Impact of Hetao Irrigation District on the Formation of Clouds in the Vicinity of the Yellow River in Summer

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1. Introduction

Land use sometimes changes rapidly due to the effects of natural processes as well as anthropogenic forcing. Irrigated farmlands are one of the most important anthropogenic land use changes. The Hetao Irrigation District in western Inner Mongolia, China, is one of the most extensive irrigations in Asia (Figure 1). It is surrounded by the Langshan Mountains, the northern Loess Plateau, and the Ulan Buh Desert. Most of the cultivated land is irrigated using the water resources of the Yellow River. The irrigation district creates a prominent heat contrast along its boundary.

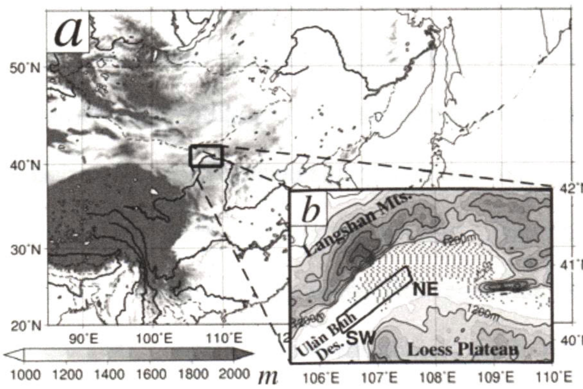

Fig. 1 (a) Map of East Asia. (b) Topography around the Hetao Irrigation District and a simplified irrigated area (dotted area) in the simulation.

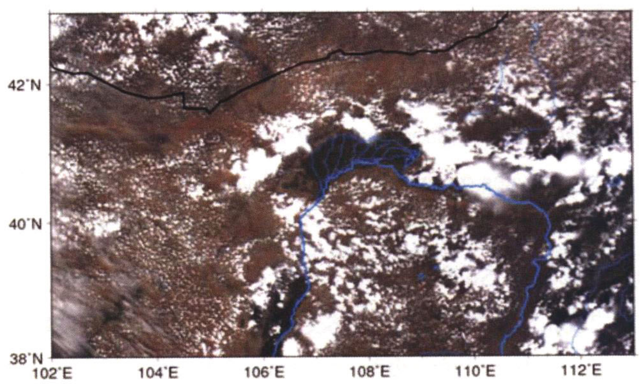

Fig. 2 True color satellite snapshots observed by MODIS/AQUA at 14:10 LST on 4 August 2005. Hetao Irrigation District is located at the center of the figure. Blue lines show rivers and blue thick line shows the Yellow River.

By a statistical analysis of satellite images, Sato et al. [2007] indicated that the frequency of cloud formation is lower over the Hetao Irrigation District than over the surrounding area. Figure 2 shows a true color snapshot on 4 August 2005 obtained with the Moderate Resolution Imaging Spectroradiometer (MODIS) on the Aqua satellite. Numerous clouds are evident around the Hetao Irrigation District although almost no clouds appear there. Sato et al. [2007] speculated that a mesoscale circulation induced by the land surface contrast is attributed to form the cloud near the irrigation district.

A contrast of land use often induces clouds and precipitation as pointed out in many studies [e.g., Chen and Avisser, 1994; Avissar and Liu, 1996; Lee and Kimura, 2001]. The clear contrast of land use around the Hetao Irrigation District may induce convective clouds. The objective of this study is to reveal the impact of the Hetao Irrigation District on cloud formation using a mesoscale numerical model. We focus on 4 August 2005 when the typical cloud distribution was observed (Figure 2).

2. Design of numerical experiments

Numerical experiments were conducted using a non-hydrostatic numerical model, Advanced Research Weather Research and Forecasting (WRF) modeling system Version 2.2 [Skamarock et al., 2005]. Two-way nested grid systems were adopted. The coarse grid system and the nested fine grid system have grid intervals of 15 km and 3 km, respectively. The initial and lateral boundary conditions for the coarse grid system are interpolated from the 6-hourly NCEP global tropospheric analysis data (1x1 degree grids). Two sensitivity experiments are conducted, i.e., experiments assuming and not assuming the Hetao Irrigation District (hereafter, SFC-WET run and SFC-DRY run, respectively). To evaluate the surface condition of the Hetao irrigation, we assume a distribution of simplified irrigated farm lands (hereafter, the irrigated area) in the SFC-WET run. The volumetric soil water content (hereafter, soil water content) is artificially kept at 0.4 in all soil layers within the irrigated area throughout the simulation, which corresponds to about 85 % of the saturated soil water content there. Besides the irrigated area, the soil water content derived from the NCEP global tropospheric analysis data is adopted as an initial value, and then the soil water content is predicted every time step. These experiments were conducted from 00 UTC 1 July 2005 to stabilize the surface soil conditions.

3. Results and Speculations

Figures 3a and 3b show the distributions of cloud water simulated by the SFC-WET run and the SFC-DRY run at 14 LST on 4 August 2005, respectively. The SFC-WET run simulates numerous clouds over the dry flat area and mountains (Figure 3a). In contrast, almost no clouds are simulated over the irrigated area. The distribution of clouds is similar to the observation (Figure 2). In contrast, the SFC-DRY run simulates clouds not only over the dry area but also over the irrigated area (Figure 3b). The distribution of clouds in the SFC-DRY run differs from the observation.

Figures 3c and 3d show the land surface temperatures at 12 LST on 4 August 2005 simulated by the SFC-WET run and the SFC-DRY run, respectively. The low surface temperature over the mountains corresponds to the decrease of solar radiation by clouds and the cooling by rainfall. A clear contrast of the surface temperature is found between the irrigated area and the surrounding dry area in the SFC-WET run (Figure 3c). In the SFC-DRY run, the contrast of the surface temperature is quite small (less than 5 K) except for the northern mountain area which is covered by the clouds. These results suggest that the contrast of the surface temperature can affect cloud formation around the irrigated area.

Figure 4 illustrates vertical cross sections of simulated wind velocity and water vapor mixing ratio along the SW-NE section in Figure 1b at 14 LST on 4 August 2005. The altitude is almost 1,000 m along the SW-NE section. In the SFC-WET run, the southwestern component of wind is predominant over the southwestern dry area, while the northeastern component of wind is predominant over the northeastern irrigated area at the layers below 1,500 m (Figure 4a). The low surface temperature on the irrigated area (Figure 3c) produces wind that blows toward the dry area with high surface temperature. The two different winds at the lower level cause the convergence over the boundary between the dry area and irrigated area. Prominent upward and downward flows are found over the boundary of the dry area and the irrigated area, respectively. Therefore the SFC-WET run simulates a clear mesoscale circulation between the dry area and the irrigated area (hereafter, land-use-induced circulation) at the lower layer. The ascending flow of the land-use-induced circulation produces clouds without mountains and hills (clouds shown by vectors in Figure 3a). On the other hand, no significant circulations are simulated in the SFC-DRY run (Figure 4b).

Moreover, the irrigated area supplies much water vapor to the lower atmosphere in Figure 4a. The moist air goes toward the dry area and then ascends above the boundary between the irrigated area and the dry area. The land-use-induced circulation also transports the evapotranspired water vapor to the dry area and then helps the cloud forming.

The Hetao Irrigation District is surrounded by the Langshan Mountains and the Loess Plateau. During daytime, the mountain-valley circulation is predominant between the Hetao Irrigation District and the mountains. The circulation also induces the downward flow over the irrigated area and transports water vapor evapotranspired from the irrigated area to the mountainous area as well as the land-use-induced circulation (figure not shown). Therefore, the land-use-induced circulation and mountain-valley circulation inhibit cloud formation over the Hetao Irrigation District and transport water vapor from the irrigated area to the surrounding dry area.

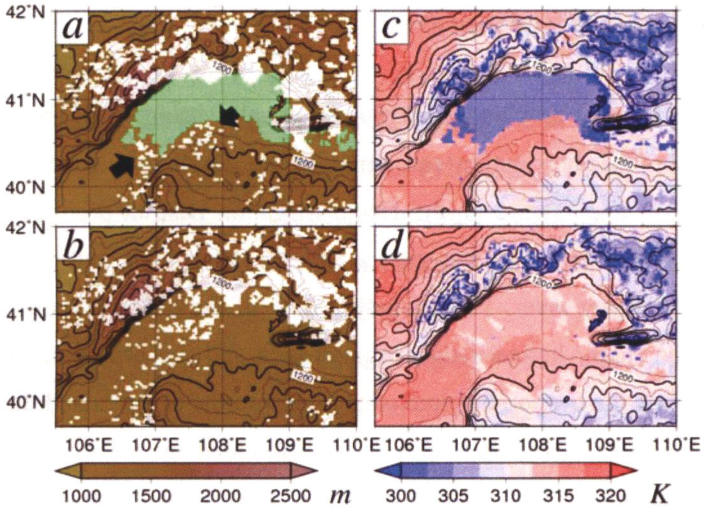

Fig. 3 Distributions of clouds at 14 LST (left) and surface temperature at 12 LST (right) simulated by the SFC-WET (top) and SFC-DRY (bottom) on 4 August 2005. The green area in Figure 3a shows the irrigated area.

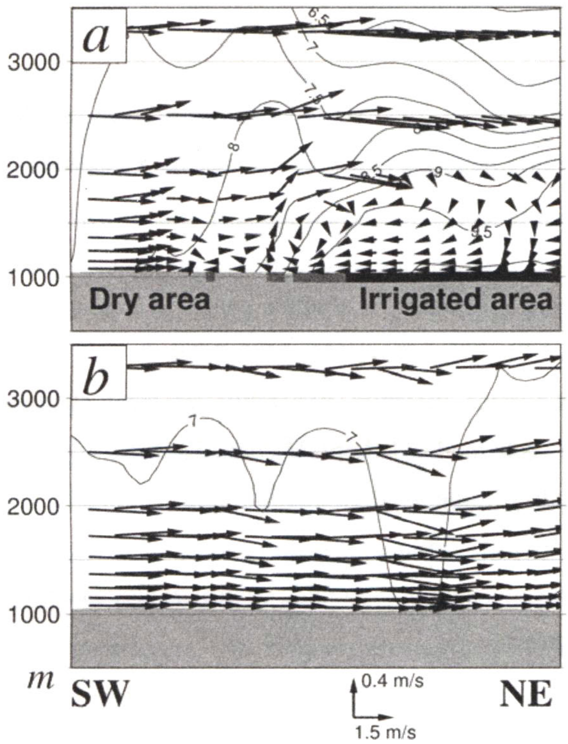

Fig.4 Vertical cross sections of wind velocity (vector) and water vapor mixing ratio [g/kg] (contour) along SW-NE in Figure 1b at 14 LST. (a) SFC-WET and (b) SFC-DRY. The winds are averaged across section SW-NE. A simple moving average is taken for five grids. Vectors are plotted every three grids in horizontal. The light-gray indicates topography. The black area shows that all of the averaged grids are the irrigated area. The dark-gray shows that the averaged grids include parts of the irrigated area.

5. Summary

An impact of the Hetao Irrigation District on cloud formation is revealed using WRF model. The numerical experiment assuming simplified irrigation can simulate the distribution of clouds observed by the satellite. The low surface temperature on the Hetao Irrigation District produces a wind that blows toward the surrounding dry area, where the surface temperature is high, and results in the land-use-induced circulation at the lower layer. The ascending flow of the land-use-induced circulation generates clouds over the boundary between the irrigated area and the dry area. The land-use-induced circulation also transports the evapotranspired water vapor to the dry area and then helps the cloud forming. Moreover, the Hetao Irrigation District is surrounded by the Langshan Mountains and the Loess Plateau. The mountain-valley circulation is also predominant between the Hetao Irrigation District and the mountains. The land-use-induced circulation and mountain-valley circulation inhibit cloud formations over the Hetao Irrigation District and transport water vapor from the irrigated area to the surrounding dry area.

Acknowledgments

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