ICAROHS - INTER-COMPARISON OF AEROSOL RETRIEVALS AND OBSERVATIONAL REQUIREMENTS FOR MULTI-WAVELENGTH HSRL SYSTEMS

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1. INTRODUCTION

Aerosols play a key role in the Earth radiation budget through direct radiative effects (extinction and reflection of solar and IR radiation) and indirect effects (impact on cloud formation and life time). In the atmospheric boundary layer they are a key component affecting air quality. The bulk part of aerosols remains in the planetary boundary and influences local and regional air quality around the source regions. Some source processes like desert dust mobilisation, forest fire burning and grassland burning, however, lead to lifted aerosol layers which are transported over large distances in the free troposphere well above the boundary layer. Particularly with respect to the long-range transport of aerosols, to air quality impacts, and to climate effects, the observation of aerosols on a global scale requires strong improvement compared to the current status.

To large extent, uncertainties in climate prediction are related to uncertainties in the contribution of aerosols to climate change (IPCC, 2007). The community has developed a strategy towards the global mapping of the aerosol properties relevant for climate impact studies (Anderson et al., 2005). This approach tackles the global mapping of key parameters governing the direct climate forcing of aerosol particles:

1. aerosol optical depth δ,
2. radiative efficiency parameter of aerosol types E, given in Watts per square meter.

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The modification of the outgoing shortwave flux at top of the atmosphere ΔF defines the direct climate forcing of aerosols. This quantity can be expressed as

$$\Delta F = \delta\, E$$

ΔF is linked to the temperature change ΔT by the climate sensitivity λ via

$$\Delta T = \lambda\, \Delta F.$$

Active remote sensing methods like spaceborne lidars are promising approaches towards the global mapping of aerosol radiative properties like the aerosol single-scattering albedo and the hemispheric upscatter fraction which both constitute the aerosol radiative efficiency parameter E.

At present CALIPSO as part of NASA's A-TRAIN is the only spaceborne lidar available. The A-Train strategy (Anderson et al., 2005) refers to this combination of spacecraft. The CALIOP instrument is designed as a backscatter lidar, which requires assumptions on the ratio of extinction to backscatter (lidar ratio) for the data analysis. The lidar ratio however depends on cloud/aerosol type and particle shape, which means that the data analysis requires a-priori assumptions on the aerosol/cloud type.

The only current methods for separating aerosol signals from molecular backscatter signals are the High Spectral Resolution Lidar (HSRL) and Raman lidar approaches. A multi-wavelength HSRL would significantly improve the distinction of different aerosol types and clouds.

It would also permit the observation of the climate-relevant aerosol parameters with one single instrument since multi-wavelength HSRL can deliver optical depth, δ, the aerosol size via the colour ratio, an estimate for aerosol absorptivity and thus aerosol type, and

E via the lidar ratio, and the anthropogenic contribution from global mapping combined with meteorological analyses.

2. ICAROHS OBJECTIVES

The ESA-funded study ICAROHS, which started on 1 April 2009 with a duration of 18 months, exploits the potential improvements and benefits of novel multi-wavelength high spectral resolution lidar technology combined with innovative retrieval methods for future satellite missions.

The main goals of ICAROHS are:

the delivery of quality-controlled and validated retrieval algorithms for primary geophysical products (backscatter profile, extinction profile, lidar ratio profile, aerosol classification);

aerosol microphysical products (effective radius, refractive index. aerosol layer height) classification from spaceborne multi-λ HSRL.

Recommendations for future multi-wavelength HSRL missions are formulated on the basis of a combined retrieval of aerosol properties from the entire available lidar and in-situ data. This retrieval study forms the benchmark for aerosol properties accessible by respective HSRL missions and defines the technical limits for required accuracy and resolution of the lidar input data to the novel algorithms.

The long-term target instrument is a spaceborne multi-wavelength HSRL configuration. The study investigates various potential configurations based on the EarthCARE simulator (ECSIM). The ATLID instrument serves as a reference instrument for the instrument configurations investigated in ICAROHS (see e.g., Ansmann et al., 2007).

The deliverables of ICAROHS are:

an evaluated multi-wavelength HSRL retrieval algorithm;

recommendations for future spaceborne HSRL missions beyond EarthCARE and CALIPSO which operate the (1+1) ATLID on EarthCARE, or the single-wavelength backscatter lidar CALIOP on CALIPSO;

a database of reference scenes for ECSIM validation;

a database of scattering phase functions of non-spherical particles for ECSIM;
validated retrieval algorithms for geophysical products including HSRL-λ = 355, 532 nm;

validated inversion algorithms for aerosol properties from multi-λ HSRL data (3+2).

3. The ICAROHS CONSORTIUM

The consortium behind ICAROHS combines the following competences in the field of lidar- and in-situ based aerosol observation and simulation:

DLR
Coordinator of ICAROHS;
HSRL – and in-situ field data implementation for algorithm validation;
airborne iodine molecular vapour HSRL algorithm.

Institute for Tropospheric Research
Fabry-Perot HSRL;
ATLID/ground-based multi-λ Raman lidar;
inversion of aerosol microphysical properties.

KNMI
EarthCARE simulator (ECSIM) algorithm development and implementation.

University of Munich
Scattering libraries for non-spherical particles calculated by the T-matrix method.

DEIMOS
Support of KNMI in technical documentation and software management.

4. ICAROHS APPROACH

The selected approach relies on the following key tools and methods to be used:

#1 Airborne 1λ - HSRL measurements for various aerosol types from field studies.

#2 Aerosol in-situ measurements aligned with 1λ - HSRL data from field studies.

#3 Ground-based multi-λ Raman lidar measurements aligned with airborne HSRL and in-situ data from field studies.

#4 T-matrix method for calculating scattering phase functions of non-spherical particles.

#5 ECSIM as the key platform for development, testing and implementation of new algorithms.

#6 Retrieval of aerosol properties from HSRL, multi-λ backscatter lidar and aerosol in-situ data for testing of uncertainties and defining the requirements for future multi-λ HSRL instruments.

Figure 1 shows a schematic overview over the study structure.

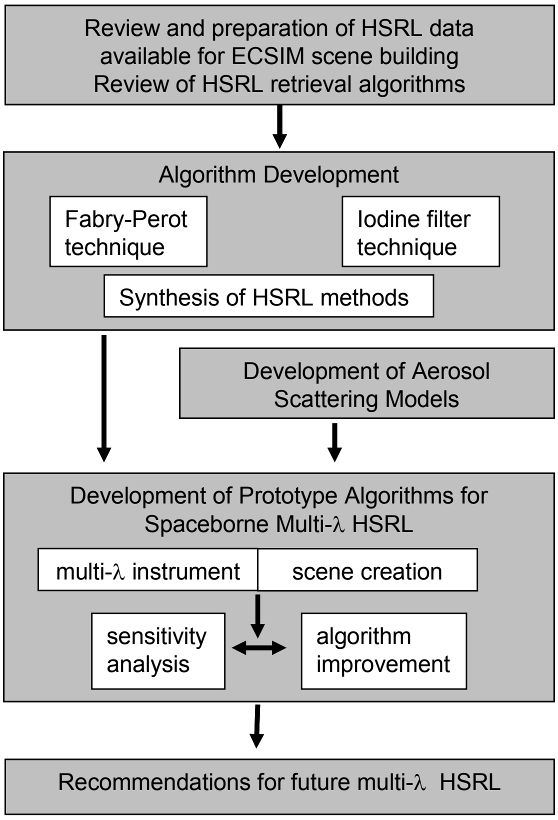

Figure 1. The ICAROHS study structure.

Current single-wavelength High Spectral Resolution Lidar (HSRL) data from several field studies are used as data base for the development of improved scientific algorithms for retrievals of aerosol optical properties and of tools for future multi-wavelength space-borne HSRL instrumentation assessments. These quality-controlled data sets feed into the existing ECSIM which is used as a platform for algorithm improvement.

The study will use observational data from airborne (aerosol in-situ, HSRL) and ground-based (multi-wavelength Raman lidar) observations from field studies coordinated by members of the consortium:

LACE	Central European continental aerosol; forest fire plumes in the free troposphere
EUCAARI	Central European continental aerosol; clean polar air masses
SAMUM-1	desert dust from NW Sahara polluted and aged desert dust marine aerosol
SAMUM-2	desert dust from the Sahel Central Africa biomass burning aerosol

Particle non-sphericity is included by means of T-matrix calculations which deliver scattering libraries for the implementation into ECSIM. ICAROHS considers multi-wavelength HSRL, which measures volume backscatter and extinction coefficients of aerosols at several wavelengths, the most promising future aerosol active remote sensing method.

The approach which is applied for the classification of various aerosol types is illustrated in Figure 2. Form the set of field data, typical combinations of aerosol properties accessible by lidar will be used as a starting point for the aerosol classification algorithm. From the respective in-situ measurements of aerosol microphysical and optical parameters of each aerosol type (see Figure 3 for an overview of deployed instruments) we deduce radiative efficiency parameters for the identified aerosol types.

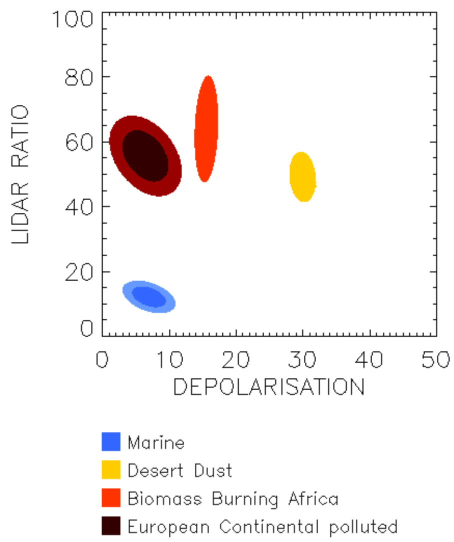

Figure 2. Lidar ratio and depolarisation for various aerosol types.

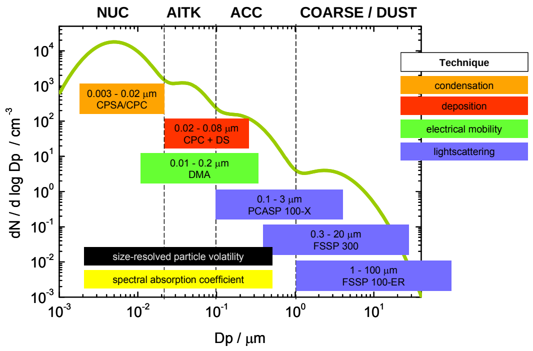

Figure 3. Schematic aerosol number size distribution and corresponding measurement methods as well as specific instruments for the various size ranges which were operated on board of the DLR Falcon research aircraft.

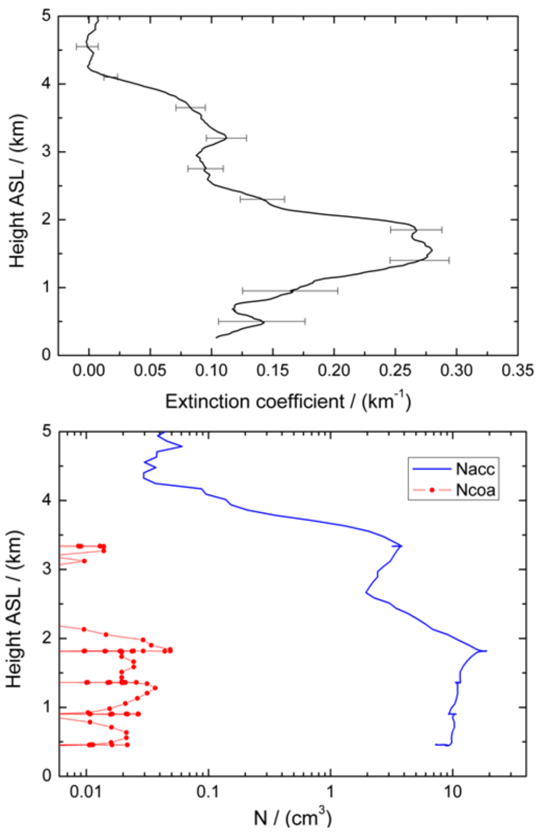

Figure 4. Example of combined lidar in-situ data: the top panel shows the HSRL extinction profile measured during SAMUM-2 on 4 February 2008 over the Atlantic ocean; the bottom panel shows respective profiles of accumulation mode aerosol (particle diameters from 100 nm to 1 µm) and coarse mode aerosol (particle diameter larger than 1 µm, see also Figure 3).

Figure 4 gives an example of the data available for the validation of the ECSIM algorithms. For selected cases lidar extinction profiles can be combined with in-situ data on aerosol profiles, particle size distributions, refractive index and aerosol mixing state.

The in-situ data permit a detailed calculation of aerosol optical and microphysical properties which serve as validation input for ECSIM aerosol products.

Extensive examples of the selected approach of calculating aerosol optical properties from microphysical parameters and combine them with measured lidar extinction data are widely discussed in Wandinger et al. (2002) for biomass burning aerosol, and in Esselborn et al. (2009); Petzold et al. (2009) and Weinzierl et al. (2009) for desert dust.

The scene building for ECSIM is one of the key steps within ICAROHS. It consists of several parts:

1. Select a case based on the real lidar observations.
2. Invert aerosol extinction and backscatter coefficients from real lidar data.
3. With the aid of aerosol in-situ data on size distribution, mixing state and aerosol absorption, decide on the aerosol types present matching an aerosol model that exists in the simulator.
4. Again with the aid of in-situ data or information from multi-wavelength inversions assign size distribution parameters to the aerosol field.
5. Format the information from steps 2, 3 and 4 into a file that can be read by *ECSIM*. As well, a file describing the T, p, ρ etc. information has to be created.
6. Make the scene.

During the validation of ECSIM algorithms the aircraft which carried the single-λ HSRL system during the field measurements will be treated as a low and slow flying satellite. This procedure allows the evaluation of ECSIM results against real HSRL scenes from the field studies.

Sensitive studies will then be performed to test the simulation models, to determine the uncertainties in the retrievals as a function of instrumental parameters, and atmospheric input parameters, and to quantify the potential and the limits of a multi-wavelength HSRL.

In summary, the selected approach is considered to provide a detailed assessment of requirements and expected benefits for any multi-λ HSRL systems for global aerosol observation. The strength of the approach is the fact that all algorithms can be tested against real data from airborne HSRL, ground-based multi-λ lidar and extensive aerosol in-situ data.

5. References

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