Monsoon **A**sian **H**ydro-**A**tmosphere **S**cientific **R**esearch and Prediction **I**nitiative (MAHASRI)

Ver. 4.1

Science Plan Proposal

by

The International Drafting Committee of the Post GAME Planning Working Group

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1. Introduction

The international research program on the water and energy cycle in the Asian monsoon, named GAME (GEWEX Asian Monsoon Experiment: http://www.hyarc.nagoya-u.ac.jp /game/) successfully finished in March 2005. Through the GAME and other monsoon projects, our understanding of the Asian monsoon has been substantially progressed. Some of the scientific results of GAME were published in the special issue of the Journal of the Meteorological Society of Japan (Vol. 79B, 2001, 22 papers) and the Hydrological Processes (In press, 9 papers). As of May 2006, 269 scientific papers were published in the peer reviewed international journals. In particular, roles of the various land surfaces over the Asian Continent on the seasonal and interannual changes of monsoon, precipitation processes closely related with land surface conditions were revealed through observational and modeling studies. The data obtained in the GAME activities were archived and published in 13 CD-ROMs and will be useful for further studies. Such publication and data information has been listed and updated in the GAME publication database (http://www.suiri.tsukuba.ac.jp/~game/index.htm). However, researches from these projects also reveal, not only long-range forecast, but also short-range forecast of monsoon rainfall are still not satisfactory. Unexpected floods and/or droughts occur frequently in the Asian monsoon region. In addition, the influence of ongoing global warming and human-induced atmospheric pollution and/or land cover/use changes on monsoon climate has not yet been fully understood. The scientific understanding, research strength, scientific collaboration, and organization from the GAME project have paved the way for investigation in the next stage of the program to improve the prediction of the Asian monsoon and its hydrological cycle.

To improve the Asian monsoon prediction, many challenging issues have to be solved. In particular, better resolution of diurnal cycles and their multi-scale interactions with intraseasonal variability are crucial for improving prediction of convection and precipitation. Seamless understanding of land-ocean-atmosphere interaction, boundary layer processes and cloud/precipitation processes is essential for improving models, including components like cumulus parameterizations. Understanding of the hierarchical structure of meso-scale systems embedded in large-scale fields and the mutual interaction between the low level jet/moist convection and large-scale fields over complex terrain and warm water pools will be particularly important for prediction of severe rainfall systems in East and Southeast Asia. The significant role of vegetation and aerosols on atmospheric heating, cloud/precipitation systems, and monsoon circulations in Asia has recently been pointed out, which was only partly noted in GAME. In addition, GAME targeted mainly land-atmospheric interactions, land-ocean-atmospheric interactions have not yet been fully understood. As for the regional foci, GAME-Tropics targeted mainly monsoon processes in the Indochina region. Monsoon processes of the entire tropical Asia including South Asia and the Indonesian maritime continent need to be studied. In a similar manner, more comprehensive studies on the East-Asian monsoon system may also be necessary. Furthermore, the processes involved in the Asian winter monsoon should also be targeted since they also interact with the water cycle in the maritime continent.

In the final GAME International Conference in December 2004, the need for further research on the Asian monsoon was approved and its initiation was strongly recommended. The CEOP (Coordinated Enhanced Observing Period) Phase-2 implementation/science is now being proposed based on the unique capabilities of the coordinated observation, data archiving, and data integration developed through the CEOP Phase-1. Very recently, the global climate research community has also agreed to a strong coordinated research framework, particularly on the Asian/Australian monsoon system both in observations and modeling/prediction (e.g., at the 1st Pan-WCRP Monsoon System Workshop held in June, 2005). Considering its huge and serious influence on human activity, WCRP has endorsed hydro-climate study of monsoon systems as a key component of WCRP Strategic Plan.

On the other hand, both in the Johannesburg Summit and the UN Millennium Developing Goals (http://www.un.org/millenniumgoals/), solutions for poverty and food problems, as well as development of a global partnership for sustainable development, are identified as important topics. Solutions for water problems are the key for both issues, and accumulation of scientific understandings is highly anticipated to attain their objectives. The ten-year Implementation Plan for the GEOSS (Global Earth Observation System of Systems: http://earthobservations.org) has been started from 2005 based on the agreement of the Third Earth Observation Summit, and new funding opportunities have emerged in Japan as well as in some other Asian countries.

However, a research strategy for the Asian monsoon, that will be a successor of the GAME project, has not been established yet. It will be very important, in conjunction with GEOSS activities, to develop studies on the Asian monsoon by strengthening and promoting our partnership with Asian countries that have been cultivated through the GAME project.

Herein, we would like to propose a new international program in Asia, named MAHASRI (Monsoon Asian Hydro-Atmosphere Scientific Research and Prediction Initiative), focusing on establishing scientific basis for predicting hydro-climate monsoon system with intraseasonal to seasonal time-scale, including developing warning systems for droughts and flood conditions of regional or river-basin scales. This program should undertake an essential role in WCRP activity in Asia, as one of the CSEs (Continental Scale Experiments in GEWEX), in cooperation particularly with CEOP Phase-II, and will contribute to other related international initiatives (e.g., CLIVAR, THORPEX, GWSP, IHP-PUB etc.).

2. Background

2.1. International research framework

WCRP is now planning a new strategic plan for the coordinated observation and prediction of the earth system, which aims to facilitate analysis and prediction of earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society. Within this framework, it is very important that efficient coordination and collaboration occurs between the WCRP activities.

One of the important and urgent targets for the WCRP Strategic Plan is the prediction of monsoon systems. Particularly, prediction of the Asian monsoon system is crucial, because over half the world’s population lives within the influence of the Asian monsoon area. Predicting Asian monsoon characteristics with regional to local scales, including their onsets, breaks, durations and variability remains a challenging scientific problem because of the complexities of the interaction involved.

As part of GEWEX, GAME was conducted for about 10 years from 1996 through 2005, and many scientific results have been obtained, particularly on hydro-meteorological processes and land-atmosphere interactions over diverse land areas in the Asian monsoon regions (sometimes called monsoon Asia) (e.g., Yasunari, 2001). On the other hand, CLIVAR has lead the

Asian/Australian monsoon panel, leading studies and coordination mainly in the atmosphere-ocean interaction processes of the monsoon system in the Indian Ocean and the western Pacific warm pool region.

These activities under WCRP have pointed out and partly revealed some important characteristic processes (e.g., diurnal cycle of convection and precipitation, coupled process of land (ocean) surface, PBL and cloud/precipitation systems, role of heating processes over the Tibetan plateau and warm oceans [Bay of Bengal, South China Sea and the western Pacific], vegetation-atmosphere feedbacks, etc.). However, further collaborated studies will really be needed for prediction of monsoons. Particularly, dynamics of seasonal march and intraseasonal variability, which are essential for predicting the Asian monsoon systems, remain unresolved and challenging. The first Pan-WCRP monsoon workshop held in June of 2005, focusing on key issues of monsoon predictions, also strongly recommended collaborated research on these issues.

A fully-coordinated framework on the Asian monsoon prediction, including its application to water resources and disaster prevention issues, are urgently required and should follow up and coordinate with the GAME activities and those of the CLIVAR Asian/Australian monsoon panel. This research framework may also need to collaborate with THORPEX in Asia, which focuses on prediction of weather regimes up to two weeks (i.e., shorter intraseasonal time scales). In addition, this new framework needs to include capacity building and training on climate research and prediction in the Asian monsoon region. This will facilitate cooperation and collaboration between the research community and operational agencies related to meteorology, hydrology, oceanography, ecology and other related sciences among countries in monsoon Asia. In this respect, this new framework is also expected to function as a substantial WCRP-side program or project, which can coordinate with START and ESSP activities in monsoon Asia.

2.2. Global Earth Observation System of Systems (GEOSS)

Understanding the Earth system -its weather, climate, oceans, atmosphere, water, land, geodynamics, natural resources, ecosystems, and natural and human-induced hazards- is crucial to enhancing human health, safety and welfare, alleviating human suffering, protecting the global environment, reducing disaster losses, and achieving sustainable development. Observations of the Earth system constitute critical input for advancing this understanding. Interested countries and organizations have collaborated to develop a 10 year implementation plan for a Global Earth Observation System of Systems (GEOSS) to build on and add value to existing Earth observation systems by coordinating their efforts, addressing critical gaps, supporting their interoperability, sharing information, reaching a common understanding of user requirements and improving delivery of information to users.

The vision for GEOSS is to realize a future wherein decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations and information. The purpose of GEOSS is to achieve comprehensive, coordinated and sustained observations of the Earth system, in order to improve monitoring of the state of the Earth, increase understanding of Earth processes, and enhance prediction of the behavior of the Earth system. GEOSS will meet the need for timely, quality, long-term global information as a basis for sound decision making, and will enhance delivery of benefits to society in the areas of disasters, health, energy, climate, water, weather, ecosystems, agriculture and desertification, and biodiversity.

There are three meanings in the phrase “a system of systems”. The first one is an integrated observation system by combining different types of observations, in-situ, airborne, and satellite. The second is an integration system that introduces data into modeling systems using techniques like data assimilation, data mining, and visualization. The third one is a system which improves data and information interoperability among different socio-economic benefit areas to contribute to socio-economic fields of study.

The GEOSS Implementation Plan endorsed at the 3rd Earth Observation Summit held in February 2005 at Brussels identified three key research and development areas as follows:

- *Improved and new instrumentation and system design for in situ, airborne, and space-based observation on a long-term basis;*
- *Life-cycle data management, data integration and information fusion, data mining, network enhancement, and design optimization studies; and,*
- *Development of models, data assimilation modules, and other algorithms that are able to produce global and regional products more effectively.*

3. Scientific goals and strategy

The scientific objective of MAHASIRI is:

"*To develop a hydro-meteorological prediction system, particularly with the time scale up to a season, through the better scientific understanding of Asian monsoon variability*".

In order to achieve this goal, the activities should focus on:

- Determine the predictability and key components of Asian monsoon variability with a time scale up to a season for the development of a hydro-meteorological prediction system.
- Develop a real-time monitoring capability for hydro-meteorological observations.
- Develop an integrated hydro-meteorological database including data rescue.
- Examine and improve the hydro-meteorological models in some specific river basins.

The key scientific issues to be solved through this program are:

- Atmosphere-ocean-land interactions in the Asian monsoon system
- Effect of various-scale orography on monsoon circulation and rainfall
- Temporal interactions among diurnal, synoptic, intraseasonal and seasonal variability of Asian monsoon
- Spatial interactions among hydro-meteorological phenomena of local, regional and continental scales
- Transferability of hydrological models and parameters for prediction of ungauged or sparsely observed basins

Regarding the international cooperation strategies, the following items are to be considered:

- Facilitate and/or improve hydro-meteorological observations in Asian monsoon countries in conjunction with GEOSS
- Cooperate with CEOP-II using observational data and hydro-meteorological studies in the Asian monsoon region
- Contribute IPY for the better observational data coverage in the Asian monsoon region

- Capacity building for observation, analysis, data-integration and modeling
- Data exchange to establish an integrated database

In the GAME project, we had four regional components, Siberia, Huai-he River, Tibet and Tropics. In the MAHASRI, regional components will be re-structured as follows:

- Tropics (including India and the maritime continent)
- Tibet/Himalaya
- East Asia
- Northeast Asia

The map of these regions is shown in Fig. 1.

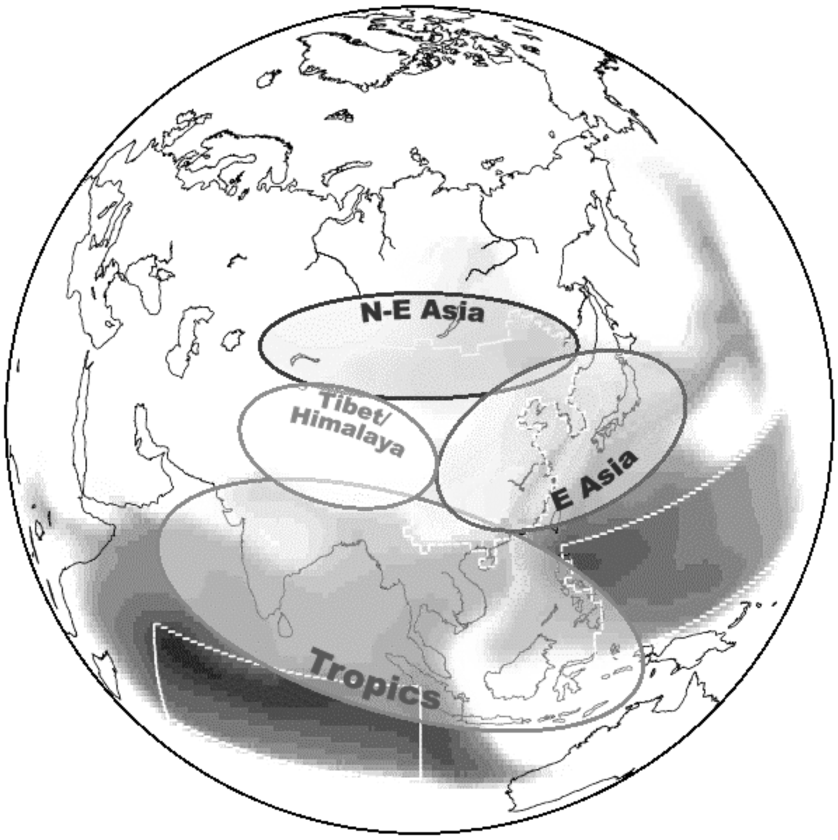

Fig. 1 Four study regions in the MAHASRI

4. Key scientific issues of Asian monsoon

4.1. General description of Asian monsoon problems

4.1.1. Summer monsoon

It is widely accepted that the development of the Asian summer monsoon (ASM) is induced by large-scale thermal gradients between the Asiatic landmass and neighboring oceans. Many researchers have indicated that the Tibetan Plateau is an important player in the heating processes as an elevated heat source in the middle troposphere (Nitta 1983; Yanai et al. 1992). In addition, numerical simulations enable us to reproduce near-real monsoon circulations by putting the South Asian tropical heat sources in a general circulation model (Ose 1998). This implies that the establishment and maintenance of the ASM is affected by the heat-induced response to tropical heating. However, the evaluation of these widely distributed heat sources is not clear and there are several discrepancies among the datasets, which should be integrated in future studies. The climatological features of seasonal evolution of Asian summer monsoon have been well documented with the help of satellite observations and meteorological objective analysis (e.g., Matsumoto, 1992; Wang and LinHo, 2002). It undergoes some drastic changes related both with seasonal and intraseasonal variations (Kawamura and Murakami, 1998). To understand the physical processes involved in the interannual variability of the monsoon, the spatio-temporal structure of the climatological features of the seasonal evolution processes in regards to the "thermal" and "heat" view need to be clarified.

Recent studies revealed a precursor signal in the fluctuation of the ASM in the form of a tropical/subtropical linkage during pre-monsoon season. For instance, Ju and Slingo (1995) showed that, once the convection over the maritime continent becomes active in late winter in conjunction with La Niña, the enhanced convection extends further westward to the north of the tropical Indian Ocean. Barlow et al. (2002) also noticed that formation of the upper-level anticyclone is dynamically induced by these anomalous tropical heat sources in the Indian Ocean. Thus, the land surface condition in the pre-monsoon season is expected to be drier than normal due to the suppression of the synoptic disturbance related to the anomalous subsidence motion (Kawamura 1998). These, in turn, favor an increase in the air temperature over the Asian continent and subsequent strong ASM.

The Asian summer monsoon is composed by South or Southeast Asian monsoon, Western North Pacific monsoon, and East Asian monsoon (Murakami and Matsumoto, 1994; Wang and LinHo, 2002). All these systems experience clear alternation of wind directions and wet/dry seasons. It has been demonstrated by numerous studies (e.g. Chen et al. 2004) that the East Asian monsoon life cycle is established by the modulation of the annual variation mode through intraseasonal (12-24 day and 30-60 day) monsoon modes. Modulations of intraseasonal monsoon modes on late spring/early summer rainstorms and typhoons in East Asia have not been well explored.

The interannual variation of the East Asian summer circulation was well depicted by Nitta (1987) with the Japan-Pacific oscillation pattern which was later confirmed by numerous studies of interannual variations in the typhoon activity in the western North Pacific (e.g. Camargo and Sobel 2005; Chen et al. 2006), rainfall variation in East China (e.g. Samel et al. The possible effect of this interannual variation mode on the monsoon life cycle, diurnal variation mode, late spring/early summer rainstorms, and intraseasonal monsoon modes are critical issues of the East Asian climate system.

Keeping these in mind, further studies should be done on the precise evaluation of the heat sources in the sub-regions embedded in the Asian continent and adjacent oceans. Also needed is an investigation of the ocean-atmosphere-land interaction by means of validation of multiple resources among the satellite-derived data, in-situ observation and numerical experiments. These studies will contribute to the better prediction of the monsoon onset timing.

4.1.2. Winter monsoon

Although summer monsoon rainfall composes a substantial portion of annual rainfall in most parts of the Asian monsoon region, in some regions, for example, the Japan Sea coastal region of Japan, east coastal region of the Philippines, Vietnam and the Malay Peninsula, winter precipitation is also important. In addition, over the maritime continent, namely over the Indonesian Archipelago, boreal winter is the primary rainy season. In some occasions, for example, November 1999, in central Vietnam, severe floods occurred under the influence of the Asian winter monsoon.

Another important feature of the boreal winter season is cold air outbreaks from the Siberian – Mongolian high which pushes southwards into southern China and the South China Sea at intervals of several days to about two weeks affects the tropics, particularly the maritime continent of Malaysia – Indonesia on very short time scales. The Japan Sea in winter is one of the important places in the world, where much of the heat and moisture fluxes are supplied from ocean to atmosphere. For long-range forecast of cold air outbreaks over the Japan Sea from several weeks to several months in advance, a correct prediction of large-scale fields such as the Arctic Oscillation is necessary.

As the cold surge reaches the South China coast, northerly winds start strengthening almost simultaneously several hundred kilometers to the south. Then, a belt of strong northeasterly winds forms within 24 hours off the South China and Vietnam coasts. This leads to a strengthening of a quasi-stationary cyclonic disturbance embedded in the near-equatorial trough that is oriented almost zonally around latitude 5^{o}N in the beginning of the season and gradually tilts to an eastnortheast-westsouthwest direction just north of the Borneo coast as the season progresses. During the early half of the season, these disturbances normally move westwards bringing heavy rain to the eastern parts of the Malay Peninsula. At times, these cyclonic disturbances, intensified by cold surges, will cause widespread heavy rainfall lasting for several days causing floods. During the later half of the season, this disturbance is referred to as the Borneo vortex (Chang et al., 2005). The Borneo vortex exhibits strong diurnal variability and is one of the main causes of heavy rain over the coastal regions of Sarawak. Some of these disturbances originate in the western pacific and propagate into the South China Sea as easterly waves (Cheang, 1977). During northern winter, the interaction between the northeast monsoon winds and the terrain makes the Borneo vortex the most well defined synoptic system with a high frequency transient mode in the equatorial belt of the Asian-Australian monsoon region (Chang, 2004). Another factor for strong convection over the southern South China Sea is the warmer SST. In comparison, in the northern and central South China Sea, the northeast winds are stronger but deep convection is much weaker (Johnson and Housze 1987) because the SST there is much lower. This pool of warm water and the SST gradient may be the trigger for the Borneo vortex and could also be the cause of the strong diurnal cycle in the convection. It has also been noted by Subramaniam et al (2005), that during El Nino periods, the SST over the southern South China Sea is warmer than usual with a weaker gradient in the temperature field and the opposite is observed during La Nina events.

The amplitude of the eastward moving MJO normally peaks during the boreal winter over the maritime continent of South East Asia (Yanai et al., 2000). This oscillation on the intraseasonal time scales produces alternating periods of enhanced and reduced large-scale convection as it passes the equatorial South China Sea region. Despite the cold surges, the MJO and the synoptic disturbances differ greatly in their origin and time scales but they may interact and influence the variability of the deep convection and the strengthening of exiting cyclonic disturbances over the South China Sea and the maritime continent. Does the intraseasonal mode have any impact on the East Asian winter monsoon? Using correlation coefficient patterns, Kiladis and Weickmann (1992) and Hsu et al. (1990) were able to isolate intraseasonal signal of the East Asian winter circulation. How this intraseasonal mode affects the East Asian winter monsoon through its modulation on synoptic disturbances and the hydrological cycle has not been well explored. To examine the impact of cold surges on the East Asian winter weather system, Campo et al. (1999) presented the spatial structure of the

12-24 day mode related to cold surges. The signal of this intraseasonal mode which stands out clearly in the East Asian surface pressure is well reflected by the coupling between the eastward propagation of midlatitude anticyclone/cyclone and cold surge activity (Chen et al. 2002). How this intraseasonal mode affects the East Asian winter monsoon rainfall is beyond our current understanding. Without proper research effort to understand the impact of intraseasonal modes on the winter monsoon rainfall in East Asia, it is unlikely to perform the seasonal prediction of the East Asian short-term climate.

Various studies have tried to advance the understanding of cold surges through numerical simulations. For example, Lim and Chang (1981) examined the dynamics of mid-latitude tropical interactions using the concept of vertical modes and suggested that the pressure surge could represent a transient, gravity wave like motion due to a pressure-wind imbalance, which then allows a fast propagation of energy from the mid-latitudes to the tropics. However, there still remains a number of challenging questions related to the boreal winter cold surges that need to be addressed;

(1) How does intense mid-latitude anticyclonic development give rise to strong northeasterly wind over the South China Sea that often spreads southward rapidly?
(2) How does cold surge interact with tropical convective system? What is the role of air-sea interaction, cold surge, and the cyclonic disturbances and the Borneo vortex in the southern South China Sea?
(3) How do the MJO and cold surges interact?
(4) How are mid-latitude-tropical and inter-hemispheric interactions dynamically linked?
(5) What is the interannual variability of cold surges and how is it linked to El Nino Southern Oscillation?

The last winter monsoon experiment (WMONEX) over the South China Sea region was conducted about 26 years ago during the boreal winter of 1978/79. Many important findings were obtained as summarized in Boyle and Chen (1987), Lau and Chang (1987), McBride (1987) and Lim and Chang (1987). Since then, many additional findings have been also accumulated for the Asian winter monsoon as recently summarized in Chang (2004), Chang (2005), and Hendon (2005). However, no systematic international observation projects have been conducted on the Asian winter monsoon after WMONEX. It is timely that intensive studies to clarify the above crucial issues be carried out as one of the objectives of the MAHASRI. An IOP during the occurrence of cold surges to coincide with the IPY in 2008 would provide valuable data to further our understanding of the issues raised here.

4.2. Monsoon variability in various temporal and spatial scales

4.2.1. Diurnal cycle

Diurnal cycles of precipitation and clouds are now recognized as key factors directly relevant to the uncertainty of climate projection by GCMs. It is well known that the one day is the most prominent period for disturbances in the atmosphere over land in the tropics and land in midlatitudes in warm seasons. Until recently, however, diurnal cycles have not received sufficient attention by climate researchers, possibly because the time scale is different from that of climate change and it was hard to imagine such a short time scale would affect climate.

Recent researchers in the field of climate point out that the representation of the diurnal variation of precipitation over land by large-scale climate models with rather coarse resolution is poor (e.g., Yang and Slingo 2001, Dai and Trenberth 2004). The predicted daily precipitation maximum often occurs several hours earlier than the observations and in some areas even opposite in phase (i.e., the model predicts the daily maximum in the early afternoon, but in observations it occurs during the night or early morning). Because the diurnal variation of precipitation accompanies the diurnal variation of cloudiness and because the variation of cloudiness strongly affects the radiation budget of the Earth system, monsoon researches agreed that one of the urgent problems to be solved is the proper representation of the diurnal variation in GCMs (e.g. AAMP-7 Draft Actions/statements, 2005).

Considering that the Asian monsoon region is one of the biggest components of the atmospheric circulation system, the resolution of the detailed characteristics of diurnal variation in this region is crucial for improving climate projection by GCMs. Because some precipitation systems governing the diurnal variation are propagating mesoscale systems (e.g., Satomura 2000, Okumura et al., 2003, Mapes et al., 2003, Kataoka and Satomura 2005), we should collect and analyze the precipitation data which covers areas of regional scales (larger than ($\sim(10^2) - \sim(10^3)$ km)^2 area) with fine temporal (at least 8 times per day) and spatial ($\sim$(10) km) resolution. One of the promising candidates for such regional precipitation data would be the data from radar networks already constructed in Thailand, Malaysia, Vietnam, Bangladesh and other tropical countries. Although some of these networks do not work routinely, by promoting proper functioning of the network, at least in short IOPs, and by collecting past radar data, we would obtain basic data sets to study the diurnal variation in a regional scale. At the same time, in order to calibrate the precipitation estimation by radar, shorter time-scale rainfall observations by automatic rain gauges are needed and it will also serve as an important capacity building. Other observations of cloud and atmospheric parameters will also be necessary for full understanding of diurnal precipitation processes. It is also inevitable that cloud-system-resolving regional scale model (CSRM) studies be conducted in parallel with the regional data analysis. Based on observation and modeling, how diurnal variations are coupled with synoptic and/or intraseasonal variations needs to be solved.

Because of the difference in heat capacity between land and ocean in both longitudinal and latitudinal directions and between low and high latitudes, the atmospheric response to the westward propagation of sun is a daily clockwise rotation of rainfall over Asia, in addition to the westward global propagation (Chen 2005). How is this diurnal mode modulated by the East Asian monsoon life cycle? It requires special care to handle the diurnal variation mode in a climate model.

4.2.2. Synoptic-scale variability

The Asian summer monsoon is strongly modulated by disturbances on various time-scales. In the South Asian summer monsoon, monsoon depressions and lows in the Bay of Bengal are the major contributors to the monsoon rains in northeastern India. It has been noted (Kumar and Dash, 2001) that the number of lows (depressions) occurrences has steadily increased (decreased) over the last two decades keeping the sum of lows and depressions approximately unchanged. Understanding of these changes and the associated effects on water resources and flood/drought occurrences in the Indian Sub-continent should be investigated in the future.

Tropical cyclones in the western North Pacific strongly influence the rainfall situations in Indochina. However, studies have not been conducted on how much these disturbances contribute to rainfall in specific regions of Indochina. Also unrevealed is the relationship between monsoon activities and tropical cyclone development and frequency. These topics need to be studied.

In the East Asian summer monsoon, synoptic disturbances along the Baiu/Meiyu front strongly modulate the state of the monsoon (e.g. Chen, 2004; Ninomiya, 2004). Synoptic-scale mid-latitude disturbances also affect the occurrences of pre-monsoon rainfalls in Indochina (Kiguchi and Matsumoto, 2005) and timing of the South China Sea monsoon onset (Chang and Chen, 1995; Ding and Liu, 2001). How these triggering events relate with seasonal time-scale heating over the continent and/or the Tibetan Plateau still need more study. The long-term variability of synoptic disturbances in East Asian Meiyu/Baiu frontal zones also needs investigation.

Synoptic-scale disturbances are also important in the Asian winter monsoon, in particular, coupled with East Asian cold surges as mentioned in 4.1.2. Some midlatitude cyclone systems in East Asia are developed from the cyclogenesis/frontogenesis between Taiwan and Okinawa by the easterly flow of eastward propagating anticyclones across a shallow surface trough extending from Philippines, across Taiwan and Okinawa, to southern Japan. Because of the lack of understanding of this cyclogenesis/frontogenesis mechanism, winter rainfall in East Asia is often difficult to simulate by climate models. Numerous studies (Lau and Chang 1987) were made during and after the Winter Monsoon Experiment in 1978/79 to explore the tropical-midlatitude interaction through cold surge activity. How cold surges affect the hydrological cycle of tropical Southeast Asia through cold-surge vortices over this region is still not well comprehended. Some serious pursuit of seasonal/interannual prediction of the winter East Asian monsoon is needed to understand these winter weather systems.

4.2.3. Intraseasonal variability

It has been recognized that intraseasonal variability with a time-scale of 7-90 days, including phenomena like the Madden-Julian Oscillation (MJO) and Quasi Bi-weekly Oscillations, play a significant role in the seasonal evolution of the Asian monsoon system. A number of researchers have tried to clarify a dominant mechanism for the abrupt monsoon onset (e.g., Yano and McBride 1998; Xie and Saiki 1999; Kawamura et al. 2002). The role of MJO disturbances in triggering the onset may be crucial in those proposed hypotheses. It is also probable that the MJO and other intraseasonal disturbances largely affect the active and break cycles of the Asian summer monsoon.

If the intraseasonal variability is quite independent of the interannual variability (Krishnamurti and Shukla 2000), the quantitative estimation of relative importance of the two variability types is very meaningful in understanding the potential predictability of seasonal monsoon precipitation. If chaotic intraseasonal disturbances induce the interannual component, however, its potential predictability is supposed to be very low (Goswami and Mohan 2001). Unfortunately, it is still uncertain which hypothesis is valid. Likewise, questions of how the intraseasonal variations modify the activity of the monsoon depression and the diurnal variation of precipitation have still not been answered satisfactorily. Another important issue is how the modification of the air-sea interaction impacts the MJO and other intraseasonal disturbances. While the MJO disturbances dynamically influence the surface layer of the tropical Indian Ocean, the ocean, in turn, plays a vital role in the growth of the disturbances.

Intensive studies to clarify these crucial issues should be performed as one of the main objectives of the MAHASRI project. In particular, the following topics should be examined:

(1) The role of the intraseasonal variability in the abrupt onset, and the active and break cycles of the monsoon system
(2) The role of the intraseasonal variability in the activity of the monsoon depression
(3) The modification of the intraseasonal variability on the diurnal cycles of precipitation
(4) The modification of the ocean-atmosphere and land-atmosphere interactions on the intraseasonal variability

4.2.4. Interannual variability

It has long been known that the atmospheric circulation associated with the summer monsoon is governed by a combination of land-ocean thermal contrast and large-scale convective heating. Both the land-surface hydrologic conditions of the Asian continent and oceanic conditions in its surrounding oceans influence monsoon activities on various time scales. The importance of the land-atmosphere interaction has been confirmed by many findings derived from GAME. However, the ocean-atmosphere interaction in the tropical Indian and Pacific Ocean is also one of the primary factors in controlling the variability of the monsoon system. Although these two types of interactions have been examined separately based on observational and modeling studies, we need to further investigate how these two interactions are possibly associated with each other to properly understand the mechanisms of the monsoon variability and explore its potential predictability. For instance, the ENSO forcing due to the ocean-atmosphere interaction changes land-surface hydrologic conditions of the continent during the pre-monsoon season (e.g., Barlow et al. 2002; Kawamura et al. 2004), which may consequently affect monsoonal rainfall during the following monsoon season. A question of how the land-atmosphere-ocean interaction greatly contributes to the interannual monsoon system variability has still not been answered satisfactorily.

GAME brought about the establishment and development of observational sites in land areas, whereas, within the CLIVAR projects, the monitoring of the oceanic conditions in the tropical Indian Ocean and western Pacific has been enhanced recently. Under such circumstances, intensive studies to clarify the above crucial issue should be performed as one of the main objectives of the MAHASRI project.

In particular, the following topics should be examined:
(1) The mechanism of the monsoon onset with special emphasis on the land-atmosphere-ocean interaction
(2) The mechanism of interannual variations of active and break cycles of the monsoon system
(3) The response of the Asian summer monsoon to ENSO-related forcing through land-surface hydrologic processes
(4) The long-term changes of the monsoon system associated with climate shifts in the tropics and global warming

4.3. Important processes relevant to monsoon variability

4.3.1. Land surface processes

In the GAME project, surface energy and water balance was observed in many kinds of landcover conditions in different climate regions. Since most of these flux measurement sites were located in remote places and GAME was a first attempt to obtain such kinds of information continuously in that area, the flux measurement itself brought us basic ideas about surface energy and water balance (Ohta et al. 2001, Tanaka et al. 2003, Toda et al. 2000). At the same time, it resulted in many new findings. For example, the latent heat flux in evergreen forests in the north part of Thailand has its maximum at the end of the dry season (Tanaka et al. 2003). This fact is different from existing studies or model estimates.

Direct measurements of turbulent fluxes of sensible heat and water vapor have already become a standard monitoring system. Although the analysis methods, like the eddy correlation method, still need some improvement, current systems are sophisticated enough, and there is no strong need for further development. Continuous monitoring during the GAME and CEOP period has revealed fundamental characteristics in the seasonal variation of energy, water, and carbon cycles. In addition, the range of inter-annual variations has become apparent to be about the same as or even larger than that of seasonal cycles. Long term monitoring is necessary not only to detect the effects of inter-annual variability such as El-Nino/La Nina, but also to clarify how meteorological anomalies in some specific years affect the response of the surface (e.g. phenology, fluxes) for that year. However, the effect can also be observed in forest ecosystems which last several years. Considering the target prediction time scale of this project is up to a season, the prediction of vegetation dynamics might be an important issue because the vegetation phenology (seasonal evolution of vegetation) is highly dependent on meteorological conditions (temperature, radiation etc.) (Suzuki and Masuda 2004, Miyazaki et al 2004), and, in turn, vegetation status can have significant feedbacks to the atmosphere.

Vast amounts of data have been obtained from these sites, and most of them have already been archived in the GAME and CEOP databases (http://erc3.suiri.tsukuba.ac.jp/~game/cdroms/CD-ROM.html). In the new project, comprehensive use of these already established (and ever-growing) databases, especially, the utilization of these observations for the improvement of land surface parameterization, is important (Yang et al. 2002). Furthermore, not only the parameterization itself, but also identification of key parameters and construction of the spatial/temporal distributions of these parameters must be addressed by combining in-situ and satellite measurements.

Regarding land-cover conditions, it is rather difficult to know the actual agricultural landuse. Because more than half of the cultivated area in the world exists in the Asian Monsoon region, realistic treatment of cropland is very important (Kozan et al. 2003). The phenology of cropland is affected by human activity (seeding /harvesting), and it is sometimes different from that of natural vegetation. Furthermore, not only from the view point of water resources, but also from surface energy balance, agricultural wateruse (irrigation, in particular for paddy field) must be taken into account (Kim et al. 2001; Yorozu et al. 2005).

One of the important issues to be addressed is deep soil moisture. Most of the current land surface models treat near surface soil moisture. Evergreen trees, especially in semi-arid regions utilize the soil moisture at a relatively deep depth. That is why they can be active (high transpiration rate) even in the dry season. Detailed measurement of soil moisture (and potential) profiles up to several 10 meters might be required. At the same time, the representativeness of the plot scale soil moisture and theta-psi relationship is still a difficult issue to be solved. Heterogeneous distribution of soil moisture results from the precipitation pattern, heterogeneity in soil texture, and redistribution caused by micro-topography (Hirose et al. 2002). Partition of runoff (surface runoff and baseflow) is another big issue. The stable isotope technique is thought to have much potential for this issue, particularly in terms of improving land surface models (Henderson-Sellers et al. 2006).

The reason why GAME and MAHASRI have paid much attention to the land surface processes is that the Asian monsoon is governed by heat contrast between the ocean and the continent. There has been a famous hypothesis that anomalous winter snow cover and subsequent anomalous soil moisture over Eurasia have a large impact on summer Asian monsoon precipitation (e.g., Hahn and Shukla 1976; Yasunari et al. 1991). It is therefore believed that the predictability of monsoon will be improved by more adequate incorporation of land surface processes and information into climate models. However, a recent study using observational records for several decades revealed that the land wetness-monsoon precipitation relationship is not so clear (Robock et al. 2003). Also, AGCM simulations showed that the predictability of seasonal-scale monsoon rainfall is not enhanced even if realistic soil wetness is provided (Kanae et al. 2006). We should make further efforts to enhance and to determine the predictability of seasonal-scale monsoon rainfall, focusing on land surface processes, with the utilization of higher resolution climate models, more advanced land-surface models, and detailed and longer observation records.

4.3.2. Sea surface processes

The Asian monsoon systems are strongly affected by variability of the sea surface temperature in the Indo-Pacific sector of the tropical oceans, while the monsoonal winds and rain, in turn, affect the sea surface temperature distribution through many oceanic processes. The basin-scale seasonal cycle associated with the monsoon is a key element in the sea surface processes. El Nino/Southern Oscillation phenomena have been focused on for more than two decades as one of the most important variable factors, which introduce significant impact on the socio-economic activities over the world. However, a wide range of spatial and temporal variability has been recognized by recent studies as key processes that determine the sea surface temperature in this area. The processes, which should be addressed for a better understanding of the ocean components of the climate variability, are;

(1) Seasonal variability in the sea surface layer associated with the monsoons
(2) Intraseasonal disturbances and their interactions with the upper ocean
(3) The Indian Ocean dipole mode and its interaction with El Nino/Southern Oscillation
(4) Decadal variability and warming trends in the upper ocean
(5) Impacts from the atmospheric and oceanic variations in the extra-tropical regions on tropical sea surface conditions
(6) Surface mixed-layer variability, including influences of salinity.

In addition, several particular ocean circulations, such as the Indonesian throughflow and the shallow overturning cells, affect heat storage and transport between different regions within the Indo-Pacific sector.

A lack of in situ observations in the ocean, especially in the Indian Ocean, limits our knowledge of the above issues and predictability of the monsoon climate system. An extended observation network within the ocean, together with high performance numerical simulations, is necessary for further advance of the study on the sea surface processes.

4.3.3. Impact of aerosols on cloud and precipitation

In recent years, indications of the impact of aerosols on cloud microphysical properties and precipitation have been reported based on in-situ and satellite observations. Model calculations with various spatial scales also show the importance of aerosol influences on cloud formation and precipitation.

There are basically two kinds of aerosol impacts on atmospheric dynamics. The first one is the so-called direct effect in which scattering and absorption of aerosol particles affect radiation fields and local heating rates. Local heating of the atmosphere by light absorbing particles, such as soot particles (primarily consisting of elemental carbon [EC] and are also called black carbon [BC] particles) can reduce cloud formation locally (semi-direct effect) and more importantly, change the vertical stability of air causing changes in atmospheric circulation (one of the direct effects). Recent observations over the Indian Ocean (INDOEX) show that heating of anthropogenic soot particles in the air has considerable impact on the energy budget of the atmosphere (Ramanathan et al., 2001). Model calculations show that heating caused by anthropogenic soot particles over central China are so large that the heating can induce vertical motion of air causing an increase in precipitation over central China and precipitation decrease over the northern part of China and Southeast Asia. This mechanism can explain the observed trend in precipitation in China during the last 40 years (Menon et al., 2002).

The other mechanism in which aerosols can impact cloud and precipitation is the indirect effect in which aerosols act as cloud condensation nuclei (CCN) and ice nuclei (IN). When water clouds are considered, an increase in aerosol particle numbers (and therefore, increase in CCN number) can result in an increase in cloud droplet numbers leading to smaller cloud droplet particles (under the same liquid water content) that result in an increase of cloud albedo (1st indirect effect). The decrease in cloud droplet size also prevents the formation of drizzle and rain droplets that result in an extension of the cloud lifetime (2nd indirect effect). In-situ and satellite observations suggest that due to emissions of anthropogenic aerosols and precursors, effective cloud droplet diameters in downwind areas are systematically smaller than those in surrounding areas and, as a result, precipitation tends to be suppressed (Rossenfeld et al., 2000). Furthermore, since most precipitation likely originates via the ice phase, aerosol effects on ice clouds might have larger consequences for the hydrological cycle than those on water clouds.

Quantitative estimates of aerosol effects on atmospheric dynamics still have large uncertainties and impacts on Asian monsoon are open questions. However, considering the new findings described above and the rapid increase in anthropogenic emissions over Asia, there is a strong need of further investigations in the MAHASRI project. Two large uncertainties should be addressed under the coming project. First, spatial and temporal variations of aerosols over Asia still have large uncertainties. Because of a lack of systematic and reliable measurements of aerosols in Asia, we have a very weak scientific basis to evaluate the aerosol impacts. Second, we have very poor understandings on several key processes of aerosol impacts, such as warm cloud droplet formation from specific aerosol distributions.

Considering these situations, the following studies need to be done within the MAHASRI project.

(1) Spatial and temporal variation of aerosols

Systematic and reliable measurements of aerosol should be done.

Because aerosol impacts depend on various aerosol parameters, it is desirable to have the following measurements: aerosol mass concentrations, aerosol size distribution, aerosol composition (inorganic and carbonaceous compounds), and optical properties. Ground based measurements of these parameters need to be done in several locations. Measurements which are free from local influences and are representative of regional distributions need to be done. In addition, measurements which are close to sources also need to be made to characterize aerosol sources, such as measurements in urban regions and locations where significant biomass burning influences are observed. These measurements may be made as a joint project with the UNEP/ABC and the GEOSS projects. Because aerosol impact can be quite different depending on their vertical distributions, measurements in the free troposphere are also important.

(2) Key processes of aerosol impacts

Several key processes need to be investigated. A relationship between CCN and IN activities, and various aerosol physical and chemical parameters, such as, aerosol size distribution, chemical composition, and mixing state need to be studied. This process is, in general, expressed empirically and therefore, explicit expression needs to be made for aerosols over Asia which can be very different from those on which the empirical formulation was made. Radiation budget as a function of altitude needs to be investigated, and for this purpose, a relationship between aerosol parameters and absorption of solar radiation should be studied.

(3) Evaluation of aerosol impacts

Based on knowledge of aerosol distribution and the key processes described above, evaluation of aerosol impacts should be made using model calculations.

4.3.4. Cloud and precipitation processes

In the GAME-HUBEX, there were intensive observations of soundings at multiple points to examine the atmospheric environment (e.g., vertical profiles of temperature, mixing ratio of water vapor and wind field), conventional meteorological radar to observe meso-α scale cloud systems, and multiple Doppler radars to observe the structure of meso-β scale cloud systems embedded in the meso-α scale cloud systems (Zhao and Takeda 1998). By using the GAME-HUBEX observation results, our understanding has progressed on the structure of the mesoscale convective systems (MCSs) in the Meiyu front (Maesaka 2003), and on isolated diurnal cumulonimbus clouds in the southern region far from the Meiyu front (Yoshida and Uyeda 2002, Shusse et al. 2005). Also, some investigations were conducted on convective systems over the GAME-Tibet region (Uyeda et al. 2001) and the Indochina Peninsula in the GAME-T region (Okumura et al. 2003). In the MAHASRI Program, we need intensive sounding data and multiple Doppler radar observations in order to understand the structure of MCSs around the Maritime Continent, Southeast Asia, and East Asia. Additionally, since there have been few statistical studies on the MCSs, we also need statistical analyses of the structure, duration time, cloud top height, and diurnal variation of MCSs using the observation results.

There have been modeling studies in the GAME region. Satomura (2000) showed the structure of the propagating MCSs over the northern Indochina Peninsula. Shinoda and Uyeda (2002) showed effective factors in developing deep convective clouds over mainland China in the southern region far from the Meiyu front. These studies described specific cases of convective cloud systems. However, no studies have been conducted on the influence of the MCSs on the atmospheric environment; that is, diabatic heating profiles affected by the development of MCSs. We can now estimate the vertical diabatic heating profiles explicitly by using high-resolution cloud resolving models (CRM), e.g., Cloud Resolving Storm Simulator (CReSS: Tsuboki and Sakakibara 2001). These profiles estimated by the results of the CRM should be compared with those calculated by the general circulation models (GCMs) and regional climate models (RCMs) which use cumulus parameterizations. In order to estimate diabatic heating profiles correctly, we also need research on the bulk microphysical processes in the CRM.

4.4 Regional sub-programs

4.4.1. Tropics

4.4.1.1. Maritime Continent

Recent observational studies over the Indonesian maritime continent (IMC) suggest the importance of horizontal convection such as meridional (Hadley and monsoon) and local (sea-land and mountain-valley) circulations. The Asian-Australian monsoon is an annually oscillating continent-ocean circulation. Its meridional component is asymmetric to the equator, and is superimposed on the equatorial symmetric Hadley circulation. The zonal component of the monsoon circulation is interacted with zonal circulations, i.e., the interannually-varying zonal Walker circulation and the eastward traveling intraseasonal variations along the equator. Interactions between these larger-scale circulations and the diurnal variations (in particular those with scales of a large island) may be the most important process in/around IMC, and also an outstanding process which must be clarified to understand and predict global climatic variations.

For approaching the issue mentioned above, we need to establish an observational network covering IMC and surroundings. As an activity of the Japan EOS Promotion Program (JEPP), stations equipped with meteorological Doppler radars and/or wind profilers started to be constructed over the IMC from FY2005. The major target in the first five years using this network is the interaction processes between the intra-seasonal variations (seen as super cloud clusters) and the smaller-scale (diurnally-oscillating island-scale) and larger-scale (annually-oscillating monsoon) circulations. In addition, a buoy network will also be constructed under JEPP for observing intra-seasonal variations over the Indian Ocean, a regional numerical model and a system for capacity building will be developed.

Due to the complex terrain, wind-terrain interactions are very important in motions with various time-scale variations from diurnal time-scale to interannual variations (Chang et al 2004, Chang 2005). The study of these interactions needs high resolution observation network and regional climate models.

4.4.1.2. Indochina

A regional sub-project for Indochina in MAHASRI will be established as the continuation of GAME-Tropics (GAME-T), which was carried out as a part of GAME. Although many interesting research results have been obtained through the GAME-T activities, in particular on the interactions between land and atmosphere (e.g., Kanae et al., 2001; Tanaka et al., 2004), several important issues are left to be solved. They are;

(1) Physical mechanisms of the onset and withdrawal of Southeast Asian monsoon and its variability (Kiguchi and Matsumoto, 2005; Yoshimura et al., 2004).
(2) Prediction studies and application of predictions for water management and flood warning.
(3) Understanding the diurnal cycle for better prediction of monsoon rainfall (Satomura, 2000).
(4) Assessment and future projection of climatic changes induced by the anthropogenic impacts on water resources/hazards.

Demonstration of usefulness of the scientific knowledge to the societies in the region is a new feature when compared with the previous activities, although scientific challenges will continue. Currently, under the JEPP program, the development of a real-time flood warning system is being prepared for a river basin located in northern Thailand. Similarly, a survey for a flood warning system is being carried out for river basins in the central part of Vietnam. Data acquisition/rescue with the continuous establishment of hydrometeorological database for the regions is a necessary task as well. In addition to the Chao Phraya river basin, the main target-basin in GAME-T project, the new regional sub-project will include Vietnam, the northeastern part of Thailand, and Malaysia. In addition the winter-monsoon becomes a new target of research, in particular in Vietnam and Malaysia. Also, hydro-climatological aspects of tropical cyclones will be a new item for investigation because tropical cyclones are one of the major sources of hydrological disasters in this region.

GAME-T and other related activities have promoted the international collaboration and capacity-building activities among hydrometeorological institutes and universities in the region. For example, annual workshops have been held these several years in Thailand with the number of participants from 50 to 200. The new regional sub-project will also enhance the collaboration and capacity-building.

4.4.1.3. South Asia

Several programs relevant to MAHASRI are being planned in India in the next 5 years. The first is the modernization of basic meteorological observational networks in India by the India Meteorological Department. Under this plan, about 1000 AWSs, 4000 automatic rain gauges, and more than 50 Doppler weather radars spread across the country are expected to be installed. The second relates to the Indian Climate Research Programme (ICRP), which has been addressing issues relevant to the Indian monsoon since 1996, and two field programs; the Bay of Bengal Monsoon Experiment (BOBMEX, July-August 1999) and the Arabian Sea Monsoon Experiment (ARMEX, 2002 – 2003) have already been carried out. A multi-disciplinary observational program called the Continental Tropical Convergence Zone (CTCZ) is being planned during the period 2007-2009 in India. The area of focus is the Indo-Gangetic plain and the adjoining Bay of Bengal. The major thrust is on understanding various components of monsoon systems over land and the Bay of Bengal, and the complete the hydrological cycle over one or two suitably selected river basins and sub-basins (watersheds). While data will be collected over the entire Indo-Gangetic basin, a sub-region will be densely equipped with AWSs, self recording rain gauges, flux towers and high resolution radiosondes. Monsoon exhibits variability on various spatio-temporal scales. In order to understand both the intraseasonal and inter annual variations, intensive observations for two to three consecutive monsoon seasons are planned. CTCZ will address the following issues.

(1) Propagation of monsoon systems over land, and associated water and energy budgets
(2) Detailed land-surface processes
(3) Complete hydrological cycle over one or two suitably selected river basins and sub-basins (watersheds)
(4) Hydrological feed-backs on monsoon systems
(5) Role of natural and anthropogenic aerosols in monsoon clouds and systems

A low inclination earth orbiting research satellite called MEGHA-TROPIQUES is being planned for launch in the year 2009 under joint Indo-French collaboration. Its orbit inclination is 20 degrees so that the tropical region is sampled very frequently (typically 4-6 times a day).

It will have three main sensors; MADRAS (Microwave Analysis and Detection of Rain and Atmospheric Structures), with channels for sea surface winds, water vapor, liquid water, rain and ice, SAPHIR (humidity sounder) and ScaRaB for Radiation Budget. The main science objective is to understand the energy and water cycle in tropical convective systems by simultaneous and frequent measurement of rainfall, water vapor, liquid water, ice, humidity profiles, surface winds and radiative fluxes.

Four radar systems currently exist in Bangladesh. At present, 2 radars are functioning and one more radar (in the southern side of the country) is committed to replace the Doppler one very soon. Besides this radar network, one more new Doppler radar at the Meghna Basin is proposed and expected to be installed by the year 2007. At present, there are 34 First Class Observatories and 10 PBO (Pilot Balloon Observatories) existing in Bangladesh. Furthermore, there are 11 new First Class Observatories proposed in different locations throughout the country. The Bangladesh Water Development Board (BWDB) and IWM (Institute of Water Management) are using a surface water model for flood monitoring and forecasting. They are using NOAA data as the model input. They need higher temporal resolution data as input to improve the accuracy of the forecast. Hopefully, the Bangladesh Government will cooperate with the proposed MAHASRI project. The mentioned facilities are available and helpful for the implementation of the MAHASRI project. In MAHASRI, the Meghna Basin is one of the important study areas for flood monitoring and forecasting. Meghna Basin has typical characteristics of diurnal variation of rainfall: the peak time of rainfall in this land is early morning (at about 03:00-06:00 am). Also the rainfall that occurs in this region is from pre-monsoon to monsoon through post-monsoon periods. The results from the Meghna Basin through MAHASRI may be used as a model for other study regions. It is planned to establish a dense distributed rainfall observation network in heavy rainfall areas of the northeastern region of the Indian subcontinent that can detect water cycle and climatic changes associated around the Meghna river basin. Several raingauges are concentrated in the relatively small target area in the southern foot of Meghalaya. Simultaneously, continuous radar observations will be conducted during the rainy season of pre-monsoon and monsoon seasons by supplying the magnetron to the Bangladesh Meteorological Department. Both the data from automatic raingauge networks and radar systems are compared and the real-time data acquisition system is completed, which will contribute to the quasi-real-time estimation of an hourly rainfall distribution map with very fine spatial resolution (-2.5km) in the Meghna river basin with the aid of the meso-scale numerical model.

4.4.2. Tibet and Himalayas

4.4.2.1. Tibetan Plateau

The Tibetan Plateau is an elevated heat source protruding into the middle of the troposphere, which has an important role in the formation of the Asian summer monsoon. During GAME, observations were focused on the land surface-atmosphere processes. In cooperation with the Chinese Research Program, TIPEX (Tibetan Plateau Experiment), an intensive surface observation network was deployed on the plateau during the IOP in 1998. After the IOP, many automatic stations have been continuously running. In particular, the BJ site (south of Naqu) was upgraded to a so-called super site in the CEOP. With these observations, Tanaka et al. (2001, 2003), Choi et al. (2004), and Bian et al. (2002) revealed the actual surface heat fluxes and their seasonal variation at individual turbulent flux sites. Tanaka (2005) used the data from extended observations and revealed the inter-annual variability of the fluxes in 1998-2002 at Amdo. Xu and Haginoya (2003) and Xu et al. (2005) utilized routine observations at operational surface stations to compute monthly average fluxes at various places on the plateau. In addition to the ground based research, satellite data are used to map the distribution of near surface soil water and surface fluxes (Ma et al. 2003, Oku et al. 2005). As for cloud activity and precipitation, which are indicators of atmospheric heating due to the latent heat release, rain gauge studies (Ueno et al. 2001) and satellite studies (Fujinami and Yasunari, 2001) were conducted in addition to the Doppler radar observations during the IOP (e.g. Uyeda et al., 2001).

Although considerable knowledge has been compiled for hydrometeorology over the Tibetan Plateau, the knowledge is not sufficient to describe the comprehensive energy and water cycle on and over the Plateau. Since observations are limited over the plateau, it is inevitably required to employ the four dimensional data assimilation approach. In this MAHASRI research, the data from available observational resources and satellite-retrieved data are integrated to describe energy and water flow through the use of four-dimensional data assimilation techniques. The research topics are:

(1) Regionalization of surface fluxes on the Tibetan plateau

(2) Mesoscale convection and its role on the atmospheric heating

(3) Water vapor flux towards and on the Tibetan Plateau and its relation with precipitation, river discharge and the resulting issues such as water resources and flood in eastern Asia.

4.4.2.2. The Himalayas

One of the prominent monsoon precipitation regions is over the Himalayas. Precipitation is an important component of the water resources through glacier mass balances in the Himalayas, but it also causes frequent orographic disasters such as landslide/avalanche by heavy rain/snow. GLOF (glacier lake outburst flood) in the Himalayas is one of the representative global environmental issues to be assessed (Yamada and Sharma, 1992). The Himalayas are also part of the Tibetan Plateau which plays an important role in composing the atmosphere-ocean system of the monsoon through thermodynamic effects (Abe et al., 2004). In the Nepal Himalayas, dense hydro-meteorological monitoring observatories are distributed by the Department of Hydrology and Meteorology (Shrestha, 2000). International projects, such as GAME-AAN, Ev-K2-CNR, and NASA/NSF, have conducted basin scale field surveys to understand the unique processes of local circulations (Egger et al., 2000; Bollasina et al., 2000; Ueno et al., 2001). Satellite datasets, such as GMS and TRMM, have been analyzed to understand structures of precipitation systems and mechanisms for diurnal variations (Barros et al., 2000; Kurosaki and Kimura, 2002; Bhatt and Nakamura, 2005). However, the lack of three-dimensional in-situ field observations have prevented the progress of understanding precipitation processes, such as mechanisms of water vapor transfer, diurnal changes of stability and their relations to complex topography. Development of new hydro-meteorological models, which could treat the super complex terrains with deep valleys and steep slopes in the Himalayas, are also challenging issues (Satomura et al., 2003). Based on such scientific interests and background, the main study objectives will be proposed as follows:

(1) Role of the Himalayas as water vapor transports and heat sources in the Asian monsoon climate

(2) Precipitation mechanisms and its modeling over complex mesoscale terrain

(3) Basin-scale nowcasting and monitoring of hydrological components for natural disaster prevention.

To achieve those issues, 1) basin scale intensive observations, 2) development of mesoscale modeling with complex topography, and 3) establishment of super hydro-meteorological observation sites, will be the important issues for the implementation plan.

4.4.3. East Asia

Based on studies over many years, it has been found that many differences exist between the monsoon circulation over India and that over East Asia. This suggests that the structure and main components of the monsoon system over East Asia is likely to be independent of the Indian monsoon system, even though there are some significant interactions. Thus, the summer monsoon over East Asia (including the South China Sea) cannot be just thought of as the eastward and northward extension of the Indian monsoon. Another important issue of the East Asian monsoon its more vital winter component compared with South and Southeast Asian monsoon. One must take into account its unique regional characteristics. During the past two decades, more and more attention has been paid to study the East Asian monsoon, because occurrence of many weather and climate disasters is closely related to the vagaries of the East Asian monsoon. Recent studies on the East Asian monsoon have been devoted to the following aspects:

(1) The onset of the East Asian summer monsoon, especially in the South China Sea and the Indochina Peninsula. It has been well documented that the earliest onset of the Asian summer monsoon occurs in this region.

(2) The seasonal march of the East Asian summer monsoon and associated major seasonal rain belts.

(3) The seasonal march of the East Asian winter monsoon and its relationship with Southeast and South Asian monsoon.

(4) The Meiyu/Baiu/Changma system and associated multi-scale weather disturbances.

(5) The multi-scale variability of the East Asian monsoon and its effect on anomalous climate events (i.e. droughts/floods), especially intraseasonal (ISO), interannual (e.g., ENSO-monsoon relationship) and interdecadal-scale variability (including effects of PDO, AO, NAO etc.).

(6) The remote effect of the East Asian monsoon through different teleconnection patterns.

(7) The physical processes and mechanisms related to the East Asian monsoon variability.

(8) The regional response of the East Asian monsoon system and its components to the global warming

(9) The predictability and prediction of the East Asian monsoon.

Major thrusts for these studies are the South China Sea Monsoon Experiment (SCSMEX, 1996-2001) and the GEWEX Asian Monsoon Experiment (GAME), especially GAME/HUBEX. Recently, the field experiment on the atmospheric boundary layer over the HUBEX area has been performed (Lower Atmosphere and Precipitation Studies led by Profs. Nakamura and Li). Several experiments on precipitation along the Baiu front have been made over the East China Sea and along the western coast of Kyushu, Japan. These experiments are aimed at the study of the structure of the moist boundary layer and its relation to the development of precipitating systems during the summer monsoon in East Asia.

The seasonal predictions in East Asia have been made by CMA, KMA and JMA and the

Joint Meeting among them have taken place on a regular basis (twice once a year) since 1998. However, accuracy of the seasonal prediction is still far from satisfactory. In order to improve prediction of the East Asian monsoon, our effort to resolve issues of the East Asian monsoon raised above will definitely help us reach this goal, particularly in the prediction of water cycles in the East Asian monsoon. The endeavor of MAHASRI will certainly meet this expectation.

4.4.4. Northeast Asia

Northeastern Asia is characterized by a rapid meridional transition of the vegetation. This transition includes boreal forest (Taiga) in the north, southern desert (Gobi) and semi-arid grassland between them. This transition is an ecological projection of the large spatial and temporal variability of the precipitation in the region. The average annual precipitation on 55 N is about 500 mm while that on the 45 N is less than 100 mm. In addition, interannual variability of the precipitation in the region is on the same order of the magnitude as its climatic average, which indicates that the vegetation in this region is thought to be highly variable. In some parts of the region, increasing precipitation as well as increasing air temperature has been observed in the last several decades (e.g., Endo et al, 2006). Furthermore, the frequency of heavy precipitation events was found to have been increased with an increasing number of rainy days in the eastern part of the region, while a decreasing number of heavy precipitation events is obvious in the northern part of the region.

During the last years of GAME, an intensive hydrometeorological and hydroclimatological studies has been conducted by a project called RAISE (Rangelands Atmosphere-Hydrosphere-Biosphere Interaction Study Experiment in Northeastern Asia) as a cooperation between Institute of Meteorology and Hydrology, Mongolia, and Japanese scientists. Especially, intensive surface hydrometeorological observations were made in Kherlen river basin since 2002. Analyses of observations gave a better understanding of the region's hydrology and meteorology, especially in its climatic view and a "snapshot" view during the observation period. A part of the RAISE observations will be also continued under the regional subprogram of MAHASRI to acquire better understanding of interannual variations of the region's hydrometeorology.

In general, gridded daily precipitation products are less accurate at higher latitudes due to poor sampling from satellites and sparse surface observation networks. In order to acquire better understandings of temporal and spatial variations of the precipitation in northeast Asia, gridded daily precipitation data need to be compared with the observations by a dense surface network and radar observations. A rain gauge meso-net will be also used to acquire better understanding of the temporal and spatial structure of the region's precipitation.

Recently, it was found that the rainy season has a "break" in the middle of July. During the break, Rossby waves are trapped in the Asian jet, and are climatologically phase-locked in seasonal evolution (Iwasaki and Nii, 2006). One possible mechanism is that localized descent over the Mediterranean Sea and the Aral Sea are induced by the remote effect of heating associated with Indian Monsoon (Rodwell and Hoskins 2001) and the associated upper-tropospheric convergence acts as the source of the stationary Rossby wave (Enomoto et al. 2003). This suggests that there is an interconnection between Indian monsoon and Rossby waves through the Asian jet, which needs to be investigated further for the long-range prediction of precipitation in northeastern Eurasia.

Since the region is thought to suffer from the largest temperature increase according to projections of global warming (e.g., Yatagai and Yasunari, 1994), the possibility of future desertification is a real threat to the local people whose economy relies on nomadic livestock. It has been found that amount of vegetation is strongly controlled by the summer precipitation, which accounts for 70% of the annual precipitation (Iwasaki, 2006). Temporal and spatial variability of the vegetation amount and its activities needs to be monitored with satellite remote sensing and ground-based measurements, and their relationship with interannual variability of precipitation should be studied

Due to strong vegetation variability, northeastern Asia can serve as a critical benchmark for land-surface models. These models will be tested with the observations at a forest and a steppe grassland to reproduce dynamics between soil moisture, plant activity and atmospheric forcing in the region. Then, stochastic framework with Monte-Carlo approach (Rodriguez-Iturbe and Porporato, 2005) will be used to predict the effect of global warming on the land-atmosphere interaction by using the prediction of atmospheric variable after the global warming (Sato et al., 2006). Moreover, regional atmospheric models will be used to predict the effect of the vegetation variability on the region's hydroclimatology, such as precipitation and temperature.

The source of water precipitated over the region has been long disputed and, therefore, should be investigated under MAHASRI. A budget analysis of water vapor using reanalysis data (Yasunari, 2003) suggested that precipitated water is evaporated from the region's land surface, while a stable isotope approach (Yamanaka et al, 2006) pointed to subtropical marine atmosphere as its origin. A regional atmospheric model that incorporates stable isotope process will be used to investigate detailed budget and path ways of atmospheric water vapor. Stable isotope approach will be also utilized to "trace" groundwater and river water (Tsujimura et al, 2006).

Dust storms frequently occur in association with the strong wind and exposed soil conditions of Mongolia (Jugder and Natsagdorj, 1992, 1993, 2002, 2003). When the phenomenon of dust and sand storms continues over several days in the Gobi Desert, Mongolian nomadic herders refer to it as the "Ugalz". While dust and sand storms disrupt local human life and economic activities, they also cause trans-boundary environmental problems in the downwind countries in NE Asia. Furthermore, they have a counter-effect to the regional climate through radiation processes. Therefore, it is necessary to establish a regional monitoring and early warning network for dust storms in Northeast Asia.

5. Observations and modeling

5.1. Observations

5.1.1. Remote sensing

Satellite observations have the advantages of spatially uniform data acquisition and repeatability. In addition, several unique space-borne sensors, such as TRMM (Tropical Rainfall Measurement Mission)-PR (Precipitation Radar), make it possible to better understand the nature and dynamics of surface and cloud processes. Moreover, FORMOSAT-3 provides temperature, humidity and height information with 1 km x 1 km resolution. Essentially, satellite images consist of a number of "snap shots" from space. The CEOP project has been successfully archived the huge satellite dataset, part of which has been partly assimilated for the numerical prediction model as a pilot case during the last two years.

From the view point of numerical modeling teams, particularly those for GCMs and RCMs, they expect that the role of satellite is to fill the “gap” between the GCM grid scale (currently T106 is popular, approximately 100km in horizontal scale) and real scale. For short and medium time forecasting, like THORPEX, accurate initial conditions obtained using data assimilation is essential. However, MAHASRI’s target period is longer than that in the THORPEX. In this case, surface sub-grid parameterizations or land-surface assimilation by satellite data would be more important, for not only the improvements in forecast accuracy, but also for better understanding the land-atmosphere or ocean-atmosphere interaction process.

Satellite observations capture “real” phenomena or changes on the surface or in the atmosphere. Thus, efforts from both directions (collaboration with modeling community, and with field scientists) would be required. Taking account of such circumstances, the role and/or efforts of the satellite community for the MAHASRI activities will be addressed as follows:

(1) To build climatological variables only by the satellites datasets, in particular, over monsoon Asia. A series of Advanced Very High Radiometer (AVHRR) boarded on NOAA satellites already has more than twenty years of use. TRMM has been working well for more than seven years except for the CERES (Clouds and Earth’s Radiant Energy System) sensor. Such long-term monitoring of the Earth by several satellites makes it possible to provide climatological variables based on satellite observation only. Inter-comparisons of these observed variables lead to the construction of the new “current” climatology, including the effect of human activities, such as land cover changes.

(2) Such activities, products, and analyzed results will provide the information for planning where the effective areas for the installation of in-situ sites are. During the GAME, satellite analyses followed and/or used the results of in-situ measurements for interpretation. However, in the MAHASRI, satellite data have to provide something for the implementations. Based on the hind-casting of accumulated variables by GCMs, inter-comparison with satellite datasets will be useful for the improvement of GCM schemes or parameterizations. Comparisons of interannual variations by GCMs with satellite datasets (e.g., cloud activity, vegetation, soil moisture, precipitation amount) will also be useful.

(3) Studies on how to assimilate the satellite data into GCMs for initial spin-up. CEOP has attempted this and MAHASRI satellites communities should collaborate with the CEOP archiving team.

(4) Capacity building beyond the sectionalism of satellite communities. Studies on data fusion or the synergy effect will be expected by collaboration with other sections (for examples, ocean research communities use similar sensors data, but have different purposes in physics and bio-chemistry). However, at present, such collaboration is not working in hydrometeorological community. A domestic workshop organized by HyARC, Nagoya University and CEReS, Chiba University in Japan was held at the end of FY2004 with great success. Such activities will have to be continued, not only in domestic (Japanese) communities, but also in the international community, which will directly be connected into CEReS, and will have to be lead by the remote sensing research community in Japan.

5.1.2. Isotopes

The survey of oxygen and hydrogen isotope composition of monthly precipitation in the Asian monsoon region is being conducted by IAEA, in cooperation with the WMO. The obtained data shows a significant lower isotopic value in the Asia monsoon region compared to other tropical regions. Aggawal et al. (2004) indicates that this isotopic feature reveals moisture source and transport patterns, however, model studies need to be performed to explain such longitudinal variation quantitatively.

The high-frequency (daily) monitoring of isotopic content of precipitation in the Asian summer monsoon region has been initiated by the GAME project, and we found the observed short-term isotopic variation is closely related with large-scale moisture transport; e.g.. isotopic content significantly decreases when large-scale disturbances pass through the region (Tian et al., 2001; Yoshimura et al., 2003). Yoshimura et al. (2003) roughly reproduces the daily isotopic variation in Thailand by using a water isotope circulation model based on the Rayleigh distillation concept and shows the stable isotope is a powerful tool to understand the environmental conditions, such as transport pathways and source region in the Asian monsoon region. Despite their success, however, the estimated isotopic value of precipitation during weak moisture transportation, such as convective cloud or diurnal variation, is underestimated. To improve this failure, we need to get the isotopic information of source moisture and incorporate more precise atmospheric vertical transportation schemes that include boundary conditions.

Recently, a Japanese isotope group successfully developed an atmospheric GCM and land surface model that incorporates water isotopes. Thus, in this new project we try to reproduce observed spatial and temporal variation of water isotopes and understand hydrological circulation in the atmosphere and land-surface over the Asian monsoon region by using more realistic models such as an isotope-GCM coupled with a more realistic land surface scheme. To validate the model results and improve the model scheme for isotopic calculation, we want to perform the following observations;

(1) Extend the monitoring station for precipitation sampling and add river water sampling regularly. Although JAMSTEC/IORGC has maintained the monitoring stations of precipitation in the Asian monsoon region, there are a few stations in the western part. Thus, we want to initiate regular water sampling in Myanmar and/or Bangladesh. We also want to initiate the monitoring of isotopic content of river water to compare the modeled isotopic variety.
(2) Construct the super station for isotopic observation. As described above, to reproduce cumulative precipitation, the model has to simulate the vertical atmospheric transportation process through the boundary layer. Furthermore, precipitation gives us limited information during times at which precipitation occurs, thus we need to get standard observation data for comparison with model results. To resolve these problems, we want to construct new super stations in the study region and carry out atmospheric moisture sampling through the atmospheric boundary layer (ABL) and evapotranspirated moisture from the land surface. At the super station, to develop the isotope scheme incorporated in the models we perform one dimensional isotope balance sampling.
(3) Carry out intensive observation for isotope sampling over the ocean. In our model, an isotopic form of bulk parameterization is used to calculate isotopic content of evaporation flux. Although the ocean is the primary source for precipitation in the study area, there are few observations for isotope flux from the tropical ocean. Thus, to reproduce the isotopic content of precipitation correctly, we have to examine whether the model can properly simulate source values.

After improving the model by using the results from observed data, we estimate the origin of water over this region more precisely and discuss what factors are controlling Asian monsoon activity.

5.2. Modeling

5.2.1. GCMs

5.2.1.1. Model development

Representation of precipitation in various temporal and spatial scales is still the main focus of monsoon modeling. The diurnal cycle is the most dominant signal among various time-scale variations in the climate system. Precise phase and timing of the diurnal cycle is a necessity for monsoon modeling as energy and water exchange between the atmosphere and underlying surface are largely regulated by the diurnal cycle (e.g. Dai 2001). Thus, the diurnal cycle in general circulation models (GCMs) has been investigated (e.g., Collier and Bowman 2004; Dai and Trenberth 2004; Arakawa and Kitoh 2005), and the state-of-the-art models still show systematic differences in the timing of the diurnal cycle. The reason for this deficiency is yet to be resolved..

The tropical intraseasonal oscillation is another phenomenon for which GCMs are unable to simulate both for the predictive mode and the simulation mode (Lin et al. 2005). Simulation of the tropical intraseasonal oscillation is known to be most sensitive to the convective parameterization (Slingo et al. 2005).

Although the land-surface component of climate models has been progressed during the GAME project, large biases remain in model climatological surface temperature, soil moisture, snow cover/snow water equivalent, and surface fluxes.

To alleviate the above problems, further improvement of model physics in clouds, aerosols and precipitation, boundary layer, and land surface processes is needed.

5.2.1.2. Simulation of the Asian monsoon system

Several studies have suggested that there are still significant shortcomings in representing the mean monsoon climate and its variation on various time scales (e.g., Webster et al. 1998; Kang et al. 2002a, 2002b; Wang et al. 2005). One of the emerging issues is the fundamental difference between the one-tier approach and the two-tier approach. This is demonstrated by calculating local SST-rainfall lag correlation. The observations show that rainfall lags behind the SST beneath for about two pentads over the western Pacific and the Indian Ocean (Arakawa and Kitoh 2004), while the two-tier approach (atmospheric GCM forced by the observed SST) cannot reproduce this SST-rainfall relationship. There are also GCM studies that indicate air-sea coupling modulates tropical intraseasonal oscillation (e.g. Rajendran and Kitoh 2005). These results suggest that the use of coupled GCMs is necessary to simulate the Asian monsoon and its variability (Wang et al. 2005; Inatsu and Kimoto, 2005).

Considering that a large part of interannual variability of the monsoon is related to a modulation of seasonal cycle, it is essential that the GCM can simulate realistically the climatological seasonal cycle, including monsoon onset and retreat. Well-known is the ENSO-monsoon relationship, for which the anomalous regional Hadley circulation and anomalous Walker circulation associated with ENSO is responsible for monsoon variations. This relationship, although statistically significant over the available long-term observed records, shows a decadal fluctuation and even shows a collapse in the relationship in recent years (e.g. Krishna Kumar et al. 1999). Some modeling groups are studying the Indian monsoon-ENSO relationship by analyzing long-term GCM simulations, however, mechanisms for fluctuations of this relationship are unresolved.

Future projection of the changes in the Asian monsoons induced by anthropogenic effects, such as increasing atmospheric concentration of greenhouse gases, aerosols, and land surface/land use changes, may be outside of the focus of the MAHASRI. However, GCM studies in reproducing monsoon changes in the past several decades using appropriate forcing need to be performed to understand monsoon variability and its mechanisms.

5.2.1.3. Prediction of the Asian monsoon

Monsoon prediction is important, not only for the total seasonal rainfall, but also for the onset, evolution, and extremes. Seasonal forecasting is operationally issued by some of the national meteorological and/or hydro-meteorological centers in charge. Despite model improvements in recent years, skill of the Indian monsoon prediction has not progressed (Gadgil et al. 2005). The East Asian monsoon also varies from year to year with flooding, hot spells or cool summers, and is influenced both from the tropics and mid-latitudes, which is still poorly predicted in advance. The predictability problem has been a main focus of monsoon studies including GAME, but is yet to be fully resolved. Systematic hindcast experiments should be done in the new MAHASRI program to clarify the predictability of monsoon forecasts to help model development. Collaboration between the research community and operational centers is highly needed.

5.2.2. RCMs & CSRMs

Non-hydrostatic, cloud-resolving global models would be ideal for modeling studies of the monsoon. However, the required computer resources by global cloud-resolving models are tremendous. Therefore, regional hydrostatic or non-hydrostatic climate models (RCMs) using nesting techniques must be used at least for several more years.

One of the topics to be studied by fine mesh RCMs including non-hydrostatic regional cloud-system-resolving models (CSRMs) are effects of topography which are $O(10 - 10^2)$ km in width and $O(10^2 - 10^3)$ km in length and are not resolved properly by coarse mesh global models. These meso-scale mountains are located near the coast of Asia in many places, and most of them align about at the right angle to the monsoon wind direction. Therefore, tremendous precipitation is observed around these meso-scale mountains (e.g., Xie et al. 2006), although the coarse mesh global models do not reproduce such heavy rainfall in those areas. Xie et al. (2006) pointed out the possibility that meso-scale mountains near the western coast of the Indian subcontinent and the Indochina Peninsula affect the South-Asian scale atmospheric circulation through the large amount of latent heat release by orographic precipitation. This point has not been well recognized yet and should be cross-examined by other models and in other regions.

Effects of fine-scale heterogeneous land surfaces also spread out widely (Sen et al. 2004), although the effect itself depends strongly on environmental atmospheric conditions (Kanae et al. 2001). Making use of less computer-resource demands of RCMs and CSRMs than those of GCMs, we can assess effects of variation of each land surface condition such as soil moisture, snow mass, vegetation, and so on, using the ensemble simulation method. The land surface condition in the South and Southeast Asia significantly varies from rainy season to dry season. Therefore, the effects of the land surface conditions probably differ from season to season, which are not yet well understood. In East Asia, on the other hand, the paddy field which keeps a shallow water body for several months in the warm season expands vastly in the plane. The shallow water body serves the warm saturated surface boundary throughout the day and, thus, makes peculiar seasonal variation of soil characteristics. For example, it is pointed out that the latent heat flux from paddy field in southeastern China largely contributes toward the development of deep convective clouds (Shinoda and Ueda 2002).

To identify the problem and to provide improved methods for cumulus parameterizations curretly used are examples of the other topics to be studied using RCMs, especially CSRMs. In this context, the Regional Atmospheric Inter-Model Evaluation Project (RAIMEP) was initiated by Y. Wang of the University of Hawaii, USA. Currently, about one dozen RCMs are planned to participate. The initial focus is on the East Asian monsoon region in summer season. Though, RAIMEP is not yet started (as of September 2006), it will provide useful information on characteristics of cumulus parameterization in both RCMs and GCMs.

It is also important to compare monsoon systems among different regions in Asia. Mechanisms of onset, break, and retreat of monsoon should be different region by region. Studies of monsoon in different regions using the same model would clarify the difference of the mechanisms and also reveal hidden problems in the model.

5.2.3. Hydrological modeling

Most present hydrological models are aimed to forecast/predict floods and water resources. However, development of hydrological modeling relies on the meteorological observations and hydrological measurements. This leads to weak applicability and less flexibility for most present hydrological models. The operational hydrological models used for flood forecasting and water resources assessment have common conceptual and lumped structure and insufficient description of hydrological processes. Therefore, the major work in application of hydrological models is calibration of model parameters rather than real forecast and prediction. On the other hand, new types of hydrological models have been developed incorporating GIS and Remote Sensing technologies since the 1980s. The major advancement is in the development of physically-based distributed hydrological models. The International Association of Hydrological Sciences (IAHS) has initiated a 10-year research program of Predictions in Ungauged Basins (PUB, 2003-2012), to integrate hydrological sciences and technologies to improve the hydrological prediction capacity for society (Sivapalan et al., 2003). The reduction and determination of uncertainties (e.g., Chiang et al., 2006) is the key of PUB. For MAHASRI, in addition, the following are the key issues in hydrological modeling.

(1) Development of the hydrologically enhanced land-surface process model

Unfortunately, most of the present land surface models focus on the vertical heat and water fluxes rather than horizontal water movement. On the other hand, hydrological models (rainfall-runoff models) tend to ignore the energy transfer. The present challenge is to bridge the gap between the land-surface scheme and hydrological model, which emerged in the middle of 1990's (Liang et al., 1994). In addition, paddy field for rice crop, a major land-use type in Asia, is not frequently considered in both land surface models and hydrological models (Kim et al., 2001). Thus, hydrologically enhanced land-surface process model (e.g., Yang et al., 2005) is urgently required in which heat-CO2 transfer (vertical direction) and water movement (both vertical and horizontal directions) are properly represented for major land use types including artificial irrigation effects. This is expected to improve atmospheric predictions through better representation of soil moisture and evapotranspiration (Shinoda and Uyeda, 2002; Koster et al., 2004), and it can expand hydrological prediction from the traditional flood and water resources to the biosphere environment.

(2) Use of atmospheric model products for water resources management

In addition to the commonly used rain gauge network, weather radars and numerical weather prediction models offer a new opportunity in hydrology to really carry out flood and drought prediction by utilizing a distributed hydrological modeling approach. In particular, it is necessary to develop a down-scaling or transferring algorithm that can make use of atmospheric model products in distributed hydrological models for the predictions at various time-ranges from a few days up to a season. Thus, it is required to pursue the development of down-scaling method based on the knowledge of space-time structure of rainfall (e.g., Shrestha et al., 2005) and to carry out a hydrological hindcast through a relatively long period for the verification of the usefulness of the atmospheric model products for hydrological prediction (Hirabayashi et al., 2005).

6. Applications

6.1. Weather/Climate Prediction – for contribution to the social welfare

The final goal of MAHASRI is to contribute to the sustainable development and to promote social welfare in the Asian monsoon region through applying the scientific findings and/or understandings of the water cycle processes and mechanisms to prevention and mitigation of water-related natural disasters and efficient water resource managements. There are three processes to reach this goal. The first is the near-real-time monitoring of the current distribution of precipitation and global and local atmospheric circulation through collecting and objectively analyzing the observation data. The key issue is to construct the regional observation and communication systems and to maintain them. The second is the regular weather/climate prediction using the numerical models, which has been mentioned in Section 5.2. Here, it should be noted that every prediction has uncertainty inevitably, and the ensemble prediction technique is one of the objective methods that quantitatively estimate the extent of uncertainty. Although the operation of ensemble prediction system seems too heavy task for this scientific project, it would be possible if there is an involvement of an operational weather/climate prediction center. The third is to make some tailored products which are suitable for the usage in the real decision-making processes in socio-economic activities of the above mentioned scientific outputs. This last stage is the most important and the most difficult task for our weather/climate information to be beneficial to the social welfare. The process requires close collaborations with the users of the weather/climate information, such as river managers and crop managers. For example, in order to clarify the climatic sensitivity in the targeted activity, it is necessary to collect fairly long-term historical data not only on weather/climate but also on indices used for the practical decision-making and related socio-economic factors. Because these data are archived at the responsible organizations and/or institutions separately, it is important to construct a mechanism to smoothly exchange the necessary data to research their relationships. MAHASRI will be able to play a major role in promoting inter-disciplinary and/or inter-institutional communication. The specific plans for the development of tailored weather/climate information will be presented in the following sections. Here, some technical issues on climate (seasonal) prediction which would be helpful for the development of tailored products will be presented.

Firstly, it is noted that the long-term re-analysis data of atmosphere-ocean-land parameters are quite useful for studying the climate variability in the global and regional scale and its relationship with local weather/climate events, since that gives us consistent and missing-free dataset (Schubert, et al. 1993). The JMA and the CRIEPI (Central Research Institute of Electric Power Industry) have finished the cooperative re-analysis project, named JRA-25 (Japanese 25-year re-analysis project), in March 2006. Their final products, providing the global atmosphere and surface analysis for the period from 1979 through 2004, have been released to the climate researchers' community since July 2006 (URL: http://jra.kishou.go.jp/). The analyzing system for the JRA-25 was based on the 3-dimensional variational data assimilation system (3D-Var) which had been used as the JMA's operational global data assimilation system until February 2005, though the horizontal resolution of the global prediction model was reduced to medium-resolution (T106L40). Since the GAME IOP data and other unique data, such as Chinese snow cover, were used in the JRA-25, the JRA-25 data are likely to have better representation of the Asian monsoon system than the previous long-term re-analyses, such as Reanalysis-1/2 by NCEP/NOAA (Kalnay et al. 1996) and ERA-15/40 by ECMWF. In fact, the precipitation amounts reproduced in JRA-25 are proved more similar to those observed from satellite (GPCP) than the previous re-analyses. The same assimilation system as in JRA-25 is being operated by the JMA for the period after 2005 on near-real-time basis. These sets of analysis data are thought to be quite useful not only for analysis and monitoring of climate system in the Asian monsoon region and verification of seasonal prediction (Annamalai et al. 1999), but also for the research on the variability and change of climate system and their effects on water cycle over the globe. Finer-scale, more accurate and longer-term re-analysis data would enhance their utility considerably. The next-generation re-analysis project, which is based on the state-of-art 4-dimensional variational data assimilation system (4D-Var) and with a higher-resolution prediction model of the JMA, is now under consideration. MAHASRI will support the next-generation re-analysis project by providing the historical observation data and other special observations archived in MAHASRI, which could contribute to the better quality of re-analysis in the Asian monsoon region.

Secondly, it is pointed that the 'downscaling' technique, both spatially and temporally, is one of the key techniques to develop a tailored products for practical decision-making (Leung et al. 2003). Many of the decision support models, such as the crop growing model and the river discharge model, need finer-scale data of meteorological parameters for input, both spatially and temporally, than those provided by global climate models. However, for the prediction period longer than a week, the reliability of daily prediction becomes so low due to the chaotic nature of atmospheric flow that only the temporally averaged or large spatial-scale quantities have meaningful information. In addition, the horizontal resolutions of most current global climate prediction models are larger than 100 km, which is hard to resolve small scale topography and meteorological phenomena controlled by it. It might be possible to extract a statistical relationship between the re-analyzed data on grids and observation data at points, if fairly large number of samples is available. On the other hand, the dynamical downscaling method, which means fine-mesh regional climate model run with its initial and boundary conditions given by a global prediction model, might be able to provide us physically consistent prediction even in the area where no long-term observational data are available, though it may have some systematic model biases to be calibrated. If the regional climate model is able to simulate meso-scale convective systems, it might be able to suggest us the possibility of occurrence of extreme weather events, which are valuable for disaster prevention. They are also useful for verifying the parameterizations used in global climate models, such as cumulus and shallow convection schemes (e.g. Lappen and Randall 2001). Thanks to the advancement of computer and telecommunication technology, operation of a regional climate model seems to become feasible in Southeast Asian countries, so it should be achieved in MAHASRI.

Finally, it is emphasized that the probabilistic prediction products should be incorporated in the decision support system. As mentioned previously, due to the chaotic nature of atmospheric flow, the climate prediction longer than a week has inherent uncertainty, which is expressed in probability. The dynamical ensemble prediction method, which runs tens of dynamical forecasts from slightly different initial and/or boundary conditions, is the objective and efficient way to estimate the uncertainty in the prediction. It is not straightforward to convert the probabilistic prediction into the quantity which is suitable for the input of the decision support system. However, an extensive research was done to use the downscaled seasonal ensemble prediction as an input of the crop yield model and the dynamic biological model for malaria epidemic prediction, and it showed a potential benefit of the ensemble prediction (Palmer et al. 2004). It should be noted that probabilistic predictions are only able to be verified using fairly large number of samples. The long-term retrospective ensemble forecast experiments, often called ‘hindcasts’, are absolutely necessary for the verification of the probabilistic seasonal prediction. They are also useful for calibrating the model’s systematic biases and deriving unbiased probabilities. Though long-term ensemble hindcasts take huge amount of computing resources, it should be promoted to assess the net value of the probabilistic seasonal prediction for the society. For the long-range forecasts longer than a season, ocean-land-atmosphere coupled models are commonly used. However, inclusion of ocean/land processes into a forecasting model may add significant systematic bias to the prediction. Some leading researches show that the ensemble prediction using different coupled models, which is called a “multi-model ensemble technique”, can reduce the systematic biases of the models and produce more reliable probabilistic prediction (Palmer et al. 2004). For implementing the multi-model ensemble technique, each operational forecasting center and/or research institution should be synchronized with each other and exchange each other’s outputs in the same format. MAHASRI is expected to be a framework of such kind of collaboration through building cooperative relationship among the relevant institutions and research communities.

6.2. Floods/droughts and water resources

6.2.1. Flood/drought prediction and warning system

The development of flood and drought prediction systems is a major way to apply the scientific knowledge obtained through GAME and MAHASRI to the societies in Asia.

Floods in Asia can be divided into two major categories. One is flash flood, and another is flood in a large river where the temporal difference between upstream flood and downstream flood is a few days to weeks, or even months. A flash flood prediction system is composed of real-time precipitation observation systems mostly utilizing radars and on-line rain gauges, and a very short-term precipitation forecast systems. Collaboration with GEOSS is recommended for the development and improvement of real-time observation systems in Asian monsoon countries. For the development of prediction system for floods in a large river, precipitation predictions corresponding to the time-scale of weather forecasts (a few days to a week) and appropriate surface-runoff simulations for a large river basin are helpful. The development of land-surface hydrological models appropriate for a large river basin is a big scientific challenge. The monitoring and data-assimilation of land surface hydrological components are of help, and the utilization of remote sensing techniques is recommended. For drought prediction systems, intraseasonal to seasonal precipitation prediction is needed. Intraseasonal to seasonal precipitation prediction would be carried out by global coupled atmosphere-land-ocean models or statistics-based models. Also, once again, the monitoring and data-assimilation of land surface hydrology is required. In this aspect, collaboration with GEOSS is also recommended. In addition to runoff processes, evaporation, snow-melting, and groundwater processes in land surface hydrological models are of focus for drought prediction.

In every temporal scale described above, quantitative aspects of precipitation prediction should not be forgotten. Quantitative precipitation prediction is a major challenge at each temporal scale. For this, probabilistic forecasts of precipitation may be used for hydrological prediction. Also, hydrological prediction may need to incorporate the ensemble approach. As a part of precipitation prediction, collaboration with THORPEX is expected both for very short-term precipitation forecasts and daily to weekly precipitation forecasts.

Warning systems require more social and engineering considerations in addition to science-based prediction systems. Actually, the development and implementation of a warning system is likely out of target in this science plan. However, a strong advantage of this scientific group is the collaboration between scientists in research institutes and officers working in operational agencies in many Asian countries. Also needed is collaboration with field-based officers who are doing management of dam operation and/or bank management. Thus, the possible connection of prediction systems with warning systems in society should be kept in mind throughout the scientific activities.

Prototypes are currently being developed: for example, a real-time forecasting system for a large river in Japan (http://yodogawa.dpri.kyoto-u.ac.jp/) developed by Kyoto University and a real-time prediction system for the entire globe (http://hydro.iis.u-tokyo.ac.jp/LIVE/) developed by the University of Tokyo. Due to the limitation in the availability of the real-time meteorological forecast data, the temporal target of both systems is relevant to short-term weather forecasting.

6.2.2. Water resources and management

In most parts of the Asian monsoon regions, water withdrawal for agricultural irrigation is the major part of water usage, and the rainy season roughly corresponds to the crop-growing season. These facts imply that the prediction of potential available water amounts a few seasons ahead is of great benefit to the societies. Thus, one of the two major objectives of GAME was to improve the seasonal prediction of the Asian monsoon and the application of the prediction for water resources management. However, only a few attempts were made for these objectives. Both the dynamical prediction methods using coupled atmosphere-land-ocean models and the statistical methods based on climate indices cannot yet get high prediction scores practically or quantitatively for water managers. “Chaos” in nature may restrict the predictability of seasonal scale water resources. In addition, the discussion between hydro-meteorological researchers and operational water management officers was not sufficient in GAME project for establishing a practical water management system utilizing prediction, particularly in developing countries. The benefit of the usage of climate prediction for water management and the cost arising from the uncertainty of prediction has not yet been fully investigated. In reality, the sentence "seasonal prediction of Asian monsoon a few seasons ahead is of benefit" itself is not verified in a scientific manner. Also needed is the evaluation of "benefit" in the long-term perspective.

Apart from the seasonal-scale prediction, an issue which we should not neglect is that the current hydrological cycles are highly affected by human activities (Nilsson et al., 2005) and such anthropogenic effects may be larger in the future (Oki and Kanae, 2006). Presumably, only scientists can assess the impacts, from the past to a possible future, of land-use change, global-warming, increase in water withdrawal, and others on hydrological cycles. The assessment is necessary for infrastructure management.

Keeping the above facts in mind and assuming that the key issues in the predictions of intraseasonal to seasonal scale are documented in other sections, the following study-items will be thoroughly carried out as a part of the MAHASRI activities:

(1) Develop a prototype of the decision-support system for water resource managers, including development of a prototype of an ensemble hydrological prediction system.
(2) Assess the net value of the above mentioned decision-support system in each temporal scale by the long-term retrospective simulation experiment.
(3) Assess the anthropogenic impacts on hydrological cycles for the planning of water resource management.

6.3. Application to the rice production in Southeast Asia

Southeast Asia is a densely populated region which occupies nearly one third of the world's population. The reason it can be habitable by such a large number of people is thought to be that it is located in the humid Monsoon Asian climate with topographic features resulting from the Alps Himalaya orogenic movement, and that consequently rice production is performed efficiently in this region. Paddy fields are filled with water, so their soil is hardly depleted of nutrients, is resistant to erosion, and maintains its fertility. They are therefore capable of producing rice under a continuous cropping system and yield a sustainable agricultural system in these areas.

In this region, the amount of precipitation greatly differs in various areas owing to the effects of geographical features. There are rivers with various lengths and catchment areas; for example, the Mekong river originating from the Tibetan plateau is about 20,000 km long, the Chao Phraya river originating from Thailand is about 4,600 km long, and the Mun and Chi rivers flowing through the valley of the Korat Plateau is about 1,200-1,400 km long. There are some areas with salt damage as a result of existing rock salt in bed rock. These factors cause the water supply available for rice production to greatly differ depending on the region.

There are many methods of growing rice such as irrigated and rainfed methods owing to the existence of various water environments. Moreover, there are also various irrigation methods used such as pumping ground water, river water and reservoir water, using flood water, colmatage, and using saltless water from low tide, depending on the topographic features of the place where the paddy field is located. In addition, the temporary change in the amount of precipitation has a large impact on cultivation management factors, such as cultivation period, cropping pattern, the cropping system and cropping rotation, and can lead to disasters such as flood, drought, salt damage, and saltwater intrusion.

We now have the large task of improving rice production under the various water conditions mentioned above to provide for the population of Southeast Asia in the future. To approach this issue, we examine the aspects of rice production, also considering cultivation management factors related to the water condition of paddy fields. We then develop a methodology of describing the impact of water conditions due to intraseasonal, seasonal, and annual changes of the amount of precipitation brought about by the effect of the Asian monsoon variation on rice production on the regional scale. We finally predict the future impact of its variation on rice production in Southeast Asia under global warming in the 21st century.

7. Data management

The main objective of data management activity in MAHASRI is to support research activity to accomplish the scientific goal of the MAHASRI by providing necessary data to the research community.

The major functions are as follows;

(1) To provide necessary data to users smoothly with minimum cost

(2) To develop a guideline for quality control(QC) and data exchange

(3) To coordinate with other projects and organizations for data exchanges.

Background

In international multilateral research cooperation, especially observational projects in earth science, data management is always one of the most important issues for success.

Its functions are mainly divided into two parts;

(1) A policy for data dissemination,provision and exchange

(2) A guideline of data treatments including QC, their opening.

Through the GAME project, a large amount of data has been obtained and produced. Now they are being utilized as valuable resources. Currently, most stations established for the GAME project are registered as the reference site in the CEOP. Their data are being archived with a sophisticated way and widely utilized under the CEOP data policy based on the experiences in the GAME.

Basic policy

Taking the circumstances mentioned above into consideration, the following items are adopted as basic policies.

(1) To maintain and develop the GAME database in the MAHASRI by establishing a core data center with a data management core group

(2) To be coordinated with WMO, GEWEX and CEOP in data policy
In particular, the sophisticated way of data control in the CEOP should be a good example.

(3) To prohibit commercial use of data and its transfer to third parties.

Framework for data management activity

The main part of data management activity should be done by the MAHASRI data center which consists of a data management core group and sub-groups for satellite, model data, etc.

In addition, some regional sub-centers should be established to share their work.

Other subjects in data management

(1) Data control

- Target data includes observational (operational and experimental) and processed data.
- Quality control should be done as the obligation of data provider.
  At that time, CEOP QC system (visualization) would be helpful.
- Appropriate meta data should be provided with data.

(2) Data opening

- Data are provided on-line, sometimes with DVD/CD.
- All the data eventually will be opened to the international research community.
- Turn around period for data release should be applied for experimental data.

(3) Data center

- Data center should operate data server and web pages for data dissemination.

(4) Other issues

- Assistance in data rescue work is also important as a part of data management activity.

8. Links with international programs/projects

8.1. GEWEX

Unlike GAME, MAHASRI does not contain any characters related with GEWEX (Global Energy and Water Cycle Experiment) in its name. However, since this program also targets hydro-meteorological research and prediction in monsoon Asia, in particular over the land where more than 60% of the world population is concentrated, it would be best to be affiliated with one of the CSEs in the GHP (GEWEX Hydrometeorology Panel) under the GEWEX/WCRP (World Climate Research Programme). Close connection should be kept with other GEWEX panels, GMPP (GEWEX Modeling and Prediction Panel) and GRP (GEWEX Radiation Panel) in close connection with CEOP.

8.2. CLIVAR

It is obvious that there is both a complementary nature and a mutual interdependence in the activities of GAME and CLIVAR Asian-Australian Monsoon Panel (AMMP) in the monsoon research (WCRP JSC-XXVI document 2005). But it is also noticed that monsoon studies in the Asian monsoon region have not been well coordinated between GAME and CLIVAR. In this context, the pan-WCRP monsoon workshop was held in Irvine in June 2005 to help in clarifying how best to move forward with the overall approach to a pan-WCRP modeling effort in this area. The communication with oceanographers who are not explicitly involved in this MAHASRI program will be promoted mainly through the CLIVAR-AAMP and coordinated workshops. Joint grand observation on Asian monsoon variability both over the land and the ocean and related modeling activity will be a good chance for the collaboration of each community.

8.3. CEOP

The Coordinated Enhanced Observing Period (CEOP), which is an element of the WCRP initiated by GEWEX, was proposed in 1997 as an initial step for establishing an integrated observation system for the global water cycle. Its guiding goal is:

> *"To understand and model the influence of continental hydroclimate processes on the predictability of global atmospheric circulation and changes in water resources, with a*

particular focus on the heat source and sink regions that drive and modify the climate system and anomalies."

CEOP, therefore, represents a unique opportunity to improve the scientific foundation needed to achieve overall water cycle documentation and prediction goals, based on coordination among the WCRP/GEWEX Continental Scale Experiments (CSEs), the Committee on Earth Observation Satellites (CEOS) members, including space agencies, and the numerical weather prediction (NWP) centers affiliated with the World Meteorological Organization (WMO).

The two overall science objectives of the Water and Energy–Cycle Simulation and Prediction (WESP) and CEOP Inter-Monsoon System Studies (CIMS) that were articulated in the CEOP Phase 1 Implementation Plan drove the requirements for CEOP and the Phase 1 datasets. Soon after the delivery of the EOP-1 in-situ dataset in early 2004, modeling center and space agency participants in CEOP became aware that the observations at CEOP reference sites could be used in studies to evaluate and validate land surface processes and other related aspects of models and satellite sensor algorithms, respectively. Examples of this work have become evidence of the current value of the CEOP datasets and their potential value to the broader research community.

As described in the GEOSS 10 Year Implementation Plan Reference Document;

"A prototype data integration system is being demonstrated by the CEOP (Coordinated Enhanced Observing Period). An overall plan for in-situ and satellite water cycle observational systems is needed so that data can be readily exchanged, standards can be set, and data quality can be monitored."

CEOP is playing an important role in GEOSS as a prototype system for "Convergence of Observation", "Interoperability", and "Data Management".

CEOP is now preparing for its second phase (CEOP-II). MAHASRI will provide some reference sites in Asian monsoon region in CEOP-II. For scientific issues, MAHASRI will focus on Asian monsoon phenomena, while CIMS activity will cover comparisons with other monsoons in the world.

8.4. TMRP

The WMO Tropical Meteorology Research Programme is designed to promote and coordinate research activities of WMO Members in high priority areas of tropical meteorology in order to help reduce the loss of life and social disruption arising from severe weather. Emphasis is on local weather systems such as tropical cyclones and monsoon related studies where variability and prediction at the regional and seasonal scale are all important.

The main objectives are:

(1) To improve understanding of the behavior and physical processes of tropical weather systems by strengthening research activities.

(2) To develop, through improved knowledge of tropical phenomena, prediction methods and techniques relating to the following areas: tropical cyclones, monsoons, tropical droughts and semi-arid zone meteorology, rain-producing tropical systems, interaction between tropical and mid- latitude weather systems, tropical limited-area modeling and operational use of numerical products for tropical forecasting.

(3) To transfer scientific knowledge of methodologies and their operational application to ensure the full exploitation of scientific advances to meet the socio-economic needs of tropical countries

As a monsoon research initiative, most of the objectives of MAHASRI are related to the East Asian and South Asian monsoon subprograms of TMRP. In particular, the key issues on monsoon variability and its prediction in various temporal and spatial scales are all key issues of TMRP's two Asian monsoon subprograms, and two of the four regional components (Tropics, East Asia) correspond directly to the high priority regions of TMRP monsoon studies.

8.5. THORPEX

THORPEX is a 10-year international global atmospheric research programme under the World Meteorological Organization (WMO) / World Weather Research Program (WWRP) to accelerate improvements in the accuracy of 1-day to 2-week high-impact weather forecasts, established by the 14th WMO Congress in May 2003.

THORPEX research topics include: global and regional influences on the evolution and predictability of weather systems; global observing system design and demonstration; targeting and assimilation of observations; and societal, economic, and environmental benefits of improved forecasts. The success of THORPEX depends on advances in the knowledge of atmospheric science, such as predictability of the atmosphere and large-scale influences or flow-regime dependency on extreme events, and on developments of the forecasting technology, such as data assimilation techniques with advanced satellite data and ensemble forecast techniques. These advances and developments will lead us to the establishment of the Global Interactive Forecast System (GIFS). GIFS is a new concept of the weather forecast system under THORPEX to demonstrate the close interaction between observation and forecast models.

Every year huge damages are caused due to heavy rainfalls and tropical cyclones in the Asian monsoon region. Heavy rainfall events occurred in China in 2003, and landfall or approach of tropical cyclones occurred in Korea in 2002 and 2003 and in Japan in 2004. Huge damages were brought about by tropical cyclones in Philippines, Vietnam, and Taiwan almost every year. THORPEX activities in Asia focus on the improvement of forecasts for these high-impact weather events over Asia, which may bring tremendous benefit to the society through better understanding of the Asian monsoon system.

8.6. CliC

The CliC (Climate and Cryoshere) is one of the WCRP projects which addresses the entire cryosphere (i.e., snow cover, sea-, lake- and river- ice, glaciers, ice sheets, ice caps and ice shelves, and frozen ground including permafrost) and its relation to climate. The principal goal of CliC is to assess and quantify the impacts that climate variability and change have on components of the cryosphere, and the consequences of these impacts for the climate system. An additional goal is to determine the stability of the global cryosphere. To support these goals, CliC seeks to enhance and coordinate efforts to monitor the cryosphere, to study climate-related processes involving the cryosphere, to model and understand the cryosphere's role in the climate system, and to assess changes in the cryosphere as indicators of global climate change. CliC was established by the WCRP in March 2000. In 2004, the Scientific Committee on Antarctic Research (SCAR) became a co-sponsor of the project. CliC held a kick-off meeting in April, 2005 in Beijing. For details of the project, refer to the Science and Coordination Plan (WCRP, 2001), and Report of the First Session of the CliC-SSG (WCRP, 2005) and website of the project (http://clic.npolar.no).

The CliC Project has the following four main CliC Project Areas (CPAs).

(1) CPA1: The terrestrial cryosphere and hydrometeorology of cold regions.
(2) CPA2: Glaciers, ice caps and ice sheets, and their relation to sea level.
(3) CPA3: The marine cryosphere and its interactions with high latitude oceans and atmosphere
(4) CPA4: Links between the cryosphere and global climate

The areas which are related to the Asian monsoon systems are CPA1 and CPA4. In CPA1, there is an interest in the cryosphere conditions in the monsoon area region such as frozen ground conditions on Tibetan Plateau, the south Asian high mountains, monsoon-fed glaciers, and high mountain snow cover in south Asia. The clarification of present condition, its variability, and those as an index of climate change is a research issue. Although these are the results of monsoon climate, they will affect the river water supplies and surface heat/water exchange processes influencing the condition of the monsoon system indirectly. In CPA4, one interest is the large-scale snow cover and atmosphere interactions, which should affect the behavior of the monsoon system. From the observational standpoint, the mountain observation network in the high altitude area in south Asia for cryosphere studies will give important information about climate, especially precipitation distribution and variations. These are regions and topics in which monsoon system studies and cryosphere studies can cooperate.

8.7. SPARC

SPARC (Stratospheric Processes And their Role in Climate), one of the WCRP programs, is intending to detect stratospheric trends which indicate climate change or could affect climate, to understand stratospheric processes and their relation to climate, and to model stratospheric processes and trends and their effects on climate. The SPARC community has learned lessons from the ozone hole that they need a synthetic view from dynamics, transport, chemistry, and microphysics to understand factors controlling the earth's climate. As one of those issues, the stratosphere/troposphere exchange processes of atmospheric minor species have been highlighted. For example, water vapor in the lower stratosphere is a key for stratospheric chemistry, and in the upper troposphere is important to the radiation budget of the atmosphere, though its concentration is very low there. The dryness in the stratosphere is regarded as the equatorial cold tropopause where the air enters the stratosphere from the troposphere, but at the same time we need to know how it is moistened in the interface region around the tropopause. One moistening process is thought to be due to the monsoon circulation that is one of the most dominant tropospheric phenomena extending into the stratosphere, resulting in the effective stratosphere/troposphere exchange. On the basis of their experience in the synthetic studies, they are trying to understand the monsoon circulation in association with the stratosphere/troposphere exchange from the viewpoint of tracer transport and coupling between the two regions. Such an approach would be very useful to understand another aspect of the monsoon circulation.

8.8. PUB

Predictions in Ungauged Basins (PUB) is a 10-years research program (2003-2012) initiated by the International Association of Hydrological Sciences (IAHS) for enhancing the prediction ability in ungauged basins that focuses on the estimation of predictive uncertainty and its reduction. A general hydrologic system contains a model that describes the key processes of interest, a set of parameters that represent those landscape properties that govern critical processes, and appropriate meteorological inputs that drive the basin response. PUB will therefore include a set of targeted scientific programmes, that attempt to make inferences about climatic inputs, parameters, and model structures (Sivapalan et al., 2003).

For water resources management in the Asian monsoon regions, the outcomes of PUB are crucial to improve the forecasting/prediction of floods, droughts, and water resources. The regions cover different areas with various topographical, geological, and climatic conditions. Thus the key scientific topics in the regions will include:

(1) Development of transferable hydrologic watershed models (HWMs) and land-surface models (LSMs) applicable across regions and scales, considering interactions between natural variation and anthropogenic activities,
(2) Development of transferable frequency estimation methods of hydrologic extremes for ungauged basins, and
(3) Development of down-scaling methods for transferring atmospheric model products and global hydrologic information to the local scale for watershed managements in ungauged basins.

China, Japan, South Korea, Nepal, and Thailand have formed national PUB working groups and begun their activities. The PUB community is open to any scientist and engineer who need hydrologic predictions in ungauged basins. Comparative studies of existing models and development of innovative models will be carried out under different hydro-climate regions in the Asian monsoon for improving predictions in ungauged basins, which will play a crucial role in the water resource management in the regions.

8.9 MAIRS-ESSP

MAIRS (Monsoon Asia Integrated Regional Study) is a new international research Program of ESSP (Earth System Science Partnership) that addresses the coupled system of human and natural processes in the Asia monsoon region. Regional-scale studies of global change, themselves at different scale, lend themselves to the undertaking of vulnerability analyses, identification of hotspots of risk and identification and simulation of syndromes of environmental degradation. Regional studies contribute substantially to the analyses of global dynamics from regional patterns and, in addition to permitting an understanding of the cause and effect systems analysis that directly address the synergies, interactions and non-linear behavior of the earth system.

The objectives of MAIRS are:

"To significantly advance understanding of the interactions between the human-natural components of the overall environment in the monsoon Asian region and implication of global earth system, in order to support the strategies for sustainable development."

The major challenges for MAIRS are:

"Is the Asian monsoon system resilient to the human transformation of the region's landscape, water resources, and air quality changes? Are societies in the region becoming more or less vulnerable to potential changes in the Asian monsoon parameters such as regional hydrology, land use, etc? What will be the consequences of regional changes for the global earth system?"

MAIRS will initially focus on the impacts of environmental changes in four key geographical zones, namely: 1) coastal zone 2) mountain zone 3) semi-arid zone 4) urban zone. Within these zones, there will be studies related to the major societal issues of biodiversity loss, water availability, air pollution and human health, energy and transport, and natural disaster management.

Collaboration with MAHASRI will include intensive atmospheric and land observations, modeling activities evaluating the human effect on Asian monsoon variations.

8.10. GWSP

The Global Water System Project (GWSP) is a newly established joint project of DIVERSITAS, an international programme of biodiversity science, the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme (IHDP), and the World Climate Research Programme (WCRP). These four global change programmes form the Earth System Science Partnership (ESSP). Over the past few decades, environmental science has produced insights into the linkages, interconnections, and interdependencies in the global water cycle. The various human and physical, biochemical, and biological facets of the cycle make up the global water system. The global water system is being transformed by major syndromes including climate change, erosion, pollution, and salinization. We know more about the physical aspects of the global water system and much less about the nutrient flows, biodiversity loss, and human dimensions.

The Global Water System Project seeks to answer the fundamental and multi-faceted question: How are humans changing the global water cycle, the associated biogeochemical cycles, and the biological components of the global water system and what are the social feedbacks arising from these changes? Three major research themes follow these overarching questions:

(1) What are the magnitudes of anthropogenic and environmental changes in the global water system and what are the key mechanisms by which they are induced?
(2) What are the main linkages and feedbacks within the earth system arising from changes in the global water system?
(3) How resilient and adaptable is the global water system to change, and what are sustainable water management strategies?

The agenda for the GWSP will incorporate impact studies on water governance, land cover change, major diversions, climate change, and nutrient and sediment flows. Linkages at different scales and the legacy of past human impacts will also be included. For example, researchers will undertake a comprehensive study to compare the requirements of human society with that of aquatic ecosystems, as well as studying the ecosystem services provided by freshwater. The GWSP will undertake key cross-cutting activities such as generating an information database on the global water system, facilitating a discourse on water between the social and natural sciences, and developing models to define scenarios for the global water system.

9. Time schedule

Major research phases:

September, 2005-October, 2006: Planning and preparation phase

October, 2006-December, 2010: Research phase I

2006-07: Build-up new observation systems

2008-09: Intensive observation year both summer and winter monsoon in conjunction with Asian Monsoon Year (AMY)

January, 2011-December, 2013: Research phase II

January, 2014-December, 2015: Concluding phase

Short-time schedule:

August 28, 2005: The 1st International Workshop for the Post-GAME Planning, Tokyo, Japan

Late September, 2005: First proposal in the GHP Science Panel, Melbourne, Australia

November 1, 2005: The Second International Workshop for the Post-GAME Planning, Tokyo, Japan

November 2-4, 2005: The 1st Asian Water Cycle Symposium, Tokyo, Japan

November 4-6, 2005: Workshop on Hydroinformatics and Atmospheric Sciences, Kanchanabri, Thailand

Early December, 2005: Submit MAHASRI Science Plan draft to the GEWEX SSG members

Mid-January, 2006: Proposal in the GEWEX-SSG, Dakar, Senegal

April, 2006: Meeting in the Symposium on Asian Winter Monsoon, Kuala Lumpur, Malaysia

August 18-20, 2006: The 1st Vietnam-Japan Joint Workshop on Asian monsoon, Halong, Vietnam

October 9-13, 2006: Pan-GEWEX meeting, Frascati, Italy. Submit revised version of the MAHASRI Science Plan

October 18, 2006: The 3rd Asia Pacific Association of Hydrology and Water Resources (APHW) Meeting at Bangkok, Thailand. Special session on “GEOSS and MAHASRI” is organized.

October 19-20, 2006: The 1-st MAHASRI International Science Steering Committee Meeting, Bangkok, Thailand.

January 8, 2006: The 1-st AMY Workshop, Tokyo or Yokohama, Japan

January 9-10, 2006: The 2nd Asian Water Cycle Symposium, Tokyo, Japan

January 11-12, 2006: GEOSS Symposium on Integrated Observation for Sustainable Development in the Asia-Pacific Region, Tokyo, Japan

July 30-August 4, 2007: The 4th Asia Oceania Geosciences Society (AOGS) meeting at Bangkok, Thailand. Special session on “GEOSS and MAHASRI” will be organized.

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Appendix-1

Acronyms

AAMP	Asian-Australian Monsoon Panel
ABC	Atmospheric Brown Clouds
ABL	Atmospheric boundary layer
AGCM	Atmospheric GCM
AMY	Asian Monsoon Year
AO	Arctic Oscillation
ARMEX	Arabian Sea Monsoon Experiment
ASM	Asian summer monsoon
AVHRR	Advanced Very High Radiometer
AWS	Automatic weather station
BC	Black carbon
BOBMEX	Bay of Bengal Monsoon Experiment
BWBD	Bangladesh Water Development Board
CCN	Cloud condensation nuclei
CEOP	Coordinated Enhanced Observing Period
CEOS	Committee on Earth Observation Satellites
CERES	Clouds and Earth's Radiant Energy System
CEReS	Center for Environmental Remote Sensing
CIMS	CEOP Inter-Monsoon System Studies
CliC	Climate and Cryosphere
CLIVAR	Climate Variability and Predictability
CMA	China Meteorological Agency
COPES	Coordinated Observation and Prediction of the Earth System
CPA	CliC Project Area
CReSS	Cloud Resolving Storm Simulator
CRIEPI	Central Research Institute of Electric Power Industry
CRM	Cloud resolving model
CSEs	Continental Scale Experiments in GEWEX
CSRM	Cloud-system-resolving model
CTCZ	Continental Tropical Convergence Zone
EC	Elemental carbon
ECMWF	European Centre for Medium-Range Weather Forecasts
ENSO	El Nino/Southern Oscillation
EOS	Earth Observation System
ERA-15/40	ECMWF 15/40 Year Reanalysis
ESSP	Earth System Science Partnership
GAME	GEWEX Asian Monsoon Experiment
GAME-AAN	GAME-Asian Automatic Weather Station Network
GAME-HUBEX	GAME-Huaihe River Basin Experiment
GAME-T	GAME-Tropics
GCM	General circulation model
GEOSS	Global Earth Observation System of Systems

GEWEX	Global Energy and Water Cycle Experiment
GHP	GEWEX Hydrometeorology Panel
GIFS	Global Interactive Forecast System
GIS	Geographic Information System
GMPP	GEWEX Modeling and Prediction Panel
GMS	Geostationary meteorological satellite
GOLF	Glacier lake outburst flood
GPCP	Global Precipitation Climatology Project
GRP	GEWEX Radiation Panel
GWSP	Global Water System Project
HWM	Hydrologic watershed model
HyARC	Hydrospheric Atmospheric Research Center
IAEA	International Atomic Energy Agency
IAHS	International Association of Hydrological Sciences
ICRP	Indian Climate Research Programme
IGBP	International Geosphere-Biosphere Programme
IHDP	International Human Dimensions Programme on global environmental change
IHP	International Hydrological Programme
IMC	Indonesian maritime continent
IN	Ice nuclei
INDOEX	Indian Ocean Experiment
IOP	Intensive observation period
IPY	International Pole Year
ISO	Intraseasonal oscillation
IWM	Institute of Water Management
JAMSTEC/IORGC	Japan Agency for Marine-Earth Science and Technology/ Institute of Observational Research for Global Change
JEPP	Japan EOS Promotion Program
JMA	Japan Meteorological Agency
JRA-25	Japanese 25-year Re-analysis Project
KMA	Korean Meteorological Agency
LSM	Land-surface model
MADRAS	Microwave Analysis and Detection of Rain and Atmospheric Structures
MAHASRI	Monsoon Asian Hydro-Atmosphere Scientific Research and Prediction Initiative
MAIRS	Monsoon Asia Integrated Regional Study
MCSs	Mesoscale convective systems
MJO	Madden-Julian Oscillation
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration

NSF	National Science Foundation
NWP	Numerical weather prediction
PBL	Planetary boundary layer
PDO	Pacific decadal oscillation
PUB	Predictions in Ungauged Basins
QC	Quality Control
RAIMEP	Regional Atmospheric Inter-Model Evaluation Project
RAISE	Rangelands Atmosphere-Hydrosphere-Biosphere Interaction Study Experiment in Northeastern Asia
RCM	Regional Climate Model
SAPHIR	Sounder for Atmospheric Profiling of Humidity in the Intertropics by Radiometry
SCAR	Scientific Committee on Antarctic Research
ScaRaB	Scanner for Radiation Budget
SCSMEX	South China Sea Monsoon Experiment
SPARC	Stratosphere Processes And their Role in Climate
SSG	Science Steering Group
SST	Sea surface temperature
START	Global Change System for Analysis, Research and Training
THORPEX	The Observing System Research and Predictability Experiment
TIPEX	Tibetan Plateau Experiment
TMRP	Tropical Meteorology Research Programme
TRMM	Tropical Rainfall Measurement Mission
TRMM-PR	TRMM-Precipitation Radar
UN	United Nations
UNEP	United Nations Environment Programme
WCRP	World Climate Research Programme
WESP	Water and Energy-Cycle Simulation and Prediction
WMO	World Meteorological Organization
WMONEX	Winter Monsoon Experiment
WWRP	World Weather Research Program
3D-VAR	3-dimensional variational data assimilation
4D-VAR	4-dimensional variational data assimilation

Appendix -2

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