Cold tongue upwelling / mixing

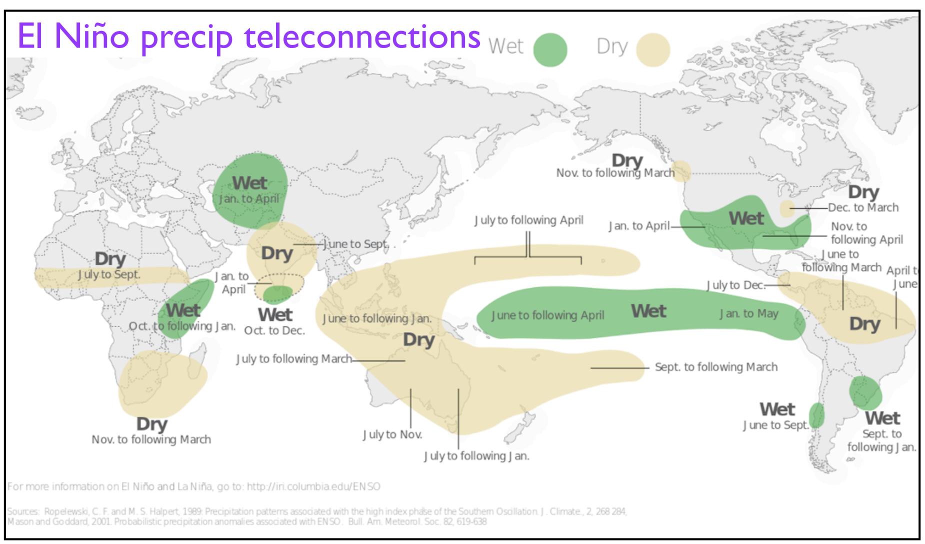
Coupled equatorial feedbacks engage the global climate.
The thermocline carries the essential ocean memory.
Upwelling/mixing enables surface-thermocline communication.

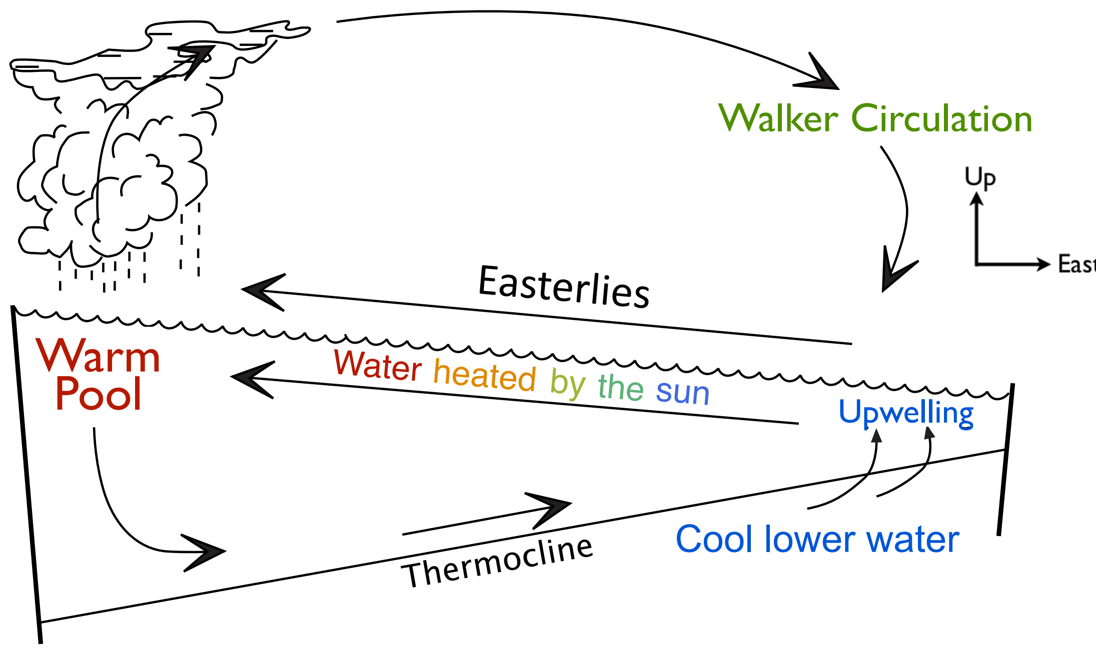
Remote consequences of these feedbacks are the main reason people outside the tropical Pacific care about what we do.

Upwelling controls property transports (BGC/nutrients/CO_2).

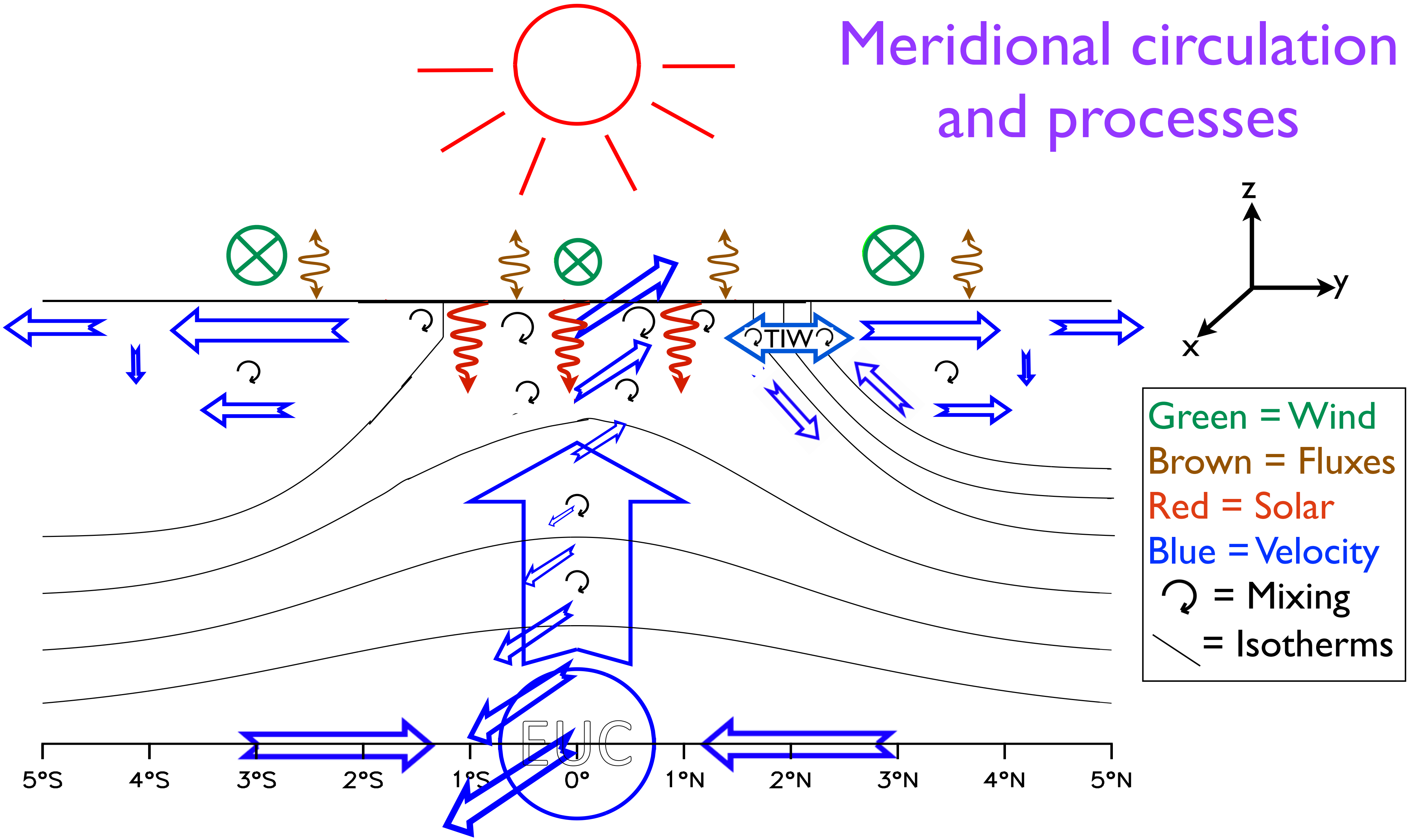
The vertical motion and exchanges produced by this circulation are now largely unconstrained by observations ...

We must get this right.





Meridional circulation and processes



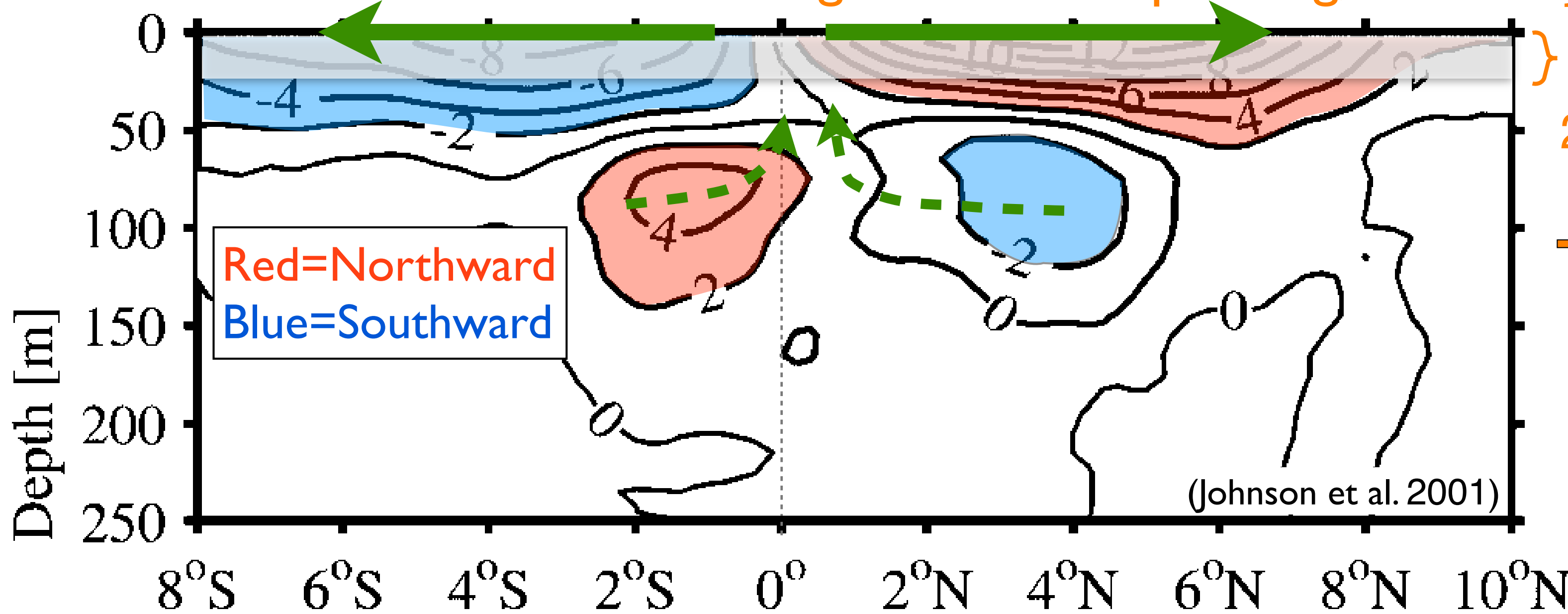
Upwelling is O(m/day) → vertical mixing must be very strong

Consider the modeling challenge ...

How well can we describe this circulation?

Observed v in the east-central Pacific: Two limitations

Near-surface Ekman divergence drives upwelling, but ...



Mean meridional current in the east-central Pacific

Shipboard ADCP over 170°W-95°W

10-year average

(8400km)

Limitations:

1) Ship ADCP does not see upper 25m

2) TIW fluctuations

Need near-surface currents to describe the structure of the divergence.

(Scatterometer winds also need referencing over strong currents.)

Modern model zonal circulations (u)

The (observationally-constrained) EUC profiles are reasonable, but its shear $\partial u / \partial y$ is too weak.

➔ We have no constraints off the equator (except space-time mean) ... models vary widely.

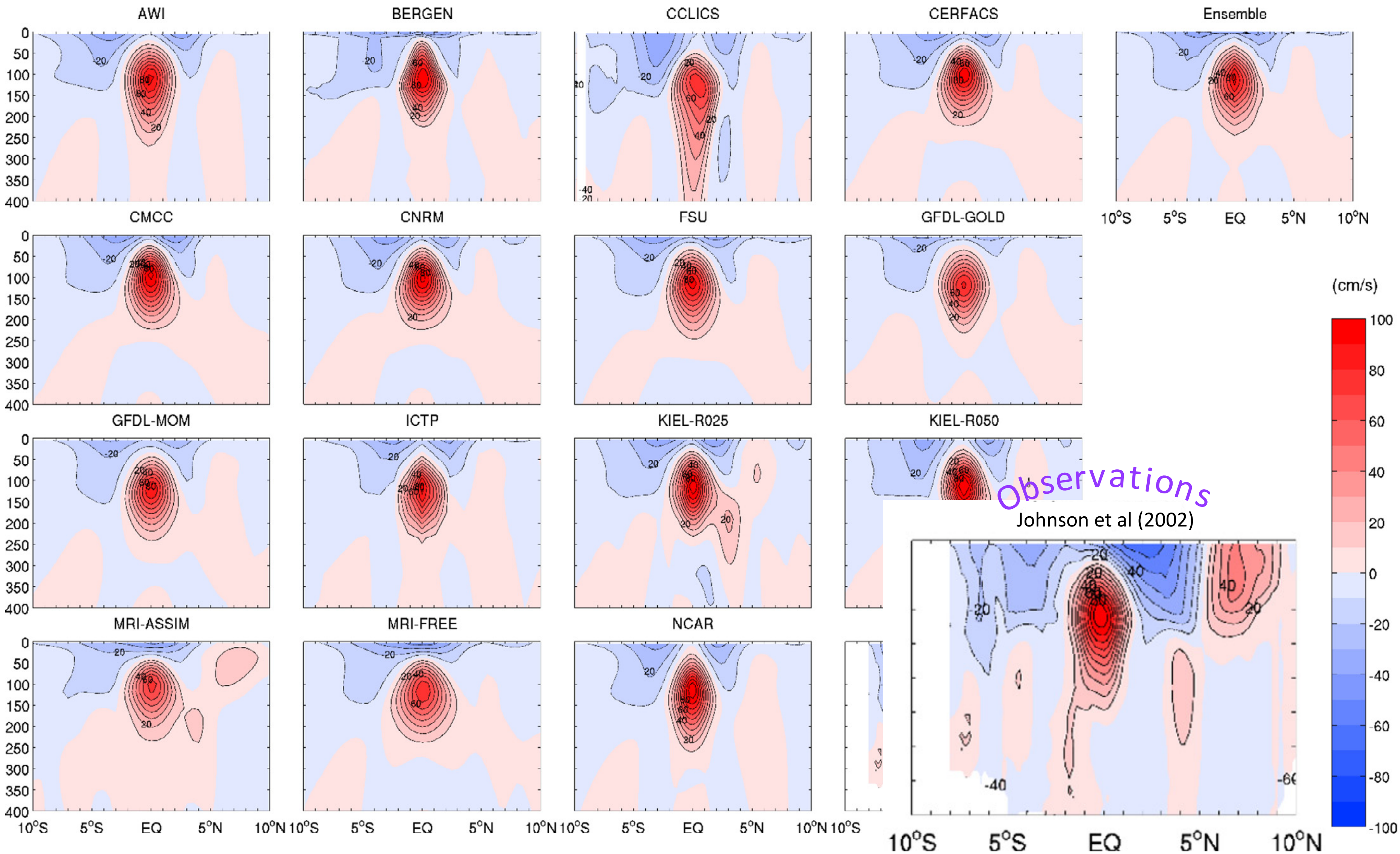


Fig. 19. Mean zonal velocity in the central topical Pacific on a meridional section (140°W) from 1986 to 2000.

(CORE-II hindcast simulations. Tseng et al. 2016)

Modern model meridional circulations

u(eq,z) very similar:
TAO equatorial current profiles "taught" models to get this right.

But:
v, w and *T(y,z)* quite different, especially near the surface:
Large implications for air-sea interaction.

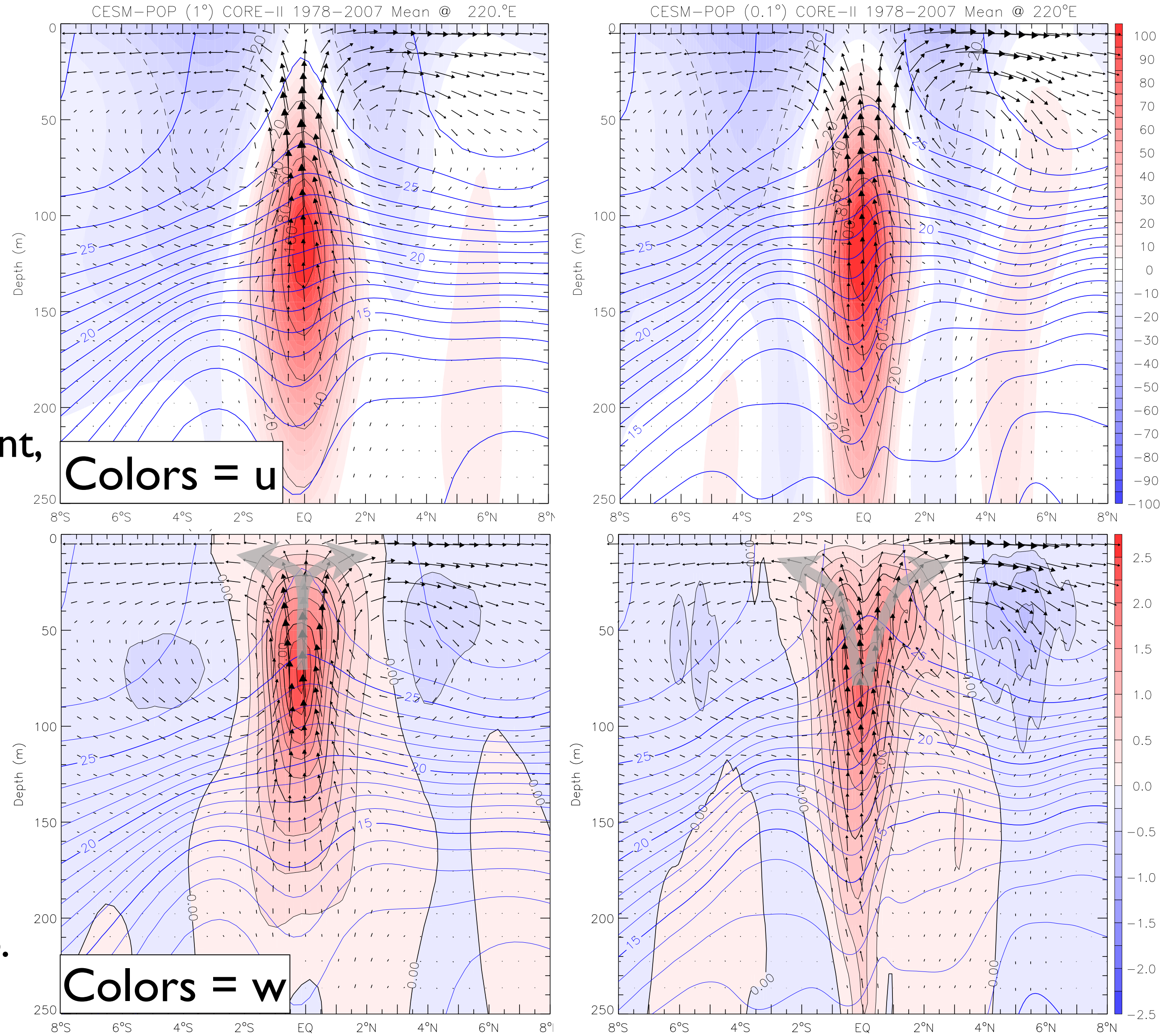
Vertical-meridional circulation unconstrained by observations.

Short meridional scales (shear and properties) unsampled by TAO or Argo.

CESM-POP with different horizontal resolutions (mean)

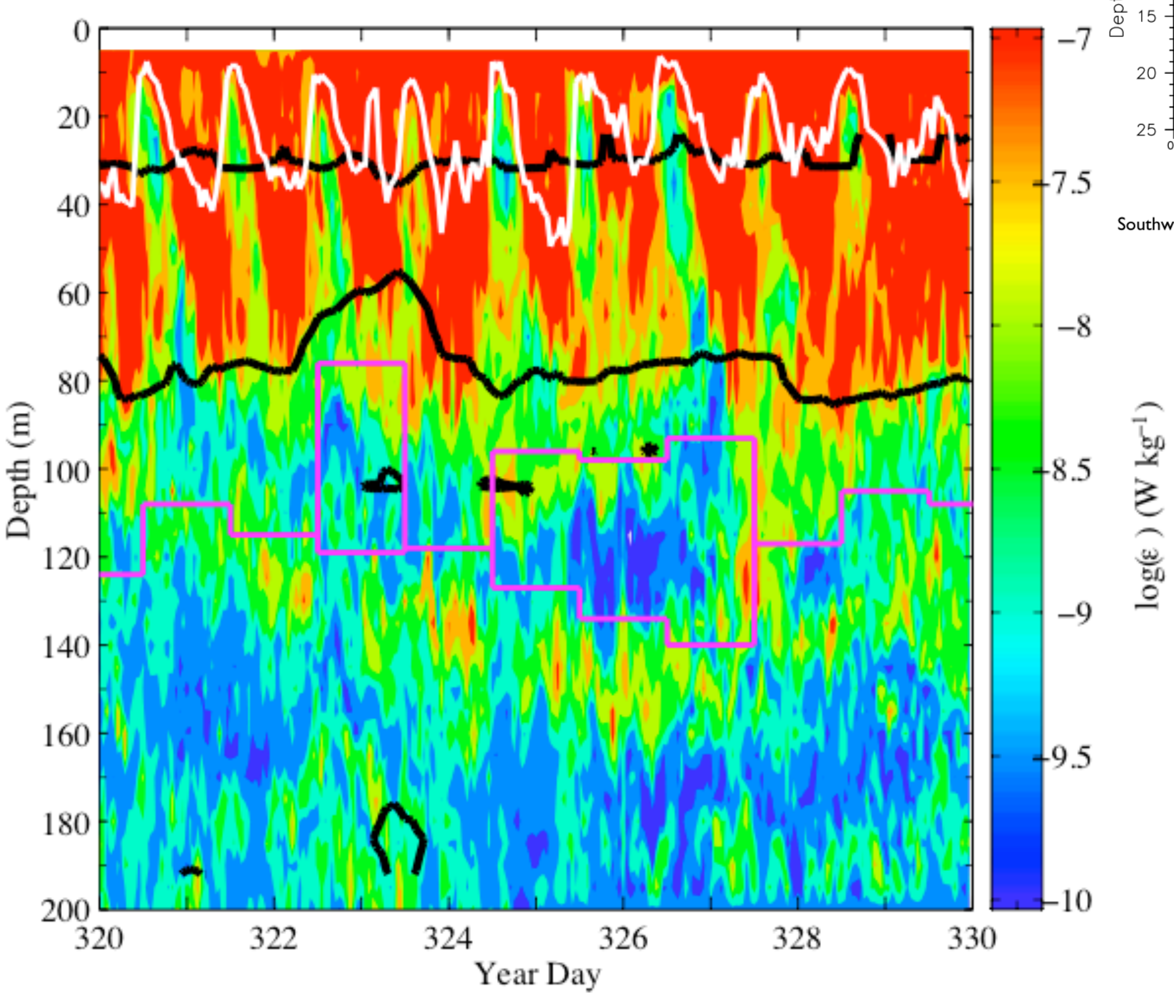
1-degree

1/10-degree



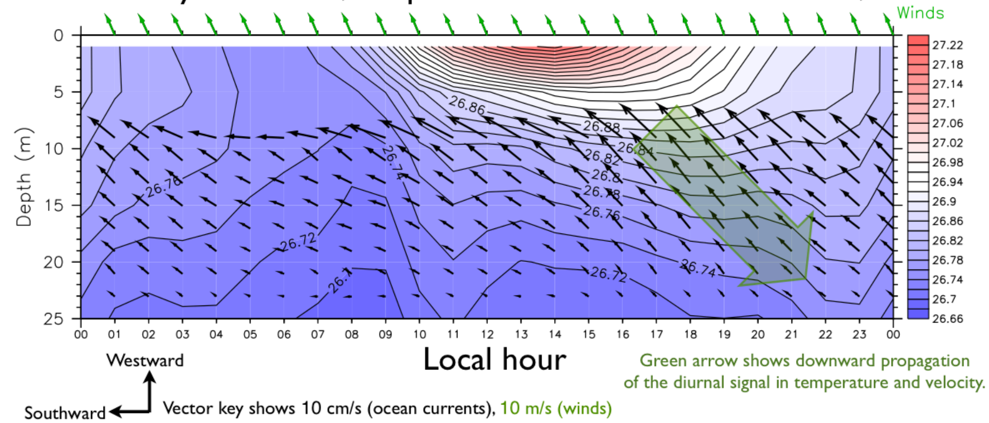
(Frank Bryan: CORE-II forcing, 30-year means)

Downward mixing on the equator



Dissipation rate during 10 days of TIWE

(Lien and D'Asaro)



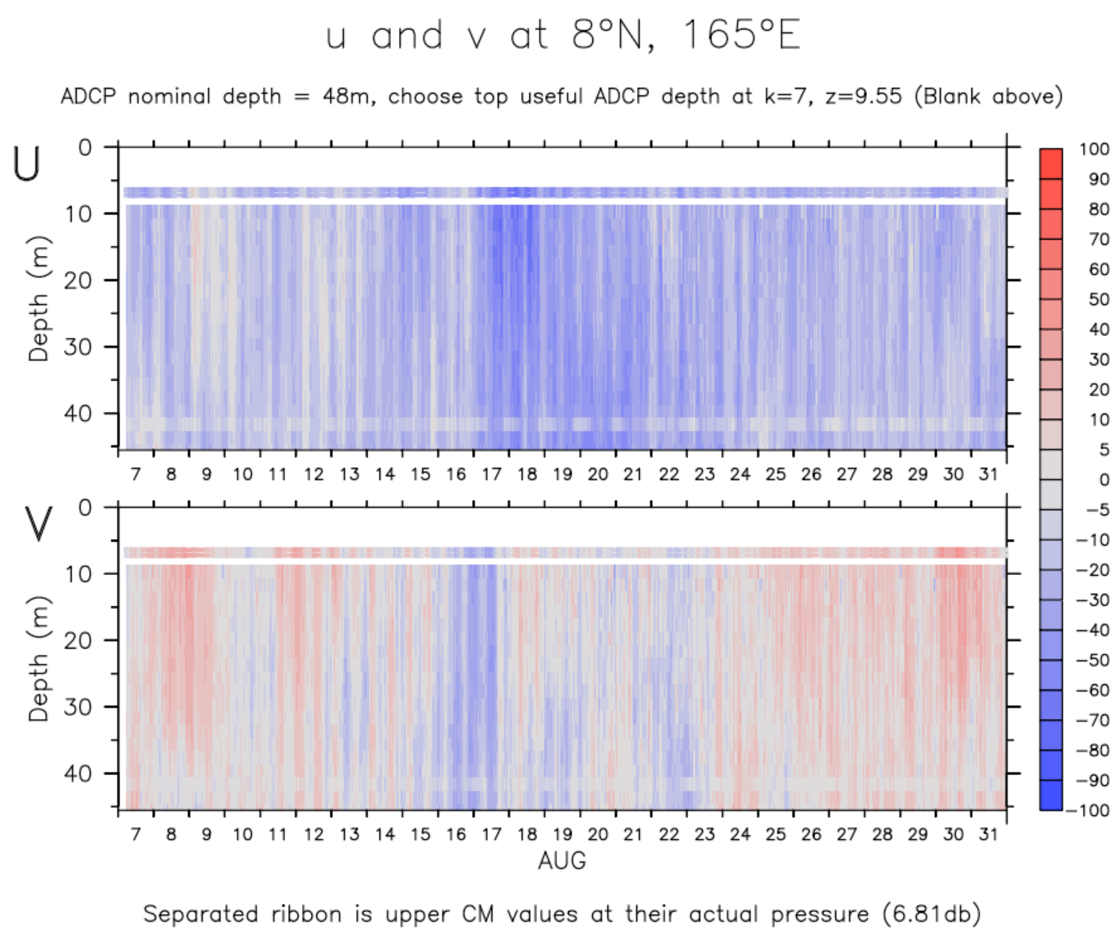
(OOMD/TPOS mooring-enhancement pilot. Realtime data!)
(Kessler/Cronin/Grissom 2017)

Diurnal turbulence extends downward into the upper EUC.

Surface-thermocline transmission of
heat and momentum.

But ship-based experiments are necessarily sparse and short-lived.
They cannot describe
the time evolution.

New capabilities enable sampling mixing and shallow velocity



(Kessler, Grissom, Cronin Enhanced realtime TAO)
(OOMD-funded TPOS pilot)

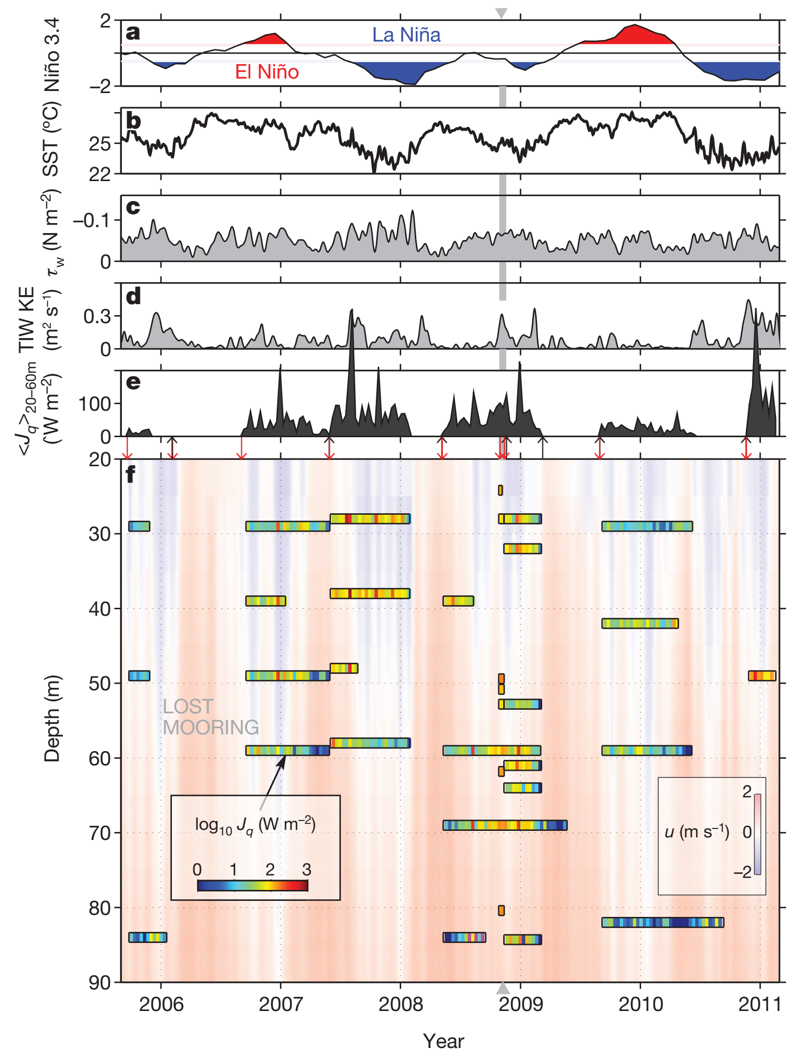
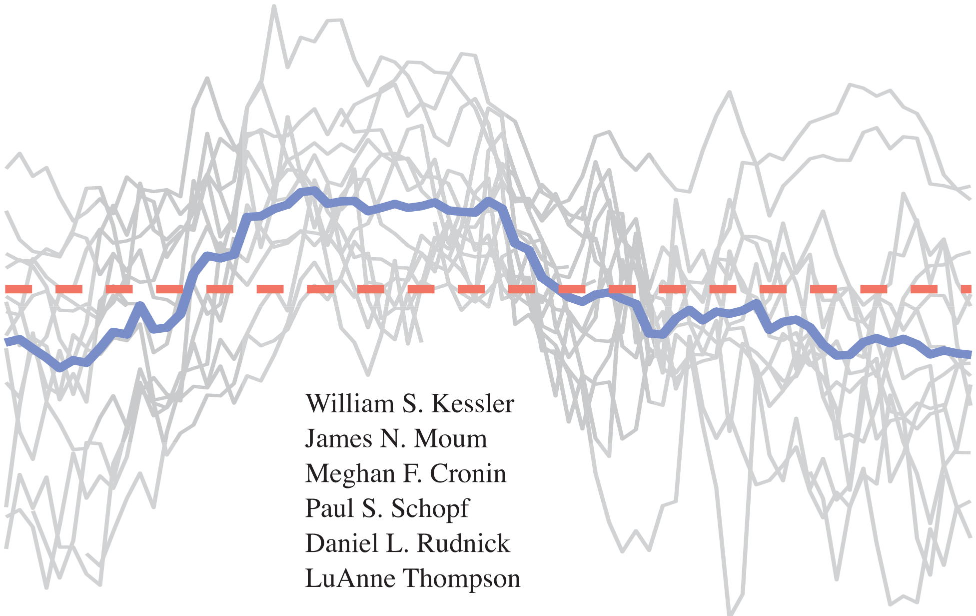


Figure 1 | Six-year record of mixing at the TAO mooring at 0, 140° W. **a**, Niño3.4 SST index, a measure of the relative strengths of El Niño and La Niña events[28]. **b**, SST. **c**, Wind stress, τ_w (7-day averages). **d**, Squared meridional velocity at 40 m filtered at 12–33 days, taken as a proxy for kinetic energy in the tropical instability wave frequency band (TIW KE). **e**, Turbulent heat flux averaged over depths 20–60 m, $<J_q>_{20\text{-}60m}$. **f**, Image plot of zonal currents (zonal velocity denoted u, eastward currents red, westward blue; see right inset colour scale). Coloured bars show depths and durations of χ-pod deployments; $\log_{10} J_q$ is indicated by the colour (10-day average, see left inset colour scale). Arrows at top of **f** show deployments (red) and recoveries (black) of moorings. Grey bars show period of comparison experiment with shipboard turbulence profiling instrumentation[12,19].

(Moum et al 2013)

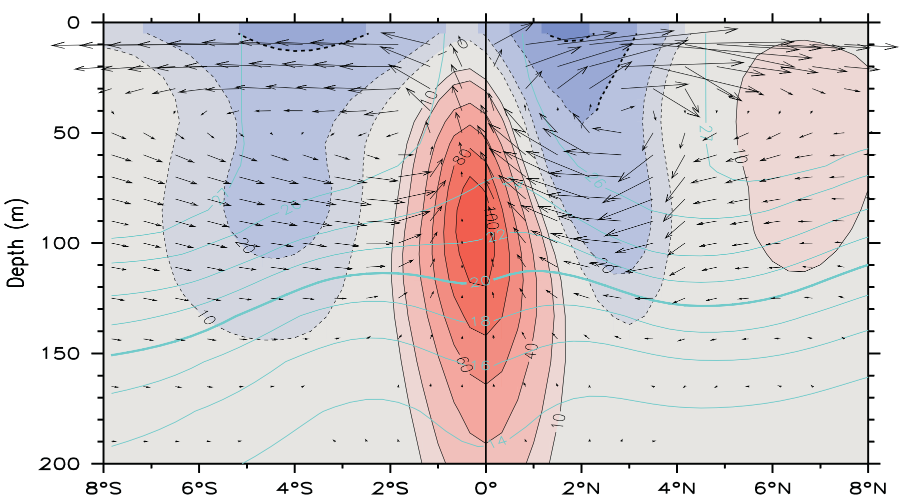
Pacific Upwelling and Mixing Physics

A Science and Implementation Plan



William S. Kessler
James N. Moum
Meghan F. Cronin
Paul S. Schopf
Daniel L. Rudnick
LuAnne Thompson

Revised January 2005



PUMP was too expensive in its day,
and our capabilities too weak,
but new technology makes it tractable now.

The primary objectives of PUMP are:

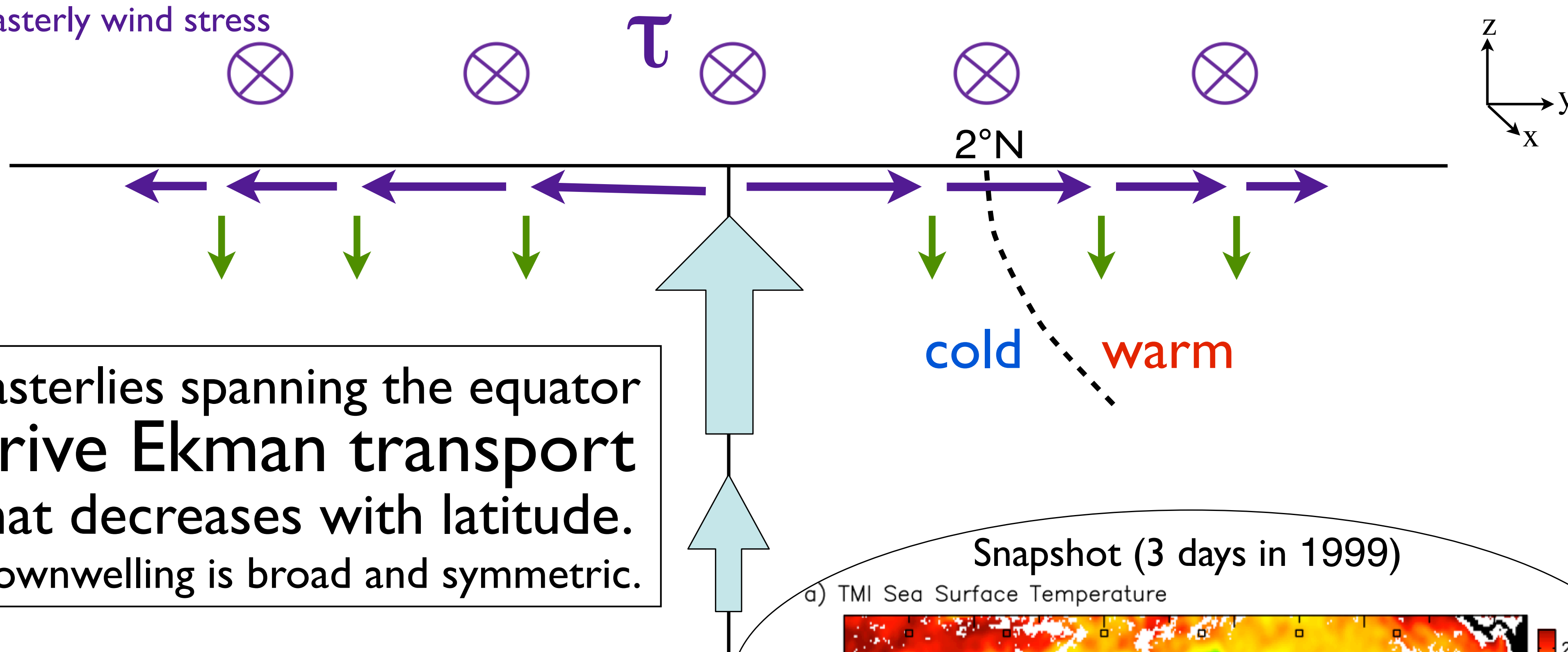
1. To observe and understand the 3-D time evolution of the near-equatorial meridional circulation cell under varying winds, sufficiently well to serve (a) as background for the mixing observations in objective 2; (b) as a challenge to model representations.

2. To observe and understand the mixing mechanisms that determine (a) the depth of penetration of wind-input momentum and the factors that cause it to vary; (b) the transmission of surface heat fluxes into the upper thermocline and the maintenance of the thermal structure in the presence of meters per day upwelling.

3. To observe and understand the processes that allow and control exchange across the sharp SST front north of the cold tongue, including both small-scale frontal dynamics and the effects of tropical instability waves.

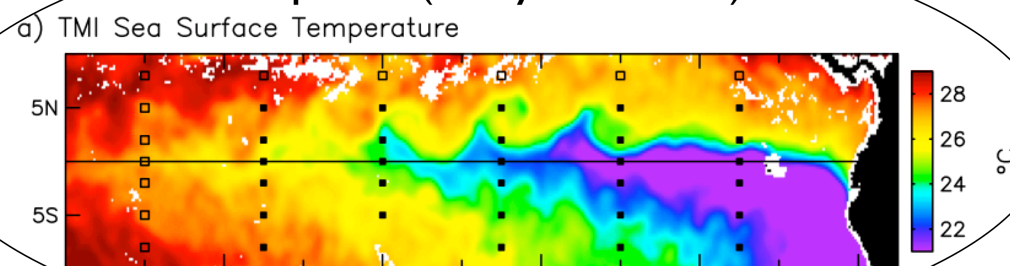
Extra slides below

The “classical” picture of equatorial Ekman divergence, but ...



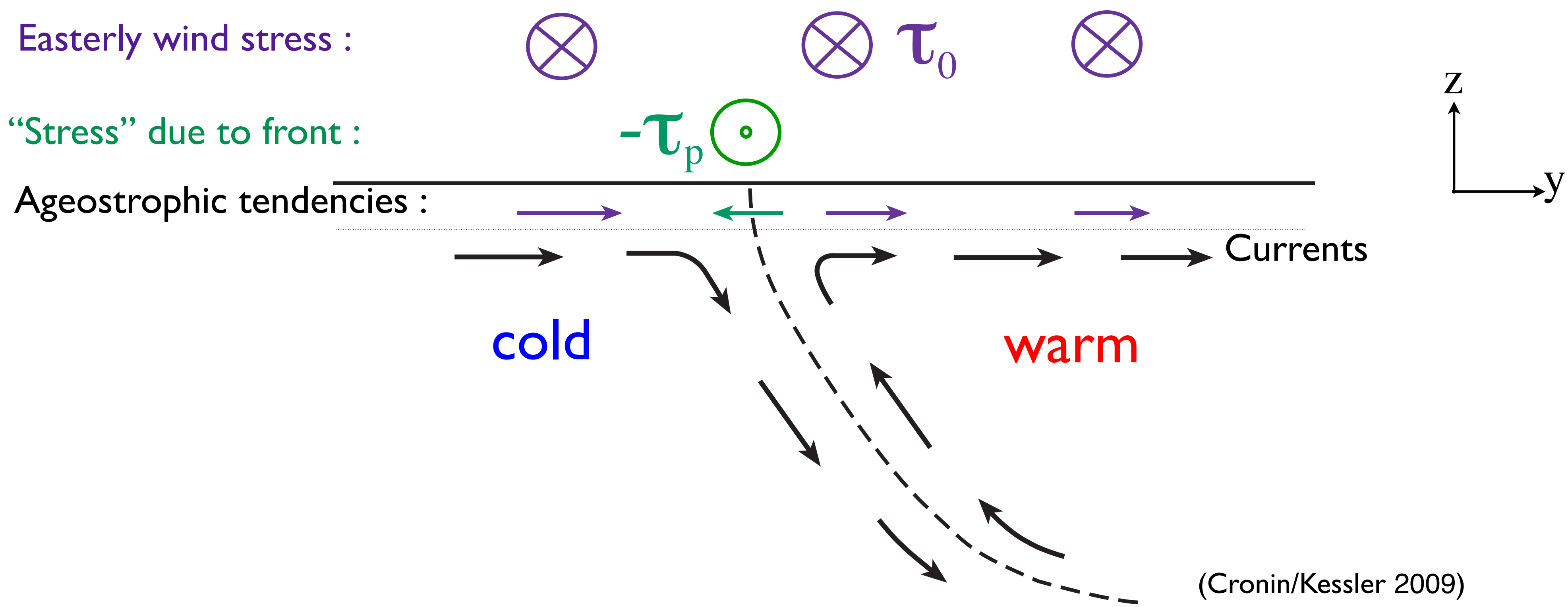
Easterlies spanning the equator
drive Ekman transport
that decreases with latitude.
Downwelling is broad and symmetric.

Snapshot (3 days in 1999)



But ...
there is a sharp SST front near 2°N.
How can the water cross the front?
What mechanism would heat it up?

How can equatorial Ekman divergence coexist with a sharp front?



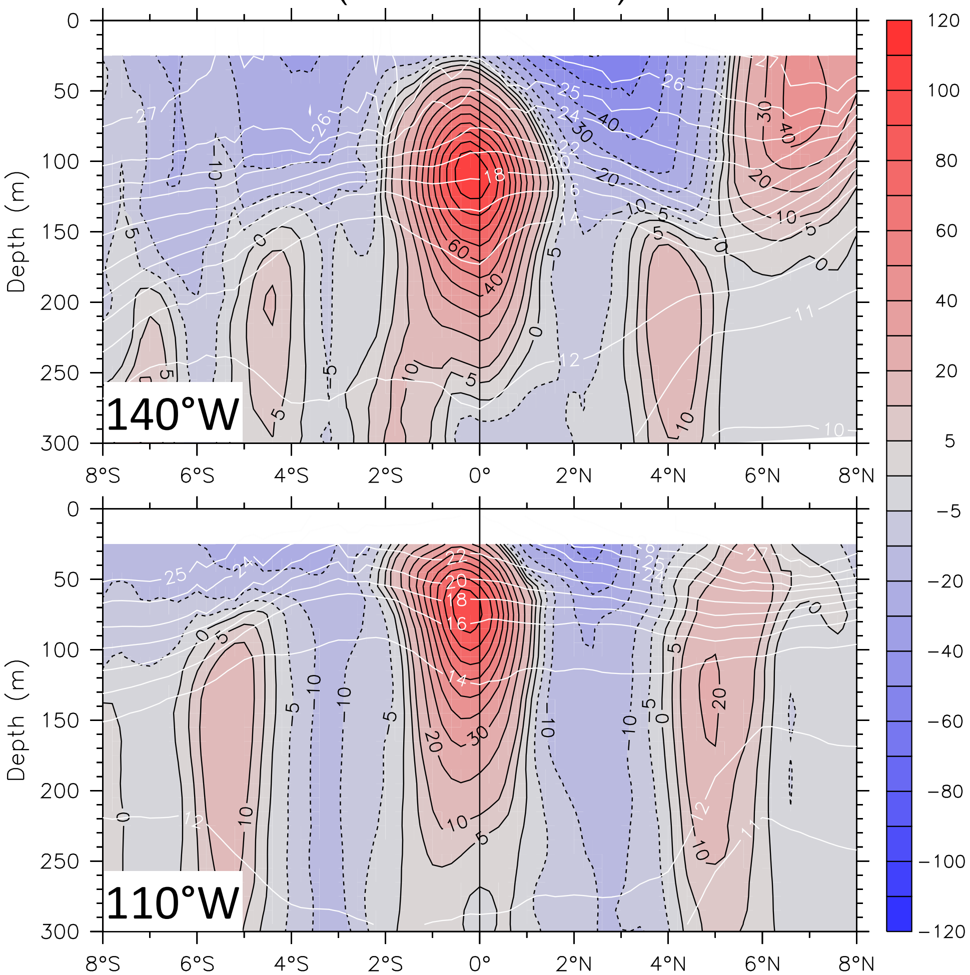
At the center of the front, shear due to the front itself balances the Ekman flow (green arrow).

→ Convergence on the cold side, and divergence on the warm side. The cold diverging water slides *under* the front.

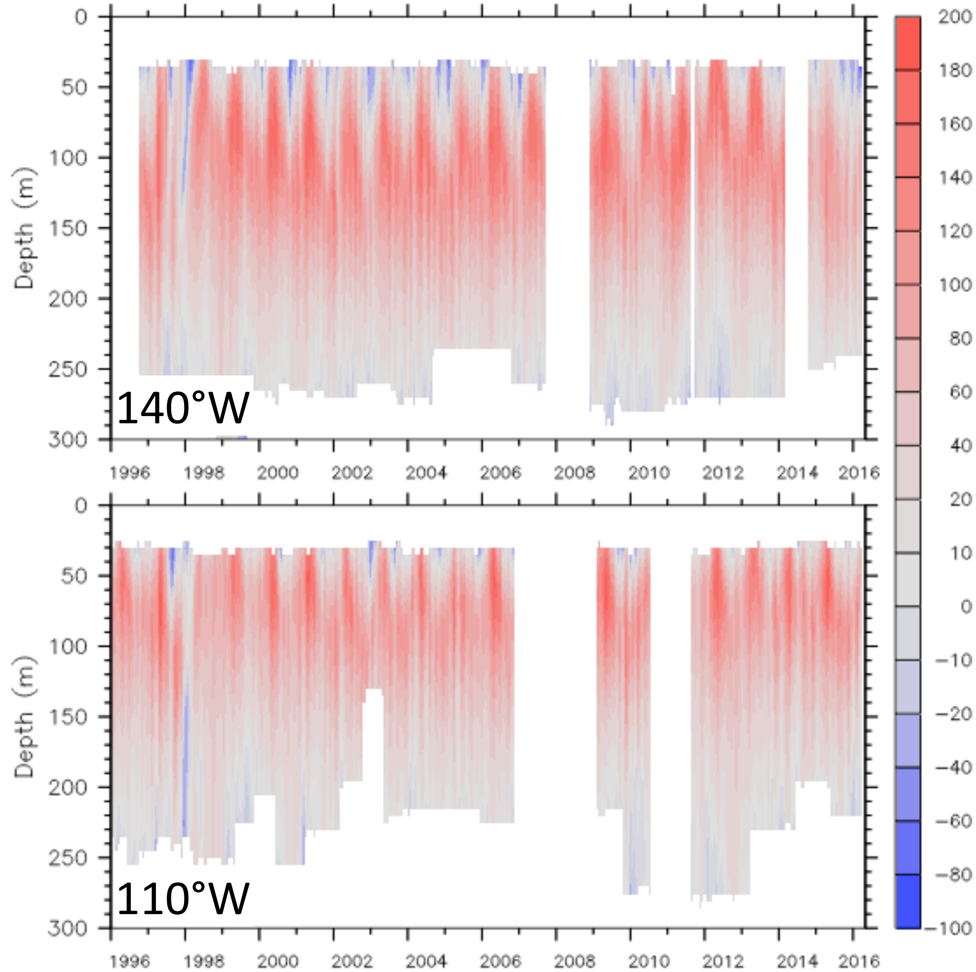
Observed u at 140°W and 110°W

Johnson et al (shipboard ADCP mean)

(White T contours)

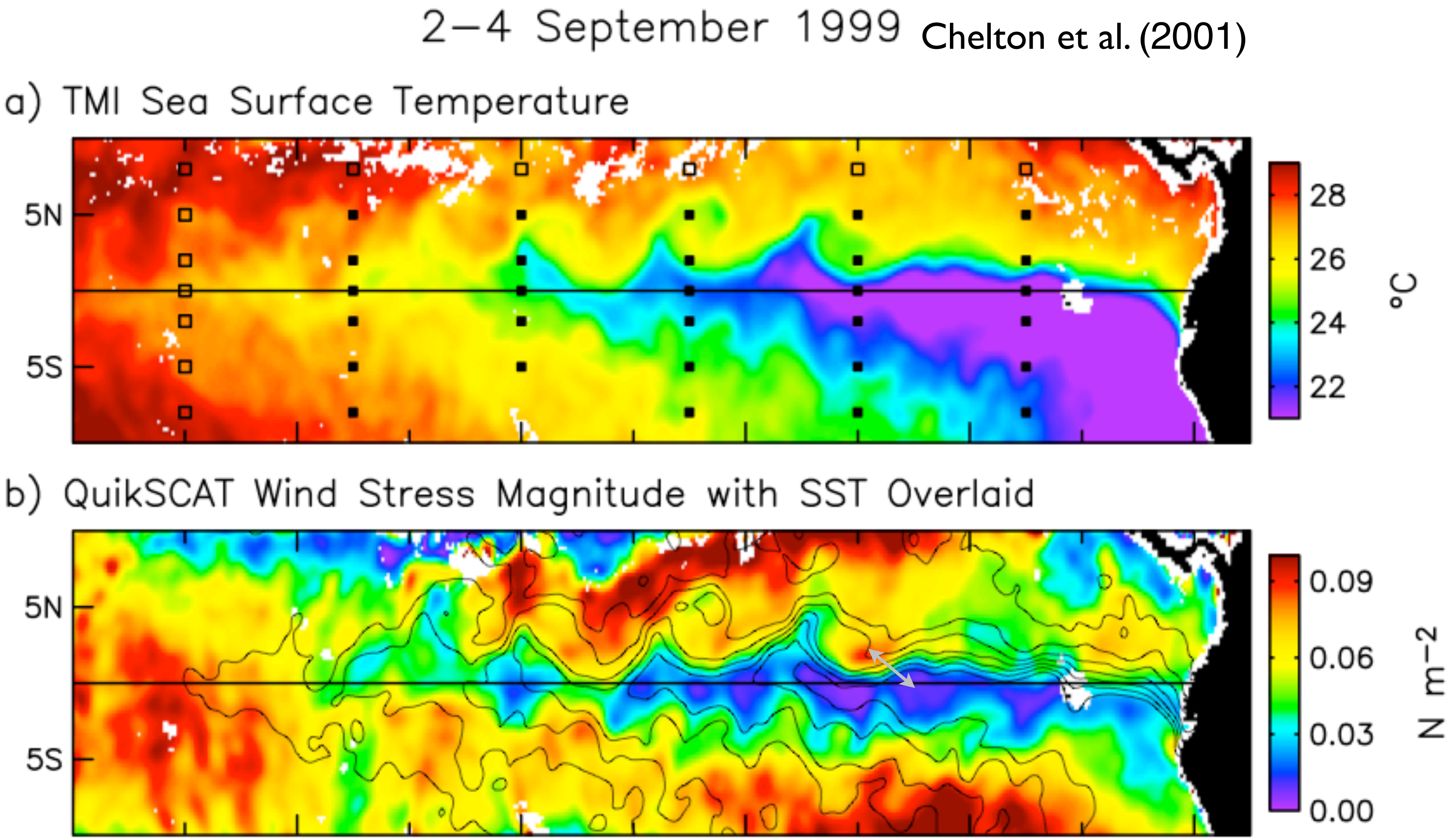


TAO ADCP at the Eq (~ monthly)



Neither the downward-looking shipboard nor the upward-looking moored ADCP samples the upper 25m

Short space/time scales



<u>Downwind</u> scale of wind at front:

(.1N/m^2 over 250km => 1m/s over 50km = 3 hr)

Surface boundary layer

How does the thermocline communicate with the atmosphere?

The <u>diurnal cycle</u> is surprisingly important …

Can we teach this to models?

Diurnal cycle composite at 2°N,140°W: Winds, current shear.

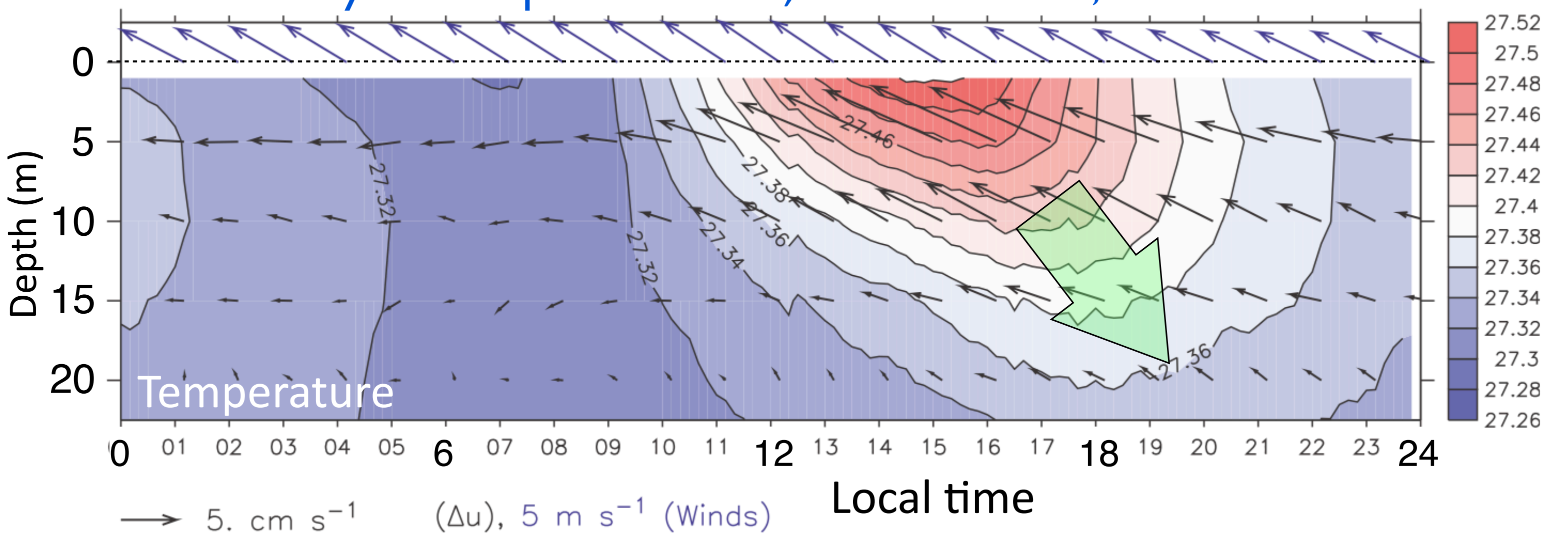


FIG. 5. Mean diurnal composite (24 May 2004–7 Oct 2004) of wind (blue vectors), temperature (color shading), and currents relative to 25 m (black vectors). The vector scale is shown at the bottom. Cronin and Kessler (2009)

Much of the work of heat and momentum transmission to the thermocline is accomplished by the diurnal cycle. ⇨ Requirement to observe the near-surface, including currents … but how much is needed?

CESM w at 140°W, 50m