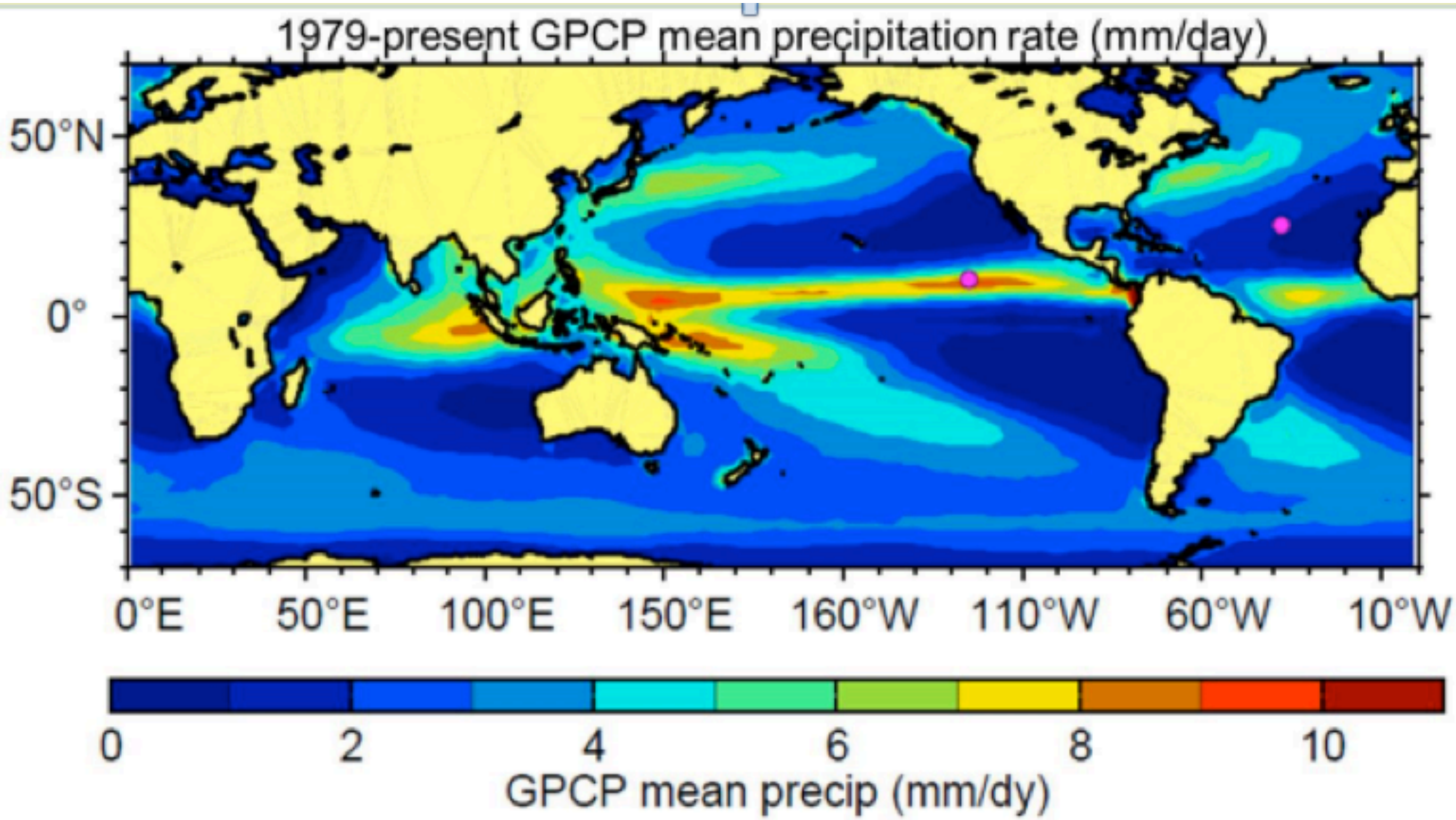
El Niño Low Salinity Equatorial Jets

Xiaolin Zhang and Allan J. Clarke

Department of Earth, Ocean and Atmospheric Science
Florida State University

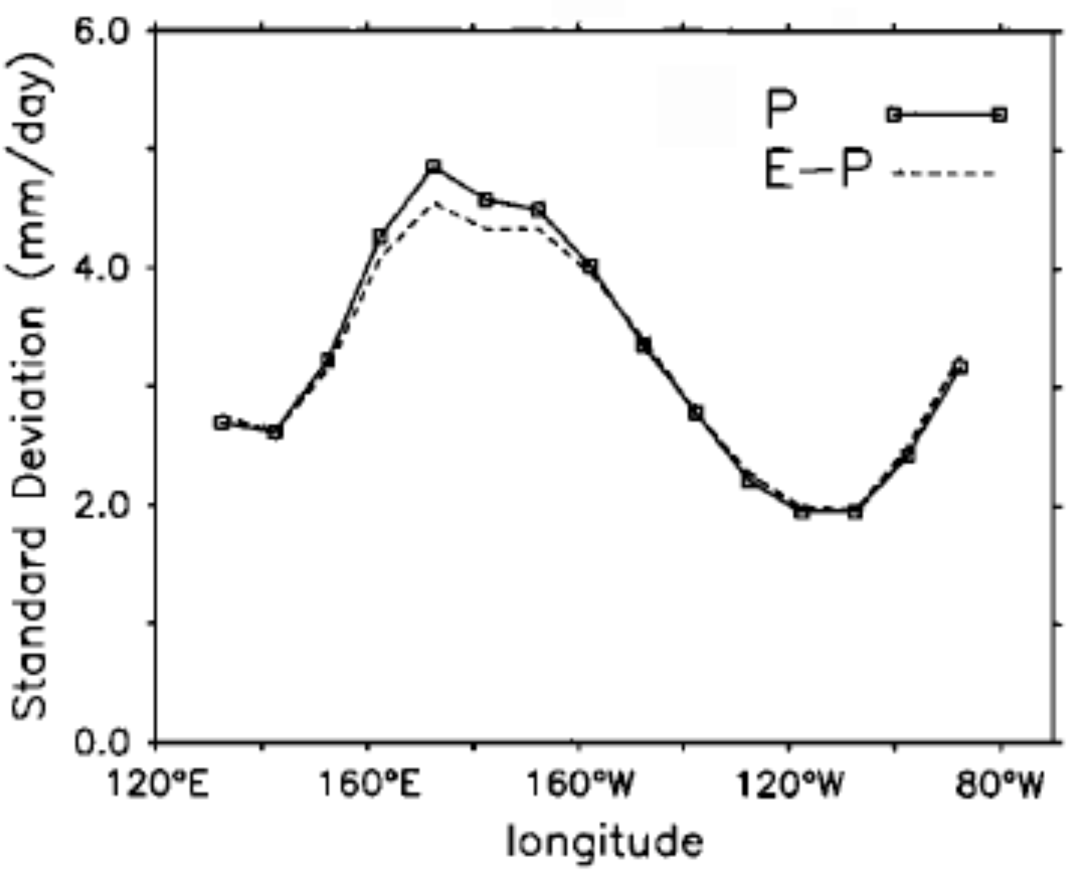
22 May 2017
Woods Hole Oceanographic Institution



Annual average precipitation from global precipitation climatology project (GPCP)
(From *Salinity Processes Upper-ocean Regional Study (SPURS-2) White Paper*, 2015)

The western equatorial Pacific: the rainiest in the world. Inside the yellow region the rainfall is greater than 100 inches/yr.

The eastern equatorial Pacific: rainfall events can also often exceed several cm/day and anomalous rainfall can easily be half a meter per year.



[From Ando and McPhaden,1997]

Standard deviations, as a function of longitude, of equatorial precipitation (P) and evaporation minus precipitation (E-P) in mm/day. $\sqrt{2}$×standard deviation is the "amplitude"$\approx 1-2\mathrm{m/yr}$

Questions

1. How does the ocean respond to this huge freshwater flux?

2. How do interannual variations in rainfall occur?

3. How does the ocean respond to this huge freshwater flux in the eastern equatorial Pacific Ocean?

1. How does the ocean respond to this huge freshwater flux?

- Mass added increases the pressure throughout the water column, i.e., the response should be barotropic (Huang and Jin 2002).

- For interannual forcing barotropic Kelvin and Rossby waves propagate all over the earth in a few weeks. Numerical models confirm this. (Lorbacher et al. 2012).

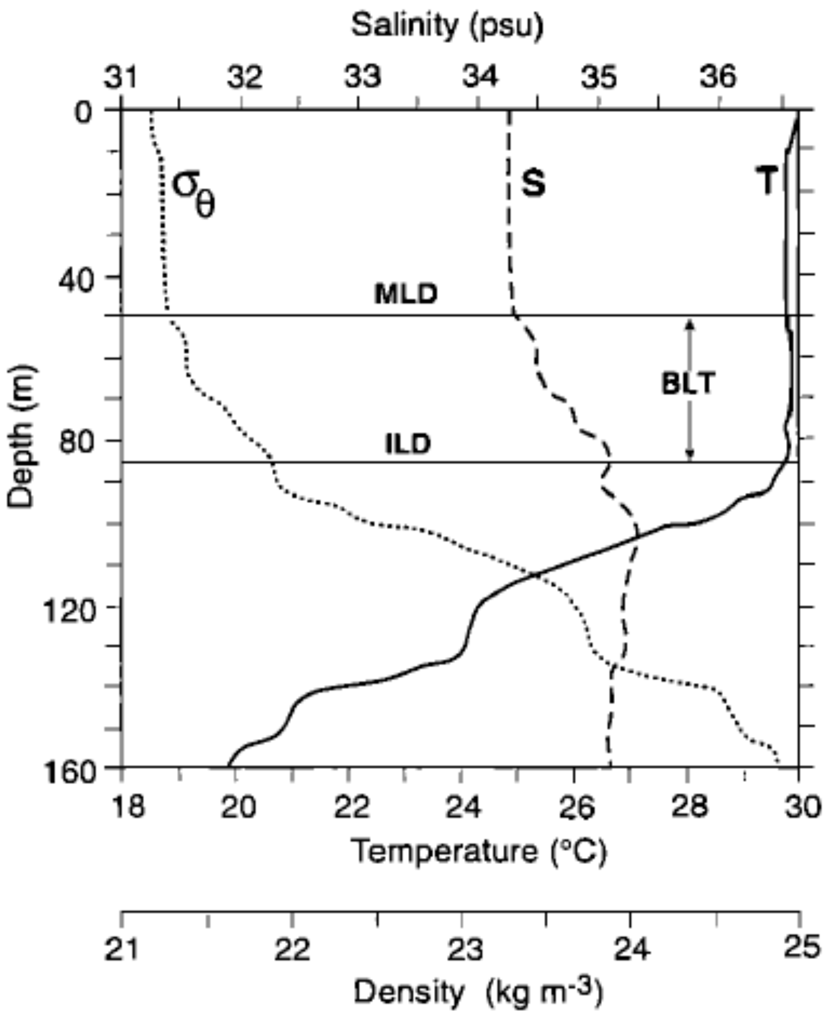
- An interannual freshwater flux over an area comparable to the continent of Australia (as in the equatorial Pacific), spread over the global ocean, causes a sea level response ≈ 1 cm.

- But the excess precipitation is compensated almost exactly by reduced interannual precipitation elsewhere in the tropics (Clarke & Kim 2005) so that globally the net freshwater flux is much smaller.

- Observations suggest the net effect ≈ few mm. Such global ENSO sea level fluctuations have been seen (Cazenave et al. 2012)

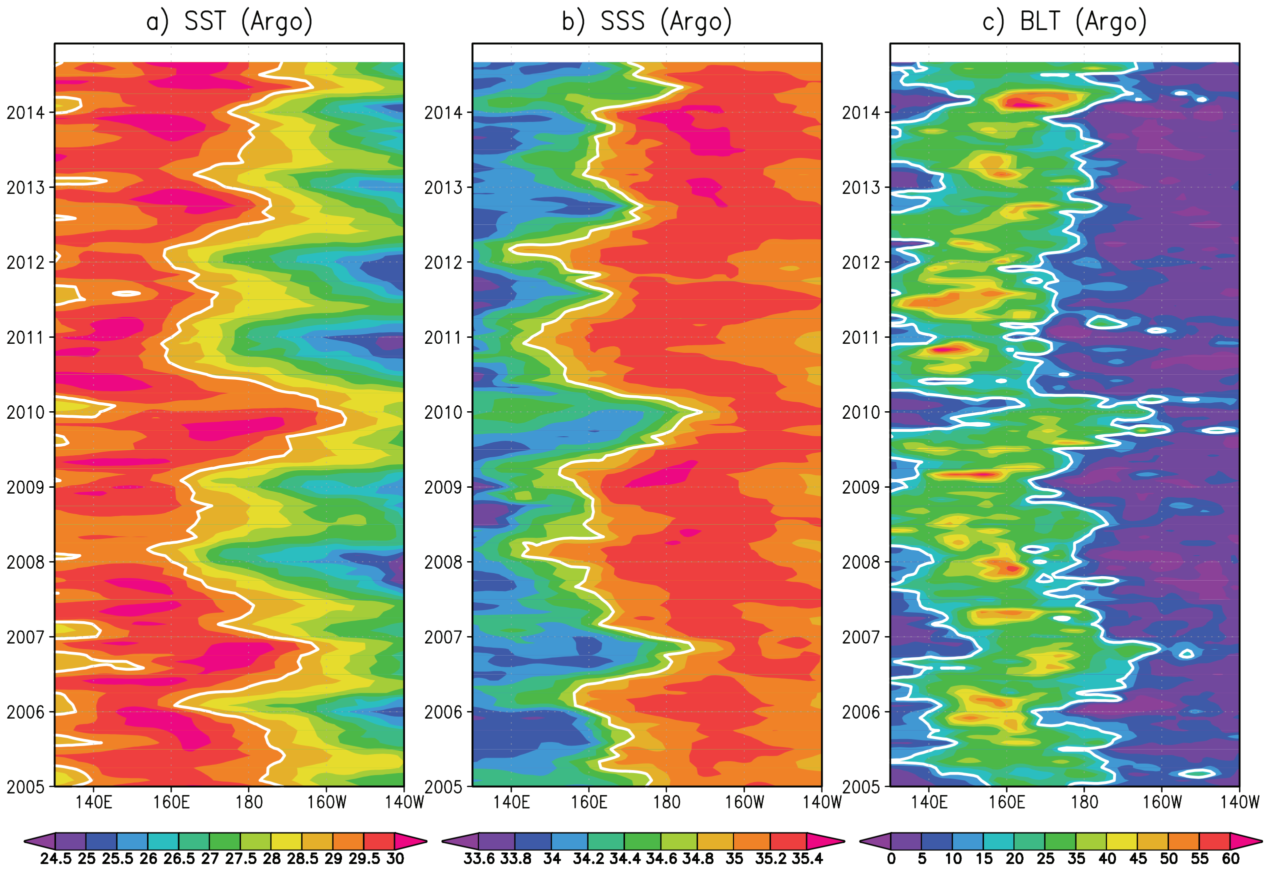
- Therefore interannual rainfall should produce a negligible response IF there were no mixing ….

- With mixing there’s a well-mixed fresher mixed layer embedded in an isothermal layer.



CTD cast showing temperature, salinity, density, and a thick barrier layer from the western equatorial Pacific. The cast was made at 0.01°S, 153.93°E on 29 April 1994 at 0427 UT (1427 LT). Temperature and salinity have been scaled respectively by the coefficients of thermal expansion and saline contraction (computed for 29°C and 35 psu) to emphasize their relative impacts on density. The MLD and ILD are indicated. The layer between these two depths is defined as the barrier layer, whose thickness (BLT) is 36m in this example (from Ando & McPhaden 1997).

2. How do interannual variations in rainfall occur?

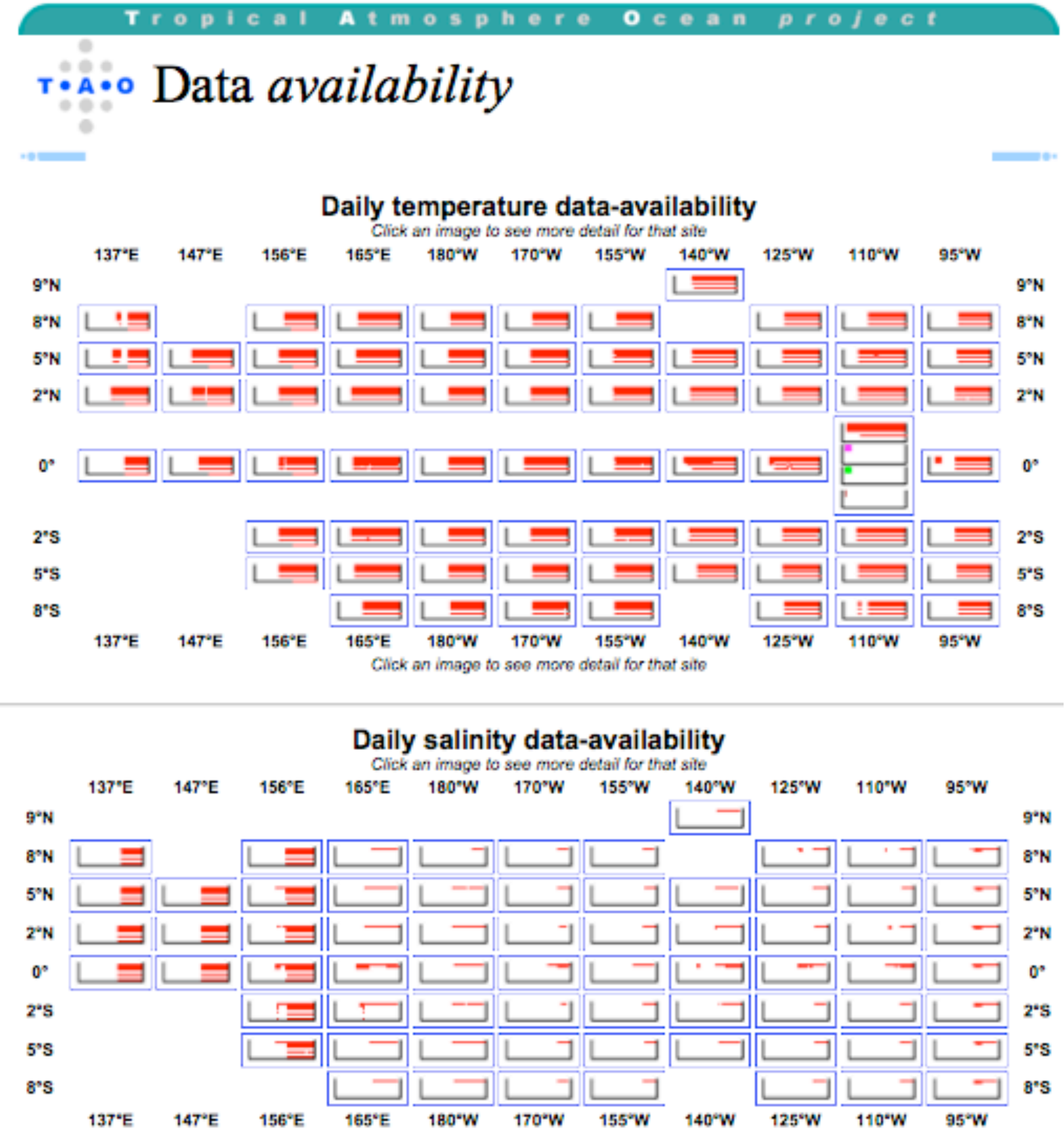


Time-longitude estimate of (a) sea surface temperature (SST), (b) sea surface salinity (SSS) and (c) barrier layer thickness from Argo floats along the equator in the western central Pacific. Units are ^oC in (a), psu in (b) and m in (c). The white lines are the 29°C, 34.8 psu and 15 m contours, respectively. [From Qu et al. 2014].

SSS and SST fronts move eastward during El Niño and westward during La Niña.

Presumably currents advect the front back and forth.

- What is the horizontal and vertical structure of these flows?
- Does the fresh water mixed layer affect this structure?



Tropical Atmosphere Ocean project

T•A•O Data *availability*

Daily temperature data-availability

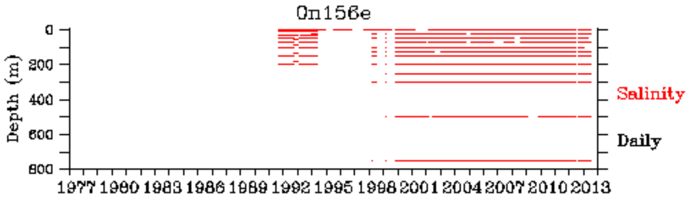
Click an image to see more detail for that site

Click an image to see more detail for that site

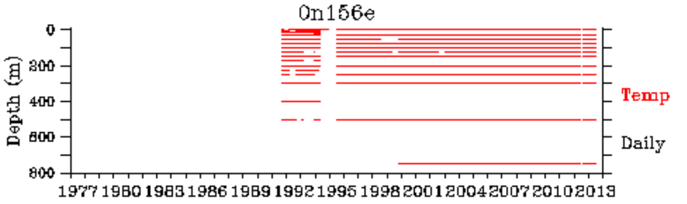
Daily salinity data-availability

Click an image to see more detail for that site

Salinity

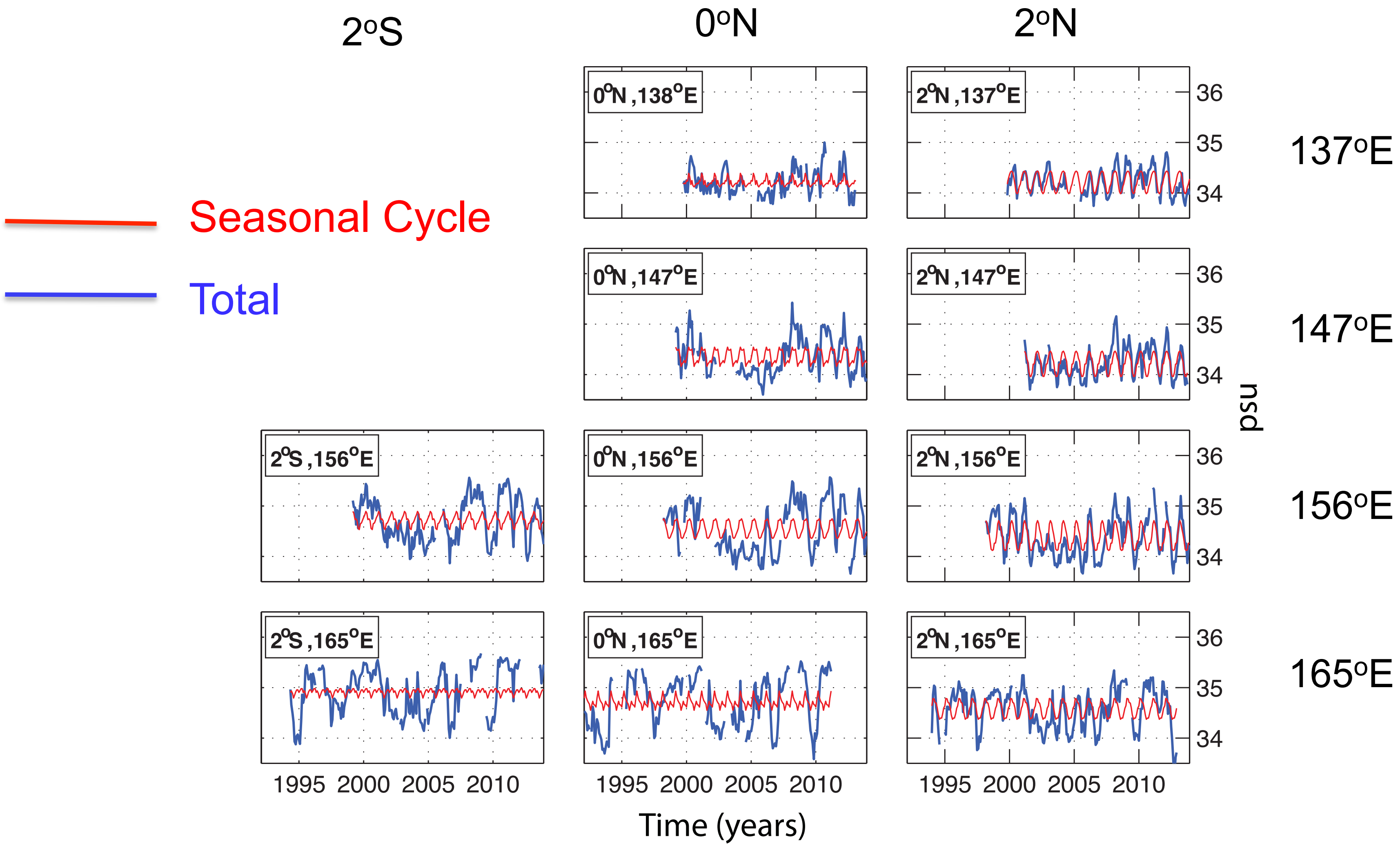


Temperature



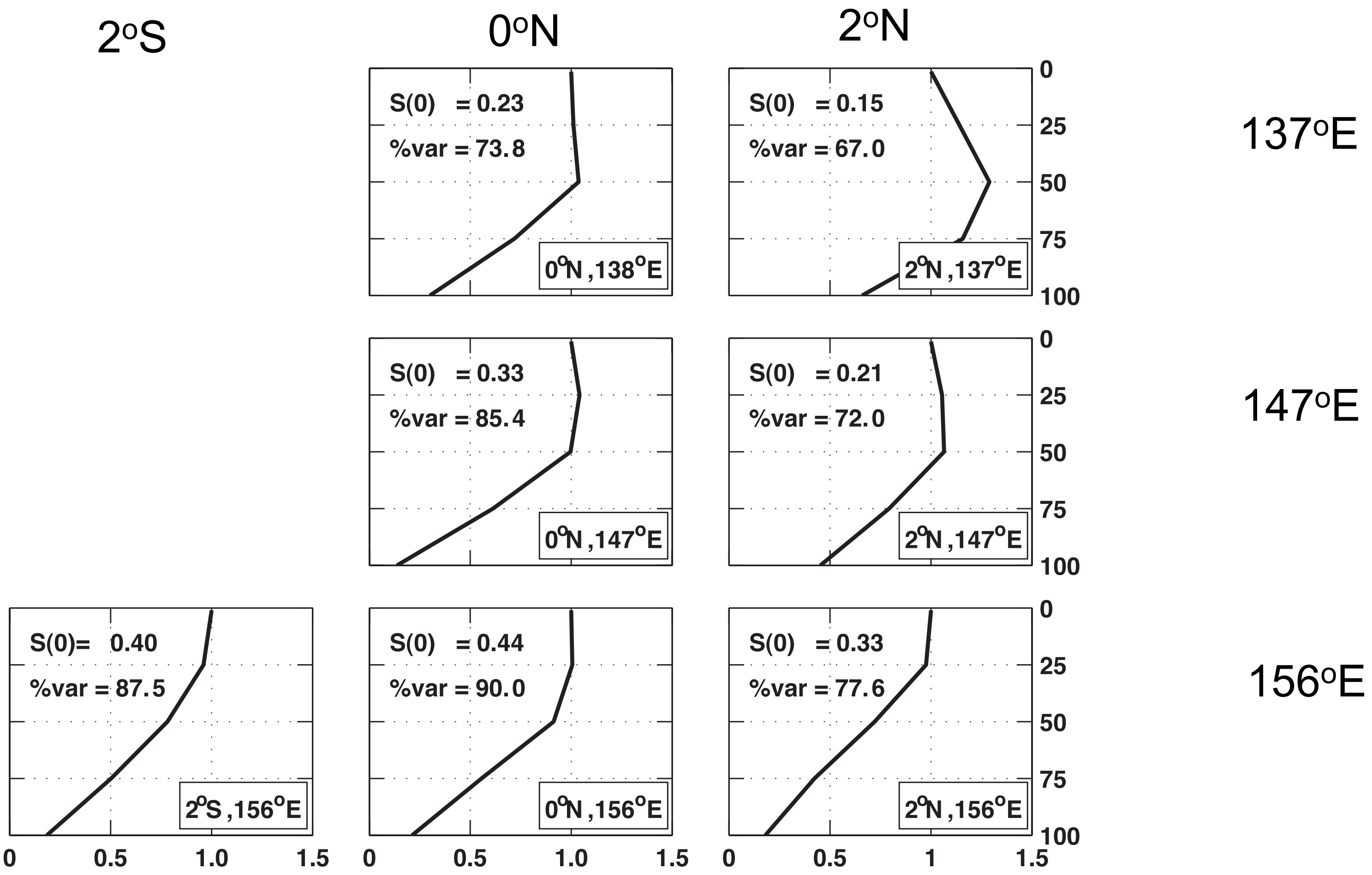
Daily temperature and salinity availability from the TAO/TRITON array. The plots above at 0^{o}N, 156^{o}E for temperature and salinity are enlargements of the corresponding panels to the left so the data availability for all sets can be gauged. From: http://www.pmel.noaa.gov/tao/disdel/fames/main.html

Observation: SSS



Monthly SSS (blue line) plotted with the monthly annual cycle (red line) from the TAO/TRITON array in the western equatorial Pacific at 2°S, 0° and 2°N. This figure was constructed from data obtained from the TAO project office PML NOAA website (http://www.pmel.noaa.gov/tao/disdel/frames/main.html).

Observation: EOF of S’(z,t)

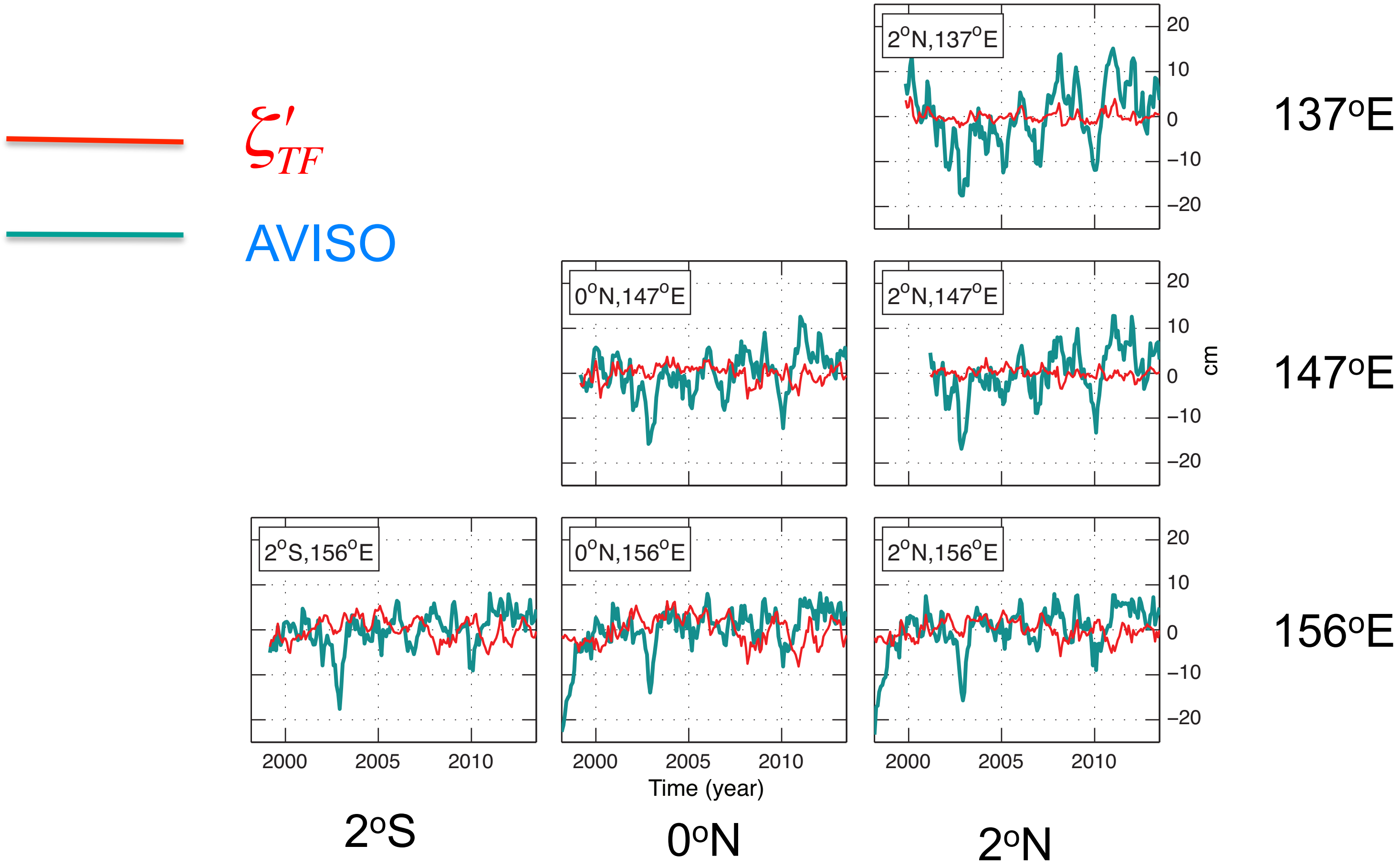


First EOF structure functions showing the depth dependence of S’ for seven stations near the equator in the TRITON western Pacific array. In each case the structure function has been normalized by its surface value so that its depth dependence can be easily seen. The % variance described by the first EOF, the station location and the amplitude (in psu) of the SSS’ are marked on each panel. Here and elsewhere each principal component is non-dimensional and has a variance 0.5 so that the corresponding dimensional EOF structure function is indicative of the amplitude of the variability.

Knowing $S'(x,y,z,t)$ and $T'(x,y,z,t)$ we can calculate the dynamic height ζ_{TF}' relative to the isothermal layer depth (about 80m) and thus estimate the effect of salinity on the SSH.

ζ_{TF}' is dominated by the salinity contribution ζ_F'.

Comparison of Sea Level Anomalies



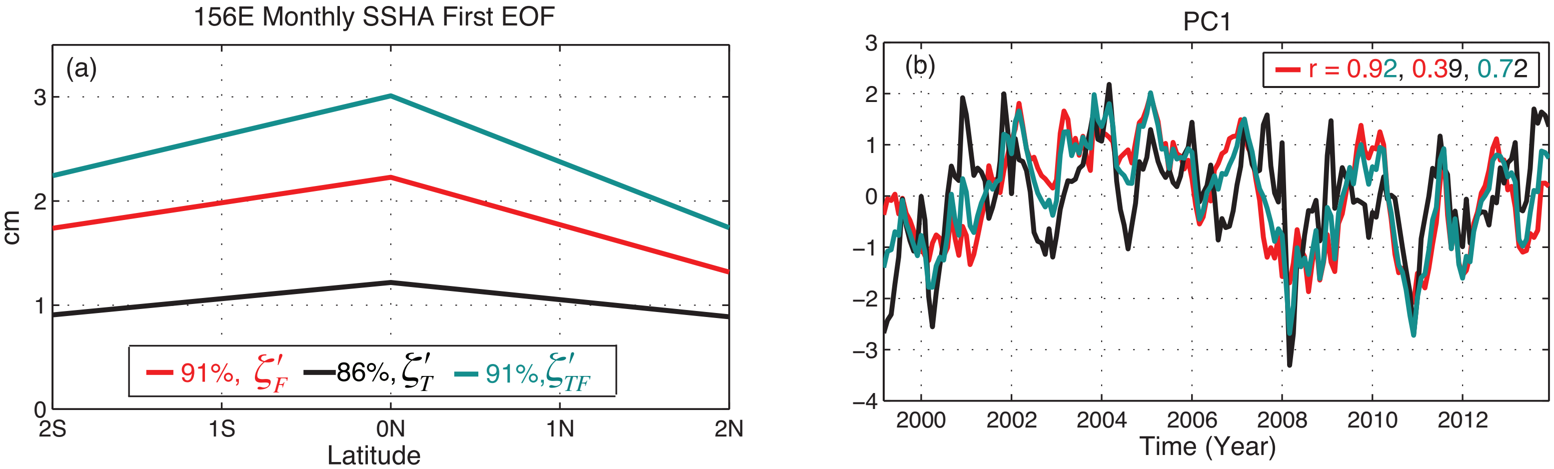
Mostly, ζ'_{TF} is much smaller than η', the total sea level η' also includes the dynamic height contribution from the thermocline beneath the ILD).

We can calculate the corresponding geostrophic currents from

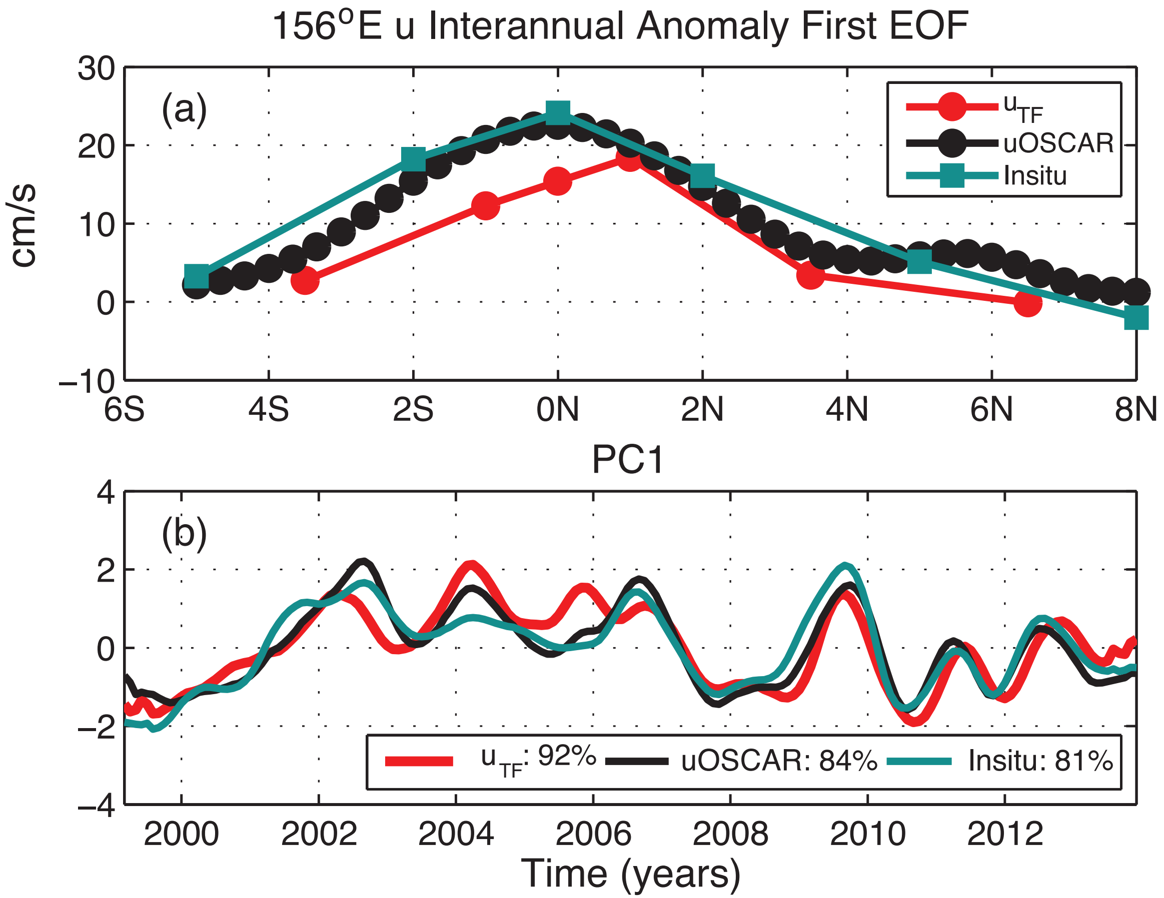
$$\boxed{fu'_{TF} = -g\left(\zeta'_{TF}\right)_y \qquad (f \neq 0)} \quad \textbf{(1)}$$

and

$$\boxed{\beta u'_{TF} = -g\left(\zeta'_{TF}\right)_{yy} \qquad (f = 0)} \quad \textbf{(2)}$$



Comparison of Surface Current



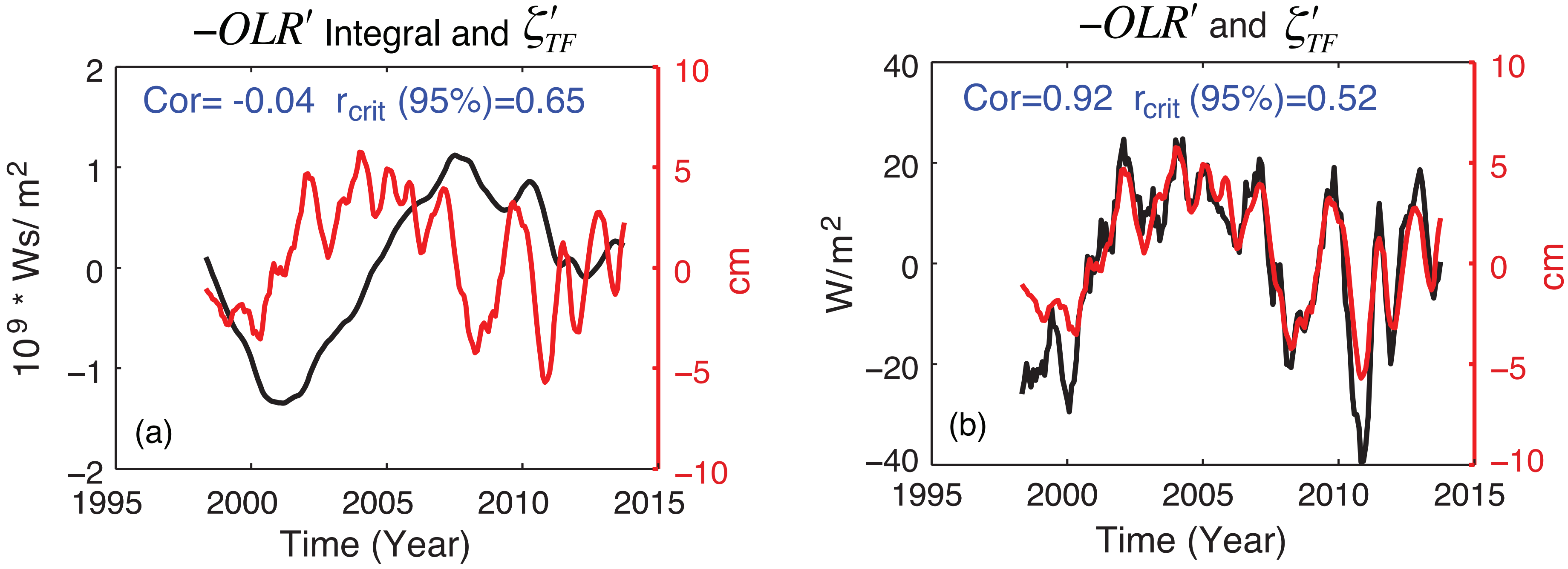
ζ'_{TF} is generally much smaller than η', yet u'_{TF} is comparable to u' !

- The zonal back and forth movement of the warm/fresh pool is associated geostrophically with $\zeta_{TF}^{'}$.

- Does the interannual rainfall cause $\zeta_{TF}^{'}$?

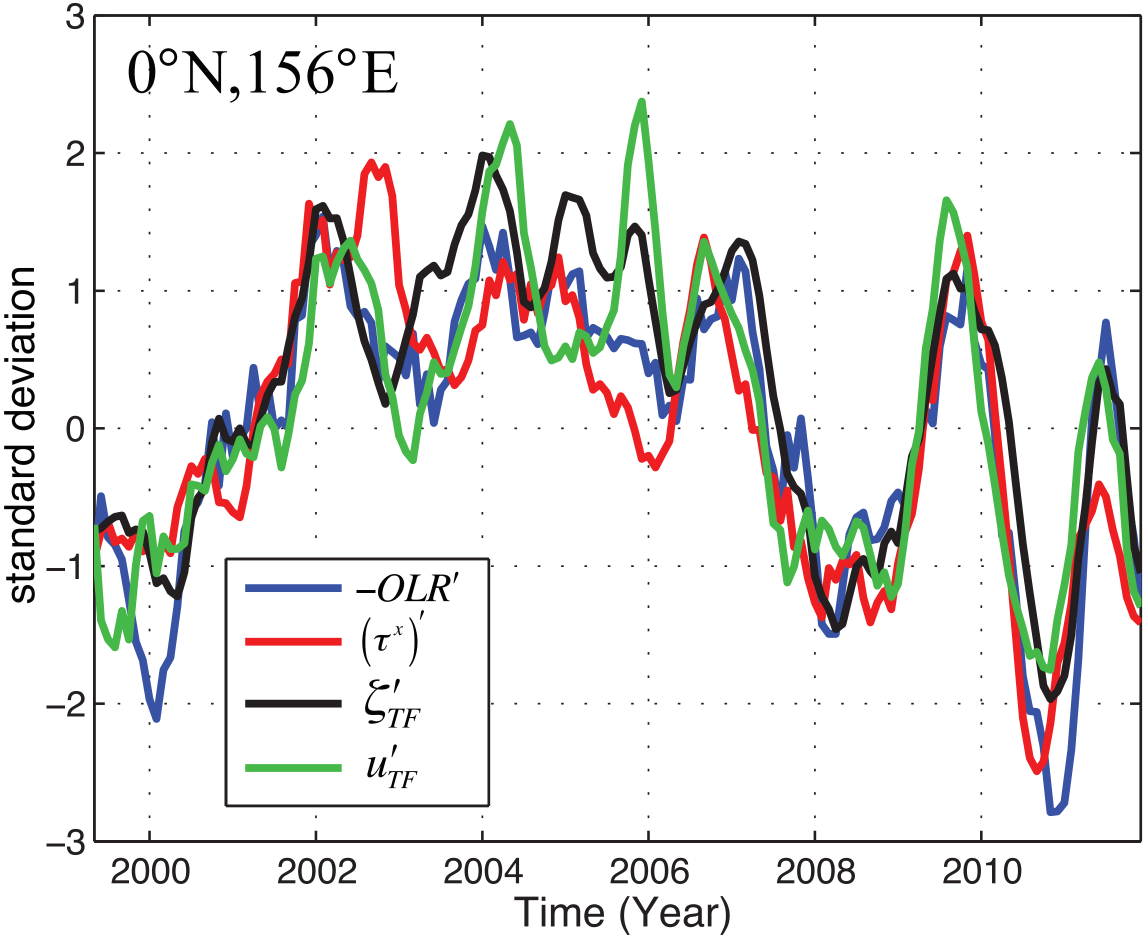
- If it did, then $\zeta_{TF}^{'}$ would be proportional to the total freshwater added, and therefore to a time integral of the rainfall rate. This is proportional to a time integral of –OLR’. Is $\zeta_{TF}^{'}$ proportional to $\int_0^t (-OLR')\,dt_*$?

No! ζ'_{TF} is proportional to the rainfall *rate*.



- But then how are ζ_{TF}' and u_{TF}' generated?

- One possibility is that eastward wind stress $(\tau^x)'$ anomalies drive eastward current anomalies (u_{TF}' and u_F') and, by geostrophy ζ_{TF}' and ζ_F' . At the same time, anomalous deep atmospheric convection (-OLR') drives anomalous eastward winds and [Clarke 1994] in this way, ζ_{TF}' , ζ_F' and –OLR' are linked.



The 5-month running mean of monthly –OLR' (blue) $[(\tau^x)']$ (red), ζ'_{TF} (black), and u'_{TF} (green) at 0°, 156°E. All time series have been normalized by their standard deviations. These standard deviations are 13.9 Wm^{-2} (OLR'), 15.9mPa$[(\tau^x)']$, 2.9 cm (ζ'_{TF}), and 22.0 cm s^{-1} (u'_{TF}).

O.K., $\zeta_{TF}^{'}$, $u_{TF}^{'}$, $(\tau^{x})'$ and (-OLR)’ all fit together well if $(\tau^{x})'$ drives $u_{TF}^{'}$ and (-OLR)’ drives $(\tau^{x})'$. All are associated with equatorial warm/fresh pool displacement.

But why does a displacement occur in the first place?

Coupled ocean-atmosphere instability

(Gill and Rasmusson 1983; Clarke 2014).

Small eastward displacement of the warm/fresh pool implies anomalous deep atmospheric convection which implies anomalous eastward wind stress anomalies (Clarke 1994) which implies anomalous u'_{TF}, which implies further eastward displacement, etc.

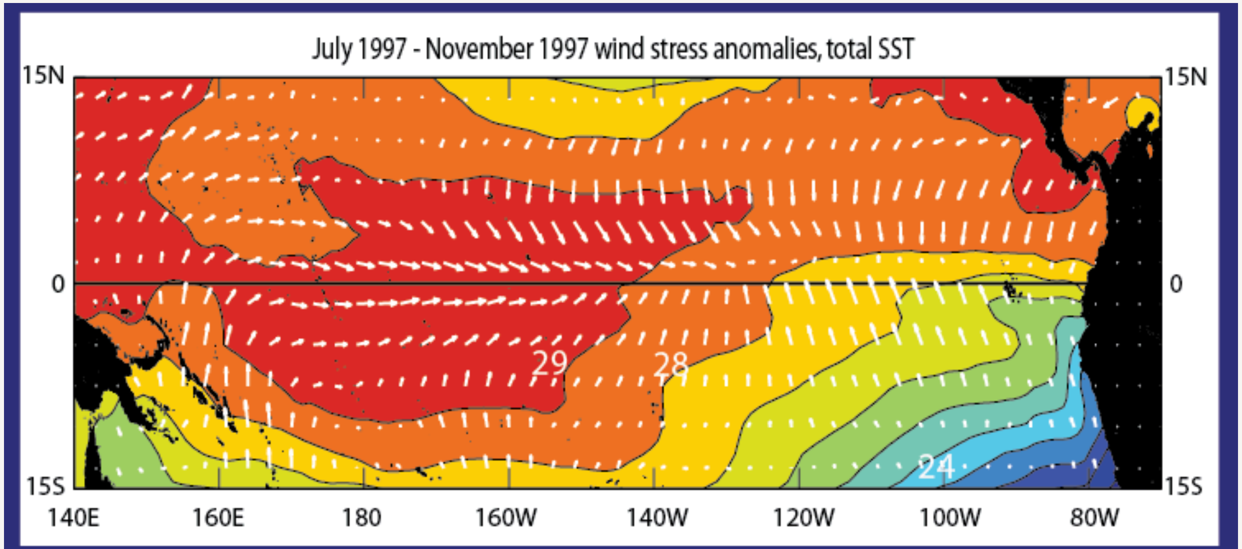
What stops the instability?

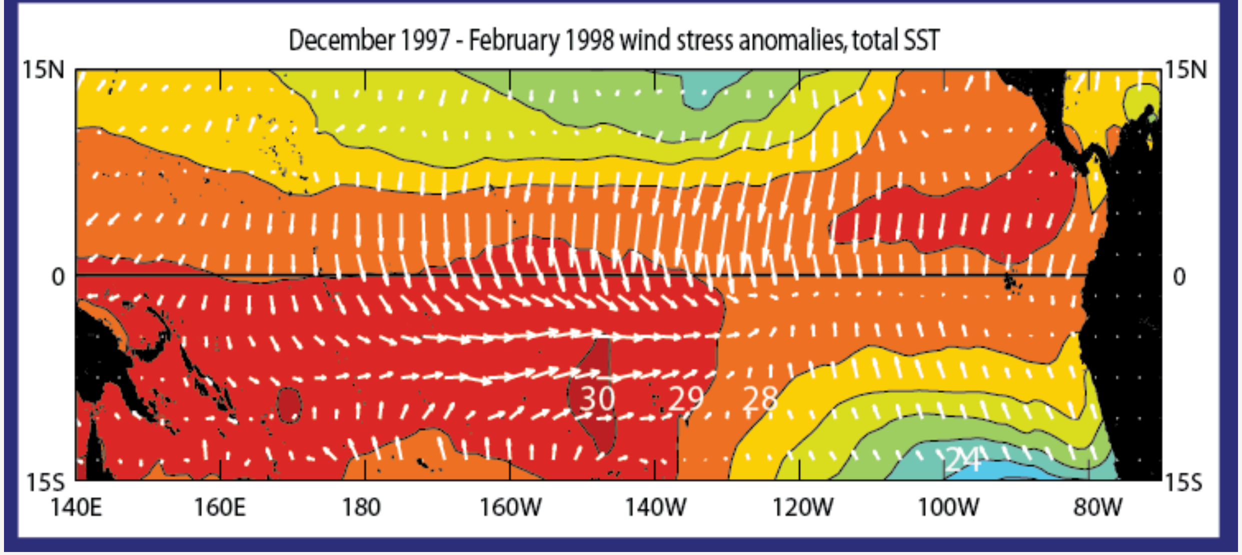
Several mechanisms have been proposed.

Probably the dominant one is that at its peak in December/January, warm water moves south of the equator with the overhead position of the sun.

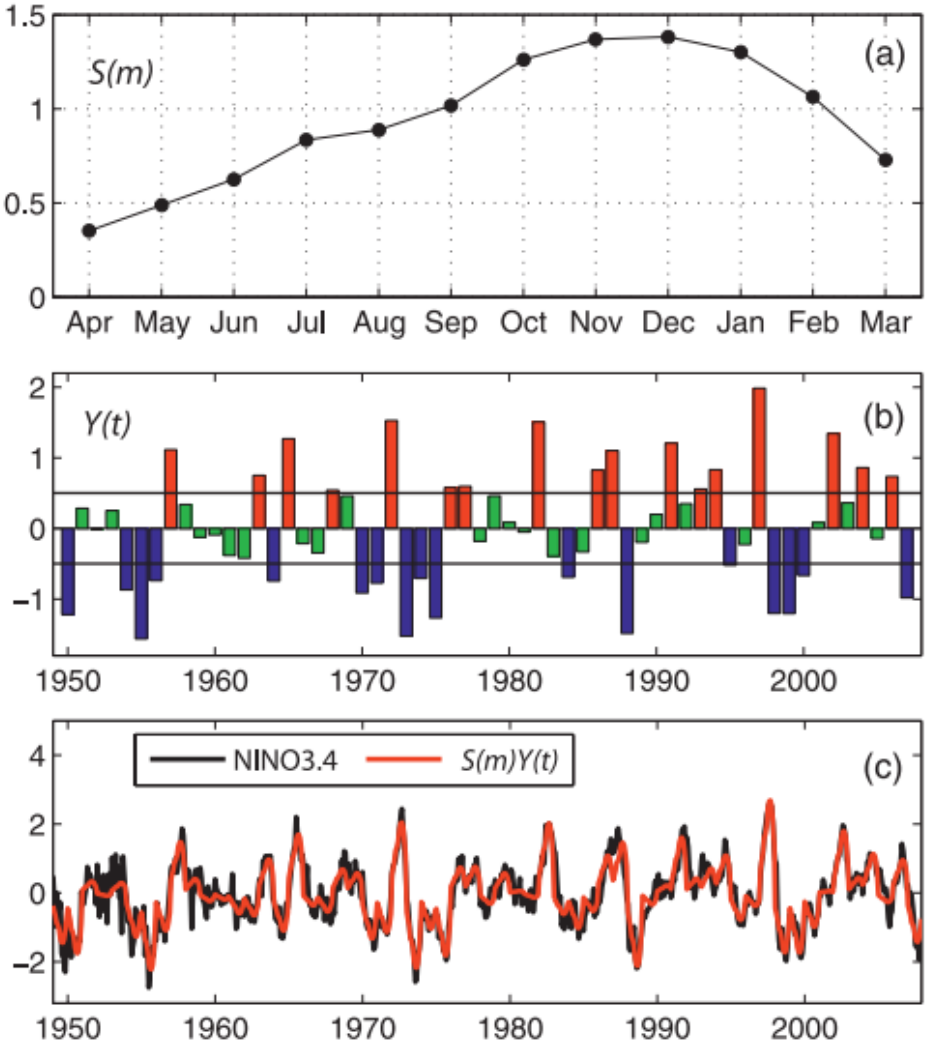
Deep atmospheric convection and thus the wind anomalies depend on total SST and move southward of the equator with the warmer water.

This kills the eastward push along the equator and phase-locks El Niño to the seasonal cycle.


July 1997 - November 1997 wind stress anomalies, total SST

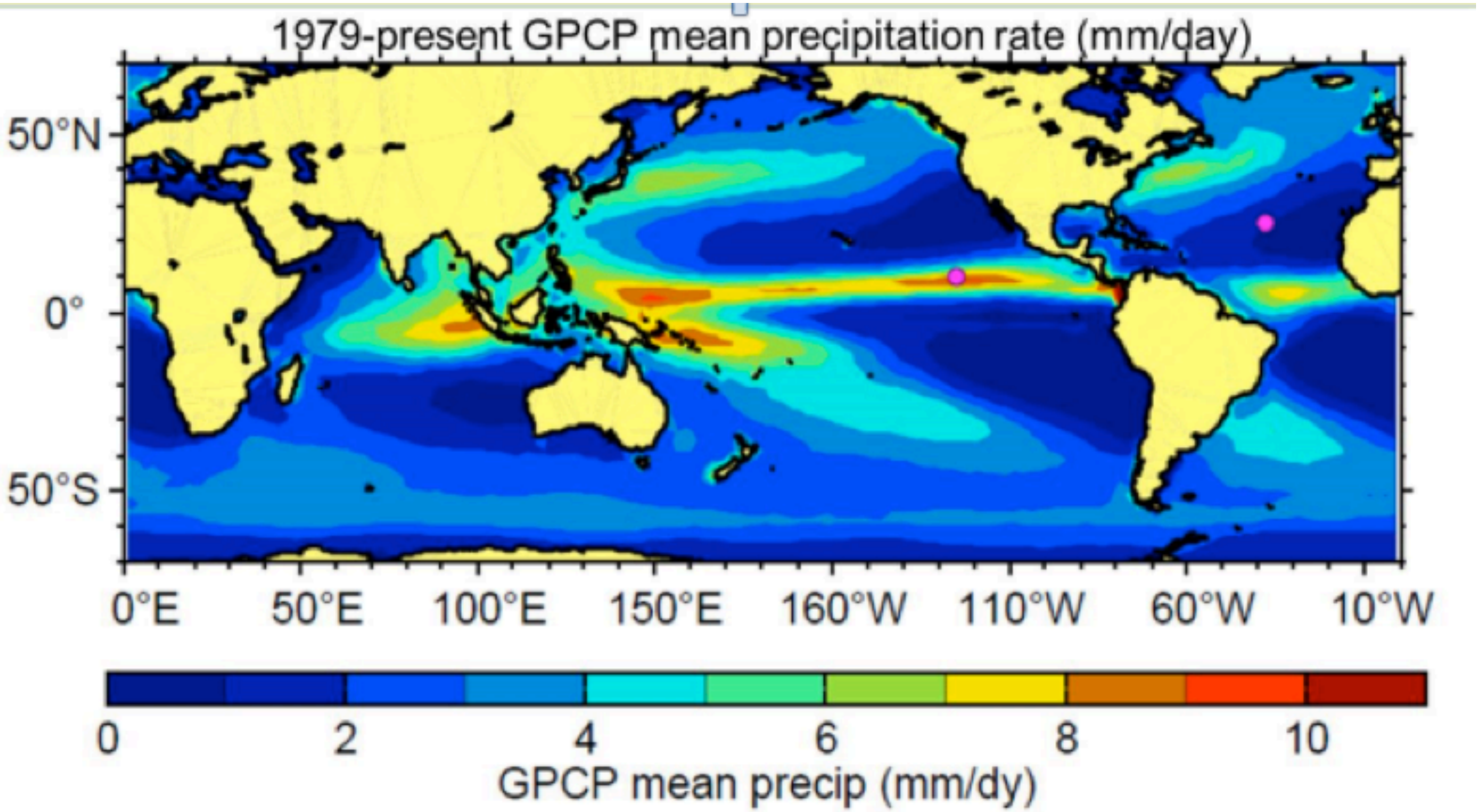

December 1997 - February 1998 wind stress anomalies, total SST

El Niño phase locked to the seasonal cycle. Stops growing in December when wind anomalies move south of the equator.



[From Bunge and Clarke, 2009]

3. How does the ocean respond to this huge freshwater flux in the eastern equatorial Pacific Ocean?



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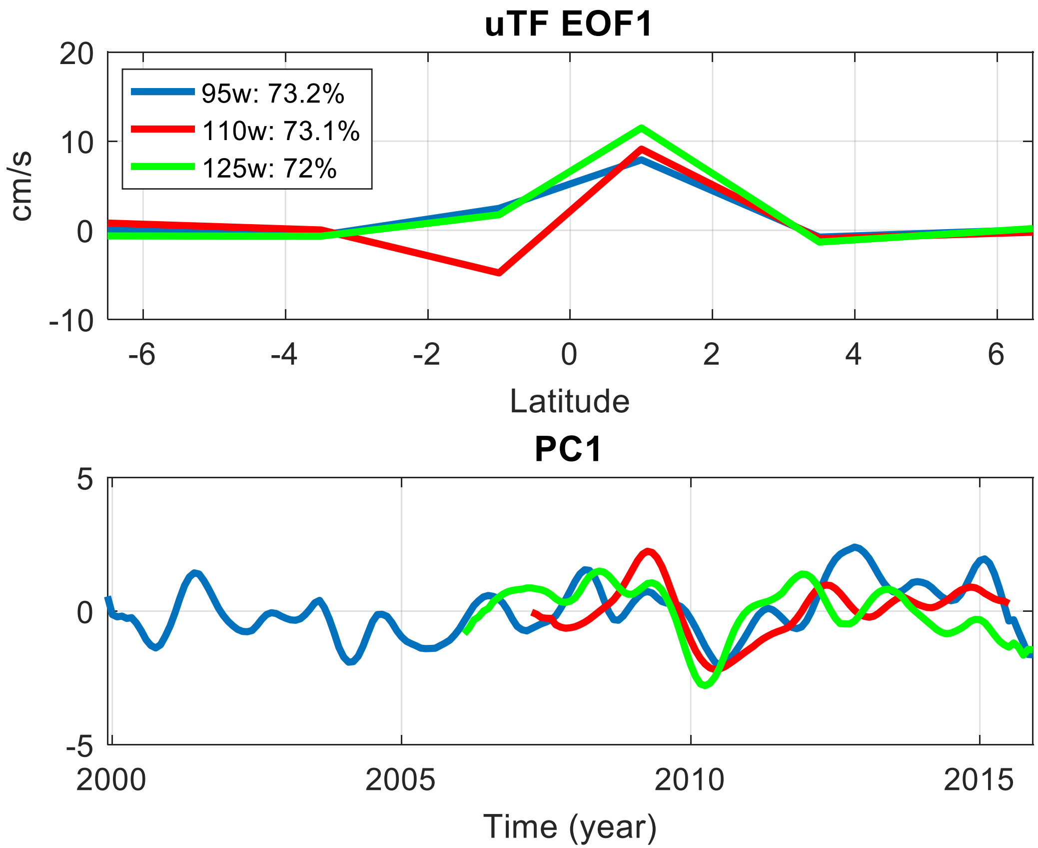
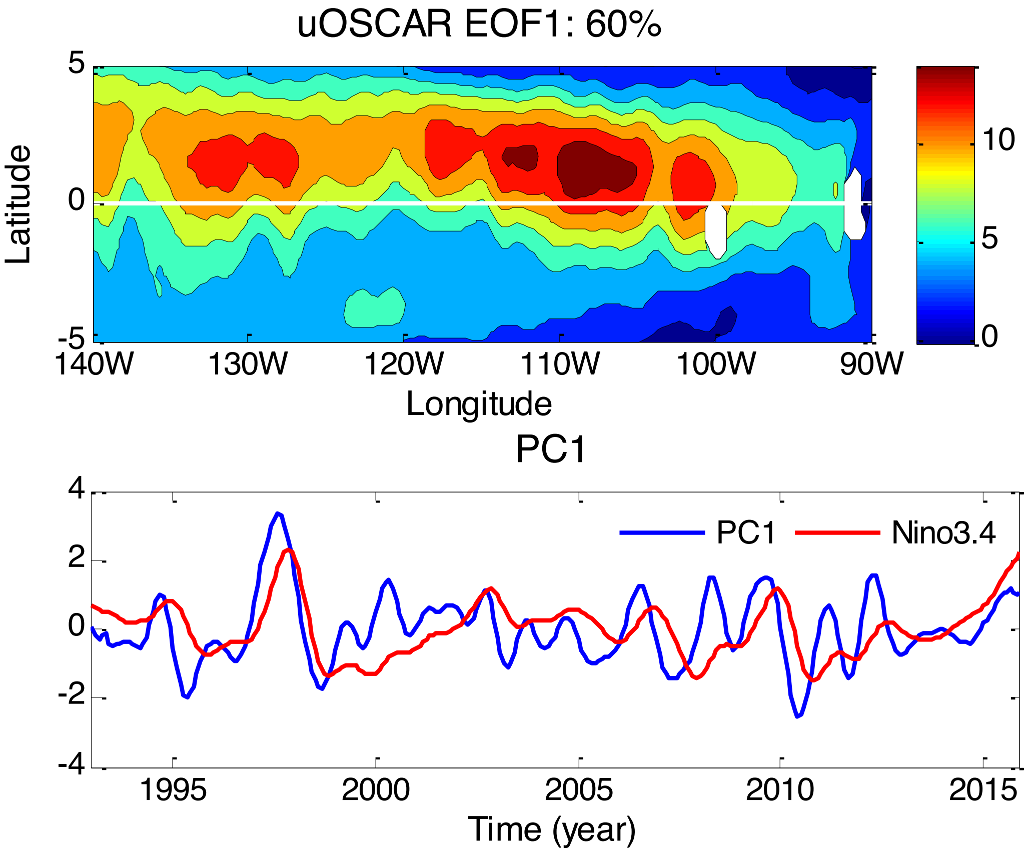
The Meridional Structure of u'_{TF}



The low-salinity interannual zonal flow centered at 1°N that stretches for thousands of km.

uOSCAR in the Eastern Pacific Ocean



The zonal flow is centered at 1°N and the first principal component of u leads Nino3.4 by 4 months.

Summary

1. Fresh water jets are key to the zonal movement of the warm pool and El Niño/La Niña. $u_{TF}^{'} \approx u_{F}^{'} \approx u'$ but $\zeta_{TF}^{'}$ is generally much less than η'.

2. Numerical models should correctly resolve the fresher mixed layer embedded in the isothermal layer to correctly model El Niño/Southern Oscillation (ENSO) dynamics.

3. Preliminary analysis in the eastern equatorial Pacific suggests that there is a previously unrecognized interannual zonal freshwater flow at 1^{o}N that stretches for thousands of kilometers. What causes this flow? How is it related to El Niño?

Thank you!

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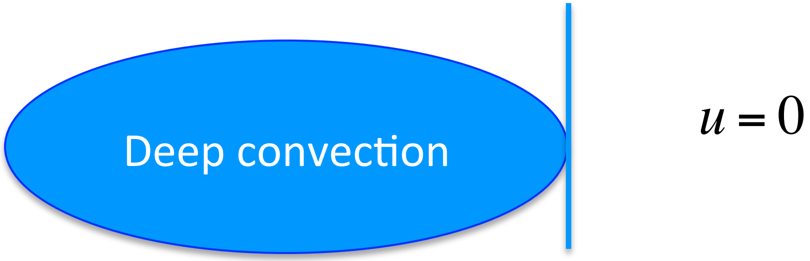
Why is the wind westerly under deep atmospheric convection? (Clarke 1994)

- Frictional atmospheric surface boundary layer model.
- Atmospheric response consists of damped equatorial Kelvin and Rossby waves.
- North south scale of anomalous deep convection is about 10°S to 5°N. Kelvin wave scale approximately 40°S to 40°N. Scale mismatch, mainly damped Rossby waves generated.

Appendix_2



Rossby waves decay westward. Therefore no response east of forcing. Therefore $u = 0$ at eastern end of forcing region.

Part of surface convergence is zonal. $u_x < 0$ and $u = 0$ at the eastern end of forcing region implies $u > 0$ in deep convection region.