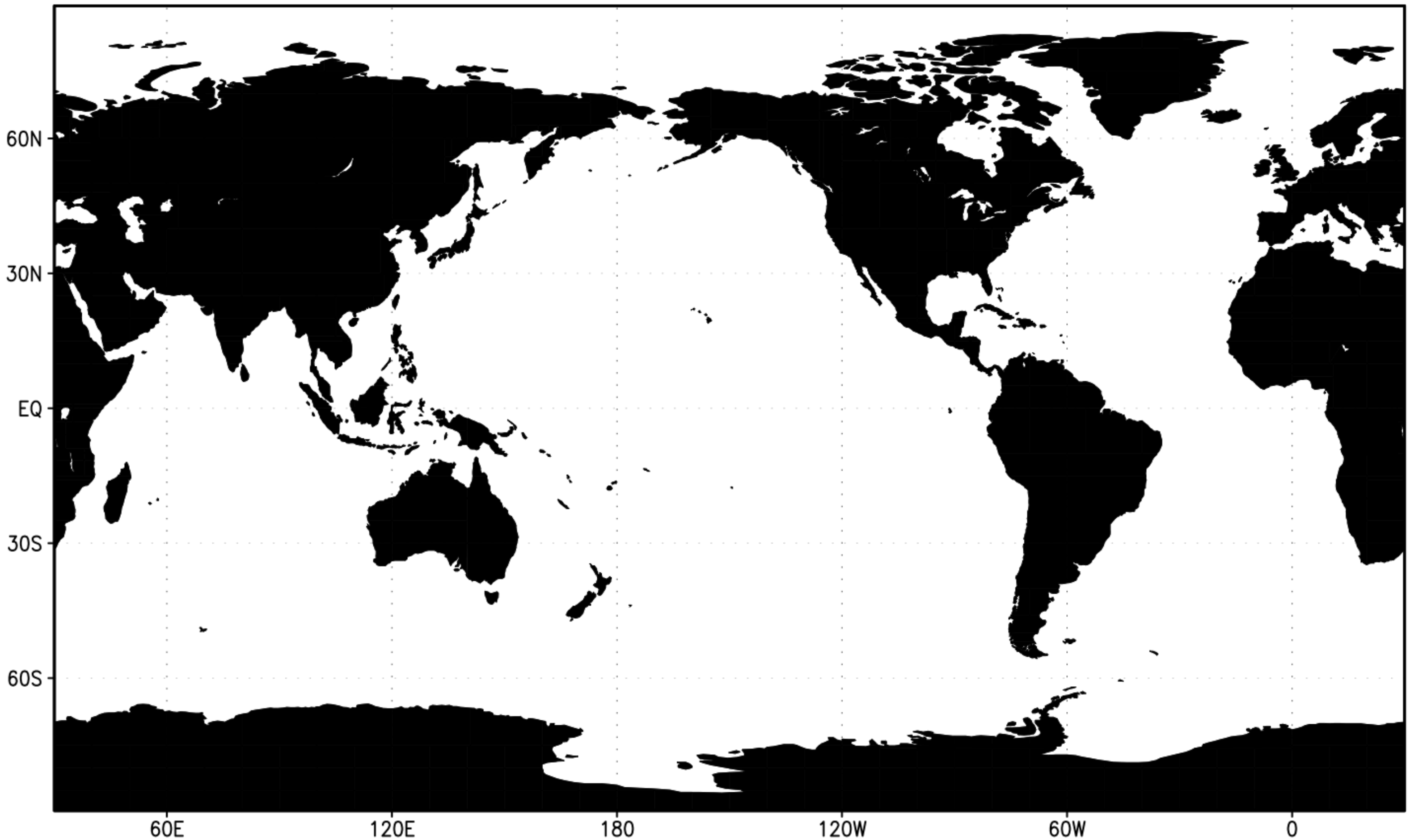
Physical oceanography/climate processes

1. General circulation in ocean & atmosphere
2. Coriolis force
3. Geostrophic flow
4. Ekman transport
5. Wind driven circulation
6. Thermohaline circulation

1. General circulation in ocean & atmosphere

Let's write down the ocean surface current.

Kuroshio? Oyashio? Gulf stream?



General circulation in the upper ocean

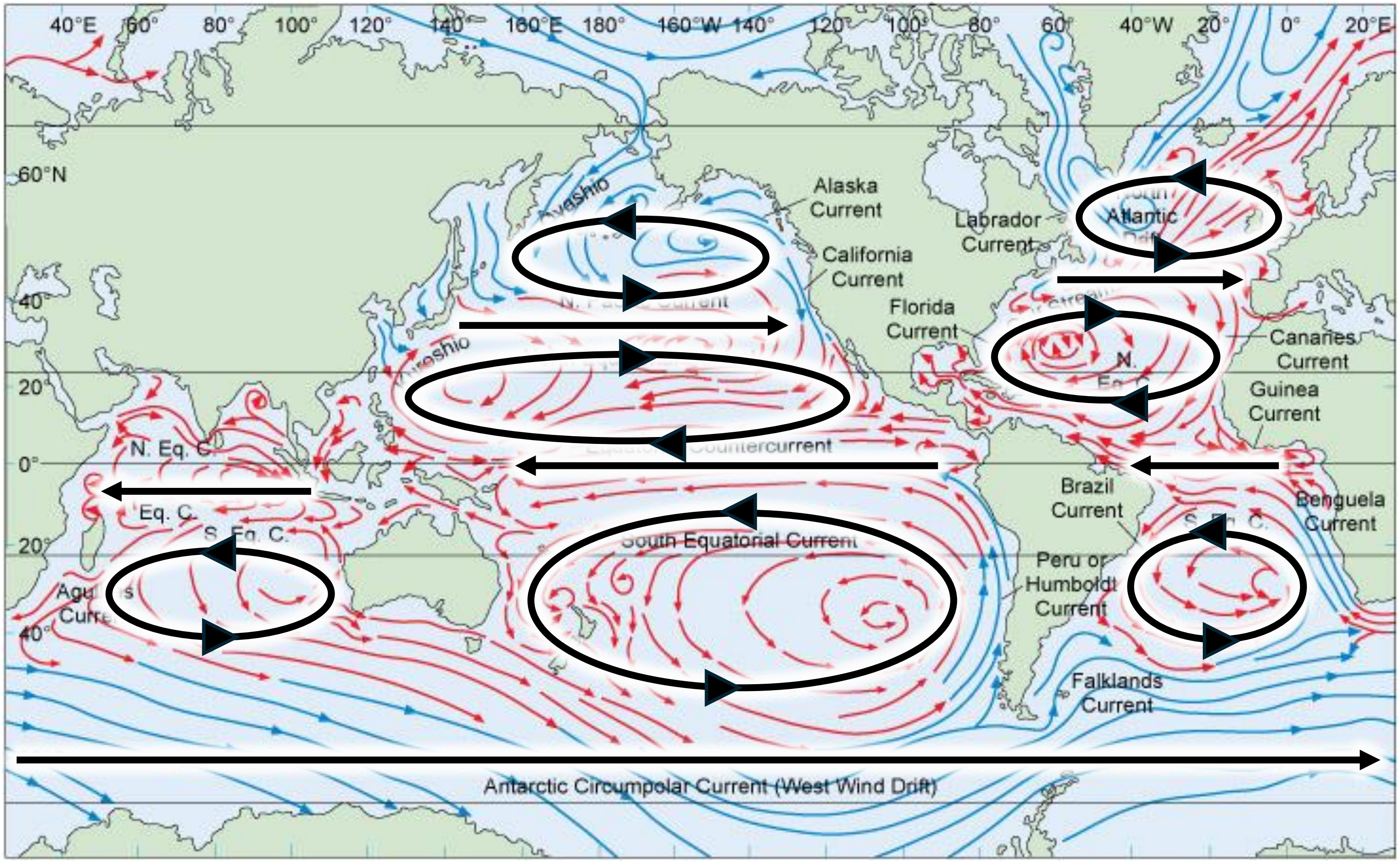
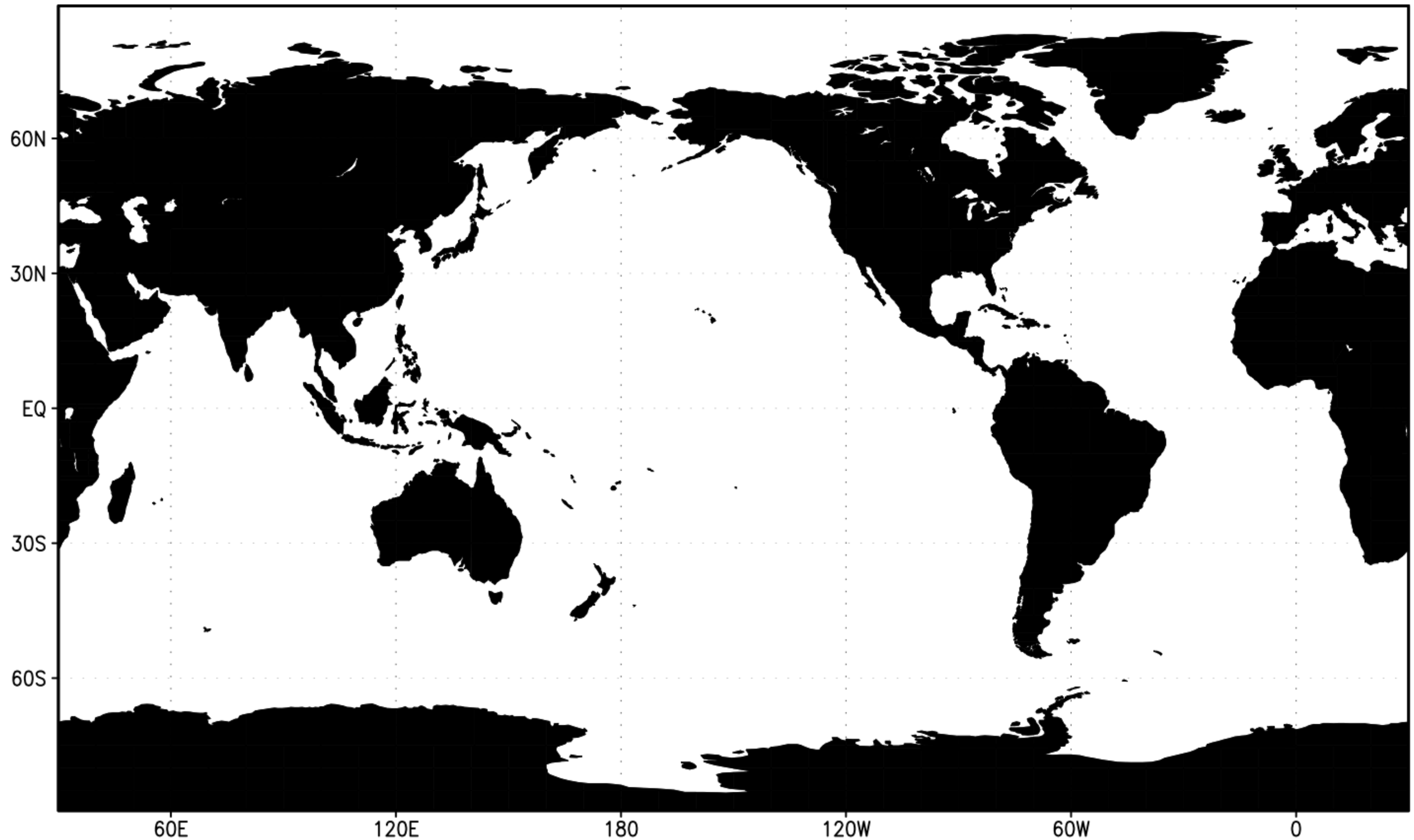


Figure 15 in Open University

General circulation in the troposphere

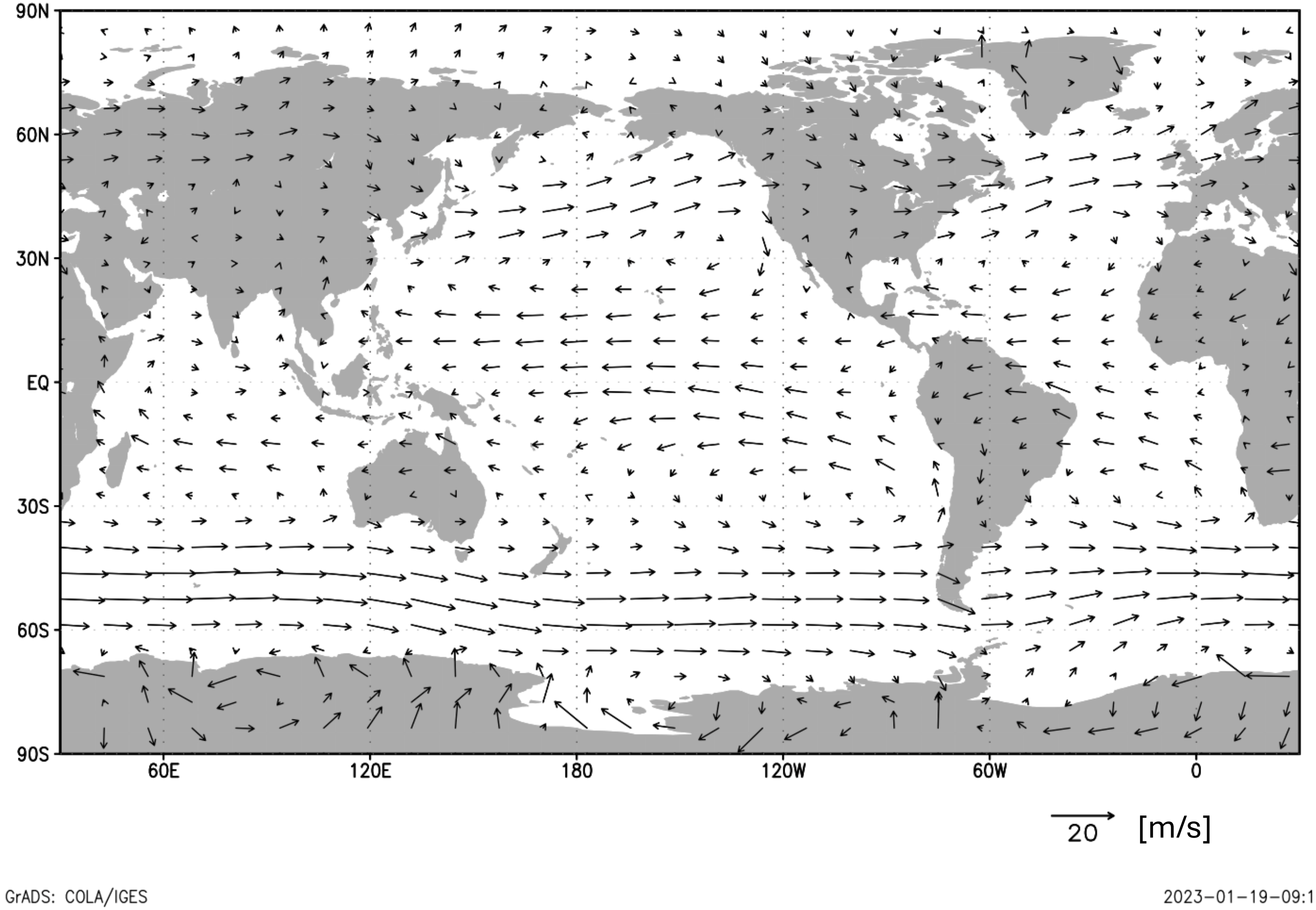
Trade wind? Westerlies?



General circulation in the troposphere

Westerlies? Trade wind?

Wind on 850hPa geopotential height (~1500m)



General circulation in the troposphere

Westerlies? Trade wind?

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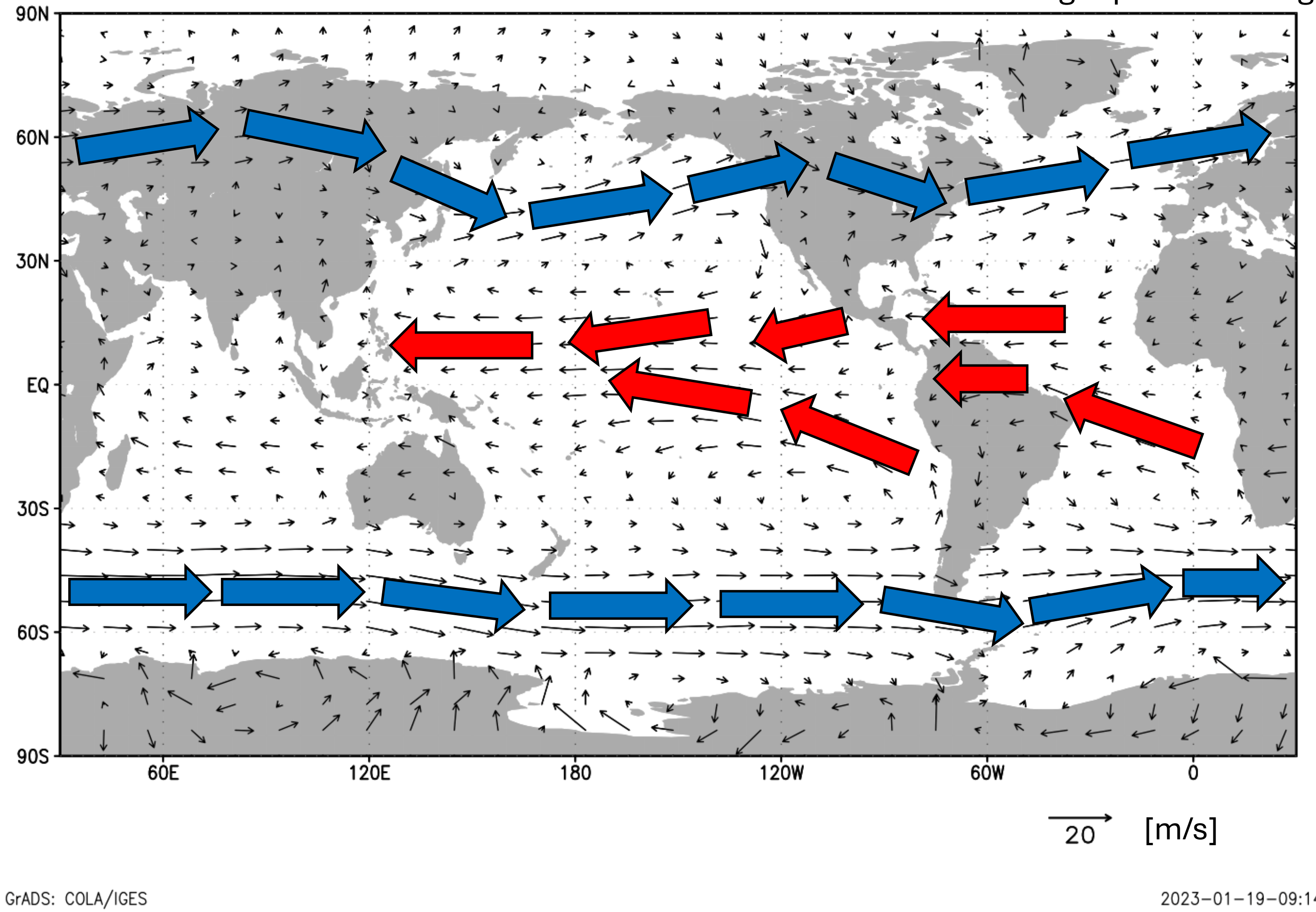
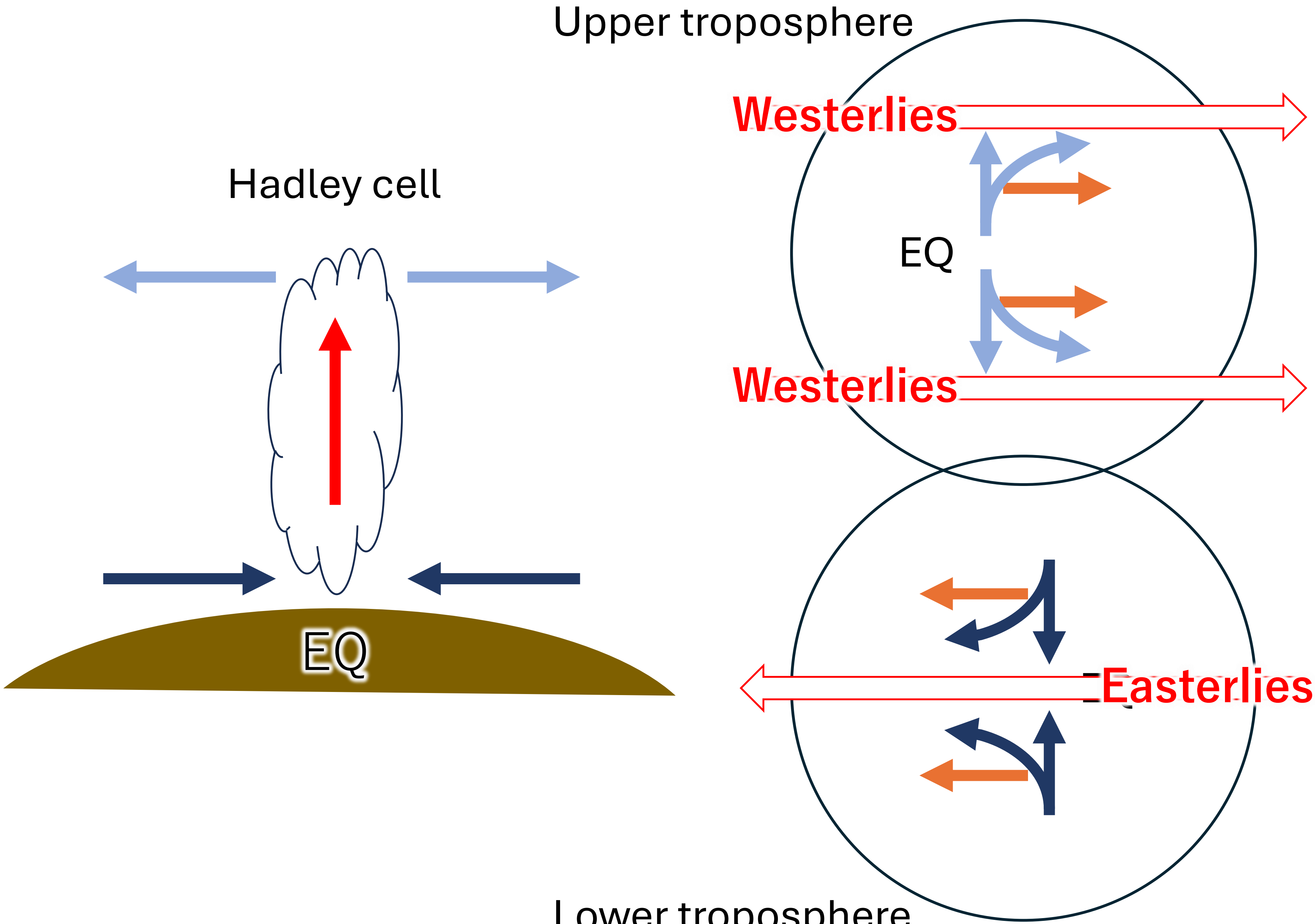


2. Coriolis force

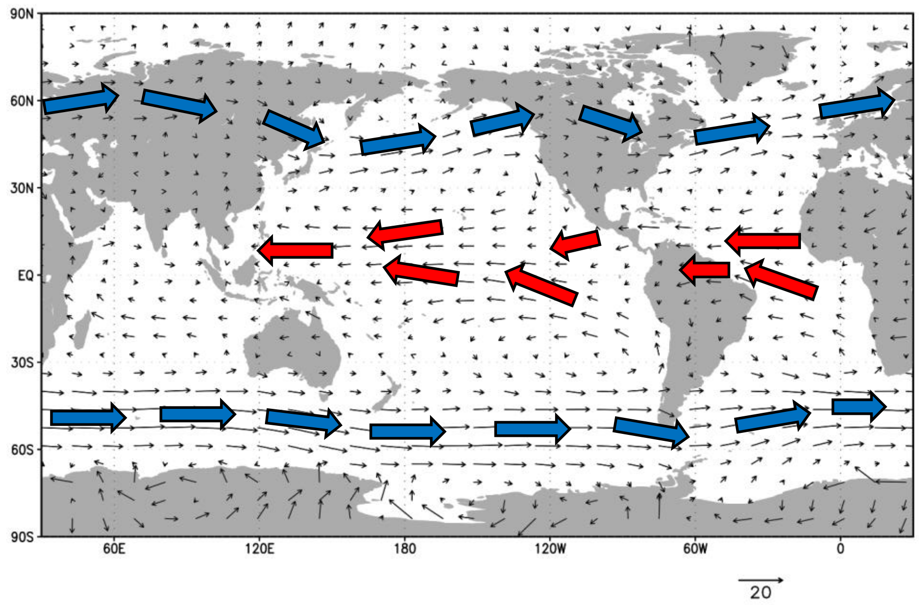
Do you know Coriolis force?

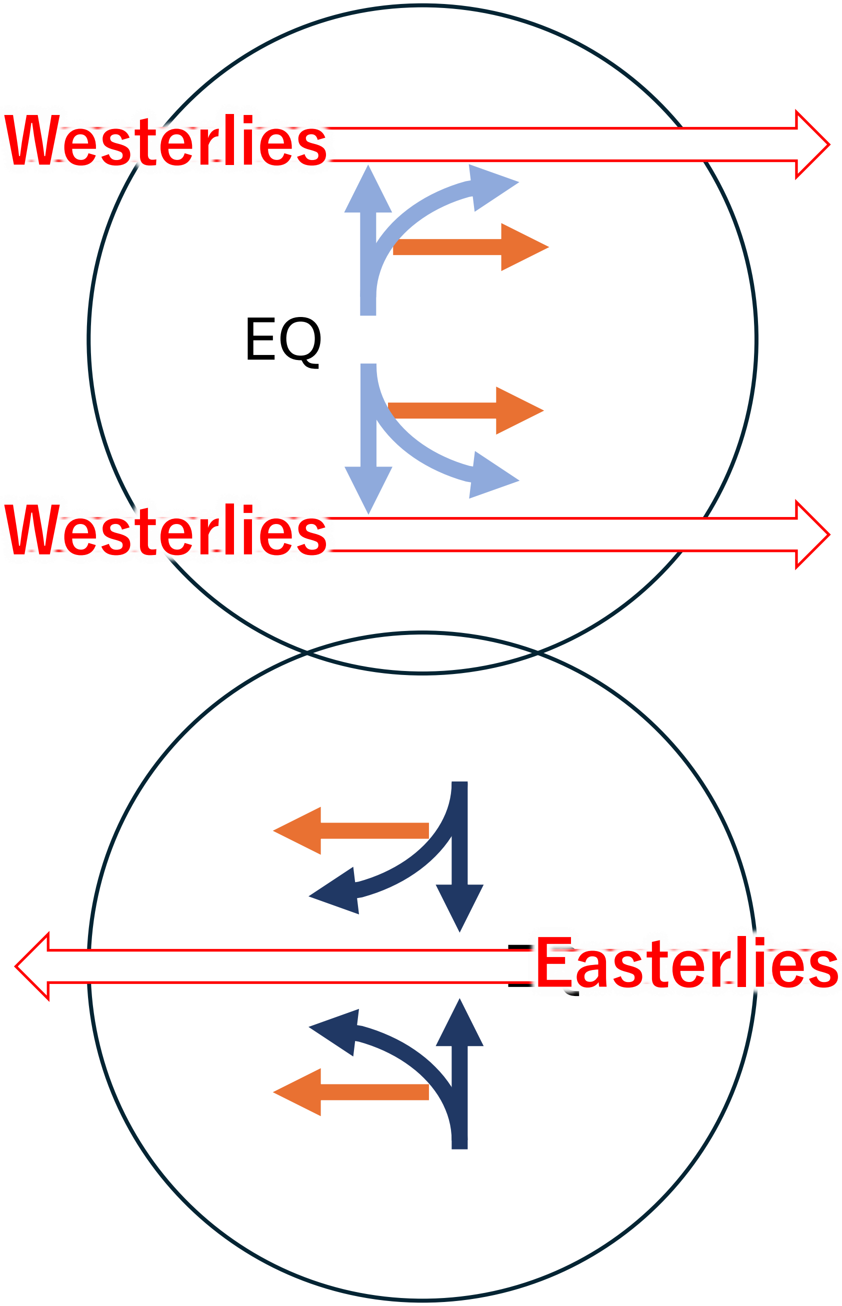
- Apparent force due to the [ ]
- Important for [ ]-scale variation on the earth
- Working to the [ ] of the current in the Northern Hemisphere
- Proportional to [ ]



Upper troposphere
Hadley cell
Westerlies
EQ
Westerlies
EQ
Easterlies
Lower troposphere

Let's compare with
the general circulation in the troposphere.

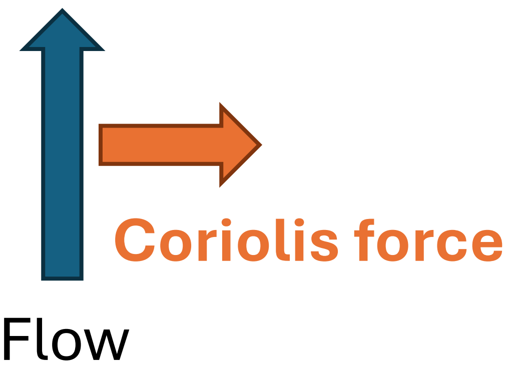




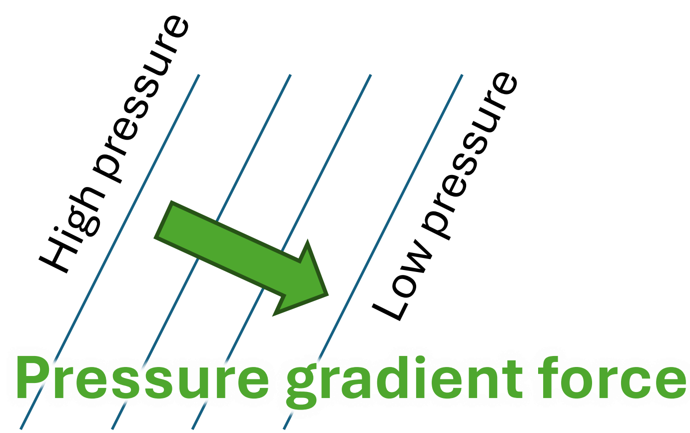
3. Geostrophic flow

What is **Geostrophic flow**?

- Flow where **Coriolis force** and **pressure gradient force** are balanced
- ~ Large-scale circulation in atmosphere and ocean



- To the right in NH
- High velocity
  -> Large Coriolis force



- From high pressure to low pressure
- Large pressure difference
  -> Large pressure gradient force

Newton's equations of motion: $\vec{F} = m\vec{a}$

Dominant forces in large-scale motion on Earth are
Coriolis force and pressure gradient force.

In a steady state,

$$\vec{a} = \frac{\partial \vec{v}}{\partial t} = 0$$

Then,

$$\vec{F} = Coriolis\ force + Pressure\ gradient\ force = 0$$

Divided into x (east-west) and y (north-south) directions,

$$fu = -\frac{1}{\rho}\frac{\partial p}{\partial y}\ , \qquad -fv = -\frac{1}{\rho}\frac{\partial p}{\partial x}$$

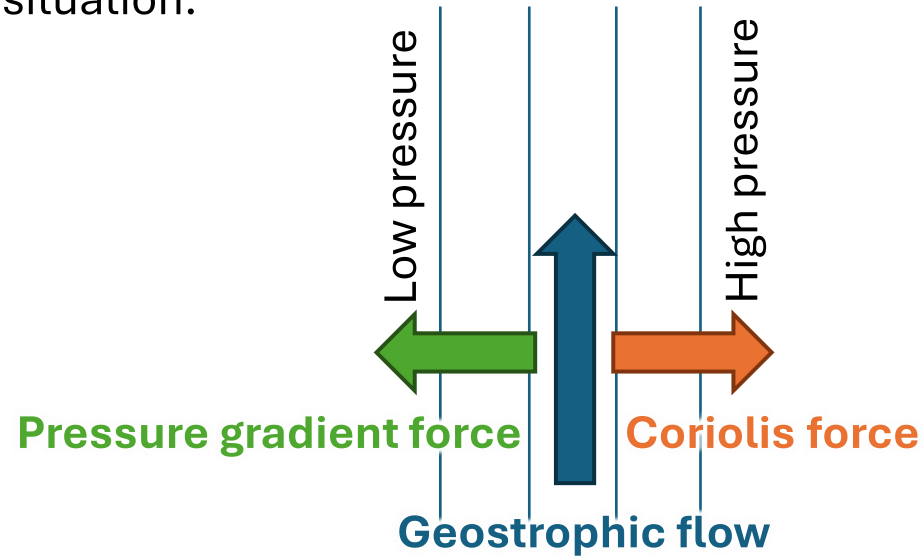
コリオリ力？　圧力傾度力？
f, u, v, ρ, p?

Geostrophic balance: $$fu = -\frac{1}{\rho}\frac{\partial p}{\partial y}, \qquad -fv = -\frac{1}{\rho}\frac{\partial p}{\partial x}$$

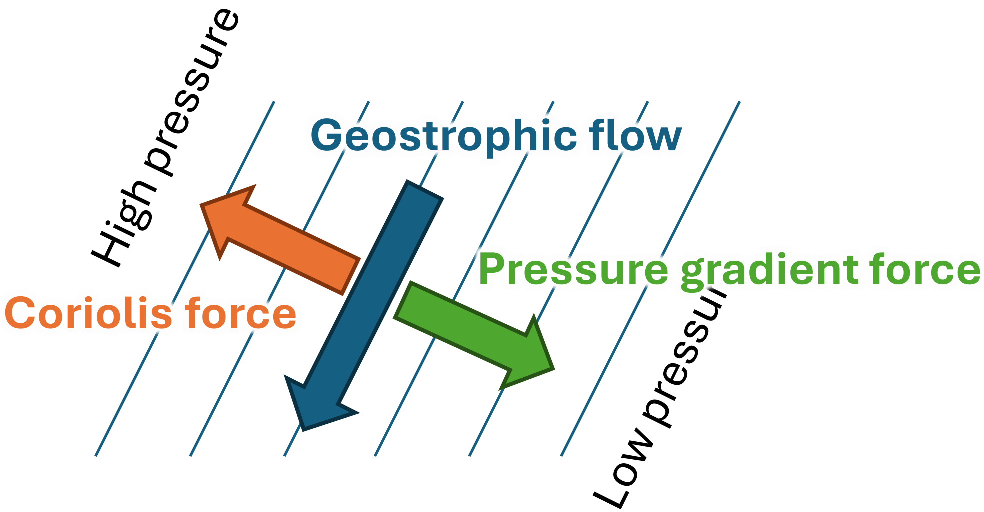
When the current is just to north,

$$u = 0, \qquad \frac{\partial p}{\partial y} = 0, \qquad fv = \frac{1}{\rho}\frac{\partial p}{\partial x}$$

Let's draw this situation.

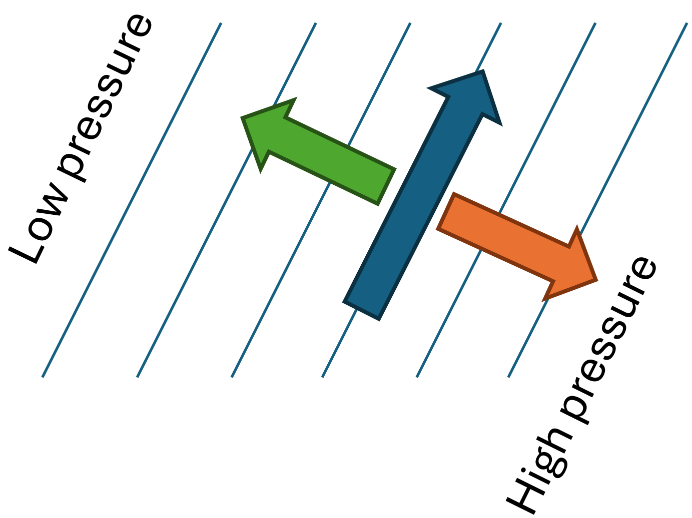


Draw a geostrophic flow with Coriolis force and pressure gradient force.

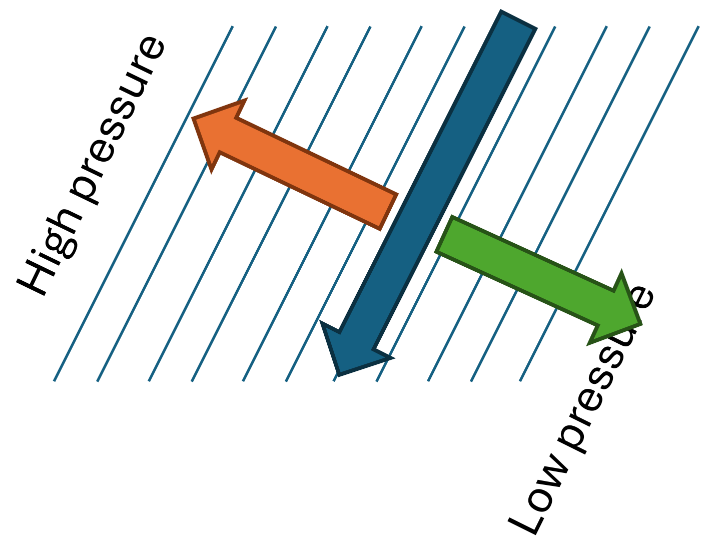


- We can know the current from the pressure distribution.
- Geostrophic flow follows isobaric lines.
- Geostrophic flow is strong where the pressure gradient is large.

- **In case pressure gradient is opposite,**

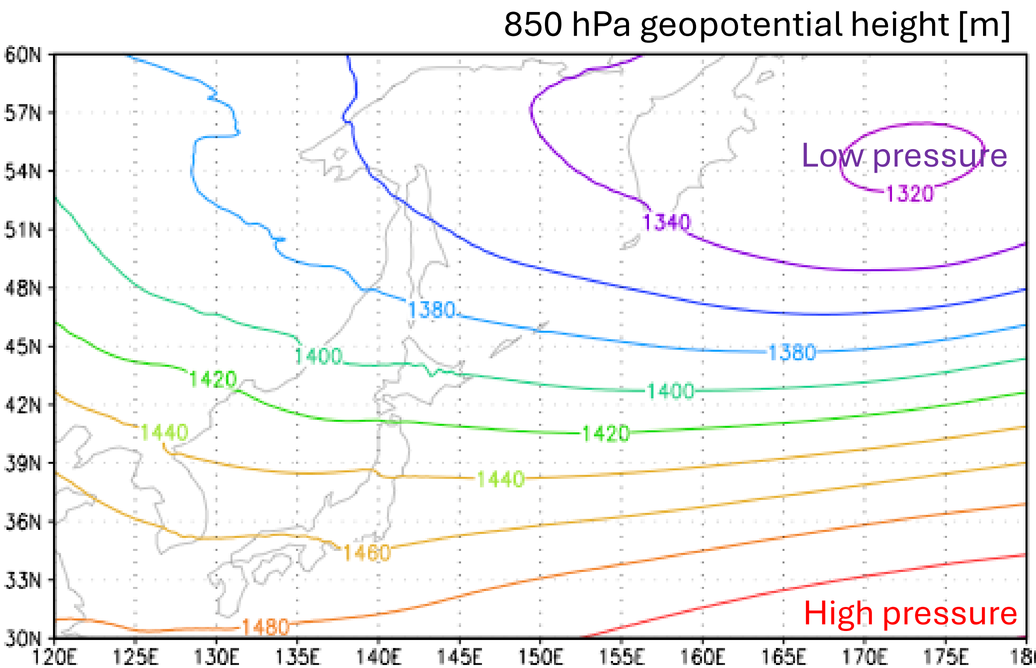


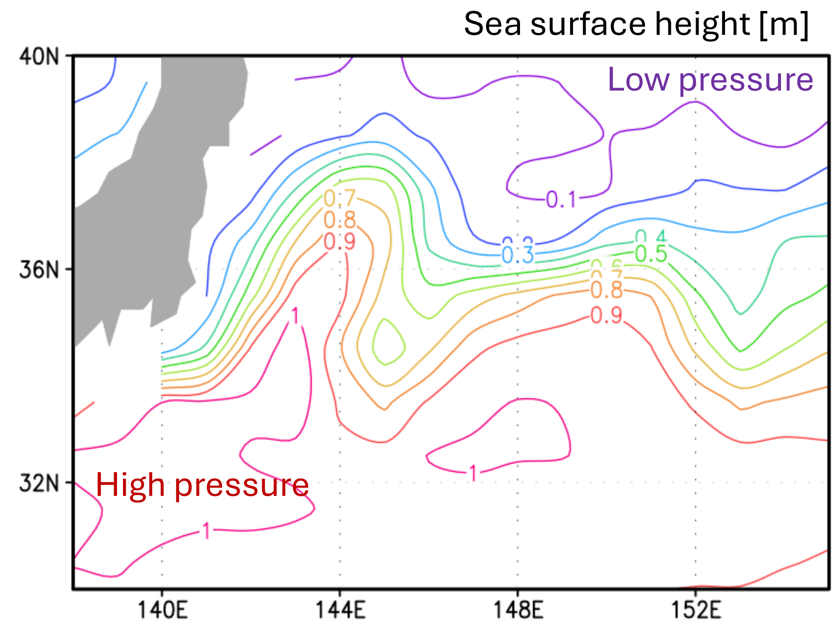
- **In case pressure gradient is large,**



We can know the wind from the pressure distribution.

We can know the current from the SSH distribution.



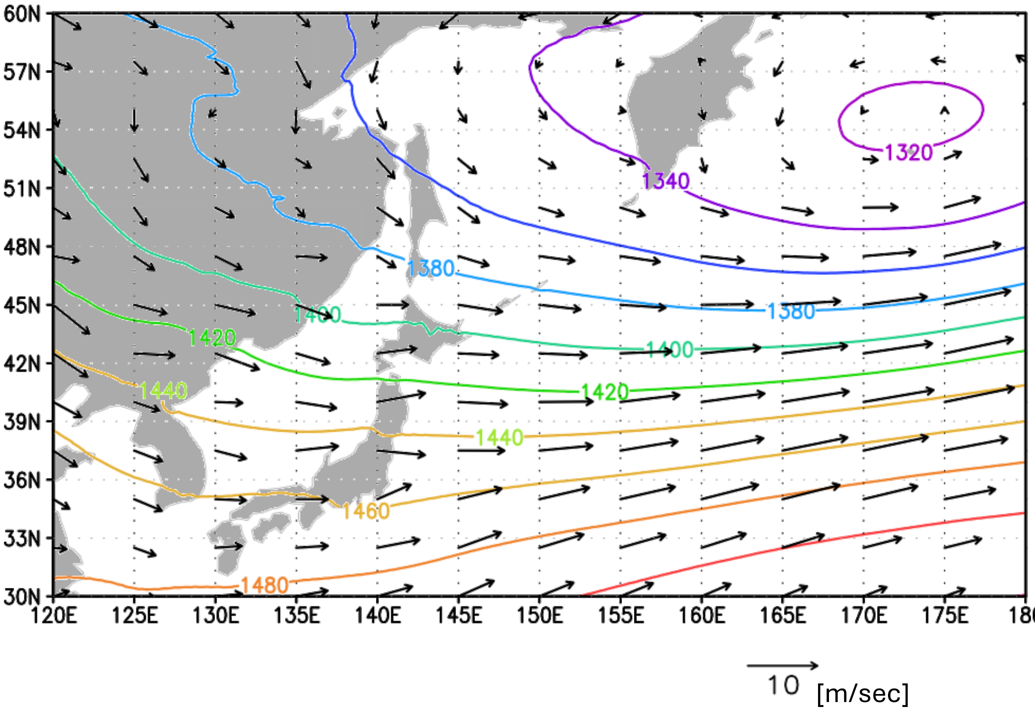


- Geostrophic flow follows isobaric lines.
- Geostrophic flow is strong where the pressure gradient is large.

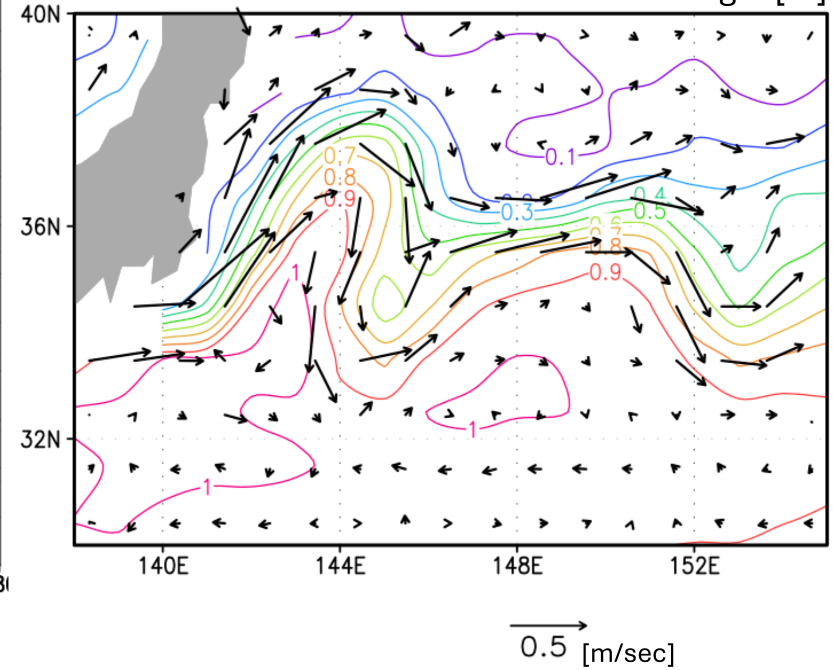
We can know the wind
from the pressure distribution.

We can know the current
from the SSH distribution.

850 hPa geopotential height [m]



Sea surface height [m]

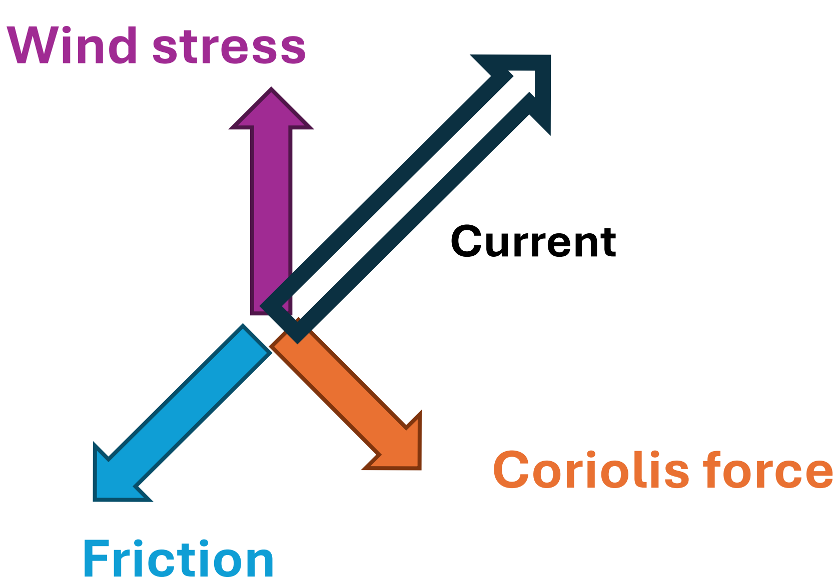


- Geostrophic flow follows isobaric lines.
- Geostrophic flow is strong where the pressure gradient is large.

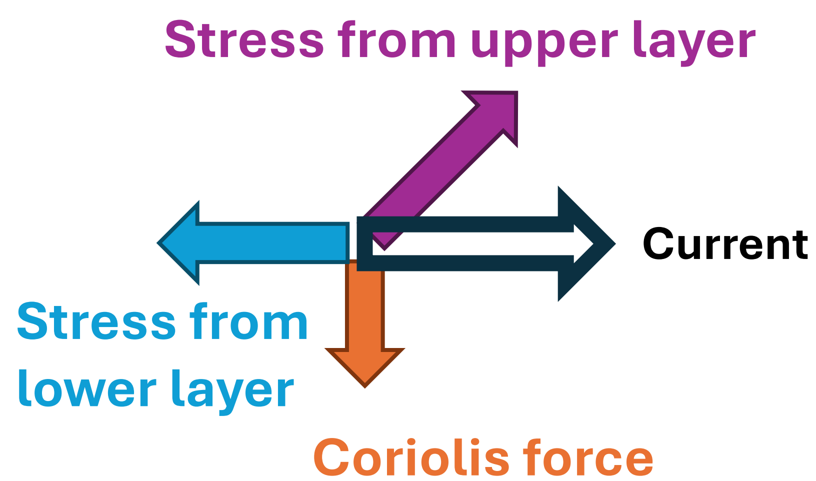
4. Ekman transport

Let’s take into an account wind stress and friction.

Force balance at surface ocean



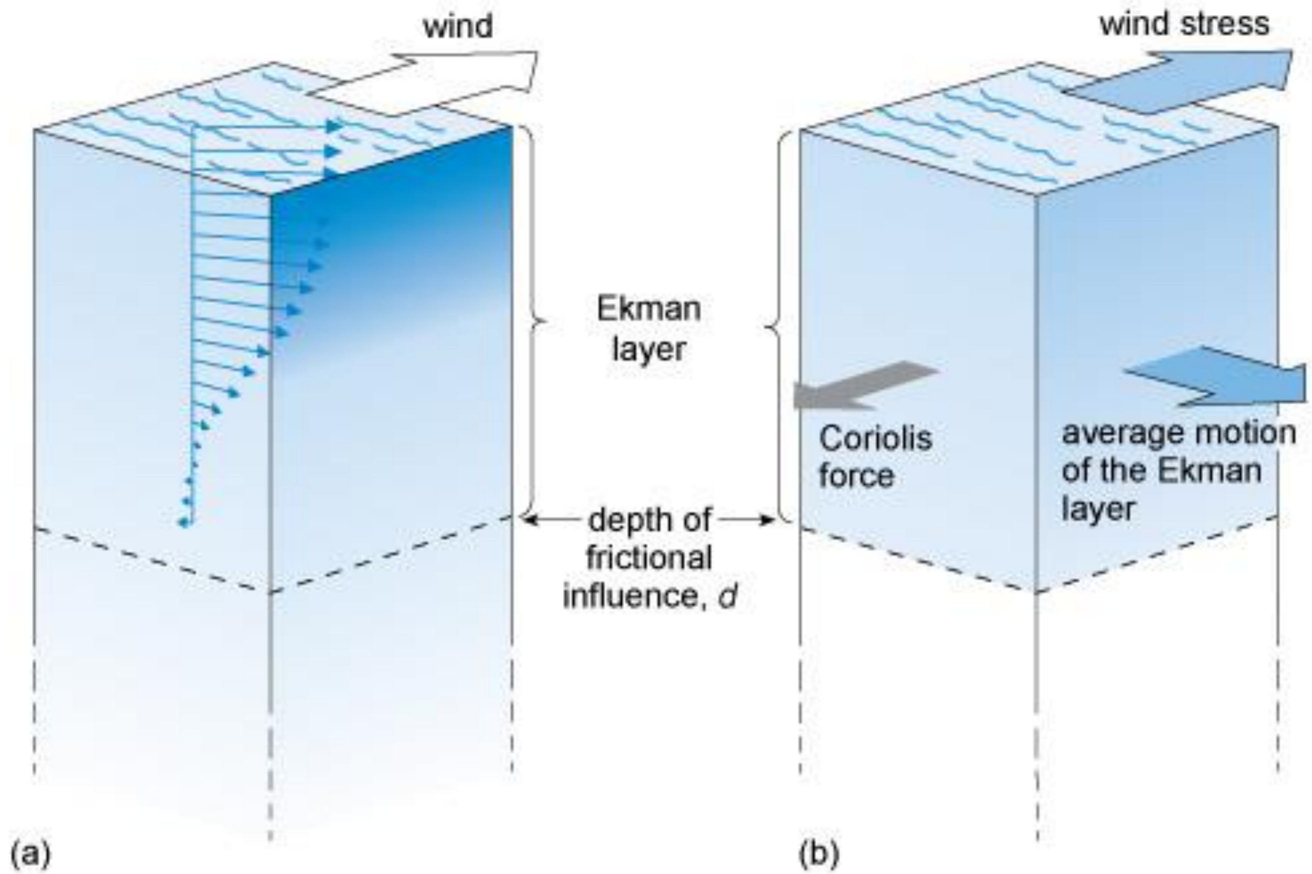
Below it,



Current decelerates & shows spiral.

in Northern Hemisphere

Current decelerates & shows spiral.



Integration in the Ekman layer

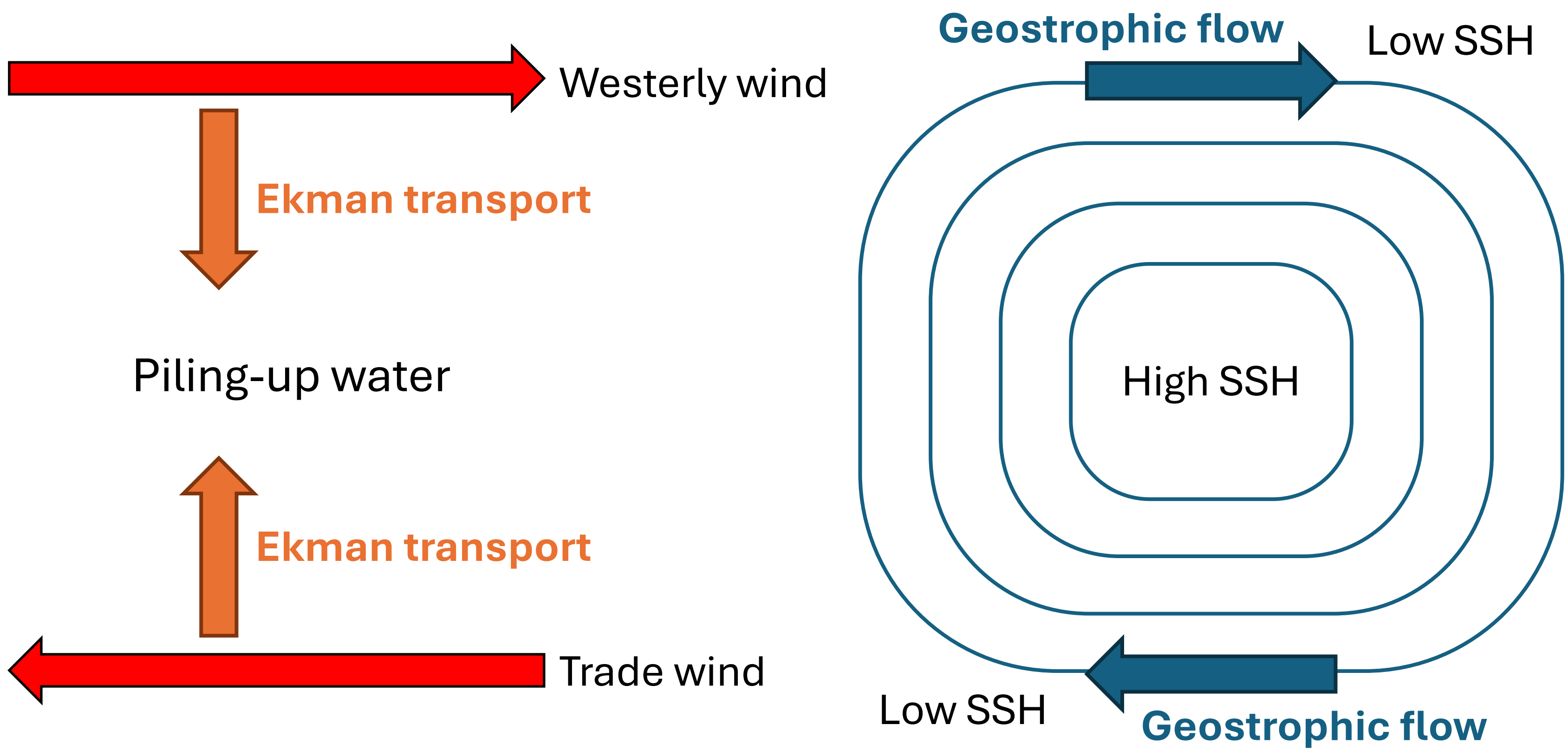
-> Average motion directs to right of wind stress.

Ekman transport

in Northern Hemisphere

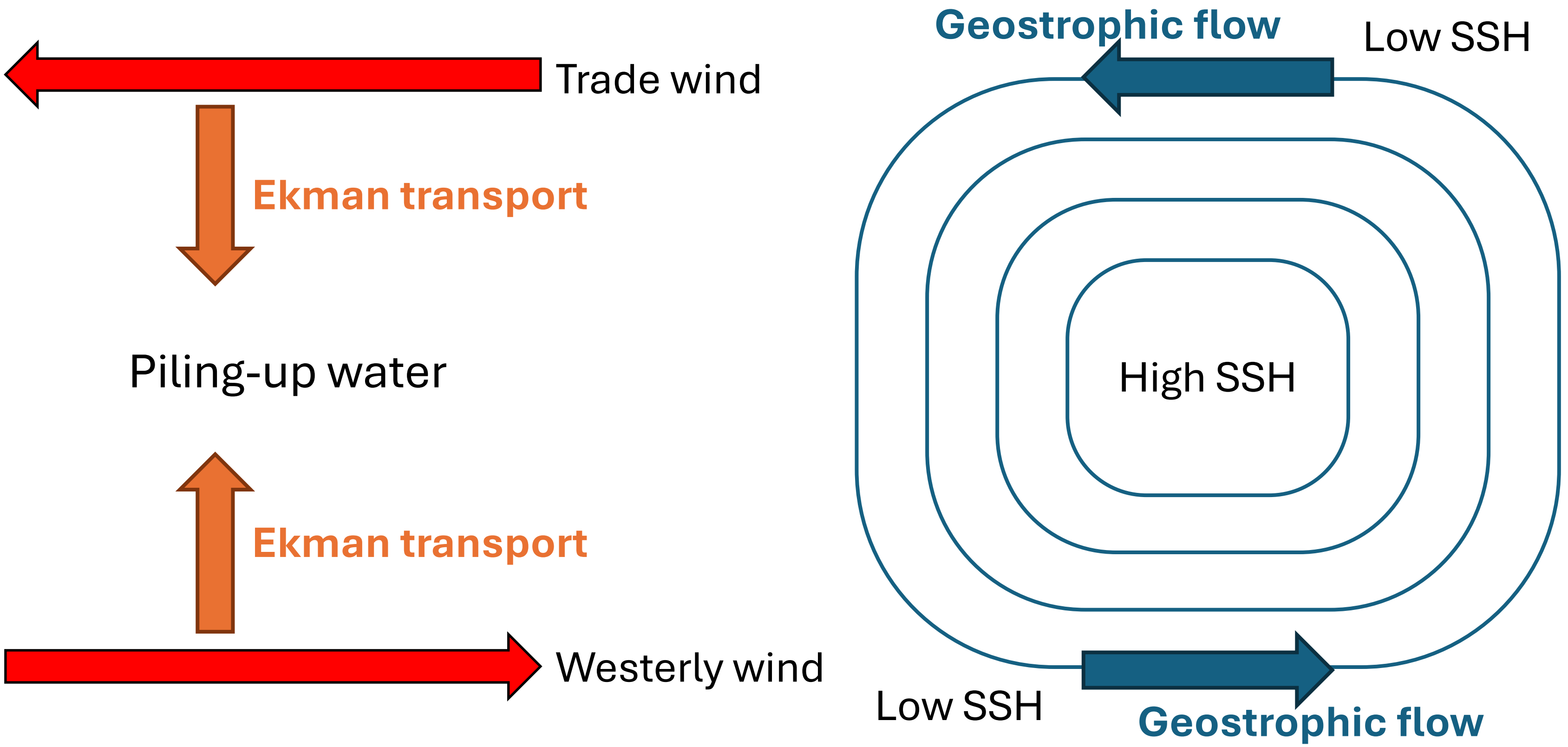
5. Wind driven circulation

Ekman transport -> Wind driven circulation



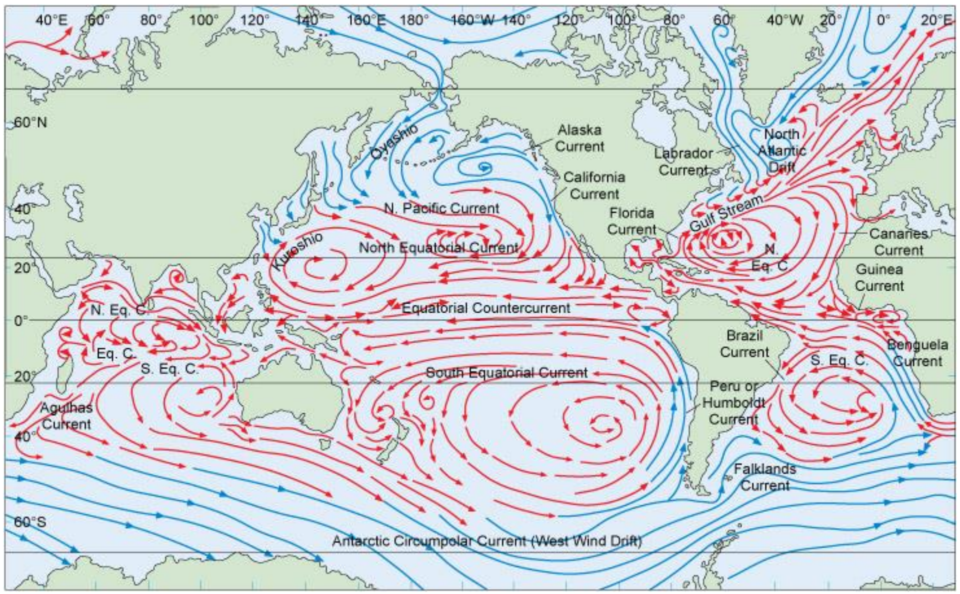
in Northern Hemisphere

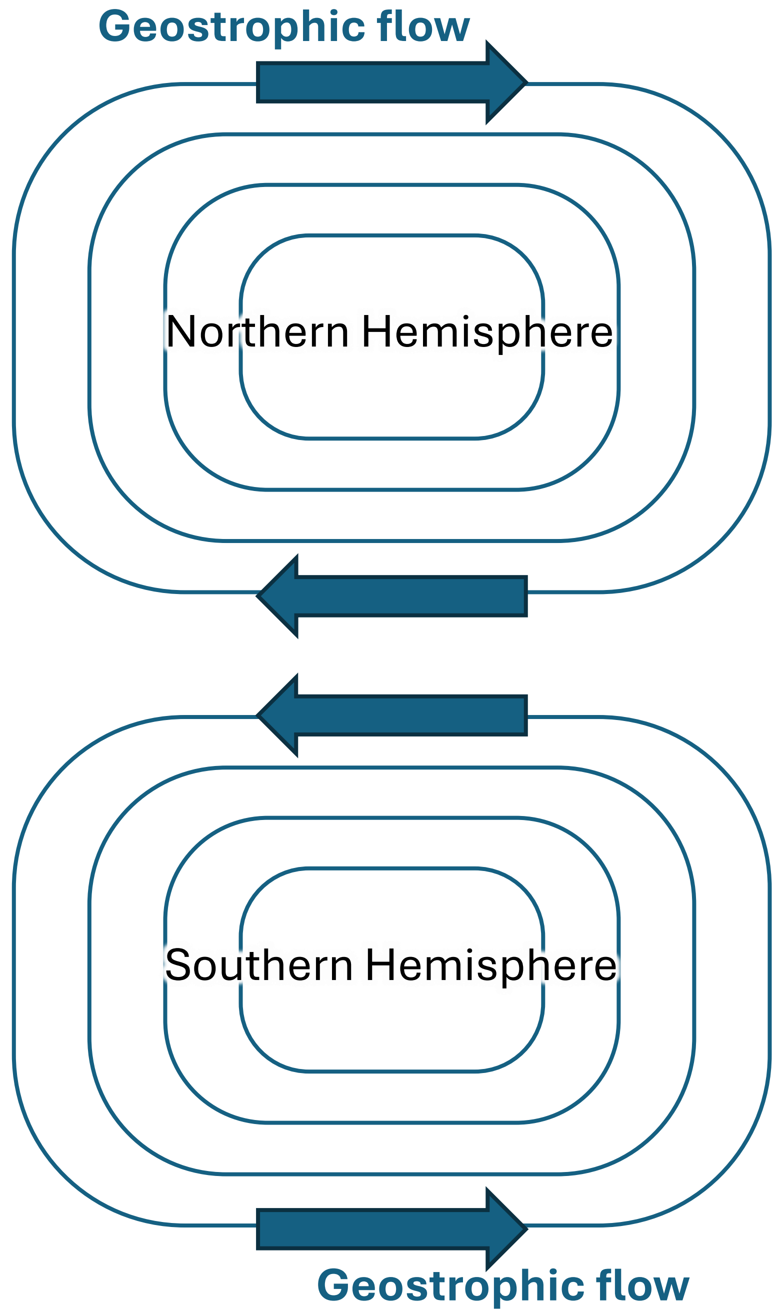
Ekman transport -> Wind driven circulation



in Southern Hemisphere

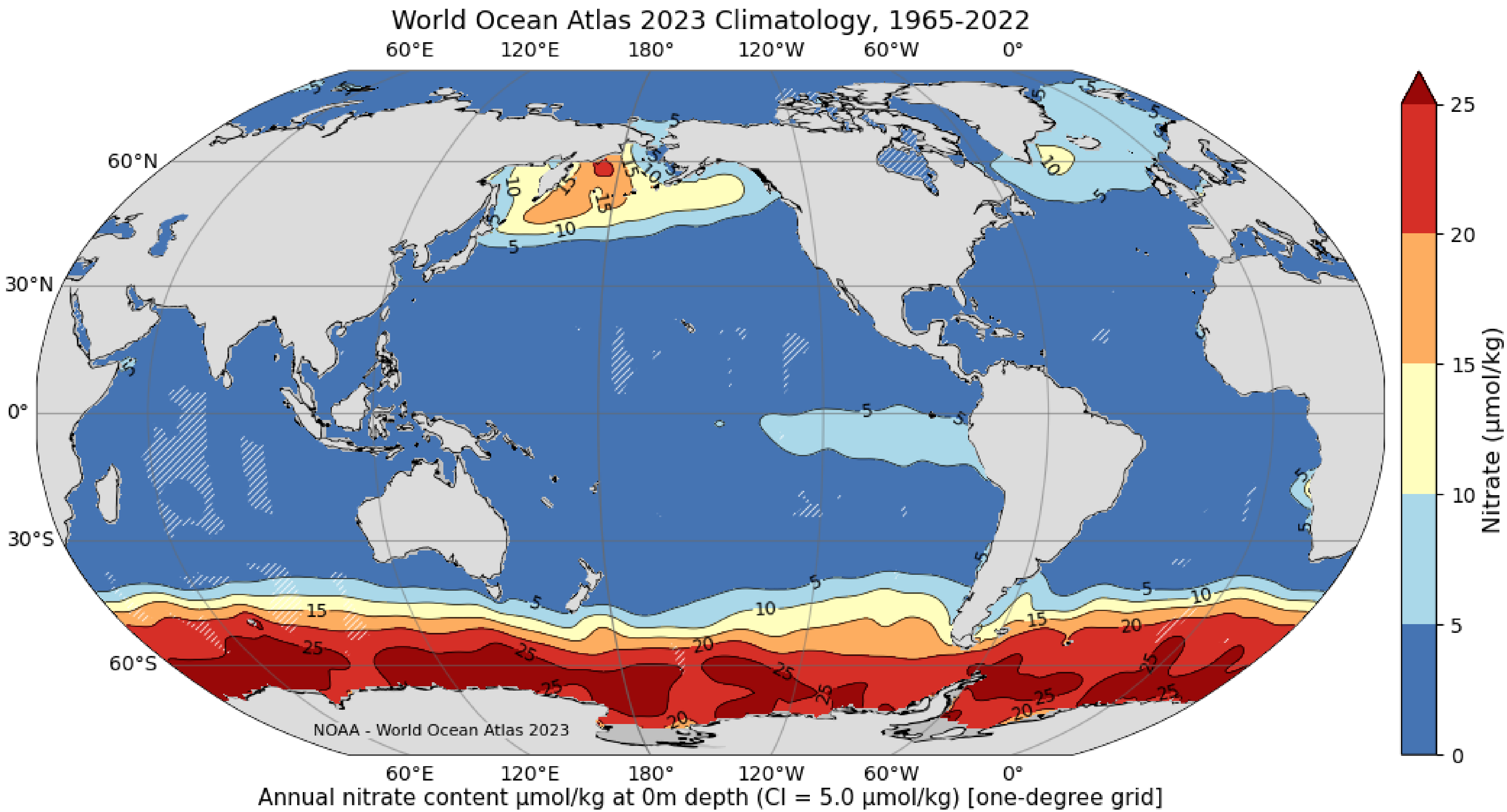
Let’s compare with
the general circulation in the upper ocean.





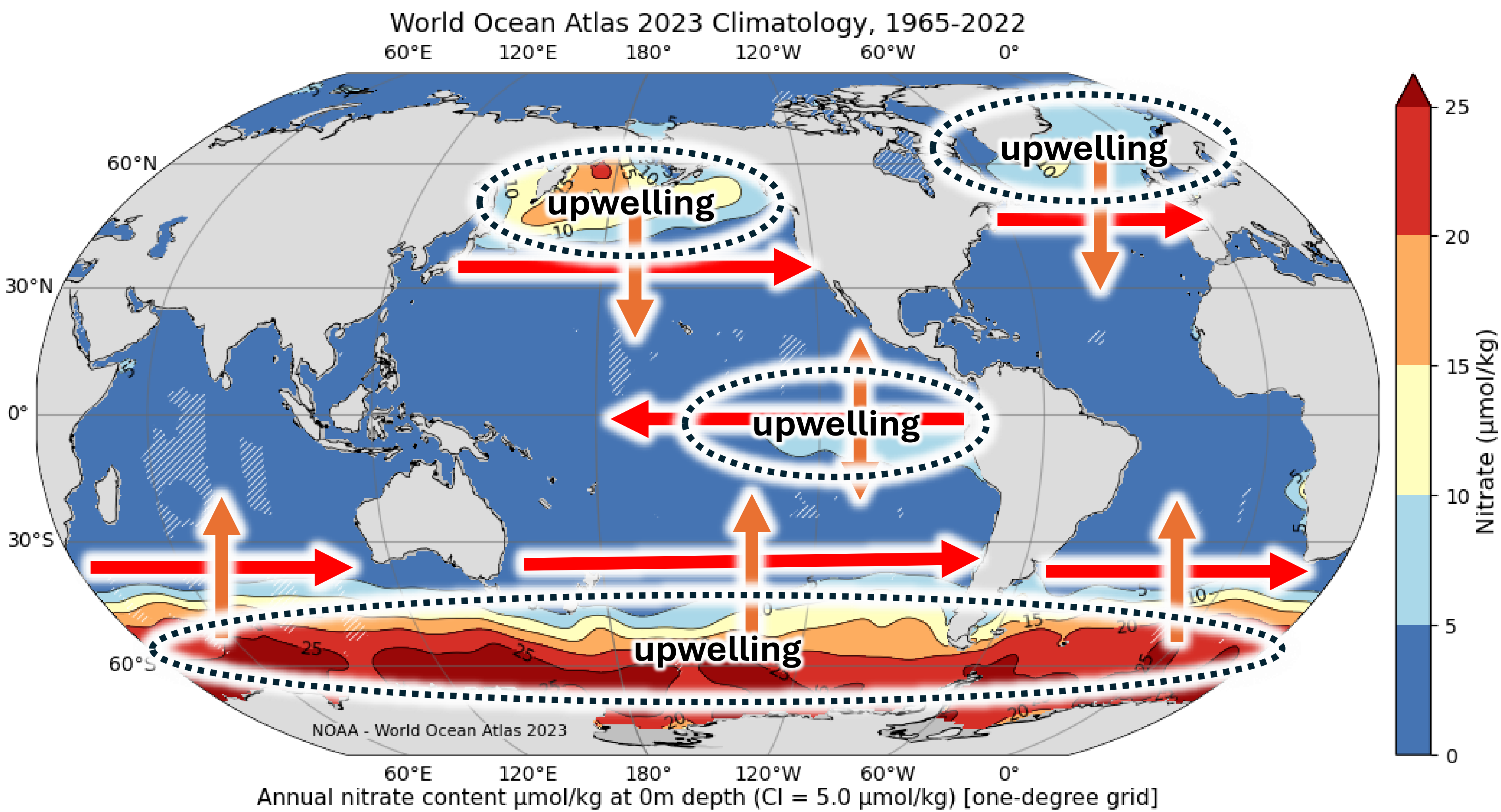
Ocean circulation affects nutrient and CO_2 flux.

Nitrate @surface (World Ocean Atlas 2023)



- Nutrient is rich in deep ocean

Nitrate @surface (World Ocean Atlas 2023)



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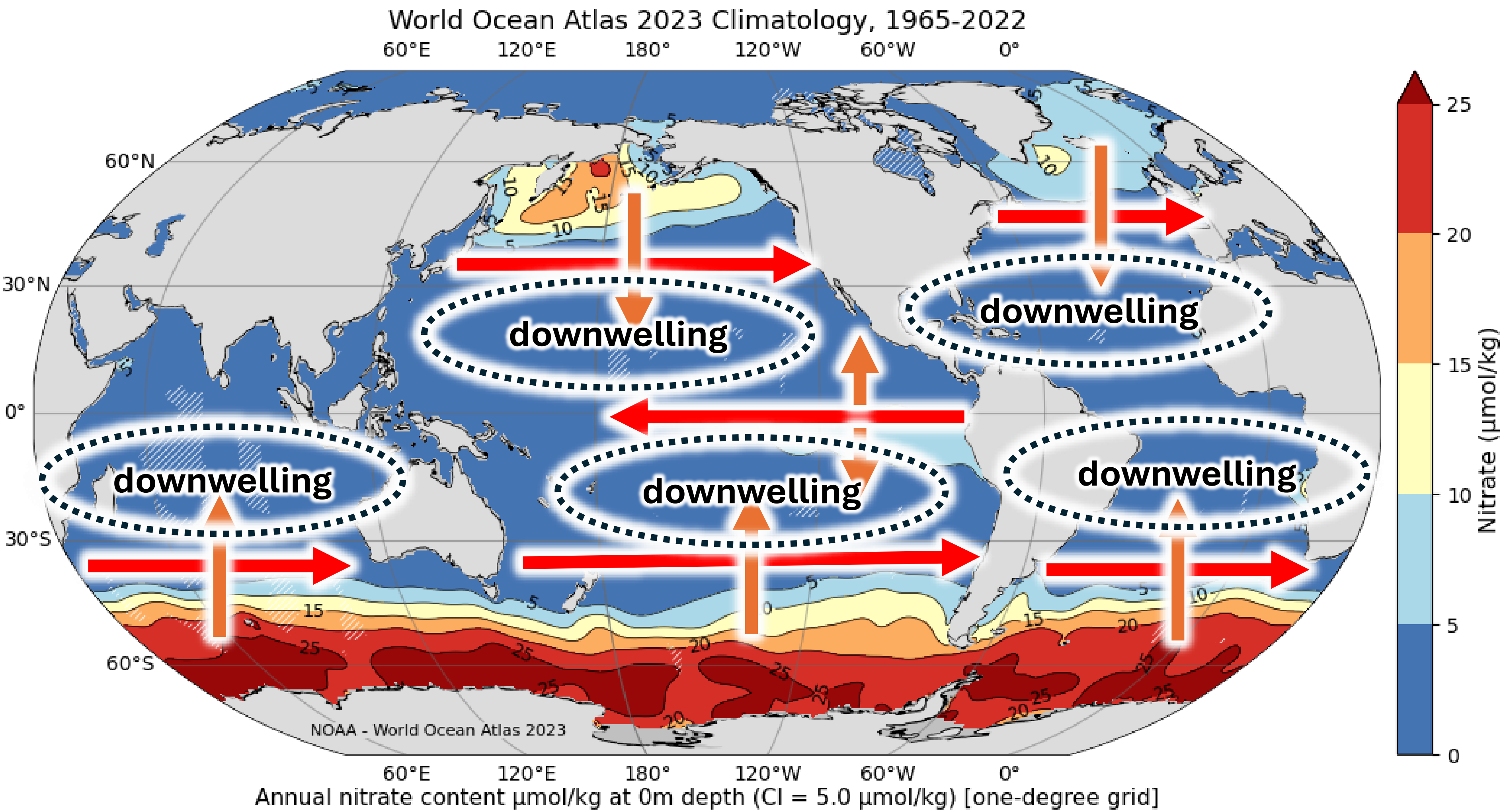

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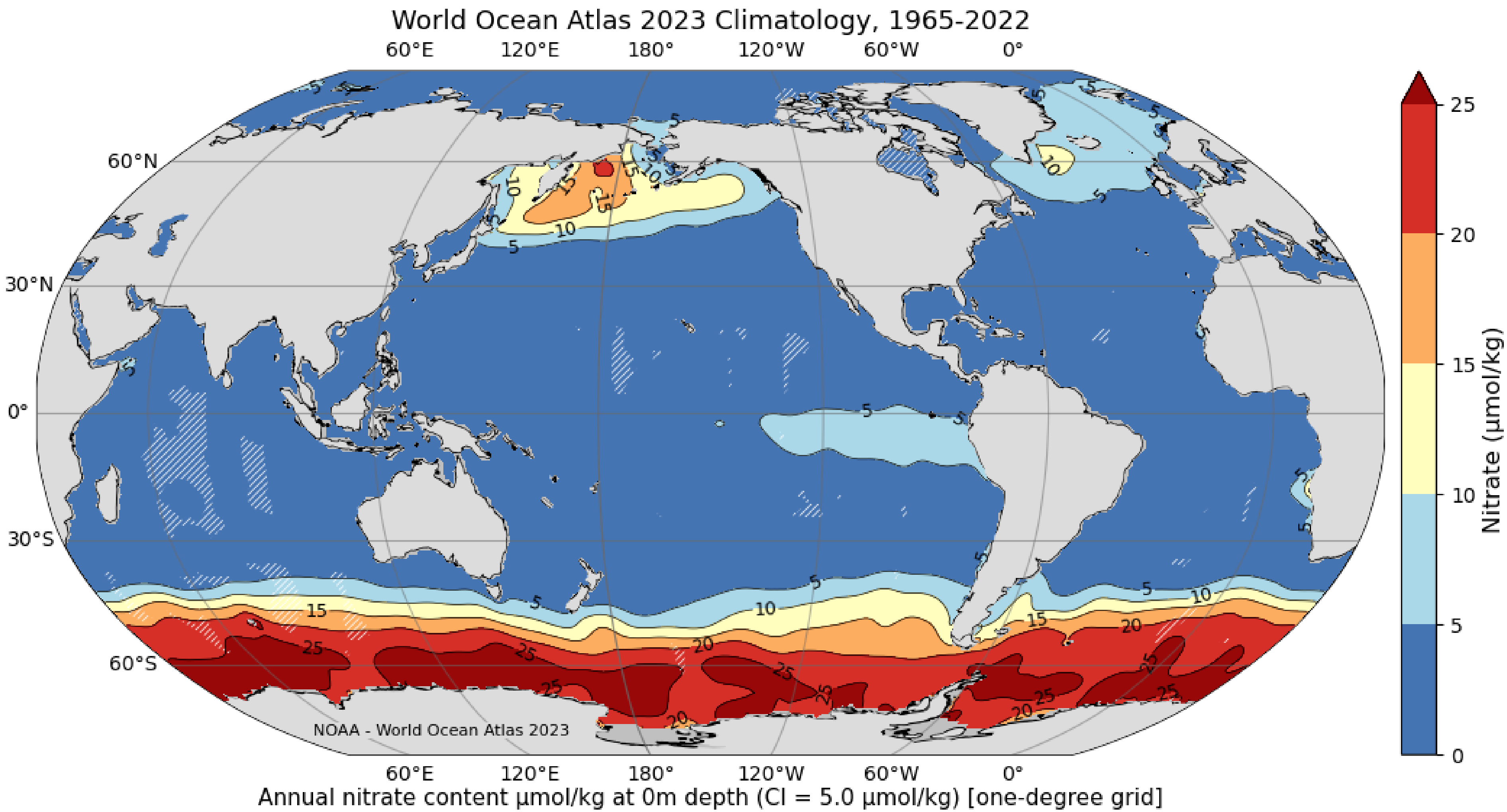
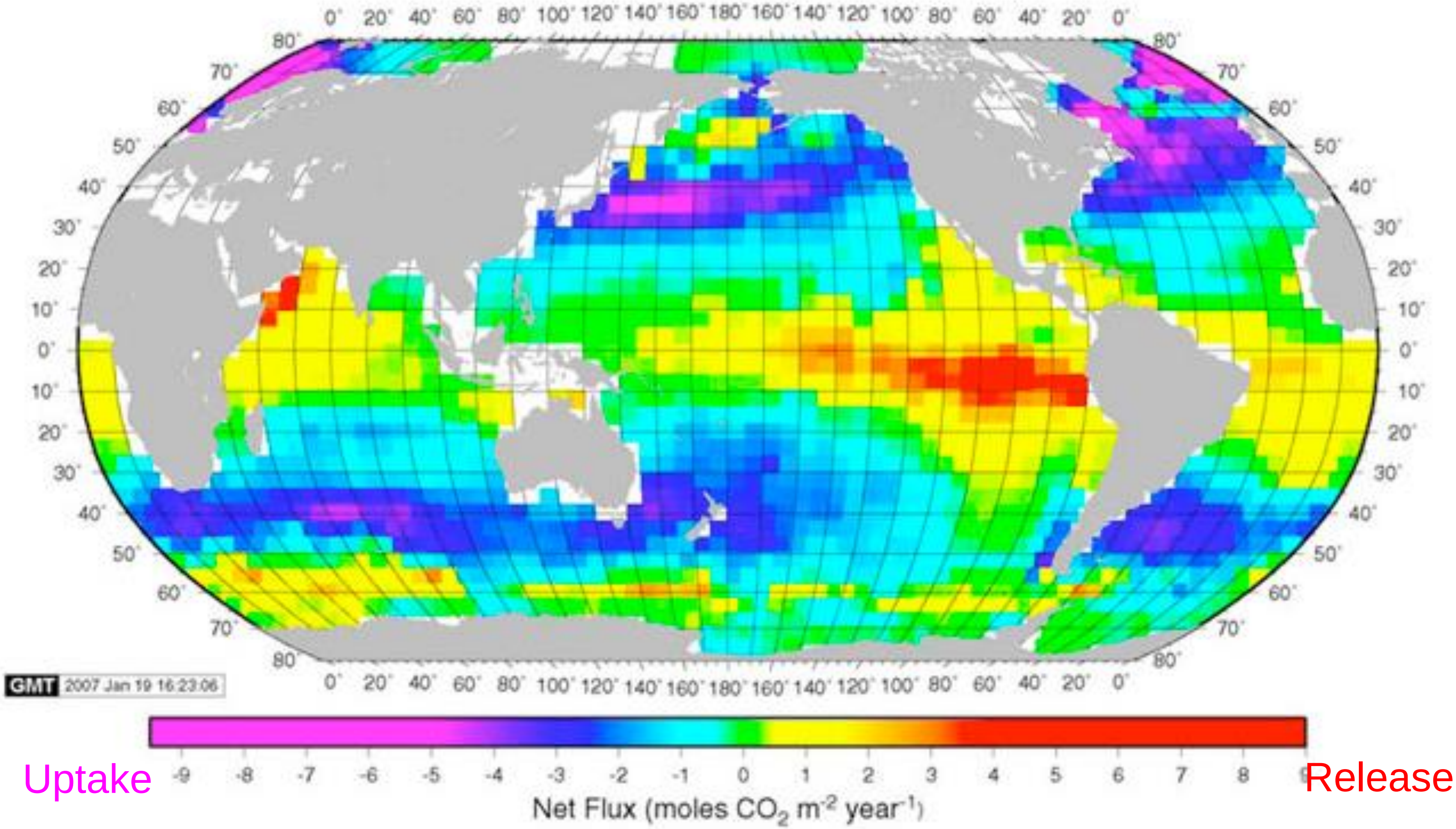


- Nutrient is rich in deep ocean

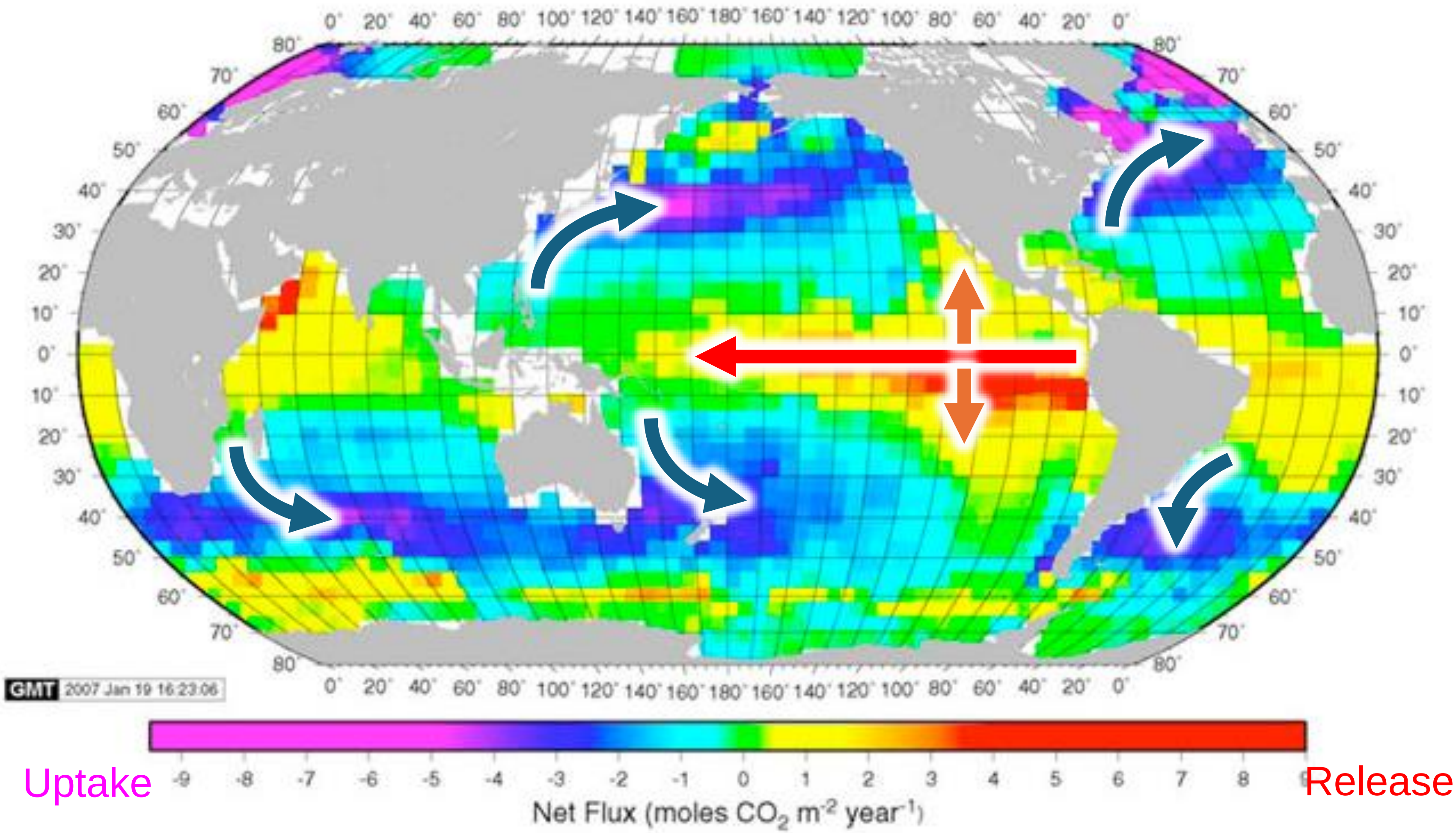
Air-sea exchange of CO_2 (for 2000)



- Carbon is rich in deep ocean.
- CO2 chemistry is related to ocean temperature.

Takahashi et al. (2012)

Air-sea exchange of CO_2 (for 2000)



- Carbon is rich in deep ocean.
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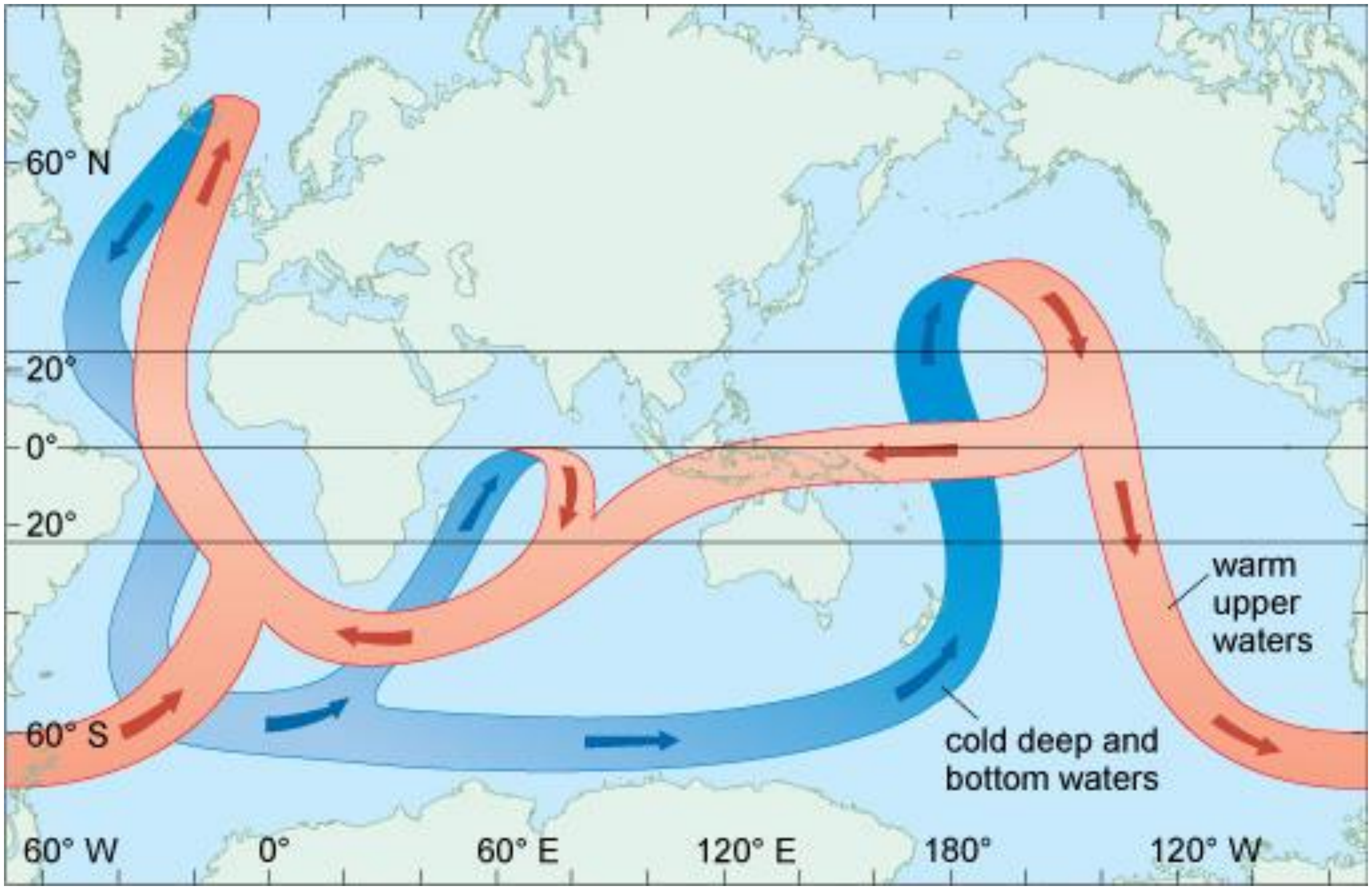
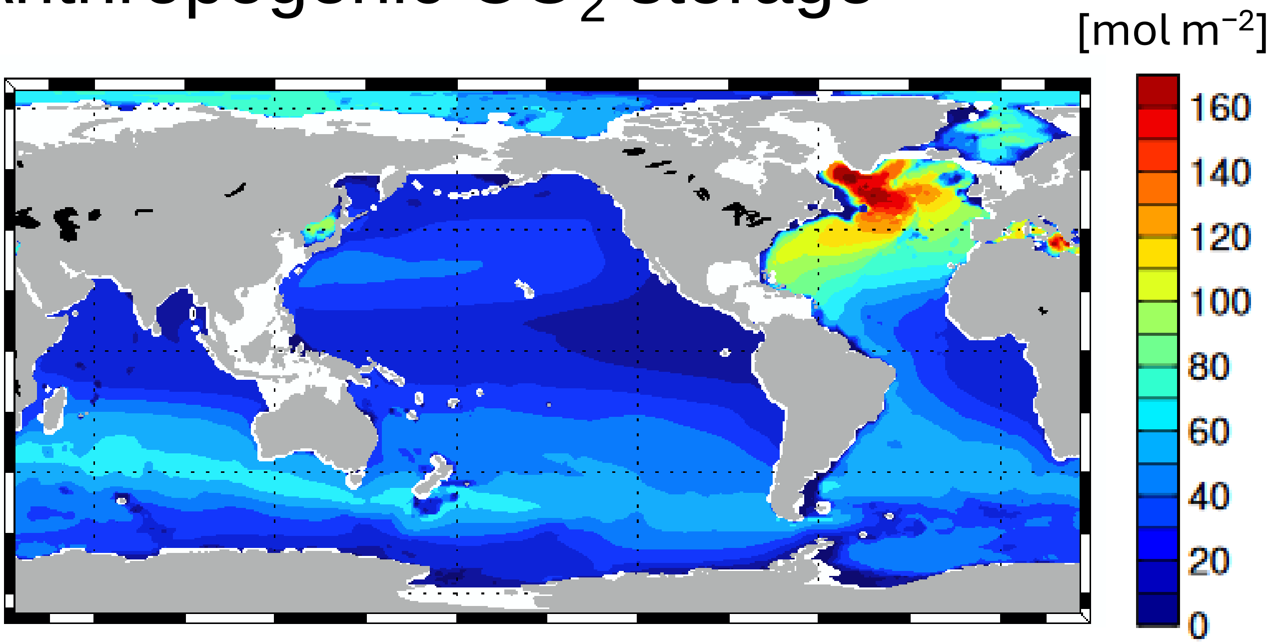
6. Thermohaline circulation

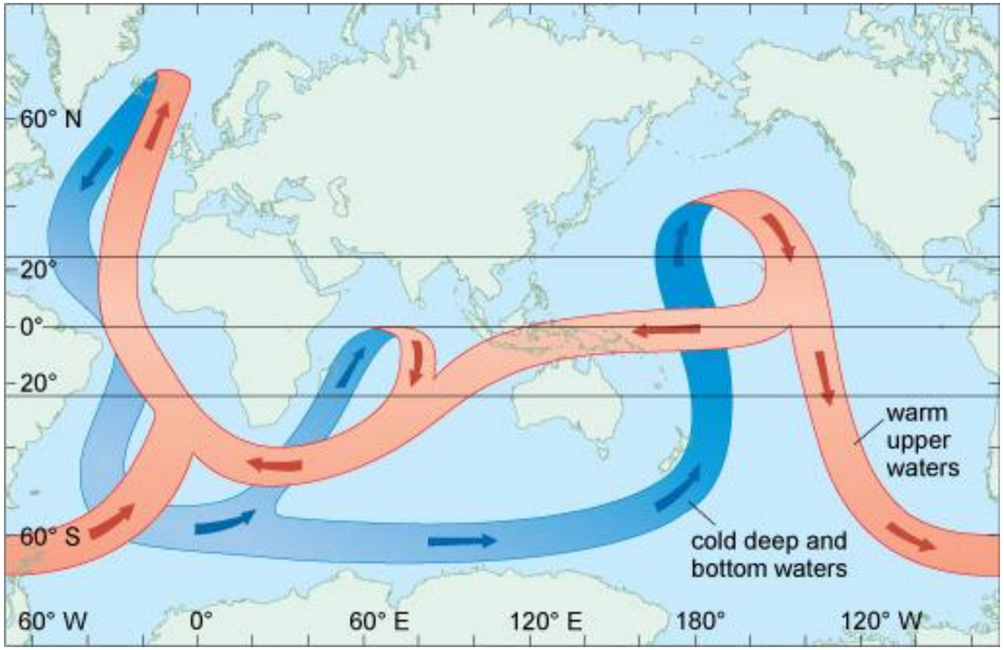


- Dense water sink under the light water.

Anthropogenic CO_2 storage



Khatiwala et al. (2013)



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