WCRP REPORT

World Climate Research Programme

Project Report

Report of the CLIVAR ITF Task Team Meeting

Jakarta, Indonesia
12th – 14th March 2012

March 2013

WCRP Informal/Series Report No. 20/2013
ICPO Informal Report 193/13

CLIVAR is a component of the World Climate Research Programme (WCRP). WCRP is sponsored by the World Meterorological Organisation, the International Council for Science and the Intergovernmental Oceanographic Commission of UNESCO. The scientific planning and development of CLIVAR is under the guidance of the JSC Scientific Steering Group for CLIVAR assisted by the CLIVAR International Project Office. The Joint Scientific Committee (JSC) is the main body of WMO-ICSU-IOC formulating overall WCRP scientific concepts.

Bibliographic Citation
INTERNATIONAL CLIVAR PROJECT OFFICE, 2013:
IFT Task Team. International CLIVAR
Publication Series No 193. (not peer reviewed).

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1. Introduction

The Indonesian Throughflow (ITF) is the leakage of water from the western Pacific into the eastern tropical Indian Ocean through the Indonesian archipelago, driven by the pressure head built up in the western Pacific by the easterly trade winds. As such, the ITF provides the only major low-latitude oceanic pathway for the transfer of climate signals and their anomalies in the global thermohaline circulation. The volume, heat, and freshwater carried by the ITF are known to impact the state of the Pacific and Indian Oceans and air-sea exchange (e.g., Godfrey 1996, Lee et al. 2002, Vranes et al. 2002, Potemra and Schneider 2007a), which can modulate climate variability on a variety of time scales (e.g., Schneider 1998, Song et al. 2007) such as the Asian-Australian monsoon systems, the El Niño-Southern Oscillation (ENSO), and the Indian Ocean Dipole (IOD).

The primary source of the surface to thermocline waters in the ITF is from the North Pacific, while the lower thermocline and intermediate water masses are drawn from the South Pacific (Gordon 1986). Secondary ITF portals enter the Indonesian seas via the western Pacific marginal seas, such as the South China Sea, and although relatively shallow, these portals can provide a significant source of freshwater that influences the ITF stratification. Within the Indonesian seas the thousands of islands and numerous passages connect a series of large, deep basins, so that the ITF actually consists of several filaments of flow that occupy different depth levels. During transit, the Pacific temperature and salinity stratification is mixed and modified by the strong air-sea fluxes, monsoonal wind-induced upwelling, and extremely large tidal forces into the distinctly fresh Indonesian Sea profile that is observed streaking across the south Indian Ocean. The enhanced mixing in the internal seas (e.g., Ffield and Gordon 1996, Koch-Larrouy et al. 2010) not only impacts the ITF water mass properties, but also the SST distribution that in turn may modulate air-sea interaction and the monsoonal response, as well as upwell nutrients that influence regional primary productivity. Climate model experiments suggested that the pattern and magnitude of precipitation and air-sea heat exchange in the Indo-Pacific region is highly sensitive to the choice of model vertical diffusivity in the internal Indonesian seas (Jochum and Potemra, 2008). To date, the spatial and temporal patterns of turbulent mixing within the internal Indonesian seas are poorly understood, yet a quantitative grasp of the associated small-scale processes is needed to properly model the regional circulation, and its role in the climate and marine ecosystems.

Many fundamental questions about the structure and variability of the ITF on climate time scales remain unanswered. The recent international INSTANT program provided the first simultaneous measurements within both the inflow and outflow passages (Sprintall et al. 2004). The measurements reveal that the semi-annual signal in ITF transport is much more dominant than previously thought (relative to the annual signal). INSTANT observations infer a three-year (2004-2006) mean ITF transport of 15 Sv, about 30% greater than historical non-synoptic measurements (Sprintall et al., 2009). However, a 3-year period was too short to provide an adequate description of low-frequency fluctuations associated with interannual and decadal climate variability. There is also evidence that ITF transport can vary by a few Sv on decadal time scales. For example, the change associated with the "climate shift" in the late 1970s inferred from XBT data (Wainwright et al. 2008) and that in the 1990s inferred consistently from a suite of ocean data assimilation products and satellite measurements of sea level and wind (Lee et al. 2010, Lee and McPhaden 2008). Therefore, the representativeness of the INSTANT estimate in terms of the long-term mean is uncertain.
Equatorial and coastal wave-guides in the tropical Pacific and Indian Ocean and the Indonesian Archipelago allow the ITF to be modulated by climate variability of the Pacific and Indian Ocean (e.g., Masumoto 2002, Wijffels and Meyers 2004, Cai et al. 2005, Potemra and Schneider 2007b). During El Niño, when the tropical easterly Pacific winds relax, the thermocline cooling and shoaling response in the western Pacific extends into the Indonesian seas, and the ITF is thought to cool and weaken. The opposite conditions prevail during La Niña. Like ENSO, the IOD also appears to influence the ITF transport in both the inflow and outflow straits, through the passage of Kelvin waves driven by IOD-related wind anomalies in the equatorial Indian Ocean (Sprintall et al., 2009). During INSTANT, a strong positive phase of the IOD in late 2006 appeared to strengthen the ITF transport through the outflow passages, hence modulating the expected influence from the concurrent 2006 El Niño. In contrast, the ITF transport was reduced in the surface layer but enhanced at depth during the 2004 El Niño, when the IOD was near zero. Longer time series are needed to understand the links of the vertical ITF transport profile to the IOD and ENSO phenomena and decadal

variability, and their implications for climate variations, such as the apparent impact on precipitation in the Australasian region. In addition, recent climate trends in the Indo-Pacific region such as the diminishing Pacific easterly trade wind strength, along with changes in the long-term variability of IOD and ENSO, are also likely to result in a changing ITF response.

2. The CLIVAR ITF Task Team

Sustained observational and modeling efforts are needed in the ITF region to provide insight into the long-term behavior and to elucidate the climatic impacts of this complex system in response to future climate change. As the ITF has multiple streams and undergoes significant modification in its stratification en route through the Indonesian seas, a cost-effective, long term monitoring system is no easy matter to design. The ITF research community proposes that an ITF Task Team be established to consider the specifics to evolve such a cost-effective plan. The overarching objective of the ITF Task Team is to identify the scientific gaps in our knowledge of the ITF and develop an integrated strategy towards an internationally sustained ITF observing system.

Development of an ITF plan would benefit from coordination under the auspices of CLIVAR. Despite the importance of the ITF to the earth climate system, in the past issues related to the climate variation within the Indonesian seas have largely been assessed in a fragmented way by the individual CLIVAR Indian and Pacific Panels and the Asian-Australian Monsoon Panel. This is possibly related to the geographical location of the Indonesian archipelago that bridges the Indo-Pacific region, while having a significant impact on the mean and variable circulation within both ocean basins. Coordination of the ITF Task Team under CLIVAR will provide a more formal linkage to these individual panels, and will help emphasize the societal benefits of ITF observations through a better understanding of the connection between the ITF variability with the IOD, ENSO and the monsoon systems.

The ITF Task Team (ITF-TT) Terms of Reference agreed by the CLIVAR SSG in May 2011 are:

1. To provide a more complete description of the pathways, structure, and variability of the ITF (including related property transports).
2. To better understand the mixing processes and their spatial and temporal patterns within the internal Indonesian seas and the role of mixing in transforming the Pacific stratification to the Indonesian profile.
3. To develop diagnostics and metrics for validation of ocean and climate models.
4. To enhance the understanding of the role of the ITF on interannual to decadal variations in the climate system, particularly in terms of their connections with Pacific and Indian Ocean variability.
5. To improve data and product distribution from ITF programs.
6. To develop strategies for cost-effective, sustained monitoring of the ITF.
7. To promote and coordinate international collaborations between observational and modeling studies, and to build capacity for researchers from within the Indonesian archipelago.

The main strategy to implement the terms of reference of the ITF-TT is to facilitate international collaboration between observational and modeling efforts, in order to target the urgent gaps towards understanding the ITF variability and maximize the scientific outcome. Numerous individual international efforts towards monitoring the ITF passages already exist or are in the planning stages. To better coordinate these efforts, a workshop was held in 12-14 March 2012 in Jakarta, Indonesia, which brought together interested ITF researchers in order to refine the science and implementation plans. One of the objectives of this meeting in Indonesia was to more readily enable Indonesian researchers and students to be directly engaged in the development and implementation of the ITF monitoring plan. This document discusses the main outcomes of this meeting. Other ongoing and planned activities of the ITF-TT can be found in the concluding Section 4.

3. Outcomes of the ITF-TT Workshop: March 2012

The workshop organized in Jakarta was attended by about 40 researchers with interests in the science related to the ITF. The workshop was structured in a way that discussions were divided into three main topics:

- Indonesian Throughflow Inflow Research.

- ITF Outflow Sustained Monitoring Strategy.
- Interior Seas.

3.1 Indonesian Throughflow Inflow Research

Ocean temperature/salinity stratification has defined the pattern of the Indonesian Throughflow (ITF) pathways (Gordon and Fine, 1996; Figure 1). We have measured varied streams of the ITF as they transverse choke points. During the INSTANT program of 2004-2006, the major components of the ITF were measured simultaneously (Gordon et al., 2010). Sustained observational and modeling efforts are needed in the ITF region to provide insight into the long-term behavior and to elucidate the climatic impacts of this complex system in response to future climate change.

Figure 1. Flow pattern of components of the Indonesian Throughflow. Sill depths are given for the major choke points and the main passages and seas are indicated.

The Makassar throughflow, composed of North Pacific thermocline and intermediate water, is drawn from the Mindanao Current branching (leakage) of tropical Pacific water near 5°N into the Sulawesi Sea. Makassar throughflow is the primary inflow path of the ITF into the Indonesian seas. Another source of the Makassar throughflow within the surface layer (within the upper 100 m) is drawn from the South China Sea and Sulu Sea throughflow (Figure 1) involving net westward flow of North Pacific subtropical water through Luzon Strait near 20°N, with export through the Sibutu Passage into the Sulawesi Sea (Gordon, et al., 2012), as well as eastward transport of South China Sea surface water into the Java Sea through Karimata Strait (Fang et al, 2010; Susanto et al, 2010). The Makassar throughflow carries ~90% of the thermocline layer component of the ITF and ~80% of the total ITF before it feeds into multiple streams to exit the Indonesian seas via the gaps in the Sunda Archipelago (Sprintall et al., 2009). The ITF inflow pathways east of Sulawesi, within northeastern seas, consisting of the Halmahera, Seram and Maluku Seas, are not well resolved, and so represent the least known element of the ITF. Elements of the Mindanao leakage may enter into the Maluku Sea; elements of the Halmahera leakage may enter into the Halmahera Sea.

The objective of the CLIVAR ITF Task Team is to identify the scientific gaps in our knowledge of the ITF and develop an integrated strategy towards an internationally sustained ITF observing system. With this in mind, the ITF-TT recommends coordinated international effort be applied to three elements of the inflow components of the ITF:

- *The Makassar throughflow.*
- *Gateway, investigating the Pacific inflow ITF via the Mindanao and Halmahera leakage and Luzon Strait throughflow*
- *The South China Sea throughflow inflow to the ITF via Sibutu Passage and Karimata Strait.*

3.1.1 Makassar throughflow:

The Makassar throughflow was monitored near 3°S in the 45 km Labani Channel constriction of Makassar Strait during the Arlindo program from November 1996 through June 1998. At the same site, the Makassar throughflow was monitored, from January 2004 through July 2011: the 2004-2006 time series, with two moorings as part of the INSTANT program, and then with a single mooring at the western of the two INSTANT moorings, until 1 August 2011 as part of the ocean observing system funded by the US NOAA program. The mooring was not re-deployed, as planned in August 2011, and was not redeployed at the time of the March 2012 workshop. Plans to redeploy the Makassar mooring were scheduled for July 2013. The CLIVAR ITF TT urges that the time series be maintained on a fully regular schedule.

3.1.2 Gateway, investigating the Pacific inflow ITF via the Mindanao and Halmahera leakage and Luzon Strait throughflow

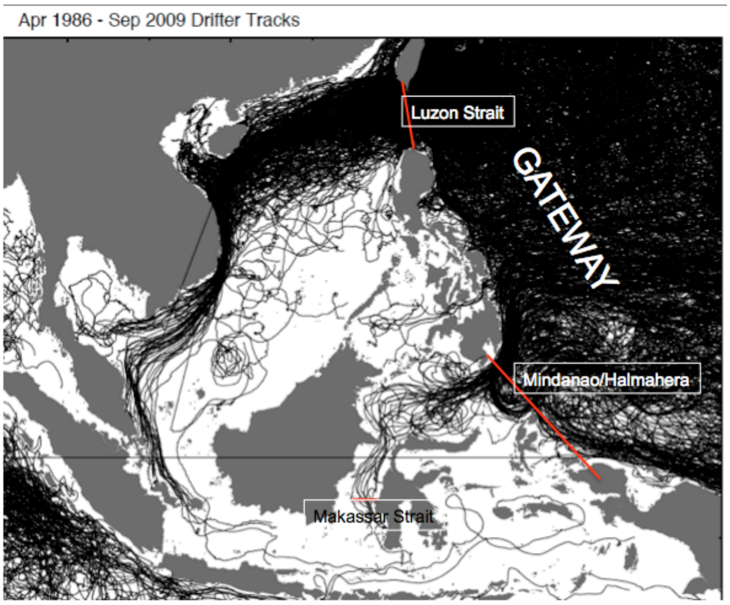

Figure 2: surface drifter tracks of the western Pacific Ocean and the Gateway region

3.1.2.1 Northeastern Seas and the ITF

Stretching ~650 km from the northern arm of the Island of Sulawesi to Irian Jaya, across the Maluku and Halmahera Seas, is the ITF portal into the eastern Indonesian seas. The gap in understanding basic ocean physics of the Indonesian seas is most acute in the Spice Island domain of the northeastern seas: the Halmahera Sea, Maluku Sea, the Seram Sea and the northern Banda Sea. These seas are exposed to the energetic Pacific western boundary currents that project into the region by way of the Mindanao and Halmahera Retroflections. The Mindanao system is part of the North Pacific regime; while the Halmahera system is part of the South Pacific regime, with its relatively salty thermocline. The winds blowing through the gaps between the Spice Islands induce a pattern of small scale clockwise and counterclockwise wind stress curl features that probably generate energetic sub-mesoscale eddies. The complex submarine topography coupled with the strong tidal action with wind induced eddies lead to a vigorous turbulent environment, one that is poorly understood, yet it is necessary to develop a quantitative grasp of the associated small scale ocean processes to properly model the regional circulation, and its role in the climate and marine ecosystems.

The deep (~2000 m) Lifamatola Passage was measured during INSTANT and during the pre-INSTANT period (van Aken et al, 2009). These field campaigns captured the spillover into the Seram and Banda Seas, but the upper thermocline and surface layers have not been well resolved. The flow through the Halmahera Sea is presently being measured as part of the IndoMix program consisting of an ADCP mooring deployed in July 2010 at the 650 m deep northern sill of Halmahera Sea at 00°04.066'N 129°12.41'E, that will likely be re-deployed in 2012 (lead PI: Ariane Koch-Larrouy). However, the ocean span of the ITF portal to the northeastern sea is great, and large survey gaps remain. We suspect that South Pacific water enters the ITF via the Halmahera Sea, but it is possible that some or maybe the bulk returns to the Pacific in the Maluku Sea west of Halmahera Island (Gordon and Fine, 1996), however there is a large degree of uncertainty. It is even possible that part of the Makassar throughflow returns to the Pacific Ocean within the northeastern seas (Gordon et al. 2010). An unknown is how much of the ITF takes a path along the eastern rim of the Indonesian seas, east of Seram Island.

3.1.2.2 Luzon Strait:

The Luzon Strait throughflow estimates range from near zero to over 6 Sv, averaging 4.5 Sv [see: Table 2 of *Fang et al.*, 2009] with the HYCOM value of 2.9 Sv [*Hurlburt et al.,* 2011]. The Luzon Strait throughflow varies with ENSO: stronger and cooler during El Niño [*Qu et al.* 2004; *Hurlburt et al.,* 2011].

3.1.3 The South China Sea throughflow inflow to the ITF via Sibutu Passage and Karimata Strait.

The South China Sea (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, feeding into southward flow in 235 m deep Sibutu Passage into the western Sulawesi Sea and northern Makassar Strait [*Hurlburt et al,* 2011; Metzger et al., 2010]; with a second, smaller export through the 45-50 m deep Karimata Strait [*Hurlburt et al,* 2011; *Fang et al.* 2010; Susanto et al., 2010] into the Java Sea, with a HYCOM annual transport of 0.6 Sv.

3.1.4 ITF Inflow Monitoring Strategy

- Makassar: As mentioned above, the Makassar Strait throughflow mooring was recovered on 1 August 2011, but not re-deployed as planned, interrupting what was a 7.5 year continuous time series. The mooring consisted of an upward looking long ranger ADCP near 500 m, a downward looking workhorse ADCP at 510 m, with three Aquadopp current meters. The CLIVAR ITF TT urges that the time series be maintained and deployed in a consistent fashion.

- Gateway: 1. Northeastern Seas (Mindanao and Halmahera leakage): The Mindanao Current flowing southward along the coast of Mindanao, forms a retroflection southeast of Mindanao. Most of the flow turns eastward to enter into the North Equatorial current, but some "leaks" into the Sulawesi Sea, as shown by the surface drafters (Figure 2). It is likely that most of the leakage enters into the Makassar Strait and will be captured by the Makassar throughflow mooring described above. However, some may follow counterclockwise patterns of flow in the Sulawesi Sea to curl back into the Maluku Sea, and contribute to the ITF within the eastern pathway (Figure 3).

The Halmahera retroflection may also leak water into the Halmahera Sea and contribute to the ITF. This will be captured by the IndoMix ADCP mooring at the northern sill entry (650 m deep) into the Halmahera Sea at 00°04.066'N 129°12.41'E, which will likely be re-deployed in 2012.

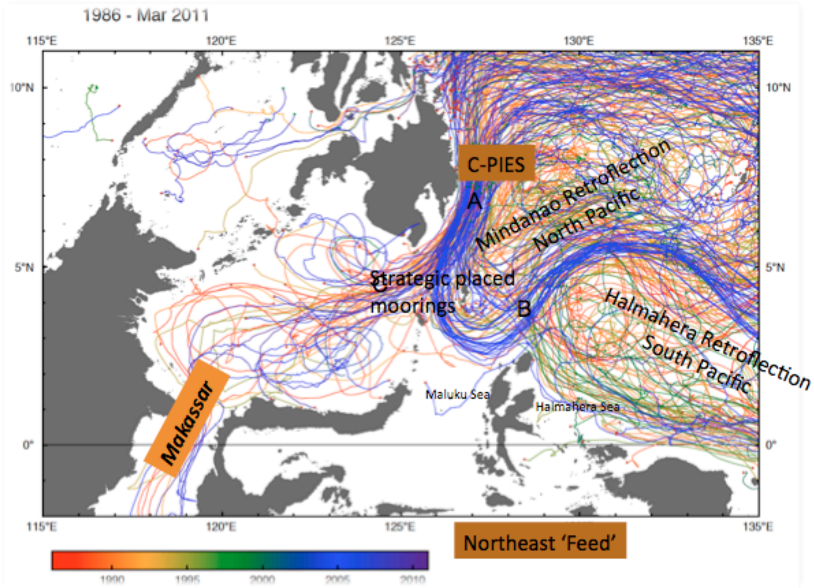

Figure 3 Gateway observation design

The observational strategy (Figure 3) is to measure the characteristics of the Mindanao Retroflection inflow and outflow to the complex region of the Mindanao Retroflection, with the objective to capture the relationship of its leakage into the ITF of the northeastern seas of Indonesia, to the large scale forcing of the western Pacific Ocean, and to the primary inflow path of the Makassar Strait throughflow.

The experimental design is coupled to the monitoring of Makassar Strait, described above and to the monitoring of the Luzon Strait described below. The activity also contributes to the CLIVAR Northwestern Pacific Ocean Circulation and Climate Experiment (NPOCE) program.

The observational components are to deploy C-PIES near 7°N to monitor the Mindanao Current inflow into the Mindanao Retroflection along with strategically placed ADCP moorings in the Mindanao retroflection to investigate the Mindanao Retroflection variability in response to the Mindanao Current input and to the leakage into the ITF (Figure 3).

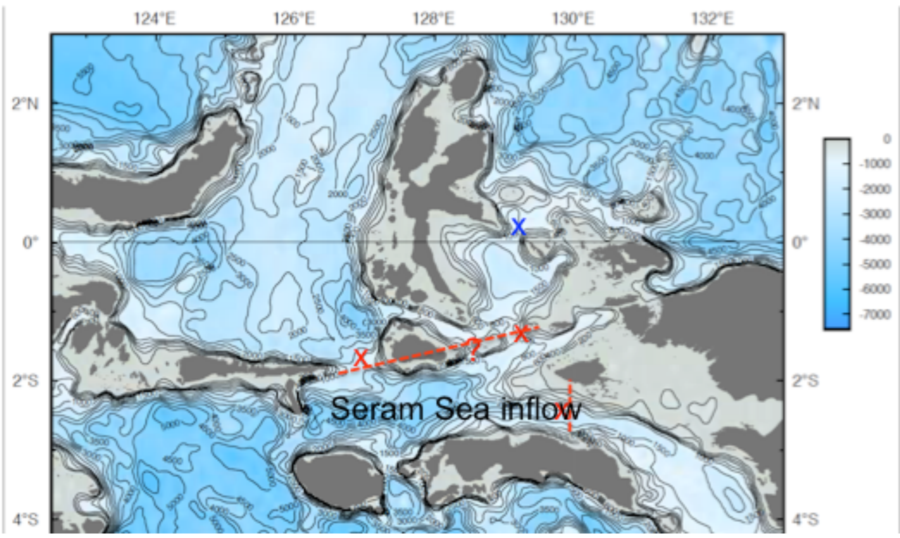

Figure 4: monitoring of the portals into the eastern pathways of the ITF

The northeastern portals into the Seram Sea that form the eastern pathways of the ITF and permit exchange between the Maluku and Halmahera seas with the Seram Sea have not been well resolved. Here we seek to cover the primary passages (Figure 4): the full depth Lifamatola Strait, the flow across the southern sill of the Halmahera Sea, noting that the some of the flow across the northern sill may be due to the east-west flow north of Obi Major.

At the northern sill entry to the Halmahera Sea of 650 m depth at 00°04.066'N 129°12.41'E, the Indomix mooring will likely be re-deployed in 2012.

2. Luzon Strait: As the only deep connection between the South China Sea and the Pacific Ocean, the Luzon Strait plays an important role in regional ocean circulation, and is a choke point of the South China Sea Throughflow. It is thus necessary to maintain long-term observations here as part of Gateway. The CLIVAR ITF-TT recommends that Luzon Strait throughflow enter into a sustained monitoring phase. The main purpose is to measure the time-varying structure and transport of flow through the Luzon Strait, on scales from a few hours to more than a year, and to capture the mesoscale eddy activities, the Kuroshio loop current and the intrusion of the Kuroshio.

Figure 5 shows a proposed experiment with two arrays of PIES/CPIES. The zonal array consists of 5 PIES along the Luzon Strait will be deployed in fall 2012 and will be maintained for one year, which is supported by the National Basic Research Program of China. The meridional array of PIES/CPIES across the Luzon Strait is still at planning stage, but it will be crucial for monitoring the South China Sea Throughflow and thus for Gateway. The two arrays combined will give a truly three-dimensional description of the flow field in the vicinity of the Luzon Strait.

In addition, there are other ongoing and planned observational efforts near the Luzon Strait and in the northern South China Sea, mostly funded by the Ministry of Science and Technology, and the National Science Foundation of China. These include deep moorings to measure the density overflow from the Pacific into the South China Sea, and three-dimensional arrays of buoys/moorings to observe the activity of mesoscale eddies and the upper ocean response to typhoons. These projects will definitely contribute the overall objective of Gateway.

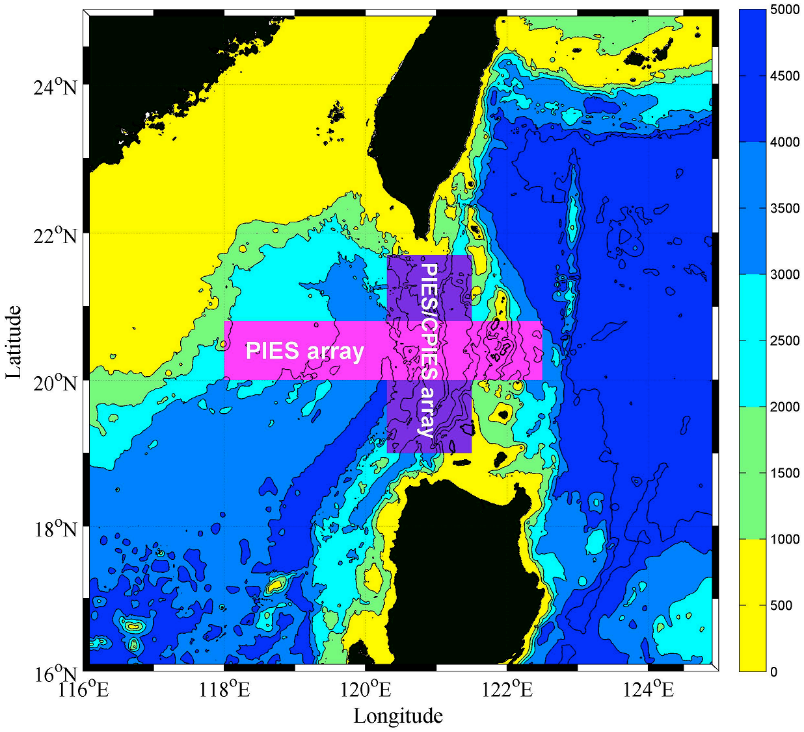

Figure 5: Luzon Strait PIES/CPIES array

• <u>Karimata</u>: The CLIVAR ITF- TT recommends the continuation of the China-Indonesia-US SITE program monitoring of Karimata Strait [Susanto et al, 2010]. The program SITE outlines an effort to measure the magnitude and variability of the water mass transport/exchange, temperature, salinity, and heat flux between the Indonesian Seas and South China Sea in the Karimata Strait by deploying a series of trawl-resistant bottom mounted acoustics current Doppler profiler (TRBM ADCP) moorings. The field work of the Phase I & II of SITE program has been implemented from November 2007 to October 2011. Data obtained in Karimata and Sunda Straits revealed that a significant water mass transport, 3.6 Sv, flowed from the South China Sea to the Java Sea in boreal winter, and about 1.8 Sverdrup from the Java Sea to the South China Sea in boreal summer [Fang et al., 2010]. This indicates that the Karimata Strait transport can contribute a seasonal variability of more than 5 Sv in the total ITF. To evaluate the seasonal and interannual variation of the Karimata throughflow, China, Indonesia and the United States will continue to carry out observation in 2012. Four TRBMs are to be deployed in the Karimata Strait in SITE program (Figure 6), and the joint program will last for three years to 2014.

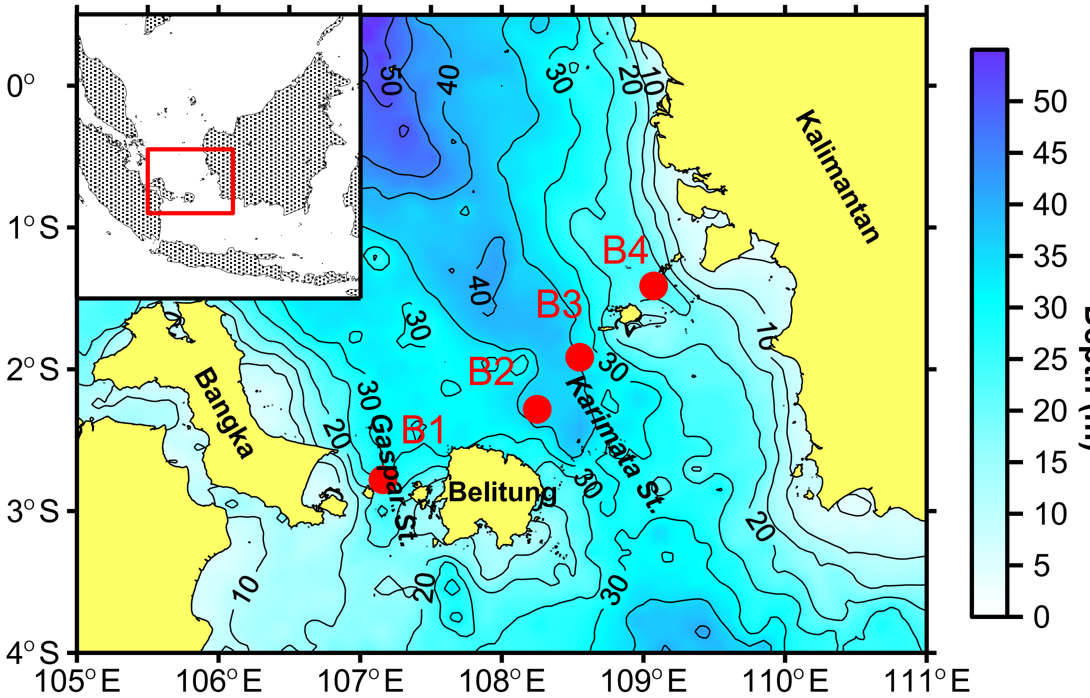

Figure 6: Monitoring of Karimata Strait

3.2 Indonesian Throughflow Outflow Research

The INSTANT program showed that the ITF is characterized by a varying and complex vertical structure (including higher vertical modes) along with a varying water mass signature (Sprintall et al., 2009). Thus simple transport proxies based on surface observations alone will not suffice to capture the volume, heat and freshwater transport variability of the ITF. Thus tall moorings, measuring both the volume and properties are required. Fortunately, the ITF passes into the Indian Ocean through a discrete set of topographically simple straits that lend themselves to monitoring by a few moorings.

The shallow Karimata and Sunda Straits can be monitored with bottom mounted ADCPs with temperature and salinity monitored at the sea floor and at the surface using altimeter measurements (Susanto et al., 2010). The deeper Lombok, Ombai and Timor Passages were monitored during INSTANT and these data show that for the former two narrow straits a single mooring is adequate to capture the transport, while for the much wider Timor Passage, three moorings is adequate. The remaining region of possible significant exchange is the very wide Australian North West Shelf.

3.2.1 Outflow Monitoring Strategy

Based on discussions at the workshop, the prospect looks very strong that all the major outflow straits will be monitored from 2013 onwards.

The Commonwealth Scientific Industrial Research Organisation (CSIRO) and the Australian Institute of Marine Science (AIMS), as part of Australia's Integrated Marine Observing System (IMOS), have instrumented a transect along a Jason altimeter track across the Australian North West Shelf , including 3 tall moorings in the Timor Trench. They have also installed a mooring in Ombai Strait at the INSTANT Ombai South location. A full year of shelf data has been collected to date, while the tall moorings were installed in June 2011 and were turned around in September 2012.

The First Institute of Oceanography, State Ocean Administration, China, in collaboration with Agency for Marine, Fisheries Research and Development, Ministry of Marine Affairs and Fisheries, Indonesia, will continue to instrument the transports through Karimata and Sunda Straits, and plan to instrument the transport through Lombok Strait in 2013, possibly with one or two tall moorings.

3.3 Indonesian Interior seas

The Indonesian archipelago is located in the warm pool region, where atmospheric convection is strongly dependent on ocean sea surface temperature (SST). In addition, with its complex topographic barriers and small seas (Figure 7), the archipelago is very energetic in a wide range of ocean processes and associated mixing. A strong water mass transformation of Pacific water mass is observed to form the Indonesian Water with a quasi-constant salinity value for the whole water column (Figure 8). Strong internal tides dissipation is thought to be the main candidate to explain such a vigorous mixing. This mixing is particularly strong in the thermocline (upper 400 m of the water column, Figure 8). Hence, cool waters are upwelled at the surface modifying significantly the SST. The above local atmospheric convection could be reduced (by 20%) and in turns via teleconnection this mixing could modify the tropical variability (Jochum and Potemra, 2008). Hence, it is critical to better understand the water mass transformation and the associated mixing. By looking only at water masses we cannot precisely deduce the pathways and the mixing region as both processes tend to alter the water mass. For a slow motion water mass, mixing is much more efficient than for a rapid flow in the same region. Dedicate studies are thus needed to better understand both pathways and mixing separately.

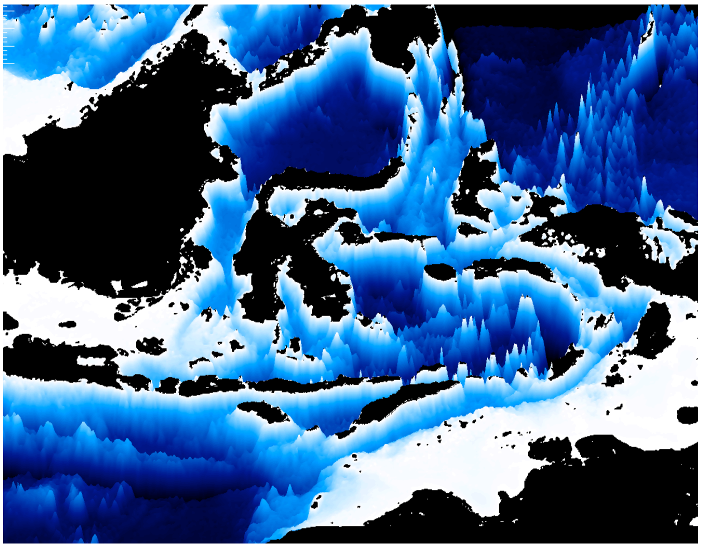

Figure 7: Sea floor topography from ETOPO2, from Koch-Larrouy , PhD 2007.

Internal tides have been attributed as the main role in the transformation. However, other processes such as eddies, instabilities of currents, lee waves, gravity waves, inertial waves, overflows and the stirring done by barotropic tides could also play a significant role in this mixing. Furthermore, dissipation and mixing concern processes that cover a wide range of spatial scales. The dissipation and mixing is associated to the breaking of waves, which occurs at scales of centimeter/milimeter, while the wave itself can propagate a few hundred kilometer from their generation site. In order to tackles these issues at very different scales, where the processes strongly interplay together, we need to use different tools and disciplines in close comparison. The different scientific communities must exchange information, in order to better separate all scales and processes from one to another.

Direct measurement of dissipation is quite challenging because you need to know where it is going to happen. Models at different resolution, looking at different processes and scales, can guide us to define precisely the location of dissipation. However, we need to validate these models against physical observational data.

The INDOMIX 2010 cruise was guided by a model experiment that showed that in Halmahera and Seram Seas the water masses were strongly transformed due to very energetic internal tides generation. This program proposed direct measurement of mixing using microstructure measurements coupled with fine structure measurements and chemical tracers in order to provide and compare three independent estimation of mixing. The results show a strong mixing in the thermocline.

In these interiors seas, the complex physical influence the biochemistry distribution, which at times will modify the distribution of halieutic spices. Strong interaction between physicists and biologists is needed to better characterize their distribution, which is relevant for controlling fisheries and resources.

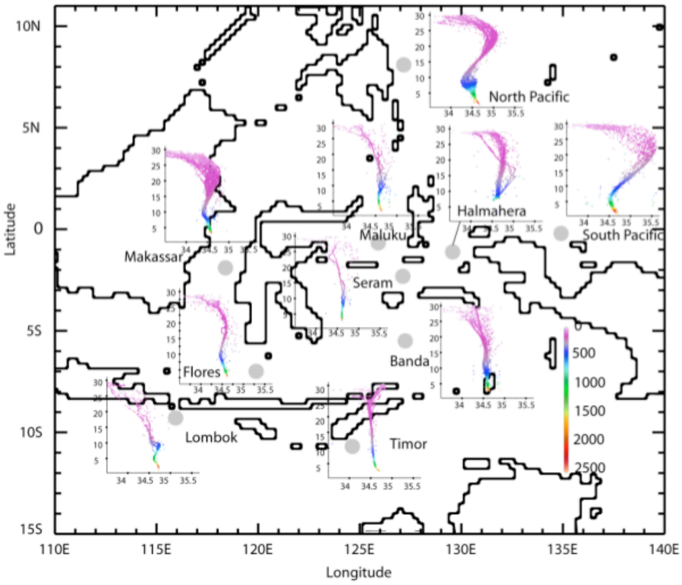

Figure 8: Water mass distribution from WODB, from Koch-Larrouy , PhD 2007.

3.3.1 ITF Interior Seas Monitoring Strategy

Several points still need to be addressed in order to provide a better understanding of the ITF in the interior seas. Water mass distribution and changes need to be more precisely understood. The mean distribution still has gaps and interannual variability is poorly known. It is necessary to re-enforce the water mass observations with profilers, CTDs and moorings, particularly in the Halmahera, Molucca, Seram seas, in the eastern most and western most part of the Banda Sea, and in Sulawesi, Flores and Sulu seas. For that, it may be necessary to do a systematic CTD cast for each cruise at sea in the region. However, a strategy is also needed to deploy ARGO and Gliders profilers in the region and equip moorings with T-S sensors more systematically. An Observing System Simulation Experiments (OSSEs) for the array of profilers would also be important, therefore a close collaboration with GODAE is necessary.

Because bathymetry is the first constraint for reproducing ocean processes associated with mixing, pathways and water masses in models, it is necessary to carefully measure it in all the complex sills and straits. One way to address this would be to plan for additional ship time to properly survey the different sills encountered during the cruise. Such data should be shared among all participants of the International ITF-TT in order to improve the bathymetry database.

Dedicated cruises to study mixing are necessary. INDOMIX has proven to be efficient to measure and quantified mixing associated to the tides. The goal is to better identify the region of mixing and quantify the level of energy available for mixing. Repeated profiles of CTD/LADCP, as many as possible during a single day would be one way to investigate this, particularly during spring tides when more energetic tidal generation occurs. Tracer-release experiments are another alternative, in addition to fixed profiler moorings (MMP), for instance, deployed in Timor where currents are less energetic and topography well constrained.

Models are to be used to fill gaps between the sparsely located in-situ measurements of water masses of the Indonesian archipelago. If they compare well to the available data of water mass and transport, they could propose possible pathways and mixing region that would be confirmed (or not) later through dedicated cruises. Also models may help separate different processes, and provide a first quantification of the importance of each mixing process. Finally, ocean/climate models should be coupled to biochemistry models to diagnose the impact of physics on the biochemistry distribution. The results of all these modeling experiments should be exchanged between the different communities so that parameterizations can be construct for coarser resolution models. Three model scales will be examined:

1. Regional scales: realistic models with realistic forcing resolution of 50km to 10km, compared to T-S observation data and transport estimate. These models would be used to understand the water mass distribution and variability, explore the different possible pathways, understand the biochemistry distribution and seasonal and interannual variability, and test how ocean physics could influence the heat fluxes and the coupling with the atmosphere on local scales and on global scales using a global model.

2. Intermediate scales: realistic models with resolution of 10km to 1km, with idealized wind forcing, or only tidal forcing. These models would be used to: explore the contribution of different processes to mixing, test and search for mixing parameterization for regional or global models, validate models to altimetry for tides, and better diagnose the spatial and temporal distribution of internal tides.

3. Fine scales: non-hydrostatic models with a few meters of resolution, compared to in-situ mixing measurements. These models would be used to show the characterisation of the waves and their breaking and parameterisation for dissipation of internal tides for fine-scales.

Better interaction with scientists of fluid mechanics and the design of a dedicated experiment for internal tides/waves generation and propagation in labs on a rotating table for example, would allow for better characterization of mixing or wave properties. It is also important to involve the biochemistry community as it can have tremendous societal impact. Biogeochemistry studies should be addressed in observational and numerical studies. The development of a more coupled system with biochemistry and pelagic species models should be encouraged, which would be validated with in situ sampling of nutrients, phytoplankton, zooplankton and pCO2, and deployment of CPRs (continuous plankton recorders).

Atmospheric forcing is a strong constraint on the total transport through the Indonesian archipelago, and its variability could generate a significant forcing for inertial waves and associate mixing. However, it is quite challenging to obtain since it is strongly constrained by the sea breeze, which is difficult to reproduce correctly due to the numerous and complex islands of the archipelago. However, in order to improve models forcing, it is necessary to improve freshwater input. Therefore, it is important to involve the atmospheric community.

4. Future Objectives of the ITF-TT

Other activities of the ITF-TT are to provide a scientific basis for developing and evaluating a cost-effective strategy for sustained monitoring of the ITF heat and mass transport over the long term for use in climate models and future predictions. A review paper to an international, peer-reviewed journal is currently being developed. The paper will review the current understanding of the structure, variability and dynamics of the circulation within the Indonesian archipelago, identify the outstanding scientific issues, and provide details of the sustained monitoring plan as developed at the March 2012 workshop required to understand the long-term ITF variability.

Another objective of the ITF-TT is to provide a capacity building component to train regional scientists with interests in the ITF and its role in the climate. Participants of the March 2012 workshop discussed some known capacity building activities that are planned for the near future and what the gaps are. INDOMIX will be running some workshops in early 2013. One clearly identified opportunity for young Indonesian investigators are the POGO Fellowships that can be targeted to Indonesian physical oceanography. A capacity building training workshop is currently being planned for early 2014 at ITB in Bandung, Central Java, Indonesia. The workshop will be for 10-days and involve at least 6 senior scientists (all members of the ITF-TT) and 20 junior scientists who have interests in circulation through the Indonesian seas. Funds to support this workshop have been sought from COSPAR, WCRP/CLIVAR and WESTPAC.

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