An Introduction to the South China Sea Throughflow:

Its Dynamics, variability, and Implication for Climate

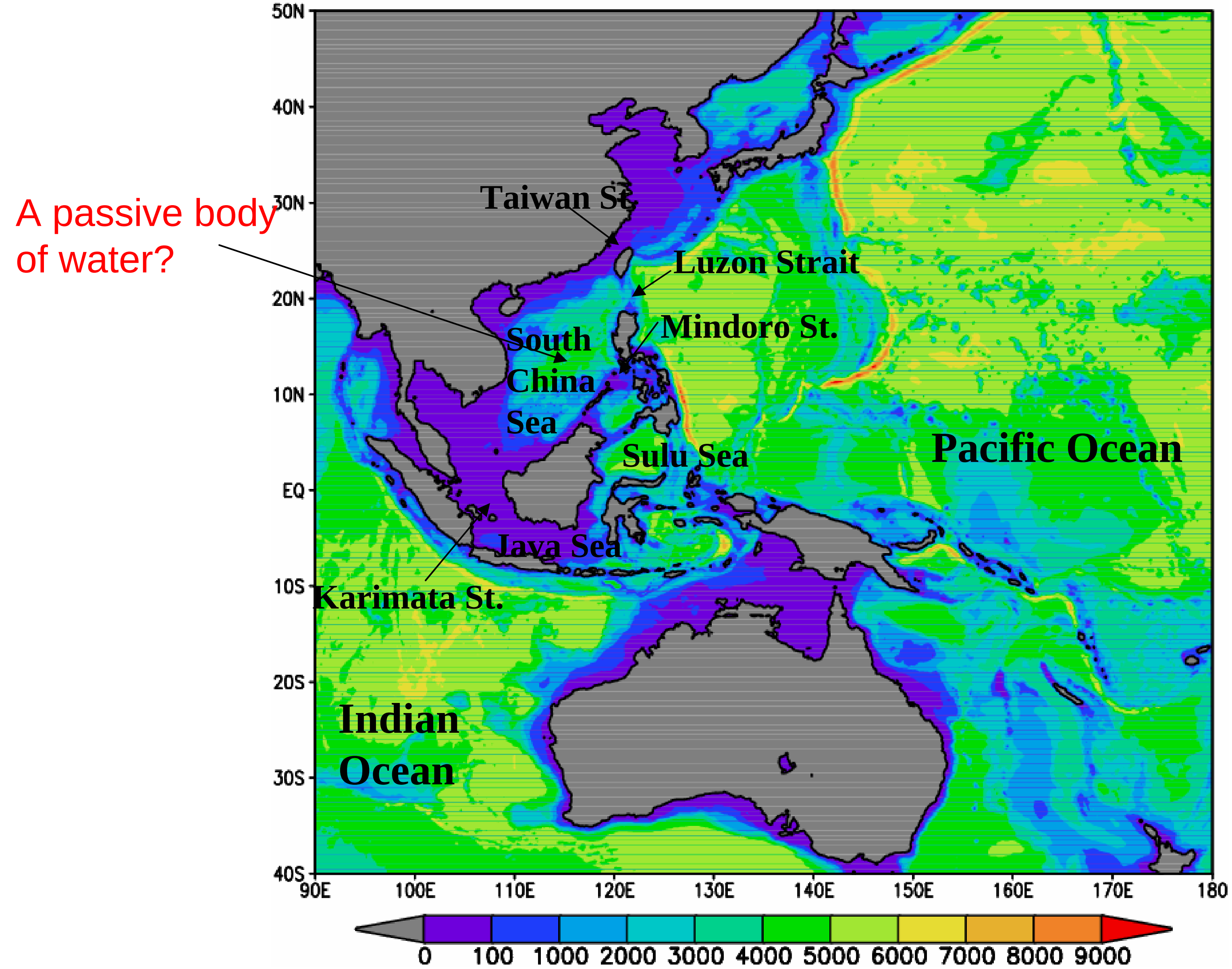
Tangdong Qu

International Pacific Research Center, SOEST, University of Hawaii

In collaboration with

Y. Du, G. Meyers, A. Ishida, H. Sasaki, T. Tozuka, and T. Yamagata

(September 2, 2008)

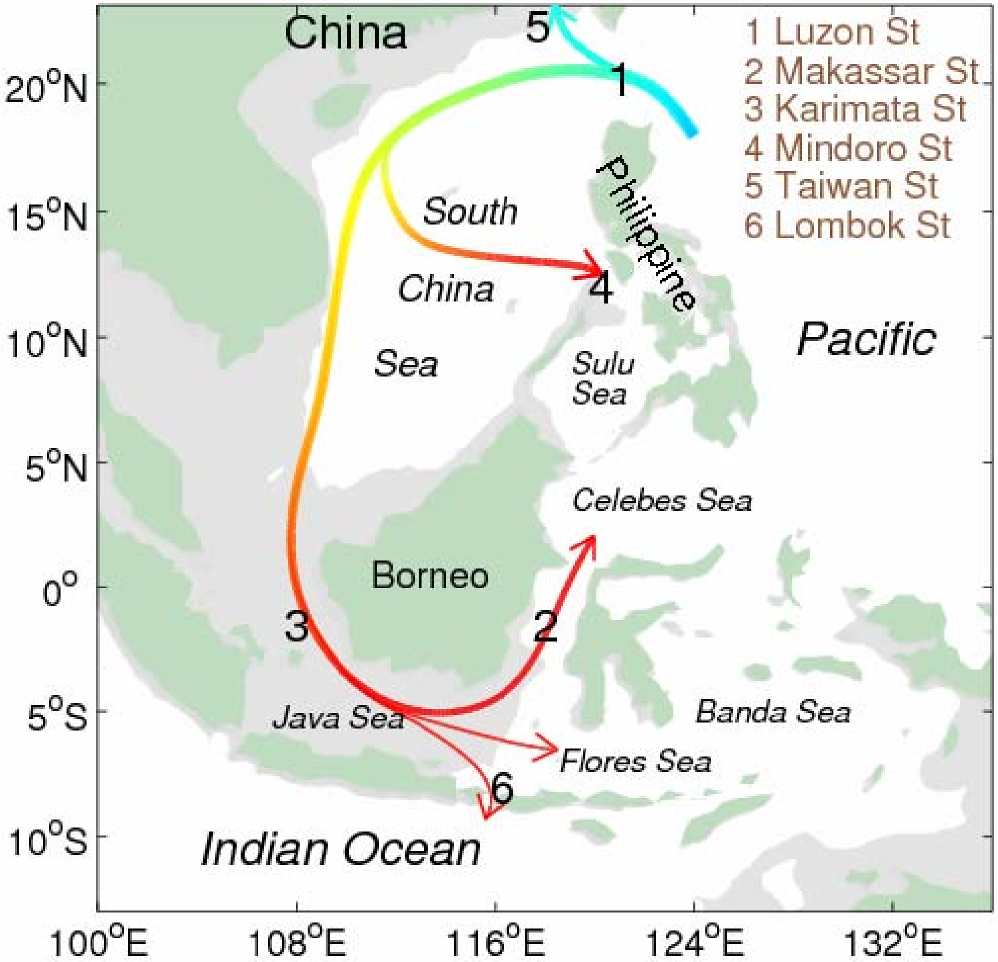


South China Sea is the largest marginal sea in the southeastern Asian waters, covering a global surface area (~3.5×10^{12} m^2) equivalent to more than one third of the continental United States. It connects in the south with the Sulu and Java Seas through the shallow Mindoro and Karimata Straits and in the north with the Pacific Ocean through the deep Luzon Strait, with its maximum water depth exceeding 4000 m.

There is a flow through the South China Sea, termed the South China Sea throughflow (SCSTF)

My message:

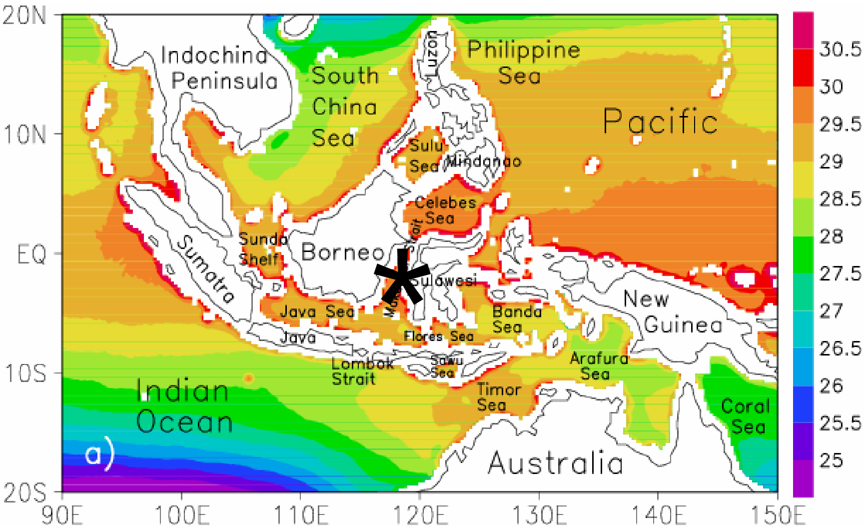
The South China Sea is not a passive body of water, and the SCSTF can play a potentially important role in modulating the Asian Monsoon and Pacific ENSO.



A schematic diagram of the SCSTF

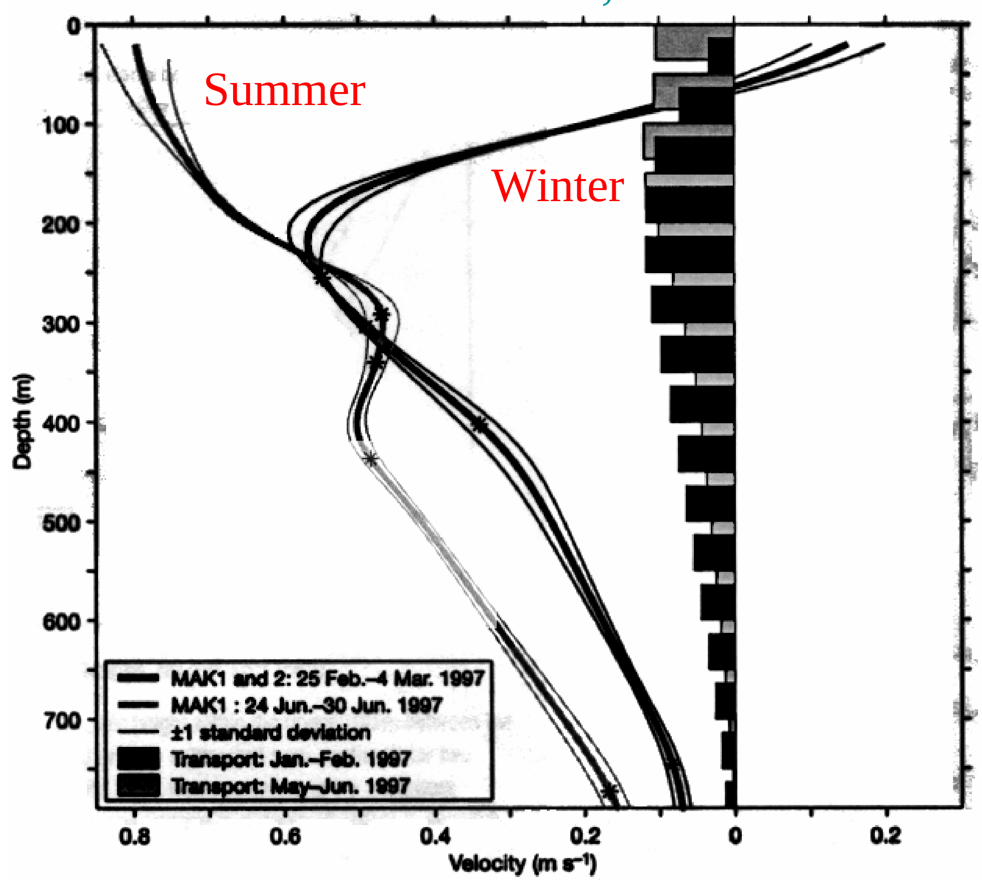
(1) Identification of the problem

An important finding of recent observations is the maximum* southward velocity in Makassar Strait occurs at subsurface (~150 m), and because of this, the actual ITF heat transport (~0.5 PW) is significantly smaller than previously thought (~1 PW). What mechanisms are responsible?

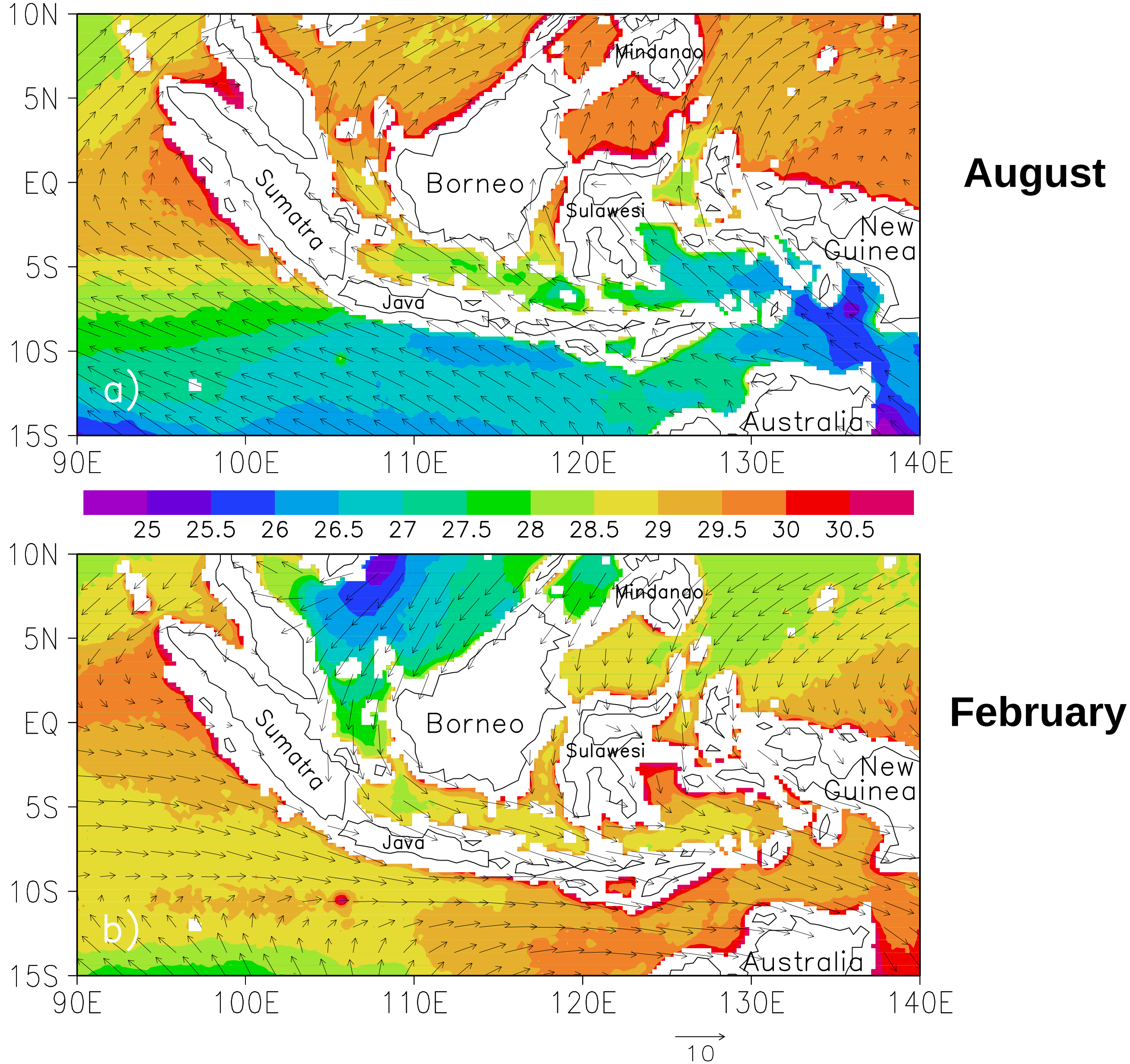


Meridional velocity profile observed in the Makassar Strait during INSTANT program.

Gordon et al., 2003

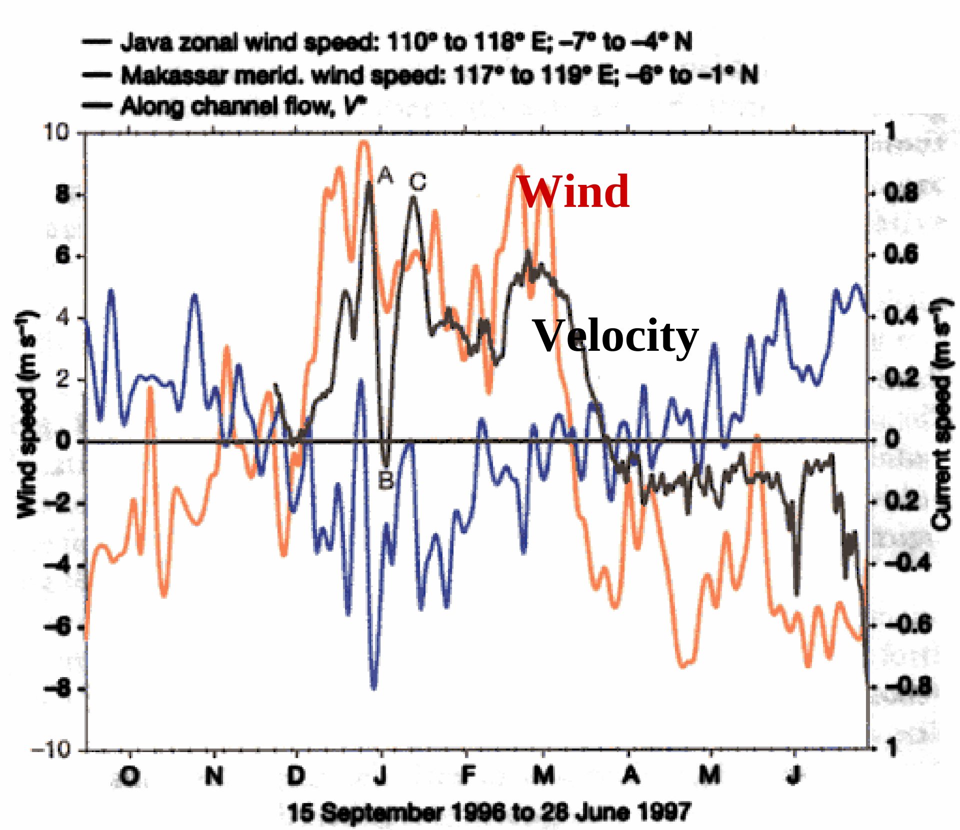


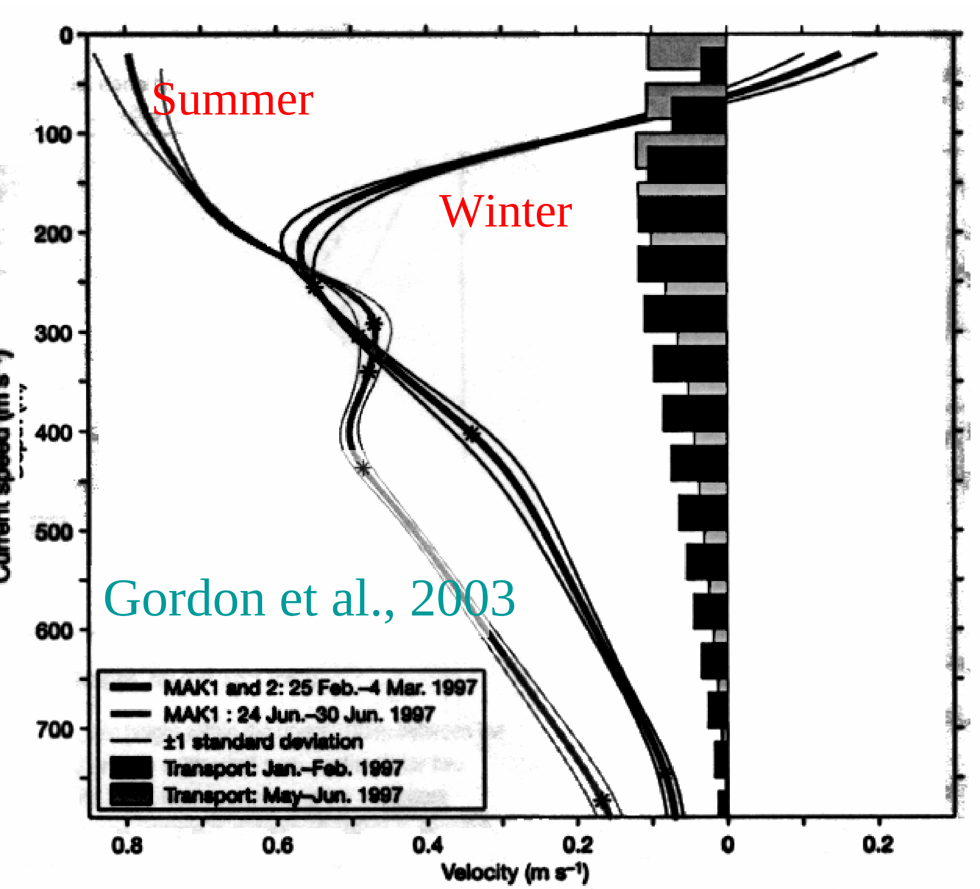
The first thing we can think of is **regional wind**



Monthly mean TRMM sea surface temperature (°C) superimposed with Quick Scatterometer (QuikSCAT) wind (m/s) in a) August and b) February. Data are averaged from December 1997 to June 2004 and from July 1999 to January 2005, respectively.

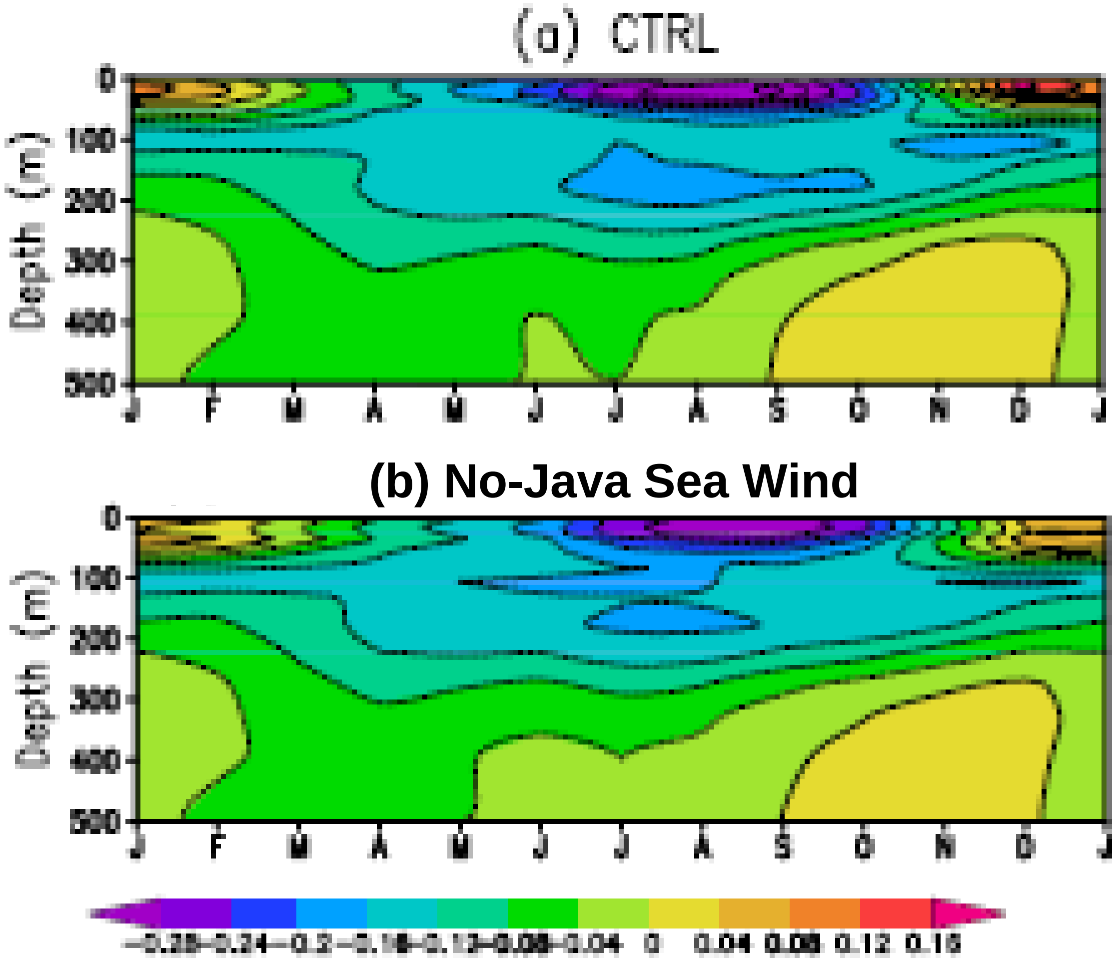
Gordon et al. (2003) noticed that the relative surface flow in Makassar St. is highly correlated (0.80) with regional wind in Java Sea. So they suggested that it is the regional wind that forces the intrusion of freshwater from the SCS and creates a northward directed pressure gradient that further drives the northward flow in the surface layer of the Makassar. Can the intrusion of the fresh water from the SCS be driven by the regional wind in the Java Sea?





Numerical experiments (Tozuka, Qu, Yamagata, 2008) suggest that the regional wind of the Java Sea cannot do the job.

Removing the Java Sea wind in the model does not change the northward flow in the surface layer of the Makassar Strait in the northern winter. So, the forcing must lay outside of the Java Sea. Where?

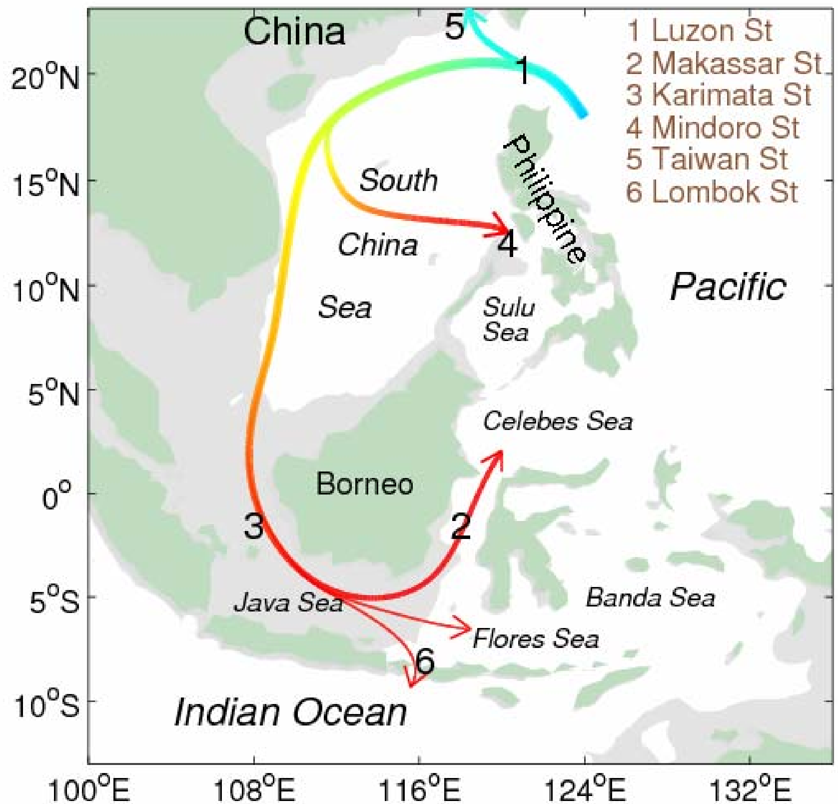


Vertical profiles of velocity in the Makassar Strait with and without the regional wind of the Java Sea in the model

Our hypothesis:

The intrusion of freshwater from the SCS is part of the South China Sea throughflow, forced by the basin-scale wind in the Asian-Pacific region.

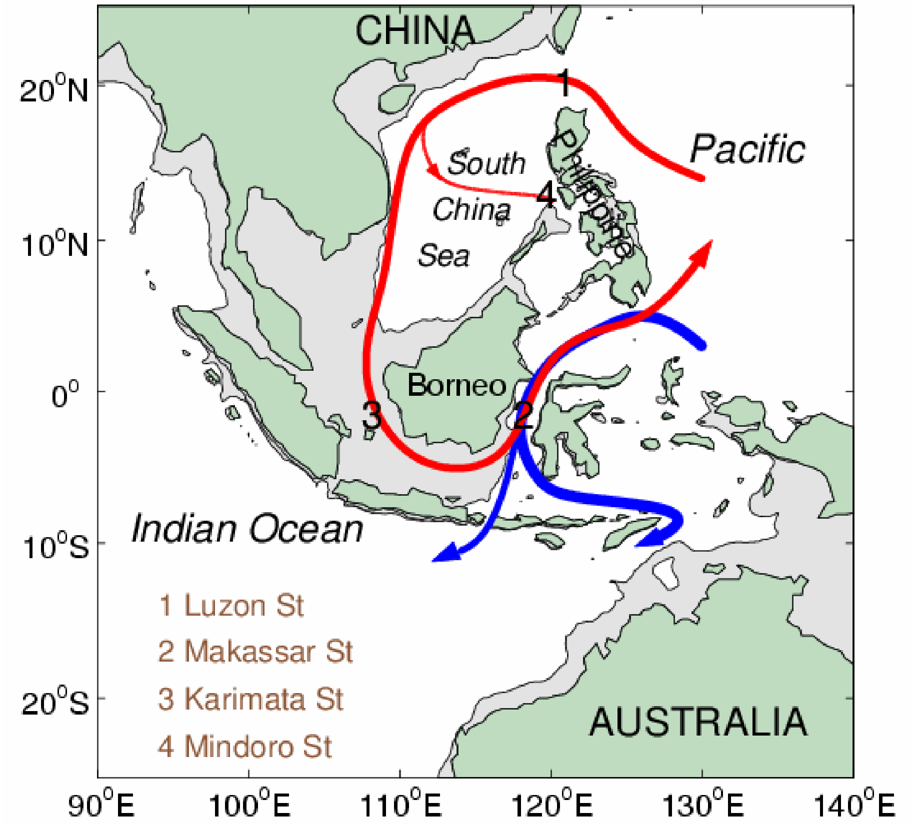
A schematic diagram of the SCSTF (after Qu et al., 2006), with colder, saltier water entering the SCS through the Luzon Strait and warmer, fresher water exiting the SCS through the Mindoro and Karimata Starit.



In the Makassar Strait, the flow is a consequence of interplay between the ITF (southward) in the thermocline and the SCSTF (northward) near the surface.

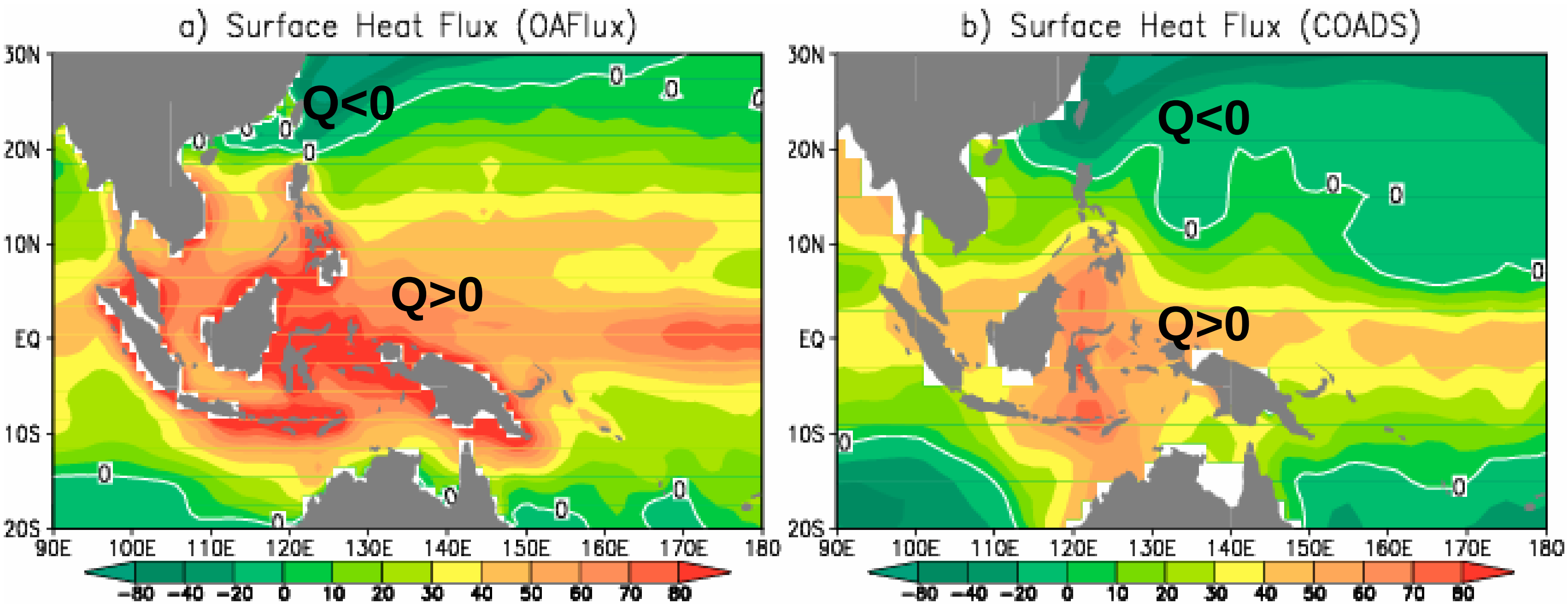
A schematic diagram showing the interplay between the SCSTF and ITF in the Makassar Strait (after Qu et al., 2005).

So, it is the SCSTF that inhibits the warm surface water from the Pacific from flowing southward in Makassar Strait.



(2) Existence of the SCSTF

From the heat point of view, ……

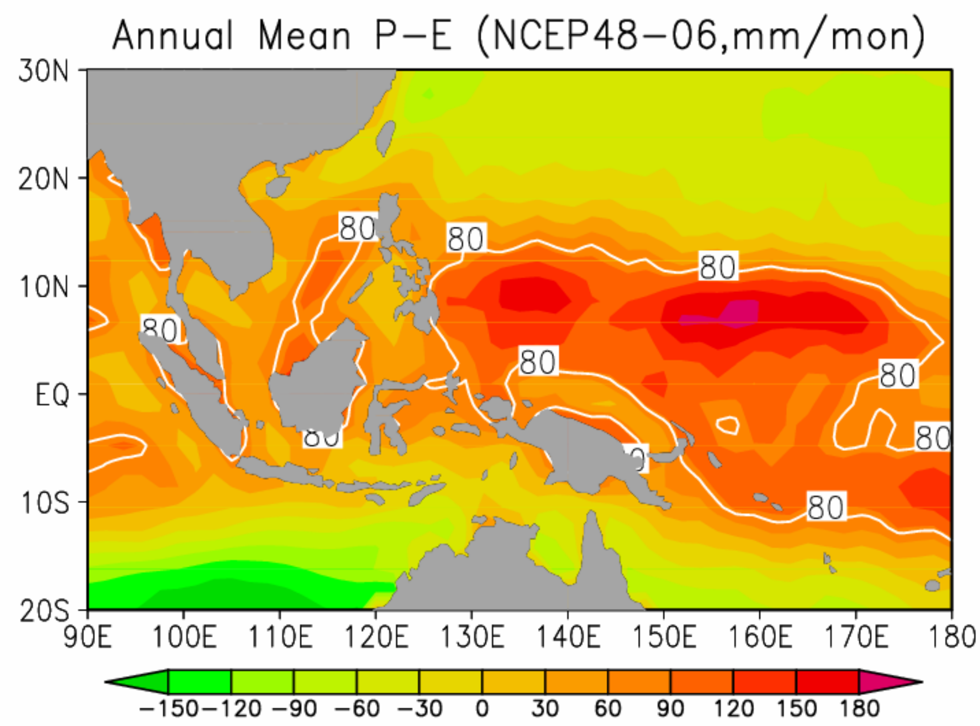


SCS gains 0.1-0.2 PW from the atmosphere

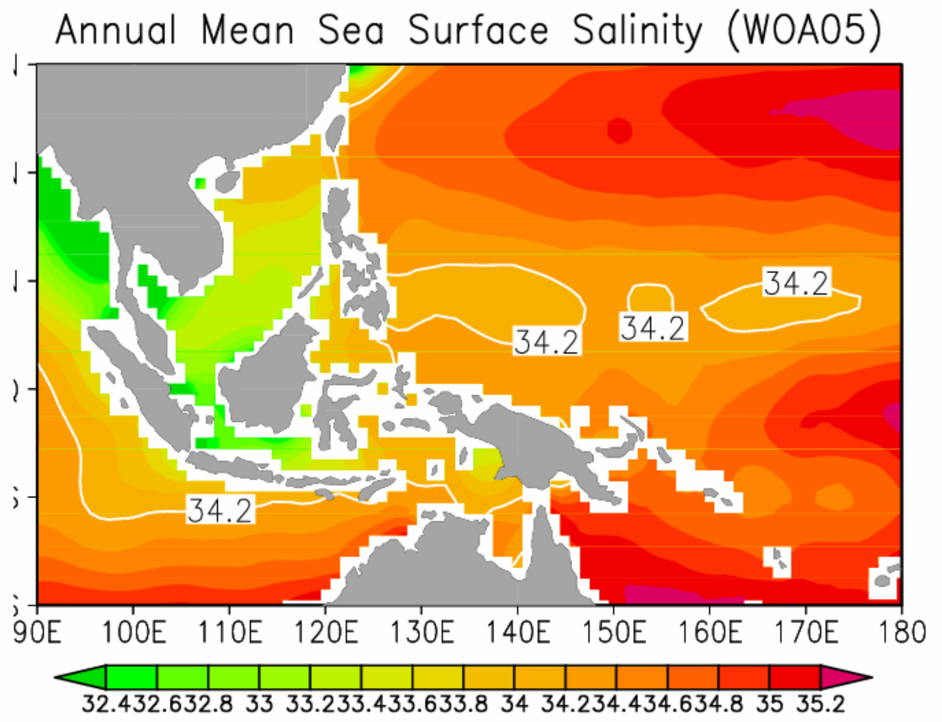
The South China Sea heat budget needs the SCSTF to balance the heat gain from the atmosphere (up to 0.1-0.2 PW)

From the freshwater point of view,…

Precipitation in the SCS exceeds evaporation (P-E) by about 0.1 Sv.



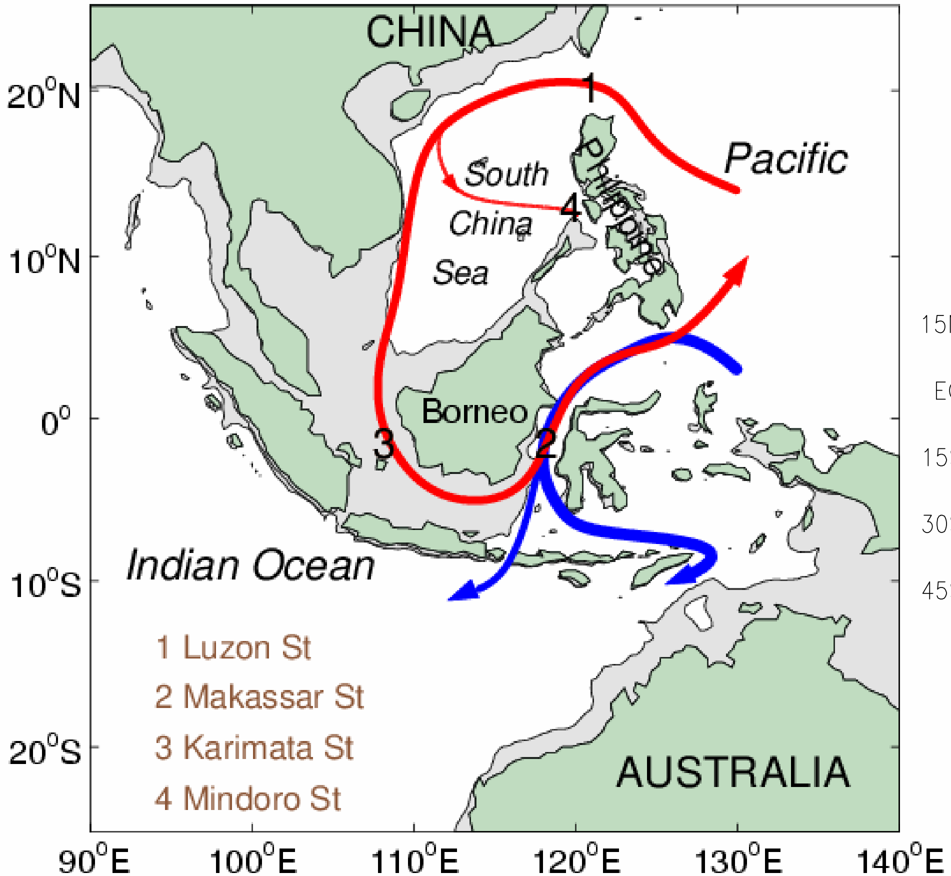
The SSS in the SCS is fresh, indicative of a recipient of heavy rainfall.



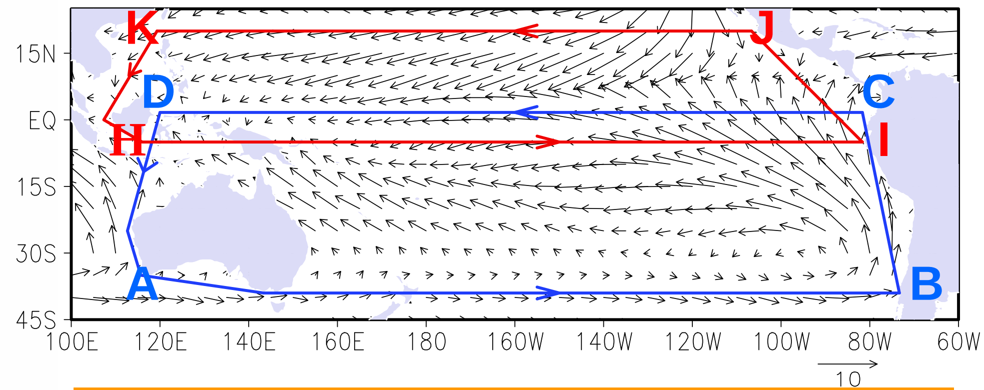
The South China Sea freshwater budget needs the SCSTF to balance the freshwater gain from the atmosphere (~0.1 Sv).

From the momentum point of view,…..

The SCSTF is a circulation around Philippine-Borneo, as can be deduced from the "Island Rule". The large-scale winds in the tropical Pacific set up a pressure head that drives the flow around the big island, the Philippine-Borneo.



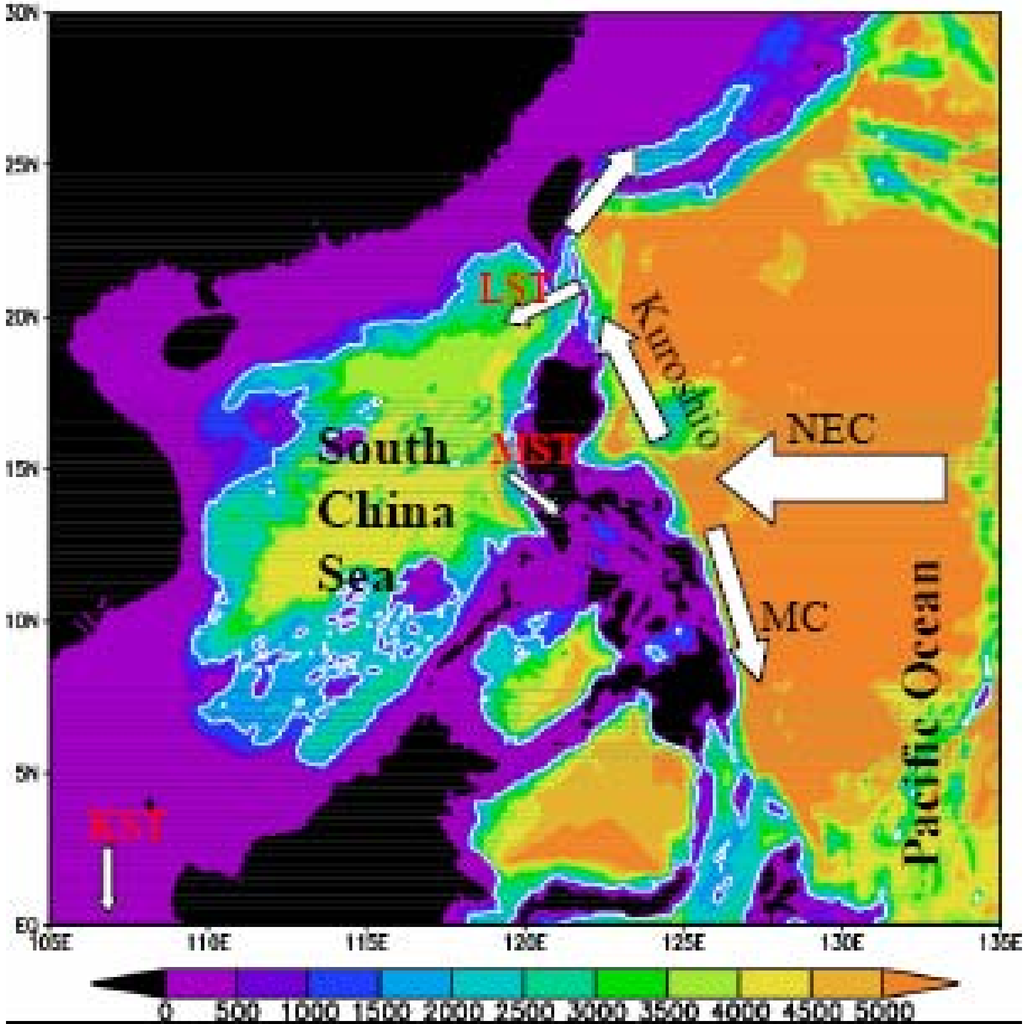
The SCS throughflow is part of the North Pacific tropical gyre, forced by the North Pacific winds.



$$T_0 = \frac{1}{(f_D - f_A)} \oint_{ABCD} \frac{\tau^{(l)} dl}{\rho_0} + \frac{1}{(f_D - f_A)} \int_{DA} F dl$$

(3) Overview of the SCSTF

A schematic diagram of the LST, MST, and KST



It has been known for several decades that part of the Kuroshio water leaks into the SCS through the Luzon Strait (LST), indicative of a close connection to the Pacific western boundary current.

a) Luzon Strait transport (LST)

Existing studies have arrived at mean transport estimates of LST ranging from 1 to 10 Sv.

Indirect observations favor a value in the middle of the range

↓

4 Sv (surface-bottom)
"Island rule"+Levitus data

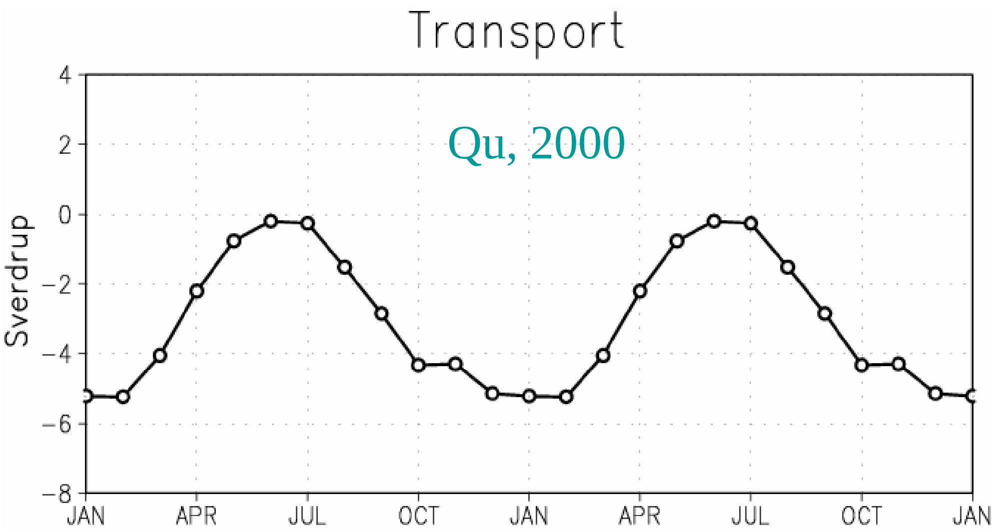
3 Sv (0-400 m)
XBT data

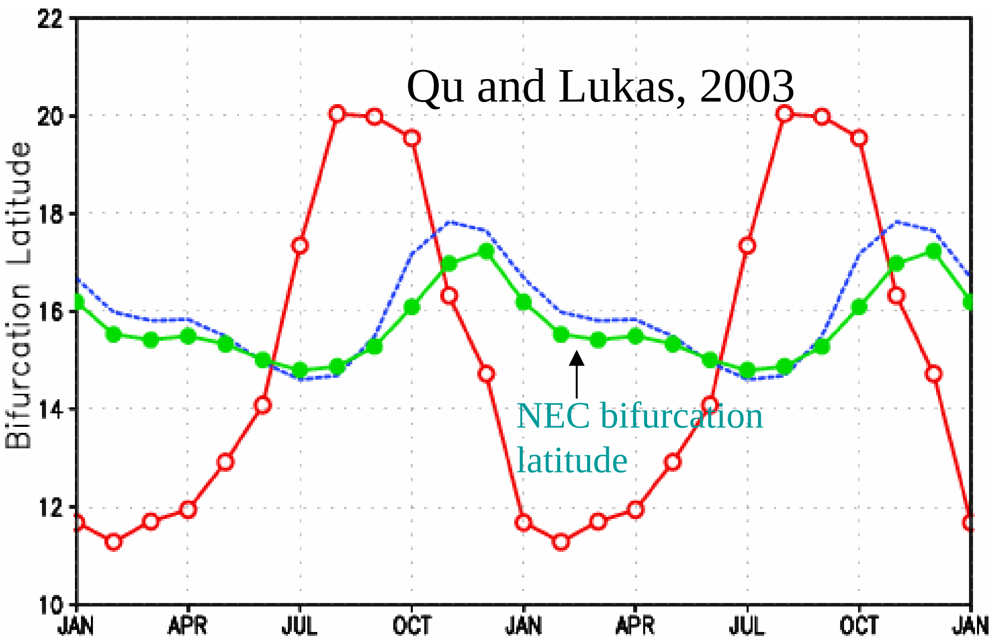
Note the LST transport contains a large uncertainty in the deep layer, which needs to be investigated by further observations.

LST's Seasonal variations

The LST is 5.3 Sv in December and 0.2 Sv in July, based on available XBT data, corresponding well with the annual migration of the NEC bifurcation.

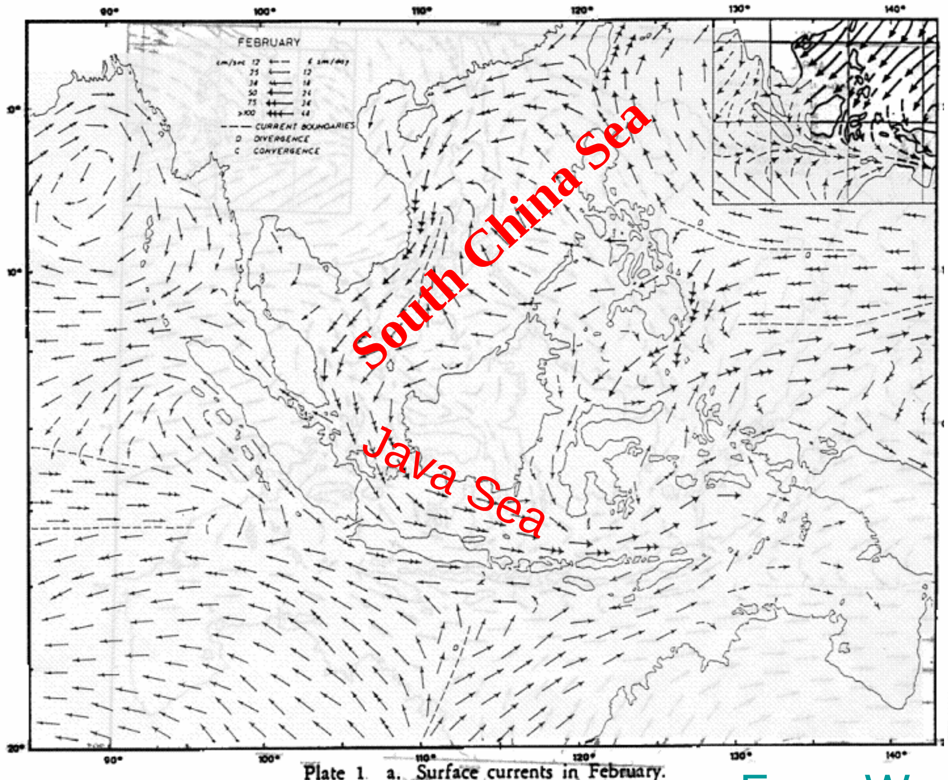
When the NEC bifurcation approaches its northernmost position in winter, the Kuroshio east of Luzon decreases, providing a favorable condition for the Pacific water to leak into the SCS (cf., Yaremchuk and Qu, 2004; Qu et al., 2004)



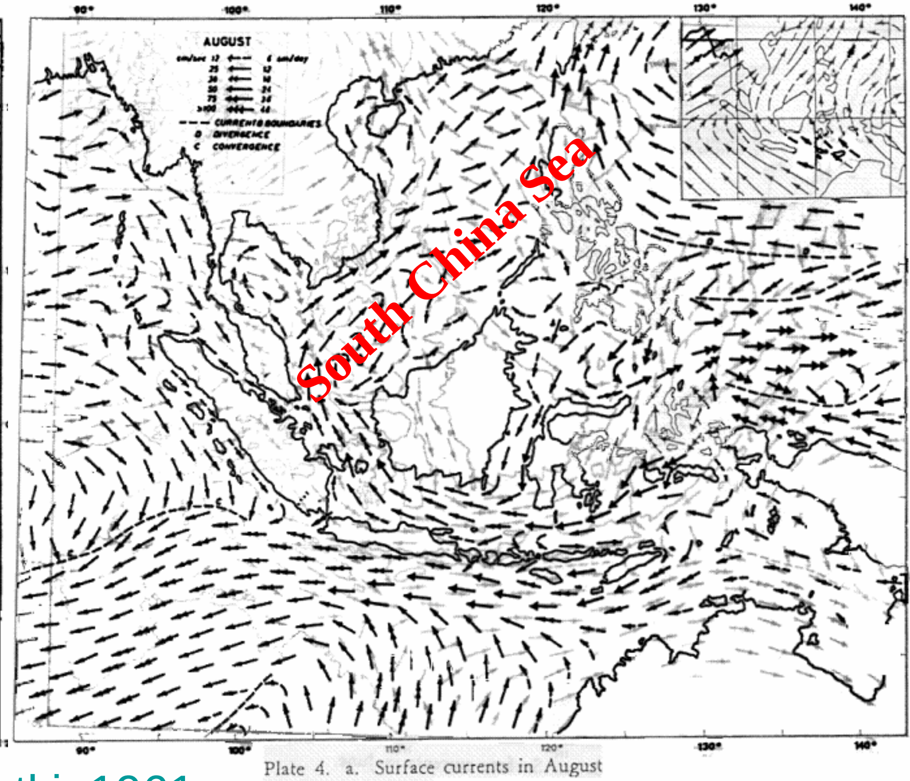


b) Karimata Strait Transport

Surface current in February



Surface current in August

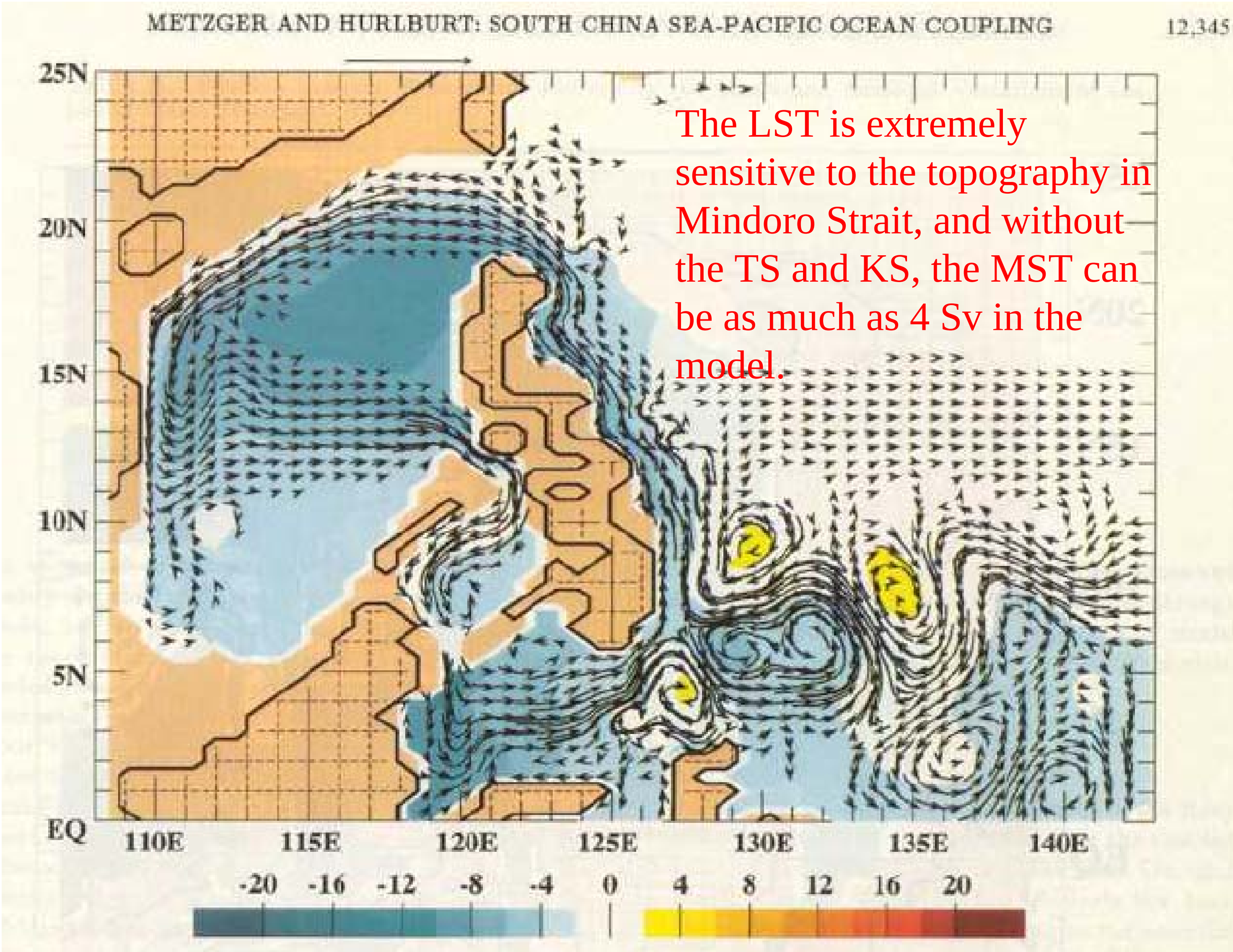


From Wyrtki, 1961

In the Java Sea: From May to September water flows to the west and from November to March to the east. The annual mean transport through the Java Sea is about 1.5 Sv eastward.

The on-going direct observations suggest a mean transport of 4.4 Sv in January-February 2008 (Fang, personal communication), providing the first observational evidence for the existence of the throughflow in the Karimata Strait.

C) Mindoro Strait Transport



The LST is extremely sensitive to the topography in Mindoro Strait, and without the TS and KS, the MST can be as much as 4 Sv in the model.

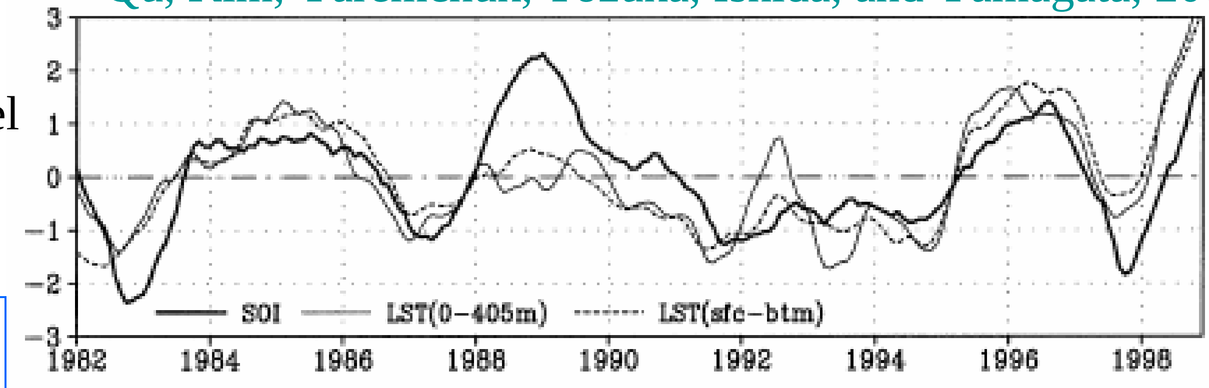
The on-going observations in the Mindoro Strait suggest a mean transport of 1-2 Sv during the period September-December 2007 (Sprintall, personal communications).

Interannual variation of the SCSTF

(model only)

Qu, Kim, Yaremchuk, Tozuka, Ishida, and Yamagata, 2004

Results from JAMSTEC model
(1982-1998)

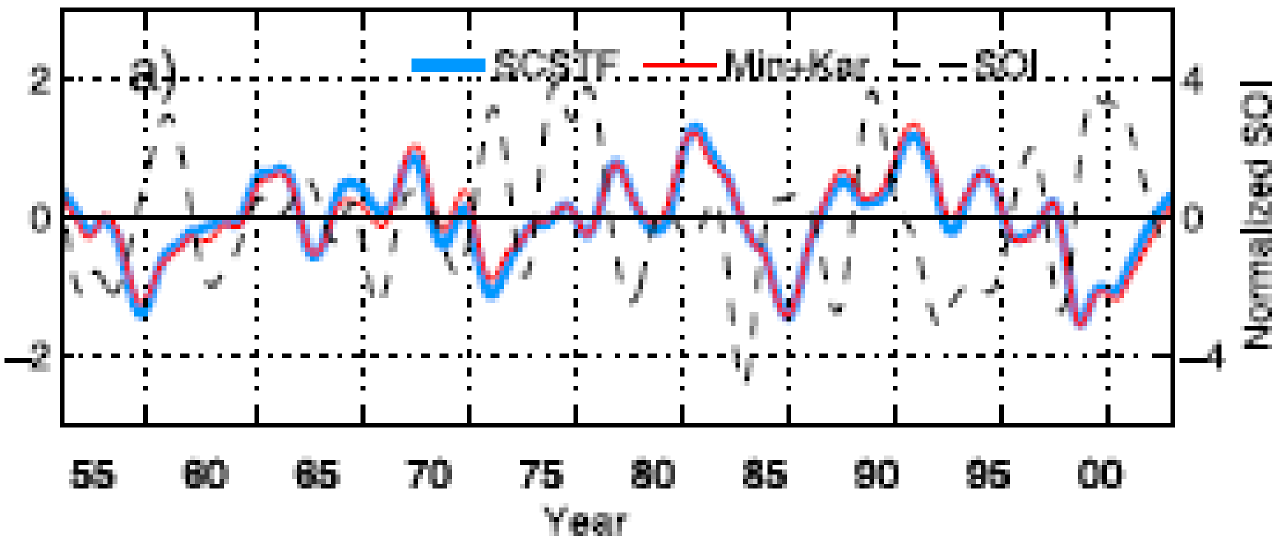


Correlation LST and SOI is 0.63, with LST leading by 1 month.

In general, the SCSTF tends to be stronger during El Nino years and weaker during La Nina years, providing an important connection between the Pacific and Indian Ocean.

Qu, Du, and Sasaki, 2006

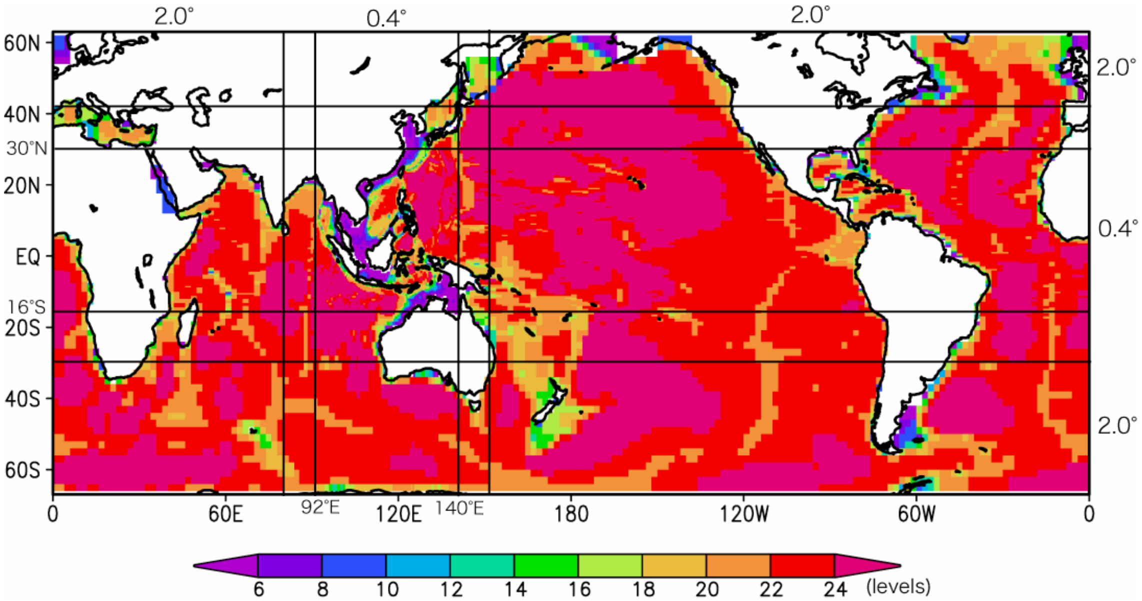
Results from OFES
(1950-2003)



Correlation LST and SOI is 0.48, with LST leading by 4 months.

Numerical Experiments confirm our hypothesis
(Tozuka, Qu, and Yamagata, 2007, 2008)

The model, based on MOM3.0, covers the global ocean from 65°S to 65°N, and the Levitus climatology is used poleward of these latitudes. The horizontal resolution varies from 0.4° in the region 92°E-140°E, 16°S-30°N to 2° in the outer region. There are 25 vertical levels with 9 levels in the upper 110m. The surface temperature and salinity are relaxed to the Levitus monthly climatology.

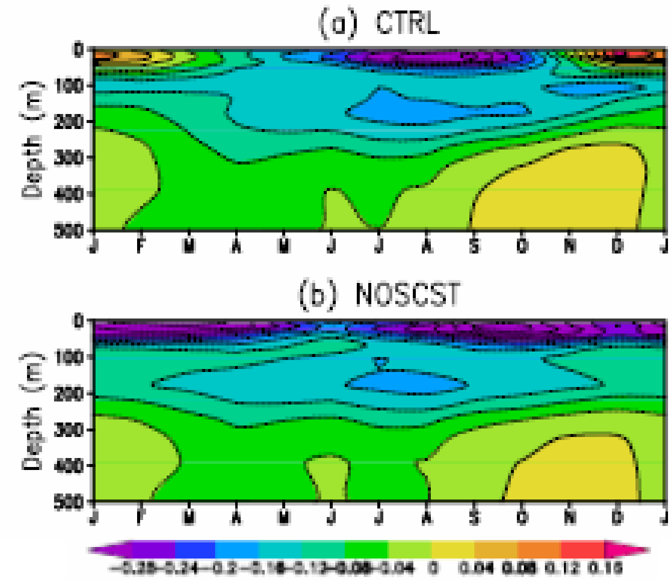


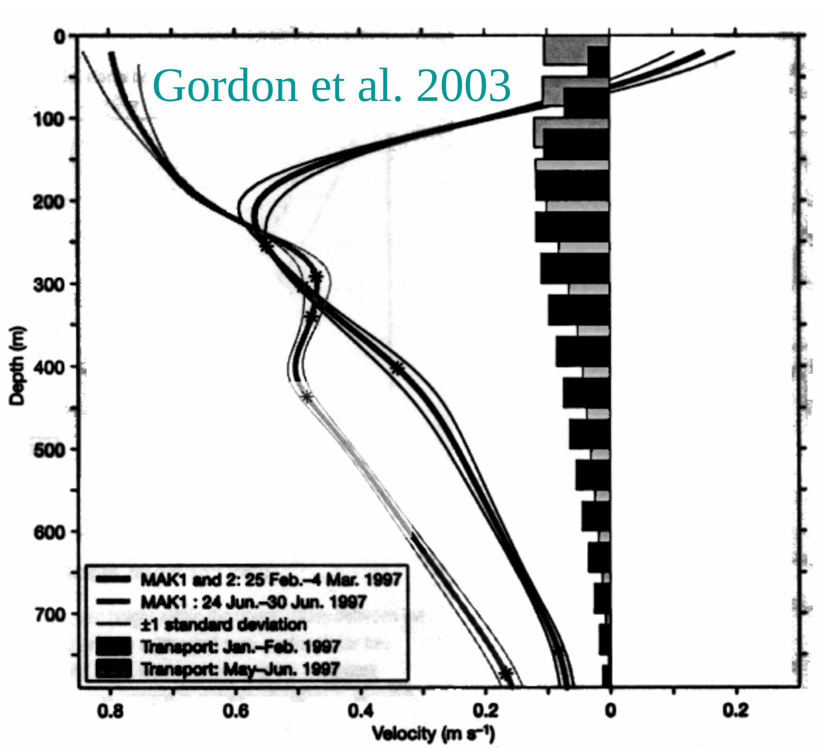
Configuration of the ocean component. Shading indicates number of vertical levels.

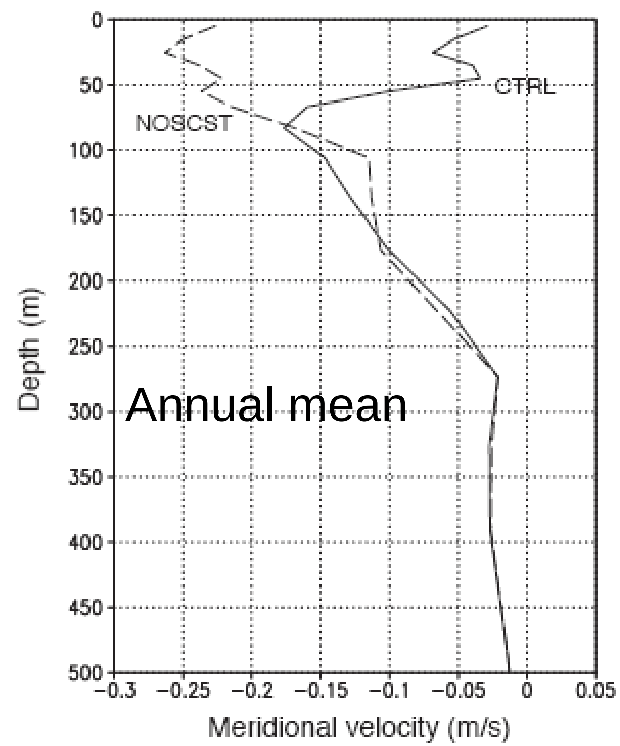
The SCSTF has a dramatic impact on the Indonesian throughflow transport

(1) Blocking the SCSTF led to an enhanced southward flow in the surface layer of Makassar Strait, and as a consequence, the subsurface maximum disappeared.

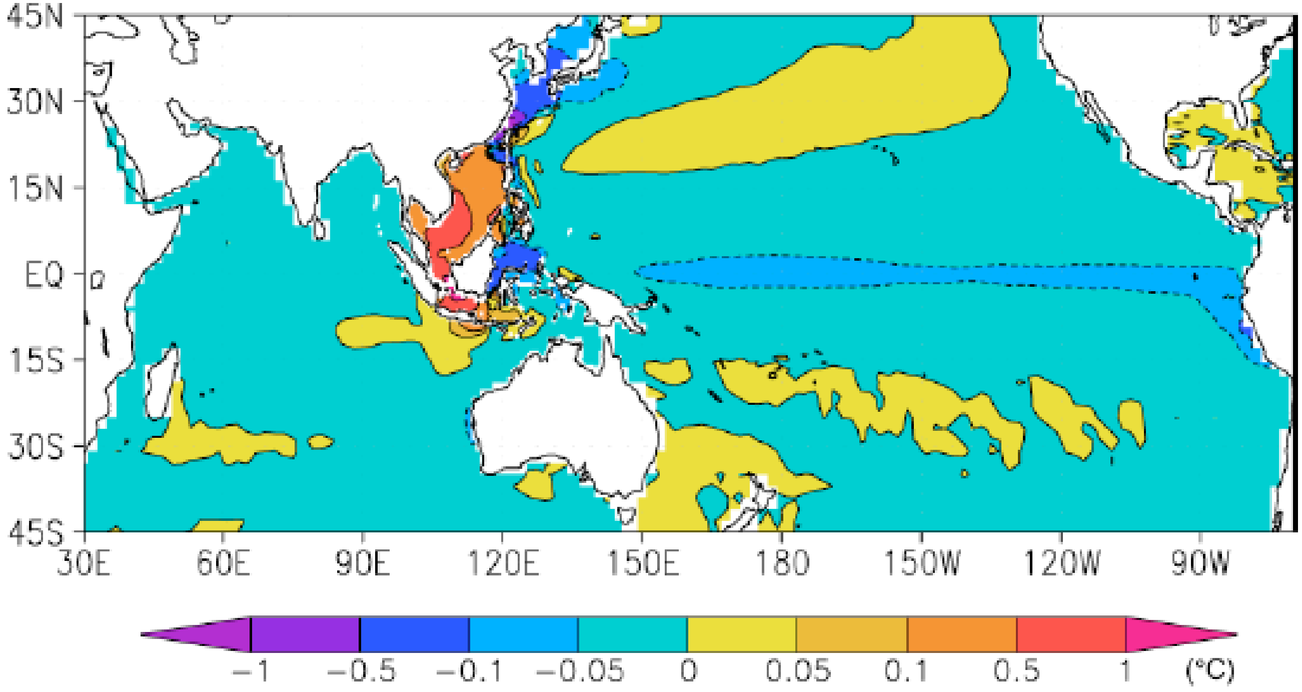
Seasonal variation







(2) Blocking the SCSTF in the model led to an enhanced ITF heat transport in Makassar Strait by as much as 47%, which is large enough to impact the SST pattern both regionally and globally.



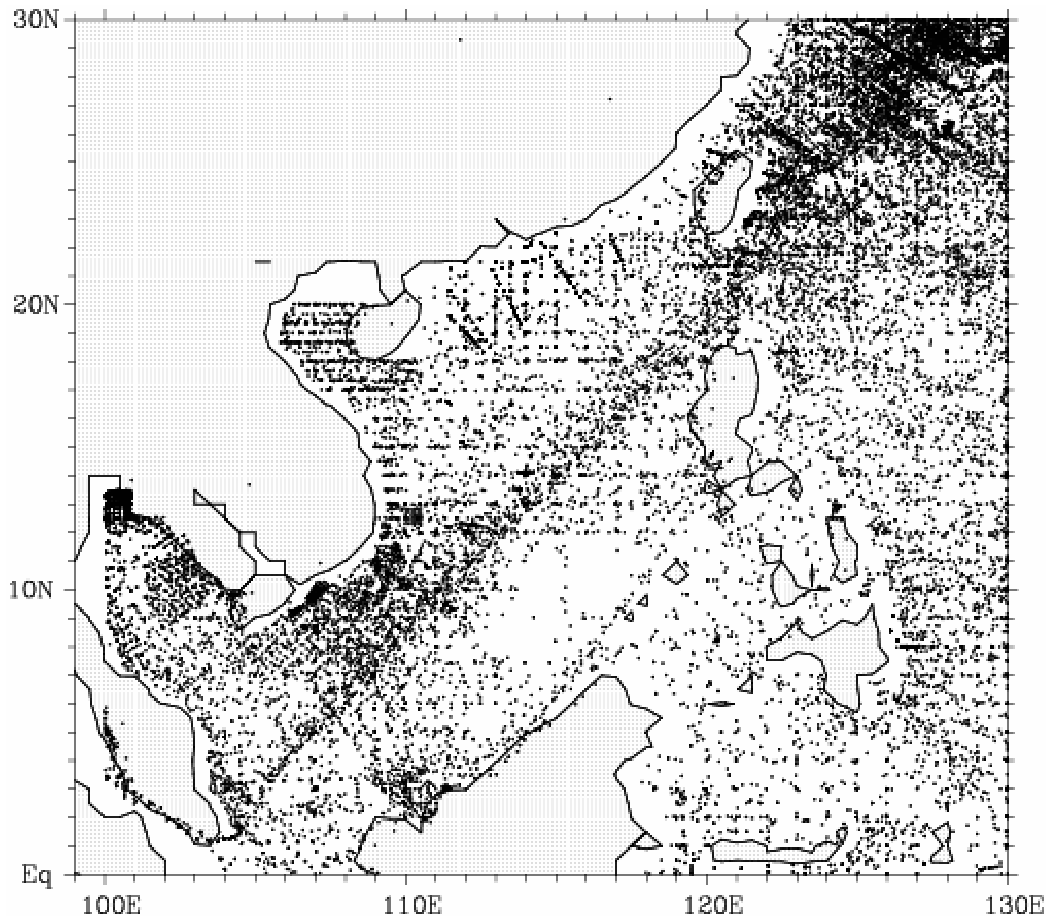
SST change between the “close” and “open” case of the SCSTF

A set of coupled GCM experiments with and without the SCSTF are underway. Preliminary results of these experiments indicate that the SCSTF plays an important role in modulating the Asian monsoon and Pacific ENSO.

(4) Future work

a) Observations

As more observations (e.g., ARGO) become available, a more comprehensive data product, similar to the WOA05 but with higher resolution and better representation of regional phenomena in the western Pacific, is being prepared.

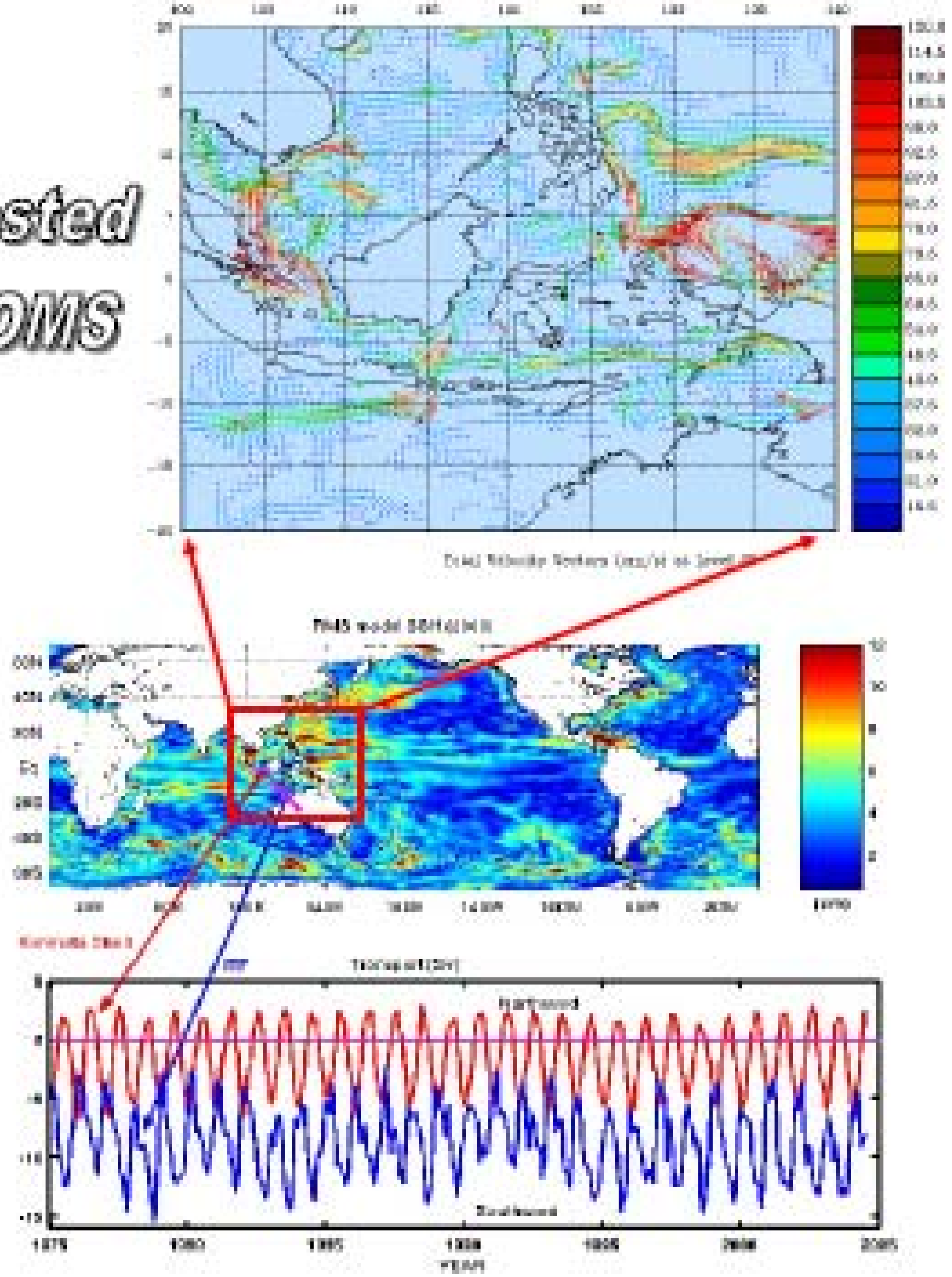


T/S profiles in the South China Sea and its adjacent western Pacific, which consist of 36200 profiles from WOD05 and 2276 profiles from ARGO (as of Dec. 2006).

b) Regional Ocean Modeling Systen

Nested ROMS

Effort is being made to develop a nested, regional ocean modeling system to offer a compromise for obtaining a higher resolution in the SCS and minimizing the overall computational cost, without losing tl global influence of large-scale dynamics.



Simulate the SCSTF and its interaction with the LLWBC and ITF;

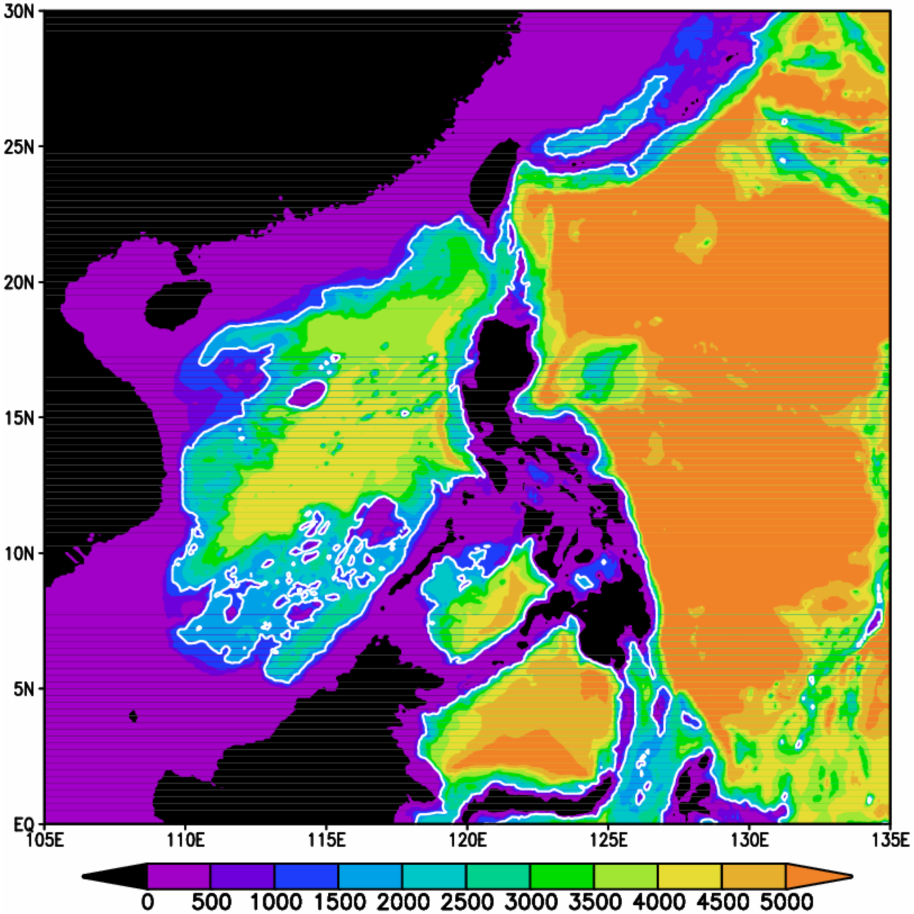
Identify the oceanic processes that control the SCSTF variability.

c) Coupled Ocean-Atmosphere General Circulation Model

Effort is being made to develop an ocean-atmosphere coupled general circulation model.

Identify the role of SCSTF in modulating the Asian monsoon and Pacific ENSO;

Provide useful information for the prediction of regional climate.



Summary

The SCSTF acts as a heat and freshwater conveyor, transferring up to 0.1-0.2 PW of heat and 0.1 Sv of freshwater from the SCS into the Indonesian Sea and its adjoining tropical Indo-Pacific Ocean;

The SCSTF is likely responsible for the subsurface maximum velocity in the Makassar Strait and significantly reduces the ITF heat transport.

Implication: **The SCS may play an active role in regulating SST patterns and modulating conditions of the Indo-Pacific warm pool, thus having important implications for climate variability.**

THANKS !!!