Numerical Experiments on the Impact of Land Surface Evapotranspiration on Atmospheric Water Circulation over Summer Asian Monsoon Region

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1. Introduction

In recent years, many studies focusing on the roles of land surface processes in atmospheric water circulation have been carried out, and their importance has been gradually recognized. In particular, evapotranspiration from the land surface is one of the key factors that regulate climate systems, because it not only provides the atmosphere with water vapor but also determines temperature near the surface via the ratio between sensible and latent heat fluxes. Shukla and Mintz (1982) examined the influence of land surface evapotranspiration on climate by numerical experiments using the General Circulation Model (GCM), and showed that rainfall, temperature and motion fields depend strongly on the land surface evapotranspiration. Thereafter various research into understanding the land-atmosphere interaction, especially related to anthropogenic land use alteration such as by deforestation, have been carried out (e.g., Lean and Rowntree 1997; Pielke et al. 1999). However, the physical processes that systematically explain the land surface evapotranspiration effect on the atmospheric water circulation are still poorly understood, and further studies are necessary. Moreover, the possibility was raised that the relationships between soil moisture (land surface evapotranspiration) and precipitation differ from region to region (Kanae et al. 1998).

To investigate this problem, eastern Asia which is covered with a warm and moist air mass in early summer is an interesting subject. A large amount of rainfall is brought by the stationary Baiu front, which appears from eastern China to Japan with an influence of monsoon. Moreover, characteristic land cover, such as paddy fields around the Huaihe river basin, widely spreads over this region (see Fig. 1), and evapotranspiration from the land surface is abundant. It is also important to clarify the relationships of the land surface evapotranspiration with precipitation in order to consider water circulation in this region.

In this study, two kinds of numerical simulations were conducted with the regional atmospheric model to investigate how changes in land surface evapotranspiration affect the atmospheric water circulation, especially in terms of precipitation. The regional model we used has another merit in comparison to GCM, in that it can clearly extract the response to the impact avoiding interaction with external of calculation domain.

2. Numerical model and experimental design

The Japan Spectral Model (JSM; Segami et al. 1989) was employed for the numerical experiments in the present study. The model has 129×129 grids with 90 km horizontal spacing and 23 vertical layers. The model and analysis domains are enclosed by the solid and broken lines in Fig. 1.

In the calculation, evapotranspiration from the land and sea surfaces is estimated using following equation.

$$E = -\rho C_h |V_a| \beta \{q_a - q_{sat}(T_s)\}$$

where E is evapotranspiration, ρ is density of air, C_h is bulk coefficient for heat, V_a is wind speed at first atmospheric vertical level, β is moisture availability, q_a and $q_{sat}(T_s)$ are specific humidity at the first atmospheric vertical level and saturated at the earth's surface temperature T_s, respectively. To introduce the realistic spatial variation of β, the land cover classification data provided by U.S. Geological Survey (USGS) was utilized (Loveland et al. 2000). These 94 types of original classification were rearranged into 9 types for simplicity, and the values of β as well as roughness z_0 for each land cover class, derived from some literature (e.g., Kondo (1994)), were determined as shown in Table 1.

Two calculations were performed for 1 month from June 1 to 30, 1998, when the GEWEX Asian Monsoon Experiment-Intensive Observation Period (GAME-IOP) was carried out (Yasunari 1998). The simulations were evaluated using the results from June 6 to 30, because the first 5 days were considered as spin-up time and not utilized. First, the Standard simulation with the realistic spatial variation of β was conducted to verify whether JSM was able to simulate fundamental features of atmospheric water circulation. Second, the calculation named NoLE, for no land surface evapotranspiration, was carried out to be compared with the results of the Standard simulation and investigate the impact of the land surface evapotranspiration variation on precipitation and atmospheric conditions. For evaporation from the sea surface, the same conditions were used, that is, β was set to 1.00 in the both simulations.

The initial and boundary conditions were supplied by the GAME reanalysis data every 6 hours (Yamazaki et al. 2000), and the sea surface temperature was estimated from the climatic monthly mean data in the both calculations.

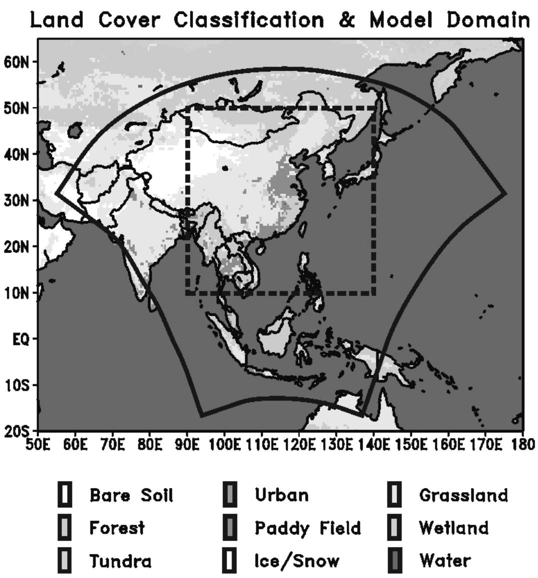

Fig. 1. Distribution of Land cover classification. Solid and broken lines indicate model and analysis domains.

Category	Moisture Availability (β)	Roughness (z_0) [m]
Bare Soil	0.00	0.0001
Urban	0.05	3
Grassland	0.20	0.2
Forest	0.30	0.7
Paddy Field	0.60	0.05
Wetland	0.40	0.1
Tundra	0.40	0.01
Ice/Snow	1.05	0.005
Water	1.00	0.0002

Table 1. Values of moisture availability and roughness for each land cover classification.

3. Results and discussion

3.1 Standard simulation

The simulated precipitation and horizontal wind at 850 hPa from June 6 to 30 with the realistic spatial distribution of β are shown in Fig. 2. The CPC (Climate Prediction Center) Merged Analysis of Precipitation (CMAP; Xie and Arkin 1997) data and the reanalysis horizontal wind data for this period are also shown in Fig. 3 to be compared with the simulation results. From southeastern China to Japan, a rainfall zone brought by the Baiu front is simulated as in CMAP data, although the width of the precipitation belt is slightly narrower. The westerly low level jet (LLJ), which is one of the atmospheric features in the summer Asian monsoon region, appears from the Bay of Bengal and merges with the southeasterly flow along the periphery of the subtropical high. It agrees well with the reanalysis data. As for other atmospheric conditions such as sea level pressure, the simulation is similar with the reanalysis data, though it tends to somewhat overestimate specific humidity and underestimate land surface temperature. Thus JSM can simulate the basic characteristics of atmospheric water circulation for this calculation period.

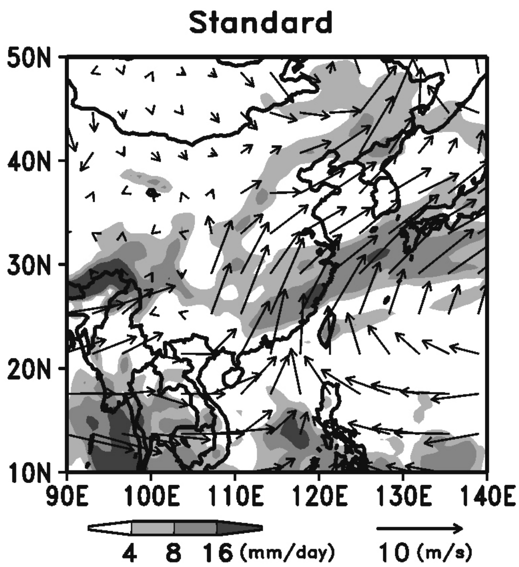

Fig. 2. 25-day averaged precipitation and horizontal wind at 850 hPa calculated by the Standard simulation.

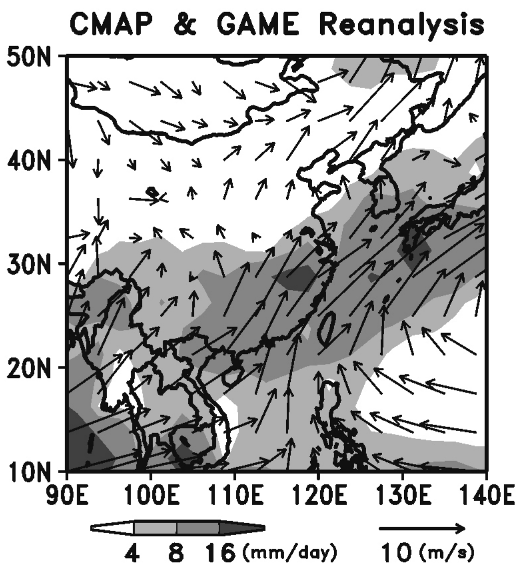

Fig. 3. Same as Fig. 2, but for the CMAP data for precipitation and the GAME reanalysis data for horizontal wind.

3.2 NoLE simulation

Figure 4 shows the calculated precipitation by the NoLE simulation with no evapotranspiration from the land surface. The rainfall zone corresponding to the Baiu front is found as in the Standard simulation, though the distribution is slightly changed, for example, the heavy precipitation belt is located more southwards than that appeared in the Standard simulation over the Eastern China Sea. To evaluate effects on the rainfall amount of the evapotranspiration cut off from the land surface quantitatively, 10-degree averaged differences in precipitation for the NoLE - Standard simulations focusing on eastern China are shown in Fig. 5. Over the region indicated as A in Fig. 5, the precipitation decrease is approximately 1 mm/day (20% to 40% in comparison with the Standard

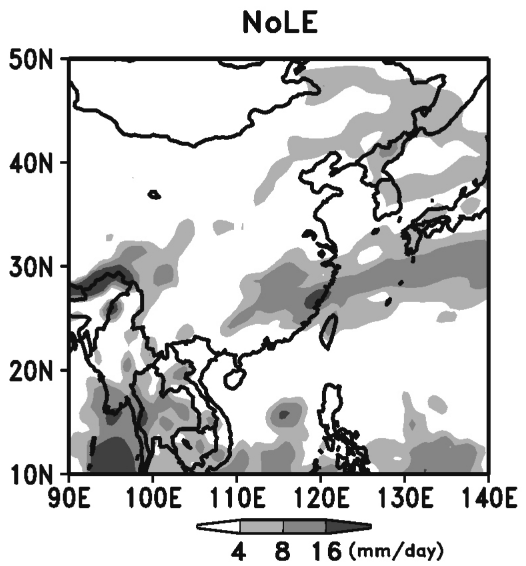

Fig. 4. 25-day averaged precipitation calculated by the NoLE simulation.

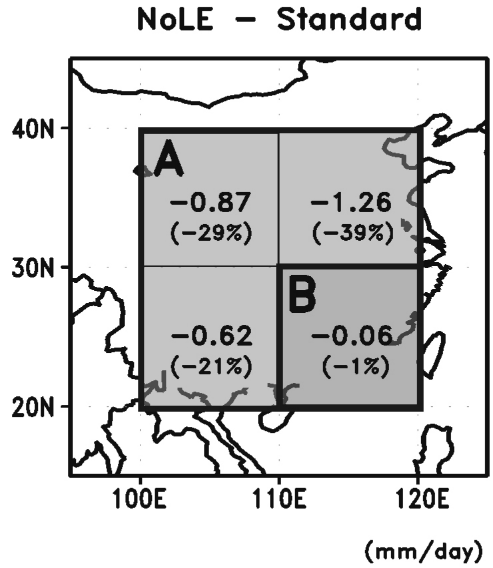

Fig. 5. 10-degree averaged difference in simulated 25-day averaged rainfall amount for the NoLE - Standard simulations over eastern China.

simulation). On the other hand, the rainfall amount is almost unchanged (about 1% decrease) over the area referred to as B.

In Fig. 6, differences in horizontal wind and specific humidity at 850 hPa between the Standard and NoLE simulations are shown. In the NoLE simulation, the southerly wind component of LLJ is intensified along the inside of the coastline, and this enhanced wind supplies larger amount of water vapor to the lower atmosphere over the coastal region. This acceleration of the LLJ results from the pressure depression due to heating the lower atmosphere by sensible heat instead of latent heat (Fig. 7). As a result, enhanced water vapor flux compensates for the land surface evapotranspiration cut off over Region B, while specific humidity in the lower atmosphere is decreased over Region A, where the increase in water vapor flux is small in comparison to the evapotranspiration decrease.

One of the important roles of the evapotranspiration from the land surface is that it provides water vapor to the lower atmosphere. Over Region A, where rainfall amount is decreased, the decrease in specific humidity in the NoLE simulation is dominant. This means the land surface evapotranspiration is important as a moisture source for precipitation over this region. In contrast, the NoLE simulation also produces a humid lower atmosphere and nearly the same rainfall amount as in the Standard simulation over Region B, however, the physical mechanism to keep the lower atmosphere humid is apparently different. The differences that regulate the effects of the land surface evapotranspiration on precipitation are considered to depend on the location of the moisture source, such as oceans, and the airflow systems which transport water vapor.

Over Region B in the NoLE simulation, specific humidity in the lower atmosphere is almost unchanged or slightly increased (Fig. 6), and surface temperature is increased (Fig. 7) in comparison to the Standard simulation. Therefore, equivalent potential temperatures in the lower atmosphere is increased as shown in the vertical profile in Fig. 8. Although this must increase convective instability and rainfall, an increase in precipitation is not found. This may indicate that it is not sufficient for rainfall variation to consider only the atmospheric conditions directly above the area.

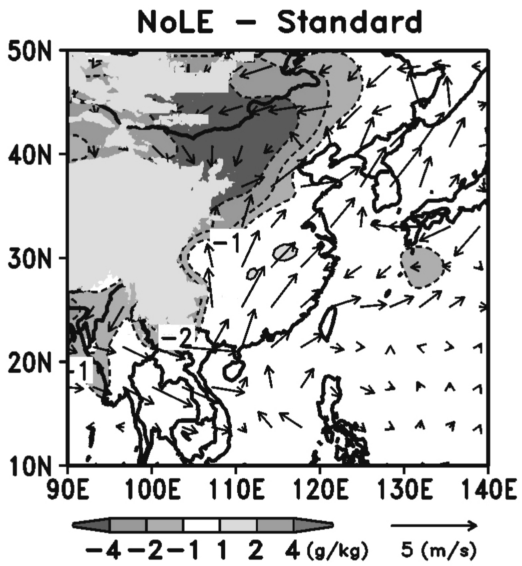

Fig. 6. Differences in 25-avaraged horizontal wind and specific humidity at 850 hPa for the NoLE - Standard simulations. Areas with mountains of more than 1500 m are shadowed.

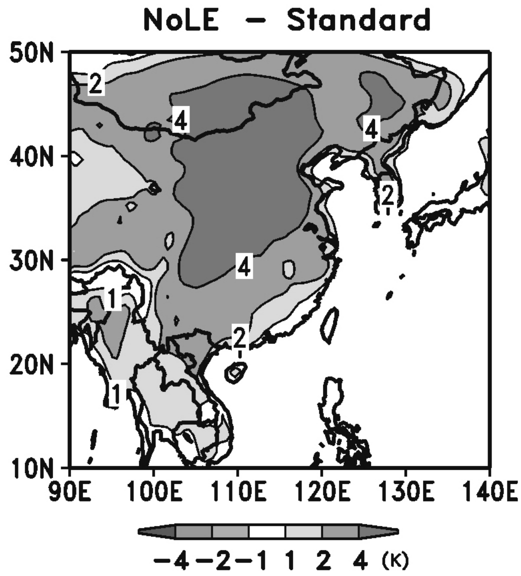

Fig. 7. Difference in 25-day averaged surface temperature for the NoLE - Standard simulations.

4. Conclusion

Numerical simulations with a regional atmospheric model were carried out to evaluate how the change in the land surface evapotranspiration affects atmospheric phenomena, especially focusing on precipitation. In the Standard simulation with realistic variation of β, JSM could reproduce the fundamental features of rainfall, LLJ and so on. The NoLE simulation with no evapotranspiration from the land surface was conducted, and two regions were identified in terms of difference in rainfall amount. Over Region A, the decrease in the rainfall amount was significant because the effect of no evapotranspiration from the land surface was dominant. In contrast, the rainfall amount was almost unchanged in spite of no land surface evapotranspiration over Region B, because the decrease in moisture due to a lack of land surface evapotranspiration was compensated

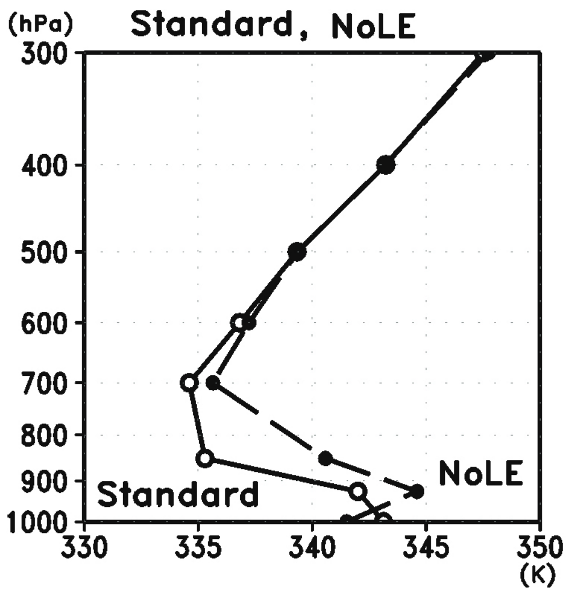

Fig. 8. Vertical profiles of 25-day averaged equivalent potential temperature for the Standard and NoLE simulations at 30ºN, 115ºE.

by the enhanced water vapor flux via the motion field induced by lower atmosphere heating by sensible heat. The differences that determine the impact of the land surface evapotranspiration on precipitation depend on whether it can be modified by the water vapor flux through other physical processes or not.

Acknowledgments

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