Upper Layer Variability of Indonesian Throughflow

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Abstract

Indonesian throughflow (ITF), the transfer water mass and heat flux of tropical/subtropical Pacific water into the Indian Ocean through the Indonesian seas plays significant part of the global ocean system of interocean fluxes, ocean-scale heat and freshwater budgets, sea-air fluxes and biogeochemical exchange. The ITF is believed to play interactive link with Asia-Australian monsoon, ENSO and Indian Ocean Dipole, and to the large extent governs the overall oceanographic stratification, circulation, and ecosystems within the Indonesian Seas.

Although the ITF measurements have been conducted for more than two decades including a simultaneous measurement at various straits during INSTANT program in 2003-2006, and Makassar ITF in 2006-2009, they failed quantify upper layer variability and freshwater fluxes which is important for the mixing and sea-air interaction within the region. The ITF branches through the South China Sea-Karimata Strait, and Tores Strait have always been ignored and have received little observational attention. There have been no field measurements to quantify the total transport and its associate heat-freshwater fluxes, even though trajectories of sea surface drifters of the Global Drifter Program from August 1988 to June 2007 have indicated that the Karimata Strait is another important channel for the Throughflow from the SCS to the Indonesian Seas.

Since December 2007, South China Sea - Indonesia Seas Transport/Exchange (SITE) has been measured using trawl resistant bottom mounted ADCP deployed in the Karimata Straits, an international collaboration between Lamont Doherty Earth Observatory (LDEO) of Columbia University-USA, Agency for Marine and Fisheries Research (BRKP)-Indonesia, and First Institute of Oceanography-China. Preliminary analysis indicated that the annual mean may be small ~1-1.5Sv, however, the seasonal volume transport associated with monsoon can reach as large as 4.4Sv.

In addition, two bottom mounted ADCP have been deployed in the Sunda Strait in November 2008 to measure the water mass and fresh water fluxes between Java Sea and eastern Indian Ocean which is the center of Indian Ocean Dipole.

For future observation, we should have an integrated observation of Indonesian throughflow and biogeochemical properties, to fill the gap of the map of global climatological mean of pCO2 and net sea-air flux of CO2.

SITE Flow/Monsoon Throughflow

Although the Indonesian Throughflow (ITF) measurements have been conducted for more than two decades, all measurements have been conducted in the eastern part of Indonesia. The ITF branch through western part of Indonesian, the South China Sea-Karimata Strait has always been ignored (Figure 1).

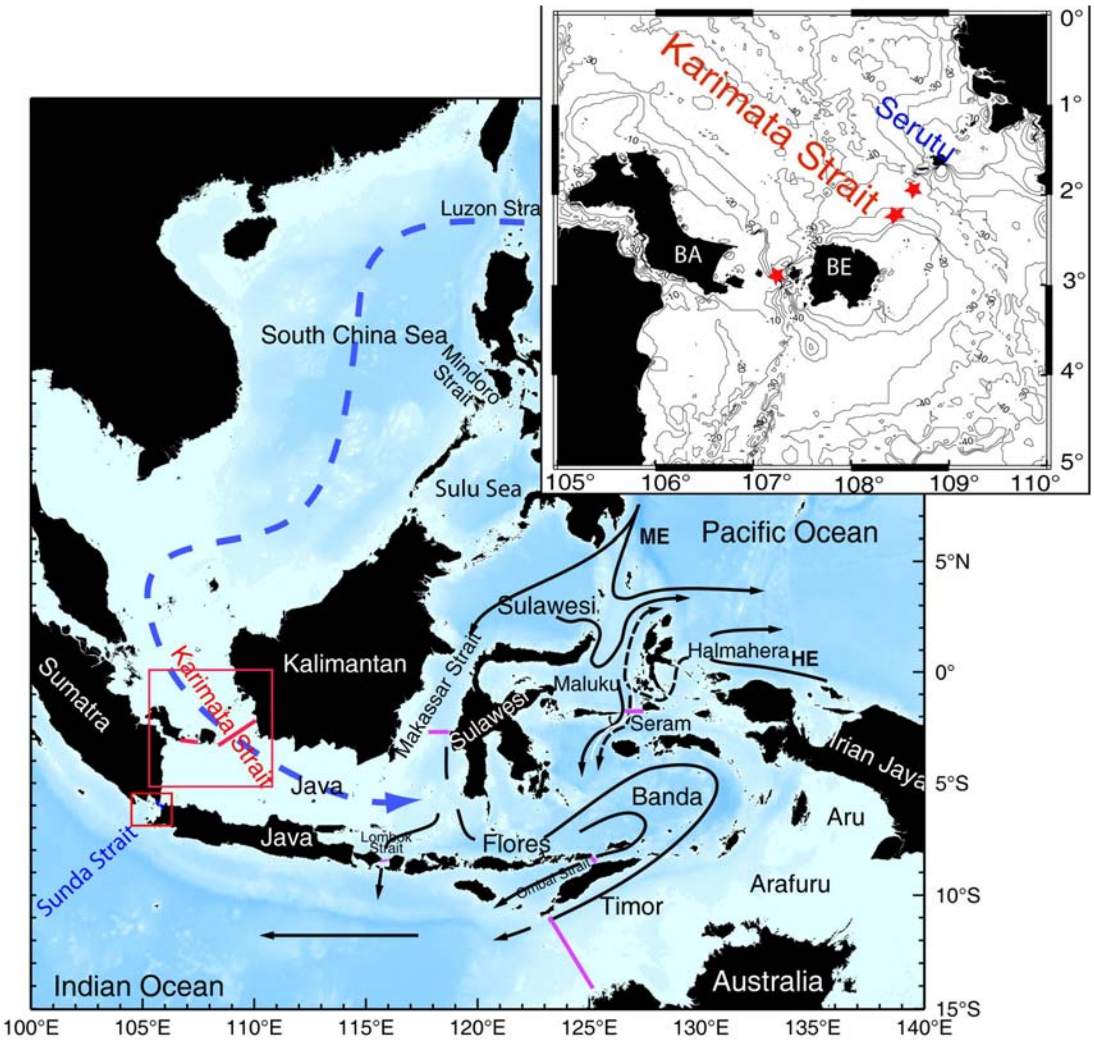

Figure 1. ITF pathways and INSTANT mooring locations (magenta lines) and the SITE flow study area in the Karimata Strait and Sunda dynamics (red box). The TRBM locations in red-stars in the insert; in the middle of the Strait are Bangka (BA), Belitung (BE) and Serutu Island. Two TRBMs have been deployed in the Sunda Strait between Java and Sumatra.

There have been no field measurements to quantify the total transport and its associate heat-freshwater fluxes, even though trajectories of sea surface drifters of the Global Drifter Program from August 1988 to June 2007 have indicated that the Karimata Strait is another important channel for the Throughflow from the South China Sea to the Indonesian Seas (Figure 2; a courtesy of the Drifter Data Assembly Center, NOAA/AOML). In fact, the total number of drifters that pass through the Karimata Strait is higher than those that pass via the main ITF path of Makassar Strait, and none of the drifters passes the Mindoro Strait. If we had known then that SITE flow plays an important role on seasonal and interannual time scales and in reshaping the vertical structure of the main ITF (Gordon et al, 2003; Qu *et al.*, 2006 and Tozuka *et al.*, 2007), we would have measured the SITE flow as part of the INSTANT[1] program.

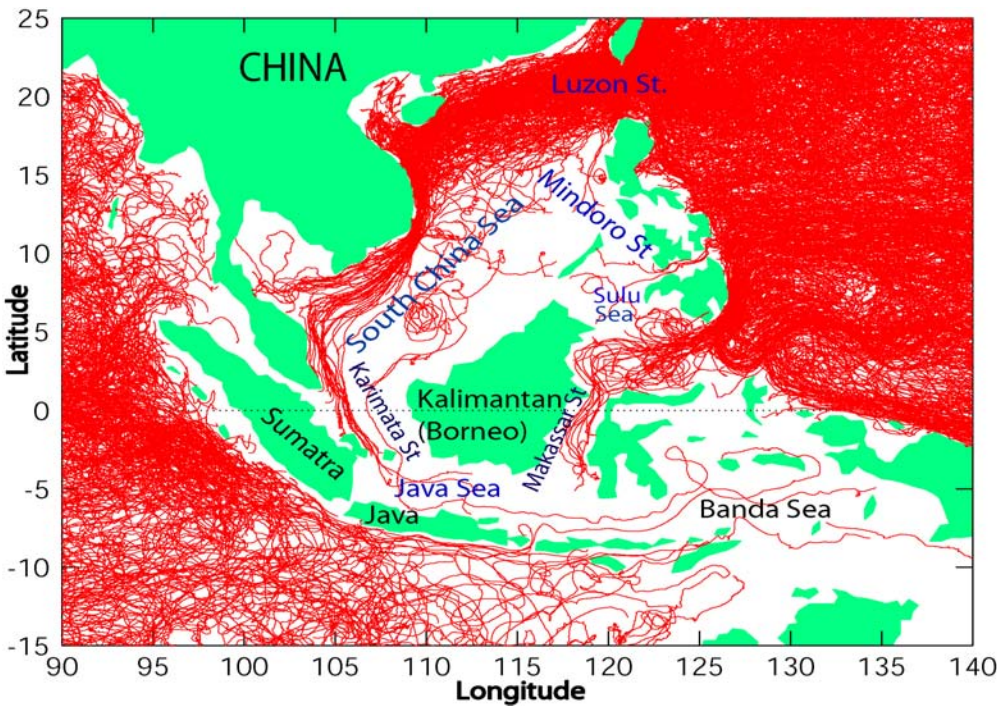

Figure 2. Trajectories of satellite-track drift buoys from the Global Drifter Program (8/1988-6/2007). The trajectories clearly show that a current intrudes into the South China Sea through the Luzon Strait and forms a throughflow branch toward the Karimata Strait. In fact, the total number of drifters through the Karimata Strait is higher than those that pass through the main ITF path of Makassar Strait. One drifter from Luzon Strait enters all the way to the Banda Sea. None of the drifters passes the Mindoro Strait. The data set is a courtesy of Drifter Data Assembly Center at NOAA/AOML.

Numerical studies indicate that this SITE flow will play a major role in controlling the dynamics of the South China Sea and Indonesian Seas and affecting the primary ITF (Shriver

[1] INSTANT: International Nusantara (Indonesian Archipelago) Stratification and Transport Program

and Herbert, 1997; Lebedev and Yaremchuk, 2000; Fang *et al.*, 2005; Qu *et al.* 2005, Qu *et al.*, 2006; Song, 2006; Tozuka *et al.*, 2007). Despite several numerical studies that have attempted to quantify the SITE flow, there has not been a consensus among numerical models, in terms of the mean and variability (Table 1). These discrepancies are probably due to the fact that there has been no field measurement to validate the numerical studies and the complex nature of the circulations in the South China Sea and Indonesian Seas.

The effects of SITE flow on the South China Sea circulation and on the long-term magnitude and variability of the ITF are not well understood, nor are its interactions with monsoons and El Niño-Southern Oscillation (ENSO) events. Therefore, monitoring the mass, heat, and salt/freshwater fluxes associated with the ITF over several seasonal cycles is important for verification of ocean circulation models for climate studies and is of primary interest to global and climate research, as outlined in the CLIVAR science plan.

Reference	**Luzon** Transport		**Mindoro** Transport		**Karimata** Transport	
	winter	Summer	Winter	summer	winter	summer
Wyrtki, 1961	–2.75Sv	2.75Sv			–4.5Sv	3.5 Sv
Metzger & Hurlburt, 1996	–8.1Sv	–0.5Sv				
Chu & Li, 2000	–13.7Sv	–1.4Sv				
Qu, 2000	–5.3Sv	–0.2Sv				
Lebedev & Yaremchuk, 2000	–6.3Sv	–4.5Sv	–1.9 Sv	–4.7 Sv	–4.4Sv	0.2 Sv
Yaremchuk & Qu, 2004	–4.8Sv	–1.2Sv				
Qu *et al.*, 2004	–6.1Sv	0.9Sv	–1.5Sv	0 Sv	–5.4Sv	1.5Sv
Fang *et al.*,2003	–7.8Sv	–1.7Sv	–3.2Sv	–0.7Sv	–4.2Sv	1.5Sv
Song, 2006	–12.2Sv	–8.2Sv			–8.9Sv*	–5.2Sv*
Tozuka *et al.*, 2007	–3.6Sv		–0.4Sv		–1.4Sv	
Our Preliminary Results	–7.5Sv		–4.4Sv		–1.6Sv	
	–9.6Sv	–5.6Sv	–4.6Sv	–4.4Sv	–5.3Sv	1.8Sv

Table 1. Previous studies on Luzon, Mindoro, and Karimata Strait transports. Positive (negative) values indicate eastward (westward) transport for Luzon Strait and northward (southward) for Karimata and Mindoro Straits, where 1 Sv = $10^6\ m^3 s^{-1}$. (*) included transport for Makassar Strait. The references to seasons in this proposal apply to the Northern Hemisphere unless otherwise specified.

As suggested by previous numerical model studies (Table 1), we hypothesize that the seasonal variability of SITE flow is large and reversed in a direction that has a strong influence on the main Indonesian Throughflow through the Makassar Strait and also affects the circulation in the South China Sea. During the northwest monsoon (October-April), water from the South China Sea flows to Java Sea, and conditions are reversed during the southeast monsoon (April-

October). Hence, Preliminary analysis indicated that the annual mean may be small ~1-1.5Sv, however, the seasonal volume transport associated with monsoon can reach as large as 4.4Sv.

Field Work

To measure the magnitude and variability of SITE flow an array of three –trawl-resistant, bottom-mounted (TRBM) ADCPs has been deployed in Karimata Strait in December 2007. Two TRBMs from the US are supported by NSF and ONR-DURIP and one TRBM from China. In addition, two TRBMs (1 USA supported by ONR + 1 China) have been deployed in the Sunda Strait which allows us to determine variability of volume transport and its associated heat-freshwater fluxes between Java Sea and Indian Ocean. In November 2008, we recovered all moorings and redeployed again in the new position (Figure 1). An attempt to recover all these mooring in August 2009 was failed, and another attempt will be carried out in October 2009. The TRBMs will be redeployed again and final recovery is planned for April 2010.

In situ measurement of SITE flow will be used as base line for numerical model calibration and validation. Having simultaneous measurements of transport and its associated heat-flux in the major inflow of primary ITF in Makassar Strait, Karimata and Sunda Straits as well as numerical model results, we are able to determine the effects of SITE to the primary ITF and its consequences to heat-flux and air-sea interaction within the South China Sea-Indonesian Seas and the Indian Ocean.

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