Lecture 17: The tropical circulation

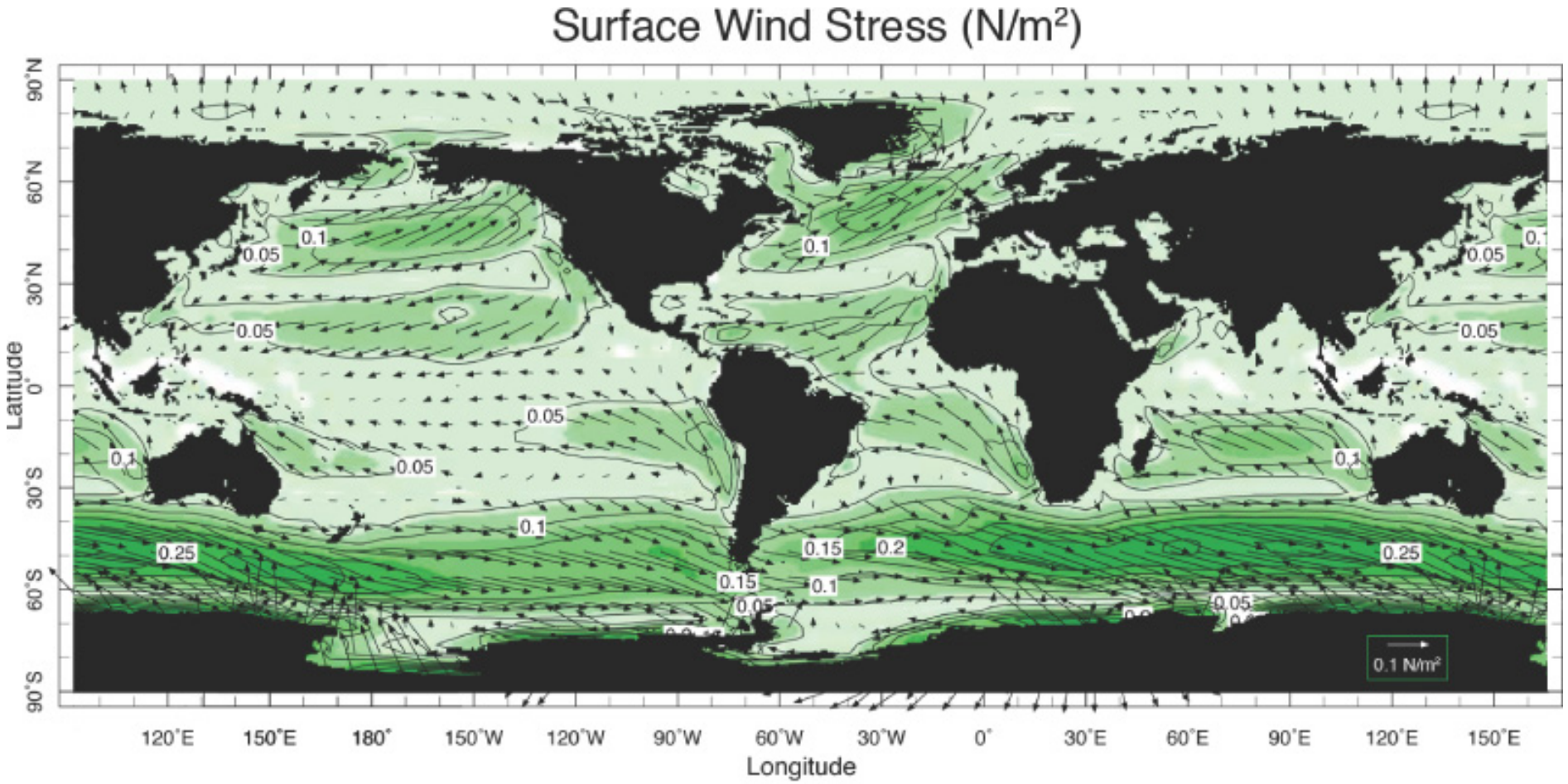
Atmosphere, Ocean, Climate Dynamics

EESS 146B/246B

The tropical circulation

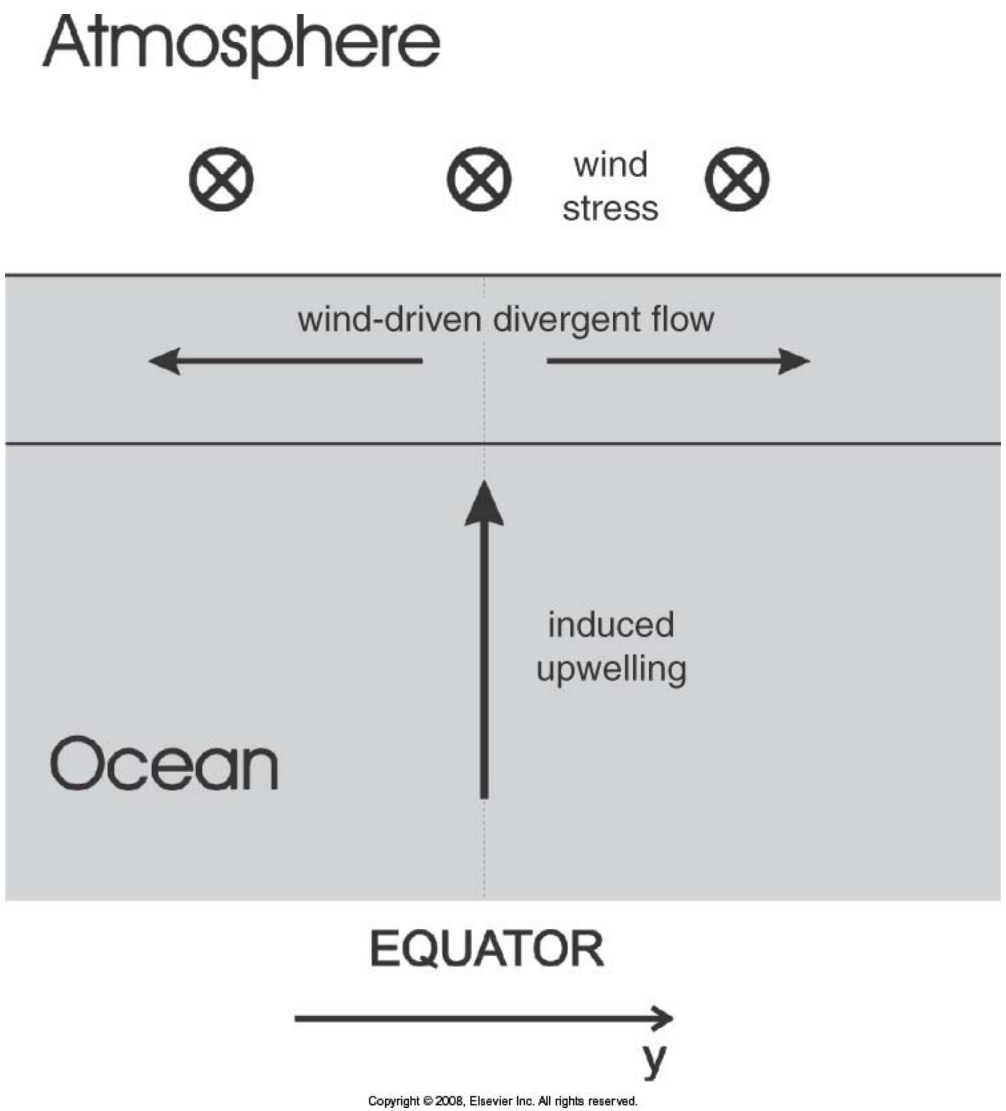
- The importance of winds in driving the circulation.
- Structure of the thermocline in the tropics.
- Meridional circulation: the tropical cells
- Zonal circulation: the North Equatorial Counter Current and the Equatorial Undercurrent.

Distribution of the wind-stress

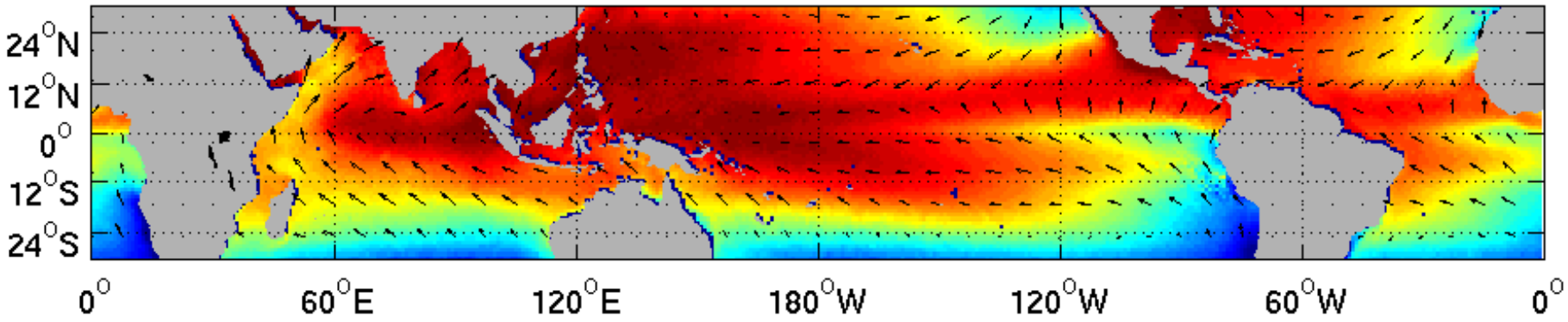


•What is the structure of the Ekman transport near the Equator?

Equatorial Upwelling

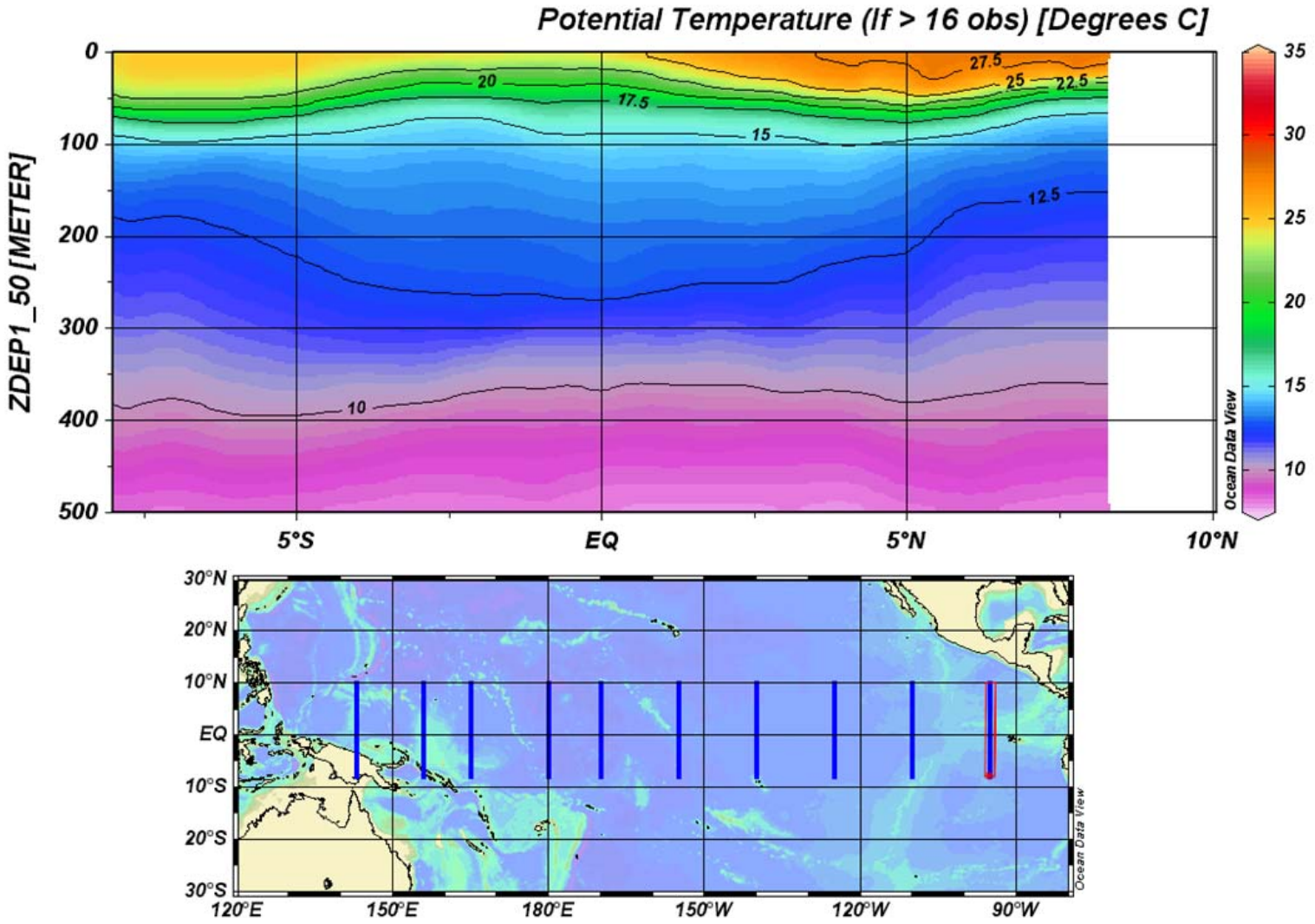


Distribution of the wind-stress and SST in the tropics



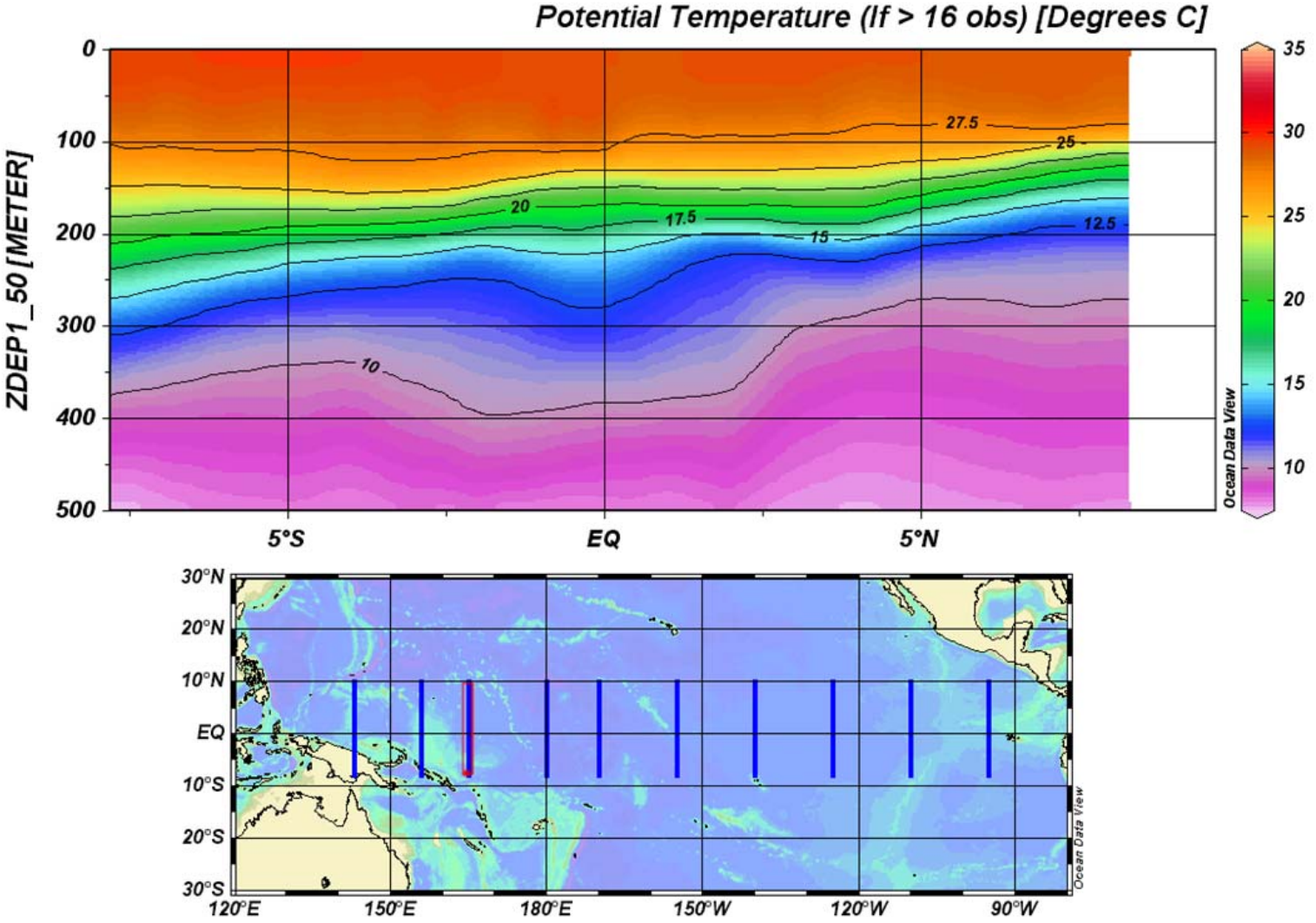
- The easterly trade winds drive a divergent Ekman transport near the Equator.
- This equatorial upwelling lowers the SST, but primarily in the eastern part of the tropical oceans.
- The regions of cool temperatures in the east are known as *cold tongues*.

Meridional sections of temperature in the eastern and western Pacific



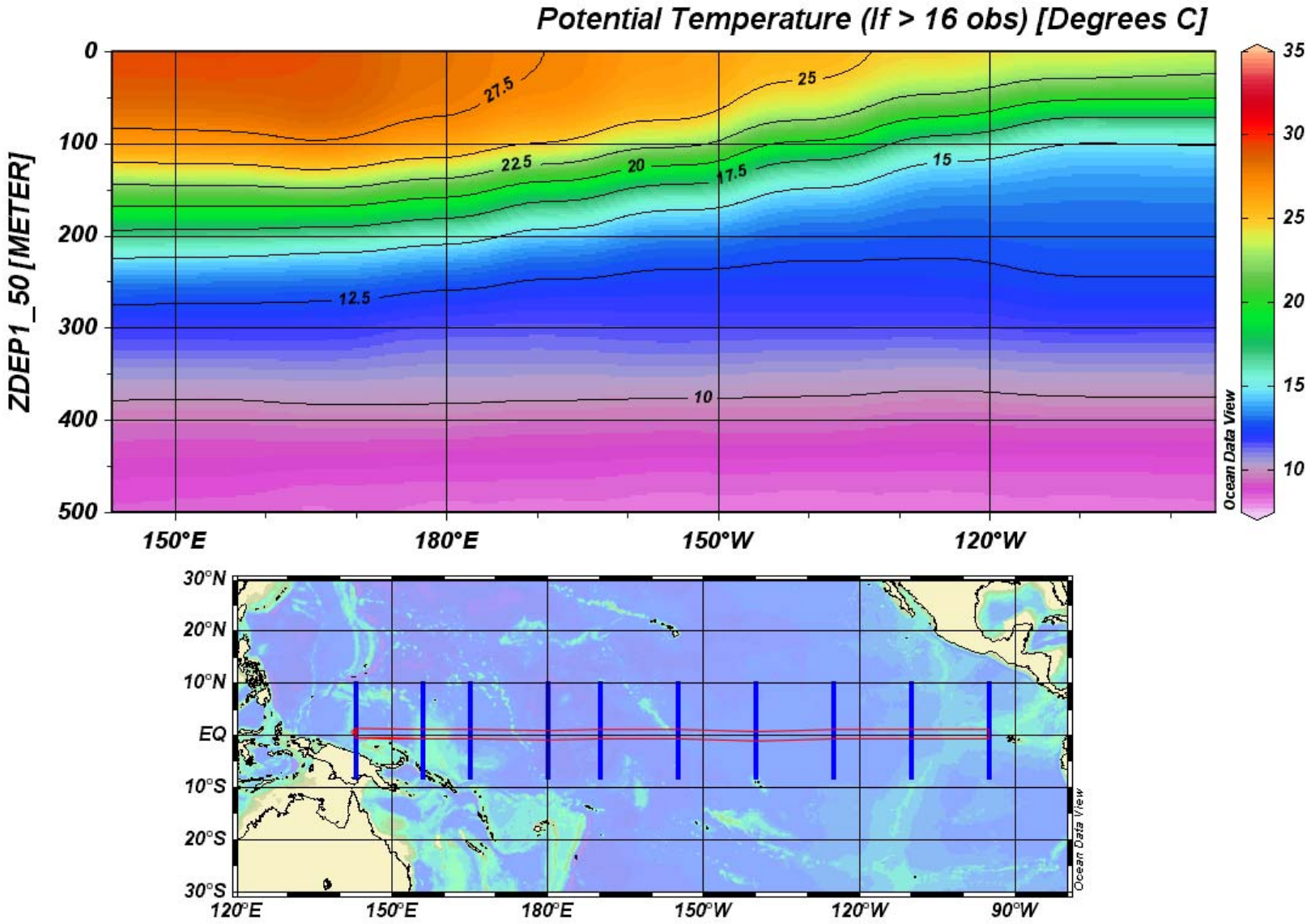
•Shallow mixed layer with cool waters.

Meridional sections of temperature in the eastern and western Pacific

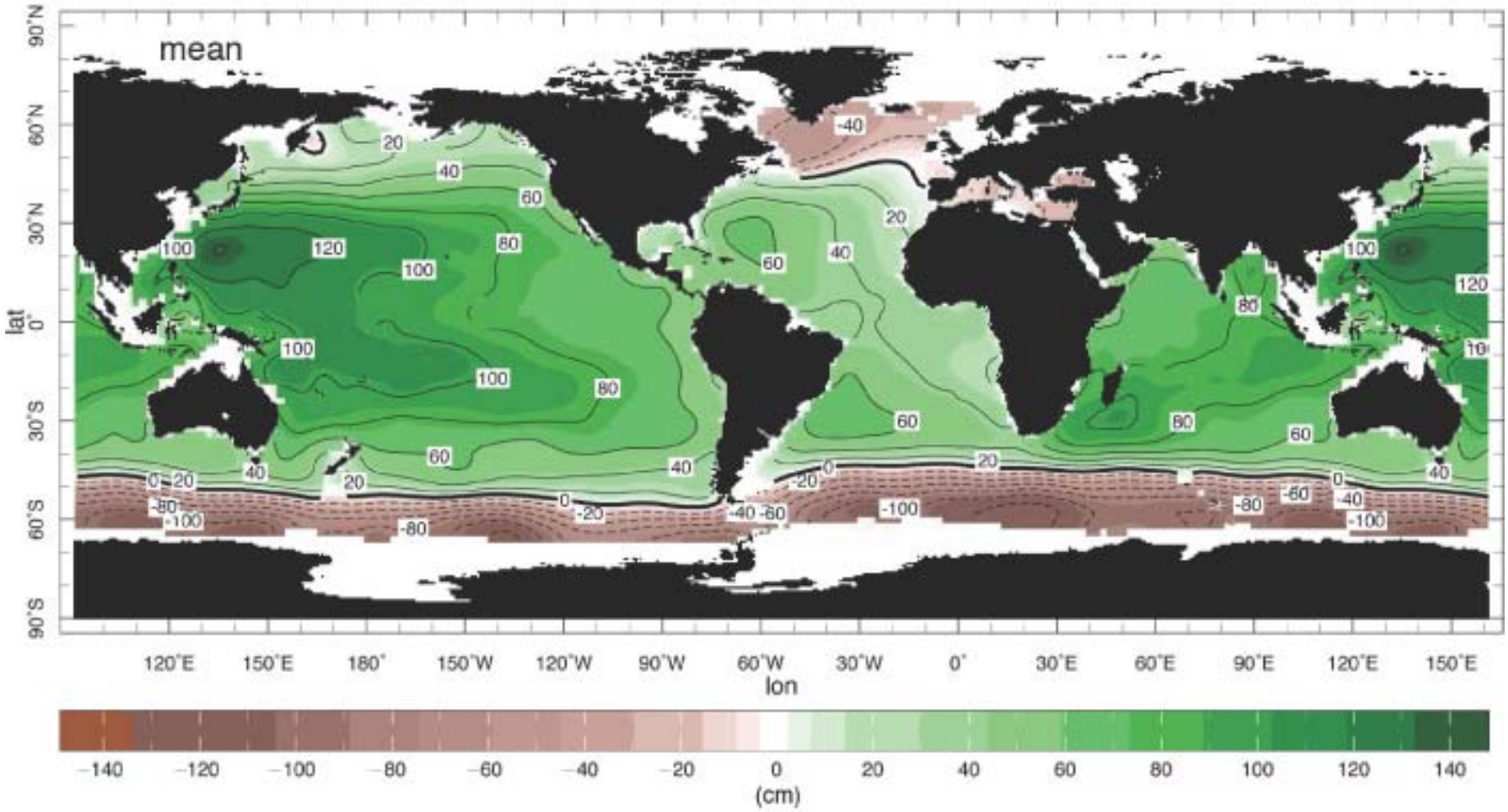


•Deep ~100 m mixed layers with warm temperatures→*western warm pool*

Zonal tilt to the thermocline



10 year mean dynamic topography



•SSH is higher in the west versus the east→water is piled up in the west.

Zonal momentum balance at the equator

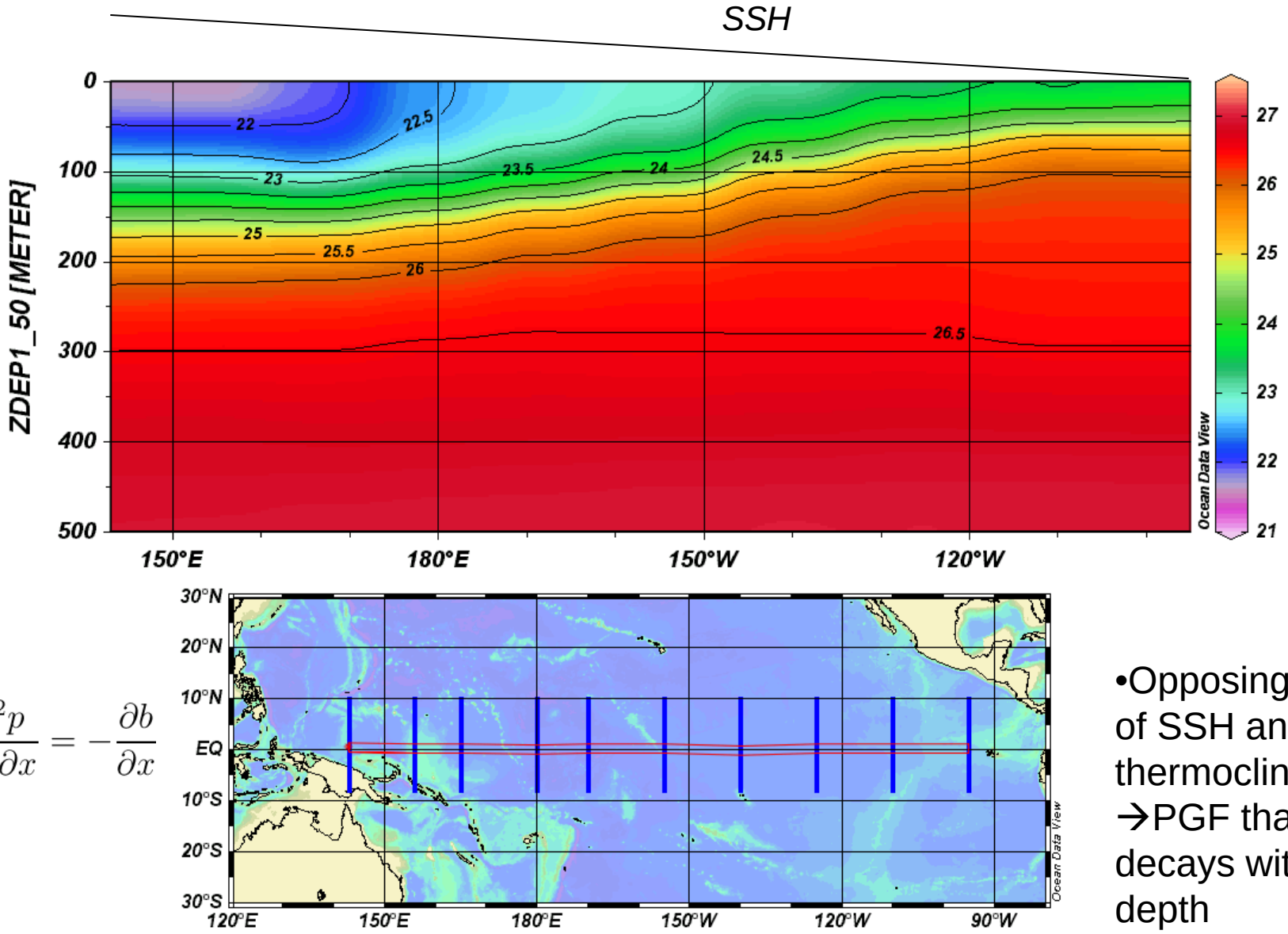
•At the equator, the Coriolis force cannot balance the zonal frictional force associated with the trade winds

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

•If the flow does not vary in the x-direction, the wind-stress will accelerate a zonal flow to the west.

•The presence of the zonal boundaries will cause water to be piled up to the west setting up a pressure gradient.

Zonal pressure gradient at the equator.



$$-\frac{1}{\rho_{ref}}\frac{\partial^2 p}{\partial z \partial x} = -\frac{\partial b}{\partial x}$$

- Opposing tilts of SSH and thermocline →PGF that decays with depth

Zonal momentum balance at the equator

•At the equator, the Coriolis force cannot balance the zonal frictional force associated with the trade winds

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

•If the flow does not vary in the x-direction, the wind-stress will accelerate a zonal flow to the west.

•The presence of the zonal boundaries will cause water to be piled up to the west setting up a pressure gradient.

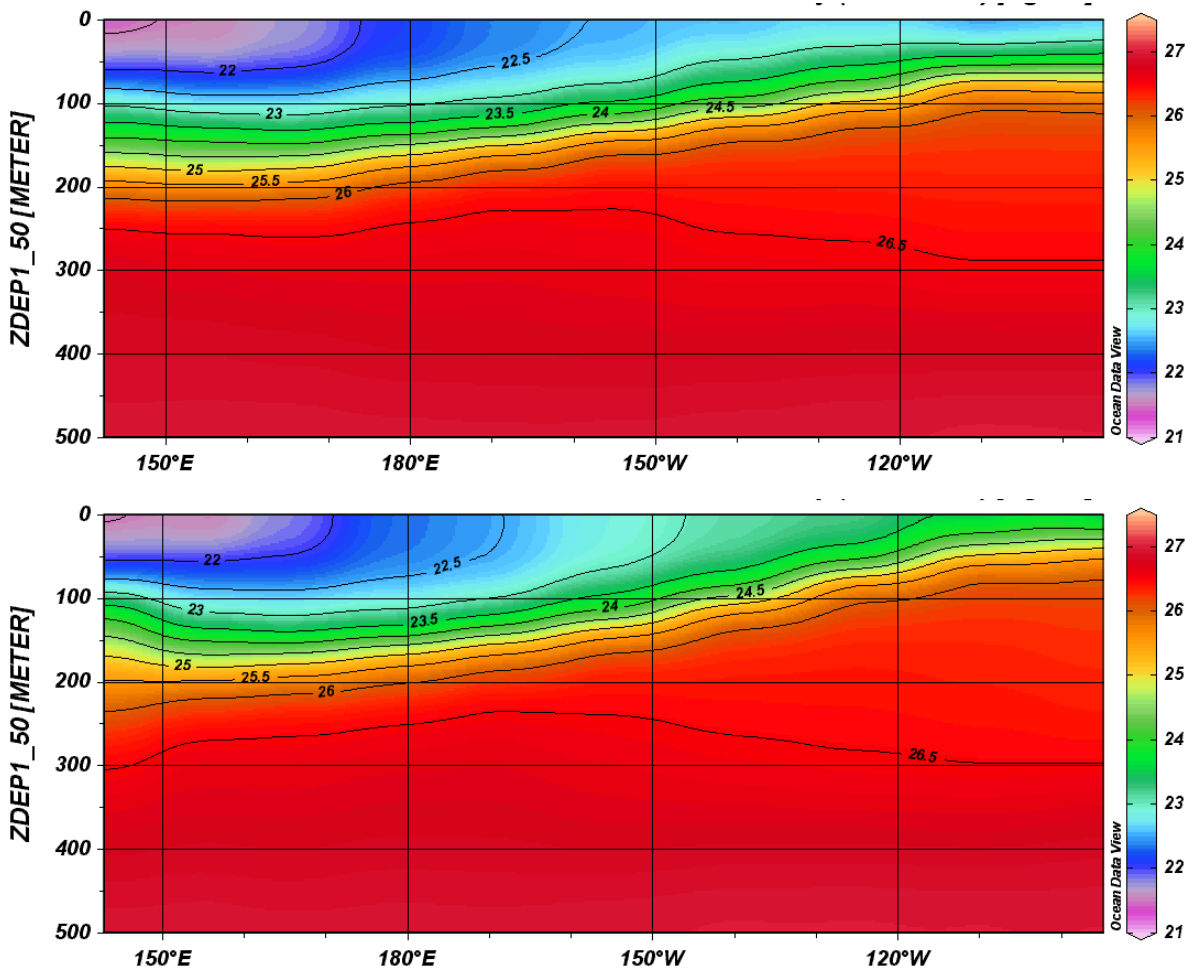
•In the surface layer where the wind-forced frictional is active the dominant balance is between the pressure gradient force and friction:

$$0 = -\frac{1}{\rho_{ref}}\frac{\partial p}{\partial x} + \frac{1}{\rho_{ref}}\frac{\partial \tau_x}{\partial z}$$

Force balance off the equator

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

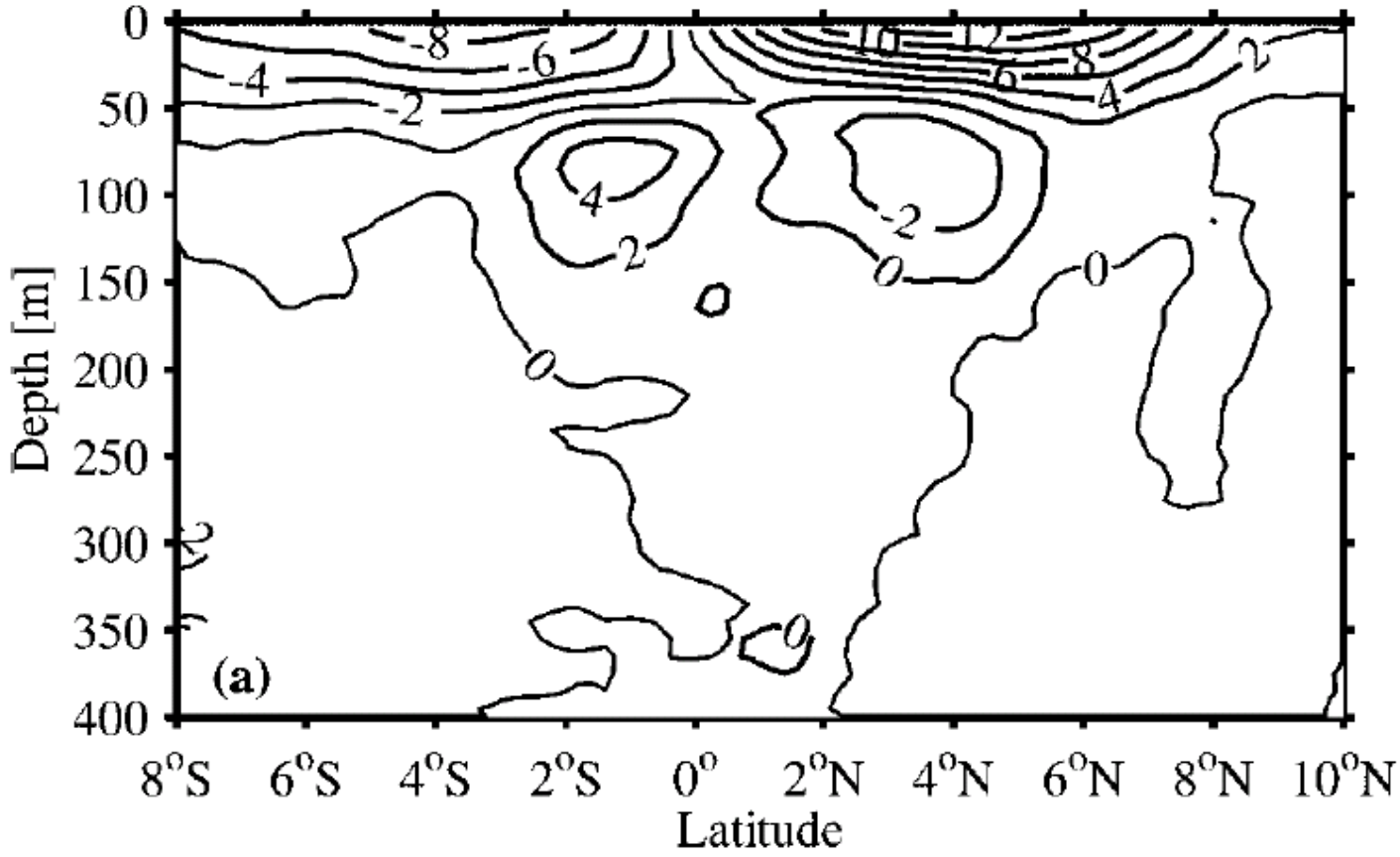
- Tilt in thermocline and SSH persists north and south of the equator →convergent meridional geostrophic flow beneath Ekman layer



2.5ºN

2.5ºS

Meridional velocity



v (cm/s)

•Meridional velocity averaged between 170W-95W, from Johnson et al 2001.

Tropical cells

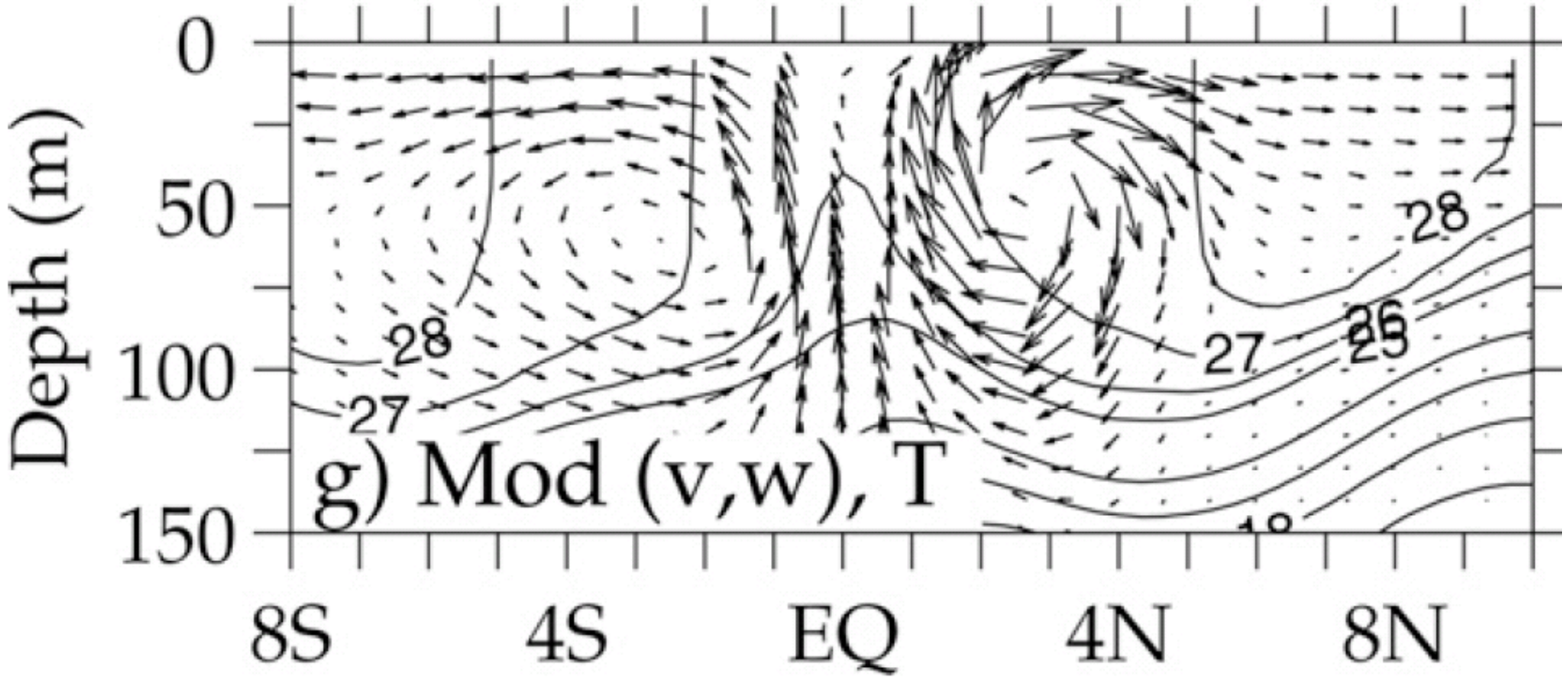


Fig. from Perez and Kessler 2009

•Divergent Ekman flow near the equator is feed by convergent geostrophic flow at depth and results in a meridional overturning circulation known as the *tropical cells*.

•The MOC of the tropical cells combined with the vertical temperature gradient results in a poleward heat transport.

Convergent Ekman flow poleward of Equator

Wind-stress curl based on the ERS scatterometer

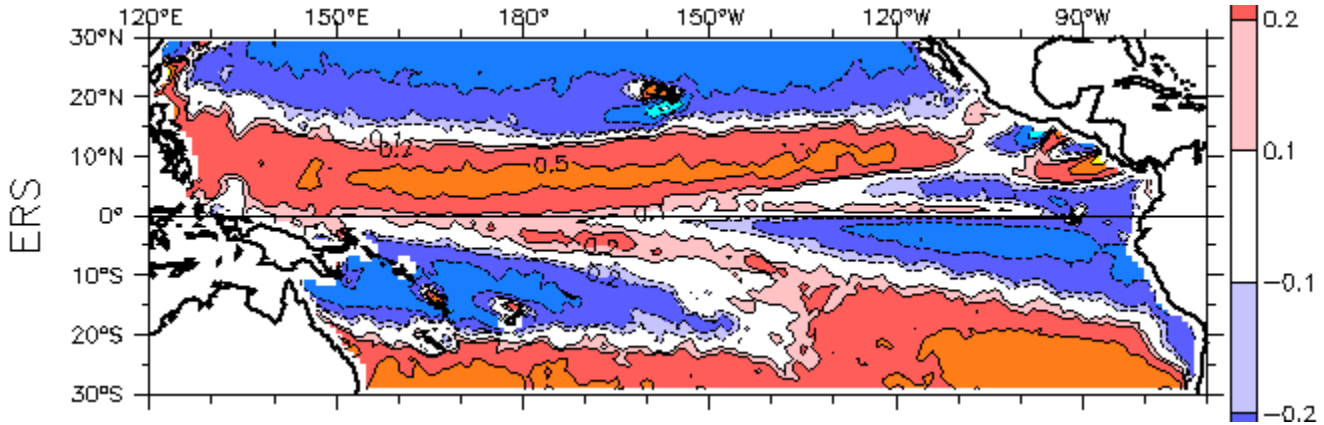


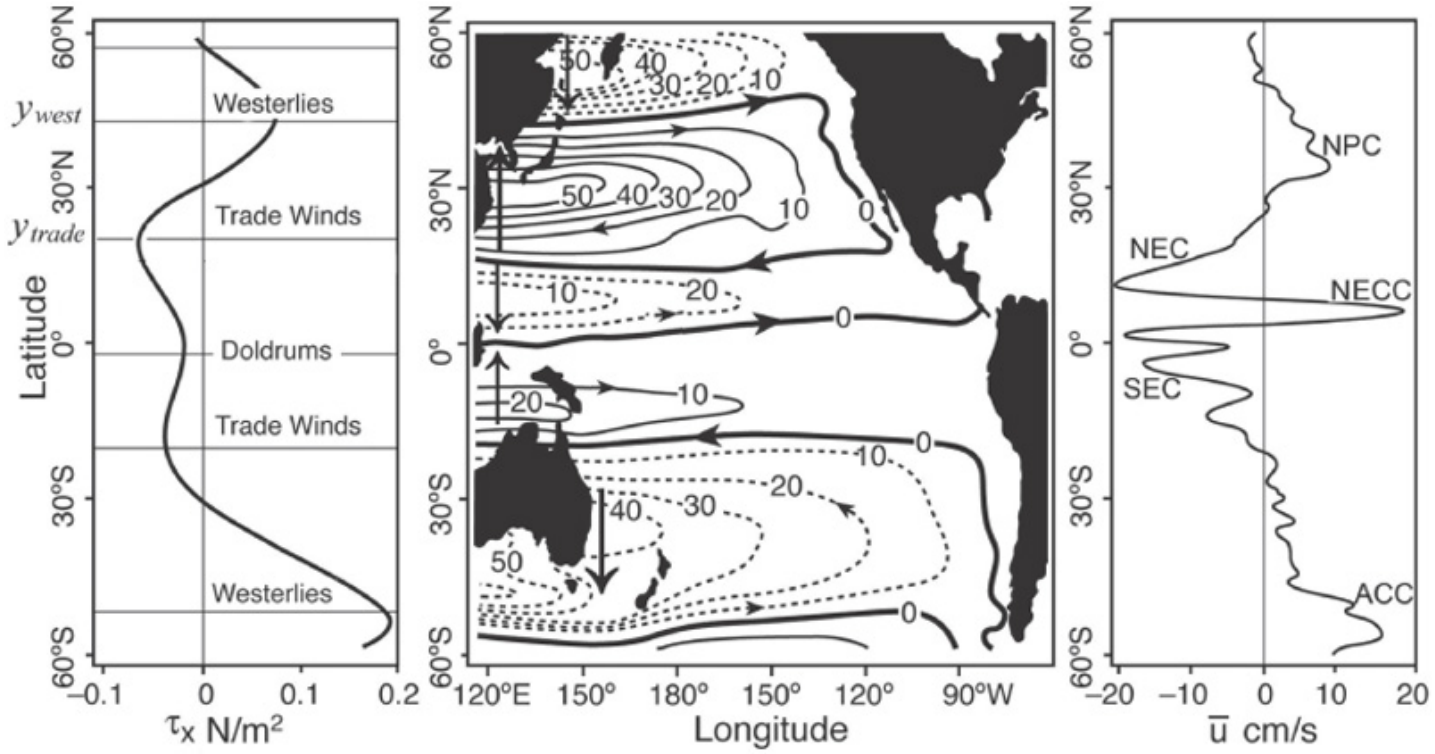
Fig. courtesy of Billy Kessler PMEL

•Ekman flow is convergent poleward of the Equator in spite of the positive (negative) wind stress curl north (south) of the Equator.

$$w_{ek} = \frac{1}{\rho_{ref}} \hat{z} \cdot \nabla \times \left(\frac{\tau_{wind}}{f} \right)$$

•The increase of the Coriolis parameter off of the equator reduces the poleward Ekman transport, driving convergence.

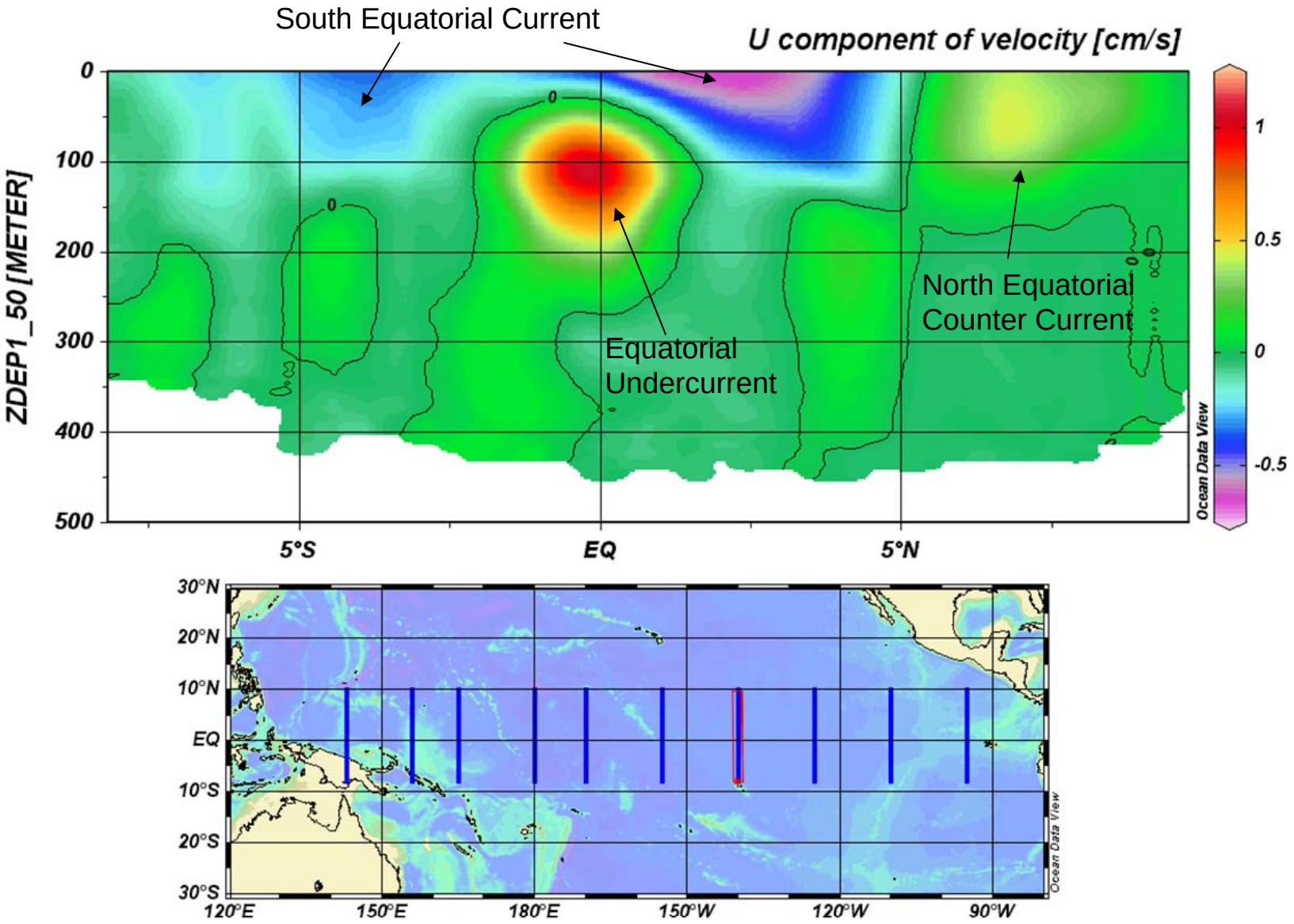
Tropical circulation predicted by the Sverdrup balance



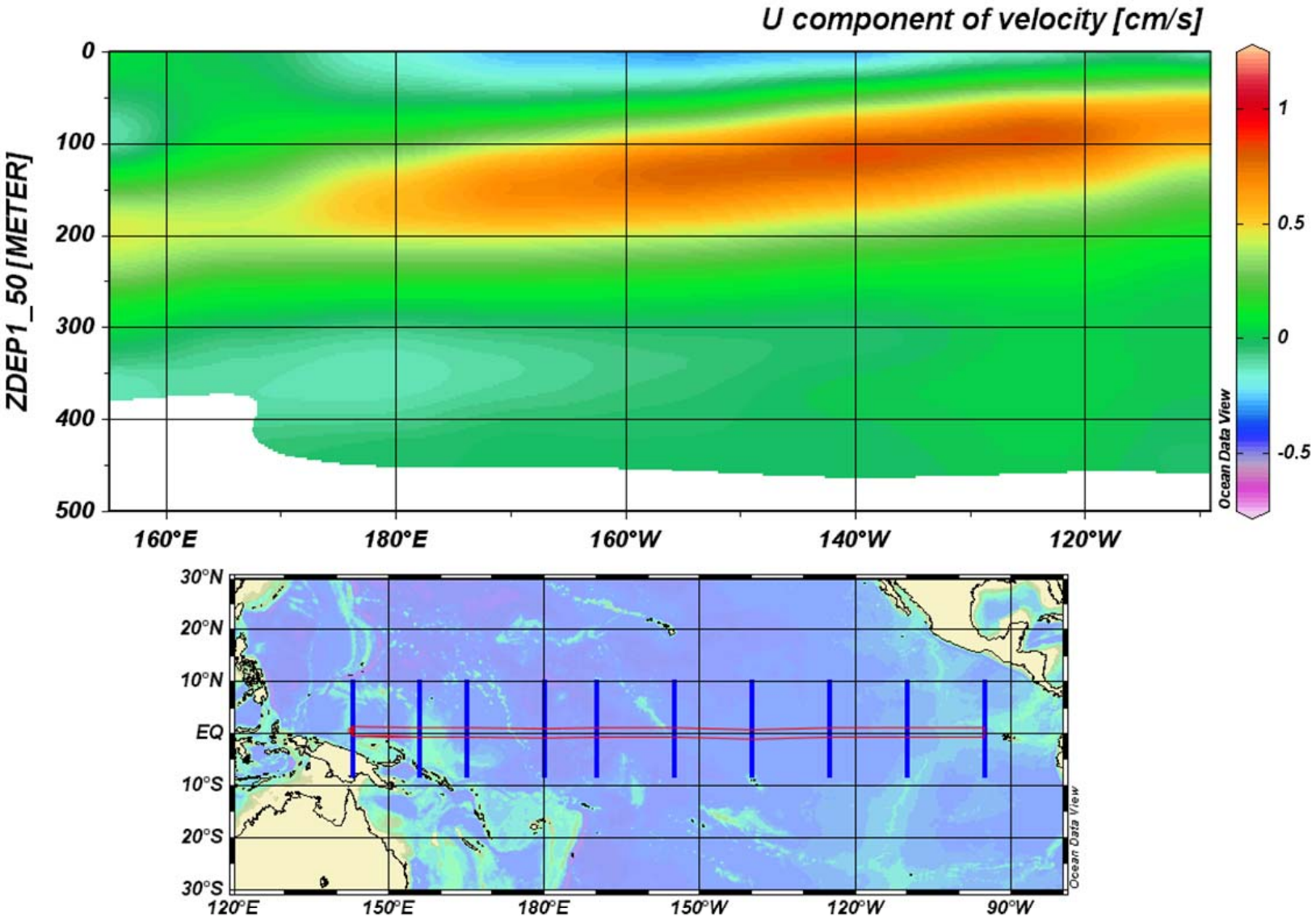
$$\psi = -\frac{1}{\beta \rho_{ref}} \int_x^{x_e} (\hat{z} \cdot \nabla \times \tau_{wind})\, dx$$

- The positive wind-stress curl north of the Equator drives a northward depth integrated flow.
- This sets up the North Equatorial Counter Current that opposes the Trade Winds.

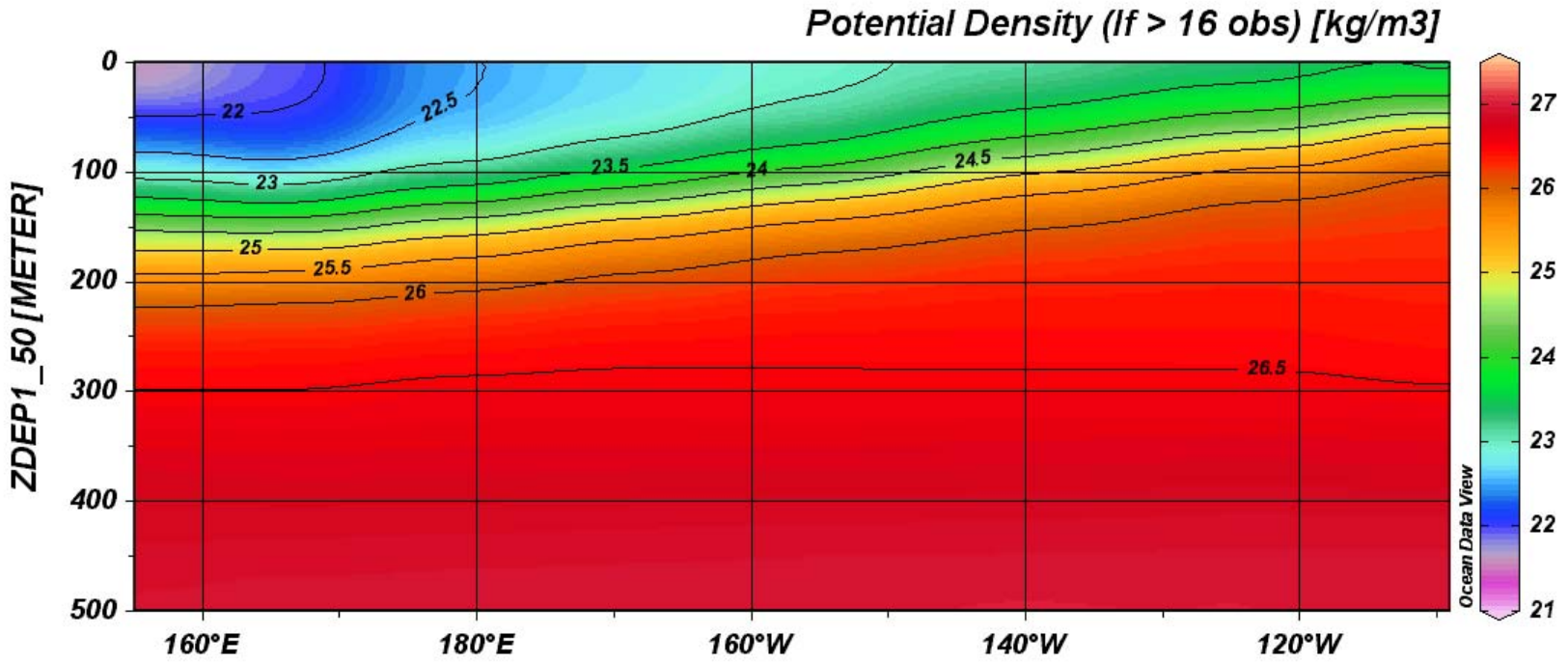
Zonal circulation



Equatorial Undercurrent



Equatorial Undercurrent

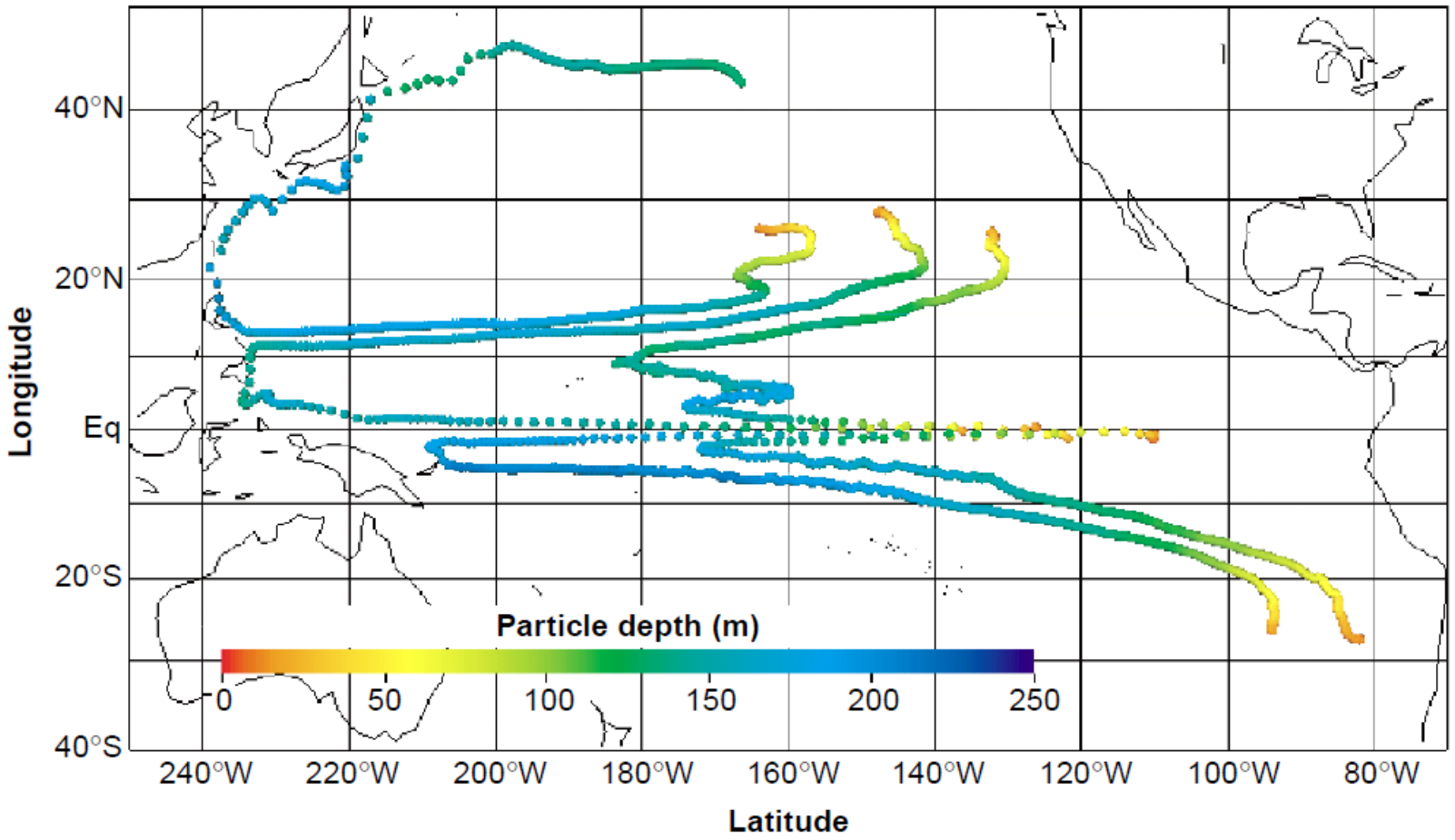


•Core of the EUC is in the lower half of the pycnocline, outside of the direct influence of the wind.

•The zonal PGF is not balanced by wind-driven friction at the level of the EUC.

- •This would accelerate an eastward flow which is eventually balanced by advection of momentum and friction.

Tropical-subtropical connections



Particle paths over 16 years

Fig. from Gu and Philander 1997

•Water subducted in the subtropical gyres can be upwelled in the eastern tropical Pacific if it follows the right path and is entrained in the EUC or tropical cells.

•Heat anomalies carried by this subducted water could drive decadal climate variability.