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***Interactive comment on* “Retrieval of cloud liquid water distributions from a single scanning microwave radiometer aboard a mobile platform – Part 2: Observation system simulation experiments” by D. Huang et al.**

**D. Huang et al.**

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Anonymous Referee #2 Received and published: 2 October 2009

Response: We are grateful to the reviewer for the help to improve this manuscript.

Major Comments: 1. p. 12066, lines 12-13: It must be clarified that in the ground-based setup, the contrast is not only between the clouds and the cosmic microwave background, but also with the wings of many resonant lines in the Earth's atmosphere. This is addressed in Sect. 4.3 in terms of the water vapor contribution even at imaging

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frequencies (or cloud measurement frequencies). This is quite an important distinction.

Response: We have rewritten the relevant text to reflect the fact that the background emission contains not only cosmic microwave background emission but also gaseous emission above the cloud top. To be more precise, we replace the term “cosmic background” with “atmospheric background” in the abstract.

2. p. 12067, lines 5-10: What are the spatial and temporal resolution needed to improve cloud representations in numerical models ?

Response: To improve cloud representations in numerical models, a variety of observational and modeling capabilities are needed. Direct evaluation of cloud representations in large scale models requires long-term, large-scale cloud statistics. Long term ground-based observations and satellite observations are well-suited for this purpose. The development of new representation schemes also needs observational and modeling efforts at much smaller scale. Process studies will need high spatial and temporal resolution cloud observations, e.g., the investigation of many cloud processes using LES requires a few tens of meters spatial resolution and less a few tens of seconds temporal resolution. Lastly, knowledge obtained from process studies can be transferred to large scale models by using Single Column Models as an intermediate layer.

3. p. 12067, lines 14-17: In terms of its use to estimate LWP, radar also suffers from the ambiguity of cloud particle sizing since the cloud particle size distribution is relatively unknown.

Response: We agree with the reviewer. The sentence has been rephrased to read: “On the other hand, active remote sensing techniques like cloud radar (Frisch et al., 1995; Hogan et al., 2005) with rapid scanning capability provide a less direct measurement of cloud LWC (since LWC is the third moment of cloud drop size distribution but radar reflectivity is proportional to the sixth moment) and also would likely be much more costly than passive methods.”

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4. p. 12068, lines 20-25: What are suitable cloud capture times ? In other words, how rapidly do the clouds change ? A chart showing various cloud types and their evolution time would be helpful.

Response: The optimal cloud observation time depends on the type of the interested cloud or the interested cloud process. The cloud tomography approach is designed to detect liquid clouds. The lifetime of fair weather cumulus clouds ranges from a few minutes to a few tens of minutes. In order to study such rapidly-evolving clouds, the duration of radiometer scan cycle should not exceed one minute. On the other hand, for more steady stratocumulus clouds (lifetime ranges from a few tens of minutes to a few tens of hours), it should be OK if a complete cloud scan can be done in a few minutes.

5. p. 12069, lines 15-25: What are the sampling time for the airborne setup and the ground based setup? Can faster sampling rates be achieved without sacrificing sensitivity for the airborne version ? Could this result in the same number of scan angles as in the ground based setup?

Response: The default integration time is 0.3 s for both the airborne and ground-based configurations and this information has been added to Table 1 in the revision. We assume the duration of scan cycle equals the product of the radiometer integration time and the number of beams. So whenever the duration of scan cycle changes, the number of beams will also change correspondently.

The random noise in radiometer measurements is proportional to the reciprocal of the square root of integration time. Thus, a shorter integration time will result in more scan angles – but at the expense of higher random noise in the measurements.

6. p. 12071, line 15: "transmission" is ambiguous and should be called "transmissivity" or similar.

Response: The word "transmission" has been replaced with a more standard term

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“transmittance”.

7. p. 12071, Eqn. (2): Eqn.(1-6) are repeated from [1]. The authors may consider removing eqn.(1-6) from this paper. It is not clear in what direction the m rays are, even in [1]. The authors should explain this maybe with the help of an illustration. The description of methodology needs to be rewritten to express how the truncated SVD and L-curve retrieval technique, explained in [1], is regularized using the L1 and L2 regularization method. The L1 and L2 norm should be expressed in terms of the retrieval parameters and the observed brightness temperatures.

Response: Although the mathematical formulation of the mobile cloud tomography problem (this paper) is very similar to that of the ground-based fixed cloud tomography problem [1], we believe it is valuable to keep these equations in this manuscript for completeness and clearness of presentation.

In our simulations, we assume the elevation angles of the rays are equally spaced within  $\pm 80^\circ$  from nadir (for the airborne setup) or zenith (for the ground-based setup). The angular increment of the radiometer scan is assumed to depend on the duration of radiometer scan cycle.

The truncated SVD is another type of regularization approach and it is not used in this research. The L-curve approach is usually used to select the optimal weight for the regularization term (or the truncation point for the truncated SVD approach). The L-curve approach is not used in this research. As described in Part I of this paper, we use an iterative inversion algorithm which determines the weight of the regularization adaptively during the iterations.

The cost function contains two terms: (1) the squared difference between predicted and observed brightness temperatures; (2) regularization term. By definition, the regularization term is a function of only the retrieval parameters.

8. p. 12073, line 19: "calculating the distribution": Is the spatial distribution meant

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here? In general, "distribution" could also mean the statistics, as in a PDF.

Response: The sentence has been rewritten to read "calculating the spatial distribution of cloud LWC".

9. p. 12073, line 26: The authors mention using various types of a priori knowledge but do not explain what they did for their retrieval. Did their least squares solution use any kind of a priori information ? If so, what was the a priori?

Response: We use two types of a priori knowledge: non-negativity and smoothness. Other types of information could also be used such as historical record of cloud LWC profiles but were not included in this research.

10. p. 12074, line 22: "Fig. 2" should be "Fig. 3".

Response: The typo has been corrected.

11. p. 12077, lines 5-6: "miles per hour" This and every other scientific journal requires the use of mks units in normal situations. (Some exceptions are made, e.g. cgs units for magnetic quantities.) Change to mks.

Response: We have switched to the International System of Units (the metric system).

12. p. 12077, lines 20-25: The authors mention that only rays within 80 degrees off the nadir or zenith are considered due to sidelobe contamination. Can the authors give some quantitative results for the sidelobe contamination suffered for the angle scanned closest to the horizon ? What are the main beam efficiency and first sidelobe level of the radiometer antenna?

Response: Sidelobe effect is not included in our simulations. We use an antenna gain pattern that decreases exponentially with the square of angular departure from the center axis (see Eq. 2).

In our simulations only the rays within  $80^\circ$  from the nadir or zenith are used because: (1) the 3-dB radiometer beamwidth is usually a few degrees; (2) water vapor emission

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is strong for low elevation angles; and (3) sidelobe contamination.

The main beam efficiency of the PSR is in the 95-97% range. The first sidelobe level is well below -27 dB.

13. p. 12079, lines 20-21: This 3 K maximum uncertainty only models directional errors (azimuth difference between the radiometer viewing direction and the wind-wave direction). At significant wind speeds, the azimuthally-averaged emission uncertainty can be much larger.

Response: We agree with the reviewer that the true uncertainty in azimuthally-averaged emission can be much larger than 3K at high wind speeds. In the sensitivity study, the uncertainty level ranges from 0 to 6 K (Fig. 8). The relevant sentence has been rephrased to read: "For example, wind-driven wave and foam can lead to an uncertainty much larger than 3 K in the simulation of directional brightness temperatures."

14. p. 12082, lines 8-9: "range of viewing angles is usually less than 140 degrees" How was this quantitatively determined? Through only the aircraft data used in Part 1 of this paper? The source of this quantity should be given or cited.

Response: We have rewritten the sentence to read: "In cloud tomography applications, the range of viewing angle  $\Omega$  is usually much smaller than  $180^\circ$  and as a consequence the retrieval problem becomes highly ill-posed." The maximum range of viewing angle for a ground-based or an airborne platform is  $180^\circ$ , but the platform will be required to translate a very large horizontal distance in order to obtain a view close to  $180^\circ$ . Furthermore, the typical beamwidth of microwave radiometer is a few degrees. If the beam is close to the horizontal direction, water vapor and surface emission may dominate the radiometric measurements.

15. p. 12083, Conclusions: The most significant new contribution of this paper is the comparison of the performance of the L1 ( total variation regularization) with that of the L2 norm (Tikhonov regularization). It is commonly thought that L2 is generally easier to

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solve and tends to provide better results than L1 norm. Therefore, the result (L1 norm better than L2 norm) obtained by the authors is an unusual result. The authors need to clearly explain the cost function in each case in terms of the observed brightness temperatures and the absorption coefficients that are retrieved. Do the authors have a "real" understanding of why the L1 norm inversion provides a better result than the L2 norm ?

Response: As shown in Eq. (7), the data constraint is always in the form of L2 norm. It is the regularization term that makes the difference. The linear L2 norm regularization is usually easier to implement. But it cannot preserve features such as large gradient because the L2 norm (square) penalizes more on large values than on small values. On the other hand, the L1 norm regularization has relatively short history compared to the L2 norm regularization. The L1 norm regularization has no preferable scale and it can better preserve discontinuous features.

16. p. 12097, second line: "expense of longer measurement time." It needs to be clarified that this "expense" is the loss of ability to measure temporally varying clouds.

Response: The sentence has been rewritten to read: "A slower platform provides more accurate retrieval at the expense of longer measurement time and possible loss of the ability to monitor rapidly-evolving clouds."

References : [1] Huang, D., Liu, Y., and Wiscombe, W.: Determination of the cloud liquid water distribution using 3D cloud tomography, *J. Geophys. Res.*, 113, D13201, doi:10.1029/2007JD009133, 2008a

More Minor (yet still important) Comments: The paper needs to be proofread carefully by a native English speaker. There are many, many instances of substandard English usage. Comments on some of the English errors are given below.

Response: The manuscript has been carefully revised by the authors for better readability.

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