Science and Operation Plan for the R/V MIRAI 2006 Indian Ocean Cruise : MISMO
"MIRAI Indian Ocean cruise for the Study of the MJO-convection Onset"

(Draft)

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Executive Summary

The dominant eastward propagating intraseasonal oscillation in the Tropics known as the Madden-Julian oscillation (MJO) is a key issue to be solved, as it influences not only the tropical atmospheric and oceanic variations but also the global climate. Since the MJO is a phenomenon coupled with deep cumulus convections, it is manifested over the warm pool region from the eastern Indian Ocean through the western Pacific Ocean. However, past major field experiments conducted in the Indian Ocean were devoted to study the summer monsoon, and there are few data especially in the boreal winter season.

Recent studies using reanalysis and satellite data revealed various aspects of the large-scale MJO structure. However, current general circulation models still fail to simulate the “slow” eastward propagation and underestimate the strength of the intraseasonal variability mainly due to the insufficient cumulus parameterization.

Based on the fact mentioned above, we at JAMSTEC have been planning to have the intensive observation using the R/V MIRAI to capture the detailed features from the ocean surface to the entire troposphere in the boreal fall-winter season (late October - November) when the onset of convection in the MJO is often found. This article describes the scientific background on the MJO with referring past studies , and then operation plan for the R/V Mirai cruise as well as other relevant observations that will be taken place in the central and eastern Indian Ocean during October - November 2006.

1. Scientific Background : Why we study the MJO ?

1.1 Atmospheric research

The Madden-Julian oscillation (MJO, Madden and Julian 1971, 1972) is the dominant intraseasonal variability in the Tropics as an eastward propagating disturbance that is mainly manifested during the boreal winter-spring season. The MJO influences not only tropical climate but also the variability of precipitation and other many atmospheric and oceanic parameters over the world through the interaction with the monsoon (e.g., Yasunari 1979, Hendon and Liebmann 1990), El Nino (e.g., McPhaden 1999), tropical cyclones (e.g., Maloney and Hartmann 2001), and others. As Raymond (2001) mentioned that the MJO becomes the “holy grail” of the tropical atmospheric dynamics, it has been extensively studied by many scientists in various ways in terms of observations, numerical modeling, and theory.

While recent analyses of satellite and reanalysis data have revealed the large-scale features of the MJO structure, current general circulation models (GCMs) fail to simulate the “slow” eastward propagation and underestimate the strength of the MJO (Slingo et al. 1996). This is mainly due to the insufficient cumulus parameterization; namely it depends on how to accurately treat the microphysics and upward water vapor transport, and so on. After solving these problems, we should address the dominance of intraseasonal oscillation, the initiation of convection in the Indian Ocean, and the slow eastward propagation using GCM.

On the onset of MJO-convection in the Indian Ocean, there has been no definitive explanation at present. Kemball-Cook and Weare (2001) reviewed the current major explanations for that and they are as follows. First one is that, extratropical Rossby wave trains propagating into the Tropics may excite the convection (e.g., Hsu et al. 1990). Second one is that circumnavigating signals in the upper troposphere may interact the convection in the Indian Ocean (e.g., Sperber 2003). Last one is that local convective instability contributes to the onset of convection and the time scale of the oscillation is determined by the radiation-convection-surface interaction and is mainly controlled by the long time scale of radiative cooling (e.g., Hu and Randall 1994, Raymond 2001). Last one is sometimes referred as discharge-recharge theory (Blade and Hartmann 1993). In any cases, however, lack of data in the equatorial Indian Ocean make difficult to answer on this onset mechanism.

As for the mechanism of the eastward propagation, there also exist various hypotheses. One of the most widely recognized theories is a so-called “frictional wave-CISK (conditional instability of the second kind)” hypothesis (e.g., Wang 1988, Maloney and Hartmann 1998, Seo and Kim 2003). This theory proposes that equatorial low-level moisture convergence leads the convections and latent heat release in the deep cumulus convection forces an eastward propagating Kelvin wave, then Kelvin wave induce the low-level moisture convergence to the east. As a theoretical dry Kelvin wave has a fast propagating speed (15-30 m/sec), most theories and modeling works try to slow down its speed by introducing the modulation factors such as boundary layer frictional effect.

Since the MJO-convection is manifested over the warm pool from the eastern Indian Ocean through the western Pacific Ocean and their propagation speed over the warm pool is slower than that of other regions, sea surface temperature (SST) is a crucial candidate as the key factor for the propagation mechanism (e.g., Flatau et al. 1997, Woolnough et al. 2000). In particular, diurnal cycle of SST and water vapor in the boundary layer may play a key role for the coupling between the ocean and convections (e.g., Slingo et al. 2003, Yoneyama 2003). Therefore, long term measurement to capture the change of ocean surface and boundary layer before and after the onset of MJO-convection with high temporal resolution (at least a couple of hours) is strongly required.

Furthermore, vertical structure of the MJO might be the key for the strength of variability. Recently, Lin et al. (2004) showed that vertical heating profile of the MJO is much top-heavy more so than climatological mean. In particular, they pointed out that the fact that current GCMs fail to simulate this top-heavy structure results in a too-weak intraseasonal variability and the role of stratiform clouds in the upper troposphere plays a key role for this heating profile. This suggests that not only the developing mechanism of cumulus convection but also life cycle including stratiform rain of MJO-convection should be studied for their mechanism and impact.

Needless to say, lack of observational study in the Indian Ocean especially focusing on the detailed structure from the ocean surface to entire troposphere makes difficult to address the features and mechanisms of the large-scale MJO. In the future, GPM (Global Precipitation Mapping) project that provides 3 hourly precipitation data over the world with high spatial resolution and other satellite projects (e.g., A-train constellation; Stephens et al. 2002) may never fail to provide very useful information on the MJO. In-situ observation from the ship, however, has also a strong impact to understand the fine scale structure and contributes to the scale interaction for the MJO study.

1.2 Oceanographic research

Major oceanic variability in the equatorial Indian Ocean occurs associated with the Wyrtki jets which are induced by the westerly winds twice a year (April-May, and October-November) during monsoon transition periods (Wyrtki 1973). The eastward strong jets of which typical current speed is about 80 cm/s in the surface layer are considered as semiannual signal, and they advect warm water eastward and accumulate it near the eastern coast. Basic mechanism of the jet is a ocean response to the semiannual westerly winds over the equatorial region and can be interpreted as local Yoshida-jet dynamics (Yoshida 1959, O'Brien and Hurlburt 1974) and subsequent eastward propagation of the equatorial Kelvin wave.

Recently, Masumoto et al. (2005) demonstrated from the data of an ADCP mooring at 0°, 90°E that the intraseasonal disturbances with the 30-50 days period dominate in the zonal current in the eastern Indian Ocean. From their coherence analysis, the intraseasonal variability of zonal currents are considered to be induced by the wind stress from 80°E to 90°E at the periods of 30-40 days. The result indicates that the semiannual characteristics of Wyrtki jet is merely a resultant of a series of distinct intraseasonal disturbances.

The intraseasonal disturbances have also connect with interannual change as the Dipole mode phenomena (Saji et al., 1999), where the zonal warm water migration plays a key role in the equatorial zone. In order to study further, it is important to reveal the process of mass, heat and salinity transports associated with the intraseasonal eastward jets induced by strong MJO wind forcing. Such interaction between interannual changes and intraseasonal disturbances is not well understood.

Further, it is not well understood how the atmosphere and ocean exchange the heat and affect each other. During the JASMINE pilot study cruises which is focusing on the air-sea interaction during the onset of boreal summer monsoon, the intensive flux measurements revealed that the surface heat flux values during the active MJO periods are remarkably higher compare to the results in the Pacific（Webster et al., 2002). However, it is not sufficient to achieve the JASMINE goals such as how intraseasonal variations connect with long term variations because the in-situ data were obtained only from research vessels and no long term mooring measurements.

As above, the MJO is one of the most important driving force to the ocean, in order to understand the oceanic variability in various time scales, it is necessary to investigate heat budget more accurately taking account the effects of mixed layer change and horizontal advection by the combination with long term measurements from moorings and comprehensive measurements from stationed vessel.

2. The significance of the R/V MIRAI observation

2.1 Features of the R/V MIRAI

The R/V MIRAI is one of the largest research vessel whose length is about 130 m and gross tonnage is 8,687 ton. It is very stable and active anti-rolling system is equipped.

The R/V MIRAI is operated as mission-oriented ship. It means that if research themes correspond with the scientific main missions, that are discussed and settled by a steering committee "MIRAI Operation Planning Committee", researchers can join the cruise through the selection of public invitation. It allows that not only original measurement systems listed in section 6 but also various observational tools from the various institutes / universities can be incorporated into the observational cruise. For example, currently “The study of air-sea interaction in the Tropics” and “Tropical Ocean Climate Study (using TRITON)” are regarded as main missions.

The coverage of observation from the MIRAI is considerably small to observe large-scale MJO structure. However, since the MJO propagates eastward, stationary observation at fixed point can measure the vertical structure effectively with fine temporal resolution and we can estimate the spatial distribution from temporal data sets.

Therefore, we can use the MIRAI as a super site at sea and the combination with other data obtained by mooring systems, satellites, and land-based sites brings much knowledge.

2.2 Past results relevant to the MJO-convection

We at JAMSTEC had conducted the four observational cruises for the study of air-sea interaction in the tropical western Pacific warm pool region from FY2000 through FY2003 (Table 1). The aim of the cruises was to observe cumulus convective systems accompanied with the MJO. During these cruises, stationary observation at 2°N, 138°E was conducted.

Table 1. Cruise summary.

Cruise code	Site	Intensive Observation Period	MJO phase	ENSO phase
MR00-K07	(2.0N, 138.0E)	Nov. 27 - Dec. 10, 2000	Active -> Inactive	La Nina
MR01-K05	(1.9N, 138.0E)	Nov. 09 - Dec. 08, 2001	Inactive -> Active	Normal
MR02-K06	(2.0N, 138.5E)	Nov. 22 - Dec. 12, 2002	(Active) -> Inactive	El Nino
MR04-01	(2.0N, 138.4E)	Mar. 02 - Mar. 14, 2004	Inactive -> Active	Normal

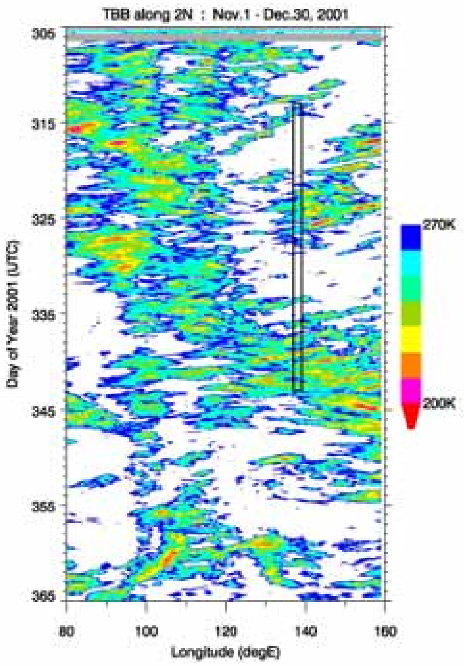

Fig. 1. Time-longitude cross section of the brightness temperature along the 2°N from November 1 (Day 305) through December 30, 2001. Solid rectangular indicates the MIRAI observation period and site.

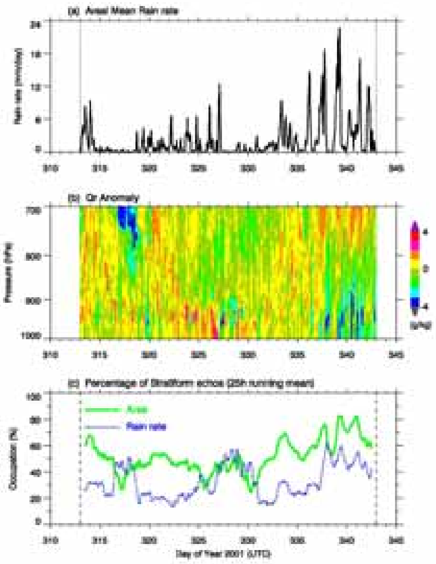

Fig.2. (a) Time series of areal mean rainfall rate averaged over 200 km x 200 km around the R/V MIRAI, (b) Time-height cross section of water vapor mixing ratio anomaly from the 30-day mean from November 9 (Day 313) through December 8, 2001, and (c) Time series of stratiform echo occupation of area (green) and rainfall rate (blue).

Figure 1 shows the time-longitude cross section of the brightness temperature along the 2N from November 1 through December 30, 2001. It is apparent that convectively active phase reached the observational site in the late period of the stationary observation. Time series of areal mean rainfall rate (Fig. 2a) shows that it increased with 1-2 days periodicity as above mentioned large-scale MJO clouds approached. This MJO clouds consists of stratiform clouds having about 70 % area coverage and 50 % rain rate (Fig. 2c) suggesting the importance of the role of the stratiform clouds. It is intriguing that water vapor in the lower troposphere becomes rather dry during this rainfall maximum (Fig. 2b). Instead, water vapor becomes maximum about 2 weeks before the rainfall maximum (Day 322-330) and upward transport is found during Day 330 - 337.

This preconditioning feature of moisture convergence in the lower troposphere is suggestive to support the frictional wave-CISK theory and/or the discharge-recharge theory.

To examine the role of MJO-convection onto the vertical water vapor distribution in detail, composite analysis was performed using radar echo data and radiosonde data obtained during the convectively active phase of four cruises. First, we classified echo data into convective / stratiform echoes following the work of Steiner et al. (1995). As the time series of convective / stratiform echo area shows the 1-2 day periodicity (not shown), we define the "convective center" as the time when the convective echo area at 2km exceeds 1,600 km^2 and being maximum within successive 24 hours. Then composite of convective and stratiform echoes are constructed (Fig. 3). The results show that shallow convection occurs about 6-9 h prior to the convective center, and the maximum of stratiform echo lags 2-3 h to the convective center and lasts longer. Occupation of stratiform echo area becomes about 80 % after the convective center.

Next, same procedure is applied onto the radiosonde relative humidity data (Fig. 4). Prior to convective center, moisture in the lower troposphere just above the boundary layer becomes high, and then high RH region is shifted upward. High RH condition continues only above 600 hPa layer after 3 hours from the convective center. Careful examination on RH distribution, there minimum layer exists around 500 hPa. Instead, it should be rather emphasized that high RH concentrates around 600hPa after 6 hours from the convective center. To reveal this feature, microphysics might be the key.

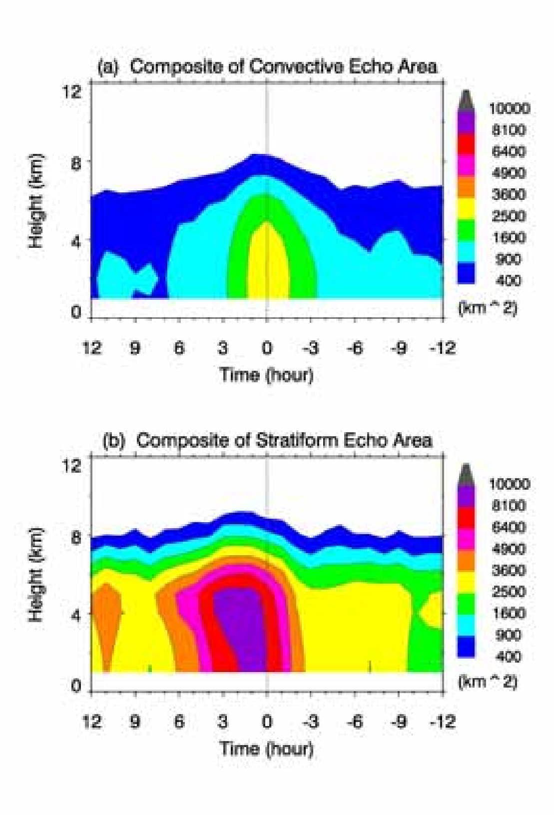

Fig. 3. Time-height cross section of the composite of (a) convective echo area and (b) stratiform echo area. Time "0" is defined as when the convective echo area at 2km becomes maximum in a day at least over 1,600 km^2. (From Yoneyama and Katsumata 2006)

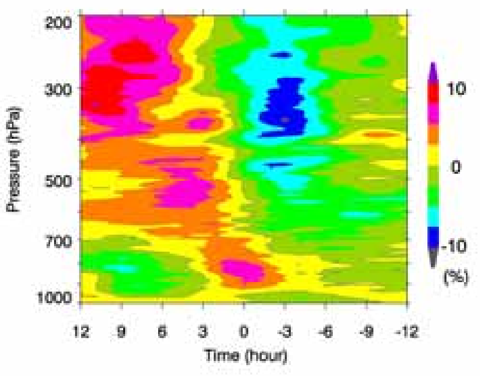

Fig. 4. Same as Fig. 3, but for relative humidity anomaly from the mean at each level. (From Yoneyama and Katsumata 2006)

2.3 Other relevant studies

Figure 5 shows the relationship between the total precipitable water (tpw) and the water vapor mixing ratio calculated from about 1400 radiosonde data obtained during not only the MIRAI cruise but also other cruises conducted in the past 9 years (Yoneyama 2003). This shows that the variability of mid-tropospheric moisture mainly contributes to that of tpw having highest correlation at 850-600 hPa layer. On the other hand, boundary layer has relatively low correlation coefficients and distinct minimum is found at the top of mixed layer known as the transition layer. From the spectral analysis conducted for the data taken during the one month stationary observation at 2N, 138E (Fig. 6), it is expected that this relationship is due to the fact that high correspondence of the peaks in the intraseasonal time scale is only found between tpw and mid-troposphere. On the other hand, variability of water vapor in the boundary layer, that is usually regarded as moisture source to the mid- and upper troposphere, is well correlated with tpw in terms of diurnal cycle (Fig. 7). This indicates that diurnal cycle is the key component for the coupling of the ocean surface and the atmosphere above boundary layer.

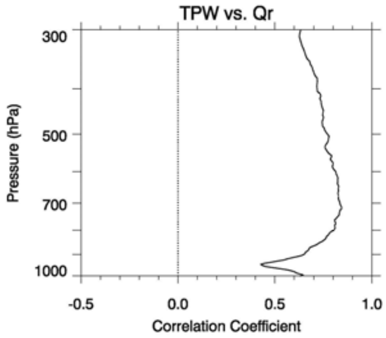

Fig. 5. Correlation coefficient between total precipitable water and water vapor mixing ratio as a function of pressure. (From Yoneyama 2003)

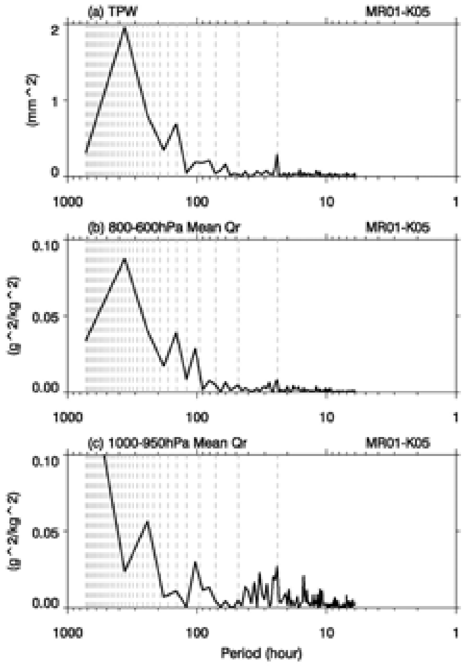

Fig. 6. Power spectrum of (a) total precipitable water, (b) 800-600 hPa layer mean, and (c) 1000-950 hPa layer mean water vapor mixing ratios. (From Yoneyama 2003)

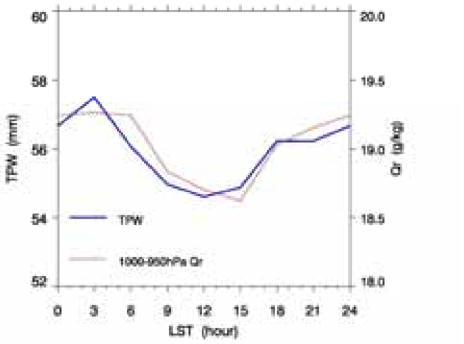

Fig. 7. Diurnal variation of precipitable water and vertically averaged water vapor mixing ratio for 1000-950 hPa layer. (From Yoneyama 2003)

3. Experiment objectives

The aim of the proposed cruise is to obtain precise vertical structure from the ocean surface to the upper troposphere for the study on the onset of MJO-convection. Based on the scientific background and the MIRAI's ability described in the previous sections, specific experiment objectives can be summarized as follows.

(1) Vertical structure of the atmosphere
  * Moisture convergence in the lower troposphere
  * Time evolution of vertical profiles of atmospheric parameters such as water vapor, divergence field, and clouds.
  * Development of cumulus convections in the range of 100 km
(2) The role of air-sea interaction
  * Diurnal cycle of SST and their change before/after the onset of MJO
  * Time evolution of ocean surface heat flux
(3) Oceanic responses to the MJO
  * Variation of ocean surface current accompanied with westerly wind bursts
  * Evaluation of warm water and saline transports
  * Heat budget of ocean mixed layer
  * Impact of the MJO onto the long-term ocean surface variation such as SST and 20°C isotherm depth obtained by ATLAS / TRITON / JEPP buoys.

4. Selection of the intensive observation period and site

Figure 8, that is produced following the work of Lin et al. (2004), shows the variability of intraseasonal precipitation and it is evident that eastern Indian Ocean is the most active regions on that time scale. From this figure, we can say that the range of 5°S - equator, 80°E - 90°E is the appropriate site for the study on the onset of MJO-convection.

MJO is regarded as one of the intraseasonal variability seen in the Tropics. Some intraseasonal variability move not only eastward but also north-eastward and south-eastward (Wang and Rui 1990). If we focus on the phenomena that moves eastward along the equator (5S-5N band), MJO signal dominates in the boreal winter-spring (Zhang and Dong 2004). According to the analyses of outgoing longwave radiation (OLR) by the U.S. National Oceanic and Atmospheric Administration / Climate Diagnostic Center (http://www.cdc.noaa.gov/), all first MJO signals can be found in the early November for the period of year 2000 - 2003. If we take account into the consideration of circumnavigating theory for the onset mechanism, we should try to catch the first MJO signal. In addition, observation should be started prior to active convective period to capture the precondition. Past studies (e.g., Woolnough et al. 2000) suggest that warm SST anomalies lead about 10 days before the convection maximum, so two-weeks lead time is at least required.

Based on the above consideration, we decide that an appropriate observation periods starts from the late October and the site is set at (0°, 80°E) to capture the onset of convection in the MJO.

Since the MJO propagates eastward, time series of vertical distribution obtained at a fixed site can be interpreted as the zonal distribution of the system. Therefore, the ship should keep the position within 20 - 30 km range to represent the research target.

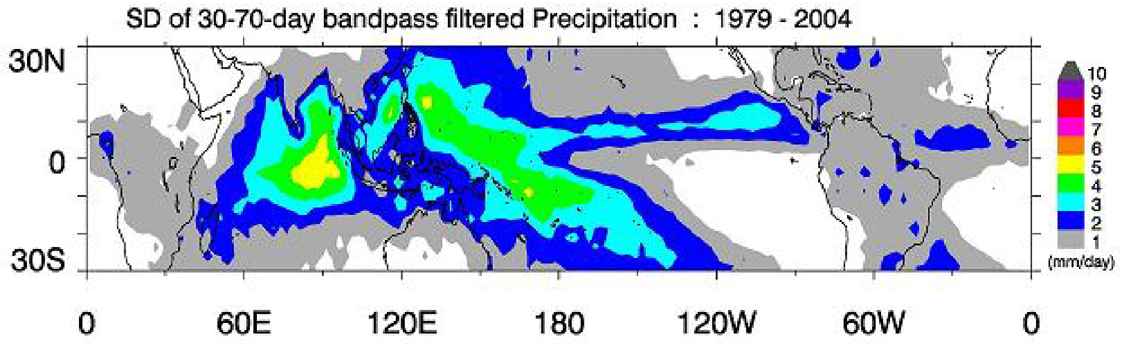

Fig. 8. Standard deviations of the 30-70-day bandpass filtered anomaly of the CMAP (Xie and Arkin 1997) precipitation from 1979-2004.

5. Schedule of the cruise

The expected schedule for the MISMO cruise is listed below as well as cruise track in Fig. 9. These dates and ports may be subject to change due to various reasons.

Year 2006	Oct. 4	Depart Sekinehama, Japan (MIRAI's mother port)
		Leg - 1
	Oct. 15 - 16	Call at Singapore
		Deployment of sub-surface ADCP moorings, m-TRITON buoys, and profiling floats
	Oct. 26 - Nov. 24	Stationary Intensive observation at (0, 80.5E)
	Nov. 27 - 28	Call at Male, Maldives
		Leg-2
		Recovery / Deployment of TRITON, m-TRITON, and sub-surface ADCP moorings in the Indian Ocean
	Dec. 13	Arrive at Singapore

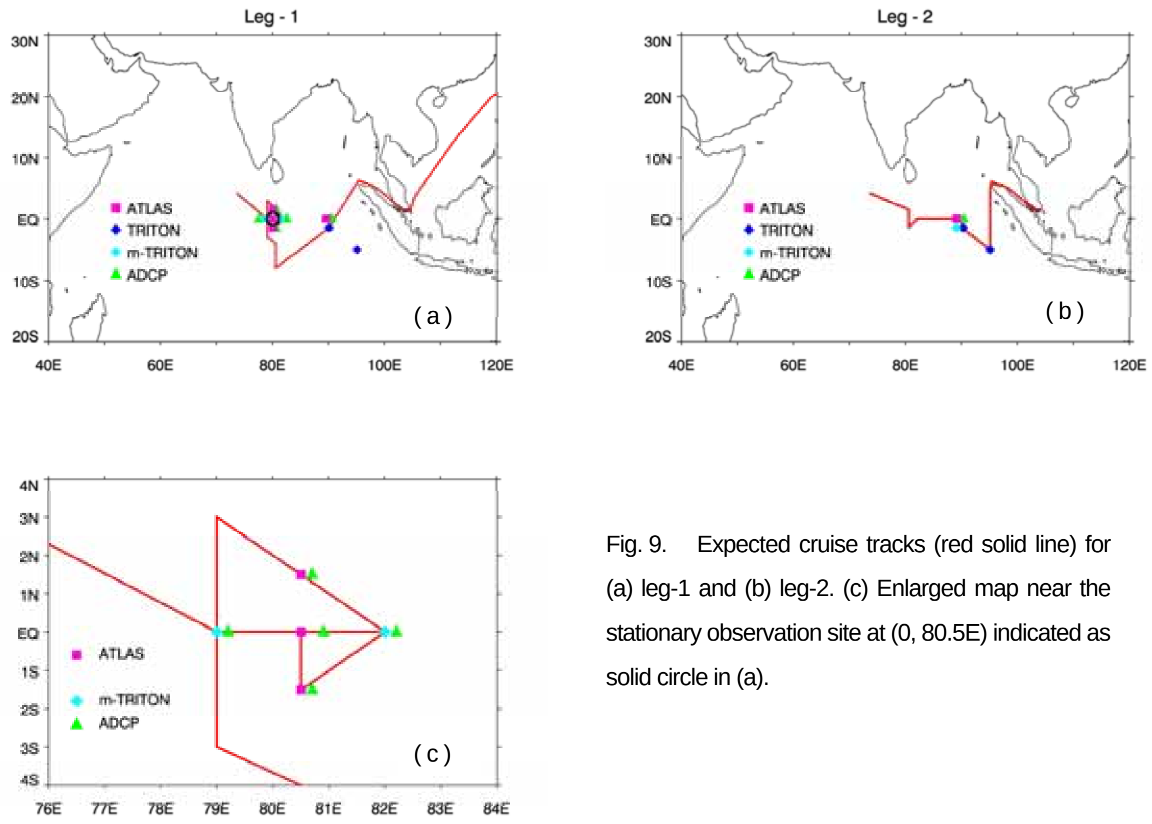

Fig. 9. Expected cruise tracks (red solid line) for (a) leg-1 and (b) leg-2. (c) Enlarged map near the stationary observation site at (0, 80.5E) indicated as solid circle in (a).

6. Measurement systems

6.1 MIRAI Observation systems

In order to capture the precise features of atmospheric and oceanic conditions, various observations listed in Table 2 will be conducted during the cruise.

Table 2. Measurement systems onboard the R/V MIRAI

instruments	remarks (operation, observed parameters, etc.)
5.3-GHz scanning Doppler radar	3-d reflectivity and Doppler velocity (1 volume scan= 7.5min)
Radiosonde (Vaisala RS92-SGP)	atmospheric sounding (8 times / day during IOP in leg-1, 2 times / day during leg-2)
Ceilometer	cloud base height
Total sky imager	cloud images/fraction in daytime
Surface met station	pressure, air/sea temperature, humidity, wind, precipitation, downward short / long wave radiation
Infrared SST Autonomous Radiometer	skin sea surface temperature
Float-type skin-SST sensor	skin sea surface temperature (only during IOP in leg-1)
Turbulent flux measurement system	3-d wind, latent/sensible heat, and momentum by eddy correlation method
Wind profiler	vertical wind profile in the lower troposphere (~5km)
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 (20 times during leg-1)
Radiosonde with hygrometer and ozone sensor	vertical profile of water vapor and ozone (20 times during leg-1)
Disdrometer	size distribution of raindrops and rainfall intensity
Rain sampler	rain sampling for stable isotope measurement
Surface water monitoring system	sea surface temperature and salinity
ADCP (Acoustic Doppler Current Profiler)	ocean current down to 400 m
CTD (Conductivity-Temp.-Depth meter) with water sampler	vertical profile of temperature and salinity (every 6 hours down to 500m during IOP in leg-1)
Biogeochemical analysis	Nutrients, pH, and TCO2 (4 times a day in the first 5 days, subsequently once a day)
Compact-CTD with Chlorophyll sensor	vertical profile of temperature, salinity, dissolved oxygen, fluorescence, light intensity, and turbidity. (every 3 or 6 hours down to 200m during IOP in leg-1)

6.2 Mooring systems

ATLAS and TRITON buoys

Surface buoy network deployed in the equatorial Indian Ocean is an essential of the current experiment, as they provide long-term variation of surface meteorological parameters as well as sea temperature, salinity, and surface current with high resolution data (10 minutes interval). Therefore, maintenance of surface meteorological sensors as well as temporal optional sensor attachment may be carried out.

In addition, newly designed two m-TRITON buoys will be deployed at (0°, 79°E) and (0°, 82°E) during the Leg-1. At the end of Leg-1, two m-TRITON buoys above mentioned will be recovered. Instead, one m-TRITON buoy will be deployed at (1.5°S, 90°E) during the leg-2 for long-term comparison with current TRITON buoy data.

Sub-surface ADCP moorings

To examine the oceanic responses to the westerly wind burst accompanied with the MJO and the heat budget of ocean mixed layer, temporary sub-surface ADCP mooring network will be deployed near the stationary site at (0°, 79°E), (0°, 82°E), (1.5°N, 80.5°E), and (1.5°S, 80.5°E) during the leg-1. In addition, we will also maintain ADCP mooring at (0°, 90°E) in the leg-2.

6.3 Sub-surface floats

Argo float

The network of Argo floats deployed over the world ocean as a part of Argo project under the international cooperation can provide the information on large-scale oceanic variations. Some Argo floats will be deployed during the cruise.

Profiling float

In order to capture the ocean response to the MJO, specially programmed profiling floats, that park at 500 m depth and sample the data once a day, will be deployed at (8°S, 80.5°E), (6°S, 80.5°E), (4°S, 80.5°E), (3°S, 79°E), (1°S, 79°E), (0.5°S, 79°E), (0°, 79°E), (0.5°N, 79°E), (1°N, 79°E), and (3°N, 79°E).

6.4 Land-based observational sites

Maldives

As the MJO propagates eastward, zonal extension of the observational area is strongly desired. The Maldives Islands along 73°E is the most appropriate site for this purpose. The following observations will be carried out under the cooperation with the Maldives officials.

a. Gan Island (0.7°S, 73.2°E)

Radiosonde	2 times / day Sep. 25 - Oct. 24, Nov. 26 - Dec. 25, 2006
	4 times / day Oct. 25 - Nov. 25, 2006
GPS Meteorology	water vapor measurement
Surface Meteorology	pressure, temperature, humidity, radiation, wind, precipitation
Ceilometer	cloud base height measurement
Disdrometer	side distribution of raindrops
9.4-GHz Doppler radar	3-d reflectivity and Doppler velocity

b. Hulhule Island (4.2°N, 73.5°E)

Radiosonde	2 times / day Oct. 25 - Nov. 25, 2006
GPS Meteorology	water vapor measurement
Surface Meteorology	pressure, temperature, humidity, radiation, wind, precipitation

c. Kadhdhoo Island (1.9°N, 73.5°E)

Surface Meteorology	pressure, temperature, humidity, radiation, wind, precipitation

Sumatera, Indonesia

Collaboration with Equatorial Atmosphere Observatory at Sumatera, Indonesia is planned.

6.5 Other observations

Satellites

To capture the large-scale conditions, satellite data is inevitable. For example, following satellite data is expected to be available:

MTSAT and INSAT (brightness temperature), TRMM (precipitation), DMSP-SSM/I (water vapor), QuikSCAT (surface wind), CloudSat (3-d clouds), Aqua (3-d temperature and humidity), and so on.

6.6 Numerical models

Not only observational instruments, but also high resolution numerical model should be used to interpret the physical process. Several cooperative work with model group have now being discussed.

7. Participants

7.1 Undertaking Institutes

JAMSTEC	Institute of Observational Research for Global Change (IORGC)
JAMSTEC	Marine Technology Center (MARITEC)

7.2 Collaborative Institutes with JAMSTEC under the MOU

National Institute of Oceanography, India
Department of Meteorology, Maldives

7.3 Institutes approved by the R/V Mirai Steering Committee

Hokkaido University
Kyoto University
Nagoya University
National Institute for Environmental Studies
Okayama University
Osaka Prefecture University
Tohoku University
Toyama University
Yamaguchi University

7.4 Technical Staff

Global Ocean Development Inc.
Marine Works Japan, Ltd.

8. Contacts

Further information and update of this experiment can be obtained by :

mail to “mismo@jamstec.go.jp“
or
web site at “ http://www.jamstec.go.jp/iorgc/mismo/ “.

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