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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Discrimination of biomass burning smoke and clouds in MAIAC algorithm" *by* A. Lyapustin et al.

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Dear Reviewers,

Thank you for your comments. The paper was modified according to your suggestions. For details, see our response below.

Reviewer 3:

Minor issues 1. I found two important references missing: Martins J. V., D. Tanre, L.A. Remer, Y.J. Kaufman, S. Mattoo, and R. Levy (2002). MODIS cloud screening for remote sensing of aerosol over oceans using spatial variability. Geophys. Res. Lett., 29, 10.1029/2001GL01352. Koren I., L. Oreopoulos, G. Feingold, L. A. Remer, and O. Altaratz (2008). How small is a small cloud? Atmos. Chem. Phys., 8, 3855-3864.

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Reply: The references were added in sec. 2.

2. Equation (5). I believe it's a misprint and the exponent 'b' should go without '-'.

Reply: Thank you! The misprint has been corrected.

3. Figure 2 is a mess and it's hard to get through. I understand that the authors wanted to show more cases with different geometry and different cloud and smoke properties. I suggest limiting the case with only two viewing angles. Also use thick solid lines for thick clouds, thin solid lines for thin clouds and just symbols for different smokes. This will improve the clarity of the Figure. I would also add there a separation line defined by Eq. (6).

Reply: Figure 2 was re-built according to your suggestion, which indeed improves its understanding. The text describing Figure 2 was edited to agree with the change.

4. Page 18658. Interestingly, spectrally neutral imaginary index leads to the decreasing smoke SSA while spectrally varying imaginary index leads to the almost constant SSA. It is worthwhile to mention in the paper. It was not clear for me if Rayleigh molecules were included in the SSA or it's a pure smoke.

Reply: The simulation numbers for SSA represent aerosol single scattering albedo. The word "aerosol" was added in the text to avoid confusion. On the other hand, we did not put an additional emphasis on dependence SSA(imaginary refractive index) as this is a very straightforward result following from Mie calculations.

5. In the legend to Figs. 1 and 3, indicate that 'CM' stands for cloud mask.

Reply: Done.

Reviewer 2:

The authors have developed and demonstrated a simple yet seemingly reliable technique to differentiate small size clouds from smoke plumes in the fine spatial resolution MODIS data. The cloud-smoke discrimination method is based in the detection of the

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enhanced absorption by BC and OC of 412 nm radiance not observed in the presence of water clouds. The paper is generally well written and should be published after consideration is given to the issues below. It is not clear in the text if the so-called 'smoke test' is applied to the 1 km gridded data (four pixels) or to the native 500 m pixels.

Reply: The 500m data are used in MAIAC cloud mask algorithm only. The rest of MAIAC processing, including aerosol retrievals and atmospheric correction, is performed at gridded 1km resolution. In addition, "smoke" test can only be implemented at 1km resolution as MODIS band B8 (0.412mkm) has a native resolution of 1km at nadir.

In the sensitivity study it is implicitly assumed that the pixel or group of pixels analyzed contains either smoke or clouds. It does not include absorbing-aerosol/ cloud mixtures which will still generate an absorption signal. Another situation of frequent occurrence during biomass burning events is the presence of smoke layers above clouds. Since in both instances above, the absorption signal will still be present, the pixels may still pass the smoke test, but the derived optical thickness will probably be over-estimated. The sensitivity analysis should be extended to these situations to provide a more clear idea of the strengths and limitations of the suggested cloud-smoke separation.

Reply: We agree, this is a valid point. If the smoke layer is present above clouds, it may trigger smoke detection resulting in potential over-estimation of the aerosol optical thickness. So far, we have not seen this in MAIAC retrievals. This may be explained by the following factors: 1) Lack of the global statistics of MODIS processing. We may obtain such statistics in 2013-2014 when MAIAC will be run on the MODIS operational processing system (MODAPS). So far, we've done analysis for the continental USA, and plan such an analysis for the South America including the Amazon region; 2) The system of MAIAC checks and balances may preclude that in many instances. For example, the initial MAIAC aerosol retrieval (prior to smoke test) is done with the weakly absorbing (background) aerosol model. If the following smoke test detects absorption, MAIAC repeats aerosol retrieval with the "smoke" aerosol model which is absorbing. An interesting feature of the absorbing media is a saturation of TOA reflectance at

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AOT∼3-8 depending on the level of absorption and view geometry. The reason for saturation is simple: with absorbing aerosols, the energy is absorbed in every instance of light scattering. The increase of AOT leads to the increase of the number of scattering events resulting in higher absorption which balances the higher AOT. Therefore, in contrast to clouds, the achievable TOA reflectance from smoke aerosols is rather limited, and in many cases it cannot reach the higher TOA reflectance generated by the non-absorbing clouds with some attenuation by the smoke layer above. In these cases, which we found to be typical, MAIAC overrides the result of smoke test and masks the pixel as cloudy. As the Reviewer may see, we have done some research in this direction which will be described separately, but the total picture is more complex than it could be presented by a simple expansion of modeling in this work. Besides, accurate retrievals in these cases would require more complex model with simultaneous assessment of both aerosol and cloud parameters. This approach has been developed by O. Torres et al. (in press) based on UV observations. To show limitations of this study, we have added the following statement at the end of sec. 3: " It should be mentioned that presented simulations are limited to the pure smoke vs cloud analysis. For more complex cases with the smoke layer above clouds see Torres et al. (in press)."

In the application examples the paper clearly lacks a validation analysis. A comparison of sun-photometer observations to MAIAC retrievals with and without the smoke-test would provide a clear way to evaluate the reliability of the proposed method of smoke-cloud separation. A simple visual inspection of radiance fields is insufficient.

Reply: Unfortunately, AERONET cannot be considered as a "litmus paper" test in the matter of aerosol-cloud discrimination, especially in conditions of high cloudiness. In the detected clear conditions, an agreement or disagreement between AERONET and retrieved AOT will characterize aerosol retrievals rather than cloud mask.

The authors have tested the technique over areas where smoke is very much the only absorbing aerosol type. It is mentioned in the paper that cloud-dust separation will be addressed separately. Another aspect that needs consideration in the MAIAC algorithm

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(although not necessarily in this manuscript) is the distinction between smoke and dust aerosols since over many regions the world the presence of either type is likely to occur, or, what is even more challenging, dust - smoke mixtures in the same atmospheric column.

Reply: We agree with these two statements. As the Reviewer mentioned, validation of MAIAC aerosol retrievals in the biomass burning regions, as well as aerosol type separation into "smoke" and "dust" will be described separately. The main goal of this paper has been an improvement of MAIAC cloud detection technique which does not filter strong and highly heterogeneous smoke plumes. Apart from the accuracy of aerosol retrievals, this problem has importance in many applications in forestry, air quality etc.

Other comments: In the comments below the green highlighted text indicates recommended additions, and the red highlighted text correspond to recommended deletions.

Abstract Line 6, describing 'a' technique Line 7, from the clouds Page 2 Line 9 ...is a the high 1km resolution of the aerosol product... Page 4 Line 9 the MAIAC CM algorithm Reply: Corrected all above as suggested

Page 5 Elaborate on the basis of equation 2 or provide reference

Reply: The discussion is provided in the paragraph containing Eq. (2).

Line 6, The spectral dependence in the UV is treated in detail by Jethva and Torres (2011), add reference.

Reply: Added

Line 11, The authors are incorrect in their description of the Aerosol Index (AI) principle . In the AI it s not required that the TOA radiance at a single channel be reduced below the Rayleigh limit. The AI is the change in spectral contrast (produced by aerosol absorption) in relation to that of a Rayleigh atmosphere. Only in rare cases of very strong absorption the radiance at a single channel (or both) may be reduced below the

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Rayleigh limit.

Reply: The sentence has been corrected accordingly.

Lines 12 to 15, not sure this statement is true. It implies that scattering alone (no absorption) reduces reflectances below the Rayleigh limit.

Reply: The sentence states that 1) at short wavelengths the number of photon scattering events is relatively high due to high Rayleigh-aerosol optical thickness; 2) when aerosols are absorbing, the energy is absorbed in each instance of scattering on aerosol particle thereby reducing the total reflected radiance.

Page 7 Line 1, The statement that the retrieved AOT 'from the previous MAIAC retrievals' is used, is very confusing. It sort of implies a 'chicken and egg' situation. When does the retrieval process actually start?

Reply: MAIAC starts with (1) cloud detection (CM algorithm) followed by (2) aerosol algorithm making retrievals with the background aerosol model. There are two types of errors from these processes related to smoke: A- CM algorithm masks dense smoke plumes as clouds; and B- MAIAC aerosol algorithm applies spatial variability analysis to filter possible clouds, which also often filters smoke plumes. The goal of the smoke test, applied next (3), is to restore the CLEAR condition for the filtered smoke pixels. For these pixels, as well as for the other clear pixels with the positive smoke test result, the new aerosol retrieval is performed using the biomass-burning aerosol model to yield more accurate AOT assessment (4).

Page 8 Line 1, To understand the capability.... Line 17 Figure 1 2 Reply: Corrected as suggested

Page 9 Line 10, It seems to me that AOD (470nm) threshold of 0.5 would severely limit the usefulness of the approach. Most sub-pixel cloud contamination shows in the range 0-0.3 AOD. A full evaluation of the effect of this threshold value could be done involving a validation analysis using ground-based AOT measurements (see previous

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comment on validation).

Reply: This test is designed to detect absorbing aerosol with optical depth $\sim$0.5 and above (in fact, the test is applied everywhere but at low AOT its results are dominated by the errors of surface reflectance). In practice, we are not finding this threshold to be limiting (definitely not severely). The sub-pixels clouds are detected by MAIAC cloud mask and aerosol spatial variability analysis.

Page 13 Line 14, I should be noted that the... Reply: Corrected as suggested

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Interactive comment on Atmos. Chem. Phys. Discuss., 12, 18651, 2012.