Water Vapor Exchange between Soil and Atmosphere over a Gobi Surface near an Oasis in the Summer

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ABSTRACT

Using data observed at Dunhuang, in the Gansu, in the arid region of northwest China in the summer, the characteristics of the soil water content, temperature, and atmospheric humidity were analyzed. It was found that the depth of the active soil temperature layer is about 5 cm, which is much thinner than that of typical soils. In addition, not only is the atmospheric humidity gradient in the surface layer often inverted, but so too is the soil water content gradient in the shallow layer. The diurnal variation of soil water content can be divided into four stages, including wet, water loss, dry, and water gain. It is shown that in soil water content profiles the depth of the active soil layer is about 10 cm, and soil water content inversion is the primary feature in the shallow layer during the ''wet'' stage. The presence of soil water content inversion indicates that soil in the shallow layer can absorb water from the air through condensation in the nighttime and emit water vapor to the air through evaporation in the daytime. The formation of a soil water content inversion is mainly related to the state of the soil surface temperature.

1. Introduction

A vast expanse of desert, or Gobi, interspersed with some small oases of different shapes is the main geomorphological feature in the arid region of northwest China (Cheng et al. 1999). Land surface processes of this region are much more complex than in other regions (Lin et al. 2002). Though oasis and desert have opposite characteristics, they remain a pair of coexisting ecosystems. The effect of the antagonism and interaction between them not only forms a balanced ecological distribution, but also reflects a dynamic tendency of desertification and oasisification in the natural world. Exchange of energy and matter, especially heat and water, is dominant in the interaction between oasis and desert. The main effect of a desert on an oasis is thermodynamic forcing, while the main effect of an oasis on a desert is to influence and modify its soil water content and atmospheric humidity (Zhang and Wang 1994). Thermodynamic forcing by the desert forms an ''oasis effect'' Lemon et al. 1957) or a ''cold island effect'' (Su and Hu 1987; Hu 1987) for which the key characteristics are that evapotranspiration is larger than the net radiation (Oke 1981) and that an atmospheric temperature inversion over an oasis is present (Zhang et al. 1992). The influence of the oasis on a nearby desert results in the frequent occurrence of a specific humidity inversion in the atmospheric surface layer of the desert (Hu et al. 1992; Wang and Yasushi 1991; Zhang and Zhao 1999).

It has been found that the oasis's cold-island effect can restrain surface evaporation and decrease the moisture dissipation caused by atmospheric turbulent mixing (Zhang et al. 2000). It was suggested that under certain conditions the water vapor profile over desert (or Gobi) might become inverted near the surface so that water vapor is transferred down as dewfall (Deacon 1969). It has not been clear, however, how the specific humidity inversion in the surface layer over the desert near an oasis affects the vertical structure of soil water content, water vapor exchange between land and atmosphere, and surface ecological processes. It has been inferred that there might be a special process of water vapor exchange between the atmosphere and the soil in the desert near an oasis: the absorption of water vapor from the air through condensation in the nighttime and the emission of water vapor to the air through evaporation in the daytime (Zhang and Zhao 1999). The inference has not been confirmed, and there is still a lack of good

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TABLE 1. Average value of soil types and physical parameters in the Shuangdunzi Gobi.

Density	Porosity	Thermal capacity	Thermal conductivity	Thermal diffusivity
1563 kg m^{-3}	0.37	1.17×10^6 J m^{-3} K^{-1}	0.176 W m^{-1} K^{-1}	1.61×10^{-7} m^2 s^{-1}

understanding of some key aspects of the water vapor exchange processes. For numerical modeling and observational analysis, it is necessary to understand fully the water vapor exchange process between soil and atmosphere in the desert near an oasis.

It is not only a matter of land surface processes in a general sense, but also a matter of the microclimate effect and ecological sustaining mechanism in the Gobi desert near an oasis where the atmospheric humidity, soil water content, and water transfer process are modified by oasis effect. This is closely related to the formation, maintenance, and degeneration of an oasis system.

2. Field experiment and research method

Three field stations were established in Dunhuang County, Gansu Province, China, for the Field Experiment on Interaction between Land and Atmosphere in the Arid Region of Northwest China (FEILARNC) project (Zhang et al. 2002a,b), with observations carried out from 25 May 2000 to 30 December 2003. Data for the analysis in this paper were collected in the Dunhuang Gobi station (40°10′N, 94°31′E, 1150 m MSL), sited in the Shuangdunzi Gobi and characterized by flat terrain and gravel and brown sand surfaces. The nearest distance from the station to the western edge of the Dunhuang oasis is about 7 km. The average values of some soil physical parameters of the Shuangdunzi Gobi are given in Table 1. Figure 1 shows the geographic location.

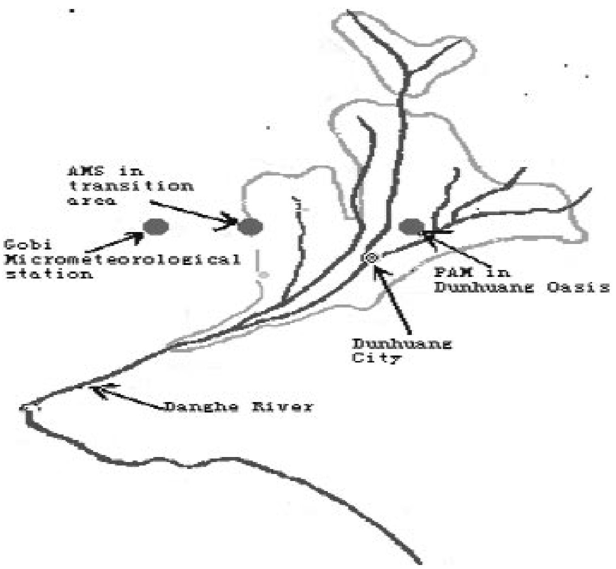

FIG. 1. A sketch map of location and layout of the Dunhuang Gobi observational site.

There is a very arid climate in Dunhuang area, with a mean annual precipitation of about 39 mm and a mean annual potential evaporation about 3400 mm. According to our observations, the diurnal variation of surface temperature is very large, with a maximum daily range close to 60°C; the recorded maximum surface temperature (thermocouple measurement made just below the soil surface) is 43.6°, and the minimum is −28.5°C. In addition, it is often cloudless. Solar radiation is strong enough to maintain a long frost-free period (~178 days) during the year. In the Gobi, strong winds and dust storms occur frequently. Because of the basin terrain of this site, the prevailing large-scale west wind is blocked and turns in Anxi County to the west of this region, and so its main wind direction is easterly, generally occurring with a frequency of more than 50%. These properties greatly affect the atmosphere over the observational site near the Dunhuang oasis.

At the station, wind speed, air temperature, and humidity were measured on a tower at four heights of 1, 2, 8, and 18 m. Soil temperatures were measured at six depths of 5, 10, 20, 40, 80, and 180 cm. Soil water contents were measured at depths of 5, 10, 20, and 80 cm, with a time domain reflectometry (TDR) soil water content hygrometer made by E.S.I. Environmental Sensors, Inc., its calibrated accuracy is about 1% (m^3 m^{-3}) volumetric soil water content. The observational error of the gradient is under 0.01% (m^3 m^{-3}) after correction through a field comparison experiment of the sensors at the same depth. The accuracy of other instruments can be found in Zhang and Hu (1992) and Wang et al. (1992). The local time of Dunhuang city is used in this study.

After considering the data representation and quality, observations during August and September of 2000, that is, just after the installation of the soil water content sensors, were selected for this analysis.

3. Analyses of results

a. *Characteristics of surface radiation and thermodynamics*

In Fig. 2, profiles of atmospheric and soil temperature and a magnified profile of soil temperature in 0–20-cm depth on a typical clear summer day over the Dunhuang Gobi are presented. Figure 2a shows that there is almost no indication of the daily temperature cycle in the soil below 40 cm. The shape of the temperature profiles are basically in accordance with those of a common soil,

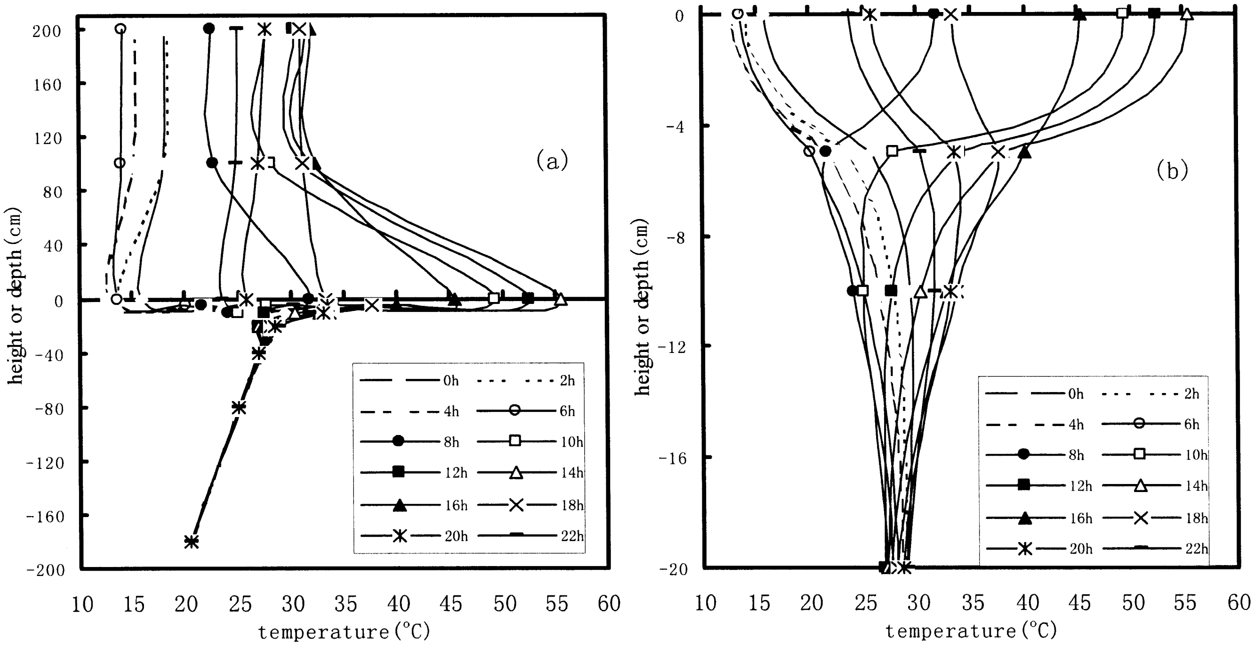

FIG. 2. Characteristics of (a) profiles of the atmospheric and soil temperatures and (b) magnified profiles of soil temperature at 0–20-cm depths on 22 Aug 2000 (a typical clear day) in the Dunhuang Gobi.

except for a more pronounced protrusion toward high temperature in the soil surface during the daytime. The atmospheric profiles in Fig. 2a show that the atmospheric surface layer is unstable after about 0700 and before about 2100 LT but is stable during about 2000–0600 LT (the next morning). Figure 2b shows more clearly that vertical variation of soil temperature occurs mainly in the layer less than 5 cm and that the temperature variation of the soil layer deeper than 5 cm is small. This indicates that the thickness of the active soil temperature layer is about 5 cm, about one-fourth of the common soil (Stull 1988). The shallow active soil temperature layer relies on the smaller soil heat diffusivity in the desert (Stull 1988). The heat diffusivity in the Dunhuang Gobi is less than one-third of that of sandy clay with 15% moisture (Hu et al. 1990). So it is reasonable that the thickness of the active soil heat layer in the Dunhuang Gobi is only one-quarter of that in moist regions. The diurnal surface temperature range is very large (the maximum daily range is close to 44°C). The maximum surface temperature is 56.2°C, and the minimum is 13.5°C. The shallow soil temperature rises sharply during the daytime and falls abruptly just after sunset.

In Fig. 3, the diurnal variations of the surface radiation budget and the soil heat fluxes in the Gobi during the period of 22–23 August 2000 are displayed. It shows that, on the first day when it is cloud free, there was a regular diurnal cycle of surface radiation budget, and the peak of the global radiation is close to 870 W m^{-2}. The downward longwave radiation is basically over 300 W m^{-2} with some variation; the upward longwave radiation is over 400 W m^{-2}, with a peak of 633 W m^{-2}. The peak of the reflected radiation exceeds 200 W m^{-2}, and the peak of the net radiation reaches 362 W m^{-2}. The upward longwave radiation and the reflected radiation both are larger than those in other regions. Although there is still a diurnal cycle of the surface radiation budget on the second day, when it was cloudy the diurnal variations of some components of the surface radiation budget exhibit some obvious indentions. The peaks of the soil heat fluxes at 2.5- and 7.5-cm depths are under 80 and 51 W m^{-2}, respectively. It is also evident that the soil heat fluxes are smaller than those in other regions. The phase difference of soil heat fluxes between two levels is about 2 h.

b. Characteristics of water vapor exchange between atmosphere and soil

Figure 4 shows the diurnal variation of the soil water content and atmospheric specific humidity at the four levels for the period during 22–23 August 2000. We can see that a diurnal cycle of soil water content occurs only at the 5-cm depth. The soil water content at the 10-cm depth decreases slightly but continuously. The diurnal cycle of the soil water content is not apparent, and the variation of soil water content at the deeper two levels is negligible. These results indicate that the shallow soil is closely related to the overlying atmospheric processes. In general, when there is no precipitation, the soil water content in the active layer should decrease gradually, hour by hour, because of evaporation. The change of the soil water content at the 5-cm depth, however,

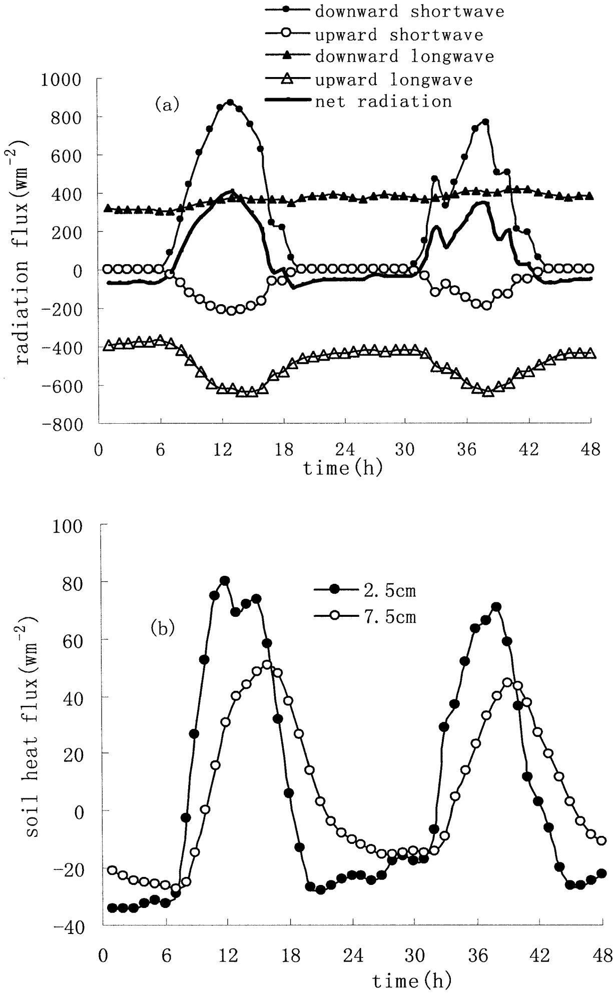

FIG. 3. The diurnal variation of the (a) surface radiation budget and (b) soil heat fluxes at two levels in the Gobi during 22–23 Aug 2000.

still shows a distinct diurnal cycle. This pattern suggests that soil water in the shallow layer may be supplied by some other systematic sources. Thus, it is probable that soil in the shallow layer obtains moisture from the air through condensation or from upward movement of water from the deeper soil layer (Zhang and Zhao 1999; Zhang et al. 2002c). The supplement of soil water at the 5-cm depth is maintained even if its water content is greater than that of the deeper soil layer. This result further indicates that the water supplement in the shallow layer is primarily due to condensation of atmospheric water vapor at the upper boundary of soil. A continuous, but slight, decrease of the soil water content at the depths of 10 and 5 cm shows that the water complemented by condensing water vapor from air cannot fully offset the water loss from evaporation. There was no supplement of precipitation. Hence, the variation of the soil water content in the shallow layer should actually exhibit a diurnal cycle with a gradually decreasing amplitude.

Furthermore, the diurnal variation of the soil water content at 5 cm shows that the diurnal variation in the shallow layer can be divided into four stages, including wet (0100–0600), water loss (0700–1100), dry (1200–1800), and water gain (1900–0000 LT). The soil always remains wet in the first stage, and it is obviously dry in the second stage. Also, the soil always keeps drier in the third stage, and it gradually becomes wet in the fourth stage. The diurnal variation of atmospheric specific humidity, which is displayed in Fig. 4b, however, is not the same as that of soil water content, and its fluctuation is weaker. This result shows that atmospheric humidity is affected by more complicated factors than those affecting soil water, namely, factors other than a clear diurnal cycle such as the atmospheric dynamic state, atmospheric thermodynamic state, landform, boundary layer processes, and so on.

The four stages make up a full diurnal cyclic process. If the process in which soil attains moisture from the air through condensation during the wet stage is called absorbing, the process in which soil releases water vapor to the air through evaporation during the dry stage is called emitting, and the other two stages are called the transition periods between absorbing and emitting, then a full diurnal cycle of the soil water content is equivalent to a full water vapor exchange process of moisture between the active soil layer and the atmospheric surface layer.

In Fig. 5, four groups of soil water content profiles in the Dunhuang Gobi on a typical clear day in August show, respectively, the four stages of the diurnal cycle. During the four stages, clearly, the four groups of soil water content profiles have, respectively, the following different characteristics:

1) During the wet stage, the shapes of the soil water content profiles are similar to each other, and there is soil water content inversion in the shallow layer. The cause of the inversion is likely that the soil obtains water from the atmospheric surface layer. Under conditions of a clear sky, no irrigation, and no surface runoff, absorbing water from the air by the condensation of water vapor at night is the exclusive way in which the Gobi soil water content in the 5-cm depth increases.
2) During the water-loss stage, the soil water content inversion gradually disappears and changes into an upward decrease of soil water content. In this stage, soil water content is controlled primarily by evaporation. It logically results in the disappearance of the soil water content inversion.
3) During the dry stage, soil water content profiles change very little, and they basically maintain an upward decrease of soil water content. This means that the soil neither loses nor gains water and that no water in the shallow layer can be available for evaporation.
4) During the water-gain stage, because of water vapor

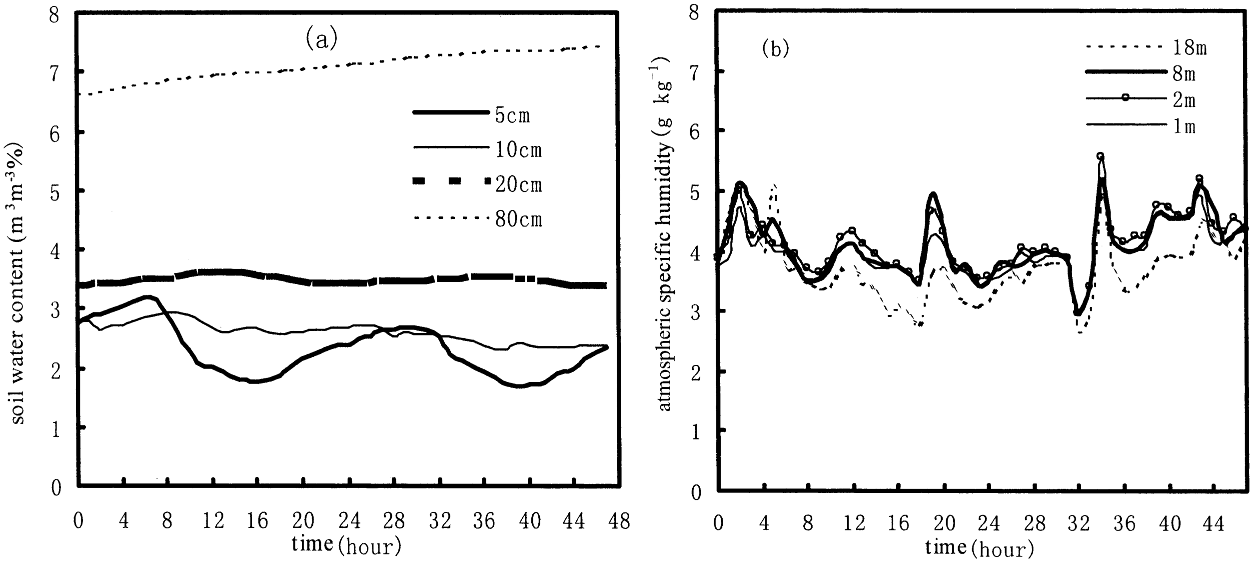

FIG. 4. The diurnal variation of (a) soil water content at four levels and (b) atmospheric specific humidity at four levels during 22–23 Aug 2000.

condensation into the soil from the atmosphere, soil water content in the shallow layer gradually increases, and the shallower the soil layer is, the greater is the water content increase, which finally results in soil water content inversion in the shallow soil layer.

According to the variations of the soil water content profiles during the four stages, it can be deduced that the variation of soil water content is largely confined in the shallow layer (about 10 cm thick) and that soil water content in the deeper soil layer basically does not change.

Figure 6 shows four groups of atmospheric specific humidity profiles during the four different stages in a diurnal cycle of soil water content over the Dunhuang Gobi on 22 August 2000 (a typical clear day). Although the four groups of atmosphere profiles always maintain a specific humidity inversion (sometimes there is a thin specific humidity inversion in the near-surface layer), there are differences among them. In past studies (Zhang and Zhao 1999), it has been preliminarily shown that the transport and diffusion of moist air over an oasis toward the Gobi resulted in the development of an atmospheric humidity inversion over the Gobi. During the wet stage and the water-gain stage, evaporation is low and atmospheric humidity in the surface layer is mainly influenced by water vapor advection from the oasis, and so the atmospheric specific humidity profile is essentially inverted (although, sometimes the specific humidity inversion only occurs in a thinner layer near the surface). During the water-loss stage and the dry stage, evaporation is higher and humidity in the surface layer is jointly controlled by evaporation and water vapor advection, and so the atmospheric specific humidity profile becomes essentially decreasing with height (although, there is mostly a very thin specific humidity inversion near the surface). Thus, it can be affirmed that a very strong downward water potential gradient is formed because the atmospheric specific humidity inversion is stable and deep during the wet stage and the water-gain stage.

Therefore, the water vapor exchange between atmosphere and soil of the Gobi near an oasis is an efficient way of reutilizing water vapor transferred from the oasis, providing a maintenance capability for the ecological community and microclimatic state.

c. Conditions for condensation of water vapor

For evaporation, in general, three components: a water source, energy, and a water vapor pressure gradient, are required. In this case, soil water is condensed from the overlying atmosphere in the 5-m soil layer during the nighttime period, and the energy in the form of solar radiation is abundant, in the Gobi. Then water vapor pressure gradient is particularly strong in the Gobi. The dewfall through which surface soil absorbs condensed water vapor on the soil in the Gobi near an oasis also depends on some objective conditions. A downward water potential of atmosphere in the surface layer, namely, a near-surface atmospheric specific humidity inversion, is required for condensation of water vapor on the soil. At the same time, a low enough temperature to reach the condition of condensation is also required. In addition, stable atmospheric stratification is required for retaining water vapor in the lower atmosphere near the surface. Figure 7 shows the comparison of diurnal variations of soil water content inversion, soil surface temperature, temperature gradient in the atmospheric surface layer (denoting stability), and specific humidity gradient in the atmospheric surface layer (denoting at-

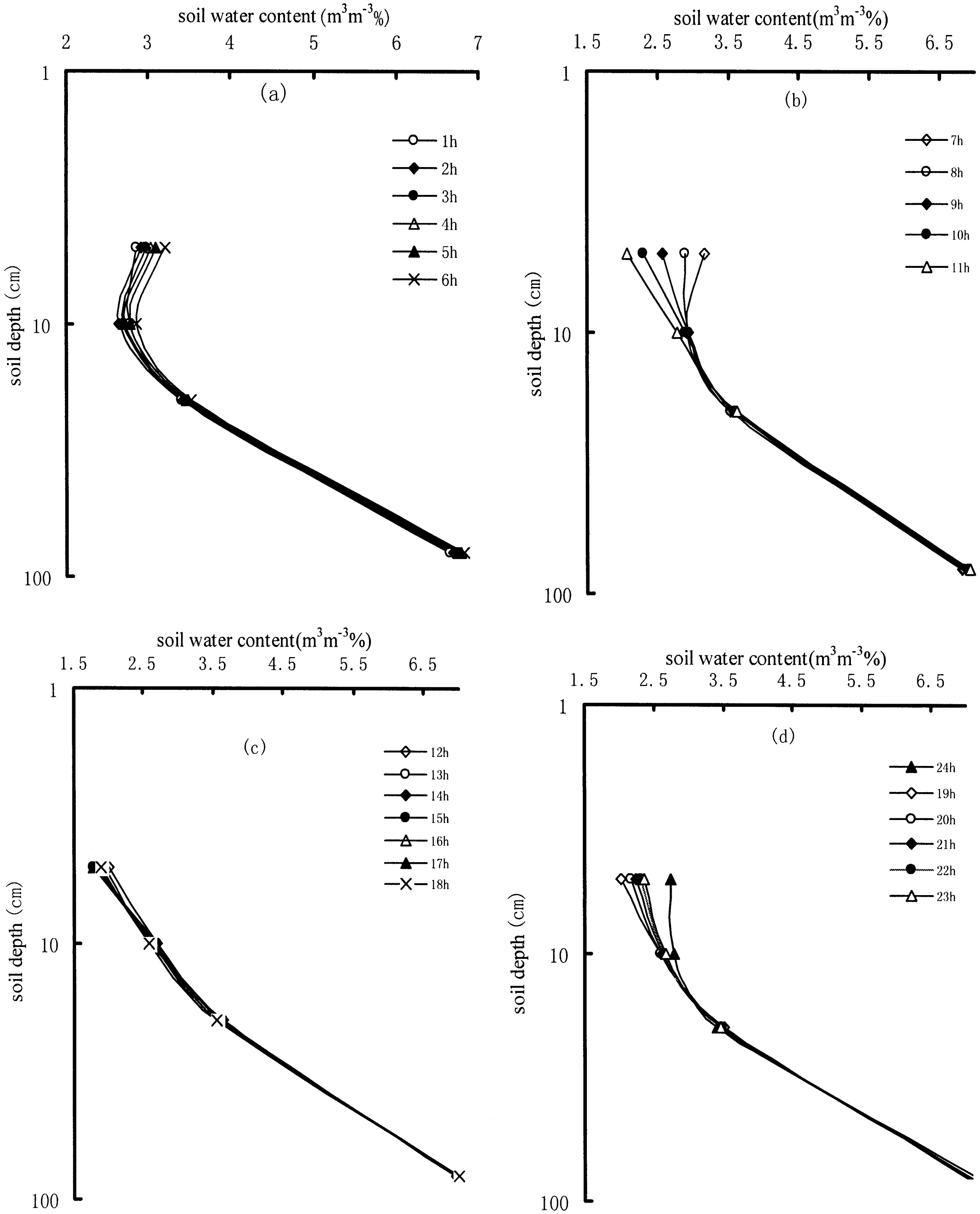

FIG. 5. Four groups of profiles of soil water content during the (a) wet, (b) water loss, (c) dry, and (d) water gain stages in the Dunhuang Gobi on 22 Aug 2000 (typical clear day).

mospheric humidity inversion) over the Dunhuang Gobi on 22–23 August 2000. It shows that the strongest soil water content inversion and the lowest surface temperature occurred generally simultaneously, which means that temperature is a critical factor in the condensation of water vapor. The stronger soil water content inversion occurs under the condition of a more stable atmosphere. It means that a stable atmosphere is also very important for water vapor to condense, and it contributes to higher humidity near the surface. Atmospheric humidity in-

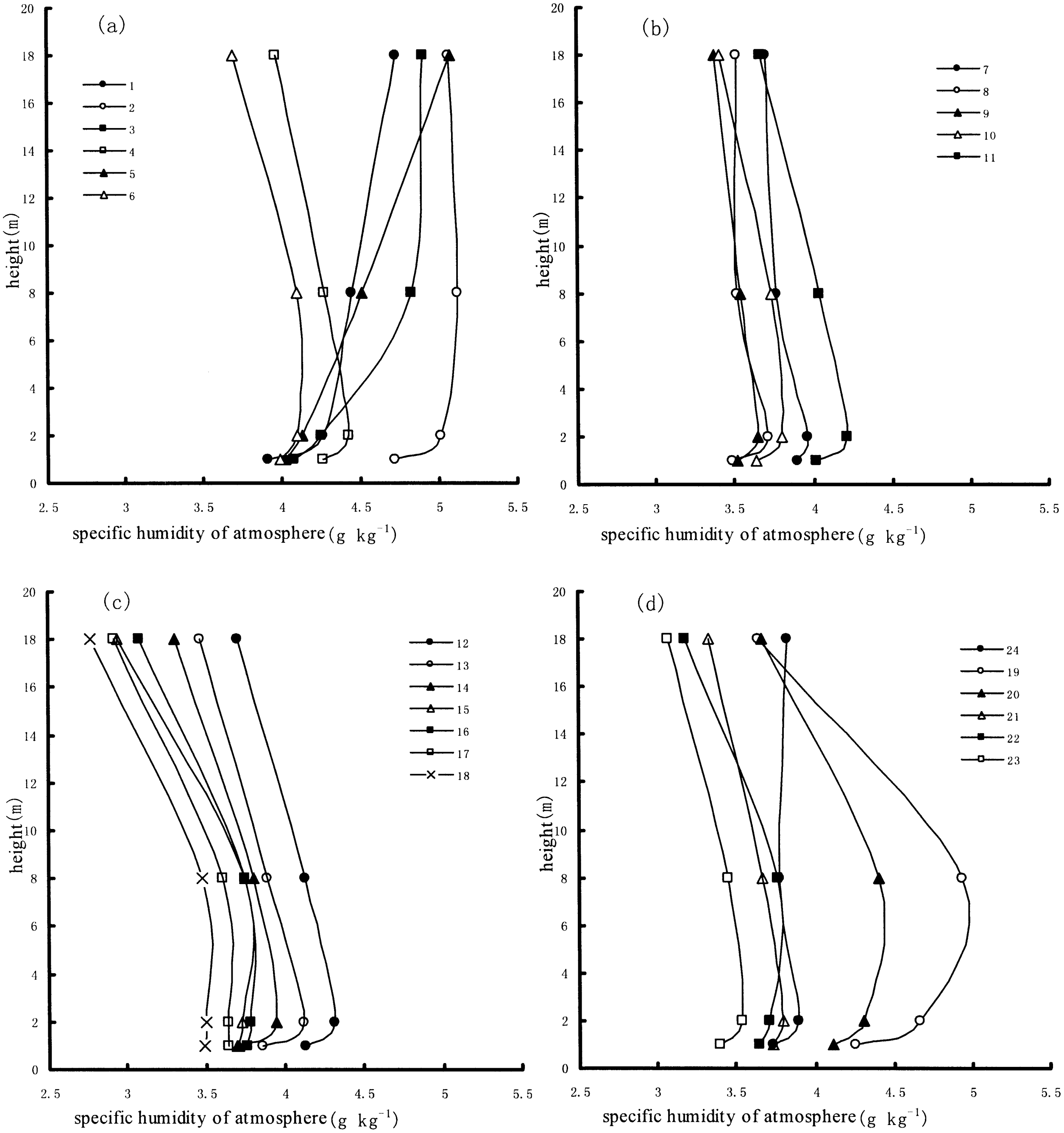

FIG. 6. Four groups of profiles of atmospheric specific humidity, respectively, during the (a) wet, (b) water loss, (c) dry, and (d) water gain stages over the Dunhuang Gobi on 22 Aug 2000 (a typical clear day).

version, which typically occurs, provides a source of water vapor, but it cannot ensure the occurrence of condensation. Atmospheric humidity inversion without the occurrence of condensation cannot affect the soil water content. In other words, the occurrence of atmospheric humidity inversion is not completely in phase with that of the soil water content inversion. It should be concluded that a temperature at the dewpoint is a necessary physical condition for the formation of soil water content inversion, atmospheric specific humidity inversion is a necessary material condition, and atmospheric stability is only an influencing factor.

Figure 8 shows the correlation of the soil water content inversion in the shallow layer with the soil surface temperature, the temperature gradient in the atmospheric surface layer, and the specific humidity gradient in the atmospheric surface layer. Through statistical analysis, it is found that the correlation between soil water content

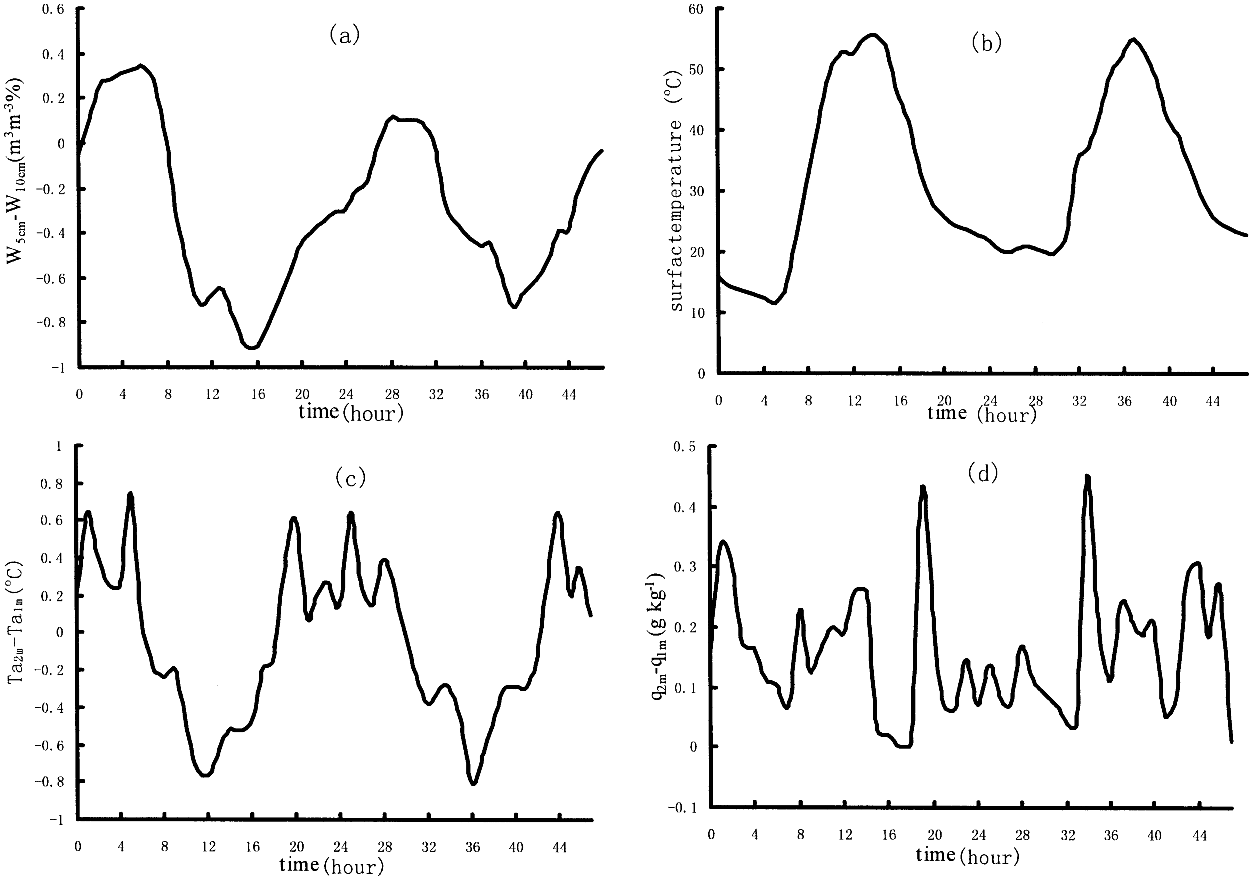

FIG. 7. Comparison of diurnal variations of (a) soil water content inversion, (b) soil surface temperature, (c) temperature gradient in the surface layer, and (d) specific humidity gradient in the surface layer over the Dunhuang Gobi on 22–23 Aug 2000; *W* denotes soil water content, Ta denotes atmospheric temperature, and *q* denotes atmospheric specific humidity.

inversion in the shallow layer and soil surface temperature is the highest (0.934), followed by temperature gradient, and then wind speed in the atmospheric surface layer, the latter two with correlation coefficients of 0.50 and 0.29, respectively. The lowest correlation is with specific humidity gradient in the atmospheric surface layer, with a correlation coefficient of only 0.21. In Fig. 8, soil water content inversion in the shallow layer occurs only when the soil surface temperature is lower than 20°C. It is apparent that only surface temperature was found to correlate with soil water content inversion and that for the other three factors there was almost no correlation for all practical purposes.

Figure 9 shows the correlation of the changing rate of the soil water content at 5-cm depth with soil surface temperature, temperature gradient in the atmospheric surface layer, specific humidity gradient in the atmospheric surface layer, and wind speed in the atmospheric surface layer. As can be seen in Fig. 9, the rate of soil water content at 5-cm depth has a good relation with soil surface temperature and temperature gradient in the atmospheric surface layer, with correlation coefficients of 0.66 and 0.65, respectively, followed by the wind speed in the atmospheric surface layer with a correlation coefficient of 0.41; the correlation with the atmospheric humidity inversion in the surface layer is the poorest, with a correlation coefficient of less than 0.3. Soil water content in the shallow layer just begins to increase when surface temperature is lower than about 32°C, the wind speed at 8-m height is weaker than about 1.8 m s^{-1}, and the atmospheric temperature is inverted (stable stratification), but in other cases it often decreases. The intensity of the soil water content inversion in the shallow layer occurs just after the water absorbed to the surface soil from the atmosphere through condensation comes to a critical value. However, the soil water content rate can reflect directly the effect of the water absorbed through condensation. Therefore, the correlations of temperature gradient and wind speed with the soil water content rate are much higher than those with the intensity of the soil water content inversion.

Atmospheric humidity inversion is the material condition, rather than a necessary and sufficient condition, in the formation of the soil water content inversion. In the general climatic state, as a result of the influence of the nearby oasis, condition of specific humidity inver-

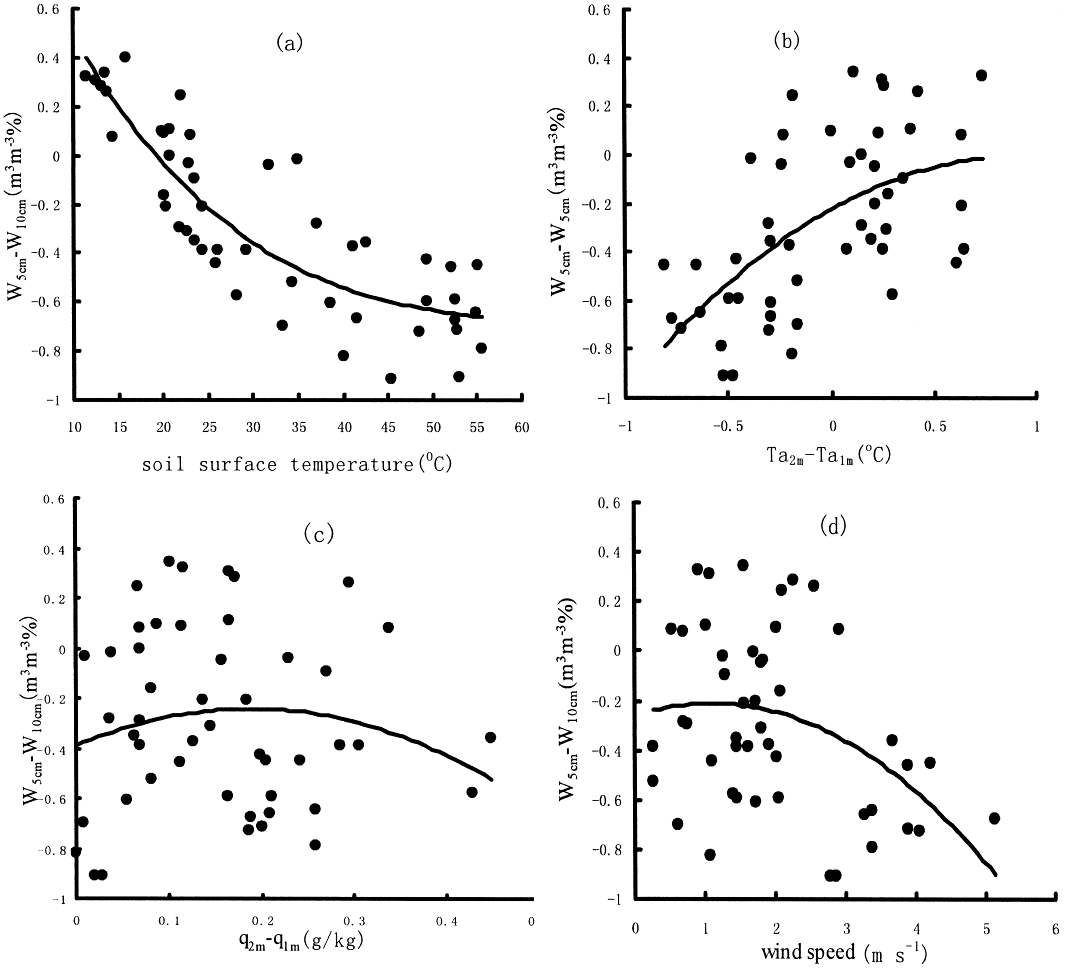

FIG. 8. Correlation of soil water content inversion in the shallow layer with (a) soil surface temperature, (b) temperature gradient in the surface layer, (c) specific humidity gradient in the surface layer, and (d) wind speed in the surface layer over the Dunhuang Gobi on 22–23 Aug 2000; *W* denotes soil water content, Ta denotes atmospheric temperature, and *q* denotes atmospheric specific humidity.

sion can always be met, and so its correlations with both the soil water content inversion and the rate of the soil water content in the active layer are not very good.

The occurrence of the soil water content inversion in the shallow layer is the necessary effect of moisture–water vapor exchange on the ground. To verify the universality of the above conclusion in summer, data observed from 22 August to 30 September 2000 (about 40 days in all) over the Dunhuang Gobi, which basically represent the characteristics of atmosphere and soil in summer, are analyzed systematically. Figure 10 shows the variation of daily maximum intensity of the soil water content inversion in the 5-cm layer. It is clear that the soil water content gradient in the shallow soil layer is inverted almost daily. It shows that although the duration of the condensation process varies from day to day, the condensation process occurs almost daily on the soil surface. The average of the daily maximum intensity of soil water content inversion is often approximately 0.4 m^3 m^{-3}%. This means that the process in which the surface absorbs water from the atmosphere through condensation is universal in the active soil water layer in the Gobi near an oasis in summer.

4. Conclusions and discussion

From diurnal variations of soil temperature and moisture over the Gobi area near an oasis, it can be inferred that the soil thermal conductivity is much smaller there, and so the thickness of the active soil temperature layer is just about 5 cm. According to the structure of the soil temperature profiles, it can be concluded roughly that the thickness of the soil water content active layer in the Gobi area is about 5 cm.

The apparent diurnal variation of the soil water content primarily occurs in the active soil water content layer. The characteristics of the diurnal cycle of soil water content in the shallow layer show that soil water content is jointly controlled by water evaporating to the

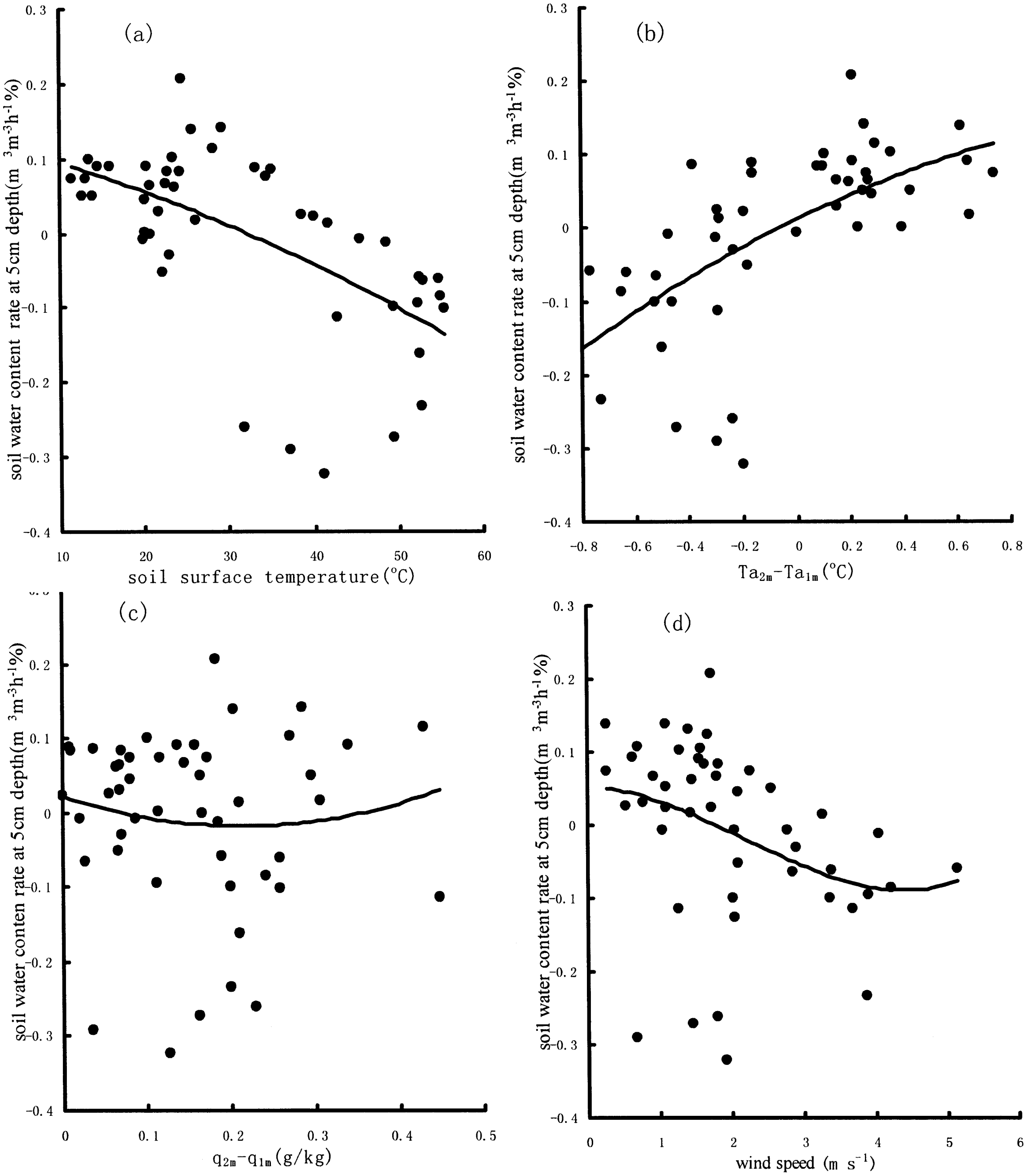

FIG. 9. Correlation of the soil water content rate at 5-cm depth with (a) soil surface temperature, (b) temperature gradient in the surface layer, (c) specific humidity gradient in the surface layer, and (d) wind speed in the atmospheric surface layer over the Dunhuang Gobi on 22–23 Aug 2000; Ta denotes atmospheric temperature, and *q* denotes atmospheric specific humidity.

atmosphere through solar heating and by water being absorbed from the atmosphere through condensation.

The diurnal variation of soil water content in the shallow layer can be clearly divided into four stages: wet, water loss, dry, and water gain. There are great differences among the four groups of the vertical profiles of soil water content during the four stages. It is noteworthy that the soil water content inversion in the wet stage has rarely been found before. Changes of the soil water content profiles match very well with changes of the atmospheric specific humidity profiles in the surface layer from one stage to another. This result means there is strong interaction between the shallow soil layer and the atmospheric surface layer.

Absorbing water from the atmosphere through condensation in the wet stage and emitting water vapor to

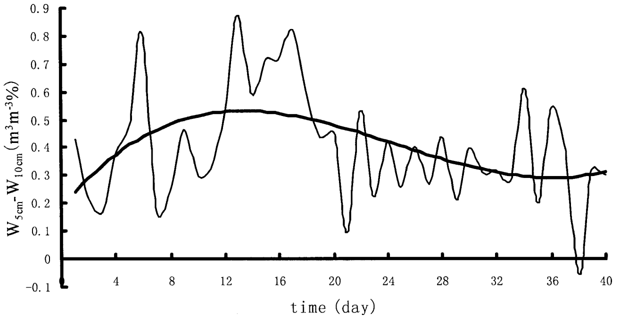

FIG. 10. Variation of daily maximum intensity of soil water content inversion in the shallow layer during 22 Aug and 30 Sep 2000 in the Dunhuang Gobi; *W* denotes soil water content.

the atmosphere through evaporation constitute a full water vapor exchange process near the soil surface during a day. The occurrence of water content inversion and the increase of soil water content in the shallow layer result partly from the condensation process. However, the water absorbed by the soil through condensation is not enough to offset the loss from soil through evaporation.

Key factors in the formation of the condensation process on the soil include the structure of the atmospheric specific humidity, the soil surface temperature, the atmospheric stability, and the wind speed. Lower soil temperature and atmospheric humidity inversion are preconditions to formation of soil water content inversion, which is a necessary condition for the condensation process of water vapor occurring on the soil. The atmospheric stability and the wind speed in the surface layer are both influencing factors in the formation of the soil water content inversion. The soil water content inversion often occurs in the active soil layer only when surface temperature is less than 20°C, and the soil water content in the active soil layer always increases when the surface temperature is lower than 32°C. Weak wind speed and a stable atmosphere are also generally required for the soil water content inversion and the increase of soil water content to occur.

In a usual climate state of the Gobi near an oasis, the correlation of the soil water content inversion in the shallow soil layer and the surface temperature is the highest, followed by the correlation with the atmospheric stability in the surface layer; the correlations with the wind speed and the atmospheric humidity gradient in the surface layer are poor. However, with the change rate of soil water content in the active soil layer, both the surface temperature and the atmospheric stability in the surface layer have better correlations, whereas wind speed and atmospheric humidity gradient in the surface layer have a smaller correlation. In theory, the atmospheric humidity inversion is a material condition for soil to absorb water from the atmosphere through condensation, lower surface temperature and weaker wind speed are necessary physical conditions, and stable atmospheric stratification is an influencing condition.

The condensation process of water vapor on the soil surface in the Gobi near an oasis is an efficient reutilization of water vapor transported from the oasis, and it can support a stronger maintenance capability of the desert ecosystem than can natural precipitation alone.

At present, it is impossible to calculate quantitatively the water vapor exchange and the interactive processes between the atmosphere and soil in the Gobi near an oasis, because of the limited observational items and the observational precision. Hope is placed on better observations and simulations of land surface processes for future analyses and studies.

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