# The Ocean as the Main Climate Influence

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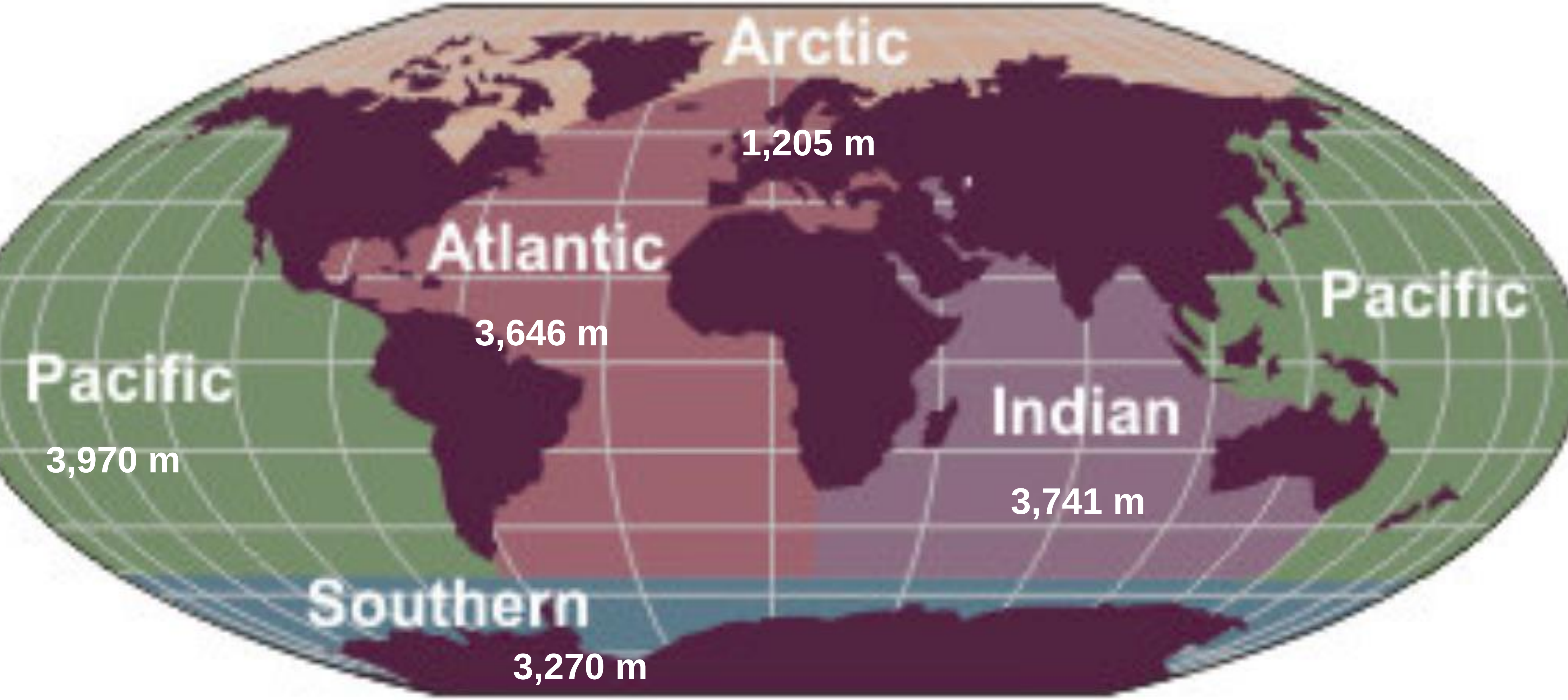
Cruces Atmospheric Science Forum Presentation

# Basis -A NOAA Tutorial
# An Introduction

- https://www.weather.gov/jetstream  on the right click The Ocean
- nearly 71% of the earth’s surface is covered by ocean
- between 96.5 and 97% of all the earth’s water is found in the ocean
- the remainder is in lakes, rivers, icecaps, glaciers, soil, and the atmosphere
- 93.7% of all CO2 is found in the oceans and other water reservoirs while the remainder (6.3%) is found mostly in terrestrial plant material
- annual human emissions of CO2 is about 0.096% of the total
- and remember Henry’s Law when considering the ocean as a source and sink of CO2




*The World's major oceans.*

*Average Depths*

The sizes of the major oceans.

| Ocean | Surface Area (miles$^2$) | Surface Area (kilometers$^2$) | Of all oceans |
|---|---|---|---|
| Pacific | 64,000,000 | 166,000,000 | 45.0% |
| Atlantic | 31,600,000 | 82,000,000 | 22.2% |
| Indian | 28,400,000 | 73,600,000 | 20.0% |
| Southern | 13,523,000 | 35,000,000 | 9.5% |
| Arctic | 4,700,000 | 12,173,000 | 3.3% |

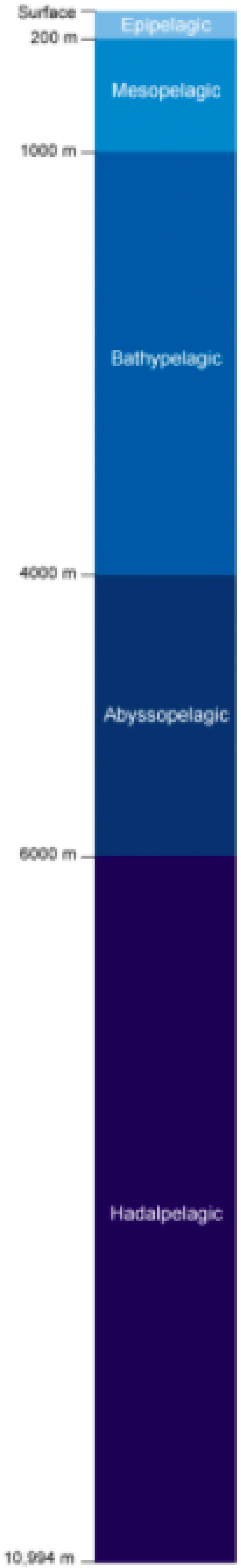
# Some More Ocean Facts

- Consider the large fraction that oceans of the earth assume in area and depth when considering their influence on the weather and climate

- half of the world's people (about 3.85 billion) live within 60 miles (100 kilometers) of the ocean

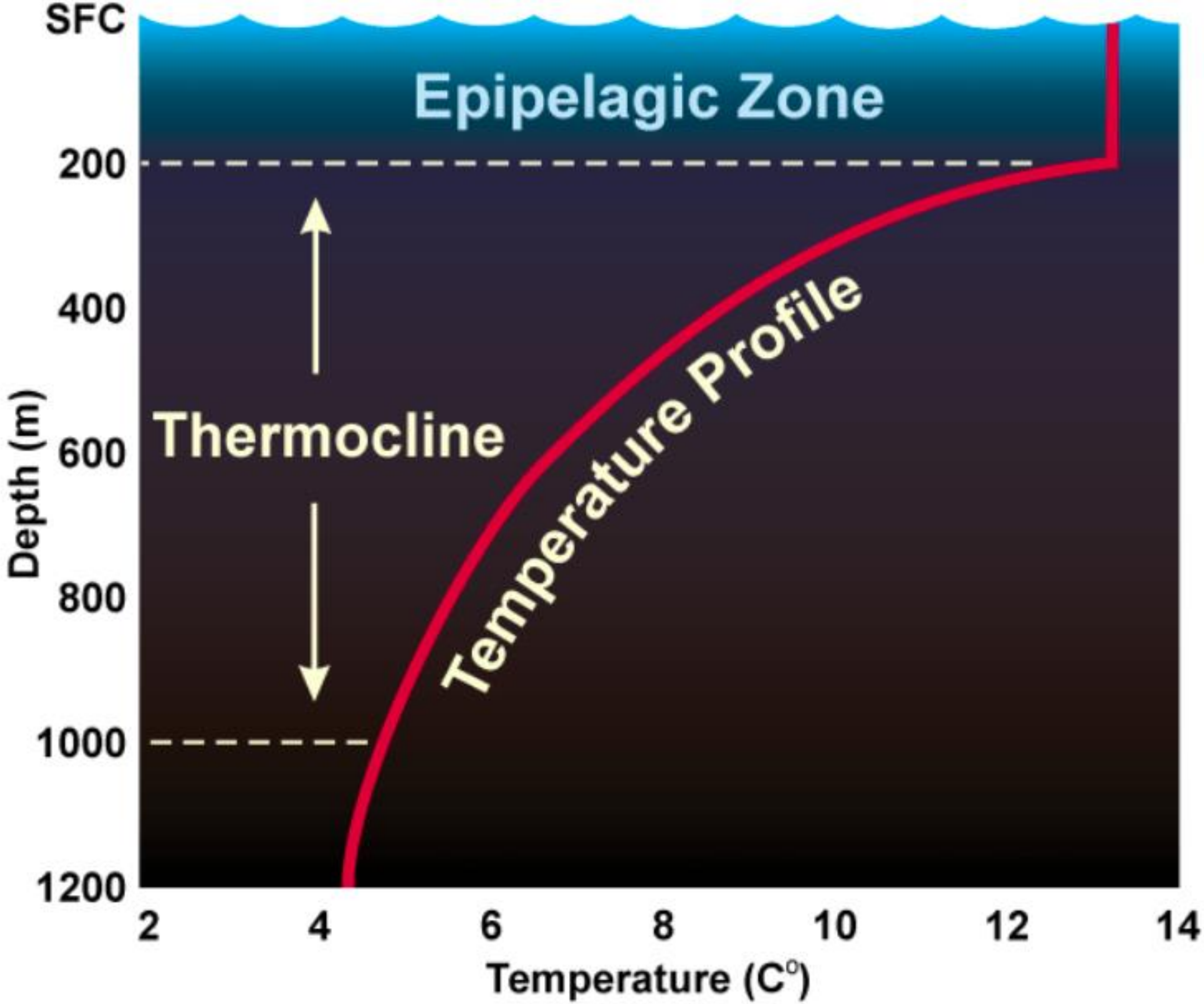
- heat storage capacity of the ocean is huge

- the top 10 feet of the ocean stores more heat than the whole of the atmosphere does




# Layers of the Ocean

- **Epipelagic Zone** is also called the sunlight zone and extends to 660 feet in depth. Most sun heating is confined to this zone and temperatures range from $97^{o}$ F to $28^{o}$ F. Wind interaction produces a mixing layer here.
- **Mesopelagic Zone** drops to 1000 feet in depth. This midwater zone is also known as the **twilight zone.** This zone contains the **thermocline** and delta temperature is the greatest here. Bioluminescence begins to appear on life forms here and large upward looking eyes are found on most fish.
- **Bathypelagic Zone** reaches down to 4000 feet. It is in constant dark and is called the **midnight zone.** Temperature is a constant $39^{o}$ F and pressure reaches over 5850 psi.
- **Abyssopelagic Zone** goes to a depth of 6000 feet. 75% of the deep ocean floor is found in this zone. Water temperature is near freezing.
- **Hadalpelagic Zone** extends to the very depth of the Mariana trench (10,994 m) and the pressure there is 8 tons psi.



SFC
Epipelagic Zone
200
400
600
800
1000
1200
Depth (m)
Thermocline
Temperature Profile
2
4
6
8
10
12
14
Temperature (C°)

# Sea Water

- We all know that sea water is salty - details to follow
- The Atlantic is the most salty of the large ocean basins
- Thermohaline effects support some unique ocean circulation patterns
- On average, there is a distinct decrease of salinity near the equator and at both poles, although for different reasons
- There are some patterns of salinity caused by a variety of reasons

# Air - Sea Interface

- This interface is one of the most physically and chemically active of the Earth's environments
- The atmosphere gains much of its heat at the interface in tropical latitudes by back radiation from the heated ocean
- In higher latitudes the atmosphere heats the ocean surface
- Atmospheric motion at the interface generates waves and currents

# More Interface Activity

- The atmosphere acquires most of its moisture and additional energy in the form of latent heat from the evaporation of water at the interface

- Enormous quantities of oxygen and $CO_2$ are exchanged between the atmosphere and the ocean at the interface which benefits marine life

- Climate effects at the interface are discussed elsewhere and involves saltiness and temperature and their impact on ocean currents

# Salinity

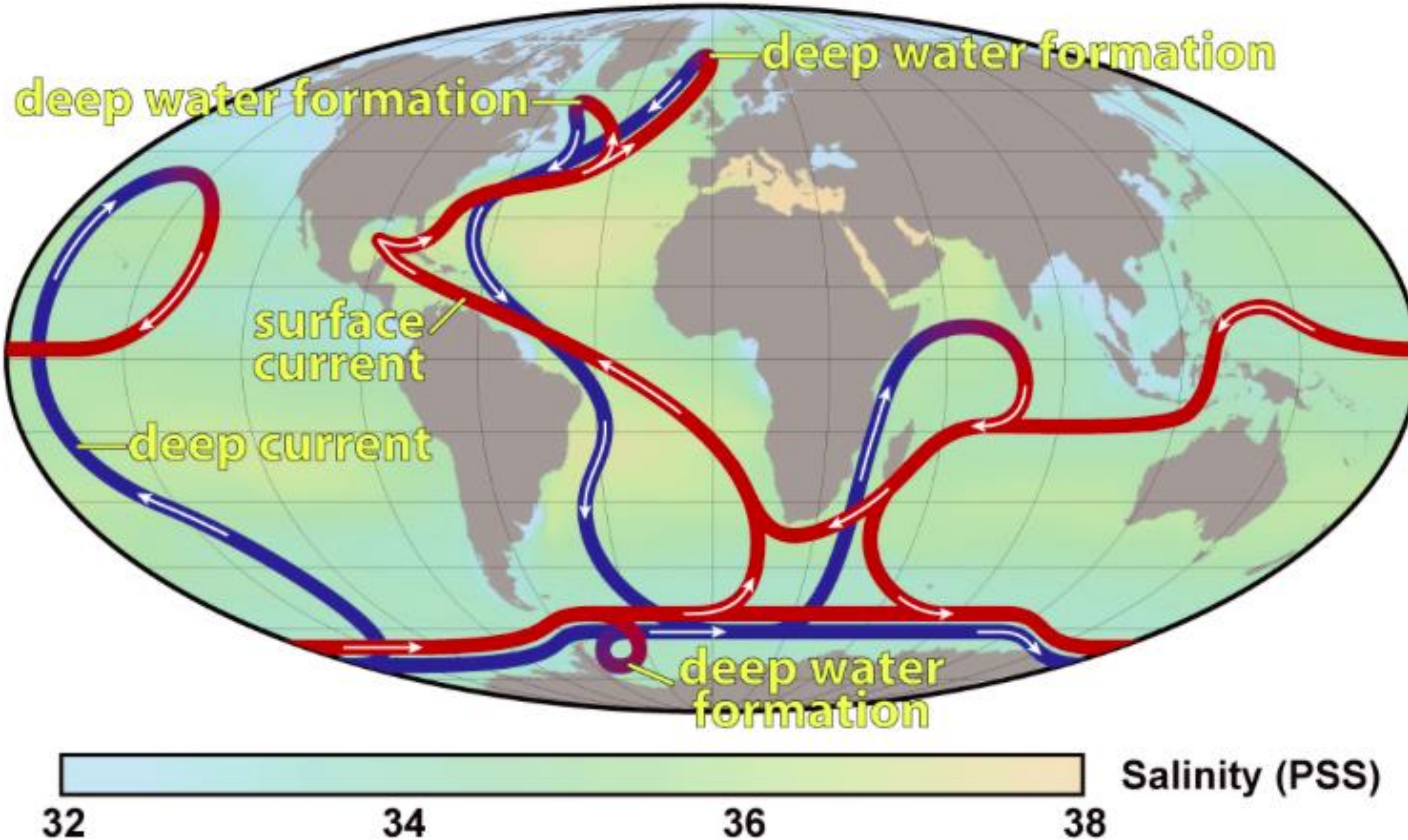
- Near the equator, the tropics receive the most rain on a consistent basis
- The fresh water falling into the ocean helps decrease the salinity of the surface water in that region
- As one moves toward the poles, the region of rain decreases and with less rain and more sunshine, evaporation increases
- Fresh water, in the form of water vapor, moves from the ocean to the atmosphere through evaporation causing the highest salinity

# Practical Salinity Units (psu)

- Ocean average psu ≈ 35 psu
- River mouth ≈ 15 psu  Dead Sea ≈ 40 psu
- Chloride 19 grams     Sodium 11 grams
  Sulfate  3 grams     Magnesium 1.5 grams
  Calcium .35 grams     Potassium .35 grams

Per kg of water = total of 35.2 grams/kg

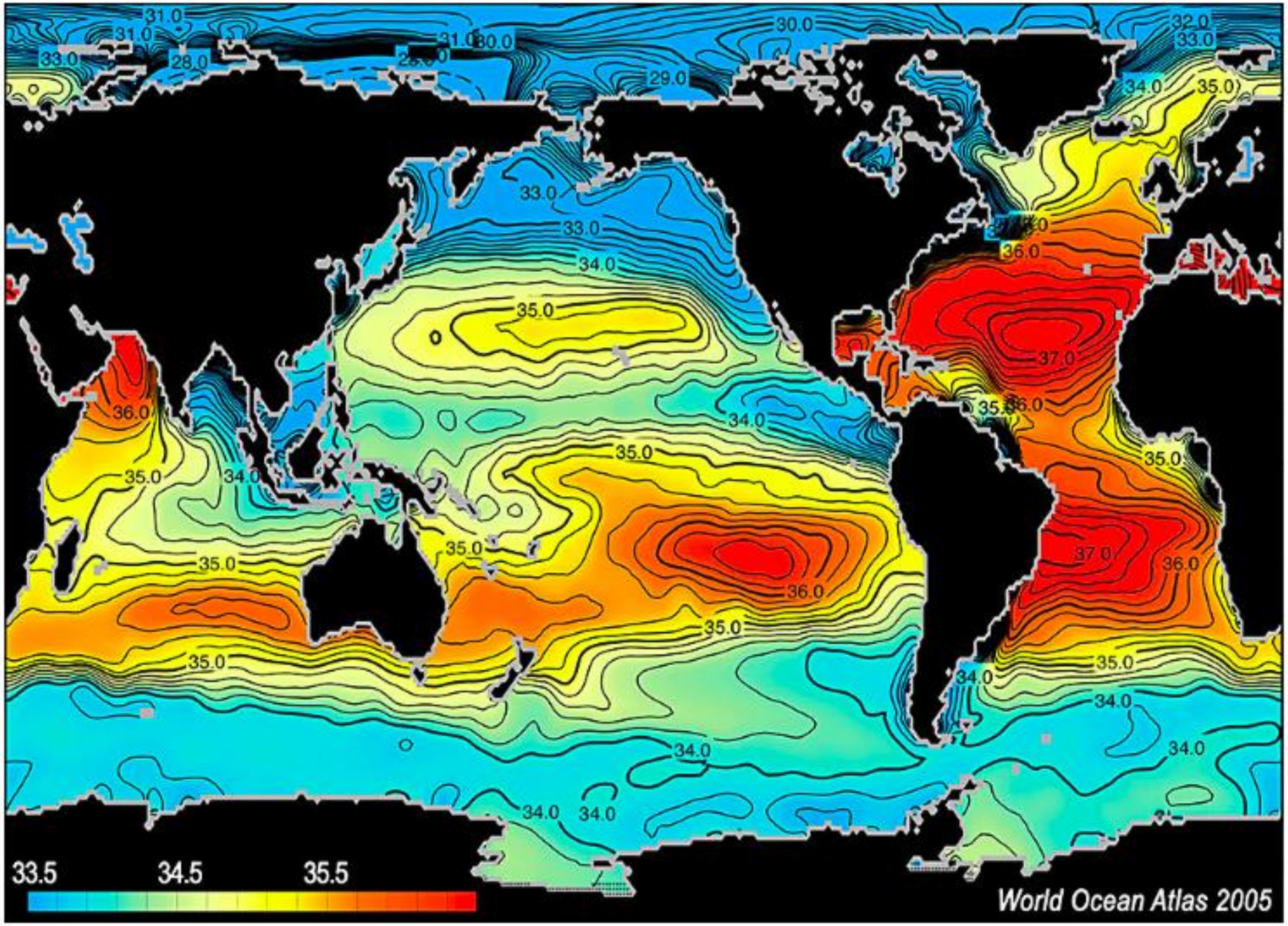
# Thermohaline Circulation



# More on Salinity

- Toward the poles, fresh water from melting ice decreases the surface salinity once again
- The saltiest locations in the ocean are the regions where evaporation is highest or in large bodies of water where there is no outlet into the ocean
- The saltiest ocean water is in the Red Sea and in the Persian Gulf region (around 40 psu) due to very high evaporation and little fresh water inflow
- The next graphic shows ocean surface salinity
- subsurface salinity will be discussed later
- the previous thermohaline current graphic is a preview

## Average ocean salinity




A map of the surface salinity of the ocean averaged from historical ship and buoy observations through 2005, with lowest values colored blue (32‰) and the highest colored red (37‰). NASA image.

# Sea Water Temperature

- Salt levels in sea water determines the temperature at which sea water freezes and that temperature is lower than the point when fresh water freezes (32$^{o}$F)

- Water with a PSU of 17 freezes at 30$^{o}$F while water with a PSU of 35 freezes at 28.5$^{o}$F

- Despite the saltiness of sea water, sea ice does not contain much salt (0.1 as much as sea water or 3.5 PSU) since ice will not incorporate salt into the ice crystalline structure

- Sea ice is “drinkable”

# Ocean Surface Temperature Effects

- A huge Pacific ocean surface warm pool can pile up in the west due to wind patterns but when those patterns shift (or more commonly when the wind dies out) the whole warm surface pool can rapidly move east toward the north and south American continent in what is known as an El Nino event

- These regular shorter cyclical ENSO* patterns can be seen in a larger 60 year cycle called the PDO* index

# Ocean Surface Temp Effects (Cont)

- The PDO is generally a sine wave temperature pattern with a cool (about 30 years) and warm cycle (about 30 years) and affects climate in the US as well as the world
- The north Atlantic surface also has an ocean pool that warms and cools in a pattern called the AMO* also about 60 years long
- There are obvious affects that these warm and cool cycles have on agriculture and weather conditions over the nearby continents

* ENSO El Nino Southern Oscillation  PDO Pacific Decadal Oscillation  AMO Atlantic multi-Decadal Oscillation

# Regional Effects Sea Surface Temperature

- Changes in sea surface temperature (SST) such as surface warming affects strengthen the force of hurricanes and typhoons

- A preponderance of El Ninos will produce rain and floods while a preponderance of La Ninas will produce drought (as seen in the PDO index)

- Warm AMO (30 year half a cycle) conditions affect NM temperatures tending to give us warmer temperatures and during the cool 30 year part of the AMO cycle we will seen cooler temperatures here

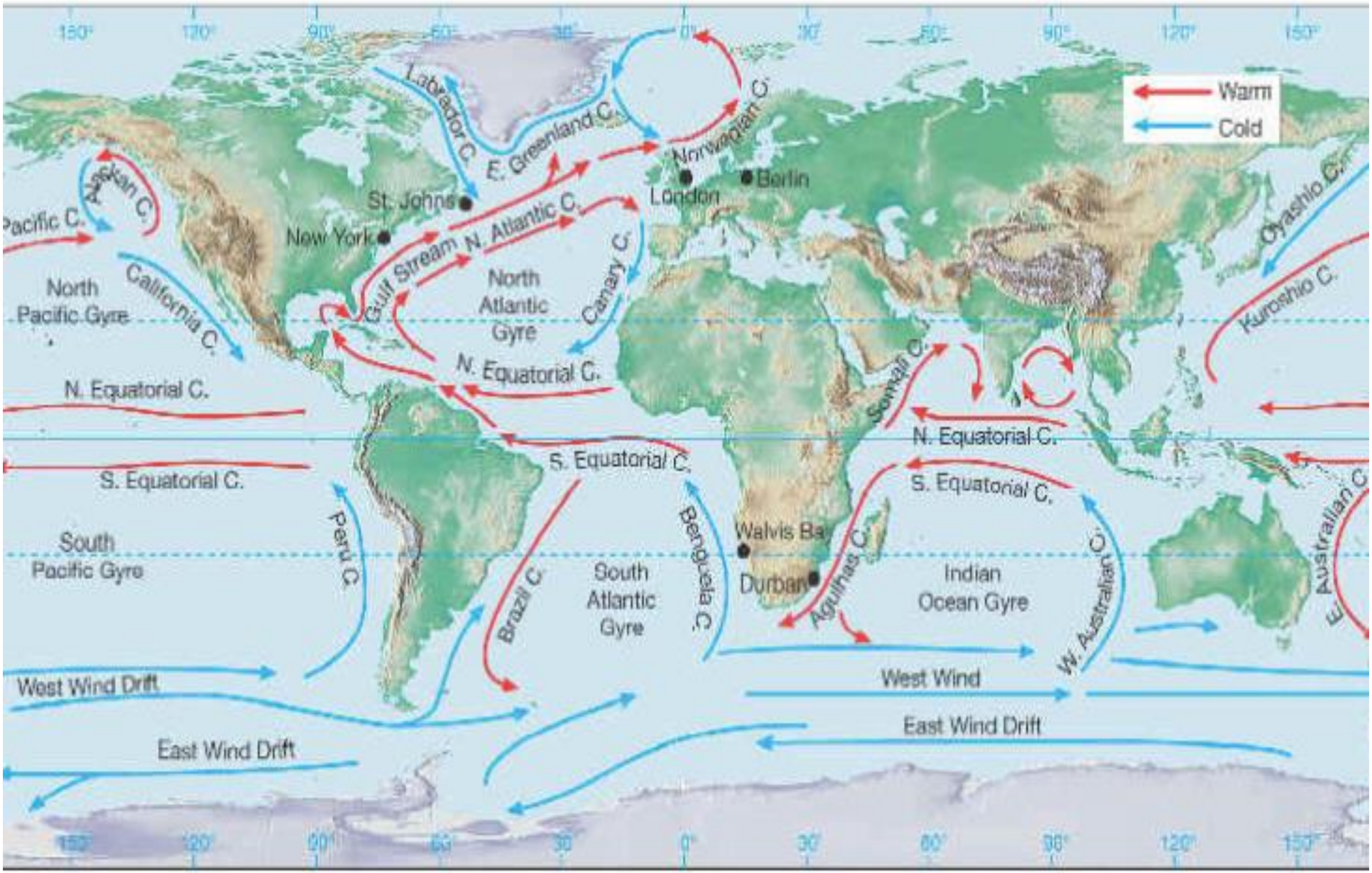
# Sea Water Density

- Fresh water has a unique property that when it cools below 40ºF the molecules bond to each other and water expands decreasing its density
- At 32ºF when water begins to freeze the molecules are locked into an expanded crystalline structure
- Ice expansion of 9% lowers density and fresh water ice will float
- As the temperature of sea water decreases and the salinity of sea water increases the density of that sea water increases
- This is unlike fresh water as noted above where temperature goes below 40ºF and down to freezing, decreasing density, turns to ice and floats

# Ocean Circulations

- Winter season ice forming as noted above causes salinity of the sea water below the ice to increase in salinity and density and that water sinks
- This sinking water is the genesis of deep ocean currents which have a major role to play in general ocean circulation
- Another very major set of ocean circulation patterns is wind spawned surface circulation patterns that are complex and wide spread (see the following graphic)
- Another dramatic event was the 1992 loss at sea of a container full of rubber duckies that scattered to the winds

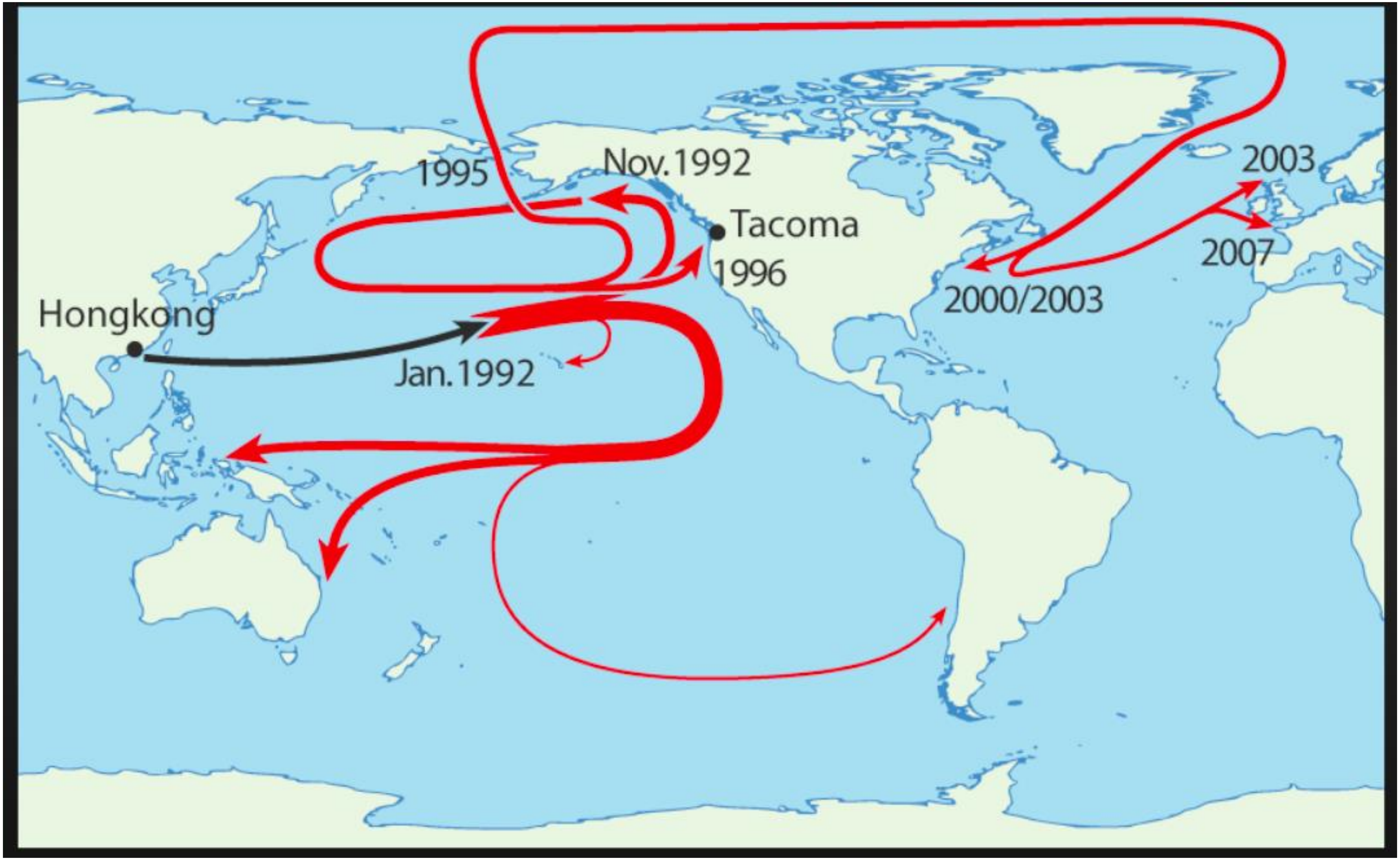
# Coriolis/Wind Driven Surface



# Where did the rubber toys go?

- In January 1992 a container ship bound for Tacoma, Washington after departing Hong Kong was near the date line in the Pacific, encountered a severe storm and lost 12 of its containers
- One of the containers was packed with 29,000 floating bathtub toys
- 10 months later these toys began to wash up on Alaskan beaches
- Over the next few years driven by wind and ocean currents they washed ashore all over the Pacific with even some were found on north Atlantic beaches

# Here here here and . . . !



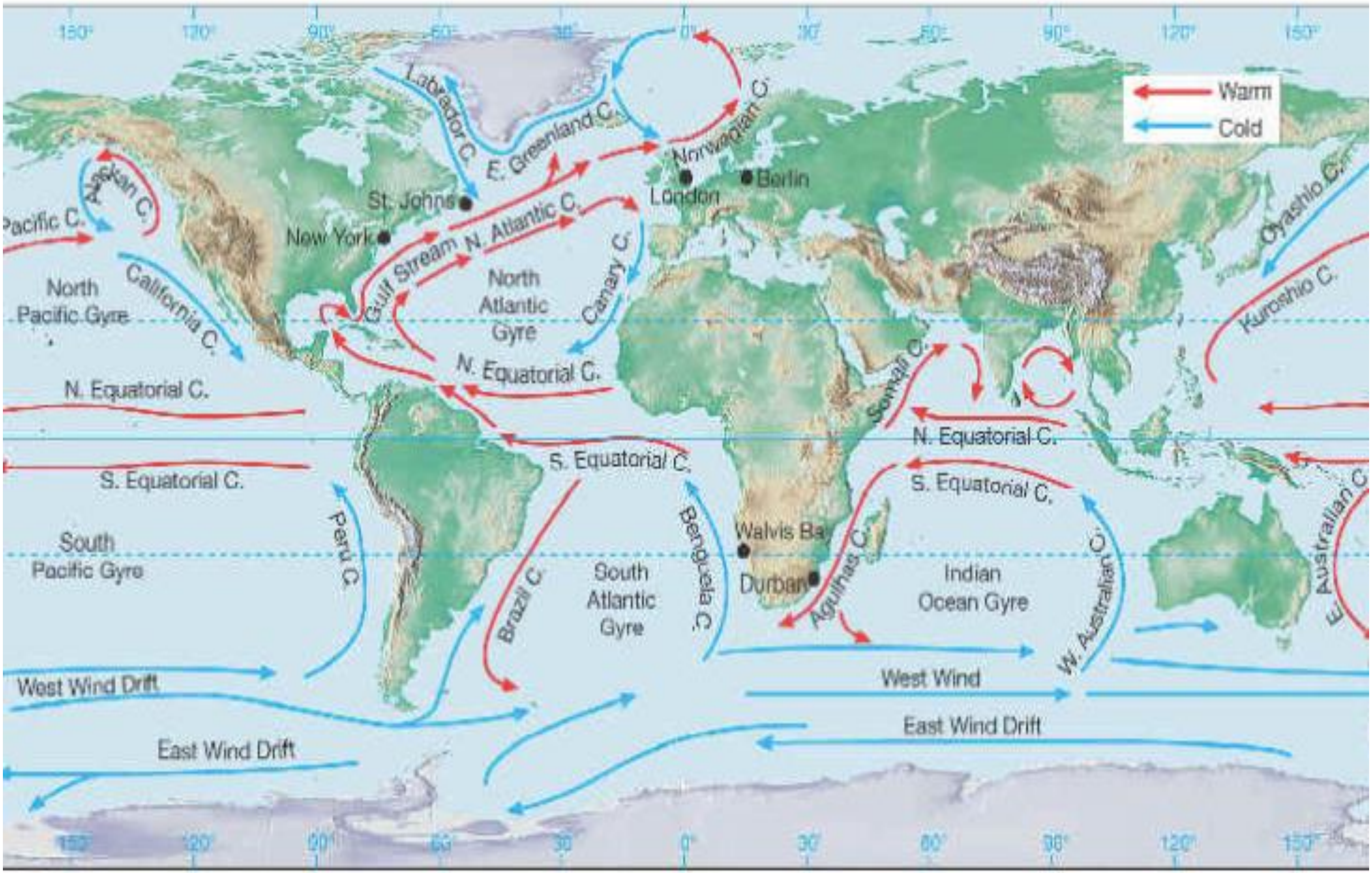
# Overview of Ocean Patterns

- Drivers of circulation – Thermohaline Conveyor Belt, surface, upper, and jetstream winds, surface, mid and deep ocean currents, convection & Tides
- Eddies, down and up welling
- Coriolis forces, geostrophic effects gyres, & Ekman spiral
- Temperature difference, thermal energy, ice formation and saline effects

# Sun - the ultimate reason for global surface ocean currents

- Heating the earth by the sun produces semi-permanent pressure centers near the surface
- When the wind blows over the ocean around these pressure centers, surface waves are generated by transferring some of the wind's energy, in the form of momentum, from the air to the water
- This constant push on the ocean is the force that forms the surface currents

# Coriolis/Wind Driven Surface



# More on Surface Currents

- Around the world, there are some similarities in the currents

- Along the west coasts of the continents, the currents flow toward the equator in both hemispheres and they are called cold currents

- They bring cool water from the polar regions into the tropical regions (the cold current off the west coast of the US is called the California Current)

- The opposite is true along the east coasts of the continents where the warm currents flow from the equator toward the poles

# The Gulf Stream, Kuroshio and the giant gyres

- The Gulf Stream is a current that flows from the equator to the north pole and is one of the strongest currents known anywhere in the world with speeds up to 3 mph

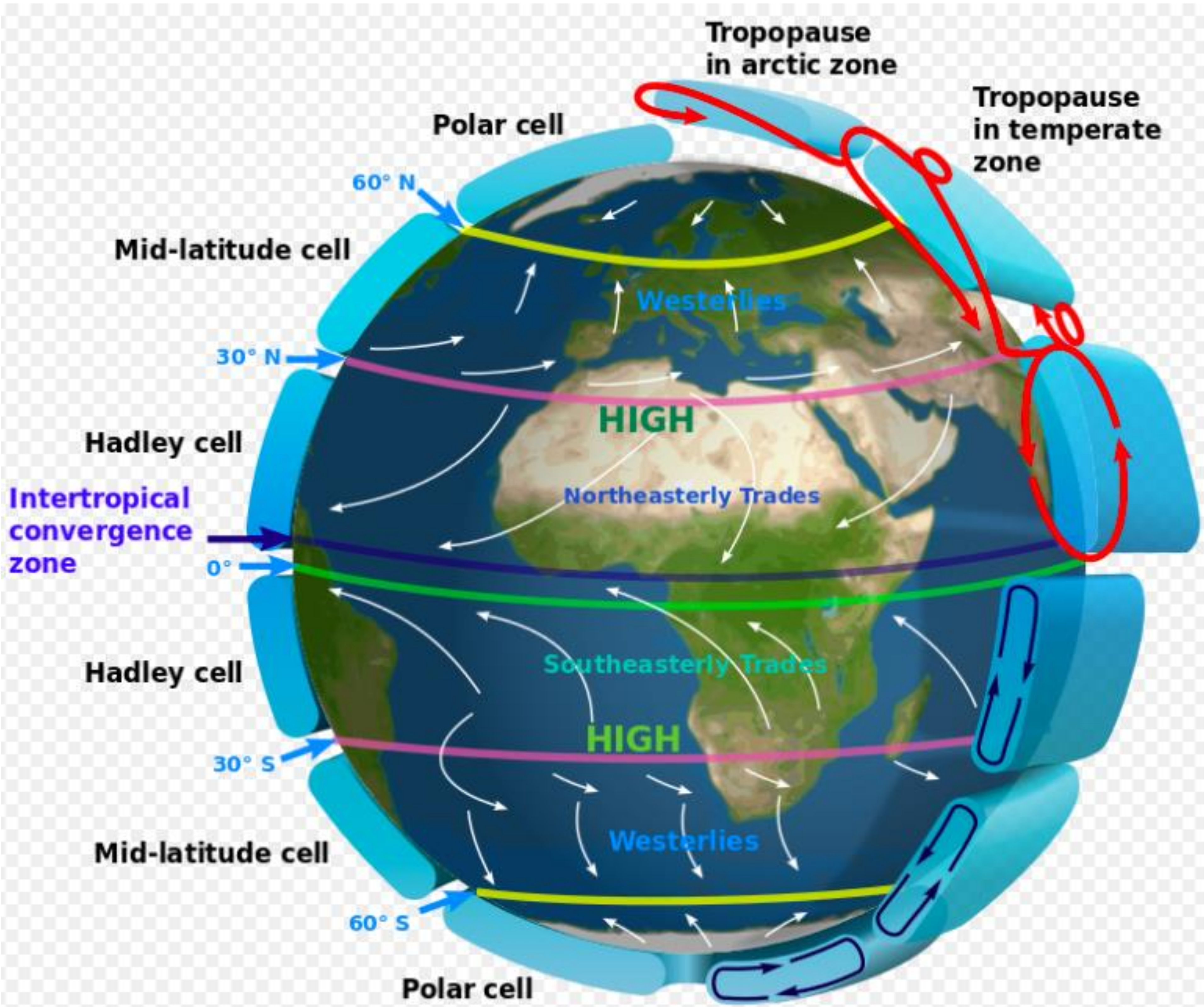
- The Kuroshio is similar to the Gulf Stream and travels north and east in the Pacific to Alaska

- The warm temperature and the large volume of the Gulf Steam waters cause Norway and the United Kingdom to be $18^0$F ($10^0$C) warmer in the winter than other countries at those same latitudes

- Coriolis forces and prevailing winds create two clockwise gyres in the northern oceans and three counter clockwise gyres in the southern oceans

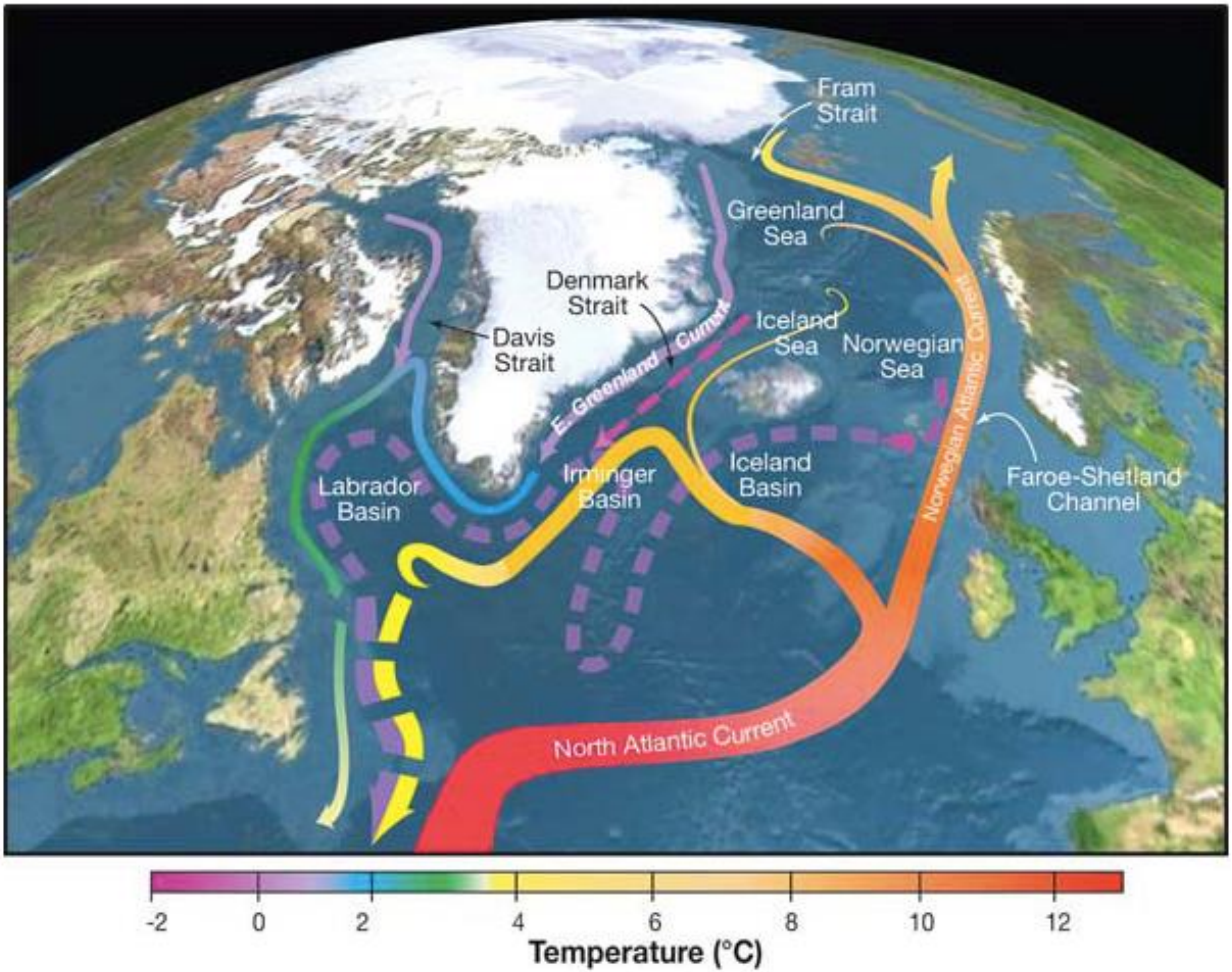
# Global Prevailing Winds

Winds - another part of the puzzle but a whole other presentation



# Non-Surface Ocean Currents

- We have mostly been discussing ocean surface currents
- There are more mysterious deeper and very deep ocean currents
- In discussing ocean salinity we have briefly looked at the Great Ocean Conveyor - the Thermohaline current that is driven by density differences and controlled by salinity and temperature

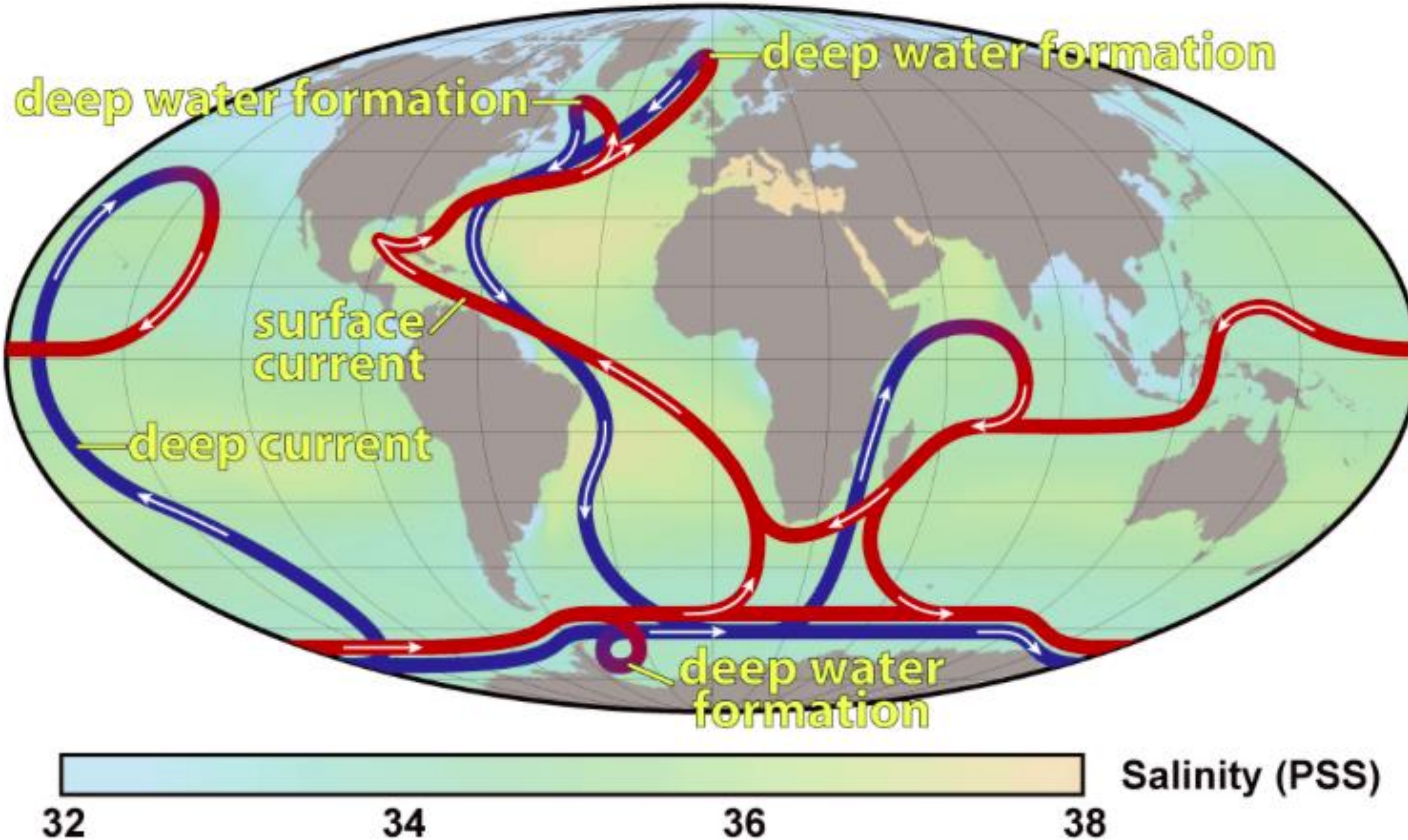


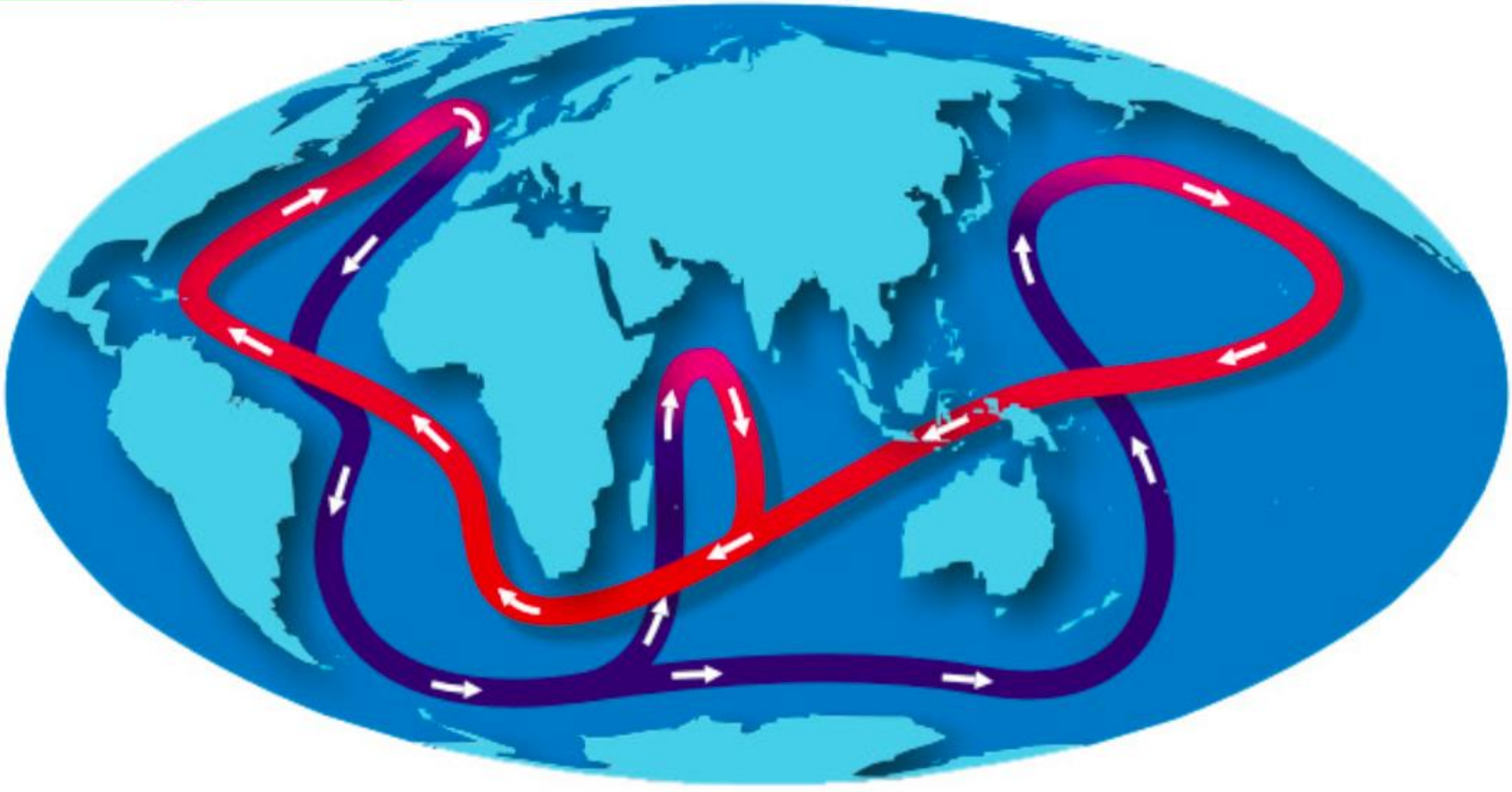
Fram Strait
Greenland Sea
Denmark Strait
Davis Strait
E. Greenland Current
Iceland Sea
Norwegian Sea
Norwegian Atlantic Current
Faroe-Shetland Channel
Labrador Basin
Irminger Basin
Iceland Basin
North Atlantic Current
-2
0
2
4
6
8
10
12
Temperature (°C)

# Deep Water Currents

- Warm Gulf Steam water flows north and branches
- The northern most branch cools and begins to form ice where salt is extracted so that the water underlying the ice becomes very saline and dense
- This dense/saline water sinks
- Thus begins the Great Ocean Conveyer slow deep current
- See the path in the next graphic that moves deep below the Southern Ocean into the north Pacific where most of the flow upwells after a familiar long period of between 1000 and 1200 years

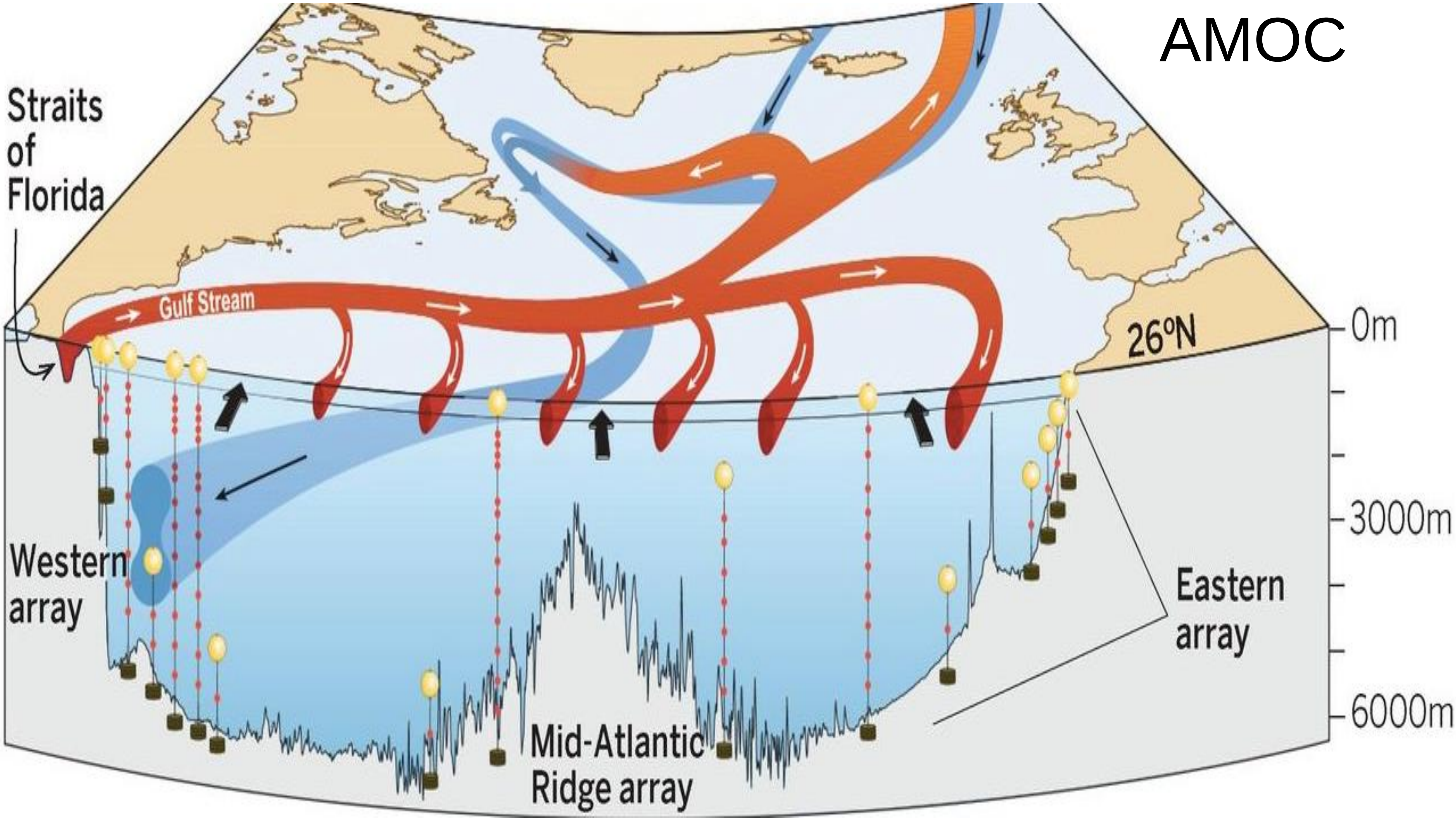
# Thermohaline Circulation





*The Great Ocean Conveyor Belt - The blue color represents the deep cold and saltier water current with the red color indicating shallower and warmer current.*

# Atlantic Meridional Overturning Circulation



# More on Deep and Middle Oceanic Currents

- The circulation patterns that relate to the AMOC are surface, mid-level and deep as seen in the previous graphic (note the moored buoys strung across the Atlantic E-W at $26^0$N that have kept track of these patterns)
- The graphic in the next slide shows more mid and deep currents in a N-S slice through the Atlantic basin with the S pole on the left and the N pole on the right
- And the next slide after the above slide gives a schematic view of surface, middle and deep currents found in all the major seas of the globe and how they are interconnected

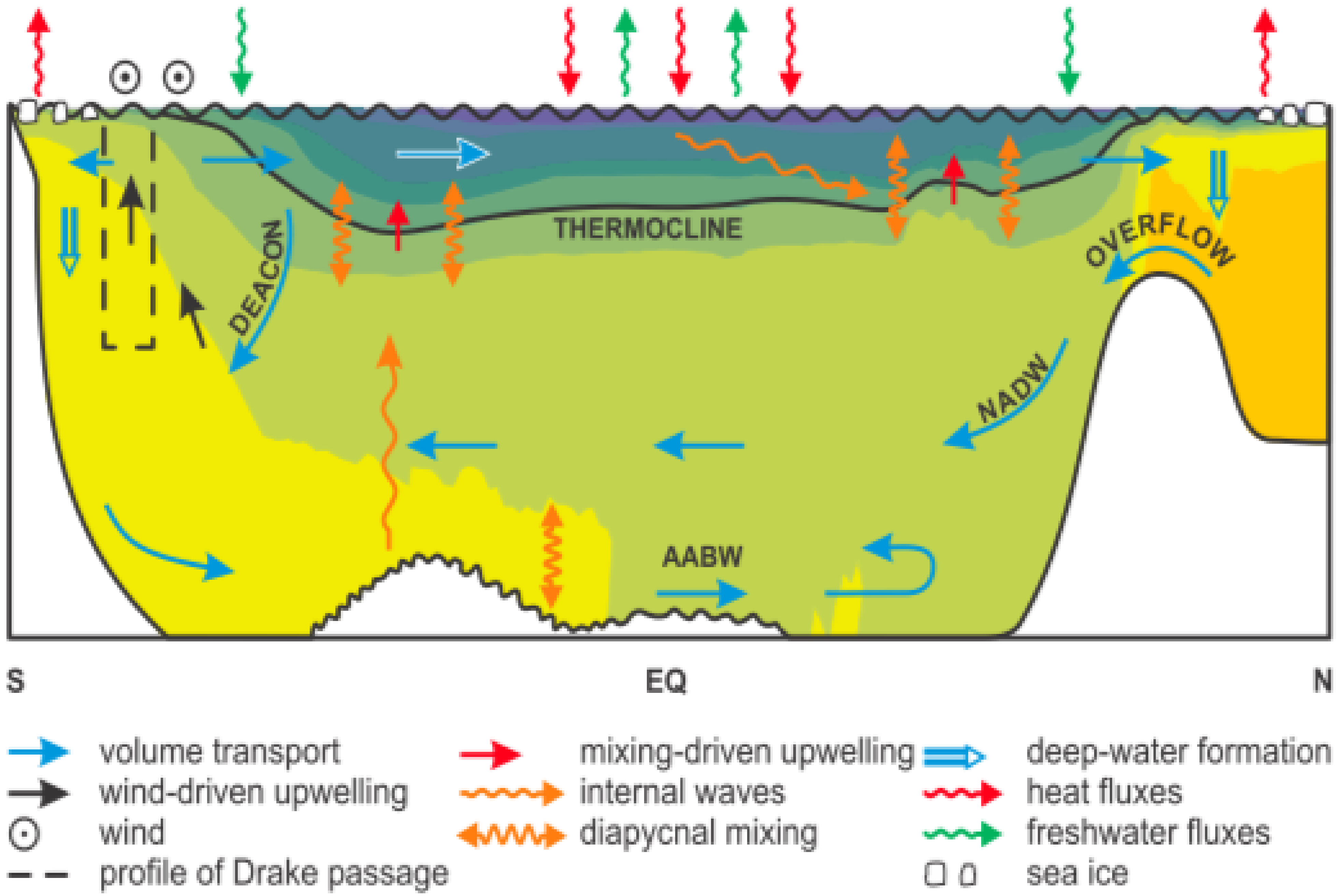
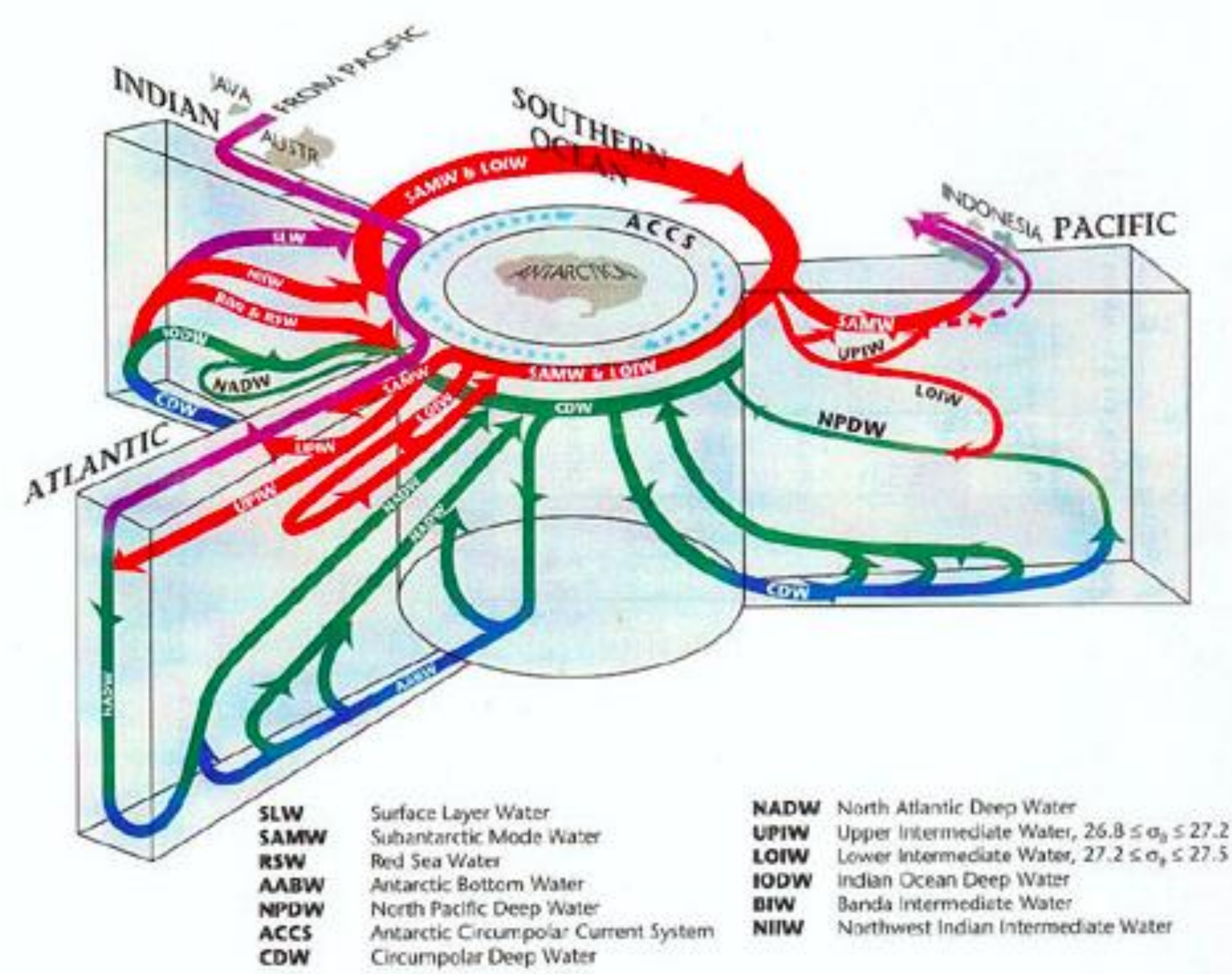
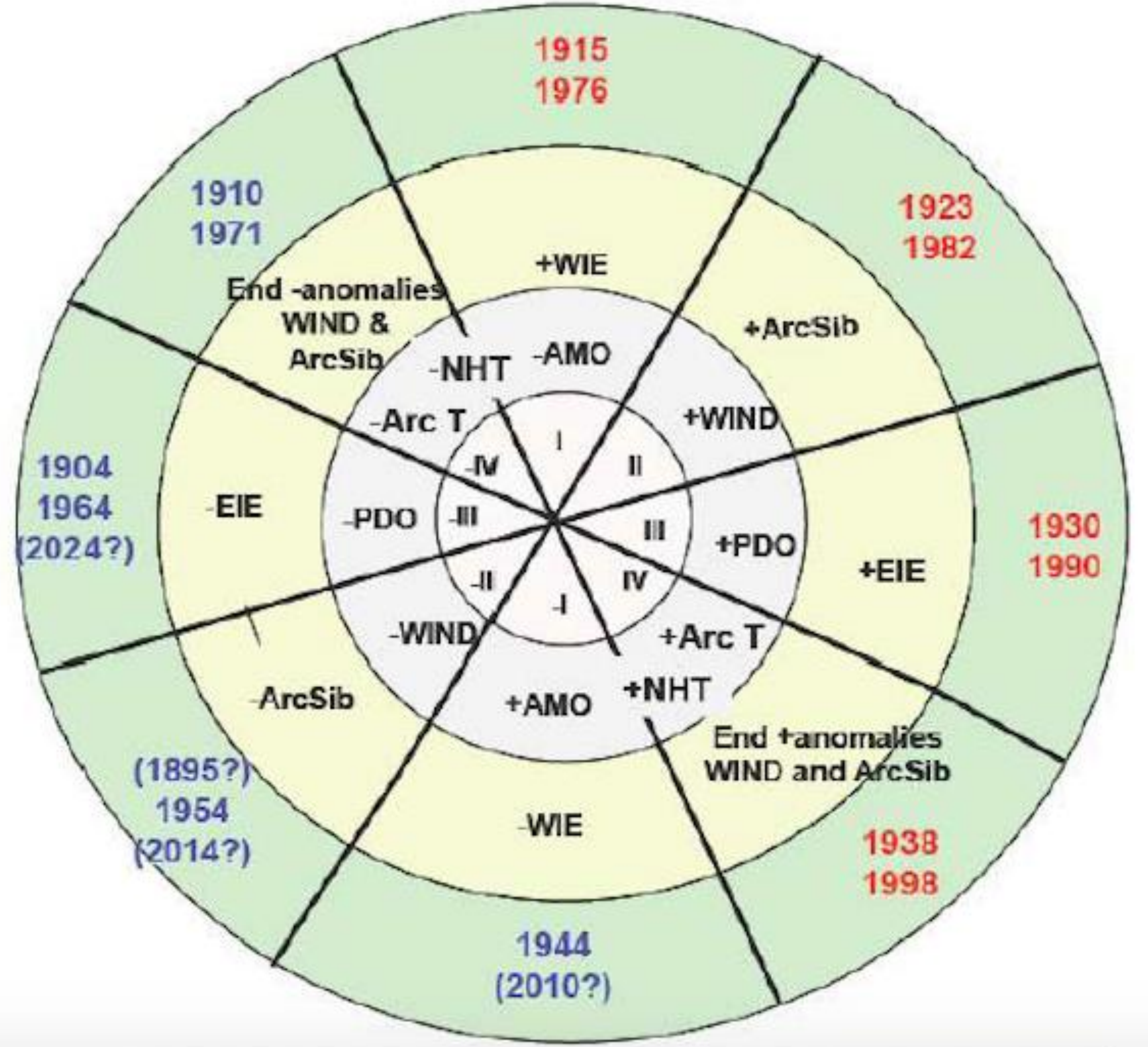



**Fig. 2** Side view of the circulation in the Atlantic, showing various flow components and mechanisms discussed in the text. Color shading shows the observed density stratification, with lightest waters in blue and densest in orange. From [Kuhlbrodt, et al., submitted].


INDIAN
JAVA
FROM PACIFIC
AUSTR
SOUTHERN OCEAN
ACCS
ANTARCTICA
INDONESIA
PACIFIC
ATLANTIC
SAMW & LOIW
SLW
NIIW
RSW & RSW
IODW
NADW
CDW
SAMW
LOIW
UPIW
NPDW
AABW
SLW Surface Layer Water
SAMW Subantarctic Mode Water
RSW Red Sea Water
AABW Antarctic Bottom Water
NPDW North Pacific Deep Water
ACCS Antarctic Circumpolar Current System
CDW Circumpolar Deep Water
NADW North Atlantic Deep Water
UPIW Upper Intermediate Water, 26.8 ≤ σθ ≤ 27.2
LOIW Lower Intermediate Water, 27.2 ≤ σθ ≤ 27.5
IODW Indian Ocean Deep Water
BIW Banda Intermediate Water
NIIW Northwest Indian Intermediate Water



1915
1976
1910
1971
1923
1982
+WIE
End -anomalies WIND & ArcSib
+ArcSib
-NHT
-AMO
-Arc T
+WIND
I
II
-IV
1904
1964
(2024?)
-EIE
-PDO
-III
III
+PDO
+EIE
1930
1990
-II
IV
-I
-WIND
+Arc T
+NHT
-ArcSib
+AMO
End +anomalies WIND and ArcSib
(1895?)
1954
(2014?)
-WIE
1938
1998
1944
(2010?)

# Some data and some theories

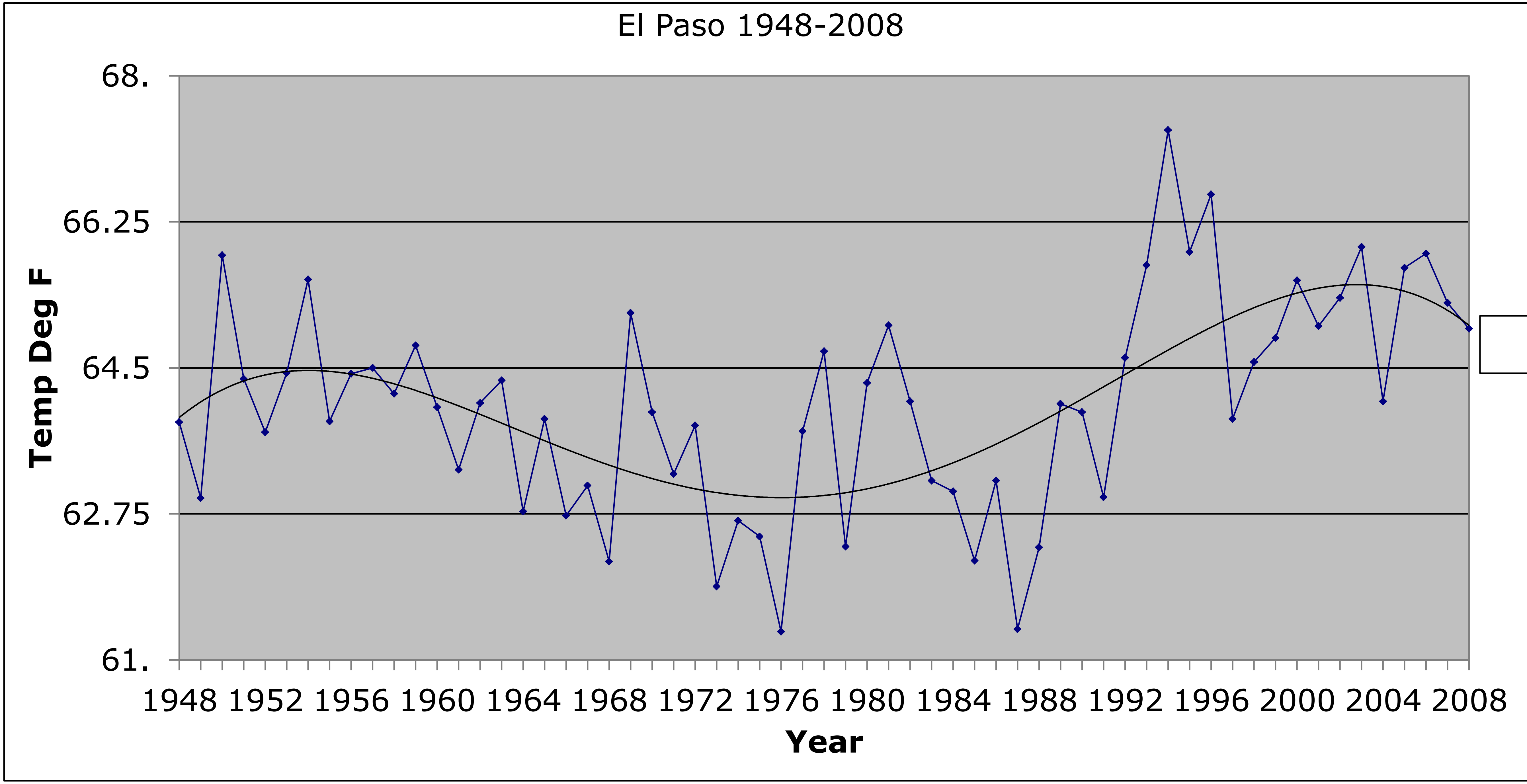
- The Atlantic ocean having the start of the Thermohaline deep current conveyor is thought to be the beginning of the Stadium Wave effect with the AMO

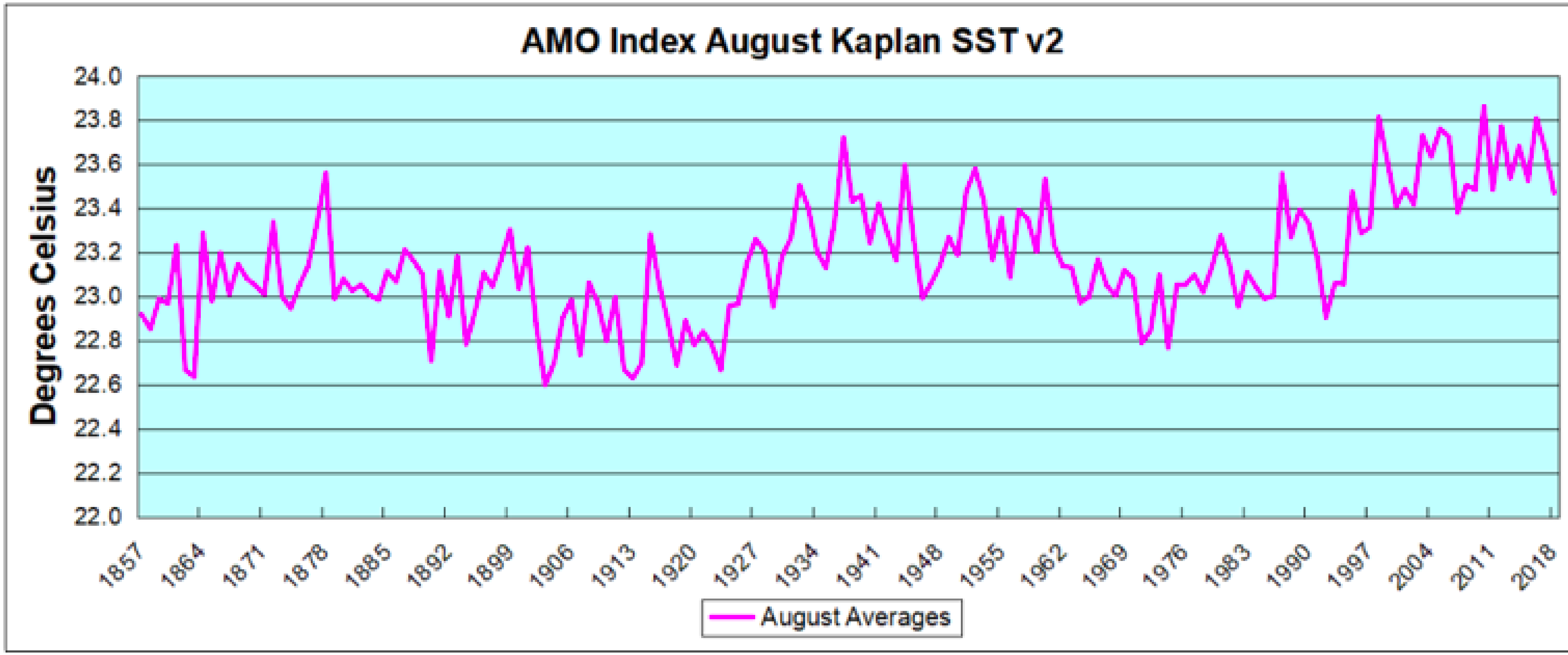
- This travels longitudinally around the planet over a 60 year period and affects PDO (whose 60 year cycle is delayed by multiples of 7.5 year periods)

- El Paso and NM temperatures have 5 to 8 year fluctuations while they also follow the AMO (30 year cool and 30 year warm) cycle

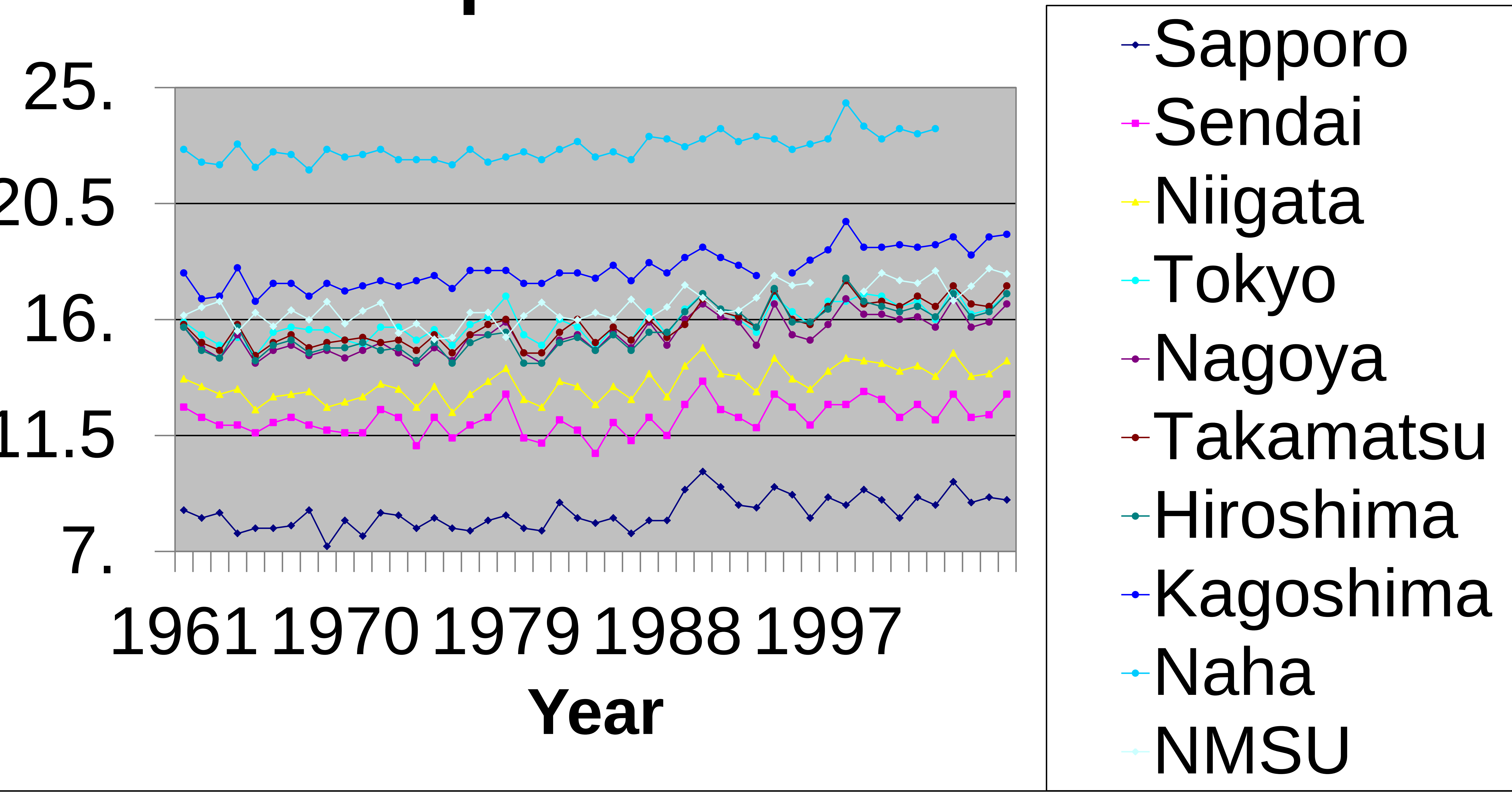
- NM short term temperature - 7.5 year fluctuations are $180^0$ out of sync with Japanese temperature fluctuations

- There are a series of 8 each 7.5 year periods in a 60 year cycle (see previous wheel depicting the stadium wave sequence)


El Paso 1948-2008
68.
66.25
64.5
62.75
61.
Temp Deg F
1948
1952
1956
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996
2000
2004
2008
Year


AMO Index August Kaplan SST v2
Degrees Celsius
24.0
23.8
23.6
23.4
23.2
23.0
22.8
22.6
22.4
22.2
22.0
1857
1864
1871
1878
1885
1892
1899
1906
1913
1920
1927
1934
1941
1948
1955
1962
1969
1976
1983
1990
1997
2004
2011
2018
August Averages

# Site Japanese Annual Avg Temp

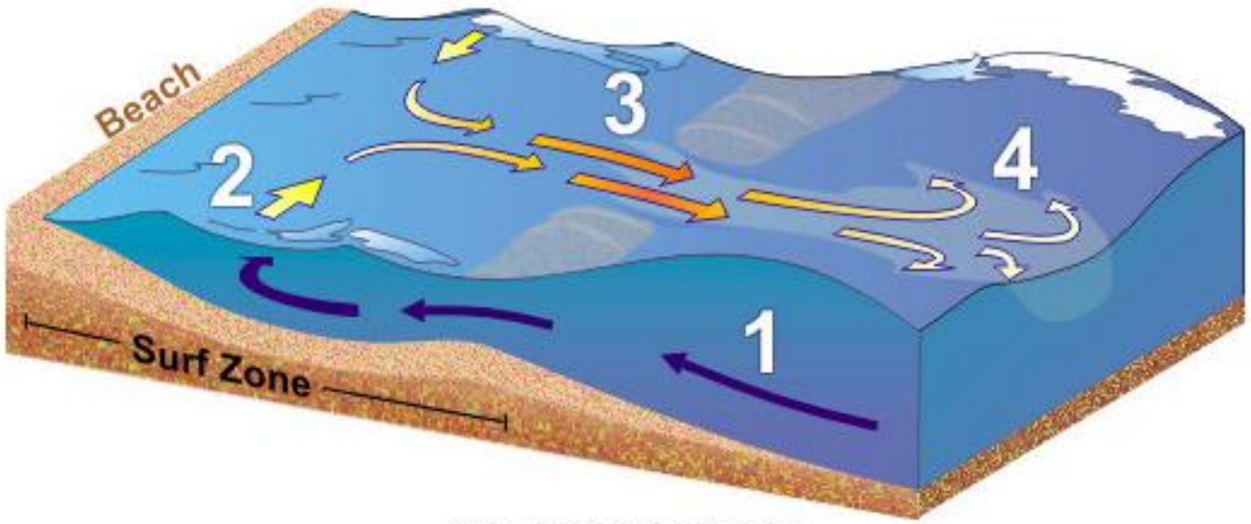


# Wind, Swell and Rogue Waves

- Wind creates waves - according to strength, duration and fetch (long distance)
- Swell - large waves that outrun the storm and may travel for 1000’s of miles
- Longer the swell the faster the wave
- Rogue waves were often thought to be mariner’s tall tales
- Characteristics 1) height > twice the size of nearby waves 2) unexpected - different from the prevailing wind direction 3) unpredictable
- Genesis from multiple swells to reach eg. 112 ft in Pacific 1933

# Other Ocean Events

- Tides - of interest in Climate studies because they modify sea surface heights to confuse the long term climate change effects of ocean rise or fall
- Sea Breeze - regional weather events in the sea/land interface. A daily occurrence along eastern coast in summer
- Marine Layer - forms along west coasts (such as California) and can persist in summer for days or weeks
- In the case of the US west coast the marine layer occurs from cool Alaskan water traveling south



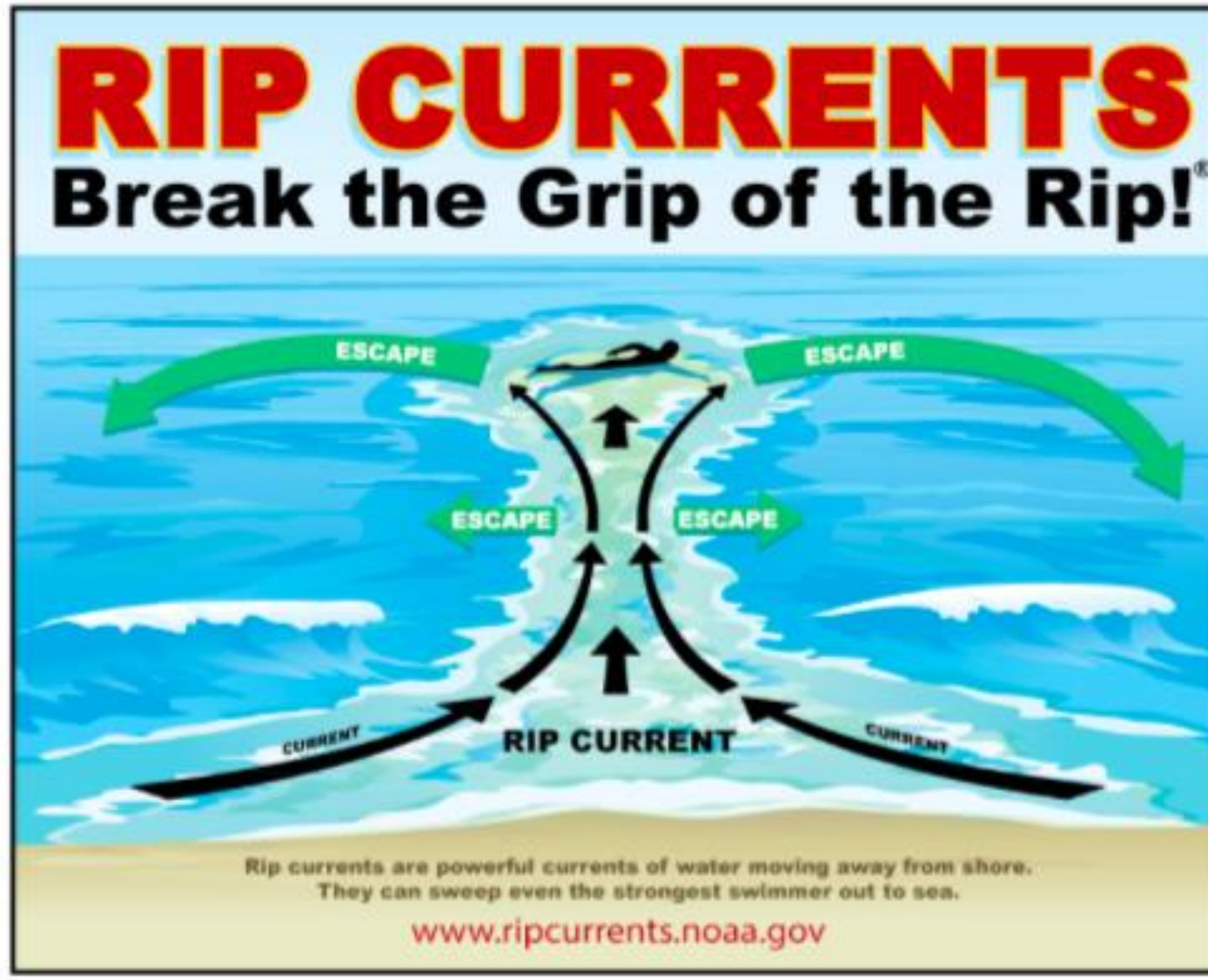

Anatomy of the Rip Current.

I learned about the mighty

Indian Ocean monsoon and

rip currents in the Seychelles

in 1966-7




## IF CAUGHT IN A RIP CURRENT

- Don't fight the current
- Swim out of the current, then to shore
- If you can't escape, float or tread water
- If you need help, call or wave for assistance

## SAFETY

- Know how to swim
- Never Swim alone
- If in doubt, don't go out

More information about rip currents can be found at the following web sites:

www.ripcurrents.noaa.gov
www.usla.org

# Conclusions

- We can see the Ocean as powerful governor that bounds climate into a series of cyclical patterns
- There are well defined Ocean cycles that abound in the various ocean basins that are commonly 60 years long
- A well known 1000 year cycle can now be attributed to a very slow deep ocean circulation system - The Great Ocean Conveyor Belt
- The Ocean is a heat and $CO_2$ sink that tempers weather and climate effects
- We see the Ocean as a natural climate driver dwarfing human climate effects