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# ***Interactive comment on “The feasibility of water vapor sounding of the cloudy boundary layer using a differential absorption radar technique” by M. D. Lebsock et al.***

## **Anonymous Referee #2**

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Title: The Feasibility of Water Vapor Sounding of the Cloudy Boundary Layer Using a Differential Absorption Radar Technique Author(s): M.D. Lebsock et al. MS No.: amt-2015-121 MS Type: Research Article

This is a reasonable approach to estimating water vapor using a dual-frequency radar. The simulated performance shows that the instrument and method are feasible. Citations of previous work and clarification of the role of non-Rayleigh scattering would improve the paper.

There are two studies that I'm familiar with on the use of radar for estimating water

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vapor that are not cited but that are relevant to the present study. The study by Ellis and Vivekanandan (Radio Sci, vol. 45, 2010 doi:10.1029/2009RS004280) describes the use of S- and Ka-band ground-based radars. In this case, the differential water vapor absorption (between S and Ka-band) is estimated in the regions between detectable radar returns. For example if the first detectable radar target is at a range  $r$ , then, assuming Rayleigh scattering at  $r$ , the difference  $\text{dBZ(S)} - \text{dBZ(Ka)}$  at  $r$  would essentially be equal to the path attenuation at Ka-band (mainly from water vapor) out to  $r$ . I think this idea is applicable to the instrument proposed in the paper. For example if the cloud top is detected at range  $r$ , then the differential water vapor attenuation from the radar to the cloud top will be given by the differential  $Z$ , again assuming the scattering at the cloud top and at both frequencies is Rayleigh.

There is an earlier study by Meneghini et al. (J. Appl. Meteor., 44, 1511-1525, 2005) using a 3-frequency differential radar where the object of the simulation is to estimate precipitation parameters as well as water vapor using a set of three frequencies around 22 GHz. The lower and upper frequencies are selected so that the water vapor absorption is approximately the same. This implies that the differential  $Z$  ( $=\text{dBZ}(\text{upper}) - \text{dBZ}(\text{lower})$ ) is nearly independent of water vapor and provides an estimate of the median mass diameter of the rain distribution. In principle, the other information provides estimates of water vapor attenuation and particle number concentration.

One of the things missing from the analysis in the paper is the recognition that, in general, the differential  $Z$  is directly related to the characteristic size parameter of the raindrop/cloud-drop distribution. Of course, if all the hydrometeors are Rayleigh scatterers then  $Z$  is just the 6th moment of the size distribution and the difference is zero. However, for precipitation sized particles, and for the frequencies that are being considered, I would guess that the differential  $Z$  is significantly different from zero. Many of these issues could be addressed by computing  $\text{del}Z = \text{dBZ}(\text{upper freq}) - \text{dBZ}(\text{lower freq})$  versus  $D0$  (median mass diameter) or  $Dm$  (mass-weighted diameter) for the various pairs of frequencies that are being considered. If a gamma distribution size distribution

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is chosen, the shape parameter must be specified; the number concentration parameter, however, will be independent of the DFR. (An alternative would be to sort the data in the radar model according to  $D_0/D_m$  and then plot the  $\text{del}Z$  versus  $D_0/D_m$  results.)

The simulated results do seem to show evidence of this type of non-Rayleigh scattering error (Fig. 7). I think it also explains why the performance improves as the frequency separation decreases – since the differential non-Rayleigh scattering is being reduced. Although the authors consider this as noise and an error in the context of water vapor retrieval, it is an important parameter from the standpoint of estimating properties of the cloud/rain.

If I'm interpreting Fig. 7 correctly, then the variability of the retrievals at the right edge of the plots corresponds to estimates made from surface returns. These should consist of two types of errors, the variability of the differential path attenuations caused by hydrometeors and the variability in the surface reflectivities. I also assume that the fraction of  $\text{del}Z$  contributed from the hydrometeors is always a positive bias. Is this correct?

Although eq. (4) is correct it should be noted that the  $\eta$ 's are equal to the integral of the backscattering cross sections of the hydrometeors integrated over the size distribution; similarly, the  $\kappa(\text{hydro})$  are equal to the extinction cross section of the hydrometeors integrated over the size distribution. Only for Rayleigh scattering are these quantities inversely proportional to the fourth power of the wavelength ( $\eta$ ) or directly proportional to frequency ( $\kappa(\text{hydro})$ ). The paper does not mention ice clouds but there seems to be no obvious reason why the method would not work for ice clouds as well as water clouds. The authors state that the system is optimized for low level water clouds but with a -35 dB detection threshold, it seems that many ice clouds will be seen as well.

I would take issue with the definition the authors use for the dielectric factor when they state on p. 5977 that 'K is the dielectric factor of the target'. But if ice and water

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clouds are detected, sometimes in the same profile, how is K to be chosen? I think it is better to choose K to be the dielectric factor for water at a particular temperature. If an ice cloud is encountered then  $\eta$  will be proportional to the dielectric factor so a  $K^2(\text{ice})/K^2(\text{water})$  will appear on the right-hand side of eq. (1).

Some discussion on the radar characteristics would be useful. Are matched beams important? Would this be a nadir-looking radar or would it be scanning?

Fig. 4: The surface reflectivity depends on incidence angle and surface type. Are ocean background and nadir incidence being assumed?

Data from the JPL APR-2 radar and the GPM-DPR, which operate at Ku/Ka-bands, show that the normalized radar cross sections of the surface, in rain-free areas, are highly correlated. This provides a stable reference against which the differential attenuation, caused by precipitation along the beam, can be estimated. For the application here, it would be differential attenuation from water vapor. Do the surface reflectivity models used here have any correlation properties (with respect to frequency) associated with them?

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