



HARMONIA CA21119

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## **Presentations and discussions of the 1<sup>st</sup> Harmonia WG4 Workshop with industrial users related with technological needs and innovation actions**

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## 1. Introduction

This Harmonia meeting marked the first Workshop of Working Group 4 (WG4). It was held at the *Physikalisch-Meteorologisches Observatorium Davos / World Radiation Center (PMOD/WRC)* on October 8, 2025. The meeting brought together over 20 participants, most of whom attended in person.



The Workshop featured a total of 14 presentations delivered by both scientists and representatives from software and instrument manufacturers. The objective was to foster collaboration between these groups and to initiate discussions on improving measurement techniques and results, in line with the main goals of WG4, which are outlined below:

**WG4:** (Industry engagement towards innovative hardware, software products) will create a hub among scientists and the industrial sector including instrument and software developers. The main aim is to demonstrate the possibilities of improvements based on synergistic and standardization aspects (WG1 to 2) and also inform on the needs of new technologies towards specific end user goals (WG3). Main tasks within this working group are to:

- Identify new value-added products resulting from synergistic approaches. Create an assessment of current measurement uncertainties versus user needs and defining a road map towards future measurement improvements needed.
- Establish a collaboration platform among scientists and instrument manufacturers aiming on instrument hardware improvement, linked with retrieval algorithms, towards improvement of aerosol retrieval accuracy.
- Suggest software, hardware and other aerosol retrieval improvements including low sensors assessment and share the information with major industrial developers inside and outside HARMONIA network.

## 2. Presentations Summaries

### 2.1. CIMEL CE318-T Operational Experience and Development Needs (by Pablo González Sicilia, AEMET - TRAGSA)

This presentation was based on the Cimel CE318-T sun-photometer. First, the technical characteristics of these instruments were described and explained, including the main parts of the instrument, the spectral range and the procedure of measuring.

After this brief introduction, the measurement capabilities and products obtained from these photometers were listed. For each one of them, the measurement method, the calibration and the uncertainties were described, as well as the wavelengths involved.

Knowing the main characteristics of the instrument, some current issues were introduced, which mainly concern to hardware problems. Among other issues, recent results show the UV channels need to be improved, especially in lunar measurements or low aerosol conditions. Moreover, regarding not only UV but also NIR, it is proposed as a future improvement to expand Cimel's spectral range in both directions. Apart from this one, other future projects were presented, such as the creation of an oceanic network based on ship-borne photometers or the harmonization of lunar AOD measurements, since yet there is no agreement in which model, correction or calibration method is better for this kind of measurements.

#### Questions/discussion:

- The example for UV wavelength given in the presentation (300 nm) is something which is nowadays being studied in order to find the one which works best to retrieve aerosol information. It is not necessarily 300 nm, but the goal is for it to be around that wavelength, so it is shorter than the current shortest wavelength.
- The Cimel calibration still has issues that need to be studied, especially the ones regarding the absolute calibration of the instrument.

### 2.2. CIMEL photometer & other passive instruments (by Stéphane Victori, CIMEL)

After a brief introduction of how AERONET was created, the main technical specifications of the Cimel CE318-T were exposed. There were also shown the rest of the Cimels instruments as well as the filters they have.

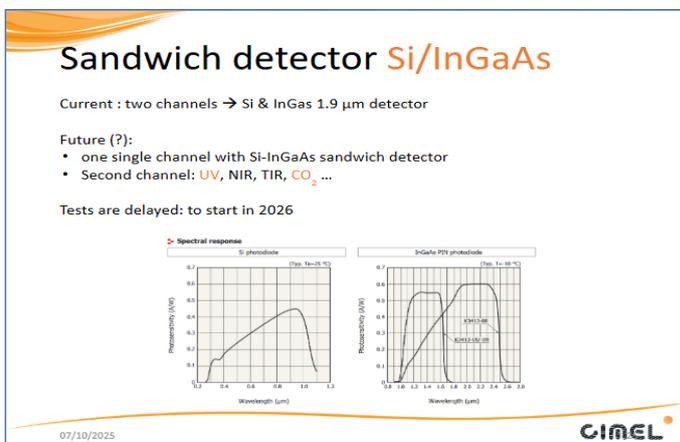
Cimel communicated the scientific community that the improvement of the four-quadrant sensor of the CE318 is still being improved. It will be replaced soon by a new four-quadrant with a multi-pixel approach. In addition to these, there were explored some of the future projects of Cimel company, which included a ship-borne network of photometers, new filters, as well as the enlargement of the CE318 spectral range using a sandwich detector to measure visible and near infrared wavelengths in only one channel. Also, some new projects based on the development of new instruments were shown.

#### Questions/discussion:

- Julian Gröbner and Natalia Kouremeti, both researchers from PMOD/WRD, reminded that in their institute, some of the issues Cimel presented, had already been tackled in the past.

Regarding the problem with the UV filters, they propose the use of black filters before the interference filter. They also showed the PFR tracking method as an example to solve the four-quadrant tracking issue.

- Some of the future projects proposed was the “Sandwich detector” as can be seen in figure below. However, the use of just only one channel to measure most of the wavelengths could cause some inconveniences, such as avoid the obtention of AOD at 1020nm with two different channels, which is generally useful to identify problems in the instrument such as dirt or the malfunction of a part of the instrument.



- It was also mentioned the cooling down issue for the IR channels. The company suggest cooling them down from 2000nm onwards. But if it is not much higher, and AOD is the object of study (as happens with some Cimels instruments in Izaña), then the cooling down is not that crucial.

### 2.3. Industry Engagement towards Innovative Hardware & Software Products- Examples from European Metrology Projects (by Julian Gröbner, PMOD/WRC)

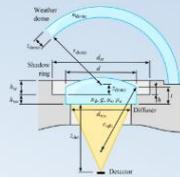
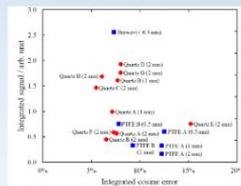
In this presentation, several examples in which meteorology-related scientist and companies have satisfactorily collaborated were exposed.

## An improved diffuser for the Brewer spectroradiometer.

European Metrology Research Programme SolarUV 2011-2014.

- Collaboration between Kipp&Zonen, CMS-Schreder and the project consortium.

Brewer spectroradiometer I. Diffuser material characterisation II. Monte-Carlo ray-tracing III. Commercial product



graubünden Education and Research.

EMRP

pmoD wrc

The slide taken from the presentation shows one of these examples. Generally, these collaborations function as a symbiosis between both interested parties. Companies aim to create the best possible product to increase their sells and make business. On the other hand, scientist need these instruments in order to get better results and reduce uncertainties. In this example, the product was a light diffuser for a brewer spectrometer. Usually, the company produce several prototypes and need the scientist knowledge and experience to try them and decide which one is better and how to improve it. An important remark from the presentation is to keep in mind that the benefits of these collaborations usually appear in the long term.

### Questions/discussion:

In this case there was no after discussion since the talk itself was a discussion to show how companies and scientist can obtain benefit from each other.

## 2.4. Prede POM photometer - user input (by Monica Campanelli, CNR, Skynet Europe)

The aim of this talk was to emphasize the importance of the collaboration between the users and the manufacturer of the Prede POM and also the necessary dialogue between them in order to improve the system. The main technical properties of the POM were shown but also from the previous versions of it, explaining how Prede improved them over time in order to fulfil user's requests.

Apart from these improvements, they were also presented some of the issues which still need to be faced, especially cloud-screening to compare different databases. After that, she mentioned the importance of the intercomparison campaigns and the importance of having long term data.

### Questions/discussion:



- Regarding the cloud screening methods, there are still issues to solve, since for example the removal of points which the algorithm thinks that are cloud, but they are not, such as high AOD events. There was a discussion comparing different cloud screening algorithms (Aeronet, CAELIS), but the conclusion was that still there is no agreement in which is better, or how they are working for lunar data in some networks. The main issue is that comparing few data, provides good results, but the more amount of data taken, the worse the comparison will be.

## 2.5. Precision Filter Radiometer (PFR) & Precision Spectro-Radiometer (PSR) Development (by Natalia Kouremeti, PMOD/WRC)

The PFR and PSR instruments were developed at PMOD/WRC in 1998 and 2010, respectively, through close collaboration between the PMOD technical department (manufacturer) and scientists to meet contemporary scientific needs. Specifically:

- PFR: developed in response to WMO requests for robust, high-precision sunphotometers with long-term stability for high-quality direct solar irradiance measurements and aerosol optical depth (AOD) monitoring at background stations.
- PSR: developed to address the lack of robust, stable, portable spectrometers for direct solar irradiance measurements and spectral AOD retrievals.

PMOD/WRC's dual role as user and developer drove a lengthy process of development, optimization, and upgrades of both instrument types. Technical characteristics, characterization procedures, and corrective actions to improve both instruments were presented (e.g., field of view, stray light).

Emphasis was placed on the latest PFR series (2019) as an example of an upgrade driven by close collaboration between users (PMOD/WRC scientists) and the manufacturer, in contrast to the 2005–2008 upgrade series, which was manufacturer-led. Long-term deployment of PFRs under varied environmental conditions, together with detailed characterization, identified the main instrumental sources of uncertainty in AOD retrievals. These were addressed in the design and optimized where possible within commercial constraints to preserve backward compatibility.

The advantages of hardware improvements over post-processing corrections are demonstrated in the detailed uncertainty budget of a PSR instrument, which attains a combined expanded relative uncertainty of 1.8% in the 400–900 nm spectral region (Figure 2.5). Although PSR was not a major commercial product for PMOD/WRC, it highlighted the need for high-quality, portable, and stable spectroradiometers.

### Questions/discussion:

- The audience wondered which are the plans for the PSR. The PFR belong to their own network, is a PSR network planned? Which is the future for these instruments?  
Natalia Kouremeti answered that there is no network intention for the near future. In the current state of the PSRs, the maintenance costs are too high and there are instruments in the market which can obtain similar results with lower costs. So, for the moment there are just 7 instruments globally distributed over 4 stations.

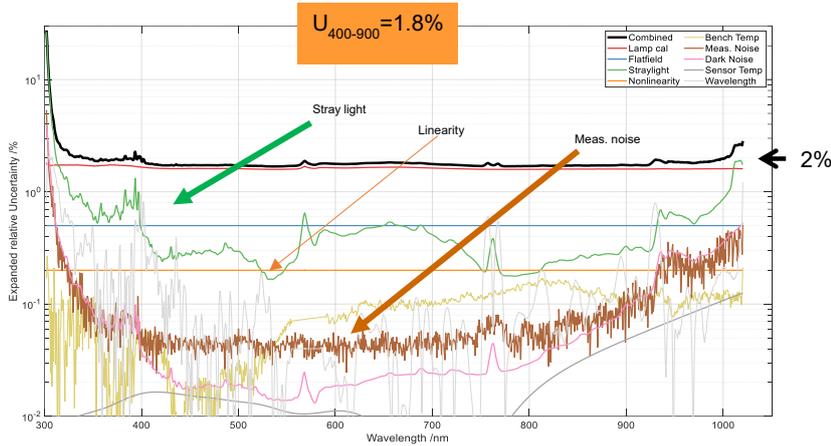


Figure 2.5: Irradiance uncertainty budget of a PSR. Gröbner J and Kouremeti N 2019 *The Precision Solar Spectroradiometer (PSR) for direct solar irradiance measurements Solar Energy* **185** 199-210, DOI: [10.1016/j.solener.2019.04.060](https://doi.org/10.1016/j.solener.2019.04.060)

## 2.6. Metrology for Filter- and Spectro- Radiometers (by Saulius Nevas, PTB)

Ground-based passive remote sensing techniques use radiometric measurement methods. The respective measuring instruments – including filter radiometers, also known as sunphotometers or spectroradiometers – are used to determine solar spectral irradiance or sky radiance. SI-traceable calibrations of the instruments require respective transfer standard with traceability to the SI and appropriate calibration setups. The calibrations include also characterisations of all relevant instrumental properties, affecting measurement results and contributing to the measurement uncertainties. E.g., the calibration of a spectroradiometer includes characterisation of the wavelength scale, spectral responsivity, bandpass functions, spectral stray light, the linearity of the detector system and all other specific properties of the respective device, such as the field of view or temperature coefficients.

As a results of an SI-traceable calibration, both filter-radiometers and spectroradiometers are traceable to the SI units W and m (Figure 2.6). At the top of the radiometric traceability chain is an absolute cryogenic electrical substitution radiometer, which is used to measure the power of a monochromatic well-defined beam irradiating a secondary radiometric detector, e.g. a Si trap detector. The obtained spectral power responsivity is transferred to further transfer standard detectors by using an appropriate calibration setup with a monochromatic spectrally tuneable source. By adding a radiometric aperture with a calibrated area to the radiometric detector, the spectral irradiance responsivity is obtained. Such a detector can be used as a reference to calibrate the spectral irradiance responsivity of a filter- or a spectroradiometer in an appropriate setup, such as a spectrally tuneable laser-based setup TULIP at PTB. Absolutely calibrated filter radiometers are employed to determine the radiometric temperature of a high-temperature blackbody radiator, which is used then in combination with an aperture of calibration area as a primary source for spectral irradiance. The

spectral irradiance is transfer via substitution to secondary standards and further transfer standards. Both filter- and spectroradiometer can be calibrated thus against primary or transfer standards for spectral irradiance.

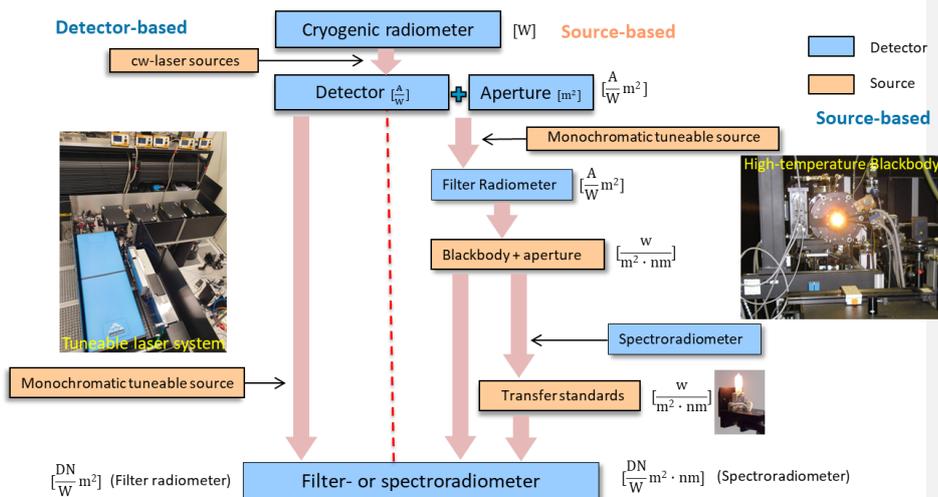


Figure 2.6: Traceability chains for radiometric calibrations of filter- and spectroradiometers using detector- or source-based transfer standards.

The established transfer standards for spectral irradiance in the spectral range from 250 nm to 2500 nm are based on quartz-tungsten-halogen (QTH) lamps. As a result of the production phase-out of such lamps, new-technology sources are needed to transfer spectral irradiance unit to measurement applications. A Metrology Partnership project 22IEM05 NEWSTAND (<https://www.ptb.de/epm2022/newstand/home>) is currently running with the objective to provide new-technology transfer standard sources and detector based dissemination methods for spectral irradiance.

Questions/discussion:

- It was proposed to use LEDs as the new transfer elements, although people were curious if there won't be stability problems with these ones. About the stability issues, Saulius Nevas explained that can be found LEDs with good stability, even more than lamps. However, the problem is with the multiple-spectral LEDs, which are the ones with stability issues.

## 2.7. Gigahertz-Optik BTS Spectroradiometers (by Ralf Zuber, Gigahertz-Optik)

The BTS-Solar/BTS2048 family are CCD-array spectroradiometer systems designed for direct and global solar spectral irradiance measurements. Outdoor versions have low maintenance (only a filter wheel

as a moving part), heated airflow for snow/water mitigation, and a sun tracker with a 4-quadrant diode. The system is modular with versions covering UV ( $\approx 280\text{--}430\text{ nm}$ ), VIS–NIR ( $\approx 280\text{--}1050\text{ nm}$ ), NIR/IR up to  $\approx 2150\text{ nm}$ , allowing full spectral coverage by combining units.

Key technical features include sophisticated filter-based stray-light reduction in the UV—implemented via filter measurements between diffuser and spectrometer and an array optics layout optimized by ZEMAX ray tracing—to preserve accuracy near the solar edge. Direct measurement FOV is approximately  $\pm 1.4^\circ$  (FWHM) and the UV bandpass is about 0.6 nm.



Figure 2.7a: BTS on solar tracker

Applications demonstrated include spectral aerosol optical depth (AOD) retrievals across 280–2150 nm (reference: Gröbner et al. 2023) and global spectral irradiance/UV Index monitoring (BTS2048-UV-S-WP), used in national networks such as the German UV monitoring. The system supports Total Ozone Column (TOC) retrievals using multiple algorithms (SolarRunner LUT, CDR/LSF by Luca Egli, etc.), with cited publications and long-term comparisons.

Calibration is straightforward due to the cosine diffuser entrance optic; units can be calibrated by the user, an external center, or returned to Gigahertz-Optik's lab. The devices are robust for transport and support the use of calibration lamps in the field.

Decades of close interaction with the scientific community and national metrology institutes have shaped Gigahertz-Optik core strengths—40 years of domain know-how, a high-end in-house ISO 17025 lab, and fully integrated expertise in optics, electronics, mechanics, software, and calibration—allowing rapidly knowledge of research needs into customized, field-ready instrument and laboratory solutions.



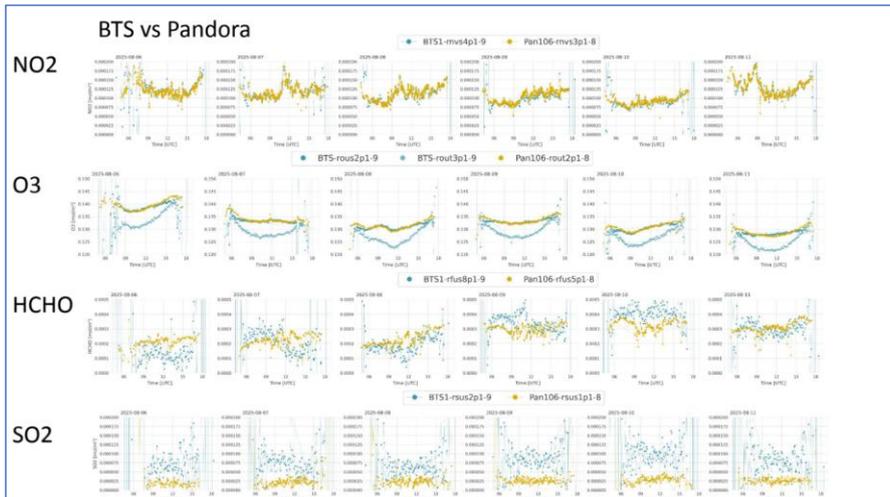
Figure 2.7b: Traceability pyramid of Gigahertz-Optik

#### Questions/discussion:

- Ralf Zuber, representing the Gigahertz-Optik team, wanted to emphasize the importance of the link with the scientific community in terms of promoting improvements of the instrument, addressing the user's needs (in terms of software, mechanics, calibration, etc), being able to customize and improve their products thanks to this feedback.

## 2.8. Pandora Spectroradiometers and Pandonia network (PNG) (by Axel Kreuter, Luftblick)

To begin with, due to the previous presentation, a comparison between BTS and Pandora measurements was presented, highlighting the advantages of Pandora instrument.



The evolution of the Pandora network was shown, which partly relies in the user's feedback. In addition to these, the latest findings from the PGN network were shared, covering an overview of the entire network, including the different instruments and their corresponding products which not only focus on AOD measurements, but also gases.

Axel Kreuter explained how Pandora can be mixed with other network/instruments products and proposed to create a common model between them.

Questions/discussion:

- Regarding the establishment of a common model, to which all the networks will connect and share data. It was discussed that this connection to a common model will also enable an interaction between different networks, which will result in an improvement of them. Axel Kreuter made an analogy on how human intelligence was developed thanks to the social interaction between them.

**2.9. Solar Radiometer comparison (by Adam R. Jensen, Technical University of Denmark)**

In the first part of the talk, it was explained the importance of comparing different versions of the same instrument, in this case, diffuse instruments. There were also shown and explained briefly the four main types of diffuse sensors.

One of the main goals of this experience was to study the role of low-cost sensors in comparison to expensive, reference instrumentation to measure solar radiation. This study was performed in terms of different aspects, not only focused on the price but also on the installation, communications, etc.

Questions/discussion:

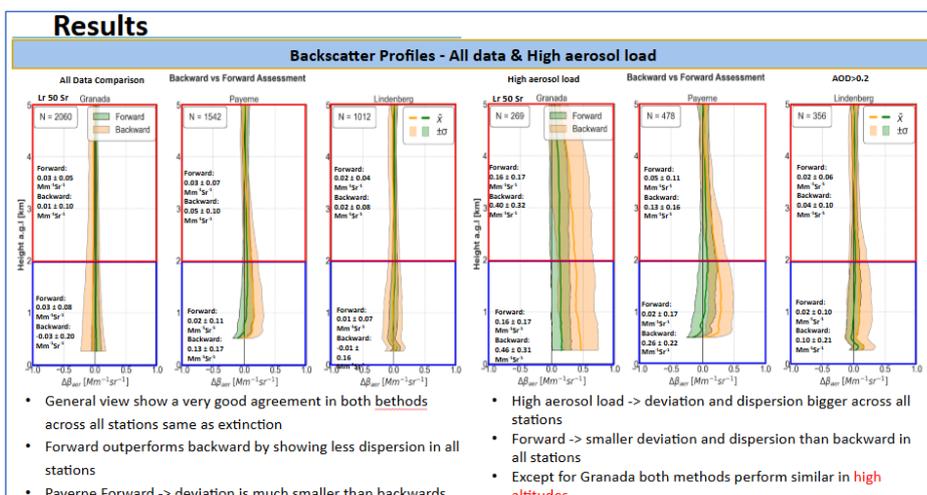
Commented [RR1]: I remember this presentation that said something about the instruments that usually fails. Could you add this part as a conclusion of the presentation?

- After a brief discussion, the audience and the speaker concluded that low-cost sensors often fail to meet performance expectations. It was agreed that such instruments should be thoroughly tested and verified for accuracy before being considered for purchase.

## 2.10. Evaluation of aerosol measurements from ceilometers on a European scale using synergistic GRASP retrievals from sun-photometers and ceilometers (by Jorge Muñiz, Universidad de Granada)

The presentation showed how ceilometer measurements can be combined with photometer data to obtain a good characterisation of the aerosols and clouds through GRASP algorithm. More specifically, the GRASP-pac algorithm was used for this purpose.

After these, two stand-alone methods for calculating aerosol backscatter from ceilometer retrieval were presented, highlighting how the forward method is usually more precise, especially in the lower layers of the atmosphere (closer to the ceilometer). To show this, and other important results, there were compared the backscatter profiles of different stations from Europe as can be seen in the image below.



### Questions/discussion:

- Various scientist from the audience wondered why in all the examples it was used the same lidar ratio and proposed to adapt it weather the aerosol particles of study are fine or coarse.
- GRASP-pac provides the lidar ratio, why it or the AERONET product is not used? Jorge Muñiz explained that the use of a constant lidar ratio is useful when we have only a stand-alone ceilometer without a close photometer. In the cases when these instruments are available, lidar ratio from AERONET or GRASP-pac could be used.



### 2.11. Atmospheric characterisation using LIDAR measurements (by Arlett Díaz Zurit, Universidad de Granada)

The technical information, the importance of using Lidars and how they work was introduced at the beginning of this talk. There were also described in detail the two main techniques of Lidar measurements (elastic and Raman).

This presentation showed how Lidar measurements are not only useful in aerosol characterization (providing important information such as the Angstrom exponent, lidar ratio, and depolarization), but they can also be used to obtain information about water vapor and hygroscopic processes.

#### Questions/discussion:

- Since Harmonia WG4 main goal is to establish a link between users (scientists) and software or instruments development companies, a discussion was proposed, since the following presentation was from a Lidar manufacturer company. They wanted to know what she, as a user, would like to ask the manufacturers to improve. Arlett Díaz asked mainly for easier and better lidar measurements during daytime.

### 2.12. Advanced Atmospheric Applications with Raymetrics Lidar Systems (by Ourania Soupiona, Raymetrics)

After a brief introduction of Raymetrics enterprise, the speaker showed how they are ready for science and for operation. To demonstrate it, she presented some of their technical innovations and how they meet ACTRIS quality requirements. The most relevant products are devoted to the calculation of profiles of temperature, water vapor, aerosols, ozone, wind and clouds (the last one solutions for civil aviation and meteorological agencies).

All this presented hardware is accompanied by its correspondent software, also developed by Raymetrics. It is meant to ensure an easy management of the system from the user's part.

#### Questions/discussion:

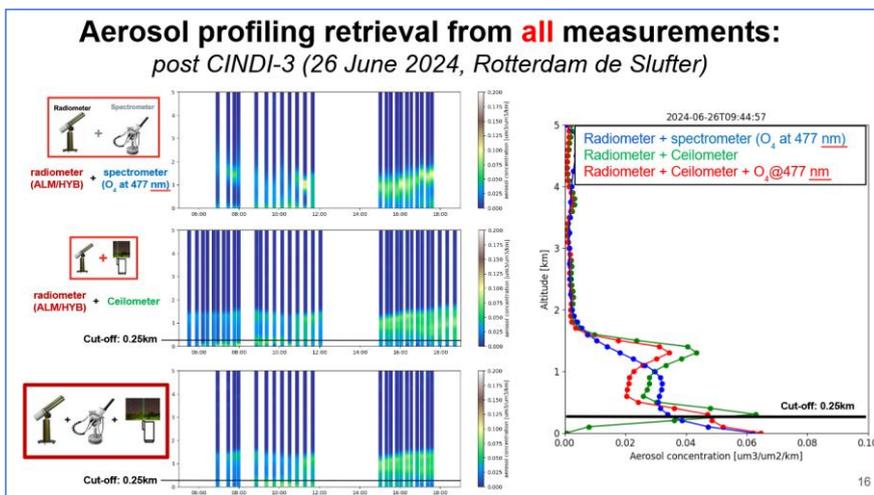
- In the previous Lidar talks, there was a lot of emphasize in the synergies between them and other instruments to, for example, characterize aerosol. What kind of measurements should be taken in order to make these instruments more synergistic with sun photometer data? Ourania Soupiona explained that algorithms such as GRASP would work with the products their instruments provide. She suggested to combine them with total column AOD data. Moreover, she recommended people to implement their instruments data into meteorological models.
- Ourania Soupiona encouraged everyone to keep close contact with the companies, suggesting asking them whatever is necessary.

### 2.13. Simultaneous profiling of aerosol and tropospheric nitrogen dioxide from synergetic ground-based observations of AERONET and PGN (by Masahiro Momoi, GRASP)

This presentation aimed to show the products of combining elements through the GRASP software. It was explained how the combination of data from Aeronet (in this case sun photometers) and data from Lidars provides a well-known good aerosol vertical profile. However, Lidar signal may have some lack of information in lower layers due to overlap issues. To solve this problem, GRASP is working to make it possible to incorporate also PGN data to this combination.

To support this idea, it was presented which are the products PGN spectrometers will add to the data mixture, focusing on the DOAS process, which mainly allows the algorithm to obtain the slant column density.

The different combinations of instruments showed in the presentation and the comparison between their results can be seen in the image bellow. The result presented in this meeting showed how the synergy between Aeronet sky radiances and multi-axis dSCD Pandonia approach can lead to a more accurate retrieval of the aerosol profile versus the stand-alone technique, being this technique sensitive to  $\text{NO}_2$  profiles.



#### Questions/discussion:

- People from the audience asked about ceilometer first point (the one which height is ground level). Usually, due to overlap, the ceilometer vertical profiles start above the height where the instrument is placed (in the example above 0.25km), but in the presentation there were points below full overlap region. Masahiro Momi explained that GRASP can make this assumption on its own, it is not necessary to inform the algorithm about these points and the Pandora measurements contain information about the aerosols at these heights.
- Another question was related to the difference between Pandora Spectrometer and ceilometer pointing. They asked him if its relevant the differences in pointing since the spectrometer points to the horizon, so far away in the distance, and the ceilometer its always pointing to the zenith of the station.



## 2.14. GRASP-Cloud Platform: Empowering Research in Atmospheric and Surface Products (by Juan Carlos Antuña, GRASP)

The presentation showed how GRASP cloud arose from ESA's DIVA project. GRASP is an open-source and free use algorithm. GRASP cloud is an online platform developed in order to increase the efficiency of the scientific results and save them time.

There were shown some examples where GRASP cloud is being used, not only with ground based, but also satellite data. The algorithm running in the cloud platform is also useful for any type of validation exercise (especially satellite validation).

Finally, Juan Carlos Antuña presented the GRASP future projects, which included a user's portal, where they can request data, services, computational power, etc.; and a workflow orchestration, which means a full automation of the product, being able to run in the background with no intervention needed.

## 3. Users Survey:

Users of the instruments/networks related to this HARMONIA Workshop were previously asked to fill in a survey to get their feedback in order to improve different aspects. There was a total of 67 answers, mainly from either instruments or data operators.

Results can be seen at the end of this document, but here are the main highlights from the user's answers:

- Although 38% of the Filter Radiometers and Photometers users see their instruments as black boxes (don't understand how they work), 50% of the users are ok with it and don't need to know more about it or have more control over their instruments.
- Similar thing happens with the Spectral Radiometers users. Although more than half of them believe their instruments are a black box, 80% of the total users are not interested in having more control over them.
- 70 % of the Filter Radiometers and Photometers users don't apply any correction to their measurements.
- Lidar/Ceilometer and Sky Cameras users were the most disappointed with their instruments (although the lowest grade was 5.5/7).
- 9 out of 15 Lidar/Ceilometer users believe the main source of uncertainty in their instruments is the overlap correction.

## 4. Main topics of the workshop, Issues discussed & Aspects for improvement

- Scientist presented their instruments and the main issues they are currently facing with the aim of showing manufacturers aspects for improvement and guiding them towards the creation of better instruments.



- On the other hand, insights from instrument manufacturers and companies developing algorithms such as GRASP were discussed.
- Some successful science-manufacturers collaborations were shown in order to encourage both interested parties.
- Presented new developments in measurement characterization and instrument calibration from the scientific community.
- Companies encouraged scientist to rent their instruments to try them before a purchase, due to the high prices.
- Discussed potential synergies in instrument advancements, not only between scientist-companies but also between researchers from different networks.
- Reflected the perspectives of instrument users through a dedicated questionnaire, which allowed companies to understand their users main request in a simple way.

## 5. Workshop Presentations: