Reply to Reviewer #2

Adaption of the MODIS aerosol retrieval algorithm by airborne spectral surface reflectance measurements over urban areas: A case study
Author(s): E. Jäkel et al.
MS No.: amt-2015-139

We thank the reviewer for the time and efforts she/he spent reading our manuscript and providing valuable advises which we truly appreciate. Please find below a discussion of the reviewer's comments (italic). Changes/additions made to the text are underlined and given in quotes.

One glaring omission in this manuscript is the lack of explanation or discussion of the poor performance of the MODIS C6 algorithm as compared to C5 when modified for an urban surface albedo. It is noted that the performance is poor, but there is no attempt to help the reader to understand why. Since C6 presumably represents the current operational algorithm, applying modified slopes for urban regions would not improve AOD retrievals, thus it is critical that this issue be addressed.

In our first version of the manuscript we found mean differences between AOD(MODIS) and AOD(AERONET) of 0.09 ± 0.18 (adapted C5) and -0.10 ± 0.18 (adapted C6). Changing the slope parameter a(NDVI0.65/2.1) in C6 as described in Eq. (7) results in a larger surface reflectance (valid for most of the cases with $0.25 < NDVI < 0.75$) than in C5. This gives lower retrieved AODs derived by the C6 method.

If we use additionally the adapted slope a(0.47/0.65) from aircraft measurements then we get a larger surface reflectance (rho_0.47) resulting in an even lower AOD. In this case an additional higher slope assumption for a(NDVI0.65/2.1) reduces the retrieved AOD even more. That's why we had a lower performance for C6 when filtering the data set for sensor zenith angles < 10° and Summer months.

The other reviewer suggested using also MODIS data without restrictions of sensor zenith angle and season. Our original intention was to minimize retrieval uncertainties due to the surface assumption by selecting data with respect to viewing geometry and season. We expected larger variability of the slope parameter for the winter months (different vegetation) and for sensor zenith angles different from nadir direction (BRDF dependence). However, in the new version of the manuscript we used the entire data set of MODIS data between 2010 and 2014. With this much larger data set the slope assumption for a(NDVI0.65/2.1) of C6 seems to be a suitable approximation. Better agreement with AERONET data is found when the sensor viewing angle gets larger than 10°, maybe caused by BRDF effects. To prove this, further measurements with different viewing geometries would be necessary.

When introducing the operational C5 and C6 methods we added some further information with respect to the main changes made from C5 to C6:

"Changes from C5 to C6 included corrections related to the Rayleigh/aerosol LUTs and modifications of the assumed aerosol type models that are prescribed for season and location (Levy et al., 2013). "

We changed Fig. 5 and the discussion of the Beijing-comparison as follows:

"Figure 5 presents the scatter plot and regression lines of the relation between AOD derived from MODIS versus measured by AERONET. Recall that when the retrieval expects a dark surface, a larger observed TOA reflectance is interpreted as enhanced aerosol contribution. Both operational algorithms systematically overestimate the AOD as compared to AERONET, which is consistent with urban surfaces being brighter than expected. However the C6 version is less biased. Since the operational C6 equations include a larger slope parameter a(NDVI0.65/2.1) than does C5, the estimated surface reflectance is larger, leading to reduced retrievals of AOD. Using the measured a(0.47/0.65)-spectral slopes in place of either C5 and C6-assumed slopes will further reduce retrieved AOD. Both modified methods show a reduction of mean differences between AOD(AERONET) and AOD(MODIS) as displayed in Table 3. However, while the mean bias is reduced in either version, modifying the measured slopes also leads to retrieval of negative AOD values, as shown in Fig. 5. Modifying the C6 version, which already had reduced bias compared to C5 operational version, tends to lead to even more retrievals of negative AOD. At the same time, the AOD standard deviations have increased (from 0.12 to 0.17) when using the modified C6 algorithm. One of the reasons might be the different sensitivity of TOA reflectance on changes of AOD over bright and dark surfaces. Over dark surfaces (as assumed in the operational retrieval), changes of AOD result in larger changes of TOA reflectance than over bright urban surfaces (as assumed in the modified retrieval). Consequently, measurement uncertainties have a larger effect on the retrieval uncertainty for an urban surface."

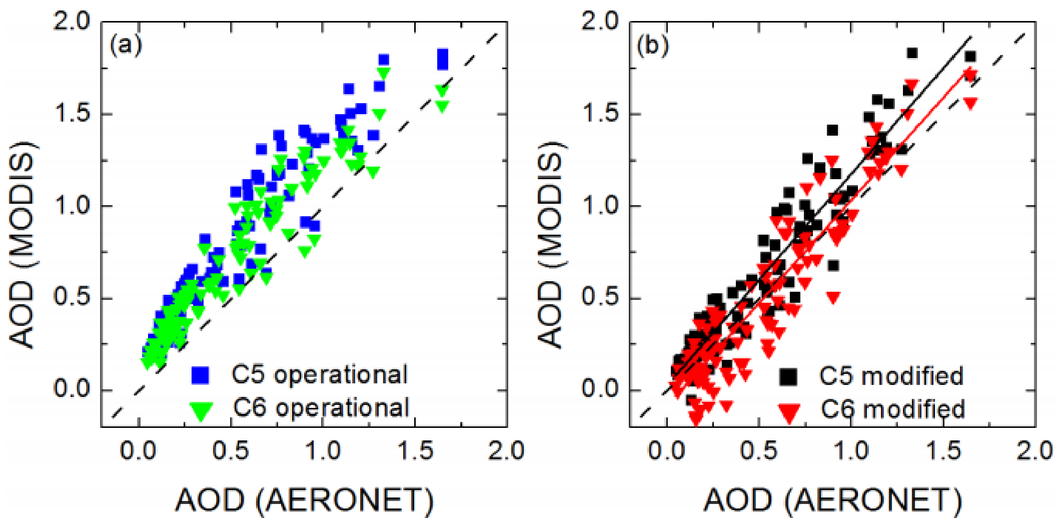

Figure 5. Scatter plot of AOD retrieved from MODIS data using (a) the operational and (b) modified collection 5 and 6 method and the AERONET data for Beijing. The dashed line marks the 1:1 relation.

Fig. 1: New version of Fig. 5 (old manuscript).

In addition we adapted also the Abstract and the Conclusions:

"A significant reduction of the differences between the AOD retrieved by the modified algorithms and AERONET was found, whereby the mean difference decreased from 0.27 ± 0.14 for the operational C5 and 0.19 ± 0.12 for the operational C6 to 0.10 ± 0.15 and 0.02 ± 0.17 by using the modified C5 and C6 retrievals. Since the modified algorithms assume a higher contribution by the surface to the total measured reflectance from MODIS, consequently the overestimation of AOD by the operational methods is reduced."

"While the operational algorithms C5 and C6 have shown a significant positive bias compared to AERONET with a mean difference of 0.27 and 0.19, the modified algorithms revealed a reduced mean difference of 0.10 and -0.02. […] For future studies airborne imaging spectrometer measurements are suggested to characterize the slope parameters for urban areas also for different viewing geometries than the nadir observation. This will improve the corrections of the operational retrievals due to effect of the bidirectional reflectance distribution function (BRDF), since the anisotropy reflection of the surface is better described by the BRDF than assuming a Lambertian surface (Escribano et al., 2014)."

Numbers of the mean differences are now listed in a separate table:

Table 3. Mean value and standard deviation of differences between AOD(MODIS) and AOD(AERONET).

Retrieval Method	Mean Difference ± Standard Deviation
C5 modified	0.10 ± 0.15
C5 operational	0.27 ± 0.14
C6 modified	-0.02 ± 0.17
C6 operational	0.19 ± 0.12

The way the paper is written leaves the question completely open as to how or if this work could be used to improve operational retrievals.

This work shows that knowledge of urban surface reflectance ratios is essential for improved AOD retrievals from satellite measurements. Since satellite retrievals of AOD over urban areas are important there should be made efforts to improve the operational algorithms. This work and other publications, which adapt the surface assumptions by measurements over urban areas, represent a feasible way to improve the retrievals. No complex changes need to be performed on the retrieval code to obtain better results.

Another issue that goes without explanation in the manuscript is the use of the full measured spectrum from the SMART Albedometer to develop slopes for the urban land cover. Given Eq 2 and 3 and that the algorithm is completely dependent on reflectance of the surface/atmosphere system at 2.1 um, it is curious that the authors do not attempt to use information from the instrument in that spectral region. Reflectances are relatively flat near 2.0 um and it seems that some information could be used rather than ignoring the dependence in Eq 2.

Fig. 2a shows the scatterplot of the surface reflectances at 0.65 and 2.0 µm as derived from aircraft measurements. We used some mean value of this poor correlation (R=0.62) for the adapted retrievals but it didn't improve at all. Furthermore, since we have more reliable data of the surface albedo we have plotted the mean spectrum between 2.0 and 2.1 µm calculated for measurements along the flight path over Zhongshan (Fig. 2b). It shows that at least for the surface albedo the surface reflection property at 2.0 µm differs from that at 2.1 µm. Therefore we did not apply a new slope assumption for 2.1 versus 0.65 µm for the adapted retrievals.

We discussed the issue briefly in the manuscript:

"According to Eqs. (2) and (3) the surface reflectance at 0.47 µm wavelength in the MODIS AOD algorithm is derived from that at 0.65 µm based on the surface reflectance at 2.1 µm. The airborne measurements of the surface reflectance are not reliable for wavelengths larger than 2.0 µm, due to the low sensitivity of the albedometer. The relation between reflectances at 2.0 µm and 0.65 µm cannot be used as approximation to modify Eq. (2) because of the strong differences between 2.0 and 2.1 µm, and the finding that reflectances at 2.0 µm and 0.65 µm are poorly correlated (R=0.62).

Therefore, our strategy is to modify only the blue/red fit parameter of Eq. (3) to match the air-borne observations above Zhongshan."

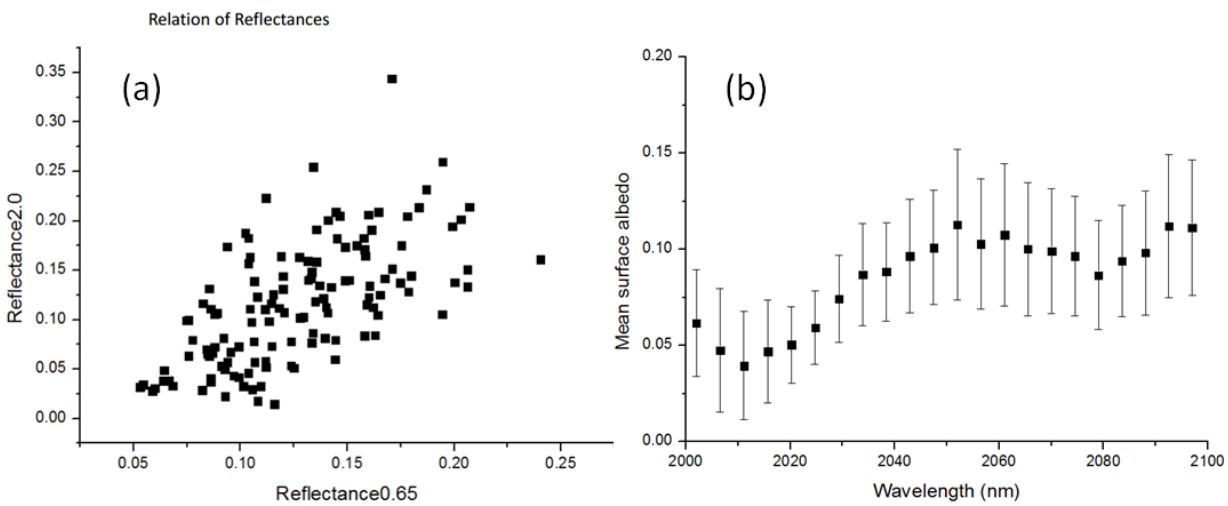

Fig.2: (a) Scatterplot of surface reflectances at 0.65 and 2.9 µm.(b) Wavelength dependence of mean surface albedo.

Specific p7336, l11 – the abstract states that "slightly lower AOD values were derived . . ."; this statement should be quantified and further qualified (explained) – this is the whole point of the paper – some values are given at the end of the abstract but again, the C6 results are ignored – this does not tell the whole story

Since the new manuscript version uses a larger data set, the abstract is adapted to the new results.

"AOD retrieval results of the operational and modified algorithms were compared for a specific case study over Zhongshan, to show minor differences between them all.[…] A significant reduction of the differences between the AOD retrieved by the modified algorithms and AERONET was found, whereby the mean difference decreased from 0.27 ± 0.14 for the operational C5 and 0.19 ± 0.12 for the operational C6 to 0.10 ± 0.15 and 0.02 ± 0.17 by using the modified C5 and C6 retrievals."

p7338, l9-10 – the meaning of the statement about chemical transport models here is unclear – this seems out of context in this paragraph (or even the paper)

The reviewer is right, we removed this sentence.

p7341, l12 – 'due to a coding error'

Changed.

p7347, l25 – 'bias between the two regressions.'

We changed the sentence as follows:

"Clearly, the measured over-urban surface reflectance relationship for Zhongshan is much different than that assumed by the retrieval algorithm, with the slope coefficient being much larger (0.85 versus 0.49).."

p7349, l8 – 'In this case, differences in the derived AOD

Changed.

' p7349, l10 – 'Data were chosen

We removed the word "pixel" to simplify the sentence:

"<u>The MODIS case was chosen to fit the time and area of the airborne measurements as best as possible in order to minimize differences due to season and viewing geometry.</u>"

' p7350, l19 – 'observe a significant improvement
Changed.

' p7353, l22 – remove dash
Changed.

' p7354, l26 – 'indicates less spectral dependence
Changed.

' p7355, l14 – 'alloy'? – not sure of the meaning of this word
We removed the sentence.

p7366, Fig 3 – the error bars for the surface reflectance are almost impossible to see – can color be used to differential and clarify the two sets of error bars? – otherwise the figures are nicely presented
Changed:

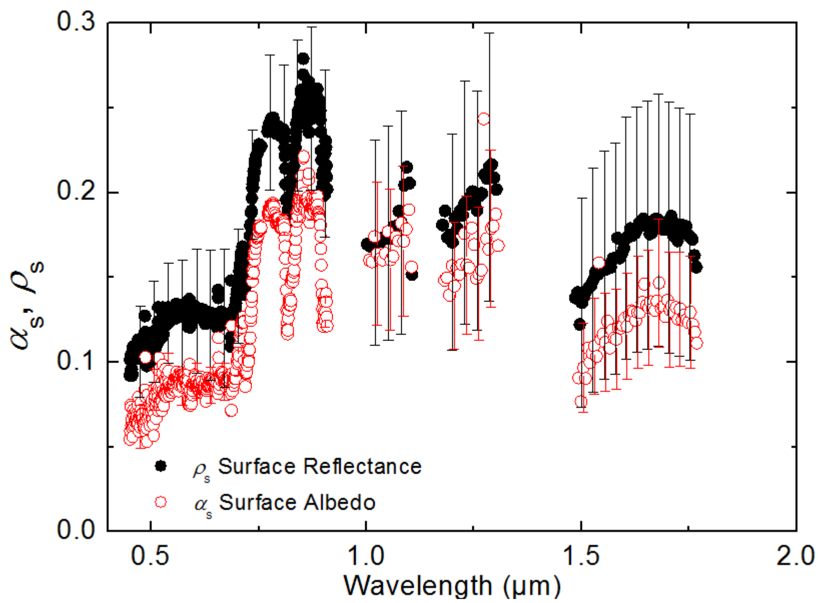

Fig.3: New version of Figure 2 (old manuscript).