The roles of orography on Northeastern Asia dry climate

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1. Introduction

Broadly spread arid regions are found between 15° and 35° in both of northern and southern hemisphere. The formations of these arid regions are considered to be caused by the subsidence branch of Hadley circulation. In Northeastern Asia, however, arid and semi-arid climate distribute over remarkably higher latitude, namely from 30°N to 50°N, characterized as Steppe in Central Asia or Mongolia, Taklimakan desert and Gobi desert.

Broccoli and Manabe (1992) investigated the influence of Tibetan plateau upon the maintenance of dry climate in midlatitude Asia, and concluded that the plateau is the main reason for these arid/semi-arid areas although its mechanism depends on the season. It is well known, however, that the seasonal variations of precipitation are different between the eastward and westward regions from the Tian-Shan mountain range.
Their theory does not cover this fact. Large unknown part still remains in the mechanism which maintains dry climate in Northeastern Asia.

2. Model description

A regional climate modeling system (RAMS) is used to simulate the precipitation in Northeastern Asia in warm and cold season with (CNTL) and without westward topography of the Tian-Shan and the Altai Mts. (NOM). The model simulates the synoptic disturbances during each whole month of June and January of 1998, by using NCEP/NCAR reanalysis as a boundary condition. The convection parameterization presented by Arakawa and Shubert (1972) and microphysical parameterization by Walko et al. (1995) are used to predict the synoptic scale disturbances with precipitation in high resolution.

3. Result

3.1 Warm season

The arid region with small amount of precipitation, less than 10 mm/month, is produced in CNTL run (fig.1), which corresponds well with satellite estimated data of GPCP. Water vapor transported into the arid region is mainly derived from Central Russia, i.e. from the northwestern part of mountain ranges, although amount of the water vapor seems evidently decreased when it is going over the mountain ranges.

The monthly precipitation of MON run shows that the arid region still exists, although the maintain ranges which would work as a trap of water vapor from western Siberia were omitted in the model (fig.2). This means that the reason of the small amount of precipitation in the Mongolian Plateau does not always seem to be the trap of moisture by the mountain range. Meridional-Time cross section of vertical motion at 85°E reveals the prominent peak in diurnal variation of upward motions over Kunlun Mts., while gentle downward motions are found over Taklimakan desert (fig.3). A couple of upward and downward motion is emphasized in 11th JUN, which causes the subsidence over the Taklimakan desert and the apparent decrease of precipitation there.

3.2 Cold season

The widespread dry climate over the Mongolian Plateau is simulated in January, although rainfall is relatively over estimated compared with GPCP. Monthly averaged mixing ratio for cloud water is shown in a longitude cross section, which seems to be trapped over the windward of the mountain range. Furthermore, the synoptic scale upward motion is found over the westward of the mountain ranges, while the downward motion locates over the eastward of them. Vertical wind pattern mentioned here is referred as a mountain wave generated by large amplitude of mountain. The eastern subsidence would also play a role as suppression of the convection over the Mongolian Plateau.

4. Conclusion

In warm season, synoptic scale frontgenetics and local scale circulation around mountains bring moderate precipitation over Northeastern Asia. When the font is approaching, the enhancement of convection over the northern edge of the Tibetan Plateau causes to reinforce the subsidence over arid region and suppress convections there.

On the other hand, the eastern mountain ranges, such as the Tian-Shan, trapped the synoptic disturbances and moisture in cold season, so that the dry air is advected into the plateau of northeastern Asia.

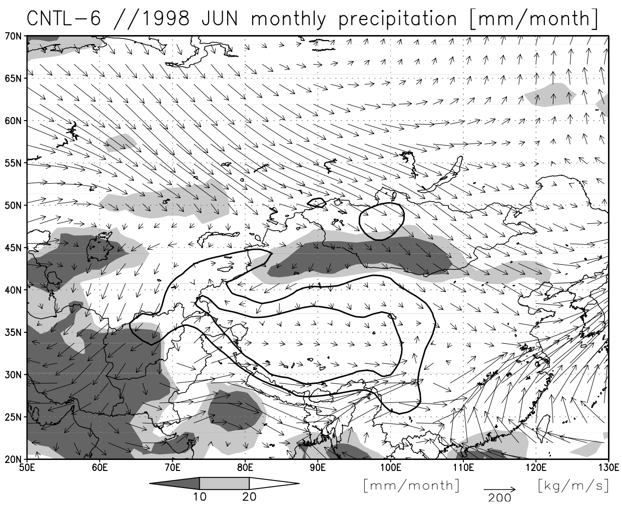

Fig. 1. Monthly precipitation and Monthly averaged water vapor transport in JUNE simulated in CNTL run. Dark shaded regions correspond to less than 10mm/montlh.

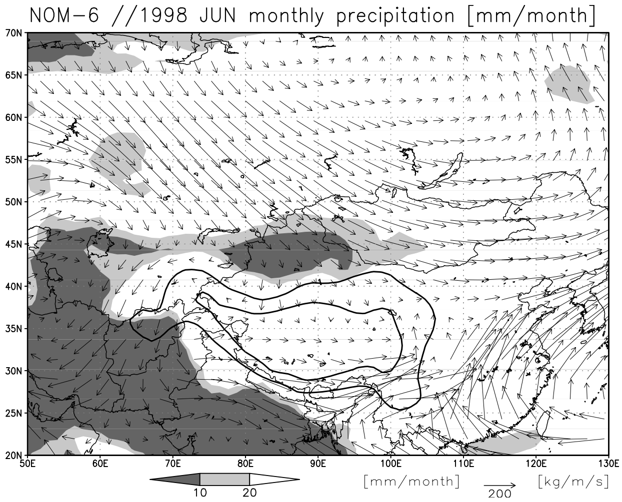

Fig. 2. Same as Fig. 1. except for in NOM run.

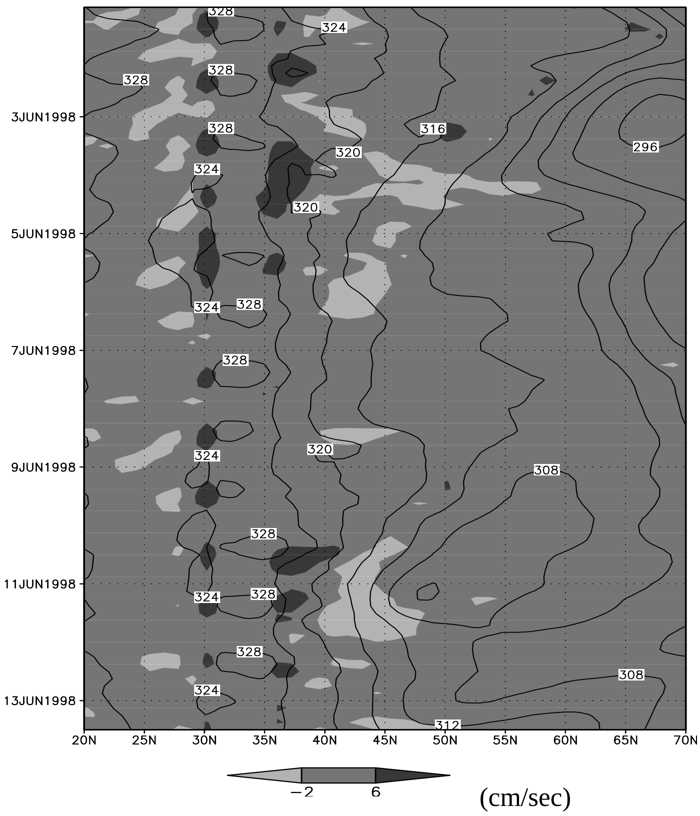

Fig. 3. Meridional-time cross section of 500 hPa vertical wind (shaded) and potential temperature (solid line) at 85°E in JUNE simulated in NOM run. Dark (light) shaded region indicates the upward (downward) motion.

5. Research plan for the mesoscale atmospheric modeling

5.1 Objectives

The objectives of the modeling study are the following two. First is to clarify the mechanism of the regional climate system and its variation around Mongolian Plateau. The second is to clarify the interaction between hydrological process and mesoscale precipitation system generated there. To achieve the second objective, characteristics of the mesoscale precipitation system must be understand on the view of the larger horizontal scale, especially of the synoptic scale. So that a study aimed at the first objective must be started at first.

5.2 Mechanism of the regional climate system

To clarify the roles of orography on Northeastern Asia dry climate regions, analytical studies and numerical modeling are going on as mentioned in the previous section. We have already some impressive results. The major climate system in these regions is controlled by the different orographically induced circulations between warm and cold seasons.

In cold season, moisture supplied by westerly is trapped by the mountain range and dry air goes down in the lee, so that the precipitation is suppressed there. Gravity waves are generated by the mountain range and by Tibetan Plateau under the strong westerly. Rossby waves are also formed as mentioned by Broccoli and Manabe (1992). These must depend on the large scale circulation and static stability. However, the activity of these waves formed by orography is still not clarified yet, and effects on the local precipitation system have not been estimated. To estimate these facts, reliability of the regional climate model is not enough. Monthly mean precipitation is overestimated during winter. One of the reasons of the low accuracy is a poor land surface physics in the model, which is not enough to estimate heat budget over snow cover. The land surface physics, especially snow cover must be improved. Another reason is the problem on the cumulus parameterization, which will be discussed in the next section. After resolved these problems of the model, orographic effects on the gravity waves and on the moisture transport should be investigated by the regional climate model using analysis data, satellite data and surface observation data.

In warm season, convection systems in Tibetan Plateau seem to restrain the precipitation of Mongolian Plateau. The convection system in Tibet is affected by the synoptic-scale disturbance such as a trough. Tian-Shan mountain range and northern mountain range of Mongolian Plateau seems to contribute reinforce precipitation along the mountain ranges during summer, in contrast to the cold season. The precipitation reinforced by these mountains shows clear diurnal variation and horizontal distribution associated with orography. These are quite important for water cycle in this region during summer.

5.3 Rainfall systems around the mountain range during warm season.

The diurnal variation and horizontal variation of rainfall in the warm season might be affected by the thermally induced local circulations. In Kanto Plain, frequency and amount of precipitation have clear diurnal cycles, and horizontal distributions of them are correlate well to the orography. These facts have been studied by radar data and surface observation data obtained by AMeDAS. Recently, precipitable water can be estimated by GPS receivers contributing to study of moisture transport. By these studies in addition to numerical studies, it found that the clear diurnal variation of precipitation around northern Kanto Plain is caused by the moisture convergence by the upslope winds during daytime. During IOP year, 2003, several GPS stations will be set up and Doppler radar echo will be continuously archived, beside intensive surface boundary layer and hydrological observation in Mongol. These data will be analyzed together with the satellite images and will be compared with that of Kanto Plain. Mesoscale numerical simulation will be also carried out to find out the major factors for the activity of the precipitation system, including orographic effects, large scale moisture advection and atmospheric static instability.

In order to simulate the diurnal cycle of the activities of cloud and rainfall, the numerical models assuming the cumulus parameterization has not good accuracy enough to simulate them. It has been well known that the phase of the diurnal cycle will be simulated incorrectly by them. A cloud resolved model, which is a non-hydrostatic atmospheric model having very high resolution, is expected to correctly simulate them using the cloud microphysics. One of the cloud resolved model TERC-RAMS, a modified version of RAMS developed by CSU, has been applied to the Kanto Plain and obtained some satisfactory results for the precipitation during summer season.

5.4 Effects of surface process on the convection system

During the warm season, precipitation system would be affected by the thermally induced local circulation around the northern mountains in Mongol. These activities may be quite sensitive to the land surface process, especially, distribution of sensible heat flux. Even precipitation system over flat plain or basin far from the mountains may be affected by them. Lee and Kimura (2001) pointed out the thermally induced upslope and downslope winds around the mountain are very sensitive in the phase of the diurnal cycle to the vegetation contrast between mountain and plain. On the other hand, Sato and Kimura (2002) showed the importance of these wind system to the transport of moisture and precipitation.

Sensitivity tests on the soil moisture and the vegetation over the mountain and plain seem to have some validity to estimate this effects and to predict the magnitude of the effects of anthropogenic surface modification to the precipitation and their feedback system.

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