Abstracts

1st Workshop on Studies of Atmospheric Aerosol Using Multi - Angle Spectropolarimetry (ISSI, Bern, July 16-20, 2012)

The comparison of retrievals using different aerosol algorithms

A. A. Kokhanovsky and aerosol retrieval team, University of Bremen, Germany

Remote sensing of aerosol from space is a challenging and typically underdetermined retrieval task, requiring many assumptions to be made with respect to the aerosol and surface models. Therefore, the quality of a priori information plays a central role in any retrieval process (apart from the cloud screening procedure and the forward radiative transfer model, which to be most accurate should include the treatment of light polarization and molecular-aerosol coupling). In this paper the performance of various algorithms with respect to the of spectral aerosol optical thickness determination from optical spaceborne measurements is studied. The algorithms are based on various types of measurements (spectral, angular, polarization, or some combination of these). It is confirmed that multiangular spectropolarimetric measurements provide more powerful constraints compared to spectral intensity measurements alone, particularly those acquired at a single view angle and which rely on a priori assumptions regarding the particle phase function in the retrieval process.

SPEX: Multi-Angle Spectro-Polarimetry for Aerosol and Cloud Characterization from the ISS

O.P. Hasekamp and the SPEX team*, SRON, The Netherlands

We present the SPEX instrument that is designed to perform multi-angle spectro-polarimetric observations from a low earth orbit satellite in order to derive aerosol and cloud properties in the Earth atmosphere. The effect of anthropogenic aerosols represents the most uncertain factor in the climate system. Aerosols affect the climate directly by scattering and absorption of solar radiation and indirectly by changing the properties of clouds. Here, the effect of aerosols on cloud properties is considered the largest yet most uncertain aerosol climate effect. To improve the estimate of the aerosol effect on clouds and climate, accurate satellite based measurements of aerosol microphysical and optical properties, as well as cloud properties, are required. The SPEX instrument is designed to provide these measurements. SPEX has been proposed in response to the Announcement of Opportunity for International Space Station Experiments relevant to the study of Global Climate Change.

Instrument description

In order to derive the relevant aerosol and cloud properties with accuracy sufficient for climate research, multiple-viewing-angle, multiple wavelength measurements of the intensity as well as the Degree of Linear Polarization (DoLP) of the light reflected by the Earth atmosphere are essential. SPEX will measure intensity, degree- and angle of linear polarization of scattered sunlight between 400 and 1600 nm, sampling each ground pixel with 25-30 viewing angles. SPEX' novel polarimetric technique allows for achieving the extremely high polarimetric accuracy (0.001+0.005DoLP) needed to derive aerosol properties with sufficient accuracy for climate research [Hasekamp and Landgraf, 2007]. SPEX' relatively high spectral resolution enables resolving the spectral feature of the O2-A absorption band, which is important for deriving aerosol and cloud height. SPEX' large number of viewing angles enables resolving the angular features resulting from light scattering by aerosol and cloud particles, and to distinguish between these types of particles.

The novel polarimetric measurement approach works as follows [Snik et al., 2009]: Incoming linearly polarized light passes through a set of birefringent polarizing crystals which, combined, result in an intensity spectrum that has the degree of polarization coded onto it as an amplitude modulated signal. The depth of the modulation is proportional to the degree of linear polarization of the incoming light, and the phase is proportional to the angle of linear polarization. This measurement approach, that uses no filter wheels or multiple apertures to determine the state of polarization, allows for simultaneous measurements of both radiance and polarization for a given ground scene. This is essential to reach the required accuracy. The SPEX geophysical data product will consist at least of: aerosol effective radius, effective variance, number concentration, refractive index of the fine and coarse mode of the aerosol size distribution, aerosol height, cloud effective radius, droplet number concentration, cloud top/base height, and cloud phase.

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Assessing accuracy requirements and their implementation in functional and actual instrument design: some recent examples

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In this talk we will briefly review current US airborne polarimeter designs and their capabilities and discuss what benefits high polarimetric accuracy can have. In particular given the interests of this group we will frame the discussion in terms of what the consequences are on the required modeling "efficiency" and fidelity as regards including more realistic surface polarized BRDF and atmospheric vertical structure if highly accurate measurements are to have any benefits. In the second part of the talk we will provide some examples of the value that is provided by airborne measurements in deriving improved models of surfaces and of evaluating how well aerosols can be retrieved over the usual ocean and land surfaces and also over unusual surfaces/lower boundaries such as snow and clouds. We will conclude with some examples of analyses of airborne data taken over broken cumulus fields for which 3D effect may (or may not) be important.

The Born Approximation

Brian Cairns, Andrew Lacis, Barbara Carlson, Mikhail Alexandrov, Kirk Knobelspiesse,
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The title says it all in playing back to almost 19th Century Physics. However it does, when considered, allow one to think about two current issues in science: courting popularity (cf. Born/Bourne/Olivia Newton John) and the use of erroneous citations (cf. The). And of course this presentation is not about either of those things other than "The"! This presentation is about "The" Born approximation as (scarcely) practiced today as a perturbative solution to the radiative transfer (RT) equation. The most widely cited introductions and applications of radiative perturbation theory (RPT) are based on calculating the propagation from a source through a medium using a forward radiative transfer solver to a perturbation and its return to a detector using an adjoint solution (to the same problem) to a detector. Although the way in which the Green's function can be constructed from forward and adjoint solutions of any differential equation is well understood this seems to be under-appreciated as regards the solution to the radiative transfer equation. Here we will present a way in which numerical algorithms can be efficiently used to construct a representation of the Green's function for any

1D vertically inhomogeneous problem at any required resolution including internal sources. These algorithms can therefore be used in the solution of retrieval problems such as those associated with clouds and aerosols and also with the construction of the radiative kernels of General Circulation Models that are use to assess radiative feedbacks and climate sensitivities.

SOSVRT: A polarized radiative transfer model and its applications

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Polarization becomes more and more important in current and future remote sensing of aerosol and cloud, as it could provide more information than that of intensity-only measurements. While forward simulation of polarization of light during its transfer in the earth-atmosphere system is still a burden for non-look-up-table retrieval, and a fast, stable and accurate forward model is of the first prerequisite in developing novel inverse algorithm. Therefore, a full vector radiative transfer model for vertically inhomogeneous plane-parallel media is developed by using the successive order of scattering approach. In this model, serveral techniques are used to speed up the simulations, and an analytic angular interpolation method of post-processing source function is also implemented to accurately interpolate the Stokes vector at arbitrary angles for a given solution. It has been tested against the benchmarks for the case of randomly orientated oblate spheroids, illustrating a good agreement for each stokes vector (within 0.01%). Some issues related simulation accuracy of intensities and polarizations of atmosphere are also discussed.

Algorithm efficiency of radiative transfer equation solution for turbid medium slab

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The discrete representation of the radiative transfer equation (RTE) requires for its numerical solution. Such discretization is based on replacement of the scattering integral by a finite sum using the spherical harmonics method or the discrete ordinates method. The physical basis of RTE is the ray approximation that inevitably gives rise to singularities in the radiance spatial - angular distribution, i.e. shadow singularities (Kellogg RB, 1974). Due to the presence of the singularity the integral cannot be replaced by the sum; thus, the analytical elimination of the solution anisotropic part is necessary for the RTE discretization. As result a new boundary value problem of RTE is formulated for the smooth remainder; this problem of RTE is available for sampling.Taking into account the analytical form of the RTE differential operator, such procedure leads in case of homogeneous turbid medium slab to a two-point boundary value problem for systems of ordinary differential equations. This system always has a unique analytic solution in the matrix form. Equivalent results are obtained by any method of the RTE solution: iterations, Monte Carlo, or invariant embedding. Therefore, all modern programs of the light field calculation in a turbid medium slab are realizations of the same solution on the computer. Modern libraries of matrix algebra, in fact, allow only one possible implementation of the algorithm. Differences between the programs of various authors are

connected with the ambiguity of the solution anisotropic part elimination. A comparison of different methods for the anisotropic part elimination is analyzed: the direct nonscattered radiation, delta-M method, TMS method – codes DISORT, Pstar, SCIAMACHY, and small-angle modification of the spherical harmonics method (MSH) – code MVDOM. The analyze shows that the most effective method is MSH which significantly increases the count rate with the same precision. The effects of hardware and software on the efficiency calculations are considered. However, the effectiveness of programs which are based on MSH is significantly reduced in the presence of peaks in the angular dependence of the scattering matrix elements in the rear hemisphere of directions. This is due to the fact that the program MVDOM uses only the discrete ordinates method to calculate smooth solutions while the other methods use the solution iteration as the post processing. In this sense, such approach is equivalent to "synthetic" acceleration methods (Kopp HJ, 1963) which essentiality comes to a combination of the approximate solution of RTE, as accurately as possible for the radiation flux at a point, with the iteration by the exact transfer operator. These procedures have the fast convergence. From these positions at a sufficiently accurate elimination of the solution anisotropic part its smooth part is close to an isotropic function of the angle; this allows its finding by the two-stream or diffusion approximations with subsequent iteration to recover the angular dependence. The accuracy of the obtained solution is over 1%.

The advanced small angle approximation in 3D radiative transfer calculations

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A new approach to the radiative transfer equation (RTE) solution within the small angle approximation (SAA) precisely accounting for the path length dispersion [1-3], is formulated. Compared to previously known SAA RTE solutions, the proposed approach is more accurate and describes a number of physical effects, ignored by other SAA solutions. Within the proposed approach, the stationary and transient solutions of the plane-parallel problem for the RTE and vectorial RTE are derived. The approximate solutions for the fundamental radiation sources (point isotropic and point directed) in the medium with highly anisotropic scattering are derived and analyzed. The problem of coherent backscattering enhancement in the medium with highly forward peaked scattering phase function can also be considered within the proposed approach [4]. The possibility of incorporation of the proposed SAA solutions in the RTE numerical schemes for regularization of the numerical instabilities due to singularities and angular anisotropy of the solution is shown. Newly developed finite difference schemes for the radiative transfer calculations, based on the proposed approach, are presented. Numerical results obtained with these schemes for different 3D problems of the atmospheric optics (twilight, broken clouds, etc.) are discussed.

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Optimized algorithm for retrieving aerosol properties from PARASOL observations over reflective land surfaces

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The presentation describes a new optimized algorithm developed for deriving accurate aerosol properties from PARASOL/POLDER observations over reflective land surfaces. The detailed concept of the algorithm is given in the recent publication by Dubovik et al. [2011]. This concept essentially relies on the accumulated positive research heritage from previous remote sensing aerosol retrieval developments, in particular those from the AERONET and POLDER retrieval activities. The general inversion scheme is designed as multi-term LSM fitting - an inversion strategy allowing for the use of a continuous space of solutions instead of a limited set of predetermined solutions as used in look-up table based algorithms. The algorithm is retrieves simultaneously both properties of aerosol and underlying land surface. In addition, as a part of the PARASOL aerosol algorithm improvement, a new aspect has been introduced for satellite data inversion. Specifically, in order to overcome difficulties related to the limited information of the PARASOL observations over a single pixel, the retrieval is organized as a simultaneous inversion of a large group of pixels within one or several images. The multi-pixel retrieval regime takes advantages from known limitations on spatial and temporal variability in both aerosol and surfaces properties. Although, similar ideas have already been used in different forms for improving satellite retrievals. Here satellite retrieval, for the first time, is designed as a statistically optimized simultaneous fitting of the observations over a group of pixels implemented under additional inter-pixel constraints. Specifically, the variations of the retrieved parameters horizontally from pixel-to-pixel or temporary from day-to-day over the same pixel are limited by the additional a priori constraints, in a similar manner to how it is applied in inverse modeling by Dubovik et al. [2008]. The inclusion of these additional constraints is expected to provide retrieval of higher consistency for aerosol retrievals from satellites, because the retrieval over each single pixel will be benefiting from coincident aerosol information from neighboring pixels, in addition to the information about surface reflectance (over land) obtained in preceding and consequent observations over the same pixel. The performance of the algorithm is illustrated by sensitivity tests, as well as, by applications to real PARASOL data over bright surfaces.

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Aerosol optical and microphysical properties from POLDER-PARASOL multi-angle photo-polarimetric measurements

Otto P. Hasekamp, Arjen Stap, Pavel Litvinov, Andre Butz

In order to make full use of the capability of satellite instruments that measure intensity and polarization properties of reflected light at multiple viewing angles, algorithms are needed that consider a continuous parameter space for aerosol microphysical properties (size distribution, refractive index) and properly account for land or ocean reflection by retrieving land/ocean parameters simultaneously with aerosol properties. In this presentation we present a retrieval algorithm based on these principles. We fit a radiative transfer model for a coupled atmosphere-ocean system to multi-angle photo-polarimetric measurements and retrieve the oceanic Chlorophyll-A concentration, wind-speed in 2 directions, and fractional foam coverage in addition to all parameters related to a bi-modal aerosol model. We demonstrate the capabilities of the algorithm using synthetic measurements and also apply it to the mulit-angle photo-polarimetric measurements of the POLDER instrument on the PARASOL micro-satellite. For POLDER-PARASOL, the retrieved values for Aerosol Optical Thickness (AOT) and Angstrom exponent agree well with sunphotometer measurements of the Aerosol Robotic Network (AERONET). We demonstrate that the POLDER-PARASOL polarization measurements improve agreement with AERONET compared to intensity-only retrievals. Finally, based on comparison of our forward radiative transfer calculations and the PARASOL measurements, we discuss the high potenitial of multi-angle photopolarimetric for the simultaneous retrieval of aerosol and cloud properties.

AEROSOL REMOTE SENSING BASED ON COMBINED USE OF REFLECTANCE AND POLARIZATION MEASUREMENTS

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Polarization and Directionality of Earth's Reflectance's (POLDER) on boarded ADEOS-1, ADEOS-2 and PARASOL provides us with aerosol information on a globe scale. The POLDER sensors have such unique features as the directionality of polarization and reflectance information in the several wavelengths. This polarization information is useful to retrieve aerosol

properties over land area because most of polarization signal is produced from light scattering by molecules and aerosols in the atmosphere. This means that the satellite signal is not largely contaminated by ground polarization. The POLDER gives the wide coverage of scattering angle from 80 to 180 degrees by multi directionality feature.

The SGLI to be mounted on the planned Japanese satellite GCOM-C1 will provide the polarization information at two wavelengths, 0.67 and 0.87 µm at suitable scattering angle for aerosol remote sensing by large tilting mechanism (± 45 degrees along track direction). Another topic of SGLI for aerosol remote sensing is the measurements at near UV wavelength (0.38 µm). This is unique feature compared to other sensors, which is heritage of previous Japanese imager (GLI) and CAI (Cloud aerosol imager) on GOSAT. The measurement at near UV is a key of detecting absorbing particles such as dusts, and biomass burning smokes.

This work describes an algorithm for retrieving optical properties of aerosols for GCOM-C1/SGLI. The rough flowchart of our algorithm is illustrated in Figure 1. In order to evaluate our algorithms and/or pretend SGLI data, simulations with two kinds of sensors as POLDER on PARASOL and CAI on GOSAT are examined.

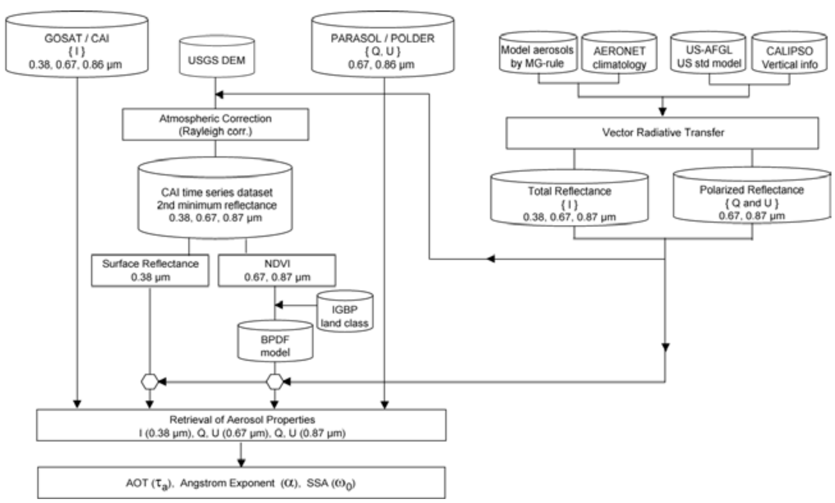

Figure 1 Block flow of aerosol retrieval based on POLDER and CAI data.

Combination of passive and active remote observations in atmospheric aerosol retrievals

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Atmospheric remote sensing relying on passive and active observations provides significantly different information about aerosol properties. Passive observations conducted by satellite or ground-based radiometers have strong sensitivity to the columnar properties of atmospheric aerosol. Such observations are widely used for estimation of aerosol loading and aerosol properties, such as aerosol particles size, shape and complex refractive index. Passive remote sensing, generally, almost insensitive to vertical structure of the atmosphere and therefore can't provide sufficient information about vertical distribution of aerosol properties. In a contrast, active remote sensing by lidar systems is very sensitive to vertical variability of atmosphere, therefore providing accurate profiling of the atmospheric properties. Presently, in order to obtain comprehensive information about both aerosol columnar proprieties and its vertical variability the co-located passive and active measurements are conducted more and more often. In addition, such combination of observations helps to improve an interpretation of some measurements. For example, passive observation provides important additional constraints regarding aerosol type and load that are useful for lidar measurements procession. This work describes the development of an inversion algorithm for simultaneous procession of lidar and radiometer observations combination that derives a united set of aerosol parameters. It is expected that such synergetic retrieval could result in additional improvements in aerosol retrieval. Application of the method for processing of co-incident ground-based observations by multi-wavelength lidar and AERONET radiometer is described. The proposed method is based on the assumption that vertical variability of aerosol spectral optical properties could be described as s mixture of fine and coarse mode aerosols with vertically constant spectral optical properties, while the vertical profiles of aerosol concentrations can change arbitrarily for each mode. Consequently the inversion algorithm retrieves the size distribution, complex refractive index, single scattering albedo and vertical distribution of both fine and coarse aerosol concentrations together with vertical profiles of both fine and coarse mode aerosol components.Potential application to different observations configurations (with or without polarimetric measurements, Raman scattering, etc.), as well as application to satellite observations are discussed.

Implications of surface albedo uncertainties to AOD retrievals from single-view and intensity only data

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It is well known that surface albedo uncertainties have an influence on the accuracy of aerosol optical depth (AOD) retrievals. Unfortunately, little is known on the quantitative AOD retrieval error due to incorrect surface albedo estimates. The error depends on the AOD retrieval sensitivity, which varies as a function of radiative transfer modeling parameters. A variable specific surface albedo leads to minimal AOD retrieval sensitivity and consequently to maximal retrieval errors due to surface albedo uncertainties. This range is referred to as critical surface albedo (CSA) and defined where the reflectance or radiance at top-of-atmosphere (TOA) does hardly depend on AOD. I will present a sensitivity study of AOD retrievals with respect to various parameters used in radiative transfer modeling. The sensitivities are derived by partial derivatives of the TOA reflectance (Jacobian matrix) with respect to AOD. My focus will be on the remarkable influence of the CSA on AOD retrievals and on the position of the CSA itself as a function of aerosol single-scattering albedo, illumination and observation geometry, wavelength and AOD. I will show that AOD retrievals of non-absorbing aerosols require dark surfaces, while strong absorbing aerosols can be retrieved more accurately over bright surfaces and that the CSA may help to estimate aerosol absorption. Many state-of-the-art AOD retrieval algorithms make use of the Jacobian matrix. But sill, many single-view and intensity only AOD retrievals neglect the presence and influence of the CSA. I suggest using the available information from the Jacobian matrix to avoid unnecessary computations with low sensitivities and large retrieval errors. Such information should also be used to provide users of AOD products with retrieval error estimates.

Benchmarking Forward 1D Radiative Transfer and Inverse Problem Solutions at JPL

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I will report on internal benchmarking exercises conducted at JPL in one-dimensional (1D) forward radiative transfer (RT) benchmarking by modelers and users, in both Earth and planetary focus areas. Part of the impetus came from Dr. A.A. Kokhanovsky's collaborative project in vector 1D RT (JQSRT 2010).

On the one hand, the JPL community has reverted to scalar 1D RT because the satellite instrument of local interest is the Multi-angle Imaging Spectro-Radiometer (MISR), which pioneered aerosol remote sensing using not only multi-spectral but also multi-view techniques, and MISR collects only intensity. That said, JPL has recently developed the Multi-angle Spectro-Polarimetric Imager (MSPI), an airborne instrument that has been deployed several times already on NASA's ER-2 platform. So there is a vigorous effort at JPL in vector 1D RT model development (Monte Carlo, Markov chain formalism, Matrix Operator Method) and exploitation (e.g., Successive Orders of Scattering, Discrete Ordinates).

On the other hand, the JPL group has pushed the benchmarking envelop significantly beyond the simple uniform layer over black surface scenario used in the 2010 JQSRT paper. These advanced benchmarking cases include a small but representative sample of aerosol particle types offering different challenges to scalar and vector RT codes. They add a small but representative sample of underlying surfaces with increasing complexity. Finally, they address forward model fidelity as well as accuracy issues by introducing atmospheres with vertically variable optical properties that are not defined by tabulation over a number of discrete layers but by analytical expressions of altitude. Basically, we have an exponentially-stratified non-absorbing Rayleigh-scattering background and a uniform layer of absorbing aerosol that can be either in the boundary layer (1-2 km) or lofted (3-5 km). Here, the Monte Carlo method alone can be customized to account for the implicitly infinite vertical resolution while all deterministic 1D RT solvers use some level of discretization.

Moreover, looking ahead toward remote sensing applications using optimization methods that explicitly call for Jacobian matrices, there is a growing interest at JPL in linearization techniques for 1D scalar and vector RT models. So far, the vector Markov chain and scalar Matrix Operator codes have been successfully linearized. As is customary, verification of the linearized code is done by comparison of outputs with Jacobian estimates using finite differences. In the latter method to estimate derivatives, one must be very careful about the choice of perturbation to ensure numerical accuracy. Somewhat paradoxically, the linearized models end up informing their non-linearized counterparts about how to properly compute finite differences. At any rate, achieving consistency between the analytical and numerical techniques is the verification criterion.

Finally, elements of the JPL (V)RT group have engaged in the aerosol retrieval algorithm intercomparisons coordinated by Dr. Kokhanovsky. This participation started with the black-surface cases with various amounts of mono-modal aerosol (AMT 2010), from which much was learned. The main lesson learned at JPL is that, if the particle type of interest is not in the look-up table (LUT) used in the MISR-style retrieval algorithm, then the retrieved aerosol optical depth is biased. JPL also contributed results to the recent exercises with Lambertian and bidirectional surfaces and a bi-modal aerosol population using a couple of retrievals based on different forward models (one vector, one scalar) coupled to different incarnations of the Levenberg-Marquardt cost-function minimization technique. Outcomes will be presented and discussed at length at the workshop.

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