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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. The quality of the manuscript has been improved by these comments and suggestions. Below are our responses to the comments. The response (in blue) follows each comment.

Anonymous Referee #2 Received and published: 12 March 2012 The MODIS operational cloud effective radius retrievals over the South-East Pacific region are compared against the in situ measurements from the VOCALS campaign. For the 17 non-drizzling cases selected, MODIS retrievals are found to overestimate in situ observations by 1∼2um. The origin of this bias is discussed and attributed to cloud vertical stratifica-

tion from the condensation growth.

General comments

It has been a frustrating problem for cloud parameterization teams that the GCM simulation of warm cloud effective radius is often about 5um smaller than MODIS retrieval (e.g. Donner et al. 2011 J. Climate, Kay et al. 2012 J. Climate). Several recent papers (e.g., Nakajima et al. 2011 JAS, Seethala and Horváth 2010 JGR, et al., 2008, JGR). Zhang and Platnick 2011 JGR) revealed substantial (5∼10um) uncertainties in MODIS effective radius retrievals. All these studies indicate satellite-based remote sensing of cloud microphysics, even for the simplest cloud system, is still highly uncertainty. In situ measurements from field campaigns, like VOCALS, provide valuable observations to address this uncertainty. This manuscript documents an investigation of MODIS effective radius retrieval uncertainty based on VOCALS measurements. Although such investigation is much needed, I feel a little disappointed after reading the manuscript. The hypothesis (i.e., cloud vertical structure due to condensation growth) raised by the authors to explain the difference between MODIS and in situ measurements are well known and well-discussed in the literature. Moreover, the evidences showed in this paper are not convincing enough to justify this hypothesis and other possibilities are not well discussed.

On the other hand, I think this manuscript may be useful contribution to the ACP special issue, as it documents the VOCALS cloud microphysics measurement cases suitable for comparing to satellite observations. Overall, I feel it needs to be considerably improved before it can be considered for ACP. Below are my comments on the manuscript and some suggestions for the authors.

Major concerns:

First of all, I don't think this study is really a "Validation of MODIS" retrievals. It is more of a comparison study. This is because MODIS retrievals and the in situ measurements presented in this study are too different in too many respects, including spatial and

ACPD

12, C2321–C2327, 2012

temporal sampling, theoretical bases and practical implementation. Although some attempts have been made to reduce these differences, I am still not convinced that it is an apple-to-apple comparison. These cases may be excellent for cloud microphysics studies, but they are not good cases for satellite validation. A well-planned validation campaign would have avoided these complications. I suggest the author reconsider the title. A more suitable one seems to be" Comparison of MODIS cloud microphysical properties with in situ measurements over the VOCALS region.

Min et al: This is a good point. We changed the title to "Comparison of MODIS cloud microphysical properties with in situ measurements over the VOCALS region", and changed "validation" to "comparison" in the manuscript accordingly.

The retrieval uncertainty of MODIS is never mentioned in this study. MODIS retrieval is not perfect. It is actually subjects to all kinds of uncertainties (see http://modisatmos.gsfc.nasa.gov/_docs/atbd_mod05.pdf). A 1∼2 um difference between MODIS and in situ measurement may be comparable, or even smaller, in comparison with MODIS uncertainty. In such case, it is meaningless to chase after the small difference. The MODIS effective radius retrieval uncertainty can be found in operational MODIS MOD06_L2 product (sds name "Cloud_Effective_Radius_Uncertainty"). This product provides an estimated relative uncertainty (i.e., in percent unit) for effective radius retrieval. this product may help clarify whether the difference between MODIS and in situ measurement is significant or not, in comparison with intrinsic uncertainty in MODIS retrieval.

Min et al: MODIS retrievals and in-situ observations subject to all kinds of uncertainties. Since 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 did not discuss here in details but cited those references.

The cases selected for this study need to be better described. The description of

ACPD

12, C2321–C2327, 2012

these cases might be the largest contribution of this paper to the cloud remote sensing community. At very least, the location, time and instrument used for these should be tabulated.

The discussion on the origin of MODIS bias seems too simple and not convincing. The authors attribute the MODIS bias to cloud vertical structure and cloud thickness. But, in Fig. 6b the MODIS and in situ Re difference seems not correlated with cloud thickness. The adjustment of in situ Re by a factor of 6/5 in Fig. 5 does not make the comparison much better. More importantly, the authors did not discuss and exclude other possibilities, such as 3-D radiative effects, sub-pixel variability, and temporal and spatial mismatch between MODIS and in situ measurements. Why are they not important?

Min et al: There are many possible reasons for differences between the MODIS retrievals and the in-situ measurements, including 3D effects, sub-pixel variability, and temporal and spatial mismatch as listed by the reviewer; the cloud mode droplet size distribution breadth, the presence of a drizzle mode, above-cloud water vapor absorption, and sensor viewing angles as investigated by Painemal and Zuidema (2011); and cloud vertical assumption associated with cloud thickness, cloud adiabaticity, and cloud drop number concentration as we focused in the paper.

The clouds we studied are the largest and most persistent deck of subtropical marine stratocumulus clouds over the Southeast Pacific off the coast of Chile. Although they concurrently experience a gradient or partition between anthropogenic and natural aerosol loading from coast to the remote ocean, the local variability in the closed cell region is relatively small. Those clouds are the best for the intercomparison of satellite remote sensing and in-situ measurements, as the cloud 3D effects and sub-pixel variability is minimal (particularly with our criteria of limiting cases to > 0.95 cloud cover). So we did not elaborate in the paper previously. However, as pointed out in the paper, it is critical to understand the effects of spatial-temporal variability of each parameter observed from multiple instruments. To deal with temporal and spatial mismatch mentioned by the reviewer, we limited the temporal difference within one hour, and used

ACPD

12, C2321–C2327, 2012

both projected and un-projected positions to collocated samples. Also, we used two averaging domains (5 and 25 km) for our comparison study. The reason for a better agreement with the 25km averaged MODIS retrieval is that averaging over a relative large domain reduces the uncertainty associated with temporal-spatial mismatch. We ellaborate more on this issues in the revised manuscript.

Painemal and Zuidema (2011) concluded that none of those reasons, i.e, the cloud mode droplet size distribution breadth, the presence of a drizzle mode, above-cloud water vapor absorption, and sensor viewing angles, can be highlighted for the cause of observed MODIS-in-situ Re bias. They suggested that combination of above reasons may conspire to produce effective radii larger than in-situ values.

In our paper, we suggested that the vertical stratification and cloud adiabaticy may impact the accuracy of retrieved cloud microphysical properties, in addition to the temporal-spatial mismatch. We have to admit that our sample size is small (only 17 cases), and the cloud microphysical and microphysical properties are complex and correlated. The limited samples cannot fully separate the impacts of cloud thickness from the impacts of CDNC. However, the tendency of the differences of MODIS-in-situ Re increasing with cloud thickness is noticeable. Certainly, the vertical stratification issue for satellite retrievals is not new. It has been investigated by many researchers: Nakajima and King (1990); Li et al. (1994); Platnick and Valero (1995); and Brenguier et al (2000), Platnick (2000) and many others. Based on VOCALS in-situ measurements, we attributed that the vertical stratification and cloud adiabaticy may be one of the causes for the differences between the MODIS retrievals and the in-situ measurements. Our simulations using VUPPM and ASPPM further illustrate this possibility.

MODIS provides not only effective radius retrieval based on the 2.1_m band, but also two other independent retrieval based on 1.6_m and 3.7_m. These bands have different penetration depth into cloud (Platnick 2000 JGR). So if the authors' hypothesis is correct, that cloud vertical structure due to adiabatic growth is the origin of MODIS bias, the authors shall find Re(3.7um)> Re(2.1um)> Re(1.6um). This may be a way to

ACPD

12, C2321–C2327, 2012

make the argument stronger.

Min et al: Painemal and Zuidema (2011)have investigated this particular issue over SEP during VOCALS field campaign, and they found that Re(2.1um)> Re(3.7 um) or Re(1.6 um). Since they have discussed this issue, we didn't discuss in our paper.

The in situ measurements are compared with 5km and 25km area-averaged MODIS retrieval. Better agreement is found with the 25km averaged MODIS retrieval. But why? What are the implications? This is somewhat counter-intuitive and worth explanation. Instead of focusing on mean value comparison, I think it might be interesting to compare the in situ measurements with the statistics of the MODIS retrievals over 5km or 25km area.

Min et al: The reason for a better agreement with the 25km averaged MODIS retrieval is that averaging over a relatively large domain reduces the uncertainty associated with temporal-spatial mismatch. This point is elaborated further in the revised version.

Specific comments: Fig 2. needs to be better explained. What do "outbound" and "inbound" mean in the figure legend? Are these terms necessary?

Min et al: "outbound" and "inbound" indicate the G-1 flew from the coast to ocean and from ocean to the coast, respectively.

The impacts of cloud vertical structure on MODIS effective radius retrievals have been discussed in several previous studies (e.g., Nakajima and King 1990 JAS, Platnick 2000 JGR). It is a well-known issue. Therefore, the section 4 is not really necessary.

Min et al: Yes, as discussed above, many studies discussed this well-known issue, and we specifically attributed this issue as one of the major causes for the differences between the MODIS retrievals and the in-situ measurements based on VOCALS in-situ measurements. Section 4 shows the simulations with specific setting of VOCALS observation to further illustrate this possibility.

ACPD

12, C2321–C2327, 2012

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ACPD

12, C2321–C2327, 2012

Interactive Comment