**Atmospheric
Chemistry
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Discussions**

Interactive
Comment

Interactive comment on "Interpretation of FRESCO cloud retrievals in case of absorbing aerosol events" *by* P. Wang et al.

P. Wang et al.

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We would like to thank referee #1 for the comments and suggestions. The manuscript has been revised and improved according to these comments and suggestions. We have used Mie phase functions for aerosols and clouds in the simulations of the O2 A band spectra and the reflectances at UV wavelengths. The wavelength dependence of the aerosol optical thickness is taken into account using the extinction efficiency calculated in the Mie phase function.

Anonymous Referee #1 Interactive comment on "Interpretation of FRESCO cloud retrievals in case of absorbing aerosol events" by P. Wang et al. Received and published: 24 January 2012

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Summary The manuscript attempts to interpret the meaning of retrieved cloud fraction and cloud top pressure by the FRESCO algorithm in the presence of thick layers of smoke, desert dust and volcanic ash layers. Two scenarios are addressed: aerosol layers are present in an otherwise water-cloud free atmospheric column, and aerosol layers are located above a cloud deck. The authors carried out a sensitivity analysis for these two scenarios using radiative transfer calculations, and then attempt the interpretation of FRESCO observations for specific situations when aerosol layer were detected by GOME-2 observations. Results of the sensitivity analysis indicate that the interpretation of the FRESCO retrievals in the presence of aerosols is only possible for aerosol layers of unusually high values of optical depth (3.65) and single scattering albedo 0.8 or lower which seem very unrealistic . If these conclusions are correct then the applicability of the FRESCO algorithm to report aerosol layer height is limited to very extreme and rare events of very high AOD and very low SSA, which would render the FRESCO method of aerosol layer height determination totally useless.

Main comment A major flaw if the presented analysis is the use of the Henyey-Greenstain (HG) approximation to represent the scattering properties of aerosols and clouds. As discussed by Hansen et al (1969), the HG phase function is inadequate for the interpretation of satellite observations that require an accurate description of the angular dependence of the scattering effects of aerosols and clouds . The HG function does not reproduce the well known angular features associated with particle scattering such as the bow effect of cloud droplets or the particle size and refractive index dependent glory feature of aerosol particles. The use of the HG analytical expression in sensitivity studies makes it very difficult to study the sensitivity to change in aerosol microphysical and optical properties. I therefore, recommend that the current sensitivity analysis be repeated using actual Mie calculations to represent clouds and aerosols. Another serious weakness of the sensitivity analysis is the

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neglect of the spectral dependence of aerosol absorption.

We agree with referee #1 that the aerosol optical thickness was too high and the single scattering was too low in the previous simulations. In the revised manuscript, we are using Mie phase functions for aerosols and clouds and perform new simulations of O2 A band spectra and UV reflectances. Aerosol optical thickness values of 0, 0.1, 0.2, 0.5, 1, 1.5, 2, 2.5, 3, 4 are used in the revised manuscript. The wavelength dependence of aerosol optical thickness is taken into account using the extinction efficiency calculated from the Mie calculations. Two aerosol models, dust and biomass burning aerosols, are used in the simulations. The aerosol and cloud particle size distribution and optical properties are summarized in two tables in section 3. Section 3 is completely re-written.

Other comments
Pg 32688 lines 15-16. Only over the oceans.

A: Pg 32687 line 15-16. In the simulations, we used a surface albedo of 0.05, which is more like a scene over ocean. For the GOME-2 FRESCO data, we have examples over ocean and over land.

Pg 32688 line 26. The AAI is also sensitive to aerosol particle size [Torres et al, 1998; Herman et al, 1997]

A: This question is about Pg 32687 line 26. We have included this remark in our paper.

Pg 32688 line 27. Knowledge of aerosol layer height is not enough to derive aerosol

optical depth (AOD) from the AAI. Information on single scattering albedo is also required. Both AOD and SSA can be simultaneously derived (if aerosol height is known) using observations of AAI and reflectance at a near UV channel.

A: Thank you for your suggestions. The sentence is revised.

Pg 32689 line 22. Please provide a reference on the cloud model used for the calculations representative of the cloudy scene, i.e, cloud droplet size distribution parameters and wavelength dependent refractive index.

A: The cloud droplet size distribution is a two-parameter Gamma distribution. The effective radius is 6 micron. The wavelength dependent refractive index is 1.36 at 340 nm and 1.33 at 760 nm. We added two tables in section 3 with all the aerosol and cloud parameters used in the simulations.

Pg 32690 line 13. It seems to me that the effective cloud fraction should also be wavelength dependent. Please explain/elaborate.

A: A short explanation is included in the sect. 2.1 after the equations.

Pg 32692 line 1. Be quantitative, how small is the MODIS-GOME2 overpass time difference at high latitudes.

A: The orbit could be overlapped. We have revised the sentence.

Pg 32692 line 2. This assumption is hard to justify for time differences larger than

about 15 minutes. Although for simple qualitative verification is probably OK.

A: We agree with referee #1. The MODIS images are used for simple qualitative verification only.

Pg 32692 line 22. Aerosol products characterized by means of cloud parameters? Explain.

A: The sentence is rewritten. We want to say that for a clear-sky scene having absorbing aerosols FRESCO retrieves aerosol height.

Pg. 32693 line 5. What is the assumed aerosol type associated with SSA values of 0.6 and 0.8? Are these SSA values regarded as typical? At what wavelengths? Provide references. The spectral dependence of absorption significantly affects the magnitude of the Aerosol Index [Jethva and Torres, 2012]. A table describing the aerosol (type, particle size distribution and wavelength dependent optical properties) and cloud models used in the sensitivity analysis should be included.

A: Thank you for the reference. The SSA of 0.6 and 0.8 was assumed for biomass burning aerosols in visible wavelength. These values are too large. In the revised paper, we added a table according to your suggestions, see section 3.

Pg. 32693. The Henyey-Greenstein scattering phase function is a very crude representation of clouds and aerosols (see main comment above). With the currently available high speed computing capabilities the H-G function is no substitute for accurate particle scattering calculations (Mie, T-matrix or Geometric Optics). See

Hansen et al (1969) for an analysis of the H-G function approximation in relation to accurate calculations.

A: Thank you for the comments. The new simulations have been performed using Mie scattering phase functions for clouds and aerosols.

Pg. 32694 line 11. What it is the 'reasonable' value?

This sentence is rewritten. It is difficult to tell a reasonable value for scene albedo. Usually FRESCO should retrieve a scene albedo value between 0 and 1.

Pg. 32695 line 26. As presented, the summary of the sensitivity analysis indicate that the interpretation of the FRESCO retrievals in the presence of aerosols is only possible for aerosol layers of unusually high values of optical depth (3.65) and single scattering albedo 0.8 or lower which seem very unrealistic as typically observed values. If these conclusions are correct then the applicability of the FRESCO algorithm to report aerosol layer height is limited to very extreme events of very high AOD and very low SSA, which would render the FRESCO method of aerosol layer height determination totally useless. I strongly suspect this finding is the result of improper modeling of the aerosol effect in which the spectral dependence of aerosol absorption seem to have been ignored.

A: In new simulations, the single scattering albedo is 0.86 for the biomass burning aerosols and is 0.92. for the dust aerosols at 760 nm. It appears that FRESCO can retrieve aerosol height over clouds if the aerosol optical thickness is larger than 3 at the O2 A band. Using the FRESCO algorithm for absorbing aerosol layer height retrieval is only possible for extreme aerosol plumes in cloudy scenes or for medium

aerosol plumes in cloud-free scenes.

Pg. 32696 line 5. An effort should be made to compare FRESCO inferred aerosol heights to CALIPSO observations.

A: We have checked the CALIPSO data, but no overlapping data were found. Therefore we cannot perform a quantitative validation of FRESCO retrieved cloud height to CALIPSO observations.

Pg. 32698, line 19. The assumption that the two plumes located a similar altitude would have similar AAI values if their optical thicknesses are similar is wrong. Differences in viewing geometry, single scattering albedo and cloud presence (either below the aerosol layer or at the same level) will also affect the magnitude of the aerosol index.

A: Thank you for pointing this out. We have rewritten these sentences.

Pg. 32702 line 21. Document the source of the SSA measurements (ground-based? satellite?) in Witte et al (2011).

A: It is OMI SSA product, so satellite measurements. Manuscript changed accordingly.

Pg 32704, line 18. Aerosol events yielding AAI values of 8 are probably among the most absorbing cases detectable. The statement that no strong absorbing aerosol cases were detected again points to the flaw of the sensitivity analysis. According to the sensitivity analysis unrealistically high (low) values of AOD (SSA) are required for a successful determination of the aerosol height by the FRESCO algorithm.

A: We agree. The FRESCO algorithm is only suitable for determinations of aerosol height for extreme absorbing aerosol cases, because then the aerosol layer blocks most of the signal from the clouds below it. For clear-sky scenes, the aerosol height can be determined for smaller AAI values. The FRESCO algorithm is mainly designed for cloud retrievals. The manuscript was corrected accordingly.

Interactive comment on Atmos. Chem. Phys. Discuss., 11, 32685, 2011.