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Atmospheric Chemistry and Physics Discussions

# *Interactive comment on* "Meridionally-tilted ice cloud structures in the tropical Upper Troposphere as seen by CloudSat" *by* J. Gong et al.

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## 1 General Comments

The article illustrates the existence of a systematic vertical asymmetry of clouds depending on the geographical region and latitude. The authors argue that not taking this asymmetry into account may lead to systematic uncertainties in ice water path (IWP) retrievals in the order of 5–20 % depending on the regions (mostly close to regions just north and south of the ITCZ). The degree of cloud-slanting is computed by comparing the difference between the IWP from integrating ice water content (IWC) at an inclination angle from south to north (forward and down in the satellite path) minus the IWP from integrating IWC at the reciprocal inclination angle from north to south (backward and down in the satellite path). This is illustrated in figure 1 in the article. This paper



mostly relies on the CloudSat RO IWC dataset for this assessment.

The conclusion is that this uncertainty aspect may be important for retrievals from limb-sounding measurements of ice clouds, retrievals from high scan angles and low resolution models, which mostly use a maximum random cloud overlap assumption within each grid box.

According to my assessment the overall point is conveyed that convective clouds appear to "climatologically" slant polewards at the edge of convective regions, but for me, many arguments are unclearly written and apparently not sufficiently justified.

The main problem with the paper is that the results presented are unclearly described and much more care must be taken to explain their line of thought and to better motivate the very strong statements made. There are many unclear sentences. I suggest finding a colleague with a english-speaking background, to read through the article and highlight to the authors which sentences are unclear and help to reformulate them so that the message comes across clear enough so the point can be made.

Scientifically, I also believe it is essential to tie "cloud slanting" to the wind fields, partly to prove the point and, most importantly, to make the results applicable. For instance, if it is true that there is a systematic tilt in the clouds, how can the modellers correct for this?

The choice of datasets also appears strange to me. Why choose both CloudSat and DARDAR? They are very similar datasets since the are based on measurements from the same instrument. For IWP, it is expected that the two datasets will be quite similar as long as the clouds are not thin.

The paper states that this uncertainty "invalidates" the plane parallel assumption used in most IWP retrievals from passive instruments. This is a very strong statement which is not explained in the paper.

Furthermore, the possible uncertainty of 5-20% due to cloud tilt is not alarmingly large

from an observational point of view since, even in the CloudSat retrievals, the errors based on simulations are at least 40 % for some assumed particle microphysics (Austin et. al. 2009). Considering the additional uncertainties induced by assuming one ice particle distribution over another along with the Radar measurements hypersensitivity to large particles in radar retrievals because of Rayleigh scattering $Z \sim D^6$, and more uncertainties, the 40 % estimate is likely too low. More likely the random errors are around 100%, give or take. For passive IWP retrievals there is an additional large uncertainty from not knowing the vertical distribution of clouds.

## 2 Specific comments

- page 24917, line 9 :: "irregular visible outlooks to internal banded mass/energy structures."
  I don't understand this sentence
- page 24917, line 10 ::"These detailed structures are often not fully resolved in satellite observations due to large sampling footprint size and, subsequently, neglected in GCMs"
  What satellite observations are you referring to? MODIS and the AVHRR-based datasets have footprint sizes comparable your reference dataset, CloudSat RO. The biggest problem is the lack of information on the vertical structure of clouds from these passive instruments.
  What do you mean by the 3D effects being neglected by models as a consequence?
- "However, studies have shown that this parameter has large geo- graphical and temporal variations around the globe, which invalidated the prevailing assumption in GCMs."
  Tone down this statement. Going so far as to say that regional variations in



cloud overlap "invalidates" the overall overlap assumptions of basically all climate models requires more sentences to convince the reader.

- Introduction: A description of what is meant by tropics in this study is missing (e.g. latitude bounds)
- Page 24918, line 22: Avoid links in the paper as they will break over time.
- Page 24919, line 1 :: There are more uncertainties in the CloudSat RO dataset that should be mentioned (see above). At least the "official" 40% uncertainty should be mentioned.
- Page 24920, lines 28–29 :: You are referring to figure 4 before it is introduced. At this point, not even figs 2 and 3 have not been mentioned yet. Maybe see over the order of the figures
- Page 24921, lines 9–10 :: "The parallax issue is mostly solved by this assumption through large sample integration."
  I don't understand this, please elaborate in the text what is meant
- Page 24921, line 21 :: " beat down the noise and distill the complex cloud information"
  I would tone this down. The ice cloud measurements are very, very coarse from the limb-sounder so I don't know if averaging 20 profiles will distil complex cloud information
- Page 24921, lines 26–27 :: "Hence, it cannot be used as an independent observational evidence but rather as a supplement." Why is not MLS considered an independent dataset compared to CloudSat RO? Granted that the uncertainties from MLS IWP are very large and the dataset might not be ideal for assessing cloud tilt, but it is quite independent from CloudSat I'd say. The DARDAR and

CloudSat RO datasets on the other hand are dependent datasets. Maybe you don't mean dependent?

- Page 24922, lines 25–26:: "The broad consistency between CloudSat and DARDAR analysis results validate the robustness of our findings."
  As mentioned earlier, these datasets are not independent

- Page 24924, lines 10–13 :: "IWC itself cannot reveal the entire cloud mass/shape structure in the lower level as liquid and mixed-phase clouds dominate the lower level (e.g., see the round-up at the bottom of Fig. 1a)."
  What does "round up" mean? And does the figure really illustrate this problem as stated?

- Page 24924, line 19:: "we will show using the WRF simulations that CloudSat results might be more reasonable."
  Show that CloudSat is more reasonable than what, DARDAR?

- Page 24926, line 5:: "The "upward and inward" mid-level ice cloud mass"
  What do you mean by "upward and inward"?

- Page 24926, line 28 :: "This indicates that on average ice clouds are slim and sporadic."
  How do you reach that conclusion?

- Page 24926, line 29 :: ""Plane-parallel atmosphere" assumption is constantly violated when ice cloud is present"
  This very strong statement is not explained. If this is so, you need convincing arguments.

- Page 24927, line 1 :: "nearly always"
  Is this globally valid?



- Page 24927, line 2 :: "more integrated ice cloud mass than the northward-view based on the CloudSat observation."
  What do you mean?

- Page 24927, lines 5–8 :: "This result is not contradictory to our finding on the systematic cloud tilt, since firstly the integration path here extends through the entire troposphere above the freezing level, and secondly the reference point is at the ground."
  How is this different from integrating CloudSat IWC?

- Page 24927, lines 11-14 :: "Another possibility, which is more likely to happen, is that the "bottom round-up" effect near the freezing level of CloudSat IWC retrieval may significantly skew the overall ice cloud mass distribution."
  I don't understand this statement at all

- Page 24928, lines 19–21 :: "Clearly, neglecting systematic cloud tilt in satellite retrieval can result in additional biases especially for limb sensors (e.g., Microwave Limb Sounder), nadir sensors at slantwise view-angles (e.g., AIRS, MODIS)"
  The maximum scan angle for MODIS is a bit more than 50 degrees if I recall correctly, i.e., much less than 77 degrees used to test the cloud-slant-problem, and the furthest off-nadir footprint is "only" a few kilometers across, i.e. a fair bit less than the length of the "curtain" used to find $\Delta$IWP (if I understand figure 1c correctly). Therefore, at worst, the error introduced by not taking the cloud slanting into account will lead to less error then the 5 –20 % found in this study. I'm not convinced that this is a problem for MODIS/ AVHRR. I could be missing something here, please convince me.

- Figure caption 1: "The blue curves whose zero values are centered around the 5 and 17 km vertical level illustrate the ice water path differences ($\Delta$ IWP) derived from the algorithm demonstrated in the diagram"

What do the blue lines mean? Zero difference in what? The text in the article didn't help me either.

- Figure 7:: The dashed lines don't show up in the legend

## 3 Technical comments

I decided to not dig into technical details as much of the text needs rewording for clarification