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DIURNAL VARIATION IN WATER VAPOR AND LIQUID WATER PROFILES FROM A NEW MICROWAVE RADIOMETER PROFILER

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1. INTRODUCTION

Diurnal variations of atmospheric water vapor affect surface and atmospheric longwave radiation, atmospheric absorption of solar radiation and thus the surface temperature. They are closely related to diurnal variations of other atmospheric and surface processes, such as moist convection, precipitation, radiation, and surface evapotranspiration. The diurnal cycle of water vapor also provides a test bed for many aspects of the physical parametrizations in weather and climate models. However, there have been few global and regional analyses of diurnal variations of atmospheric water vapor because the operational observing system for atmospheric humidity profiles, radiosonde observations, are usually available only twice a day (00 and 12 UTC).

A new microwave radiometer profiler (MWRP) has been developed by Radiometrics Corporation, and has been deployed at the central facility (CF) of the Atmospheric Radiation Measurement's (ARM) Southern Great Plains (SGP) site. Profiles of temperature and water vapor up to 10 km and cloud liquid water in one layer are retrieved from the MWRP radiance data in about 10-min temporal resolution. In this paper, we use the 10-min MWRP data to study diurnal variations of water vapor profiles as well as atmospheric precipitable water (PW), compare them with radiosonde data, and use other datasets to study causes for observed diurnal variations.

2. INSTRUMENT AND DATA

The microwave profiler measures the radiometric brightness temperature of the sky at 12 microwave and one infrared frequencies. Seven of them correspond to oxygen absorption lines from 51 to 59 GHz, and are used to retrieve the temperature profiles; the other five frequencies range from the center of the water vapor line at 22 GHz out to 30 GHz and are used for retrieval of water vapor profiles. Cloud liquid water content (LWC) profiles can be obtained using the combined microwave and infrared bands. Profiles of temperature, water vapor, and cloud liquid water are derived from measured brightness temperatures with a neural network retrieval algorithm (Solheim et al. 1998).

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The MWRP provides continuous, real-time vertical profiles of temperature and water vapor up to 10 km in both clear and cloudy conditions and cloud liquid water in one layer from the surface up to 10 km. The data are in about 10-min temporal resolution and are available at 47 levels: from 0 to 1 km above ground level at 100-m intervals, and from 1 to 10 km at 250-m intervals. The MWRP data used in this study were obtained at the CF of the ARM's SGP near Lamont, Oklahoma during two periods, 15 February -- 8 August 2000 and 10 July -- 13 September 2001.

The ARM radiosonde data in 2000 and 2001 at the CF are available four times a day (05, 14, 17 and 23 local solar time or LST) and are compared with the MWRP data. The ARM surface data from the surface meteorological observation system (SMOS) are used to analyze diurnal variations of precipitation and other surface parameters. The data from objective variational analysis of the ARM IOP data (Zhang et al. 2000) are analyzed for diurnal variations of vertical velocity, convergence profiles and other parameters to help us understand observed diurnal variations of water vapor profiles.

3. COMPARISONS WITH RADIOSONDE DATA

Vertical profiles of water vapor mixing ratio (MR) anomalies at 05, 14, 17 and 23 LST were calculated from the ARM radiosonde data at the CF from March to August 2000 and compared with the MWRP data (Fig. 1). Two datasets show good agreements in both the sign and the magnitude of anomalies except in the middle troposphere at 05 and 14 LST in summer where the radiosonde data generally show larger variabilities. Such disagreement in the middle troposphere contributes to differences in PW anomalies between radiosonde and MWRP data at 05 and 14 LST in summer (Fig. 2). The overestimate of PW by MWRP at 5 LST in summer is likely due to missing MWRP data under rain conditions. The retrievals of temperature, water vapor, and liquid water from MWRP radiance data are invalid if it is raining or has recently rained so that there is water on the radiometer's polycarbonate foam window (referred as "wet-window" data). There are more "wet-window" MWRP soundings from the middle night to the early morning with a maximum of 20% at 4 LST (not shown).

The comparison of PW from coincident MWRP and radiosonde data in 2000 shows that the MWRP data are moister than radiosonde data with an increasing bias at high PW (Fig. 3). This is partly due to the dry bias in the Vaisala RS80_H radiosonde data since Vaisala RS80_H radiosondes were used before 1 May 2001 at the CF (Wang et al. 2001). However, the comparison for data in 2001 when Vaisala RS90 (free of dry bias) was used still shows the moist bias of MWRP data at high PW. Liljegren et al. (2001) also found moister PW from the MWRP data than that from the 2-channel microwave radiometer at high PW. This is probably due to moister retrievals of the neural network method than a statistical regression method and the fact that the statistical method is more accurate than the neural network (Guldner and Spankuch 2001). The application of a single set of retrieval coefficients for the entire period rather than monthly retrievals may also contribute to the moist bias at high PW in MWRP data.

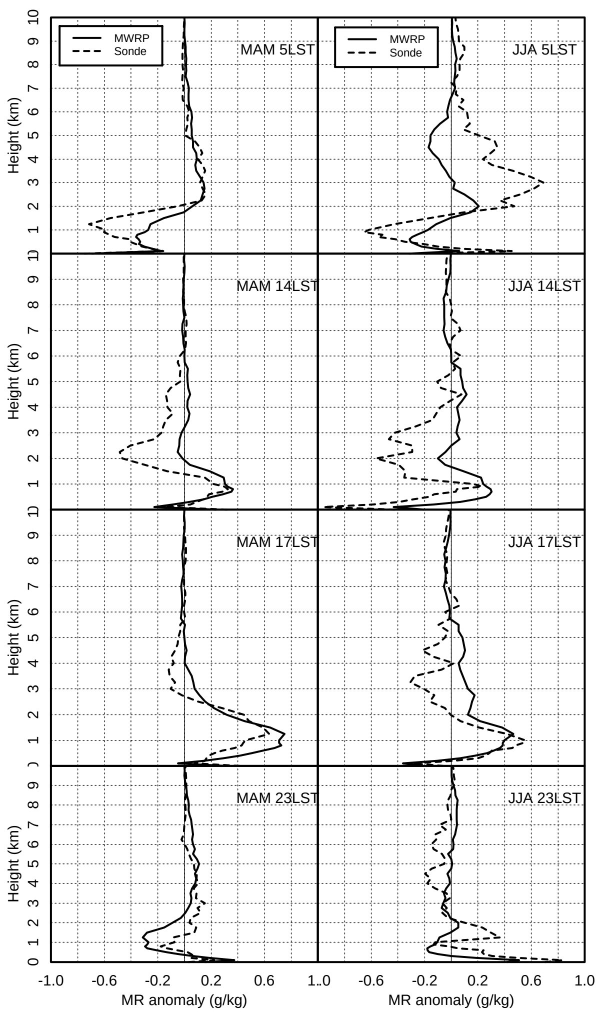

Figure 1. Comparisons of mean MR anomaly profiles from MWRP and radiosonde data at 5, 14, 17, and 23 LST in MAM and JJA in 2000.

4. DIURNAL VARIATIONS

Nomalized seasonal-mean diurnal anomalies of MR are calculated from the MWRP data for spring of 2000 (March-April-May) and for summer of 2000 and 2001 (June-July-August) (Fig. 4). The MR in the upper troposphere (above ~6 km) in both spring and summer is significantly higher in the early morning (00-08 LST) than during the day (08-18 LST). In the lower troposphere (~0.5-3 km), the MR in both seasons tends to be lower in the morning than in the afternoon and at night, and reaches a minimum around 08 LST and a maximum around 18 LST. The MR near the surface shows features similar to that in the lower troposphere in spring, but shows moist anomalies at night and in the morning (07-11 LST) in summer. This near-surface morning moist anomaly in summer expands and propagates upward to about 2 km around 18 LST. In the middle troposphere (3-6 km), MR in summer shows diurnal features consistent with that in the upper troposphere (Fig. 4), but it is noisy and has complicated diurnal variations in summer. Diurnal variations of MR profiles shown in Figure 4 are consistent with those derived from 3-hourly radiosonde data during the ARM water vapor IOPs for 1994-2000 at the CF except in the middle troposphere in summer (see Fig. 7 in Dai et al. 2001). Radiosonde data in summer show the same diurnal variations in the middle troposphere as in the upper troposphere (Dai et al. 2001). The precipitable water (PW) peaks around 17 LST in both spring and summer (Fig. 2). Diurnal variations of cloud LWC profiles and liquid water path (LWP) are small and noisy.

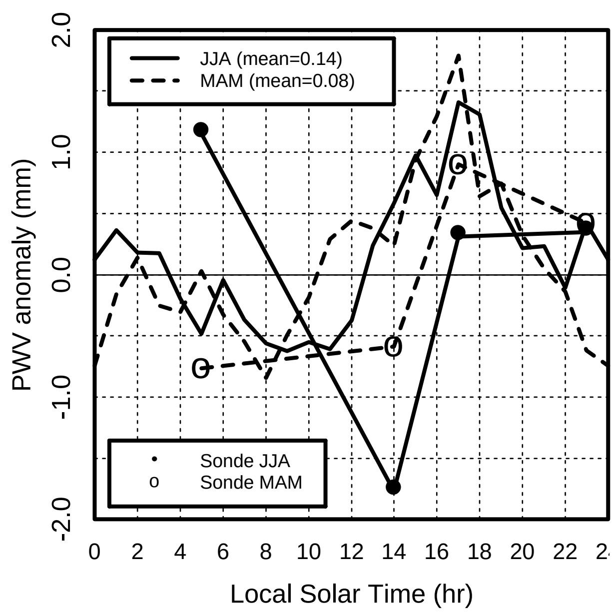

Figure 2. Diurnal variations of PW anomaly (mm) from MWRP and radiosonde data in 2000.

5. EXPLANATIONS ON DIURNAL VARIATIONS

Atmospheric large-scale vertical motion is likely to be an important factor controlling the diurnal anomalies in the upper troposphere shown in Fig. 4. The large-scale vertical motion at Lamont, OK is upward at midnight and downward at 11.5 and 17.5 LST in July based on the 1975-1995 data from NCEP analysis (Fig. 5a, Dai et al. 1999) and the objective analysis data (not shown). The nocturnal precipitation maximum in summer in the SGP shown by the SMOS data (Fig. 5b) is consistent with the summer positive anomalies of near-surface MR at night since precipitation can moisten the near-surface air by evaporation (Fig. 4). The peak surface evaporation around noon in both seasons (Fig. 5c) accumulates water vapor in the boundary layer before the convection breaks up and results in a peak MR within the lowest 1-2 km in the late afternoon (Fig. 4). The diurnal variation in JJA in the middle troposphere still can not be explained and are not seen in radiosonde data, so it may be noisy.

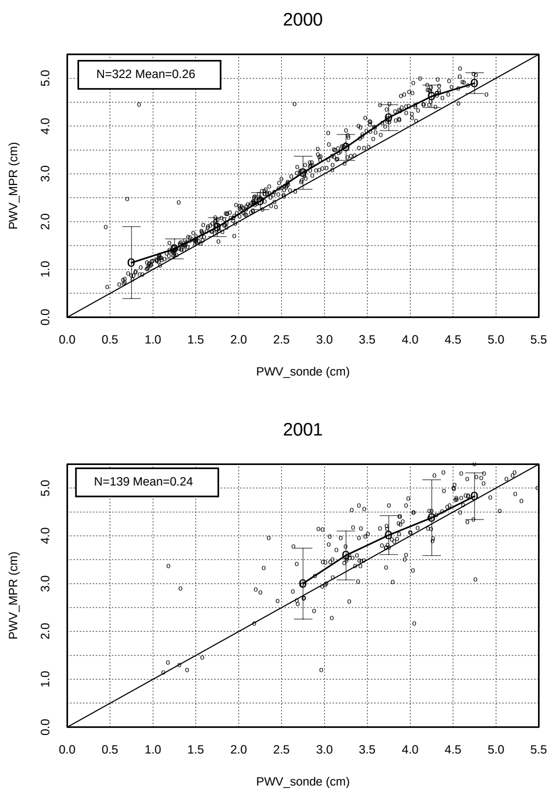

Figure 3. Comparisons of PW from coincident MWRP and radiosonde data in 2000 and 2001. Mean and standard deviation of MWRP-derived PW are also given as a function of radiosonde-measured PW.

6. SUMMARY

The MWRP data collected in 2000 and 2001 at the CF of the ARM SGP site are analyzed to study diurnal variations in water vapor profiles. Significant diurnal variations of PW were found in both spring and summer with a peak around 17 LST and average magnitudes of 0.08 mm and 0.14 mm in spring and summer, respectively. The vertical structure of MR diurnal variations exhibits interesting features. MR in the upper troposphere in both seasons is significantly higher in the early morning than during the day, while it tends to be lower in the morning than in the afternoon and at night in the lower troposphere. MR near surface shows the similar features as that in the lower troposphere in spring, but shows moist anomalies in the morning and at night in summer.

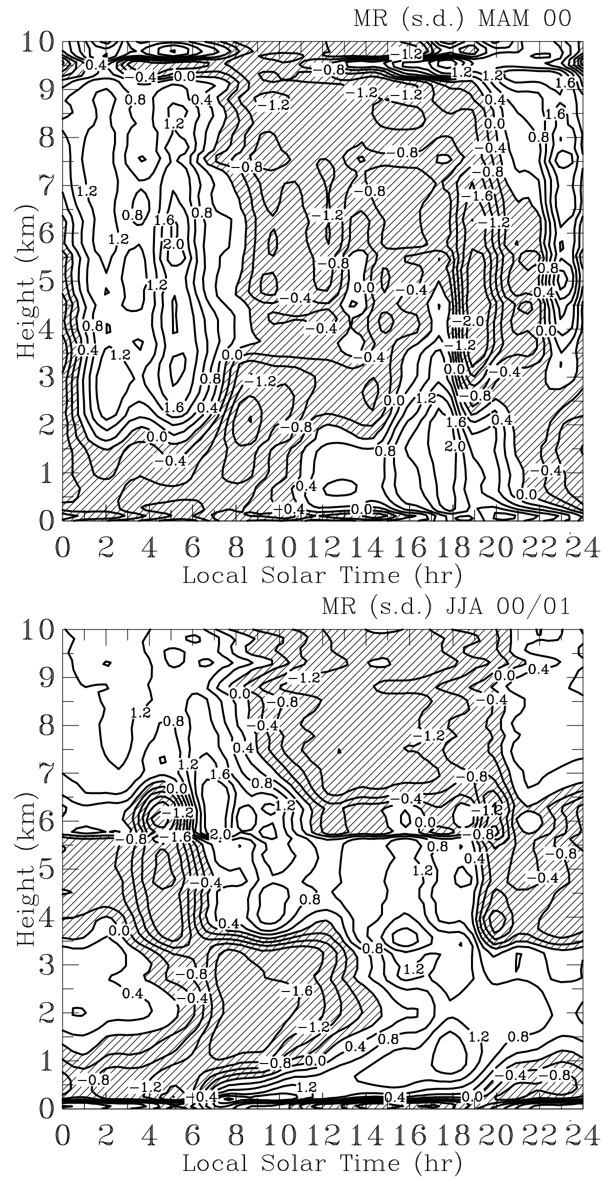

Figure 4. Seasonal-mean diurnal anomalies (normalized by diurnal standard deviation at each level) of atmospheric MR derived from MWRP data. Negative anomalies are hatched.

The comparison of PW from coincident MWRP and radiosonde data in 2000 shows that the MWRP data are moister than the radiosonde data with a increasing bias at high PW. This is likely due to the dry bias in the Vaisala RS80_H radiosonde data and moist bias in the neural network retrieve method used for MWRP data.

Diurnal variations of MR profiles derived from MWRP data are consistent with those derived from radiosonde data except in the middle troposphere in summer. The disagreement in the middle troposphere in summer is likely attributed to missing MWRP data under rain conditions.

We found that atmospheric vertical motion (upward at night and downward during the day) is an important factor controlling diurnal anomalies of water vapor in the upper troposphere. The precipitation and surface evaporation contribute to diurnal variations of water vapor near surface and in the boundary layer. More analyses are needed to explain the complicated diurnal variations in summer in the middle troposphere.

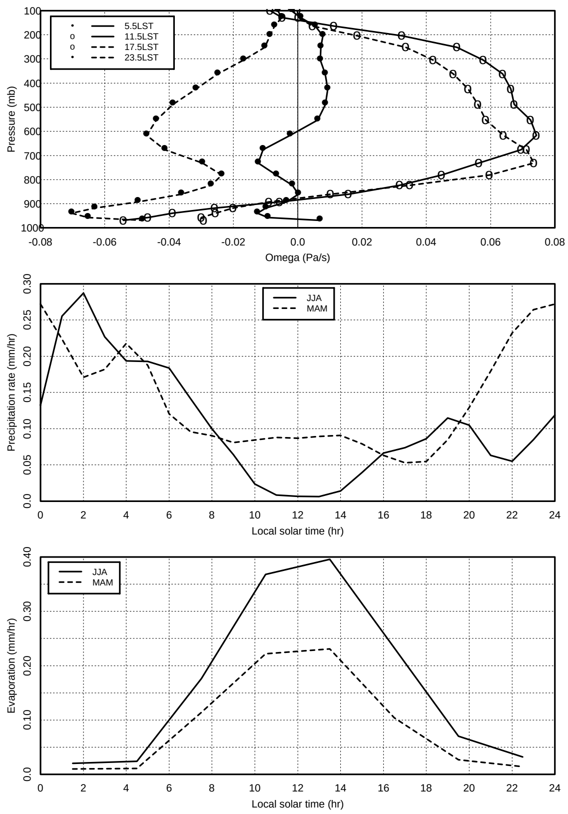

Figure 5. Omega profiles at 5.5, 11.5, 17.5, 23.5 LST in July from the 1975-1995 NCEP analysis data (a), diurnal variations of precipitation rate in JJA and MAM from the 1998-2000 SMOS data (b), and diurnal variations of surface evaporation in MAM and JJA from the 1994-1999 ARM IOP variational objective analysis data.

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