ESA Climate Change Initiative

aerosol_cci

Algorithm Theoretical Basis Document (ATBD) New POLDER algorithm GRASP (Generalized Retrieval of Aerosol and Surface Properties)

Version 1

DOCUMENT STATUS SHEET

	FUNCTION	NAME	DATE	SIGNATURE
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EXECUTIVE SUMMARY

New PARASOL algorithm GRASP (Generalized Retrieval of Aerosol and Surface Properties) is designed to retrieve complete aerosol properties globally. The algorithm retrieves the parameters of underlying surface simultaneously with aerosol. In all situations, the approach is anticipated to achieve a robust retrieval of complete aerosol properties including information about aerosol particle sizes, shape, absorption and composition (refractive index). In order to achieve reliable retrieval from PARASOL observations even over very reflective desert surfaces, the algorithm was designed as simultaneous inversion of a large group of pixels within one or several images. Such, multi-pixel retrieval regime takes advantage from known limitations on spatial and temporal variability in both aerosol and surface properties. Specifically the variations of the retrieved parameters horizontally from pixel-to-pixel and/or temporary from day-to-day are enforced to be smooth by additional appropriately set a priori constraints. This concept provides satellite retrieval of higher consistency

Issue	Date	Modified Items / Reason for Change
1.0	20.04.2017	Version 1.0

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1 INTRODUCTION

This document describes the theoretical basis of GRASP (Generelized Retrieval of Aerosol and Surface Properties) algorithm, version 1.00 for Aerosol-CCI project.

1.1 Scope

GRASP algorithm version 1.00 has been described in peer-reviewed papers [1-4]. The main features of the algorithm:

- The algorithm fits the complete set of PARASOL angular measurements in all spectral bands (with the exception of the channels dominated by gaseous absorption such as 0.763, 0.765 and 0.910 μm) including both radiance and linear polarization measurements.
- It deals with a continuous space of aerosol and surface solutions [1-8]. This allows reliable retrieval of extended set of parameters affecting measured radiation. Specifically, in processing observation over land, the algorithm is set to retrieve both the optical properties of aerosol and underlying surface.
- The algorithm is based on statistically optimized fitting (optimal estimation and multi-term least square approaches) [1,8]. The method includes advances prior information based on temporal, spatial and spectral smoothness mechanisms applied on a single pixel or a cluster of pixels [1-4].
- The algorithm is desighned for multi-instrument remote sensing [1-3].

1.2 References

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2 ALGORITHM CHARACTERIZATION

The design of the algorithm enhances accuracy and completeness aerosol retrieval from PARASOL by emphasizing profound statistical optimization in inversion procedure. This concept relies on pronounced data redundancy (excess of the measurements number over number of unknowns) that is inherent to the multi-angular polarimetric POLDER observations. Since this positive data redundancy is not common for currently operating satellites sensors, the idea of such enhanced retrieval was not fully considered by satellite community, while the concept has been successfully adopted and refined in the operational AERONET aerosol retrieval [Dubovik and King, 2000, Dubovik et al, 2000, 2006].

The details of the algorithm have been reported already in depth description of many aspects of the model are provided in paper by Dubovik et al. [2011], [2014].

2.1 Algorithm principles

The algorithm fits a complete set of PARASOL observations including both measurements of total radiances and polarized at all available spectral channels. This allows reliable retrieval of extended set of parameters affecting measured radiation. Specifically, in processing observation over land, the algorithm is set to retrieve both the optical properties of aerosol and underlying surface. In addition, the algorithm provides more detailed (compare to current operational PARASOL algorithm) information about aerosol properties over land including information about aerosol sizes, shape, absorption and composition (refractive index, and volume factions of main chemical components).

In addition, a new unique inversion option has been realized in the algorithm: a simultaneous inversion of a large group of pixels within one or several images. Such, multi-pixel retrieval regime takes an advantage from known limitations on spatial and temporal variability in both aerosol and surfaces properties. Specifically the pixel-to-pixel or day-to-day variations of the retrieved parameters are enforced to be smooth by additional appropriately set a priori constraints. This new concept is expected to provide retrieval of higher consistency for aerosol retrievals from satellites by enriching the retrieval over each single by co-incident aerosol information from neighboring pixels, as well, from the information about surface reflectance (over land) obtained in preceding and consequent observation over the same pixels.

2.2 Atmosphere model

The modeling of the aerosol scattering matrices has been implemented following the ideas employed in AERONET retrieval algorithm by Dubovik and King [2000], Dubovik et al. [2002b, 2006].
In order to account for aerosol non-sphericity, the atmospheric aerosol is modeled as an ensemble of randomly oriented spheroids. Specifically, AERONET operational retrieval uses the concept by Dubovik et al. [2006] and models the particles for each size bin as mixture of spherical and non-spherical aerosol components. The non-spherical component was modeled by ensemble of randomly oriented spheroids (ellipsoids of revolution).

2.3 Surface treatment

The adequate choice of land surface reflectance is critical for achieving adequate aerosol retrieval over land surfaces since the surface contribution generally dominates the satellite signal. In order to address this aspect, several surface reflectance models were adapted into Dubovik et al. (2011) algorithm, including semi-empirical RPV (Rahman et al., (1993)) and Ross-Li (Ross, (1981); Li, X., Strahler (1992)) models of BRDF and Nadal-Breon (Nadal and Bréon, (1999)) and Maignan et al. (Maignan et al., (2009)) models of BPDF, as well as, physically based combined model for BRDF and BPDF by Litvinov et al. (2011, 2012).

We have analyzed the variability of aerosol retrieval results due to the differents choices of the surface model. The preliminary results show that the good performance of PARASOL retrieval can be achieved with a combination of simple and fast Ross-Li BRDF model for BRDF and Maignan et al. model for BPDF. At the same time, the analysis revealed a high potential of physically based models (Litvinov et al. (2011, 2012)).

3 ALGORITHM VALIDATION ON SYMTHETIC MEASUREMENTS

GRASP algorithm was tested on synthetic measurements inversion. We simulated two months of PARASOL measurements over Binizoumbou. Aerosol and surface properties and aerosol concentration in the simulation were taken typical for Banizoumbou in January, February 2008. The geometries for the two months were choosen the same as for PARASOL measurements over Banizoumbou in January, February 2008. Physical model for land surface reflection matrix (Litvinov et al., 2012) was used in the simulation.

The simulated synthetic measurements were inverted with GRASP algorithm without any appriori information about about aerosol and surface properties and with generalized set of smoothness contsraints, which are usually used in inversion of real PARASOL measurements.

Figures 1-3 show the result of GRASP inversion of the synthetic measurements.

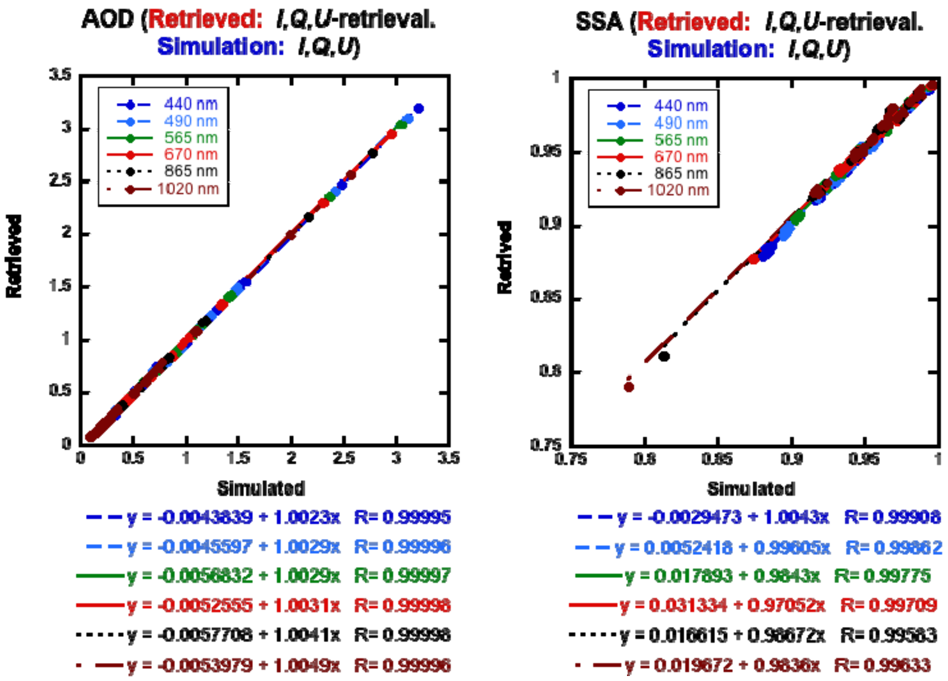


Figure 1. The examples of AOD and SSA retrieval from synthetic measurements.

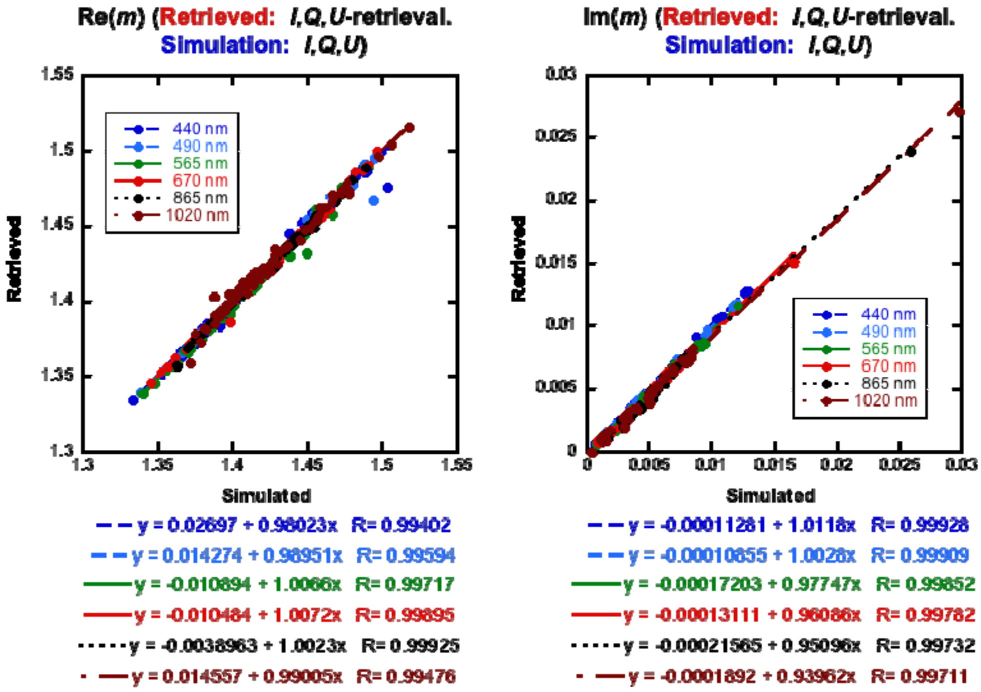


Figure 2. The examples of complex refrective index retrieval from synthetic measurements.

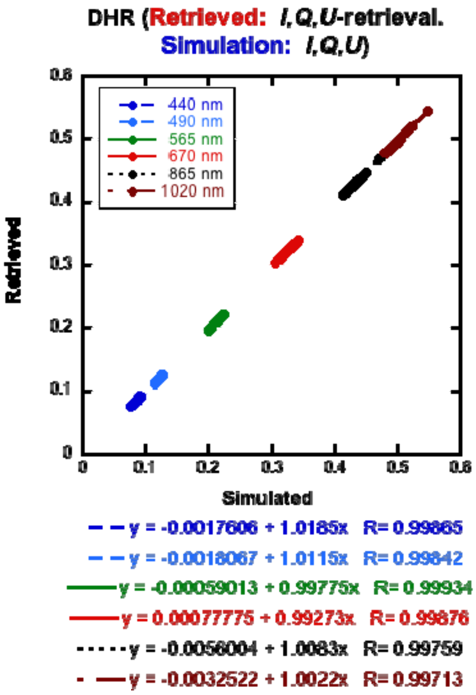


Figure 3. The example of surface albedo (Directional Hemi-spherical Albdedo (DHR)) retrieval from synthetic measurements.

As can be seen from the synthetic mesurements retrieval, when aerosol and surface models are accurate enough, GRASP algorithm provides highly accurate retrieaval of aerosol and surfaces properties.

4 ALGORITHM VALIDATION VERSUS AERONET MEASUREMENTS

As a part of ESA CCI (Climate Change Initiative) project, the performance of GRASP algorithm on real data was tested for the whole 2008 year of the PARASOL data over four extended geographical zone of 1200 x 1200 km centered at the following AERONET stations: (i) area centered near Banizoumbou/Niger AERONET site, (ii) area centered near Mongu/Zambia and (iii) the area centered at Beijing/China and Kanpur/India. These areas correspond to very different eco-systems with different types of surface reflectance and aerosols. Banizoumbou area has been chosen for the analysis because it represents an example of a location with very high surface reflectance and frequent presence of desert dust outbreaks and biomass burning events. Mongu region demonstrates essential changes of vegetation cover from season to season with biomass burning aerosol domination in August and September. Beijing and Kanpur regions represent urban surface with industrial and dust aerosols.

The GRASP aerosol retrievals from real POLDER/PARASOL over four extended geographical zone observations were successfully validated against AERONET data. The summary of the comparisons of PARASOL results with AERONET observations are shown in Figures 4-7.

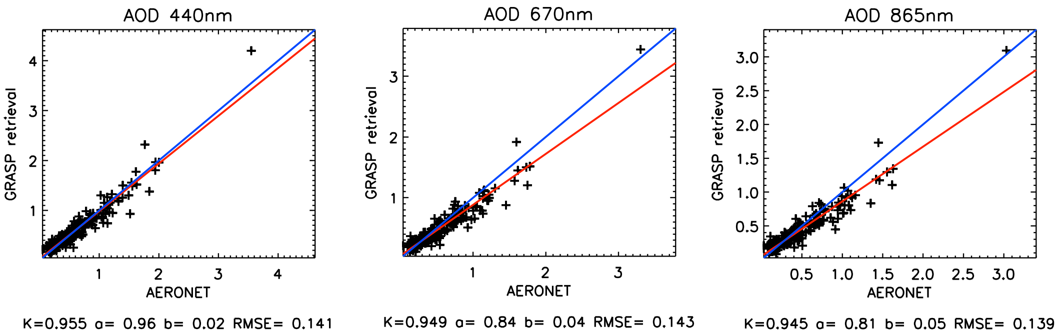


Figure 4. The comparison of GRASP/PARASOL AOD at different wavelengths vs. AERONET over Mongu, Banizoumbou, IER_Cinzana, Agoufou, Ilorin sites in Africa for 2008.

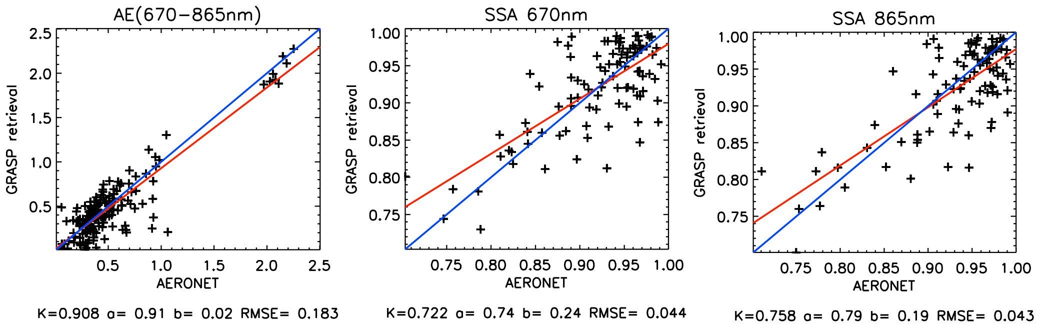


Figure 5. The comparison of GRASP/PARASOL Angstrom Exponent (AE) and SSA at different wavelengths vs. AERONET over Mongu, Banizoumbou, IER_Cinzana, Agoufou, Ilorin sites in Africa for 2008.

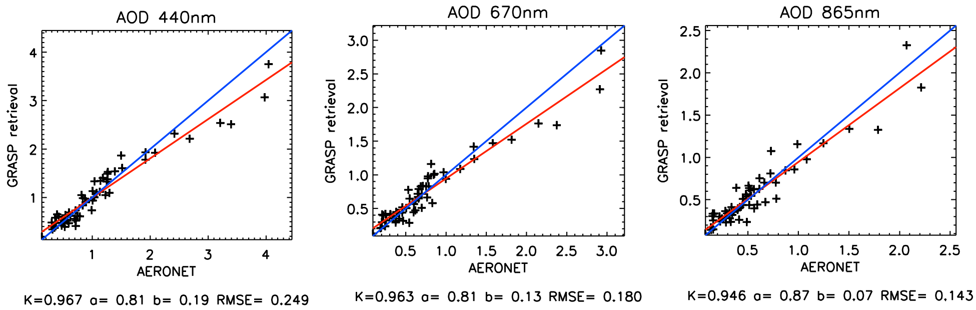


Figure 6. The comparison of GRASP/PARASOL AOD at different wavelengths vs. AERONET over Beijing and Kanpur for 2008.

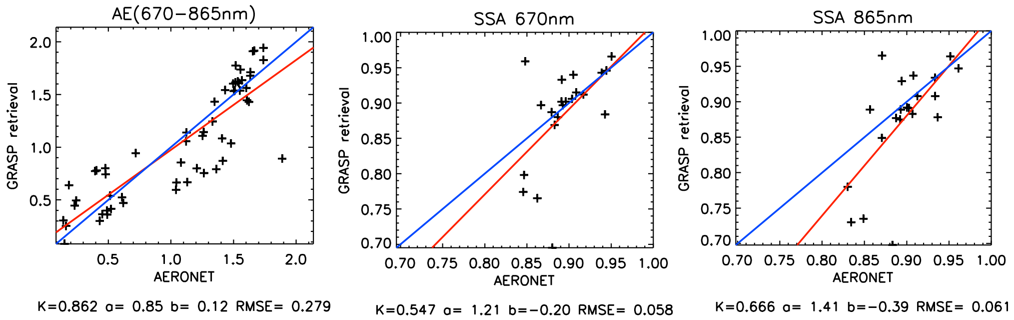
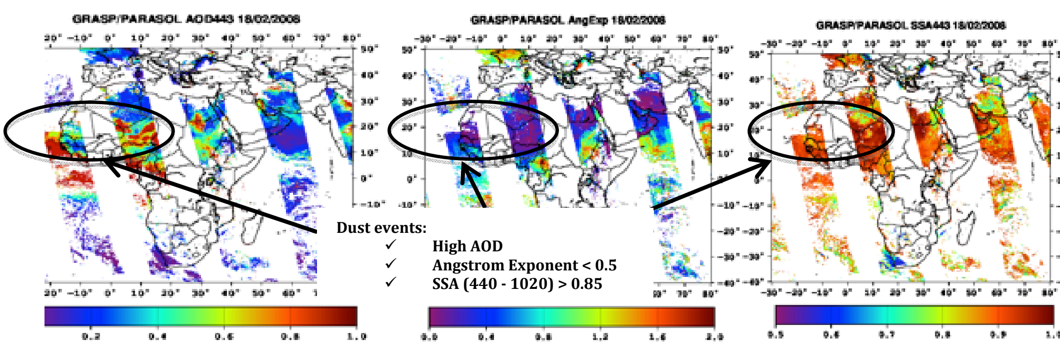


Figure 7. The comparison of GRASP/PARASOL Angstrom Exponent (AE) and SSA at different wavelengths vs. AERONET over Beijing and Kanpur for 2008.

As can be seen from the figures 4-7, GRASP aerosol retrievals are in a good agreement with AERONET observations: the correlation coefficients (*K*) are very high and RMSEs (Root Mean Square Error) are very small. One can clearly see the clustering of different aerosol types from the figure of AE. High AE values of ~2 correspond to a fine mode dominated aerosol that is typically observed over Mongu during biomass burning seasons or over Kanpur site (Figs.4-7). Smaller values of Angstrom exponent are observed for Banizoumbou, Ilorin, Agoufou sites strongly influenced by desert dust or mixed fine and coarse aerosols (Figs.4, 5). Figures 6 and 7 show good GRASP performance for very high pollutions events typical over Beijing and Kanpur.

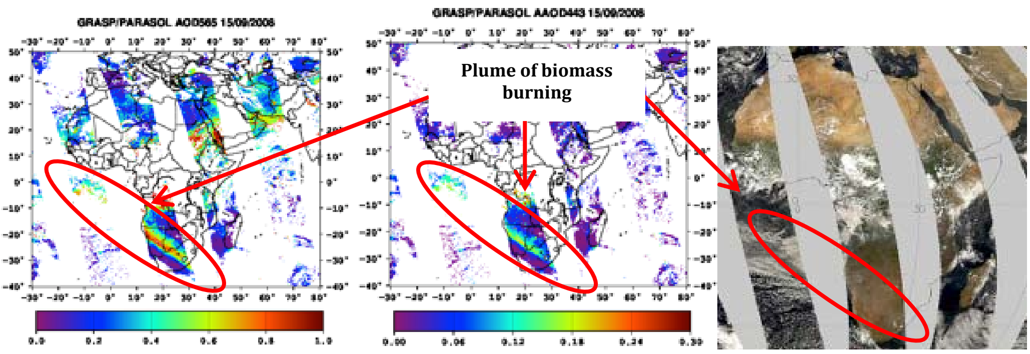
The clustering of different aerosol types observed for AE is also evident and logical for SSA. One can see the absorbing smoke in Mongu, industrial pollution in Beijing and Kanpur, nearly non-absorbing desert dust in Banizoumbou/Niger and moderately absorbing mixed aerosol characteristic for the locations over Ilorin AERONET station (Figs.4-7).

The analysis of extended aerosol and surface properties retrieved by GRASP from multi-spectral, photopolarimetric POLDER/PARASOL measurements provides possibilities of aerosol type classification and aerosol sources identification with unprecedented for satellite retrieval confidence.



Figures 8. GRASP/PARASOL retrieval over Africa. Dust aerosol properties characterization and sources identification. Left panel: retrieved AOD(443). Central panel: Angstrom exponent. Right panel: SSA(440).

Figure 8 shows GRASP retrieval over Africa with clearly seen dust events identified with spectral AOD, relatively small Angstrom Exponent value, and spectral SSA.



Figures 9. PARASOL retrieval of AOD over Africa. Aerosol properties characterization and biomass burning sources identification. Left panel: retrieved AOD(565 nm). Central panel: retrieved AAOD(443 nm). Right panel: PARASOL RGB image.

Seasonal biomass burning events on Southern Africa can be well seen from GRASP retrieval (Fig.9). Good indicator of biomass burning can be Absorption Aerosol Optical Thickness (AAOD) defined from AOD and SSA: AAOD=AOD*(1-SSA).

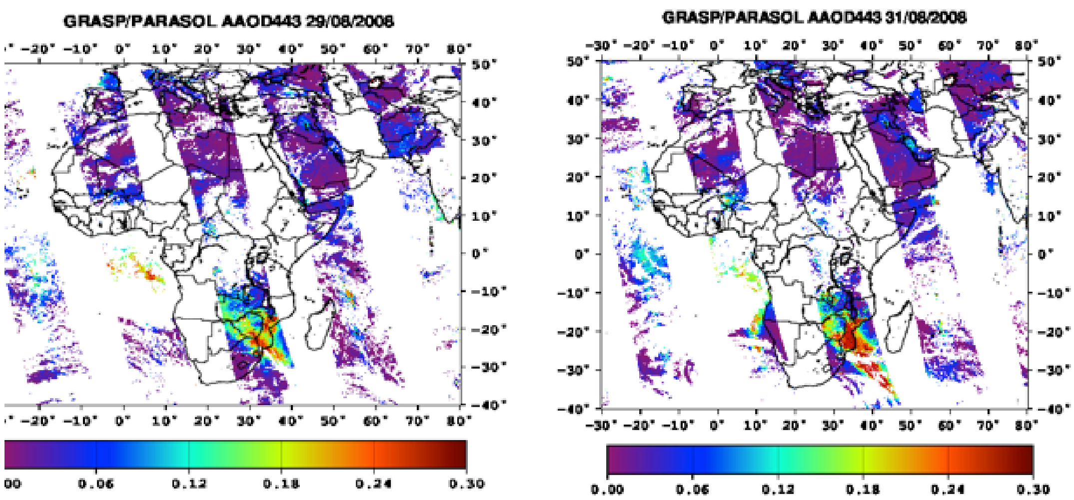


Figure 10. Evolution of "river of smoke" from PARASOL/GRASP AAOD(440 nm) retrieval.

Figure 10 shows the evolution of biomass burning plume as it is seen from GRASP AAOD retrieval. It is frequently refereed as "river of smoke" coming from hundreds of fires burning in Mozambique, South Africa, and Swaziland (Swap et al., 2003; Reid et al., 2009).

From Figures 8-10 one can clearly see the differences in properties of desert dust (low values of angstrom exponent and high values of SSA) and biomass burning (high values of angstrom exponent and relatively low values of SSA) aerosols provided by GRASP/PARASOL retrieval.

The results of GRASP/PARASOL retrievals and comparisons with AERONET suggest that GRASP algorithm provides robust extended aerosol characterization from the multi-spectral, multi-angular, polarimetric observations (PARASOL) over diverse land cover areas including very bright surfaces. It assumes that GRASP/PARASOL retrieval can be used as quasi-reference for satellite datasets in addition to validation vs AERONET.

5. ALGORITHM OUTPUT

GRASP algorithm provides retrieval of extended aerosol and surface parameters:

- AOD □□□□□□□total aerosol optical depth at 7 wavelengths: 443, 490, 550, 565, 670, 865 and 1020 nm
- AAOD □□□the absoption aerosol optical depth at 7 wavelengths: 443, 490, 550, 565, 670, 865 and 1020 nm
- FM_AOD □□□□□□□fine mode aerosol optical depth at 7 wavelengths: 443, 490, 550, 565, 670, 865 and 1020 nm
- CM_AOD □□□□□□□coarse mode aerosol optical depth at 6 wavelengths: 443, 490, 550, 565, 670, 865 and 1020 nm
- ANG = Angstrom Exponent
- SSA □□single scattering albedo at 6 wavelengths: 443, 490, 565, 670, 865 and 1020 nm
- Fraction of spherical particles.
- Surface albedo at 6 wavelengths.
- Parameters of BRDF/BPDF models.

The datasets of GRASP/PARASOL processing (L2 native resolution and L3 1 degree resolution) is available at ICARE ftp server.

6. CONCLUSIONS

GRASP algorithm provides possibility for extended aerosol/surface characterization from PARASOL measurements. Comparisons of total AOD, SSA and Angstrom exponent derived from PARASOL measurements with ground based AERONET retrieval show a good correlation. The results suggest that GRASP algorithm should provide robust aerosol retrieval for the PARASOL observations over diverse land cover areas including very bright surfaces.

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