Atmos. Meas. Tech. Discuss., 4, C2853–C2858, 2012
www.atmos-meas-tech-discuss.net/4/C2853/2012/

Atmospheric Measurement Techniques Discussions

Interactive comment on "Satellite retrieval of the liquid water fraction in tropical clouds between -20 and $-38\,^{\circ}$C" *by* D. L. Mitchell and R. P. d'Entremont

Anonymous Referee #2

Received and published: 23 February 2012

The article describes a technique for retrieving the liquid water fraction of clouds with a low liquid water fraction. The technique focuses on 4 MODIS channels: 11 μm and 12 μm for retrieving phase fraction and particle size, and 2 CO_2 channels for retrieving cloud top temperature and 13.3 μm absorption optical thickness.

The article suffers several major flaws which are outlined below.

1. Incomplete description of the cloud retrieval algorithm
   I feel that one mark of an acceptable scientific paper is that the results should be reproducible. To many details are missing in this paper for that to be the

   case. For example, the authors state that they are using observations at 11 and 12 μm to retrieve cloud emissivities and 13.3 and 14.2 μm to retrieve cloud temperature. They never explain *exactly* how they retrieve cloud temperature. My guess is that a CO_2-slicing approach was used, but no discussion of quality control or algorithm assumptions is given. There are numerous papers on the topic that make clear that while the retrieval is simple theoretically, it requires care in practice. In addition, more than one CO_2 channel pair is typically used. In addition, while it's implied that the errors in cloud temperature retrieval are less than 0.14 K (page 7663, lines 26-30), that error is in fact due only to potentially errors in spectral cloud emissivity. In fact, there is no real error analysis of the cloud top temperature retrieval, which could have large impacts on retrieved IR cloud properties.

   In general, the retrieval methodology lacks sufficient details for someone to reproduce the results. Relationships between mid-layer temperature and cloud (top?) temperature are not explained, important details about microphysical property assumptions are not summarized.

   Even more importantly, the authors show that the retrieved fraction of liquid water is incredibly sensitive to small changes in assumed liquid effective particle size, but the impacts of this and other retrieval errors is not explored. Nor is the possibility of a small ice crystal mode is not explored.

2. Incomplete description of the data set.
   The authors state that they are working with MODIS observations of cloud fields off of Costa Rica on 22 July and 5 August 2007. They state that a cirrus mask is applied so that cirrus clouds are isolated and evaluated and that all retrievals are over ocean and correspond to single-layer clouds (page 7667, lines 1-6). In addition, only cases with $\epsilon \leq 0.7$ are included. This description of the data sampling is not sufficient. How does the cirrus cloud detection work? How is it ensured that the non-unity retrieved cloud emissivity is due to cloud transparency

rather than cloud coverage within the pixel? How is it determined that the clouds are single-layered? The answers to these questions are crucial to interpreting the results of the study.

In addition, comparisons with existing MODIS MYD06 retrieval products including cloud top temperature would have been very useful in assessing the quality of the data sampling and cloud top temperature assumptions. The comparisons with CALIPSO outlined on page 7665 lines 16-22 are not very detailed and the impacts of the differences between retrieved heights is not discussed. In addition, it would have been very easy to get estimated cloud top and midlayer temperatures from the CALIPSO products for comparison with these retrievals.

3. Uncommon and/or inconsistent language that may introduce confusion.
A major issue is the use of the phase *cirrus cloud*. While the abstract clearly states that the paper is about retrieving the liquid fraction in mixed-phase clouds, the paper discusses retrieving the liquid fraction of cirrus clouds. Since *cirrus cloud* has the connotation of a cloud completely composed of ice crystals, the phrasing is extremely problematic and raises the obvious question"Why are water retrievals being done on ice clouds" The easy solution would be to change *cirrus cloud* to *mixed-phase cloud* in the text. But, I do not feel that would be either sufficient or appropriate due to the assumptions the authors appear to have made in selecting their data set and in how the retrieval technique is based on the authors' previous work on cirrus cloud retrievals using data from the same field campaign. For example, the authors are willing to call scenes indicating cloud conditions are almost all liquid as cirrus (Page 7671, lines 5-6). If the authors are implying that traditional cirrus clouds typically contain a detectable amount of liquid water, they need to make that clear from the start.

   Another example is the use of the phase single-layer. Page 7676 lines 6-8 reads "the lidar analysis reveals the presence of liquid-dominated cloud under the CALIOP flight path corresponding to the two MODIS scenes, mostly between

7 and 9.5 km." The presence of the lower-level cloud conflicts with the statement that the study was screened to include only single-layer cirrus clouds (page 7667, line 6).

Another more minor point is the fact that the author does not make clear that *photon tunneling* contributions are an artifact of using the ADT approximation to calculate absorption efficiencies.

4. Insufficient motivation and mediocre organization.
I feel that a major issue with the paper's organization is that the retrieval of the water fraction of *cirrus* clouds should have been presented instead as a hypothesis that undetected liquid water was necessary to explain the observed radiances. If this were the case, the authors would probably have done a better job of tying this work to previous work (including the Mitchell et al paper referenced frequently in this work). As presented, it is difficult to see the motivation of the work since a full range of the liquid fractions can not be retrieved using the technique. As more minor notes, the paper would have been easier to read if it had followed a more traditional style of motivation, data, model, algorithm, results, and conclusion. Also the figure captions did not always define all of the data on the plots.

Because of the major issues listed above, I do not feel that the authors' (unstated) hypothesis that a liquid water contribution is necessary to produce cloudy radiances observed in the data set can be supported. There are too many other possible interpretations that the authors have not addressed.

In addition, I've listed a number of technical comments below.

1. Page 7663, line 1"For ice clouds, the real refractive index" should read "For bulk ice, the real refractive index"

2. Page 7663, line 13: The microphysical assumptions reported in Mitchell et al.

(2010) should be summarized given their importance in the retrieval algorithm and results.

3. Page 7666, lines 8-10: regarding the g-based scattering correction to Q and β. I believe that the g-parameterization in Yang et al 2005 was based on an assumed set of particle size and ice crystal shape distributions. Since I'm assuming this study does not use the same crystal shape and size distributions, is the g-parameterization still applicable?

4. Page 7667, Line 1-3 and Page 7687 (Figure 3): Please mention which MODIS channels are mapped to R, G, and B to create the false color image.

5. Page 7667, Line 12. Please list the temperature intervals used in Fig. 5.

6. Page 7668 line 1: "This is only possible due to this curious relationship that Mother Nature has provided" is not the best sentence for a scientific paper.

7. Page 7668, Line 22: "Otherwise the cloud is assumed glaciated." Given the use of the term cirrus in this paper, I feel it is necessary to define what is meant by *glaciated* here.

8. Page 7670, Lines 13-14: It would be good to make clear that the retrieval is also sensitive to the shape of the water droplet size distribution by rewriting"Changing the droplet dispersion parameter from 5 to 15 changed the liquid fraction by $\pm$26%" as "The retrieval is also sensitive to the water droplet size distribution; changing the droplet dispersion parameter from 5 to 15 changed the liquid fraction by $\pm$26%.

9. Page 7670, Lines 16-18: "For ice crystals this sensitivity is due to the photon tunneling phenomena and for water droplets this is due to Beer's Law absorption effects between wavelengths (Mitchell et al., 2010)." is out of place here.

10. Page 7673, Lines 11-12: Note that as plotted, these size distributions do not show particles with maximum dimension less than 10 microns.

11. Page 7673, Line 24: "However, this may be a consequence of low levels of liquid water." I feel that this statement should be qualified to make clear that this is not the conclusion of Cooper and Garrett (2010). Something like"Based on the results of this study, we feel that the results of Cooper and Garrett (2010) may be a consequence of low levels of liquid wate'r'. Otherwise, the Cooper and Garrett results do not support the hypothesis of this paper.

12. Page 7674, Line 19-20: "For the Yang et al. optical properties, tunneling is greatest for quasi-spherical ice particles (droxtals) and less for bullet rosettes" It would be more appropriate to say here that "for the Yang et al., optical properties, the differences between calculated Qa and ADT Qa is greatest for quasi-spherical ice crystals and less for bullet rosettes" since tunnelingis not an assumption made in the Yang calculations.

13. Page 7675, Line 13-14, "Thus all cloud levels contribute significantly to the radiance observed by the satellite sensor". I disagree with the authors. Not all cloud layers contribute equally, therefore I am not certain that the retrieval will not be affected by the vertical partitioning. Retrieval techniques that make use of absorption (such as this one, and size retrievals at 2.1 or 1.6 microns) are much more sensitive to vertical partitioning than scattering-based techniques. The possibility that the sensitivity to liquid fraction reaches a saturation point at some optical depth into a cloud bears study.

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