33. 地球温暖化時の東アジアの気候変化
– 全球モデルに接続した地域気候モデル –

Climate Change over East Asia simulated by Regional Climate Model nested in a GCM

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ABSTRACT : Two continuous five-year long simulations over eastern Asia and the Japan islands, one for present day climate (control) and one for climate under doubled carbon dioxide concentration (2XCO2) are completed with a regional climate model (RegCM) nested in a general circulation model (GCM). The GCM is run at R15 resolution (4.5×7.5° lat×lon) and the RegCM is run at 50 km grid point spacing. In the control run both the GCM and the RegCM reproduce the seasonal migration of the westerly jet, but produce a stronger monsoonal circulation than the observed, which result in a significant overestimate of summer precipitation over the eastern Asian continent. Under 2XCO2 forcing, warming in the range of 4-11°C is simulated, greater in winter than in summer and increasing toward high latitudes. The strength of the monsoonal circulation increases in 2XCO2 conditions, leading to a general increase in precipitation over all regions by 10-30%.

KEY WORDS : climate change, general circulation model, regional climate model

1 Introduction

The climate of East Asia is characterized by marked monsoonal circulations. The Japan Islands and Korean Peninsula are either entirely omitted, or are very roughly represented, by current General Circulation Models (GCMs), since these are quite narrow and present complex topographical features. The use of nested Regional Climate Models (RegCMs), however, allows to reach resolutions of up to a few tens of km, and thus can provide important insights into the effects of local forcings on climate change.

In this paper we carried out two continuous 5-year simulations, one for present day conditions (control experiment) and one for conditions under doubled carbon dioxide concentration (2XCO2 experiment). The main goals of the present work are (1) to assess what level of accuracy in the simulation of present day climate is obtained with the RegCM driven by a coupled GCM/ocean model over East Asia; and (2) to examine the regional structure of the simulated responses to 2XCO2 forcing as affected by local forcings.

2 Description of Models and Simulation Procedure

Driving fields for our nested model runs were taken from a recent climate simulation performed with a version of the National Center for Atmospheric Research (NCAR) Community Climate Model (CCM) developed by Washington and Meehl (1984) and further modified by Washington and Meehl (1993). It is a R15 spectral (7.5° × 4.5°), σ-vertical coordinate model with nine layers in the vertical.

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The atmospheric model is coupled to a 50 m mixed-layer ocean model which crudely accounts for seasonal heat storage and neglects processes such as horizontal and vertical heat transport by oceanic circultations. No flux correction terms are included in the model.

The NCAR Regional Climate Model (RegCM) is an augmented version of the mesoscale model MM4 (Anthes et al., 1987). The MM4 is a primitive equation, σ-vertical coordinate, grid point limited-area model. For application to climate studies, a number of physics parameterizations were incorporated in the model (see Giorgi et al., 1993a,b). These include a surface physics package, BATS (Dickinson et al., 1993), an explicit planetary boundary-layer formulation (Holtslag et al., 1990), a detailed atmospheric radiative calculation package used in the CCM2, and a Kuo-type cumulus parameterization scheme.

Figure 1 depicts the topography of the RegCM for the selected domain (5200×4700 km^2). In this paper, we will show results over three broad regions in **Fig.1**; region-3,5,6 for south China, Korea, and Japan, respectively. We performed with the RegCM two continuous 5-year simulations, one for present day and one for 2XCO2 conditions. The RegCM was initialized only once, and the boundary conditions were taken from 5-year windows of control and 2XCO2 100 year runs completed by Washington and Meehl (1993) described above. All the results presented in the next sections are thus from averages of control and 2XCO2 5-year long simulations.
The simulated circulations over the domain are compared with ECMWF analyses of observations from 1979 to 1990. Precipitation and surface air temperatures are validated against the half degree resolution dataset of Legates and Willmott (1990a,b).

3 Validation of the control run

We first examined whether the average large scale fields in the nested model were significantly different from those in the driving GCM. In the mid-troposphere these differences were generally small, less than 2 m/sec, 1° and 1 g/kg, for wind, temperature and water vapor mixing ratio, respectively. Overall, throughout the troposphere the RegCM was warmer and drier than the CCM in summer.

Fig.2 showes observed, RegCM and CCM control run monthly precipitation over the regions of **Fig.1**. The seasonal precipitation patterns in the RegCM and CCM show similar trends. However, the precipitation overprediction by both models is evident, although the seasonal cycle of precipitation, featuring a pronounced monsoon summer maximum, is generally captured by the model.

Summer precipitation in the RegCM is greater than in the CCM over Korea and Japan, whose land masses are not represented by the CCM grid. It is evident that both models produce much rain over central-eastern China as a result of the overestimate of the strength of the southerly monsoon flow as shown in **Fig.3**, which represents CCM 500mb summer wind over the regions surrouding the RegCM domain. In **Fig.3**, a southerly flow of moist air appears over south-eastern Asia which is much stronger than observed.

Next, we compared the average monthly surface air temperature for observations, RegCM and CCM control run (see **Fig.4**). The results are as follows. Overall, the simulated monthly surface temperatures are within a few degrees of observed. The largest errors, 4-6 K, occur over the northernmost regions, Mongolia and north-eastern China in the extreme seasons, winter and summer. The results from all regions indicate that, compared to the observations, both models tend to overpredict the seasonal temperature range. A similar overprediction in seasonal range was found for the Pacific SSTs at the mid and high latitude (not shown) as a result of the absence in the CCM ocean model of meridional mixing. This bias in SSTs may also affect the land bias during seasons of prevalent on-shore winds. In particular, during the winter, sea ice extended too far south over the sea of Okhotsk and the northwestern Pacific, which caused the low temperatures simulated by the CCM over the region.

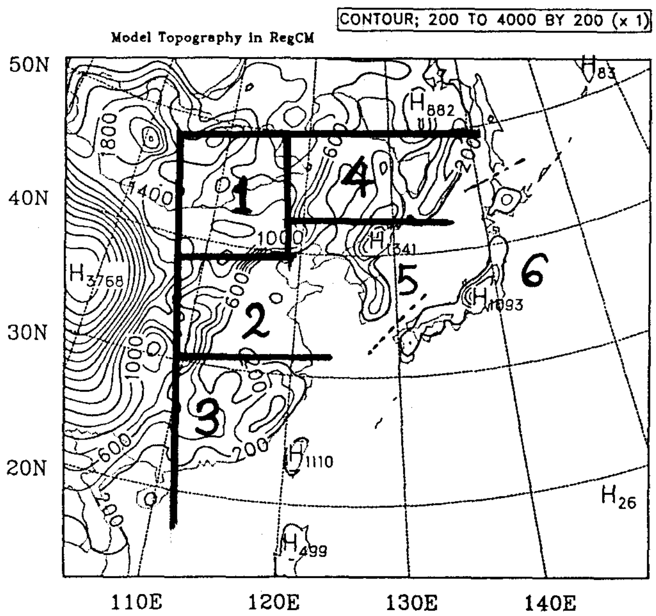
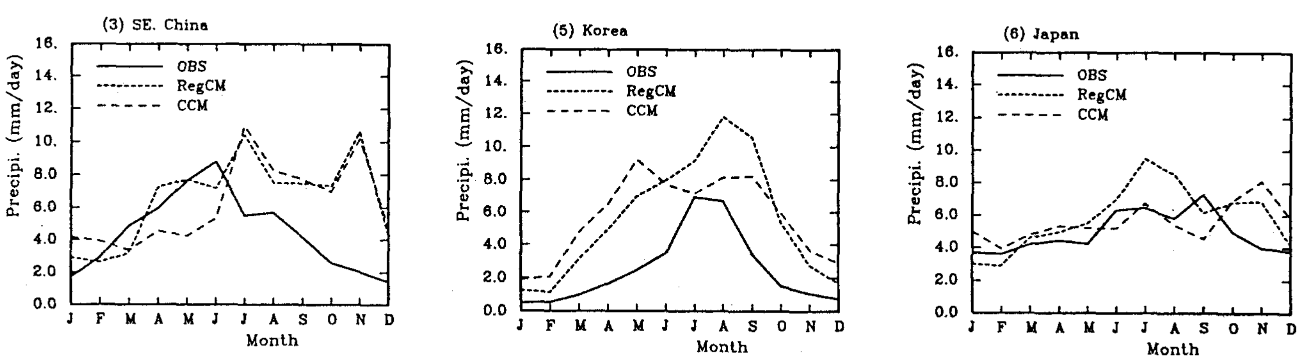


Figure 1. Regional Climate Model (RegCM) domain and topograpy over East Asia. The contour line is 200m. The Regions 1–6 represent Mongolia, North China, South China, North-eastern China, Korea and Japan, respectively.

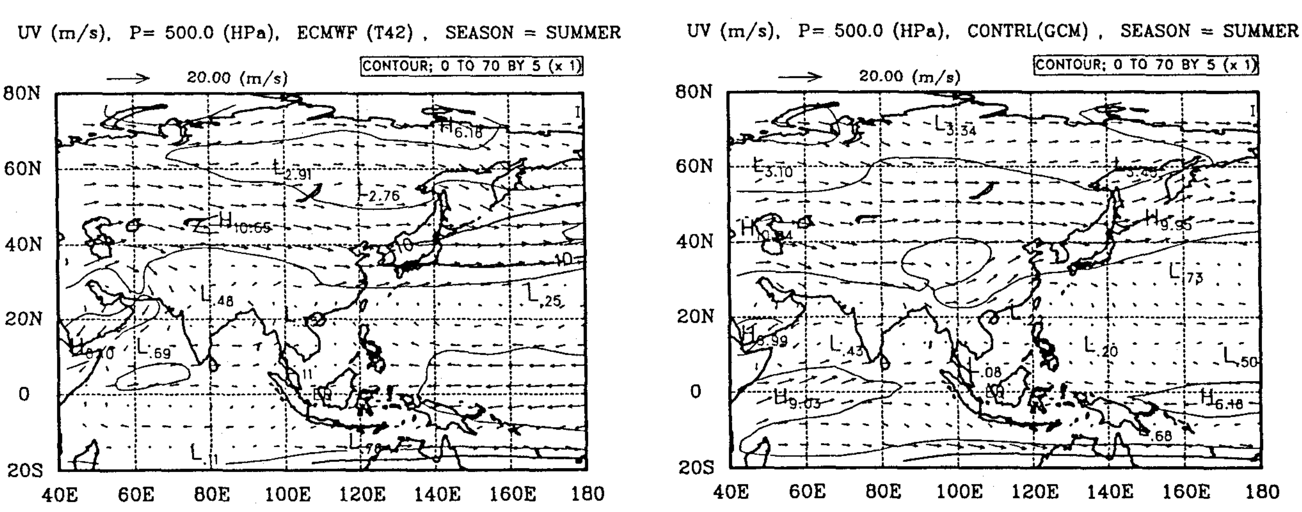


(a) South China (Reg–3)

(b) Korea (Reg–5)

(c) Japan (Reg–6)

Figure 2. Average observed, RegCM control run and CCM control run monthly precipitation (mm/day) over the region–3,5,6 of Fig.1.



(a) ECMWF observation

(b) CCM control run

Figure 3. Average summer ECMWF and CCM 500 mb wind (m/s) over the regions surrounding the RegCM domain. The contour intervals are 5 m/s.

4 Regional climate change under 2XCO2 forcing

4.1 Temperature change and large scale circulation

Figure 5 showes the differences in surface air temperature between 2XCO2 and control runs produced by the RegCM for winter and summer, respectively. We hereafter refer to these differences as "temperature change" or "warming". The 2XCO2 warming patterns show a general increase in warming towards higher latitudes and greater warming in winter than in summer. Note the large temperature change over the sea of Okhotsk in winter which is caused by the simulated retreat of sea ice.

Figures 6 showes the temperature changes simulated by CCM and RegCM averaged over the three regions of **Fig.1**. Regional average monthly values of warming range from about 5°C in August over south China to ~12°C in January over Korea. The seasonal warming trends produced by the CCM and RegCM show similar patterns, with maxima during the winter months. Differences in the simulated warming by CCM and RegCM of up to 2°C are however found on individual months.

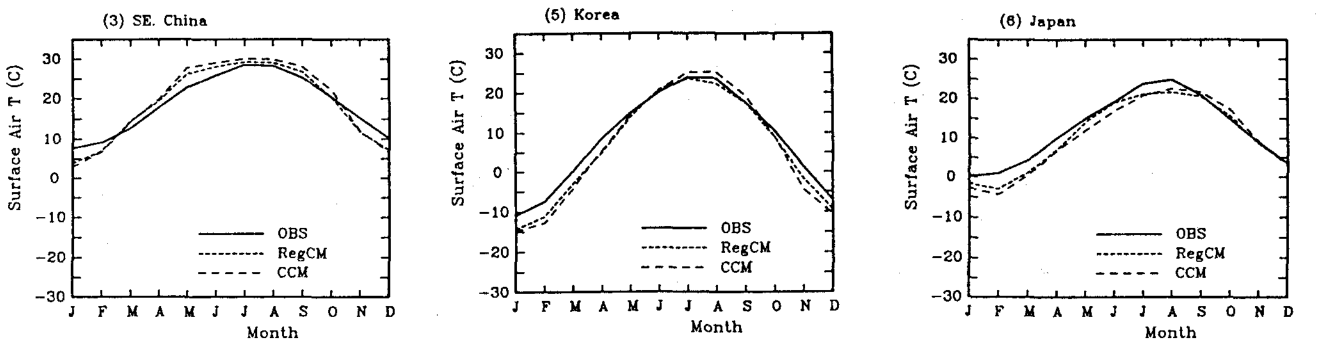
Figure 7 showes the RegCM-simulated differences between 2XCO2 and control run winter and summer 500 mb wind. In winter over eastern Asia, the model simulates a northward gradient of mid-tropospheric 2XCO2 warming (not shown), varying from ~4°C at 20°N to ~7°C at 50°N. This causes a decrease in the mid-latitude meridional temperature gradient and, as a consequence, a weakening of the mid-latitude jet between 30 and 40°N. On the other hand, the anticyclonic summer monsoonal circulation is intensified in the 2XCO2 run in response to a mid-tropospheric heating maximum over the northwestern Pacific.

4.2 Precipitation change

The difference between the RegCM-simulated 2XCO2 and control run precipitation (hereafter referred to as "precipitation change") is shown in **Fig.8**. The large scale patterns of precipitation change produced by the RegCM are similar to that by the CCM. In response to the weakening of the midlatitude winter jet, and despite a ubiquitous increase of water vapor content throughout the troposphere (not shown), a band of decrease in precipitation is simulated between 20 and 40°N. This region of negative precipitation change extends farther into central China in the CCM simulation than in the RegCM simulation. The RegCM produces a more pronounced increase in precipitation over the southeastern China regions and adjacent ocean areas than the CCM.

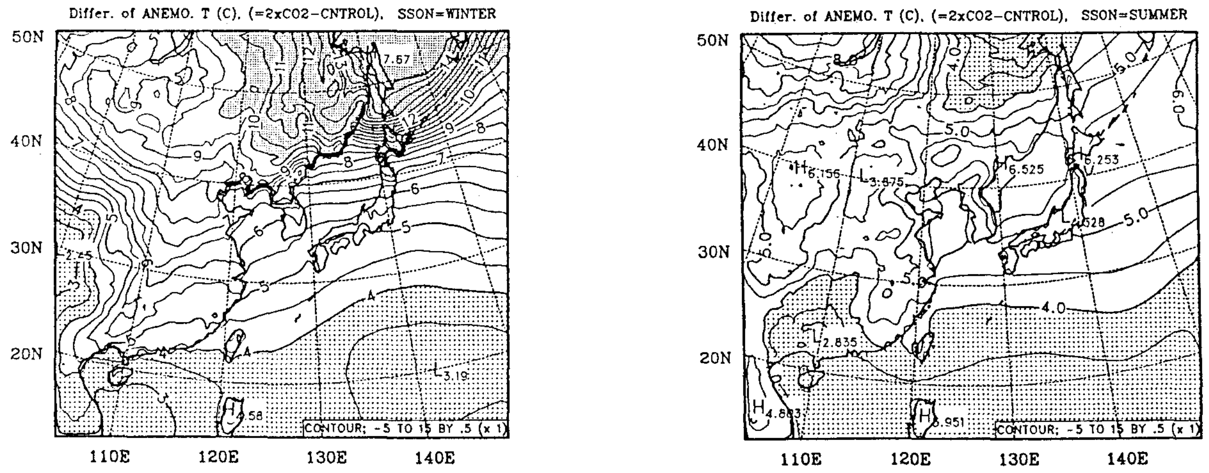
In summer, the intense anticyclonic monsoonal circulation in 2xCO2 run results in increased southerly and southeasterly flow over east China which leads to increased precipitation in the monsoon rain-belt. Also in summer, the large scale patterns of precipitation change in the CCM and RegCM are similar, but marked regional precipitation differences in the magnitude and the positioning of areas of positive and negative change can be observed between the CCM and RegCM runs, especially over Japan and Korea.

Figures 9 showes the average monthly precipitation changes over the three regions of **Fig.1**. Generally, the monthly precipitation change patterns in the RegCM follow those of the GCM. However, substantial differences between the RegCM and CCM results can be observed. Overall, the RegCM produces changes of greater magnitude than the CCM, especially in summertime, as if the regional model acted to amplify the signal produced by the CCM over the region. Furthermore, several instances occur in which even the sign of the simulated change differs between the CCM and RegCM experiments.



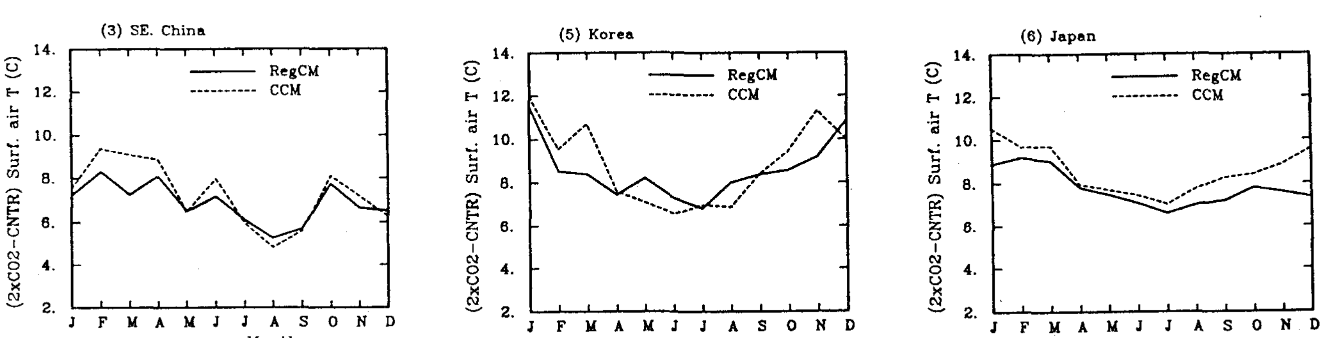
(a) South China (Reg–3) (b) Korea (Reg–5) (c) Japan (Reg–6)

Figure 4. Average observed, RegCM and CCM control run monthly surface air temperature (°C) over the region–3,5,6 of Fig.1.



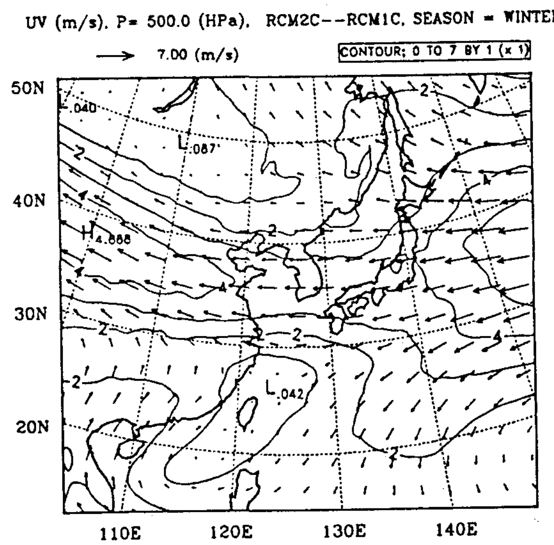
(a) Winter (b) Summer

Figure 5. Surface air temperature difference (°C) between RegCM 2XCO2 and control run. (a) winter ; (b) summer. The contour intervals are 0.5 °C.

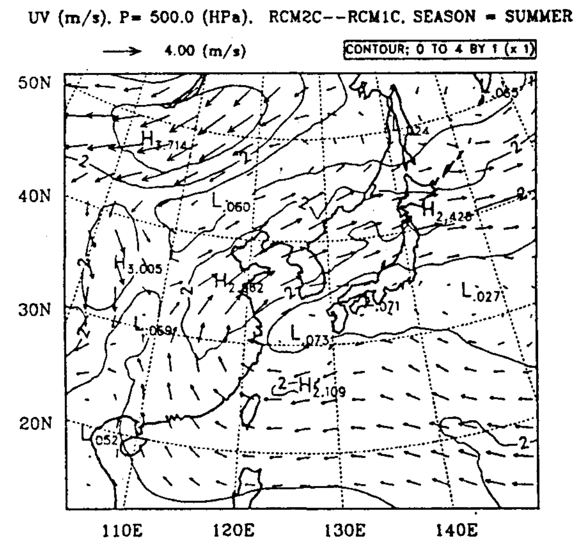


(a) South China (Reg–3) (b) Korea (Reg–5) (c) Japan (Reg–6)

Figure 6. Monthly surface temperature difference (°C) between 2XCO2 and control run simulated by RegCM and CCM over the region–3,5,6 of Fig.1.

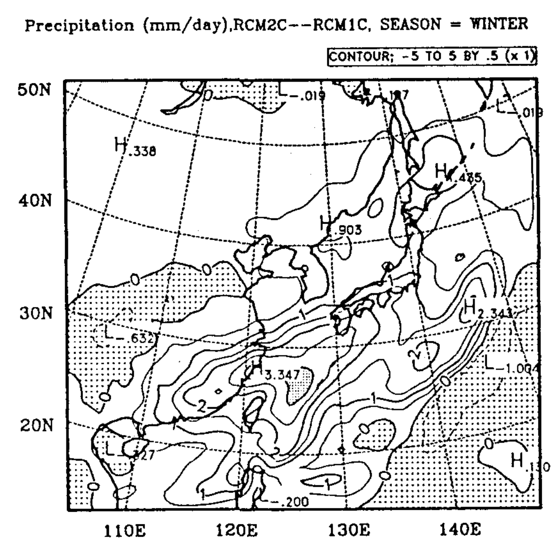


(a) Winter

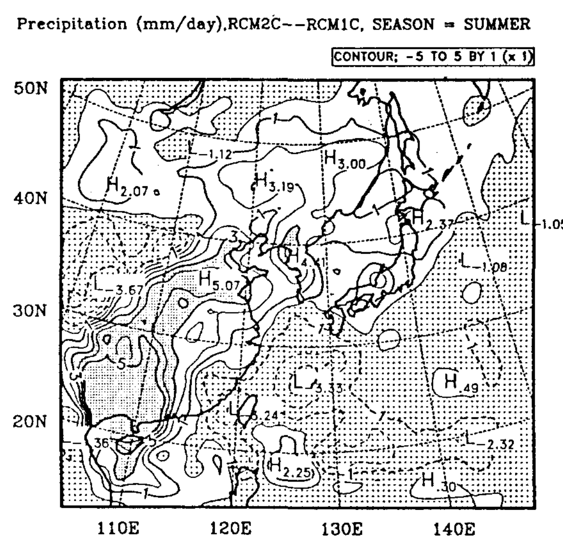


(b) Summer

Figure 7. 500 mb wind differences between RegCM 2XCO2 and control run. The contour intervals are 1 m/s.

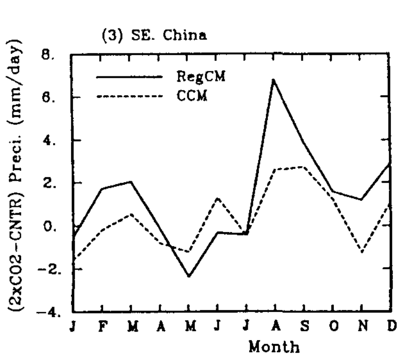


(a) Winter

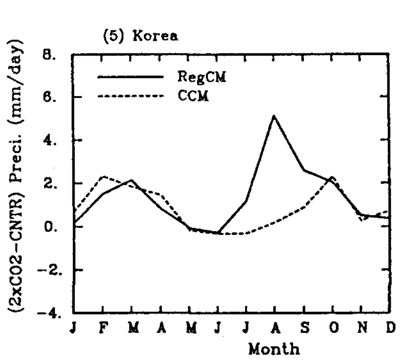


(b) Summer

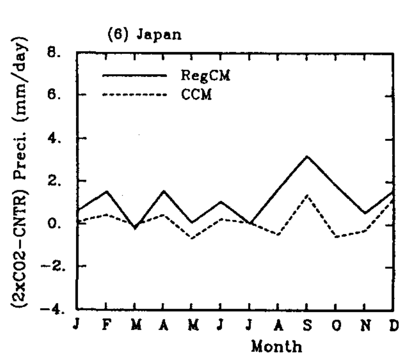
Figure 8. Precipitation difference (mm/day) between RegCM 2XCO2 and control run. The contour intervals are 0.5 mm/day in winter and 1 mm/day in summer.



(a) South China (Reg-3)



(b) Korea (Reg-5)



(c) Japan (Reg-6)

Figure 9. Monthly precipitation difference (mm/day) between RegCM 2XCO2 and control run over the region-3,5,6 of Fig.1.

5 Summary and conclusions

In the control simulation, the model reproduced the basic seasonality of the monsoon-dominated cycle, although the monsoon circulation was stronger and reached too far north inland than the observations, so that precipitation was substantially overestimated over much of the eastern Asia continental areas.

Under 2XCO2 conditions, the simulated warming was in the range of 4-11°C, greater during the cold season than the warm season and increasing towards high latitudes. Under 2XCO2 forcing the nested modeling system simulated an increase in strength of the summer monsoon circulations and associated summer rain over the eastern Asia land areas. In winter, a simulated weakening of the midlatitude jet caused a relatively small increase in precipitation. Overall, the RegCM produced more marked changes and a more pronounced increase in precipitation especially in summer over land areas. Significant sub-regional detail over areas of complex topography and coastline, such as Japan and Korea, was produced.

Because of the presence of large precipitation anomalies in the control run, the 2XCO2 results are probably not reliable enough to be used in assessements of impact of climate change. However, our work has shown that the regional modeling technique can be effectively applied to long-term climate simulations over eastern Asia.

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