

The Latest on Tropical Atmospheric Disturbances: The MJO

The Madden-Julian Oscillation (MJO) is a major within-season atmospheric disturbance that travels around the world in the tropical belt. Understanding and modeling this disturbance is of great interest to IPRC scientists, who hope to develop procedures for its prediction. In late Fall 2004, several well-known MJO researchers visited the IPRC: **Roland Madden**, senior researcher at the National Center for Atmospheric Research (NCAR); **Julia Slingo**, director of the Centre for Global Atmospheric Modelling at Reading University in England; and **Ken Sperber**, research scientist, Program for Climate Model Diagnosis and Intercomparison at Lawrence Livermore National Laboratory. It was a great opportunity for discussing the most recent findings and challenges in this field of research. Accordingly, **Xiuhua Fu** and **H. Annamalai**, scientists with the IPRC Asian-Australian Monsoon System Team, organized the “Tropical Intraseasonal Variability Mini-Workshop” on November 19, 2004.

Madden gave a historical perspective on his and **Paul Julian’s** discovery of the MJO. During the 1960s, the study of tropical phenomena was blossoming. The stratospheric quasi-biennial oscillation had just been discovered; interest in its governing mechanism abounded and prompted a search for large-scale waves in the tropical stratosphere. In 1966, Yanai

and Maruyama identified waves with a westward phase speed that turned out to correspond to mixed-Rossby gravity waves, consistent with Matsuno’s theory of equatorial waves. Later, Kelvin waves, also predicted by this theory, were identified. Analyzing the Line Island data, Madden and Julian noted disparate results in the 60- and 120-day records. To understand what this might mean, they studied a 10-year record of winds, temperatures, humidity, and surface pressure from Kanton Island. Their analysis of this record, unusually long for the late 60s, was made possible by the new “fast” computers and recently developed Fast Fourier Transform (FFT). To their surprise, they found strong variations with a period of 40–50 days. Co-spectra revealed the zonal winds at 850 hPa and 150 hPa were out of phase. Madden and Julian interpreted the phenomenon at first as zonal circulation cells: Because the data were not seasonally stratified, the coherent relationship between the zonal and meridional winds on intraseasonal time scales went unnoticed. Though much has been learned about the MJO since its discovery, Madden mused at

the end his talk, “Much still remains a mystery, and we still cannot explain why the MJO has this time scale, why it propagates eastward, and why it has this very large spatial scale. The more observations we gather, the more complex the disturbance is becoming.”

Slingo raised several challenges in modeling the MJO. First, current cloud schemes represent only two types of clouds and cannot capture the important MJO cloud build-up from cumulus to cumulus congestus to cumulonimbus stages. Research conducted at her center revealed that increasing vertical resolution in the free troposphere resolves the freezing level better and gives a more realistic representation of a tri-modal cloud distribution; this, in turn, improves the MJO in the Hadley Centre climate model. Second, to understand the physics of the MJO better, Slingo believes air-sea coupled models are needed. Third, the suppressed phase of the MJO needs more investigation. For instance, since the cumulus congestus clouds have a strong diurnal cycle, the cycle needs to be resolved to accurately represent the rise in sea surface temperature (SST) that precedes deep



Visiting scientists at the MJO workshop (from left) Fritz Schott, Ken Sperber, Julia Slingo, Tony Slingo, and Roland Madden.

convection. To resolve the SST change, high vertical resolution (about 1 m) is needed in the ocean mixed layer.

Sperber presented an analysis of the MJO in coupled and uncoupled models. Most of the models had difficulty in simulating variance patterns of daily and intraseasonal outgoing longwave radiation and the eastward propagation of MJO convection. Flux-adjusted coupled models using the ECHAM4 atmospheric GCM gave credible simulations of the MJO, including the lead-lag relationship between convection and SST, and the vertical structure of divergence and humidity. Similar to observations, low-level moisture convergence and free-tropospheric interactions were central for maintaining the eastward propagation of the simulated MJO. Unanswered questions include why a systematic MJO develops in some models and not in others, and why the oscillation is strong in some years and weak in others.

The talks by IPRC scientists are listed on our website at iprc.soest.hawaii.edu/meetings/workshops/iprc_tropical_intraseasonal_vari.htm.

A lively discussion followed the presentations. The gist was that global reanalysis data have given a quite good understanding of the large-scale dynamics of the MJO: the disturbance is manifested as a coupled Rossby-Kelvin wave. How the dynamics interact with relevant physical processes, however, is not well understood. The role of extra-tropical events in the evolution of the MJO remains unclear: Convection is observed to be excited by an upper-level trough over the Indian Ocean, which brings in energy from mid-latitudes. Perhaps the biggest unknown is what

sets the MJO in motion—according to Slingo, “What starts it is the holy grail. Once one is able to start the MJO in a model, the oscillation continues.” Though plenty of challenges remain, Slingo summarized optimistically, “At least we have models now that produce the MJO and that take it slowly enough through the (Pacific) warm pool.”

Tracking Indian Ocean Climate

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The Indian Ocean is taking an ever more important place in Earth’s climate system, climatologists are finding. For one, the seesaw in the east-west sea surface temperature (SST) contrast may affect not only rainfall in regions bordering the Indian Ocean but in regions as far away as North America. For another, from 1992–2000 the average SST of the Indian Ocean rose by approximately 0.25°C, the largest warming of any of the world’s oceans.

It is thus not surprising that scientists on two international climate panels (CLIVAR Asian/Australian Monsoon and CLIVAR Indian Ocean panels) recognized the need to identify gaps in their knowledge of ocean-circulation processes in the Indian Ocean as they relate to the climate system and to improve capabilities in modeling these processes. The panels also recognized that simulation experiments could contribute information to the observational and diagnostic studies for developing an *in situ* observing system in the Indian Ocean. To lay the groundwork for such

information gathering, **H. Annamalai** and other IPRC researchers organized the “Indian Ocean Modeling Workshop” November 29–December 3, 2004, at the East-West Center in Honolulu. More than 70 participants from 10 countries attended.

The workshop opened with a celebration of the 60th birthday of IPRC Director **Julian McCreary**, a leading theoretician and ocean-modeler. Talks by friends and colleagues reviewed his many contributions to understanding the circulation of the global oceans and provided a broad background to the specific topics of the workshop—monsoons and the Indian Ocean.

The presentations included reviews of regional climate and ocean dynamics, diagnostic studies and results from forced, stand-alone ocean models and from coupled ocean-atmosphere models. The talks and discussions demonstrated that scientists are capable of simulating the observed behavior of the Indian Ocean and its role in the climate system, such as the large-scale variability of surface currents in response to basin-scale variations in the monsoon and its seasonally reversing winds. They can also simulate realistically the reversing cross-equatorial winds, the zonal winds during monsoon transitions, and the relatively steady trade winds of the Southern Hemisphere. Interannual variation in currents associated with the Indian Ocean Dipole is also simulated reasonably well (see www.jamstec.go.jp/frgc/whatsnew/2004/1227/index_e.html).

Present-day ocean and coupled models, however, do not simulate well some of the most important regional climate phenomena. Because the Asian

landmass blocks currents near 25°N and there is an opening to the Pacific near the equator through the Indonesian archipelago, the Indian Ocean has a unique, three-dimensional, overturning circulation in its uppermost layers. This circulation plays a crucial role in the ocean-atmosphere heat budget and its variability. Aspects of this unique circulation and its variability are not understood and not modeled well, for example,

- the upwelling and subduction processes that connect the horizontal surface and subsurface current systems;
- the thermodynamics of thin low-salinity surface layers prevalent beneath some of the most important atmospheric action centers (e.g. Bay of Bengal, Indonesian Seas);
- the dynamics and thermodynamics of the so-called Eastern Gyral Current and its relationship to the origin and maintenance of the Leeuwin Current along the coast of Australia, which is a key element of the regional climate system;
- the relationship between the surface Somalia Current and the monsoon-driven equatorial Rossby waves, which seem to propagate to deeper levels in the western ocean.

All these processes affect SST and feedbacks to the atmosphere. For instance, the Indian Ocean Dipole and intraseasonal oscillations are important coupled ocean-atmosphere modes. The above shortcomings in the ocean component will need to be

resolved before coupled models can realistically simulate these phenomena. Better modeling will come from a better understanding of the physical processes based on observations.

The first results of the observing-system simulation experiments were also presented at the workshop. Model runs had started after the February 2004 meeting of the CLIVAR/GOOS Indian Ocean Panel, at which the planning took place for the Indian Ocean sustained ocean climate observing system. The system will have an integrated mooring array consisting of Argo floats, XBT lines, surface drifters and tide gauges. The panel recognized that a basin-scale mooring array is essential to observe the fast, upper-ocean fluctuations associated with the intraseasonal oscillations. In anticipation of certain problems, compromises to the system had to be made. For example, because

of heavy fishing and anticipated vandalism, surface moorings were not planned near the eastern boundary and in a few other places. Moreover, the southwestern Indian Ocean is poorly covered owing to its remoteness. The modeling experiments helped to answer such questions as What are the consequences of the compromises? Does the plan have the best possible mixture of Argo and XBT sampling to complement the moored array?

The simulation experiments ranged from evaluating the performance of the planned observation-system to determining the ideal set of observations, assuming a “perfect” model. The experiments also evaluated time scales ranging from intraseasonal variability to decadal and longer changes. The results from the experiments improved approaches for integrating different types of

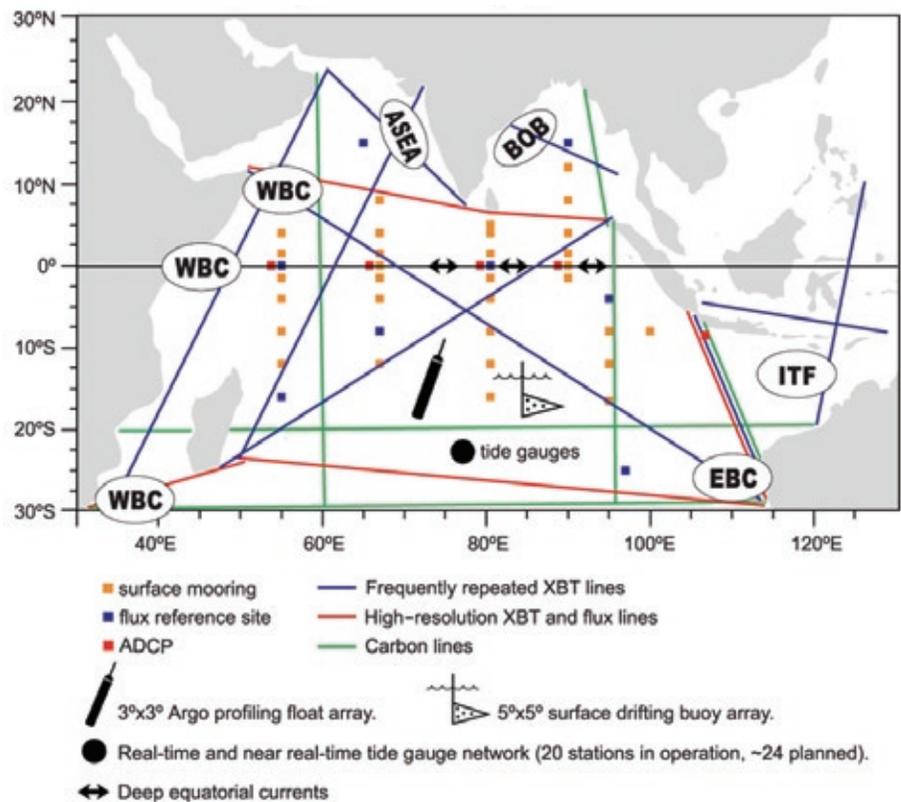


Figure 1. Indian Ocean Integrated Observing System.

observations in regions where upwelling and remote forcing of the thermocline affect SST (e.g. Java/Sumatra upwelling and the SECC ridge), and identified observations critical for observing change in the cross-equatorial heat transport.

The simulation experiments confirmed that the original plan for an initial observing system was adequate, but they also contributed to important modifications to the final plan (Figure 1) that emerged from the following findings:

- The planned system is able to map much of the interannual variability in the Indian Ocean well (high-frequency IX-1 XBT is essential to cover the Indonesian region, and the normal 10-day sampling by Argo floats is adequate);
- Not much is gained by 5-day Argo sampling because it does not fully resolve the intraseasonal time scale;
- Regarding variability in cross-equatorial heat transport, (a) on interannual time scales, variability is determined mainly by zonal wind in the eastern equatorial zone off the equator (Ekman pumping); on longer time scales, surface heat flux in the subduction zone (~100°E, 20–30°S) becomes important; (b) full-depth moorings are not necessary for interannual variability; (c) all the flux reference sites in the plan are helpful for long-term observation of this variability, but the one east of Madagascar (which is needed for intraseasonal-to-interannual variability) is most important.

In sum, the simulation experiments were a useful test of the observing-system plan and contributed to its improvement. Panel members recommended these experiments should continue until their evaluation of the plan is complete.



Workshop organizers (from left) Henry Diaz, Raymond Bradley, Bette Otto-Bliesner, and Jamie Schulmeister.

Ancient and Modern Pathways of Climate Signals

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Sponsors of the workshop on “Tropical-Extratropical Climatic Teleconnections” were the National Science Foundation, Past Global Changes (PAGES), and the IPRC.

Recent research shows that climate changes in regions that are far apart are often linked. An excellent example is the tropical El Niño–Southern Oscillation (ENSO) that brings about anomalous weather patterns around the globe. Changes in mid-latitude Pacific climate and sea surface temperatures (SSTs) feed back to the tropics through the ocean circulation; changes emanating from the western tropical to high-latitude Pacific can have a global signature. Climate changes in the North Atlantic may lead to synchronous and phased climate responses in the tropical Atlantic, the Southern Hemisphere and even in the far away western North Pacific. Although the recent global impacts of ENSO and other natural climate signals are becoming evident, the teleconnections—the atmospheric and oceanic pathways and mechanisms by which these signals affect climates in far away regions—are still not fully understood.

To bring together atmospheric scientists, oceanographers, and paleoclimatologists on this topic of telecon-



Participants of the “Tropical-Extratropical Climatic Teleconnections” workshop gather in the Japanese Gardens of the East-West Center.

nections, the American Geophysical Union held a Chapman Conference on “Tropical-Extratropical Climatic Teleconnections, A Long-Term Perspective” February 8–11, at the East-West Center in Honolulu, with the IPRC as host. The meeting was dedicated to the late **Geoff Seltzer**, the 1998–2004 leader of PAGES Pole-Equator-Pole-1 focus. Seltzer had originated the idea of a Chapman Conference to help remove barriers that separate researchers studying distant-past and modern climates: The conference was to provide scientists of modern climate with a better understanding of paleoclimate records, and paleoclimatologists with the opportunity to place their records into the larger context of climate processes. Over 65 specialists in climate and ocean dynamics and in paleoclimate attended the conference from 8 countries. The group included experts in observations, theory, and modeling of modern atmospheric and oceanic teleconnections between the

tropics and extratropics, and experts in analyses of past records of interannual-to-millennial climate variability. Topics centered on tropical climates, monsoon dynamics, mid-latitude circulation, and ocean dynamics.

The workshop’s paleoclimate presentations showed how useful proxy records are for reconstructing past climate periods, ranging from the last millennium, the Quaternary, to the Pliocene. Records found in ocean-, lake- and peat-sediments, fossil corals, ice cores, speleothems, paleosols, and tree rings reveal connected climate changes in the tropics and extratropics. These climate fluctuations appear on various time scales—over thousand-year periods and over Earth’s orbital phases and solar radiation fluctuations. The causes for climate changes in different periods, however, may differ. Records of changes in tropical SST, for instance, suggest that on orbital time scales, atmospheric CO₂ is a primary factor; on millennial time scales variations correspond to prominent changes in the North Atlantic, such as the fresh-water influx during the Younger Dryas, which evoked a response, though muted, as far away as the western tropical Pacific.

Similarly, well-preserved fossil corals in eastern Indonesia record a cooling event of about 100 years in duration at the same time that an anomalous cold event occurred in the North Atlantic about 8200 years ago. Such synchrony supports the idea that atmospheric teleconnections (and even oceanic teleconnections, see p. 10) rapidly propagate this kind of climate signal to the tropics.

The paleoclimate record of the Asian summer monsoon winds also shows a robust teleconnection between ENSO and North Atlantic climate. Strong monsoon winds correlate with strong winds in the tropical Pacific (La Niña) and warm North Atlantic conditions; weak monsoon winds correlate with a cool North Atlantic, a cooling that includes a southward displacement of the Intertropical Convergence Zone when extensive land- and sea-ice covered the Northern Hemisphere. Antarctic ice cores have different layers that may be tied to variations in moisture sources at low latitudes.

Modern teleconnection pathways and mechanisms, identified through observational diagnostic analyses and

model simulations, provide the basis for understanding the paleoclimate records. The global heat budget constrains the climate system greatly by requiring systematic movement of energy. The major atmospheric heating process and source of atmospheric teleconnections is the latent heat released in precipitation. In the tropics, precipitation patterns are anchored in the land-sea contrasts (monsoons) and SST patterns (ENSO). As ENSO and the monsoons change, the westerlies and storm tracks at higher latitudes change, and so do the precipitation patterns. The monsoons, dominating large areas of the tropical and subtropical climate, result from coupled atmosphere-ocean-land phenomena that are characterized by a strong cross-equatorial atmospheric pressure gradient and regulated by negative feedbacks within the system.

In climate models, teleconnections originating from changes and variations in tropical SST patterns are sensitive to changes in the magnitude of the oscillation between El Niño and La Niña phases and to patterns of warming in the tropical Pacific and Indian oceans. The ocean's thermohaline circulation, too, affects interactions between tropical and extratropical climate. Simulations with a coupled atmosphere-ocean model demonstrate that millennial-scale abrupt climate changes in the model are associated with sustained freshwater addition to the North Atlantic, and are synchronized globally through rapid adjustments in both the ocean and the atmosphere.

The interdisciplinary mix of researchers at this Chapman Conference led to lively discussions and provocative questions; new contacts have

forged new collaborations to study the climate system over longer times. Further meetings are being planned to continue application of paleo-proxy and instrumental data, and numerical modeling of past, present, and future climates to our understanding of climate change and our ability to predict it.

IPRC Hosts Workshop for Upcoming Climate Assessment Report

The Intergovernmental Panel on Climate Change (IPCC) plans to release its Fourth Assessment Report on Climate Change in 2007. Like the previous IPCC reports, this one will reflect the current state of scientific knowledge on climate change and assess the extent to which climate change is human induced. The IPCC assessments are huge efforts that extend over several years. On March 1–4, the IPRC hosted a major meeting that provided a forum for the scientific community to present results on analyses of climate change seen in the global circulation models



Meeting organizer Gerald Meehl with IPRC's Axel Timmermann at the IPCC Workshop.

used for the IPCC report. The meeting was convened by U.S. CLIVAR and took place at the East-West Center in Honolulu.

Meeting organizer **Gerald Meehl**, senior scientist at the National Center for Atmospheric Research, explained the process for developing the large part of the report content dealing with model simulations: "Fourteen research centers ran simulations with ocean-atmosphere coupled climate models under 20th century climate conditions and three different 21st century greenhouse-gas emission scenarios. Simulations with these models were also run with greenhouse gases



Opening the "Workshop on Analyses of Climate Model Simulations"



Lead authors of IPCC Working Group 1 at the East-West Center.

stabilized at current levels to determine how much we are already committed to future climate change. The outputs from these simulations were then posted on the internet so that climate researchers worldwide could analyze the simulations according to their interests.”

At the workshop, scientists presented their findings on analyses of these global climate simulations. Among the 125 scientists from 21 countries who presented their analyses were four IPCC scientists: **H. Annamalai, Kevin Hamilton, Markus Stowasser, and Axel Timmermann.** The ‘input’ from the papers that will come out of the work discussed at this conference is a key part of the report.

The link between greenhouse gas emissions from human activities and global warming is becoming clearer. “Reconstructions of past temperatures from proxy records, such as tree rings, sediments, and corals, all tell us that temperatures during the last 1,000 years were never as high as during the last decades,” says Meehl. “Earth’s temperature, however, is affected by

different things, for example, aerosols, volcanic eruptions, and changes in radiation from the sun. The beauty of these ocean-atmosphere coupled models is that we can do experiments to isolate the response of the climate system to specific individual forcing factors. We can run all these elements affecting temperature together in the models, and then separately. This gives us the fingerprint of each element on climate change. What we find is that if you pull out greenhouse gases in the simulations, it does not get as warm, and sea level does not rise as much.”

A peculiar aspect of global temperature evolution in the 20th century has puzzled scientists. During the first part of the 20th century, Earth got warmer, then temperatures leveled off or even dropped a bit, only to rise again in the last 30 years. Because these fluctuations were poorly understood, some scientists questioned the link between increased greenhouse gases and warming.

“Now we can say that the early 20th century warming was mostly due to increasing solar radiation, and temp-

eratures leveled off after WWII when there were large increases of sulfate aerosols whose cooling effects masked the effect of increasing greenhouse gases. These aerosols started to be reduced in North American and western Europe in the 1970s because of the recognition of their damaging effect on the environment, while greenhouse gases concentrations continued to increase. It was then that it became clear that the increase in global surface temperatures was due mostly to greenhouse gas emissions from human activities.”

The upcoming report will state climate information in probabilities, something that progress in modeling has made possible. “Many of our climate change forecasts will be worded similar to weather forecasts, for example: ‘By the year 2050, there is an 80% chance that average temperatures will have gone up by three degrees in a particular region,’” explains Meehl.

“Extreme climate events matter a lot to people, and the report will also assess new research on what we can expect with such events,” said Meehl,

remembering the 2003 heat wave in Europe and the deluge that caused over \$50 million damages to the University of Hawai'i library in October 2004.

The assessment report still has to go through several drafts, including a technical review by outside scientists. Since the report is to provide information to governments, there will be a special summary for policy makers, and participating governments will also review the report. In a plenary session in early 2007, government delegates of the countries participating in the UN Framework Convention on Climate Change Parties, along with the scientists who were the authors, will then adopt the final version of the report.



Implementing iROAM at the Earth Simulator Center: (from left) Takashi Mochizuki, Yuji Sasaki, Toru Miyama, and Yuqing Wang.

Forecasting Climate: The Kyosei-7 Project

IPRC scientists are participating in the Japanese Kyosei-7 Project, an ambitious project to develop a coupled ocean-atmosphere simulation and assimilation system for improving seasonal-to-interannual climate forecasts. In January 2005, project members and scientists from the Frontier Research Center for Global Change held a workshop on “Coupled Model Simulation and Assimilation” in Yokohama. Over 50 scientists from Frontier, the University of Tokyo,

the Japan Meteorological Agency, the Earth Simulator Center, Yonsei University (Korea), and the U.S. National Centers for Environmental Prediction presented designs and results from their climate models. Their presentations showed the headway being made in modeling and assimilation. IPRC scientists **Bin Wang, Shang-Ping Xie, and Haiming Xu** described results from the IPRC global and regional models.

The IPRC regional ocean-atmosphere model (iROAM) has been implemented to run on the Earth Simulator as part of this project and is producing promising results. In a multi-year integration, the model kept the Pacific Intertropical Convergence Zone north of the equator. This is a major accomplishment that many global models still have difficulty achieving. IPRC and other Kyosei-7 researchers also had the opportunity to discuss current challenges and future directions in monsoon research and coupled ocean-atmospheric modeling. Among pressing issues identified are the ability to distinguish atmospheric forcing of the ocean from ocean feedback and to represent stratus clouds and their interaction with the ocean. The Kyosei project is supported by the Japan Ministry of Education, Culture, Sports, Science and Technology.

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