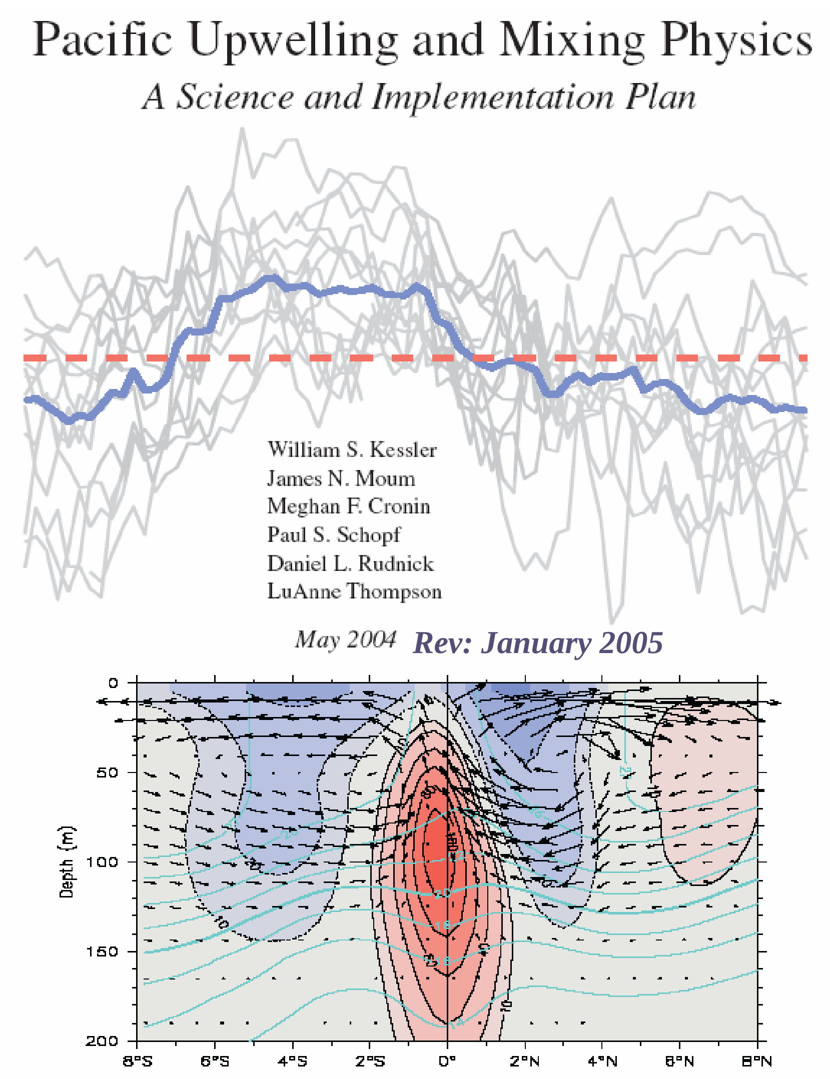


PUMP

PUMP is a process study to observe and model the complex of mechanisms that connect the thermocline to the surface in
the equatorial Pacific cold tongue.

Its premises are:

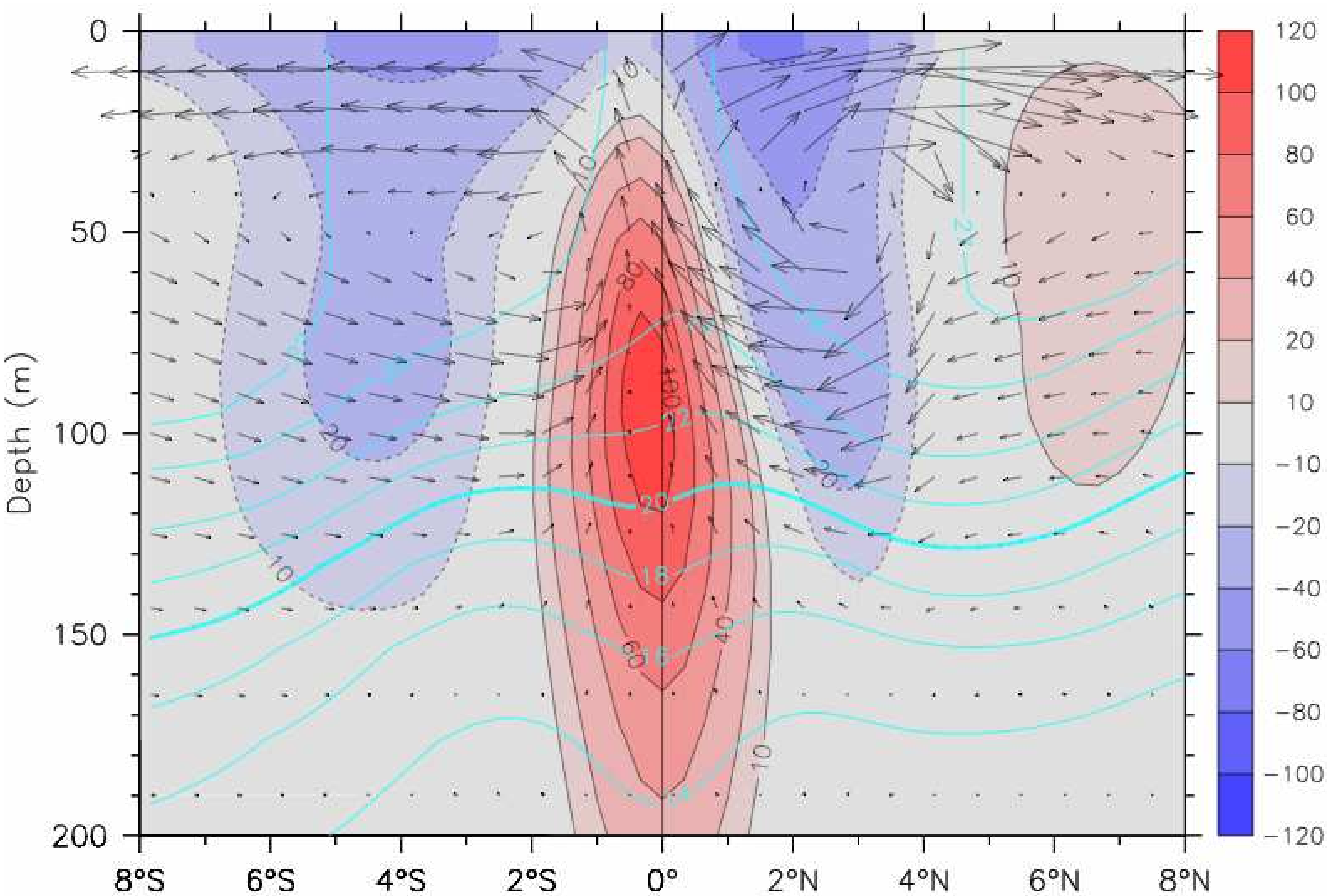
- climate-scale ocean models are ready to exploit realistic vertical exchange processes, but need adequate observational guidance
- historical records now exist upon which we can target process experiments (TAO)
- observational capabilities are superior to what they were 20 years ago

ENSO is not a solved problem!

The past few years have shown that we are a long way from being able to make accurate ENSO forecasts even a few months ahead.

There are few targets the climate community could set for itself that would make more difference to more people than to improve our ability to forecast ENSO and its effects.

OGCM meridional circulation

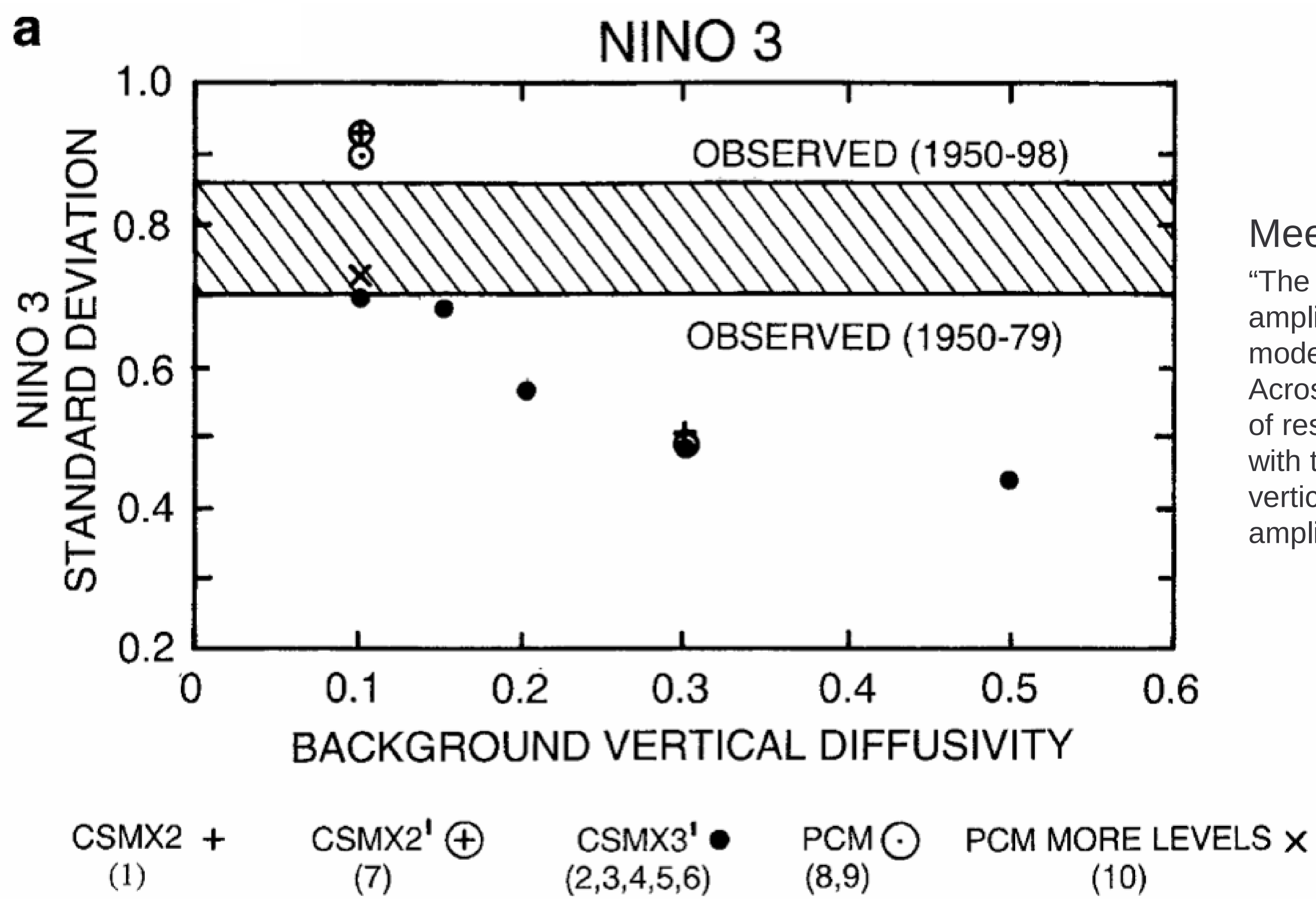


MOM2 seasonal run (Vecchi)

140°W

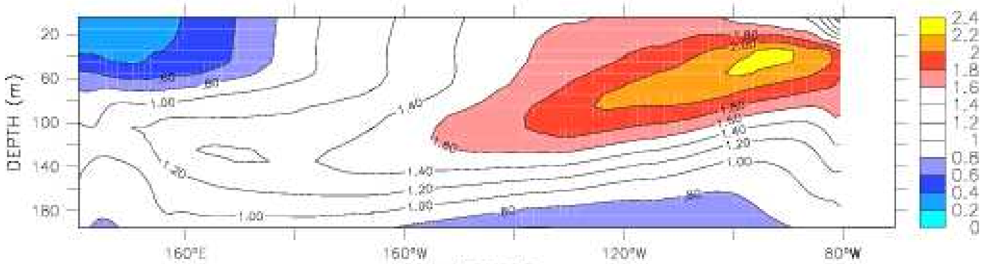
Colors = u
Vectors = (v,w)
Contours = T

ENSO amplitude is principally controlled by the efficiency of communication between the thermocline and the surface

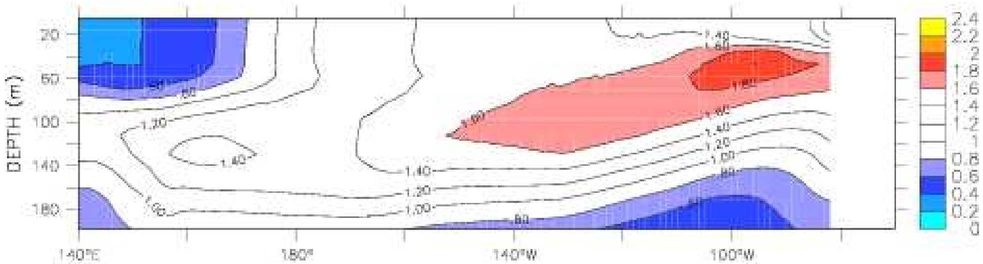


Meehl et al (2001)

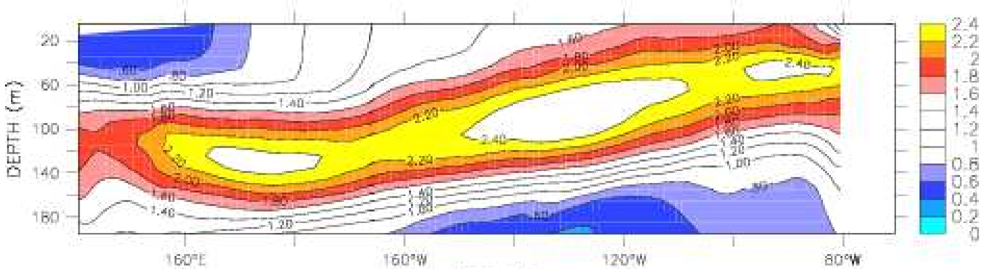
"The dominant influence on El Nino amplitude is the magnitude of the ocean model background vertical diffusivity. Across all model experiments, regardless of resolution of ocean physics, the runs with the lowest values of background vertical diffusivity have the largest Nino3 amplitudes."



GFDL OM-3 anomalies



NCAR gx1v3 anomalies



Assimilation anomalies

Interannual RMS temperature along the Equator

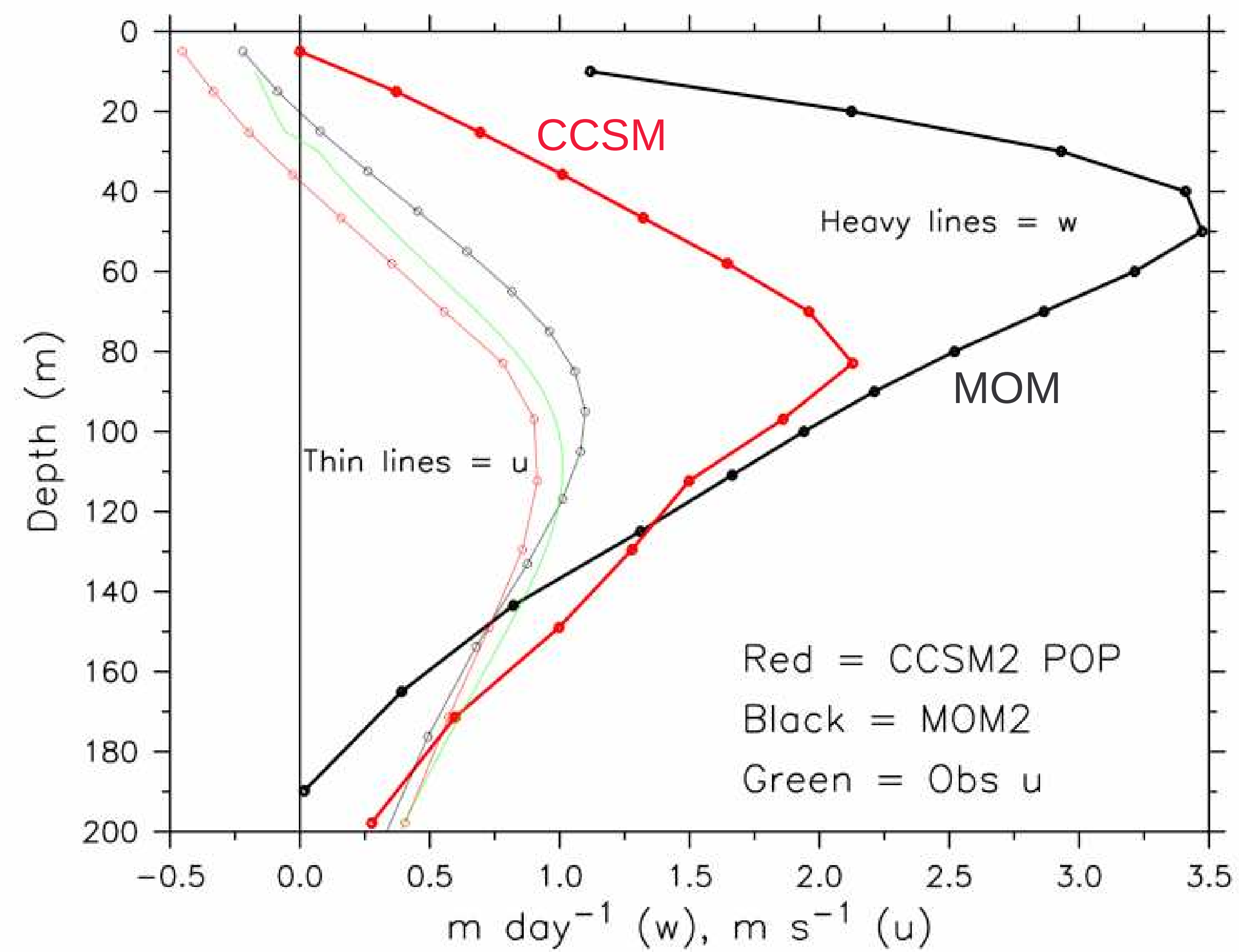
Forced OGCMs:
GFDL OM-3,   NCAR gx1v3
Large & Yeager forcing (1958-2000)

ï   These models have reasonable ENSO SST (though underestimated and with the maximum too far west), apparently with incomplete physics.

ï   It is possible to get the right phase of anomalies for the wrong reason.

Rosati and Wittenberg, 2004

OGCM meridional circulations are very different



CCSM (Bryan), MOM (Vecchi)

Mean u and w at 0°, 140°W

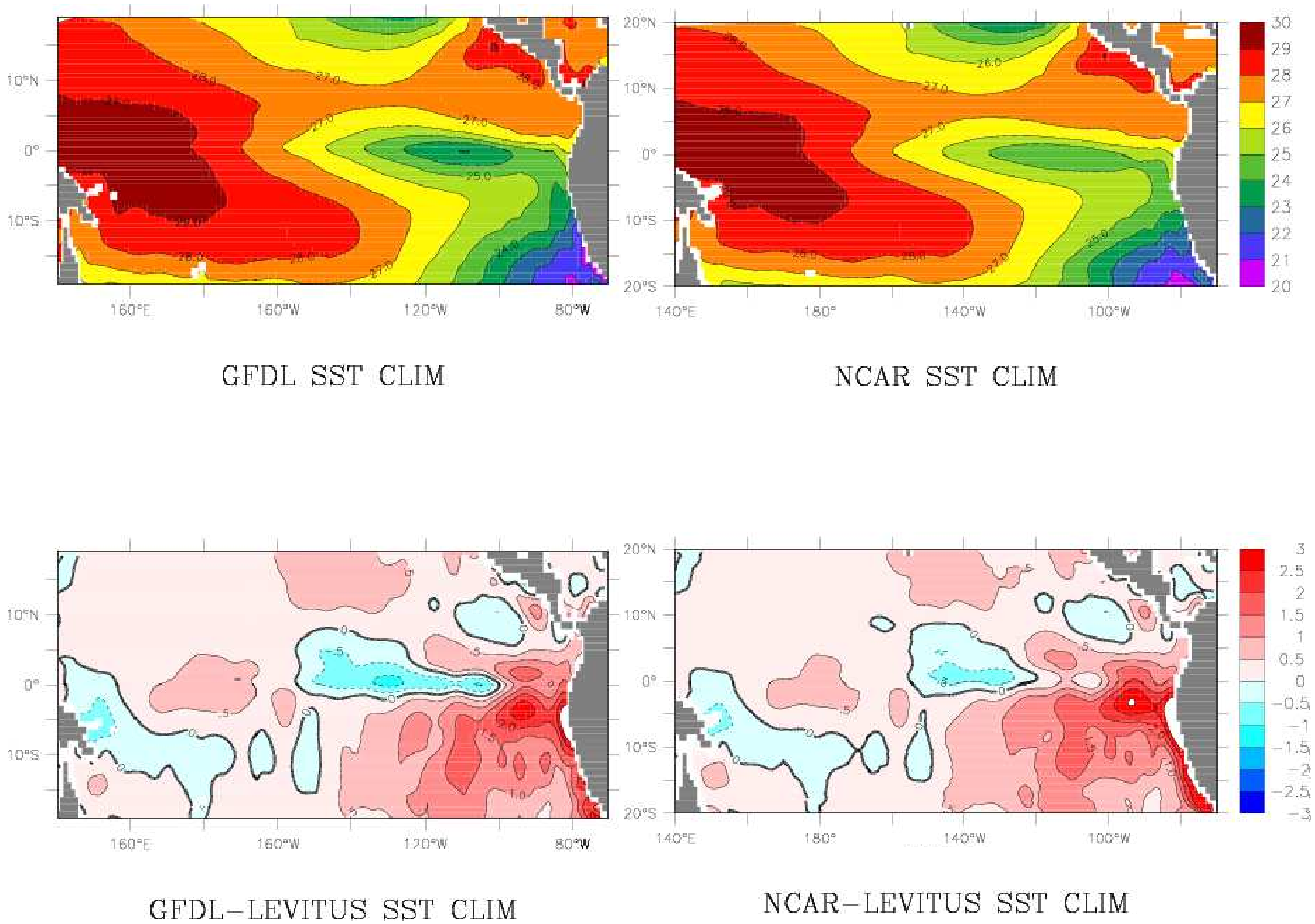
Compare two forced OGCMs: MOM2 (1/3°) vs CCSM2 (1/10°)

The usual comparisons of u(Eq,z) can be misleading

Δ_1 , Δ_2

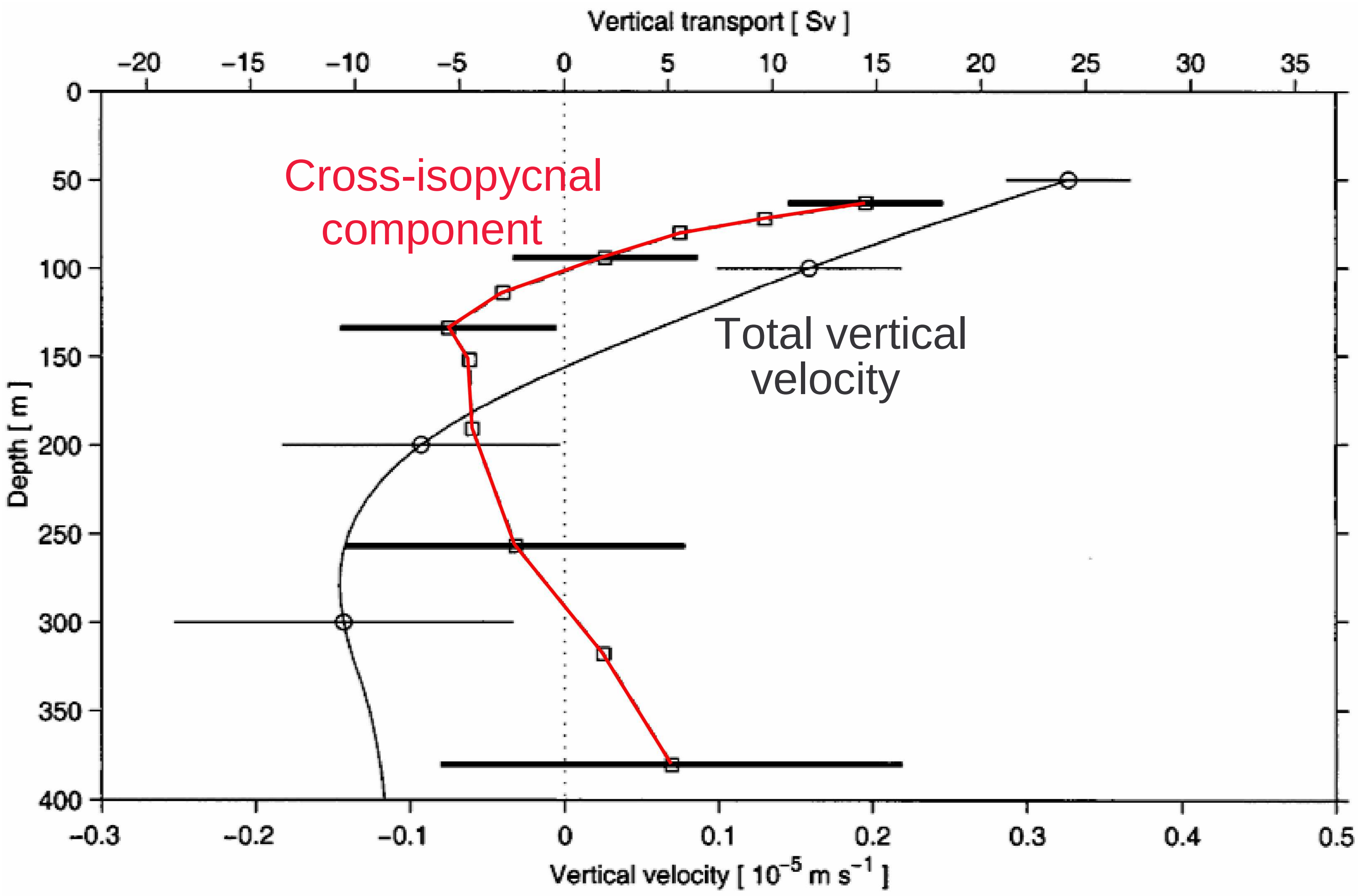
Cold bias occurs in forced OGCMs

Forced OGCMs:
GFDL OM-3, NCAR gx1v3
Large & Yeager forcing (1958-2000)



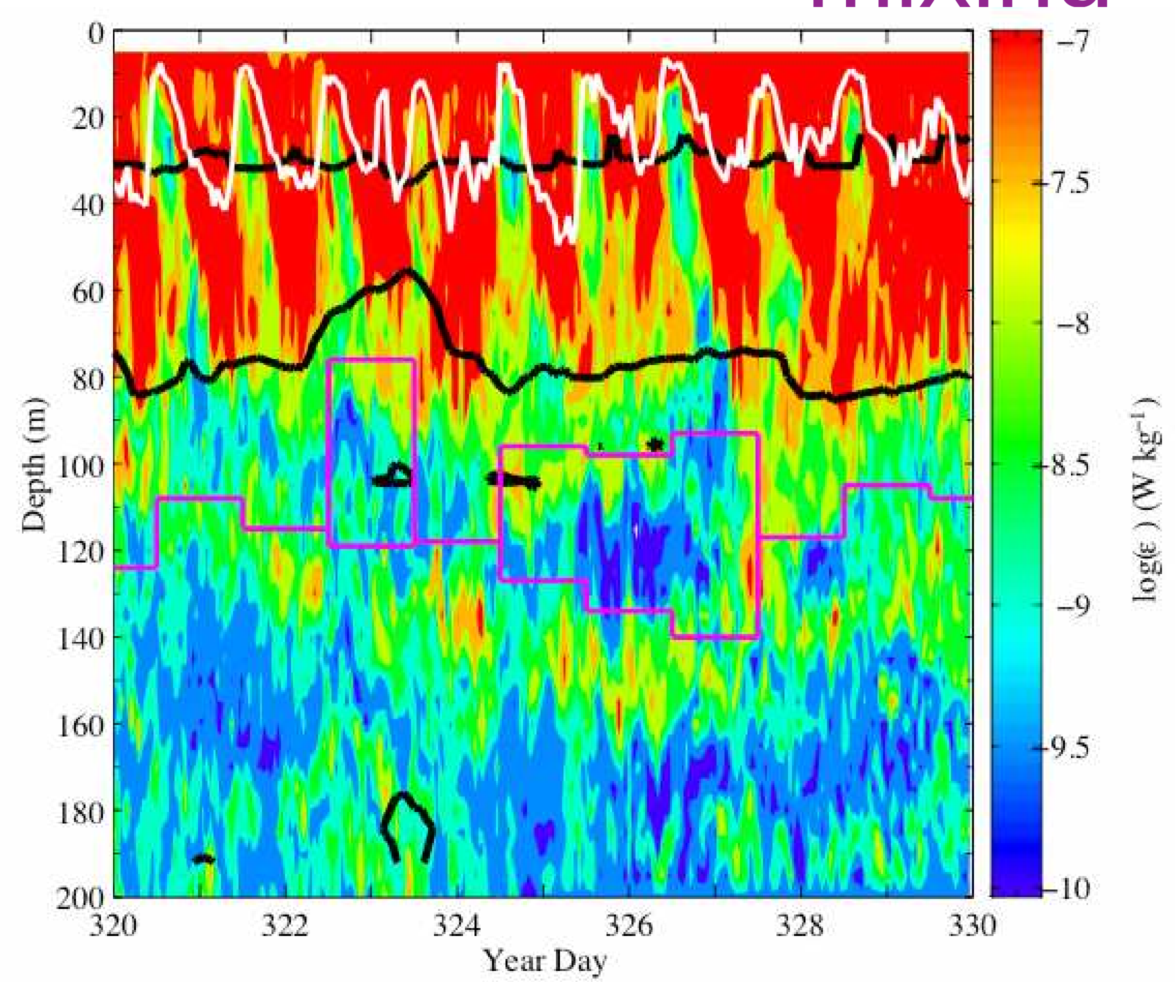
Rosati and Wittenberg, 2004

Upwelling requires mixing



Meinen et al (2001)

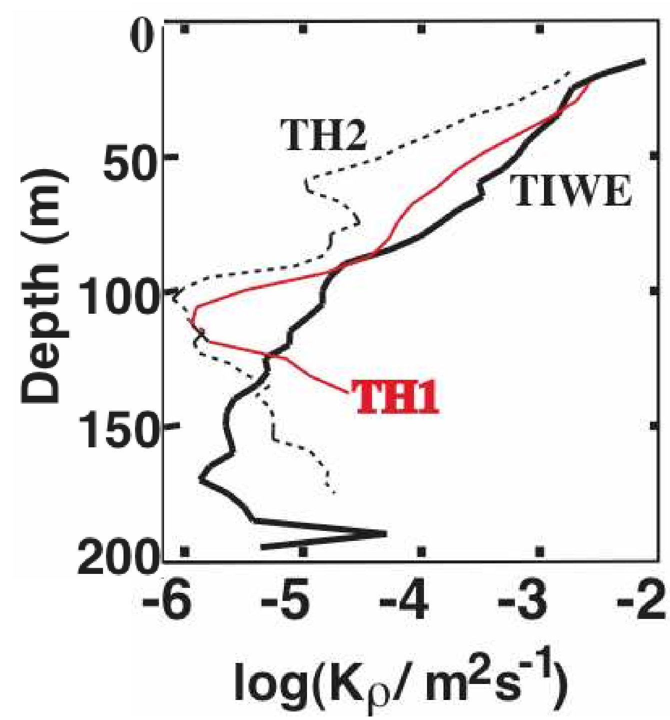
We do not understand the regime-dependence of equatorial mixing



Dissipation rate during 10 days of TIWE

Lien and D'Asaro

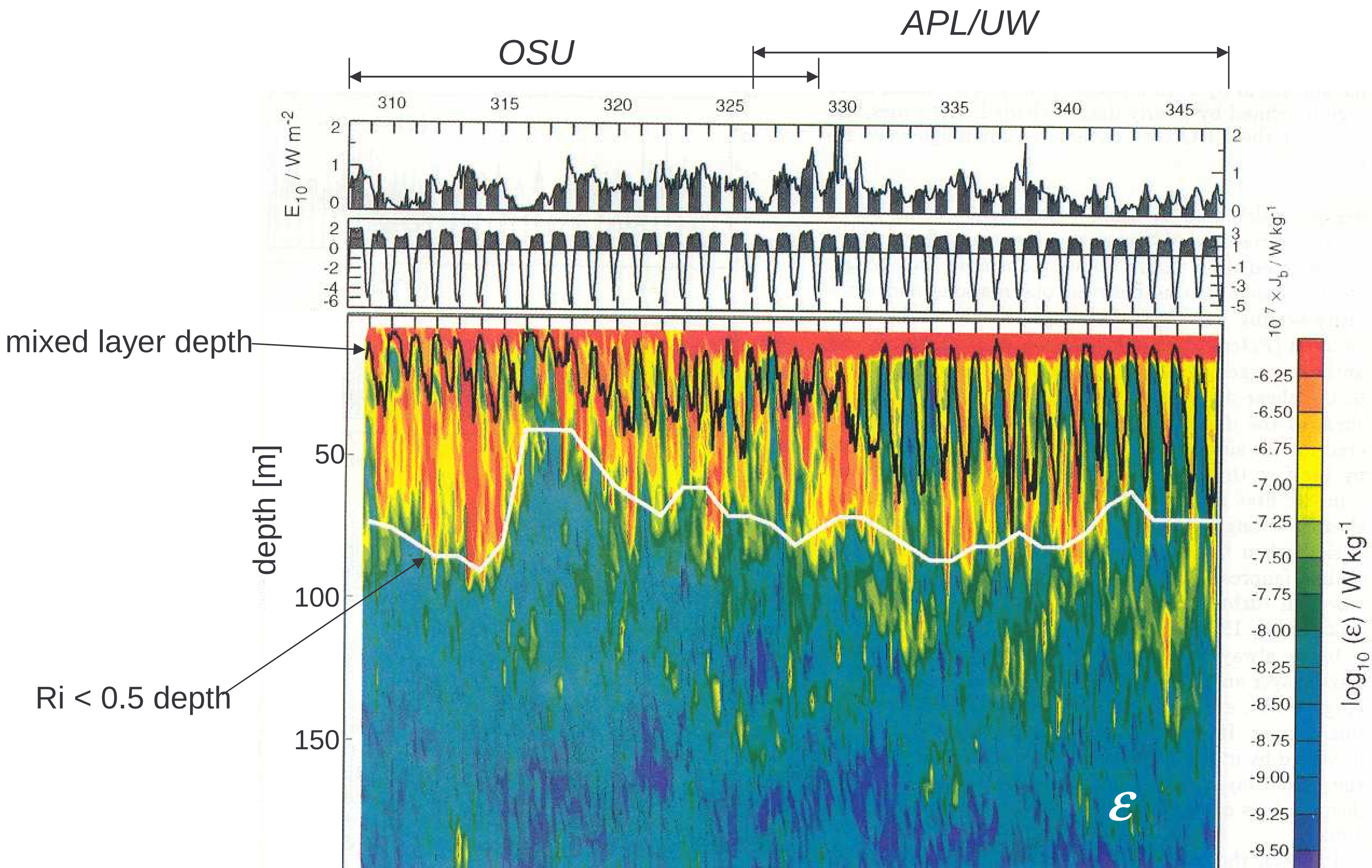
All existing eddy diffusivity profiles in the cold tongue



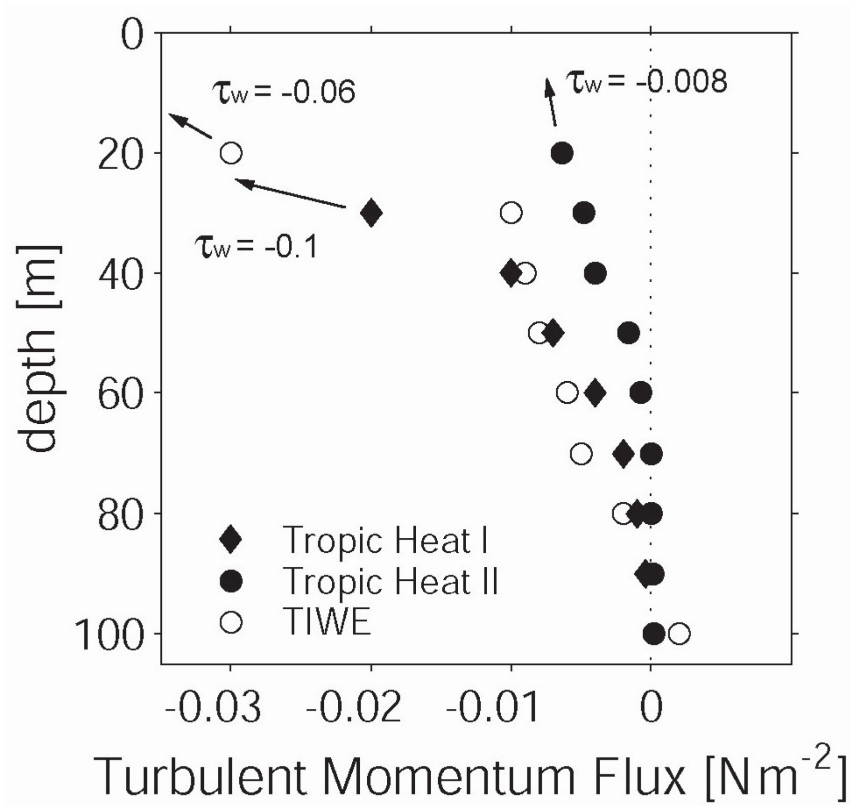
Gregg (1998)

time series

TIWE Variability over 38 days at 0° 140°W late Fall 1991



Lien et.al., 1995

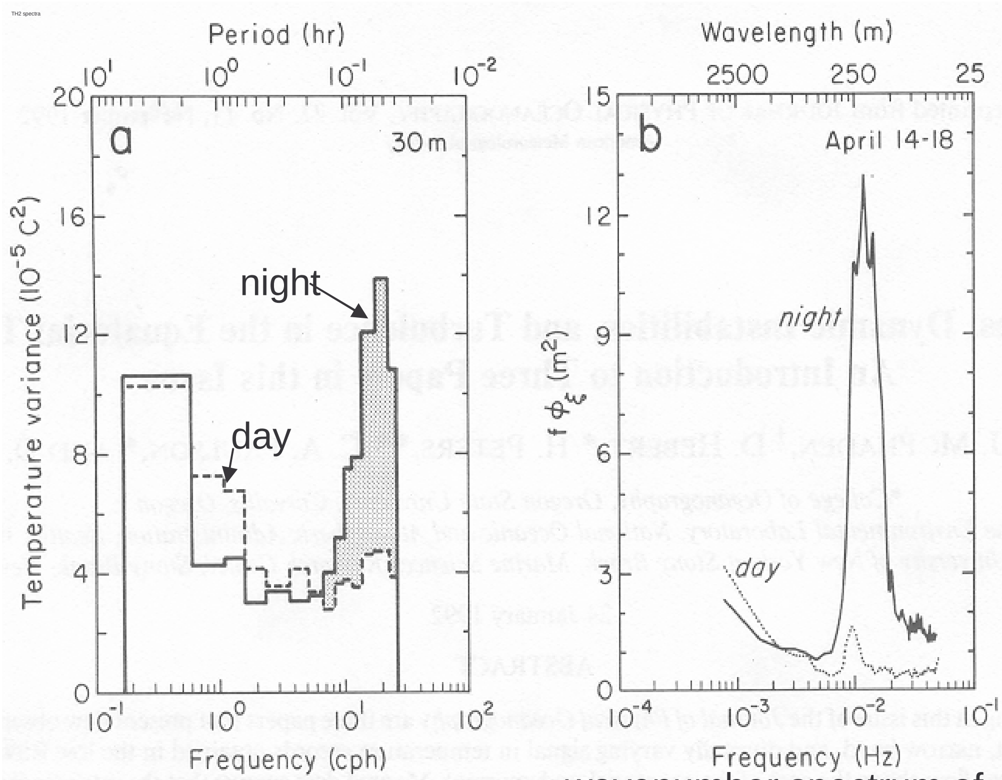


Turbulence flux profiles cannot balance ZPG.

Something else is required
→ Internal Gravity Waves?

- Lien et al. 1996 single anecdote (*not* averaged)
  $\langle u'w' \rangle_{wave} \sim 0.3\ Nm^{-2}$
- Smyth & Moum 2002 idealized study
  $\langle u'w' \rangle_{wave} \sim 30\ Nm^{-2}$
  (Several orders of magnitude > ZPG)

→ *NO* sensible estimates to date



frequency spectrum of temperature from mooring

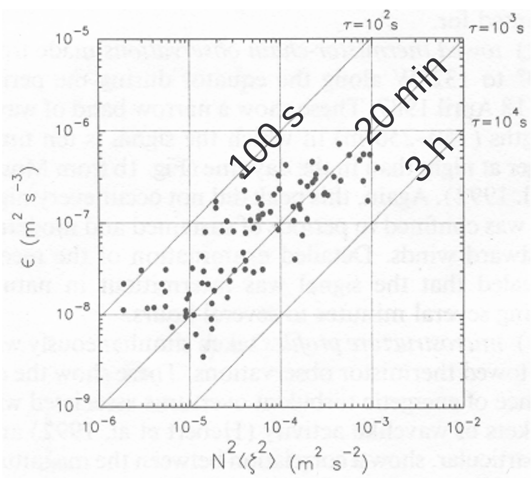
wavenumber spectrum of isotherm displacement from towed thermistor chain

Theoretical studies

- confirm scales of instabilities
- suggest role of wave radiation in vertical momentum transport

Observational quantification

of momentum transport by vertically-propagating internal waves is lacking



Wave PE *vs* ε

Hourly average values are highly correlated and related through a decay time scale which is at most a few hours v

What’s new?

- 20-year records at the equator to aid in targeting the process experiment
- new types of observations
- new ways of thinking about ocean turbulence observations
- advances in modeling capabilities, resolution and techniques

Primary Objectives of PUMP

To observe and understand:

1) The evolution of the equatorial cell under varying winds

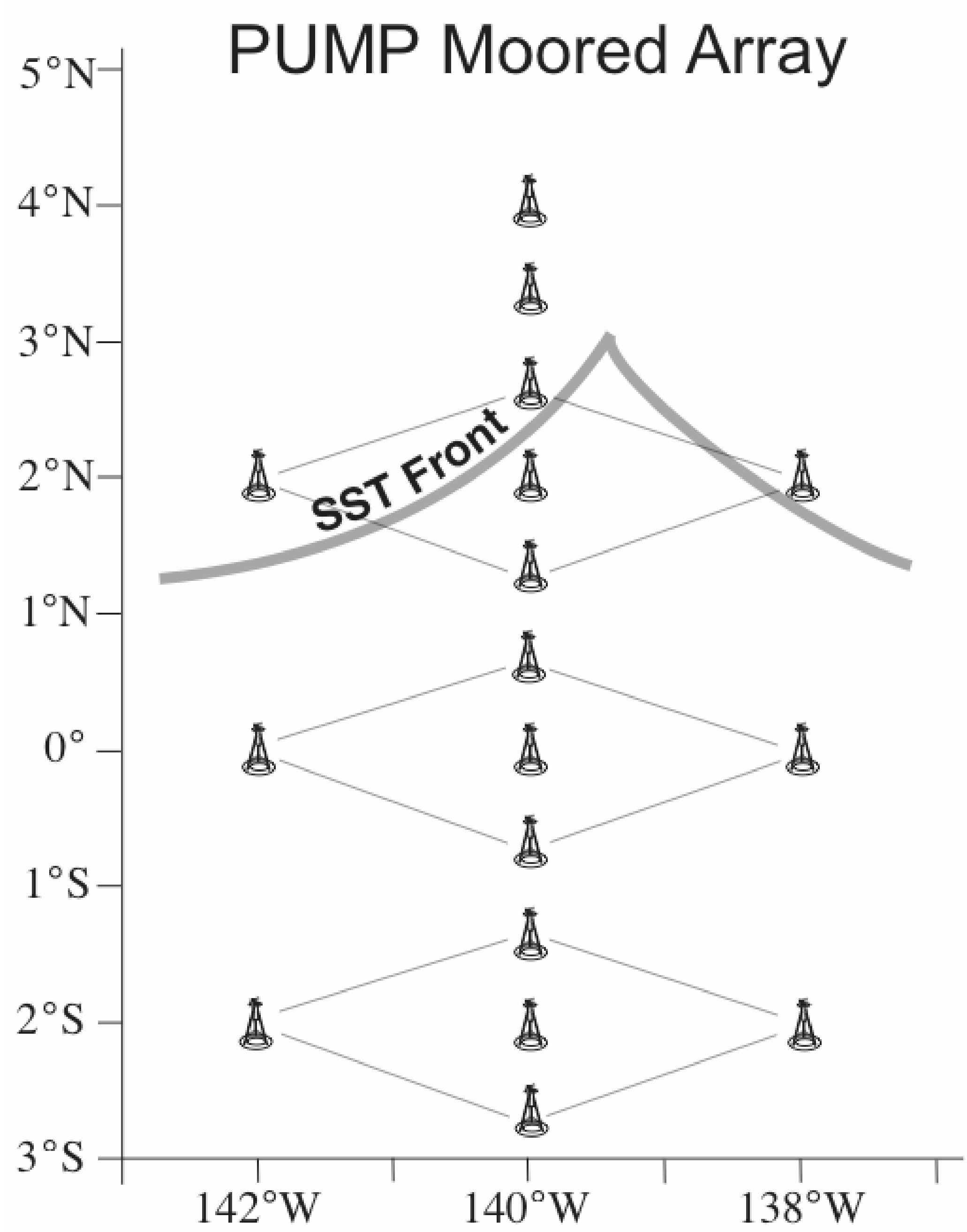
2) The mixing mechanisms that determine
   (a) the depth of wind-input momentum
   (b) the transmission of surface heat fluxes into the upper thermocline

3) The processes that allow and control exchange across the sharp SST front north of the cold tongue

PUMP will put mixing observations in their regime conte

Components of PUMP

- Reanalysis of historical data
- Multi-scale modeling effort
- 2-3 year moored array along 140°W, to establish the scales and variability of equatorial upwelling
- Two IOPs, both on and just north of the equator at 140°W, to quantify the relative effects of upwelling and mixing



Each mooring is a pair:
Surface buoy + ADCP

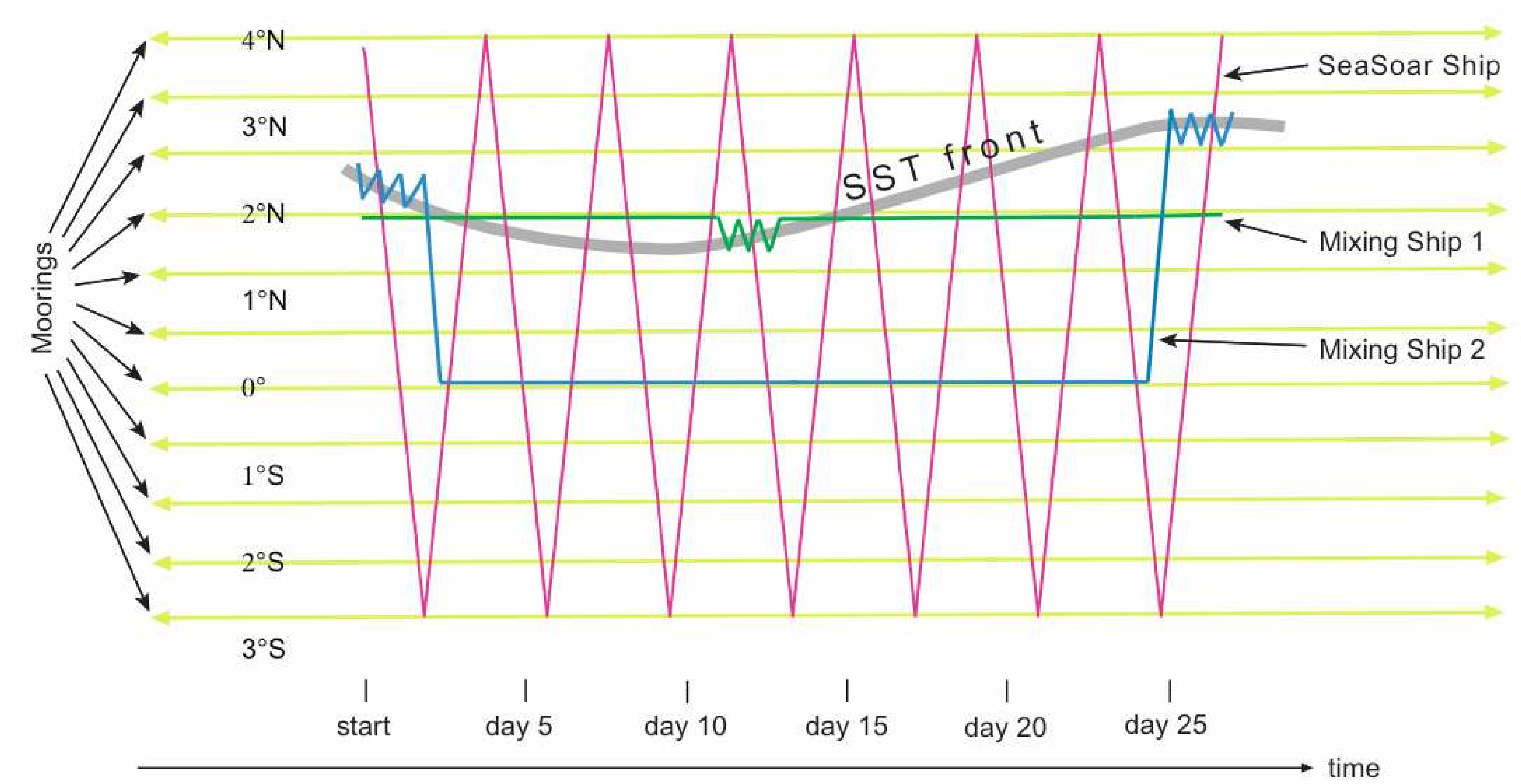
Goal is to determine:

- The structure of ũ(x,y,z,t) over 2 annual cycles.
- The spinup of the poleward limb of the meridional circulation under varying winds. Δ
- The (y,z) structure of horizontal divergence and upwelling.
- The downwelling at the SST front, and its relation to TIW.
- The rate of diapycnal conversion, accounting for heat fluxes.

OSSEs will refine the array

PUMP Intensive Observing Periods

Δ



Goal is to determine:

- The mechanisms by which internal waves are modulated, on and off the Eq
- The spatial structure of mixing across the equatorial region
- The variability of mixing and air-sea forcing across the SST front
- The turbulent heat flux integral on a scale to be compared to upwelling
- The nature of mixing during the rapid and reduced cooling periods

Perfecting OGCMs for climate forecasting

Four elements:

1) Improve the forcing fields

2) Provide benchmark data sets to compare
model circulations across the upwelling cell

3) Improve mixing parameterizations

4) Learn to use sparse sustained observations

What is already happening?

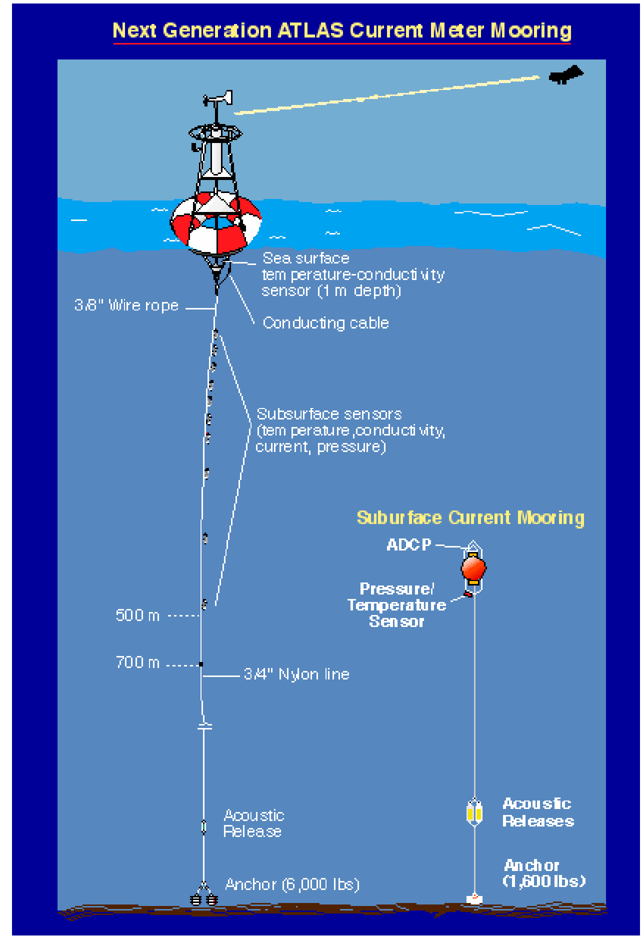
1) Test measurement of near-surface shear
   Point doppler current meters at 5-25m
   on a test mooring at 2°N,140°W

2) Funding for a post-doc to study array
   design (OSSEs). Arriving at PMEL this
   summer.

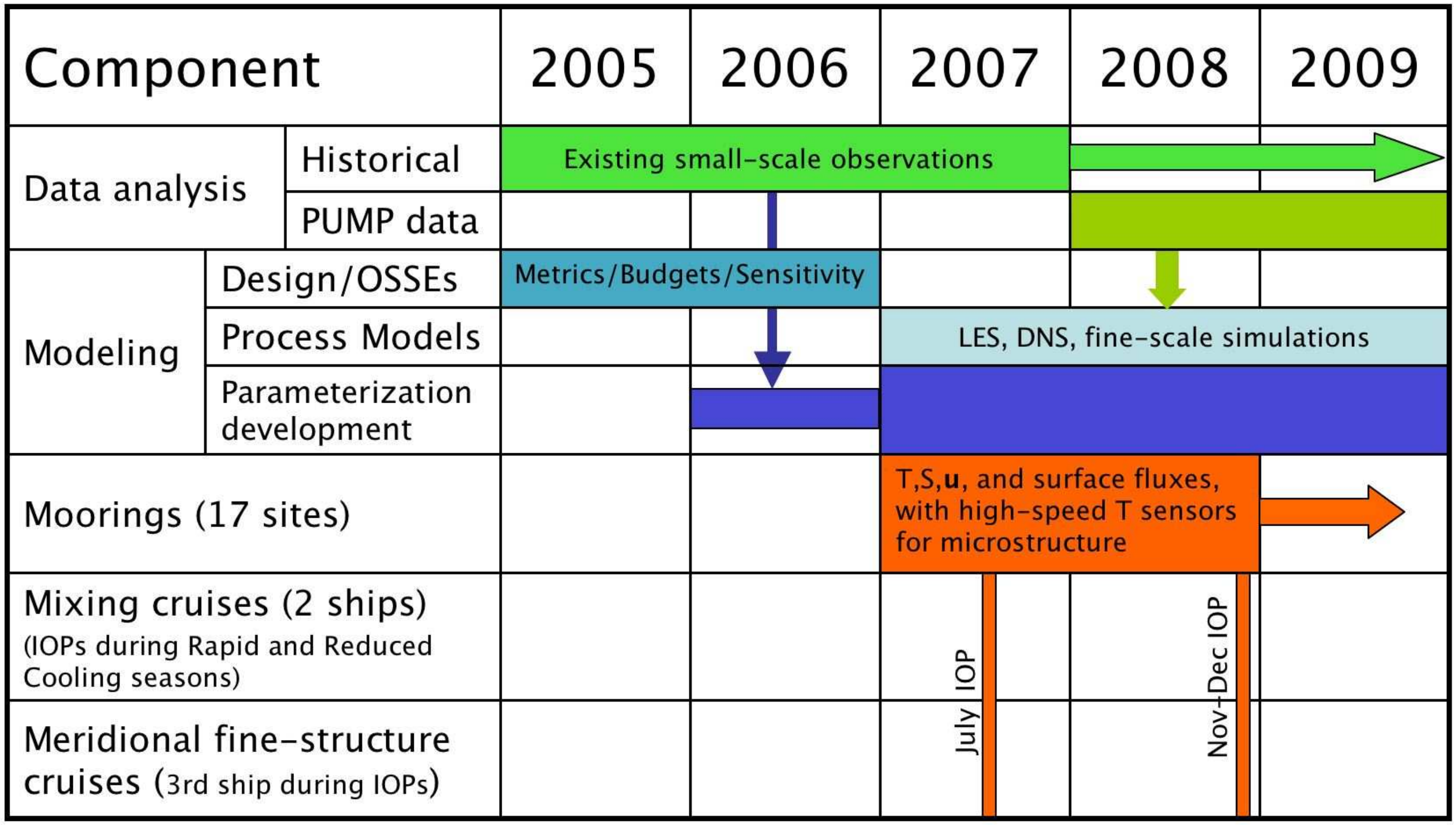
3) Test moored mixing sensors (fast-
   response thermistors). To be deployed
   at 0°,140°W later this year.

χpod – ***MOORED***
mixing measurement

1st Test deployment
0°140°W / TAO
August 2005



PUMP timeline:



Strawman Budget

$0.5M

$3.0M

$8.1M

$8.1M

$19.7M

Summary rationale for PUMP:

1. The processes of mixing and upwelling that control equatorial SST are poorly understood and modeled.
2. Present-generation OGCM representations of the upwelling cell are not adequately constrained by observed reality and differ widely among models.
3. This deficiency contributes to the fundamental problems of coupled models of the tropical climate.
4. The tools both to observe these phenomena and to improve the models are at hand.

Œ PUMP will spur a leap in our ability to diagnose and model the
tropical Pacific (and Atlantic) and to predict its variability.

EXTRA
FIGURES
BELOW

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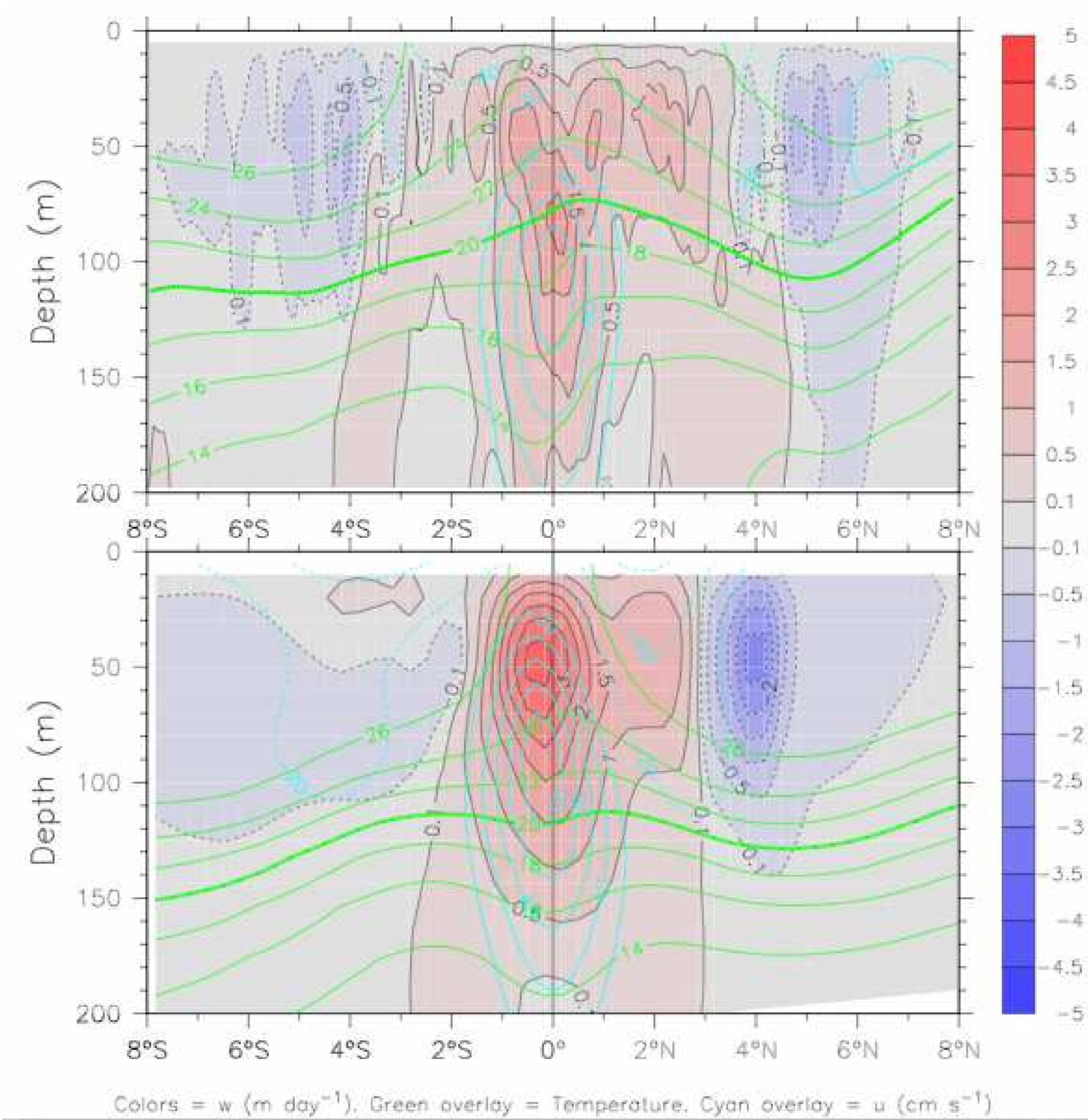
OGCM w,u,T(y,z)

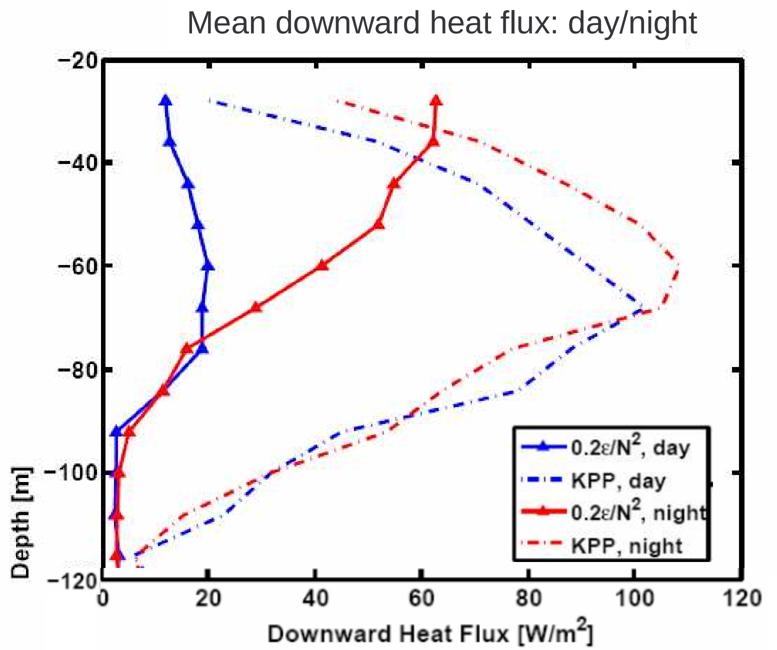


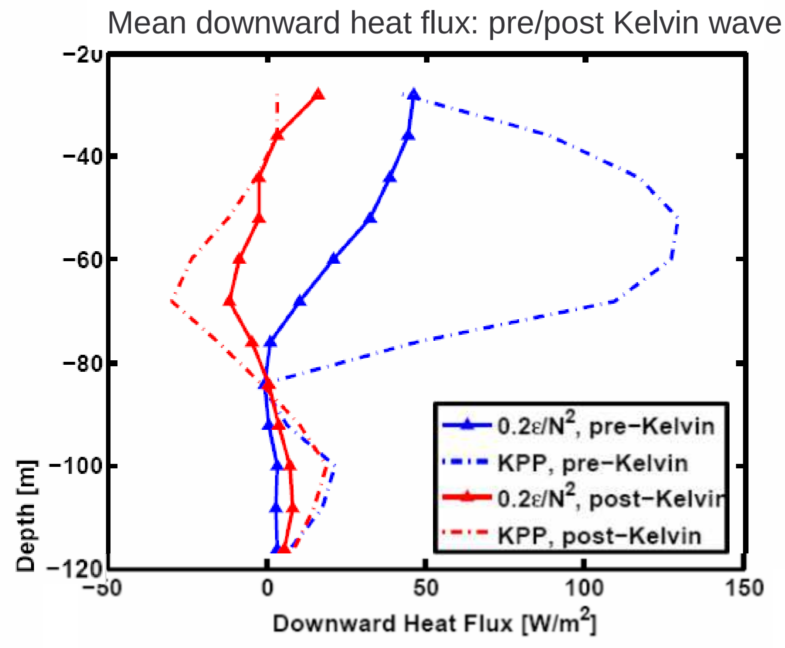
Compare CCSM2 (top) vs MOM2 (bottom)

Colors = w (m/day)
Green = Temperature
Cyan = u (cm/s)

CCSM2 (Bryan)
MOM2 (Vecchi)

KPP heat flux based on TIWE data





Ed Zaron OSU

SST at 0°,140°W: Rapid and reduced cooling periods

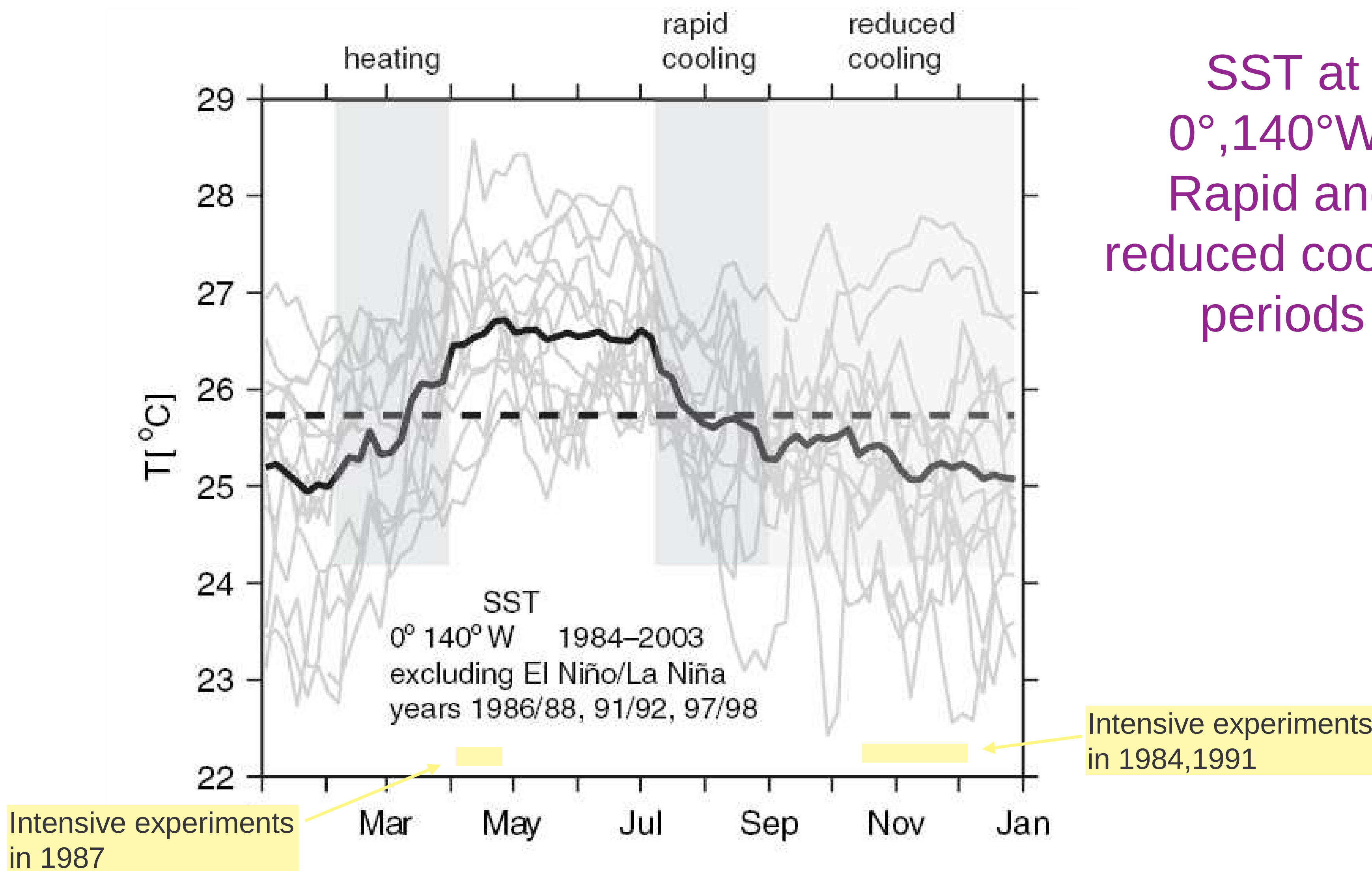


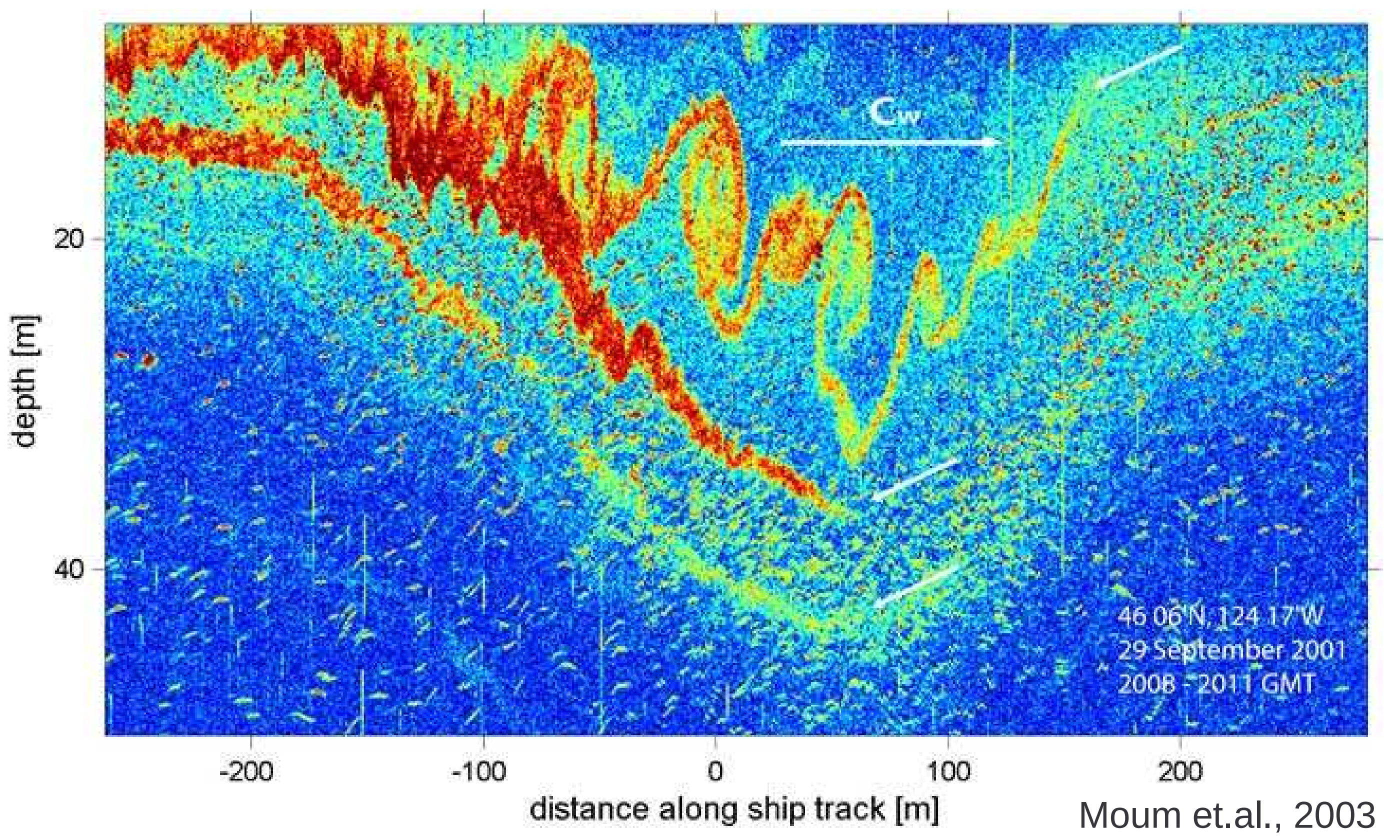
Figure 1: Annual cycle of SST at 0°, 140°W, illustrating the periods of heating and cooling during the year. Light gray lines show each individual year since 1984 overlaid (years of strong ENSO anomalies have been omitted as noted). The heavy black line shows the average annual cycle. Shading shows the months of maximum heating and maximum cooling, and a period of reduced cooling with active tropical instability wave activity, that occur consistently in almost all years.

Questions

- what triggers low-Ri instabilities/waves/growth/mixing?
- what is vertical momentum flux via IGW?
- what distinguishes *rapid* cooling from *reduced* cooling phase?
- what is the role of turbulent mixing in each case?
- how does the mixing regime change during a TIW?

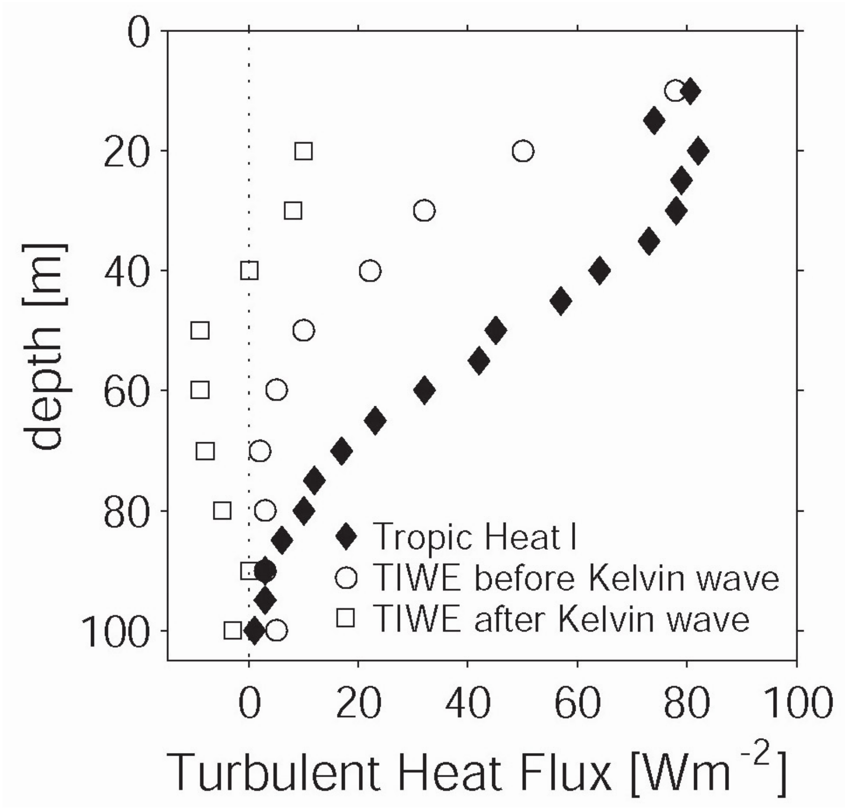
Geophysical flows

- instabilities are a part of the continuum of fluid motions
- *neither* origins nor consequences are generally clear



Moum et.al., 2003

Turbulent heat flux profiles



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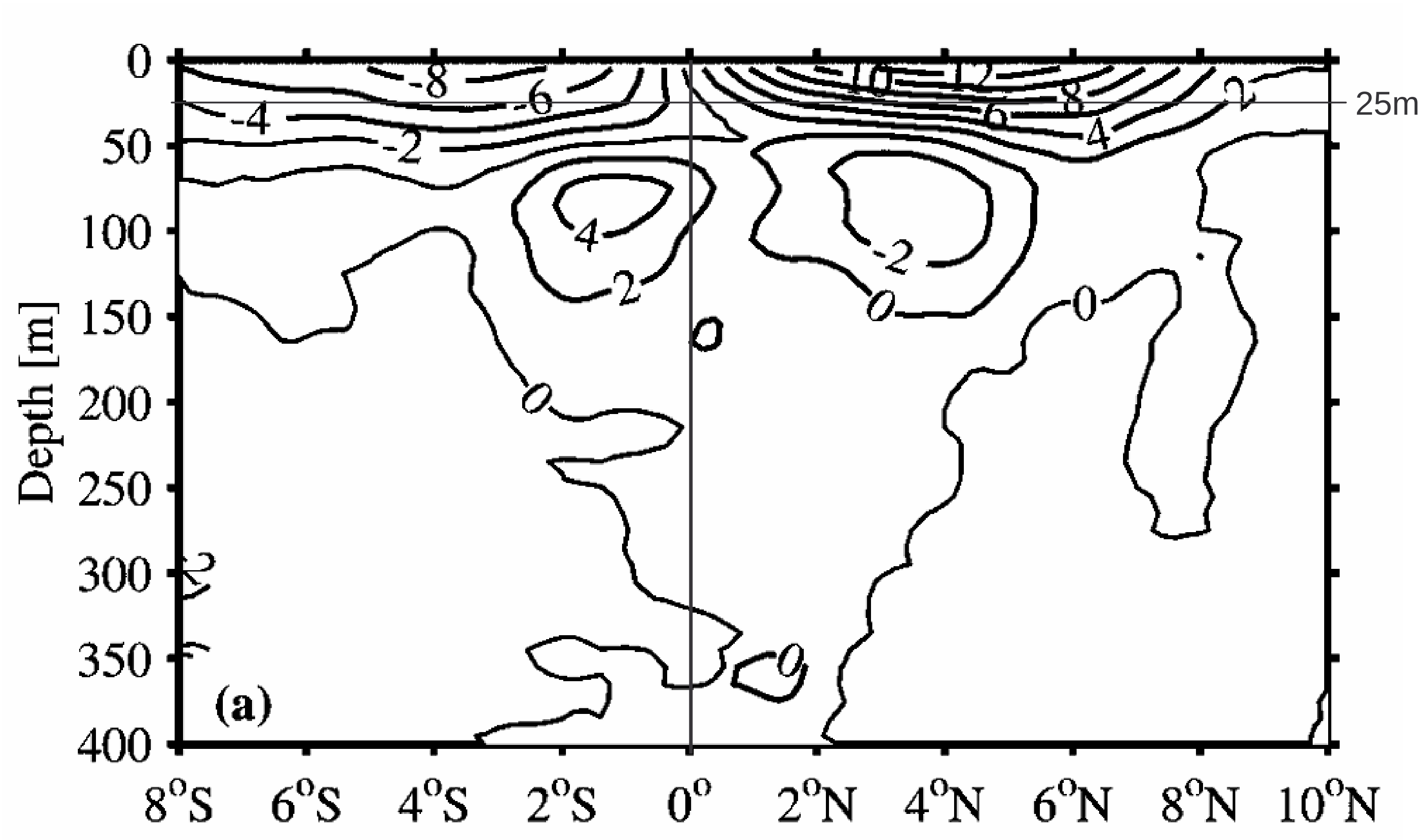
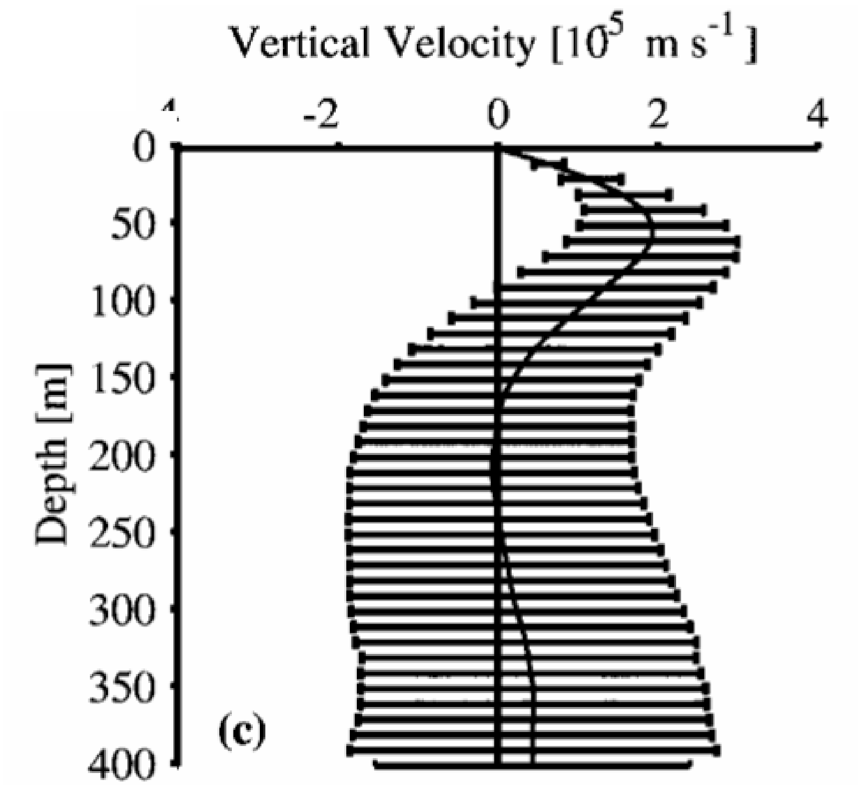
Divergence must be sampled very near the surface



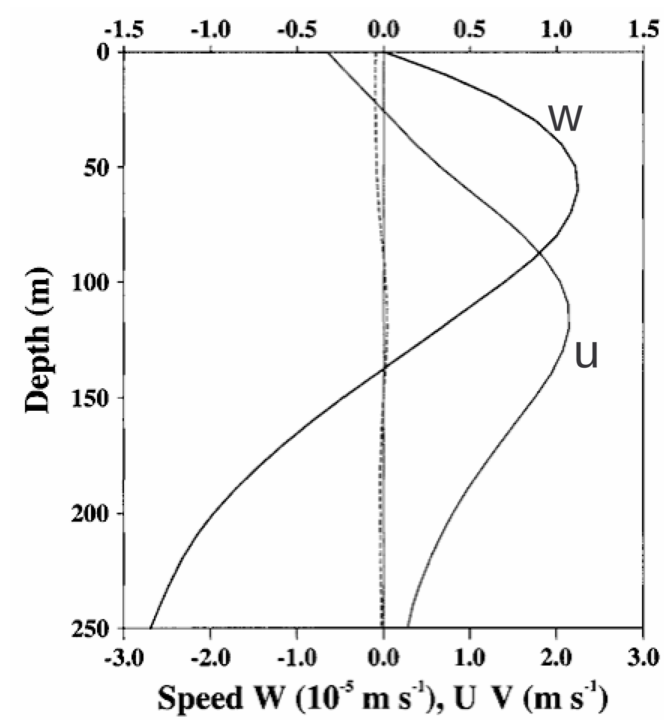
Johnson (2001)

Back

Observed estimates of w

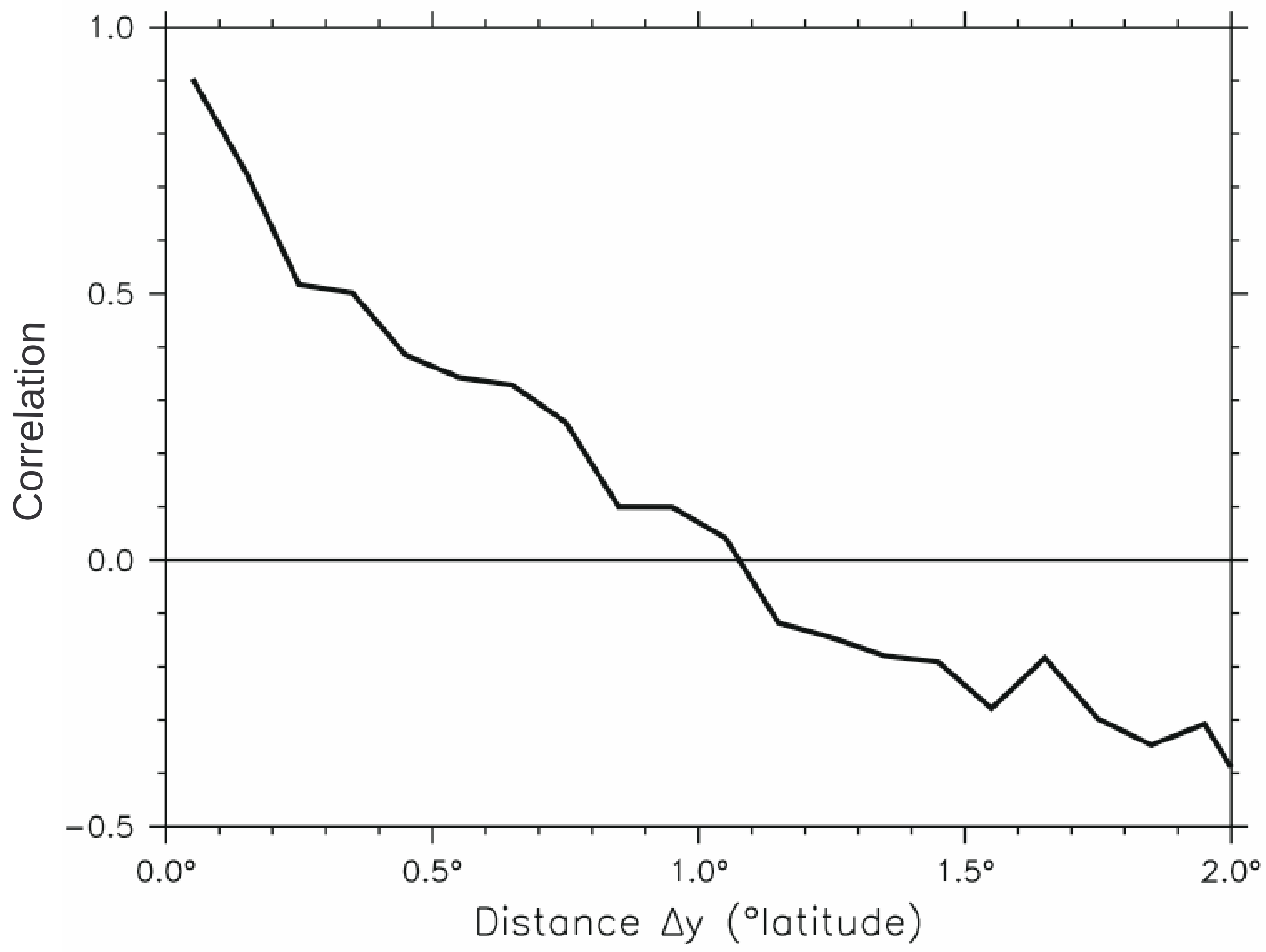


Johnson et al (2001)
Mean over shipboard ADCP



Weisberg and Qiao (2000)
Moorings at 0°, 140°W

Estimate of meridional scale of v



The front north of the Equator

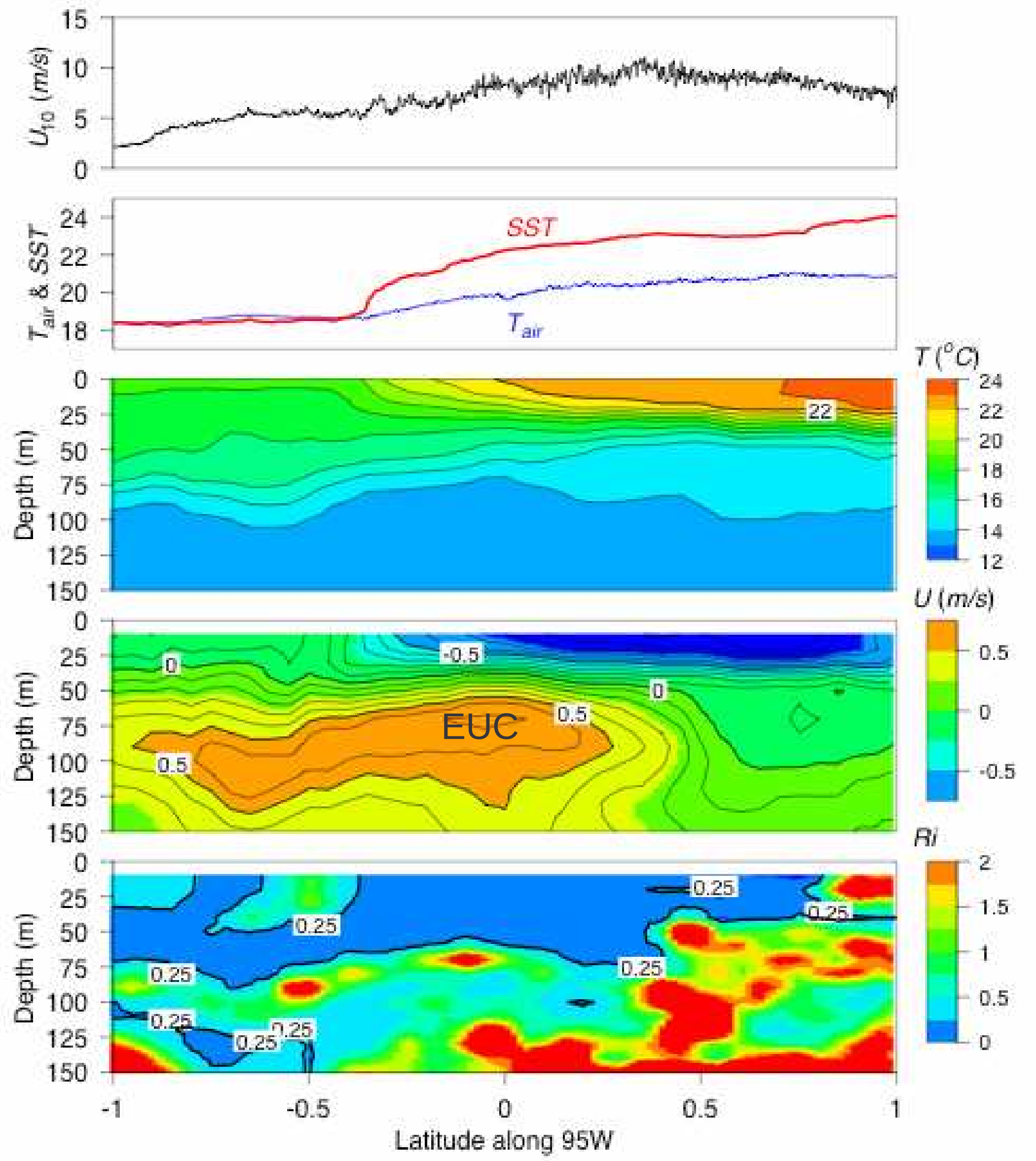
u10 m

SST, T_{air}

T(y,z)

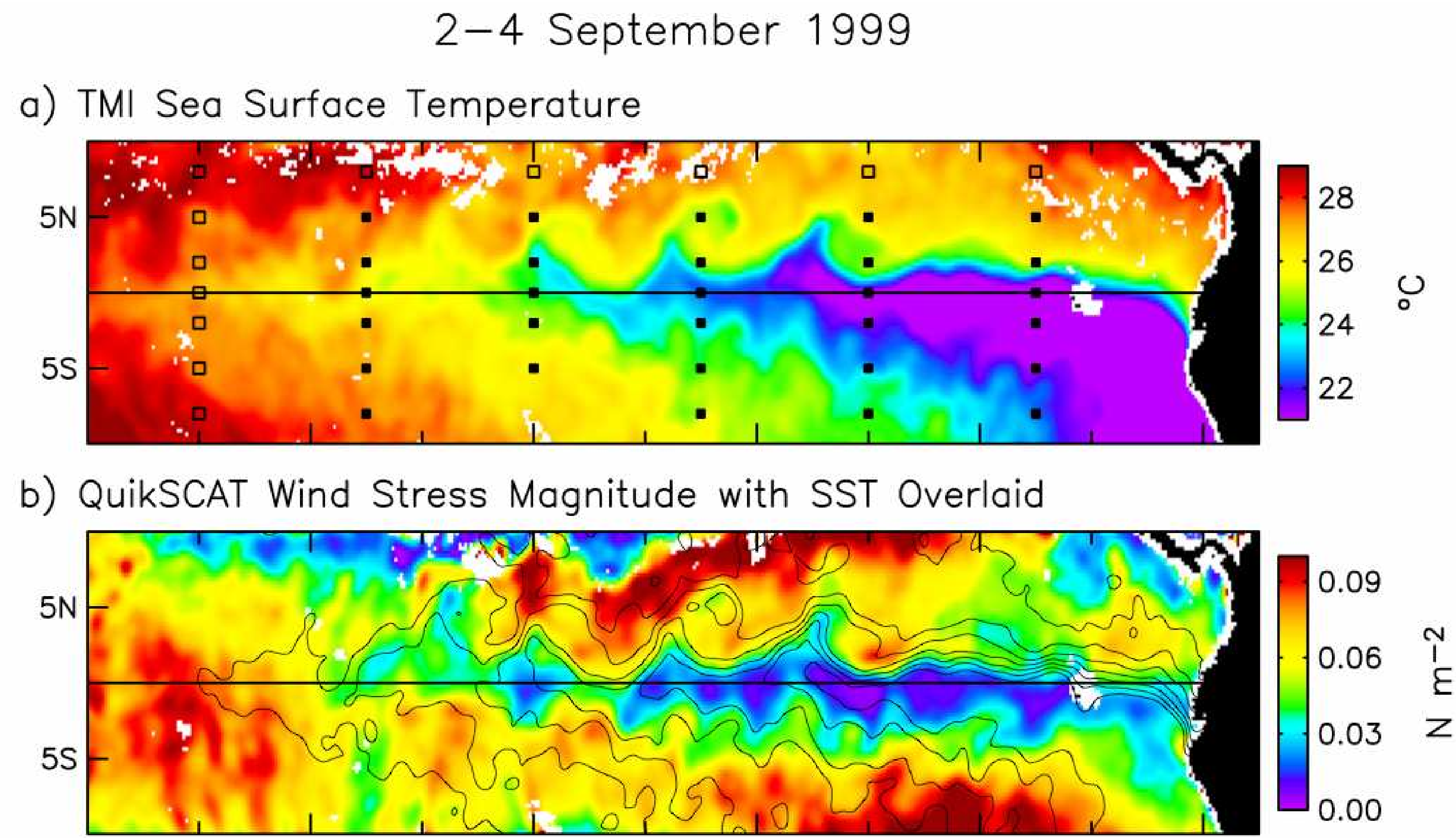
u(y,z)

Ri(y,z)



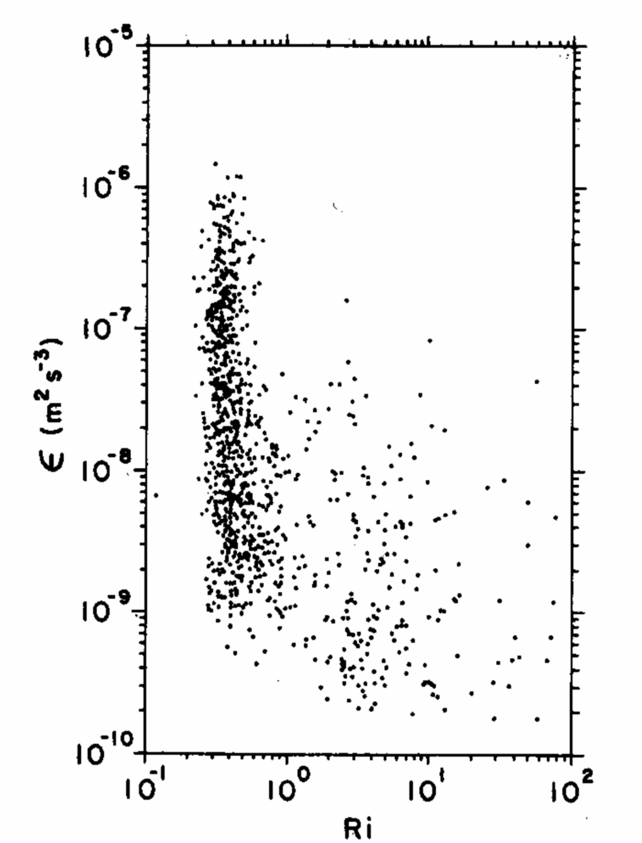
Section along 95°W during EPIC 2001. (Wijsekera, Paulson, Rudnick)

Sensitivity of winds to SST

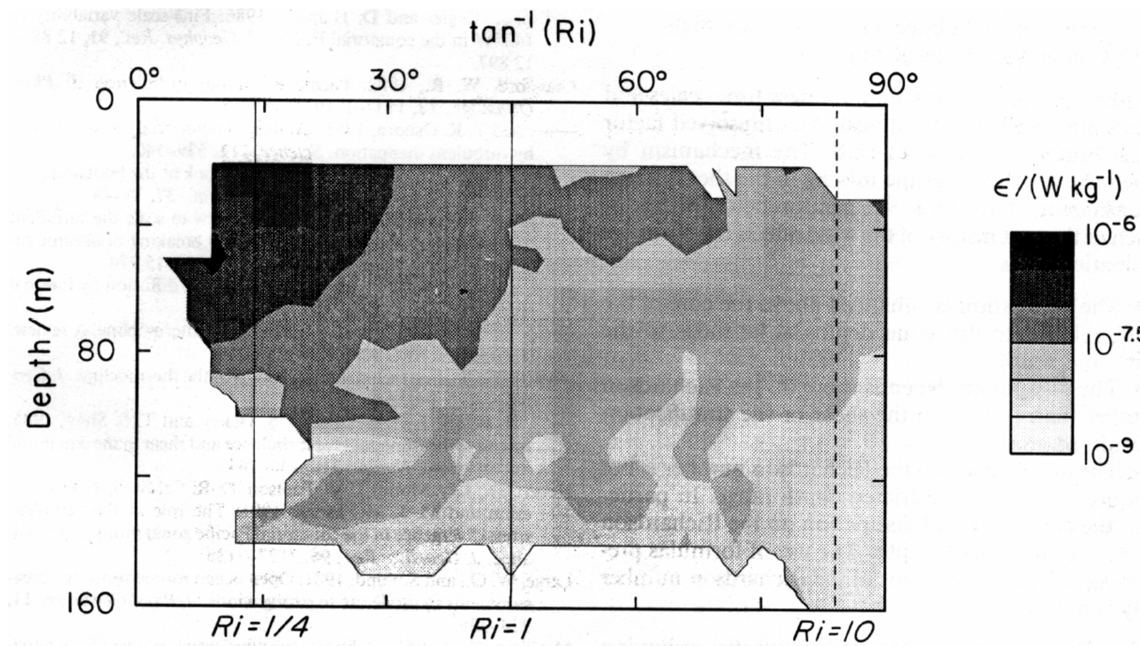


Chelton et al (2001)

Dependence of mixing on Ri is not simple



Moum etal 1989



Hebert etal 1991

Cold tongue SST is a function of the entire circulation cell