Science Plan for Asian Monsoon Years (2007–2012)

(Last revision, April 9 2008)

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Summary

The Asian Monsoon Years (AMY 2007-2012) is a cross-cutting initiative as part of the International Monsoon Study (IMS), a coordinated observation and modeling effort under the leadership of the World Climate Research Programme (WCRP). The long-term goal of AMY is to improve Asian monsoon prediction for societal benefits through coordinated efforts to improve our understanding of Asian monsoon variability and predictability. It is believed that coordination and cooperation of individual participating and partner projects will greatly facilitate the efforts to reach this goal.

The specific objectives of AMY are:

- To better understand the ocean-atmosphere-land-biosphere interactions, the multi-scale interactions among time scales ranging from diurnal, intraseasonal to interannual, and the aerosol-cloud-water cycle interactions in the Asian monsoon system;
- To improve the physical representations of these interactions in coupled climate models, and to develop data assimilation of the ocean-atmosphere-land system in the Asian monsoon region.
- To determine predictability of the Asian monsoon on intraseasonal and seasonal time scales, and the roles of land initialization in continental seasonal rainfall prediction.
- To better understand how human activities in the monsoon Asia region interact with monsoon and its related environment.

These objectives will be fulfilled through coordination of the ongoing and planned field experiments and modeling projects in the Asian monsoon region which form contributions to AMY.

The AMY stems from grass-root scientific and societal imperatives. It has been endorsed by the Joint Scientific Committee (JSC) of the World Climate Research Programme (WCRP) as well as the WCRP Climate Variability and Predictability (CLIVAR) Project and the Global Energy and Water Cycle Experiment (GEWEX). It has been identified as a cross-cutting weather and climate activity by WMO World Weather Research Programme (WWRP) Monsoon Panel in the WWRP Strategic Plan. The AMY program is gaining increasing support within the broad community represented by many national projects, operational centers and monsoon research scientists at large.

The planned activity consists of field observations, data management, and modeling components. A Science Steering Committee, International Program Office, and three Working Groups have been set up as an outcome of the first AMY workshop at Beijing on April 23-25, 2007 hosted by State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics (IAP). A draft of this science plan was discussed at the Second AMY'08 workshop jointly hosted by CLIVAR and GEWEX and BPPT, Indonesia at Bali, Indonesia on September 3-4, 2007. This revised version will facilitate the working groups in formulating the Implementation plan.

1. Introduction

About 60% of the world population inhabits the region of the Asian monsoon. Agriculture and, more widely, economy and society across Asia are critically influenced by the variability of the monsoon. Many of the Asian countries are developing countries whose economies are fast growing yet considerably affected by anomalous climate and disastrous weather events. Future change in the Asian monsoon climate is also of the greatest concern to the world economy and sustainable development.

The scientific importance of the Asian monsoon cannot be overemphasized. The giant Asian monsoon system dominates the entire Eastern Hemisphere tropics and subtropics. It interacts with the El Niño-Southern Oscillation (ENSO) and extratropical circulations, and has far-reaching impacts on global climate and environment. The Asian monsoon exemplifies the most complex interactions between the Earth's land surface, ocean, atmosphere, hydrosphere, cryosphere and biosphere including human activities.

Monsoon science has advanced enormously in the last two decades due to a wealth of new data from satellite observations and field experiments, and due to advances in computing power and mathematical representations of coupled climate systems. Driven by the needs to better understand and predict monsoons on all time scales from daily weather to climate change, monsoon research has received much attention in Asian monsoon regions. The AMY is a timely endeavor to integrate and coordinate these activities.

1.1 Programmatic development

Many major monsoon research activities and field projects are being planned in the time frame of 2008-2010 in China, Japan, India, Korea and many other countries. All funding supporting these projects comes from the individual nations. The Asian Monsoon Years 2007-2012 (AMY2007-2012) is based on these grass-root national efforts.

The concept of AMY was first proposed during the international workshop, "Impact of elevated aerosols on radiation-monsoon-water cycle interaction" in Xi'ning, China, in August, 2006. It was recognized that for a successful AMY, it is critical for an international body to provide science oversight, to facilitate promotion of collaboration and partnership among national programs, and to provide stewardship of the vast amount of data collected for the benefit of all interested parties.

The proposal soon gained strong support from the Climate Variability and Predictability (CLIVAR) Project and the Global Energy and Water Cycle Experiment (GEWEX) of WCRP (all acronyms in the text are listed in Table 1). The AMY concept stimulated continuing discussions at the GEWEX/Monsoon Asian Hydro-Atmosphere Scientific Research and Prediction Initiative (MAHARSI) monsoon workshop, Tokyo, held from January 8-10 2007, the GEWEX SSG meeting, Honolulu, January 22-25 2007, and the CLIVAR/

Asian-Australian Monsoon Panel (AAMP) Meeting, Honolulu, February 19-22, 2007. On March 26-30 2007, the 28th Session of the WCRP Joint Scientific Committee (JSC) was held in Zanzibar, Tanzania. A document “MONSOON ACTIVITIES IN WCRP AND THE YEAR OF TROPICAL CONVECTION” (JSC-XXVIII/Doc. 2.3 (19. II. 2007)), was drafted for this meeting by J. Matsumoto, Bin Wang, H. Cattle, R. Lawford, G. Wu, D. Walliser and T. Yasunari. Presentations to the JSC on monsoons were made by G. Wu (assisted by R. Lawford and H. Cattle), T. Yasunari and J. Shukla. The JSC subsequently endorsed the concept of the AMY as a contribution to an International Monsoon Study, a major initiative to promote broad-based climate research for the monsoon systems of the world. The AMY initiative was visualized as “a coordinated national and international observation and modeling activity to better understand the ocean-land-atmosphere interaction and the aerosol-cloud-radiation-monsoon interaction of the Asian monsoon system, for improving monsoon prediction”.

A series of conferences/workshops have been organized to coordinate ongoing activities and to plan the AMY after the WCRP JSC meeting. China hosted the first International Workshop on AMY in Beijing, April 23-25 2007. Informal discussions continued in the Monsoon system session of the XXIV General Assembly of International Union of Geodesy and Geophysics (IUGG) in Perugia, Italy July 2-13 2007, the International Symposium, “Celebrating the monsoon”, July 24-28 2007 held at Bangalore, India, and at the fourth meeting of the Asia Oceania Geosciences Society (AOGS), Thailand July 30-August 4 2007. The Second AMY workshop jointly hosted by CLIVAR and GEWEX, and BPPT, Indonesia was held at Bali, Indonesia on September 3-4, 2007. The draft science plan was discussed in the workshop. Based on the discussion, the draft version has been revised.

1.2 Participants

AMY integrates existing national and international research programs in the Asian monsoon regions. Currently, AMY has involved 24 national and multi-national projects and a total of 24 participating organizations (Table 2). These include the following national and regional projects:

- Japan- JEPP (Tibet, SEA, Thailand, IO, Maritime Continent: HARIMAU), JAMSTEC/IORGC, JAMSTEC/FRCGC, CREST-SEA, ARCS-Asia, PRAISE
- China- AIPO, SCHeREX, TORP, SACOL, NPOIMS
- India- STORM, CTCZ, IITM/Rain, CAIPEEX
- Korea- Japan: PHONE08
- USA- JAMEX, SMART-COMMIT, TIGERZ
- Chinese Taipei- SoWMEX, TiMREX, EAMEX
- China-Japan JICA/Tibet Project
- CEOP/WEBS

The approximate regional extent of these projects is shown in Fig. 1.

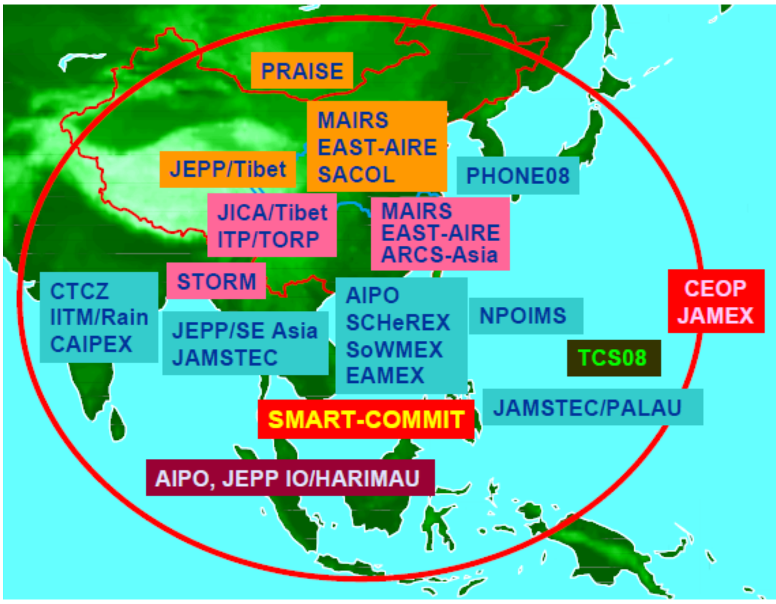

Fig. 1 Participating national/regional projects contributing to AMY.

In addition, the following international projects and the activities of the APEC Climate Center (APCC) provide a wider geographical and international perspective:

- GEWEX- CEOP, MAHASRI, GaME-T
- CLIVAR- AMMP, IOP, POP
- ESSP- MAIRS
- WWRP-TMR- TCS08

2. Background

The Asian monsoon is an enormous circulation system, which consists of two major monsoon subsystems: the Indian monsoon and the East Asian monsoon. Prominent monsoon activity in winter is closely linked to the Australian and Indonesian monsoon. The advances in Asian monsoon studies have been comprehensively reviewed by leading scientists in recent publications (Webster et al. 1998, Wang, 2006). This section describes the present understanding and the scientific issues associated with physical processes governing the Asian monsoon variability and predictability on diurnal, intraseasonal and interannual time scales that are relevant to the AMY objectives and activities. Our primary concerns here include observational aspects and process studies, our capacity in modeling and prediction of the climate variations and high impact weather events, as well as future changes of the Asian monsoon.

2.1 Observational and process studies

a. Diurnal cycle

The diurnal cycle is one of the most fundamental atmospheric responses to the solar radiation forcing; it also plays an important role in regulating monsoon rainfall and circulation. Diurnal cycles driven by solar forcing provide an efficient way for verification of physical parameterizations in models, including those for surface fluxes and the planetary boundary layer and cloud (Yang and Slingo, 2001). The diurnal cycle is most relevant for revealing monsoon modelling problems because the largest precipitation diurnal cycles are associated with monsoons and because the most complex behaviors associated with the diurnal cycle are located in the monsoon regions (Kikuchi and Wang, 2007).

It has been recognized for a long time that strong diurnal variation of rainfall is a basic feature in the tropical land regions including monsoon Asia. After the launch of the geo-stationary satellites, minute diurnal features of convective activities have been revealed by using infrared radiation data (Murakami, 1983; Nitta and Sekine, 1994). Comparisons of satellite and gauge data have been conducted in Indochina in the GAME project (Ohsawa et al., 2001). Recently, accumulation of the Tropical Rainfall Measuring Mission (TRMM) satellite observations has enabled us to capture the minute features of diurnal variations in the entire tropics (e.g., Sorooshan et al., 2002; Nesbitt and Zipser, 2003; Kikuchi and Wang, 2007). Observation by surface radar also provides a detailed view of the fast moving cloud and rainfall systems (Okumura et al., 2003). Some of these features have been reproduced in regional model simulations (Satomura, 2000).

However, the description of the diurnal cycle using satellite data is, in many cases, only for clouds and rainfall; the related circulation and/or other fields have not been fully analyzed, although a few previous intensive observational results have provided a comprehensive view of regional scale characteristics (e.g., Mori et al., 2004; Sakurai et al., 2005). The phase propagation of the precipitation diurnal cycle over the Bay of Bengal and Maritime Continent offers one of the best opportunities for observing, understanding, and modeling of the diurnal cycle in the context of AMY. Wind profilers are one of the possible tools for detecting the diurnal features of circulation. High temporal resolution upper-level wind observations are necessary. In situ GPS derived precipitable water can also add information on the moisture field. AMY needs to address:

- What is the fundamental relationship between the diurnal cycle and surface orography and land/sea configurations? What causes inland and ocean-ward propagation of the diurnal cycle from the coastal regions?
- To what extent do the diurnal variations over the open ocean affect the cloud/rainfall variations?

- How are diurnal cycles modulated by, and how do they interact with, the intraseasonal oscillation (ISO) and the seasonal/annual cycle?

b. Annual cycle

The monsoon is a manifestation of the annual cycle (Webster et al. 1998, Zeng and Li, 2002; Goswami et al. 2006, Wang and Ding, 2008), so the understanding of the basic characteristics and mechanisms of the annual cycle is fundamental to many topics in the study of monsoon. Beyond scientific importance, the onset and withdrawal of the monsoons is of vital importance to the larger community, because agriculture and other human activities are strongly influenced by the spatial and time distribution of the monsoon rainy season. Although solar radiation forcing is sinusoidal in nature, the seasonal cycle of the Asian monsoon system is more complex and includes both relatively smooth and abrupt changes (e.g., Tao and Chen, 1987; Ninomiya and Murakami, 1987; Matsumoto, 1992, 1997; Ding, 1994, 2004; Wang and LinHo, 2002; Ueda and Yasunari, 1996; Minoura et al., 2003; Ueda, 2005; Chang et al., 2005a, b).

Many studies have identified two stages of the onset of the Asian monsoon. The first stage starts from the Andaman Sea in the end of April and then rapidly extends northeastward toward Indo-China in early May, and to the South China Sea (SCS) and Okinawa in mid May to establish the early season rain band (e.g., Tao and Chen, 1987; Wang and LinHo 2002; Ding 2004, 2007). This elongated rain band is planetary scale in length and in the mature stage can extend from the Arabian Sea to the northwestern Pacific Ocean (e.g., Chen and Chang, 1980; Kiguchi and Matsumoto, 2005). The convective rainfall produces upper tropospheric heating in its vicinity (Ishizaki and Ueda, 2005; Kodama et al., 2005) as well as over the Tibetan Plateau (Ueda et al., 2003; Taniguchi and Koike, 2007).

A critical question is: what are the processes that produce this drastic onset in late spring? Since both internal dynamics and lower boundary forcing likely play important roles, a second question that has large ramifications for society is, to what extent the onset in each of the different parts of the Asian monsoon domain is predictable? Influence of slowly varying lower boundary forcing (e.g. ENSO) on the Indian monsoon onset over Kerala arises through modulation of meridional gradient of the tropospheric temperature over the region (Goswami and Xavier 2005, Xavier et al. 2007). The onset over the northern SCS is often associated with southward-propagating fronts from mainland China (Chang and Chen, 1995), making the onset in eastern China distinct from India where northerly disturbances are blocked by the Tibetan Plateau. In many instances, onset over the SCS is connected with the development of a low-level vortex over the Bay of Bengal, often associated with the passage of the Madden-Julian Oscillation (MJO) in the Indian Ocean, and this vortex serves to transport moisture across Indo-China to the SCS (Ding and Liu, 2001). The monsoon onset over India is frequently accompanied by an onset vortex over the Arabian Sea. A third question is, are these synoptic and intraseasonal motions a response of the broad scale regime changes or do they interact with the basic state to play a critical role in the onset?

The second stage of monsoon onset is usually characterized by the synchronized initiation of the Indian rainy season and the Meiyu/Baiu in early to mid-June. In addition to the two stages of the onsets the Asian monsoon undergoes prominent intraseasonal oscillations (ISOs), Periods of active rainfall over India followed by breaks on a 10-20 day time scale are routinely observed during the summer monsoon. This active-break cycle has been attributed by Sikka and Gagdil (1980) and others to northward-propagating intraseasonal oscillations (ISOs); to disturbances moving westward from the SCS with a 10-20 day period by Krishnamurti and Bhalme (1976); to bifurcating cyclonic vortices representing trailing Rossby waves behind a rapidly propagating Kelvin wave (Lawrence and Webster, 2001); to processes within the monsoon region itself that cause it to be a self-regulating, coupled system (Wang et al., 2004); and to an interaction between deep convection and the deep-tropospheric, zonally sheared, monsoon flow (Wang, 2005). A distinctive feature is that a significant part of the oscillations is calendar locked. This climatological intraseasonal oscillation (CISO) or sudden changes within the seasonal march (Wang and Xu, 1997) reflects a monsoon singularity and its mechanism is another major question that should be addressed.

On the broader scale the seasonal march of the Asian-Australian monsoon can be described by the evolution of the regional rainfall regimes. The central and pivotal area where the different regimes intersect and interact directly is situated between the tropical western Pacific and the tropical eastern Indian Ocean, where the complex land-sea distribution encompasses the Bay of Bengal, the Indo-China Peninsula, the SCS, the Philippines, and the Maritime Continent and adjacent land and sea areas. This is a region with abundant heat sources where local development often closely interacts with the annual cycle of the entire Asian monsoon domain. In general the Bay of Bengal, Indo-China Peninsula and Philippines are in the Asian summer monsoon regime while the Maritime Continent experiences a wet monsoon during boreal winter and a dry season during boreal summer. Newly available satellite observations together with long-term historical station rainfall data reveal a complex structure of the monsoon regimes of all four seasons (Chang et al., 2005a, 2006). The annual cycle is dominated largely by interactions between the complex terrain and a simple annual reversal of the surface monsoonal winds throughout all monsoon regions from the Indian Ocean to the SCS and the equatorial western Pacific. The semiannual cycle is comparable in magnitude to the annual cycle over parts of the equatorial landmasses, but only a very small region reflects the twice-yearly crossing of the sun. Most of the semiannual cycle is due to the influence of both the summer and the winter monsoon in the western part of the Maritime Continent.

Analysis of TRMM data reveals a structure whereby the boreal summer and winter monsoon rainfall regimes intertwine across the equator and both are strongly affected by local wind-terrain interactions. In particular the boreal winter regime extends far northward along the eastern flanks of the major island groups and landmasses.

In the transitional seasons the seasonal march is not symmetric. In fall, the maximum convection follows a gradual southeastward progression path in the transition from the Asian summer monsoon to the Asian winter monsoon. However in spring the transition from winter to summer monsoon is sudden. This asymmetric feature has long been recognized through its manifestation in the positions of the ITCZ (Meehl, 1987; Matsumoto and Murakami, 2002). A fundamental question is, what are the processes leading to this spring-fall asymmetry? Are they the result of asymmetric global-scale atmosphere-ocean interaction (Webster et al., 1998), wave responses to tropical heat source forcing (Hung et al., 2004), or the redistribution of mass between land and ocean areas during spring and fall that results from different land-ocean thermal memories (Chang et al., 2005a; Wang and Chang, 2008)? Since the sudden spring transition makes seasonal prediction of the Asian summer monsoon difficult, this question is closely related to that of the abrupt monsoon onset and may also be related to the “spring prediction barrier” problem.

c. Extreme and high-impact weather

Severe local thunderstorms, rain and snow storms are major hazardous extreme weather events that have high socio-economic significance. Improvement in understanding the occurrence, processes and mechanisms of these severe stormy weathers is of immense scientific importance for the better prediction of high-impact weather events and needs to be addressed.

For the Asian winter monsoon, the interactions between the cold surge from Siberia, local synoptic circulation and intraseasonal variability (mainly the MJO) often produce snow storms and high winds in East Asia as well as heavy rainfall over Southeast Asia and the Maritime Continent (Chang et al, 2005b, 2006). The outbreaks of two severe cold waves in the 2004/2005 winter and the prolonged snowfall and freezing rain event in the Huai-Yangtze river basin in January of 2008 are most remarkable extreme and high-impact weather in East Asia in recent winter years. In Southeast Asia, interactions with the diurnally varying local circulation were important for the continuous torrential rains that occurred in Jakarta in early February, 2007 (Wu et al., 2007b). In addition, interaction between cold surges and tropical circulations including MJO and tropical cyclone activity may be the key features of severe rainfalls in the central coastal area of Vietnam (Yokoi and Matsumoto, 2008). An extreme typhoon case occurred in December 2001 when Typhoon Vamei formed in the equatorial South China Sea as a result of interactions between a cold surge and a terrain induced stationary equatorial vortex (Chang et al., 2003; Chambers and Li, 2007).

For the East Asian summer monsoon in which heavy rainfall is often dominated by the Meiyu-Baiu-Changma system, southwesterly monsoon surges that occur during monsoon onset and active periods, and after the passage of topical cyclones, also led to torrential rainfall around the northern South China Sea, East China Sea, southern China and the Yangtze River basin (e.g., Jou and Deng, 1998; Chen et al., 2003; Chen, 2004; Ding and Chan, 2005; Johnson et al., 2004; Johnson, 2006; Lee et al., 2006). Interactions between larger scale mid-latitude disturbances and upper tropospheric potential vorticity as well as with diurnal convection and vorticity generation mechanisms in the Tibetan Plateau region often play critical roles in causing severe rainfall events in the Yangze River Valley. Examples include the notable summer monsoon rainfall events in 1992 (Chang et al., 1998, 2000b) and 1998 (Yasunari and Miwa, 2006). The cross-equatorial propagation of the preceding strong Southern Hemisphere annular mode (SAM) signal from the Southern Hemisphere to the Northern Hemisphere, associated with the anomalous subseasonal oscillation of the western Pacific subtropical high (WPSH), has also been suggested as a possible factor contributing to the strong summer coexistence of droughts/floods during the summer monsoon season in the Yangtze River Valley (Wu et al., 2006b, c). For the South Asian summer monsoon, major heavy rainfalls and monsoon depression and storms occur in the period of the active monsoon, which often bring about devastating floods in the central and northern India and Bangladesh (Ding and Sikka, 2006).

At sub-seasonal time scales, synoptic systems such as monsoon depressions having a horizontal scale of about 2000-3000 km form over the quasi-stationary seasonal monsoon trough. They are, by far, the most important components of the monsoon circulation. During the peak monsoon season (July-August), a majority of them form over the warm waters of northern Bay of Bengal, and move in a west-northwesterly direction with an average phase spead of about 3 m s^{-1} On average 4-6 systems form each year. Their observational characteristics are well documented and readers are referred to Sikka (2006). In most places over central India, the rainfall associated with monsoon depressions contributes to about 50% of the seasonal mean, with almost all extreme rainfall events there attested to them (Sikka, 2000). A careful analysis of observed daily rainfall along the monsoon trough reveals an increase in the incidence of intense rainfall events in recent decades (Goswami et al., 2006).

d. Monsoon Intraseasonal Oscillation (MISO)

The MISO is a dominant mode of subseasonal variability that links weather and climate. MISO is closely related to the onset, active and break periods of the monsoons. The behavior of MISO is linked to the equatorial eastward propagating MJO but more complex than MJO due to interactions between monsoon flows and the MJO. The monsoon circulation can fundamentally modify MJO during boreal summer. In addition, the monsoon has its own intraseasonal variability (ISV) modes,for instance, the bi-weekly mode (Murakami, 1975; Krishnamurti and Bhalme, 1976, Chatterjee and Goswami, 2004) and independent northward propagating 30 day mode (Wang and Rui, 1990a, b; Hendon et al., 2007).

It has been generally recognized that the MISO has the following distinctive and essential features (Goswami 2005, Waliser et al., 2006): (a) northward propagation in the Indian monsoon region (Yasunari, 1979, 1980; Sikka and Gadgel, 1980) and northwestward propagation in the western North Pacific (e.g., Lau and Chan, 1986; Nitta, 1987; Hsu and Weng, 2001); (b) formation of a NW-SE tilted anomalous rain band near Sumatra (Maloney and Hartmann, 1998; Annamalai and Slingo, 2001; Kemball-Cook and Wang, 2001; Lawrence and Webster, 2002; Waliser et al., 2003a, b); (c) initiation in the western Equatorial Indian Ocean (EIO 60°-70°E) (Wang et al., 2005, 2006b; Jiang and Li, 2005), (d) phase-lock to the monsoon annual cycle, or climatological ISO (CISO) (Nakazawa, 1992; Wang and Xu, 1997; LinHo and Wang, 2002), and (e) a prominent 10-25 day oscillation in the off-equatorial South Asian monsoon trough (Murakami, 1975; Krishnamurti and Bhalme, 1976; Chen and Chen, 1993; Wu and Zhang, 1998, Chatterjee and Goswami, 2004, Kikuchi and Wang, 2007; Wen and Zhang, 2007a, b; Krishnamurthi and Shukla, 2008) and 10-20 day ISVs in the upper tropospheric water vapor (UTWV) over both South Asia and East Asia (Zhan et al., 2006). In addition, MISO has close interaction with ISVs in the mid-latitude region (Iwasaki and Nii, 2006; Ding and Wang, 2007) due to its proxy to the subtropics.

Theories have been proposed to explain the essential features of the MISO. A review is provided in Wang (2005). The northward propagation has been explained in terms of boundary layer destabilization-convective stabilization (Webster, 1983; Goswami and Shukla, 1984), air-sea interaction (Kemball-Cook and Wang, 2001; Fu et al., 2003), and the effects of the monsoon easterly vertical shear (Jiang et al., 2004; Drbohlav and Wang, 2004). The westward propagating 10-20 day ISV seems to owe its origin to a convectively unstable gravest meridional mode equatorial Rossby mode in the presence of the mean monsoon flows (Chatterjee and Goswami, 2004). The formation of the NW-SE tilted precipitation belt has been interpreted as a bifurcation of the MJO in decaying equatorial MJO disturbances and emanation of convectively coupled equatorial Rossby waves (Wang and Xu, 1997; Lawrence and Webster, 2002; Annamalai and Sperber 2005). The re-initiation of the monsoon active-break cycles has been attributed to local SST and hydrological feedback (Stephens et al., 2004) and a self-induction mechanism (Wang et al., 2005, 2006b). The role of the topographic effect of the maritime continent has also been discussed (Hsu et al., 2004; Hsu and Lee, 2005).

However, full interpretation of the MISO phenomena remains elusive. MISO involves multi-scale interactions among diurnal, meso-, synoptic, MJO, and monsoon annual cycle scales. AMY should consider what the priority is for future field and modeling studies and for improving observing and modeling strategies. In this regard, the following issues require investigation:

- What are the major modes of the MISO? Are there any fundamental differences between MISO and the MJO?
- What is the typical multi-scale structure of MJO and MISO?
- How are organized convection systems linked to large scale forcing? What are triggers for organized convective events in general?
- Are multi-scale interactions essential for development and maintenance MJO and MISO and if so how?
- How do we get a complete theoretical framework for describing the characteristics of MJO?
- How is MJO in the Indian Ocean affected by the dynamic and thermodynamic effects of the islands in the Indonesian Maritime Continent?
- Why is there a 10-20 day oscillation and how is it related to MISO?

It is suggested that AMY should promote integrated usage of satellite observations to conduct comprehensive studies of the 3-D structure and evolution of MJO. AMY field campaigns should aim at observing the organization of convection and multi-scale structure of the MJO over the equatorial Indian Ocean, Maritime Continent, and along the tropical monsoon trough.

e. Interannual variability

A great portion of the monsoon literature has documented the year-to-year variability in various monsoon regions, including the Indian monsoon (e.g., Mooley and Parthasarathy, 1984; Shukla and Mooley, 1987), the Indonesian-Australian monsoon (e.g., Yasunari and Suppiah, 1988; Hamada et al., 2002), the East Asian monsoon (e.g., Nitta, 1987; Huang and Wu, 1989; Li and Zeng, 2002, 2003, 2005; Zhou and Yu, 2005), and the western North Pacific monsoon (Wu and Wang, 2000). The rainfall and circulation anomalies in many of the aforementioned regions exhibit a major two-to-three-year spectral peak (e.g., Meehl, 1987; Lau and Shen, 1988; Ropelewski et al., 1992; Chen and Yoon, 2000; Meehl and Ablaster, 2002). This is often referred to as the Tropospheric biennial Oscillation (TBO) (Meehl, 1993; Miyakoda et al., 1999). Comprehensive reviews have been recently provided by Webster (2006) and Yang and Lau (2006).

The Asian-Australian monsoon (A-AM) region, spanning from about 40ºE to 160ºE and from 30ºS to 40ºN, covers one-third of the global tropics and subtropics. The entire Indo-Pacific warm pool is under the influence of the

A-AM. Efforts have been made toward understanding the A-AM's broad-scale interannual variability (e.g., Meehl, 1987; Webster and Yang, 1992; Goswami et al. 1999, Navarra et al., 1999; Kim and Lau, 2001; Wang et al., 2003; Lau and Wang, 2005; Li et al., 2006). These studies have paid specific attention to the relationship between El Niño-Southern Oscillation (ENSO) and the monsoon. An integral view of the year-to-year variability of the entire A-AM system has been developed. Two major modes of variability for the period 1956-2004 have been identified (Wang et al., 2007). The leading mode exhibits a prominent biennial tendency concurrent with the turnabout of ENSO, providing a new perspective of the seasonally evolving spatial-temporal structure for the Tropical Biennial Oscillation (TBO). The second mode leads ENSO by one year and is driven by SST anomalies associated with La Niña (Zhou et al., 2007).

The remote forcing from the eastern Pacific through atmospheric teleconnection is no doubt a chief factor in Asian monsoon variations. But this is not the full story. Slingo and Annamalai (2000) suggested the active role of ENSO-induced regional SST anomalies in overshadowing the suppressing effect of ENSO on the monsoon. Recently, Gadgil et al. (2004) has shown that Indian monsoon rainfall variability is determined by both ENSO and equatorial Indian Ocean variability. These works reconfirm the Charney-Shukla (1981) hypothesis regarding the effect of boundary conditions on climate predictability (Shukla, 1998). A simple conceptual model that was presented by Krishnamurthy and Shukla (2000) suggests that the observed seasonal rainfall is a nearly linear combination of boundary forced larger scale seasonal mean and regional anomalies associated with intraseasonal variations.

The monsoon-warm pool ocean interaction can generate SST anomalies in the Indian Ocean. The Indian-Ocean dipole (IOD) or zonal mode is a beautiful example (Saji et al., 1999; Webster et al., 1999). The IOD has profound impacts on monsoon rainfall anomalies in the Indian Ocean and over India and South Asia, East Africa, Maritime continent, East Asia, and the western North Pacific (Guan and Yamagata, 2003). The processes supporting IOD have been attributed to equatorial Bjerkness positive feedback (IOD/IOZM) (Webster et al., 1999; Saji et al., 1999) and the off-equatorial convectively coupled Rossby wave-SST feedback (Wang et al., 2000, 2003). The Rossby wave-SST dipole feedback can be either positive or negative depending on background flows (the monsoon annual cycle). The monsoon basic flow can not only regulate the nature of the atmosphere-ocean interaction (Nichols, 1983) but also significantly modify the monsoon response to remote ENSO forcing and cause seasonal march of interannual anomalies (Meehl, 1987). Thus, the remote El Niño forcing, the monsoon-warm pool ocean interaction, and the influence of the annual cycle are three fundamental factors for understanding the behavior of the leading mode (Wang et al., 2003).

Monsoon-ocean interaction can also provide an important negative feedback by monsoon-induced anomalies in the surface heat fluxes (Lau and Nath, 2000) or Ekman transport of ocean heat (Webster et al., 2002; Loschnigg et al., 2003). This negative feedback often offsets the impacts of the remote ENSO forcing, making the Indian summer monsoon more resilient to interannual variation and more difficult to predict. In addition, this negative feedback is potentially important for supporting the monsoon TBO (Webster et al., 2002). Another process that contributing to the TBO is in the memories of ocean mixed layer changes land-sea contrast (Meehl, 1994, 1997).

The effects of the soil moisture and snow cover have long been recognized as a source of Asian monsoon variability, especially for the rainfall over continental monsoon regions (Bamzai and Shukla, 1999; Zhang et al., 2004). Yasunari (1991) and Dirmeyer et al. (1999) found that the land surface conditions in spring have an impact on the following summer monsoon. Shen et al. (1998) investigated the impact of Eurasian snowfall and concluded that it plays a part but does not overwhelm the SST-impacts. Further, observational studies on the seasonal march of the temperature and circulation fields over Eurasia from spring to summer have shown that the influence of snow cover and related soil moisture anomaly on the temperature and circulation anomalies in the lower troposphere is limited primarily to when and where snow cover exists seasonally (Shinoda et al., 2001; Robock et al., 2003). Therefore, more studies are needed to understand how snow in the Eurasian continent and/or over the Tibetan Plateau can affect succeeding monsoon activity.

On the interannual scale, there are strong signals of links of the variation of the continental tropical convergence zone (TCZ) with convection over the equatorial Indian Ocean, in addition to the well known link with ENSO (Gadgil et al., 2004). Understanding the mechanisms responsible for the variation of convection over the critical regions of the equatorial Indian Ocean, therefore, assumes enormous importance for our understanding the variations of the continental TCZ on both the intraseasonal and interannual scales.

f. Interdecadal variability and trends Significant interdecadal variations in summer monsoon rainfall have been known from study of long instrumental records, for instance, the all Indian summer monsoon rainfall (1871-present) and the rainfall in Seoul (1778-present) (Kripalani and Kulkarni, 1997; Goswami 2006, Wang et al., 2006a). An extratropical teleconnection mechanism has been proposed (Goswami et al. 2006) for observed strong linkages between multidecadal variability of Indian monsoon and the Atlantic Multidecadal Oscillation (AMO). In the past 50-60 years, there have been clear signals in rainfall pattern changes in the East Asian summer monsoon (Nitta and Hu, 1996; Chang et al., 2000a; Yu et al., 2004; Li and Zeng, 2005) around the late 1970s. It is, however, not clear just what the coherent structure of this interdecadal change is and how this rapid change occurred.

Uncertainty in the reanalysis datasets (Kinter et al., 2002) is one of the major road blocks for determining the processes determining the interdecadal variations.

The Indian monsoon-ENSO relationship is non-stationary, so is the ENSO property. The anticorrelation between Indian summer monsoon and ENSO has been weakening since the late 1970s (Shukla, 1995; Webster et al., 1998; Kumar et al., 1999; Krishnamurthy and Goswami 2000, Chang et al., 2001). However, the relationships between ENSO and the western North Pacific, East Asian, and Indonesian monsoons have all become enhanced during ENSO's developing, mature and decaying phases since the late 1970s (Wang et al., 2007). The latter appears to override the weakening of the Indian monsoon-ENSO relationship so that the overall coupling between the A-AM system and ENSO has become strengthened. These interdecadal changes have been attributed to changes in ENSO properties as previously documented (Wang, 1995; Gu and Philander, 1996; An and Wang, 2000). The increased magnitude and periodicity of ENSO since the late 1970s and the associated strengthened monsoon-ocean interaction may be responsible for the changes in monsoon-ENSO relationship. On the other hand, Kawamura et al. (2005) has noted that although the relationship between the all-India monsoon rainfall index and ENSO has weakened after the late 1970s, when viewed regionally the relationship is still robust between the rainfall in northeast India and ENSO. Such regional features in the whole A-A monsoon domain have not been fully revealed yet and should be examined. Annamalai et al. (2007) examined the IPCC AR4 models and noted that the models that have realistic mean monsoon precipitation climatology and ENSO characteristics, capture the details in the ENSO-monsoon association. They further noted that the relationship waxes and wanes at decadal-multidecadal time scales but do not vanish in a global warming scenario.

Issues: Overall and with the development of decadal prediction systems there is an urgent need to document the behavior of the major modes of interdecadal variation of the Asian monsoon system and determine the coherent structure and dynamics of the global monsoon system on decadal and centennial time scales and their linkage to the global ocean.

g. Oceanic processes in regions related to the Asian monsoon system

The tropical western Pacific and eastern Indian oceans are regions under direct monsoonal forcing of the Maritime Continent. Within these regions, sea surface temperatures (SSTs) are highest within the global oceans and changes in the SST are weak. Despite their small amplitudes, the subtle SST signals have been found to result in significant changes in the vigour of the monsoon and the weather patterns across the Indo-Pacific basin (e.g., Ashok et al., 2001; Neale and Slingo, 2003; McBride et al., 2003).

The small SST variation is likely related to advection by ocean currents. In the tropical North Pacific, important oceanic pathways from subtropics to tropics involve low-latitude western boundary currents (WBCs). The physics of the WBCs is extremely complex, and present climate model resolutions are too coarse, and parameterizations too crude, to give confidence in the results of numerical experiments involving advection and mixing in this region. For a better understanding of the long-term changes in the western tropical Pacific and of its roles in controlling the regional surface ocean heat budget, it is crucial to obtain accurate analyses of the cross-gyre exchanges that occur in the region, where the North Equatorial Current (NEC) encounters the Philippine coast and splits into the Kuroshio and the Mindanao Current (Toole et al., 1990). Equally important is to clarify the partitioning of the Mindanao Current transport that contributes to the Indonesian Throughflow (see below). The bifurcation of the NEC and partitioning of the Mindanao Current is affected by remote forcing from the interior of the Pacific, from the north along the western boundary, by local monsoonal wind and buoyancy forcing, and by meso-scale eddies (Qiu et al., 1999). The correct modeling of the interaction of these processes is essential to the modeling of WBCs and their impact upon the regional SST changes. An intensive process study is needed to provide the observational basis for assessing existing models, for overcoming deficiencies, and for determining the minimum long-term observing elements needed to support accurate analyses. A similar situation also exists in the tropical South Pacific there the westward-flowing South Equatorial Current splits upon reaching the Australian coast, into the northward-flowing North Queensland Current (NQC) and southward-flowing East Australian Current (Kessler and Gourdeau, 2007). The NQC connects to the New Neania Coastal Current system which contributes ultimately to the watermass characteristics of the Pacific equatorial current systems and the Indonesian Throughflow. As the South Pacific circulation is more directly connected to the Equator than the North Pacific circulation is, its changes have been argued to influence and modulate the equatorial background state upon which ENSO evolves (Tsuchiya et al., 1989; Goodman et al., 2005). As noted in previous sections, changes in the ENSO phase can indirectly impact the Asian monsoon system. Compared to its Northern hemisphere counterpart, the low-latitude South Pacific Ocean has complicated topography and is less well observed. Fortunately, a program named "SPICE" (Southwest Pacific Ocean Circulation and Climate Experiment; http://www.pmel.noaa.gov/people/ganachaud/spice/SPICEscienceplan_bkgnd.pdf) is being put together under the auspices of, and endorsed by, the International CLIVAR Pacific Panel. As the SPICE program covers both the oceanic and atmospheric (specifically, the SPCZ) variability in the Southwest Pacific region, the results from SPICE could contribute significantly to the scientific goals of AMY.

A part of the convergent Mindanao and New Guinea western boundary currents in the Western Pacific feeds the Indonesian Throughflow (ITF) westward through the Indonesian Seas, entering the eastern Indian Ocean between Australia and the Indonesian Archipelago. Despite its significance to the regional and global climate, the mass, heat, and freshwater transports of the ITF are still poorly known, and their variability is high, albeit based on limited observations (Gordon, 2005). Coupled and uncoupled GCM studies, with the Indonesian Archipelago open vs closed, have indicated that the ITF affects both the Indian Ocean SST patterns and the Austral-Asian monsoon system (Wajsowicz, 2002). The ITF may also be involved in ENSO and Indian Ocean dipole mode (IODM) evolution, as they affect the variability of the heat budget of the western tropical Pacific and the eastern Indian Oceans on climate time scales. At present, a concerted, multi-national, in-situ measurement program called INSTANT is being conducted in the ITF region (http://www.ldeo.columbia.edu/res/div/ocp/projects/instant/projectDescription.html). The observational results from the INSTANT program will likely be useful for AMY in quantifying the regional SST changes due to oceanic advection, eddy mixing, and surface wind and buoyancy forcings.

A potentially important process that influences SST in the Maritime Continent is what has been termed the South China Sea throughflow (SCSTF), which involves inflow of cold, salty water through the Luzon Strait and outflow of warm, fresh water through other straits along the South China Sea (Qu et al., 2005, 2006). Preliminary model experiments also suggest that the SCSTF reduces the Indonesian throughflow heat transport by as much as 47% (Tozuka et al., 2007), thus having a considerable impact on heat distribution in the Maritime Continent and its adjoining tropical Indian and Pacific Oceans. Specific issues to be addressed include: How does the SCSTF vary, and what is the three-dimensional structure of this variability? What processes are primarily responsible for the SCSTF variability? How is the SCSTF related to the Pacific western boundary current and how does it impact the Indonesian throughflow? Can the SCSTF play a role in modulating conditions of the Indo-Pacific warm pool? If so, how? How does the SCSTF influence the regional climate?

h. Tibetan Plateau

A unique feature of the Asian monsoon is the presence of the Tibetan Plateau. Recent comprehensive reviews on the effects of Tibetan Plateau are provided by Yanai and Wu (2006) and Wu et al. (2007a).

It has been recognized that the elevated Tibetan Plateau is a huge heat source in boreal summer and has profound impacts on the atmospheric general circulation. The upward transport of sensible heat and the release of latent heat due to water vapor condensation yield the heat source in the troposphere (Luo and Yanai, 1984; Yanai and Li, 1994). The vertical motion forced by the Tibetan Plateau surface sensible heating converges the surrounding near-surface atmosphere from below, acting as a sensible-heat driving air-pump (SHAP, Wu et al., 1997, 2004b), which greatly enhances the East Asian monsoon to its south and east and the desert climate to its west

(Duan and Wu, 2005; Wu et al., 2007a). The Tibetan Plateau forcing, together with the sub-continental-scale land-sea distribution in South Asia, also influences the Asian monsoon onset (Yanai et al., 1992; Wu and Zhang, 1998; Wu et al, 2004b; Liang et al., 2005, Xavier et al. 2007). Its elevated heating in summer can also force biweekly atmospheric oscillations (Liu et al., 2007).

In order to understand the water and energy cycle over the plateau and its roles in the Asian Monsoon and in the occurrence of disastrous weather events over Eastern Asia, several projects (TIPEX, GAME-Tibet, CEOP-Tibet, CAS/ITP TORP comprehensive observatories, and JICA-Tibet) have been implemented since 1998 (e.g., Xu et al., 2002; Ma et al., 2005, 2006, 2007). These experiments have led to many new findings such as the diurnal cycle of thermal roughness lengths (Ma et al., 2002; Yang et al., 2003; Ma et al., 2005), the structure of the atmospheric boundary layer, the mountain-valley circulation (Yang et al., 2004), and the proportion of convective vs. stratiform precipitation (Yamada and Uyeda, 2006). These experiments have also provided the basis for developing and validating physical process schemes and remote sensing algorithms (Fujii and Koike, 2001; Yang et al., 2002, 2007; Ma et al., 2003, 2006, 2007; and Oku et al., 2006).

However, the regional-scale interactions between the land surface and the atmosphere over the Tibetan Plateau have not been elaborated in the context of the Asian monsoon system. In the framework of new GEWEX/CEOP (Coordinated Energy and water cycle Observation Project) activity, the Tibetan Plateau is recommended as a hydroclimate “hotspot”. It is critical to assess how reliable the reanalysis, current model outputs, and various satellite products are over the high Tibetan region. There are urgent needs for better determination of the climatological mean and seasonal-to-inter-annual variability of soil moisture, the regional heat source and water vapor sink, and of the surface energy budget over the Tibetan Plateau.

2.2 Numerical modeling and prediction

a. Diurnal cycle and annual cycle

Accurate description and prediction of the spatial and temporal variation of diurnal rainfall around the globe remains one of the critical unsolved problems in climate system modeling. Sperber and Yasunari (2006) summarized the problems in the simulation by GCMs of the diurnal cycle. Adequate resolution of the planetary boundary layer (PBL) is important and a coupling between the planetary boundary layer and deep convection holds a key to improving the diurnal cycle in GCMs. In general, the diurnal cycle of precipitation is better simulated in RCMs. This suggests that global cloud-system resolving models are desirable to model and predict monsoons.

Recent assessment indicates that in some AGCMs the simulated diurnal rainfall peaks are 2-3 hours too early (Lau and Kim, 2007). On the other hand, the regional distribution and diurnal variations of the rainfall in and around Sumatra Island were shown to be realistically replicated by using a cloud microphysics scheme in a regional model (Wu et al., 2008).

The performance of models in simulating and forecasting seasonal mean states is closely related to their capability to predict seasonal anomalies (Sperber and Palmer, 1996; Slingo et al., 1996; Lee et al., 2007; Zhang and Li, 2007; Annamalai et al., 2007). Getting the annual cycle right is of critical importance for models to reproduce accurate teleconnection and climate anomalies away from the ENSO region. What are the major weaknesses of the climate models in simulation of the annual cycle? Kang et al. (2002b) found that all 11 GCMs that participated in the AAMP intercomparison project overestimate the amplitudes of climatological seasonal variations of the Indian summer monsoon rainfall but underestimate the amplitudes in the western Pacific rainfall. The AGCMs simulate a poor annual cycle over the western North Pacific heat source region with a large range of spread among the models in both the amplitude and phase (Wang et al., 2004). Recent evaluation of the DEMETER and APCC climate prediction models confirms that a major common weakness lies in the western North Pacific and East Asian monsoon region. Most models failed to simulate the correct monsoon annual cycle in that sector (Lee et al., 2007).

To identify models' common errors requires knowledge of the characteristics of the principal modes of global precipitation diurnal cycle and annual cycle. The following questions remain to be addressed:

- What determines the structure and dynamics of the diurnal and annual cycles of the coupled atmosphere-ocean-land system?
- How can the major weaknesses of climate models in simulation of the diurnal cycle and annual cycle of global precipitation be remedied?

b. Modeling and prediction of Intraseasonal variations

The capability of models in reproducing MJO and MISO has been continuously assessed in the last ten years (e.g., Slingo et al., 1996; Sperber et al., 2001; Waliser et al., 2003a, b). In a recent assessment of MJO in the 14 IPCC AR4 models, Li et al. (2006) found that only one or two models have realistic representation of the MJO. The MJO variance is too small and it does not have a pronounced spectral peak but rather a reddened spectrum. Pertaining to the boreal summer MISO simulations, Sperber et al. (2001) have examined the performance of 7 AGCMs and found that the models have difficulty in representing the pattern of precipitation associated with the dominant mode; and also usually fail to project the subseasonal modes onto the seasonal mean anomalies. Waliser et al. (2003) analyzed the MISO in the 10 AGCMs that participated CLIVAR/AAMP AGCM intercomparison project and found that (a) the most problematic feature is the overall lack of variability in the equatorial Indian Ocean, (b) most of the model ISO patterns did exhibit some form of northward propagation, but they often show a southwest-northeast tilt rather than the observed northwest-southwest tilt, (c) the fidelity of a model to represent boreal summer versus winter intraseasonal variability (ISV) appears to be strongly linked. In contrast to AGCMs, all coupled models that participated in the IPCC AR4 exercise showed appreciable skill in capturing the eastward equatorial intra-seasonal rainfall variability over the Indian Ocean, while only a few simulated the observed northwest-southwest tilt (Annamalai et al., 2007).

Why do AGCMs have considerable difficulties in simulation of the MJO? Modelling of the ISO in these complex models must entail a series of interacting parameterizations including moisture transport, clouds and convection, and radiation transfer; thus, uncertainties in mathematical descriptions of these multi-scale interactive parameterizations could jeopardize the model's capability in simulating the MJO (Wang, 2005). For instance, it is critical for models to get correct heating partitioning between the convective and the precipitation associated with the stratiform clouds and between the small-scale high frequency and large-scale, low frequency disturbances. Recent TRMM precipitation radar measurements reveal that stratiform precipitation contributes more to intraseasonal rainfall variations than it does to seasonal mean rainfall (Lin et al., 2004; Wang et al., 2006b). AGCMs might be underestimating the portion of condensational heating released by stratiform precipitation. The inadequate treatment of cumulus parameterization and the multi-scale interaction processes could be the major hurdles for realistic simulation of MJO.

The prediction skills of ISV have been assessed recently in the hindcast experiments made by DEMETER and APCC/CliPAS models. Kim et al. (2007) reported that the models involved tend to considerably underestimate the largest ISV variances over the western North Pacific (WNP) and Indian monsoon regions. Only a few models can realistically capture the evolution and structure of the boreal summer ISO, such as the NW-SE slanted precipitation band. The good news is that although models have large systematic biases in the spatial pattern of dominant variability, the leading EOF modes of the ISV activity in the models are closely linked to the models' ENSO, which is a feature that resembles the observed ISV and ENSO relationship.

In hindcast experiments, the signal to noise ratio over the A-AM region, shows that nearly all models show a drop of forecast skill after about a week in the summer monsoon regions when unfiltered data were used for evaluation (Kim et al., 2007). However by including air-sea interaction in an AGCM, it has been shown that the predictability of MISO can be extended by about a week (with filtered data) (Fu et al., 2006).

Many issues remain unresolved regarding the modeling and prediction of MISO including:

- What is the role of radiative heating in the tropical heating profile? How do models properly moisten the lower-troposphere?

- Do models correctly simulate the heating partitioning between the high frequency disturbances and large-scale, low frequency disturbances?
- What is the role of mesoscale systems in determining the heating profile (convective/stratiform) and how does this impact the evolution of ISO? How can this be correctly represented in models? In general, how can we correct the systematic errors in models' simulation of the MJO?
- How important is the modulation of the diurnal cycle in intraseasonal monsoon variations? Will the models which get the diurnal cycle right also have improved representation of low-frequency variability (intraseasonal to interannual)? How does the diurnal variability in SST influence the SST variability at ISO time scales?
- How do the errors in simulating ISOs impact simulation of the interannual variability?
- To what extent is the MISO predictable?
- What roles do atmosphere-ocean-land interactions play in sustaining MISO?
- What are the relative roles of entrainment, upwelling, and advection in controlling ISV of SST? To what extent are these processes dependent on atmospheric forcing? How does intraseasonal SST anomaly feedback to ISO?
- What is the influence of the MJO on tropical cyclone and extratropical predictability?
- How do low-frequency components of climate modulate MISO and its statistical properties?

c. Seasonal to interannual predictability and prediction

The source of predictability beyond two weeks must come from lower boundary conditions because of the chaotic nature of the atmosphere, and seasonal mean variations are largely controlled by slowly varying SST and land surface conditions (Charney and Shukla, 1981; Shukla, 1998). The seasonal mean variations thus consist of signal and noise parts; the former controlled mainly by SST and the latter by the atmospheric stochastic processes. Dynamical seasonal predictabity in the monsoon regions is limited by the facts that monsoon variability is more controlled by the noise than the signal and that model capabilities to simulate the signal is poor (Goswami 1998, Kang et al., 2004; Kang and Shukla, 2006). Additionally use of multi-model ensembles (MMEs) has been shown to provide superior skill compared to that derived from any individual model's performance, by reducing model independent errors. But, the skills of MMEs also depend on having good models (Kang and Yoo, 2006). Thus, improvement of models is of central importance for better climate forecasts. Improvement of models requires identification of model common errors. For this purpose, many model intercomparison programs (MIPs) have been organized in the last 15 years.

Use of forecast type experiments to evaluate models and study climate sensitivities should be encouraged.

Intercomparison of the capability of AGCM's to reproduce interannual monsoon anomalies has been a major concern in the last decade. Sperber and Palmer (1996) examined 32 models that participated the AMIP project. The Asian monsoon variability in those models was not well simulated. They found that the Webster and Yang (1992) index (vertical wind shear) was better simulated than the all-India rainfall and that interannual variation was better simulated in the models which were able to generate a better climatology. After model revisions, simulation of interannual variability was found to be significantly improved (Sperber et al., 2000). However, in assessment of the performance of 10 AGCMs that participated in the AAMP intercomparison project on simulation of monsoon anomalies during 1997 and 1998 (Kang et al., 2002a), Wang et al. (2004) claimed that the simulation of anomalous monsoon rainfall is still very poor, particularly over Southeast Asia and the western North Pacific region (5N-30N, 80E-150E) during northern summer. They argued that the neglect of air-sea interaction is a major cause of the models' failure. Examination of 5 AGCM-alone 21-year hindcast experiments indicates that the state-of-the-art AGCMs, when forced by observed SST, are unable to simulate Asian-Pacific summer monsoon rainfall (Wang et al., 2005). The models tend to yield positive SST-rainfall correlations in the summer monsoon region that are at odds with observations. Thus, in the summer monsoon region, treating the atmosphere as a slave to specified SSTs may prohibit correct simulation of the summer monsoon rainfall anomalies.

Recent evaluation of a 21-year hindcast of 10 coupled climate models (one-tier systems) participating in the DEMETER (Palmer et al., 2004) and APCC/CliPAS projects shows that use of MMEs has improved skill in predicting monsoon rainfall compared to the forecast made by AGCMs forced by pre-forecast SSTs (two-tier approach). Both the DEMETER and APCC/CliPAS MME one-month lead predictions capture the first two leading modes of variability that are at least comparable to or even better than that of the reanalyses (ERA 40 and NCEP-2). This is perhaps due to the fact that the MMEs included ocean-atmosphere interaction processes, which are not in the reanalysis.

Evaluation of 18 IPCC coupled models revealed that the ENSO-monsoon teleconnection is represented in models that have realistic monsoon precipitation climatology as well as space-time evolution of SST and associated diabatic heating anomalies in the equatorial Pacific during El Nino (Annamalai et al., 2007). Thus, for coupled models to be successful in monsoon seasonal prediction, simulation of ENSO in all details appears pre-requisite.

Evaluation of ensemble hindcast results derived from 17 state-of-the-science coupled and AGCM-alone models that participated in the DEMETER and APCC/CliPAS projects has shown that the seasonal prediction of the A-AM in general has moderate skill. But precipitation forecasts over the continental monsoon region have essentially no useful skill (Wang et al., 2007). The climate prediction of monsoon Asia remains low-skill due to our insufficient understanding of the important physical processes relating to climate variation and the poor performance of current climate prediction models. It is also important to correct coupled model systematic errors in modeling of the annual cycle, to further improve the slow coupled dynamics in the coupled models (ENSO for instance), to improve coupled model initialization in the interior ocean and the land surface, and to improve model resolutions and capability to make probabilistic forecasts of extreme events. Particular attention should be paid to the following questions and issues:

- How predictable is A-AM seasonal anomalies especially in the continental monsoon region? What factors limit the climate models' predictability?
- What roles do land surface processes and atmosphere-land interaction play in short-lead monthly and seasonal prediction? How do we improve seasonal prediction in continental monsoon regions?
- How do we best design metrics for objective, quantitative assessment of model performance on interannual variability and identification of key modeling issues which help to lead to development of an effective strategy for improving models?
- How do we improve initialization schemes, initial conditions, and representation of slow coupled physics in coupled climate models?
- How can we better understand the physical basis for seasonal prediction and the ways to quantify the uncertainties associated with prediction?

d. High resolution modeling

Torrential rainfall often involves orographic effects. The rainfall associated with orography is better represented in high resolution models. High resolution models may also be able to resolve the Mei-Yu front better (Kawatani and Takahashi, 2003, Sumi et al., 2004). Synoptic disturbances play an essential role in determining monsoon climate variability. The number, frequency and tracks of monsoon depressions are critical in determining intraseasonal and seasonal rainfall. Mesocale organized convection systems are also crucial for monsoon variability. If models cannot capture monsoon disturbances and their tracks and life cycle, there will be little chance for models to make any successful dynamical prediction of monsoon variations. Stanhill and Annamalai (2008) noted that coarse-resolution coupled models, despite simulation of realistic monsoon precipitation climatology, failed to capture the life-cycle of monsoon disturbances.

Increased horizontal and vertical resolution is important for resolving complex surface topography which, in general, has essential impacts on diurnal variations. Arakawa and Kitoh (2005) reported that the representation of the spatio-temporal characteristics of the rainfall diurnal cycle can be improved to a certain extent by using a super high resolution atmospheric general circulation model (20 km-mesh). Their results suggest the significance of using high resolution, cloud resolving numerical models for regional and global climate system modeling. It is urgently necessary for us to apply such a kind of model to various places over the Asian Monsoon region, to improve the predictions of rainfall and its variability at various time scales. Numerical experiments with the global cloud-system resolving model (NICAM) developed at the Frontier Research Center for Global Change (FRCGC) have demonstrated the promise of very high resolution modeling in simulating multi-scale structure of the MJO (Nasuno et al., 2007).

Aldrian et al (2005) have shown that contrasts of land sea rainfall pattern are pretty much related to the distribution of the land sea mask. Wu et al. (2008) have also noted that the high-frequency (on time scale of minute) precipitation distribution related to topography and land/sea configuration in the maritime continent islands is not very realistic even in 20-km GCM result. However a regional model with 4-km resolution can provide a better simulation.

2.3 The monsoon environment and its future changes

a. Impacts of aerosols

There is now a growing body of evidence suggesting that aerosol forcing may substantially alter the redistribution of energy at the earth's surface and in the atmosphere, and therefore significantly impact monsoon rainfall variability and long term trends (Menon et al., 2002; Chung and Ramanathan, 2006; Ramanathan et al., 2005; Lau et al., 2006; Lau and Kim, 2006, 2007). AMY provides an excellent opportunity for the aerosol and monsoon research community to work together to address the scientific and societal problems arising from aerosol-monsoon interactions.

Aerosols scatter and/or absorb solar radiation, reduce the amount of shortwave reaching the surface causing it to cool (the direct effect), also referred to as the "solar dimming" effect. Quantifying the solar dimming effect requires extensive and high-quality measurements of radiation budget, aerosol and cloud properties, which is one of the objectives of the East Asian Study of Tropospheric Aerosols: an International Regional Experiment (EAST-AIRE) conducted in China since 2004 (Li et al., 2007a). Under this US-China collaborative project, extensive and continuous measurements have been made at baseline stations and a nation-wide observation network. Aerosol reduction of surface shortwave irradiance amounts to more than half of the reduction due to cloud cover over industrialized eastern China near Beijing and Shanghai (Li et al., 2007b; Xia et al., 2007). Moreover, the aerosols are so strongly absorbing that they hardly alter the radiation budget at the top of the atmosphere. As a result, the solar energy failing to reach the surface is trapped in the atmosphere, drastically altering the heating profile and atmospheric stability and thus affecting convection (the semi-direct effect).

Because of the diverse distribution of sources of natural (dust, wild fire, biogenic emissions, volcanic eruption and sea salt) and anthropogenic aerosols (fossil fuel and biofuel combustions and anthropogenic biomass burning) in space and time, and because of the long-range transport of fine aerosol particles, solar dimming is important not only locally, but rather globally (Stanhill and Cohen, 2001). Furthermore, aerosols can affect the water cycle through interaction with cloud microphysical processes. Aerosols increase the number of cloud condensation nuclei (CCN) forming smaller water droplets that increase scattering cross-sections and brighten cloud, which then reflects more solar radiation – the 1st indirect effect (Twomey, 1977). The small droplets limit collision and coalescence, prolonging the life time of clouds and inhibiting the growth of cloud drops to raindrops – the 2nd indirect effect (Albrecht, 1989; Rosenfeld, 2000). The indirect effects lead to more clouds, and increased reflection of solar radiation, causing further cooling at the earth surface. Additionally, dust aerosols have been shown to act as giant ice-nuclei in initiating ice-phase precipitation at high altitudes, thus favoring deep convection and increased rainfall (Sassen et al., 2002). However, these aerosol forcings are primarily local processes. Recent studies using global satellite data and a cloud resolving model (Li and Yuan, 2006; Yuan et al., 2007) revealed a very complex aerosol indirect effect. While aerosols generally reduce cloud particle size and suppress precipitation in arid or semi-arid environments with weak dynamical forcing, they could have an opposite effect under moist conditions with strong dynamical forcing typical of monsoon regions. From a global perspective, the aerosol forcing from different regions and at different times collectively contribute to changes in the distribution of heating between the atmosphere and the earth's surface and the horizontal heating gradient in the atmosphere and at the surface, driving an anomalous (relative to the mean state) general circulation. Feedback processes from atmospheric water vapor, cloud and precipitation may cause further changes in the large-scale circulation, altering aerosol transport and deposition, aerosol chemistry, and aerosol-aerosol mixing processes. The chemical transport processes then lead to redistribution of the aerosol concentration and aerosol properties, further altering the aerosol local forcing. The interaction of aerosol with the large-scale circulation is therefore a very complex process.

In the Asian monsoon and adjacent regions, the aerosol forcing and responses of the water cycle are even more complex, because of different aerosol types and heavy rainfall affecting aerosol wet deposition processes. Dust transported by the large-scale circulation from the Middle East and Pakistan deserts to India, and from the Taklamakan desert to East Asia, sulfate and black carbon from industrial pollution in China and India, and organic and black carbon from biomass burning from Indo-China contribute to the variability in differential heating and cooling of the atmosphere and to the land-sea thermal contrast. The magnitude of the total aerosol forcing due to sulfates and soot have been shown to be quite large corresponding to a surface radiative cooling of 20-40 Wm^{-2} over the Asian monsoon land in the pre-monsoon season (Chung et al., 2005). However, the combined forcing from all species of aerosols found in the monsoon regions, including possible aerosol-aerosol mixing is not known. Even less known, are the possible responses and feedbacks of the subsequent monsoon water cycle, especially precipitation over land, to aerosol forcing. By better defining the precipitation forcing function in the monsoon atmosphere-land interaction through aerosols, it may be possible to increase the predictability of monsoon rainfall over continental regions. However, because so much is unknown, the aerosol-monsoon water cycle presents new challenges to monsoon climate research (Lau et al., 2008).

b. Assessment of future changes

A summary report regarding the future changes of the Asian monsoon has been provided by Kitoh and Uchiyama (2006). Large uncertainties remain especially for monsoon rainfall changes. It has been hypothesized that the tropical atmospheric moisture content, latent heating, and overall hydrological cycle will enhance with increasing tropospheric temperature (e.g., IPCC 2001). Coupled GCM simulations with increasing greenhouse gas content generally show increased intensity of the Asian summer monsoonal circulations (e.g., Meehl and Washington, 1993; Hulme et al., 1998). Coupled models that show fidelity in simulating mean monsoon precipitation and ENSO-monsoon teleconnection in the 20th century integrations, do indeed suggest a possible increase in time-mean monsoon precipitation in a global warming scenario (Annamalai et al., 2007; Stanhill and Annamalai, 2008). A further study in which a high-resolution regional model was nested in a coarse-resolution coupled GCM indicated an increase in the frequency of intense monsoon disturbances (Stanhill and Annamalai, 2008). However, inclusion of aerosols, seems to suppress the simulated increasing trends in Southeast Asia seen in many general circulation model simulations (e.g., Mitchell and Johns, 1997), but not in all (e.g., Roeckner et al., 1999). Analysis of land-based rain gauge observations, however, reveal an overall weakening of the global land monsoon precipitation in the last 56 years, primarily due to weakening of the summer monsoon rainfall in the Northern Hemisphere (Wang and Ding, 2006). This feature has not been successfully captured in the IPCC AR4 models (Kim et al., 2007). More careful assessment of future changes in the Asian monsoon remains a major task for AMY.

Climate change over the Tibetan Plateau is of central importance for understanding the future changes of the Asian monsoon. AMY will be strongly dependent on the Tibetan Observation and Research Platform (TORP) project to address this issue. TORP aims at: studying the characteristics of the Plateau's climate and its interactions with global change; determining the effects of global warming on the glaciers, lakes, and frozen soils and other processes on the Tibetan Plateau, and the ways these changes feedback to global climate change; understanding the roles of glaciers, lakes, rainfall, and soil moisture with respect to greenhouse gases and aerosols; and establishing relationships between modern climate and physical, chemical, and biological proxies by using remote sensing data and the high resolution records.

c. Human activity and changing monsoon environment

Changes in the Asian monsoon could have profound impacts on social development, human well-being and health. At the same time, rapid economic and social development, which drives environmental changes, may also be helping to reduce vulnerabilities. Evidence for historical changes in the monsoon system has not yet been systematically fragmented into those components which can be attributed to human activities and which cannot. Through better histories and models we are now in a position to begin exploring relative contributions. Environmental change in the monsoon Asia region is not independent of global changes.

There is still little knowledge about how and how many regional and global environmental systems are coupled. Crucial cross-cutting issues are related to natural resources in water, energy, food security, biodiversity, air quality and in disasters. The AMY should make an effort to understand how and why monsoon systems will change in a global warming environment, in particular, to understand the effect of human influences (i.e., aerosols, land-use change, and greenhouse-gas increase) on hydro-meteorological variations in Asian monsoon regions. Collaboration with MAIRS project will be essential on this point.

3. Science foci

Among AMY individual projects that are planned in various geographic regions, a number of cross-cutting themes on physical processes and overarching questions are of particular importance because they provide the basis for a coherent program. A number of these are addressed below.

3.1 Cross-cutting science themes

a. Multi-scale interactions

Understanding multi-scale interactions from diurnal to intraseasonal time scales is of great importance for determining the monsoon intraseasonal predictability. These scale interactions involve a variety of atmospheric internal dynamics.

The large-scale rainfall over India, the Indo-China peninsula, and the South China-Philippine Seas during the boreal summer is associated with a tropical convergence zone (TCZ), which stretches from India across the Indo-China peninsula to the Philippine Sea, connecting to the Pacific Intertropical Convergence Zone (ITCZ). It is often called the South Asian monsoon trough during boreal summer. Over South Asia, the TCZ resides along 15°-25°N. The total summer rainfall over Southern Asia is highly correlated with the rainfall in this TCZ or monsoon trough zone. Further the variation of the large-scale rainfall in the tropical Asian summer monsoon is linked to the space-time variation of the TCZ.

During summer, the intensity of the TCZ shows large-amplitude fluctuation on the 30-60 day time scale. The space-time variability of the TCZ involves a variety of scales. Synoptic scale disturbances are embedded in it and the rainfall associated with the TCZ is organized on the meso-scale. Prominent bi-weekly oscillations propagate westward along the TCZ (Krishnamurti and Bhalme, 1976; Murakami, 1980; Chen and Murakami; 1988) , and cloud processes such as cloud-radiation feedbacks are bound to play a role. It is an ideal system for investigating multi-scale interactions in the tropics. This area is of common interest among the CTCZ, MAHASRI, and AIPO projects.

On the intraseasonal time scale, the Asian monsoon strongly interacts with the Madden-Julian oscillation. The monsoon intraseasonal oscillation consists of two major components: the 30-60 day oscillation and a quasi-biweekly oscillation or 10-20 day oscillation. On the synoptic scale, the CTCZ project strives for better understanding and prediction of (i) genesis of synoptic scale systems over the warm oceans as well as over the land surface, (ii) tracks of monsoon lows and depressions and the role of land surface conditions in determining these tracks, and (iii) their life span. On the cloud and cloud system scale, cloud system characteristics and the microphysics of warm and cold clouds need to be elucidated. Scale interaction also includes spatial interactions among hydro-meteorological phenomena of local, regional and continental scales, which is a special interest of MAHASRI.

ISV provides a pivotal focus point for AMY studies of multi-scale interaction for several reasons: 1) it has practical importance to Asian monsoon variability including onset and retreat; 2) it involves active multi-scale interaction; 3) it's relation to seasonal prediction remains a major issue; 4) it provides a close linkage to WWRP and YoTC; 5) it has relevance to IMS.

Note that the active and weak spells of the continental TCZ originate from the oceanic TCZ where monsoon-ocean interaction plays a critical role. Air-sea interaction, i.e. the exchange of energy, momentum and mass across the sea-air surface, in the Asia and Indian-Pacific Ocean (AIPO) warm pool region is one of the key factors that lead to large-scale, persistent or explosive meteorological disasters.

b. Atmosphere-ocean-land-cryosphere-biosphere interactions

Understanding the variety of interactions between the various components of the climate system (atmosphere, ocean, land, cryosphere and biosphere) is of great importance for both seasonal and longer term prediction. These interactions involve climate feedback processes among different components of the Earth's climate system as well as ENSO-monsoon interactions.

The South Asian TCZ consists of both oceanic and continental components. It is strongly influenced by the world's highest region, the Himalayan-Tibetan Plateau and by the overall ocean-land configuration and it's complex orography. Thus, the TCZ is an ideal natural laboratory for studying the complex feedback processes among the atmosphere, ocean, land, and cryosphere. As noted above, in this region, one encounters nearly all the atmospheric internal forcing processes that govern both the weather and intraseasonal variations and the climate feedback processes among different components of the Earth's climate system that determine seasonal to interannual predictability.

Over the continental TCZ region of India, Indo-China, and the Philippines, the feedbacks of the coupled land-atmosphere-hydrosphere-biosphere system will play a role in determining the variability. The time-scales of the weak or dry spells of the continental TCZ may be influenced by the land hydrological feedbacks as well as the presence of dust and other aerosols. Under the CTCZ project, it is proposed to undertake detailed observations and modeling studies of the processes specific to the CTCZ such as the atmosphere-hydrosphere-biosphere feedbacks (in which land surface processes, aerosols will play important roles).

The land surface has limited heat capacity, whereas the ocean possesses a huge heat capacity. As a result, in winter continents become a heat sink for the atmosphere while the oceans act as a heat source. On the other hand in summer, the continents become a heat source while the oceans act as a heat sink (Wu and Liu, 2003; Liu et al., 2004; Wu et al., 2004a). Such a reversal in thermal contrast between land and sea over South and East Asia provides a continental- scale forcing for the occurrence of Asian monsoons. In summer, a wet monsoon climate over South and East Asia and a dry and desert climate over West and Middle Asia are therefore formed. Land surface processes are an important aspect for global climate change studies. The SACOL project strives to elucidate drought processes, aiming at improving parameterizations of a variety of physical, chemical, and biological processes associated with drought. Effects of various-scales of orography on monsoon rainfall in both summer and winter are of the primary concern of the MAHASRI project.

For the entire Tibetan Plateau, the CEOP/WEBS (Water and Energy Budget Study) project is developing a long-term dataset of soil moisture and surface water and energy budgets. This dataset will be used to reveal the interface processes between cryosphere and atmosphere, and between hydrosphere and cryosphere.

c. Aerosol-cloud-monsoon interaction

Recognizing the critical importance of aerosol-water cycle interaction in monsoon climate research and in societal impacts, the Joint Aerosol-Monsoon Experiment (JAMEX) has been proposed as a core element of AMY with the objective: to unravel the physical mechanisms and multi-scale interactions associated with the aerosol-monsoon water cycle in the Asian Indo-Pacific region. JAMEX will examine the relative importance and interplay among the following factors in aerosol-monsoon interaction as suggested by recent studies:

• *The Solar Dimming (SDM) effect.* Atmospheric Brown Clouds (ABCs) are characterized by layers of air pollution consisting of black carbon, organic carbon, fly ash and dust as well as other anthropogenic aerosols such as sulfates and nitrates (Ramanathan and Crutzen, 2003). ABCs cool the earth's surface and heat the atmospheric column with comparable magnitudes. The effects are strongest (>15-20 Wm^{-2}) over the major monsoon regions (South Asia, East Asia, the Maritime Continent, West Africa, South America, and Mexico) due to the combination of desert dust, smoke and black carbon from biomass burning, and sulfate and soot from industrial and biofuel pollutions. Coupled ocean-atmosphere GCM experiments have shown that the SDM effect causes a reduction in surface evaporation, decrease in meridional sea surface temperature gradient and increase in atmospheric stability and reduction in rainfall over India (Ramanathan et al., 2005).

• *The " Elevated Heat Pump" (EHP) effect.* Recently, Lau et al. (2006) proposed the "Elevated Heat Pump" effect suggesting that atmospheric heating by absorbing aerosols (dust and black carbon), through water-cycle feedback, may lead to a strengthening of the South Asia monsoon. The EHP posits that dusts transported from the Middle East and Pakistan deserts accumulate over the Indo-Gangetic Plain (IGP) against the foothills of the Himalayas, and, mixed with local emissions of black carbon aerosols, provide an elevated heat source, which accentuates the seasonal upper troposphere heating over the Tibetan Plateau (Wu et al., 1997; Wu and Zhang, 1998; Yanai and Li, 1992). The aerosol-induced heating produces a positive feedback in the monsoon water cycle which leads to a) an advance of the rainy season in May-June in northern India and foothills of the Himalayas, b) subsequent increase of the monsoon rainfall over the entire India in June-July, and a corresponding reduction in rainfall in the northern Indian Ocean, and c) a reduction in rainfall over central East Asia, due to combined local aerosol forcing and downstream influence from the aerosol-induced large-scale circulation over the Tibetan Plateau.

• *The aerosol-microphysics (in-direct) effects.* During episodes of increased pollution in the pre-monsoon season, bright clouds are often seen to form over the polluted IGP, compared to the relatively clean cloud over the Tibetan Plateau. Satellite data analysis has shown that the polluted clouds generally have smaller effective cloud radius (<10 m) compared with the clean clouds, providing possible hints of the aerosol indirect effect. However, it is not clear how a pre-conditioning of the cloud system by aerosol indirect effects in the periods just preceding the monsoon onset, may interplay with the SDM and EHP effects in further affecting the subsequent evolution of the monsoon water cycle. If the aerosols consist of mostly fine-mode industrial pollution they will increase the number density of CCN, and suppress rainfall. On the other hand, if they consist primarily of coarse mode particles from dust they may promote ice-nucleation and lead to more frequent outbreak of deep convection in periods leading up to the monsoon onset. Additionally, when mixed with anthropogenic aerosols (e.g., sulfate, black carbon, etc.) dust can act as an effective aerosol scavenger to modulate surface radiative forcing (Ramanathan et al., 2001). These aggregate dust-soot mixtures could potentially absorb much more solar radiation in the atmosphere than by either dust or soot alone and thus exert stronger forcing in the radiative energy balance in the earth-atmosphere system.

• *Coupled atmosphere-ocean-land interactions*. In studying the aerosol-monsoon interaction problem it is important to remember that the monsoon is driven primarily by the evolution of large-scale heat sources and sinks stemming from the seasonal variation of solar radiation, and associated land-sea thermal contrast, orographic forcing, latent heat of precipitation, and large-scale dynamics. Aerosol-induced heating and cooling, through SDM and EHP effects, and interaction with cloud microphysics may constitute significant perturbations, especially in the pre-monsoon seasons and during prolonged break periods, to induce a redistribution of heat sources and sinks, and possibly alter the monsoon climate state, but only through coupled atmosphere-ocean-land processes. Hence it is important to understand how aerosol effects may alter the forcing and responses of the monsoon water cycle through interactive land surface processes and sea surface temperature, as well as other remote forcing agents.

Observationally effects of the monsoon water cycle are likely to be confounded by monsoon responses to El Niño, soil moisture, snow cover as well as land use, land change and anthropogenic greenhouse warming effects, both local and remote. Sorting out the impacts of aerosol forcing and responses, and identifying modulating effects from remote forcing will be one of the main challenges of JAMEX.

3.2 Overarching science questions

Each individual project has specific science questions/issues to be addressed. Here are some overarching questions that AMY will focus on:

- What are fundamental causes for, and how predictable is, Asian monsoon intraseasonal, interannual, and interdecadal variability?
- Is current inability to make skillful monsoon predictions due to fundamental lack of monsoon predictability, or is it because of inaccurate models and modeling strategies? Will ultra-high resolution models be able to describe mulit-scale interactions and therefore enhance the predictability of intraseasonal and seasonal variations?
- How do atmosphere-land interactions (including those associated with the cryosphere), atmosphere-warm ocean interaction, and Tibetan Plateau processes affect monsoon seasonal prediction?
- What are the impacts of absorbing aerosols (dust and black carbon) and scattering aerosols (sulfate) on the monsoon water cycle? What are the microphysical effects on clouds and rainfall from natural sources and mixing with anthropogenic aerosols? Do aerosols weaken or strengthen the Asian monsoon?
- How will the Asian monsoon system change in a global warming environment and under human transformation of land, water and air?

4. Goals and objectives of AMY (2007-2012)

4.1 The overarching goals

The goal of AMY is to improve Asian monsoon predictions on intraseasonal and seasonal time scales for societal benefits by advancing our understanding of the physical processes determining the Asian monsoon variability and predictability, development of high-resolution climate models and data assimilation systems, and by promoting societal applications in order to support strategies for sustainable development. Success in meeting this overarching goal is critical to the new WCRP strategic Plan 2005-2015.

4.2 Objectives

In meeting the above goal, the AMY aims to

- Better understand the ocean-atmosphere-land-biosphere interactions, the multi-scale interactions among time scales ranging from diurnal, intraseasonal to interannual, and the aerosol-cloud-water cycle interactions in the Asian monsoon system;
- Improve the physical representations of these interactions in coupled climate models;
- Determine the predictability of the Asian monsoon on intraseasonal and seasonal time scales, and the roles of land initialization in continental seasonal rainfall prediction;
- Develop a high-resolution hydro-meteorological prediction system (with lead time up to a season) for the monsoon region;
- Develop data assimilation of the ocean-atmosphere-land system in the Asian monsoon region; and

- Better understand how human activities in the monsoon Asia region interact with environment.

It is recommended MAHASRI to develop a hydro-meteorological prediction system (with lead time up to a season) in Southeast Asia.

5. Strategy

To fulfill the aforementioned goal and objectives, AMY will take the following strategy.

5.1 Balanced and integrated approach

AMY will seek to take a balanced approach that integrates observations, modeling, and understanding. Observations provide data for validation of model physics, initial conditions for predictive models and ground truth for gauging satellite measurements. Modeling provides the basis for prediction, helped through assimilation of data into the prediction systems themselves to provide initial conditions; it also acts as a tool to help better understanding of the complex interaction processes which take place in the monsoon environment. Improved understanding feeds into the representation of physical processes in models, provides guidance for setting priority for future field studies and gives insights to help develop the observing and monitoring strategy for monsoon systems. AMY will integrate observation, analysis, data-integration and modeling. AMY emphasizes an open policy for data exchange and establishment of an integrated database.

5.2 Development of monsoon prediction systems

AMY will encourage and facilitate development of next generation cloud-system resolving models of the atmosphere and eddy-resolving ocean models. Collaborations among various modeling groups (large-scale modelers, meso-scale modelers, and cloud modelers) are critical for attacking the multi-scale interaction problem and improving the modeling capability for ISV and its influence on interannual variations. This collaboration is also important for extension of individual model successes to other models. In this context, AMY should pay attention to development of an effective strategy for validation of model representations of physical processes and for model improvements relevant to monsoon prediction. Use of data from field experiments will be crucial here.

5.3 Geographic foci and capacity building

It is recognized that selection of key target areas is important, for instance, the Maritime Continent, Tibetan Plateau, Bay of Bengal and South China Sea. The physical processes that AMY needs to pay attention to are cloud-aerosol interaction, ocean-land-atmosphere interactions, and the water and energy balance over the Tibetan Plateau.

MAHASRI will seek to take actions to facilitate and improve hydro-meteorological observations in Asian monsoon countries in conjunction with YOTC, GEOSS and CEOP-II. Related capacity building will focus on developing countries in the Southeast Asia, including setting up of hydrological observing systems and technical training activities.

5.4 Utilization of satellite observations

Since the 1990's, the availability and use of multi-decadal merged satellite-gauge precipitation datasets from the Global Precipitation Climatology Project (GPCP) and the CPC Merged Analysis Precipitation (CMAP) activity have greatly advanced our understanding of monsoon variability in providing better spatial and temporal descriptions of monsoon rain systems, and better validation of atmospheric general circulation models.

Recently, high-resolution Satellite data products (TRMM and NASA A-Train series of satellites, including Cloudsat-Calipso, MODIS, CERES, AIRS/Aqua, OMI/Aura) have provided unprecedented information for studies of the physical characteristics of clouds, aerosol properties, land surface vegetation and ocean bio-productivity, vertical structure of temperature and water vapor, and precipitation systems in monsoon regions. AMY should take advantage of these datasets in planning field experiments, data assimilation, and numerical modeling and prediction. In this regard, AMY will closely collaborate with the WCRP/WWRP YOTC project.

5.5 Organization

In order to address the overarching goal, a science steering committee has been formed. The AMY Science Steering Committee is a coordination body, with representatives from different panels or groups, to provide guidance for the program. An AMY project office is also established at Institute of Atmospheric Physics (IAP), Beijing, China.

AMY has established three complimentary science working groups focusing on, respectively, the field experiments and observation coordination, central data archiving and management, and coordination of monsoon modelling and prediction. The Chairs and members of the SSC and of the working groups are listed in Table 3.

The SSC and working groups intend to work together following completion of this science plan to develop the implementation plan of AMY. For the Implementation Plan, an overall timeline needs to be developed, including steps and mechanisms for collating, archiving and disseminating data, staging model experimentation, research activities and workshops, as well as promoting and fostering programmatic connections and contributions.

A headquarters for the intensive field observations listed in 6.1 is indispensable for our well coordinated observations. The South China Sea Institute of Oceanology (SCSIO), Guanzhou, China will take this role. Another important activity is data management. As described in 6.2, AMY will basically adopt a data sharing system among major data centers that manage the data obtained by the participating projects in each country. JAMSTEC/FRCGC, Japan will take responsibility for the coordination of these data centers.

5.6 Collaboration and linkages

The different components of AMY will closely collaborate. The ways by which this will be done needs to be articulated. In addition, the AMY will coordinate with various other international programs and activities. These include:

- WCRP-THORPEX-YOTC
- WCRP CLIVAR AAMP, IOP and POP
- WCRP GEWEX CEOP
- WWRP/THORPEX/ T-PARC
- WWRP/TMR (SCHeREX, SoWMEX, TiMREX, TCS08)
- IGBP /START/MAIRS
- APCC and other regional climate centers
- JAMEX (Joint Aerosol-Monsoon Experiment) with contributions from the following subcomponents:

- SHARE-Asia, Italy
- Atmospheric Brown Cloud (ABC), US
- Pacific Aerosol-Cloud-Dust Experiment (PACDEX), US, 2007
- East Asian Study of Tropospheric Aerosols, an International Regional Experiment (EAST-AIRE), US, 2008
- Deployment of the Atmospheric Radiation Measurement Mobile Facility (AMF) in China, US, 2008
- TIGERZ, Indo-Gangetic Plain, pre-monsoon experiment, 2008, India-US collaboration.
- 7 Southeast Asian Studies (7-SEAS) for aerosol-meteorology interaction in the maritime continent.

6. Planned activity

6.1 Observations

One of the purposes of the field campaigns is to provide observations that are useful for validating and improving numerical models. Field campaigns also provide valuable ground truth data for calibration of satellite measurements and parameterizations. Improvement of initial conditions for coupled climate models is possible only when satellite data are fully utilized. Another important aspect of the field observations is to find out the unknown physical processes/phenomena related to monsoon variability which has not been accounted for in the models but which is crucial for better representation of monsoons by the models. Combination of in-situ observations with satellite observations is essential for understanding the large-scale processes. Since AMY targets land-ocean-atmospheric interactions and aerosol-monsoon interactions under the Asian monsoon system, well coordinated ocean, land, aerosol and atmospheric observations should be conducted including intensive field observation campaigns. Since AMY also targets high impact weather, special meso-scale observations will be conducted in collaboration with THORPEX and WWRP of WMO.

One of the main targets of the AMY should be study of the dynamics and predictability of intraseasonal variability (ISV) of both 30-60 days and biweekly period through new observations and modeling. Land-atmosphere and ocean-atmosphere interactions should be re-examined through intensive observations focusing on their roles in the ISVs. The time-space structures of the ISVs seem to have been changing during the past several decades, which may, at least partly, be related to the anthropogenic forcings including the impact of aerosols etc.

AMY coordinated field experiments are classified into three categories: ocean observations, land observations and special process observations. Special process observations include meso-scale experiments for observing heavy rainfall and tropical cyclones, and aerosol-cloud-radiation experiment.

AMY will seek to coordinate field campaigns in various individual research projects. Indeed the coordination of these observations is essential for the success of AMY. The major targeting period of these observations can be classified into (1) pre-monsoon period in March-May; (2) monsoon onset phase in May-June; (3) monsoon mature phase in July-August; (4) winter monsoon in December. Some projects will target specific weather events. In such cases, the coordination of simultaneous observations in different regions by different projects will be a key role for the SCSIO. Details will be addressed in the implementation plan.

6.2. Data management and data assimilation

To achieve the goals of AMY, data obtained by its observational, modeling and data assimilation components should be shared among the the participants of AMY. They should also eventually be open to the wider (global) community. Because of the diversity of AMY and lack of central funding, a large part of data management of AMY needs to be conducted in a distributed manner. Issues of data policy, data management, and data assimilation remain to be addressed. This will be done as a component of the implementation plan.

Regional atmospheric reanalysis with high-resolution models, regional ocean data assimilation over the monsoon oceans and warm pool oceans, and land surface assimilation, especially over the Tibetan Plateau, are encouraged.

6.3. Modeling and prediction

The objectives of AMY require coordinated efforts on modelling and prediction experiments. The objectives include: (1) determining the predictability of the Asian monsoon on intraseasonal and seasonal time scales; (2) determining the roles of land initialization in prediction of warm season precipitation especially over the land; (3) development of a hydro-meteorological prediction system (with lead time up to a season) in Southeast Asia and (4) coordinated regional modeling, modeling of aerosol impacts and exploration of decadal monsoon variability and its prediction. The AMY modeling activity will seek to fulfill these objectives. CLIVAR/AAMP and the APCC are expected to play a leading role in organization and coordination of these modeling activities. In particular, AMY encourages the following activities.

a. Analysis of operational numerical weather prediction (NWP) products

AMY strongly encourages scientists working in monsoon countries to engage in analysis of the NWP products produced at major operational centers worldwide. These include analysis of the predictability of the monsoon onset, predictability of the monsoon disturbances (heat lows, monsoon depressions, cyclones), and case studies made by cloud-resolving global models (ex. NICAM).

b. Analysis of operational and research monthly and seasonal to interannual prediction

AMY should consider making an organized analysis of existing hindcast datasets through APCC/CliPAS project and the planned WCRP Task Force on Seasonal Prediction (TFSP) Climate-system Historical Forecast Project (CHFP), identifying a range of suitable metrics relating to the AAM for application to the outputs, to (1) assess seasonal to interannual prediction skills and identify common weakness of the current dynamic predictions of the Asian monsoon, (2) determine the predictability of Indian Ocean Dipole which is an objective of the CLIVAR/GOOS Indian Ocean Panel, and (3) study the role of the MJO in the onset of the (1997) El Niño.

c. Coordinated AGCM/CGCM experimental prediction of the monsoon ISO

The aim of this activity is to better understand the cause of monsoon ISVs, determine their intraseasonal predictability, and overcome major difficulties in modeling and predicting MISO. AMY should focus on improved representation of convection in models (seeking commitment of resources to model development), design diagnostic studies for the behavior of convection in models, and make appropriate observations to support improved model representaion of convection. The MJO WG has also attempted to predict the lifecycle of MJO at several operational centers worldwide. AMY should encourage an organized effort to pursue predictions of monsoon ISOs. The main focus of AMY should be placed on boreal summer and winter monsoon onset, active/break phases and retreat. Both AGCMs and coupled GCMs can be used. Both hindcast and real time prediction are encouraged.

d. Coordinated seasonal monsoon prediction experiments with CGCMs

For seasonal prediction, the importance of data assimilation and initialization for climate models cannot be overemphasized. The AMY implementation plan needs to consider how to: (1) enhance the atmospheric and oceanic observing system, especially in the Indian Ocean; (2) improve atmosphere-ocean initial conditions and develop coupled ocean-atmosphere-land data assimilation; (3) examine impact of land-ocean initialization on monthly to seasonal prediction. This is of particular importance. To determine the roles of land initialization in continental seasonal rainfall prediction, AMY should consider proposing a coordinated hindcast experiment within the Asian monsoon community on the impact of land surface initialization and land-atmosphere interaction on the prediction of Asian summer monsoon rainfall in the continental regions in collaboration with GEWEX and CLIVAR's WGSIP and the TFSP CHFP. (4) using CGCMs, to explore the predictability of coupled variability in Indian Ocean (including IOD, oceanic ENSO teleconnections, and monsoon/ENSO interaction). Its sensitivity to ocean and land initial conditions should be determined.

e. High resolution modeling and development of a hydro-meteorological prediction system

It is recommended that coordinated multi-high resolution model ensemble experiments be organized to investigate sub-seasonal to interannual factors that influence extreme events, such as tropical cyclones, severe droughts, devastating floods. The coordinated high resolution modeling proposed by Sieg Schubert at NASA has been endorsed by CLIVAR/AAMP and APCC, and forms a very useful starting point for developing a high resolution modeling activity. AMY is strongly urged to use this proposed study as a framework. It is also strongly recommend that the global cloud-resolving models developed or developing at FRCGC (NICAM) and other institutes will be used to carry out short-term simulations of up to a year to understand the predictability of the monsoon onset and hydro-meteorological systems.

f. Regional modeling

AMY has noted the utility of regional climate models in generating local information from seasonal prediction and climate change projection products of global coarse-resolution models for use in impact assessment. Such regional modeling activities may also focus on, for example, monsoon variability over Vietnam, Malaysia, Indonesian maritime continent, Southeastern India and Sri Lanka, which are areas of significant local impacts. MAHASRI aims at development of a hydro-meteorological prediction system over the Southeast Asia. Over SE-Asia including the Maritime Continent, diurnal cycles, land-sea breezes, 2-3 day westerly or easterly events and intraseasonal oscillations are vigorously interactive. The MJO intraseasonal variability over the tropics tends to break up within the maritime continent due to the land topography and complexities of land-sea interaction. Since high time/space resolution radar and wind profiler data are extremely useful to validate fine mesh models and will provide a good opportunity for coordinated observation and modeling studies, it is strongly recommended that these observational data are obtained continuously under MAHASRI/JEPP HARIMAU project and other related projects.

g. Aerosol impacts

Possible impacts of aerosols on the radiation budget and on regional climate should be studied using regional models within the ARCS-Asia framework. A smoke haze model for the Asian monsoon region should be developed. The development of such a model involves emission inventory and smoke haze trace modeling. The implementation of smoke haze modeling within a regional model means that it can be used for operational forest fire smoke warnings**.** In these modeling efforts, temporal and spatial variations of aerosols observed over Asia will be studied, and the direct and indirect effects of aerosols on Asian monsoon will be evaluated.

h. Coordinated decadal monsoon predictability experiments

In order to determine importance of internal climate dynamics versus increasing greenhouse gas forcing, coordinated decadal monsoon predictability experiments is encouraged. In addition, AMY calls for more analysis of the IPCC AR4 and future such CMIP model outputs.

7. Expectations

It is expected that AMY will transform the manner in which monsoon research and prediction have been done in the past century. The unprecedented amounts and quality of new data will help understand monsoon phenomena. Application of advances in cloud resolving models, computer power, and communication technology an be expected to provide breakthroughs in monsoon prediction.

AMY will provide high-accuracy data sets for India, the Tibetan Plateau, East China, Indo-China and the Maritime Continent and adjacent ocean regions, which may be used to force GCMs or RCMs for study of Asian Monsoon variability, seasonal prediction and forecasting of disastrous weather. Research scientists in monsoon regions will be provided ready access to monsoon literature, monsoon datasets and model outputs from predictability and prediction studies. Timely workshops and conferences will be organized to summarize the major areas of progress made during AMY.

The coordination of the various national projects will facilitate mutual data exchange and new scientific findings, which will lead to a deeper understanding of the Asian monsoon, in particular the linkage among regional components, i.e. between the monsoon variability over India, the Tibetan High, the East Asian Monsoon, and the West North Pacific Monsoon, as well connections with mid-latitudes.

Our researches will lead to improved understanding of atmosphere-ocean-land-biosphere interactions, multi time scale interactions, and aerosol-cloud-monsoon interactions, which are expected to reveal new sources of monsoon predictability, improve capability to model and predict short-term climate variations of the Asian monsoon, and enhance the overall performance of disaster prevention and mitigation activities.

The AMY will enhance the international collaboration between it’s own activities and other international programs or projects. This is expected to provide valuable experience which will facilitate expanding AMY to become a key component in the WCRP’s International Monsoon Study (IMS) 2008-2012, promoting coordination with AMMA, NAME, MESA and other planned and follow-on monsoon activities of WCRP in Africa and South America. It is expected that AMY will herald a new era of collaborative research among monsoon countries which may lead to a joint multi-antinational activity for prediction of the Asian monsoon system.

With participation of MAIRS, AMY will improve our understanding of how and why monsoon systems will change in a global warming environment, in particular, better understanding of the effect of human influences (i.e., aerosols, land-use change, and greenhouse-gas increase) on hydro-meteorological variations in Asian monsoon regions.

Appendix A Tables

Table 1 Acronyms

AAF	Aerosol Air-Quality Facility
A-AM	Asian-Australian monsoon
AAMP	Asian-Australian Monsoon Panel
ABC	Atmospheric Brown Cloud
AC	Annual Cycle
ADCP	Acoustic Doppler Current Profiler
AERONET	Aerosol Robotic Network
AGCMs	Atmospheric General Circulation Model
ABC	Atmospheric Brown Cloud
AIPO	Ocean-Atmosphere Interaction over the Joining Area of Asia and Indian-Pacific Ocean and Its Impact on the Short-Term Climate Variation in China
AMF	Deployment of the Atmospheric Radiation Measurement Mobile Facility
AMIP	Atmospheric Model Intercomparison Projects
AMMA	African Monsoon Multidisciplinary Analyses
AMMP	Asian-Australian Monsoon Panel
AMY	Asian Monsoon Years
AOGS	Asia Oceania Geosciences Society
APCC	APEC Climate Center
APEC	Asia-Pacific Economic Cooperation
ARCS	Aerosol and Regional Climate Studies
BMRC	Bureau of Meteorology Research Centre
CCN	Cloud Condensation Nuclei
CAIPEEX	Cloud Aerosol Interaction and Precipitation Enhancement Experiment
CAS	Chinese Academy of Sciences
CEReS	Center for Environmental Remote Sensing
CISO	Climatological Intraseasonal Oscillation
CliPAS	Climate Prediction and Its Application to Society
CLIVAR	Climate Variability and Predictability
CEOP	Coordinated Energy and water cycle Observation Project
CGCM	Coupled With Ocean-Atmosphere General Circulation Model
COMMIT	Chemical, Optical, and Microphysical Measurements of In-situ Troposphere
CREST	Core Research for Evolutional Science and Technology
CTCZ	Continental Tropical Convergence Zone as a component of coupled Land-Ocean-Biosphere-Atmosphere System
CTZ	Coastal Transition Zone
DEMETER	

DPRI	Disaster Prevention Research Institute
EAST-AIRE	East Asia Study of Tropospheric Aerosol: an International Regional Experiment
EAMEX	East Asian Monsoon Experiment
EHP	Elevated Heat Pump
EIO	Equatorial Indian Ocean
ENSO	El Niño-Southern oscillation
EOF	Empirical Orthogonal Function
ESSP	Earth System Science Partnership
FRCGC	Frontier Research Center for Global Change
GAME	GEWEX Asian Monson Experiment
GaME-T	GEOSS and MAHASRI Experiment in the Tropics
GCM	General Circulation Model
GEOSS	Global Earth Observation System of Systems
GEWEX	Global Energy and Water Cycle Experiments
GPS	Global Positioning System
HARIMAU	Hydrometeorological Array for Iintraseasonal-Monsoon Automonitoring
HyARC	Hydroshperic Atmospheric Research Center
LASG	State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics
IAP	Institute of Atmospheric Physics
IGBP	International Geosphere-Biosphere Programme
IGP	Indo-Gangetic Plain
IMS	International Monsoon Study
IOD	Indian-Ocean dipole
IOP	Indian Ocean Panel
IORGC	Institute of Observational Research for Global Change
IOZM	Indian Ocean Zonal Mode
IPCC	Intergovernmental Panel on Climate Change
ISO	Intraseasonal Oscillation
ISV	Intraseasonal Variability
ITCZ	Intertropical Convergence Zone
ITF	Indonesian Throughflow
ITP	Institute of Tibetan Plateau research
IUGG	International Union of Geodesy and Geophysics
JAMEX	Joint Aerosol-Monsoon Experiment
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
JEPP	Japan EOS Promotion Program
JICA	Japan International Cooperation Agency
JSC	Joint Scientific Committee
LDAS-UT	Validation of the land data assimilation system at The University of Tokyo

MAHASRI	Monsoon Asian Hydro-Atmosphere Scientific Research and Prediction Initiative
MAIRS	Monsoon Asia Integrated Regional Study
MIPs	Model Intercomparison Programs
MISO	Monsoon Intraseasonal Oscillation
MJO	Madden-Julian Oscillation
MME	Multi-Model Ensemble
MODIS	Moderate Resolution Imaging Spectroradiometer
NAME	North American Monsoon Experiment
NCEP	National Centers for Environmental Prediction
NEC	North Equatorial Current
NICAM	Numerical experiments with global cloud-system resolving model
NPOIMS	Variability of the Subtropical North Pacific Ocean Circulation and its Impacts on the Dynamic Environment of the Marginal Seas
PACDEX	Pacific Aerosol-Cloud-Dust Experiment
PHONE	Pukyong National University and HyARC, Nagoya University Observation Network (for GRL) over East China Sea
POAMA	Predictive Ocean Atmosphere Model for Australia
POP	Pacific Ocean Panel
PRAISE	Pacific Regional Aquaculture Information Service for Education
RAISE	Rangelands Atmosphere-Hydrosphere-Biosphere Interaction Study Experiment in Northeastern Asia
Rajo-Megha	Radiation Aerosol Joint Observations – Monsoon Experiments over the Gangetic Himalayas Area
RCM	Regional Climate Model
SACOL	Semi-Arid Climate and Environment Observatory of Lanzhou University
SAM	Southern Hemisphere annular mode
SCS	South China Sea
SDM	Solar Dimming
SEA	Southeast Asia
SoWMEX	Southwest Monsoon Experiment
SCHeREX	Southern China Heavy Rainfall Experiment
SCSIO	South China Sea Institute of Oceanology
SCSTF	South China Sea Throughflow
SPICE	Southwest Pacific Ocean Circulation and Climate Experiment
START	SysTem for Analysis Research and Training
SMART	Surface-sensing Measurements for Atmospheric Radiative Transfer
STORM	Severe Thunderstorms – Observations & Regional Modeling
TBO	Tropospheric biennial Oscillation
TC	Tropical Cyclone
TiMREX	Terrain-influenced Monsoon Rainfall Experiment

TCS08	Tropical Cyclone Structure 2008
TCZ	Tropical Convergence Zone
THORPEX	The Observing-System Research and Predictability Experiment
TiMREX	Terrain-influenced Monsoon Rainfall Experiment
TIPEX	Tibetan Plateau Experiment
TORP	Tibetan Observation and Research Platform
T-PARC	THORPEX Pacific Asian Regional Campaign
TRMM	Tropical Rainfall Measuring Mission
UTWV	Upper tropospheric water vapor
WCRP	World Climate Research Programme
WEBS	Water and Energy Budget Study
WMO	World Meteorological Organization
WNP	Western North Pacific
WPSH	Western Pacific subtropical high
WWRP	World Weather Research Programme
YOTC	Year of Tropical Convection

Table 2 List of participants

- Australia: BMRC
- China: IAP/CAS, ITP/CAS, CAMS/CMA, NCC/CMA, SCSIO/CAS, Nanjing Univ. of Information Science and Technology
- Chinese Taipei: NTU, CWB, NCU
- India: IITM, CAOS/IISc, ESSD/DST, IMD, NCMRWF, IIT
- Indonesia: BPPT, BMG
- Japan: IORGC/JAMSTEC, FRCGC/JAMSTEC, JMA, MRI, Univ. Tokyo, Tokyo Metrop. Univ., Tsukuba Univ., Nagoya Univ., Chiba Univ., Kyoto Univ.
- Korea: APCC, Seoul National Univ., Pukyong National Univ.
- Malaysia: MMD, National University of Malaysia
- Mongolia: IMH
- Nepal: DHM
- Philippine: PAGASA
- Thailand: TMD, Kasetsart University, Chulalongkorn University, RID, RFD, BRRAA
- USA: Univ. Hawai, GSFC/NASA, Naval Postgraduate School, COLA, NCAR, George Mason Univ./IGES, Univ. Maryland
- Vietnam: NHMS, Hanoi Univ.

Hydrometeorological agencies in other counties in Asia will also participate.

Table 3 AMY Organization

<u>Scientific Steering Committee</u>

Co-Chairs: Bin Wang and Jun Matsumoto

Members: C.-P. Chang, Y. Ding, C. Fu, S. Gadgil, T. Koike, W. Lau, J. Shukla, D. R. Sikka, T. Yao, T. Yasunari, G. Wu, R. Zhang

AMY Program Office at Beijing: Director Jianping Li

Observation Coordination Working Group:

Co-Chairs: Dongxiao Wang and Manabu D. Yamanaka

Data Archiving and Management Working Group:

Co-Chairs: Kooiti Masuda, Guangqing Zhou

Modeling and Prediction Working Group:

Co-Chairs: Harry Hendon, Takehiko Satomura, Akio Kitoh

Table 4 Funding and sponsors

AMF: Funded by the US Department of Energy and the Chinese Academy of Sciences.

CREST: Funded by the Japan Science and Technology Agency, Japan

CTCZ: Individual project mode support to participating Indian scientists is being provided by the Department of Science and Technology and Ministry of Earth Sciences, Government of India as part of the ICRP. It is expected that financial support for the planned observational programme and the modeling studies of the CTCZ programme will also be provided by these and other ministries in Gov. of India involved in climate research.

IITM/Rain: The proposed experiment by IITM is towards understanding interaction between tropical clouds and large scale environment and will involve several campaigns between 2009-2012 involving a mobile cloud radar and a X-band radar. Fully funded by Ministry of Earth Sciences, Government of India.

CAIPEEX: A national experiment involving a large number Institutions led by IITM. Extensive observations with instrumented aircraft and ground based measurements (radars) are planned during 2009-2012. Funded by Ministry of Earth Sciences, Government of India.

EAST-AIRE: Funded by NASA and China's Ministry of Science and Technology

JEPP: Funded by the Ministry of Education, Culture, Sports, Science and Technology, Japan related with GEOSS.

MAIRS: China National Key project: aridity in northern China and human adaptation (2006-2010), 30 million Yuan for 5 years. CAS Key project: The characteristics of changes of climate and hydrological cycle and its interaction over northwest China (2006-2008), 2 million for 3 years.

SACOL: Sponsored by Lanzhou University through 985 Program; the National Basic Research Program of China under grant of 2006CB400501, the National Science Foundation of China under grants of 4063301.

SCHeREX: China National Key project: Theories and Methods for Monitoring and Predicting Heavy Rainfall in South China (2004-2009), 30 million Yuan for 5 years. State Key Laboratory of Severe Weather (LaSW), CAMS.

SoWMEX: Funded by NSC and CWB of Chinese Taipei
STORM: Special funding for additional observational systems, other than routine operational observational systems of India Meteorological Department and other government agencies, implementation of multi-year field phases and follow-on research studies are being provided by the Department of Science and Technology, Government of India.
TiMREX: Funded by NSF with field phase facility support from NCAR, USA.
TCS08: Funded by ONR, USA.
TORP: Sponsored by the Chinese Academy of Sciences, and the Ministries of Science and Technology and of Education, and the State Forest Administration of the People's Republic of China, and China Meteorological Administration, and the Tibetan Autonomous Region of China.

References

Aldrian, E., D. Sein, D. Jacob, L. Denil-Gates, and R. Podzun, 2005: Modelling Indonesian rainfall with a coupled regional model. *Climate Dyn.*, 25, 1–17.

Albrecht, B., 1989: Aerosols, cloud microphysics and fractional cloudiness. *Science,* 245, 1227–1230.

An, S.-I., and B. Wang, 2000: Interdecadal change of the structure of ENSO mode and its impact on the ENSO frequency. *J. Climate*, 13, 2044–2055.

Annamalai, H. and J. Slingo, 2001: Active/break cycles: Diagnosis of the intraseasonal variability of the Asian Summer Monsoon. *Climate Dyn.*, 18, 85–102.

——, and K. R. Sperber, 2005: Regional heat sources and the active and break phases of boreal summer intraseasonal (30-50 day) variability. *J. Atmos. Sci.*, 62, 2726–2748.

——, K. Hamilton, and K. R. Sperber, 2007: South Asian summer monsoon and its relationship with ENSO in the IPCC-AR4 simulations. *J. Climate,* 20**,** 1071–1092.

Arakawa, O. and A. Kitoh, 2005: Rainfall diurnal variation over the Indonesian Maritime Continent simulated by 20km-mesh GCM. *SOLA*, 1, 109–112, doi:10.2151/ sola.2005–029.

Ashok, K., Z. Guan, and T. Yamagata, 2001: Impact of the Indian Ocean Dipole on the relationship between Indian Ocean monsoon rainfall and ENSO. *Geophys. Res. Lett.,* 28, 4499–4502.

Bamzai, A., and J. Shukla, 1999: Relation between Eurasian snow cover, snow depth and the Indian summer monsoon: An observational study. *J. Climate*, 12, 3117–3132.

Chambers, C., and T. Li, 2007: Simulation of formation of a near-equatorial Typhoon Vamei (2001). *Meteor. Atmos. Phys*., DOI:10.1007/s00703-006-0229-0.

Chang, C.-P, and T. Chen, 1995: Tropical circulations associated with southwest monsoon onset and westerly surges over the South China Sea. *Mon. Wea. Rev.*, 123, 3254–3267.

——, S. C. Hou, H. C. Kuo, and G.T. Chen, 1998: The development of an intense East Asian summer monsoon disturbance with strong vertical coupling. *Mon. Wea. Rev*., 126, 2692–2712.

——, Y. Zhang and T. Li, 2000a: Interannual and interdecadal variation of the East Asian summer monsoon rainfall and tropical SSTs. Part 2: meridional structure of the monsoon. *J. Climate*, 13, 4326–4340.

——, L. Yi, and George T. J. Chen, 2000b: A numerical simulation of vortex development during the 1992 East Asian summer monsoon onset using the Navy's regional model. *Mon. Wea. Rev.*, 128, 1604–1631.

——, P. Harr, and J. Ju, 2001: Possible roles of Atlantic circulations on the weakening Indian monsoon-ENSO relationship. *J. Climate*, 14, 2376–2380.

——, C. H. Liu, and H. C. Kuo, 2003: Typhoon Vamei: An equatorial tropical cyclone formation. *Geophys. Res. Lett.*, 30, 50, 1–4.

——, Z. Wang, J. McBride and C. H. Liu, 2005a: Annual cycle of Southeast Asia – Maritime Continent rainfall and the asymmetric monsoon transition. *J. Climate,* 18, 287–301.

——, P. A. Harr, and H. J. Chen, 2005b: Synoptic disturbances over the equatorial South China Sea and western Maritime Continent during boreal winter. *Mon. Wea. Rev.*, 133, 489–503

——, Z. Wang, J. McBride and C. H. Liu, 2005: Annual cycle of Southeast Asia – Maritime Continent rainfall and the asymmetric monsoon transition. *J. Climate,* 18, 287–301.

——, ——, and H. Hendon, 2006: The Asian Winter Monsoon. *The Asian Monsoon*, B. Wang, Ed., Praxis, Berlin, 89–127.

Charney, J., and J. Shukla, 1981: Predictability of monsoons. In: J. Lighthill and R. P. Pearce (eds), *Monsoon Dynamics.* Cambridge University Press, Cambridge, UK, 99–108.

Chatterjee Piyali and B. N. Goswami , 2004: Structure, genesis and scale selection of the tropical quasi-biweekly mode, *Q. J. R. Meteorol. Soc*. 130, 1171-1194

Chen, G. T. J., 2004: Research on the phenomena of Meiyu during the Past Quarter Century: An over view. In: C.-P. Chang (ed.), The East Asian Monsoon, World Scientific Publishing, 357–403.

——, and C.-P. Chang, 1980: Structure and vorticity budget of early summer monsoon trough (Mei-Yu) over Southeastern China and Japan. *Mon. Wea. Rev.*, 108, 942–953.

——, Z. Jiang, and M. C. Wu, 2003: Spring heavy rain events in Taiwan during warm episodes and the associated large-scale conditions. *Mon. Wea. Rev*., 131, 1173–1188.

Chen, L., F. Schidmt, and W. Li, 2003: Characteristics of the atmospheric heat source and moisture sink over the Qinghai-Tibetan Plateau during the second TIPEX of summer 1998 and their impact on surrounding monsoon. *Meteor. Atmos. Phy*., 83, 1–18.

Chen, T., and J. Chen, 1993: The 10-20-day mode of the 1979 Indian monsoon: its relation with the time variation of monsoon rainfall. *Mon. Wea. Rev.*, 121, 2465–2482.

——, and M. Murakami, 1988: The 30-50 day variation of convective activity over the western Pacific Ocean with the emphasis on the northwestern region. *Mon. Wea. Rev.*, 116, 892–906.

——, and J. Yoon, 2000: Interannual variation in Indochina summer monsoon rainfall: possible mechanism. *J. Climate,* 13, 1979–1986.

Chung, C., and V. Ramanathan, 2006: Weakening of North Indian SST gradients and the monsoon rainfall in India and the Sahel. *J. Climate,* 19, 2036–2045.

——, ——, D. Kim, and I. Podgorny, 2005: Global anthropogenic aerosol direct forcing derived from satellite and ground-based observations. *J. Geophys. Res.*, 110, D24207, doi: 10.1029/2005JD006356.

Ding, Q., and B. Wang, 2007: Intraseasonal teleconnection between the Eurasian wavetrain and Indian summer monsoon. *J. Climate*, 20, 3751–3767.

Ding, Y., 1994: *Monsoons Over China*, Springer, New York, 419.

——, and Y. Liu, 2001: Onset and evolution of the summer monsoon season over the South China Sea during SCSMEX field experiment in 1998. *J. Meteor. Soc. Japan,* 79, 255–276.

——, 2004: Seasonal march of the East-Asian summer monsoon. In: C.-P. Chang (ed.), *The East Asian Monsoon*, World Scientific Publishing, 3–53.

——, 2007: The variability of the Asian summer monsoon. *J. Meteor. Soc. Japan,* 85B, 21–54.

——, and C.L. Chan, 2005: The East Asian summer monsoon: an overview. *Meteor. Atmos. Phys.*, 89, 117–142

——, and D. R. Sikka, 2006: Synoptic systems and weather. In: The Asian Monsoon. B. Wang, ed., Praxis, Chichester, UK, 131–202

Dirmeyer, P., A. Dolman, and N. Sato, 1999: The pilot phase of the global soil wetness project. *Bull. Amer. Meteor. Soc.,* 80, 851–878.

Duan, A., and G. Wu, 2005: Role of the Tibetan Plateau thermal forcing in the summer climate patterns over subtropical Asia. *Climate Dyn.*, 24, 793–807.

Drbohlav, H., and B. Wang, 2004: Mechanism of the northward propagating intraseasonal oscillation in the south Asian monsoon region: Results from a zonally averaged model. *J. Climate*, 18,952–972.

Fu, X., B. Wang, T. Li, and J. P. McCreary, 2003: Coupling between northward propa- gating, intraseasonal oscillations and sea-surface temperature in the Indian Ocean. *J. Atmos. Sci.,* 60, 1733–1753.

——, ——, D. Waliser, and L. Tao, 2006: Impact of atmosphere-ocean coupling on the predictability of monsoon intraseasonal oscillations. *J. Atmos. Sci.,* 64, 157–174.

Fujii, H., T. Koike 2001: Development of a TRMM/TMI algorithm for precipitation in the Tibetan Plateau by considering effects of land surface emissivity. *J. Meteor. Soc. Japan*, 79, 1B, 475–483.

Gadgil, S., P. Vinayachandran, P. Francis, and S. Gadgil, 2004: Extremes of the Indian summer monsoon rainfall, ENSO and equatorial Indian Ocean oscillation. *Geophys. Res. Lett.*, 31, L12213, doi: 10.1029/2004GL019733.

Goodman, P. J., W. Hazeleger, P. de Vries, and M. Cane, 2005: Pathways into the equatorial undercurrent: A trajectory analysis. *J. Phys. Oceanogr.*, 35, 2134̃2151.

Gordon, A. L., 2005: Oceanography of the Indonesian Seas and their throughflow. *Oceanography*, 18, 14̃27.

Goswami B.N., Venugopal V., Sengupta D., Madhusoodanan M.S., Xavier Prince K., 2006: Increasing trend of Extreme Rain Events over India in a Warming Environment, *Science*, 314, 5804, 1442-1445.

------------, Wu G., Yasunari T. *2006:* Annual cycle, Intraseasonal oscillations and Roadblock to seasonal predictability of the Asian summer monsoon, *J. Climate, 19,* 5078-5099

-----------., M. S. Madhusoodanan, C. P. Neema, and D. Sengupta, 2006: A physical mechanism for North Atlantic SST influence on the Indian summer monsoon, *Geophys. Res. Lett.*, 33, L02706, doi:10.1029/ 2005GL024803

---------- and Xavier Prince K., 2005: ENSO control on the South Asian Monsoon through the length of the rainy season *Geophys. Res. Lett. 32, L18717, doi:10.1029/2005GL023216.*

-------------, 2005: South Asian Monsoon: in *Intraseasonal Variability of the Atmosphere-Ocean Climate System,* Eds. William K. M. Lau and Duane E.Waliser Chapter 2, Praxis, Springer Berlin Heidelberg, 19-61 pp.

------------- 2005: The Asian monsoon: Interdecadal Variability, in *The Asian Monsoon,* Eds, Bin Wang, Chapter 7, Praxis, Springer Berlin Heidelberg, 295-327 pp

--------------, Annamalai H and Krishnamurthy V 1999: A broad scale circulation index for interannual variability of the Indian summer monsoon, ***Q. J. Roy. Met. Soc.,*** 125, 611-633.

--------------, 1998: Interannual variation of Indian summer monsoon in a GCM: External conditions versus internal feedbacks, *J. Climate,* 11, 501-522

------------, and J. Shukla, 1984: Quasi-periodic oscillations in a symmetric general circulation model. *J. Atmos. Sci.*, 41, 20–37.

Gu, D., and S. Philander, 1996: Interdecadal climate fluctuations that depend on exchanges between the tropics and extratropics. *Science*, 275, 805–807.

Guan, Z., and T. Yamagata, 2003: The unusual summer of 1994 in East Asia: IOD teleconnections. *Geophys. Res. Lett.*, 30(10), 1544, doi: 10.1029/2002GL016831.

Hamada, J.-I., M. Yamanaka, J. Matsumoto, S. Fukao, P. Winarso, and T. Sribimawati, 2002: Spatial and temporal variations of the rainy season over Indonesia and their link to ENSO. *J. Meteor. Soc. Japan*, 80, 285–310.

Hendon, H., M. Wheeler, and C. Zhang, 2007: Seasonal dependence of the MJO-ENSO relationship. *J. Climate*, 20, 531–543.

Hsu, H.–H., and C.-H. Weng, 2001: Northwestward propagation of the intraseasonal oscillation during the boreal summer: mechanism and structure. *J. Climate*, 14, 3834–3850.

——, ——, and C.-H. Wu, 2004: Contrasting characteristics between the northward and eastward propagation of the intraseasonal oscillation during the boreal summer. *J. Climate*, 17, 727–743.

——, and M.-Y. Lee, 2005: Topographic effects on the eastward propagation and initiation of the Madden-Julian Oscillation. *J. Climate*, 18, 795–809.

Huang, R., and Y. Wu, 1989: The influence of ENSO on the summer climate change in China and its mechanism. *Adv. Atmos. Sci.*, 6, 21–32.

Hulme, M., T. Osborn, and T. Johns, 1998: Precipitation sensitivity to global warming: Comparison of observations with HADCM2 simulations. *Geophys. Res. Lett*., 25, 3379–3382.

Hung, C.-W., X. Liu, and M. Yanai, 2004: Symmetry and asymmetry of the Asian and Australian summer monsoon. *J. Climate,* 17, 2413–2426.

Ishizaki, N. and H. Ueda, 2006: Seasonal heating processes over the Indochina Peninsula and the Bay of Bengal prior to the monsoon onset in 1998. *J. Meteor. Soc. Japan*. 84, 357–387.

Iwasaki, H., and T. Nii, 2006: The break in the Mongolian rainy season and its relation to the stationary Rossby wave along the Asian jet. *J. Climate*, 19, 3394–3405.

Jiang, X. and T. Li, 2005: Reinitiation of the boreal summer intraseasonal oscillation in the tropical Indian Ocean. *J. Climate*, 18, 3777–3795.

——, ——, and B. Wang, 2004: Structures and mechanisms of the northward propagating boreal summer intraseasonal oscillation. *J. Climate,* 17, 1022–1039.

Johnson, R. H., P. E. Ciesielski, and T. Keenan, 2004: Oceanic East Asian monsoon convection: Results from the 1998 SCSMEX. In: C.-P. Chang (ed.), The East Asian Monsoon, World Scientific Publishing, 436–459.

——, 2006: Mesoscale processes. In: B. Wang (ed.), The Asian Monsoon, Praxis Publishing, 331–356.

Jou, B. J.-D., and S.-M. Deng, 1998: The organization of convection in a Mei-Yu frontal rainband. *TAO*, 9, 553–572.

Kang, I.-S., K. Jin, KM Lau, J. Shukla, V. Krishnamurthy, SD Schubert, D. Wailser, WF Stern, V. Satyan, A. Kitoh, GA Meeh, M. Kanamitsu, V. Galin, JK Kim, A. Sumi, G. Wu, and Y. Liu, 2002a: Intercomparion of atomospheric GCM simulated anomalies associated with the 1997-98 El Niño. *Journal of Climate*, 15, 2791–2805.

——, K. Jin, B. Wang, K.-M. Lau, J. Shukla, and coauthors, 2002: Intercomparison of the climatological variations of Asian summer

monsoon precipitation simulated by 10 GCMs. *Climate Dyn*., 19, 383–395.
——, J.-Y. Lee, and C.-K. Park, 2004: Potential predictability of summer mean precipitation in a dynamical seasonal prediction system with systematic error correction. *J. Climate*, 17, 834–844,
——, and J.-H. Yoo, 2006: Examination of multi-model ensemble seasonal prediction methods using a simple climate system. *Climate Dyn.*, 26, 285–294.
——, and J. Shukla, 2006: Dynamic seasonal prediction and predictability (Chapter 15). *The Asian Monsoon, Edited by Bin Wang,* Springer Praxis, Chicherster, 585–612.
Kawamura, R., K. Uemura and R. Suppiah, 2005: On the recent change of the Indian summer monsoon-ENSO relationship. *SOLA*, 1, 201–204, doi:10.2151/sola.2005–052.
Kawatani, Y., and M. Takahashi, 2003: Simulation of the Baiu front in a high resolution AGCM. *J. Meteor. Soc. Japan,* 81, 113–126.
Kemball-Cook, S., and B. Wang, 2001: Equatorial waves and air-sea interaction in the boreal summer intraseasonal oscillation. *J. Climate*, 14, 2923–2942.
Kessler, W.S., L. Gourdeau, 2007: The annual cycle of circulation of the southwest Subtropical Pacific, analyzed in an Ocean GCM. *J. Phys. Oceanogr.*, 37, 1610−1627.
Kiguchi, M., and J. Matsumoto, 2005: The rainfall phenomena during the pre-monsoon period over the Indochina peninsula in the GAME-IOP year. *J. Meteor. Soc. Japan,* 83, 89–106.
Kikuchi, K., and B. Wang, 2007: Diurnal precipitation regimes in the tropics. *J. Climate*, submitted.
Kim, H.-M, I.-S. Kang, B. Wang, and J.-Y. Lee, 2007: Interannual variations of the Boreal summer intraseasonal variability predicted by ten atmosphere-ocean coupled models. *Climate Dyn.*, in press.
Kim, K. M., and K. M. Lau, 2001: Dynamics of monsoon-induced biennial variability in ENSO. *Geophys. Res. Lett*., 28, 315–318.
Kinter Ⅲ, J. L., K. Miyakoda and S. Yang, 2002: Recent changes in the connection from the Asian monsoon to ENSO. *J. Climate*, 15, 1203–1215.
Kitoh, A., and T. Uchiyama, 2006: Changes in onset and withdrawal of the East Asian summer rainy season by multi-model global warming experiments. *J. Meteor. Soc. Japan,* 84, 247–258.
Kodama, Y.-M., M. Katsumata, S. Mori, S. Satoh, and H. Ueda, 2005: Seasonal transition of predominant precipitation type and lightning activity over tropical monsoon areas derived from TRMM observations. *Geophys. Res. Lett*., 32, L14710, doi:10.1029/2005GL022986.

Kripalani, R., and A. Kulkarni, 1997: Climatic impacts of El Niño/La Niña on the Indian monsoon. *Weather*, 152, 39–46.

Krishnamrthy, V., and J. Shukla, 2000: Intra-seasonal and inter-annual variations of rainfall over India. *J. Climate*, 13, 4366–4375.

Krishnamurthy V and Goswami B. N. 2000: Indian monsoon-ENSO relationship on inter decadal time scales, *J. Climate*, 13, 579-595.

Krishnamurthy V., and J. Shukla, 2008: Seasonal persistence and propagation of intraseasonal patterns over the Indian monsoon region. *Climate Dyn.* 30, 353–369.

Krishnamurti, T., and H. Bhalme, 1976: Oscillations of a monsoon system. Part I. Observational aspects. *J. Atmos. Sci.,* 33*,* 1937–1954.

Kumar, K., B. Rajagopalan, and M. Cane, 1999: On the weakening relationship between the Indian monsoon and ENSO. *Science*, 284, 2156–2159.

Lau, K. –M, V. Ramanathan, G-X. Wu, Z. Li, S. C. Tsay, C. Hsu, R. Siika, B. Holben, D. Lu, G. Tartari, M. Chin, P .Koudelova, H. Chen, Y. Ma, J. Huang, K. Taniguchi, and R. Zhang., 2008: the Joint Aerosol-Monsoon Experiment: A new challenge in monsoon climate research. *Bull. Am. Meteor. Soc.*, in press.

——, and P. Chan, 1986: Aspects of the 40-50 day oscillation during northern summer as inferred from OLR. *Mon. Wea. Rev*., 114, 1354–1367.

——, and K. Kim, 2006: Observational relationships between aerosol and Asian monsoon rainfall, and circulation. *Geophys. Res. Lett.,* 33, L21810, doi:10.1029/2006GL027546.

——, and ——, 2007: A GCM study of the effects of radiative forcing by Saharan dust on the climate and atmospheric water cycle of West Africa and the Atlantic. *J. Climate,* Submitted.

——, M. Kim, and K. Kim, 2006: Aerosol induced anomalies in the Asian summer monsoon- the role of the Tibetan Plateau. *Climate Dyn.*, 26 (7–8), 855–864, doi:10.1007/s00382–006–0114–z.

——, and S. Shen, 1988: On the dynamics of intraseasonal oscillations and ENSO. *J. Atmos. Sci.,* 45*,* 1781–1797.

Lau, N.-C., and M. J. Nath, 2000: Impact of ENSO on the variability of the Asian-Australian monsoons as simulated in GCM experiments. *J. Climate*, 13, 4287–4309.

——, and B. Wang, 2005: Interactions between the Asian monsoon and the El Niño/Southern Oscillation. In B. Wang (ed.) *The Asian monsoon.* Springer/Praxis Publishing Ltd., New York, 479–511.

Lawrence D. M., and P. J. Webster, 2001: Interannual variations of the intraseasonal oscillation in the south Asian summer monsoon region. *J. Climate*, 14, 2910–2922.

Lawrence, D., and P. Webster, 2002: The boreal summer intraseasonal oscillation: Relationship between northward and eastward movement of convection. *J. Atmos. Sci., 59,* 1593–1606.

Lee, C.-S., Lan Lin, Y.-L., and K. W. Cheung, 2006: Tropical Cyclone Formations in the South China Sea Associated with the Mei-Yu Front. *Mon. Wea. Rev*., 134, 2670–2687

Lee, J.-Y., B. Wang, I.-S. Kang, J.-S. Kug, J. Shukla, E.-K. Jin, and coauthors, 2007: Performance of climate prediction models on annual modes of precipitation and its relation with seasonal prediction. *Climate Dyn.*, Submitted.

Li, J., and Q. Zeng, 2002: A unified monsoon index. *Geophys. Res. Lett.,* 29(8), 1274, doi:10.1029/2001GL013874.

——, and ——, 2003: A new monsoon index and the geographical distribution of the global monsoons. *Adv. Atmos. Sci.*, 20, 299–302.

——, and ——, 2005: A new monsoon index, its interannual variability and relation with monsoon precipitation. *Climate Environ. Res.*, 10, 351–365.

Li, T., P. Liu, X. Fu, and B. Wang, 2006: Spatiotemporal Structures and Mechanisms of the Tropospheric Biennial Oscillation in the Indo-Pacific Warm Ocean Regions. *J. Climate*, 19, 3070–3087.

Li, Z., and Coauthors, 2007a: Preface to special section: Overview of the East Asain Study of Tropospheric Aerosols: an International Regional Experiment (EAST-AIRE). *J. Geophy. Res. Special section on EAST-AIRE,* in press.

——, and Coauthors, 2007b: Aerosol optical properties and their radiative effects in northern China. *J. Geophys. Res.,* 112, D22S01, doi: 10.1029/2006JD007382.

——, and T. Yuan, 2006: Exploring aerosol-cloud-climate interaction mechanisms using the new generation of earth observation system data, *Current problems in atmospheric radiation,* (Eds. H. Fischer and B.-J. Song). Deepak Pub, 1–4.

Liang, X., Y. Liu, and G. Wu, 2005: The role of land-sea distribution in the formation of the Asian summer monsoon. *Geophys. Res. Lett.*, 32, L03708, doi: 10.1029/2004GL021587.

Lin, J., B. Mapes, M. Zhang, and M. Newman, 2004: Stratiform precipitation, vertical heating profiles, and the madden-Julian Oscillation. *J. Atmos. Sci.,* 61, 296–309.

LinHo, and B. Wang, 2002: The time-space structure of the Asian-Pacific summer monsoon: A fast annual cycle view. *J. Climate*, 15, 2001–2019.

Liu, Y., B. Hoskins, and M. Blackburn, 2007: Impact of Tibetan Orography and heating on the summer flow over Asia. *J. Meteor. Soc. Japan,* 85B, 1–19.

——, G. Wu, and R. Ren, 2004: Relationship between the subtropical anticyclone and diabatic heating. *J. Climate*, 16, 1617−1642.

Loschnigg, J., G. Meehl, J. Webster, J. Arblaster, and G. Compo, 2003: The Asian monsoon , the tropospheric biennial oscillation, and the Indian Ocean zonal mode in the NCAR GCM. *J. Climate*, 15, 2001−2019.

Luo, H., and M. Yanai, 1984: The large-scale circulation and heat sources over the Tibetan Plateau and surrounding areas during the early summer of 1979. Part II: Heat and moisture budgets. *Mon. Wea. Rev*., 112, 966–989.

Ma, Y., and Coauthors, 2002: Analysis of aerodynamic and thermodynamic parameters over the grassy marshland surface of Tibetan Plateau. *Prog. Nat. Sci*., 12, 36–40.

——, and Coauthors, 2003: Regionalization of surface fluxes over heterogeneous landscape of the Tibetan Plateau by using satellite remote sensing. *J. Meteor. Soc. Japan*, 81, 277−293.

——, and Coauthors, 2005: Diurnal and inter-monthly variation of land surface heat fluxes over the central Tibetan Plateau area. *Theor.l and Appl. Climatol.*, 80, 259–273.

——, and Coauthors, 2006: Determination of regional distributions and seasonal variations of land surface heat fluxes from Landsat-7 Enhanced Thematic Mapper data over the central Tibetan Plateau area. *J. Geophys. Res*., 111, 10305–10305.

——, and Coauthors, 2007: Estimation of the regional evaporative fraction over the Tibetan Plateau area by using Landsat-7 ETM data and the field observations. *J. Meteor. Soc. Japan*, 85A, 295–309.

Maloney, E., and D. Hartmann, 1998: Frictional moisture convergence in a composite life cycle of the Madden-Julian Oscillation. *J. Climate,* 11, 2387–2403.

Matsumoto, J., 1992: The seasonal changes in Asian and Australian monsoon regions. *J. Meteor. Soc. Japan*, 70, 257–273.

——, 1997: Seasonal transition of summer rainy season over Indochina and adjacent monsoon region. *Adv. Atmos. Sci,* 14, 231–245.

——, and T. Murakami, 2002: Seasonal migration of monsoons between the northern and southern hemisphere as revealed from equatorially symmetric and asymmetric OLR data. *J. Meteor. Soc. Japan*, 80, 419–437.

McBride, J., M. Haylock, and N. Nicholls, 2003: Relationships between the Maritime Continent heat source and the El Niño–Southern Oscillation phenomenon. *J. Climate*, 16, 2905–2914.

Meehl, G., 1987: The annual cycle and interannual variability in the tropical Pacific and Indian Ocean region. *Mon. Wea. Rev.*, 115, 27–50.

——, 1993: A coupled air-sea biennial mechanism in the tropical Indian and Pacific regions: Role of the ocean. *J. Climate*, 6, 31–41.

——, 1994: Coupled land-ocean-atmosphere processes and south Asian monsoon variability. *Science*, 266, 263–267.

——, 1997: The south Asian monsoon and the tropospheric biennial oscillation. *J. Climate*, 10, 1921–1943.

——, and J. Arblaster, 2002: The tropospheric biennial oscillation and Asian-Australian monsoon rainfall. *J. Climate*, 15, 722–744.

——, and W. Washington, 1993: South Asian summer monsoon variability in a model with doubled atmospheric carbon dioxide concentration. *Science*, 260, 1101–1104.

Menon, S., J. Hansen, L. Nazarenko, and Y. Luo, 2002: Climate effects of black carbon aerosols in China and India. *Science*, 297, 2250–2253.

Michell, J., and T. Johns, 1997: On modification of global warming by sulfate aerosols. *J. Climate*, 10, 245–267.

Minoura, D., R. Kawamura, and T. Matsuura, 2003: A mechanism of the onset of the South Asian summer monsoon. *J. Meteor. Soc. Japan*, 81, 563–580.

Miyakoda, K., A. Navarra, and M. N. Ward, 1999: Tropical-wide teleconnection and oscillation. Ⅱ: The ENSO-monsoon system. *Quart. J. Roy. Meteorol. Soc.*, 125, 2937–2963.

Mooley, D., and B. Parthasarathy, 1984: Fluctuation in all-India summer monsoon rainfall during 1871-1985. *Climate Change*, 6, 287–301.

Mori, S., J.-I. Hamada, Y. Tauhid, M. Yamanaka, N. Okamoto, F. Murata, N. Sakurai, H. Hashiguchi, and T. Sribimawati, 2004: Diurnal land-sea rainfall peak migration over Sumatera Island, Indonesian maritime continent, observed by TRMM satellite and intensive rawinsonde soundings. *Mon. Wea. Rev.*, 132, 2021–2039.

Murakami, M., 1983: Analysis of the deep convective activity over the western Pacific and Southeast Asia. Part I: Diunal variation. *J. Meteor. Soc. Japan,* 61, 60–76.

Murakami, T., 1975: Interannual Cloudiness Changes. *Mon. Wea. Rev.*, 103, 996–1006.

——, 1980: Empirical orthogonal function analysis of satellite observed out-going longwave radiation during summer. *Mon. Wea. Rev.*, 108, 205–222.

Nakazawa, T., 1992: Seasonal phase lock of intraseasonal variation during the Asian summer monsoon. *J. Meteor. Soc. Japan,* 70, 257–273.

Nasuno, T., H. Tomita, S. Iga, H. Miura, and M. Satoh, 2007: Multiscale organization of convection simulated with explicit cloud processes on an aquaplanet. *J. Atmos. Sci.*, 64, 1902–1921.

Navarra, A., M. Ward, and K. Miyakoda, 1999: Tropical-wide teleconnection and oscillation. Ⅰ: Teleconnection indices and type Ⅰ/type Ⅱ states. *Quart. J . Roy. Meteor. Soc*., 125, 2909–2935.

Neale, R., and J. Slingo, 2003: The maritime continent and its role in the global climate: A GCM study. *J. Climate*, 16: 834–848.

Nesbitt, S. W., and E. J. Zipser, 2003: The diurnal cycle of rainfall and convective intensity according to three years of TRMM measurements. *J. Climate*, 16, 1456–1475.

Nicholls, N., 1983: Air-sea interaction and the quasi-biennial oscillation. *Mon. Wea. Rev.*, 106, 1505–1508.

Ninomiya K., and T. Murakami, 1987: The early summer rainy season (Baiu) over Japan. Monsoon Meteorology, C.-P. Chang and T. N. Krishnamurti, Eds., Oxford University Press, 93–121.

Nitta, T., 1987: Convective activities in the tropical western Pacific and their impact on the Northern Hemisphere summer monsoon. *J. Meteor. Soc. Japan,* 65, 373–390.

——, and Z.-Z. Hu, 1996: Summer climate variability in China and its association with 500 hPa height and tropical convection. *J. Meteor. Soc. Japan,* 74, 425–445.

——, and S. Sekine, 1994: Diurnal variation of convective activity over the tropical western Pacific. *J. Meteor. Soc. Japan,* 72, 627–641.

Ohsawa, T., H. Ueda, T. Hayashi, A. Watanabe, and J. Matsumoto, 2001: Diurnal variation of convective activity and rainfall in tropical Asia. *J. Meteor. Soc. Japan,* 79, 333–352.

Oku, Y., H. Ishikawa, S. Haginoya, and Y. Ma, 2006: Recent trends in land surface temperature on the Tibetan Plateau. *J. Climate*, 19, 2995–3003.

Okumura, K., T. Satomura, T. Oki, and Warawut Khantiyanan, 2003: Diurnal variation of precipitation by moving mesoscale systems: Radar observations in northern Thailand. *Geophys. Res. Lett.*, 30, 2073, doi: 10.1029/2003GL018302.

Palmer, T. N., A. Alessandri, U. Andersen, P. Cantelaube, M. Davey, and co-authors, 2004: Development of a European multi-model ensemble system for seasonal to interannual prediction (DEMETER). *Bull. Amer. Meteor. Soc.*, 85, 853–872.

Qiu, B., M. Mao, and Y. Kashino, 1999: Intraseasonal variability in the Indo-Pacific throughflow and the regions surrounding the Indonesian Seas. *J. Phys. Oceangr.*, 29, 1599–1618.

Qu, T., Y. Du, J. Strachan, G. Meyers, and J. Slingo, 2005: Sea surface temperature and its variability in the Indonesian region. *Oceanogr.,* 18, 50–61.

Qu, T., Y.Du, H. Sasaki, 2006: South China Sea throughflow: A heat and freshwater conveyor. *Geophys. Res. Lett*, 33, doi: 10.1029/ 2006GL028350.

Ramanathan, V., C. Chung, D. Kim, T. Bettge, L. Buja, J. T. Kiehl, W. M. Washington, Q. Fu, D. R. Sikka, and M. Wild, 2005: Atmospheric

Brown Clouds: Impacts on South Asian Climate and Hydrological Cycle. *PNAS*, 102, 5326–5333.

——, and P. J. Crutzen, 2003: Atmospheric Brown "Clouds". *Atmos. Environ.*, 37, 4033–4035.

——, ——, J. Kiehl, and D. Rosenfeld, 2001: Aerosols, climate, and the hydrological cycle. *Science*, 294, 2119–2124.

Robock, A., M. Mu, K. Vinnikov, and D. Robinson, 2003: Land surface conditions over Eurasia and Indian summer monsoon rainfall. *J. Geophy. Res*., 108, 4131, doi:10.1029/2002JD002286.

Roeckner, E., L. Bengtsson and J. feichter, 1999: Transient climate change simulations with coupled atmosphere-ocean GCM including the tropospheric sulfur cycle. *J. Climate*, 12, 3004–3032.

Ropelewski, C., M. Halpert, and X. Wang, 1992: Observed tropospherical biennial variability and its relationship to the Southern Oscillation. *J. Climate*, 5, 594–614.

Rosenfeld, D., 2000: Suppression of rain and snow by urban and industrial air pollution. *Science,* 287, 1793–1796.

Saji, N., B. Goswami, P. Vinayachandran and T. Yamagata, 1999: A dipole mode in the tropical Indian Ocean. *Nature*, 401, 360–363.

Sakurai, N., F. Murata, M. Yamanaka, S. Mori, J.-I. Hamada, H. Hashiguchi, Y. Tauhid, T. Sribimawati, and B. Suhardi, 2005: Diurnal cycle of cloud system migration over Sumatera Island. *J. Meteor. Soc. Japan.*, 83, 835–850.

Sassen, K., Z. Wang, V. Khvorostyanov, G. Stephens, and A. Bennedetti, 2002: Cirrus cloud ice water content radar algorithm evaluation using an explicit cloud microphysical model. *J. Appli. Meteor.*, 41, 620–628.

Satomura, T., 2000: Diurnal variation of precipitation over the Indo-China Peninsula: Two dimensional numerical simulation. *J. Meteor. Soc. Japan.*, 78, 461–475.

Shen, X., M. Kimoto, and A. Sumi, 1998: Role of land surface processes associated with interannual variability of broad-scale Asian summer monsoon as simulated by the CCSR/NIES AGCM. *J. Meteor. Soc. Japan.*, 76, 217–236.

Shinoda, M., H. Utsugi, and W. Morishima, 2001: Spring snow-disappearance timing and its possible influence on temperature fields over central Eurasia. *J. Meteor. Soc. Japan.*, 79, 37–59.

Shukla, J., 1998: Predictability in the midst of chaos: A scientific basis for climate forecasting. *Science*, 282, 728–731.

——, and D. Mooley, 1987: Empirical Prediction of the Summer Monsoon Rainfall over India. *Mon. Wea. Rev.,* 115, 695–704.

____, 1995: Predictability of the tropical atmosphere, the tropical oceans, and TOGA. Pp 725-730 in Proceedings of the international conference on the Tropical Ocean and Global Atmosphere (TOGA) programme, 2. WCRP-91. World Climate Research Programme, Geneva, Switzerland.

Sikka, D., and S. Gadgil, 1980: On the maximum cloud zone and the ITCZ over Indian longitudes during the southwest monsoon. *Mon. Wea. Rev.,* 108, 1840–1853.

——, 2000: Monsoon floods. Joint COLA/CARE Report No. 4, Available at: COLA, 4041, Powder Mill Road, Calverton, MD, USA.

——, 2006: A study on the monsoon low pressure systems over the Indian region and their relationship with drought and excess monsoon seasonal rainfall. COLA Report No. 217, Available at: COLA, 4041, Powder Mill Road, Calverton, MD, USA.

Slingo, J., J. Boyle, J. Ceron, M. Dix, B. Dugas, and Coauthors, 1996: Intraseasonal oscillations in 15 atmospheric general circulation models: Results from an AMIP diagnostic subproject. *Climate Dyn.*, 12, 325–357.

——, and H. Annamalai, 2000: The El Nino of the century and the response of the Indian summer monsoon. *Mon. Wea. Rev.*, 128, 1778–1797.

Sorooshian, S., X. Gao, K. Hsu, R. Madox, Y. Hong, and Coauthors, 2002: Diurnal variability of tropical rainfall retrieved from combined GOES and TRMM satellite information. *J. Climate*, 15, 983–1001.

Sperber, K., and T. Palmer, 1996: Interannual tropical rainfall variability in general circulation model simulations associated with the atmospheric model intercomparison Project. *J. Climate*, 9, 2727–2750.

——, J. Slingo, and H. Annamalai, 2000: Predictability and the relationship between subseasonal and interannual variability during the Asian summer monsoon. *Quart. J. Roy. Meteor. Soc.,* 126, 2545–2574

——, and coauthors, 2001: Dynamical seasonal predictability of the Asian summer monsoon. *Mon. Wea. Rev*., 129, 2226–2248.

——, and T. Yasunari, 2006: Workshop on monsoon climate systems. *Bull. Amer. Meteor. Soc*., 87, 1399–1403.

Stanhill, G., and S. Cohen, 2001: Global dimming: a review of the evidence for a widespread and significant reduction in global radiation with discussion of its probable causes and possible agricultural consequences. *Agric. For. Meteor.,* 107, 255–278.

____, and H. Annamalai, 2008: Coupled model simulations of boreal summer intraseasonal (30-50 day) variability, Part I: Systematic errors and caution on use of metrics. *Climate Dyn.,* in press.

Stephens, G., P. Webster, R. Johnson, R. Engelen, and T. L'Ecuyer, 2004: Observational Evidence for the Mutual Regulation of the Tropical Hydrological Cycle and Tropical Sea Surface Temperatures. *J. Climate*, 17, 2213–2224.

Sumi, A., and Coauthors, 2004: Development of A High Resolution Climate Model by Using the Earth Simulator. *Annual Report of the Earth Simulator Center*, Chapter 1, 31–34.

Taniguchi, K. and T. Koike, 2007: Increasing atmospheric temperature in the upper troposphere and cumulus convection over the eastern part of the Tibetan plateau in the pre-monsoon season of 2004. *J. Meteor. Soc. Japan.*, 85A, 271–294.

Tao, S., and L. Chen, 1987: A review of recent research on the East Asian summer monsoon in China. In C.-P. Chang and T. N. Krishnamurti (eds.) *Monsoon Meteorology.* Oxford University Press, New York, 60–92.

Toole, J.M., R.C. Millard, Z. Wang, and S. Pu, 1990: Observations of the Pacific North Equatorial Current bifurcation at the Philippine coast. *J. Phys. Oceanogr.*, 20, 307–318.

Tozuka, T., T. Qu, T. Yamagata, 2007: Dramatic impact of the outh China Sea on the Indonesian Throughflow. *Geophys. Res. Lett.*, 34, doi:10.1029/2007GL030420.

Tsuchiya, M., R. Lukas, R.A. Fine, E. Firing, and E. Lindstrom, 1989: Source waters of the Pacific Undercurrent. *Prog. in Oceanogr.*, 23, 101–147.

Twomey, S., 1977: The influence of pollution on the shortwave albedo of clouds. *J. Atmos. Sci.,* 34, 1149–1152.

Ueda, H., 2005: Air-sea coupled process involved in stepwise seasonal evolution of the Asian summer monsoon. *Geogr. Rev. Japan*, 86, 825–841.

——, and T. Yasunari, 1996: Maturing process of summer monsoon over the western North Pacific - A coupled ocean/atmosphere system. *J. Meteor. Soc. Japan,* 74, 493–508.

——, Kamahori, and N. Yamazaki, 2003: Seasonal contrasting features of heat and moisture budgets between the eastern and western Tibetan Plateau during the GAME IOP. *J. Climate*, 16, 2309–2324.

Wajsowicz, R. C., 2002: Air-sea interaction over the Indian Ocean due to variations in the Indonesian throughflow. *Climate Dyn.*, 18, 437–453.

Waliser D., K.-M. Lau, W. Stern, and C. Jones, 2003a: Potential predictability of the Madden-Julian Oscillation. *Bull. Amer. Meteor. Soc.*, 84, 33–50.

——, K. Jin, I.-S. Kang, W. Stern, S. Schubert, and Coauthors, 2003b: AGCM Simulations of intraseasonal variability associated with the Asian summer monsoon. *Climate Dyn.*, 21, 423–446.

——, K. Weickmann, R. Dole, S. Schubert, O. Alves, and Coauthors, 2006: The experimental MJO prediction project. *Bull. Amer. Met. Soc.*, 87, 425–431.

Wang, B., 1995: Interdecadal changes in El Nino onset in the last four decades. *J. Climate*, 8, 267–258.

——, 2005: Theories. In: K.-M. Lau and D.E. Waliser (eds.), Intraseasonal Variability of the Atmosphere-Ocean Climate System. Springer-Verlag, Heidelberg, Germany.

——, 2006: The main parts. In B. Wang (ed.) *The Asian monsoon.* Springer/Praxis Publishing Ltd., New York, 1–679.

——, and Q. Ding, 2006: Changes in global monsoon precipitation over the past 56 years. *Geophys. Res. Lett.*, 33, L06711, doi:10.1029/2005GL025347.

——, and ——, 2008: The global monsoon: major modes of annual variations in the tropics. *Dyn. of Atmos. and Ocean*, 44, 165–183.

——, ——, and J. Jhun, 2006a: Trends in Seoul (1778-2004) summer precipitation. *Geophys. Res. Lett.,* 33, L15803, doi: 10.1029/2006GL026418.

——, I.-S. Kang, and J.-Y. Lee, 2004: Ensemble simulations of Asian-Australian monsoon variability by 11 AGCMs. *J. Climate,* 17, 803–818.

——, J.-Y. Lee, I.-S. Kang, J. Shukla, J.-S. Kug, A. Kumar, J. Schemm, J.-J. Luo, T. Yamagata, and C.-K. Park, 2007: How accurately do coupled climate models predict the Asian Australian monsoon interannual variability. *Climate Dyn*., Revised.

——, and LinHo, 2002: Rainy seasons of the Asian-Pacific monsoon. *J. Climate*, 15, 386–398.

——, and H. Rui, 1990a: Dynamics of the coupled moist Kelvin-Rossby wave on an equatorial beta -plane. *J. Atmos. Sci.,* 47, 397–413.

——, and ——, 1990b: Synoptic climatology of transient tropical intraseasonal convection anomalies: 1975-1985. *Meteor. Atmos. Phys.*, 44, 43–61.

——, P. Webster, K. Kikuchi, T. Yasunari, and Y. Qi, 2006b: Boreal summer quasi-monthly oscillation in the global tropics. *Climate Dyn.*, 27, 661–675.

——, ——, and H. Teng, 2005: Antecedents and self-induction of the active-break Indian summer monsoon. *Goephys. Res. Lett.*, 32, L04704.

——, R. Wu, and X. Fu, 2000: Pacific-East Asian teleconnection: How does ENSO affect East Asian climate? *J. Climate*, 13, 1517–1536.

——, ——, and T. Li, 2003: Atmosphere-Warm Ocean interaction and its impact on Asian-Australian Monsoon variation. *J. Climate*, 16, 1195–1211.

——, and X. Xu, 1997: Northern Hemisphere summer monsoon singularities and climatological intraseasonal oscillation. *J. Climate,* 10, 1071–1085.

Wang, Z., and C.-P. Chang, 2008: Mechanism of the Asymmetric Monsoon Transition as Simulated in an AGCM. *J. Climate*, 21, in press.

Webster, P. J., 1983: Mechanisms of monsoon low-frequency variability: Surface hydrological effects. *J. Atmos. Sci.,* 40, 2110–2124.

——, 2006: The coupled monsoon system. In *The Asian monsoon.* B. Wang (ed.) Springer/Praxis Publishing Ltd., New York, 3–65.

——, E. F. Bradley, C. W. Fairall, J. S. Godfrey, P. Hacker, and Coauthors, 2002: The JASMINE pilot study. *Bull. Amer. Meteor. Soc.*, 83, 1603–1630.

——, V. Magaña, T. Palmer, J. Shukla, R. Tomas, M. Yanai and T. Yasunari, 1998: Monsoons: Processes, predictability, and the prospects for prediction. *J. Geophys. Res.* 103, 14451–14510.

——, A. Moore, J. Loschnigg, and R. Leben, 1999: Coupled ocean-atmosphere dynamics in the Indian Ocean during 1997-1998. *Nature*, 401, 356–360.

——, and S. Yang, 1992: Monsoon and ENSO: Selectively interactive systems. *Quart. J . Roy. Meteor. Soc*., 118, 877–926.

Wen, M., and R. Zhang, 2007a: Quasi-biweekly oscillation of the convection around Sumatra and low-level tropical circulation in boreal spring. *Mon. Wea. Rev.*, in press.

——, and R. Zhang, 2007b: Role of the quasi-biweekly oscillation in the onset of convection over the Indochina Peninsula. *Quart. J. Roy. Meteor. Soc.*, 133, 433–444

Wu, G., and Y. Liu, 2003: Summertime quadruplet heating pattern in the subtropics and the associated atmospheric circulation. *Gephys. Res. Lett*. 30, 1201, 1–4.

——, and Y. Zhang, 1998: Tibetan Plateau forcing and the timing of the monsoon onset over South Asia and the South China Sea. *Mon. Wea. Rev.,* 126, 913–927.

——, W. Li, H. Guo, H. Liu, J. Xue, and Z. Wang, 1997: Sensible heat driven air-pump over the Tibetan Plateau and its impacts on the Asian summer monsoon. In Ye Duzheng (ed.), *Collections on the Memory of Zhao Jiuzhang*, Chinese Science Press, Beijing, 116–126.

——, Y. Liu, J. Mao, X. Liu, and W. Li, 2004a: Adaptation of the atmospheric circulation to thermal forcing over the Tibetan Plateau. In: Xun Zhu (chief ed.)*, Observation, Theory and Modeling of Atmospheric Variability* (selected papers of Nanjing Institute of Meteorology alumni in commemoration of Professor Jijia Zhang). World Scientific, Singapore, 92–114.

——, J. Mao, A. Duan, and Q. Zhang, 2004b: Recent progress in the study on the impacts of Tibetan Plateau on Asian summer monsoon. *Acta Meteor. Sinica*, 62, 529–540,

——, J. Li, and coauthors, 2006a: The key region affecting the short-term climate variations in China: The joining area of Asia and Indian-Pacific Ocean. *Adv. Earth Sci.*, 21, 1109–1118.

——, Y. Liu, T. Wang, R. Wan, X. Liu, and Coauthors, 2007a: The Influence of mechanical and thermal forcing by the Tibetan Plateau on Asian climate. *J. Hydrometeorology,* 8, 770–789.

Wu, P., M. Hara, H. Fudeyasu, M.D. Yamanaka and J. Matsumoto, 2007b: The impact of trans-equatorial monsoon flow on the formation of repeated torrential rains over Java Island, *SOLA*, 3, 93–96.

——, M. Hara, J. Hamada, M. D. Yamanaka and F. Kimura, 2008: Nocturnal heavy rainfall generated offshore by afternoon mountain convection over Sumatra Island, submitted.

Wu, R., and B. Wang, 2000: Interannual variability of summer monsoon onset over the Western North Pacific and the underlying processes. *J. Climate*, 13, 2483–2501.

Wu, Z., J. Li, J. He, and Z. Jiang, 2006b: Occurrence of droughts and floods during the normal summer monsoons in the mid- and lower reaches of the Yangtze River. *Geophys. Res. Lett*., 33, L05813, doi: 10.1029/2005GL024487.

——, ——, ——, and ——, 2006c: The large-scale atmospheric singularities and the summer long-cycle droughts-floods abrupt alternation in the middle and lower reaches of the Yangtze River. *Chin. Sci. Bull.*, 51, 2027–2034.

Xavier P. K., C. Marzin and B. N. Goswami, 2007: An objective definition of the Indian summer monsoon season and a new perspective on ENSO-monsoon relationship, *Q. J. Meteorol. Soc.* 133, 749-764

Xia, X., Z. Li, P. Wang, H. Chen, and M. Cribb, 2007: Aerosol optical properties and radiative effects in eastern China, *J. Geophy. Res. Special section on EAST-AIRE,* in press.

Xu, X., and Coauthors, 2002: A comprehensive physical pattern of land-air dynamic and thermal structure on the Qinghai-Xizang Plateau. *Science in China (Series D)*, 32, 577–594.

Yamada，H., H. Uyeda, 2006: Transition of the rainfall characteristics related to the moistening of the land surface over the central Tibetan Plateau during the summer of 1998. *Mon. Wea. Rev*., 122, 305–323.

Yanai, M., and C. Li, 1994: Mechanism of heating and the boundary layer over the Tibetan Plateau. *Mon. Wea. Rev*., 134, 3230–3247.

——, ——, and Z. Song, 1992: Seasonal heating of the Tibetan Plateau and its effects on the evolution of the Asian summer monsoon. *J. Meteor. Soc. Jap*an, 70, 319–351.

——, and G. Wu, 2006: Effects of the Tibetan Plateau. In B. Wang (ed.) *The Asian monsoon.* Springer/Praxis Publishing Ltd., New York, 513–549.

Yang, G., and J. Slingo, 2001: The diurnal cycle in the tropics. *Mon. Wea. Rev*., 129, 784–801.

Yang, K., and Coauthors, 2002: Improvement of surface flux parameterizations with a turbulence-related length. *Quart. J. Roy. Meteor. Soc.*, 128, Part B, 2073–2088.

——, T. Koike, and D. Yang, 2003: Surface flux parameterization in the Tibetan Plateau. *Boundary-layer Meteorology,* 106, 245–262.

——, and Coauthors, 2004: The daytime evolution of the atmospheric boundary layer and convection over the Tibetan Plateau: observations and simulations. *J. Meteor. Soc. Jap*an, 82, 1777−1792.

——, and Coauthors, 2007: Auto-calibration system developed to sssimilate AMSR-E data into a land surface model for estimating the soil moisture and surface energy budget. *J. Meteor. Soc. Jap*an, 85A, 229–242.

Yang, S., and K.-M. Lau, 2006: Interannual variability of the Asian monsoon. In *The Asian monsoon* B. Wang (ed.). Springer/Praxis Publishing Ltd., New York, 259–293.

Yasunari, T., 1979: Cloudiness fluctuations associated with the Northern Hemisphere summer monsoon. *J. Meteor. Soc. Japan,* 57, 227−242.

——, 1980: A quasi-stationary appearance of 30-40 day period in the cloudiness fluctuations during the summer monsoon over India. *J. Meteor. Soc. Japan,* 58, 225–229.

——, 1991: The monsoon year: A new concept of the climate year in the tropics. *Bull. Amer. Meteor. Soc.,* 72, 1331−1338.

——, and T. Miwa, 2006: Convective cloud systems over the Tibetan Plateau and their impact on meso-scale disturbances in the Meiyu/Baiu frontal zone -a case study in 1998. *J. Meteor. Soc. Japan,* 84, 783–803.

——, and R. Suppiah, 1988: Some problems on the interannual variability of Indonesian monsoon rainfall. *Tropical Rainfall Measurements*, edited by J. S. Theon and N. Fugono, Deepak, Hampton, Va., 113–122.

Yokoi, S., and J. Matsumoto, 2008: Collaborative effects of cold surge and tropical depression on heavy rainfall in central Vietnam, submitted.

Yu, R., B. Wang, and T. Zhou, 2004: Tropospheric cooling and weakening of East Asia monsoon trend. *Geophys. Res. Lett*. Vol. 31, L22212, doi: 10.1029/2004GL021270.

Yuan, T., Z. Li, R. Zhang, and J. Fan, 2007: Increase of cloud droplet size with aerosol optical depth: An observation and modeling study. *J. Geophys. Res.*, in press.

Zeng, Q., and J. Li, 2002: On the interaction between Northern and Southern Hemispheric atmospheres and the essence of tropical monsoon, *Chin. J. Atmos. Sci.*, 26, 207–226.

Zhan, R., J. Li, and A. Gettelman, 2006: Intraseasonal variations of upper tropospheric water vapor in Asian monsoon region. *Atmos. Chem. Phys. Discuss.*, 6, 8069–8095.

Zhang, L., and J. Li, 2007: Seasonal Rotation Features of Wind Vectors and Application to Evaluate Monsoon Simulations in AMIP Models. *Climate Dynamics*, DOI: 10.1007/s00382–007–0327−9, in press.

Zhang, Y., T. Li, and B. Wang, 2004: Decadal change of the spring snow depth over Tibetan Plateau: The associated circulation and influence on the East Asian summer monsoon. *J. Climate*, 17, 2780–2993.

Zhou, T.-J., and R.-C. Yu, 2005: Atmospheric water vapor transport associated with typical anomalous summer rainfall patterns in China. *J. Geophys. Res.*, 110, D08104, doi: 10.1029/2004JD005413.