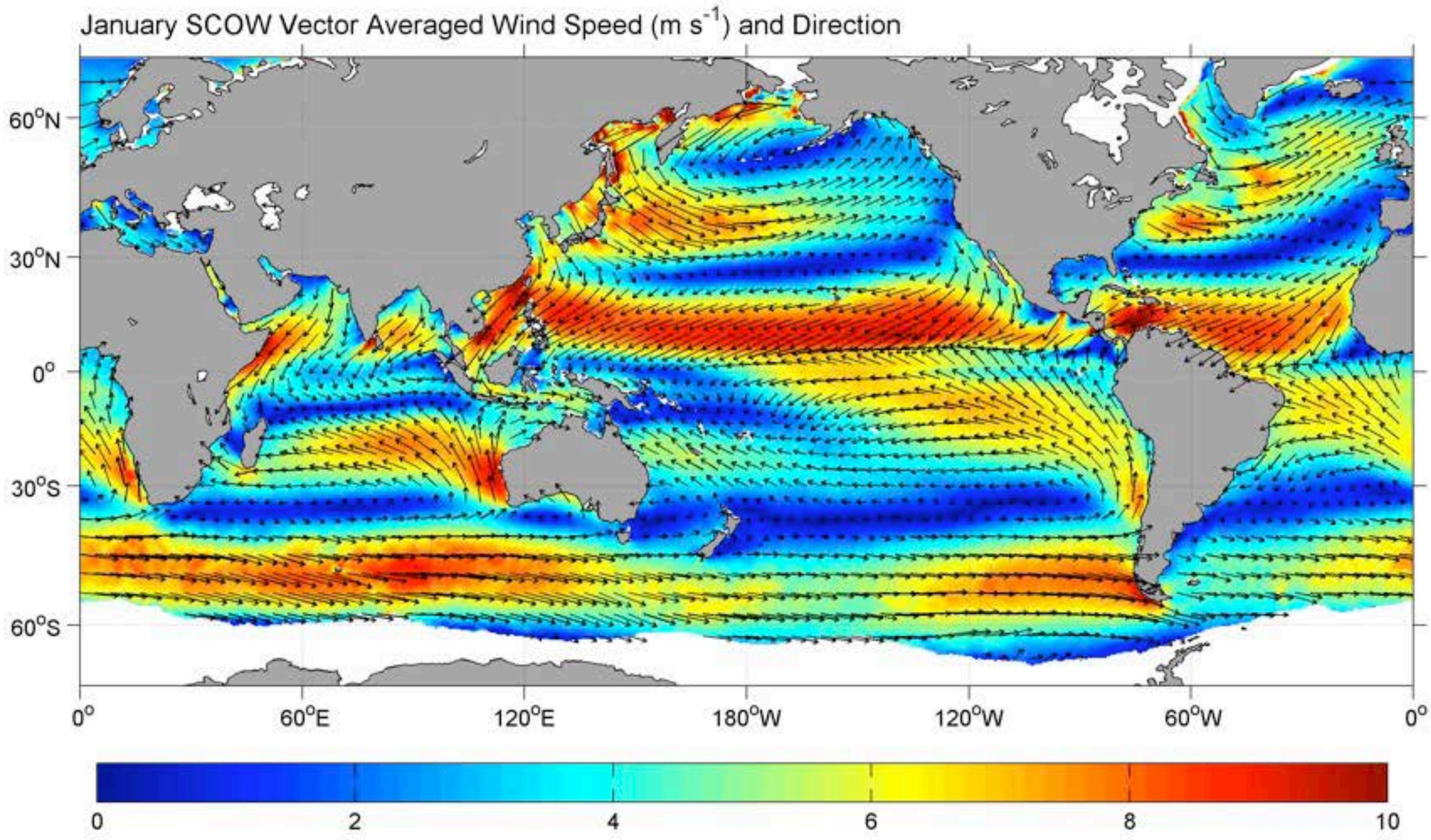
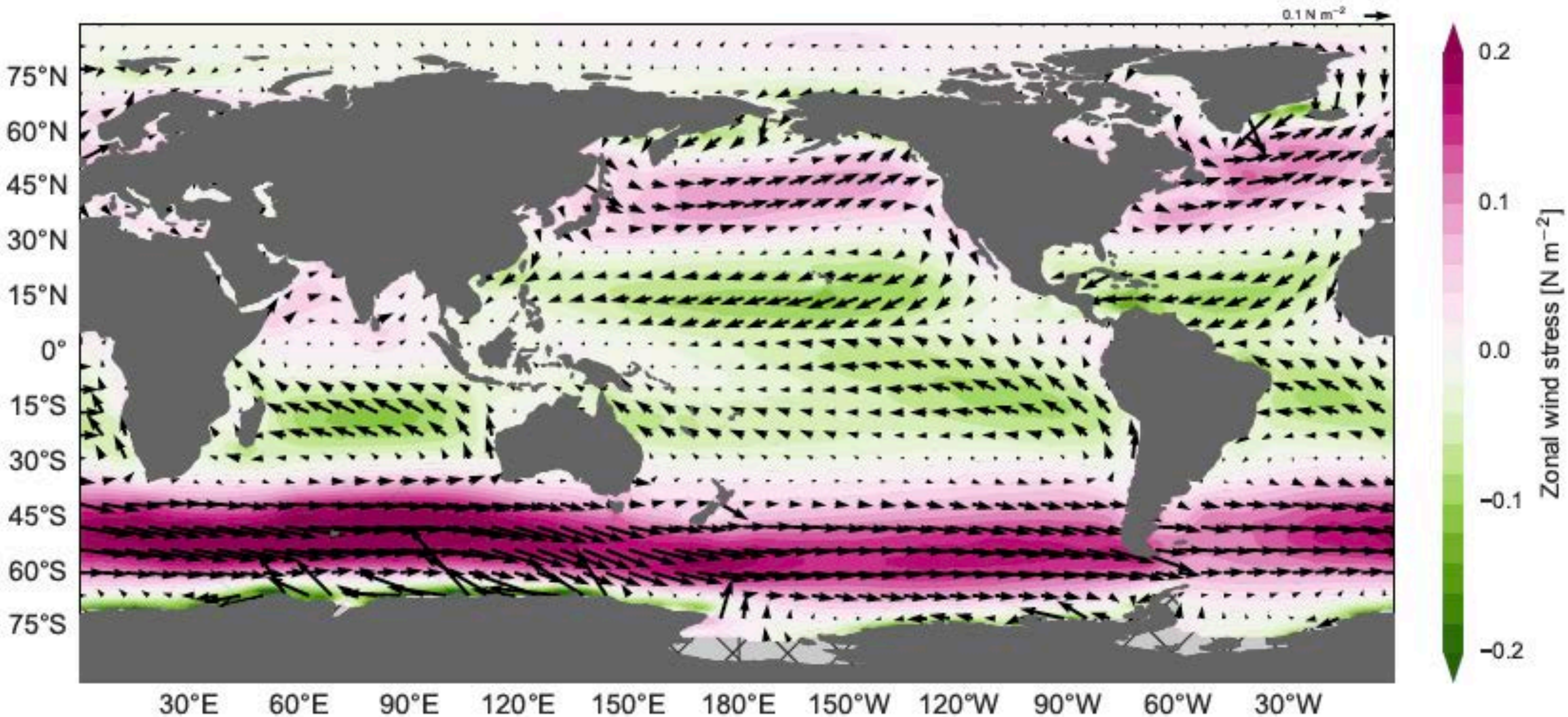
Ocean: #3
Wind-driven circulation

Averaged wind speed



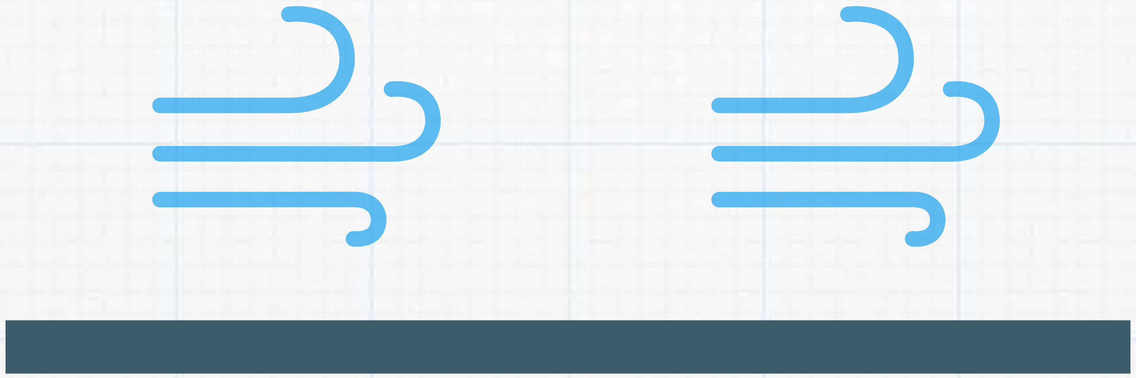
Averaged wind stress



Wind and wind stress

Wind = wind stress ?

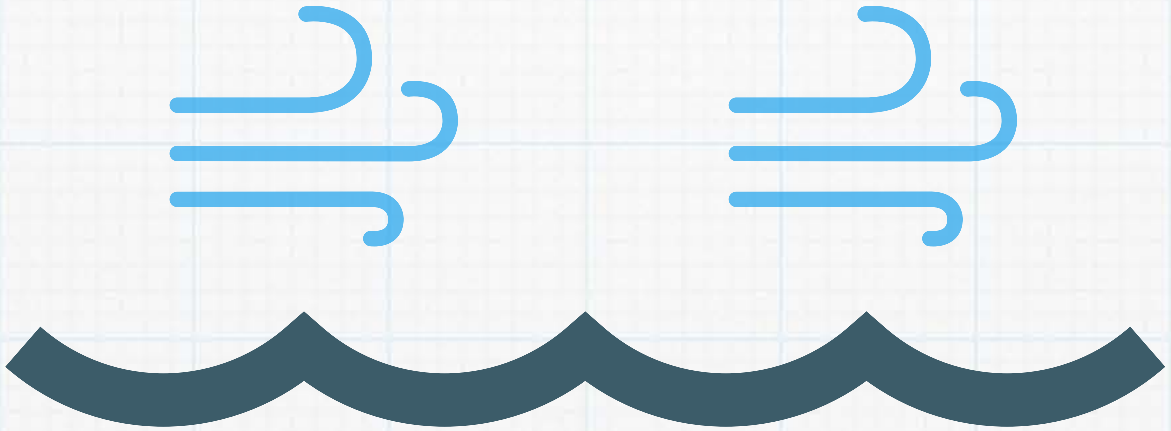
Weak stress



Wind and wind stress

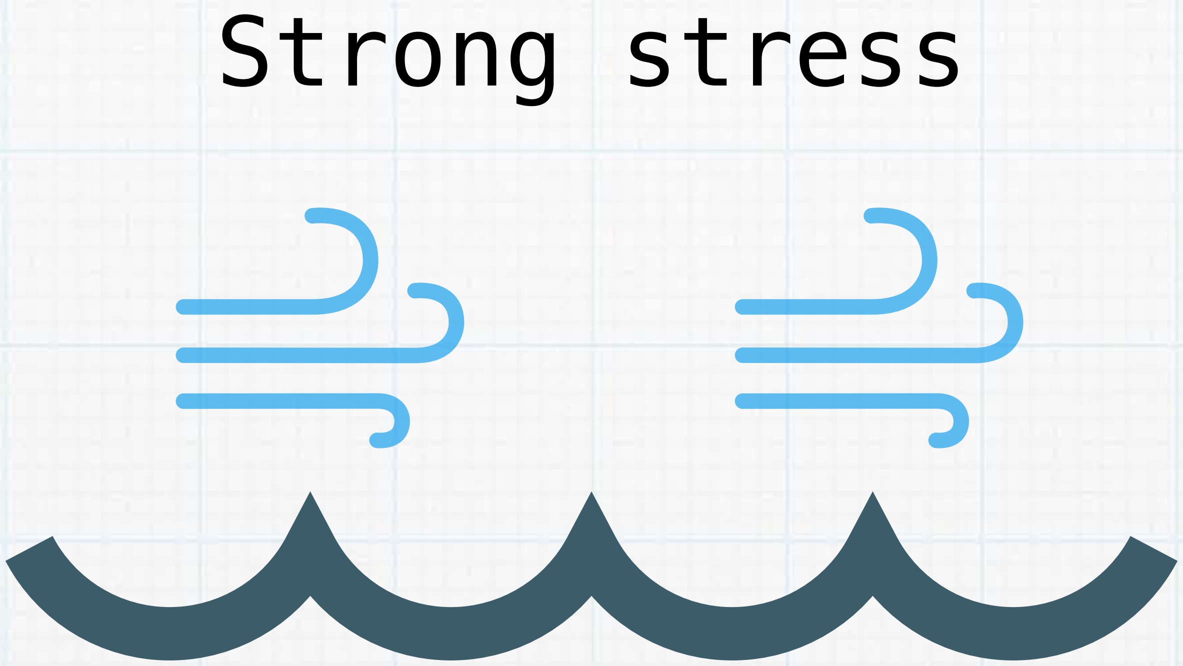
Wind = wind stress ?

Moderate stress



Wind and wind stress

Wind = wind stress ?



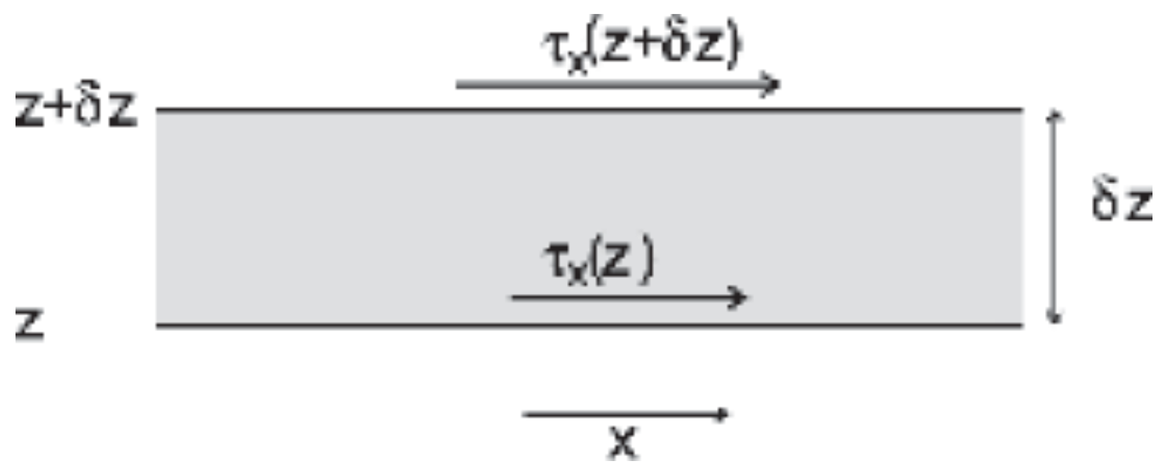
Wind and wind stress

Drag coefficient

$$\text{Wind stress} = \underbrace{c_D}_{\text{Drag coefficient}} \rho_{air} \left| u_{air} - u_{water} \right| \left(u_{air} - u_{water} \right)$$

$$\text{Wind stress} \propto u_{air}^2$$

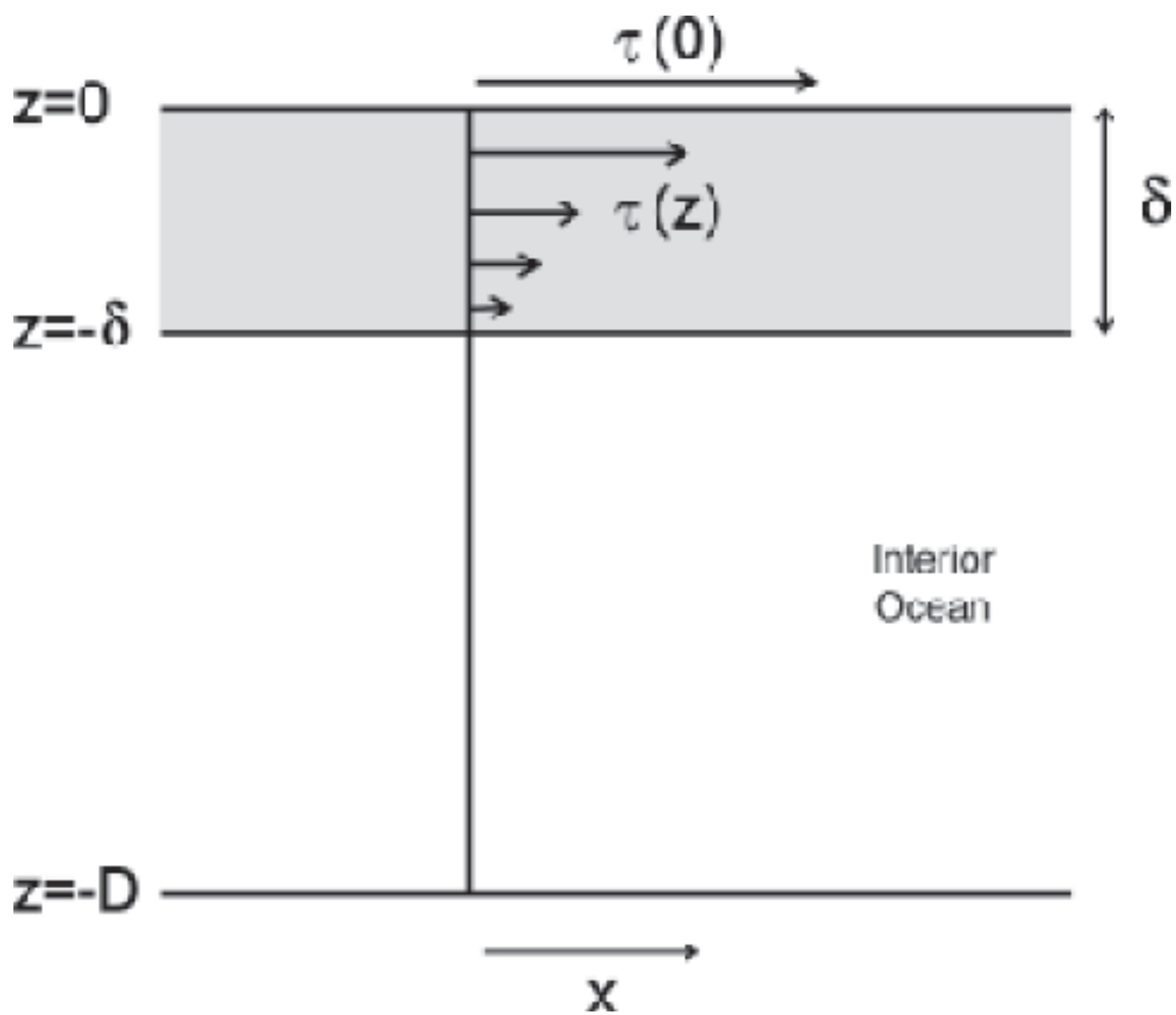
How does the ocean feel the wind stress?



$$F_x = \frac{\tau_x(z+\delta z) - \tau_x(z)}{\rho_{ref}\delta z} = \frac{1}{\rho_{ref}}\frac{\partial \tau_x}{\partial z}$$

$$F_y = \frac{\tau_y(z+\delta z) - \tau_y(z)}{\rho_{ref}\delta z} = \frac{1}{\rho_{ref}}\frac{\partial \tau_y}{\partial z}$$

How does the ocean feel the wind stress?



Ekman layer

Wind stress decreases rather rapidly with depth.

Dynamics in the Ekman layer

$$-fv + \frac{1}{\rho_{ref}}\frac{\partial p}{\partial x} = F_x$$

$$-fv + \frac{1}{\rho_{ref}}\frac{\partial p}{\partial x} = \frac{1}{\rho_{ref}}\frac{\partial \tau_x}{\partial z}$$

$$-f(v_g + v_a) + \frac{1}{\rho_{ref}}\frac{\partial p}{\partial x} = \frac{1}{\rho_{ref}}\frac{\partial \tau_x}{\partial z}$$

$$-fv_a = \frac{1}{\rho_{ref}}\frac{\partial \tau_x}{\partial z}$$

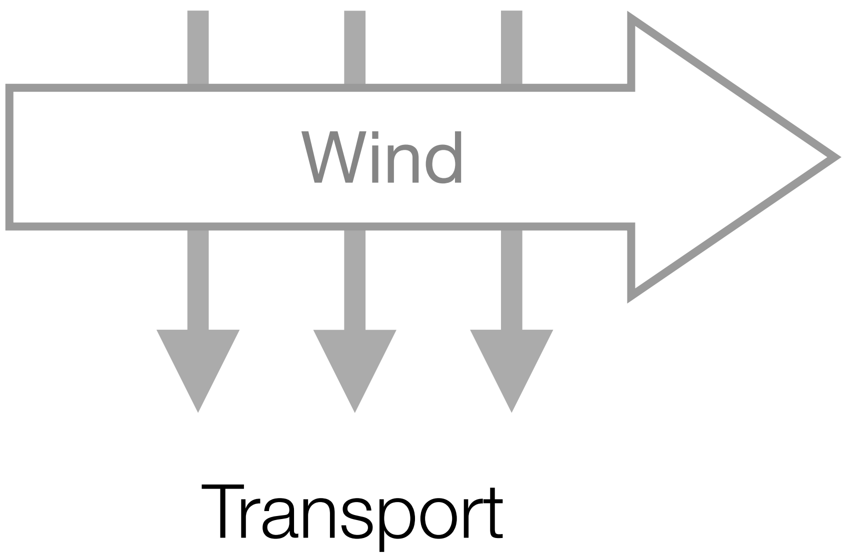
Dynamics in the Ekman layer

$$-fv_a = \frac{1}{\rho_{ref}} \frac{\partial \tau_x}{\partial z} \quad \Rightarrow \quad -f\rho_{ref} \int_{-\delta}^{0} v_a dz = \tau_{x,wind}$$

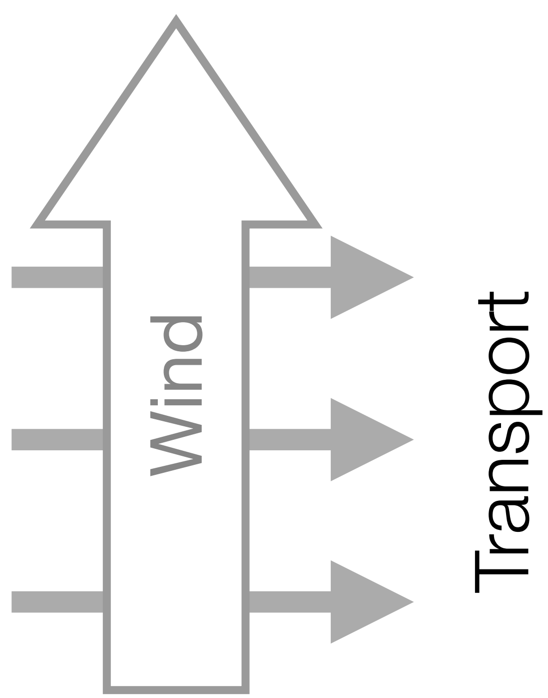
$$fu_a = \frac{1}{\rho_{ref}} \frac{\partial \tau_y}{\partial z} \quad \Rightarrow \quad f\rho_{ref} \int_{-\delta}^{0} u_a dz = \tau_{y,wind}$$

Dynamics in the Ekman layer

North hemisphere



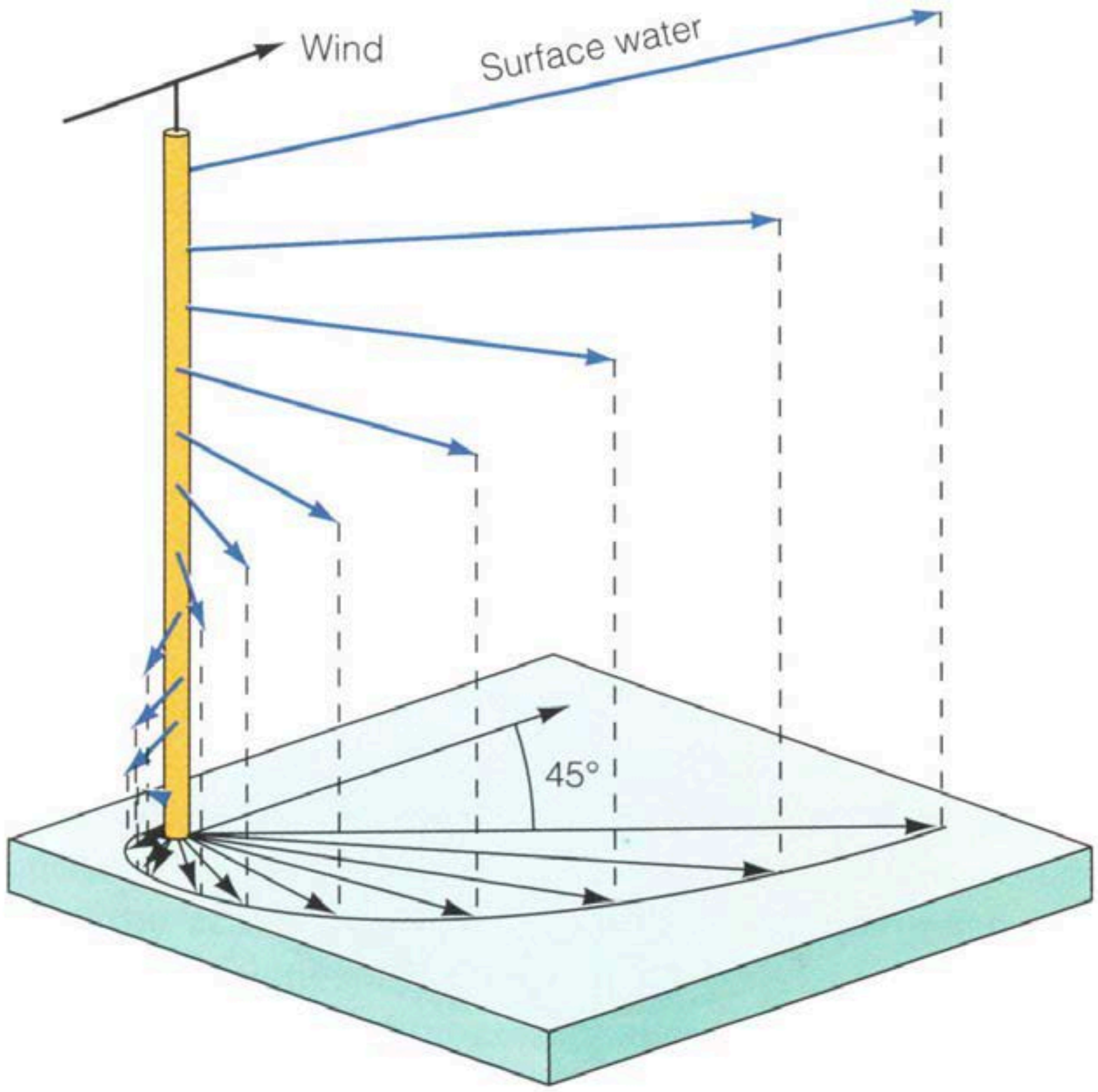
$$-f\rho_{ref}\int_{-\delta}^{0} v_a dz = \tau_{x,wind}$$



$$f\rho_{ref}\int_{-\delta}^{0} u_a dz = \tau_{y,wind}$$

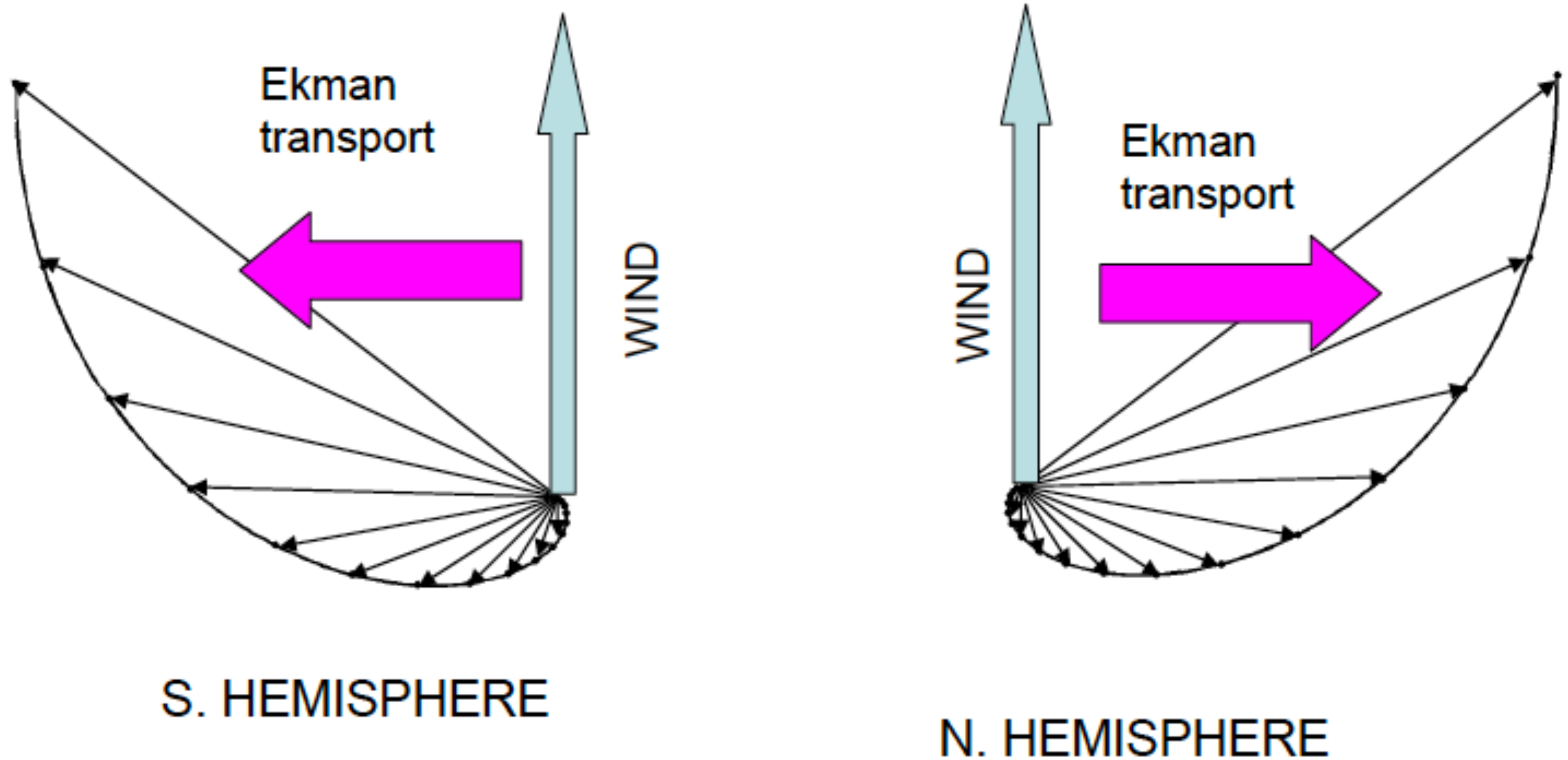
Dynamics in the Ekman layer

- Transport of the water in the Ekman layer is to the right of the wind stress direction in the northern hemisphere
- Transport of the water in the Ekman layer is to the left of the wind stress direction in the southern hemisphere.
- Ekman spiral

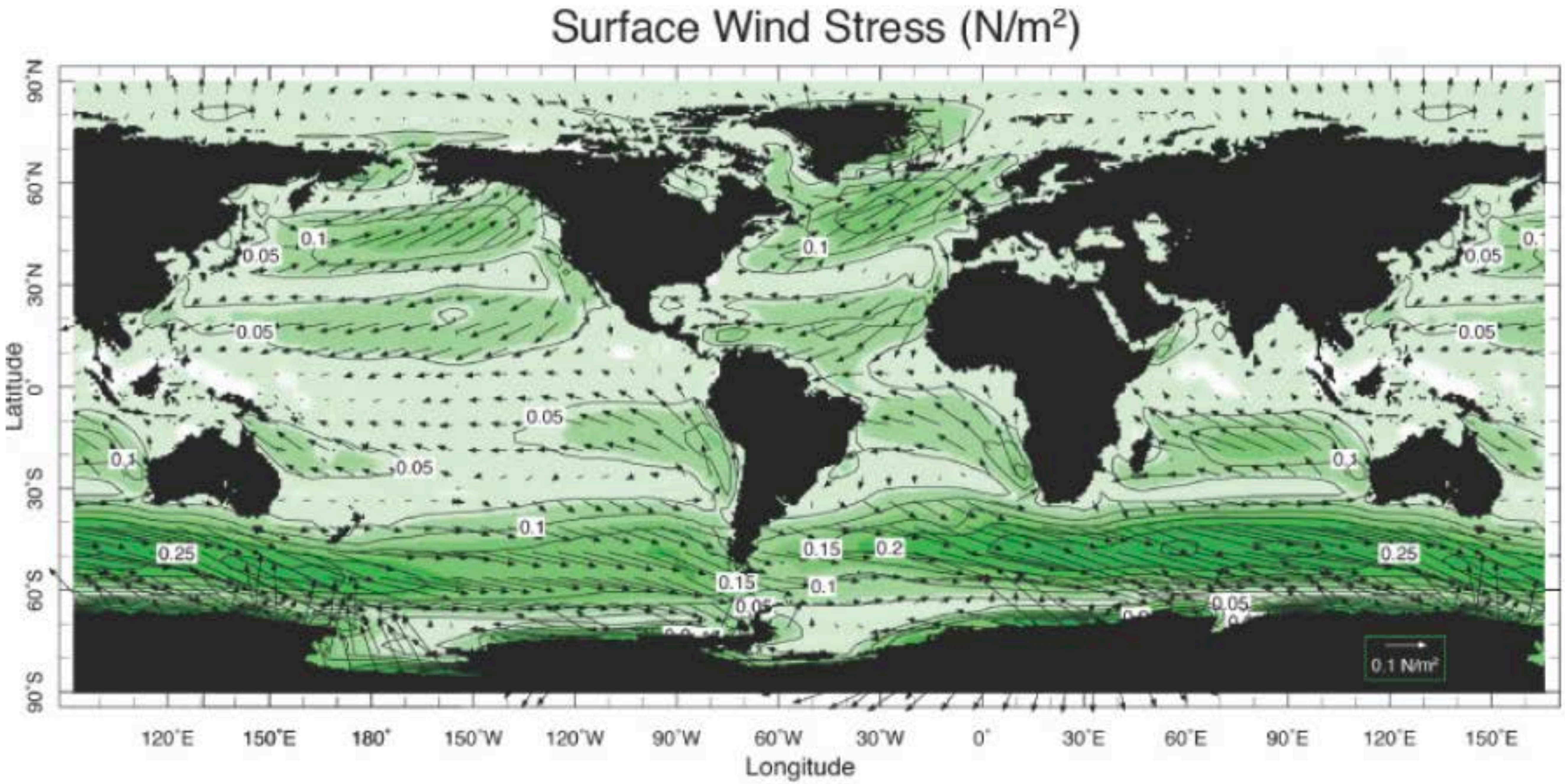


a

Ekman spiral

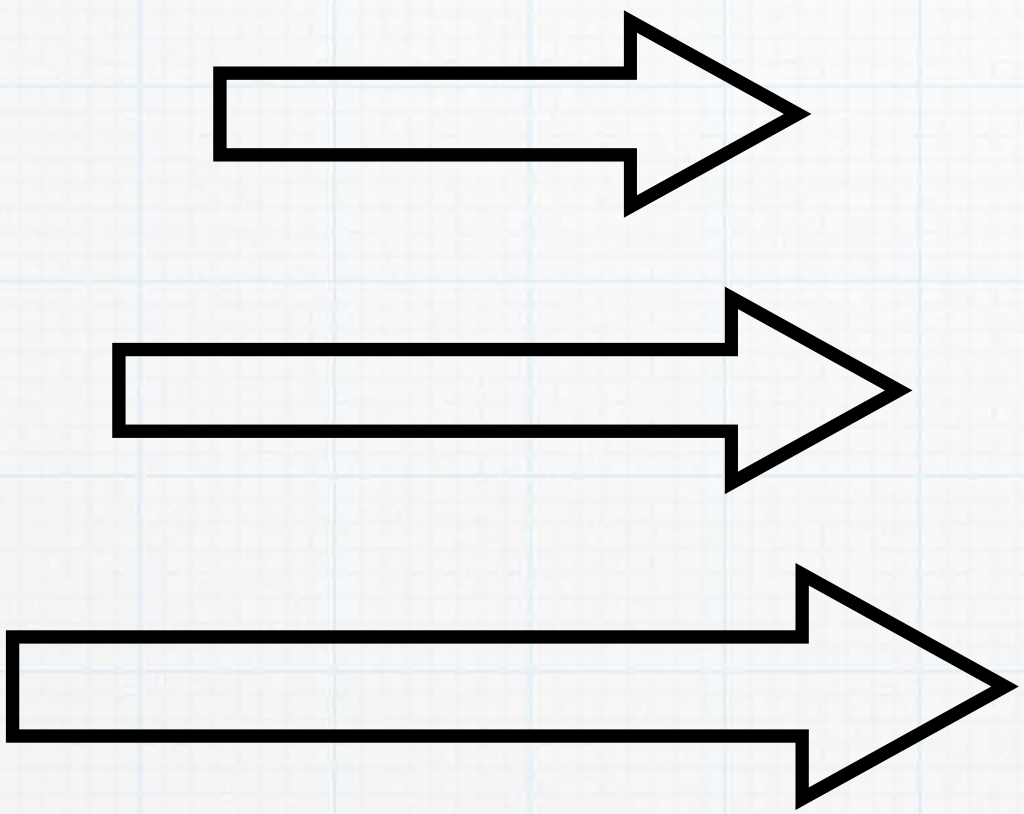


Wind stress structure



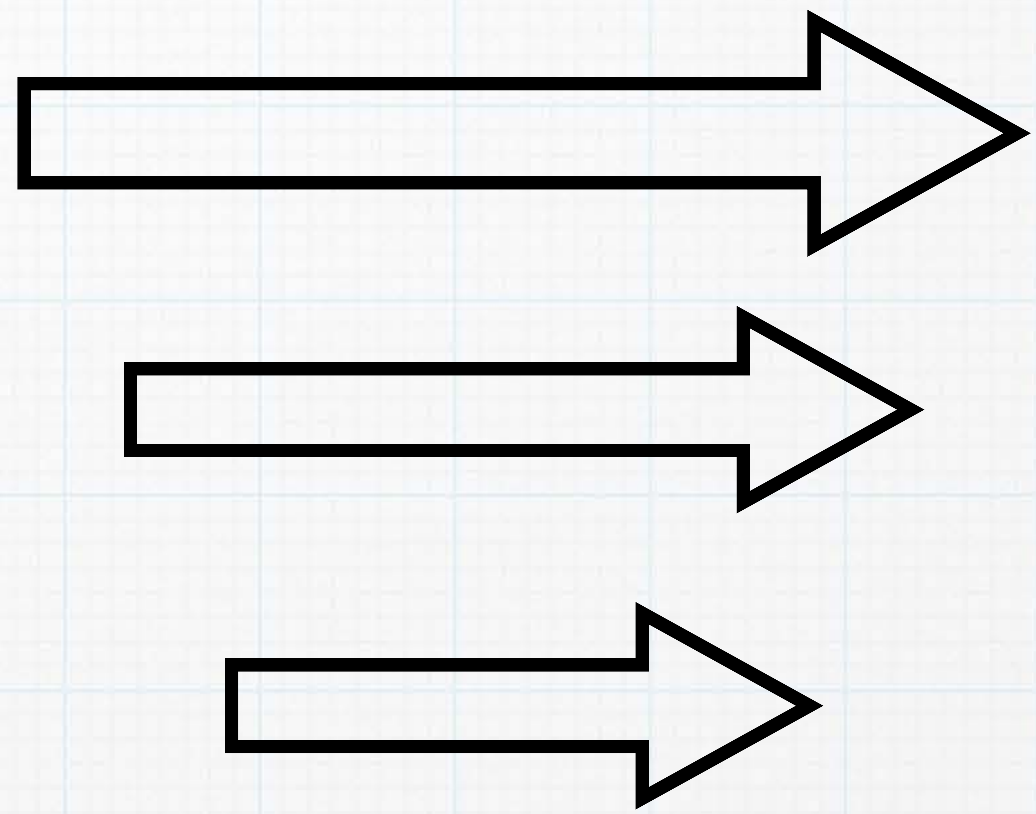
Wind stress structure

$$\frac{\partial \tau_x}{\partial y} < 0$$



- Northern H. : divergence
- Southern H. : convergence

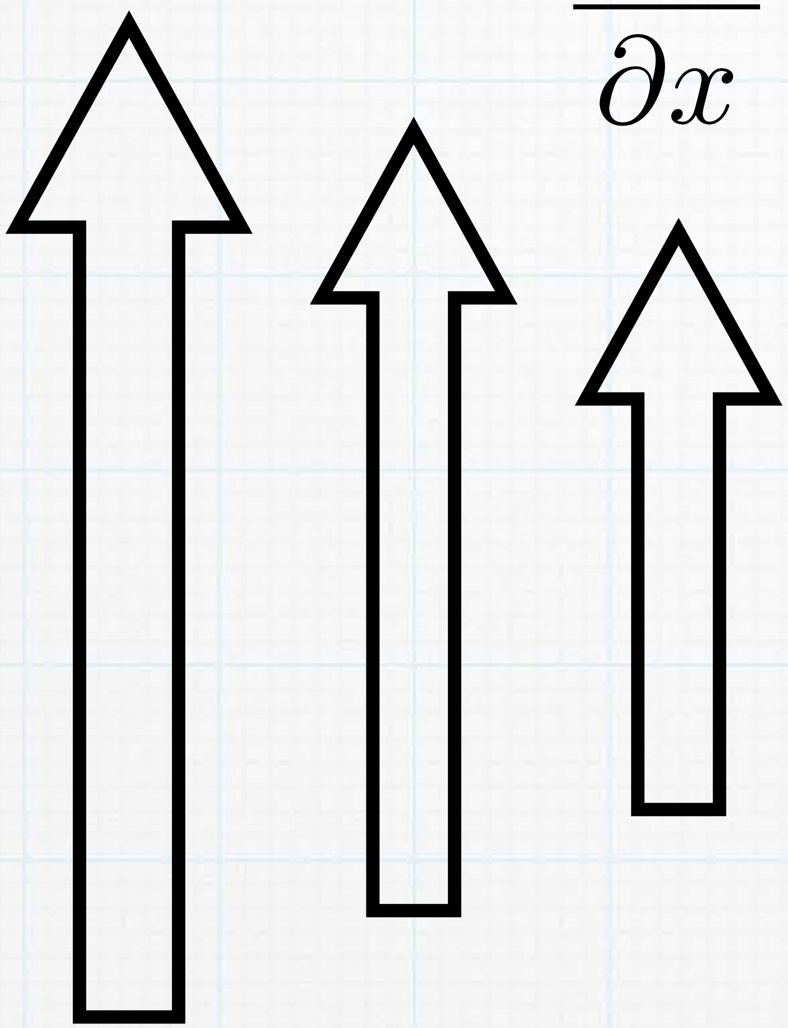
$$\frac{\partial \tau_x}{\partial y} > 0$$



- Northern H. : convergence
- Southern H. : divergence

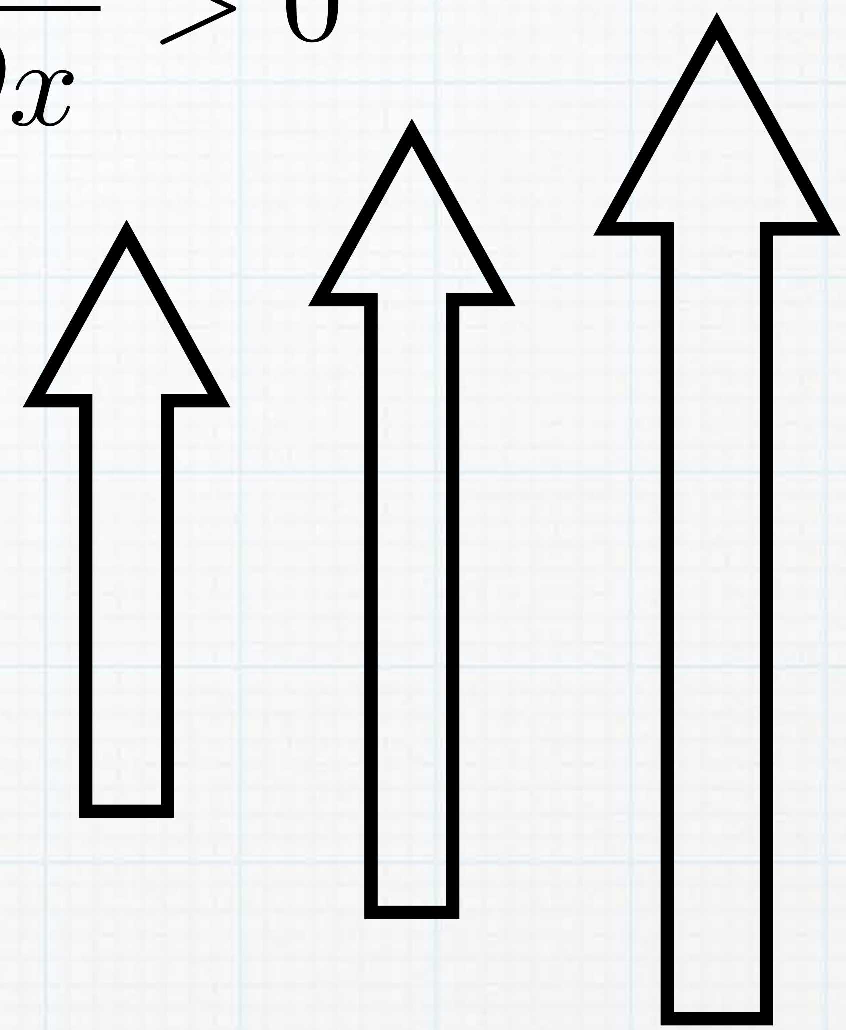
Wind stress structure

$$\frac{\partial \tau_y}{\partial x} < 0$$



- Northern H. : convergence
- Southern H. : divergence

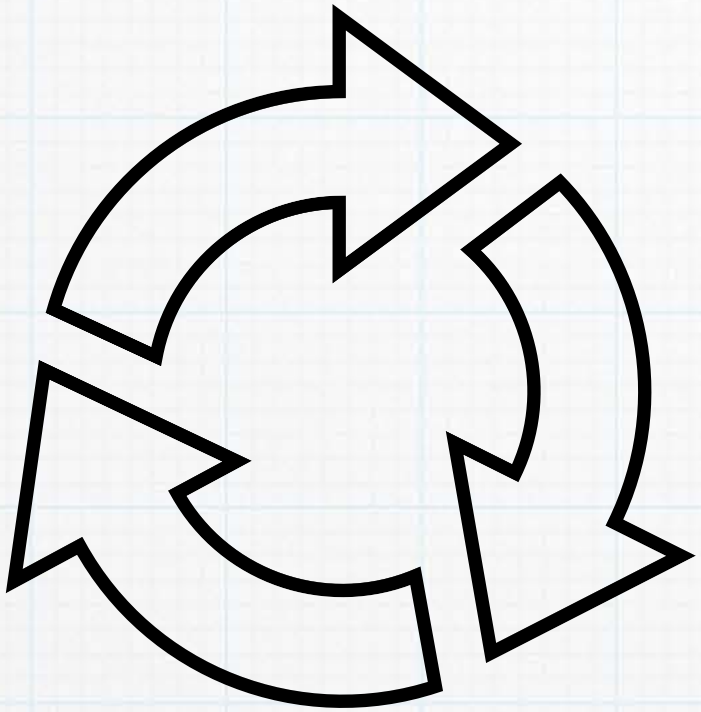
$$\frac{\partial \tau_y}{\partial x} > 0$$



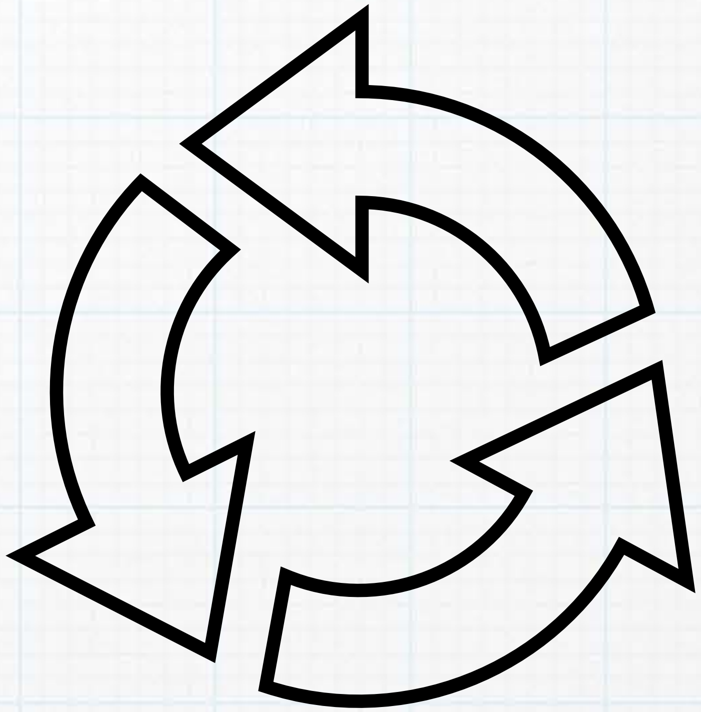
- Northern H. : divergence
- Southern H. : convergence

Wind stress structure

$$\frac{\partial \tau_y}{\partial x} - \frac{\partial \tau_x}{\partial y} < 0$$



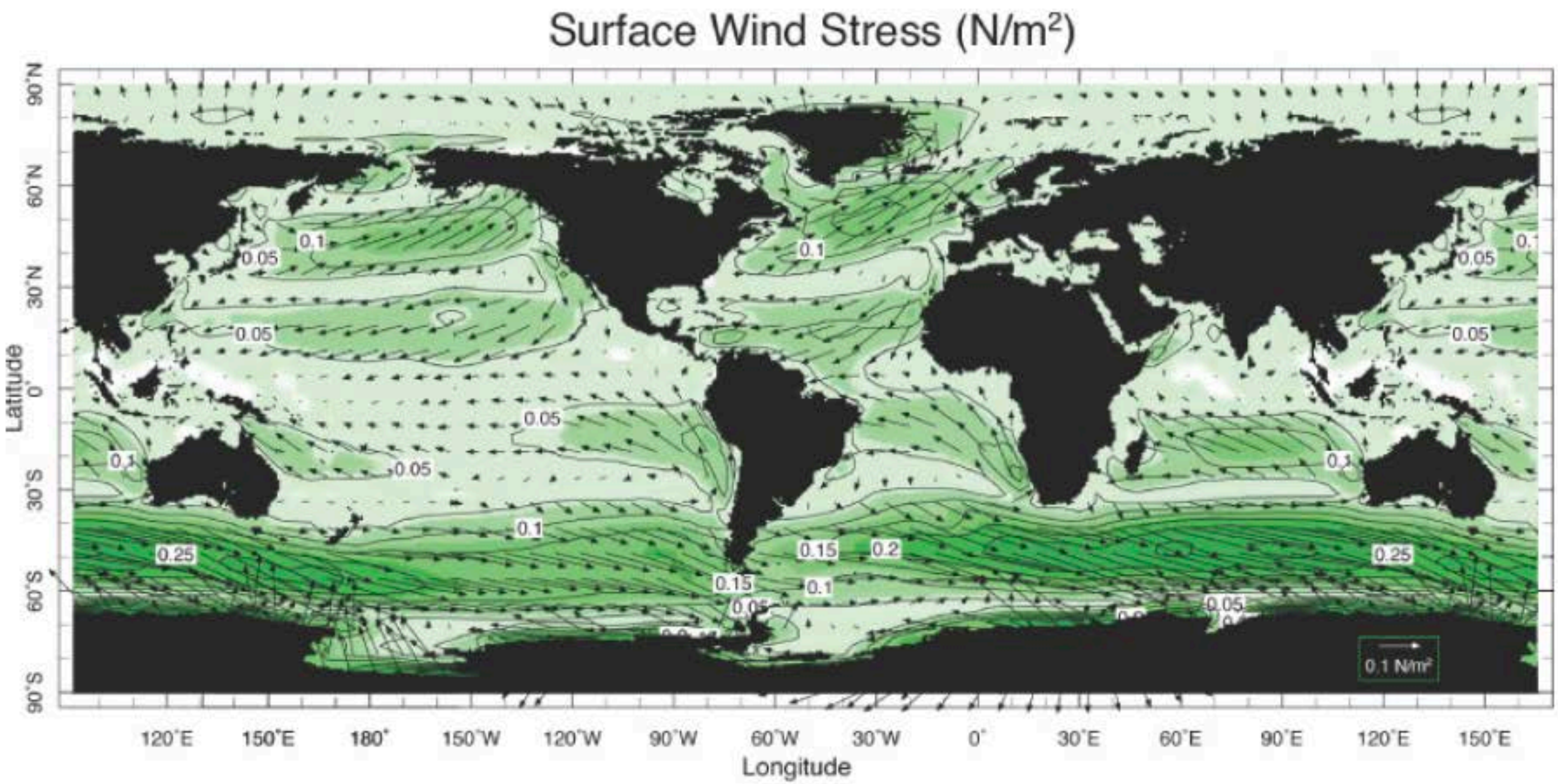
$$\frac{\partial \tau_y}{\partial x} - \frac{\partial \tau_x}{\partial y} > 0$$



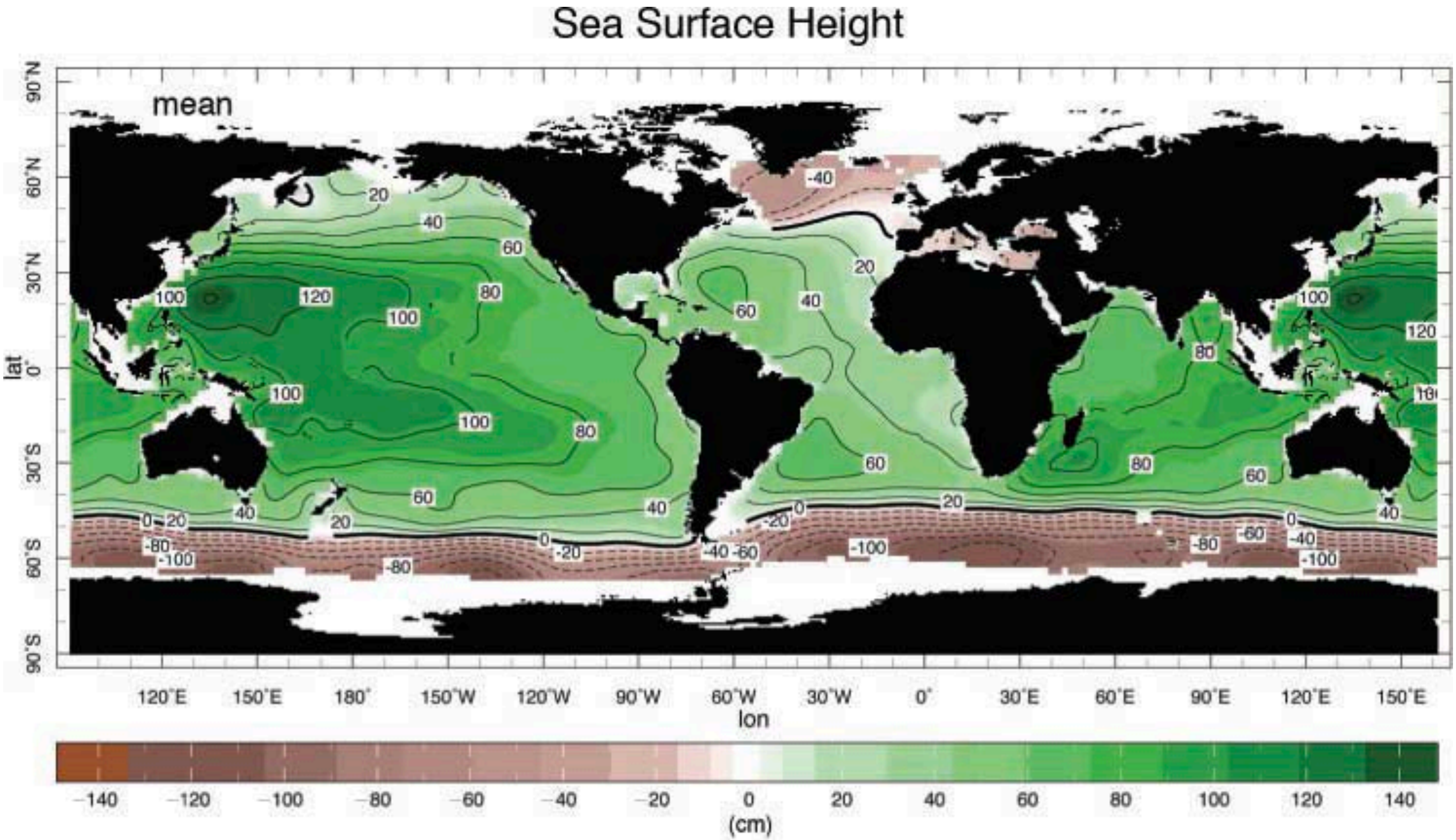
- Northern H. : convergence
- Southern H. : divergence

- Northern H. : divergence
- Southern H. : convergence

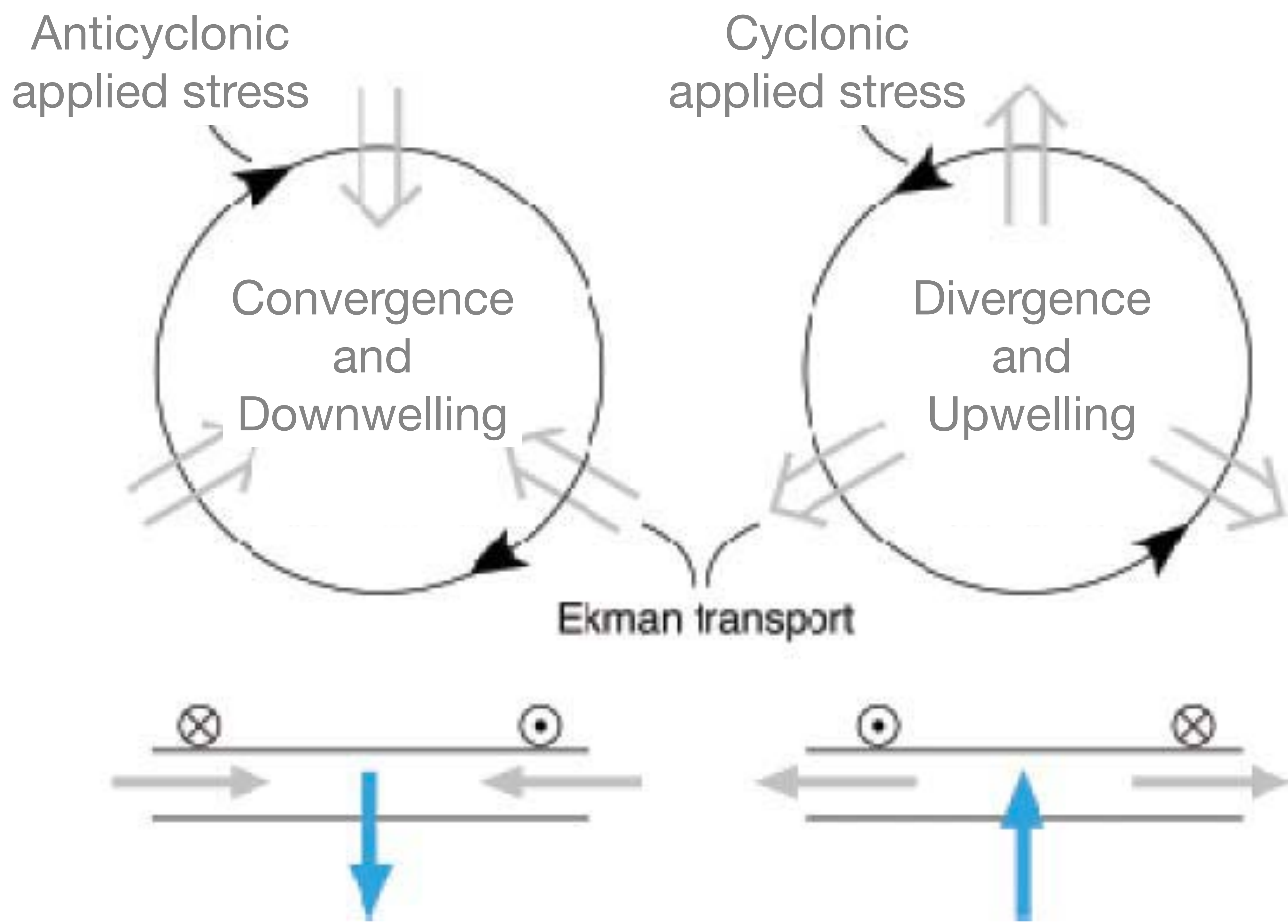
Wind stress structure



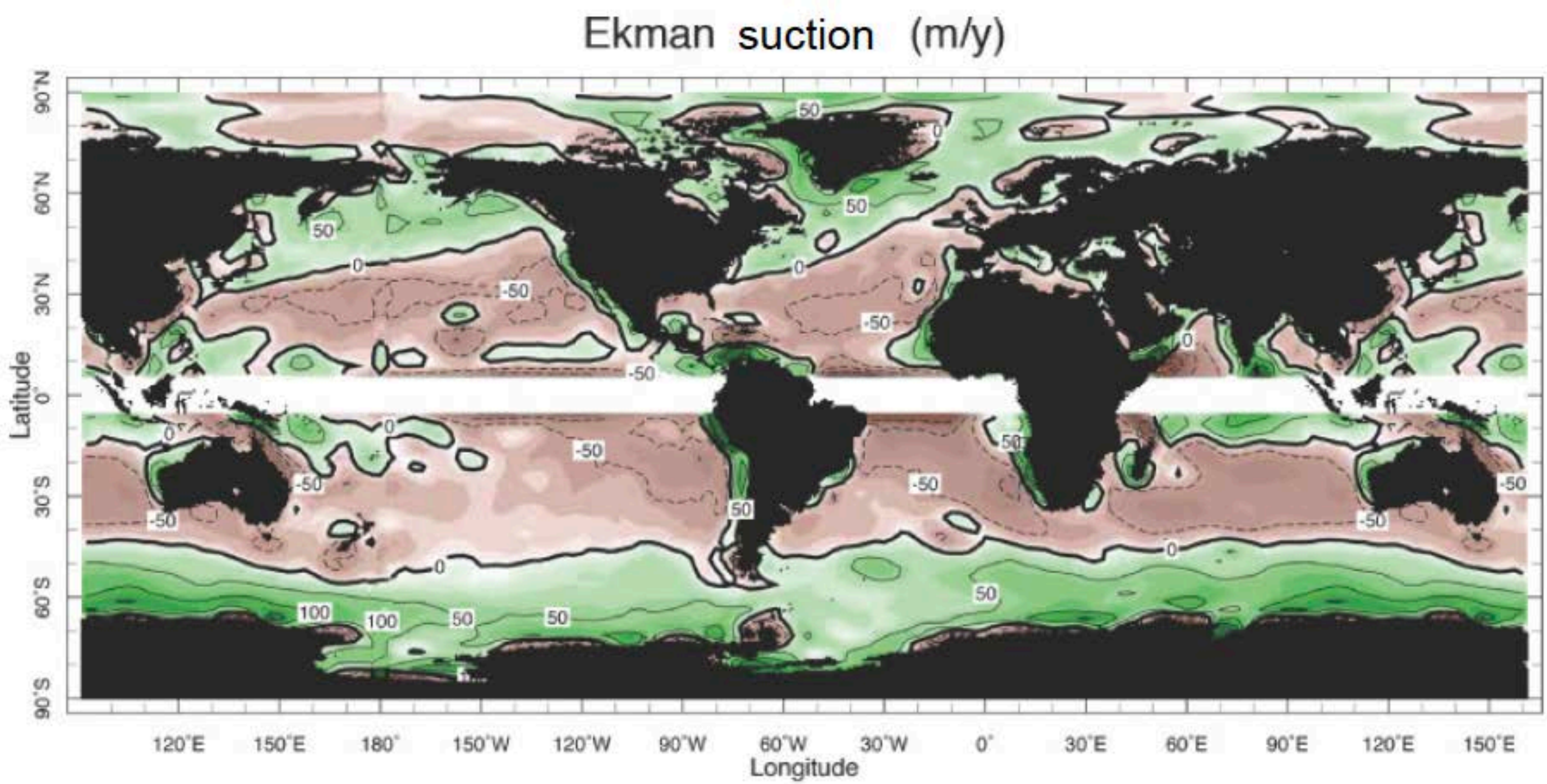
Sea level


Sea Surface Height
mean
lat
90°N
60°N
30°N
0°
30°S
60°S
90°S
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0°
30°E
60°E
90°E
120°E
150°E
lon
−140
−120
−100
−80
−60
−40
−20
0
20
40
60
80
100
120
140
(cm)

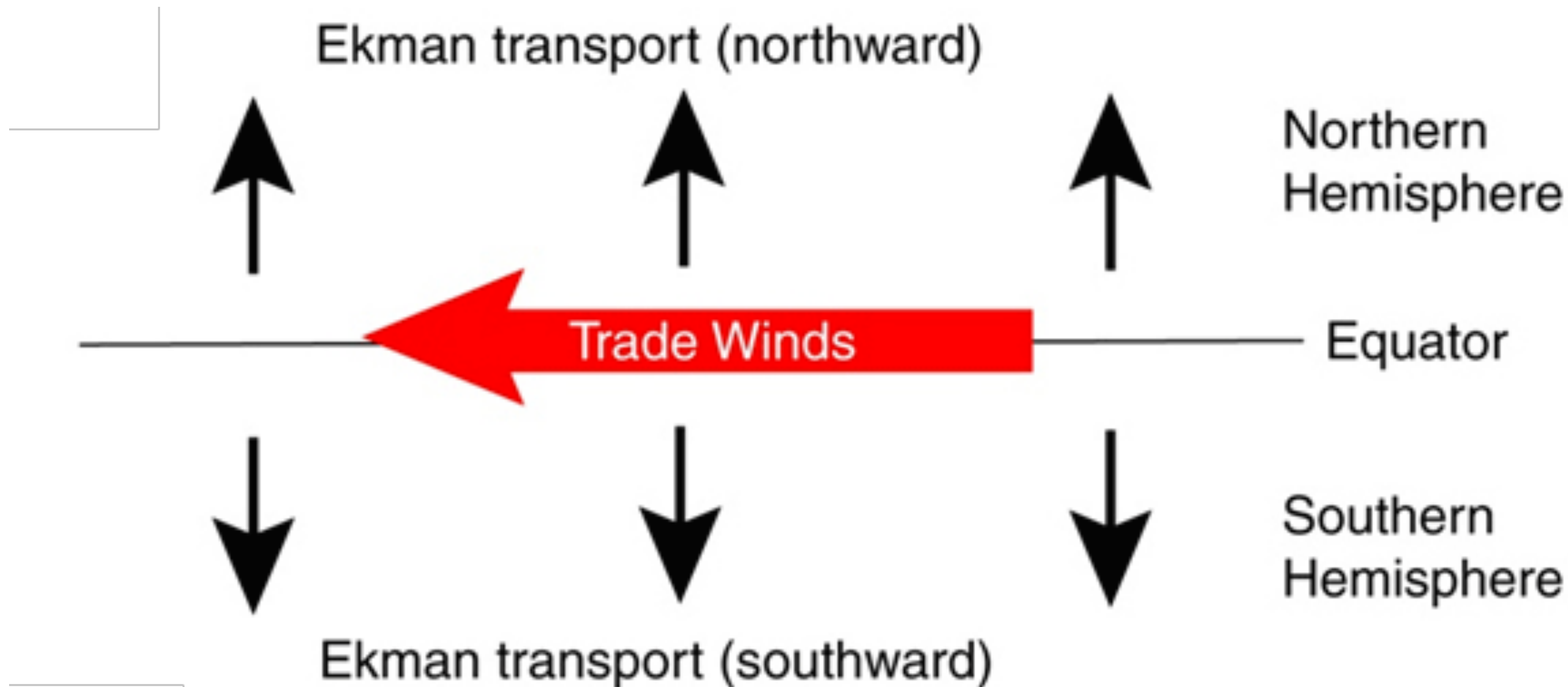
Ekman pumping / suction

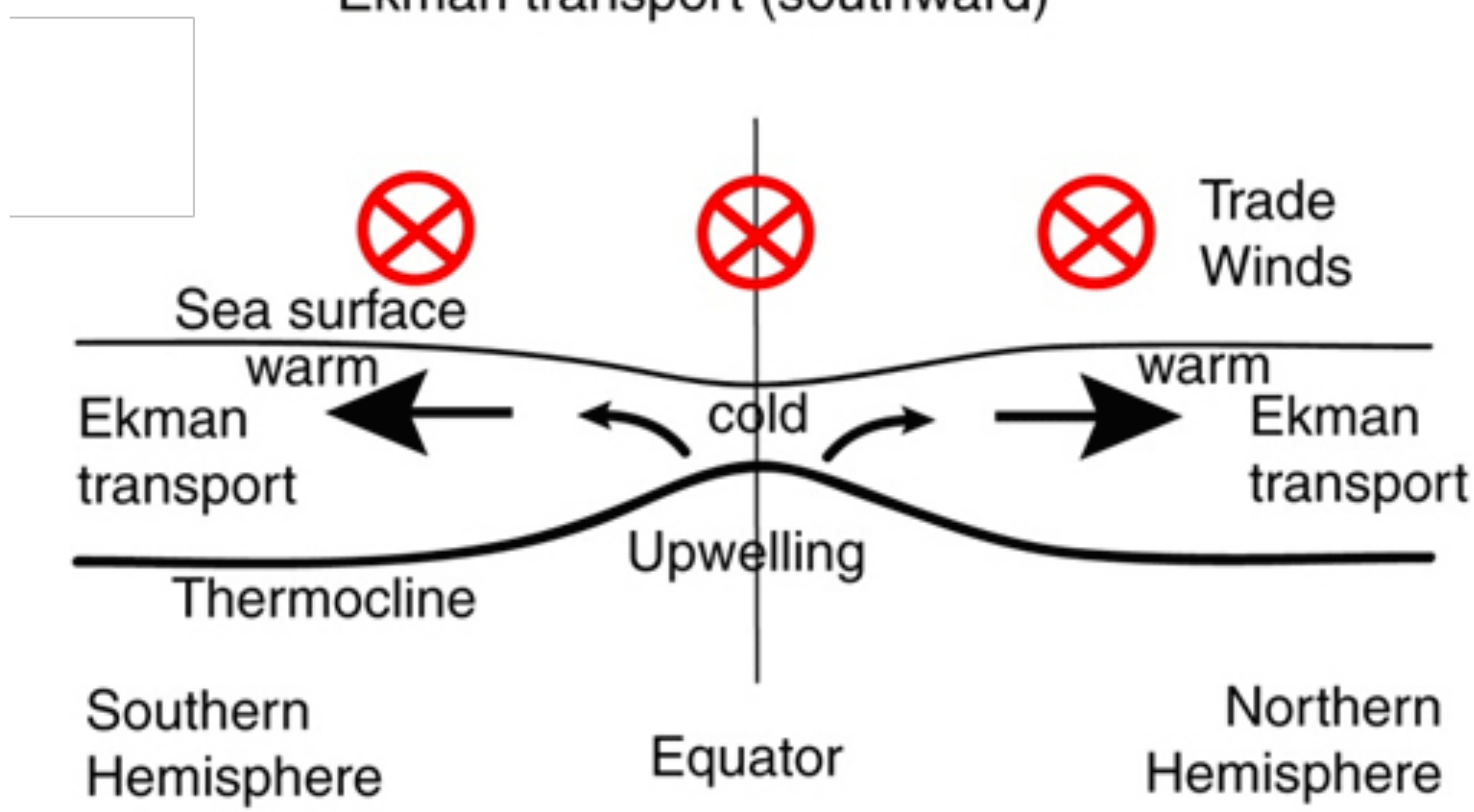


Ekman pumping / suction



Ekman pumping at the equator





Ekman pumping / suction and temperature