Agronomy 406
World Climates

February 1, 2018

Ocean properties and circulation.

Measuring the oceans.

Team 2 Climate News on Tuesday.

Review for today:

Rahmstorf, S.: The Ocean Thermohaline Circulation: A Brief Fact Sheet

For Tuesday:

Online textbook: 5.2.1 El Niño-Southern Oscillation

El Niño, La Niña, and ENSO FAQ

Climate News

See notes for January 18 regarding things to focus on when preparing your Climate News story.

- Do background work to make sure you understand the original source and the basic facts relevant your story (terms, locations, etc).
- Your team's presentation should tell a story with a beginning, middle, and end rather than separate pieces stuck together.

Also read "Recommendations for presentations" in the Pages section on the AGRON 406 Canvas page.

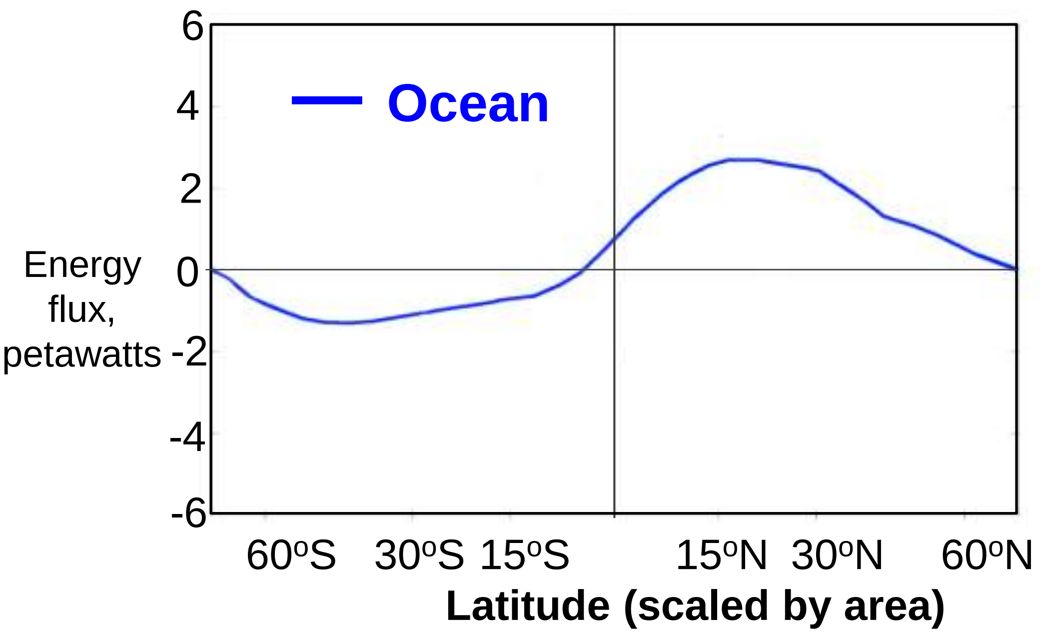
Bring your presentation on a USB stick and load it before the start of class.

Ocean circulations

Ocean circulations transport energy comparable to the atmospheric sensible or latent heat fluxes.

This has big effects on climate, such as warming by the Gulf Stream and North Atlantic Drift.

Look at processes that cause ocean circulation.



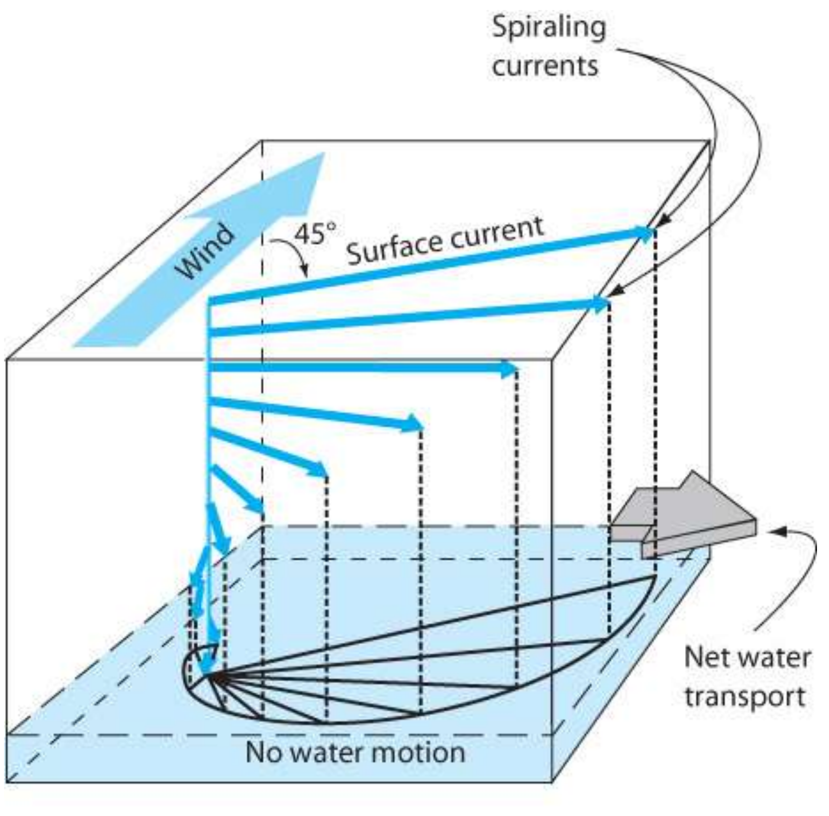
adapted from Bryden (2004)

Water moves to the right of the wind

Each deeper layer moves a little more to the right than the layer above.

Looking from the top, the motion appears to "spiral" rightward with depth.

- This is the Ekman spiral (after V. Ekman, who first solved the equations for it).
- Averaged over the whole depth, the water moves 90º to the right of the wind.



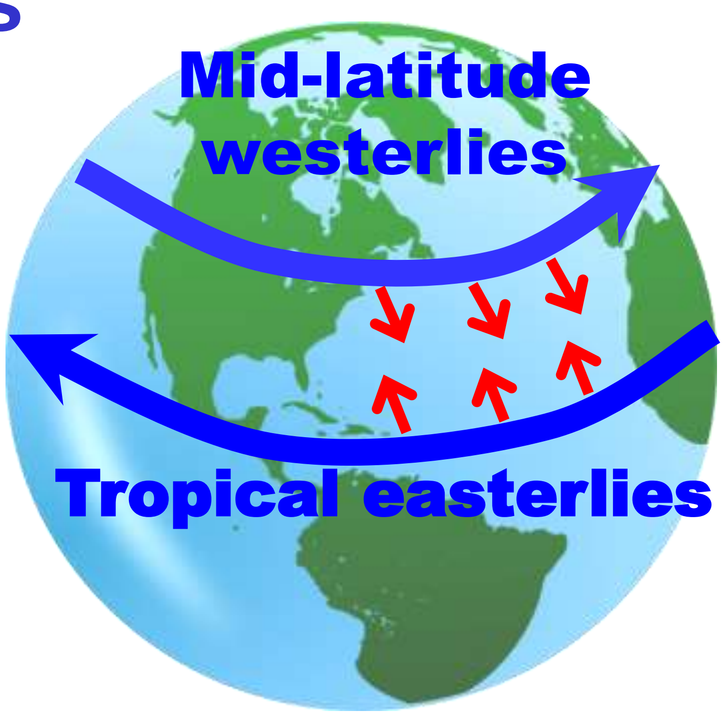
(a) Ekman spiral in the northern hemisphere

- Theoretical result – real world differs somewhat.

Wind forcing causes convergence of ocean water in subtropics

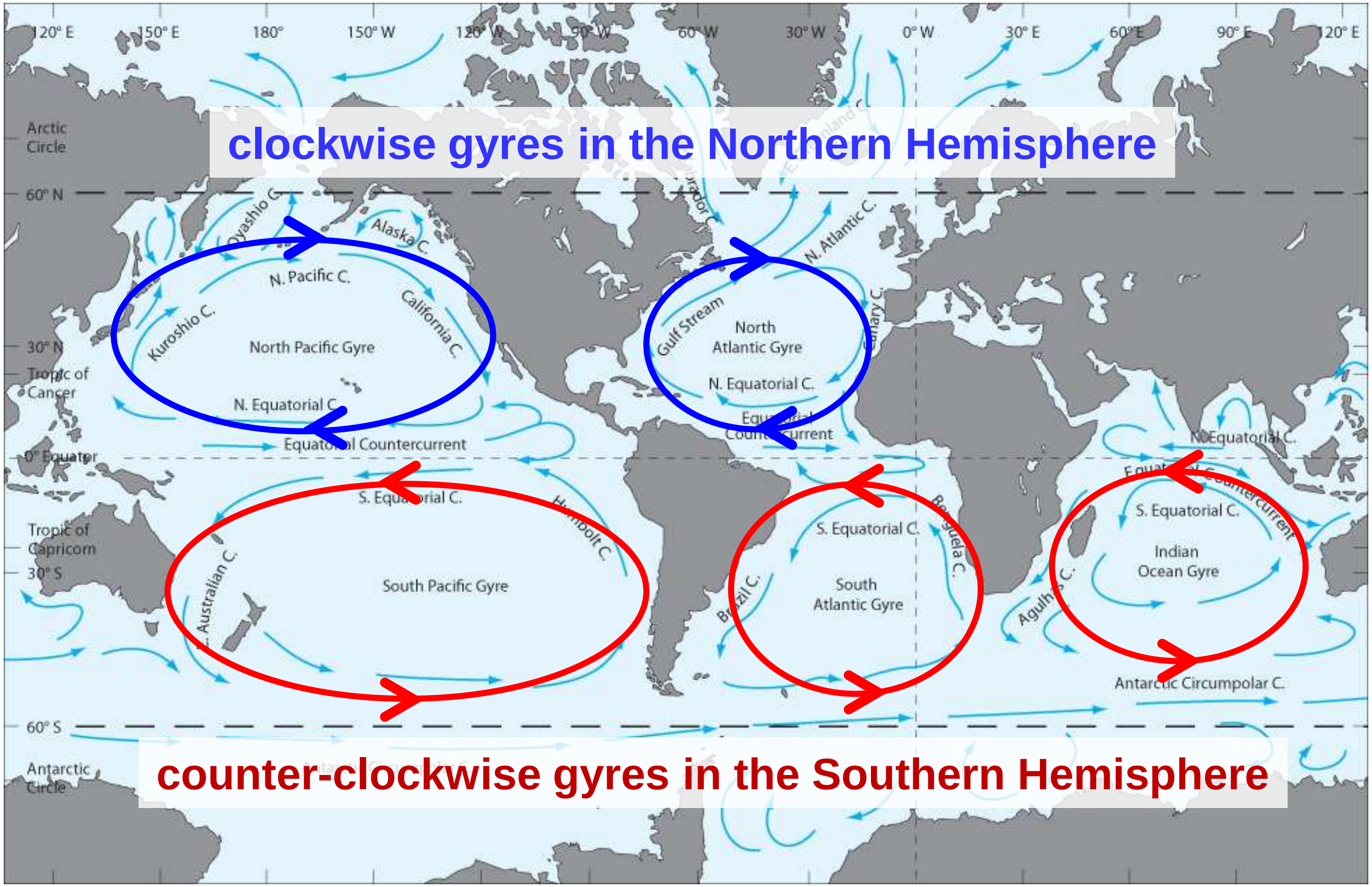
Given:

- Winds in the mid-latitudes are westerly.
- Winds in the tropics are easterly.
- Coriolis force causes water to move **to the right of the wind** in the Northern Hemisphere.



This causes water to converge in the region between the easterlies and westerlies.

Ocean gyres


clockwise gyres in the Northern Hemisphere
counter-clockwise gyres in the Southern Hemisphere
120° E
150° E
180°
150° W
120° W
90° W
60° W
30° W
0° W
30° E
60° E
90° E
120° E
Arctic Circle
60° N
30° N
Tropic of Cancer
0° Equator
Tropic of Capricorn
30° S
60° S
Antarctic Circle
Oyashio C.
Alaska C.
N. Pacific C.
California C.
Kuroshio C.
North Pacific Gyre
N. Equatorial C.
Equatorial Countercurrent
S. Equatorial C.
Humboldt C.
Australian C.
South Pacific Gyre
Gulf Stream
N. Atlantic C.
North Atlantic Gyre
N. Equatorial C.
Equatorial Countercurrent
S. Equatorial C.
Benguela C.
Brazil C.
South Atlantic Gyre
N. Equatorial C.
Equatorial Countercurrent
S. Equatorial C.
Indian Ocean Gyre
Agulhas C.
Antarctic Circumpolar C.

Temperature and salt

Ocean water is affected by **salt content:**

- Average salinity is about 35 parts / thousand ($^{o}/_{oo}$).

Salty water freezes at lower temperature than fresh water.

Density depends on both temperature and salinity:

- **Density increases with increasing salt content.**
- **Density increases with decreasing temperature.**
- Unlike fresh water, **sea water becomes denser with colder temperature until it freezes.**

What processes in the climate system can change the **temperature** of ocean water?

What processes can change its **salinity**?

Discuss in your teams:

- Think of two processes that can change the **salinity** of the ocean.
- Think of two processes that can change the **temperature** of the ocean.

Processes that can change density

Change temperature

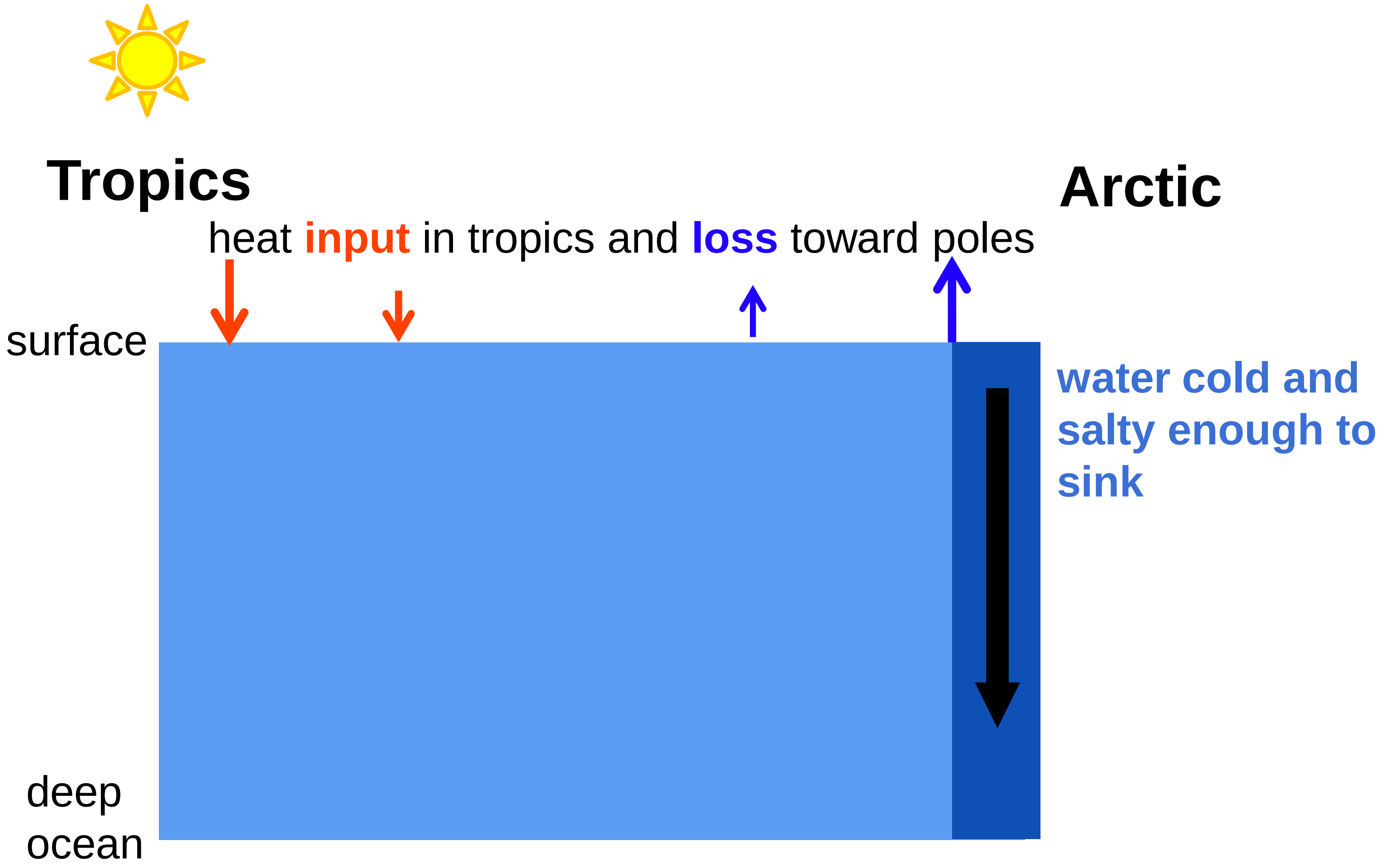
- ice melting
- cloud cover
- cold front
- daytime heating
- evaporation (latent heat)
- greenhouse effect (global warming)
- sea vents
- upwelling and downwelling

Change salinity

- ice melting
- precipitation
- fresh water from rivers
- evaporation
- circulation in the ocean
- upwelling and downwelling

When you open the drain in a bathtub, what happens to water at the other end of the tub?

Sinking of cold, salty water drives the thermohaline circulation



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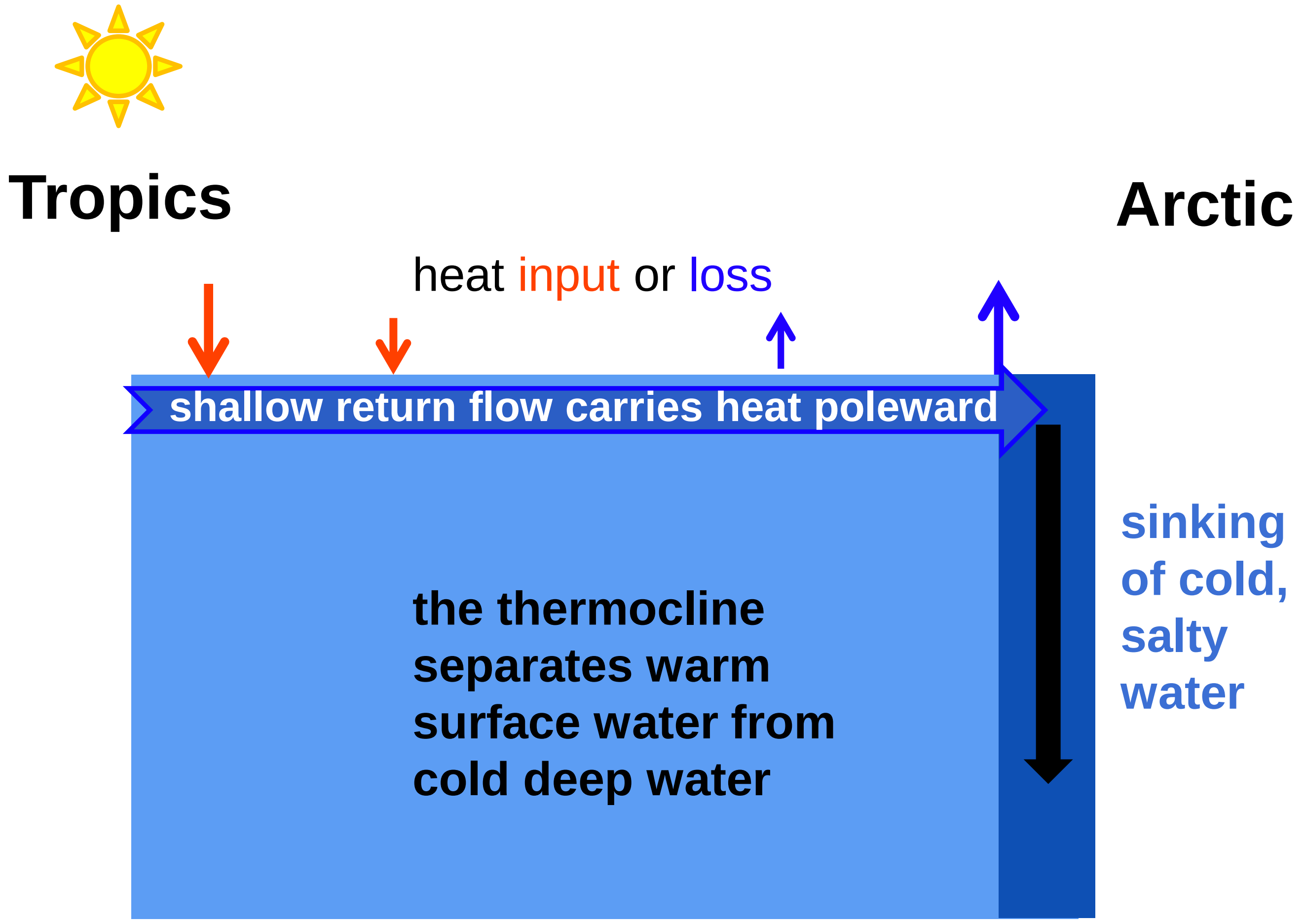

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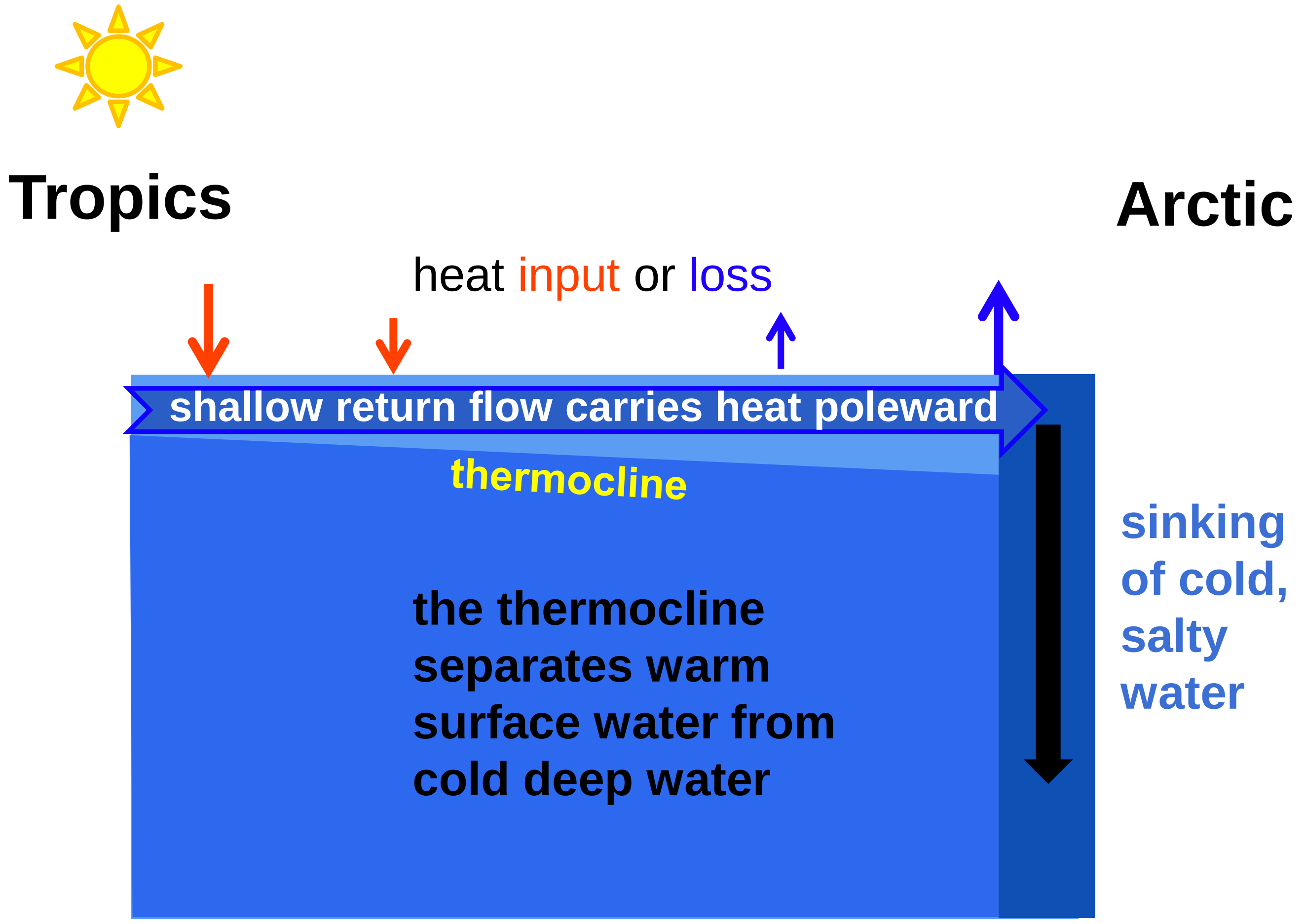
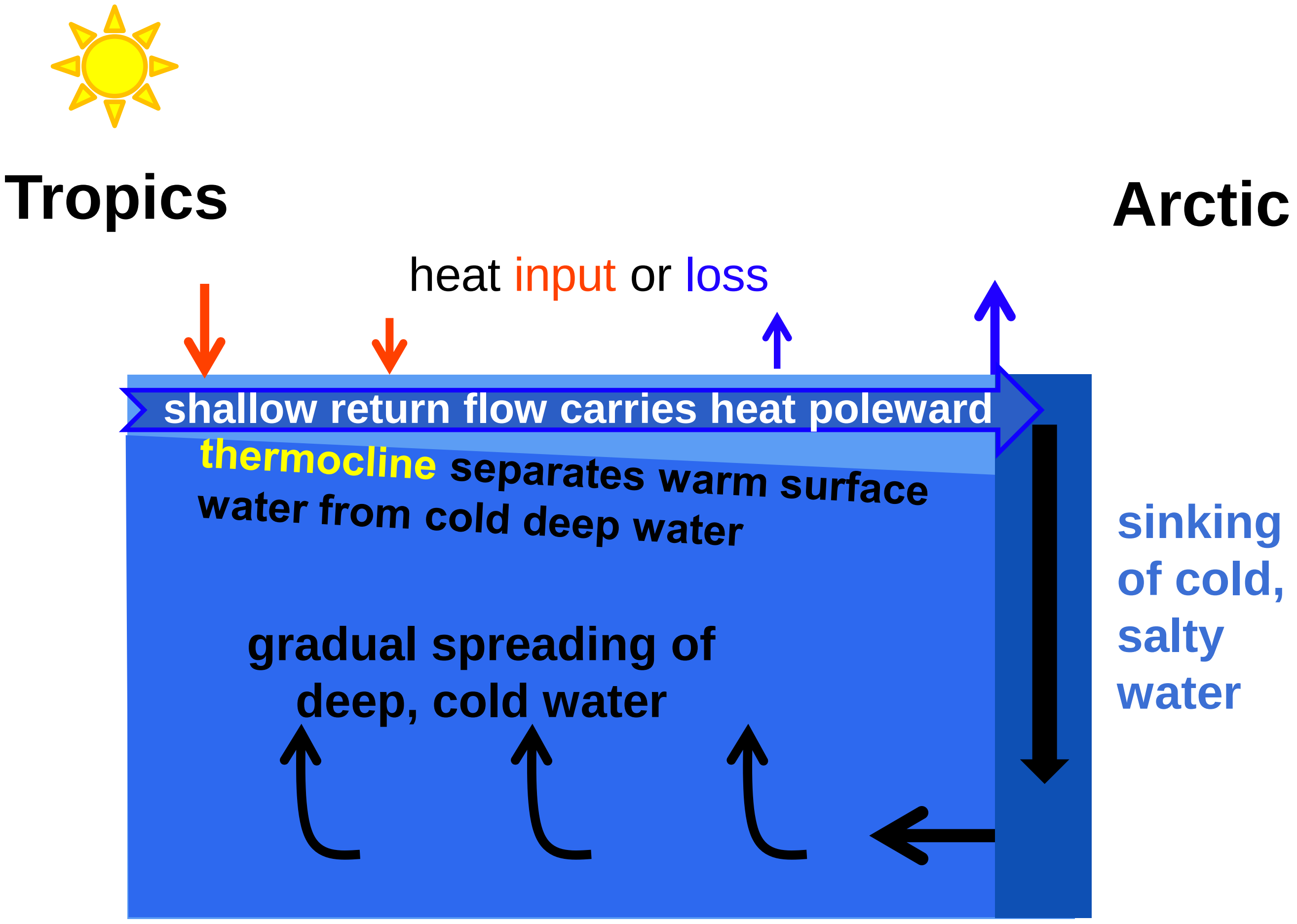


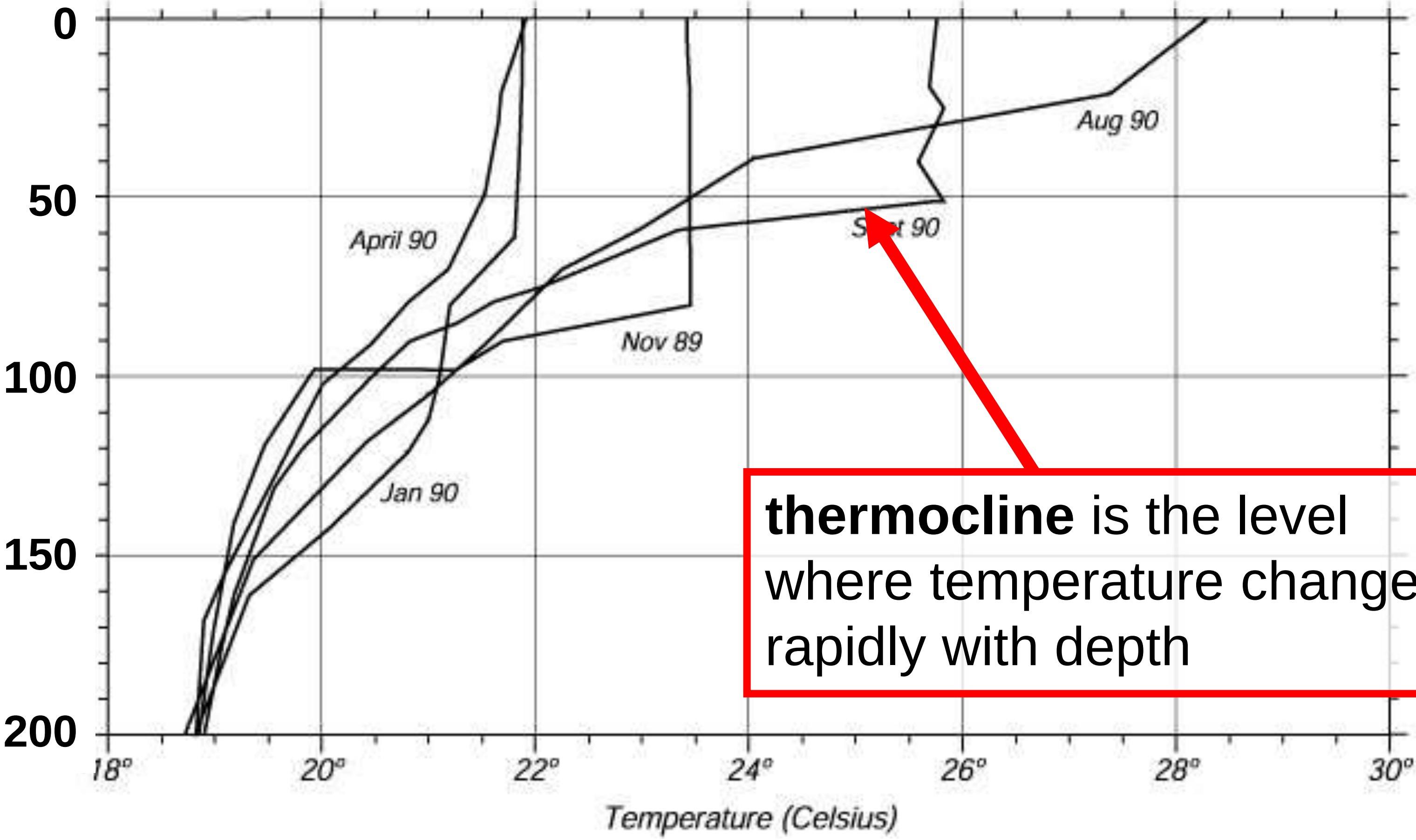
Sinking of cold, salty water drives the thermohaline circulation



Vertical temperature profile of the ocean

warm water "floats" on top of colder, denser water

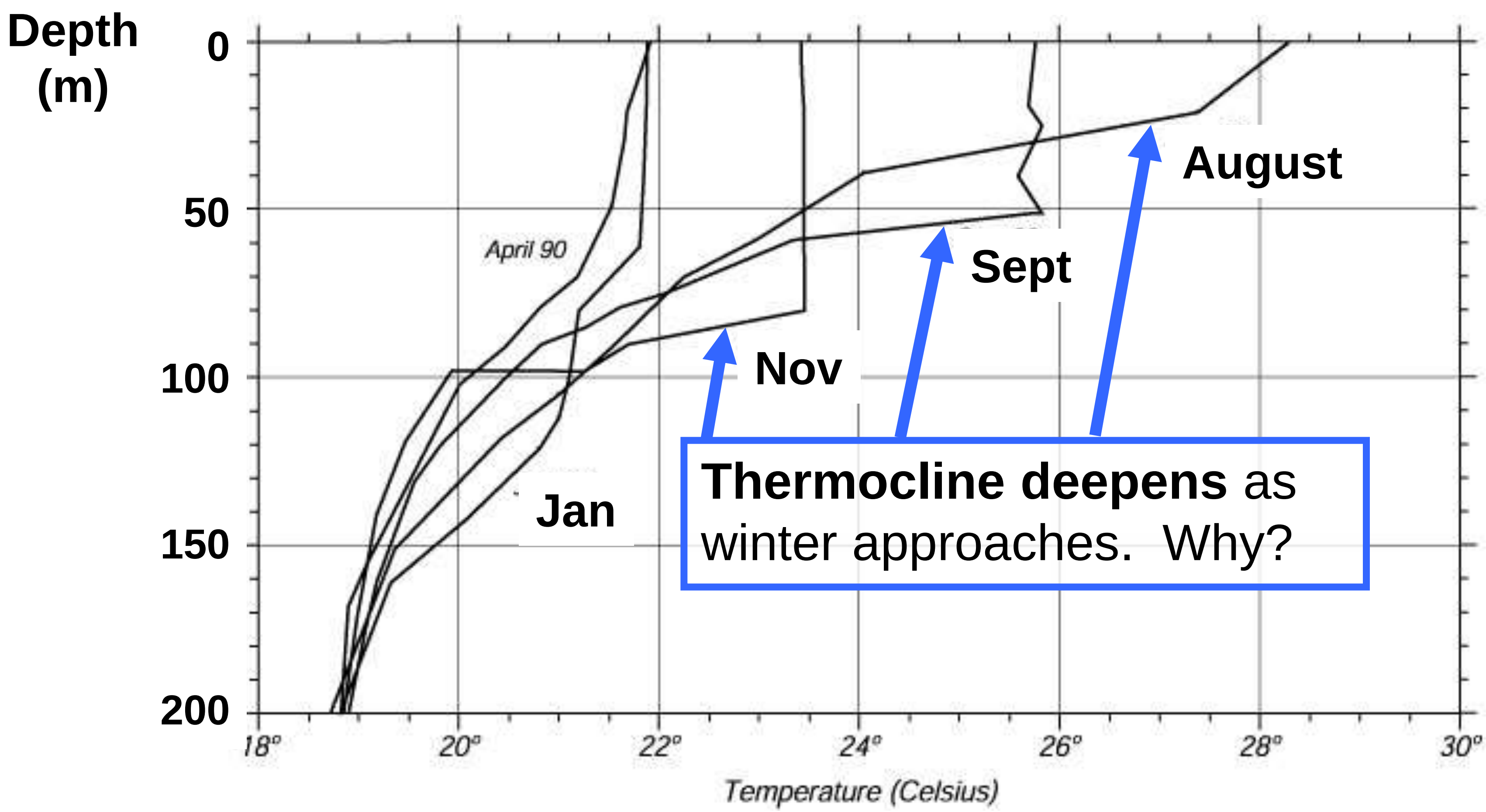
Depth (m)



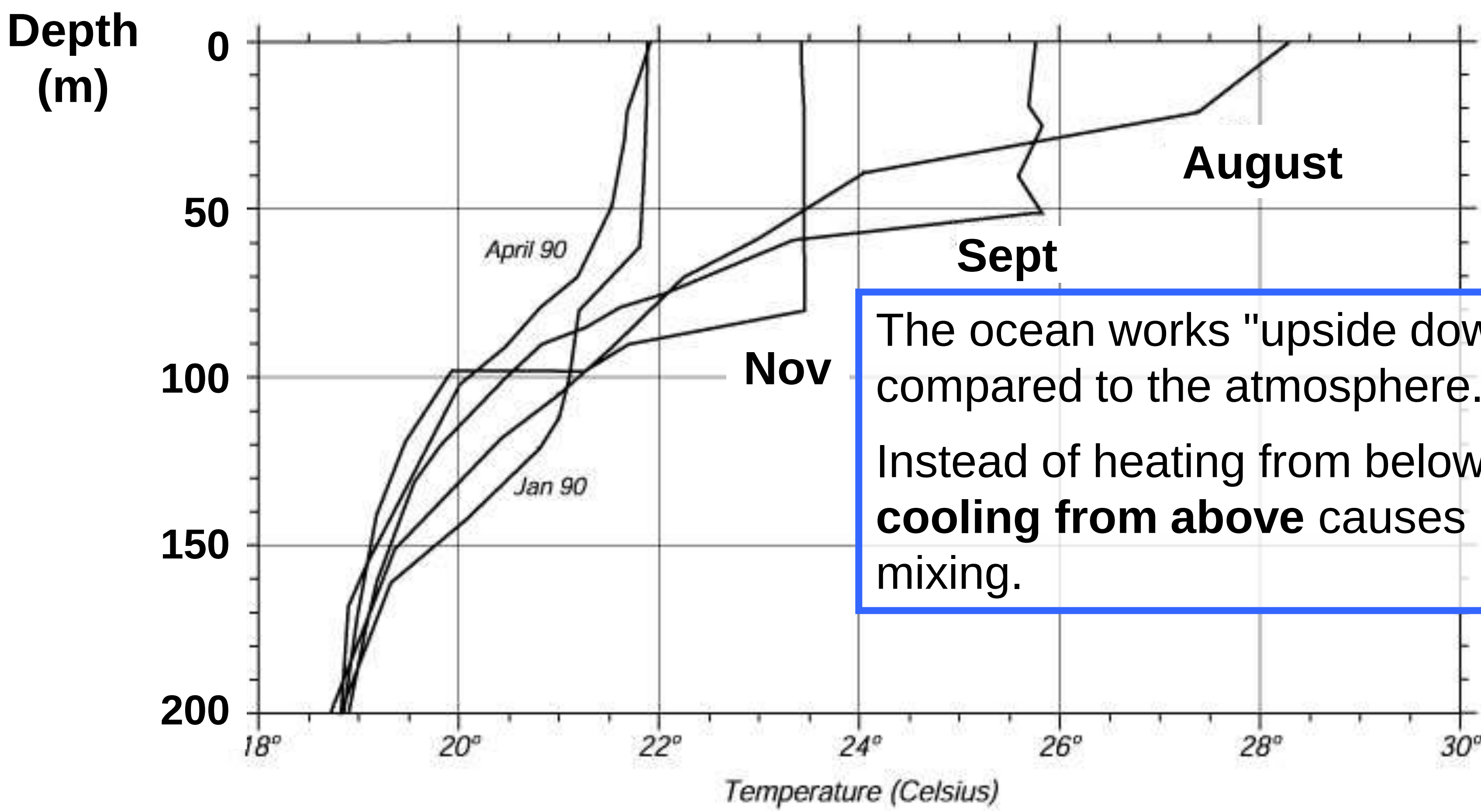
thermocline is the level where temperature changes rapidly with depth

(1 decibar ~ 1 meter depth)

Vertical temperature profile of the ocean



Vertical temperature profile of the ocean



The ocean works "upside down" compared to the atmosphere.

Instead of heating from below, **cooling from above** causes mixing.

Thermohaline circulations: Deep water formation

Sinking of cold, salty water in **deep water formation** regions is the main control on the thermohaline circulation.

There are only a few deep water formation regions:

- Greenland-Norwegian Seas (north of Iceland)
- Labrador Sea (between Canada and Greenland)
- Weddell Sea (off Antarctica, on the Atlantic side)
- Ross Sea (off Antarctica, on the Pacific side)
- Mediterranean Sea (off the south coast of France)

Thermohaline circulation: The ocean conveyor belt

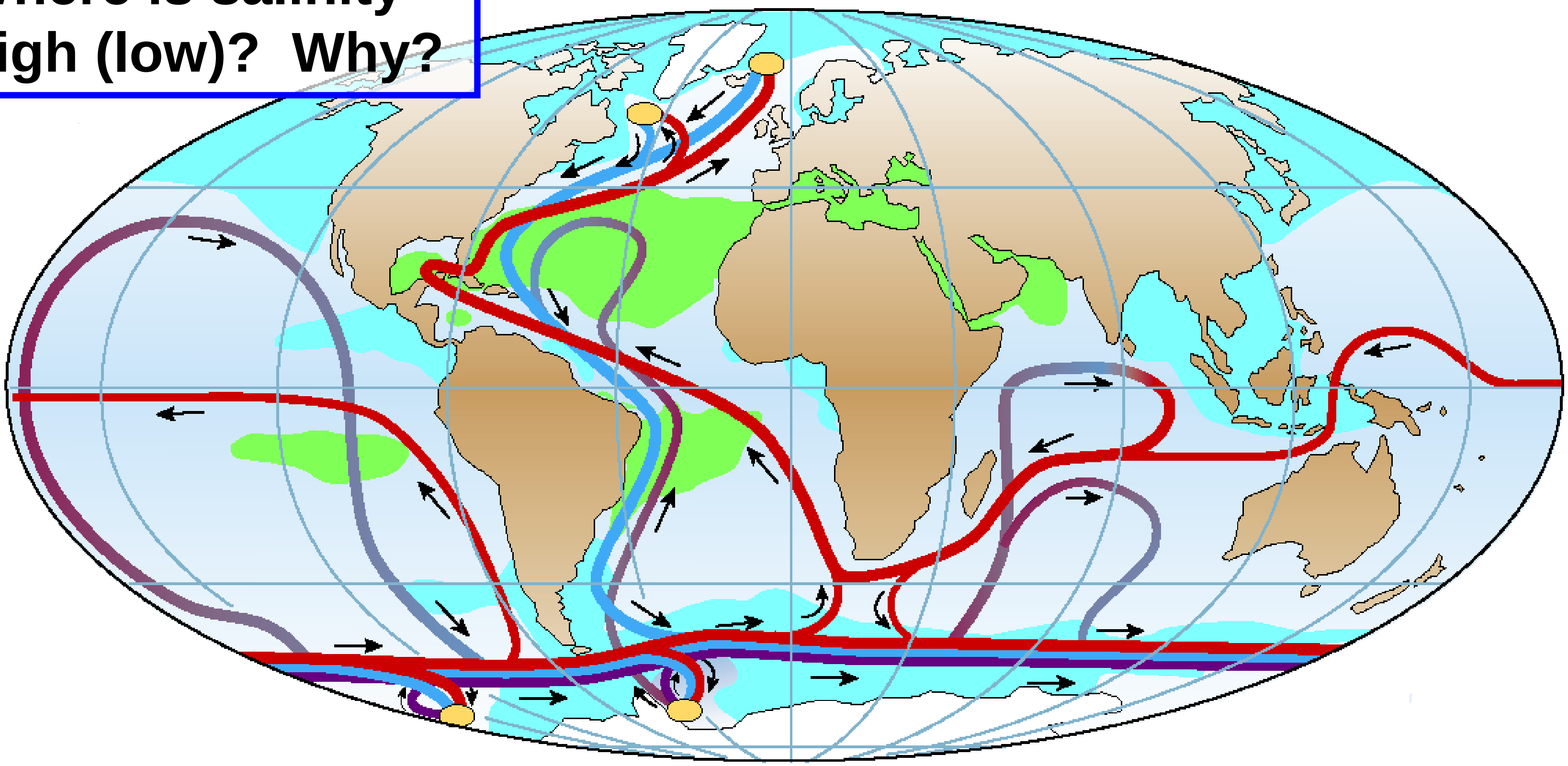
Sinking of cold, salty water in deep water formation regions is the main control on the **thermohaline circulation.**

Combined with wind-driven circulation, produces the **ocean conveyor belt** that connects surface and deep waters.

> Thermohaline circulations move slowly: Time to make a complete transit around the ocean conveyor is of order **1000 years.**
>
> The conveyor transports energy (heat) around the world. Also transports whatever is dissolved in the ocean – salt, oxygen, nutrients.

The ocean conveyor belt

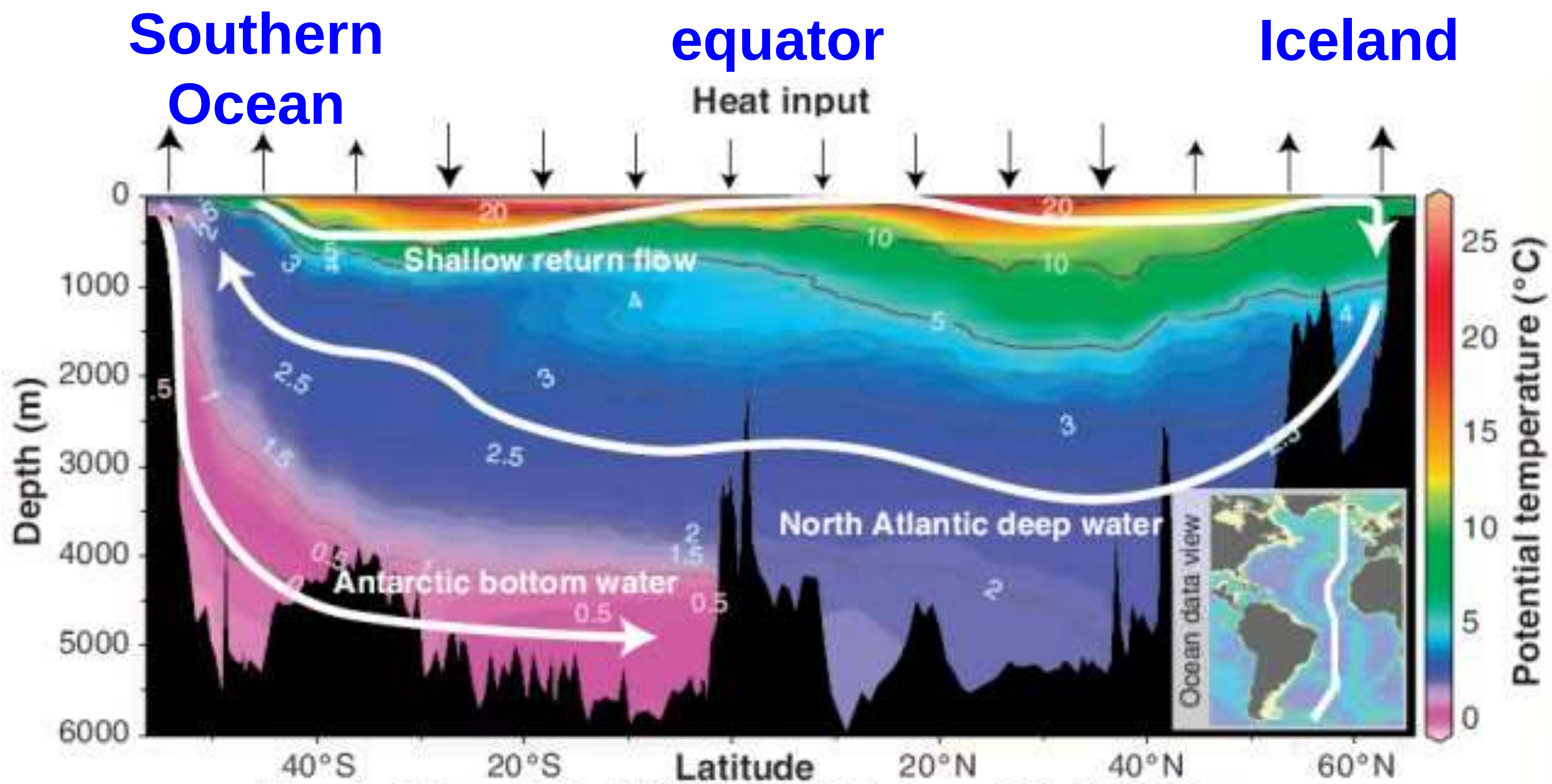
Where is salinity high (low)? Why?



- Surface water
- Deep water
- Bottom water
- Deep water formation areas
- Salinity above 36 $^{o}/_{oo}$
- Salinity below 34 $^{o}/_{oo}$

from Rahmstorf (2002), *Nature*

Actual thermohaline circulation is a little more complicated



Hegerl, G.C. and Bindoff, N.L. 2005. Science 309: 245-255

more ocean cross sections available at
http://www.ewoce.org/gallery/index.html

Why do we care?

The ocean conveyor belt transports heat poleward – important to the global energy balance.

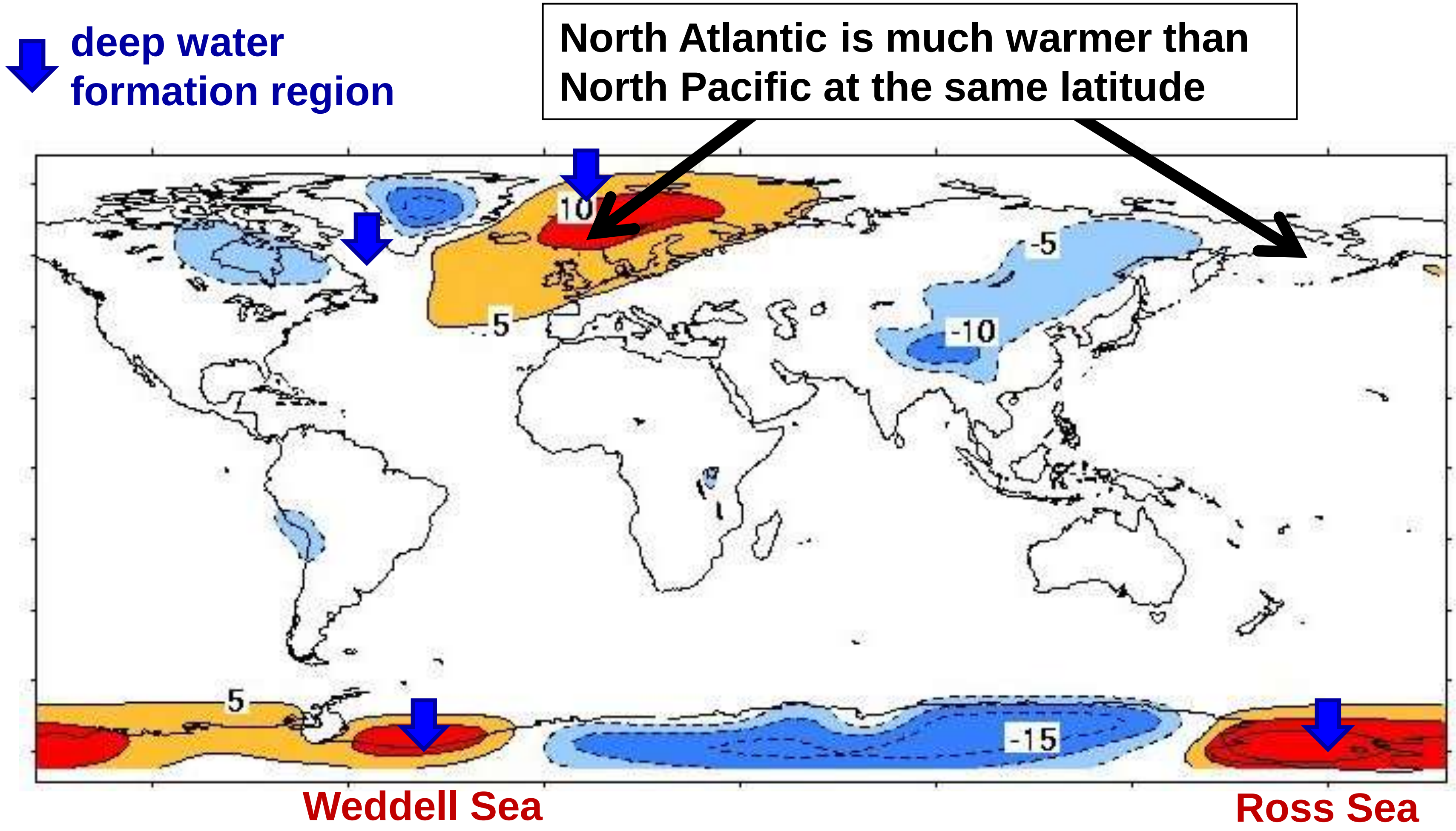
Sinking carries heat into the ocean:

- Most of the excess heat due to increasing greenhouse gases has gone into **ocean,** down to about 700 meters.
- But probably not the "very deep" or **abyssal** part of the ocean (deeper than ~2000 meters).

Poleward heat transport in the ocean conveyor belt keeps some regions much warmer than they would be otherwise.

Thermohaline circulation has important effects on temperature, especially in the North Atlantic

Temperatures shown as deviations from the average at each latitude



Ocean measurements

- Satellites
- Buoys
- Ships

Each has advantages and disadvantages.

Satellite observations

Sea surface temperature:

Measured from infrared and microwave radiometers.

Corrections have to be applied for effects of clouds, atmosphere and solar radiation.

Only "sees" the ocean surface.

Winds and surface stress:

A **scatterometer** works sort of like a radar. Waves on the surface affect the amount of energy that is scattered back to the satellite.

Measurements of the same point from different angles allow estimates of wind speed and direction.

Salinity

SMOS (Soil Moisture and Ocean Salinity)

SMAP (Soil Moisture Active and Passive)

Aquarius

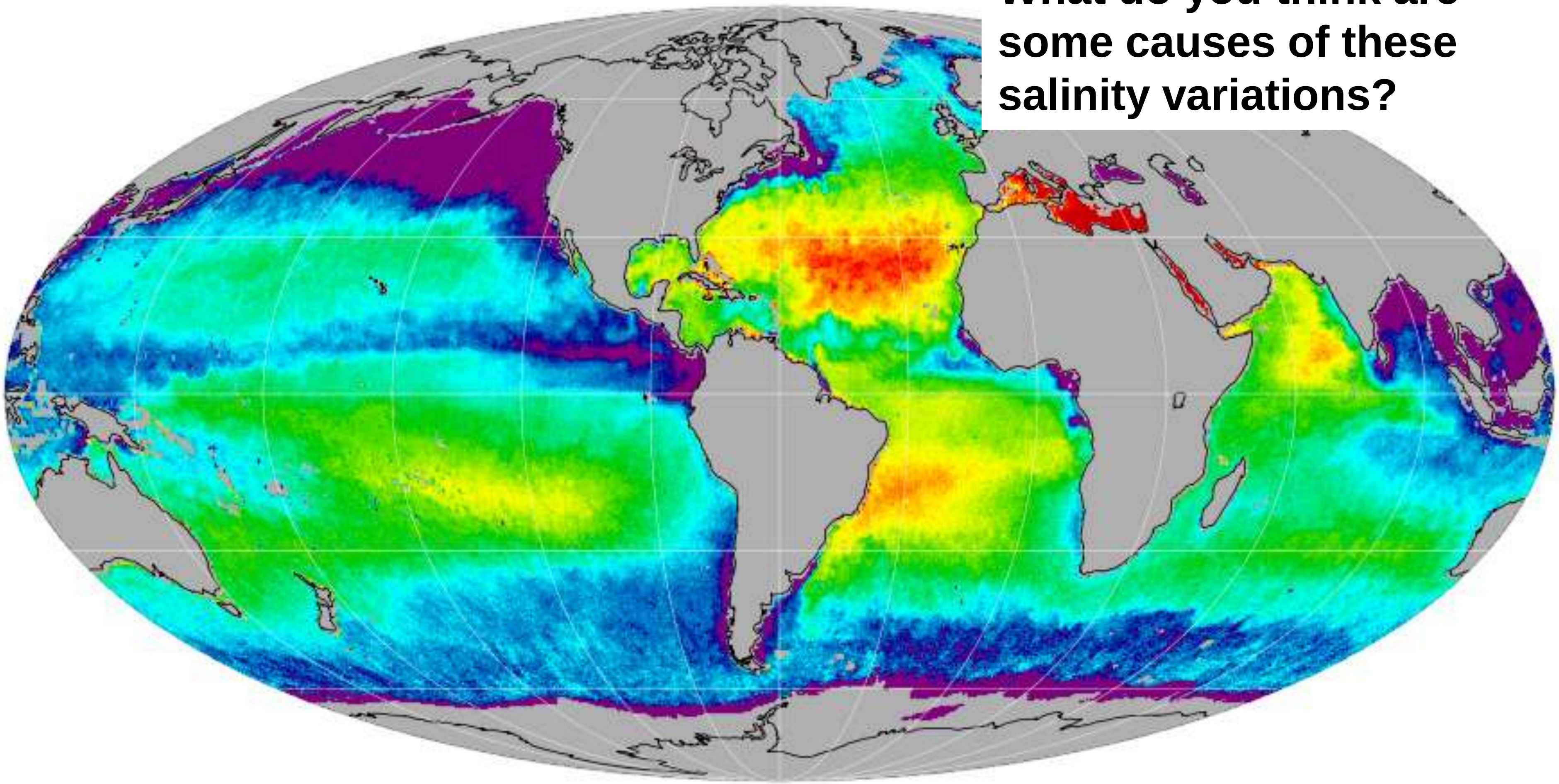
Salinity affects electromagnetic properties of water.

The satellite measures electromagnetic radiation from the sea surface, which is then converted to sea surface salinity.

Only "sees" the ocean surface.

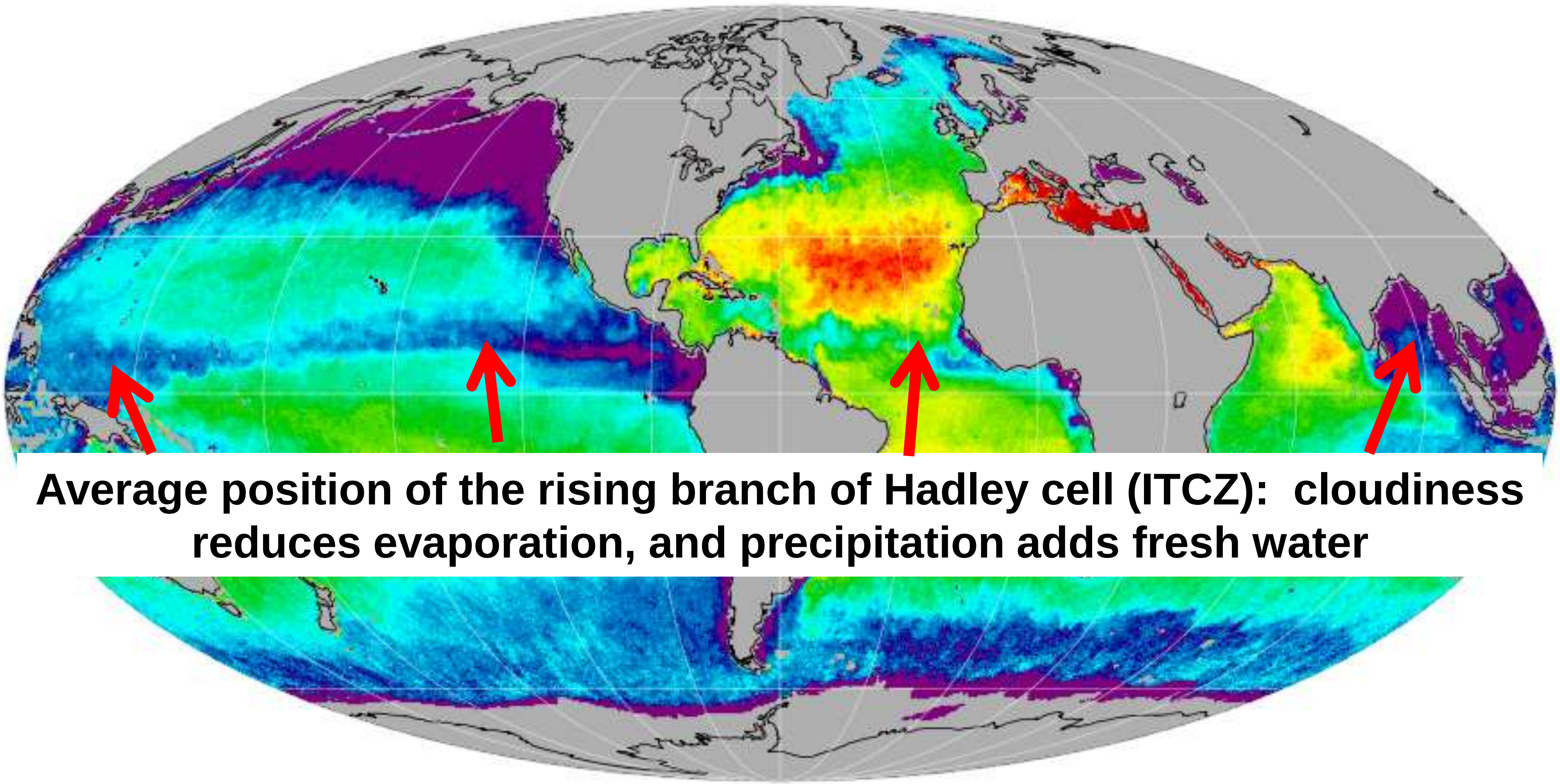
Most recent sea surface salinity from the Soil Moisture Active Passive satellite

What do you think are some causes of these salinity variations?



from https://aquarius.umaine.edu/cgi/gal_smap.htm

Some reasons for salinity variations



Average position of the rising branch of Hadley cell (ITCZ): cloudiness reduces evaporation, and precipitation adds fresh water

from https://aquarius.umaine.edu/cgi/gal_smap.htm

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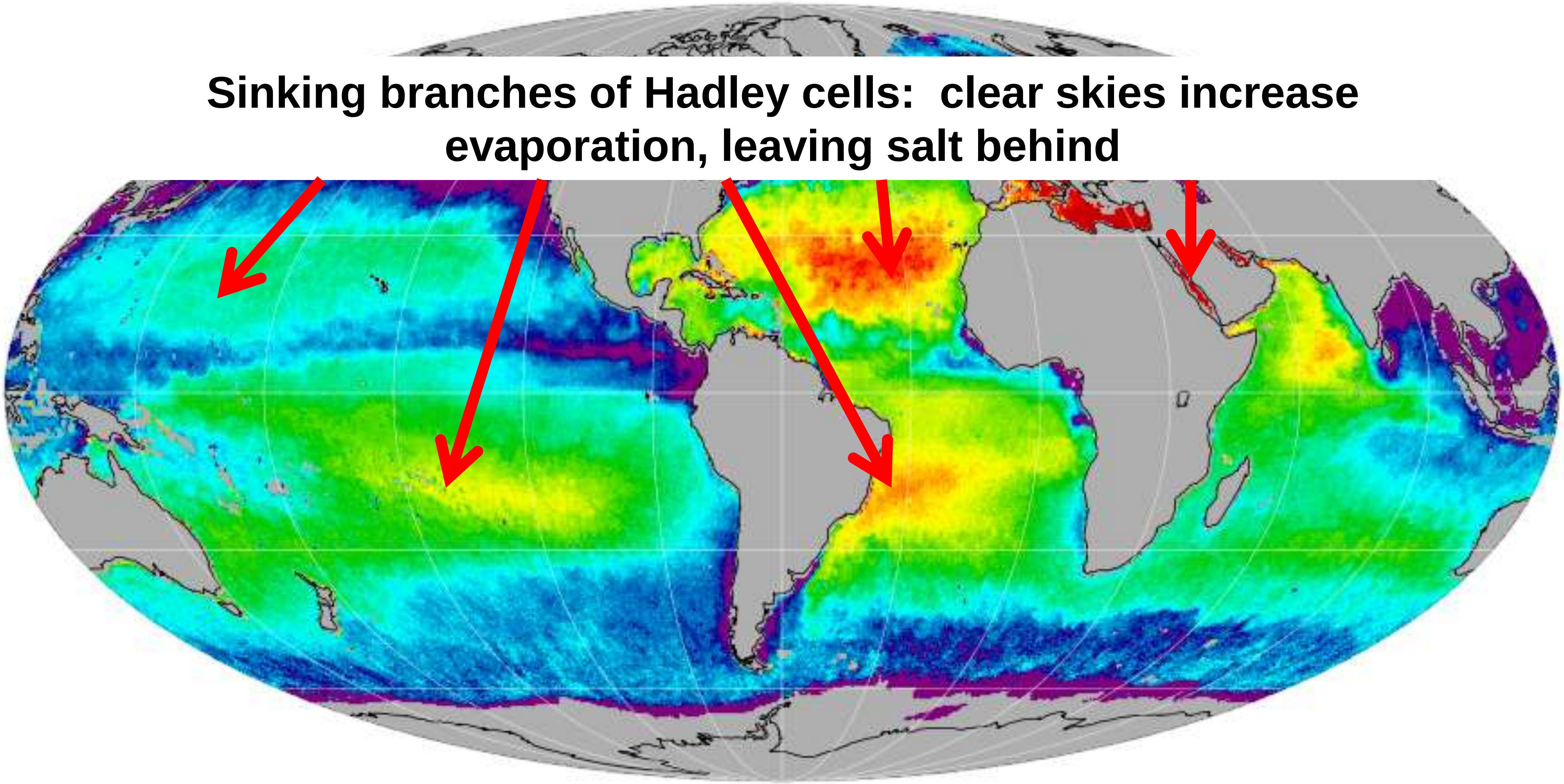

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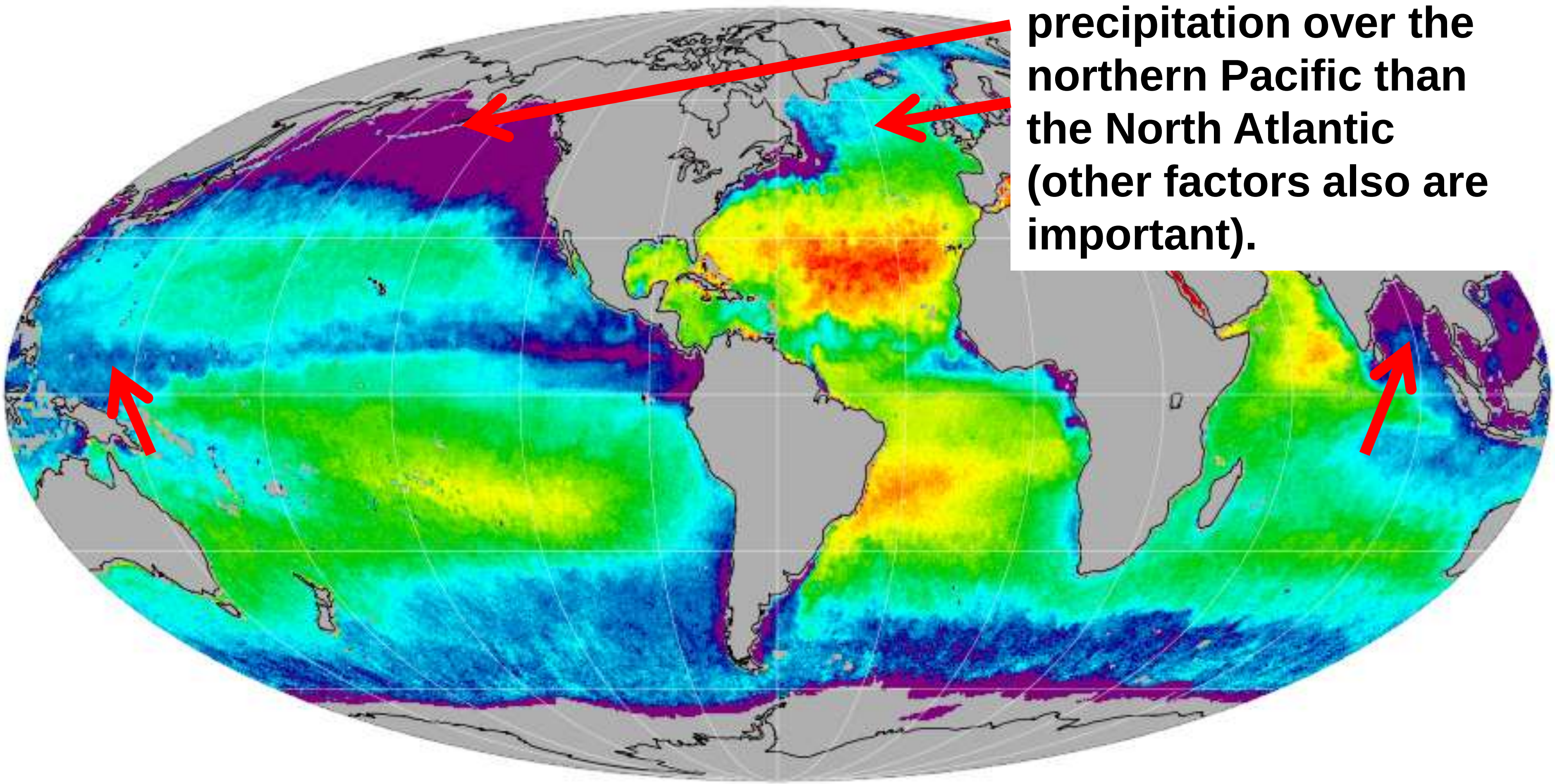
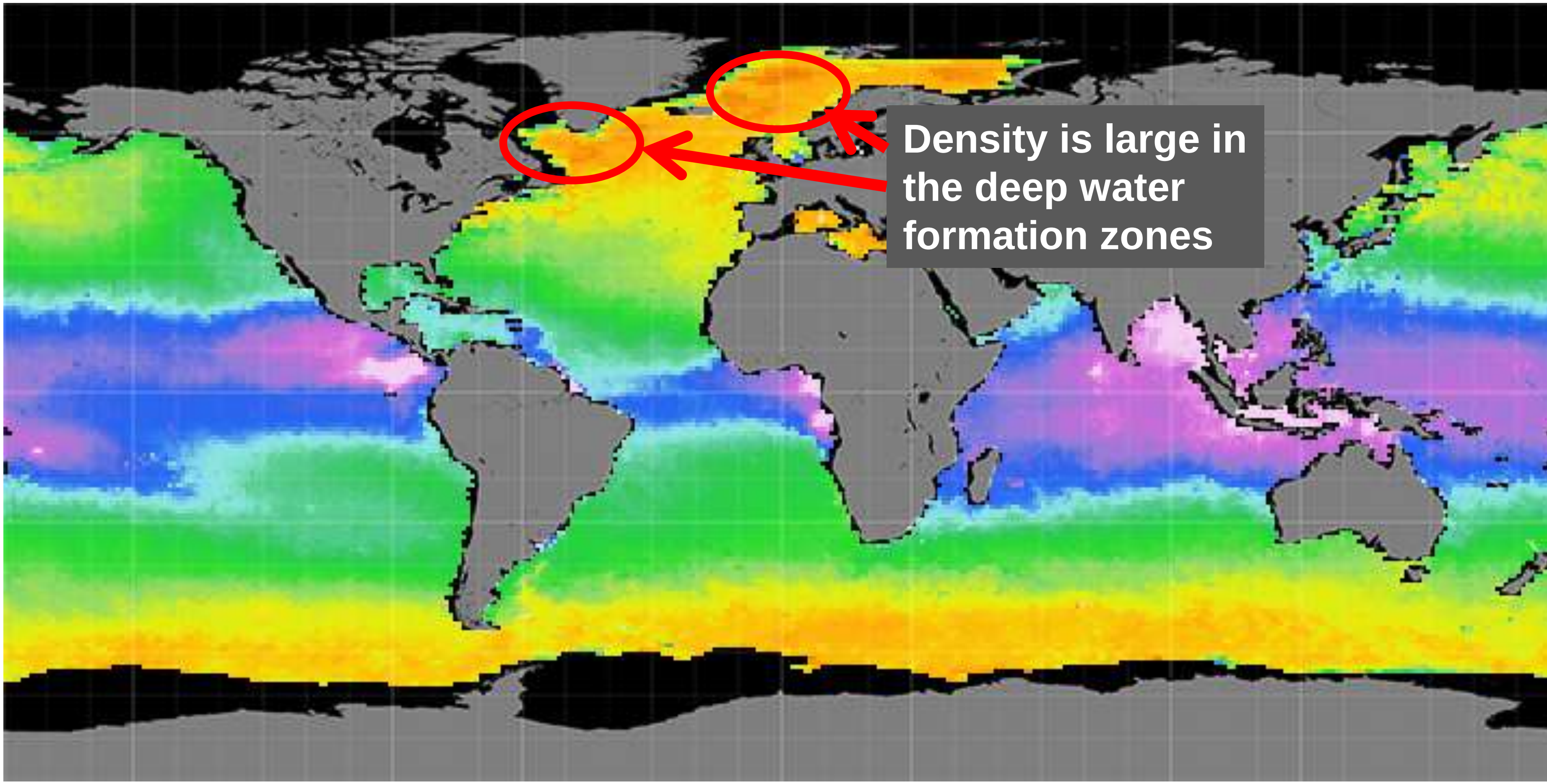


There is more precipitation over the northern Pacific than the North Atlantic (other factors also are important).

from https://aquarius.umaine.edu/cgi/gal_smap.htm

Sea surface density from the Aquarius satellite



April 2015

from https://aquarius.umaine.edu/cgi/gal_density.htm

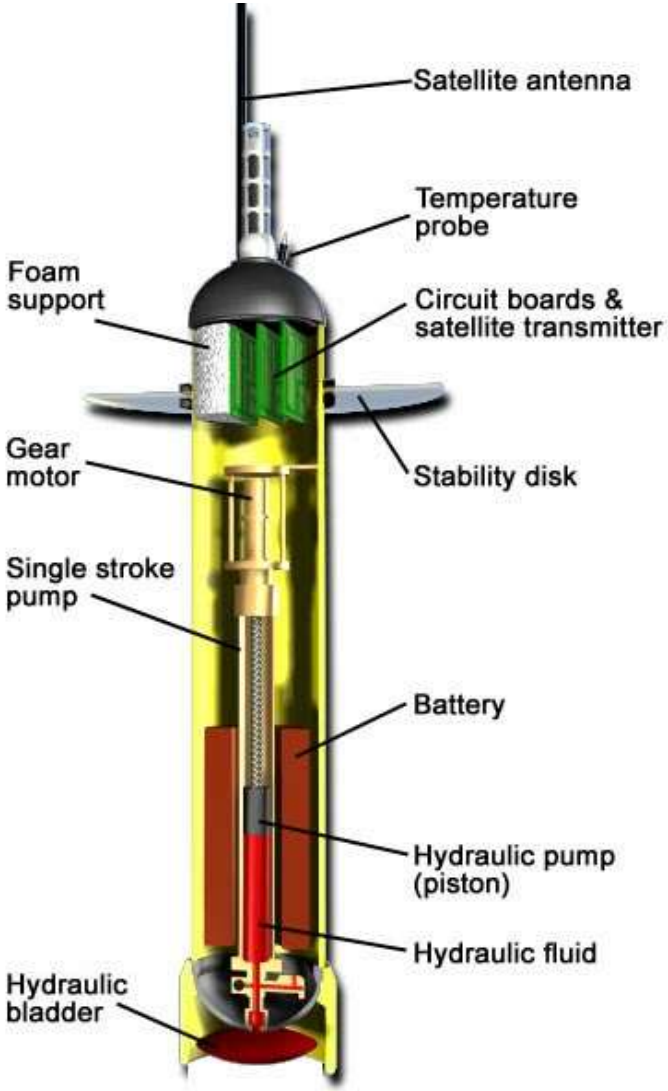
Always remember…

- Satellites **do not** measure temperature.
- Satellites **do not** measure wind speed.
- Satellites **do not** measure salinity.

Satellites measure **amount of radiative energy flux** (radiance) at certain wavelengths.

Radiances have to be converted to the variables we want using mathematical algorithms and corrections. These conversions can be uncertain and prone to error.

Argo floats

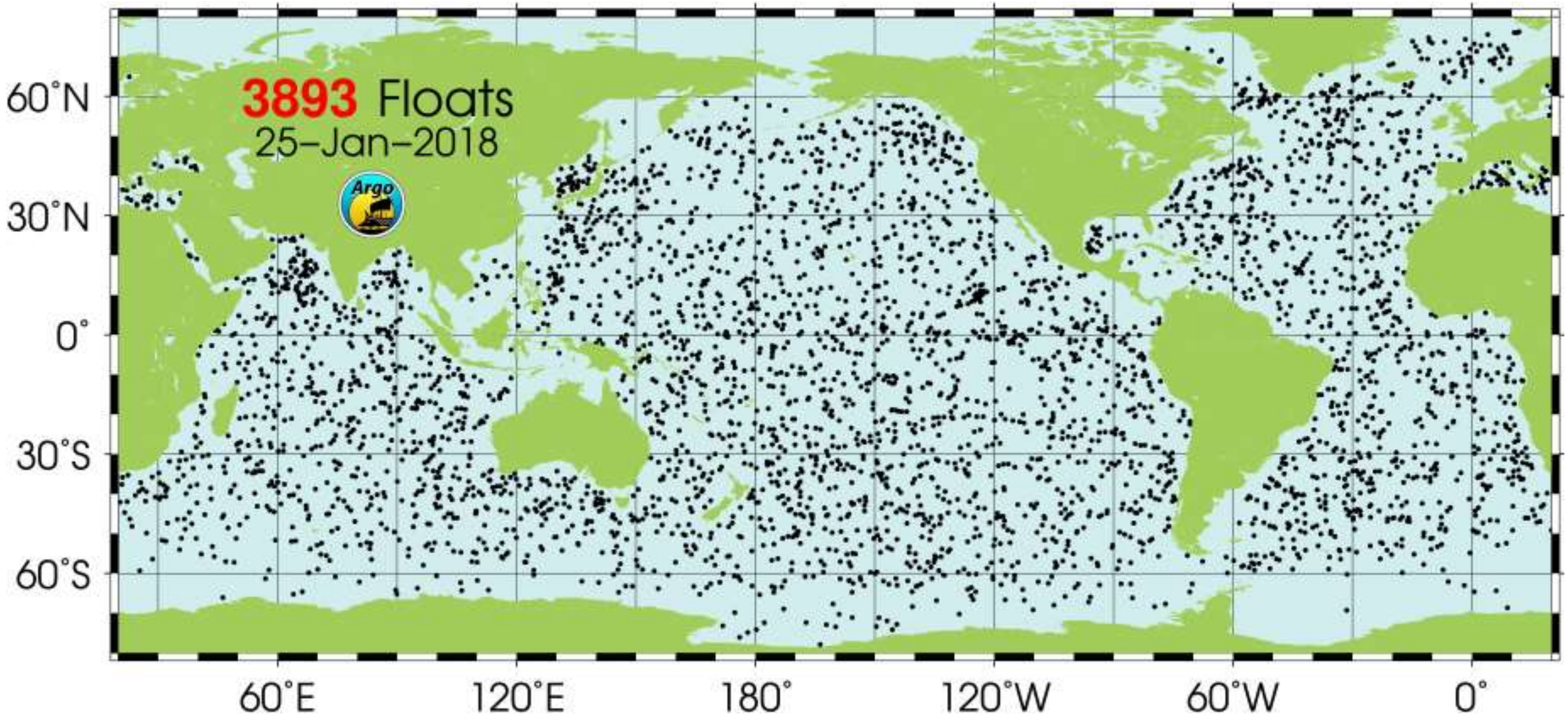


Spends most of its time drifting at a depth of 1000 m.

About every 10 days, the float descends to 2000 m and takes measurements as it rises to the surface.

[Video of float operation]

Positions of Argo floats that reported data in the 30 days before January 25, 2018



from http://www.argo.ucsd.edu/

Argo floats

Floats don't last forever:

A float can go through about 150-200 cycles of ascent and descent before its battery gets too weak.

About 800 new floats must be deployed per year to maintain the current network.

Operating one float costs about $30,000 (about half for the float itself, and half for data processing and infrastructure).

images from jamstec.go.jp