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MISMO : MIRAI Indian Ocean cruise for the Study of the MJO-convection Onset

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1. Introduction

The Madden-Julian Oscillation (MJO, Madden and Julian 1971, 1972) is known as dominant intraseasonal variability in the tropics. The MJO is an eastward propagating disturbance, occurring primarily during the boreal winter-spring season, with strong atmospheric convection which usually appears at first in the central-eastern equatorial Indian Ocean. Influences of the MJO spread not only within the tropical region but also to the atmospheric and oceanic conditions over the world through interactions with the monsoon (e.g., Yasunari 1979), El Niño (e.g., McPhaden 1999), tropical cyclones (e.g., Maloney and Hartmann 2001), and others. Although previous studies have revealed the various aspects of the MJO, so far there is no definitive explanation on the onset of the MJO convection over the Indian Ocean and associated upper-ocean variability.

As for the atmospheric convection itself, recent studies have suggested several key components that have to be clarified by observations. For example, Johnson et al. (1999) demonstrated the trimodal cloud distribution (cumulus, congestus, and cumulonimbus) in the tropics. In particular, it was shown that congestus clouds developed during the suppressed phase of the MJO moistened the mid-troposphere and preconditioned for the active phase with deep convection (Johnson et al. 1999, Kikuchi and Takayabu 2004). Furthermore, the large diurnal cycle in the sea surface temperature in a light wind condition seems to be crucial for the initiation of shallow cumuli and congestus clouds, suggesting the important role of coupling between the atmosphere and the upper ocean in the MJO-convection onset (Slingo et al. 2003). These studies suggest that fine-scale observation from the ocean surface to the entire troposphere is required for better understanding of MJO-convection. The TOGA COARE program in the tropical western Pacific during 1992 and 1993 (Webster and Lukas 1992) was one such observational effort. There are no intensive observations, however, in the Indian Ocean, though fine-scale observations are strongly desired for the study on the initiation of the MJO convection there.

For the upper-ocean variability in the central-eastern tropical Indian Ocean, it has been well known that a strong zonal jet and associated thermocline displacement appear twice a year during the monsoon transition periods (April-May, and October-November). These are known as the Wyrtki jets (Wyrtki 1973). Using current data from an ADCP mooring at 0°, 90°E, Masumoto et al. (2005), however, demonstrate that intraseasonal disturbances with the 30-50 days period dominate the zonal current in the eastern equatorial Indian Ocean. From their coherence analysis, the intraseasonal variability of zonal currents is considered to be induced by the wind stress between 80°E and 90°E at the periods of 30-50 days. However, details of generation mechanisms for the intraseasonal variability remain unsolved. Thus, it is important to obtain fine resolution data sets to reveal the air-sea interaction processes at the intraseasonal time scale. The data will also be able to be used for validating numerical models and satellite observations, and in turn the models will help in understanding the complex physical processes.

Based on these recent areas of progress, an observational cruise by the R/V Mirai named as MISMO (Mirai Indian Ocean cruise for the Study of the MJO-convection Onset), has been designed to conduct the needed intensive atmospheric and oceanic observations. In the following sections, basic information on the MISMO project will be briefly described.

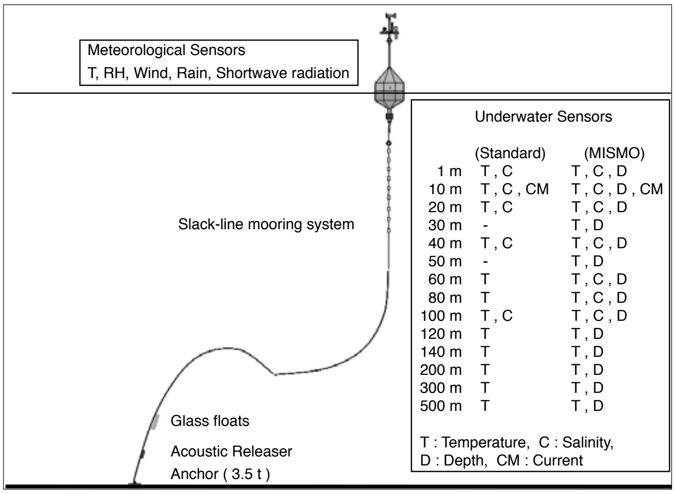
2. Objectives

The aim of MISMO is to reveal the atmospheric and oceanic features of the central-eastern equatorial Indian Ocean in November, where and when the convection in the MJO is often initiated. Special emphases are put on the following issues:

a. *Vertical structure of the atmosphere*
- Moisture convergence in the lower troposphere
- Variation of vertical profile of atmospheric parameters such as water vapor, divergence field, and clouds
- Development of cumulus convection

b. *Role of the air-sea interaction*
- Diurnal cycle of SST and its difference in behavior before/after the onset of the MJO
- Variation of ocean surface heat flux

c. *Oceanic responses to the MJO*
- Variation of ocean surface currents accompanied with westerly wind bursts
- Evaluation of warm water and salinity transports



	(Standard)	(MISMO)
1 m	T , C	T , C , D
10 m	T , C , CM	T , C , D , CM
20 m	T , C	T , C , D
30 m	-	T , D
40 m	T , C	T , C , D
50 m	-	T , D
60 m	T	T , C , D
80 m	T	T , C , D
100 m	T , C	T , C , D
120 m	T	T , D
140 m	T	T , D
200 m	T	T , D
300 m	T	T , D
500 m	T	T , D

T : Temperature, C : Salinity,
D : Depth, CM : Current

Figure 2.Basic configuration of the small-size-TRITON buoy. A few more depth sensors will be added as standard.

- Heat budget in the upper-ocean mixed layer

3. Observations

Based on previous studies on the dominant season and location of convective activity in the MJO (e.g., Kemball-Cook and Weare 2001, Zhang and Dong 2004), the intensive observation period and sites will be in October/November and around 80.5°E on the equator, where an ATLAS buoy has been deployed as the intensive flux site by PMEL/NOAA. A proposed observation network during the MISMO is shown in figure 1 (page 16), while a brief summary is as follows.

3.1 R/V Mirai

The main missions of the R/V Mirai are to conduct intensive observations around (0, 80.5°E) for one month and to deploy a mooring buoy array. Since many institutes have been approved to join the cruise through the public invitation process in addition to JAMSTEC and their cooperative institutes, various observations will be carried out during the cruise. Observation items and participating institutes are summarized in Tables 1 and 2.

3.2 Mooring buoy array

A buoy array, consisting of surface and sub-surface moorings, is a major part of the experiment, as it will provide basic upper-ocean conditions as well as ocean surface fluxes. During the MISMO period, newly designed two small-size-TRITON buoys (Fig. 2) will be deployed at (0°, 79°E) and (0°, 82°E), and four sub-surface ADCP moorings will be deployed at (0°, 79°E), (0°, 82°E), (1.5°N, 80.5°E), and (1.5°S, 80.5°E). In addition to these one-month-long moorings, three ATLAS buoys at (1.5°N, 80.5°E), (0°, 80.5°E), (1.5°S, 80.5°E) and a sub-surface ADCP mooring will be replaced before the MISMO cruise by PMEL/NOAA and NIO. The squared buoy array will enable us to calculate the surface heat flux, warm water convergence/divergence, and, hence, the heat budget in the upper ocean.

3.3 Argo floats

In addition to the standard Argo float 10-day interval sampling from 2000m depth, ten specially programmed Argo floats, which park at 500 m depth and sample once a day, will be deployed along the 80°E line from 8°S to 3°N, to capture the oceanic response to the MJO.

3.4 Land-based sites

To construct the large-scale atmospheric flux array, meteorological measurements will be carried out at three islands, Gan (0.7°S, 73.2°E), Kadhdhoo (1.9°N, 73.5°E) and Hulhule (4.2°N, 73.5°E), in the Republic of Maldives under the cooperation with the Department of Meteorology, Maldives. In addition to the standard surface meteorological measurements, radiosonde observations (2 or 4 times / day) will be conducted at Gan and Hulhule Islands. Furthermore, Doppler radar will be operated at Gan Island.

4. Schedule

The planned schedule of the MISMO cruise (Leg-1 and Leg-2) is as follows. These dates may be subject to change due to various reasons such as weather conditions.

a. *Year 2006*

- Oct. 4, Depart Sekinehama, Japan
- Oct. 15 – 16, Call at Singapore
- Leg-1, Deployment of ADCP moorings, small-size-TRITON buoys, and Argo floats
- Oct. 26 - Nov. 24, Stationary intensive observations at (0, 80.5°E)
- Recovery of ADCP moorings and small-size-TRITON buoys
- Nov. 27 – 28, Call at Male, Maldives
- Leg-2, Recovery/Deployment of TRITON, small-size-TRITON, and ADCP in the Indian Ocean
- Dec. 13 – 14, Call at Singapore
- Leg-3, Recovery / Deployment of TRITON in the western Pacific Ocean

b. *Year 2007*

- Jan. 16, Arrive at Sekinehama, Japan

5. Concluding remarks

Table 1. Measurement systems on-board the R/V MIRAI

INSTRUMENTS	PARAMETERS
5.3-GHz scanning Doppler radar	3-d reflectivity and Doppler velocity
Radiosonde	temperature, humidity, and wind (8 times/day during IOP)
Ceilometer	cloud base height
Total sky imager	cloud images/fraction in daytime
Surface meteorological station	pressure, air/sea temperature, humidity, wind, rain, radiation
Infrared SST Autonomous Radiometer	skin sea surface temperature
Turbulent flux measurement system	surface turbulent flux of momentum and latent/sensible heat
Wind profiler	vertical wind profile in the lower troposphere
Mie Scattering Lidar	vertical profiles of aerosols and clouds
95-GHz Cloud radar	vertical profiles of clouds and rain
Sky radiometer	solar radiation (optical thickness)
Videosonde	images of precipitation and cloud particles within clouds
Radiosonde with hygrometer/ozone sensor	vertical profile of water vapor and ozone
Rain sampler	rain sampling for stable isotope measurement
Surface water monitoring system	sea surface temperature, salinity, DO, chlorophyll, and pCO2
75-kHz Acoustic Doppler Current Profiler	current vector profile in the upper ocean
CTD with water sampler and fluorometer	vertical profile of temperature, salinity, DO, chlorophyll, pH and nutrients (4-8 times /day during IOP

Table 2. Participating institutes for the R/V Mirai cruises

JAPAN	JAMSTEC National Institute for Environmental Studies Hokkaido Univ. Tohoku Univ. Kyoto Univ. Toyama Univ. Osaka Prefecture Univ. Okayama Univ. Yamaguchi Univ. Global Ocean Development Inc. Marine Works Japan Ltd.
U. S.	Univ. of Miami RMR Co. International Pacific Research Center
INDIA	National Institute of Oceanography

During the one-month intensive observation period of MISMO, various atmospheric and oceanic measurements will be carried out at the stationary site and the nearby regions. The data obtained may add new insights to the MJO related variability in both the atmosphere and the ocean and they will be open to the scientific community within a certain period (one or two years). Further information and updates of this experiment can be found at the MISMO web site at http://www.jamstec.go.jp/iorgc/mismo/

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The first 1.5 years of INSTANT data reveal the complexities of the Indonesian Throughflow

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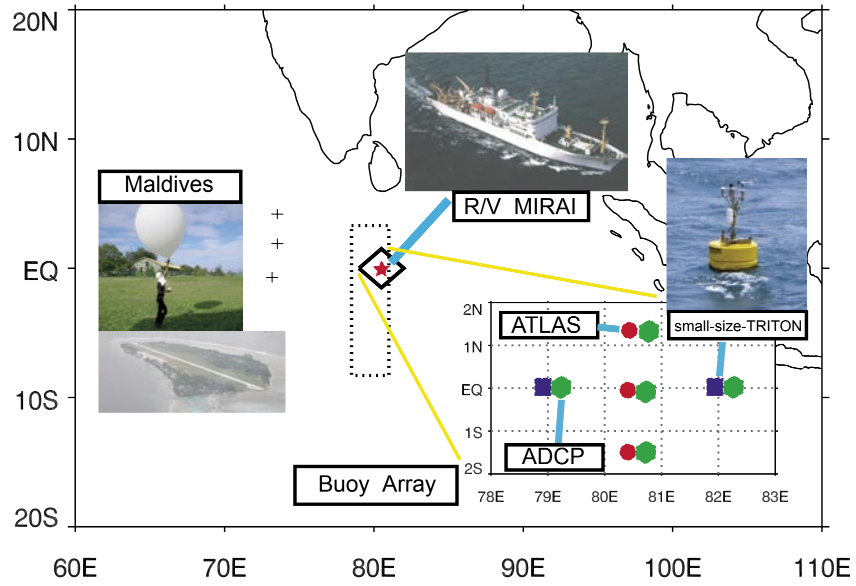
The major ocean basins are connected by passages of varied widths and depths. These passages allow for interocean exchange of water properties, which tend to reduce, though not remove, the thermohaline differences between the oceans. Such interocean exchange influences the heat and freshwater budgets of each ocean basin and in so doing represents an important part of the climate system. Most of the interocean exchange routes are at high latitudes, allowing for the establishment of the Antarctic Circumpolar Current and for low salinity surface water flow into the Arctic Sea by way of the Bering Strait. At mid-latitudes there is leakage of subtropical Indian Ocean thermocline water into the South Atlantic around the southern rim of Africa. The Indonesian seas alone allow for an interocean exchange of tropical waters in what is referred to as the Indonesian Throughflow (ITF): a transfer of warm, relatively low salinity Pacific waters into the Indian Ocean. The ITF affects both oceans, though perhaps more so the thermohaline stratification of the smaller Indian Ocean. While the literature of the last 45 years offers a very wide range of annual mean transport values for the ITF, from near zero to 25 x 10^6 m^3/sec, the more recent estimates narrow the range to 10 ± 5 x 10^6 m^3/sec with large seasonal and intraseasonal variability (Wijffels and Meyers, 2002; Gordon, 2005).

The ITF stream is fed from the North Pacific thermocline waters, though within the lower thermocline and deeper levels the waters are drawn directly from the South Pacific. The primary inflow passage is Makassar Strait, with the Lifamatola Passage east of Sulawesi the dominant deep-water route. During residence in the Indonesian seas the inflowing Pacific stratification is modified by mixing, with energy derived from dissipation of the powerful tidal currents within the rugged sea floor topography, and by buoyancy flux across the sea-air interface. This results in a unique Indonesian tropical stratification—one of a strong, though relatively isohaline, thermocline. The Indonesian water is exported into the Indian Ocean via the three major passages within the Sunda archipelago: Timor Passage, Ombai Strait and Lombok Strait. The waters of the ITF are apparent within the thermocline as a cool, low-salinity streak across the Indian Ocean near 12°S (Gordon, 2005) and at intermediate depths as a band of high silicate (Talley and Sprintall, 2005). These ITF waters have no choice but to exit the Indian Ocean within the poleward-flowing western boundary Agulhas Current, though not before mixing and recirculating with ambient Indian Ocean thermocline water and interacting with the monsoonal atmosphere. The ITF acts to flush the Indian Ocean thermocline waters to the south by boosting transport of the Agulhas Current, increasing both the southward ocean heat flux across 20-30°S and the sea-air heat fluxes within the Agulhas Retroflection, over the no-ITF condition (Gordon, 2005).

The ITF is a fundamental component of the climate system and affects the marine ecosystems of the Indonesian seas, yet it is poorly observed and simulated in ocean and climate models. The main throughflow passages have been monitored but over different years and for varied lengths of time, making it impossible to assemble a simultaneous picture of the multiple corridors of the ITF. The International Nusantara Stratification and Transport (INSTANT) program (Sprintall et al, 2004) will do much to develop a far more quantitative appreciation of the Throughflow phenomena. INSTANT is a multi-national (Indonesia, United States; Australia, The Netherlands, France) program to measure the velocity, temperature and salinity of the Indonesian Throughflow within all of the primary inflow and outflow passages simultaneously (Fig. 1, page 16), a feat never before accomplished.

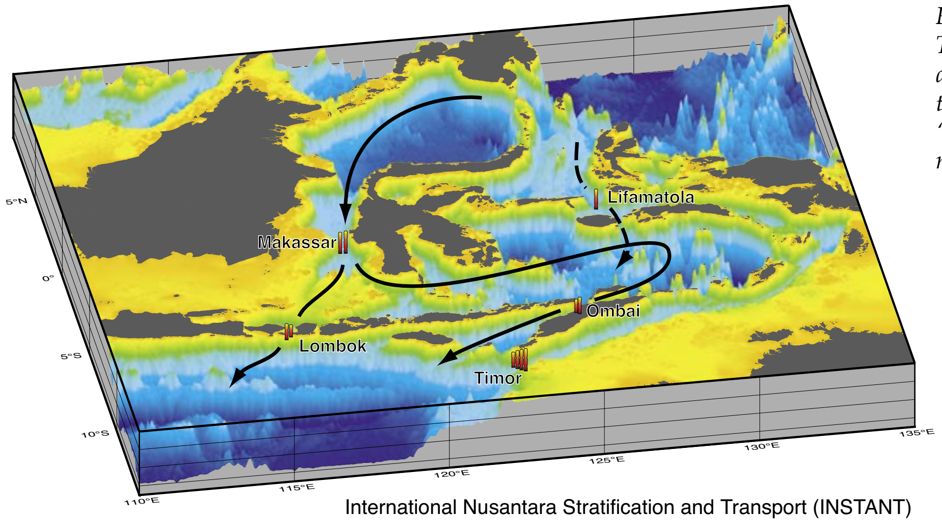
From Yoneyama et al, page 8: MISMO : MIRAI Indian Ocean cruise for the Study of the MJO-convection Onset

Figure 1.Observation network for MISMO. Argo floats will be deployed within dotted rectangle. Stationary observations at (0, 80.5°E) will be conducted from Oct. 26 to Nov. 24, 2006.



From Gordon et al, page 10: The first 1.5 years of INSTANT data reveal the complexities of the Indonesian Throughflow

Figure 1. The array of INSTANT moorings. The black arrows show the ITF pathways. The dashed arrow in Lifamatola Passage represents the overflow across the 1940 m sill. The red "poles" mark the positions of the INSTANT moorings.



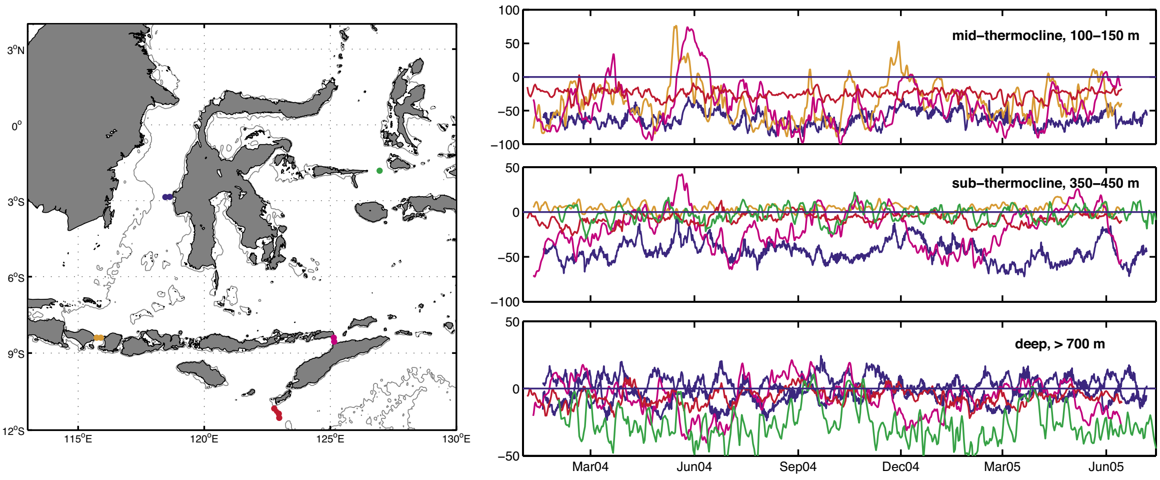


Figure 2. A composite view of the along-axis speeds [cm/sec; tides removed] from select moorings within each passage as measured during the first 1.5 years of INSTANT. Negative speeds are towards Indian Ocean. Color coding: Blue: Makassar; Green: Lifamatola; Orange: Lombok; Purple: Ombai; Red: Timor.