

# Ocean

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ATM2016



# Why do we study ocean?

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- It is interesting in its own right.
- It plays an important role in climate and climate variability.
  - Abrupt climate change
- The air we breathe
  - The ocean produces over half of the world's oxygen and absorbed 50 time more carbon dioxide than the atmosphere

**How the ocean is different from the atmosphere?**

# Difference #1: Type of the fluid

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- **Atmosphere = air : Compressible fluid**
- **Ocean = water : Nearly incompressible**
- Internal energy can go up or down in the compressible fluid (like air) by changing the volume.
- Internal energy can go up or down in the incompressible fluid (like water) by heating or cooling it.

It is interesting to note that if seawater were really incompressible, sea level would be about 50 m higher than it is.

## Difference #2: Latent heat

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- **The atmosphere has moisture.**
  - Moisture can be a source of latent heat.
- **The ocean does not have counterpart to atmospheric moisture.**
  - (Well, latent heat can be release when sea-ice forms.)

# **Polynyas :**

Opening of the ocean  
in the middle of sea ice

**Sea ice free**



**Sea ice**

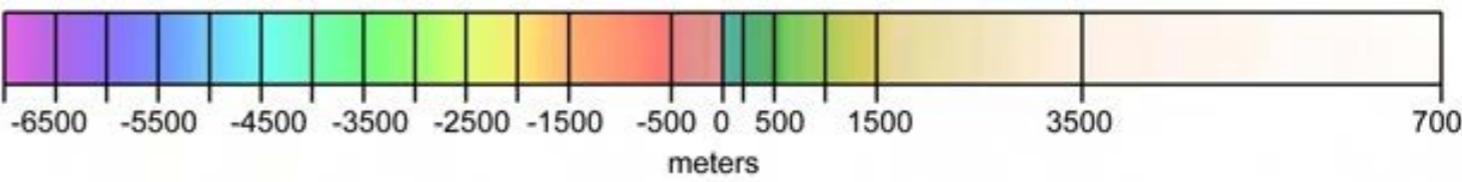
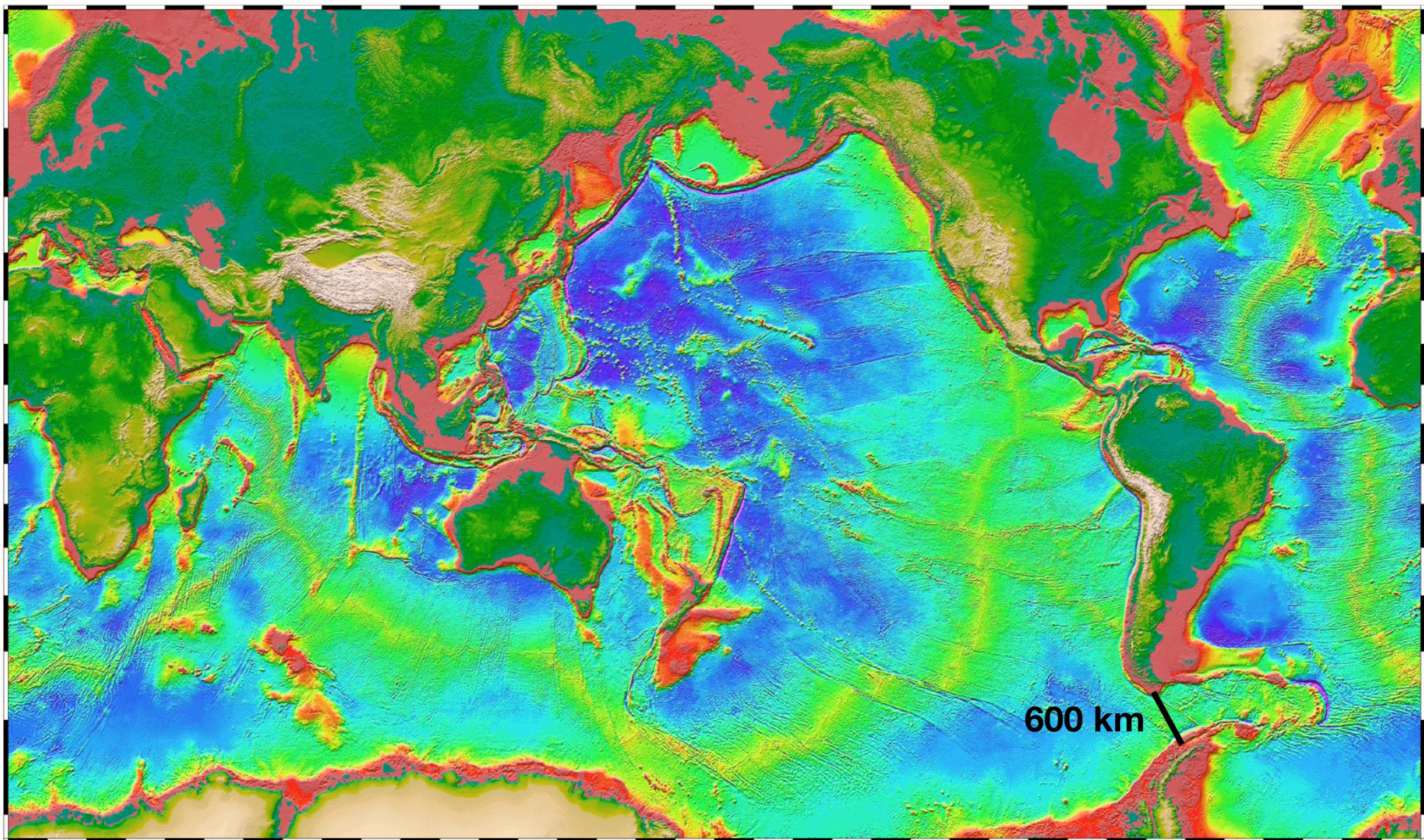
**Antarctica**

## Difference #3: Boundaries

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- **The atmosphere has no boundaries.**
  - The air can flow continuously without being blocked.
- **All oceans are bounded by continents.**
  - (Well, there is one exception: The Southern Ocean.)

# Bathymetry



# Difference #4: Heating

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- **The atmosphere is heated from below.**
  - Convection transport heat upward.
- **The solar radiation heats the ocean surface.**
  - Heating at the surface does not result in convection.
  - If the surface ocean becomes heavy, then convection can happen.

There are sources of geothermal heating at the bottom of the ocean but, in an average sense, this accounts for only a few milliwatts/m<sup>2</sup> of heat input, compared to air-sea heat fluxes of  $\pm 10$  to  $100\text{W/m}^2$ .

## Difference #5: Stress

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- **The atmosphere does not get a stress from the ocean.**
  - The air flows according to the state of the atmosphere.
- **The ocean can be driven by winds.**
  - Winds blowing over the ocean surface exert a stress.
  - The wind is a major driver of ocean circulation.

# **Physical characteristics of the ocean**

# 1. The ocean basins

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- The ocean covers 71% of the Earth's surface.
- Mean depth is 3.7 km
- The ocean's bottom topography is rougher than the land's surface.
- The ocean has huge heat capacity, approximately 1000 times that of the atmosphere.

## 2. The cryosphere

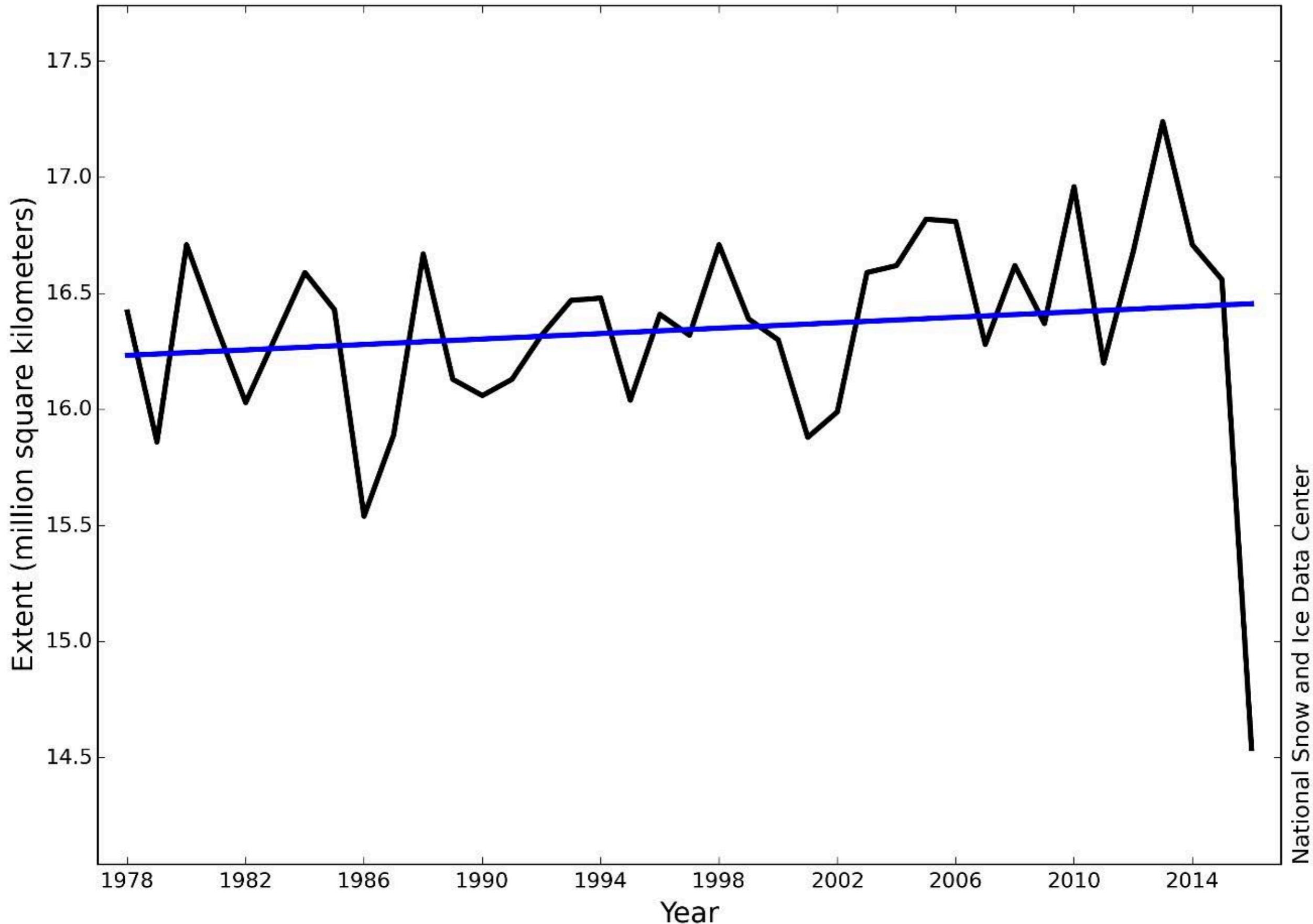
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- Originated from Greek, it means “cold” “globe”.
- About 2% of the water is frozen in different forms like
  - Ice sheets, sea ice, snow, glaciers, frozen ground.
- Antarctica has 89% of frozen water. (The average depth of the ice sheet is 2 km.)
- It plays an important role in climate system with high albedo (70%).



# Average Monthly Antarctic Sea Ice Extent

## November 1978 - 2016



### 3. Salinity

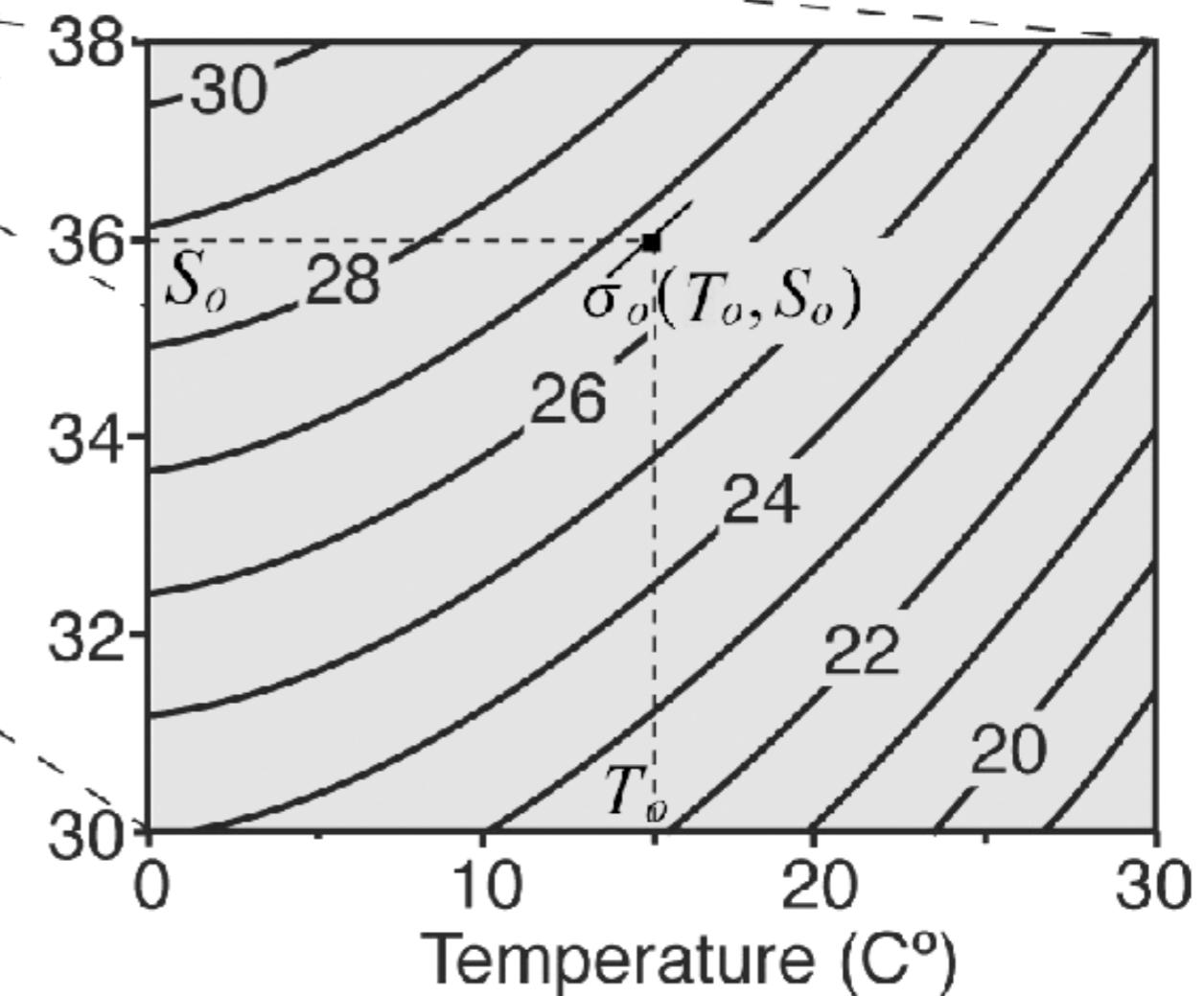
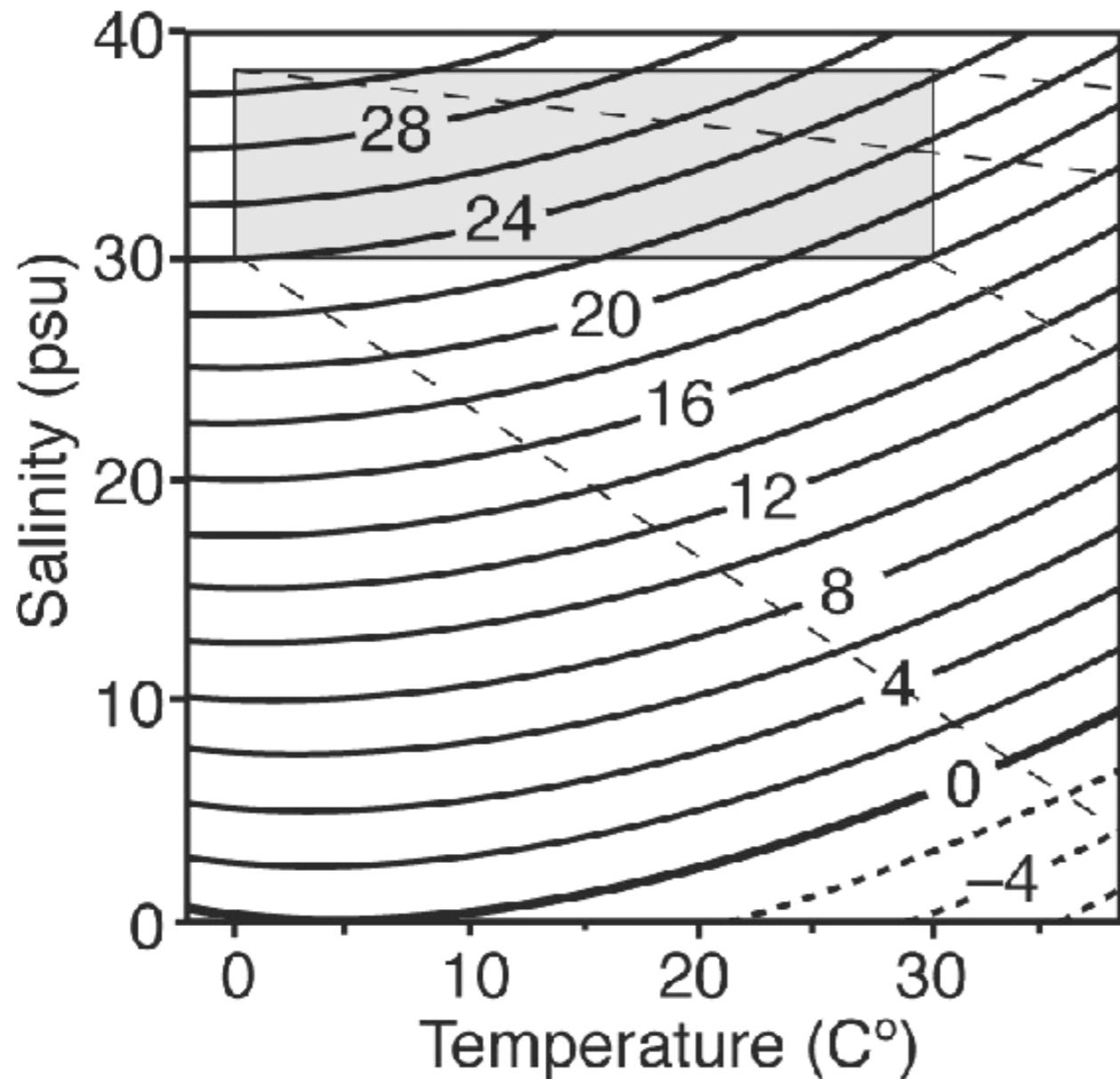
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- A measure of amount of salt dissolved in the ocean
- The unit of salinity is about the ratio of salt in the water:
  - psu, g/kg, ‰
- The typical salinity is 34.5 psu = 34.5g of salt in 1kg of water.

## 4. The density

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- The density of pure water at 4°C  $\approx 1000 \text{ kg m}^{-3}$
- The mean density of the ocean  $\approx 1035 \text{ kg m}^{-3}$ , and varies very little.
- The density depends on temperature (T), salinity (S) and pressure (P) in a nonlinear manner :  $\rho = \rho(T, S, P) \rightarrow$  determined from lab measurements.
- The widely used property is density anomaly :  
$$\sigma = \rho - \rho_{\text{ref}} = \rho - 1000 \text{ kg m}^{-3}$$



Contours of seawater density anomalies ( $\sigma$ )

## 4. The density

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- Salty water is more dense than fresh water.
- Warm water is less dense than cold water.
- Fresh water has the maximum density at 4°C.
  - This is why ice forms on the top of freshwater lakes.
  - Typically, temperature has greater impact on the density because it varies over the wide range (0 - 30°C)

# Sensitivity of density to T and S

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$$\alpha_T = -\frac{1}{\rho_{ref}} \frac{\partial \rho}{\partial T}$$

$$\beta_S = \frac{1}{\rho_{ref}} \frac{\partial \rho}{\partial S}$$

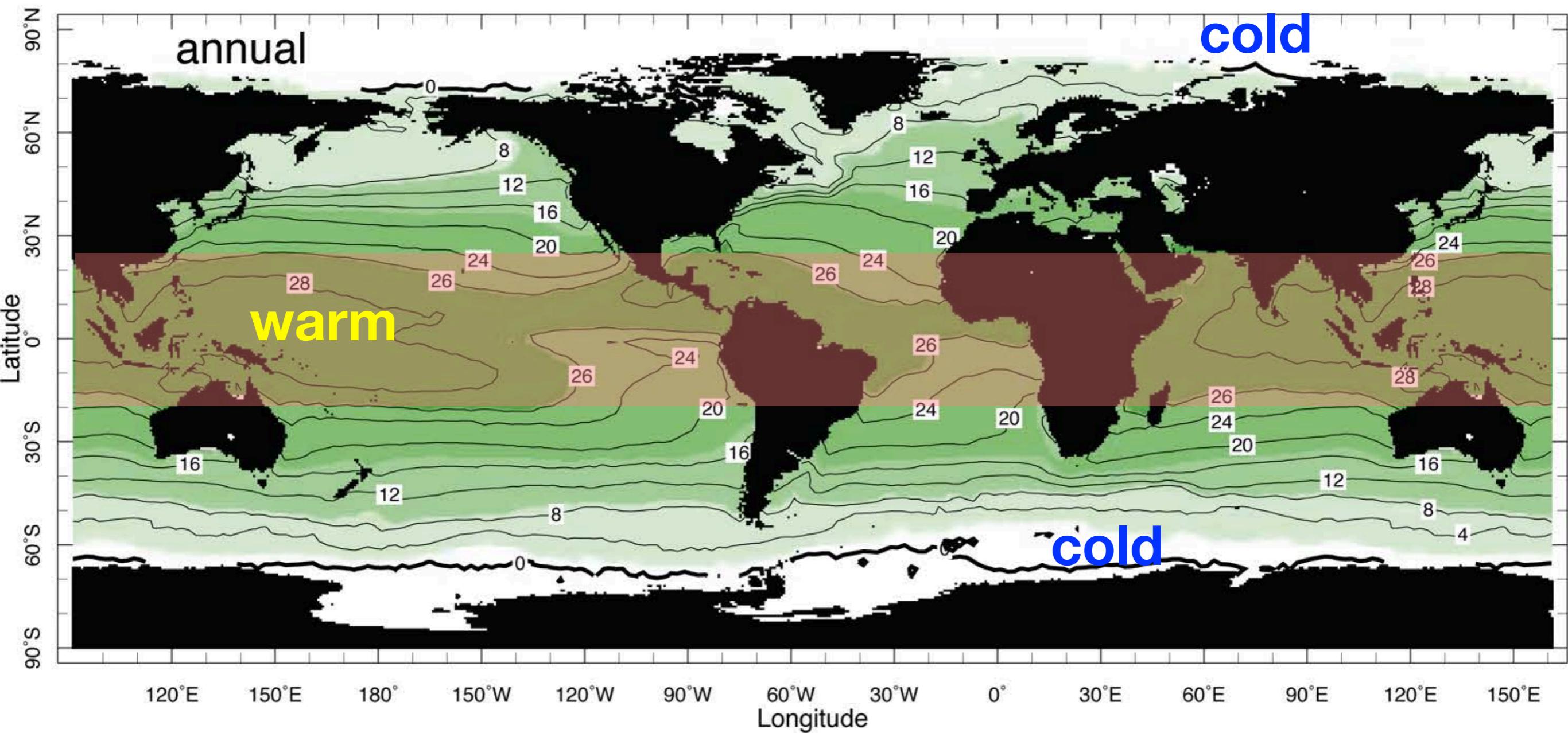
Surface				
$T_o$ (°C)	-1.5	5	15	
$\alpha_T$ ( $\times 10^{-4} \text{ K}^{-1}$ )	0.3	1	2	
$S_o$ (psu)	34	36	38	
$\beta_S$ ( $\times 10^{-4} \text{ psu}^{-1}$ )	7.8	7.8	7.6	
$\sigma_o$ ( $\text{kg m}^{-3}$ )	28	29	28	
Depth of 1 km				
$T_o$ (°C)	-1.5	3	13	
$\alpha_T$ ( $\times 10^{-4} \text{ K}^{-1}$ )	0.65	1.1	2.2	
$S_o$ (psu)	34	35	38	
$\beta_S$ ( $\times 10^{-4} \text{ psu}^{-1}$ )	7.1	7.7	7.4	
$\sigma_o$ ( $\text{kg m}^{-3}$ )	-3	0.6	6.9	

$$\sigma = \sigma_0 + \rho_{ref} \left( \alpha_T [T - T_0] + \beta_S [S - S_0] \right)$$

## 5. Temperature structure

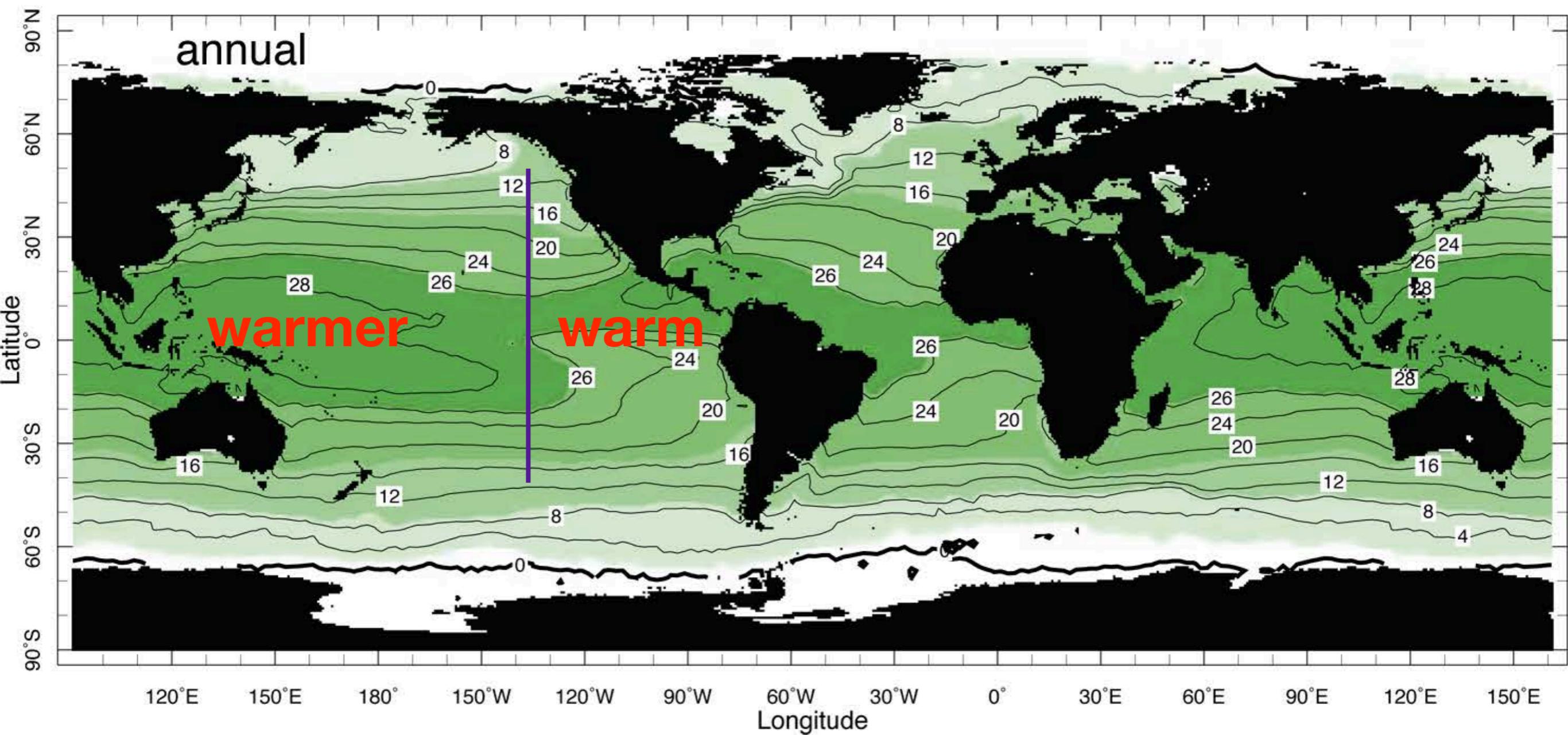
Low albedo → heating at the surface

Sea Surface Temperature ( $^{\circ}\text{C}$ )



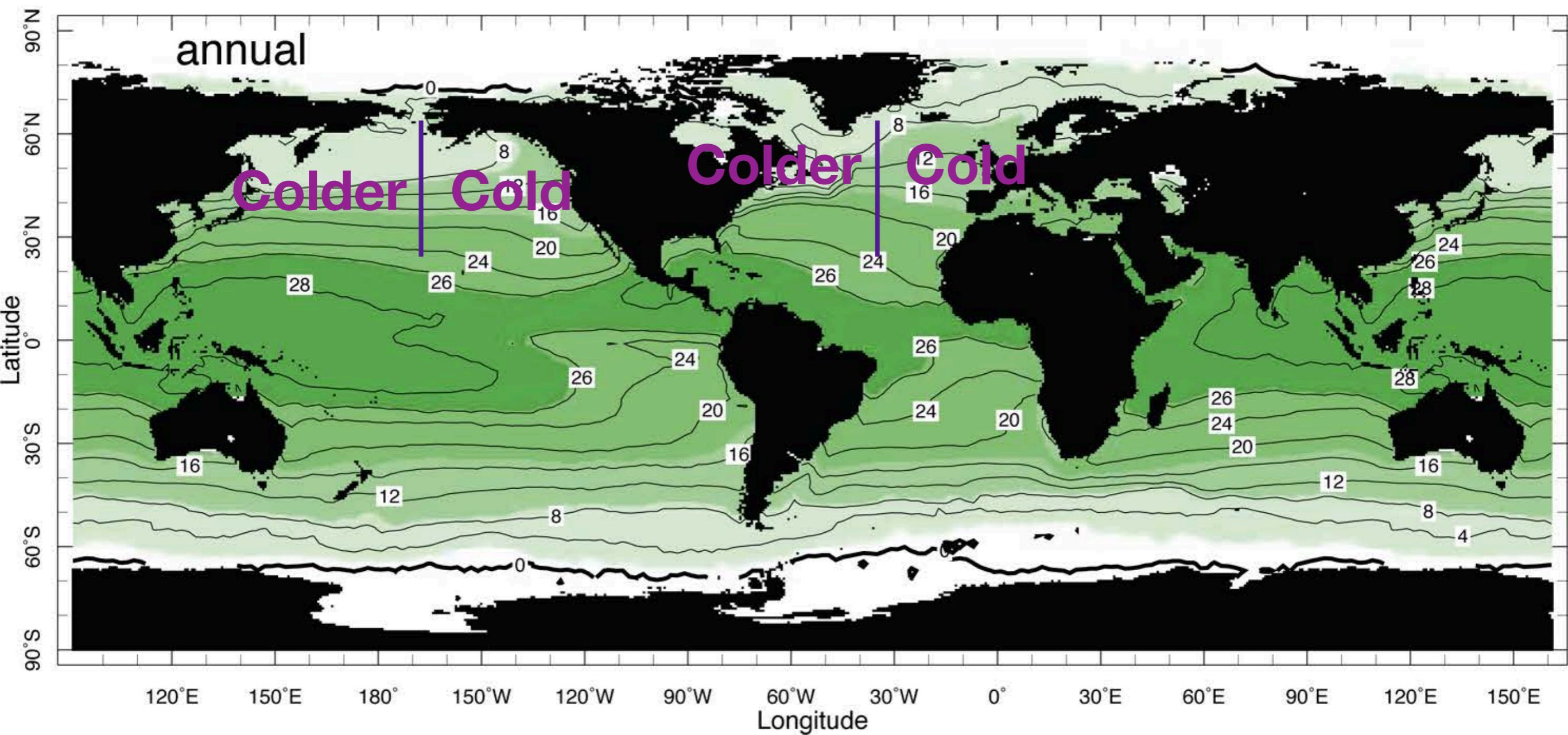
## 5. Temperature structure

Sea Surface Temperature ( $^{\circ}\text{C}$ )



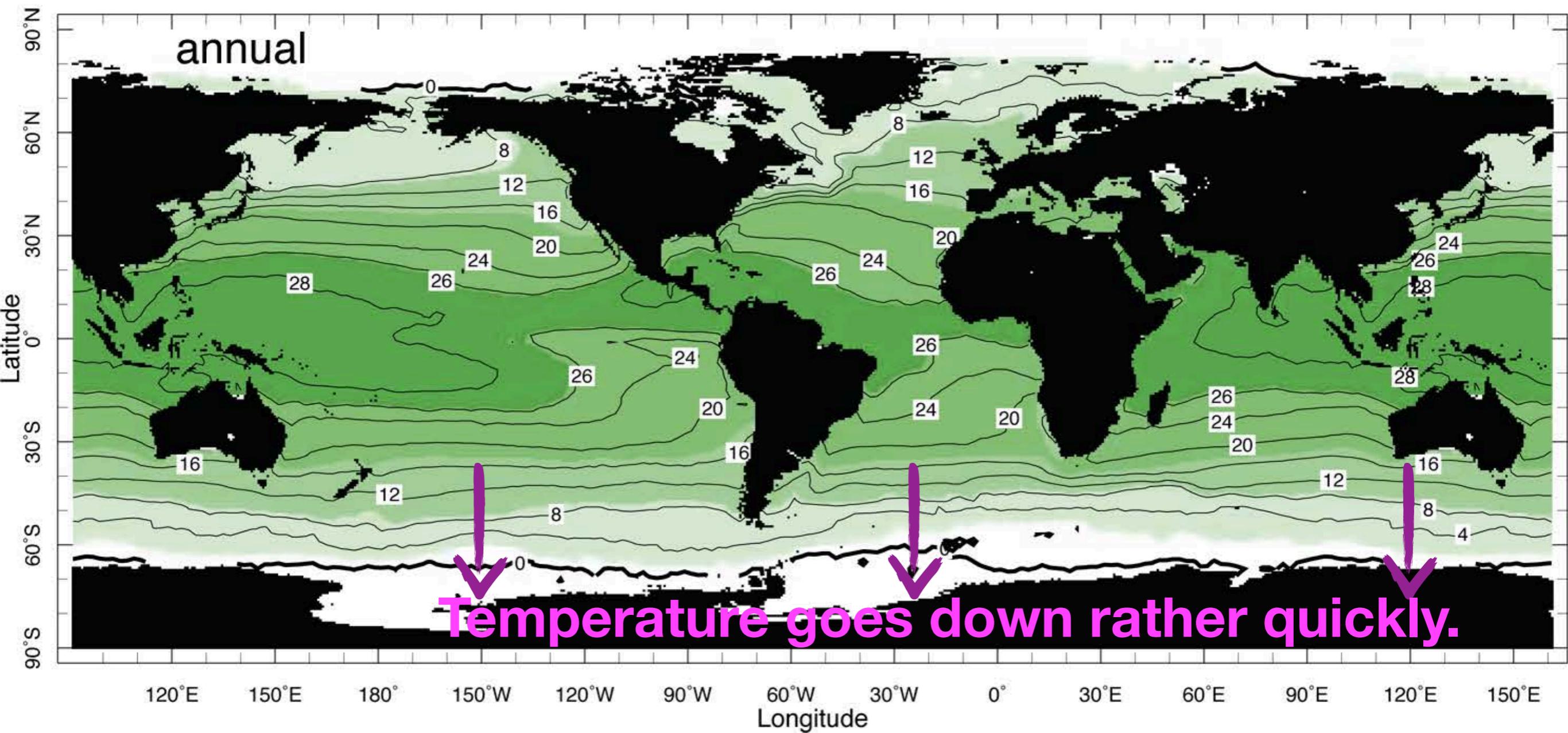
## 5. Temperature structure

Sea Surface Temperature ( $^{\circ}\text{C}$ )

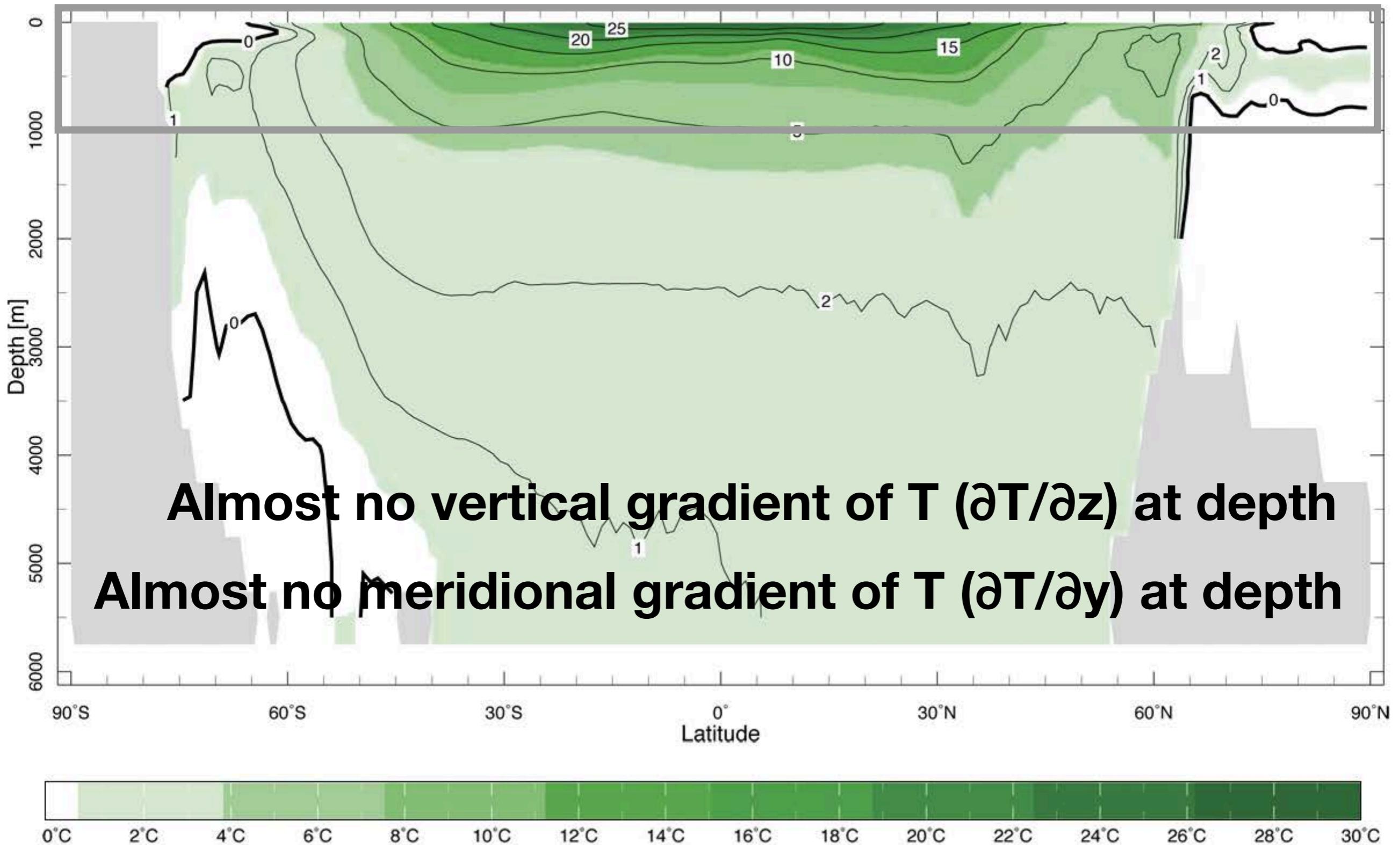


## 5. Temperature structure

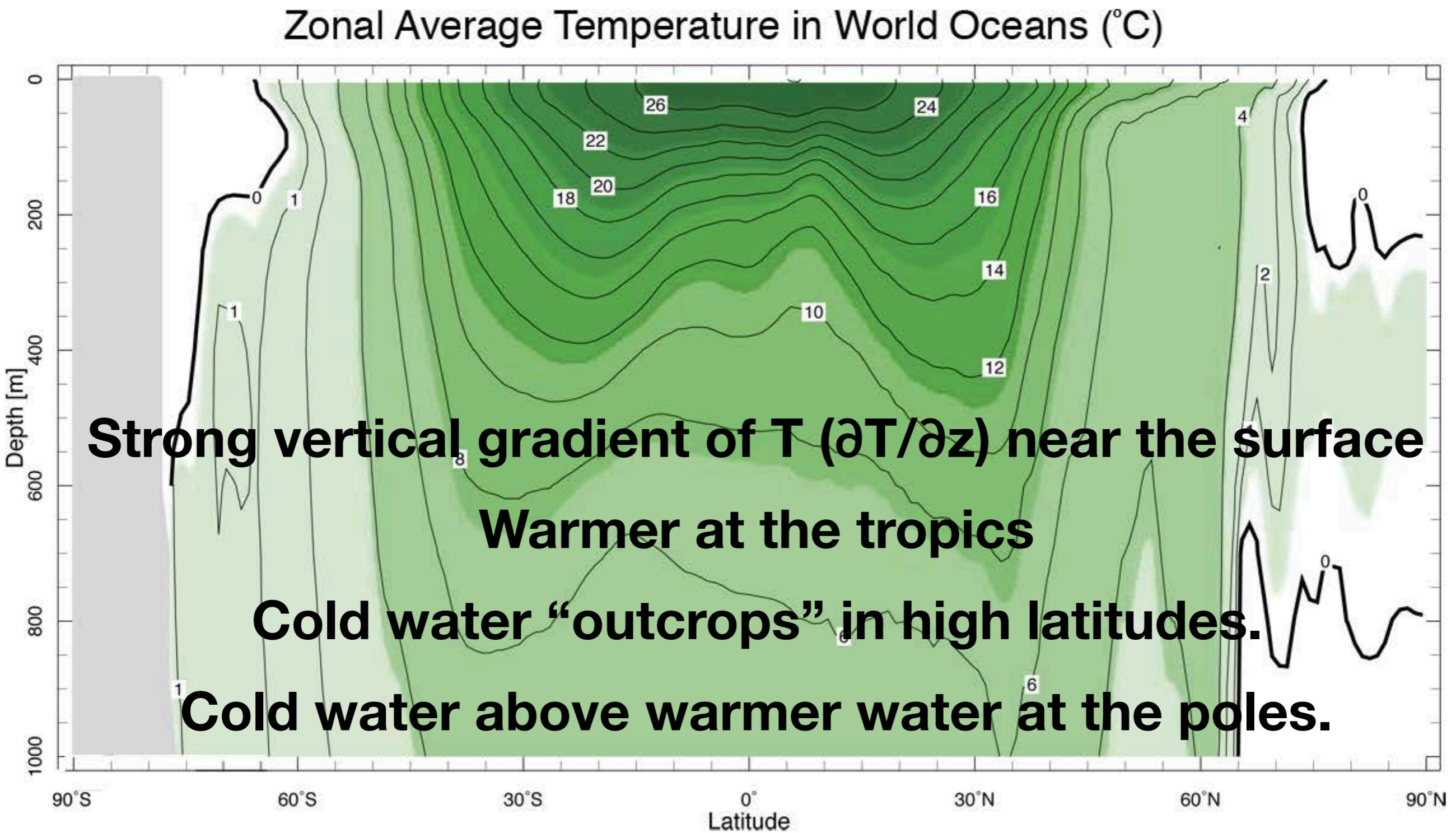
Sea Surface Temperature ( $^{\circ}\text{C}$ )



## 5. Temperature structure: zonal-average mean



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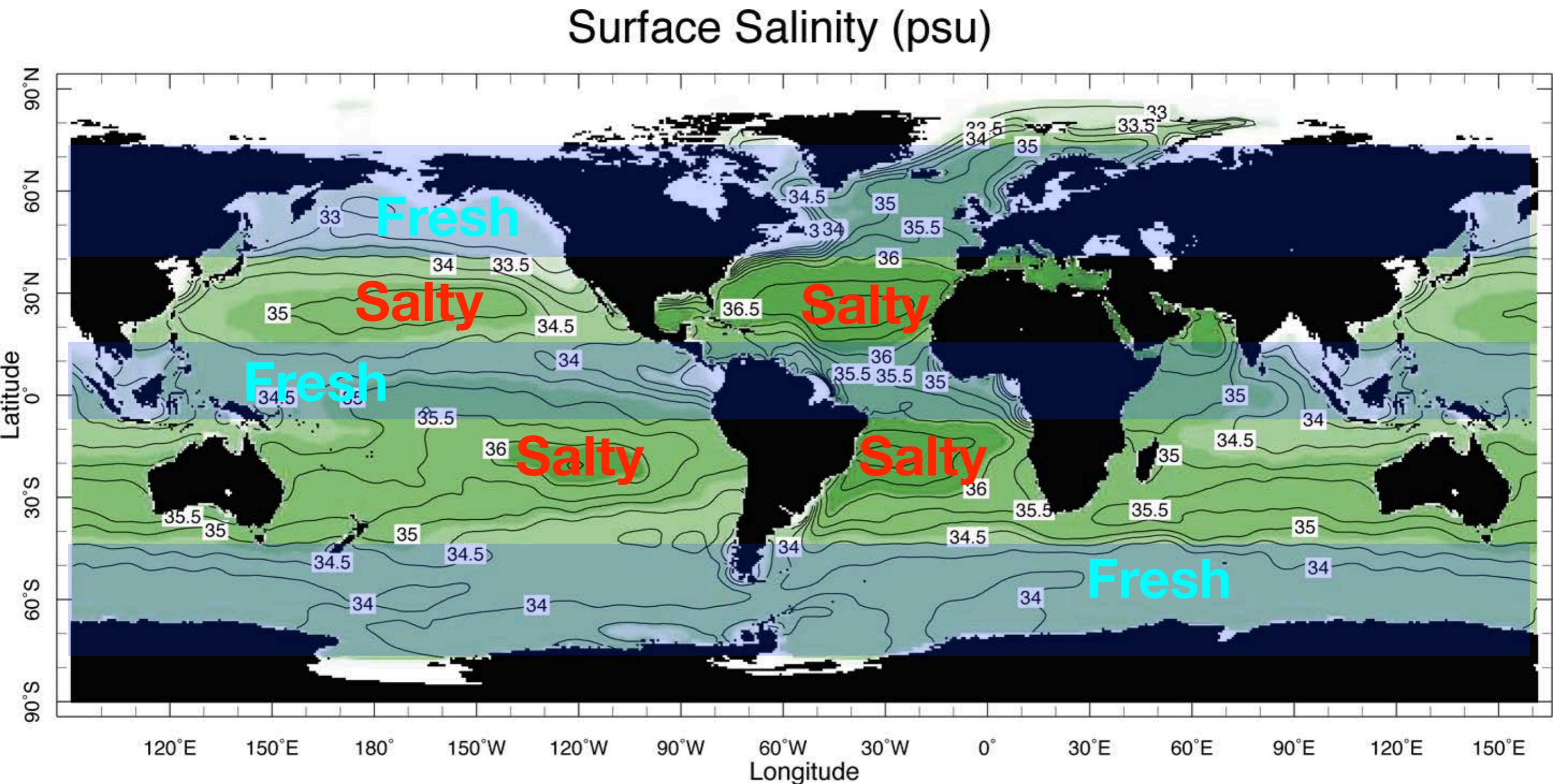
2017

polynya →

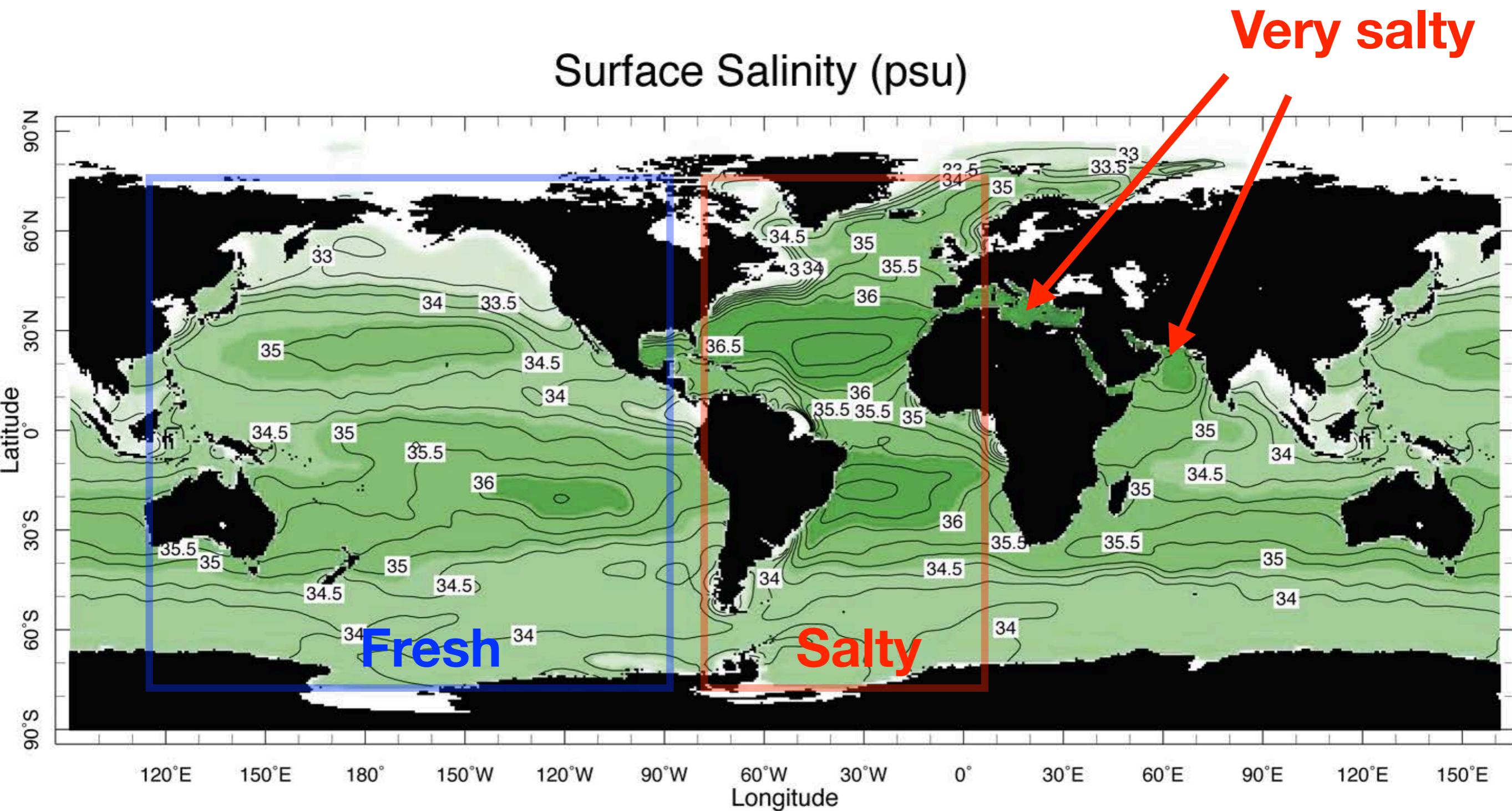


Antarctica

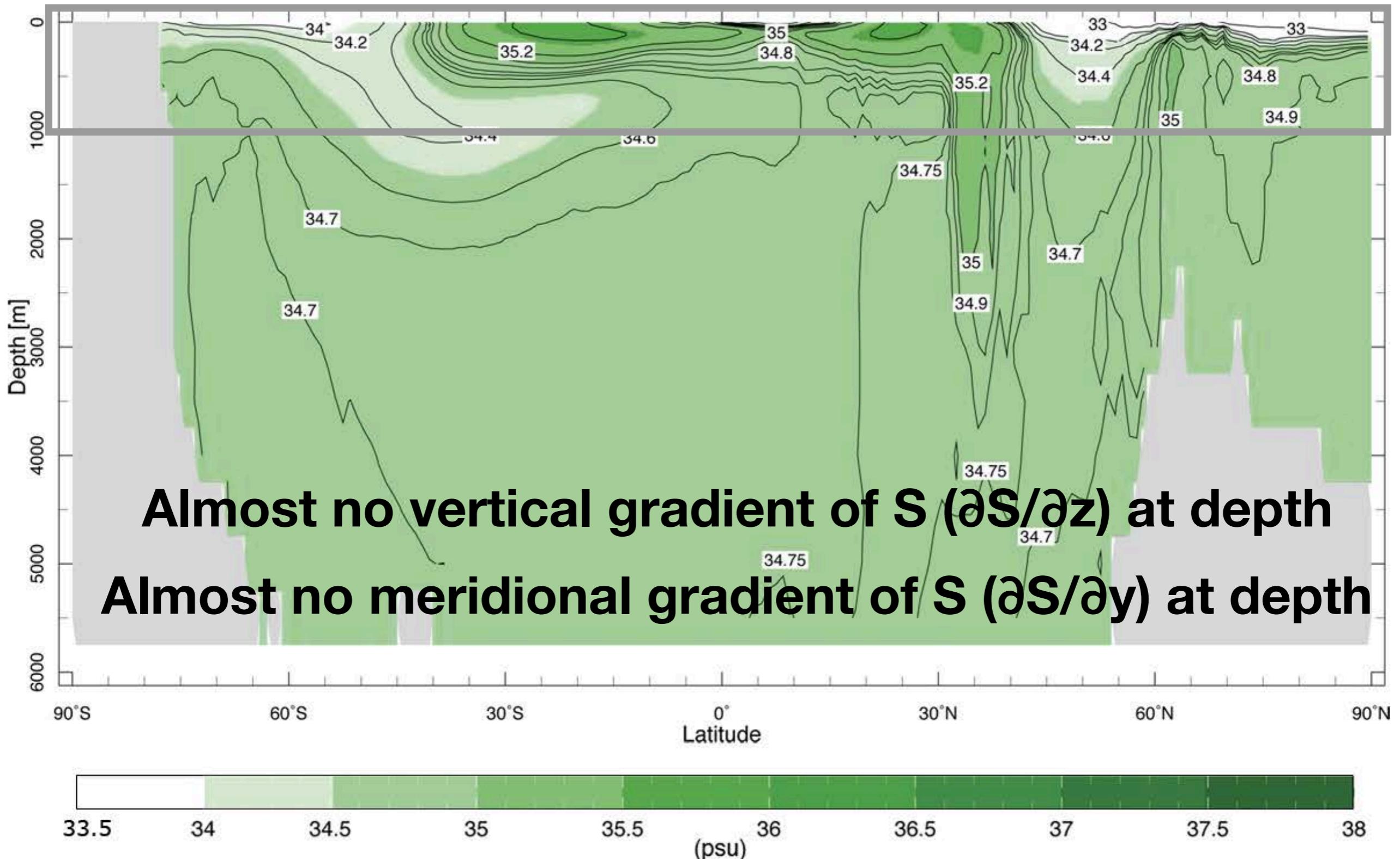
## 5. Salinity structure



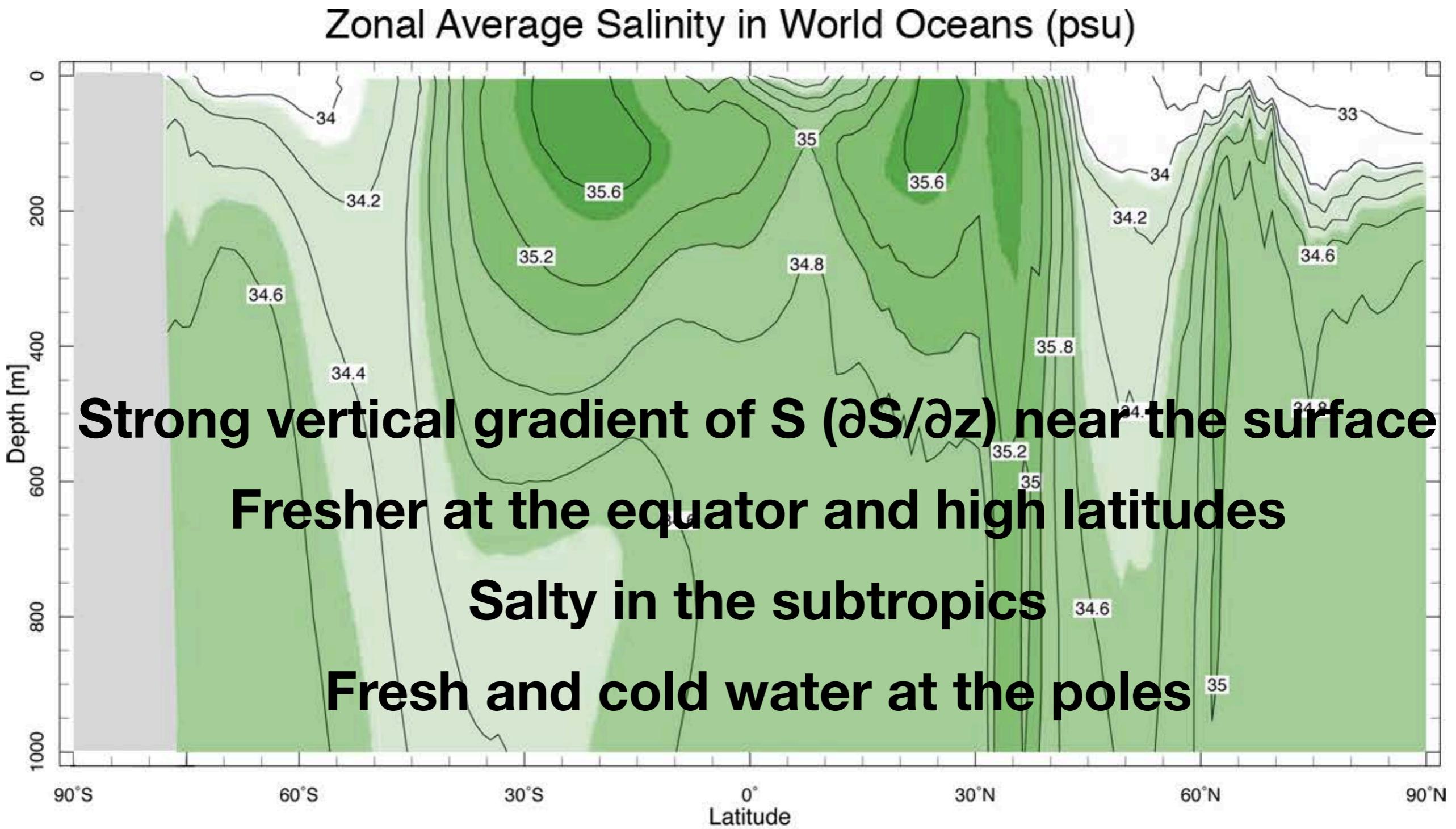
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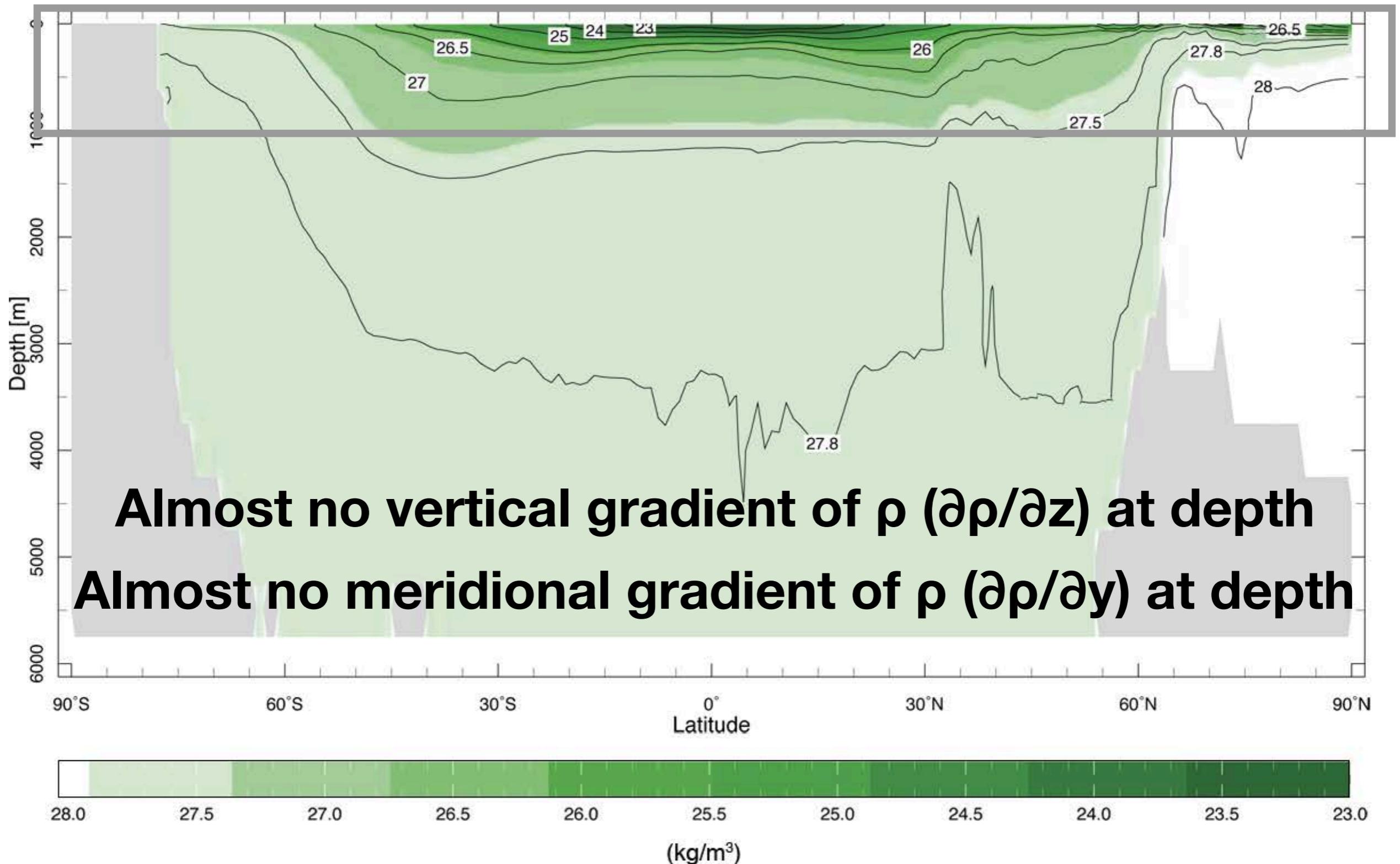
## 5. Salinity structure : zonal-average mean



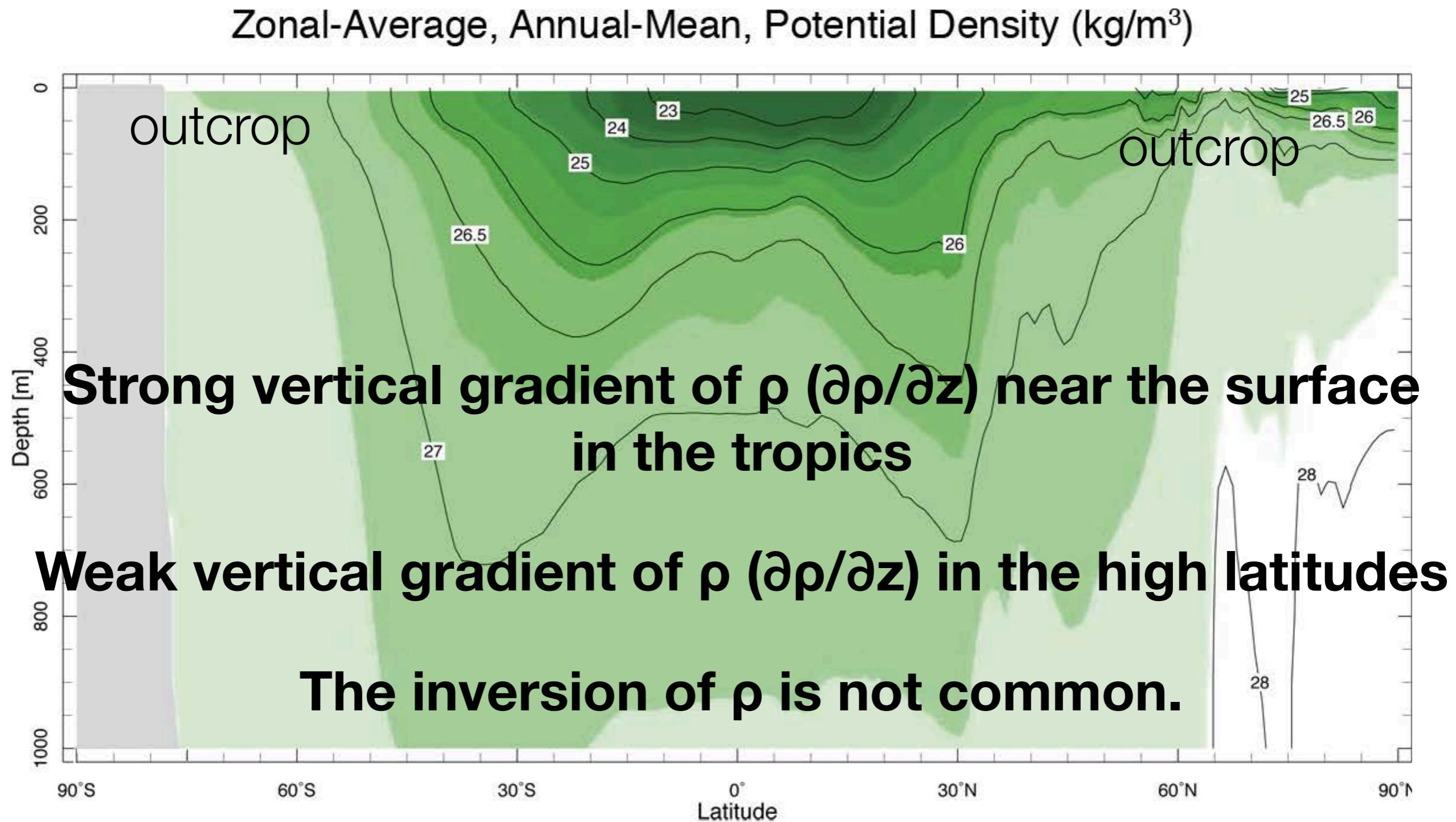
## 5. Salinity structure : zonal-average mean



## 6. Density structure : zonal-average mean

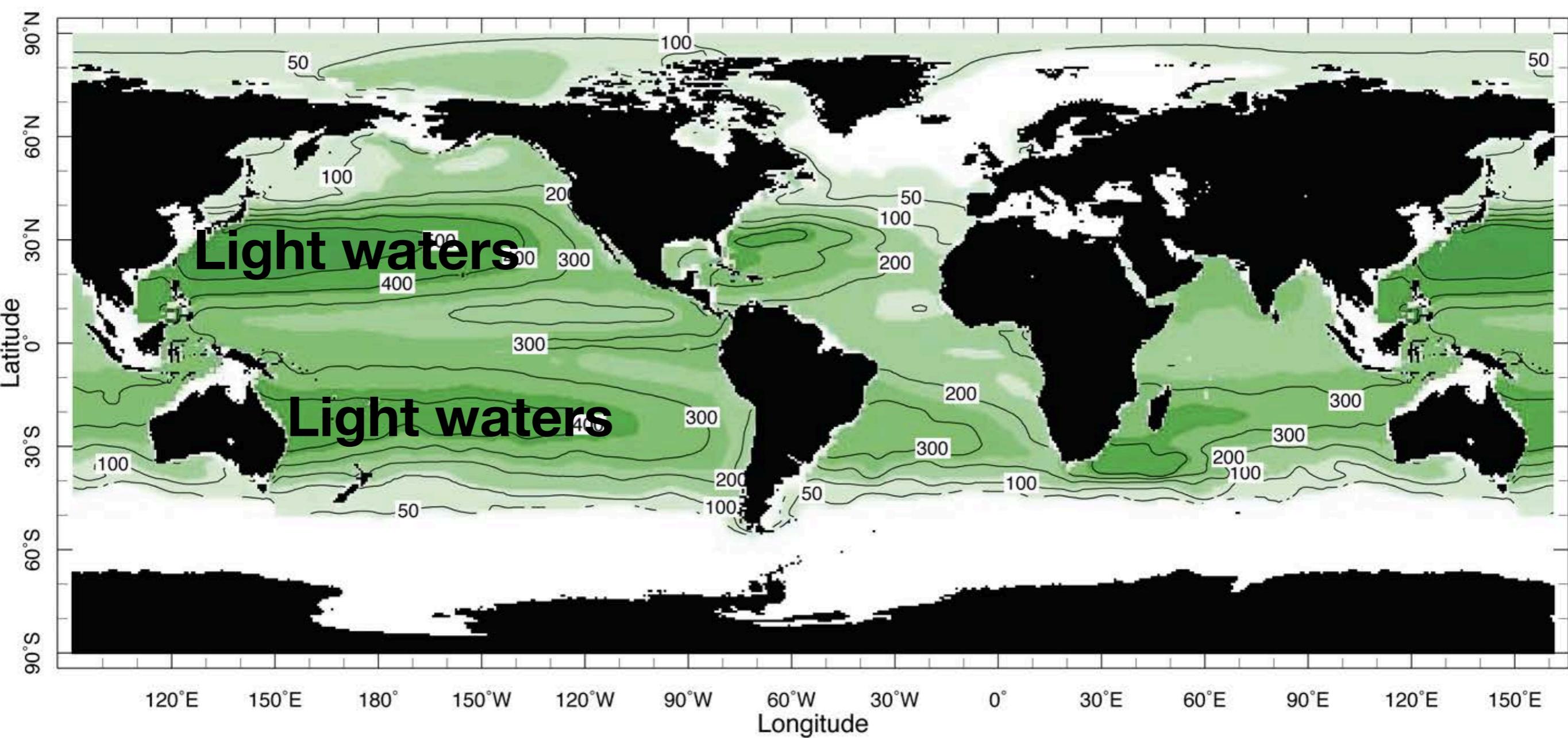


## 6. Density structure : zonal-average mean



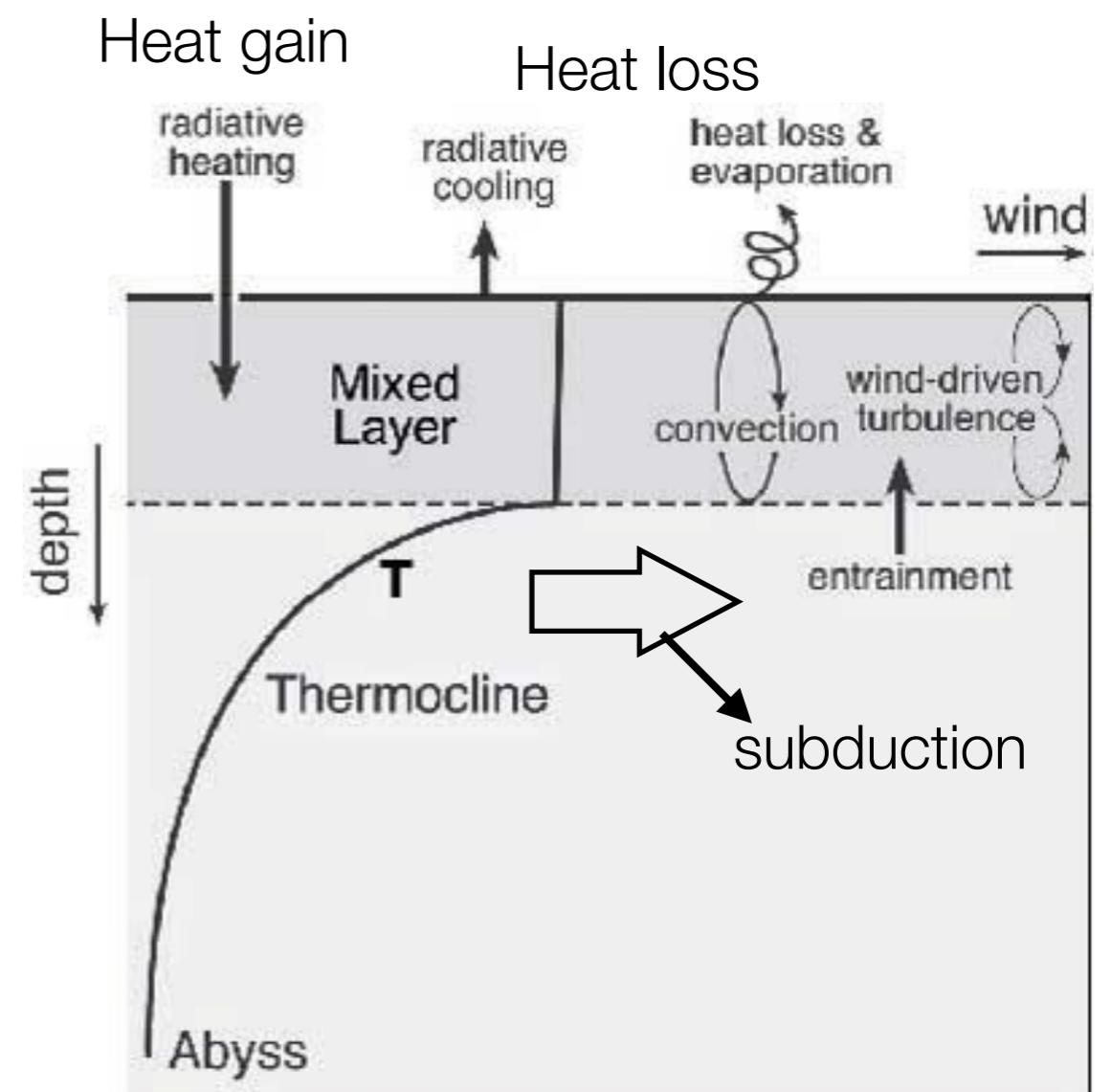
## 6. The depth of 26.5 density surface

Depth of 26.5 Density Surface (m)



# The mixed layer

- At the surface of the ocean, there is a well-defined mixed layer.
- Stirred by wind and convection
- Properties are relatively uniform in the vertical.
- Communicates with thermocline (in high latitudes, with abyss)



IR is absorbed within a few mm, blue/green light may penetrate to almost 100m in especially clear water, but is usually attenuated much more rapidly.

# Buoyancy

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- An upward force

$$b = -g \frac{\rho_p - \rho_e}{\rho_p}$$

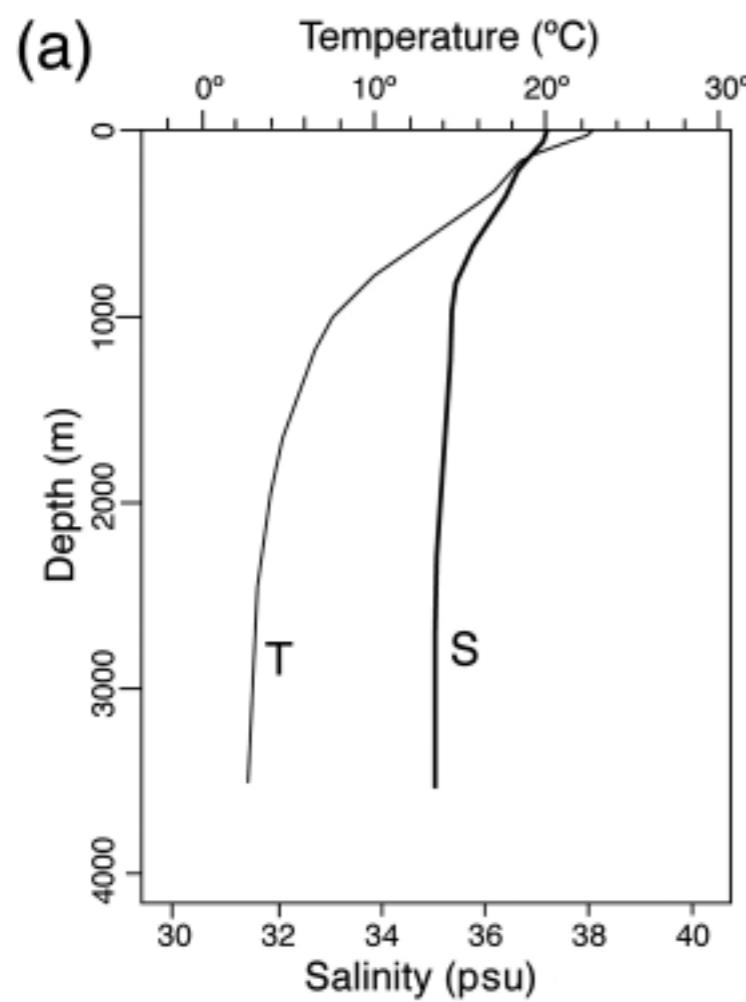
- Buoyancy loss  $\rightarrow$  sink
- Buoyancy gain  $\rightarrow$  float
- Buoyancy frequency :

$$N^2 = -\frac{g}{\rho_{ref}} \frac{\partial \rho_e}{\partial z} \approx g \alpha_T \frac{\partial T}{\partial z}$$

# Buoyancy frequency

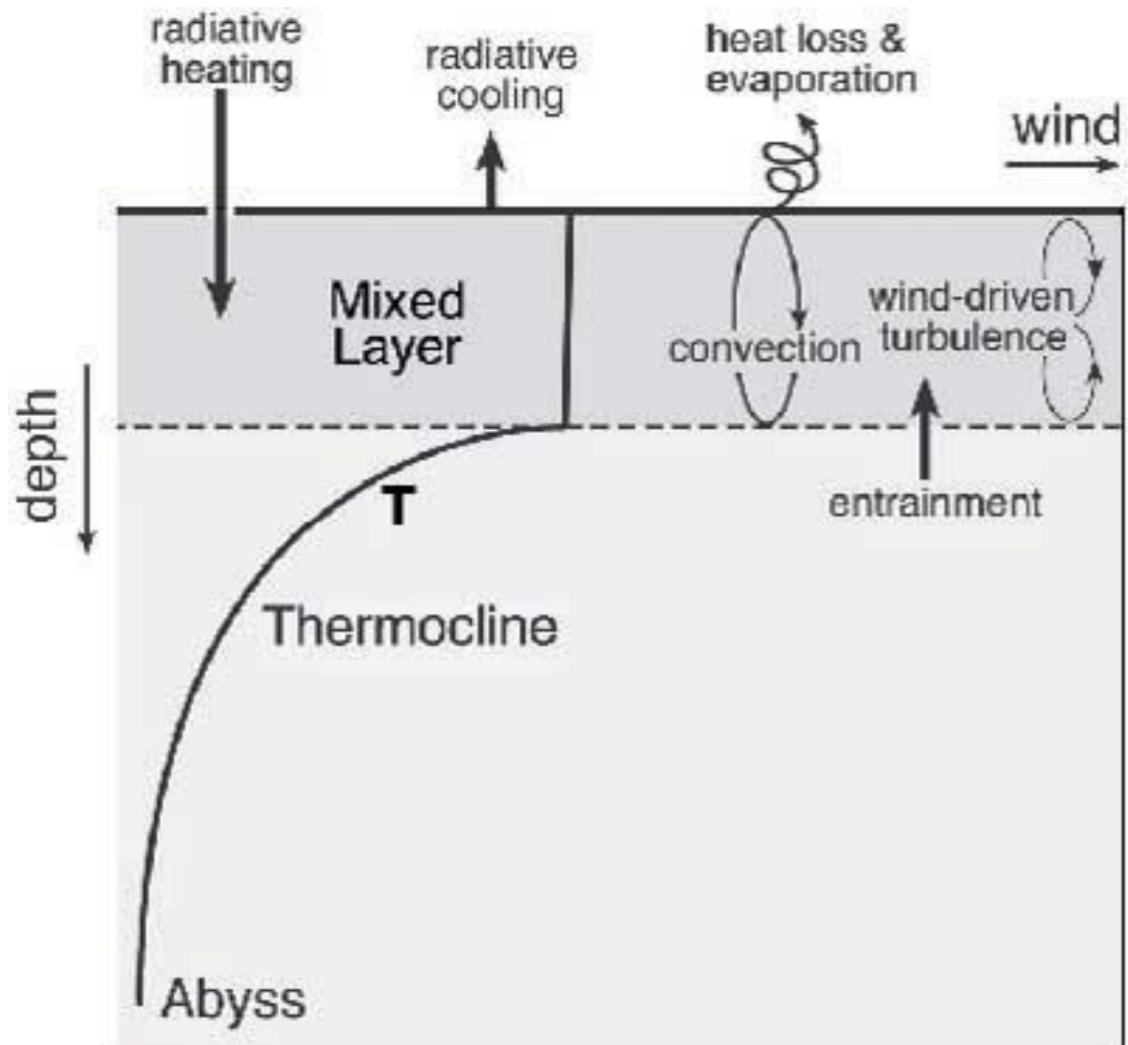
$$N^2 = - \frac{g}{\rho_{ref}} \frac{\partial \rho_e}{\partial z} \approx g \alpha_T \frac{\partial T}{\partial z} = 10 \times 2 \times 10^{-4} \times \frac{15}{1000} = 30 \times 10^{-6} \text{ s}^{-2}$$

$\downarrow$   
 $2 \times 10^{-4} \text{ K}^{-1}$

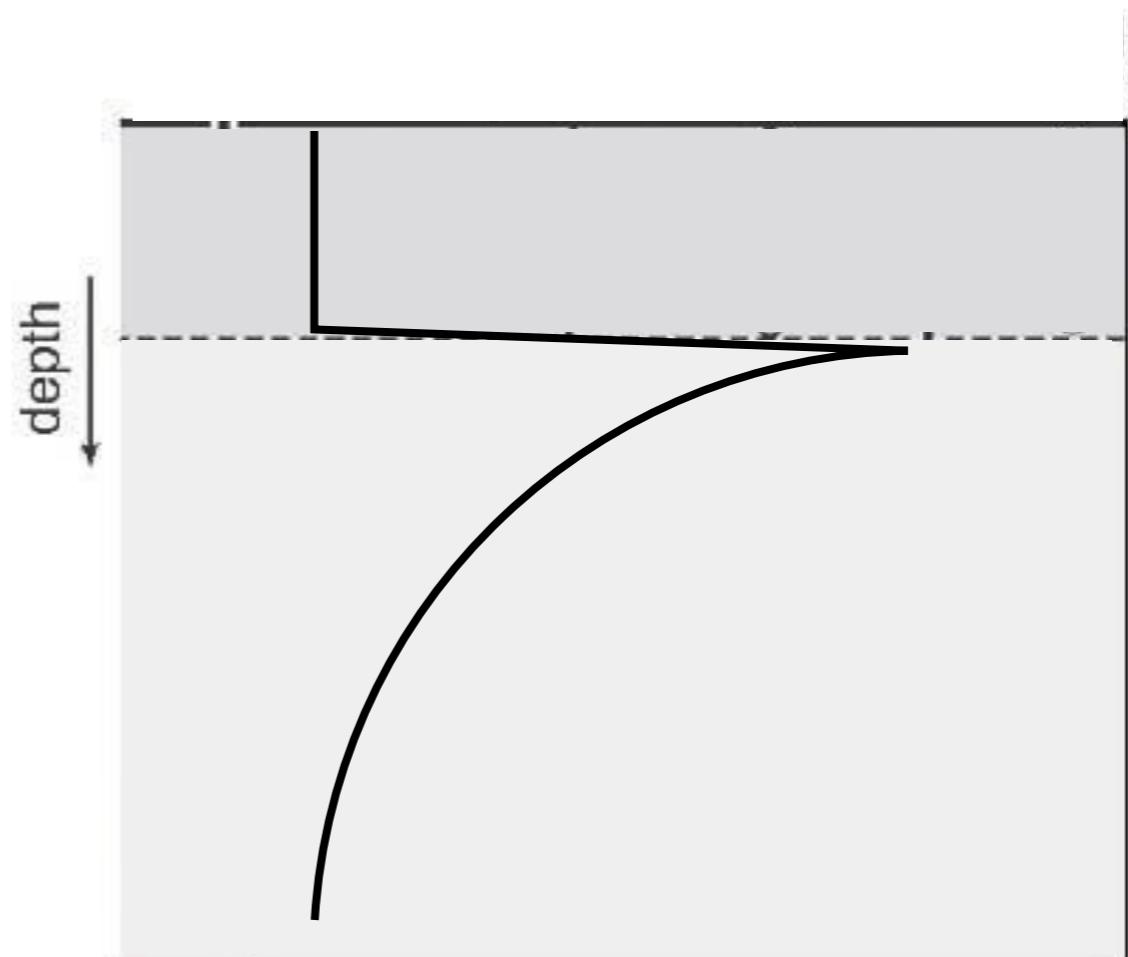


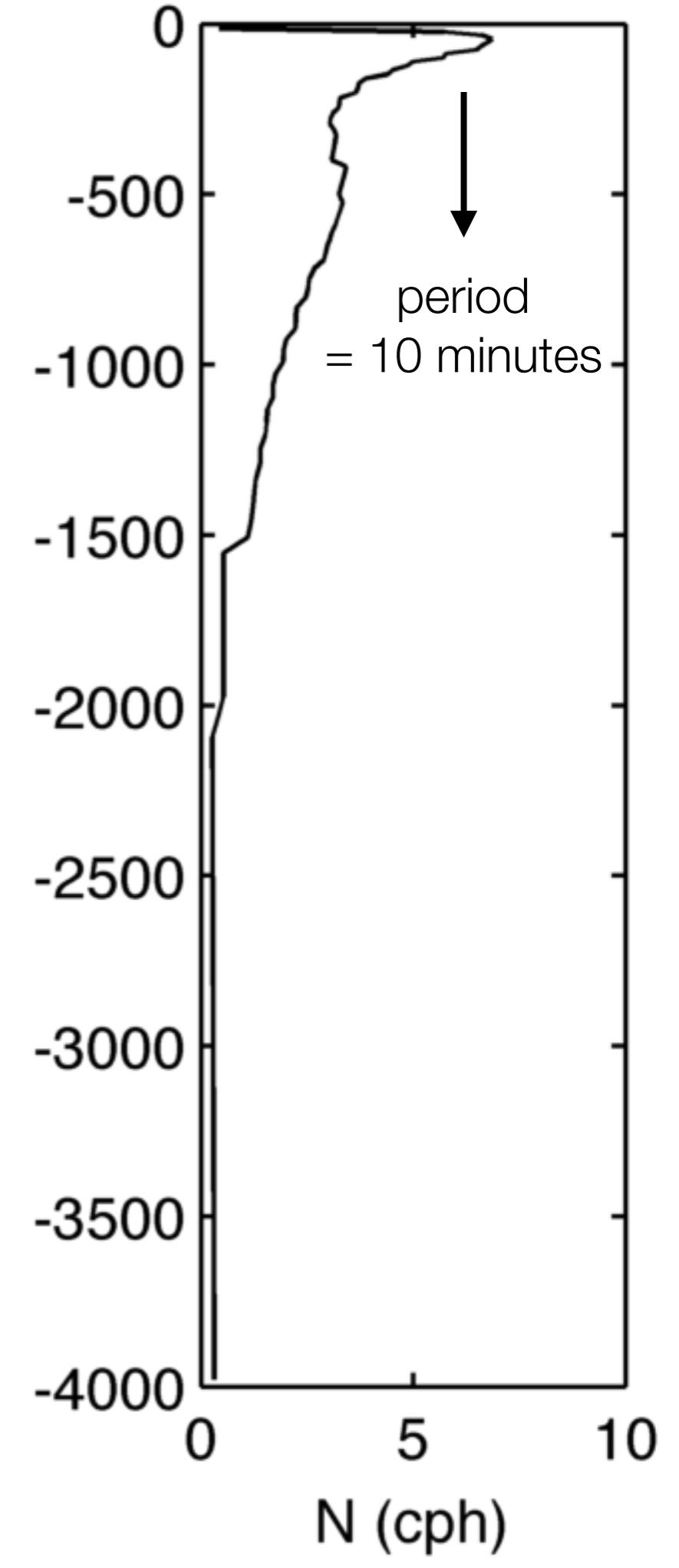
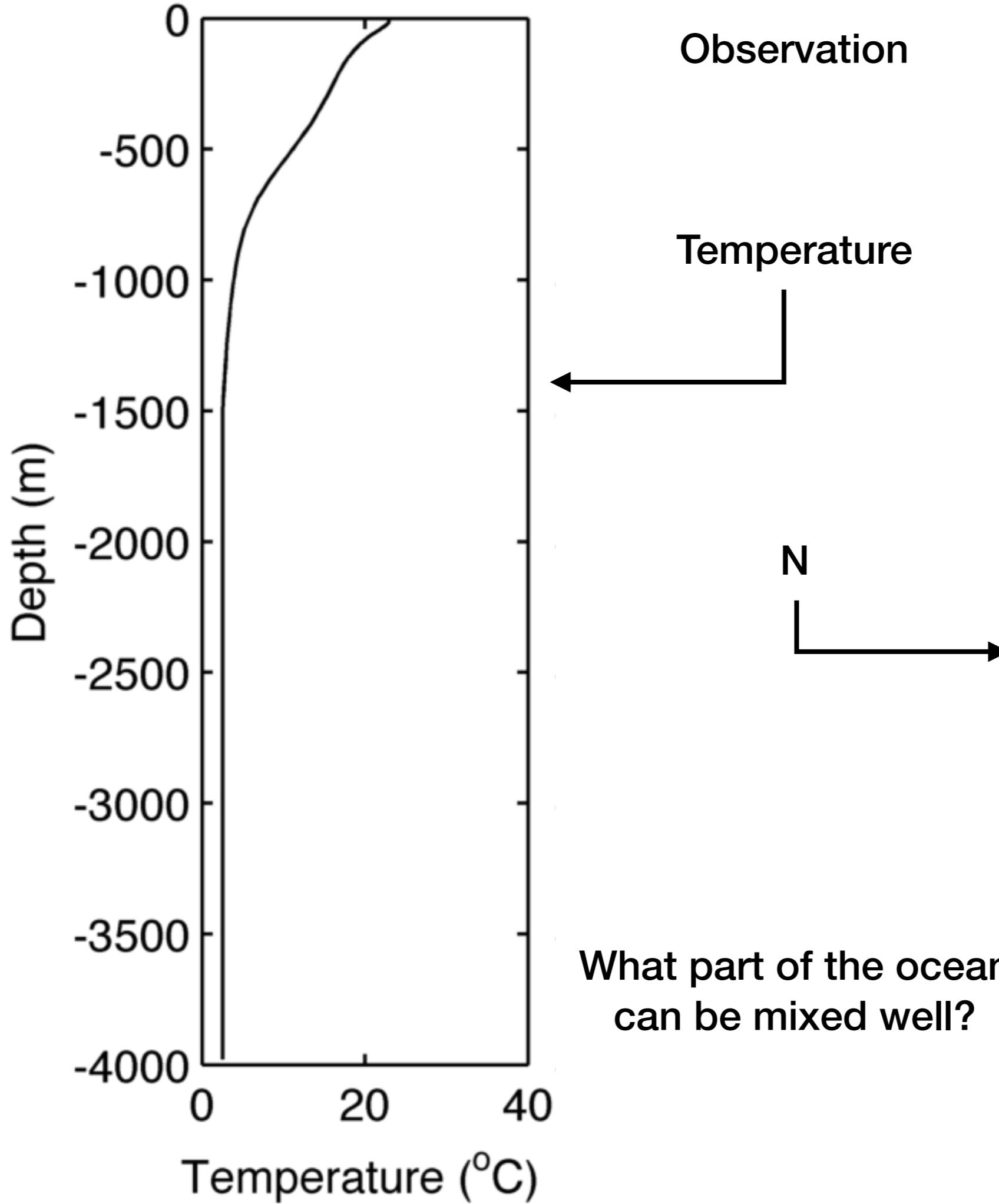
$$\begin{aligned} \text{Period} &= 2\pi / N \\ &= 20 \text{ mins} \end{aligned}$$

# Temperature



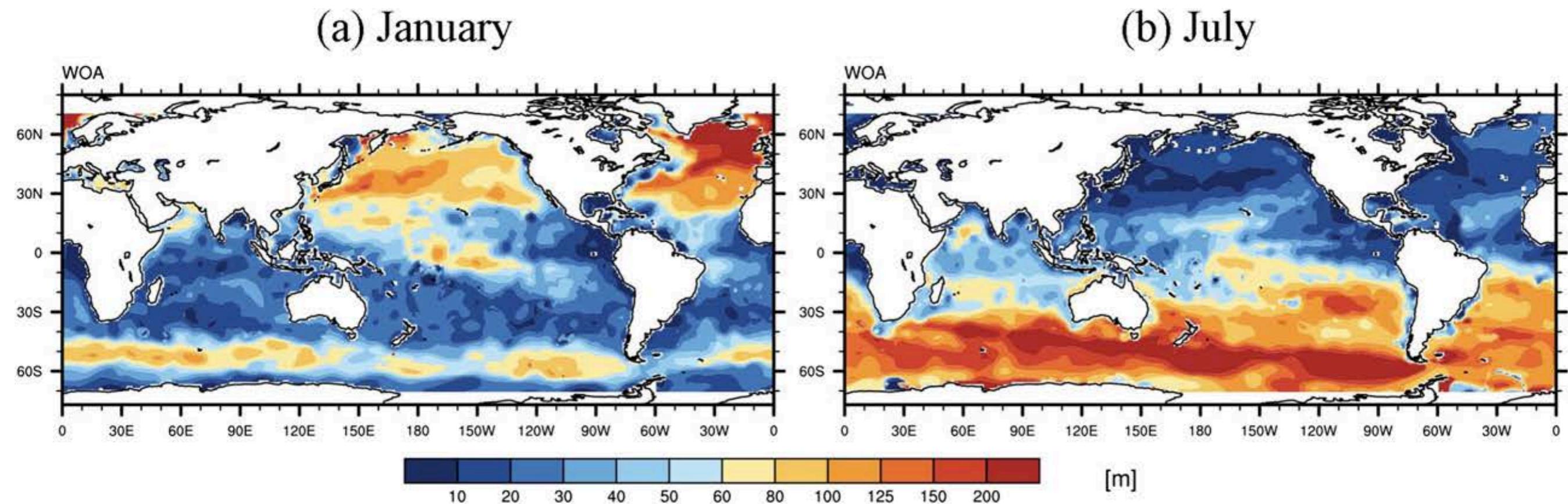
# Buoyancy frequency



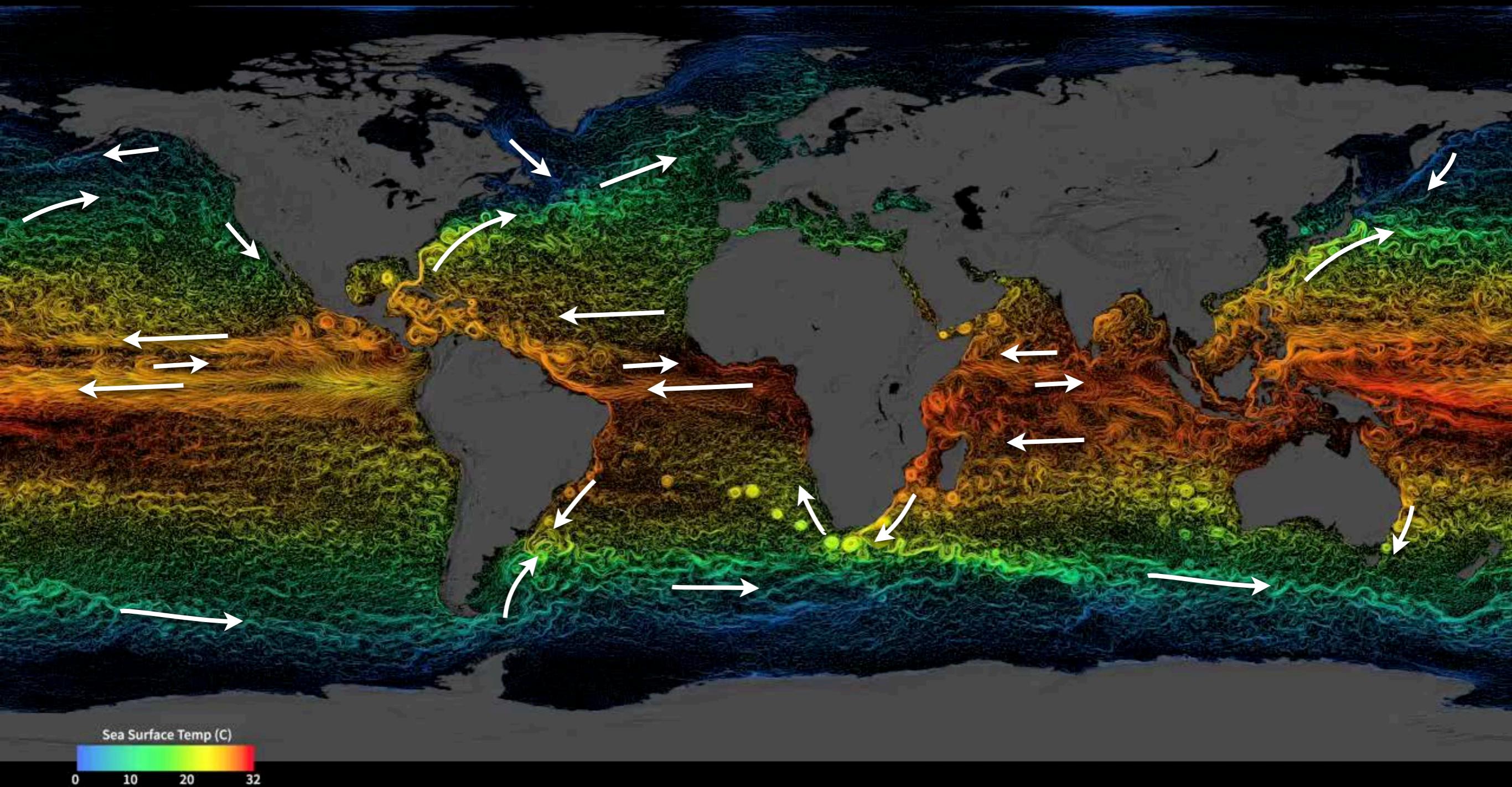


# The mixed layer

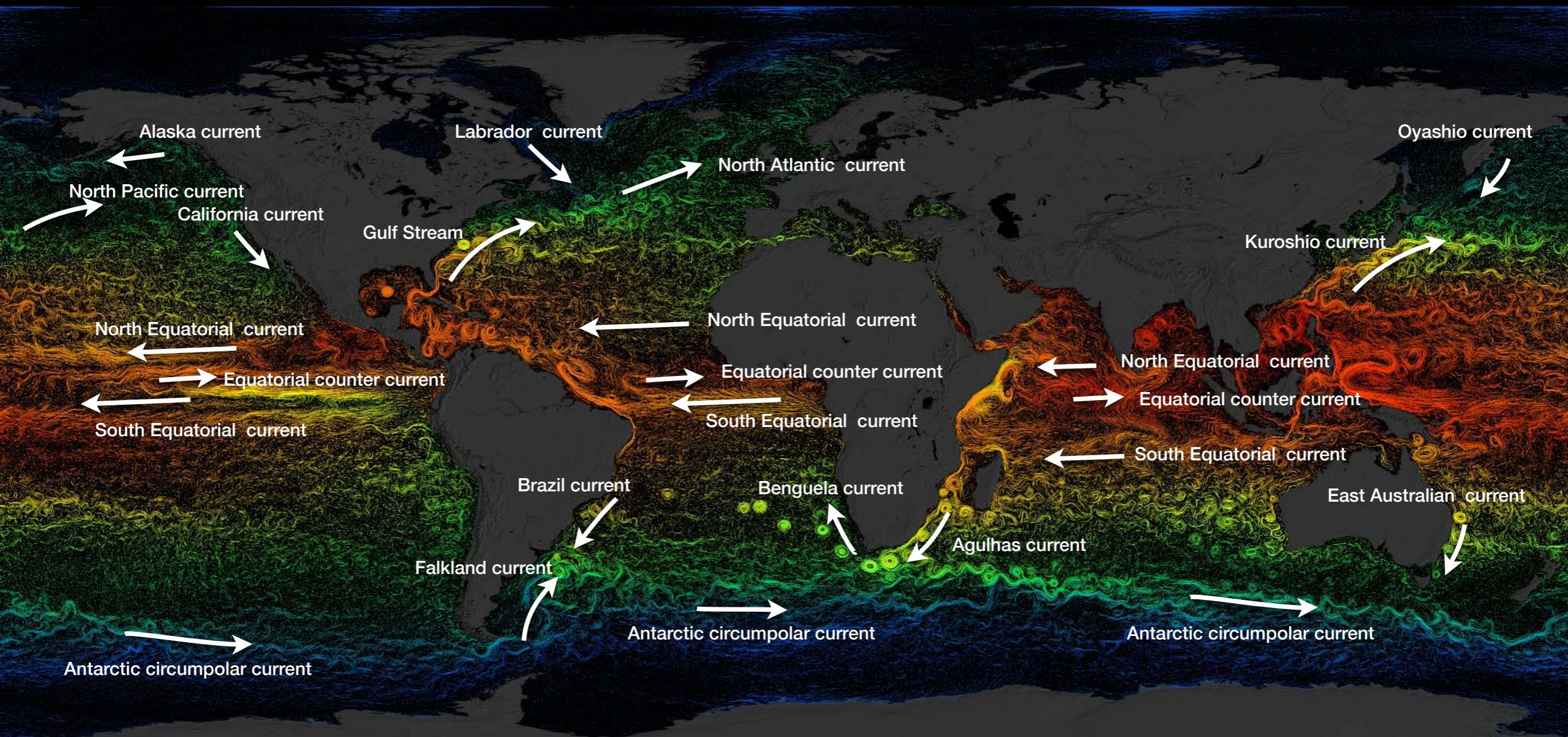
- The typical depth of the mixed layer is 50-100 m.
- At high latitudes, mixed layer depth can be a few hundred meters, even up to 1 km.

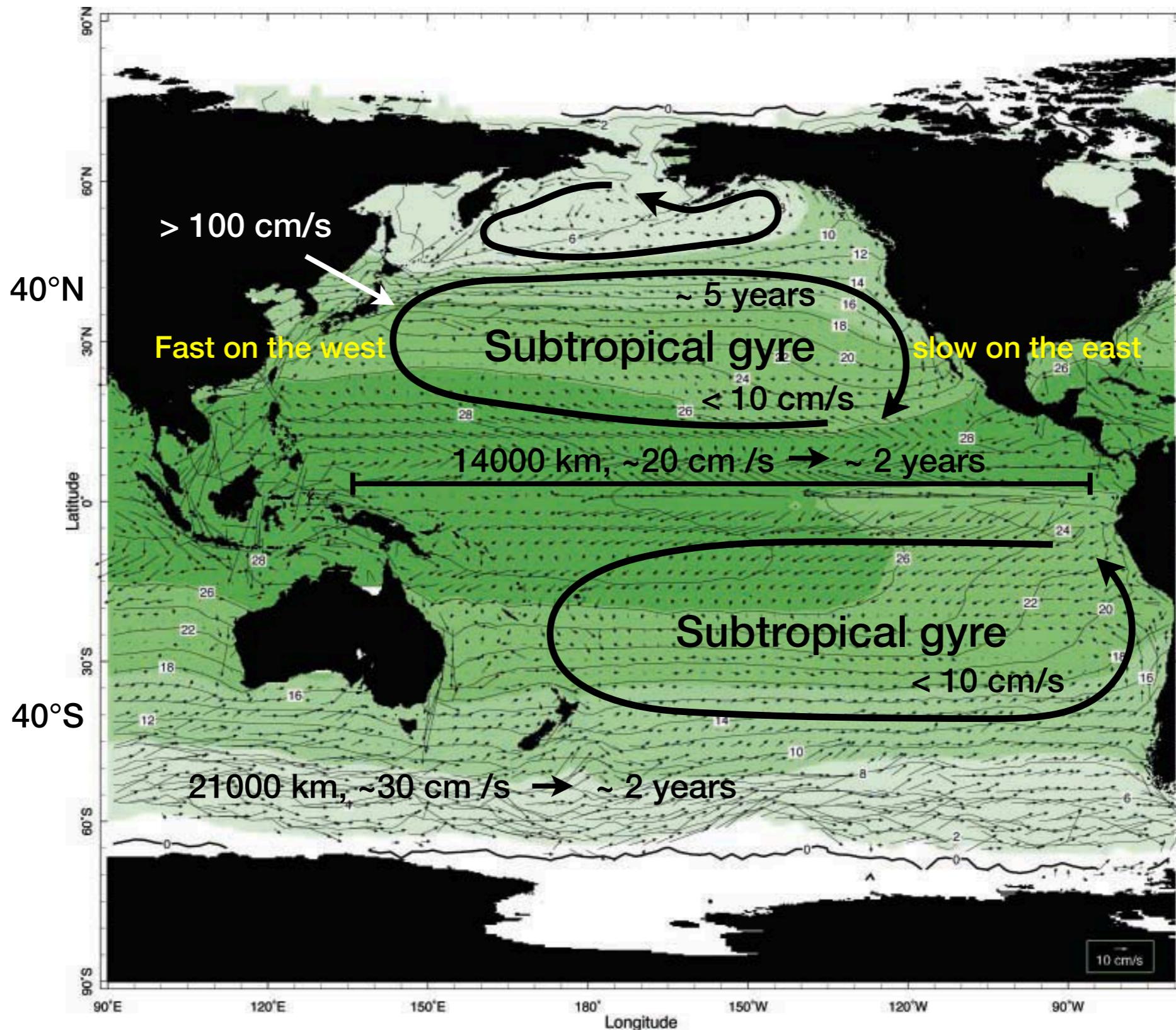


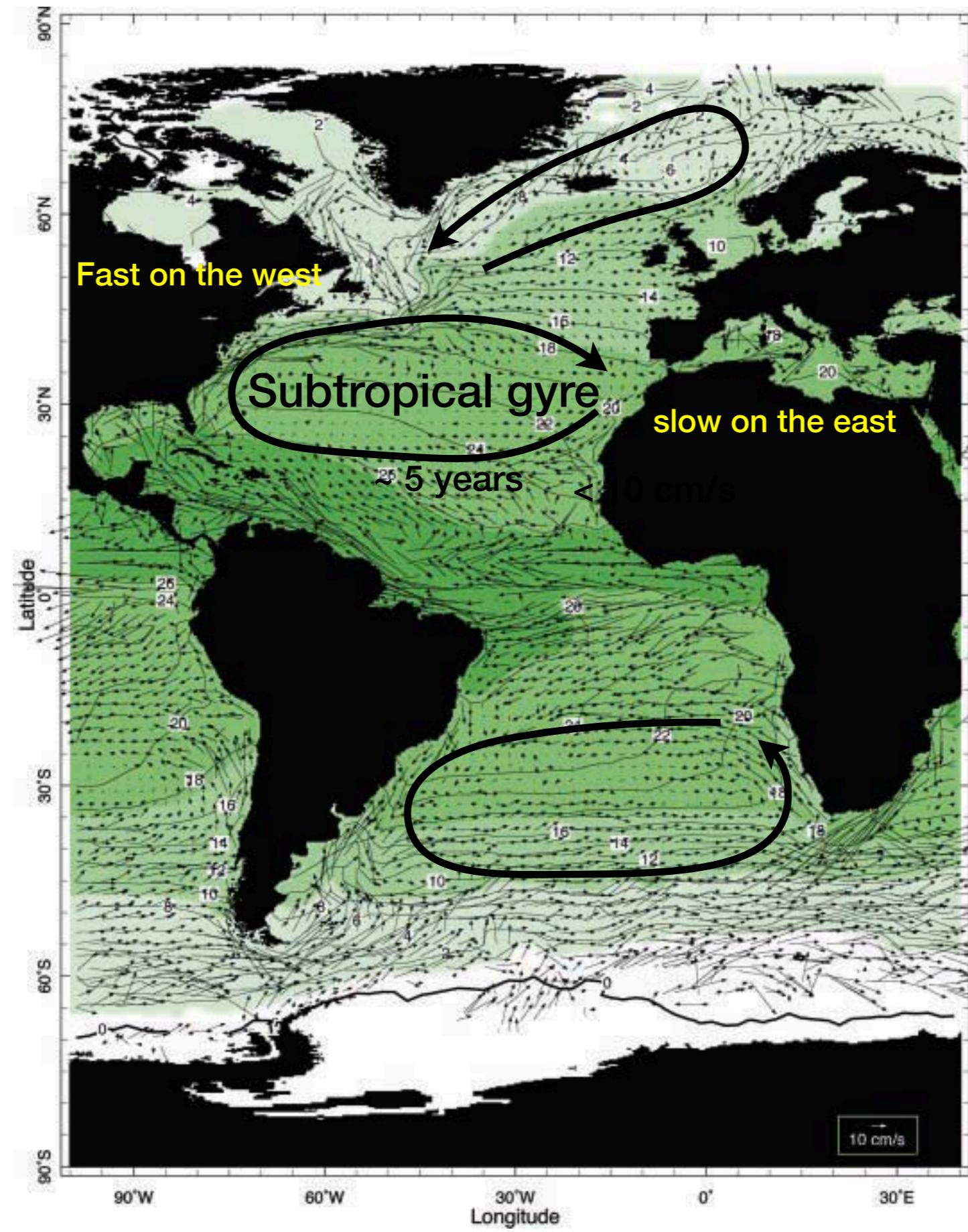
# Global Sea Surface Currents and Temperature

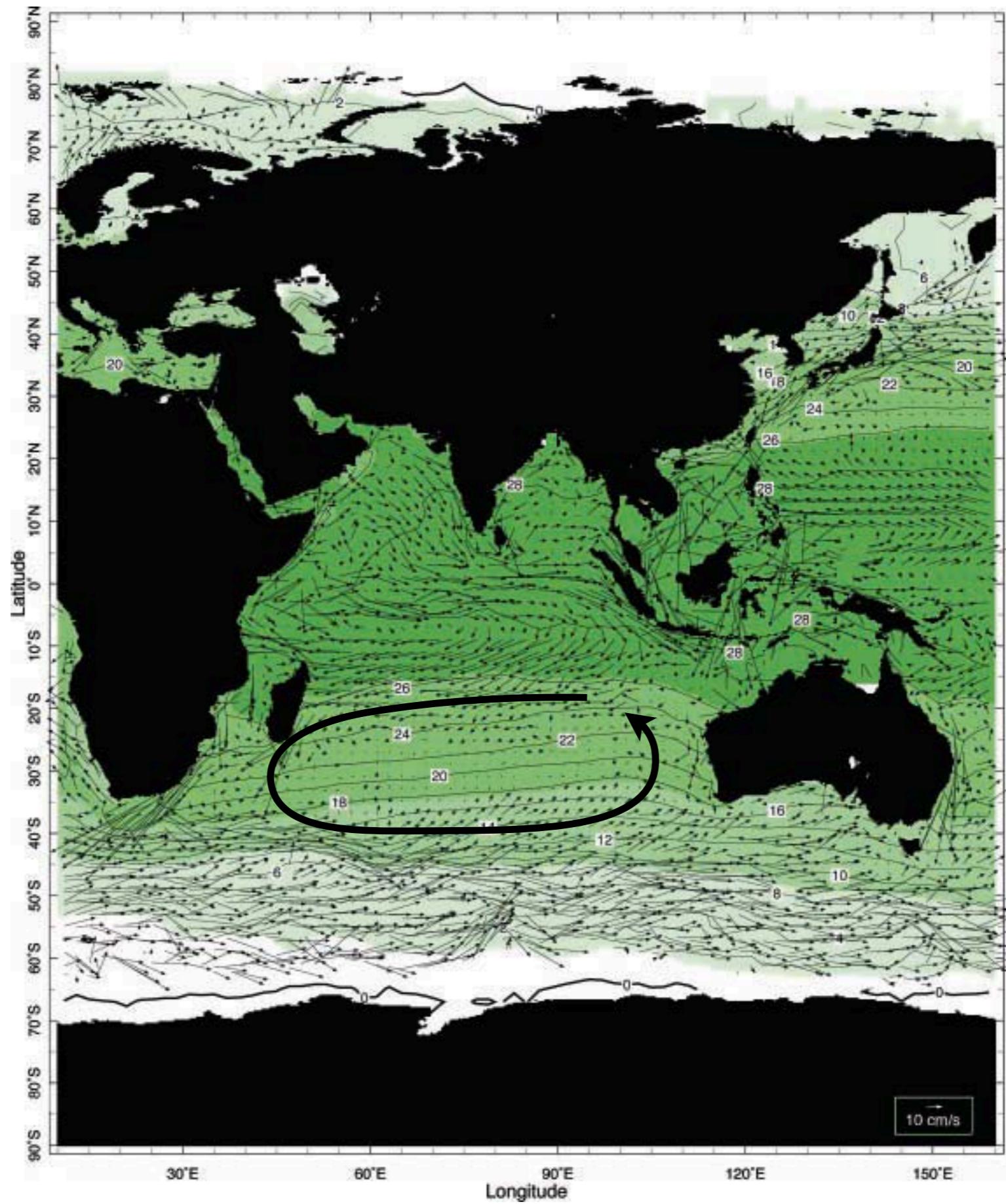


<https://svs.gsfc.nasa.gov/3912>

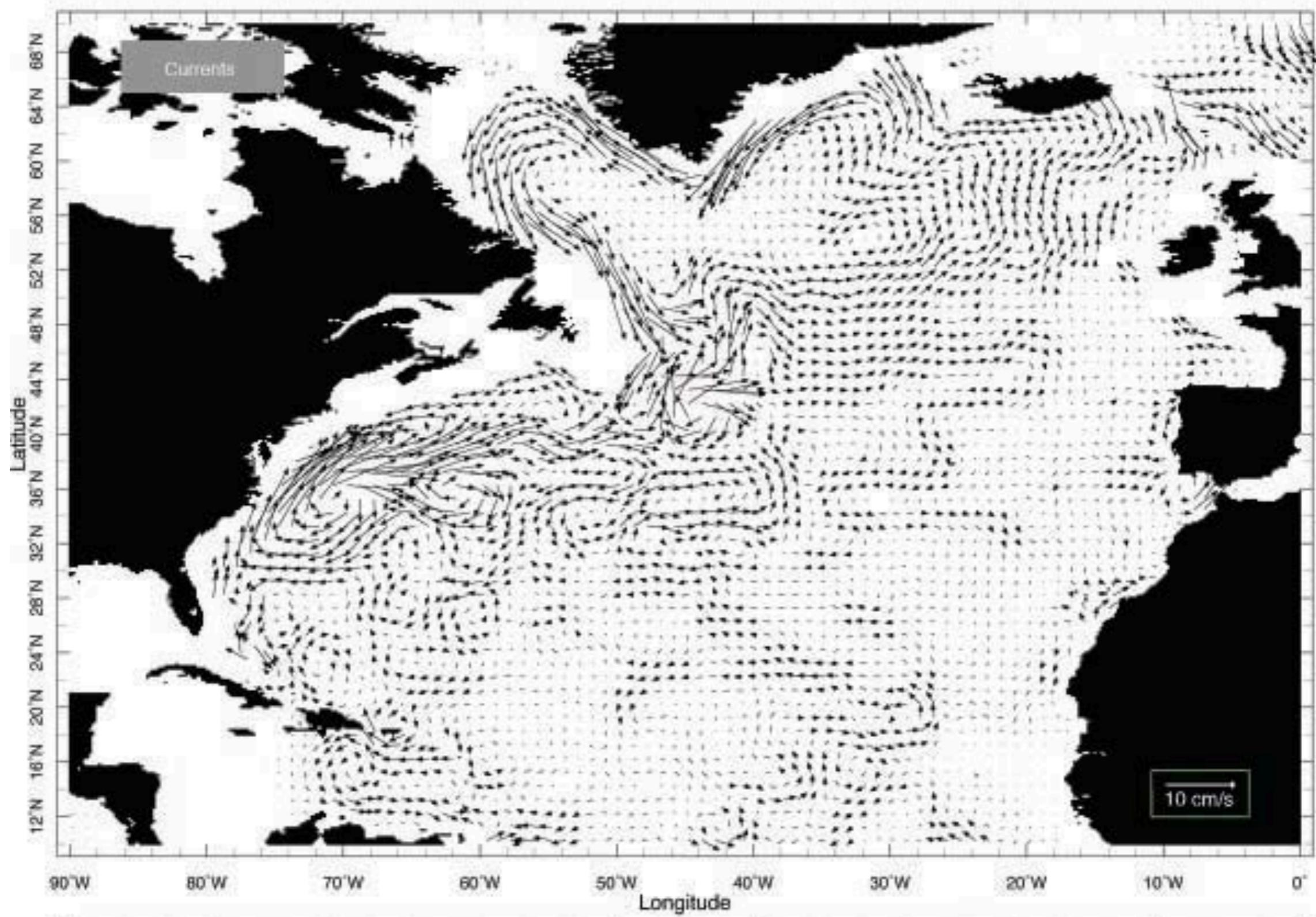




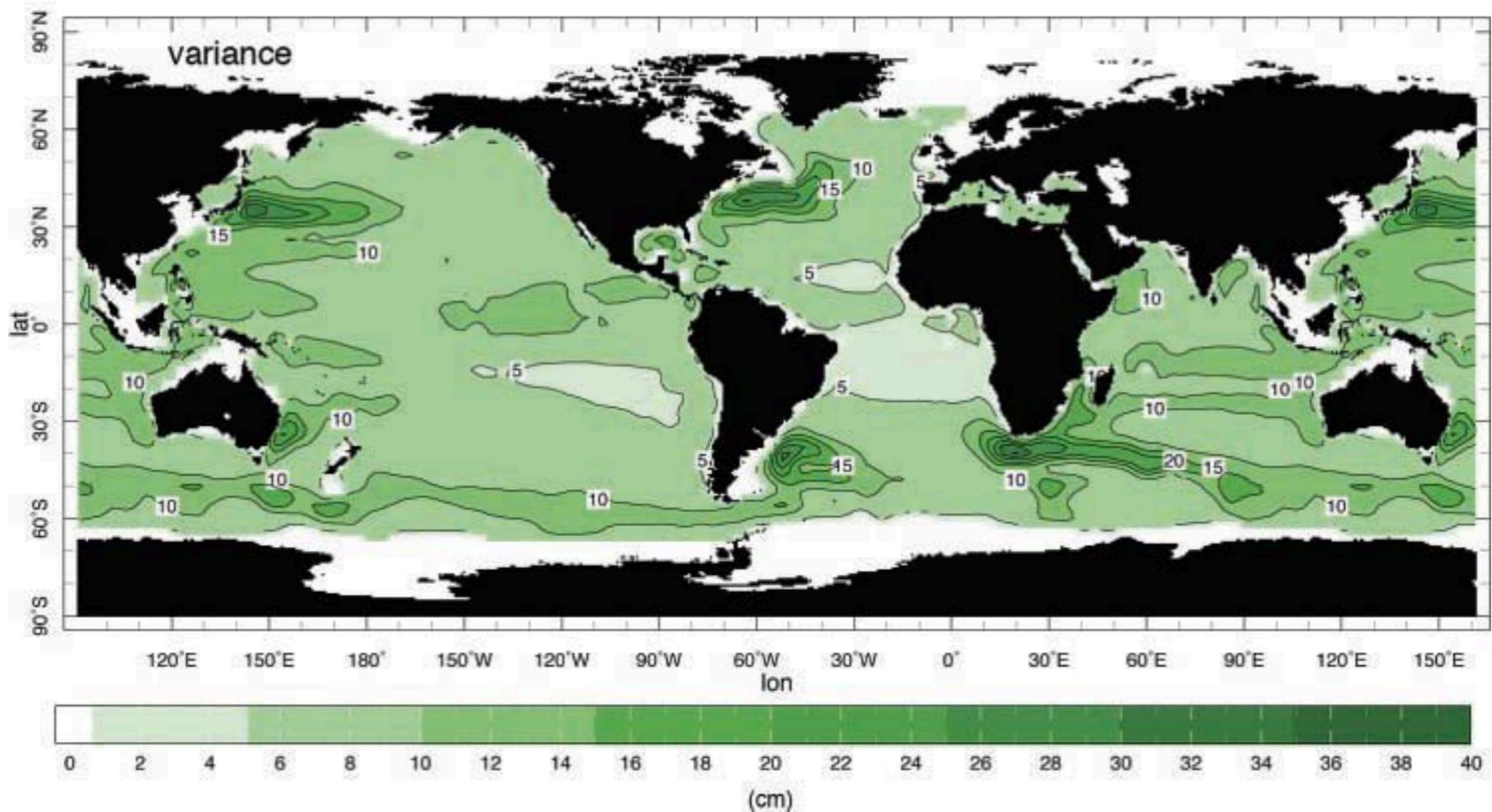
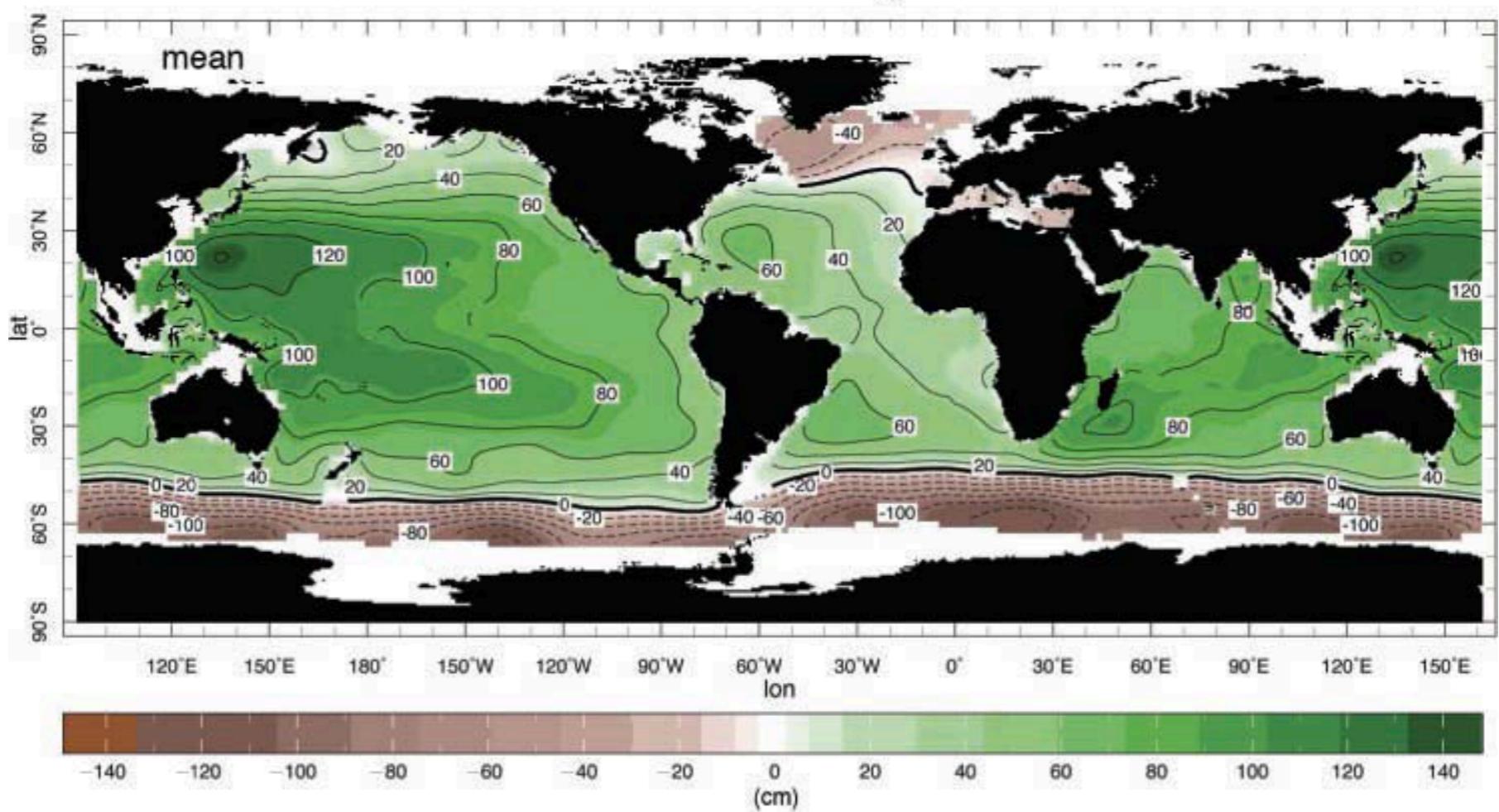




## Currents And Pressure at 700m in The Atlantic



# Sea Surface Height



### Zonal-Average, Annual-Mean, Potential Density ( $\text{kg/m}^3$ )

