BRIDGING WEATHER AND CLIMATE IN RESEARCH AND FORECASTS OF THE GLOBAL MONSOON SYSTEM

BY CHIH-PEI CHANG, NGAR-CHEUNG LAU, RICHARD H. JOHNSON, AND MEIYAN JIAO

A BROADENED WORKSHOP. The Fourth International Workshop on Monsoons (IWM-IV) was the first World Meteorological Organization (WMO) quadrennial monsoon workshop organized under the new World Weather Research Programme (WWRP). The previous emphasis of this workshop series on seasonal and long-term variations was expanded in IWM-IV to encompass all time scales (mesoscale, synoptic, intraseasonal, and climate) that are relevant to the forecasting of high-impact weather events, such as heavy rainfall, tropical cyclones, and droughts, in the world's monsoon regions. In addition to providing a forum for researchers and forecasters to discuss recent advances and current issues, it also served as a means to transfer such knowledge to operational practices at National Meteorological and Hydrological Services (NMHS) in these regions. To facilitate the interactions between the research and forecast communities working in the weather and climate fields, the overall program of IWM-IV included the WMO Training Workshop on Operational Monsoon Research and Forecast Issues, the Second Pan-World Climate Research Programme (WCRP) Monsoon Workshop, and the Fifth Asian Monsoon Years Workshop.

THE FOURTH INTERNATIONAL WORKSHOP ON MONSOONS (IWM-IV)

WHAT: More than 130 researchers and forecasters met to review and discuss recent research and forecast issues ranging from mesoscale weather to climate change in various monsoon regions of the globe

WHEN: 20–25 October 2008

WHERE: Beijing, China

Monsoons are some of the most prominent atmospheric circulation systems and they affect many densely populated regions in the world. The timing of the climatological monsoon cycle, as well as the variations of monsoon intensity and temporal evolution in individual years, exerts a tremendous impact on the agriculture, the economy, and human activities in the affected regions. Monsoon weather also often leads to extreme rain and flooding events that can cause loss of lives. Monsoon circulations span a broad spectrum of space and time scales, which range

AFFILIATIONS: CHANG—Naval Postgraduate School, Monterey, California; LAU—NOAA/Geophysical Fluid Dynamics Laboratory, and Princeton University, Princeton, New Jersey; JOHNSON—Colorado State University, Fort Collins, Colorado; JIAO—China Meteorological Administration, Beijing, China
CORRESPONDING AUTHOR: Chih-Pei Chang, Dept. of Meteorology, Naval Postgraduate School, Monterey, CA 93943
E-mail: cpchang@nps.edu

DOI:10.1175/2010BAMS2984.1

In final form 1 October 2010

from individual convective vortices to planetary-scale circulations, and from the diurnal cycle to long-term climate changes. Because the monsoon flow patterns are strongly influenced by local land–sea contrasts and orography, they exhibit rather distinct characteristics in various geographical regions, such as different parts of Asia, the Americas, western Africa, and northern Australia. In view of the rich variety of processes contributing to monsoon systems in these regions, and the noticeable effects of monsoonal circulations on local weather, researchers and forecasters alike have long maintained a strong interest in advancing our understanding of monsoons.

A series of quadrennial International Workshops on Monsoons (IWM) have been organized by the World Meteorological Organization (WMO), with the objectives of reviewing the recent progress of monsoon research and promoting interactions among monsoon scientists and forecasters. At the fourth workshop (IWM-IV) in this series, there were 63 invited attendees who contributed oral presentations on the status of monsoon studies on topics ranging from mesoscale processes to the impacts of climate change. Representatives from major monsoon and tropical programs, such as those concerned with studies of mesoscale heavy rainfall systems and severe monsoon weather [Terrain-Induced Monsoon Rainfall Experiment (TiMREX), Southwest Monsoon Experiment (SoWMEX), and Pukyong University and Hydrospheric Atmospheric Research Center (HyARC), Nagoya University Observation Network over East China Sea (PHONE)], tropical cyclones in the western Pacific monsoon region [The Observing Research and Predictability Experiment-Pacific Asian Regional Campaign (T-PARC)], and tropical convection [Year of Tropical Convection (YOTC)], as well as various regional projects [Asian Monsoon Years (AMY), African Monsoon Multidisciplinary Analysis (AMMA), Variability of the American Monsoon Systems (VAMOS), North American Monsoon Experiment (NAME), etc.], were present to discuss their plans. These presentations were augmented by 74 posters. A collection of the invited papers after a review and revising process is being published in a scientific monograph entitled *The Global Monsoon System: Research and Forecast, Second Edition*.

The highlights of various scientific presentations and programmatic activities at IMW-IV are summarized in the following sections.

MODEL SIMULATIONS. A strong case was made for the explicit representation of tropical convective clouds in global atmospheric models. These convective cloud clusters play a fundamental role in the tropical circulation and have horizontal scales of less than 10 km. Accurate weather forecasting and climate change projection in the tropical zone would require models with ultrahigh resolution. Preliminary results from the Frontier Research Center for Global Change (FRCGC) in Japan with a 3.5–7-km grid mesh demonstrated the capability of such models in simulating supercloud clusters, Madden–Julian oscillations (MJO), the diurnal cycle in precipitation, and tropical cyclones (Fig. 1).

The simulation of mesoscale and synoptic-scale monsoon weather in long-term climate model integrations facilitates the investigation of interactions among the various scales of monsoon circulations. A review of high-resolution general circulation models (GCMs) at various research and operational centers showed significant progress. For example, the global Geophysical Fluid Dynamics Laboratory (GFDL) model with a grid mesh of about 55 km was able to reproduce the structure and temporal evolution of the East Asian mei-yu–baiu frontal systems during early summer and the severe cold air outbreaks in winter. This model also simulated the diurnal cycle of precipitation and near-surface circulation over many parts of the tropics.

A comprehensive review was presented on the model improvements that could increase prediction skills in various monsoon regions. These model enhancements include higher model resolution, as well as better treatments of air–sea and air–land interactions, convection, clouds, radiation, boundary layer processes, and aerosols. Projections by various models of the impacts of future climate change on different Asian monsoon characteristics were examined. It is particularly noteworthy that the summertime precipitation over East Asia is projected to increase toward the end of the twenty-first century. Model results on the role of aerosols and land cover changes in altering monsoon climates were also discussed. Evidence was presented on the interactions between various types of aerosols and monsoon dynamics, which in turn produce feedback effects on the atmospheric water cycle, and thereby influence the monsoon circulation. The importance of the correct incorporation of air–sea feedbacks in the GCM experiments was noted. Failure to do so could lead to erroneous attributions of causes and effects.

PREDICTION AND PREDICTIBILITY. Several presentations highlighted the applications of modeling tools to the prediction of monsoons in different regions. Precipitation forecasts over East

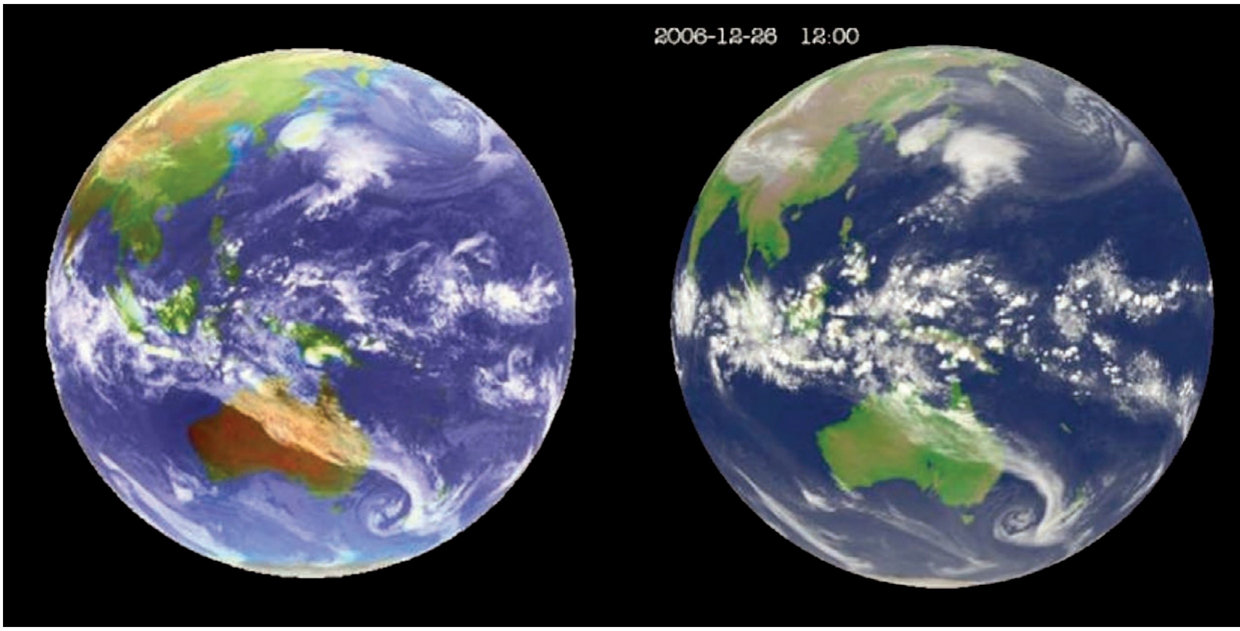

Fig. 1. (left) Observed cloud image covering the Asian/Australian monsoon region on 1200 UTC 26 Dec 2008 and (right) the 36-h prediction by the Nonhydrostatic Icosahedral Atmospheric Model (NICAM), from T. Matsuno's presentation at IWM-IV.

Asia in the 10-day range were successfully demonstrated by a superensemble of 10 models, which was superior to the forecast by the best model in the suite. The model products are useful for projecting the occurrence of the South China Sea monsoon onset, the life cycle of mei-yu rains, and flooding episodes after typhoon landfalls. Over the Indian and Australian monsoon regions, recent progress in the real-time prediction of intraseasonal variability has led to coordinated efforts by operational modeling centers to forecast MJO-related phenomena. Progress has also been made on MJO prediction with dynamical and statistical methods. A combination of these two approaches has higher skill than either one of the methods. The prediction skill of dynamical models is improving and in some instances is better than that of statistical/empirical schemes. For the Indian monsoon, skillful forecasts with lead times of up to about 20 days have been achieved.

On seasonal time scales, sea surface temperature (SST) variations accompanying El Niño–Southern Oscillation (ENSO) are an important source of predictability over many major monsoon regions, including South and East Asia and the Americas. ENSO-related SST changes contribute to the predictability of premonsoon rainfall, but the predictability during the monsoon season is reduced because of local air–sea interactions that may conflict with remote forcing from ENSO. In some cases, ENSO exerts a stronger influence on the frequency (and intensity) of extreme rainfall events than on the monthly or seasonal rainfall anomalies. The impact of ENSO on heavy rainfall events in South America is more noticeable than that on moderate and light precipitation episodes. Such relationships are of considerable practical interest, in view of the societal and economic consequences of extreme events.

MESOSCALE WEATHER AND HEAVY PRECIPITATION. Within the large-scale monsoonal regime, local processes dictate when and where heavy rainfall and floods (Fig. 2) will occur. Research reports on these processes included the forcing of mesoscale precipitation systems and cyclonic vortices along the mei-yu/baiyu/changma front and topographic impacts on heavy precipitation over East Asia; coupling between the African easterly jet, heterogeneous boundary layer properties, aerosols, and mesoscale convective systems over West Africa; linkages between easterly waves, topography, and convection in the North American monsoon; the role of the South American low-level jet (LLJ) in producing mesoscale convective complexes to the lee of the Andes; the role of sea/land breezes and convective outflows in producing intense storms in the Australian monsoon; and mechanisms for the mesoscale convective systems and extreme rainfall in the Indian monsoon.

Several presentations described the role of the Tibetan Plateau in producing downstream vortices

Fig. 2. Summer monsoon flood of Yangtze River near Wuhan City, Hubei, China, 26 Jul 1998. (Image courtesy of Beijing Climate Center/East Asian Monsoon Activity Center, China Meteorological Administration).

and associated heavy rainfall. Mesoscale modeling studies show that increasing the resolution of smaller-scale topographic features over the Plateau leads to improved forecast skill of heavy precipitation over the Yangtze River Valley. The long-standing problem of heavy rainfall upstream of mountain barriers (e.g., the Western Ghats) in monsoon regions is being addressed via observations, such as high-resolution Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar data, and modeling studies.

Many talks focused on the diurnal cycle and its associated impacts on the boundary layer, local circulations in mountainous regions and along coastlines, and on LLJs. Mechanisms for the diurnal cycle of convection over land, particularly the afternoon maximum in precipitation, are generally well understood, but the timing of precipitation and propagation downstream of mountain barriers is often not well handled in models. Several theories for the diurnal cycle over the ocean have been proposed that involve surface and free-tropospheric radiative heating or their horizontal gradients; however, the precise mechanisms remain unclear and are not well represented in many of the global models.

TRAINING WORKSHOP FOR FORECASTERS. The training workshop at IWM-IV was designed for National Meteorological and Hydrological Services (NMHS) forecasters in the monsoon region. Special efforts were made to help those from developing countries update their scientific knowledge and become familiar with new forecasting techniques. The training sessions consisted of three main parts; the first focused on heavy rainfall nowcasting and forecasting. Lectures were given on the techniques used to identify small- and mesoscale weather features through better use of radar monitoring and analysis techniques, and on multiple factors influencing the development of mesoscale convective systems.

The second part was on weekly monitoring and intraseasonal forecasts of monsoon weather. The former topic was presented in a lecture introducing the global monsoon monitoring products at the U.S. National Oceanic and Atmospheric Administration (NOAA)/Climate Prediction Center. The forecasting aspect was covered in a half-day short course on the recent development of statistical and dynamic forecast techniques at the Centre for Australian Weather and Climate Research. Characterization of intraseasonal monsoon variability on the basis of MJO lifecycles was emphasized.

The third part was the introduction of seasonal forecast operations at two very different and complementary operational climate centers: the Asia–Pacific Economic Cooperation (APEC) Climate Center, in Busan, South Korea, where a multimodel ensemble was used for seasonal forecasting and statistical downscaling predictions; and the Beijing Climate Center of the China Meteorological Administration, which has unique experience in forecasting the East Asian monsoon and delivering services oriented to both decision makers and the general public.

FUTURE COLLABORATIONS. Throughout the workshop and in the closing discussion session, many participants remarked on the importance of the interactions among the many scales of the monsoon system, and the artificial nature of the traditional organizational boundary between weather and climate. Barriers between monsoon phenomena in various portions of the atmospheric spectrum (e.g., convection and rainfall, mesoscale and synoptic-scale weather, intraseasonal and seasonal variability, climate and climate change) may hinder research and forecasting. IWM-IV was a milestone for the WWRP and WCRP communities in their efforts to promote existing and future cooperation in monsoon research and forecasting.

Given the many regional and national efforts in field observations, the participants discussed ways to foster cooperation and coordination. They recommended the establishment of special data centers to archive intensive observation period data from past and future monsoon field campaigns, and to gather centralized information on radar data collected from special experiments and from the continuously expanding operational radar networks operated by the growing number of NMHSs in the monsoon region. Another area of strong interest is the research of extreme weather events. A coordinated effort to monitor and archive such events in the monsoon region will be very valuable for systematic study of their possible relationship with climate change.

ACKNOWLEDGMENTS. We thank Yihui Ding, Robert Fovell, Sulochana Gadgil, Alice Grimm, Brian Mapes, Jun Matsumoto, Taroh Matsuno, B. N. Goswami, Andrew Turner, Bin Wang, Matthew Wheeler, Guoxiong Wu, and Tetsuzo Yasunari for their input to the UCLA Tropical Meteorology and Climate Newsletter on IWM-IV edited by Michio Yanai, which helped the preparation of this summary article.

REFERENCES

Chang, C.-P., Y. Ding, G. N.-C. Lau, R. H. Johnson, B. Wang, and T. Yasunari, Eds., 2011: *The Global Monsoon System: Research and Forecast, 2nd Edition.* World Scientific Series on Asia-Pacific Weather and Climate, Vol. 5, World Scientific Publication Company, 590 pp.