# P3.16 EFFECT OF THE TIBETAN PLATEAU ON THE EAST ASIAN MONSOON CIRCULATION : A REGIONAL CIMATE MODEL STUDY

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## 1. INTRODUCTION

The monsoon is basically a response of the atmosphere to the differential heating between the land mass of the Asian continent and the adjacent oceans. The atmospheric response, however, may be quite complicated due to the interactions between the atmospheric heat sources, land-sea contrast and topography. The East Asian monsoon exhibits a particularly complex seasonal behavior resulting from combination of strong tropical and middle latitude influences.

Many studies have reported that large-scale mountains such as the Tibetan Plateau (TP), play essential roles in forming and developing the present East Asian monsoon system. Several General Circulation Model (GCM) studies also verified that mountain height of TP could affect activity of East Asian monsoon considerably. Hahn and Manabe (1975) showed that mountains have an important effect on the onset and temporal variations of the Asian monsoon. Prell and Kutzbach (1992) conducted experiments with no mountains, half mountains, and full mountains by National Center for Atmospheric Research Community Climate Models, and concluded that at least half of the present-day elevations are a prerequisite for a strong Indian summer monsoon. Kitoh (2004) reported in his GCM study that the North Pacific High (NPH) strengthened by the TP uplift leads to more moisture transport toward the East Asian region.

Meanwhile, most of the previous studies on the role of TP in the East Asia monsoon have been conducted by using GCMs or simple models. However, GCM studies have several limitations to understanding mechanisms responsible for East Asian monsoons. One of these typical limitations is the predictability problem due to long-term integration.

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Another is due to a coarse-resolution of GCMs covering the globe. To circumvent the resolution problem in GCMs, the regional climate model (RCM) approach has been actively utilized. For example, Ji and Vernekar (1997) showed that a regional model nested in a GCM simulates the monsoon circulation and precipitation over India and East Asia better than a GCM. In this study, we also use a RCM approach to get an advantage of high resolution model on investigating the effect of TP height on the East Asian monsoon system. As well, because a RCM has an advantage of allowing isolation of the regional feedbacks due to using reanalysis data as a lateral boundary conditions, we use a RCM in this study. Particularly, effect of mountain heights on the East Asian monsoon in the RCM has been investigated by performing several experiments which changed mountain heights of TP every 20% from zero to 140 percents.

## 2. MODEL AND EXPERIMENTAL DESIGN

The National Centers for Environmental Prediction (NCEP) Regional Spectral Model (RSM, Juang et al., 1997) is used in this study. The physics options are the same as a version of the global model when created the NCEP/DOE Reanalysis Ⅱ data. The RSM domain (53-151°E, 2°S-57°N) covers Indian monsoon and East Asian monsoon regions. The number of grid points in Cartesian coordinates is 151 in west-east direction and 110 in north-south direction. A 60km resolution is chosen so that the RSM captures meso-α scale features embedded in the planetary-scale monsoon system. The initial conditions and large-scale lateral boundary forcing were obtained from the NCEP/DOE Reanalysis Ⅱ data (Kanamitsu et al. 2002). Three months runs are designed starting from 0000 UTC 1 June 2004.

Similarly to Kitoh (2004), nine runs are designed to investigate the role of TP height variation in the simulation of the East Asian summer monsoon. The control run (M10) was integrated with a realistic land-sea distribution and orography. In the M0 run, the TP mountain height was set to zero, but the land-sea distribution was kept the same. The M2, M4, M6, and M8 runs used the 20%, 40%, 60%, and 80% height of the M10 orography. The initial conditions of all mountain runs are the same. Also we included the M12 and M14 runs that used the increased mountain height of 120% and 140%, respectively.

## 3. RESULTS AND DISCUSSION

### *a. Control simulation (M10)*

Overall, the M10 experiment reproduces precipitation and large-scale features very well in terms of seasonal mean (Table 1) as well as intra-seasonal variability. The model successfully simulates observed rainfall and the circulation associated with the summer monsoon over whole domain. Four rainfall areas which represent Chang-ma, Mei-yu and Baiu frontal rainfall and Indian monsoon precipitation, were well-simulated over each region - the Korean peninsula, Japan, South China and Indian continent (Fig. 1.). Also, the circulation associated with the summer monsoon is well-simulated. In case of intra-seasonal variation, the control run is well-simulated evolution of the monsoonal precipitation(not shown). The model results exhibit some details related to the orography distribution, for example, a peak at the western flank of the Indian continent. Note that detailed features in precipitation are absent in the observation due to a grid resolution of 1°.

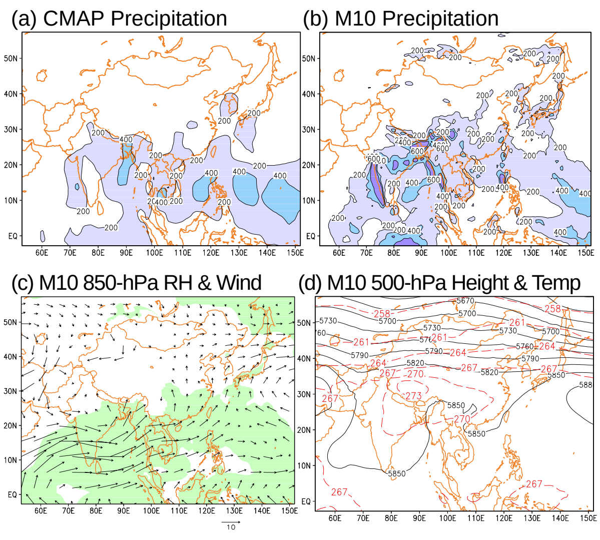



Fig. 1. Seasonal mean of (a) observed rainfall (mm month$^{-1}$) and (b) simulated rainfall value greater than 200 mm month$^{-1}$ (mm month$^{-1}$). Seasonally averaged fields of control simulation for (c) 850hPa wind (vector, m s$^{-1}$) and RH (shaded greater than 70%, %) and (d) 500-hPa height (solid line, gpm) and temperature (light dashed line, K).

### *b. Seasonal change due to height of TP*

In the whole experiments, differences of the simulated rainfall amount over the equatorial region near India are not large (Table 2). It means that the all the experiments simulated the typical Indian monsoon rainfall very well. However, over East Asian region – in particular over the east China region -, monsoon precipitation amount due to TP height change shows clear differences. Change in precipitation pattern over the east Asian region can be easily seen in Fig. 2.

Table 1. Statistics of control experiment (M10) compared with CMAP for precipitation and Reanalysis II data for large – scale mean field during summer in 2004.

| Variables | Bias | RMSE | Pattern Correlation |
|---|---|---|---|
| Precipitation (mm/day) | 1.03 | 4.38 | 0.61 |
| 850-hPa temp. (K) | - 0.32 | 0.81 | 0.91 |
| 500-hPa temp. (K) | - 0.01 | 0.32 | 0.96 |
| 300-hPa temp. (K) | 0.16 | 0.47 | 0.98 |
| 850-hPa wind (m/s) | 0.54 | 1.80 | 0.82 |
| 200-hPa wind (m/s) | 0.61 | 1.83 | 0.97 |
| 500-hPa height (gpm) | - 6.0 | 7.9 | 0.91 |

Figure 2 shows the rainfall differences between the runs with 40% lower and higher height of TP and the control experiment. Big differences appear over the China and Japan region The precipitation amount increases/decreases in case of higher/lower height of TP over East China region. However the precipitation difference due to the height variation over Japan represents the opposite aspects to the China area. The local rainfall in this region is weakened/enhanced in case of hight/lower TP height.

These changes in precipitation amount over the east Asian region including Korea and Japan is directly due to the change in moisture transport at the lower atmosphere connected with the monsoon circulation. According to the pattern of low-level moisture flux at the 850 hPa level (not shown), the M6 experiment shows weakened moisture transport from the equatorial region to the east Asia compared to the control run. As well, the main moisture flow originated from the Indian monsoon region is deflected to the east China area. On the contrary, the M14 case simulates the strengthened low-level moisture flow represents toward the east Asian region.

In order to examine the changes in the physical processes, we investigate the difference of the sensible heat flux with variation of the TP height in Fig. 3. In the M6 case, lower TP leads to smaller sensible heat flux over the Plateau, but larger flux over the surrounding area such like the northern India and east China. Smaller sensible heat flux over the

TP is presumably due to the smaller albedo by the lower height. On the contrary, the M14 run simulates the larger sensible heat flux over the TP and the smaller flux over the India and China regions. The change in the sensible heat flux over the land can considerably affect on the monsoonal flow which is caused by the different heating between the land and ocean. In fact, change rates of sensible heat flux over land compared with M10 are 0.95 and 1.02 for M6 and M14, respectively. Therefore these differences can lead to changes in the intensity and main direction of the monsoonal flow..

Table 2. Rate of M6 and M14 precipitation compared with M10 for summer over the Korea and Japan (121~145°E, 25~45°N), East China (105~121°E, 25~45°N), South China (95~145°E, 5~24°N), North India (64~95°E, 17~30°N) and South India (64~95°E, 25~45°N).

| Area | M6 | M14 |
|---|---|---|
| Whole domain | 0.99 | 0.99 |
| Korea and Japan | 0.93 | 0.90 |
| East China | 0.95 | 1.14 |
| South China | 0.99 | 1.03 |
| North India | 0.99 | 0.99 |
| South India | 1.01 | 0.99 |

(a) M6 – M10 (b) M14 – M10

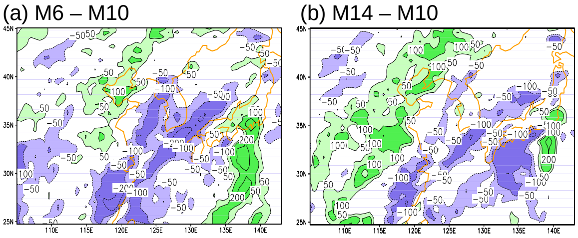


Fig. 2. Difference of precipitation (mm $JJA^{-1}$) over the East Asian region in summer of 2004. (a) represents M6 minus M10 and (b) is M14 minus M10. Contour intervals are 400 mm and shaded area denotes the greater value than 200 mm.

Figure 4 shows the change in Tibetan High due to the change of TP height. It is clear that the height of TP has an great influence on strength of Tibetan High, leading to the change in the upper level pressure system over the East Asian region. In case of experiment with lower TP height, Tibetan High is weakened over the whole Tibet region, leading to weakening updraft. In contrary, the M6 experiment shows that eddy height at the upper level over the lee-side of TP is higher than that of the control run. The noticeable feature in Fig. 4(a) is that the vertical velocity becomes smaller over the East China region and larger over the Japan region.

(a) M6 – M10 (b) M14 – M10

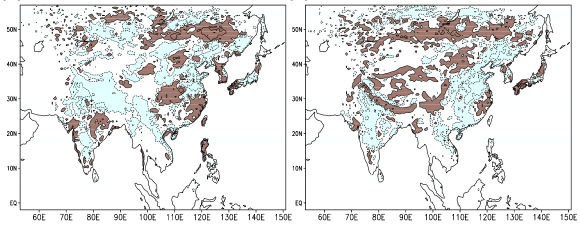


Fig. 3. Difference of sensible heat flux (W $m^{-2}$) compared with control experiment (M10). Brown shaded is positive value and blue shaded is negative value for (a) M6 minus M10 and (b) M14 minus M10 of JJA mean.

Meanwhile, in the run with higher TP, higher eddy height appears over the wide region ranging from the TP to the lee-side. Also upward motion is intensified over the East China region. Especially, the change in the upper tropospheric flow is affected on the Changma due to the middle latitude jet. The jet move to higher/lower latitude and the rainfall decrease/increase over the Korean peninsula.

(a) M6 – M10 (b) M14 – M10

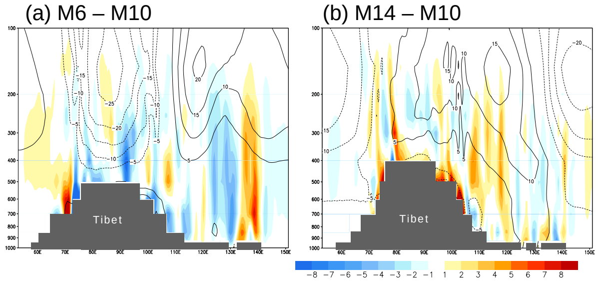
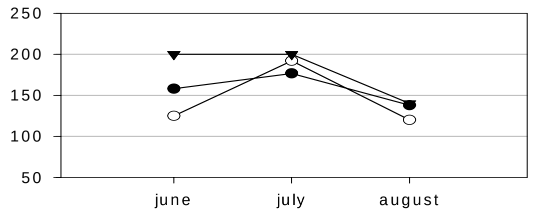



Fig. 4. Longitude-pressure cross sections of difference of the eddy height (m) (contour) and vertical velocity (×$10^{-2}$ Pa $s^{-1}$) (shaded) for (a) M6 minus M10 and (b) M14 minus M10 of JJA mean. Contour interval is 5 m.

*c. Intra-seasonal change due to height of TP*

In this section, we describe the effect of the TP height on the intra-seasonal variation of the east Asian monsoon. Speaking in conclusion, the change in the monsoon circulation due to the TP height change does not show the same aspect during the evolution period of the east Asia summer monsoon. Figure 5 represents the accumulated monthly precipitation over two different regions. The difference of precipitation amount on June and July when the summer monsoon is developing over the east Asian region is clearly showed up, but the rainfall difference is unclear on August. However, evolution feature of monthly precipitation over two regions (Figs. 5a and 5b) shows the contrary changes consistently with Fig. 2.

(a) East China




(b) Korea and Japan

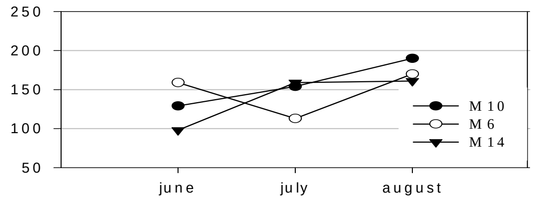



Fig. 5. Temporal evolution of monthly accumulated precipitation (mm month$^{-1}$) over (a) East China and (b) Korea-Japan region.

From Fig. 5, it is clear that the mountains have an important effect on the onset and intensity variations of the east Asian summer monsoon, in particular. On June when the east Asian monsoon starts to be developed climatologically, the baroclinic instability is momentous over the East Asia. This period is well known as a period when the thermal forcing of TP becomes the maximum. Therefore, it is presumable that the difference in thermal forcing due to the TP height provokes the large impact on the east Asian summer monsoon in this period. As well, this impact decreases gradually with the lapse of time due to the decrease of baroclinic instability over this region during the mutual and decaying stage of the monsoon.

## 4. SUMMARY AND CONCLUSION

This study using the RSM indicates that the simulation of the East Asian monsoonal precipitation is sensitive to the variation of height of the TP. The changes in large-scale fields depending on the height of TP area directly related to weakening and enhancement of Tibetan High. Also the corresponding changes in precipitation pattern are clearly different from each other over the prescribed the East China, Korea and Japan. Because the monsoon trough is moved and weakened/strengthened due to variation of thermal forcing of TP, upper troposphere flow and transport moisture over the East Asia.

Impact of the Tibetan Plateau on the East Asian summer rainfall was examined with the advantages of RCMs, which was not possible previous GCM studies. These are emphasized that mountains have an important effect on the onset and large-scale variation of the EASM. Our results are valuable in a sense that the importance of real topography which is effected on change of precipitation and large-scale field.

## ACKNOWLEDGEMENTS

This research was supported by the Climate Environment System Research Center sponsored by the SRC program of Korea Science and Engineering Foundation, and by the Korea Meteorological Administration through the R&D project.

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