Atmos. Meas. Tech. Discuss., 6, C2917–C2926, 2013
www.atmos-meas-tech-discuss.net/6/C2917/2013/

Atmospheric Measurement Techniques Discussions

Interactive comment on "Assessing remote polarimetric measurements sensitivities to aerosol emissions using the GEOS-Chem adjoint model" *by* B. S. Meland et al.

B. S. Meland et al.

brian.meland@du.edu

Received and published: 16 October 2013

Response to General comments: We would like to clarify that the main focus of this paper is not to drive instrument designs based on the simulated satellite parameters used therein. Rather, we are assessing the feasibility of coupling observed TOA reflectance data in constraining aerosol emissions. We do this by using a simulated set of observations that would be obtained from two simulated satellites, one capable of only intensity based measurements and one capable of polarimetric measurements. We then determine the sensitivities of these simulated observations to aerosol parameters. It is only after this assessment of the model sensitivities that we plan to incorporate existing

satellite polarimetric measurements for constraining aerosol emissions. We hope that this is clearer after our responses to the comments below and from the changes that have been made to the text.

Specific comments:

1a) Response: We are in agreement with the reviewer that multi-angle measurements provide a significant gain in the amount of information retrieved by remote sensing instruments and are aware that current polarimetric sensors typically employ a sampling scheme that allows for the observation of multiple viewing zenith angles. In the introduction, we have discussed the findings of Kokhanovsky et al. (2010) and Knobelspiesse et al. (2012) who found that multi-angle and multi-spectral observations lead to more accurate retrievals of aerosol properties.

This work is not advocating the adoption of single zenith viewing angle polarimetric observations. As was discussed in the Introduction, we have chosen to use the same viewing geometry for both the radiant and polarimetric simulated observations to instead highlight the differences in the sensitivities due to the intrinsic differences between the radiant and polarized reflectance. We believe that implementing multi-angle observations for the simulated polarimetric sensor would have obscured these innate differences in the reflectances for the comparative analysis we have performed in this work. Furthermore, most of current/planned sensors measure both intensity and polarizations at multi-angles, and often, the angels for measuring intensity are more than the number of angles for measuring polarization. Therefore, by focusing on analyzing the intensity vs. polarization at one angle and one wavelength, this manuscript can provide a foundation for our future studies on the more complicated/real instrument configuration. The strategy here is similar to some early studies of comparative analysis of using intensity and polarization for aerosol retrievals (e.g., Mishchenko and Travis, 1997, focusing on single wavelength at 870 nm).

However, we do agree that the adoption of multiple viewing zenith angles in our simu-

lated polarimetric satellite could highlight differences in the sensitivities that would be more typical of real world instruments. For this reason, in the original manuscript (see Sec. 5), we implemented observations of 12 separate viewing zenith angles in the simulated polarimetric sensor. It was found that this implementation did "increase the fractional change in the polarized reflectance for a given fractional change in the radiant reflectance increased by a factor of $\sim$1.5 on average for different aerosol species".

We have added additional comments in the introduction to point out that we have made efforts to address changes to our calculated sensitivities that could results with the implementation of multiple viewing zenith angles.

Mishchenko, M.I., and L.D. Travis, 1997: Satellite retrieval of aerosol properties over the ocean using polarization as well as intensity of reflected sunlight. J. Geophys. Res., 102, 16989-17013, doi:10.1029/96JD02425.

1b) Response: We have chosen to present the results of the polarimetric and radiant reflectances separately throughout this work in order to highlight differences between their sensitivities to aerosol properties that might otherwise be obscured by implementing a total reflectance which is the sum of the two. In other words, it can be easier to see changes in two quantities when examining the ratio x/y than by the ratio (x+y)/y particularly for quantities which can be vastly different in magnitude.

However, we agree that including an actual comparison of the effects of using polarization and intensity measurements in one simulated satellite observation would be preferable. We have included analysis of how the total reflectance sensitivities to aerosol emissions compare with those of the radiant reflectance at the end of Sec. 4.3. Here we used the sensitivities of the total reflectance to aerosol concentrations as the forcing terms in an adjoint calculation. An additional figure has been added to the manuscript, Figure 11, in order to show the results of this calculation. As expected, we see an increase in the sensitivities of the total reflectance to aerosol emissions, particularly for black carbon.

2a) Response: Radiative transfer calculations in this work were constrained to 650 nm. It was an oversight on our part to omit this information. Comments have been added to the introduction as well as Section 2.2. We have also added comments to the Conclusions sections to reiterate that the results presented in this work are only strictly valid for the 650 nm wavelength channel. We agree that the sensitivities of the TOA reflectances to aerosol properties may change for different wavelength bands, but must reiterate here that we are doing a comparative analysis between the sensitivities of the radiant and the polarized reflectance to aerosol properties. We use the same wavelength and viewing geometry for each set of simulated observations to reduce the number of variables which may obscure differences that are due to changes in the Stokes parameters themselves. It may be interesting to do a similar set of analysis for a few other wavelength bands, but we believe that this is may be outside the scope of the current paper. It is perhaps best to explore the spectral dependence of these model calculations in the context of comparing to a multispectral, multi-viewing angle instrument, such as POLDER, which is planned for future work.

2b) Response: Perhaps we are misunderstanding this comment, but we believe that we have extensively explored the uncertainties in the calculations of these sensitivities in the original manuscript. The entirety of Sec. 4.4 explores the role of uncertainties in the input aerosol microphysical properties on detecting set changes in the aerosol emissions. In that section, we also compare our maximum allowable uncertainties to theoretical values for aerosol retrievals from Mishchenko et al. (2004) as well as from estimates for the uncertainties in the retrievals from the Glory satellite (APS) from the discussion in Mishchenko et al. (2007). These calculations uncertainties were done for both the polarimetric and intensity based calculations and the results were given in Table 3.

2c) Response: The radiative transfer codes used in this work do calculate the full TOA Stokes vector as is stated in the manuscript. It is from these vectors that we derive the reflectances (see Eq. A2-A4) and the sensitivities of those reflectances to aerosol

properties. Since the dependence of the reflectance on aerosol properties comes from the Stokes elements themselves, we often referred to the Stokes parameters when discussing how these sensitivities were calculated. We have replaced the reference to Stokes parameters in a number of sections where it may have caused confusion.

For this work, we are only using the linear polarization as the contribution circular polarized light tends to be negligible in radiative transfer calculations. The radiative transfer code for these calculations, VLIDORT, does calculate the entire Stokes vector, but we do not use the circularly polarized component in our calculations for the reflectances. This was discussed in our definition of R_I and R_P (equations A3 and A4 respectively), but we agree that it could have been made more clear in the manuscript and have thus reiterated this point in Sections 2.2 and 2.3.

3) Response: It is correct that the 646 nm surface reflectance is obtained from the MODIS data. We are only performing radiative transfer calculations at 650 nm as discussed in our reply to comment 2a.

No attempts to retrieve the surface reflectances are made in this work. These reflectances are all constrained by the values obtained from the MODIS data. The radiative transfer model that is used in this work, VLIDORT, set the lower boundary on the radiative transfer calculation using a bidirectional reflectance distribution function, BRDF. The BRDF contains the information on the geometry of the surface (i.e roughness, shadowing, etc.) and is used to link the incident and scattered Stokes vector. For this work, we use the MODIS data to constrain the magnitude of the surface reflectance and BRDF to account for differences in the reflectance for different viewing angles. Additional comments have been added to Sec. 2.2.

4) Response: Text has been added to the abstract to clarify that these simulated observations were strictly over land. Addition text has been added to the end of the introduction reiterating that simulated observations were over land and that aerosol particles were assumed to be spherical in our radiative transfer calculations

5) Response: The implication of the different sampling schemes for the polarimetric (using a narrow swath grid) and the radiant (using a wide swath grid) simulated observations is that even with reduced spatial coverage, the polarimetric observations are more sensitive to changes in aerosol emissions than those of the radiant observations. Even with fewer data points to force the GEOS-Chem adjoint calculations, which determine these sensitivities, the polarimetric reflectances were found to be more than 3 times more sensitive than the radiant reflectances. We have added statement to the Conclusions clarifying that the results presented in this work may be subject to our sampling scheme.

We don't understand the statement "Rather than maps, wouldn't the best way of assessing sensitivity be to do hypothesis tests for the entire dataset?". Is the reviewer suggesting that we use the wide-swath grid for the calculation of both the polarimetric and the radiant reflectance sensitivities? The implementation of separate sampling schemes was an attempt to impose a plausible limitation on the simulated polarimetric sensor.

6) Response: Cloud screening has been performed using the MODIS L2 cloud fractions for the grid cells that lie along the simulated flight paths that were used in these calculations. We had not originally explicitly mentioned this in the text, though we did indicate that quality control tests were applied to each pixel. We agree that this point should be stated and have now added comments to Sec 3 clarifying that we were removing pixels in cases where clouds were present.

7) Response: Figure 1 was mentioned in the beginning of Sec. 2 in the original text. We have added a few additional sentences explaining the content of that figure to make it stand out more.

8) Response: As is discussed in Section 4 of the text, Figure 4 shows our model validation results. The analytic model sensitivities are plotted along the x-axis while the sensitivities from a finite difference calculation are plotted along the y-axis. A perfect

agreement between the analytic and finite difference calculation would therefor appear as a straight line with a slope of 1 on these plots. We have clarified this point in the text in Sec. 4. We have also corrected a typo in Figure 4. The plot in the first column of the middle row should be the normalized sensitivities of the reflectance with respect to the variance, ν, not the standard deviation, σ, of the aerosol size distribution.

We are normalizing the sensitivities in this validation plot to be consistent with the rest of the figures. We discuss our reasoning for the presentation of normalized sensitivities throughout the paper in our response to Comment 9 below.

In response to your question about the "vastly different values", we assume you are referring to the span of the magnitudes of the sensitivities for each of the plots. This figure is showing the normalized sensitivities with respect to the concentrations (top row), the effective variance and radius of the size distribution (middle row), and emissions (bottom row). The functional dependence of the TOA reflectance on each of these quantities is quite different as can be seen in the equations given in the appendix. Contrast equations A11 an A15 for example. It is therefore not surprising that these sensitivities can differ by orders of magnitude.

9) Response: The sensitivities have been normalized because the variables we are taking these derivatives with respect to can differ by orders of magnitude. For example, if you look at Figure 5 in the text, you can see that the concentrations for the different aerosol species range from near 5x10-8 kg/m2 for black carbon on the western coast of Mexico to near 9x10-6 kg/m2 for SO2 in the NE United State. If we did not normalize these values, we would tend to have the highest sensitivities where the absolute changes in the concentrations are highest regardless of the aerosol properties and composition of that aerosol. By using the normalized sensitivities, we can look at relative changes between the aerosol species. The value x/R*dR/dx is just the percent change in the reflectance with respect to some percent change in x. By presenting the sensitivities in the way we have, one could determine how much the reflectance would change by reducing the concentrations by 50% for each aerosol species rela-

tively easily. We have added a paragraph explaining our rationale for using normalized sensitivities to the end of Sec. 4.1.

We disagree with the reviewer's assessment that the sign of these sensitivities are meaningless. We have not made the claim that we are only interested in whether an instrument is or is not sensitive to the presence of a certain aerosol species anywhere in this work. The sensitivity of the reflectance with respect to the concentration of black carbon is negative because of the high imaginary component of the refractive index of black carbon, and hence stronger absorption of light, leading to less light being scattered back to a remote detector.

We also disagree with the reviewer's assertion that these figures "need to be redone, using the absolute value of the sensitivity, and a uniform normalization so that actual differences between sensor types and aerosol species can be assessed". Even after normalization, the magnitudes of these sensitivities for different species can differ by orders of magnitude. In addition, there is a strong spatial component to these sensitivities, which is perhaps most evident in Figure 6a. Our goal for these figures was to present them in a way so that all subplots in each figure would use the same colorbar to avoid any confusion of the magnitudes of the sensitivities for each plot. We have done this by scaling all intensities in each subplot by the scaling factors which have been inset in each plot. If we remove all scaling, it would be exceedingly difficult to see some of the smaller sensitivities, such as those for black carbon. It would also "wash out" a lot of the spatial dependence that we can currently see in the figures. We had explored the idea of presenting these sensitivities on a logarithmic scale, but as the sensitivities can be negative this approach will also not work. We hope the reviewer will understand the choices we made in presenting these results now that we have explained our reasoning.

10) Response: The radiative transfer calculations of the TOA reflectance were only performed for regions in N. America as was discussed in Sections 2.2, 3, and 4.3. We have added an additional comment in the introduction to make this clearer. However,

the reflectances over N. America are dependent on global emissions of aerosols due to intercontinental transport. The GEOS-Chem and GEOS-Chem adjoint calculations were therefore global in scale to capture the impact of remote emissions on regional measurements of the reflectance. The results presented in Figures 8 and 9 are the normalized sensitivities of the reflectance over N. America to emissions everywhere else in the world. In cases where the emissions are low, this quantity will also be very small and will thus show up as white in the colorbar for that figure. We have added some additional comments to the beginning of Section 4.3 to address these concerns.

11) Response: We agree that a different colorbar would help distinguish values of the ratio that are less than 1 from those that are greater than 1. We have made the necessary changes to this figure.

12) Response: In Section 4.4, we calculate the maximum allowable uncertainties in the aerosol microphysical properties that would allow us to detect a 50% in aerosol emissions assuming the simulated observations presented in this work. In this setup, we are using surface reflectances obtained from MODIS (see response to Comment 3) and are only performing radiative transfer calculations at 650 nm (see response to Comment 2a). In order to highlight differences in the sensitivities of the radiant and polarimetric reflectances measured at TOA owing to aerosol optical properties and not instrument measurement characteristics (see response to Comment 1a), we have employed the same viewing geometry for both simulated instruments. In other words, we have treated these values as certain in order to make this problem tractable. While we do agree that there is definite value in determining the sensitivities of the TOA reflectances to all of these parameters utilizing the techniques developed in this paper, we also feel that these things may be outside of the scope of this paper and could be addressed better with a focused study on each.

In order to avoid confusion on the uncertainties that we are calculating in this section, we have added additional comments to Section 4.4

Interactive comment on Atmos. Meas. Tech. Discuss., 6, 5447, 2013.