**Atmospheric
Measurement
Techniques
Discussions**

Interactive
Comment

Interactive comment on "Aerosol Optical Depth (AOD) retrieval using simultaneous GOES-East and GOES-West reflected radiances over the Western US" *by* H. Zhang et al.

H. Zhang et al.

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We thank reviewer #2 for the helpful comments and have made a lot of revisions on the manuscript following the suggestions.

Following are the response to the comments:

In this manuscript, the authors develop a new aerosol optical depth retrieval algorithm that combines both GOES-East and GOES-West visible band observations. The retrieved AOD is validated over three AERONET sites. The AOD is slightly improved based on the more accurate retrieval of surface BRDF. The

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Discussion Paper

hybrid algorithm increases the number of valid retrieval pixels compared to the single satellite method.

General comments:

1. The description of the strategy of the algorithm needs to be improved. E.g. what information is stored in the LUT in section 3, and how the LUT is used for the AOD re- trieval, only to calculate the Se and Sw?

We made revisions on the description of the algorithm. For LUT, we added:

The LUT stores ρ_D and functions for calculating $F_{iso}, F_{vol}, F_{geo}$ at different geometry and AOD, similar to that used in Lyapustin et al. (2010) but for single aerosol model and single band. The LUT is used in retrieving surface reflectance, AOD and calculating sensitivity quantities in the retrieval algorithm as described in the following section.

Since the surface BRDF are already retrieved in the process why the authors still assume Lambertain surface which will introduce errors although relatively small.

We also tested non-Lambertian surface assumption in the retrieval. The retrieval accuracy does not have much difference than that of the Lambertian surface retrieval. Therefore, the small difference does not affect the results and the conclusions of the paper.

2. Page 7958 line 15, this assumption is not correct. It depends on the back scattering or forward scattering directions and also specific land types.

This part was revised to:

In addition, the surface reflectance sequence is sorted by UTC time. It is assumed that the surface reflectance does not change much from one time step to another observed from a specific satellite. The surface reflectance at a particular time should be within a range determined by the values in the sequence before and after it, and it is removed

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if it falls outside that range.

 3. Explain more about the threshold 0.4 BRDF and 0.04 in line 10 on page 7958 and the 0.03, 30% filter in line 20.

Added description for filter (2) in Sect.4.2:

 The value of the threshold is chosen through observation of surface refelctance variation from day to day. For a given observation time, the surface reflectance variation is usually observed to be about 10% or 20% and mostly below 0.03 or 30%. Therefore, variation larger than the threshold is most likely to be introduced by cloud, cloud shadow or large AOD variation and such data should be removed.

and for filter (3):

 Similar to the previous one, the threshold is also chosen through the observation of the data: as shown in Fig. 2 and later in Fig. 11, the variation of surface reflectance in half hour is usually small and mostly less than 0.02 or 20%.

 4. The hybrid method improves at the Boulder site but gets similar results as single satellite method over the UCSB and Railroad Valley sites? It's important to explore the details because this would guide the advantage of the hybrid method.

A paragraph was added to discuss the possible reason for this:

 To understand the reason that hybrid algorithm is more accurate than the other algorithms at Boulder but not the other two sites, Fig. 11 shows the diurnal variation of the surface reflectance from BRDF retrieval over the three sites. Of the three sites, UCSB has the lowest surface reflectance and Railroad Valley has the highest. The hybrid algorithm can improve retrieval if TOA reflectance from one satellite is more sensitive to aerosol and that from the other is more sensitive to the surface. The difference between the hybrid algorithm and the other algorithms comes mainly from the difference in a value and its effect on AOD retrievals. For UCSB, the surface reflectance is about

0.04 from the satellite with lower surface reflectance geometry. The surface variation from one day to another is usually below 20%. A 20% correction from a value can introduce 0.008 change in surface reflectnace and corresponding AOD correction is of magnitude of 0.05-0.1, which is probably too small to show the effect in the statistics. For Railroad Valley, the surface reflectance between 17:00 to 22:00 is around 0.2 and is so high that the TOA reflectance is not sensitive to AOD enough to have AOD retrievals. For observation time before 16:00, the low scattering angle makes the AOD retrieval less sensitive to the correction of surface reflectance. At Boulder, the low surface reflectance is about 0.1-0.15. A correction of 20% can introduce 0.02-0.03 change in surface reflectance retrieval, which is about 0.1-0.3 change in AOD and is much larger than those of UCSB. This is probably the reason that improvement of using hybrid algorithm is only observed at Boulder but not at the other two sites.

5. Both GOES-East and West observations should be used for the BRDF retrieval in the morning and afternoon. The BRDF retrieval can be improved from more observations from different solar-view geometries.

We do use both observations of GOES-East and GOES-West.

6. The conclusion part is just the summary of the results. I would suggest to discuss some limitations of this method. And how about the performance of this method over the urban area? The equation 2 doesňt consider the non-linear multi-scattering between the surface and atmosphere which limits the application of this method over high surface reference area.

A paragraph was added in the conclusions:

Several factors limit current GOES AOD retrieval. Current GOES only has one visible channel that can be used for aerosol retrieval, and therefore the algorithm does not have the degree of freedom to choose aerosol type. Less spectral channels in current GOES also limit its ability in cloud masking and therefore cloud contamination is expected to be higher than that in MODIS AOD retrievals. No onboard calibration also

limits the accuracy of the measured TOA reflectance and further affects AOD retrieval accurary. The next generation GOES-R series satellites will have spectral channels similar to MODIS for aerosol retrieval and cloud masking (Schmit et al.,2008). It is expected that the limitations with current GOES can be overcome when the new GOES-R series data are available.

If you mean urban area to be high surface reflectance area, the paper shows the results from Railroad Valley and Boulder sites. Railroad Valley has surface reflectance range of 0.1-0.35, and Boulder has surface reflectance range of 0.1-0.18.

As above, the high surface reflectance area does not show degraded accuracy than low surface area, i.e. UCSB. Therefore, the application of equation 2 on high surface reflectance area does not introduce noticable errors.

Specific comments:

Page 7948 line 5, I would suggest to add a figure of diurnal AOD from AERONET data, single satellite, hybrid and combined methods with the scattering angles as the x axis to show the accuracy of different methods.

Fig. 8 (originally Fig.9) was revised to include the diurnal AOD and RMSE of single satellite, hybrid, combined AOD vs. UTC time. We did not use scattering angle here as x axis because GOES-East and GOES-West have different scattering angle and it may confuse the readers if scattering angle is x axis.

Page 7948 line 13, should be "It should be possible, however, to add additional information from the radiances and reflectances from the two satellites, a "hybrid retrieval", by giving additional ..."

Changed.

Page 7948 line 7, explain more about the "large scattering angles".

Changed to "large differences in scattering angles"

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Page 7949 line 24, what does the western "third" mean?

Added " (to the west of 100°W)".

Page 7950 line 1, references are needed to support the statement "It is found...".

This part was removed according to reviewer #1's comments.

Section 2.2, do the authors consider the QA quality flag of MODIS BRDF product?

We did not consider QA quality flag, since it is not shown in MCD43D19, MCD43D20, and MCD43D21 products. On the other hand, because we use seasonal average BRDF, the influence of low quality data, if there are any, should be averaged out.

Page 7952 line 22, list the latitude/longitude of the three sites (UCSB, Railroad Valley and Boulder).

Added.

Page 7956, line 12, It would be good to use the data from the three AERONET sites for the validation instead of the GSFC site.

Changed.

Figures:

Fig 4, "a" should be Italic.

Changed.

Fig 8. The AOD data are mainly less than 0.3. The improvement of correlation coefficient from hybrid method is mostly for the AOD larger than 0.3 over the Boulder site. Discuss more about this. While the hybrid method has the worst slope, so the accuracy of the retrieved AOD would decrease with the increase of AOD.

If we look closely, the difference in hybrid scatter plot and the other algorithms are mainly for AOD retrievals less than 0.3, where the other algorithms have a lot of over-estimates in that range. On the other hand, the differences of AOD in the range above 0.3 between different algorithms are not big. Therefore, the improvement of correlation is mainly due to the improved accuracy of the AOD below 0.3. The slope here does not tell much. As we can see (the new version of the plot Fig. 7), in hybrid algorithm at Boulder, all the AOD retrievals above 0.3 fall in the expected error (EE, $\pm(0.05+0.15\tau)$) range.

Fig 10, add the color bar and should also plot the combined method results.

Added color bar. The combined method results are the same as the single satellite result with lower scattering angle and therefore not plotted. In this case, combined method is the same as GOES-West plot at 16:45 UTC and is the same as GOES-East plot at 22:15 UTC. This is because the scattering angle is lower for GOES-West (GOES-East) at 16:45 UTC (22:15 UTC) for the whole area of interest, as can be seen in Fig. 1(b) in the revised paper.

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