Monitoring the Indonesian Throughflow in Makassar Strait

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1. Project Summary

The ocean, representing 97.5% of Earth's water and consequently a key component of the Earth's climate system, is segmented into basins (Atlantic, Pacific, Indian, plus a few seas). The form and efficiency of inter-ocean exchanges between these basins govern the global marine characteristics, including sea surface temperature (SST), that the ocean projects onto the climate system [see: Gordon, A.L. (2001) "Interocean Exchange". In: Ocean Circulation and Climate, G. Siedler, J. Church, and J. Gould (Eds.), Academic Press, 303-314].

The 'mega'-archipelago between Southeast Asia and Australia, the only tropical interocean pathway, offering a maze through which warm Pacific water spreads into the Indian Ocean, the Indonesian Throughflow (ITF; figure 1), influencing large-scale oceanic heat and freshwater inventories. As the ITF region is at the nexus of ENSO (El Niño/La Niña) and the Asian monsoon phenomena, it is highly likely, as indicated by model studies, that the ITF impact on SST patterns affect ENSO and monsoon behavior. Recording the ITF is a cost effective way to monitor a core element of the ocean and climate system, with the goal to enable improved climate predictive capability. As Makassar Strait is the pathway for 80-85% of the total ITF, it is the obvious focus of an ITF monitoring array. The Makassar Strait throughflow time series, at 2°51' S; 118°28' E; 2147 m, in the Labani Channel 45 km wide constriction of Makassar Strait, began with NSF funded Arlindo program in 1996-1998, and continued with NSF funded INSTANT 2004-2006 (November) and NOAA OCO 2006 (December), with the most recent recovery in August 2011. The NOAA OCO project is a cooperative program between the Lamont-Doherty Earth Observatory of Columbia University and the Agency for Marine & Fisheries Research (Balitbang KP), Ministry of Marine Affairs and Fisheries, Indonesia.

The Makassar throughflow time series reveals that after 2006, particularly in 2008-2009 boreal summer (June-September), the Makassar throughflow profile changed dramatically: the summer velocity maximum increased from 0.7 to 0.9 m/sec and shifting from 140 m into warmer waters at 70 m. HYCOM model simulation indicates that ENSO related changes in the South China Sea (SCS) throughflow, drawn from Luzon Strait, into the Indonesian seas is the likely cause of the

observed changes. Increased SCS throughflow during El Niño with a commensurate increase in the southward flow of buoyant, low salinity surface layer water, from the Sulu Sea into the northern Makassar Strait via Sibutu Passage, inhibits the injection of Pacific surface layer from the Mindanao Current into the ITF. During La Niña the Sibutu Passage throughflow is reduced or reversed allowing increase Pacific surface layer inflow. Increased inflow of warmer tropical Pacific water into Makassar Strait during La Niña affects the ITF spread into the eastern Indian Ocean, impacting on the thermocline and SST, with possible impact on climate.

The NOAA funded Makassar moorings is part of a growing international effort to observe the ITF. The Australian Integrated Marine Observing System [IMOS; see: http://imos.org.au/waimos.html] Indonesian Throughflow Moorings forms an important companion the NOAA-OCO funded Makassar mooring. The Korea Ocean Research & Development Institute (KORDI) is developing an additional international companion program. A. Gordon is a member of the KORDI science advisory group specifically for coordination of ITF observations. KORDI plans to deploy ITF observing moorings in the Maluku and Halmahera seas in 2012/13 to observe the inflow paths from the Pacific Ocean into the eastern Indonesian seas.

The NOAA-OCO Makassar time series data is available in delayed mode at: http://www.ldeo.columbia.edu/res/div/ocp/ITF/cm_data/ The 2009-2011 data will be added in Spring 2012, when the processing reaches near final form.

Intended users of the resulting data and products are the ocean and climate modeler communities, as the ITF is indicative of larger scale ocean and climate system. Additionally, Makassar Strait has much oil activities. Knowledge of the currents in Makassar Strait enables safer operations and mitigation of possible oil spill. I have informed oil company personnel [at ConocoPhillips, Niko Resources (Limited, Marathon Oil, EXXON-Mobil] of the NOAA-ITF program and provided the time series [including the 2010-2011 segment].

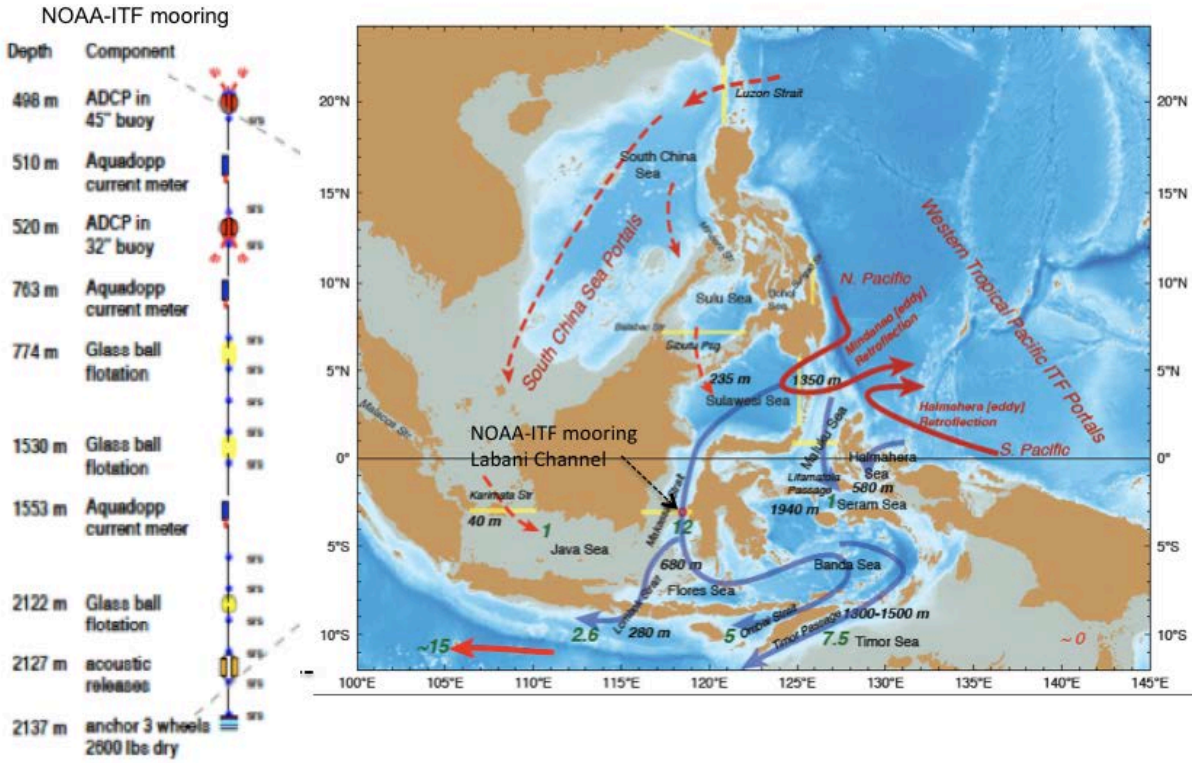

***Figure 1. Left Panel**: configuration of the NOAA-ITF mooring; **Right Panel**: Schematic of the Indonesian Throughflow circulation. The primary source for the ITF is the western tropical Pacific at ~ 4°N, but additional inflow is derived from the South China Sea, drawn from Luzon Strait. Topographic sill depths are given in black italics. The blue arrows depict the ITF. ITF transports in Sv (10^6 m3/s) are shown for each passage in green [from the INSTANT program, 2004-2006]. Makassar Strait Throughflow NOAA OCO mooring site is identified.*

2. Scientific and Observing System Accomplishments

a. Program Deliverables

The NOAA OCO supported time series within Makassar Strait, which carries 80-85% of the ITF, contributes to the following "observing system's program deliverables":

- Sea Surface Temperature and Surface Currents, to identify significant patterns of climate variability and change. *The ITF influences the SST of the eastern tropical Indian Ocean, Song and Gordon, 2004.*
- Ocean Heat Content and Transport, to better understand the extent to which the ocean sequesters heat; to identify where heat enters the ocean and where it emerges to interact with the atmosphere; and to identify changes in thermohaline circulation and monitor for indications of possible abrupt climate change. *The Indonesian Throughflow (ITF) affects the heat and freshwater inventories of the tropical Pacific Ocean and Indian Ocean, and associated climate phenomena (see sections b and c, below).*

- Air-Sea Exchanges of Heat, Momentum, and Fresh Water, to identify changes in forcing functions driving ocean conditions and atmospheric conditions; and to elucidate oceanic influences on the global water cycle. *The ITF affects SST. The increased, warmer, Makassar flow in 2008-2009 is expected to increase the SST in the eastern tropical Indian Ocean and increase sea to air flux of heat and freshwater, with a potential to energize the SE Asian monsoon.*

b. What did you achieve during FY2011?

The Makassar time series began with Arlindo in 1996-1998, and continued with INSTANT 2004-2006 and without a gap until recently with funding support from NOAA. The mooring was recovered on 1 August 2011, but was not redeployed because the mooring shipment did not arrive in Makassar in time. The time series in-hand is just fantastic [see subsections c and d], revealing unexpected variability of many aspects of the throughflow. The understanding of these fluctuations will advance our view of the forces that govern the ITF and of its impact on regional oceanography and marine ecosystems. Discontinuity of the time series will be a ‘blow to science’, and associated applications of the insight gained from the observations.

A January 2012 deployment will give us a data gap of 5 months, which is not damaging to the time series. I view deployment as late as April 2012 is not overly damaging. A larger gap extending into the maximum throughflow period of May-Sept 2012 period will require a 're-thinking' of the program, as discussed below, section e.

c. What Scientific advances were made and/or facilitated through your activities?

A summary of the science return of the NOAA funded ITF time series is best presented in the following text excerpted from a manuscript in preparation: "South China Sea Throughflow Impact on the Indonesian Throughflow" to be submitted Nature Geoscience (Authors: A. L. Gordon, B. Huber, E. J. Metzger, R. D. Susanto, H. Hurlburt, Rameyo Adi). Figures 3-4 cited in the text but are not shown in the text except for the caption, but are included in the attached PowerPoint file as slides 4 and 5, respectively.

The archipelago between Southeast Asia and Australia offers a maze through which tropical Pacific water spreads into the Indian Ocean, the Indonesian Throughflow (ITF), influencing ocean heat and freshwater inventories and large-scale SST patterns, which influence ENSO and the Asian monsoon. A 1996-1998, 2004-2011 observational time series of the Makassar Strait throughflow, the primary pathway for the ITF, indicates an ENSO role in governing the Pacific Ocean surface water contribution. Here we show that after 2006, particularly in 2008-2009 boreal summer, the Makassar throughflow profile dramatically changed, with the summer velocity maximum increased from 0.7 to 0.9 m/sec and shifting from 140 m to as shallow as 70 m. HYCOM simulation indicates that ENSO related changes in the South China Sea (SCS) throughflow, drawn from Luzon Strait, into the Indonesian seas is the cause of the observed changes. Increased SCS throughflow during El Niño with a commensurate increase in the southward flow of buoyant, low salinity surface layer water, from the Sulu Sea into the western Sulawesi Sea via Sibutu Passage, inhibits the injection of Pacific surface layer from the Mindanao Current into Makassar Strait, to a greater extent than does the shallower Karimata

Strait throughflow into the southern Makassar Strait. During La Niña the Sibutu Passage throughflow is reduced or reversed allowing increase Pacific surface layer inflow. Increased inflow of warmer tropical Pacific water into Makassar Strait during La Niña affects the ITF spread into the eastern Indian Ocean, impacting on the thermocline and SST, with possible impact on climate.

The only tropical connection between oceans is that afforded by the Indonesian seas allowing transfer of Pacific Ocean water into the Indian Ocean. The ITF is approximately 15 Sv (Sv = 10^6 m^3/sec). The complex arrangement of passages and sea of varied dimensions makes for a network of paths of Pacific water spreading towards the Indian Ocean (figure 1). The primary inflow path is North Pacific water flowing into Makassar Strait from where the Pacific water column spreads towards the export passages of the Sunda islands, altered en route by tidal induced mixing, Ekman pumping and sea-air buoyancy flux, into a unique Indonesian stratification, before export across the Indian Ocean near 12°S.

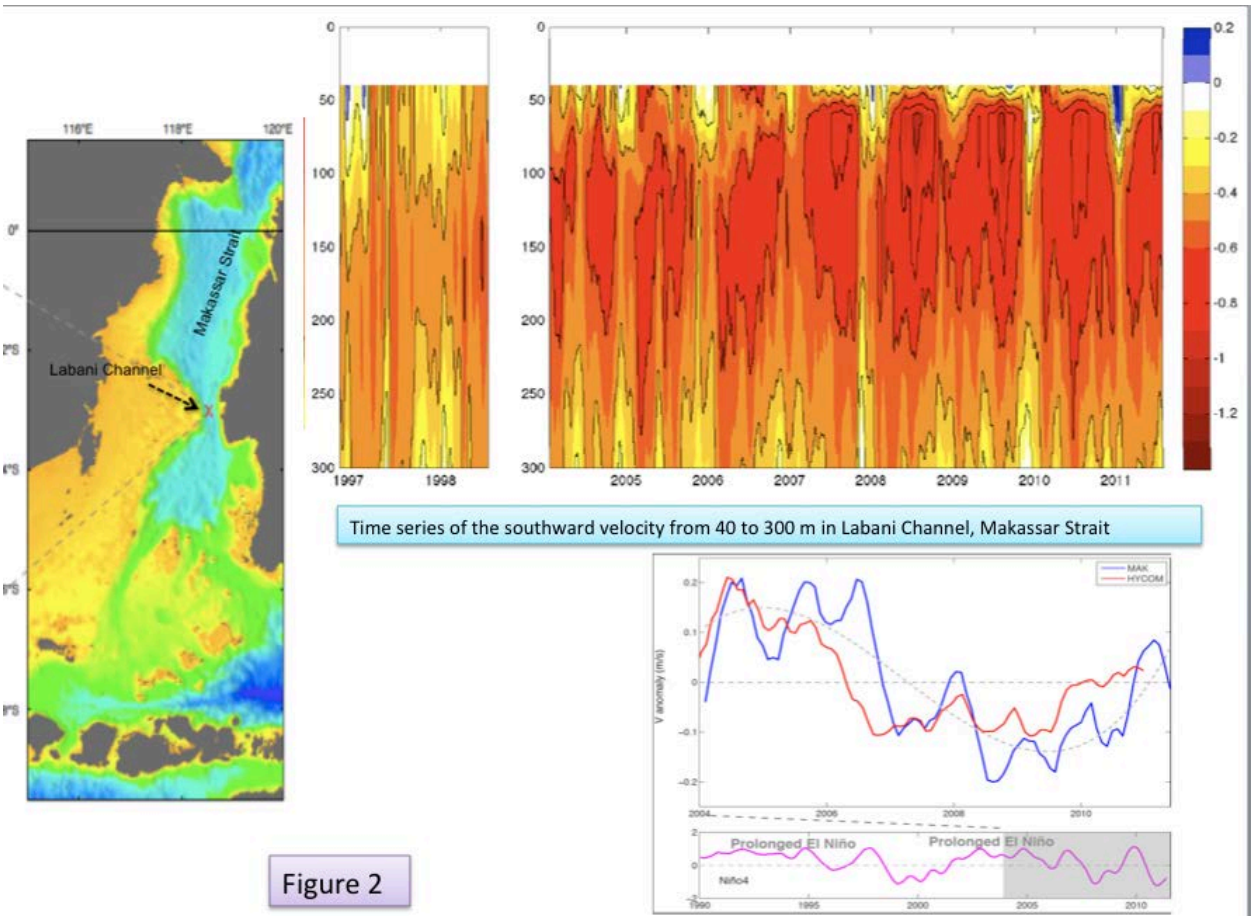

Figure 2. Upper right Panel*: Time series of along channel flow m/sec within Labani Channel of Makassar Strait derived from observations from Arlindo (1996-98), INSTANT (2004-07) and NOAA ITF (2007-2011) programs. Flow towards the south are negative values. The mooring location is depicted by the red dot on figure 1, and in upper left panel. The velocity maximum shoaled, with increasing maximum speed, through 2007, reaching peak in maximum speed in 2008/2009. The throughflow is weakest in boreal winter, strongest in boreal summer.*

***Lower Panel**: North-south monthly velocity anomaly at the mooring site at 60 m from the 2004-2011. Blue: Makassar ADCP moored time series; red: HYCOM output. 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 Makassar time series. 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.*

The Makassar Strait throughflow was measured at two sites within the Labani Channel, a 45 km wide constriction near 3°S, during the Arlindo program from late 1996 to mid-1998; at the same two sites by the INSTANT program from January 2004 to the end of November 2006 and at the western site during the NOAA ITF program from December 2006 through July 2011 (Fig. 2). The depth profile of the Pacific water flowing into Makassar Strait exhibits thermocline intensification, inducing a cooler transport-weighted temperature than surface intensified profile. 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.

As reported earlier the Makassar southward velocity (Fig. 2) reaches a maximum within the thermocline, tending towards greater speeds as the velocity maximum layer shallows. A distinct seasonal cycle is evident, reaching a maximum during the southeast monsoon (boreal summer), with minimum speeds in the northwest monsoon (boreal winter). During 2006, reaching a more dramatic change in 2008 and 2009, the southward speeds increase and shallowed significantly, from mid-thermocline depths of ~120-150 m to upper thermocline depths of 70-100 m. The Makassar Strait average temperature profile over the 1958-2007 Simple Ocean Data Assimilation (SODA) re-analysis period defines the thermocline layer in the 50-200 m interval with a mean vertical temperature gradient of 0.31°C/10 m. The mean temperature at 140 m is 20°C at one standard deviation of 1.5°C, at 70 m its 27°C at one standard deviation of 2.5°C; the 18°C isotherm heaves upward during El Niño, deeper during La Niña (167 m in the 1997 El Niño; 205 m in the 1999 La Niña). The shallowing of the velocity maximum from 140 m to 70 m observed in 2008 and 2009 draws warmer water into the ITF.

We hypothesis that the change in the Makassar through profile is a consequence of the greater westward transport within Luzon Strait and associated SCS throughflow via Sibutu Passage during El Niño relative to La Niña. The polynomial fit to the smoothed north-south monthly velocity anomaly in Labani Channel at 60 m (Fig. 2) from the 2004-2011 Makassar ADCP moored time series and from HYCOM output shows that the 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. We investigate the relationships among the SCS throughflow and the Makassar Strait throughflow with the 1/12° non-assimilative global HYCOM experiment 18.2 over the period 2003-2010.

FIGURE 3

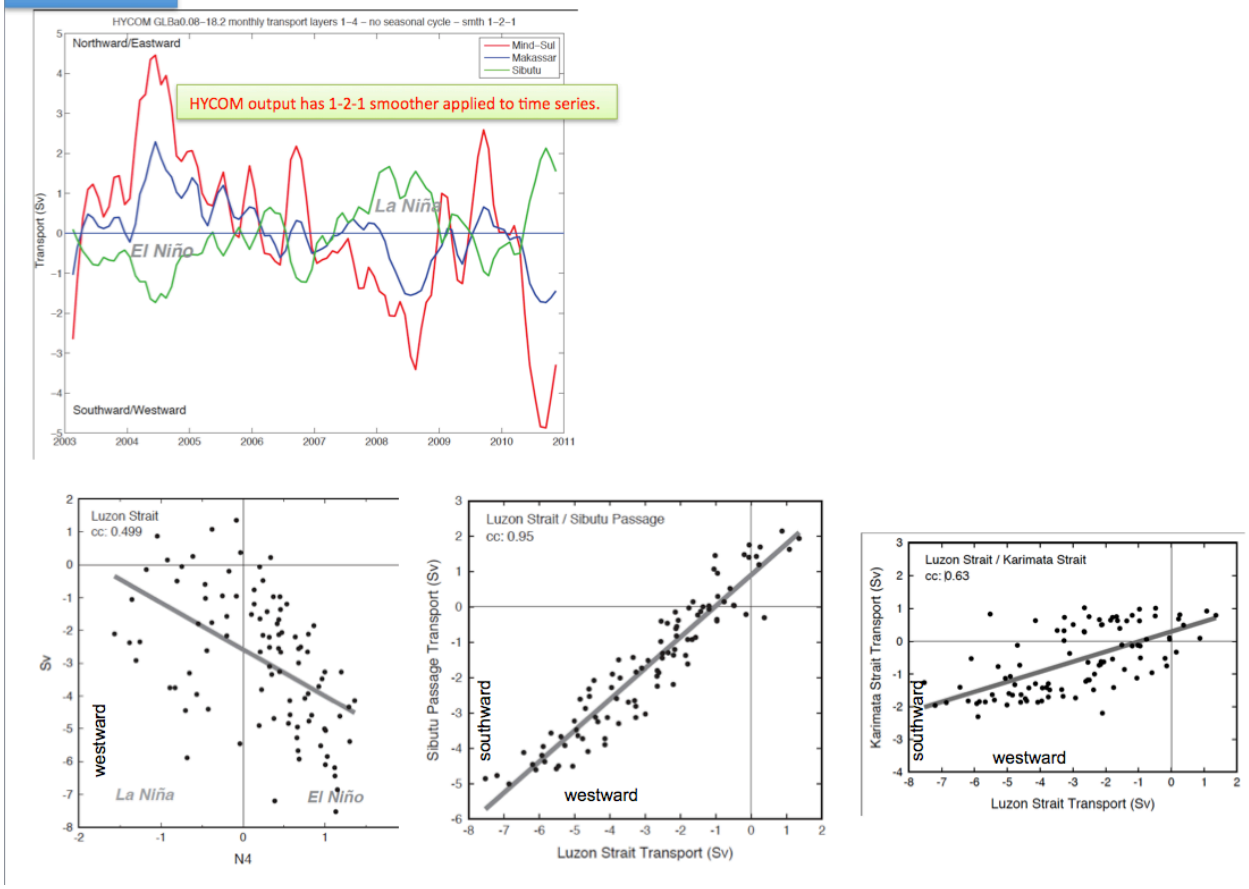

Figure 3. Upper Panel*: HYCOM monthly transport anomaly relative to 2003-2010 of the HYCOM layers 1-4, coinciding with the upper ~85-100 m of the Makassar Strait, Sibutu Passage, and the Mindanao-Sulu Sea input from the Western Pacific (see figure 1 for the positions of these sections). Values from HYCOM; seasonal cycles were removed. During El Niño the southward transport of South China Sea surface water within the Sibutu Passage increases, decreasing during La Niña. The Makassar Strait southward surface layer transport is reduced during El Niño, as is the westward surface layer transport between Mindanao and Sulawesi, with the opposite response during La Niña.* ***Lower left panel****: HYCOM full depth Luzon Strait transport scales to nino4. The westward throughflow within Luzon Strait, which feeds the South China Sea throughflow into the Indonesian seas, responds to ENSO: larger westward throughflow during El Niño.* ***Lower middle right panel****: HYCOM full depth Sibutu Passage southward transport is significantly correlated to the Luzon Strait throughflow, both out-of-phase with the Makassar Strait and Mindanao-Sulu transports.* ***Lower right panel****: HYCOM full depth Karimata Strait southward transport is increases with the Luzon Strait westward throughflow, but with lower correlation and much reduced transport than that of the Sibutu Passage. About 70-75% of the South China Sea throughflow is channeled into the Indonesian seas via Sibutu Passage.*

Model output indicates that the Luzon Strait throughflow varies with the ENSO cycles: stronger and cooler during El Niño. The Luzon Strait throughflow estimates range from near zero to over 6 Sv, averaging 4.5 Sv, with the HYCOM value used here of 2.9 Sv, warms and freshens within the SCS by an estimated 23 to 49 W/m^2 and 0.11 Sv (from P-E and river discharge), respectively, making it an important freshwater 'conveyor' of the Pacific' western marginal seas. The warmed, freshened SCS water is exported in approximately equal magnitude through Taiwan Strait and into the Indonesian seas (); the latter mainly along two paths: through Mindoro Strait, into the Sulu Sea, with an additional inflow of 1 Sv from the Pacific primarily through Surigao Strait into the Bohol Sea of the Philippines (HYCOM output; the Surigao Strait inflow is estimated from observations at 0.3 Sv), feeding southward flow in 234 m deep Sibutu Passage into the western Sulawesi Sea and northern Makassar Strait; with the 2nd smaller export through the 45-50 m deep Karimata Strait into the Java Sea, with a HYCOM output, 0.6 Sv.

HYCOM (Fig. 3) shows that the net flow through Luzon Strait is towards the west, into the SCS: larger westward (into SCS) during El Niño, reduced during La Niña. The Sibutu Passage throughflow matches the ENSO dependence of the Luzon Strait throughflow, while the Karimata transport, displays a weak relationship to ENSO, is mostly seasonal. The inflow of the Mindanao Current surface layer into the Sulawesi Sea (Fig. 3), exhibits an ENSO relationship but it is out-of-phase with the Sibutu Passage throughflow; the westward transport of the Mindanao Current surface layer greater during La Niña. Makassar Strait surface layer throughflow exhibits an ENSO relationship similar to Mindanao Current inflow, albeit at a lower correlation, as the out-of-phase Sibutu throughflow into Sulawesi compensates.

d. Significance of these advances?

We conclude (Fig. 4) that the SCS southward throughflow of low salinity surface layer during prolonged El Niño periods builds a pool of buoyant surface water in western Sulawesi Sea that inhibits the surface layer contribution from the western tropical Pacific water via the Mindanao Current, into Makassar Strait, the primary pathway for the ITF. The HYCOM results indicate that the Sibutu Passage transport does not fully compensate the reduced Mindanao input (Fig. 3), leading to reduced surface layer contribution to the Makassar throughflow during El Niño. During La Niña, the Sibutu Passage throughflow is near zero or northward, reducing the buoyant pool in the western Sulawesi Sea, permitting greater contribution of western tropical Pacific water into the Makassar throughflow.

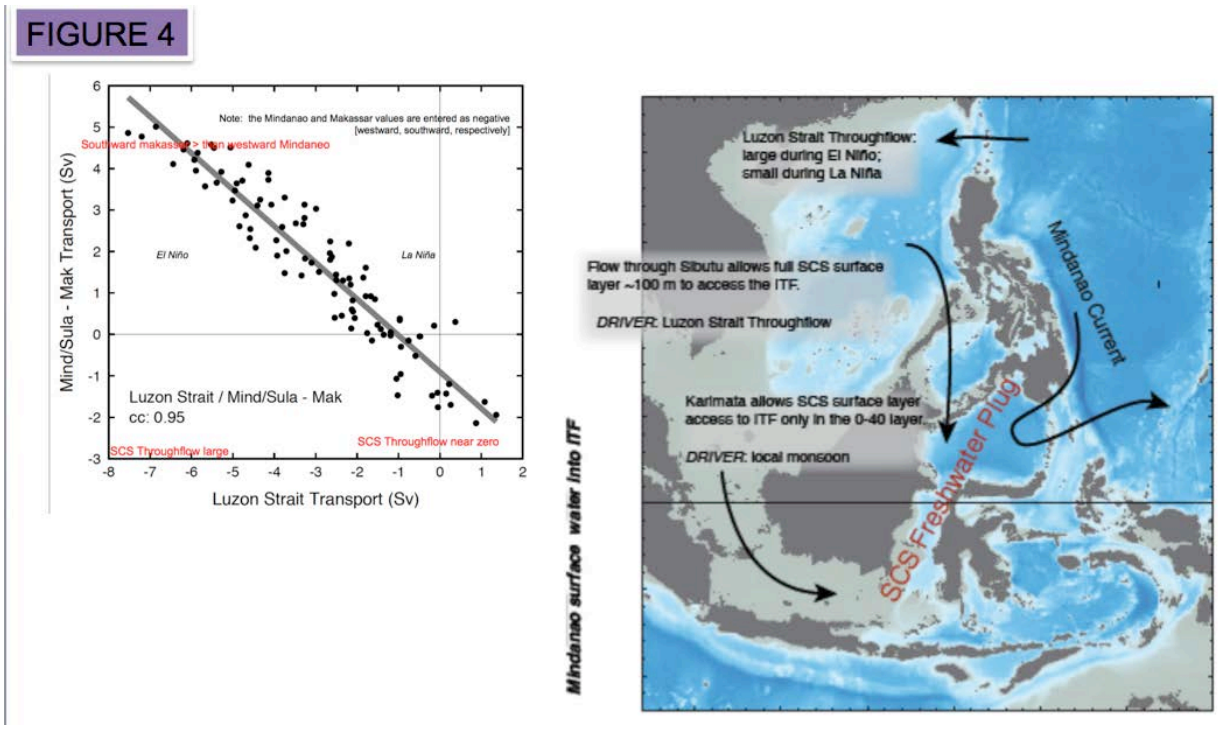

Figure 4. ***Left Panel****: The HYCOM results show that the Luzon Strait transport anomaly, which correlated highly with the southward Sibutu Passage transport as part of the SCS throughflow, is out of phase with the Mindanao contribution to the Makassar throughflow. Small or no Luzon Strait throughflow as occurs during El Niño leads to Mindanao equal to Makassar throughflow; large westward throughflow in Luzon Strait as in La Niña, suppresses the Mindanao contribution to the Makassar throughflow.* ***Right Panel****: 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 ~235 m Sibutu Passage allows the full 0-100 buoyant SCS surface layer to enter into the western Sulawesi Sea to inhibit Mindanao injection into the Makassar throughflow, the primary component of the ITF.*

In this manner the ENSO sensitive SCS throughflow, by builds a 'freshwater plug' in the western Sulawesi Sea during prolonged El Niño periods, results in a deeper, cooler velocity maximum within Makassar Strait; whereas during La Niña the 'freshwater plug' dissipates, leading to an increase, and shallowing into the warmer, upper thermocline layer, of the Makassar Strait throughflow velocity maximum. As the Makassar throughflow amounts to 80-85% of the total ITF, the SCS effect is a major contributor to the overall variability of ITF vertical structure. Increased, warmer ITF is expected to have an impact on the heat budget of the Indian Ocean, as well as on the residence time of the waters of the tropical Indian Ocean and thermocline and SST patterns. The ITF plume in 2 to 4 years spreads into central tropical Indian Ocean. The vertical profile of the ITF transport is important in regulating the stratification and surface heat fluxes of the Indian Ocean. A thermocline-intensified ITF, relative to a surface-intensified ITF, cools the surface layer of the Indian Ocean while warming the Indian Ocean below the thermocline. The observed shallowing of the ITF velocity maximum by way of the SCS throughflow effect, during La Niña, would move the ITF impact on the Indian Ocean closer to that of surface-intensified ITF, warming the eastern tropical Indian Ocean SST and associated links to the monsoon

climate, and therefore must be properly represented in ocean and climate models in vertical profile of ITF transport.

e. What, if any, information was jeopardized due to a lack of funding, lack of instrumentation, or inability to carry out the work?

The Makassar time series began with Arlindo in 1996-1998, and continued with INSTANT 2004-2006 and without a gap until recently with funding support from NOAA. The mooring was recovered on 1 August 2011, but was not redeployed because the mooring shipment did not arrive in Makassar in time. A January 2012 deployment was arranged by A.L. Gordon with Niko Resources Limited. Rameyo Adi, Balitbang KP, Indonesia, who oversees the NOAA Makassar time series program, e-mail 26 October 2011: "About the redeployment of the mooring in Makassar Strait, basically I strongly agree with your suggestion and we will contact BP Migas to ask the Oil Company (Niko Resources Co.) to help us on the redeployment BP Migas is the government agency under Pertamina, which manages all the cooperation with oil companies in Indonesia. We will inform you very soon once we have an audience with BP Migas." Unfortunately this did not work out.

A January 2012 deployment would have given us a data gap of 5 months, which is not damaging to the 7.5 year continuous time series. Another opportunity for Niko help in deployment is April 2012 *(I believe the a long term agreement with the oil industry to service the Makassar moorings would be an effective partnership to reduce the yearly costs of maintaining the time series).* Other deployment possibilities from the Indonesian research vessels are being investigating. I view deployment as late as 1 May 2012 is not overly damaging. A larger gap extending into the maximum throughflow period of May-Sept 2012 period would likely end the time series data collection, as the major interannual fluctuations are seen in these boreal summer months.

If the time series resumes before 1 May 2012 then we continue the program, though altering the methods of servicing the mooring. However, should the time series gap extend beyond 1 May 2012, I recommend: to maintain good relationships with the Indonesian marine science agencies and ocean community, so as to keep alive future possibility of collaborative efforts to monitor the ITF variability, and to capitalize on the existing time series:

- *Terminate the time series and move into a reduced budget mode to cover a two year ramp-down phase during which the present data are fully processed made available to the user community, results published; we complete capacity building tasks currently underway, which is primarily completion of the PhD program for Asmi Marin tan Napitu graduate; a third year of only Asmi Napitu fellowship may be needed for award of the PhD.*

- *Continue the effort to restart the time series at some time after 1 May 2012. The reorganization described in the following paragraphs offers some hope that we will be successful.*

Reorganization details:

> Adi message of 27 October 2011: "AMFRD has decided the new research policy and framework as follow:
> The Institute of Marine Research and Observation (IMRO) in Bali is under the Centre of Marine Technology Engineering & Assessment (MTEA) management since October 2011;
> IMRO will responsible for all oceanographic & marine dynamic (including sea-air interaction system) research activities, while my center, the Research and Development Centre of Marine & Coastal Resources (CMCR) will focus on marine resources research activities, including the blue carbon and resources management;
> MTEA/IMRO will coordinate the implementation of INAGOOS as well as the collaboration research projects, ITF, JUV and SITE; while CMCR and Capture Fishery Research Centre will continue to make their contribution as member scientists with focus on marine and fisheries resources development. The new contact persons for ITF collaboration research will be Dr. Aryo Hanggono (Director of MTEA), Mr. Berni Subky (Deputy Director), and Dr. Agus Setiawan (Head of IMRO)."
> "Following with the policy, AMFRD will send formal letter to LDEO to inform and to clarify about new policy and framework above, while CMCR will be requested to report the on going status, including all output and products for all cooperation works based on the agreement or arrangement respectively. Particularly for ITF project, there will be a new or amended arrangement/agreement required. MTEA/IMRO will arrange to develop the renewal arrangement."

This reorganization has not yet (as of 4 January 2012) occurred, but if it does happen we can negotiate resumption of the Makassar time series with the new oversight directors [with whom there is reason to be optimistic of a successful outcome].

f. For projects involved with data collection, please address the following five questions:

a. Are your data distributed in real time on the Global Telecommunications System? *no*
b. Where do your real time data reside? Are the data available online? *not available in real time*
c. Where do your delayed mode data reside? *At Lamont-Doherty Earth Observatory at http://www.ldeo.columbia.edu/res/div/ocp/ITF/cm_data/* Are the data available online? *Yes* What is the date of the most recent data available publicly? *February 2009*
d. Where are your data archived and with what frequency? *~12 months after data retrieval from the field, which is roughly every second year.*
e. What is the web site where the data for your program can be accessed? *http://www.ldeo.columbia.edu/res/div/ocp/ITF/cm_data/*
f. Have you successfully retrieved your program's data from the website or Data Assembly Center where your data reside, just to ensure the accessibility of the data? *Yes*

2.1. Outreach and Education

The NOAA funded program includes capacity building. This includes training of Indonesian researchers in the deployment of the mooring, and in data processing and analysis; as well as Indonesian researchers attending AGU Ocean Science meeting. In this way the NOAA-OCO funded ITF project is training the next generation of ocean and climate researchers in Indonesia.

The NOAA-OCO project also the support for Asmi Marintan Napitu from Balitbang KP, presently a graduate student under my supervision at Columbia University. She is now in her 2nd year at Columbia. Asmi's research objective is to use a satellite derived sea surface temperature (SST) data set to investigate the relationship of the spatial/temporal variability of the SST patterns in the Indonesian seas to larger scale climate fluctuations, e.g. ENSO, IOD; and to evaluate the role of Madden-Julian Oscillations in governing the SST patterns and sea-air heat flux within the Indonesian seas. A relationship of SST to the form of the ITF is expected.

3. Publications and Reports

3.1. Publications by Principal Investigators

Tillinger, D., A.L. Gordon (2010) “Transport Weighted Temperature and Internal Energy Transport of the Indonesian Throughflow” Dynamics of Atmosphere and Ocean: doi:10.1016/j.dynatmoce.2010.01.002 “Modeling and Observing the Indonesian Throughflow”, Guest Editors: A.L. Gordon and V.M. Kamenkovich, vol(50) 224-232.

Metzger, E.J., Hurlburt, H.E., Xu, X., Shriver, J.F., Gordon, A.L., Sprintall, J., Susanto, R.D., van Aken, H.M. (2010) “Simulated and Observed Circulation in the Indonesian Seas: 1/12° Global HYCOM and the INSTANT Observations.” “Modeling and Observing the Indonesian Throughflow”, Guest Editors: A. L. Gordon and V.M. Kamenkovich, Dynamics of Atmosphere and Oceans vol(50) 275-300

Gordon, A.L., Sprintall, J., Van Aken, H.M., Susanto, D., Wijffels, S., Molcard, R., Ffield, A., Pranowo, W., Wirasantosa, S. (2010) “The Indonesian Throughflow during 2004-2006 as observed by the INSTANT program.” “Modeling and Observing the Indonesian Throughflow”, Guest Editors: A. L. Gordon and V.M. Kamenkovich, Dynamics of Atmosphere and Oceans vol(50) 115-128

Conference:

Gordon, A.L. (2010) Is the Pacific warm pool too big to care about the Indonesian Throughflow? (Invited), session OS51E. Ocean Circulation Variability and Air-Sea Interactions in the Western Tropical Pacific II at the AGU Fall 2010 meeting, San Francisco, CA.

Gordon, A.L. (2011) The South China Sea portals are key to understanding the western tropical Pacific surface layer coupling to the ITF. Key Note presentation at the IOC/WestPac meeting in March 2011 in Busan Korea:

3.2. Other Relevant Publications

Pujiana, K., A. L. Gordon, E. J. Metzger, A, L. Ffield (in press) "The Makassar Strait Pycnocline Variability at 20-40 Days" Dynamics of Atmospheres and Oceans