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Atmospheric Chemistry and Physics Discussions

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Interactive Comment

# *Interactive comment on* "Tropical thin cirrus and relative humidity observed by the Atmospheric Infrared Sounder" *by* B. H. Kahn et al.

**B. H. Kahn et al.**

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The authors are grateful to the reviewer for his/her thoughtful and helpful comments on the manuscript and appreciate the compliments offered about its quality and usefulness to the scientific community. The authors have responded to each reviewer comment and concern below. In the case that the manuscript was modified in response to a comment, the changes are highlighted. We hope that the responses appropriately address the reviewer's comments and suggestions.

Anonymous Referee #1:

Referee: This manuscript reports on the tropical thin cirrus and relative humidity derived from the Atmospheric Infrared Sounder (ARS) measurements. Overall, the manuscript is well organized and clearly presented. No major technical errors are founded [sic], and the results are reasonable. The topic addressed in this manuscript is appropriate for Atmospheric Chemistry and Physics and should be of interest to atmospheric researchers. This reviewer recommend [sic] that the manuscript be formally published after some minor revisions. Below are the reviewer’s specific comments for the authors’ consideration.

Author response: The authors appreciate the helpful comments, of the reviewer.

Referee: (1). The first paragraph of the introduction where the importance of cirrus: D. K. Lynch, K. Sassen, D. O. Starr and G. Stephens (Eds.), Cirrus, (Oxford Univ. Press, New York, 2002) should be cited.

Author response: We have added the Lynch et al. reference to line 2 in the first paragraph.

Referee: (2) There are several definitions of the effective particle size in the literature. To prevent potential confusion, the authors are suggested to provide the definition of the effective particle size, which is 3/2*total volume/total projected-area [Eq. (4) in Yue et al. 2007].

Author response: Since we use the ice scattering models of Baum et al. (2007) in place of the ice model combinations used in Yue et al. (2007), we instead refer to Eqn. (4) in Baum et al. to not confuse the reader. They define De precisely as the reviewer states. Thus, we have added the following text on p. 16191, line 8:

“Here De is defined as 3/2 times the ratio of the total volume to the total projected area following eqn. (4) in Baum et al. (2007) and cited references therein.”

Referee: (3) Sec. 2.3: Potential biases in thin cirrus retrievals: In the retrieval algorithm developed by Yue et al. (2007), scattering effect is neglected, as is evident from Eq. (1) in Yue et al. (2007). Can the present authors comment on the potential errors due to this approximation? In the literature, all the IR-based retrieval algorithms assume



ACPD

7, S8845–S8850, 2008

Interactive Comment

that scattering effect is small. But quantitative information is usually not offered.

Author response: One of the co-authors of this paper (Q. Yue) has developed a multiple scattering version of the retrieval method discussed in Yue et al. (2007) using a delta-four stream (D4S) modification (for a preliminary analysis and model description, see Q. Yue and K.N. Liou, “Investigation of the Radiative Forcings of Thin Cirrus in the Tropical Atmospheres Based on AIRS/ARM Data”, presented at the Fall 2007 AGU meeting, abstract #A41B-0441).

The D4S retrieval program is undergoing testing at present but preliminary inter-comparisons between thin cirrus pixels with varying values of optical depth (OD) are contained in Yue and Liou (2007). For a small set of footprints, the D4S reduces OD by at most a few percent and increases the mean De by a slightly larger percentage, but with more scatter. For OD $>$ 0.3, the D4S approach reduces OD by an average of 38% (for a limited set of AIRS footprints) and increases De by a similar magnitude as in the OD $<$ 0.3 cases. In summary, the number of samples is small, but it appears the impact of multiple scattering on OD is more important for OD $>$ 0.3. The impact of the D4S on De appears to increase it, although these results are more uncertain than the impacts on OD because of the larger scatter. So, to answer the reviewer’s question, based on a limited set of cases the effects of scattering are quite significant for cirrus with OD $>$ 0.3.

At this time, we believe a brief summary of this work is not mature enough to be included in the manuscript. Q. Yue and K.N. Liou will publish this work elsewhere at a later time using a larger set of cases to evaluate biases in OD and De using non-scattering and D4S versions of thin cirrus retrievals.

Referee: (4) Sec. 3.3: Vertical structure and thin cirrus and RH_ic: A recent study (Hong, et al, 2007: The sensitivity of ice cloud optical and microphysical passive satellite retrievals to cloud geometrical thickness, IEEE Trans Geosci. and Remote Sensing, 45, 1315-1323) shows that the IR-based cirrus property retrievals are quite sensitive to cloud physical thickness.

Author response: Thanks to the reviewer for pointing out this paper; we have added it to the list of references. For the types of clouds observed in this study (cloud heights between 10-15 km, cloud thicknesses less than 3 km – with many less than 1 km, and OD less than 1.0), the errors that are introduced in the IR simulations according to Hong et al. (2007) if cloud thickness is not accounted for could lead to a high bias in De by 0-20% and a low bias in OD from 0-10%. Thus, we have added the following text to p. 16191, line 28:

“Furthermore, the effects of cloud thickness are not included in the modified approach of Yue et al. (2007) that is presented here. Hong et al. (2007) simulated MODIS IR bands to show that, for the types of thin cirrus investigated here, a low bias in OD up to 10% and likewise a high bias in De up to 20% may be introduced by not considering cloud thickness.”

A cursory inspection of Fig. 5 suggests that the magnitudes of De and OD may be slightly affected, but the slopes, magnitudes, and spacing between the different OD, De, and Tcld bins are significantly larger than these biases, thus the conclusions of this paper remain robust.

Referee: (5) Thin cirrus optical thickness can also be derived from the MODIS 0.66 and 1.375 bands (e.g., Meyer, 2007: Tropical ice cloud optical depth, ice water path, and frequency fields inferred from the MODIS level-3 data Atmos. Res. 85, 171-182). It could be of interest to compare the distribution of cirrus clouds derived from the present AIRS algorithm and the MODIS 0.66/1.375-um method. Additionally, could the authors briefly comment on the advantages/disadvantages of the IR and VIS/NIR algorithms?

Author response: Thanks again for another relevant reference (Meyer et al. 2007); it has been added to the modified manuscript. With regard to comparing cirrus retrievals from this work with the MODIS operational approach and the 1.38 micron approach, some preliminary comparisons have been performed in context with in situ measure-



ACPD

7, S8845–S8850, 2008

ments in Davis (2007) [Note: I am citing the Ph.D. thesis of S. M. Davis (2007), the reference has been added to the revised manuscript.] Collaboration between B. Kahn, S. Davis, and K. Meyer is culminating in a manuscript to be submitted. Also, B. Kahn has compared the AIRS retrievals with the MODIS operational OD and reff and finds tremendous scatter/differences that seem to be controlled to a large extent by multi-layered cloud structure (discussed in the manuscript under preparation mentioned above).

With regard to the general advantages and disadvantages of the IR and VIS/NIR techniques relevant to this study, there are several points to make. For brevity, please find below the additional paragraph added to the modified manuscript on p. 16191 after the last paragraph in Sect. 2.1 that addresses the reviewer’s suggestion.

“Other cirrus retrieval approaches to obtain OD and De use various combinations of visible (VIS) and near-infrared (NIR) reflectances (e.g., Dessler and Yang 2003; Platnick et al. 2003; L’Ecuyer et al. 2006; Meyer et al. 2007; and references therein). The operational MODIS retrieval uses combinations of VIS/NIR window channels that are sensitive to clouds throughout the atmospheric column (Platnick et al. 2003). Although this approach excels at low cloud property retrievals over a large dynamic range of OD and De unlike the thermal IR, the presence of underlying cloud layers under thin cirrus can introduce large biases in OD and De (Davis 2007). Biases caused by multi-layered cloud structures as viewed by the IR are generally smaller since they depend on relatively small thermal contrasts between the surface and low cloud. The MODIS 1.38 micron band constrains cirrus OD more accurately than the operational approach because the underlying water vapor absorption either reduces or eliminates the reflectance contributed by low cloud layers (Meyer et al. 2007). However, this channel alone cannot constrain De nor observe cirrus at nighttime. The lower limit of sensitivity to cirrus using the operational MODIS cloud mask is near OD ˜ 0.3, whereas the 1.38 micron channel is much more sensitive to thin cirrus (Dessler and Yang 2003) and more closely resembles the sensitivity of AIRS. Although any IR retrieval approach has its own set of limitations, it provides a global and diurnal view of cirrus OD and De not available from the VIS/NIR methods.”

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ACPD

7, S8845–S8850, 2008