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Effect of off-zenith observations on reducing the impact of precipitation on ground-based microwave radiometer measurement accuracy

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ABSTRACT

Microwave radiometers (MWRs) can be useful for the detection of mesoscale phenomena because they provide thermodynamic profiles in a minute time scale. These profiles are mainly used in non-precipitation conditions due to degraded accuracy of the MWR measurements in precipitation. Recently, Radiometrics Corporation used proprietary neural network methods to retrieve temperature, humidity and liquid profiles from off-zenith (15° elevation) radiometer observations to provide higher accuracy during precipitation. In this paper, using the MWR-retrieved temperature and humidity profiles with collocated radiosondes from June 2010 to September 2013 in Wuhan, the impact of precipitation on the MWR measurement accuracy as well as the effect of off-zenith neural network methods on it is investigated. In precipitation, the correlation coefficients of the MWR temperature and vapor density profiles against radiosondes are smaller than those in non-precipitation, and the bias and RMS against radiosondes also increase, especially around 2 km heights. For the MWR relative humidity profile, the correlation coefficient in precipitation is obvious smaller than that in non-precipitation below 4.5 km, and the bias and RMS against radiosondes are clearly larger above 5.5 km. Moreover, the differences between the precipitation and non-precipitation cases mostly are statistically significant. Compared with the results of the zenith observation, the off-zenith observation makes a positive effect on reducing the impact of precipitation on the accuracy of MWR temperature and vapor density retrievals. On the whole, the MWR temperature bias and RMS against radiosondes in precipitation are reduced from 3.6 and 4.2 K to 1.3 and 3.1 K, respectively, and the MWR vapor density bias is also reduced from 1.10 g/m^3 to 0.18 g/m^3 with the RMS decreasing from 2.90 g/m^3 to 1.91 g/m^3. The temperature correlation coefficient between the MWR and radiosonde in precipitation is clearly improved above 3 km heights, and the temperature bias and RMS are significantly reduced at most heights. For the MWR vapor density retrievals in precipitation, the correlation coefficient, bias and RMS against radiosondes are clearly improved above 2 km heights. Additionally, the off-zenith observations during non-precipitation cases are also better compared to zenith observations. Therefore, off-zenith observations generally are better than zenith observations. This could be due to the fact that the off-zenith observations are more representative of the conditions in which radiosonde observations are also taken.

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1. Introduction

Atmospheric temperature and humidity profiles are significant for meteorological research and commonly obtained with traditional radiosondes, which are launched only twice each day in operation. Many of the meteorological phenomena occurring at mesoscale require observations sufficiently close together in time and space. However, the lack of observations necessary to define mesoscale systems is a critical meteorological problem. Ground-based microwave radiometers (MWRs) retrieve the temperature, humidity and liquid profiles up to 10 km by measuring the radiation intensity at a number of frequency channels in the microwave spectrum that are dominated by atmospheric water vapor, cloud liquid water and molecular oxygen emissions. These profiles are available nearly continuously, at intervals of several minutes (Chan, 2009). The high temporal resolution is able to resolve detailed mesoscale thermodynamic and limited microphysical features of various rapidly changing mesoscale and/or hazardous weather phenomena (Knupp et al., 2009). In addition, continuous time series of traditional forecast indices generated from MWR data can be combined algorithmically to predict early stage convection hours before it is detected by widely used electric field mill convective prediction methods (Madhulatha et al., 2013). Over the past decade MWRs are installed in many countries and applied in nowcasting convective activity, data assimilation, and climate studies (Liu et al., 2009; Chan and Hon, 2011; Cimini et al., 2011; Spänkuch et al., 2011; Xie et al., 2011; Tang et al., 2012; Cadeddu et al., 2013; Huang et al., 2013; Madhulatha et al., 2013; Raju et al., 2013; Venkat Ratnam et al., 2013; Ware et al., 2013).

Continuous MWR measurements can be very useful for the detection of mesoscale phenomena that require very high spatial and temporal scales. Twice-daily radiosonde data are commonly used to generate Stability Indices for lightning, rain, hail and gusty wind prediction several hours in advance. However, several hours after launch the radiosonde data typically become stale and ineffective. In contrast, a MWR provides continuous thermodynamic soundings from which continuous Stability Indices can be generated. The resulting Stability Index time series provide promising new tools for local high-impact weather forecasting. For example, lightning prediction of more than 2 h in advance is reported using an algorithm that combines Stability Index time series (Madhulatha et al., 2013). Thus, an important MWR performance requirement is the capability for accurate upper-air thermodynamic surveillance in all weather conditions (Ware et al., 2013). Yet the MWR measurement technology is based on an indirect measurement and, as such, it is necessary to know the uncertainty of these measurements, especially in comparison with radiosonde. It is found in studies that since the measurement principles of MWRs and radiosonde are different (volume integral above a fixed location on the ground for MWRs vs. point measurement of a drifting balloon for radiosonde), there are biases and spreads of the data points, but the two data sets typically agree within the observation error assigned to radiosondes when they are assimilated into numerical weather models (Ware et al., 2003, 2013; Knupp et al., 2009; Cimini et al., 2011) and follow similar trends in the evolution of the temperature and humidity inside the troposphere (Güldner and Spänkuch, 2001; Chan and Hon, 2011; Madhulatha et al., 2013). Some studies show that a MWR is mainly suited for continuous observations in the low troposphere (Liu, 2011; Löhnert and Maier, 2012), and calibration corrections should be applied to reduce the system bias between MWR and radiosonde observations before obtaining the MWR potential benefits in operational activities (Calpini et al., 2011; Tan et al., 2011; Güldner, 2013; Sánchez et al., 2013).

Although a MWR has an advantage of high temporal resolution, it is mainly used in non-precipitation conditions because the radiometer measurements become less accurate in the presence of a water film on the outer housing (radome) of the equipment. Moreover, the radiometer retrieval normally does not include the scattering and emission/absorption effects of rain. Recently there are some progress in applying rain-effect mitigation methods to the radiometer, such as a hydrophobic radome and forced airflow over the radome surface (Chan, 2009). In addition, the Radiometrics Corporation retrieved temperature, humidity and liquid profiles from off-zenith (15° elevation) radiometer observations to provide higher accuracy during precipitation by minimizing the affect of liquid water and ice on the radiometer radome (Cimini et al., 2011; Ware et al., 2013). In this study, the impact of precipitation on MWR measurement accuracy is evaluated against radiosonde using a 3 year data set of MWR-retrieved temperature and humidity profiles with collocated vertical soundings of the atmosphere in Wuhan, China, and the effect of off-zenith observation on reducing the impact of precipitation is also explored.

2. Instruments and methods

Wuhan (30.6°N, 114.1°E, 23 m above sea level) is an operational radiosonde station in central China. A MWR was installed in Wuhan in June 2010. This paper focuses on the period from June 2010 to September 2013. The data used in this paper were collected by continuous MWR observations (at about 3-min intervals) and by radiosonde ascents (at 12-h intervals). The MWR is a Radiometrics MP-3000A unit, which observes 21 K-band (22–30 GHz) and 14 V-band (51–59 GHz) microwave channels at multiple elevation angles, one zenith infrared (9.6–11.5 μm) channel, and surface temperature, humidity and pressure sensors (Cimini et al., 2011; Ware et al., 2013). Vertical retrieval intervals are 50 m from the surface to 500 m, 100 m to 2 km, and 250 m to 10 km. To minimize such errors caused by liquid water on the MWR antenna radome, the radome is made hydrophobic to repel liquid water, and a special blower system is used to sweep water beads and snow away from the radome (Chan, 2009). A rain sensor is combined with the MWR, which is used to provide a “Rain Flag” for data that is potentially contaminated by some liquid water on the radome. The rain flag data is 0 (Rain = 0) and 1 (Rain = 1) in non-precipitation and precipitation conditions, respectively.

The MWR receives roughly a picowatt of Planck radiation emitted by atmospheric oxygen and water vapor molecules and liquid water, in multiple frequency channels. The atmosphere is semi-transparent in the K-band and lower V-band channels during non-precipitation conditions, receiving emission from the atmosphere in addition to cosmic background radiation. The microwave, infrared and surface meteorological observations are automatically converted into continuous temperature, humidity and liquid profiles using radiative transfer equations and neural networks. The neural