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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.

**David R. Thompson et al.**

david.r.thompson@jpl.nasa.gov

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We thank the reviewer for their feedback, which we have duly incorporated. A point by point explanation of our changes follows.

## General Comments

The authors present a study employing an airborne VSWIR imaging spectrometer to examine very high spatial resolution (sub-kilometer scale) column water vapor. The



technique is presented with sufficient detail and the results argue for similar structure function scaling exponents that are observed over many decades of scale; a perhaps somewhat surprising result. As a proof of concept, the manuscript is more than adequate for publication. Perhaps one weakness would be the need to expand the literature a bit to include some examples of more meteorological/climatological applications focusing on column/precipitable water vapor spatial/temporal structure. This would help better motivate the study and draw greater interest for a broader community. This broader literature review wouldn ÌĄt need to be more than one paragraph

We agree, and have added a new paragraph in the opening that provides context on meteorological and climatological implications of PWV variability: "The complex spatial distribution of atmospheric water vapor surrounding clouds and precipitation structures has important consequences for parameterizing moist processes in atmospheric models. At the scale of General Circulation Models (GCMs), water vapor plays an important role in tropical moist convection and its associated precipitation (Tompkins et al., 2001; Bretherton et al., 2004). The mean and variability of precipitation rate in the tropics are strongly dependent on the atmospheric water vapor (Peters et al., 2006; Holloway et al., 2010), a fact which has implications for parameterizing convection. Another ubiquitous property of convection is its tendency to aggregate (Bretherton et al., 2005). There is evidence the degree of aggregation will change as the climate warms, potentially changing the cloud feedback (Wing et al., 2019). Models (Muller et al., 2015) and observations (Lebsock et al., 2017) suggest that the tendency of convection to aggregate depends on the degree of spatial variance in the water vapor field. Over land surfaces with heterogeneous surface conditions the variability in atmospheric water vapor can be larger and is seen as a critical component of the timing of deep convection (Stirling et al., 2004; Wulfmeyer et al., 2006). These variations in water vapor over convective continental environments are primarily driven by variability below 2 km and within the Planetary Boundary Layer (PBL) (Couvreux et al., 2009). Accurate water vapor parameterization is also important for Cloud-Resolving or Convection-Permitting models operating at kilometer scales, and Large Eddy Simulations at sub-kilometer resolution. Across all scales, water vapor variability, and its coupling to cloud types and multi-scale organization, is key for advancing the parameterization and simulation of cloud processes."

One other point to address is to clarify some of the language. It is confusing at times, for example, which spatial scales you are referring to. See below in my minor comments.

(addressed below)

**Minor comments**

Line 13. Water vapor and cloud formation are important for all numerical models of the atmosphere, not just General Circulation Models (GCMs). Even at very high resolutions where deep convection is resolved (i.e. km-scale) such as "Cloud-Resolving models" or "Convection-Permitting Models" and even for "Large Eddy Simulations" ( 100m-scale), cloud microphysical processes which critically depend on water vapor are still parameterized.

We have added additional text to this effect: "Atmospheric water-vapor is highly variable in space and time. Clouds and precipitation structures are embedded within complex spatial distributions of water vapor that have important consequences for parameterization of moist processes in General Circulation Models (GCMs). In global models, the dynamic relationship between water vapor sources, sinks, and atmospheric mixing leads to highly variable humidity at the sub-grid scale. Accurate water vapor parameterization is also important for Cloud-Resolving or Convection-Permitting models operating at kilometer scales, and Large Eddy Simulations at sub-kilometer resolu-



tion. Understanding this variability, and how it couples to a myriad of cloud types and multi-scale organization, is key for advancing the parameterization and simulating cloud processes at all scales."

Line 19-20 You should be clear as to what spatial scales you're referring to. Convective and non- Convective systems would typically be 10s of kms to maybe 100km and quasi-geostrophic motions would be 1000km and greater from Edwards et al., (2019).

We now state explicitly that prior studies have applied structure functions to atmospheric phenomena at scales from tens to hundreds of kilometers.

Line 24 "but in general water vapor variability is considered horizontally isotropic." This idea is a bit unclear, what exactly do you mean horizontally isotropic particularly with respect to spatial scales?

Here we simply mean that the scaling does not have any preferential orientation, i.e. the structure function is rotationally symmetric. We have modified the text to make this clear.

Line 35 "consistent with 2/3 over distances of multiple kilometers." Do you mean several kilometers here?

Changed.

Line 41 "at scales above 11 km" I assume you mean at scales greater than 11km. " Above 11km" sounds as if you are speaking in the vertical sense.

Changed.

Line 49 Just write "...compared them to GCMs, ...."

Changed.

Line 58. “These studies contribute to a growing body of literature on water vapor scaling.” I think it would be good to include a paragraph on some of these studies. Not only techniques for measuring PWV, but theoretical as well as applied studies to meteorology/climate. Are there modelling studies which have used these scaling arguments as metrics? PWV is certainly a critical if not “the” critical variable for deep convection in the Tropics. There are numerous studies observational, modeling and theoretical which focus on this relationship, including temporal and spatial scaling arguments. This would help motivate this study a bit more and why it has more “global” importance.

We have provided additional information and references in the introduction, described under main question 1 above.

Line 85 Write “... build upon these results.”

Changed.

Line 105 Write out RTM. I assume you mean Radiative Transfer Model, but just to be clear for the reader.



Changed.

Line 155 “We solve it with a trust region gradient descent optimization.” You might want to clarify what this is.

We have added a short explanation and a reference to the original text.

Line 183 I think it would be clearer to write “leave-one-out cross-validation”

Changed.

Line 203 Spell out “AFGL”

Changed.

Line 213 Write “Some discrepancies in the optical paths remain, which become larger for column water vapor in the free troposphere than in the planetary boundary layer.”

Changed.

Line 251 Write “This artifact, indicated by a white arrow, may be related to pathological effects from the sun glint bidirectional reflectance distribution or the aircraft shadow. Therefore, it was excluded from the statistics.”

Changed, incorporating additional suggestions by reviewer 1.

Line 258 Write "second-order"

Changed.

**Figures**

Figure 1. Left: ... with gray arrows. The arrows look red to me.

Changed.

Figure 2. Left: Write ".... In reality, the sun

Changed.

Figure 6. Left: flightine is mispelled.

Changed.

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