ENVRI^{plus} DELIVERABLE

D1.4

Report on integration across networks: common strategy and common sensors for LIDAR and aerosol extinction measurements

WORK PACKAGE 1 – New sensor technologies: innovation and services

LEADING BENEFICIARY: FORSCHUNGSZENTRUM JÜLICH

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ABSTRACT

As part of ENVRIplus Task 1.2: Common methodologies for inter-comparison and joint field tests: "use Case2: Common sensors", this report describes a strategy to measure the aerosol extinction coefficient within the atmospheric domain RIs ACTRIS, IAGOS and ICOS. An inter-comparison campaign was successfully realized in summer 2015, combining in-situ and remote sensing measurements of the aerosol extinction coefficient.

The aerosol extinction coefficient describes the attenuation (absorption + scattering) of solar radiation by atmospheric solid and fluid particles and is one of the governing parameters describing the aerosol climate interactions. At ACTRIS sites the extinction coefficient is measured as function of height using the Raman LIDAR (Light Detection And Ranging) technique, whereas IAGOS will measure this parameter in situ using the Cavity Attenuated Phase Shift (CAPS) technique onboard in-service passenger aircraft. Here, height profiles are measured during takeoff and landing of the aircraft. CAPS is an absolute measurement technique, thus there is no need for calibration.

This report compiles a short description of the selected techniques; the benefits compared to other techniques and references of the associated data processing chains. Furthermore this document summarizes performed tests and selection criteria used to choose the methods mentioned above.

As a result of the discussions within ENVRIplus community, it turned out that the RI ICOS is mainly interested in estimating the Planetary Boundary Layer (PBL) height. Here the participant RI ACTRIS offered guidance using Doppler LIDAR instruments to measure PBL Dynamics instead of the previous preferred ceilometer technique which was also rated not applicable for aerosol extinction / PBL measurements within ACTRIS. As a first step is was agreed to share measured PBL heights between ACTRIS and ICOS.

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Amendments, comments and suggestions should be sent to the authors (u.bundke@fz-juelich.de)

TERMINOLOGY

A complete project glossary is provided online here:
https://envriplus.manageprojects.com/s/text-documents/LFCMXHHCwS5hh

Acronyms used in this document are also listed in the Glossary section

PROJECT SUMMARY

ENVRIplus is a Horizon 2020 project bringing together Environmental and Earth System Research Infrastructures, projects and networks together with technical specialist partners to create a more coherent, interdisciplinary and interoperable cluster of Environmental Research Infrastructures across Europe. It is driven by three overarching goals: 1) promoting cross-fertilization between infrastructures, 2) implementing innovative concepts and devices across RIs, and 3) facilitating research and innovation in the field of environment for an increasing number of users outside the RIs.

ENVRIplus aligns its activities to a core strategic plan where sharing multi-disciplinary expertise will be most effective. The project aims to improve Earth observation monitoring systems and strategies, including actions to improve harmonization and innovation, and generate common solutions to many shared information technology and data related challenges. It also seeks to harmonize policies for access and provide strategies for knowledge transfer amongst the RIs. ENVRIplus develops guidelines to enhance transdisciplinary use of data and data-products supported by applied use-cases involving RIs from different domains. The project coordinates actions to improve communication and cooperation, addressing Environmental RIs at all levels, from management to end-users, implementing RI-staff exchange programs, generating material for RI personnel, and proposing common strategic developments and actions for enhancing services to users and evaluating the socio-economic impacts.

ENVRIplus is expected to facilitate structuration and improve quality of services offered both within single RIs and at the pan-RI level. It promotes efficient and multi-disciplinary research offering new opportunities to users, new tools to RI managers and new communication strategies for environmental RI communities. The resulting solutions, services and other project outcomes are made available to all environmental RI initiatives, thus contributing to the development of a coherent European RI ecosystem.

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REPORT ON INTEGRATION ACROSS NETWORKS: COMMON STRATEGY AND COMMON SENSORS FOR LIDAR AND AEROSOL EXTINCTION MEASUREMENTS

Introduction

At present, atmospheric aerosols are considered one of the major uncertainties in climate forcing (Forster, 2007; Boucher, 2013), and a detailed aerosol characterization is needed in order to understand their role in the atmospheric processes as well as human health and environment. The most significant cause of uncertainty is the large variability of aerosols in space and time. Due to their short lifetime and strong interactions, their global concentrations and properties are poorly known. For these reasons, the large-scale three-dimensional aerosol distribution in the atmosphere should be continuously monitored. Which aerosol parameter must be observed and which resolution and accuracy is required depends strongly on the scientific objective. For example, for radiative studies, it is useful to measure aerosol optical properties, whereas for studies on the impact on the environment and health, it is more relevant to investigate aerosol microphysical properties. Specifically for climate studies related to aerosol–cloud–radiation interaction, it is necessary to measure aerosol optical properties, size, morphology, and composition as a function of time and space, with a high resolution in both domains to account for the large variability. Since it is in particular the information on the vertical distribution that is lacking, advanced laser remote sensing e.g. LIDAR (LIght Detection And Ranging) is the most appropriate tool to close the observational gap for ground based measurement sites (Pappalardo et al., 2014).

As long as remote sensing techniques need to be calibrated using in situ instruments a ground truth measurement is needed. The RI IAGOS is capable to provide in situ measured profiles of atmospheric aerosol extinction during takeoff and landing of in service aircrafts on a regular basis. Here the Cavity Attenuated Phase Shift (CAPS) technique as an absolute measurement technique can provide aerosol extinction measurement with high temporal and spatial resolution.

The framework of ENVRIplus gives the possibility to adjust measurement techniques used across the different atmospheric domain research infrastructures ACTRIS, IAGOS and ICOS. First, a survey of the different techniques available for remote sensing and in situ measurement will be presented.

REMOTE SENSING TECHNIQUE: LIDAR

LIDAR techniques represent the optimal tool to provide range-resolved aerosol data. Several LIDAR techniques are suitable for aerosol studies. In the last ten years rapid progress in laser technology, detection techniques, and data acquisition systems has contributed to a much wider use of these techniques for aerosol monitoring, ranging from the simple elastic backscatter LIDAR to the most advanced multi-wavelength Raman LIDAR systems.

Basic Setup of a LIDAR system

The basic setup of a LIDAR system is shown in Figure 1 In principle, a LIDAR system consists of a transmitter and a receiver. Short light pulses in the range of a few to several hundred nanoseconds and specific spectral properties are emitted by the laser. At the receiver side a telescope collects the photons backscattered from the atmosphere. The collected light is then usually transferred toward an optical analyzing system. Here, depending on the application, specific wavelengths or polarization states out of the collected light are selected. The following detector converts the optical signal into an electrical signal. The intensity of this signal as function of the time elapsed after the transmission of the laser pulse is determined electronically and stored in a computer. (Weitkamp, 2005)

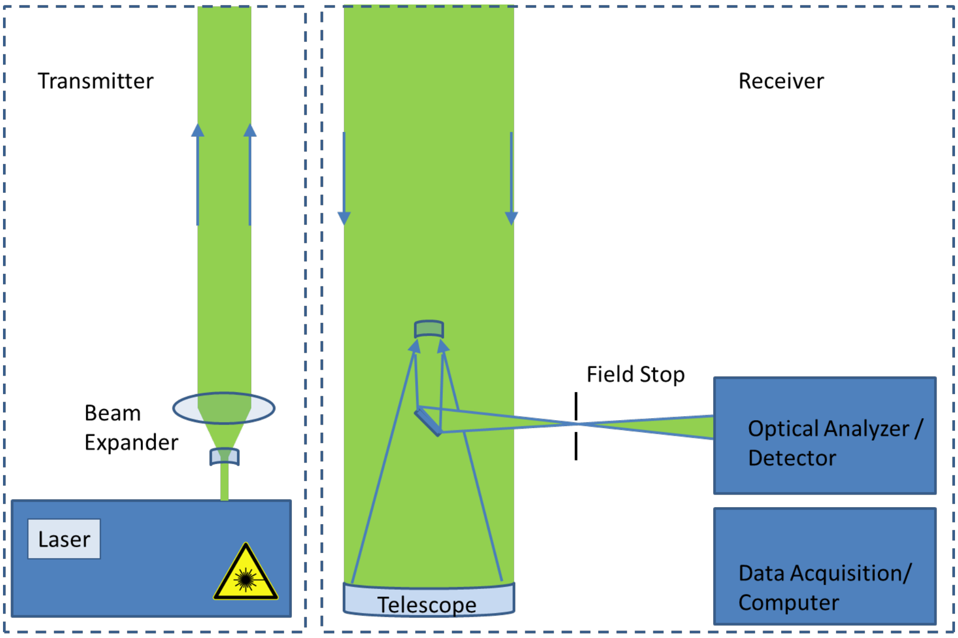

FIGURE 1 PRINCIPLE SETUP OF A LIDAR SYSTEM. MODIFIED FROM (WEITKAMP, 2005)

Standard backscatter LIDARs are widely used for aerosol profiling due to the simplicity and robustness of their setup. They provide profiles of attenuated atmospheric backscatter signal. However, the climate relevant aerosol extinction cannot be measured directly with standard backscatter LIDARs. Only with the assumption of the aerosol extinction-to-backscatter ratio, the so-called LIDAR ratio, aerosol extinction coefficients can be retrieved by means of inversion algorithms (Klett, 1981; Klett, 1985). However, the aerosol LIDAR ratio is a highly variable quantity which depends heavily on the aerosol type. Therefore, large errors in the retrieval must be expected if the LIDAR ratio is not known exactly. For instance, the LIDAR ratio depends on the aerosol size distribution, its refractive index and morphology (Evans, 1988; Mishchenko et al., 1997; Ackermann, 1998). Raman LIDAR measurements reveal the large variety of this quantity: E.g. Sea salt particles can be characterized by a LIDAR ratio ranging from 20 sr to 35 sr (Ansmann et al., 2001), biomass burning aerosol shows LIDAR ratios ranging from 70 sr up to 100 sr (Franke et al., 2001). Similar results have been obtained from High Spectral Resolution Lidar observations (Gross et al., 2013).

Raman LIDAR

Raman scattering is an inelastic pure molecular scattering that has been successfully used in LIDAR remote-sensing techniques since the late 1960s (Cooney, 1970). In a Raman LIDAR, wavelength λ_R of the scattered light is shifted with respect to emitted laser wavelength λ_L, and such a shift depends on the scattering molecule. For detection of the Raman scattering of a gas with known atmospheric density, such as nitrogen or oxygen, the backscatter coefficient in the Raman LIDAR equation is known, and only the aerosol extinction and its wavelength dependence remain as unknowns.

With the detection of the Raman scattered light, independent aerosol extinction profiles can be determined. One can also use this information to derive the aerosol backscatter without any assumption about the extinction-to-backscatter ratio (LIDAR ratio), which is an important parameter because it is directly related to the microphysical properties of the particles (Pappalardo et al., 2004).

High spectral resolution LIDAR (HSRL) can provide direct and independent observations of the backscatter from molecules and aerosols (Esselborn et al., 2008). In contrast to a Raman LIDAR, the HSRL detects the Rayleigh-Brillouin scattering which is several orders of magnitude more intense.
To separate the Rayleigh-Brillouin scattering from the Mie scattering of aerosols, a HSRL takes advantage of the different spectral broadening of light, backscattered by molecules and aerosols, respectively. At atmospheric temperatures close to 300 K the Doppler-broadening of the molecular backscatter spectrum amounts to 2.6 GHz for green light with a wavelength of 532 nm. The Doppler-broadening is due to the fast thermal motion of molecules. In contrast, aerosol backscatter is hardly broadened due to the relatively slow wind-driven motion of heavy aerosol particles, so that it can be characterized by the laser frequency distribution.

Principally, a HSRL separates the returned atmospheric LIDAR signals into two channels. One of which is equipped with an extremely narrow band optical filter which strongly suppresses the aerosol backscatter while transmitting the molecular backscatter. Thus, only molecular backscatter is measured. The signals are compared to a reference signal calculated from atmospheric temperature and pressure profiles. Aerosol extinction coefficients are calculated by comparing the measured molecular signal, which is attenuated by aerosol extinction, to the calculated un-attenuated molecular signal. Thus, no assumption about the LIDAR ratio is needed. The narrow band optical filter can be realized by interferometers like Fabry-Perot etalons and atomic or molecular vapor filters, respectively. Both filter methods show specific advantages and shortcomings. The choice of a specific technology depends on several design criteria like the available laser technology, the measurement platform (ground-based, airborne or space borne) or system requirements HSRL systems are currently prepared for space-borne operation on satellites like EarthCARE.

Aerosol classification by LIDAR

Vertical profiles with high resolution provided by Raman LIDARs and HSRL allow the optical characterization of atmospheric aerosol layers in the planetary boundary layer (PBL) as well as in the free troposphere. The aerosol characterization can be further improved by the use of multi-wavelength Raman LIDAR equipped with depolarization channels and by combination with passive radiometry, e.g., sun photometers. These data can be inverted to provide information about aerosol microphysical properties such as size, shape, refractive index, and effective radius (Muller et al., 1999; Veselovskii et al., 2002; Muller et al., 2004; Bockmann et al., 2005; Gasteiger et al., 2011; Veselovskii et al., 2012). LIDAR observations can be even more beneficial if used in coordinated networks. Furthermore, the combination of aerosol-related LIDAR properties like the LIDAR ratio, the color ratio or the depolarization ratio can be used for aerosol classification(Gross et al., 2013).

EARLINET (www.earlinet.org) was established in 2000 as a research project funded by the European Commission, within the Fifth Framework Program, with the main goal of providing a comprehensive, quantitative, and statistically significant database for the aerosol distribution on a continental scale. EARLINET includes 27 LIDAR stations (Raman LIDAR stations, multi-wave Raman LIDAR stations, back-scatter Raman LIDAR stations: see Figure 2) After the end of this 3-year project, the network activity continued based on a voluntary association and was finally merged into ACTRIS research infrastructure http://www.actris.eu/ (Pappalardo et al., 2014).

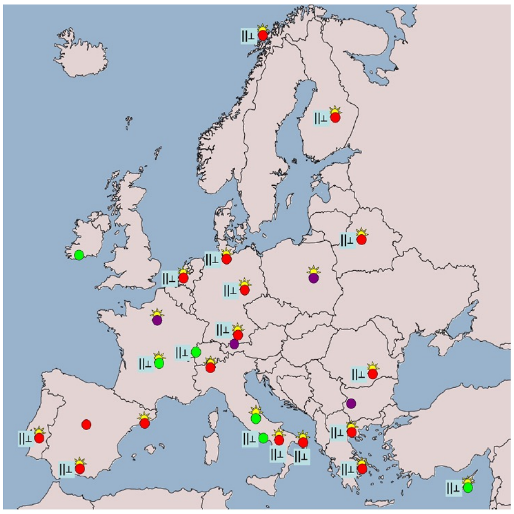

FIGURE 2 MAP OF THE EARLINET STATIONS CURRENTLY ACTIVE. RED DOTS INDICATE MULTI WAVELENGTH RAMAN LIDAR STATIONS (EARLINET CORE STATIONS). GREEN DOTS CORRESPOND TO STATIONS WITH AT LEAST ONE RAMAN CHANNEL. VIOLET DOTS DENOTE LIDARS WITH ONLY ELASTIC BACKSCATTER CHANNELS. THE ||⊥ SYMBOL INDICATES THAT THE STATION HAS DEPOLARIZATION-MEASUREMENT CAPABILITIES. THE "SUN" SYMBOL MEANS COLLOCATION WITH AN AERONET SUN PHOTOMETER(HTTP://AERONET.GSFC.NASA.GOV/). ADAPTED FROM (PAPPALARDO ET AL., 2014)

EARLINET single calculus chain (SSC)

Interpreting LIDAR raw signals, complex physical models have to be inverted using advanced mathematical methods. Thus, there is a strong need to develop a single calculus chain used across an observational network to get comparable results.

The EARLINET Single Calculus Chain (SCC), is a tool for the automatic analysis of LIDAR measurements. The development of this tool started in the framework of EARLINET-ASOS (European Aerosol Research Lidar Network – Advanced Sustainable Observation System); it was extended within ACTRIS (Aerosol, Clouds and Trace gases Research Infra Structure Network), and it is continuing within ACTRIS-2. The main idea was to develop a data processing chain that allows all EARLINET stations to retrieve, in a fully automatic way, the aerosol backscatter and extinction profiles starting from the raw LIDAR data of the LIDAR systems they operate. (D'Amico et al., 2015)

The calculus subsystem of the SCC is composed of two modules: a pre-processor module which handles the raw LIDAR data and corrects them for instrumental effects and an optical processing module for the retrieval of aerosol optical products from the pre-processed data. The preprocessor is described in detail in D'Amico et al. (2016) and the optical products by Mattis et al. (2016)

In situ measurement technique:

The European Research Infrastructure IAGOS In-service Aircraft for a Global Observing System; www.iagos.org) responds to the increasing request for long-term, routine in situ observational data by using commercial passenger aircraft as measurement platform. However, scientific instrumentation for automatic airborne measurements of atmospheric constituents requires major modifications of existing instrumentation before being deployable aboard in-service passenger aircraft.

Cavity ring–down spectroscopy (CRDS) is an emerging method for investigating aerosol optical properties like extinction and complex index of refraction (e.g. (Strawa et al., 2003; Langridge et al., 2011)). However, most of the instruments are yet used in the laboratory or in ground–based field studies. Similar to Cavity ring–down spectroscopy, , a compact and robust family of optical instruments based on the cavity attenuated phase shift (CAPS) technique has become available for measuring light extinction by atmospheric particles (Kebabian et al., 2007; Massoli et al., 2010). In particular, the CAPS PM_{ex} particle optical extinction monitor has demonstrated sensitivity of less than 2 Mm^{-1} in 1 second sampling period; with a 60 s averaging time, a detection limit of less than 0.3 Mm^{-1} can be achieved. This technique was successfully deployed for ground-based atmospheric measurements under various conditions (Petzold et al., 2013). Modifications for operation aboard aircraft and its suitability for the free troposphere until the tropopause was demonstrated within the Framework of the FP 7 collaborative project IGAS (www.Igas-project.org) under Grant agreement no. 312311. (Petzold et al., 2014; Perim de Faria et al., 2015; Bundke et al., 2016).

CAPS Technique

The CAPS technique, similar in its basic principle to cavity ring-down, relies on the use of a short (26 cm) sample cell employing high reflectivity mirrors (Kebabian and Freedman, 2007; Kebabian et al., 2007). Square-wave modulated light emitted from a light emitting diode (LED) is directed through one mirror into the sample cell (see Figure 3).The distortion in the square wave caused by the effective optical path length within the cavity (approx. 2 km light path) is measured as a phase shift in the signal and is detected by a vacuum photodiode which is located behind the second mirror. The signal is generated in the instrument via light extinction by particles (CAPS PM_{ex}) or light absorption by NO_2 molecules (CAPS NO_2). A detailed description of the method including first results from laboratory characterization and field deployment is given by Massoli et al. (2010), while Yu et al. (2011) reports an application to the direct measurement of combustion particle emissions from aircraft engines. The IAGOS Instrument P2e combines CAPS PM_{ex} and CAPS NO_2 detectors.

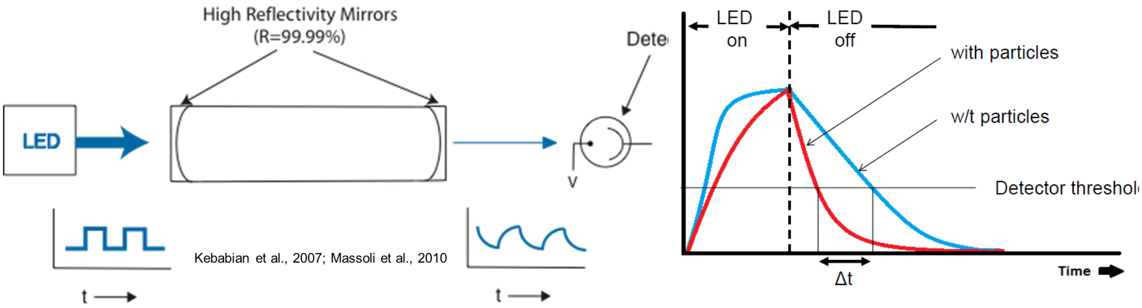

FIGURE 3. LEFT: OPERATION PRINCIPLES AND KEY COMPONENTS OF THE CAPS METHOD (LED WAVELENGTH 630 NM FOR CAPS PM_{EX} AND 450 NM FOR CAPS NO_2); RIGHT: SCHEMATIC OF THE SIGNAL GENERATION IN A CAPS INSTRUMENT.

The left panel of Figure 3 illustrates the key components of a CAPS instrument whereas the right panel sketches the signal generation. The signal background of the instruments is determined by the signal fluctuations when particle-free air (CAPS PM_{ex}) or air free of NO_2 (CAPS NO_2) is sampled and originates from Rayleigh scattering of light by “air” molecules. The signal is determined by subtraction of the background signal (without particles/NO_2) from the total signal (with particles/NO_2). During operation, the instruments samples during pre-defined intervals particle-free or NO_2 – free air and determines the Rayleigh background of the instrument. Thus, the fluctuation of the background signal determines the limit of detection (LOD) of the instrument, i.e. the minimum detectable light extinction coefficient or NO_2 mixing ratio, respectively.

CAPS single calculus chain

The calculation using CAPS Raw phase-shift data is straightforward and described in detail by (Kebabian and Freedman, 2007; Kebabian et al., 2007)

Joint ACTRIS IAGOS inter-comparison campaign

During the BALTEX (BALTic sea Experiment) campaign 2015 organized by the AWI. IAGOS P2c and P2e Instruments where installed on the POLAR 6 Aircraft (see Figure 4). Main goal of the campaign was to detect and characterize ship emission plumes.

FIGURE 4 INSTALLATION ON POLAR6 AIRCRAFT

On the way back to Bremerhaven (see Figure 5) a vertical profile of aerosol light extinction was measured over the Lindenberg Observatory of the German Weather Service. The aerosol extinction coefficient profile measured with a Raman LIDAR is compared with our in situ measurements using CAPS and Mie calculations (BHMie code (Bohren and Huffman, 2007)) using our size distribution measurement of the P2e OPC. (See Fig. 4, 5a and 5b.)

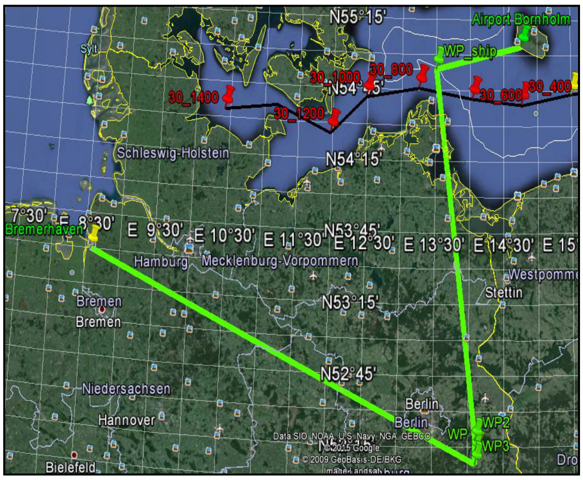

FIGURE 5 FLIGHT TRACK BORNHOLM BREMERHAVEN VIA LINDENBERG OBSERVATORY SITE

The profiles are adjusted to wavelength l=630nm. The linear regression of Figure 7 (right) shows a linear LIDAR correction factor of 0.79 which equals an expected humidity correction factor of the extinction at RH=50% with respect to particles assuming a hygroscopicity parameter (Hänel, 1976) of B^0=0.6 using the parameterization by(Bundke, 2002) see Page 145 GL 6.30. This factor as well as the offset is also considered in the profiles shown in Figure 6. The origin of the offset might be caused by a baseline drift of the CAPS instrument during the decent.

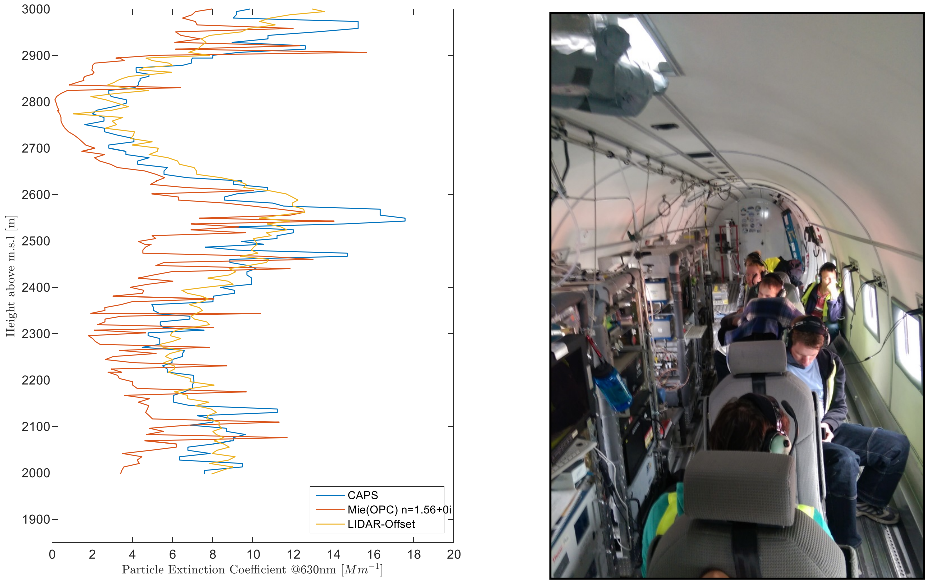

Figure 6. Height profiles of the LIDAR data are wavelength corrected to 630nm using an Angstrom Coefficient of 1.6 measured by a sun photometer in Lindenberg. The linear correlation CAPS vs LIDAR shows an linear factor of 0,79 which is corrected in this plot. This factor is caused by the humidity effect on scattering.

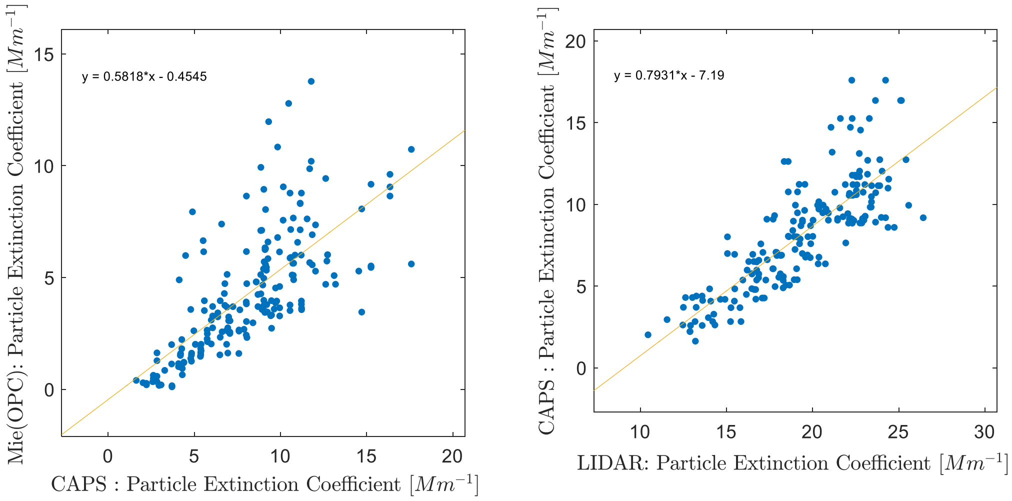

Figure 7 Linear regression analysis and associated scatter-plots of the profile data. About 60% of the variance of the residuals of the Mie calculation is explained by the

LINEAR REGRESSION (RIGHT) THE REMAINING VARIANCE IS CAUSED DUE TO THE CUT OFFS OF THE SIZE MEASUREMENT.

ICOS PBL measurements

The depth of the atmospheric vertical mixing by turbulence within the planetary boundary layer has a large effect on greenhouse gas concentrations measured in ICOS; it is however not always well represented by atmospheric transport models. To reduce the adverse impact on inversion results, information on mixing heights can be used(Kretschmer et al., 2012).

This mixing height information can be retrieved through active optical methods, combined with robust retrieval algorithm to process measurements. In the frame of ICOS in collaboration with external partners, optimized version of retrieval algorithm is in development. Good mixing heights detection score and improved candidates selection are obtained using both ceilometers and LIDARs.

Using database obtained during CeilInEx2015 experiment (Görsdorf, 2016), whose purpose is to test the performance and behavior of the automatic LIDARs and ceilometers (ALCs) that are typically used in the E-PROFILE and TOPROF community, optimized algorithm shows that retrieved daytime PBL height differed from radiosonde data by less than 250m around 50% of the time for the better instruments. Schween et al. (2014), showed that differences between aerosol-based MLH retrieval and Doppler wind LIDAR measurements were greater during PBL transition times and that on average the aerosol-based MLH was higher by 300m (600 m) in the morning (late afternoon). Also, the daily aerosol-based maximum MLH is larger and occurs later during the day and the average morning growth rates are smaller than those derived from the vertical wind.

Madonna et al. (2015) showed that *“ceilometers are quite sensitive to the large changes in external temperature and collected background levels that occur on daily or seasonal bases; this generates adjustments of system parameters that affect the stability of sensor response over time.”*

Meanwhile, Kotthaus et al. (2016) states that: *”If data are collected according to best practice, as recommended (…) issues are being corrected for in the post-processing (e.g. applying the proposed methods) and sensors are carefully calibrated, then the attenuated backscatter observations might prove useful for NWP model verification and evaluation, and potentially even for data assimilation.”* Recent research shows also that it is possible to correct overlap function which is temperature dependent (Hervo et al., 2016).

In the end, recent development in retrieval algorithm show promises to overcome some of the ceilometers shortcomings. Also, the ceilometers represent a network of several hundred across Europe. Collaboration continues with the TOPROF (European COST Action aiming to harmonize ground-based remote sensing networks across Europe) user community to try and improve instrument and data processing of BLH retrievals from ceilometers.

CONCLUSIONS

All proposed goals in use case 1 have been achieved. Selection criteria as well as the selection of measurement techniques have been summarized. One goal was to plan a cross RI joint inter-comparison campaign between in-situ and remote sensing instruments. With the help of Alfred

Wegner Institute, Bremerhaven, section “Sea ice physics” this campaign could be realized within this project, in summer 2015.

After the successful inter-comparison of in-situ and remote sensing methods for the measurement of aerosol light extinction, the prototype of the IAGOS instrument will be converted into a certified and operational instrument, ready for operation within the RI IAGOS.

Independent of the instrument development and certification of the IAGOS instrument prototype, further inter-comparison studies are planned back-to-back to otherwise funded research activities. It is envisaged to provide a set of this kind of studies at the end of the ENVRIplus project lifetime which will be used to evaluate the combination of in-situ and remote sensing methods for building global data sets on aerosol optical depth and aerosol light extinction profiles.

IMPACT ON PROJECT

The definition of standard methods measuring the aerosol extinction coefficient support the cross fertilization of the RIs ACTRIS, IAGOS and ICOS. This has been demonstrated by the coordination and realization of the joint measurement campaign. Here, direct contacts of individual scientists and technicians have been initiated and will sustain through enhancing the knowledge and data transfer on a direct personal way across RIs.

IMPACT ON STAKEHOLDERS

Defining standards for LIDAR and complementary in situ technologies and calculus chains will help RIs to enhance their data quality and to build joint data sets. Especially, RIs like ICOS which is in the planning phase will profit from the knowledge transfer from the start. Furthermore, standardized observations mean that e.g. data sets from different platforms are merge-able.

Based on the unexpected success of an inter-comparison of LIDAR and in-situ data at this early stage, this use case is assumed to provide important input for the design of future integrated observation systems for aerosol light extinction, even during the lifetime of ENVRIplus. Furthermore, significant input to the development of satellite calibration-validation strategies in WP2.3 is expected.

ICOS RI is interested in the LIDAR technique to retrieve the Planetary Boundary Layer (PBL) height and not in the retrieval of the aerosol optical properties. ACTRIS offered feedback regarding the potential use of ceilometers or single backscatter LIDAR for the PBL retrieval from specific studies and measurements campaigns carried within ACTRIS and related projects(Haeffelin et al., 2012; Pal et al., 2013; Wiegner et al., 2014; Madonna et al., 2015; Pal and Haeffelin, 2015). Moreover ACTRIS offered guidance using Doppler LIDAR instruments to measure PBL Dynamics. As a first step is was agreed to share measured PBL heights between ACTRIS and ICOS. Within ACTRIS a series of campaigns, involving different ceilometrs, LIDAR and Doppler LIDAR operation/comparison, will be organized and these are an optimal opportunity for ICOS RI; the list of the campaigns is available at http://www.actris.eu/Outreach/News/Campaigns.aspx.

IAGOS RI offered in-situ information for the determination of the PBL height from atmospheric state variables and related in-situ data. This application will be further elaborated during the lifetime of ENVRIplus.

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APPENDICES

Document can also include direct appendices of e.g. manuscripts, publications, etc. If you need help on e.g. merging PDF documents, consult the ENVRIplus project office.

GLOSSARY

ACTRIS: Aerosol, Clouds, and Trace gases Research Infra Structure Network	5
ACTRIS-2: ACTRIS Integrated Activity in Horizon 2020 Research and Innovation Framework Program	8
BALTEX: BALTic EXperiment 2015	10
CAPS cavity attenuated phase shift	9
CAPS NO$_2$: Aerodyne Reseach NO$_2$ Monitor	9
CAPS PM$_{ex}$: Aerodyne Reseach Particle Monitor for extinction	9
CEA: Commissariat a l Energie Atomique et aux Energies Alternatives	1
CNR: Consiglio Nazionale Delle Richerche	1
CRDS: Cavity Ring-Down Spectroscopy	9
FZJ: Forschungszentrum Jülich	1
HSRL: High Spectral Resolution LIDAR	7
IAGOS: In-service Aircraft for a Global Observing System	8
ICOS: Integrated Carbon Observation System	5
IGAS: IAGOS for the GMES Atmospheric Service, GMES has recently renamed "Copernicus"	9
INFREMER : Institute Francais de Recherche Pour l’Exploitation de la Mer	2
LED: light emitting diode	9
LIDAR: LIght Detection And Ranging	5
LOD: limit of detection	10
MLH: Mixing Layer Height	12
OPC: Optical Particle Sizer	10
P2c: IAGOS Package 2 Option "c" (aerosol microphysic)	10
P2e: IAGOS Package 2 option "e" (Aerosol Optics)	9
RI: Research Infrastructure	5
SCC: Single Calculus Chain	8