3.6 APPLICATION OF MICROWAVE RADIOMETRY TO IMPROVING CLIMATE DATA RECORDS

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1. INTRODUCTION

Microwave radiometers deployed by the U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) Program (Stokes and Schwartz 1994) provide crucial data for a wide range of research applications. The accuracy and stability of these instruments also make them ideal for improving climate data records: to detect and correct discontinuities in the long-term climate records, to validate and calibrate the climate data, to characterize errors in the climate records, and to plan for the future Global Climate Observing System (GCOS) reference upper-air network. This paper presents an overview of these capabilities, with examples from ARM data.

Two-channel microwave radiometers (MWRs) operating at 23.8 and 31.4 GHz (Liljegren 1994) are deployed at each of 11 ARM Climate Research Facility (ACRF) field sites in the U.S. Southern Great Plains (SGP), Tropical Western Pacific (TWP), and North Slope of Alaska (NSA), and at the ARM Mobile Facility in Niamey, Niger, for obtaining precipitable water vapor (PWV) and liquid water path (LWP) data. At these locations, PWV ranges from as low as 1 mm (1 kg/m^2) at the NSA to 70 mm or more in the TWP; LWP can exceed 2 mm at many sites. The MWR accommodates this wide dynamic range for all nonprecipitating conditions with a root-mean-square error of about 0.4 mm for PWV and 0.02 mm (20 g/m^2) for LWP. The calibration of the MWR is continuously and autonomously monitored and updated to maintain accuracy (Liljegren 2000). Site-specific linear statistical retrievals for PWV and LWP are used operationally (Westwater 1993); more sophisticated site-independent retrievals are applied during post-processing of the data (Liljegren et al. 2001). These retrievals use the monoRTM microwave radiation transfer model monoRTM (Boukabara et al. 1999; Clough et al. 2004) and current spectroscopic parameters (Rothman et al. 2005; Liljegren et al. 2005).

2. MONITORING RADIOSONDE PERFORMANCE

Because PWV is an integral measure, derived from both the relative humidity and temperature profiles of the radiosonde, it is a particularly useful reference quantity. Comparisons of PWV derived by using the MWR with PWV from Vaisala RS92 radiosondes for the AMF (Niamey, Niger), SGP (Lamont, Oklahoma), and TWP (Darwin, Australia) sites are presented in Figs. 1-3 for all nonprecipitating conditions during January-June 2006. Although the overall results are good, dry biases and diurnal trends as well as general calibration variability in the radiosondes can be observed. Fig. 4 reveals the transition from RS80 to RS92 radiosondes at Darwin, Australia, in January 2006. Figs. 5-7 reveal a significant dry bias during the daytime due to solar heating. These results are consistent with previous findings (Turner et al. 2003; Miloshevich et al. 2006). To

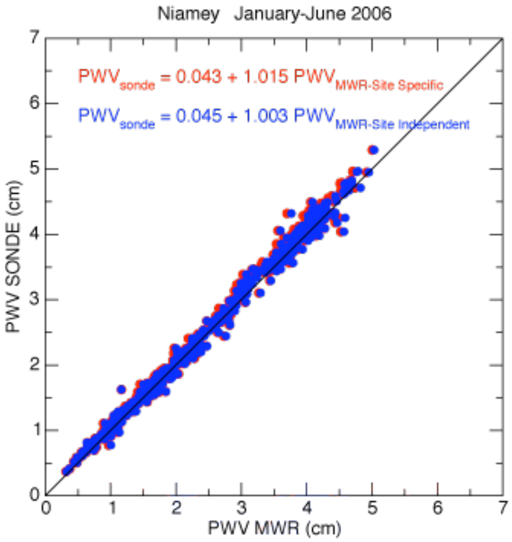

Figure 1. Comparison of PWV from Vaisala RS92 radiosondes with PWV from MWR at Niamey, Niger for a site-specific statistical retrieval using monthly coefficients (red) and a site-independent retrieval (blue).

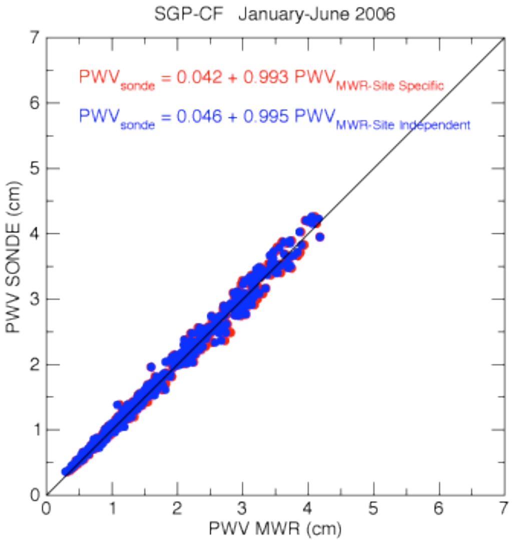

Figure 2. Same as Fig. 1 but for SGP (Oklahoma).

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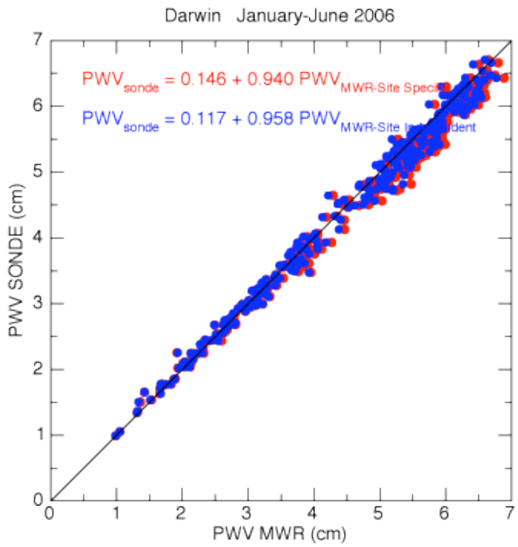

Figure 3. Same as Fig. 1 but for Darwin, Australia.

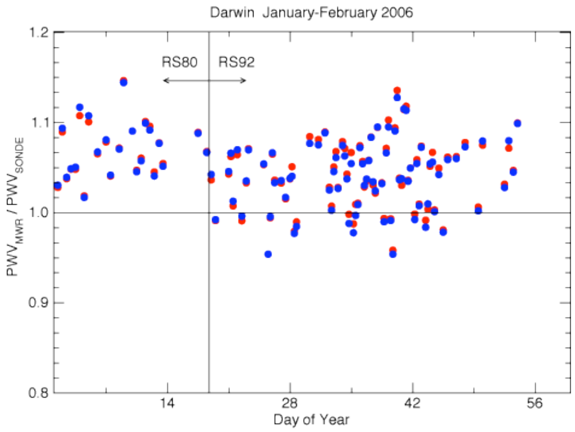

Figure 4. The ratio of PWV from MWR to PWV from radiosondes. Colors correspond to the MWR retrieval methodology, as in previous figures. The change in radiosonde type from RS80 to RS92 on 18 January 2006 is revealed by the change in bias. A large sonde-to-sonde variation is also evident.

correct the bias and reduce the variability, ARM scales the relative humidity measurements from the radiosondes to produce agreement with the PWV measured by the MWR. Comparisons of infrared-spectral-radiances calculated by using these scaled radiosondes with high-spectral-resolution measurements exhibit dramatically reduced bias and variability. This ability to detect and correct errors in the radiosonde measurements will be critical for detecting climate change.

3. MONITORING REMOTE SENSOR PERFORMANCE

MWRs have also been used for a variety of ground- and satellite-based remote sensor retrieval development and validation studies, including PWV and slant-water-vapor retrievals using the global positioning system (GPS) (Braun et al. 2003). The MWR can provide a valuable comparison for GPS-derived zenith wet delay and PWV estimates (e.g., for evaluating improved mapping functions and detecting errors due to, for example, multipath contributions). Fig. 8 shows PWV derived from the MWR measurements with PWV derived from a SuomiNet GPS station (Ware et al. 2000) at Darwin, Australia, during January-June 2006. Although the general agreement is good, for low PWV

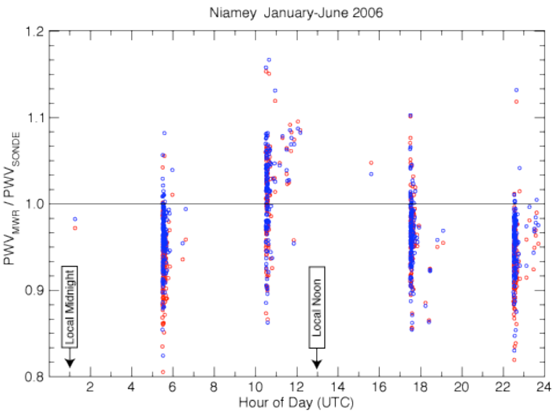

Figure 5. Ratio of PWV from MWR to PWV from Vaisala RS92 radiosondes for Niamey, Niger, revealing daytime dry bias of sondes. Colors indicate retrieval methodology as before.

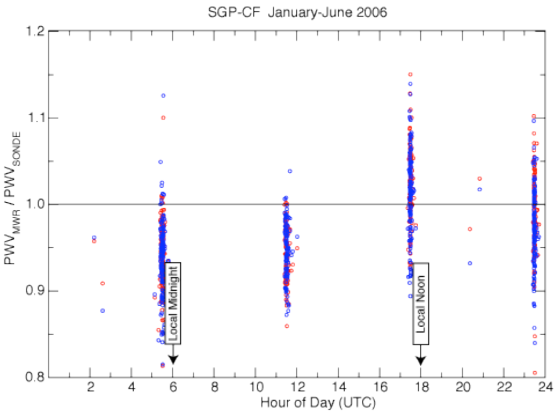

Figure 6. Same as Fig. 5 but for SGP (Oklahoma).

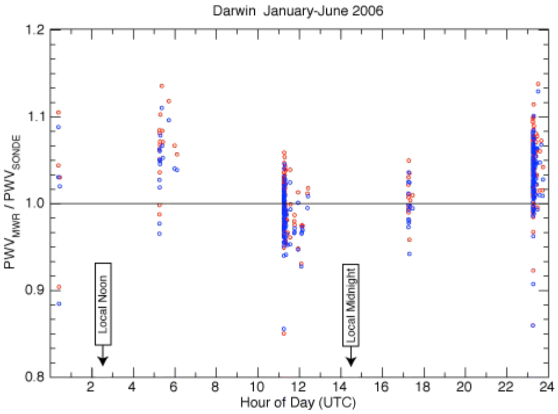

Figure 7. Same as Fig. 5 but for Darwin, Australia.

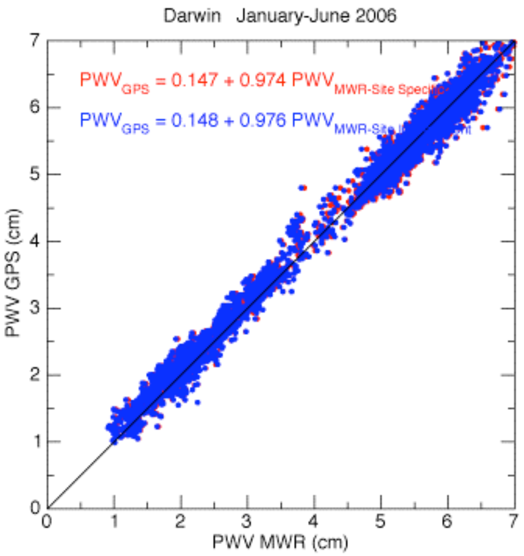

Figure 8. Comparison of PWV from SuomiNet GPS with PWV from MWR at Darwin, Australia, for a site-specific statistical retrieval using monthly coefficients (red) and a site-independent retrieval (blue).

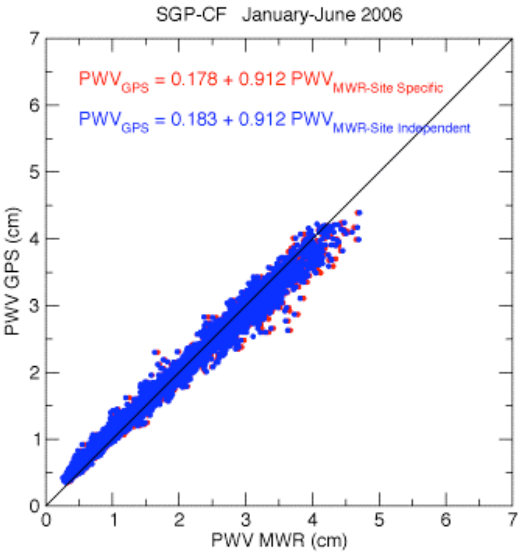

Figure 9. Same as Fig. 5 but for SGP (Oklahoma).

amounts, the variability is considerably greater than exhibited by the MWR-radiosonde comparisons. The MWR-GPS comparison from the ARM SGP site in Oklahoma shown in Fig. 9 reveals a problem with the GPS data processing that had gone undetected for over a year (T. Van Hove, 2006, pers. comm.) until this comparison was performed.

GPS-based PWV measurements offer two significant advantages over MWRs, which makes them superior for deployment at all GCOS radiosonde launch sites: The hardware costs are much less (about a tenth), and they are not sensitive to liquid /water, which allows them to operate during precipitating conditions. Nevertheless, MWRs located at GCOS reference sites can provide a valuable check on the performance of the GPS-based measurements of PWV or zenith wet delay. Moreover, 12-channel microwave radiometers designed to provide profiles of temperature and humidity (Solheim et al. 1998) could also provide profiles of refractivity in the troposphere for comparison with tropospheric refractivity profiles measured by the Constellation Observing System for Meteorology Ionosphere and Climate (COSMIC) (Rocken et al. 2000).

4. MONITORING POLAR SENSOR PERFORMANCE

For PWV amounts less than 4 mm, which commonly occur in cold, dry polar conditions, the 0.4-mm root-mean-square error of the MWR PWV measurement is problematic. Radiosondes have been shown to also be problematic for Arctic conditions (Mattioli et al. in press). To obtain increased sensitivity under these conditions, a G-band water vapor radiometer (GVR) operating at 183.31±1, ±3, ±7, and ±14 GHz has been deployed at the NSA site at Barrow, Alaska (Cadeddu et al. in press). Fig. 10 compares the PWV derived by using the MWR and GVR with the PWV measured by collocated RS92 radiosondes in January 2006. The GVR offers a valuable reference for radiosonde and GPS water vapor measurements at Arctic locations that are expected to be particularly sensitive to climate change and where accurate measurements will be necessary.

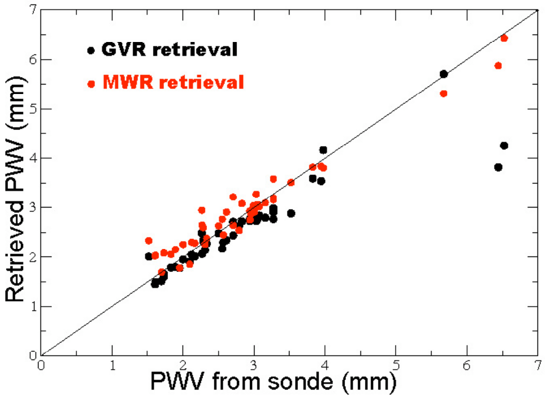

Figure 10. PWV from MWR (red) and GVR (black) compared with Vaisala RS92 radiosondes for low PWV conditions at Barrow, Alaska. GVR outliers at 6.5 mm are due to radar interference.

5. CONCLUSIONS

The ARM Program has deployed a variety of microwave radiometers at its various field sites. They have provided accurate, stable, and reliable measurements of PWV that have proved valuable for identifying and correcting biases, diurnal trends, and general calibration variability in radiosonde soundings. The measurements have provided a useful reference for other remote sensors, including GPS-based measurements of PWV. For these reasons, microwave radiometers will be critical instruments for GCOS upper-air reference sites.

ACKNOWLEDGEMENTS

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