Sea surface salinity variability in the equatorial Pacific and ENSO

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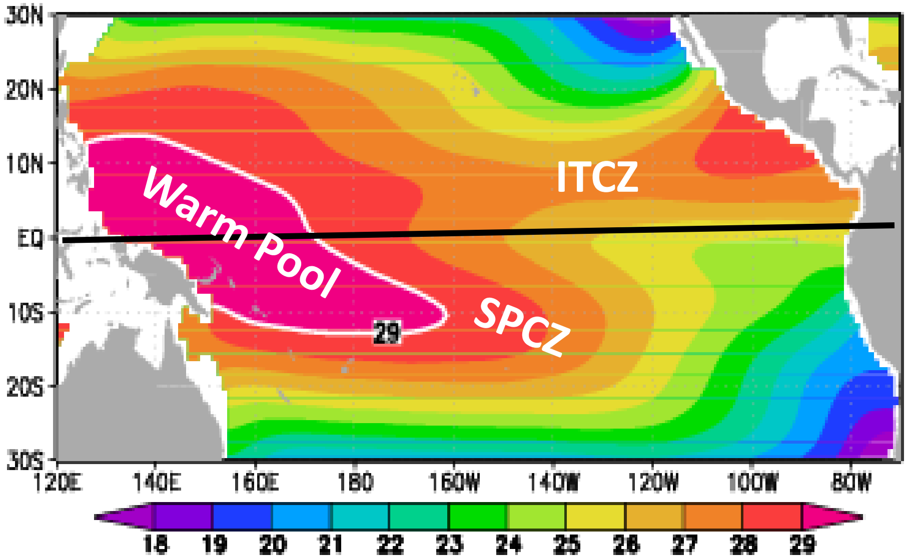
October 21, 2015, Qingdao

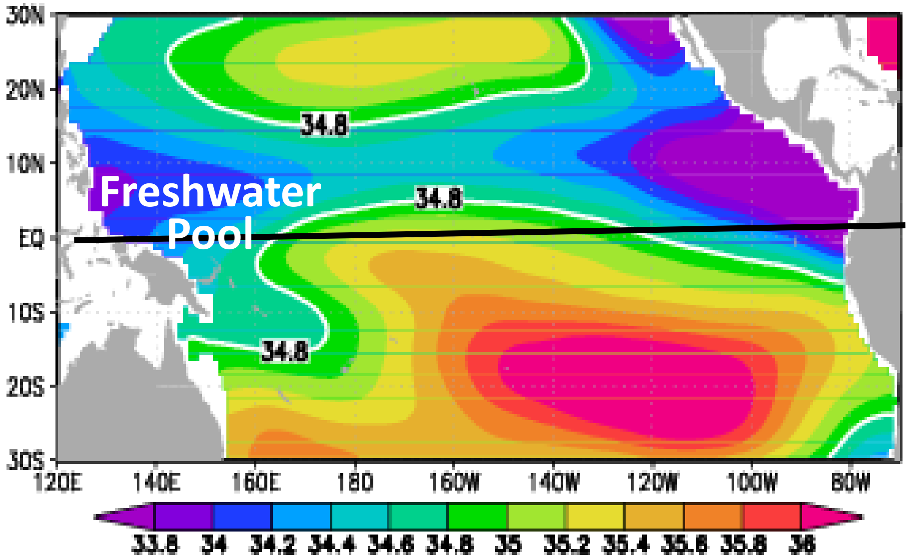
The western Pacific warm pool

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

Sea surface temperature from WOA09



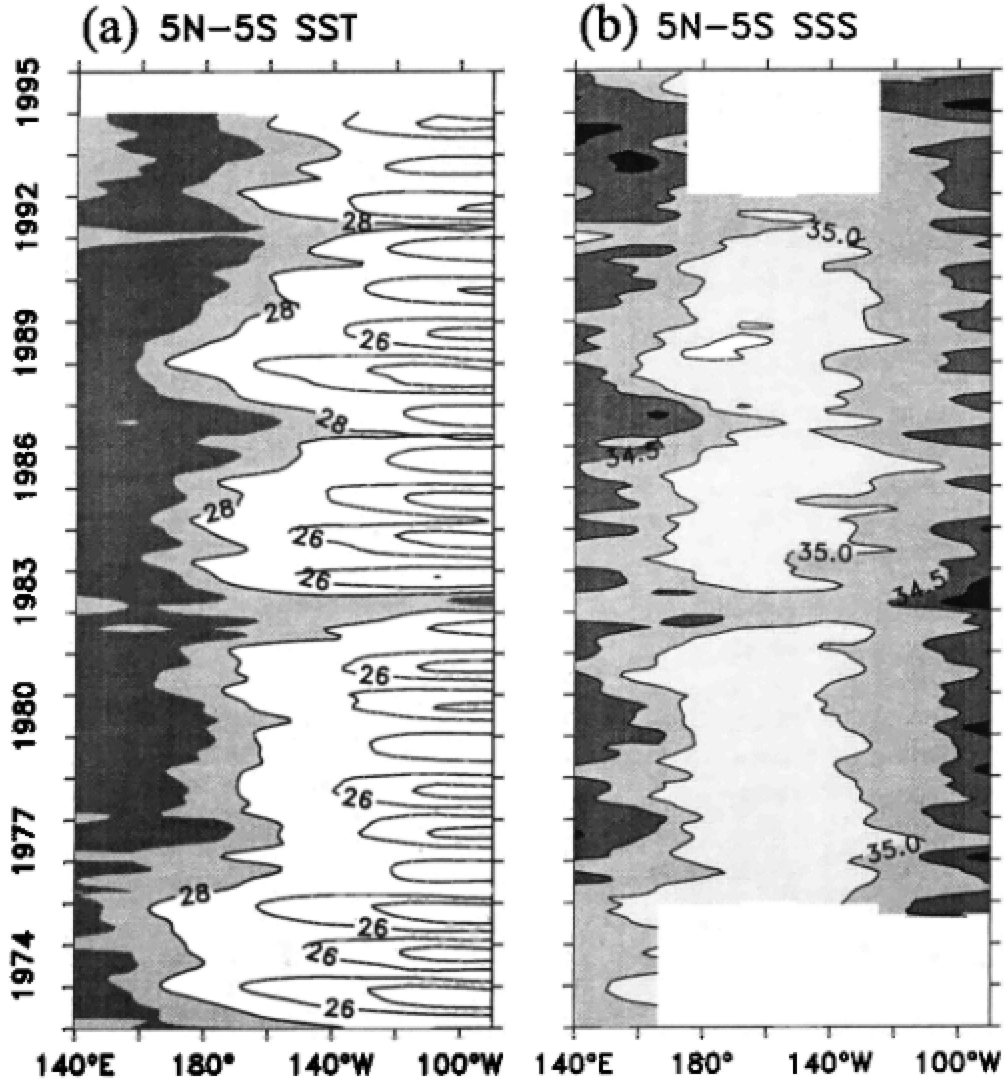
Sea surface salinity from WOA09



Though not well defined in SST, the eastern edge of the western Pacific warm pool is characterized by a strong SSS front near 160°E in the mean, whose zonal gradient can sometimes reach as high as 0.5 psu in 1° longitude.

SSS front and El Nino

Delcroix 1998

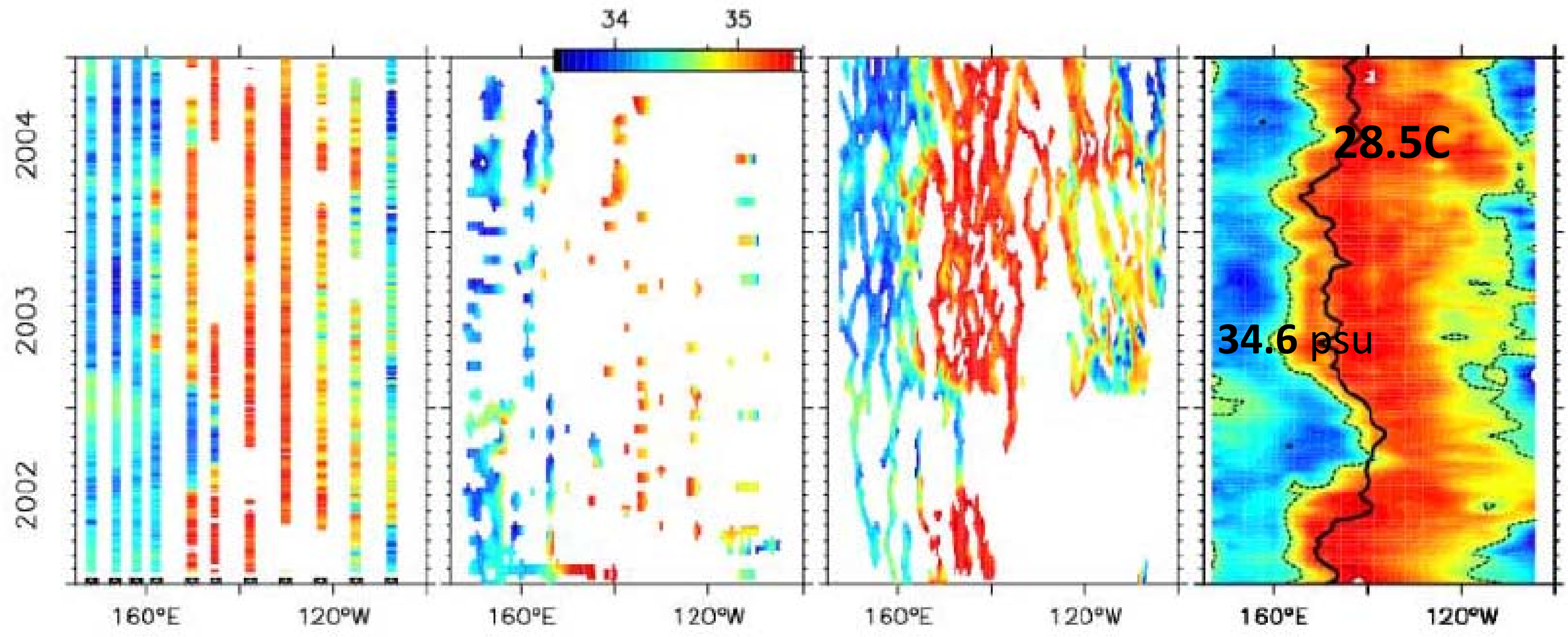


Based on limited SSS data from individual cruises and Voluntary Observing Ships before 1995

The longitudinal location of the SSS front (35.0 psu isohaline) varies rather consistently with the eastern edge (28C) of the warm pool, suggesting that it can be used as an index to identify El Nino events.

Similar results from recent observations

SSS front as an index of El Nino

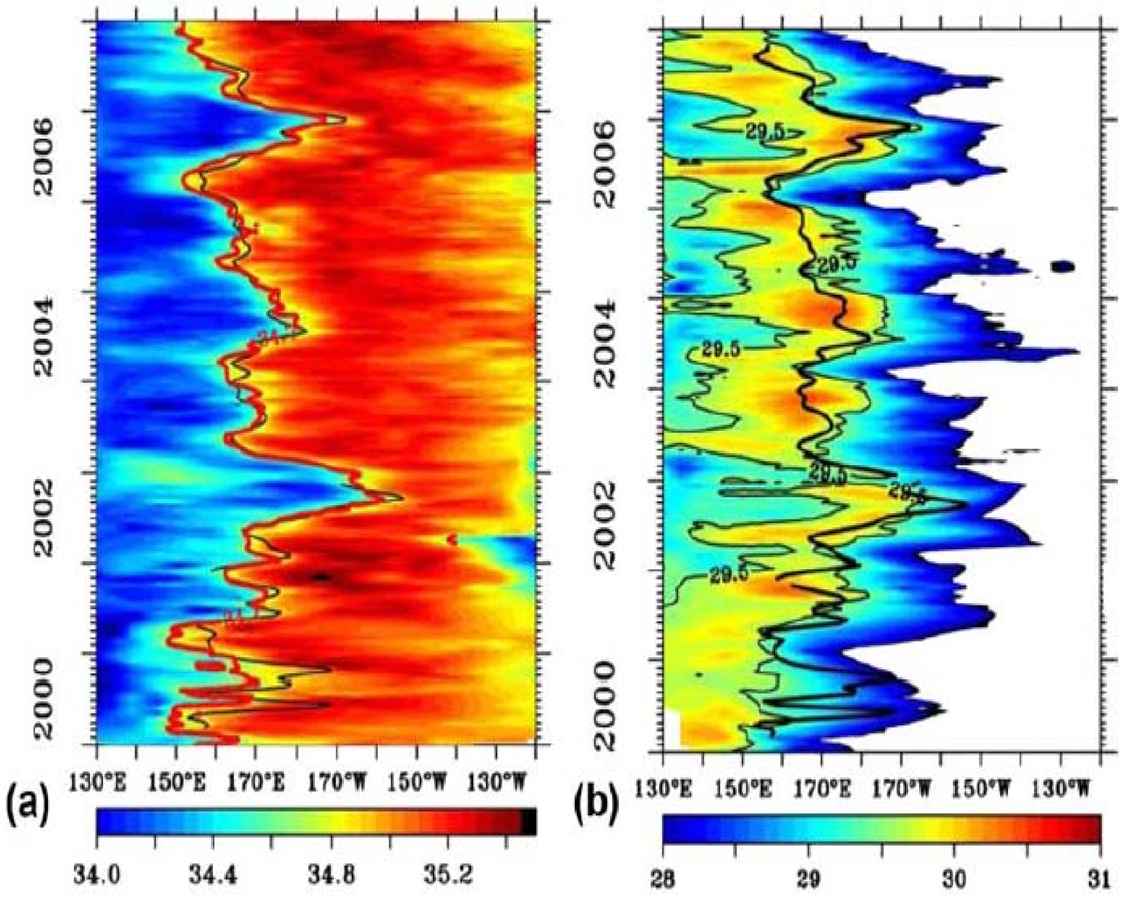


Based on SSS data from TAO/Triton, , thermosalinographs (TSG), and Argo floats for a relatively short period 2002-2004

Maes et al. 2006

Similar results from recent observations

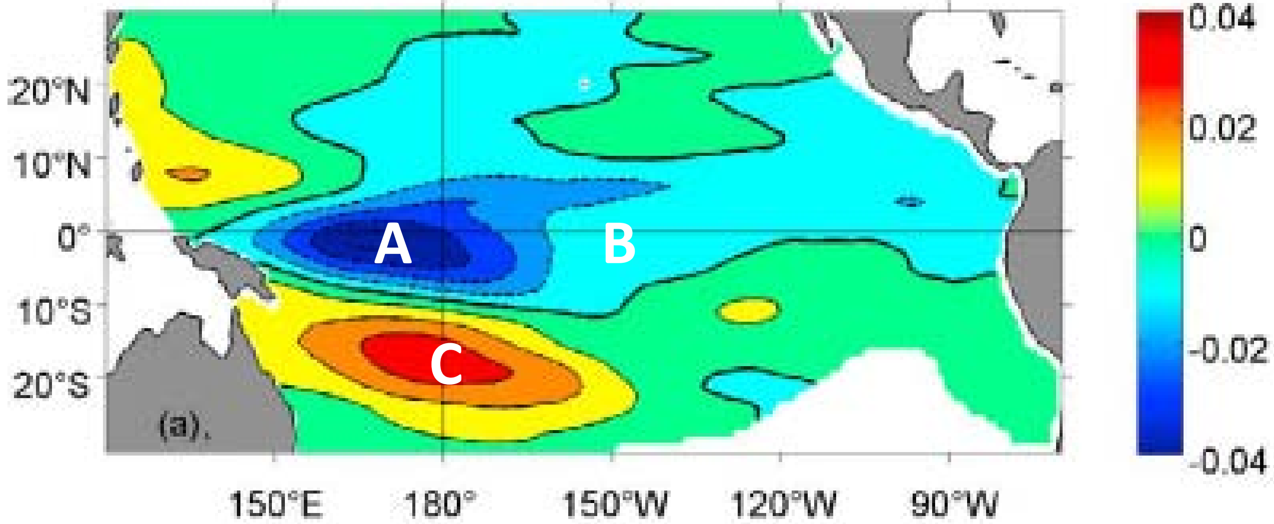
SSS front as an index of El Nino



Bosc et al. (2009) based on available CTD, thermosalinographs (TSGs), and early-stage Argo profiles the period 2000-2007

Similar results from recent observations

Singh et al. 2011



First EOF pattern based all available SSS data from 1950 to 2008

SSS El Nino Index: Normalized   B-A (equivalent to the SSS front)
SSS ENSO Index: Normalized   C-(A+B).

Why SSS indices?

Salinity observations are sparse, and thus our understanding of SSS indices didn’t make much progress in the past decade. With more SSS data from satellite and Argo becoming available in recent years, the issue of SSS indices has received increasing attention.

The question is

We already have SST indices, including Nino-4, Nino-3.4, Nino-3, and Nino-1+2. **Why do we need SSS indices?**

A few words before moving further,

1. Since no negative feedback exists between the ocean's surface salinity and freshwater flux, the SSS and SST indices may be controlled by different processes;

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

$$\frac{\partial T_m}{\partial t} = \frac{Q_0 - q_d}{\rho C_p h_m} - u_e \cdot \nabla T_m - u_g \cdot \nabla T_m - \frac{w_{ent}(T_m - T_d)}{h_m} + SSP$$

A few words before moving further,

2. Since the damping processes for salinity are oceanic and less efficient than those for temperature, the SSS indices must have more power than the SST indices towards lower frequency variability.

----Because heated water diffuses more readily than salty water.

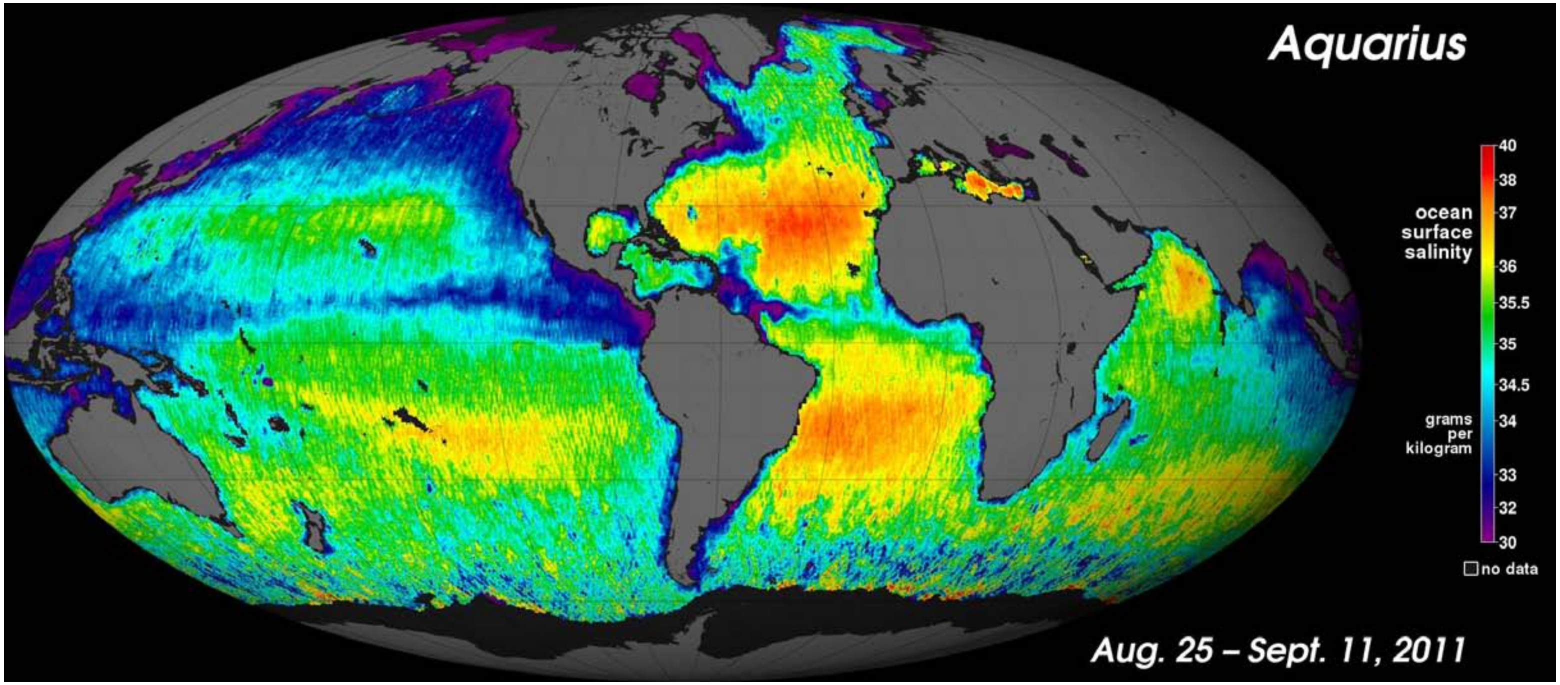
We therefore have reason to believe

the SSS indices may help reveal new dynamics of ENSO.

Data from satellite

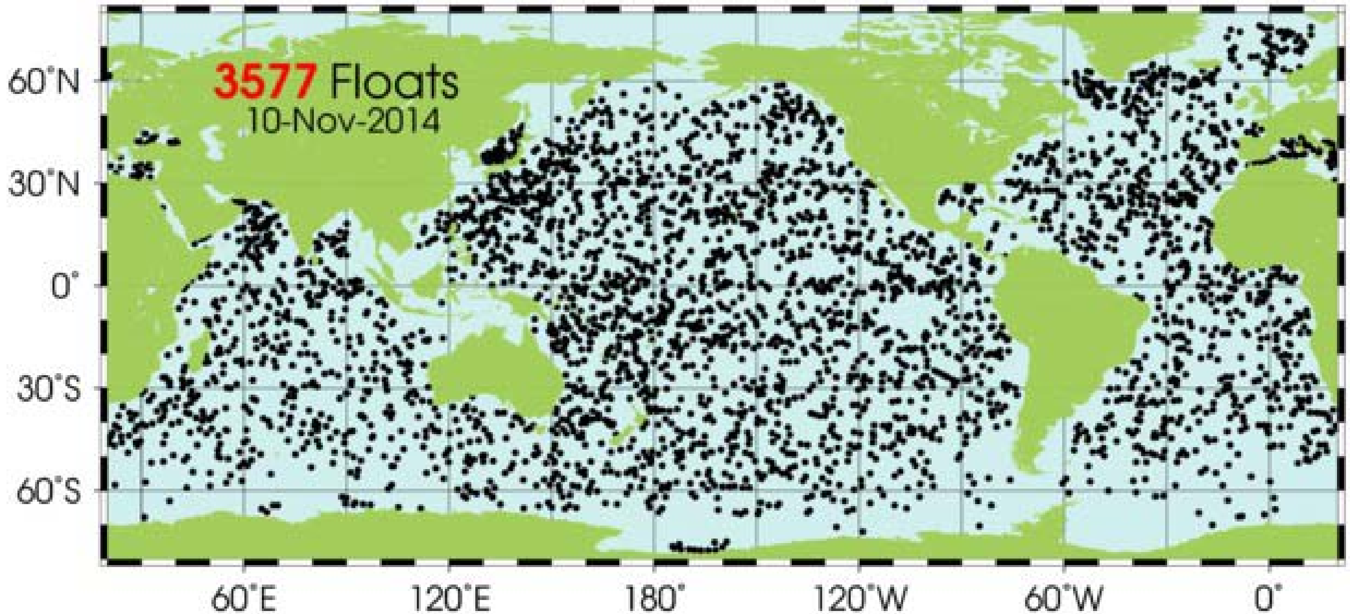
SMOS: November 2009-present

Aquarius: June 2011-June 2015.

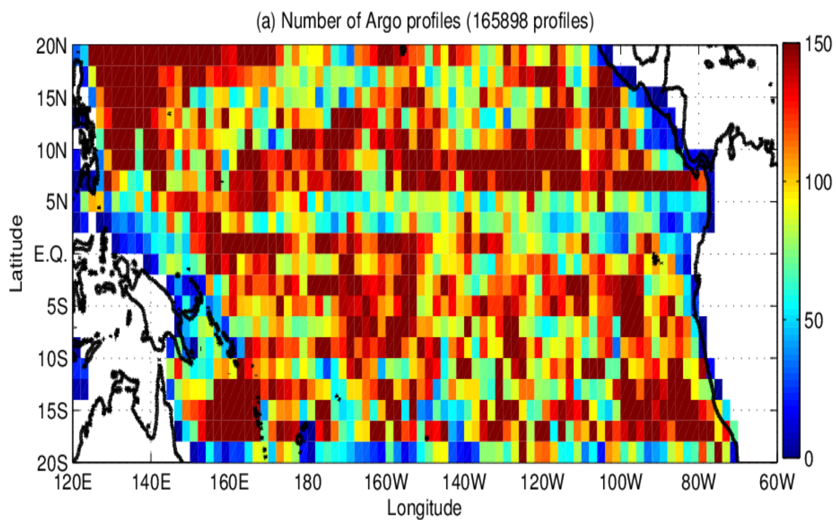


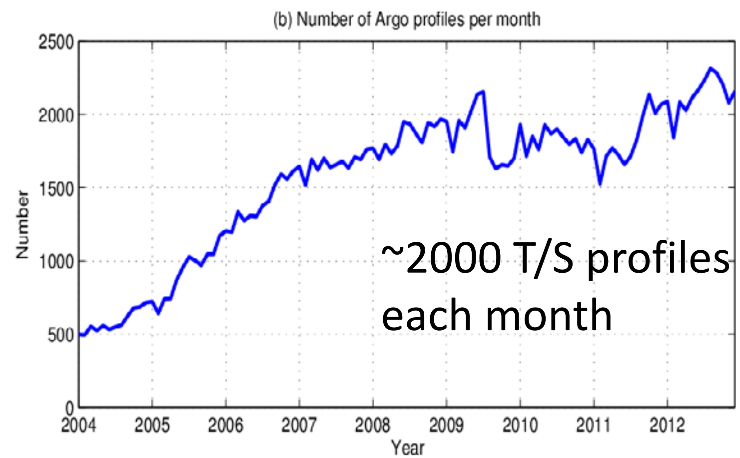
Providing a global observing capability of the ocean, generating near-synoptic SSS maps on global scale at a spatial resolution of ~150 km every 7 days.

Data from Argo



In the tropical Pacific

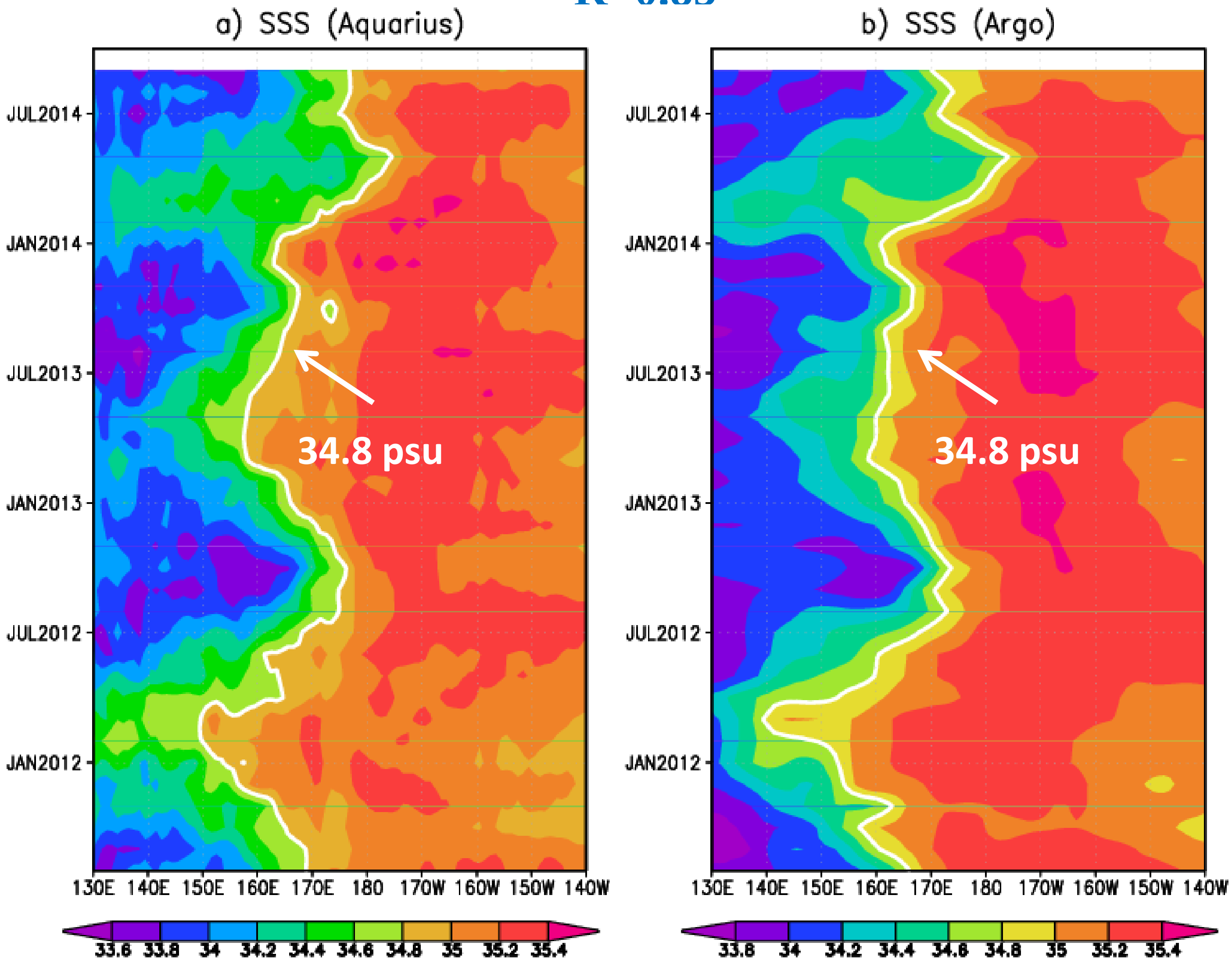




Zonal displacement of the SSS front

----during the period (08/11-09/14)

R=0.85



Both datasets are able to detect the SSS front and its variability.

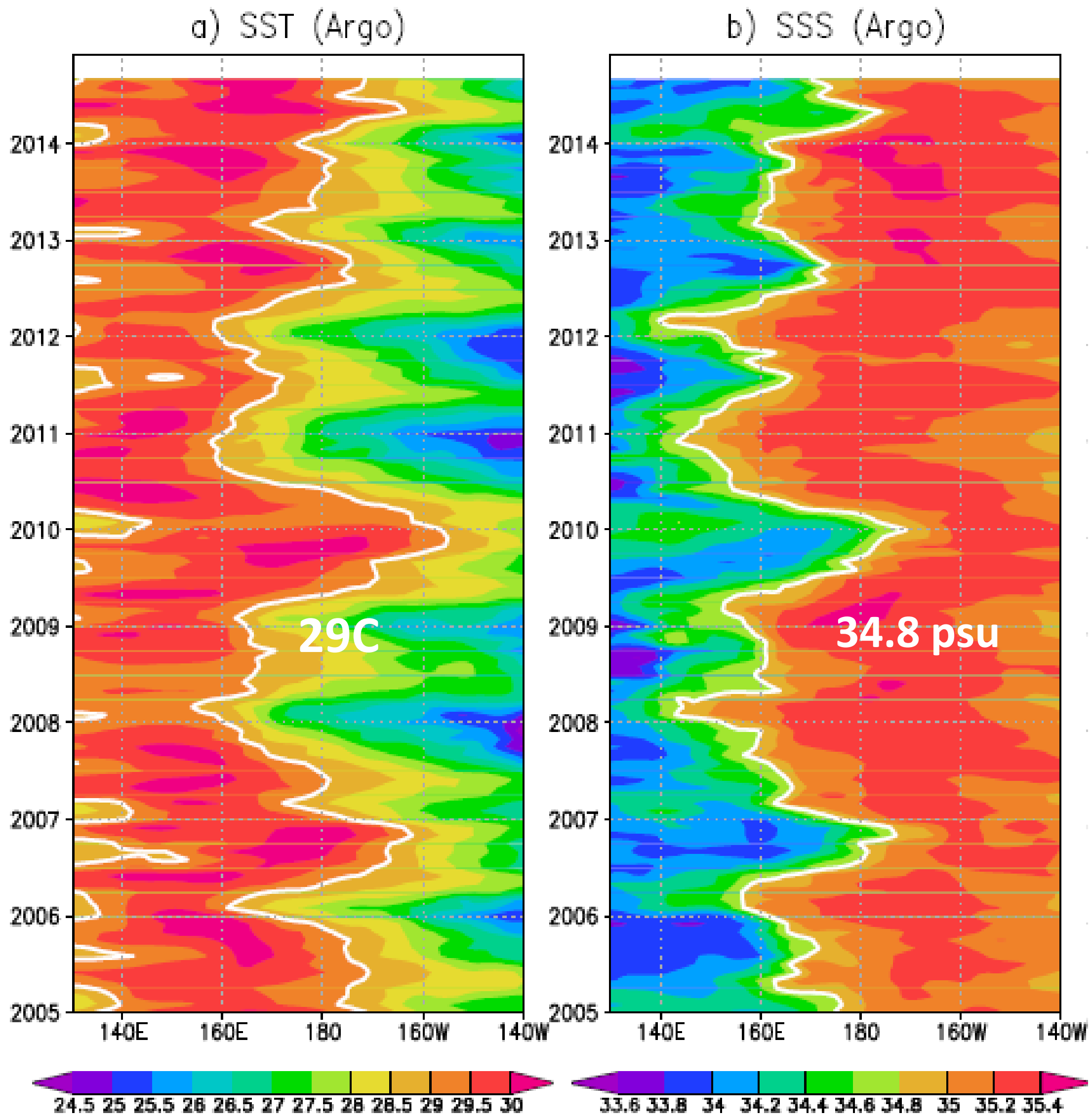
Qu et al. 2014

Zonal displacement of the SSS front and warm pool

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

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

R=0.91

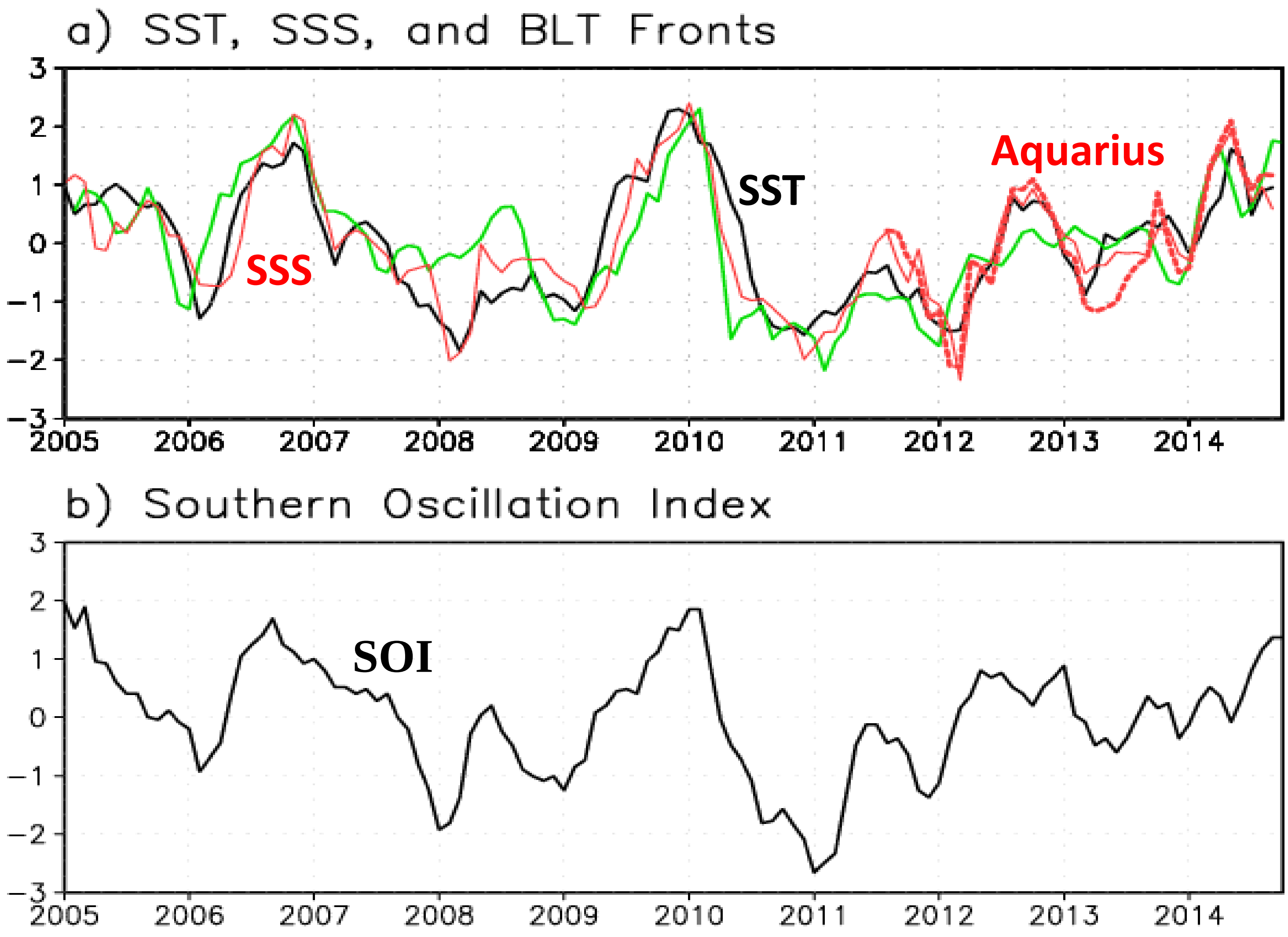


Qu et al., 2014

Link to SOI

---during the Argo period

SST (29C) ~ SOI: - 0.82
SSS (34.8psu)~SOI: - 0.84

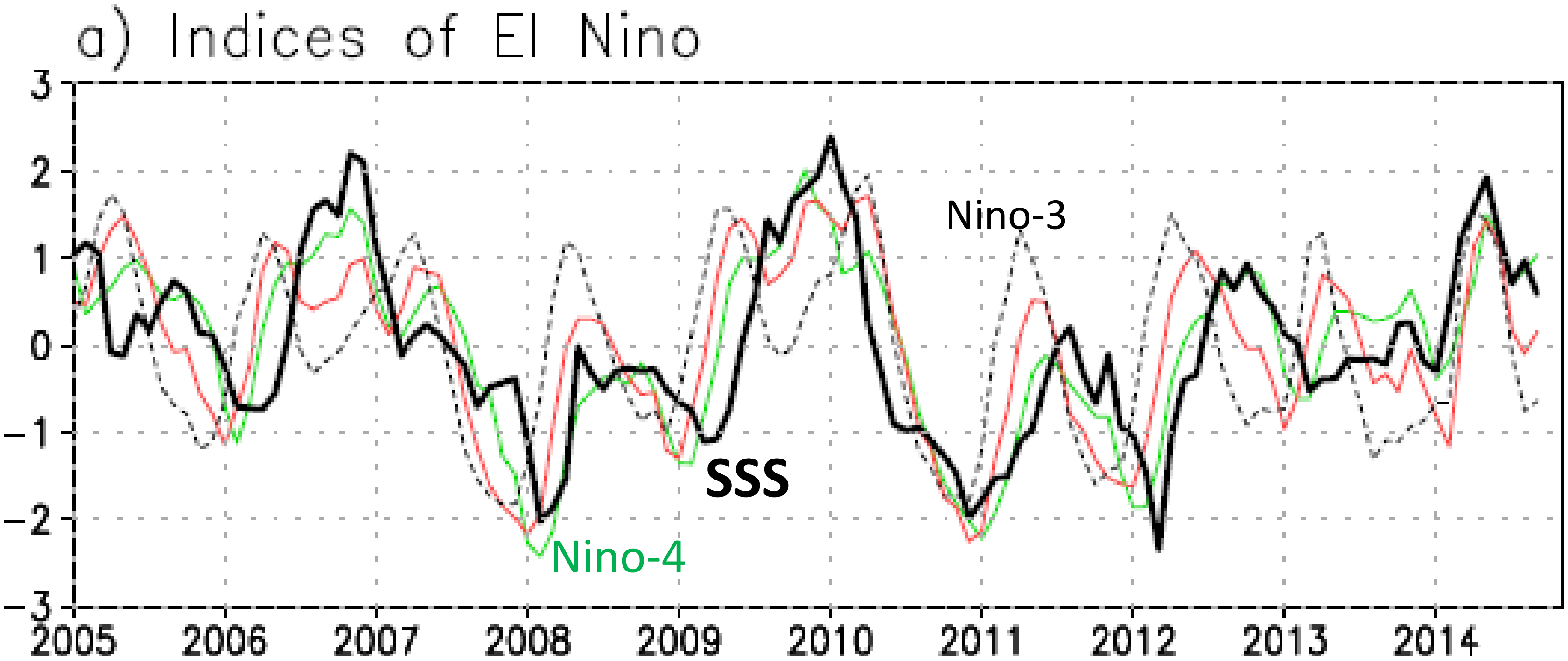


Time series of 29C isotherm, 34.8 psu isohaline, and 15 m BLT compared with SOI.

Link to Nino-4

----during the Argo period

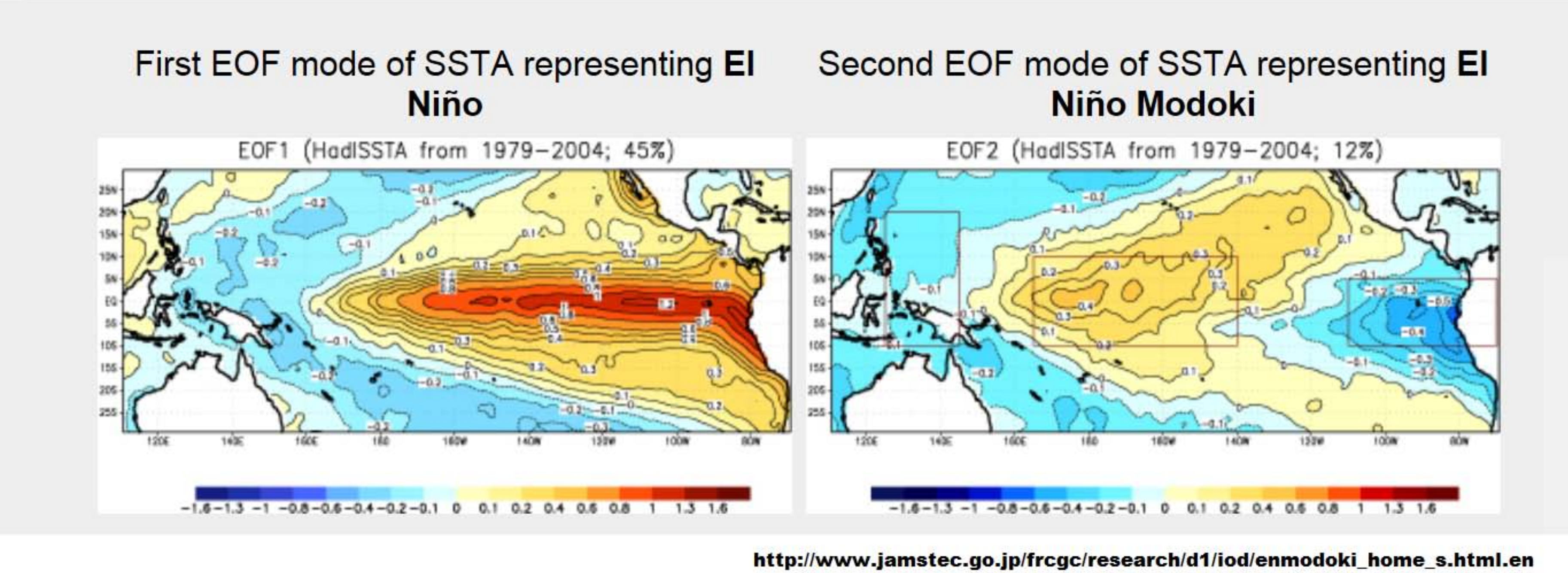
SSS front ~Nino-4: - 0.88



The result confirms that the longitudinal location of the SSS front, termed Nino-S34.8, can be used as an index to identify El Nino events.

Type of El Nino

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



Ashok et al., 2007

EMI and TNI from Argo

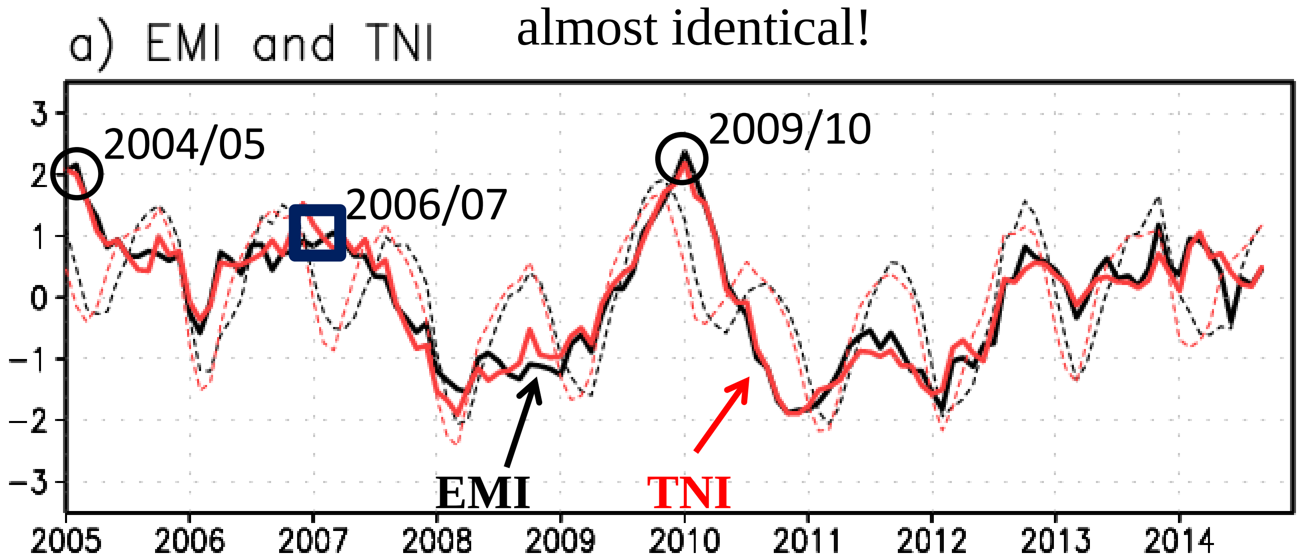
----during 2005-2014

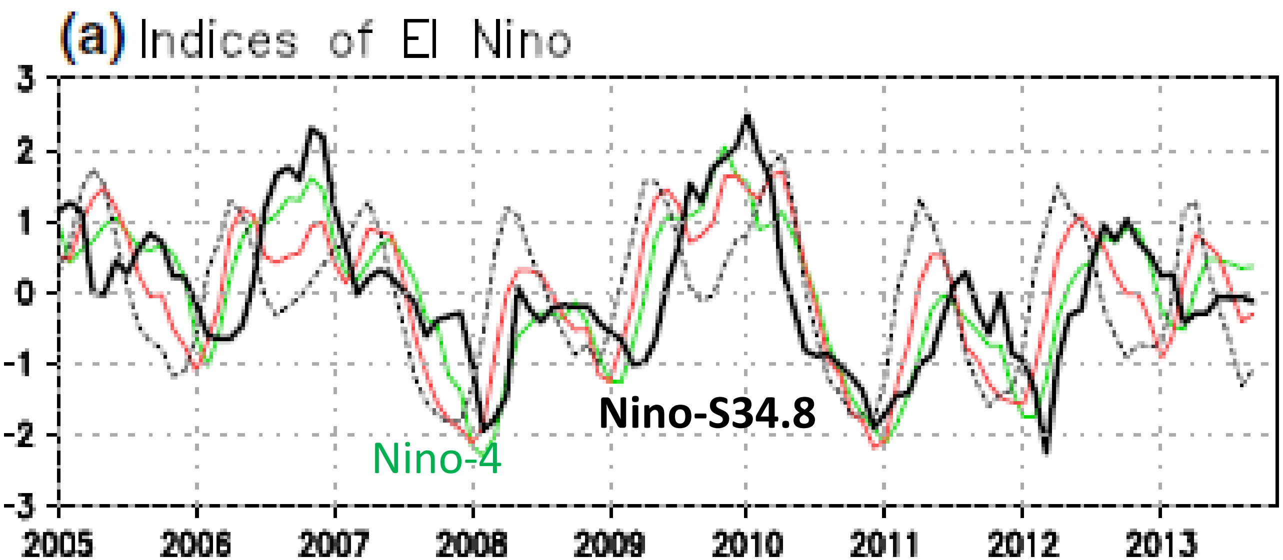
EMI: Ashok et al. (2007)

Trans-Niño index (TNI): Trenberth and Stephaniak (2001)

: CP El Nino

: EP El Nino

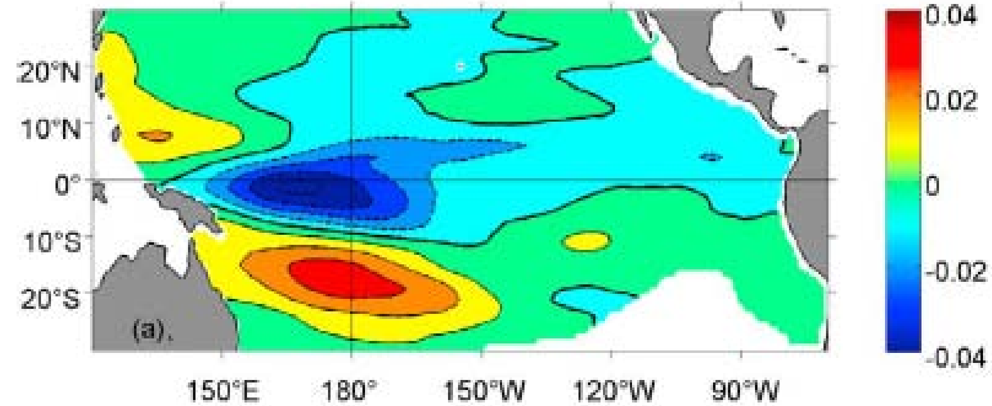


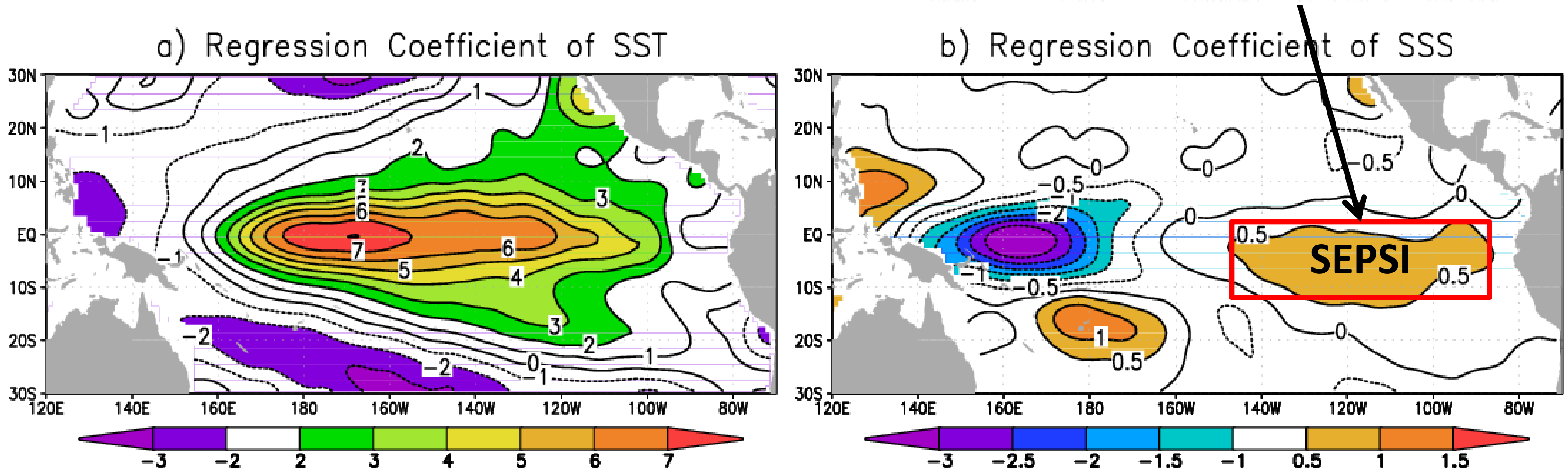


SSS index for type of El Nino

The Southeastern tropical Pacific salinity index or SEPSI.

Singh et al 2011

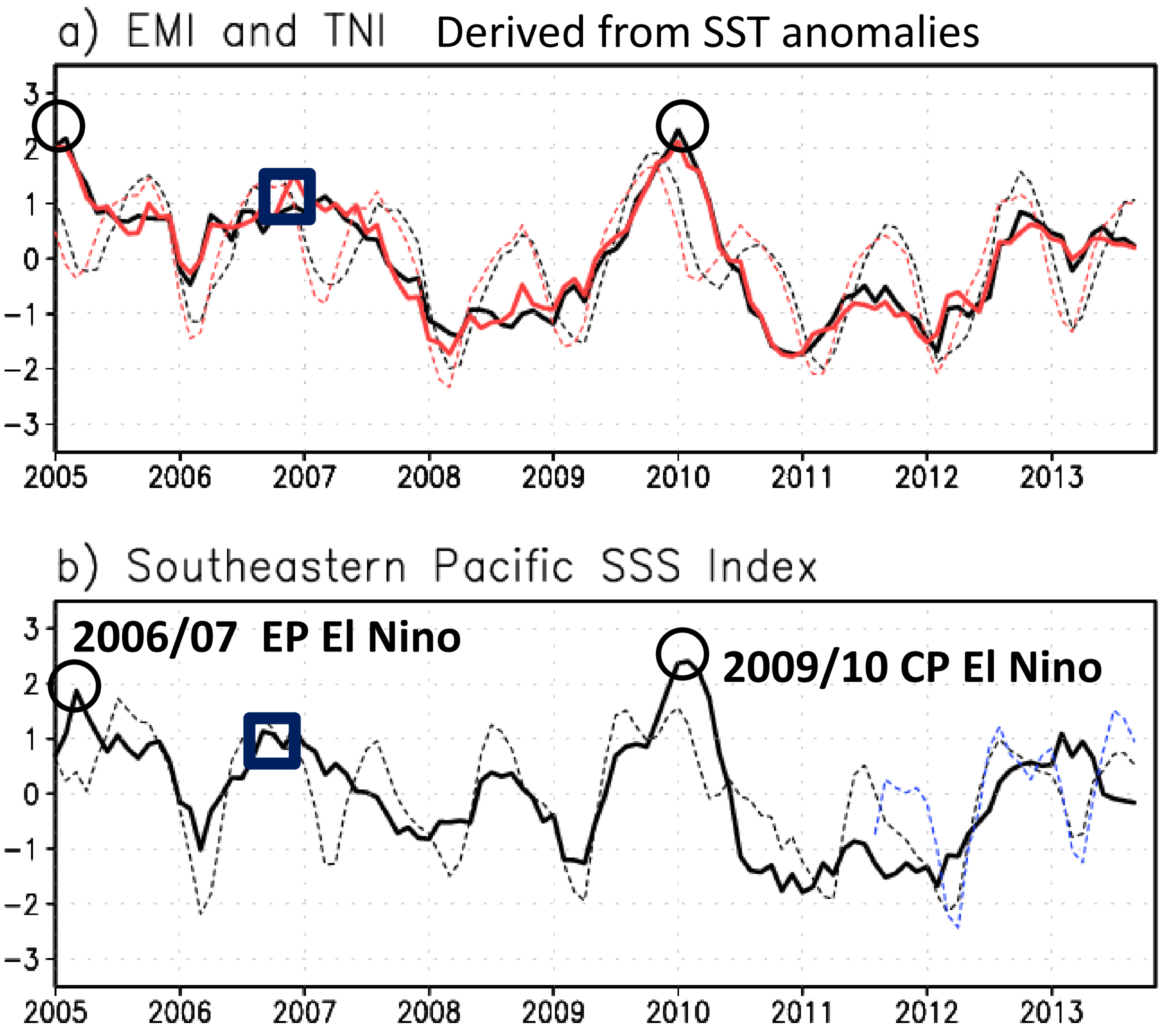




Regression coefficients of a) SST and b) SSS anomalies toward the **Niño-S34.8** index in the tropical Pacific for the period 2005-2014. (Qu and Yu 2014)

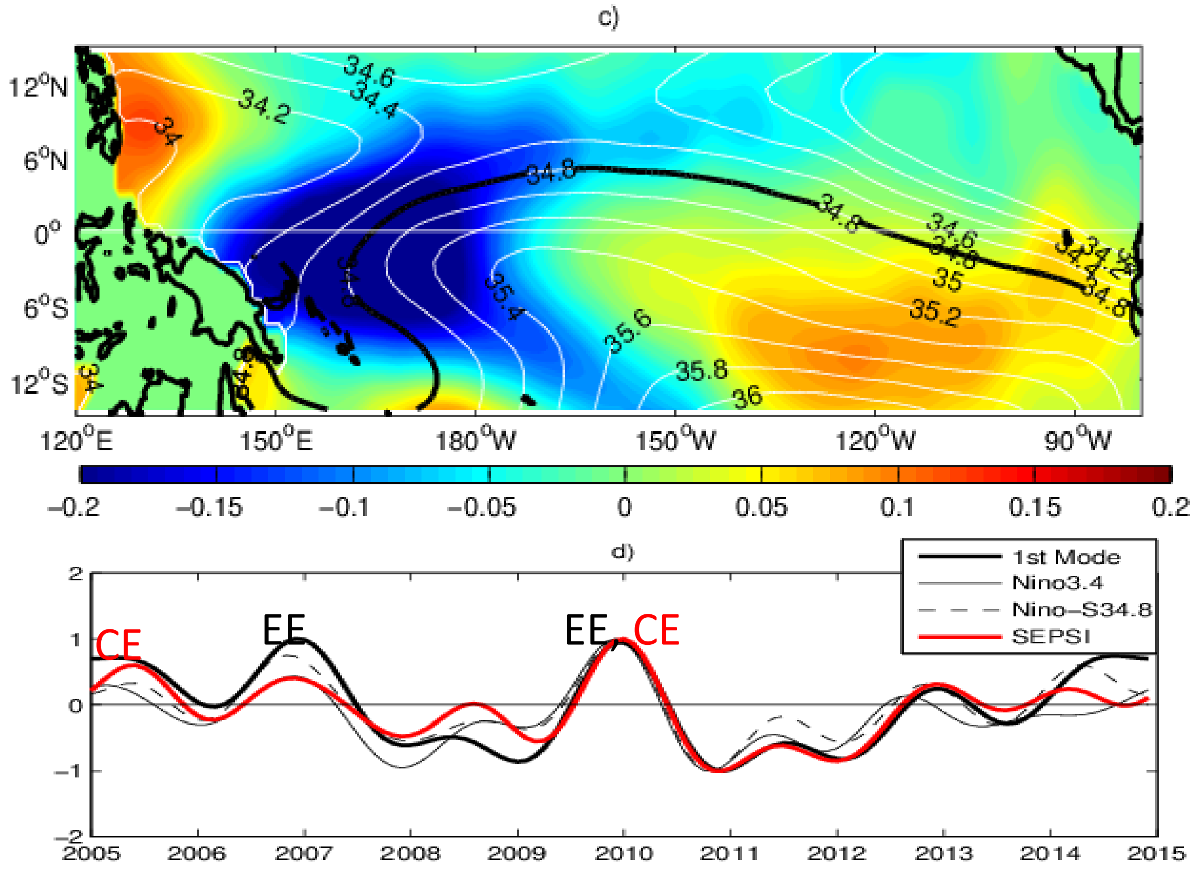
SEPSI

----- is highly correlated with the SST indices of EMI and TNI, suggesting its usefulness in characterizing type of El Nino.



R=0.85

An EOF analysis of SSS



First EOF pattern and its time series from Argo

Nino-S34.8 can be used to identify El Nino events;
SEPSI can be used to identify El Nino types

What processes control the SSS indices of El Nino?

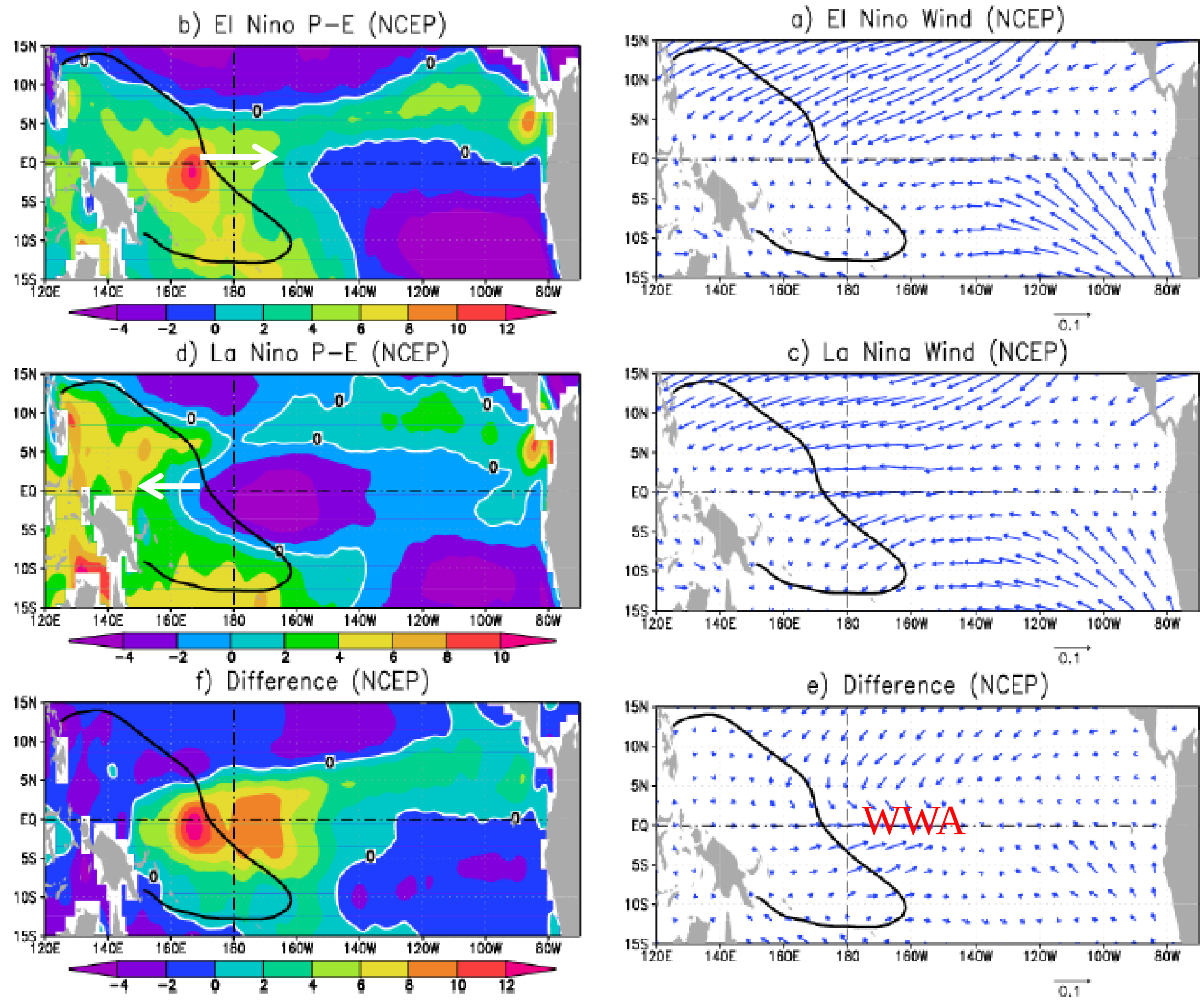
El Nino: 2006/07, 2009/10;

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 zonal displacement of SSS front is controlled by surface freshwater flux and surface current anomalies.

Vertical entrainment is a big unknown, and it was ignored in most cases by previous studies.

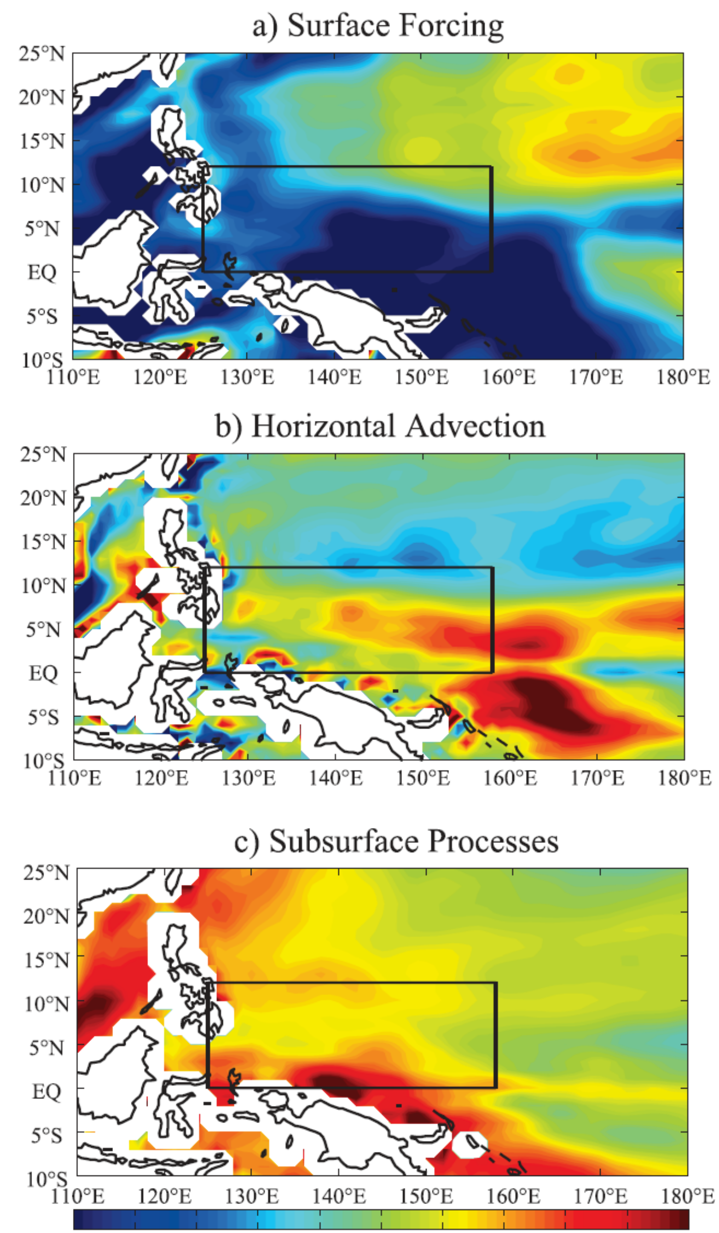


Salinity budget analysis

Results from OGCM indicate that, except for the freshwater pool, vertical entrainment is significantly less than E-P and horizontal advection, because vertical salinity gradient is small there.

Does this mean that vertical entrainment of subsurface water is not important?

No!



Gao et al. 2014

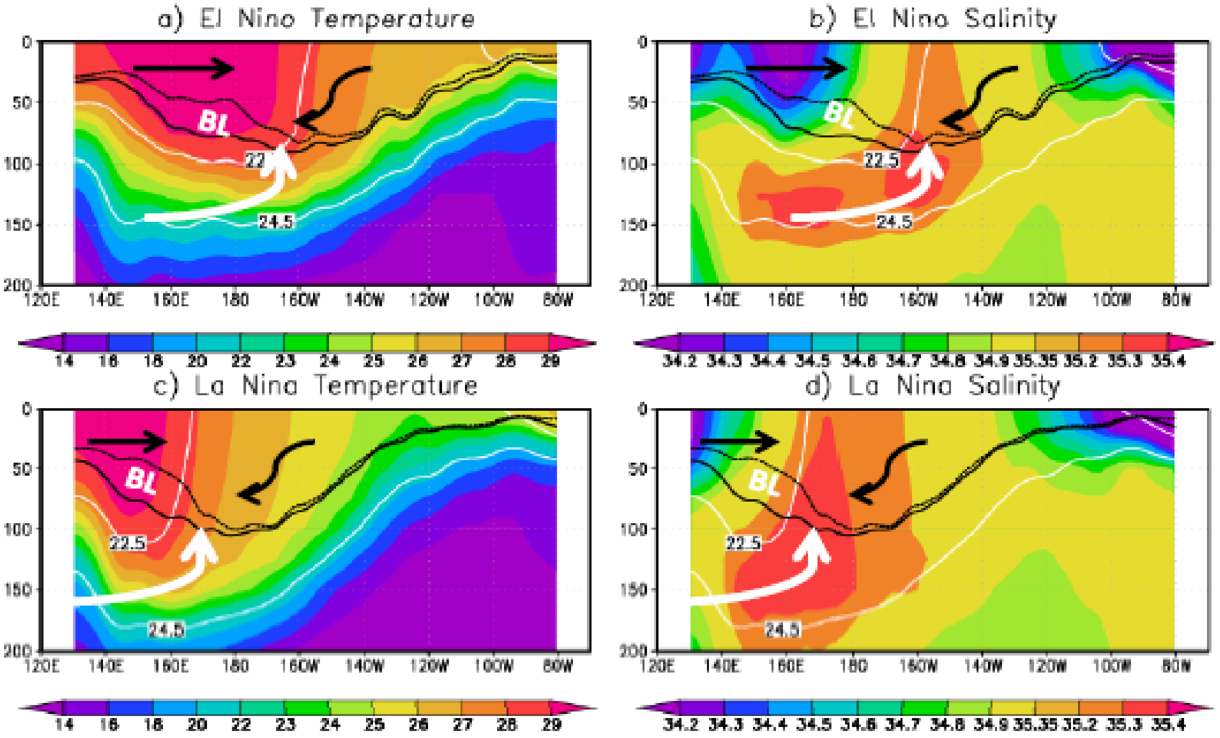
Vertical salinity distribution

El Nino: 2006/07, 2009/10;

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

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

Despite its small vertical salinity jump, the zonal displacement of the resurfacing high salinity water seems to dominate the zonal displacement of SSS front.



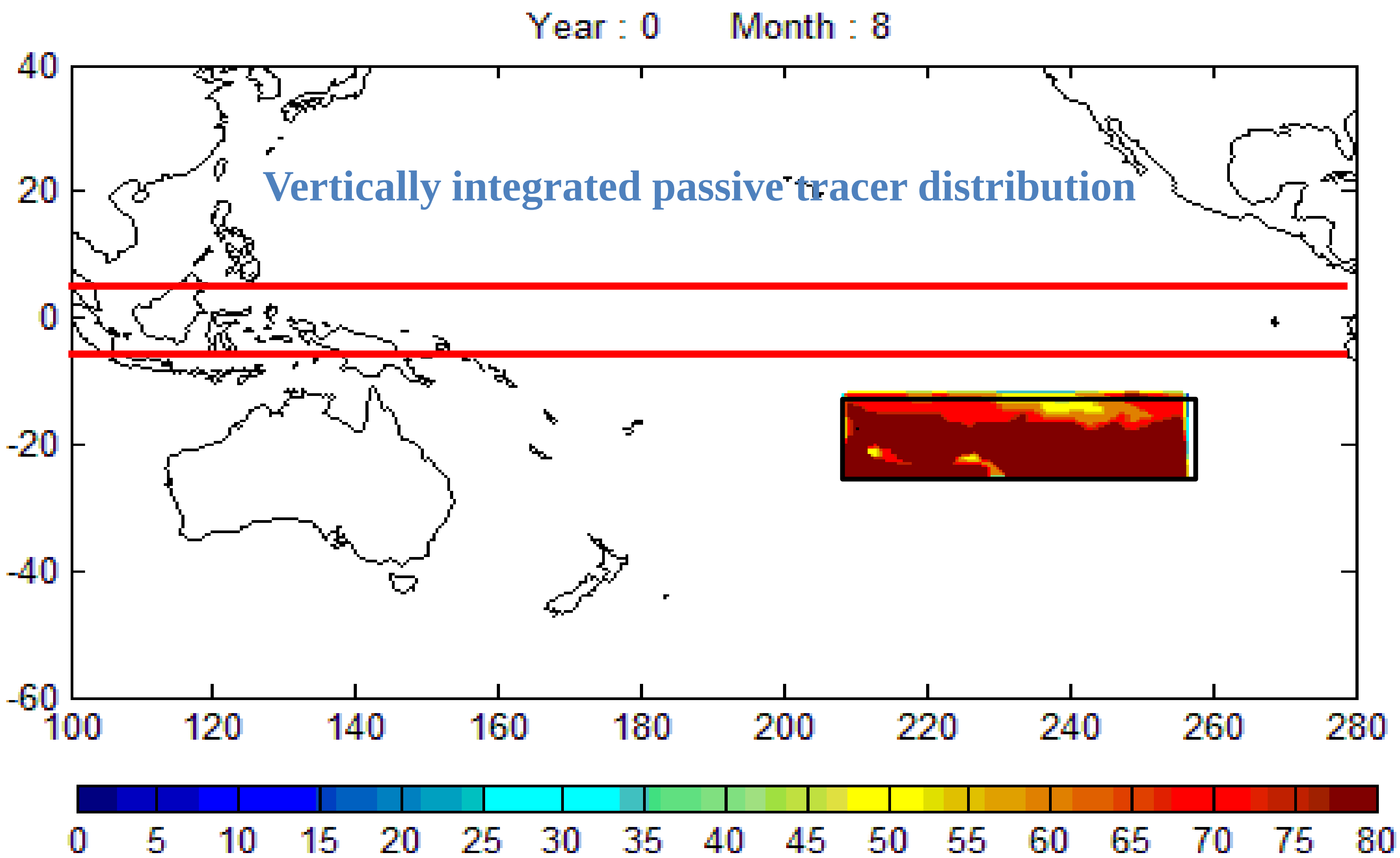
The vertical entrainment of high salinity water moves consistently with the SSS front, eastward during El Nino and westward during La Nina.

Hypothesis

Vertical entrainment of the high salinity subtropical water (SPTW and NPTW) is an important process that modulates the halocline structure, alters the surface stratification (e.g., the barrier layer), and shifts the SSS front along the equator, thereby playing a role in ENSO evolution.

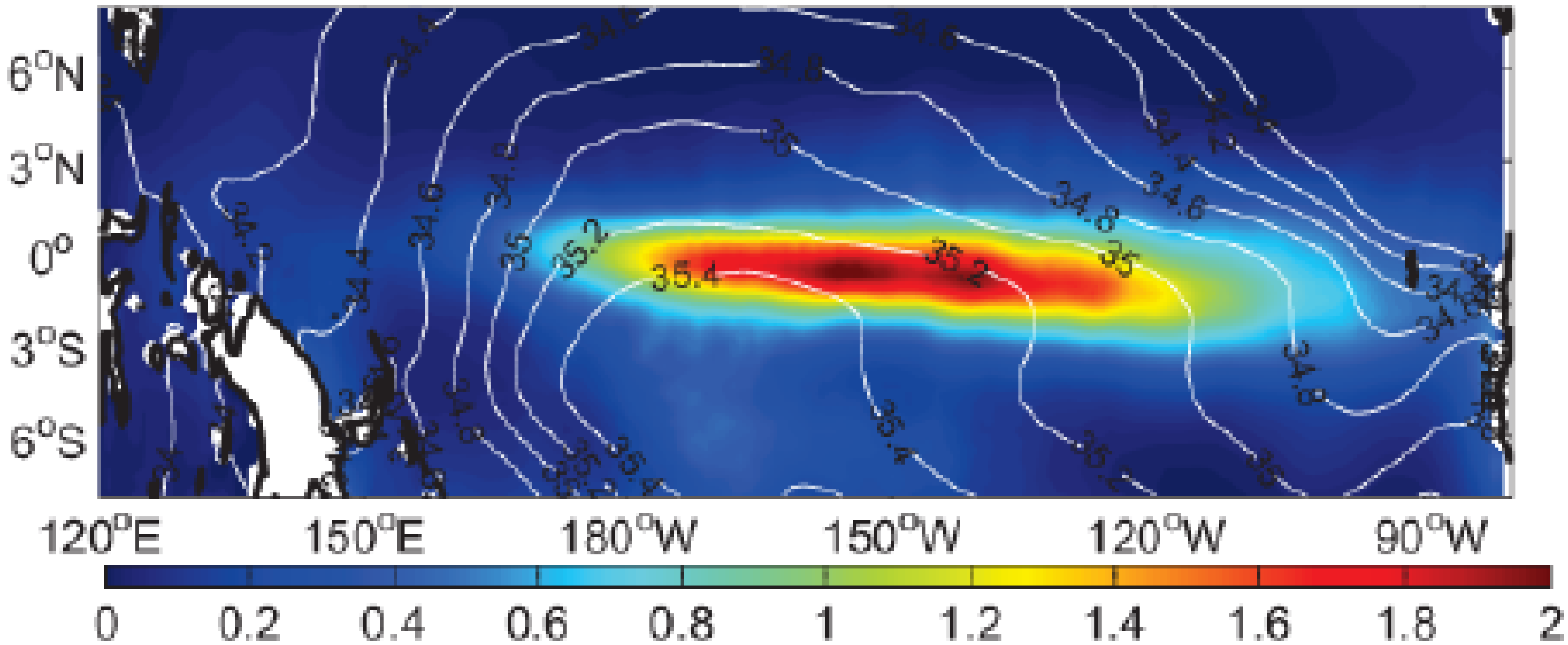
To confirm this hypothesis, we conducted a passive tracer experiment by releasing passive tracer in the winter mixed layer of the South Pacific SSS maximum (SPTW) and tracing it forward using ECCO’s offline circulation from 1993 to 2012.

Resurfacing in the equatorial Pacific



When a tracer-tagged water parcel enters the surface mixed layer in the equatorial (5S-5N) Pacific, it is considered to be resurfaced and no tracking of this water parcel will be further conducted.

Location of the resurfaced of SPTW high SSS



Concentration (color) of passive tracer that has entered the surface mixed layer .

Do the volume and location of the SPTW that resurfaces in the equatorial Pacific vary with time?

A set of passive tracer experiments are underway.

Summary

(1) Both satellite and Argo data are able to precisely detect the SSS front in the equatorial Pacific;

(2) The SSS indices can be used to identify both the event and type of El Nino;

(3) Vertical entrainment of high salinity water from subtropics may play an important role in modulating these SSS indices.

To be continued.


Thank You
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