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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Validation of MODIS cloud microphysical properties with in situ measurements over the Southeast Pacific" *by* Q. Min et al.

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We thank the reviewer for very thorough and constructive comments. These comments and suggestions have helped to greatly improve the quality of the paper. Below are our responses to the comments. The response (in blue) follows each comment.

Anonymous Referee #3

This paper (M12) compares in-situ derived values of effective radius, droplet concentrations and liquid water path (from aircraft profiles) with Terra satellite derived values (using the adiabatic cloud assumption) that were within one hour of the flight profiles. It also performs radiative transfer calculations for an adiabatically stratified liquid water

profile cloud and compares them with those from a vertically uniform model (similar to what is used for MODIS cloud retrievals of Re and optical depth).

The paper is quite similar to another recent paper (Painemal, JGR, 2011; P11) that also uses data from the VOCALS campaign. The main difference is that M12 also uses data from both the G-1aircraft and the C-130, whereas P11 used only C-130 data. Section 4 of M12 also makes it unique from P11. These differences probably make M12 sufficiently different to merit publication. However, there are a number of serious issues, such as wrong statements and misinterpretations that first need addressing. The main issues are listed below. Typos and grammar corrections (plus additional comments) are documented in the modified manuscript further below.

Main issues:- Abstract, p. 1434 "and the inability to accurately account for either of them in retrievals lead to substantial uncertainties and biases in satellite retrieved cloud effective radius, cloud liquid water path, and cloud drop number concentration. However, strong correlations between satellite retrievals and in situ measurements suggest that satellite retrievals of cloud effective radius, cloud liquid water path, and cloud drop number concentration can be used to investigate aerosol indirect effects qualitatively."

»> I think that these statements go a little far, especially when the comparisons between the retrieved and measured CDNC (and other variables) are fairly reasonable, (e.g. Fig. 8), particularly if some subadiabaticity is assumed. Have you also looked at the errors associated with the satellite retrievals of optical depth and Re to see if they can account for the differences? Likewise there should be more discussion of the errors in the aircraft observation measurements.

Min et al: We have changed the statement as "substantial" to "some". Yes, relatively, the comparisons between the retrieved and measured CDNC (and other variables) are fairly reasonable, with correlation coefficients of 0.91 and 0.93 using 5 and 25 km averaging scales, respectively. However, the slopes of a linear fit for both scales are not close to 1 (1.23 and 1.27, respectively). Only if the subadiabaticity is taken into account, the slopes are closer to 1.

Many papers have discussed the errors and uncertainties in both the satellite and in-situ measurements in details (King et al., ATBD, 1997; Kleinman et al, ACP, 2012; Painemal and Zuidema, JGR, 2011). We will note point but refer readers to these references for more information on the issues.

p.1425 – ". For an adiabatic cloud, the mean Re is 5/6 of the cloud top Re " »> This is not what is stated in Brenguier (2000). The effective radius in a vertically uniform cloud (for the same optical depth and LWP) would be 5/6 of the effective radius at the top of an adiabatically stratified cloud. The effective radius is proportional to hˆ(1/3) for an adiabatic cloud. Therefore, the mean Re over an adiabatic cloud would be 3/4 of the cloud top Re. Thus, I think that there is some confusion here. Min et al.: You are right. We made changes in the manuscripts

", which is equivalent to the averaged Re over the top 30% of the cloud (Brenguier et al, 2000)." »> This doesn't make sense since the mean over the whole cloud cannot be exactly the same as the mean over the top 30% of the cloud. If you mean that the mean Re over the top 30% of the cloud is equal to the cloud top Re *5/6 then I think that this is also wrong. My calculations suggest that the mean Re over the top 30% of an adiabatically stratified cloud would be the cloud top Re*0.95. So the quoted means over the upper 30% will actually probably be close to the cloud top Re, which is actually what the satellite likely samples (likely the Re 1-3 optical depths from the top of the cloud – see Painemal, 2011) for refs.

Confusion on this appears throughout the paper and needs to be rectified. Presumably the statistics in Fig. 5 and Table 1 are calculated using the actual values (and not *6/5). The addition of the 6/5 line in these plots adds to the confusion. Removal of the mentioning of the 5/6 factor until section 4 (where it actually applies) would help to reduce the confusion.

Min et al: We used the mean values of the upper 30% of clouds for all comparison

in the paper. We clarified this in the current manuscript, and removed the 6/5 lines in Figure 5.

p. 1427 and Fig. 3 I am concerned here about the possibility of uncertainties in the cloud top and cloud base heights affecting this outcome. The theoretical adiabatic max LWP varies with the square of the cloud depth and would be very sensitive to the assumed cloud depth. The data points here need errorbars to estimate this effect.

For example, small amounts of LWC above the position of max LWC (hereafter zmax) in an otherwise adiabatic profile would could act to increase the theoretical adiabatic LWP substantially, leading to a much lower value of the adiabaticity as calculated here. However, as long as the LWP above zmax is not substantial, the effective radius seen by a satellite looking down would be close to that at zmax and the overall LWP would be similar to the adiabatic case.

Thus, the parameter A might not be a good measure of how well the satellite retrieval is likely to be unless all of the profiles are linear with very little cloud depth above zmax. Can it be verified that this was the case? Perhaps a better measure might be the ratio of the max LWC of the observed profile to that expected from an adiabatic ascent to there from cloud base?

Min et al: The cloud top and base heights were determined by requiring three continuous altitude bins have values greater than 0.02 g/m-3 and 5 cm-3 for PVM and CAS measurements, respectively. As the reviewer pointed out, small amounts of LWC above the position of max LWC (zmax) would result in a lower value of the calculated adiabaticity. We have visually inspected all profiles of LWC, CDNC, and the ratio of LWC/LWCAdia. We rather have good cases than more cases, so all cases shown in Figure 3 either have little LWC above zmax or LWC above zmax reducing gradually. The reviewer's suggested definition may not be good for the latter cases.

p.1430 and other places.

Using the CTT and the estimated cloud base height from reanalysis would be quite an indirect way of inferring cloud top height anyway. The estimation of the cloud base height would also introduce large errors.

Cloud geometric height is usually estimated using the measured LWP and assuming a linear increase of LWC with height (along with Nd, as in Bennartz 2007). It would be better to test this method using the in-situ data. Or the mention about cloud depth might be removed as it is not key here (although the CTT comparison is still useful)

At the least the LWP method should be mentioned.

Min et al: We included the comparison of the estimated cloud geometrical thickness through the adiabatic cloud assumption (Bennartz, 2007). The Figure R1 shows the comparison and more discussion is in the revision.

p.1430

"Our validation indicates that the differences between MODIS retrieved and in situ measured microphysical parameters have strong dependencies on the cloud geometrical thickness and cloud droplet number concentration."

»> I disagree – they are not particularly strong for the cloud thickness dependency (Fig. 6b). And also, are the percentage changes in Re are strong as a function of CDNC (since CDNC is a strong function of Re)? Might be better to plot Fig. 6 as percentage differences.

Min et al: We plotted Figure 6 as percentage differences, shown in Figure R2. Both differences and percentage differences between the MODIS retrieved and the in situ measured microphysical parameters have dependencies on the cloud geometrical thickness and cloud droplet number concentration. In general, the thicker the clouds the larger differences between the two. We removed the word, "strong".

p.1431 "more cloud water is located at the top of cloud, resulting in higher cloud optical depths near the cloud top, enhancing photon path length. At a water (or ice) absorb-

ing band, the enhanced photon path length near the cloud top results in increased absorption and suppressed cloud reflection as compared to a vertically uniform cloud. Therefore, the retrieved LWP is overestimated (Fig. 10c) and consequently cloud effective radius is overestimated."

»> This statement needs justifying through some analysis or a reference. Otherwise it should be suggested as a speculation rather than fact.

Min et al: We added three references of Nakajima and King (1990); Li et al. (1994); Platnick and Valero (1995).

"As shown in Fig. 10b, the difference between VUPPM ("retrieved") Re and ASPPM Re decreases with increasing cloud drop number concentration."

»> It looks to me like the difference between the expected VUPPM of 5/6*Re_ASPPM at cloud top and the actual VUPPM increases with increasing CDNC from Fig. 10b.

Min et al: From Figure 10b, for a given Re, it seems that the difference between the expected VUPPM of 5/6*Re_ASPPM at cloud top and the actual VUPPM increases with increasing CDNC. However, this situation (the same Re) corresponds to different cloud optical and geometric depths, since a cloud with a high drop number for a fixed LWC has a small effective radius. Thus, the differences between the expected VUPPM of 5/6*Re_ASPPM depend on cloud geometric thickness, as shown in Figure 11. We changed this statement to "As shown in Fig. 10b, the difference between VUPPM ("retrieved") Re and ASPPM Re decreases with increasing cloud drop number concentration for fixed cloud depths."

p.1432 "It clearly illustrates the importance of knowing the cloud geometric thickness."

»> I don't really agree with this – the CDNC retrieval seems fairly robust regardless of the cloud depth for the adiabatic clouds.

Min et al: The differences seem very small in the scale of 0-400 cm-3, shown in Figure 12. However, there are systematic differences (up to a few percentages) with different cloud geometric thicknesses.

"Furthermore, as shown in Fig. 12b, the "retrieved" CDNC can be underestimated or overestimated, strongly depending on the cloud adiabaticity. In this sensitivity test, the cloud geometric thickness is assumed to be 350 m. As the clouds in SEP exhibit a coherent relationship between cloud geometric thickness and adiabaticity, variations in both cloud geometric thickness and adiabaticity would introduce substantial uncertainties in the estimation of cloud CDNC from satellite remote sensing."

»> It is not clear what Nd has been calculated for the ASPPM values for the sub-adiabatic clouds in Fig. 12b. Has the expected reduction in Nd with reducing effective Cw been taken into account? (Nd proportional to Cwˆ(1/2)). I.e. are these results just what would be expected based on the adiabatic model? Or are there some other deviations due to the VUPPM assumption?

Min et al: In the sub-adiabatic cases, the cloud drop number is assumed to be constant vertically, and the rate of increase of LWC with altitude is set to be consistent with there adiabaticity. The vertical profile of effective radius and the cloud optical depth are calculated from defined LWC and CDNC accordingly. We didn't vary the cloud drop number vertically.

Section 4 The definition of the cloud profile used for the VUPPM LWC should be explained.

Min et al: The cloud profile of LWC is constant vertically.

Interactive comment on Atmos. Chem. Phys. Discuss., 12, 1419, 2012.

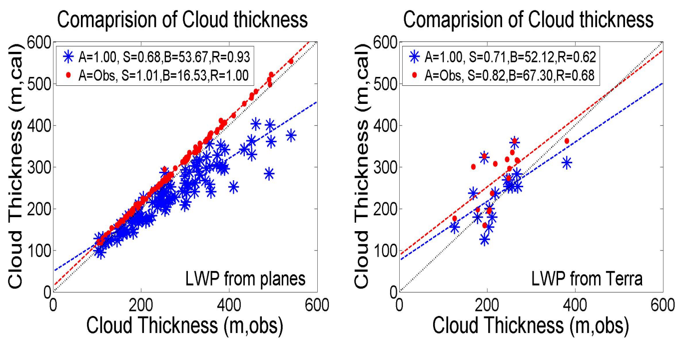

Figure R1. Comparison of retrieved cloud geometrical thickness with the in-situ measurements.

Fig. 1. Comparison of retrieved cloud geometrical thickness with the in-situ measurements.

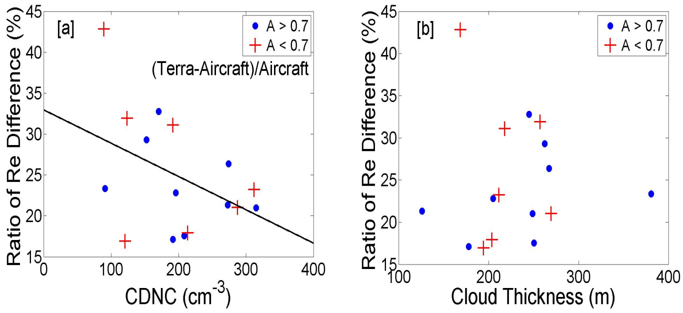

Figure R2 the percentage differences between Terra-MODIS retrievals and aircraft measurements of cloud effective radius as a function of cloud drop number concentration and cloud geometric thickness

Fig. 2. the percentage differences between Terra-MODIS retrievals and aircraft measurements of cloud effective radius as a function of cloud drop number concentration and cloud geometric thickness