B-1.5 Study on the Evaluation of Regional Scale Climate Change (Final Report)

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Abstract In order to project the regional scale climate change over the east Asia, a regional climate model is developed. A preliminary year-long test run of the model revealed that the model failed to simulate the precipitation distribution in the Baiu-season (early summer). To solve this problem, numerical experiments using the model are performed to understand the formation mechanism of the Baiu, while a systematic sensitivity study on cumulus convection schemes is performed to understand the behavior of the schemes. With the results of these studies, the model is improved so that it can realistically represent the regional climate over the east Asia including the precipitation distribution in the Baiu-season. A preliminary climate change experiment using this model is also conducted and its potential effectiveness is discussed.

Key Words Regional Climate Model, East Asia, Precipitation Distribution, Baiu-Season, Cumulus Convection

1. Introduction

The spatial resolution of current generation global climate models (hundreds of kilometers) that have been used for the future climate change projections are not sufficiently fine to represent regional characteristics of the climate change. Therefore, the utilization of "Regional climate models", which limits its computational domain to a certain region of interest in order to realize a resolution ten times as fine as that of global models, for the climate change projection has been highly requested.

In this study, a regional climate model for the east Asia has been developed and validated against observational data (Section 2). It was found that the representation of precipitation distribution in the early summer, the so-called Baiu-season, was particularly difficult with the model. To solve this problem, numerical experiments using the model are performed to understand the formation mechanism of the Baiu (Section 3), while a systematic sensitivity study on cumulus convection schemes is performed to understand the behavior of the schemes (Section 4). With the results of these studies, the model is improved so that it can realistically represent the regional climate over the east Asia including the precipitation distribution in the Baiu-season (Section 5). A preliminary climate change experiment is also conducted using this model (Section 6).

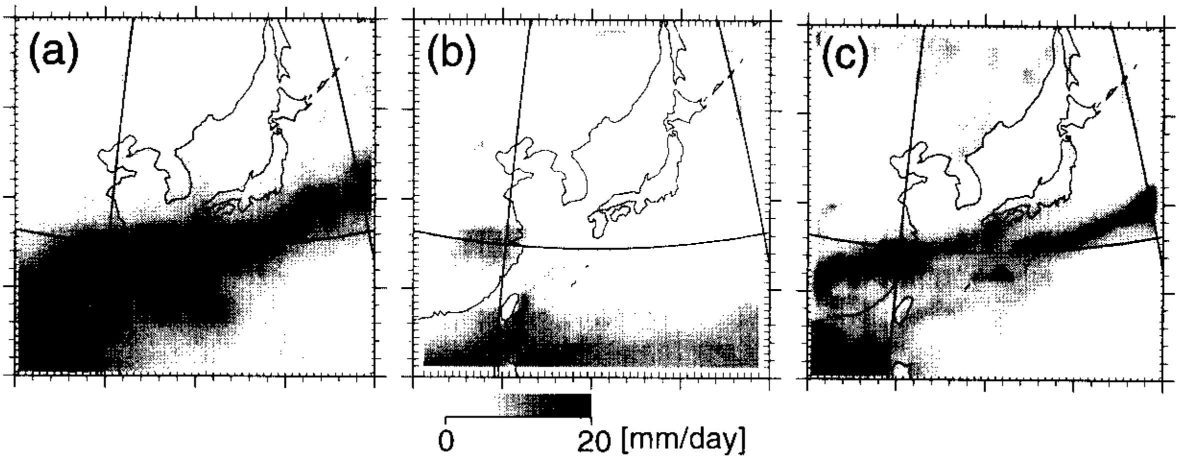

Fig. 1: Monthly mean precipitation over east Asia in June 1994; (a) observational data (Xie and Arkin, 1996), (b) model result before improvement, and (c) model result after improvement. See Section 5 for the detail of the improvement.

2. Development and Validation of Regional Climate Model

The regional climate model developed in the present study is named NIES/CCSR RAMS. It is based on the Regional Atmospheric Modeling System developed at the Colorado State University (CSU-RAMS; Pielke et al., 1992) and most of the physics parameterizations of RAMS are replaced by those of our global climate model, CCSR/NIES AGCM (Numaguti et al., 1995). The parameterizations include a k-distribution 2-stream radiation scheme (Nakajima et al., 2000), a cumulus convection scheme based on Arakawa and Schubert (1974), a prognostic total water scheme for large-scale condensation based on Le Treut and Li (1991), and a land-surface scheme, MATSIRO, which is developed in our group for the use in global and regional climate models. The vertical diffusion scheme in NIES/CCSR RAMS is the level 2.5 closure of Mellor and Yamada (1982), while CCSR/NIES AGCM uses the level 2.

To evaluate the performance of this model, a year-long integration of the climate of the year 1994 was made and validated against observational data. The computational domain is 4000 km $\times$ 4000 km in the horizontal and is 18 km in height. The horizontal grid spacing is 80 km and the number of vertical levels is 23. The ECMWF objective analysis data with 2.5° $\times$ 2.5° horizontal resolution and twice daily temporal resolution were used for the initial and boundary conditions. For the surface boundary conditions, analyzed sea surface temperature (SST) of NCEP (Reynolds and Smith, 1994) was used.

As compared with the observational data, the model successfully simulated the precipitation distribution in winter. The precipitation due to the passage of developing extratropical cyclones to the south of Japan islands and the precipitation maximum on the west side of Japan, which is due to the cold air outbreak from the Siberian high and the topographical effect of the mountain range of Japan, are simulated well. However, in early summer, the model failed to simulate the typical persistent rain belt accompanying the frontal structure related to the east Asian monsoon, the Baiu front. The modeled precipitation over the Baiu front was too weak, while an unrealistic precipitation peak was produced around the southern boundary of the domain, which is over the north Pacific subtropical high (Fig. 1a, b).

3. Formation Mechanism of Baiu Front

In order to examine the possibility of successfully reproducing the Baiu front in regional climate models, the formation mechanism of the Baiu front should be deeply understood. Therefore, a series of idealized numerical experiments are conducted to investigate the formation mechanism of the Baiu front using the regional climate model.

The model used is basically the same as NIES/CCSR RAMS, though some physical parameterizations are different. For the cumulus convection scheme, a Kuo-type scheme was mainly used instead of the Arakawa-Schubert type used in the standard NIES/CCSR RAMS. A wider computational domain was taken to include the whole potion of Tibetan plateau, while a coarser horizontal resolution of 100km was used. A zonally uniform and temporally constant atmospheric field obtained by ten-day averaged zonal mean ECMWF data was utilized as the initial and boundary conditions (zonal mean simulation).

The simulated Baiu front has similar structures to the real Baiu front, i.e., the Low Level Jet (LLJ) run parallel to the precipitation zone and the Upper Level Jet in the eastern part. Fundamentally, 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 distribution of the rainfall in the Baiu front depends on the cumulus convection schemes, the fundamental structure of the Baiu front does not depend on them.

In comparison between the zonal mean simulations of early and late June, the Baiu front is formed northward in late June, when the westerly is weak and the upper level jet is located northward. The location of the Baiu front is quite sensitive to the zonal mean field. The Baiu front accompanied by the LLJ is also represented by experiments excluding the topography, suggesting that the Baiu front could be reproduced only by two factors of the zonal mean field and the Sea/Land contrast. However, the orography including the Tibetan plateau intensifies the LLJ and the precipitation over the Baiu front.

The LLJ also appears in experiments without the condensation process, although the LLJ locates in the northern side of the Upper Level Jet. Accordingly, it is speculated that the condensation process acting on the atmospheric field is necessary to keep the LLJ in the southern side of the Upper Level Jet as in the real Baiu front.

4. Sensitivity Study on Cumulus Convection Schemes

It was likely that the cumulus convection scheme was responsible for the problem in the representation of precipitation field in the Baiu-season in NIES/CCSR RAMS. In order to examine the characteristics of the scheme and to find the direction of improvement of the scheme, a series of sensitivity experiments on cumulus convection schemes are performed.

First, the Arakawa-Schubert (AS) type scheme used in the NIES/CCSR RAMS was tested in a global model, CCSR/NIES AGCM, with T42 horizontal resolution and was compared with two schemes of different types, Kuo and Moist Convective Adjustment. It was found that AS was superior to the other schemes in the representation of seasonal-mean horizontal pattern of precipitation, while it was inferior to the others in the representation of temporal variability from daily to seasonal timescales — the temporal variability was significantly underpredicted with AS compared with the observational data.

The schemes are further examined in a single-column model with prescribed large-scale forcing constructed from TOGA-COARE (Tropical Ocean and Global Atmosphere, Coupled Ocean Atmosphere Response Experiment) observation. The overall variation pattern of the observed precipitation was reproduced with any of the three schemes. However, AS

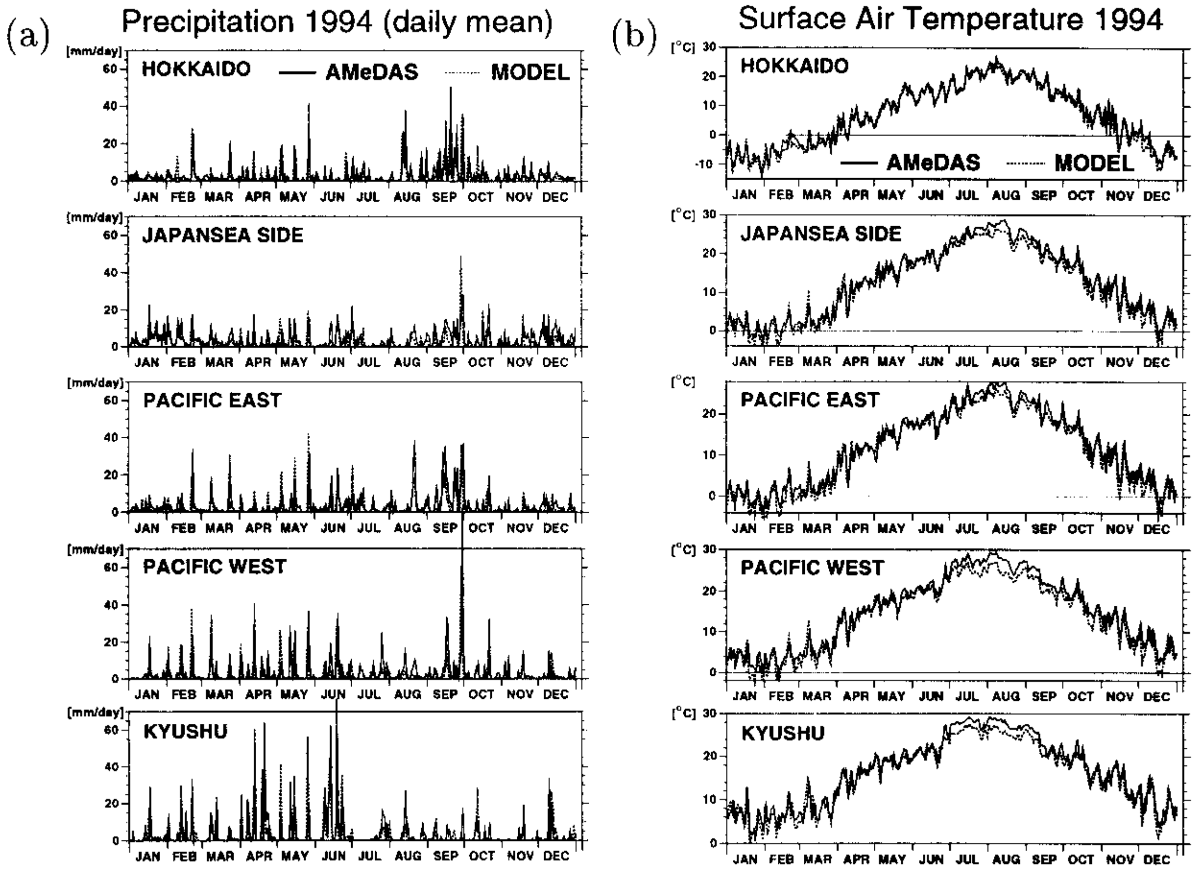

Fig. 2: Comparison between the model result and AMeDAS observation. Time sequence of daily-mean values averaged over five sub-regions of Japan are shown; (a) precipitation and (b) surface air temperature.

overpredicted precipitation during a period when precipitation is completely suppressed in reality and in the experiments with the other two schemes.

From the results in the above, it can be deduced that the AS scheme tends to underpredict the temporal variability of precipitation because precipitation is not suppressed properly when it should be suppressed in reality. Thus, some possible conditions to suppress precipitation was added to AS and tested in the global model and the single-column model. As a result, the temporal variability of precipitation was significantly improved. The improvement was especially clear when a criteria of minimum column-averaged relative humidity was applied to the onset of cumulus convection. It is suggested from the experiments that the suppression of cumulus convection due to dry air above boundary layer plays a significant role in the temporal variability of precipitation.

5. Improvement of Regional Climate Model

It is suggested in the Section 3 that the basic structure of the Baiu front can be represented in the regional climate model, and in the Section 4 that the Arakawa-Schubert type cumulus convection scheme can be improved with additional minimum relative humidity criteria. NIES/CCSR RAMS was tested again after modifying the cumulus scheme with the relative humidity criteria. The horizontal resolution was also improved and set to 50km.

The improved model successfully represented the precipitation distribution in the Baiu-season. In the old model, cumulus convection was active over the north Pacific subtropical high and the low-level water vapor flux flowing into the Baiu front from the south was reduced there (Fig. 1b). In the improved model, cumulus convection was suppressed over the subtropical high because of the dry environmental air due to the prevailing subsidence motion, resulting in a substantial supply of low-level water vapor flux into the Baiu front and the realistic intensity of precipitation over the Baiu front (Fig. 1c).

Precipitation over Japan is further validated with the Automated Meteorological Data Acquisition System (AMeDAS) station data. The model successfully simulated the phase and peak values of the precipitation events (Fig. 2a). The simulated variation of surface air temperature was also fairly realistic (Fig. 2b).

6. Climate Change Projection

For projecting the future climate change, two ten-year long integrations of NIES/CCSR RAMS were conducted driven by the outputs of two integrations of CCSR/NIES AGCM. The atmospheric concentrations of greenhouse gases and the distribution of SST is differently prescribed in the two global model integrations and, accordingly, in the corresponding two regional model integrations. One integration is for the present climate (1XCO2) and the other is for the climate when the atmospheric concentration of greenhouse gases is doubled (2XCO2). In 1XCO2, SST is prescribed with the analyzed SST of NCEP (Reynolds and Smith, 1994), while, in 2XCO2, the SST perturbation calculated from a transient global warming experiment with a coupled ocean-atmosphere model (Emori et al., 1999) was added to the analyzed SST.

It was found in the 1XCO2 results that both the regional model and the global model realistically represented the precipitation distribution over the east Asia in winter. However, in summer, precipitation over lower latitudes are too strong and the suppression over the subtropical high is not represented either in the global or the regional model, though the modification of the cumulus convection scheme suggested in the Section 4 were applied both in the global and the regional models. It was shown that the representation of summer climate over the east Asia including the precipitation distribution is not sufficient especially in the global model. To make a climate change projection experiment meaningful, the improvement of the representation of the present climate in the global model, especially in summer, is of primary importance.

The projected climate change, which is the difference between the 2XCO2 and 1XCO2 results, are analyzed only for winter, in which the present climate (1XCO2) was realistically represented. It is suggested from the experimental result through statistical test that the precipitation in 2XCO2 climate will be less than in the present climate over a southern part of China and a southwest part of Japan. This change can be explained by the shift in westerly jet due to the enhanced warming over the continent. It is also suggested that, in 2xCO2 climate, snow water equivalent over the west side of northern Japan will be less than in the present climate.

7. Summary and Discussion

A regional climate model is constructed based on the dynamical framework of CSU-RAMS and the physical parameterizations of CCSR/NIES AGCM. The model driven by the ECMWF objective analysis is validated against the observational data, while the model driven by CCSR/NIES AGCM is used for preliminary experiments of the future climate change projection.

In the course of the model development, some new findings on the regional climate over the east Asia are obtained. One is on the formation mechanism of the Baiu front. It is suggested from the numerical experiments that the low level jet, which is one of the important climatic structure accompanying the Baiu front, is reproduced through the interaction between the zonal mean atmospheric field and the land-sea heat contrast.

The other is on the suppression of cumulus convection. It is suggested that the suppression of cumulus convection due to dry air above the boundary layer plays an important role in the temporal variation of cumulus convection as well as in the precipitation distribution over the east Asia in early summer.

As for the effectiveness of future climate change projection using the regional climate models, the following suggestions could be obtained from the experience of this study:

1. The improvement of the driving global climate model in the reproduction of present day climate is of primary importance.

2. The uncertainty in the future climate change projection by the global models should be kept in mind. The use of some different driving data (e.g., SST anomaly) from different global climate models will be useful.

3. Regional climate models can add regional scale climate change information, which cannot be resolved in the global models, to the large-scale information projected by the global models. Information on the snow depth distribution over the western side of Japan will be a good example.

4. To make the information as scientifically reliable as possible, the information should be statistically tested and the mechanism of the change taking place in the model should be analyzed and explained.

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