Monitoring the Indonesian Throughflow in Makassar Strait

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1. Project Summary

The archipelago between Southeast Asia and Australia, the only tropical interocean pathway, offers a maze through which warm Pacific water spreads into the Indian Ocean, the Indonesian Throughflow (ITF), influencing large-scale oceanic heat and freshwater inventories. As the ITF region is at the nexus of ENSO (El Niño/La Niña Southern Oscillation) 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, but not re-deployed due to logistical complications. The mooring was deployed on 5 August 2013, after a two-year gap in the time series.

The time series of the Makassar Strait throughflow, which carries ~80% of the total ITF and ~90% of the ITF within the thermocline, has revealed some startling changes in the ITF, which may have large scale significance to the ocean and climate system, with possible improvement in long term (interannual) predictions.

In 2008/09 the profile of the Makassar Strait throughflow changed dramatically (Gordon et al. 2012): the characteristic thermocline velocity maximum increased from 0.7 to 0.9 m/sec and shifted from 140 m to 70 m, advecting much warmer water into the Indian Ocean. ENSO induced change of the South China Sea (SCS) throughflow drawn from the Luzon Strait is the

likely cause. Increased westward Luzon Strait throughflow during El Niño forced buoyant SCS surface water into the northern Makassar Strait, inhibiting tropical Pacific surface water injection from the Mindanao Retroflection; during La Niña SCS throughflow is reduced to near zero, allowing increased surface water leakage from the Mindanao Retroflection. We find that commensurate with the change in the ITF profile, there is a change in the development of the Kuroshio off the east coast of Luzon. During La Niña there is greater injection of tropical Pacific water from the North Equatorial Current Bifurcation into the Kuroshio. As the Luzon Strait westward La Niña throughflow is reduced to near zero, it is free to fully project into the Kuroshio recirculation cell of the western subtropical North Pacific. During El Niño the Kuroshio recirculation cell is 'isolated' from the North Equatorial Current Bifurcation. During El Niño the increased western throughflow in Luzon Strait drains the Kuroshio recirculation gyre waters, thus exporting the accumulated tropical water input during the previous La Niña phase.

Besides the impact on the Pacific Ocean the Indian Ocean also is affected, with La Niña warmer and stronger ITF leads to warmer sea surface temperatures in the eastern tropical Indian Ocean within 2 years. This is an ‘ocean-bridge’ linking the Indian Ocean to ENSO. Warmer SST within the eastern tropical Indian Ocean can affect the strength of the Asian Monsoon and induce a negative Indian Ocean Dipole. It has been found (Wilson et al. 2013) that negative IOD can project via stronger Madden-Julian Oscillation (MJO) eastward over the Indonesian maritime continent towards the Pacific, an ‘atmosphere bridge’ of Indian to pacific climate events. Might such MJO events then trigger an El Niño, about 4 years after the La Niña induced warmer ITF?

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.

2. Scientific and Observing System Accomplishments

Report on your accomplishments and on each deliverable specified in your prior year’s Work Plan. Please address the following questions:

a. *How did your project deliverables serve the observing system’s program deliverables:* The Makassar Strait throughflow time series, as discussed above, alters the ‘Ocean Heat Content and Transport’. The La Niña effect on the ITF is to increase the transport of upper, warm, thermocline water from the Pacific into the Indian Ocean. The resultant warmer thermocline of the eastern Indian Ocean can be expected to warm the SST, mainly in the upwelling regime along the south coast of Sumatra and Java. Indeed, SST patterns of the eastern Indian Ocean support this speculation (paper in prep), warmer SST can be expected to affect the atmosphere. Therefore the Makassar time series is relevant to identifying where ocean ‘emerges to interact with the atmosphere’. Through anticipated improved ENSO prediction it contributes to NOAA’s Climate Goal societal challenge specifically to ‘Prepare for drought and water resource challenges.’

b. *What did you achieve during FY 2013?* I am most pleased that the Makassar ‘Inagoos’ mooring has been re-deployed in early August, about 2 years after the last recovery. I consider the information gained from the Makassar time series as highly indicative of the complex linkage of the varied components of the Pacific/Indian Ocean (inter-ocean exchange) & Climate

(ENSO, Asian Monsoon) Systems, and of central importance to understanding the ocean and marine ecosystems of the Indonesian seas. I am very thankful to Ngurah N. Wiadnyana and Pak Aryo of Agency for Marine and Fisheries Research and Development for their support of the Makassar time series. The deployment could not have been achieved without the effort of Kandaga Pujiana (recent PhD from Columbia, research: intraseasonal variability in the Indonesia Throughflow; post doc for 1 year, august 2012 to August 2013, on NOAA grant) and Asmi Napitu (graduate student at Columbia, as part of the capacity building effort)

c. What scientific advances were made and/or facilitated through your activities? (For multi-institution proposals, provide your top 2 or 3 advances.):

ENSO related changes in the ITF and the larger regional scale impact (Figure 1): In 2008/09 the profile of the Makassar Strait throughflow, ~80% of the total ITF, changed dramatically: the characteristic thermocline velocity maximum increased from 0.7 to 0.9 m/sec and shifted from 140 m to 70 m, advecting much warmer water into the Indian Ocean. ENSO induced change of the South China Sea (SCS) throughflow drawn from the Luzon Strait is the likely cause. Increased westward Luzon Strait throughflow during El Niño forced buoyant SCS surface water into the northern Makassar Strait, inhibiting tropical Pacific surface water injection from the Mindanao Retroflection; during La Niña SCS throughflow is reduced to near zero, allowing increased surface water leakage from the Mindanao Retroflection. We find that commensurate with the change in the ITF profile, there is a change in the development of the Kuroshio off the east coast of Luzon. During La Niña there is greater injection of tropical Pacific water from the North Equatorial Current Bifurcation into the Kuroshio, which as the Luzon Strait westward La Niña throughflow is reduced to near zero, is free to fully project into the Kuroshio recirculation cell of the western subtropical North Pacific. During El Niño the Kuroshio recirculation cell is 'isolated' from the North Equatorial Current Bifurcation. During El Niño the increased western throughflow in Luzon Strait drains the Kuroshio recirculation gyre waters, thus exporting the accumulated tropical water input during the previous La Niña phase.

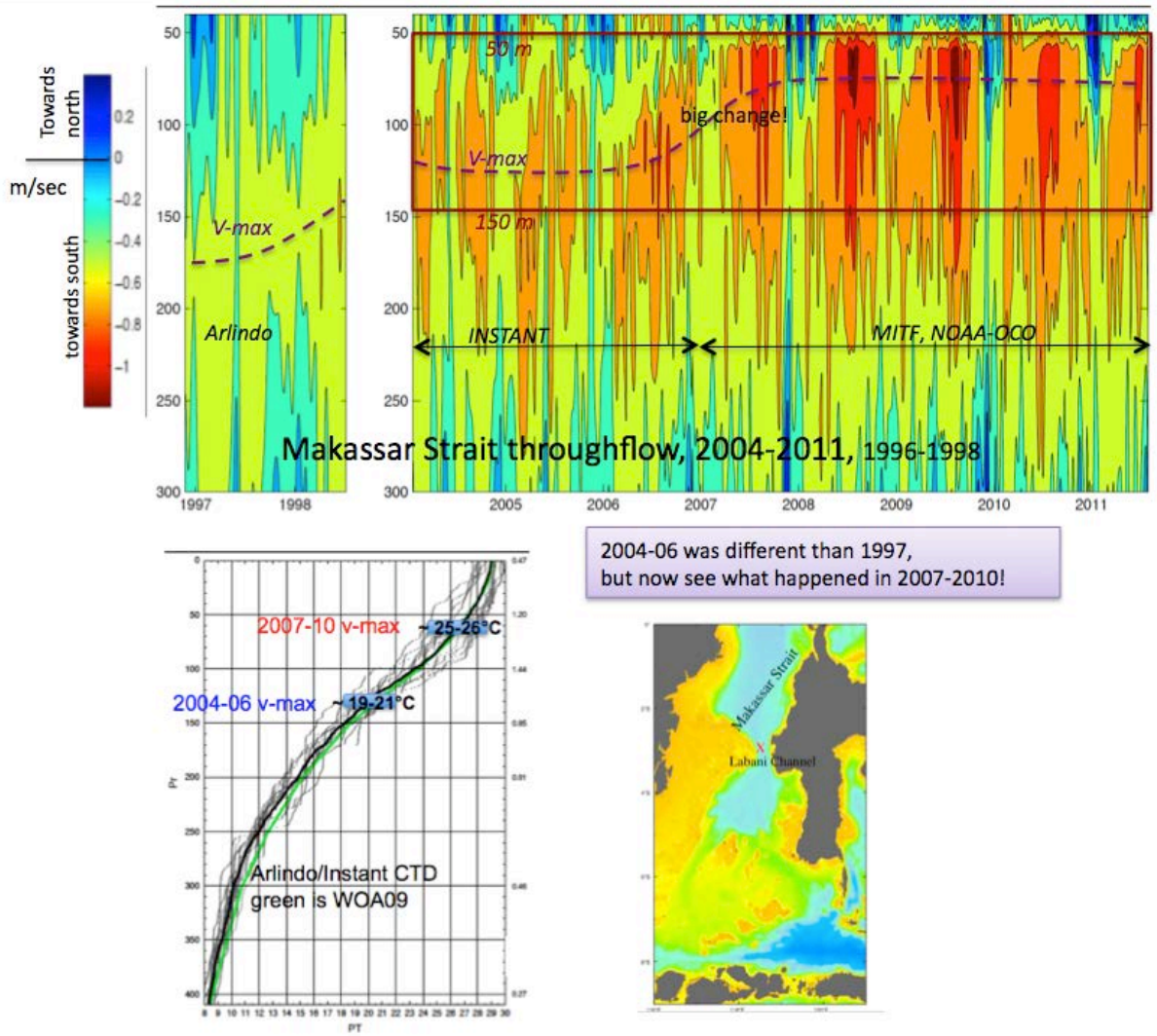

Figure 1 from Gordon et al, 2012: Makassar Strait throughflow 1997-1998; 2004-2011 § In 2008/09 the Makassar Strait throughflow thermocline velocity maximum increased from 0.7 to 0.9 m/sec and shoaled from 140 m to 70 m, advecting much warmer water (transport weighted temperature ~17°C).

With Indonesian graduate student Asmi Napitu: The Sea Surface Temperature (SST) variability at intraseasonal timescales (20-90 days) within the Indonesian seas is mainly governed by air-sea heat fluxes attributed to the Madden-Julian Oscillations, horizontal advection associated with the Indonesian Throughflow (ITF) and entrainment mixing controlled by Ekman pumping. In this study, we assess the unique SST responses to two major MJO events occurring during the fall and spring months of 2007-2008 (MJO case-1) and 2011-2012 (MJO case-2) by examining in-situ, satellite derived, and reanalysis data. We propose that SST responses in internal Indonesian seas to MJO-1 differed from MJO-2: air-sea heat fluxes were predominant during the case-1 period, while competing surface fluxes and entrainment mixing characterized the case-2 episode. During the case-1 period, the SST fluctuation followed the net surface heat flux variability, which was primarily a function of latent heat flux and shortwave radiation. Although increased

wind stress was observed throughout case-1 period, the latent heat flux was more influenced by the difference between air-sea specific humidity. Warmer ITF transport advected into the Indonesian seas, corresponding to a strong La Nina phase during case-1 caused deeper thermocline, isolating the mixed layer heat content to be solely influenced by surface heat fluxes. As to the case-2 period, the correspondence between SST and surface net heat flux was less obvious as eastward propagating feature was less evident in SST. This is so because Ekman pumping forced by sheared zonal wind stress played a larger role in modulating SST as reflected by the increased degree of correlation between the rate of SST cooling with vertical velocity associated with the pumping. Nevertheless there was a consistent feature observed from both cases: a strong (weak) MJO episode resulting in net SST cooling (warming) is succeeded by a weak (strong) MJO event causing net SST warming (cooling) observed in the Indonesian seas.

d. *What is the significance of these advances?* The ENSO induced changes to the ITF has major impact on the Indian Ocean (Figure 2): with La Niña, warmer and stronger ITF leads to warmer sea surface temperatures in the eastern tropical Indian Ocean within 2 years, which can affect the strength of the Asian Monsoon and induce a negative Indian Ocean Dipole that can project via Madden-Julian Oscillation eastward over the Indonesian maritime continent to the Pacific, triggering an El Niño. The estimated time scale of the La Niña induced change of the ITF and Indian Ocean triggering of an El Niño is ~ 4 years. Another even more remote consequence of the La Niña induced increase of the ITF is ultimately the increase of the Agulhas Current and its leakage into the Atlantic with consequences to the Atlantic Meridional Overturning Circulation (AMOC).

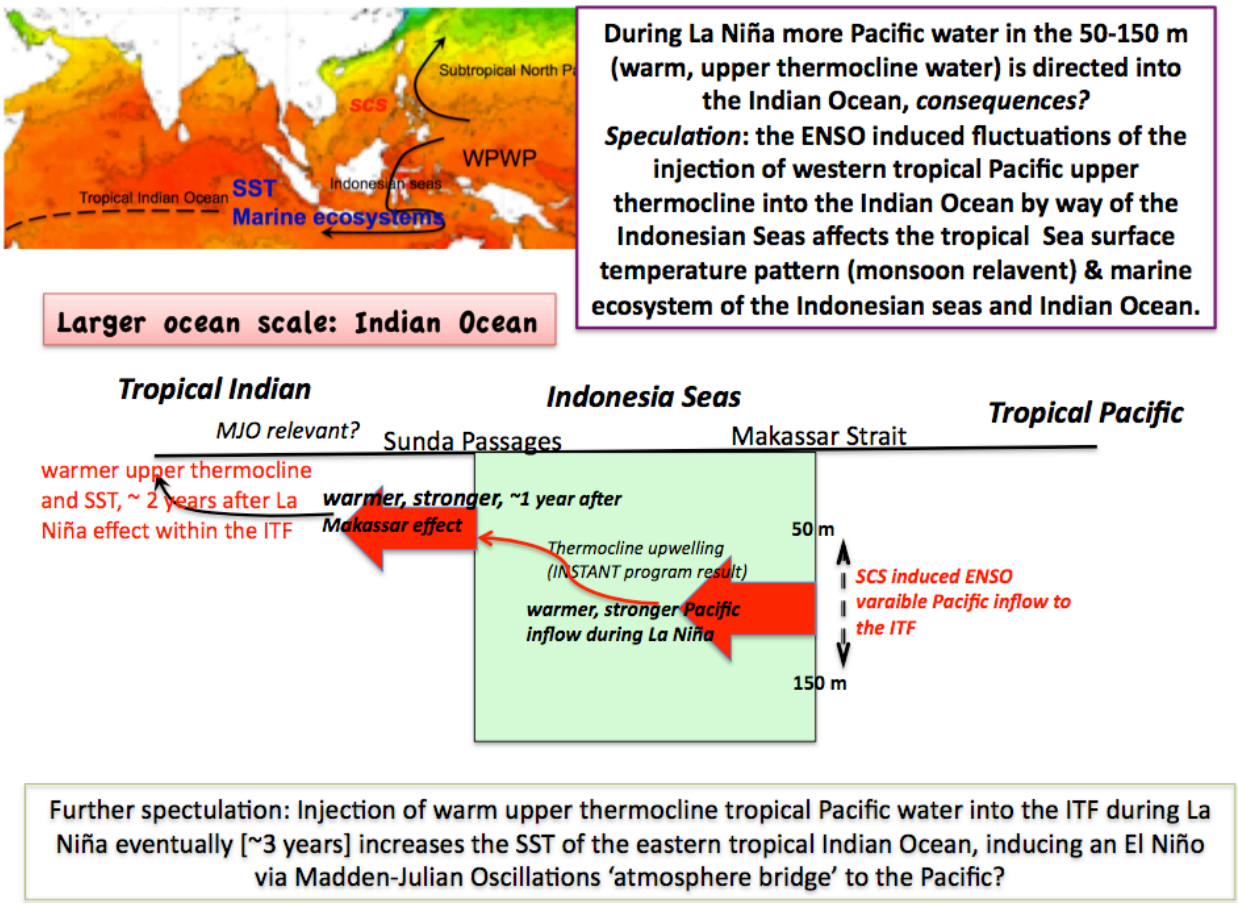

Figure 2. During La Niña more Pacific water in the 50-150 m (warm, upper thermocline water) is directed into the Indian Ocean. It is expected that ~2 to 3 years later the eastern tropical Indian Ocean sea surface temperature will warm. This may be relevant to the monsoon characteristics & marine ecosystem of the Indonesian seas and Indian Ocean.

e. What, if any, information was jeopardized due to a lack of funding, lack of instrumentation, or inability to carry out the work? Primary issue is arranging implementation of the program within Indonesia. Funds are needed for capacity building and perhaps for ship time. It is recommenced that NOAA negotiate a uniform arrangement to cover its ocean sustained time series within Indonesian waters and vicinity, including the Makassar mooring and RAMA.

What is the web site for your program?
http://www.ldeo.columbia.edu/res/div/ocp/noaa_cod/

<u>For projects involved with data collection, please address the following questions:</u>

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? Are the data available online? What is the date of the most recent data available publicly?
Delayed mode data are received and processed at Lamont-Doherty Earth Observatory. The data are available on line through the most recently acquired data (July 2011).

d. Where are your data archived and with what frequency? *Processed data are archived approximately 12 months after the date of collection. Presently, the archive is at Lamont-Doherty Earth Observatory, utilizing the network's mass storage archival system. Data are backed up at every stage of acquisition and processing on a weekly basis. We are currently engaged in obtaining an OceanSITES moored platform ID so the data can be archived with the OceanSITES system.*

e. What is the web site where the data for your program can be accessed? If you haven't updated your web site recently, please do so now. *The data are currently available at http://www.ldeo.columbia.edu/res/div/ocp/noaa_cod/ . This is a web portal for access to all of the NOAA COD funded moored data collected by the PI's. The web site is updated every 6 months, last update 18 October.*

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? If not, please do this now and address any problems with data access. *Data access has been successfully tested as of 18 October.*

g. 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. *Our data management plan can be downloaded from the data portal web site by following the link there to "Makassar Strait Throughflow":* http://www.ldeo.columbia.edu/res/div/ocp/noaa_cod/

3. Outreach and Education

Asmi Napitu, (from Indonesia, an employee of Agency for Marine and Fisheries Research and Development, KKP) is enrolled in the graduate program of the Department of Earth and Environmental Sciences at Columbia University, under the direction of Prof Arnold L. Gordon. It is expected that she will achieve the PhD in the spring or summer of 2015. Her PhD thesis deals with the interaction of Madden-Julian Oscillations (MJO) with the Indonesian seas. A primary objective is to determine the conditions within the Indonesian seas that affect the strength of MJO events passing over Indonesia en route to the western tropical Pacific Ocean.

Kandaga Pujiana, was a graduate student under my supervision from 2005 to 2012. He received his PhD in August 2012, with the NSF INSTANT support. NOAA paid for his Lamont post doc from August 2012 thru August 2013, before he moved to a post doc position at Oregon State University (OSU) with Jim Moun (studying Madden-Julian Oscillations in the Indian Ocean) directly after participating in the July/August 2013 Makassar mooring deployment. He has a faculty position at ITB in Indonesia, where he plans to move to in ~ 1 year. He is setting up a CLIVAR meeting on the ITF at ITB in January 2014. Kandaga's PhD involves study of Intraseasonal fluctuations in the Makassar Strait throughflow. He published 3 papers on the subject in peer review journals. He represents a major contribution to capacity building within Indonesia.

During the NOAA ITF funded 1-year post doc for Kandaga Pujiana, he was trained for

mooring deployment. He served as chief scientist on the July/August 2013 Makassar deployment cruise, and in the proceeding two months, supervised the preparation of the mooring equipment for deployment. He shared his knowledge with fellow researchers at KKP and BPPT. Asmi also participated on the July/August 2013 deployment cruise, dealing mainly with handling administrative items between KKP and Lamont-Doherty. Because of Kandaga's science knowledge and his field experience, he would make an excellent partner at ITB for future ITF programs. Asmi Napitu is expected to play an increasing role in the administration of the programs at KKP.

As part of the Makassar mooring deployment in summer 2013, I agreed to support three researchers/students (other than Napitu or Kandaga) from KKP to attend the AGU Ocean Science meeting in Honolulu, with one of the three spending ~1 month at Lamont before or after the AGU meeting, which may prove particularly beneficial in developing joint publications on the Indonesian Throughflow

Participating on Makassar mooring cruises: On all of the prior Makassar mooring deployments, including the August 2013 deployment cruise, the US program covered the travel and sea pay of KKP personnel to participate on the cruise. Bruce Huber trained them in mooring recovery/deployment. The at-sea training of Indonesian researcher has been a significant capacity building accomplishment. The August 2013 deployment of the Makassar mooring involved no non-Indonesian citizens. With no non-Indonesian citizens participating in the mooring recovery/data downloading/deployment cruises, there was far more flexible scheduling of at-sea operations, as lengthy clearance actions were not needed.

Outreach by workshop and lectures:
§ Hosted a special Indonesian Throughflow session at the Indian Ocean and Pacific Conference in Bali, Indonesia on 21 June 2013.
§ On 20 June 2013 I presented a lecture on the oceanography of the Indonesian seas to students at the Faculty of Marine and Fishery Science, Udayana University, Bali.

4. Publications and Reports

4.1. Publications by Principal Investigators

- Published:

Wilson, E. Gordon, A.L., Kim, D., (2013) “Observations of the Madden Julian Oscillation during Indian Ocean Dipole Events” Journal of Geophysical Research – Atmospheres: doi:10.1002/jgrd.50241 vol(118).

Pujiana, K., Gordon, A.L., Sprintall, J. (2013) “Intraseasonal Kelvin wave in Makassar Strait” Journal of Geophysical Research Oceans: doi:10.1002/jgrc.20069 vol(118), 2023-2034.

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.

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.

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 35(sup1): 82-97. DOI:10.1080/01490419.2012.718209

- In press: none
- Proceedings from conferences (if peer-reviewed) none
- Technical reports: none
- Data reports: none

4.2. Other Relevant Publications

Xu D. and P. Malanotto-Rizzoli (2013) The seasonal variation of the upper layers of the South China Sea (SCS) circulation and the Indonesian through flow (ITF): An ocean model study. Dynamics of Atmospheres and Oceans Volume 63, September 2013, Pages 103–130