INTERNATIONAL ASIAN MONSOON SYMPOSIUM

THE SEVENTH WORKSHOP ON EAST ASIAN CLIMATE

THE THIRD WORKSHOP ON REGIONAL CLIMATE MODELING

International Pacific Research Center
University of Hawaii
Honolulu
February 17 – 20

ABSTRACTS

Multi-model Seasonal Predictability of Monsoon precipitation

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Seasonal predictability of summer-mean precipitation over the Asian Monsoon-Western Pacific region is assessed by using 21 year hindcast predictions of five models for 1979-1999. The five models consist of the operation seasonal prediction models of NCEP, NASA, JMA, KMA, and SNU. The potential predictability of individual models are shown by various methods including the signal to noise ratio and anomaly correlations. A statistical method for correcting the bias of the model prediction is developed and applied to individual model predictions. It is shown that the statistical correction is effective for enhancing the predictability, particularly for the Asian Monsoon – Pacific region, where the large model bias is included in the leading eigenmodes of forced signal. Seasonal predictability of multi-model ensemble predication is also assessed by using several methods including simple composite, various super-ensemble techniques and a composite of corrected multi-model predictions. It is shown that a reasonably good seasonal predictability can be achieved when the multi-model predications are combined based on the composite of the individual predications after applying the statistical correction.

Potential Predictability and Extended Range Prediction of Active and Break Phases of Indian Summer Monsoon Intraseasonal Oscillations

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Prediction of the active (rainy) and break (dry) phases of the Indian summer monsoon intraseasonal oscillations (ISO's) two to three weeks in advance is of great importance for agricultural planning and water management of the country, but is currently unavailable. Potential predictability inherent in the quasi-periodic nature of the monsoon ISO's is investigated from daily rainfall and circulation data for 23 years. A fundamental difference between transitions from active to break and that from break to active conditions is discovered and shown that the transitions from break to active conditions are intrinsically more chaotic (less predictable) compared to transitions from active to break. Crude estimates of limit on potential predictability of active and break conditions have been made and shown that monsoon breaks are potentially more predictable than the active conditions with predictability limit of about 20 days for breaks compared to 10 days for active conditions.

The potential for prediction of the monsoon ISO is explored by developing a multiple regression model that predicts the first four principal components (PCs) of Climate Prediction Center Merged Analysis of Precipitation (CMAP). The first four PCs of rainfall and the first two PCs of surface pressure are used as predictors. The model is developed in a step wise manner with 10-90 day filtered precipitation and surface pressure data over 17 northern summers (1 June to 30 September of 1979-95) and tested over recent 6 summers. Useful predictions of intraseasonal component of rainfall over most of Indian monsoon region are possible up to a lead time of 18-days. The phase and northward propagation of the precipitation ISO are reasonably well predicted by the model. Predictions are found to be dependent on initial conditions. The predictions made from transition states (from dry to wet or from wet to dry) as well as from break conditions are only marginally skillful while those made from active (wet) conditions are significantly skillful. Predictions of area averaged rainfall over central India show that the 15 and 18 day predictions of breaks have significant and useful skill. The skill shows potential for application of these predictions of breaks in real-time. However, 15 or 18-day predictions of active conditions from a break in the monsoon trough region while statistically significant, do not have useful skill

Using Pentad Annual Cycle as the Foundation of Monsoon Forecasting (Research)

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Current surge of observations allow us to compile reliable pentad annual cycle particularly aimed to understand monsoon evolution. The resolution of pentad appears fine enough to detect abrupt changes and suppress weather noise. We advocate a 'Scientific' farmer's almanac which reconstructs the time-space manifold of monsoon. The comprehension of local natural seasons leads to a monsoon weather calendar. Those singularities can be either tightly phase locked to calendar or appear in a sequential way. A few examples will be given to highlight such an approach.

Asian/Pacific Monsoon Predictability: Sensitivity to Annual Cycle and ENSO Variations

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The physical basis for atmospheric predictability on seasonal time scales resides primarily on the notion that slowly varying anomalous lower boundary forcing can have significant impact on atmospheric development. Such external forcing is generally thought to be associated with sea surface temperature (SST) anomalies, though the effect of long-lived anomalies in soil moisture and snow cover may also play a significant role. It is clearly important to be able to access where on the global atmospheric variations are sufficiently affected by oceanic forcing to enable practical seasonal prediction. This requires measurements of atmospheric potential predictability. It is commonly believed that lower boundary conditions dominate interannual variability in the tropics and major monsoon systems. Therefore, the atmospheric variability may be highly predictable in those regions. But is there any detailed regional differences? For example, would one expect the circulation over the equatorial eastern Pacific to be more predictable than the North Pacific warm pool. Further, one might also question whether the short-term climate predictability is the same throughout the year. In particular, how does the annual cycle influence the relative impact of anomalous lower-boundary forcing? An ensemble of ten 45-yr (1956-2000) ECHAM4 GCM integrations, forced throughout by the observed SST and sea-ice datasets, are used together to provide regional assessment of potential seasonal predictability, its annual-cycle dependency. The impact of phase and amplitude of ENSO on the Asian/Pacific monsoon predictability is also discussed.

Changes of Monsoon and its Precipitation Characteristics by Global Warming

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There are numerous GCM results on possible changes in Asian monsoon by global warming. First, an overview on the global warming impact on Asian monsoon will be given. This summary will include changes in summer monsoon in South Asia, Southeast Asia and East Asia, monsoon onset, ENSO-monsoon relationship and changes in winter monsoon in East Asia. Then, using the daily precipitation output of the MRI CGCM simulations under the SRES A2 and B2 scenarios, projected changes in tropical precipitation characteristics such as rainy days, drought duration, heavy precipitation and probability distribution of precipitation will be shown. It is found that both the frequency and intensity increased in about 40% of the globe, while both the frequency and intensity decreased in about 20% of the globe. In between, which occupies around one third of the globe, the precipitation frequency decreased but its intensity increased, suggesting a shift of precipitation distribution toward more intense events by global warming. In the East Asian region, a delay in the Baiu rain withdrawal with no change in onset is found. This is associated with El Nino like mean SST and circulation changes in the subtropical Pacific.

Development of a cloud parameterization allowing aerosol-cloud-climate interaction in simulating the East Asian summer monsoon

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Recent studies indicate that the cloud radiative forcing (CRF) provides a significant heat sink in East Asian summer monsoon (EASM) and that the CRF exhibits strong interannual variation (Wang et al., 2003). The CRF is a macroscopic parameter revealing the total (solar and thermal) radiative effect associated with vertical distribution of cloud cover and cloud optical properties, the latter are sensitive to aerosols and their evolution into cloud particles. In recent years, concerns have been raised abut the aerosol loadings (sulfates, dust, etc.) over East Asia, not only for their direct effects on the radiative forcing, but also their indirect effect on cloud microphysics in which the aerosol-cloud particle interaction affects strongly the lifetime of cloud and certainly the precipitation process and climate.

To consider interactive aerosol-cloud scheme in GCMs for climate simulations requires the models to include the factors that control the cloud condensation nuclei which depends on the size distribution of water-soluble species (sulfates, organics, sea salt and nitrates), and the degree of solubility and the amount of mixing of individual species within a given size fraction. Although considerable progress is being made in recent years to include in GCMs of parameterization for aerosol-cloud droplet interaction and explicit microphysics for cloud water/ice content, inadequate understanding of the processes, in particular those affecting the cloud droplet number concentration, contribute significant uncertainties in model simulated climate changes. The present study describes a comprehensive approach to parameterize the aerosol-cloud-climate interaction for simulating EASM. Preliminary results will be shown and discussed within the context of current parameterization used in the climate models.

Wang, W.-C., W.-S. Kau, H.-H. Hsu, and C.-H. Tu, 2003: Characteristics of cloud radiative forcing over East Asia. J. Climate, East Asian Climate Special Issue, (in press).

An Eddy-Permitting OGCM and the Relevant CGCM

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An eddy-permitting OGCM with a homogeneously horizontal resolution 0.5°X0.5°, the LASG/IAP Climate Ocean Model (LICOM), was developed in this study. The model LICOM does not can capture the essential characters of the large-scale circulation only, but also well simulates the western boundary currents including Indonesian Through Flow (ITF). Another experiment has been carried out with LICOM forced by daily ERA wind stresses from 1979 to 1993. The model can simulate the ENSO (El Niño-South Oscilation) signal in the Pacific and IOD (Indian Ocean Dipole) signals in the Indian Ocean very well. EOF analysis of 20°C isotherm depth exhibited that the significant signal is interannual variability. The simulated ITF transport is large during El Nino and small during La Niña. The interannual variation of ITF is decided by the difference of sea surface height (SSH) between the western Pacific Ocean and the eastern Indian Ocean.

Based on NCAR Flux Coupler 5, the oceanic component model POP of CCSM2 was replaced with the ocean model LICOM. The coupled model, named as FGCM version 1, has been integrated more than 200 years. There is no serious climate drift in the extended coupled integration, although the coupled model suffers from some very common biases as the other directly coupled model. Meanwhile, the coupled model also simulates significant ENSO and Indian Dipole variability.

The Asian monsoon system as simulated by a set of AMIP-type experiments

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The South Asian monsoon and the Indian summer monsoon have been studied in a set of AMIP-type experiments with the Echam4 GCM with prescribed SST from 1956 to 1999. The experiments have been realized at different resolutions, T30, T42 and T106, and the sensitivity to the horizontal resolutions have been highlighted. These experiments have been compared with a set of experiments with the SINTEX coupled model and the main differences on the two different types of simulation have been analyzed.

Asian Monsoon Climate during Middle Holocene Climatic Optimum (6000 Years B.P.) by the Multi-Model Ensemble

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According to astronomical orbital parameters of the Earth at 6 kyr B.P. (Before Present), a 6 kyr B.P. Asian paleoclimate was simulated by performing an integration of the multi-model ensemble with 18 Paleoclimatic Modeling Intercomparison Project (PMIP) models, and compared to the similarly simulated control climate but for the present conditions. At 6 kyr B.P., annual fluctuation of the insulation at the top of the atmosphere was larger in the Northern Hemisphere, but smaller in the Southern Hemisphere, than at present. The present distributions of SST and sea ice were used for simulation not only for the present but also for 6 kyr B.P. The atmospheric CO_2 concentration at 6 kyr B.P. and present value are set to 280 and 345 ppm, respectively.

The results from the multi-model ensemble reveal that the reconstructed winter surface air temperature of the 6 kyr B.P. over East Asia were lower than the present one due to the reduced shortwave radiation at the top of atmosphere. The mean winter (Dec.-Jan.-Feb.) surface air temperature of the 6 kyr B.P. is 0.85 ^{o}C lower than the present one, owing to the land differences, especially in the northern Indian and Korean Peninsulas, and China continent. The mean summer (June-July-Aug.) surface air temperature of the 6 kyr B.P. is 0.21 ^{o}C higher than the present day value, due to the land mass distributions above 40 ^{o}N .

The results show that the reconstructed precipitation of 6 kyr B.P. over northern Indian Peninsula were more abundant than the present value. However, precipitation decreased at the low latitude around 10 ^{o}N during the 6 kyr B.P. compared to that of the present one. The mean winter precipitation of the 6 kyr B.P. over East Asia is 0.067 mm/day larger than the present value. However, mid-China, Taklimakan and Gobi desert area show lower precipitation value (- 0.2 ~ -0.4 mm/day) than the present one. The mean summer precipitation of the 6 kyr B.P. is 0.017 mm/day higher than the present one. Especially it increased in the northern Indian monsoon area and northern land area of East Asia.

An Evolution of the Asian summer monsoon associated with the Mountain Uplift -Study with the MRI coupled GCM

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We had six simulations with different mountain heights, i.e., 0% (M0), 20% (M2), 40% (M4), 60% (M6), 80% (M8), and 100% (M, control run) of the present global orography, respectively, to study climate changes due to progressive mountain uplift, with the MRI atmosphere-ocean coupled GCM. The changes of the Asian summer monsoon, with progressive mountain uplift are focused on.

An active convection region extends with mountain uplift to form a moist climate in South and East Asia.Monsoon circulation, such as low-level westerly and upper-level anticyclonic circulation, is also enhanced with mountain uplift. The increase in precipitation, and the enhancement of southwesterly, in the later stages of the mountain uplift, appear only over India and the south and southeastern slope of the Tibetan Plateau. Over the coastal region of Southeast and East Asia, where the maximum precipitation appears in M0, precipitation decreases gradually with mountain uplift, and the southwesterly in the later stages becomes weaker. In the connection with these changes, surface heat flux changes remarkably over moist Asia in the earlier stages of mountain uplift, compared with that in the later stages. The intensity of the Indian, Southeast Asian, and East Asian monsoon was investigated with indices which are defined by area mean precipitation. The Indian monsoon becomes strong gradually with mountain uplift; particularly, in the later stages, the remarkable enhancement is found. The intensity of the South Asian monsoon is the strongest in M4. Thus, in the later stages of mountain uplift, that becomes weaker in association with the northwestward migration of the convective activity. Although the East Asian monsoon is enhanced gradually with mountain uplift, the enhancement in the earlier stages is larger than that in the later stages. In the equatorial Indian Ocean, SST also increases with mountain uplift, resulting in the increase in precipitation.

Zonal Asymmetry of Monsoon Circulations in an Idealized GCM

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The applicability of axisymmetric theory to the asymmetric monsoon is explored using an atmospheric general circulation model (GCM) with a perpetual boreal summer setup. The GCM features a full moist convection scheme and a slab ocean, with simplified treatment of land surfaces and a bucket hydrology. A subtropical northern hemisphere landmass is implemented at several levels of complexity: an axisymmetric (2D) model setup, a 3D model setup with zonally symmetric continent, and a 3D model setup with asymmetric continent. It is found that the axisymmetric theory is limited by the interactive nature of the land surface forcing, so that it is difficult to predict the strength and location of the monsoon; however, there is good agreement between the theory and the 2D model runs in terms of the existence of the monsoon. The 3D setup with zonally symmetric continent is dominated by the mean flow with circulation and precipitation which are nearly zonally symmetric and very similar to the 2D runs; the eddies are weak and act to suppress the monsoon. In contrast, a zonally asymmetric continent features a different dynamical regime where the monsoon is primarily driven by baroclinic disturbances of a low-level easterly jet along the coastline. With a zonally asymmetric landmass, the continental precipitation is most intense over the southeastern corner of the continent, with the dominant moisture source for the precipitation located over the equatorial ocean near the southern coastline. The import of low moist static energy air into the continental interior by the large scale flow is primarily responsible for the differences between the 3D cases with zonally symmetric and asymmetric continental geometry. The inclusion of a `thin wall' to emulate the East African Highlands has little impact on the monsoon with a zonally symmetric continent, but does increase the strength and extent of the monsoon with an asymmetric continent.

Rainfall Anomaly in Indonesia: Observation during 1980-2000 and Simulation for 2010-2039

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Since 1980s, a lot of meteorology researchers consider that in the future there would be a climate change such as increasing of the air temperature, evaporation, and rainfall in various spatial and temporal scales. However, such a climate change in Indonesia has not been so much confirmed, because appropriate observational data set and prediction model have not been prepared. In this study, to observe a rainfall anomaly during 1980-2000, a daily occurrence frequency analysis in two periods, 1980-1990 and 1991-2000, was conducted, for rainfall and diurnal and nocturnal temperature data observed by agroclimatic stations of type A at Tamanbogo in East Lampung, Cimanggu, Muara Bogor, and Margahayu in West Java, and Genteng, Jambegede and Ngale in East Jawa, and Maros in South Sulawesi. In this study tendencies of temperature and rainfall data were also analyzed using an annual moving average. For simulation ARPEGE Climat version 3.0 model was used. Rainfall anomaly is predicted as a difference between monthly averages of rainfall conditions in the initial period (1950-1979) and in the next period (2010-2039) for 25°N-25°S and 150°E. Observational data showed that the anomaly frequency of rainfall, particularly rainfall of 100-150 mm/day was significant (59%) for all the stations. The anomaly frequencies of diurnal temperature of 32-38°C and nocturnal temperature of 20-24°C were 1-122% and 4-194%, respectively. For the 2010-2039 period it is predicted that there will be an increase of the sum of rainfall over Indonesia region, and that there will be changes of rainfall zones with positive anomaly in the Malacca and Kalimantan Straits and Banda and Arafura Seas.

Variability of Eastern Asia Monsoon and Meiyu from ECHO-G

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Abstract

Eastern Asian summer monsoon (EASM) and Meiyu are very important to Chinese agriculture and economy. Based on modern observation data, researchers can figure out some features of EASM and circulation patterns, which are associated with Meiyu. Because of the variation of large scale circulation, the intensities of monsoon and Meiyu have significant inter-annual and long term changes.

In this paper we use different monsoon indices based on monthly data from a 500 year ECHO-G experiment and NCEP to study long term variation of eastern Asian monsoon and Meiyu. By comparing monsoon intensity indices from Webster and Yang (1992), Lau et al.(1999), and ourselves, the relationships between these indices, sea level pressure (SLP), sea surface temperature (SST) and summer precipitation in eastern China (Jianghuai basin) are discussed.

Climate Scenarios in East Asia monsoon region due to human activities Using Global Coupled Model

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In the last 100 years, the global climate is characterized by the global warming. According to conclusion of the IPCC 3rd Assessment Report on Climate Change, the global mean surface temperature has increased by 0.4~0.8? during recent 140 years. The regional climate in East Asia and China has had a warming tendency similar with the global climate change.

In the first part of this presentation, we analyzed the climate change over East Asia and China using the simulations provided by IPCC DDC and NCC/IAPT63 model. The results have indicated that GCM has a good capability to past simulate climate change due to human activities; there were no significant correlations between the observations and control simulations in globe, East Asia and China, but there were obvious correlations between experiments with CO_2 and CO_2 plus sulfate aerosol, and observations. Warming amplitude is greater in China and East Asia than in globe. A comparison of the last 50 years with 100 years in 20th century has indicated that liner trend is near to observations in 1951~2000 years. It might have some signals and evidences to indicate the human activities on warming over East Asia for the last 50 and 100 years.

The second part of this presentation is to deal with projection of regional climate change in East Asia and China in the next 50 years, especially East Asia monsoon region. The projections have shown that the warming would continue to occur in the next 50 years of this century. The precipitation in East Asia and China would also change with a general increasing tendency. The intensity of summer monsoon will increase over South Asia and South China Sea. The winter monsoon has changed over East Asia, with a decreasing tendency in intensity in North China. Intensity and frequency of cold waves in East Asia will be decreasing.

Possibilities, Limitations, and Improvement of Dynamical Prediction of Asian Summer Monsoon Precipitation

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Possibilities and limitations of dynamical prediction of Asian summer monsoon precipitation are assessed using the Atmospheric GCM data obtained from 5 different modeling groups of JMA, KMA, NASA, NCEP, and SNU. Prediction data utilized in this study are the 21-year hindcast products for 1979-99 from SMIP-II simulations of the four dynamical models of JMA, KMA, NCEP, and SNU and from AMIP-II simulations of NASA models. Analysis of variance and perfect model correlation show that the state-of-the-art atmospheric GCMs have not much capacity to predict Asian summer monsoon precipitation because of large contribution of internal atmospheric processes. Besides, imperfections of model itself due to incomplete parameterization, absence of air-sea coupling processes, inappropriate land-surface processes and so on give arise to mean and anomaly biases. Although some parts of biases are very systematic and then successively correctable using a statistical postprocessing based on SVD method, large parts are too noisy to be corrected. It is suggested that improvement can be achieved by use of a statistical downscaling process based on finding an optimal predictor area from which predictability signal comes for predictand. In Each AGCM, predictability source regions, predictor areas, are quite different each other for a specific predictand because of nonlinear conversion of global SST information to atmospheric circulation produced by AGCM. Further improvement is achieved using multi-model spatial-ensemble scheme based on statistical downscaling applied to each model. It is shown that sophisticated superensemble schemes can not help much to improve forecast skill because all independent variables, grid-point values of each model, have low skill scores. Thus, it is suggested that anomaly bias correction or statistical downscaling is necessary before applying multi-model ensemble forecast.

Comparison of Monsoon Rainfall Between Simulated and Reconstructed Data in China

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The monsoon rainfall related to Eastern Asian summer monsoon (EASM) has large variability in different time scales, such as interannual, decadal and centennial variations, and leading to some serious dry and wet periods. This study is to explore the law and causes of the variation by comparing reconstructed data and modeling result.

The model data used here is from ECHO-G, a coupled global circulation model from MPI and GKSS, which run more than 500 model years from 1465 to 1990. The reconstructed precipitation and dry/wet index time series are from China.

The results show that ECHO-G model can give some features of monsoon rainfall and its variation in the different time scales. Some variation periods are comparable between model and reconstructed data, but the model output could not agree with reconstruction in some periods and showed opposite trend; The long term run from ECHO-G is helpful to understand the long-term variation of monsoon rainfall and dry/wet periods change. Based on reconstructed precipitation and dry/wet index data and modeling results, we can find the main factors and mechanisms which control monsoon rainfall and dry/wet variation.

On the climate predictability of the Seasonal Mean monsoon rainfall Variability

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Climate predictability is model dependent. Assessment of the multi-model ensemble simulations made by 11 atmospheric general circulation models (GCMs) show a common feature: no skills in modeling seasonal rainfall variations over the Asian-Pacific monsoon convergence zone during the summers of 1997 and 1998 when the unprecedented 1997 El Nino occurred. Is this failure suggest that all models are poor or that the strategy used in climate simulation has deficiencies? We address this issue through analysis of observations and numerical experiments with a couple GCM.

Over the Asian-Pacific monsoon convergence zone (a.k.a. Intertropical convergence zone), the observed summer mean SST and rainfall anomalies tend to show a significant negative correlation. This negative correlation reaches maximum when the rainfall leads SST by one-month (using monthly mean data), suggesting that the atmosphere plays an active role in changing local SSTs over the monsoon convergence zone. When the ECHAM AGCM is coupled with an ocean model, the coupled model realistically reproduced this negative correlation. In contrast, the ECHAM model alone simulation forced by the same daily SST generated by the coupled model yields a positive rainfall-SST correlation, suggesting that in the forced model simulation, the SST anomalies determine the atmospheric response.

These results suggest that the atmosphere-warm ocean interaction plays an essential role in realistic modeling (or predicting) summer monsoon rainfall. The atmospheric precipitation anomalies cannot be realistically reproduced by AGCM alone with observed SST as a forcing. Therefore, improvement of an atmospheric model based on its stand-alone performance is a poor strategy. Similarly, the two-tier approach for seasonal mean rainfall prediction may work in many regions of the world but not in the major summer monsoon convergence zones, where the local air-sea interaction rather than the ocean memory provides a source of predictability.

Solutions to instabilities in the Polar Regions and bright future of global grid-point models

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The atmospheric model is a necessary tool for climatic studies and weather predictions. Many kinds and many versions of atmospheric models have been developed in the world since 1980s, such as the NCAR CAM2 that builds on the NCAR Community Climate Model 3 (CCM3, Kiehl et al, 1996), ECHAM (Roeckner E et al, 1996), IAP AGCM (Zeng et al, 1989; Zhang et al, 1990; Wu et al, 1996; Wang et al, 1997) and so on. Dynamical core is the basic part of a model. A lot of attempts on dynamical cores have been made (Zhang et al, 1990; Held et al, 1994; Chen et al, 1997; Fox-Rabinovitz et al, 2000; Ringler et al, 2000; Rivier et al, 2002). Generally, there are three kinds of commonly used numerical methods for designs of dynamical cores. These methods are respectively finite difference method, spectral expansion method and Lagrangian method. The finite difference scheme is a favorite method for solving atmospheric equation. It is in a simple and intuitionistic way, which is easy to be constructed, easy to be coded, easy to be parallelized, easy to keep physical conservations, easy to deal with terrains, easy to nest or be nested, and easy to couple with other components of climate system models. However, this method has a fatal weakness that is the instabilities in the Polar Regions caused by the singularities of the atmospheric equations at the poles. It is due to this weakness that the time step-size of a global grid-point model is greatly limited and numerical chaos is produced without filtering or smoothing. Especially, it becomes more and more expensive following the increase of the model resolutions. This is why the most popular global models in the recent 20 years are not gird-point models but spectral models.

Actually, the performances of spectral models are not as good as they are anticipated. Some physical variables are not continuous enough that they cannot meet the requirements of spectral expansions. For example, the specific humidity and terrain are two typical discontinuous variables. Negative values will be produced when these variables experience the spectral expansions. Obviously, the negative values of the variables are non-physical
and may affect the modeling of other physical variables. Especially, this kind of discontinuity will become stronger and stronger when the horizontal resolutions are increased. However, the good stabilities and high precisions endow the spectral model with a vigorous life in the past 20 years.

In recent years, the Lagrangian model has been developed quickly. It is a kind of grid-point model with good stability of the spectral model. It has the advantages of the grid-point model by finite difference method on dealing with complex terrain, nesting or being nested, coupling with other components of climate system models, as well as the advantage of the spectral expansion method on having large time step. This kind of model, however, has the difficulties on the huge computations for solving an elliptic equation and the difficulties to deal with the particles passing through the poles.

Besides the aforesaid three kinds of methods, some other methods such as the finite element method and the finite volume method are under attempt, but so far they can hardly

be commonly applied to numerical modeling of climatic problems and numerical weather predictions.

From the above discussion, it is easy to know that every method has its own advantages and disadvantages. But, to my opinion, the grid-point model based on finite difference method has underlying superiority. Once its instability problem in the Polar Regions is resolved, it will obtain more potential vigor than other kinds of models. The day to completely solve the instability problem of the grid model in the Polar Regions is coming. A new global grid-point model by using efficient finite difference method and semi-Lagrangian method has been successfully established. The new model is as stable as the spectral model is, and in the meantime it reserves all the advantages the traditional grid-point models have. Out of question, it shows the bright future of global grid-point model.

In this paper, the detail method for designing the new dynamical core will be introduced. The core of the method includes the integral-grid-moving semi-Lagrangian scheme to deal with the upper jets, the implicit difference scheme with exact linear and quadratic conservations to solve the external and the internal gravity waves and the explicit difference with exact linear and quadratic conservations to solve the rest slow waves. The model physics are chosen from NCAR CAM2. Numerical tests and comparisons are included.

Boundary Forcings and Intraseasonal Variations of Indian Summer Monsoon Rainfall(ISMR)-An analysis of their dependency for understanding challenges of predictability of ISMR

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Mechanisms responsible for Interannual variability of seasonal mean monsoon fall into two categories (Shukla, 1987, Webster et al., 2002a). These are "internal dynamics (ID) or intraseasonal variations attributed to day to day synoptic scale and semi-permanent transient weather systems" and " Forcing Functions or external boundary forcings(EBF) attributed mostly to heat functions or SST like ENSO whose effects are of lag time scale from month to year or decade". Former Mechanism correspond to dynamical instability manifested as synoptic scale non-linear interaction among various disturbances, scales of motion, thermal-orographic forcing, tropical-extratropical interactions etc. while later mechanisms correspond to the influence of ENSO, local SST anomalies, Eurasian snow cover, ground moisture contents etc. on monsoon variability.

Part of summer monsoon variability over India controlled by boundary conditions e.g. SO, Himalayan snow etc. was studied in early parts of nineteen century or before (Blanford, 1884 and Walker, 1923: 1924). Many similar studies since then have also been undertaken for identification of new regional and global parameters and forecast of seasonal monsoon rainfall over India empirically based upon these boundary parameters. By numerical experiment, Charney and Shukla(1981) established that monsoon in time scale of a month is more predictable by NWP model than weather systems in similar time scale for extrartropics because the former partly controlled by boundary forcings such as ENSO. Since then, further studies are made for making both Numerical and empirical forecast of monsoon a success by identification of new predictors from new ocean-atmosphere data sets available from special experiment like INDOEX, MONEX, BOBMEX, ARMEX etc and new generation Satellites. A brief review of these empirical and NWP models are available in Thapliyal and Kulushrestha(1992), Hasternath and Greichar (1993) and Gadgil and Sajani(1998) and Gadgil et al., 2002. One serious drawback of these predictors is that their relationship with ISMR is not stable and followed epochal variations due to which some of the predictors lost their relationship with time which makes it difficult to scrutinize them from year to year for their fruitful use in operational purpose of long range forecast.

Till 1997, though many studies has been undertaken on finding role of boundary forcings on monsoon variability over India, relative contribution of ID to intraseasonal variation of ISMR was not known much. All of these studies got a major review look when Indian summer monsoon in 1997 escaped the negative effect of most intense El-Nino of century and further attempts to find out causes were focused on two separate ways to find cause of such interannual variation of ISMR One way is to search further new boundary forcings or predictors which is still maintaining strong link with ISMR and identifying predictors which have lost relationship with ISMR out of old predictors. Studies of role of Indian Ocean SST anomalies, Eurasian snow cover, Atlantic circulations, decadal changes in ENSO monsoon coupling and global warming on ISMR by various authors(Webster et al., 2002b; Clark et al., 2000; Webster et al., 1999; Lau and Wu, 1999; Lau and Wu, 2001; Chang et al., 2001; Slingo and Anamalai, 2000; Shen and Kimoto, 1999; Krishna Kumar et al., 1999) are nothing but new attempts to understand monsoon variability from role of boundary forcings on ISMR with sophisticated data sets. As yet, there is no conclusive result on the relative importance of each factor on ISMR. This problem becomes more complex due to the revival of ENSO-ISMR relationship again in recent 2002 when a weak to moderate El-Nino could be able to associated with very bad rainfall e. i. drought over India during the year in contrast

to 1997 when it did not affect irrespective of its very high intensity. It may be noted here that the cause of failure of ENSO-ISMR relationship of 1997 has already been studied prominently by several authors immediately after such happening (Krishna Kumar et al., 1999, Chang et al., 2001; Slingo and Anamalai, 2000; Shen and Kimoto, 1999;). Hence failure of ISMR in 2002 contrast to 1997 further complicated present long range forecast models of monsoon. In coming days, many results will come for finding the cause of failure of ISMR in 2002 and henceforth empirical models have to be tuned accordingly in future again. We do not know when we test these new modified models for forecasting drought/flood years to be occurred in future, we may end with failure of such model results in some cases and certainly we will get again some new causes for understanding that drought/flood year rather than using already existing mechanisms known to us to explain such new year extreme monsoon. Hence predicting extreme ISMR correctly by empirical methods is becoming very difficult based on these EBF parameters. Also NWP models for monsoon predictions based on boundary conditions still remains a challenging task by all global general circulation models used by all international centers because of many limitation in the model configuration, initial data used, orography etc.(Gadgil et al., 2002).

Another hurdle with Indian summer monsoon is that it is the most complicated monsoon system among all global monsoon regions of the world as it shows lowest interannual variation with drought and floods over India rarely extended to more years with rainfall oscillating roughly biennially (Mehl, 1994, Webster et all, 2002b) from slightly above normal to slightly below normal. This biennial oscillation happens because of ocean and atmosphere, in concert act to limit the seasonal extremes of the monsoon. The bienniality of the monsoon and the Indian Ocean are integral parts of a suite of processes and phenomenon that regulate the interannual variation of the monsoon. Except ENSO-Monsoon interaction (Webster and Yang, 1992) which explain why some ENSO events are associated with some cases of drought/flood years over India, Webster et al.(2002b) have shown in one of recent studies, how best Indian Ocean alone could interact with Indian summer monsoon in intraseasonal time scale of day to week through a particular very complex unique coupled ocean-atmospheric interaction mechanism not seen in any other ocean which has periodicity of same biennial oscillation as Indian summer monsoon.. Hence the only other way is understanding monsoon variability from second mechanism i.e. ID which was not much studied before 1997 though it was known to be responsible for interannual variation of monsoon from Shukla(1987). This mechanism is also nothing but effect of day to day intraseasonal oscillation of circulation, distribution of heat fluxes, or in other words daily spatial location of intraseasonal monsoon systems on ISMR. Intraseasonal monsoon systems over Indian region can be basically divided into two parts; synoptic disturbances of transient characteristics and semipermanent systems of quasi-permanent characteristics. These features are nothing but spatial manifestation of large scale intraseasonal variation of monsoon flow over Indian region. Role of such intraseasonal oscillations on interannual variation of ISMR have been recently debated by many authors after failure of ENSO-ISMR relationship in 1997(Krishnamurthy and Shukla, 2000; Lawrence and Webster, 2001; Lawrence and Webster, 2002, Webster et al., 2002a; Srinivasan and Nanjundiah(2002)). They have not studied effect of such intraseasonal oscillations on interannual variation of ISMR from day to day synoptic and semi-permanent features evolutions. Study of Charney and Shukla(1981) would have been certainly a guidance to peruse the empirical/dynamical modeling studies in a more vigorous way if most of recent literature as stated above on monsoon would not have highlighted contribution of intraseasonal oscillations or ID on interannual variation of monsoon. Though many studies in recent years have been undertaken on contribution of intraseasonal oscillations or ID and boundary forcings to interannual variation as stated above, many important following questions still to be answered.

1) Is day to day characteristics of weather systems explaining significant interannual monsoon variability?

2) Does any epochal variation also exist in interdecadal time scale (i.e. interdecadal variations) in characteristics of monsoon weather systems and their relationships with ISMR?

3) Is monsoon variability due to intraseasonal oscillations controlled and modified by large scale planetary forcings or are the intraseasonal instabilities themselves determining interannual variation of monsoon?

4) Are monsoon variability due to EBF and ID differing from each other both spatially and intraseasonally over India?

In the present study, an attempt has been made to find some answers for above questions. Role of day to day synoptic and semi-permanent features on interannual variation of ISMR quantitatively has already been studied explicitly recently by Jenamani(2001a) and Jenamani and Dash(2003). Their results as shown in Table below too show significant part of interannual variation of ISMR are due to day to day characteristics and spatial location of intraseasonal features of ISMR or ID compared to variability of ISMR due to Nino3 SST which is main EBF of ISMR.

Jenamani and Dash(2001b) have also shown that relationship between ID of ISMR e.g. monsoon disturbances days and ISMR follows strong epochal variation in decadal time scale and hence decadal periods of their strong dependency and independence can be determined like epochal relationship of ISMR and ENSO like EBF of ISMR.

In the present study, further attempt has been made in this direction to find dependency of these components of intraseasonal variation that mainly controls ISMR on main EBFs e.g. ENSO, recently found Dipole Mode indices of Indian Ocean etc. Also, distinct characteristics of monsoon rainfall of an year from other years are determined from spatial distribution and daily variation of rainfall over India when former year is dominated by a particular synoptic or semipermanent components while later one dominated by one external forcings e.g. ENSO. For the present study, required data from IMD and NCEP/NCAR according to their period of availability are used.

Result of dependency of monsoon disturbance days which is main components of intraseasonal variation or ID that mainly controls ISMR on main EBFs e.g. ENSO from **Fig. 1** shows that they are more strongly coupled and correlation coefficients (CC) between monsoon disturbances days and Nino 3 SST and CC between monsoon disturbances days and ISMR are more stable compared to CC between ISMR and its main EBF e. g. SST of Nino 3.

Result of effect of ID on spatial variation of ISMR show that monsoon disturbances and monsoon trough are the most important components of ID of ISMR and variation of characteristics (e.g. formations, movements, life period etc.) of such disturbances and intensity of monsoon trough from day to day in the season are found to be responsible for deficient(excess) rainfall distribution in spatial scale, during 1965, 66 (1961, 94) over a large belt of India. This area continuously extends from Orissa-Gangatic-West Bengal of east coast of India, to West Rajsthan of north west India, through central India, over which monsoon disturbances and monsoon trough normally pass. Hence it is interesting to note from this rainfall data analysis that when ISMR is strongly affected by components of ID as studied above, the characteristics of ID plays a more dominant role in controlling an unique spatial variation of ISMR which is not observed when ISMR is strongly affected by EBF e.g. ENSO, Eurasian snow cover etc.. Hence, this study shows that for an accurate forecast of ISMR mainly in long range time scale, a hybrid model has to be developed to predict final ISMR which will take as inputs from characteristics of different components of ID already simulated daily for whole monsoon season in long run from global coupled GCM and statistical long range forecast model predictions of initial ISMR based upon lag EBF.

Detection and projection of East-Asian monsoon variations for the 20th and 21st centuries due to the human emissions as simulated by the CCSR/NIES2

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Detection and projection of East-Asian monsoon change for the 20th and 21st centuries due to the human emissions as simulated by the CCSR/NIES2 coupled model with the SRES scenarios have been investigated in this research.

According to the diagnostic analyses of the East-Asian monsoon based on the observed global sea level pressure for the last 100 years by Guo et al. (2003), both winter and summer monsoon over East Asia (110E – 160E) weakened in the 20th century. The linear trends of the changes of both winter and summer monsoon index for 1890~2000 were -0.02/111years and -0.33/111years, respectively. The CCSR/NIES2 coupled model with the greenhouse gases and sulfate aerosols simulated the weakened winter and summer monsoon index over East Asia in the 20th century reasonably. The simulated linear trends by the model were -0.10/111years and -0.08/111years, respectively. It implicated that the weakened winter monsoon in East Asia for the 20th century might be relative to the increasing human emissions. The cooling and more frequent floods over some parts of South China and the more frequent hot waves and droughts over the Huabei Plain of North China in summer for the last 25 years likely linked with both natural and anthropogenic actions as simulated by the CCSR/NIES2 with human emissions.

The winter monsoon will likely weaken and the summer monsoon might enhance over East Asia for the 21st century as projected by the CCSR/NIES2 with SRES A1, A2, B1 and B2, respectively, especially for B1 (winter monsoon) and B2 (summer monsoon). The projections also indicate that more frequent floods might occur over the most parts of East Asia, but little bit more frequent droughts might appear over some parts of East Asia. The days of heavy rain might increase in the most parts of East Asia, except for the central part of East Asia. The numbers of the annual typhoons over the tropical northwestern Pacific Ocean might decrease that is relative to the warming SSTA over the Nino regions in the 21st century.

The validations and uncertainties of the climate change over East Asia have been analyzed by using the climate models and scenarios (such as CCC-GG, CCSR/NIES-GG, CSIRO-GG, DKRZ-GG, GFDL-GG, HADL-GG, NCAR-GG, GCM7-GG, CCC-GS, CCSR/NIES-GS, CSIRO-GS, DKRZ-GS, GFDL-GS, HADL-GS, NCAR-GS, GCM7-GS, LASG/IAP-GG, LASG/IAP-GS, LASG/IAP-GSS, NCC/IAP T63-GG, NCC/IAP T63-GS, YONU-GG, RegCM/CN-GG, RegCM/CN-GS, CCSR/NIES2 A1, CCSR/NIES2 A2, CCSR/NIES2 B1 and CCSR/NIES2 B2). More researches should be conducted in future to narrow the uncertainties.

Simulating the Regional Climatic Effects of the Atmospheric Brown Cloud

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In a recent international study, the Indian Ocean Experiment (INDOEX) (Ramanathan et al. 2001), frequent occurrence of widespread pollution was observed over large sections of the Indian Ocean, South Asia, and Southeast Asia. The dense brownish pollution haze layer, now known as the Atmospheric Brown Cloud (ABC), is about 3 km thick and the size of the continental U.S. Analyses of the INDOEX field observations revealed significant impacts of the haze layer on regional climate. Besides having an effect on human health, the Asian Brown Cloud could also lead to significant reduction in agricultural productivity through the effects of aerosols on solar radiation and hydrological cycle.

To understand the impacts of the ABC on regional climate and hydrological cycle, a regional climate model based on the Penn State/NCAR Mesoscale Model MM5 has been applied to a large region covering all of Asia and the surrounding oceans at 60 km resolution. Two 10-years simulations of 1990-2000 have been performed with large-scale conditions provided by the global reanalyses. The simulations were performed with and without the atmospheric radiative forcing calculated offline by a Monte Carlo Aerosol-Cloud-Radiation model using the INDOEX observed cloud properties and aerosol distribution (Ramanathan et al. 2001). Results showed that because of the presence of aerosols over large extent covering India, Southeast Asia, and the surrounding areas, the seasonal mean solar radiation reaching the surface was reduced by up to 35 W/m^2, which maximized in spring. As a result, surface temperature was cooled by up to 1^oC over India and Southeast Asia. These are generally consistent with results reported by Chung et al. (2002), who used a global climate model with the same prescribed aerosol forcing. However, a warming was found over the Tibetan Plateau, which was related to reduced cloud cover in the INDOEX simulation. Analyses are being performed to further investigate the mechanisms for the warming and cooling signals and possible changes in large-scale and mesoscale circulation and hydrological cycle induced by the aerosols.

East Asian monsoon simulations using a variable-resolution GCM

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The CSIRO variable-resolution Conformal-Cubic Atmospheric Model (C-CAM) has been used for several 10-year present-day climate simulations of the East Asian monsoon. For these simulations, NCEP sea surface temperatures were used, in conjunction with nudging from far-field NCEP winds. Results will first be shown from the simulation submitted for the RMIP-2 intercomparison. Whilst rainfall patterns were generally good for all seasons, the amounts tended to be excessive. A recent improved simulation will also be shown, where changes have been made to both the shallow and deep convection schemes. The local time of maximum precipitation at a variety of locations will be examined for both simulations, and compared with observations.

The utility of long-term reconstructions with regional climate models

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The spectral nudging method to force a regional atmospheric model allows for a space-time detailed reconstruction of the regional weather stream during the past decades. This reconstruction has the advantage that it provides a homogeneous data set with high temporal and spatial resolution, but it certainly suffers from some biases.

We have prepared such a reconstruction for Europe, 1958-2001; data are available on a 50 km grid and with an hourly increment. In the talk, the different applications this data set has been used for are reviewed – assessment of changing regional storminess, of ocean wave conditions and storm surges as well as transport and deposition of harmful substances.

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A Regional Numerical Prediction Model and its simulations on the heavy rainfalls along the Yangtse River

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Facing significant effects of the Tibetan Plateau and many other steep mountains on the weather, especially on the precipitation, in China, a regional Eta-coodinate model (REM) has been developed since 1985. The REM has been popularly used to the summer precipitation predictions and the heavy rainfall studies in China since 1995. The REM shows its great capabilities in reproducing the heavy rainfall amounts and maximum rainfall locations by predicting experiments during four summer rainy seasons (1998, 2001, 2002 2003).

Case studies show that the REM captures reasonable structures and evolutions of the rainfall systems along the Yangtze River. The rainfalls along the Yangtze River exhibit their regional differences on synoptic circulations, trigger conditions, vertical dynamic structures, etc.

In the east periphery of the Tibetan Plateau, the upper reaches of the Yangtse River, a mesoscale eddy, southwest vortex(SW vortex), is resident in the lower troposphere over Sichuan Basin. At the middle troposphere, the air appears strong humid baroclinic because of the junction of the dry-cold air from the northeast flank of the Tibetan Plateau and the warm-humid air from southwest. When mesoscale eddy moves from the top of Tibetan Plateau to the upper level of Sichuan Basin and overlaps to the quasi-stationary southwest vortex, the coupled vortex could reach to the upper troposphere. When the system grows mature, the ascending motion is strong in the center of the vortex and the large latent heating in the middle troposphere enhance the deep convection, the torrential rain occur. The precipitation is dominated by the deepened deep convective clouds.

In the lower reaches of the Yangtse River, the air in the lower troposphere possesses weak stratification stability. The atmosphere in the low troposphere appears strong humid baroclinic caused by the join of warm-humid airflow from southwest and cold-dry airflow from the north. This local humid baroclinic is often strengthened and the mesoscale system is often triggered by the disturbance frontgenesis of potential pseudo-equivalent temperature front in the low troposphere. At this particular environment, the rainfall system is limited in the lower level. Even if the system grows mature, the maximum vertical velocity can not exceed upward to 600hpa. Therefore, in the lower reaches of the Yangtse River, the latent heating and moistening is limited below 600hpa and the precipitation is dominated by stratus middle level cloud.

The REM quite well reproduces the distinct dynamical structures of precipitation in different regions of Yangtze River.

Improvement of SNURCM Land Surface Parameterization for East Asian Summer Monsoon Simulation

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In recent years, the Seoul National University Regional Climate Model (SNURCM) based on the NCAR MM5 by implementation of the NCAR Land Surface Model (NCAR LSM) and a spectral nudging technique has been applied for long-term climate simulation and extreme case experiments for East Asian summer monsoon. The land surface parameterization scheme of the SNURCM was improved using the NCAR Community Land Model 2 (CLM2) developed for the Coupled Climate System Model (CCSM). Major improvements are 1) the more detailed land-use datasets represented by five primary sub-grid land cover types including vegetations, 2) the increased soil layers for temperature and moisture with explicit treatment of liquid water and ice, and 3) the improved biogeophysical parameterizations.

To evaluate the improved land surface parameterization scheme of SNURCM, two experiments for the severe floods over East Asia during the 1998 summer (MJJA) were conducted using different land surface parameterization schemes, the NCAR LSM (LSM experiment) and the CLM2 (CLM experiment). The CLM experiment reduced systematic cold bias of the LSM experiment over land area. The CLM experiment simulated better temporal and spatial variations of the abnormally developed Meiyu monsoon fronts over China during the 1998 summer. Especially, the intensity and spatial distribution of heavy precipitation over the Yangtze River basin in June 1998 were also better simulated in the CLM experiment.

Controlling the large scales of regional climate reconstructions

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The main goal in downscaling is to obtain regional weather phenomena that are influenced by the local orography or other small scale features. Since the continental scale atmospheric state is well resolved in the reanalysis data it is to be retained by the regional model. If the regional model is only fed boundary conditions without controlling spacious weather phenomena in the model interior some problems with large scale features may occur, especially for blocking weather situations. The application of a spectral nudging technique forces the model to approximate the large scales to the reanalysis data for the whole integration area while the small scales develop exclusively according to the regional model. Large-scale control of regional climate modeling overcomes the fundamental problem of dealing with an ill-posed boundary value problem, but its usefulness depends on the specific application.

Several high-resolution state-of-the-art climate simulations were calculated, using NCEP reanalyses data for reconstructing the weather details in Europe. The method of spectral nudging in regional climate modeling is discussed, and its utility in forcing the known large-scale state without suppressing regional and local variability is demonstrated.

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An attempt toward a precise regional non-hydrostatic climate model

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For atmospheric sciences in the 21st century, atmospheric numerical models with high precision are indispensable tools to be an exact science. Development of non-hydrostatic models, based on fully compressible dynamic equations in particular, are given high priority because they use the least approximation in dynamical equations.

There are several variations of governing dynamic equations among compressible numerical models in meteorology. One of the big differences is whether the model uses fully compressible (i.e. without any approximations) equations (e. g., Satomura, 1989; Saito, 1997) or a quasi-compressible (with one or more approximations) equations (e. g., Klemp and Wilhelmson, 1978; Dudhia, 1993; Xue et al., 1995). Another difference is whether the equations are in flux forms or in advective forms.

In this paper, we focus on the latter difference among fully compressible models and examine the accuracy under the constraint of hydrostatic balance using a simple finite difference expression.

We examined five forms of two-dimensional fully compressible non-hydrostatic Euler equations and found that the form

$$\frac{\partial U}{\partial t}+\frac{\partial uU}{\partial x}+\frac{\partial wU}{\partial z}+\frac{\partial p'}{\partial x}=0$$
$$\frac{\partial W}{\partial t}+\frac{\partial uW}{\partial x}+\frac{\partial wW}{\partial z}+\frac{\partial p'}{\partial z}=-g\rho'$$
$$\frac{\partial p'}{\partial t}+\frac{c_p R}{c_v p_0}\left(\frac{p}{p_0}\right)^{R/c_p}\left(\frac{\partial q'U}{\partial x}+\frac{\partial qW}{\partial z}\right)=0$$
$$\frac{\partial \rho}{\partial t}+\frac{\partial \rho U}{\partial x}+\frac{\partial \rho W}{\partial z}=0$$

was the most accurate in the sense of energy conservation and the background hydrostatic balance.

Intercomparison of RCM simulated cloud characteristics over East Asia

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Substantial differences in cloud radiative forcing (CRF) were found among global climate model simulations of East Asian summer monsoon (Wang et al., 2003). The differences, also exist in the regional climate models (RCMs) simulations, can be attributed to different simulated vertical distribution of cloud cover and cloud water as well as the treatment of cloud radiative effect. Because of a lack of observations, we conduct an inter-comparison of these cloud characteristics simulated from five RCMs in which different cloud parameterizations are used. Association between the cloud characteristics and surface temperature and precipitation will also be examined. In addition, sensitivity experiments were conducted using selective RCMs to study the effect of different cloud parameterizations on the vertical distribution of cloud characteristics.

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A study of the cloud-radiation processes in multi-yr simulations of the East Asian climate using the Regional Climate Model RegCM-NCC

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The cloud-radiation interaction is one of the most important physical processes in the East Asian monsoon climate. Based on the 5-year continuous simulations of present day climate(1996-2000),firstly we have validated the performance of the CCM3 cloud-radiation parameterization scheme for use in the regional climate simulation over China. Then, with the purpose of testing some key parameter of the scheme, a series of sensitivity experiments have been carried out, focusing on the weakness and strength in simulations of climate characteristics of China.

The seasonal variations of annual mean TOA(top of the atmosphere)absorbed shortwave radiation(SW) flux and the outgoing longwave radiation(OLR) flux over China can be simulated well, except for some differences in magnitude. The simulated TOA SW and OLR consistently are 20 Wm^{-2} lower than the observed ones, respectively, so the net earth system radiation budget has a negative bias of 5.65 $Wm^{-2.}$ This would lead to a cold bias for model climatology. The simulated geographical distribution of the TOA SW and OLR flux compare well with the satellite observations. However, two major bias regions of the simulated TOA absorbed SW radiation are found in the Yangze-Huaihe River Basins and the Tibetan Plateau. The TOA absorbed SW bias pattern is consistent with that of the total cloud cover bias, with the reduced (increased) cloud cover corresponding to the increased (reduced) TOA absorbed SW radiation. In the Yangze-Hauihe River Basins, the positive TOA absorbed SW bias is likely to be contributed mainly from the negative bias of the total cloud cover, e.g., with the significantly underestimated cloud cover leading to more TOA absorbed SW radiation. In contrast, over the Tibetan Plateau the cloud cover bias is only 10-20% higher than the observations, while the TOA absorbed SW bias is much larger than those of other areas. This significant difference can not be fully explained with the cloud cover bias. One possible reason is due to the effect of cloud optical properties.

The systematic errors in simulated total cloud cover possibly exert an apparent effect on precipitation field. It is very evident that the negative bias center of simulated cloud lies in the south of 27? N from January to March, and jumps around 33? N in July, then gradually retreats southward in September. Due to these biases, the rainfall amount is obviously underestimated in the pre-summer rainy season in South China, which is associated with too little simulated cloud cover; the Meiyu period is much shorter due to the negative bias of clouds in the Yangze-Huaihe River Basins; and the simulated cloud cover is more in North and Northeast China from mid-summer to mid-autumn, thus leading to a longer rainy season there and the late southward retreat of the seasonal rain belt until late September.

The vertical resolution of the model can affect the radiation flux and other variables. It can be seen that there is no obvious change in cloud vertical structure when the resolutions are 14 and 17 levels, whereas cloud is thinner and changes from mid-high cloud to high cloud when the model has a finer vertical resolutions of 20 levels. Naturally,

the change of cloud vertical structure will affect the radiation redistribution, thus changing the atmospheric temperature profile and surface temperature. It is apparent that the surface temperature under 20 levels is higher than those of 14 and 17 levels, even 1K higher than the value of control experiment. This is owing to the fact that low clouds have an obvious reflectivity while high clouds have obvious greenhouse effects to warm the atmosphere.

An evaluation of the East Asian summer monsoon simulation by the Purdue Regional Model

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This study used the Purdue Regional Model (PRM) to simulate the East Asian summer monsoon for the 10 summers from 1991-2000. Objective statistical methods were applied to evaluate the performance of the PRM. All simulated variables except precipitation exhibit small errors and high pattern correlations with the observation. An analysis of the precipitation errors reveals the existence of a spatially-coherent systematic error pattern. After removing this pattern, the precipitation errors reduce significantly and the pattern correlations rise from 0.3-0.4 to 0.6-0.8. The PRM simulates the interannual variability of the regional-averaged precipitation anomalies reasonably well. In the intraseasonal time scale, the PRM well simulates the amplitudes and phases of the 850hPa vorticity fluctuations in the South China Sea. Overall speaking, the PRM is able to simulate the East Asian summer monsoon variability from sub-seasonal to interannual time scale.

The Interannual Variations of the East Asian Monsoon Simulated by a Regional Climate Model

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This study uses MM5 to perform down-scale regional climate simulations of East Asian summer monsoon (5/1~8/31) for 1990~2002. The initial and lateral boundary conditions are extracted from the EC/TOGA assimilation data with 2.5° x 2.5° resolution. The horizontal resolution of the regional model is still 45 km x 45 km.

The results show that the dynamically down-scaling simulation can significantly intensify the perturbation of synoptic scale systems, particularly over the continent. The model can not simulate well a strong system (such as a tropical cyclone), if the system develops inside the model domain rather than migrates from the lateral boundary into the domain. A regressed reconstruction method proposed in this study can significantly improve the down-scaling simulations and regional climate forecasts. Finally, the multi-year simulations show that the regional climate model can capture the annual variation, the quasi-biennual oscillation and the decadal oscillation of the east Asian monsoon.

Numerical Simulation of Boundary Layer Structure and Cross-Equatorial Flow in the Eastern Pacific

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Recent satellite observations from scatterometer and microwave imager have mapped the low level flow over the equatorial eastern Pacific and its relationship with sea surface temperature (SST). A marked deceleration towards the cold tongue and acceleration across its northern SST front is regularly seen. A high-resolution numerical model is used to examine this change in flow. The model used here has a 1.5 level turbulence closure scheme to help explain the atmospheric Planetary Boundary Layer (PBL) response. The principal result is that a sharp pressure gradient drives the northward acceleration. Because of thermal advection by the mean flow, the pressure gradient is located downstream of the SST gradient and consequently divergence occurs over the SST front, as observed by satellite. Comparisons are made between the model results and observations from the recent Eastern Pacific Investigation of Climate Processes (EPIC) campaign. Similar PBL structures are seen in model and EPIC observations along 95 W, suggesting the model has reasonably captured the physics. In particular, a shallow PBL is seen over the cold tongue as a result of the higher static stability there, compared with unstable regimes to the north and south which have deeper PBLs. Cloud is seen in the inversion layer which slopes upwards away from its lowest level over the cold tongue and towards higher latitudes. There is a maximum of low level cloudiness over the SST front.

A Ten-year Climatology of Summer Monsoon over South China from a Regional Climate Model

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The summer monsoon over South China (SC) and the South China Sea (SCS) is an important component of the East Asia summer monsoon. A regional climate model has been developed at City University of Hong Kong based on a modified version of RegCM2 at the National Climate Center of China. The model has been tested and found to be able to simulate to a large extent the precipitation over SC and the SCS for the months of May and June. To study the interannual variability of the summer monsoon over these regions, it is necessary to establish a model climatology to serve as a comparison and to remove any systematic model biases. This paper presents analyses of such a 10-year climatology (1991-2000). The interannual variability of rainfall, wind fields, moisture transport and other parameters relevant to the summer monsoon over SC and the SCS will be presented. Preliminary analyses suggest that the model is capable of reproducing the major variability of precipitation in these regions although the absolute magnitudes generally tend to be smaller, especially over the SCS. Possible reasons for these "systematic" errors will be discussed.

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High Resolution Simulations of the Island Induced Circulations for the Island of Hawaii during HaRP

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The diurnal variations of surface winds, temperature, and rainfall under summer trade-wind conditions during the Hawaiian Rainband Project (HaRP, July 11 – August 24, 1990) were simulated by using the MM5 model coupled with the Oregon State University land surface model (OSU-LSM), and validated with the 50 HaRP Portable Automated Mesonet (PAM) surface station data. The LSM has four layers underground: 10, 40, 100, and 200 cm. The land use and vegetation cover from the U.S. Geological Survey (USGS) 30' resolution data were used. A two-way nesting procedure with four nested domains is used with horizontal resolutions of 81 km, 27 km, 9 km and 3 km, respectively. The MM5/LSM was run for two months prior to the HaRP period with the initial soil moisture specified according to the soil type to generate the required soil moisture and soil temperature fields for HaRP simulations. Starting from July 10, each simulation during HaRP for each day was run for 48 hours initialized at 1200 UTC using the NCEP/NCAR reanalysis data and the 24-h forecasts of the soil moisture and soil temperatures of the previous day. The output from the 12^{th} hour and the 36^{th} hour was used to represent the simulated diurnal cycle of the following day.

Overall, the island blocking, orographic lifting, and the diurnal cycles of the surface winds, temperature and rainfall over the Island of Hawaii are well simulated. The simulated splitting airflow, strong winds over the northern and southern tips, Waimea Saddle, and Humu'ulu Saddle of the island of Hawaii are in good agreement with observations. At most areas on the windward side and the Kona coast on the leeside, the upslope (downslope) flow duration and the morning (evening) transition time from downslope (upslope) flow to upslope (downslope) agree well with observations. The diurnal rainfall maxima were well simulated with a maximum in the afternoon hours on the windward slopes and the leeside slopes, and a nighttime maximum over the windward coastal areas.

Some discrepancies exist between the model simulations and the observations. The simulated daytime upslope flow is 1 – 2 m s?¹ smaller than observations. The simulated rainfall accumulation during HaRP is 10 - 50% smaller than the observations with larger relative errors on the leeside areas and the windward slopes. The simulated surface temperature during HaRP is ~ 0.5º - 2.5º C lower than observations on most areas of the island except on some areas of the windward lower slopes, where the simulated surface temperature is ~ 0.5º higher. Factors attributed to the simulation errors will be discussed.

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Validations of the NCEP MSM Coupled with an Advanced LSM over the Hawaiian Islands

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The hydrostatic version of the Regional Spectral Model (RSM) with a 10-km resolution was implemented into the operational runstream for the state of Hawaii by the National Centers for Environmental Prediction (NCEP) in early 1997. From preliminary analyses and feedback from forecasters, it is apparent that the 10-km RSM forecasts show improvements over the Global Forecast System (GFS) runs. However, orographic effects and diurnal weather patterns are not well simulated by the RSM because the complex island terrain is not adequately resolved by the 10-km horizontal grid. Recently, the nonhydrostatic version of the RSM (referred to as the Mesoscale Spectral Model, MSM) was developed at NCEP. Preliminary applications of the MSM in Hawaii at high resolutions (= 3 km) show improvements over the 10-km RSM in simulating localized heavy rainfall and high wind events. Nevertheless, the MSM poorly resolves the diurnal cycles of temperature and wind within the boundary layer over the Hawaiian Islands due to the fact that the heterogeneous surface properties are not adequately represented by the MSM. In this work, the MSM has been coupled with an advanced Land Surface Model (LSM) with improved lower boundary conditions for three sub-regions of the state of Hawaii: the Hawaii-Maui-Molokai domain at a 3-km resolution, the Oahu domain at a 1.5-km resolution, and the Kauai domain at a 1.5-km resolution. Since April 2002, we have been conducting daily high-resolution (1.5 km), 48-h experimental forecasts for the Oahu domain using the coupled MSM/LSM with improved surface boundary conditions.

Our results suggest that: (a) over land with adequate representation of the terrain and surface properties, the coupled MSM/LSM shows improvements over the RSM and MSM in simulating 2-m temperature, 2-m dew point temperature and 10-m wind. In particular, the daytime cold bias and over-estimation of surface wind speed experienced by the RSM and MSM are largely removed by the coupled MSM/LSM; and (b) the high-resolution (= 3 km), coupled MSM/LSM demonstrates substantial improvements over the 10-km RSM in simulating localized heavy rainfall and high wind events over the Hawaiian Islands. A major model bias is that the MSM/LSM tends to over-estimate (under-estimate) precipitation on windward (lee) side of steep mountains.

A macro-scale land surface hydrological model with 50 × 50 km^2 resolution for river basins in China

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Due to the impact of global climate change on temporal and spatial distributions of precipitation and temperature, the temporal and spatial distributions of runoff and evapotranspiration are changing over time. Therefore, it is very important to adequately simulate the runoff patterns over large areas in space and time to facilitate water resources planning and management, and regional sustainable development. This paper presents a macro-scale physically-based, distributed land surface hydrological model based on the 50 × 50 km^2 resolution to simulate streamflow for the entire region of China, where the new surface runoff parameterization that represents both Horton and Dunne runoff generation mechanisms with the framework of considering subgrid spatial scale soil heterogeneity in VIC is applied. The mainland area of China is represented by 4355 cells with a resolution of 50× 50 km^2 for each cell. A macro-scale horizontal routing model is applied, which describes the concentration time for runoff reaching the outlet of a grid box as well as the transport of water in the channel system with the assumptions that the water can leave the grid cell through (at least) one river in the direction of one of its eight neighboring grid cells, and then is added to the water in the river routing scheme. Soil parameters needed are derived from the soil classification information of global 5-min data provided by the NOAA hydrology office and re-gridded to 50 × 50 km^2 resolution. The vegetation parameters are derived based on AVHRR (Advanced Very High Resolution Radiometer) and LDAS (Land Data Assimilation System) information. The forcing data are obtained through interpolation methods based on 740 meteorological stations. All of the data (i.e., soil, vegetation, and forcings) needed by the model are compiled at the 50 × 50 km^2 resolution for the entire region of China, and the daily forcing data are available for the period of 1980 to 1990. The model is run on every grid cell over the whole China, and the routing scheme is run with the daily input of surface runoff and drainage from the model to get hydrograph at basin outlets. The spatial patterns of simulated runoff and mean annual precipitation are consistent very well. The VIC discharge simulations over Huaihe, Yellow river, and Yangtse river basin will be presented and compared with the observations.

High-resolution Atmospheric Model Simulation of Marine Boundary Layer Clouds

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Marine boundary layer clouds cover on an average one third of the earth's oceans and play an important role in climate over a wide range of space and time scales. Despite their climatic importance, these clouds are poorly represented in most of the global atmospheric general circulation models (GCMs) because of insufficient model resolution and/or inadequate physical parameterizations. This deficiency in simulating boundary layer stratocumulus (SCu) clouds appears to be responsible for the failure of many coupled GCMs to keep the ITCZ north of the equator and maintain an equatorial cold tongue of adequate strength over the tropical eastern Pacific.

In this paper, we will demonstrate the importance of both model resolution and physics to the realistic simulation of marine boundary layer SCu clouds over the Southeast Pacific off South America during August and September 1999. With the standard settings in the control experiment, the regional atmospheric model developed at IPRC (IPRC–RegCM) captures the major features of the boundary layer in the region, including a well-mixed marine boundary layer, a capping temperature inversion, SCu clouds, cloud regime transition, and the decoupling of the boundary layer. A series of sensitivity experiments are performed to identify the factors critical to the realistic simulation of these features, including sensitivities to the shallow cumulus parameterization, subgrid vertical mixing, cloud droplet number concentration (CDNC), drizzle parameterization, and both the horizontal and vertical resolutions.

With the shallow cumulus parameterization turned off, the simulated SCu clouds are increased dramatically and the boundary layer structure becomes unrealistic. With reduced penetrative mixing at the top of shallow cumuli in the shallow convective parameterization, the simulated SCu clouds are increased while the boundary layer structure is retained. Reducing the CDNC increases the size of cloud droplets and thus reduces the cloud albedo but has little effect on the simulated boundary layer structure and clouds, while allowing more drizzling decreases the boundary layer clouds considerably. It is also shown that the simulated depth of the boundary layer and its decoupling depend strongly on the model horizontal and vertical resolutions. In general, insufficient horizontal and vertical resolutions produce the temperature inversion and boundary layer clouds too low with the cloud regime transition and decoupling of boundary layer almost disappeared.

Effects of the Andes on Eastern Pacific Climate: A Regional Atmospheric Model Study

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A regional atmospheric model (IPRC-RegCM) is used to study the effects of the narrow and steep Andes on eastern Pacific climate. In the Southern Hemisphere cold season (August-October 1999), the model reproduces key climatic features including the intertropical convergence zone (ITCZ) north of the equator and an extensive low-level cloud deck to the south that is capped by a temperature inversion. Blocking the warm easterly winds from South America, the Andes help maintain the divergence, temperature inversion and hence the stratocumulus cloud deck off South America. In an experiment where the Andean mountains are removed, the warm advection from the South American Continent lowers the inversion height and reduces the low-level divergence off shore, leading to a significant reduction in cloud amount and an increase in solar radiation that reaches the sea surface.

In March and early April 1999, the model simulates a double ITCZ in response to the seasonal warming on and south of the equator, in agreement with satellite observations. Under the same sea surface temperature forcing, the removal of the Andes prolongs the existence of the southern ITCZ for three weeks. Without the mountains, the intrusion of the easterlies from South America enhances the convergence in the lower atmosphere, and the transient disturbances travel freely westward from the continent. Both effects of the Andes removal favor deep convection south of the equator.

Same sensitivity experiments are repeated with orography used in T42 global models, and the results confirm that an under-representation of the Andes reduces the stratus cloud cover in the cold season and prolongs the southern ITCZ in the warm season, both acting to weaken the latitudinal asymmetry of eastern Pacific climate. The implications of these results for coupled modeling of climatic asymmetry are discussed.

Simulated climatic snow and rain fall distribution over Japan Island during winter monsoon season using a cloud resolved regional climate model

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Lack of water resource due to the climate change or the surrounding environmental change has been serious problems in many countries. For examples, the radical reduction of Aral Sea in the central Asia and the lake of Chad in African continent are speculated to be caused by the excessive irrigation and taking water. Although the irrigation has an important role to raise the ability of agricultural products, a lack of water is often caused in other neighboring area. It has been indicated that the understanding of the cycle system of water resource is indispensable to solve the problems. To utilize a hydrological model is supposed to be the best method to study the cycle system of water resource; however a lot of problems are still remained. One of the most serious problems is the rainfall distribution data for model input. In particular, it is greatly difficult to observe the detail of rainfall distribution because there are few observation points in the steep mountain area, although the large amount of rainfall is occurred in the mountain area. Therefore the hydrological model can not be fully showed its ability so far and this is preventing the reveal of water circulation system. High resolved numerical simulation might be a useful way to represent the detail of rainfall distribution. In this study, we are trying to represent the rain fall distribution using a regional climate model and indicate the possibility to reveal the water circulation system. Some numerical simulations are conducted to reproduce the rainfall over the Japan Islands during winter monsoon season. The nesting technique is used in those simulations. The first domain is covering all over Japan Islands with 20km grid spacing, and the nested domain is applied in the limited area of TOHOKU region with 5km grid spacing. The predictability of climatic rain fall distribution is planed to evaluate comparing to the observed runoff indirectly. It means that the simulated snow and rainfall is used as the input data for hydrological model, and the simulated runoff is evaluated comparing to the observed ones. At present, it is identified that the detailed rainfall distribution is well reproduced by the nested fine mesh of 5km grid spacing rather than only the coarse mesh of 20km grid spacing comparing to observed rain gauge data of Automated Meteorological Data Acquisition System (AMeDAS) because of the more detailed topographical expression in fine mesh nested domain.

Regional Simulations of Seasonal Rain-belt March over East Asia

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In this study, a multi-year integration for summer season driven by the observed field was made to simulate the seasonal rain-belt march in summer over East Asia by using the regional climate model of National Climate Model (RegCM_NCC). The primary comparisons between the simulations and observations have shown that RegCM_NCC has some capabilities in simulating the major rain-belt marches in summer over East Asia region.

The RegCM_NCC is based on the NCAR/RegCM2 (1996 version) and has been developed through modifying various schemes, especially the physical process parameterization schemes, such as the land-surface process model, the cumulus convective and radiation transfer process schemes, and so on. The RegCM_NCC has been used for simulations over different regions, as well as the operational seasonal predictions experiments.

Additionally, the various model configurations, with emphasis on the scheme options of the land-surface and the cumulus convective processes, and so on, have also been tested for the model performance in modeling the seasonal marches of the main rain-belts.

Simulations of Palaeo-climates over Eastern Asia and the Tibetan Plateau at 6 ka and 21 ka B.P. by a Regional Climate Model

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Using a regional climate model with the detailed land surface processes, East Asian monsoon climate at 6 ka and 21 ka BP is simulated by employing the present-day vegetation and the paleovegetation converted from the pollen fossil record in the East Asia region, and the effect of the changes in vegetation on East Asian climate is investigated as well. The climatic evolution figures with a higher resolution obtained from the regional climate simulations show that the enlargement of the seasonal cycle of insulation, the reducing of perpetual snow and sea ice in high latitudes, and the increasing of polar sea temperature at 6ka B.P. led to the weakening of winter continental cold anticyclones and hence the diminishing of the amplitude of winter temperature decline over China; by the inclusion of paleovegetation in simulation, the surface albedo was reduced, thus further increasing in the winter temperature. This result not only made a break through the limitation of the winter temperature decline (compared with the present) obtained from many simulations of Paleoclimate Modeling Intercomparison Project (PMIP), but also renders the seasonal characters of simulated temperature changes in a better agreement with the geological records. The temperature rise in whole year during the 6ka BP over the East Asian continent resulted in the strengthening of the East Asian summer monsoon and the weakening of the winter monsoon; the precipitation and effective precipitation increase, and the monsoon rain belt spreads westwards and northwards. In contrast, the temperature declined throughout the year during the 21ka BP, it is an important factor that leads to the strengthening of the East Asian winter monsoon and the shrinking of the summer monsoon. The precipitation during the 21 ka BP was reduced in most areas of East Asia compared with the present, but precipitation and effective precipitation were increased in both the Tibetan Plateau and Central Asia. Correspondingly the perpetual snow over the Tibetan Plateau was also increased, which is favorable to the development of glaciers and tundra in the plateau region, leading to that the permafrost spreads southwards to areas of 30^{o} N.

Indian Summer Monsoon - Global Ocean Interactions

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Detecting and understanding how the Indian monsoon interacts with the global oceans in both observations and coupled model simulations is difficult because of complications associated with separating the signal associated with the interactions from the noise within the climate system. A new coupled modeling approach, called interactive ensembles, has been developed that is specifically designed to reduce interference from climate noise and serves to isolated coupled interactions between the atmosphere and the ocean. This new procedure is applied within the context of state-of-the-art coupled general circulation models and proves to be ideal for studying how the Indian monsoon affects and is affected by global ocean variability. This talk describes the interactive ensembles approach as applied to the COLA anomaly coupled general circulation model with particular attention to how interannual Indian monsoon variability interacts with ocean variability in the Indo-Pacific region. Three key results are presented from multi-century simulations (i) Monsoon variability has significant impacts on the subsequent evolution of warm events. A weak (strong) monsoon enhances (weakens) an ongoing warm event. The monsoon impacts are manifested in the surface zonal wind stress anomalies in the western-central Pacific. (ii) Central-eastern equatorial Pacific sea surface temperature (SST) anomalies can affect the Indian monsoon by both a shift of large-scale east-west circulation across the equatorial Indian-Pacific Oceans and a Rossby wave type response over the eastern North Indian Ocean-western North Pacific. (iii) Capturing (i) and (ii) above critically depends on coupled air-sea interactions in the Indian Ocean particularly in terms of evaporation.

Interactive feedback between the Indian Ocean and ENSO

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Influence of the Indian Ocean on ENSO oscillation is investigated by using observed data and various models. Demonstrated here is that warming in the western Indian Ocean during the mature phase of El-Nino produces easterly wind stress anomalies over Indonesia and the western edge of the Pacific. We also demonstrate that the anomalous easterly wind in the western Pacific during El-Nino help a fast transition to La Nina by generating negative Kelvin waves. Thus the warming in the western Indian Ocean, which is a part of El-Nino signal, plays as a negative feedback mechanism to ENSO. This Indian Ocean feedback appears to operate mostly for strong El-Ninos and results in La-Nina one year after the mature phase of the El-Nino. This one-year period of phase transition implies a possible role of Indian ocean-ENSO coupling in the Biennial Tendency of the ENSO.

Atmospheric GCM experiments show that the Indian Ocean SST forcing is mostly responsible for the easterly wind anomalies in the Western Pacific. An intermediate ocean-atmosphere coupled model reproduces the observed fast transition from El-Nino to La-Nina, when the wind stress anomalies induced by the Indian Ocean warming are added in the western edge of the Pacific

Subsurface influence on SST in the Tropical Indian Ocean: Structure and Interannual Variability

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Interannual variations of subsurface influence on SST in the Indian Ocean show strong
seasonality. While the subsurface influence confines to the southern Indian Ocean in boreal winter and spring, it is observed on both sides of the equator in boreal summer and fall. Interannual long Rossby waves are at the heart of this influence, and contribute significantly to the coupled climate variability in the tropical Indian Ocean. Principal forcing mechanism for the generation of these interannual waves in the Indian Ocean, and the relative influence of two dominant interannual signals in the tropics, namely, El Nino Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD), are also discussed. Two distinct regions dominated by either of the above climate signals are identified. IOD dominates the forcing of the off-equatorial Rossby waves, north of 10^{o}S, and the forcing comes mainly from the anomalous Ekman pumping associated with the IOD. However, after the demise of IOD activity by December, Rossby waves are dominantly forced by ENSO, particularly south of 10^{o}S.

It is found that the subsurface feedback in the northern region (north of 10oS) significantly influences the central east African rainfall in boreal fall. The Indian Ocean coupled process further holds considerable capability of predicting the east African rainfall by one season ahead. Decadal modulation of the subsurface influence is also noticed during the study period. The subsurface influence north of 10^{o}S coherently varies with the IOD, while it varies coherently with the ENSO south of this latitude.

Austral climate anomalies associated with Indian Ocean Dipole mode events

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The nature and relevance of SST variability in the Indian Ocean had been unclear for decades. However recent studies are rapidly advancing a better understanding of SST variability in this region, both on interannual and intraseasonal timescales, with practical implications for seasonal predictability. On interannual time scales, the so-called Indian Ocean Dipole mode (IOD) events have a significant impact on local climate variability over the rim countries. Recently it has been demonstrated that IOD events also have a large impact on subtropical climate variability through teleconnection processes. Here we focus on the impact of IOD events on climate anomalies in the southern hemisphere, where the associations are particularly robust.

For this study, correlation and composite analysis was carried out on a 42 year long gridded data set of observed surface air temperature over land regions. The impacts of IOD events on austral climate anomalies are significant during the winter(JJA) and spring(SON) seasons. During these seasons, IOD events induce large scale intercontinental correlations of surface air temperature amongst Australia, Africa and South America. Surface temperature rises(drops) abnormally and coherently in the subtropical regions of these continents during positive(negative) IOD events. Interestingly, variability during non-IOD years is considerably weaker than during IOD years over these regions suggesting that IOD events are a significant and predictable source of climate variability during the austral winter and spring seasons. Analysis of geopotential anomalies at various pressure levels (source:NCEP/NCAR renalysis) show that the surface temperature anomalies are associated with geopotential height anomalies that have an equivalent baroptropic structure. Further the diagnosed Rossby wave activity flux is seen to emanate from the eastern Indian Ocean and propagate along the subtropical and subpolar jet streams qualitatively in agreement with linear wave dynamics.

Simulation of the Indian Ocean Dipole and its teleconnection to Asian Summer Monsoon and African Short Rains by SINTEX-F CGCM

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Tropical climate variability is shown to influence the global climate system on multiple time scales. On the interannual time scale, the El Niño/Southern Oscillation (ENSO) phenomenon of the tropical Pacific Ocean is documented as a dominant climate signal. Recent discovery of the Indian Ocean Dipole (IOD) (sometimes also known as the Indian Ocean Zonal Mode) has added a new aspect to the studies of these tropical basins' influence on global climate. In the present study, we have investigated the evolution of the IOD and its teleconnection in a coupled model simulation results. Data paucity of the observed data in both time and space did not allow us to reliably extend our analysis beyond 1950s. Therefore, the 220-yr long simulation results added confidence to the statistical significance of the analyses. The SINTEX-F coupled model used in the study is developed under the EU-Japan collaboration and is an upgraded version of SINTEX model. The model integration is carried out on the Earth Simulator.

The model simulated IOD and ENSO events are very realistic. Statistical inferences derived from the time series of the two phenomena are comparable with that of the observation. The correlation coefficient between the dipole mode index and Niño3 is 0.4 for the whole year (0.51 for the boreal fall season). The high September-November correlation between the two indices is consistent with the observation suggesting about 26% of the model IOD events co-occur with model ENSO. However, simple statistical technique like composite method and partial correlation analysis revealed the independent nature of the model IOD.

The IOD is shown to affect the pressure variability at Darwin, one pole of the Southern Oscillation. Therefore, it could contribute to the intensification of the SST warming in the eastern Pacific. We investigate this newfound relationship using the coupled model simulations and a stand-alone AGCM simulation. The SINTEX-F model results are also analyzed to understand other observed teleconnection of the IOD. It is found that the East African short rains variability is strongly associated with the IOD rather than ENSO. The model IOD also influences the Sri Lankan Maha rainfall, Indian summer monsoon rainfall, East Asian (including Japan) summer conditions. In the Southern Hemisphere, the IOD influence is significant over Australia and Brazil. All those results are quite encouraging for the predictability of the Indo-Pacific climate system.

Structure and evolution of southerly surges over the eastern Indian Ocean during Austral winter

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Meridional wind surges from extratropics to tropics have been recognized as one of major regulators of tropical convective activity in many observational studies. The aim of this study is to confirm that the southern hemisphere (SH) meridional surge which is a form of extra-tropical forcing play a considerable role in modulating the tropical atmospheric and oceanic variability in the equatorial Indian Ocean neighboring the South Asian monsoon region. We explore the low-level surges on the submonthly (6-25 day) timescale occurring over the eastern Indian Ocean and associated tropical convection and large-scale atmospheric fields during the SH winter (June-August) season. For this study, the NCEP-2 reanalysis and NOAA/CDC OLR data on the daily basis for the 23-yr period from 1979-2001 are used, and composite analysis is carried out. A low-level surge index has been calculated using the 850hPa meridional component of wind over a key region where a local maximum of submonthly scale variance locates (17.5-2.5S, 87.5-97.5E). A total of 54 surge events are selected from the 6-25-day band-pass filtered index. Then, composites of various atmospheric and surface elements are generated based on this index to establish the relationships between the surge events and the large-scale fields.

From the composites, the low-level meridional wind surges appear to be initiated by the mid-latitude Rossby wave passages along the mean westerly flow over the southern Indian Ocean and South Pacific. As the mid-latitude wave propagates eastward and develops in the entrance of the mean subtropical jet to the east of Australia, the low-level southerly surge blows through the subtropics into the equatorial region. The amplified wave and surge signals lead to a cold dry air incursion from the extratropics to the tropics. 2 to 4 days later with the surge peak, negative OLR anomalies develop near the key region, which is indicative of the local flare up of convection in the SH side equatorial region. This occurrence of convection can be explained by the influence of the incursion of cold and dry air accompanied by the southerly surge event. The enhanced southerly cold dry air flows from the mid-latitude into the tropics increase latent and sensible heat flux from the sea surface, which charges the low-level moist static energy in the near equatorial region. As a result of these processes, local unstable condition is set up in the lower troposphere, and subsequent convective motion is triggered. The potential roles of such surge events in preconditioning the atmosphere for convection will be discussed in terms of the extratropical forcing and air-sea interaction.

Convective activity in the eastern Indian Ocean observed during R/V Mirai cruises MR02-K04 and MP03-K03

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Doppler radar observation and rawinsonde soundings were carried out in the eastern Indian Ocean (05N-05S, 90-95E) during R/V Mirai cruises MR02-K04 (July 2002) and MR03-K03 (July 2003) to study convective activities and their variations over the ocean. Remarkable diurnal cycle of convective activity is obtained by a statistical analysis using the Doppler radar data. A crucial phase difference in the diurnal variation between convective and stratiform rainfall fractions is also shown. Different characteristics of the diurnal variability are presented between MJO active (MR02-K04) and inactive (MR03-K03) phases. Amplitude of the diurnal variation during the MJO inactive phase is larger than that during the MJO active phase, whereas a total rainfall amount is larger during the active phase than that during the inactive phase. A contribution of each rainfall fraction to the total rainfall amount is also different during between MJO active and inactive phases. Several case studies regarding mesoscale convective system (MCS) observed by the Doppler radar system are presented too. Moreover, simultaneous rawinsonde soundings were conducted at Kototabang (0.20S, 100.32E) and Tabing (0.88S, 100.35E) over Sumatra Island to study a regional variability of convective activity among over the ocean, coastal, and inland regions. Characteristics convective activity, e.g., diurnal cycle, rainfall amount, rain type fraction, and their difference among three regions are also discussed.

The Characteristics of Indian Ocean Dipole Mode: Preliminary Study of the Monsoon Variability in the Western Part of Indonesian Region Especially on the West Sumatera

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The prediction of the upcoming of El-Nino and Southern Oscillation (ENSO) Event in Indonesia, generally is corresponded to the Sea Surface Temperature anomaly (SSTa) and Southern Oscillation Index (SOI) along West to East Pacific Ocean between Darwin (Australia) and Tahiti (Hawaii Island). This phenomena is assumed having a good correlation with the moving average of convective cloud activity, especially from the Western part of Indonesia region which mostly covered by the giant clouds such as Cumulonimbus (Cb) clouds. Since only a few atmospheric and oceanography data in this region, we are interested to investigate the correlation between the characteristics of Indian Ocean Dipole (IOD) and rainfall at West Sumatera Stations. We used the Sea Surface Temperature (SST), Sea Level Pressure (SLP) and Outgoing Longwave Radiation (OLR) of Dipole Mode Index (DMI) anomaly. By applying the spectrum method and wavelet analysis, we found that the most predominant peak of these parameters are three months oscillation, especially for SST and SLP data analysis. This is corresponding well with the daily rainfall daily over Kototabang, Sicincin and Padang Panjang Station which have three months oscillation. We supposed this is caused by the Madden-Julian Oscillation (Mc Bridge, 1992). While, for the OLR data, the most predominant peak is six months oscillation. We suspect these phenomena are correspond the transition season from dry to rainy season for SST and SLP, and Monson season for OLR.
Keywords : Monsoon variability, Indian Ocean dipole and ENSO

The North Pacific as a regulator of summertime climate over North American and the Asian Monsoon

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The interannual variability of summertime rainfall over the U.S. may be linked to climate anomalies over Pacific and East Asia through teleconnection patterns that may be components of recurring global climate modes in boreal summer (Lau and Weng 2002). In this study, maintenance of the boreal summer teleconnection patterns is investigated. The particular focus is on the potential effects of North Pacific air-sea interaction on climate anomalies over the U.S. Observational data, reanalysis and outputs of a series of NASA NSIPP AGCM and AGCM coupled to NASA GSFC MLO model experiments are used.

Statistical analysis of observations and NSIPP AMIP type simulations indicates that, the interannual variability of observed warm season precipitation over the U.S. is related to SST variation in both tropical and North Pacific, whereas the NSIPP AMIP simulated summertime U.S. precipitation variation mainly reflects impact of ENSO in tropical Pacific. This implies the potential importance of air-sea interaction in North Pacific in contributing to the interannual variability of observed summer climate over the U.S. The anomalous atmospheric circulation associated with the dominant summertime teleconnection modes in both observations and NSIPP AMIP simulations are further diagnosed, using stationary wave modeling approach. In observations, for the two dominant modes, both anomalous diabatic heating and anomalous transients significantly contribute to the anomalous circulation. The distributions of the anomalous diabatic heating and transient forcing are quadrature configured over North Pacific and North America, so that both forcings act constructively to maintain the teleconnection patterns. The contrast between observations and NSIPP AMIP simulations from stationary wave modeling diagnosis confirms the previous conclusion based on statistical analysis. To better appreciate the role of extra-tropical air-sea interaction in maintaining the summertime teleconnection pattern, various dynamical and physical fields and their inter-linkage in the series of NSIPP AGCM and AGCM coupled to MLO model experiments are examined in-depth. Based on comparison between different model experiments, we will discuss the physical and dynamical mechanisms through which the air-sea interaction in extratropics, and transient mean flow interactions over the North Pacific, affects interannual variation of U.S. climate during boreal summer.

Simulation of the Establishment and Maintenance of the East Asian Monsoon Anomaly during ENSO Episodes

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A suite of experiments with a GFDL GCM have been designed to study the impact of ENSO events on circulation anomalies in different parts of the globe, including the East Asian sector. These model runs entail the prescription of observed time-varying SST forcing in the equatorial central and eastern equatorial Pacific, and incorporation of simplified atmosphere-ocean coupling elsewhere.

Model results are presented on ENSO influences on the evolution of the East Asian monsoon during the period extending from autumn in the year of ENSO onset to the spring of the following year. Attention is focused on the spatio-temporal development of the near-surface anticyclonic anomaly over the South China and Philippine Seas during a typical warm ENSO episode. This simulated feature is established rather abruptly in early October. It strengthens considerably and migrates eastward during the next few months. The occurrence of this subtropical high pressure center is accompanied by prominent anomalies in the wind, temperature and precipitation fields over East Asia. Many aspects of the model simulation are in good agreement with observational results. The roles of the pre-existent large-scale ambient circulation, intraseasonal fluctuations, and air-sea interactions in various stages of development of the simulated anticyclone over the Philippine Sea have been identified. The inferences from model output on the mechanisms contributing to the initiation and sustenance of this anticyclone are also consistent with those based on observational diagnoses.

A break in the Indo-Pacific warm pool over the South China Sea in boreal winter: Seasonal development and interannual variability

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The Indo-Pacific warm water pool in boreal winter shows a conspicuous gap over the South China Sea (SCS) where sea surface temperature (SST) is considerably lower than over the oceans both to the west and east. The formation mechanisms for the climatology and interannual variability of SCS SST in boreal winter are investigated using a suite of new satellite measurements. The winter SCS is divided into two parts by the axis of the maximum northeasterly monsoonal winds. The positive wind curl in the southeastern half of the ocean drives a cyclonic gyre circulation in the deep basin. As its western boundary current, an intense southward flow is found south of Vietnam on the continental slope separating the Sunda Shelf to the west and the deep SCS basin to the east. This slope flow exceeds 50 cm/s in speed and advects cold water from the north. This cold advection results in a distinct cold tongue in the winter SST climatology. Both the slope current and cold tongue are strongest in November to February. This winter cold tongue displays considerable interannual variability that is highly correlated with eastern equatorial SST. In an El Nino, the winter monsoon weakens, causing the SCS ocean circulation to spin down. The reduced western boundary current and its thermal advection result in a warming in the SCS winter cold tongue. Both SST variance and its correlation with ENSO peak along the climatological cold tongue, indicating that ocean dynamics are an important player in SCS climate variability.

Air-sea interaction in monsoonal Asian seas

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New satellite observations are revealing the structure of the ocean and the overlying atmosphere in detail never possible before. This paper presents a few examples to illustrate how such high-resolution satellite observations can be used to study air-sea interaction phenomena in marginal seas. These seas generally have a basin size of 1,000 km or less, scales most of existing climate datasets do not resolve.

In summer, as the southwesterly winds impinge on Annam Cordillera—a north-south running mountain range on the east coast of Indochina—a strong wind jet occurs at its southern tip offshore east of Saigon, resulting in strong wind curls that are important for ocean upwelling off the coast. In July and August an anticyclonic ocean eddy develops to the southeast in response to this wind curl forcing, advecting the cold coastal water offshore into the open South China Sea (SCS). Corroborating evidence for this cold filament is found in ocean color observations that show a collocated tongue of high chlorophyll concentration. The development of this cold filament disrupts the summer warming of the SCS and causes a pronounced semi-annual cycle in SST. Moreover, the cold filament is an important player in interannual variability in the summer SCS.

While orographic effect on wind is well known, it may sound improbable that submerged bottom topography can change winds and clouds, but satellite observations reveal such a bathymetric effect over the Yellow and East China Seas. These seas, located between China, Korea and Japan, together form one of the largest shelf seas of the world. Under intense surface cooling in winter, water properties are well mixed up to 100 m deep. Ocean depth thus has a strong influence on SST of the continental shelf, leading to a remarkable collocation of warm tongues and deep channels. High winds and increased cloudiness are found over these warm tongues; one such band of ocean-atmospheric co-variation meanders through the basin, following a deep channel for an amazing distance of 1000 km. In addition to these climatic effects, the Kuroshio Front—where the warm current meets the much colder shelf water—strengthens the growth of storms.

Interannual signals in the northwestern Pacific and its marginal seas: Their evolution, air-sea coupling process and relationship with climate anomaly in winter over China*

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By applying the XBT data sets (1980-2001), we investigated the interannual variation of heat content in the western Pacific upper layer water (from the surface to thermocline), artificially defining the northern, equatorial and southern sub-domains. The relationship between the heat content released from the tropical Pacific during El Niño event and the intensity of El Niño event is found to be linear dependence. The two off-equator parts of the tropical western Pacific also participates in the ENSO heat pumping, for instance, the northern part, which initialize the heat content adjustment, is leading the equatorial part by 6 months.

Regarding the relationships of leading and lagging correlation between the Nino3 index and the heat content anomaly in the tropical western Pacific, the interannual adjustment in the tropical western Pacific shows meridionally asymmetric distinctly. The heat content anomaly in the northern sub-domains, initializes the interannual adjustment of the tropical western Pacific. The southern sub-domain lags the northern one. The signature consequent diagram of the tropical western Pacific heat content anomalies is found that the signal appears firstly in the northern sub-domain, then spreads to the equatorial and southern sub-domains, and extends along the equator to the eastern tropical Pacific in the end.

The relationship between sea surface temperature anomaly (SSTA) in the domain from the northwest of the Pacific Ocean to the China Seas (NWP-CS) and climate (precipitation and surface temperature) anomaly in winters over East of Chinese Mainland (ECM) are investigated with statistic methods. The results suggest that 1) SSTA in NWP-CS usually behave "seesaw" pattern, i.e., the sign of SSTA in northwest to the Philippines region is positive (negative) while in southeast is negative (positive), we call it SSTA "seesaw" positive (negative) pattern. When SSTA "seesaw" positive pattern appears, the surface temperature in ECM is higher (lower) than the usual winters, but the precipitation anomaly is not distinct. 2) There are two anomalous anticyclones (cyclones) locating at northwest Pacific and east to the Philippines in 850hPa, and an anomalous locate anti-Hadley (Hadley) circulation which descend (ascend) in south of 18°N, ascend (descend) north of 18°N. 3) Heat flux anomaly from ocean into atmosphere is weaker (stronger) in northwest to the Philippines, but stronger (weaker) in southeast to the Philippines than usual winters, because the weak (strong) northerly prevails in northwest to the Philippines

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and strong (weak) northeaster in southeast to the Philippines that induced by anomalous anticyclones (cyclones).

Above-mentioned relationship can be explained by a diagnosis tool of the local Hadley circulation, in which the theory of forced meridional circulation in a symmetric vortex. Results reveal the SST seesaw pattern and its associated surface heating is responsible for anomalies in atmospheric meridional circulation.

Seasonal Characteristics of the Atmosphere-Ocean Interaction over the Western North Pacific Region

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In this study, the reversed relationship between SST and precipitation anomaly over the Western North Pacific region depending on the season are estimated on the basis of the observational data. During boreal summer, decreased precipitation anomalies induced the increase of the downward net shortwave flux to the surface, and in turn, it causes the increase of SST anomalies over this region. While, increased SST anomalies forced the increase of rainfall during boreal winter. These seasonal contrast is distinguished from those over the Eastern Pacific, where shows similar positive relationship all the year around. Interestingly, AGCM simulation cannot capture theses seasonal dependency, although not only CGCM, but also simple slab ocean mixed-layer model reproduces these features. To investigate the mechanism of these characteristics, the seasonal relationship between mean state and anomaly field and the effect of ocean components interacting with SST are analyzed and compared. Simple model experiments are followed to examine the exact effects of each part.

A study on variations of deep-rain properties with the sea surface temperature over the tropics utilizing TRMM PR2a25 and TMI data

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Stimulated by the infrared iris hypothesis proposed by Lindzen et al. (2001; LCH2001) and following critical works, we approached the issue by statistically examining the variations of tropical rain characteristics associated with SST. By utilizing TRMM Precipitation Radar (PR) data, not only we can directly classify convective rain and the stratiform rain, but also we can know the precipitation top heights (PTH). It is assumed that deep stratiform cloud cover would be in a positive correlation with the deep stratiform rain (PTH>5km; DSR) cover.

All path data of PR2a25 version 5 for the period from January 1998 to December 2000, except for January 1999 and September to November 1999 where data were missing, were utilized in a pixel by pixel basis. Classification between the convective rain and the stratiform rain depends basically on the rain flag provided by the PR2a23 data set. Warm isolated rain pixels were reclassified from the stratiform to convective rain, following the suggestion by Schumacher and Houze (2003). PTH for each pixel was identified with a threshold of 0.3mm/hr. Before the statistics, daily gridded rain data were made into 2.5deg x 2.5deg longitude-latitude grids. Rain pixels over the ocean and over the land are separately counted utilizing the surface data for each pixel. In order to obtain the information for the local sea surface temperature where the rain was observed, we utilized the 3-day running mean gridded sea surface temperature estimated form the TRMM Microwave Imager data with Shibata's algorithm. Next, we binned the daily 2.5degx2.5deg rain data into 1degC SST bins for the same day and same grid. Then we made statistics of the coverage, amount, and intensity of deep convective rain (PTH>8km; DCR) and DSR over ocean in relation to SST for four tropical regions as shown in Fig.1 (Region B: 30N-30S, 130E-170W, GMS region in LCH2001, Region D: 15N-15S, 125E-90W, North Pacific ITCZ, Region E: 5N-10S, 60E-100E, equatorial Indian Ocean, Region F: 20N-20S, 0-360E, entire tropics). Counted rainy 2.5deg grid numbers are 212599, 115650, 48888, 646099, for regions B, D, E, F, respectively.

Primary results are as follows: Statistically significant results are obtained over the warmer water (SST>25C). The coverage and the amount of DCR and DSR both significantly increase with SST, except for over the Indian Ocean, where the DSR amount shows a negative correlation with SST. On the other hand, intensities of DCR and DSR have a tendency to decrease with SST. Over the colder SST in the GMS region (region B here), their relation differs completely. The negative correlation of the anvil cloud cover with the cloud weighted mean SST suggested by LCH2001 may be an artifact by averaging over the GMS region mixing properties over the subtropics and the deep tropics, as already pointed out by Hartmann and Michelsen (2002).

However, when we examine the ratio of DSR cover to DCR cover or amount, we find that these values have significant negative correlation with warmer (>26C) SST. The decrease rate of DSR-cover/DCR-cover and DSR-cover/DCR-amount for SST>26C are, 12-25%/1degreeC and 9-22%/1degreeC, respectively, in good agreement with what

suggested by LCH2001. The ratio of DSR-amount versus DCR-amount also significantly decreases with SST. It is notable that these DSR properties normalized by DCR show very similar behavior in relation to SST independent of the regions.

In conclusion, over the tropical warm ocean (SST>25C), while DCR and DSR intensity both slightly decrease with SST, DSR cover mostly increase with an exception over the Indian Ocean. DCR and DSR amount, as a result, have positive correlation with SST. Therefore, although DSR cover normalized by DCR cover or by DCR amount both decrease with SST, it does not result in the reduction of DSR coverage and most probably the high stratiform cloud amount. Instead, an increase of stratiform cloud cover with SST is statistically suggested. However, as shown with the Indian Ocean case, the relationship between deep stratiform cloud and SST are also controlled by factors other than convective enhancement, such as surface solar irradiance, surface winds and the oceanic mixed layer depths. In order to capture the cloud-SST relationship accurately, we have to understand the air-sea interaction. On the other hand, very robust relationship of DSR properties normalized by DCR values, free from regional differences, is suggested. These relations may become a clue to the variation of rain properties associated with the climate change in future studies.

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East-west SST Contrast over the Equatorial Oceans and the Western North Pacific Summer Monsoon

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The circulation and SST anomalies in the post El Nino Asian summer monsoon season are examined through data analysis and linear equatorial beta plane model calculations. An east-west SST anomaly contrast dominates over the tropical Indian and Pacific Oceans, with positive anomalies over the Indian and western Pacific Oceans and vice versa over central to eastern Pacific. This anomaly contrast exerts the Kelvin response with a low-level easterly anomaly along the equator over the western to central equatorial Pacific. Over the Philippine Sea, a low-level anti-cyclonic anomaly and embedded negative precipitation anomaly prevail as a stationary moist Rossby wave. Such east-west SST contrast over equatorial oceans also affects the number of formation of typhoon over the western North Pacific. The equatorial low-level easterly anomaly as a Kelvin response accompanies an area with negative vorticity on its sides. It is newly proposed that the reduction of Ekman pumping due to the negative vorticity anomaly is a plausible cause of the appearance of the stationary moist Rossby wave over the Philippine Sea.

Tropical Pacific SST Anomalies and Indian Monsoon: A CGCM Study

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The relationship between tropical Pacific SST anomalies and Indian summer monsoon is investigated using MRI coupled GCM. The climatological features and year to year variation of Indian monsoon are simulated reasonably well by the CGCM. In the model, interannual variability of India monsoon is strongly related to ENSO and the model shows high propensity for a quasi-biennial time scale for ENSO. Pacific SST anomalies were found to influence monsoon through modulating the precursory signatures and onset, subseasonal and seasonal variations. Positive SST anomalies in the eastern equatorial Pacific are mainly accompanied with a shift in east-west walker circulation over the Asia-Pacific and found to coincide with negative rainfall anomalies over India. In addition, positive SST anomalies over the Indian Ocean accompanied by weaker Hadley circulation also results in negative rainfall anomalies.

A zonal atmospheric coupling associated with differences of SST anomalies between the Indian Ocean and the Pacific and a meridional coupling due to the temperature difference between equatorial Indian Ocean and Indian landmass are evident. Positive (negative) phases of this coupling could enhance the impact of ENSO warm (cold) events on monsoon dynamics. Results of CGCM intercomparison with those from observation and from atmosphere-alone integrations forced with coupled SSTs will be presented.

Indian Ocean Dipole: Influence on Boreal summer climate of Indo-Australian sector

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It is known that Indian Ocean Dipole (IOD) events in last two decades of 20th century played an important role in weakening the ENSO-Indian monsoon relationship. We confirm using composite analysis of observed rainfall anomalies over India that IOD events reduced the ENSO influence over India when they occur with the same phase. Also, we used an AGCM to prove that a strong positive IOD event reduces the co-occurring ENSO influence on the Indian monsoon. Our experiments have shown that during an El Niño event, the Walker circulation over the West Pacific-tropical Indian Ocean is anomalously modulated. This results in anomalous divergence at lower levels over the Indian region, causing anomalous subsidence and weakened rainfall over India. When a positive IOD event simultaneously occurs with El Niño, an anomalous divergence center can be seen over the eastern tropical Indian Ocean, as compared to the 'pure' El Niño event. The anomalous divergent flow from this center, crossing the equator, converges over the Indian monsoon region, and thus reduces the ENSO induced subsidence and the related deficit of rainfall.

The CMAP rainfall and GISST datasets from 1979-1997 were used to assess the influence of the IOD events on the Australian winter (JJAS) rainfall. Our partial correlation studies show that the IOD mode index (IODMI) has significant negative partial correlations with rainfall over the south-western and southern regions of Australia. These negative partial correlations between the IODMI and the winter rainfall extend south-eastward from Indonesia all the way to south east Australia. Our AGCM experiments indicate that the relatively cold SSTA to the west of the Indonesian archipelago during a positive IOD event introduce an anomalously anticyclonic circulation at lower levels over the eastern tropical and subtropical Indian Ocean as well as much of the Australian continent. This results in anomalous subsidence over regions of south-western and southern Australian continent and also reduces the rainfall.

The Relationship between the Interannual Variation of the Indian Ocean SST induced by the Indian Monsoon and ENSO

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The relationship between the interannual variation of the surface wind in the north Indian Ocean (30E-100E, equator-30N) and El Nino-Southern Oscillation (ENSO) during boreal summer is investigated and its influence on the sea surface temperature (SST) anomaly is evaluated. The June-August mean of the sea surface wind anomaly obtained from NCEP Reanalysis is decomposed by the EOF analysis. The result reveals that two modes exist in the surface wind variation, both of which flow in the meridional direction. The correlation relationship is estimated between the two modes of the surface wind anomaly, the OLR anomaly from NOAA OLR and the Nino3 SST anomaly. It is found that the wind anomaly of the first mode is southerly (northerly) during the development phase of El Nino (La Nina), which is caused by the intensification (weakening) of the meridional difference of the convection anomaly in the eastern Indian Ocean. In contrast, the wind anomaly of the second mode is northerly during the decaying phase of El Nino, which is remotely driven by the suppressed convection anomaly in the tropical northwestern Pacific Ocean through the atmospheric Rossby wave, and vice versa for La Nina. The linkage of the first mode to ENSO is obvious during 1990's, while that of the second mode is clear during 1980's.

The local thermal forcings caused by these contrastive two modes, which are evaluated in terms of the latent heat flux due to the change of the wind speed and the thermal advection of the Ekman transport, are compared with the time change of the SST anomaly obtained from Reynolds SST. The relationship between the climatological wind and the wind anomaly indicates that the wind anomalies of two modes induce two different patterns of the change of the SST anomaly; the first mode induces the meridionally antisymmetric structure of the SST time change during 1990's, while the second mode causes the basinwide SST time change during 1980's. Consequently, it is found that the two different patterns of the time change of the SST anomaly can be related to ENSO during boreal summer through the bimodal variation of the surface wind anomaly.

Monsoon Variability over South and East Asia vis-à-vis Indian Ocean Dipole Mode

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The influence of the Indian Ocean dipole mode on the summer monsoon rainfall over South Asia (India) and East Asia (China, Korea, Japan) has been investigated applying simple statistical techniques of correlation and composite analysis. While the observed rainfall data are used as a measure of rainfall activity, the NCEP-NCAR Reanalysis data are used to examine the circulation features associated with the extreme dipole and monsoon phases. The data used covers the period 1960-2000.

Results reveal that the positive phase of the dipole is favorable for following year's rainfall activity over India and China, but is unfavorable for the following year's monsoon activity over Korea and Japan. The relationships are more consistent and stronger for the remote Korean and Japan regions, rather than for the near Indian Ocean region. While the monsoon variability over China, Korea and Japan appear to have no impact on the dipole variability, a strong Indian monsoon damps the positive dipole mode.

The Indian Ocean variability during autumn influences the following summer monsoon variability over East Asia via the northern hemisphere mid-latitudes or via the eastern Indian Ocean / west Pacific route. Anomalous strong convection over the Indian Ocean region induces a zonal wave pattern over the mid-latitudes of Asia propagating eastwards and displacing the north Pacific subtropical high (NPSH) over northeast Asia. On the other hand the warming over the eastern India ocean / west Pacific inhibits the westward extension of the NPSH. Thus the mid-latitude Rossby waves may displace this high in an east-west zonal direction, while the west Pacific heating may induce a meridional wave train and displace it in a north-south direction. The location and shape of this high plays a dominant role in the monsoon variability over East Asia Thus the origin for the displacement of the NPSH appears to be in the Indian Ocean associated with the dipole mode.

On the mechanism of the seasonal variability of SST in the tropical Indian Ocean

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A general form of equation that diagnoses SST change is derived. All other equations that widely used are the special case of it. Combining the date from an Ocean General Circulation Model (MOM2) with integration of 10 years (1987-1996), the relative importance of various processes that determine SST variations in the tropical Indian Ocean are compared mainly for January, April, July and October, respectively. It is showed that (1) The net surface heat flux is the most important factor that affects SST over the Arabian Sea, Bay of Bengal and the region south of equator in January. In April, its influence covers almost the whole region studied, while for July and October, this term shows significance mainly in the region south of 10^{o}S and north of equator, respectively. (2) The horizontal advection dominates in the East Africa-Arabian coast and the region around equator in January and July, as well as the region south of 10S in October. (3) The entrainment is significant only in a band region centered on 10^{o}S in April and the coast region around Arabian Sea and the equator in July. (4) As for SST, it decreases in Arabian Sea and the Bay of Bengal in January and July, increases in April and October, showing a semiannual variability; by contrast, the SST in the region south of equator has annual variability, decreasing in April and July and increasing in October and January.

Changes in the Vertical Profiles of Temperature in the top 200 meters of Southeast Arabian Sea in the Cochin to Lakshadweep sector during May 2002 to May 2003

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Understanding the spatio-temporal variability of the upper ocean thermal structure of tropical Indian Ocean has become an important problem in meteorology as the heat storage anomalies in this region are found to play key roles in the variability of Indian monsoon. Prior to monsoon onset, a pool of warm waters covers a large area of the tropical Indian Ocean's top layer. This warm pool is the warmest area of the world oceans during May. In 2002-2003 as part of the Arabian Sea Monsoon Experiment (ARMEX), cruises were conducted in the Cochin-Lakshadweep area to collect temperature data up to depths of about 700 meters deploying XBT probes. The variation of ocean temperature in the vertical, for May 2002 shows the mixed layer is having a depth of about 30m from the sea surface. In the coastal zone at depths of 60m and below the temperatures are about 8°C colder than the corresponding open ocean temperature. In active monsoon season the mixed layer depth has decreased by about 5m from its depth during premonsoon. But the mixed layer temperature decreased by about 3°C. The thermocline has also gone up by about 50m from the May position. In the coastal area the mixed layer depth is only about 10m and mixed layer temperature about 1°C colder than the open sea temperature. Thus it is seen that from May to August there is strong upwelling both in the coastal zone and in the open sea. From active to postmonsoon, the mixed layer temperature has warmed through 1°C and mixed layer depth has deepened from 25m to about 40m. The thermocline has moved downwards through greater than 30m showing strong downwelling. The vertical profiles in winter show that the mixed layer temperature has not changed from that of postmonsoon. But mixed layer depth has further deepened by about 30- 40m, showing the continuation of the downwelling process. In the coastal zone some of the winter profiles have shown an inversion in temperature. In pre-monsoon 2003 mixed layer is slightly colder than in 2002 and mixed layer depth is about 10m less. The thermocline is higher in 2003. This preliminary examination therefore show strong interannual variability between 2002 and 2003.

Impact of temperature inversions on SST evolution in the South-Eastern Arabian Sea during the pre-summer monsoon season

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During the 6 months prior to onset of the southwest monsoon in June, the South-Eastern Arabian Sea (SEAS) presents striking features: it becomes the warmest area of the world ocean, with a mini-warm pool of SST exceeding 30°C in April-May. SST variability in the SEAS is of prime importance for driving the Northern Indian Ocean – summer monsoon coupled system. Hence a comprehensive understanding of the evolution of the ocean thermal structure is fundamental to understanding of air-sea coupling in this region.

Temperature inversions are known to occur in the near-surface ocean regime where salinity stratification is large enough to influence the density field. However, they have not been known as features that alter near-surface processes significantly to influence the sea surface temperature (SST). From the analysis of new observed datasets as well as of state-of-the-art numerical model outputs, this study shows that heat trapped within a temperature inversion makes significant contribution to warming of SST in the SEAS during the pre-summer monsoon season.

The Air-sea heat exchange at Xisha areas during the onset of southwest monsoon in 2000

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Using the observational data of the Second SCS Air-Sea Flux Experiment on the Xisha air-sea flux research tower during May 7 and June 17, 2000, the radiation budget, latent and sensible heat fluxes and net oceanic heat budgets before and after summer monsoon onset were calculated. It is fond that, after summer monsoon onset there are considerable changes on air-sea fluxes, especially on latent heat fluxes and net oceanic heat budget. Furthermore, the analyzed results of five synoptic stages are compared and the special characteristics of flux transfer during the different stages around onset of SCS monsoon are discussed. The fluxes change show that there is an oceanic heat accumulating process in pre-onset and break period and an oceanic heat loss process in the onset period. Also the latent fluxes and water vapor transported to continent can be influenced by the duration and intension of the southwester especially, further influence to the rainfall appearance in China continent. Finally, through comparison of the Xisha fluxes with those obtained from Indian Ocean and western Pacific Ocean, their differences may be seen. It can explain why after Monsoon onset, the SSTs can keep stable values over SCS while over Arabian Sea and Bay of Bengal they decrease quickly.

Role of vegetation and soil on Asian monsoon. Part I. Revisit to the monsoon as a LAND-ocean contrast

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(% Speaker; invited talk)

The monsoon is classically understood as an atmospheric circulation system induced by heating contrast between land (continent) and oceans. However, we still do not understand well what kind of effect of land is actually essential for producing the heating contrast between land and oceans. In this presentation, we attempt to understand and estimate relative roles of land surface conditions (vegetation, topography, soil conditions etc.), which play in determining the intensity and geographical extent of Asian monsoon activity, by conducting a series of numerical experiments of medium horizontal resolutions (T42) using CCSR/NIES AGCM v5.7b.

In this talk, evaluation of overall impact of the land surface conditions on Asian monsoon in an atmosphere-land-ocean system is reported. Albedo and field capacity essentially determine the available solar energy input and evaporation efficiency in the model. Surface water and energy budget, modified by the different values of albedo and field capacity, will influence the tropospheric circulations. Transfer of water into the continental interior by recycling may also be greatly regulated. Particular impact of change in field capacity and albedo on climate and water cycle over the Eurasian continent is presented in a paired presentation by Dr. Saito and others.

Preliminary experiments with 50-m mixed layer ocean showed that no vegetation or desert albedo condition from realistic albedo associated with full vegetation drastically changed the monsoon circulation particularly in the tropics. In contrast, the run only with reduced field capacity decreases summertime precipitation from Southeast Asia to the Meiyu/Baiu frontal zone, and changed overall climate condition in the higher latitudes. In the tropical monsoon region, the monsoon circulation in the Indian Ocean and southwestern Pacific is moderately weakened. Despite of decreased evaporation and increased sensible heat flux the land-sea temperature contrast is not so remarkably intensified in the tropics, due to the relatively weak surface pressure gradient. These results strongly suggest that vegetation with its albedo and soil moisture, in reality, plays a crucial role for producing the strong monsoon and wetter climate in the eastern half of the continent from the tropics through the higher latitudes. This may imply that the vegetation is an active (rather than a passive) component of the earth climate system controlling energy and water cycling processes of the system.

Thermal Effects of the Tibetan Plateau on the Evolution of the Asian Summer Monsoon

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The importance of the Tibetan Plateau as an elevated heat source for the establishment and maintenance of the Asian summer monsoon circulation has been discussed by many authors, The seasonal heating of the elevated surface and the consequent reversal of the meridional temperature gradient south of the Plateau trigger the large-scale change of the circulation over Asia and the monsoon burst over the Indian subcontinent. Using daily Q1 (apparent heat source) and Q2 (apparent moisture sink) fields obtained from the 15-yr ECMWF reanalysis (1979-93), seasonal cycle and regional differences of heating and its components are examined further. Many of the previous findings are confirmed or refined. The effects of asymmetric distribution of continental heating between the two hemispheres on the asymmetric behaviors of the Asian and Australian monsoons are also discussed.

Role of vegetation and soil on Asian monsoon. Part II. Sensitivity of climate and water cycle over the Eurasian continent

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(% Speaker)

The monsoon is classically understood as an atmospheric circulation system induced by heating contrast between land (continent) and oceans. However, we still do not understand well what kind of effect of land is actually essential for producing the heating contrast between land and oceans. In the paired presentation by Prof. Yasunari we reported overall impact of the land surface conditions on Asian monsoon in an atmosphere-land-ocean system, evaluated by a series of numerical experiments of medium horizontal resolutions (T42) using CCSR/NIES AGCM v5.7b.

In this talk, we focus on field capacity and albedo in land surface parameterization, and quantitatively evaluate the impact on climate and water cycle over the Eurasian continent under more idealistic land surface conditions. Field capacity determines maximum soil water content and evaporation efficiency in the model, and influences surface water and energy budget to different degrees in different latitudes.Changes in the budget at surface alter the atmospheric circulations above, and may also regulate transfer of water into the continental interior through recycling.

Preliminary experiments with 50-m mixed layer ocean showed that modestly reduced field capacity decreases summertime evaporation (increases sensible heat flux) over the continental interiors, especially in the extratropics (north of 40 degree). At surface and low-level in the atmosphere temperature rises and sea-level pressure decreases. In contrast in the upper half of the troposphere, thickness decreases in the extratropics while it decreases in the subtropics.

Extremely reduced field capacity will further alter evaporation in the tropical regions, and the budget of water and energy at surface from the tropics to the higher latitudes. Sensitivity of climate and water cycle over the Eurasian continent on ranges of field capacity, and of albedo, will be presented and discussed in details.

Land-atmosphere disequilibrium with respect to annual solar-SST forcings

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The atmosphere and land subsystems of the monsoon have relatively short response times compared to the ocean. However, these response times are still finite, such that the monsoons lag the seasonal cycles of insolation and SST by a finite amount. To elucidate this time lag, a land-atmosphere GCM has been utilized. The model is run with the ordinary climatological seasonal cycle of SST and insolation, and in quasi-perpetual runs with the SST and insolation held constant for 5 days corresponding to each calendar date. The difference between calendrical climatologies for these two types of integration indicates the magnitude and sense of land+atmosphere disequilibrium. The principal disequilibrium of the Asian monsoon involves onset in south Asia. In contrast, the principal disequilibrium of the North American summer monsoon involves the midsummer drought.

Development of a simplified numerical model of frozen soil for regional climate study

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Land–atmosphere interaction has been widely recognized as important to the climate system. Frozen soil, including permanent and seasonal, occupies large area in continental land and play a important role in land surface processes study for climate study because of its unique characteristics such as high thermal conductivity, large latent heat capacity owing to its freezing and thawing activity and its low permeability when frozen.

In this report, a simplified and physical based one dimensional model of freezing soil model will be presented and discussed, which is derived from a complete and complicate model based on magnitude order analysis. The model includes mass balance of ice and liquid phase and energy balance and interactive with air forcing conditions. Since the simplified physical based model is a highly nonlinear system, a layered numerical scheme is developed for solution obtaining. Since the model is coupled mass transport, phase change and energy transport one and some nonlinear terms, such as liquid flow and latent heat release or absorption of phase change, are strongly interacted which adds computational difficulty to the solution obtaining, a numerical scheme for the iterative solution convergence are discussed. Finally, using field observed dada, the preliminary evaluation and verification of the model is conducted. Some numerical results will be presented compared with observed data. Through the comparison, it is clearly shown that the simplified model can reasonably reproduces the observed data. It means the model can be used in the current land surface model improvement.

Numerical Simulation of the impact of vegetation change on variability of East Asian summer monsoon

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Two sets of numerical experiments by using Simplified Simple Biosphere (SSiB) land surface scheme coupled to NCEP Global Circulation Model (T42L18) were carried out to investigate the climate impacts of vegetation cover and leaf area index (LAI) on East Asian summer monsoon. One set employed prescribed vegetation cover and LAI according to the climate vegetation distribution in SSiB (named CaseC), the other with vegetation cover and LAI retrieved from satellite observation from the International Satellite Land Surface Climate Project (ISLSCP) (named CaseI). Each set of experiment consists of six cases which start from May 1, 3, 4 of the calendar year 1987 (1988) and were integrated to the end of the year with observed SST. The simulations of the two experiments were compared to investigate the influence of vegetation cover and LAI on seasonal precipitation in East Asia area. It was found that CaseI produced seasonal precipitation and interannual variabilities more consistent with observation than CaseC, better representations of vegetation index and its interannual variation in CaseI may be the main reason. The difference between 1987 and 1988 indicated that with the increase of vegetation cover and LAI, local evaporation and precipitation intensified, while surface temperature and sensible heat flux decreased. Further study showed that moisture flux variations associated with the general circulation changes contributed to the interannual variability of precipitation.

Role of cloud radiative forcing in East Asian Summer Monsoon

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Recent observational study by Wang et al. (2003) indicates that the cloud radiative forcing (CRF) provides a significant net radiative cooling (e.g., ~60 Wm^{-2} in May) over the Yangtze-Huai River valley (YHRV) during the East Asian summer monsoon (EASM). The cooling is dominated by cloud solar albedo cooling (~110 Wm^{-2}) due mainly to low level clouds, and a compensating cloud longwave greenhouse heating (~50 Wm^{-2}) due to the high level clouds. Consequently, the vertical cloud distribution plays an important role in determining the magnitude of CRF, which raises the question of the relative importance of CRF to other heating/cooling sources (e.g., latent heating) in EASM. In the present study, we used the reanalysis data to compare the temporal evolution of CRF with other heating/cooling sources and evaluate the role CRF in affecting the large-scale circulation over East Asia.

Wang, W.-C., W.-S. Kau, H.-H. Hsu, and C.-H. Tu, 2003: Characteristics of cloud radiative forcing over East Asia. J. Climate, East Asian Climate (EAC) Special Issue, (in press).

Spatial and Temporal Variability in the Relationship between the Indian Summer Monsoon and Tibetan Snowcover

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More than a century ago, Blanford suggested that an inverse relationship existed between summer rainfall over Northwest India and the spring snow cover in the western Himalayas. Recently it has been argued that there is a positive correlation between Tibetan snow cover and Indian Monsoon Rainfall (IMR), a result opposite to that of Blanford. To clarify this rather confusing situation, we use a high-resolution snow cover dataset to explore spatial and temporal variability in the relationship between the IMR and Tibetan snow cover. The results show that there exists an east-west dipole in the correlation between snow cover over Tibet and the IMR. We find a seasonal dipole exists between Himalayan snow cover and the IMR with a negative correlation during the winter and a positive correlation during the spring. Around 1985, there was a reduction in the statistical significance of the seasonal dipole as well as a reversal in the sense of the spatial dipole. We propose that this behavior is evidence of decadal variability in the relationship between Tibetan snow cover and the IMR.

Effects of Vegetation over the Tibetan Plateau on Summer Precipitation

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Two 14-year (1979-1992) integrations were carried out with a Global Coupled Ocean-Atmosphere-Land Systems model (GOALS/LASG) that contains the Simplified Simple Biosphere Model (SSiB) for studying the possible effects of biosphere feedback over the Tibetan Plateau on the precipitation and general circulation. In the control experiment, areas of the Tibetan Plateau over 3000 m were specified as mixed bare soil and grassland, while in the afforestation experiment, these areas were specified as improverished broadleaf trees and groundcover. Except for this difference, all other initial and prescribed AMIP monthly mean climatological SSTs were kept identical in both integrations.

Results suggest that the forests over the Tibetan Plateau may appear to have a negligibly small effect on the simulated climate. Afforestation over the Tibetan Plateau produces teleconnection wave rays and causes anomalies in general circulation through the variations in the surface albedo. And also large transpiration of the forests could provide enough moisture for the monsoon precipitation over the Tibetan Plateau. In particular, deforestation over the Tibetan Plateau region would increase rainfall in central China, but decrease in northern and southern China and also have an impact on the global rainfall correspondingly. These anomaly variations in the simulated precipitation are consistent with the observed changes during the past 40 years in China. Therefore, the change in the vegetation is evidently a major factor in determining the Asian monsoon response to afforestation over the Tibetan Plateau. This study confirms that vegetation feedbacks over the Tibetan Plateau should be taken into account when performing future climate studies.

Validating a Biosphere Model (SSiB) for the Huaihe River Basin Using GEWEX/GAME/HUBEX Data

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Offline simulations of Simplified Simple Biosphere model (SSiB) are performed for various surface types (forest, farmland and paddy field) and different seasons (spring, summer and autumn), located at Huihe River basin in China. When initialized and driven by the observed atmospheric forcing, the model reproduced the observed surface heat fluxes and their seasonal and diurnal variations realistically. The model is also able to simulate the tendency of soil water content well. However, during some dry periods, there are errors in the peak simulations of surface latent and sensible heat fluxes. The sensitivity experiments found that initial soil water content may be partly responsible. In this regard, the realistic initial soil water content is critical to a correct assessment of the surface energy fluxes.

Effect of surface fluxes over Indochina on the summer monsoon over south China

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The onset of the Asian summer monsoon is commonly considered to be first begins over the region of the Bay of Bengal and Indochina. As shown in a number of studies, a heating center can be found over the Indochina peninsula in May, at the time of the Southeast Asian monsoon onset. This heating center is characterized by the presence of an anticyclone in the upper troposphere. While it appears that the development of the heating center over the Indochina region is important to the onset of the Southeast Asia monsoon, the factors that determine its establishment and location are not clearly known. Since the heat capacity of landmass is generally much less than that of the ocean, solar radiation reaching land surfaces can go back to the atmosphere quickly. Considering this point and the particular geographical location of Indochina, we focus on the heating effect of the Indochina landmass in the development of the heating center and the onset of the Southeast Asia monsoon. Monsoon precipitation over Southern China due to the heating effect of Indochina will also be investigated.

The model we use in this study is a regional climate model developed by the National Climate Center of China and the City University of Hong Kong. This is a suitable tool for this study because of its relatively high spatial resolution compared with a GCM. The design of the experiment for the present study is try to isolate the thermal effect of the Indochina landmass on the atmosphere by setting the longwave radiation emission from the ground equal to the longwave radiation reaching the ground. For heat exchange at the surface, we shut down the surface sensible heating and evaporation. By the above setting the presence of the Indochina landmass should have no particular effect on the atmosphere other than providing the drag. The next step of this study is to investigate the contribution of latent heat flux over the Indochina landmass in the total heating effect.

By isolating the heating of the Indochina landmass, we find that both the monsoon circulation and precipitation are significantly affected. Preliminary results suggest that the heating effect of the Indochina landmass on the Asian summer monsoon is most significant in May but much less in June. Precipitation is reduced significantly in remote regions of southern China and northwestern Pacific Ocean. In the lower troposphere, the heating effect is to induce a cyclonic circulation over the regions of Eastern China and northwestern Pacific Ocean. The result is that the strength of the southwestern monsoon stream is reduced. The anomalous geopotential height fields show a northeastward shift as the monsoon season proceeds. The anomalous flow and geopotential height fields in the upper troposphere are closely related to those in the lower troposphere but with reverse phases. However, the amplitudes of the anomalies are much larger than those in the lower troposphere. This indicates the sign of upper atmospheric heating and suggests that the corresponding atmospheric circulation in the lower troposphere may be driven by this heat source.

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Energy Budgets Over Huaihe River Basin During HUBEX Field Observation Periods In 1998 and 1999

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By using the observation data over Huaihe River Basin during HUBEX/GAME Field Observation Periods in 1998 and 1999, the energy budgets over 4 types of underlying surfaces(water body, paddy field, farmland, forest) and in various synoptic conditions are calculated and analyzed, the conclusion is as follows,

The diurnal variation of energy budgets over water body, farmland, paddy field and forest over intensive observation region of HUBEX have their similarities and differences. The similarities: the maximum of the terms of the energy budgets occurs just afternoon; The differences: the maximum is only one over water body and paddy field but it is two or more over farmland and forest.

The seasonal variations of energy budgets are obvious over four surfaces. The wave number of daily energy budgets over farmland, forest and paddy field is only one in spring and two or more in summer and only one in autumn, which indicating that the plant growth differences during different seasons maybe cause the variations. But to the water body, the wave number is only one in summer and autumn.

In different synoptic conditions and at different time scales, the analysis of the energy budgets by Bowen Ratio Method and Bulk Schemes over Huaihe River Basin during the field observation periods of HUBEX in 1999 shows: (1) the averaged latent heat flux is an order of magnitudes more than the averaged sensible heat flux during the observation period. (2)The variation of total cloud amount is out of phase with the terms of energy budgets except for the downward long-wave radiation which maybe is related to the cloud's height and class. (3) The values of sensible and latent heat fluxes are small during rain episodes, but thereafter, the values become high and then up to maximum. It's similar to the other terms of the energy budgets except the downward long-wave radiation. The diurnal variation of energy budgets indicates that the daytime precipitation exerts great influence to the energy budgets, but the nighttime precipitation makes little influence. (4) The variation of the latent heat flux is in phase with the evaporation, which indicates that the latent heat flux calculated by bulk schemes is reliable. (5) The means of the sensible and latent heat flux and momentum flux by bulk schemes for the time period from May to August are, respectively, 30.71 W/m^2, 116.81 W/m^2, $2.86X10^{-2}N/m^2$ in 1998 and 30.28 W/m^2, 107.35 W/m^2, $2.74X10^{-2}N/m^2$ in 1999. The values of these two years are similar. During summer in 1999 the magnitude and activity of sensible heat flux is strongest in June and the latent heat flux is in August.

The Synoptic Study on Establishment of the Southwest Monsoon and Changes of Rain Belt over the South China Sea in 2002

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Based on the data of air-sea flux of observation in South China Sea (SCS), NCEP, GPCP, OLR and GMS-5 cloud image, the paper synthetically analyzed establishment process of SCS southwest monsoon and changes of rain belt in May and June 2002, insuring that May 14 was the onset day of Xisha and north SCS, and May 15 was the onset day of whole SCS monsoon, which belonged to normal year. Wind direction, wind speed, cloud, precipitation, humidity, moisture flux, radiation and sea surface state et al had evident changes on the monsoon onset. In the radiation components, variations of short-wave radiation and net radiation budget of ocean are especially evident. Abrupt variations of the lower and upper-air structure are corresponding to large-range adjusting of the general circulation.

The change processes of atmosphere circulation prior to and after the onset are as follow: cross-equatorial flow in 80-90ºE intensified first, meanwhile, India-Burma low intensified, and air pressure gradient in Bay of Bengal intensified also, then cyclone on east Asia developed and moved eastward, subtropical high withdrew eastward, equatorial westerly in front of low pressure trough in Bay of Bengal intensified and crossed Indochina Peninsula, and strong southwesterly arose in north SCS, then SCS monsoon began onset in whole SCS. It is a continuous process that from southwesterly in Bay of Bengal intensified to SCS monsoon began onset. The continental cold front movement southward acts important trigger action. The earlier onset of the SCS monsoon in the northern part was influenced by the interaction of mid-latitude and low- latitude system.

At the time of SCS monsoon onset, it appeared single rain belt, and then transited from single to double rain belts. The belts were affected by subtropical high and monsoon system, moving with subtropical high. Onset periods of the monsoon (subtropical high moved eastward) were associated with substantial rainfall over center and northern part of SCS. Break periods of the monsoon (subtropical high moved westward) were associated with minimum rainfall over northern part of SCS but substantial rainfall over the Bay of Bengal, Indian and areas of Yangtze River. It Shown two kind of precipitation patters. The variation period was about 30 days that may be reflect the intraseasonal oscillations of 30-40 day time scale.

Dynamics of the winter time wet spells over the Arabian region

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The dynamics of the evolution of the wintertime wet-spells over the Arabian region is investigated using observations and reanalysis data. The diagnosis of atmospheric data reveals that the dynamical features of the wintertime wet-spells are associated with midlatitude weather disturbances: with shallow vertical structure mostly confined to the lower troposphere. These weather disturbances originate as a weak cyclonic circulation over Mediterranean region and propagate southeastward in the midlatitude wave-guide characterized by a low preceded by a high. The elongated low over the southwest Saudi Arabia prior to the wet-spell enhances the moisture transport from the Red Sea to the mountainous region in Asir province. Furthermore, the eastward propagation of rainfall pattern coincides with the eastward movement of the cyclonic circulation. Our study suggests that the orographic effect, thermal advection (due to land-ocean thermal contrast during winter over Asir province) and low level baroclinicity are crucial in the intensification of the rain producing weather systems over Saudi Arabia. Following a significant rainfall event over the Arabian region, the precipitation area propagates eastward to the east of Iran. The wet-spells over Arabia have significant contribution to the total wintertime rainfall in spite of the high intraseasonal variability. Further analysis of the dynamics of these weather disturbances are in progress using a high resolution atmospheric GCM.

Atmospheric Moisture Transport associated with Anomalous Summer Rainfall over China for 1951-1999

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The vertically integrated atmospheric water vapor transport associated with the anomalous summertime monsoon rainfall over China is inspected by using the observed precipitation data combining the NCEP reanalysis outputs for the period 1951-1999. The first leadning mode of summer precipitation appears as a heavy rainfall belt along the Yangtze River valley. Regression of the PC1 upon the vertically integrated water vapor transport reveals a convergence of northeast moisture transport from higher latitudes with the southwest moisture transport from lower latitudes. The related circulation changes include the southwestward extension of the western Pacific subtropical high at 500 hPa and a southward shift of the jet at 200 hPa. The second leading mode appears as a heavy rainfall belt along the Huai River valley (approximately 5 degree north of the Yangtze River valley). The associated water vapor transport has the pattern of the convergence of northwest moisture flux from higher latitude with the extratropical southwestern moisture flux, and the later seems to have a western Pacific origin. The corresponding circulation changes include a northwestward extension of the subtropical high at 500 hPa and an eastward shift of the jet center at 200 hPa. The third leadning mode of summer rainfall appears as heavy rainfall over the North China, and this mode is directly connected to a northward transport of the moisture along the eastern coast of the continental China. The anomalous circulation is dominated by two cyclones at the northwestern and eastern sides of the continental coast, which forms a narrow path for moisture transport. It's worth of noting that on evidence is found to support the idea that the anomalous summer rainfall over continental China is disturbed by the moisture transport from the South Hemisphere.

The study on the relations between moisture flux in East Asian and the South China Sea Summer Monsoon*

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The average moisture flux (qv) and the South China Sea (SCS) monsoon intensity are analyzed. Some results are gotten:

1. Strengthening periods of monsoon are all accompanied by increasing of moisture flux and extending to the high level of the atmosphere, and moving of moisture vector convergence from 105°E to near130°E in bottom layer.
2. There are two high value centers in SCS and Yangtze River basin in the east to 110°E. In the last decade of July, the high moisture flux center in SCS alternates with in the Yangtze River basin, and it is the time for moving of rain band to the north.
3. In the years of strong monsoon, the moisture flux anomalies are positive from India Ocean to SCS, and the others are negative from the north of SCS to the Yangtze river and south-east of China. The convergence area of moisture vector is easterly. In the years of weak monsoon, the anomaly distribution is opposite to the years of strong monsoon. This is the main reason why the rainfall in China occurs differently between the weak and strong monsoon.

key word: South China Sea Summer Monsoon, moisture flux.

* Supported by Climbing Programme under Ministry of Science and Technology of China: the South China Sea Monsoon Experiment (SCSMEX) and the National Natural Science Foundation of China under Project No.40075003

Diagnosis of moisture transport to the arid and semi-arid regions of Saudi Arabia

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Diagnostic study of atmospheric moisture flux derived from 54-year NCEP/NCAR reanalysis reveals flux divergence on and above the middle troposphere during all seasons over the mountainous region of southwestern Saudi Arabia. The local Hadley and Walker circulation cells show the influence of orographic ascent of warm moist air transported from the Red Sea. This helps in the development of shallow convection in the region. Although the presence of precipitable water in the middle troposphere is very high (>25 mm), because of strong divergent of moisture flux and the associated gross moist stratification produces less precipitation over this semi-arid region during summer monsoon season. The net atmospheric moisture flux over the arid and semi-arid regions of Saudi Arabia shows seasonal and interannual variability. The seasonal variability has a strong semi-annual signal having highest peak during February – March – April and a second peak in June – July - August. This is consistent with a similar semi-annual signal in observed rainfall climatology. Moisture budget of the Saudi Arabia shows restricted moisture supply only to the southwestern part during summer season explaining confined summer rainfall over that region. However, winter precipitation is widespread covering area beyond that region. The interannual variability of net atmospheric moisture flux is strongly influenced by El Niño and positive Indian Ocean Dipole (IOD) mode events. It is observed that both events have positive influence on the net moisture transport to this semi-arid region having larger influence of incoming flux across the Red Sea side and outgoing flux across the Persian Gulf side. It has also been observed that influence of positive IOD is stronger than El Niño. The partial lag correlation analysis with net moisture flux shows that positive IOD has a peak correlation coefficient of about 0.63 with 4 months lead and El Niño has a peak correlation of 0.55 with almost 6 months lead. The weak variability in the moisture flux index during the period from1968 to 1979 shows the decadal nature of moisture flux variability in relation to the decadal changes on IOD and ENSO occurrences. The numerical experiments using high resolution coupled model are in progress in order to further understand the influence mechanism of IOD and El Niño on the net moisture flux over semi-arid region of Saudi Arabia.

An Estimation of Downward Surface Radiation over China

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A method is presented for estimating the downward surface solar and long-wave radiation fluxes from routine meteorological dataset. The surface solar radiation flux is obtained from sunshine duration with using of the parameters taken from Jordan sunshine recorder. The surface long-wave radiation flux is obtained from the estimated solar radiation, surface air humidity and temperature. The influences from topography, high altitude, etc. are also taken into the consideration. Calculations have been checked by the in situ observations. Calculations were carried out for 31 observatories located in China during recent 30 years (from 1971 to 2000). Surface solar and long-wave radiation fluxes range 140-240 Wm^{-2} and 220-380 Wm^{-2} in daily mean value over China, respectively. The climatic changes of the downward surface solar and long-wave radiation fluxes have been investigated. Except Hotan and Lushi, 29 observatories exhibit increasing trends of surface long-wave radiation flux from 1971-2000. Surface solar radiation shows decreasing trends in the big cities. For the input data, all of these 31 observatories are shown increasing trends of the surface air temperature in recent 30 years; vapor pressure is in increasing trend in most of the stations. The estimated solar radiation have compared with the satellite-based SRB dataset from Langley. It is found that these two datasets agree with each other very well in the rural areas. Estimated surface solar radiation less than the Langley data in some big cities. In the Tibetan Plateau, Langley data less than the estimated data. Geographic climatic distribution map for surface solar radiation flux has been presented.

Life Cycle and Onset of the East-Asian Summer Monsoon

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Regardless of numerous recent studies devoted to explore the interannual variation of the East Asian summer monsoon, the life cycle and onset of this monsoon have not been properly portrayed/defined. An effort was made to depict the life cycle and to determine the onset of the East Asian monsoon based on the synoptic evolution of the East Asian weather system during the warm season.

Life cycle of the East-Asian summer monsoon rainfall has long been believed to be caused by the transition of weather regimes in company with the evolution of monsoon circulation. However, this claim was neither comprehensively analyzed nor convincingly demonstrated. Four datasets (CMAP rainfall, NCEP/NCAR reanalysis data, JMA 6-h surface analysis maps, and JTWC 6-h tropical cyclone tracks) were used to depict the climatology of the monsoon rainfall life cycle and to explore the cause of this life cycle, particularly through the relationship between the seasonal evolution of the monsoon circulation and the associated synoptic disturbance activity. The monsoon life cycle in the southern part of East Asia is basically developed by the sequential passages of the Meiyü rainband in early summer, the western Pacific subtropical high in mid summer, and the tropical cyclone activity in late summer. Although the monsoon onset in the northern part of East Asia, particularly Japan, is triggered by the Meiyü-Baiu rainband, the monsoon break follows the rainband's dissipation caused by the northward-migrating subtropical high, and the monsoon revival accompanies the arrival of the midlatitude frontal activity. In view of the role played by the subtropical high in developing the monsoon break, the phase lag of the monsoon life cycle between the south and north is a result of this subtropical high's northward progression. Two rainfall maxima in the revival phase of the Japanese monsoon are generated by two different mechanisms; the first is a result of the collaborative contribution of the frontal and tropical cyclone activity, but the second is primarily due to the midlatitude frontal activity.

Coincident occurrences of the sudden increase in rainfall and the abrupt direction change of prevailing wind at surface were routinely/operationally used to define the South Asian monsoon onset. Can this definition be applied to the East Asian monsoon onset? This monsoon onset was considered to be triggered by the northward progression of the Meiyü rainbelt. Actually, it was shown by station observations along the island chain from southern Japan to Taiwan that the summer monsoon rain onset is about three weeks ahead of the direction change of surface prevailing wind. Because the cold fronts associated with the slowly eastward-propagating synoptic disturbances bring rainfall to East Asia, the monsoon rain onset is initiated by the first frontal passage across latitude of 25^{o}N. After the passage of three cold fronts in average across this latitude, the northward migration of the East Asian jet prevents cold fronts and associated synoptic disturbances from passing across this latitude and the intensification of the continental thermal low of East Asia results in the direction change of surface prevailing wind.

Annual Cycle of Southeast Asia - Maritime Continent Rainfall and the Asymmetric Monsoon Transition

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This work uses station and satellite data to study the local variations of the annual cycle over the Maritime Continent. The annual cycle is dominated largely by interactions between the complex terrain and a simple annual reversal of the surface monsoonal winds. The semiannual cycle is comparable in magnitude over parts of the equatorial landmasses, but only a very small region reflects the twice-yearly crossing of the sun. The boreal summer and winter monsoon rainfall regimes intertwine across the equator, with the winter regime extends far northward along the eastern flanks of the major island groups and landmasses.

A hypothesis is presented to explain the asymmetric seasonal march in which the maximum convection follows a gradual southeastward progression path from the Asian summer monsoon to the Asian winter monsoon but a sudden transition in the reverse. The hypothesis is based on the redistribution of mass between land and ocean areas during spring and fall that results from different land-ocean thermal memories. This mass redistribution between the two transition seasons produces sea- level patterns leading to asymmetric wind-terrain interactions throughout the region, and a low- level divergence asymmetry in the region that promote the southward march of maximum convection during boreal fall but opposes the northward march during boreal spring.

Climate effects of the deep continental stratus clouds Generated by Tibetan Plateau

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Evidence is presented to show that the annual mean cloud optical depth in the leeside of the Tibetan Plateau exhibits a global maximum between 60°S and 60°N. This large cloud optical depth is due to the persistence of deep stratus clouds (primarily the nimbostratus and altostratus) during winter and spring. These deep stratus clouds are generated and maintained by the frictional and blocking effects of the Tibetan Plateau. The plateau slows down the over-flow, inducing downstream mid-level divergence; meanwhile it forces the low-level surrounding-flows to converge downstream, generating sustained large scale lifting and stable stratification that maintains the thick stratus clouds.

This stratus clouds produce extremely strong cloud radiative forcing at the top of the atmosphere, which fundamentally influences the local energy balance and climate change. Analysis of the long-term meteorological station observation reveals that the monthly mean anomalous cloudiness and surface temperature vary in tendon. In addition, the surface warming leads to destabilization and desaturation in the boundary layer. These evidences suggest positive feedbacks between the continental stratus clouds and surface temperature through changing lower-tropospheric relative humidity and stratification. It is shown that the positive feedback mechanism is more robust during the period of the surface cooling than during the period of surface warming. It is suggested that the positive climate feedback of the continental stratus cloud may be instrumental in understanding the long-term climatic trend and variation over the East Asia.

Organization and latent heating profiles of monsoon convection

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Analysis of radar and sounding data collected during the South China Sea Monsoon Experiment (SCSMEX) reveals that lower and middle level vertical shears exert a dominant control over the structure and orientation of mesoscale convective systems over the northern South China Sea. The findings are consistent with those of LeMone et al. (1998) for TOGA COARE, except two new organizational modes have been identified: shear-parallel bands for strong low-level shear and weak midlevel shear when the air is dry aloft, and shear-parallel bands for strong shears in both layers when the shear vectors are in the same direction. Midlatitude influences likely contributed to these two additional modes by producing strong westerlies (in the latter case) during the passage of a strong upper-level trough and midtropospheric drying (in the first case) following passage of the trough.

Using data from the SCSMEX sounding network, apparent heat and moisture sources and sinks (Q1 and Q2) have been computed. Q1 and Q2 are found to depend on the mode of organization of mesoscale convective systems. Shear-perpendicular modes exhibit Q1/Q2 profiles more characteristic of vigorous, deep convective systems, whereas shear-parallel convective bands (extending through the entire troposphere) have profiles indicating a greater proportion of stratiform precipitation. Convective/stratiform partitioning of radar reflectivity data supports these results.

Diurnal Variation of the Convective Activity over Bangladesh in the Summer Monsoon Season and its Relation with the Nocturnal Jet

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Using raingauge data of Bangladesh meteorological department and additional raingauge network installed by JICA project, the diurnal rainfall variations are investigated. Two major types of diurnal variations are detected. Over the heavy precipitation areas in the northeast and southeast parts of this country, the peak of the rainfall is in midnight-early morning. On the other hand, over the plain area in the central to southwestern part, the afternoon peak is dominant. To identify the mechanism that causes such diurnal variations of precipitation, we conducted intensive rawin-sonde observation that resolves the diurnal variations of whole the troposphere. The diurnal wind variation exhibits the nocturnal-jet like variations with the acceleration of wind speed and the clockwise change of wind direction after evening during midnight. This change is consistent with the midnight-early morning rainfall peak over the northeastern part of the country. This diurnal wind variation is further confirmed through the analysis of the pilot balloon data.

A Unified Definition of the Summer Monsoon Onset over the South China Sea and East Asia

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Climatologically, the mean summer monsoon onset in the South China Sea (SCS) is an abrupt event. However, defining the onset date for individual years is not as straightforward. The lack of a universally accepted definition is a major roadblock for studying interannual variability of the monsoon onset. In this paper, we recommend a unified definition for the summer monsoon onset over the SCS. The local onset of the SCS summer monsoon is determined objectively by using U_{SCS}, the 850hPa zonal winds averaged over the central SCS (5^oN-15^oN and 110^oE-120^oE). This local index depicts both the sudden establishment of the monsoon southwesterlies in the SCS and the start of the rainy season in the central-northern SCS. It is shown that this local index Uscs also signifies large scale East Asian summer monsoon onset. Thus this SCS monsoon onset index unifies the local winds change, rainy season start and the large scale monsoon onset over entire East Asia.

To demonstrate the linkage between local SCS onset index and large scale East Asian monsoon onset, we define the onset of the broad-scale East Asian summer monsoon objectively by using the principal component of the dominant empirical orthogonal mode, $U_{EOF1,}$ of the 850hPa zonal winds over East Asia and the western North Pacific region (0-40°N, 100°E-140°E). It is shown that the local index Uscs represents U_{EOF1} extremely well and thus can be practically used to determine both the SCS and East Asian summer monsoon onsets.

The result indicates that the SCS summer monsoon onset signifies the onset of the summer monsoon over East Asia and the adjacent western Pacific Ocean. Evidence is provided to show the two salient phases of the East Asian summer monsoon progression: the onset of the SCSSM and the start of the Meiyu (the rainy season in Yangtze River and Huai River basin and southern Japan). Causes for the controversies in determining the SCS monsoon onset are discussed in detail.

Seasonal variation of diurnal cycle of local circulation observed at Serpong, West Jawa, Indonesia

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A seasonal variation of diurnal cycle of wind at Serpong, West Jawa, Indonesia (6.4 S, 106.7 E, 50 MSL) was investigated with utilizing a UHF-band wind profiler data from 1993 to 2002 except for 2000. Serpong is situated at the south of Java Sea coastline which roughly extends to east - west direction and there are no high mountains between the coast line and Serpong.

We defined the diurnal cycle of wind as subtracted daily mean value at each height. Since the geographical feature around Serpong, the vertical structure of meridional wind showed a feature like the sea-land breeze circulation. Northerly anomaly (onshore component) was observed at 0.4-1.2 km height, and southerly anomaly (offshore component) was at 1.2-2.0 km from 12 LST to 21 LST. The circulation was dominant in dry season (from April to October). Southerly anomaly (offshore component) at 1.2-2.0 km height in daytime became weak from November to December, and it was unclear from January to March (rainy season).

We analyzed the time of most intense sea breeze (northerly anomaly) blowing on a daytime and the time of wind direction change from land breeze to sea breeze in the morning. These times had clear annual cycle, and both times ware early in rainy season and late in dry season.

Observational evidence for westward propagation of temperature inversions in the southeastern Arabian Sea

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A warm pool forms in the southeastern Arabian Sea (SEAS) prior to the onset of the summer monsoon over India in early June; the core of this warm pool is in the Lakshadweep Sea (LS). XBT and surface salinity data collected in the LS during May-2002--May-2003 show that temperature inversions occur off the southwest coast of India in early December with the arrival of low-salinity waters from the Bay of Bengal. The low-salinity waters and the inversions propagate westward along with the downwelling Rossby waves that constitute the Lakshadweep sea-level high; inversions occur in the western LS (~ 73E) about 40~days after they occur near the coast in the eastern LS (~ 75.5E). They disappear in April, when the Tropical Convergence Zone moves over the SEAS and the warm pool engulfs the region. Ocean dynamics and air-sea fluxes are together responsible for the formation and westward propagation of the inversions.

An Observational and Numerical Study of Heavy Rainfall Event in Shanghai on 05 August 2001

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An extremely heavy rainfall event was observed in Shanghai on 5 August 2001. It had the maximum 24-h accumulated precipitation of 275.2 mm and caused serious flooding disaster locally. This paper aims to reveal the characteristic features and to document the detailed evolutionary process of this event by using all available observational data, such as GMS (Geostationary Meteorological Satellite of Japan)-5 satellite images, WSR-88D (Weather Surveillance Radar 88 Doppler) radar data, automatic raingage data, objective reanalysis data and sounding data of Shanghai. The synoptic situation prior to the heavy rainfall was characterized with a N-S oriented trough at 500 hPa and a surface meso-scale low at 00 UTC 6 August 2001. A LLSJ (Lower-Level Southerly Jet) provided the continuous humid air supplies for the heavy rainfall. There existed a surface cyclonical circulation in accordance with the surface meso-scale low system before the heavy rainfall. The sounding observations indicated that the atmosphere was most unstable before and during the rainfall because the CAPE (Convective Available Potential Energy) was large. The characteristic features of convection, significant vertical wind shear and VIL (Vertical Integration of Liquid) associated this heavy rainfall event were revealed well by WSR-88D radar data.

In order to capture the fine features of the rainfall systems, a high-resolution simulation of 8-km with the latest version 4.3 of RAMS (Regional Atmospheric Modeling System) model was designed. In this simulation, the model domain covers 120 x 95 x 23 grid points, and the integration time step is 15s. The initial and boundary values as well as the skin surface temperature data used in the model were prepared by analyzing the conventional observation data of upper and surface levels objectively. Also 1^o x 1^o AVN data on 5 August 2001 were employed as the background fields in constructing the initial and boundary data. A 24-h integration of RAMS that started from 00 UTC 5 August 2001 reproduced the main features of meso-scale convective system. During the model run, the Klemp-Lilly type of lateral boundary values and the skin surface temperature data was updated for 24-h. The simulated results show that in the earlier 12 hours of integration, the pattern and location of accumulated rainfall agree well with the observations. However, in the later 12 hours of integration, the simulated rainfall does not agree well with the observation. It suggests that there still remain some problems to be solved for the improving of precipitation prediction accuracy.

Characteristics, Evolution and Mechanisms of the Asian Summer Monsoon Onset over the Southeast Asia

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Based on the 1979-1995 mean pentad reanalysis data, the climatological characteristics and physical mechanism of the Asian summer monsoon (ASM) onset are investigated. A special focus is whether the ASM onset first commences over the Indochina Peninsula and why the ASM is established earlier over Southeast Asia than over India. The thermal forcing of the landmass in the lower latitudes of Asian continent on the seasonal transition is also investigated.

An examination of thermodynamic and dynamic quantities confirms the previous result that the ASM onset commences first over the Indochina Peninsula. The characteristics not only include the earliest active convection and rainfall, but also the earliest reversal of meridional gradient of temperature throughout the entire troposphere and the corresponding establishment of an easterly vertical wind shear. The convergence of southwesterly flow from the Bay of Bengal (BOB) vortex and easterly winds associated with the subtropical anticyclone over the South China Sea (SCS) accounts for the first characteristic. The last two features are responsible of the upper-level warming due to the vertical transport of latent heat through cumulus- and turbulence-induced eddies in convection.

A new criterion for the tropical ASM onset is proposed by considering both the rainfall and the reversal of the part of planetary-scale circulation. It appears that the ASM onset occurs first over the southwestern Indochina Peninsula in early May, and then advances to the north on May 16-20. Over the SCS, the onset starts in the fourth pentad of May and the monsoon covers the entire region by the end of May. A similar onset process is found to commence over the eastern Arabian Sea, India and western BOB in the last pentad of May, and the complete establishment of ASM over India is accomplished in mid June. In the process of the onset of each component of the ASM, the overturning of upper-level planetary-scale circulation strongly depends on the reversal of the meridional temperature gradient. Over the Indochina Peninsula, the seasonal transition of upper-level temperature results from convection–induced diabatic heating, while over western Asia it is attributed to the subsidence warming induced by the active ascending motion over the former region.

The steady increase in surface sensible heating over the Indian subcontinent and the latent heating over the tropical Indian Ocean in April to early May appear to be the major impetus for the development of the cyclonic vortex over the BOB. A similar enhancement over the Arabian Peninsula and the surrounding regions is also identified to be crucial to the development of the cyclone over the Arabian Sea, and then ultimately to the ASM onset over India. Due to its later seasonal transition versus the tropical region, the thermal

forcing of the Tibetan Plateau appears to have little influence on the ASM onset over the Indochina Peninsula in early May.

An Alternative Index For The Onset Of Summer Monsoon and Circulation Patterns to Heating Location

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An alternative index for the onset of summer monsoon over the South China Sea (SCS) has been designed and the affections of heating in the East Asia and in the Southeast Asia on the characteristics of summer monsoon onset over the South China Sea (SCS) have been discussed using the reanalysis data of the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP/ NCAR). It is found that the difference of geopotential thickness between the vicinities near Guangzhou and Manila can be used as an alternative index for the onset of summer monsoon over the SCS. Since the adiabatic heating alter the geopotential height and the distance between vicinities near Guangzhou and Manila is in synoptic scale, in the framework of geostraphic, the index can represents the strength of heating and the first baroclinic cell over the SCS. By comparison among different indices, we found that, the summer monsoon onset over SCS can be ascertained by vertical zonal wind shear between 200 hPa and 850 hPa, zonal wind at 850 hPa, OLR anomaly (or TBB) and the alternative index. The meridional component of wind shear between 200 hPa and 850 hPa are always appear earlier over the SCS, and cannot be used as an index for the onset of summer monsoon over the SCS. Heating on the mainland of Asia continent plus the latent heat release over the western Pacific caused the southwesterly of summer monsoon prevailing over the north and central part of SCS while the heating caused by the enhancement of convective near the Philippines area affected the westerly summer monsoon mainly over the central and south part of the SCS.

The dynamics of climatological monsoon break (CMB) over Southeast Asia in boreal summer

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The temporal and spatial structures and mechanism of the atmospheric circulation associated with CMB over the Indochina Peninsula were investigated using pentad rainfall data in Thailand and NCEP/NCAR reanalysis for 50 years (1951 to 2000). In this study, the terminology of CMB was defined by climatological monsoon break over the Indochina peninsula, which tends to occur in late June, even when we made 50 years climatology.

The temporal and spatial characteristic of the variations of rainfall over Thailand was investigated with EOF analysis. The leading EOF shows simultaneous variation over the whole of Thailand. The score time series for the 44 years almost corresponds to the climatological rainfall averaged for the whole of Thailand. This mode also proves the appearance of CMB in late-June over the Indochina Peninsula. In terms of atmospheric circulation, it was found that southerly wind anomalies in the lower troposphere bring large rainfall while northerly wind anomalies bring less rainfall over Indochina Peninsula, which may be affected by orography. In mid-June an active convection is located over the northern Bay of Bengal (BOB), which accompanies northward propagation of active convective zoon. Another active convection appears over the western North Pacific (WNP) (120E-140E, 5N-15N), which causes penetration of monsoon westerly to Indochina Peninsula. In this manner, near-simultaneous appearance of the two active convective systems is likely to cause northerly wind anomalies over Indochina Peninsula.

To clearly understand the mechanism of CMB, atmospheric circulation fields are composited, in terms of CMB for each year. The result indicated that CMB appears associated with westward propagation of an anti-cyclonic anomaly (ACA) along 15N from WNP. Its ACA is centered over BOB at CMB. Thus northerly wind over Indochina Peninsula induces CMB associated with the ACA over BOB. Moreover it suggests that the seasonal phase-lock of CMB is closely related to a couple of ACA over BOB and cyclonic anomaly over WNP, which is nearly phase-locked to seasonal march in mid-June. The dynamics of seasonal phase-lock remain to be solved.

Developing Phase of the South Pacific Convergence Zone and the Cross-Equatorial Flow in the Western Tropical Pacific

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This paper is focused on the investigation of the subtleties in the process of the South Pacific Convergence Zone (SPCZ) development (in the boreal autumn) by taking advantage of a combination of satellite observations of the ocean and atmosphere such as TRMM satellite microwave imager (TMI) estimated SSTs, rain-rates and surface wind speeds. We supplement the above datasets with long-term SSTs, winds as well as OLR.

Based on analysis of these satellite data, a conceptual model is presented that traces the origin of the development of SPCZ, critically, to the difference winds (winds of the present month minus that of the last month) that appear to be, at least in part, related to the thermal winds to the east of New Guinea in August. Along with the northerly difference winds, a decrease in velocity of the prevailing southeasterly wind could lead to a drop in evaporation at the sea surface, which, in turn, might cause an increase in SST and in low-level convergence in the vicinity of the SPCZ. The heat surplus, due to the less evaporation, produces the SST to rise at a rate of about 0.05-0.25°C per week in the southwestern Pacific compared with its counterpart in the central Pacific in the course of SPCZ development.

The SPCZ is especially intensified from October to November measured by an SPCZ index which is defined as the average rain rates (mm/h) along 10°S between 150.125°E and 170.125°W. It appears that a cross-equatorial flow adjacent 145°E in the western tropical Pacific occurs in advance of the substantial intensification of the SPCZ. This northerly cross-equatorial flow, which is certainly related to the seasonal adjustment of the Asian monsoon, deflects to the east after it comes to the Southern Hemisphere, e.g. close to the 10°S, forced by the Coriolis effect to produce the northwesterly wind. In addition, influenced by the elevation of New Guinea, the northwesterly wind speeds up along the northwest-southeast trending mountains in New Guinea and encounters the prevailing southeasterly wind to the east of New Guinea, thus causing more intense convergence and more convective extended cloud belts and more rainfall.

Therefore, the whole developing phase of the SPCZ can be divided into two stages. The mechanism of atmosphere-ocean interaction appears to contribute much to the earlier stage of the SPCZ development, while the second stage is marked by the interaction between the Northern Hemisphere and the Southern Hemisphere combined with the effect of the terrestrial elevation and orientation, which is the underlying cause for the substantial intensification of the SPCZ.

Relationship Between the Intensity of South China Sea Summer Monsoon and the Precipitation in Raining Seasons in China

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Four indexes are compared and analyzed that indicate the intensity of the South China Sea summer monsoon in 1951-1998. It is found that they are generally consistent in the interannual variation and have basically the same years of monsoon intensity as determined by them, though with some differences in some years. The relationship between the monsoon intensity and the precipitation in raining seasons in China is statistically studied and the results are as follows. In the years of strong (weak) summer monsoon in the South China Sea, the rain bands are of Pattern One (Three) distribution in the summer of China and the rainfall of the Changjiang R. Valley in June and July is mainly below and drought (above and flood), whereas rainfall is flood (normal and drought) during the yearly-second raining season in the Guangdong province. The intensity indexes for the South China Sea summer monsoon are in high anticorrelation with the precipitation over the middle and lower reaches of the Changjiang R. Valley and Huaihe R. Valley but in high correlation with that in the region south of Changjiang R. and the yearly-second raining season in southern China. Severe floods taking place in the summertime of China (like the extra severe floods in the Changjiang R. Valley in 1998 and the extra severe heavy rains in southern China in 1994) are associated with intensity anomalies of the summer monsoon in the South China Sea. In addition, meridional wave train anomalies teleconnection of the 500 hPa geopotential height field in East Asia in the Northern Hemisphere, which is resulted from the strong and weak summer monsoon activity in the South China Sea, is an important mechanism contributing to the summer precipitation in China.

A case study of an appearance of dry air at Kototabang, West Sumatera, Indonesia

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A simultaneous observation with a boundary layer radar and rawinsondes was conducted at Kototabang (100.32E, 0.20S, 865m MSL), West Sumatera, Indonesia during 27 September - 7 October 1998. A dry air with low equivalent potential temperature observed at a height of 2-3 km and it corresponded to an appearance of strong westerly more than 10 m/s. In this period usual afternoon convection at Kototabang was suppressed. The dry air appeared when the low total precipitable water observed by TRMM/TMI appeared in the west coast of Sumatera. It looks like that a n=1 Rossby wave disturbance related to the appearance of dry air.

Observational study about diurnal cycle of cloud system migration over Sumatera Island in Indonesian maritime continent

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Diurnal cycles are especially dominant over the land in the tropics. Interesting diurnal cycle of migration of cloud systems was observed with GMS IR1 data over Sumatera Island in Indonesian maritime continent. There are mountainous districts in the western part and plains in the eastern part. Convective activities start getting active in the western part of the mountainous area in the afternoon, and cloud systems migrate westward and/or eastward at a distance of several hundreds kilometers from midnight to morning. In this presentation we will show the characteristics of cloud systems which migrate to each direction with rawinsonde data at two stations (Jambi and Kototabang) in November 2001and GMS IR1 data from May 2001 to April 2002. Jambi is located in the plains and 100 km inland from the east coast (103.64oE, 1.63oS, 25 m MSL) and Kototabang is located in the mountainous area (100.32oE, 0.2oS, 865 m MSL). From the analysis of rawinsonde data following points are found. Wind directions of zonal wind anomalies in low (1.5-4 km) and high (9-12 km) layers correspond to the convergence and divergence of cloud systems which migrate westward or eastward at both stations. Migratory directions of cloud systems and appearance frequency depend on areas and seasons. The westward migration tends to appear almost every month. On the other hand the eastward migration tends to occur mainly in/near the ITCZ, which is shifted northward and southward with an annual cycle. It is considered that the development of convective activities in each migration is different: the development causes of cloud systems which migrate westward are due to supply of water vapor from the sea and enforcement ascent by mountains and westerly wind in the low layer, and that of the eastward migration is due to a supply of water vapor by large scale convergence such as the ITCZ.

Memorial Characteristics of East-Asian Monsoon

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An autocorrelation of time series is regarded as an indication of its memory, so we estimate the autocorrelations of the time series of East-Asian monsoon indices for 1873 to 2000, and the relevant statistic features are analyzed too, such as its trends in different periods, interannaul change. In particular, we focus on the decadal to centennial changes in East-Asian monsoon, which are connected to a long time memory of the East-Asian monsoon.

In order to understand the long time memory of the East-Asian monsoon, the detrended fluctuation analysis (DFA) is applied to the time series *x(i)* (*i*=1,..., N) of East-Asian monsoon. The departure series of *x(i)* are calculated and the integrated series of x(*i*) are denoted as *y(k)*.Then *y(k)* is divided into segments of equal length *s* and the least-square line fitting the data in each segment, $y_n(k)$, is calculated. The series *y(k)* is detrended by subtracting the local trend $y_n(k)$, and the root-mean square fluctuations of the detrended series *F(s)* are computed:

$$F(s) = (\sum_{k=1}^{N} [y(k) - y_s(k)]^2 / N)^{1/2}$$

F(s) is computed for all "segment-size" *s*. Typically, *F(s)* increases with *s*. If log *F(s)* increases linearly with log *s*, then the slope of the line relating *F(s)* and *s* in a log-log scale gives the scaling exponent a.

According to the random walk theory, the fluctuations *F(s)* in a given time segment of length s are related to the autocorrelation function *C(s)*. For the long time power law correlations show a power spectra: C(s)~$s^{-?}$, the fluctuations *F(s)* increase as a power law: *F(s)* ~ s^a, a=1- 1/?.The power law scaling of long time memory in the Indian monsoon has been found, which hints to predictability. We have computed the East-Asian monsoon indices with the DFA. The results show that the East-Asian monsoon exhibits a long time memory; it means the East-Asian monsoon has significant persistence in the yearly series. For winter monsoon, a=0.55, ?=0.9; but for summer monsoon, a=0.73, ?=0.54. It is shown that the difference between long time memories of monsoons in winter and in summer is remarkable. As the weather and the climate over China and East-Asia are strongly influenced by the East-Asian monsoon, in particularly, in summer, so the long time memory of the summer monsoon hints better predictability for climate change. The East-Asian monsoon in winter is directly connected to the strong Siberia high, which has large variability in daily to yearly scales; it may be able to explain why the power exponent a of the winter monsoon is quite low, though it is higher than a white noise (a=0.50).

Impact of Monsoon Extremes on the Socio Economic Conditions of Peninsular India

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Monsoons over India undergo wide inter-annual variations. Such variations have impact on all facets of life, as the Indian economy and life of majority of Indians are related to agriculture, the largest consumer of water. In spite of extensive irrigation facilities large area of farmlands still relies directly on monsoons. Water related problems are more complex and multi faceted in the peninsular part of India. During the years of extreme monsoons that lead to floods or droughts, the entire region plunges into social, economic, environmental and political crises. The most serious domestic water dispute in India, the Cauveri water dispute among the southern states has been continuing for more than a century without an amicable solution, just because of political reasons. Situation is relatively calm in good monsoon years, but it worsens and often turns violent when the monsoon fails. West coast of peninsula west of the Western Ghats Mountains is rich in rainfall, whereas the interior peninsula that is a rich agricultural land is deficient in rainfall. Agriculture in the interior peninsula depends on water from east flowing rivers and there exist several water disputes among different users, all along the borders that have adversely affected the agricultural production and water related development activities. The societal impact is large, as a good percentage of farmers living here are marginal and poor. The southern State of Kerala depends on hydroelectric projects for most of its power needs and life here becomes uncomfortable in weak monsoon years. Most of the people use open wells for domestic water needs and unrest spreads in society in low monsoon years, because of insufficient groundwater recharge that affects water availability. Increased dependability on groundwater in such years leads to environmental problems such as lowering of water table and salinity intrusion in coastal area. West coast of peninsula receives more than three times the global average rainfall and intense rainfall creates floods here, causing widespread damage. Northeast monsoon falls only in the east coast and southern tip and its strength has a key role in solving water related problems in the southern states. In this paper, a comprehensive study of the characteristics of monsoon rainfall over peninsular India –its interannual variability, extremes, relationship with global anomalies- during the last century, various socio economic and environmental problems associated with extreme rainfall conditions and possible changes of existing water related problems in an altered rainfall pattern have been made. Suggestions for policy development and better management to cope with extreme conditions have been provided.

Interaction between Two Propagating Rossby Waves and its Role in the Boreal Summer of 1998

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Teleconnection patterns often occur in the East Asian summer. This study discusses two teleconnection patterns and their wave train propagation. The first originated from the Lake of Baikal and passed over the Sea of Okhotsk through the area off the east coast of Japan towards subtropical regions (hereafter OKJ), as pointed out by Wang (1992). The other rose in the Philippines and traveled through the area off the east coast of Japan to North America (hereafter P-J), as shown by Nitta (1987) and Kurihara and Tsuyuki (1987). The results are as follows: (1) the OKJ propagation occurs frequently, in early summer and in the middle of summer according to EOF analysis. On some occasions, OKJ propagation occurs in late summer, as in the summer of 1998. Times when OKJ and P-J propagations are generated in the same period are not rare. (2) The Rossby wave of the P-J pattern, which starts from the Philippines and moves towards North America, propagates in different phases and even in a reversed phase. While it is excited by the convective activity around the Philippines, its propagation with the opposite phase might result from the convective activity around Japan. In the latter situation, the negative geopotential height anomaly over the sea east of Japan is caused by the Rossby wave propagation. (3) Simultaneous propagations of OKJ and P-J in reversed phase occurred twice in the summer of 1998. The intersection of the two wave trains resulted in a deepening of a cyclonic circulation off the east coast of Japan. The continual OKJ propagation and this kind of interaction between the two waves play an important role in suppression of the northward progress of the west Pacific subtropical high.

On Droughts of the Indian Monsoon

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It is well known that there is a link between droughts of the Indian monsoon and El Nino. However, of the 22 droughts that occurred during 1871-2001, only 11 were associated with El Nino. I discuss the results of an investigation of the link of the Indian summer monsoon rainfall to the atmospheric convection over the equatorial Indian Ocean, which was triggered by observations of the evolution of the Indian summer monsoon of 2003 and comparison with the unanticipated drought of 2002. During the summer monsoon, convection over the western (eastern) equatorial Indian Ocean appears to be favourable (unfavourable) for the monsoon rainfall over the Indian region. Over the equatorial Indian Ocean when convection is enhanced over the western part it tends to be suppressed over the eastern part and vice versa. We find that the impact of this oscillation (which is reflected in the pressure gradient and surface winds along the equator) is comparable to that ENSO and that every season with excess rainfall/drought during 1979-2002 can be attributed to the favourable/unfavourable phase of either this oscillation or ENSO or both.

Impacts of western Pacific, Indian Ocean, and Eurasian land surface on Asian monsoon and their difference from ENSO's direct influence

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Based on results from observational analyses and general circulation model simulations, the authors have provided evidence of the impacts on the Asian summer monsoon by tropical-extratropical western Pacific SST, Indian Ocean SST, and Eurasian land surface process, which is interacted with large-scale natural variability. The study has explored the seasonally-dependent dominant modes in the Indian Ocean and their relationship with monsoon, the upstream precursory signals of the monsoon, and the relative importance of tropical and extratropical SST of the western Pacific for Asian monsoon. The difference between these influences and ENSO's direct impact is discussed and the role of these phenomena in modifying ENSO-monsoon relationship is also addressed.

The Oscillation between East Asian monsoon system and ENSO system with the quasi-two years time scale.

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It is analyzed by using NCEP/NCAR reanalysis monthly averaged data from Jan. 1970 to Dec.2002. It is showed that there exists obvious interaction between anomalous East Asian monsoon circulation and ENSO cycle in terms of the quasi-two years time scale. It is reflected by existence of the oscillation of sea level pressure anomalies between the northwestern Pacific and the eastern tropical pacific. Analysis also indicated that this oscillation of sea level pressure anomalies links the East Asian monsoon system with the ENSO system. Therefore, the oscillation of sea level pressure anomalies between the northwestern pacific and the eastern tropical pacific is recognized reflection of the oscillation between the East Asian monsoon system and the ENSO system in terms of the quasi-two years time scale. The results further pointed out that in terms of the two years time scale, there only is the positive response of the ENSO cycle with inter-annual time scale for the forcing of the East Asian monsoon circulation anomalies, but there are the negative and the positive responses of the East Asian monsoon with the seasonal and the inter-annual time scales respectively for the forcing of ENSO cycle.

Finally, the mechanism of the oscillation between the East Asian monsoon system and the ENSO system with the quasi-two years time scale is discussed. The result showed that in terms of quasi-two years time scale, there is a low-frequency dipole system of the anomaly circulation, which is rotated around over the basin of the northern pacific and it takes tow years when it rotates one cycle. Then it causes the sea level pressure oscillation between the northwestern pacific and the eastern tropical pacific with the quasi-two years time scale.

Biennial and Lower-Frequency Variability Observed in the Early Summer Climate in the Western North Pacific

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In the western North Pacific, early summer climate is largely controlled by the Baiu phenomenon. Meridional fluctuations of the Baiu front on interannual time scales and the associated large-scale circulations are examined using the empirical orthogonal function (EOF) analysis and composite or correlation analyses based on the EOF time coefficients.

The first EOF mode indicates a five or six year low-frequency fluctuation (LF mode) appearing south of 35°N. The development is concurrent with the horseshoe sea surface temperature anomalies (SSTAs) in the entire tropical Pacific that are associated with the El Nino/Southern Oscillation (ENSO). SSTAs in the western North Pacific control anomalous southward expansion of the Baiu front through modification of the convection around 20°-35°N. The LF mode is negatively correlated with the South-Southeast Asian summer monsoon.

The second EOF mode is characterized by the meridional seesaw-like fluctuation with a node around 28°N and a time scale of biennial oscillation (BO mode). The horseshoe SSTAs again control the anomalous meridional circulations but with a different spatial phase through a convection off the Philippines. The spatial phase difference between the two horseshoe patterns is about 90° in both the zonal and meridional directions. The BO mode is negatively correlated with the tropical western North Pacific monsoon.

SSTAs associated with the BO mode tend to be confined to the tropical western Pacific, while the signals of LF mode extend rather broadly in the tropical Pacific-Indian Ocean sector, suggesting that the tropical BO is an aborted ENSO in the tropical central-western Pacific. The spatial phase of horseshoe SSTAs adjusts a detailed interannual variability of the meridional fluctuation of Baiu front.

Sea Surface Temperature Forcing of the Monsoon-ENSO system

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In this talk, we use recent observations and a Coupled General Circulation Model (CGCM) simulation in order to assess the relationships of the Indian Summer Monsoon (ISM), El Niño-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) events with Sea Surface Temperature (SST) anomaly patterns over the Indian and Pacific oceans. The focus is on the predictability of various components of the tropical Indo-Pacific climate and their links to Indian Ocean SST forcing.

It is found that southern Indian Ocean SST acts as a major boundary forcing for the Late ISM (LISM), ENSO and IOD events during recent decades. Weak (strong) LISMs, Niños (Niñas) and positive (negative) IOD events are preceded by significant negative (positive) SST anomalies in the southeastern subtropical Indian Ocean, off Australia during boreal winter. These SST anomalies are mainly linked to subtropical Indian Ocean dipole events, recently studied by Behera and Yamagata (2001) and to ENSO. These SST anomalies are highly persistent and affect the northwestward translation of the Mascarene high from austral to boreal summer. The southeastward (northwestward) shift of this subtropical high associated with cold (warm) SST anomalies off Australia causes a weakening (strengthening) of the whole Indian monsoon circulation through a modulation of the local Hadley cell during the LISM. Furthermore, it is suggested that the Mascarene high interacts with the underlying SST anomalies through a positive dynamical feedback mechanism, maintaining its anomalous position during the LISM. At the same time, observations suggest that these subtropical SST anomalies and the associated anomalous anticyclone may be a trigger for both the wind-thermocline-SST positive feedback off Sumatra and the development of westerly wind anomalies over the western Pacific which are well-known key-factors for the evolution of IOD and Niño events. Interestingly, these relationships are also well simulated in the control run of a state-of-the art CGCM, the ARPEGE-ORCA model which is among the best models for simulating ENSO-like phenomenon in the study of AchutaRao and Sperber (2002).

The Precipitation Patterns over Australia and East Asia during Australian Summer Monsoon Season

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The spatial and temporal variability of the precipitation patterns over the vast area from Australia to Northeast Asia (100-150°E, 40°S-40°N) is investigated. Four data sets are used in this study: the CRU and GISS surface observed global land precipitation monthly anomalies in 1920-1995, CPC Merged Analysis Precipitation in 1979-2001, and NCEP-NCAR reanalysis monthly data set in 1949-2001. The station data in Taiwan during 1920-2001 is intensively used for verification.

Three pronounced precipitation patterns over the area from Australia to East Asia are identified. The patterns are determined based on three key areas, namely, south China and Taiwan, the Philippine Sea and northwestern Australia. Pattern-one has wet anomalies over south China, Taiwan, and Japan but dry anomalies over the Philippine Sea and northwestern Australia. Pattern-two has opposite anomalies to the pattern-one in aforementioned key areas. Pattern-three has wet anomalies over the Philippine Sea but dry anomalies over south China and northwestern Australia. After performing composite, EOF and regression analyses to the data sets, we find that pattern-one is mainly a response to El Niño and the warm SST anomalies over the Indian Ocean. Pattern-two is a response to cold SST anomalies over the equatorial central Pacific, the marginal seas of Asian continent from the South China Sea to the East China Sea, and the subtropical northwestern Pacific. Associated with the cold SSTs, there are compensating warm SSTs over the eastern south Indian Ocean, the Philippine Sea and the subtropical north Pacific. The SST anomalies associated with pattern-three are similar to pattern-two in the tropics, but distinctly different over the northwestern Pacific, particularly in the subtropics. The contrast in the precipitation patterns and the associated large-scale fields suggests that the subtropical SST anomalies can influence the precipitation patterns in the region of study through a global-scale teleconnection mechanism. When the SSTs are warmer over the Philippine Sea and subtropical northwestern Pacific, the convection is stronger in that area, which subsequently enhance the downstream Rossby wave train that can subsequently enhance the intensity of the Asian winter monsoon. The intensity of the Asian winter monsoon makes directly impact on the phase relationship between the precipitation over south China, the Philippine Sea and the northwestern Australia.

Characteristics of East-Asian Summer Climate Revealed by Newly Defined Indices

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To investigate the characteristics of East-Asian summer climate, we have defined EASR (East-Asian summer rainfall) and EASMI (East-Asian summer monsoon index). EASR is defined as the summer rainfall anomaly averaged over the region [30N-50N, 110E-145E] and EASMI as the value of the time series of the first EOF (empirical orthogonal function) of the rainfall data over the region [20N-50N, 80E-170W] multiplied by the averaged eigenvector over the same area as EASR. EASMI describes well the characteristics of the East-Asian monsoon system. The characteristics of EASMI are similar to those of WNPMI (western North Pacific monsoon index, Wang et al., 2001), which explains the characteristics of western North Pacific monsoon. Therefore, EASMI is considered as the tropics-related precipitation, and the difference between EASR and EASMI is considered as the extratropics-related one. The tropics-related precipitation is related to the monsoon frontal system and the teleconnection pattern like PJ (Pacific-Japan, Nitta, 1987) or EAP (East Asia/Pacific, Huang and Sun, 1992). The extratropics-related precipitation is related to the heavy rain, the baroclinic wave and so on and has high positive correlation with EU (Eurasian) index.

From the correlation and regression analysis, the tropics-related precipitation is related to the positive SSTA in the Pacific and the Indian Ocean and the negative SSTA in western Pacific Ocean in the previous winter and spring. The positive correlation between EASMI and SSTA in the Indian Ocean continues from winter to summer. The precipitation over East Asia in summer tends to increase in the decaying phase of El Nino by the strengthening of the western North Pacific subtropical high (WNPSH) (Chang et al., 2000; Lau and Weng, 2001; Wang et al., 2000). WNPSH develops in autumn of the developing phase of El Nino and become weaker in the next spring and develops again in summer of the decaying phase of El Nino. The relationship between WNPSH and SSTA in the tropics has been investigated by Watanabe and Jin (2002) using the linear baroclinic model (LBM, Kimoto and Watanabe, 2000, 2001) and Lau and Nath (2000) using AGCM. In this study, the relationship between WNPSH and SSTA in the tropics in spring and summer is investigated with LBM.

NAO impact on the East Asia monsoon and ENSO

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As follows from the recent published results, NAO influence on the East Asia/western Pacific monsoon and ENSO is due mostly to the changes of winter-spring temperature and snow conditions over Euro-Asia in different NAO phases (e.g., Yasunari and Seka, 1992; Bamzai and Shukla, 1999; Chang et al., 2001; Kumar et al., 1999; Polonsky et al., 2003). Spectrum of NAO index is characterized by two significant peaks in the interannual range of periods (T=2-3 and 6-8 years). The interannual increasing of NAO index is accompanied by strengthened zonal winds between 50 and 60N in the troposphere and by weakened blocking activity in the Euro-Atlantic sector. This leads to the positive temperature anomalies over the most Northern Europe and Asia (Glowienka-Hense, 1990; Werner and von Storch, 1992; Kozuchowski, 1993; Polonsky, 1997; Roger, 1997 and others). The overwhelming majority of data suggest that the cyclone pathways (and the atmospheric centers of action in the North Atlantic) in this period are shifted to the northeast as compared to the years with the intermediate NAO index magnitudes.

There are also 60-80yr North Atlantic variations which are visible from selected instrumental data and found in the paleodata with a reasonable statistical significance. Likely, they are the manifestation of low-frequency variability of global thermohaline circulation generated in the North Atlantic (Marshall et al., 2001; Polonsky et al., 2002). This variability can modulate the interannual monsoon/ENSO signal in the western Pacific. This presentation aims to discuss this mechanism and to revise the NAO>monsoon/ENSO influence for different temporal scale using long-term hydrometeorological time series (including Euro-Asian rivers' run off) and NCEP/NCAR reanalysis output.

It is found that the ENSO events tend to follow to winter-spring NAO weakening on the interannual scale, while on the multi-decadal scale, there is an opposite tendency. The multi-decadal NAO index rising is accompanied by displacement of Iceland Low and Azores High to the South-West. In the other words the interannual and interdecadal tendencies of displacement of the North Atlantic centers of action for different NAO phases are opposite one another. At the same time it is found the significant correlation between winter-spring NAO index and surface heat flux in the Northwestern subtropical Pacific. The signs of correlation are opposite for the interannual and multi-decadal scales. Temperature Asia-Pacific contrasts and associated monsoon intensity depend significantly on the surface heat flux anomalies in the Northwestern subtropical Pacific associated with different NAO phases. On the multi-decadal scale this is a crucial factor. Thus, the slow variations of thermohaline circulation can impact on the ENSO event directly (through the change of basis state of equatorial ocean) and indirectly (through the change of the temperature Asia-Pacific contrasts and following ENSO-monsoon interaction).

Long-term droughts in the South Asian monsoon region in a 1000 year global coupled model simulation

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A 1000-year integration with the Parallel Climate Model, a global coupled ocean/atmosphere/land/sea-ice climate model currently in use for studies of climate variability and climate change, is analyzed to identify anomalies in the climate system associated with long-term droughts in the South Asian monsoon region. Here we define such droughts as periods longer than 20 years when the 11-year running means of area-averaged seasonal or annual precipitation anomalies are negative. In the monsoon region, pronounced long-term droughts occur throughout the 1000-year period of the model integration. Inspection of annual time series associated with these extended low frequency dry periods indicates that the distributions of anomalously wet and dry years are shifted, such that wet years still occur during low frequency droughts, but far more years are dry than wet during those time periods. Singular value decomposition of filtered (timescales longer than 11 years) global precipitation and sea level pressure indicates extended dry periods in the south Asian monsoon region and North America are related, such that extended dry conditions over North America tend to occur in conjunction with wetter than normal periods over the South Asian monsoon region, and vice versa. Analysis of associated sea surface temperature anomalies in the model points to the importance of the equatorial western Pacific, and eastern Pacific ITCZ, regional SST anomalies for connecting extended wet and dry periods in South Asia and North America. Results indicate that low frequency variability in the ocean, manifested by SST anomalies over the Pacific and Indian Oceans, likely has the largest contribution to anomalously dry periods in the South Asian monsoon region.

The Indian Ocean, the TBO, and the Asian-Australian Monsoon

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The tropospheric biennial oscillation (TBO) is defined as the tendency for a elatively strong Asian-Australian monsoon to be followed by a relatively weak one, and vice versa. The transitions occur in northern spring and involve coupled land–atmosphere–ocean processes over a large area of the Indo-Pacific region. A series of GCM sensitivity experiments isolates the effects of each of the transition conditions to document their respective influences on the anomalous patterns of monsoon rainfall associated with TBO transitions. The anomalous tropical Indian and Pacific Ocean SST anomalies produce a larger monsoon response in the model compared to the anomalous meridional temperature gradient over Asia indicating they are the dominant conditions associated with TBO transitions. The interaction of the Indian Ocean dynamics and the TBO is analyzed in a 300-yr period from the control run of the National Center for Atmospheric Research (NCAR) Climate System Model (CSM). Singular value decomposition (SVD) analyses of model and observations show that the model reproduces the dominant observed TBO transition mechanisms that are involved in the development of the TBO's influence on the south Asian monsoon: large-scale forcing from the tropical Pacific and regional forcing associated with both the meridional temperature gradient between the Asian continent and the Indian Ocean, as well as Indian Ocean SST anomalies. In observations and the model, the Indian Ocean zonal mode (IOZM) is an inherent feature of the Asian summer monsoon and the TBO. The IOZM is thus a part of the biennial nature of the Indian–Pacific Ocean region. The coupled ocean–atmosphere dynamics and cross-equatorial heat transport contribute to the interannual variability and biennial nature of the ENSO–monsoon system, by affecting the heat content of the Indian Ocean and resulting SST anomalies over multiple seasons, which is a key factor in the TBO.

What is the cause for the inter-decadal variation of the Asian monsoon system

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In recent decades, numerous investigators have indicated the inter-decadal variations of the Asian monsoon system. In particular, the East Asian summer monsoon has shown a continuous decrease in intensity since late 70's. And the major seasonal rain belt has had a significant southward shift, thus leading to droughts in North China and floods in South China. In all India, the summer monsoon rainfall has shown a slight increase since 80's despite the more frequent occurrence of El Nino events in this period.

Two types of physical causes have been proposed for explanation of the variations of the Asian monsoon system: natural factors, including SST change in Pacific (PDO) and Indian Oceans (IOD), the effect of North Atlantic Oscillation (NAO), and impacts of snow cover and depth over Eurasia and the Tibetan Plateau, and anthropogenic factors, including global warming and climate consequences of aerosols (sulfate aerosols and black carbon/Asian brown cloud (ABC)). A critical review will be given of these possible mechanisms.

Based on our study, the change in heat sources over the Tibetan plateau is likely to be a primary cause leading the inter-decadal variation of the Asian monsoon system. An abrupt weakening of the heat sources in spring and summer over the Tibetan plateau has been revealed since late 70's. This weakening took place concurrently with an abrupt increase in the winter snow cover and snow depth over the Tibetan plateau. Thus, the land-sea thermal contrast and the Asian summer monsoon system have been reduced. The significant evidences have been provided to document this chain of events. The effects of aerosols might be of secondary importance.

Variability of the Summer Monsoon over South China and the South China Sea: from Interdecadal to Intraseasonal

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This paper presents results from a number of recent studies from the author's group on the variability of the summer monsoon over South China (SC) and the South China Sea (SCS). It is found that both the onset date and the intensity of the summer monsoon over these regions exhibit large variabilities on timescales from interdecadal, interannual to intraseasonal. The interdecadal variations appear to be related to the coupling between the Pacific Decadal Oscillation and the El Niño/Southern Oscillation (ENSO). An in-phase condition between these two oscillations allows a good prediction of the intensity of the monsoon while an out-of-phase situation reduces the predictability. On an interannual timescale, the variations are largely contributed by ENSO. Intraseasonal variations can result from either the 30-60-day oscillation or the 10-20-day oscillation or both, depending on which mode(s) of oscillation is/are active during a particular year. The physical processes in each of these variations will be presented.

Summertime ENSO Teleconnections over the Eurasia: The possible cause of East Asia cool summer in developing El Nino summer

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The atmosphere over the extratropical regions thousands of kilometers remote from the equatorial Pacific is sensitive to the warming of those waters during El Nino. It is apparent, however, that not all extratropical regions are sensitive to El Nino, nor is its impact uniform throughout the year. Furthermore, different El Nino events have been accompanied by an assortment of climate anomalies in the extratropics. Within the Northern Hemisphere, a distinct annual cycle of ENSO-related teleconnections occurs, with a strong response in boreal winter. During El Nino, the East Asian countries are warmer in winter, whereas cooler in summer, respectively. The previous studies explained the influence of El Nino on the East Asian winter monsoon (Kimoto and Yasutomi, 1998; Wang et al, 2000). However, the impact on the global climate of El Nino summer is not well established. Our inquiry into this problem begins with an analysis of the observed and model data, to identify the teleconnections that link the tropics and the extratropics during El Nino summertime.

In order to further understanding mentioned above, the statistical methods and an AGCM experiment have been carried out. The model has been forced at the lower boundary with the monthly evolving global SSTs. The 8-member ensemble for period of 1948-98 has been constructed. These simulations differ only in their only in their specification of the atmospheric initial conditions, and each realization experiences the same monthly evolving SSTs. According to the correlation, it is not highly correlated between SST in NINO 3.4 and observed mean surface temperature observed mean surface temperature over Korea both summer and winter. Although the correlation coefficients are low or the marginal value, it is easily recognized by pro-ability density function (PDF).

It is obvious that the PDF shifts toward negative in JJA El Nino and positive in JJA La Nina regimes when the NINO 3.4 SST anomalies are positive and negative, respectively. During El Nino and La Nina DJF, we get an opposite PDF distribution those of JJA. It is found that PNA-like pattern over the up-stream region with respect to the westerly in midlatitudes, in addition to zonally elongated anomaly from North Africa reached to the East Asia with 95 % significance. The latter anomaly has a barotropic structure and it applies to El Nino summer. The observational relation will be assessed further using experimentation with linear baroclinic models.

Interdecadal change in the Asian-Australian monsoon

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This study focuses on the decadal change in the Asian-Australian monsoon region, especially the impact from the "climate shift" occurred in 1970s. The sea surface temperature (SST) in the Indian Ocean during 1975-95 is warmer than that in 1950-70. Compared with the change of low-level air temperature over the Asian continent, the land-sea thermal contrast is decreased after 1970s. This results in an anomalous winter-monsoon-type anti-cyclonic flow in Asia. Due to the decreasing of the land-sea thermal contrast, the south Asian (SAS) monsoon rainfalls in 1975-95 are weaker than that in 1950-70. On the other hand, the Aleutian low is stronger and the SST in the northern Pacific (30-50N) is colder after this climate shift. The enhanced Aleutian low and the anti-cyclonic flow over Asia increase the northerly wind along the eastern coast of Asian continent. An anomalous trough connected to the Aleutian low reaches southeastern China in Northern Hemisphere spring. This pattern explains that the spring rain in Taiwan during1975-95 is stronger than that in 1950-1970.

The relationship between the rainfalls in SAS and northern Australian (NAU) is examined in 1900-98. Due to the increasing of SST over the maritime continent, the convection corridor linked SAS and NAU is enhanced in recent decades. The result shows that the recent decades (after 1970s) are within the period when the Asian and Australian monsoons are strongly coupled. However, such coupling was not existed in some early decades. The decadal change of the Australian monsoon is discussed in this study.

Detection and Dynamics of the Principal Mode of Asian Summer Monsoon Variability

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Principal modes of Asian summer monsoon variability are identified. By using vertically integrated moisture flux, principal modes represent better separation than commonly used variables such as rainfall, winds and OLR. An EOF of vertically integrated moisture flux within the South, Southeast and East Asia during summertime is analysed. The first and second EOFs of the moisture flux are found out to be the principal modes of the Asian monsoon variability. In summer, there are two modes dominant in the Asian monsoon region; one consists of low-level circulation over the subtropical western Pacific near Philippines and associated convective dipole centers located over the western Pacific and Indonesia. The other consists of ENSO signal and the Pacific-Japan (PJ) pattern pointed out by Nitta (1986, 87), called ENSO-PJ mixed mode. The dynamics of the first mode, called Pacific-Indo dipole is analyzed in detail. This pattern is detected as the first EOF mode of a simulation with an AGCM giving the climatological mean SST. The Pacific-Indo dipole pattern is found out to be excited without external forcing like a specific sea surface temperature anomaly. Moreover, the Pacific-Indo dipole pattern appears as the preferred structure of variability by giving small perturbations to a three-dimensionally varying basic state in summertime by using a linear baroclinic model.

Factors of the basic state which help to excite and maintain the Pacific-Indo dipole pattern are examined. Free, stationary Rossby waves can be excited in the region of low-level westerly extending from the Indian Ocean to the South China Sea which blows as a part of the monsoonal flow in summer. Rossby waves at the eastern end of the low-level westerly where the basic state converges can extract the kinetic energy from the basic state. The circulation constituting the Pacific-Indo dipole pattern can be resonantly excited by a small perturbation given to the monsoon jet.

When the cyclonic circulation is formed, the moisture of the basic state converges and is advected to the northwestern Pacific, evaporation is activated at the southern part of the circulation anomaly, and then the field becomes unstable. Then a divergent circulation, an ascent over Philippines and a descent over Indonesia, are made, and the dipolar centers of convection are formed. The cyclonic circulation is enforced by the convection over Philippines. When an anticyclonic circulation over Philippines is formed, the reverse pattern of convection is formed. The circulation over the northwestern Pacific enforced by the convection composed of the Pacific-Indo dipole collects moisture and strengthens the dipolar convective anomalies. The Pacific-Indo dipole pattern is maintained by feedback between circulation and convection mentioned above.

Interaction between Circumglobal Teleconnection and Asian Monsoon during the Northern Summer

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With the 54-year NCEP/NCAR reanalysis data, we show the existence of a geographically fixed, circumglobal teleconnection pattern over the midlatitude of the Northern Hemisphere from June to September. This anomalous wave train is located within the tropospheric jet-stream waveguide and has a zonal wave number 6 structures whose phases are locked to preferred longitudes. Accompanying this global wave train, regions of significant rainfall anomalies emerge in the northern Europe, India, East Asia and continental United States. A positive interaction between this teleconnection pattern and the anomalous Indian summer monsoon is proposed to explain the concurrence of the two phenomena.

To examine the mechanism of the teleconnection pattern, a barotropic model, linearized about the 300 hPa climatological mean summer flow, is forced by a number of idealized local divergence source distributed throughout the tropics and midlatitude. A wave train that is similar to the observed circumglobal teleconnection pattern tends to recur in a series of steady response of the model, suggesting that this teleconnection is a preferred mode of the northern summer climatological flow. This recurrent mode is sensitive to the forcing over Atlantic and India monsoon region. The coupling between the teleconnection pattern and Indian summer monsoon is supported by an ensemble integration of the linear baroclinic model and a general circulation model.

Decadal Variability of Tropical Cyclone Activity over the Western North Pacific

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Time series of tropical cyclone (TC) counts over the Western North Pacific from 1965 to 2001 were analyzed by a statistical change-point analysis. Results reveal two major epochs of activity. The epoch during 1989-1997 is marked by high activity in contrast to the low activity during 1968-1988.

Large-scale environmental conditions conducive to cyclone activity during the peak typhoon season (July through October) for the active (1989-1997) and inactive epochs (1968-1988) are investigated. Relative to the inactive epoch, a warmer ocean surface over the region where TCs are generally formed is found in the active epoch, although this warming is rather small (0.1°C). Anomalous low-level cyclonic vorticity and a huge, anomalous cyclonic circulation gyre over the Philippine Sea are noted when the inactive period is subtracted from the active period. Weaker vertical wind shears, stronger ascending motion, and increased precipitable water over the major genesis area are found during the active epoch as opposed to the inactive epoch. These changes in environmental conditions collectively favor higher cyclone activity for the recent epoch.

Interdecadal variations of various intraseasonal features of Indian summer monsoon, their relationship, possible causes and climatic effects

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Various types of weather systems of different spatial scales are observed during the Indian summer monsoon in intraseasonal time scale. These systems play very dominant role in the behavior of monsoon circulation and accompanying rainfall over India. These intraseasonal features can be basically divided into two parts; (i)synoptic disturbances of transient characteristics and (ii)semi-permanent systems of quasi-permanent characteristics. Synoptic weather systems during Indian summer monsoon consist of monsoon disturbances, off-shore trough/vortex along west coast of India, etc.(Rao,1974)

Amongst all the monsoonal weather systems, monsoon depressions are recognized as the main rainfall producing synoptic weather systems over India. Effect of these important synoptic systems on intraseasonal and interannual variation of Indian summer monsoon rainfall(ISMR) has been explained by many authors including Rao(1976), Molley and Shukla(1989), Jenamani and Dash(1999), and Jenamani and Desei(1999). In addition to the interannual variation, ISMR exhibit strong interdecadal variations as shown by Thapliyal and Kulushrestha(1991), Parthasarathy et al.(1994), Webster et al.(1998), and Krishnamurthy and Goswami(1998). Such interdecadal variability is also evident in various other monsoon parameters such as, the homogenous monsoon rainfall based on sub-divisions covering the north-western and central parts of India (Parthasarathy et al., 1993) and circulation features such as the April position of the 500 hPa ridge (Kripalani et al.,1997). Study of many other major climatic features over the globe by several authors shows presence of strong variation in similar iinterdecadal time scale.

Apart from ISMR and its related parameters, most of the large scale tropical features e.g. El- Nino and Southern Oscillation (ENSO) and North Atlantic Oscillation(NAO) exhibit interdecadal variations(Hurrel, 1995; Hurrel and Loon,1997; Hoeling, 2001; Wunsch, 1999; Krishnamurthy and Goswami, 1998; Webster et al., 1998; Torrence and Webster, 1999, Kachi and Nita, 1997; Zhang et al., 1997). Decadal behavior has also been noticed in the relationship of ISMR with Indian ocean SST(Clark et al.(2000)), .with SST over the tropical Pacific Ocean (Angell, 1981), annual sun-spot numbers (Ananthakrishnan and Parthasarathy, 1984), northern hemispheric surface temperature(Verma et al., 1985), the southern oscillation (Elliott and Angell, 1987), Bombay and Darwin pressure (Parthasarathy et al, 1991), sub-tropical ridge, Darwin pressure tendency and SST over the Arabian Sea(Hasternath and Greischar, 1993).

Since most of large scale tropical feature shows interdecadal variation and characteristics of monsoon disturbances and ISMR have good relationship in intraseasonal and interannual time scale. Hence a very important question can be raised in the present study.

Does any epochal variation also exist in interdecadal time scale in intraseasonal weather systems of ISMR which mainly contributes for rainfall distribution in season and

their relationships with ISMR?

Jenamani and Dash(2001a, 2001b) have attempted to study variation of characteristics of monsoon disturbances which are main intraseasonal features and its relationship with ISMR in longer time scale i.e. interdecadal and 30-years time scale. Their results show dominant existence of interdecadal shifts in their characteristics and their relationship with ISMR in seasonal time scale.

It is beyond our doubt that epochal variation of relationship of ISMR with its predictors for last many years, may not produce any significant climatic effect on the spatial variation of ISMR and other various related intraseasonal feature e.g. break monsoon days, heavy rainfall etc.. Since monsoon disturbances are the main rainfall producing systems themselves and also control day to day monsoon activities and spatial distribution of ISMR significantly, existence of strong decadal variations of characteristics(particularly intensity) of monsoon disturbances and its relationship with ISMR likely to produce a significant climatic effect on many different intraseasonal features of Indian summer monsoon which are affected by these disturbances..

In the present study, first an attempt has been made to understand more closely how 11-years running means of seasonal and monthly frequencies of different monsoon disturbances(lows. depressions and CS) for the period 1889-1998 vary in decadal time scale and which monsoon months contributes maximum for the dominant mode of such variation from decade to decade. Their area of formation and movement are also compared for the particular months and for some contrasting decades when maximum trends are observed to find out whether their exists a decadal shift of area formation and movement due to which a particular decades atmospheric environments becomes favorable to have very high number of depressions and hence affecting the subsequent coastal subdivisional rainfall Then Interdecadal variation of some other different intraseasonal features e.g. break monsoon days of July and August, monthly rainfall, number of extreme rainfall days and heavy rainfall events over India have also been studied .

Various climatic effects of interdecadal variation monsoon disturbances are further studied by analyzing relationship between interdecadal variation of other different intraseasonal features which are normally affected by formation of these disturbances and interdecadal variation monsoon disturbances .These features are monthly rainfall, break monsoon days of July and August, spatial rainfall over subdivision particularly over those subdivision of India which lie along coasts and over monsoon trough region and regularly affected by these disturbances, number of extreme rainfall days and heavy rainfall events over India.

Based on observational analysis, Gray(1968) suggested six parameters of atmospheric and oceanic conditions for genesis of tropical storms. These are SST, Coriolis force, and relative vorticity in the lower levels, vertical wind shear, vertical stability and relative humidity in the lower and middle troposphere. However, SST in the Bay of Bengal where maximums of the monsoon disturbances are formed is generally high throughout the year with values greater than 28 C. Also, the mechanisms of the formation of cyclonic storms and depressions in monsoon seasons over Indian region are different from those of tropical storms in other seasons over India itself and from other areas of globe. The former systems are formed under strong moist-barotropic-baroclinic environment prevailing during the season. Based on case studies, it has been established that strong horizontal and

vertical wind shears support the formation of monsoon depressions through the conversion of basic flow kinetic energy and available potential energy to perturbation energy.

Therefore, an attempt has been made in the present study to examine whether any such variability also exists in the dynamical parameters representing the monsoon circulation such as upper and lower level horizontal and vertical wind shear, SST, and OLR. Such study is essential to understand whether the decadal variations of dynamic parameters favor the occurrence of high/low number of depressions. Also one needs to know whether convection becomes weak due to the decrease in number of depressions over the Bay.

Except above parameters studied from NCAR data, following features have also been examined to find other causes responsible for decreasing trend of monsoon depressions over Bay as these features are strongly synoptically linked.

1)Spatial variation of trends of frequencies of monsoon depressions over Bay of Bengal and adjoining northwest Pacific

2)Trends of frequencies of remnants of typhoons entering to Bay of Bengal from adjoining northwest Pacific

3)Spatial shifting of initial genesis of monsoon disturbances from north Bay to south Bay. Presence of eastern end of monsoon trough at lower levels in former case favor intensification of these systems during their developing stage.

Monthly frequencies of cyclonic storms and depressions during monsoon season over Indian region are collected from India Meteorological Department (IMD) (1979, 1996) for 1889-1990 for the present study. In this study, the number of cyclonic storms is counted by including all disturbances with intensities of cyclonic storms and above. The same data for recent period 1991 to 1998 are updated based on monsoon summaries published in "Mausam". 11-years running means are computed for all the months for the period 1890-1999. Monthly Reynolds SST at 2° X 2° grids and NCEP/NCAR wind re-analysis at 2.5° X 2.5° grid for the period 1948-98 are also used. Horizontal wind shears at 850hPa and 200hPpa and vertical wind shear between these two layers are calculated over the Indian region and then averages are found. However SST and OLR anomalies are computed over Bay of Bengal where these disturbances are formed. 11-years running means of all these parameters are computed. Data from JMA for cyclogensis over north west Pacific are referred for 1950-1998 for the present study. For climatic effect of decadal decreasing trend of depressions on other interrelated intraseasonal features over Indian region, data from IMD are referred.

Studies on the occurrence of monsoon depressions over a long period such as 1889 to 2002 show a significant decrease of their seasonal frequencies after 1960. Also examination of monthly frequencies indicates that the decreasing trend was maximum in July followed by September and August and with no trend in June.

Result of decadal variation of other intraseasonal features shows that depressions and break monsoon shows both the curves of break monsoon and frequencies of CS and depressions for 110 years period (1889-1998) shows that break monsoon and monsoon depressions are mutually exclusive up to 1970s. Afterwards, both of their frequencies are showing significant decreasing trends with record number of their lowest values are observed in 1990s. ISMR of June(July) has been in increasing(decreasing) mode from 1950s till recent years while ISMR of Aug(Sept) have been showing bi-modal type of

mode with already reached maximum(minimum) in 1970s and decreasing(increasing) thereafter till recent years.

Similar analysis of sub-divisional rainfall distribution over India show that rainfall over sub-divisions lies south(north) of eastern end of monsoon trough over east coast e.g. Orissa and Coastal Andhra Pradesh (Gangatic West Bengal and Assam) have been receiving less(more) than normal rainfall for many of recent years because of decadal shifts of formation, intensification and movement of monsoon disturbances which is another important climatic effect of such decadal variation of intraseasonal features.. The relationship of all these decadal changes with decadal change of heavy rainfall characteristics over India and extreme rainfall days over India, are also discussed for finding climate effect in decadal scale.

Preliminary results of NCAR data analysis for finding cause show similar decadal decrease in the horizontal and vertical wind shears and convection for the entire period of study. Thus in the present study, the decreasing trend in the number of monsoon depressions have been supported by the fact that the atmospheric dynamical parameters which favor formation of monsoon depressions have weakened in the recent years.

The Interdecadal Abrupt Change of African-Asian Summer Monsoon in 1960's

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On the basis of comprehensive analyses of recent climatic data, this paper exposes a decadal abrupt change of African-Asian Summer Monsoon in 1960's.The results indicate that, before abrupt change, surface temperature presents positive anomalies over African-Asian continents, and negative anomalies over Indian Ocean and west Pacific Ocean. Therefore, the ocean-continent thermal contrast increased. Correspondingly, it is inversed after abrupt change. On the surface pressure fields a strong warm low center over African-Asian continents weakened through abrupt change. Simultaneously, strong African and East Asian Monsoon in summer weakened significantly. Results shows that East Asian Monsoon, Indian Monsoon and North African Monsoon change synchronously. The most remarkable feature of this abrupt change is that in arid and semi-arid belt, from North African Sahara-Sahel to Middle East, North India and North China, Rainfall changes abruptly from abundant to seldom. The opposite trend happens on the two sides of this belt.

Based on the above fact we defined a Africa-Asia Monsoon index by the surface temperature difference between Indian Ocean and Euro-Asian continents. This index can reflect the interdecadal variation of Africa-Asian monsoon intensity. When the monsoon index is in low phase, the summer monsoon is strong; when the index is in the high phase, the summer monsoon is weak.

Interannual Variability of the Mascarene High and Australian High and Their Influences on the East Asian Summer Monsoon

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Based on the reanalysis data from NCEP/NCAR and other observational data, interannual variability of the Mascarene high (MH) and Australian high (AH) during boreal summer from 1970 to 1999 is examined. It is shown that interannual variability of MH is dominated by the Antarctic oscillation (AAO), and MH tends to be intensified with the development of the circumpolar lows in the high southern latitudes. On the other hand, AH is correlated with AAO as well as El Niño and Southern Oscillation (ENSO), and tends to be intensified when El Niño occurs.

Composite analysis of the difference between the positive and negative MH shows that, with the intensification of MH, the Somali jet and Indian monsoon westerlies tend to be strengthened. Concurrently, AH and the associated cross-equatorial current become stronger whereas the trade wind over the tropical western and middle Pacific become weaker. In association with the above changes, convective activities near the Philippine Sea are largely suppressed, as a consequence, exciting a negative convection anomaly and a Rossby wave train from East Asia via North Pacific to the western coast of North America (a negative Pacific-Japan pattern). Corresponding to the negative Pacific-Japan pattern, there is more rainfall from the middle and lower valley of the Yangtze River to Japan while less rainfall is found outside of this region.

The case study of 1980 indicates that, MH, AH and the associated cross-equatorial currents exhibit a quasi-biweekly oscillation. Moreover, the position and intensity of the western Pacific subtropical high (WPSH) on intraseasonal timescale is largely modulated by the oscillation of the two highs. On interannual timescale, however, MH plays a major role in the WPSH and the related summer rainfall over East Asia.

This study implies that, as a strong signal, AAO plays an important role in interannual variability of the East Asian summer monsoon. Furthermore, due to the seasonal persistence of AAO during boreal spring through summer, the strength of MH in boreal spring may provide some valuable information for summer monsoon forecast over East Asia.

The Relationship between East-Asian summer monsoon/western North Pacific subtropical high and the tropical SST

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To clarify the relationship between East-Asian summer monsoon/western North Pacific subtropical high and the tropical SST, which is revealed in the observational analysis and the linear barotropic model experiments by the previous presentation of Prof. Jhun, several AGCM experiments are carried out. SNU AGCM T31 with the prescribed SST forcing as the boundary condition is used. The SST forcing is composite SSTA in the strong East Asian monsoon year (the positive EASMI, East-Asian summer monsoon index). The effect of the Indian Ocean, the western tropical Pacific, and the eastern tropical Pacific on the circulation over East Asia in summer and the western Pacific subtropical high are investigated in these experiments.

To investigate the air-sea interaction in the Indian Ocean and the western Pacific associated with East Asian summer monsoon, AGCM/SOM (SNU AGCM coupled with slab ocean model) experiments are performed. The SST in eastern Pacific is prescribed and the SST in other region is forecasted by mixed layer model. The difference between the experiments by AGCM and AGCM/SOM shows the effect of the air-sea interaction in the Indian Ocean and the western Pacific on the East-Asian summer monsoon and the western North Pacific subtropical high.

A diagnostic study of Asian summer monsoon and its variability

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In this study, we investigate the mean circulation features, the large-scale budgets of kinetic energy, heat and moisture of Asian summer monsoon are studied with NCEP/NCAR reanalysis data sets for the period 1948-1999. Also, the contrasting features of the Asian summer monsoon are examined in composite of the surplus and deficient monsoon seasons over India with 52 year reanalysis data. Further, the evolution, advancement (active/break or stagnation epochs) and retreat processes associated with the Indian summer monsoon are investigated. The daily averaged (00 and 12 UTC) reanalysis data sets of NCEP/NCAR for the period 1948-1999 are used to examine the dynamic and thermodynamic characteristics over Asian summer monsoon region (30^o E-120^o E and 15^o S- 45^o N).

It is found that the entrance/exit regions of the tropical easterly jet (TEJ) are characterized by production/destruction of kinetic energy, which is essential to maintain outflow/inflow prevailing at the respective locations of the TEJ. The heat and moisture budgets evince that the monsoon domain is characterized by strong convergence of heat and moisture over the monsoon region. The horizontal convergence of heat and moisture facilitates enhancement of diabatic heating and in turn leads to the formation of diabatic heat sources. The horizontal convergence of moisture and diabatic heating are crucial to sustain the summer monsoon circulation. The remarkable aspect noticed in this study is that the Western Indian Ocean and Arabian Sea branch of monsoon circulation is more vigorous during surplus monsoon season, while the eastern Bay of Bengal branch is stronger during the deficient monsoon. The various large scale budget terms of kinetic energy, heat and moisture are found to be consistent and in agreement with the seasonal monsoon activity over India.

The flux divergence of kinetic energy over Somali Coast in the low levels intensify with the evolution of monsoon. The arrival of the summer monsoon over the Bay of Bengal is preceeded by an influx of heat and moisture which in turn consequently leads to rainfall over Bay. On the other hand, influx of heat and moisture are found to be insignificant over the Arabian Sea till the monsoon sets over southern tip of India (Kerala Coast). The large scale budgets of kinetic energy, heat and moisture budget depicts significant changes over the monsoon trough zone from pre-break to break period. The central equatorial Indian Ocean receives excess flux convergence of heat and moisture during post-retreat period of the monsoon.

Impact of EL NINO and Siberian High on the Temperature of Heilongjiang in the past 120 years

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Heilongjiang is located at northeastern China, a middle-high latitude area. Using the orthogonal function expansion technique on temperature in Heilongjiang, with get the first eigenvector, it is occupy 76% of general variance. The result shows that the temperature change in Heilongjiang is consistent. Thus temperature change in Harbin, the state capitol of Heilongjiang, can fully represent temperature change in Heilongjiang.

1 Characteristics of temperature change of Harbin in recent 120 years

With temperature data during year 1881-1999, 10 years running mean and 30 years mean are used for comparison. The result is shown in Table 1. Over the 119 years, temperature increases 1.4? in average, with 0.4~0.5? every 30 years. It has greatest increase of 1.8? in spring and winter, and 1.1? in winter in recent 30 years. There is no significant change in summer and fall.

Table 1

	year	Spring	summer	autumn	winter
1881~ 1910	2.8	4.2	20.4	4.3	-17.6
1911~ 1940	3.3	4.6	21.5	4.5	-17.6
1941~ 1970	3.7	5.1	21.3	4.9	-16.9
1971~ 1999	4.2	6.0	21.4	4.8	-15.8
(1971~ 1999)-(1881~ 1910)	1.4	1.8	1.0	0.5	1.8

2 Characteristics of abrupt temperature change

T-test is used for 10 years running mean of temperature in Harbin with $|t_{a=0.01}|=3.2$. The significant temperature increase in year 1897 and 1990 exceeds the test, with roughly 1.7? higher in latter than former. The winter is also. There is no significant abrupt temperature change in other seasons. Thus it indicates the temperature increases significantly after year 1980.

3 Comparison of temperature change in Heilongjiang with China and its north, central, and south area

China is divided as north, central and south area, which corresponds to north of Huang River, between Huang River and Yangtze River and south of Yangtze River. Average temperature of each 10 years during 1951-2000 is compared among Heilongjiang, nation, the north, the central and the south area. There is no significant temperature change in Heilongjiang and nation during the 1950s to 1970s. Temperature in Heilongjiang begins to increase in 1980s, with significant increase of 0.9? in 1980s over the previous two decades and 0.5? in 1990s over 1980s. In 1980s, temperature increases 0.4? in the north, 0.2? nationwide, and zero in the central and the south area. In 1990s, temperature increase is 0.4? nationwide and in all the other areas. Thus there is nationwide temperature increase

in the 1990s, with higher increase in Heilongjiang than other areas. Comparing the temperature increase in recent 50 years, Heilongjiang has the greatest increase, the north as the next greatest with 1.0? increase, and the central and south with only 0.4? increase.

4. Consistent temperature change trend in Heilongjiang, Globe and Northern Hemisphere

10 years running mean of temperature shows that it's cold phase in all three areas during 1881 -1925. During 1926-1946, it's warm phase for both globe and northern hemisphere, and temperature increase phase for Heilongjiang. During 1947-1967, it's warm phase for Heilongjiang, transition from warm to cold phase for globe and northern hemisphere with below negative anomaly. In all three areas, it's cold phase during 1968-1977, and high temperature phase from 1978 until now. In temperature transition period, changes occur in globe and northern hemisphere prior to Heilongjiang.

5 Effect of EL NINO on summer temperature of Heilongjiang weakens

EL NINO is an important factor in cool summer of Heilongjiang before 1990. After 1990, summer in Heilongjiang is warm as EL NINO occurs. Table 2 shows the correlation between seawater temperature in NINO C area and temperature in Heilongjiang. The negative correlation is at the peak in the period of 1960s to 1990s, and not significant in recent 30 years as it continues weakening. The correlation factor field distribution of sea temperature in NINO C area and northern hemispheric 500hpa height in July summer of the same periods in Table 2 supports the above fact. In view of 30-year 500hpa correlation field during 1951 to 1980, the area with negative correlation greater than –0.20 is over Heilongjiang; pressure in eastern Asia area is low in northwest and high in southeast, shaped as northwest-southeast seesaw; Heilongjiang is at cold low, which brings the great possibility of cool summer. During 1961-1990, the negative correlation of Heilongjiang increases to –0.30. During 1966-1995 and 1971-1999, the area with the most negative correlation of –4.0 migrates westward to Tamil peninsula, while correlation of Heilongjiang turns from negative to +0.10, indicating Heilongjiang has the higher probability of warm summer as EL NINO occurs. This is how the effect of EL NINO on summer temperature of Heilongjiang changes, so does on winter temperature.

Table 2

1951~ 1980	1956~ 1985	1961~ 1990	1966~ 1995	1971~ 1999
-0.37	-0.44	-0.48	-0.42	-0.19

6 Impact of Siberian high change on temperature

In view of correlation factor field distribution of winter temperature in Heilongjiang and northern hemispheric sea level pressure during four periods, including 1881~1910, 1911~1940, 1941~1970, and 1961~1992, winter temperature change is highly correlated with Siberian and north pacific highs. Temperature in Heilongjiang is very low when Siberian high is strong. Temperature increases significantly in 1902,1930, 1955~1965, especially after 1980, during which Siberian high weakens. The weakening of Siberian high after 1980 is the second significant weakening in recent 100 years. Meanwhile, north pacific high further strengthens.

The interannual and interdecadal variability of summer climate in Taiwan

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Summer (JJA) climate in Taiwan is under the combined influence of the Pacific abrupt climate change, the western North Pacific summer monsoon (WNPSM), and the North Pacific tropical cyclone (TC) activity. Roles of these three climate factors in the interdecadal and interannual variability of summer climate in Taiwan for the period 1950-2000 are examined. Major findings of this study are outlined as follows:

- The summer temperature in Taiwan exhibits a clear warming trend with a promising climate shift around 1978, showing a consistent phase change with the abrupt climate change in the Pacific region.
- Interannual variations of the summer temperature and rainfall in Taiwan tend to be out of phase, indicating rainfall processes are a possible mechanism to regulate temperature variability.
- On the interannual timescale, the rainfall anomaly and circulation anomaly over Taiwan may be dynamically consistent or inconsistent. For the dynamically consistent cases (i.e., anomalous wet-anomalous low, anomalous dry-anomalous high), Taiwan is located in the center of an anomalous circulation which is a sub-component of the meridional teleconnection pattern associated with the WNPSM. Vertical motion is the major mechanism to affect rainfall variability.
- For the dynamically inconsistent cases, Taiwan is located along the outer rim of the circulation anomaly. The WNPSM pattern becomes discernible, while the dominating circulation anomalies are associated with the Pacific abrupt climate change. Vertical motion over Taiwan is relatively weak. Moisture advection is the major reason for the rainfall variability.
- When Taiwan is in an anomalous dry condition, strength of seasonal rainfall mechanism and frequency of TC to affect Taiwan are both reduced. When Taiwan is in an anomalous wet condition, seasonal rainfall mechanism becomes strengthened, but frequency of TC to affect Taiwan does not increase accordingly. Overall, the seasonal rainfall mechanism plays a more important role than TC frequency in the interannaula variability of summer rainfall in Taiwan.

Inter-decadal variability of the South China Sea summer monsoon

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China is greatly affected by monsoon activity. South China Sea (5°-20°N, 110°-120°E) summer monsoon is located between the East Asia summer monsoon system and India summer monsoon system. It is a very sensitive region in the Asia monsoon system. Author use the NCAR/NCEP reanalysis data (1958-1997) to study the inter-decadal variability of the South China Sea summer monsoon. The highlight is to show the inter-decadal variability of South China Sea Summer monsoon and its relationship to precipitation in South China and North China. Since 1958, the summer monsoon intensity represented by the Webster and Yang index has decreased continuously. At the same time, the precipitation in South China has continuously increased, while the precipitation in North China has continuously decreased. A possible explanation is: due to the weakening of the SCS summer monsoon, the monsoon airflow and associated moisture transport only reached the region to south of the Yangtze River basin and can not go northward to North China. The anomalous northerly wind developed significantly in East China, thus suppressing the northward moisture transport by southwest monsoon.

Seasonal Changes and their Decadal Variability over East Asia

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Seasonal changes and their decadal variability over East Asia were examined using Surface weather charts analyzed by JMA, atmospheric fields by NCEP/NCAR and ECMWF reanalysis, precipitation, temperature, and sunshine duration data. First, seasonal changes of frontal frequency, lower temperature and moisture field are examined. Regional differences are clearly recognized between those in China (115E) and around Japan (140E). In spring (late February to middle May), although frequency of front is relatively high both in China and around Japan, stationary front appears frequently only over China. After the end of Baiu or Meiyu season in late July, frequency of front decreases rapidly, while it becomes nearly equal to that in Baiu season around Japan during Akisame or autumn rain season (early September to late October) in autumn. The relationship between the frontal frequency and temperature and moisture fields shows clear seasonal variations.

Seasonal march of mid-summer to early autumn (from late July to early September) in central and western Japan has found to be drastically changed in recent decades. In the 1960s and 1970s, after the end of the Baiu season, pronounced high sunshine duration is observed from late July to early August, while relatively little sunshine period is found from late August to early September. In the latter period, many typhoons hit and approached western and central Japan. In the 1980s and 1990s, on the other hand, the end of the Baiu season is often delayed and sunshine duration becomes shorter in late July and early August, under the more pronounced influence of the Okhotsk High. While, in late August and early September, sunshine duration is prolonged comparable to that in early August. Temperature in this period becomes higher than that in the 1970s. This indicates the prolonged mid-summer in the recent years, because of stronger influence of the Pacific High and the clear changes of typhoon tracks.

Response of the Asian Summer Monsoon to changes in ENSO properties

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Based on 1950-1975 (PRE76), and 1977-2001 (POST76) El Niño composites of observed precipitation and reanalysis products we note that the Western North Pacific Monsoon (WNPM) was stronger than normal in both epochs, while the Indian Summer Monsoon (ISM) was weaker than normal during the entire monsoon season (during onset and withdrawal phases) during PRE76 (POST76), but stronger than normal during the established phase (July-August) in POST76, and we investigate the possible reasons for these similarities and differences. More specifically, we explore the hypothesis that in PRE76 El Niño forcing dominated the WNPM-ISM variability while in the latter epoch, the Indian Ocean zonal/dipole mode and /or the intensity of El Niño itself favored a stronger ISM-WNPM in July-August primarily through modulations of eastern equatorial Indian Ocean (EEIO) precipitation. This is investigated using atmospheric reanalysis products, and from a suite of numerical experiments with an Atmospheric General Circulation Model (AGCM) that has realistic ASM precipitation climatology. Diagnostics from observed precipitation and reanalysis supports the hypothesis. The basic mechanism through which the intensity of El Niño combined with Indian Ocean zonal/dipole events modulate the ISM-WNPM during POST76 is proposed. Both forcing factors reduce the EEIO precipitation and the anti-cyclonic circulation anomalies forced by this heat sink in the lower atmosphere enhances precipitation over the ISM-WNPM regions, and the north-south heating gradient favors a local meridional circulation.

Using an AGCM, 10-member ensemble simulations, separately for PRE76 and POST76 El Niño events, and cases where SST anomalies inserted over (i) tropical Indo-Pacific-TIP, (ii) tropical Pacific only-TPO, and (iii) tropical Indian Ocean only-TIO, are conducted. The TPO solutions support the hypothesis in both epochs, and underscore the dominance of remote forcing (Pacific SST) on the ASM variability. Despite a modest response in the TIO solutions, the TIP solutions indicate that SST anomalies that develop as a complementary pattern in the tropical Indian Ocean act to enhance the remote forcing, particularly during the established phase of the ASM through EEIO precipitation variations. Model solutions imply that all aspects of SST anomalies in the tropical Indo-Pacific regions need to be considered to understand the ENSO-monsoon teleconnection, and ultimately for a successful prediction of the ASM.

Intraseasonal Oscillation of Asian Summer Monsoon

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Intra Seasonal Oscillation (ISO-40) of period around 40 days plays a dominant role in the spatio – temporal variability of the Asian summer Monsoon (ASM). Two ISO-40 cycles are needed to complete the ASM onset process. At the end of the first ISO-40, a large area of deep convection gets established over the equatorial Indian Ocean south of the Bay of Bengal and a large amount of moisture gets pumped up into the atmosphere around. During the second ISO-40, this area of deep convection moves to Southeast Asia and the South China Sea monsoon onset takes place. One to two pentads later begins the formation and intensification of a spatially large convective heat source extending from east Arabian sea to the west Pacific through the Bay of Bengal that generates a Low Level Jetstream (LLJ) crossing the equator close to the east African coast. At the onset of monsoon over India (Kerala) about two pentads later, this heat source and the LLJ become very strong.

During the nearly 100 day life span of the ASM, the convective monsoon heat source and the associated LLJ have an Active – Break cycle which is also a manifestation of ISM – 40. During active monsoon spells the convective heat source is around latitude 15^0N - 17^0N, between 70^0E and 140^0E longitudes and the latitude of the LLJ axis is close to it and to its south. During break monsoon the main heat source is around the equator between longitudes 70^0E and 100^0E and the LLJ axis passes through it carrying moisture to the western Pacific to sustain the typhoon and monsoon activity there and depriving moisture supply to south Asia. Literature shows that the convective cloud band over the Indian Ocean moves slowly northwards from the equatorial areas to the Himalayas at speeds of 0.5 to 1 degree latitude per day. Instead, the heat source and the LLJ are found to jump from the equator to the latitudes 15^0N -17^0N and from there back to the equator in the active-break cycle.

Sea Surface Temperature (SST) data from TMI (TRMM) of the 6 years 1998-2003 with spatial resolution of about 25 kilometres show several interesting features. SST variability over the tropical Indian and west Pacific oceans is found to be related to the ISO-40 associated with the monsoon onset process over south Asia. For instance, the active convection over equatorial Indian Ocean at the end of the first ISO-40 cycle is found to be associated with very warm SST over the Bay of Bengal. The observed jumps in convection and the LLJ in the Active-Break cycles are found to be related to SST over the Indian Ocean. In the equatorial Indian Ocean there is a warm pool with SST more than 29^0C between latitudes 5^0S and 5^0N. North of this area, between 6^0N and 12^0N, there is a tongue of cold water between longitudes 70^0E and 95^0E caused by the strong upwelling at the southern Indian and Sri Lankan coasts and the eastward spreading of the upwelled cold waters. The SST here is between 27^0C and 28^0C. North of this area, in the north Bay of Bengal there is another warm pool with SST maximum close to 29^0C. In both these warm pools SST undergoes ISO-40 oscillations but with different temporal phases.

Intraseasonal variability in the East Asian and Western North Pacific monsoon region

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The intraseasonal oscillation in the East Asian and Western North Pacific (EA/WNP) monsoons exhibits unique regional characteristics. This review summarizes the major findings documented in the past 30 years. The content includes the general characteristics of the monsoon system, the seasonality, periodicity, and regionality in the ISV, the intimate relationship with monsoon system, the spatial structure and temporal evolution of the ISO, the tropical-extratropical interaction and teleconnection associated with the ISV, and the modulation on the typhoon activity. Outstanding issues are also discussed.

The Role of Intraseasonal Wave Activity in the Onset and Active-Break Phases of the Indian Monsoon

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Much recent work has emphasized the potential role of the Madden-Julian Oscillation (MJO) in determining the timing of the onset of the Indian monsoon, as well as intraseasonal fluctuations in monsoon activity (active-break cycles). We show that a broad range of other convectively coupled equatorial disturbances also contribute substantially to the pattern of intraseasonal rainfall and circulation over the Indian subcontinent and adjacent regions during northern summer.

The MJO is often implicated in the onset of the Indian monsoon, although we show that monsoon onset can also be tied to the passage of a convectively coupled Kelvin wave. Kelvin waves propagate eastward at a phase speed of around 15 m/s, much faster than the typical phase speed of the MJO (roughly 5 m/s) over the Indian sector, and can typically be traced back to origins over South America or the eastern Pacific. In addition, westward propagating equatorial Rossby (ER) waves originating over the western tropical Pacific or southeastern Asia are also commonly involved in determining the onset timing of the monsoon over southern India, as well as active and break phases. While these disturbances typically make up the larger scale envelope of the MJO, they can occur inisolation as well during the monsoon season and account for a large portion of the observed monsoon variability. Several cases of so-called "double monsoon onsets" are shown to be due to the precise timing of intraseasonal equatorial modes with respect to the usual seasonal cycle of monsoon onset evolution. A first "bogus onset" typically occurs during early May, which is then followed by a protracted dry spell and heat wave over India prior to the true onset sometime in June. We show that the bogus onsets of 1979 and 1995 were caused by early May occurrences of Kelvin waves passing through the Indian Ocean ITCZ. During other years such as 1986, 1997, 1998, and 2002 and 2003 bogus onsets occur in conjunction with an MJO, however these are preceded by Kelvin pulses propagating off of Africa which appear to "trigger" the formation of the MJO itself. It will also be shown that the usual monsoon onset signal is composed of significant Kelvin, ER, and MJO components, all of which are needed to adequately describe a statistical composite onset scenario, although the roles of each vary from one year to the next.

Intra-seasonal Variability of the Summer Monsoon over North Indian Ocean as Revealed by the BOMEX and ARMEX Field Programs

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During the summer monsoon season over India a range of intra-seasonal modulations of the monsoon rains occur due to genesis of weather disturbances on synoptic and low frequency (10-50 day) temporal scales over the Bay of Bengal and the east Arabian Sea. The amplitudes of the fluctuations in the surface state of the ocean (sea surface temperature (SST) and salinity) are quite large due to these monsoonal modulations as shown by the data collected during the field programs under BOBMEX (July-August 1999) and ARMEX (June-July 2002 and March-June 2003). Whereas the focus of BOBMEX was to understand the role of ocean-atmospheric processes in organizing convection over the Bay of Bengal on intra-seasonal scale, ARMEX-I was aimed at understanding the coupled processes in the development of deep convection off the west coast of India and ARMEX-II focused on the formation of the mini-warm pool across southeast Arabian Sea in April-May and its role in the abrupt onset of the monsoon along southwest coast of India and its further advancement along the west coast.

A good number of studies have been reported in the literature on different facets of the monsoon processes as revealed by the study of data from these three field programs. This paper attempts to integrate the results of these studies with respect to the role played by ocean-atmosphere processes in regulating the synoptic and the low frequency intra-seasonal episodes as well as onset of monsoon, which are important monsoonal signatures in the north Indian Ocean. The basic questions which are addressed in the paper relate to whether the warming of the surface waters in Bay of Bengal/Arabian Sea leads and triggers organization of convection or the atmospheric processes related to the strengthening of the low level jet (LLJ) on synoptic and low frequency intra-seasonal scales promotes the formation of synoptic / super-synoptic episodes. The study shows that:

(i) The seasonal warming of the Bay of Bengal and the Arabian Sea provide a favorable environment for the organization of monsoonal convection, prior to the onset of monsoon.

(ii) The strengthening of the LLJ triggers the formation of monsoonal disturbed episodes which are responsible for decrease in insolation, and increase in rainfall, followed by significant fall in the salinity of surface waters

(iii) Ocean-atmospheric exchanges under the warm ocean surface fuels the convective episodes resulting in cooling of the SST suggesting Ocean's role in regulating the monsoon and intern being impacted by it.

(iv) During suppressed convective episodes over the north Bay of Bengal under the low-frequency modulation of the monsoon, the SST rises substantially and the north-south gradients in SST recover which intern create favorable environment for the propagation of convection from south Bay to north Bay of Bengal in the mid-monsoon season.

(v) The wind induced changes in the lower-troposphere play a crucial role in triggering large-scale convective episodes. The ocean surface response to these modulations and regulates the monsoon processes which have higher fluctuations in parameters like rainfall, atmospheric moisture content in the lower mid-troposphere, SST and salinity compared to the intra-annual fluctuations in these parameters.

Westward propagating mechanisms of sub-monthly scale disturbances during summer Asian monsoon season

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An analysis of the vorticity budget equation with the ECMWF 40 Years Re-Analysis ERA40) dataset reveals westward propagating mechanisms of sub-monthly scale disturbances in the south and Southeast Asia during the summer monsoon season. The disturbances are observed mainly in the lower troposphere and propagate westward with speeds of a few meters per second. The strong westerly jet, however, prevails in the lower troposphere and thus is considered to prevent them from the westward propagation. This study demonstrates how the disturbances overcome the contrary westerly jet.

The disturbances are observed at various latitude in the south and Southeast Asia. In this study, two types of disturbances are analyzed separately; one type has a cyclonic circulation which centers at 10N, 90E (termed D10), and the other has a cyclonic circulation which centers at 20N, 90E (termed D20). 56 D10-type and 63 D20-type disturbances are detected in 21-year summer monsoon seasons.

For both disturbances, the beta terms, which represent the advection of the planetary vorticity by the disturbances, contribute well to the westward propagation which are similar to the Rossby wave dynamics, while the advection terms of the disturbances by the environmental wind inhibit the westward propagation, as mentioned above. Other contributing terms of the D10 and D20 differ. For the D10, the advection term of the environmental relative vorticity by the disturbance contributes to the westward propagation, while that term of the D20 does not. For the D20, the stretching term of the planetary vorticity by the disturbance and the other stretching terms contribute well which are accompanied by the negative OLR anomaly.

The difference between the effects of the advection terms of the environmental relative vorticity by the D10 and D20 is discussed in terms of the relative position of the disturbance and the local maximum of the environmental relative vorticity which centers at around 85E, 15N.

Indian Monsoon Variability during 2002 and 2003 : Role of Intra-seasonal Oscillations

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The seasonal summer monsoon rainfall from 1 June to 30 September for India as a whole during 2002 was 81% of its Long Period Average, while for 2003 it was 102%. Thus while the southwest monsoon of 2002 was a severe all-India drought, monsoon of 2003 was marked by near-normal rainfall distributed equitably over both space and time (India Meteorological Department www.imd.ernet.in). The seasonal monsoon variability is partly due to the external surface boundary forcing and partly due to its internal dynamics. The intra-seasonal variability dominant during the monsoon season constitutes this internal dynamics. The inter-annual changes in the intra-seasonal variability are an important potential source of inter-annual fluctuations of Indian summer monsoon rainfall strength.

The main intra-seasonal oscillations during the monsoon season over India have quasi-periods of approximately 3-7 days, 10-20 days and 30-60 days. While the 3-7 days periodicity is associated with the oscillations of the monsoon trough, the 10-20 days periodicity is associated with the westward moving waves or the synoptic-scale convective systems generated over the warm Bay of Bengal. Northward movement of convection associated with the ITCZ from the equatorial Indian Ocean region characterizes the 30-60 days periodicity.

Hence in this study the relative roles of these periodicities are examined during monsoon 2002 and 2003. Daily-observed rainfall, CPC merged rainfall, outgoing long-wave and TRMM data sets have been subjected to techniques of Band-pass filter and wavelet analysis. Results reveal that while monsoon 2002 was dominated by the slower 30-60 days mode, monsoon 2003 was dominated by the faster 10-20 days mode. Even within the monsoon season a change from active to weak spell clearly shows that the period of oscillation increases from less than 20 days to more than 50 days. This was very obvious during the long dry spell of July 2002. In contrast a change from weak to active spell shows the periodicity length decreasing. Further the active (break) spells are strengthened when the positive (negative) phases of both these oscillations appear simultaneously ie they are phase-locked. During the mid-season it is likely to foreshadow the subsequent behavior of this oscillations, this could serve as a guiding tool for medium and extended range forecasting.

Different propagation characteristics of the MJO during boreal summer and winter: Impact of the monsoon circulation on the northward movement of convection associated with the MJO

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To elucidate the reason why the propagation characteristics of the Madden-Julian oscillation (MJO) are different between boreal summer and winter, we compared the propagation characteristics of the MJO during boreal summer to winter. Convections associated with the MJO shows eastward movement from the western Indian Ocean to the western Pacific Ocean throughout a year. However, the behavior is much complex during boreal summer. In addition to the eastward movement, northward or northeastward movement of convection appeared over the Indian Ocean or the western Pacific Ocean during boreal summer.

We constructed the composite life cycle of the MJO for each season using total precipitable water (TPW) obtained from Special Sensor Microwave/Imager (SSM/I), OLR from NOAA, and reanalysis and operational analysis data of the European Centre for Medium-Range Weather Forecasts (ECMWF). To examine the difference of atmospheric responses to equatorial heating between boreal summer and winter, we compared the composite life cycle during boreal summer to winter during the period when convection moved eastward along the equator from the western Indian Ocean to the central Indian Ocean in both seasons. During this period OLR anomaly was nearly symmetric to the equator and was quit similar in both seasons. However, atmospheric disturbances were much different. Rossby wave response in the lower troposphere during boreal summer was stronger than winter and showed strong asymmetry. The northern part of Rossby wave response was stronger than the southern part. On the other hand, Rossby wave in the lower troposphere during boreal winter was weaker and stronger Kelvin wave response appeared. Differences in increasing rate of TPW were found corresponding to these response differences. Greater increasing rate of TPW was found over the region where Rossby wave response or Kelvin wave response was stronger. Accumulation of TPW and convective development were strongly connected and the former always precedes the latter, then we concluded that the different structure of accumulation of TPW made seasonal dependent propagation characteristics of the MJO.

Finally, to understand the reason why atmospheric response differs from boreal summer to winter, we examined vorticity budget analysis. We found that the difference of atmospheric response in the lower troposphere to convective heating caused by meridional shear of zonal wind. Thus the appearance of northward or northeastward movement of convection may be the result of strengthening of Rossby wave response due to the strengthening of zonal wind shear in the Northern Hemisphere during boreal summer.

A study of the simulation of the intraseasonal variability on East Asian Summer Monsoon using different horizontal resolution AGCMs

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The East Asian summer monsoon (EASM) is the result of interactions over many differing spatial length scales from synoptic up to planetary scale. Thus, in modeling the EASM and its intraseasonal march, it is important to take in account the sophisticated scales. Because of these reason, recently, many studies have investigated the characteristics of the EASM through a GCM with improved horizontal resolution.

Pope and Stratton (2002) had investigated that the model biases were reduced when resolution was increased in HadAM3 as four times for resolution ranging from N48 (2.5°x3.75°) to N144(0.833°x1.25°). In addition, Kawatani and Takahashi (2003) have found that the front disappeared early without being continued until July, through simulation of the Baiu-Meiyu-Changma front using a T106L60 AGCM. They attempted to overcome this limitation in physical parameterizations and unfortunately so far we still have continued to solve the problems. On the other hand, Giorgi and Marinucci(1996) had pointed out that resolution dependence of physical parameterizations in a climate model could lead to increase errors when resolution was increased. Zhou and Li (2002) simulated the EASM with a variable resolution of AGCM, which has the different horizontal resolution with denser resolution for interested area. They emphasized the weakly reproduced monsoon was seen in the model because of the insufficient plateau heating and the resulting weak land-sea thermal contrast.

In this study, using NCAR CCM3 with three different horizontal resolution – T42, T106, and T213 – experiments, the monsoon circulation will be simulated and its sensitivity to changes in the model's horizontal resolution is examined. Furthermore, the different cumulus parameterizations' effect on the EASM simulation is investigated. The model is NCAR CAM2.0.1, the cumulus parameterizations are Zhang-McFarlane scheme, which was involved in NCAR CAM2, and Relaxed Arakawa Schubert scheme (Maloney and Kiehl, 2002). Special emphasis will be laid on the hydrological and energy cycles over the land types in the Asian monsoon system.

Interactions among seasonal, intraseasonal and diurnal variations over the Indonesian maritime continent: An observational strategy

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Based on observational studies of my group over the Indonesian maritime continent (IMC), behaviors of (i) large-scale (Hadley, Walker and monsoon) circulations (including ITCZ), (ii) intraseasonal variations (or cloud super clusters) and (iii) regional-scale circulations (diurnal cycles of cloud generation and movement) are overviewed, and their interactions are discussed from a theoretical viewpoint. Over the surface condition with distribution of both land and sea in IMC, (iii) must be the most dominant phenomena. The activity of (iii) may be highly affected by the distance between the coastline and mountain ridge of each island, and also by the superimposition of a larger-scale flow which makes differences between the windward and lee sides of a mountain ridge. On the other hand, (ii) must be generated by a CISK-like mechanism over the ocean, and the Hadley and monsoon circulations in (i) must be generated by latitudinal and hemispheric inhomogeneities of the solar heating. Both (i) and (ii) may induce the larger-scale flow affecting the activities of (iii). The net effect (cloud latent heating and its induced upward flow) of (iii) over IMC induces the Walker circulation and longitudinal inhomogeneities of Hadley and monsoon circulations in (i). In order to confirm these scenarios, a strategy of observational studies using the station network over IMC will be introduced.

Intraseasonal variability of the Asian summer monsoon in a modestly high resolution general circulation model

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Intraseasonal variability is an important component of the Asian summer monsoon. In addition to the equatorial eastward-moving mode, northward and westward moving modes exist in the northern Indian and norhtwestern Pacific basins on 30-60 day time scales. Recent improvement of the representation of such modes in a modestly high resolution version (T106, 56 vertical levels) of the CCSR/NIES AGCM is reported. The improved resolution (relative to a T42, 20-level version) also help resolve better the Baiu-Meiyu front and frontal disturbances in the East Asian monsoon. Sensitivity to cloud parameterizations in the AGCM and the performance in a model coupled with an eddy-permitting ocean (1/4 x 1/6 degrees, 48 levels) are also reported.

Sensitivity of MJO Predictability and Prediction to GCM and Ocean-Atmosphere Coupling

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This presentation will discuss evidence from observations and modeling studies suggesting that ocean-atmosphere coupling plays a critical role in the evolution and maintenance of the Madden-Julian Oscillation (MJO). Introductory material will include a very brief/basic description of this form of tropical variability as well as a brief enumeration of the extensive interactions it has with other components of the Earth's weather and climate systems. This material will be used to motivate the need for obtaining a clearer understanding of the underlying physical processes associated with the MJO in order to properly represent it in our global climate and weather forecast models. In particular, the discussion will focus on the impacts that the MJO has on near-surface ocean processes, and in turn the manner these processes provide a feedback to the MJO which influences its strength, phase and propagation characteristics. Special emphasis will be placed on the importance that ocean-atmosphere has for forecasting the MJO and the weather/climate components that it interacts with and/or influences. This is likely to include a comparison of predictability analyses of the MJO in both coupled and uncoupled settings.

An Experimental MJO Prediction Program

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Over the past two years, NASA has hosted two workshops focusing on the potential for improving forecasts at lead times from a week to a season. Several sources of unrealized predictability on subseasonal time scales were highlighted, including the Madden-Julian Oscillation (MJO). One recommendation from the workshops was that a website be developed to display and intercompare experimental MJO forecasts. At the same time the US CLIVAR Asian-Australian Monsoon Working Group recommended an experimental MJO prediction program due to the significant influence that it has on the character and evolution of the Asian-Australian monsoons. NOAA's Climate Diagnostics Center agreed to host the MJO website and it was established in late summer 2003.

Initial efforts are geared toward acquiring and displaying forecast grids from a variety of forecast agencies. Both empirical and general circulation model predictions will be updated and displayed in real time. Two regional foci will be on the Pacific-North American extratropics and the Asian-Australian monsoon regions. Future plans include MJO signal extraction, forecast verification and online discussions of the status and forecast of the MJO. The project will allow participants to take advantage of the potential skill in forecasting the MJO, as well as lend a modeling resource to those trying to remedy MJO simulation problems or diagnose interactions between the MJO and other aspects of weather and subseasonal variability.

Different ISO solutions exist in an atmosphere-ocean coupled model and an atmosphere-only model

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A series of small-perturbation experiments has been conducted to demonstrate that an atmosphere-ocean coupled model and an atmosphere-only model produce significantly different intensities of boreal-summer intraseasonal oscillation (BSISO) and phase relationships between convection and underlying SST associated with BSISO. When exact the same initial conditions and SST from the coupled model are used to force the atmosphere-only model, both of them produce identical ISO solutions. Once a small amount of noise is introduced into the initial conditions and SST, the atmosphere-only model generates a considerable different ISO solution from the coupled model though the climatologies between them are almost the same.

The coupled model not only simulates a stronger ISO than the atmosphere-only model, but also generates a realistic phase relationship between intraseasonal convection and underlying SST. In the coupled model, positive (negative) SST fluctuations are highly correlated with more (less) precipitation with a time lead of 10 days as in the observations, suggesting that intraseasonal SST is a result of atmospheric convection, but at the same time, positively feeds back to increase the intensity of the convection. In the atmosphere-only model, however, SST is only a boundary forcing for the atmosphere. The intraseasonal convection in the atmosphere-only model actually is less correlated with underlying SST. The maximum correlation between convection and SST occurs when they are in phase with each other, which is in contrast to the observations. These results indicate that an atmosphere-ocean coupled model produces a more realistic ISO compared to an atmosphere-only model.

Asian Summer Monsoon Intraseasonal Variability in General Circulation Models

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Boreal summer intraseasonal variability over the eastern hemisphere consists of a complex set of interactions involving eastward propagation of equatorial convection with the accompanying Rossby wave response being associated with the poleward spread of convection. The break (active) monsoon over India and the active (break) monsoon over the west Pacific are mutually interactive systems that cannot be addressed in isolation from one another. Using the observational framework established by Annamalai and Sperber (2003), we analyze intraseasonal variability in general circulation models (GCMs). Model data is projected onto the observed modes of intraseasonal variability and linear regression is used to investigate the space-time structure of the boreal summer intraseasonal variability. Near surface data will be analyzed to assess if the models capture the moisture convergence preconditioning that is associated with the propagation of the tropical convergence zone. Where possible, the vertical structure will be evaluated to assess if the models realize the contribution of free-tropospheric process in the life-cycle of the intraseasonal variability. Additionally, the role of air-sea interaction will be investigated by comparing integrations run with observed SST to those in which the same atmospheric model is coupled to an ocean GCM.

Meridional Propagation of the MJO/ISO and Prediction of Off-equatorial Monsoon Variability

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In this study we examine the links between tropical heating, the Madden Julian Oscillation (MJO)/Intraseasonal Oscillation (ISO), and the off-equatorial monsoon development. We examine both observations and idealized "MJO heating" experiments employing the NASA Seasonal-Interannual Prediction Project (NSIPP) atmospheric general circulation model (AGCM). In the simulations, the model is forced by climatological SST and an idealized eastward propagating heating profile that is meant to mimic the canonical heating associated with the MJO in the Indian Ocean and western Pacific.

The observational analysis highlights the strong link between the Indian summer monsoon and the tropical ISO/MJO activity and heating. Here we focus on the potential for skillful predictions of the monsoon on subseasonal time scales associated with the meridional propagation of the ISO/MJO. In particular, we show that the variability of the Indian summer monsoon lags behind the variability of tropical ISO/MJO heating by about 15 days when the tropical heating is around 60E and 90E. This feature of the ISO/MJO is reproduced in the AGCM experiments with the idealized eastward propagating MJO-like heating, suggesting that models with realistic ISO/MJO variability should provide useful skill of monsoon breaks and surges on subseasonal time scales.

Structures and Mechanisms of the Northward Propagating Boreal Summer Intraseasonal Oscillation

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The spatial and temporal structures of the northward-propagating boreal summer intraseasonal oscillation (BSISO) are revealed based on the analysis of both the ECHAM4 model simulation and the NCEP/NCAR reanalysis. The BSISO structure and evolution characteristics simulated by the model bear many similarities to those derived from the NCEP/NCAR reanalysis. The most notable features are remarkable meridional symmetries, relative to the BSISO convection, in the vorticity and specific humidity fields. A positive vorticity perturbation with an equivalent barotropic structure appears a few latitude degrees north of the convection center. The maximum specific humidity also shows a clear northward shift in the lower troposphere.

Two internal atmospheric dynamics mechanisms are proposed to understand the cause of the northward propagation of the BSISO. The first is the vertical shear mechanism. The key process associated with this mechanism is the generation of the barotropic vorticity due to the coupling between the free-atmosphere baroclinic and barotropic modes in the presence of the vertical shear of the mean flow. The induced barotropic vorticity in the free atmosphere further causes a moisture convergence in the planetary boundary layer (PBL), leading to the northward shift of the convective heating. The second mechanism is the moisture-convection feedback mechanism. Two processes contribute to the northward shift of the low-level moisture. One is the moisture advection by the mean southerly in the PBL. Another is the moisture advection by the BSISO wind due to the mean meridional specific humidity gradient. The asymmetric specific humidity further contributes to the northward shift of the convective heating.

A theoretical framework is further constructed to investigate the instability of the northward-propagating BSISO mode and the relative roles of various mechanisms including air-sea interactions. An eigenvalue analysis indicates that the northward propagation of the BSISO is an unstable mode of the summer mean flow in the monsoon region. It has a typical wavelength of 2500 km. While the easterly shear contributes to the northward propagation primarily north of 5oN, the moisture feedback and the air-sea interaction also contribute significantly, particularly in the region near and south of the equator. The internal atmospheric dynamics are essential to cause the northward propagation of the BSISO over the tropical Indian Ocean.

The interannual variability of the intraseasonal variation over the South China Sea

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The convective activity over the South China Sea (SCS: 110E-120E, 10N-20N) has large intraseasonal variability (ISV), and two preferred spectrum band, one between 30 and 60 days, and the other between 10 and 25 days, as suggested by several studies. Meanwhile, the convection over the SCS has also large interannual variability on intraseasonal time scale throughout the boreal summer, as intermediate region between the Southeast Asian monsoon and the western Pacific monsoon. In this study, the interannual variability of these ISV over the SCS from 1979 to present was investigated using the daily and pentad mean NCEP/NCAR reanalysis data, OLR, SST and precipitation data.

The onset date of SCS monsoon (SCSM) were defined and the activity of ISV of two modes after SCSM onset were investigated. It was found that the two modes of ISV activity were related to each other, and also associated with the onset date during first half of monsoon season. If the SCSM onset occurred early as usual, the 30-60days mode was prominent, 10-25days mode was relatively weakening, and it appeared the clear monsoon break in July. In contrast, in the case of delayed onset, the 10-25days mode was conspicuous. Hence, there was negative correlation between the activities of two ISV modes for first half of rainy season. The significant relationships were not found during the latter half.

In seasonal (and monthly) mean field, the active convection area meridionally extend both over the Indian Ocean and the western Pacific in 30-60days mode active year, while that area in 10-25days mode active year zonally extend, especially, toward to the mid-Pacific from the northwestern Pacific. It is suggested that the contribution of ISV activity has large effects to not only the first half of monsoon evolution but also the interannual variability of the seasonal mean field.

Interannual Variations of the Boreal Summer Intraseasonal Oscillation in the Asian-Pacific Region

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A finite-domain wavenumber-frequency analysis was proposed to objectively measure the interannual variability of the boreal summer intraseasonal oscillation (ISO) in the Asian-western Pacific region. The strongest interannual variations of the ISO are found in the off-equatorial western North Pacific (WNP). In summers when El Niño is developing, both the westward and northward propagating waves with periods of 15-40 days and 8-10 days are enhanced in July-October. The northward propagating ISO in the Indian monsoon region, however, has little linkage with El Niño-Southern Oscillation (ENSO).

ENSO affects the northwestward propagating ISO mode in the WNP through changing the mean circulation. During July-October in El Niño developing year, the easterly vertical shears over the tropical western Pacific are considerably increased, which in turn promote development and northwestward emanation of Rossby waves away from the equatorial western-central Pacific, reinforcing the WNP ISO. In the Indian summer monsoon region, the ENSO-induced circulation changes are too weak to significantly modify the strong easterly-sheared monsoon mean circulation. Therefore the northward propagating ISO is insensitive to ENSO.

Unlike the wintertime Madden-Julian Oscillation (MJO), which is uncorrelated with ENSO, the May-Jul MJO is strengthened during El Nino developing years. Why there is a seasonal dependence of the MJO-ENSO relationship and how ENSO directly affects the May-Jul MJO require further investigations.

Dynamics and vertical structure of boreal summer intraseasonal variability

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The boreal summer intraseasonal variability (BSISV) is represented by the co-existence of three modes, poleward propagation of convection over the Indian and tropical west Pacific longitudes and eastward propagation along the equator. The interaction among the three modes has been investigated using observed OLR, NCEP-NCAR reanalysis products, a new diagnostic tool to capture the life-cycle of the BSISV, and solutions from an idealized linear model that identifies the relative impacts of local heating anomalies to the overall flow. In addition, the vertical structure of winds, humidity, divergence and upward motion are examined. The linear regressions and model solutions identify four new findings that are important for the life-cycle of the BSISV. First, the circulation anomalies forced by suppressed convection over the equatorial Indian Ocean precondition the ocean-atmosphere system in the western Indian Ocean and trigger the next active phase of the BSISV. Specifically, the low-level easterly wind anomalies act against the mean flow, warm the sea surface, enhance the convergence and moisture to initiate the convection. Second, the low-level wind anomalies that develop as a Rossby wave response to equatorial convective anomalies influence the active-break phases over tropical west Pacific. In particular, the westerly wind anomalies during suppressed convection extend all the way into the west Pacific to strengthen the monsoon there. Third, due to the rapid development of convection over the tropical west Pacific the westerly wind anomalies in the northern Indian Ocean do not recurve over north India but extends into the west Pacific and initiates break over India. Finally, the north-south heating gradients favor local meridional circulations and free tropospheric convergence rather than surface convergence may be important for the life cycle of the BSISV. The results imply that the convective and circulation anomalies over the entire Asian Summer Monsoon region need to be understood for a realistic simulation of the BSISV in general circulation models.

Coherent Life Cycle of Intraseasonal Convection and Extratropical Circulation during El Nino and La Nina Years

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Coherent life cycle of intraseasonal tropical convection and extratropical circulation has been studied with the NCEP/NCAR Reanalysis data during boreal winters from 1979 to 2000. The intraseasonal time scale of 30-60 day has been chosen as an optimal frequency for the coherent structure.

During El Nino years, tropical intraseasonal variability extends to far eastern Pacific, while it intensifies over the Indian Ocean/western Pacific with weak eastward propagation in La Nina years. In accordance with the tropics, extratropical intraseasonal variability extends zonally in El Nino years, and meridionally in La Nina years. It is found that the eastward propagating intraseasonal tropical convection is coherent with the advection of absolute vorticity by the divergent wind which plays as a bridge to the energy source of Rossby wave over the extratropics.

One of the most prominent El Nino and La Nina year are selected as the representative of El Nino and La Nina to investigate the interaction process for the purpose of excluding the common features among the climate states that have not been extracted by the compositing method.

Diurnal and intraseasonal rainfall variations in a mountainous region of Sumatera, Indonesia

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Rainfall variabilities in a mountainous region of western Sumatera and their association in cloud disturbances were investigated by using dense rainfall observations. The most remarkable characteristic of rainfall variations was the contrast between the coastal and the inland mountainous region. Seasonal variations with southern-hemispheric summer maximum was predominant for the inland rainfall, whereas intraseasonal variations were dominated for the coastal rainfall distribution. Inland rainfall variations are mainly associated with monsoon and local circulation mainly during low-level easterly winds. Coastal rainfall variations were associated with large-scale cloud disturbances over the Indian Ocean accompanying low-level westerly winds. Besides, amplitude of diurnal rainfall variations was larger and peak rainfall time tended to be appeared earlier (early afternoon) at the coastal stations than the inland stations (evening to morning).

We also conducted intensive rawinsonde observation in November 2002 at Bukit Kototabang in mountainous region of western Sumatera. Large-scale cloud disturbances were located in the Indian Ocean, and intraseasonal variations of lower tropospheric zonal wind were observed (easterly to westerly). Coastal rainfall was more abundant in the beginning of westerly wind phase, whereas inland rainfall was continuously observed during observation period. We will present the detailed observational results on the characteristics of diurnal rainfall variations in relation with intraseasonal variations of wind/convection activities at the symposium.

Intraseasonal changes of temperature inversions over Indochina peninsula related to winter monsoonal cold surge

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Using the NCEP/NCAR reanalysis data, we examined the thermodynamic process of the intraseasonal inversions variation from December 1999 to February 2000. The inversion strength in 2-5 km fluctuates dominantly in about 35 days period. This inversion fluctuation was mainly contributed by the temperature change below the inversion. This temperature change was prevailingly brought by the fluctuations of cold surge blowing from Siberia.

Submonthly (7-20-day) Convective Variability over and around the Tibetan Plateau

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Submonthly (7-20-day) convective variability over the Tibetan Plateau and its associated large-scale convections and atmospheric circulations were examined over Eurasia and the adjacent oceans. Analysis was made in the mature phase of the Asian summer monsoon (July-August), in some prominent years (1986, 93, 98) of about 14-day convective fluctuations over the plateau. Some interesting relationships between the midlatitudes and the Asian summer monsoon region were observed.

A notable feature is a clockwise rotation of convection signals centered around 28N, 90E over and around the Tibetan Plateau, including Indochina, the Bay of Bengal and India. Other significant signals also appear around the Philippines and the South China Sea. The southern track of the clockwise rotation is likely to consist of the westward moving monsoon depressions, while the northern track is affected by the midlatitude waves
along the northern periphery of the plateau. Associated with the convective fluctuation over the plateau, there is a well-developed wave train extending from the North Africa to the far-east Asia along the Asian subtropical jet at the upper-level troposphere. The waves show a quasi-stationary behavior having a Rossby wave-like downward wave train of approximately wavenumber 7 scales and a slow eastward phase speed. The waves play an important role for controlling convective fluctuations over the plateau.

During transition phases to active convection over the plateau, an upper-level tough is stablished and deepens to the west of the plateau, while a ridge is strengthened over the plateau. This atmospheric structure forms east-west asymmetric convection anomalies to the west and east of the plateau. Synchronized with the deepening of the trough to the west of the plateau, the westward moving cyclonic anomaly is also enhanced over India between the lower and the middle troposphere. This simultaneous development of the two troughs induces a southerly moist flow toward the plateau ahead of the troughs. The preceding moistening of the lower atmosphere, an increase of precipitation and probably upper-level divergent fields provide a favorable condition for a following active moist convection over the plateau. Possible processes for linking the convection signals between the midlatitude and the Asian monsoon region are also discussed.

Contrast of the 30-60 Day Intraseasonal Oscillation and Its Impact on the East Asian Summer Monsoon during 1997/98 ENSO Cycle

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The 30-60 day ISO exhibits rather different propagation and impact on the East Asian summer monsoon (EASM) in summer of 1997/98, corresponding to the developing and decaying phase of the 1997/98 ENSO. Evidences have suggested that during the summer of 1997, the 30–60 day intraseasonal oscillation (ISO) exhibits as a typical equatorially trapped, eastward propagating convective anomalies in 30–60 day period. During the summer of 1998, however, robust signals of the 30–60 day ISO are found over the Bay of Bengal to the east of the Philippine Sea, and the WNP as well, where the monsoon trough and the subtropical anti-cyclone appears as an anti-clockwise spatially propagation with enhanced and suppressed convective anomalies.

The activity of the South China Sea (SCS) summer monsoon can be alternatively modulated by the enhanced/suppressed convection in 30–60 day period, respectively coming from the tropical Indian Ocean and the Bay of Bengal in 1997 and 98. However, the precipitation in the Yangtze River valley exhibits a rather different response to the influence of the 30-60 day ISO during the ENSO cycle. In summer of 1997, the subtropical anti-cyclone appears as a northeastward movement when the 30-60 day convection propagates into the tropical western Pacific Ocean, which results in the Yangtze River valley suffering a much dry summer. In summer of 1998, however, the monsoon trough and the subtropical anti-cyclone appears as an anti-clockwise spatially propagation over the western North Pacific (WNP) and successively dominates the East Asia, which causes the severe floods over the SCS, southern China, and the Yangtze River valley in 30–60 day period.

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Mechanism of the northward propagating intraseasonal oscillation: Results from a zonally averaged model

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The mechanism of the intraseasonal oscillation (ISO) in the South Asian summer monsoon region is examined with a zonally averaged atmospheric model (2D model). In the 2D model the effects of zonally propagating atmospheric waves is intentionally excluded. The model does specify mean flows. The model contains the lowest baroclinic mode and a barotropic mode, which are coupled by mean state vertical shear. The model atmosphere produces a 15-20 day oscillation, which is characterized by northward propagation of convection in the Northern Hemisphere and reinitiation of convection in the region between 10S and the equator.

The northward propagation in the 2D model is driven by the phase relationship between convection and the barotropic divergence in the free troposphere. The vertical advection of July-mean easterly vertical wind shear by perturbation vertical motion inside the convective regions ($-w' \frac{\partial \overline{u}}{\partial p} > 0$) induces barotropic divergence (convergence) to the north (south) of convection. This barotropic divergence triggers the moisture convergence in the boundary layer to the north of convection and causes the northward propagation of precipitation.

The initiation of convection in the Southern Hemisphere is produced by the barotropic divergence in the free troposphere. When convection is located in the Indian monsoon trough region, producing Hadley-type circulation, the downward advection of anomalous zonal wind momentum by July-mean vertical motion ($-\overline{w} \frac{\partial u'}{\partial p} < 0$) induces free tropospheric barotropic divergence (or boundary layer convergence) south of the equator. Especially, due to the strong July-mean vertical motion ($\overline{w} < 0$) at 10S, the region between 10S and the equator becomes a preferred place for convection to reinitiate.

Since the specific humidity of atmosphere is fixed to the time-mean value in 2D model, the baroclinic mode of the free atmosphere acts to enhance existing convection, and contributes little to the propagation. However, it is speculated that the baroclinic mode, in reality, would affect the northward propagation, especially near the equator.

Multi-model Ensemble Forecast of Intraseasonal Oscillation in Asian Monsoon Region

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The forecast skill of low-frequency variability is usually deteriorated by internal atmospheric variability. Whether the forecast skill of 30-60 day mode associate with East Asia Summer Monsoon can be improved by several multimodel regression methods is explored in this study. These methods are applied to daily OLR derived from six models of AMIP-II (Atmospheric Model Intercomparison Project). All the multimodel ensemble forecasts greatly improved the performance of the individual models in Asian monsoon region. The " superensemble" forecast introduced by Krishnamurti et al (2000) performs best during the training period. During the forecast period, the difference between the forecast skills of these multi-model forecasts is small. However, their improvement may be limited by the atmospheric internal forcing in Asian monsoon region. The multimodel forecasts are only slightly superior to the climatological forecast in Asian monsoon region. The pattern correlation of all models significantly declined from April and reached minimum value in May. The occurrence of this poor performance of model simulation of ISO in May is coincided with the sudden northward change of position of 30-60 day OLR in May. The atmospheric internal dynamics may play an important role on the initiation and development of ISO in May and is less predictable in GCM.