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East Asian Precipitation Increase under the Global Warming

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Abstract

The East Asian rainfall response to global warming is investigated by a transient greenhouse increase integration with a state-of-the-art coupled global general circulation model. Two seasons are focused: spring and summer, in which the East Asian rainfall is the heaviest. At first, we examine the ability of the model in reproducing the observed relationship between the anomalies of rainfall and large-scale atmospheric circulation associated with interannual variability, by using a 1000-yr control integration of the model. Then we document the changes in East Asian rainfall and associated circulation/specific humidity response to global warming, and find rainfall increase is accompanied by anomalous southerly and more moisture over the coastal East Asia. The good simulation of mean climate and the reproducibility of the relationship between precipitation and circulation associated with interannual variability over East Asia by the model give more credibility for regional climate change signals.

Key words: East Asian rainfall, global warming, circulation-rainfall relationship

1. Introduction

Numerical climate projections for future climate based on coupled atmosphere-ocean models are still uncertain at the regional scale. Although there were many studies showing that precipitation increases in East Asia in summer (Hu *et al.*, 2000, Bueh *et al.*, 2003; Min *et al.*, 2004; Kimoto, 2005; Kitoh *et al.*, 2005), large uncertainties exist among models in simulating future precipitation changes (Hu *et al.*, 2003; Kimoto, 2005).

Particularly, current climate models show a poor performance for simulating summer climate variability in East Asia and the western North Pacific (Kang *et al.*, 2002; Kato *et al.*, 2005). Mitchell *et al.* (1987) argued that the response of a model to CO_2 increase depends on the simulation of the present-day climate. Only these models, which simulate the present-day mean climate and its variability more realistically, can give us more confidence in the simulation of climate change. In addition, these models are expected to be more likely to simulate well the physical processes of climate change caused by the global warming. In general, the changes in large- scale circulation induced by the global warming are more reliable than those in precipitation. This is reasonable, since precipitation, particularly East Asian precipitation, is difficult to be simulated well by current models (Kang *et al.*, 2002). In this study, we focus on the change in large-scale atmospheric circulation and its relation to precipitation change. A good relation between precipitation and large-scale circulation and a model with ability of reproducing this relation are a prerequisite of using this approach.

Most previous studies focused on the change in East Asian precipitation in summer, which is the major rainy season. However, spring precipitation is only slightly less than summer precipitation in East Asia. In particular, spring is a pronounced rainy period in South China (e.g., Tian and Yasunari, 1998). On the other hand, spring is the sowing season for most areas in East Asia. Therefore, in order to study

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hydrological cycle changes in East Asia and to assess their impact on society due to global warming, changes in both spring and summer seasons shall be investigated.

2. Model

The model used in this study is a state-of-the-art coupled atmosphere-ocean general circulation model developed at the Hadley Centre (HadCM3). The atmospheric component of HadCM3 has 19 levels with a horizontal resolution of 2.5° of latitude by 3.75° of longitude (Pope *et al*., 2000), and the oceanic component has 20 levels with a horizontal resolution of 1.25 by 1.25° (Gordon *et al*., 2000). The two components are coupled once a day. The model does not require flux corrections to maintain a stable climate. The mean climate and its stability in a 1000-yr control simulation are discussed in Gordon *et al*. (2000). A single realization of a standard 1% yr^{-1} CO_2 increase experiment is examined and periods of years 1-20 and 61-80 when CO_2 doubles are used to depict the climate change.

The HadCM3 is one of the fully coupled atmosphere-ocean models with a relatively better performance for simulating East Asian climatology (Jiang *et al*., 2005). In addition, it has a considerable ability in reproducing the climatological means in the Asia monsoon region and western North Pacific, and captures well the features of ENSO-Asian monsoon interaction (Li *et al*., 2007). The ENSO-Asian monsoon interaction plays an important role in influencing the climate in East Asia (Huang and Wu, 1989; Zhang *et al*., 1999, 2002; Wang *et al*., 2000). Thus, it is crucial for such an interaction to be captured by the models that are used to estimate the climate change in East Asia under the global warming.

3. Results

a. Relation between the East Asian Precipitation and Large-scale Circulation

As the first step, we show the model's performance for simulating East Asian climatology of precipitation and lower-tropospheric wind (Figure 1). The model captures the main feature of the subtropical anticyclone over the western North Pacific, which is formed in spring and becomes strengthened and extends further northward in summer. In addition, it reproduces the seasonal state of mid-latitude circulation, that is, westerly over the northern Eurasia and northwesterly over Northeast Asia in spring and the great weakness of these flows in summer.

The model also basically reproduces the East Asian rain band in both spring and summer. The rain band appears over South China and extends northeastward into west Pacific in spring, and shifts northward in summer. The significant intensified summer monsoon rainfall in South Asia and the tropical western North Pacific is also well captured. However, the model simulates a relatively strengthened and equatorward located rain belt in summer, which is associated the similar discrepancy in the southwesterly over East Asia and the western North Pacific.

Then, we examine the interannual variability by focusing on the relationship between the East Asian precipitation and large-scale circulation in observations and check whether the HadCM3 has the ability to reproduce this relationship in its 1000-yr control integration. Figure 2 shows the 850-hPa horizontal wind regressed onto the standardized precipitation averaged over East Asian region (110-140°E, 27.5-35°N) in observations and HadCM3 control simulation, respectively. For observations (from 1979 to 2003), wind data are obtained from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis dataset, and precipitation data from the Climate Prediction Center (CPC) Merged Analysis of Precipitation (CMAP; Xie and Arkin, 1997). The mean precipitation over the East Asian region in simulation (observations) is 5.14 (5.01) and 7.41 (6.26) in spring and summer, respectively, and its interannual standard deviation in simulation (observations) is 0.71 (0.55) and 1.09 (0.74) in spring and summer, respectively. These values suggest that the model realistically simulates, although somewhat overestimates, the mean precipitation over the region and its variability, including the sea-

sonal change between spring and summer.

In observations, associated with more precipitation in East Asia in spring, there is a significant southerly anomaly in lower troposphere over South China, East China Sea and South China Sea, which is associated with an anticyclonic anomaly over the tropical and subtropical western North Pacific (Figure 2a). This southerly anomaly, overlapped on the climatological southerly flows, strengthens the moisture flux into East Asia. In summer, the pattern of circulation anomalies associated with more precipitation in East Asia resembles that in spring, but with larger magnitude. For instance, there are also a significant southerly anomaly over South China, an anticyclonic anomaly over the tropical and subtropical western North Pacific, and a cyclonic anomaly in the North Pacific (Figure 2b).

The HadCM3 basically reproduces these circulation anomalies associated with more precipitation in East Asia both in spring and in summer (Figures 2c and 2d). A significant southerly anomaly appears over South China, East China Sea and South China Sea, and is also linked with an anticyclonic anomaly over the tropical and subtropical western North Pacific.

b. Projected Change in East Asian Precipitation

Shown in Figure 3 are the precipitation anomalies of the 20-year average (years 61 to 80) at the time

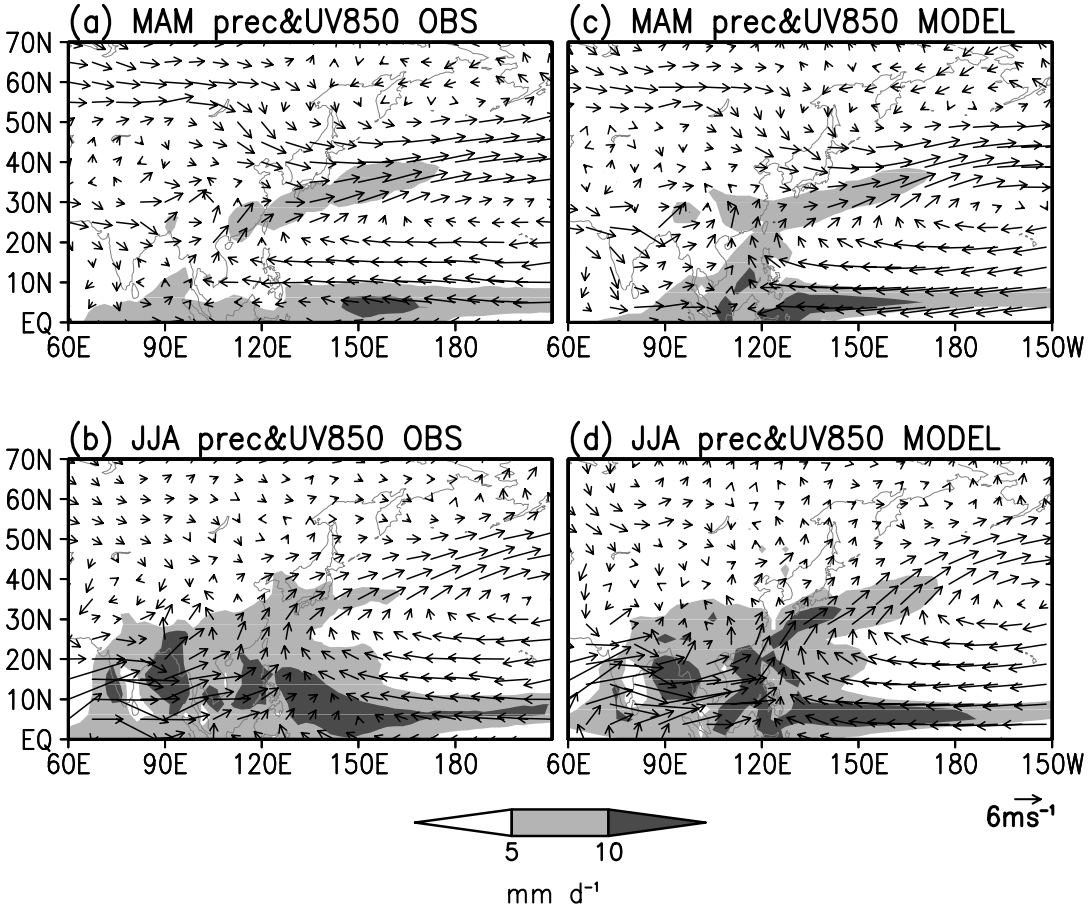

Fig. 1. The climatological precipitation and 850-hPa horizontal wind, with precipitation as shades and wind as vectors, in spring (a and c) and summer (b and d), and in observations (a and b) and HadCM3 control simulation (c and d), respectively.

when CO_2 doubles relative to the initial 20 year mean from the 1% yr^{-1} increase of atmosphere CO_2 simulation of HadCM3. It clearly demonstrates the enhancement of spring precipitation in South China and central China under the global warming. The region of the enhancement extends eastwards into southern Japan. In summer, the enhanced precipitation appears in a broader area of East Asia (Figure 3b), extending into North China and Korea. Over the region (110-140°E, 27.5-35°N), which is used to denote

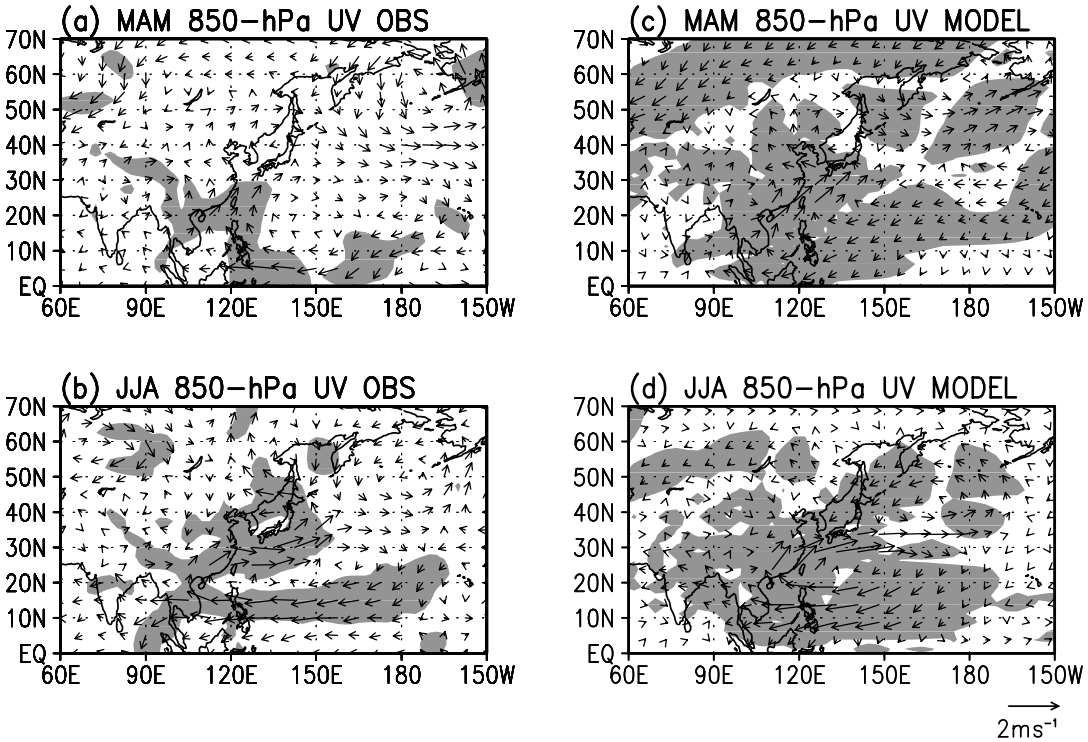

Fig. 2. The 850-hPa horizontal wind regressed onto the standardized precipitation averaged over the region (110-140°E, 27.5-35°N) in spring (a and c) and summer (b and d), and in observations (a and b) and HadCM3 simulations (c and d), respectively. Unit: ms^{-1}. The shaded regions indicate statistical significance at 95% level for either zonal or meridional wind anomalies based on the F-test.

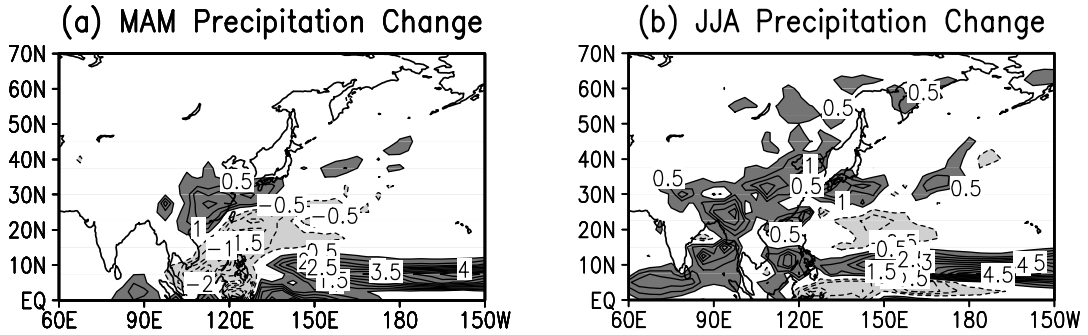

Fig. 3. Simulated precipitation anomalies of the 20-year average (years 61 to 80) at the time when CO_2 doubles relative to the initial 20 year mean from the 1% yr^{-1} increase of atmosphere CO_2 simulation of HadCM3. Unit: mm day^{-1}. (a) Spring; (b) Summer.

East Asia in this study, the enhancement of precipitation is pronounced both in spring and in summer. The enhancement of summer precipitation in East Asia is consistent with previous findings (e.g., Hu *et al*., 2000; Kimoto, 2005).

Under the global warming, a lower-tropospheric southerly anomaly is projected over the eastern extent of China in spring and summer (Figures 4a and 4b). There is also an anticyclonic anomaly over the subtropical western North Pacific. The pattern of these circulation anomalies resembles to that associated with interannual variability in observations (as shown in Figure 2), but the anomalous southerly extends further polewards into North China and Northeast China. The moisture content at 850 hPa is increased in the whole domain of the figures, while the most pronounced increase appear over South China and central China in spring and East Asia and Northeast Asia in summer (Figures 4c and 4d). Similar increase of moisture content in India under the global warming has been identified by Kitoh *et al*. (1997).

4. Conclusions

A fully coupled atmosphere-ocean model, HadCM3, which is found to have the ability of reproducing the observed relationship between the East Asian precipitation and large-scale circulation associated with interannual variability in its control integration, is utilized to investigate the East Asian precipitation changes in spring and summer under the standard 1% yr^{-1} CO_2 increase. The model's projected circulation anomalies basically resemble those associated with more precipitation in East Asia in interannual variability based on observations. Under the global warming, enhanced southerly flows lead to enhanced moisture transport over East Asia from the tropics

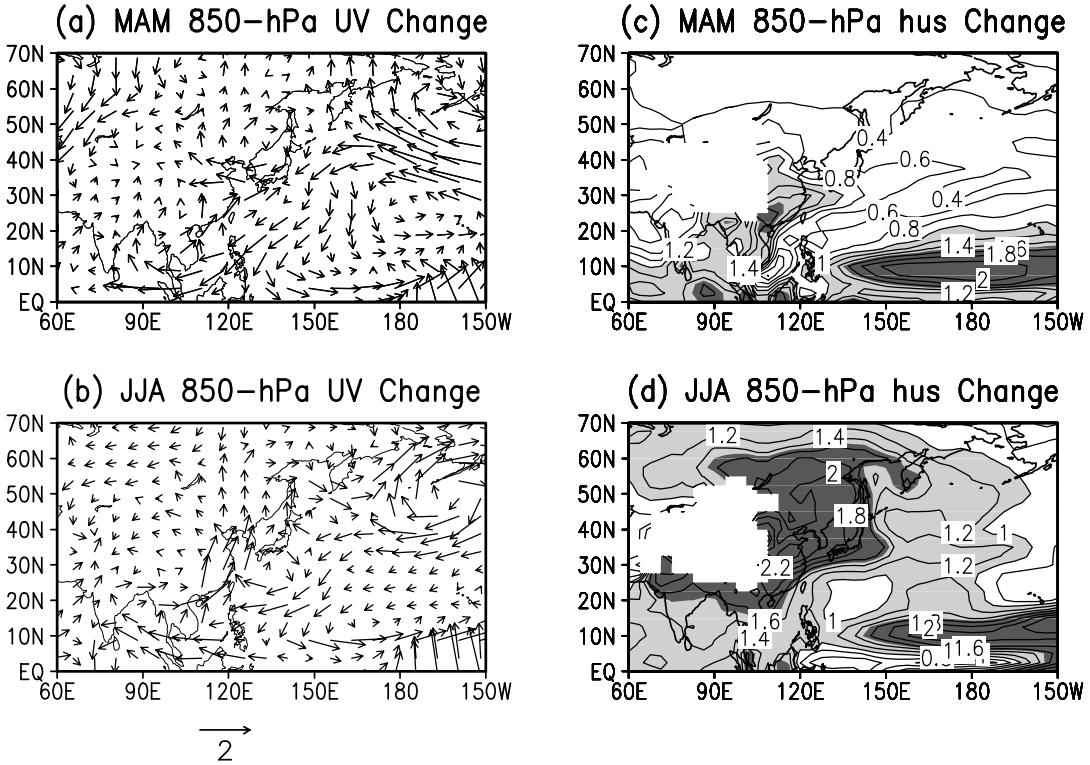

Fig. 4. As Figure 3, but for anomalies in horizontal wind (a and b, unit: m s^{-1}) and specific humidity (c and d, unit: 10^{-3}kg kg^{-1}) at 850 hPa, in spring (a and c) and summer (b and d), respectively. The values of specific humidity change larger than 1.0 and 1.5 are shaded lightly and heavily, respectively.

and resultant increased precipitation and moisture content. The present result on increased precipitation in East Asia in summer is consistent with previous results, most of which are obtained by the approach of multi-model ensembles. However, the good simulation of mean climate, its interannual variability, and the reproducibility of the relationship between precipitation and circulation associated with interannual variability over East Asia by HadCM3 give us more confidence for regional climate change signals in such model.

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REFERENCES

Bueh, C., U. Cubasch, Y. Lin, and L. Ji, 2003: The change of North China climate in transient simulations using the IPCC SRES A2 and B2 scenarios with a coupled atmosphere-ocean general circulation model. *Adv. Atmos. Sci.*, **20**, 755-766.

Gordon, C., C. Cooper, C. A. Senior, H. Banks, J. M. Gregory, T. C. Johns, J. F. B. Mitchell, and R. A. Wood, 2000: The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. *Climate Dyn.*, **16**, 147-168.

Huang, R., and Y. Wu, 1989: The influence of ENSO on the summer climate change in China and its mechanism. *Adv. Atmos. Sci.*, **6**, 21-32.

Hu, Z.-Z., M. Latif, E. Roeckner, and L. Bengtsson, 2000: Intensified Asian summer monsoon and its variability in a coupled model forced by increasing greenhouse gas concentrations. *Geophys. Res. lett*, **27**, 2681-2684.

_____, S. Yang, and R. Wu, 2003: Long-term climate variations in China and global signals. *J. Geophys. Res.*, **108**, 4614, doi:10.1029/2003JD003651.

Jiang, D., H. Wang, and X. Lang, 2005: Evaluation of East Asian climatology as simulated by seven coupled models. *Adv. Atmos. Sci.*, **22**, 479-495.

Kang, I.-S., et al., 2002: Intercomparison of the climatological variations of Asian summer monsoon precipitation simulated by 10 GCMs. *Climate Dyn.*, **19**, 383-395.

Kato, H., N. Oshima, and S. Kadokura, 2005: Performance of global climate models for reproducing present SLP field over eastern Asian region in the CO_2 transient run. *J. Meteor. Soc. Japan*, **83**, 169-188.

Kimoto, M., 2005: Simulated change of the East Asian circulation under the global warming. *Geophys. Res. Lett.*, **32**, L16701, doi:10.1029/2005GL023383.

Kitoh, A., M. Hosaka, Y. Adachi, and K. Kamiguchi, 2005: Future projections of precipitation characteristics in East Asia simulated by the MRI CGCM2. *Adv. Atmos. Sci.*, **22**, 467-478.

_____, S. Yukimoto, A. Noda, and T. Motoi, 1997: Simulated changes in the Asian summer monsoon at times of increased atmospheric CO_2. *J. Meteor. Soc. Japan*, **75**, 1019-1031.

Li, Y., R. Lu, and B. Dong, 2007: The ENSO-Asian monsoon interaction in a coupled ocean-atmosphere GCM. *J. Climate*, in press.

Min, S.-K., E-H. Park, and W.-T. Kwon, 2004: Future projections of East Asian climate change from multi-AOGCM ensembles of IPCC SRES scenario simulations. *J. Meteor. Soc. Japan*, **82**, 1187-1211.

Mitchell, J. F. B, C.A. Wilson, and W.M. Cunnington, 1987: On CO_2 sensitivity and model dependence of results. *Quart. J. Roy. Meteor. Soc*., **113**, 293-322.

Pope, V. D., M. L. Gallani, P. R. Rowntree, and R. A. Stratton, 2000: The impact of new physical parameterizations in the Hadley Centre climate model - HadAM3. *Climate Dyn*., **16**, 123-146.

Tian, S.-F., and T. Yasunari, 1998: Climatological aspects and mechanism of spring persistent rains over central China. *J. Meteor. Soc. Japan*, **76**, 57-71.

Wang, B., R. Wu, and X. Fu, 2000: Pacific-East Asian teleconnection: How does ENSO affect East Asian climate? *J. Climate*, **13**, 1517-1536.

Xie, P., and P. A. Arkin, 1997: Global precipitation: A 17-year monthly analysis based on gauge observations, satellite estimates, and numerical outputs. *Bull. Amer. Meteor. Soc.*, **78**, 2539-2558.

Zhang, R., A. Sumi, and M. Kimoto, 2002: Moisture circulation over East Asia during El Niño episode in Northern winter, spring and autumn. *J. Meteor. Soc. Japan*, **80**, 213-227.

_____, _____, and _____, 1999: A diagnosis study of the impact of El Niño on the precipitation in China. *Adv. Atmos. Sci.*, **16**, 229-241.