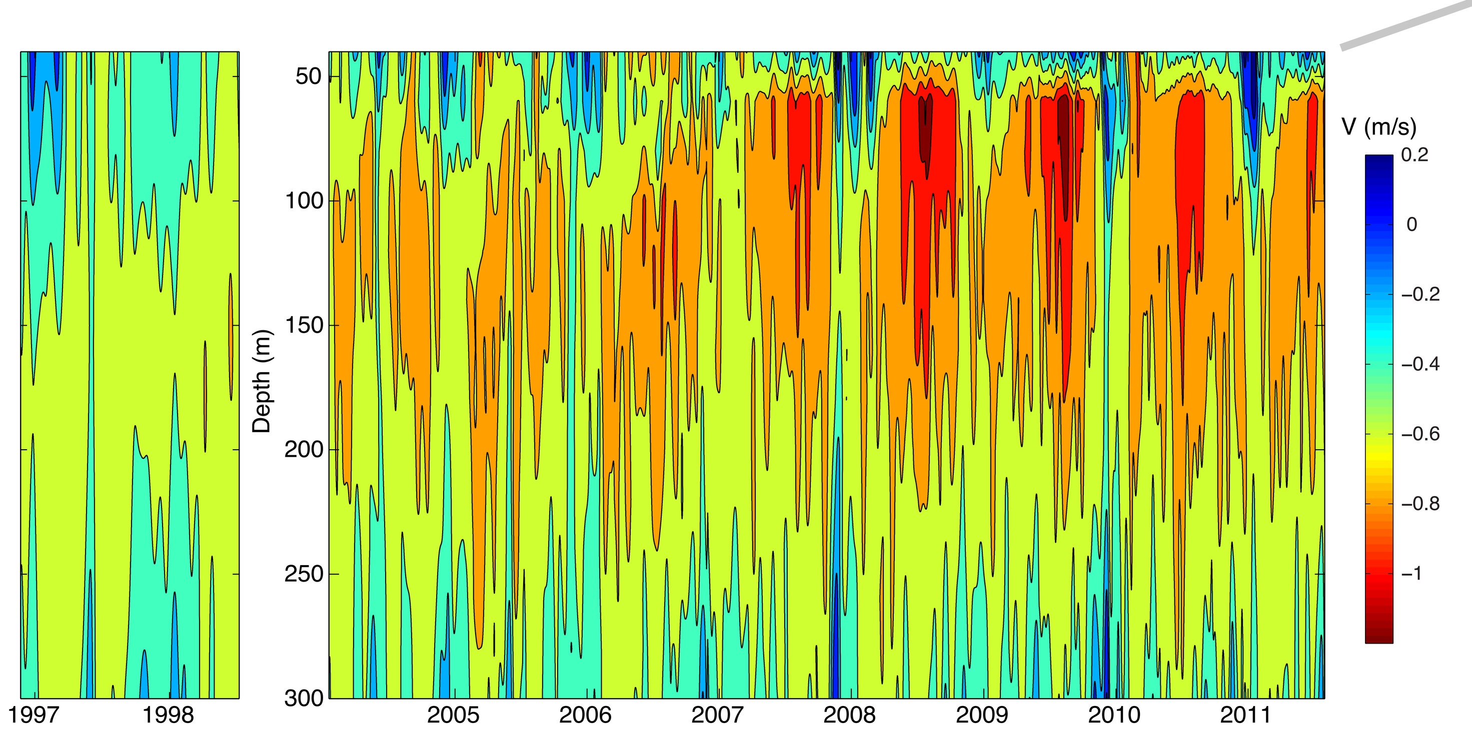
South China Sea Throughflow Impact on the Indonesian Throughflow

A. L. Gordon[1], B. Huber[1], E. J. Metzger[2], R. D. Susanto[1], H. Hurlburt[2], Rameyo Adi[3]

The transfer of western Pacific Ocean water into the Indian Ocean, the Indonesian Throughflow (ITF), influences ocean scale heat and freshwater inventories, and associated sea surface temperature (SST) patterns. The ITF effects on SST patterns link the ocean to such climate phenomena as ENSO and the Asian monsoon.

A 1996-1998 and 2004-2011 observational time series of the Makassar Strait throughflow, the primary pathway for Pacific inflow into the ITF, sheds light on the nature of the tropical Pacific Ocean surface water contribution to the ITF. The depth profile of the Pacific water flowing into Makassar Strait exhibits thermocline intensification, inducing a cooler transport-weighted temperature than might otherwise be expected.



North-South flow in Labani Channel, Makassar Strait, from moored ADCP measurements during the Arlindo (1996-98), INSTANT (2004-07) and MITF (2007-present) programs. The mooring location is depicted by the red circle on the map.

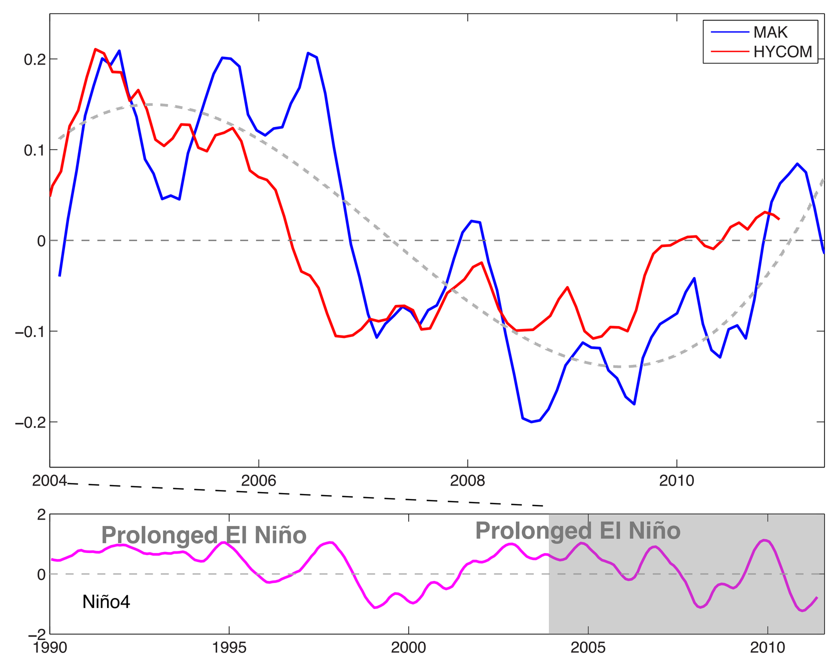
The strong 1997/98 El Niño suppressed the throughflow. The velocity maximum shoaled, with increasing maximum speed, through 2007. The peak in maximum speed occurred in 2008/2009.

The throughflow is weakest in boreal winter, strongest in boreal summer.

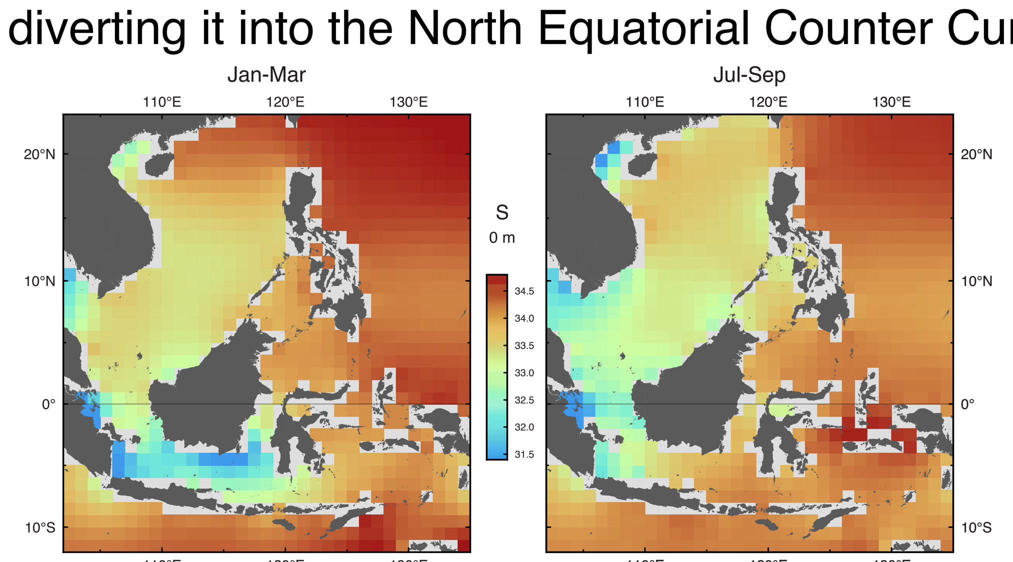
North-south monthly velocity anomaly in Labani Channel at 60 m from the 2004-2011 Makassar ADCP moored time series (blue) and from HYCOM output (red). The seasonal signal has been removed, and the data smoothed with a 7-month running mean. The gray dashed curve is a 3rd order polynomial fit to the MAK data.

Note the apparent regime change in 2007, roughly coinciding with a shift from prolonged El Niño to a period of more frequent El Niño/La Niña transitions.

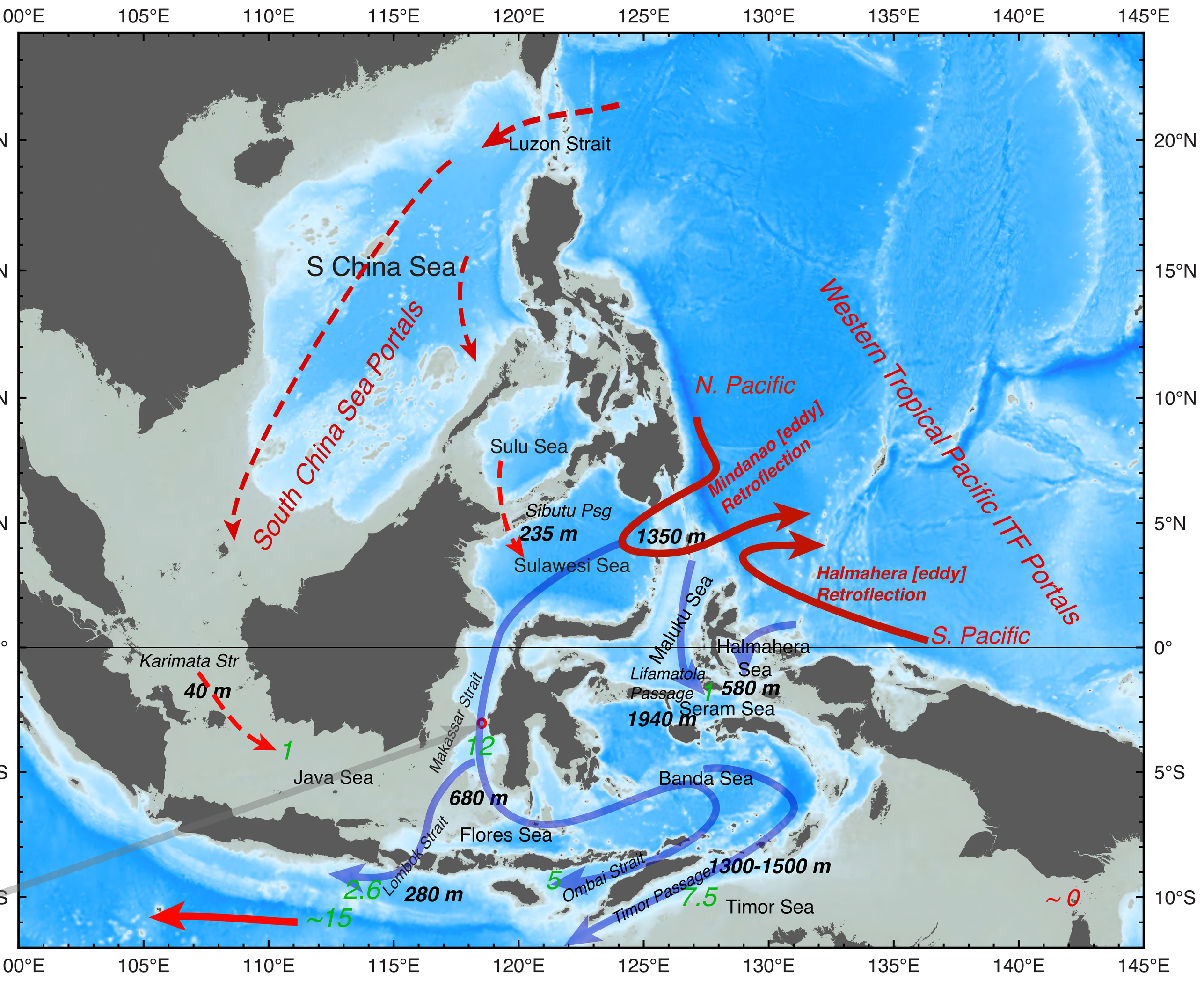
The HYCOM output in Makassar Strait agrees remarkably well with the observations, so can we investigate the relationships among the inflow sources and ITF using HYCOM-derived transport anomalies.



The profile changes with season and interannually, and likely longer time scales. The participation of surface ocean water in the ITF is clearly restricted, protecting the warmest of the tropical Pacific water from leakage into the Indian Ocean. The restriction of the surface water component of the ITF is likely a consequence of the injection of low salinity, buoyant surface water from the South China Sea (SCS) into the Makassar Strait, which blocks entry of Mindanao Current surface water into Makassar Strait, diverting it into the North Equatorial Counter Current.



Sea surface salinity seasonal averages from World Ocean Atlas 2009 (NODC)

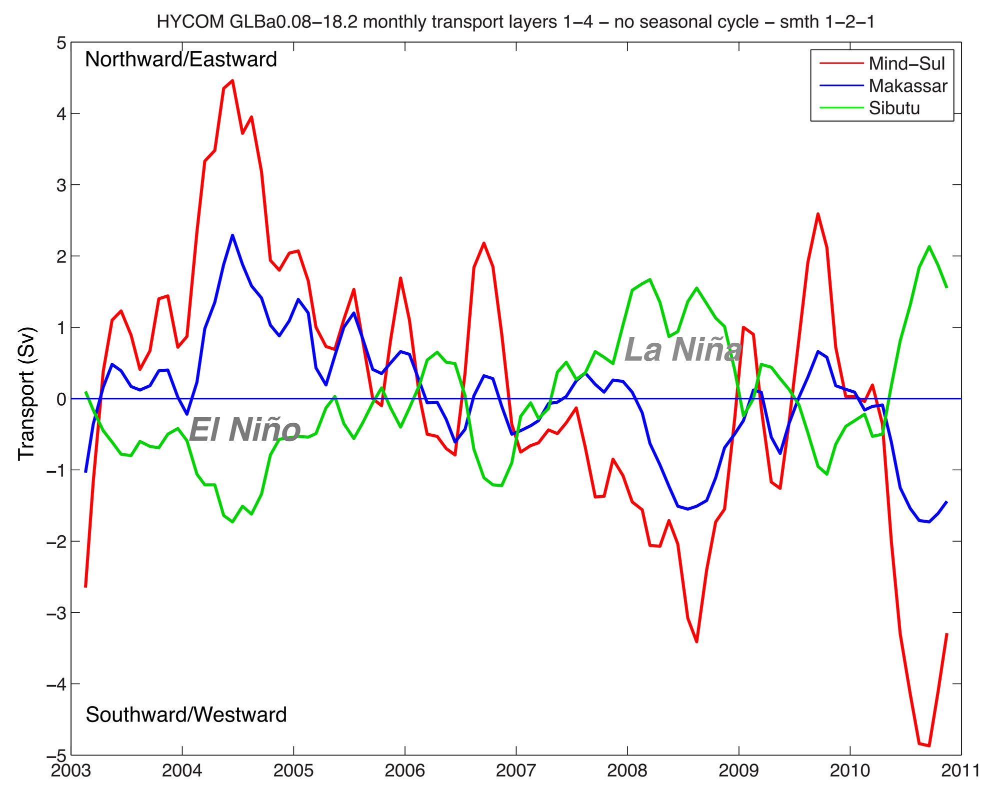


Schematic of the Indonesian Throughflow circulation. The primary source for the ITF is the western tropical Pacific at ~ 4°N, but additional inflow is derived from the South China Sea, drawn from Luzon Strait.

Topographic sill depths are given in black italics. The ITF is depicted by the blue arrows. ITF transports in Sv (10^6 m^3/s) are shown for each passage in green [from the INSTANT program, 2004-2006].

Makassar Strait Throughflow mooring site is indicated by the red circle. Makassar Strait carries 80-85% of the total ITF.

The SCS surface water derives from the Pacific Ocean via the Luzon Strait, which is diluted with excess freshwater, before entering into Makassar Strait, both from the south through Karimata Strait and from the north by a pathway through the Sulu Sea and Sibutu Passage.

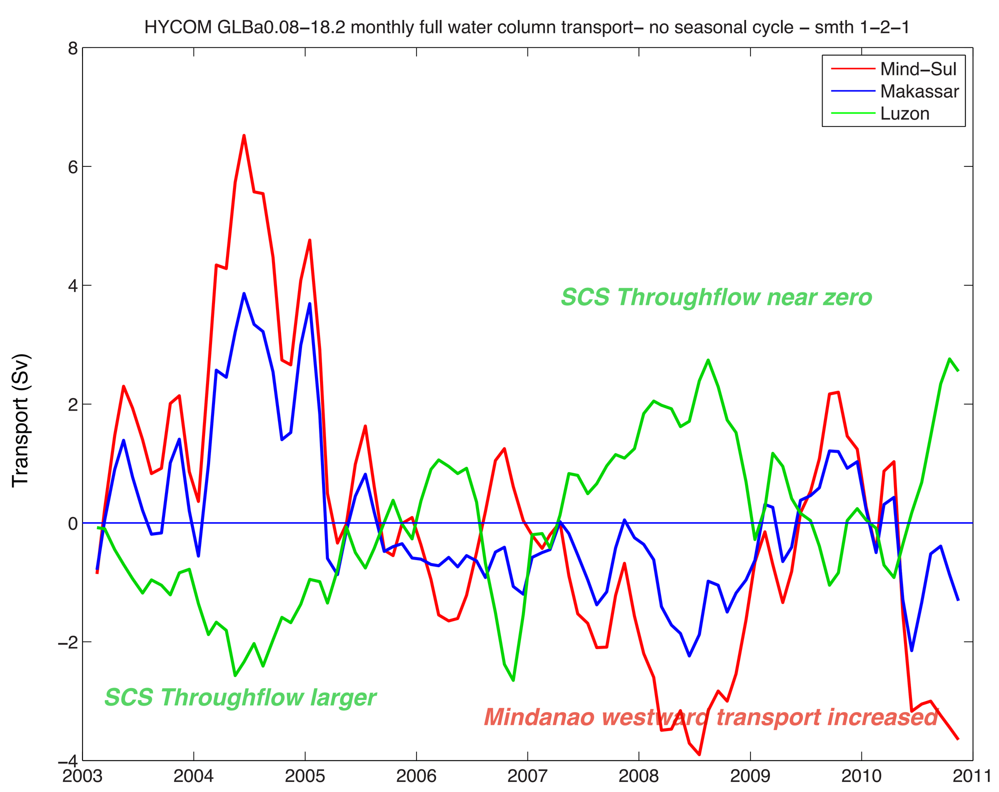


Above: Monthly transport anomaly (rel 2003-2010) of the upper 100 m through Makassar Strait, Sibutu Passage, and the Mindanao-Sulu Sea input from the Western Pacific. Values from HYCOM; seasonal cycles were removed.

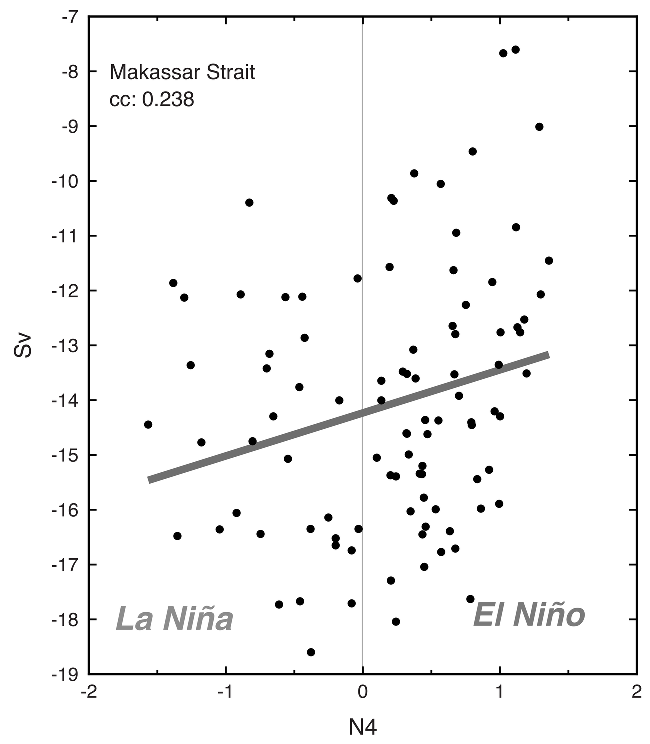
Below: Monthly transport anomaly for the full water column, Makassar, Mindanao- Sulu Sea and Luzon Strait. Values from HYCOM; seasonal cycles removed.

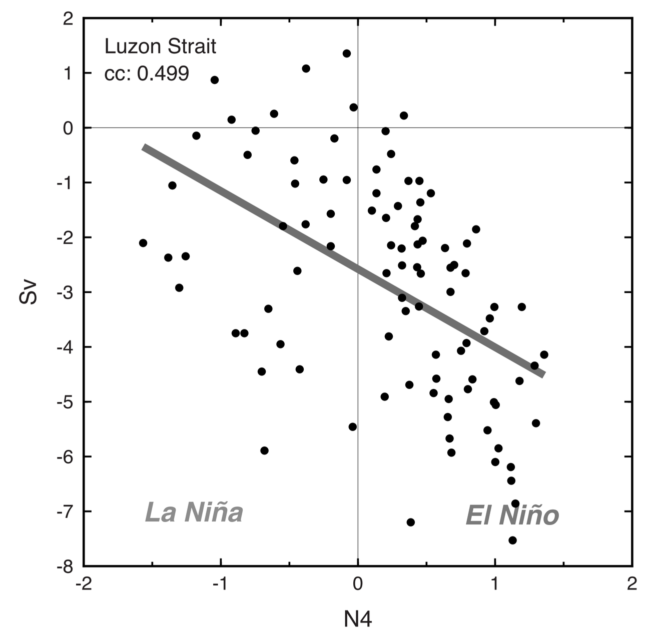
Sibutu Passage inflow tracks Luzon Strait - both are in approximate anti-phase with the Makassar Strait and Mindanao-Sulu transports.

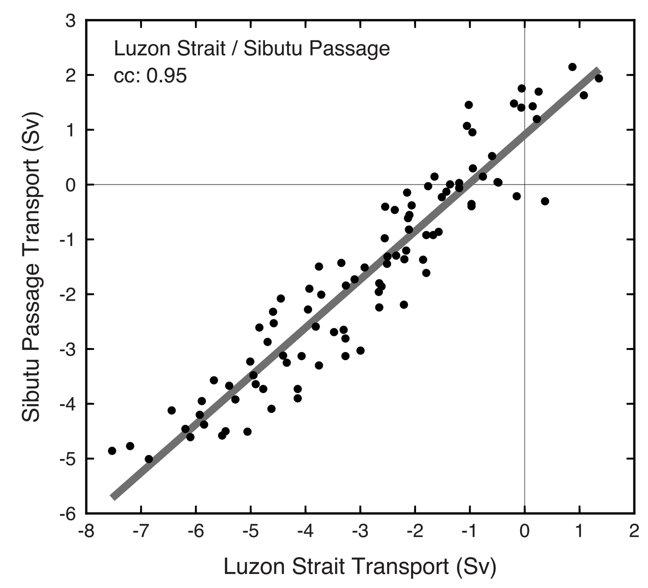
The South China Sea throughflow via Sibutu is large (negative anomaly) during El Niño and reduced (positive anomaly) during La Niña.



The SCS throughflow (Luzon Strait to Makassar Strait) is ENSO dependent via the Sibutu pathway, while the ~40 m Karimata path appears to be mostly forced by the local monsoon wind. During El Niño the SCS throughflow is high, blocking and hence reducing the surface layer contribution into the ITF from the Mindanao Current; during La Niña, the SCS throughflow is low, permitting greater contribution of Mindanao current surface water into the ITF, altering its depth profile and associated volume and heat transport.







Monthly full water column transports from HYCOM and their potential ENSO relationships (N4 - Nino4 index) -

Top left: Makassar Strait shows a weak ENSO dependence, with reduced transport during El Niño.

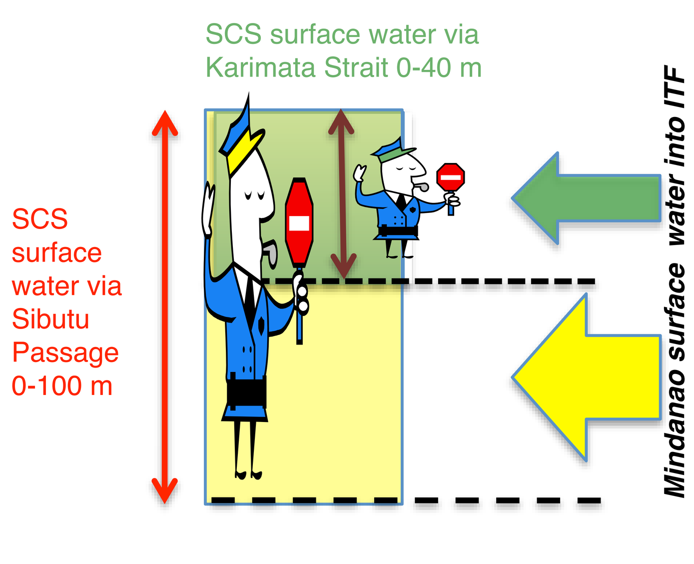
Top right: Luzon Strait displays a stronger relationship to ENSO, with increased transport into the SCS during El Niño.

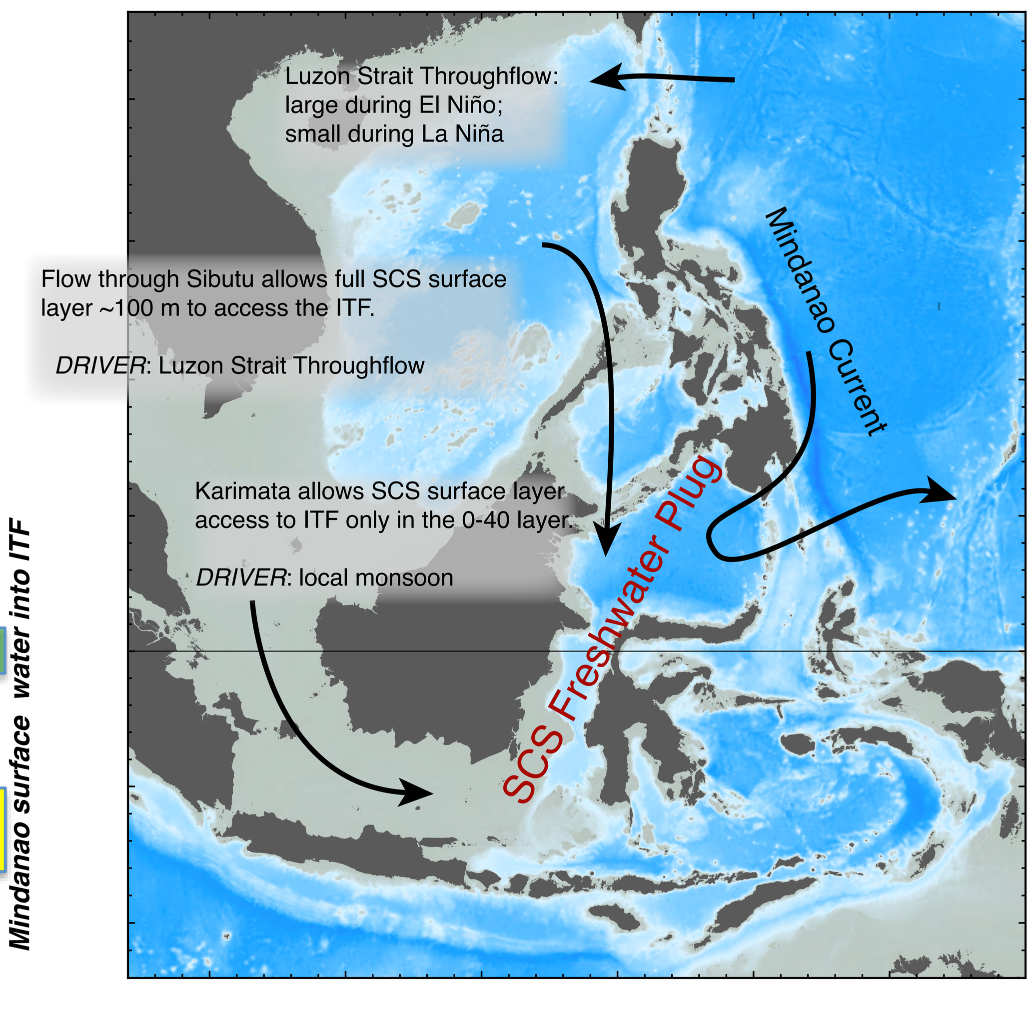
Bottom left: Luzon Strait transport is highly correlated with Sibutu Passage transport.

The South China Sea hydrological budget and throughflow have an impact on the larger scale SST patterns and climate phenomena, by exerting a 'freshwater plug' inhibiting tropical Pacific surface water participation in the ITF.

The transfer of buoyant SCS surface water via Karimata Strait inhibits Mindanao injection to ITF in the 0-40 m layer; the SCS surface layer transfer via Sibutu Passage inhibits Mindanao injection to ITF in the 0-100 m layer.

Hypothesis: "Turning off" Luzon Strait & Sibutu Passage throughflow reduced the "freshwater plug" leading to the observed 2007-2008 condition. An ENSO role is proposed.





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Affiliations
1. Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY 10964
2. Naval Research Lab, Code 7323, Stennis Space Center MS, 39529-5004
3. Balitbang-KP, Jakarta, Indonesia

Lamont-Doherty Earth Observatory
Columbia University | Earth Institute