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Abstracts

Aerosol/surface properties retrieval over land: experience of applying new POLDER retrieval algorithm GRASP

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The new algorithm for aerosol/surface properties retrieval (GRASP, Generalized Retrieval of Aerosol and Surface Properties) is developed now in LOA. The algorithm is based on statistically optimized inversion and takes advantages of using continuous space of aerosol and surface properties. Though algorithm can be applied to different aerosol remote sensing instruments (MERIS, AATSR, MISR, POLDER/PARASOL etc), its entire potential can be discovered on multispectral, multiangular photopolarimetric measurements. The basic principle of the algorithms and its functionality will be described and illustrated using PARASOL data. We will demonstrate the potential and the performance of the algorithm presenting regional maps of aerosol/surface parameters and providing comparison with AERONET. The main issues, advantages and perspectives of the GRASP algorithm will be discussed.

POLDER retrievals over ocean and land

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To reduce the large uncertainty on the aerosol effects on cloud formation and climate, accurate satellite measurements of aerosol optical properties (optical thickness, single scattering albedo, phase function) and microphysical properties (size distribution, refractive index, shape) are essential. Satellite instruments that perform multi-angle photopolarimetric measurements have the capability to provide these aerosol properties with sufficient accuracy. The only satellite instrument currently in space that performs multi-angle photopolarimetric measurements is the POLDER-3 instrument onboard the PARASOL microsatellite. PARASOL provides measurements of a ground scene under (up to) 16 viewing geometries in 9 spectral bands (3 for polarization). In order to make full use of the capability of PARASOL measurements of intensity and polarization properties of reflected light at multiple viewing angles and multiple wavelengths, we developed a retrieval algorithm that considers a continuous parameter space for aerosol microphysical properties (size distribution and refractive index) and properly accounts for land and ocean reflection by retrieving land and ocean parameters simultaneously with aerosol properties. Here, we present the key aspects of our PARASOL retrievals, both over ocean and land. Also, we perform a validation of retrieved aerosol properties with ground-based measurements of the AERONET network.

Use of neural networks in spectropolarimetric aerosol retrievals

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During the recent years, SRON has developed an algorithm for the retrieval of the aerosol properties from satellite multiangle spectropolarimetric measurements (Hasekamp, 2010; Hasekamp et al., 2011). The retrieval code, originally developed for the inversion of POLDER measurements and successively extended to ground-based retrievals, can be exploited in order to invert measurements from the ground-based version of the Spectropolarimeter for Planetary Exploration (SPEX) instrument (Snik et al., 2010). The algorithm performs an iterative fitting of the aerosol properties starting from a first guess that is generated by a look-up table. Since the retrieval problem is highly nonlinear, the generation of a good first guess is very important for a successful convergence of the algorithm. In this talk, we will discuss the possibility of improving the convergence and the retrieval accuracy of the algorithm by replacing the look-up table with a neural network as first guess. The neural network design process will be discussed, and the results of a comparison between the look-up table and the neural network based retrieval algorithms over an extended set of simulated ground-based observations will be shown. The generated test cases encompass noise-free as well as noisy observations, and situations where the assumed values for the non-retrieved aerosol parameters differ from the actual ones.

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Inverse methods applied to coupled atmosphere-surface systems: What if MODIS had polarization capabilities?

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Simultaneous retrieval of aerosol and surface properties by means of inverse techniques based on coupled atmosphere-surface radiative transfer modeling and optimal estimation can yield a considerable improvement in retrieval accuracy based on radiances measured by MERIS, MODIS, and similar instruments compared with traditional methods. As an example, we discuss simultaneous retrievals of aerosol and marine parameters in coastal waters from ocean color data using a unique inversion algorithm. This algorithm employs a one-step nonlinear optimal estimation method instead of the traditional two-step look-up table approach to improve retrieval accuracy. A radial basis function neural network is used to replace the forward radiative transfer model for the coupled atmosphere-water system and thereby increase retrieval speed without loss of accuracy. This algorithm has been used to analyze SeaWiFS. MERIS, and MODIS images obtained over coastal waters. Five parameters are obtained from the retrieval: aerosol optical depth, aerosol bi-modal fraction, chlorophyll concentration, absorption by colored dissolved organic matter, and backscattering coefficient. The water leaving radiance is provided as a by-product.

However, there are uniqueness problems associated with photometric remote sensing measurements (like MODIS) that ignore polarization effects, and rely on measuring only the radiance. For example, it has been shown that if only one wavelength is available, accurate aerosol information over an open ocean scene requires a sensor that measures the Stokes parameters Q and U in addition to the total radiance I. Use of polarization measurements is particularly important for absorbing aerosols over coastal waters as well as over bright targets such as snow and ice, where it has proved difficult to retrieve aerosol single-scattering albedo from radiance-only spectrometers such as MERIS and MODIS. We use a vector radiative transfer model for the coupled atmosphere-surface system in conjunction with an optimal estimation/Levenberg-Marquardt method to quantify how polarization measurements can be used to overcome the uniqueness problems associated with radiance-only retrieval of aerosol parameters. How can future instruments, which unlike MERIS and MODIS measure the Stokes parameters Q and U in addition to the total radiance I, be used to enhance our ability to retrieve accurate aerosol parameters over turbid coastal waters and bright targets like snow and ice?

Aerosol retrievals from single-scattering measurements in the visible spectrum: resolved microphysical properties, fundamental limitations, and the benefits of polarization

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This talk focuses on the sensitivity of single-scattering measurements to aerosol microphysical properties, like size distribution and complex refractive index. We present a theoretical study which analyses several hypothetical sets of single-scattering measurements at three visible wavelengths (405, 532, and 780nm). Full data includes all angularly dependent scattering-matrix elements and both the volume scattering and absorption coefficients. Information content and microphysical parameter resolution is computed for full data and for several incomplete data subsets. Comparing resolution for these measurement sets allows us to quantify, for instance, the importance of polarization for resolving the size-distribution and complex refractive index. After a brief review of single-scattering by airborne particles, the following theoretical results will be discussed: 1.) While the phase-function alone offers reasonable constraints on the size distribution for larger particles, all single-scattering measurements fail to constrain the size distribution for very-small particles. 2.) Uncertainty estimates for particle number concentration are much worse than for other loading parameters, like particle surface-area density and particle volume density. 3.) Polarimetric measurements improve retrieval uncertainty estimates in the size distribution and complex refractive index for larger particles. 4.) Measuring the absorption coefficient becomes increasingly important for determining the complex refractive index of smaller particles as their scattering behavior approaches the Rayleigh limit.

Although these results apply to single-scattering measurements only, they may provide useful intuition about satellite and aircraft retrievals of aerosols in the atmosphere.

Estimation of aerosol properties based on SGLI onboard GCOM-C1

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The second global imager (SGLI) is going to be equipped on the GCOM-C (global change observing mission - Climate #1) satellite by JAXA (Japanese space agency). The SGLI is a push broom type imager and observes Earth reflectance with 19 wavelength channels from near ultra violet to thermal infrared [380 nm, 12 µm]. The advantage of SGLI sensor in comparison with other sensors is as follows:

1) The near UV-data are available for detection of absorbing aerosols.

2) The measurements are taken with high resolution (250 m) in all visible and near- infrared channels. Then better cloud screening is expected for aerosol retrieval.

3) Polarization measurements are taken at wavelengths of 670 nm and 865 nm with tilting angles of forward (+45 º) or backward (−45 º) direction according to the latitude. Note that the polarization information involves 1 x 1 km resolution which is provided by averaging 4 x 4 detector values because of the optics adopt same telescope and linear CCD.

As a result, the precise aerosol information is estimated on a global scale by using SGLI measurements. That is to say, two standard aerosol properties as optical thickness of aerosols and its spectral tendency are retrieved based on the near infrared polarization measurements. Furthermore, near UV data is useful to retrieve absorbing aerosols as carbonaceous particles.

The 2D/3D vector radiative transfer

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One of the most efficient and widely used multi-dimensional deterministic method to solve scalar radiative transfer in the atmospheric sciences is the Spherical Harmonics Discrete Ordinate Method (SHDOM) developed by Frank Evans. Therefore, the question arises how this method can be extended and generalized to treat the far more complicated case of polarized three-dimensional radiative transfer. In this talks we address the issue how the multi-dimensional scalar Spherical Harmonics Discrete Ordinate Method (SHDOM) can be extended to the vector case. The vector model uses complex and real generalized spherical harmonics in the energetic representation of the Stokes vector. Also it retains some powerful features of the scalar model, as for example, the combination of the generalized spherical harmonic and the discrete ordinate representations of the radiance field, the use of a linear short characteristic method for computing the corner-point values of the Stokes vector, and the application of the adaptive grid technique.

The performance of the vector SHDOM is illustrated by some examples. The analysis of our numerical simulations shows that the accuracies of the solutions obtained by using the real and the complex generalized spherical harmonics are identical, but the real implementation is, on average, by a factor of 1.4 faster. Performing runs for different spatial grids and split accuracies gives an impression about the CPU requirements of the vector SHDOM implementation.

Land surface reflection modelling for satellite remote sensing

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Earth surfaces are important component of the climate system. Their interaction with incoming solar radiation as well as radiative interaction with atmosphere greatly impact on Earth energy budget. Intrinsic reflectance properties of surfaces are described by the bidirectional reflection matrix (BRM) **R**, which provides a relation between the Stokes parameters of scattered and incident radiation. On the basis of knowledge of the BRM the surface properties can be retrieved from the remote sensing measurements. Moreover, accurate models of BRM at visible and infrared wavelengths are required for retrieval of aerosols properties over Earth surfaces. Over the ocean the surface contribution is relatively small and can for most scenes be modeled with sufficient accuracy using physically-based model of BRM for water surfaces. Over land the surface reflection contribution is, in general, much larger, and shows large spatial variability, representing one of the most important problems for aerosol retrieval algorithms.

Here we will discuss the main issues and share our experience of surface reflection modeling for satellite remote sensing in visible and infrared ranges. The effect of the surface reflection modelling on aerosol/surface properties retrieval will be shown applying new PARASOL algorithm GRASP (Generalized Retrieval of Aerosol and Surface Properties).

SPEX2earth instrument development and first ground based retrievals

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SPEX, the Spectropolarimeter for Planetary EXploration, is a compact, robust and low-mass multi-viewing angle spectropolarimeter designed to operate from an orbiting satellite platform. Its purpose is to simultaneously measure, with high accuracy, the radiance and the state (degree and angle) of linear polarization at optical wavelengths of sunlight scattered in a planetary atmosphere and/or reflected by a planetary surface. In particular the degree of linear polarization is extremely sensitive to the microphysical properties of atmospheric or surface particles. Spectro-polarimetric measurements as performed by SPEX are therefore crucial for disentangling the many parameters that describe planetary atmospheres and surfaces. SPEX uses a novel technique for its radiance and polarization measurements: through a series of carefully selected birefringent crystals, the radiance of scattered sunlight is spectrally modulated. The amplitude and phase of the modulation are proportional to the degree and angle of linear polarization respectively. The technique is entirely passive, i.e. there are no moving parts or active components employed to establish the polarization modulation. We will present results of ground-based measurement with the SPEX prototype near the Cabauw Experimental Site for Atmospheric Research (CESAR) during the PEGASOS campaign in May 2012. Retrievals of aerosol parameters have been performed using only polarimetric data as well as both polararimetric and radiance data of the SPEX prototype. Furthermore, we will present recent instrument developments to extend the SPEX concept for a dedicated Earth atmosphere satellite mission, named SPEX2Earth.

Airborne Multiangle SpectroPolarimetric Imager (AirMSPI) observations over California during NASA's Polarimeter Definition Experiment (PODEX)

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The Airborne Multiangle SpectroPolarimetric Imager (AirMSPI) is a pushbroom camera mounted on a gimbal to acquire multiangle imagery over a ±67° along-track range. It flies aboard NASA's high-altitude ER-2 aircraft. Radiance data are obtained in the ultraviolet, visible, and near-infrared, and linear polarization is measured in three of the instrument's eight spectral bands. We will present and discuss examples of data acquired over California during January-February 2013 as part of NASA's Polarimeter Definition Experiment (PODEX). In particular, we will show AirMSPI observations of aerosols, low- and mid-level cloud fields, cirrus, and clear skies over the San Joaquin Valley and the Pacific Ocean during PODEX. Analyses of radiance and polarization imagery will be presented to illustrate instrument sensitivity to aerosol and cirrus cloud optical depths and microphysical properties. AirMSPI polarimetric sensitivity to cloud droplet size distributions will also be presented and discussed.

The Potential of Passive VNIR Observations in Gaseous Absorption Regions to Retrieve Aerosol Vertical Profiles

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The direct and indirect roles aerosols play in the radiative budget of the Earth are major uncertainties in our ability to predict climate change [IPCC, 2007]. Since aerosols originate from a variety of sources, are distributed across a wide spectrum of particle sizes and have atmospheric lifetimes that are much shorter than those of most greenhouse gases, their concentrations and composition have great spatial and temporal variability. Despite the urgent need to better understand the spatial distribution of aerosols, there is a paucity of systematic vertical profile measurements of size-segregated or even total atmospheric aerosol physical, chemical and optical properties. For these parameters, no climatological database exists that can be used to evaluate the performance of climate models that include aerosols as active constituents. Consequently there is a pressing need to develop novel methods to better observe the vertical distribution of aerosol optical properties from satellites and from the ground. We show that polarimetric measurements of the O_2 *A* band (757–772 nm) by the Japanese Greenhouse Gases Observing Satellite (GOSAT) can be used to retrieve aerosol vertical profiles. The fundamental physical reason for using the O_2 *A* band is its large dynamic range of absorption as a function of wavelength. Where there is significant absorption, the reflected signal that reaches the satellite comes from the upper part of the atmosphere. On the other hand, where the absorption is negligible, scattering from lower layers becomes increasingly more pronounced. Further, O_2 is well mixed with known concentration in the atmosphere and the extinction due to Rayleigh scattering is also known. Thus, it is possible to separate the effects of aerosol scattering from O_2 absorption and Rayleigh scattering. Jiang et al. [2003] and Boesche et al. [2008] showed that the degree of linear polarization inside the O_2 *A* band offers an additional constraint on the vertical distribution of aerosol and cirrus clouds. The change in polarization between the continuum and the line cores reflects the different polarizing properties of the aerosols in the lower and upper parts of the atmosphere. In other words, polarization provides information about the location as well as the type of aerosol. The latter is not possible with radiance-only measurements. Further, even the former is hard to attain without high spectral resolution. We have carried out a quantitative analysis of the information content and degrees of freedom in the profile retrieval of aerosols from measurements of O_2 absorption in the *A* band. We show results for the degrees of freedom for aerosol profile retrievals, estimated using this technique, as a function of instrument parameters such as spectral resolution and SNR. We also demonstrate the added benefits due to including polarimetric measurements.

Polarimetric sensitivities to absorbing aerosol height and single scattering albedo

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The central concern of this work is the assessment of the effects of absorbing aerosol properties in light of measurement uncertainties achievable for the next generation of multi-angle polarimetric imaging instruments. We focus on sensitivities to absorbing aerosol layering and refractive indices resulting in various single scattering albedos (SSA) for both spherical and non-spherical absorbing aerosol types. In particular, we consider one flaming smoke type and two smoldering smoke types, whose refractive indices are constrained by direct measurements, and two dust types whose refractive indices are calculated according to observationally-constrained hematite content. The phase matrices for the spherical smoke particles were calculated using a standard Mie code, while those for the non-spherical dust particles were calculated using the numerical approach described by Dubovik et al., 2006. Modeling experiments were performed to determine how the measured Stokes vector elements in the ultraviolet, visible, and near-infrared (UV/VNIR) range are affected by the vertical distribution, mixing and layering of smoke and dust aerosols, and aerosol SSA. Based on these studies, we demonstrate advantages and disadvantages of wavelength selection in the UV/VNIR range to assess absorbing aerosol properties. In particular, polarized UV channels do not show a significant advantage for absorbing aerosol height or property characterization due to the dominance of the Rayleigh scattering signal. Although the polarimetric sensitivity to SSA is small, it may be non-negligible when attempting to retrieve other aerosol parameters using polarimetric measurements.

Linearized Principal Component Analysis as a Tool to Speed up Remote Sensing Retrievals

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Radiative transfer (RT) computations are an essential component of many remote sensing retrieval problems. In particular, RT models are required for the generation of simulated radiances from satellite, ground-based and other platforms. In many inverse-modeling applications, RT models are also needed to calculate Jacobians (partial derivatives of radiances with respect to atmospheric, surface or other parameters). However, full treatment of RT processes is computationally expensive. This is particularly true for Observation System Simulation Experiments (OSSEs); these experiments are often designed to investigate possible strategies for instrument synergy, and they invariably require massive RT forward modeling over wide spectral ranges. Furthermore, new-generation low-orbit and geostationary satellite instruments coming up for launch in the next decade will be generating data at rates that current computing power is unlikely to match. For these and other reasons, there is a pressing need for RT performance enhancement for a wide range of applications. Over the years, several techniques have been proposed to enhance the speed of RT modeling; these include correlated-k methods [Lacis and Oinas, 1991], spectral binning [Crisp, 1997]; optimal spectral sampling [Moncet et al., 2008], asymptotic methods for semi-transparent media (see [Nauss and Kokhanovsky, 2011] for a review), low-stream interpolation methods [Duan et al, 2005; O'Dell et al., 2010], and low-orders of scattering approximations [Natraj and Spurr, 2007]. A comprehensive review of RT performance enhancement methods has appeared in a recent paper [Natraj, 2013]. Natraj et al. [2005] demonstrated the ability of a technique using principal component analysis (PCA) to speed up scalar RT simulations (no polarization) at high resolution in and around the O2 A band; this technique was later expanded to RT modeling with polarization for the O2 A band and the weak and strong CO2 absorptions bands (1.61 μm, 2.03 μm) [Natraj et al., 2010]. In the PCA method for RT performance enhancement, empirical orthogonal functions (EOFs) are developed for binned sets of inherent optical properties that possess some redundancy; costly multiple-scattering RT calculations are only done for those (few) optical states corresponding to the most important principal components, and correction factors are applied to approximate radiation fields. Here, we extend the PCA method to a much wider set of applications in remote sensing and OSSEs. This work has a number of new theoretical developments, mainly concerning the analytic linearization of the PCA itself, and the subsequent development of analytic Jacobians for the PCA-based radiation fields. We will present results for applications involving extended backscatter simulations over the UV and visible ranges, and over spectral ranges requiring treatment of thermal emission (alone) and coupled scattering/emission. We also show that the PCA method may be employed to speed up total ozone retrievals using spectral fitting.

A hierarchy of Jacobian calculations: using the Green's function to construct hybrid approximations

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Clearly the easiest way to calculate the perturbations required in an optimal estimation scheme is to use the single scattering approximation. However when looking down, the often large and spectrally varying contributions of the surface are not effectively captured by the single scattering approximation, particularly at shorter wavelengths where diffuse transport plays a significant role. The first, and easiest modification to calculating Jacobians using the single scattering approximation is therefore to evaluate the effect of surface perturbations exactly using the Green's function for transport to the surface and back to the top of the atmosphere (or an aircraft embedded in the atmosphere). The variations in the atmospheric contribution as a function of the retrieved parameters when calculated using the single scattering approximation, will again be less well modeled at shorter wavelengths where diffuse transports are more important. The next step in the hierarchy of approximations for the Jacobians is therefore to recognize that a better approach includes diffuse transport of the single scattering source term using the Green's function for transport from any interior point back to the top of the atmosphere (or aircraft). The final step in the hierarchy is the exact calculation of Jacobian's using Green's functions for transport of radiation into and out of the atmosphere and their coupling through the usual radiative perturbation theory. Thus any radiative transfer technique that provides the Green's function can be used to construct a hierarchy of approximations for Jacobians with increasing levels of computational cost and accuracy. This presentation shows how such a hierarchical approach can be used in an iterative retrieval scheme.

Radiative transfer in coupled atmosphere-ocean-cryosphere systems: A review of recent developments based on the discrete-ordinate method

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Reliable, accurate, and efficient modeling of the transport of electromagnetic radiation in turbid media has important applications in the study of the Earth's climate by remote sensing. For example, such modeling is needed to develop forward-inverse methods used to quantify types and concentrations of aerosol and cloud particles in the atmosphere, the dissolved organic and particulate biogeochemical matter in lakes, rivers, coastal, and open-ocean waters. In addition it is needed to simulate the performance of remote sensing detectors deployed on aircraft, balloons, and satellites as well as radiometric detectors deployed on buoys, gliders and other aquatic observing systems. Accurate radiative transfer modeling is also required to compute irradiances and scalar irradiances that are used to compute warming/cooling and photolysis rates in the atmosphere, primary production and warming/cooling rates in the water column, and the radiation available for photochemistry and energy deposition in the cryosphere. A review will be provided of the current status of radiative transfer methods based on the discrete-ordinate method starting with the scalar case applicable to a single slab, and its extension to a coupled system consisting of two adjacent slabs with different indices of refraction. Extensions needed for twilight geometry will be discussed, and examples of radiative transfer computations in coupled atmosphere-ocean-cryosphere systems will be provided. Finally, an extension of the discrete-ordinate method to include polarized radiative transfer in coupled atmosphere-ocean-cryosphere systems will be presented.

Polarized radiative transfer through terrestrial atmosphere and ocean: modeling with SCIATRAN

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The SCIATRAN 3.1 package is a result of further development of the SCIATRAN 2.X software family which, similar to previous versions, comprises a radiative transfer model and a retrieval block. After an implementation of the vector radiative transfer model in SCIATRAN 3.0 the spectral range covered by the model has been extended into the thermal infrared. The databases of aerosol and cloud scattering characteristics are provided for the spectral range 0.24-40 μm. Another major improvement is accounting for the underlying surface effects. Among others, a sophisticated representation of the water surface with a bidirectional reflection distribution function (BRDF) has been implemented accounting for the Fresnel reflection of the polarized light and for the effect of foam. A newly developed representation for a snow surface allows radiative transfer calculations to be performed within an unpolluted or soiled snow layer. Furthermore, a new approach has been implemented allowing radiative transfer calculations to be performed for a coupled ocean-atmosphere system. This means that, the underlying ocean is not considered as a purely reflecting surface anymore. Instead, full radiative transfer calculations are performed within ocean allowing the user to simulate the polarized raditive transfer both in the atmosphere and the ocean. Similar to previous versions, the simulations can be performed for any viewing geometry typical for atmospheric observations in the UV-Vis-NIR spectral range (nadir, limb, off-axis, etc.) as well as for any observer location within or outside the Earth's atmosphere including underwater observations. The new model is freely available for non-commercial use via the web page of the University of Bremen (www.iup.physik.uni-bremen.de/sciuatran). In this presentation a short description of the software package, especially of the new features of the radiative transfer model is given. Furthermore, some applications of SCIATRAN for the solution both atmospheric and ocean optics problems are shown.

Polarized radiative response of 3D inhomogeneous scenes

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In the presented work, fields of solar radiation in the Rayleigh scattering atmosphere with three-dimensional inhomogeneities of the underlying landscape are investigated. The key questions addressed in this study are 1) how important are the polarization measurements for the retrievals ? And 2) what is the impact of inhomogeneous or unknown landscape beneath?

Radiative transfer calculations are performed with the computer algorithm based on the discrete ordinates (DO) approach. Finite difference scheme with upwind differences is implemented. Angular distributions of the intensity and polarization parameters of the radiation field are approximated with the spherical Gaussian quadrature of 29^{th} order (302 nodes on the sphere).

To validate the algorithm, one-dimensional RT calculations have been performed and compared against the benchmark results (http://www.iup.uni-bremen.de/~alexk/). Three-dimensional scenes with flat layered Rayleigh scattering atmospheres and inhomogeneous underlying landscape were also simulated.

For different observational configurations, the Bayesian likelihood function are calculated and analysed. Optical thickness retrievals with different reflective properties of the landscape have been considered 1) optical thickness retrieval with a priori known reflective parameters of the landscape and 2) joint retrieval of the atmospheric optical thickness and landscape reflectivity both for 1D and 3D models. Role of the polarization measurements in the retrieval in different observational configurations is discussed.

AN OVERVIEW OF ACCELERATION TECHNIQUES FOR LINEARIZED RADIATIVE TRANSFER CODES

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Several acceleration techniques for linearized radiative transfer codes are analyzed. We performed the linearization of the left eigenvector matrix approach and the telescoping technique to investigate their impact on the computational time. For ozone retrieval, the presented methods provide a relative speedup of about 15 % and 40 %, respectively. We present the optimization of the radiative transfer computations in which the cloud layer is involved. It provides almost a double speed-up of computations. We also compare two techniques of treating a multilayer system: the whole atmosphere approach and the matrix operator method. The numerical simulations showed that the linearized version of the whole atmosphere approach is 3 times faster than the linearized matrix operator method in the case of 40 layer atmosphere. To accelerate the processing of data, V.Natraj proposed to use the principal component analysis (PCA) to reduce the dimensionality of the optical parameters of the atmosphere. We demonstrate the flexibility of this method by introducing several dimensionality reduction techniques for the optical parameters. Besides the principal component analysis, these techniques include local linear embedding methods (locality pursuit embedding, locality preserving projection, locally embedded analysis), and discrete orthogonal transforms (cosine, Legendre, wavelet). By linearizing the corresponding radiative transfer model, we analyze the applicability of the proposed methods to a practical problem of total ozone column retrieval from GOME measurements. The design of a linearized radiative transfer model has been established without specializing the linearization approach to a specific dimensionality reduction method.

Forward vector radiative transfer model intercomparison: status report and future plans

Anthony Davis, and the extended JPL radiative transfer taskforce

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I will report on advances in forward 1D scalar and vector radiative transfer benchmarking activity at JPL, with participation from NASA Langley and Bremen University. Two Phases are defined, each with a particular computational challenge for the models. In Phase 1, the lower boundary condition is always black (purely absorbing), which approximates an dark oceanic surface, but varies significantly the atmosphere while in Phase 2 the surface can be black or one of 6 different types representative of water or land with different levels of polarimetric complexity.

Phase 1 considers one Rayleigh, with depolarization, and 3 carefully selected aerosol atmospheres: they are at once geophysically relevant and add optical complications one-by-one. Thus we start close to previously performed benchmarks (standard Rayleigh and a single aerosol model), and add complexity incrementally. Specifically, the fine "smoke" particle has just a little more phase function variability than the Rayleigh case, but is strongly absorbing. The non-absorbing coarse "salt" particle has strong forward and backward peaks. Finally, the coarse "dust" particle is forward-peaked, absorbing, and non-spherical (thus requiring two more independent phase matrix elements than the other two). In all three cases, the aerosol phase functions or matrices are provided to the modelers in the form of 1/4-degree tabulation. The main challenge of Phase 1 however is the of Rayleigh and dust aerosol for which we have defined 6 cases: low and high aerosol layer, with three Rayleigh optical depths. The mixing is defined as spatially continuous with Rayleigh extinction following an exponential decay with altitude while the aerosol layer is uniform, and the reference Monte Carlo model was customized to treat this stratification exactly (no discretization into sublayers). The sun is maintained at 60 degrees from zenith and the output of interest is limited to the 9 MISR viewing directions in the upper principal plane (both forward and backward looking) and, more realistically, in a plane at 45 degrees from it.

Phase 2 restricts the atmosphere to either a pure Rayleigh case, without depolarization, or the pure salt particle case with the difference that the modelers can use either the previously provided tabulation or the microphysical definition of the spherical particle population, and thus regenerate their own tables and/or expansion coefficients using Lorentz-Mie code. First, the black surface is revisited with the sun at 30 degrees from zenith and many more (fore and aft) angles in the upper principal plane and the 15 degree azimuth plane. This observation geometry emphasizes interesting features in the various reflective surface models. These are on the one hand, a depolarizing Lambertian case and a depolarizing anisotropic one (using the "mRPV" parameterization), and on the other hand, a pure specular (Fresnel interface) case and a roughened ocean (Cox-Munk) case along with a hybrid Lambertian-Breon micro facet case to capture a partially polarizing land surface case. A new shadowing function was derived to ensure energy conservation in this last case at all incidence angles. As in Phase 1, surface complications are added one-by-one to help modelers diagnose possible issues. Most participating models needed to supplement their existing surface portfolio with one or more of these benchmark cases.

For both Phases, the accuracy of the predicted radiances or Stokes vectors are compared to instrumentally pre-defined goals for both radiometry and polarimetry, primarily using the degree of linear polarization. All the participating models can achieve these goals most of the time. However, the cost of reaching them in CPU time can be considerable. At present, we assess this cost in terms of how many streams, Legendre expansion terms, and azimuthal modes are required. This is important information for the design of future aerosol/surface retrieval schemes. We plan to perform rigorous efficiency comparisons at least for some of the participating models that can be easily ported to the same platform and recompiled.

Aerosol retrievals in cloud-contaminated scenes

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Small amounts of cloud-contamination can cause large errors and/or biases in the retrieval of micro-physical and optical aerosol parameters from satellite observations. Therefore, it is common practice to only perform aerosol retrievals for scenes that are strictly screened for clouds. This, unfortunately, removes many near-cloud scenes from data-sets, while exactly those scenes are interesting for analyses of the aerosol cloud interactions. Observations and retrieval methods that can deal with cloud-contamination are required. Instruments that do multi-angle observations of intensity and especially polarization are most capable to separate between aerosols and cloud-contamination, since scattering by cloud droplets produces a distinctive feature in the degree of linear polarization at a scattering angle of about 140 degrees. The only instrument that currently performs those observations is POLDER3 on board the PARASOL satellite. Hasekamp et.al. [J. Geophys. Res., 116, D14204, 2011] have developed an algorithm that makes full use of the information in POLDER3 measurements for clear sky scenes. Our aim is to extend the retrieval scheme to also retrieve aerosol properties in cloud contaminated scenes. As a first step, the effects of residual cloud cover/cloud-contamination on the aerosol retrieval algorithm are analyzed. In order to do so cloud properties obtained from the MODIS Cloud Product have been co-located with the POLDER3 observations and the retrieved micro-physical and optical aerosol parameters are compared with independent ground based measurements from AERONET for different amounts and types of cloud contamination. The validity and limitations of the retrievals in cloud-contaminated scenes are discussed and the latest results of retrievals with an algorithm that simultaneous retrieves the cloud properties are presented.