10 Years of MAHASRI: Accomplishments and the International Science Conference Wrap-Up

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Overview of MAHASRI and Related Projects

The Monsoon Asian Hydro-Atmosphere Scientific Research and Prediction Initiative (MAHASRI; *http://hydro.iis.u-tokyo.ac.jp/mahasriwiki/wiki/index.html*) was implemented in 2006 as a successor to the GEWEX Asian Monsoon Experiment (GAME; 1996–2005). After GAME concluded, the first Pan-WCRP Monsoon Workshop was held in June 2005 in Irvine, California, USA, and the participants strongly recommended that collaborative research on monsoon prediction issues be continued in Asia. At a post-GAME international planning workshop held in Tokyo, Japan in 2005, an International Drafting Committee was organized to develop a science plan for MAHASRI, which was presented at the 18th meeting of the GEWEX Scientific Steering Group (SSG) in Dakar, Senegal in January 2006. The feedback on the plan that was received from the SSG members was incorporated into the final MAHASRI Science Plan (*http://hydro.iis.u-tokyo.ac.jp/mahasriwiki/before_wiki/documents/MAHASRI_SciencePlan_v4.1.pdf*), which was presented and accepted at the Pan-GEWEX Meeting held in Frascati, Italy in October 2006. MAHASRI was approved as a GEWEX Continental-scale Experiment (CSE) of the Global Hydrometeorology Panel (GHP). After the Pan-GEWEX Meeting, GHP was merged into a new GEWEX panel called the Coordinated Energy and Water Cycle Observations Project (CEOP), co-chaired by Toshio Koike and the late John Roads. In 2010, the CSEs were redefined as Regional Hydroclimate Projects (RHPs) under what is now the GEWEX Hydroclimatology Panel (GHP).

The primary objective of MAHASRI was to use the scientific understanding of Asian monsoon variability to develop a hydrometeorological prediction system up to seasonal time scales. In its implementation, real-time monitoring capabilities for hydrometeorological observations and an integrated hydrometeorological database were developed, including data rescue and examination and improvement of hydrometeorological models in specific river basins. The scientific foci of MAHASRI included: (i) atmosphere-ocean-land interactions in the Asian monsoon system; (ii) the effects of multiscale orography on monsoon circulation and rainfall; (iii) temporal interactions among diurnal, synoptic, intraseasonal and seasonal variability of the Asian monsoon; (iv) spatial interactions among hydrometeorological phenomena of local, regional and continental scales; and (v) transferability of hydrological models and parameters for prediction of ungauged or sparsely observed basins.

In the initial stages of MAHASRI, facilitation and improvement of hydrometeorological observations in Asian monsoon countries were conducted in cooperation with the Global Earth Observation System of Systems (GEOSS) and the Coordinated Enhanced Observing Period (CEOP-II). GEOSS (GEO, 2007) and Japan Earth-Observation System Promotion Program (JEPP) funds supported these activities.

MAHASRI was loosely comprised of four sub-regions: Northeast Asia, Tibet/Himalaya, East Asia and the Tropics (see Figure 1). Hirohiko Ishikawa of Kyoto University initially led the JEPP-Tibet Project in collaboration with the Chinese Academy of Sciences (CAS). Later, major activities were focused in two regions. The Northeast Asia (primarily Mongolia) Post-Rangelands Atmosphere-hydrosphere-biosphere Interaction Study Experiment in Northeast Asia (PRAISE) was led by Jun Asanuma. The Tropics region was subdivided into (i) the Northeast Indian Subcontinent (India and Bangladesh), led by Taiichi Hayashi; (ii) Thailand [Integrated study project on hydro-Meteorological Prediction and Adaptation to Climate change in Thailand (IMPAC-T)], led by Taikan Oki; (iii) Vietnam and the Philippines [Vietnam Philippine Rainfall Experiment (VPREX)], led by Jun Matsumoto; and (iv) the Indonesian Maritime Continent [Hydrometeorological Array for Isv-Monsoon Automonitoring (HARIMAU)], led by Manabu D. Yamanaka.

Asian Monsoon Year (AMY)

During its implementation, the WCRP Joint Scientific Steering Committee (JSC) recommended that MAHASRI conduct its Asian monsoon research within a broader context by including the Climate Variability and Predictability (CLIVAR) Project, specifically, the CLIVAR/Asian-Australian Monsoon Panel (AAMP). As a result, a crosscutting activity, the Asian Monsoon Year (AMY; 2007–2012), was organized as a part of the International Monsoon Study (IMS), a coordinated observation and modeling effort under WCRP. AMY conducted an Intensive Observation Period (IOP) from 2008 to 2010, in which MAHASRI participated. In September 2007, a series of meetings related to AMY, the Pan-GEWEX Monsoon Study and CEOP were organized in Bali, Indonesia; this marked an important milestone in the build-up phase of MAHASRI. AMY organized eight international workshops in China, Japan, Indonesia, Korea and India, and an Open Science Conference in October 2013 in Zhuhai, China. The activities of AMY and its scientific results in the Indonesian Maritime Continent were summarized in Matsumoto et al. (2016). AMY and MAHASRI in situ observational data have been archived and are available to the worldwide research community through the Data Integration and Analysis System (DIAS; *http://dias-dss.tkl.iis.u-tokyo.ac.jp/ddc/finder?lang=en*) hosted by the University of Tokyo, Japan. The data are also available from the MAHASRI web page (*http://hydro.iis.u-tokyo.ac.jp/mahasriwiki/wiki/data/index.html*). The Meteorological Research Institute (MRI) of the Japan Meteorological Agency (JMA) conducted AMY Reanalysis for the period 2008–2010, including AMY observational data. This data set will be made available to the public soon. Some of the scientific results of

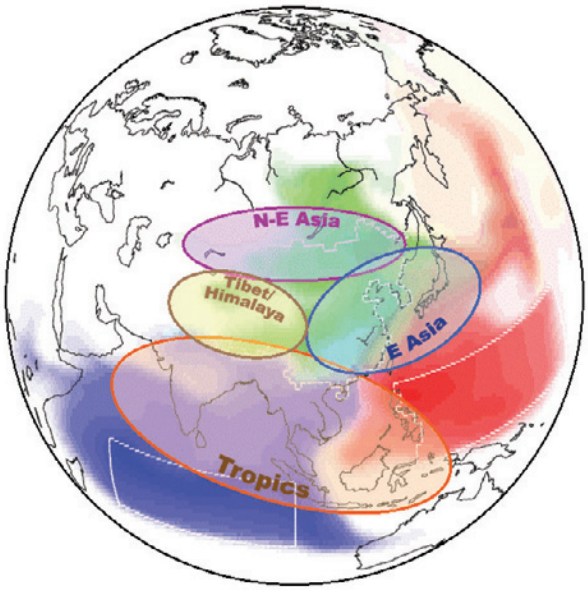

Figure 1. Target regions of MAHASRI.

MAHASRI and AMY were published in the "Special issue of MAHASRI" in the *Journal of the Meteorological Society of Japan* (Matsumoto et al., 2011).

During MAHASRI, international Asian monsoon hydroclimate sessions were organized occasionally at the Japan Geoscience Union (JpGU) annual meetings in Japan, and AMY-related sessions were organized at the Asian Oceania Geoscience Society (AOGS), the American Geophysical Union (AGU), the European Geosciences Union (EGU), the International Association of Meteorology and Atmospheric Sciences (IAMAS) and the International Union of Geodesy and Geophysics (IUGG) meetings. MAHASRI-related international workshops on the Asian monsoon were held four times in Vietnam (in 2006 at Ha Long, in 2009 and 2013 at Da Nang and in 2011 at Nha Trang). Each MAHASRI sub-regional project organized its own bilateral and/or international workshops.

Major Outcomes of Regional Projects

One of the important scientific outcomes of MAHASRI was the discovery of the extensive role that the East Asian winter monsoon (cold surge) plays on the various monsoon components in both South and Southeast Asia, including the Indonesian Maritime Continent. MAHASRI was the first organized international project targeting the Asian winter monsoon since the Winter Monsoon Experiment (WMONEX) was conducted from 1978 to 1979 (Johnson and Chang, 2007). Takahashi et al. (2011) investigated the role of cold surges on the development of cyclonic disturbances in the Indian Ocean and Hattori et al. (2011) analyzed the Cross-Equatorial Northerly Surge (CENS) and its impact on rainfall in the Indonesian Maritime Continent. Extensive studies were also conducted on the dynamics of autumn and winter extreme rainfalls in Indochina (e.g., Yokoi and Matsumoto, 2008; Tangang et al., 2008; Wu et al., 2011; Chen et al., 2012, 2013, 2015a, 2015b), large scale interactions related to cold surges, easterly waves, the Madden-Julian Oscillation (MJO) and tropical disturbances. In addition, the importance of the effect of coastlines on precipitation in the tropics was for the first time quantitatively evaluated by Ogino et al. (2016) using data from the Tropical Rainfall Measuring Mission (TRMM).

Many MAHASRI projects tackled regional scientific targets. HARIMAU radars in the Indonesian Maritime Continent helped establish that the coastal diurnal cycle is the most important cause of precipitation. Among the most prominent achievements of MAHASRI, IMPAC-T developed a hydrometeorological data collection and prediction system in the Chao Phraya River Basin in Thailand. Papers have been collected and published in a *Special Collection of the Hydrological Research Letters (HRL) of the Japan Society of Hydrology and Water Resources* (*http://www.hrljournal.org/special-collections/special-collection-2*). Work by Jun Asanuma's group in Mongolia on land-atmosphere interaction observations (PRAISE) and sources of precipitation on Mongolian grasslands was reported in Koike et al., 2014. The results of these projects are summarized in separate articles in this newsletter by the corresponding project leaders.

In Southeast Asia, climatological and interannual variations of the local monsoon onset were revealed in Myanmar (Htway and Matsumoto, 2011)**, Vietnam** (Nguyen-Le et al., 2014, 2015; Nguyen-Le and Matsumoto, 2016) **and the Philippines** (Akasaka et al., 2007; Akasaka, 2011)**.** The heat flux from the land surface during the premonsoon season in the inland region of Thailand was revealed by Kiguchi et al. (2013), and the relationship between premonsoon rain and monsoon onset over the Indochina Peninsula was studied by Kiguchi et al. (2016). Seasonal variations of rainfall induced by tropical cyclones were analyzed for the western North Pacific by Kubota and Wang (2009), and for the eastern coastal area of Vietnam by Nguyen-Thi et al. (2012a, 2012b). Takahashi et al. (2015) clarified the role of westward-propagating tropical cyclones from the western North Pacific on the interannual variation of summer monsoon season rainfall in central Thailand, including the severe flooding in 2011. This suggests a role for disturbances in the western North Pacific Ocean on summer monsoon rainfall in Indochina (see Figure 2 on next page). Rainfall variability in large regions extending from north India, including part of the Tibetan Plateau east-southeastward to the western Pacific, may be affected in a similar way along the climatological monsoon trough. Long-term changes of extreme rainfalls occurring mainly in the latter half of the last century have also been revealed (Endo et al., 2009; Villafuerte, et al., 2015; Villafuerte and Matsumoto, 2015). Furthermore, the interdecadal variability of tropical cyclone landfall in the Philippines during the past 104 years was identified by Kubota and Chan (2009), and a 117-year Pacific-Japan teleconnection pattern index using station-based atmospheric pressure data was developed by Kubota et al. (2016).

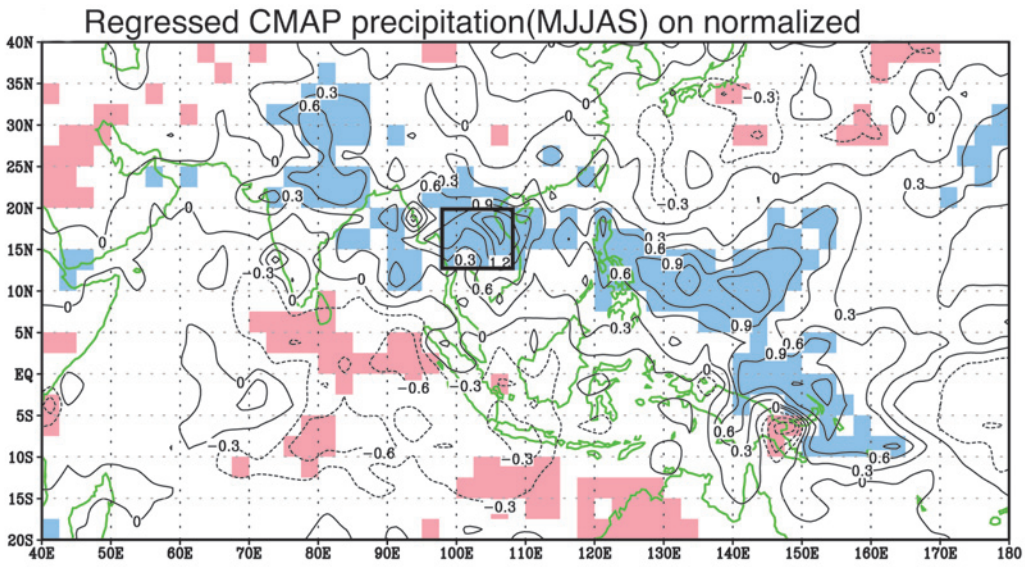

Figure 2. Regression of National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC) Merged Analysis of Precipitation (CMAP) data during the rainy season (May–September) over the reference region of Indochina (12.58–208N, 97.58–107.58E) in the rectangular box against the normalized data (mm/day) from 1979 to 2011. Areas with colors are statistically significant at the 90% level, as determined by correlation coefficients based on 31 degrees of freedom (Takahashi et al., 2015).

In the Northeastern Indian Subcontinent, which experiences some of the heaviest rainfall in the world, a precipitation measurement network was developed in the Indian states of Assam and Meghalaya, and in Bangladesh (Murata et al., 2007). Fifteen rain gauges were installed in Assam, five in Meghalaya and seventeen in Bangladesh. Several timescale rainfall variations were clarified, such as year-to-year, seasonal, intra-seasonal and daily variations, using these newly observed rainfall data and the historically archived rainfall data of the India Meteorological Department (Hayashi et al., 2009). The target region featured daily rainfall variations with a period of 10–20 days, as well as those of 30–60 days, which are also prominent in the rest of the Indian Subcontinent. Rainfall occurring between midnight and early morning prevailed in this area (Fujinami et al., 2011, 2014). Spatial distribution of rainfall over the two countries of India and Bangladesh was integrated as one area. In addition, preliminary results related to the impacts of meteorological factors on human behaviors were collected (Wagatsuma et al., 2009).

In central Vietnam, field observations targeting heavy rainfall events from autumn to early winter were conducted in 2010 and 2012. The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) in collaboration with the National Hydrometeorological Service of Vietnam (VNHMS), the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) and other related agencies worked together to obtain the data. The impact of additional radiosonde observations during VPREX2010 was investigated by performing observing system experiments using the local ensemble transform Kalman filter (LETKF) and the atmospheric general circulation model for the Earth Simulator (AFES) by Hattori et al. (2016). Besides intensive observations in the IOP, with support by the JEPP project in Southeast Asia, approximately 30 automatic rain gauges were installed in central Vietnam and in the northeastern Indian subcontinent, respectively, to capture the rainfall features in those regions. After the termination of the JEPP Southeast Asia Project, observation activities have been maintained by JAMSTEC in central Vietnam, and by Kyoto University in the Northeast Indian Subcontinent as described in the previous section. JAMSTEC also maintained two automated weather stations at Laoag and Daet in the Philippines, whose data are transmitted directly to JAMSTEC on a real-time basis with strong support from PAGASA. Recently, a lightning detection system was installed at Los Vanos, near Manila, and solar and longwave radiation observation capabilities were established in Laoag, also in collaboration with PAGASA. They are partly supported by the Climatic changes and evaluation of their effects on Agriculture in Asian Monsoon Region (CAAM) Project, under the research framework of the Green Network of Excellence (GRENE), by the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT) for the Japanese fiscal year period 2011–2015. A similar system supported by VNHMS was installed at Son Tay near Hanoi in North Vietnam. The performance of Global Satellite Mapping of Precipitation Data (GSMaP_MVK, version 5.222.1; Ushio et al., 2009) over the VuGia–ThuBon River Basin and surrounding areas in central Vietnam was examined on a monthly basis in comparison with rainfall gauges at eight meteorological stations and a gridded rainfall product of the Asian Precipitation–Highly-Resolved Observational Data Integration Towards Evaluation of Water Resources Project (APHRODITE, V1003R1; Yatagai et al., 2009, 2012) by Ngo-Duc et al. (2013).

The CAAM Project and the Thai Meteorological Department (TMD) developed a Green Network of Excellence, an environmental information version (GRENE-ei) of CAAM that serves a 0.05°×0.05° gridded daily precipitation data product for the lowlands of Thailand (below 500 m in elevation). The product is based on data from approximately 1,100 TMD rain gauges that were constructed for 1979–2011 (available at: *http://dias-dss.tkl.iis.u-tokyo.ac.jp/ddc/viewer?ds=GRENE_ei_CAAM_Thai_Grid_DailyRain&lang=en*). Also in collaboration with the VNHMS, the Vietnam National University (VNU) of Science, the University of Science and Technology of Hanoi (USTH) and the Foundation of River and Basin Integrated Communications of Japan, Gridded Precipitation (VnGP) data sets were constructed at 0.25° and 0.1° resolutions utilizing 481 stations in Vietnam for the period 1980–2010 (Nguyen-Xuan et al., 2016). The data are also available from DIAS (*http://dias-dmg.tkl.iis.u-tokyo.ac.jp/dmm/doc/VnGP_025-DIAS-en.html* and *http://dias-dmg.tkl.iis.u-tokyo.ac.jp/dmm/doc/VnGP_010-DIAS-en.html*, respectively). MAHASRI also digitized meteorological data obtained prior to World War II in Japan, the Philippines, Vietnam, Myanmar, China, Bangladesh, Indonesia and some other countries to provide a more complete record of rainfall observations in this region.

MAHASRI International Science Conference

The MAHASRI International Science Conference was held in Tokyo, Japan from 2–4 March 2016. Over 110 participants from 14 countries gave 47 oral and 49 poster presentations summarizing results obtained over the Project's 10-year history. The conference was organized by the International Scientific Committee chaired by Jun Matsumoto and hosted by the Research Center for Climatology (RCC) of the Tokyo Metropolitan University (TMU). Sponsors included TMU, the Institute for Space-Earth Environmental Research (ISEE), Nagoya University, the Institute of Industrial Science (IIS), The University of Tokyo, the Tokyo Institute of Technology (TIT) and the Strategic R&D Area Project "Strategic Research on Global Mitigation and Local Adaptation to Climate Change (S-14)" of the Environment Research and Technology Development Fund supported by the Ministry of Environment, Japan. The conference book of abstracts is available at: *http://tmu-rao.jp/wordpress/wp-content/uploads/2015/11/c4b1a9047021a17ae-82beb0e3cb07946.pdf*.

Oral sessions were organized into seven scientific sessions and two special sessions. In the first session, Peter van Oevelen, Director of the International GEWEX Project Office, introduced current monsoon research activities within GEWEX, and Jan Polcher, co-chair of GHP, presented the history and evolution of that Panel.

In Session 2, results of the regional and related projects of MAHASRI were introduced. Fadli Syamsudin (Agency for the Assesment and Application of Technology, BPPT) introduced studies conducted in the newly developed Maritime Continent Center of Excellence (MCCOE; *http://tisda.bppt.go.id/mccoe/*) in Indonesia. Mike T.C. Chen (Iowa State University) showed the development and formation mechanism of the Southeast Asian winter heavy rainfall events. G.S. Bhat (Indian Institute of Science) presented the evolution and propagation of monsoon cloud systems over India revealed by the Continental Tropical Convergence Zone Program (CTCZ; *http://www.incois.gov.in/portal/datainfo/ctczsp.jsp*). Subcontinental-scale diurnal variations over South China and the South China Sea were presented by Johnny C.L. Chan (City University of Hong Kong; Huang and Chan, 2011).

Session 3 concerned monsoon precipitation that is strongly affected by regional topography in timescales from diurnal to intraseasonal. Akio Kitoh (University of Tsukuba) showed the current understanding of past changes and future projections of global and regional monsoon precipitation. Interesting features of diurnal variations of precipitation in South Asia were presented by Shoichi Shige (Kyoto University).

Session 4 was related to atmosphere-land-ocean interactions. Yaoming Ma (Institute of Tibetan Plateau Research) presented observational studies on land-surface heat fluxes and evapotranspitation over heterogeneous landscape of the Tibetan Plateau and the surrounding region (Third Pole region) and introduced Tibetan Observation and Research Platform (TORP) activities. The Science Plan for an upcoming field observation campaign called Years of the Maritime Continent (YMC; 2017–2019) was introduced by Kunio Yoneyama (JAMSTEC) and is available at: *http://www.jamstec.go.jp/ymc/docs/YMC_SciencePlan_v2.pdf*. Multi-decadal regional climate changes, particularly drought and heat waves in Mongolia and the roles of regional land-ocean-sea ice distributions on atmospheric variations, were presented by Tomonori Sato (Hokkaido University, Erdenebat and Sato, 2016).

Extremes were discussed in Session 5, with an emphasis on precipitation extremes. Fumiaki Fujibe (TMU) showed the long-term changes of extreme precipitation in Japan. Fredolin T. Tangang (National University of Malaysia; UKM) presented the possible roles of various factors affecting the intensity and location of extreme precipitation events over the east coast of Peninsular Malaysia at the end of December 2014.

Session 6 was related to climate. Two special sessions were organized: "From IMPAC-T to ADAP-T" led by Taikan Oki, and "Urban climate changes in Jakarta" led by Manabu Kanda of the Tokyo Institute of Technology. General Discussion Session 7 was chaired by Jun Matsumoto, who noted that one of the most important outcomes of MAHASRI has been the continued research collaborations with Asian operational agencies and research communities that have continued since GAME and how strongly they stimulate research activities in these regions, particularly Thailand, Indonesia, Vietnam, the Philippines, Bangladesh, India and Mongolia.

Potential future research targets were summarized as follows:

- Multi-scale interactions: diurnal/synoptic/ISO/seasonal changes in time, or local/regional/global changes in space
- Land–ocean–atmosphere interactions
- Changes and attribution of extremes

- Decadal variations of the Asian monsoon
- Effects of humans on the hydrological cycle
- Developing an adaptation strategy for climate changes

Future Plans

The scientific outcomes of MAHASRI and related research will be summarized in a special collection of papers on the "Asian monsoon hydroclimate" to be published in the *Progress in Earth and Planetary Science* of the Japan Geoscience Union. A Special call for Excellent Papers on hot topics (SPEPS; *http://progearthplanetsci.org/index.html#modal*) was issued in August with a deadline of 31 January 2017. Planning for a MAHASRI follow-on project will be proposed at the next GHP meeting.

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