ADVANCES IN ATMOSPHERIC SCIENCES, VOL. 25, NO. 6, 2008, 999–1008

Notes of Numerical Simulation of Summer Rainfall in China with a Regional Climate Model REMO

CUI Xuefeng*[1,2] (崔雪锋), HUANG Gang[2] (黄 刚), and CHEN Wen[2] (陈 文)

[1]*Department of Geography, University of Liverpool, UK*

[2]*Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing* 100029

(Received 16 May 2007; revised 29 February 2008)

ABSTRACT

Regional climate models are major tools for regional climate simulation and their output are mostly used for climate impact studies. Notes are reported from a series of numerical simulations of summer rainfall in China with a regional climate model. Domain sizes and running modes are major foci. The results reveal that the model in forecast mode driven by "perfect" boundaries could reasonably represent the inter-annual differences: heavy rainfall along the Yangtze River in 1998 and dry conditions in 1997. Model simulation in climate mode differs to a greater extent from observation than that in forecast mode. This may be due to the fact that in climate mode it departs further from the driving fields and relies more on internal model dynamical processes. A smaller domain in climate mode outperforms a larger one. Further development of model parameterizations including dynamic vegetation are encouraged in future studies.

Key words: regional climate model REMO, summer rainfall in China, running mode, domain choice

Citation: Cui, X. F., G. Huang, and W. Chen, 2008: Notes of numerical simulation of summer rainfall in China with a regional climate model REMO. *Adv. Atmos. Sci.*, **25**(6), 999–1008, doi: 10.1007/s00376-008-0999-z.

1. Introduction

Summer rainfall in China, characterized by the East Asian monsoon (e.g., Webster et al., 1998), is known for its identical narrow meridional scale organized meso-scale convective systems (Chen et al., 1998). It accounts for a large portion of the annual total precipitation and is mainly produced by the subtropical front (mei-yu front in Chinese). The variability of summer rainfall may have large impacts on water-related disasters in China threatening the society, economy, agriculture and the environment. For example, there were 12 severe droughts that occurred in at least one of the major river basins in China during 1949–95 (King et al., 2001, Wang et al., 2002). In the last decade alone, three devastating floods occurred in 1991, 1998, and 1999 along the Yangtze River valley and northeastern China and sustained droughts occurred in 1997, 1999, and 2000 over North China. The catastrophic flood of 1998 in China was estimated to have caused direct economic losses in excess of US $ 23 billion. Global warming is very likely to have a major impact on the hydrological cycle and consequently on available water resources, the potential for floods and droughts, and agricultural productivity (IPCC, 2001).

Therefore, understanding the rainfall variations and changes under global warming, and possible prediction, is a major requisite for China, one of the most densely populated regions and one of the fastest developing economic areas. However, the variability of climate over East Asia is particularly complex and hard to predict correctly for the long-range since it is affected by SSTs over the tropical central-eastern Pacific. These SSTs are associated with ENSO, the western Pacific warm pool, the dynamical and thermal effects of the Tibetan Plateau (TP), the snow cover and soil moisture over the Eurasian continent and so on (e.g., Huang et al., 2003). Given the idea that realistic summer rainfall simulation is a big challenge for GCMs (King et al., 2001), one of the significant advancements in the last decade has been the application of regional climate models (RCMs) for the study of the

*Corresponding author: CUI Xuefeng, x.cui@liv.ac.uk

East Asian monsoon system (Leung et al., 2003). Climate impact studies are normally based on the output from RCMs since it can provide more realistic signals for temperature and precipitation than driven GCMs, especially in regions such as China with strong mesoscale forcings such as orography, lakes, and land surface heterogeneity (Leung et al., 2004).

Great attempts have been made among the Chinese and international climate communities to improve the simulation of summer rainfall in China. The Monsoon Asia Integrated Regional Study (MAIRS; www.mairs-essp.org) is an example of this. However, a lot of issues are still unclear due to the complexity of the rainfall-produced processes and model uncertainties. The overall goal of this study is to report our findings from a series of experiments performed with a regional climate model. This includes the sensitivities of the model to domain choices, running mode, boundaries and surface conditions. Section 2 will briefly introduce the model and experimental setups. The validation dataset is given in section 3. We discuss the model results and comparisons with observations in section 4. Finally, a brief summary is given in section 5.

2. Model and experimental setups

The hydrostatic regional climate model REMO (version 5.0) was developed at the Max Planck Institute for Meteorology in Hamburg (Jacob and Podzun, 1997). The set of physical parameterizations adapted from the GCM ECHAM-4 (Roeckner et al., 1996) are applied and evaluated in this study, which has been applied in several areas throughout the world and is suitable for grid scales from 100 to 10 km. The finite difference equations are solved on an Arakawa-C grid within a terrain-following the hybrid coordinate system (σ-coordinates near the surface transforming gradually into pressure coordinates). Leap-frog time-stepping with semi-implicit correction and an Asselin-filter are used. Radiation is calculated with a two-stream approximation which divides the spectrum into two short-wave bands and six long-wave bands. The parameterization of clouds and precipitation is distinguished between grid scale (Roeckner et al., 1996) and convective characteristics. For more details of the model, please refer to: http://www.mpimet.mpg.de/en/wissenschaft/ueberblick/atmosphaere-im-erdsystem/regionale-klimamodellierung.html

One of the purposes of developing regional climate models is to simulate and analyze regional-scale anomalous climate variations such as dry or wet years, which have highly hydrological impacts on agriculture, water resource management and natural disaster assessment. Three case studies are chosen in this study including 1996 (normal year), 1997 (dry year), and 1998 (wet year). The details of the three cases will be discussed later when analyzing the model results in section 4. Atmospheric initial and boundary conditions were extracted from the analysis produced by the European Centre for Medium Range Weather Forecast (ECMWF) reanalysis (ERA, Gilbson et al., 1997). During the model runs, the 6-hourly data are linearly interpolated in time. Generally, the prognostic variables in REMO are adjusted to the external forcing within a relaxation zone of 8 grid points at the lateral boundaries. The model can be operated in a "climate mode" or a "forecast mode". In "climate mode", initial and boundary conditions are obtained from driving data. During the whole integration, only at lateral boundaries, is the model nudged by large-scale information. "Forecast mode" means that the results of consecutive short-range weather forecast (30 hours used here) are used to analyze a time span on the order of weeks. More discussion will be provided in section 4. Table 1 lists the detailed information of these experiments and Fig. 1 shows the different domains.

3. Validation dataset

A special gauge-based, daily precipitation dataset over East Asia developed by Xie et al. (2007) is employed in this study (hereafter, named as Xie). The dataset covers a 26-year period from 1978 to 2003 with a 0.5° lat/lon grid. Three individual data sets are used to construct the gauge-based analyses over East Asia. These are the Global Telecommunication System (GTS) daily summary files archived by the NOAA Climate Prediction Center (CPC) for a period from 1977 to the present, a collection of Chinese daily observations (CHN) at over 700 stations for a period from 1971 to the present, and the daily gauge data at over ~1000 hydrological station from the Chinese Yellow River Commission (YRC) for a period from the 1930s to the present. Combined, observations of daily precipitation at over 3000 stations are available over the target domain of this dataset (5°–60°N, 65°–145°E) (Xie et al., 2007). The analysis is capable of representing precipitation variations with good quality over most of the regions and its quality depends primarily on the gauge-network density. Gauge coverage is available over most of the land areas of the East Asia domain, while network density is very high along the Yellow River, making it possible to create a high resolution precipitation analysis with reliable quality over this region.

4. Results

The model behavior, with realistic forcing, should,

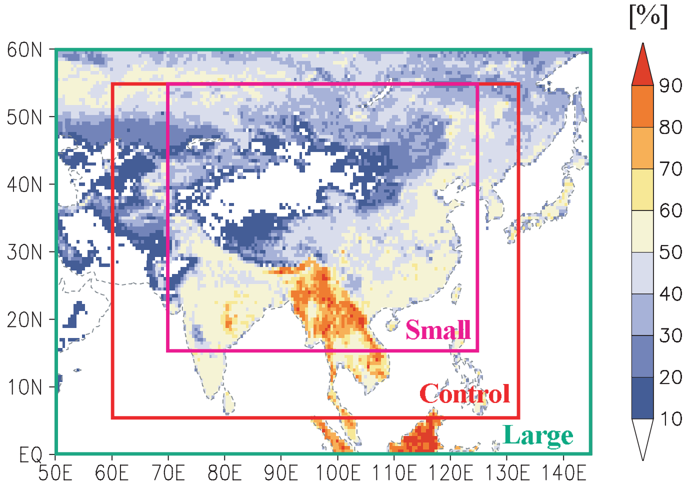

Fig. 1. Three types of domain choice (control: red; larger: green; and smaller: purple). Shaded are fractional vegetation used in REMO with 0.5 degree horizontal resolution obtained from AVHRR (U.S. Geological Survey, 2002).

Table 1. Information of experiments analyzed. "F" represents forecast mode while "C" for climate mode; "CL" stands for climate mode with larger domain, while "CS" for smaller domain.

	REMO-F96	REMO-F97	REMO-F98	REMO-C	REMO-CL	REMO-CS
Grids	0.5° × 0.5° (55 km×55 km)					
Domain	Control (C)				Large (L)	Small (S)
Points	145 × 101				193 × 121	109 × 81
Area	5.5°–55.5°N, 60.5°–132.5°E				0–60°N, 50.5°–146.5°E	15.5°–55.5°N, 70°–124°E
Integration	1 April–31 Oct 1996	1 April–31 Oct 1997	1 April–31 Oct 1998	1 April 1996–31 Oct 1998	1 April 1996–31 Oct 1998	1 April 1996–31 Oct 1998
Mode	Forecast	Forecast	Forecast	Climate	Climate	Climate

ideally, ideally, be close to the real atmosphere if the model is perfect. However, this is never the case in reality. Differences between model experiments driven by analyses and observations could disclose the model biases primarily caused by the internal model dynamics and physics. As discussed earlier, rainfall is one of the most important parameters for impact studies and therefore will be focused on in this section.

4.1 *Climate anomalies*

During summer, a large amount of moisture is transported into the East Asian region by three circulation systems (e.g., Liu et al., 1996). On the eastern boundary the Pacific subtropical high induced anticyclonic circulation that brought moisture in from the southern rim but transported moisture out from the northern rim of the pressure system. As a result, the net moisture transport from the eastern boundary is relatively low. On the southern boundary, a cross-equatorial current was bringing moisture into the domain. The major moisture source, however, came from the Indian westerly monsoonal airflow, which turns northwestward around the southern tip of the Tibetan Plateau and is then joined by the southerly flow. Since atmospheric moisture transport is an important source of moisture during summer in East Asia, large-scale circulation systems will have important influence on the summer rainfall pattern and amount. In this section, we will discuss the results of REMO simulations in forecast mode (REMO-F96, REMO-F97, and REMO-F98 in Table 1) under three different driving systems represented by three different years.

4.1.1 *Wet year 1998*

It is difficult to validate precipitation over the oceans due to lack of observed data, thus it is not addressed in this study. Shown in Fig. 2c, several local rainfall centers can be identified in this region. One of them is located in the Yangtze River valley with maximum of up to 1300 mm, which is what caused

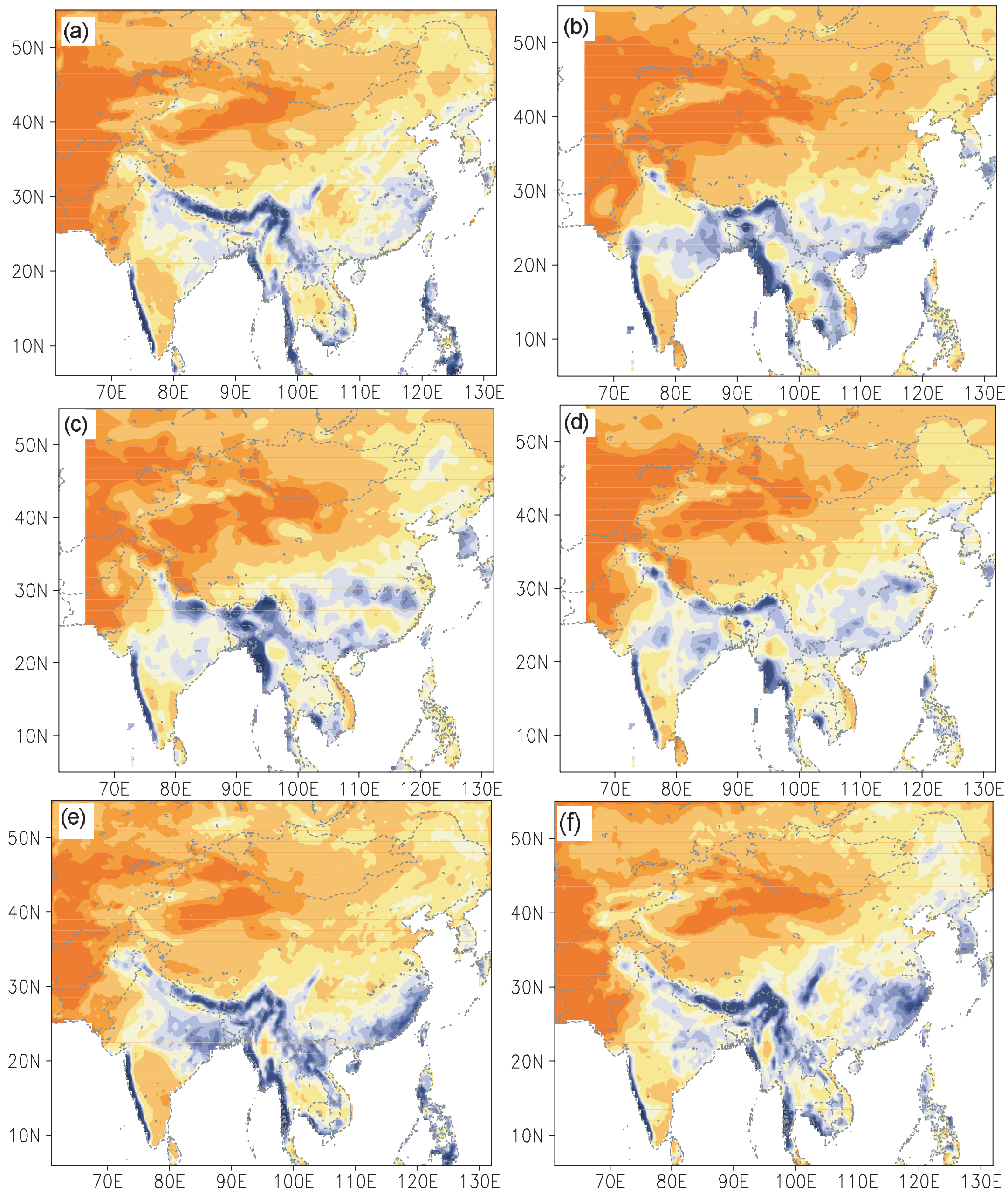

Fig. 2. Comparison of accumulated summer (JJA) rainfall between observations (left) and model output (right) in 1996 (top), 1997 (middle), and 1998 (bottom). The white column at the western boundary in left panel represents the region where no data is available.

the catastrophic flood in the summer of 1998 leading to massive economic loss. However, unlike the observed precipitation, the rain-band simulated by REMO is stronger near the coast than inland (Fig. 2f). The model simulates large amounts of precipitation throughout almost all of the coastal regions of southeast China. REMO reproduces reasonably the location and magnitude of the second rainfall center which is located over the south part of the Tibetan Plateau and extends to the northeast Indian and the Indo-China Peninsula. However, there are still some local differences. For example, there is less precipitation in southern China while heavier precipitation falls over the south-central part of China. Rainfall also appears over the northern part of the Himalayas in model. REMO reproduces the local observed center over south of the Korean Peninsula and a small part of Japan. In the northern part of China, the relatively dry region, REMO produces more rainfall than the observed in both the northwest and northeast parts. In general, REMO captured the approximate location and strength of the mei-yu rainbelt in this wet year.

4.1.2 *Dry year 1997*

The characteristics of rainfall in 1997 are largely different from that of 1998. As shown from Fig. 2b, the heavy rain-band is located further south than that in 1998 (Fig. 2c), stretching from the south of the Tibetan Plateau and extending continuously to East Asia, including the coastal region of south China and to the south of Korea and Japan. Compared to the observation, REMO represents higher precipitation not only in the coast region, but also in most parts of East China (Fig. 2e). In general, REMO reproduces the relatively reasonable location and magnitude of the mei-yu rainbelt in 1997.

4.1.3 *Normal year 1996*

Shown in Fig. 2a, there was less rainfall in all of the East Asian region in 1996 than the other two years. The heavy rainfall belts are located to the south of the Tibetan Plateau and central China along the Yangtze River-Huaihe River valleys. REMO reasonably reproduces the rainfall center to the south of the Tibetan Plateau and in the downstream sections of the Yangtze River (Fig. 2d). The false rainfall on the northern slope of the Himalayas happens in each of the three years, which might reveal the irrelevant orographic rainfall processes in the model that need to be addressed in future studies.

The three experiments are all conducted in forecast mode, with only 30 hours continuous integration. Therefore, even the interior domain could be heavily influenced by the driving large-scale data. In such an experimental setup, REMO reproduced the different characteristics of the observed rainfall pattern in the three years, such as the heavy rainfall along the Yangtze River valley in 1998 and the drought conditions in central-north China in 1997. We also notice that amongst the three experiments, REMO performs better in 1997 than the other two years, judged by the location and magnitude of the East Asian summer rainbelt. However, the three experiments are using the same surface condition setup, which are extracted from a global dataset of land surface parameters (Hagemann, 2002). It does not include inter-annual variations of vegetation and that are believed to partly restrict the model performance, especially in precipitation, the highly local-dependent parameter. In forecast mode, the model cannot fully develop its own dynamical system due to short period continuous integration and thus the local influence is weakened. The inter-annual differences among the three experiments confirm this assumption. Such inaccurate surface conditions might have larger impact in climate mode than in forecast mode, which will be discussed in next section.

4.2 *Forecast mode vs. climate mode*

REMO can be used in the forecast mode, as used in REMO-F96/7/8, or in climate mode, as used in REMO-C/CL/CS. Climate mode means continuous runs for long time periods (up to decades) with updates of the lateral boundaries only. It cannot be expected that in simulations using REMO in climate mode every single weather event is calculated realistically in time and space (Jacob et al., 2001). However, climate mode has the advantage in simulating mesoscale phenomena, which are not presented in the driving fields due to coarse horizontal resolution, or which are, for example, initiated through a more detailed land surface representation in the regional model. In climate mode, the model could develop such mesoscale phenomena within the simulation domain without strong constraints from the outside, in theory. Using forecast mode with restarts every 30 hours, for example, which is used in this study, restricts the lifetime of these mesoscale phenomena developed by the model dynamical processes and therefore stays closer to the driving field. In this section, we will compare the difference of summer rainfall simulation between the two running modes with REMO.

Figure 3 shows the accumulated summer rainfall of 1996 to 1998 produced by REMO-C. In general, they agree with observation in only a few places for the three summers. The rain-belt simulated in 1997 is located near the coastal area similar to observations. In 1998, the model does not represent the heavy rainfall in the Yangtze River valley, but replaces it with drought in central China and wet conditions in North China. In 1996, the model produces more rainfall in South China than in forecast mode REMO-F96, but still disagrees with observations. Comparing with the simulation results obtained in forecast mode, REMO in climate mode is less successfully in reproducing the interannual variation of summer precipitation in East Asia. Our findings that REMO in forecast mode outperforms that in climate mode agree with the conclusions found in other studies (Jacob et al., 2001)

4.3 *Domain size*

Since the primary purpose of RCMs is dynamical downscaling, it is evident that the RCM output should contain mesoscale details that are absent from the external data. The differences between the RCM and the provided large-scale data will derive mainly from the better representation of topography and other surface

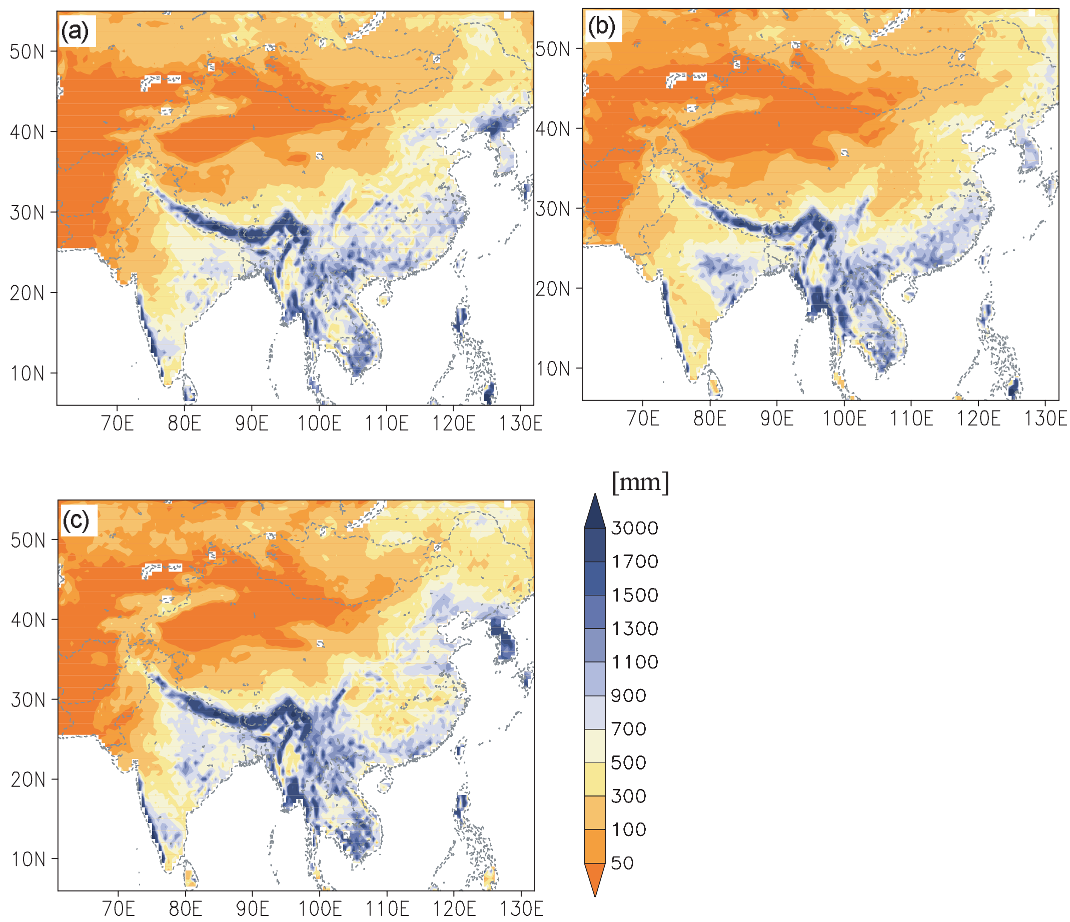

Fig. 3. Accumulated summer (JJA) rainfall in (a) 1996, (b) 1997, and (c) 1998 simulated by REMO-C.

characteristics in the regional model, and often form the differences in the representation of sub-grid processes. The acceptable amount of deviation of the RCM from the external data is a matter of debate. Since the external data are usually only provided near the lateral boundaries, large domains will result in significant RCM-forcing differences at the synoptic scale. It has been suggested that, in most cases, RCM-forcing differences should provide only high-resolution details, and that it is possible to optimize the domain size for this purpose (von Storch et al., 2000). The lateral boundary issue may give less cause for concern when RCM deviates less from the external forcing, but it cannot be avoided totally.

The choice of an appropriate domain is not trivial. The influences of the boundary forcing can reduce as region size increases (Jacob and Podzun, 1997) and may be dominated by the internal model physics for certain variables and seasons (Noguer et al., 1998). This can lead to the RCM solution significantly departing from the driving data, which can make the interpretation of down-scaled regional climate changes more difficult. Seth and Giorgi (1998) concluded that the domain size is of great importance in the East Asia climate simulation. Because East Asia is surrounded by the highest topography at the western boundary, a strong convection region in the South China Sea, and the subtropical high at the southeastern boundary, the size and lateral locations of the model domain for the East Asian region are expected to be more important than in other regions of the world.

The domain size has to be large enough so that it could include relevant local forcings and fully develop the effects of enhanced resolution of the boundary conditions. It is likely that by using a larger model domain, one can generate a better simulation of the extreme flood case (Leung et al., 1999). Given the limited computational resources, conventional wisdom has been to simply move the lateral boundaries sufficiently far from the area of meteorological interest so that their effect is within acceptable limits during the period of integration (Warner et al., 1997). Normally, location of boundaries over areas with significant topography may lead to inconsistencies and noise genera-

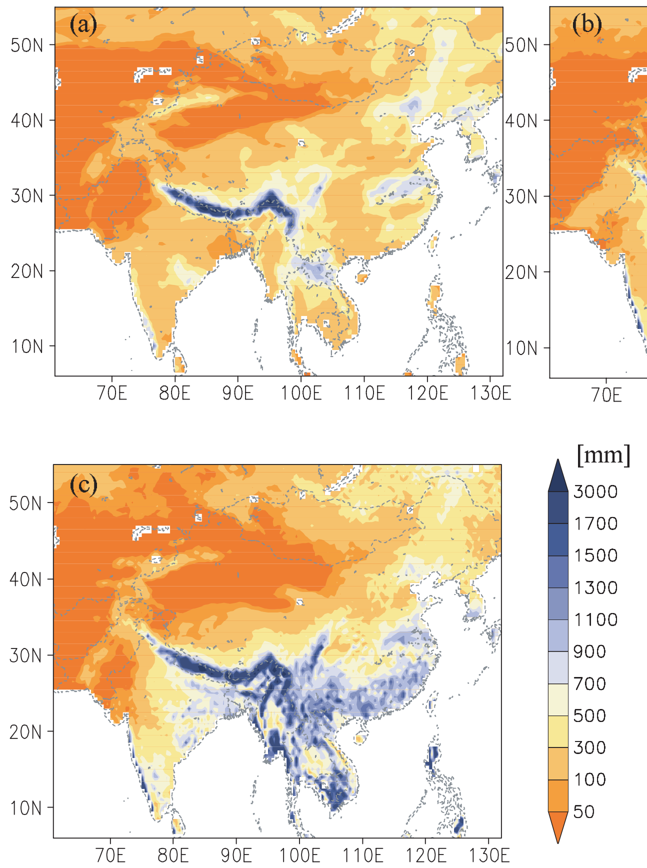

Fig. 4. Same as Fig. 3, but from larger domain simulation REMO-CL.

tion (e.g., Hong and Juang, 1998). This can seriously affect the simulations because differences in the representation of surface topography between the large-scale and regional models can produce gravity-inertia waves that propagate to the interior of the domain. However, in our case, it is difficult to avoid placing the western boundary far away from the Tibetan Plateau because it is such a massive feature. Taking all these factors into account, all experiments domains, including the smallest one, are centered over China and cover the whole Tibetan Plateau, Mongolia, part of the Western Pacific and the India and Indo-China peninsula.

Figure 4 is the same as Fig. 3 but for the simulation with a larger domain (REMO-CL in Table 1). In 1996, REMO-CL reproduces drier biases over most of East Asia except for the southern portions of the Himalayas. For a limited area model, the model internal dynamics needs to "spin-up" mesoscale structures that are responsive to the large-scale and local forcing. The summer of 1996 is only two months from the model starting, which might still lie in the model spin-up period. It is interesting to find out that the characteristics of 1997 and 1998 summer rainfall are in good agreement with that of REMO-C simulation, which runs with the control domain (Fig. 3). It may suggest that a larger domain than that of the control does not improve the capability of the model to respond to the large-scale forcings in summer.

Figure 5 is the same as Fig. 3 but only for the 1997 and 1998 summer rainfall from a smaller domain simulation. Due to technical problems, the data in 1996 are missing. Unlike the simulation from the larger and control domain, it more accurately produces the heavy rain belt along the Yangtze River valley in 1998 and shows reasonable differences between 1997 and 1998.

The small and large domain results with REMO demonstrate that simulated precipitation and moisture transport are affected by the choice of limited-area domain. The summer precipitation produced in the small domain are closer to observation than those from the large domain, since the boundaries of a smaller domain constrain the interior solution more toward the driving fields (which are derived from observations). This is in agreement with Jones et al. (1995) and Seth and Giorgi (1998). Since all the simulations in this study are driven by "perfect boundaries", the biases of the model are assumed to come from model physics

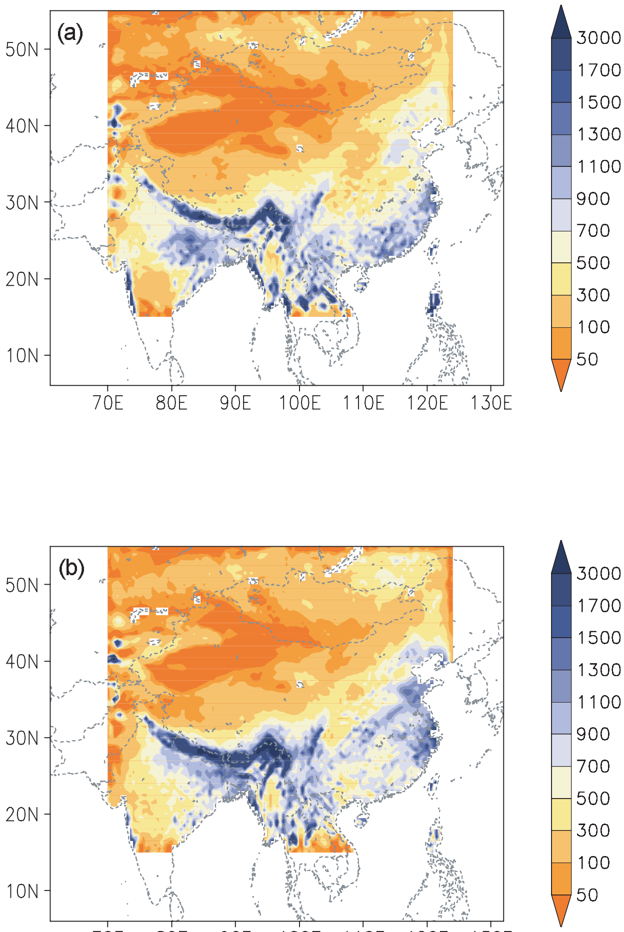

Fig. 5. Same as Fig. 3, but from smaller domain simulation REMO-CS. Only (a) 1997 and (b) 1998 are shown. Similar plot areas are chosen for easier comparison with other experiments, although no data beyond the model domain.

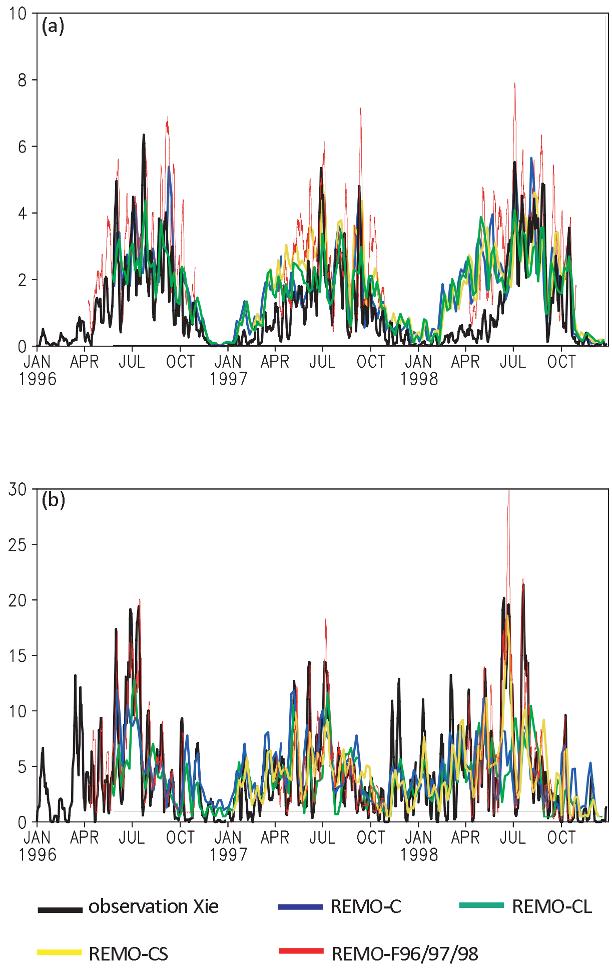

Fig. 6. Evolution of area averaged daily precipitation (unit: mm d^{-1}) for (a) Western China (32.5°–40°N; 80°–100°E), and (b) Yangtze River valley (27.5°–32.5°N; 110°–120°E).

and dynamics, which might be insufficient for rainfall processes in China. There are a lot of reasons responsible for this and they need to be addressed in the future, particularly in model inter-comparison projects (e.g., Fu et al., 2003). One of these reasons might be the poor representation of the vegetation in the model. The vegetation parameter values in REMO are extracted from a global dataset of land surface parameters (Hagemann, 2002). It does not include inter-annual variations of vegetation or vegetation feedback to surface processes (so-called dynamical vegetation). The high interannual variability of the East Asian monsoon represents quite unstable climate conditions, which in turn influence ecosystems across this region (Huang et al., 2003). This made the vegetation dynamical processes one of the key processes to accurately simulate the climate in East Asia.

To reveal the temporal evolution of the rainfall events in all experiments and their differences, Fig. 6 shows the area averaged rainfall in West China (32.5°–40°N; 80°–100°E) and the Yangtze River valley (27.5°–32.5°N; 110°–120°E). The comparison against the observations shows a good agreement in general, especially in the Yangtze River valley. In forecast mode, the model better captures the extreme events in summer than in climate mode. However, model generally produces more rainfall in spring in West China, both in forecast and climate running mode. Given quality observed large-scale forcing fields, relatively small domains, in which a tight lateral forcing prevails, are likely to give better overall simulations. Thus, a prerequisite for worthwhile RCM nested in GCM simulations is that the large-scale climatology of the driving GCM must be realistic over the region of interest. However, the GCMs always show poor performance in the Asian monsoon region (Kang et al., 2002). Therefore, as Seth and Giorgi (1998) suggested, in this case, larger domains, in which the model solution is more free to respond to variations in internal parameters, is likely to be preferred.

5. Conclusions and outlook

Notes are taken from numerical simulation experiments performed with a regional climate model in the three years of 1996–1998. Different running modes and domain sizes are tested to reveal the model capability and incapability in simulating summer rainfall.

We found that the regional climate model REMO is capable reasonably simulating the accumulated summer rainfall in China in forecast mode. It can also reasonably represent the interannual differences, e.g., the heavy rainfall over the Yangtze River in 1998 and the dry conditions in 1997, given the good large-scale fields. However, in climate mode, REMO is less successful in representing such inter-annual differences in summer rainfall. With longer time integration, RCM tends to depart away from the driving fields and is relatively free to respond to variations in internal parameters. Results also show that the smaller domain in climate mode outperforms the larger one. Our findings imply that climate mode is suitable to study long term mean climate but not the individual climate events. This also discloses the incapability of the current version of the model to accurate present the rainfall-produced processes in China. Implementation of dynamic vegetation should be one of the priorities of future regional climate model development. A sub-grid scale scheme capable of resolving complex topographical features (Leung et al., 1999) and processes' parameterizations suitable for East Asia also need to be developed and validated for better model simulation.

Our simulation is only performed for three years, which might not fully reveal the model ability in simulating interannual transition. For example, the ECMWF soil temperature values are only used for initialization but this leads to an unrealistically cold initialization of the deep soil, which needs about 5 years to come to equilibrium (Jacob et al., 2001). Hence, longer period model simulations may be required to confidently assess the mesoscale response of a RCM (Jones et al., 1995).

REFERENCES

Chen, S. J., Y. H. Kuo, W. Wang, Z. Y. Zhao, and B. Cui, 1998: A modeling case study of heavy rainstorms along the mei-yu front. *Mon. Wea. Rev.*, **126**, 674–701.

Fu, C. B., and Coauthors, 2003: Regional climate model inter-comparison project for Asia (RMIP). *Bull. Amer. Meteor. Soc.*, **86**(2), 257–266.

Gilbson, J. K., P. Kallberg, S. Uppala, A. Nomura, A. Hernandez, and E. Serrano, 1997: ERA description. *ECMWF Re-analysis Project Report Series*, Vol. 1, 77pp.

Giorgi, F. and L. O. Mearns, 1999: Introduction to special section: Regional climate modeling revisited. *J. Geophys. Res.*, **104**(D6), 6335–6352.

Hagemann, S., 2002: An improved land surface dataset for global and regional climate models. Report No. 336, Max-Planck-Institut fuer Meteorologie, Hamburg, 10pp.

Hong, S. Y., and H. M. H. Juang, 1998: Orography blending in the lateral boundary of a regional model. *Mon. Wea. Rev.*, **126**, 1714–1718.

Huang, R. H. L. T. Zhou, and W. Chen, 2003: The progresses of recent studies on the variabilities of the East Asian monsoon and their causes. *Adv. Atmos. Sci.*, **20**, 55–69.

IPCC, 2001: *The Scientific Basis*. Houghton et al., Eds., Cambridge University Press, 785pp.

Jacob, D., and R. Podzun, 1997: Sensitivity studies with the regional climate model REMO. *Atmospheric Physics*, **63**, 119–129.

Jacob, D., and Coauthors, 2001: A comprehensive model intercomparison study investigating the water budget during the BALTEX-PIDCAP period. *Meteorology and Atmospheric Physics*, **77**(1–4), 19–43.

Jones, R. G., J. M. Murphy, and M. Noguer, 1995: Simulation of climate change over Europe using a nested regional climate model. Part I: Assessment of control climate, including sensitivity to location of lateral boundaries. *Quart. J. Roy. Meteor. Soc.*, **121**, 1413–1449.

Kang, I. S., and Coauthors, 2002: Intercomparison of the climatological variations of Asian summer monsoon prediction simulated by 10 GCMs. *Climate Dyn.*, **19**, 383–395.

King, L., M. Gemmer, and R. Wang, 2001: Hochwasserschutz und Landnutzung am Yangtze. *Geographische Rundschau*, **53**(10), 28–34. (in German)

Leung, L. R., S. J. Ghan, Z. C. Zhao, Y. Luo, W. C. Wang, and H. L. Wei, 1999: Intercomparison of regional climate simulations of the 1991 summer monsoon in eastern Asia. *J. Geophys. Res.*, **104**(D6), 6425–6454.

Leung, L. R., L. O. Mearns, F. Giorgi, and R. L Wilby, 2003: Meeting summaries on workshop of regional climate research: Needs and opportunities. [Available online from http://www.esig.ucar.edu/rcw/]

Leung, L., Y. Qian, X. Bian, W. Washington, J. Han, and J. Roads, 2004: Mid-century ensemble regional climate change scenarios for the western united states. *Climatic Change*, **62**, 75–113.

Liu, Y., R. Avissar, and F. Giorgi, 1996: Simulation with the regional climate model RegCM2 of extremely anomalous precipitation during the 1991 east

Asian flood: An evaluation study. *J. Geophys. Res.*, **101**(D21), 26199–26215.

Noguer, M., R. G. Jones, and J. M. Murphy, 1998: Sources of systematic errors in the climatology of a nested regional climate model (RCM) over Europe. *Climate Dyn.*, **14**, 691–712.

Roeckner, E., and Coauthors, 1996: The atmospheric general circulation model ECHAM-4: Model description and simulation of present day climate. Max-Planck Institute for Meteorology report, No. 218, 90pp.

Seth, A., and F. Giorgi, 1998: The effects of Domain choice on summer precipitation simulation and sensitivity in a regional climate model. *J. Climate*, **11**, 2698–2712.

von Storch, H., H. Langerberg, and F. Feser, 2000: A spectral nudging technique for dynamical downscaling purposes. *Mon. Wea. Rev.*, **128**, 3664–3673.

Wang, J. A., H. Sun, W. Xu, and J. Zhou, 2002: Spatial-temporal changes of drought disaster in China in recent fifty years. *Journal of Natural Disasters*, **11**, 1–6. (in Chinese)

Warner, T. T., R. A. Peterson, and R. E. Treadon, 1997: A tutorial on later boundary conditions as a basic and potentially serious limitation to regional numerical weather prediction. *Bull. Amer. Meteor. Soc.*, **78**(11), 2599–2617.

Webster, P. J., V. O. Magaña, T. N. Palmer, J. Shukla, R. A. Tomas, M. Yanai, and T. Yasunari, 1998: Monsoons: Processes, predictability, and the prospects for prediction. *J. Geophys. Res.*, **103**(C7), 14451–14510.

Xie, P., A. Yatagai, M. Chen, T. Hayasaka, Y. Fukushima, C. Liu, and Y. Song, 2007: A gauge-based analysis of daily precipitation over East Asia. *Journal of Hydrometeorology*, **8**, 607–627.