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Atmospheric Measurement Techniques Discussions

Interactive comment on "Differential Absorption Radar Techniques: Water Vapor Retrievals" *by* Luis Millan et al.

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We thank the reviewer for his/her comments. Below are our responses in blue.

The paper is an extension of work by Lebsock et al (2015). In the present paper, a much more detailed error model is used to evaluate the method. The authors also consider different wavelength combinations to optimize the retrievals under clear, cloudy and rainy conditions. I found the paper to be informative and well written. I was interested to find that the 'most persistent potential bias is due to the water vapor line width uncertainty' (p. 6).

I recommend publication. There are, however, several issues below that the authors should address.

For the Ku- and Ka-band DPR radar aboard the GPM satellite, the standard deviation of the normalized surface cross section, NRCS, is quite high over land at nadir and near-nadir incidence at both frequencies – greater than 5 dB in many cases. Over ocean and off-nadir incidence over land, the standard deviation is much smaller, usually on the order of 1-2 dB. I'm less familiar with this variability for CloudSat but the authors should know these data well; I'm surprised not to see this as part of the uncertainties listed in Table 2.

On the other hand, since the measurement is differential, I would expect the errors caused by variations in the NRCS to be much less since the quantity of interest is the variance of the difference rather than the variance of either NRCS alone. This suggests that the quantities that need to be specified are the variances of the NRCS and the correlation coefficient, p, of the NRCS at the two frequencies. Although I would expect p to be close to 1, this value, as well as the variance, will be a function of incidence angle, surface type and frequency separation and could be important parameters to be considered in the radar design.

Similar land ocean differences in the NRCS standard deviation are observed in CloudSat data, and we expect similar variability in G-BAND NRCS. We characterize the NRCS uncertainty by the uncertainty called Surface Wind in Table 2. The change in surface wind affects the surface roughness, which in turn changes the NRCS. (We assumed a surface wind of 12 ms^{-1} rather than 3 ms^{-1} (see table 1.)). The reviewer is correct in assume that errors caused by variation in the NRCS are tiny due to the differential nature of the measurement. As shown in Figure 5, the uncertainty due to Surface wind is less than 0.01 cm. This error may be slightly larger over land surfaces, however we do not have an adequate model to test this behavior and the differential nature of the measurement provides good reason to suspect that this error will remain small. This is discussed in the first paragraph of Radiometric Model section. In table 2 we will add in the comment section for surface wind: “to characterize uncertainties in $\sigma_0(\nu)$”

With respect to the incidence angle we will specify in section 3, that we are only assuming Nadir viewing angles in this study. Further we will add a sentence stating: “Viewing angles off the nadir, provided by using a scanning radar, are not explored in this study but, apart from the extra attenuation due to the longer paths, are fundamentally the same as when using the nadir view.”

For range profiling, the analogous assumption to constant or known variation in the NRCS is that the radar reflectivity factors be constant at the two frequencies (Z(f1)=Z(f2)). Although for most clouds, this assumption is reasonable, under raining conditions, I would guess that the assumption is problematic and that this is the main reason for choosing the frequencies to be close together (169, 172 GHz). Is this correct? A plot of the difference Z(f1)-Z(f2) versus f2-f1 (for a center frequency of, say, 170 GHz), using one of the rain or snow PSD’s in the table, would be useful.

That is correct. As is stated in page 6 line 7 of the original document for total column water measurements. Further, that is why for range profiling (page 7 line 25) the main uncertainty are the hydrometeors uncertainties. Even though, the optimum frequency selection process attempted to minimize them they still dominate the error budget.
We will update Figure 1 to include perturbed transmittance and backscattering reflectivites due to hydrometeors, as well as the ocean. See updated figure attached. The caption will be modified to include: “Thin line show the impact of assuming a different particle size distribution or a different surface wind. These lines have been offseted to ease comparison against the unperturbed ones.” Further, at the end of the theoretical basis section, after: “Through this model we asses the impact of spectral variation of

the particulate extinction and the backscatter coefficient, the impact due to absorption of other gases, the impact of the temperature and pressure profiles assumed, the impact of the assumed hydrometeor particle size distribution and the impact of the spectroscopy uncertainties, among others” we will add: “(see for example, Figure 1 thin lines)”

Is the focus around 183 GHz rather than around 22 GHz because of the larger dynamic range available at 183 GHz or is it because of an interest in cloud profiling rather than rain profiling? Or is it because there are more cloudy regions than raining regions?
In general, it is due to the larger dynamical range available at 183 GHz but the reviewer is correct in pointing out that there are far more cloudy targets than rainy targets. In the introduction we will add the following sentence: The water vapor line at 183 GHz is used rather than the 22 GHz because its attenuation is stronger which provides a greater dynamical range allowing us to explore cloud and rain profiling.

Although the issues of cloud detection and estimation are not discussed, I assume that the objective is to retrieve cloud parameters as well as water vapor.
Yes, with an off-line radar tone. At the end of the first paragraph in section 4, we will add something along the lines of “These end-to-end retrievals assume knowledge of the hydrometeors vertical distribution. This knowledge is assumed to come from an off-line radar tone using CloudSat-like retrievals. The impact of attenuation on this radar tone/retrievals is not investigated here.”

p. 2, line 27: ‘dielectric factor’ rather than ‘dielectric constant’ – dielectric factor is a function of the dielectric constant but not identical to it. In this case, we do use the dielectric factor of the target. It is not a constant in our radiometric model.

p. 4, line 9: 'close to the 183 GHz ...' ok

p. 5, lines 17-18: 'The strength of the surface reflection ..' But this strength depends on surface type and incidence angle that will affect the dynamic range.
That is correct but as stated on page 4 line 6 of the original document (section 3 - Radiometric model): Note that, even-though all the simulations presented in this study used an ocean backscatter model, typical land surface back scattering coefficients are also weakly frequency-dependent and hence, due to the differential nature of the technique, the results shown here can reasonably be expected to be similar to those found over land.

With respect of the viewing angles: nadir viewing is assumed throughout the study, see response above

p. 6, line 4: 'used' rather than 'use'. ok

p. 8, line 28: 'to develop'; 'to characterize'. ok

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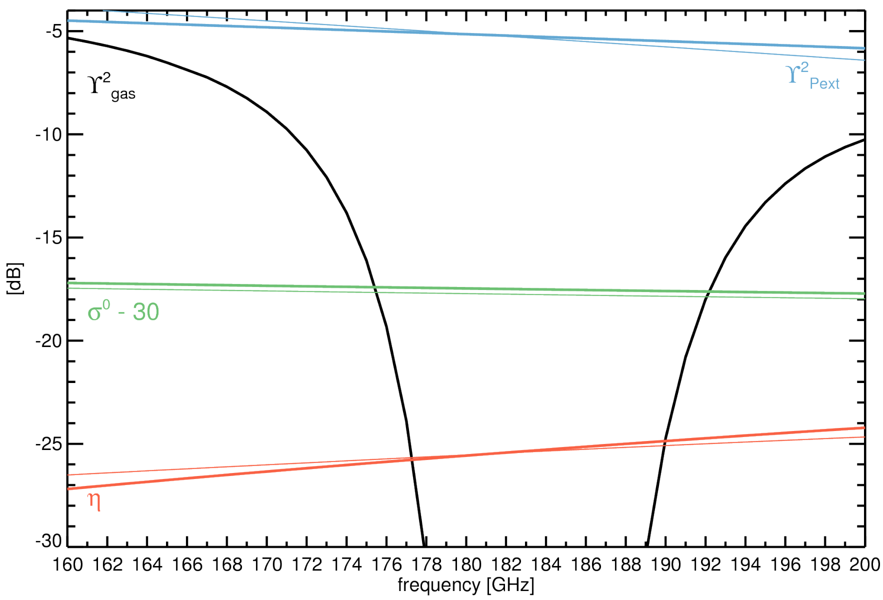

Fig. 1.