Preface

Regional climate models are useful tools for regional climate research. They are especially helpful for studying the effects of topography, coastlines, and other complex land-surface properties on regional climate and for simulating these effects realistically. Although regional climate modeling started more than ten years ago, improvements in model physics and performance have been slow. There has been some discussion of uncertainties in regional climate model simulations, but little effort has been made to reduce those uncertainties.

To identify problems in regional climate modeling and to enlighten future regional climate model development and application, the International Pacific Research Center (IPRC) at the University of Hawaii, Honolulu, Hawaii, is sponsoring *The First IPRC Regional Climate Modeling Workshop*. The workshop focuses on the following topics: review of status of regional climate models and modeling studies; identification of problems, weaknesses, and uncertainties in regional climate models and modeling approaches; methods to improve regional climate models and model physics in order to improve simulation of different regional scale motions; algorithms used to verify model results and to validate the model physics that use new satellite datasets; and directions of future developments and improvements in regional climate models.

The organizing committee is grateful to Dr. Julian P. McCreary, Director of the International Pacific Research Center, for sponsoring the workshop.

The Organizing Committee,
    Lorenz Magaard, IPRC, University of Hawaii
    Bin Wang, IPRC, University of Hawaii
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Regional Climate Modeling: An Overview

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Regional climate modeling has been demonstrated to be a useful technique for regional climate research, especially for process studies and realistic simulation of those phenomena related to the effects of topography, coastline, and complex land-surface properties. In this talk, an overview on the regional climate modeling approaches will be given, including the current status of regional climate model development, the applications of regional climate models in climate research and in climate change issues; inherent deficiencies and uncertainties in regional climate models and modeling approaches; difficulties in verification of regional climate model simulations and validation of model physics. The opportunities and needs in this area of research will be also discussed, including how the regional climate modeling communities can contribute to the major national and international programs related to climate research, such as CLIVAR; what type of observational data can be used to verify the model simulations and to validate the model physics; what possibilities there are to perform explicit simulation using sophisticated cloud microphysics parameterizations in regional climate models; and whether regional climate models can play a role when high-resolution mesoscale global general circulation models are developed and used routinely in the near future.

SUNYA Modeling Program on Studying Regional Climate over East Asia

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Development of a Highly Resolved Regional Climate Modeling System at IPRC

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Two research themes at the International Pacific Research Center (IPRC), the Asian-Australian monsoon system and the impact of global changes on the Asian-Pacific regional climate, require conscientious modeling efforts using a highly resolved regional climate modeling system. Such a modeling system is expected to be highly resolvable for a wide range of scale interactions and to be able to realistically simulate regional and mesoscale features of the Asian-Australian monsoon system and associated hydrological cycle, such as the Meiyu front, mesovortices and tropical cyclones.

Efforts, therefore, have been made at the IPRC to develop a highly resolved regional climate model. As with most other regional climate models, we started with a mesoscale model, which was originally developed for tropical cyclone research by Y. Wang (1999, 2001). This model was chosen because it is highly resolvable for organized mesoscale motions and has its strength in both turbulence closure scheme and cloud microphysics parameterizations. The sophisticated radiation package developed by Edwards and Slingo (1996) has been implemented into the model. The land surface model BATS (Dickinson et al. 1993) has been coupled with the model. The model has several unique features, including the interactive cloud-radiation interaction, contribution of clouds to the turbulent mixing, interactive surface albedo-radiation feedback, and a diagnostic scheme for cloud fraction that accounts for the effect of both relative humidity and cloud water/ice contents in mixed-ice phase clouds.

The ability of the model to simulate different climate systems will be demonstrated, including an idealized simulation of tropical cyclones, an explicit simulation of the ITCZ, and a four-month simulation of the East Asian summer monsoon in 1998.

Present View on Development
of MRI Regional Climate Models

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At the Meteorological Research Institute (MRI) of Japan, a regional climate modeling group has developed a method by which the locally high-resolution atmospheric model can reproduce the current climate well when both lateral and surface boundary conditions are prescribed with coarse spatial resolution, i.e., several hundred kilometers (Kida et al., 1991; Sasaki et al., 1995; Mabuchi et al., 2000; Sasaki et al., 2000).

This method uses a regional climate model of Japan with a 40-km resolution (RCM40) to simulate the climate around Japan. An East Asian model of 120-km resolution (RCM120) is introduced between the global model and the RCM40 to allow smooth spatial interpolation. Both the RCM120 and RCM40 were originally developed at the Japanese Meteorological Agency (JMA) for operational forecasts. A model very similar to the RCM40, but with a sophisticated biosphere-atmosphere interaction model and a 30-km resolution was tested by replacing the boundary conditions with the analyzed values of coarse resolutions (about 200 km), and the model was run from 1986 to 1991. The agreement between the observed monthly averaged precipitation over Japan and that calculated by the model is satisfactory except in a few cases.

The MRI group has applied the system to the global warming problem, by using the results obtained in the transient CO_2 run with the MRI-CGCM1 to prescribe boundary and surface conditions. In January, the control run with the RCM40 simulates realistic precipitation along the Japan Sea side of the mountain range, which is completely missing in the MRI-CGCM1. In July, precipitation corresponding to the Baiu front is improved substantially in the RCM40 and also in the RCM120. Preliminary results on climate changes for July at the time of CO_2 doubling show substantial reductions in precipitation except in the western part of Japan. To increase our confidence in the results, we have to improve the modelled climate further by improving both spatial resolution and the physical processes of the model.

* Kazuo Mabuchi, Hidetaka Sasaki, Kazuyo Adachi, Izuru Takayabu

Numerical Experiments of Regional Climate Model at NCC

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The regional climate model at NCC (RegCM/NCC) has been developed from the Second-generation Regional Climate Model (RegCM2) of the National Center for Atmospheric Research (NCAR). Our developments and improvements are devoted to the parameterization schemes of the physical processes. On the basis of the simulation experiments and analyses, several new schemes have been planted into the RegCM2, such as the Betts-Miller scheme, the Mass Flux scheme and the CCM3 radiation transfer scheme.

The RegCM/NCC has been used to simulate the 1998 flood in China. The center of the domain is 120°E, 30°N. The horizontal resolution is 60 km. There are 16 vertical layers in the sigma coordinate. The initial and lateral boundary conditions are made from the GAME data. The lateral boundary conditions are updated at 12-hour intervals with the relaxation, exponential technique. SST is updated with the lateral boundary conditions and is interpolated at 12-hour intervals from the observed monthly mean SST of 1°x 1°. The simulation period is April 1–August 31, 1998. The time step is 120 seconds. The domain is the region of East Asia and the West Pacific, 100°E–150 °E,10°N–45°N. The top level in the model is at 100 hPa. There is a 15-layer buffer zone on the sides. The elevation and vegetation data are derived from a global 10-minute data set. There are 18 kinds of vegetation. The research region includes part of the Tibetan Plateau, with the highest elevation being 5200 m. The main vegetation types of the underlying surface in the domain are grassland, tropical and subtropical forest, deciduous forest, coniferous forest, desert, savannah and agricultural land. Two kinds of simulation experiments have been done. The first experiment used only one initial condition, April 1, and the simulation was continually integrated over 5 months. The second experiment used the first day in each month as the initial conditions (April 1, May 1, June 1, July 1 and August 1) and the simulation was integrated over 5 1-month periods. The two experiments simulated the transition of the West Pacific subtropical high and the rain belt, but overestimated precipitation. There are some differences between the two simulations, and a comparison shows that the simulation of experiment 2 is the better one.

Explicit Modeling of Regional Climate in the LSA-East with the Coupled MM5/SSiB Model

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Despite significant progress in climate research, little work has been done to model explicitly the regional climate. Previous studies showed that the realistic simulation of cloud developments depends strongly on land-surface processes interacting with cloud microphysics and larger-scale forcings. In this study, we present the explicit modeling of the predictability of regional climate over the LSA-East at weekly to monthly time scales, using the coupled MM5/SSiB model.

The LSA-East in June 1998 was characterized by the passage of seven cyclones and the development of three mesoscale convective systems (MCSs), causing regional widespread anomalous precipitation with local flood conditions. In this study, the NCEP Eta analysis is used to provide the lateral and initial conditions for the coupled MM5/SSiB model. One-month simulations of the regional variabilities in climate and precipitation are performed using the nonhydrostatic, multi-nested version of MM5. For the finest-mesh domain, we use a grid size of 3 km, state-of-the-art cloud microphysics and detailed land-surface-atmosphere interaction schemes with access to 30-second resolution USGS terrain and vegetation data.

The results demonstrate that the coupled MM5/SSiB model could reproduce reasonably well the daily precipitation and diurnal surface temperature at the LSA-East scale. Most of the weather events during June 1998 are well captured. It is found that the simulated climate variables are sensitive to the grid resolution and model physical processes (e.g., land-surface schemes, convective parameterization schemes and cloud microphysics). In general, the simulations with higher grid resolution are in better agreement with the observations.

At the time of presentation, we will also show the factors that determine the predictability of some weather events. Water and energy budgets will be estimated at different time scales to clarify the relative importance of local evaporation/energy and the horizontal energy transport in the production of clouds/precipitation.

Development of the U.S. Weather Research and Forecast (WRF) Model

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The Weather Research and Forecast (WRF) Model is being developed by a large group of academic researchers and civilian/military forecasting operators in the US. It is intended to provide a common framework for mesoscale atmospheric modeling (horizontal grid 1-10 km) within both communities for the next decade and beyond. The early work has been accomplished primarily by a consortium including:

    NWS National Centers for Environmental Prediction

    Air Force Weather Agency

    National Center for Atmospheric Research

    Forecast Systems Laboratory (NOAA)

    Center for Analysis and Prediction of Storms (Univ. Oklahoma)

The consortium is rapidly expanding as a variety of physics package developers and applications interests are entrained.

The model is being configured with two alternative dynamical cores, both employing a "sigma" style vertical coordinate. *Eulerian*: standard dynamical advection scheme for conserved variables. Fast and slow split time schemes are applied, in which the "fast" sound waves are addressed with short time steps, while slowly changing physics and advection are treated at longer time steps. *Semi-lagrangian, semi-implicit*: a semi-lagrangian version is being developed which allows for longer time steps. The semi-implicit component treats the "fast" sound wave terms implicitly using a fast matrix solver.

A variety of physics packages (e.g., radiation, convective cloud parameterizations, planetary boundary layer, atmospheric surface layer, near-surface ocean layer(s), multiple ground sub-surface layers, sea ice parameterization) are presently being developed by various groups.

The WRF model is undergoing forecast-oriented, real-time testing; case-study simulations; and idealized theoretical testing on a wide spectrum of scales, from 100-meter cold and warm

bubbles to idealized baroclinic instability on a hemisphere. The model is expected to be officially released in a research mode version in Fall 2002; this version will include a nesting capability. "Friendly users" may acquire an unvalidated version now.

Development teams have been established in order to coordinate progress toward a complete model framework on several fronts. Currently these working groups include: software architecture, dynamics and numerics, data assimilation (standard initialization, 3DVAR, 4DVAR), analysis and visualization, testing/validation, ensemble forecasting, atmospheric physics, atmospheric chemistry, land surface models, user/community interests, data handling, operational requirements, and forecaster training.

Discussions have recently begun on the application of WRF to regional climate modeling problems. For example, a regional climate modeling working group is under consideration. Tropical, midlatitude, and polar applications are considered. We report on the status of these discussions.

Asian-Australian Monsoon Variability during the 1997-1998 El Niño Simulated by Eleven AGCMs

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The performance of eleven atmospheric general circulation models in simulating the Asian-Australian Monsoon (A-AM) was assessed for a two-year period covering the 1997/98 El Niño. The assessment focused on precipitation and low-level circulation anomalies in three sub-regions. In spite of a wide spread among individual model solutions, the all-model ensemble robustly reproduces circulation anomalies *over the Australian and western North Pacific-East Asian monsoon regions, yet fails to simulate the Indian monsoon anomalies*. Simulation of rainfall anomaly patterns over the A-AM domain (40E-160E, 30S-30N) is notably poorer than simulation of those over the El Niño region (160E-80W, 30S-30N) with the first EOF mode showing considerable discrepancies due to an erroneous shift of the Indonesian leg of the anomalous Walker circulation.

The models' performance in simulating A-AM rainfall anomalies during boreal summer depends neither on their skill in rainfall climatology nor on their performance in simulating rainfall anomalies over the El Niño region. Their better simulation of El Niño rainfall anomalies does not mean better simulation of those over the Maritime Continent (MC), and their superior simulation over the MC is not indicative of a superior simulation of anomaly patterns over the rest of the A-AM domain. Thus, our results do not support the notion that El Niño affects boreal summer A-AM by changing the Walker circulation. Evidence is presented to show that the local SST anomalies in the warm pool ocean can have a profound impact on the A-AM monsoon rainfall variability. Since the SST anomalies over the monsoon ocean result from local air-sea interaction, uncovering the nature of the monsoon-ocean interaction may be a key to advancing our understanding of monsoon variability.

Monsoonal Climate from ECHAM4.6 and CCM3.6.6 with Different Resolutions and Truncations

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Two atmospheric general circulation models, the ECHAM4.6 and CCM3.6.6, are integrated to study their ability to simulate the monsoonal climate with different horizontal resolutions at wave numbers of 21/30/42/63 and triangle and rhomboid spectral truncations. Each integration has over ten years of output, and the last five-year mean is taken as model climate. The area 60E~150E, 5N~45N is defined as the whole monsoon region (WM), which is divided into three subregions: Indian monsoon (INM), Western North Pacific monsoon (WNPM) and East Asian monsoon (EAM). Time series of area-mean rainfall output shows that all the simulations have an apparent monsoonal seasonal cycle over these subregions. Compared with observational and reanalysis data, patterns of rainfall and other fields show that the INM climate has been reasonably simulated by all model versions while simulations of WNPM are not so good. The EAM simulations are the worst for all integrations. It is also shown that higher horizontal resolution, such as 63, does not seem to be better than lower resolution. Triangular and rhomboidal truncations of CCM3.6.6 show similar results. A change in the land process and convective scheme in ECHAM4.6 at T42 shows a significant improvement in reproducing the maxima rainfall centers over the INM region, which suggests that the climate in this area is more sensitive to physical processes of a GCM. However, such an improvement does not happen over the EAM region. A much higher resolution like the T106 case is needed to verify this conclusion, especially for the EAM climate simulation.

Coupled GCM Simulations

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A coupled atmosphere-ocean GCM was developed at IPRC. The atmospheric component is the ECHAM 4.0 and the oceanic component is MOM 2.0. The atmosphere and ocean interact in such a way that the atmosphere influences the ocean through surface wind stress; surface heat fluxes that include the shortwave and longwave radiation and latent and sensible heat fluxes; and precipitation; the ocean influences the atmosphere through the change in SST. Without any heat flux correction, this coupled GCM reproduces reasonable climatological annual mean and summer low-level winds and precipitation patterns even through the annual mean SST in the warm pool region is underestimated by about 1-1.5°C compared with observations. An ENSO-like interannual oscillation is simulated by the model in the tropical Pacific domain, with two significant power-spectrum peaks at 2.3 and 3.5 years respectively. South Asian monsoon rainfall has a strong biennial (2 to 3 year) variability. The monsoon-ENSO relationship is examined and the results are compared with the observations.

Study on the Formation Mechanism of the Baiu Front Using a Regional Climate Model

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Numerical experiments were conducted to reproduce the Baiu front using a regional climate model. The Baiu front, accompanied by the low-level jet (LLJ), is formed in the experiments using the zonal mean field in early and late June 1998 as the initial and the boundary conditions. The simulated Baiu front has similar structures to the real Baiu front, i.e., the LLJ is located parallel to the precipitation zone and also to the upper level jet in the eastern part of the domain. The numerical experiments fundamentally show that the Baiu front can be formed by the deformation of the zonal mean field due to the sea/land contrast and the topography. Although the amount of rainfall in the Baiu front depends on the cumulus convective parameterizations, the fundamental structure of the Baiu front does not depend on them. In comparison with the zonal mean simulations of early and late June, the Baiu front is formed more northward in late June, when the westerlies are weak and the upper level jet is located relatively far north. The location of the Baiu front is speculated to be quite sensitive to the zonal mean flow. The Baiu front and accompanying LLJ are also represented in numerical experiments without topography, suggesting that the Baiu front could be reproduced by only both the sea/land contrast and the zonal mean field. The orography including the Tibetan plateau intensifies the precipitation in the Baiu front, and its effects are significant when the westerlies are stronger and the upper level jet is located southward. The South Pacific Convergence Zone (SPCZ) also can be simulated in the same way as the simulation of the Baiu front. In contrast to the Baiu front, the SPCZ forms almost independently of land/sea contrast.

An Interactive Cloud Water–Climate Scheme in the SUNYA Regional Climate Model for Studying the East Asia Summer Monsoon

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In their regional climate model (RCM) study of the East Asia summer monsoon, Wang et al. (2000) and Wang and Gong (2000) used *specified* cloud water vertical distribution (independent of seasons and geographical locations) for radiative heating/cooling calculation. Despite the reasonably good simulation of large-scale climate, this treatment nevertheless does not consider interactions between cloud water and climate. This study describes the design of an interactive cloud water–climate scheme and its use in the RCM for simulation of the East Asia summer monsoon. In this scheme, cloud water is generated, depending on the large-scale climate state, either by being prognosed from an explicit microphysical parameterization or diagnosed from an empirical formula relating the cloud water to water vapor. Therefore, this hybrid approach for cloud water considers the interactions among the relevant parameters of cloud microphysics, cloud water, radiative heating/cooling and climate.

Two aspects of the RCM simulations using the interactive cloud water-climate scheme will be discussed. First, the differences between the hybrid and specified schemes with regard to their cloud water characteristics and associated solar and thermal radiation will be illustrated. Second, simulations of the two severe flood events in 1991 and 1998 over East China will be presented and compared with available observations.

Evaluation of the Land Surface Model Implemented into the IPRC-RegCM1

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An advanced land surface model (BATS) has been implemented into a regional climate model (IPRC-RegCM1) recently developed at the International Pacific Research Center (IPRC) of the University of Hawaii. The coupled model has been applied to the 1998 severe flood in China to evaluate several aspects of the model's performance including land surface processes. In the simulation, driving fields from NCEP-NCAR re-analysis data and SST field from Reynolds data were used. The soil moisture fields were initialized such that the initial soil moisture depends on the vegetation and soil type defined for each grid cell. The integration has been performed over a period between April 28 and August 31. The results were then compared with both the driving fields and the station data available for that period. The preliminary evaluation showed that BATS adequately defines the boundary processes at the land-atmosphere interface across China, although a cold bias of 1–2°C in surface air temperature and a dry bias in surface relative humidity were observed over a portion of the simulation period. The reasons for this are not yet known but some possibilities will be discussed.

Verification of the Climatic Features of a Regional Climate Model with BAIM

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Verification of local climatic features produced by a regional climate model (JSM-BAIM), which incorporates the Biosphere-Atmosphere Interaction Model (BAIM) in the Japan Spectral Model (JSM), was performed. The data used in the verification were the results of a 6-year integration calculated by the JSM-BAIM. In the time integration of the JSM-BAIM, the spectral boundary coupling (SBC) method was used. The ability of the model to reproduce horizontal distribution features and local and seasonal changes in the principal climatic elements was investigated using a finer scale than that used by Mabuchi et al. (2000).

Comparisons of the model results with the Japan Meteorological Agency's (JMA's) objective analysis data were performed with respect to geopotential heights, temperatures, and winds at the 850 hPa and 500 hPa levels. Statistically significant differences appeared mainly in the summer temperature field and in the winter wind field. The statistically significant differences in the summer temperature field are thought to be due to the effects of land surface processes and the summer convective processes over the southern ocean. The statistically significant differences in the winter wind field are thought to result from differences between the topography in the regional model and that of the analysis data.

Comparisons of the model results with the observations from a very dense observation network, the "AMeDAS" (the JMA's automated surface meteorological observation system with about 17 km resolution), were performed with respect to precipitation, surface air temperature, and radiation at the land surface over the typical four climate areas of the Japanese Islands. The model reproduced reasonably well the features of the seasonal and interannual observed variations for each area. There were, however, some differences in seasonal and regional features between the model results and the AMeDAS data.

Using the spectral boundary coupling (SBC) method for the long time integration, the JSM-BAIM was sufficiently accurate to investigate the interaction between the terrestrial ecosystems and climate with regard to seasonal and interannual variations, and with regard to the climatic classification of the Japanese Islands. There remains, however, the need for further verification with the observational data, especially the results concerning the near-land surface temperature over the natural vegetation environment and the atmospheric data over the ocean.

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Numerical Simulations of Summer Trade-Wind Weather over the Island of Hawaii

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The largest island in the Hawaiian chain, Hawaii, is dominated by two volcanic mountains exceeding 4 km in elevation, well above the typical height of the trade-wind inversion (~ 2.2 km). The island's horizontal dimension is about ~ 140 km. In the summer months, the nearly continuous exposure to easterly trade winds (5-10 m s^{-1}) makes the island ideal for studying airflow and precipitation patterns due to the effects of orographic lifting, dynamic blocking, and thermally driven circulations.

Initialized by the composite upstream sounding during HaRP (Hawaiian Rain Band Project 11 July–24 August 1990), high-resolution numerical experiments are conducted using PSU/NCAR MM5 to study the island-scale airflow and weather. Without considering the diurnal heating cycle, the orographic clouds on the windward slopes, flow deceleration and splitting on the windward side, lee-side vortices, and cool and moist (warm and dry) conditions on the windward (lee) side are well simulated. In addition to Fr (Froude number), the simulated island airflow and clouds are sensitive to net diabatic heating associated with clouds, precipitation, and rain evaporative cooling. The orographic clouds in the high-inversion days and the coastal band clouds in the low-inversion days are simulated in the model with the same Fr upstream. It is apparent that in addition to Fr, accurate representation of trade-wind inversion height, the moisture profile upstream, and convective feedback effects in the model is crucial for the simulation of island airflow and trade-wind weather over the Hawaiian islands.

We also simulate the evolution of island airflow and weather over the island of Hawaii at night. The model has successfully simulated the major observed features associated with the nocturnal flow regime. Furthermore, rain evaporative cooling also affects the depth, strength, and offshore extension of the simulated katabatic flow. In the early evening, the nocturnal cooling provides the land-sea thermal contrasts for the development of the simulated downslope flow on the windward slopes. In the evening, with continued nocturnal cooling and rain evaporation, the simulated katabatic flow extends toward the coast. The simulated convergence zone and overall cloudy areas also move seaward and reach the Hilo coast around midnight. Throughout the night, the simulated offshore flow deepens and extends farther over the ocean. In the early morning,

clouds frequently form within the offshore convergence zone and move westward in the model. They weaken over the deep (~ 300 m) offshore flow before reaching the coast.

In the model, the nocturnal cooling not only affects the near surface airflow over the slope surface and coastal areas, but also the airflow aloft and upstream. The simulated low-level flow deceleration is most significant in the early morning. At that time, the simulated offshore flow has the largest horizontal extent (~ 20 km) with a maximum depth.

Far-Field Effects of Hawaiian Islands:
Observations and MM5 Simulations

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The Hawaiian Islands, with a maximum elevation of 4,201 m, are a significant barrier for the trade winds. A wind wake forms and extends for a distance of 3,000 km downstream, making it the longest wake ever observed (Xie et al. 2001, *Science,* **292**, 2057). It is puzzling that this Hawaiian wake is many times longer than the theoretical upper limit for wake length (~ 500 km). This leads us to believe that other physical mechanisms are involved in maintaining this extraordinarily long wake.

Satellite wind measurements show the wind wakes induced by individual islands as well as a broader wake further downstream. Tropical Rain Measuring Mission (TRMM) data further reveal a cloud band in the wind wake that extends beyond the international dateline and is collocated with a band of high sea surface temperature (SST). This warm SST band is due to the advection of warmer water from the west by an eastward ocean current, which is in turn driven by the wind wake west of Hawaii. Thus, the long Hawaiian wake, along with the ocean currents and SST, should be viewed as the coupled ocean-atmospheric response to the barrier effect of high mountains on Hawaii.

Here we test the atmospheric aspect of the above hypothesis. To this end, we use the MM5 to investigate the response of the Hawaiian wake to SST perturbations. The domain was set to a single grid (145 x 75 x 36 grid points at 21-km horizontal spacing) centered at 161 W and 21 N (slightly west of Hawaii). The following parameterization schemes were used: full microphysics (Goddard), Kain-Fritsch cumulus parameterization, MRF (Hong-Pan) PBL scheme, and a 5-layer soil model. The NCEP reanalysis is used both as the initial and lateral boundary conditions. Starting on 1 August 1999, the model was integrated for 30 days and the output from the last 27 days was used for the analyses. The model maintains a trade inversion around 800 mb, an observed feature that we believe is important for the atmospheric response to both orographic and SST forcing.

Two simulations were completed: a control run with TRMM-based SST and a second run with a dipole band of SST anomalies (1°C) added. The MM5 simulated surface wind field compares reasonably well wit the QuikSCAT measurements. The model also captures the return

lee-flow and hydraulic jumps associated with the wake. The comparison of the control and perturbed-SST runs shows clear effects of the banded SST structure. The warm SST enhances near-surface wind convergence, leading to increased cloudiness (via stronger vertical motion). Compared to the control run, the wake in the perturbed case extends further downwind, consistent observations. It is noteworthy, however, that the maximum increase in cloudiness is not located directly over the maximum SST anomaly but is noticeably shifted in the direction of the cold SST band to the south, presumably indicative of SST gradient forcing.

Abstracts

Submitted by Scientists

Who Could not Attend the

First IPRC-Regional Climate Modeling

Workshop

Regional Climate Model Inter-Comparison Project for Asia

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To improve the hierarchical integration of global and regional climate models that focus on the simulation of climate variability, regional climate changes and extreme events have been listed as high priority areas for further action in climatic change study (IPCC 2001).

In recent years, an increasing number of research groups is developing or using different regional climate models (RCMs) to simulate the regional climate change in Asia. Some studies have demonstrated that RCMs can reproduce the seasonal evolution of monsoon rain-belts over Asia, which is not often captured by GCMs. However a more systematic analysis of RCM performance in Asia and a study comparing the capacity of various RCMs in simulating the regional climate of Asia and comparing RCM with GCM simulations will be of great benefit for the further improvement of the RCMs for Asia.

This presentation introduces briefly the Regional Climate Model Inter–Comparison Project (RMIP) for Asia, a joint effort of the Asia-Pacific Network for Global Change Research (APN), the Global Change System for Analysis, Research and Training (START), the Chinese Academy of Sciences (CAS), and other national projects. The project is a collaboration of 10 research groups from Australia, China, Japan, S. Korea and United States, and involves also scientists from India, Italy, Mongolia, North Korea, and Russia.

The designated tasks include three phases to be implemented in four years beginning with the Year 2000.

Phase	Simulation periods	Inter-comparison topics	Implementation years
Phase one	18 months	Full annual cycle and two extreme cases	2000-2001
Phase two	10 years	Statistical behavior	2001-2003
Phase three	scenarios	Projection for the 21st century	2003-2004

The preliminary results of Phase One will be introduced in the presentation.

Abrupt Changes during the First Transition of the Asian Summer Monsoon: A Challenge for Regional Climate Simulation

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Climatologically, the Asian summer monsoon goes through two major transitions. The first one occurs in mid-May and marks the onset of the East Asian summer monsoon. This study investigates the characteristics of large-scale circulation during the first transition by a compositing technique, using ECMWF analysis, ISCCP data, and NCEP reanalysis data. The major changes in circulation are the sudden development of the low-level cyclonic circulation in South Asia and the convection in the Bay of Bengal, the Indochina Peninsula and the South China Sea.

The sea surface temperature in the Bay of Bengal continues to rise before the first transition and drops quickly afterward. Before the first transition, low surface wind, sparse cloud cover, and small optical thickness characterize the atmospheric conditions in the Bay of Bengal. Such conditions favor the rising of the sea surface temperature through increasing shortwave radiation and low latent heat flux. During and after the transition, strong low-level winds and convection result in the drop of sea surface temperature by decreasing shortwave radiation and increasing latent heat flux.

Before the first transition, the Indochina Peninsula is the only place, between 5°N and 25°N in South and Southeast Asia, where upward surface energy flux and column-integrated diabatic heating occur, while downward energy flux and diabatic cooling occur in other regions. The 'hot' mountain surface of the Indochina Peninsula seems to play an important role in initiating the first transition.

The abrupt changes in the atmospheric circulation during the first transition are affected, at least partially, by the ocean-atmosphere-land interaction. Since the onset of the East Asian summer monsoon is highly related to the first transition described above, it seems important for a regional model to take into account the effect of the large-scale circulation and the ocean-atmosphere-land interaction.

Simulation of Onset of the
1998 East Asian Summer Monsoon

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The Purdue Regional Model (PRM) is used at the Department of Atmospheric Sciences, National Taiwan University for regional climate simulation study. The PRM is a hydrostatic model based on conservation of mass, heat, and momentum with comprehensive physics in radiation, turbulence, and precipitation processes. It has been successfully applied to study the 1988 drought and 1998 flood in the USA. The recent attempt is using the model to simulate the onset of the 1998 East Asian summer monsoon. In this particular simulation, the ECMWF advanced data with 0.5 degree by 0.5 degree resolution were used as the lateral boundary condition. The model resolution is 60 Km and the model domain is from 80°E to 150°E and from 10°S to 50°N. The integration was carried out from 1 May to 30 June. The preliminary results indicate the model's ability to simulate the overall evolution of the event. Several problems were also identified and will be presented.

The Development of a Climate System Model at LASG

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In the State Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences (CAS), the development of the first coarse resolution CGCMs was initiated in the early 1990s. The first global CGCM was developed based on the IAP two-layer AGCM and the IAP four-layer OGCM in 1992. The model was integrated for forty years and showed some ENSO-like interannual variability dominated by a westward propagating coupled mode. In 1994, a twenty-layer OGCM (including a thermodynamic sea ice model) was developed and coupled with the two-layer AGCM to simulate the enhanced greenhouse effect. From 1995 to 1998, a preliminary global ocean-atmosphere-land system (GOALS) model was presented and continually improved. The model consists of the twenty-layer OGCM and a nine-layer spectral AGCM, which is a version of the nine-level spectral AGCM with a rhomboidal truncated wave number of 15 originally introduced from Simmonds (1995) and reconstructed by G. Wu. The K-distribution radiation scheme of G. Shi and the simplified simple biosphere (SSiB) model of Y. Xu. were successfully adapted to the AGCM. In September of 1997, the model became one of the nineteen CGCMs developed by fifteen institutions around the world, joining the Coupled Model Intercomparison Project (CMIP).

In 1999, we decided to advance climate system modeling at LASG through collaboration. The goal was to set up a climate system model that needs no flux correction, is flexible, and any component is easily replaced. The National Center for Atmospheric Research (NCAR) Climate System Model has been widely used in climate studies. The component models in NCAR CSM communicate through a flux coupler, which controls the time coordination of the integration and calculates most of the fluxes at the interface of the model components. Although no flux correction is applied to momentum, heat and fresh water fluxes, the model does not show any significant climate drift in a 300-year-integration. The first stage, therefore, was to set up a preliminary flexible climate system model at LASG that is based on NCAR CSM but in which the oceanic component model of NCAR CSM is replaced with the IAP thirty-layer OGCM. From this, the basic version of the LASG flexible coupled general circulation model (FGCM-0) was developed. The FGCM-0 has been integrated 60 years successfully. Although the flux correction is not employed in the coupled model FGCM-0, the model shows no obvious climate drift. The model shows not only a reasonable long-term mean climatology, but also reproduces many features of the

interannual variability of climate, e.g., it simulates the ENSO-like events in the tropical Pacific Ocean and the dipole mode pattern in the tropical Indian Ocean. Comparing FGCM-0 with the NCAR CSM-1, some common features are found, e.g., the overestimation of sea ice in the North Pacific and the simulated double ITCZ etc. The FGCM will be continually developed with major emphasis on the atmospheric component.

Design of a High-Resolution, Adiabatic Model
of Atmospheric Dynamics

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A model of atmospheric dynamics is a necessary tool for climatic studies and weather predictions. The model framework is the basic part of a model. Although the model resolution and the description of the model physics have been improved greatly following the rapid development of the computer technique, the available models can not yet meet the requirements of further studies on climatic problems and weather problems. Thus, to design higher-resolution models becomes an urgent task in the field of numerical simulation of atmospheric problems. Increased model resolution, however, may cause the exponentially increased high-frequency effects in the Polar Regions, and the computational stability of the model may not be ensured, because the poles are the singular points of a global model of atmospheric dynamics. For example, when the model resolution is set to be $0.5^0 \times 0.5^0$, the grid size at the equator is about 55 km, but the size at the zones closest to the poles are less than 0.5 km. It is found that the ratio of the two grid sizes is more than 100. If the model resolution is improved to be $0.1^0 \times 0.1^0$, the two grid sizes will be respectively 11 km and 0.02 km, and their ratio will be more than 500. Obviously, the difference between the two grid sizes at the equator and the zones closest to the poles will become bigger and bigger, with increased model resolution. It is difficult to find a general-use numerical method which can be efficient and computationally stable for solutions in both the equator regions and the polar regions. Therefore, finding an efficient scheme to design high-resolution models of atmospheric dynamics is becoming more and more important.

In this paper, a careful study on the integral properties of the primitive equation system of baroclinic atmosphere is carried out, and a new scheme to design the global adiabatic model of atmospheric dynamics is put forward. This scheme includes a technique of equal-area mesh generation and a new numerical method for solving the primitive equation system. By using this scheme, we established a model framework with adjustable high resolution acceptable to the available computer capability, which is stable without any filtering and smoothing. On the SGI Origin 3000 computer system with 16 processors, the framework with a horizontal resolution 0.2 x 0.2 runs successfully. A numerical test of the framework is included in the paper. And finally, it is applied in an atmospheric general circulation model (AGCM). The results show that this framework can improve simulation of East Asian climate.

Numerical Experiments on the Effects of a Topographic Buffer Zone in the Lateral Boundary of a Regional Climate Model[1]

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It is well known that regional climate modeling is generally conducted with a meso-scale model driven by large-scale observation or GCM assimilation output, the latter affecting regional circulation by providing boundary condition consecutively. To avoid the inconsistency in the lateral boundary area between large-scale driven fields and high-resolution circulation induced by local forcings, a lateral boundary buffer zone for the atmosphere is commonly set up. In the buffer zone, the large-scale driving fields are blended with the regional high-resolution circulation generated by internal physics. But the topography in the buffer zone is generally the mesoscale one, which is usually interpolated from a latitude-longitude global terrain data set with high resolution, and the blended circulation is not always consistent with the mesoscale topography. This idea provides the motivation for experiments with blended topography in the buffer zone (referred as topographic buffer zone, TBZ).

In this paper, the effects of TBZ on regional circulation are investigated with the Regional Integrated Environmental Model System (RIEMS), developed by START Regional Center for Temperate East Asia (START TEA-RC). The framework of the model system is based on the mesoscale model MM5 (V2) that incorporates the Biosphere-Atmosphere Transfer Scheme (BATs) and has some modifications in the radiative transfer scheme. For all simulation experiments, the model uses a Mercator projection, with a domain of 5400 km × 5400 km centered over China, a horizontal grid-point spacing of 60 km, and a ten-grid-point-wide buffer zone. The western boundary of the model domain is located on the Tibetan plateau, where the difference between large-scale topography associated with driving fields and the mesoscale topography is significant. Three experiments were performed, the control run and two comparison runs, one with linear and one with exponential blending topography in the TBZ. The period of simulation is from June 1

through August 31, 1998, that is, three months during the severe flooding in central and northeast China.

The rmse of zonal wind averaged meridionally at 200, 500 and 850 hPa as a function of grid-point is smaller when the linear and exponential TBZ is used than in the control run, especially in the western buffer zone. From west to east, the rmse increases gradually for the simulations with and without TBZ; it remains stable in the interior of the domain when the large-scale forcing and internal physics have approximately the same effects; the rmse is almost the same for the eastern boundary where the model domain is over the ocean. The rmse of 3.49m/s, 3.29m/s, and 3.44m/s at 200 hPa for the control, the linear and the exponential TBZ runs, respectively, show clearly that the TBZ is useful in regional climate modeling; the corresponding rmse at 500 hPa and 850 hPa are 3.31 m/s, 3.08 m/s and 3.23m/s; and 5.25 m/s, 5.05 m/s and 5.11 m/s, respectively. The rmse and their relative percentages compared with the control run for zonal wind, temperature and relative humidity are shown in table 1.

From the time-evolution of mesoscale kinetic energy, we can see that the mesoscale systems induced by the model physics are still maintained when the TBZ is set, for the characteristics of the time-evolution are almost the same with and without TBZ. But the total averaged ones with TBZ are less than that without TBZ, which suggests that the model integration is more stable with TBZ The spin-up time is also different at lower, middle and upper levels, namely, about 5 days at upper levels, and 8-9 days at lower and middle levels.

Table 1 rmse and their relative percentage against control run[*]

	Pressure level	NTBZ	LTBZ	ETBZ
rmse (u) (m/s)	200 hPa	3.49	3.29 (-5.7%)	3.44 (-1.4%)
	500 hPa	3.31	3.08 (-6.9%)	3.23 (-2.4%)
	850 hPa	5.25	5.05 (-3.0%)	5.11 (-2.7%)
rmse (T) (^{0}K)	200 hPa	1.81	1.62 (-10.5%)	1.68 (-7.2%)
	500 hPa	1.12	1.00 (-10.7%)	1.04 (-7.1%)
	850 hPa	2.68	2.41 (-10.1%)	2.45 (-8.6%)
rmse (rh) (%)	200 hPa	9.05	8.81 (-2.7%)	8.65 (-4.4%)
	500 hPa	13.37	12.81 (-4.2%)	12.60 (-5.3%)
	850 hPa	12.11	11.80 (-2.6%)	11.36 (-6.2%)

* Where NTBZ , LTBZ, and ETBZ means without TBZ, linear TBZ and exponential TBZ, respectively