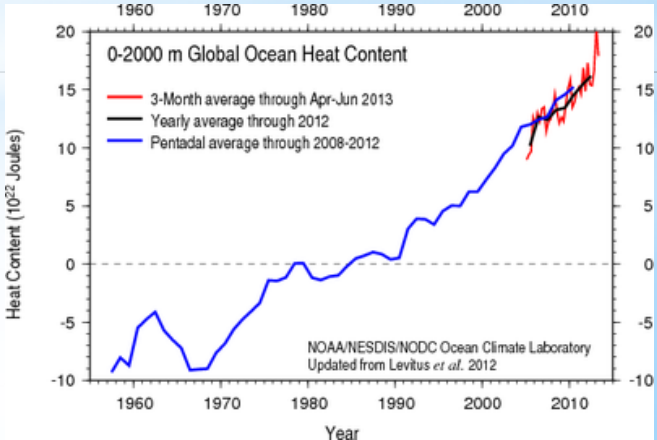
*Media for this week

- Video – density differences in the ocean
  - ✧ Pycnocline (thermo- vs. halo-cline)
  - ✧ Internal waves vs. surface waves
  - ✧ Water masses
  - ✧ Wind mixing
  - ✧ Nutrient transport





- Podcast – the ocean as a global thermostat
  - ✧ Heat storage – where is it going?
  - ✧ Consequences
    - Sea level
    - Solubility of gases

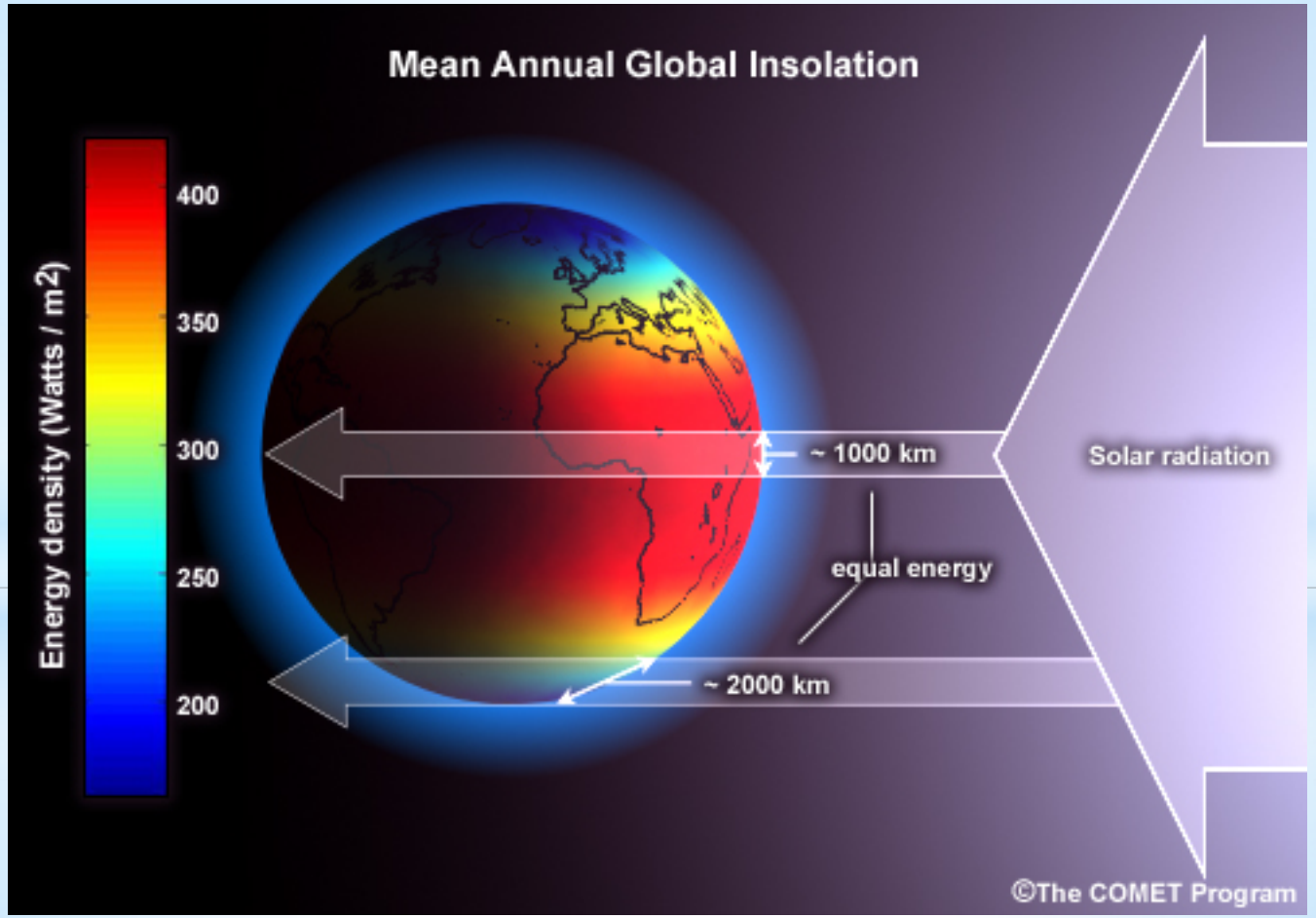


Spheres have issues

*Sphere = uneven heating

- Solar radiation reaching earth varies due to:
  - ✧Latitude
  - ✧Season

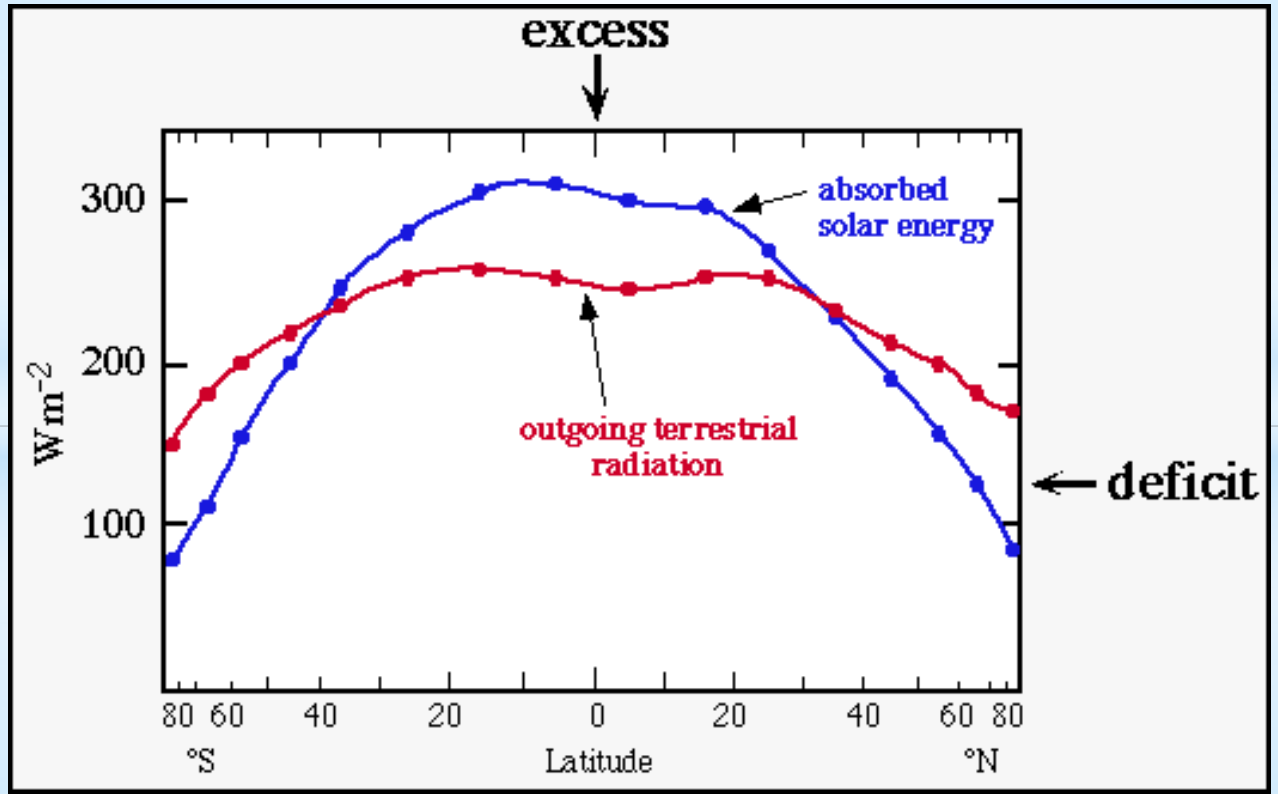
} Oblique angle of rays



Net radiation imbalance

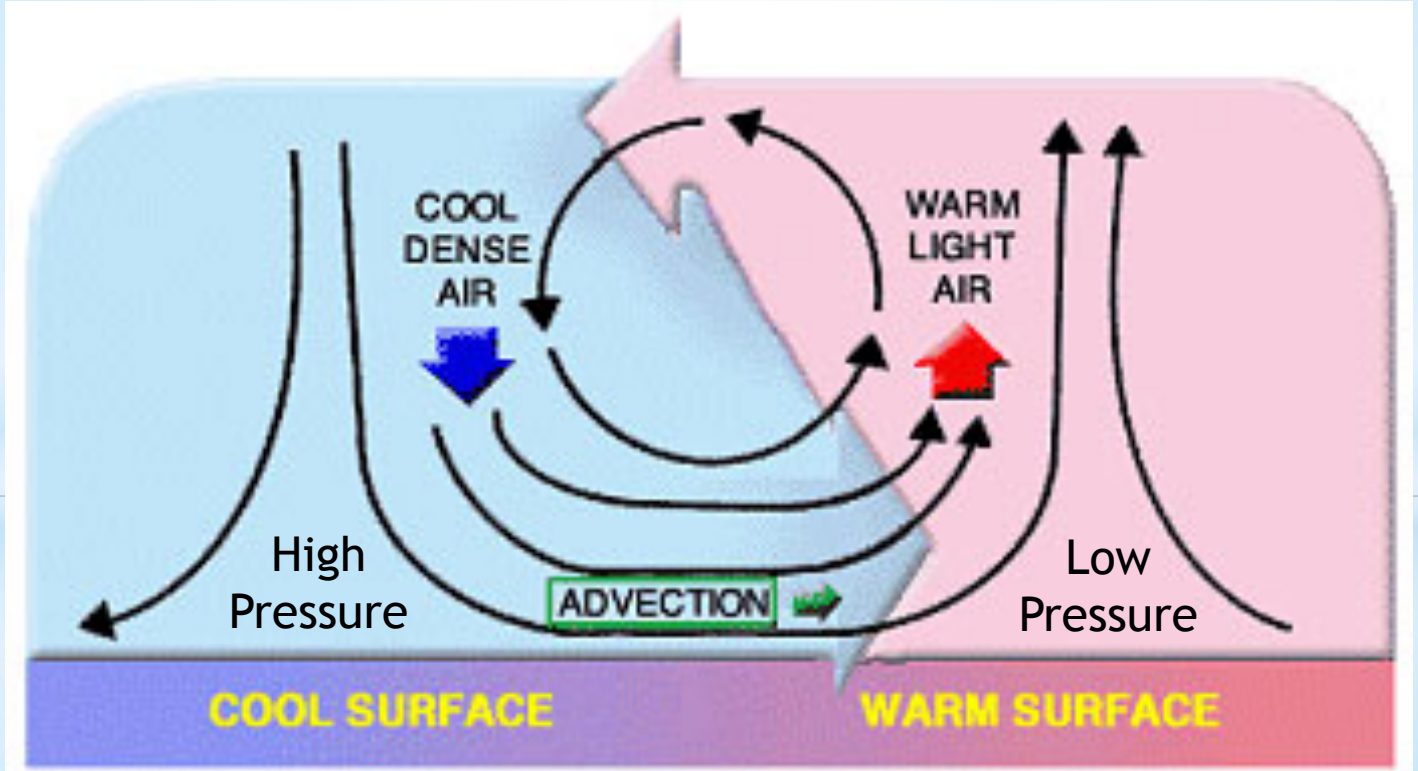
- Poles radiate more energy into space than received
- Tropics/subtropics gain more energy than lose

How come the poles don't just keep getting colder while the tropics get hotter and hotter???



Global circulation

- Atmospheric and oceanic circulation very similar – a means of maintaining thermal balance
- Air is less viscous, lower heat capacity so it moves easier than oceans



Convection Process

NASA

Convection cells: idealized, non-rotating earth

- High pressure
  - descending air
  - clear skies
  - low precipitation
- Low pressure
  - ascending air
  - clouds
  - heavy increased precipitation

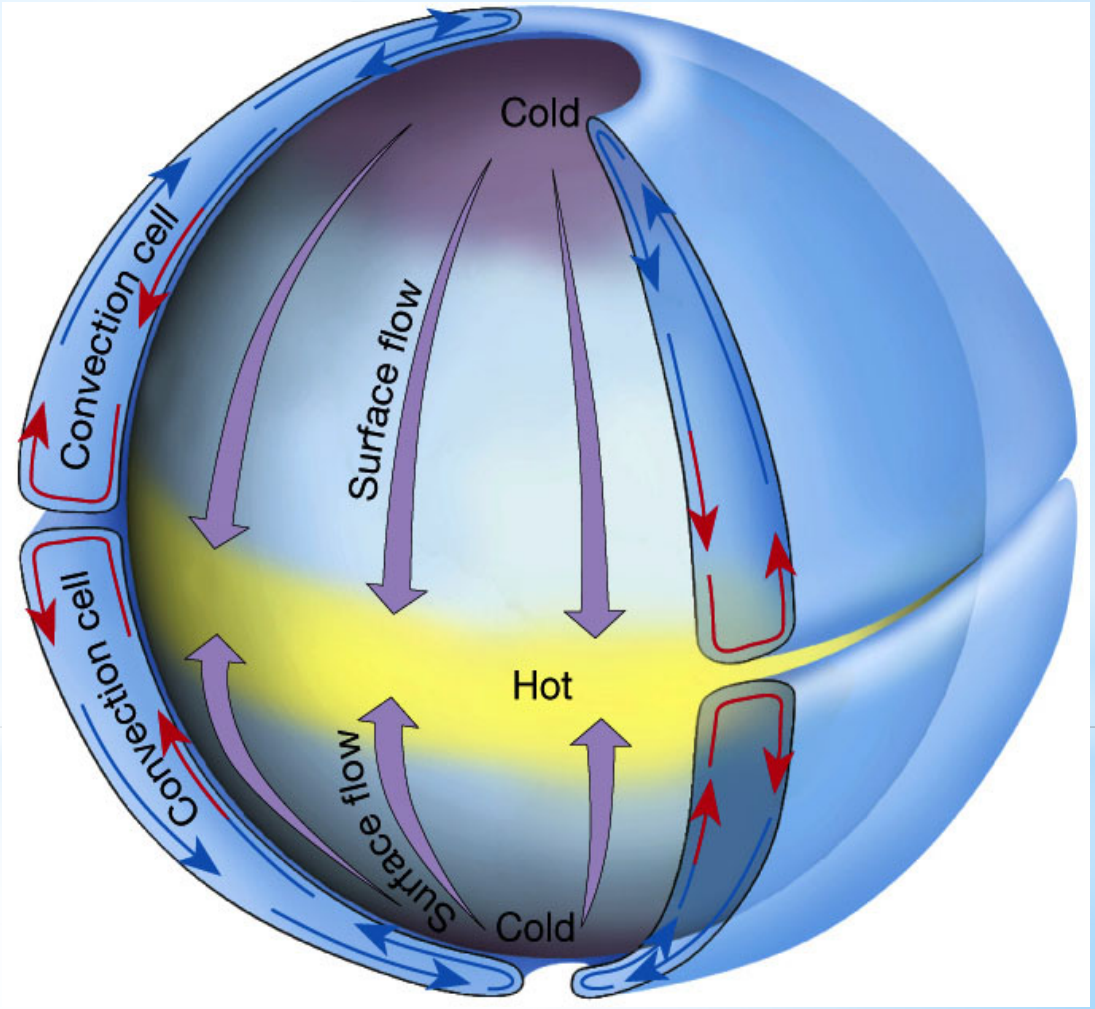
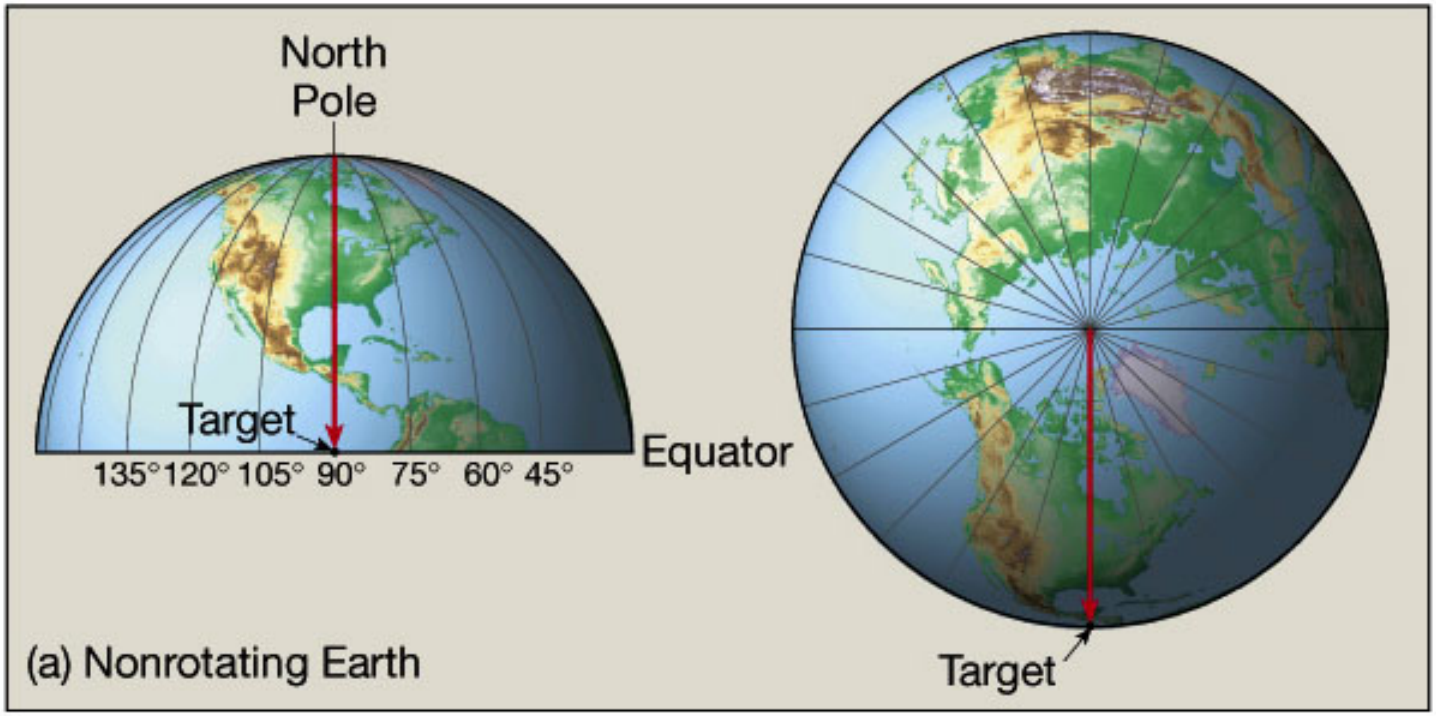
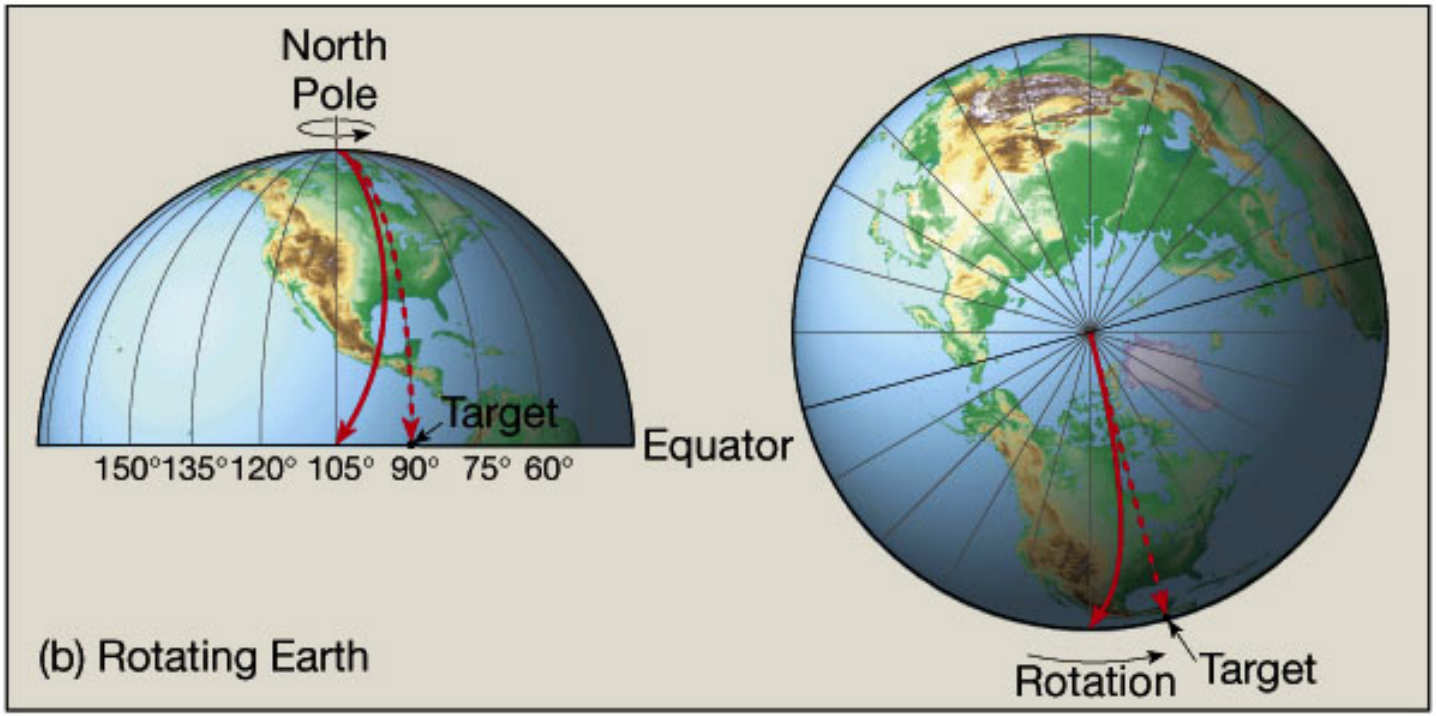


Figure 7.5 in *The Atmosphere, 8th edition*, Lutgens and Tarbuck, 8th edition, 2001

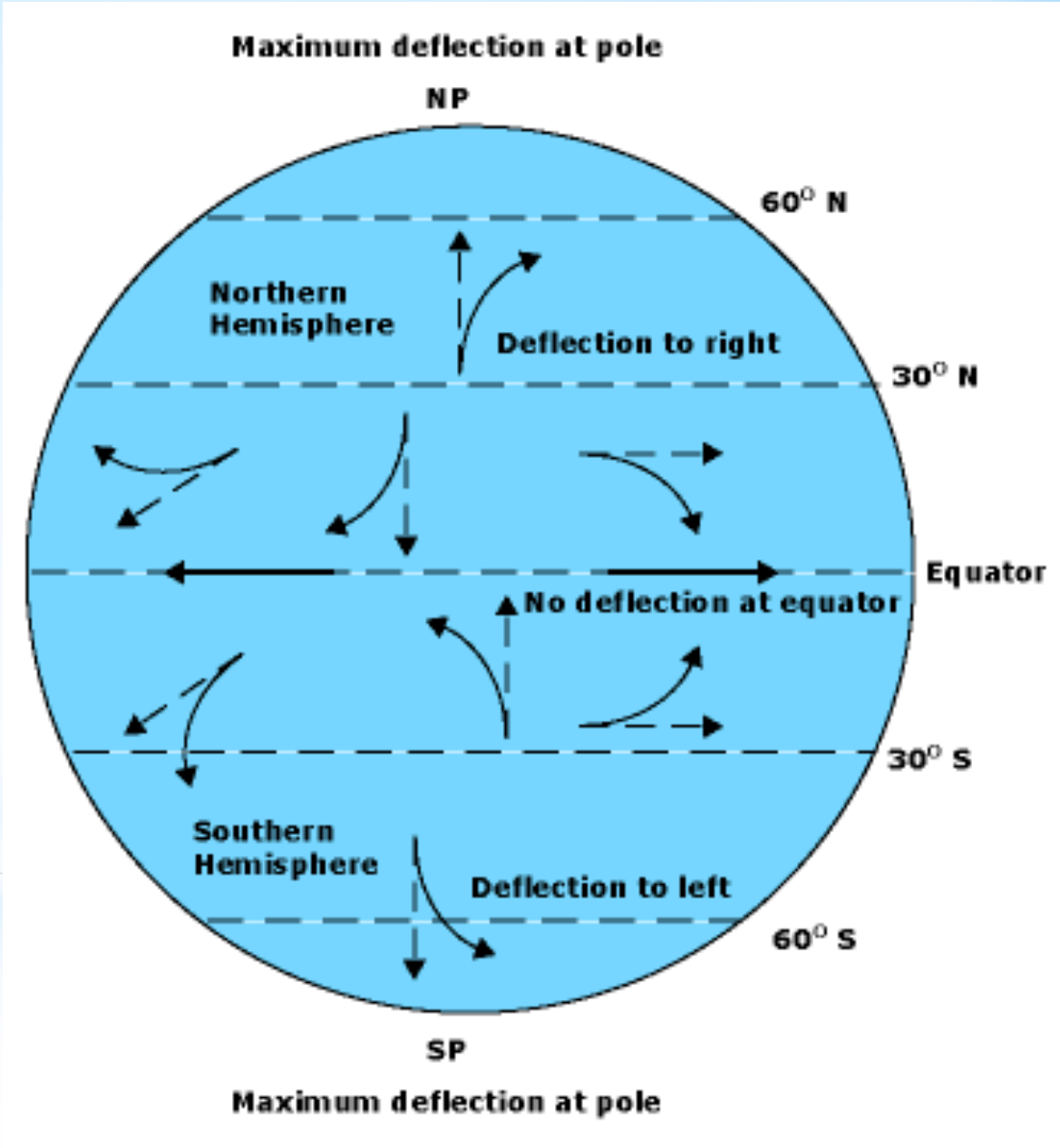




*Alas, we've rotated.

= Coriolis effect

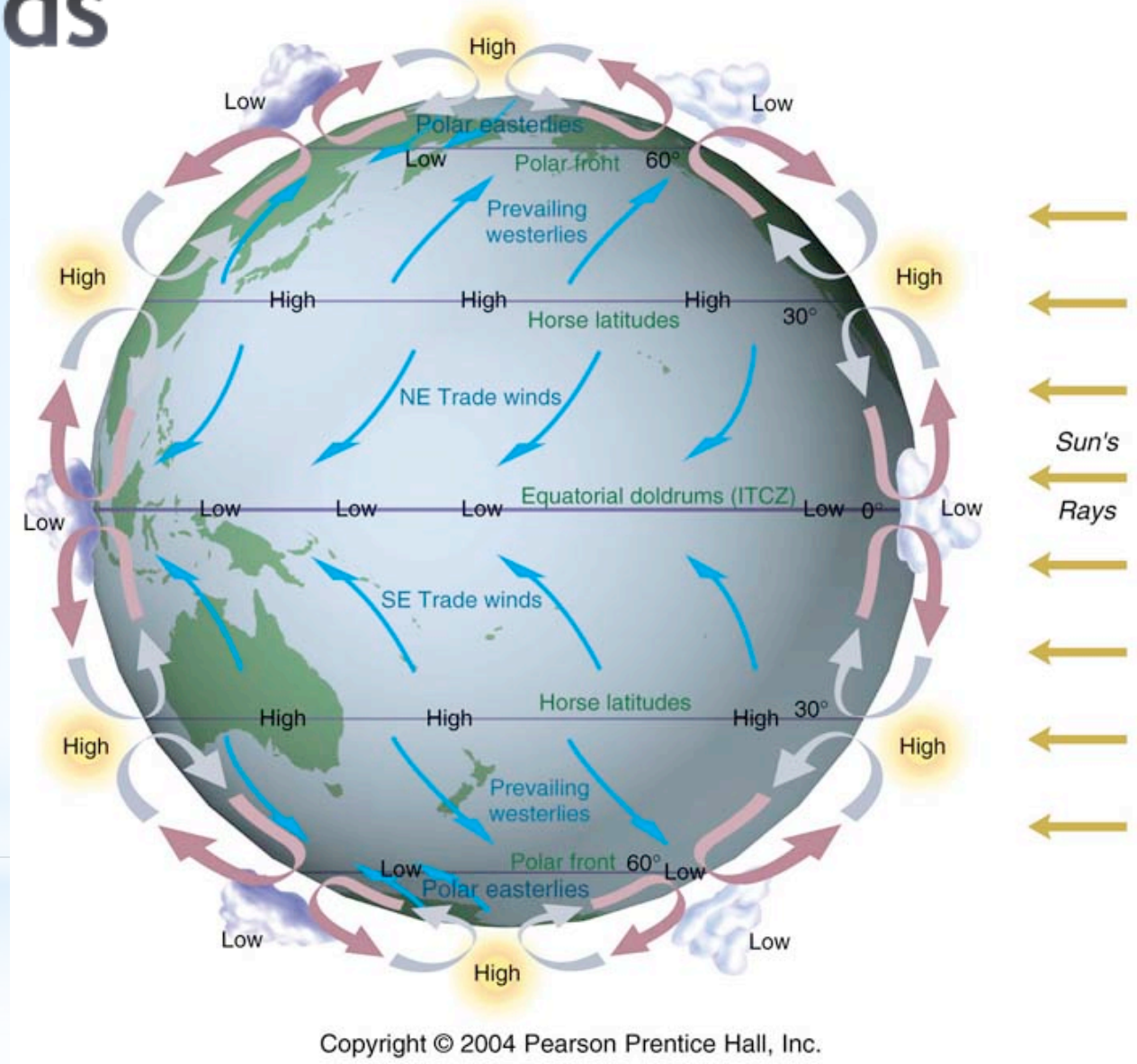
- Deflection tied to the difference in rotation speed by latitude



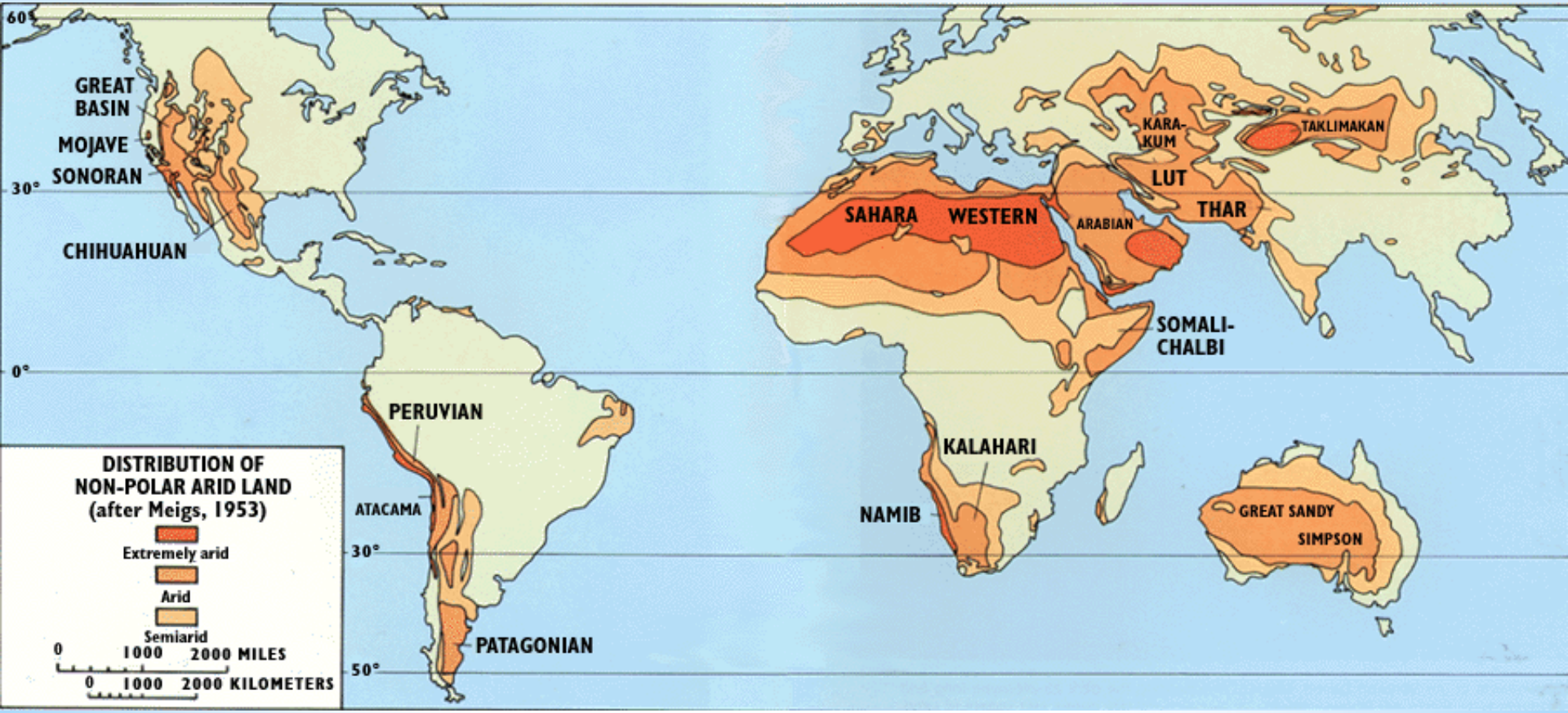
*Wind bands

- Three main convection cells
  - ✧Trade winds
  - ✧Westerlies
  - ✧Polar easterlies

- Wind bands formed due to drag, inertia, gravity, and <u>conservation of angular momentum</u> (Coriolis effect becomes too strong)



*Convection cells drive prevailing climates!

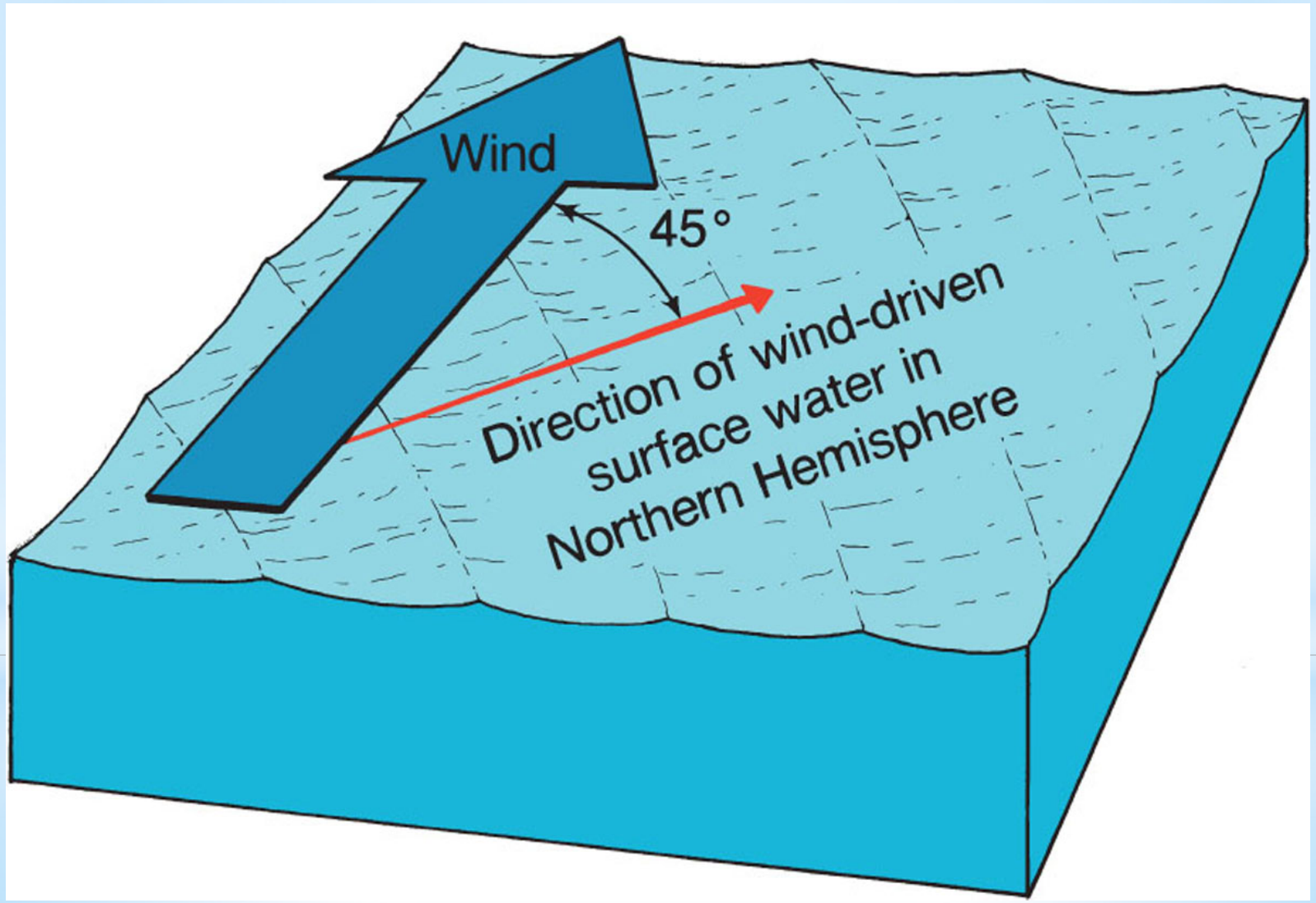


USGS

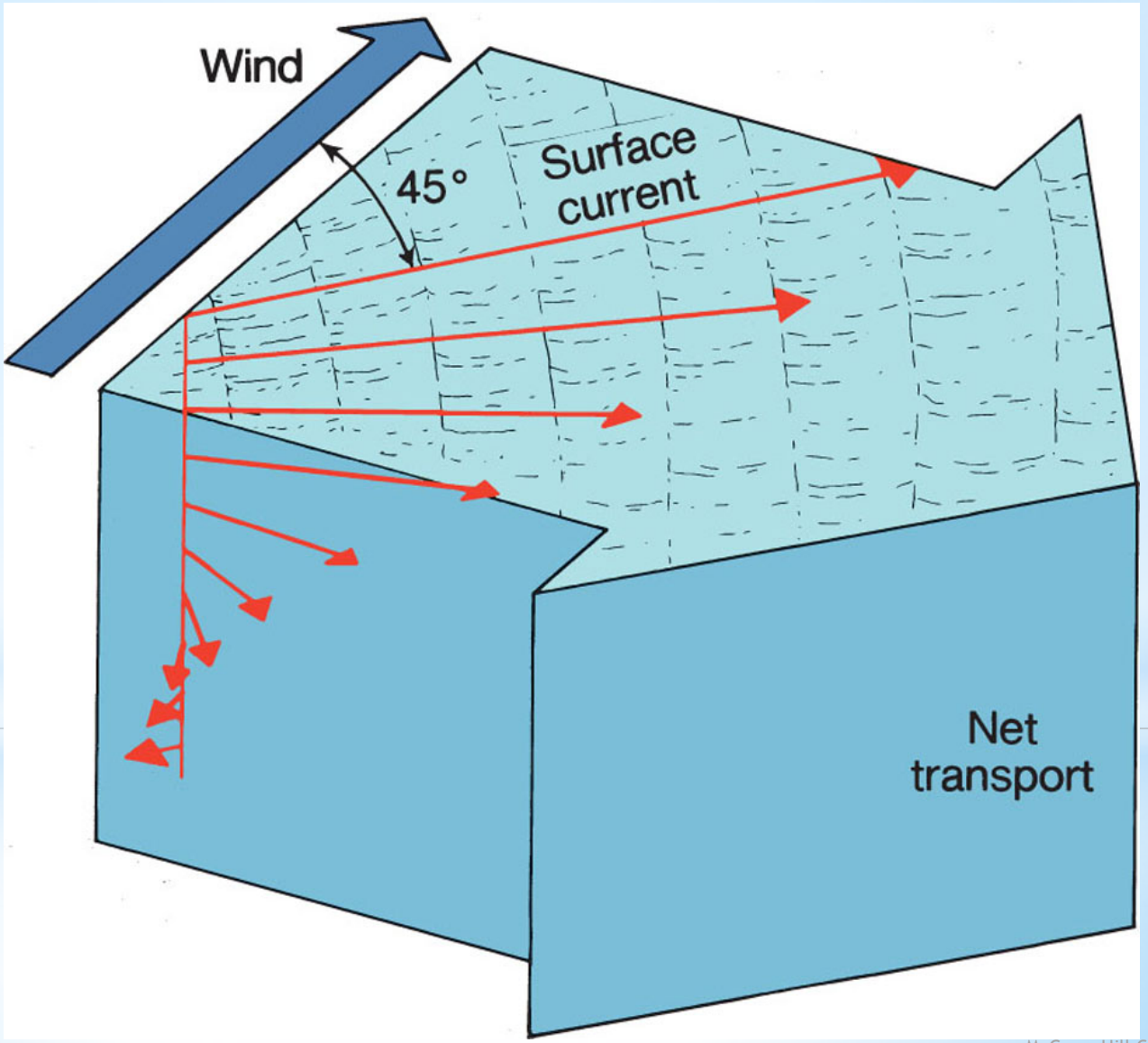
What's the impact on the ocean?

Coriolis impact on surface currents

- Wind over water = drag = sets in motion



Ekman spiral



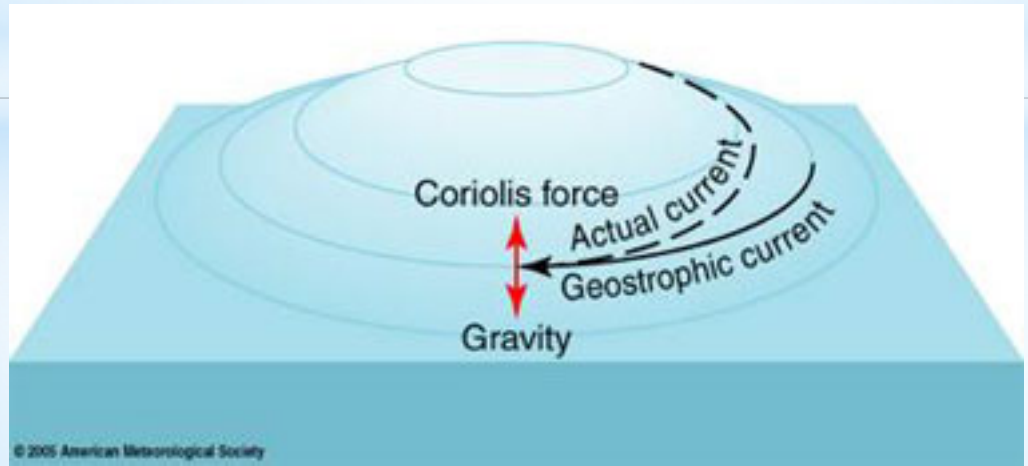
Formation of gyres - *N. hemisphere*

- Net transport of water to RIGHT of prevailing wind
- Bordering land masses also direct water clockwise
- Water begins to “pile up” in center

Gyre formation from <u>geostrophic flow</u>

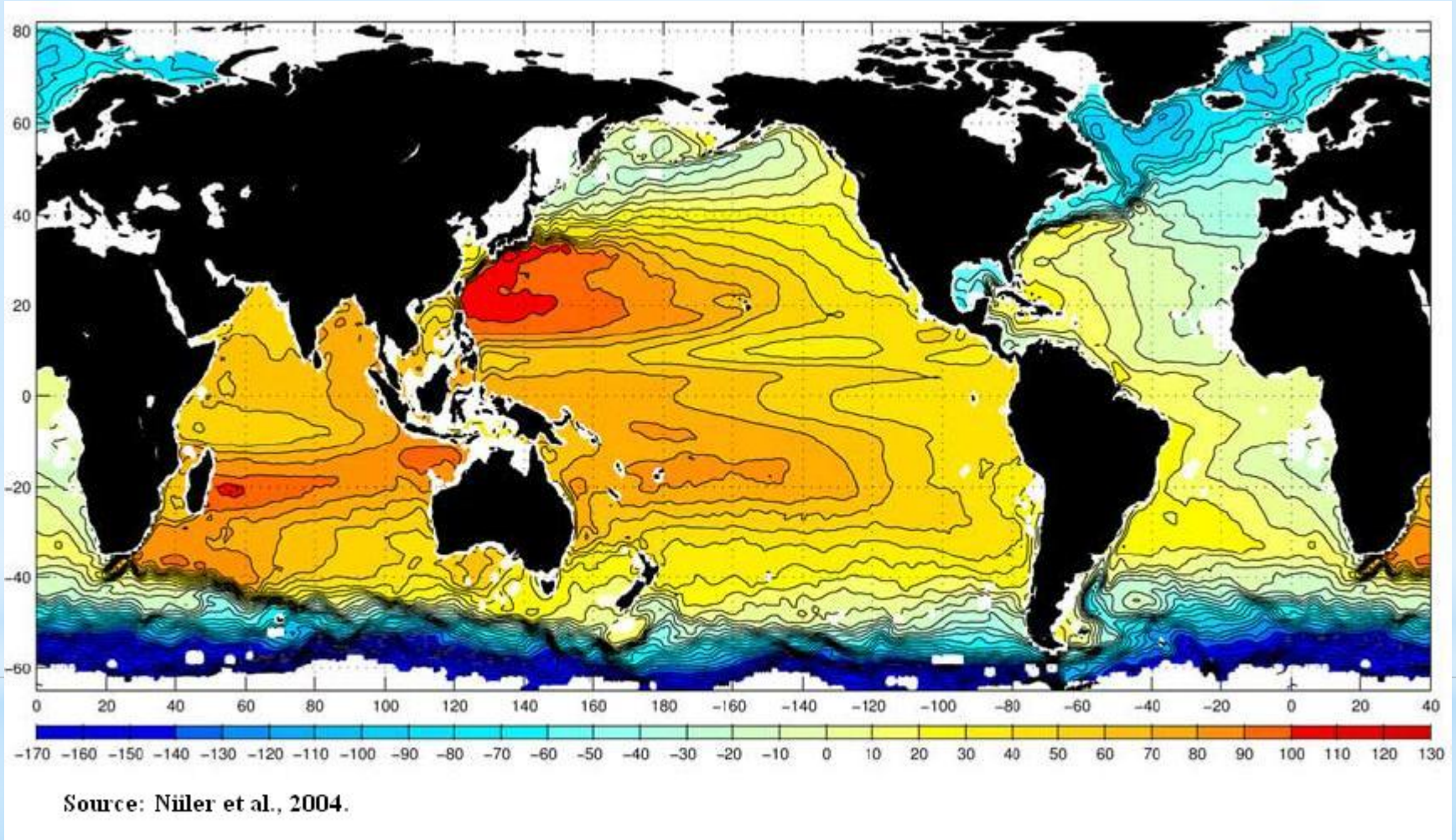
balance between forces:

- ✧ Coriolis (piling water ‘uphill’)
- ✧ Gravity (water flowing ‘downhill’)



Sea surface height

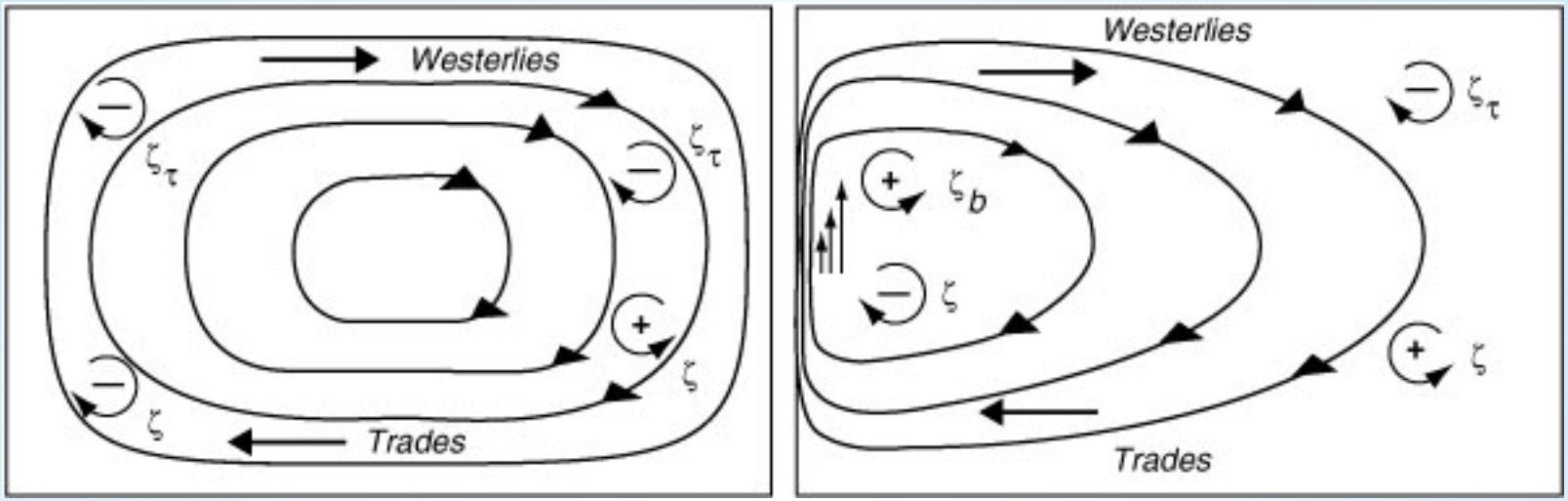
- Difference between middle and edges of gyre < 1m



Why are gyres not centered in middle of Pacific?

Westward intensification

- Water piles up on westward border of gyre (both N & S hems)



Potential vorticity = ζ

Due to balance between:

Planetary vorticity

- Coriolis force varies with latitude

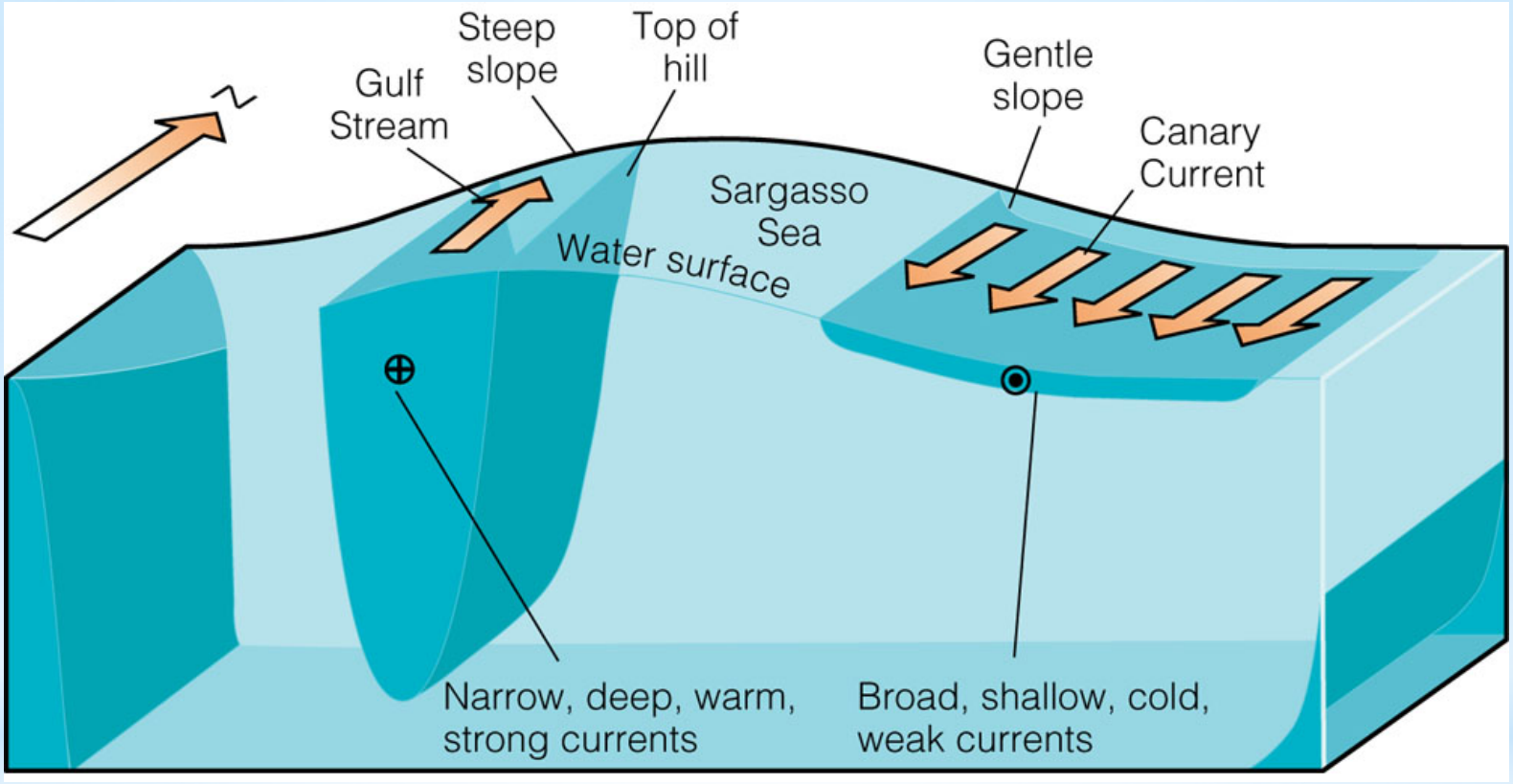
Relative vorticity

- Friction
- Wind stress

→ Really cool physics which we don't have time to cover in this class…

☹

*Westward intensification



e.g., Gulf Stream, Kuroshio

Western Boundary Currents

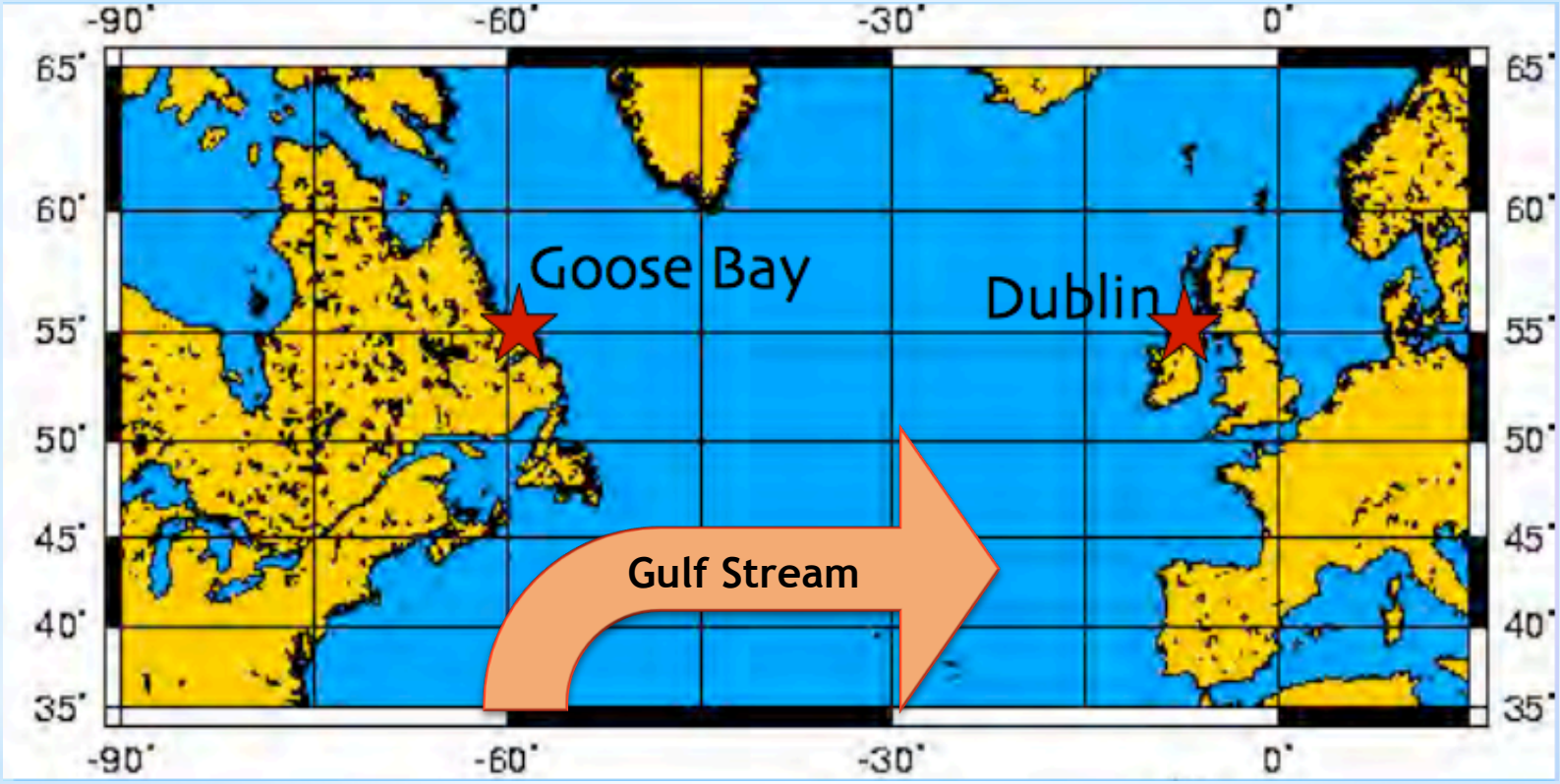
- Fast (~100+ km/day)
- Deep (~2km)
- Narrow (100km)
- Sharp boundaries

Eastern Boundary Currents

- Slower (10's km/day)
- Shallow (<500m)
- Broad (1000 km)
- Diffuse boundaries

e.g., Canary, California,

Why do we care?

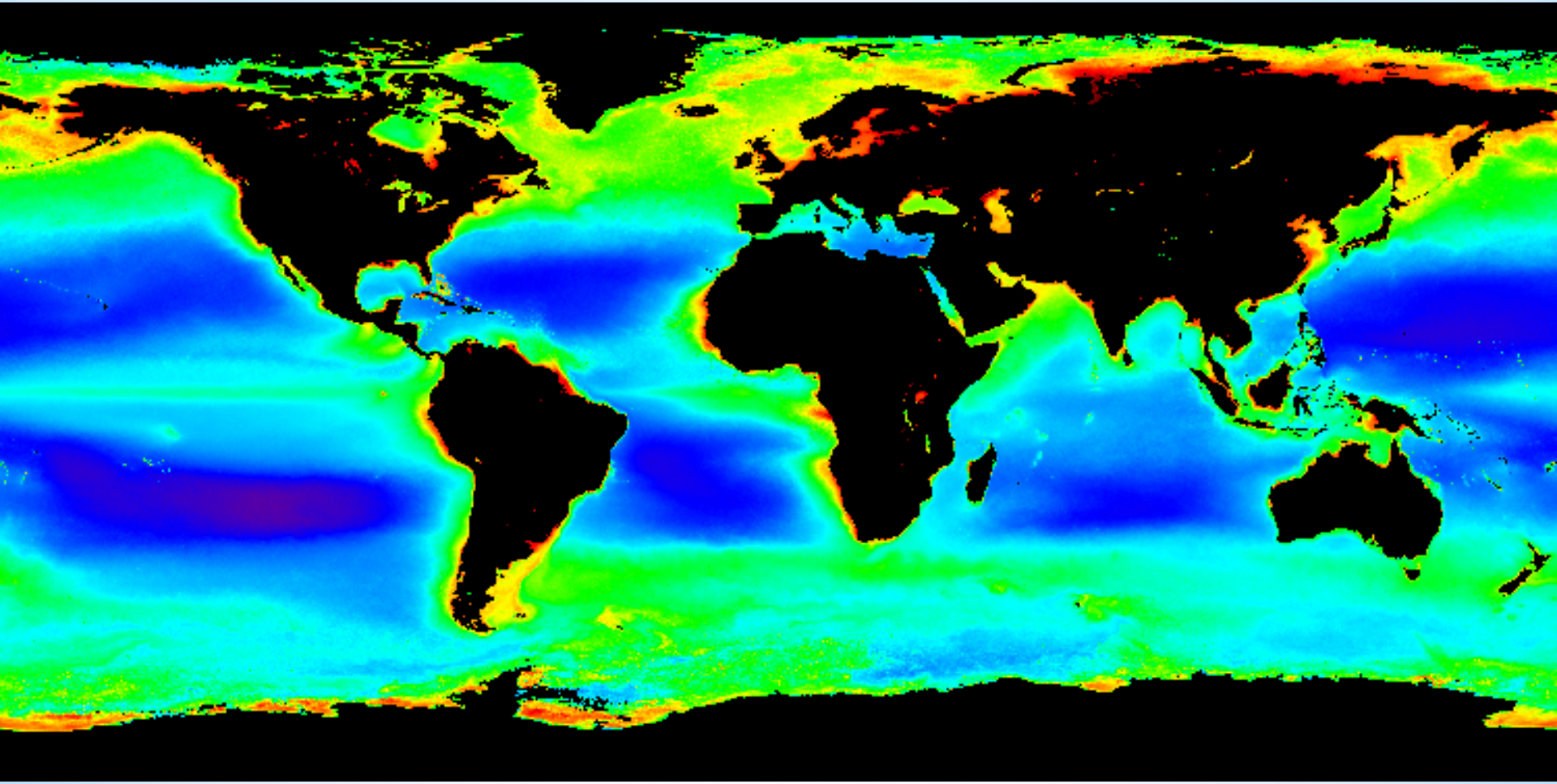


HEAT TRANSPORT

Goose Bay: Mean temperature -0.3°C, 113 days/year with snow or freezing precipitation

Dublin: Mean temperature 9.6°C, and no snow

*Sea Surface Chlorophyll a



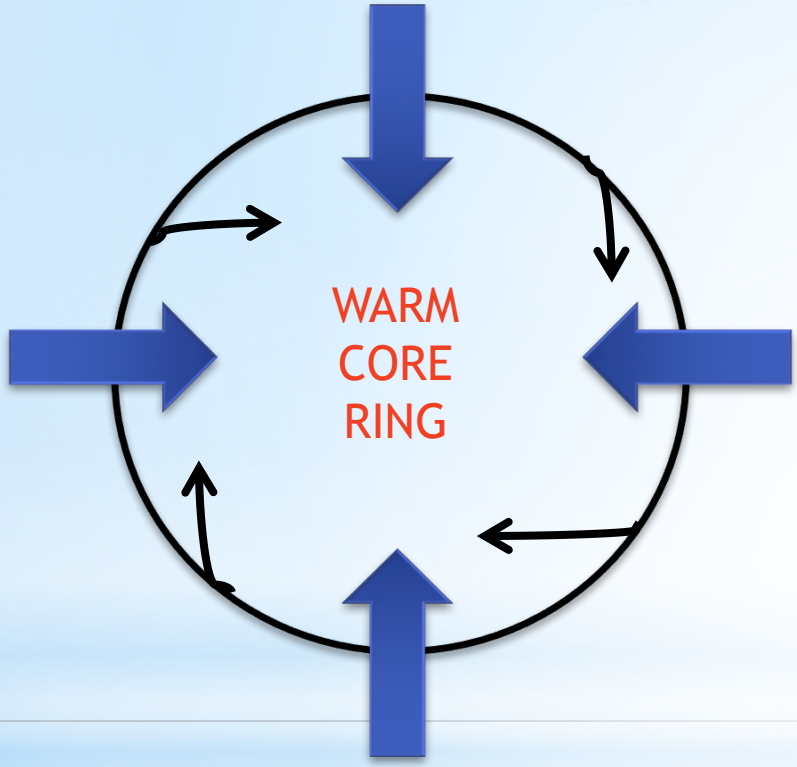
What do phytoplankton need to photosynthesize?

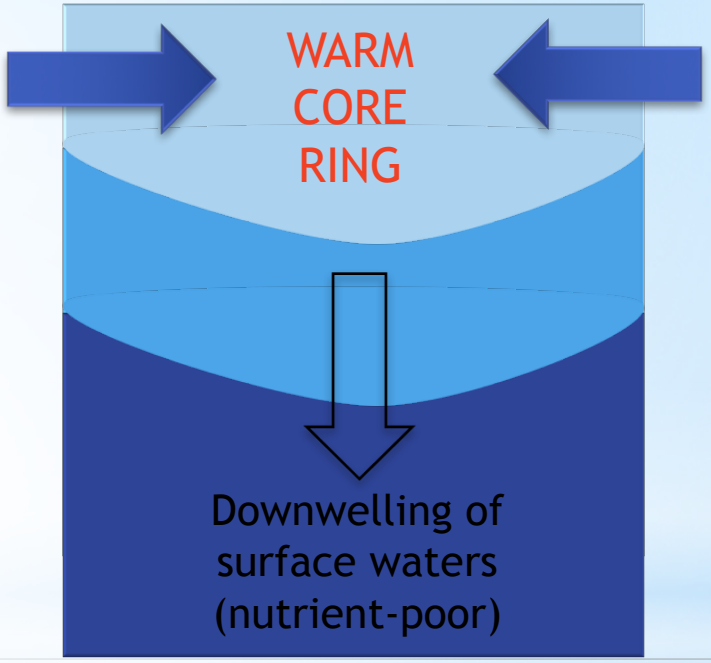
NASA/WHOI

* Open-ocean vertical movement

Northern Hemisphere

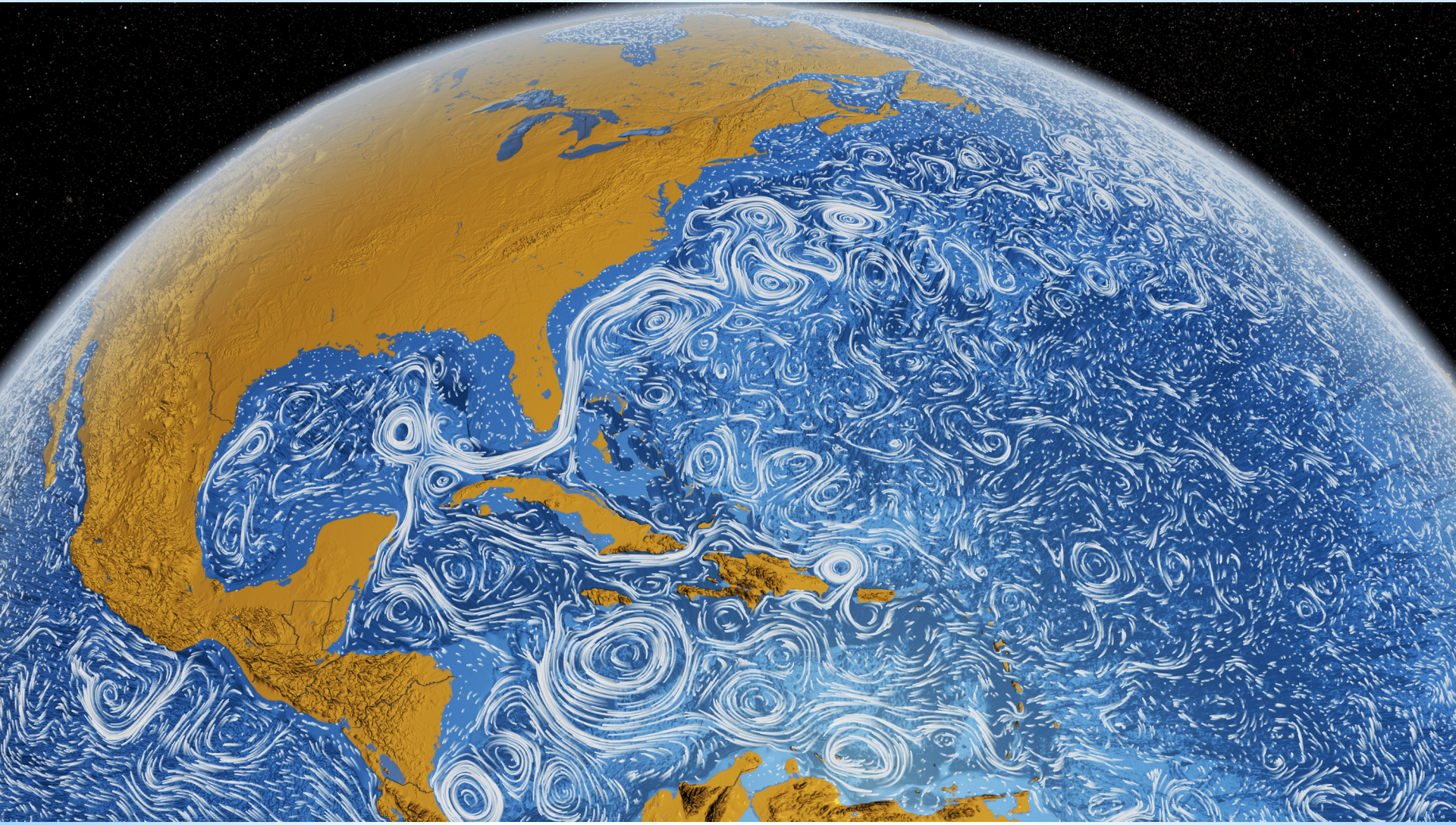
(Coriolis deflection to the right)



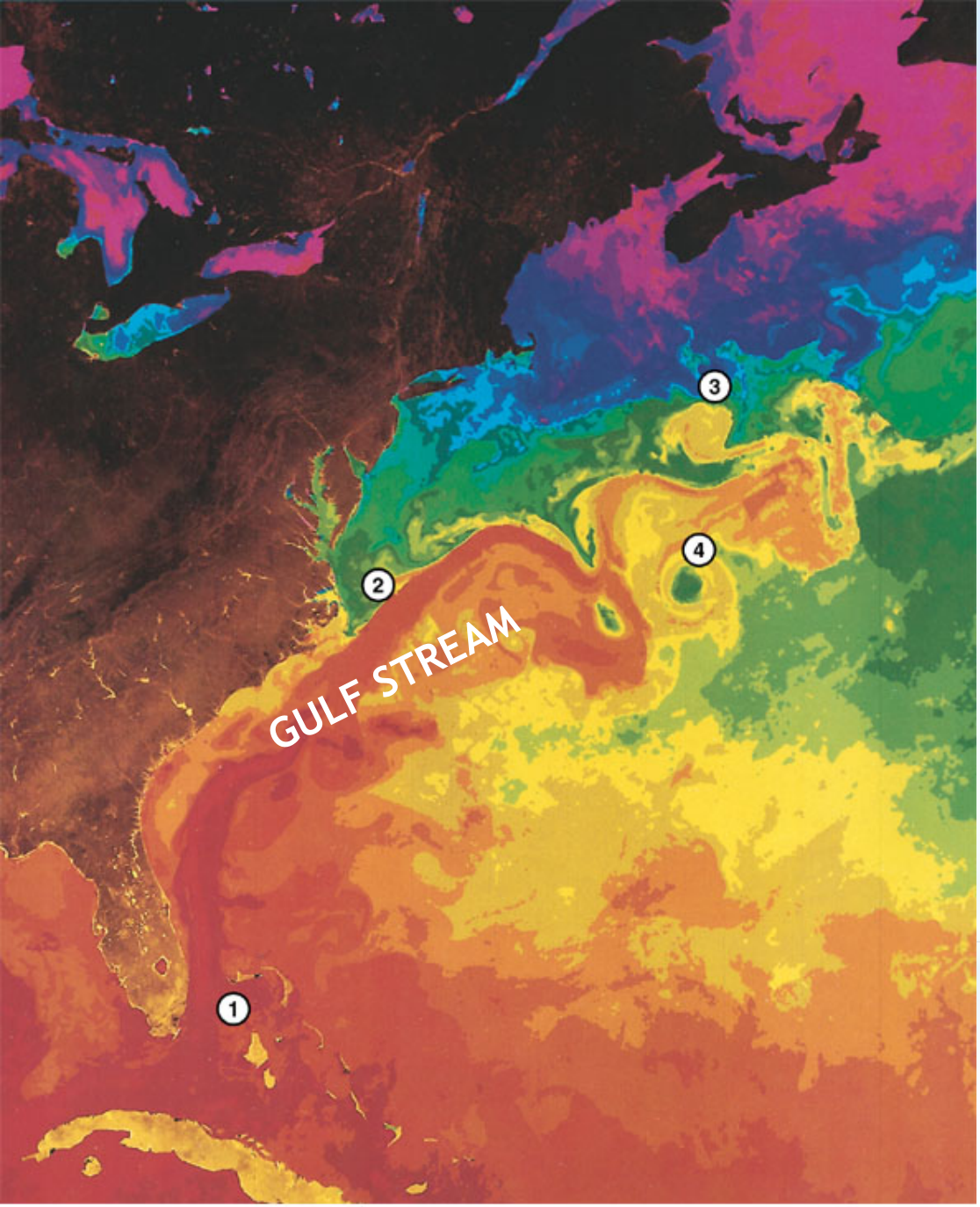


- Warm ring has high pressure downwelling in the center
- Depth of **pycnocline** (large density gradient) increases
- Moves nutrient-rich waters away from the light
- Low primary production (low Chl a)

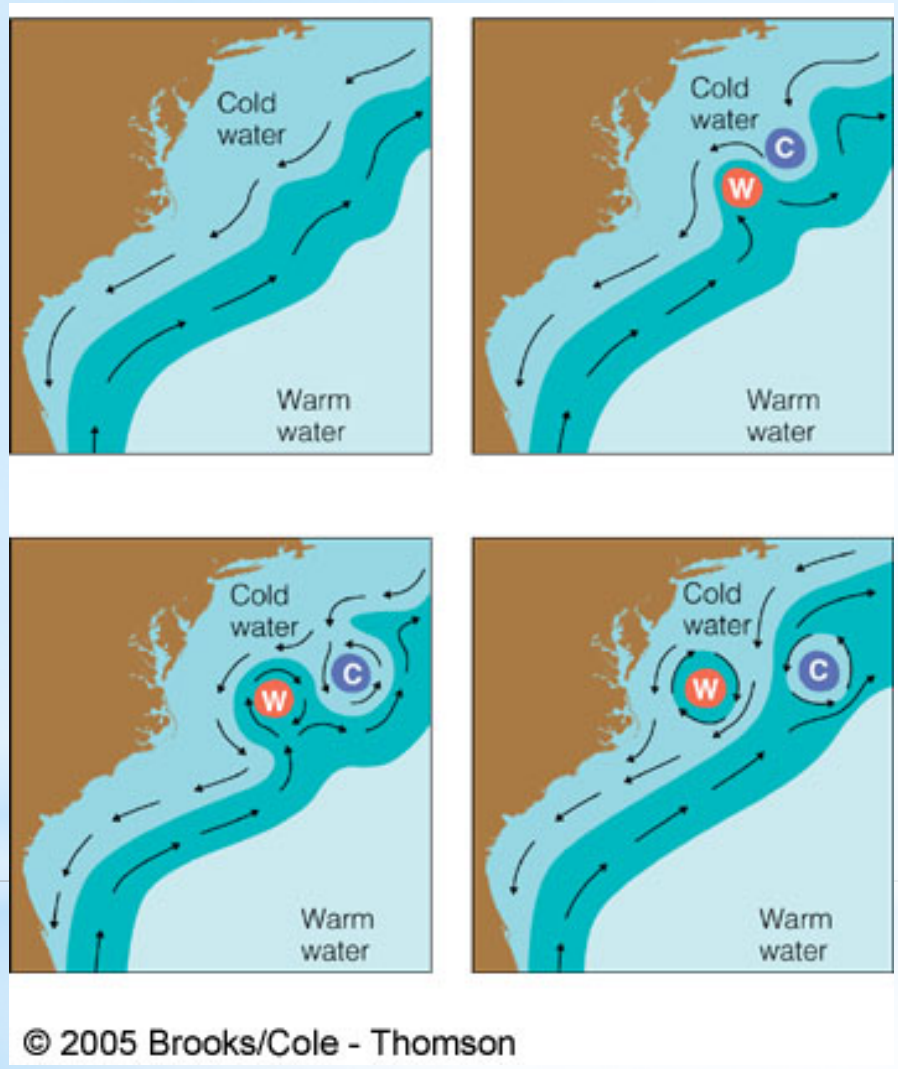
* Luckily, the ocean is much more complex than its major gyres….



NASA – Scientific Visualization Studio



- Currents lack well-defined edges, so have friction with adjacent boundaries
- Meander as they flow
- Sometimes get rings (warm and cold core) pinched off
- Warm-core eddies rotate CW (N. hemisphere)
- Cold-core eddies rotate CCW (N. hemisphere)
- Can be 1000 km in diameter, persist for years, effects may be felt to the bottom of ocean

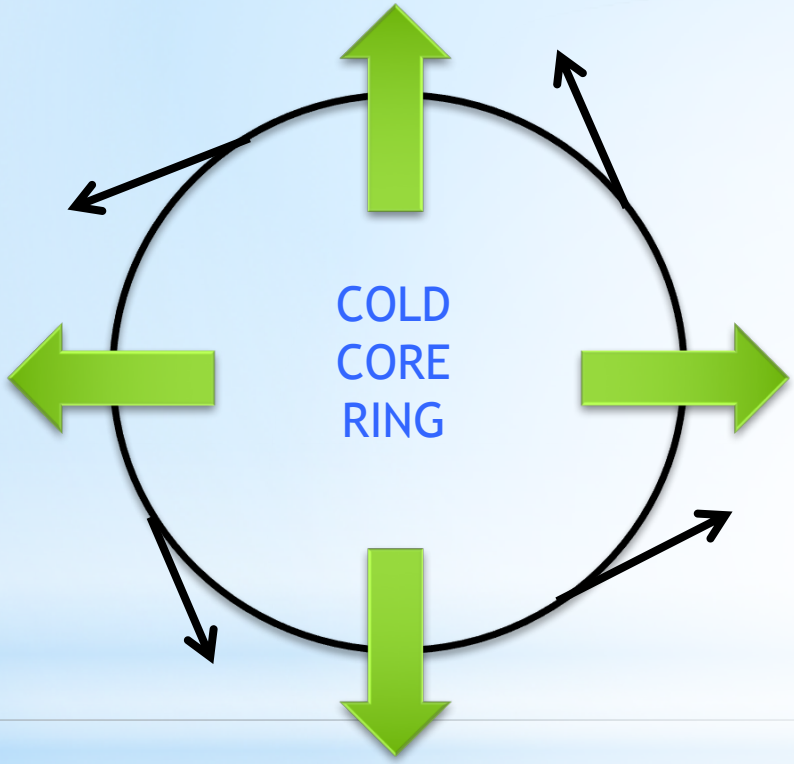


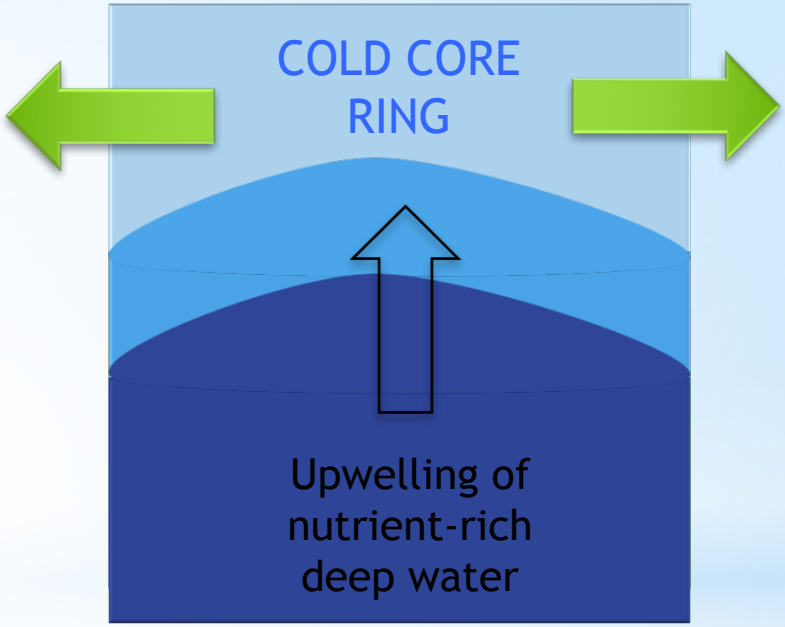
- Currents lack well-defined edges, so have friction with adjacent boundaries
- Meander as they flow
- Sometimes get rings (warm and cold core) pinched off
- Warm-core eddies rotate CW (N. hemisphere)
- Cold-core eddies rotate CCW (N. hemisphere)
- Can be 1000 km in diameter, persist for years, effects may be felt to the bottom of ocean

Open-ocean vertical movement

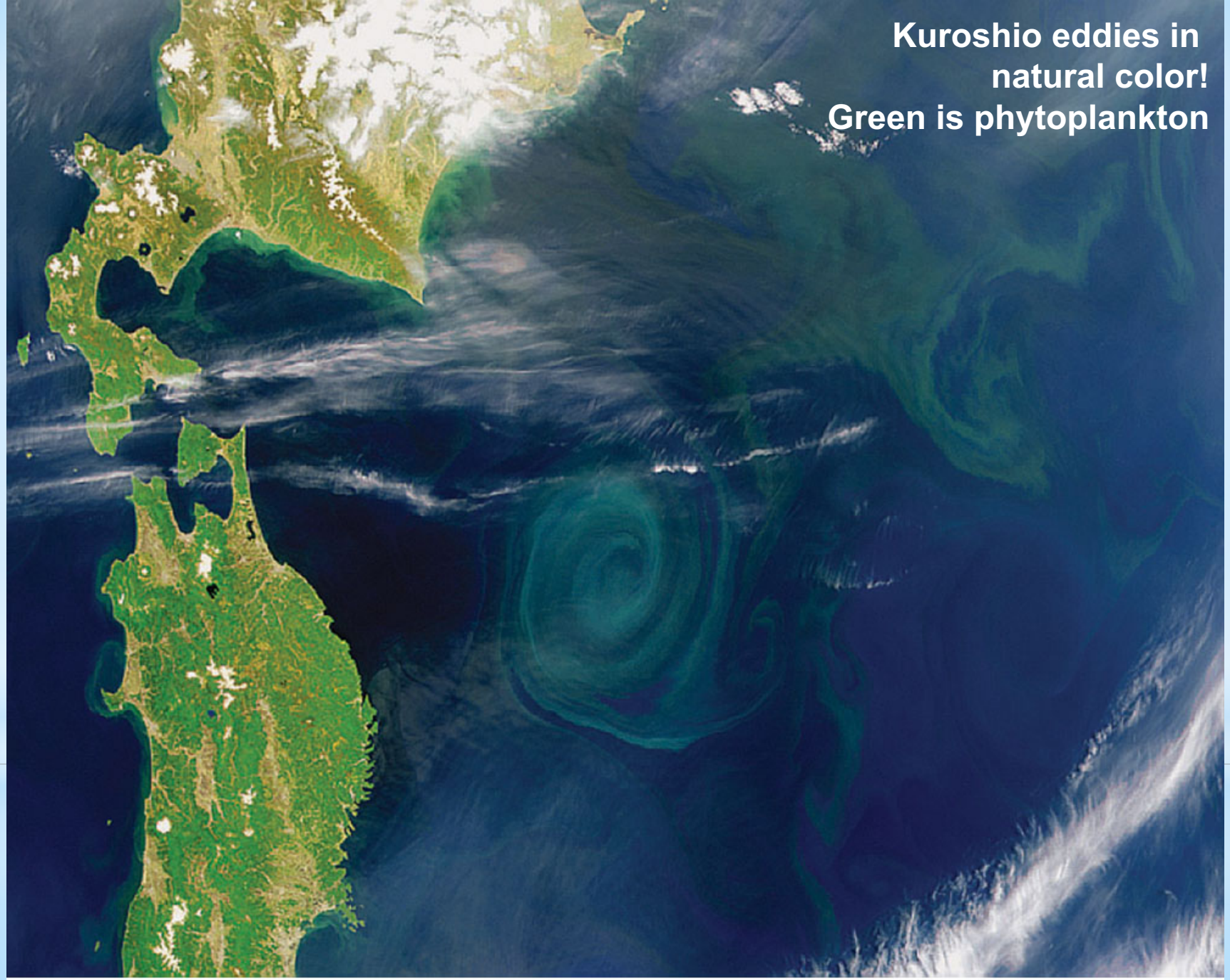
Northern Hemisphere

(Coriolis deflection to the right)



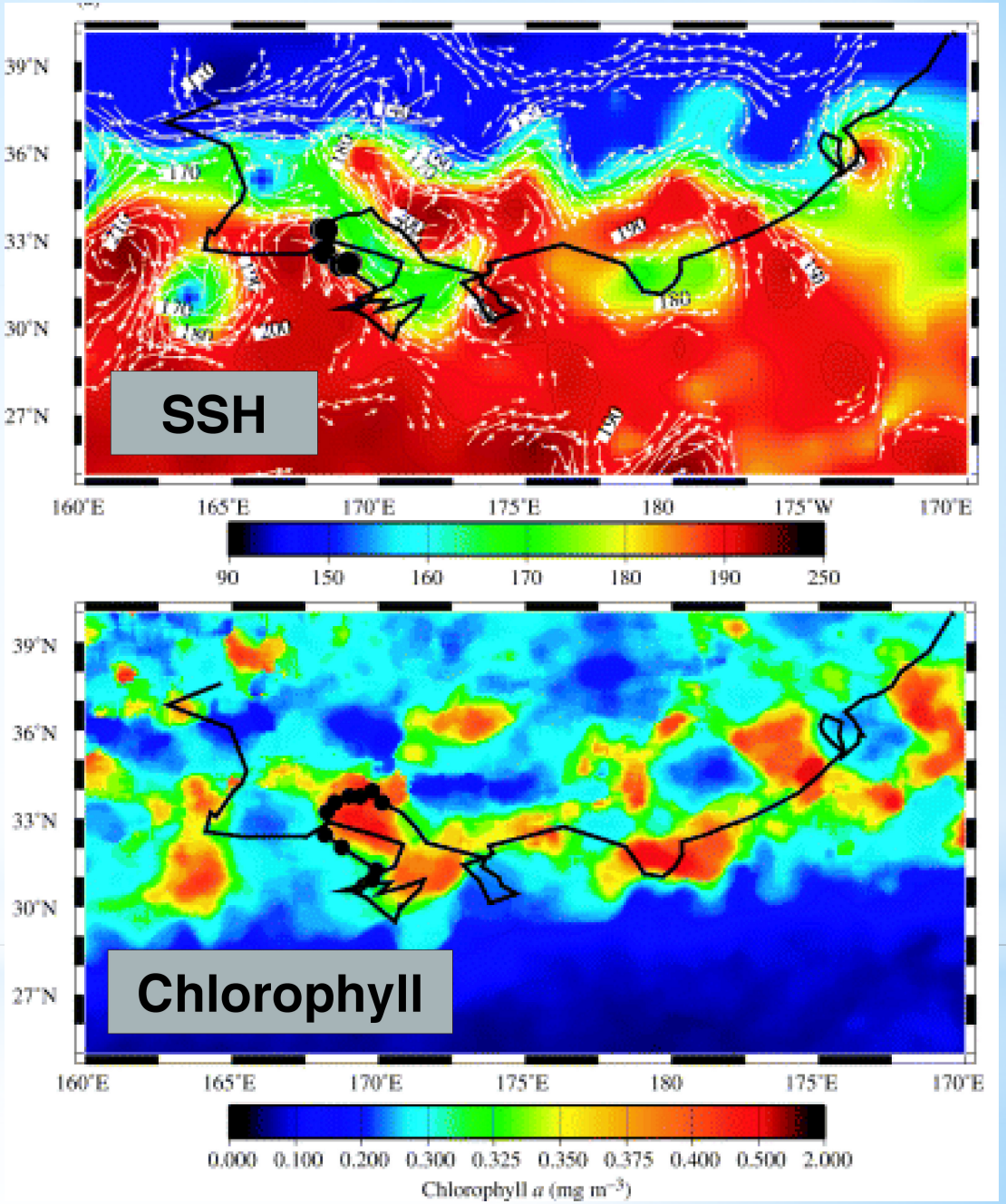


- Cold ring has low pressure upwelling in the center
- Depth of **pycnocline** decreases
- Nutrient-rich waters closer to (well-lit) surface
- Primary production increases!!



Loggerhead turtle track (solid line) overlain on satellite maps of sea surface height (SSH) and surface Chlorophyll a content

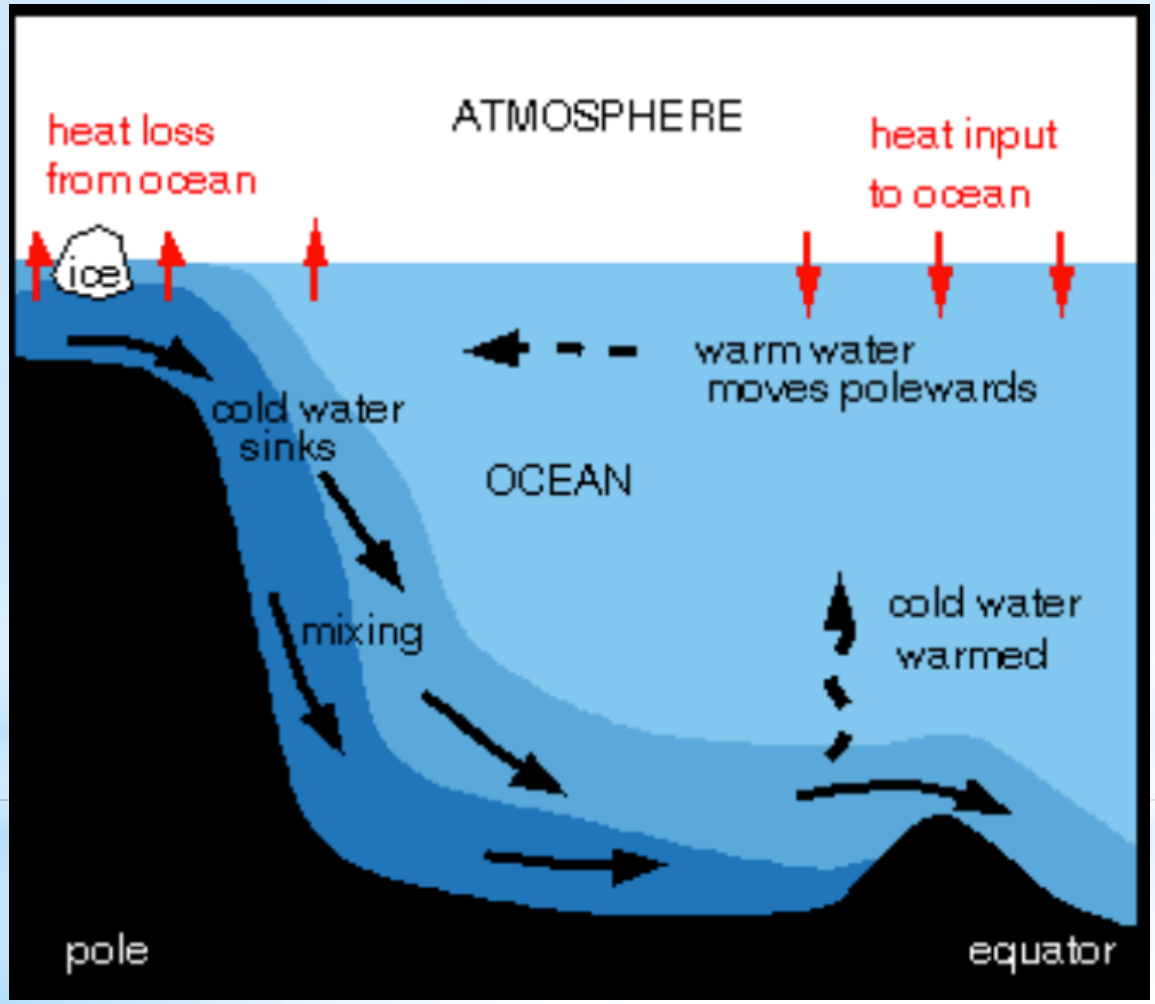
- ✧ Note relationship between SSH and primary production
- ✧ Why are the turtles going to these high Chl a areas?



Polovina *et al.* (2000), Fisheries Oceanography, 9, 71-82.

What happens to Gulf Stream heat?

Polar sinking

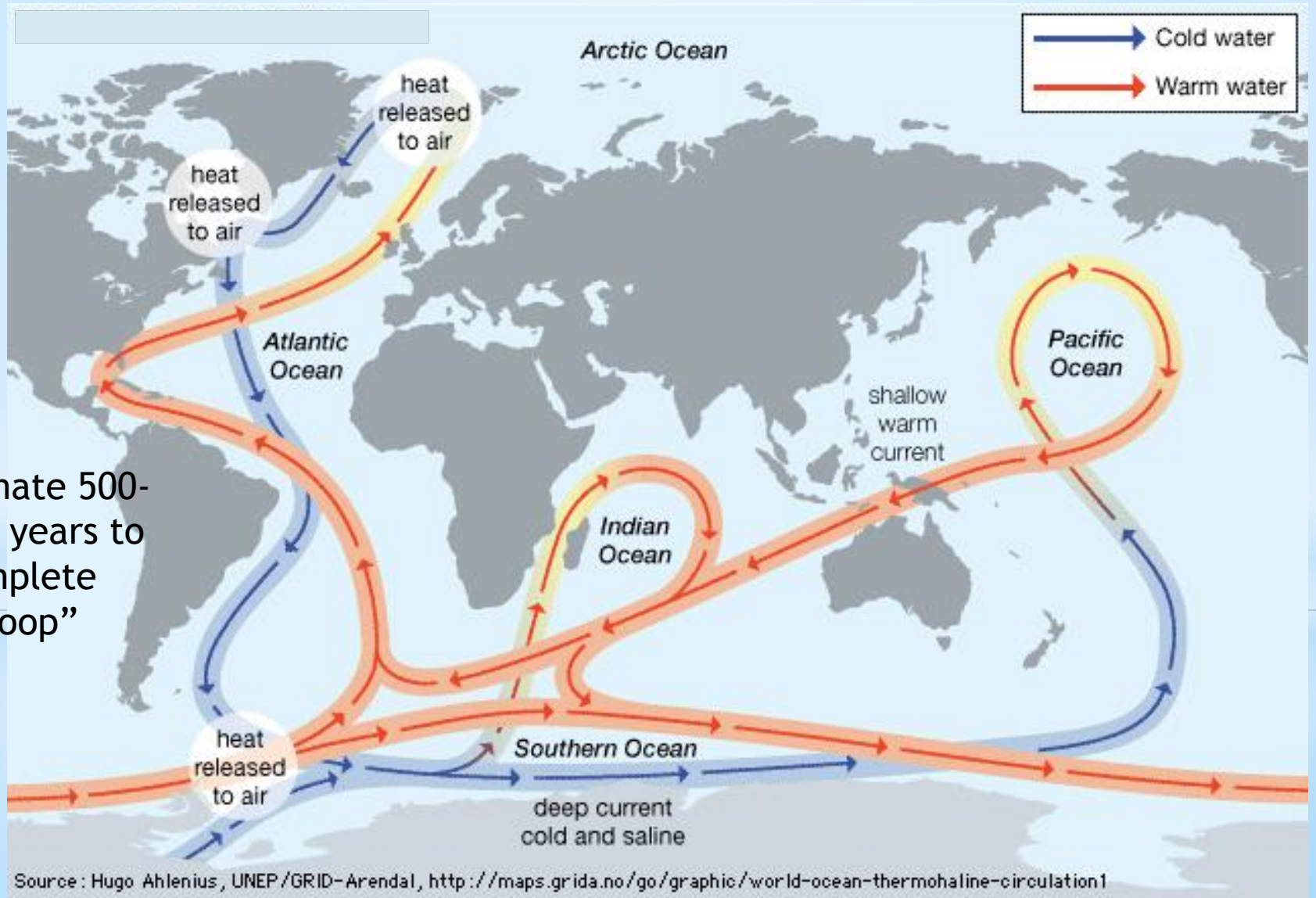


- Surface waters cool dramatically at the poles
- As ice forms, salt is pushed out, makes surrounding water saltier
- Colder, saltier water = **DENSE** = SINKS
- Feeds into deepwater circulation

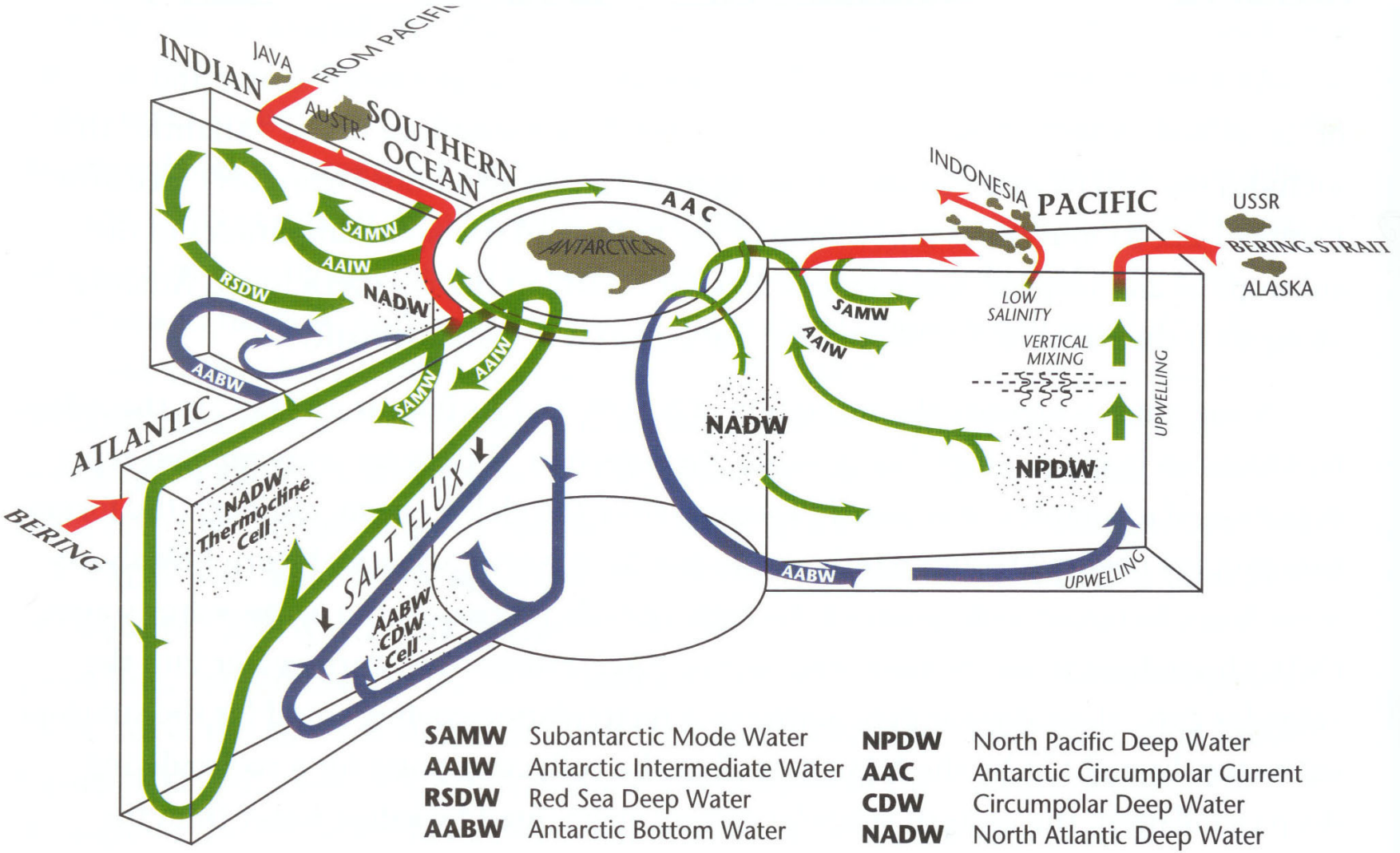
*Thermohaline circulation (THC)

thermo = heat **haline** = salt

with wind-driven surface currents



Estimate 500-1000 years to "complete the loop"



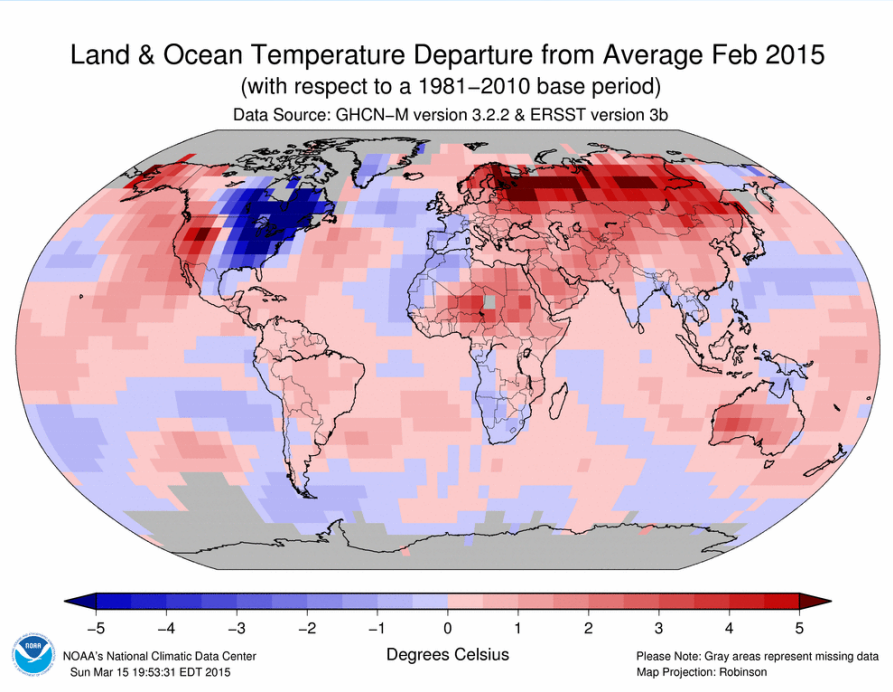
SAMW	Subantarctic Mode Water	**NPDW**	North Pacific Deep Water
AAIW	Antarctic Intermediate Water	**AAC**	Antarctic Circumpolar Current
RSDW	Red Sea Deep Water	**CDW**	Circumpolar Deep Water
AABW	Antarctic Bottom Water	**NADW**	North Atlantic Deep Water

Importance of deep circulation

- Nutrients and oxygen are not evenly distributed throughout the oceans
- Wind mixing penetrates relatively shallow
- Without THC deep ocean would be anoxic, ocean could not act as a CO_2 sink, nutrients would not be as readily returned to surface
- Circulation patterns have changed or stopped over geological time… imagine the consequences

Climate Indices

- Our attempt to characterize the patterns of a geophysical system (e.g., a circulation pattern) based on **standard departure from the mean**



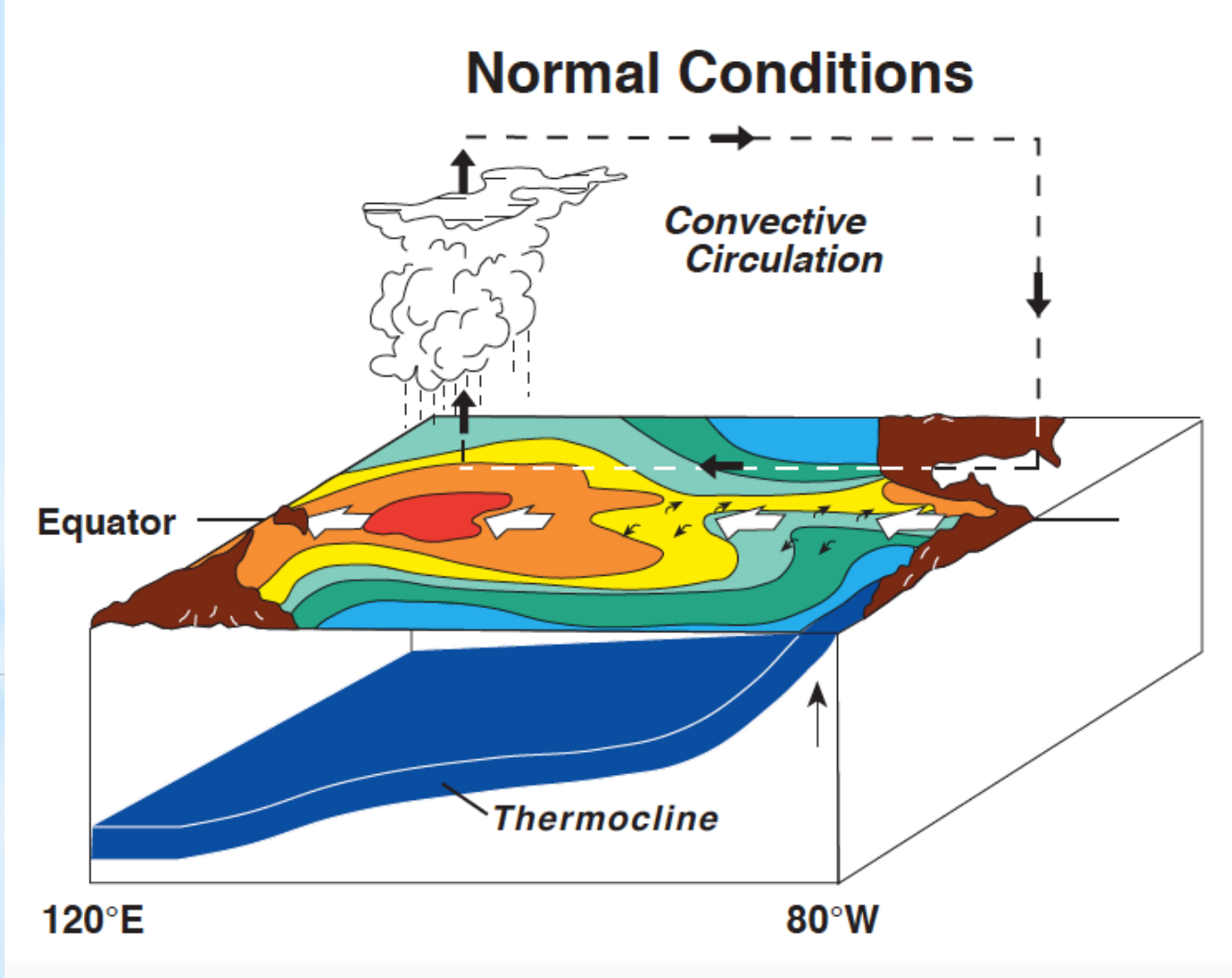
The ever-varying patchwork caused by heating contrasts between poles/equator, land/sea, seasons, etc.

Indices or Oscillations can be characterized based on any number of variables, including:

- ✧ Sea level pressure
- ✧ Sea surface temperature
- ✧ Precipitation
- ✧ Wind speed

El-Niño Southern Oscillation (ENSO)

- What is it, and how does it fit into what we've learned?

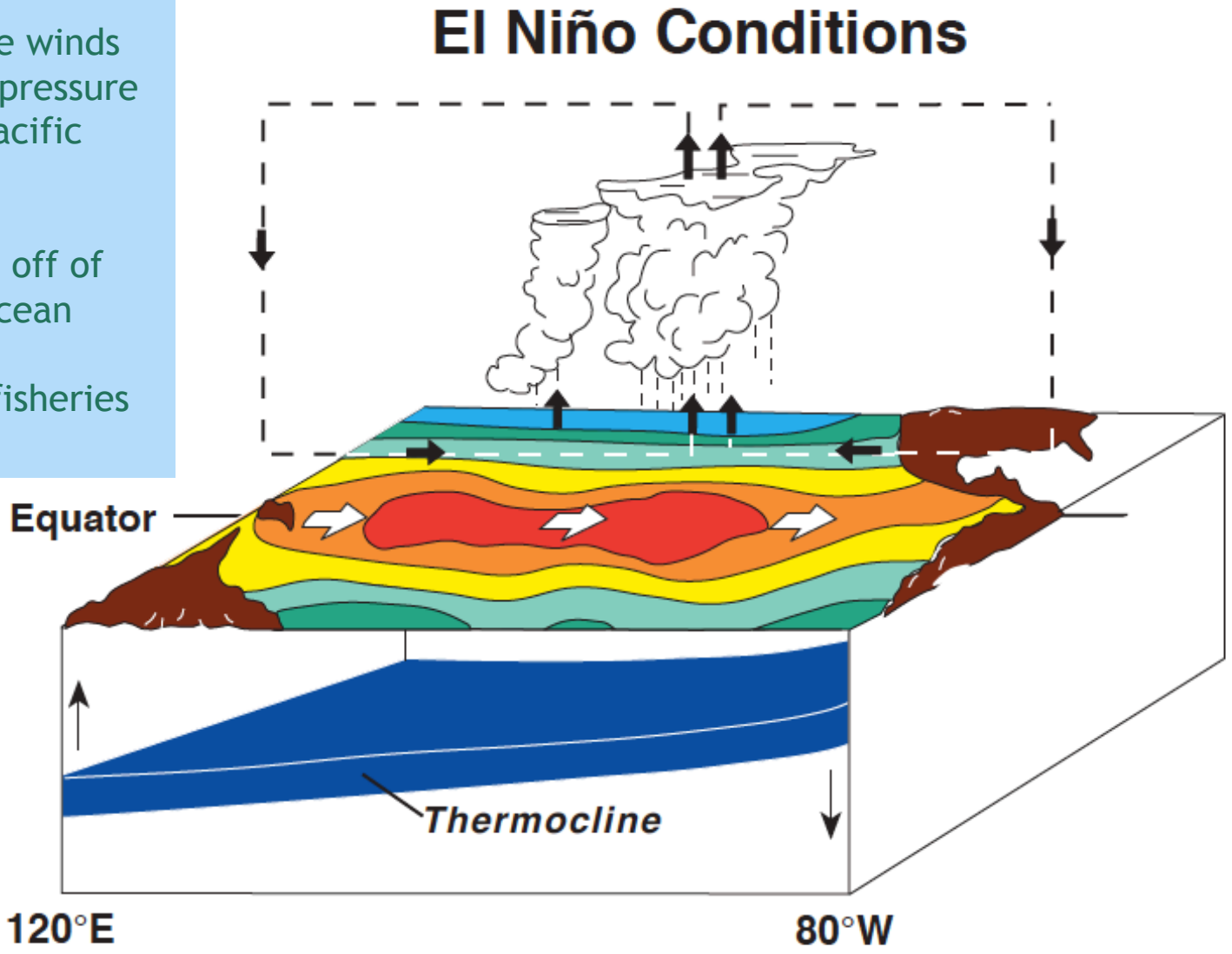


NOAA

El-Niño Southern Oscillation (ENSO)

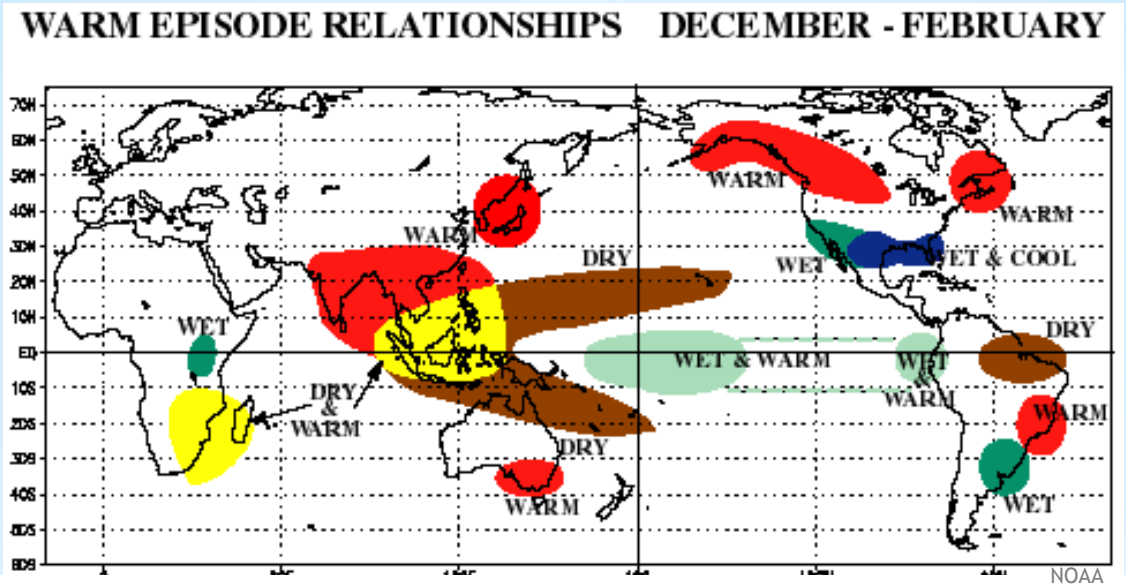
Symptoms:
- Weakened trade winds
- Rise in surface pressure over western Pacific

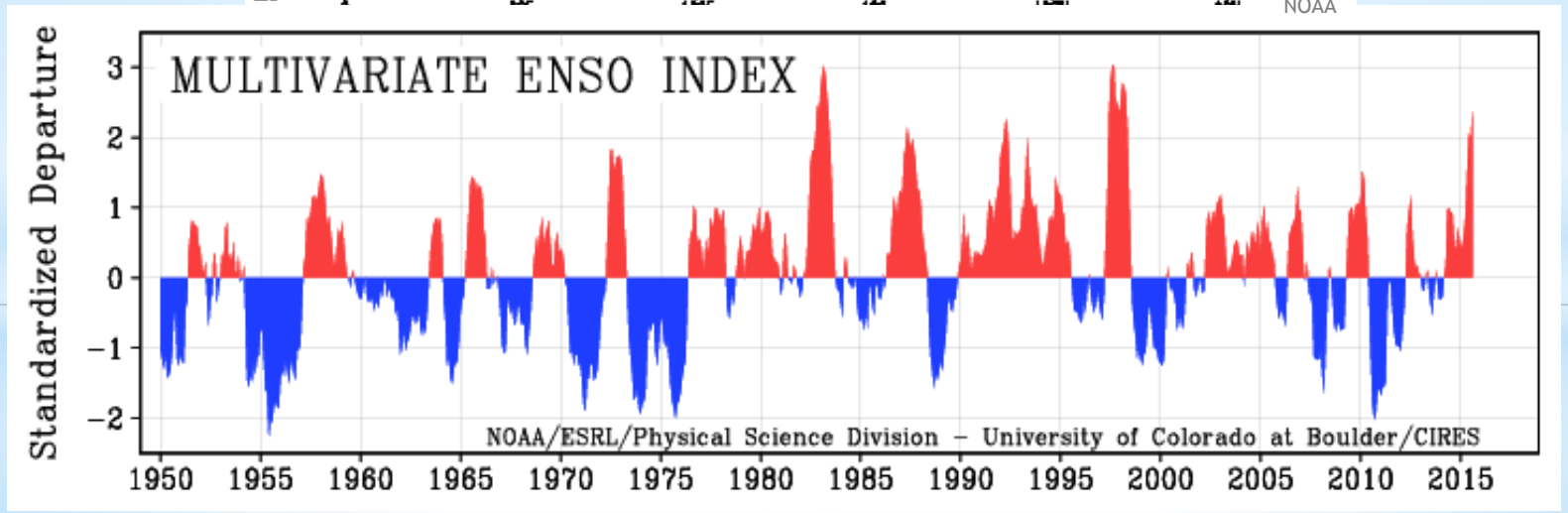
Consequences:
- Ocean warming off of Peru, bad for ocean productivity
- Collapse of SA fisheries
- Flooding in SA



NOAA

El-Niño Southern Oscillation (ENSO)

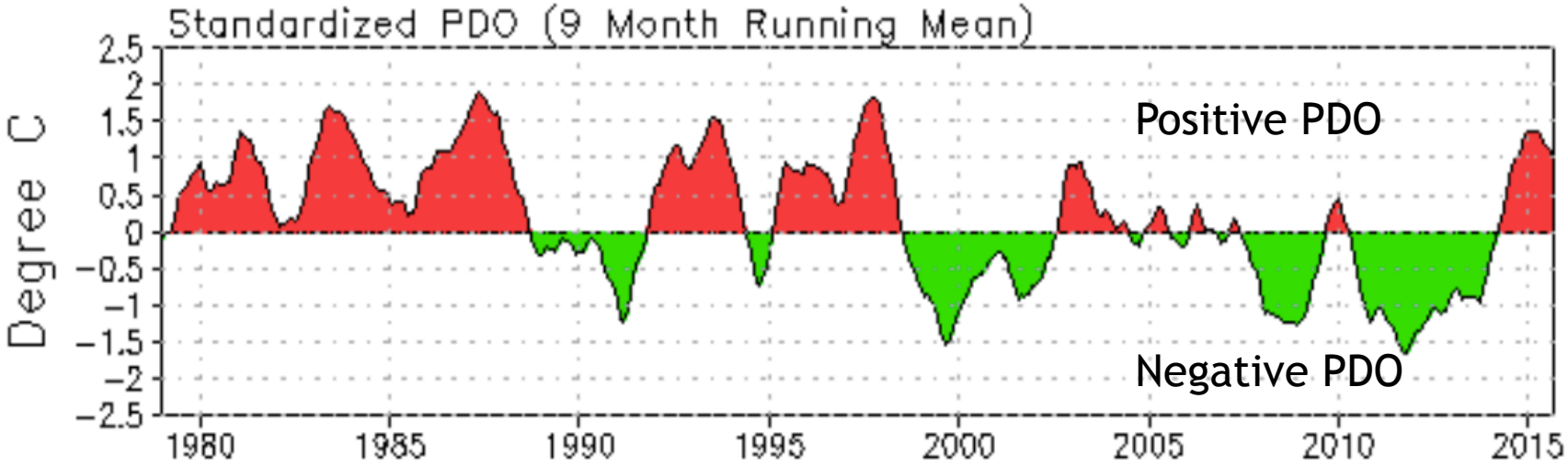




Time scale: irregular, 2-7 years

Pacific Decadal Oscillation (PDO)

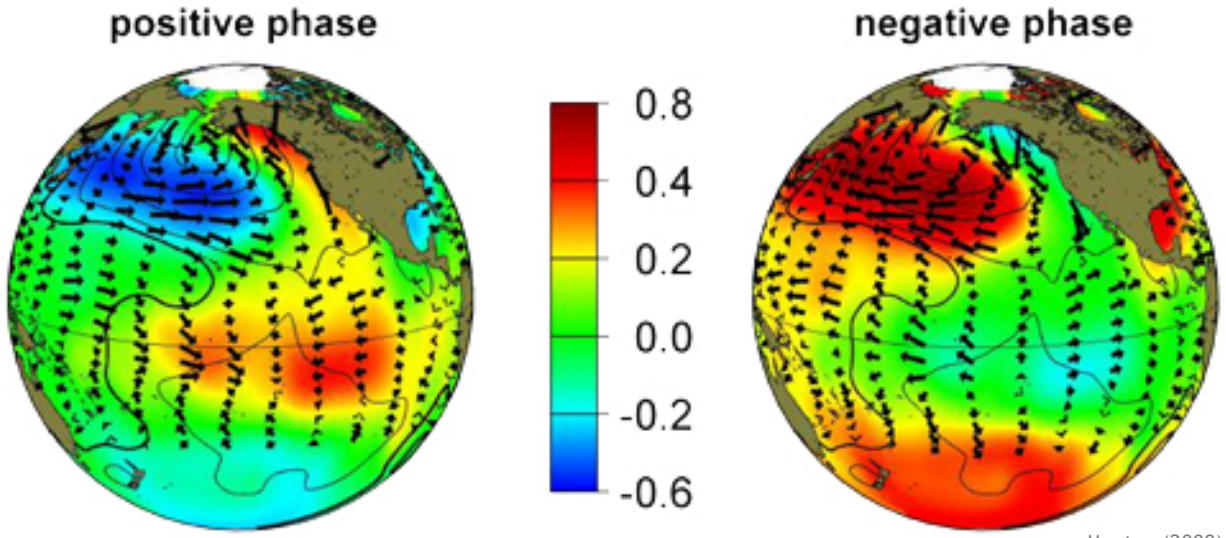
Time scale: irregular, 40-60 years



NOAA

Effects on us in the Pacific NW:

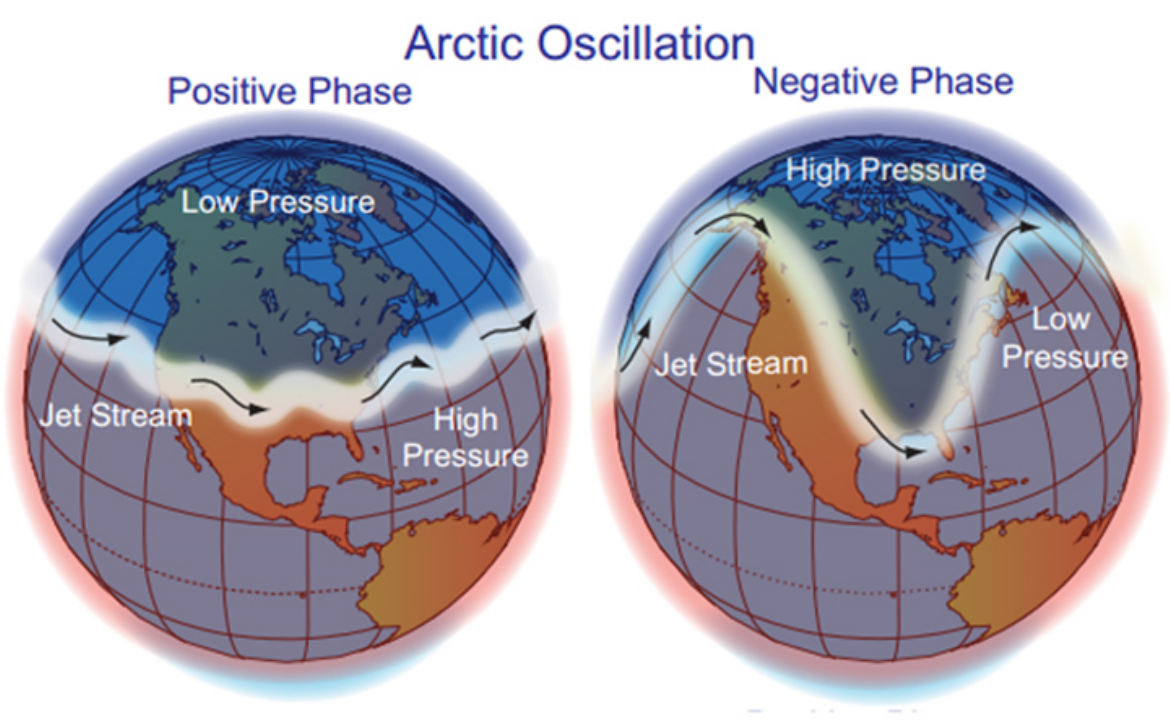
+ phase =
  drier, hotter
- phase =
  wetter, cooler



Mantua (2000)

Arctic Oscillation (AO)

Time scale: no particular periodicity



- Low pressure at high latitudes
- Very cold air confined north
- Warmer middle latitudes

- Pressure systems weaker
- Very cold air spills into mid latitudes
- Warm air can move northward (to us!)

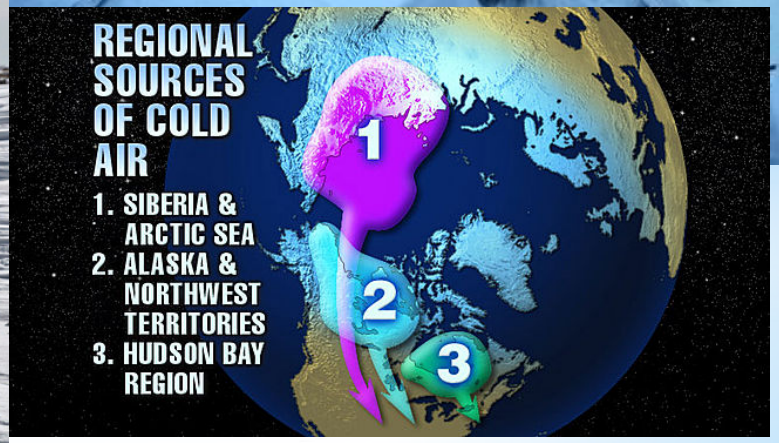
* Negative AO =

POLAR VORTEX/SNOWPOCALYPSE

- Historic snowstorms/cold temps all over eastern U.S. in 2014 & 2015
- Negative AO has persisted since 2014, just recently equilibrated

Lea Green

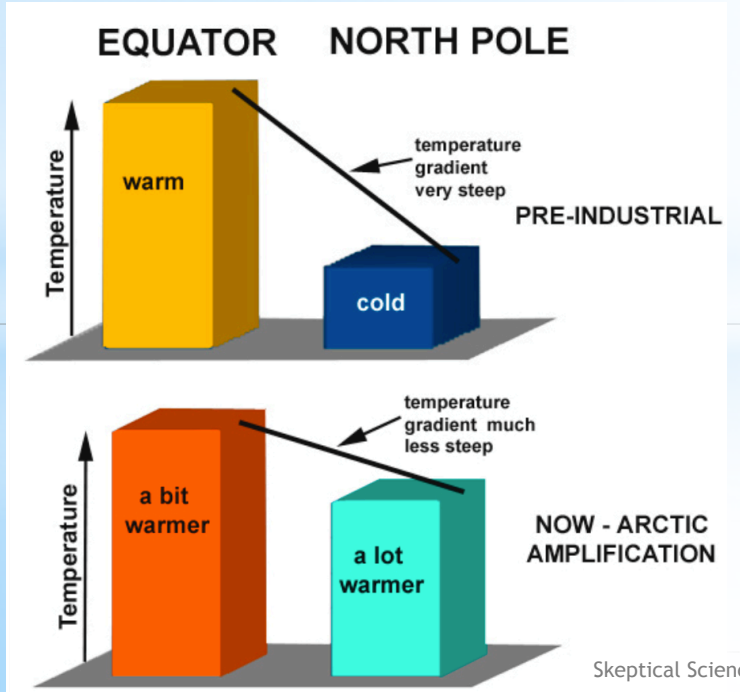
John Mason



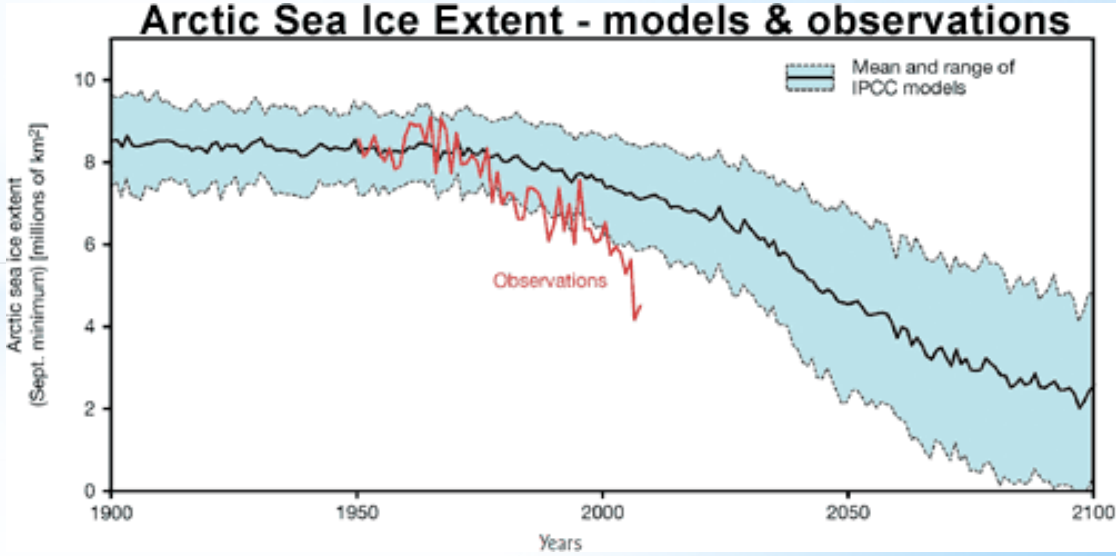
Pendleton Gazette

Arctic Amplification

- Arctic is experiencing disproportionate effects of climate change
- Results in weakening of pressure gradient/temperature gradient between higher latitudes and lower latitudes
- Jet Stream strength relies on that gradient
- Weakened jet stream = similar to negative AO conditions
- Loss of Arctic sea ice compounds the problem
  - ✧ Loss of **albedo** = reflectivity of surface
  - ✧ Less albedo = more absorption = faster melting



Skeptical Science



Wunderground

MOTION OF THE OCEAN: GLOBAL

See you next week – Sept 21st

Next module will be posted by this Tues evening

Wikimedia commons