A characteristic daily variation in water vapor in the atmospheric boundary layer and free atmosphere in the Loess Plateau of China

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1. Introduction

In East-Asia, vast areas belonging to severe climate spread in northern China. The Loess Plateau, the area of which is about 0.58 million km^2, is included in the semi-arid region and locates in the middle area of the Yellow River basin. It is important to clarify the water vapor transport over the plateau, and its influences to the water cycle in the Yellow River basin. In May 2004, we established the systems for measuring the atmospheric boundary layer (ABL) in southern region of the Loess Plateau. Broad areas are occupied by the agricultural fields planted with wheat, corn, and apples on the tableland of the plateau. In dry season, rare occurrence of rainfall causes severe drying of surface layer in the soil and increases of surface temperature. Under such condition, the ABL develops strongly (Nishikawa et al., 2005). Strong vertical wind, which can reach a free atmosphere, developed in daytime under calm wind condition (Nishikawa et al., 2005). However, the water vapor transport has not been fully understood in such condition.

We have conducted the observation of water vapor profile with a high-time resolution using the ground-based microwave radiometry, in order to clarify the water vapor transport in the Loess Plateau of China. This study reports the diurnal variations in water vapor in the atmosphere from the ground to a height of about 10 km, which were measured during summer in 2005 and 2006.

2. Observation and methods

The observation site is located in the southern part of the Loess Plateau. Agricultural fields of wheat, corn, and apple trees spread in and around the observation site. The ground-based microwave radiometry (MR) (TP/WVP-3000, Radiometrics Co., USA) was installed at the wheat field in the Changwu Agro-Ecological Experimental Station in Loess Plateau (35.24^{o}N, 107.68^{o}E, 1224m a.s.l.) to observe the one-dimensional vertical profiles of water vapor and air temperature up to a height of 10 km with a vertical spatial resolution of 100 m up to 1 km, above which the resolution was 250 m up to 10 km, and with a time resolution of 1 minute. The one-dimensional vertical profile of wind vector was also observed using the Wind Profiler radar (WPR) (L-28, Sumitomo Electric Industry, Japan) up to a height of 8 km with a vertical spatial resolution of 100 m and with a time resolution of 1 minute. The measurement of turbulence has also been conducted at this site from May 2004 by Flux-Radiation Observation System (FROS, Climatec Co., Japan). Three sonic anemometers/thermometers (R3, Gill Instruments Limited, UK) were installed to FROS at heights of 32 m and 12 m, and 2 m. Three dimensional components of wind velocity and air temperature were recorded to the logger (CR-5000, Campbell Co., USA) at a frequency of 10 Hz. Precipitation was measured using the tip-bucket type rain-gauge.

We conducted the integrated observations during the periods from 11 May to 13 July in 2005 and from 15 May to 10 July in 2006. During these periods, we have observed amount and types of clouds almost every 1 hour in daytime. Cloud amount was recorded as the value from 0 to 10 according to the cloud-covered area of the whole sky. Cloud types were recorded based on the category which distinguishes cloud types into 10 types.

3. Results

Figure 1 shows seasonal variation in daily averaged values of water vapor contents in the troposphere, fluxes of sensible heat and latent heat at the land surface, precipitation, and soil water content. We can see that water vapor content and heat fluxes had clear seasonal variations, although data of water vapor was missed during the period from July 2005 to April 2006, which was caused by troubles of the electric power. Most amount of precipitation occurs in summer but seasonal change of soil water is different between 2005 and 2006 according to the events of precipitations. That is, soil water content increased rapidly in late of June in 2005 and, on the other hand, in late of August in 2006. Latent heat flux in summer is a little larger in 2005 than in 2006.

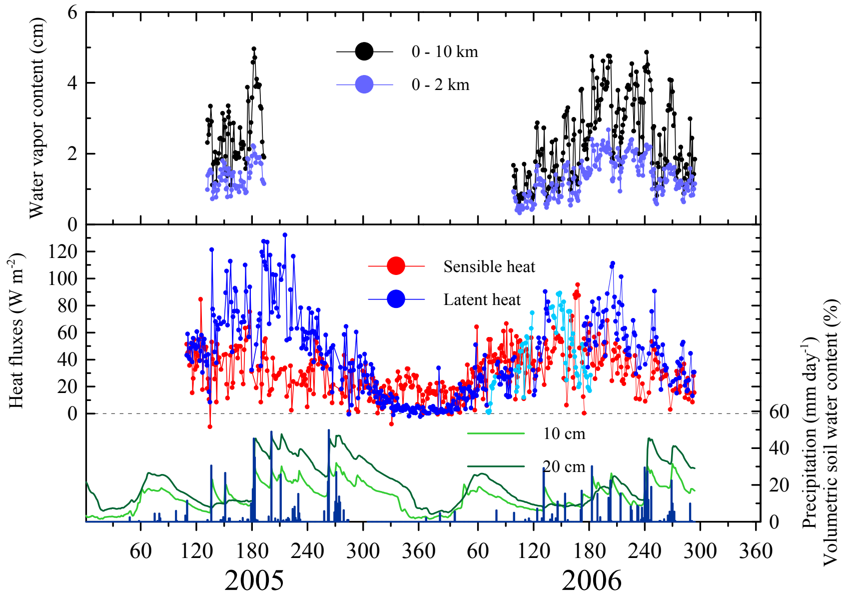

Fig. 1. Seasonal variations in daily averaged values of (upper panel) water vapor contents in the troposphere, (middle panel) surface fluxes of sensible heat and latent heat, (lower panel) precipitation and soil water content. In the lower panel, blue colored bars indicate precipitation.

Figure 2 shows similar figure but for the IOPs. In Fig. 2, amount and types of cloud are also shown. Active cumulus appeared frequently from late of June in each year. In presence of active cumulus, characteristic diurnal variations in water vapor contents were observed in the lower atmospheric layer and the upper atmospheric layer, as shown in Fig. 3 (a), in which time series of water vapor contents during 17-21 June in 2005 were shown. Here, we distinguished the atmosphere into two layers, which are divided by a height of 2 km. The solid line indicates water vapor in the lower layer, the dotted line indicates that in the upper layer and the dashed line indicates sum of those. During this period, water vapor decreased in the lower layer in daytime, and increased in the upper layer. Minimum in the lower layer and maximum in the upper layer appeared at around late of the afternoon.

Motion of air observed by WPR tended to be downward in the afternoon (figure is not shown). This downward wind could enhance the decrease in water vapor in the afternoon. Figures 3 (b) and (c) show the vertical profiles of potential temperature and absolute humidity, respectively, on 19 June 2005. Such opposite behavior of water vapor shown in Fig. 3 suggests that water vapor in the lower layer was transported vertically in daytime and this resulted in the increase in the upper air, the upper layer, in addition to the influence of horizontal advection of water vapor. The decrease of water vapor in the lower layer is dominant in the layer below around 1 km, and, the increase of water vapor in the upper layer was observed from around 2 km to around 7 km. On the other hand, such diurnal variations in water vapor were not observed under the conditions of the other cloud types or under no cloud cover. This suggests that active cumulus acts an important role in the diurnal variation in water vapor in the upper and lower atmosphere. Due to convective activity inside of the active cumulus like cumulonimbus, upward and downward motions were enhanced in and around the cloud layers. It can be considered that active cumulus acted like a pump that transports water vapor from the lower atmosphere to the upper atmosphere. Several researchers has reported decrease in precipitable water in daytime over an inland, mountain, and coastal areas and concluded that a local circulation had an important role (Takagi et al., 2000; Wu et al., 2003; Fujita et al., 2006). In such conditions, convective activity is considered to have a critical role to enhance the local circulations. This study showed that strong convective activity by active cumulus has actually significant effect on the vertical transport of water vapor between the ABL and free atmosphere. However, water vapor content in the lower layer already began to decrease in the early morning. The upward wind was observed in the lower layer from the ground to around 1 km in the morning (figure is not shown). Such motion of air may have a critical role in the decrease in water vapor in the lower layer in the morning. Fujita et al. (2006) showed that the downward motion driven by a local circulation resulted in daytime decrease in the precipitable water. Such downward motion of air might also occur in somewhere around our site as the compensate motion of the upward motion of air observed over our site. That is, a large-scale motion of the atmosphere might be formed around our observation site and had some influence to the observed diurnal variation in water vapor. We need more researches to clarify whether such local circulation is actually generated and its influences to the vertical transport of water vapor.

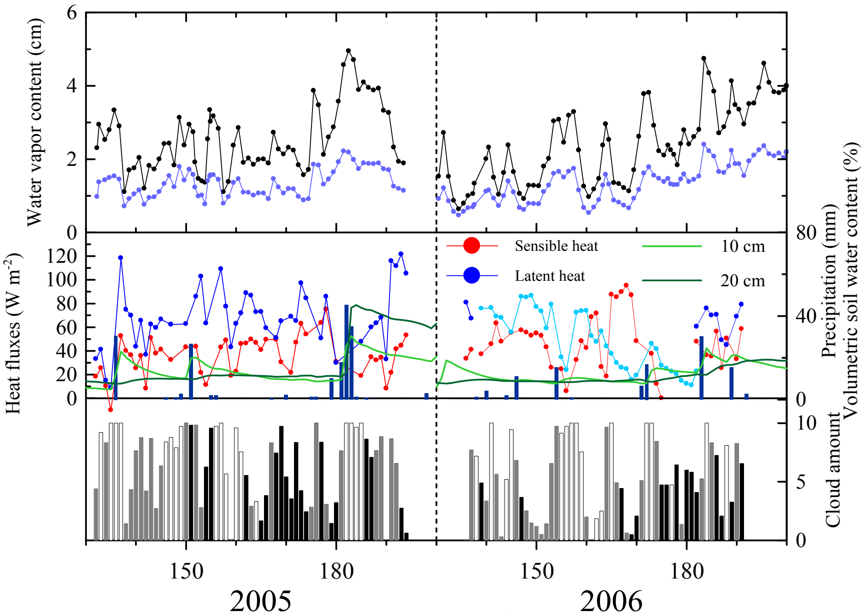

Fig. 2. Seasonal variations in daily averaged values of (upper panel) water vapor contents in the troposphere (black: 0-10 km, blue: 0-2 km), (middle panel) surface fluxes of sensible heat and latent heat, precipitation, soil water content, and (lower panel) amount and types of clouds. In the middle panel, the light blue-colored line is the latent heat flux measured at a height of 2 m, since the instrument at 32 m height had a trouble during this period. In the lower panel, the black-colored bars indicate the presence of active cumulus, the grey-colored bars indicates presence of forced cumulus but no active cumulus, and the white-colored bars indicate the other types of clouds.

4. Conclusions

This study revealed that characteristic diurnal variations in water vapor content in the atmosphere were observed in the southern part of the Loess Plateau in summer in 2005 and in 2006. Water vapor decreased from the early morning till late afternoon in daytime in the atmosphere lower than a height of 2 km and increased in the atmosphere above it up to a height of 10 km, when the active cumulus developed. Moderate upward motions of wind field were frequently observed in the lower atmosphere below than a height of about 1 km in the morning on clear days, and then the strong vertical wind was generated in the afternoon following the development of the atmospheric mixing layer. Such strong convective activity was especially observed under the conditions that strong sensible heat was supplied to the atmosphere from the ground, and that active cumulus developed in the afternoon. The enhanced vertical wind which was induced by active cumulus has a possible to have a critical role in such daily variation in water vapor. Such local conditions might also have relations with the heat low developed in synoptic scale.

More study will be needed to clarify the diurnal variations in water vapor in the troposphere in the Loess Plateau. We will promote further this study to investigate, in detail, how such variation was generated in Loess Plateau and how it influenced the water vapor transport in the Loess Plateau, using a cloud-resolved numerical simulation in future.

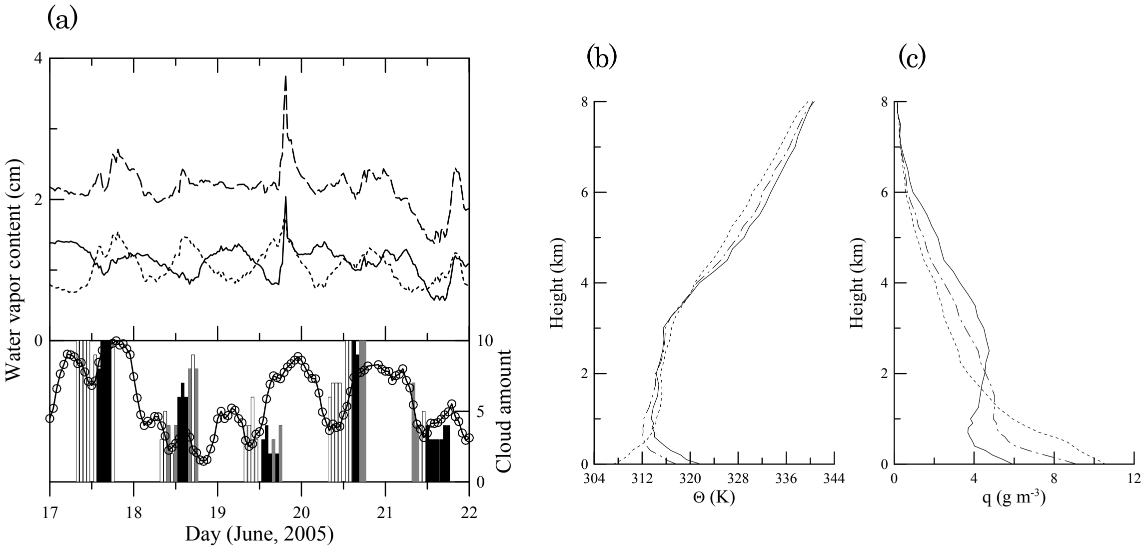

Fig. 3. (a) The upper panel shows the diurnal variation of water vapor content measured during 17-21 June 2005. Broken line shows the total amount of water vapor in the troposphere, the solid line shows the integrated water vapor from the ground to a height of 2 km, and the dotted line shows the integrated water vapor from a height of 2 km to a height of 10 km. The lower panel shows amount and types of clouds. The meanings of colors of each bar are same as those in Fig. 2. It should be noted that the observation of amount and types of clouds were done only in daytime. Open circles are the cloud amount estimated by GOES9 data over the region 32.5N-37.5N, 105E-110E. Right two figures are the vertical profiles of 30 minutes-averaged (b) potential temperature and (c) specific humidity on 19 June 2005. Dotted line: 7:30-8:00LST, dashed-dotted line: 11:30-12:00LST, solid line: 15:30-16:00LST.

References

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