HARMONIA

International network for harmonization of atmospheric aerosol retrievals from ground based photometers

HARMONIA CA21119

Deliverables 5.2&5.1

• D5.1 Share the recordings and the presentations of the training School on solar, lunar, stellar radiation-based techniques

• D5.2 Share the recordings and the presentations of the training School to aerosol measurement scientists and operators

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1. Introduction

The MC of the CA21119 decided to organize in 2024 a training school especially designed for young researchers to better understanding the solar, lunar, stellar radiation-based techniques, along with one dedicated to aerosol measurement scientists and operators.

This report represents the description of the following deliverables of HARMONIA:

- **D5.1: Share the recordings and the presentations of the training School on solar, lunar, stellar radiation-based techniques.**
- **D5.2: Share the recordings and the presentations of the training School to aerosol**

The results of the training schools contribute to the main objective of HARMONIA Action:

"Establish a mechanism in order to: introduce to aerosol scientists and instrument users, the outcome of the homogenization, the SOPs and the new techniques and measurement improvements."

"Sky Over Berlin" training school on aerosol measurements (photometry) was organized by the HARMONIA COST Action in Berlin and Lindenberg, Germany, during 8-10 April 2024. The host was Deutscher Wetterdienst / Meteorologisches Observatorium Lindenberg – Richard-Aßmann-Observatorium and Freie Universität Berlin / Institut für Meteorologie. The program is detailed in Annex A.

The aim of the school was the convergence of knowledge and expertise in understanding atmospheric aerosols and the transfer of skills to new generations. This was a unique opportunity for the participants not only to enhance their theoretical understanding but also provided hands-on experience with real data. As part of the program was also a visit to the meteorological observatory of Lindenberg (Deutscher Wetterdienst), providing participants with a firsthand look at state of the art instruments.

At the school more than 20 experts in aerosol remote sensing participated as lecturers and presented the state of the art at the field. Thirty-five students were trained in aerosol measurements for three days spanning from master students, PhDs and early post-doctoral researchers. Travel grants were available for eligible attendees, to facilitate their participation.

The main activities of the school consist of the following. High profile experts in aerosol science gave lectures about different aspects of aerosol remote sending. An overview of those lectures is provided in Section 2. Interactive exercises were conducted by different teams, guided by experienced supervisors. The attendees had the opportunity to apply their knowledge to real-world scenarios through hands-on training sessions with authentic aerosol data. A visit to DWD meteorological observatory of Lindenberg was organized and the trainees had the opportunity to gain insights into the latest advancements in aerosol research. During this exclusive tour the attendees got up close with state-of-the-art instruments and got the chance to interact with trained personnel and experts in the field.

A special part of the school was dedicated to hands on training for the participants. Four working groups were created towards working on different exercises. Group exercises provided the opportunity for students to process real data and gain high level results. A description of those exercises is given in Section 3. The outcome of the work from those 4 working groups were presented at European Meteorological Society (EMS) conference, September 2024 in Barcelona and specifically at the session “Harmonia COST Action: Aerosol observations and links with atmospheric and solar energy studies” organized by the Action. This outcome from students validates the high level of the school and the valor in training new generations of scientists.

The goal of these networking event si to increase the dissemination of the produced outcomes of the WG1-4 activities of the HARMONIA COST Action, to aerosol scientists, instrument users and other HARMONA participants inside and outside the HARMONIA consortium, towards measurement improvement, new techniques and measurement approaches, sharing of protocols etc. thus contributing to the objectives of the Action.

2. Description of the subjects presented during the school

A short description of the different subjects presented during SY over Berlin training school is given in this section, including the title of the presentation along with a short summary and the main points. All presentations of the school are available at the following link:

https://www.dropbox.com/scl/fi/1sgdffowwqkxjscvawuxd/Sky-Over-Berlin-Presentations.zip?rlkey=kz0ii46mgljd9rscum18z58r1&e=1&dl=0

2.1 The AERONET network

In this lecture given by Elena Lind (NASA GSFC) an overview of the AERONET network was given with a title "AERONET: Three Decades of Atmospheric Aerosols Measurements". At the beginning the team of the AERONET at NASA GSFC was presented. The Aerosol Robotic Network (AERONET, https://aeronet.gsfc.nasa.gov) provides for 30 years Observations and Research. It is a federated network of almost 600 permanent stations worldwide in 102 countries and territories (Figure 1 Thirty years of AERONET observations and research.).

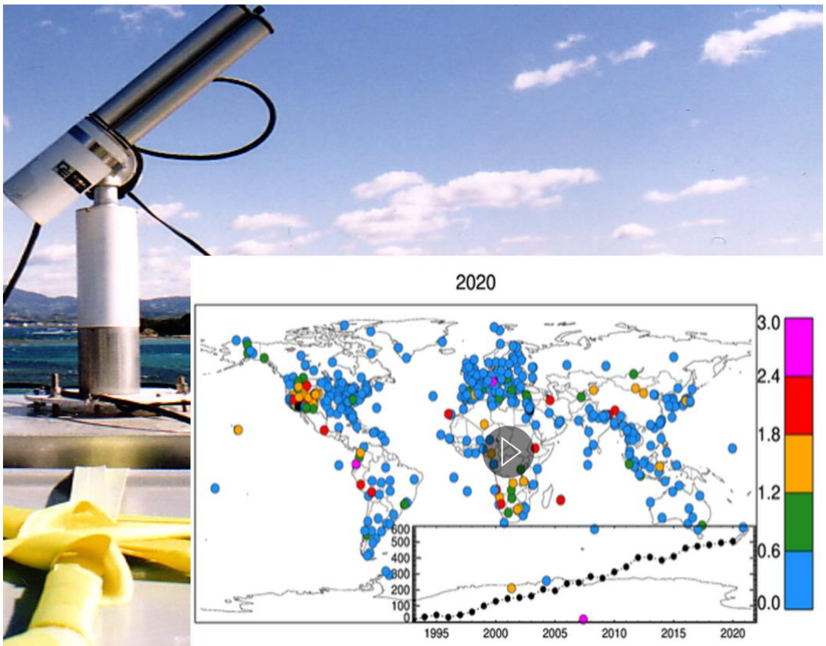


Figure 1 Thirty years of AERONET observations and research.

The AERONET Component Networks (AERONET standard, Ocean Color component of AERONET-OC, -MAN and Solrad-Net) were presented. AERONET is a consortium of networks and calibration centers with standardized instrumentation, calibration, data processing, data quality assurance, data quality control and data distribution. local PIs support for instrument maintenance and swap outputs. AERONET is a network of sun-moon-sky photometers (passive remote sensing). Basic measurements consist of direct solar/moon scattered irradiance and sky scattered solar radiances at 9 wavelengths (340, 380, 440, 500, 675, 870, 937, 1020, 1640 nm). The main products are aerosol optical and micro-physical properties and water vapor. The technical specifications of the AERONET instrumentation were presented, which are the CIMEL multiband photometers. The ideal requirements for site selection were discussed. The products of the direct irradiance measurements are the Aerosol Optical Depth (AOD) at different wavelengths, the Ångström exponent at different pairs of wavelength and water vapor. Micro-physical properties at four standard AERONET sky wavelengths (440, 675, 870 and 1020nm) are the inversion products of sky radiance measurements.

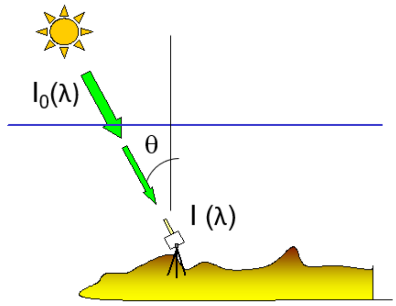
At the second part of this lecture the AERONET standardized operation and calibration activities were presented. At the third part of the lecture the spectrum of the different applications related to the AERONET datasets was provided (e.g. decadal changes in AOD, smoke detections from forest fires, satellite validation support). Finally, a new automated shipborne photometer was presented, with additional modules to track boat movements and an air pump to avoid sea spray.

2.2 ACTRIS Calibration of sun photometers

Stelios Kazadzis and Carlos Toledano gave a lecture regarding the ACTRIS Calibration of sun photometers. The lecture given by Carlos Toledano (University of Valladolid) was focused on how we measure atmospheric turbidity, the theoretical background, the instrumentation utilized and the calibration techniques. The theoretical background lays on the radiative transfer theory, the radiative transfer equation was discussed. Using the Beer-Bouguer-Lambert law for the direct component we can retrieve the aerosol optical thickness ($\tau(\lambda)_{aer}$) using the equation in Figure 2, under cloudless conditions.

Atmospheric extinction

- Optical thickness: $\tau(\lambda) = \frac{-1}{m} \ln \left(\frac{I}{I_0} \right)$ [unitless]



m=1/μ =1/cos θ (Airmass)

$$\tau(\lambda)_{aer} = \tau(\lambda) - \tau(\lambda)_{mol} - \tau(\lambda)_{gas}$$

Figure 2 Aerosol optical depth retrieval method.

The instruments used for those retrievals are radiometers (direct sun or moon or star and diffuse sky). The elements of a radiometer needed to measure direct and diffuse spectral flux and convert it into signal were presented. The ideal conditions for the optical thickness calibration with the solar Langley method was presented. Cloudless sky is a prerequisite, with no aerosol and for this high elevation sites are selected and a fast change in solar elevation and for these low latitudes are needed. The related uncertainty is 0.2-0.5% (0.002-0.005 in τ). The side-to-side calibration and radiance calibration were also discussed. The protocols followed for the calibration of the filed instruments and reference instruments were also presented. Finally, the network standardization of calibration was discussed like the one in AERONET network. The AERONET protocols adopted in ACTRIS.

The lecture given by Stelios Kazadzis (PMOD/WRC) had to do with the SI traceable calibrations. Langley calibrations are based on instrument units (e.g. volts). The current traceability and calibration process using the Langley method was described along with its disadvantages (e.g. Significant logistical overhead, etc). Then the reasons why we care about traceability were listed: 1) A measurement without an indication of its uncertainty is meaningless. 2) Comparability of results within a network, and between networks, needs a common reference. 3) Comparability of results within a network, and between networks, needs a common reference. Then the objectives of the MAPP project were presented which had to do with the Metrology for Aerosol optical properties. The goal was to provide SI traceable measurements and the retrieval of traceable spectral AOD using narrowband filter radiometers was presented. Then the current procedure followed by AERONET for the retrieval of aerosol optical properties was compared with the one without Langley and the one without Langley and the irradiance SI to radiance (and radiance SI to irradiance) calibration conversion using solid angle field of view. However, the consistency between radiance and irradiance calibrations is still under investigation. It was also concluded that the Change from Langley to 100% SI traceability needs a lot of effort and practical decisions, only the first steps have been performed. Finally, it was shown that the SI traceable PFR instruments (PMODWRC-PTB) continuously measuring at AERONET/ACTRIS Calibration facilities (Figure 3).

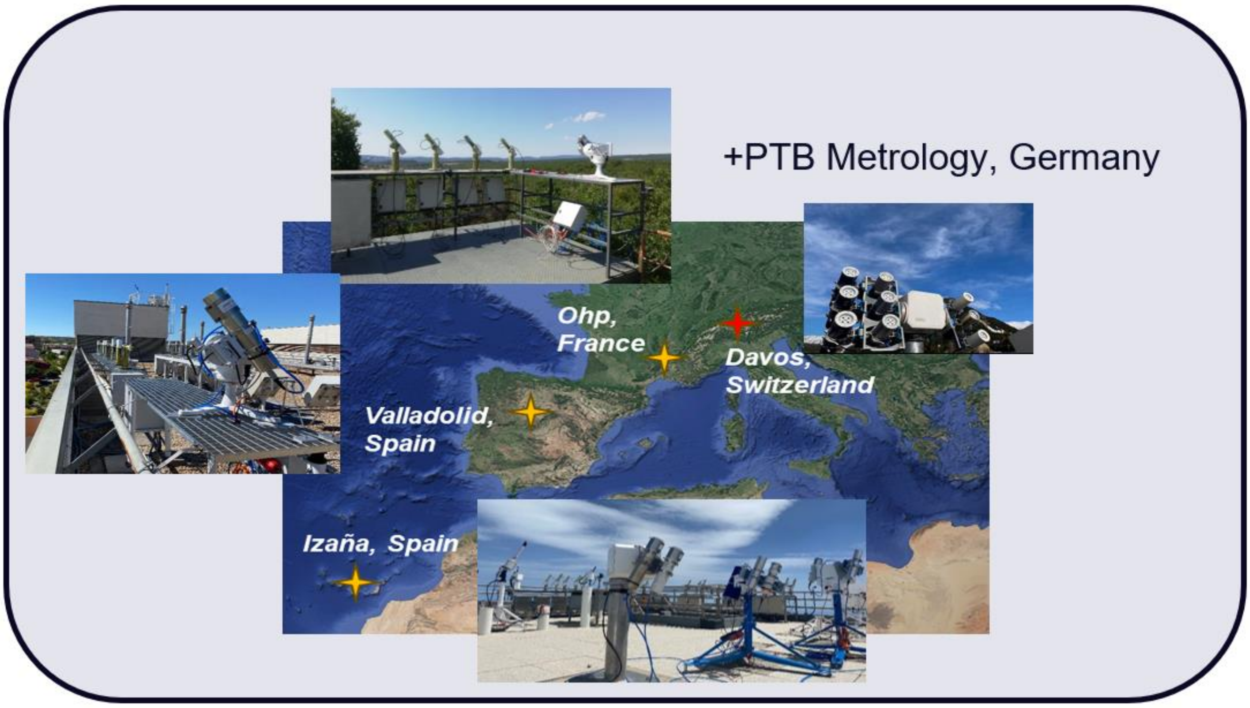


Figure 3 ACTRIS Calibration facilities.

2.3 Aerosol inversions

Aerosol inversion techniques were described by Masahiro Momoi (GRAPS SAS). At the beginning an overview of the aerosol observation technique was presented and then a special focus on sky radiance observations was given and which are the aerosol information that we can retrieve from those measurements. Basic theoretical aspects regarding radiance observations for aerosol retrievals were discussed like target wavelengths (to minimize molecular absorption), observational geometry (e.g. almucantar plane). Instrument aspects were also discussed like the field of view, pointing, etc. Then the concept of inversion was introduced (Figure 4 which is also related to Oleg Dubovik's subsequent lecture). It is an 'estimate' of physical quantity from observation. In our case aerosol properties (like volume size distribution, complex refractive index, etc.) can be estimated using radiance observations (from ground- and satellite-based instruments). In addition, several modelling aspects that are related to radiative transfer model (RTM) assumptions were discussed. For instance, the use of plane parallel atmosphere approximation instead of taking account earth's sphericity, the homogeneous (1D) atmospheric layers instead of 3D atmosphere and the homogeneous surface instead of taking account topology and surface heterogeneity. Finally, the GRASP (Generalized Retrieval of Atmosphere and Surface Properties) algorithm was introduced.

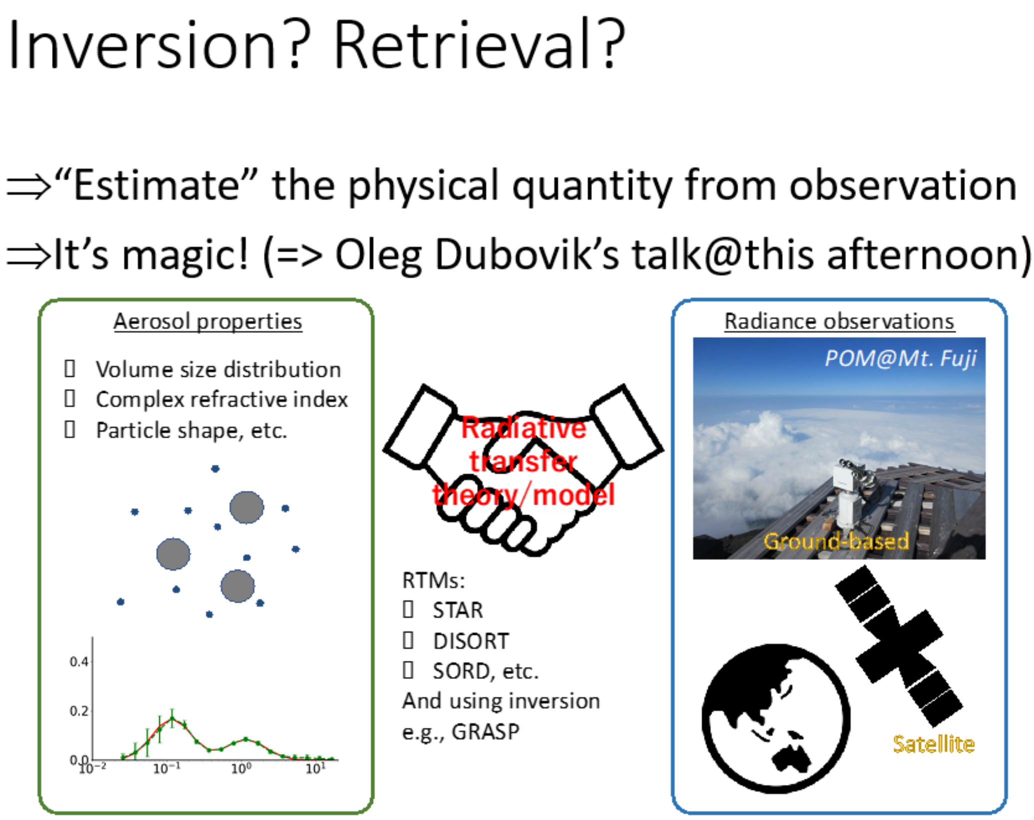
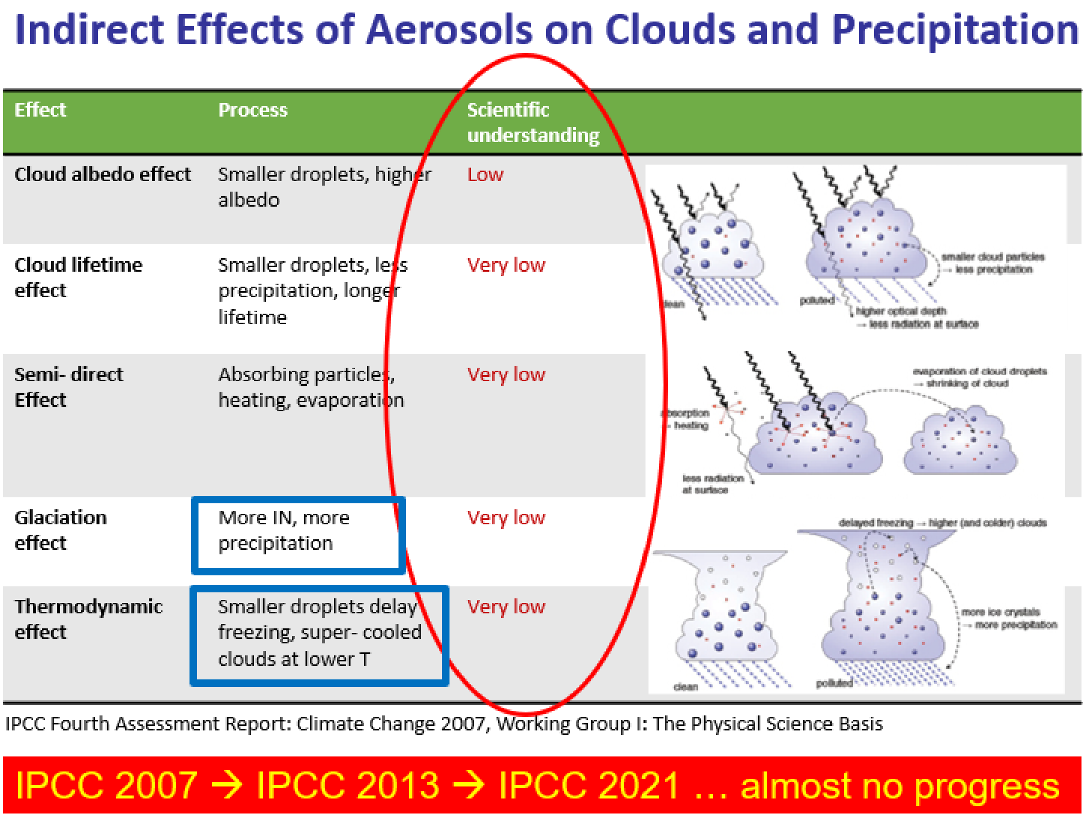


Figure 4 The inversion concept.

2.4 Aerosol clouds interactions

The lecture given by Albert Ansmann (TROPOS) was focused on aerosol-cloud interactions, the response of clouds to aerosol perturbations. The lecture starts by introducing the importance of aerosol- cloud interactions. In IPCC report of 2007 simple parameterizations were applied for the indirect effects of aerosol on clouds and precipitation, while almost no progress has been recorded ever since (Figure 5). Then the complexity of aerosol-cloud interactions was highlighted due to many processes involved. The physical variables related to different types of clouds (mixed-phased, ice) were presented along with the instruments and their synergies that provide those retrievals. The key parameters in aerosol-cloud interaction studies are cloud droplet number concentration (CDNC), ice crystal number concentration (ICNC), cloud condensation nuclei concentration (CCNC), ice-nucleating particle concentration (INPC) and vertical wind velocity (Updraft speed). Aerosols and meteorological conditions like updrafts, downdrafts and turbulence influence cloud evolution.



Effect	Process	Scientific understanding
Cloud albedo effect	Smaller droplets, higher albedo	Low
Cloud lifetime effect	Smaller droplets, less precipitation, longer lifetime	Very low
Semi- direct Effect	Absorbing particles, heating, evaporation	Very low
Glaciation effect	More IN, more precipitation	Very low
Thermodynamic effect	Smaller droplets delay freezing, super- cooled clouds at lower T	Very low

Figure 5 Indirect effects of aerosols on clouds and precipitation.

Then some examples of lidar cloud observations (e.g. wind (doppler) lidar, Dual-FOV polarization lidar) from stations and campaigns (e.g. MOSAiC) were presented to highlight the importance of lidar (and radar) for profiling purposes. The mechanisms of homogeneous and heterogeneous ice nucleation were also discussed.

The main part of the lecture was dedicated to lidar (and radar) basic and key methods in aerosol and cloud profiling which are polarization lidar, dual FOV lidar, LIRAS-ICE which is a lidar-radar synergy providing ice cloud microphysics and POLIPHON data analysis which is a lidar-AERONET synergy.

First, the lidar principle was shown (Figure 6) and discussed. Then the principle of the polarization lidar was presented and the relevant applications (in detecting the shape of the particles using depolarization ratio δ(R)), assuming single scattering. Due to multiple scattering, a fraction of the laser light is not scattered out of the RFOV and remains in the RFOV. This is NOT considered in the basic single-scattering lidar equation; hence the attenuation of laser light is lower than expected and the depolarization of laser light is higher than expected.

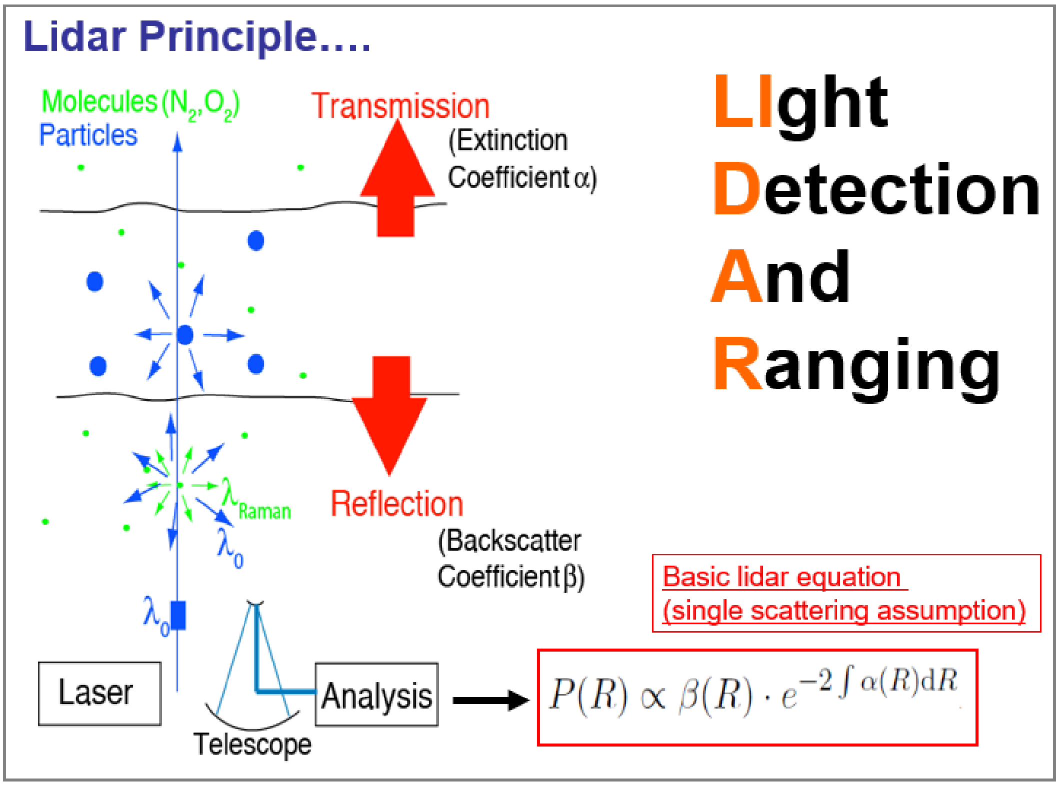


Figure 6 The lidar principle.

Then the lidar with two receiver field-of-views (RFOV) the dual FOV polarization lidar (e.g. Polly) was presented, which is a multiple scattering lidar. The goal is to measure the link between cloud condensation nucleus concentrations (CCNC) and cloud droplet number concentration (CDNC). Here, the smaller the droplets, the larger the difference between the depolarization ratios measured with two FOVs. The data analysis of the dual FOV polarization lidar gives parameters like liquid water content (LWC) and CDNC.

In addition, the Lidar Radar Synergy-Retrieval of ICE microphysical properties (LIRAS-ICE) was presented and an overview of the retrievals of cloud ice profiles: Ice water content (IWC), ice crystal number concentration (ICNC) and ice extinction coefficient (IEC). Then the combining Polarization lidar and AERONET photometer network observations (POLIPHON) method was described. The retrievals of this method are particle mass concentrations for basic aerosol components (marine, dust, continental pollution) and cloud relevant parameters of CCN and INP for the aforementioned basic aerosol types, for studies focused on aerosol-cloud interactions.

2.5 Advancements and limitations in retrieving detailed aerosol properties from remote sensing observations

Oleg Dubovik gave the lecture regarding the Advancements and limitations in retrieving detailed aerosol properties from remote sensing observations. The main concept of inversions was covered, and the following questions were answered: i) how to derive maximum information, ii) what does it mean quantitatively and iii) what to do if information in the measurements is not sufficient?

Inversion is an inherent part of any remote sensing approach (from ground and space). The Generalized Retrieval of Atmosphere and Surface Properties (GRASP) algorithm was introduced. GRASP is an advanced algorithm for retrieval of aerosol, gas and surface properties from diverse remote sensing observations and any combination of them (Figure 7). It is based on Forward Model for rigorous simulation of atmospheric radiation and inversion with applying multiple a priori constraints.

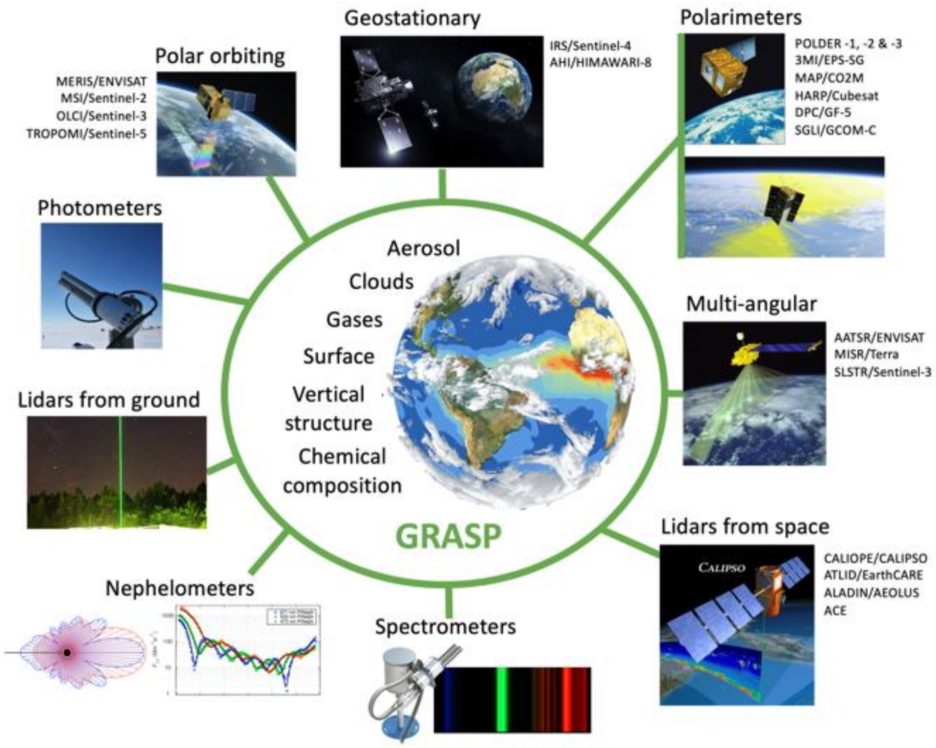


Figure 7 The concept of GRAPS algorithm.

The general structure of the GRAPS algorithm was described and then details of the GRAPS forward model and the inverse problem. The key messages are: i) Statistical optimization is a fundamental basis for overall theory of inverse problems, ii) The Optimal Estimation (Rodgers, 2000) is a very popular concept in remote sensing inversion, while it has methodological limitations. iii) The Multi-Term LSM is an efficient concept for constraining inversion. It proposes additional potential for designing inversion compared to Optimal Estimation.

2.6 ESA Missions for Aerosols

An overview for the ESA missions for aerosols concerning passive instruments was given by Rene Preusker and Jonas von Bismarck. At the beginning a brief description of ESA and EUMETSAT and an explanation of terms programme, mission, satellite and instrument was given. The future satellite FLEX (Fluorence Explorer) needs precise aerosol characterization, particularly the aerosol layer height, to detect the fluorescence signals of vegetation. Then SENTINELS satellite missions were presented focusing on Sentinel 3, 4, 5p and 5. In addition the Copernicus Sentinel

Expansion Missions were introduced and specifically CO2M, LSTM and CHIME (Figure 8).

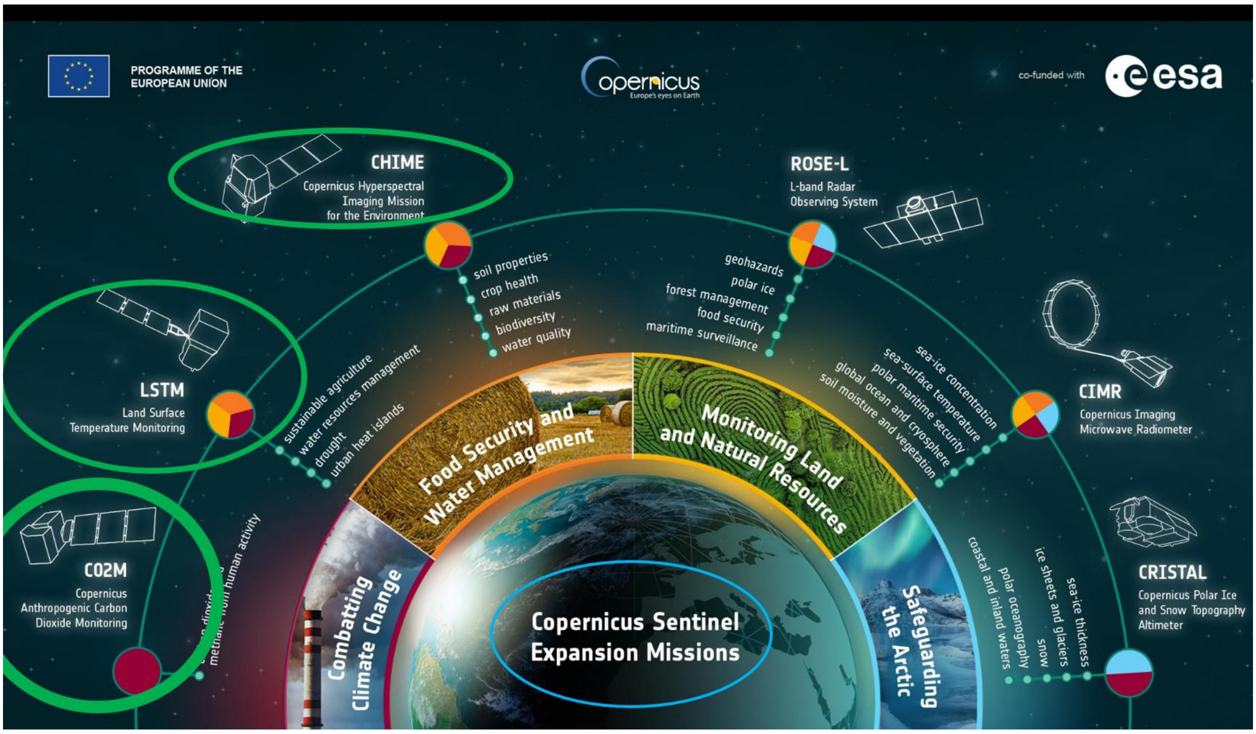


Figure 8 Copernicus Sentinel Expansion Missions.

One instrument of CO2-M will be MAP (Multi Angle Polarimeter). CO2 amount estimation needs precise multiple scattering. Aerosols MAP is dedicated for aerosol remote sensing. At the end EUMETSAT Polar System – Second Generation (EPS-SG) programme was presented and the Metop Second Generation (Metop-SG) A and B, where Metop-SGA1 is expected to be launched in 2025/26. The 3MI will be one of the instruments for aerosol measurements. There were two take home messages from this lecture. There are few European (ESA) satellite missions that provide Aerosol information from passive measurements. However, 2025/26 will be the years of MAP and 3MI, instruments measuring polarization on multiple views, instruments dedicated to passive RS of aerosols.

2.7 CIMEL sun photometer

A lecture about the CIMEL sun photometer was given by Stéphane Victori.

This is a specialized instrument used in atmospheric research, particularly within the AERONET network for tracking and analyzing aerosols, water vapor, and solar radiation. Key features of the CE318 photometer include autonomous operation (solar-powered), weather resistance, and high measurement precision across day and night. It performs Sun, sky, and moon observations, and its modular design allows customization for various applications, such as polarimetric and oceanic measurements.

Notable advancements include enhanced tracking, UV and NIR spectrum extensions, and applications on mobile platforms (e.g., shipborne research).

CIMEL is also developing the Multispectral Hemispherical Radiometric (MHR) camera, an innovative, multispectral tool for in-air and in-water observations to support Earth observation efforts, with prototypes expected by 2025. This camera aims to offer high radiometric accuracy for environmental monitoring, satellite calibration, and atmospheric studies, broadening CIMEL's capabilities in monitoring and analyzing Earth’s atmospheric and oceanic conditions.

The photometer is extensively deployed in research initiatives like MOSAiC and OCEANET-ATMO (few examples in Figure 9), which explore global warming, aerosol impacts, and radiative transfer models. Future advancements under consideration include UV extensions for ozone studies, enhanced tracking, and the integration of near-infrared channels.

CE318-T photometer aboard the Marion Dufresne (Credits: LACY/Université de la Réunion)

Figure 9 Examples of results from measurements onboard ships.

2.8 PFR-PSR photometers

Natalia Kouremeti's lecture provides an in-depth overview of two key instruments developed at the Physikalisch-Meteorologisches Observatorium Davos (PMOD/WRC) for atmospheric radiation measurements: Precision Filter Radiometers (PFR) and Precision SpectroRadiometers (PSR) (Figure 10). Here's a summary of the key points:

1. **Precision Filter Radiometers (PFR)**:
    - **Description**: PFRs use a set of filters and photodiodes to measure direct solar irradiance. They are temperature-stabilized and have a narrow field of view, making them highly accurate for measuring aerosol optical depth (AOD).
    - **Operation**: The PFR performs solar irradiance measurements every minute and includes internal dark measurements for calibration.
    - **Applications**: PFRs are part of the Global Atmosphere Watch (GAW) network, which performs long-term trend analysis for aerosol loads and AOD across various sites worldwide.
    - **Calibration**: Calibration is done using the Beer-Lambert law at stable sites like Izaña (Spain) and Mauna Loa (Hawaii), where the aerosol load remains stable for extended periods.
2. **Precision SpectroRadiometers (PSR)**:
    - **Description**: PSRs are high-resolution instruments that measure solar irradiance across a wide spectral range (300–1030 nm) with high accuracy. They are designed to be stable over a wide temperature range and can measure irradiance using finely tuned filters and sensors.
    - **Characterization**: The PSR is characterized using spectral calibration and stray-light correction techniques, ensuring precise measurements even under varying temperature and irradiance conditions.

- **Calibration and Uncertainty**: Extensive procedures, such as the use of FEL lamps and tunable laser systems, are employed for wavelength calibration and irradiance correction. The uncertainty for irradiance is around 1.8%.

3. **Synergistic Use of PFR and PSR**:

- The document emphasizes the synergetic use of both instruments, particularly in calibration tasks. They provide accurate measurements for atmospheric studies, including aerosol and radiation properties.

4. **WMO AOD Reference and Comparisons**:

- PFRs and PSRs are frequently used in international comparison campaigns, such as the World Meteorological Organization's Filter Radiometer Comparison (FRC). These comparisons ensure traceability to SI units and validate the long-term stability of the instruments.

In conclusion, both PFR and PSR are crucial instruments for precise atmospheric radiation measurements, particularly for AOD and irradiance monitoring, and their synergy enhances calibration accuracy across networks like GAW.

Figure 10 Precision Filter Radiometers (PFR) and Precision SpectroRadiometers (PSR) measuring in Davos at the Physikalisch-Meteorologisches Observatorium (PMOD/WRC).

2.9 Sky Camera use for AOD retrievals

Roberto Roman gave a lecture describing how sky cameras (Figure 11) are used for AOD retrievals. Here's a summary:

- **Sky Radiance and Aerosols**: Sky radiances are influenced by atmospheric gases and aerosols, where Rayleigh scattering dominates for gases and Mie scattering for aerosols. Sky radiances at different angles provide insight into aerosol properties such as AOD and aerosol types.

- **All-Sky Cameras**: These devices offer a cheaper and quicker alternative to traditional photometers by capturing full-sky images in different wavelengths quasi-instantaneously. However, they are less accurate and precise, with lower resolution and linearity compared to photometers.

- **Advantages**: Sky cameras allow for the capture of radiance at various wavelengths and exposure settings, enabling high dynamic range (HDR) imaging. They provide a cost-effective means of measuring AOD and other aerosol properties, especially under low to moderate aerosol loads.

- **Limitations:** Sky cameras are less precise than traditional instruments. Challenges include handling reflections in the dome and achieving accurate scattering angles. Despite this, they can effectively retrieve uncalibrated radiances that are proportional to actual sky radiances, aiding in aerosol studies.

- **Retrieval Techniques**: The study references the GRASP algorithm to retrieve aerosol and surface properties from sky camera data. For accurate inversion, small and large scattering angles are critical in characterizing aerosol properties.

- **Recommendations**: The study highlights the need for improvements in all-sky cameras, particularly in eliminating reflections, to cover a wider range of scattering angles for more accurate measurements.

In conclusion, sky cameras provide a promising tool for AOD retrievals, especially in cost-sensitive scenarios, though further refinement is needed to match the precision of traditional photometers.

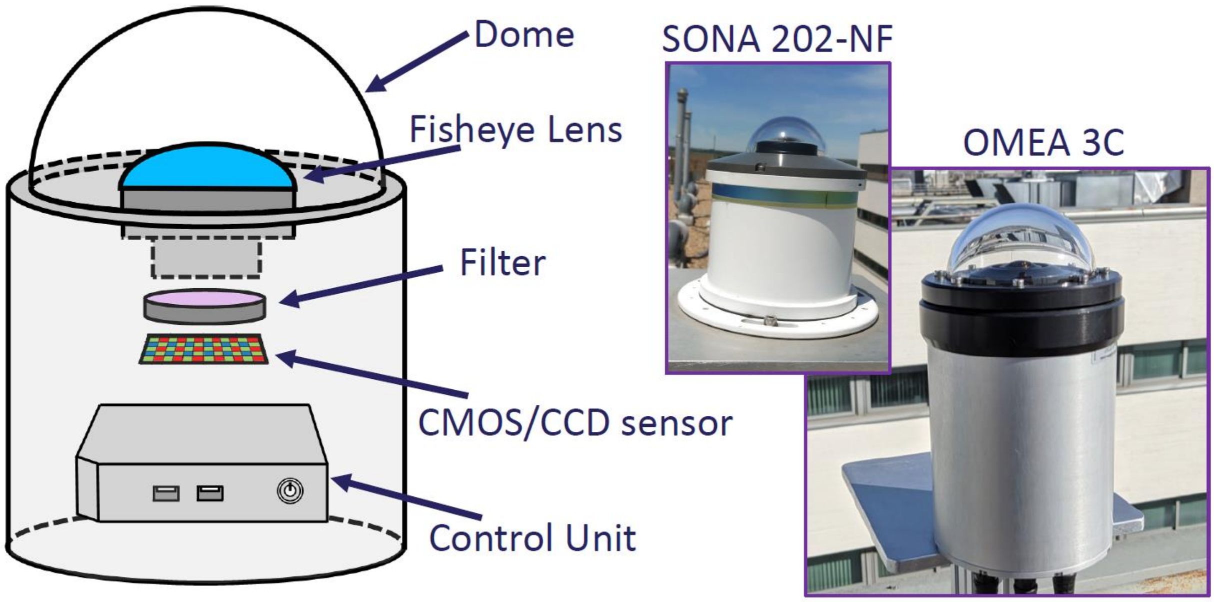


Figure 11 All sky camera components and two commercially available instruments.

2.10 Synergies Raman Lidar and Photometers in Ny-Alesund

Christoph Ritter discusses the synergy between Raman Lidar and photometers in Ny-Ålesund, a research site in the European Arctic (Figure 12).

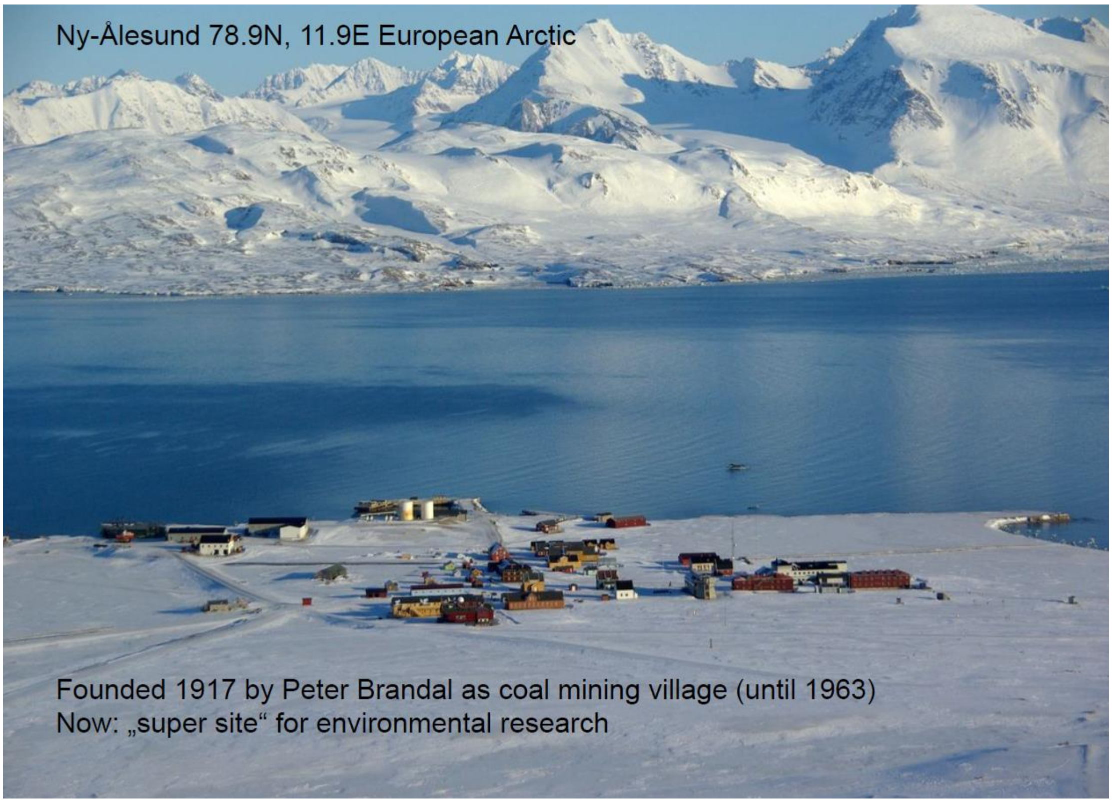


Figure 12 Ny-Ålesund Research Facility.

Key points of this presentation include:

- **Ny-Ålesund Research**: Located at 78.9N, 11.9E, this area is a hub for environmental research, offering benefits like accessibility and connection to long-term data. Challenges include warm temperatures for the Arctic and complex local meteorology.

- **Photometers and Raman Lidar**:

  Photometers measure light extinction and are used from March to October (sun) and during moonlit periods. They capture broad atmospheric characteristics but lack height resolution.

  Raman Lidar emits laser pulses to gather detailed data on aerosol backscatter, extinction, and depolarization, allowing for height-resolved observations. It can distinguish between spherical and non-spherical particles.

- **Synergy Challenges**: Combining data from these instruments can be challenging due to factors like multiple scattering and differing perspectives. However, their integration can provide a fuller picture of atmospheric conditions by merging whole-column data (photometers) with detailed vertical profiles (lidars).

- **Scientific Goals**: The research aims to understand Arctic-specific phenomena like the Arctic Haze, polar amplification, and the relationship between Arctic conditions and broader climatic patterns.

- **Applications**: These measurements help track aerosol characteristics, such as size and mixing state, and their role in phenomena like cloud formation and direct aerosol forcing, which are critical for understanding climate dynamics in polar regions.

Overall, the document emphasizes the importance of using multiple instruments to obtain a comprehensive understanding of atmospheric processes in the sensitive Arctic environment.

2.11 Lunar Photometry by Africa Baretto (Izaña Atmospheric Research Center -AEMET) and Natalia Kouremeti

(Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center, PMOD/WRC).

Africa Baretto's lecture details advancements in lunar photometry, focusing on aerosol measurement and calibration techniques. Key topics include challenges in lunar photometry, such as dealing with moon phases, libration (variations in lunar brightness), and atmospheric interference, requiring sophisticated irradiance models like ROLO and LIME (Figure 13). These models improve precision in measuring lunar irradiance, crucial for calibrating Earth observation instruments. The document also discusses instrumentation developments, such as the CE318-T photometer, which allows nighttime aerosol monitoring. The importance of these techniques is emphasized for environmental monitoring and enhancing satellite data accuracy.

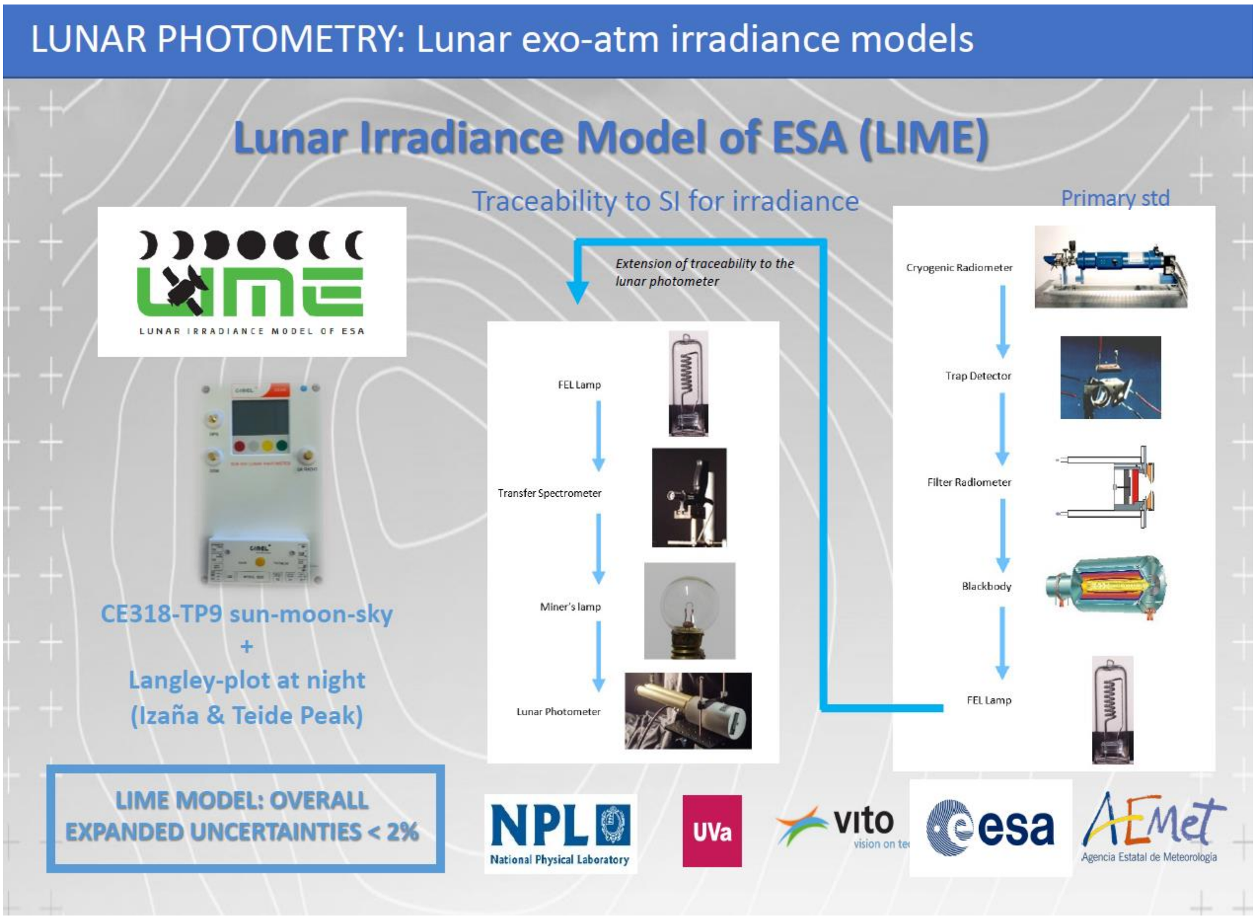


Figure 13 Lunar Irradiance Model of ESA (LIME).

The lecture by Natalia Kouremeti provides a detailed exploration of measuring lunar irradiance using a Precision Filter Radiometer (PFR) for aerosol optical depth (AOD) calibration and monitoring. Key points include:

- ***Motivation:*** Enhanced AOD measurement accuracy for nighttime observations, especially useful in polar regions with phenomena like Arctic haze (Figure 14).

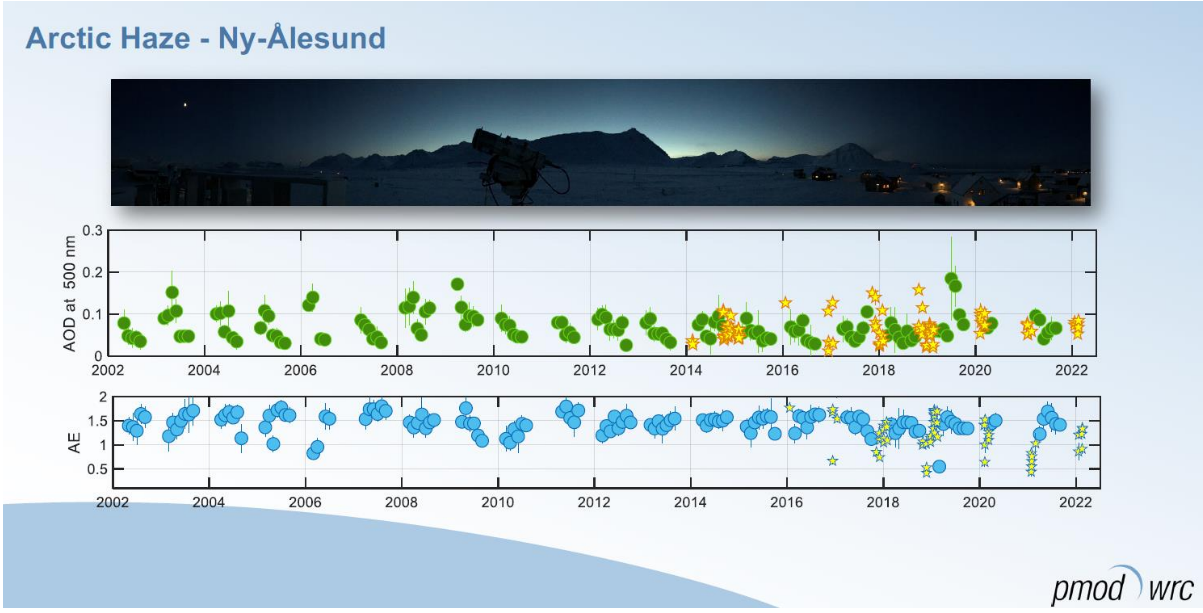


Figure 14 Artic measurements 2002-2022.

- **PFR Characteristics:** The PFR is finely tuned with multiple narrowband channels, stabilized photodiodes, and a precise field of view to maintain high accuracy in irradiance measurements.
- **Calibration Techniques:** The PFR undergoes thorough calibration, including comparison of irradiance standards and response to laser wavelengths, ensuring uncertainty remains under 1%.
- **Irradiance Models:** Comparison of lunar irradiance models, particularly ROLO and RIMO, reveal phase angle dependencies and variances, impacting calibration and necessitating ongoing refinement.
- **Future Work:** Plans for expanded calibration methods, additional wavelength channels, and verification efforts to improve reliability in global AOD monitoring.

These advancements aim to provide traceable and reliable lunar irradiance data for atmospheric and environmental monitoring, enhancing both accuracy and consistency.

2.12 Stellar photometers by Liviu Ivanescu and Karl-Heinz Schulz (University of Sherbrooke / NRC-CNRC, Canada)

The lecture given by Liviu Ivănescu on star-photometry covers atmospheric remote sensing techniques that complement traditional sun-photometry. It highlights star-photometry's utility in measuring atmospheric optical depth at night, allowing for aerosol, ozone, and water vapor observations through thin clouds. This method operates effectively during polar nights (Figure 15), provides 24-hour monitoring capability, and enables multi-star Langley calibration for stable readings.

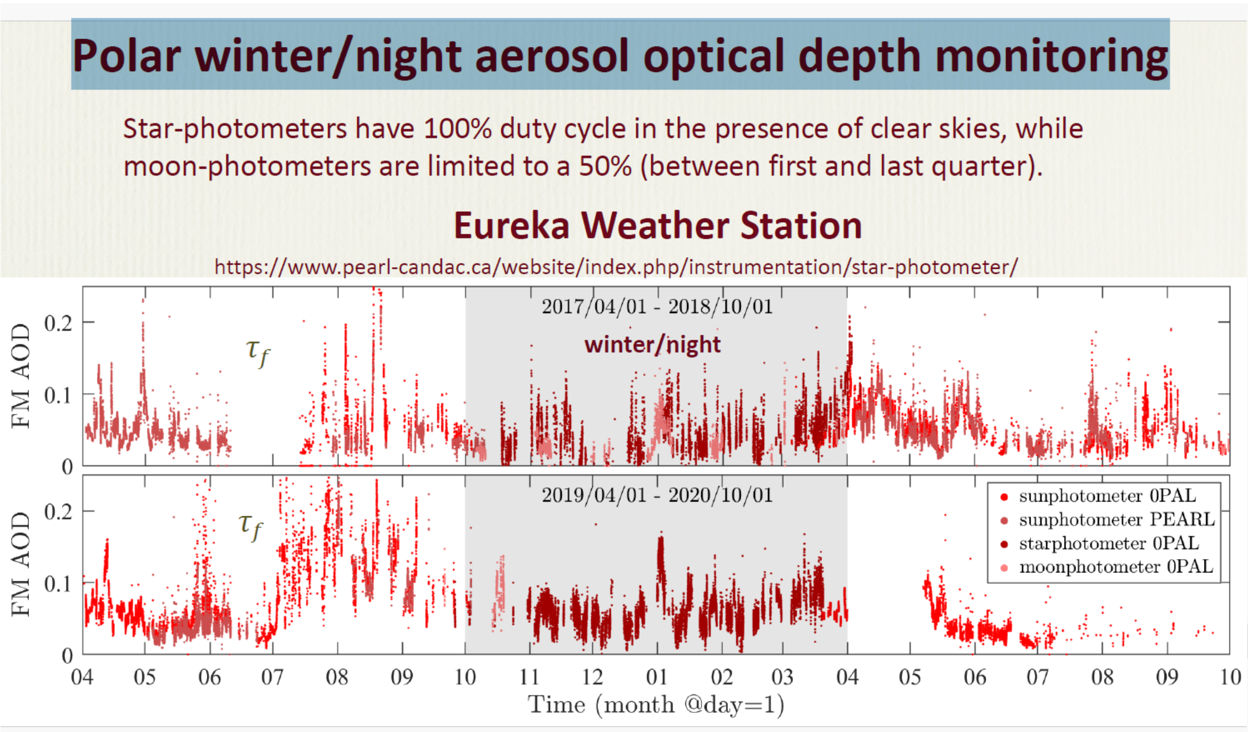


Figure 15 An example of star-photometer measurements during the polar night EUREKA station.

Key points of the lecture include:

- **Capabilities:** Star-photometers provide nighttime measurements of spectral optical depth, detecting particle size and density. They can observe through thin clouds, capturing data on aerosols, ozone, and water vapor.

- **Methodology:** The document covers calibration techniques such as the one- and multi-star Langley calibration, using star brightness data to estimate atmospheric optical depth.
- **Challenges and Uncertainties:** It addresses issues like calibration uncertainties due to star magnitude databases and forward scattering, which affect measurement accuracy.
- **Advantages:** Star-photometry allows continuous operation during polar night and clear skies, can observe in challenging conditions, and complements sun-photometry for 24-hour monitoring.

The approach enables a fuller understanding of atmospheric processes but requires accurate star data and regular maintenance.

Challenges include the need for accurate star magnitude databases and managing calibration complexity. The document also notes the advantages of star-photometry over moon-photometry in terms of cloud penetration and continuous data capture.

2.13 Dust aerosol remote sensing

A lecture about remote sensing of mineral dust was given by Kerstin Schepanski. At the beginning some basic information regarding the size distribution, the sources and transport of dust particles was given along with their optical properties. Then the effect of dust layers on both solar and thermal parts of the spectrum was discussed in combination with different retrieval algorithms. The dark-target (DT) approach at the visible wavelengths was developed for MODIS and it is applicable to all sensors that measure reflectance in the visible, NIR, SWIR. Deep Blue algorithm is applied in the 412 nm band for the AOD retrieval. The UV Aerosol Index is applied to different instruments like TOMS, OMI, S5P/TROPOMI. The MSG SEVIRI provides the IR dust index (Figure 16), and the details of the retrieval algorithm were discussed. The RGB colors were also presented and the RGB rendering of the desert dust product. There is a sensitivity on dust optical properties, the altitude of the layer within atmosphere, the surface temperature and atmospheric conditions like humidity.

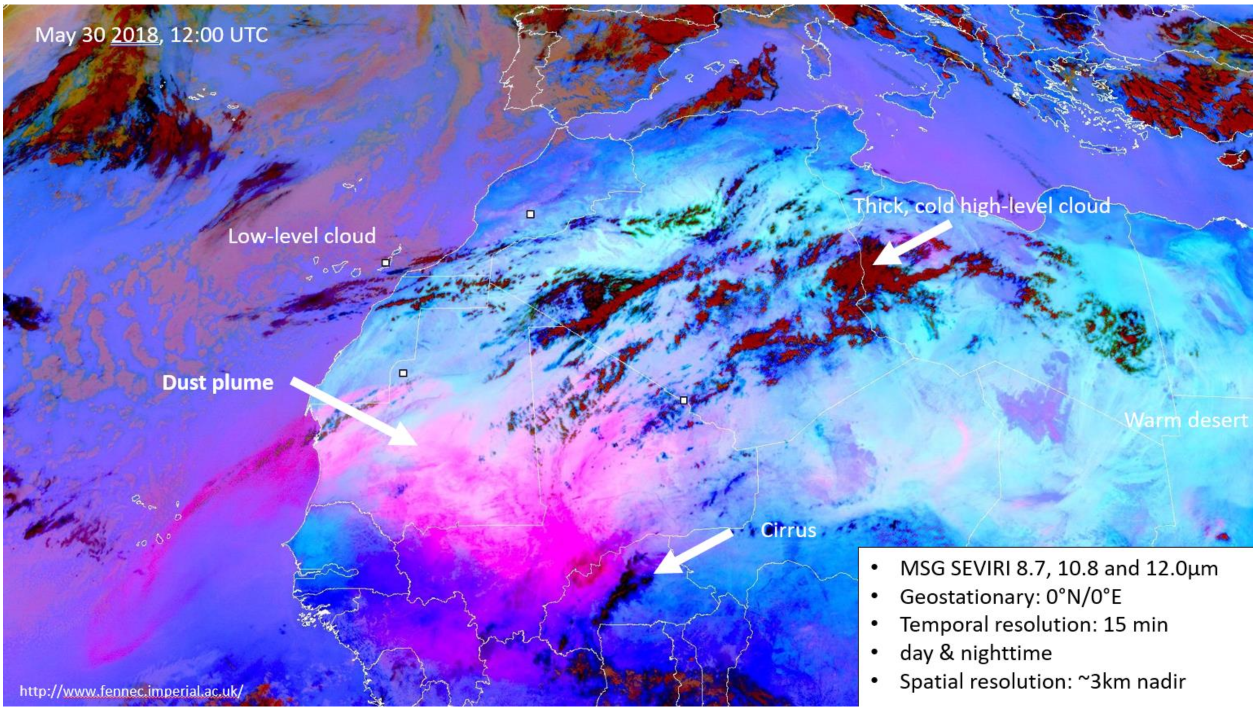


Figure 16 MSG SEVIRI, 09-04-2024, 12 UTC Desert Dust product.

2.14 Airborne experiments on aerosols and clouds

Silke Gross described airborne experiments on aerosols and clouds. The lecture started by presenting the research aircrafts at DLR for aerosol and cloud missions Falcon and HALO. The aerosol and cloud instrumentation onboard combines in-situ and passive and active remote sensing measurements. Then all the flights experiments used for aerosol and cloud studies were presented (Figure 17). Regarding a moving platform there are different things to be considered. The roll angle and pitch angle, what altitude to use (pressure or geometric) and the unstable environment (thermal conditions). WALES is the lidar system onboard, which is a combined airborne water vapor DIAL and HSRL lidar, which developed and built at DLR. Then the lecture was dedicated to the related applications. One of them is the aerosol characterization and classification and related studies were presented. Another scientific topic has to do with the aerosol impact on cloud formation and properties. Related studies were also discussed like the aviation induced aerosol effect on cirrus clouds and the ongoing work of characterization of long-range transported dust into the Arctic and impact on cloud properties.

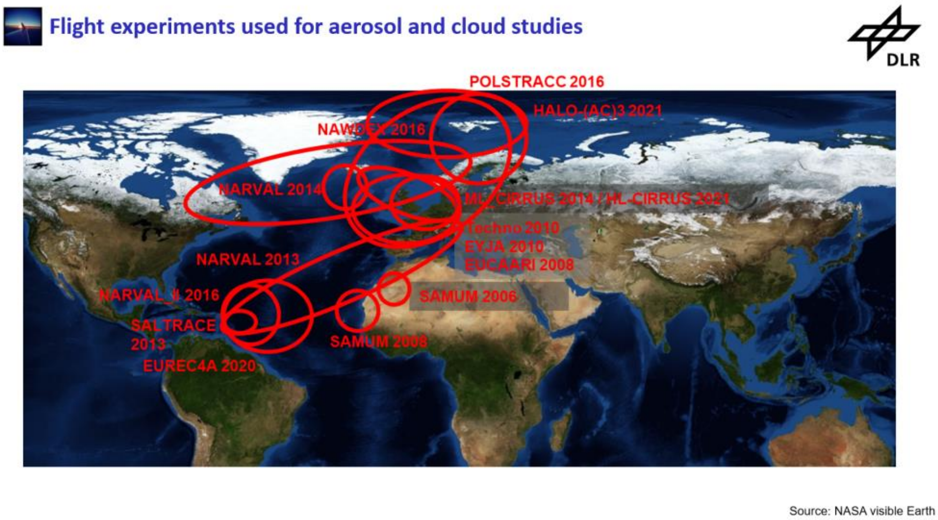


Figure 17 Flight experiments.

2.15 Managing a sun photometer network

A lecture about how to manage a sun photometer network was given by Monica Campanelli. At the beginning the reasons why a network is needs. There are several steps to set up a network (Figure 18). As a first step, what you want to study must be determined. The second step is to select the appropriate instruments. Then the rules for joining the network should be established (e.g. data policy agreement, etc). The fourth step is the creation of a datacenter. A plan for instrument maintenance and calibration should also be created. Final step is to establish mechanisms to ensure the goodness of raw data at measuring sites, the ones provided on the web page and of data transmission. At the end of the lecture, some examples were provided comparing four networks: SKYNET, AERONET, GAW-PFR and PANDONIA.

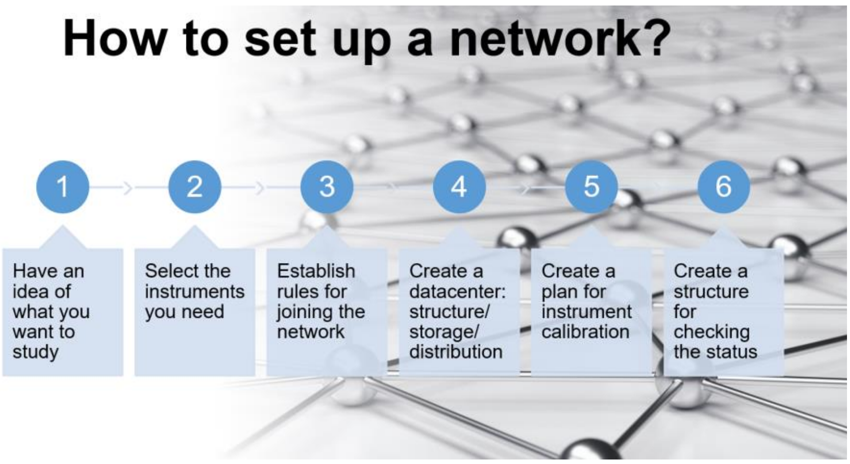


Figure 18 The steps to set up a network.

3. Group projects

This section contains the description of the four group projects that the trainees of SKY Over Berlin school participated in. The following subsections are separated per subject of the group project. The presentations of the results of each of the project groups are available in the following link:

https://www.dropbox.com/scl/fi/1sgdffowwqkxjscvawuxd/Sky-Over-Berlin-Presentations.zip?rlkey=kz0ii46mgljd9rscum18z58r1&e=1&dl=0

The corresponding abstracts of the results presented in EMS2024 in the Session organized by HARMONIA COST Action are also provided in the Anex B, and the full program of the HARMONIA Session is under the link:

https://meetingorganizer.copernicus.org/EMS2024/session/51014

3.1 Project 1: Lunar

The subject of Project 1 **was combining solar and lunar photometry for aerosol optical depth retrievals at the free troposphere of the Subtropical North Atlantic** and the trainer was Africa Barreto.

Since the 1990s, solar photometry has provided reliable, long-term information about key aerosol properties to better understand the role of aerosols in Earth's climate. However, this technique alone has been unable to capture day-to-night variations, introducing a bias in climatological studies and a critical lack of information to understand aerosol processes. Lunar photometry is an emerging technique capable of filling the gaps in aerosol monitoring at nighttime. This is particularly crucial in high latitudes and polar regions due to the prolonged absence of solar illumination.

The trainees were taught the principal technique for retrieving Aerosol Optical Depth (AOD) at nighttime using data from the Cimel CE318-TS instrument located at Roque de Los Muchachos (La Palma, Canary Islands, Spain). This high-altitude observatory (2396 m above sea level) is an excellent location for astronomy and atmospheric observations. A long series of AOD observations since 2018 is available to conduct aerosol climatology analyses during both day and nighttime (only since 2023).

The following tasks were completed by the trainees in the context of Project 1:

1. Learn about the different techniques available in lunar photometry, their different pros/cons and the inherent problems in lunar photometry.

2. Install the different modules (in Python or Matlab) necessary to compute the RIMO lunar exo-atmospheric irradiance model.

3. Perform the photometric calibration during daytime using the Langley-Plot technique.

4. Perform the photometric calibration at night by means of the day-to-night calibration transfer using the RIMO extraterrestrial lunar irradiance model.

5. Retrieve the AOD series for day and night, including for nighttime the AOD calculated by means of the RIMO Correction Factor (RCF) technique.

6. Comparison of solar and lunar products with the operational products of the NASA-AERONET network (routine AOD at day and the provisional lunar data).

The main goal of this project was to develop the necessary skills to retrieve AOD at nighttime using various techniques, comparing their respective results, and proceeding with the characterization of aerosols during both day and nighttime in the free troposphere of the Subtropical North Atlantic. The presentation which was given by the group of Project 1 is available in the following link:

https://www.dropbox.com/scl/fi/1sgdffowwqkxjscvawuxd/Sky-Over-Berlin-Presentations.zip?rlkey=kz0ii46mgljd9rscum18z58r1&e=1&dl=0

An abstract was submitted to the EMS2024 Harmonia session, with the following title:

Nocturnal Aerosol Monitoring at Roque de los Muchachos high-altitude station: Lunar Product Comparison, Barreto et al.

The abstract is provided in Annex B.

3.2 Project 2: Networks

The subject of Project 2 was the **analysis of the differences between the three main aerosol photometry networks in AOD retrieval methods** and the trainer was Lionel Doppler.

There are three main aerosol photometry networks. These are AERONET (AErosol RObotic NETwork, using the Cimel CE318 instruments), SKYNET (SKY Measurements NETwork, using Prede-POM instruments) and GAW-PFR (Global Atmosphere Watch – Precision Filter Radiometer network, using the instruments PFR). These networks use not only different instrumentation, but also different retrieval methods. These different approaches of retrievals lead to artificial differences in the final AOD (Aerosol Optical Depth) products delivered by the three networks. It is one objective of the COST Action HARMONIA to find a harmonized method to retrieve the AOD, that suits to the stations of all three networks.

The idea was to find out and point out the differences in the retrieval methods and to evaluate the consequences on the final AOD products between the three main networks. The dataset of station “observatory Lindenberg”: DWD, MOL-RAO (Deutscher Wetterdienst, Metorologisches Observatorium Lindenberg) in Lindenberg (Tauche, Germany) were considered, since all three instruments and networks are present at this station. They first showed the differences in the AOD final product of the three different networks. In a second step they investigated what are the differences in retrieval procedures: Airmass computation, Rayleigh Optical Depth computation, AOD corrections of gas absorption (Ozone, NO2) and aiming to find a common way to reprocess the data in order to avoid these artificial differences in the final products.

The following tasks were completed by the trainees in the context of Project 2:

1. Get the AOD dataset of some given days for the station “observatory Lindenberg” for all three instruments-networks couples: Cimel-AERONET, PFR-GAW, Prede-SKYNET.

2. Find out the common wavelengths for the three networks’ products and make daily plots of AOD for all three networks for each common wavelength in order to visualize the differences. Make an analysis of these graphics.

3. Investigate in the dataset with help of publications and documentation (papers, reports) how the following processes are treated in the different networks: Air-mass, Rayleigh optical depth, absorption of ozone, absorption of NO2. Make a tabulation report.

4. Define a strategy to optimize the treatment of these processes, considering the other measurements of the station “observatory Lindenberg” (supersite for atmospheric and meteorological measurements), for instance atmospheric pressure ad ozone total column (TOC).

5. Reprocess the data of all three networks using the here above defined strategy of processing and analyze the improvements regarding the differences between the products of the instruments of the three networks.

6. (If time) extend the study to one or several years (up to ten years data available) of data at the station “observatory Lindenberg”.

The overarching goal of this project was to understand the retrieval processes of AOD retrieval for all three main networks (AERONET, SKYNET, GAW- PFR) and to propose a harmonized retrieval strategy to get rid of artificial differences in the final AOD products. In addition to present the results for the dataset of the station “observatory Lindenberg” (DWD, MOLRAO). Under the following link the presentation given by group 2 is provided:

https://www.dropbox.com/scl/fi/1sgdffowwqkxjscvawuxd/Sky-Over-Berlin-Presentations.zip?rlkey=kz0ii46mgljd9rscum18z58r1&e=1&dl=0

An abstract was submitted to the EMS2024 Harmonia session, with the following title:

AOD differences analysis Prede-PFR-Cimel on a 11 years dataset at Meteorological Observatory Lindenberg, Doppler et al.

The abstract was withdrawn.

3.3 Project 3: Dust

The subject of Project 3 was the **sun photometric dust optical properties and comparison with the Metal-WRF model** and the trainers were Stavros Solomos and Ilias Fountoulakis.

Mediterranean countries are significantly affected by dust originating from North Africa and/or Middle East. Depending on its origin (i.e., soil composition at the source), dust composition varies. Dust properties can change further while it is traveling due to mixing with aerosols of other types (i.e., polluted aerosols) and/or hygroscopic growth. The size, shape, and chemical composition of dust define its optical properties and subsequently its impact on the solar radiation that reaches the Earth surface. Nevertheless, uncertainties in the estimates of the radiative effects of dust in models and satellite algorithms are still large.

The idea was to use measurements of aerosol optical properties from different AERONET stations located at Mediterranean and central European countries to investigate how dust optical properties change depending on its origin and throughout its travel, and at which extent the METAL-WRF model can capture such changes. Furthermore, the group tried to quantify the effect of changing optical properties on dust radiative effects and solar energy production.

The following tasks were completed by the trainees in the context of Project 3:

1. Find 5-6 intense dust events that happened in the last 10 years where dust originated from areas with different soil composition. We will use satellite data (e.g., from IASI) to identify events that have affected at least 3-4 AERONET stations at relatively large distances from each other to follow the plume evolution.

2. Use the METAL-WRF model to determine the origin, the trajectories and the composition of dust for the different events and compare the findings of the model with the satellite information.

3. Investigate the changes in the optical/physical properties of dust (SSA, Angstrom, size distribution) with respect to its source and the traveling path using data from different stations for the selected events. Try to explain the differences/similarities.

4. Estimate the optical properties of dust based on the composition of the dust mixture as described by METAL-WRF and compare with AERONET and the chosen satellite products.

5. Compare the theoretical (WRF-CHEM) and measured optical properties and estimate the impact of using different optical properties on the simulations of SSR. Estimate and analyze the differences in SSR attenuation and solar energy losses with respect to the origin and the path of dust.

6. Incorporate any other interesting ideas from the people who will work on the topic.

The goal of this project was to study the optical properties and the radiative effects of dust with respect to its origin and path and evaluate the potential of the METAL-WRF to model dust optical properties. The following link provides the results presented by group 3 at the end of the school:

https://www.dropbox.com/scl/fi/1sgdffowwqkxjscvawuxd/Sky-Over-Berlin-Presentations.zip?rlkey=kz0ii46mgljd9rscum18z58r1&e=1&dl=0

Two abstracts were submitted to the EMS2024 Harmonia session:

Development of METAL-WRF model for the description of mineral dust processes in the atmosphere based on NASA's EMIT satellite retrievals, Solomos et al.

Desert dust outbreaks at the Mediterranean Basin: Optical properties and impact on surface solar radiation, Chadoulis et al.

The abstracts are provided in Annex B.

3.3 Project 4: Megacities

The subject of Project 4 was the **aerosol optical depth (AOD) (ground and satellite based) regime over Megacities and possible links with their population changes** and the trainer was Stelios Kazadzis.

About 55% of the world’s population resides in urban areas and this number is projected to increase to 70% by 2050 (UN, 2019). This population growth in cities raises urgent and critical environmental issues, such as air quality (WHO, 2021) and its degradation, which is known to be related to increased morbidity and mortality rates. In particular, air pollution in cities constituted the 4th leading risk factor for early death on a global scale (HEI, 2020) in 2019. The worst pollutant affecting megacities is suspended particulate matter or aerosols, which can be quantified in optical terms using AOD. The latter is the most comprehensive variable for assessing the aerosol load of the atmospheric column. In a recent study by Papachristopoulou et al. (2022) the state of urban aerosols in 81 cities with a population over 5 million was investigated. This was based on AOD from satellite measurements, with a fine spatial and temporal resolution (0.1°, daily), and over an 18-year period (2003 – 2020). An AOD decrease was found for US/Canadian, European, and East Asian cities. For Chinese cities although they were found to have the highest aerosol loads, they also have the highest AOD decrease, in response to the rigorous emission control measures implemented in the country, especially after 2010. The highest AOD increase was found in Indian cities, reflecting the increasing urbanization and industrialization of the country.

The goal of this project was to use ground based (e.g. AERONET) or/and spaceborne (e.g. MODIS) measurements of AOD for different megacities of the world and to investigate possible links between changes in cities' aerosol loads and their population and emissions.

The following tasks were completed by the trainees in the context of Project 4:

1. Calculate the MODIS AOD trends (for megacities or cities with the greatest population growth). Try to link the results for selected cases with information about emissions for the selected city.

2. Calculate the AERONET AOD trends for cities with available time series for at least 8 years.

3. Calculate the population changes for the same period (UN 2018).

4. Try to find links between AOD and population trends.

5. Investigate the dust contribution using the MIDAS DOD (Gkikas et al., 2021) product and filter the dust affected cities.

6. Explore possible emission time series from the literature.

7. Calculate the geographical distribution (for cities with adequate satellite data availability at 0.1° pixel) of changes gridded estimates of human population counts for the years 2000, 2005, 2010, 2015, and 2020 (possible spatial extent) using the Gridded Population of the World, Version 4 (GPWv4) (CIESIN 2018) dataset.

8. Find the corresponding changes in AOD to investigate if the AOD changes are related spatially with the city's expansion.

9. Find cities with more than 1 available AOD ground based stations and relate the spatial variability with those from high spatial resolution satellite data and gridded population data.

The presentation which was given by the group of Project 4 is available in the following link:

https://www.dropbox.com/scl/fi/1sgdffowwqkxjscvawuxd/Sky-Over-Berlin-Presentations.zip?rlkey=kz0ii46mgljd9rscum18z58r1&e=1&dl=0

An abstract was submitted to the EMS2024 Harmonia session, with the following title:

Aerosol optical depth regime over megacities and possible links with their population changes, Papachristopoulou et al.

The abstract is provided in Annex B.

Annex A

This is the full program of the school.

SKY OVER BERLIN
HARMONIA
2024 TRAINING SCHOOL

Monday 08.04.2024 – FU Berlin		
9.00	Welcome and registration	
9.20	FU Berlin atmospheric research activities	Stephan Pfahl
9.45	Harmonia Action	Stelios Kazadzis
10.00	The AERONET network	Elena Lind
10.45	Break	
11.10	ACTRIS Calibration of sun photometers	Stelios Kazadzis/ Carlos Toledano
11.30	Aerosol inversions	Masahiro Momoi
12.00	Lunch Break	
14.00	Aerosol Cloud interactions	Albert Ansmann
14.40	Advancements and limitations in retrieving detailed aerosol properties from remote sensing observations	Oleg Dubovik
15.20	ESA Missions for Aerosols	Rene Preusker/ Jonas von Bismarck
16.00	Workshop exercises 4 teams and supervisors	Supervisors

SKY OVER BERLIN

HARMONIA
2024 TRAINING SCHOOL

Tuesday 09.04.2024 – Lindenberg		
8.00	leaving from Berlin by bus	
9.45	Welcome in Lindenberg, Infos and Presentation of DWD and MOLRAO	Lionel Doppler, Franz Berger (head),
10.15	CIMEL sun photometer	Stéphane Victori
10.35	PFR-PSR photometers -	Natalia Kouremeti
10.55	Sky Camera use for AOD retrievals	Roberto Roman
11.15	Synergies Raman Lidar and Photometers in Ny-Alesund	Christoph Ritter
11.45	Lunch Break	
12.45	Balloon Launch (in situ radiosounding measurement)	
13.00	Presentation of DWD and MOLRAO	Franz Berger (head), Lionel Doppler
13.45	Tour of Lindenberg Observatory	Lionel Doppler, Stefan Wacker, Ralf Becker (DWD)
16.00	Stellar photometers	Liviu Ivanescu, Karl-Heinz Schulz
16.30	Walk to Wettermuseum	
17.00	Wettermuseum expositions and Social Dinner	
20.00	Bus to Berlin departure	

SKY OVER BERLIN
HARMONIA
2024 TRAINING SCHOOL

Wednesday 10.04.2024 – FU Berlin		
9.00	Dust aerosol remote sensing	Kerstin Schepanski
9.30	Airborne experiments on aerosols and clouds	Silke Gross
10.10	Lunar Photometry	Africa Baretto/ Natalia Kouremeti
10.40	Break	
11.00	Managing a sun photometer network	Monica Campanelli
11.30	Communicating science	Anca Nemuc
	Lunch Break	
13.30	Harmonia funding tools and dissemination strategy	Pavla Dagsson & Panos Raptis
14.00	Presentation preparations	
17.00	Presentation from students and discussion	
19.00	End of the school	

Annex B

B.1 Project 1 EMS2024 Abstract

Nocturnal Aerosol Monitoring at Roque de los Muchachos high-altitude station: Lunar Product Comparison

África Barreto[1,2], Roberto Román[2], Andrea Balotti[3], Claudia Frangipani[4,5], Miguel Ángel Gamonal[6], Daniel González-Fernández[2], Pablo González-Sicilia[1], Angelos Karanikolas[7,8], Simone Pulimeno[5,9], Cedric Busschots[10], and **Stelios Kazadzis**[7]

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[9]Ca' Foscari University of Venice, Venice, Italy

[10]Royal Belgian Institute for Space Aeronomy, Brussels, Belgium

Lunar photometry is an emerging technique capable of filling the gaps in aerosol monitoring at night-time. This is particularly crucial in high latitudes and polar regions due to the prolonged absence of solar illumination. One of the most principal obstacles we encounter in monitoring aerosols at night-time using the Moon as a light source is the need for accurate extraterrestrial lunar irradiance due to the fast change of the Moon's illumination over time. The RIMO (ROLO Implementation for Moon's Observation; Barreto et al., 2019) model is an implementation of the ROLO (RObotic Lunar Observatory) model. RIMO was performed by the polar aerosol community to estimate the AOD at night-time, transferring the calibration of the solar channels to nocturnal measurements by means of the Sun-Moon gain factor method. A further correction of the RIMO model, the so-called RIMO correction factor (RCF), has served to improve the accuracy of the lunar product (Román et al., 2020). Similar approaches to correct the ROLO or RIMO biases have been developed by AERONET and Skynet teams (Uchiyama et al., 2019).

In this study, we will use an 11-month dataset of day- and night-time photometric measurements taken with the CE318-T photometer at Roque de Los Muchachos (La Palma, Canary Islands, Spain). This high-altitude observatory (2396 m above sea level) is an excellent location for astronomy and atmospheric observations. Day and night photometer observations performed at this pristine site are used to study and evaluate the differences between the AOD retrieved with the CE318-T photometer using RCF and AERONET lunar products.

Acknowledgments: This article/publication is based upon work from COST Action Harmonia CA21119, supported by COST (European Cooperation in Science and Technology). The authors would like to thank the NASA-AERONET network, AEROSPAIN Central Facility (https://aerospain.aemet.es/) and ACTRIS (grant agreement No 871115) to ensure the calibration of the sun photometers.

References:

Barreto et al.: Evaluation of night-time aerosols measurements and lunar irradiance models in the frame of the first multi-instrument nocturnal intercomparison campaign, Atmospheric Environment, Volume 202, Pages 190-211, ISSN 1352-2310, https://doi.org/10.1016/j.atmosenv.2019.01.006, 2019.

Uchiyama et al.: Nocturnal aerosol optical depth measurements with modified sky radiometer POM-02 using the moon as a light source, Atmos. Meas. Tech., 12, 6465–6488, https://doi.org/10.5194/amt-12-6465-2019, 2019.

Román et al.: Correction of a lunar-irradiance model for aerosol optical depth retrieval and comparison with a star photometer,, Atmos. Meas. Tech., 13, 6293–6310, https://doi.org/10.5194/amt-13-6293-2020, 2020.

How to cite: Barreto, Á., Román, R., Balotti, A., Frangipani, C., Gamonal, M. Á., González-Fernández, D., González-Sicilia, P., Karanikolas, A., Pulimeno, S., Busschots, C., and Kazadzis, S.: Nocturnal Aerosol Monitoring at Roque de los Muchachos high-altitude station: Lunar Product Comparison, EMS Annual Meeting 2024, Barcelona, Spain, 1–6 Sep 2024, EMS2024-1045, https://doi.org/10.5194/ems2024-1045, 2024.

B.2 Project 3 EMS2024 Abstracts

Development of METAL-WRF model for the description of mineral dust processes in the atmosphere based on NASA's EMIT satellite retrievals

Stavros Solomos[1], Christos Spyrou[1], Nikolaos S. Bartsotas[1], Christina Kalogeri[1], Ilias Fountoulakis[1], Christos S. Zerefos[1,2,3], Yeşer Aslanoğlu[4], Rizos-Theodoros Chadoulis[5], Georgia Charalampous[6,7], Sara Herrero-Anta[8], Celia Herrero del Barrio[8], Dimitra Kouklaki[9,10], Anna Moustaka[5,10], Michail Mytilinaios[11], and Alkistis Papetta[12]

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[12]The Cyprus Institute, Nicosia, Cyprus

Mineral dust stands out as a pivotal climate modulator due to its substantial mass, optical depth, and long-term atmospheric life cycle. It impacts the atmospheric radiative balance, influences cloud dynamics and precipitation patterns, and exerts notable effects on terrestrial and aquatic ecosystems as well as human health. The extent and intensity of these impacts are governed by the mineral composition of dust particles sourced from diverse regions worldwide. METAL-WRF is an advanced numerical framework extending the GOCART-AFWA dust scheme in WRF-Chem 4.4.1 and it is designed to simulate the atmospheric dynamics of dust mineral components, including emission, transport, dry deposition due to gravitational settling, and wet deposition due to the scavenging of dust particles by the hydrometeors. The model accounts for ten mineral types: illite, kaolinite, smectite, calcite, quartz, feldspar, hematite, gypsum, phosphorus, and iron. In the previous version of METAL-WRF the mineralogical composition of dust is derived from the global geological datasets GMINER30 and FERRUM30. A significant improvement in the mapping of dust composition comes from NASA's EMIT sensor that has been operational aboard the International Space Station (ISS) since July 2022. EMIT utilizes advanced imaging spectroscopy to capture light across visible and infrared wavelengths, identifying distinct spectral signatures indicative of surface mineral composition. In this study, we introduce the integration of the first comprehensive EMIT mineralogical dataset in METAL-WRF. The model is used for the simulation of atmospheric dust in HARMONIA 2024 Berlin school. We discuss the comparative distribution of various mineral dust types in the Mediterranean between METAL-WRF simulations incorporating EMIT mineralogy data and earlier versions relying on GMINER30 and FERRUM30 geological databases. The effects of the

different mineral types in radiative transfer and ice nuclei activation are examined for specific case studies in comparison with ground based and spaceborne observations.

Acknowledgments. The authors acknowledge financial support from the Hellenic Foundation for Research and Innovation project "Mineralogy of Dust Emissions and Impacts on Environment and Health (MegDeth - HFRI no. 703)" and from the COST Action CA21119, "HARMONIA: International network for harmonization of atmospheric aerosol retrievals from ground-based photometers".

How to cite: Solomos, S., Spyrou, C., Bartsotas, N. S., Kalogeri, C., Fountoulakis, I., Zerefos, C. S., Aslanoğlu, Y., Chadoulis, R.-T., Charalampous, G., Herrero-Anta, S., Herrero del Barrio, C., Kouklaki, D., Moustaka, A., Mytilinaios, M., and Papetta, A.: Development of METAL-WRF model for the description of mineral dust processes in the atmosphere based on NASA's EMIT satellite retrievals, EMS Annual Meeting 2024, Barcelona, Spain, 1–6 Sep 2024, EMS2024-176, https://doi.org/10.5194/ems2024-176, 2024.

Desert dust outbreaks at the Mediterranean Basin: Optical properties and impact on surface solar radiation

Rizos-Theodoros Chadoulis[1], S. Yeşer Aslanoğlu[2], Georgia Charalampous[3,4], Sara Herrero-Anta[5], Celia Herrero del Barrio[5], Dimitra Kouklaki[6,7], Anna Moustaka[2,7], Michail Mytilinaios[8], Alkistis Papetta[9], Stavros Solomos[10], Antonis Gkikas[10], Christos Spyrou[10], Nikolaos Papadimitriou[10,11], Sophie Vandenbussche[12], and Ilias Fountoulakis[10]

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The Mediterranean Basin is one of the sunniest regions globally. Thus, aerosols, and especially dust, play a key role in radiative transfer processes in the atmosphere, which locally can be comparable to or even more significant than the role of clouds. The physical (i.e., size, shape) and chemical (e.g., composition) properties of dust that is transported across the Mediterranean Basin depend strongly on its origin, as well as on its ageing and mixing with other atmospheric constituents. For instance, the mixing of dust with anthropogenic particles can alter its chemical composition and hygroscopicity/ hygroscopic properties. Changing physical and/or chemical properties of dust also alter its optical properties and subsequently its radiative effects.

By analyzing synergistically back-trajectories of the air masses at different altitudes from the HYSPLIT model, aerosol optical properties from Aerosol Robotic Network (AERONET), and dust optical depth from the ModIs Dust AeroSol (MIDAS) climatology, we identified three strong dust events in the period 2015 – 2022 where dust originated from different regions of Africa and the Middle East and travelled over many AERONET stations located in (and near) the Mediterranean Basin (in an area covering latitudes from 30° N to 45° N and longitudes from -10° E to 40° E. After identifying the origin of desert dust, we studied the changes in its optical (Optical Depth, Angstrom Exponent, Single Scattering Albedo) and microphysical (size distribution) properties as derived from different AERONET stations, using quality assured, AERONET level 2 (version 3), products. Finally, Radiative Transfer (RT) simulations for clear sky (cloudless) conditions were performed, employing the UVSPEC model from the libRadtran package in order to estimate the impact of dust, as well as the effect of its changing optical properties, on downwelling surface solar radiation in terms of Global Horizontal Irradiance (GHI) and Direct Normal Irradiance (DNI).

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B.3 Project 4 EMS2024 Abstract

Aerosol optical depth regime over megacities and possible links with their population changes

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More than 50% of the global population is hosted in cities of the world. The United Nations estimate that the number of inhabitants in the cities will be increased by about 2.5 billion people by 2050. Worldwide, the most pronounced urban population growth (up to 90%) is projected for Asia and Africa. Such a population increase is expected to also increase the emissions of fine aerosols originating from anthropogenic activities. The World Health Organization estimates that the exposure to fine aerosol particles is responsible for 4.2 million premature deaths on an annual basis. In some countries, strategic national measures (i.e., U.S. and European Clean Air Acts, China's Air

Pollution Prevention and Control plan) are applied for the mitigation of aerosol emissions. Such initiatives have been designed to tackle the urgent needs for combating air quality degradation, which in turn has subsequent impacts on human health.

In this study, high resolution satellite-based data of aerosol optical depth (AOD) from the MODerate resolution Imaging Spectroradiometer onboard the Aqua satellite (MODIS-Aqua), in addition to ground-based sun photometric aerosol measurements and population data for 81 megacities (cities with more than 10 million inhabitants) are analyzed. Aspects that are addressed deal with the correlation of AOD variability and population growth and the effect of regional emissions in the AOD vs population links. As an example, India and China show contradictory AOD trends, being continuously increasing for India and declining for China, despite the recorded population growth in both countries. In addition, high spatial resolution data identify intra-city correlations among aerosols and population growth. In this case ground-based observations are also used aiming to understand possible spatial AOD inhomogeneities within a few kilometers in megacities and in the neighboring areas. Moreover, in the context of this work, long-term AOD retrievals obtained by the MAIAC (Multi-Angle Implementation of Atmospheric Correction) will be used for better data availability and for the potential to use additional auxiliary data to investigate the effects on several aspects. Finally, as a number of megacities are affected by natural aerosols (e.g. desert dust) we have tried to eliminate such effects as they are not linked with population growth, by using a fine spatial resolution dust optical depth product derived by the MIDAS (ModIs Dust AeroSol) dataset.

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