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DOE/SC-ARM-19-029

Demonstration of a New Water Vapor Radar Field Campaign Report

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ARM

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Acronyms and Abbreviations

ARM	Atmospheric Radiation Measurement
DOE	U.S. Department of Energy
SGP	Southern Great Plains
SNR	signal-to-noise ratio
VIPR	vapor in-cloud profiling radar

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1.0 Summary

Campaign Location: U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility Southern Great Plains (SGP) observatory.

Campaign Dates: April 1-14, 2019.

Notable Observations: G-band (167/174.8) Differential radar reflectivity profiles. High-frequency radiosonde launches during stormy periods and thick clouds.

Derived Quantities: In cloud/precipitation absolute water vapor content profiles derived from differential G-band radar reflectivities.

Campaign Purpose: The purpose of the project was to demonstrate and validate observations from a new differential absorption radar, which uses an active sounding approach to remotely measure water vapor within clouds and precipitation. The instrument, the vapor in-cloud profiling radar (VIPR), is the first radar of its kind using a differential absorption technique to profile water vapor. The demonstration and validation of these data is essential to proving the utility of these observations in combination with the standard remote-sensing approaches employed at SGP. This initial effort is an essential element to facility the incorporation of the VIPR radar or its derivatives in future focused efforts to understand the role of water vapor in shaping the convective environment.

The project leveraged the suite of water vapor sounding observations made at the ARM SGP site to demonstrate and validate the VIPR observations in a range of clouds including shallow cumulus, thick cirrus, and stratiform precipitation associated with convective storms. The project had several goals:

1. Validate the VIPR in-cloud water vapor observations against radiosonde measurements.
2. Compare water vapor profiles from VIPR with those of the standard suite of profiling instruments at SGP and demonstrate the complementarity of the radar observations with those from passive sounding instruments and lidars.
3. Perform calibration of the VIPR radar reflectivities using spherical calibration targets suspended at distance of approximately 500 m from the radar.
4. Obtain the world's first coincident Ka/G-band radar reflectivities.

2.0 Results

Figure 1 displays a curtain plot of observed reflectivity (in absolute dBZ units) and corresponding derived humidity in the presence of thick clouds, with continuous water vapor profiles spanning more than 6 km with 180-meter resolution. The results presented here employ a new retrieval algorithm that explicitly includes known systematic sources of uncertainty in the final estimate of humidity error. The improved algorithm allows for less temporal averaging in order to compare favorably with coincident radiosonde measurements, with the results shown here using a 30-second averaging period. This should be compared to other active humidity profilers (e.g., Raman lidar) that have averaging periods on the order of 10 minutes. Furthermore, it is important to note that, in the case of VIPR, the temporal averaging is performed in order to average over different parts of the cloud as it advects over the instrument, since the heterogeneous cloud structure introduces systematic error sources that must be averaged over. The bottom of Figure 1 shows a comparison between coincident in situ and remotely sensed water vapor profiles during this measurement, with excellent agreement over more than 6 km in height. Furthermore, using the averaged humidity profile from five radiosondes launched during this measurement period, we can create a correlation plot of VIPR versus radiosonde humidity (Figure 1, bottom right), which highlights the accuracy of the VIPR water vapor product over long time scales.

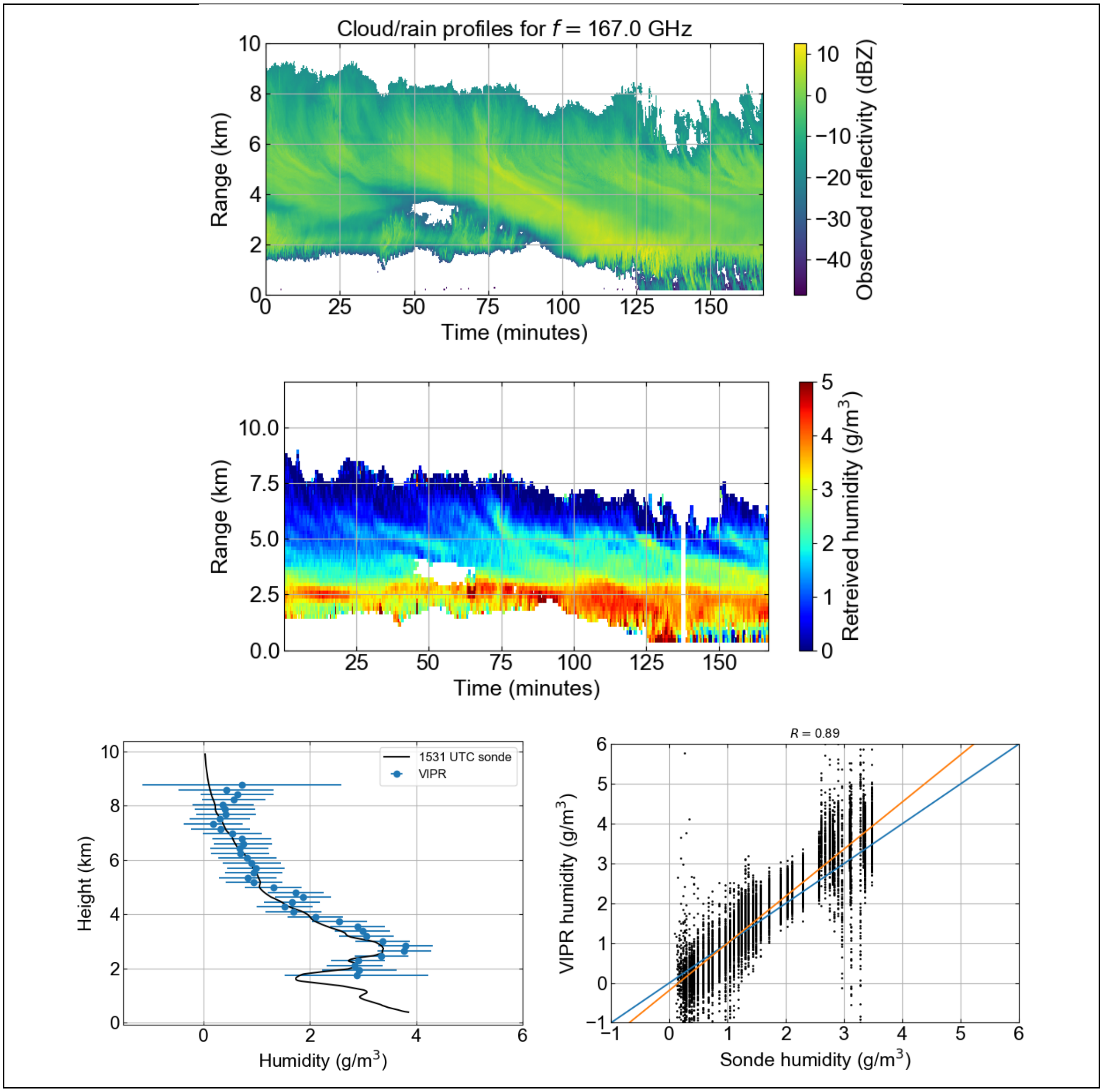

Figure 1. Curtain plots of the 167 GHz radar reflectivity (top) and derived water vapor (middle) for a nearly 3-hour, zenith-pointing measurement. Measurements with a signal-to-noise ratio (SNR) less than unity have been removed. VIPR is able to detect with high SNR out to 9 km in range, and perform continuous in-cloud humidity profiling over more than 6 km. The agreement between VIPR retrieved humidity profiles and that from radiosondes is quite good (bottom left). The bottom right figure is a correlation plot for the entire time series of humidity versus the averaged radiosonde profile for four launches spaced throughout the measurement period.

Next, in Figure 2 we show partial-column water vapor measurements that measure the integrated water vapor from the surface to the cloud base. Here the cloud base is at roughly 7 km. This measurement includes no extra fitting parameters to realize the agreement with radiosonde measurements (black in Figure 2, bottom right). These measurements verify VIPR's ability to provide accurate water vapor information with high temporal resolution when clouds are absent from an airborne platform using the earth surface as a scattering target. These measurements are of interest in characterizing moisture variability in a variety of scenarios, including in the convective environment.

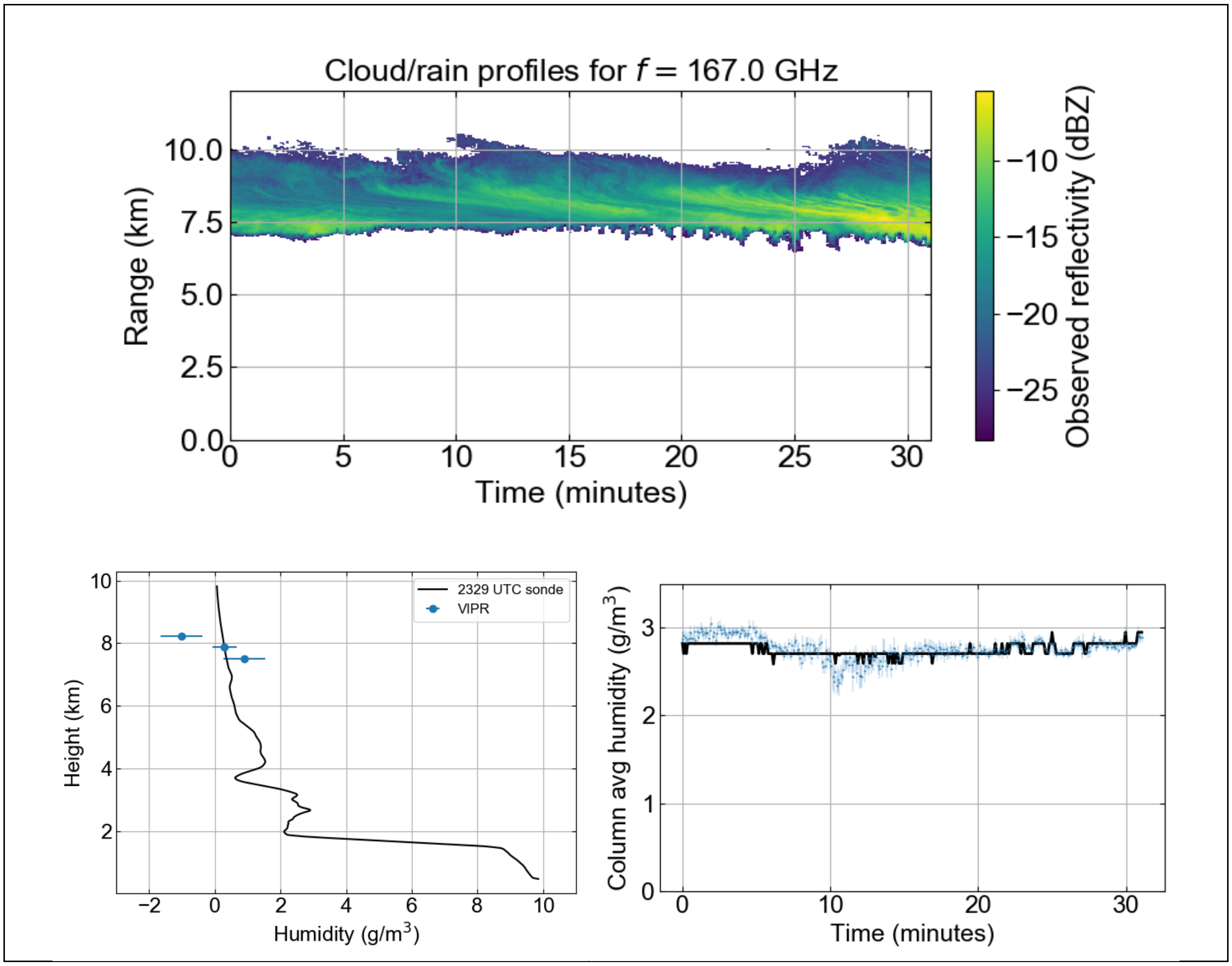

Figure 2. VIPR measurements of high-level cirrus clouds (top – observed 167 GHz reflectivity). Though VIPR's primary sensitivity for profiling water vapor resides in the lower atmosphere, it is capable of measuring the column of water vapor between the surface and high-level cloud base with high accuracy. (Bottom left) Radiosonde profile and a few upper-tropospheric, in-cloud humidity measurements from VIPR. (Bottom right) The entire time series of average humidity between the surface and cloud base, showing the excellent agreement between VIPR (blue points) and the radiosonde (black line) derived values.

These results show for the first time the validity of the water vapor profiles derived from differential absorption radar. The National Aeronautics and Space Administration is likely to continue development and demonstration activities of VIPR in the context of the National Academies Decadal Survey to incubate instruments for measurements of the planetary boundary layer. There are likely to be a number of possibilities for continued collaboration between DOE and the VIPR team in this context over the coming decade, both for validating instruments and for purely scientific investigations focused on the planetary boundary layer.

3.0 Publications and References

Roy, RJ, MD Lebsock, L Millan, and KB Cooper. "Validation of a G-band differential absorption cloud radar for humidity remote sensing." Submitted to *Journal of Atmospheric and Oceanic Technology*.

R Roy, M Lebsock, K Cooper, L Millan, RR Monje, and J Siles. 2019. The vapor in-cloud profiling radar (VIPR): Field deployment and validation of in-cloud humidity profiles retrieved using a 170 GHz differential absorption cloud radar." Presented at the 39th International Conference on Radar Meteorology, New and Emerging Radar Technology. Nara, Japan.

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