Newsletter of the Climate Variability and Predictability Programme (CLIVAR)

Exchanges

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The Asian Monsoon

From C-P Chang page 16: The Maritime Continent Monsoon

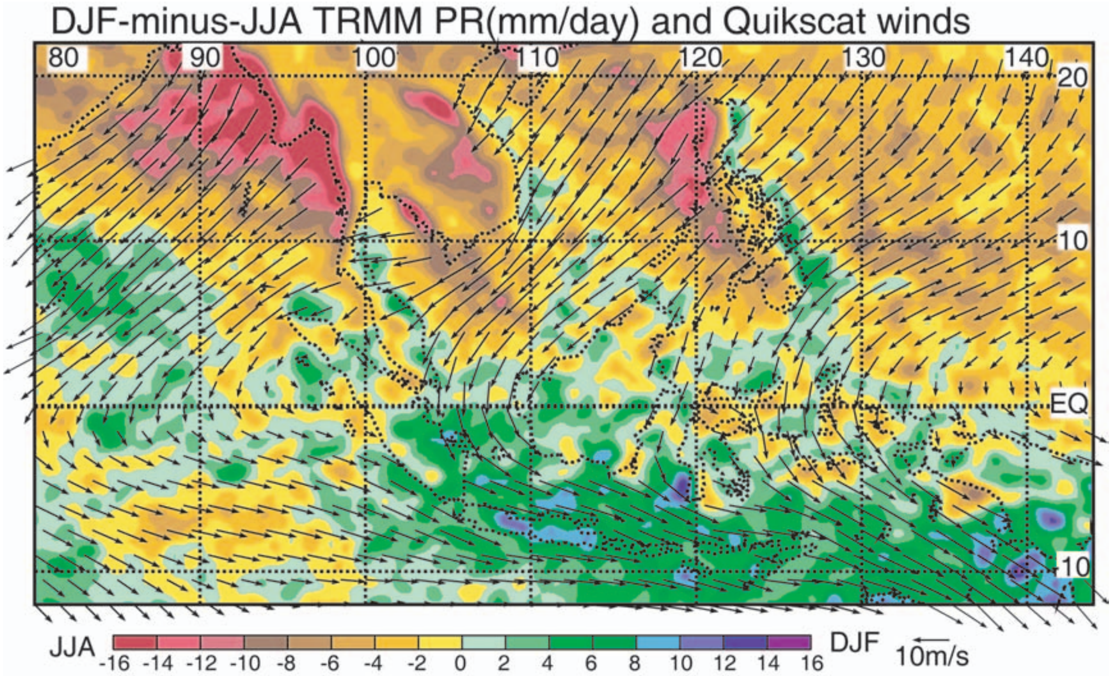

Fig. 1 Differences of TRMM Precipitation Radar data and QuikSCAT winds between boreal winter and boreal summer (DJF minus JJA). Warm colors are the boreal summer monsoon regime and cool colors are the boreal winter monsoon regime.

CLIVAR is an international research programme dealing with climate variability and predictability on time-scales from months to centuries.

CLIVAR is a component of the World Climate Research Programme (WCRP). WCRP is sponsored by the World Meteorological Organization, the International Council for Science and the Intergovernmental Oceanographic Commission of UNESCO.

Latest CLIVAR News http://www.clivar.org/recent/

CLIVAR/OOPC/GOOS/Argo Workshop on the South Pacific; Concepcion, Chile, 11-14 October 2005

Tropical Atlantic Variability Workshop; Venice, Italy, 17-19 October 2005

See the CLIVAR Calendar *http://www.clivar.org/calendar/index.htm*

Call for Contributions

The next issue of CLIVAR Exchanges will be on the Southern Ocean and the International Polar Year and will feature papers from the Modes of Southern Hemisphere Climate Variability Workshop held in Cambridge, United Kingdom from 27 - 30th June 2005

Editorial

As you will see, the Asian monsoon system forms the primary focus of this issue of Exchanges. Societies across southern Asia are critically dependent on the monsoon rains, and failures such as happened in the 2002 monsoon seasonal have a devastating effect. The challenge for CLIVAR is monsoon prediction and its links to applications, activities that are focussed in CLIVAR's Asian Australian Monsoon Panel (AAMP). The panel had its 7th meeting in Irvine, California from 18-19 June, immediately following the 1st pan WCRP Workshop on the Monsoon Climate Systems (15-17 June 2005), also held in Irvine and itself focussed on improving the coordination of WCRP efforts to predict the monsoon systems of the world. The AAMP meeting, co-chaired by Kumar Kolli and Bin Wang, covered a number of key aspects of WCRP's efforts in this area, including the status and development of coordinated coupled model AA monsoon prediction experiments, aspects of monsoon predictability and prediction, the role of intra-seasonal oscillations, the application of regional modelling to prediction of the AA monsoon, the role of the Pacific and how the AA monsoon system might be influenced by anthropogenic climate change. A number of issues emerged from the discussions, some of which will be tackled in collaboration with other CLIVAR Panels, in particular CLIVAR's Working Group on Seasonal Prediction and Pacific Science Implementation Panel. A report of the meeting is in preparation, but for the present a number of the presentations can be viewed on the CLIVAR web site linked to www.clivar.org/organization/aamon/aamp7/agenda.htm.

The Joint CLIVAR/GOOS Indian Ocean Panel (IOP) currently acts, from a CLIVAR perspective, as a sub-panel of the AAMP. The IOP is critical to the development of the sustained observing system in the Indian Ocean region. Observations from the present and planned Indian Ocean arrays will form a key long-term input to both our understanding of the role of the Indian Ocean for the AA monsoon and our ability to predict it. The IOP had its second meeting in Hobart, Australia from 30 March -2 April 2005 and the report by Zhongwei Yan on page 4 gives a summary of the outcomes of the meeting, the full report of which can be found at: www.clivar.org/organization/indian/docs/92_IOP2.pdf.

Report of another monsoon-related meeting, namely the 8th session of the CLIVAR Variability of the American Monsoon Systems (VAMOS) Panel will be found on page 5 whilst on the page opposite is an outline of the currently-planned Tropical Atlantic Climate Experiment (TACE). TACE is a key activity of CLIVAR's Atlantic Panel, linking strongly also to aspects of African climate, in particular in the Sahel and Gulf of Guinea region. In addition, two papers relating to both the monsoon systems in South America and West Africa will be found at the end of this edition.

The 1st pan WCRP Workshop on the Monsoon Climate Systems, which was jointly organised by CLIVAR and GEWEX, was held just prior to the 5th International GEWEX Scientific Conference and at the same location. We were indeed very grateful for local GEWEX support for the workshop at this busy time for them, not least from Soroosh Sorooshian the GEWEX Chair and his staff, Diane Hohmbaum and Huiling Yuan. The workshop was co-chaired by Ken Sperber and Tetsuzo Yasunari who are now working hard on the outcomes. One was a clear call for greater cross-WCRP coordination of monsoon activities, which will need some careful thinking through in terms of mechanisms. On the science front there was clear concern that despite all the advances in modelling and parametrizations over the years, monsoon simulations still suffer from major errors. In particular, for example, the diurnal cycle of rainfall isn't simulated correctly in terms of timing in many models. The call was for use of a hierarchy of models, including cloud-resolving models in high resolution simulations, to try to home in some of these problems, so providing one focus for CLIVAR/GEWEX interactions in this area. The diurnal cycle was seem as one area of attack, the hypothesis being that because of its potential rectification onto sub-seasonal variability (e.g. the Madden Julian Oscillation) improvement in its representation may lead to an improved representation of intra-seasonal variability and improved skill of monsoon forecasts on medium range to seasonal timescales. What was also evident was the need for coupled ocean-atmosphere models (rather than just atmospheric models alone) for monsoon simulation & prediction. PDF versions of most of the presentations at the workshop can be found on the workshop web page at www.clivar.org/organization/aamon/WCRPmonsoonWS/monsoonWS.htm.

As I write, Zhongwei Yan is leaving the ICPO for a new post in the Institute of Atmospheric Physics in Beijing. Zhongwei has been with the ICPO, supported by US CLIVAR, for the past 4 years and has been responsible for looking after four CLIVAR panels, namely AAMP, the IOP, the joint CLIVAR/Commission for Climatology Expert Team on Climate Change Detection, Monitoring and Indices and, more recently, CLIVAR PAGES. We wish Zhongwei well in his new post, which will involve him in research on climate indices.

Finally, some late breaking news. We have heard today, that Roberta Boscolo who now works for the ICPO from the Observatoire Oceanologique de Villefranche Villefrache sur mer, France has been delivered with a baby boy, Leonardo. We wish Roberta, Emilio and Leonardo every happiness together. Similar congratulations and good wishes go to Mike Sparrow and Moira on the birth of their son Jaime on 10 May this year. The ICPO productivity has certainly taken an upturn!

Howard Cattle

TACE: Tropical Atlantic Climate Experiment

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The ocean has a major influence on tropical Atlantic variability mainly through the influence of tropical Atlantic SST on variations of the Atlantic marine ITCZ complex. The most notable climate impacts involve the variability of rainfall over northeast Brazil and the coastal regions surrounding the Gulf of Guinea, and the fluctuations in rainfall and dustiness in sub-Saharan Africa (Sahel). Many studies indicate a high degree of potential predictability for climate variations in the tropical Atlantic region. However, progress in tropical Atlantic climate prediction has been slow to come due to insufficient understanding of ocean-atmosphere processes that determine climate variability, lack of adequate data to initialise forecasts, and systematic errors in the models used for prediction (Figure 1).

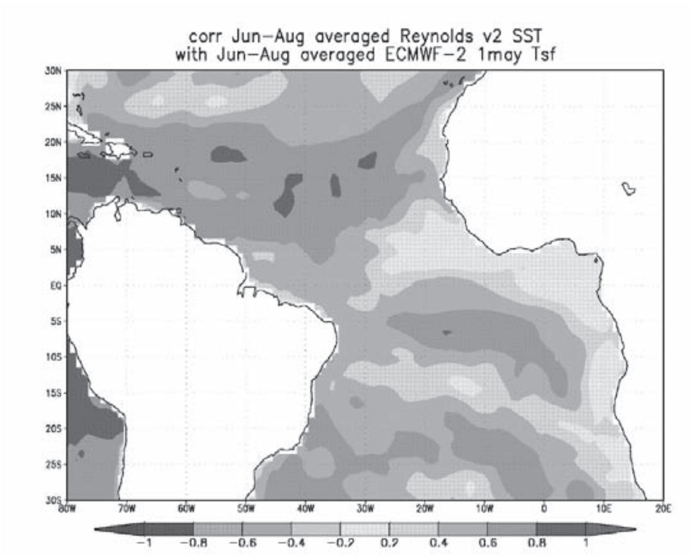

Figure 1. Correlation between observed sea surface temperature in June, July, August and sea surface temperature that is predicted at May 1st using ECMWFs seasonal forecasting system over the years 1987-2001. Note the lack of skill in the eastern tropical Atlantic (Hazeleger and van Oldenborgh, in preparation).

Understanding tropical Atlantic climate variability, with the goal of improving its predictability and identifying and quantifying its societal impacts, are important research goals recognized by CLIVAR. Concerted international effort is needed to improve the understanding of the regions' climate variability and the mechanisms that underlie its observed behaviour. A "Tropical Atlantic Climate Experiment "(TACE) has been proposed to address these issues. TACE is envisioned as a program of enhanced observations and process studies in the tropical Atlantic spanning a period of approximately 6 years (2006-2011). Its goal is to provide a focused observational and modelling effort to advance climate predictability in the surrounding region and to provide a basis for assessment and improvement of coupled models. The results of TACE are expected to contribute to the final design of a sustained observing system for the tropical Atlantic (Figure 2).

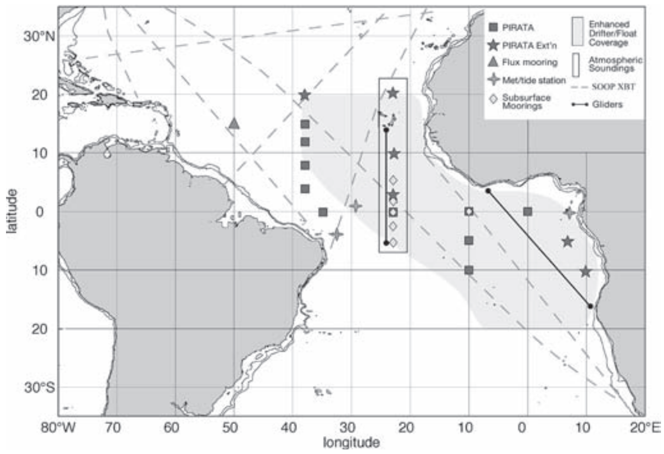

Figure 2. TACE Observational Strategy. The proposed observing system components include (see legend): Continuation of PIRATA moorings, PIRATA extensions along 23 º W and 5-10º E, equatorial subsurface (non-realtime) moorings along 23 ºE and at 10º W, island meteorological and tide gauge stations, enhanced float/drifter coverage in the eastern TA, repeated atmospheric soundings along 23 º W, ship-of-opportunity XBT lines, and selected glider transects (see the "TACE Synopsis" for more details

A TACE "White Paper" (http://www.clivar.org/science/atlantic.htm) provides an overview of the physical processes affecting climate variability in the tropical Atlantic and priorities for further study. An abbreviated synopsis of TACE (http://www.clivar.org/science/atlantic.htm#NEWS) outlines its major scientific thrusts and provides recommendations for new and/or continuing observations and modeling studies that are thought to be essential for TACE. These recommendations represent the culmination of planning efforts that have been carried out between 1999-2004 at several workshops, including the recent Tropical Atlantic Workshop in de Bilt, Netherlands (June 2004). Details of implementation were discussed at these meetings and represent the current consensus on the required observational and modeling components of the program.

To further develop TACE, a one-day "TACE Implementation Workshop" was held in Miami, Florida on February 3, 2005. The participants endorsed the TACE initiative as timely and relevant to CLIVAR goals, and supported its unified observational, modeling and synthesis concept. Many of the observational elements of the TACE plan are currently in place or proposed. TACE will encourage and perform further enhancements to observations in the tropical Atlantic, promote model intercomparison studies to identify model biases and their causes, and set up a data archive to facilitate synthesis studies As an outcome of the workshop, two working groups will be established: (i) a TACE "Observations Working Group" to coordinate observational logistics and develop needed enhancements, and (ii) a TACE "Modeling and Synthesis Working Group" to coordinate modeling efforts and encourage collaboration between research modelers and operational centers. These activities are expected to significantly speed progress toward improved seasonal and interannual prediction in the tropical Atlantic, and to begin to advance understanding of possible impacts of global change on the tropical Atlantic and its global teleconnection patterns.

Report of the Second Indian Ocean Panel Meeting (IOP–2) 30 March – 2 April 2005, CSIRO, Hobart, Australia

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The CLIVAR/GOOS Indian Ocean Panel (IOP) held its second meeting at the CSIRO Marine Laboratories, Hobart, Australia, 30 March – 2 April 2005. Twenty-eight panel members and invited experts from Australia, China, France, Germany, India, Indonesia, Japan, South Africa, the United Kingdom and the United States attended the meeting, aiming at completing the Implementation Plan for a sustained integrated observing system for climate in the Indian Ocean (IO) and developing a strategy of IO-related climate study.

A symposium on IO climate was organized prior to panel discussions, providing a scientific background for panel business. Invited speakers introduced a wide range of topics, including intra-seasonal prediction of Asian-Australian monsoons, global and IO mean and variability of air-sea heat fluxes, IO deep mixing and the surface heat budget, The West Australian Indian Ocean Climate Initiative, IO circulation variability, its modeling and climate relevance. The science overview talks and subsequent discussions provided a base for a consensus view that the panel is keen to play a role in developing a science plan for IO climate research.

Since the last panel meeting, IOP has developed the concept of an IO integrated observing system in active email discussions and contributed to the co-sponsor programmes by participating in the

- CLIVAR Data Management Meeting, March 2004, SIO La Jolla;
- Indian Ocean GOOS, April 2004, Colombo;
- OOPC-9, June 2004, Southampton;
- CLIVAR Conference, June 2004, Baltimore;
- GSOP Workshop and Panel, November 2004, Boulder;
- Ocean Technology/Oceans '04, November 2004, Kobe;
- Organization of the Indian Ocean Modeling Workshop, December 2004, Honolulu;
- Development of a CLIVAR Data Policy (GSOP-led email discussion); and
- Preparation of the CLIVAR SSG Report to WCRP JSC, March 2005 , Guayaquil.

The first draft plan for sustained observations emerged at IOP-1, based primarily on observational studies. The panel reviewed recent advances in Observing System Simulation Experiments (OSSEs) and climatologies of surface fluxes at IOP-2, which helped refine the location of surface moorings, flux reference sites and direct current measurements by ADCP. and the relationship between components of the system, including (Figure 1)

- surface fluxes reference sites;
- a basin-scale mooring array;
- a 3^ox3^o array of Argo floats;
- a 5^ox5^o surface drifters; and
- an enhanced XBT network.

Based on the discussions, the panel agreed to complete the Implementation Plan by June 2005, with a summary for the Bulletin of American Meteorological Society and more detailed papers for a special issue of CLIVAR Exchanges.

The panel was briefed on plans for process studies, including VASCO-CIRENE (France) and MISMO (Japan) to investigate air-sea interaction at intraseasonal time-scales and INSTANT to directly measure Indonesian Throughflow and devise proxy methods for long-term monitoring. Routine cruises by R/V's Indian Sagar Kanya and Chinese Xue-Long and Ocean-1 were identified as opportunities to build the basin scale mooring array and deploy Argo floats. Opportunities to collaborate with international development of the Tsunami Warning System were identified. It was recommended that all relevant research cruises and projects be proactively tracked for IOP to coordinate the implementation of the observing system.

The panel reviewed its role in WCRP/CLIVAR and IOC/IOGOOS. IOP is concerned with the role of Indian Ocean circulation dynamics in a broad range of climate variability and change processes. It also plays a unique role in bridging between CLIVAR's science and IOC's operational activities. The panel recognized that the in-depth discussion of Indian Ocean oceanography as it relates to the climate system, and the coordination and initiation of activities supporting the climate observing system cannot take place anywhere else in CLIVAR at this time. The members felt that IOP should have a longer lifetime (than the originally expected 3 annual meetings) for a continuous implementation process even if only for maintaining the observing system, and that it should be a distinct basin-panel, as with the Pacific and Atlantic Oceans.

IOP-2 ended as a fruitful success in terms of bringing together a wide range of research and operational issues, facilitating in-depth discussions for finalizing the Implementation Plan and resulting in some consensus view on the panel's future. The attendees highly appreciated the hosting of the meeting by the CSIRO Marine Laboratories, Hobart and Dr. Meyers and looked forward to further collaborations in the near future. A more detailed report is available at: http://www.clivar.org/organization/indian/.

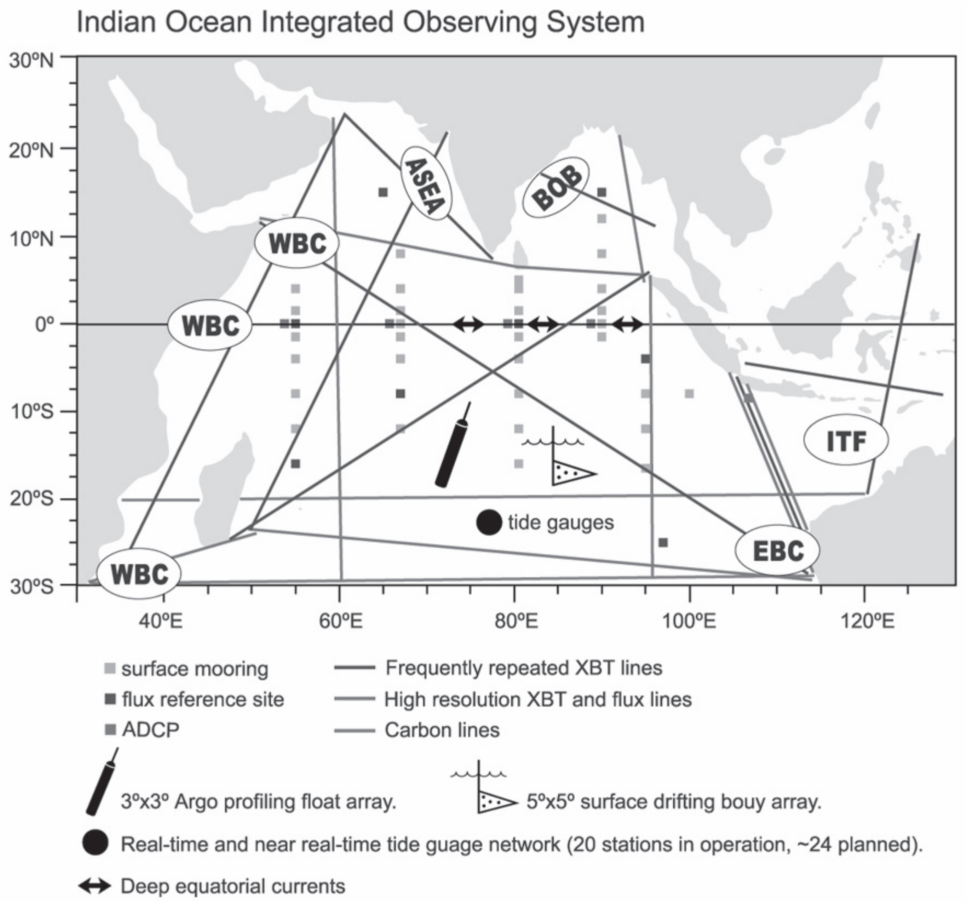

Figure 1: An integrated observing system for the Indian Ocean

Meeting Report: The eighth session of the CLIVAR VAMOS Panel – Executive Summary

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The eighth session of the WCRP/CLIVAR VAMOS (Variability of the American Monsoon System) Panel (VPM8) was hosted by the Servicio Meteorológico Nacional (SMN), in Mexico City, Mexico, 7-9 March, 2005. VPM8 consisted of a VAMOS Modeling Workshop and the VAMOS Panel meeting. It was followed by the MESA SWG-1 and NAME Data Analysis and SWG-7 meetings on 9-11 March, 2005. The event was attended by 85 participants from 8 countries.

VAMOS implementation includes 3 major science components (North American Monsoon Experiment (NAME), Monsoon Experiment South America (MESA) and VAMOS Oceans-Clouds-Atmosphere-Land Study (VOCALS)), the VAMOS Data Information Server and the VAMOS Programs Project Office. The chairs of each of the Science Working Groups (SWGs) reported on recent progress in their programs.

The NAME 2004 field campaign was carried out during June-September 2004. Participation included more than 30 universities and government laboratories in the U.S., Mexico, Belize and Costa Rica. The NAME 2004 enhanced observations provide the climate modeling and research community with unprecedented opportunities to improve understanding, simulations and ultimately predictions of the North American Monsoon. The field campaign strengthened international collaboration across Pan America, especially between participating operational and research groups. NAME also provides a template for future observing systems to monitor the North American Monsoon.

MESA is now integrating the objectives of the different projects in South America (SALLJEX, PLATIN, LBA) into a unified program that improves understanding, simulations and prediction of the South American Monsoon System (SAMS). During 2004, progress was made on the SALLJEX data quality control and generation of new datasets. Preliminary studies using SALLJEX data are providing quantitative information on the regional errors of global reanalyses, confirming that regional models are capable of simulating the basic features of low-level warm season circulations over tropical South America, but have difficulties in reproducing the observed diurnal cycle. The VAMOS/PLATIN Group made a successful contribution to the first phase of the GEF Framework Program for the La Plata Basin (LPB), producing surveys of the LPB's hydroclimate, including the systems used for its prediction and monitoring.

The goal of VOCALS is to better understand, simulate, and predict the Southeast Pacific cool-ocean climate regime and its interactions with the larger-scale coupled ocean-atmosphere-land system on diurnal to interannual time scales. VOCALS was developed in response to the awareness that present models have large errors in the stratus deck regions off northern Chile and Peru and that such regions play a significant role in the global climate system. Models have difficulty getting sea surface temperature (SST) and shortwave radiative forcing correct in this region. Since October 2000 a series of cruises to the region and data from a surface mooring located near the center of the climatological maximum in cloud cover have provided observations that have matured the foci and plans of VOCALS. A multinational, multi-investigator process study is planned in the region for October 2007.

A first proposal for an Intra-Americas Study of Climate Processes (IASCLIP) was presented at VPM8. The IASCLIP domain includes the Caribbean Sea, the Gulf of Mexico and the adjacent land areas over southern North America, Central America and northern South America. A Statement of Need for a research program in the region and the science foci were discussed, and the VAMOS Panel was asked to provide feedback on the program, including science priorities and linkages to the community.

The VAMOS Modeling Workshop reviewed the status of modeling relevant to VAMOS research, bringing together leading modeling groups to focus on developing recommendations for a long-term VAMOS modeling strategy. The workshop was organized into four sessions:
Physical Processes in the Monsoon Regions
Climate Forecasting in the Monsoon Regions
VOCALS modeling activities
Integrated MESA–NAME–VOCALS Modeling Activities.

Discussions led to a basic modeling strategy (end-to-end prediction system) and a set of VAMOS themes (e.g. drought, extreme events). The Modeling Group for VAMOS (MGV) is drafting a VAMOS Modeling Strategy Report to be reviewed by the CLIVAR SSG and presented at the WCRP Monsoon Workshop (Irvine, Ca. USA) in June 2005.

During the VAMOS Panel Executive Session the implementation strategy for the MGV was discussed. The panel also developed recommendations for the VAMOS science components and the emerging IASCLIP program. The theme for the 2nd issue of the VAMOS NEWSLETTER was discussed and approved. The 9th VAMOS panel meeting will be held back-to-back with the 8th AMS International Conference on SH Meteorology and Oceanography, in Foz do Iguazu, Brazil, in April 2006. MESA and NAME SWG meetings will also be held at that time. Finally, the panel developed recommendations for the 2005 membership rotation and forwarded these to the CLIVAR SSG for consideration.

The panel would like to express sincere thanks to Dr. Michel Rosengaus, Director of the Servicio Meterologico Nacional of Mexico (SMN), for his support to the 8th VAMOS panel meeting, and to Dr. Miguel Cortez (SMN) for coordinating an excellent set of meetings. The key contributions of V. Detemmerman (WCRP), M. Patterson (NOAA OGP), J. Huang (NOAA OGP), Jose Meitin (UCAR JOSS), and Tara Jay (UCAR) are also warmly acknowledged.

Observational Evidence Of Effects Of Absorbing Aerosols On Seasonal-to- Interannual Anomalies Of The Asian Monsoon

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Absorbing aerosols, such as dust and black carbon, are characterized by their ability to heat the atmosphere by absorbing solar radiation. In contrast, non-absorbing aerosols such as sulfate, scatter solar radiation and have relatively small atmospheric heating effect. Yet, both absorbing and non-absorbing aerosols cause surface cooling by blocking solar radiation from reaching the earth's surface. This has been referred to as the "global dimming" effect (Stanhill and Cohen 2001). The dimming effect is global, even though sources of aerosols are local, because of the abundance and diverse geographic locations of the sources, continuous emission, and long-range transport of aerosols. In recent coupled model experiments, Ramanathan et al (2005) show that as a result of "global dimming", the Indian monsoon is reduced on decadal or longer time scales. From atmospheric GCM experiments, Menon et al (2002) showed that heating by increasing atmospheric loading of black carbon in the Asian monsoon region may be responsible for the long-term drought pattern over northern China. More recently, Lau et al (2005) point out that, on intraseasonal to interannual time scales, heating by absorbing aerosols may induce a tropospheric temperature anomaly over the northern India and Tibetan regions in late spring and early summer, subsequently leading to an earlier onset and intensification of the Indian monsoon. They propose the importance of the "elevated heat pump" effect of atmospheric heating by dust transported from the nearby deserts to northern India, stacking up against the southern slopes of the Himalayas. The dust combined with the black carbon from industrial and agricultural pollution in northern India provide an anomalous diabatic heat source, which triggers positive feedback in monsoon convective heating, enhancing the Indian monsoon. These results suggest that aerosol effects on monsoon water cycle dynamics are complex and likely to be a strong function of spatial and temporal scales.

Up to now, there has been no convincing observational evidence of aerosol effects on monsoon climate variability because of the lack of long-term (> 10 years) aerosol data. Recent satellite observations such as MODIS, MISR from NASA EOS have provided much needed, but still inadequate information on aerosol radiative properties. Since aerosol-induced anomalies are likely to be further confounded by the strong influence of a variety of forcing agents, including El Niño, Indian Ocean and West Pacific sea surface temperature anomalies, and possibly from global warming, the lack of reliable, long-term aerosol data make it very difficult to extract significant signals of aerosol effects on monsoon water cycle variability. In

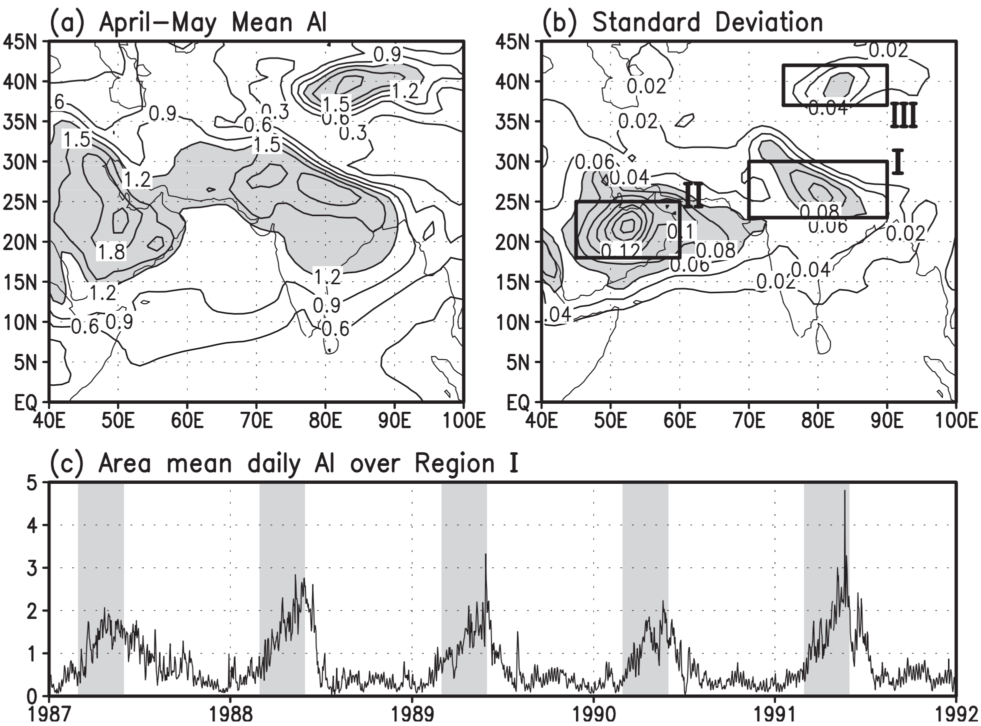

Figure 1 Climatological distribution of absorbing aerosols over the Indian subcontinent and adjacent areas based on the TOMS Aerosol Index (AI) for April-May showing a) the bi-monthly mean distribution, and b) the standard deviation, and c) Area mean daily AI over region I. Key source regions are marked by numbered rectangles in b)

this regard, the aforementioned modeling studies will provide valuable guidance on how and where to look for such signals in observations.

In this article, we show observations in support of the notion that aerosol forcing in late spring and early summer may induce Asian monsoon anomalies, and discuss how the radiative imbalance induced by absorbing aerosols may be instrumental in triggering dynamical feedback in the monsoon water cycle. For aerosol observations, we will use the Total Ozone Mapping Spectrometer (TOMS) Aerosol Index (AI). The TOMS AI is a measure of the wavelength-dependent change in Rayleigh-scattered radiance from aerosol absorption and is especially suitable for detecting the presence of absorbing aerosols above high reflecting surfaces, such as desert, and snow/ice over land, where MODIS has difficulties (Hsu et al. 1999). The AI data set is the only long-term continuous daily global record for absorbing aerosols (mainly black carbon and dust). It starts in November 1978 and, with the exception of a data gap from May 1993 to August 1996, runs to the present.

Figure 1a shows the April-May climatological (1979-1992) distribution of AI over the greater Indian monsoon region. Three major source regions can be identified: I) The Ganges Plain over northern India (marked by the rectangular box in the figure), II) Saudi Arabia and the Iran/Afghanistan/Pakistan deserts, and III) Western Asia over the Taklamakan desert. The interannual variability of the aerosol loading (Fig. 1b) is found to be about 10-15% of the bimonthly mean, and is strongest over the Middle East region, but also significant over region I and III. Aerosol radiative forcing from these regions may alter the large-scale thermal contrast in the troposphere and between the land surface and the adjacent oceans. In addition, dusts from Regions II may be transported to Region I, and mix with the black carbon produced from local emissions, further altering the atmospheric heat source and sink distribution. Since aerosol emission and transport is dependent on the soil types, the winds and the rainfall, the total dust loading in all three source regions undergo multi-scale variability associated with the monsoon climate system. The AI index in Region I (Fig. 1c) shows the strong seasonality of the aerosol loading, with increasing concentration in boreal spring (March-April-May), maximum near the latter part of May, and reducing concentration in fall and winter. The yearly variability as well as the intraseasonal variability of aerosol amount is quite obvious. Some years, the removal of aerosol from the atmosphere is very rapid, reaching minimum level days after the Indian monsoon onset in early-to-mid June, e.g. 1988. Other years, the aerosol removal is much slower, e.g. 1987. The year 1987 (1988) is well known as a weak (strong) monsoon year. The real question here is whether aerosol is a contributing factor to the monsoon anomaly.

The latitude-time cross sections of composite of four years (1980, 1985, 1988, 1991) of high AI anomaly (Fig. 2a, page 17), shows a slow build up of the aerosol loading up to May, and the rapid removal in June-July-August during the monsoon season. There appears to be a northward migration of rainfall anomaly from equatorial oceanic region to the monsoon land region, and an intensification of the monsoon rainfall (15°N–25°N) in June-July (Fig.2b), following the aerosol build-up in May. Over the Indian subcontinent, the rainfall season seems to have advanced with more rain appearing in the early part, and less rain in the latter part of the season. Fig. 2c shows that the rainfall increase in June-July is pan-India, with most pronounced signal over the Western Ghats, and the land region around the Bay of Bengal. The strengthened Indian monsoon is evident in the anomalous low level westerlies over the Indian subcontinent. Over East Asia, a strong anticyclonic anomaly is found, suggesting an intensification, and a westward shift of the Western Subtropical High. As a result, the Mei-yu rainbelt is pushed north of the Yangtze, and eastward over Japan, giving rise to the characteristic north-south dipole rainfall anomaly over East Asia (Lau et al. 2000). The aforementioned results suggest that the large-scale dynamical structure of the entire Asian monsoon system may have been modified by the aerosol forcing.

How can absorbing aerosols over Asia continent trigger a large-scale dynamical monsoon response? We recall that the net radiative effect of aerosols on the atmosphere and the surface depends not only on the aerosol type but also on the albedo and the temperature of the underlying surface. Fig. 3 shows the radiative balance at the top of the atmosphere and at the earth's surface for an amount of desert dust with optical thickness equal to unity over land (albedo = 0.35), and over ocean (albedo = 0.03). The spectral dust properties used in the calculations are based upon values reported in OPAC (Optical Properties of Aerosols and Clouds) for 0.5 μm dust particles (Hess et al. 1998), in which the corresponding equivalent broadband single scattering albedo is approximately 0.92. The calculation is conducted using a climatological atmospheric temperature and moisture sounding over land and ocean, respectively. The net aerosol forcing is defined as the difference in total radiation flux between a pristine atmosphere and a dusty atmosphere.

When we look at aerosol forcing over land and ocean surfaces for these conditions we find that the total atmosphere-land system warms by 8 Wm^{-2}, while the total atmosphere-ocean system cools by 78 Wm^{-2}. For the atmospheric component itself (surface minus top-of-atmosphere), our calculations show that the atmosphere over the ocean is heated by 97 Wm^{-2}, while over land the atmospheric heating is significantly stronger at 115 Wm^{-2}. This is due to enhanced dust absorption associated with the multiple reflections of solar radiation between the high albedo land surface and the dust layer. The overall result is that the cooling over land surfaces is usually much smaller than that over ocean surfaces. It is possible, over elevated land such as snow covered surfaces of the

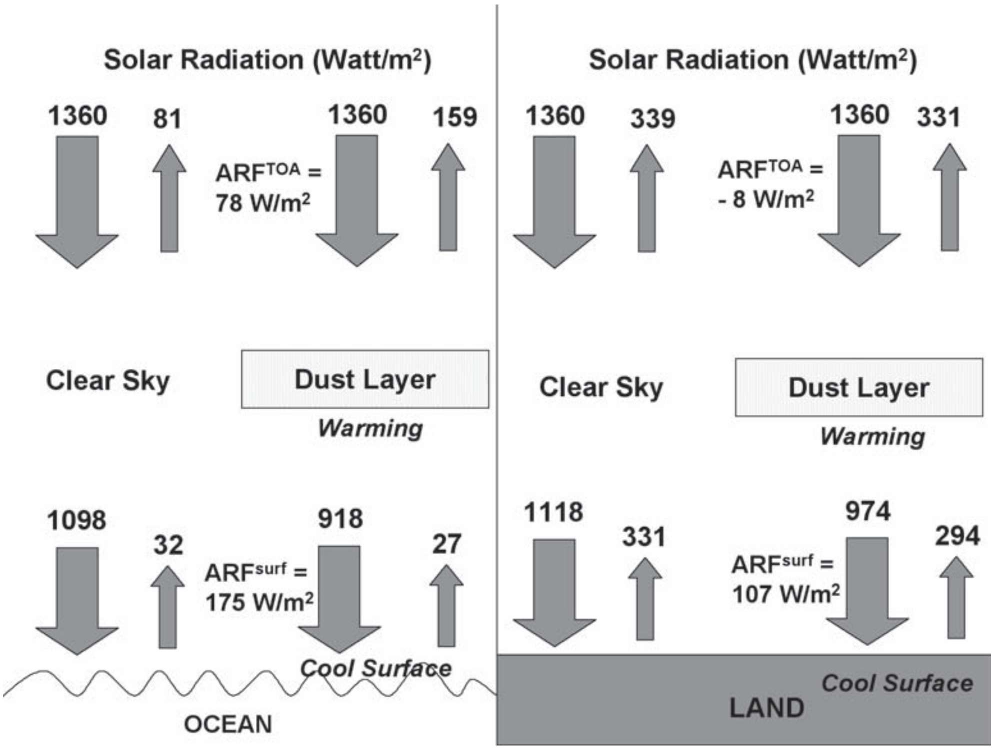

Figure 3 Schematic showing the aerosol radiative forcing induced a dust layer of unit optical thickness over a dark ocean (left panel) and over a bright land surface (right panel).

Himalayas, that the aerosol forcing, combined with the sensible heat flux from the dust layer to the surface, may reverse the sign of the net aerosol forcing at the surface and cause the land surface to warm. The reversal of the meridional gradient in upper tropospheric temperature between the Tibetan Plateau and the oceanic region to the south is known to have a strong control on the timing of the onset and evolution of the Asian monsoon (Li and Yanai, 1996). Therefore, it is possible that, the aerosol-induced differential heating in late spring, amplified through the "elevated heat pump" effect may cause an early reversal of such a temperature gradient subsequently leading to an advance of the monsoon season, and an intensification via induced feedback processes associated with the monsoon water cycle.

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A Cold Pool In The Bay Of Bengal And Its Interaction With The Active–break Cycle Of Monsoon

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1.Introduction

The most important Intra Seasonal Oscillation (ISO) of the Indian summer monsoon is the Active – Break cycle - Rao (1976). The cross equatorial Low Level Jetstream (LLJ) of the monsoon found by Joseph and Raman (1966) and Findlater (1969) with its core near 850 hPa level is closely associated with this cycle. Joseph and Sijikumar (2004) found that during active monsoon spells, the core of the LLJ passes through peninsular India between latitudes 12.5°N and 17.5°N and is associated with a large area of strong cumulonimbus convection in the Bay of Bengal. When the convection weakens there, the LLJ turns clockwise over the Arabian Sea and during the break monsoon that follows the LLJ bypasses India and flows with its core between latitudes 2.5°N and 7.5°N. They also found that the strength of the convective heat source as represented by the Outgoing Longwave Radiation (OLR) over the Bay of Bengal and the strength of the zonal wind at 850 hPa through peninsular India (LLJ) both between latitudes 10°N and 20°N have the highest linear correlation at a lag of 2 to 3 days, OLR leading.

Krishnamurti et al (1988) established an association between the active – break cycle and the fluctuations of Sea Surface Temperature (SST) of the Bay of Bengal. A recent study with data from moored buoys in the north Bay of Bengal (Sengupta and Ravichandran, 2001) has shown a large amplitude ISO of SST during the monsoon season of 1998. Measurements in the Bay of Bengal during field experiments such as BOBMEX (Bhat et al, 2001) and JASMINE (Webster et al, 2002) have shown large amplitude ISO in the net heat flux. There is thus the possibility of active ocean – atmosphere interaction in the active – break cycle of the monsoon.

Since 1998 we have good measurements of 3 day composite SST on a 25 km grid from TRMM Microwave Imager (TMI) for the global region between latitudes 40°S and 40°N. The accuracy of the TMI SSTs is roughly 0.5°C (Wentz, 1998). TMI SST compare well with buoy measured SST in Bay of Bengal (Senan et al 2001). Thus TMI gives accurate and reliable SST measurements at high resolution.

2.The ‘Cold Pool’ of Bay of Bengal

Using TMI SSTs we report on the existence of a large tongue of cold water in the Bay of Bengal during the monsoon season in the latitude belt 3°N to 10°N. It is inbetween two warm pools one around the equator and the other in the north Bay of Bengal. Composite monthly TMI SST of the six years 1998-2003 of June, July and August are shown in Fig.1 (page 17). In the latitude belt 3°N to 10°N a narrow tongue of low SST is seen in June, which expands in length (east -west) and width (north –south) during the following July and August. We have named this the ‘Cold Pool’ of the Bay of Bengal. From June to August the temperature of the Cold Pool falls. It is well known that low level winds of the summer monsoon have an along–shore

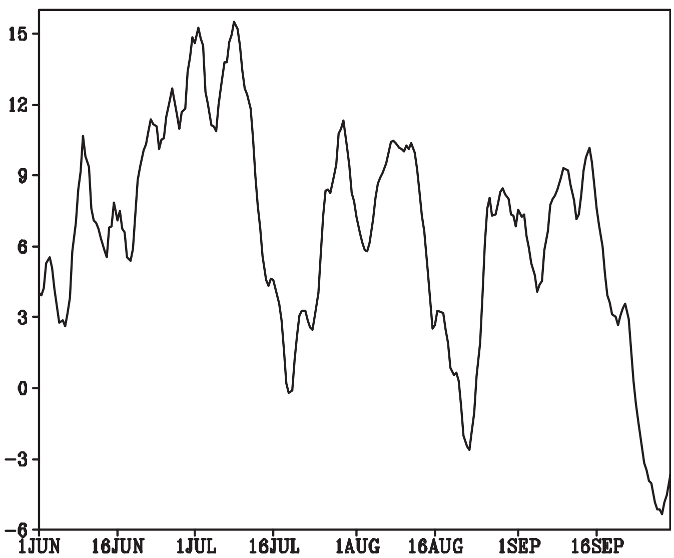

Figure 2: Daily 850 hPa zonal wind in ms^{-1} averaged over the area 70°E-95°E, 12.5°N-17.5°N for the monsoon of 1998. The active and break cycle is seen in the wind speed variation.

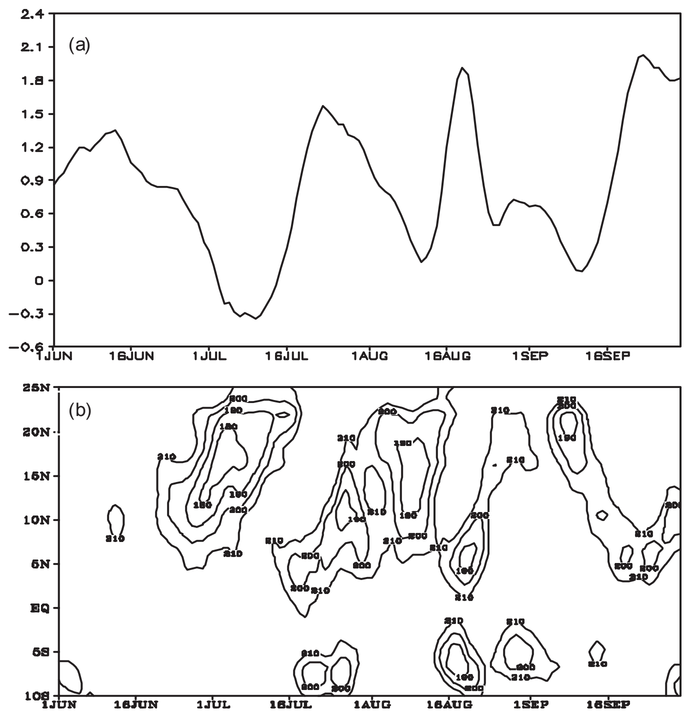

Figure 4: (a) Variation of SST gradient in °C (mean SST of warm pool box minus mean SST of Cold Poolbox as defined in the text) during monsoon 1998. (b) Hovmuller diagram of OLR in Wm^{-2} averaged over longitudes 80°E to 100°E (Bay of Bengal) during 01 June to 30 September 1998.

component over the west coast of Kerala (India) and Sri Lanka which generate strong coastal upwelling. The cold pool could be due to the spreading east of this upwelled cold water by the ocean currents in the Bay of Bengal. That suitable currents exist there has been shown by Vinayachandran et al (1999). Open ocean upwelling during break monsoon spells as described later in section-5 may also contribute.

3.Active – Break Cycle of Monsoon

The studies of Sikka and Gadgil (1980), Yasunari (1981) and Krishnamurti and Subramanyam (1982) have shown a prominent northward propagating monsoon ISO. The picture that emerged from these studies is that an east-west elongated band of deep convection associated with strong monsoon low level westerlies forms near the equatorial Indian Ocean and moves north to the Himalayas at a speed of about half to one degree latitude per day. When the convective band is in the latitude range 10°N-20°N we get an active monsoon, with strong winds at 850 hPa through peninsular India. When the convective cloud band moves north to 20°N -30°N another convective band forms near the equator. This state is the break monsoon. This sequence gets repeated 1-3 times during a monsoon season June to September. Koteswaram (1950) had shown that during the break monsoon spells, low pressure areas form in the Bay of Bengal between latitudes 10°N and 15°N. These lows give widespread rainfall in this latitude belt and the movement of this rain belt northwards brings about active monsoon conditions. From an examination of OLR data of several years it is seen that during the break monsoon, convection forms between the equator and latitude 10°S, but for the break to active transition it is the convection forming north of the cold pool that moves to the northern Bay of Bengal. It appears that the cold pool area is not favourable for deep convection. The current models of northward propagating ISO of monsoon convection require revision.

4. Active-Break cycle of 1998

Active and break monsoon spells could be identified using the 850 hPa wind field as done in several research works of recent decades discussed in Joseph and Sijikumar (2004). Fig.2 gives the variation of the daily zonal wind of 850 hPa level averaged over an area bounded by latitudes 12.5°N and 17.5°N and longitudes 70°E and 95°E for the period of 01 June to 30 September 1998. The strongest winds are during active monsoon conditions. During breaks the wind in this box is very weak. Thus during the monsoon of 1998 there were three active spells and 3 break spells.

Fig. 3 (page 17) gives a Hovmuller diagram of TMI SST for 01 June to 30 September 1998 averaged between longitudes 83°E and 95°E. In the latitude belt 15°N to 20°N we find a large amplitude ISO in SST as discussed

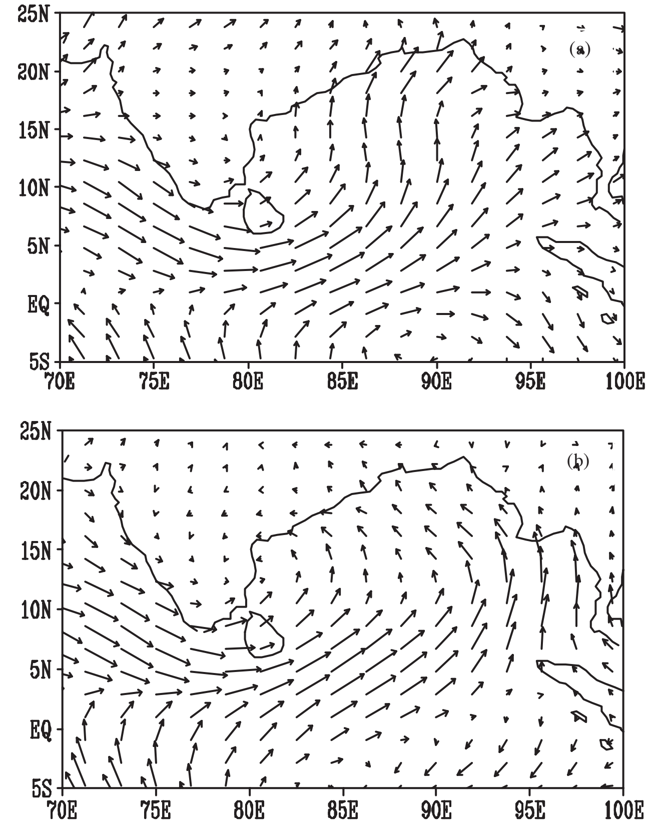

Figure 5: Mean 10m wind during a) 17 to 21 July 1998 and b) 20 to 24 August 1998 showing the wind flow over the Bay of Bengal during typical break monsoon spells.

by Vecchi and Harrison (2002). A prominent ISO in SST is also seen in the Cold Pool area. It is seen that during break monsoon spells the SST in the box (15°N-20°N, 83°E-95°E) covering north Bay of Bengal warms rapidly and that in the Cold Pool box (03°N-10°N, 83°E-9°E) cools, thus making the SST gradient between the two boxes relatively large as may be seen in Fig.4(a). We speculate that one of the factors for the generation of active monsoon convection over the Bay of Bengal is the SST gradient as per the mechanism suggested by Lindzen and Nigam (1987). Vecchi and Harrison (2002) also suggest a similar mechanism but their SST gradient is caused by the variation of SST in the north Bay warm pool box only, where SST variations are caused by variations in net heat flux which is controlled by the surface wind and the convection.

5. ISO of SST in the Cold Pool.

What makes the SST in the Cold Pool area have a strong ISO? In this area SST rapidly cools during break monsoon spells. Joseph and Sijikumar (2004) have shown that the axis of the LLJ is around latitude 5°N during breaks when the cyclonic wind shear zone of the LLJ is over the Cold Pool. Fig.5 shows the wind flow at 10 m level obtained from NCEP reanalysis during two break monsoon spells of 1998. The Cold Pool has strong forcing by cyclonic wind stress curl that can induce strong open ocean upwelling there.

6. Conclusion.

It is seen that the warm pool of the north Bay of Bengal and the newly discovered Cold Pool of south Bay of Bengal have prominent roles in the active break cycle of monsoon. Lead - lag correlation between the daily SST gradient and the daily mean OLR over the Bay of Bengal shows almost simultaneous and large positive correlation of 0.67, which shows that SST gradient becomes large when the Bay of Bengal is cloud free, that is during break monsoon spells. From Fig.4, It is seen that when SST gradient reaches a maximum, convection is triggered just north of the Cold Pool, which later moves north and amplifies taking THE monsoon to an active spell.

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South Asian Monsoon Precipitation Variability: Coupled Climate Model Projections under IPCC AR4

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1. Introduction

Climate modeling groups around the world have been performing an unprecedented set of coordinated 20th and 21st century climate change experiments, in addition to commitment experiments extending to the 22nd century for the Inter-governmental Panel on Climate Change Fourth Assessment Report (IPCC AR4). The resulting multi-model dataset is a unique resource to assess model performance, model sensitivity and model response to a variety of forcing for the 20th through the 22nd century climate and climate change.

The importance of the monsoon rainfall over a vast populated India, in excess of one billion, as a socio-economic feature with its impacts on the agricultural output and the national economy has been well documented. A recent United Nations report also forecasts that India will surpass China as the world's most populous nation by 2030. India is estimated to reach a population of 1.593 billion by 2050. Thus this region of high human population and significant monsoon related economy and food production could be highly vulnerable to climate variability/change. Hence the variation in seasonal monsoon rainfall may be considered as a measure to examine climate variability/change over the Indian monsoon domain in the context of global warming.

In view of the above we have analyzed the 20th century simulated summer monsoon (June through September) precipitation over the Indian landmass and neighborhood for all the available models and runs (to date) with respect to the annual cycle, spatial patterns and inter-annual variability (Kripalani et al 2005). These simulated features are compared with the observed features and how well the models agree with each other. Based on this analysis three models viz. (i) Meteo-France/Centre National de Recherches Meteorologiques, France (acronym cnrm_cm3); (ii) Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies and Frontier Research Center for Global Change (JAMSTEC): Model for Interdisciplinary Research on Climate, Japan (acronym miroc3_2_hires) and (iii) Hadley Center for Climate Prediction and Research / Met Office, UK (acronym ukmo_hadcm3) are selected to examine future precipitation projections.

2. Data and methodology

The IPCC standard output from coupled ocean-atmosphere GCMs is collected and archived by the JSC/CLIVAR WGCM (Working Group on Coupled Models) Climate Simulation Panel and the Program for Climate Model Diagnosis and Inter-comparison (PCMDI) at the Lawrence Livermore National Laboratory, USA. For the status of the IPCC database, model documentation, related references and other information one can visit the website http://www-pcmdi.llnl.gov/ipcc/info_for_analysts.php.

One of the highest priority output fields is the precipitation flux (variable name: pr; units: kg/m^2/s; multiplying by 86400 gives the value in units of mm/day). The monthly data for this variable for the models and all the available runs (based on different initial conditions) under the control run (acronym '20c3m') were downloaded. There are several scenarios under which projections are available. Here we restrict our analysis and examine transient runs under the 1% per year compounded increase in CO_2 until CO_2 doubling (experiment acronym '1pctto2x') and held constant thereafter. Results of the transient run (experiment '1pctto2x') are compared with control run ('20c3m') results.

For all the 3 models runs for 80 years are available under the 1% per year CO_2 increase experiment. However for the model cnrm_cm3 only a further run of 90 years is available under the CO_2 stabilization period. We analyze time slices for the period centered at the time of doubling (i.e. idealized years 61-80 of the transient run designated here as transient1) and, for model cnrm-cm3, 20 years at the end of the CO2 stabilisation period(transient2). These time-slice projections are compared with the mean simulated climatology for the last 20 years under the '20c3m' experiments (control) with the respective models.

3. Projections

3.1 Projected Spatial Patterns

The projected spatial patterns of seasonal rainfall (Figure 1 (page 18)) are depicted as differences from the control expressed as a percentage of the corresponding control rainfall. On an average model cnrm_cm3 shows an increase of 5 to 10% over the land area around the time of CO_2 doubling (Figure 1 (page 18) top left). Even after CO_2 stabilization (top right) there appears to be no further increase in precipitation, except over northeast India. However over the equatorial Indian Ocean there is decrease of rainfall of about 5% for both periods. Model miroc3_2_hires (Figure 1 (page 18) bottom left) shows an increase of nearly 20 to 40 % over northwest India, the southeast peninsula and the eastern equatorial Indian Ocean. Finally model ukmo_hadcm3 shows an increase of 60 to 100% over northwest India and 20 to 40 % over southeast peninsula, a reduction of rainfall over the central Arabian Sea and no substantial change over the equatorial region. In summary the models project more rainfall over the land area in particular over the areas of low rainfall in the control i.e. northwest India and the

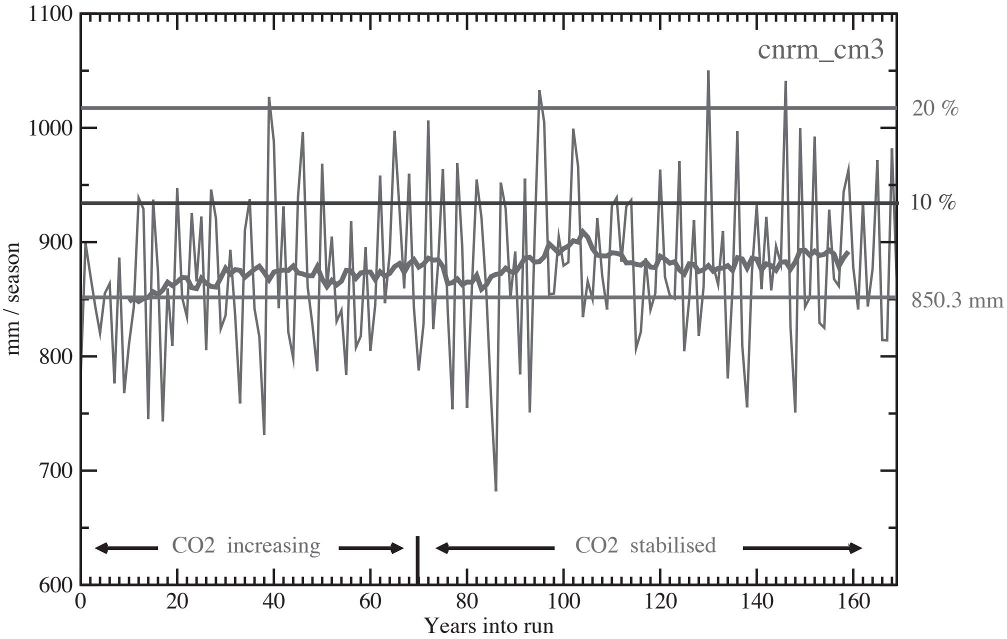

Figure 2: Time series plot of the seasonal rainfall over India for the transient CO2 doubling and stabilization scenarios for the cnrm_cm3 coupled model. The horizontal line of 850.3 mm depicts the control run mean for this model. Lines at 10% and 20% represent values with respect to the control run mean. The solid line super-imposed on the inter-annual variations is a smoothed 21-year low pass filter.

southeast peninsula, and project low rainfall increases (and in the case of cnrm-cm3, a decrease over the oceanic equatorial convergence zone.

3.2 Committed Changes after CO_2 Stabilization

Out of the 3 models discussed, an extended run for the CO_2 stabilized period is available for the cnrm_cm3 model only. Hence we examine the committed changes / projections based on this model in a little more detail. Time series of the summer monsoon rainfall for this model under the control and transient runs have been prepared by averaging rainfall over the Indian landmass. The transient plot is shown in Figure 2. During the period of CO_2 increase, the rate of increase of precipitation appears to be practically constant till the time of doubling and reaches about 4 % in excess of control Thereafter during the period the CO_2 is held constant and allowed to stabilize, the precipitation rate increases faster for about three decades, followed by a decrease with the rate remaining constant thereafter at about 5 % in excess of control

The observed Indian monsoon rainfall exhibits considerable inter-decadal variability with alternate epochs, which last for about 3 decades, of above and below normal rainfall (e.g. Kripalani et al. 2003). Webster et al. (1998) attribute inter-decadal variability of the Pacific Ocean to be the primary factor for decadal scale variation of monsoon activity. Changes in solar irradiance may also be a probable source of this variability. Further the Indian monsoon rainfall also exhibits biennial oscillation (Meehl 1997). Hence to examine whether these dominant low-frequency modes in the seasonal rainfall time series are likely to change in the warming world, wavelet analysis is applied to the control run ('20c3m" 1860-1999) and the transient ('1pctto2x' 1860-2029) run series for the cnrm_cm3 model. Wavelet transform (WT) is a common tool for analyzing localized variation of power within a time series. By decomposing a time series into time-frequency space, one is able to determine both the dominant modes of variability and how those modes vary in time (Torrence and Compo 1998). The computational procedure/algorithm for WT is available on website http://ion.research-systems/IONscript/wavelet.

The wavelet spectrum for the control and transient run is shown in Figure 3 (page 18). The wavelet spectrum for the control run reveals that in general the maximum variance (red color) is centered in the low-frequency 8-64 year periodicity (above panel). However for the transient run during the CO_2 stabilized (lower panel after year 1930) there is a clear indication that the period of oscillation reduces from around 30 years (lower panel 1940-1960) to around 2-4 years (lower panel after 1980), indicating that monsoon rainfall is projected to change from low-frequency to high frequency variability which may be related with the Quasi-biennial oscillation (QBO). This is also apparent in the alternate inter-annual fluctuations after 1980 (Figure 2 last 20-30 years). Since the Indian Ocean has an important role in the QBO (Meehl 1997), this may imply that greater mean monsoon precipitation and its variability could be more related with the Indian Ocean than with the Pacific Ocean in a warming world (Meehl and Arblaster 2003). This is also supported by the fact that the models project reduced rainfall over the equatorial Indian Ocean (Figure 1) and more over land, probably implying that the moisture over the Indian Ocean may be transported towards land.

4. Summary

Future monsoon precipitation scenarios are examined with respect to 3 models. For country as a whole precipitation is projected to increase by about 5%, but regional precipitation over northwest India and southeast peninsula is projected to increase by about 40%. Wavelet Analysis suggests that in the warming world, the low frequency monsoon variability normally associated with the decadal Pacific variability may shift to high frequency variability related with the biennial Indian Ocean Oscillation.

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We acknowledge the international modeling groups for providing their data for analysis, the Program for Climate Model Diagnosis and Inter-comparison (PCMDI) for collecting and archiving the model data, the JSC/CLIVAR Working Group on Coupled Modeling (WGCM) and their Coupled Model Inter-comparison Project (CMIP) and Climate Simulation Panel for organizing the model data activity, and the IPCC WG1 TSU for technical support. The IPCC Data Archive at Lawrence Livermore National Laboratory is supported by the Office of Science, U.S. Department of Energy. Finally, thanks are due to Dr. G.B. Pant, Director, Indian Institute of Tropical Meteorology for encouragement and providing all the facilities to carry out this work at this institute.

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NEW BOOK

EAST ASIAN MONSOON

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Contents:

•East Asian Summer and Winter Monsoon

Seasonal march of East Asian monsoon (Y Ding, Natl Climate Ctr China); Eastern Asian winter monsoon (J Chan, City U Hong Kong, C Li, Chinese Acad Sci); Maritime Continent monsoon (C-P Chang, P Harr; NPS, J McBride BMRC Australia, H Hsu, Natl Taiwan U).

•Interannual Variations

Interannual variability, global teleconnection, potential predictability associated with Asian summer monsoon (W K M Lau, K Kim, J Li; GSFC/NASA); East Asian monsoon-ENSO interactions (B Wang, T Li, U Hawaii); Climate variations of summer monsoon over China (R Huang, CAS).

•General Circulation Modeling

Coupled atmosphere-ocean model simulations of ENSO-related variability (N-C Lau, M Nath, H Wang, Princeton U); Current status of AGCM monsoon simulations (I-S Kang, Seoul Natl U); Simulation studies using the CCSR/NIES AGCM (A Sumi, X Shen, M Kimoto, U Tokyo).

•Synoptic and Mesoscale Processes

Meiyu research during the past quarter century (G T-J Chen, NTU); Large and mesoscale features of Baiu front (K Ninomiya, FRSGC Japan); Oceanic Asian monsoon convection: Results from SCSMEX (R Johnson, P Ciesielski, Colorado State U, T. Keenan, BMRC Australia).

•Interactions with Other Circulations

Monsoon-related tropical cyclones in East Asia (R Elsberry, NPS); Subtropical anticyclone dynamics (G Wu, Y Liu, P Liu, CAS); Maintenance and seasonal transitions of the stationary waves during East Asian monsoon (M Ting, Columbia U, R Joseph, U Illinois).

The Maritime Continent Monsoon

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1. Introduction

The Maritime Continent is a large area of land-sea complex, consisting of Indonesia, Malaysia and the surrounding areas between 10ºS and 10ºN (Ramage 1968). The complex terrain gives rise to strong local variations of the rainfall annual cycle. In addition, the rainfall also exhibits significant interannual variations, and is subject to strong influences of intraseasonal and synoptic scale disturbances. This note is a summary of Chang et al. (2004a,b; 2005a,b).

2. Annual cycles and seasonal transitions

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 equatorial western Pacific. Figure 1 (front cover) shows a clear demarcation of the boreal summer and winter monsoon regimes over the entire region, showing the two regimes intertwining across the equator. There are stronger intrusions of the winter regime northward into the summer regime due to strong northeasterly monsoon winds in the South China Sea and the western Pacific east of the Philippines. These monsoon winds produce strong onshore flow and excess rainfall along the eastern flanks of the major island groups and land masses. During boreal summer, the interaction between the southwest monsoon wind and terrain also affects strongly the distribution of the summer monsoon rainfall, with maximum rainfall occurring on the windward side of terrain in the Indian Ocean, the Indochina Peninsula, and the South China Sea.

Figure 2 (page 18) delineates the asymmetry of the seasonal march between boreal fall and boreal spring. During boreal fall the convection maximum occurs in the eastern Indian Ocean, Malay Peninsula and Sumatra, and southern South China Sea. This general area forms the midpoint of the path of the southeastward progression of convection from the Asian summer monsoon to the Asian winter monsoon. During boreal spring the maximum convection does not retrace the process but stays near and south of the equator. This asymmetric feature is a manifestation of the asymmetric locations of the spring and fall ITCZ noted by many investigators (e.g., Lau and Chan 1983; Meehl 1987; Yatsunari 1991; Matsumoto and Murakami 2000).

The cause of this asymmetry was analyzed from the spring-fall surface pressure differences. The result (not shown) suggests two possible effects: (1) the low-level wind and terrain interactions throughout the region during boreal fall that do not have counterparts in boreal spring, and (2) an intervening region between the equator and 20ºN in the longitudes of Southeast Asia / Maritime Continent that in the low levels has a convergence tendency in boreal fall and a divergence tendency in boreal spring. Both effects can be related to the SLP differences between spring and fall that appear to be the result of the global-scale mass redistribution between the land and ocean regions, which is driven by their different thermal memories. Because of the orientation of the Asian and Australian landmasses, this redistribution facilitates the southeastward march of maximum convection from the Asian summer monsoon to the Asian winter (Australian summer) monsoon, but it deters the reverse march in boreal spring.

3. Interactions of cold surges, synoptic disturbances, and MJO

The western part of the Maritime Continent that surrounds the equatorial South China Sea is influenced by large-scale disturbances that vary over a wide range of time scales: the quasi-biweekly cold surges from the north, the intraseasonal Maddan-Julian Oscillation (MJO) from the west, and the synoptic-scale vortices near the west coast of Borneo. Due to the interaction between northeast monsoon winds and the terrain, these Borneo vortices have the highest frequency of occurrence than any other quasi-stationary synoptic disturbance in the entire equatorial belt.

Nearly 1/3 of boreal winter days have one or more vortex centers in the western Borneo-southern South China Sea region. In days without a Borneo vortex, deep convection tends to be suppressed over the South China Sea and Borneo and enhanced downstream over the landmasses on the western and southern peripheries of the equatorial South China Sea. The pattern is reversed in days with a vortex. The presence of a cold surge enhances these two opposite patterns (Figs. 3a and 3b, page 19). Convection over the southern South China Sea is strongest when both surge and vortex cases are present (Fig. 3b). An extreme case of the interaction between a strong cold surge and a Borneo vortex is the rare formation of Typhoon Vamei near the equator on 26 December 2001 (Chang et al. 2003). However, such a formation is extremely rare because cold surges tend to shift the vortex center towards Borneo, where the vortex is unlikely to intensify into tropical cyclone strength over land.

The frequency of cold surges and vortex days is reduced during periods when the MJO is present, often as a result of the MJO-scale circulation pattern which tends to directly oppose the cold surge wind pattern. Within a MJO cycle the wet phase is associated with a higher cold surge frequency than the dry phase. Primarily due to the impact of the MJO on cold surge intensity and frequency, two-third of the vortex cases occur during non-MJO periods. The Borneo vortex is least likely to appear when the dry phase of the MJO extends to the Maritime

continued on page 21

From Lau et al (page 7) Observational evidenc eof effects of absorbing aerosols on season-to-interanuula anomalies of the Asian Monsoon

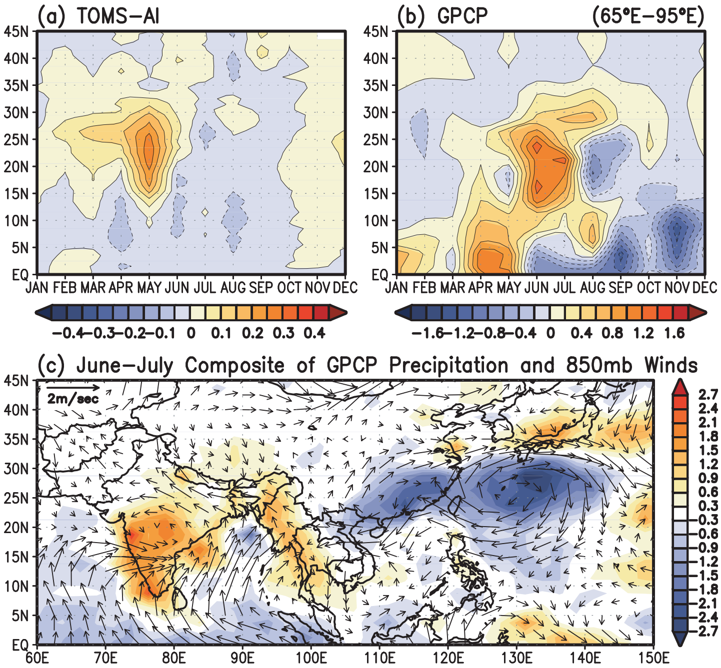

Figure 2 Time-latitude cross-sections showing composite seasonal evolution during year of high AI of a) the AI anomalies, and b) the observed rainfall anomalies, and c) composite of rainfall and 850 hPa wind pattern during years of high AI anomalies.

From Joseph et al page 10: A Cold Pool in the bay of bengal and its interaction with the active-break cycle of monsoon

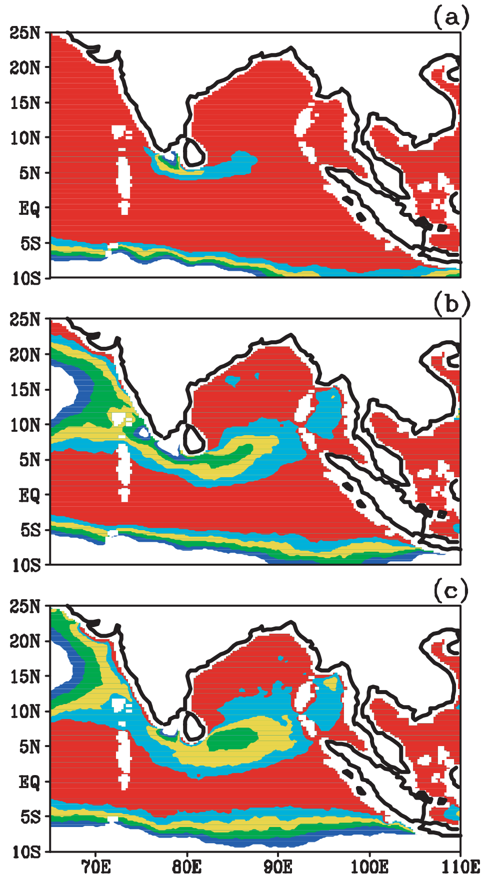

Figure 1: Composite SST (TMI) in °C for a) June, b) July and c) August (1998-2003)

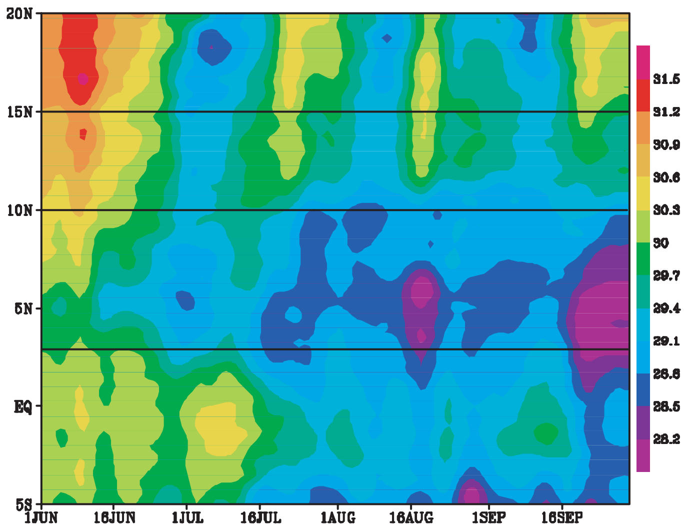

Figure 3: Hovmuller of SST (TMI) in °C averaged over longitudes 83°E-95°E for monsoon 1998. The cold pool between 3°N and 10°N is marked by the lines. The warm pool SST variations are in the zone 15°N to 20°N.

From Kripalani et al, Page 13: South Asian Monsoon Precipitation Variability: Coupled Climate Model Projections under IPCC AR4

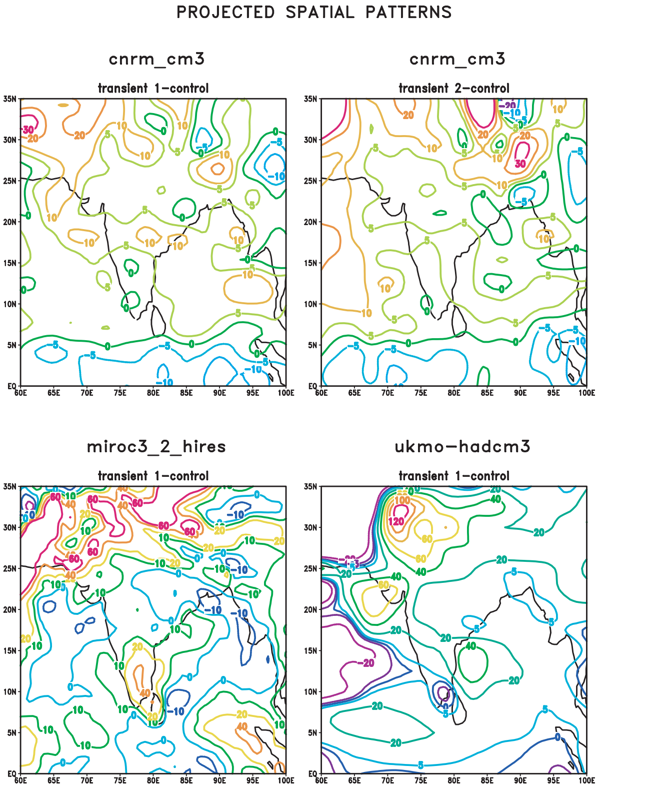

Fig. 1: Spatial patterns of seasonal rainfall as differences between the transient and the control runs expressed as a percentage of the corresponding control (control: average of last 20 years of control run; transient1: average of 20 years centred at the time of CO_2 doubling; transient2: average of last 20 years of the CO_2 stabilization period)

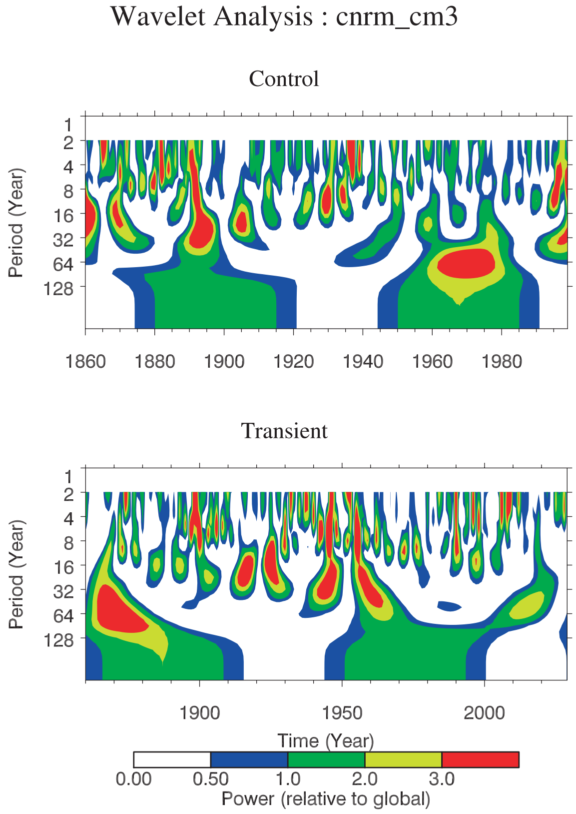

Figure 3 : Wavelet spectrum for the control (above) and the transient (below) runs for the cnrm_cm3 model. The x-axis denotes the scenario years as given in the model outputs and the y-axis the period in years in powers of 2.

From C-P Chang page 16: The Maritime Continent Monsoon

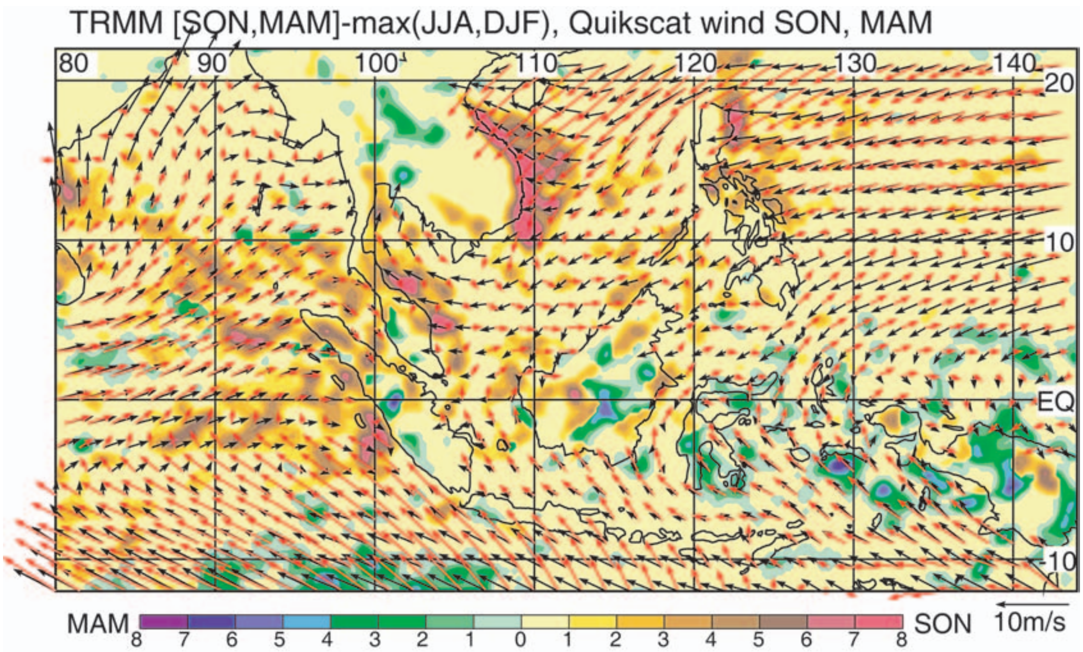

Fig. 2 Monsoon Regimes during transition seasons as defined by TRMM PR rainfall. Warm colors are the boreal fall monsoon regime and cool colors are the boreal spring monsoon regime. The regimes are identified if the rainfall during one of these two seasons is the maximum in the annual cycle, and the values plotted are the differences from the rainfall of winter or summer whichever is highest. QuikSCAT winds of the two seasons are plotted for the entire domain.

From C-P Chang page 16: The Maritime Continent Monsoon

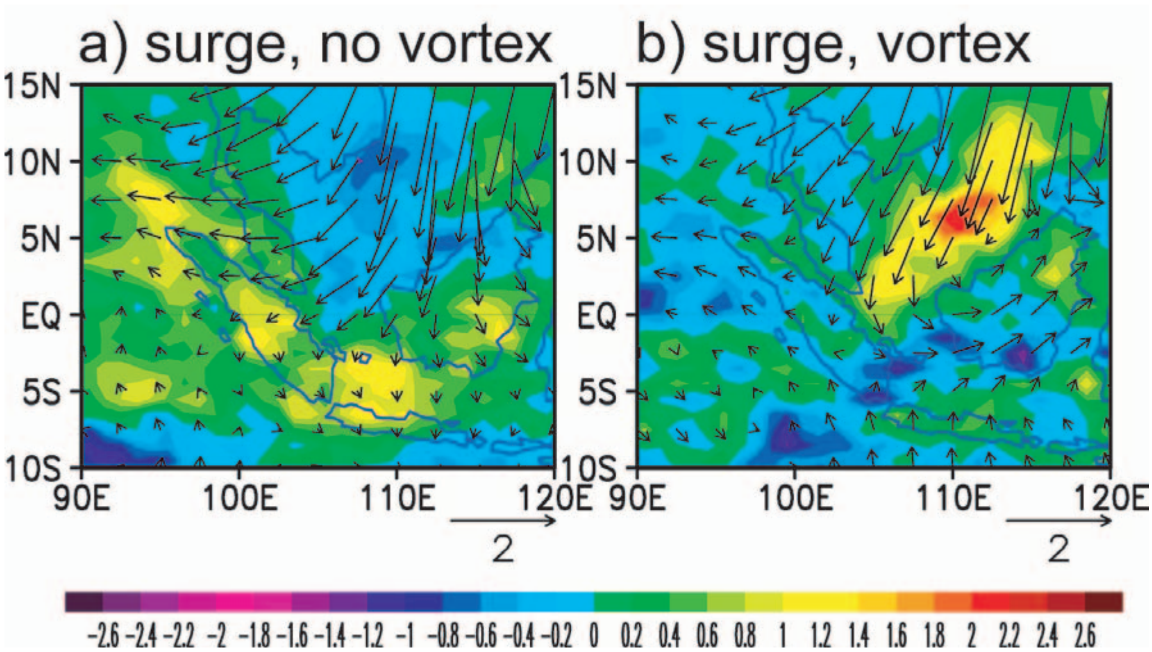

Fig. 3 Composite maps of convective index and 925 hPa winds(m s-1) for (a) surge and no vortex cases, and (b) surge and vortex cases.

From Zhao et al, page 24: Ccharacteristics of diurnal variations of rainfall in China for the recent years

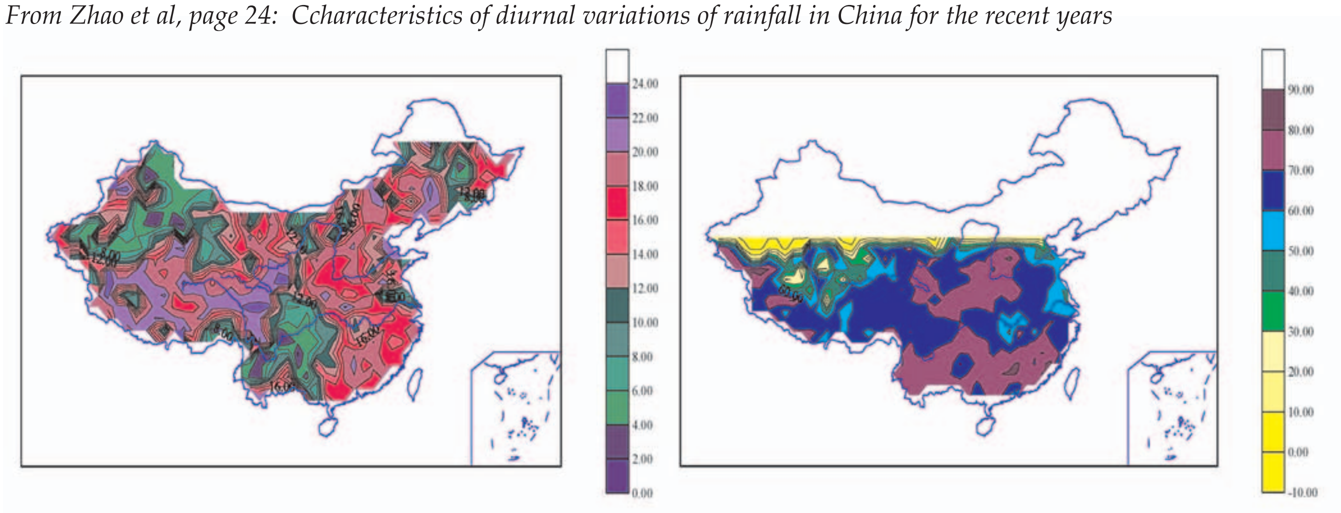

Fig.3 Mean hours of maximum rainfall in summer of 2002~2004 (left) and ratio (%) of convective rain and total rain in summer of 2004 (right) (calculations from TRMM data

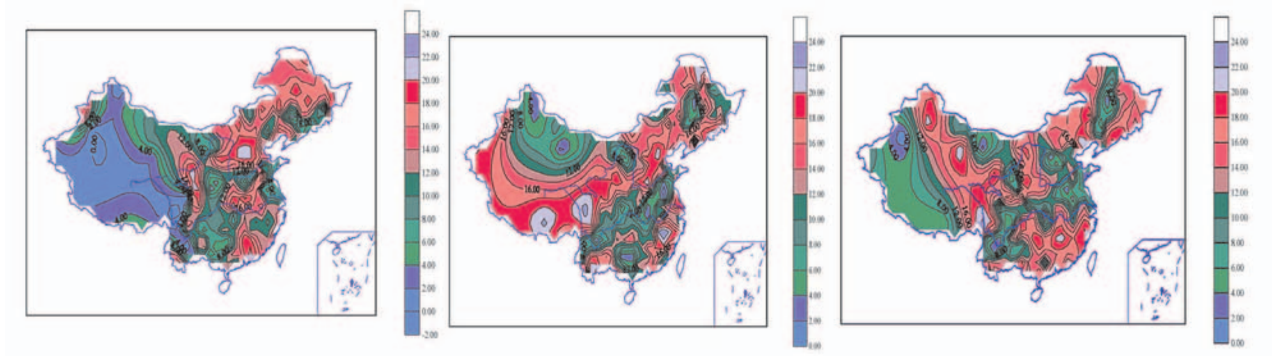

Fig.4 the same as Fig.1 except for June, July and August (from left to right)

From Chaves et al (page 30): Seasonal Climate Prediction for South Amerrica with FSU Multi-model Synthetic superensemble Algorithm.

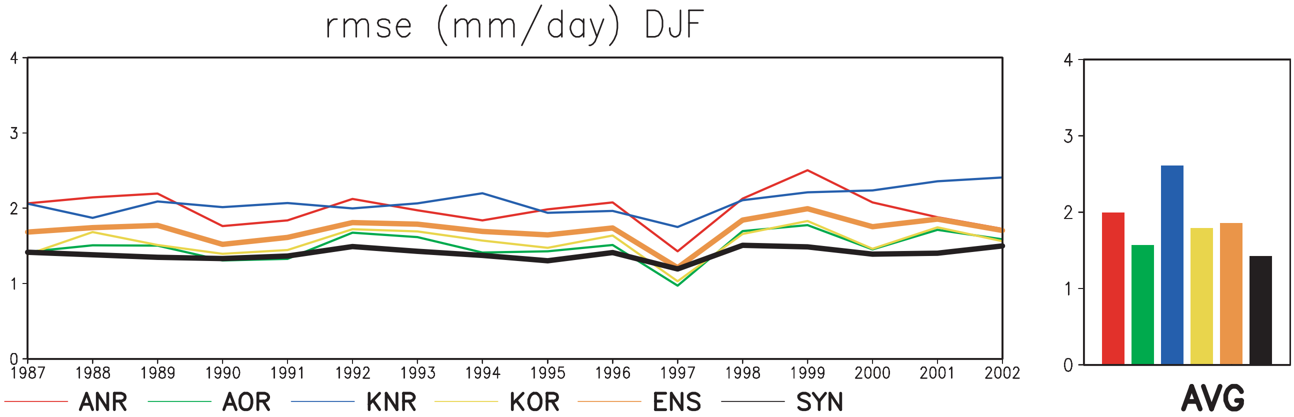

Fig. 1 - Time series of the RMS errors of precipitation forecasts from four 4 FSU models, ensemble mean and synthetic superensemble mean over the South America from DJF 1997/98 to 2002/03 (mm/day). The average over whole period is showed in the right side

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From Druyen et al, page 34: Mesoscale climate analysis over West Africa

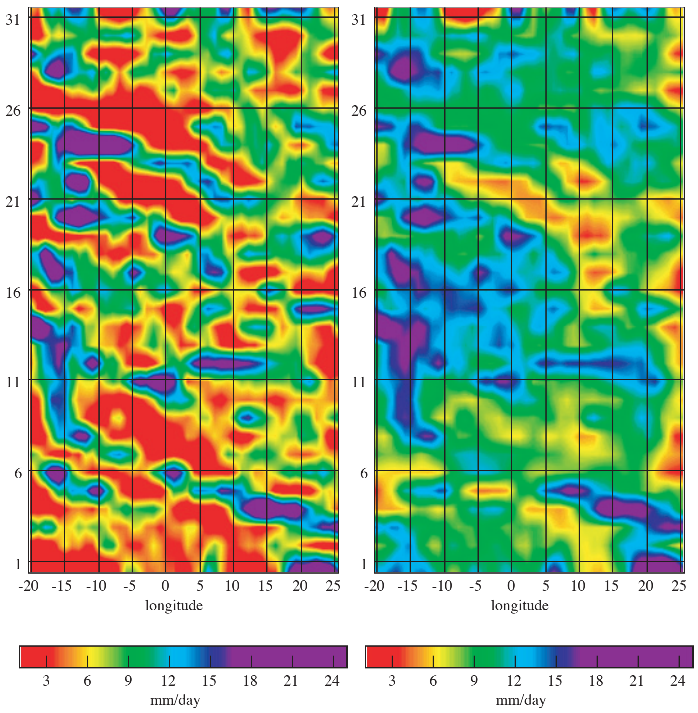

Fig. 1. a,left) Time-longitude distribution of TRMM daily precipitation rates during August 2003, averaged over 5-15°N (courtesy DAAC/GSFC/NASA). b, right) Time-longitude distribution of corresponding RM3 daily precipitation rates.

C-P Chang: continued from page 16

Continent with large-scale low-level diffluence that acts to restrict the impact of cold surges on convection in the southern South China Sea. This complex relationship among MJO, cold surges and the Borneo vortex and the effects of the topography contribute to the variability in western Maritime Continent convection patterns during boreal winter.

4. Relationship with ENSO

There is considerable influence of ENSO on the Indonesian and Australian rainfall but the impact is very weak during the boreal winter season (e.g., McBride and Nicholls 1983; Hendon 2003). The strong effect of the wind-terrain interactions over the Maritime Continent region may lead to local rainfall-ENSO relationships that vary among different sub-regions during northern winter, when the region is affected by cold surges from the north, Indian Ocean zonal wind anomalies from the west, and cross-equatorial flow from the south. During 1979-2002 the correlations between DJF rainfall and Nino3 SST (Fig. 4) are mostly negative over a significant part of the region except in the vicinity of Sumatra and Malay Peninsula, where the correlations range from zero to weakly positive. Thus, low correlations between Indonesian monsoon rainfall and ENSO may result from averaging of rainfall in regions with opposite characteristics. There is also an interdecadal change around the late 1970s with an overall trend that the rainfall is more negatively correlated with ENSO in the recent decades. However, the correlations remain lower than those of the dry (boreal summer) and transition (boreal fall) seasons. This is especially so for January, which has consistently insignificant correlations for all regions and decadal periods.

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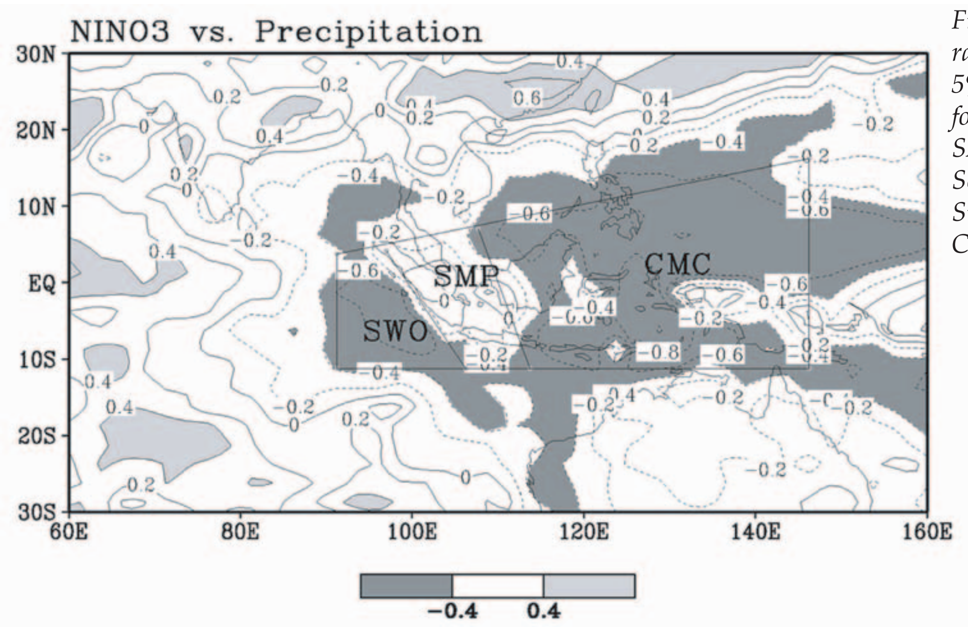

Fig. 4 Correlations of 1979-2002 CMAP rainfall with Nino3 SST. Areas above the 5% significance level are shaded. The following rainfall regions are delineated: SMP: Sumatra-Malay Peninsula; SWO: Southwest oceanic area southwest of Sumatra; and CMC: Central Maritime Continent.

Sea Surface Temperature in the Bay of Bengal as a Predictor for Monsoon Rainfall in Bangladesh: A Canonical Correlation Analysis

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Introduction

Bangladesh extends from 20° 45'N to 26° 40'N latitudes, and from 88° 05'E to 92° 40'E longitudes. Most of the country is a low plain, with hills in the southeastern parts of the country. However, the country is surrounded by the Assam Hills to the east, by the Meghalaya Plateau to the north, with the lofty Himalayas beyond. The Bay of Bengal, which lies to the south of the country, extends from 0° to 20° N latitudes and 80° to 95° E longitudes (Fig. 1).

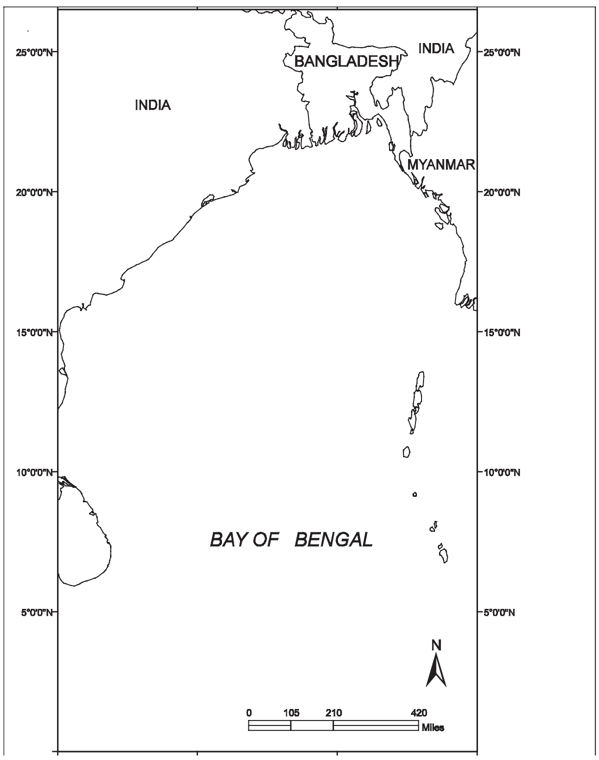

Figure 1. Study area showing location of the Bay of Bengal and Bangladesh

Bangladesh climate is characterized by a cool dry season, a hot humid summer season, and the rainy monsoon season. Less than 5 percent of the annual rainfall occurs during the dry season. March through to April is the pre-monsoon hot season. It is characterized by high temperatures and the occurrence of convective storms. Rainfall during this season accounts for 15 to 20 percent of the annual rainfall.

The rainy season, which coincides the monsoon season with the summer monsoon season, prevails from early June through the middle of October. The June rainfall in Bangladesh is important for the variability and vulnerability of rain-fed aman (variety needs rainwater) rice productivity during the monsoon season (Mahmood et al., 2003). During the monsoon season 75 to 80 percent of the annual rainfall occurs (Ahmed and Karmakar, 1993). Southerly and southeasterly winds, widespread cloud cover, high humidity, and long spells of rain characterize this season. Rainfall is caused by the tropical depressions that enter Bangladesh from the Bay of Bengal.

Monsoon failure often brings famine to the affected regions, and strong monsoon years can result in devastating floods. An accurate long-lead prediction of monsoon rainfall can improve planning to mitigate the diverse impact of monsoon variability. Monsoon prediction studies use atmospheric circulation, land surface conditions, and oceanic SSTs. The teleconnection between Bay of Bengal SST and monsoon rainfall in Bangladesh has not been addressed by previous studies.

Data

The present study used monthly rainfall data for Bangladesh from 1912 to 2001 for twelve stations (Fig. 2) and monthly SST of the Bay of Bengal for the period of 1912 through 2001 at 2°x2° grid cells from the Comprehensive Ocean-Atmosphere Data Set (COADS). The area encompasses the Bay of Bengal and consists of 80 grid cells. The 90-year rainfall data are collected from the Department of Earth and Planetary Science at the University of Tokyo, Japan. This department has collected these data partly from the unpublished Data provided by the Bangladesh Meteorological Department (BMD) and the Indian Meteorology Department (IMD), and partly from the publications of Indian Weather Review, and Monthly Rainfall of India, published by the IMD and the Pakistan Weather Review published by the Pakistan Meteorological Department (PMD). The long-term rainfall data covers all four regions (northeast, northwest, southeast, and southwest) of the country. Monsoon rainfall from June to September is considered. The pre-monsoon month of May has also been taken into consideration in the analysis to determine any lag relationships between SST and monsoon rainfall in Bangladesh. The total number of observations for each station is 450.

Statistical Model

In order to understand and explore the notion of the signature pattern in the Bay of Bengal SST and its predictive relationship with monsoon rainfall in Bangladesh, a statistical model is used for analysis of the present data sets. It is thought that the SST of Bay of

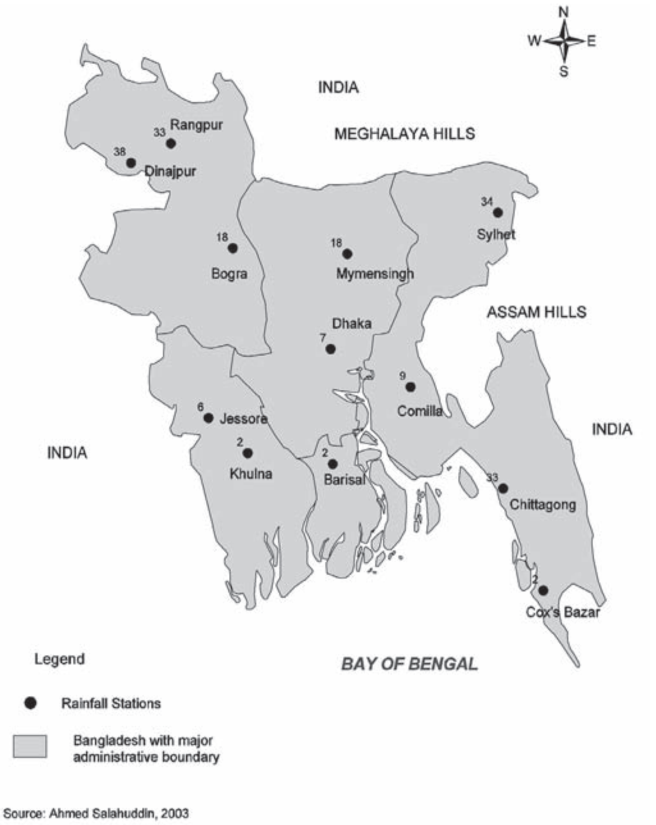

Figure 2. Selected rainfall stations and their elevation (in meter) from the mean sea level

Bengal will be predictive for analyzing the rainfall both spatially and temporally. The model used for the data set analysis is the Canonical Correlation Analysis (CCA).

The fundamental equation for the canonical correlation used for the study is $\boldsymbol{R} = \boldsymbol{R}_{yy}^{-1}\,\boldsymbol{R}_{yx}\boldsymbol{R}_{xx}^{-1}\,\boldsymbol{R}_{xy}$ where

$\boldsymbol{R}_{yy}$ = correlations between the variables in criterion set; $\boldsymbol{R}_{xx}$ = the correlations between the variables in predictor set, and $\boldsymbol{R}_{xy}$ and $\boldsymbol{R}_{yx}$ are the two matrices of correlation between criterion and predictor sets. A significance test is performed to see whether one or a set of canonical correlation differs from zero (Monmonier and Finn, 1973).

Results and Discussion

There is a significant positive (0.64) relationship between the June through September All-Bangladesh Monsoon Rainfall (ABMR) and SST over the Bay of Bengal in the month of June. The first canonical vector has the highest negative canonical coefficient (0.405) at 81° longitude and the highest positive coefficient (0.591) at 87° longitude. This reveals that the SST in the Bay of Bengal has a strong longitudinal dependence, but does not significantly change with latitude. The only significant canonical weight is found in station Comilla on the criteria set (Fig. 3). The first canonical vector thus indicates that rainfall in station Comilla is positively correlated with sea surface temperature in the western Bay of Bengal.

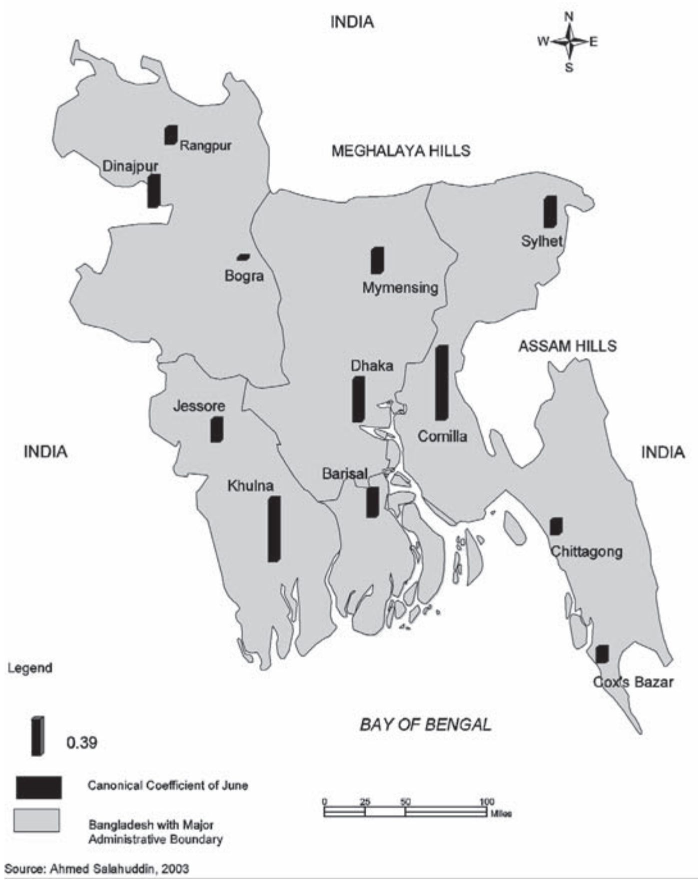

Figure 3. June canonical coefficient for criterion (rainfall) set

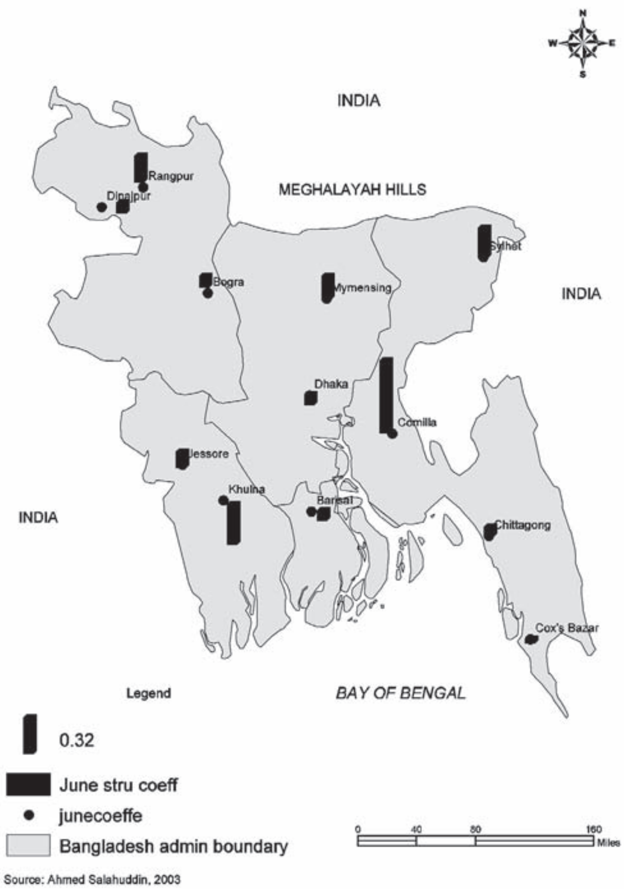

Figure 4. June structure coefficient for criterion (rainfall) set

The first canonical variate pair in the predictor set shows largest correlation at 93° longitude (0.396). For the first canonical variate pair in the criterion set, the largest correlation is Comilla (0.404). The interpretation of the first pair is that rainfall in station Comilla is related to the sea surface temperature at 93° longitude. This may be caused by the low-pressure gradient formed in the southern part of the Bay of Bengal. The value of the first canonical variate pair is presented in Fig. 4. The figure shows that the rainfall in Khulna station is negatively (0.358) correlated with the SST of the Bay of Bengal. This negative relationship is perhaps due to the windward location of the station and tracks of the monsoon depressions that enter Bangladesh from the Bay of Bengal during the summer monsoon season. The negative correlation relationship might be affected by the Sundarbans mangrove forest in the south. Looking for the power to predict the relationship between SST and rainfall it is seen that the squared canonical correlation coefficient, i.e., eigenvalues, suggest that the first set of weighted variable has substantially more variance (40.4 percent) than does the remaining set of variate scores. This result suggests that the first function is the most helpful in interpreting relationships across the two variable sets.

In summary, SST immediately south of Bangladesh, between 87°E and 93°E in June is most significantly related to June rainfall in Comilla. Here the wind is southeasterly, due to the deflection of wind by the coastal hills. The orographic effect in the east and northeastern part of the country enhances the rainfall amount in that area.

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Characteristics of diurnal variations of rainfall in China for the recent years

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Abstract

Based on both observational data of hourly precipitation at 194 Chinese international exchange stations and TRMM/NASA/NASDA satellite data, characteristics of diurnal variations of rainfall in China for four seasons of the recent years (2002-2004) have been investigated, especially for summer.

1. Introduction

China is located in the East Asian monsoon region. Most rainfall occurs in the summer. Heavy rainfall over several hours might cause economic losses as well as losses of life in China. Therefore, scientists have paid much attention to the seasonal and annual predictions of floods and heavy rainfall by numerical models.

Some researches have concentrated on the diurnal variations of precipitation by using the observed stations data in the USA (Dai et al., 1999; Trenberth et al., 2004). Data from TRMM TMI (NASA/NASDA, USA and Japan) and CLAUS (EU) in the tropical regions have shown the time of maximum rainfall in summer to be during the late afternoon and early evening (16:00-19:00) over the tropical land regions, including some parts of China (south of 40N) (Yang and Slingo, 2001; Nesbitt and Zipser, 2003; Nakamura, 2004; Furuzawa, personal communication).

In the research reported here, we focus on the characteristics of diurnal variations of rainfall in China for recent years (2002-2004).

2. Data and methods

The observed hourly rainfall data at 194 international exchange stations of China for 2002 and 2003 were provided by the Data Division of the National Meteorological Center, China Meteorological Administration. Due to lack of data or no rainfall at some stations, about 170~180 stations were used in the research. For investigation of diurnal cycles of rainfall, the seasonal averages of hourly rainfall amount, intensity, and maximum and minimum hours during 2002, 2003 and the means of 2002 and 2003 were calculated. Four seasons were selected: summer (June-July-August), autumn (September-October), spring (April-May) and winter (November-December-January-February-March). The hourly data were indicated by the local time.

For comparing with the station data, three hourly averaged TRMM/NASA/NASDA data (Tropical Rainfall Measuring Mission, http://lake.nascom.nasa.gov/tovas/3B42RT) over East Asia and China (resolution 0.25x0.25 degrees, south of 50N) for summer (JJA) of 2002-2004 have also been used.

3. Results

(1) Climate mean patterns of maximum intensity and hour

For the means of 2002 and 2003, Fig.1 shows the patterns of hours and intensities at which maximum hourly rainfall for both spring and summer seasons occurred. close examination of these shows that the maximum rainfall occurred at the afternoon (13:00-20:00) for Spring and

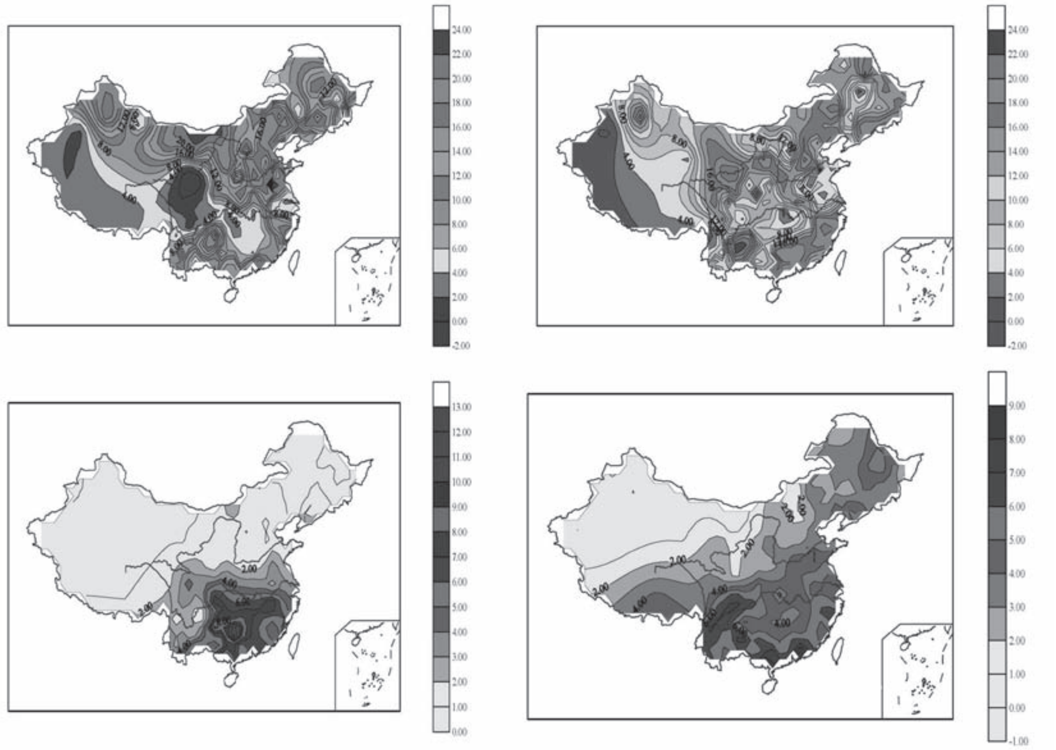

Fig.1 Geographical distributions of the hours (upper) and intensities (unit: X 0.1mm/hr) (bottom) at which occurred maximum rainfall in AM (left) and JJA (right) for the means of 2002 and 2003

Summer in Northeast China, central and eastern Inner-Mongolia, Huabei (northern-central China), Huadong (Southeast China) and Huanan (Southern-south China). It is also found that the hours of maximum rainfall appeared at night and early morning (21:00-4:00) in Xizang (Tibetan Plateau) and Southwest China for the most seasons, and at the morning time in Huai River, Huazhong (Central China), Xinjiang and Northwest China for summer. In addition, in some parts of China and some seasons there were no obvious diurnal variations.

(2) Characteristics in sub-regions

Fig.2 (page 26) shows the diurnal variations of rainfall in six sub-regions of China for the summer season (JJA) of 2002-2004. The data are averages based on both TRMM/NASA and situ data. Both satellite data and station data show similar results. We see that the maximum rainfall occurs in late afternoon (around local time 17:00) in most regions. There are weaker diurnal cycles over the arid regions such as Xinjiang and Northwestern parts of China in which the total rainfall was only about 0~50 mm per year. Maximum intensities of 0.30~0.45mm/hr in South China and 0.15~0.25mm/hr in North China were found for the summer period averaged by 92 days for both 2002-2004 and 2002-2003. The minimum hourly rainfall in most parts of the Yangtze and Huaihe River Valley (YZHH) occurred at midnight and early morning.

(3) Possible relations between maximum hour and convective rain

Generally speaking, convective rain was 50-75% of the total rain in summer. It is found that the higher ratios (percentages) of convective rain corresponded to maxima at late afternoon and early evening (15:00-20:00) (Fig.3 page 19).

(4) Large scale synoptic systems and hours of maximum rainfall

Heavy rainfall in China is caused by many factors, such as the large-scale circulation background and synoptic patterns, as well as the local climatic characters. It also links with several special phenomena such as the East Asian winter and summer monsoons, Mei-Yu (May, June and July), typhoons and tropical cyclones. As an example, the hours of maximum rainfall in summer change with time (months) due to different synoptic systems and local characteristics, such as the locations and intensities of the sub-tropical High at 500 hPa that causes the varying locations of rain belts in China. General speaking, the rainbelts are located in the South of Yangtze River for June, between the Yangtze and Huaihe Rivers in July, and along the Yellow River in August, respectively. Therefore, the hours of maximum rainfall in those regions appear in the morning rather than late afternoon and early evening (Fig.4 page 19).

4. Conclusions and discussions

Our researches have indicated that the diurnal variations of rainfall in China are more complicated than in the tropics. Based on the observational data of both situ and satellite for the recent years (2002-2004), and consistent with previous researches, there were clear signals of diurnal cycles in China for summer. The hours of maximum rainfall over the most parts of East China (east of 110E) occurred at late afternoon and early evening (15:00-20:00), except for the lower reaches of Yellow and Huai Rivers, middle reaches of Yangtze River, and Central parts of Northeast China in which they occurred in the morning. There was a midnight and early morning maximum in the most parts of West China, except for Gansu and Shannxi Provinces. The larger convective rain in summer corresponded to the maximum rainfall at late afternoon and early evening.

The interactions between land and sea and the effects of the complicated topographies also caused different patterns.

In future, the observed hourly data of more years will be added. A regional climate model will also be used to simulate the periods of this study and to investigate the relative physical mechanisms involved.

Acknowledgements
This research was supported by PNNL (USA). We sincerely thank Data Division of National Meteorological Center (China) for the hourly data (2002~2003) and TRMM/NASA/NASDA for the satellite data (2002~2004), Zhong Liu for the TRMM data information, Jinhong Zhu and Daoyi Gong for plotting-software in China, and W.Gustafson Jr. for help with computing. The first author also thanks PNNL and NCC for their support.

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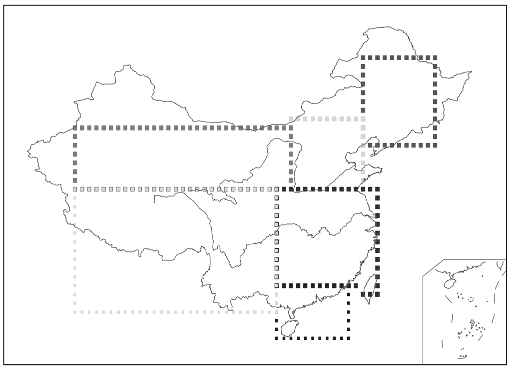
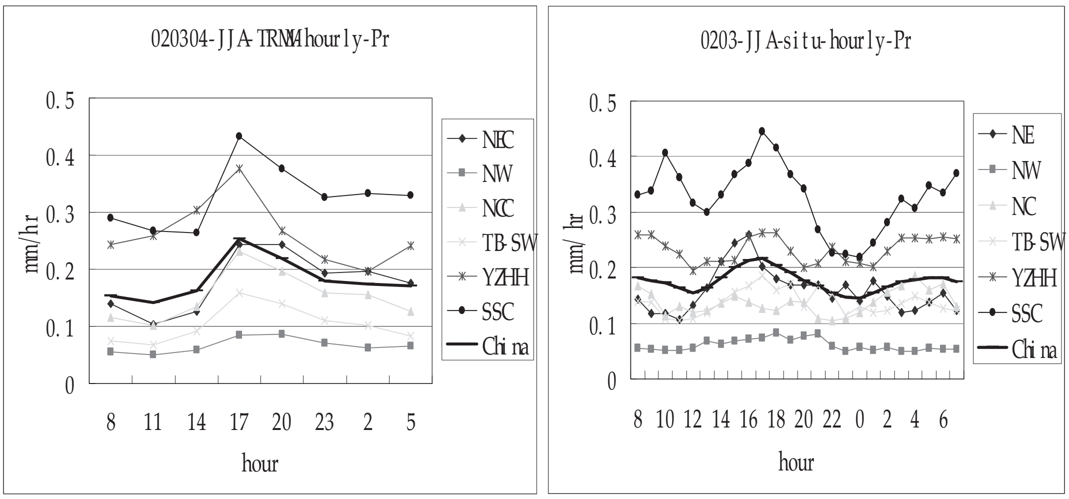


Fig.2 Diurnal variations of rainfall in six sub-regions of China (left) for summer (JJA) of 2002~2004 means (bottom left: TRMM data at local time) (right: based on the station data of China) NEC: Northeast China, NW: Northwest China, NCC: North China, TB-SW: Tibetan Plateau and Southwest China, YZHH: Yangtze and Huaihe River Valley, SSC: southern China. The locations are indicated in the top figure.



Weakening trend of monsoon Low Level Jetstream through India 1950 to 2003

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Introduction

A strong cross-equatorial Low Level Jetstream (LLJ) with its core close to the 850hPa level exists over the Indian Ocean and south Asia during the summer monsoon season June to September - Joseph and Raman (1966) and Findlater (1969). The LLJ has two main functions. It is a conduit carrying the moisture generated by the trade winds over the south Indian Ocean and the evaporative flux from the Arabian Sea to the areas of monsoon rainfall production over south Asia. In addition the cyclonic vorticity north of the LLJ axis in the atmospheric boundary layer is a dynamic forcing for the generation of vertical upward air motion and rainfall and for the genesis of monsoon depressions in north Bay of Bengal.

The Asian summer monsoon has a strong Intra Seasonal Oscillation (ISO), the active-break cycle. Active monsoon spells last 2 to 4 weeks when most parts of India get copious rainfall. During break monsoon spells that last 1 to 3 weeks most parts of India have highly deficient rainfall and the rainfall is abundant only over northeast India, the Himalayan slopes and extreme southeast India. A recent study by Joseph and Sijikumar (2004) has shown that during the active monsoon the core of the LLJ passes eastward through peninsular India between latitudes 12.5N and 17.5N. In the break monsoon the LLJ moves southeastwards from the central Arabian sea and by-passing India passes eastward between latitudes 2.5N and 7.5N. Figure 1 shows the LLJ as composites of large number of active and break monsoon spells of the period 1979 to 1990, extracted form Joseph and Sijikumar (2004).

Long term changes in zonal flow through India

Figure 2 (a) gives the June to September zonal (u) component of wind at 850hPa level for each year of the period 1950 to 2003 averaged over area-A marked in Figure 1 bounded by latitudes 10N and 20N and longitudes 70E and 80E. The wind data are from the global data sets generated on a twice-daily time scale in the NCEP-NCAR reanalysis project – Kalnay et al. (1996). The monsoon flow through the box-A during 1950 – 2003 has a statistically significant decreasing trend (of 18%). One possible cause for this decrease could be the increase in the duration of the break monsoon spells. Break monsoon spells could be identified using 850hPa wind field as done by several researchers over the recent decade discussed in Joseph and Sijikumar (2004). Defining a break monsoon day as one with mean zonal wind of 850hPa of box-A less than or equal to $9ms^{-1}$, the number of such days during June to September of each year are shown in Figure 2(b). Linear trend shows that the number of break monsoon days per monsoon season has increased by 31%.

Long term changes in the daily monsoon rainfall of India

It is found that the linear correlation between the daily rainfall of India and the strength of the zonal wind averaged over the peninsular India box –A during the monsoon season is very high and statistically significant. IITM Pune has derived time series of the daily averaged rainfall of India. Kumar and Desai (2004) have described this series and shown that break monsoon can be defined as days with daily rainfall of India less than 9mm per day. Fig.2(c) gives the number of such break monsoon days in each monsoon season of the period 1950 to 2002. Linear trend shows that the number of break monsoon days per monsoon season has increased by 33%. Increasing trend is particularly prominent after 1980 as seen from the seven year moving average.

Long term changes in Monsoon Depression frequency

One of the favourable conditions for the genesis of monsoon depressions in the north Bay of Bengal is the presence of a strong LLJ through peninsular India – Sikka (1977). It is also known that monsoon depressions do not form during break monsoon periods – Rao (1976). Thus from the preceeding descriptions of the decrease in the zonal westerlies through peninsular India and the increase in the number of break days one may speculate a decreasing trend in the number of monsoon depressions per monsoon season. This is what has happened as may be seen from Figure 2(d). The decrease of monsoon depression frequency is particularly steep after 1980. In 2002 there were no monsoon depressions a record for the previous 130 years. Depression frequency data for the period 1950 to 1990 were taken from IMD (1996). Similar data for each of the later years are taken from IMD's Quarterly Journal of Meteorology – MAUSAM.

Cross equatorial flow and monsoon rainfall of India

After a long period (1988 to 2001) of consecutive years of good monsoon rainfall, India had two monsoon droughts in 2002 (Gadgil et al, 2002) and in 2004. As a result of the weakening of the monsoon current through peninsular India will there be frequent monsoon droughts in India in the coming years? That the droughts of 2002 and 2004 were associated with month long spells of break monsoon adds strength to this speculation. Parthasarthy et. al (1994) has derived a time series for the Indian Summer Monsoon Rainfall (ISMR) of 1 June to 30 September as defined in their paper which has been updated by IITM Pune in their website. This time series shown in Figure 3(a) has only decadal variations and no significant linear trend. To find out how the seasonal monsoon rainfall of India was not affected by the decreasing trend in the

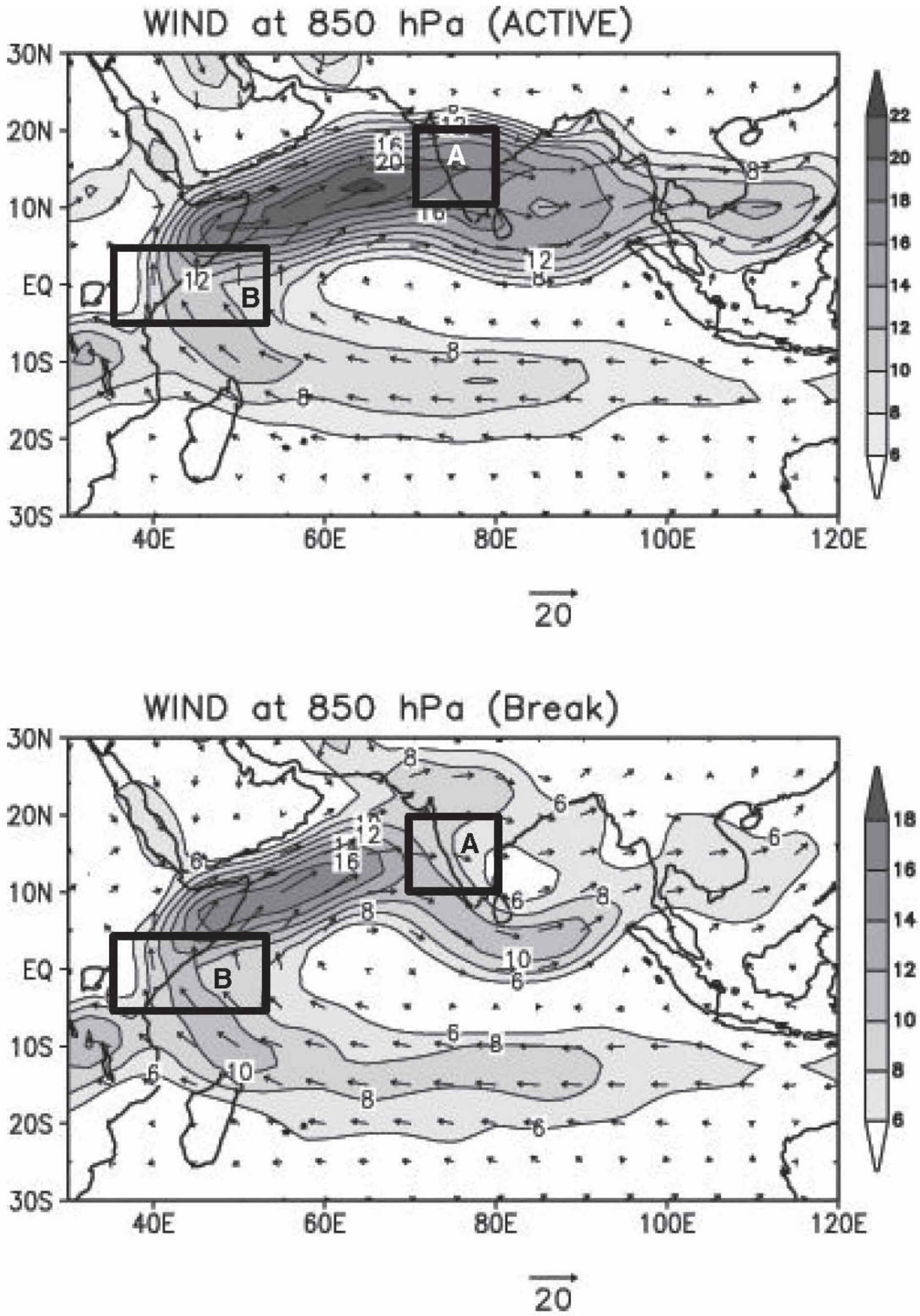

Fig. 1:- Composites for active and break monsoon days during June to August of 1979 to 1990 extracted from Joseph and Sijikumar (2004). Top figure gives the wind flow at 850hPa in m/s for active spells and bottom figure the wind flow at 850hPa for break spells.

zonal westerlies through peninsular India, we examined the cross equatorial flow of the LLJ. The meridional (v-component) of monsoon flow during each monsoon season at 850hPa averaged over the box-B bounded by latitudes 5S and 5N and longitudes 35E and 55E is shown in Figure 3(b). This flow has only decadal variations and no significant long term trend. For the period 1950 to 2002 the correlation coefficient between the mean monsoon zonal wind of box-A and ISMR is 0.65 and that between the mean monsoon meridional wind of box-B and ISMR is 0.64. The multiple correlation among these three parameters is 0.72. All these correlations are high and statistically very significant. The cross equatorial meridional flow brings to India the moisture produced over the south Indian Ocean through the LLJ and the zonal flow through India gives the dynamics for the monsoon rainfall of India. During the period 1975 to 1995 when the zonal flow through box-A was decreasing, the meridional flow through box-B was increasing. After 1995 the zonal flow continued to decrease but the meridional flow has become steady and is showing a tendency to decrease.

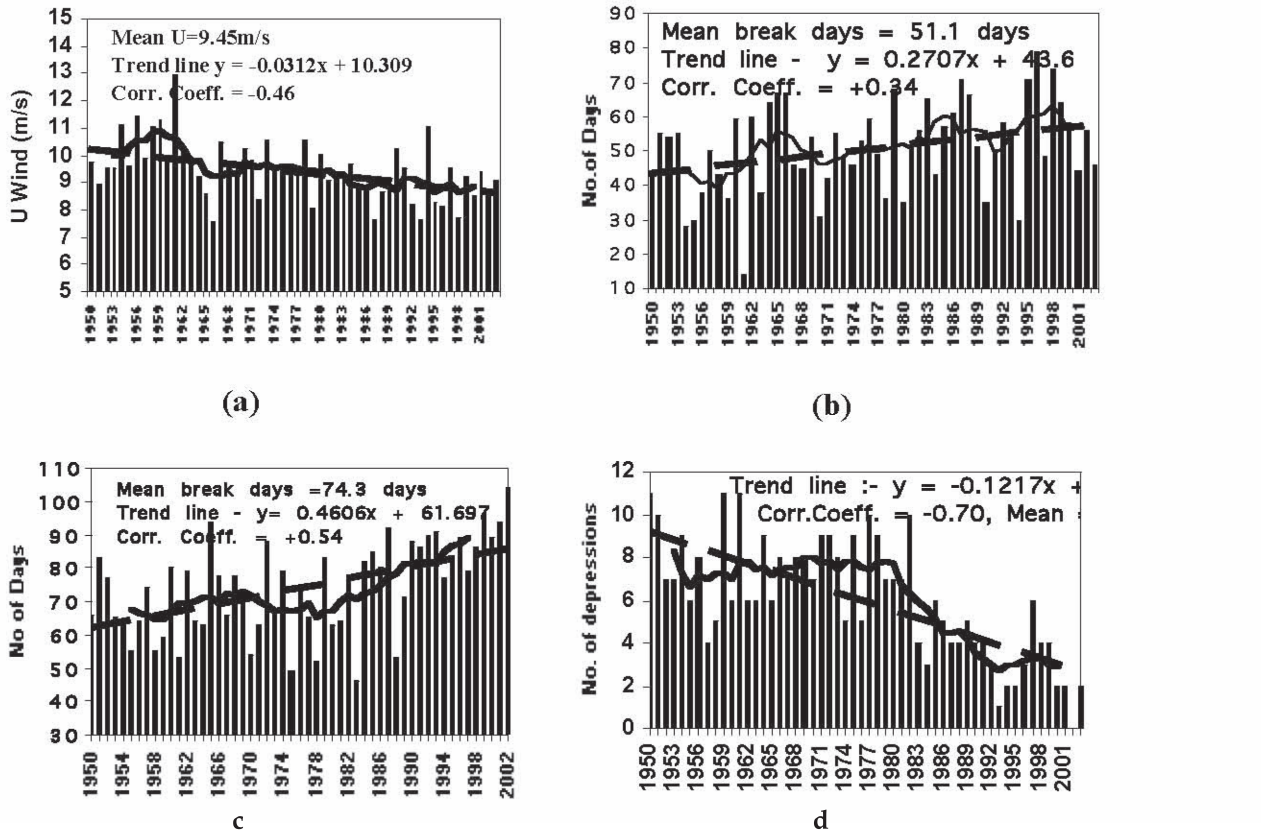

Fig. 2:- Long-term change during 1950 to 2003 of (a) Average 850hPa zonal wind during monsoon season over box-A (A as in Fig.1) (b) & (c) Number of break monsoon days per monsoon season as defined by 850hPa zonal wind and daily rainfall of India respectively and (d) Number of monsoon depressions per monsoon season. The linear trend lines are marked by the broken lines. The thick lines show 7-year moving averages. All linear trends are statistically significant. Correlation coefficients shown are between the parameters represented by x and y-axes.

Conclusions

Modelling and diagnostic studies are needed to understand the factors that control the zonal and meridional monsoon flows discussed in this paper. From the current knowledge it could be inferred that if convective activity during the monsoon season increases in the western Pacific north of the equator it could decrease the strength of the zonal flow through India and increase the duration of break monsoon spells. The observed increasing frequency of tropical cyclones over the northwest Pacific Ocean since 1980 could be an indicator that such changes are occurring. The authors are now studying the 850hPa and 200hPa velocity potential fields to understand the long term changes in the atmospheric diabatic heating patterns. Meridional flows may be affected by changes taking place over the Asian continent. Finally it has to be seen what role global warming has in the long term changes discussed in this paper. Attention of readers is drawn to Stephenson et al. (2001) who have shown that the monsoon wind shear indices of Webster and Yang (1992) and Goswami et al. (1999) have been decreasing at a rate of 0.1 – 0.3% per year based on NCEP/NCAR reanalysis data (1958-1998).

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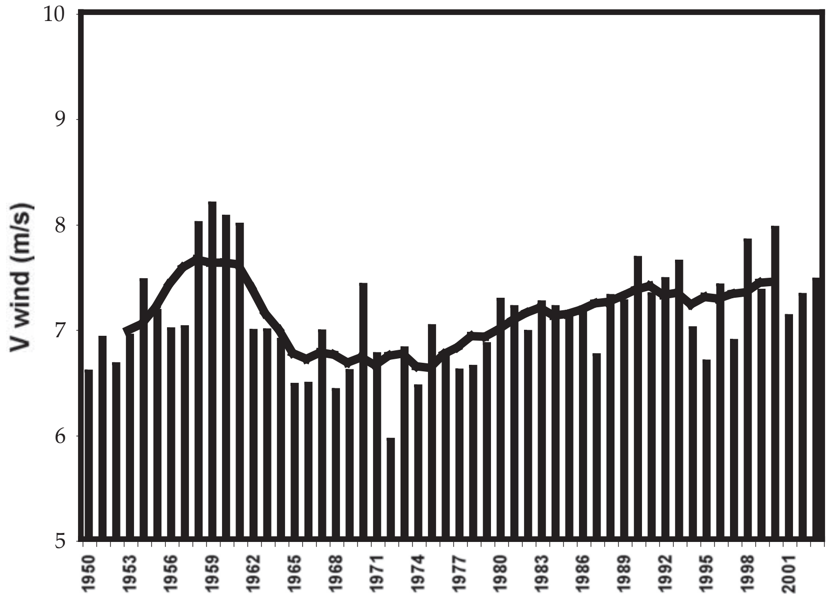

Fig. 3(a) Indian Summer Monsoon Rainfall (ISMR) for the period 1950-2002. (b) Meridional wind flow at 850hPa during the monsoon season averaged over the box-B (B as in Fig.1) for 1950 to 2003. Seven year moving averages are marked by the thick lines

Seasonal Climate Prediction for South America with FSU Multi–Model Synthetic Superensemble Algorithm

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Abstract

Objective combination schemes of predictions from different models have been applied to seasonal climate forecasts. These schemes are successful in producing a deterministic forecast superior to individual member models and better than the multi-model ensemble mean forecast. Recently, a variant of the conventional superensemble formulation was created to improve skills for seasonal climate forecasts, the Florida States University (FSU) Synthetic Superensemble. The idea of the synthetic algorithm is to generate a new data set from the predicted multimodel data sets by multiple linear regression. The main contribution of this paper is to discuss the feasibility of seasonal prediction based on the synthetic superensemble approach and to demonstrate that the use of this method on a coupled models data set can reduce the errors of seasonal climate forecasts over South America. In this study, the forecast produced by the proposed method outperforms other conventional forecasts. These results suggest that the methodology and database employed are able to improve seasonal climate prediction over South America when compared to the use of single climate models or from the conventional ensemble averaging. The results show that anomalous

conditions simulated over South America are reasonably realistic, with the precipitation anomalies for the summer monsoon seasons of 1997/98 and 2001/02 predicted by the Synthetic Superensemble formulation quite well.

1. Introduction

Climate fluctuations over South America significantly impact important economic activities like agriculture, hydroelectric power generation, as well as several other activities. One recent example of these impacts was the Brazilian energy crisis caused by rainfall deficits during summer and fall 2001. The large-scale nature of the deficits, affecting nearly the entire country, resulted in an energy crisis that forced the government to impose energy conservation measures in order to avoid total loss of power (blackouts). These restrictions had a significant negative impact on Brazil's economy. Therefore, a more accurate climate prediction over South America would be very useful. The main contribution of this paper is to discuss the feasibility of seasonal prediction based on the behavior of the multimodel synthetic superensemble approach (Yun et al. 2005) and to demonstrate that the use of it to data sets of coupled models (Mitra el at. 2005; Krishnamurti et al. 2005) can reduce the errors of seasonal climate forecasts over South America (Chaves et al. 2005a, 2005b).

2.Methodology

Different versions of the FSU CCGM are used, with different combinations of the parameterizations of the physical processes of deep cumulus convection and radiation, as in Mitra et al. (2005) and Krisnahmurti et al. (2005). The performance of this coupled model was evaluated by Krishnamurti el at. (2004). These four versions of the FSU coupled climate model were used to carry out 1440 experiments for the period from December 31 1986 to February 28 2003, starting every 15 days and run out to 3 months. In this study only the forecasts made from the initial condition closest to the end of a calendar month were used. Thus, only 720 experiments of the total were used. These experiments are referred as KOR for Kuo type convection with the old radiation scheme (Chang 1979), KNR for Kuo type convection with the new radiation scheme (Lacis and Hansen 1974), AOR for AS type convection with old radiation scheme and ANR for AS type convection with new radiation scheme.

3. Results

The skill of performance of the aforementioned member model, multi-model ensemble mean forecast, and synthetic superensemble formulation are compared using RMS error. Figure 1 (page 20) shows the RMS errors for seasonal forecasts of total precipitation for the member models, their multi-model ensemble mean, and for the synthetic superensemble for South America from DJF 1987/88 to 2002/03. The bar diagram in these figures represents 16 years (1987-2002) of averaged RMS skills. The synthetic superensemble mean shows better performance over South America when compared to member models. The forecasts produced by synthetic algorithms show better scores than those of the multi-model ensemble means and the individual model forecasts in terms of RMS. The synthetic superensemble forecasts show the lowest RMS error (highest skill) on average with a mean value of nearly 1.4 mm/day and a mean value for the ensemble mean of 1.7 mm/day (bar diagram).

The precipitation events of DJF 1997/98 and DJF 2001/2002 are used to show the improvement in geographical distribution of seasonal total rainfall obtained with the use of the synthetic superensemble. These events are examples of a recent relatively dry and wet season. A useful overview of the accuracy of the synthetic superensemble is shown by the rainfall field of DJF 1997/98 (Fig. 2a,b,c page 33). During this season the synthetic superensemble performed very well. The anomalous rainfall patterns were reproduced by this approach. This method shows the SACZ southward of its usual position and a deficit of precipitation in most of South America. For DJF 2001/2002 the precipitation totals were underestimated over South America by the multi-model ensemble mean (Fig.2e,f). The synthetic superensemble also underestimates the rainfall over the continent (Fig. 2d,f); it does not reproduce the area of rainfall above of 10 mm/day over central part of South America, however the rainfall patterns were reproduced. It is important to note that the season of DJF 2001/02 was characterized by strong intraseasonal variability related to the Madden-Julian Oscillation-MJO, and most of the models had difficulty capturing realistic intraseasonal oscillations.

The prediction of significant rainfall anomalies can have very positive socioeconomic impact. Thus, the primary objective of this study was to explore the feasibility of seasonal prediction of the precipitation over South America with synthetic superensemble approach on the time scale of one to three months. Here the focus is on assessing the performance of the model in simulating excessive dryness and wetness as seen in seasonal anomalies. The forecast skill of seasonal precipitation anomalies is central to any climate forecast. Such seasonal anomaly prediction from the synthetic superensemble is verified in Figure 3 (page 33) for DJF 1997/98, when negative precipitation anomalies were observed over most of South America, except for the subtropical region. The pattern of precipitation anomalies for DJF 1997/98 was captured by the synthetic superensemble (Fig. 3a) and multi-model ensemble mean (Fig. 3b) when compared to the observed anomalies from Xie and Arkin (1997; Fig. 3c). However, the pattern and intensity of the anomalies were better reproduced by the synthetic superensemble approach to most part of the South America. Over the subtropical region of the continent this approach underestimated the rainfall anomalies; the simulated anomalies were 1 mm/day, while observed precipitation anomalies were above 4 mm/day.

4. Conclusions

In this study the performance of a multi-model ensemble system for long-range forecasting using a synthetic superensemble, is evaluated over South America. The purpose of this technique is to improve long-range (monthly and longer) forecast skills. The most important result of this work was the finding that the FSU synthetic superensemble has some useful predictive skill for precipitation over the South America. This approach reproduced very well the rainfall anomalies over South America for DJF 1997/98. These results are most encouraging, suggesting that this vast database and synthetic superensemble approach are able to provide some useful answers to the seasonal monsoon forecast issue compared to the use of single climate models or from the conventional ensemble averaging. Overall, the RMS errors were reduced considerably. Based on these results, the synthetic superensemble formulation with the one synthetic dataset can be one of the solutions for long-range prediction over South America.

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NEW BOOK

The Global Monsoon System: Research and Forecast,

Editors: C.-P. Chang, Bin Wang and N.C. Gabriel Lau, WMO/TD No. 1266, 542 pp. March 2005.

This volume is the Report of the International Committee of the Third International Workshop on Monsoons held in Hangzhou, China, November 2004. It contains 28 chapters in three parts:

Part A: Monsoon Forecasting.
This part includes essays on bridging the gap between scientific research and the forecast user community, forecast applications and impacts, and a monsoon forecaster's perspective. This part is concluded with the summary of a discussion session among researchers and forecasters during the Workshop;

Part B: Regional Monsoon Topics.
Here the major monsoon systems around the world are organized into five regimes according to major geographical areas and seasons:
1. South Asian monsoon;
2. East Asian summer monsoon,
3. Asian winter monsoon and Australian summer monsoon;
4. American monsoon, and
5. West African monsoon.

Part C: Scientific Issues and Weather System Topics.
This part is organized into four major topic groups:
1. Physical Processes (including monsoon-ocean interactions, land-atmosphere interactions, and internal dynamics);
2. Numerical Modeling (including forecast, simulation and predictability);
3. Major Scales of Variability and (including intraseasonal, interannual and interdecadal variations);
4. Imbedded Systems (including mesoscale and synoptic motions, and tropical cyclones).

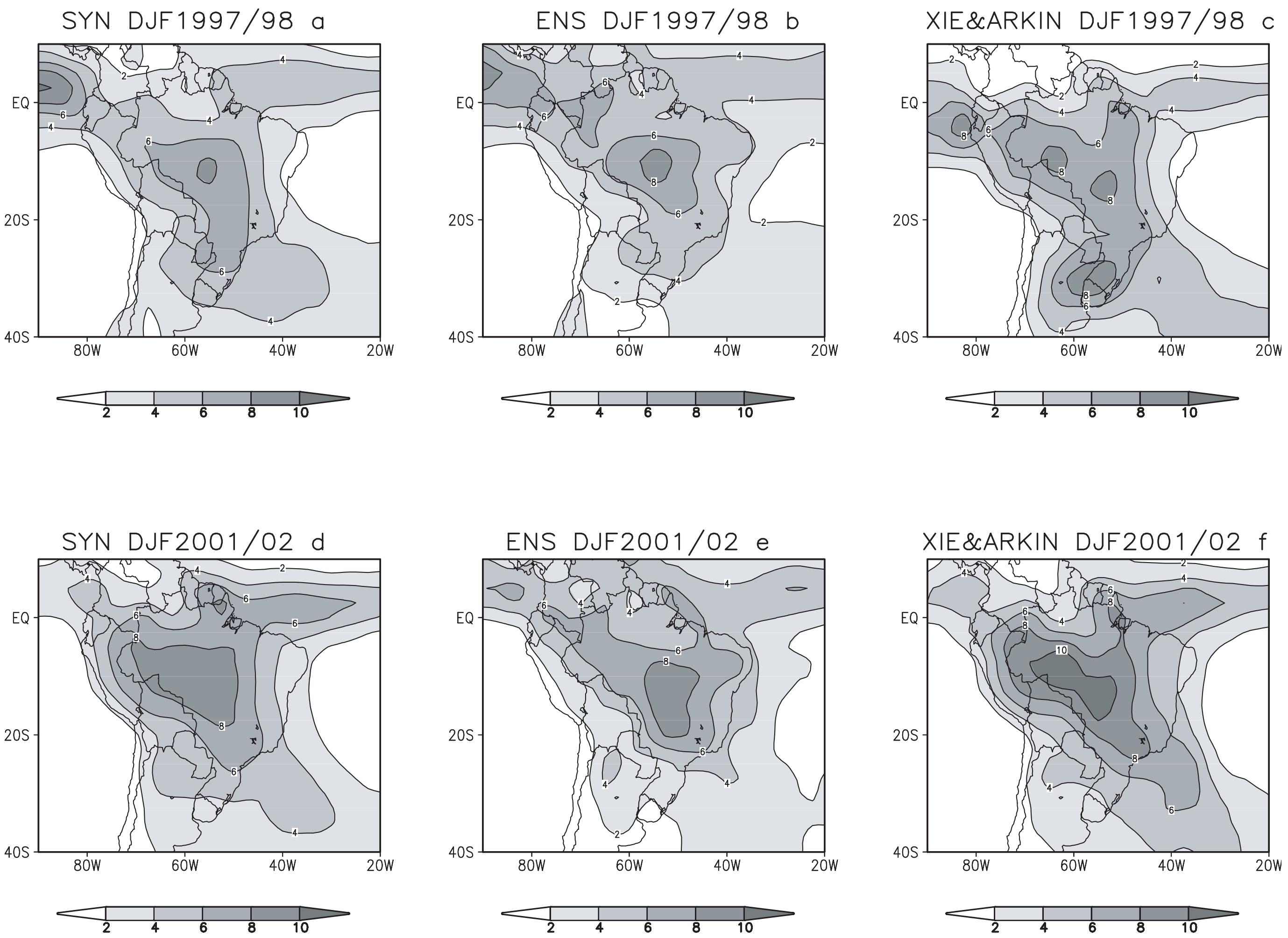

Fig. 2 - Rainfall of the FSU synthetic superensemble mean, ensemble mean and mean observed from the Xie and Arkin datasets from DJF 1997/98 and 2001/2002 (mm/day).

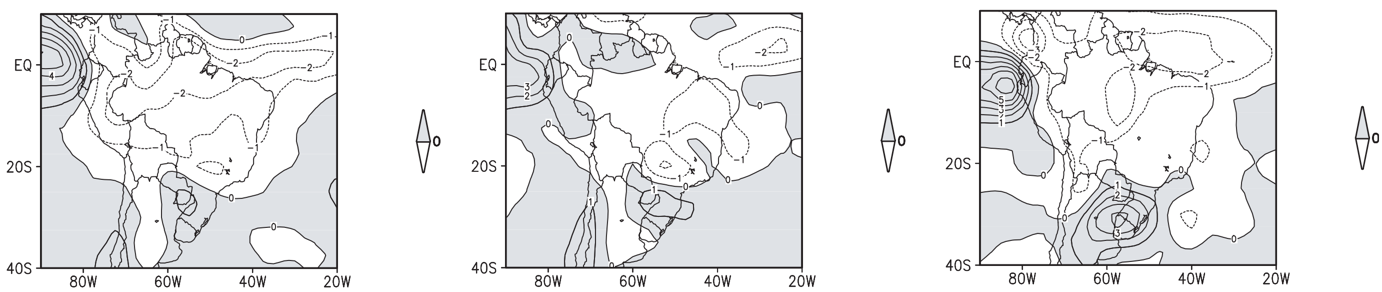

Fig. 3 - Seasonal precipitation anomaly for DJF 1997/98 (mm/day) of the synthetic superensemble mean, ensemble mean and mean observed based on Xie and Arkin (1997) (mm/day).

Mesoscale climate analysis over West Africa

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Introduction

The study focuses on the West African climate during August, the month marking the farthest northward advance of monsoonal rains. Characteristics of westward propagating precipitation maxima associated with African wave disturbances (AWD) are analyzed from two independent sources of data. In a recent CLIVAR Exchanges issue, Ward et al. (2004) stressed the importance of studying the interannual variability of such synoptic disturbances over West Africa in order to better understand the predictability of the summer monsoon climate. Detecting and monitoring AWD associated precipitation over this data-sparse region is paramount to these objectives.

TRMM

The Distributed Active Archive Center (DAAC) at the NASA/Goddard Space Flight Center provides the 3B42 on-line data set from the Tropical Rainfall Measuring Mission (TRMM) satellite. These TRMM data are estimates of daily precipitation rates (Huffman et al. 1997) for 1° by 1° squares between 40°N-40°S, beginning in 1998. The daily estimates are based on a modification of the Global Precipitation Index (GPI) from GOES geostationary satellite infrared (IR) measurements. To form the final data set, GPI values are calibrated by TRMM microwave, radar, visible and IR observations. Recent information from NASA indicates that the TRMM satellite could very well be retired toward the end of the summer of 2005 (Berger 2005). There is no comparable observing system scheduled until 2010.

No extensive validation of TRMM daily precipitation totals has apparently been made against rain gauge measurements. Lau et al. (2004) reported a favorable comparison between TRMM 3B42 data during July 2001 and daily rain gauge measurements at two stations in the Himalayas, including the detection of a heavy precipitation event on 19-20 July 2001, but this validation may not be relevant for West Africa.

RM3 Regional climate model

RM3 is a third generation regional atmospheric model run exclusively at Columbia University CCSR and NASA/GISS. It incorporates the GISS GCM land surface process model and the GISS GCM parameterizations of deep cumulus convection and cloud liquid water. For this study the model was integrated at 15 vertical levels on a horizontal grid with 0.5° spacing bounded by 35°N-20°S; 35°W-35°E.

RM3 simulations were made for each August, 1998-2003, the years for which TRMM estimates of daily August precipitation rates are available. The set of six simulations uses NCEP reanalysis data for the initial conditions and lateral boundary conditions. In order to improve the compatibility of moisture distributions with the RM3, preliminary simulations were begun on July 29 of each year. All fields, except the specific humidity, were then reinitialized at 00 UT on August 1.

Case study

We have been examining TRMM daily estimates over West Africa represented on time-longitude Hovmöller diagrams. Fig. 1a (page20) shows such a distribution for August 2003, for which the individual observations at each longitude between 20°W-25°E were averaged over 5-15°N. Fig. 1a clearly shows a number of diagonal bands of heavy precipitation that imply westward propagation of maxima, at speeds of about 6° day^{-1}, or about 7 ms^{-1}. Such precipitation trajectories have been called the "footprints" of AWD and have been simulated by GCMs (Xue and Shukla, 1993, Druyan and Hall, 1996).

As noted, the six RM3 simulations used NCEP reanalysis data as initial conditions and lateral boundary conditions. The simulation discussed here for August 2003 is representative of RM3 performance in that it was qualitatively similar to those for the other years that

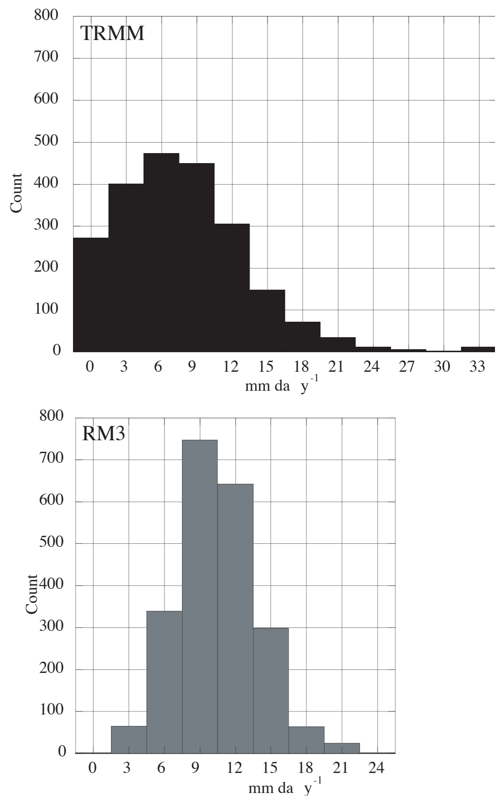

Fig. 2. Frequency distributions of the data plotted in Fig. 1a (top) and Fig. 1b (bottom), but only from August 8-31.

were analyzed. Fig. 1b shows that the RM3 did indeed simulate the AWD precipitation "footprints".

The location and timing of many of the precipitation bands in Fig. 1b follow the TRMM pattern shown in Fig. 1a, but less so during the first week. In all six simulations, RM3 precipitation was highly correlated to the corresponding TRMM pattern- but only after 5-8 days. The adjustment to NCEP reanalysis initial conditions was actually the most rapid in the example shown here for August 2003. Note, for example, the RM3 simulation of the TRMM-observed precipitation maximum that moves westward from 25°E on August 3. The following quantitative evaluation refers only to the data for August 8-31 in Fig. 1 so as not to consider the adjustment period. The correlation coefficient between TRMM and RM3 daily precipitation rates is 0.79, which is significant with >99% confidence. However, TRMM and RM3 do not agree on the absolute values of precipitation rates. The RM3 mean of the data shown in Fig. 1b (between August 8-31) is 2.7 mm day^{-1} greater than the corresponding TRMM value. Moreover, TRMM estimates reveal a much larger variability, as evidenced by their larger variance, 29.8 mm^2 day^{-2}, compared to only 11.5 mm^2 day^{-2} for the RM3. Fig. 2 shows the frequency distributions for the two data sets. The most glaring difference is that the RM3 has simulated very few rates between 0-4.5 mm day^{-1}. On the other hand, many more rates between 7.5-15 mm day-1 are modeled than are estimated by TRMM. We found that daily precipitation rates for NCEP reanalysis do not show well-correlated AWD footprints for any of the August periods considered.

Hovmöller time-longitude plots of additional RM3 simulated data averaged over 5-15°N were also examined for August 1-5 (but not shown here). In most cases, the patterns of the meridional component of the 12 UT 700 mb wind vector (v7) and the component of the 700 mb vorticity due to zonal gradients of the meridional wind (z=dv/dx), showed westward movement during the five days of a southerly wind maximum and z maximum parallel to a TRMM precipitation band. RM3 daily simulations during August 1-5 showed patterns of westward propagating sequential bands of northerlies and southerlies at 700 mb typical of AWD. The positive z associated with the wind shifts at the wave troughs ran mostly parallel and slightly east of TRMM observed precipitation maxima, which have the character of convective complexes. This suggests that RM3 circulation patterns are realistic even within the initial adjustment period.

Conclusion

The West African monsoon climate and its seasonal prediction cannot be studied without careful attention to African wave disturbances, whose characteristics are best monitored via daily precipitation distributions. We have found that TRMM estimates of daily precipitation rates are very helpful in this regard. While RM3 precipitation rates do not always match TRMM estimates, data from these two completely independent sources are well correlated in time and space. This correlation suggests that both the RM3 and the TRMM estimates describe the same reality.

TRMM may unfortunately be retired from service after this summer (2005) and a comparable replacement will not fly at least until 2010. Accordingly, the capability demonstrated here (and in additional results slated for future publication) to produce time-space distributions of precipitation using a mesoscale atmospheric model that are highly correlated with TRMM observations becomes very significant. Considerable experience has demonstrated that daily precipitation fields from NCEP reanalysis are not at all realistic over much of the tropics, and especially not over West Africa. Although this may relate to the performance of the moist convection parameterization in the NCEP model, it undoubtedly also reflects the coarse resolution of the global model, a resolution that is not optimum for capturing the interaction between terrain, circulation and temperature gradients leading to the formation and evolution of African wave disturbances. Our work suggests, however, that dynamic downscaling of global meteorological analyses by the RM3 or a comparable model can create realistic daily precipitation data sets. However, using the system for daily weather prediction will not be practical until the 5-8 day adjustment to observed initial conditions can be bypassed.

Results here also suggest that the RM3 could successfully provide regional detail to climate model seasonal predictions for West Africa. Testing has demonstrated that the positive aspects of RM3 simulations are not diminished in continuous four-month seasonal downscaling experiments. Still, the quality of RM3 seasonal climate predictions will also depend on the quality of the GCM predictions driving it. The RM3 shares the same ground hydrology and moist convection schemes with the GISS GCM. This may be an advantage for coupling the two models in order to explore the potential for seasonal climate model predictions for the summer monsoon season over West Africa.

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