MAUSAM, **74**, 2 (April, 2023), 231-238

MAUSAM

DOI : https://doi.org/10.54302/mausam.v74i2.6070
Homepage: https://mausamjournal.imd.gov.in/index.php/MAUSAM

UDC No. 551.553.21 : 551.509

A quarter century of WMO-Organized international cooperation in monsoon research : International Workshop on Monsoons

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सार – पिछले 25 वर्षों में, विश्व मौसम विज्ञान संगठन ने उष्णकटिबंधीय मौसम विज्ञान अनुसंधान पर अपने कार्यकारी समूह के माध्यम से मॉनसून अनुसंधान और पूर्वानुमान को बढ़ावा देने के लिए अंतरराष्ट्रीय मॉनसून कार्यशालाओं (IWM) की श्रृंखला के माध्यम से एक प्रमुख अंतरराष्ट्रीय सहयोग का प्रयास शुरु किया है। इस शोध पत्र में मॉनसून अनुसंधान और पूर्वानुमान की प्रगति में महत्वपूर्ण योगदान के इतिहास की समीक्षा की गई है और इसकी परिणति एवं विकास पर चर्चा की गई। इस अवधि के दौरान मॉनसून अनुसंधान की अवधारणा, कार्यक्षेत्र और मॉनसून की समझ सभी काफी उन्नत हुए हैं।

ABSTRACT. Over the last 25 years, the World Meteorological Organization through its Working Group on Tropical Meteorology Research carried out a major international collaboration effort to foster monsoon research and forecast centered around the series of International Workshops on Monsoons (IWM). This paper reviews the history of this activity and discusses its development and evolution that contributed significantly to the progress of monsoon research and forecast. Throughout this period the concept, scope and depth of monsoon research have all advanced considerably.

Key words – International workshops on monsoons, IWM.

1. Introduction

The monsoon is probably the most important atmospheric circulation system in terms of the impact on human lives. It covers more than one half of the globe and affects three quarters of the world's population. For these people, monsoons have played a vital role in societies' culture, lifestyle and activities. Monsoon regions are also prone to floods and droughts that cause the loss of lives, destroy homes and displace millions of people. For example, floods, including seasonal monsoon floods in China and India, accounted for five of the top ten costliest disasters in 2019 according to the World Meteorological Organization (WMO) (Taalas, 2021). Most of the world's monsoon regions are in the tropics and sub-tropics, hence monsoon research largely overlaps with the study of tropical meteorology. Accordingly, WMO has identified monsoon research as one of the two most important components in its Tropical Meteorology Research Programme (TMRP). Starting in 1985, the Working Group on Tropical Meteorology Research (WGTMR), organized the International Workshop on Tropical Cyclones (IWTC) every four years as its flagship activity. In 1995 the proposal to organize an International Workshop on Monsoons was discussed, leading to the First International Workshop on Monsoons (IWM-1) in February 1997. As is the case with IWTCs, the IWMs are identified as a part of the WMO major quadrennial symposia and workshops with the purpose of facilitating exchanges between researchers and forecasters in different parts of the world. This objective made IWTC and IWM different from typical scientific conferences in that the latter normally do not emphasize the exchange with operational forecasters.

The workshops organized exclusively by WMO prioritize the topics relevant to the operational mission of National Hydrological and Meteorological Services

(NMHS). The IWTC has established a tradition of highly structured meeting program that centered in the common issues of TCs. The basic topics of the First IWTC held in Bangkok, Thailand, in 1985 had both global and regional perspectives: Tropical Cyclone (TC) structure, TC formation, TC intensity and structural change, TC motion, numerical modeling of TCs, TC measurements and analysis techniques, TC coastal impacts and assessing and improving forecast warnings. These topics formed the backbone of the workshop agenda, which were adopted in all subsequent IWTCs regardless of their locations because the physics and dynamics of TCs in all tropical regions are virtually identical. Consequently, discussions between participants from different regions and between researchers and forecasters, turned out to be efficient and avoided different regional interpretations.

The purpose of the IWMs is also to facilitate exchange and interaction between researchers and forecasters in different regions. However, unlike TCs, monsoon characteristics vary considerably between different regions and even in the same region the monsoon can exhibit considerable local variability over a range of temporal and spatial scales. It would not make much sense if the term "TC" in most of the IWTC topics were simply replaced by "monsoon" in IWM scientific programs. In particular, compared to IWTC, IWM involves an additional dimension of challenges in promoting the collaboration between communities whose background and problems in monsoon research and forecasting may vary considerably.

The long-term objectives of the TMRP promulgated by the seventh (1975), eighth (1979) and ninth (1983) sessions of the World Meteorological Congresses also include "the effective transfer of scientific knowledge on methodologies so as to help in the application of research results to operational services in tropical countries" and "help scientists, especially those from developing countries, to participate in studies of tropical meteorology conducted elsewhere". As a result, WGTMR also has held a series of monsoon training workshop for NMHS forecasters from tropical and developing countries. These training workshops were often held within or in conjunction with the IWM sessions.

This paper will review the history of the series of the seven IWMs organized so far and the related international collaboration activities in monsoon research undertaken by WGTMR. The main purpose is to explain the evolution of the scientific interests and foci of the program during the 25 years since IWM-1, culminating in the current state and scope of monsoon research presented in IWM-7.

2. A history of IWM series and the evolution of scientific foci and scope

IWM-1 was held in February 1997 in Denpasar, Bali, Indonesia. It was organized in a way similar to a typical scientific conference. Papers were received from individual authors or co-authors that addressed topics related directly or indirectly to the monsoon. The program of oral and poster papers was organized according to the number of submitted papers in each topic, rather than a pre-designed structure according to scientific foci and priority as in the IWTCs. The distribution of the topics and the lack of focus was not only due to the variation of the monsoon phenomena in different geographic regions and time scales, but it was also affected by the fact that no dedicated or designated monsoon center existed in any of the NMHS. This situation is different from the operational TC community, in which a number of national or international centers have been formally designated as NMHS (*e.g*., WMO Regional Specialized Meteorology Centers and Tropical Cyclone Warning Centers). Thus, discussion in the IWTCs benefited from common technical language and close coordination during TC seasons.

In IWM-1 most papers were empirical studies of long-term time series of station data or sea-surface temperature for a given season in a local region. Basically, it may be characterized as a conference on monsoon climatology. Studies of cold surges observed in the Intensive Observation Period of the 1978 Winter Monsoon Experiment in the South China Sea were among the few papers that analyzed weather events. The workshop was held before the rapid advance of numerical modeling. Very few presentations concerned modeling or theoretical studies.

IWM-2 was held in March 2000 in New Delhi, India, only three years after IWM-1. The schedule was moved up by one year to coincide with the celebration of the 125^{th} anniversary of the India Meteorology Department (IMD). During the planning of IWM-2, the CLIVAR (Climate and Ocean: Variability, Predictability and Change) Project of the World Climate Research Programme (WCRP) decided to hold a CLIVAR Science Conference in the first week before the IMD celebration. The CLIVAR conference attracted many monsoon climate scientists, but most of them departed at the end of the science conference. As a result, the organizers of IWM-2 were only able to conduct the training program for NMHS forecasters from tropical developing countries, leading to essentially no interaction between researchers and forecasters. That said, this CLIVAR science conference involved scientific discussions largely on the monsoon climate and might be considered to have played the role of the research segment of an IWM.

IWM-3 was held in November 2004 in Hangzhuo, China. An international organizing committee (IOC) was formed for the first time to plan the program of the workshop. In addition, each IOC member gave an invited review that served as the focus of their respective sessions. After the workshop, the reviews were written into manuscripts and published after peer review and revisions in a volume entitled, "*The Global Monsoon System: Research and Forecast"* (Chang *et al*., 2005). It was distributed to the NMHS in the monsoon regions and has been made available to academic and research communities.

For a long time, the term monsoon was defined as the circulation that is driven by the seasonal reversal of large-scale land-ocean thermal contrast. Monsoon studies mostly refer to the study of the structure, mechanism and variations of this system of large spatial and time scales. Studies of monsoon onset, break, withdrawals address shorter time scales but were often considered in a climate context. When the IOC for IWM-3 was formed, the great majority of members were identified as climate scientists studying large scale topics. Shorter spatial or time scales were less represented at IWM-3, but that limitation was to be addressed at future IWMs.

IWM-4 was held in October 2008 in Beijing, China. Around that time, WMO had conducted a major reorganization of its research programmes, by expanding the World Weather Research Programme (WWRP) to include all meteorology-related working groups and closing the TMRP. The main purpose of the reorganization was to support THORPEX (The Observing system Research and Predictability Experiment), whose main objective was to accelerate improvements in the utility and accuracy of weather forecasts up to two weeks in advance. This objective was based on the prospect of improved numerical weather prediction (NWP) in middle latitudes and all working groups except WGTMR focused on aspects that related directly or indirectly to NWP, including model development, data, use, application and impacts of NWP. WGTMR was the only working group that focused on the study of weather phenomena. Data availability and modeling were (and still are) also more challenging in the tropics than in the mid latitudes. In addition, monsoon research has been mostly on the climate side of the spectrum and NWP has a more limited utility on operational weather forecasting in monsoon regions.

The merging of WGTMR into WWRP turned out to be an opportunity to strengthen international collaboration of monsoon research by increased attention to the weather scales. Starting with IWM-4 the IOC membership composition was adjusted by including more weather, especially mesoscale, experts and the workshop became an important venue for facilitating interactions between climate/large-scale and weather/mesoscale scientists. The close interaction of the two communities can be seen from the participation of several WCRP committees in the IOC of this WWRP workshop. Meanwhile in IWM-4, the Madden-Julian Oscillation (MJO) with its intra-seasonal time scale naturally became a mutual focus as it received high interest from both the weather and climate scientists. It also became an important source of predictability for the NMHS forecasters.

For most of the 20th century, the Indian monsoon was nearly synonymous with the term "monsoon" in the scientific community. The title of the Global Monsoon System book series published after each workshop since IWM-3 highlights the transformation of this regional definition to the concept of the global monsoon system. In IWM-4 considerable attention was drawn to this new concept. The monsoon is a much larger and complex system that affects weather and climate over the tropical and subtropical parts of other continents including Australia, Africa, South and North America and the western North Pacific. The East Asian monsoon possesses distinct characteristics and dominates the weather and climate over a large longitudinal and latitudinal span from tropical Southeast Asia to mid latitude Northeast Asia. While the Asian monsoon with its South and East Asia components is considerably stronger and influences a far larger area and population than the monsoon in other parts of the world, all monsoon regions share the common feature of a thermally driven seasonal-reversal circulation with a well-defined period of abundant rainfall in the annual cycle.

During IWM-4 a monsoon training workshop was held at the Institute of Atmospheric Physics of the China Academy of Science, as a part of the activity celebrating the 80th anniversary of the Institute.

The invited reviews from IWM-4, after updating and peer reviews, were published in Volume 2 of the Global Monsoon Systems (Chang *et al*., 2011a). At the recommendation of WGTMR, WMO invited the World Scientific Publishing Company (WSPC) as the publisher of this volume for WSPC's broad distribution channels in the scientific and academic communities. In addition, a summary of IWM-4 with the title, "Bridging weather and climate in research and forecasts of the global monsoon system", was published in the *Bulletin of the American Meteorological Society* (BAMS) (Chang *et al*., 2011b).

IWM-5 was held in October 2013, in Macao, China. It continued the organization format of integrating climate

and weather research and forecasting topics, with global monsoon and regional monsoon as the two pillar sessions as in IWM-4. More time was allocated for sessions in numerical modeling, climate change and extreme weather, reflecting the increased interest and progress in these areas. The associated monsoon training workshop took place in Hong Kong, China, as a part of the commemoration of the 25th anniversary of the Hong Kong Meteorological Society. Volume 3 of the Global Monsoon System, based on the IWM-5 reviews, was published by WSPC (Chang *et al*., 2017).

IWM-6 was held in November 2017, in Singapore. More scientific communities from outside the WWRP WGTMR joined the organizing effort of IWM-6 than in the previous IWMs. They included the representatives of the WCRP CLIVAR/GEWEX (Global Energy and Water Cycle Experiment) Monsoon Panel, the MJO Task Force, the sub-seasonal to Seasonal (S2S) Steering Group, the Years of the Maritime Continent (YMC) Scientific Steering Committee, the Meteorological Service Singapore, the Chinese University of Hong Kong, the National University of Singapore and the Asia-Pacific Economic Cooperation (APEC) Climate Center headquartered in Busan, Korea.

The workshop opened with a special lecture in memory of Mr. D. R. Sikka, former Director of the Indian Institute of Tropical Meteorology (IITM), Pune, India. The lecture was delivered by Professor Sulochana Gadgil of the Indian Institute of Science. The remarkable progress of modeling MJO over the decade from IWM-4 to IWM-6 was one of the highlights presented at the workshop (Kim *et al*., 2020). Another paper reported on the discovery of the cause of the difficulties in boreal winter rainfall forecast in the western Maritime Continent. The cause was traced to the improper dependence on SST for predictability in climate models and this finding was the result of discussions between researchers and forecasters at the IWMs (Chang *et al*., 2021). The workshop closed with of the WMO Monsoon Training Workshop for NMHS forecasters and a Panel Discussion of the Global Monsoons Model Inter-Comparison Project (GMMIP) contribution to Phase 6 of the WCRP Coupled Model Inter-comparison Project (CMIP6).

The IWM-6 publication, Volume 4 of the Global Monsoon System, also published by WSPC, has a slightly modified title, "The Multi scale Global Monsoon System" (Chang *et al*., 2021). In addition, a report of the summary of IWM-6, "The Multi scale Global Monsoon System - Research and Prediction Challenges in Weather and Climate", was published in BAMS (Chang *et al*., 2018). The revised title underlines the perspective that the monsoon is a complex system in which the interactions between different scales play critical roles in its mechanisms.

A noteworthy development in IWM-6 was the increased participation from India. The proximity of the venue in Singapore made it possible for more Indian experts to attend. WSPC, the publisher of the Global Monsoon System volumes 2, 3 and 4, is headquartered in Singapore. It also helped by sponsoring the travel of some Indian participants. This development added to the momentum of holding IWM in India again, which has been the goal of WGTMR for some time because of the importance of monsoon in India and its large research and forecast communities. This goal was realized in IWM-7.

IWM-7 was held in March 2022 in New Delhi, with a delay of one year from the original schedule and held in virtual mode due to the pandemic. Nevertheless, its program included more invited and oral presentations than previous IWMs. The 38 invited talks, 72 oral talks and 70 other presentations were given in eight the matic sessions. They were: (*i*) Regional Monsoons, (*ii*) Sub-seasonal to Seasonal (S2S) Predictions, (*iii*) Modelling monsoon processes, (*iv*) Climate Change and Monsoons, (*v*) High Impact Monsoon Weather, (*vi*) Field Experiments and Observational Campaigns, (*vii*) Monsoon Information and Prediction for Societal Benefit and (*viii*) New Technologies and Tools. These themes reflect closely the current priority of monsoon research as the second quarter of the 21st century is approaching.

The monsoon training workshop associated with IWM-7 focused on the sub-seasonal to seasonal (S2S) prediction of monsoons. It was delivered online in November 2021.

IWM-7 also marked an important milestone in the WMO monsoon program. It took place soon after the establishment of the International Monsoon Project Office (IMPO) at IITM, Pune, India through an agreement between WMO and IITM with support from the Ministry of Earth Sciences, Government of India. IMPO was set up with an overarching objective to support coordination of monsoon research activities under the WWRP as well as WCRP across all international monsoon communities. The IMPO is a key contribution of India to global monsoon research and is part of India's Monsoon Mission (CLIVAR, 2020), an ambitious and well-resourced research programme with international participation. IWM-7 was the first major activity that IMPO played a major role in the organization and preparation, including the associated S2S Training Workshop mentioned above.

Fig. 1 shows the six IWM publications issued so far.

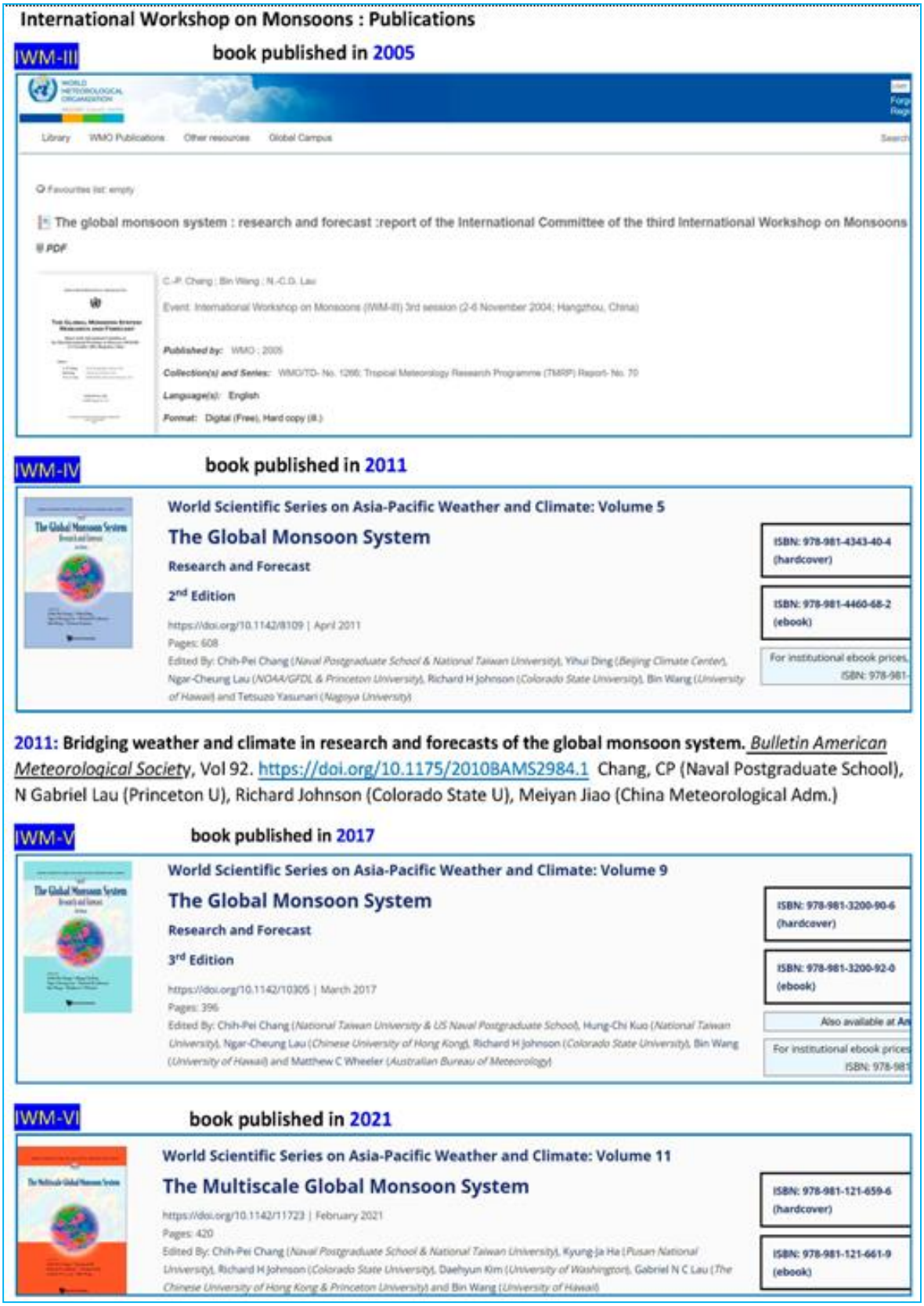

Fig. 1. IWM Peer Reviewed Publications

Selected papers from IWM-7 are published in this special issue of the peer-reviewed journal MAUSAM: Quarterly Journal of Meteorology, Hydrology & Geophysics issued by the IMD. This special issue represents Volume 5 of the Global Monsoon System series and we are very pleased that IMD with its highly capable staff took over the important role as its publisher.

3. Intraseasonal workshops

In addition to the quadrennial IWMs, WGTMR also organized a series of other workshops in the intervening years of IWMs, focusing on high-impact weather, especially heavy rainfall. The topics range from mesoscale to climate scales.

In April 2006, the Symposium "Winter MONEX: A Quarter-Century and Beyond" was held in Kuala Lumpur, Malaysia to commemorate the 25th anniversary of the 1978/79 Winter Monsoon Experiment and to highlight the research on East Asian winter monsoon since the experiment. This was one of the first monsoon conferences that covered a wide spectrum of time scales, from mesoscale to climate. The keynote sessions dealt with observations and modeling of tropical convection, dominant modes of monsoon variability, prediction of the South China Sea monsoon onset and monsoon predictability. Other sessions included the following topics: observations of the monsoon, diurnal and mesoscale processes, interannual variations, monsoon modeling studies, winter monsoon and cold surges, forecasting and predictability of the monsoon, the annual cycle and long-term and decadal variations. A summary of the symposium was published in BAMS (Johnson and Chang, 2007).

After the merging of TMRP activities into WWRP, WGTMR started a series of Workshops on Monsoon Heavy Rainfall (MHR) to focus on mesoscale and extreme rainfall research. The first workshop (MHR-1) was held in November 2011 in Beijing, China. The main agenda was to discuss the draft proposal of the Southern China Monsoon Rainfall Experiment (SCMREX) (Luo *et al*., 2017, 2019). The proposal was the result of the encouragement by the WWRP Joint Science Committee for China to initiate a research project directly relevant to WWRP, as a demonstration project for the monsoon community. This proposal was reviewed and revised in the second workshop (MHR-2), held in December 2012 in Kuala Lumpur, Malaysia. An international team consisting of experts from U.S., Japan, Korea and Australia and professors from Peking University, City University of Hong Kong and National Taiwan University, discussed the plan in detail and recommended the revised plan be approved as a WWRP Research and Development Project.

Other MHR-2 sessions concentrated on presentations and discussions of research results on the observation, modelling and prediction of heavy rainfall in the monsoon region. TCs are an important source of heavy rainfall in Asian-Australian monsoon regions and were a topic discussed in the high impact weather sessions of the IWMs. In MHR-2 a dedicated session was included for typhoon rainfall.

MHR-3 was held in September 2015 in New Delhi, India. With the strong support of the government of India and enthusiastic participation from IMD, IITM and other organizations of the India monsoon community, the number of participants in MHR-3 approached the scale of the IWMs. MHR-4 was held in April 2019 in Shenzhen, China. A highlight of the workshop was the results of the first two phases of SCMREX. The more recent status of SCMREX is discussed in Luo *et al*. (2017) in this special issue.

In view of the importance of climate change and impacts in the world monsoon regions, WGTMR decided in its September 2018 meeting in Auckland, New Zealand to conduct a project to assess the attribution of climate change in monsoon rainfall. In the ensuing year the Working Group organized an expert team of 25 invited experts to prepare reviews on past monsoon changes and their primary drivers, the projected future changes and key physical processes and to discuss challenges of the present and future modeling and outlooks. The summary of the report was published in BAMS (Wang *et al*., 2021). The report also served as an important basis in the relevant part of the IPCC AR6.

4. Outlook

Starting from its humble beginning 25 years ago, the IWM series has become a unique forum to discuss recent advances and current issues covering all time scales (mesoscale, synoptic, intraseasonal, climate) that are relevant to the forecast of high-impact weather in the world's monsoon regions. It brings theoreticians, field observation specialists, modelers and forecasters together to make progress in monsoon science and forecast applications. Significant advances in understanding and prediction of the South and East Asian, Maritime Continent, North and South American and African monsoons include the following: the roles of ocean-land-atmosphere coupling; internal dynamics; mechanisms in winter and summer monsoons; ENSO interactions; the diurnal cycle; intraseasonal variability; extreme weather; interannual and interdecadal

variability; topographic and vegetation effects; microphysics, radiation and aerosols; numerical modeling; climate change; and mesoscale, synoptic, sub-seasonal and seasonal predictions.

The success of the IWM series and its associated meetings and projects is the result of close collaboration of the scientific researchers and the operational communities. In particular, the enthusiastic participation and support of the NMHSs that hosted the workshops, including Indonesian Agency for Meteorological, Climatological and Geophysics, India Meteorological Department, China Meteorological Administration, Macao Meteorological and Geophysical Bureau, Meteorological Service Singapore, Malaysian Meteorological Service and Hong Kong Observatory. The establishment of the IMPO in India prior to IWM-7 will further facilitate future international collaboration of monsoon research and forecast applications. With dedicated support along with increased financial, logistical and human resources in monsoon regions, the WMO efforts to promote the international collaboration and interaction of the research and operational communities will continue to facilitate monsoon research and improve forecast on both weather and climate scales. The future is bright that these collaborations will generate more positive impacts and provide increasing benefits to the vast population in the world's monsoon regions.

Acknowledgements

The success of the IWM series and the related WGTMR monsoon activities would not have been possible without the strong support of the stakeholders including the NMHSs that hosted the meetings and projects. Among the many enthusiastic individuals are three WGTMR chairs: Dr. Greg Holland of Australia Bureau of Meteorology and Professors Chen Lianshou and Duan Yihong of China Meteorological Administration. We want to especially thank the extraordinary contributions made by Professor Phua Kok Khoo, Chairperson of the World Scientific Publishing Company, who views the promotion of scientific research and education, especially in Asia, as the primary purpose of the company and Ms. Nanette Lomarda of the WMO WWRP office, whose dedication was crucial to overcoming many obstacles encountered in organizing the WGTMR monsoon workshops and projects. Professor Richard H. Johnson of Colorado State University and Dr. Rupa Kumar Kolli of IITM read the manuscript and suggested improvements.

Disclaimer : The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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