Monitoring the Indonesian Throughflow in Makassar Strait

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1. Project Summary

The ocean is segmented into basins: Atlantic, Pacific, Indian, and marginal seas. The form and efficiency of inter-ocean exchanges between these basins govern the large-scale ocean characteristics, including sea surface temperature (SST) that projects onto the climate system, with impact on marine ecosystems. 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; fig 1, 2), influencing large-scale oceanic heat and freshwater inventories. The ITF responds to, and affects, the larger scale ocean and climate system, and so acts as a measure of that large, complex network. Makassar Strait carrying 80-85% of the ITF is a key, cost effective site to build the needed time series that essentially integrates the larger scale ocean and atmosphere.

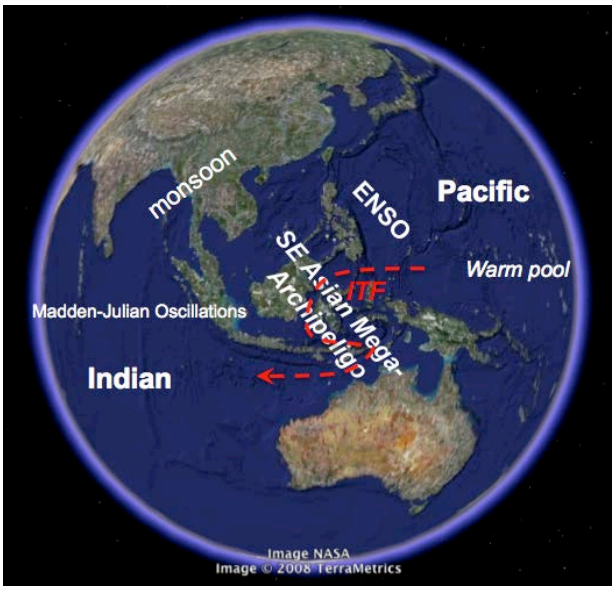

Figure 1. The 'mega'-archipelago between Southeast Asia and Australia, the only tropical interocean pathway, offering a maze through which warm Pacific water spreads into the Indian Ocean, the Indonesian Throughflow (ITF; figure 1), influencing large-scale oceanic heat and freshwater inventories. The ITF responds to, and affects, the larger scale ocean and climate system, and so acts as a measure of that large, complex network.

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 (fig 2), 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 (fig. 3). The NOAA OCO project is a cooperative program between the Lamont-Doherty Earth Observatory of Columbia University and the Agency for Marine & Fisheries Research, Ministry of Marine Affairs and Fisheries, Indonesia.

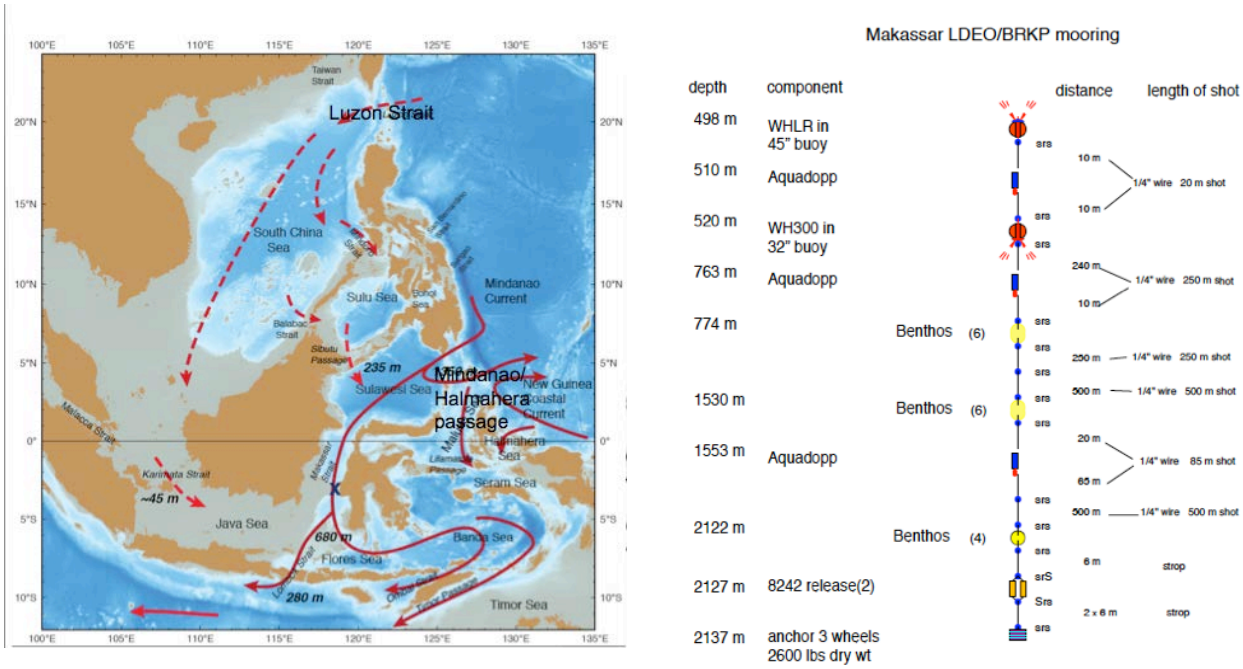

Figure 2. Left Panel: The Pacific Gateway to the Indonesian Seas and Indian Ocean is dominated by two portals: The Mindanao/Halmahera passage into the Sulawesi Seas, and the Luzon Strait that feeds the South China Sea throughflow that plays a surprisingly large role in governing the nature of the Indonesian Throughflow (ITF). Makassar Strait Throughflow mooring site (2004-2011) is identified by an X. Right panel: NOAA OCO Makassar mooring configuration.

In 2008-2009 the Makassar throughflow profile changed dramatically, particularly in 2008-2009 boreal summer (June-September): the characteristic thermocline velocity maximum increased from 0.7 to 0.9 m/sec and shifted from 140 m to 70 m, amounting to a 47% increase in the transport of warmer water between 50 and 150 m during the boreal summer. The resulting warmer ITF reaches into the Indian Ocean, potentially affecting regional sea surface temperature and climate [lag of 2-4 years]. The ENSO changes in the ITF are mainly in the upper 150 m and may be primarily reflecting the ENSO sensitive South China Sea throughflow (Gordon et al, 2012).

The NOAA funded Makassar mooring 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 to 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 2013 or 2014 to observe the inflow paths from the Pacific Ocean into the eastern Indonesian seas.

The NOAA-OCO Makassar time series data through August 2011 is available in delayed mode at:
http://www.ldeo.columbia.edu/res/div/ocp/projects/MITF/

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].

2. Scientific and Observing System Accomplishments

a. Program Deliverables

The ITF responds to, and affects, the larger scale ocean and climate system, and so acts as a measure of that large, complex network. Makassar Strait carrying 80-85% of the ITF is a key, cost effective site to build the needed time series that essentially integrates the larger scale ocean and atmosphere.

• 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.*
• 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.*
• 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 FY2012?

The mooring was recovered on 1 August 2011, but was not redeployed because the mooring shipment did not arrive in Makassar port in time. A re-deployment plan is underway, as discussed at the 8th Annual Indonesia – U.S. Ocean and Climate Observations, Analysis and Applications Partnership Meeting in Bogor, 21-23 October 2012.

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

In 2008-2009 the Makassar throughflow profile changed dramatically (fig. 3), particularly in 2008-2009 boreal summer (June-September): the characteristic thermocline velocity maximum increased from 0.7 to 0.9 m/sec and shifted from 140 m to 70 m, amounting to a 47% increase in the transport of warmer water between 50 and 150 m during the boreal summer. The resulting warmer ITF reaches into the Indian Ocean, potentially affecting regional sea surface temperature and climate [lag of 2-4 years]. The ENSO changes in the ITF are mainly in the upper 150 m and may be primarily reflecting the ENSO sensitive South China Sea throughflow (Gordon et al, 2012).

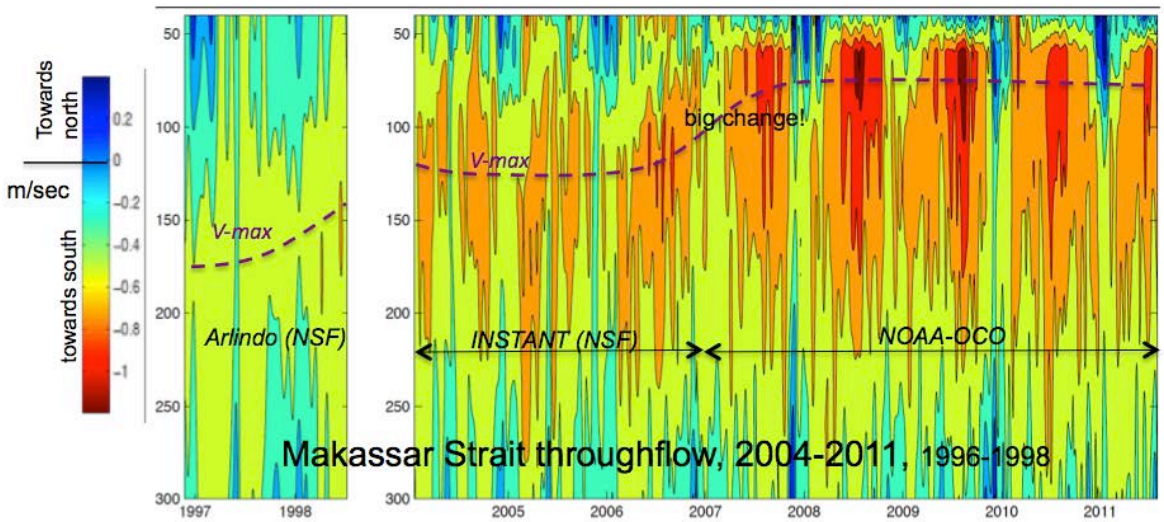

Figure 3. The Makassar Strait throughflow displays a thermocline V-max, with seasonal intraseasonal imprints. The along channel flow reveals marked changes in profile associated with ENSO: the 1997-98 period was the "El Niño of the century"; 2004-2006 was marked by prolonged, albeit weak, El Niño, while 2007-2011 exhibited more frequent La Niña periods. The ENSO alters the ITF mainly in the upper 150 m and is the consequence of the ENSO sensitive South China Sea throughflow (Gordon et al, 2012).

The understanding of the ENSO governed fluctuations of the ITF profile; mass and heat/freshwater transport will advance our view of the forces that couple the ITF regional ocean and climate systems, as well as marine ecosystems.

d. Significance of these advances?

Gordon et al, 2012 conclude 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 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 surface layer water into the ITF (fig. 4).

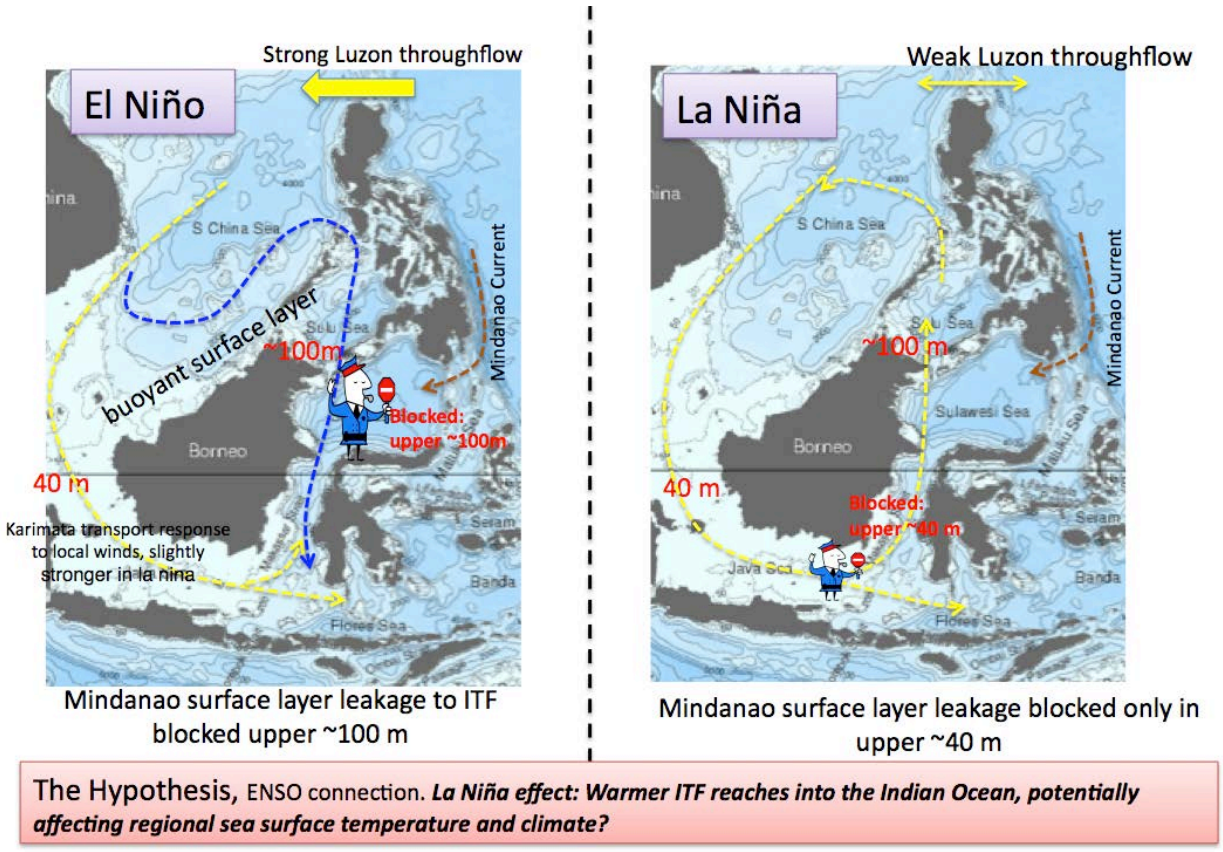

Figure 4. The Hypothesis of the ENSO control of the ITF (Gordon et al. 2012). Luzon Strait transport anomaly, which correlated highly with the southward Sibutu Passage transport as part of the SCS throughflow, is out of phase with the Mindanao contribution to the Makassar throughflow. Small or no Luzon Strait throughflow as occurs during La Niña leads to Mindanao equal to Makassar throughflow; large westward throughflow in Luzon Strait as in El Niño, suppresses the Mindanao contribution to the Makassar throughflow. 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 building 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 shoaling 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 shoaling 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 mooring was recovered on 1 August 2011, but was not redeployed because the mooring shipment did not arrive in Makassar port in time. Many options were discussed for the re-deployment. A promising plan is now underway, as discussed at the 8th Annual Indonesia – U.S. Ocean and Climate Observations, Analysis and Applications Partnership Meeting Bogor, 21-23 October 2012 for the deployment in the 2012/13 period.

f. web site: http://www.ldeo.columbia.edu/res/div/ocp/projects/MITF/

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/projects/MITF/
d. Are the data available online? *Yes* What is the date of the most recent data available publicly? *August 2011*
e. Where are your data archived and with what frequency? *~12 months after data retrieval from the field, which is roughly every second year. Data are archived at Lamont.*
f. What is the web site where the data for your program can be accessed? http://www.ldeo.columbia.edu/res/div/ocp/projects/MITF/
g. 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*
h. Do you have a data management plan for the data collected as part of your project? If so, list the url where the data management plan can be found. *Yes – available for download at the project web site http://www.ldeo.columbia.edu/res/div/ocp/projects/MITF/*

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 provides support for Asmi Marintan Napitu from Balitbang KP, presently a graduate student under my supervision at Columbia University. She is now in her 3rd year at Columbia. Asmi's research uses satellite derived sea surface temperature (SST) data set to investigate the intraseasonal spatial/temporal variability of the SST patterns within the Indonesian seas, and to evaluate the role of Madden-Julian Oscillations in governing the SST patterns and sea-air heat flux within the Indonesian seas. Asmi presented her research "Mechanism Controlling Intraseasonal Sea Surface Temperature Across Indonesian Seas" at the 8th Annual Indonesia – U.S. Ocean and Climate Observations, Analysis and Applications Partnership Meeting Bogor, 21-23 October 2012.

3. Publications and Reports

3.1. Publications by Principal Investigators

published:

Gordon, A.L., Huber, B.A., Metzger, E.J., Susanto, R.D., Hurlburt, H.E., Adi, T.R. (2012) South China Sea Throughflow Impact on the Indonesian Throughflow" Geophysical Research Letters: doi:10.1029/2012GL052021 vol (39) L11602

Susanto, R.D., Ffield, A., Gordon, A.L., Adi, T.R.(2012) "Variability of Indonesian Throughflow within Makassar Strait: 2004 – 2009" Journal of Geophysical Research Oceans: doi:10.1029/2012JC008096 vol(117) C09013

Pujiana, K., Gordon, A.L., Metzger, E.J., Ffield, A.L. (2012) "The Makassar Strait Pycnocline Variability at 20-40 Days" Dynamics of Atmospheres and Oceans vol(53-54) 17- 35

in press:

Cazenave, A., Henry, O., Munier, S., Delcroiz, T., Gordon, A.L. Meyssignac, B., Llovel, W., Palanisamy, H., Becker, M. (2012) "Estimating ENSO influence on the global mean sea level over 1993-2010" Marine Geodesy (in press)

in revision:

Pujiana, K., A. L. Gordon, J. Sprintall Intraseasonal Kelvin Wave in Makassar Strait JGR-ocean]

Abstracts:

Gordon, A. L. March 2012 ITF review; Pacific inflow into the Indonesian Seas at the CLIVAR ITF Task Team, Ancol, Indonesia.

Gordon, A. L. June 2012 "Oceanography of the Indonesian Seas" at the Seminar on the Science of the Halmahera Sea, Jakarta, Indonesia