United States Participation in the 2011 Cooperative Indian Ocean Field Experiment

Introduction

In recognition of the important role that the tropical intraseasonal variability (TIV), especially the Madden-Julian Oscillation (MJO), plays in weather and climate, scientists from Japan, Australia, the United States, China, India, and France have recently started a dialogue on a field experiment in 2011 targeting physical processes of the MJO/TIV over the Indian Ocean. The objective of this field experiment is to collect in situ observations to advance our understanding of the MJO/TIV, with the ultimate goal of improving intraseasonal and seasonal prediction. This document describes the background and scientific rationale for this experiment, and the motivation and justification for the US participation. Improvement in model capability of simulating and predicting the MJO/TIV will benefit the forecasts of hurricanes, the North American monsoon, ENSO, and extreme temperature and rainfall events over North America. The US contribution, including a research vessel of Doppler radar capability, will be critical to the success of the field experiment.

Background

There has been mounting evidence for the importance of the MJO/TIV in weather, climate, and their connection. The MJO often spawns tropical cyclones, modulates their activity in all ocean basins, and hence affects their prediction, including hurricanes near the Americas. They affect the onset and intraseasonal fluctuations of the monsoons and rainfall in general over Asia, Australia, Americas, and West Africa. As efficient sources of stochastic forcing, the MJO/TIV influence the initiation, intensification, and irregularity of ENSO. The Indian Ocean Dipole Zonal Mode (IODZM), while modulating MJO activities, can be affected by the MJO through nonlinear air-sea interaction. The MJO strongly influences the Indonesian Throughflow (ITF), the main artery connecting the Pacific and Indian Oceans. Tropical large-scale convective centers organized by the MJO/TIV excite teleconnection patterns that emanate into the extratropics and thereby induce remote fluctuations in rainfall and temperature. Some of the extreme rain events in southern California are directly related to such teleconnection patterns (e.g., the "atmospheric river" of water vapor) induced by the MJO. The global angular momentum, the Earth's rotation rate and the length of the day all fluctuate on the intraseasonal timescale because of the MJO/TIV. The MJO also causes intraseasonal perturbations in chemistry and the biosystem in the atmosphere (e.g., ozone, CO_2, and aerosols) and ocean (e.g., chlorophyll). There is of little doubt that accurate prediction of the MJO/TIV would benefit many fields in the Earth system on both weather and climate scales in the US as well as the rest of the world.

The current prediction skill for the MJO is, however, very low (< 10 days) compared to its prediction limit of more than 20 days based on MJO predictability studies. Deficiencies in prediction models are the main reasons for the poor prediction skill. There is a great prediction potential on the intraseasonal scale related to the MJO that has yet to be fully exploited. Through their connections to ENSO, the MJO/TIV also affect seasonal prediction. The key to enhancing intraseasonal-seasonal prediction is improvement of model physics relevant to the MJO/TIV. This has been proven very difficult mainly because of our poor understanding of the processes involved. The most striking testament of this difficulty is the inability to reproduce the MJO/TIV by most models used for climate projection. The goal of developing a seamless weather-climate prediction system cannot be achieved without the MJO/TIV being fully represented and well predicted in numerical models. The MJO/TIV have become standard model validation targets and their numerical reproductions are commonly taken as milestones of model improvement.

The importance of the MJO/TIV in global weather and climate and the urgency for expediting their studies to improve intraseasonal-seasonal prediction are well recognized by the research community. The THORPEX International Science Plan[1] lists the MJO as one of the targets in its research objectives. Two international workshops organized by ECMWF[2] and WCRP/THORPEX[3] in 2003 and 2006, respectively, have focused on the MJO/TIV. The WCRP/THORPEX workshop specifically recommended a field experiment, preferably in the Indian Ocean to target MJO initiation. Substantial improvement of extended-range/subseasonal forecasts of the MJO/TIV is one of the overarching goals of the WCRP-WWRP/THORPEX international initiative Year of Tropical Convection (YOTC)[4]. US CLIVAR has established an MJO Working Group[5] with tasks on several issues related to simulation and prediction of the MJO. The important role of the MJO in modulating tropical cyclone is emphasized in a recent report of the US Climate Change Science Program[6].

Scientific Rationale

A life cycle of the MJO typically begins over the equatorial Indian Ocean. There, atmospheric deep convective systems start to be organized into a large-scale center that, in coupling with the large-scale circulation, propagates eastward into the Pacific Ocean. Skills in predicting such an initiation in MJO convection are more limited than predicting MJO propagation. Initiation of MJO convection therefore presents a difficult challenge to the understanding and predicting the MJO. This difficulty is magnified by a stunning lack of direct observations of the atmospheric vertical structure over the Indian Ocean. As a result, initiation of MJO convection is among the least understood aspects of the MJO.

Possible factors affecting initiation of MJO/TIV convection include atmospheric energy recharge, multi-scale interaction of convective systems, influences from extratropics or from upstream by previous circumnavigating MJO/TIV events, air-sea interaction, and stochastic processes. There is no agreement from data analyses, theories, and numerical simulations as which one might be more probable than others. These mechanisms can be

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[1] http://www.wmo.ch/pages/prog/arep/thorpex/documents/brochure_e.pdf
[2] http://www.ecmwf.int/newsevents/meetings/workshops/Intra-seasonal_variability/index.html
[3] http://cdsagenda5.ictp.trieste.it/pdf_display.php?ida=a04205
[4] http://www.wmo.ch/pages/prog/arep/wwrp/new/documents/WCRP_WWRP_YOTCscienceplan_final.pdf
[5] http://www.usclivar.org/Organization/MJO_WG.html
[6] http://www.climatescience.gov/Library/sap/sap3-3/final-report/

consolidated into two competing but not mutually exclusive hypotheses:

A. Dynamical (or external) Initiation: Intraseasonal convective centers are initiated mainly by changes in the large-scale circulation pattern due to influences from either the extratropics or upstream (west) that efficiently organizes deep convection over the equatorial Indian Ocean;

B. Convective (or local) Initiation: Intraseasonal convective centers are initiated mainly by convective self-organization over the Indian Ocean, due either to atmospheric energy buildup, multi-scale interaction, air-sea interaction, or stochastic processes, into a structure with optimal upscale effects on the large-scale circulation.

Once an intraseasonal convective center is initiated by either hypothesized process, it would engage in a full coupling with the large-scale circulation. Such convection-circulation coupling is central to the dynamics of the MJO/TIV.

Quantitatively testing these hypotheses, evaluating all possible mechanisms, and forming new ideas on initiation of MJO/TIV convection require systematically exploring the evolution of convective cloud, the large-scale atmospheric circulation and the ocean mixed layer from pre- to post-initiation phases of the MJO/TIV. This demands concurrent observations of continuous time series in the vertical structure of the atmosphere, air-sea fluxes of momentum, heat, freshwater, and the upper ocean. Particularly essential are vertical profiles of convective instability and inhibition, convective cloud and precipitation structures, heat and moisture budgets, and winds. Data assimilation products, satellite observations, and numerical simulations all provide necessary and complementary information. The core data needed, namely, a continuous evolution in vertical structures of atmospheric convective systems and their heat/moisture budgets over the open ocean, can be reliably acquired only from field campaigns. No such data are available to date over the equatorial Indian Ocean[7].

Historically, observations from field experiments covering different climate and weather regimes form an irreplaceable foundation for the improvement of numerical models. The steady, however slow and painstaking, process of improving traditional cumulus parameterizations in weather and climate models, the design of super-parameterizations, and the birth of global cloud-resolving models would all have been impossible without the repeated usage of in situ observations from previous field experiments (e.g., GATE, TOGA COARE and many others). Every single carefully crafted field experiment with a narrowly focused topic, even if limited in its coverage, adds invaluably to the breadth of the observational database collectively crucial to the improvement of numerical models. The recent advances in global high-resolution models that explicitly resolve both large-scale circulation and convective systems directly observable by field campaigns would make field observations much more valuable in model validation and hypothesis testing.

In addition to the MJO/TIV, there is a broad range of pressing climate issues and studies

[7] INDOEX and JASMINE did not target the MJO/TIV.

that may benefit from in situ data in the equatorial Indian Ocean. They include the reason for and the impact of more rapid surface warming in the Indian Ocean than in other tropical oceans, effects of aerosol on cloud and precipitation, cloud-water vapor feedback to a changing climate, etc. A field experiment in the equatorial Indian Ocean with an emphasis on the MJO/TIV but embracing other climate issues is long overdue and would be an excellent investment in climate studies. In short, the time is ripe for a field experiment in the equatorial Indian Ocean that focuses on the single largest, repeatable convective structure on the planet, the MJO, and benefits climate studies in many ways.

Preliminary Plan

The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) has recently committed R/V MIRAI for a field experiment in the Indian Ocean in 2011. The minimal design of the experiment (see figure) would be to form a triangle sounding array consisting of R/V MIRAI and two islands of Maldives (Gan 0.7°S, 73.2°E and Hulhule 4.2°N, 73.5°E) for budget estimates of heat and moisture, a Doppler radar onboard of R/V MIRAI, surface rainfall measurement at three islands (Gan, Hulhule, and Kadhdhoo 1.9°N, 73.5°E) and nearby moorings, surface flux and oceanographic measurement from R/V MIRAI and nearby moorings. A planned duration of the experiment is about 50 days between November 2011 and January 2012.

MISMO, a field experiment in the Indian Ocean conducted by JAMSTEC in 2006, has demonstrated the shortcomings as well as values in observations collected from such a minimal design. The major shortcoming with a single research vessel is a limited duration. A 50-day period cannot guarantee the full coverage of an MJO convective initiation, because of the wide range of the MJO period (30 to 90 days). With its duration of 33 days, MISMO missed a major MJO event. International participations in the 2011 experiment may help overcome this shortcoming. Additional research vessels can prolong the experiment by rotating with R/V MIRAI on station. Doppler radar is essential for understanding the nature of the convective systems that form in the initial stages of the MJO/TIV and constraining the budget estimates. Other countries (Australia, China, India, France) can make valuable contributions to the experiment. None of them, however, can offer research vessels with Doppler radar capability.

A US contribution to the experiment with a research vessel of Doppler radar capability (preferably R/V Ron Brown) is therefore sorely needed. This and onboard atmospheric soundings of at least 4 times a day for 50 days to rotate with the R/V MIRAI would extend the experiment duration to 100 days and thereby optimize the opportunity to fully capture an MJO convective initiation process without compromising data quality. Other measurements can be included onboard the US research vessel (e.g., oceanography, remote sensing for satellite data validation, aerosol). The cruise would also help with implementation of the Indian Ocean moored array (RAMA) via deployment of additional moorings in the region. Targeted enhancements to RAMA for the duration of the experiment would expand the dimension of the data set to advance our understanding of the atmosphere-ocean environment in which MJO/TIV convection is initiated.

This field experiment can benefit tremendously from existing observations in the tropics. The mooring array that is under development in the Indian Ocean (RAMA) and the Indian Ocean Observing System (IndOOS) in general provide excellent background information at the surface and in the upper ocean. A program HARIMAU (Hydrometeorological Array for ISV-Monsoon Automonitoring) has been established over Sumatra since 2006 for long-term monitoring the MJO/TIV and monsoon with radar, soundings, and wind profilers. The A-Train satellites provide repeated snapshot information of vertical profiles in cloud, aerosol, and precipitation that has been proven valuable to document and understand vertical structures of tropical convective systems. Only the field experiment, however, can fill the gap of the missing element essential for the study of the MJO/TIV, namely, a continuous time record of the atmospheric vertical structure over the central equatorial Indian Ocean.

A proposal has been independently submitted to the DOE ARM Program for a field experiment at Manus (147˚E, 2˚S). This field experiment, motivated also by the importance and a lack of understanding of the MJO, will deploy a C-band mobile radar, atmospheric soundings, and the standard ARM ground observational instruments at its Manus site for six months from October 2010 to March 2011. Dialogues among the scientists interested in the Manus and Indian Ocean experiments have begun to explore the possibility to coordinate between the two. It would be ideal if the two could be conducted simultaneously so that at least one MJO event will be covered from its convective initiation to mature phases downstream.

All observations and numerical model products (data assimilation, prediction, simulations) related to the field experiment will be collected under the protocol of YOTC. A hallmark of the YOTC protocol is the integration of high-resolution (including cloud-system resolving) numerical modeling, satellite measurements, field-campaign measurements, and theoretical-dynamical insights. This approach is intended to add value to field campaigns in the following way. Extensive numerical experimentation would take place *prior to the field phase* in order to sharpen and add to the scientific objectives, unify satellite measurements and field-campaign measurements, and be a practical basis for improved prediction within the tropics and its interaction with the extratropics. Such activities would continue through the post-campaign analysis phase. In other words, the proposed Indian Ocean field experiment can be an intensive observation phase for an extended YOTC (the present YOTC timeframe is May 2008-November 2009).

Summary

A field experiment in the central equatorial Indian Ocean with a focus on the MJO and tropical intraseasonal variability (TIV) in general is urgently needed and justified because of (1) the importance of the MJO/TIV in weather, climate, and their connection, (2) our poor understanding of the MJO/TIV processes which severely limits our ability of simulating and predicting them, (3) the progress of the study on the MJO/TIV is impeded by a lack of in situ observations in the tropical Indian Ocean, and (4) the proven utility of in situ observations in validation and development of weather and climate models.

An Indian Ocean experiment led by JAMSTEC will be conducted in 2011. Its details are yet to be determined, pending the commitment from other countries. International participations will make it the first multiplatform field campaign in the equatorial Indian Ocean under multinational collaboration in the same spirit of GATE and TOGA COARE. As the only country other than Japan that can offer a research vessel with Doppler radar capability, the US can and should make a crucial and unique contribution to the experiment that will qualitatively enhance the collected observations. Such an unprecedented observation collection will no doubt be a jewel in the study of MJO/TIV and tropical convection in general that, as the GATE and TOGA CAORE data, enables us to advance our understanding of their processes and aid development of weather and climate models. Improving intraseasonal-seasonal prediction, the ultimate goal of this field experiment, will substantially benefit the US as well as the rest of the world.

Encouragement and support from the US weather and climate research communities, funding agencies, and government laboratories for the US participation in the 2011 Indian Ocean field experiment are sincerely sought and highly appreciated.

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Endorsed by the US CLIVAR MJO Working Group