

Sea Surface Salinity Variability and ENSO

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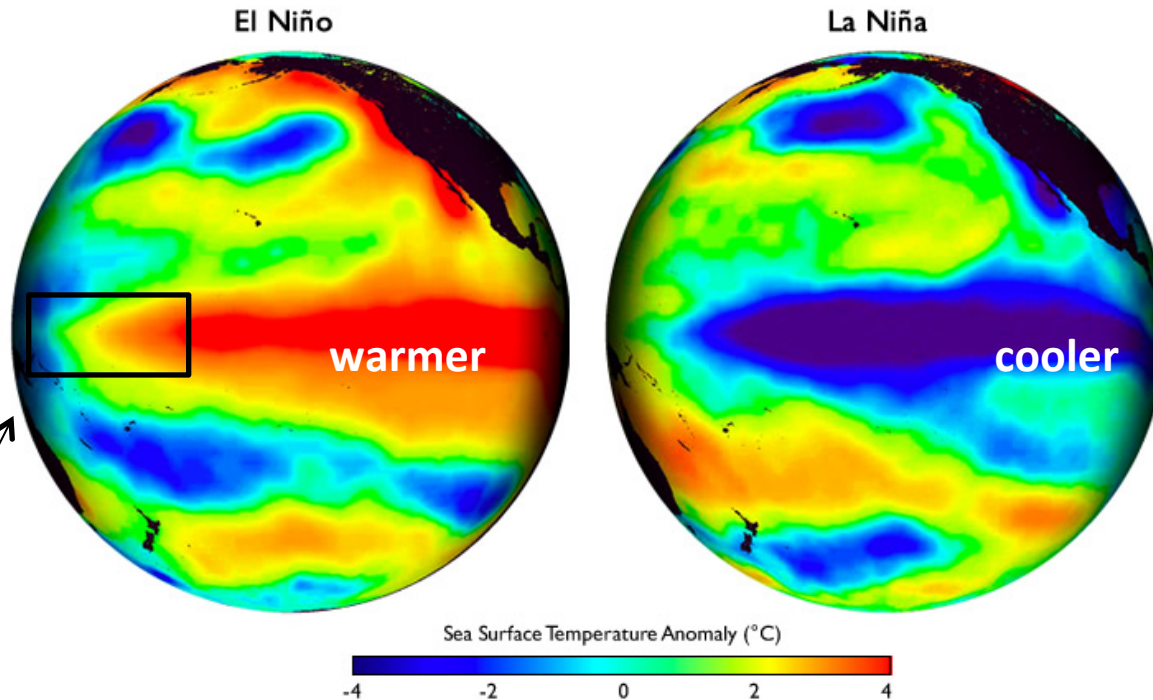
In Collaboration with

Y. T. Song, C. Maes, and J-Y. Yu

Seattle, November 11, 2014

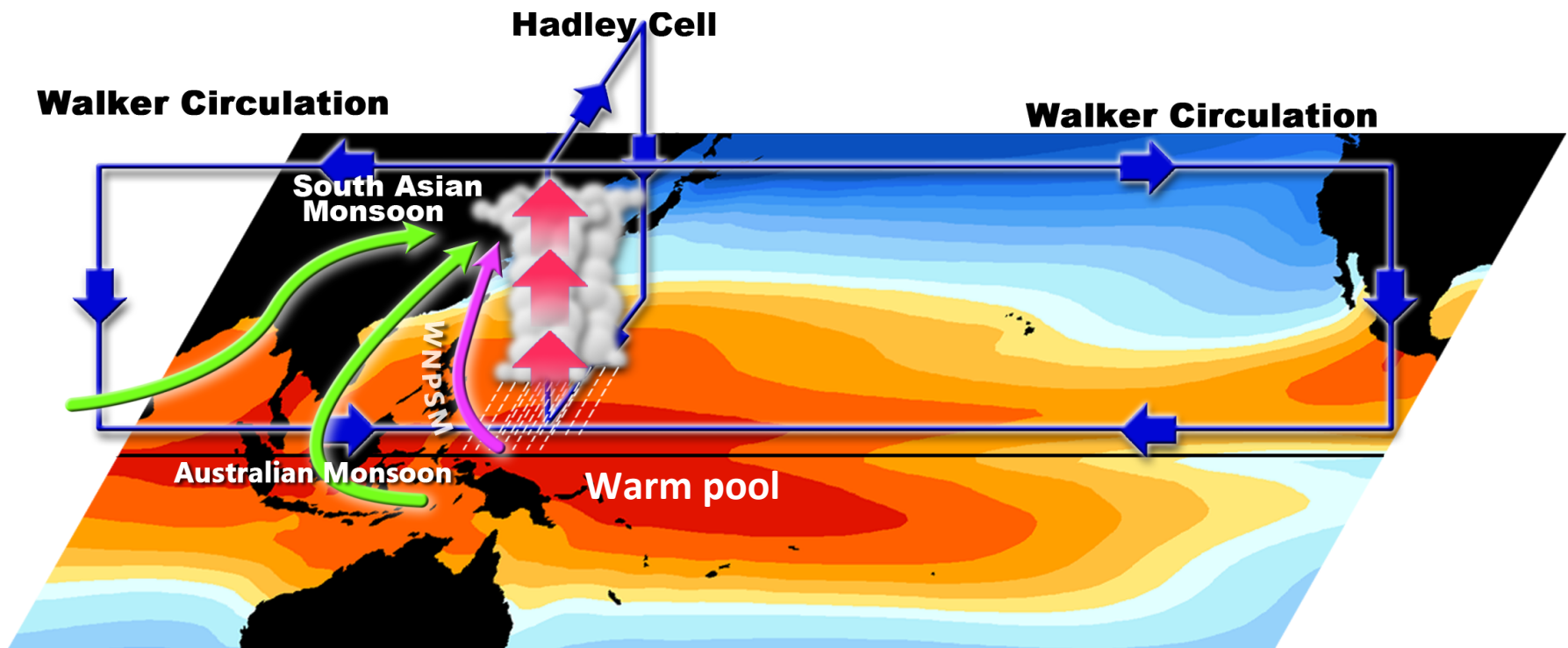
About El Niño

El Niño is a band of anomalously warm ocean water temperatures that periodically develops off the western coast of South America and can cause climatic changes across the Pacific Ocean-----[Wikipedia](#)



El Niño actually starts from the western equatorial Pacific.

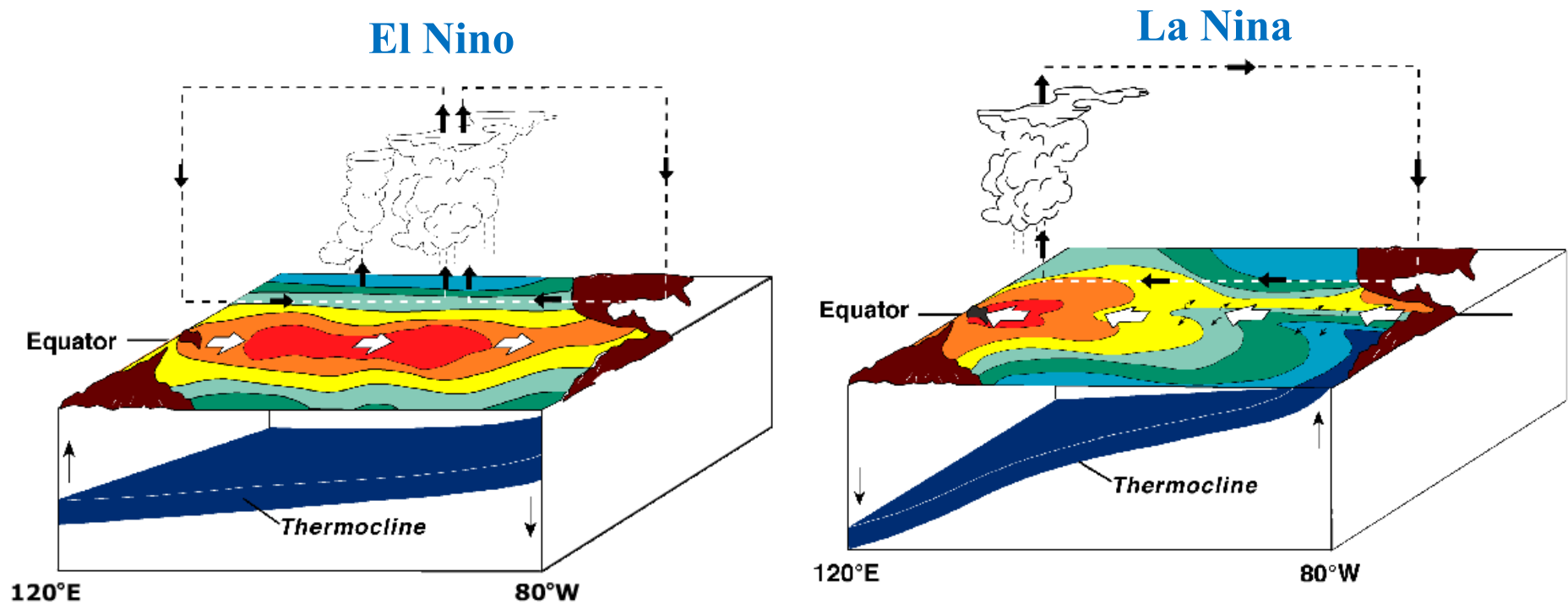
In the western equatorial Pacific, SST is $>28^{\circ}\text{C}$ (warm pool), which is the spawning area of El Niño.



From NPOCE Science and Implementation Plan

The warm pool moves eastward during El Nino and westward during La Nina

---- Its zonal displacement is a key characteristic of ENSO.

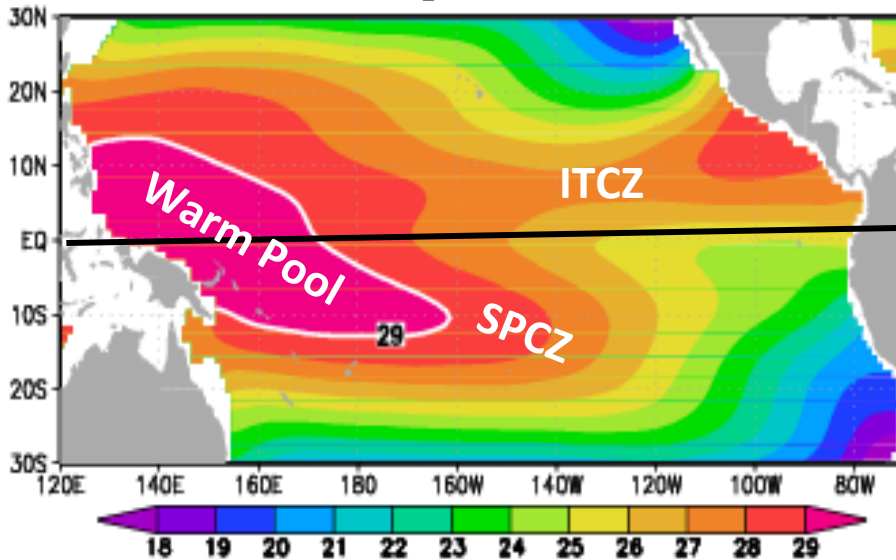


Schematic Diagram

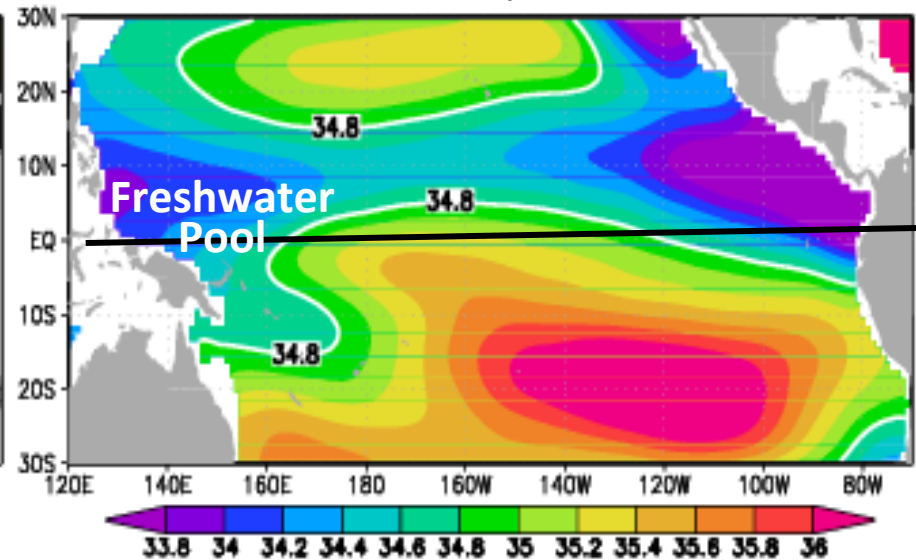
The western Pacific warm pool

----is characterized by a strong SSS front at its eastern edge. .

Sea surface temperature from WOA09



Sea surface salinity from WOA09



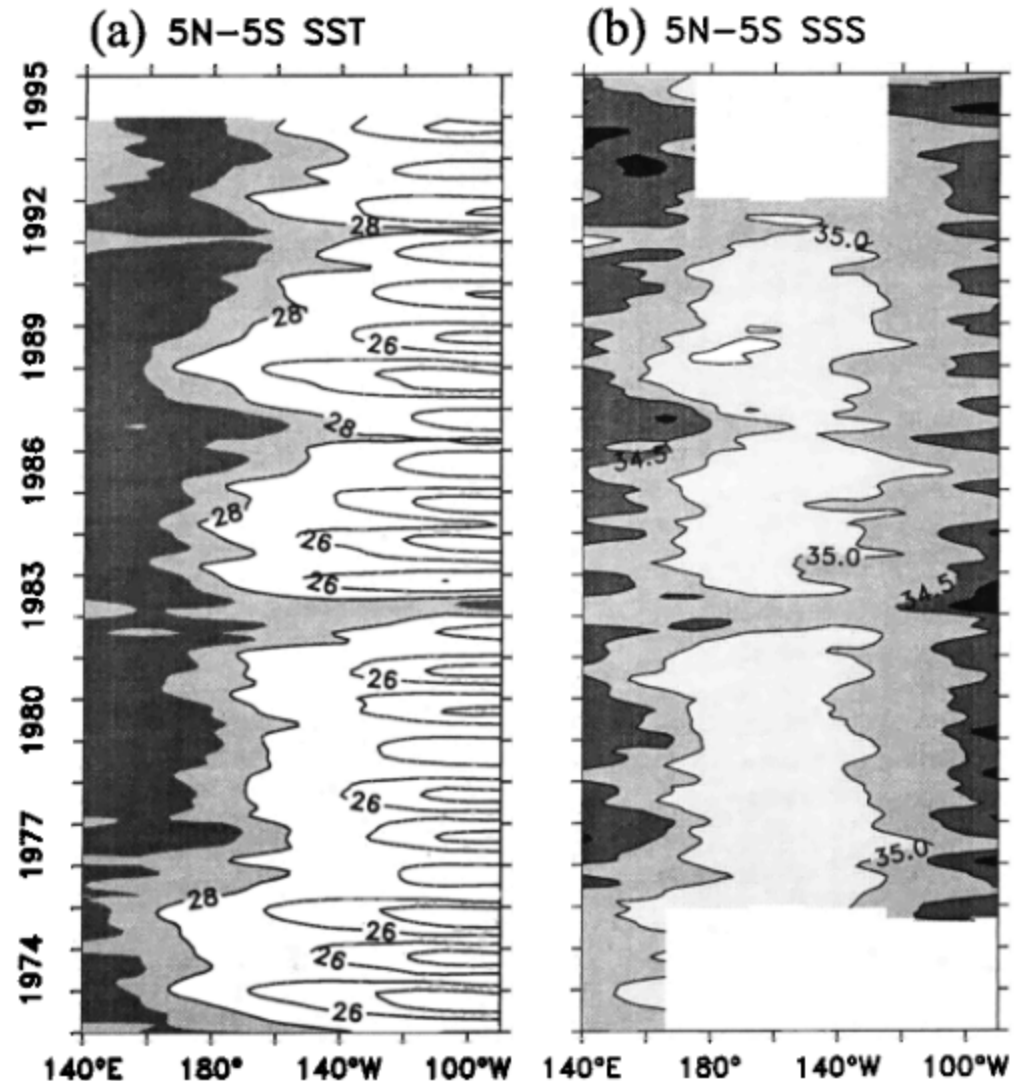
Though not well defined in SST, the eastern edge of the western Pacific warm pool is characterized by a strong SSS front, whose zonal gradient can sometimes reach as high as 0.5 psu in 1° longitude.

A natural question: Can the SSS front be used to characterize ENSO?

Dating back to 1998

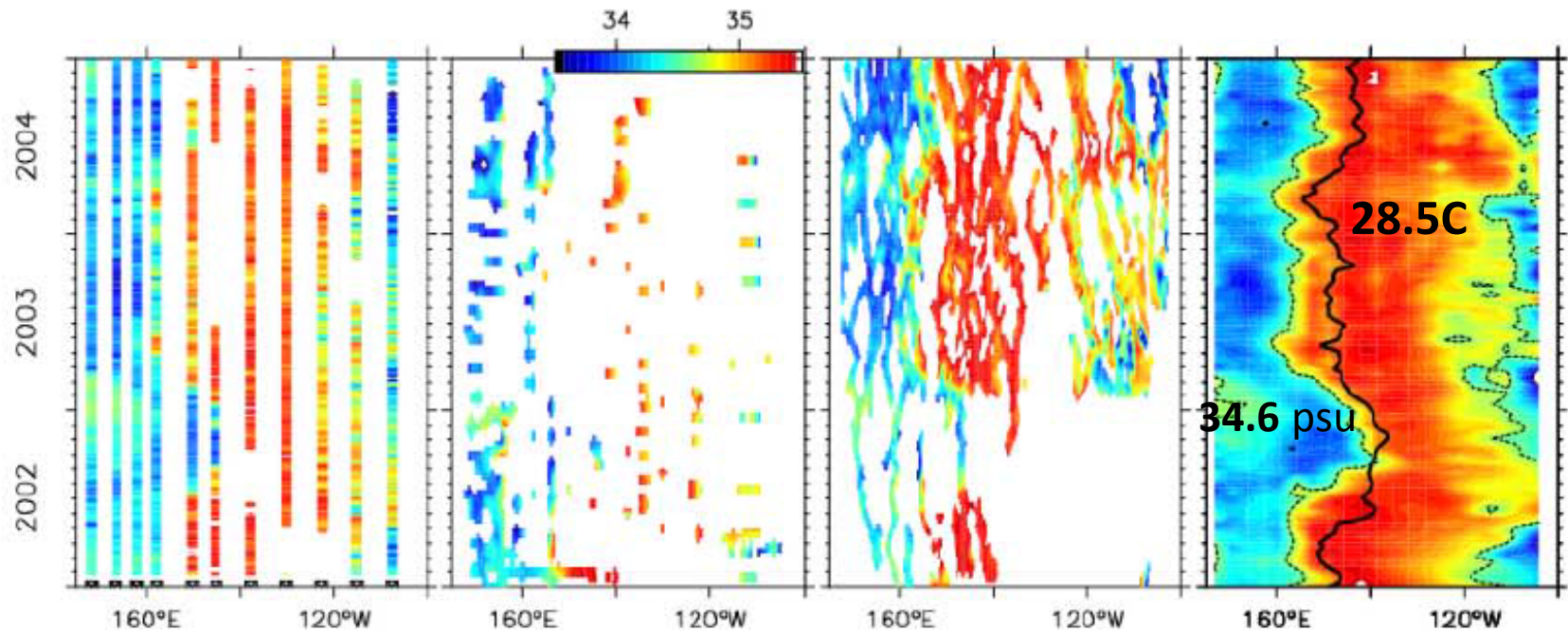
Delcroix (1998) noticed that the longitudinal location of the SSS front (35.0 psu isohaline) varies consistently with the eastern edge (28C) of the warm pool, suggesting the possibility of using this SSS front as an index of El Nino.

Delcroix 1998



Based on limited SSS data from individual cruises and Voluntary Observing Ships

Similar results from recent observations

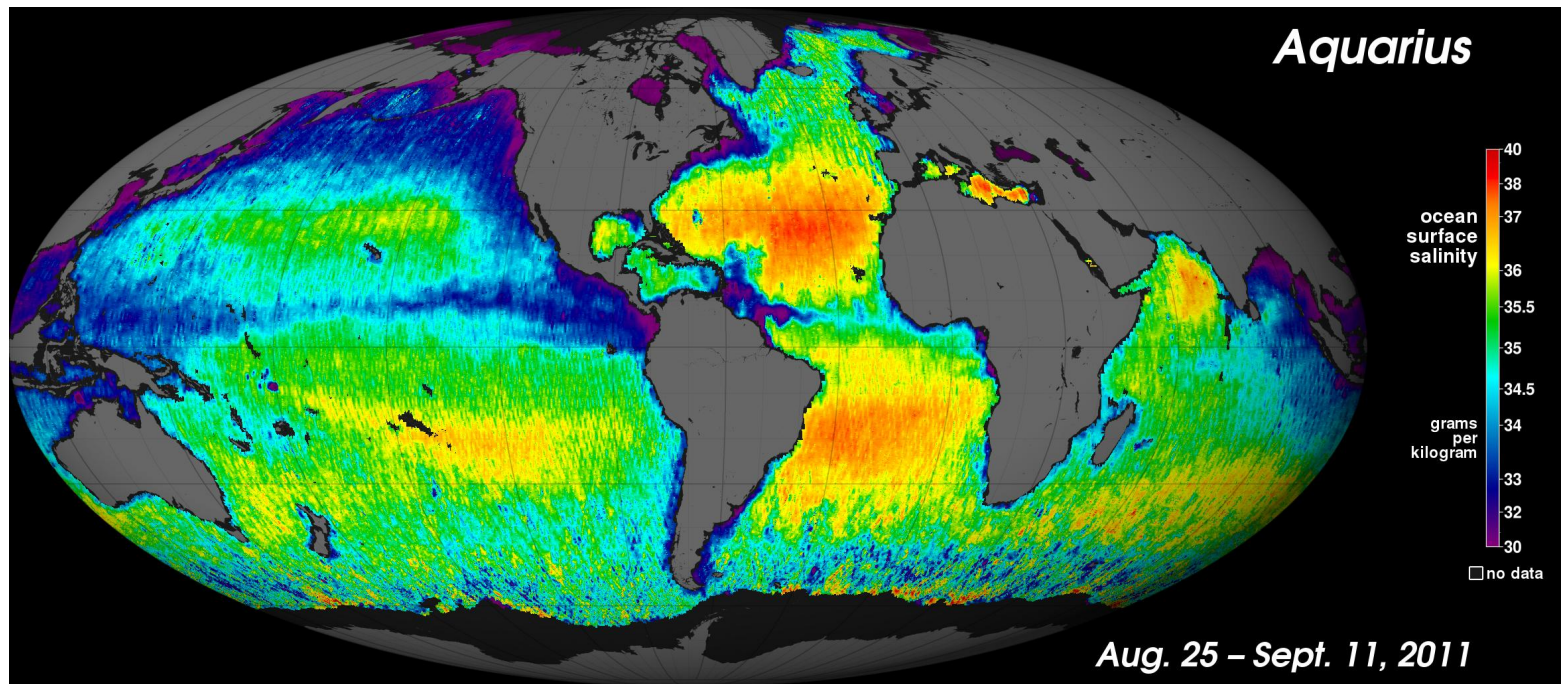


Based on SSS data from TAO/Triton, TSG, and Argo floats

Maes et al. 2006

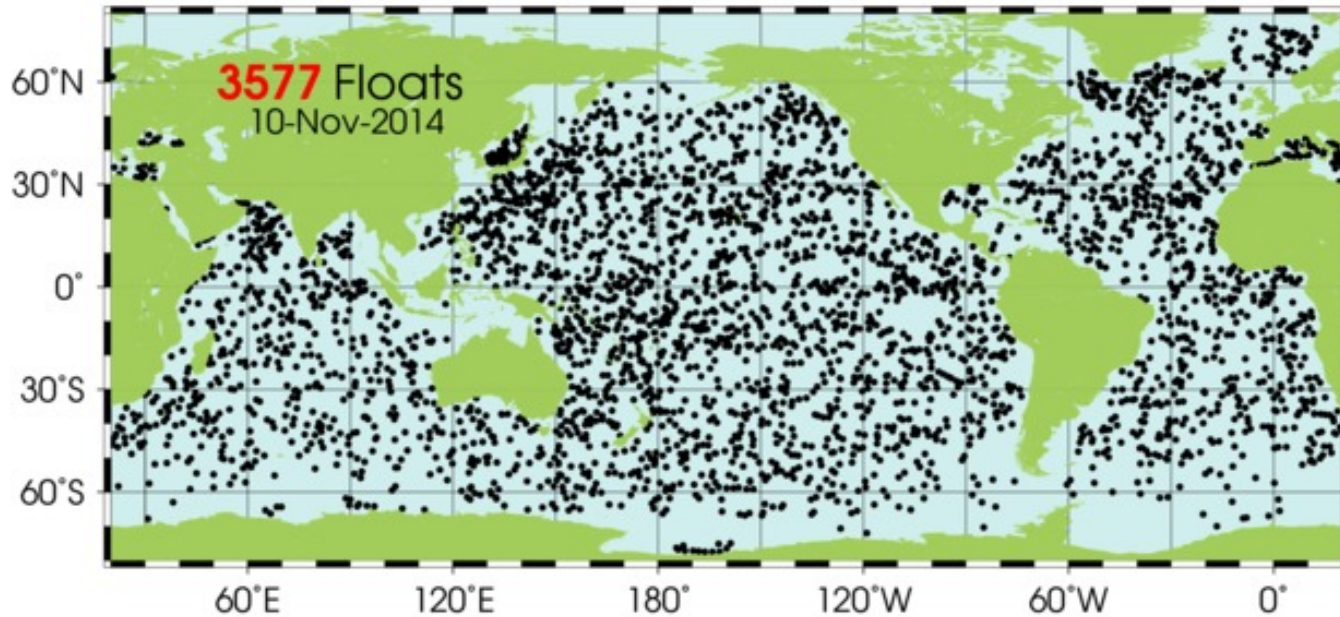
Until recently, salinity data are very sparse both in time and space.

Aquarius: launched in June 2011.

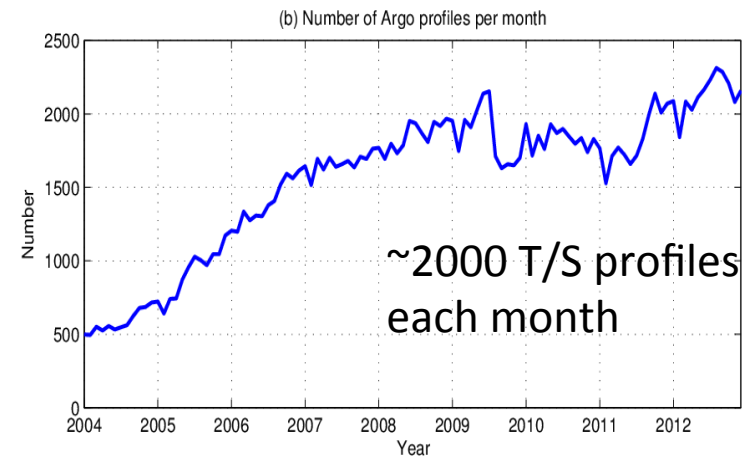
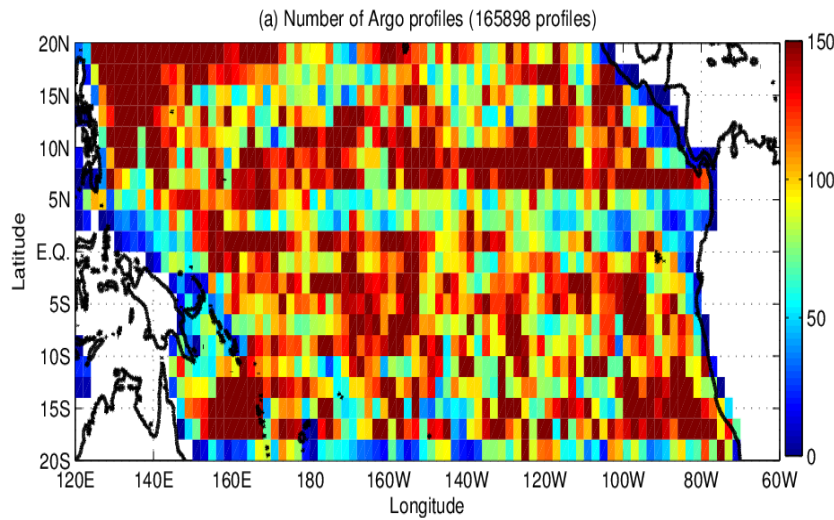


Providing a global observing capability of the ocean, generating near-synoptic SSS maps on global scale at a spatial resolution of ~ 150 km every 7 days.

Argo: A large number of Argo floats deployed in the past decade.

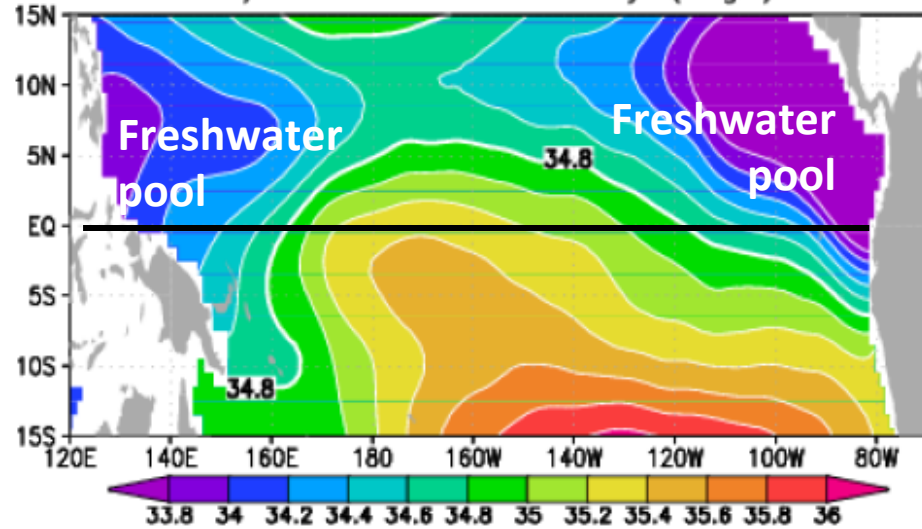


In the tropical Pacific

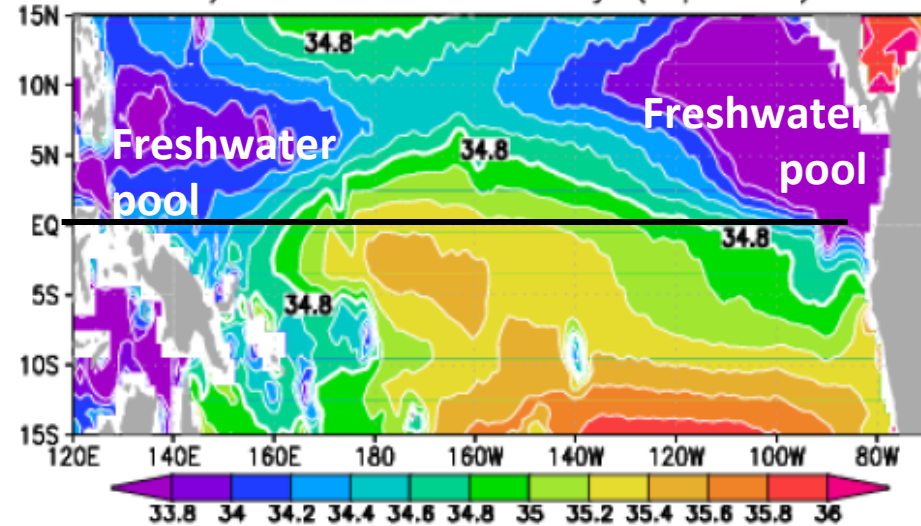


Aquarius and Argo provide a unique opportunity to study SSS,
-----which has never been possible before.

a) Sea Surface Salinity (Argo)



b) Sea Surface Salinity (Aquarius)

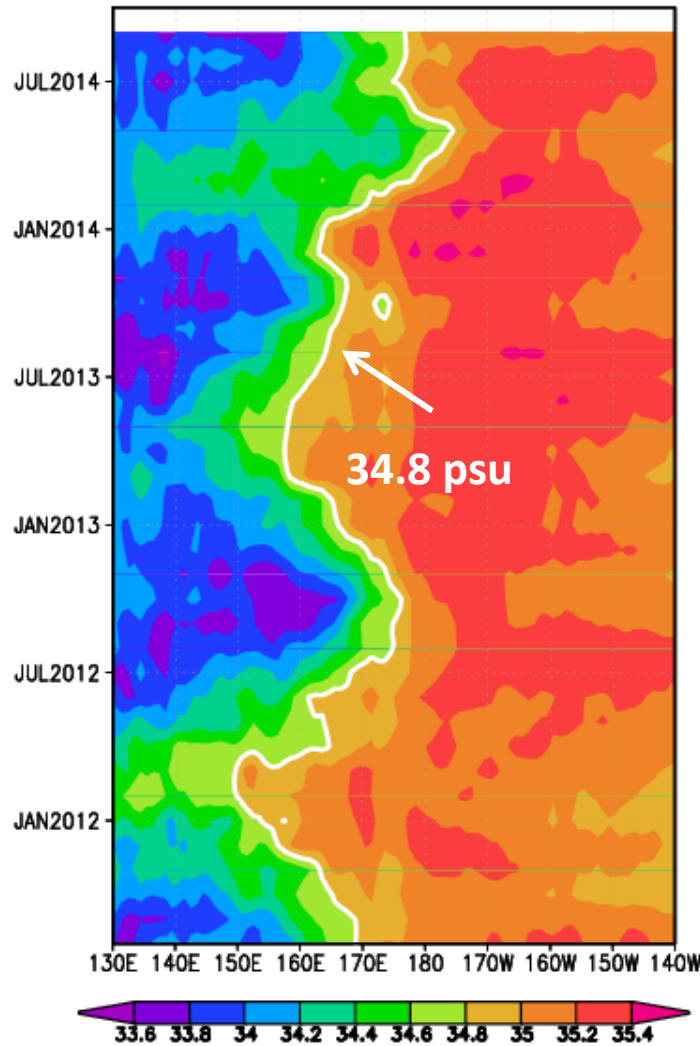


The mean SSS patterns from the two datasets are essentially the same.

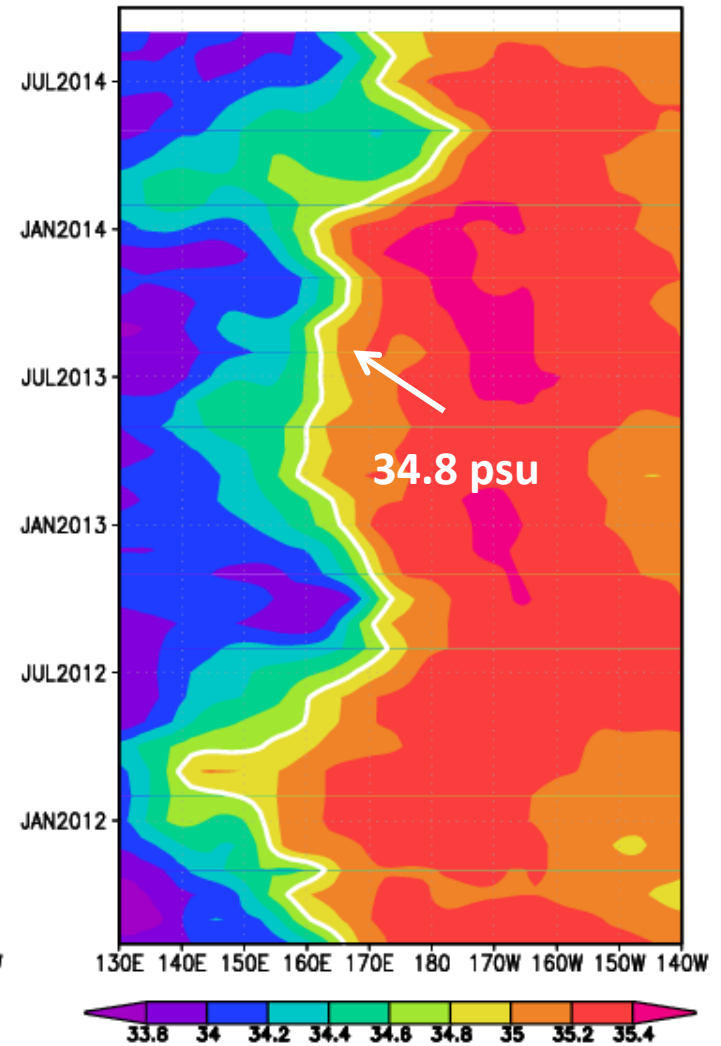
Zonal displacement of the SSS front ----during the Aquarius period (08/11-09/14)

R=0.85

a) SSS (Aquarius)



b) SSS (Argo)



Showing a good agreement during the past 38 months

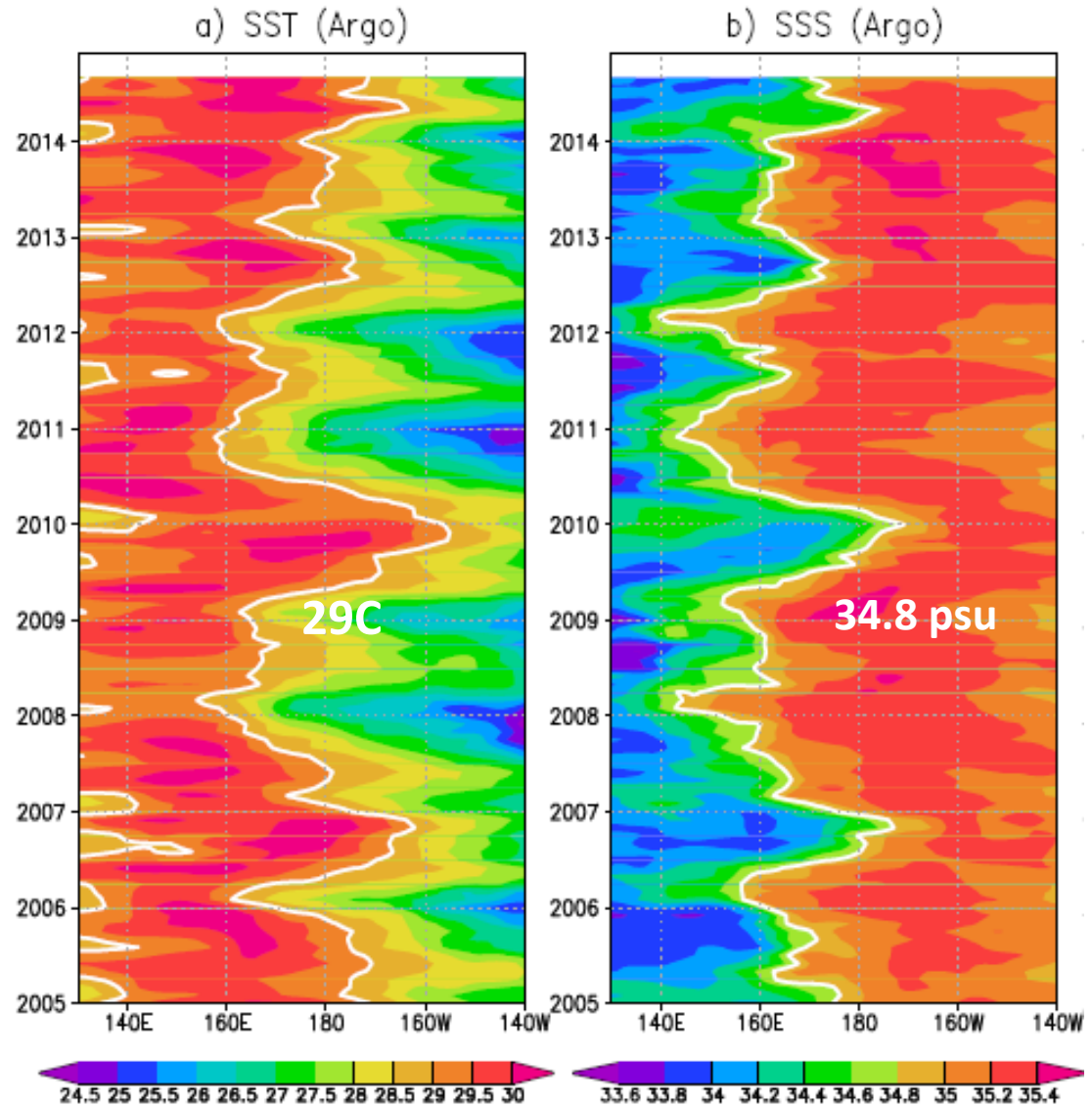
The 34.8 psu isohaline as a proxy of SSS front along the equator

Zonal displacement of the SSS front and warm pool

----during the Argo period (2005-2014)

The eastern edge (29°C) of the warm pool moves rather consistently with the SSS front (34.8 psu) during the past decade.

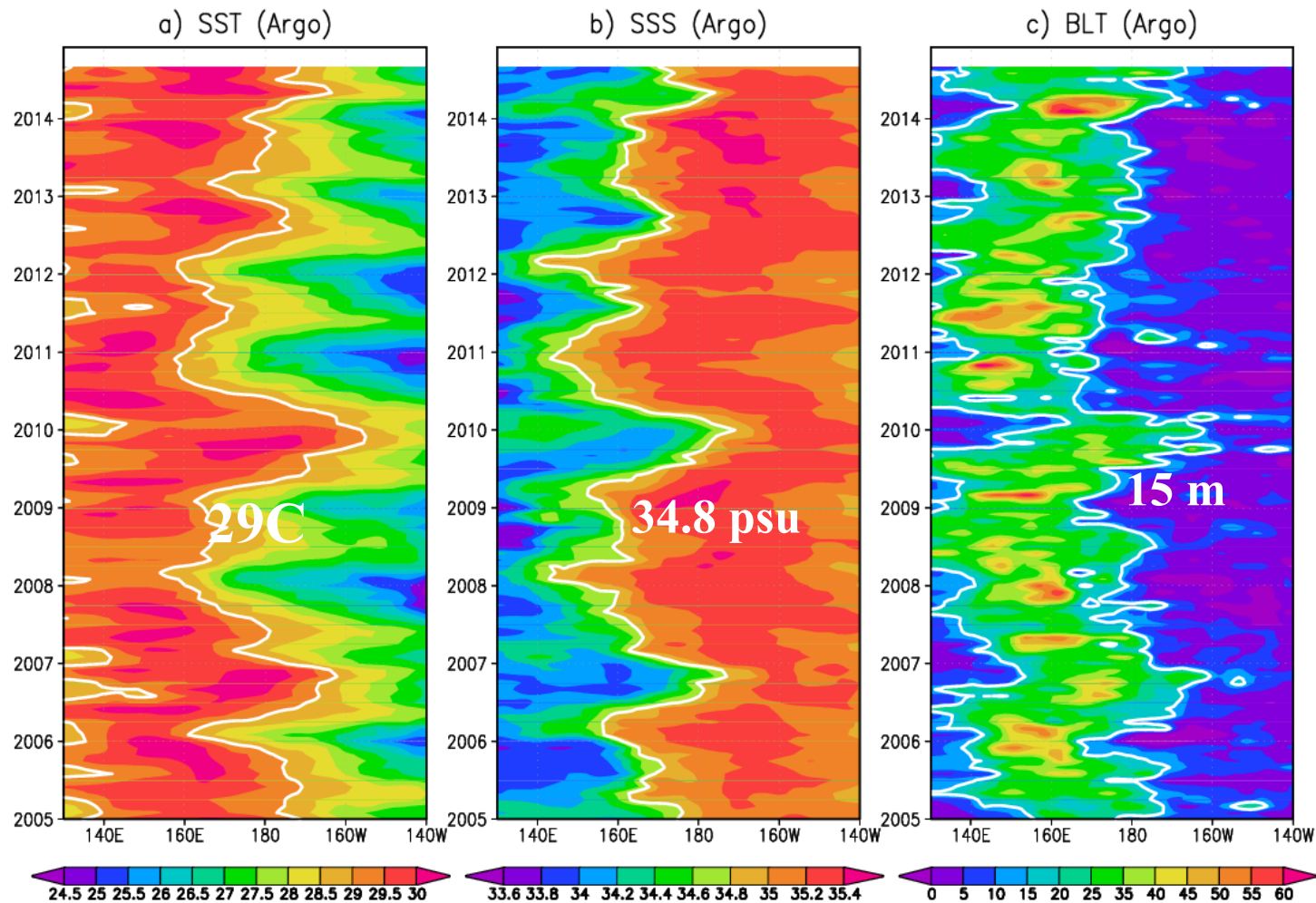
R=0.91



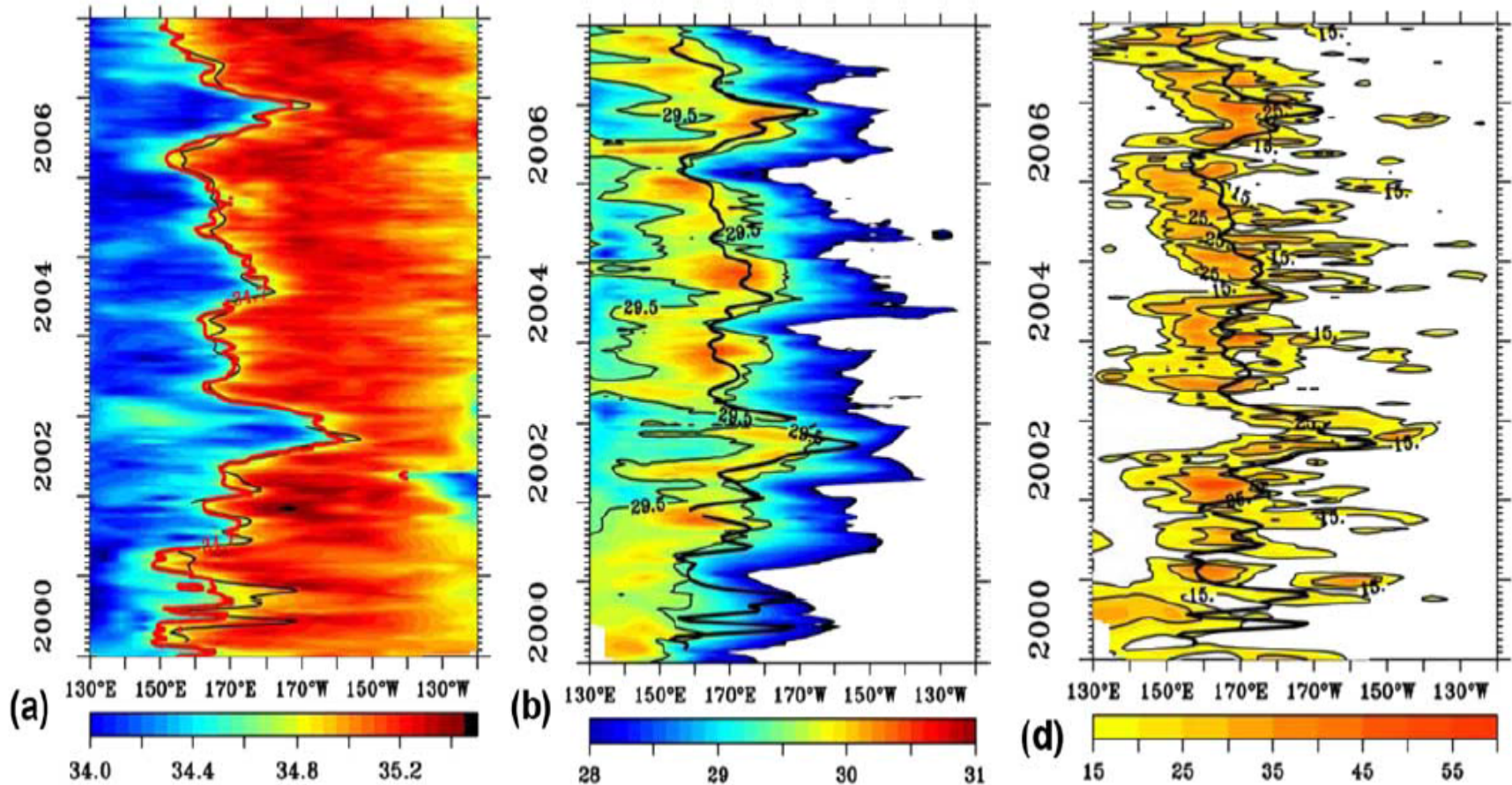
Zonal displacement of thick barrier layer

---- during the Argo period (2005-2014) .

A thick (>15 m) barrier layer also moves back and forth consistently with the SSS front during the past decade.



Similar results were reported for an earlier period (2000-2007)



Bosc et al. (2009) based on available CTD, thermosalinographs (TSGs), and early-stage Argo profiles

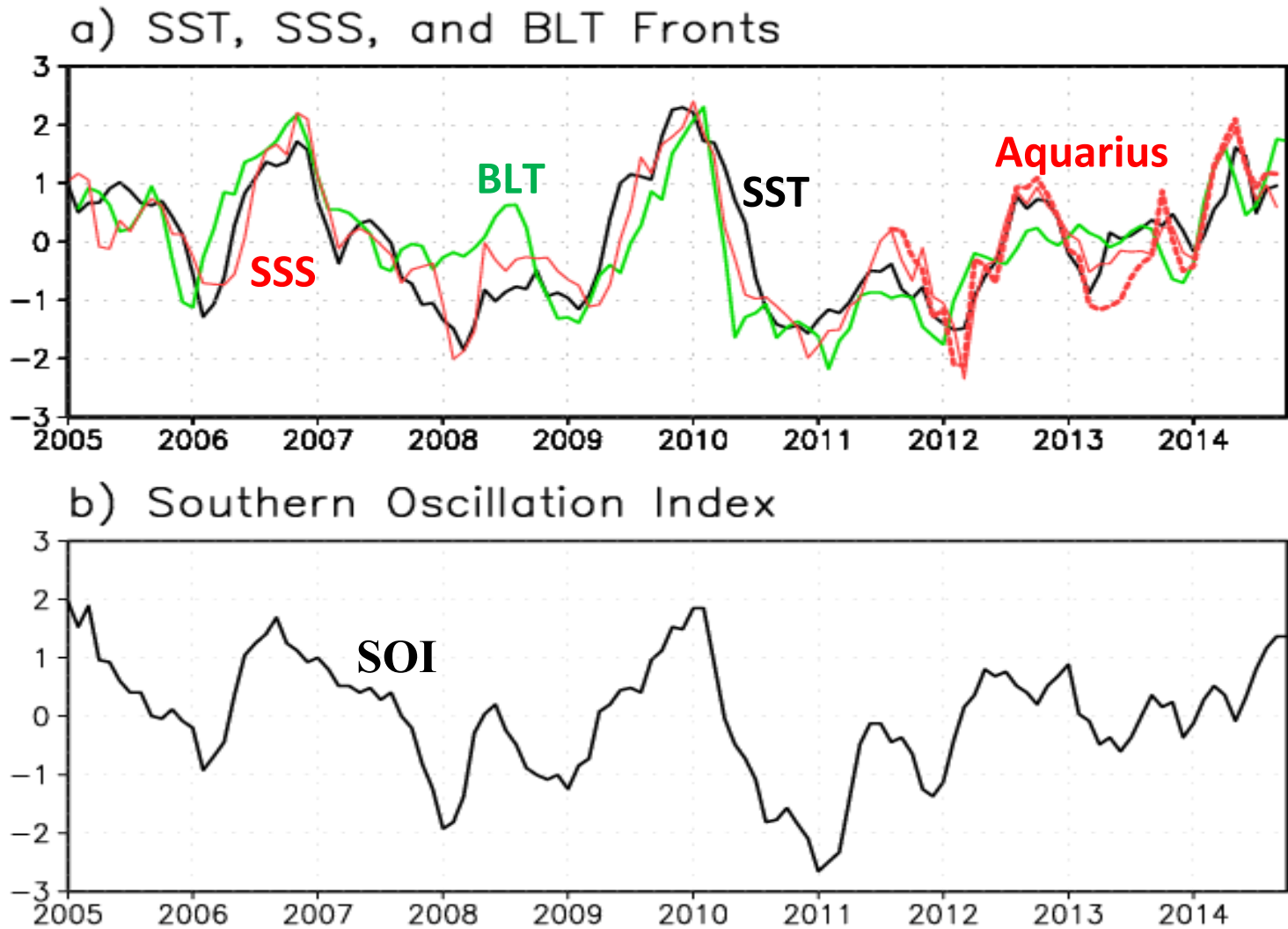
Link to SOI

---during the Argo period

SST (29C) ~ SOI: - 0.82

SSS (34.8psu)~SOI: - 0.84

BLT (15 m) ~ SOI: - 0.81

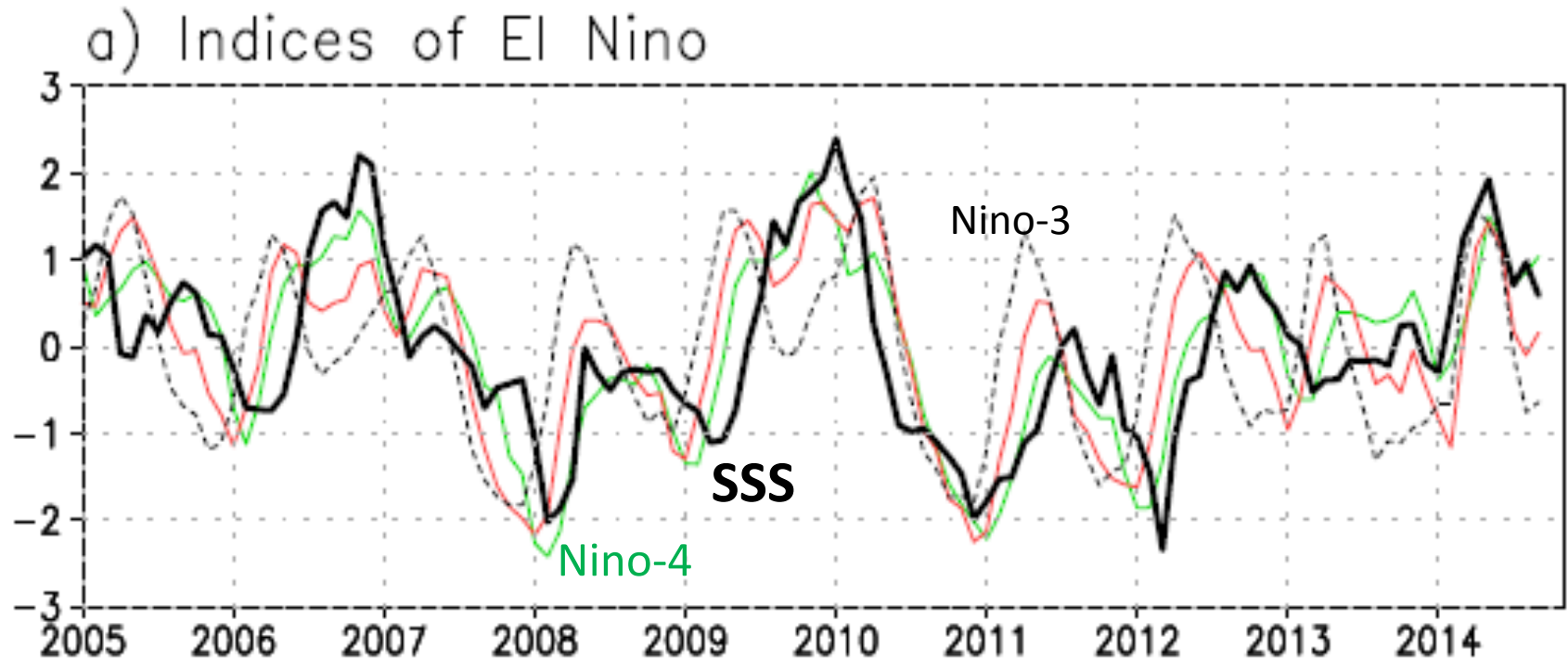


Time series of 29C isotherm, 34.8 psu isohaline, and 15 m BLT compared with SOI.

Link to Nino-4

----during the Argo period

SSS front ~Nino-4: - 0.88

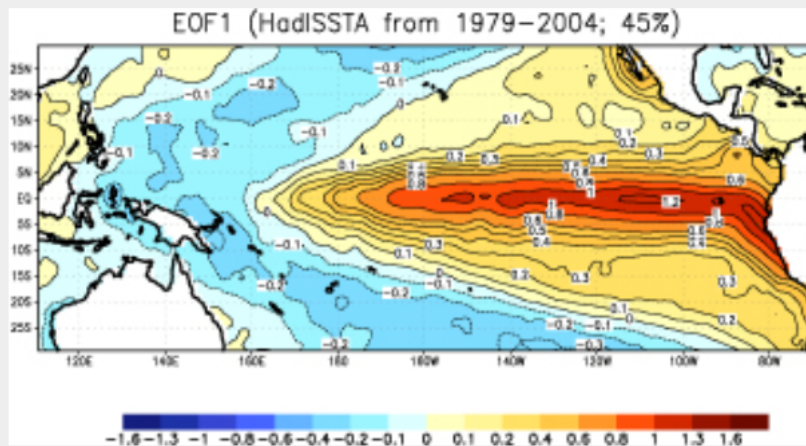


So, the longitudinal location of the SSS front can be defined as an index of El Niño, termed Nino-S34.8 in the following discussion.

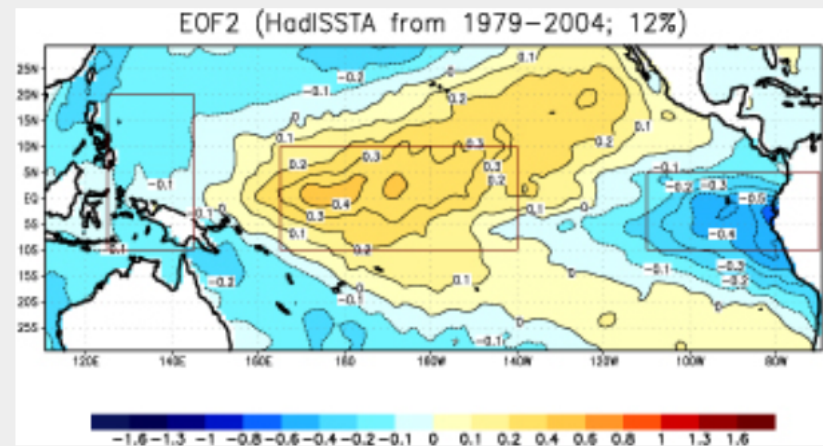
Type of El Nino

EP type El Nino and CP type El Nino or El Nino Modoki
(e.g., Yu et al. 2007; Ashok et al. 2007; Kao and Yu 2009).

First EOF mode of SSTA representing El Niño



Second EOF mode of SSTA representing El Niño Modoki



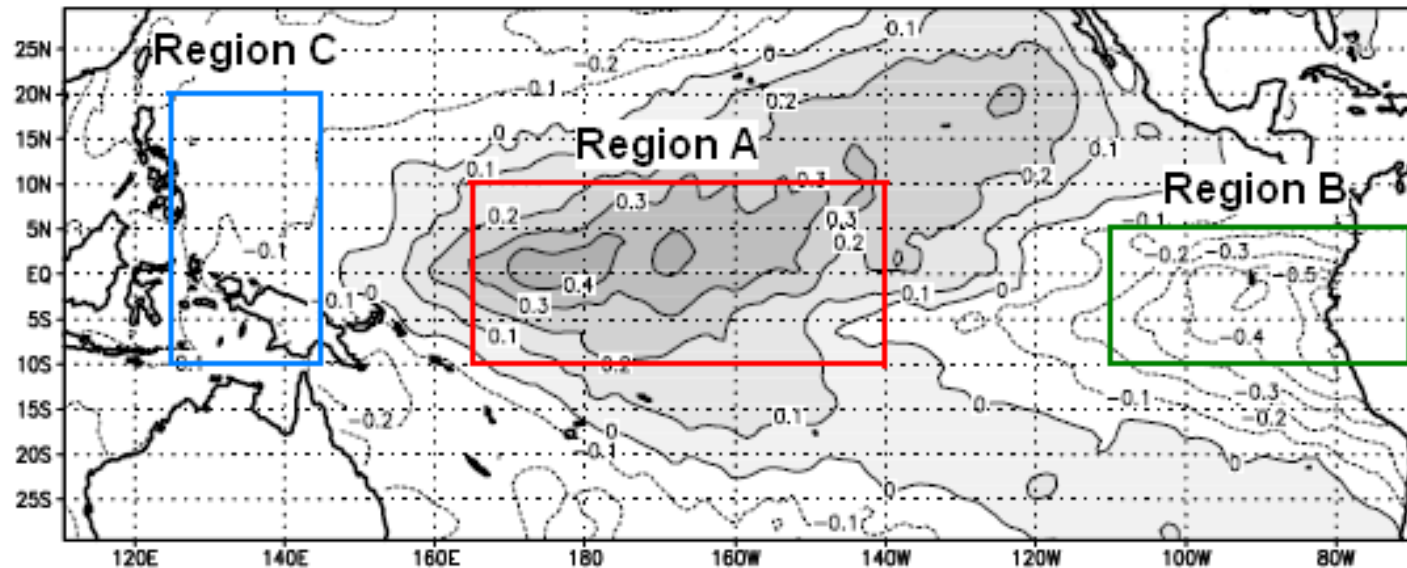
http://www.jamstec.go.jp/frcgc/research/d1/iod/enmodoki_home_s.html.en

Ashok et al., 2007

Indices used for type of El Nino?---El Nino Modoki Index (EMI)

$$\text{EMI} = [\text{SSTA}]_A - 0.5 * [\text{SSTA}]_B - 0.5 * [\text{SSTA}]_C$$

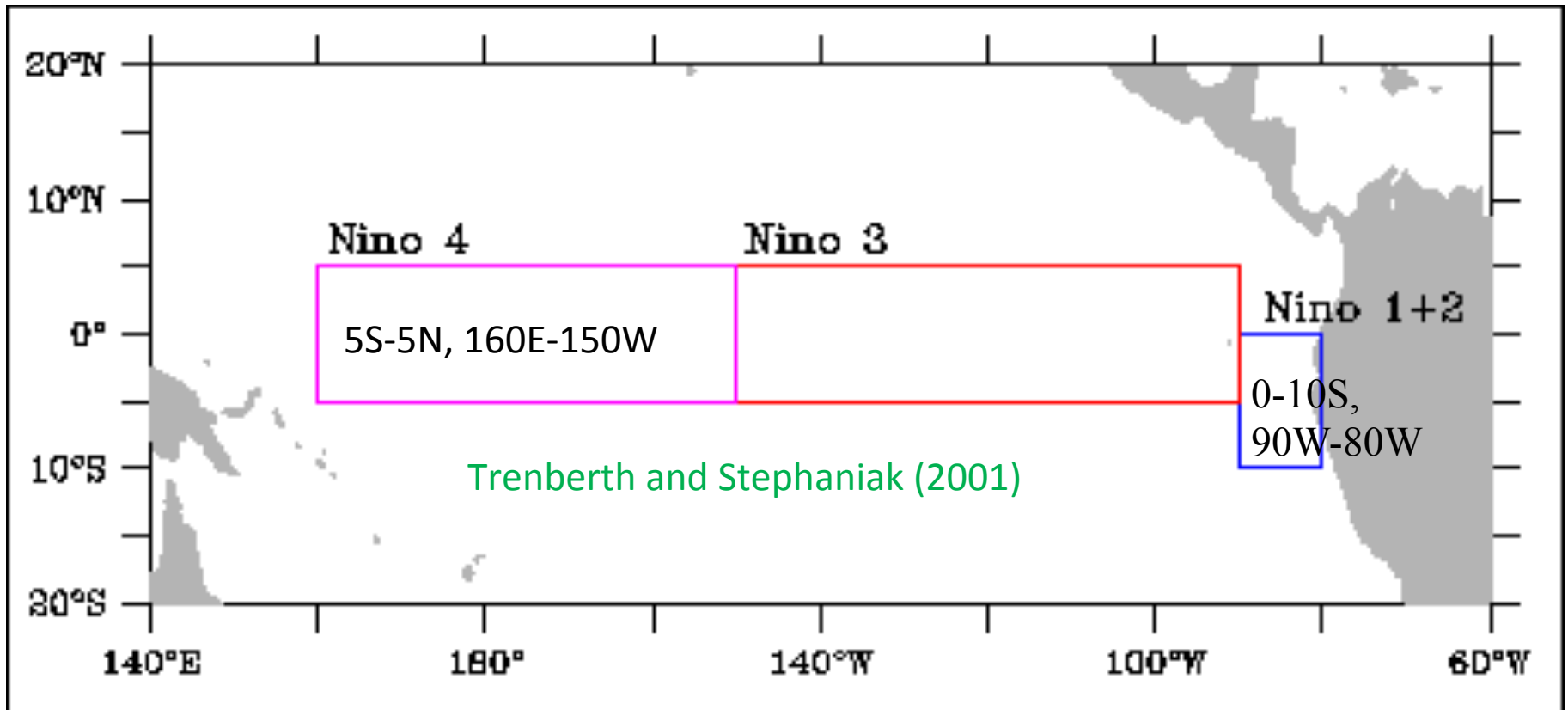
(b) EOF2 (HadISSTA from 1979–2004; 12%)



Ashok et al., 2007

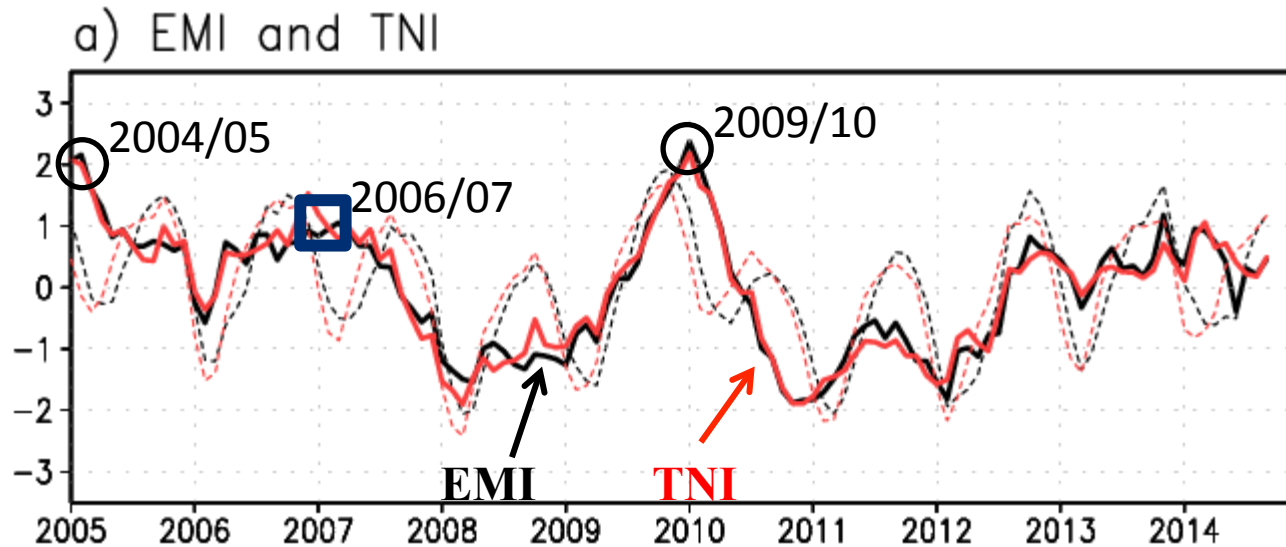
Indices used for type of El Niño?---Trans-Niño index (TNI)

TNI was defined as the difference of normalized SST anomalies between the Niño-4 and Niño-1+2 regions.



EMI and TNI from Argo

----during 2005-2014



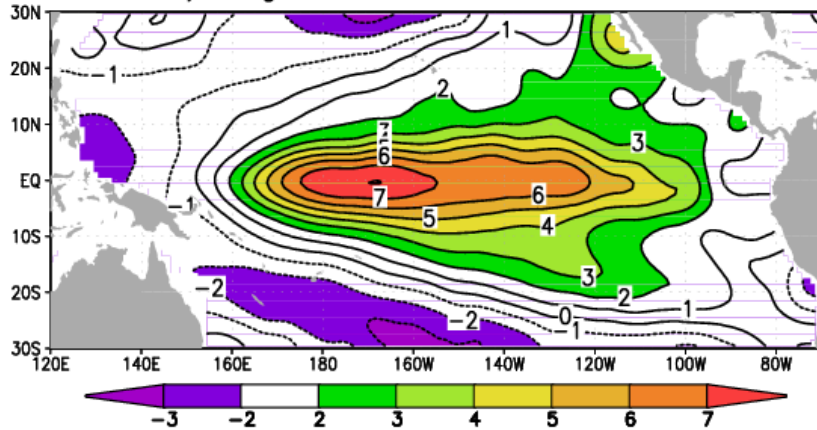
Time series of normalized El Niño Modoki index and Trans-Niño index. The heavy solid lines indicate interannual variability relative to the mean seasonal cycle

Can SSS be used to identify type of El Niño?

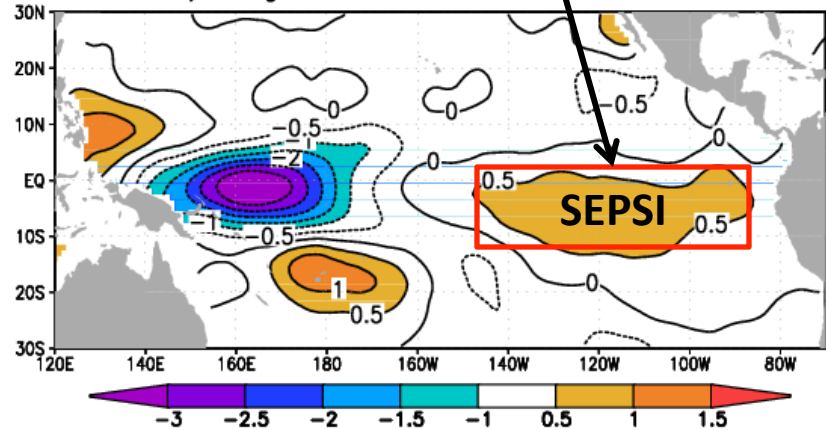
SSS index for type of El Nino

Positive anomalies are associated with zonal SST gradients and zonal wind anomalies.

a) Regression Coefficient of SST



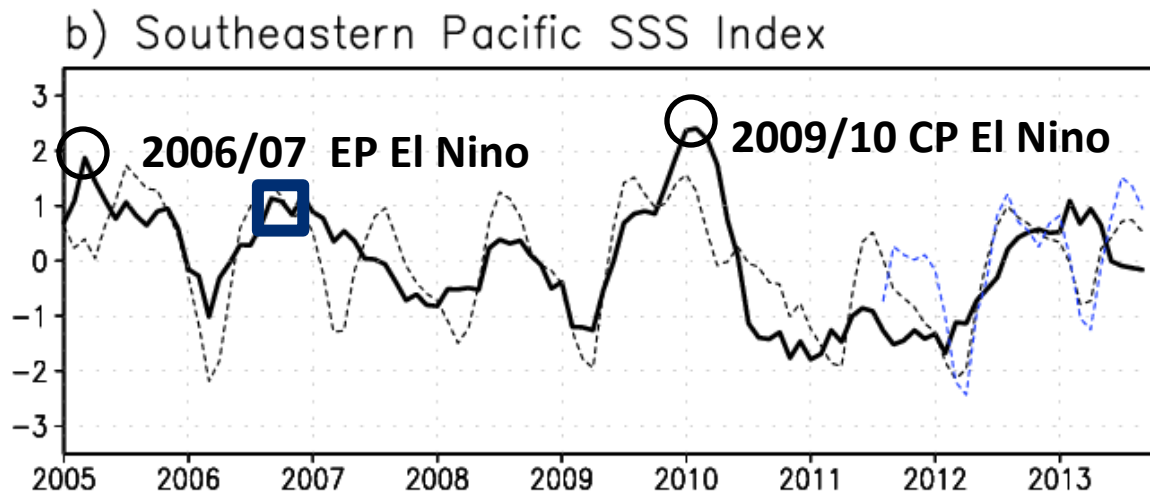
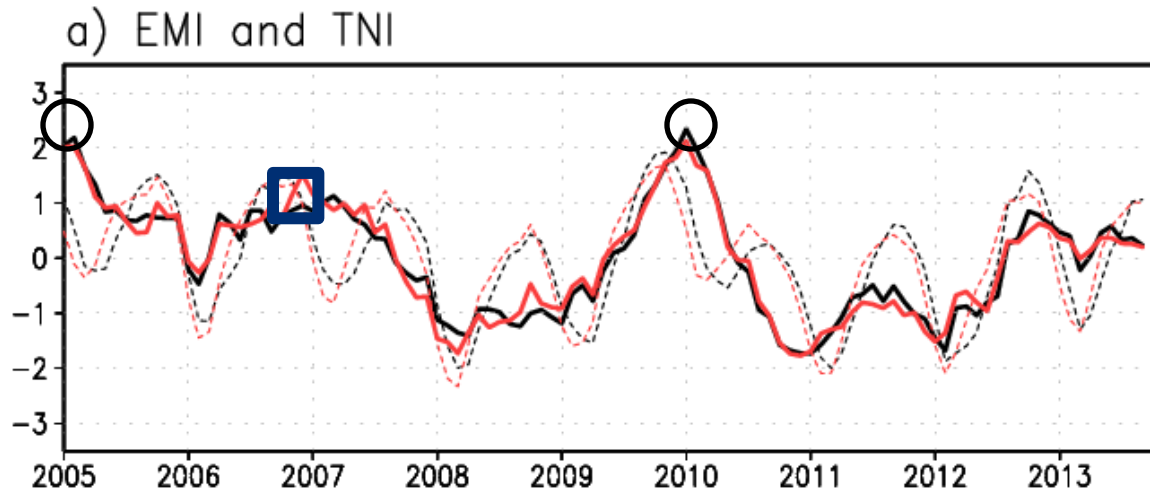
b) Regression Coefficient of SSS



Regression coefficients of a) SST and b) SSS anomalies toward the Niño-S34.8 index in the tropical Pacific for the period 2005-2014.

SEPSI

----- is highly correlated with the SST indices of EMI and TNI

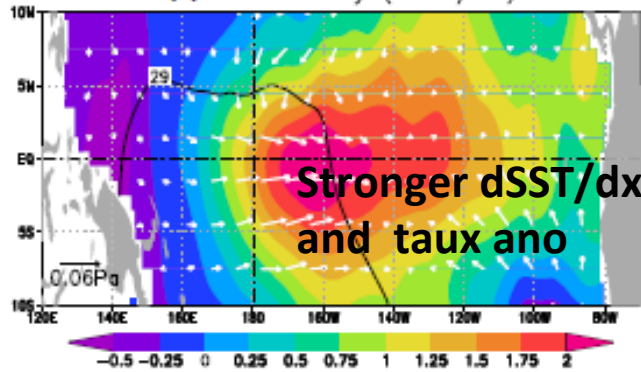


R=0.85

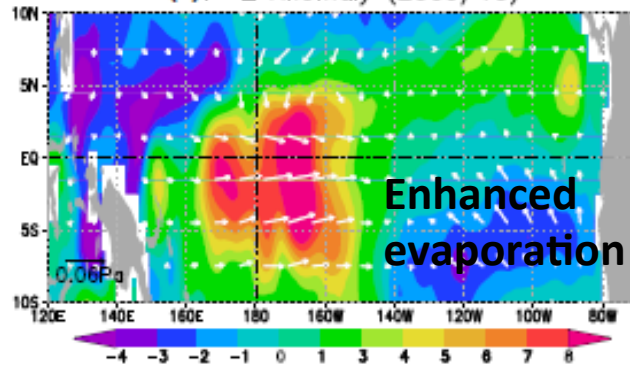
How SEPSI works?

CP -- El Nino

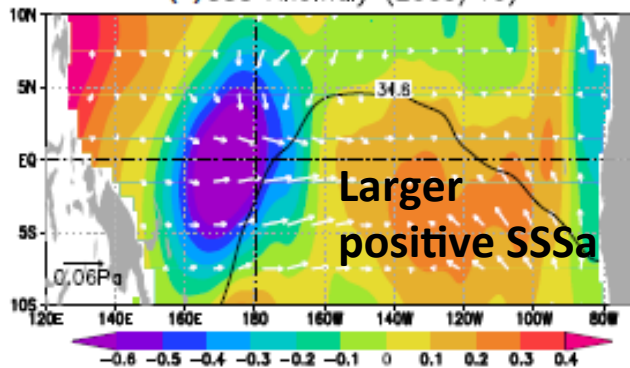
(a) SST Anomaly (2009/10)



(c) P-E Anomaly (2009/10)

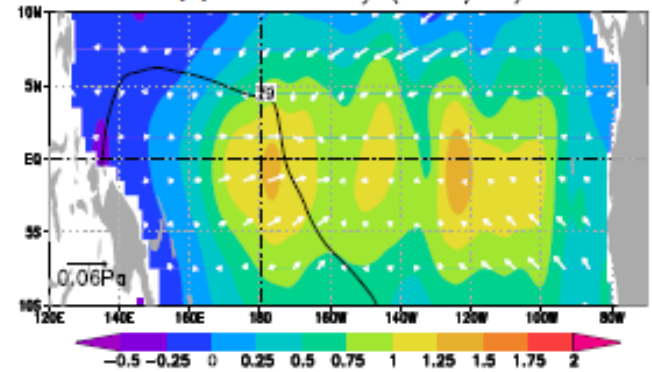


(b) SSS Anomaly (2009/10)

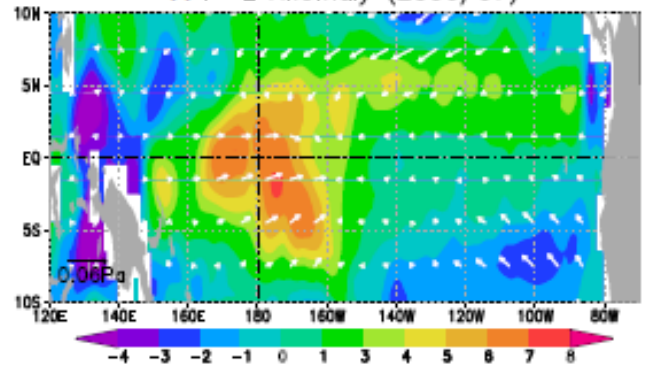


EP -- El Nino

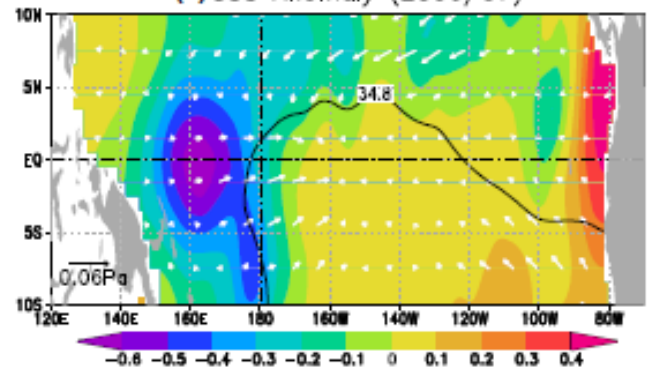
(d) SST Anomaly (2006/07)



(f) P-E Anomaly (2006/07)



(e) SSS Anomaly (2006/07)



Both sea surface wind and freshwater flux contribute to the SEPSI variability.

A question that may immediately arise: Why SSS indices?

- (1) Since no negative feedback exists between the ocean's surface salinity and freshwater flux, the SST and SSS indices are controlled by different processes;
- (2) Since the damping processes for salinity are oceanic and less efficient than that for temperature, the SSS indices may have more power than the SST indices towards lower frequency variability.

Implication: Nino-S34.8 and SEPSI may have advantage in understanding the interannual to decadal variability, helping reveal new dynamics of ENSO.

How?

Freshwater flux and horizontal advection

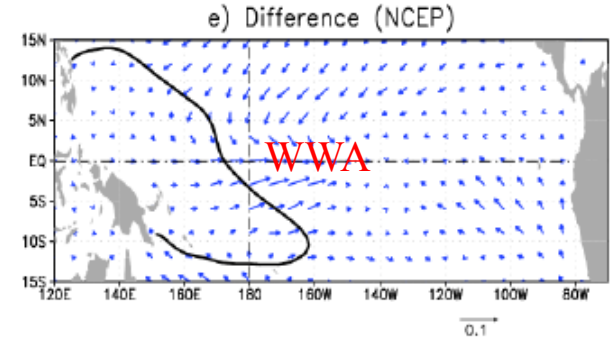
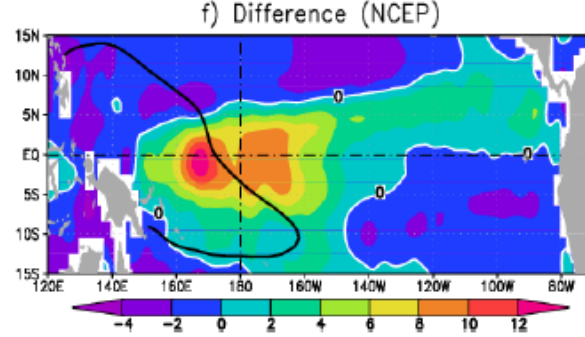
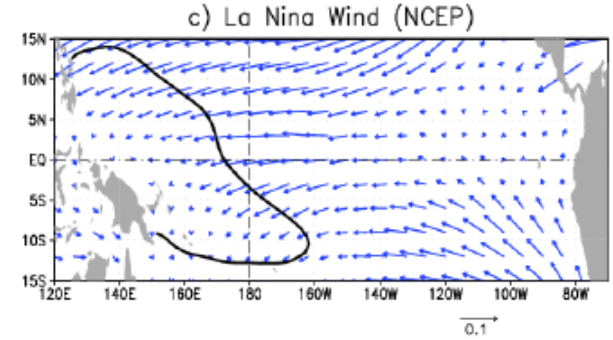
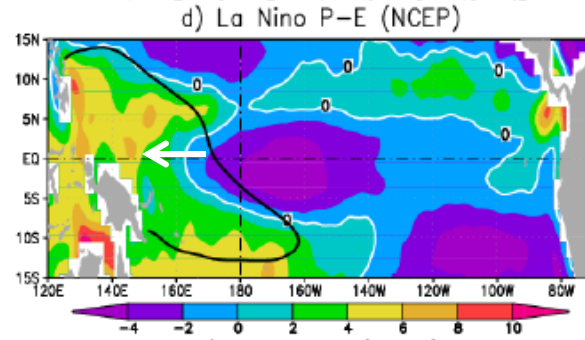
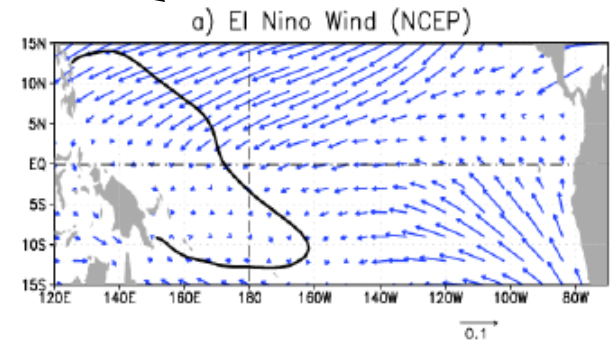
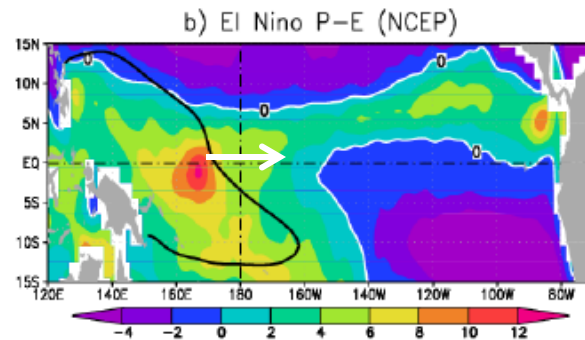
El Nino: 2006/07, 2009/10;

La Nina: 2007/08, 2010/11, 2011/12

For example, the Nino-S34.8 is governed in part by surface freshwater flux and surface flow anomalies.

Vertical entrainment is a big unknown.

$$\frac{\partial S}{\partial t} = \underbrace{\frac{(E - P)S}{h_m}}_{\text{freshwater flux}} - \underbrace{u_e \cdot \nabla S}_{\text{horizontal advection}} - \underbrace{u_g \cdot \nabla S}_{\text{horizontal advection}} - \frac{w_e \Delta S}{h_m} + ssp$$

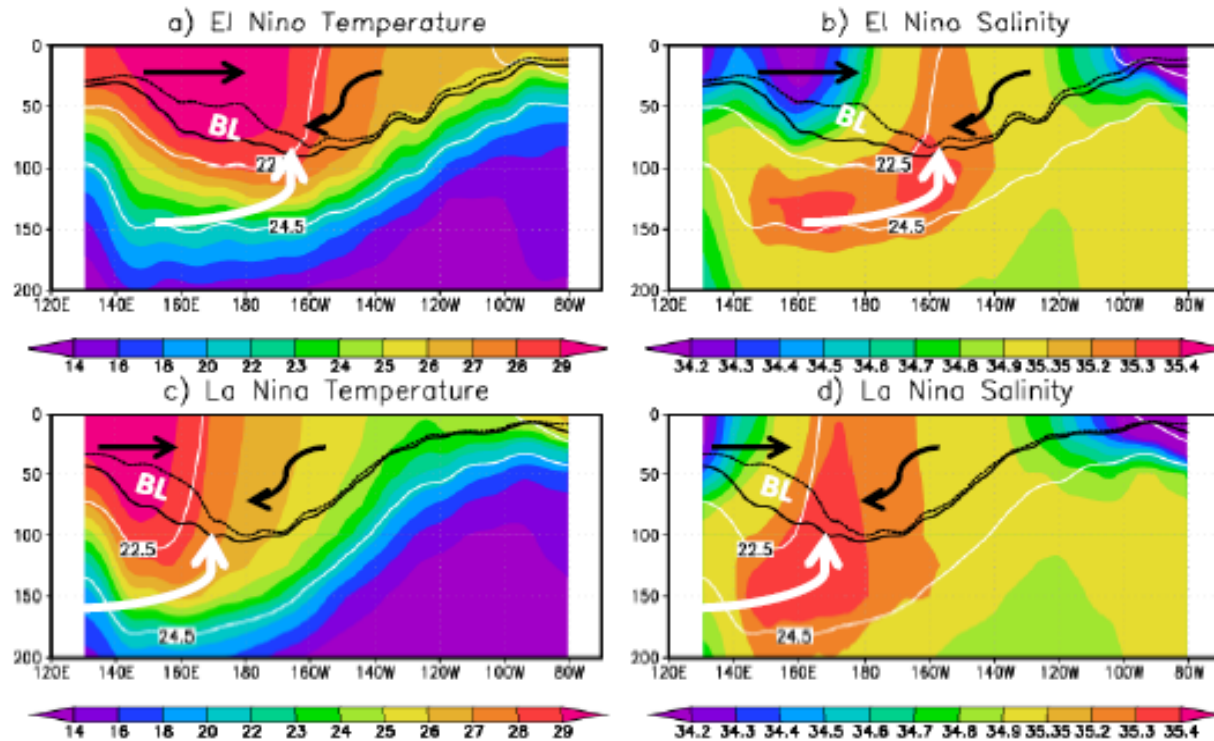


Vertical salinity distribution

El Nino: 2006/07, 2009/10;

La Nina: 2007/08, 2010/11, 2011/12

$$\frac{\partial S}{\partial t} = \frac{(E - P)S}{h_m} - u_e \cdot \nabla S - u_g \cdot \nabla S - \frac{w_e \Delta S}{h_m} + ssp$$



The vertical entrainment of high salinity water moves consistently with the SSS front, eastward during El Niño and westward during La Niña.

Hypothesis

Vertical entrainment of high salinity subtropical water (SPTW and NPTW) can modulate the halocline structure, alter the surface stratification (e.g., the barrier layer), and shift the SSS front along the equator, thereby playing a role in ENSO evolution.

To confirm this hypothesis, we are conducting a passive tracer experiment by releasing the passive tracer in the winter mixed layer of the South Pacific SSS maximum (SPTW) and tracing it forward using ECCO's offline circulation from 1993 to 2010 ([Fukimori et al. 2004](#))

To be continued.....

Summary

- (1) Aquarius is able to precisely detect the SSS front in the equatorial Pacific;
- (2) The SSS front moves consistently with the eastern edge of the warm pool, both having a strong signature of ENSO;
- (3) Two SSS indices can be defined to identify the event and type of El Nino, helping reveal new characteristics of ENSO;
- (4) Resurfacing of subtropical water in the equatorial Pacific likely plays an active role in ENSO evolution (not shown in this presentation)

Thank you !