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Atmospheric Measurement Techniques
Discussions

Interactive comment on "Boundary-layer water vapor profiling using differential absorption radar" *by* Richard J. Roy et al.

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Dear Professor Mace,

Thank you for your comments and suggestions regarding our manuscript. Listed below are our itemized responses, with the original comment/question displayed in italics.

1. *At what point will multiple scattering become a limiting factor? At these high frequencies and the typical optical depths of shallow cumulus - perhaps with co-existing precipitation - it seems that multiple scattering may be an issue.*

   Please see our detailed response to reviewer #1 on this same point.

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2. *Will the accuracy be sufficient to measure realistic supersaturations in cumulus updrafts? It seems that from a science perspective such knowledge is key. Then combining this instrument with more traditional radars and lidars, one could examine aerosol cloud interaction problems by knowing the cloud droplet number concentration and humidity near cloud base where aerosol populations become activated. Additional science applications could examining the entrainment processes near cloud top where dry tropospheric air is mixed into the marine boundary layer. It seems as though the accuracy required for these topics might push the limitations of the technology.*

   These questions regarding the impact of DAR humidity measurement accuracy on science applications are very important, and will be the subject of future focused study after performing validation measurements with coincident measurements from radiosondes, water vapor DIALs, etc. We will provide some useful numbers here which will lay out the expected *precision* of our system, but must leave the *accuracy* discussion for future work. The relative error in the DAR humidity measurement for a two-frequency system in the high-SNR regime is given by $\sigma_\rho/\rho = \xi(N_b)/(\Delta\tau\sqrt{N_p N_b})$, where all of these parameters are defined in the manuscript. As a specific example, we imagine measuring convective updrafts from a ground-based platform, and allow the DAR system to measure for 1 minute. In this case, for 2 transmit frequencies and 1 ms pulse duration, we acquire $N_p = 3 \times 10^4$ pulses, and then use the same downsampling that is used in the paper, $N_b = 11$. For typical boundary-layer parameters, the differential absorption cross section between 174.8 and 167 GHz is $\Delta\kappa = 0.06$ km^{-1}/(g/m^3). Therefore, using the same retrieval step size as in the paper $R = 200$ m, we find a humidity precision of

$$\frac{\sigma_\rho}{\rho} = 0.19 \times \frac{1\,\mathrm{g/m}^3}{\rho}. \tag{1}$$

   If we're observing a level within the updraft with a temperature of 20 °C, the corresponding saturated water vapor density is 17 g/m^3. Thus, for 10% supersaturation we would have a measurement precision of 1%. At 0 °C, the saturated density is 5 g/m^3, making the expected precision 4%. These calculations show that it is possible to achieve the necessary precision to measure large supersaturations (10-20%) in intense updrafts. Such supersaturation values are predicted in models that include prognostic supersaturation, but have yet to be observed. However, for ordinary convection, including shallow convection, where supersaturation does not typically exceed 1%, a DAR measurement confirming supersaturation would not be possible. Additional considerations for such a measurement include the necessary retrieval resolution and the timescale over which an initially supersaturated volume becomes one with RH $\leq$ 100 (e.g. from advection).

Additionally, it is important to point out that with more freedom to transmit in other frequency bands near the 183 GHz line, the retrieval resolution and precision can be substantially reduced. It is easy to find a pair of frequencies for which $\Delta\kappa$ is an order of magnitude larger or more. If such frequencies were used, one can use that factor of 10 increase in sensitivity to reduce the step size R, the humidity precision, or a combination of both.

It is not exactly clear to us what is meant by the final sentence as it pertains to dry-air entrainment near cloud tops. As an example measurement for this phenomenon, imagine an airborne DAR flying just above the marine boundary layer. From the first radar echos (in range) one can measure the short water column between the aircraft and the cloud top. Then, the in-cloud humidity profile can be retrieved using the subsequent radar returns from throughout the cloud volume. We would expect the dry-air entrainment signature to be a sharp gradient of the water vapor density collocated with the cloud top inferred from the reflectivity profile. With the current DAR system (i.e. in the 167 to 174.8 GHz band), the retrieval resolution is too coarse to resolve this mixing process at the top of the stratocumulus layer, which has a spatial scale on the order of 10 meters. As mentioned in the previous paragraph, a DAR operating closer to the line center

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achieves much higher spatial resolution, and could potenitally resolve this effect.

3. *For the topics identified in point 2, validation with radiosondes would be inadequate. Would current in situ technology for measuring water vapor allow for validation of the technique?*

4. We're not quite certain what is intended by this comment and question. In general, our validation approach will be to utilize radiosonde measurements in scenarios where they measure RH and T very accurately, and compare this with the DAR measurements. Note that in typical cloud scenarios, RH $\approx 100\%$ and is measured well by radiosondes, with the resolution, precision and accuracy exceeding that expected for the DAR. Since there is nothing fundamentally different from a millimeter-wave scattering perspective between the proposed validation scenario and those referenced in point 2, we see no need for improved validation data.

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