Seasonal changes in the conditions of atmospheric boundary layer, land surface, and synoptic field over the Loess Plateau in China

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1. Introduction

Atmospheric boundary layer (ABL) plays an important role on the heat and water vapor exchanges between land surface and the free atmosphere (FA). Diurnal change of ABL transports water vapor from land surface to ABL and FA, which often induces generations of cumulus clouds near the top of the ABL. Diurnal change of ABL also changes the stratification of daytime lower atmosphere into near-neutral. However the interaction between ABL and convective precipitation has not been investigated over the Loess Plateau in China, previously.

On sunny days in the early summer of 2005 and 2006, we showed fair-weather cumulus have frequently generated over the Loess Plateau in China [*Nishikawa et al.*, 2007]. When active cumulus developed, water vapor exchanged diurnally between the ABL and FA [*Takahashi et al.*, 2007]. However the detailed structures of cumulus generation and relation to surface and ABL features over the Loess Plateau have not been investigated. Based on this background, we investigate seasonal changes in ABL, land surface and synoptic field over Changwu, the Loess Plateau in China, using the data obtained from April to July in 2005. Moreover the effect of ABL to the synoptic-scale disturbance is discussed.

2. Observation and data set

The study site is located at the research field of Changwu Agro-Ecological Experimental Station on the Loess Plateau (35.24°N, 107.68°E, 1224 m a.s.l.). We analyzed vertical profiles of three-dimensional wind velocity and those of echo intensity measured by a Wind Profiler Radar (WPR, L-28H, Sumitomo Electric Industries, Japan). We also determined surface heat fluxes and radiation fluxes using data obtained by a Flux & Radiation Observation System (FROS, Climatec, Japan). Details of the study site and the instrumentation at this site were shown in *Hiyama et al.*, [2005].

In order to investigate synoptic conditions, we used 6-hourly reanalysis data produced by National Center for Environmental Prediction (NCEP) / National Center for Atmospheric Research (NCAR) [*Kalnay et al.*, 1996]. We also used hourly IR-Tbb data derived from GOES-9. Spatial resolutions of the reanalysis and Tbb data are 2.5° x 2.5° and 1° x 1°, respectively.

3. Results and discussion

3.1 Seasonal changes in ABL, land surface, and synoptic field

Figure 1 shows seasonal changes in meteorological elements and surface conditions. Specific humidity was gradually increased from April to July. Broad areas of the Plateau tableland were occupied by agricultural fields planted with wheat, maize and apples. Maize was seeded in the middle of April, and wheat was harvested in the end of June.

Figure 2 shows seasonal changes in daytime mean surface heat fluxes and daily maximum ABL heights. From the spectral analysis of daily precipitation, the power spectral peak of daily precipitation appeared in 3 - 5 days (figure not shown). This means the precipitation occurred with 3 - 5 days intervals in this season. In the same way, from the spectral analysis of latent heat flux, the power spectral peak of latent heat flux appeared in 2 – 5 days (figure not shown). The power spectral peak of latent heat flux corresponded to that of precipitation. This means latent heat flux became higher after precipitation event, then before the precipitation event, i.e. after a long no-rain period, latent heat flux gradually decreased due to decreasing surface soil moisture. On the other hand, the power spectral peak of sensible heat flux has not been appeared in any intervals. This indicates that the seasonal change of sensible heat flux was unclear.

Figure 2-(c) shows seasonal changes in ABL heights on sunny days. A green bar represents the daily maximum ABL height determined by the median filtering method [*Angevine et al.*, 1994]. A black bar represents the daily maximum ABL height estimated by a slab model [*Tennekes*, 1973; *Garratt*, 1992]. The seasonal change in ABL height determined by the median filtering method was unclear. When the ABL height of the median filtering method was large as well as the difference of ABL heights determined by both methods was large, cumulus clouds have been frequently generated in the daytime. Thus, when this difference was large, we assumed cumulus clouds have been generated and developed from April to July in 2005.

When cumulus clouds generated, the atmospheric stability became near-neutral from 600 hPa to 700 hPa. At the study site, 600 - 700 hPa corresponds to 2 - 3 km height in which cumulus clouds appeared. Moreover, the seasonal change in the potential temperature gradient between 600 hPa and 700 hPa showed good agreement with the seasonal change of the difference in ABL heights determined by two methods (figure not shown). Therefore, it could be concluded that generations of cumulus clouds were strongly related to the atmospheric stability.

3.2 Effect of ABL on the synoptic scale disturbance

Before the effect of ABL to the synoptic scale disturbance is discussed, we show the synoptic conditions during a precipitation event over the Loess Plateau. Figure 3 shows longitude-time section of Tbb along 35.25°N from 13 to 19 May. The southern part of the Loess Plateau located in the middle latitude, which is affected by the subtropical jet. Thus the precipitation, which was observed at the study site on 15 - 16 May, resulted from the eastward transportation of the disturbance from the Tibetan Plateau. Moreover we confirmed all precipitation events have been resulted from eastward transportations of disturbances.

Figure 4 shows longitude-time section of Tbb along 35.25°N from 17 to 23 June. At the study site, the precipitation was observed at 19 BST (Beijing Standard Time) on 19 June. This precipitation occurred due to the synoptic disturbance. When the disturbance approached to the southern part of the Loess Plateau, the convective activity was intensified. Then the disturbance was decayed around there. In the daytime of 19 June over the study site, it was sunny and fair-weather cumulus clouds generated, and ABL developed up to around 3 km height. This means a neutral stratification was formed up to 3 km height due to the ABL development. Before and after the precipitation event, the synoptic-scale water vapor advection has been kept constant over this area (figures not shown). Therefore it could be concluded that ABL intensified the disturbance in this case.

4. Summary

In order to clarify effect of ABL to cumulus clouds generation and precipitation, we investigated seasonal changes in ABL, land surface and synoptic field over Changwu, the Loess Plateau in China, using the data obtained from April to July in 2005. Especially the effect of ABL to the synoptic scale disturbance was discussed.

Latent heat flux became higher after the precipitation event, then after a long no-rain period, latent heat flux became lower due to decreasing surface soil moisture. The interval was 2 - 5 days, which corresponded to intervals of precipitation. On the other hand, seasonal change of sensible heat flux was unclear, and thus seasonal change of ABL height was also unclear. This is because cumulus clouds were frequently appeared from spring to summer. Generation of cumulus clouds were related not only to surface fluxes but also to the atmospheric stability.

The precipitation which was observed at the study site resulted from the eastward transportation of the disturbance. One of the cases which ABL affected to the synoptic scale disturbance was shown. In the daytime of 19 June, ABL developed up to about 3 km height and this made fair-weather cumulus to develop. Because synoptic-scale water vapor advection has been kept constant over the area, it could be concluded that ABL intensified the disturbance in this case.

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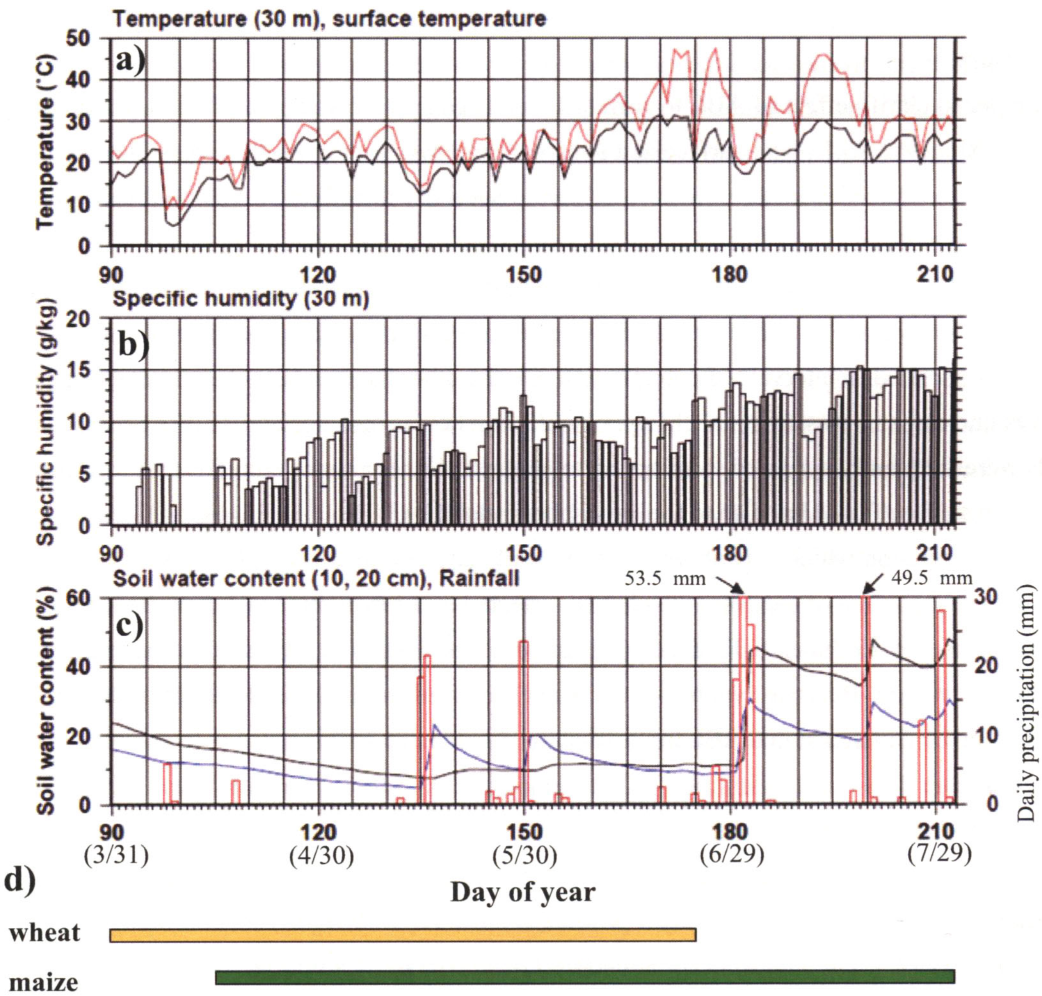

Figure 1. Seasonal changes in a) daytime mean surface temperature (red) and daytime mean air temperature at 30 m (black), b) daytime mean specific humidity at 30 m (black bars), c) daily precipitation (red bars) and daily soil water content at 10 cm depth (blue line) and 20 cm depth (black line), and d) growing season of wheat (yellow bar) and maize (green bar).

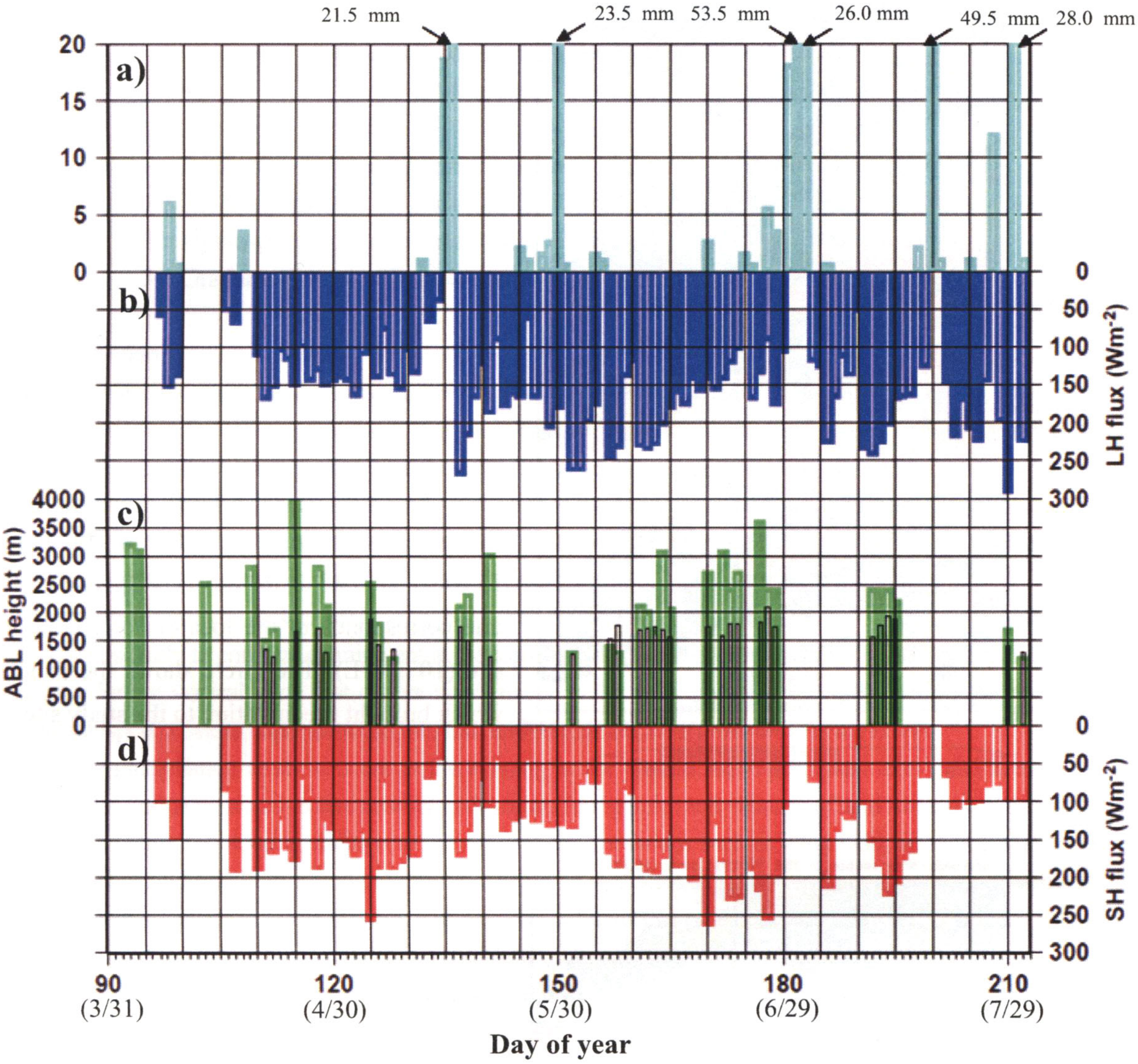

Figure 2. Seasonal changes in a) daily precipitation, b) daytime mean latent heat flux (LH flux), c) daily maximum ABL height determined by the median filtering method (green bars) [*Angevine et al.*, 1994] and that estimated by a slab model (black bars) [*Tennekes*, 1973; *Garratt*, 1992], and d) daytime mean sensible heat flux (SH flux).

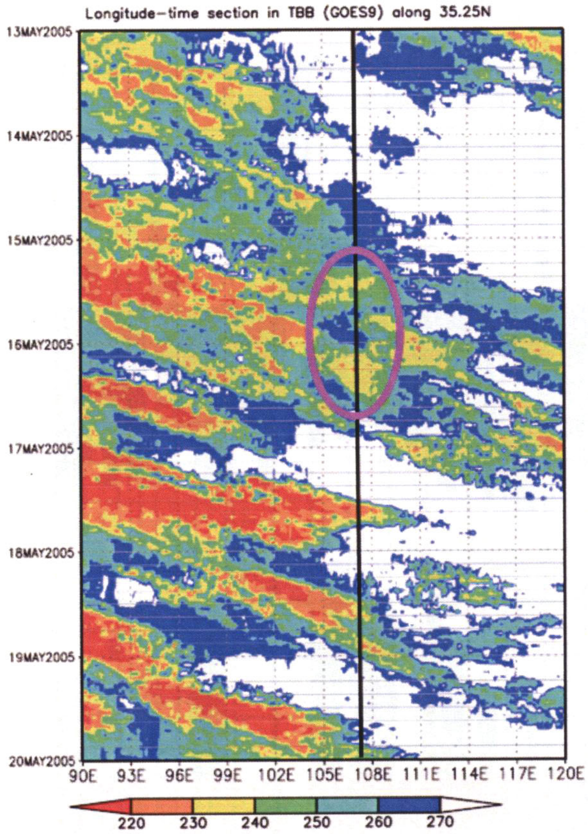

Figure 3.Longitude-time section of Tbb along 35.25°N from 13 to 19 May (UTC). The black line corresponds to the location of the study site (107.68°E). The circle shows the clouds which brought precipitation to the study site.

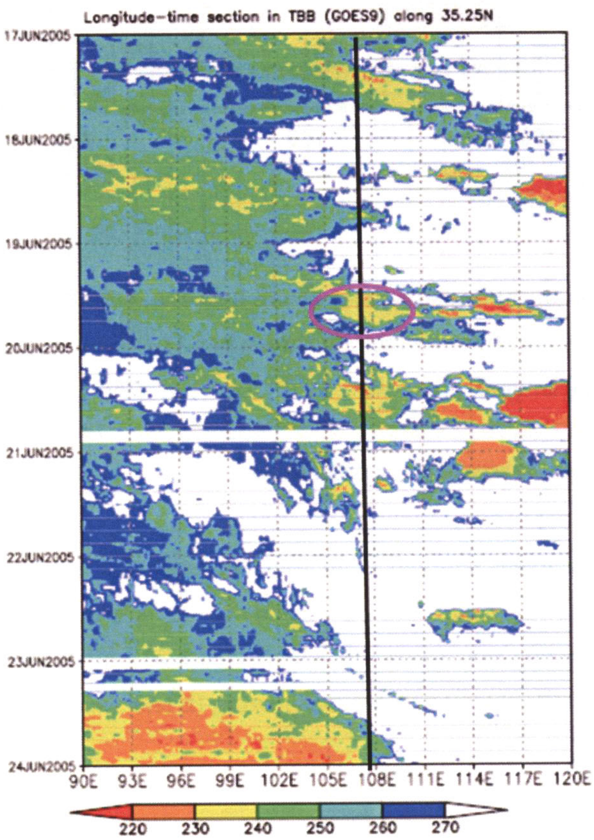

Figure 4. Same as Fig. 3 but from 17 to 23 June (UTC).