

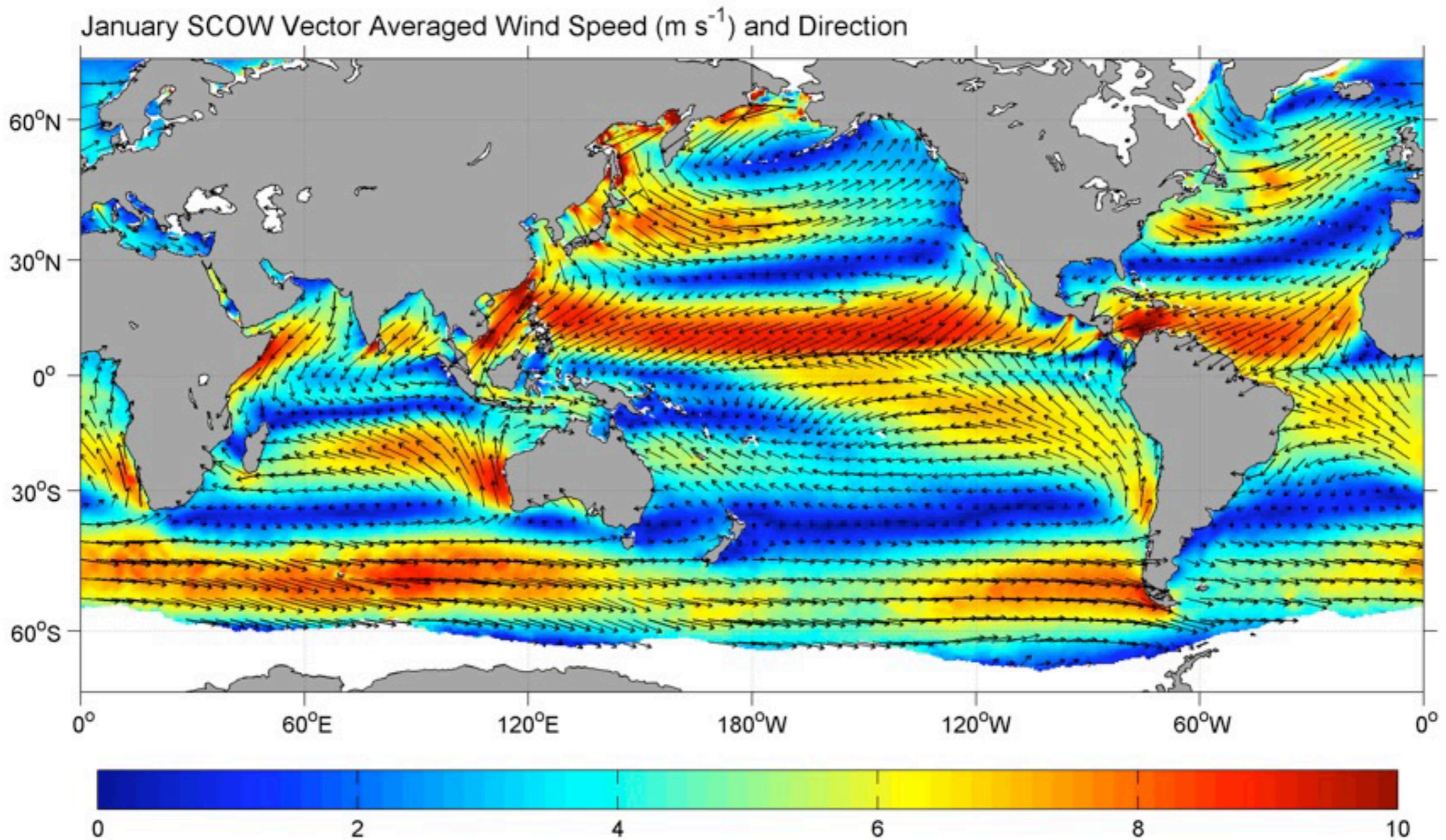
# Ocean: wind-driven circulation

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ATM2016

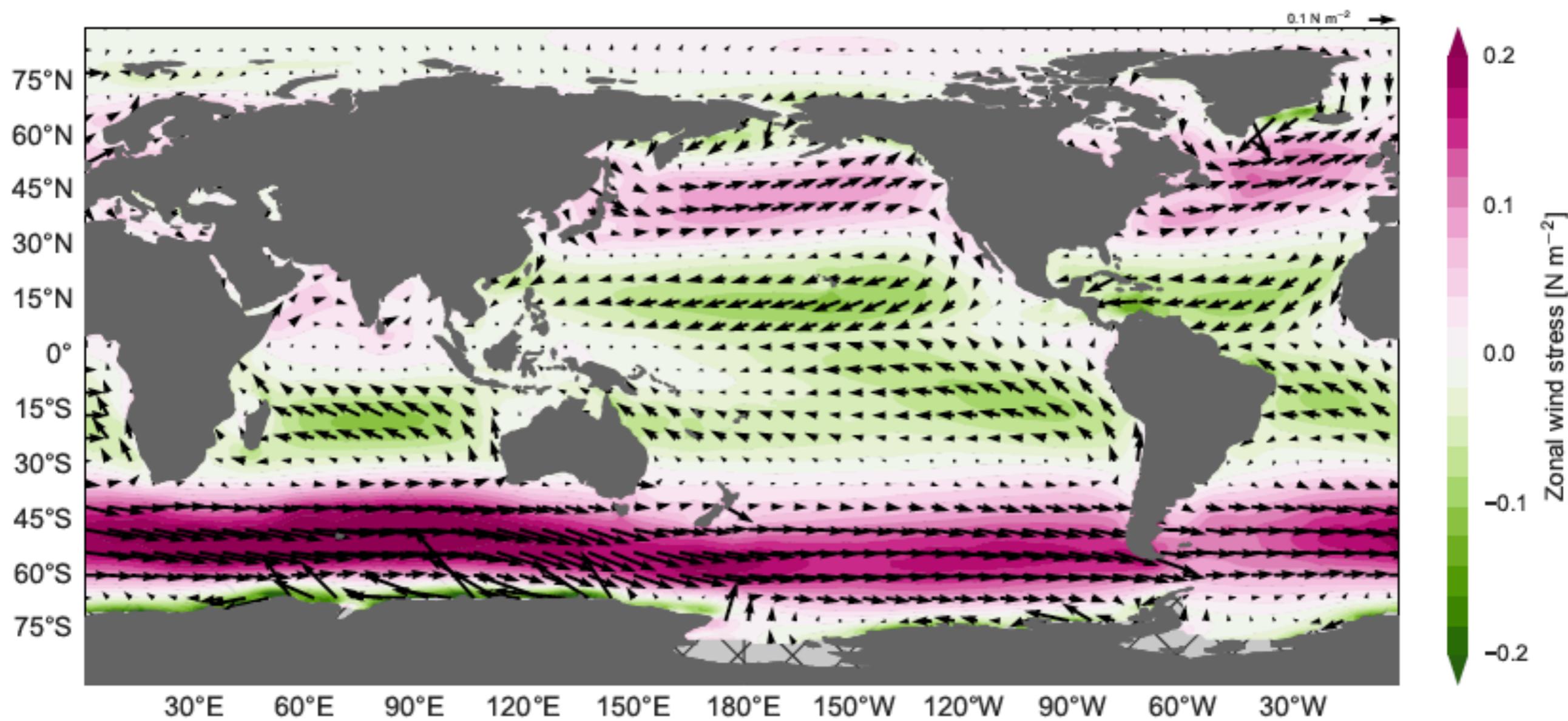
# Wind and wind stress

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# Wind and wind stress

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# Wind and wind stress

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Wind = wind stress ?

Weak stress

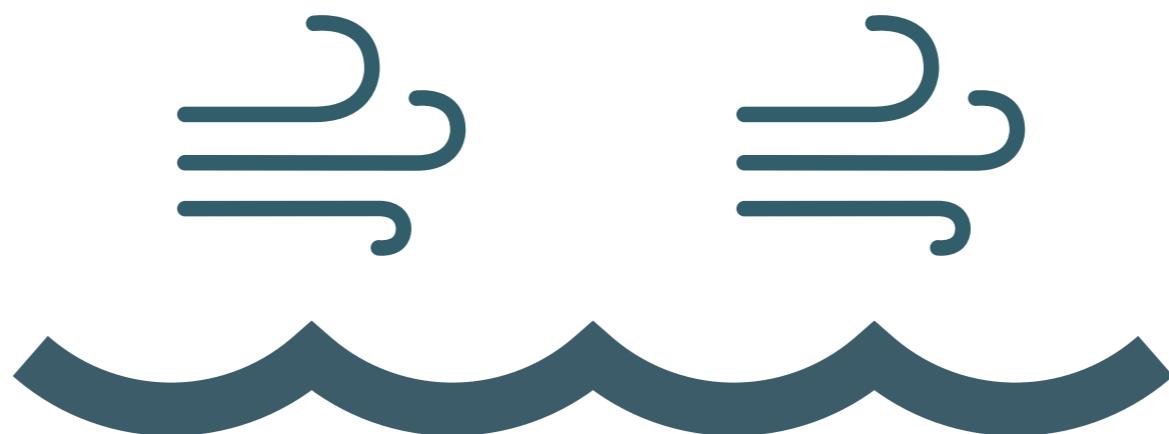


# Wind and wind stress

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Wind = wind stress ?

Moderate stress



# Wind and wind stress

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Wind = wind stress ?

Strong stress



# Wind and wind stress

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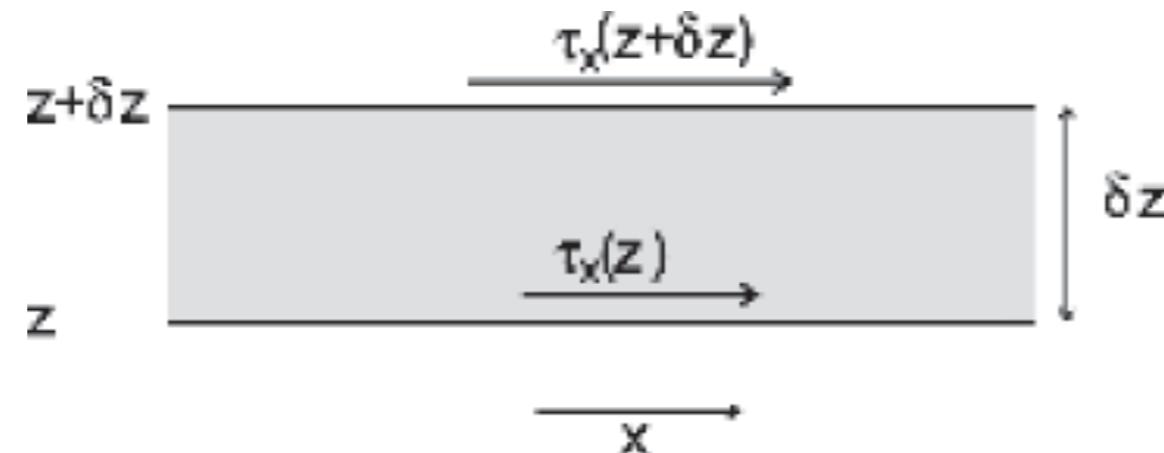
↓ Crag coefficient

$$\text{Wind stress} = C_D \rho_{\text{air}} |U_{\text{air}} - U_{\text{water}}| (U_{\text{air}} - U_{\text{water}})$$

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

# How does the ocean feel the wind stress?

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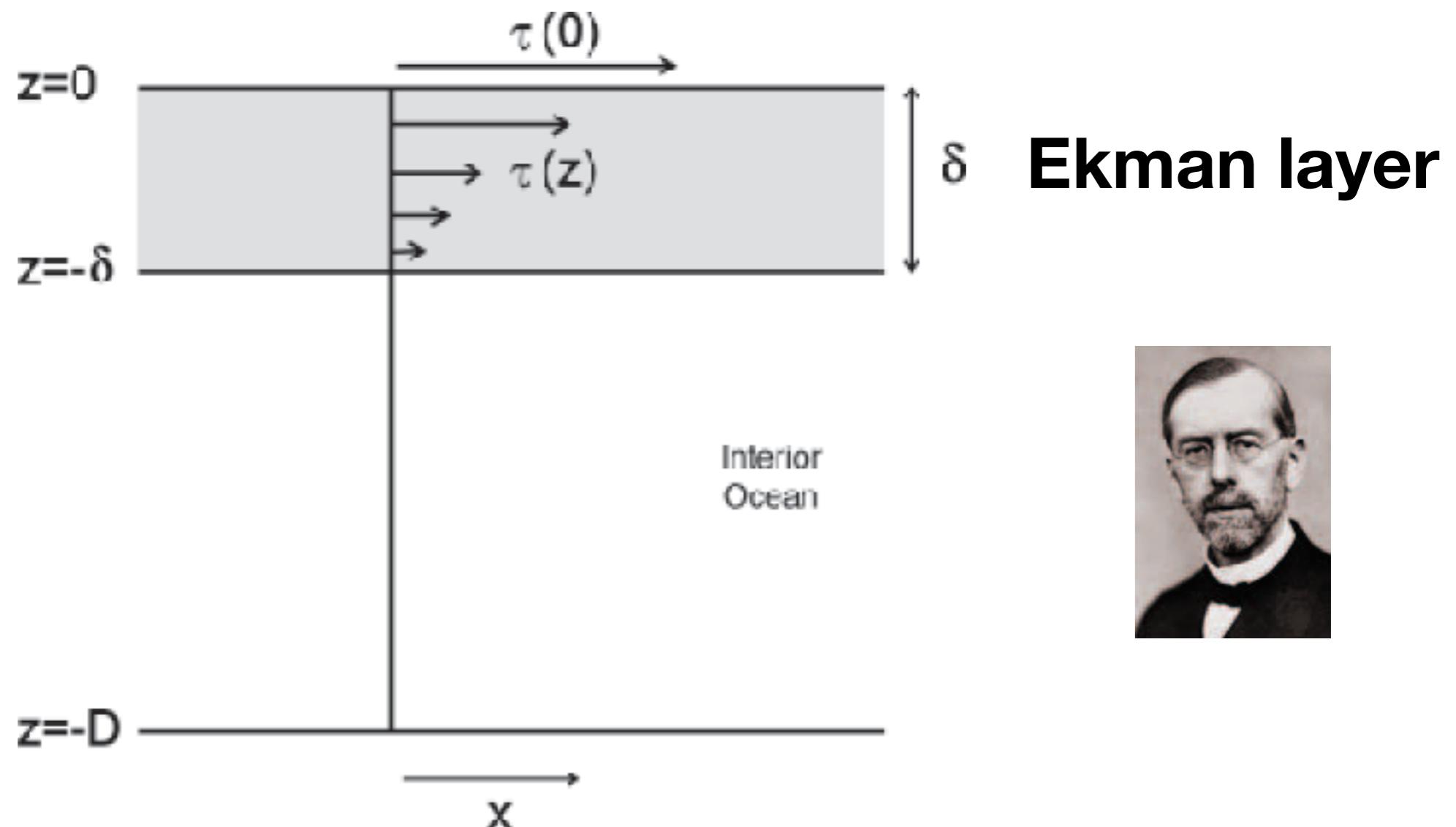


$$F_x = \frac{1}{\rho_{ref}} \frac{\partial \tau_x}{\partial z}$$

$$F_y = \frac{1}{\rho_{ref}} \frac{\partial \tau_y}{\partial z}$$

# How does the ocean feel the wind stress?

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Wind stress decreases rather rapidly with depth.

# Dynamics in the Ekman layer

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

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

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

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

# Dynamics in the Ekman layer

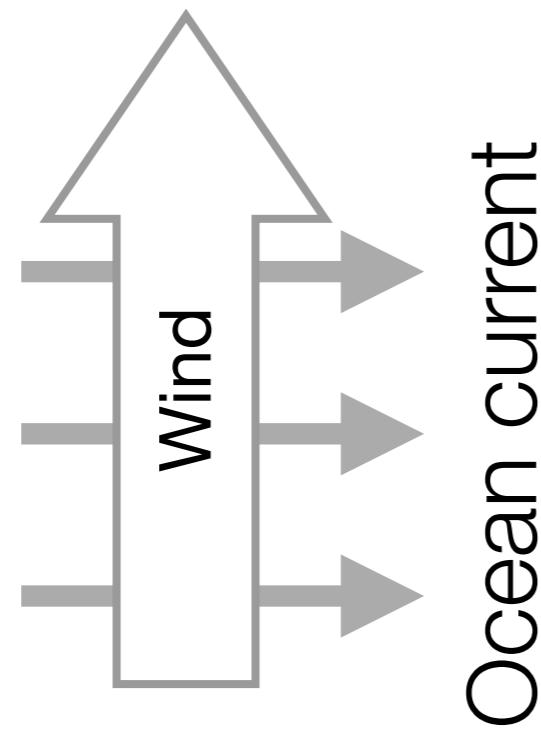
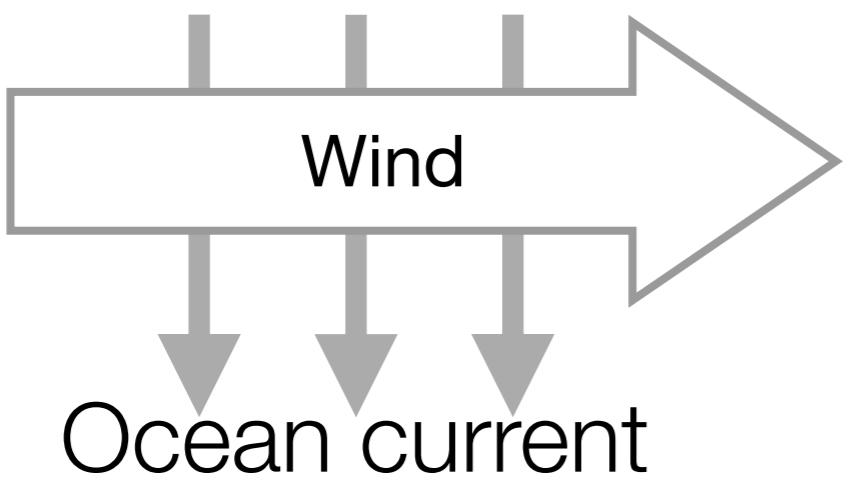
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$$-fv_a = \frac{1}{\rho_{ref}} \frac{\partial \tau_x}{\partial z} \rightarrow -f\rho_{ref} \int_{-\delta}^0 v_a dz = \tau_{x,wind}$$

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

# Dynamics in the Ekman layer

North hemisphere

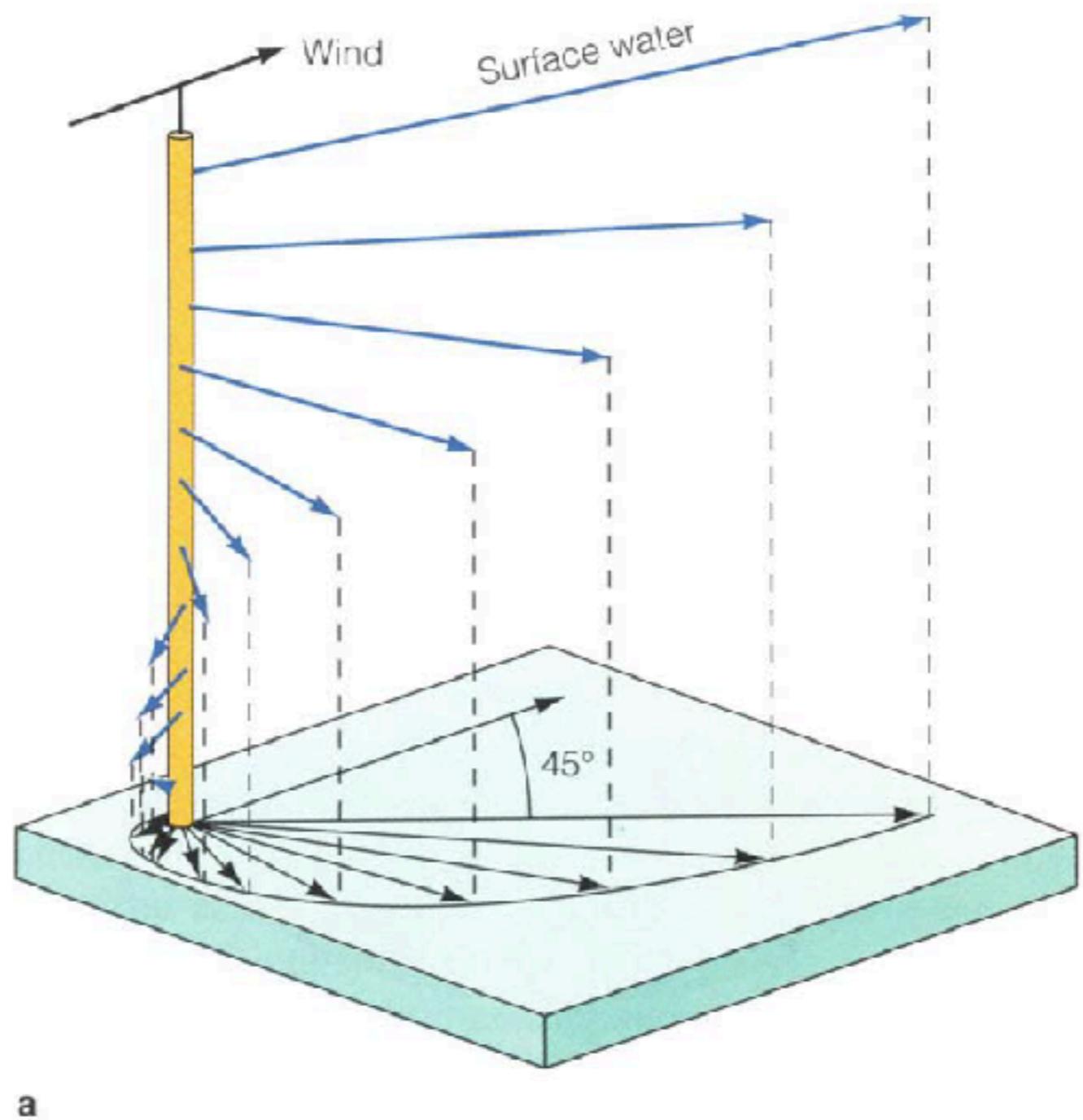


$$-f \rho_{ref} \int_{-\delta}^0 v_a dz = \tau_{x,wind}$$

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

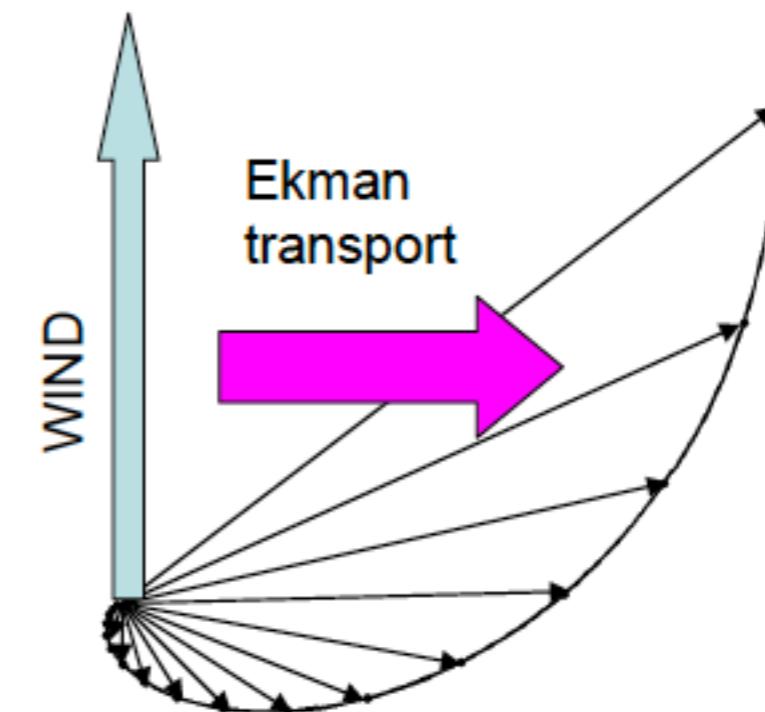
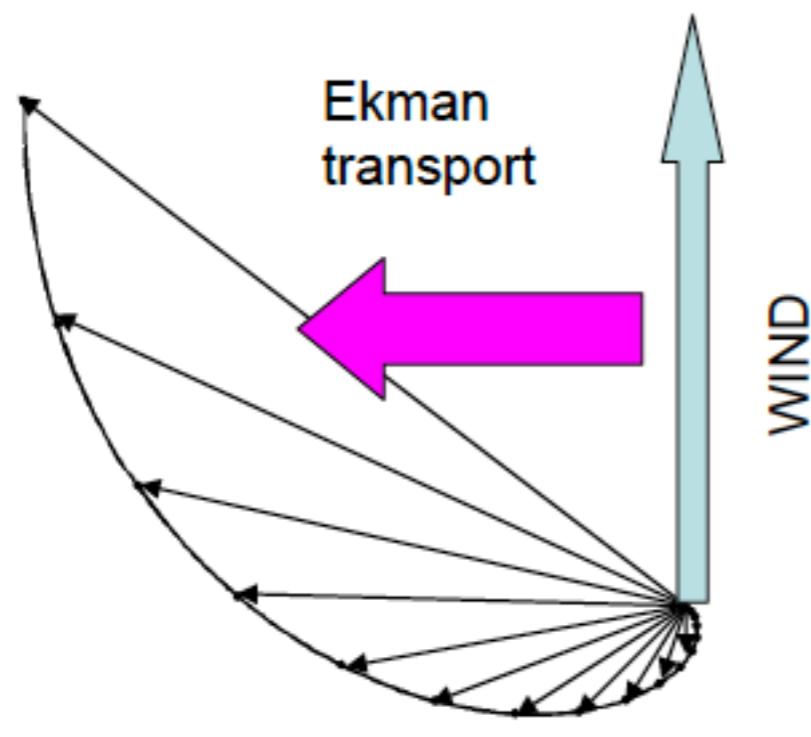
# Dynamics in the Ekman layer

- 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

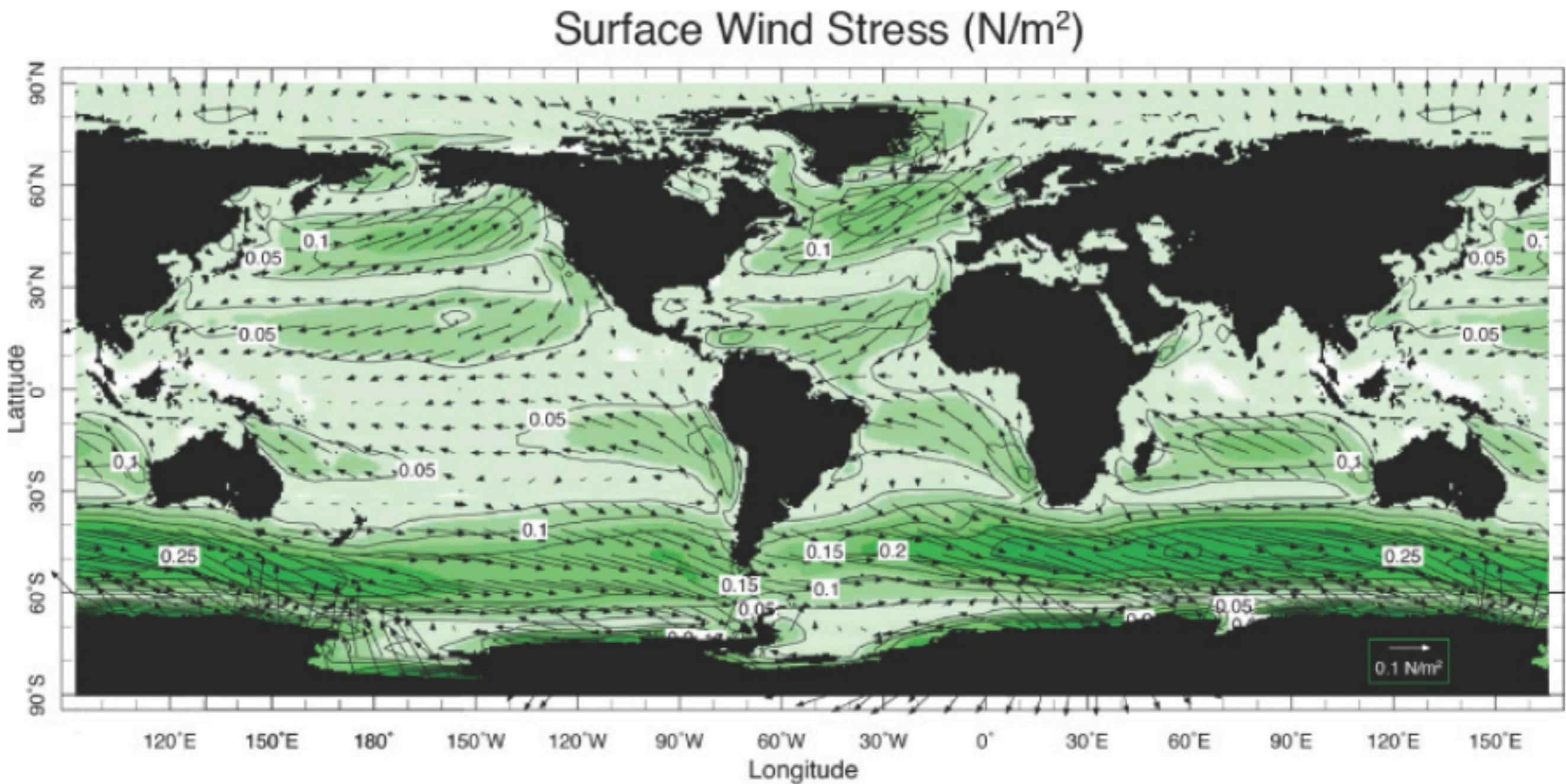


# Ekman spiral

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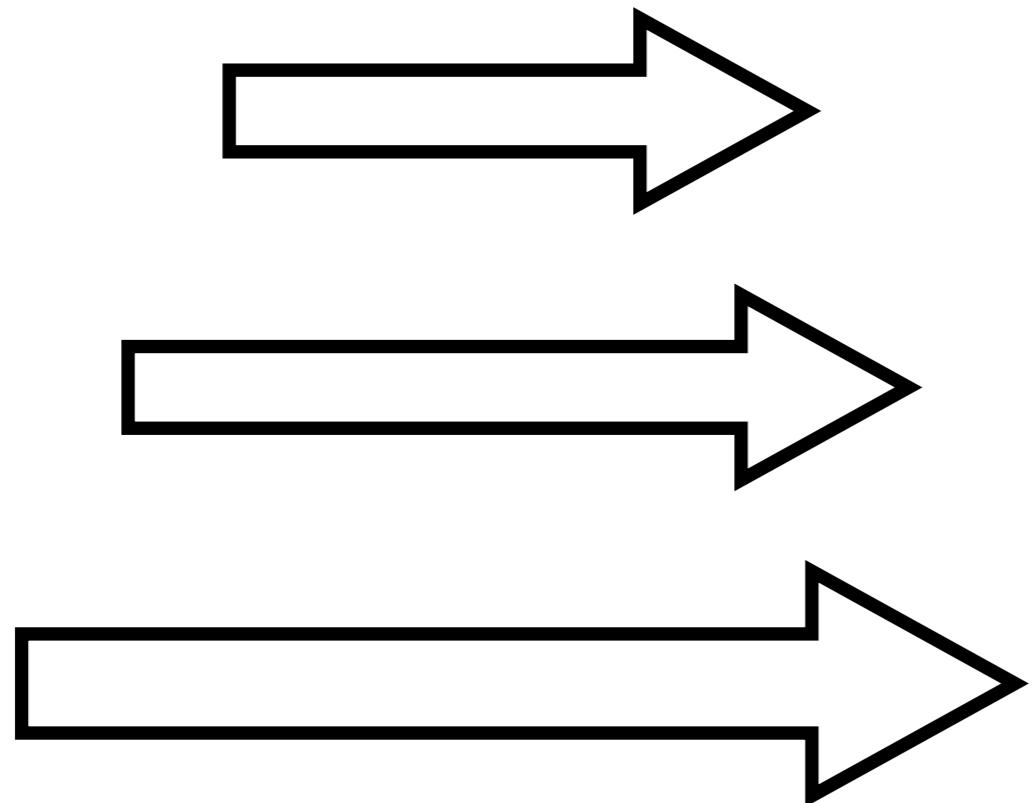
# Wind stress structure



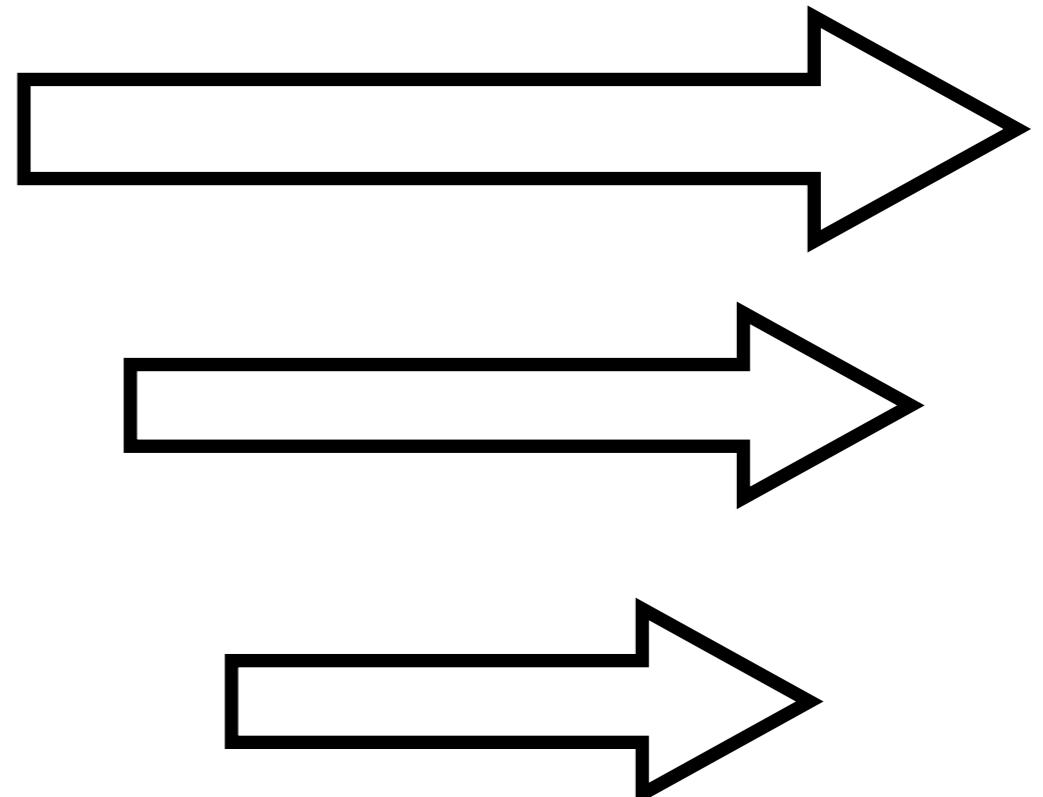
# Wind stress structure

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



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

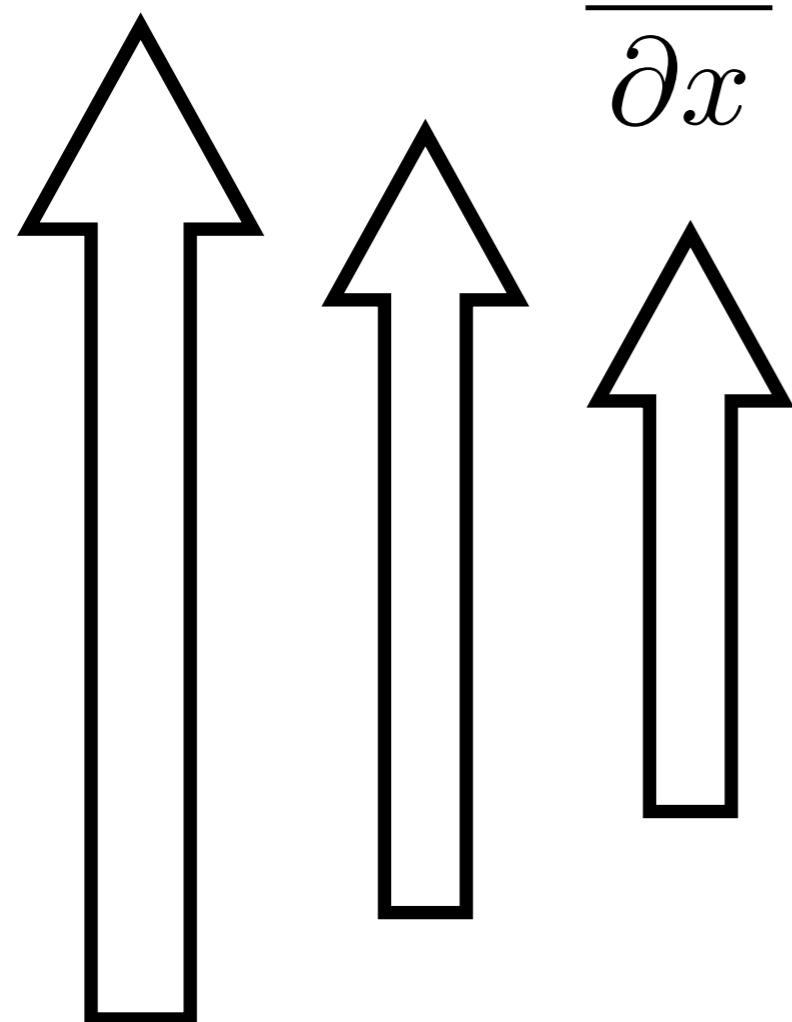


- Northern H. : divergence
- Southern H. : convergence

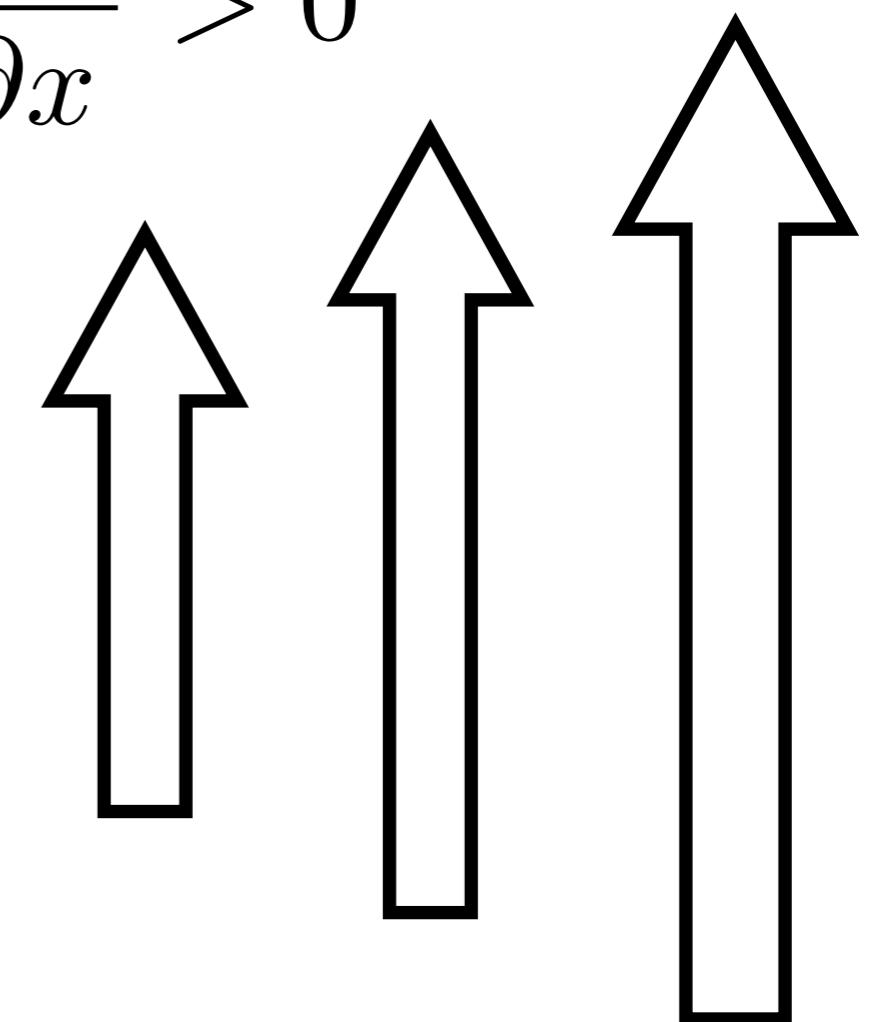
- Northern H. : convergence
- Southern H. : divergence

# Wind stress structure

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



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

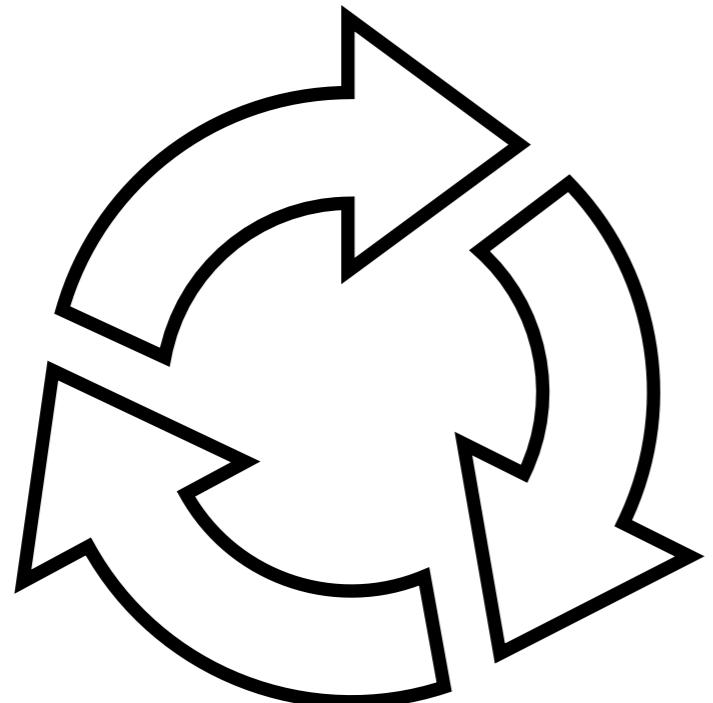
- Northern H. : convergence
- Southern H. : divergence

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

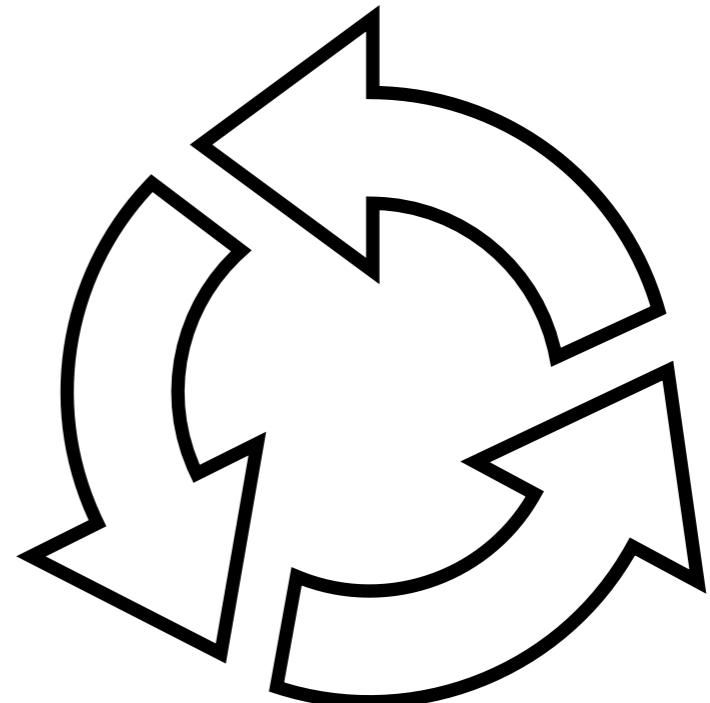
# Wind stress structure

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



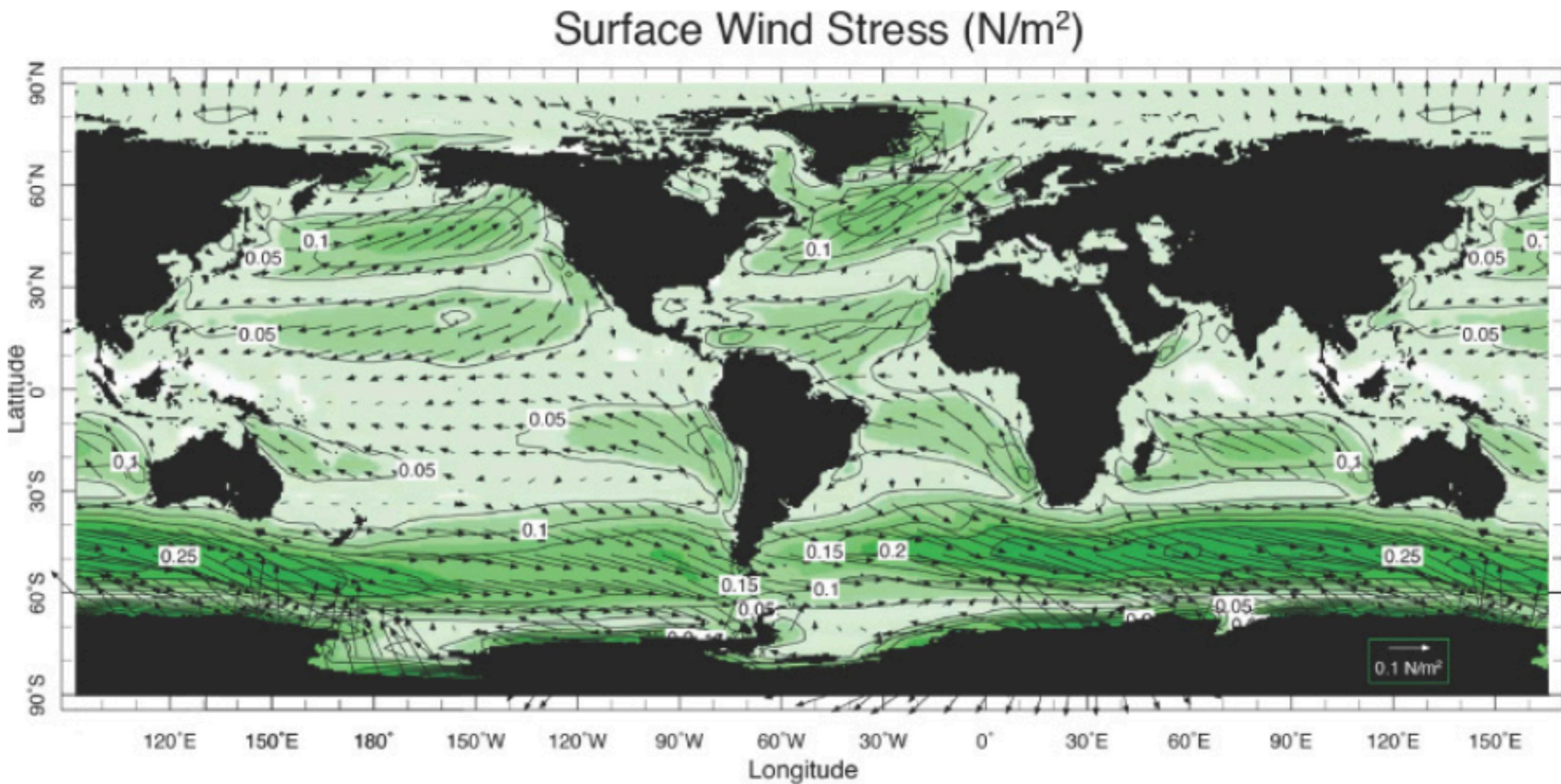
$$\frac{\partial \tau_y}{\partial x} - \frac{\partial \tau_x}{\partial y} > 0$$



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

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

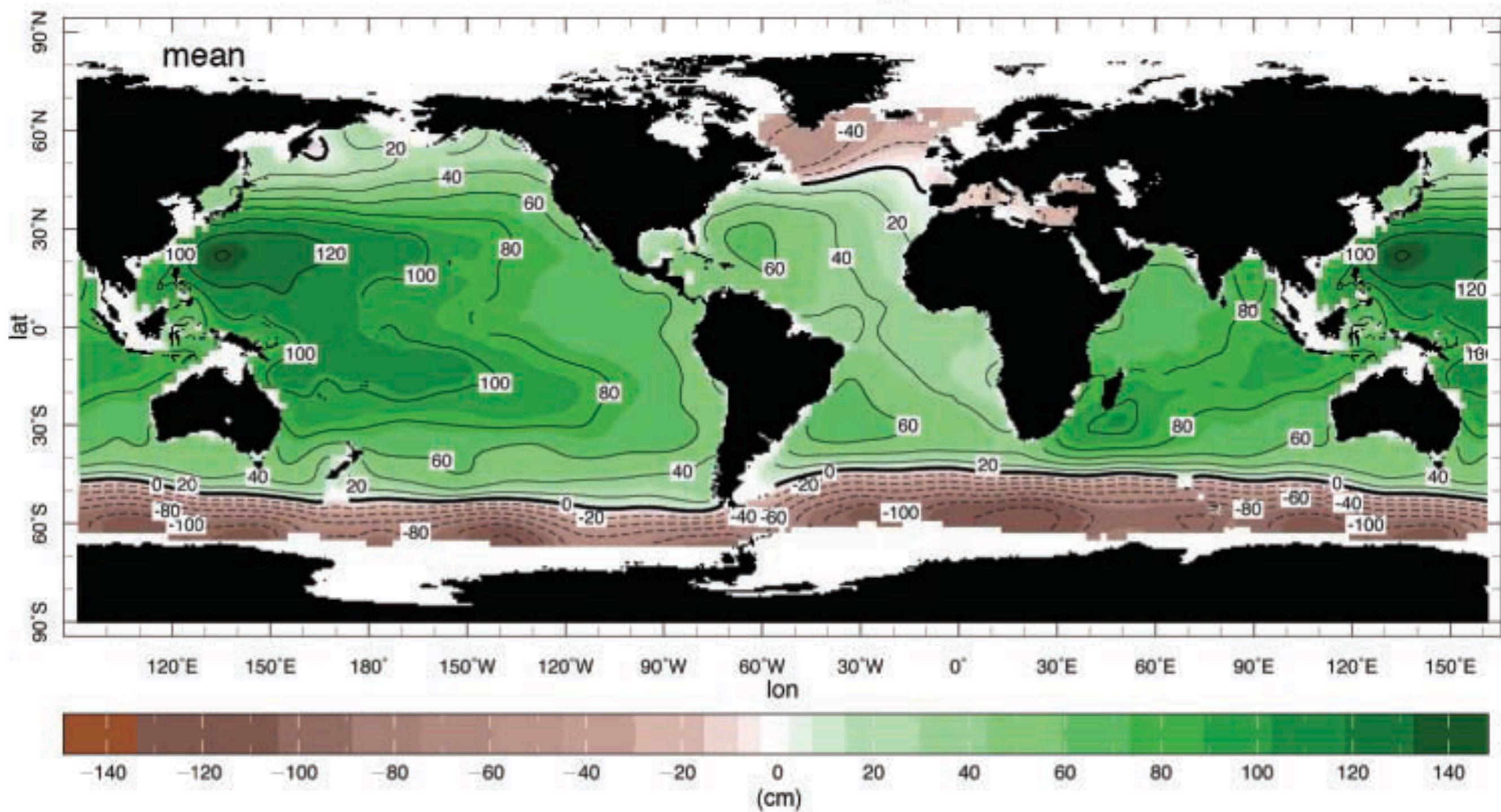
# Wind stress structure



# Sea level

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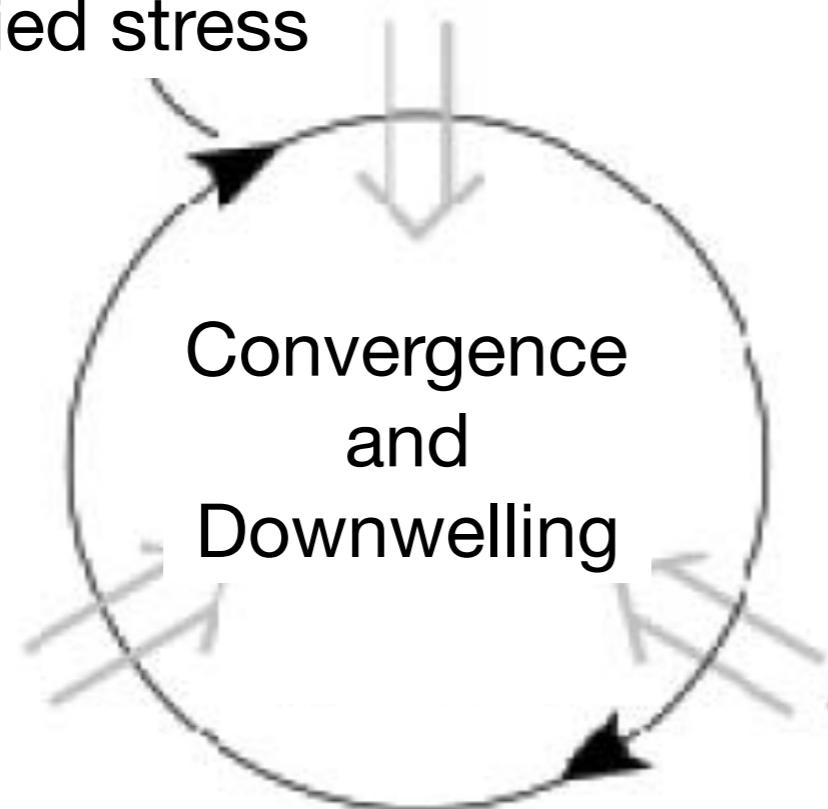
Sea Surface Height



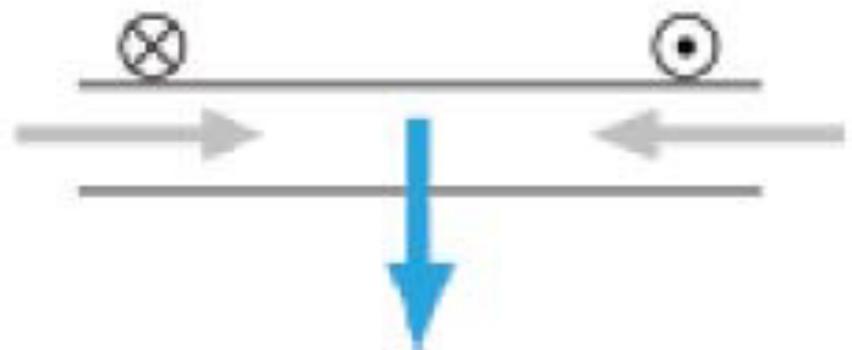
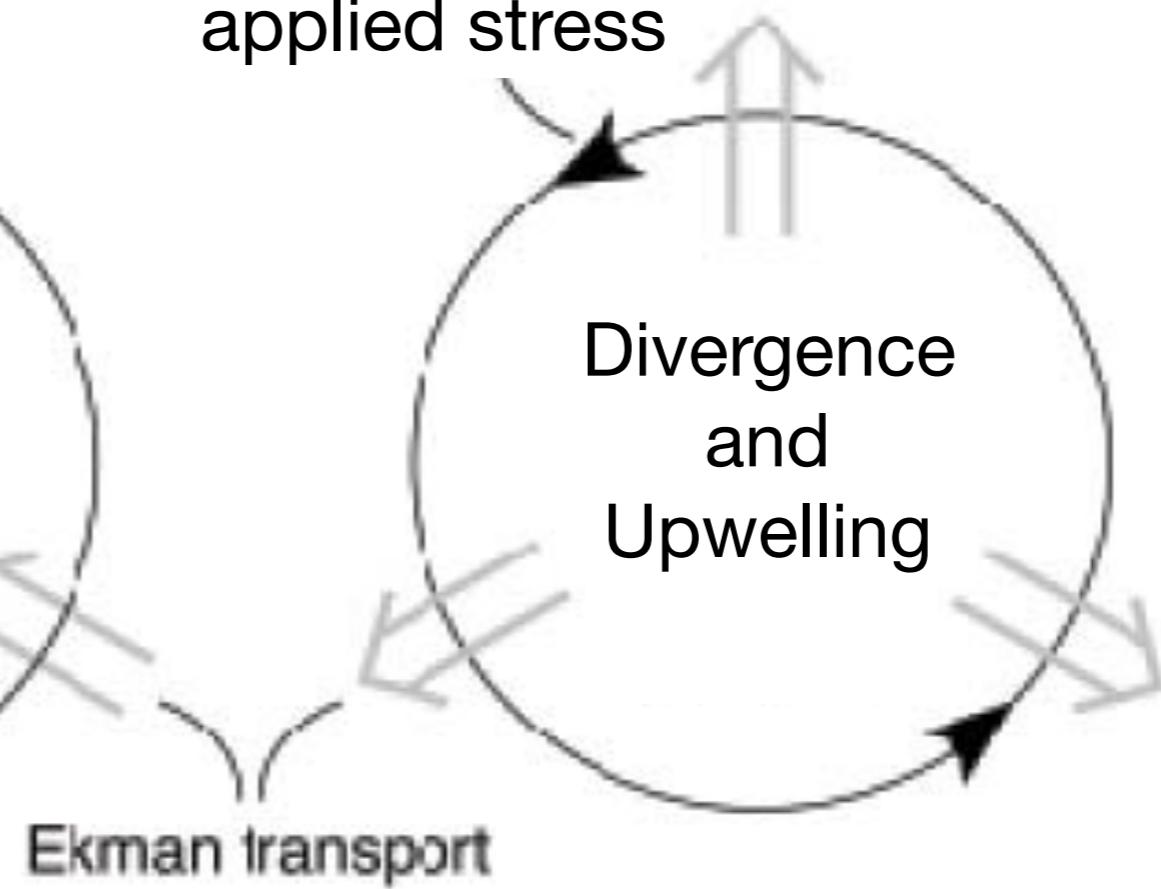
# Ekman pumping / suction

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Anticyclonic  
applied stress

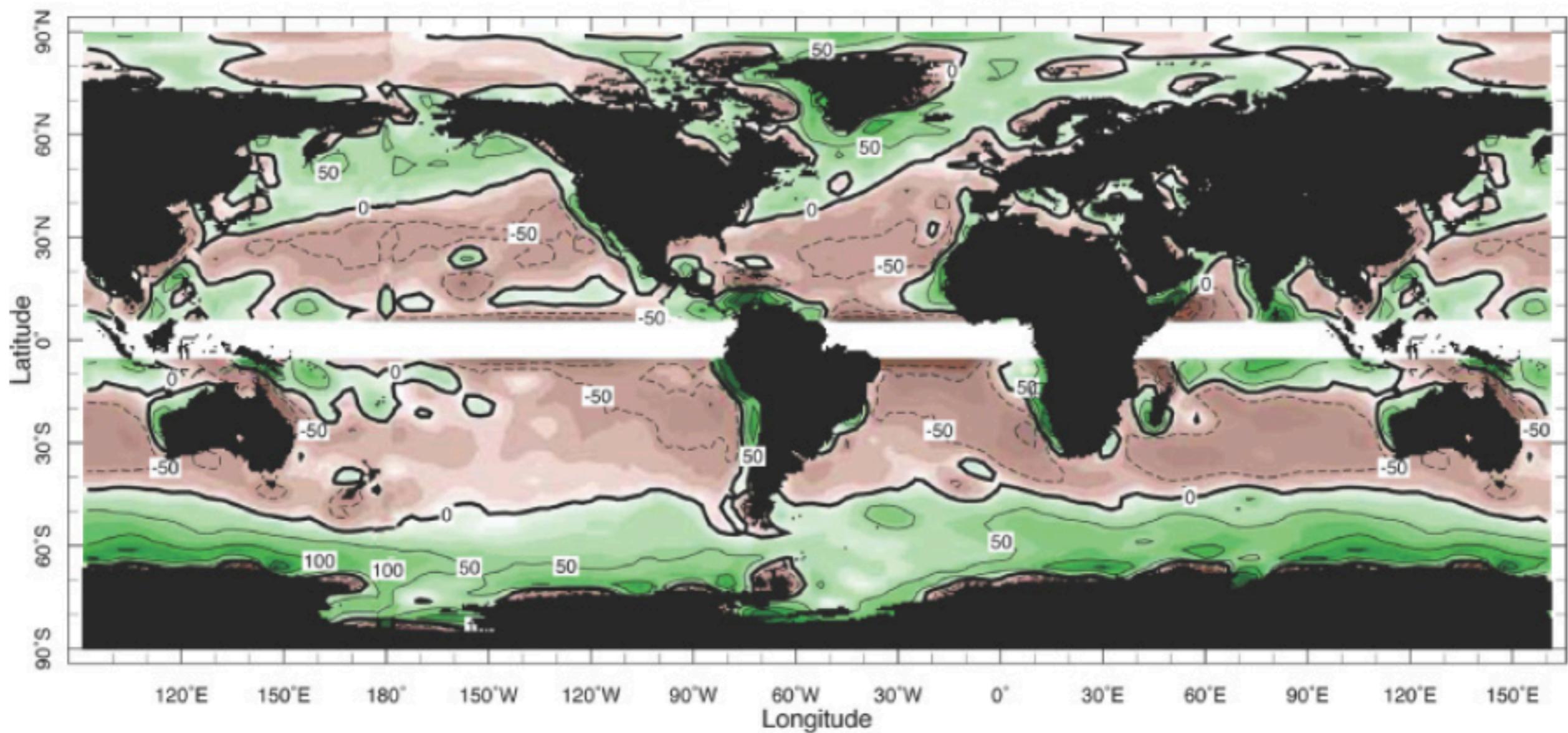


Cyclonic  
applied stress

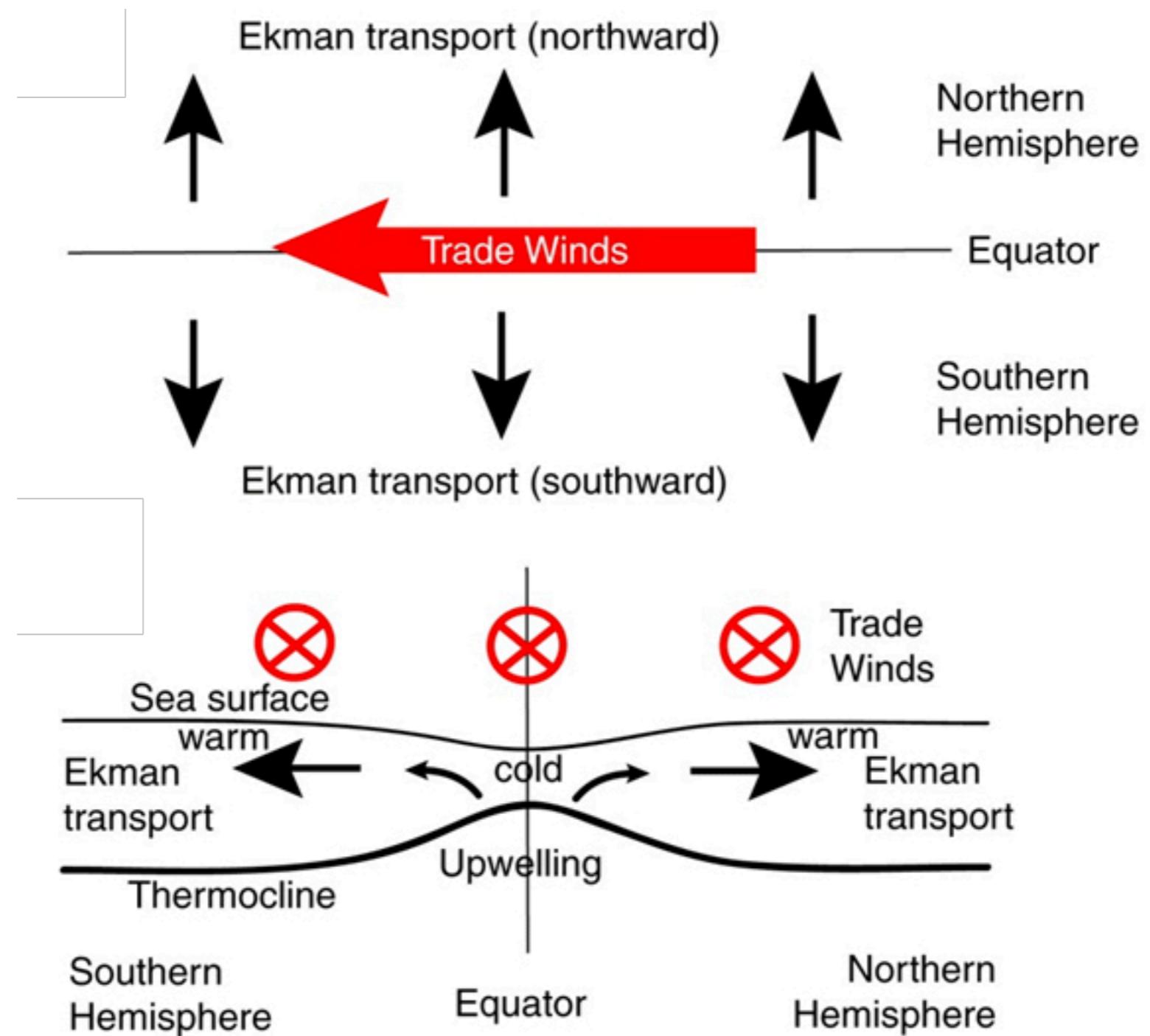


# Ekman pumping / suction

Ekman suction (m/y)



# Ekman pumping at the equator



# Ekman pumping / suction and temperature

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