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Atmospheric Measurement Techniques Discussions

# *Interactive comment on* "Validating MODIS Above-cloud Aerosol Optical Depth Retrieved from "Color Ratio" Algorithm using Direct Measurements made by NASA's Airborne AATS and 4STAR Sensors" *by* Hiren Jethva et al.

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RC: Referee comments

AR: Author's response

We thank Dr. Sayer for providing his comments and sharing his own thoughts and experience of validating the extended "Deep Blue" above-cloud aerosol retrieval.

RC: About the claim of first validation of the satellite-derived above-cloud AOD

AR: The results presented in this manuscript were actually derived about 2 years ago



and also presented in talks and posters several times in NASA Goddard and elsewhere (2014 AGU Fall Meeting). The manuscript was written last year when no such study existed. A recent paper written by the reviewer (Sayer et al., 2016), who also validates his extended Deep Blue algorithm-based above-cloud AOD retrieval for the same case studies that are shown in our paper. Since the reviewer was fast enough to publish his results earlier than us, we will take back this claim from our manuscript.

RC: About Cloud Optical Depth Comparison

AR: As correctly pointed out by the anonymous referee #3, in addition to the microphysical properties of aerosols, in this case the imaginary part of refractive index and thus single-scattering albedo, the amounts of aerosol loading also plays a determinant role in the resultant bias in the retrieval of cloud optical depth for the above-cloud absorbing aerosols scenes. The AODs for the ACE-ASIA case studies measured/retrieved by AATS/MODIS are relatively smaller in comparison to those of SAFARI-2000. Smaller magnitudes of AOD and higher SSA (less absorption) imply smaller impact on retrieved COT. As stated in the manuscript "the negative bias in COD retrieval is directly proportional to the strength of absorption above cloud, which is expressed as the absorption aerosol optical depth (AAOD=AOD*(1-SSA))." Smaller amounts of aerosol loading with higher SSA yield smaller AAOD and thus result in lesser bias in COT retrieval.

The lower AOD aspect of the bias in cloud retrieval has been discussed in the revised paper.

RC: About the Co-location Criteria and Satellite-Aircraft Time difference

AR: We agree with the Dr. Sayer that the airborne measurements and satellite data were not taken simultaneously. Following is the description of the time differences between MODIS and AATS/4STAR for each flight considered in the validation analysis.

SAFARI-2000 The SAFARI-2000 flight on September 13, 2000 flew between 8 and 14 hours (UTC) over the Walvis Bay, Namibia, whereas Terra/MODIS overpassed the region at 9:25 (UTC). The co-location procedure yields most matchups between hour 10 and 12 (UTC), leading to a time difference of about 30 minutes to 2 $\frac{1}{2}$ hours between satellite overpass time and airborne AATS measurements.

ACE-Asia 2001 For the ACE Asia 2001 flights, the time differences between the co-located AATS and Terra/MODIS were about 6 hour, 2-4 hour, and 3 $\frac{1}{2}$ hours, for the flights operated on Apr 20, 30, and May 04, 2001. For the case of May 04, 2001, we found all matchups (N=38) around Longitude 126°E and Latitude 30°N at hour 6 (UTC), whereas Terra/MODIS flew over the matchup region at 02:25.

SEAC4RS-2013 For the SEAC4RS-2013 flight on Aug 06, 2013, we used MODIS retrievals from both Terra (19:50 UTC) and Aqua (21:30 UTC) platforms for the validation. The time difference between the co-located 4STAR and MODIS observations was from 30 minutes to two hours for Terra, and $\pm$ 2 hours for Aqua. Figure 2 in the original manuscript shows data from Terra and Aqua together. However, the revised Table 2 now shows the statistics for both platforms separately as well as satellite-airborne time difference for each case study.

We agree that the time difference between AATS/4STAR and Terra-Aqua/MODIS overpass for all validation flights considered in the present analysis were larger than in the typical validation exercise of the clear-sky satellite products (30 minutes or even less). However, reviewer should be aware that these are the only major flights of measurements of aerosols above cloud we found after searching the entire past record of AATS and 4STAR. Any changes in the aerosol and cloud fields between the time domain of airborne measurements and satellite retrievals will inevitably introduce mismatch in the comparison.

We have added the time difference attribute of the MODIS vs. AATS/4STAR comparison in section 2.2 “Co-location of Satellite-Airborne Sensors” and also a discussion on the uncertainty in section 4.1 “Sources of Uncertainties in ACAOD” in the revised manuscript.



RC: About Scaling of aircraft-measured AOD to MODIS cloud top pressures

AR: As mentioned in the original manuscript, the absolute error in the aircraft-mounted AATS and 4STAR measurements of AOD for these flights was mostly in the range 0.02 to 0.03 with maximum error reaches up to 0.05 for certain measurements. Assuming the profile of AOD and MODIS-retrieved cloud top pressure are accurate, and therefore scaling itself, the minimum uncertainty expected in the AOD validation analysis would be about 0.03-0.05. A sensitivity study for the SAFARI-2000 case in which the cloud top pressure perturbed by $\pm$ 50 hPa and $\pm$100 hPa from its retrieved values from MODIS resulted in the RMS difference (MODIS minus AATS) of $\pm$0.02 and $\pm$0.05, respectively. These magnitudes of error are comparable to the absolute error in the AATS measurements. The reason for low errors in AOD scaling for this case could be the fact that the AOD measured by AATS between 850 and 900 hPa is almost similar and the MODIS-retrieved cloud top pressure for the matchups points mostly fall in this range of pressure, making not much difference in the scaling even if cloud top pressure is perturbed by $\pm$100 hPa. It is possible that the uncertainty associated with the scaling of AOD would be larger than 0.05 if the sign of error in measurements and cloud retrievals both are on one side, or even can cancel each other if the sign is in opposite direction.

The scaling procedure is now better demonstrated with equations accompanied by a figure for the SAFARI-2000 case in section 2.3 Co-location of Satellite-Airborne Sensors. Also the sensitivity results discussed above have been included in section 4.1 Sources of Uncertainties in ACAOD in the revised manuscript.

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**Table 2.** Statistical summary of the MODIS versus airborne above-cloud AOD comparison.

| Field Campaign | Event Date | N | RMSD | % Matchups Within Predicted Uncertainty (Jethva et al., 2013) | ΔT |
|---|---|---|---|---|---|
| SAFARI-2000 | Sept 13, 2000 | 122 | 0.052 | 99.18 | 30 mins to 2 1/2 hours |
| ACE-ASIA 2001 | Apr, 20, 30, May 04 | 67 | 0.051 | 83.58 | 2 to 6 hours |
| SEAC4RS-2013 | Aug 06, 2013 | 34 | 0.100 | 50.00 | T: 30 mins to 2 hours |
| | | T:16 A:18 | T:0.103 A:0.095 | T:35.29% A:61.11% | A: 2 hours |

N: Number of Matchups

ΔT: time difference between satellite overpass and airborne measurements

RMSD: Root-Mean-Square-Difference

T: Terra, A: Aqua

**Fig. 1.** Statistical summary of the MODIS versus airborne above-cloud AOD comparison.



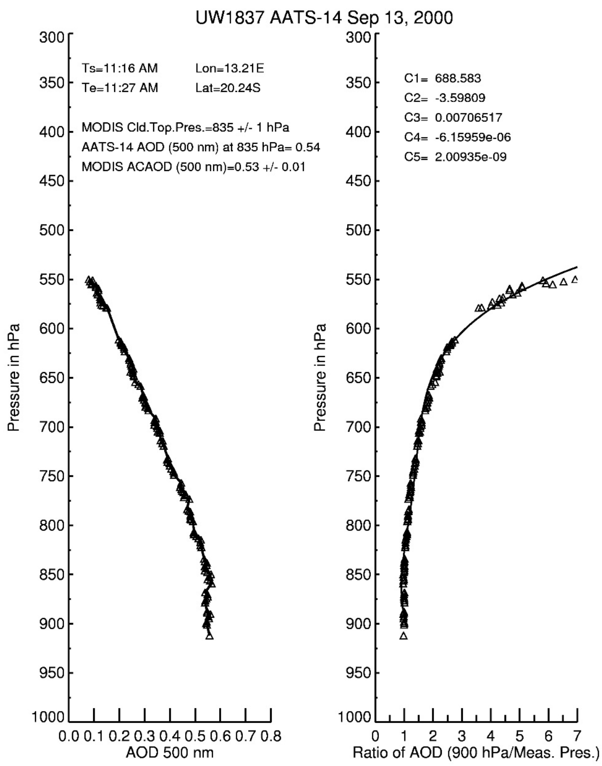


**Fig. 2.** Vertical profile of above-aircraft columnar AOD (left) and ratio of AOD (right) measured by AATS-14 during SAFARI-2000 flight UW1837 flew on September 13, 2000 over the Walvis Bay.