Numerical simulations on local circulation and cumulus generation over the Loess Plateau in China

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1. Introduction

The previous study showed both surface wetness and vertical profiles of relative humidity affected cumulus generation using a numerical large eddy simulation (LES) of the atmospheric boundary layer (ABL) under a flat and homogeneous surface [*Takahashi* et al., 2007; this issue]. However, the Loess Plateau in China consists of dissected flat tablelands with steep gullies. Thus, the topographical effect on cumulus generation should be considered. Therefore, in order to estimate the topographical effect on cumulus generation, we conduct numerical simulation on the ABL development under the bottom boundary condition being the real-terrain. In this study, we describe the difference in the cumulus generation between under the flat-terrain and under the real-terrain. Then the structure of the local circulation induced by the ABL development is presented.

2. Model description

Four cases in numerical experiments conducted in this study are shown in Table 1. The bottom boundary conditions applied in the experiments were either the real-terrain or the flat-terrain. The flat-terrain condition means the flat and homogeneous surface at 1224 m a.s.l., and this altitude corresponds to the altitude of the tableland at the study site. Based on an observational study over the Loess Plateau [*Li et al.*, 2008], the evaporation efficiency (β) was set to 0.05 assuming a dry case, and 0.2 assuming a wet case. The topography of the real-terrain is depicted in Figure 1. The green area corresponds to the flat tableland ranging from 1200 to 1224 m a.s.l.. The tableland extends from northwest to southeast directions, and gullies whose depth is about 200 m existed northern and southern parts of the tableland. We set the center of the simulation domain as the observational site (35.24°N, 107.68°E) located on the tableland of the Loess Plateau. Hereafter we refer to flat-terrain run for Case 1 and Case 3, real-terrain run for Case 2 and Case 4.

The numerical model used for the experiment is the Cloud Resolving Storm Simulator (CReSS) which uses a 1.5-order turbulence kinetic energy (TKE) closure scheme [*Tsuboki and Sakakibara*, 2003]. Because the bottom boundary applies the real-terrain, we changed the settings from the previous report [*Takahashi* et al., 2007; this issue]. The major changes are as follows. The lateral boundary was set open boundary conditions. In order to take wide buffer region, the simulation domain was spanned 50,000 m × 50,000 m × 11,292 m with a mesh of 500 × 500 × 110 points. In this study, the center domain of 20,000 m × 20,000 m × 11,292 m is used. Time step is set to be 0.5 s.

3. Results and discussion

Figure 2 shows the distribution of vertical integrated cloud liquid water over all integrated time. Cumulus clouds were generated near the top of updrafts. For flat-terrain run (Case 1, 3), small amount of cumulus clouds were generated. However, for real-terrain run (Case 2, 4), large amount of cumulus clouds were generated. If the evaporation efficiency was changed from 0.05 to 0.2 under the same bottom boundary (Case 1 → Case 3, Case 2 → Case 4), cloud liquid water increased. If the bottom boundary was changed from the flat-terrain to the real-terrain under the same evaporation efficiency (Case 1 → Case 2, Case 3 → Case 4), cloud liquid water drastically increased. The increment of cloud liquid water in the latter change was more than that in the former change. For real-terrain run, more cloud water appeared around the edge of the tableland, and thus cumulus clouds were generated in the upwind side of the edge of the tableland.

Structure of a local circulation induced by ABL development was investigated. Figure 3 shows horizontal cross-section of vertical and horizontal wind velocities for Case 1 and Case 2 obtained at 13:20 BST (Beijing Standard Time). For Case 1, updrafts showed the systematical distribution which had Bénard-Rayleigh type cellular convective structures, and compensated downdrafts appeared around the updrafts. For Case 2, updrafts developed around the edge of the tableland, and compensated downdrafts appeared around the gullies. In order to describe the detail structure of ABL, Figure 4 shows x-z cross-section of vertical wind velocity at 13:20 BST. At 0 km in the x axis, an updraft developed, and compensated downdrafts appeared at around the upwind or downwind. At 3 km height of upwind side of the updraft, weak return flow developed. This means a local circulation developed. The horizontal and vertical scales of the local circulation are about 2 km. The vertical scale could be corresponded to the ABL height.

4. Summary

In order to evaluate topographical effect on cumulus generations over the Loess Plateau in China, numerical simulations of ABL are conducted using CReSS. For real-terrain run, large amount of cumulus clouds were generated over the edge of the tableland. This process is explained as follows. Updrafts clearly developed around the edge of the tableland. Local circulations whose vertical scale corresponded to the ABL height were also developed. Because water vapor was accumulated on the tableland by local circulations and thermals, cumulus clouds clearly developed near the top of the updraft. It is concluded that the topography over the Loess Plateau plays an important role on small-scale cumulus generations. These simulation results also showed the topography is more crucial for cumulus generation than surface wetness.

References

Li, W., T. Hiyama, A. Takahashi, M. Nishikawa, N. Kobayashi, A. Higuchi, W. Liu and Y. Fukushima (2008), Seasonal variations in the surface fluxes and surface parameters over Loess Plateau in China, *Hydro. Process.*, revised.

Takahashi, A., T. Hiyama, M. Nishikawa and Y. Fukushima (2007), Impact of change in land surface condition on the development of the atmospheric boundary layer and cumulus clouds over the Loess Plateau in China —Numerical experiment—, Proceedings of YRiS meeting October 2007 (Ishikawa), (this issue).

Tsuboki, K. and A. Sakakibara (2003), Large-scale parallel compuing of cloud resolving storm simulator, *High Peformance Computing*, 243-359, Springer.

Table 1. Summary of the numerical simulation. β is evaporation efficiency.

Case	Case 1	Case 2	Case 3	Case 4
bottom boundary	flat-terrain	real-terrain	flat-terrain	real-terrain
β	0.05	0.05	0.2	0.2

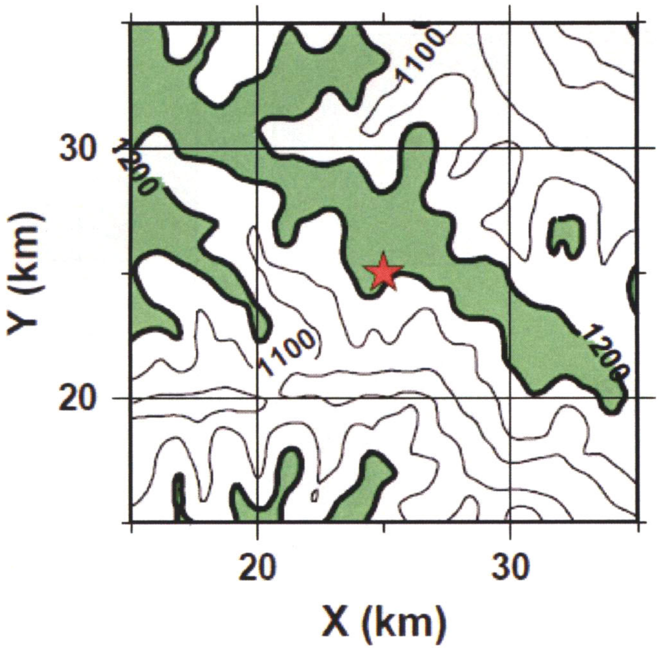
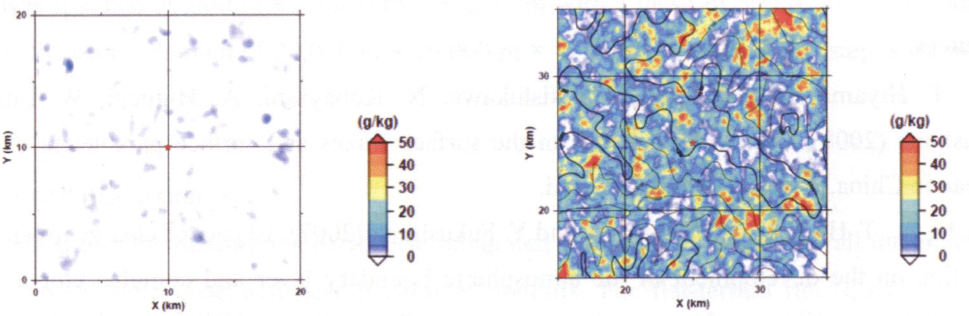


Figure 1. The topography of the real-terrain which is applied to bottom boundary conditions. The green area corresponds to the flat tableland of 1200 - 1224 m a.s.l. The red star represents the center of the simulation domain. (http://www2.jpl.nasa.gov/srtm/)

a) Case 1 (flat, β=0.05)

b) Case 2 (real, β=0.05)



c) Case 3 (flat, β=0.2)

d) Case 4 (real, β=0.2)

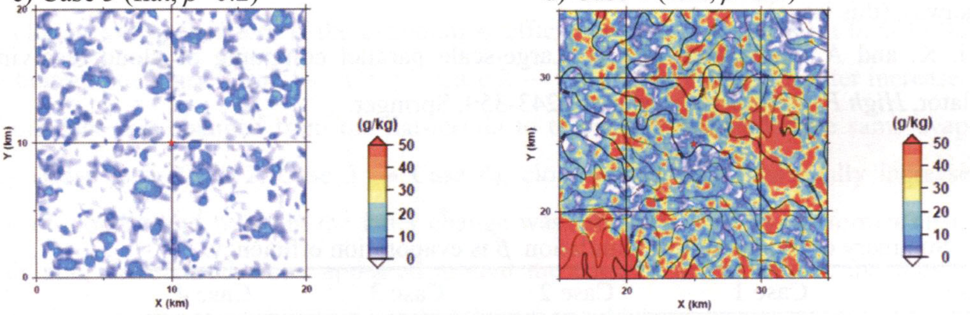
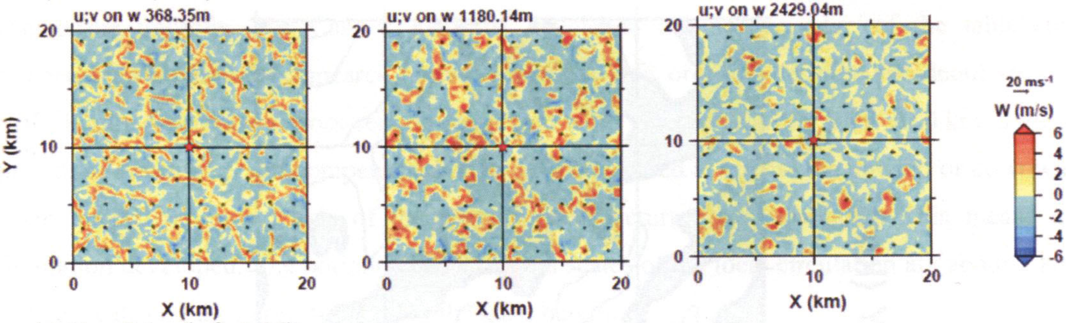


Figure 2. The distribution of vertical integrated cloud liquid water over all integrated time. The contour for real-terrain run is represented every 100 m.

a) Case 1 (flat, β=0.05)



b) Case2 (real, β=0.05)

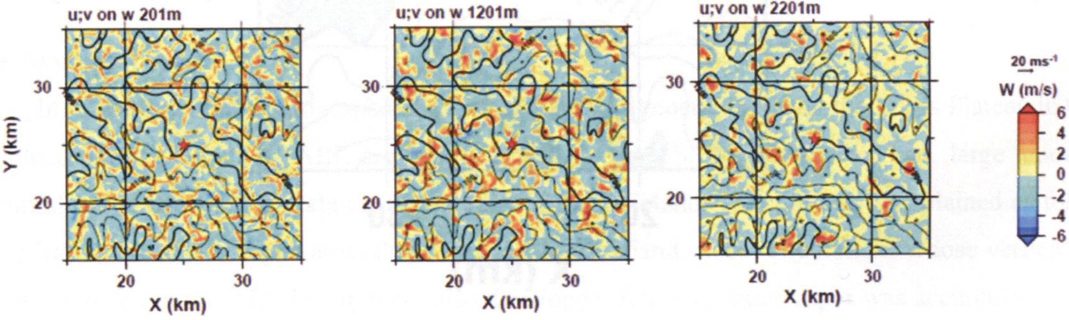


Figure 3. Horizontal section of vertical and horizontal wind velocities at 13:20 BST for a) Case 1 at 368.35 m height (left), 1180.14 m height (middle) and 2429.04 m height (right), b) Case 2 at 201 m height (left), 1201 m height (middle) and 2201 m height (right). Those heights stand for the heights from the tableland surface (1224 a.s.l.) The color represents vertical wind and the vector represents

horizontal wind.

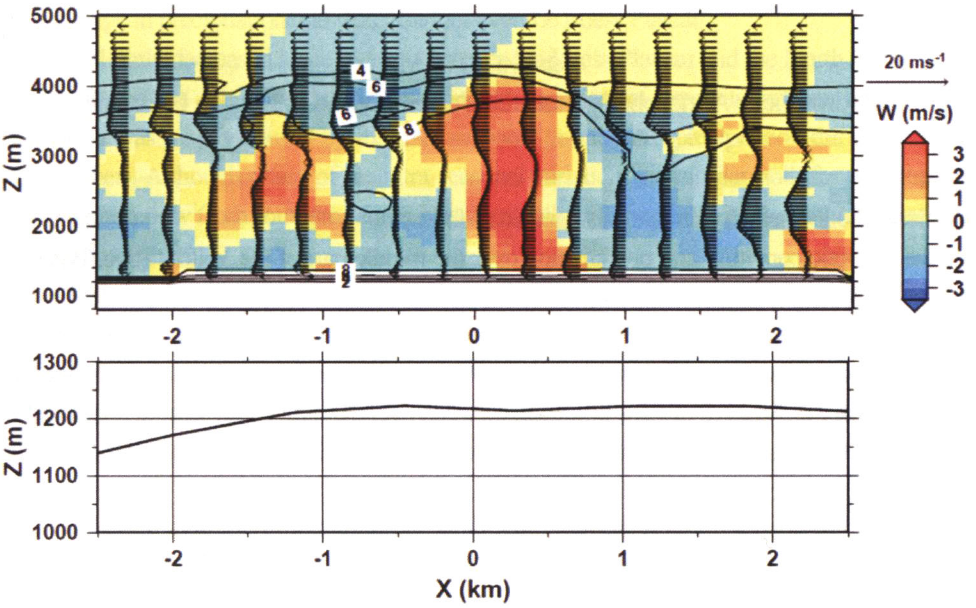


Figure 4. x-z cross-section of vertical and horizontal wind velocities at 13:20 BST for Case 2 (top), x-z cross-section of the altitude (bottom). The color represents vertical wind and vector represents horizontal wind. The contour line represents mixing ratio of every 2 g/kg. The value of 0 km in x-axis is the center of the simulation domain. z-axis is represented as a.s.l..