NOTES AND CORRESPONDENCE

A Significant Evening Peak of Vapor Pressure at an Oasis in the Semi-Arid Region

By Osamu Tsukamoto

College of Liberal Arts and Sciences, Okayama University, Okayama 700, Japan

Jiemin Wang

Lanzhou Institute of Plateau Atmospheric Physics, Chinese Academy of Sciences, Lanzhou, China

and

Yasushi Mitsuta

Disaster Prevention Research Institute, Kyoto University, Uji, Kyoto 611, Japan

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Abstract

Significant evening peaks were observed in the diurnal variations of vapor pressure over an oasis surrounded by desert in the north-west part of China. They appeared not only in the surface layer measurement but also in the upper air soundings below 500 m. According to the surface flux measurements, it was observed that sensible heat flux was much stronger over the desert than over the oasis during the daytime. The upper-air sounding data shows that the oasis is a cool and moist island capped by dry and hot air which would be advected from the surrounding desert. In these situations, upper-layer convective mixing is considered to be much stronger than in the lower cool island, and this can lead to water vapor flux divergence in the afternoon. In the evening, convective mixing, which is suggested by the sensible heat flux from the ground, decreases over the desert and in the upper layer over the oasis. It was observed that evapotranspiration from the surface still continues upward. It is suggested that water vapor flux convergence can occur near the oasis surface.

1. Introduction

Studies of the air-ground interface in the semi-arid region was carried out in the Gansu Province, China as a Sino-Japan cooperative study. The objective area is the Heihe river basin, and the project is called "HEIFE" (Heihe river Field Experiment, Mitsuta *et al.* (1990)). The behavior of water vapor is the most interesting subject in this kind of arid region. The origin of the river water is snow and rainfall in the Qilian mountains, south of the HEIFE area. The river can irrigate some parts of this area. Accordingly, various types of surface covers are observed, such as sand desert, Gobi, and oasis.

It is well known that diurnal variation of rela-

tive humidity is observed as a result of air temperature variation. However, diurnal variation of vapor pressure or absolute humidity are reported in a few cases (Seagal *et al.*, 1992). The present authors have found out significant evening peak of vapor pressure in the basic meteorological data in the oasis area which is surrounded by dry desert.

2. Observed diurnal variations of vapor pressure

Figure 1 shows the vapor pressure variations observed over a bean field at Zhangye station (38°50'N, 100°25'E, 1500 m from mean sea level) during 3–20 Aug. 1991. In the HEIFE area, there are five basic stations which have 20 m towers to measure profiles of meteorological parameters. Two of them are lo-

Fig. 1. Vapor pressure variations during 3 Aug–20 Aug 1991 at Zhangye Oasis at 1m height.

Fig. 2. Diurnal variations of air temperature (T), vapor pressure (E) and relative humidity (RH) at 1 m height and 2 hourly latent heat flux (LE) at 2.9 m (17 Aug. 1991).

cated in oasis area, and Zhangye station is one of the oasis stations. Zhangye Oasis extends about 15 km (NW to SE) $\times$ 25 km (NE to SW) and is surrounded by Gobi or desert. The station is located in the south-west part of the oasis and the distance to the boundary is about 8 km except for the NE side. A remarkable increase of vapor pressure was observed in the evenings in 13–19 Aug. It was also observed on 5 and 6 Aug. These days with a remarkable evening peak of vapor pressure are identified as the days of fine and calm conditions.

Figure 2 presents the diurnal variations of air temperature, relative humidity and vapor pressure at 1m height on 17th August 1991, a typical day of vapor pressure peak. The diurnal variation of latent heat flux is also illustrated, which is evaluated from eddy correlation flux measurement with a sonic anemometer and an infrared hygrometer

(Tsukamoto, 1991). The original data consists of 30-minute averages of air temperature (Pt resistance) and relative humidity (VAISALA Humicap). The air temperature shows a minimum around 6:30 BST (Beijing Standard Time, 1 hour advance of the local time) and a maximum at 16:30. This is a typical diurnal change, and the relative humidity is almost inverse of the temperature. However, the variation of vapor pressure shows a notable increase during 16:30–19:00 of nearly 9 mb. During this period, the air temperature gradually decreases after the maximum, following a sudden decrease due to sunset around 20:00.

At Zhangye Station, basic meteorological parameters are obtained at heights of 1 m, 2 m, 4 m, 8 m and 20 m. Figure 3 shows the vapor pressure variations at three representative heights (1 m, 4 m and 20 m). The overall tendency of the variations are

Fig. 3. Diurnal variations of vapor pressures at the heights of 1 m, 4 m and 20 m on 17 Aug. 1991.

Fig. 4. Vertical distribution of vapor pressure peak amplitude in the evening on 17 Aug. 1991.

almost identical, however the amplitude of the vapor pressure peak in the evening is larger for the lower layers. It is about 8.6 mb at 1 m height, but 5.5 mb at 20 m height. The vertical distribution of the amplitudes (defined by the difference between 16:30–19:00) is drawn schematically in Fig. 4. It is found that the amplitude decreases with height.

This kind of humidity peak was also observed at another smaller oasis station, Linze, during 5th to 9th July, 1991 over a wheat field. According to the low-level radiosonde sounding at Shaoton Oasis (near Linze), it was also observed that there was a specific humidity increase in the evening up to 500 m from the ground, as shown in Fig. 5 (based on Nagai, 1992). The amplitude of the peak decreased with height, which is consistent with the present Zhangye Station data.

Fig. 5. Time variations of specific humidity at the surface, 100 m, 300 m and 500 m heights obtained from low-altitude sonde observation at Shaoton Oasis. Data show synthesized mean values of typical 8 days (re-arranged from Nagai, 1992)

3. Discussion

Baumgartner *et al.* (1982) have classified the diurnal variation of vapor pressure into three types. It depends upon the amount of water available for vaporization and on the intensity of the exchange processes.

1. The oceanic type: minimum in the morning and maximum in the afternoon
2. The continental type: two minima in the morning and in the afternoon
3. The desert and steppe type: maximum in the morning and a minimum in the afternoon.

The vapor pressure peak in the present HEIFE data is considered to have appeared after the secondary minimum in Type 2.

Fig. 6. Diurnal variations of sensible (H) and latent (LE) heat fluxes and vapor pressure (E) observed at Zhangye (closed circles) and Desert (open circles) stations. Data are based on 2-hourly turbulent flux measurements on 17th Aug. 1991.

Deacon (1969) also wrote about a secondary minimum in the afternoon. In the inland area, the upper layer is drier than the lower layer. The vertical diffusion of water vapor caused by developed convection during the day can offset the effect of increased evaporation, and lead to a secondary minimum of vapor pressure in the afternoon.

According to these descriptions, the evening peak can be explained as follows. An oasis is a kind of small, moist and cool island surrounded by a dry and hot desert in the daytime. Figure 6 shows the comparisons of sensible and latent heat fluxes and vapor pressure at Zhangye and Desert stations during a typical day of the evening peak. It is observed clearly that a large amount of sensible heat is supplied over the desert during the daytime. The air above the oasis is very dry and as hot as that over the desert, as shown in Fig. 7. This is based on a tethered balloon measurement at the Desert Station and a low altitude radiosonde sounding at Shaoton Oasis. It is found that a moist and cool layer ex-

ists below 500 m over the oasis. The dry air over 500m can be advected from the surrounding desert. During the daytime, a large amount of sensible heat flux over the desert can lead to strong convective mixing. Then a larger amount of upward water vapor transport in the upper layer can exist than in the lower layer. The water vapor flux divergence in the upper layer and lower layer leads to a humidity decrease in the afternoon, as Deacon (1969) has pointed out. The humidity decrease might also be explained by the horizontal advection of dry air from the desert near the surface, which would be due to larger-scale local circulation. However, the quantitative comparison between the vertical divergence and the horizontal advection remains a problem. In the evening, upward turbulent transport of water vapor can be weakened in the upper layer due to the decay of convective motion. The decay is observed in the diurnal variation of sensible heat flux over the desert (Fig. 6). The duration of the rapid decrease of sensible heat flux corresponds to the increase of vapor pressure in the evening. However, the water vapor transport still continues upward (about 90 W/m^2 at 18:00 as shown in Fig. 2) and lead to water vapor flux convergence near the surface. This finally cause the humidity increase in the evening. After the evapotranspiration from the surface stopped (around 20:00), the humidity decreases again.

Assuming horizontal homogeneity, the time change of specific humidity in the near-surface layer is related to the water vapor flux convergence as follows.

$$\frac{\partial q}{\partial t} = -\frac{\partial (\overline{w'q'})}{\partial z} \quad (1)$$

The observed vapor pressure increases are 8.6 mb/2.5 hrs at $z=1 \text{ m}$ and 5.5 mb/2.5 hrs at $z=20 \text{ m}$, which are equivalent to specific humidity changes of 0.71 (mg/kg)/sec and 0.46 (mg/kg)/sec , respectively. These time changes correspond to latent heat flux convergences of $1.7 \text{ (W/m}^2\text{)/m}$ and $1.1 \text{ (W/m}^2\text{)/m}$ with Eq. (1) (the latent heat of vaporization being taken as 2440 Joule/g). However, it is not confirmed experimentally, because the turbulent flux measurements were carried out at only one level (2.9 m from the surface).

The evening humidity peaks were observed notably in Summer (June–August). Similar evening peaks are reported by Schollman (1968) with much smaller amplitudes (less than 2 mb) at heights of 2, 10 and 50 m at Garching near Munich, Germany. He presented the data of July, October and January, and the evening peaks are observed only in July, which is consistent with the present results. The evening peaks were not observed over the desert in the HEIFE area, as shown in Fig. 6. Even in the oasis, peaks are not observed on cloudy or windy

Fig. 7. Vertical profiles of potential temperature (θ) and specific humidity (q) obtained from a low-altitude sonde at Shaoton (dashed line: 14:45) and those from a tethered sonde at Desert Station (solid line: 13:07) on 19th Aug 1991.

days. These conditions suggest the importance of water vapor flux from the surface and the dry and hot layers above the cool and moist island (oasis) in the daytime. The latter situation can be more frequently observed in low wind speed conditions.

4. Conclusions

It is found that the vapor pressure over an oasis shows a definite peak in the summer evening. The amplitude of the peak decreases with height. According to the upper-air soundings during the daytime, hot and dry air was observed over the oasis on fine days in summer. This means that convective mixing is much stronger and transports much more water vapor in the oasis upper layer than in the lower layer. It is considered that the water vapor supply from the surface due to evapotranspiration is not enough to keep the vapor pressure constant during the daytime. In the evening, the decay of convective turbulence can lead to smaller water vapor flux in the upper layer. However, evapotranspiration still continues upward and lead to a water vapor flux convergence near the surface. The latent heat flux convergence was estimated as 1–2 (W/m^2)/m according to the calculation with vapor pressure increase. This is considered to be a unique phenomenon over moist areas surrounded by desert.

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半乾燥地域で夕方に観測された水蒸気圧の顕著なピークについて

塚本 修

(岡山大学教養部)

王 介民

(中国科学院蘭州高原大気物理研究所)

光田 寧

(京都大学防災研究所)

周囲を砂漠で囲まれた中国西北部のオアシスで、夕方になると水蒸気圧に顕著なピークが観測されることがわかった。これは夏の晴天で風の弱い日に特徴的に見られる。

地表面付近でのフラックス観測や上層のゾンデ観測から、この原因として以下の様なことが考えられる。周囲の砂漠よりも湿潤で低温なオアシス上空に高温・乾燥の砂漠の気塊が移流してきて、昼間は上層の鉛直輸送が下層大気よりも活発になる。これが水蒸気の発散を引き起こすが、夕方になると砂漠での顕熱輸送量の急減により、上空での鉛直輸送が押えられる。すると、水蒸気輸送量の収束が起こり、水蒸気圧のピークに結びつくのではないかと考えられる。