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Atmospheric Chemistry and Physics Discussions

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Interactive Comment

Interactive comment on "A multi-angle aerosol optical depth retrieval algorithm for geostationary satellite data over the United States" *by* H. Zhang et al.

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

In my opinion this paper cannot be published in its current form. The methods are analysis are not very convincing. The whole premise is to improve the AOD product from GOES by improving surface reflectance assumptions of the GASP product using the 2.12 micron BRDF adjustments from MODIS. Seasonal averages are used from MODIS to accomplish this. The MODIS and GOES

have very different spectral response functions and calibration is often poor for GOES. Even though vicarious calibrations coefficients are used, I am not sure that these are applicable for aerosols, especially at low to moderate aerosol loadings in moderate surface reflectance regions. I found numerous issues with the paper that I have highlighted below. To make matters worse, I found the methodology rather convoluted and the paper as a whole needs to be written better. I am sorry that I cannot be more positive at this time.

The abstract of this paper is rather vague and qualitative. At every instance where words and phrases such as - high, more accurate, comparable, good agreement etc - are used, numbers must be provided. Otherwise the abstract cannot be used to glean important information.

In the revised version, we put those numbers in and the relavent part is modified as:

The AOD retrievals from the new algorithm demonstrate good agreement with AERONET retrievals at several sites across the US with correlation coefficients ranges from 0.71 to 0.85 at five out of six sites. At the two western sites Railroad Valley and UCSB, the MAIAC AOD retrievals have correlations of 0.8 and 0.85 with AERONET AOD, and are more accurate than GASP retrievals, which have correlations of 0.7 and 0.74. At the three eastern sites, the correlations with AERONET AOD are from 0.71 to 0.81, comparable to the GASP retrievals. In the western US where surface reflectance is higher than 0.15, the new algorithm also produces larger AOD retrieval coverage than both GASP and MODIS.

Also, the word BRDF for channel one for GOES is misleading in the abstract. What angular information can you get from for a pixel from GOES at a given instance?

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We didn’t mention GOES BRDF is for a given instance. For one day, GOES has about twenty measurements with the Sun at different locations. Therefore, we do get angular information from GOES data, although not for a given instance.

The GASP assumes Lambertian.

GASP assumes Lambertian only for a given instance and for a period of 28 days.

The references for aerosol forcing and air quality/human health are rather old. Much has been done since Charlson and Kiehl.s work. Plus it is not only the TOA that is important.

More references are added on the effects of aerosols:

Aerosols play an important role in the atmosphere by modifying radiative forcing, climate, weather, and air quality. They can affect the Earth’s radiative budget by directly changing the radiation reflected from the Earth and can also indirectly change the radiative forcing by modifying the cloud properties through microphysical process (Charlson et al., 1992; Kiehl et al., 1993; Ramanathan et al. , 2001; Lohmann and Feichter , 2005; Intergovernmental Panel on Climate Change , 2007). Besides radiative forcing, aerosols influence other aspects of climate and weather such as precipitation (Rosenfeld et al., 2008), monsoon (Lau et al. , 2008), lightening (Yuan et al. , 2011), etc. In addition, aerosols also influence the air quality close to the surface and affect the human health (Pope et al., 2002, 2006; Chow et al., 2006; Pope et al., 2009).

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Page 12521, The writing is very sloppy and I am surprised at the lack of specificity in the writing (GASP retrievals) given that one of the coauthors is responsible for the current GASP algorithm. Case in point: AOD at the second darkest day is 0.02? If you are retrieving AOD then why assume this. I know what this sentence implies but it needs to be written carefully so the reader is not confused.

The description of GASP retrieval is modified as: The current operational GASP product uses 28-day composite image from channel 1 (visible channel with spectral range of 0.52-0.72 μm) to find the second darkest day at each observation time and uses it to retrieve surface reflectance. The GASP algorithm assumes that the surface reflectance does not change during the 28-day period for each observation time. To retrieve surface reflectance, AOD at the second darkest day is assumed to be 0.02.

The GOES uncertainty discussion is generic. You need to back that up with numbers. Take a look at either Chu et al.s paper or Zhang et al .s paper in JGR that talks about uncertainties in calibration, surface reflectance and aerosol models . quantitatively!

We included the uncertainty analysis from Zhang et al (2001) here:

"Analysis of uncertainties from aerosol model, surface reflectance, and calibration for GOES can be found in Zhang et al. (2001): the AOD uncertainty from calibration error is about 10% for small AOD (τ=0.5) and 7 % for large AOD (τ=1.5), from aerosol model is 10% for small AOD (τ=0.5) and 32 % for large AOD (τ=1.5). The uncertainty in the surface reflectance retrieval may result in large error in AOD retrievals. As shown in Zhang et al. (2001), 1% error in surface reflectance can introduce 10% AOD error for small AOD (τ=0.5). In reality, we sometimes can observe 20% to 30% change

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in surface reflectance within 28 days, which can lead to much larger uncertainty than those from aerosol model and calibration."

Here we would like defer the discussion of 20%-30% surface reflectance change to other sections, otherwise we would have too long introduction with many distractions.

In 28 days the color of vegetation changes so much that the surface reflectance assumption is not good? Given the calibration uncertainties of GOES and the broadband of the channel, I am not sure that this argument is valid. If you want to say that, then we need proof (not just from one site with no mention of how you achieved that reflectance).

We don't know what the magnitude of calibration uncertainty is in your mind. From Zhang et al (2001), the AOD uncertainty from calibration error is around 10% for small AOD (0.5) and 7% for large AOD (1.5), which is not big at all.

In section 3, we added a paragraph describing the effect of the change of vegetation on surface reflectance:

"In table 2, we show the surface reflectance change caused by the change in vegetation color and cover. MODIS BRDF in the red band and green band are used to calculate the surface reflectance at GOES geometry in the $200 \times 200km^2$ area centered at GSFC for the period between October 7 and November 8, 2008. To focus only the effect of the change in vegetation color and cover, the geometry is fixed at 1800 UTC on October 7, 2008. We can see that the red band surface reflectance increases from 0.072 to 0.092 in the 24-day period from October 7 to October 31, and the green band surface reflectance increases from 0.080 to 0.088 in this period. Since GOES visible channel covers these two bands, we expect the surface reflectance change in GOES visible channel have the similar change in magnitude during October."

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Table 2 can be found at the end of the document.

We think the proof from one site should be fine. If the GASP assumption is not good at one site, it will not be good at other places with similar surface properties. In this sense, one site doesn't mean one pixel in GOES retrieval.

The whole premise is to develop a new surface reflectance algorithm and therefore careful wording is necessary in the Introduction and elsewhere in the manuscript. Remember that you make a major assumption that the polar orbiting 2.12 MODIS reflectance - seasonal average - represents the conditions that GOES would see. You are using that to compare against GOES visible channels, given that the spectral widths and the calibration are all completely different between sensors (GOES and MODIS).

Data. Since small changes in surface reflectance for low to moderate aerosol loadings could cause large errors in retrieved AOD, the authors must not only show a web site reference for GOES calibration but must quantify the uncertainties. How good is this vicarious calibration FOR AEROSOLS?

The uncertainty from calibration for aerosols is discussed in the previous question on uncertainties in general and has been added into the introduction.

GASP provides values at 550 nm but the measurement is between 0.52 and 0.72. What are the uncertainties here?

The uncertainty is the same as the uncertainty of choosing a fixed aerosol model, since once the aerosol model is determined, i.e. size distribution, refractive index

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etc, the relation between 0.55 μm AOD and the GOES channel 1 TOA reflectance is determined. The uncertainty in AOD retrieval caused by using a fixed aerosol model has also been discussed in previous question and added introduction section.

MODIS data. How good is the cloud clearing and aerosol identification in these products? MCD43D19, MCD43D20, and MCD43D21 since this is critical for the development of this paper.

The detail of cloud clearing method in MODIS surface reflectance retrieval is not documented. We expect it to be similar as those used in aerosol retrieval algorithm. Aerosols usually have negligible effect on 2.1 μm band except in the existence of dust, which happens rarely in the US. MODIS surface reflectance has an uncertainty of 0.005+0.05ρ (Vermote and Kotchenova, 2008). Since MODIS surface reflectance is used for deriving BRDF, we can assume that the surface BRDF uncertainty is of similar magnitude.

page 12524 : these types of sentences must be tightened up throughout the paper 'derive the aerosol properties with a 10 km resolution (Levy et al., 2007).' What resolution? Nadir? It is km squared not km.

Changed to "10 km spatial resolution at nadir."

But "10 km^2" is not the convention for spatial resolution in the literature.

Aerosol optical depth retrieval algorithm. The first paragraph makes a dramatic statement about one site - GSFC. What season and what was this highly accurate source for this 28 day change. What data set was used?

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The season is already in the original text: "in the fall".

Following text is added to further describe the data set: The surface reflectance is obtained through atmospheric correction of GOES channel 1 TOA reflectance using AERONET AOD.

Remember that most satellite algorithms use a bi-weekly type of composite anyways and therefore daily changes are hard to measure. Plus GASP uses 28 day composites for each pixel for each hour.

We are able to retrieve surface reflectance if we know both the TOA reflectance and AOD. At AERONET site, we do know both of them.

How much can SZA change for a 28 day period for one pixel that is 1 to 4 km? I am not convinced of the arguments in paragraph 1.

We modified the sentence referring to SZA as: "However, due to the change of the Sun-satellite geometry and the change of ..."

Surface reflectance depends on the relative position of the Sun and the satellite. At some positions, such as those close to the back-scattering geometry, surface reflectance changes are large with small change in the relative position between the Sun and the satellite.

At GSFC, change of SZA has a maximum of about 10 degree in 28 day period for a pixel.

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You cannot assume uniformity in 24 km grids based on Anderson's work alone. That was rather regional. You need to assess your data including air mass wind speeds to find the best spatio-teomporal fit to the data.

The direct proof of this assumption is out of the scope of the paper. For the whole US, we need to look at temporal variability of AOD all the AERONET sites and all the seasons. And then find a reasonable spatial uniformity value from the wind speed. Or, we can look at the variability of MODIS AOD to find the average size of spatial uniformity region for US. Such content would be enough for another paper.

An indirect proof is from MAIAC for MODIS, which uses the same assumption and gets good AOD retrievals (JGR, Lyapustin et al., 2011). If this assumption does not work, MAIAC for MODIS cannot have such good AOD retrievals.

At the risk of sounding overly negative in this review, I do like the image coregistration part of the analysis.

I completely disagree with his approach $>>$ "Since the resolutions of two IR channels are 4 km, we break each pixel into 4$\times$4 pixels with 1 km in size and assign each of the new pixels with the same value as the original one. With such arrangement, CLAVR algorithm can be applied at 1km resolution." $>>$ You are creating a finer spatial resolution data from a coarser spatial resolution data set simply to run an algorithm at 1 km. If we were do this then we can convert all the MODIS 1km pixels to 250 km which is meaningless.

CLAVR involves channel 1, 2, and 4. Channel 1 has spatial resolution of 1 km (nadir). Channel 2 and 4 has spatial resolution of 4 km. In GASP, channel 1 is averaged to 4 km resolution to run CLAVR. In our case, we do the reverse so that the test involving channel 1 can be done at 1 km resolution.

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The following is the test in CLAVR involves channel 1: a pixel is marked as cloud if the reflectance of channel 1 is greater than 0.44. Consider this case: the average of channel 1 is less than 0.44 but there are some 1 km pixels with reflectance greater than 0.44, and all of them pass other tests in CLAVR. If we run CLAVR in 4 km resolution as GASP, we will miss those cloudy pixels. Therefore, there exist 1 km cloud pixels if we run CLAVR at 1 km resolution, while in GASP the size of cloud pixels can only be 4 km.

Breaking of channel 2 and 4 to 1 km pixels is only conceptual. In implementation, we can run tests involving channel 2 and channel 4 at 4 km, and those involving channel 1 at 1 km to save computing resources.

In addition, we also apply the following criterion to determine cloud pixels that fail to be masked in CLAVR algorithm $>>$ How do you know this, by visual inspection? What criteria?

Although MODIS cloud mask product MOD35 uses 21 bands, Martins et al (2002) still found cloud contaminated pixels. For GOES, we only have three bands for cloud mask in CLAVR. We can expect that there must be failed detected cloud pixels from CLAVR, even without any examination. We did visually examine the cloud masks. Also, the AOD close to cloud is usually contaminated and much higher when we compare them with AERONET AOD.

if the standard deviation of a 3x3 box surrounding a pixel in channel 1 TOA reflectance is greater than 0.015, the pixel is also marked as cloudy, which is similar to the MODIS cloud mask algorithm by Martins et al. (2002) $>>$ Is this applicable for your domain? Martins et al applied this OVER OCEAN and your study is over land. Surface textures are completely different.

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Although spatial variability test was first developed for ocean in MODIS, it was later modified and applied on land. Following is quoted from MOD04 update document (http://modis-atmos.gsfc.nasa.gov/C005_Changes/C005_Aerosol_5.2.pdf): "A separate but similar cloud mask for masking clouds over land was developed later and not implemented until November 2002. The spatial variability cloud mask over land improved the aerosol retrievals, especially when it came to confusing heavy aerosol with cloud. However, isolated, residual cloud contamination in the product remained. For Collection 005, we have made a few adjustments to the technique, but maintained the general philosophy and structure of using spatial variability tests coupled with threshold tests only in the 1.38 μm channel. This seems to remove isolated artifacts in the retrieval.."

Therefore, we believe spatial variability test is important and effective in cloud masking for both ocean and land. In our algorithm, we use a different threshold than Martins. The only places that affected by the texture of the land surface are the boundaries with high contract. These boundaries are usually identified as cloud pixels. However, it is good to remove such boundaries since they are most likely to reduce retrieval accuracy due to the residue error in image co-registration.

Page 12527, Line 13- you are calling GOES surface reflectance as GOES BRDF. Why?

In this algorithm, we don't retrieve surface reflectance. We retrieve BRDF, which is represented by three coefficients of Ross-Li model. After BRDF retrieval, surface reflectance at a specific geometry can then be calculated from the Ross-Li model.

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Page 12527, the second paragraph starting with 'after cloud masking', is painfully convoluted and I am not sure that I understand this at all. May be the other reviewers did. What is time sequence? How many time steps? Where from?

The time sequence includes GOES channel 1 data over the same area measured at different times. The number of time steps is determined by the size of the queue. In our implementation, the size of the queue is 20. Given the GOES measurements of every half hour (day time), the queue can hold about 1 day of data. Therefore, we use 1 day of data before the current measurement to retrieve BRDF.

If all you are doing is looking for differences in GOES and MODIS reflectance values for a certain pixel that comes from two different methods, this technique is not at all robust and highly questionable.

The effect of the algorithm depends on how good is the assumption stating that GOES BRDF and MODIS BRDF have the same shape. If the assumption is good, the technique for retrieving the ratio is robust. The idea is to look for the AOD (for each block) and SRC (for each pixel) that minimize the difference between measured TOA radiance and calculated (or theoretical as in the paper) TOA radiance for the whole time sequence, i.e. $\sum_k \sum_{i,j} \{R_{ij}^{Meas,k} - R_{ij}^{Th,k}\}^2$. Assume we have K blocks in the time sequence and N^2 pixels in each block. Similar to the analysis in Lyapustin (2011), the total number of unknown is N^2+K. The total number of measurements is KN^2. As long as $KN^2 >= N^2 + K$, we have more measurements than unknowns and therefore we can solve the problem. In our case, N=24, we can get the problem solved if $K >= 2$.

We have not improved anything for GOES retrievals if we are using MODIS 2.12

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micron values on a seasonal basis!

We can retrieve GOES BRDF using 1 days of data. GASP needs 28 days.

Figure 3 did not help me any. You can probably use actual pixel values to demonstrate your point.

We don't know how to do this. The other reviewer doesn't have any problem in understanding our algorithm.

Section 4.2. The authors do not appear to believe in their cloud mask since they continue to remove data - again - 'we remove the pixels adjacent to cloud, require more than 10 effective pixels in the 25 pixels, and require standard deviation of AOD in the 5×5 box is less than 0.2.' Now notice that for GASP they use the Prados et al filters that are not the same as the filter above?

The cloud mask is certainly not as good as MODIS's, which has several times of bands more to screen the cloud. To have a fair comparison against GASP, we plotted in Figure 10 (original version) the scatter plots in which MAIAC and GASP AOD have one-to-one correspondence. Those data represent the GOES retrievals that passes cloud masks of both MAIAC and GASP and thus should have the least cloud contamination. The differences of those retrievals are mostly originated from the difference in surface reflectance retrievals, especially in the low AOD cases where aerosol model effect is also small.

In summary, I believe that the paper cannot be published in ACP in its current form and requires more thought and analysis. The fundamental question to ask

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is : Given the poor quality of the GOES sensor (the current one) can we really extract any more aerosol information? It has very few channels, lacks onboard calibration, spectral widths are large, etc.

Given the analysis and the retrieval results from this paper, the answer is yes.

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Table 2. Surface reflectance change in red and green bands from MODIS BRDF due to the vegetation change. Surface reflectance statistics (mean $\pm$ standard deviation) is calculated in the area (land surface only) centered at GSFC with $200 \times 200km^2$ using MODIS BRDF in red and green bands. The geometry is fixed in GOES East geometry at 1800 UTC on October 7 of year 2008, in order to remove the effect of the geometry change.

day	October 7	October 15	October 23	October 31	November 8
red	0.072 ± 0.022	0.077 ± 0.022	0.088 ± 0.023	0.092 ± 0.025	0.090 ± 0.025
green	0.080 ± 0.017	0.081 ± 0.016	0.088 ± 0.017	0.088 ± 0.019	0.083 ± 0.021