Editor

We are grateful to the Editor and to the referee for the attention and for the comments. It is our belief that this manuscript has the potential to open discussion, within the scientific community, on the use of hyperspectral visible and near infrared data for improvement of aerosol retrievals.

With new satellite mission being prepared, this kind of data will be soon available to users. The authors feel that this discussion, aimed to address the limits and benefits of the new observation systems, is much needed at this time to get the scientific community prepared to a proper exploitation of the hyperspectral data.

In the attached document the authors have replied to referees comments, which have been used to improve the manuscript on both scientific content and formal presentation.

Anonymous Referee #4

Atmos. Meas. Tech. Discuss., 4, C2900–C2904, 2012
Received and published: 18 March 2012

We would like to thank the Anonymous Referee #4 for the extensive and constructive comments to improve our manuscript.

*** General comments**

This paper is looking at spectral radiance as a function of aerosol and surface reflectance, which were simulated in preparation for a potential spaceborne hyperspectral remote sensing instrument. It shows results from a forward radiative transfer model (6S) for varying aerosol optical depths (AOD), two aerosol models and two surface types. It compares those results to the expected spectral signal to noise ratio (SNR) of this instrument to find the corresponding minimal 'measurable' difference in AOD (retrieval fidelity).

***Reply**. Statement from the Referee has clearly and correctly identified the aim of the paper. The authors focused on the potential improvement of the aerosol optical thickness retrieval accuracy which will be brought by the use of hyperspectral data in the visible spectral domain. In particular referring to PRISMA-like sensors, idealized conditions were chosen to determine the results of the study.*

The paper touches two important questions on how to improve state of the art in aerosol retrieval by adding more spectral bands by using a hyperspectral instrument, and on how to remove the aerosol effect from such data to retrieve other parameters. Unfortunately, it does not provide new aspects to solve those relevant problems. It would be favorable if the paper would provide more insights to the independent information content of hyperspectral data for aerosol retrieval problems. How far can hyperspectral data compensate for missing multiple viewing geometries and polarization measurements.

***Reply**. The aim of this study is to demonstrate the potential impact of hyperspectral data on the accuracy of aerosol optical thickness retrievals. The goal was pursued by addressing the sensitivity of these observations to the natural variability of the aerosols properties (optical thickness, aerosol type, etc), and of the conditions in which the retrieval has to be performed (background surface properties). The sensitivity was referenced to*

the instrument signal to noise ratio (SNR).

The theoretical work presented in this paper has shown that the two factors could be beneficial to the accuracy of aerosol retrieval, in particular condition defined in the last Table of the paper by using the large number of channels in the visible domain provided by an hyperspectral sensor. The independent information content of hyperspectral data was the basis of the presented analysis in the sense that the authors investigated and identified spectral regions and field of view surrounding target conditions better suited to achieve a aerosol optical thickness retrieval accuracy of 0.02.

The last consideration of the referee is on the compensation of the hyperspectral data for missing viewing geometries and polarization measurements. This would certainly be an interesting comparison between the available remote sensing data and the future ones, but this kind of analysis is beyond the scope of this work.

The paper should be also improved by being shorter and less repetitive. In the present form, the paper contains a bit of everything. A clear focus on either sensor performance and information content or on the forward model or on the retrieval method (inversion) or on the sensitivity of various parameters on the TOA reflectance. Except from the inversion, the current paper touches all this topics. I would therefore suggest to remove common knowledge, repetitions and elaborate more on a comprehensive, realistic error (fixed, bias and random errors) or sensitivity analysis including more than just the SNR. The SNR is a measure for the theoretical instrument fidelity and is only one component of the total error. It is therefore more of engineering than of scientific interest.

***Reply**. Following the referee's suggestion, some sections were rewritten in more synthetic form avoiding repetitions, and the principal goal of this work was further clarified.*

As previously mentioned, the authors have clarified the role of SNR to avoid misunderstanding. According to the concept developed in this study, the variability in observed radiances introduced by environmental factors (such as the adjacent effect) and the uncertainties introduced to sensor characteristics (SNR) are keys to understanding limits and benefits of using hyperspectral data for improvement of the aerosol optical thickness retrieval accuracy. For example, given a specific SNR, if a dark surface is used to for aerosol optical thickness retrieval, the accuracy could be limited by the adjacent effect of a dark surrounding in urban regime, and by taking it into explicit account would allow for a more accurate and trustworthy inversion.

Thus, the authors believe that the observed radiance to be inverted, is therefore a combination of the upwelling radiance coming from viewed-target, along with the contribution induced by the adjacent effect and the SNR of the sensor.

With that said, I encourage the authors to perform major revisions in order to increase the scientific relevance of this manuscript. I hope the following comments provide some guideline.

***Reply**: The authors have critically reviewed the paper in the light of these comments, improving the manuscript as kindly suggested by the referee.*

*** Specific comments**

p. 7212 l. 17-21: 'improvement of the retrieval for (...) aerosol' is too vague. Provide information on what exactly can be improved by using hyperspectral data. Presumably the authors refer to the retrieval of AOD. This applies to the rest of the manuscript as well. Further, the authors should distinguish between a physical based forward (radiative transfer) model and an inversion technique, which searches for the best fit between the model and obs.

***Reply**. p. 7212 l. 17-21 were changed and the reference to the retrieval of AOD was clarified throughout the paper.*

p. 7215 l. 4-16: These two paragraphs should be given in the introduction. Lines 8-9 can be removed. Please mention in this part of the introduction why water and sand targets were chosen. The term 'Costal regions' is be too general because the reader expects not only clear water and pure sandy surfaces in a costal region.

***Reply**. The two paragraphs were moved in the introduction, the lines 8-9 are removed, and the explanation about the choice of water and sand for their reflectivity properties of darkness and brightness has been explained in the first paragraph. Besides, the term 'coastal regions' has been removed.*

p. 7217 l. 9-10: Relax the statement which sounds like aerosols would dominate extinction. This is often not true due to Rayleigh scattering at shorter wavelengths and also not true in absorption bands. It should be always clear to the reader if the authors refer to the aerosol, molecular (Rayleigh) or total optical depth. Thus, add 'aerosol' in front of optical depth and add a sub- or superscript to tau.

***Reply**. The statement has been relaxed. The 'aerosol' term and a superscript to tau have been added throughout the paper.*

p. 7217 l. 18: Use newer literature on the actual AOD retrieval accuracy of MODIS (e.g. Levy et al.(2010)), which is generally lower (less accurate) than the given pre-flight requirements. Btw., the values are not correctly reported and it should be mentioned if they apply to the ocean or land product.

***Reply**. The new literature suggested by the referee has been added to the manuscript.*

p. 7218 l. 1-5: Rephrase, because an aerosol model itself describes only the optical and microphysical properties, which themselves can influence the solar radiation field scaled by their abundance.

***Reply**. This part of manuscript has been checked and improved.*

p. 7218 l. 6-8: Check the list of given references to the used aerosol models, which were entirely defined by d'Almeida et al.(1991).

***Reply**: The authors have checked the list removing the other references.*

p. 7219 Sect. 2.4 l. 1-12: A sensor description should not be placed in the Methods section.

***Reply**. The authors have removed the sensor description from Methods section and placed in the introduction of Specific results for PRISMA-like section.*

p. 7219 l. 8: How should the adjacency effect be beneficiary to the AOD retrieval? It adds a new dimension to the complexity of the radiative transfer model and the inversion.

***Reply**. The authors are conscious of the increasing of complexity due the adjacent effect. Contextually, the results highlighted that explicit consideration of the adjacent effect appears of undoubted help in improving the accuracy of the retrieval aerosol optical thickness in specific condition dictated by the surface reflectivity properties (dark and bright) and aerosol regime (urban and continental). Thus, we prefer to maintain the 'benefits' term.*

p. 7219 Sect. 2.4 l. 13-18: See General Comments on SNR, error analysis and information content.

***Reply**. The authors have explained in 'General Comment' about the role of the SNR on this study.*

p. 7219 l. 22-26: The chosen case of maximal solar irradiance intensity leads to a lager SNR and therefore better results when comparing L to deltaL (SNR). An average or even low irradiance case would be more adequate to really test the required performance for the AOD retrieval. Now, the presented results are only representative to the one singular

observational case.

***Reply**. The authors are very grateful to the referee for this comment. The analysis has been tested in a case with solar zenith angle equal to 66.26° (high) showing the accuracy limits on the aerosol loading retrieval when the solar irradiance intensity is low.*

p. 7220 l. 1: What is the 'view factor'? Please explain your definition or use a more common term to avoid misinterpretation.

***Reply**. The authors have removed the 'view factor' and explained the at-nadir view angle like the viewing configuration for the symmetry in azimuth of the environment contribution, reporting the reference to the Fig. 5 of Vermote et al. (1997).*

p. 7220 l. 7-21: Refer to literature supporting your findings on the impact of aerosol loading on the observed radiance (e.g. Seidel and Popp(2011)).

***Reply**. The authors have added the suggested reference.*

p. 7220 l. 4 and Fig. 2-4 on p. 7235-2737: A deltaAOD of 1.0 is (too) high. I suggest to use 0.1 and provide the results in a difference plot with L-L(AOD=0) since the authors make their point on the relative changes and not on the absolute values of L. y=0 value would be given by the L(AOD=0) results. Maybe even (L-L(AOD=0))/L would be an appropriate y-axis.

***Reply**. Following the referee comment, the authors have calculated the observed radiance with deltaAOD=0.1. The figures are given by (L-L(AOD=0))/L, like required.*

p. 7221-7225 Subsect. 3.2 and Sect. 4: Although, Fig. 3-7 contain interesting results on adjacency effects on radiance, the corresponding sections remain purely descriptive. I strongly suggest to use this opportunity and add scientific value to those sections and to add explanations of the radiative processes and the consequences to AOD retrievals. E.g. mention that the AOD retrieval in the presence of strong absorbing aerosols (urban) over dark targets is very challenging due to the missing sensitivity (see Fig. 4 lower left panel).

***Reply**. The authors have appreciated that the referee finds interesting the results on adjacent effect. An effort has been made to add scientific value to the mentioned section. The impact of the adjacent effect on the observed radiance could be an important factor for accurate aerosol retrieval by using hyperspectral data.*

p. 7222 l. 8-12: This paragraph is a repetition of the two preceding paragraphs.

***Reply**. The paragraph has been removed.*

p. 7238 Fig. 5: Please indicate the SNR requirements of the sensor (ie. 200) with another

contour plot to visualize where AOD retrievals will not be possible with the requested fidelity due to the low AOD sensitivity to radiance. Why does the provided contours show a wiggelig structure. I assume that this is related to numerical accuracy and interpolations. Please remove them non physical features or at lest describe their origin.

***Reply**. The authors have tried to change the plots. The results are not as well as to introduce a contour plot to the figures for SNR = 200. Thus, the authors have chosen to maintain the figures of the previous version like the better plots obtained.*

The problem of the structures of the figures are originated to the interpolation made during the surface construction. The authors have described their origin in the paper.

*** Technical corrections**

p. 7212 l. 6: remove 'the' at the end of the line

***Reply**: Done.*

p. 7212 l. 17-21: improve language

***Reply**: Done.*

p. 7212 l. 25: latest IPCC report is sufficient

***Reply**: Done.*

p. 7216 l. 3-4: improve language

***Reply**: Done.*

p. 7216 l. 21: remove 'mainly'

***Reply**: Done.*

p. 7217 Eq. 2: change one of the two arrows indicating the direction of the calculated transmittance from upwards to downwards

***Reply**: Done.*

Thanks for this comment. The authors have checked and corrected the equation. The two arrows have to indicate the same (downward that is Sun-Target) and not different versus, like reported in Vermote et al., 1997. Besides, the upwards total transmittance is separated in the two components, direct and diffuse, to define the two environment contribution on the observed radiance.

p. 7220 l. 2: Remove 'radiative'.

***Reply**: Done.*

The 'radiative' term has been removed from the titles and subtitles of the manuscript.

p. 7222 l. 20-23: improve language

Reply: Done.

*** References**

[Levy et al.(2010)] R. C. Levy, L. A. Remer, R. G. Kleidman, S. Mattoo, C. Ichoku, R. Kahn, and T. F. Eck. Global evaluation of the collection 5 MODIS dark-target aerosol products over land. Atmos. Chem. Phys., 10(21):10399–10420, 2010.

Reply: Added.

[d'Almeida et al.(1991)] G. d'Almeida, P. Koepke, and E.P. Shettle. Atmospheric Aerosols: Global Climatology and Radiative Characteristics. Deepak, Hampton, Virginia, USA, 1991. 561 pp.

Reply: Present in the paper.

[Seidel and Popp(2011)] F. C. Seidel and C. Popp. Critical surface albedo and its implications to aerosol remote sensing. Atmospheric Measurement Techniques Discussions, 4(6):7725–7750, 2011. doi: 10.5194/amtd-4-7725-2011.

Reply: Added.

Anonymous Referee #5
Atmos. Meas. Tech. Discuss., 4, C2938–C2941, 2012
Received and published: 23 March 2012

***General comments**

The aim of this paper is to study the variability of the combined atmospheric aerosol and surface reflectance contributions to the top of atmosphere (TOA) hyperspectral radiance in the spectral range (400 – 2500) nm, making use of simulated observations performed by the 6SV1 Radiative Transfer Model (RTM).

Two very different 6S aerosol models (urban/continental), in particular in terms of spectral single scattering albedo (SSA), and two very different 6S spectral surface reflectance (sand/clear water) within the instantaneous FOV (viewed target) and as assigned to surrounding pixels (adjacent targets) are considered.

The main interesting feature of the paper is to perform a sensitivity analysis of TOA simulated PRISMA (Hyperspectral Precursor of the Application Mission) radiance to the aerosol optical thickness (AOT) variability at 500 nm in the range (0 - 2), considering the effect of the lambertian surface reflectances of surrounding pixel (adjacency effect). Result on the relative variability of simulated TOA radiance are compared to the nominal SNR of the PRISMA instrument with the aim to better address in the next future the use of the PRISMA observations for the satellite aerosol retrieval.

***Reply**. The referee has properly identified the goal and the methodology presented in the paper. In particular, the aim of the paper is, in fact, to highlight the potential of the hyperspectral data in improving the accuracy of aerosol optical thickness retrieval. In particular, the accuracy of the AOT achievable with ground observing systems has been used as reference for desired accuracy that satellite derived retrievals should meet.*

As referee, I suggest to take into account the following remarks before to publish the paper in AMT.

***Reply**. Thanks for helping us to the improvement of the paper.*

***Specific Comments**

- Selected study area

The authors take into account the importance to refer the simulations to realistic situation,

but they select the typical location for their study as ‘coastal areas’ (see, for instance, abstract, Chapters 2,4,5) with an instantaneous FOV over Rome (see Chapter 3). In this context, the choice of urban and continental aerosol for a coastal area cannot be properly done without considering at least a background of maritime aerosol (for both models the oceanic/sea-salt component is null, as indicated in Table 1). On the other hand the author have to better discuss the concept of surrounding pixel if the selected location is a viewed pixel of (30x30) m2 over Rome and the related surface reflectance is ‘sand’ and the related surrounding pixels are typically ‘clear water’ (without chlorophyll). A proper selection and discussion of the area (viewed and adjacent targets) are necessary.

Reply*. The 'coastal areas' has been removed from the text to avoid misunderstanding. The authors were interested in studying the radiative effects of the urban and continental aerosol models on the observed radiance. In order to perform the analysis in function of the reflectivity properties of the surface, a dark and a bright surface used in 6SV1.1 were chosen, i.e. water and sand. Thus, it was possible to show the spectral behavior of radiative impact on the maximum and minimum reflectance of a surface.*

It was also added, as explanation about the choice, that the water and sand background were considered representative of a darkness and brightness surface reflectivity properties, respectively.

- Aerosol Models

The path radiance due to the aerosol can be considered proportional to the product of the three aerosol parameters: phase function, SSA and AOT. So, it can be useful to add, for instance in the Fig. 1, the plot of SSA as function of wavelength for the 2 aerosol model employed. For each observed geometry also the spectral trend of the phase function is important. The employed models are hygroscopic aerosols. What is the value of the Relative Humidity? This is necessary to reconstruct the related aerosol optical properties.

Reply*. The authors found this comment very relevant. They are conscious that the two employed models are hygroscopic aerosols and for this reason, the simulations have been performed in dry condition.*

Following the suggestion of the referee, the plot of the SSA as function of wavelength has been added to the paper and the dry condition for the simulation has been added on the text.

- PRISMA acronym

The better english translation would be “Hyperspectral Precursor of the Application Mission” (see for instance http://www.asi.it/en/flash_en/observing/prisma).

***Reply**. The acronym translation has been changed.*

- 6SV1 RTM

This RTM is extensively employed. It is necessary to justify this choice for the selected application and provide information on the exact version employed (6SV1.1 or V1.2).

***Reply**. Following this comment, the authors have added the version of the code.*

- PRISMA instrument

Also the choice to simulate and provide results only for PRISMA-like data up to 1000 nm must to be better justified. It depends also on the spectral trend of the selected aerosol class and surface reflectances?

***Reply**. The authors have clarified the point in the text. The referee has a good point, as the analysis was performed where the aerosol class and the surface reflectance have a weight on the observed radiance.*

About this point the authors consider this domain as those for which the aerosol effects are relevant. The opinion of the referee is that also selected PRISMA wavelengths greater than 1000 nm will be employed for the aerosol retrieval (or atmospheric correction). See for instance the difference within the range (1000 - 1500) nm of the spectra of top plates of Fig. 2 as function of the AOD variation.

***Reply**. The authors are conscious of the future application of PRISMA data (aerosol retrieval and atmospheric correction). In the cited figure, the observed radiance has a different behavior for the spectral domain below 1000nm whereas for wavelength greater than 1000nm the spectral behavior is independent from the aerosol type and surrounded targets. It is worth emphasizing that the spectral domain beyond 1000nm is outside of the aims of this work.*

It is necessary remember what is the slit function employed in this case: Is it a simply box function with a specific FWHM? Is this choice done because specific instrumental data are not yet accessible?

***Reply**. The authors have convolved the hyperspectral radiative quantities simulated by 6SV1.1 on Gaussian response function with the central wavelength and the FWHM available for each channel. The authors have added 'Gaussian' to 'response function'.*

- Observation geometry

It is not clear the choice of the at-nadir-viewing angle.

***Reply**. Point was clarified in the following way: "The at-nadir viewing angle was chosen to verify the symmetry in azimuth of the environment contribution (adjacent effect) on the observed radiance, like showed in Fig. 5 of Vermote et al. (1997)."*

- On the radiative impact of aerosol loading on the observed radiance (sec. 3.1)

The most significant quantity for the discussion about the sensitivity and impact of aerosol loading on the observed radiance is "DeltaRad / Rad" as function of the wavelength, being DeltaRad the difference between the TOA radiance simulated in presence (AOD not equal zero) and in absence (AOD equal zero) of each type of aerosol loading.

***Reply**. Following the referee comment, the figures are given by DeltaRad / Rad with the results of the simulations obtained improving the sampling of the observed radiance (deltaAOD=0.1) in order to show a more accurate variation of the radiance at AOT variation.*

Thus, regarding the Fig. 2, the referee suggest to check and support the considerations reported between line 15 and line 20 in Sec. 3.1 after plotting for the 4 cases of Fig. 2 the ratio "DeltaRad/Rad" as function of the wavelength. We expect that for a continental aerosol the sensitivity to the aerosol loading of TOA radiance is better over dark surface respect to the bright surface.

***Reply**. Referee suggestions were adopted in the text.*

***Technical corrections**

Table 1 : Use the same name "sea salt" or "Oceanic" in the caption and in the table.

***Reply**. The "Oceanic" term has been used to uniform the basic component to the 6SV1.1 code.*

Table 3: Please, add a reference at the end of the caption.

***Reply**. The reference has been added to the caption.*

In general, for the plots of the same figure it would be better to have the same scale of the y-axis and to have the same numerical value for the LUT of the grayscale of the last 3 figures.

***Reply**. The authors have tried to change the plots. The results are not as well as to introduce them in the paper. Thus, the authors have chosen to maintain the figures of the previous version like the better plots obtained.*