Pacific to Indian Ocean Throughflow (PIOT) and its South China Sea Branch (SCSB)

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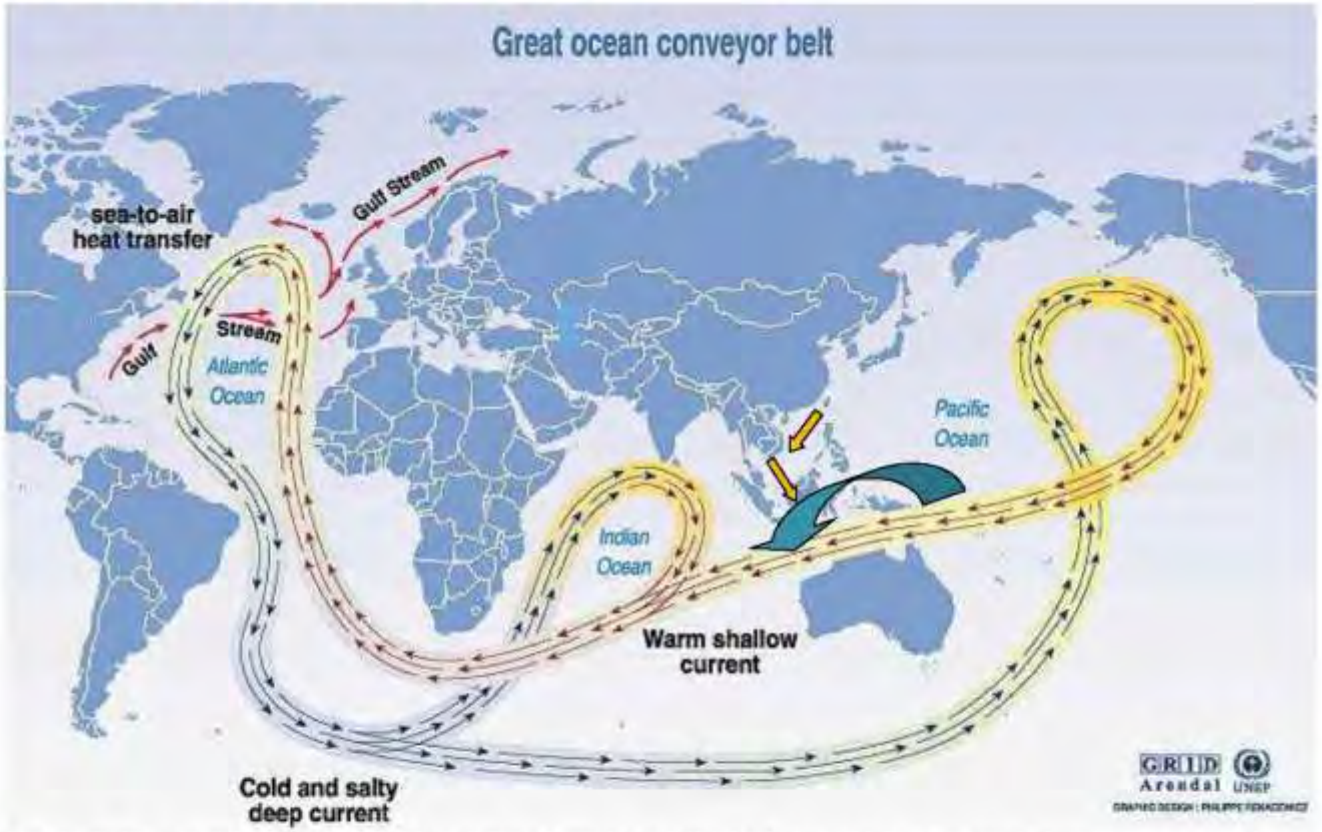
Outline

- Introduction
- Brief reviews on the historical research
- The key scientific issues
- Summary

I. Introduction

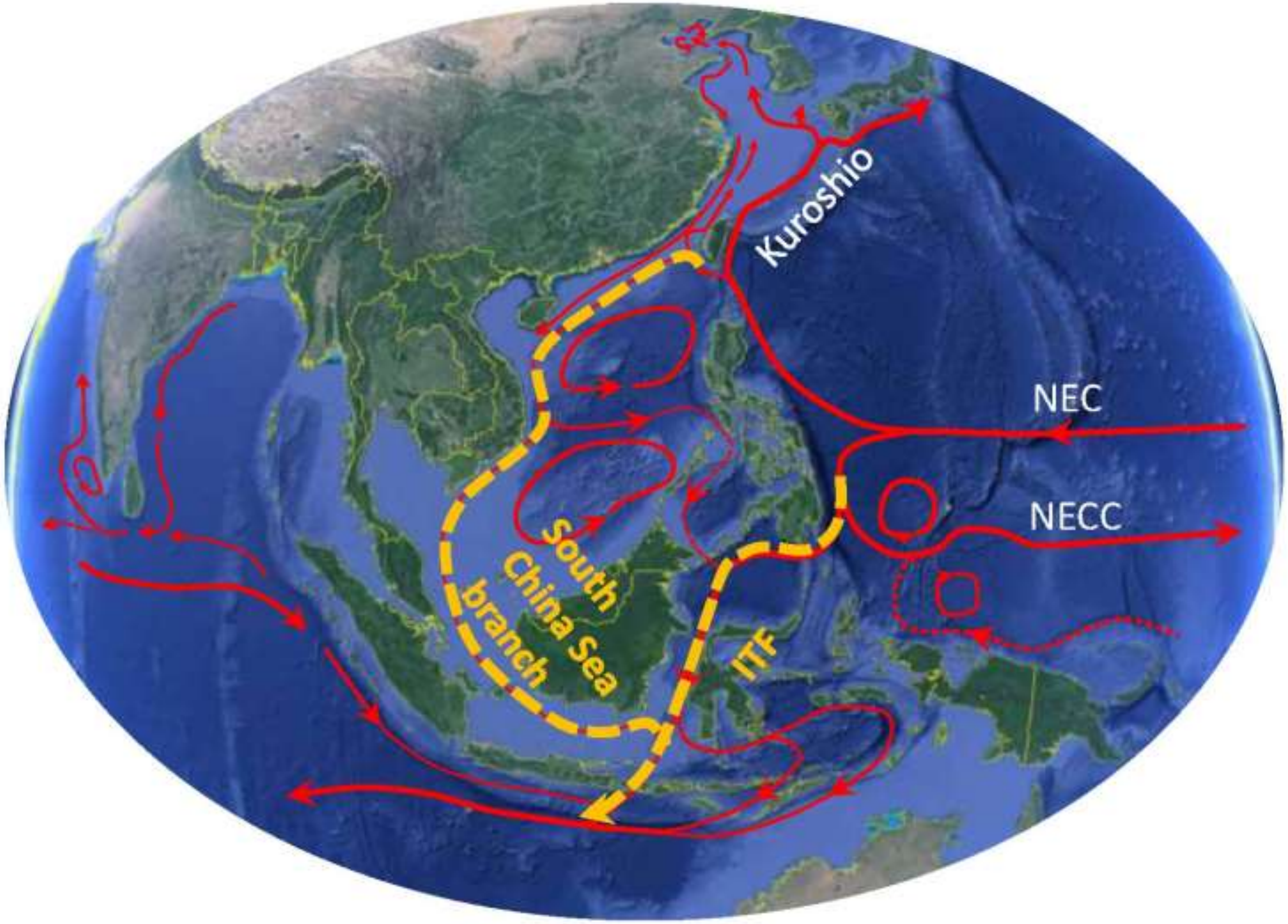


Source: Broecker, 1991, in Climate change 1995, Impacts, adaptations and mitigation of climate change: scientific-technical analyses, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

Global Great Ocean Conveyor and Pacific to Indian Ocean Throughflow

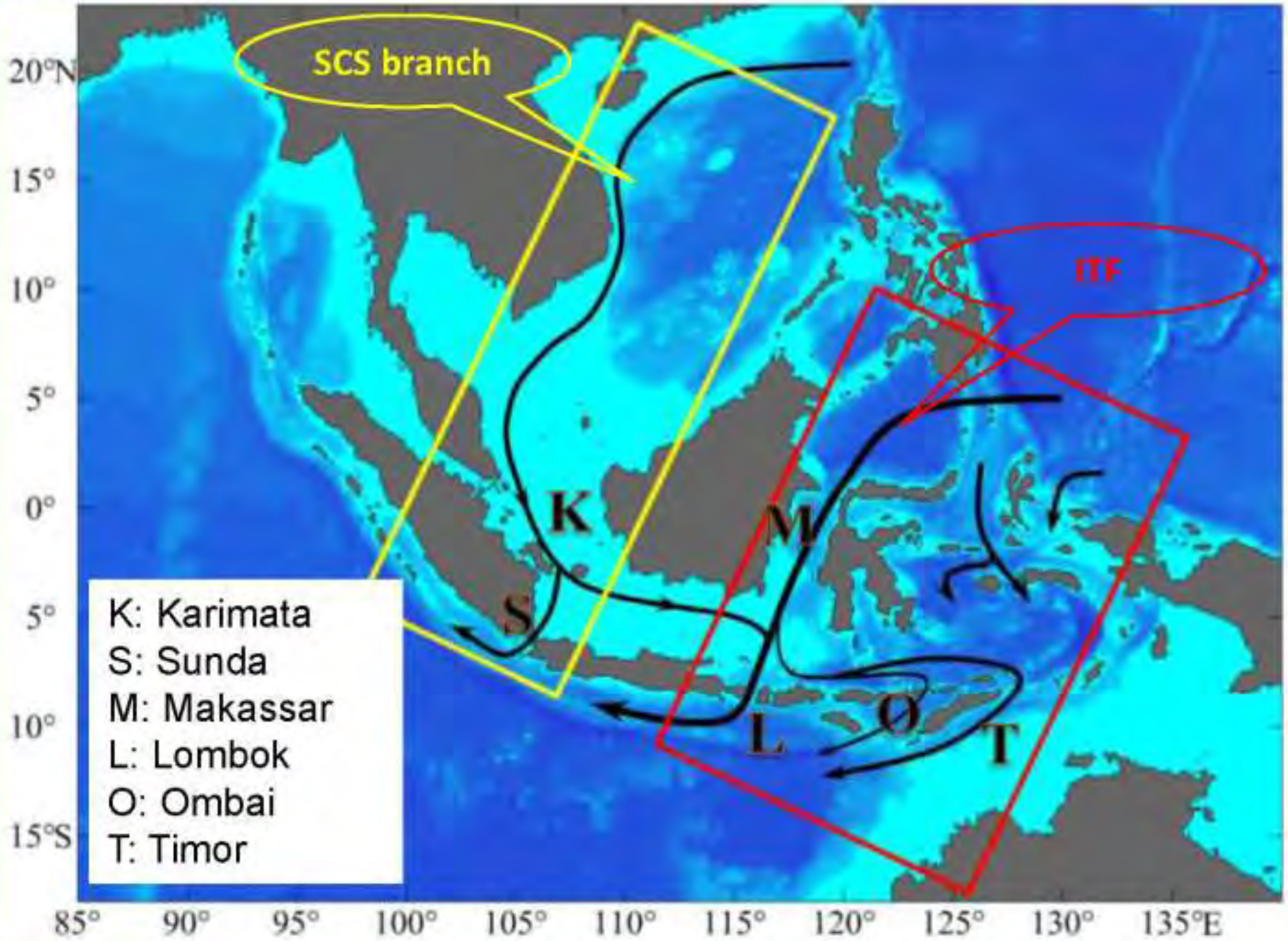
It plays very important role in global transport and climate change

I Introduction



Ocean circulation system in Tropical Pacific and Indian Ocean
（Guan, 1994; Fang et al., 2009; Schott et al., 2009)

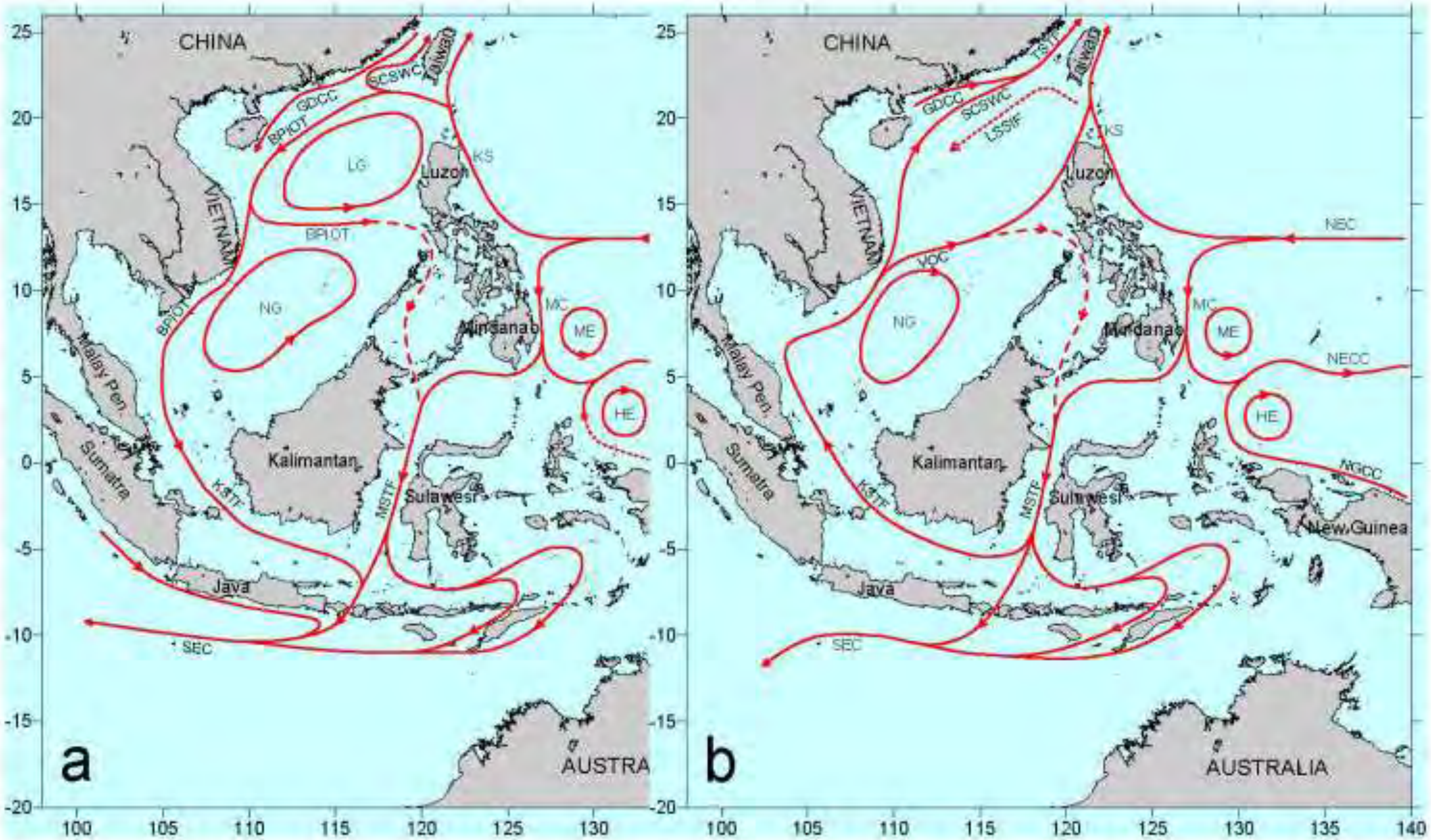
I Introduction



PIOT（Fang et al., 2002, 2005, 2009）

The annual mean volume transport of the PIOT is estimated over 10 Sv (1 Sv=10^6 m/s) with heat transport at about **0.5~1.2 PW** (1 PW=10^{15} W), which is comparable with the net surface heat flux over the west Pacific warm pool.

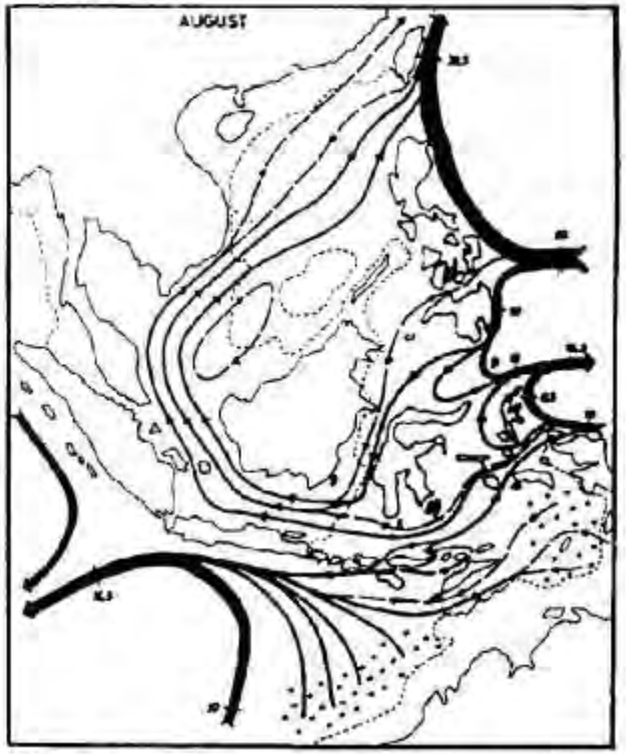
2. Brief reviews on the historical research



Fang et al. 2009

Wyrtki's (1961) early study

b. Transports of surface circulation in million m^3/sec. + upwelling, o sinking.

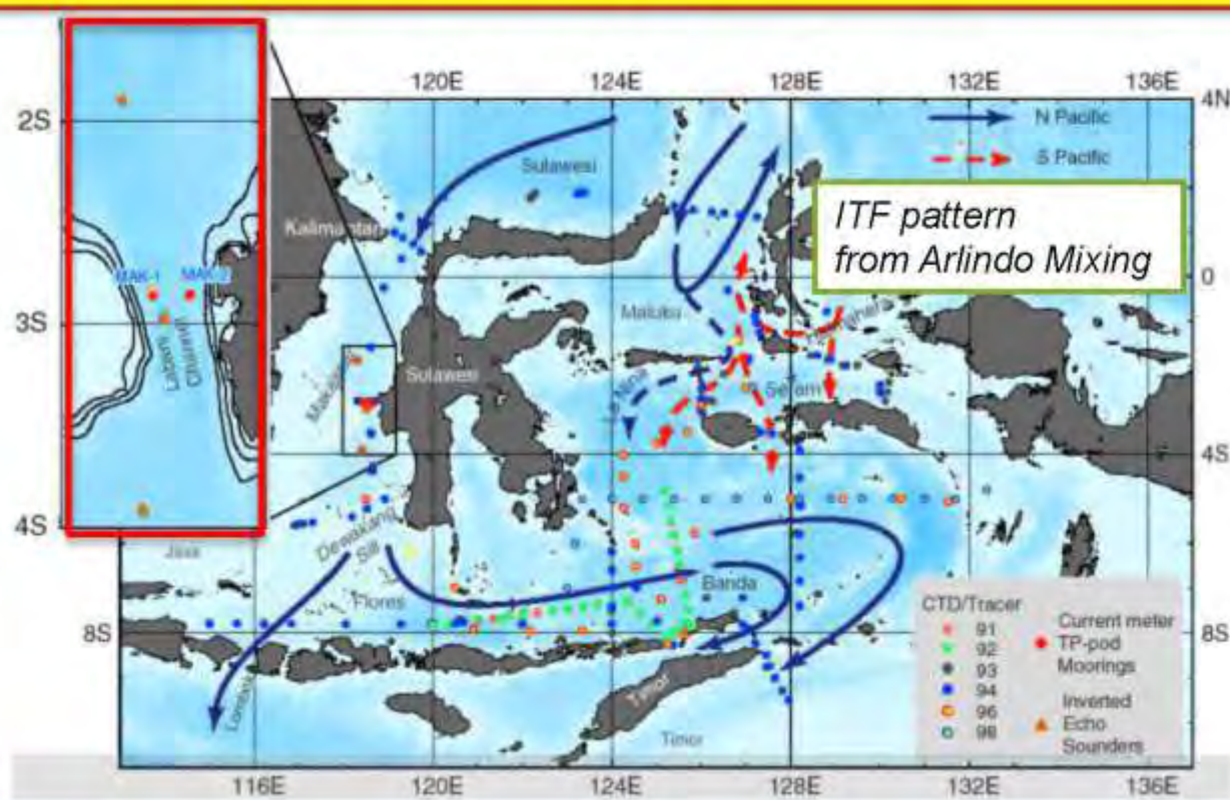


b. Transports of surface circulation in million m^3/sec. + upwelling, o sinking.

Wyrtki's circulation patterns in winter (Feb) and summer (Aug), which are mainly based on ship drift data.

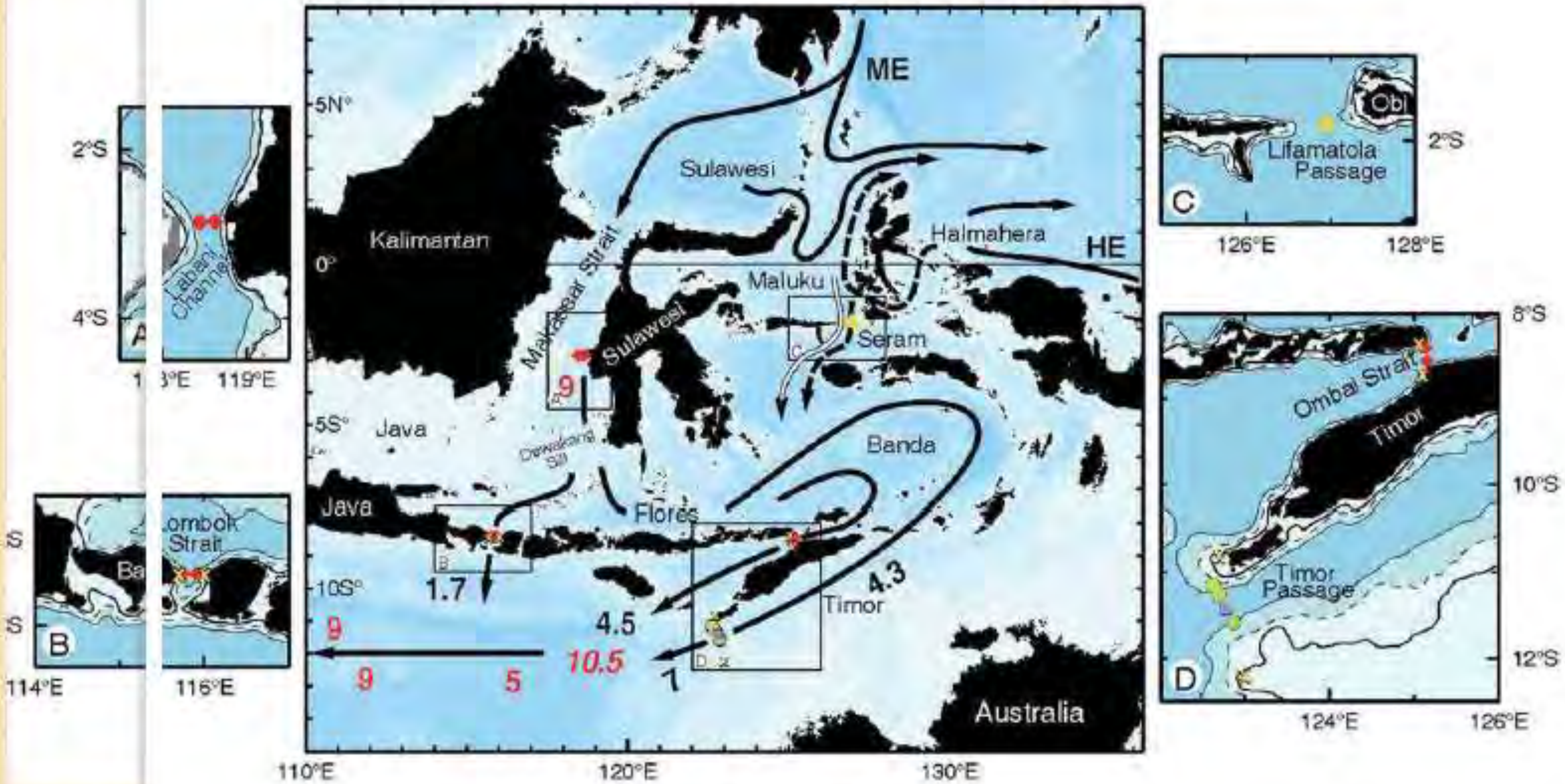
Arlindo Program

- *Phase 1, Mixing: 1993-1994, resolved the ITF pathways and its source waters from the Pacific*



- *Phase 2, Circulation: 1996-1998, Makassar throughflow ~9 Sv*

Eos, Vol. 85, No. 39, 28 September 2004



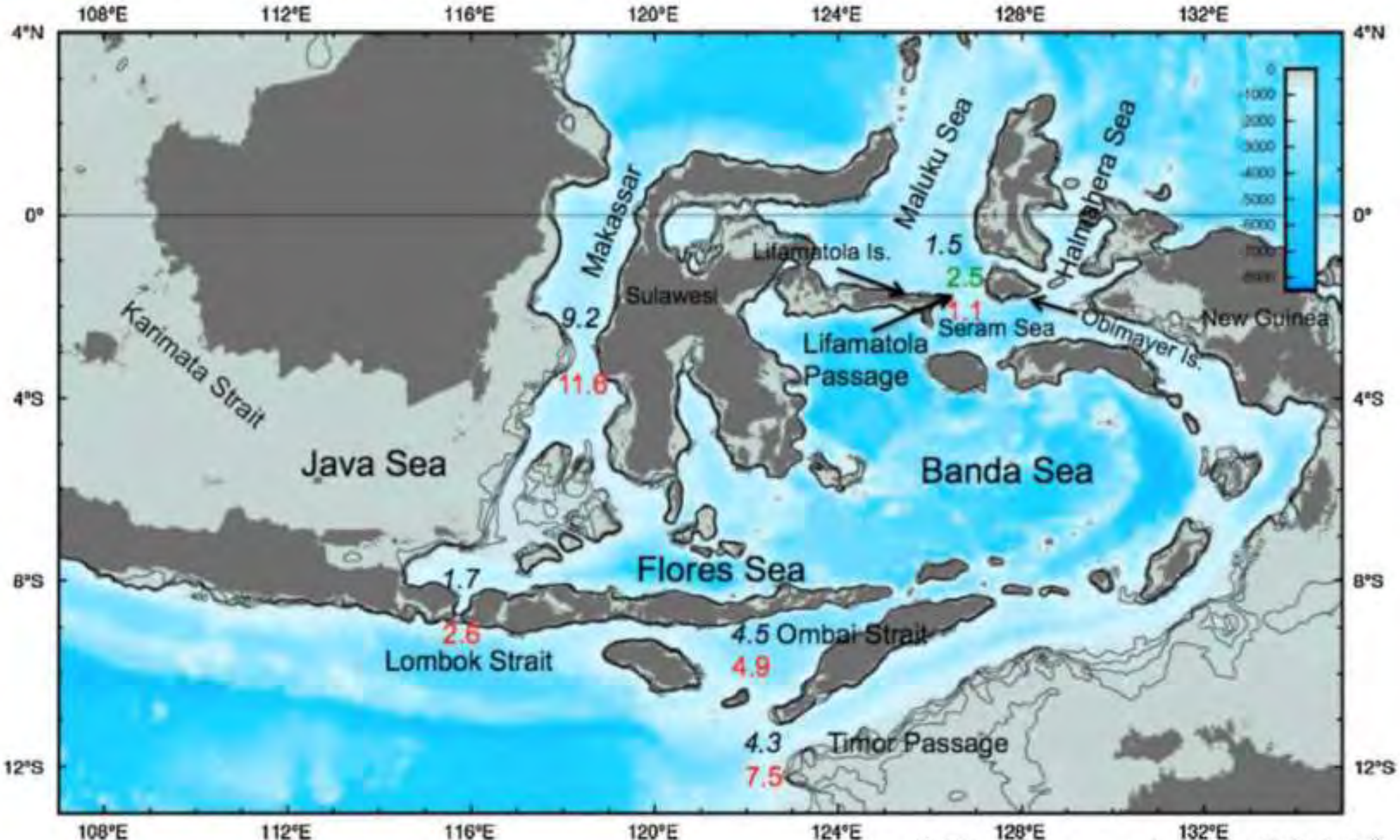
INSTANT

To directly measure the leakage of warm and fresh waters from the western equatorial Pacific into the South Indian Ocean via Indonesian passages.

Indonesia, France, Netherlands, USA, Australia.

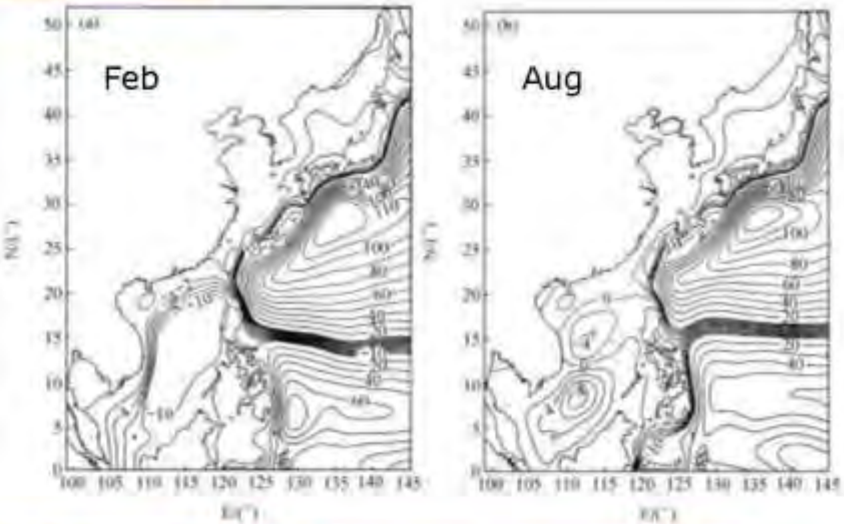
(2004-2008)

INSTANT: 2004-2006



（Gordon et al., 2010）

"Branch of Pacific-to-Indian Ocean throughflow" (or briefly, "South China Sea throughflow") proposed by Fang et al. 2002, 2005.



Steamfunction from a variable-grid global ocean model (Fang et al., 2002)

The 5th Cross-Strait Ocean Sciences Conference (2002, Taipei)

太平洋—印度洋貫穿流南海分支及其南海海洋學意義

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以往許多基於觀測和數值方法的研究均表明，通過呂宋海峽海水有西向淨流量自西太平洋進入南海。扣除通過臺灣海峽的出流量，其餘大部分通過民都洛，巴拉巴克，卡里馬塔和馬六甲諸海峽流向印度洋。我們建議把這支海流稱爲太平洋—印度洋貫穿流南海分支，或簡稱南海貫穿流。

這支海流流量的不確性還很大，估計年平均體積輸運爲 4±1.5Sv，相當於印尼貫穿流的 1/4 左右。就年平均輸運而言，其基本驅動機制與印尼貫穿流相同，是全球性的風場和熱鹽效應，而不是黑潮動力效應。

由於強烈的季風作用，該海流季節變化很大，冬季流量大，且明顯形成一支通過呂宋海峽，沿南海北面陸坡，越南外海和卡里馬塔等海峽流向印尼海域的強流，春，秋轉換期流量變小，夏季則完全被阻斷，即其季節變化的位相與印尼貫穿流相反。

呂宋海峽緯向流的垂直分佈與 Wyrtki (1961)的概念結構有所不同，大體上呈現 4 層結構，表層爲 Ekman 層，其海流緯向分量在東北季風期間向西，西南季風期間向東。在 Ekman 層之下的次表層和中層基本爲西向流，但局部存在東向流。深層以東向流爲主，底層則基本爲西向流。

浅层域际环流

深层域际环流

太平洋—印度洋貫穿流南海分支(或南海貫穿流)的存在表明，引起太平洋—印度洋貫穿流的這種驅動力也可以引起貫穿南海的海流，其效應深及整個南海。因此西菲律賓海海水在呂宋海峽入侵的基本機制是全球風場和熱鹽效應，它比單純的黑潮動力作用影響更深遠，更重要。由於這支貫穿南海的海流，南海海水得以不斷地更新，其時間尺度爲 40±15 年。這表明南海海水具有較強自淨能力。這支海流的存在還可以解釋爲什麼南海整個深水區的鹽度垂直分佈具有西菲律賓海海水的特徵，即次表層高鹽，中層低鹽。此外，這支海流把較涼的海水輸入南海，把較暖的海水輸出南海，從而起到對海面大氣的冷卻作用，使南海成爲大氣的一個熱彙。

本文將根據一個嵌套於全球的南海及鄰近海域高解析度海洋模式結果，結合觀測結果予以闡述。

The South China Sea Branch of Pacific to Indian Ocean Throughflow

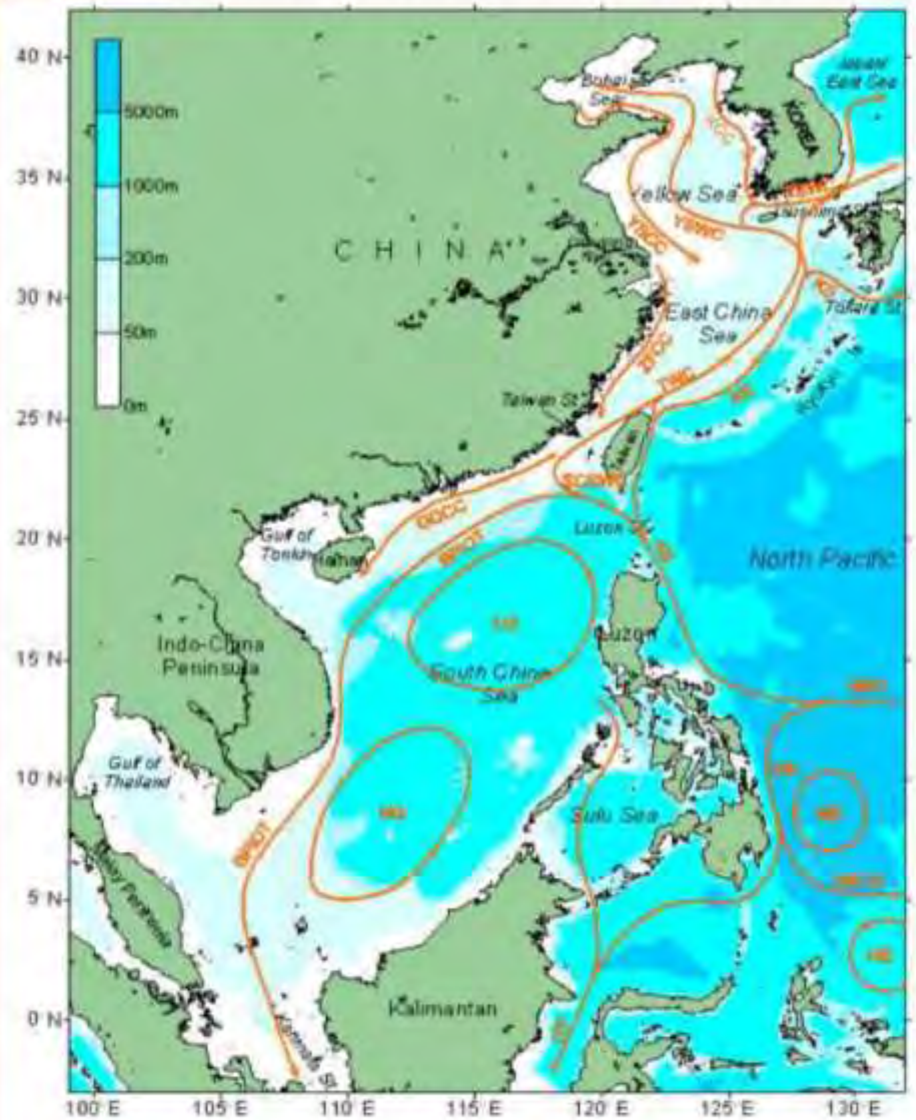


Figure 1. Topography and schematic representation of the major winter currents in the Yellow, East, and South China Seas. The current system diagram is a composite mainly based on *Su et al.* [1990] and *Fine et al.* [1994] for the western North Pacific, *Guan* [1988] for the Yellow and East China Seas, and *Fang et al.* [1998, 2005] for the South China Sea, with some modifications. The abbreviations stand for the following: BPIOT, Branch of the Pacific-to-Indian Ocean Throughflow; GDCC, Guangdong Coastal Current; HE, Halmahera Eddy; ITF, Indonesian Throughflow; KCC, Korea Coastal Current; KS, Kuroshio; LG, Luzon Gyre; MC, Mindanao Current; ME, Mindanao Eddy; NEC, North Equatorial

Zheng, Fang and Song (2006)

" South China Sea throughflow" proposed by Qu et al. 2006.

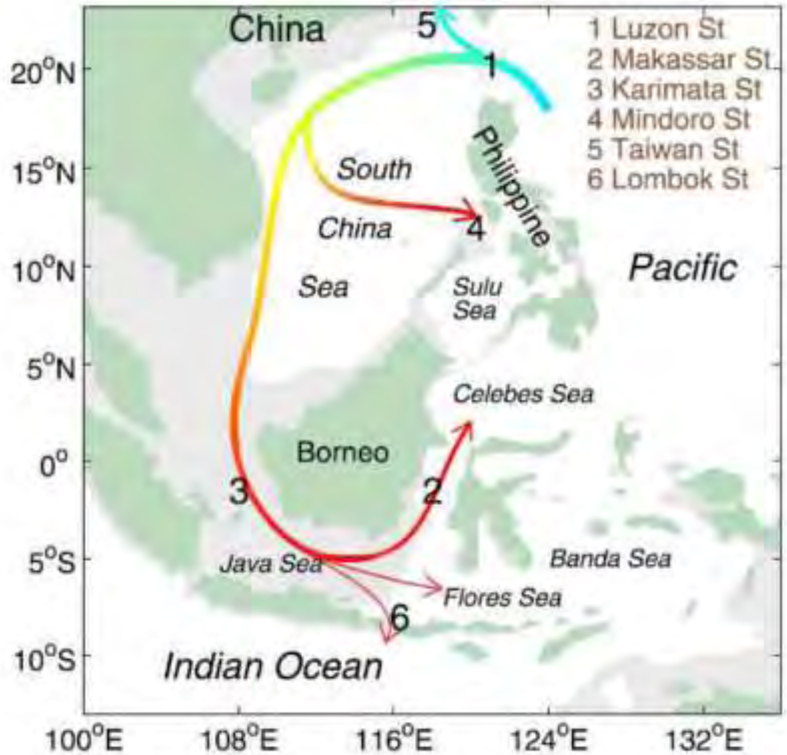


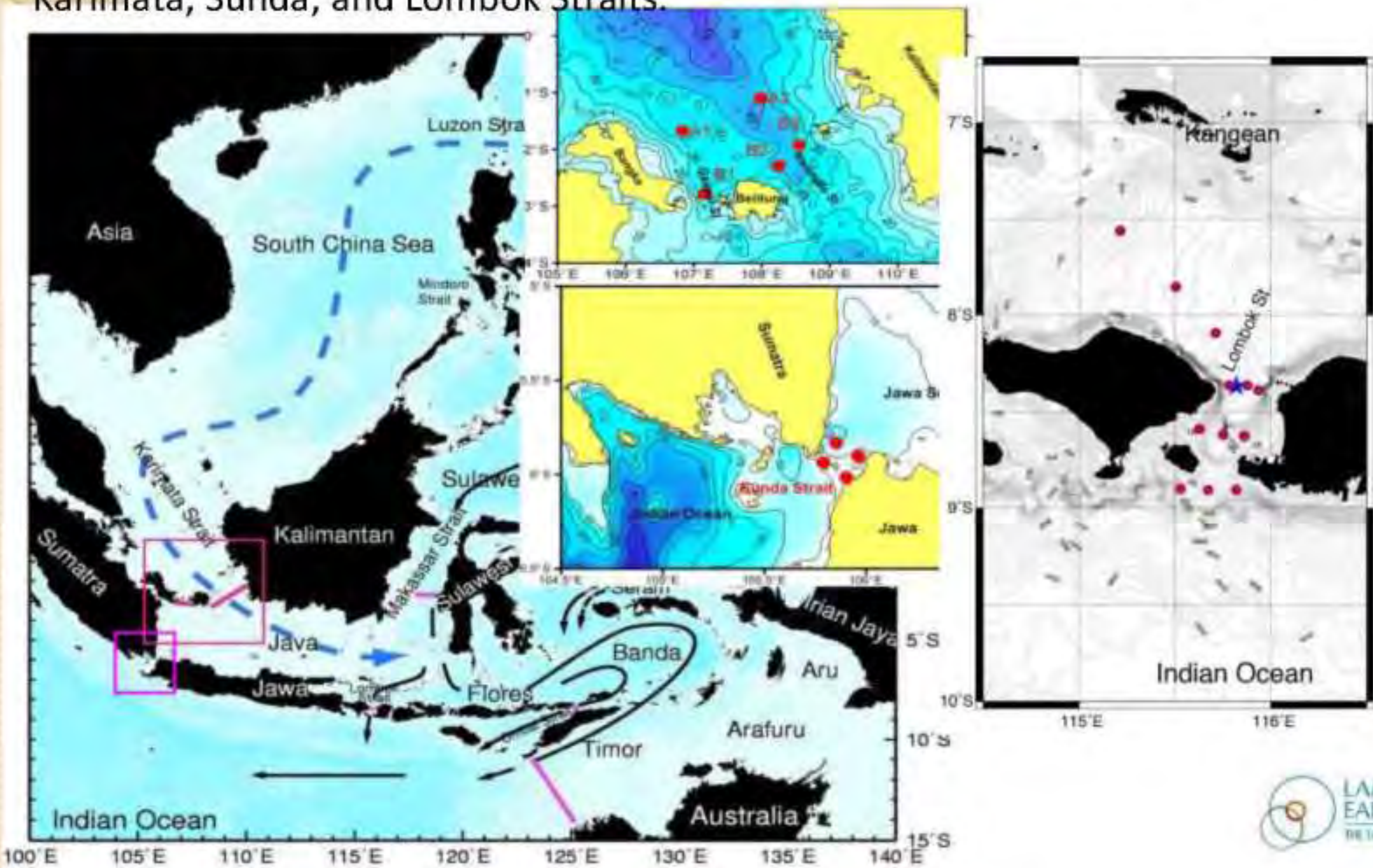
Figure 1. A schematic diagram showing the South China Sea throughflow adopted from *Qu et al.* [2005]. Water entering the South China Sea through Luzon Strait is lower in temperature (blue) than water leaving it through Karimata, Mindoro, and Taiwan Strait (red).

From Qu et al.,2006,GRL

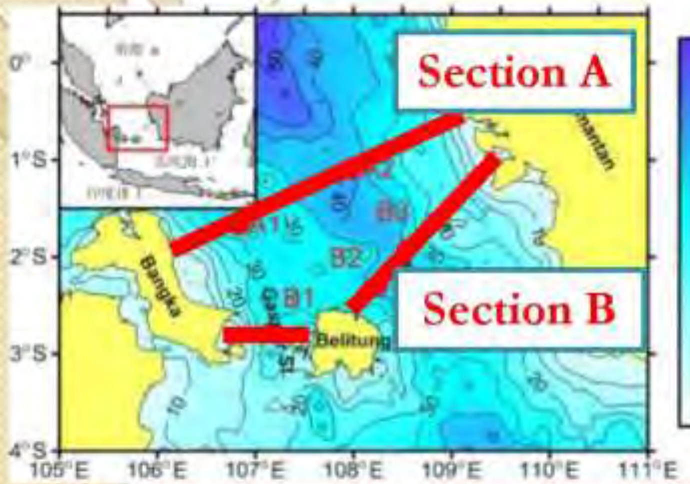
Observation of SCS branch (SITE)

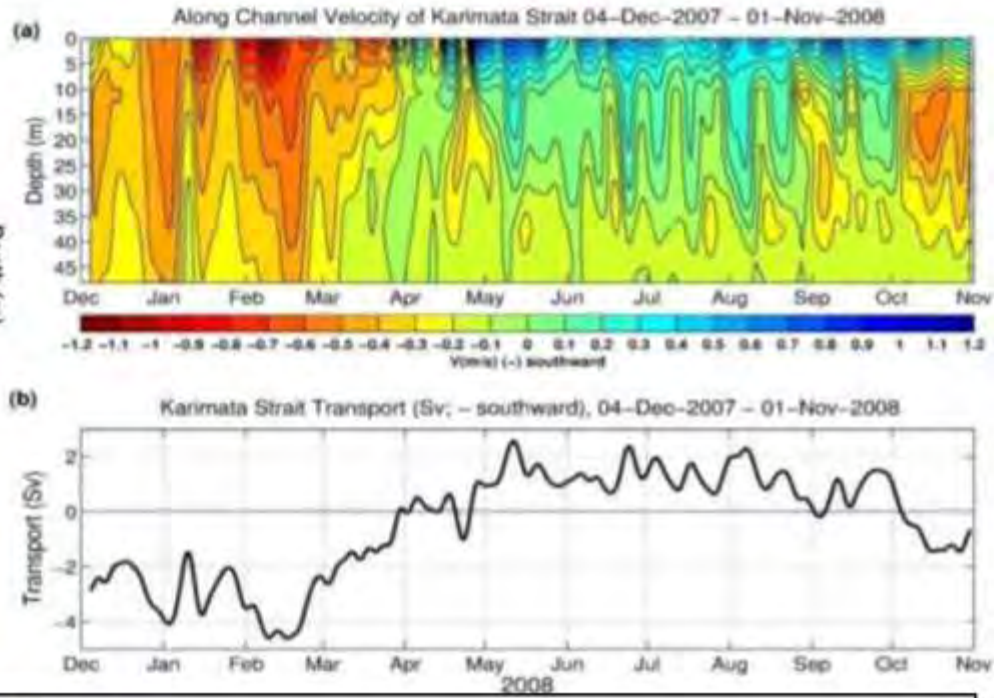
Oct 26, 2006: "SCS-Indonesian Sea Transport/Exchange (SITE)" program were signed by China and Indonesia.

Until Oct, 2015: 17 cruises were conducted for in situ current and CTD observations in Karimata, Sunda, and Lombok Straits.



Observation of SCS branch(SITE)

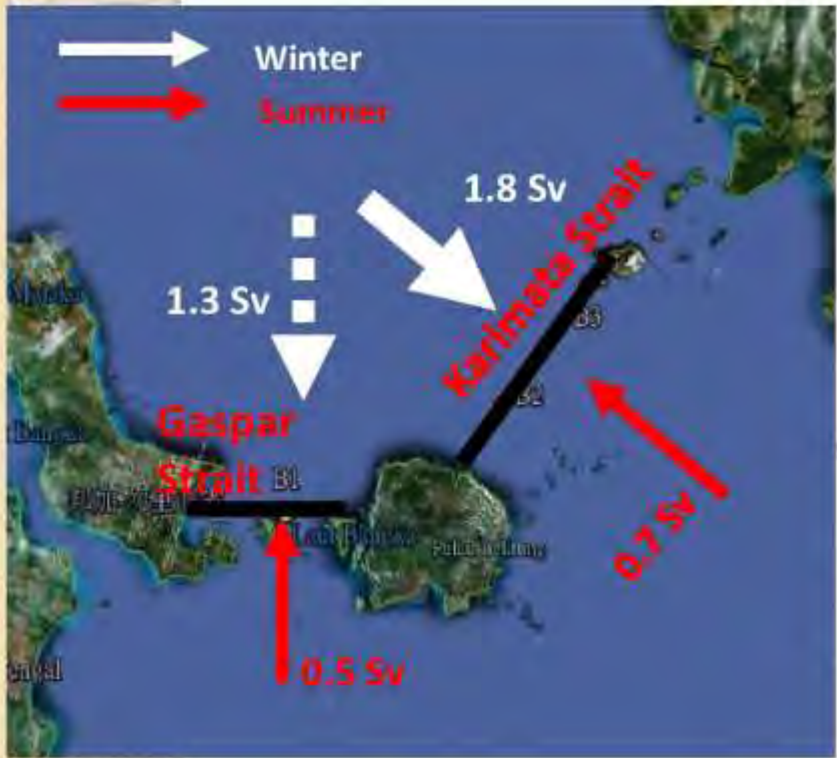


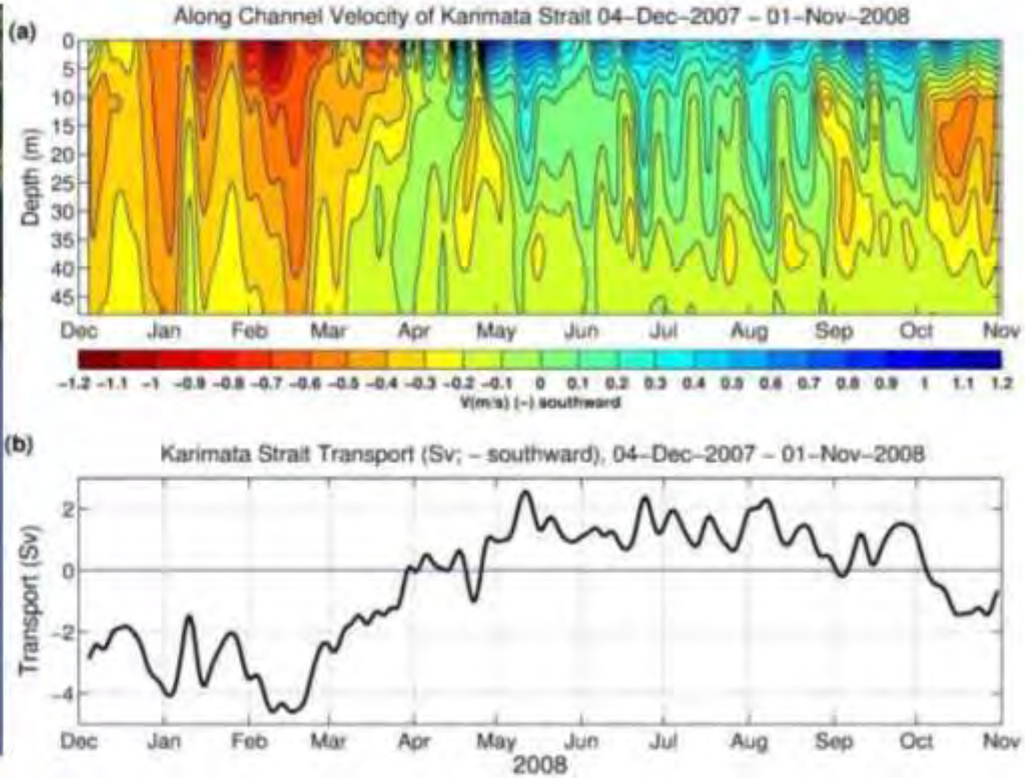


Confirm the SCS Branch of PIOT

Fang G., Z. Wei, B. Choi, et al., Science in China(Series D), 2003
Wei Z., G. Fang, B. Choi, et al., Science in China(Series D), 2003
Wang Y., G. Fang, Z. Wei, et al., Journal of Hydrodynamics, 2004
Fang G., D. Susanto, I. Soesilo, et al., Advances in Atmosphereic Sciences, 2005
Fang G., Y. Wang, Z. Wei, et al., Dynamics of Atmospheres and Oceans, 2009
Fang G., D. Susanto, S. Wirasantosa, et al., J. Geophys. Res., 2010
Susanto R Dwi, Wei Z., Adi Rameyo T, et al., Acta Oceanol. Sin., 2013

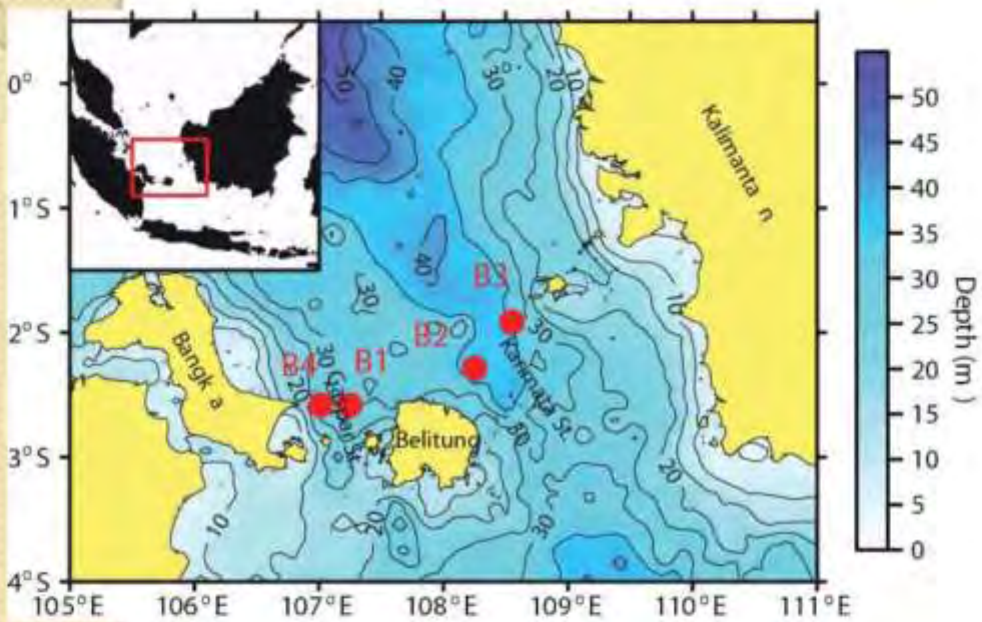
Observation of SCS branch(SITE)



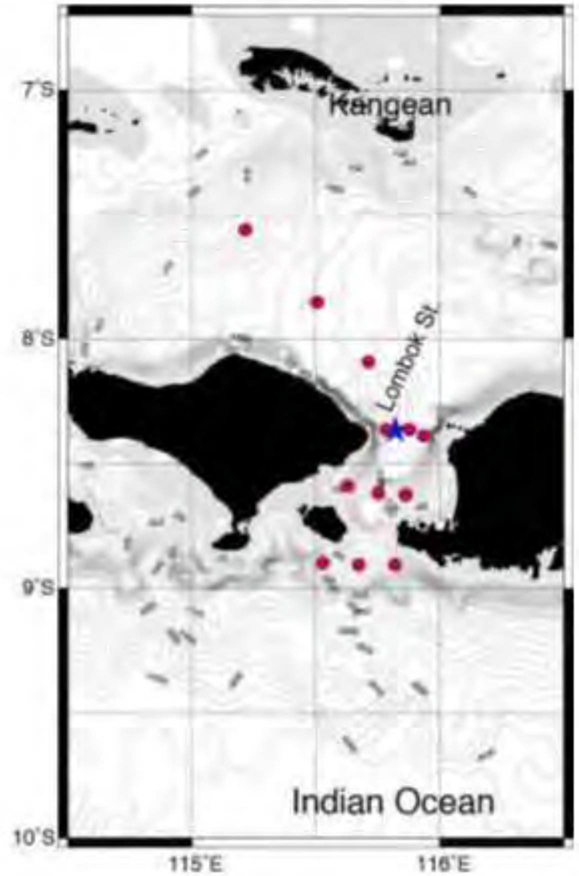


- Significant seasonal variability of water transport through Section A in Karimata
- -3.1 Sv in boreal winter
- 1.2 Sv in boreal summer
- Annual mean transport is -0.5 Sv

Observation is still on going

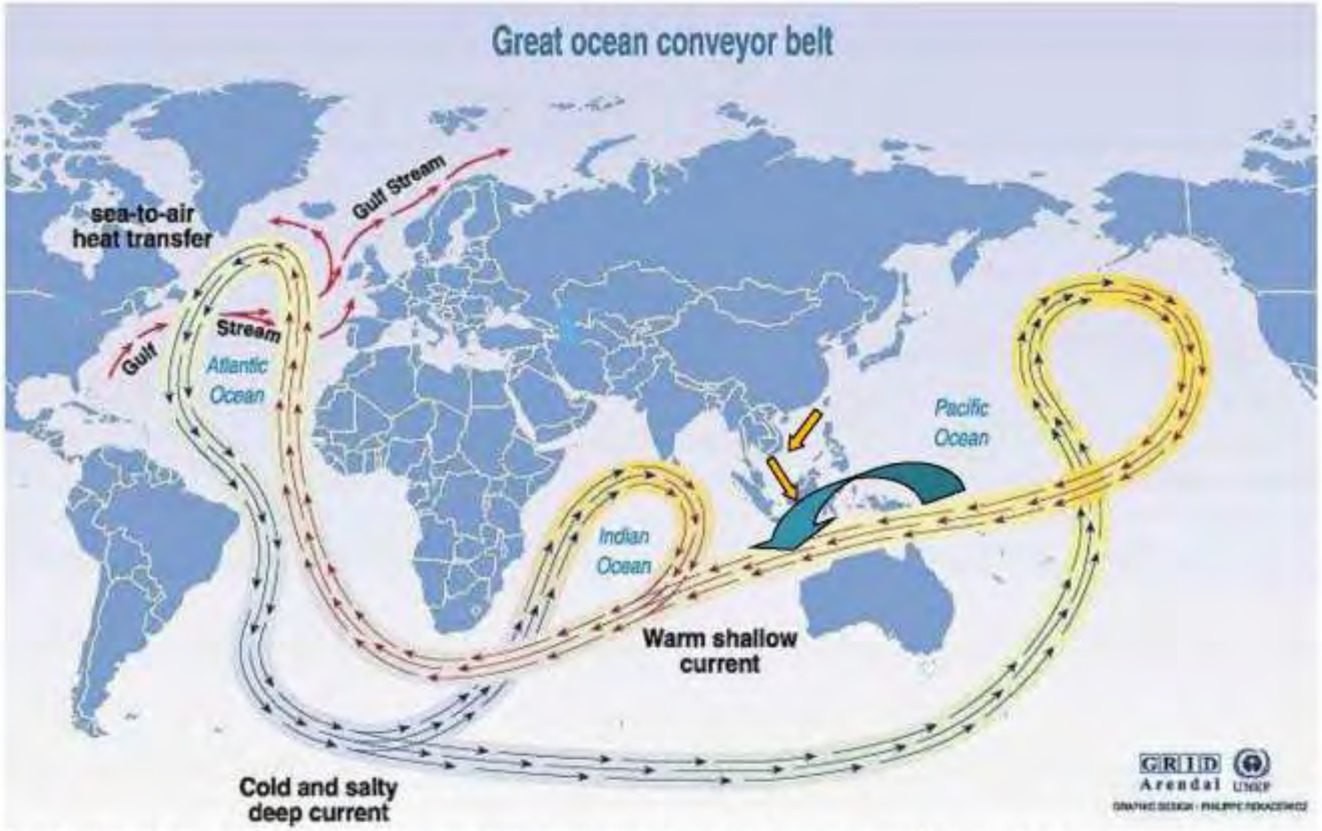


Karimata Strait



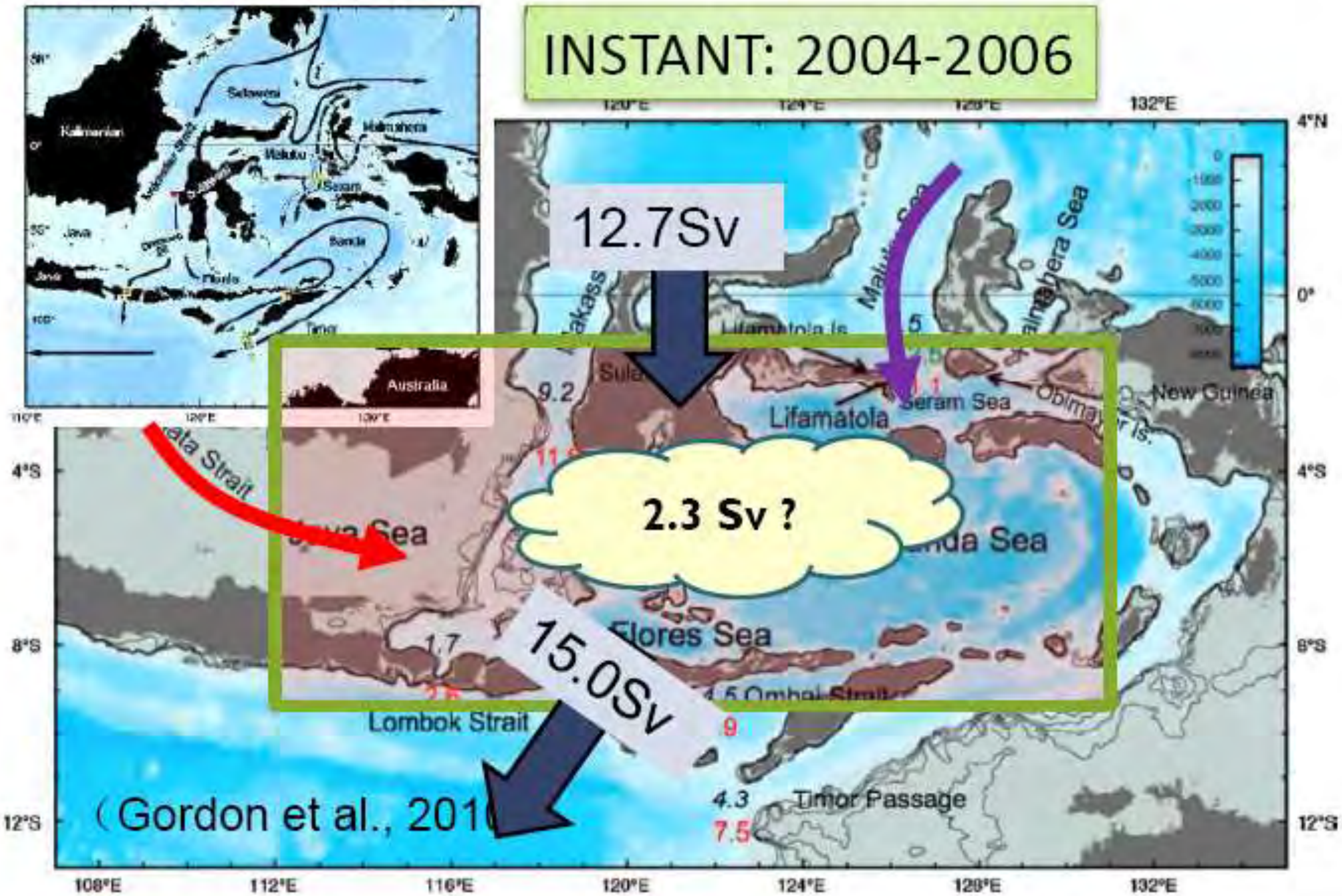
Lombok Strait

3. The key scientific issues

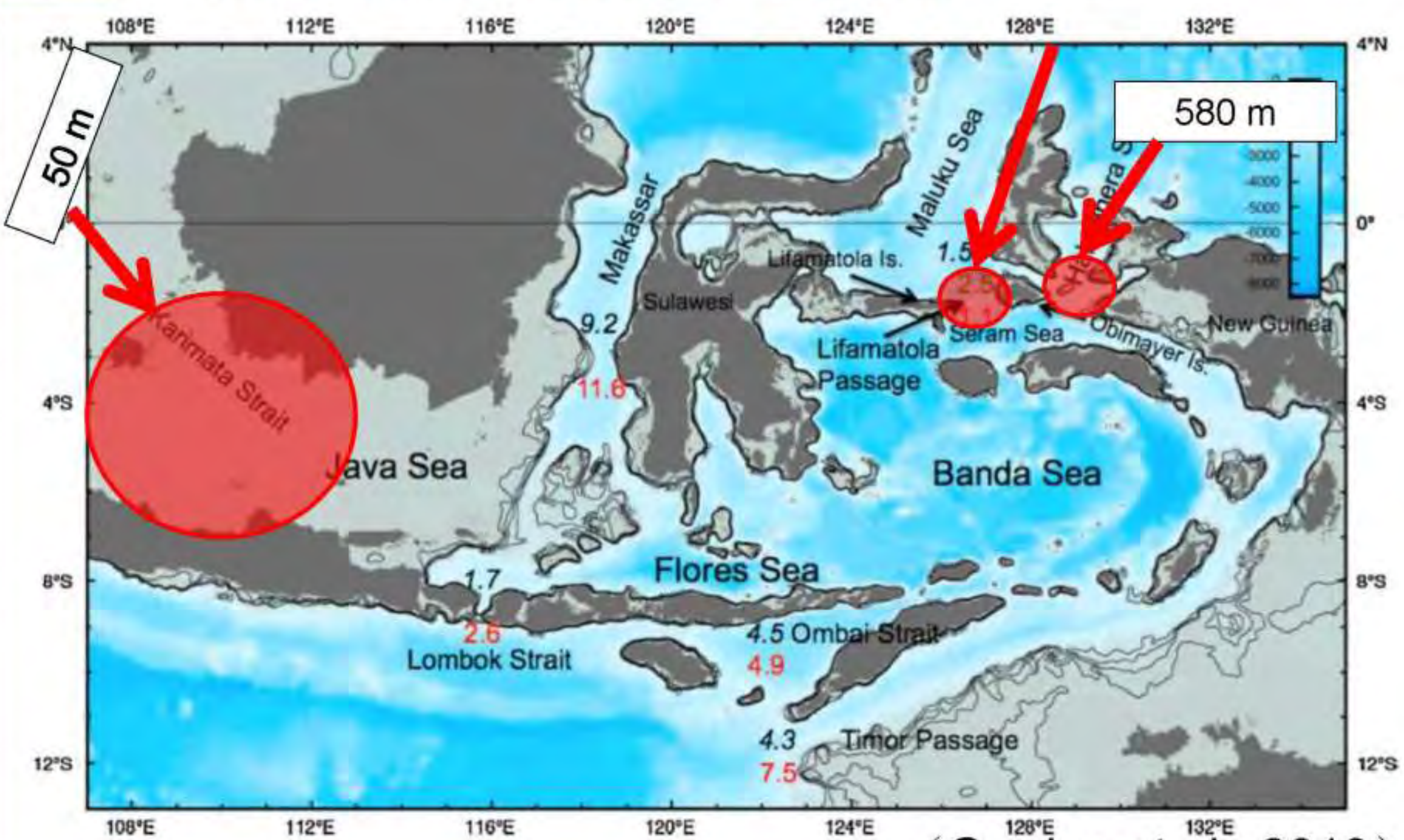


Source: Broecker, 1991, in Climate change 1995, Impacts, adaptations and mitigation of climate change: scientific-technical analyses, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

(1) The volume Transport balance of PIOT



INSTANT: 2004-2006



(Gordon et al., 2010)

(2) Interaction region between Rossby wave and Kelvin wave

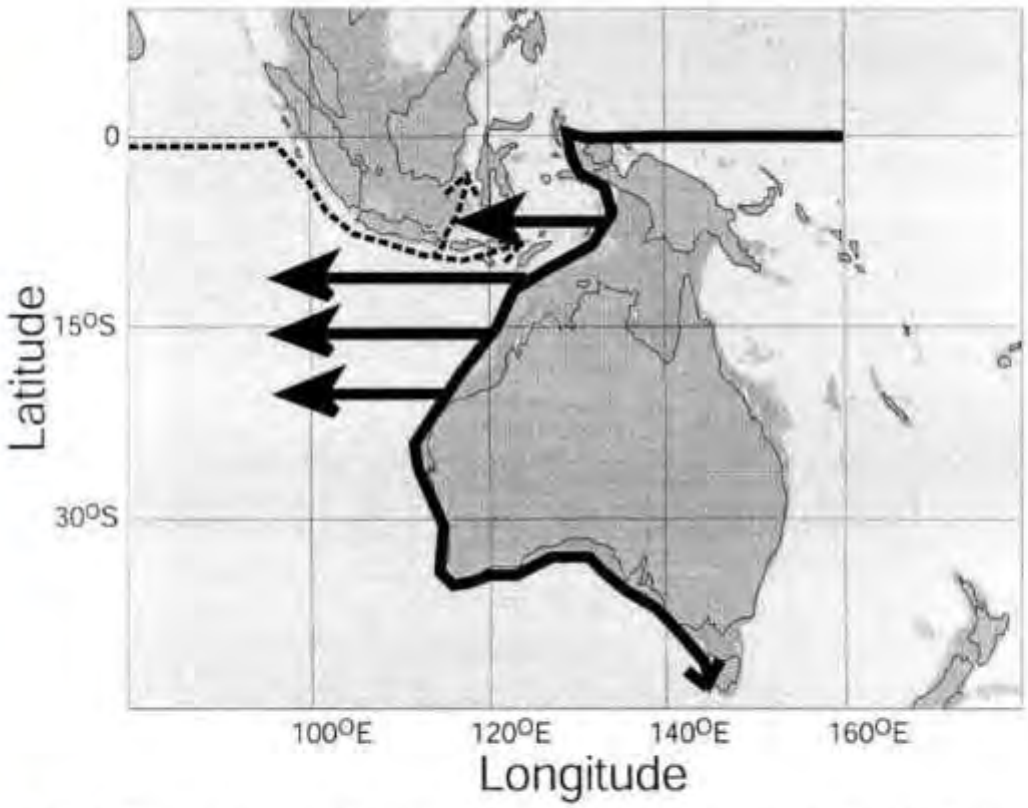
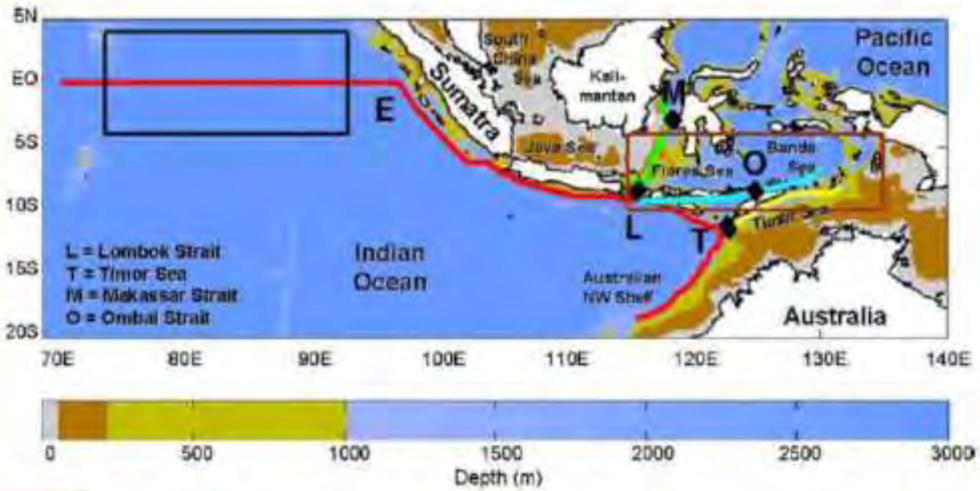


FIG. 20. Schematic of remotely forced wave pathways into the throughflow region. Thin broken lines show the waveguide from the equatorial Indian Ocean, with energy spreading into the internal seas through both Lombok and Ombai Straits. Solid black arrows show the pathways for equatorial Pacific wind energy traveling down the Papuan/Australian shelf break and radiating westward-propagating Rossby Waves into the Banda Sea and South Indian Ocean.

- There are obvious annual, half-annual, interannual, intraseasonal signals in ITF region.

Clarke and Liu (1994) , Wijffels and Meyers(2004) referred that interannual wind signal in the Indian Ocean can eastward propagate in Kelvin wave to Indonesian Ocean, which make it the interaction region of two waves.

Intraseasonal variability



From observation and model results, there is significant intraseasonal variation which origins from the wind stress variation in the tropical Indian Ocean, and it propagates to this area by Kelvin wave after 14 days.

Schiller et al.(2010), Pujiana et al., 2013

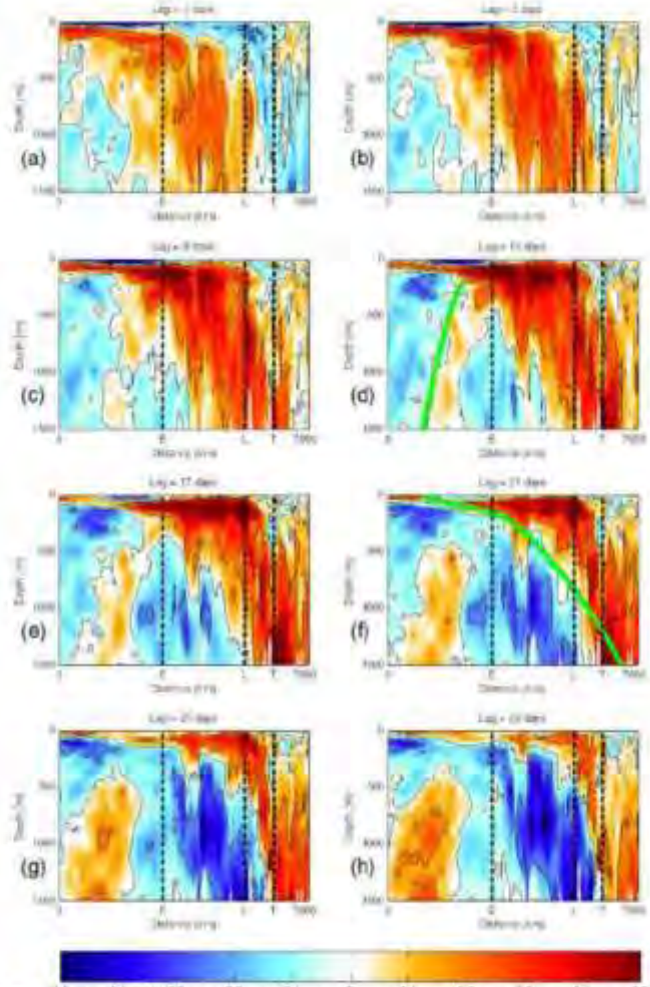
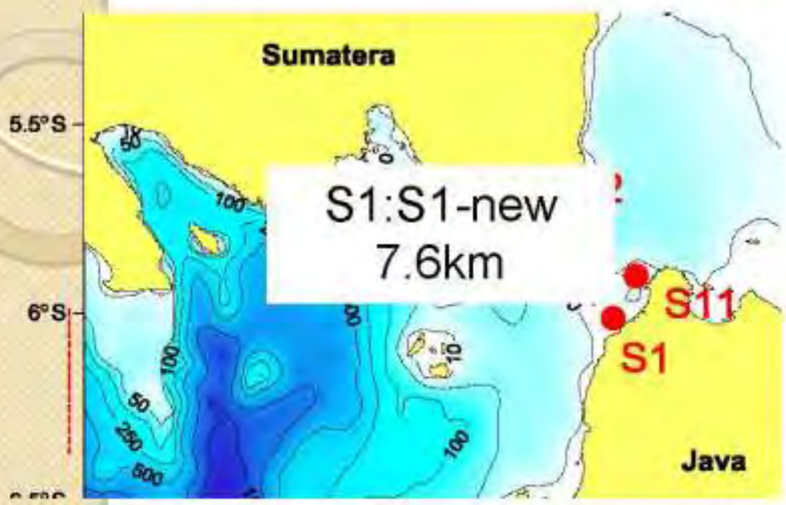
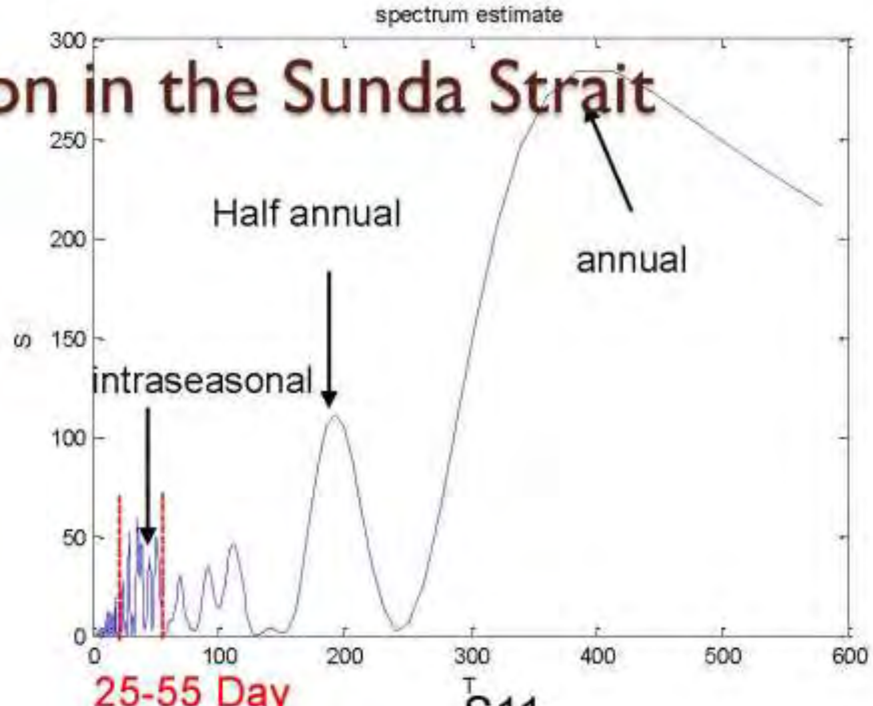


Figure Correlation of simulated potential temperature anomalies with equatorial Indian Ocean wind stress along ray path Sumatra–Java–Australia (red line in Fig. 1). Green line in (d) denotes ray path of equatorial Rossby wave and green line in (f) denotes ray path of Kelvin wave.

The Intraseasonal variation in the Sunda Strait

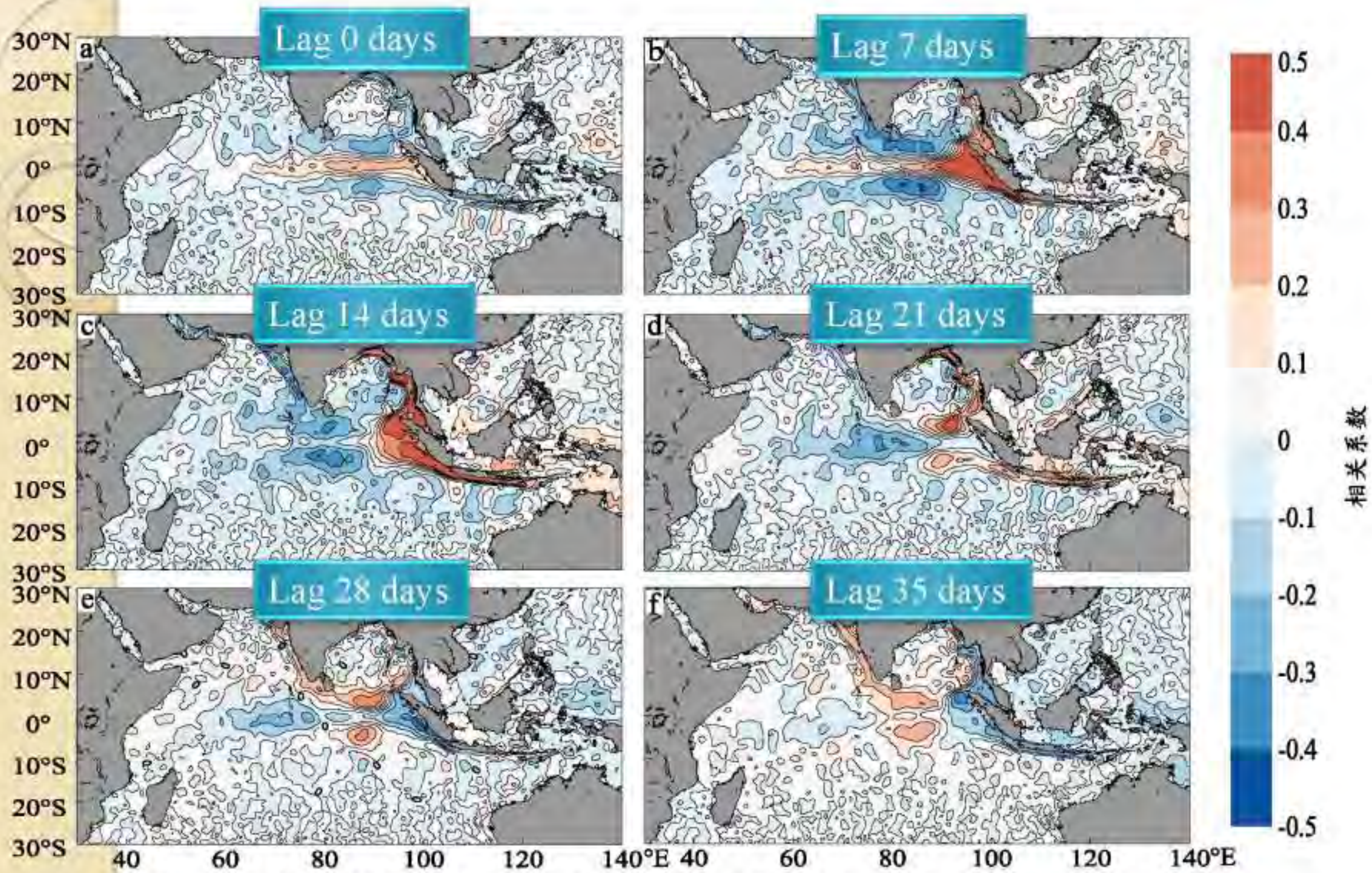


S1

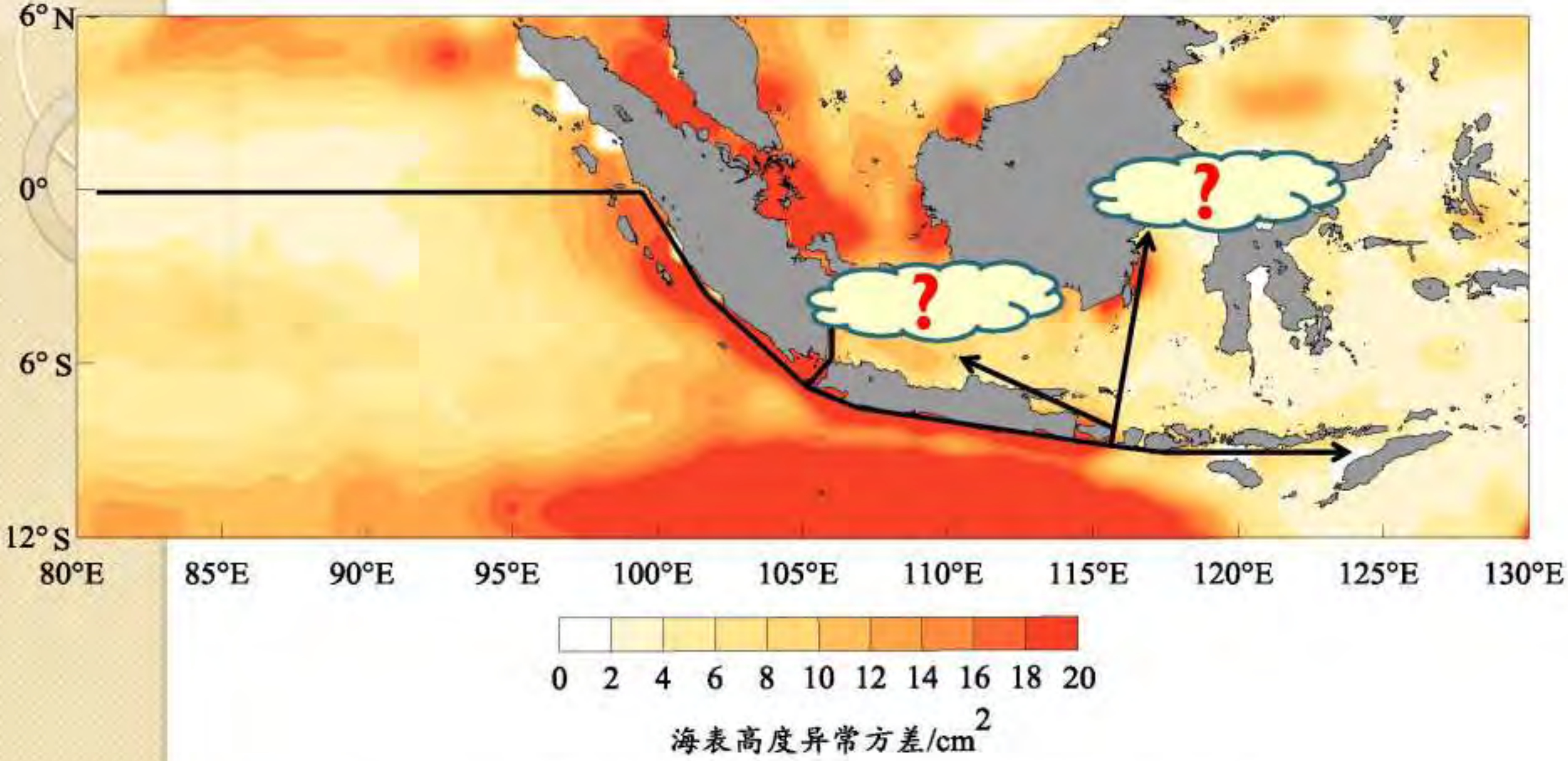


S11

The red line represents the band pass filtered result of 20-90 day



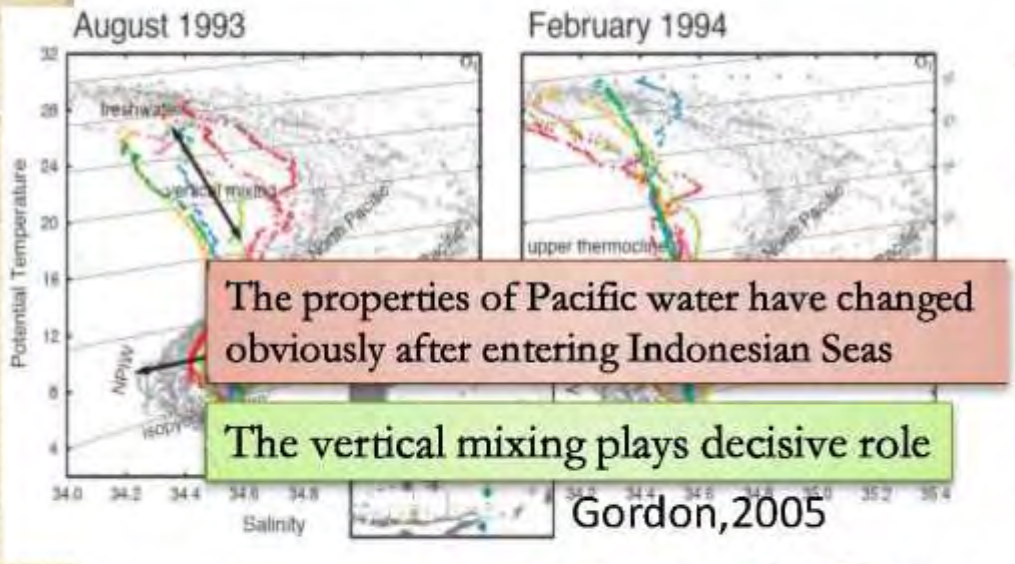
Lagged correlation of 20-90 days bandpass-filtered SSHA in the Indonesian Throughflow region and its surrounding waters and the zonal wind anomalies over the central equatorial Indian Ocean, a, b, c, d, e, f fig stands for sea level anomalies lag zonal wind anomalies 0-35 days successively (Refer to Schiller, Wijffels, et al 2010)



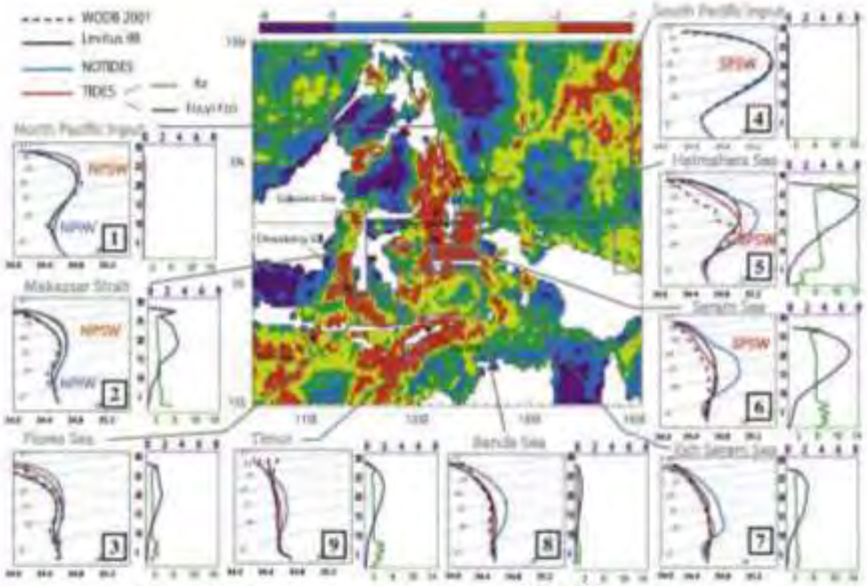
Variance distribution of 20-90 days bandpass-filtered SSHA in the Indonesian Throughflow region and its surrounding waters (1993-2012) (Unit: cm²). Black arrow stands for four possible propagation paths of intraseasonal signals.

Cao, Wei, et al. 2015

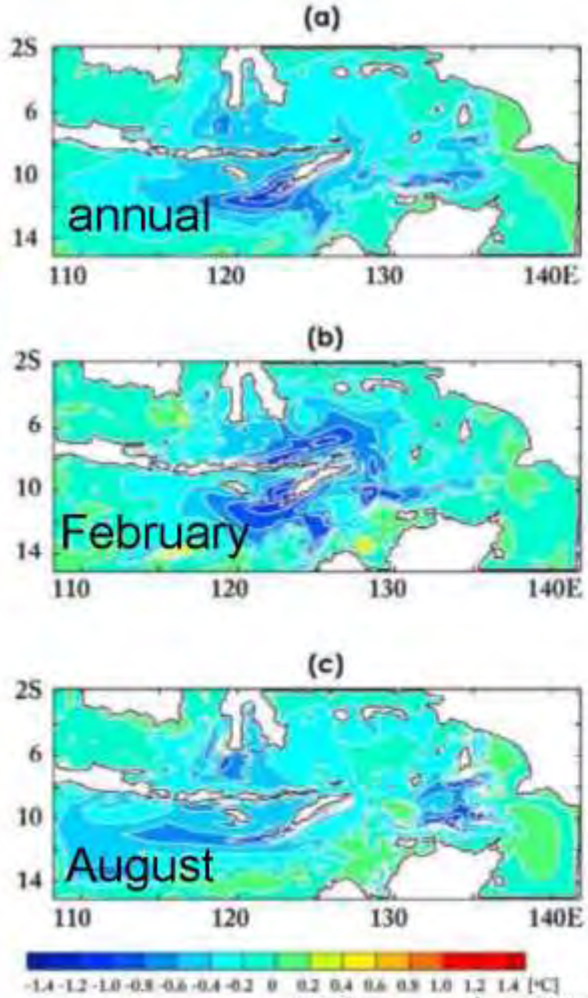
(3) The influence of mixing on ITF



Gordon,2005

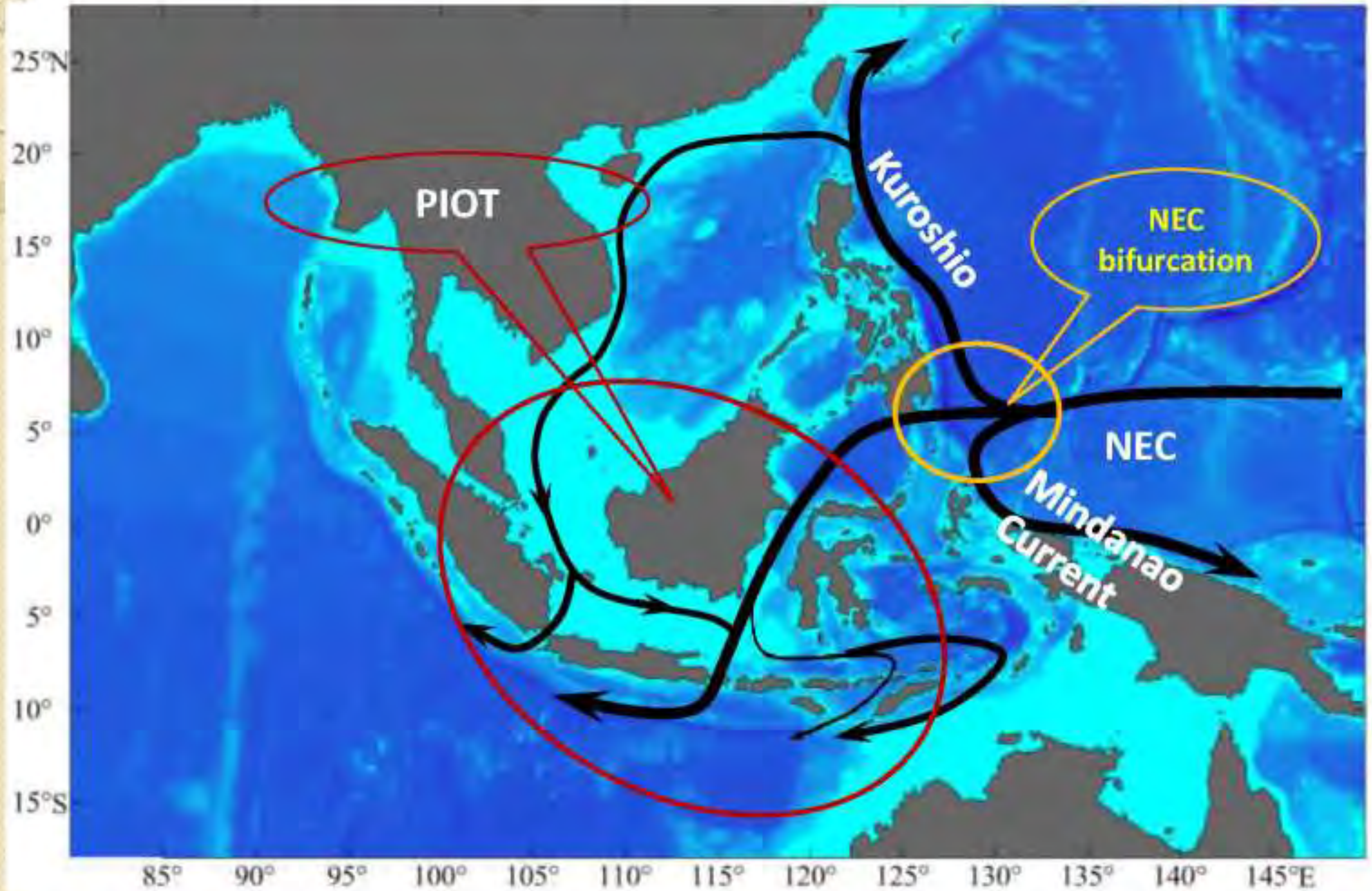


Koch-Larrouy et al.,2007

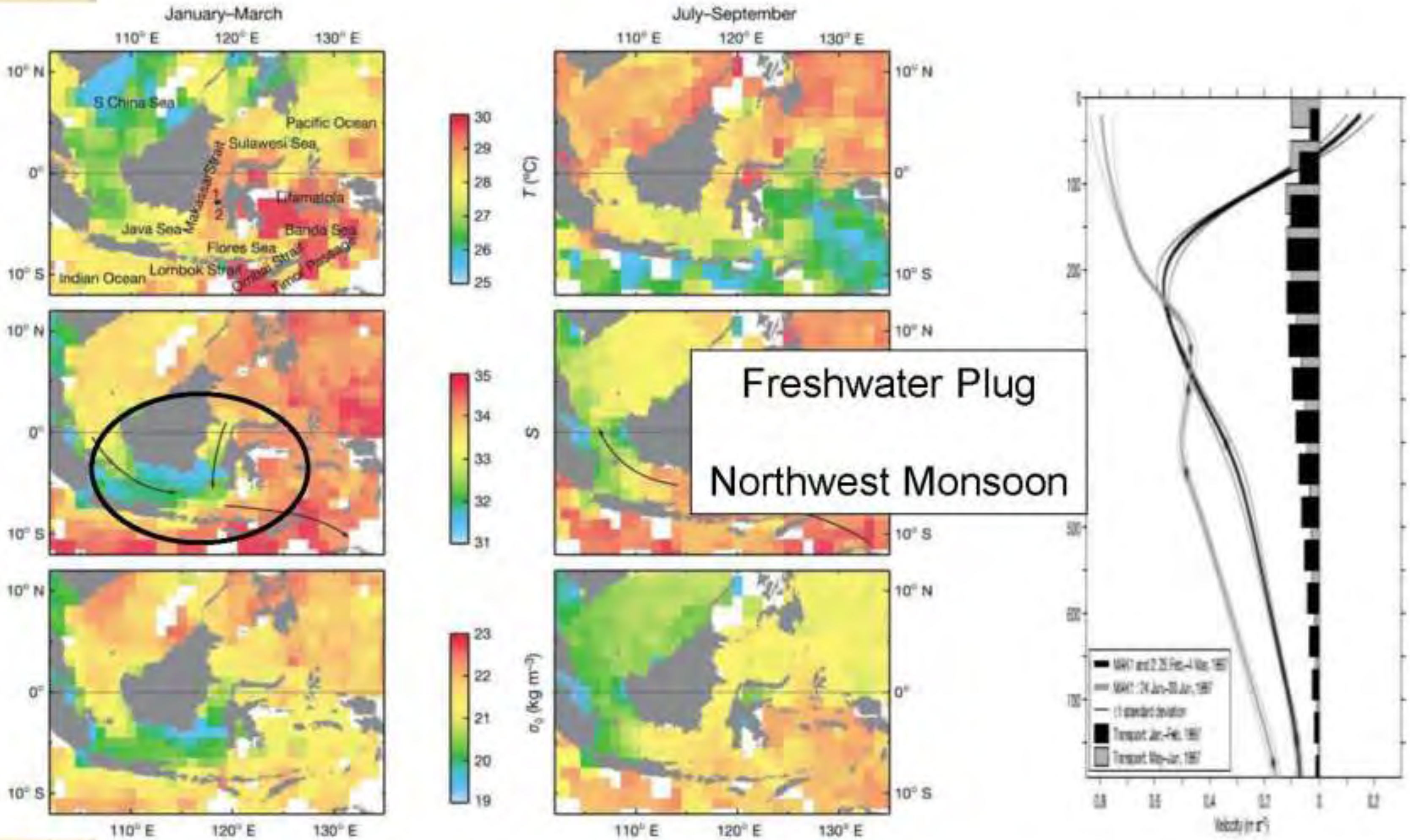


Kida et al.,2012

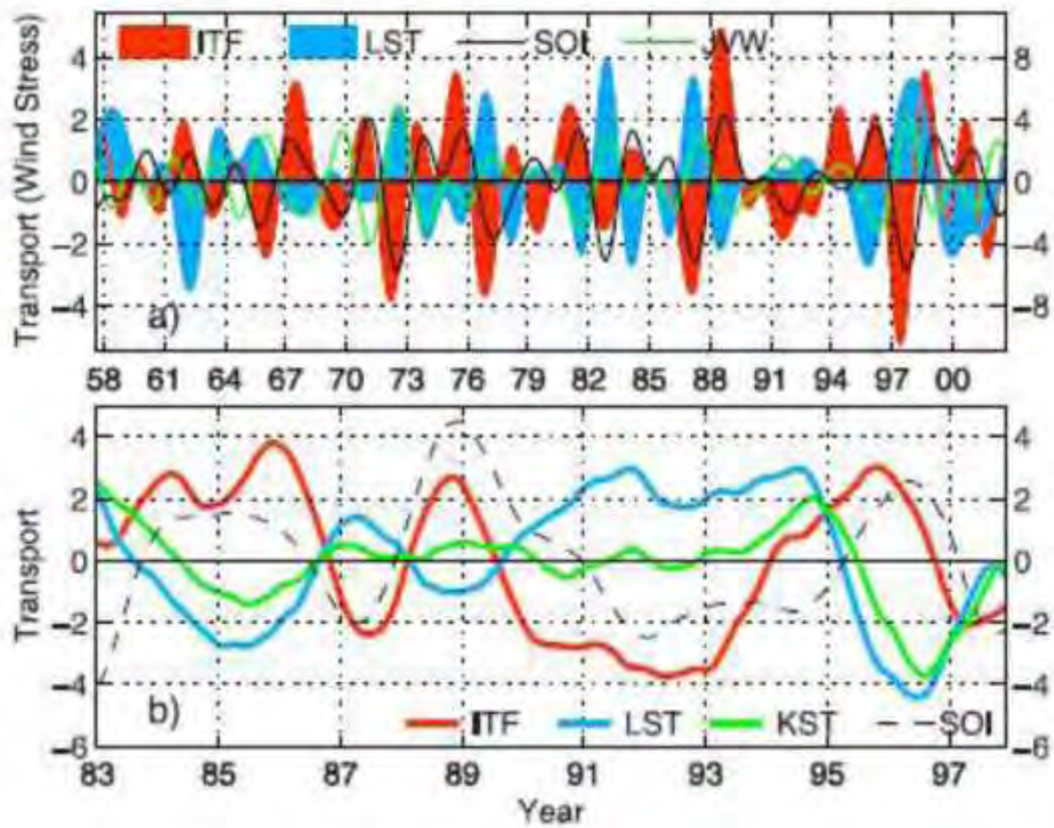
(4) The interaction between ITF and SCSB



PIOT connects the Pacific and Indian Ocean. The PIOT, NEC, Kuroshio and Mindanao current influence each other, and has similar response to the ESNO signal.



Gordon et al., 2003



Results from Island rule based on ERA-40 wind

Model results

Qu et al.,2005

- Some model results show that the transport of Luzon Strait is in reverse phase with the transport of ITF in interannual scale, and it related with the wind variation in tropical Pacific (Qu et al. 2005; Liu et al., 2006, 2007.)

Lag-correlations of the NBL and the ITF volume transport

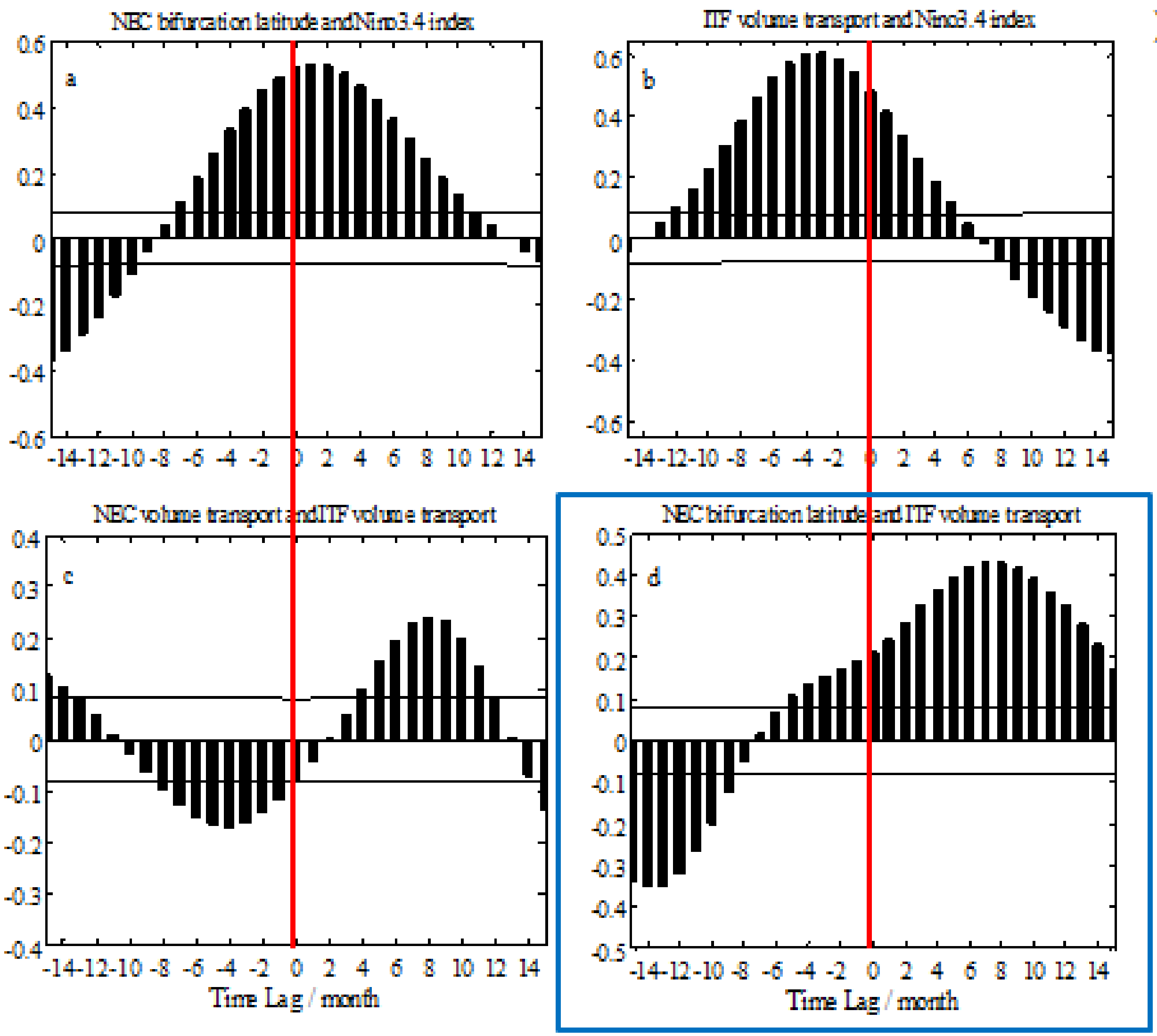
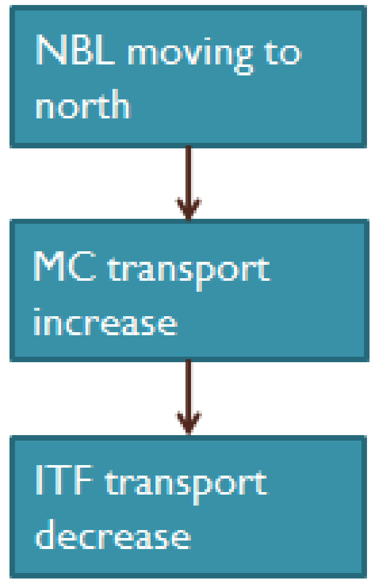
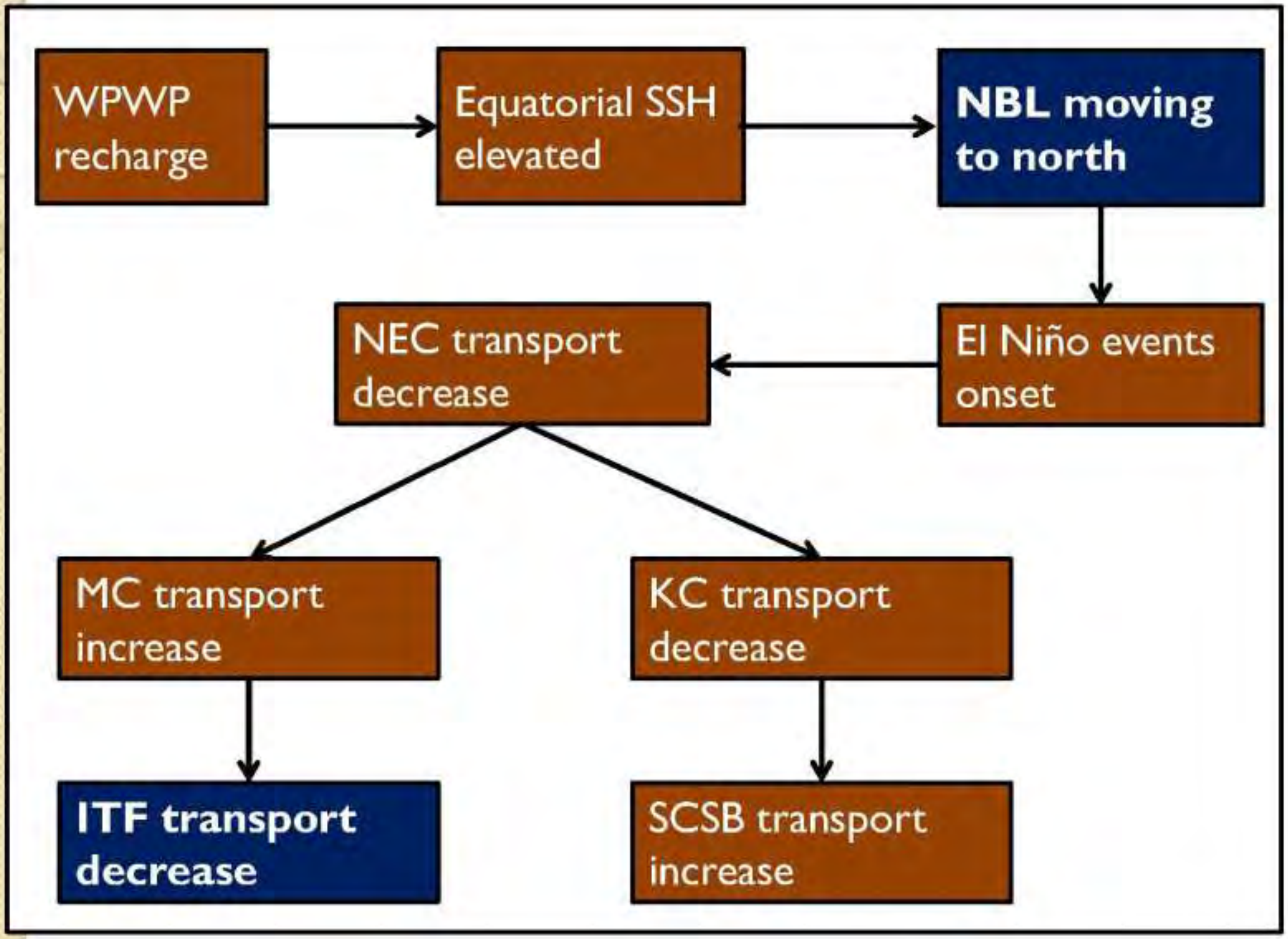


Fig. Lag-correlations of the NEC bifurcation location, NEC volume transport, ITF volume transport and the Niño3.4 index. The solid lines are the 95% confidence level lines.

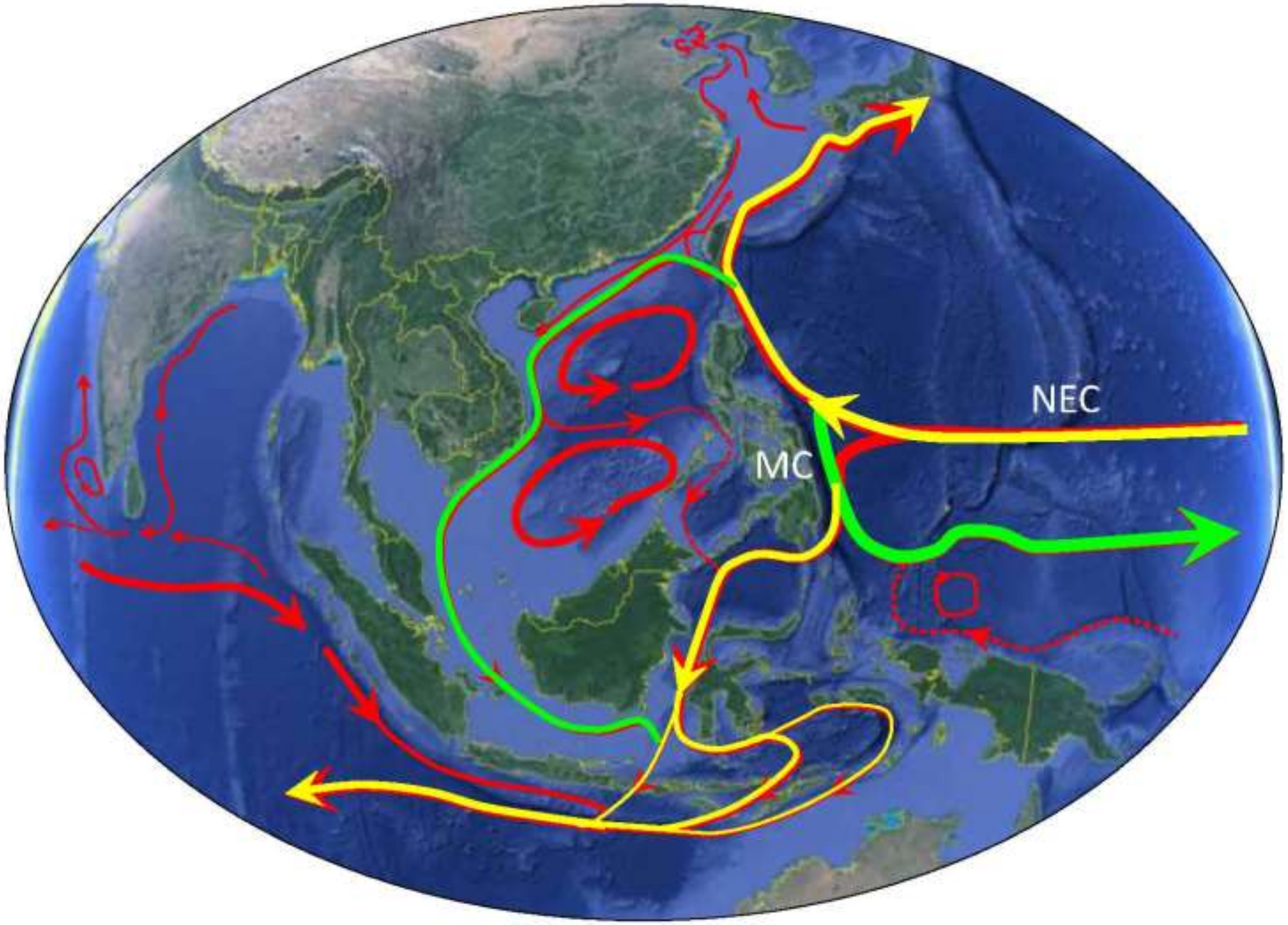
- The positive correlations suggest that after the NEC bifurcation moving to the north for 7 months, the ITF transport is in downtrend. (the ITF transport values are negative)



Zhao, Wei, et al. 2015



Zhao, Wei, et al. 2015

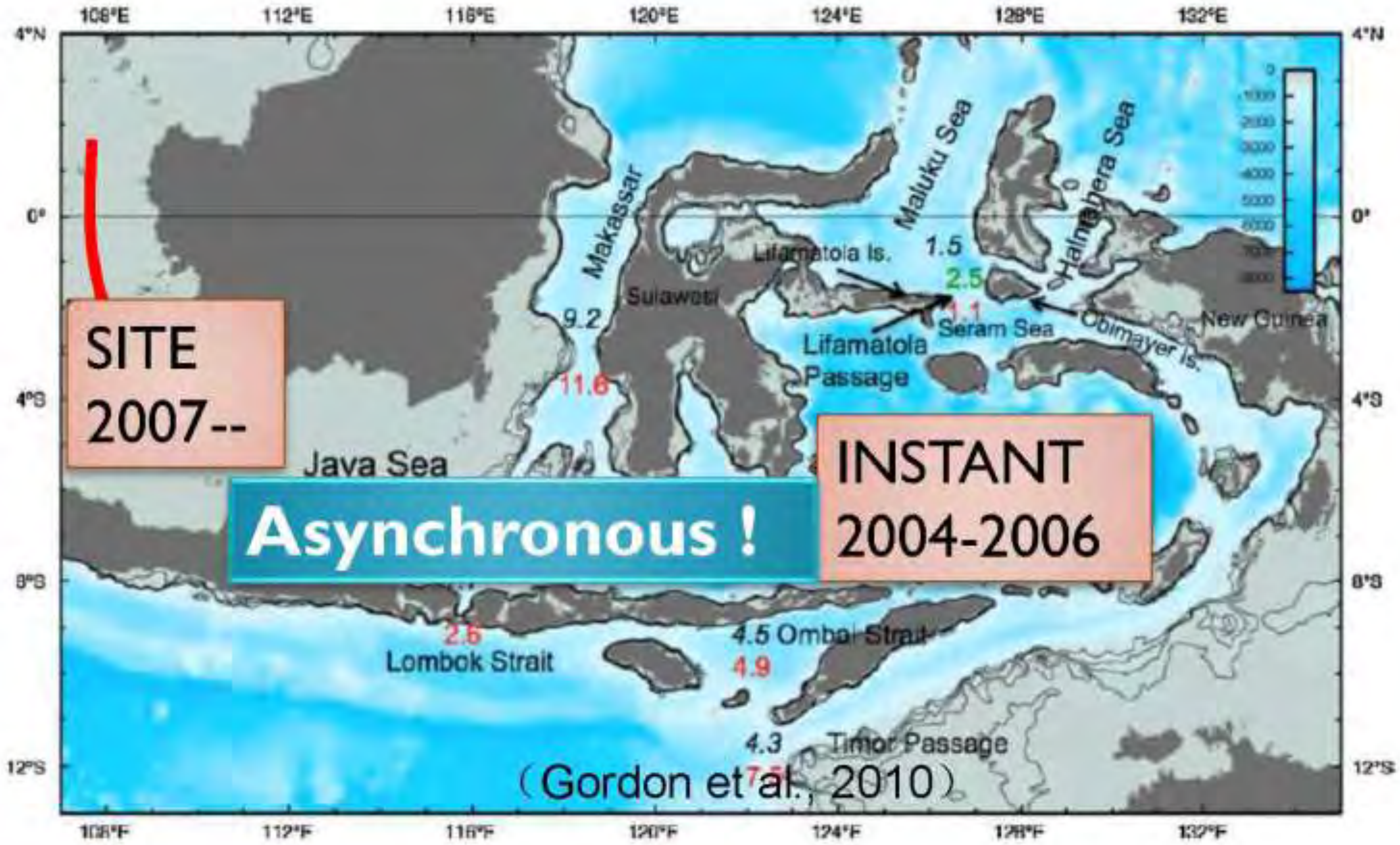


Ocean circulation system in Tropical Pacific and Indian Ocean

4 Summary

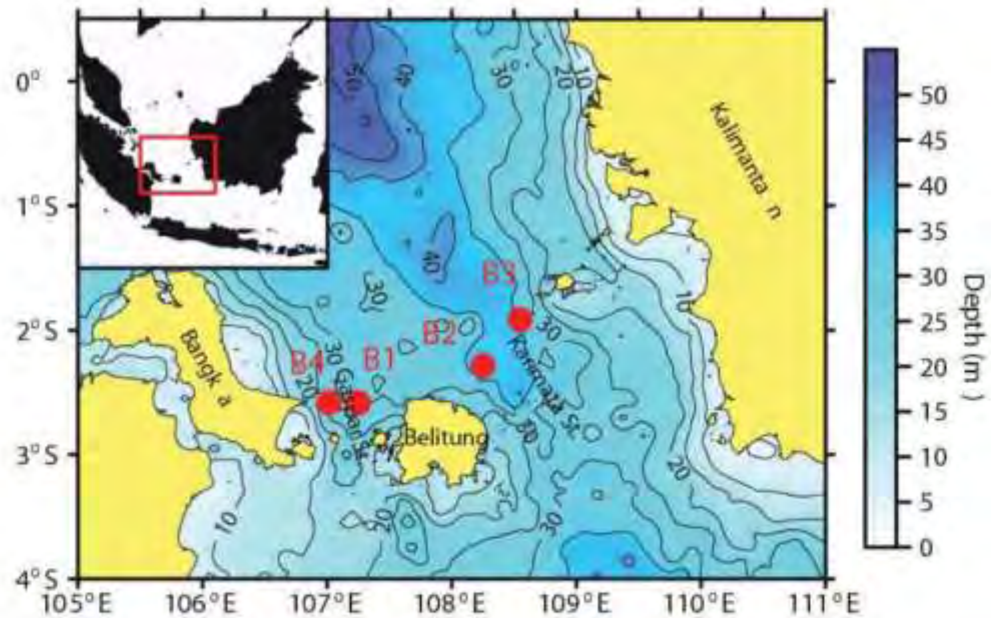
1. The Pacific to Indian Ocean throughflow, including ITF and South China Sea branch, plays not only important roles in the water and heat exchange between the two oceans, but also in the Indo-Pacific climate variability, even in the abrupt global climate.
2. We carried out a series of in situ observation focus on the SCS branch of Pacific to Indian Ocean throughflow through international cooperation **"SCS-Indonesian Sea Transport/Exchange (SITE)"** . The program is now extended to both SCS branch and ITF region**(TIMIT)**.
3. There are still some scientific problems on the PIOT and its SCS Branch.
4. **Further observation and study** are expected to reveal the characters and dynamics of PIOT and SCSB.

Future plan of international cooperation

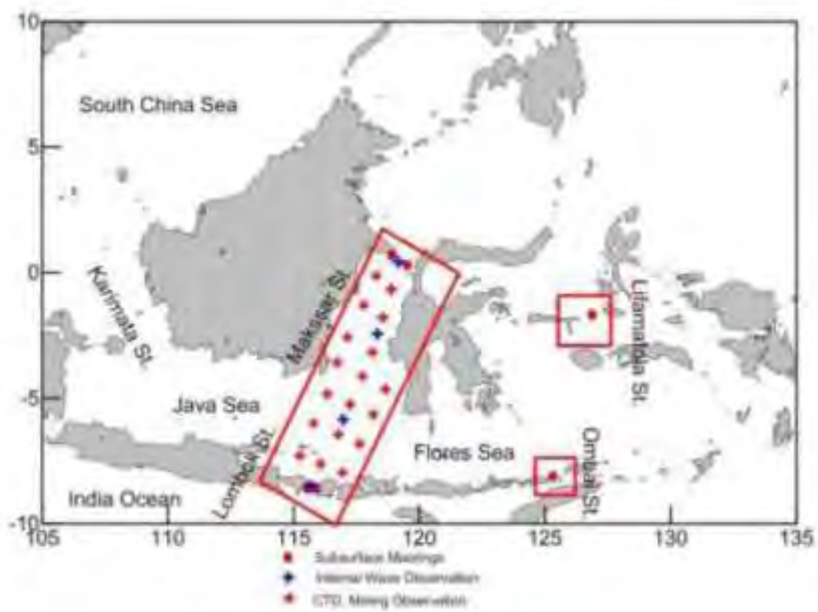


PSIE—Pacific-South China Sea-Indian Ocean water exchanges and their impacts on regional oceanography and climate

SITE project



New project :TIMIT,
The Transport, Internal Waves and Mixing in the Indonesian Throughflow regions



Thank you!