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GRASP: a versatile algorithm for characterizing the atmosphere

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A unified algorithm for retrieving a variety of atmospheric properties is applicable to remote sensing observations obtained from space, ground, and aircraft.

GRASP (Generalized Retrieval of Aerosol and Surface Properties) is the first unified algorithm to be developed for characterizing atmospheric properties gathered from a variety of remote sensing observations (an introductory video is available elsewhere[1]). GRASP is based on a recent algorithm[2] created to improve aerosol retrieval from the French Space Agency's PARASOL[3] imager over bright surfaces like deserts where high surface reflectance dwarfs the signal from aerosols. Moreover, GRASP relies on the heritage of retrieval advances[4–7] implemented for AERONET,[8] a worldwide network of over 200 radiometer sites that generate the data used to validate nearly all satellite observations of atmospheric aerosols. The AERONET retrievals derive detailed aerosol properties,[6] including absorption, providing information of vital importance for reducing uncertainty in assessments of climate change.

GRASP is based on several generalization principles with the idea of developing a scientifically rigorous, versatile, practically efficient, transparent, and accessible algorithm. There are two main independent modules. The first, *numerical inversion*, includes general mathematical operations not related to the particular physical nature of the inverted data (in this case, remote sensing observations). The second module, the *forward model*, was developed to simulate various atmospheric remote sensing observations.

Numerical inversion is implemented as a statistically optimized fitting of observations following the multi-term least squares method (LSM) strategy, which combines[9] the advantages of a variety of approaches and provides transparency and flexibility in developing algorithms that invert passive and/or active observations and derive several groups of unknown parameters. For example, in PARASOL and AERONET retrievals[2,4] we applied different smoothness constraints simultaneously on aerosol size distributions and spectral dependencies of the aerosol refractive index and surface reflectance parameters. In addition, we used the multi-term LSM to formulate multi-pixel retrieval,[2] which implements optimized inversion of a large group of satellite pixels simultaneously. This inversion scheme improves retrieval consistency by using known limitations on spatial and/or temporal variability of retrieved parameters. For example, in PARASOL retrieval,[2] the

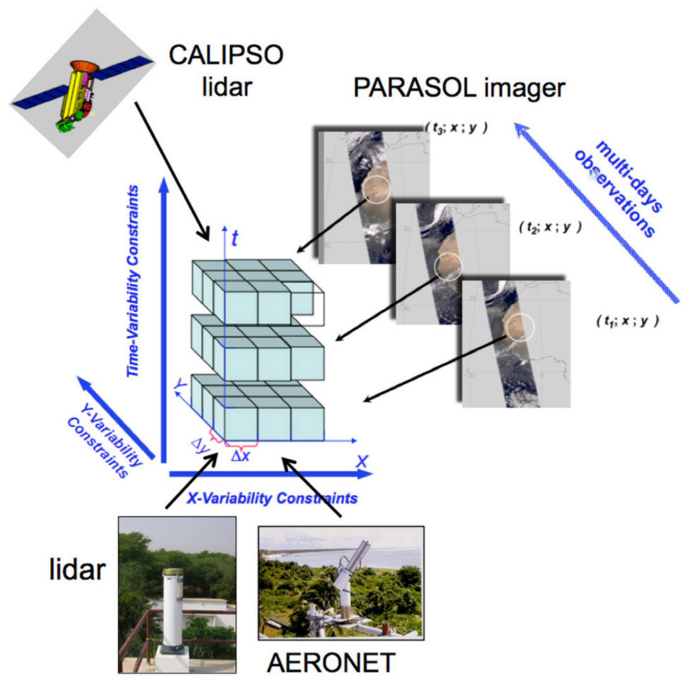

Figure 1. Diagram illustrating the principle of combined synergetic processing of complementary observations using a multi-pixel[2] retrieval approach. CALIPSO is a joint lidar mission of NASA and the French Space Agency, which also manages the PARASOL imager. AERONET is a worldwide network of radiometer sites.

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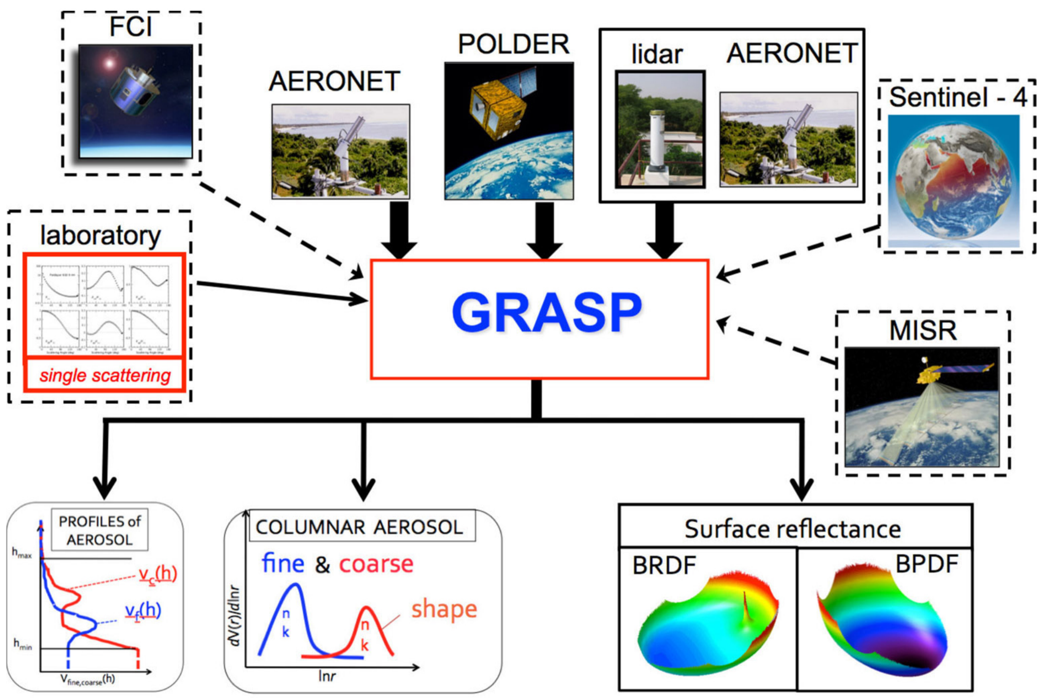

Figure 2. *Diagram showing the applicability of the GRASP algorithm to various observations and potential retrieved output characteristics. The dashed boxes indicate the sections of the algorithm that are not fully completed. The three panels at the bottom—profiles of aerosol, columnar aerosol, and surface reflectance—refer to possible outputs of the algorithm. FCI: Flexible Combined Imager. POLDER: Passive optical imaging radiometer. Sentinal-4: Part of a European Space Agency multi-satellite mission. MISR: Multi-angle Imaging SpectroRadiometer. BRDF: Bidirectional reflectance distribution function. BPDF: Bidirectional polarization distribution function.*

horizontal pixel-to-pixel variations of aerosol and day-to-day variations of surface reflectance are deliberately smoothed by an additional set of a priori constraints. This concept is also promising for developing synergetic retrievals using observations that are not fully coincident in time or space (see Figure 1).

The forward model simulates atmospheric radiation resulting from interaction of incident light with atmospheric gases, aerosols, and the underlying surface. The aerosol model is assumed to be a mixture of two components: spherical particles and nonspherical particles. Each fraction is characterized by the same particle size distribution in a manner similar to AERONET retrievals.[4] The nonspherical component is modeled as a mixture of randomly oriented spheroids with a fixed shape distribution.[2,7] A bidirectional reflectance distribution function (BRDF) and bidirectional polarization distribution function (BPDF) are used to model the effects of surface reflectance. The algorithm takes into account multiple interactions of scattered solar light with aerosol, gas, and surface by solving a radiative transfer equation using the successive order of scattering formalism.[10] All calculations are done online without having to search a precalculated lookup table. The structure of the algorithm is convenient for adapting and testing alternative routines for handling aerosol, surface, gas, or multiple scattering contributions.

GRASP is highly versatile algorithm. Depending on the input data, GRASP can retrieve columnar and vertical aerosol properties and surface reflectance (see Figure 2). For example, we are adapting GRASP for reprocessing PARASOL observations. Figure 3 shows the aerosol optical thickness retrieved over a bright surface in Africa from two consecutive observation days, and Figure 4 shows the high variability of smoke aerosol ω_0 (ratio of scattering to scattering plus absorption) clearly correlated with locations of fires observed by MODIS (Moderate-resolution Imaging Spectroradiometer) from a satellite. GRASP can also be applied to ground-based observations. Moreover, the GARRLiC (Generalized Aerosol Retrieval from Radiometer and Lidar Combined data) algorithm as a branch of GRASP was developed for inversion of coincident multi-spectral lidar

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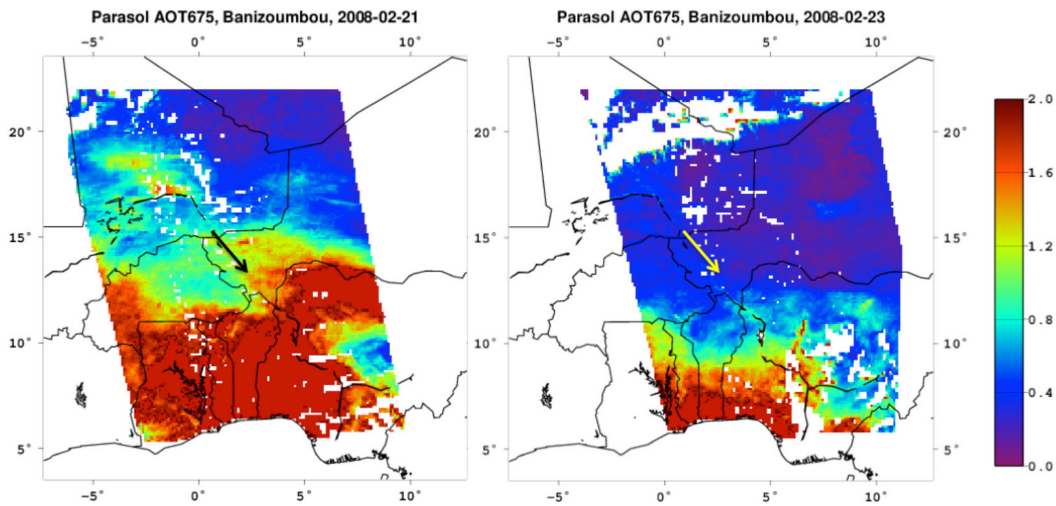

Figure 3. *Examples of aerosol optical thickness (AOT) at 0.67μm retrieval during two consecutive POLDER/PARASOL observations on 21 and 23 February 2008 over an 1800×1800km area centered at the Banizoumbou, Niger, AERONET site (indicated by an arrow).*

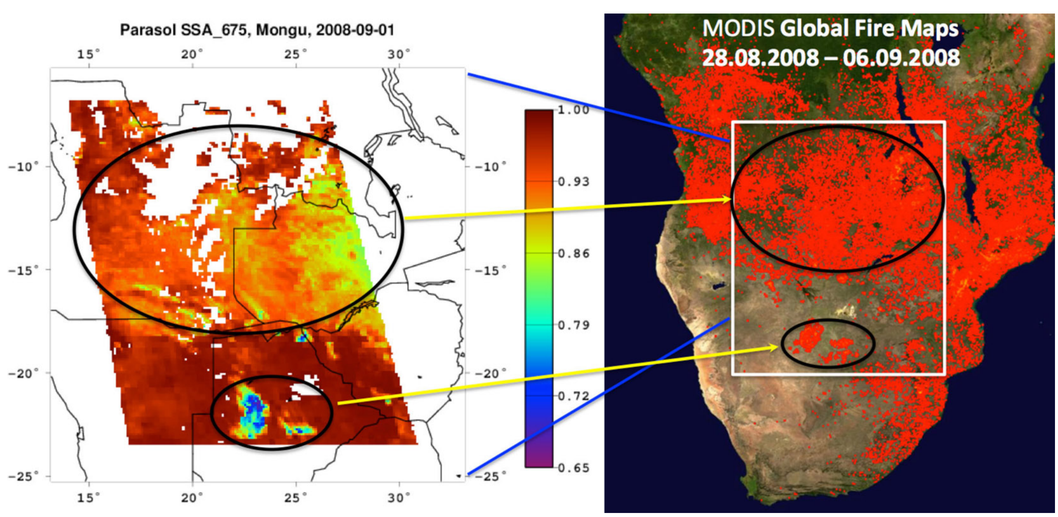

Figure 4. *Left: The variability of aerosol ω_0(0.67μm) retrieved from POLDER/PARASOL on 1 September 2008 over an area of 1800×1800km around the AERONET site at Mongu, Zambia. Right: Map of fire locations retrieved from MODIS (Moderate-resolution Imaging Spectroradiometer) over the same area (the white rectangle circumscribes the area corresponding to the map shown at left).*

and radiometer observations.[11] Using this synergy, GARRLiC/GRASP retrieves improved aerosol columnar properties together with details about vertical aerosol variability, including profiles of fine and coarse aerosol mode concentrations and vertical profiles of $\omega_0(\lambda)$ (see Figure 5). In addition, we have ongoing plans to use GRASP for processing the polar orbiting observations from MERIS/Envisat, future Sentinel-3, and 3MI/MetOp-SG missions, and geostationary observations from Sentinel-4 and FCI/MTG.

We designed GRASP as an open-source software package that will be available for distribution to the community in the near future. The scientific GRASP code is complemented by a framework project that manages configuration of the code execution, as well as preparation of the input and output for a group of customized applications. Finally, we are redesigning a version of GRASP as a highly parallelized routine ported to a GPGPU

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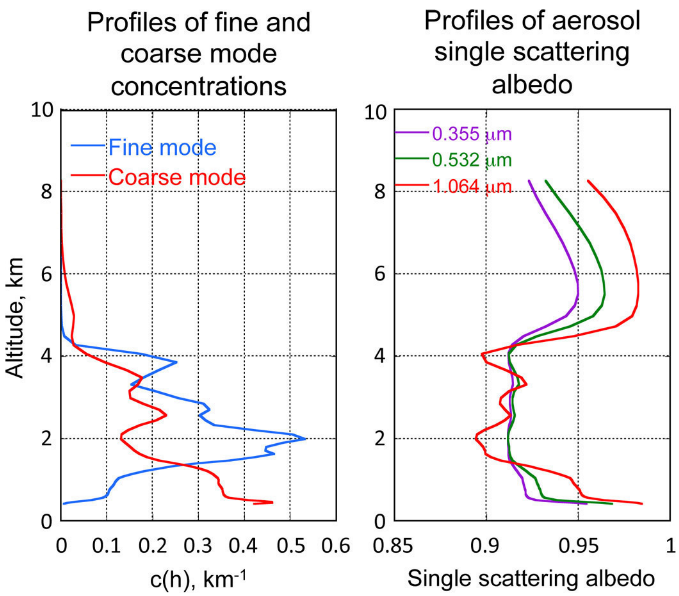

Figure 5. *Results of the GaRRLiC (Generalized Aerosol Retrieval from Radiometer and Lidar Combined data)/GRASP retrieval of aerosol vertical profiles from the coincident observations of AERONET radiometer and multi-wavelength lidar (transported smoke over Minsk, Belarus, on 13 August 2010). Left: Profiles c(h) show vertical distribution of aerosol volume concentrations of fine and coarse aerosol modes; c(h) are normalized to 1. Right: Retrieved vertical distributions of aerosol single-scattering albedo $\omega_0(\lambda)$ (ratio of scattering to scattering plus absorption).*

(general-purpose computing on graphics processing units) accelerator. This GPU version provides sufficient computational speed for a complex algorithm such as GRASP to process large volumes of satellite data.

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References

1. http://www.youtube.com/watch?v=PcDeqwDF15A Explanation of the Generalized Retrieval of Aerosol and Surface Properties (GRASP) algorithm. Accessed 31 July 2014.
2. O. Dubovik, M. Herman, A. Holdak, T. Lapyonok, D. Tanré, J. L. Deuzé, F. Ducos, A. Sinyuk, and A. Lopatin, *Statistically optimized inversion algorithm for enhanced retrieval of aerosol properties from spectral multi-angle polarimetric satellite observations*, **Atmos. Meas. Tech. 4**, pp. 975–1018, 2011.
3. D. Tanré, F. M. Bréon, J. L. Deuzé, O. Dubovik, F. Ducos, P. François, P. Goloub, M. Herman, A. Lifermann, and F. Waquet, *Remote sensing of aerosols by using polarized, directional, and spectral measurements within the A-Train: the PARASOL mission*, **Atmos. Meas. Tech. 4**, pp. 1383–1395, 2011.
4. O. Dubovik and M. D. King, *A flexible inversion algorithm for retrieval of aerosol optical properties from Sun and sky radiance measurements*, **J. Geophys. Res. 105**, pp. 20673–20696, 2000.
5. O. Dubovik, A. Smirnov, B. N. Holben, M. D. King, Y. J. Kaufman, T. F. Eck, and I. Slutsker, *Accuracy assessments of aerosol optical properties retrieved from Aerosol Robotic Network (AERONET) Sun and sky radiance measurements*, **J. Geophys. Res. 105**, pp. 9791–9806, 2000.
6. O. Dubovik, B. Holben, T. F. Eck, A. Smirnov, Y. J. Kaufman, M. D. King, D. Tanré, and I. Slutsker, *Variability of absorption and optical properties of key aerosol types observed in worldwide locations*, **J. Atmos. Sci. 59**, pp. 590–608, 2002.
7. O. Dubovik, A. Sinyuk, T. Lapyonok, B. N. Holben, M. Mishchenko, P. Yang, T. F. Eck, *et al.*, *Application of spheroid models to account for aerosol particle nonsphericity in remote sensing of desert dust*, **J. Geophys. Res. 111**, p. D11208, 2006. doi:10.1029/2005JD006619
8. B. N. Holben, T. F. Eck, I. Slutsker, D. Tanré, J. P. Buis, A. Setzer, E. Vermote, *et al.*, *AERONET—a federated instrument network and data archive for aerosol characterization*, **Rem. Sens. Environ. 66**, pp. 1–16, 1998.
9. O. Dubovik, *Optimization of numerical inversion in photopolarimetric remote sensing*, in G. Videen, Y. Yatskiv, and M. Mishchenko (eds.), **Photopolarimetry in Remote Sensing**, pp. 65–106, Kluwer, Dordrecht, 2004.
10. J. Lenoble, M. Herman, J. L. Deuzé, B. Lafrance, R. Santer, and D. Tanré, *A successive order of scattering code for solving the vector equation of transfer in the earth's atmosphere with aerosols*, **JQSRT 107** (3), pp. 479–507, 2007.
11. A. Lopatin, O. Dubovik, A. Chaikovsky, P. Goloub, T. Lapyonok, D. Tanré, and P. Litvinov, *Enhancement of aerosol characterization using synergy of lidar and sun-photometer coincident observations: the GARRLiC algorithm*, **Atmos. Meas. Tech. 6**, pp. 2065–2088, 2013. doi:10.5194/amt-6-2065-2013