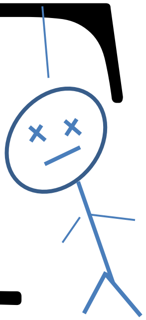
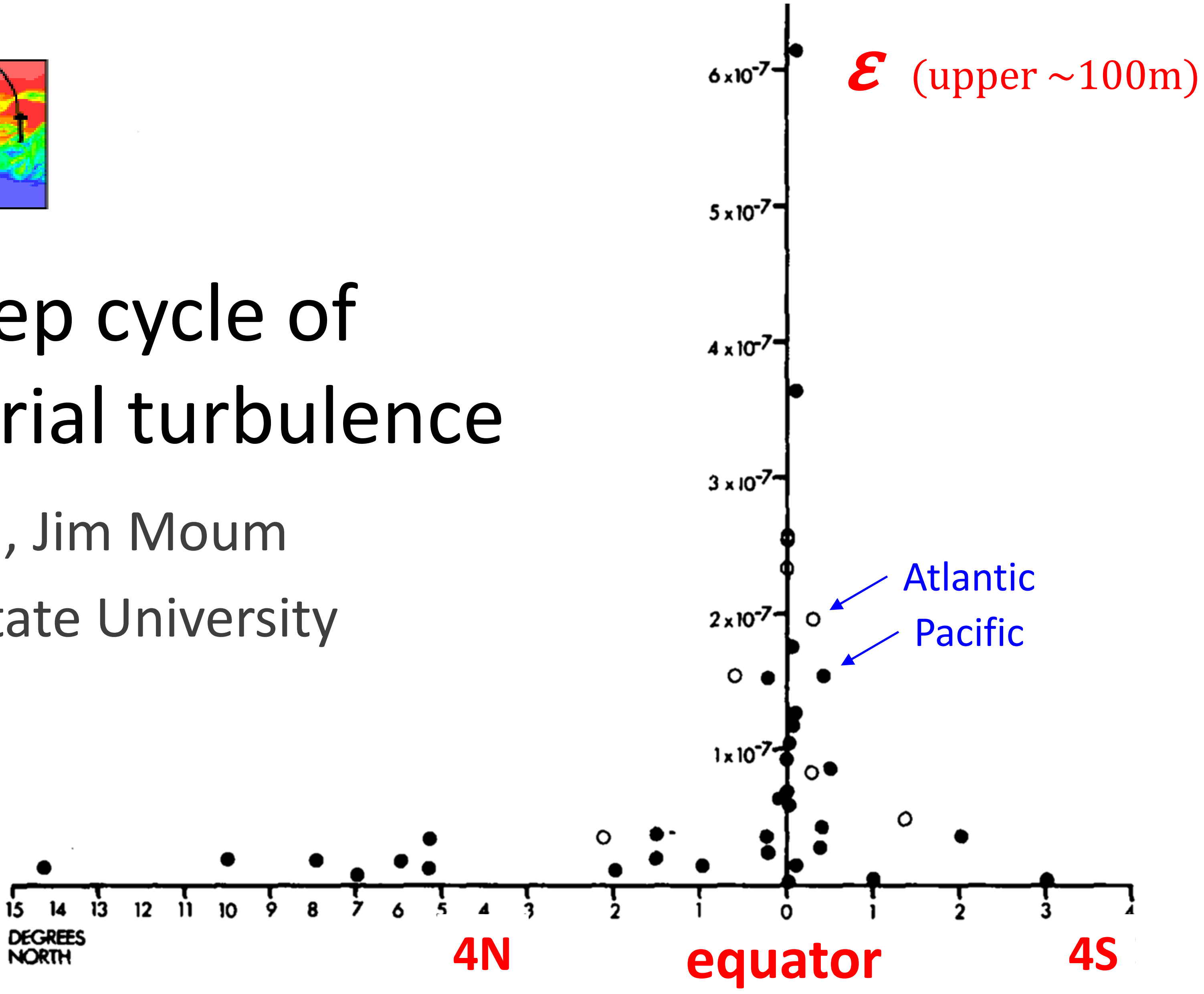


$$\Gamma = 0.2$$

The deep cycle of equatorial turbulence

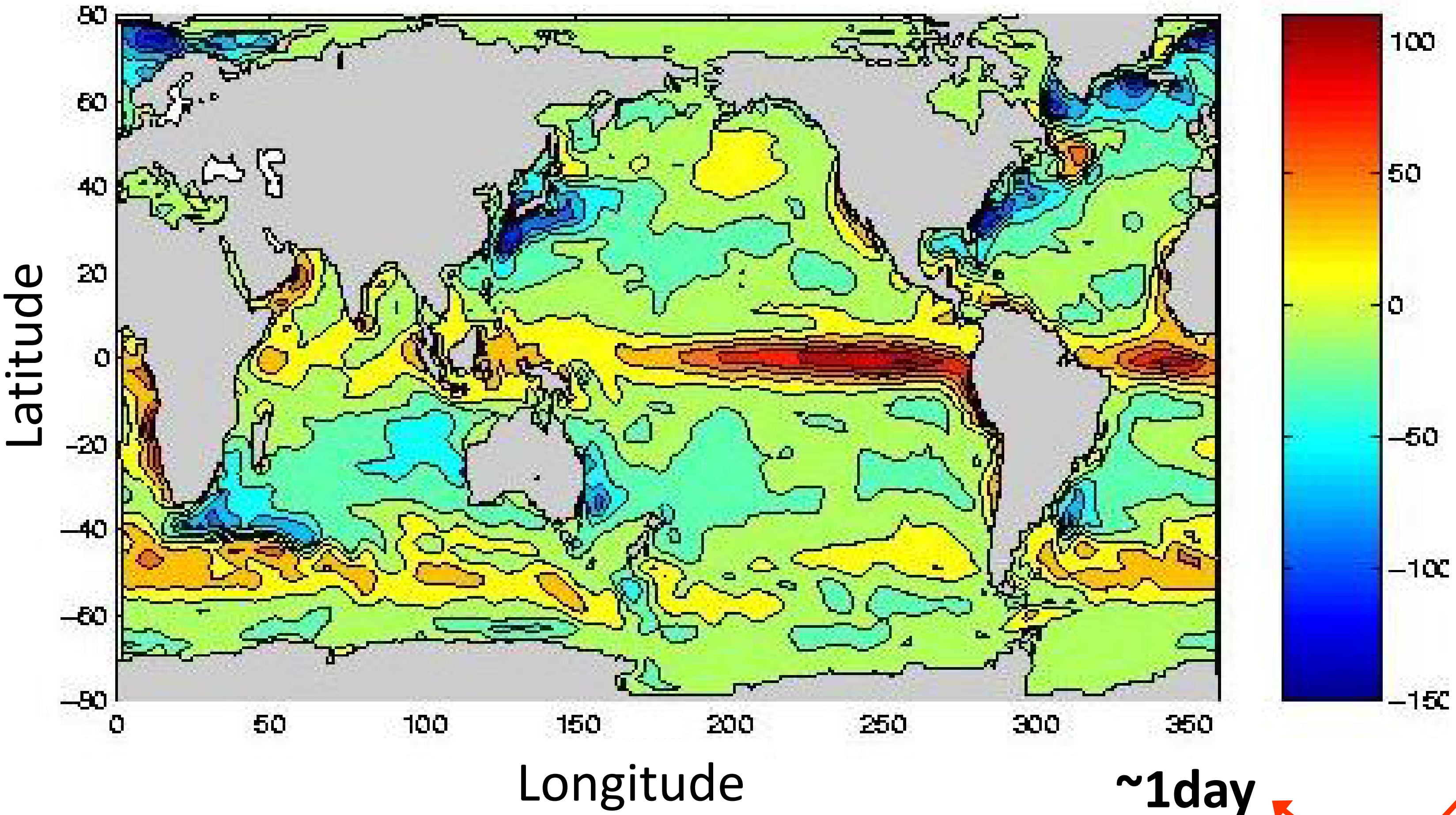
Bill Smyth, Jim Moum

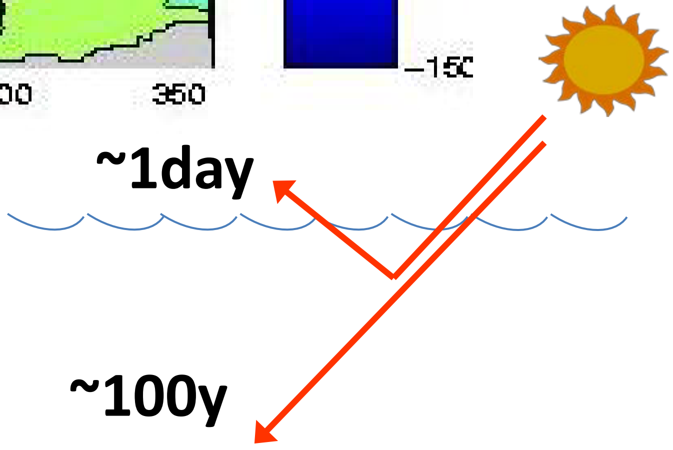
Oregon State University



Crawford (1982, JPO)

mean surface heat flux





Outline

1) The deep cycle of equatorial turbulence

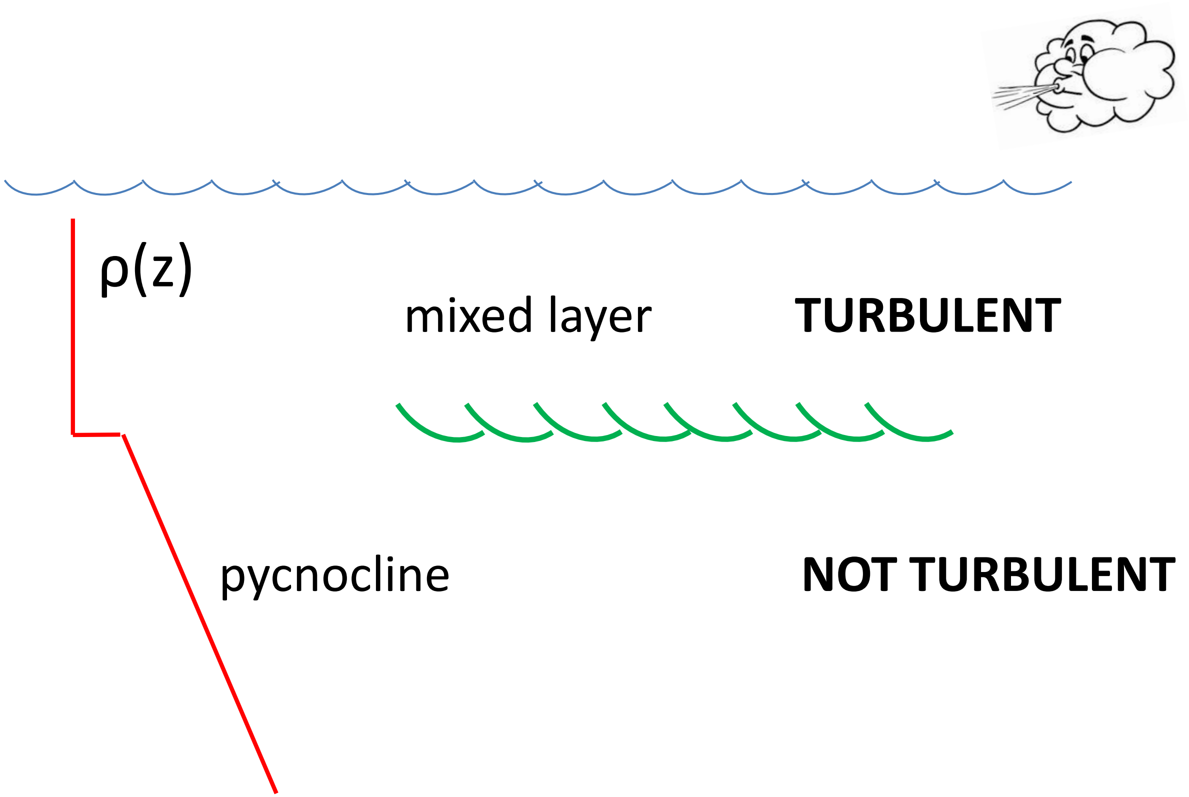
2) How does it work?

3) Parameterizing long-term variability

4) Applications to historical mooring data

- **ENSO**
- **deep cycle carries ~1/2 of surface heat flux**

For comparison: the “slab” model of the upper ocean mixed layer



$\rho(z)$

mixed layer **TURBULENT**

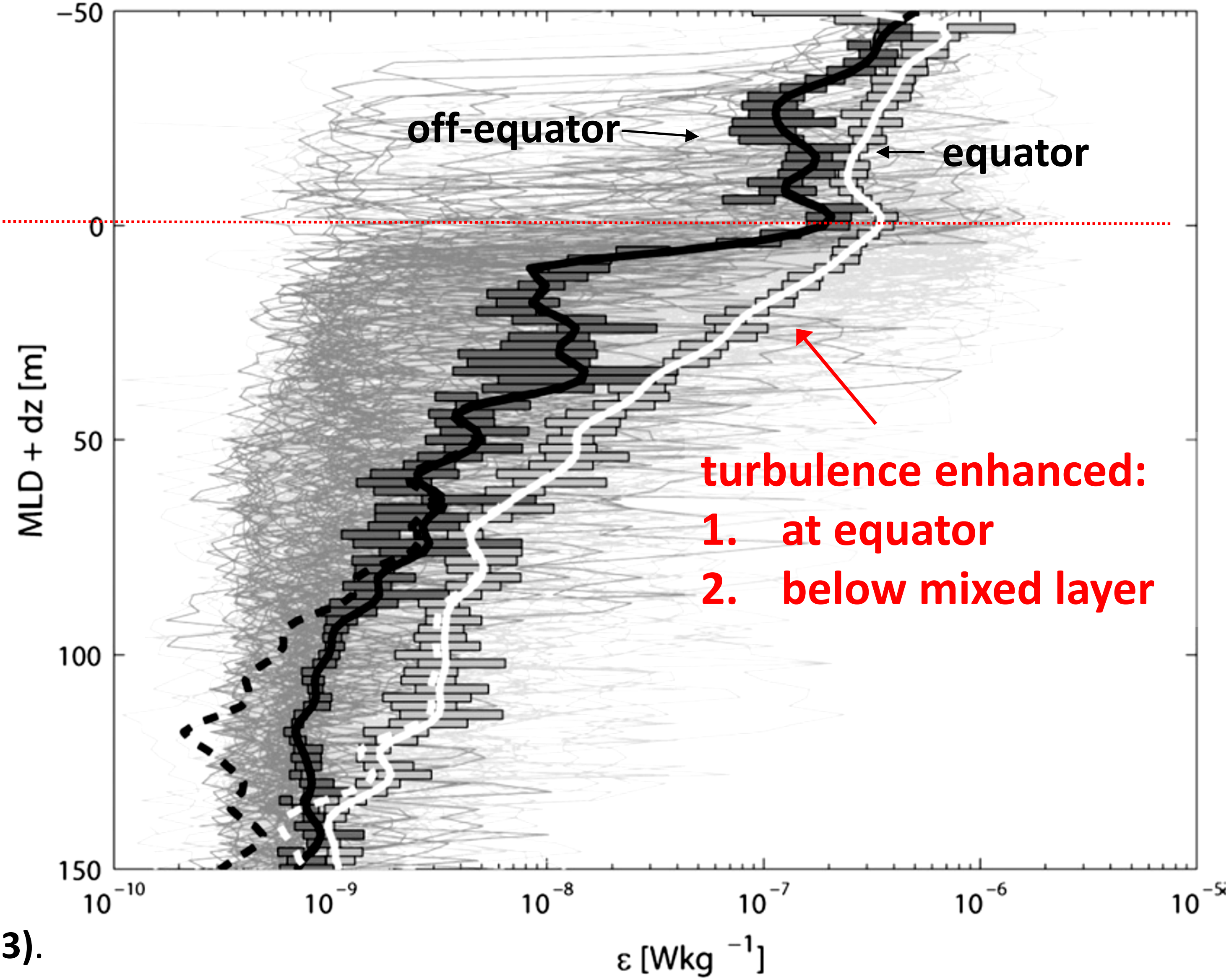
pycnocline **NOT TURBULENT**

At the equator, it’s different.

Vertical/meridional structure

Mixed layer

thermocline



off-equator

equator

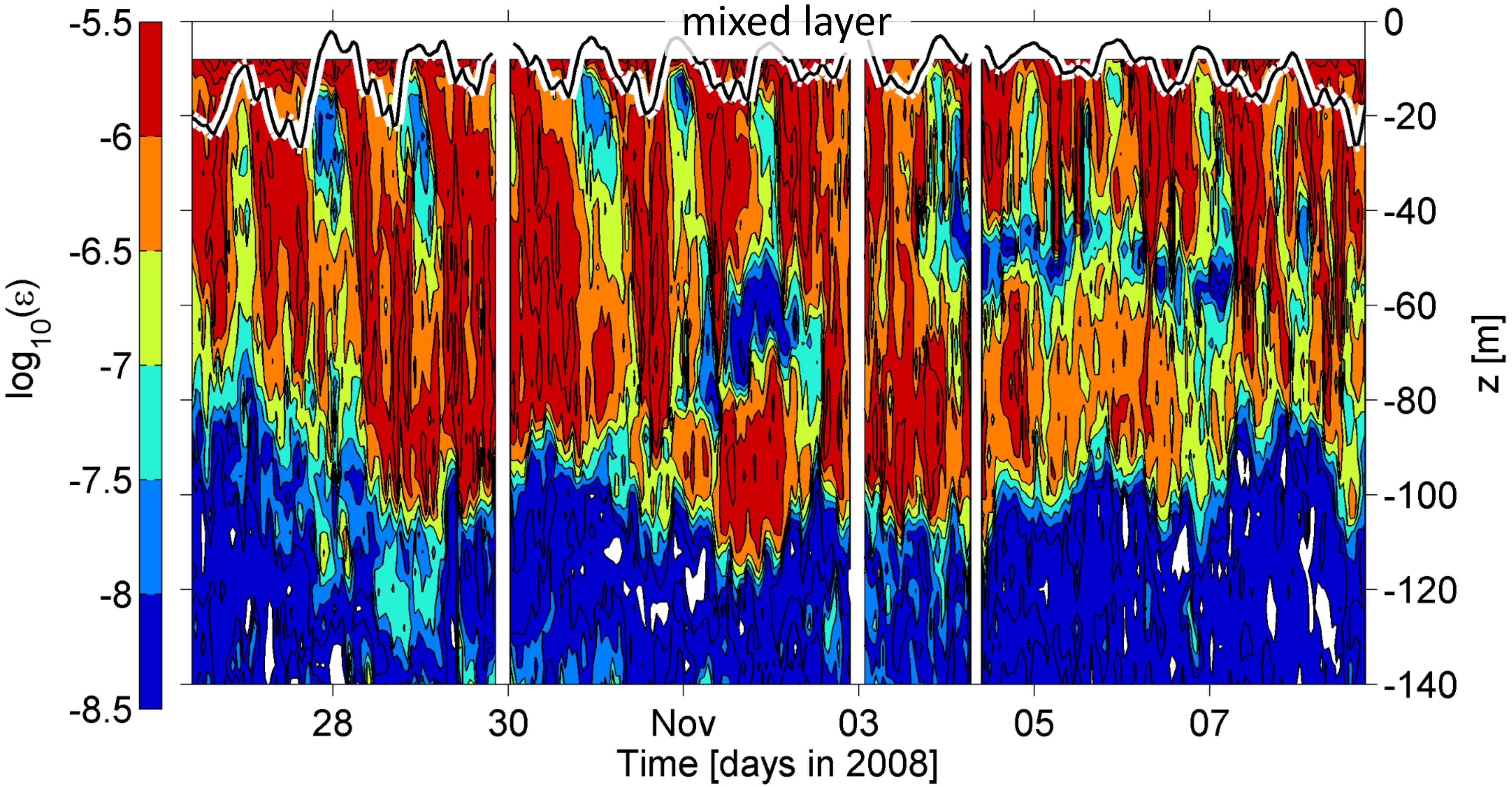
turbulence enhanced:

1. **at equator**
2. **below mixed layer**

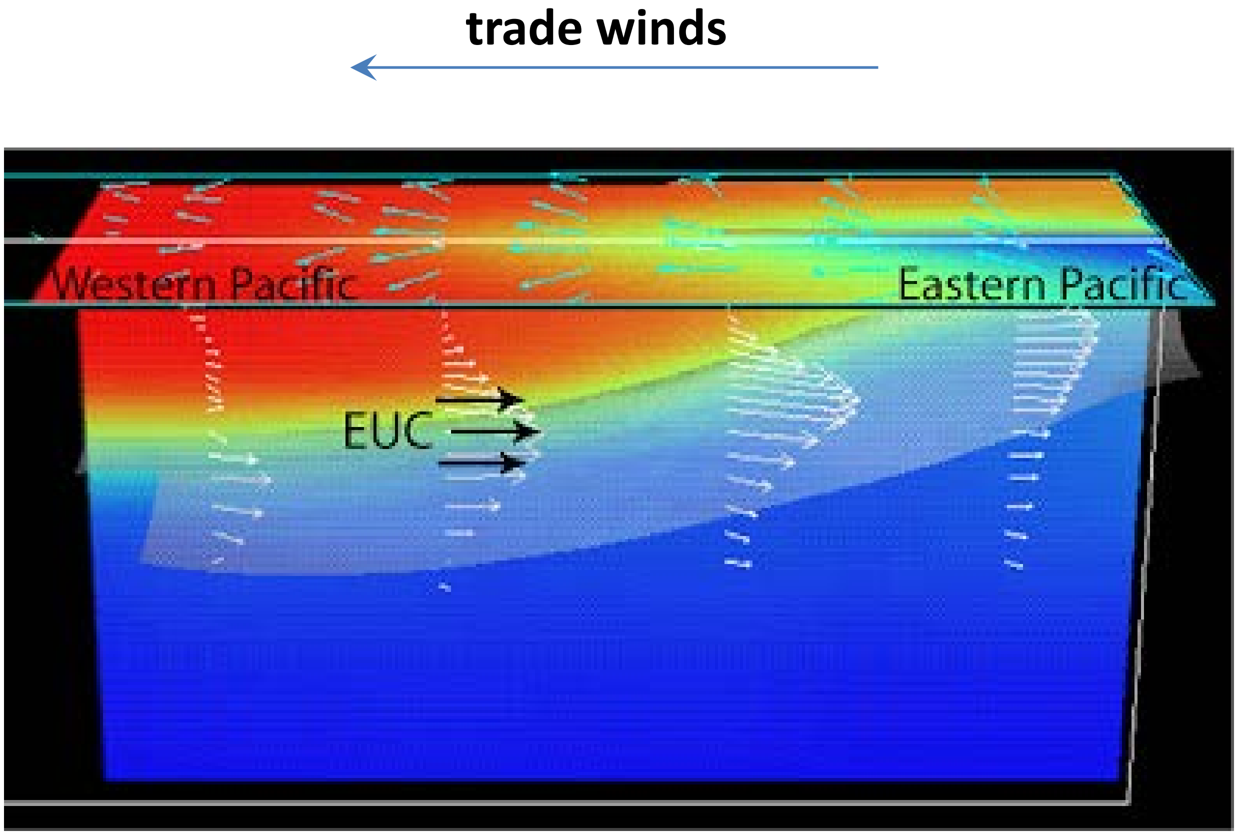
Hummels et al. (2013).

Diurnal variability

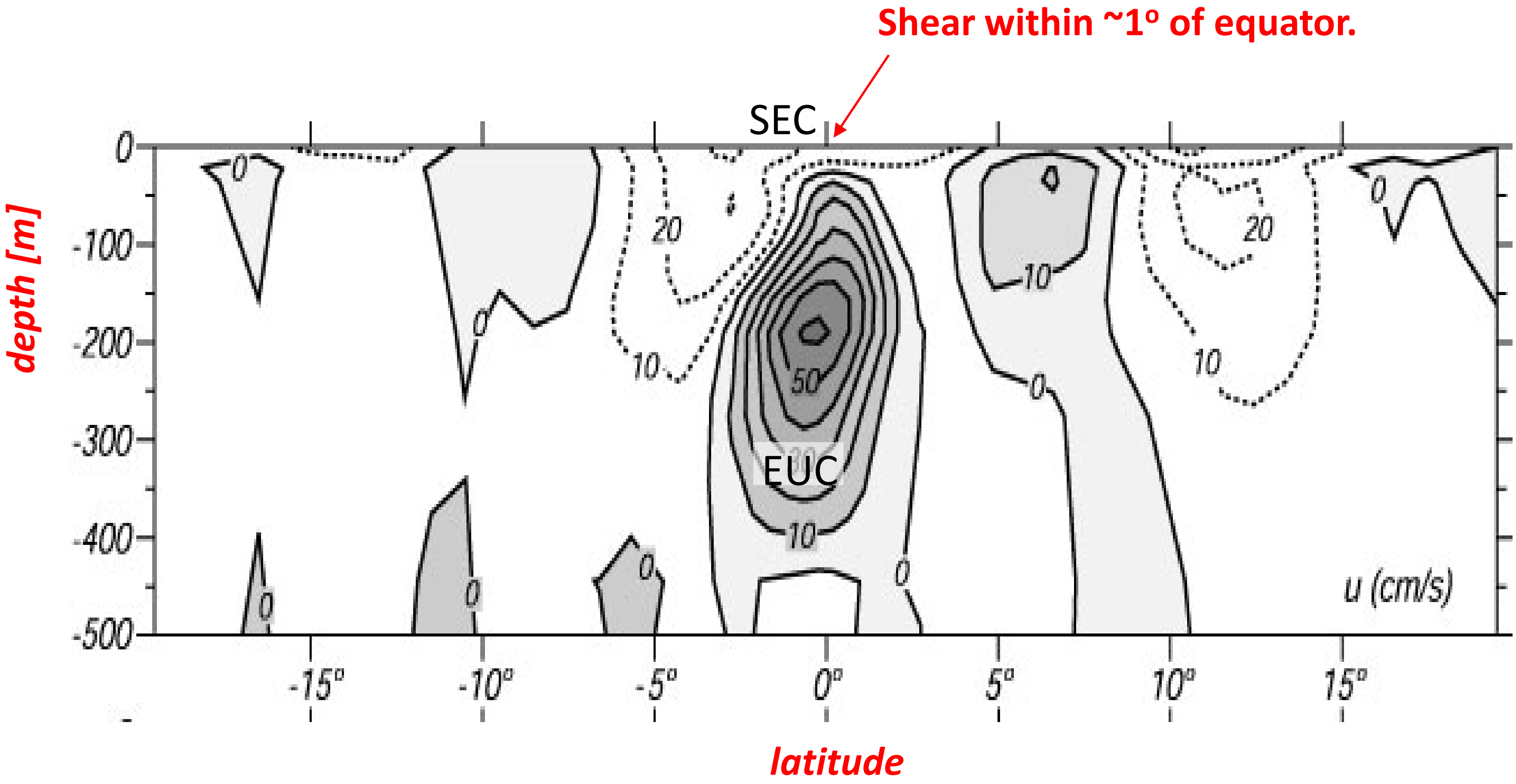
dissipation rate ε



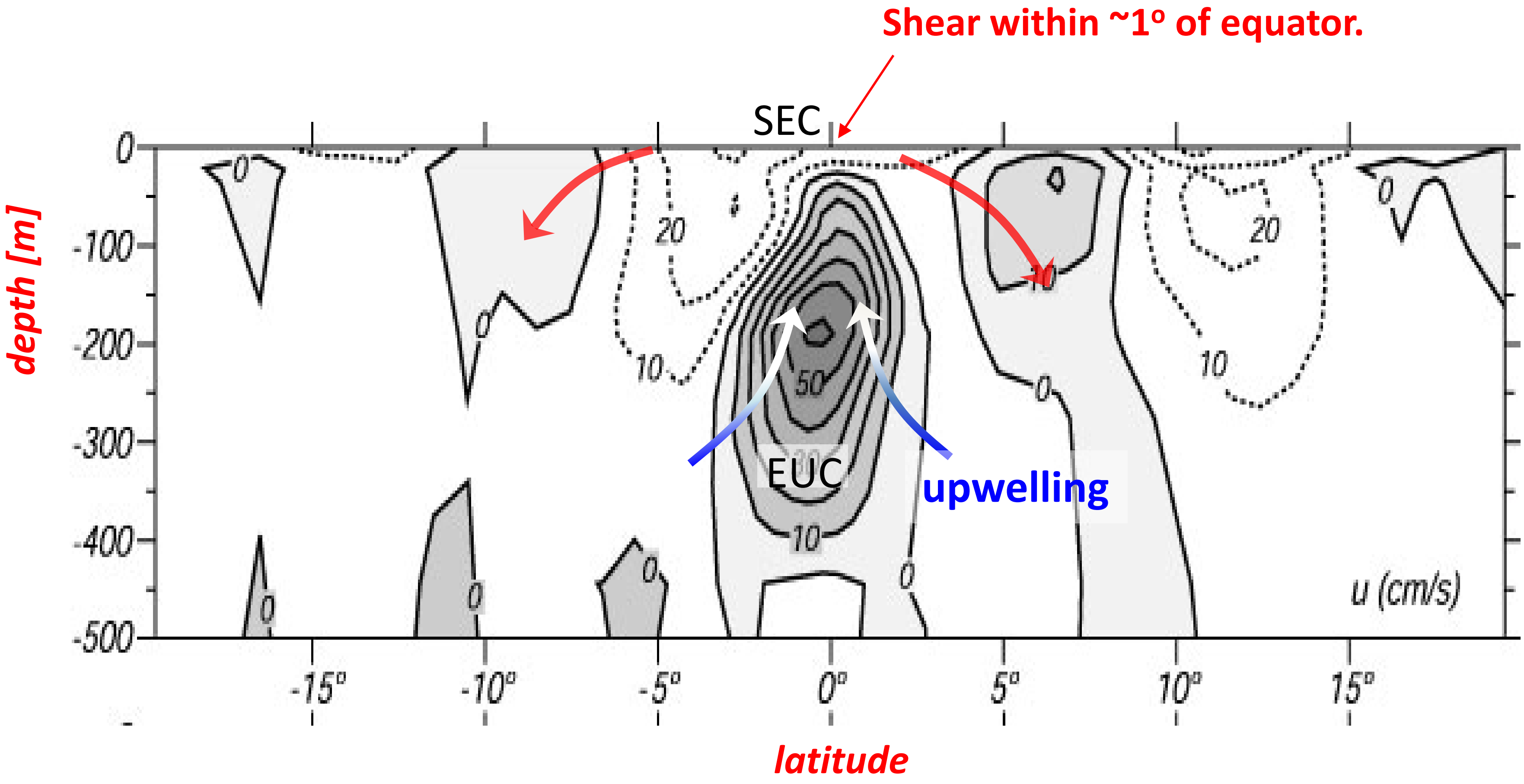
2) How does it work?



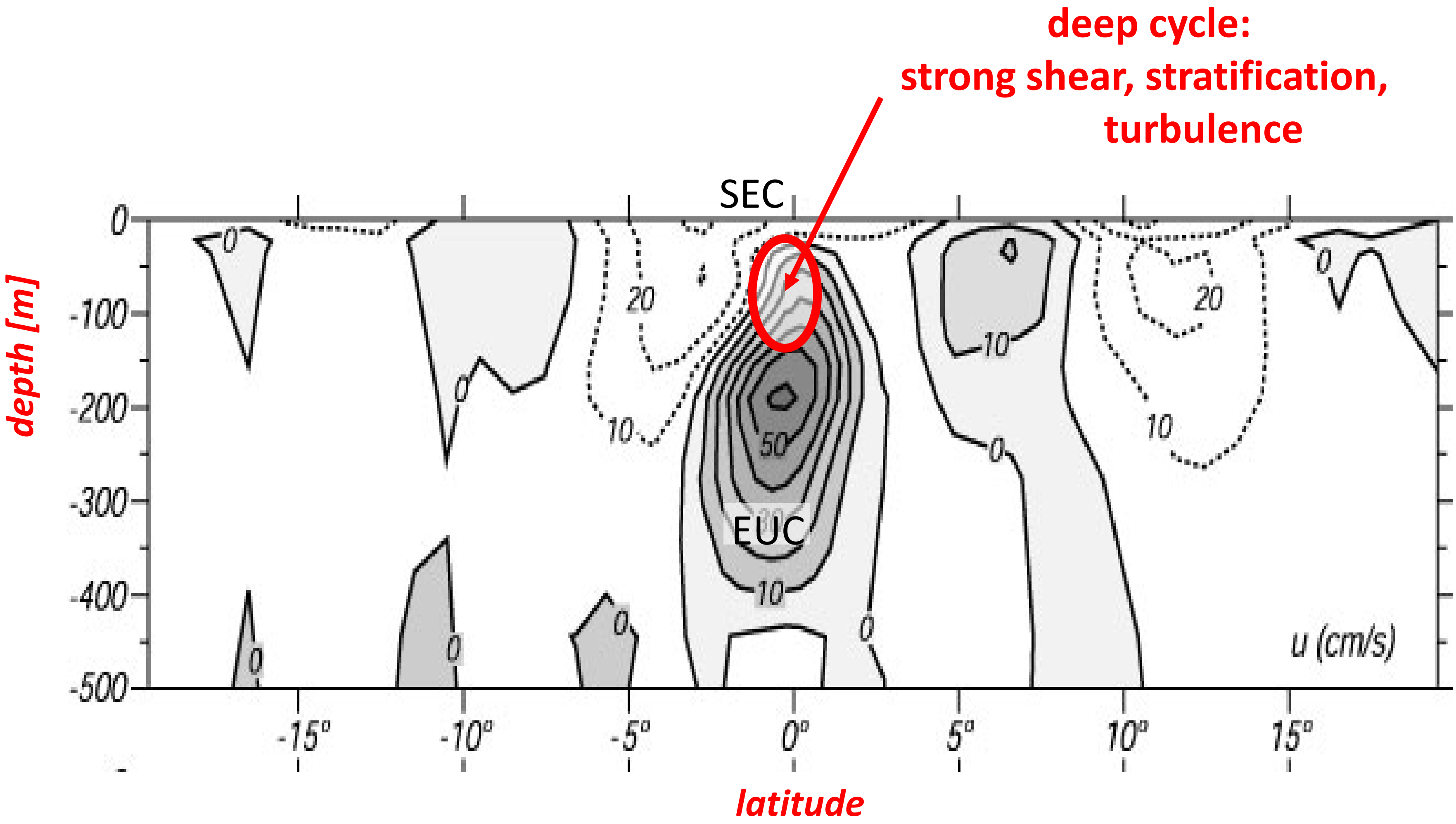
depth-latitude structure



depth-latitude structure

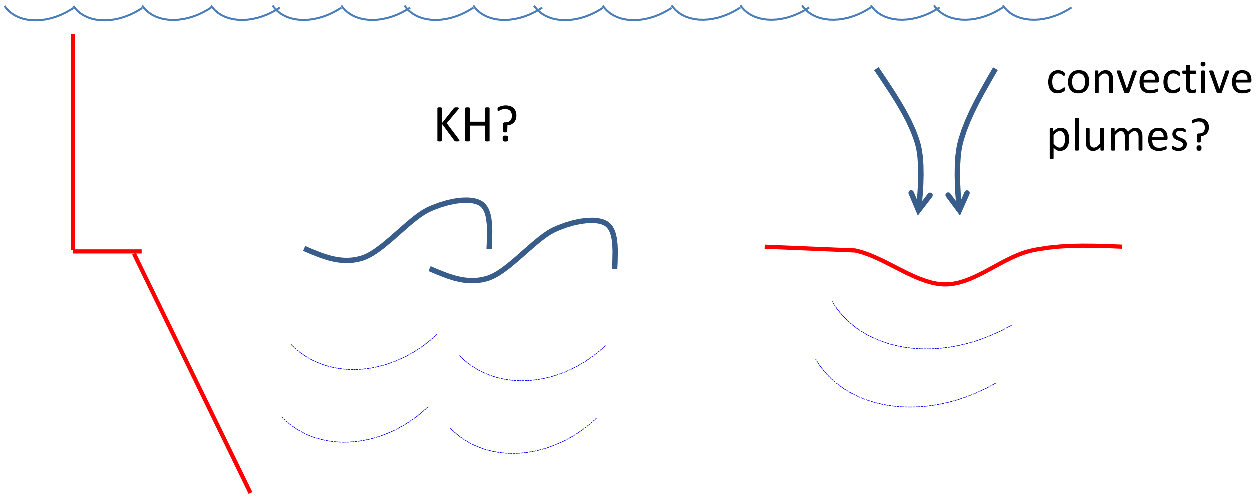


depth-latitude structure



Why is the deep cycle diurnal?

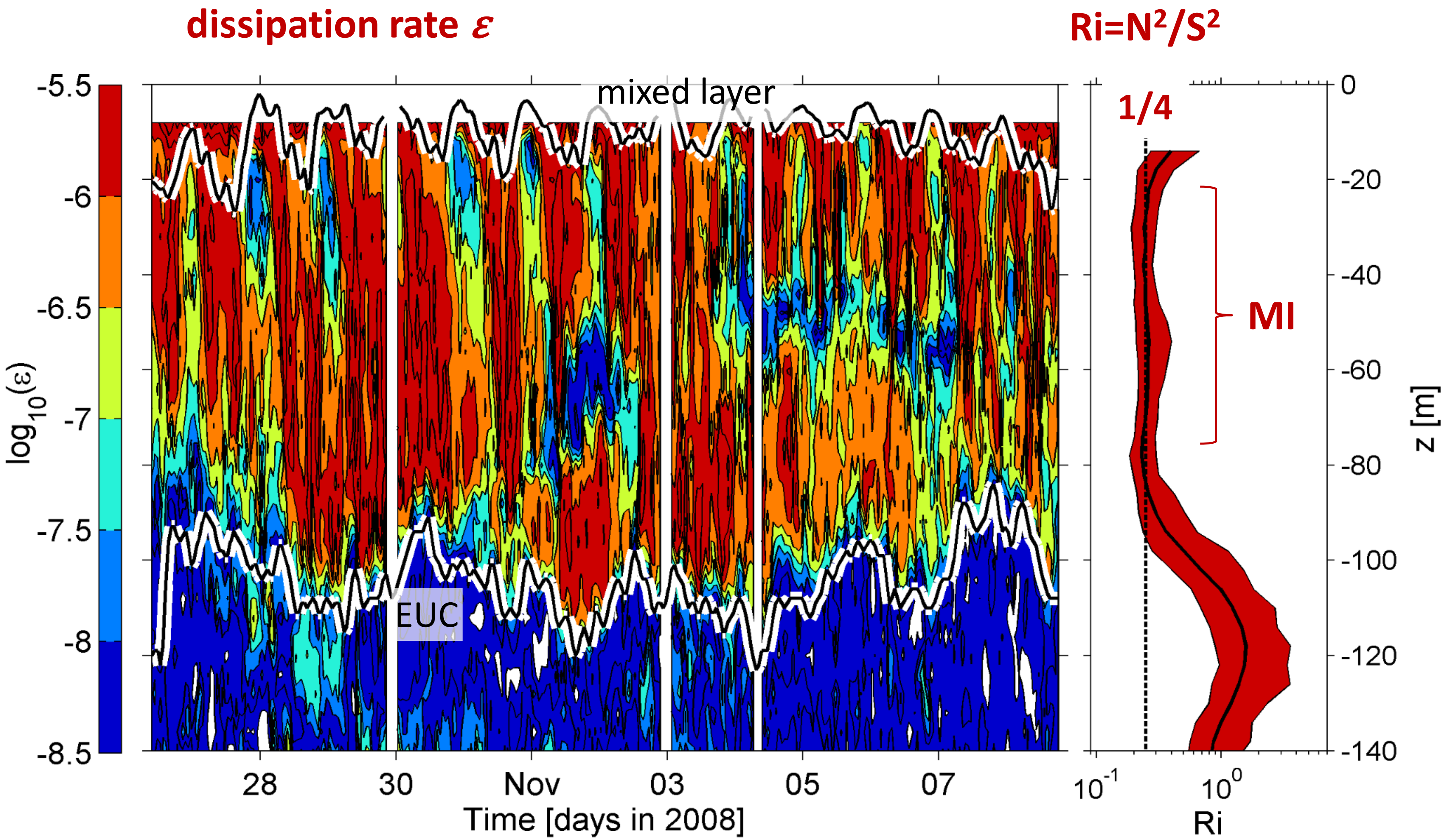
- Diurnal ⇒ surface forcing, e.g. heat flux.
- Need a transmission mechanism, e.g. **internal waves**



- Region below ML must be **unstable**
- But it **can’t be too** unstable because it’s calm during the day

⇒ marginal instability

Marginal instability



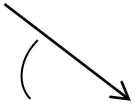
The sandpile analogy

(Bak et al. 1988)

Trade Winds ⇔ sand source

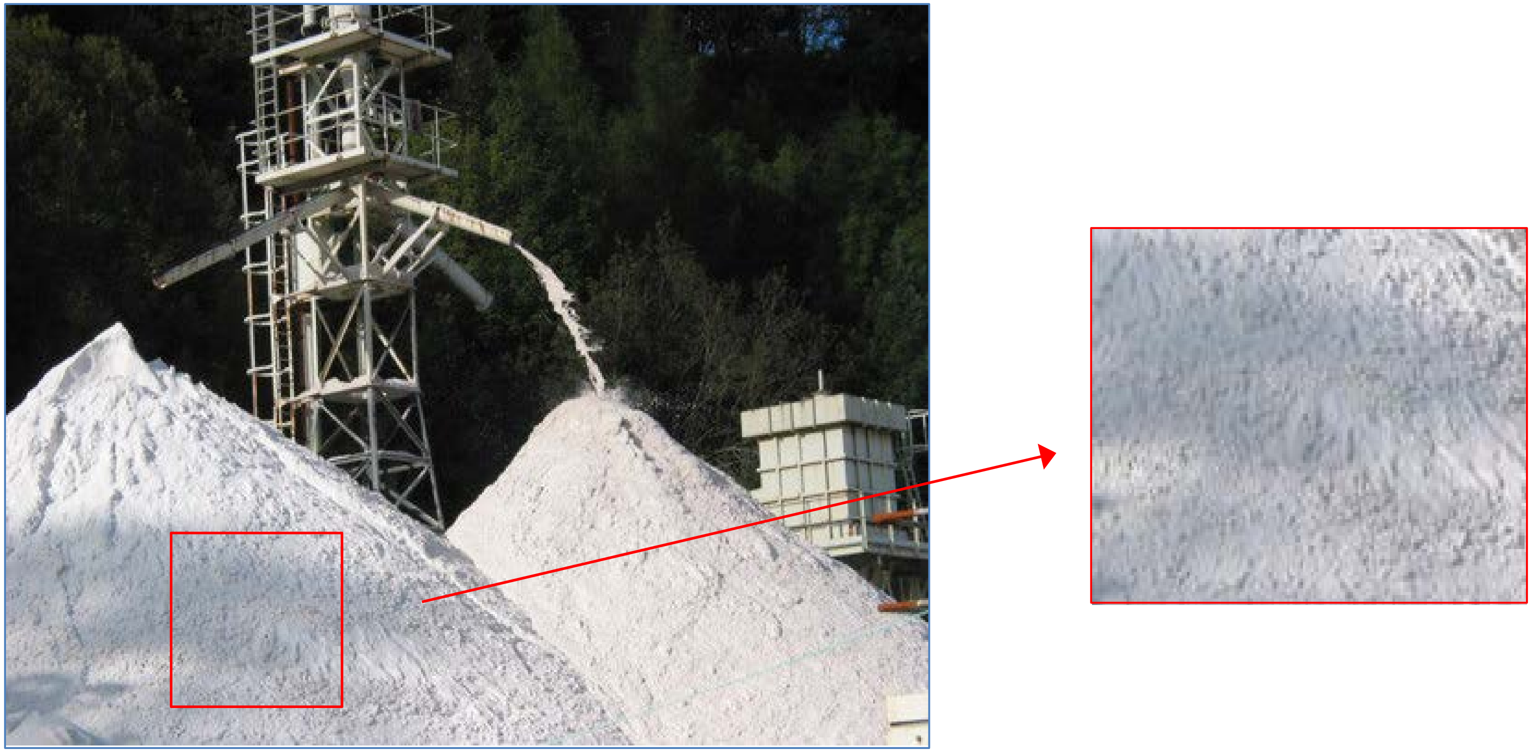
Turbulent eddies ⇔ avalanches

Ri=1/4 ⇔ angle of repose



The sandpile analogy

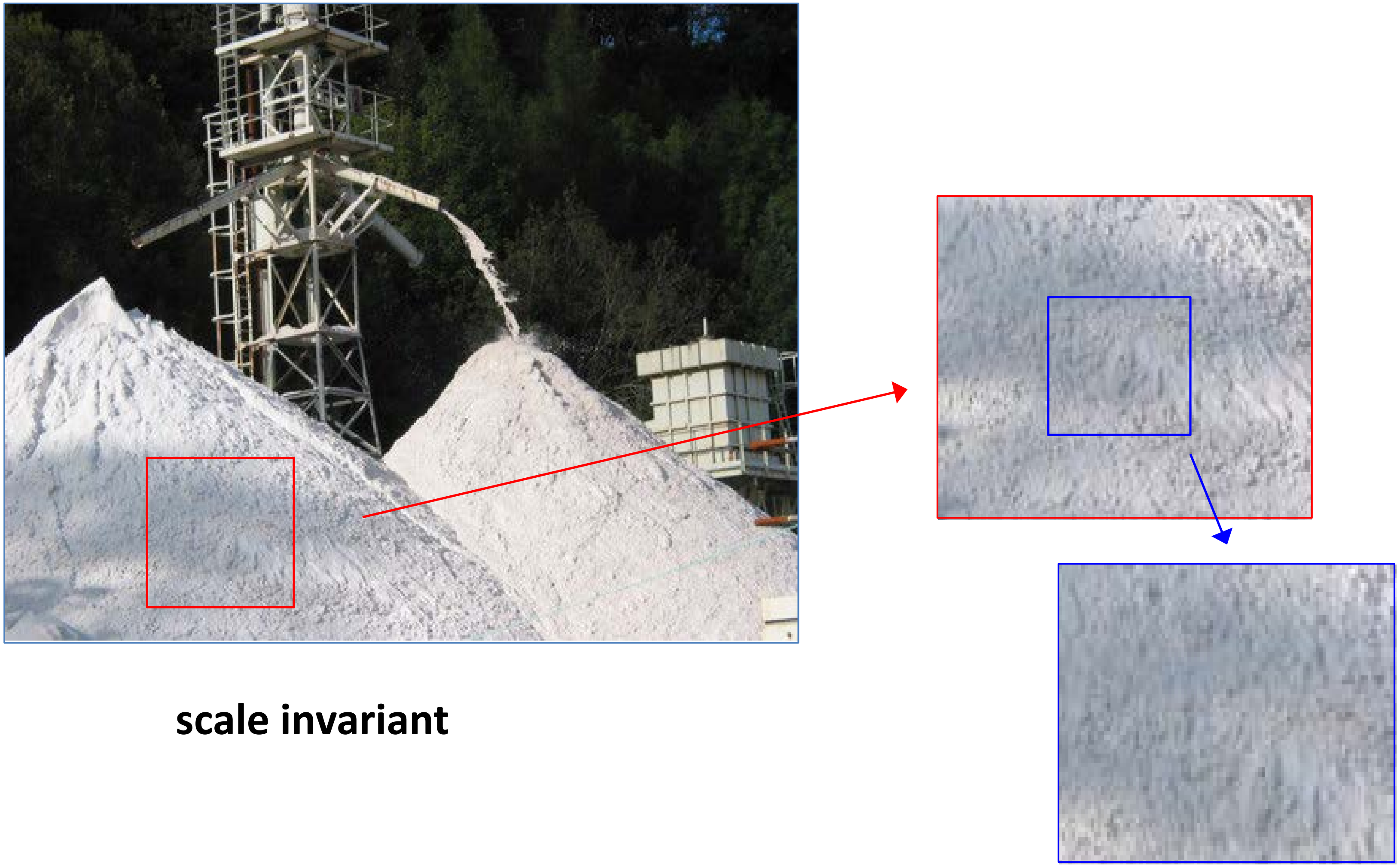
(Bak et al. 1988)



scale invariant

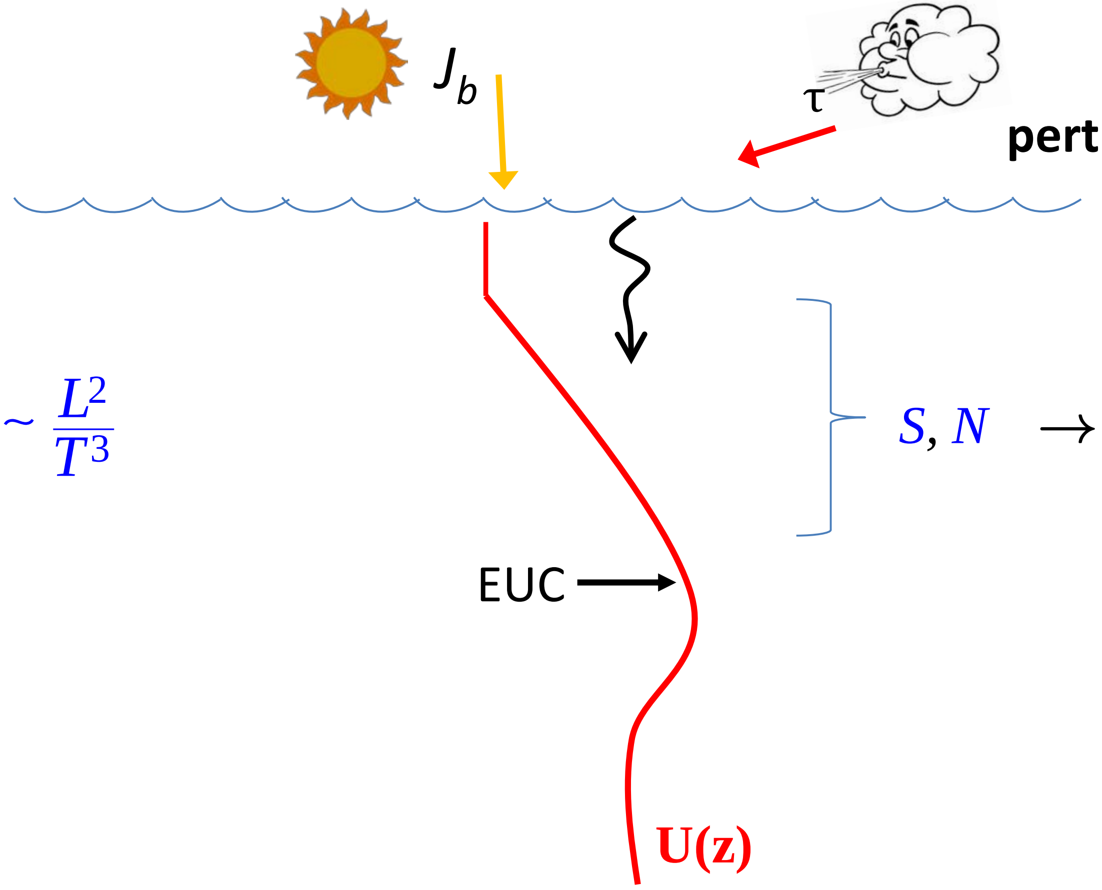
The sandpile analogy

(Bak et al. 1988)



scale invariant

3) Parameterizing the deep cycle

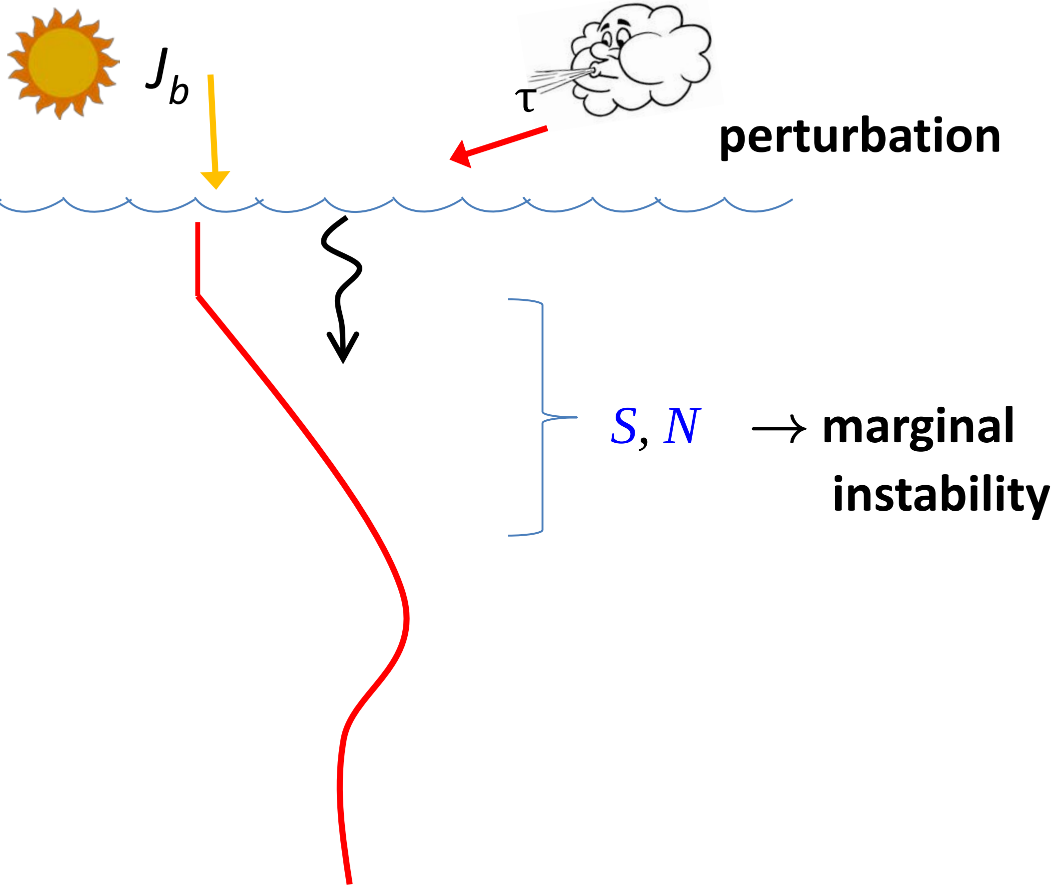


perturbation

$\varepsilon \sim \frac{L^2}{T^3}$

S, N $\rightarrow$ **marginal instability**

3) Parameterizing the deep cycle



$$\varepsilon \sim \frac{L^2}{T^3}$$

Deep cycle layer:

1. time scale $T = S^{-1}$ or N^{-1}.

2. length scale $L = ?$

Marginally unstable layer has no preferred length scale.

HYPOTHESIS: The length scale is set by the perturbation.

Parameterizing the deep cycle

1. time scale = S^{-1}.

2. length scale $= D \sim u_*^3 / \overline{J_b}$

friction velocity $u_* = \sqrt{\tau/\rho}$

daily mean buoyancy flux

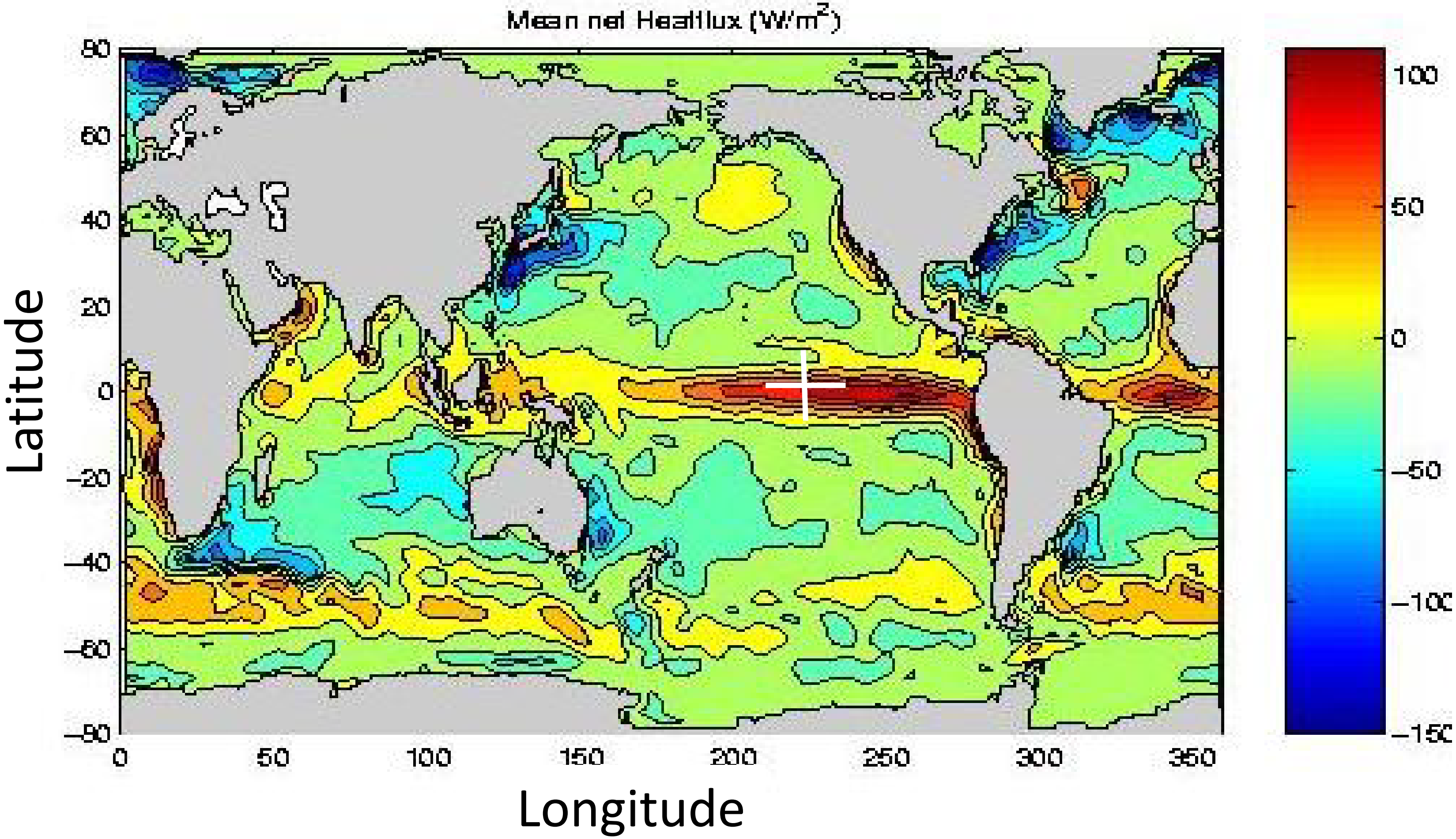
3. Dimensional analysis
Parameters: S, N, D

$$\Rightarrow \quad \varepsilon = D^2 S^3 f(Ri) \equiv \varepsilon_{scale} \, f(Ri)$$

4. Generalize for wind direction:

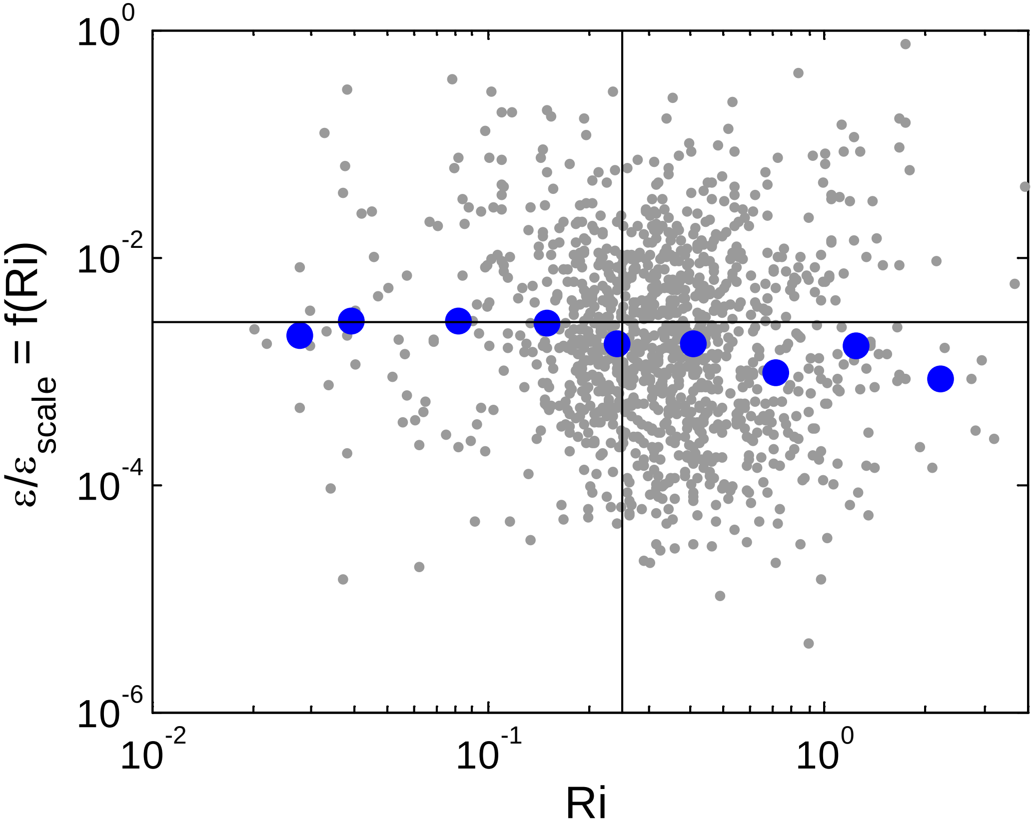
$$\varepsilon_{scale} = \left(\frac{\vec{\tau}}{\rho} \bullet \vec{S} \right)^3 \frac{1}{J_b^2}$$

Calibrating f(Ri)
χpod deployment at 0N, 140W, 2005-2011



f(Ri)=constant.

Scaling applied to 1800 daily averages of S, N, D averaged over -75m < z < -45m.

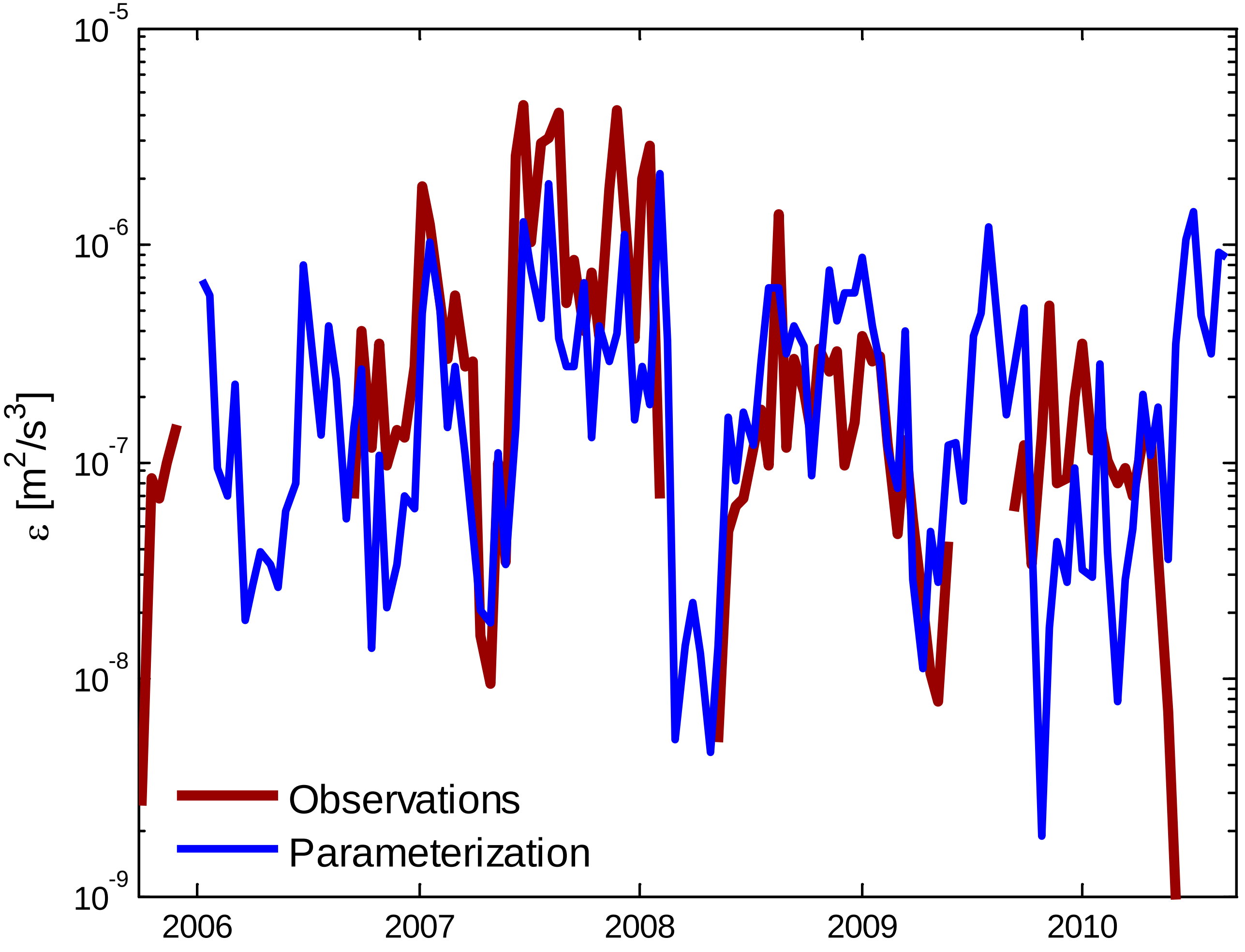


Least-squares fit to
$\varepsilon = \varepsilon_{scale} \times f$

$$f = \frac{<\varepsilon\, \varepsilon_{scale}>}{<\varepsilon_{scale}{}^{2}>} = 2.7\times10^{-3}.$$

$$\Rightarrow \quad \varepsilon = 2.7\times10^{-3}\left(\frac{\vec{\tau}}{\rho}\bullet\vec{S}\right)^{3}\frac{1}{J_b^2}$$

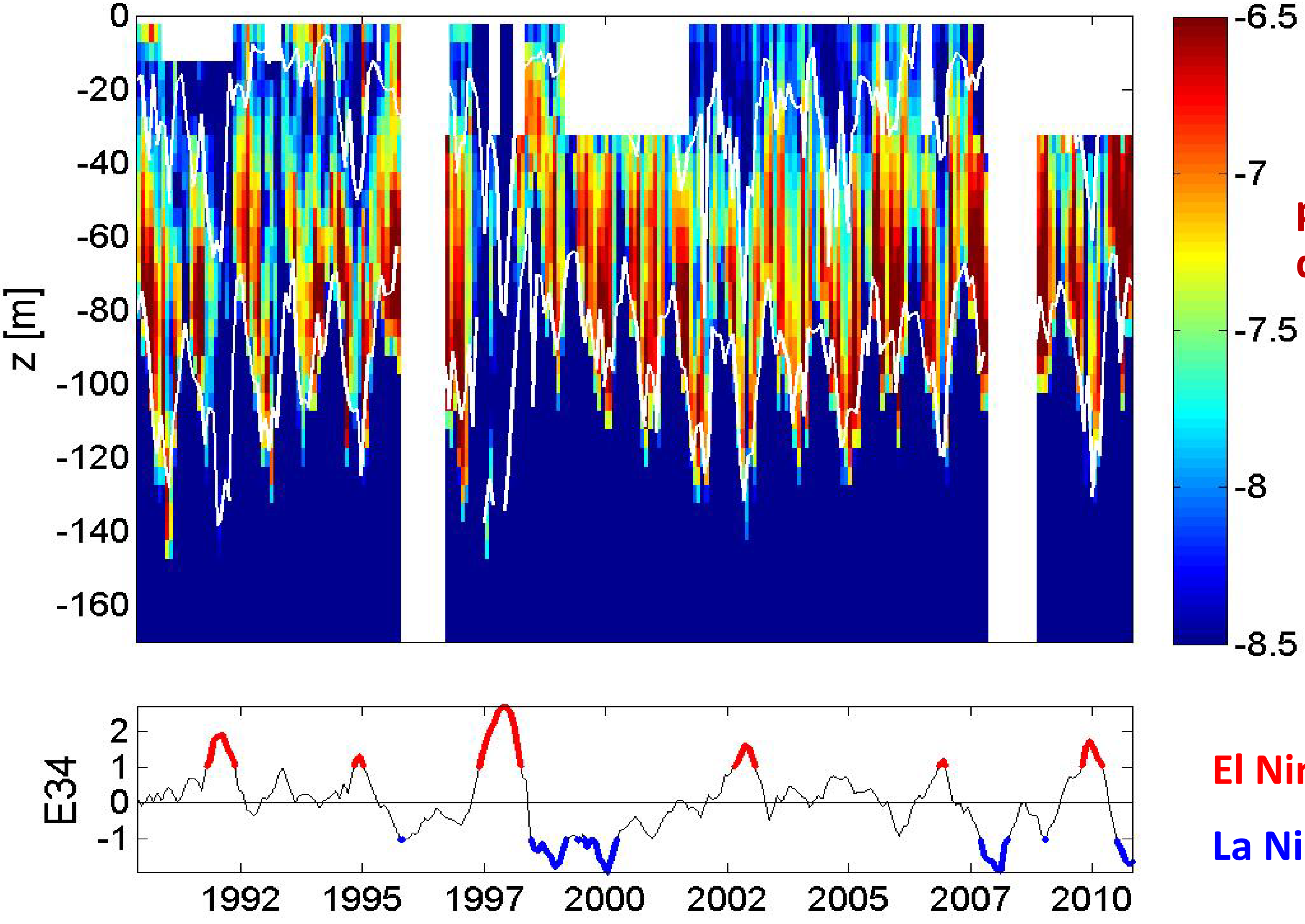
Compare annual cycle



45-75m
Monthly average
is plotted.

4) TAO mooring at 0N 140W, 1990-2010

daily-averaged surface fluxes, currents, stratification ⇒ dissipation

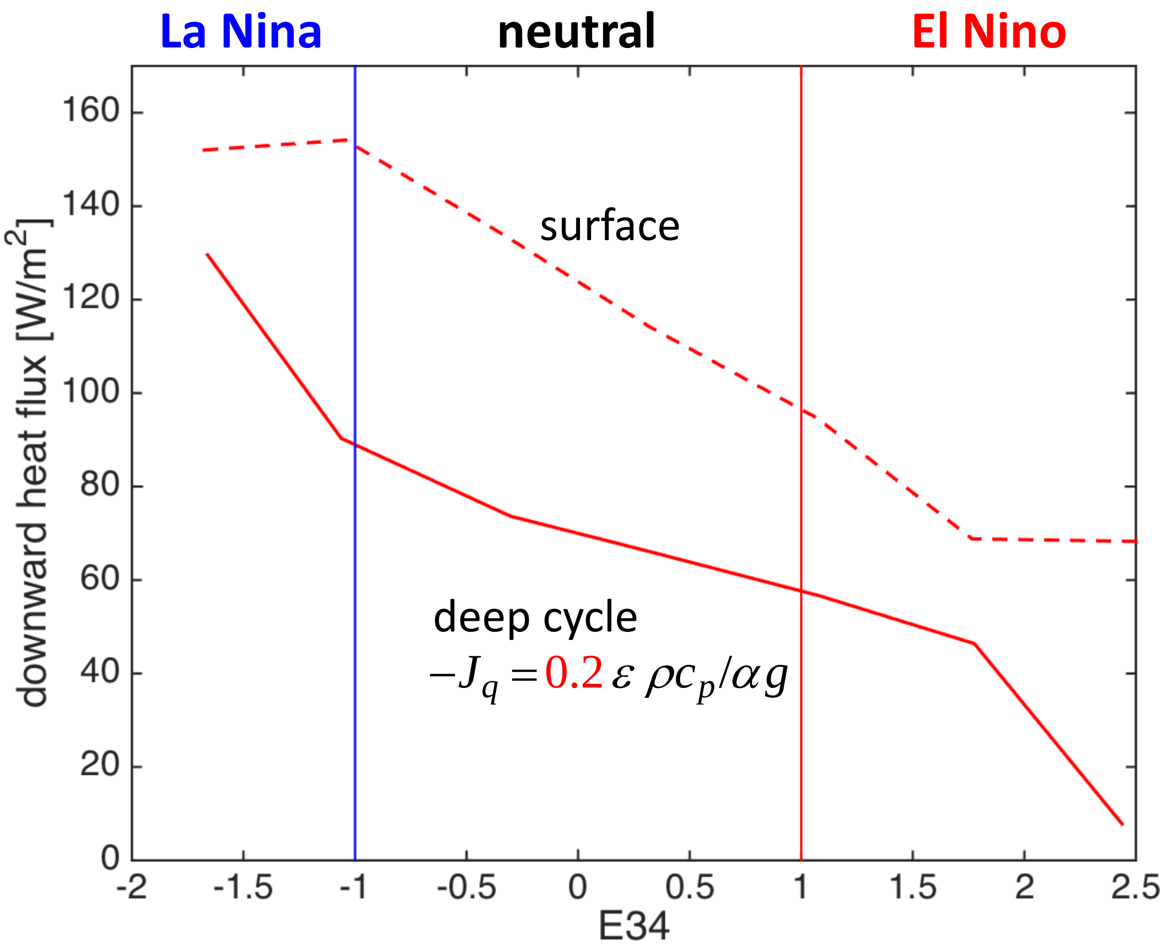


parameterized dissipation rate

El Nino

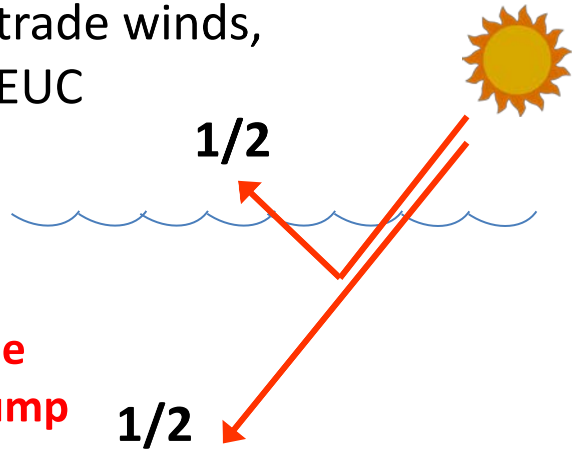
La Nina

Heat flux vs. ENSO



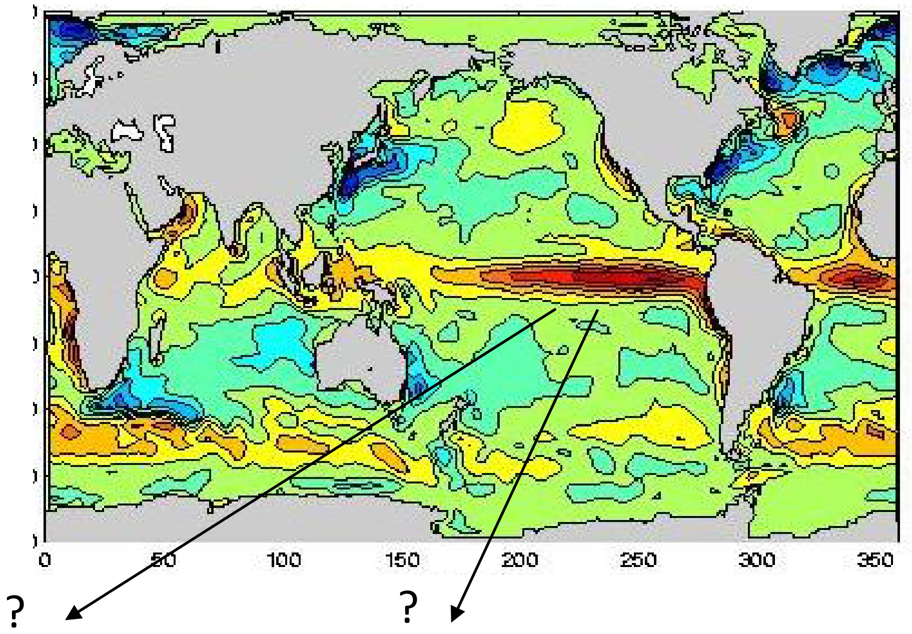
high SST,
clouds

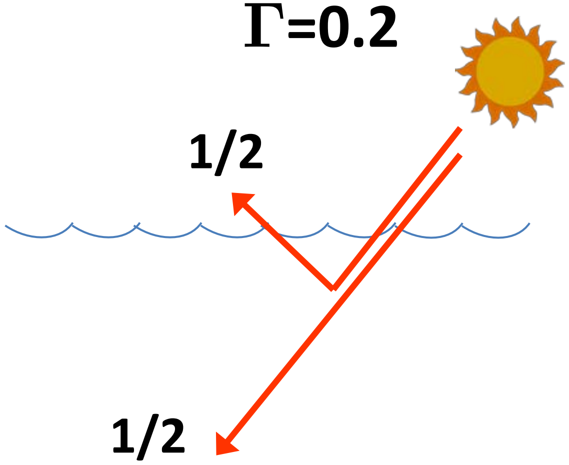
no trade winds,
no EUC



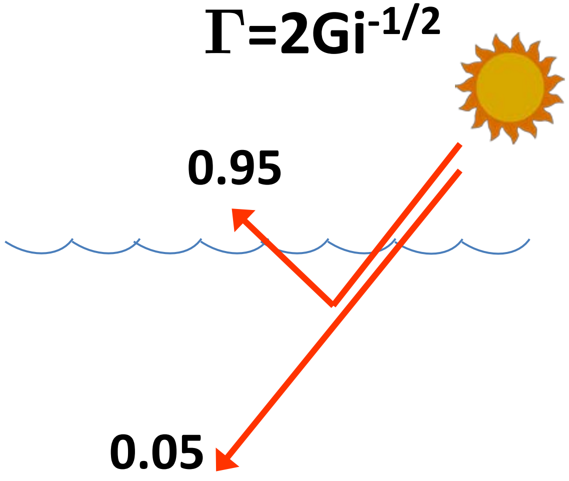
deep cycle
= heat pump

Effect of mixing efficiency





Γ=0.2



Γ=2Gi$^{-1/2}$

$$-J_q = {\color{red}0.2}\,\varepsilon\,\rho c_p/\alpha g$$

Conclusions

- Deep cycle turbulence depends on
  - marginal instability
  - perturbations
- $$\Rightarrow \varepsilon \approx 2.7\times10^{-3}\,\frac{1}{J_b^2}\left(\frac{\vec{\tau}}{\rho}\bullet\vec{S}\right)^3$$
- Deep cycle heat flux
  - carries ~1/2 of surface heat uptake (if Γ=0.2).
  - decreases during El Nino.

NEXT:

- Check Γ
- Account for other perturbations (e.g. IGW).

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TAO/TRITON mooring data: NOAA, JAMSTEC.