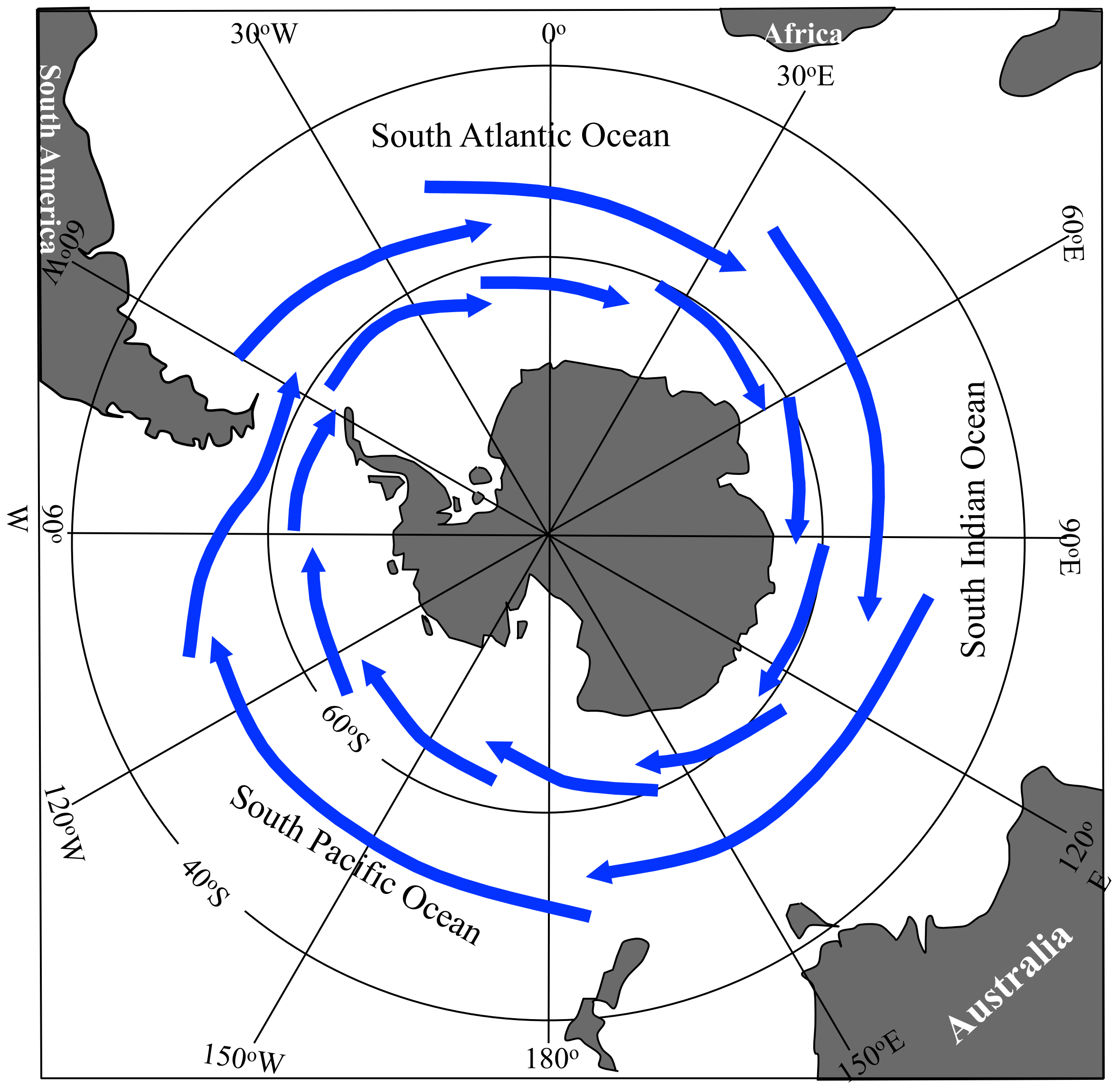
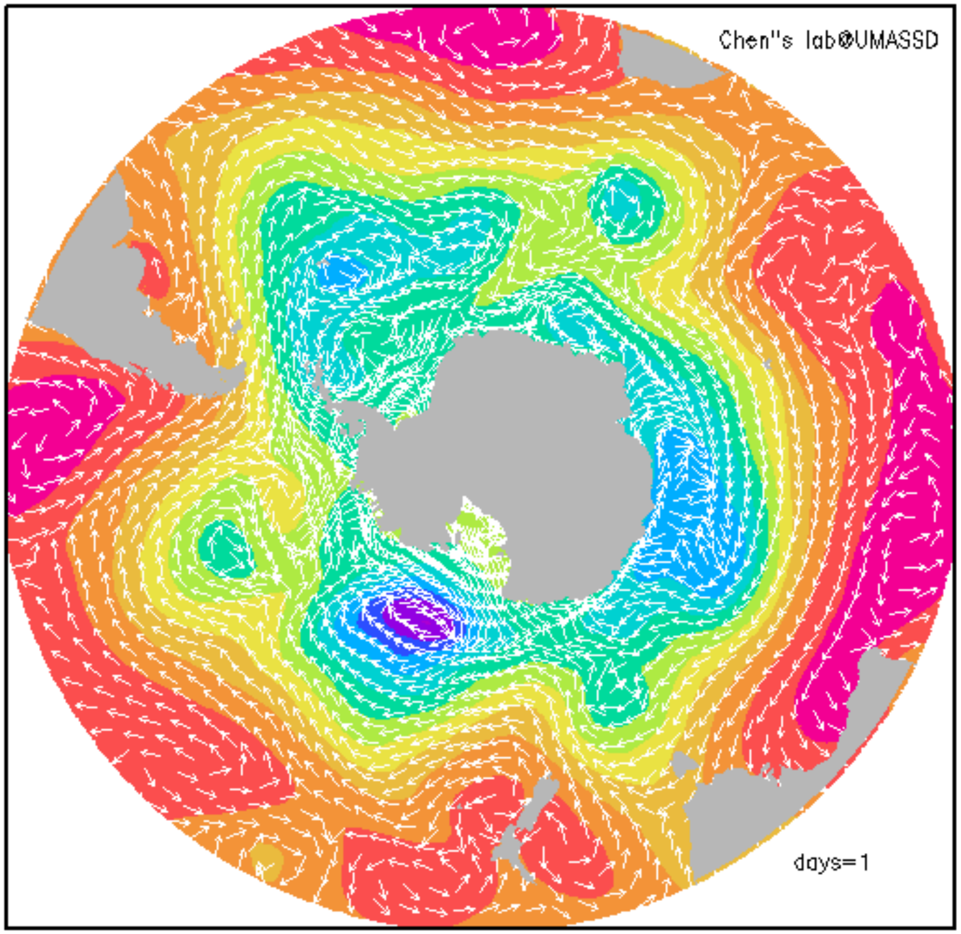
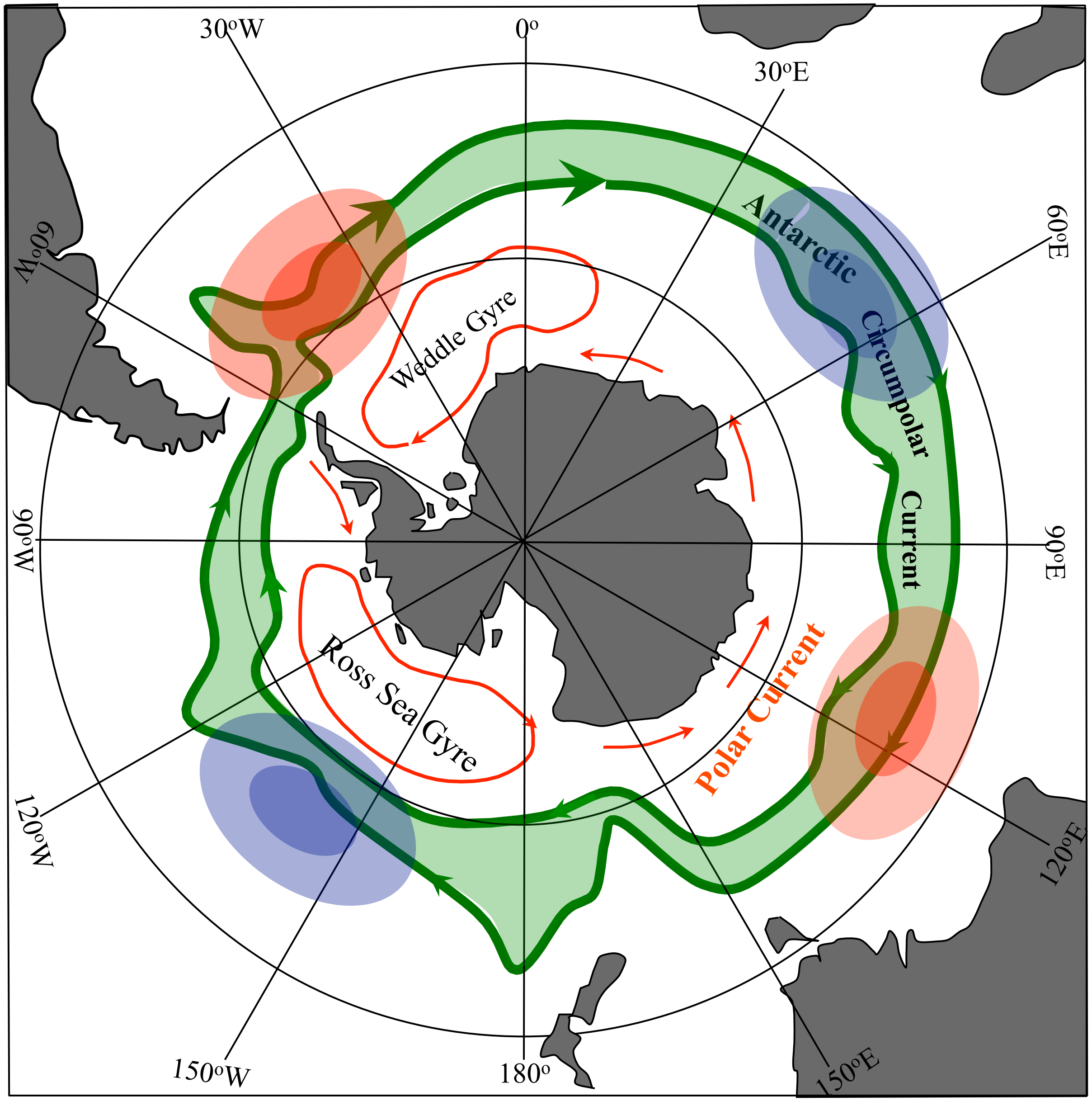
Lecture 8: Ecosystem in the Southern Ocean




Chen"s lab@UMASSD
days=1



The Antarctic Circumpolar Current (ACC) moves eastward around the Antarctic

ACC velocity: 4 to 20 cm/s

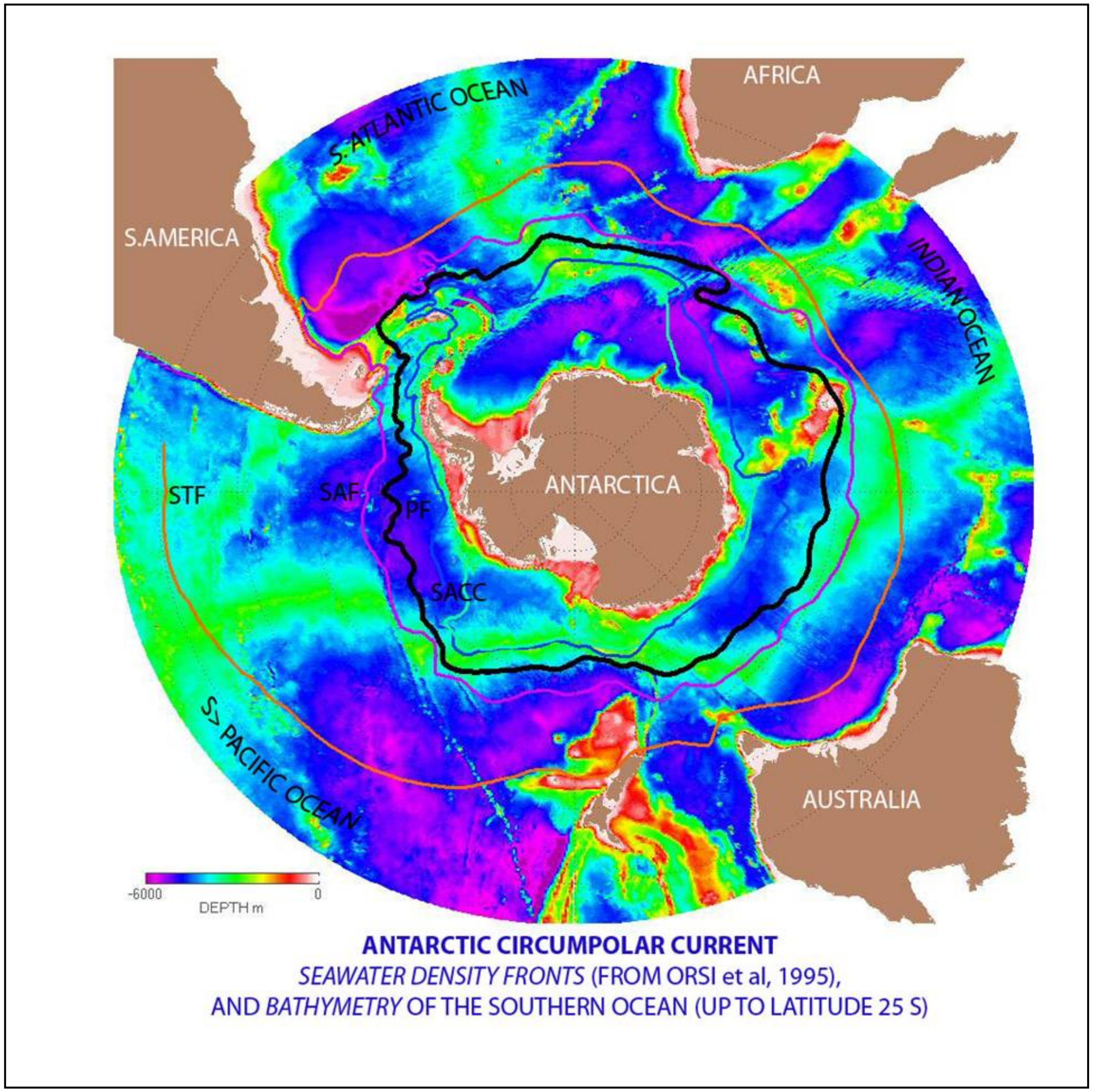
ACC features two maximum jets and

two colder pools;
two warmer pools
(2-3° C colder or warmer)

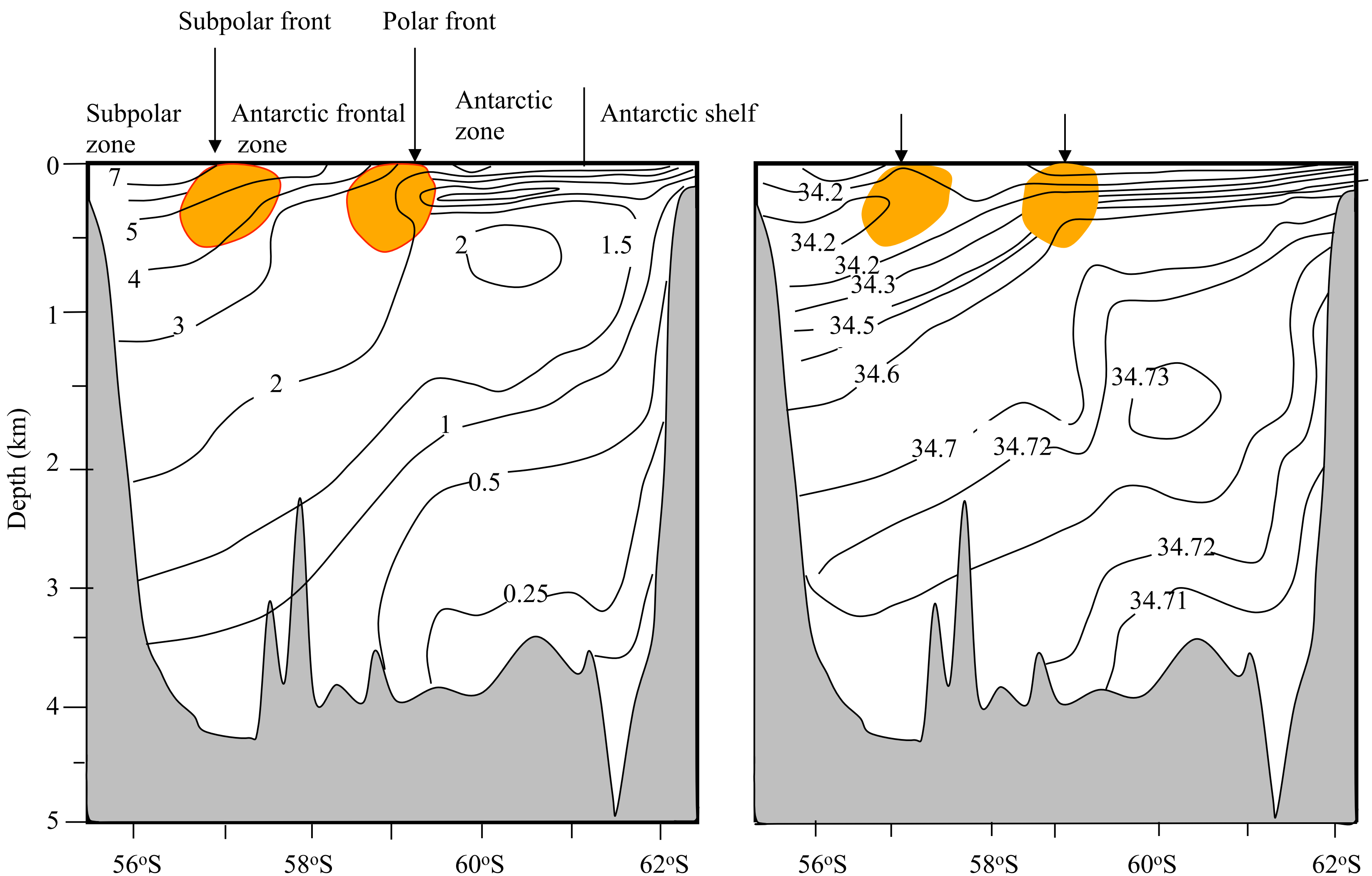
Propagates along the Antarctic Circumpolar Current (ACC) and takes 8-9 years to travel around a circle.

ACC is driven by the wind and density gradient.

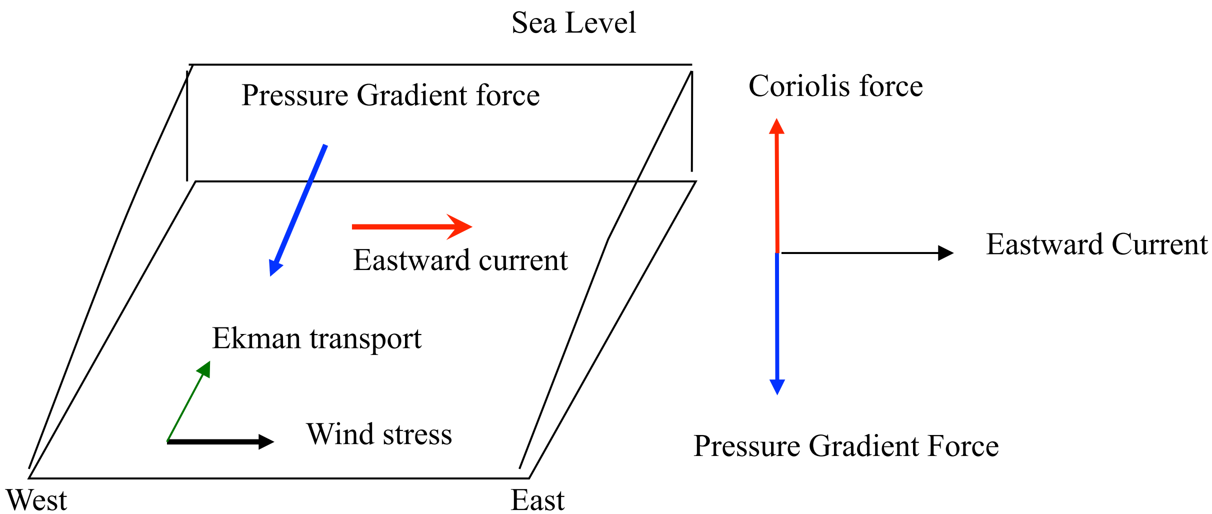
Locations of density fronts in the southern ocean-from NASA JPL website



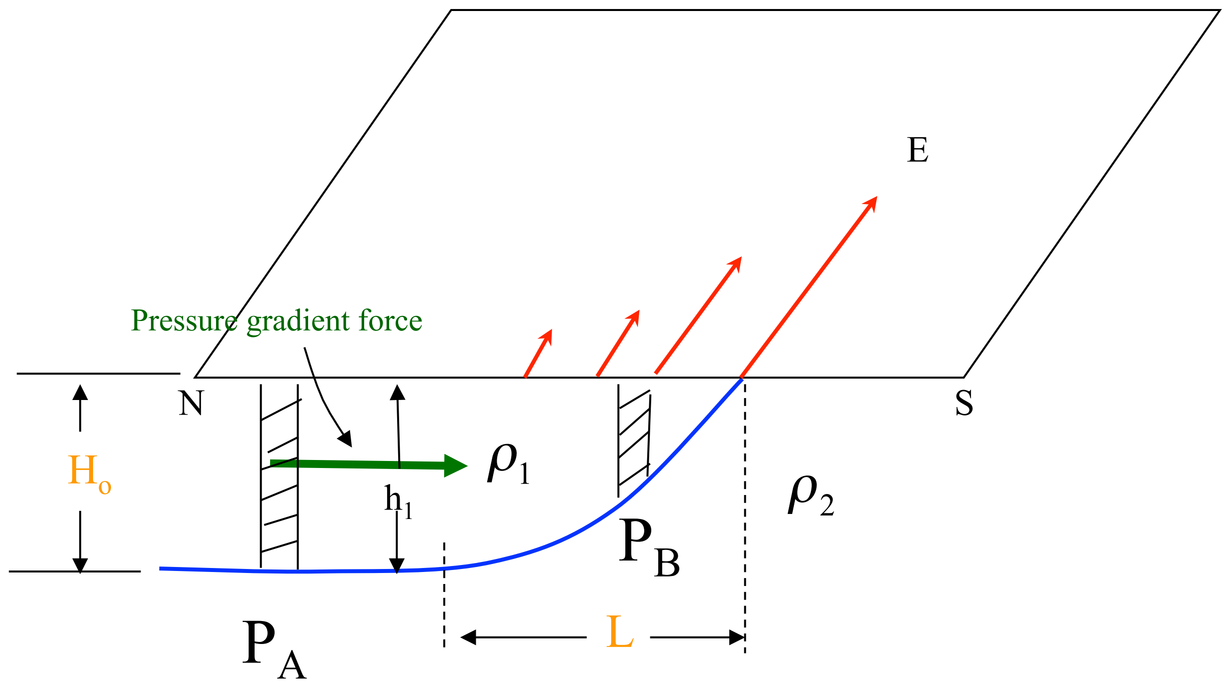
http://www.jpl.nasa.gov/media/20051206a/images/pic2.jpg

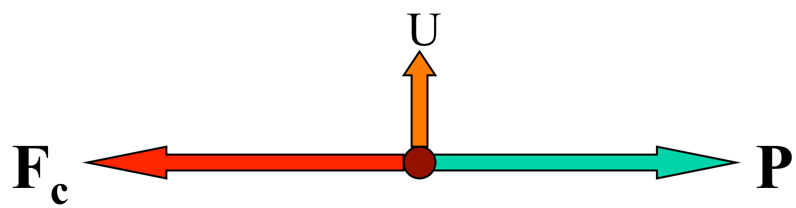

Subpolar front
Polar front
Subpolar zone
Antarctic frontal zone
Antarctic zone
Antarctic shelf
Depth (km)
0
1
2
3
4
5
7
5
4
3
2
1
0.5
0.25
2
1.5
56°S
58°S
60°S
62°S
34.2
34.2
34.2
34.3
34.5
34.6
34.7
34.72
34.73
34.72
34.71
56°S
58°S
60°S
62°S

The Wind-induced Eastward Current



$$u = -\frac{g}{f}\frac{\partial \zeta}{\partial y}$$





$$P_1(y,z) = P_o - \rho_1 g z$$

$$P_2(y,z) = P_a + g h_1 - \rho_2 g (z + h_1)$$

$$\frac{\partial P_1}{\partial y} = \frac{\partial P_a}{\partial y}$$

$$\frac{\partial P_2}{\partial y} = \frac{\partial P_a}{\partial y} - (\rho_2 - \rho_1) g \frac{\partial h_1}{\partial y}$$

Assume that there is no motion in the lower layer, yield,

$$\frac{\partial P_a}{\partial y} = (\rho_2 - \rho_1) g \frac{\partial h_1}{\partial y} \longrightarrow f u_1 = -\frac{1}{\bar{\rho}} \frac{\partial P_1}{\partial y} = -\frac{\rho_2 - \rho_1}{\bar{\rho}} g \frac{\partial h_1}{\partial y}$$

Assume that

$$g' = (\rho_2 - \rho_1) g / \bar{\rho} \ \text{ and } \ h_1 = H_o (1 - e^{-y/L})$$

↑ Reduced gravity

Therefore,

$$u_1 = -\frac{g' H_o}{f L} e^{-\frac{y}{L}}$$

$f < 0$, $u_1 > 0$

u_1 reaches a maximum at $y = 0$ (at front)

decreases exponentially away from the front

QS: How could we determine L?

$$\frac{f+\zeta}{h_1} = \frac{f}{H_o}, \quad \zeta = -\frac{\partial u_1}{\partial y}$$

Therefore,

$$\frac{\partial u_1}{\partial y} = f\left(1 - \frac{h_1}{H_o}\right) \qquad u_1 = -\frac{g' H_o}{fL} e^{-\frac{y}{L}}$$

then,

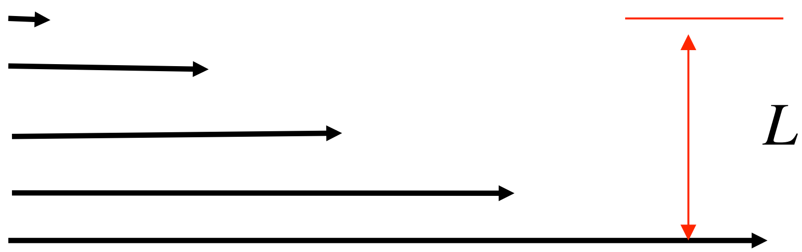
$$\frac{g' H_o}{fL^2} = f, \quad \boxed{L = -\frac{\sqrt{g' H_o}}{f}}$$

Internal Rossby Reformation Radius

The horizontal scale depends on vertical stratification and Coriolis parameter. L is larger as the reduced gravity increases. For a given reduced gravity, L is smaller as latitude increases.

$$u_1 = -\frac{g'H_o}{fL} e^{-\frac{y}{L}} \qquad L = -\frac{\sqrt{g'H_o}}{f}$$

$$u_1 = \sqrt{g'H_o}\, e^{-\frac{|y|}{L}}$$

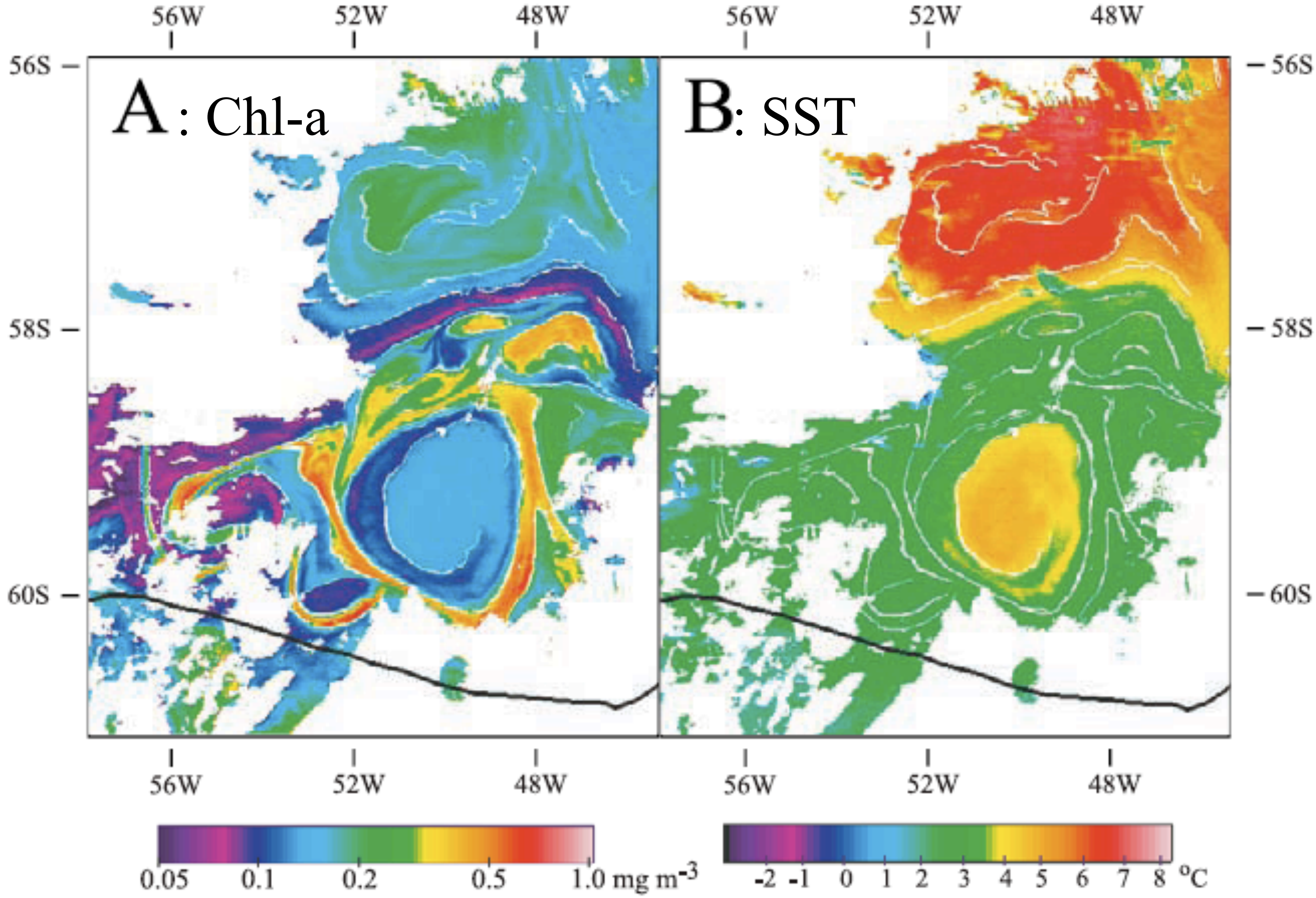


$$L = -\frac{\sqrt{g'H_o}}{f}$$

Density difference;
Mixed layer thickness;
Latitude

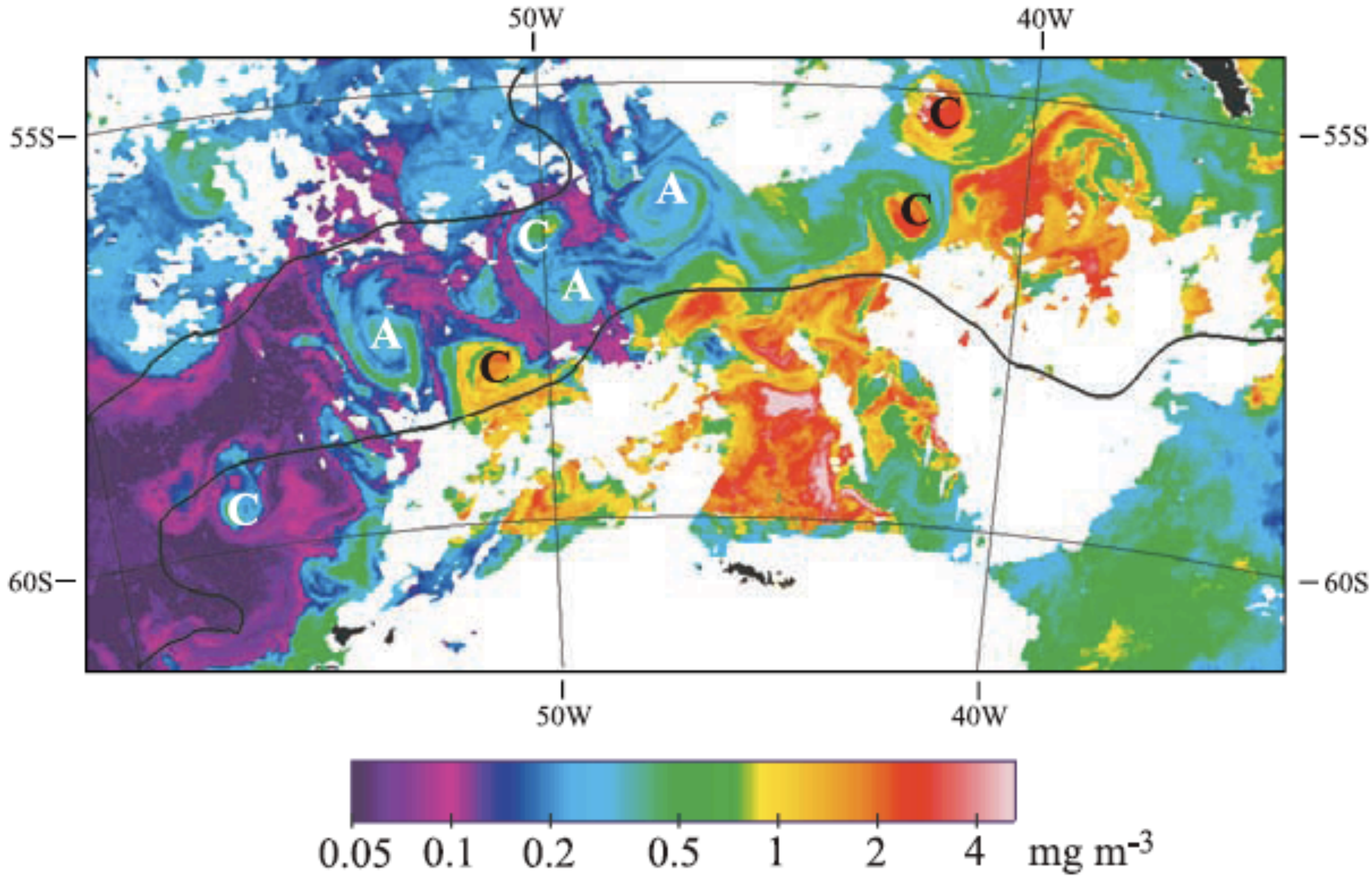
$$u_1 \sim \sqrt{g'H_o}$$

January 28,2004



From Kahru et al. (2007)-JGR-Ocean

Chl-a concentration (January 26-30, 2005)



From Kahru et al. (2007)-JGR-Ocean

Characteristics of the biological field in the Southern Ocean

1) High nutrients and low chlorophyll-a concentration
2) Phytoplankton blooms often occur at subpolar and polar frontal zones.
3) Phytoplanton growth is limited by iron concentration

NO_3: 27 μmol/L; NO_2: 2 μmol/L, nitrogen is not a limit factor;

Si (silica): < 0.6 μmol/L in the interior, but ~11.7 μmol/L within frontal zone.

The availability of silica directly control the diversity of phytoplankton species in the Southern Ocean. Within frontal zone, the phytoplankton is dominated by diatom, while in the other region, it is characterized by non-diatom species.

Distribution of Iron in the Circumpolar region

In the Circumpolar Current zone: Fe: 0.31~0.49 nM, with minimum value of 0.17 nM.
In the frontal zone: Fe: 1.9 nM.

Processes controlling the phytoplankton bloom:

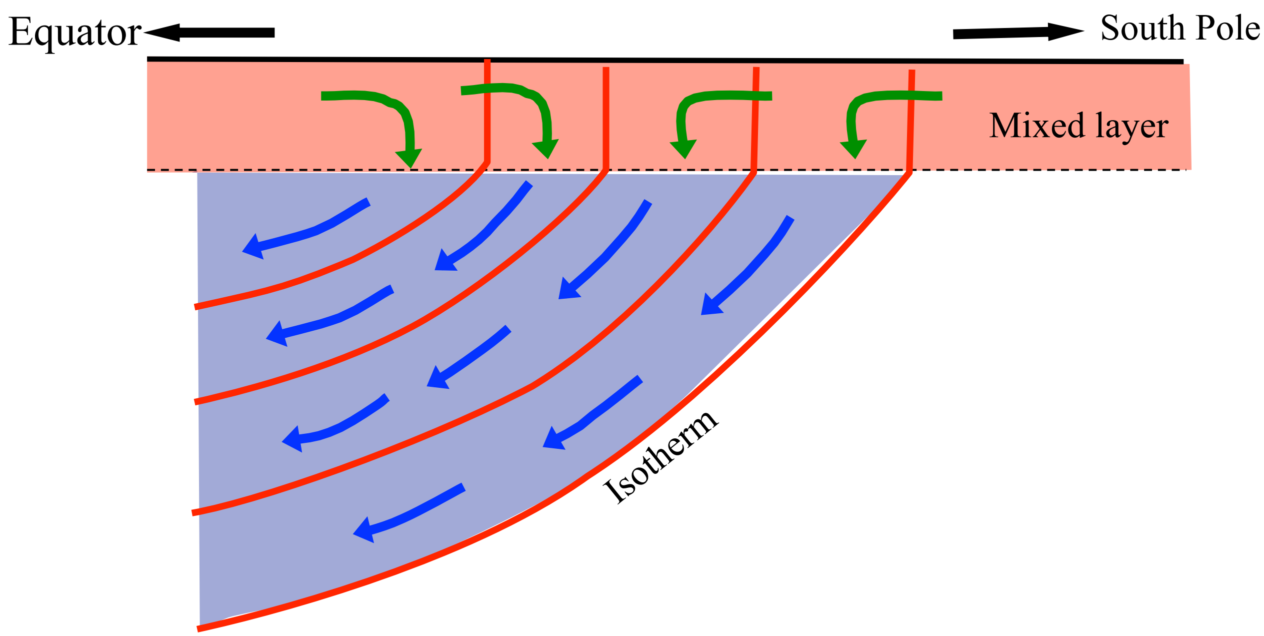
1) **High concentration of irons**
2) **The thin mixed layer**
3) **Low grazing rate by zooplankton.**

As iron concentration increases, the chl-a concentration at the front could be up to 10-50% .

In the Circumpolar current, the mixed layer is shallower than the surrounding water. Based on the Sverdrup's theory, the bloom easily occurs.

10-30% of the new produced phytoplankton is grazed by zooplankton.

Circumpolar Frontal Subduction



Horizontal wind-induced current convergence and cooling causes the subduction of the water from the mixed layer to the weekly mixed thermocline layer in the sub-polar frontal zone. These waters will move downward along the isotherm surface (or density surface) to the deep region.

Sources of irons in the Southern Ocean:

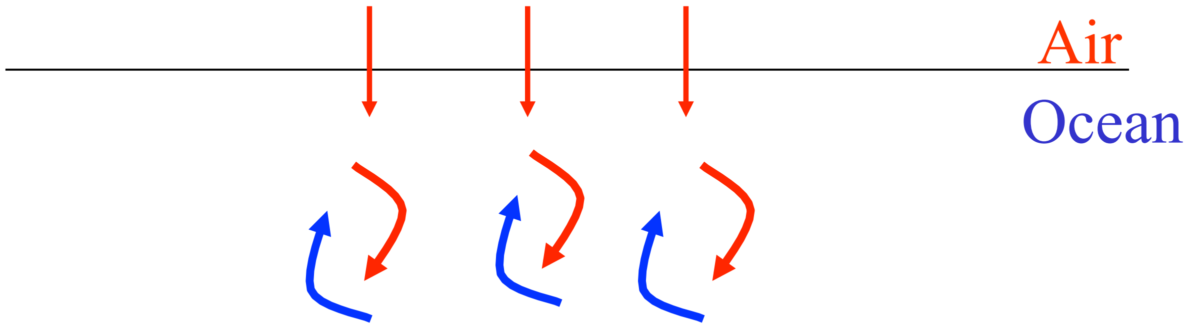
- Wind-induced mixing and upwelling;
- Input from atmospheric dust from the land;
- Ice melting;
- Lateral input of sediment from the continental edge.

Wind's impacts

Mixing:

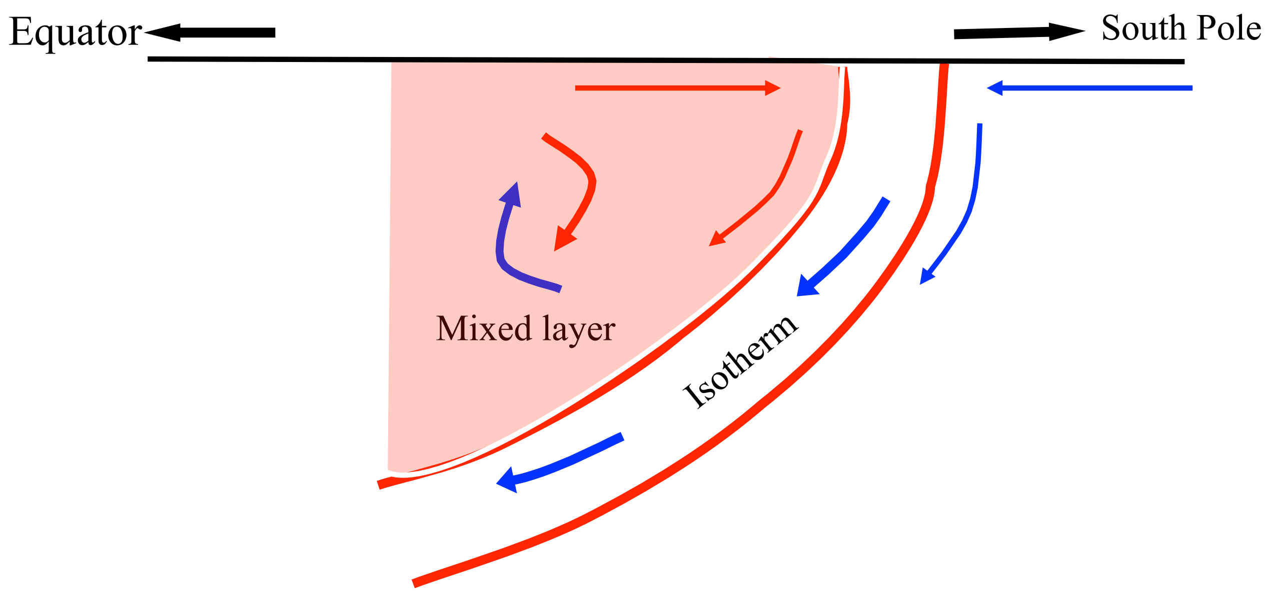
1) Strong winds, and vertical turbulent mixing, the wind direction remains little change with season. The wintertime wind stress is twice as large as the summertime wind stress. For a given season, the wind stress is one time stronger in the Antarctic Ocean than in the subpolar region on the northern hemisphere.

$K_m \sim 3\times10^{-5}$ m^2/s, it is 3 times bigger than the value found in the North Pacific Ocean.



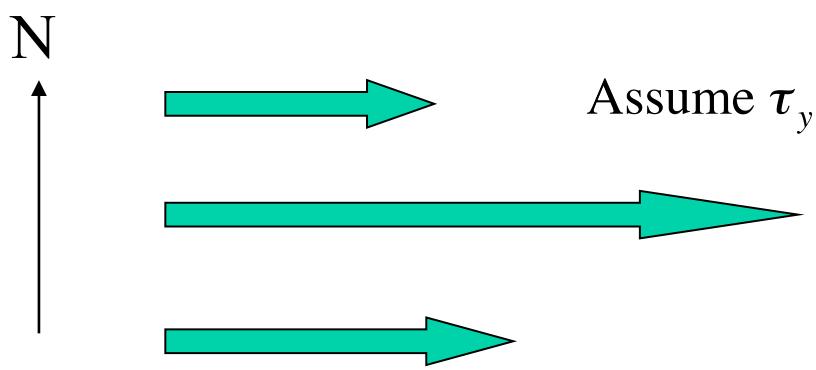
Question: Why is the mixed layer is thinner under stronger wind condition?

This is a dynamics system driven by both winds and density



Ekman Pumping

$$w\big|_{z=-h_E} = \frac{1}{\rho f}\left(\frac{\partial \tau_y}{\partial x} - \frac{\partial \tau_x}{\partial y}\right)$$



$$\text{Assume } \tau_y = 0; f < 0, \frac{\partial \tau_x}{\partial y} < 0; \quad w\big|_{z=-h_E} < 0$$

$$\text{Assume } \tau_y = 0; f < 0, \frac{\partial \tau_x}{\partial y} > 0; \quad w\big|_{z=-h_E} > 0$$

Total upward iron flux due to Ekman pumping and vertical mixing is

1.68×10^{-12} mol/m^2/s,

5 time bigger than the value found in the subpolar region in the North Pacific Ocean, but still is smaller than the value found in subpolar and polar frontal zone in the Antarctic Ocean.

Observational Evidence:

In the vertical direction, the high phytoplankton concentration could deepens to 70 m below the surface. It usually occurs within the frontal zone.

↓

Subduction

Wind or cooling-induced downward movement of the oceanic water from the mixed layer to the weakly mixed thermoclinic layer.

Example: Horizontal wind convergence: in sub-tropic region, and sub-polar frontal zone.

$$S_d = -w_m - \vec{v} \cdot \nabla h_m$$

where Sd: the subduction rate from the mixed layer to the thermoclinic layer;
w_m: the vertical velocity at the bottom of the mixed layer
v_m: the horizontal velocity at the bottom of the mixed layer
h_m: the mixed layer depth

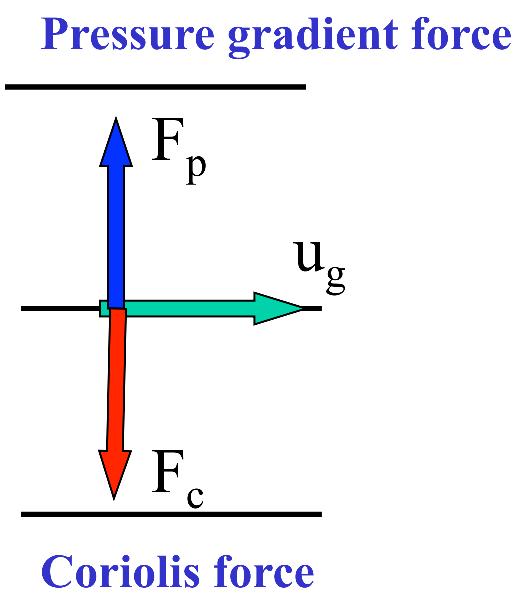
Another Important Physical Mechanism:

Frontal Instability and Eddy Formation

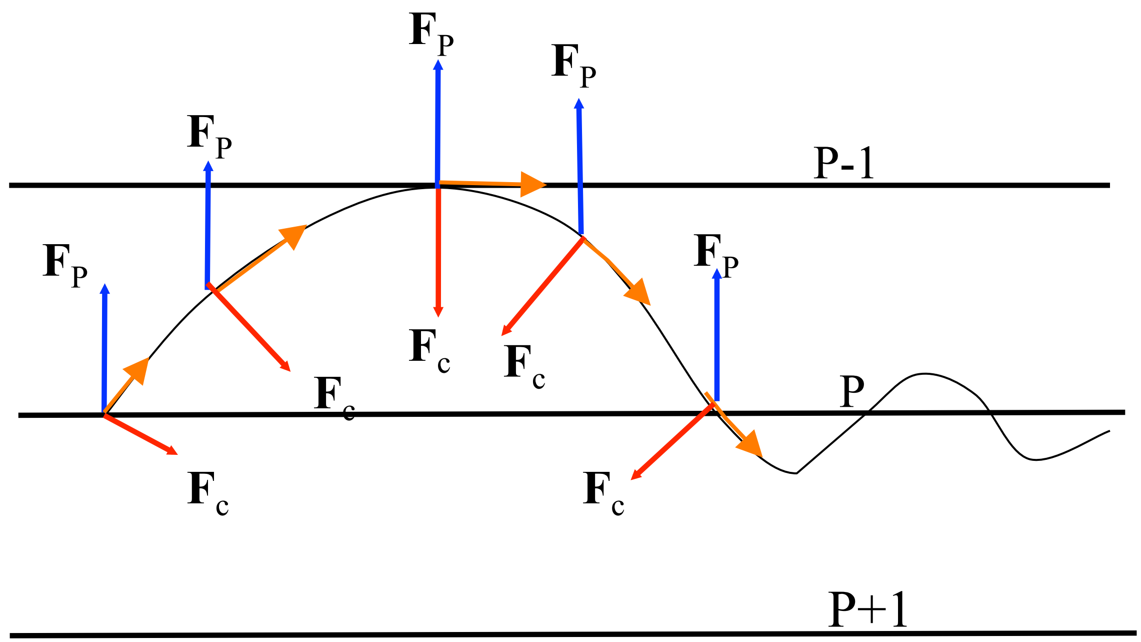
- **Geostrophic Instability: Pressure distribution**
- **Barotrophic Instability: Horizontal current shear**
- **Baroclinic Instability: Vertical current shear**

Geostrophic Instability

Before perturbation

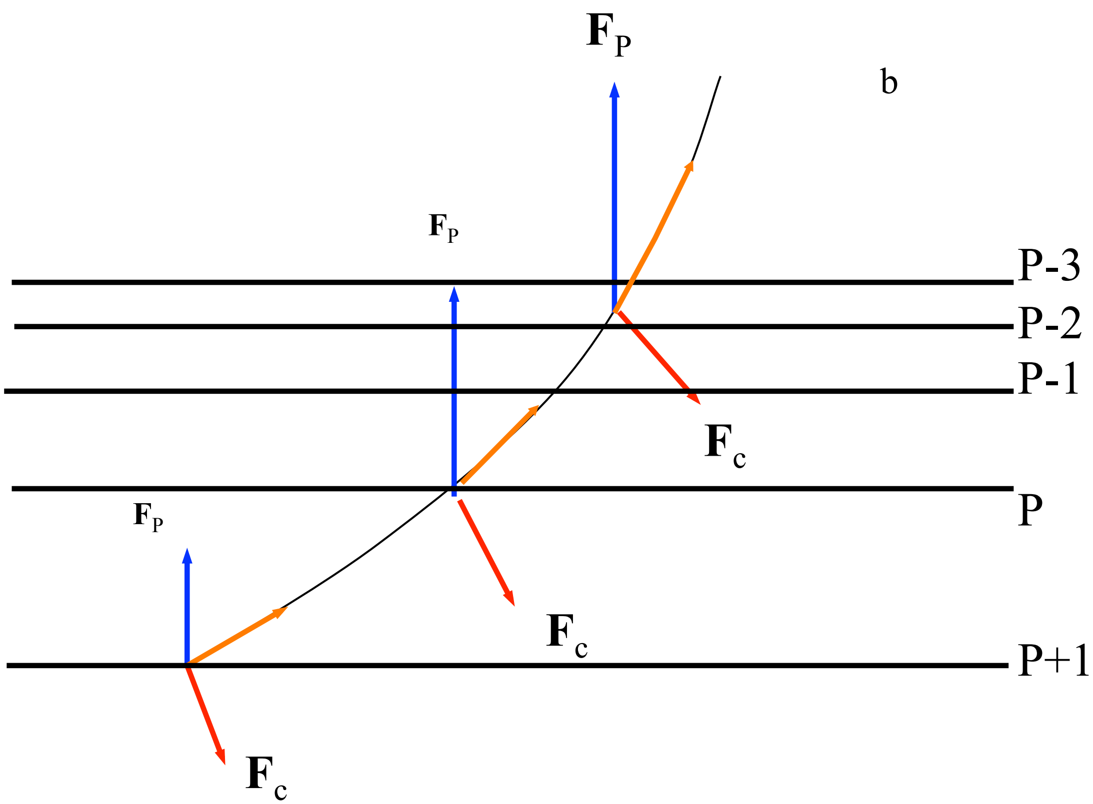


After perturbation



Pressure gradient remains unchanged (with uniform space of pressure contours), while the Coriolis force increases with the increase of the velocity.

Stable!

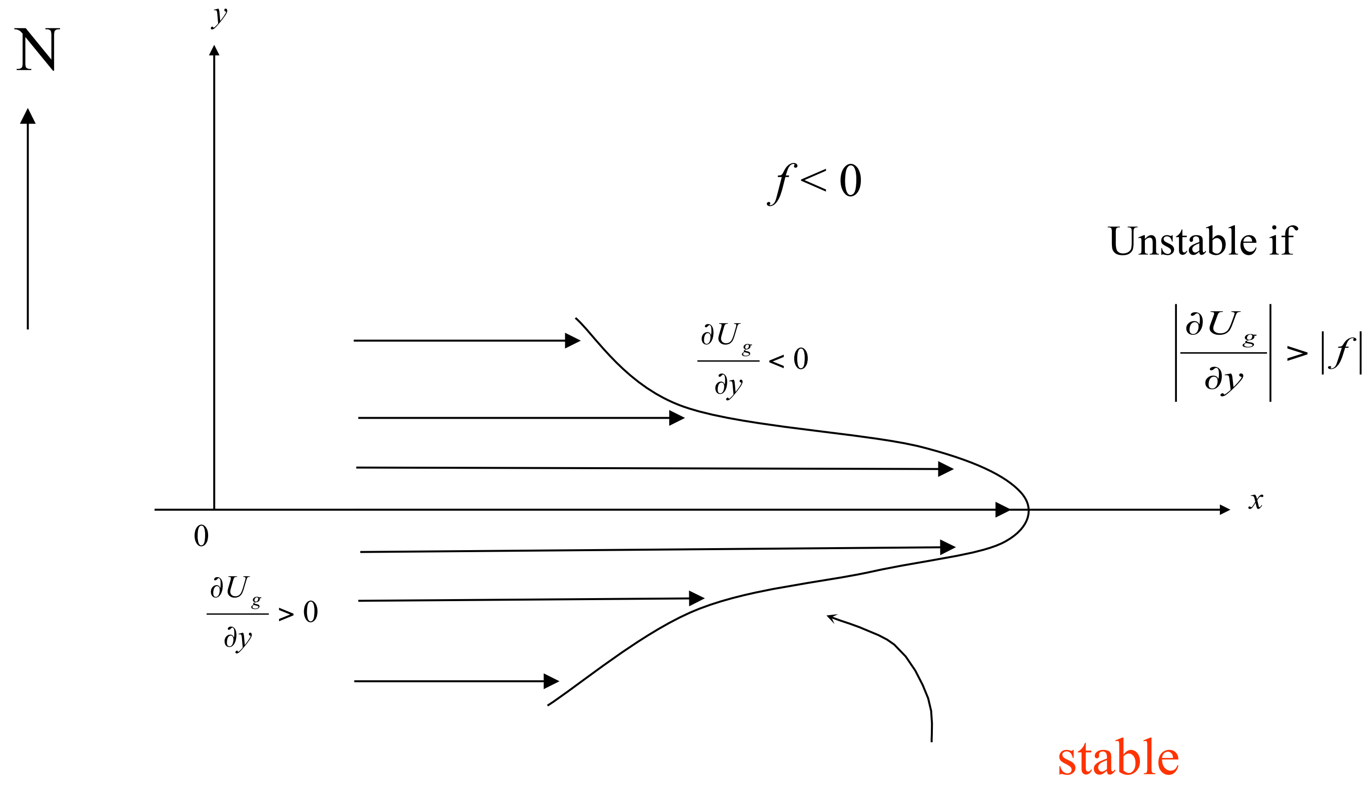


The increase rate of the horizontal pressure gradient is larger than the increase rate of the Coriolis force:

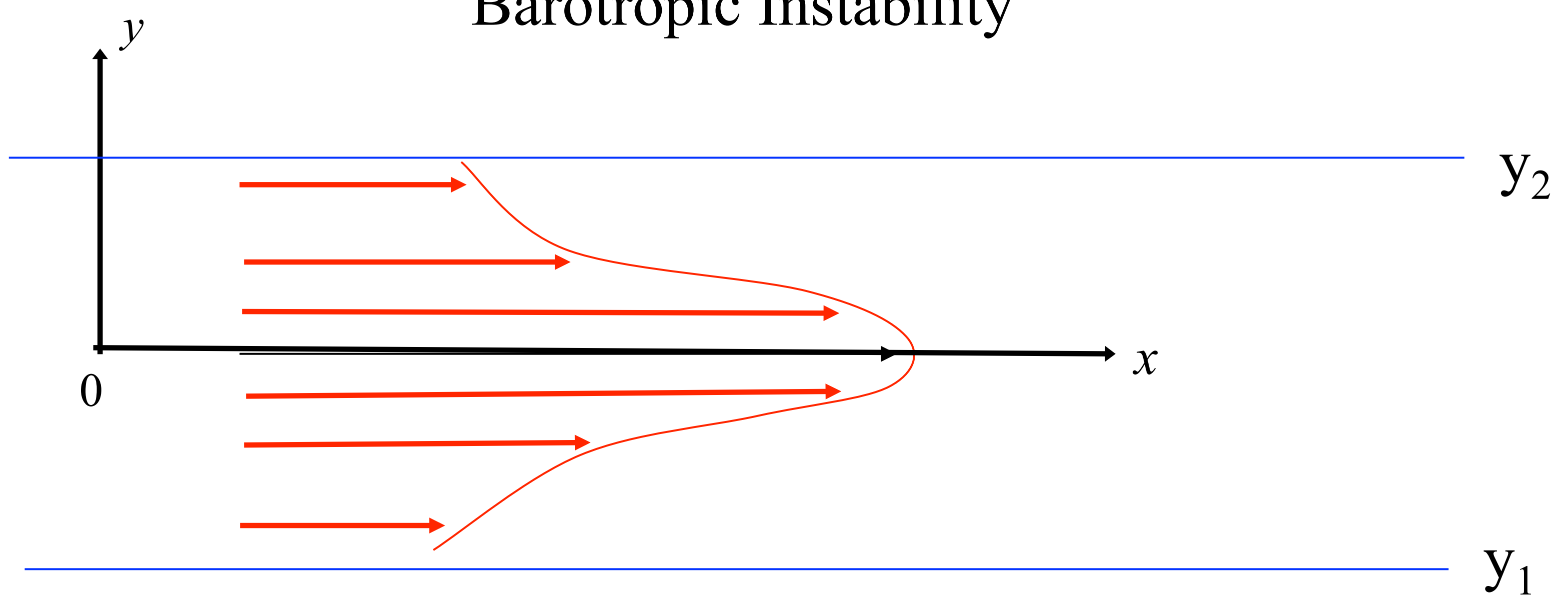
Unstable!

The criterion condition on the southern hemisphere:

$$f - \frac{\partial U_g}{\partial y} = \zeta_a \begin{cases} > 0 & \text{Unstable} \\ = 0 & \text{Neutral} \\ < 0 & \text{Stable} \end{cases}$$



Barotropic Instability



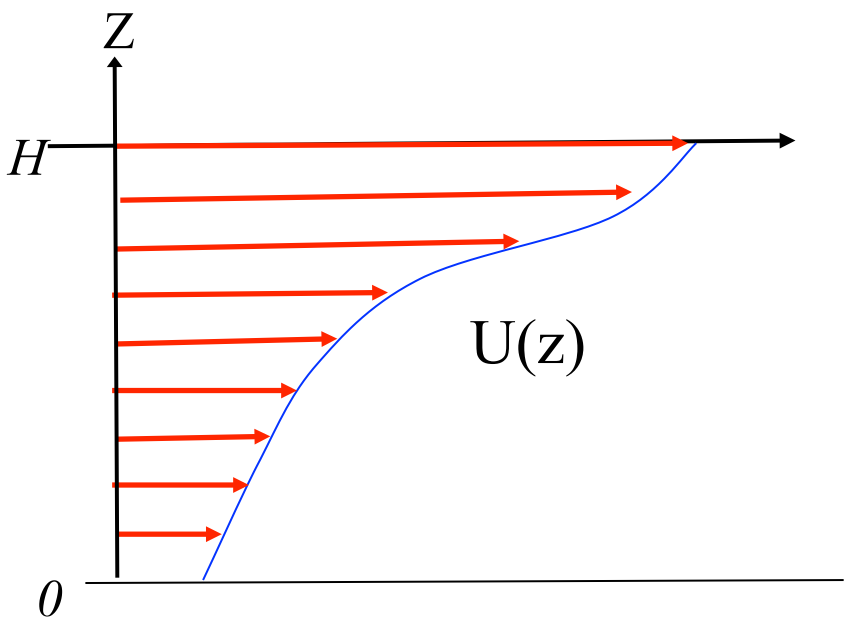
Absolute Vorticity:

$$\zeta_a = f + \zeta = f + \frac{\partial V}{\partial x} - \frac{\partial U}{\partial y} = f - \frac{\partial U}{\partial y}$$

Necessary Condition for barotropic instability:

$$\left.\frac{\partial \zeta_a}{\partial y}\right|_{y=y_k} = \left.\left(\frac{df}{dy} - \frac{\partial^2 U}{\partial y^2}\right)\right|_{y=y_k} = \left.\left(\beta - \frac{\partial^2 U}{\partial y^2}\right)\right|_{y=y_k} = 0 \qquad y_1 < y_k < y_2$$

Baroclinic Instability



The potential vorticity:

$$PV = [\beta - \frac{1}{\rho_s}\frac{\partial}{\partial z}(\rho_s \frac{f^2}{N^2}\frac{\partial U}{\partial z})]y$$

where $N^2 = -\frac{g}{\rho_o}\frac{\partial \rho_s}{\partial z}$

Necessary condition for baroclinic instability:

$$\left.\frac{\partial PV}{\partial y}\right|_{z=z_k} = [\beta - \frac{1}{\rho_s}\frac{\partial}{\partial z}(\rho_s \frac{f^2}{N^2}\frac{\partial U}{\partial z})]\Big|_{z=z_k} = 0 \qquad 0 < \mathrm{z_k} < H$$