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Atmospheric Measurement Techniques Discussions

Interactive comment on "Spectroscopic Imaging of Sub-Kilometer Spatial Structure in Lower Tropospheric Water Vapor" *by* David R. Thompson et al.

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We thank the reviewer for their feedback and suggestions for additional discussion topics. We have revised the manuscript accounting for these recommendations. A point by point explanation of our changes follows.

General Comments

This manuscript presents spatially highly resolved two-dimensional AVIRIS-NG spectrometer measurements of the tropical water vapor column over the Bay of Bengal. Focus of this case study is to quantify the water vapor variability using second-order structure functions. The paper is suitable for AMT as it presents an innovative methodical approach to quantify the variability. I have three general comments.

First, unfortunately, the presented data set is very small. It only covers four about 9x2km large rectangular domains on two different days. I understand that these represent the best available high-resolution measurements over water. But still, this is disappointing. How nice would it be to have a complementing example over land, or over a land-sea interface, or in a different climate zone, etc., even if the data were a little noisier. Please explain why your data set is so small, or show more.

We agree and would also have preferred a larger dataset. In this case, the limiting factor was not the quantity of imaging spectrometer data, but rather the near-zenith solar angles needed for a high spatial resolution measurement. This condition only happens near or in the tropics, outside the range of most AVIRIS-NG campaigns. Limiting ourselves to solar zeniths less than 10 degrees reduced us to the flight days reported here. Now, having established the technique, we believe that we can apply it in the future to much larger datasets that will be made available by NASA's EMIT mission and the anticipated SBG investigation. Additional work in preparation will demonstrate algorithmic techniques to relieve the solar zenith requirement, which should help generalize it to a much larger range of latitudes. We have included new text in the discussion to make this explicit.

Second, these few data, displayed in Figures 5 to 7, lack more explanation and description. Figures 5 and 6 show irregular patterns of water vapor column variability that could be related to turbulent processes in the boundary layer or at its top, but additional data and explanations on the meteorological conditions are lacking. Do we see eddies in the boundary layer, undulations of its top height, or features above, or a mixture of all? How would you interpret this variability? What are the underlying physical processes? For illustration, even already a photo out of the aircraft window could help set the scene a little. But it would be good to show more useful auxiliary data.

We agree, and have added four new graphics with contextual information based on MERRA-2 reanalysis of the overflight days (Figure 1 of this document). We have also updated the text with our interpretation. The atmospheric conditions were generally similar between the 12th and 14th, with light trade winds and the lack of an obvious inversion to stratify boundary layer processes. There were also some differences. Wind velocity changed slightly, but was not obviously tied to any change in atmospheric turbulence. The relative humidity was generally higher on the 14th. The lapse rate was slightly more variable: 8 K km^{-1} at 760 hPa as opposed to 7 K km^{-1} on the 12th. These changes were consistent with a slightly more turbulent atmosphere and a shallower scaling exponent, though there was no obvious step change in atmospheric stability.

Third, I am lacking some discussion on possible implications due to the issue that the vertical water vapor distribution may be complex. The missing vertical resolution may lead to a superposition in the column between different atmospheric regimes, such as convective and non-convective, or boundary-layer and free-troposphere, blurring the variability in a particular layer and making the results in Figure 7 quite questionable. It is clear that most of the column is from the lower troposphere, but you should be more precise on this issue. How likely is it that variability in the mid- to upper troposphere is superposed to the lower troposphere patterns? At least, you should use a tropical humidity profile to show how much contribution to the column comes from the different layers.

We agree this issue deserves a more nuanced treatment, and have introduced a new discussion section to address the issue of vertical sensitivity. There we analyze a large dataset of measured atmospheric water vapor profiles from an airborne lidar campaign (Figure 2 of this document). Specifically, we calculate the correlation coefficients between the total column water vapor content and that of the lowest atmospheric layers. A new figure quantifies the relationship. The strength of the correlation varies slightly for different flights. However, in all three cases the lower troposphere dominates the short-lengthscale variability in atmospheric water vapor. In all cases over 70% of the variance is explained by the lower two kilometers, and over 90% by the lower three kilometers. This suggests that the total column measurement an informative indicator of lower tropospheric variability. Naturally the relationship is statistical rather than direct, and we agree with the reviewer that it is important to include this explanation. With the reviewer's permission, we will borrow some of their phrasing directly for the new discussion.

Specific comments

Line 2: "total atmospheric column wv" but the title says ". . . Lower Tropospheric WV", better make it more homogeneous. This issue is related to my third general comment above, that some discussion on the vertical wv distribution is missing.

We agree and have changed the title to the "atmospheric water vapor," reserving the issue of vertical sensitivity for the new discussion section.

Line 62, "at the finest scales, small sample sizes can increase uncertainty. . .": usually, spectra and structure functions provide lowest uncertainties at the small scales due to high sampling. This sounds like a contradiction. Furthermore, I do not see a relation with the sentence before on one-dim versus two-dim observations. Please explain.

Thank you for identifying this confusing explanation. Our point is that the structure function measurements fall into two categories: vast two dimensional maps by AIRS, with millions of datapoints but coarse resolution; and aircraft data, which have finer spatial resolution but also smaller sample sizes since they only acquire samples along a flight trajectory. We have adjusted the text to clarify.

Line 117, "tens or hundreds of meters": this is much too small, you probably mean "tens or hundreds of km"?

In fact the phrase was written as intended. The left panel of Figure 2 shows that, after accounting for the vertical distribution of water vapor, observations at low solar zenith angles do have effective spatial resolutions in this range; the coarsest resolution indicated on the vertical axis is 1000 m. Since only a small fraction of these have resolutions finer than 100 meters, we have changed the phrase to "hundreds of meters" to avoid confusion.

Line 130, "the spatial footprint projected on the ground is not radially symmetric; it is long and thin": this may entail issues with spatially oriented wv structures, you may want to comment on this?

We have added some additional text here. "For isotropic structure functions, the effective spatial resolution thus constitutes a worst case, with the true resolution improving as one calculates structure functions in directions more orthogonal to the sun." Future work will investigate this strategy as a method to measure accurate structure functions at larger solar zenith angles.

Table 1: an extra column giving the length of the flight line in km would be fine.

Done.

Figure 6: make a white box in Fig 5 to show the location of Fig 6.

Done.

Technical corrections

Line 252, "pathological effects", better "issues"

Done.

Caption of Fig 5: "A white arrow in B indicates. . ."

Done.

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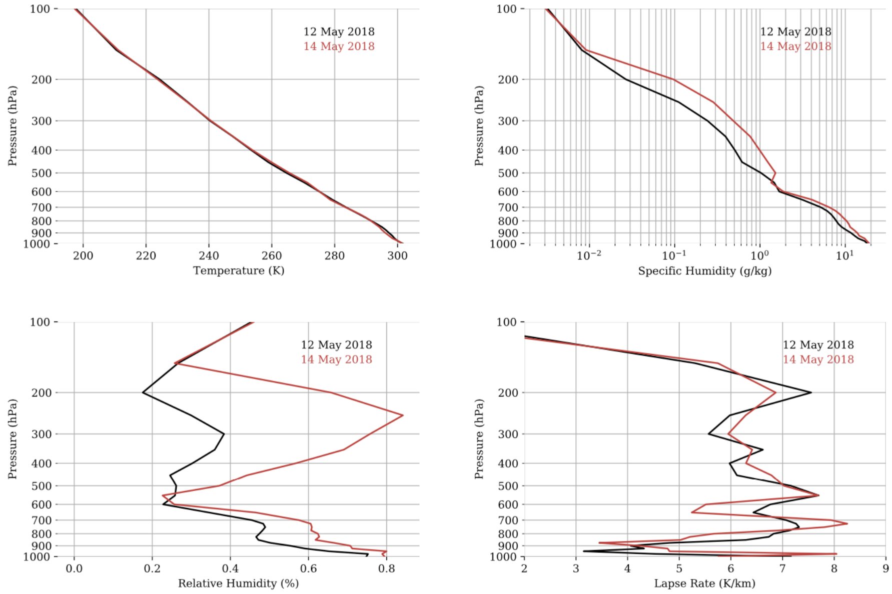

Fig. 1. MERRA-2 Reanalysis

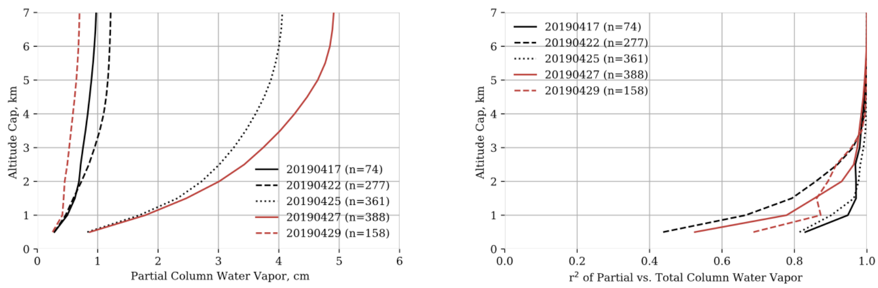

Fig. 2. Airborne Lidar Profiles