WORKSHOP ON MONSOON CLIMATE SYSTEMS

Toward Better Prediction of the Monsoon

BY KENNETH R. SPERBER AND TETSUZO YASUNARI

The Earth's monsoon systems are the lifeblood of more than two-thirds of the world's population through the rainfall they provide to the mainly agrarian societies they influence. In some cases the monsoon is remarkably regular, for example, over India the interannual standard deviation of the rainfall is about 10% of the annual mean, but the perturbations are strong enough to lead to natural disasters resulting from flood or drought and associated land-use impacts. During the course of the monsoon season there can also be strong variations in rainfall. Intraseasonal (30–60 day) oscillations (ISOs) influence the onset of the monsoon and give rise to protracted active (i.e., enhanced) and break (i.e., deficient) periods of rainfall. Foreknowledge of the active and break phases of the monsoon is important for crop selection, the determination of planting times, and mitigation of potential flooding and short-term drought. Poor simulation of the ISO has been a pervasive problem in all scales of modeling. Though there are exceptions to this latter statement, attempts to translate "success" in simulating the ISO from one model to another have met with limited success at best. Additionally, the poor simulation of ISOs is a limiting factor for medium-range to seasonal forecasting. The success of empirical methods in forecasting intraseasonal variability indicates that there is skill to be gained through improved dynamical models. Observational and modeling studies indicate that the diurnal cycle of radiative heating and surface fluxes over the ocean are rectified onto the intraseasonal time scale, indicating that a synergistic approach to studying monsoon variability is necessary. The diurnal cycle of precipitation and clouds, which directly influence radiative heating and surface fluxes, are also poorly represented, especially in the global models. Thus, it is anticipated that improving the simulation of the diurnal cycle of precipitation

MONSOON CLIMATE SYSTEMS WORKSHOP

WHAT: More than 60 experts gathered to assess the current understanding of monsoon variability and highlight outstanding problems simulating the monsoon.
WHEN: 15–17 June 2005
WHERE: University of California, Irvine

AFFILIATIONS: SPERBER—Program for Climate Model Diagnosis and Intercomparison, Lawrence Livermore National Laboratory, Livermore, California; YASUNARI—FRCGC/JAMSTEC and HyARC/Nagoya University, Nagoya, Aichi, Japan
CORRESPONDING AUTHOR: Kenneth R. Sperber, Program for Climate Model Diagnosis and Intercomparison, Lawrence Livermore National Laboratory, P.O. Box 808, L-103, Livermore, CA 94550
E-mail: sperber1@llnl.gov
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and clouds in global models will contribute to an improved ability to simulate ISOs. Improved understanding and simulation of the diurnal cycle is also important because it influences low-levels jets and the associated transport of moisture as well as the rainfall over regions of complex topography. Furthermore, from a physical standpoint, study and improved modeling of the monsoon is also important because the associated large-scale energy exchange due to the cycling of water vapor in the atmosphere is central to the development of the general circulation of the atmosphere.

Because of the potentially grave societal impacts of monsoon variability on numerous time scales, and because modeling monsoons remains a challenge, the World Climate Research Programme (WCRP) sponsored the first Pan-WCRP Workshop on Monsoon Climate Systems to promote closer interaction between two WCRP projects—Climate Variability and Predictability (CLIVAR) and the Global Energy and Water Cycle Experiment (GEWEX). This effort is part of a new WCRP strategic framework for Coordinated Observation and Prediction of the Earth System (COPES). The urgent requirement of full coordination and cooperation of monsoon-related research activities between these two projects for better understanding and seamless prediction of the monsoon systems was the background of the proposal for this workshop. Improvement of multiscale interactions in global general circulation models (typically used by CLIVAR) is anticipated through the experience gained by GEWEX through its continental-scale energy and water cycle experiments and regional and cloud-resolving modeling. Our workshop[1] consisted of modeling and observations presented by representatives of CLIVAR monsoon panels, GEWEX projects, invited expert presentations highlighting the fundamental physics and dynamics of monsoons, and breakout discussion groups to suggest the future path of monsoon climate research.

Out of necessity, because of the longer time scales considered (CLIVAR based), global climate models (GCMs) that are used for subseasonal, interannual, and climate studies are coarser in horizontal and vertical resolution and are less complex in terms of physical parameterizations than the (GEWEX based) regional climate models (RCMs) and cloud-resolving models (CRMs) that are used for diurnal to subseasonal studies. The diurnal cycle of convection emerged as an important component of the climate system that could be addressed near term through close cooperation between CLIVAR and GEWEX. The diurnal cycle is a forced mode of variability that needs to be adequately captured in order to properly represent the moisture and heat budgets over both ocean and land. It is not uncommon for GCMs to have phase errors of 2–6 h in the time of maximum precipitation compared to observations. The phasing and amplitude of the diurnal cycle of precipitation is typically better represented in RCMs.

CONCERNS. In global GCMs there are numerous limiting factors to the simulation of the diurnal cycle of convection and clouds. Results indicate that adequately resolving the planetary boundary layer (PBL) is important for the fidelity of the diurnal cycle of convection because it is intimately related to the surface diurnal heating that is essential for the organization of cumulus cloud ensembles. Simulations produced by a GCM with an embedded two-dimensional cloud-resolving model in place of a typical convection scheme resulted in a more realistic diurnal cycle of convection. Results suggest that, at a minimum, coupling between the PBL and deep convection is necessary to improve the diurnal cycle in GCMs. At present only the Arakawa–Schubert convection scheme contains a PBL submodel that tends to give a more realistic representation of the diurnal cycle of precipitation. Based on observations over the Amazon region and results from a CRM, a realistic representation of the diurnal cycle of rainfall requires turbulent moisture convergence to be adequately resolved at the top of the PBL. In order to adequately realize this in a GCM it was necessary to increase the vertical resolution in the PBL. Added benefits included an improved representation of the South Atlantic convergence zone and a reduction of SST errors over near-coastal stratocumulus regions.

Increased vertical (and horizontal) resolution will result in more adequately resolving complex orography. This is necessary, for example, over the Maritime Continent to capture diurnal land–sea-breeze influences that extend hundreds of kilometers offshore. Additionally, orography acts to anchor rainfall at specific geographic locations (e.g., the western Ghats, the Burma Highlands, the Tibetan Plateau, and the Philippines). Poorly resolving these orographic anchor points contributes to er-

[1] The meeting was chaired by Tetsuzo Yasunari and Kenneth R. Sperber. Special thanks are given to S. Sorooshian and his staff at University of California (UC) Irvine for hosting the workshop. Funding for the meeting was provided by WCRP, U.S. CLIVAR, and UC Irvine.

rors in the simulation of the amplitude and spatial distributions of rainfall. Thus, a potential benefit of resolving complex orography is better simulation of the mean state. Importantly, reduction of mean state errors has resulted in improved variability [e.g., the Madden–Julian (30–60 day) ISO] in GCMs.

In coupled ocean–atmosphere GCMs, inadequate vertical resolution of the upper ocean precludes adequate representation of the diurnal cycle of SST. In observations over the ocean under light wind conditions, a strong diurnal cycle in SST tends to be present with the late-afternoon cumulus congestus clouds. Thus, an inadequate representation of the diurnal cycle of SST in models can also lead to an unrealistic radiation balance with poor phasing of the surface fluxes compared to observations. This may preclude adequate moistening of the atmosphere by shallow convection, which is a necessary precursor to the deep convection that occurs during the active phase of the ISO.

Errors in the amplitude and phase of the diurnal cycle of precipitation also exist over land, indicating that a better understanding of land–atmosphere interactions is required. It was found that models with weak land–atmosphere coupling tend to exhibit onset and peak diurnal rainfall earlier than in observations. Possible reasons for weak soil moisture–precipitation feedback in models include the inability of land surface schemes to correctly partition energy into the latent and sensible heat components, inadequately resolving the boundary layer (e.g., the need to include weak mixing from above), and convection schemes that are too sensitive to instabilities in the boundary layer.

Low-level jets (LLJs) are an integral component of monsoons that provide the conduit for the transport of moisture that fuels monsoon systems. LLJs exhibit a strong diurnal component that also affects rainfall. LLJs are intimately related to numerous processes, including (but not limited to) PBL processes, large-scale upper-level synoptic influences, land–sea contrast, surface friction, and land surface interactions. Modeling studies indicate that land–atmosphere coupling is particularly strong over India, East Asia, West Africa, and the Great Plains of North America. The complicated interactions involved in the formation and maintenance of LLJs provide an excellent test bed for understanding interactions of a number of physical parameterizations. Improvement in the simulation of LLJs should lead to a better representation of the phase and amplitude of the diurnal cycle of precipitation and thus the warm-season rains. This is a severe test for models given the unique land–sea distributions, surface types, and orographic influences of the disparate monsoon regions.

As noted, RCMs are typically superior to GCMs in representing the diurnal cycle of precipitation. With better-resolved orography and more comprehensive physical parameterizations, important aspects of the monsoon can potentially be realized. Given the much longer time scales considered in GCM simulations, and in many cases the need for ensembles of integrations, it is not viable to simply transplant the more complex RCM physics directly into a GCM. Rather, through a better understanding of the important physical processes it may be possible to develop more complete parameterizations for GCMs.

OBSERVATIONAL PROJECTS. Observations are crucial for understanding processes in the climate system and they provide the foundation for future model improvements. In addition, real-time observations are essential for assimilation into numerical weather (and seasonal to interannual) prediction models, generation of boundary conditions for regional and cloud-resolving models, and parameterization development to simulate unresolved scales. A detailed analysis of the present observing system and observationally based datasets (e.g., reanalysis) was not possible given the time limitations of the workshop. However, concern was voiced over the decay of the present observing system, in particular, the decrease in the number of sites from which routine sondes are launched. New satellite products enable near-global observations of the water and energy cycle on diurnal and longer time scales, and have revealed shortcomings in the representation of the vertical profile of moisture in reanalysis during the life cycle of the MJO. It was stressed that in situ data are needed despite the revolution in satellite data acquisition that is presently underway.

The WCRP Coordinated Enhanced Observing Period (CEOP) program is an example of the approach of multiscale evaluation in terms of time scale and models. The CEOP observations obtained from 2001–04 allow the validation of a hierarchy of models. New concerns were voiced regarding the role of high levels of aerosols over the Asian–African region, and their role in the water and energy cycle. In addition to acting as cloud condensation nuclei (and therefore as heat sources and sinks in the atmosphere), aerosols also perturb the radiation balance. The extent to which these effects feedback to influence the monsoon mean state and variability is an open question.

Over Africa the current sustained observing system is not adequate to 1) evaluate and improve models of key phenomena and processes (e.g., diurnal cycle, heat low, African easterly jet, etc.), 2) support climate prediction and its impact, and 3) validate satellite products. To begin to address these shortcomings the African Monsoon Multidisciplinary Analysis (AMMA) project, a comprehensive observational campaign of the west Africa monsoon, with enhanced and special observing periods in 2005–07, has been launched. In addition to better understanding and predicting the physical system, including atmospheric, oceanic, biological, and chemical (aerosols) components, a major goal is to address socioeconomic impacts due to environmental change, land use, and human activities. The results from AMMA should also help to establish the configuration of a sustained observing system over Africa.

Enhanced observations gathered during the North American Monsoon Experiment (NAME) in 2004 provided an unprecedented set of atmospheric, oceanic, and land surface data for investigating the relationship between moisture transport, monsoon onset, and surge events, as well as for understanding the diurnal cycle of moisture over the ocean and complex terrain. Future NAME project milestones include the assessment of global and regional model simulations of NAME2004, the reproduction of the diurnal cycle of observed precipitation over the core monsoon region, the evaluation of changed parameterizations, the quantification of the relative roles of ocean versus land surface influences, and the improved skill of warm-season rainfall forecasts.

The South American Low-Level Jet Experiment (SALLJEX) was carried out in November 2002–February 2003. Goals included an improved representation of the tropospheric flow on diurnal and longer time scales, resulting from the heretofore sparse sounding network, and a better understanding of the vertical structure of the LLJ and its relationship with mesoscale cloud systems and precipitation. Hindcasts using SALLJEX data showed an improved representation of regional rainfall anomalies in 24-h forecasts.

While there was no formal presentation on the Indian Ocean observing system of buoys, there was strong support for this developing resource for understanding air–sea interaction and the role the Indian Ocean plays in the summer and winter monsoon. The lack of routine Indian Ocean observations is seen as an impediment to progress in understanding key processes and forecasting of the monsoon. VASCO/CIRENE is a series of observational campaigns in the western Indian Ocean just south of the equator in which ocean–atmosphere observations have been or will be taken during the boreal winters of 2005–07. Measurements include those associated with ocean physics, air–sea fluxes, the atmosphere, and ocean biogeochemistry. The experiment will revolutionize our understanding of processes related to 1) the role of the diurnal cycle in the warm-layer formation in the upper ocean, 2) the origin of intraseasonal SST variability, and 3) seasonal to interannual variations of equatorial wave dynamics and ocean mixed layer physics. In addition to process studies, the attendees support and encourage the placement of a sustained monitoring system in the Indian Ocean to improve the basic understanding of the interactions that occur in this basin and to improve predictability. An implementation plan for sustained oceanic observations over the region has been developed by the joint Global Ocean Observing System–CLIVAR Indian Ocean Panel.

In early 2006 the Tropical Warm Pool International Cloud Experiment took place, with Darwin, Australia, as the focal point. From surrounding land and ocean locations, measurements from radiosondes, precipitation and cloud radars, flux sites, aircraft, and satellites were taken. It was the first time that coordinated measurements of cloud properties and their effect on the local environment had been taken in combination with measurements of the heat, moisture, and momentum budgets. The emphasis was on cirrus clouds because they are not well understood. The new data will also be a resource for validating CRMs and parameterization development for global models.

New approaches for investigating systematic model error include the Climate Change Prediction Program Atmospheric Radiation Measurement Parameterization Testbed (CAPT) in which station observations are used to investigate error growth in GCM hindcasts that have been initialized from reanalysis data. Interest in expanding this approach to additional models and for the CEOP (and other) station data has been expressed.

THE FUTURE. Through the working group and plenary discussions, consensus was that more effort and collaboration is needed for improving monsoon modeling and prediction, including the following: 1) correct simulation of diurnal cycles of precipitation and convection; 2) comprehensive modeling of surface interactions, the PBL, and convection; 3) understanding intraseasonal oscillations; 4) impact of atmospheric moisture distribution and transport; 5) the need for more process studies and modeling of the Maritime Continent and the Indian Ocean;

6) sensitivity testing to determine the resolution necessary in global models to simulate the multiscale interactions that dominate the Earth's monsoon systems; 7) the need for improved and sustained observations over sparsely sampled regions of the Tropics; 8) better observations of land surface conditions (e.g., soil moisture, snowcover, and snow depth); and 9) reversal of the decay of the present in situ observing system. Initial implementation of these collaborative tasks within WCRP will occur through a series of targeted workshops that will try to meet in conjunction with (or as components of) planned meetings. A more complete list of recommendations is in the full meeting report, which has been published as a WCRP document and is available on the WCRP, CLIVAR, and GEWEX Web site (e.g., online at http://eprints.soton.ac.uk/19335/01/icpo_pub_103.pdf).

In the near term the emphasis will be on improving the diurnal cycle of precipitation in global models. Given that regional and cloud-resolving models perform much better in this respect, we envision that a better understanding of the factors involved (e.g., physics and resolution) in realistically simulating the diurnal cycle in these models can be translated to an improved representation in global models. This activity will require close interaction in monsoon-related modeling activities under CLIVAR and GEWEX as part of a new Pan-WCRP initiative of monsoon research within the COPES activity. The regional climate modeling studies and the efforts of numerous GEWEX Cloud System Study (GCSS) working groups will provide fertile ground for initiating collaborations with CLIVAR for improving the diurnal cycle of convection in GCMs. Additional input from experts in land–atmosphere interactions, for example, the Global Land Atmosphere Coupling Experiment (GLACE), will be an essential component to this task. Anticipated benefits of improving the diurnal cycle of convection include a better representation of intraseasonal oscillations, the seasonal cycle, interannual variability, and the mean state.

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