# IDEAS-QA4EO Cal/Val Workshop#4

28th February - 2nd March 2023 – Potsdam (Germany)



The fourth **IDEAS-QA4EO Cal/Val Workshop** (WS#4) was held in Potsdam (Germany) and hosted by the German Research Centre for Geosciences (GFZ). The workshop featured discussions around 34 presentations covering the IDEAS-QA4EO R&D activities across the domains of Atmosphere, Cryosphere, Lands, and Oceans with a particular focus on the cross-cutting Metrological aspects. During the workshop, the teams assessed their progress in the Cal/Val activities, highlighted recent achievements, and explored potential synergies and future developments for the remaining 20 months of the IDEAS-QA4EO contract. Detailed information, including the workshop agenda and all presentations, can be accessed at the following link: https://earth.esa.int/eogateway/events/ideas-qa4eo-cal-val-workshop-4

## DAY 1 - 28 February 2023

## GFZ - Welcome / Potsdam team activities

Martin Herold provided an insight into the initiatives of the German Research Centre for Geosciences (GFZ) in the field of remote sensing for Earth sciences. He also highlighted ongoing projects, including ESA ForestCarbon (2022-23), and ESA CCI-Biomass (2022-24), which are currently in their start-up phase. Of notable significance is GFZ's role in the management of the EnMAP programme, where the institute acts as the scientific Principal Investigator (PI). The EnMAP program involves the selection of specific sites for validation and independent monitoring of radiometric, geometric, atmospheric, and spectral data quality. Among these methods, the use of ASD instruments for EnMap BOA validation stands out. Examples of ground-based infrastructure equipment were also included, especially StrucNet for lidar-type missions with laser scanning campaigns at different sites. Potential collaborative synergies between GFZ and NRCC were emphasized. Lastly, it was highlighted that the upcoming LPV meeting at ESRIN will provide a natural opportunity for follow-up discussions, promoting advancements in the field.

## Serco - Status and Perspectives of the IDEAS-QA4EO Cal/Val framework

Fabrizio Niro opened the meeting by recalling the underlying philosophy and overarching vision behind the Task 2 Cal/Val activities. He emphasized that today's research and development has the potential to evolve into the operational practices of the future. In this context, the contract serves as a fertile ground for fostering innovative concepts, and maturing them into operational applications and services. The presentation underlined the importance of metrological practices successfully demonstrated in Phase 1.

Gabriele Brizzi then gave an overview of the Task 2 structure, highlighting the inclusion of new activities, synergies and collaborations through CCNs. Phase 2 commenced in May 2022. The number of partners and activities has increased, reflecting the continuous progress and expansion of the service. A brief overview of the WPs by domain was given, showing the variety of the work underway. The presentation recalled the specific reporting requirements for ESA (monthly and quarterly contributions, as well as input to the SRM and participation in the QA4EO Cal/Val workshops).

The meeting's objectives and agenda were then introduced, providing a roadmap for the subsequent discussions and presentations. With 20 months remaining in this contract phase, there are still significant milestones to be achieved.

## Metrology and Traceability

## NPL - Metrology R&D and support to FDR

Sam Hunt presented the NPL activities and emphasised the critical role of uncertainties in ensuring the credibility and reliability of data interpretation. The CEOS QA4EO website (http://qa4eo.org) was updated to include training material. Emma Woolliams is planning a series of workshops focused on providing guidance for data/system comparisons, which will be a valuable resource for the community. An important development is the release of the CoMet Toolkit, which is based on Python and can be accessed at www.comet-toolkit.org. Several practical examples of its application for uncertainty propagation in interpolation were given, including its use in projects such as HYPERNETS (which involves producing several levels of products, containing uncertainty and error correlation information), LIME (the toolkit is used for interpolation along a high-resolution model and propagation), EUMETSAT RPV4PICS (focusing on uncertainty reduction for selected Pseudo-Invariant Calibration Site where observations are processed with the CISAR algorithm and then spectrally interpolated), RadCalNet (seeking to add Ocean Sites to the regular processing), and HyperInSPACE Community Processor (with uncertainties added as part of FRM4SOC-2). Furthermore, two new Metrology case studies have been proposed. The first, Altimetry for Hydrology, revisits the uncertainties associated with altimeter-based hydrology in line with GCOS requirements. This research aims to support ongoing projects such as St3TART and FDR4ALT, facilitating a unified approach to uncertainty evaluation, and prepare for SWOT calibration/validation campaigns. The second study, LULC, focuses on the validation of Land Cover (LC) maps, traditionally assessed using a confusion matrix, by employing innovative and statistically rigorous metrological evaluation methods. Philippe emphasized the importance of these WPs as they contribute to cross-cutting metrological support. The CoMet tool is available to all and should be actively promoted within the EO community.

[REC-1] The CoMet toolkit should be further promoted as a valuable means for supporting new product development and a comprehensive approach to uncertainty management. All teams are encouraged to actively participate in the testing of the toolkit within their respective activities.

## PMOD - SI-traceable systems for lunar irradiance

Natalia Kouremeti discussed the developments of the PMOD SI-traceable systems concerning lunar irradiance PFR measurements. The Lunar PFR-L002 instrument has been thoroughly characterised (e.g., spectral response, gain) at the PTB facility using TUnable Lasers In Photometry (TULIP) as part of the 19ENV04 MAPP project. This new characterization corrects previous calibration errors. PFR-L002 provides Top-Of-Atmosphere lunar irradiance measurements ranging from UV to 1000 nm, with an expanded relative uncertainty U < 0.5%. This represents a significant improvement over the previous characterization performed with ATLAS. The presentation included an in-depth uncertainty analysis, as well as a comparison of calibration methods and a stability analysis. The instrument was used to measure the September 2022 lunar cycle at Izaña, Tenerife. The resulting data were analyzed, leading to the acquisition of five Langley calibrations. The presentation showcased lunar irradiance and Aerosol

Optical Depth (AOD) time series. Comparisons were made between the PFR-L Top-of-Atmosphere lunar irradiance and the RIMO model, revealing an offset of 6-10%. The use of state-of-the-art solar spectra (TSIS-1) in these retrievals represents a significant advancement. Additionally, SI-traceable AOD retrievals were derived using characterized Sun-PFR and TSIS-1, QASUME-FTS TOA solar spectra, thereby providing AOD values equivalent to the standard Langley calibration. Plans include the development of a second lunar PFR and the organization of solar and lunar field campaigns during the summer of 2023.

[REC-2] Lunar irradiance is currently a topic of discussion, and it is crucial to extensively involve and actively engage stakeholders. It is essential to establish coordination with concurrent activities within GSICS and LIME.

## LOA - Metrology and Cal/Val for Aerosol Monitoring

Philippe Goloub presented the AERONET/ACTRIS calibration activities, emphasizing their commitment to ensure continuous traceability to GAW-PFR/WORCC-AOD and within the AERONET network. The strategy for measuring aerosol properties involves maintaining a permanent observatory in the Indian Ocean and conducting specific monitoring campaigns. In the Indian Ocean, the Marion Dufresne vessel has a permanently installed automated shipboard photometer system that has been operational for 2 years. In just one year of observations, the system has collected nearly the same number of AOD measurements as were gathered over the past 14 years of manual operations during several MAN/AERONET campaigns in the same area. A paper is being prepared using these new data. An improved version of the instrument was embarked on the Jaywun Marine research vessel for the AREAD campaign (December 2022 - January 2023), travelling from Vigo (Spain) to Abu Dhabi (UAE). Another campaign (AMAGAS-AMARTLLIS) is planned for spring 2023, involving a transit from La Réunion to Barbados, using a twin setup of CE318T shipboard photometers and an automated lidar system. The PLASMA-3D mobile photometer prototype, originally designed for airborne use, has undergone further development and testing to address acquisition issues and create a more compact system. Construction of the pre-industrial version is expected in Q3 2023, with funding being sought from Labex CaPPA. An associated software tool (STRAP) is also being developed. To incorporate the vertical dimension for aerosol structures, joint sun-photometer, and micro-lidar aerosol profile retrievals are being tested. Two systems were described in detail: LILAS (the old system) and LIFE (the new system, compact and portable, improving aerosol type classification by introducing fluorescence), providing crucial parameters such as extinction, backscatter, and depolarization. These lidar systems can be combined for aerosol profiling and cloud retrievals, including calibration/validation for EarthCARE, and 3MI. A summary of the planned sea campaigns was presented, including AERO-HDF (Northern France, June-July 2023 with an in-situ component from LISA), AMARYLLIS (Atlantic, April-July 2023), and NASA/NOAA (Atlantic, 2023). A new shipboard photometer has been ordered and is expected to be delivered soon. An AERONET workshop is scheduled to take place in Lille in May 2023, in parallel with the GRASP-ACE workshop. May 2023 marks 30 years of AERONET operations (1993-2023).

## Atmosphere Cal/Val: Part I

## Luftblick - Pandonia improved uncertainty estimation

Ilias Bougoudis presented Luftblick activities focusing on the determination of the common (systematic) uncertainties associated with Total Ozone Column (TOC) retrievals. In particular, discrepancies were identified between TOC values derived from literature references (TO3 from climatology) and those obtained from measured references (fitted TO3). These differences serve as an effective indicator of the common uncertainty. A comparison was made between Pandora-retrieved O3 effective temperatures and columns, and external datasets including MERRA-2, O3 sondes, and EUBREWNET data from the Davos station. The best agreement was observed during the spring season in all instances. The uncertainty components associated with Pandora measurements were presented and compared with those of the Brewer instrument. The primary source of uncertainty for Pandora is the systematic component, whereas, for the Brewer instrument, it's the random (independent) factor. The comparison between Brewer and Pandora TOC revealed a remarkable agreement. As of April 2023, the current work package (WP) will be completed, and extension activities will be proposed. The PGN retrieval software will be upgraded from version 1.8 to 1.9, incorporating all the latest developments, including improved uncertainty assessment capabilities. The validation of PGN data uncertainties will be extended through the integration of collocated PGN instruments, facilitated by a statistical framework. It's worth noting that the current PGN uncertainty scheme does not take into account Level 1 uncertainty, but this aspect will be considered in future work.

## SpectralEarth - Pandonia advanced products and system

Jürgen Fischer provided an update on the Pandora-2s instruments and their operational sites. He highlighted the ongoing efforts in continuous spectral characterization and temporal stability analysis, leading to improved spectral parameters. The verification of Pandora L1 data was carried out using the Radiative Transfer Model MOMO, considering different aerosol loads, albedo, and viewing conditions, as well as Total Column Water Vapor (TCWV) content. A strong agreement was observed between Pandora's spectral downward radiances and the modeled values. The presentation focused on the diurnal radiance variation captured by Pandora measurements, primarily attributed to different geometries and scattering effects. Specific attention was directed towards the instrument temperature in the range of 890-970 nm, which is crucial for accurate H2O retrieval. A novel retrieval algorithm for TCWV based on the Optimal Estimation approach is under development. This algorithm incorporates a 1D approach and AI-CNN. Initial results from TCWV and AOT retrievals are promising, showing remarkable agreement with AERONET data, particularly at the Lindenberg site. Upcoming steps in the research involve advancing towards the simultaneous retrieval of Aerosol and TCWV, and making comprehensive comparisons with data from OLCI/GNSS (for TCWV) and AERONET (for AOT).

## AUTH - Aerosol Layer Height (ALH) validation

Konstantinos Michailidis presented the AUTH activities with a focus on the validation of TROPOMI ALH using EARLINET datasets. The ALH retrieval method relies on the absorption within the O2A band (758-770nm). EARLINET contributes a robust and extensive database encompassing continental-scale aerosol distribution information. Seven EARLINET stations located at low altitudes in coastal regions were selected for this validation exercise. The validation methodology, including colocation criteria (spatial averaging of TROPOMI pixels within a 150 km radius with a maximum time difference of ±4 h) and filtering procedures, was recalled. A purpose-built automated tool, called ATLANTIS, was developed at AUTH to facilitate these validation tasks. The presentation highlighted detected dust episodes in the Eastern Mediterranean and emphasized synergies between satellite observations, ground-based lidar observations, models, and back trajectory calculations. Notably, the S5P L2_ALH products encounter limitations, particularly over land where high surface albedo negatively influences the ALH retrievals, leading to underestimation. The effects of cloud contamination, topography, aerosol type and layering have been thoroughly investigated. Validation results covering the period May 2018 – July 2022 were shown, differentiating between land and ocean pixels. TROPOMI performed well over the ocean but faced challenges over highly reflective surfaces. EARLINET consistently reported lower ALH values than those retrieved from S5P. The analysis will be repeated using the forthcoming TROPOMI RPRO (reprocessed) data. EARLINET was acknowledged as a valuable tool for validating satellite sensors and algorithms, providing high quality assured data on aerosol optical properties. Validation papers have been published in the ACP journal.

## GRASP - Aerosol and trace gases retrieval

Oleg Dubovik provided an update on ongoing efforts to enhance joint retrievals of aerosol-surface reflectance-gas parameters. The primary objective of this work package (WP) is to incorporate gas-related parameters into the GRASP code, thereby extending the GRASP modeling of the Surface-Atmosphere system. The GRASP framework finds utility in various projects, including GROSAT, and 3MI retrieval. Noteworthy software improvements have been implemented such as BRDF modeling, optimization of a priori constraints, accommodation of distinct spatial resolutions, and the enhancement of radiative transfer (RT) calculations. These RT optimizations are particularly important for handling scenarios with pronounced angular features, necessitating the use of a large number of polynomials. A novel IMS truncation and correction method (Momoi et al., 2022) has been adopted. This technique incorporates a third-order multiple scattering correction for the forward lobe, leading also to improved retrievals over Sun-glint regions.

Marcos Herreras-Giralda presented advances in the integration of spectrometric observations into GRASP's synergetic retrievals. While GRASP was originally tailored for aerosol and surface analysis, both of which featuring spectrally smooth spectra, substantial updates have been applied to incorporate Line-by-Line (LBL) gas absorption. This integration maintains GRASP's philosophy of being instrument agnostic and complements prior applications. The Kbin code is used to perform accurate gas absorption calculations, with the assumption that the vertical shape of molecular profiles remains constant and renormalized. Several combinations of data sources, such as PSR+AERONET and AERONET+PANDORA, were evaluated to jointly

retrieve gas concentrations and aerosol properties. The feasibility of using the Pandora NO2 concentration from collocated instruments to replace the AERONET climatology was investigated. This adjustment had no discernible impact on AOD at 440 nm, although it introduced a consistent bias in the Single Scattering Albedo (SSA) at 440 nm. The methodology was also applied to retrieve Aerosol Layer Height (ALH) from OLCI data (O2 A-band). In general, the incorporation of gas absorption information yielded enhancements in aerosol characterization. There are plans to extend this approach to other satellite platforms, such as POLDER and IASI, and to ground-based combined retrievals. The workshop scheduled for May in Lille, as well as the GRASP summer school were highlighted. Gabriele inquired about the possibility of completing the S5P AOD dataset which has been developed as part of the ESA S5p+Innovation AOD/BRDF project and is currently available for a limited time. Oleg emphasized the need to obtain the necessary funding to continue the data processing.

## LISA - Aerosol Characterisation at Gobabeb

Paola Formenti from CNRS/LISA presented the activities at the newly established (in April 2022) research station at the Gobabeb Namib Research Institute in Namibia. This station is designed for long-term, in situ observations of the optical and microphysical properties of aerosols. The Southern African region, where the station is located, is largely unexplored and is considered a climate change hotspot with temperatures rising at about twice the global rate, leading to likely dramatic warming. Aerosol particles play a critical role in the Earth's climate system, with both direct and indirect influences, and they represent the largest uncertainty in estimating global radiative forcing. The research center is located at a crossway of aerosols with different light absorption and hygroscopic properties. It has been active since the 1990s, primarily conducting long-term observations of aerosol column properties, long-lived gases, and radiation, but also preparing and validating satellite sensors. Since 2021, the center is part of ACTRIS-FR and includes a RadCalNet automated station. Scientific objectives of the activity span from acquiring new knowledge on aerosols' life cycle and their radiative impact, to improve the reliability of climate models and aerosol remote sensing with reference observations. The newly implemented in-situ instrumentation provides Essential Climate Variables (ECVs) for atmospheric aerosol products (L2/L3). The first year of operations focused on setting up the station and assessing its ability to provide new insights into aerosol content, optical properties, transport, and seasonality. Data products are distributed from the ACTRIS-FR catalogue. Ongoing analyses include comparison of Gobabeb in situ measurements with collocated AERONET AOD. Surface observations typically represent the entire column, except during the August to October period, when AOD is higher due to the transport of biomass-burning aerosols at high altitudes. Collaborative efforts are underway to evaluate CAMS products and to validate regional and global climate models. A presentation is planned at EGU 2023, and a publication is in preparation. Future perspectives are the AEROFOG project (2024), a French/German collaboration for aerosol/fog interactions, extending measurements to hygroscopic properties with CNRS funding.

[REC-3] Extending the collaboration between LISA and LOA is of utmost importance, and the installation of a Lidar system in Gobabeb will be crucial. Likewise, contribution to RadCalNet is also encouraged, by evaluating the accuracy of radiative transfer modeling to TOA level.

## Night-time ground-based observation for aerosol/trace gases retrievals

## Luftblick - Pandora

Leonie Haunold from Luftblick discussed the Pandora lunar measurements for trace gas retrieval. While the Pandora systems are designed for night-time acquisitions, it was deemed necessary to assess the ability to retrieve trace gas columns from these lunar measurements, which required tuning of the retrieval settings. The study focused on the instrument at Rome Sapienza, specifically Pandora 117. The initial approach to the lunar retrieval scheme for $O_3$, $NO_2$, $H_2O$, and $NO_3$ was to use a reference spectrum obtained from solar measurements. However, the effect of using a lunar reference spectrum had to be investigated and quantified as a bias was observed depending on the calibration source. A lunar spectral albedo correction was developed using a parameterization derived from the ROLO model. The impact is generally small because the smooth spectral features (lunar albedo) are well captured by closure polynomials in the retrieval. However, it was found that instrumental artifacts appear to contribute to this bias, highlighting the need for proper instrument characterization. Furthermore, the presentation discussed the investigation of the impact of radiance "dilution" during twilight. Inelastically scattered light (Raman) was found to contribute to ~10% of the bias, but further testing is required to better understand this. Potential activities for extending the study include identifying the source of the bias, and developing radiance "dilution" corrections for solar twilight conditions, where diffuse sunlight entering the lunar light path affects the retrievals.

## ARPA - Brewer

Henri Diémoz (ARPA) presented the development and application of trace gas retrievals from night-time Brewer observations. The Brewer network consists of about 200 instruments retrieving a total $O_3$ column (UV), with approximately 80 of them also capable of retrieving $NO_2$ (VIS). There have been only a few studies on night-time $O_3$ retrievals with Brewers, and so far, no studies have been conducted on night-time $NO_2$ retrievals. During Phase 1, several instrumental and algorithmic issues were addressed to establish a regular night-time schedule in Rome (Brewer #067). These included optimizing the $NO_2$ algorithm using the five longest wavelengths, enforcing instrumental reset at sunset to avoid midnight discontinuities and pointing issues during moon measurements, as well as characterizing and correcting spectral stray light for $O_3$ retrievals. The next step is to calculate the combined uncertainties and to produce fully automated real-time $O_3$ and $NO_2$ cloud-screened datasets from night-time measurements. Preliminary comparisons were made with co-located Pandora instruments with good agreement. Also in-situ at surface measurements capture the main daily peaks. Additionally, a future expansion to the Aosta-Saint-Christophe observation site in the Italian Alps is planned.

## ISAC/CNR - PREDE-POM

Henri Diémoz, on behalf of M. Campanelli, presented the CNR-ISAC night-time (lunar) observations using Prede-POM sun-sky radiometers. The overall goal is to establish the first automated network of sun-moon photometers within Skynet/Europe, using

four sites (three in Italy) equipped with Prede POMs Moon version (POM01 / POM02) to retrieve aerosol optical depth and PWV (precipitable water vapor). The retrieval techniques and calibration procedures for lunar measurements are being defined in collaboration with the University of Valencia and NIES (Japan). The first processing baseline for moon data will be ready in the summer of 2023. Validation campaigns, such as at the Izana Observatory, will be carried out to transfer the calibration from POM01 to POM02 for the common wavelengths. Prede POM systems, along with AERONET, SKYNET, and PANDONIA instruments, will be exploited for night-time measurements at BAQUININ sites.

## DAY 2 - 1 March 2023

## Atmosphere Cal/Val: Part II

## PMOD - Improved ground-based aerosol retrievals using NO2 correction

Stelios Kazadzis presented the work on enhancing surface-based Aerosol Optical Depth (AOD) retrievals. He recalled the principles of AOD retrieval and discussed the potential use of global ground-based networks to standardize global aerosol measurements and retrievals. AOD retrieval from direct sun measurements is predominantly influenced by radiometric calibration, cloud screening, and NO2 and O3 absorption. A common practice in AOD retrieval algorithms is to use a NO2 climatology (or sometimes no correction), even though NO2 has a high spatio-temporal variability. To investigate the impact of NO2 correction, two sites in Rome were selected. These sites were equipped with both aerosol and NO2 real-time measurements obtained from Pandora, PREDE, and CIMEL photometers. The results demonstrated that NO2 correction effectively enhances the quality of ground-based AOD measurements. and highlighted a systematic AOD overestimation (δAOD~0.01) across the networks. Corrections are lower for AERONET and higher for SKYNET, particularly on days with elevated NO2 levels. AOD trends were also examined but the timeframe is considered insufficient to establish them as climatological patterns. The research specifically focused on days with elevated NO2 concentrations in Rome and verified the results against satellite data, specifically MODIS Deep Blue measurements. The synergistic use of AERONET and Pandora data proved valuable in capturing the diurnal variations between aerosols and molecular components. The findings of this study are under review for publication in AMT. Results are closely linked to the activities of the COST Action Harmonia led by PMOD. Results from ACTRIS OHP station, which employs CIMEL, Pandora, and PFR sun photometers, show the importance of this correction. The extension will focus on multi-sensor synergies to improve cloud detection algorithms. This enhancement will directly impact the accuracy of sun-photometric retrieved amounts, particularly addressing systematic overestimations of AOD attributed to cirrus clouds, and facilitating improved discrimination between cloud and aerosol load events.

## ISAC/CNR - DOAS-BO: Towards a new FRM4DOAS-compliant site

Elisa Castelli described the ongoing efforts to address the lack of ground-based DOAS measurements in the Po Valley and to enhance the Italian expertise in the DOAS

technique. During the previous phase of the contract, the activity focused on assessing the performance of a custom-built research-grade MAX-DOAS instrument (TROPOGAS) in accordance with FRM4DOAS requirements. Additionally, CNR-ISAC independently purchased two fully FRM4DOAS-compliant MAX-DOAS systems (SkySpec-2D by Airyx). Inter-comparison campaigns were conducted in Bologna and Rome to ensure the quality of the measurements. One of the SkySpec-2D systems has been permanently installed at the "Giorgio Fea" observatory in San Pietro Capofiume and will soon be integrated into the FRM4DOAS network. In the second phase, systematic processing of MAX-DOAS data was initiated, and the tropospheric $NO_2$ VCDs were compared with data from TROPOMI. Moreover, a retrieval algorithm for $NO_2$ and aerosol extinction profiles from MAX-DOAS measurements (DEAP) was developed and validated. The DEAP algorithm uses $O_4$ slant columns to retrieve aerosol extinction and then employs this information to derive $NO_2$ profiles. The DEAP retrieval code was evaluated against the FRM4DOAS reference synthetic data with performance comparable to the official algorithms (MMF and MAPA). Collocated aerosol profiles from ground-based instrumentation are also used as initial guesses for MAX-DOAS retrieval. Additionally, synergies between MAX-DOAS and an automated LIDAR/Ceilometer for aerosol remote sensing are exploited. A CIMEL instrument was recently installed in SPC, and its data are available through AERONET since 6 February 2023. The next step will focus on incorporating HCHO (Formaldehyde) retrievals to study the behavior of $HCHO/NO_2$ ratio vs $O_3$, thus expanding the capabilities of the observatory. Philippe stated that this work package emphasizes the process of achieving full FRM compliance, and highlights the importance of adhering to established protocols for sensors and data processing to ensure accurate and reliable measurements.

## BIRA - AOTF-based NO2 camera for urban pollution imaging

Emmanuel Dekemper presented the activities to improve the AOTF-based $NO_2$ prototype camera for urban pollution imaging developed at BIRA-IASB. This is a new WP starting in March 2023. The instrument concept originates from the ALTIUS mission and several field campaigns preparing for S5P (e.g., AROMAT-II). The AOTF (acoustic-optical tunable filter) operating principle for spectral imaging was introduced. Laboratory measurements confirmed the suitability of the AOTF spectral resolution (~0.6 nm) for the $NO_2$ spectral structures, and preliminary results provided dSCD maps of power plant plumes, capturing the dynamics of the $NO_2$ field. The instrument will be upgraded in all aspects (with new features such as autonomous azimuthal/elevation scans and a protective case) and will be fully characterized (PRNU, gain, Mueller matrix) including an error propagation model based on metrological guidelines. Preliminary validation against a MAX-DOAS instrument provided good overall consistency. A field campaign will take place at the BAQUNIN urban site (Rome) with three weeks of operations and comparisons against colocated Pandora, MAX-DOAS, and CIMEL instruments. Future developments include exploring the $O_4$ retrieval in the 470-480nm range, investigating aerosol sensitivity using AOTF polarization capabilities, and pursuing 3D $NO_2$ field reconstruction by combining the use of multiple cameras. Regarding polarisation, the AOTF-based camera has strong polarisation sensitivity with three output beams, which can be exploited to estimate some parameters of the polarisation state.

## Cryosphere Cal/Val

## Serco/LEGOS - Satellite-based altimetry for Sea Ice monitoring

Alice Carret's presentation highlighted the use of satellite-based altimetry for monitoring sea ice. Sea ice thickness serves as both an indicator of and a contributor to global warming, as changes in sea ice extent directly influence the Earth's albedo. Various techniques have been used to compare predictions with actual observations: Buoys, moorings, aircraft and satellite observations. Observations from SMOS and CryoSat-2 have provided valuable insights. SMOS uses passive microwave radiometry, while CryoSat-2 employs altimetry. However, these techniques exhibit complementary characteristics. SMOS lacks sensitivity over thick ice, while CryoSat-2 faces significant uncertainties over thin ice. The presentation emphasized the measurement of sea ice thickness and freeboard using altimetry. Challenges related to snow depth were tackled using laser and the Ku band. Estimates of the SIT uncertainty budget were presented. The CRYO2ICE project facilitated a direct comparison between laser and Ku-band measurements by aligning the CryoSat-2 and IceSat-2 orbits. This initiative provided coincident measurements along 20 tracks each month over the Arctic Ocean. By deriving and comparing laser and Ku-band FreeBoard products, a snow depth product (LaKu) was created within this project. This product was validated against various snow depths and in-situ data. Impressively, the LaKu product showed strong agreement with in-situ measurements. This activity prepares for the CRISTAL mission, which includes a bi-frequency altimeter. Additionally, the integration of the SARAL/Altika mission, featuring a Ka-Band, is being explored to investigate surface roughness.

## FMI - Ground-based validation of satellite snow products

Cemal Tanis presented the operational monitoring of snow cover through NRT processing using the FMIPROT portal with input from five camera networks. A number of improvements have been introduced, spanning from metadata, visual elements within webpage interfaces, processing options, and even metrics in the comparison between webcam and satellite data. Furthermore, a new server and webpage (https://fmiprot.fmi.fi) were implemented to enhance the monitoring capabilities. Specific cases of ROI geolocation, particularly when cameras were oriented towards mountainous terrain, were presented. In-situ snow depth observations in the northern hemisphere were added from the Global Telecommunication System (GTS) to validate satellite-derived products. The application of machine learning techniques for estimating Fractional Snow Cover (FSC) is currently undergoing a feasibility study. The possibility of adopting a GPU infrastructure is being considered to overcome the SW/HW challenges. Of particular note is the ongoing commitment to creating digital twins for Cal/Val activities through the GPU-powered Digital Twin project within NVIDIA Omniverse.

[REC-4] Several tools were developed in the frame of QA4EO, which are valuable to the EO Cal/Val community. Yet, there is a need to increase awareness about these tools. As a first step, it is recommended to make an inventory of these tools and as a second step, to establish a central repository with relevant documentation on how to use these tools.

## Land Cal/Val: Part I

## GFZ - Land validation over temperate and tropical forests

Benjamin Brede presented the GFZ's involvement in the SRIX4VEG campaign and StrucNet. In the context of SRIX4VEG, a prototype processing pipeline was developed specifically for the Cubert Firefleye hyperspectral images. This was necessary as no standard workflow was available. Geometric processing was carried out using Structure-from-Motion software along with Ground Control Points (GCPs). A radiometric correction was performed based on the data collected from deployed calibration panels. As a result, hyperspectral ortho-mosaics were successfully generated. The next SRIX4VEG project meeting is scheduled for October 2023. StrucNet is a network designed for the monitoring of vegetation structure (LAI, phenology). It is a collaborative initiative between GFZ and the University of Ghent (Kim Calders). This network employs a combination of lidar (LEAF) and Internet of Things (IoT) technology, specifically TreeTalker, to contribute to the preparation of upcoming space-borne missions e.g., GEDI, BIOMASS, CHIME. Specific UAV campaigns are carried out in synergy with on-ground sensors. The network is progressively expanding: the Demmin site was detailed, and new StrucNet sites in Ghana are being established for a laser scanning campaign across the savannah. The first StrucNet User Workshop is planned for the spring.

[REC-5] The connection of StrucNet with other international initiatives (e.g., HYPERNETS, ICOS, GGBOV) should be strengthened, and the number of sites within Europe should be increased. Coordination with CEOS-WGCV-LPV is also recommended to engage the relevant land Cal/Val community.

## GEO-K - UAV-based observations for BRDF estimation

Daniele Latini presented the activities related to BRDF estimation using a UAS platform. The primary objective of this work is to define a flight protocol for collecting an in-situ reference validation dataset that is optimal for assessing the performance of operational BRDF correction algorithms. The system employs a UAV-mounted multispectral S2-like sensor (MAIA camera) that has been tested over various land cover types, such as vegetated surfaces and asphalt. The UAV acquisition plan involves a combination of VAA (ranging from 0° to 360° at 30° intervals) and VZA (ranging from 0° to 60° at 10° intervals) replicating a goniometer-type acquisition system. These flights were conducted at an altitude of 120 meters and coincided with overlapping Sentinel-2 satellite passes. The MAIA Field Measurements underwent several correction processes, including band coregistration, geometric correction, and radiometric calibration. The HCRF, approximating BRDF, was modeled using the Ross-Li model. The sensitivity of the estimated surface BRDF parameters was assessed using statistical analysis, which demonstrated good agreement between the measured and modeled values. The pointing accuracy is a few degrees in the azimuth. The MAIA-estimated parameters were compared with MODIS operational parameters, considering its narrow spectral bands and lower spatial resolution. Preliminary results from the SRIX4VEG campaign in Barrax, Spain, alongside a developed neural network

approach for retrieving the BRDF parameters were presented. The investigation and analysis will continue, including surveys conducted at test sites of particular interest, such as snowy areas.

## Brockmann Consult - Towards a ground-based network for satellite cloud mask validation

Jan Wevers presented the ground-based sky-camera network designed for independent validation of cloud mask algorithms. This initiative addressed technical challenges related to geometry mismatch, lens distortion, solar interferences, and image classification methods (including Random Forest, Neural Network, and Gradient Boosting). Additionally, the UoM stereo cloud base height estimation algorithm was evaluated and sky-camera-based cloud bottom heights were compared with RAP cloud bottom heights. The network was expanded to include a new site in Valencia, Spain, bringing the total number of sites to six. The operational implementation was explored, considering two potential processing solutions: the QA4EO Cal Val platform and the EuroDataCube (EDC) Service. The EuroDataCube Service was favored due to its easier integration, user-friendliness, and the potential for ESA NoR funding. The sky-camera validation approach was presented to the science communities at LPS, S3QWG, S3VT, and OLCI/SYN, and has now become a routine part of the Optical Mission Performance Center's quality reporting. The presentation also touched upon the Cloud Mask Inter-comparison Exercise - II, discussing its organization on both ESA and NASA sides and the schedule. The exercise primarily focused on Sentinel-2 and Landsat 8/9 missions, with Prisma data not yet available. The inter-comparison protocol and reference datasets were defined during the first workshop in June 2022. Further discussions and testing of reference datasets are planned for the second workshop in December 2023, with the number of participants having doubled.

## Brockmann Consult - Development of AATSR cloud shadows mask based on IdePix

During the presentation, Jan Wevers gave an update on the AATSR Level 2 product, which is already largely compliant with the CARD4L specification. However, there's still work to be done on the correct implementation of the cloud shadow mask to ensure full CARD4L compliance. The cloud shadow algorithm used for MERIS and OLCI, and integrated into the SNAP IdePix tool, has been successfully adapted for application with AATSR data to accurately project clouds onto the Earth's surface. Nevertheless, challenges remain in accurately accounting for cloud top heights and viewing geometries. The methodology employed involves converting all shadow calculations to the pixel grid geometry, and consolidating cloud flags to create a cloud mask. A fixed cloud top height (CTH) is assumed to simplify the calculations. Parallax correction is also applied. Incorporating these adjustments compensates for the discrepancy between the apparent position from the satellite's perspective and the actual position on the ground (nadir view). Limitations remain in two key areas: the determination of cloud top height when the solar zenith angle (SZA) is below 45°, and the identification of cloud shadows due to the precision of the cloud mask.

## TU Wien - International Soil Moisture Network (ISMN): status and pathway towards FRM

Irene Himmelbauer presented the International Soil Moisture Network (ISMN), a global in situ database that is crucial for validating satellite soil moisture products. The network was initiated in 2009 through collaboration between ESA and international organisations like the GCOS and CEOS. A sustainable solution for long-term funding was achieved when the German Ministry took on the role of new funder and host. Initially hosted by the Technical University of Vienna, Austria (TUW), the database was successfully transferred to the German Federal Office of Hydrology, in December 2022. The transfer process took 20 months, from May 2021 to December 2022. This phase involved organizational restructuring, recruitment of a new team, technical integration, and parallel operations. The database comprises 74 networks and 2949 stations. However, there are concerns about data gaps within the Southern Hemisphere. The FRM4SM project was presented. It started in May 2021 with the idea of using the ISMN as a resource for establishing the FRM. The project encompasses various activities, including enhancing ISMN datasets with novel Quality Indicators, developing FRM protocols and procedures tailored to soil moisture, promoting best practices in validation, ensuring traceability, and uncertainty budget calculations. The representativeness of Quality Indicators is assessed by means of triple collocations. To enhance traceability, each dataset is assigned a Digital Object Identifier (DOI). Additionally, efforts are underway to develop a traceability diagram for uncertainty as part of the FRM4SM project. The project also includes plans to advance the Quality Assurance for Soil Moisture (QA4SM) online validation platform. Philippe Goryl recalled that the motivations for the FRM4SM project were identified during the QA4EO workshop in Davos, and the realization of this idea into a tangible accomplishment is a significant achievement. Nigel Fox clarified that FRM is exclusively meant for satellite validation, not for in-situ monitoring purposes. In collaboration with Philippe, NPL is currently drafting a paper under the CEOS-WGCV framework, that will outline a comprehensive set of guidelines for achieving FRM compliance through a step-by-step approach.

## TU Wien - QA4SM Platform for SM validation

Pietro Stradiotti introduced the QA4SM platform designed for product inter-comparison and validation, and introduced the project's web pages. The validation of satellite-derived soil moisture (SM) data poses numerous challenges and demands the adoption of best practices. QA4SM addresses this challenge by providing a comprehensive set of community-driven validation guidelines through a single, open-access tool equipped with powerful computational and programming resources, ensuring transparency and traceability. This tool empowers users to effectively assess their datasets against reference measurements, promoting a high degree of flexibility in the validation process. The validation source code is open source, allowing the community to contribute and enabling the validation of user-generated datasets while also facilitating data uploads by users. The platform is evolving towards a Data Analysis Ready service and further improvements will come from the FRM4SM project.

[REC-6] The QA4SM activity has significant relevance in the context of CEOS-LPV. The package may contain functionality that could be valuable for establishing a similar validation platform focusing on other ECVs. It is recommended to ensure coordination

with CEOS-LPV efforts to improve the validation stage of the ECVs under consideration.

## Rayference - Surface Reflectance protocol based on artificial targets

Yves Govaerts presented advancements in developing a protocol for the validation of Fiducial Reference Measurements (FRM) of surface reflectance using UAV systems. The focus lies in identifying the measurand for performing a surface reflectance FRM. The Top-of-Canopy Bidirectional Reflectance Factor (TOC BRF), which is solely dependent on illumination and viewing angles, cannot be directly observed in the field due to the inherent influence of sky radiation. On the other hand, the Bottom-of-Atmosphere Hemispherical Directional Reflectance Factor (BOA HDRF) is observable and depends upon atmospheric conditions, specifically the state of illumination. Two specific viewing positions have been identified that exhibit reduced sensitivity to atmospheric effects. Notably, the nadir view is considerably less influenced by variations in Aerosol Optical Thickness (AOT) compared to the oblique view. The proposed protocol moves from BOA HDRF to TOC BRF. This is achieved through Radiative Transfer Model (RTM) simulations coupled with atmospheric processing, which aims to remove atmospheric effects with the CISAR algorithm. The protocol also entails designing an artificial target with precisely controlled and well-known reflective properties. This target's characteristics are inspired by the RAMI example and consist of a modular cube, each with a diameter of 0.5 meters, comprising floating disks. TOC BRF and BOA HDRF will be simulated using the Eradiate software. The actual target simulations are expected to be completed in June. By the end of 2023, the target design will be finalized, incorporating manufacturing constraints.

## EOSense - Innovative Methods for Inflight Calibration

Steve Mackin presented the software package developed to process Proba-V data, ensuring consistent and reliable data quality monitoring. The tool extracts SNR, gain, and non-linear behaviour between detectors and is of interest for characterising in-flight uncertainty at pixel level. The relative gain algorithm is discussed in detail. The tool employs a robust approach to derive equalisation coefficients leveraging statistical techniques rather than relying on specific calibration images. This methodology corrects for small additive and multiplicative errors, regardless of surface type or cloud presence. The basic principles are explained using both homogeneous and heterogeneous scenes, which help to evaluate correlations between adjacent pixels. A real image from Proba V (missing data, clouds, surface pixels) is analysed by calculating histograms of column pair ratios and assessing the long-term consistency through residual correlation. A similar analysis is applied for non-linearity: shorter wavelength bands of S3-OLCI, S2-MSI, and PROBA-V show multiplicative effects, while longer wavelength bands show an asymptotic effect with an additive component. The approach is statistically based and does not depend on specific calibration sites or observation conditions. It remains applicable across different scenarios. However, it's crucial to use radiance data that have not been resampled across detectors. This preserves the relationship between neighbouring pixels. The software is currently in a preliminary state and is still under development in collaboration with VITO.

## NRCC - Novel advances for Mer Bleue and SRIX4Veg intercomparison experiment

Pablo Arroyo-Mora gave a comprehensive overview of the participation in the ESA SRIX4Veg intercomparison exercise held in July 2022 at the Las Tiesas Experimental site in Spain. The team used the HySpex Mjolnir VS-620 hyperspectral system, renowned for its reliability, radiometric calibration, and traceability. The presentation emphasized the Bottom-up Approach for Satellite product validation, similar to the methodology employed during the Mer Bleue campaign. This approach encompassed Laboratory and Field Panel Characterization, Field Spectroscopy, and comprehensive workflows for Hyperspectral Imagery from UAV, airborne, and satellite platforms. These workflows ensure precise spectral/spatial resampling (fully accounting for PSF of the different sensor characteristics) and processing to reflectance. The development of an enhanced flight planning tool, HyPlanT, in collaboration with CABO, contributed to improved UAV flight protocols. During the SRIX4Veg campaign, the NRC provided essential Sky Irradiance Measurements and deployed Calibration Panels. A specific Flight Plan with a spiral measurement sequence to sample the Bidirectional Reflectance Distribution Function (BRDF), along with Lidar for Digital Surface Model (DSM) data, was executed. Preliminary results were presented. Looking ahead, the focus will be on uncertainty assessment and propagation involving NRC up-scaling model. Collaborative efforts are required, including collaboration with NPL for the uncertainty diagram tree. Additionally, a new UAV Hyperspectral Imaging campaign is planned for the summer at the Mer Bleue site, where a LabSphere mirror-based system will be tested.

[REC-7] In order to support ongoing advancements in UAV system validation for land applications, it is recommended to establish a collaborative working group within QA4EO, in partnership with FRM4VEG. The active involvement of NPL, NRCC, and GFZ within this working group is essential for enhancing and refining methodologies and practices for UAV-based validation.

## TPZ-FR - Spectral Band Adjustment Factors (SBAF): methods and processing

Sébastien Saunier presented the project on the analysis of Spectral Band Difference Effects (SBDE) and the development of a dedicated tool for cross-calibration. The relative spectral response (RSR) plays a central role in deriving simulated surface reflectance from satellite sensors. Several valuable SR resources were mentioned, including the Hyperion Database for real-world surface reflectance observations, the JPL ECOSTRESS compilation providing spectra at a 2 nm sampling interval for natural and man-made materials, the CEOS WGCV RadCalNet service for SI-traceable TOA reflectances, which supports post-launch radiometric calibration and validation of optical imaging sensor data, and the PICSAND database containing optical properties of sand in the solar spectral domain (400 to 2500 nm). During the presentation, examples of Spectral Band Adjustment Factor (SBAF) corrections for Sen2Like sensors were showcased based on the PICSCAR CEOS initiative, with a focus on the Libya 4 site. The variability of SBAF was evaluated using an ANOVA approach. It was recommended to contact David Doelling and collaborate on the presentation at upcoming GSICS VNIR meetings.

## Serco - ICOS match-up database for S2/S3 land validation

Erminia De Grandis outlined a feasibility study involving the validation of S2/S3 land data through in-situ measurements over the ICOS sites. The ICOS research infrastructure plays a key role in offering standardized observations related to ECV anthropogenic GHG fluxes. It encompasses over 140 stations spread across Europe and gathers valuable biophysical parameters such as land surface albedo, leaf area index, above-ground biomass, and soil carbon measurements. The primary objective of this study was to establish a match-up dataset, enabling the validation of satellite-based bio-geophysical products. Two cloud-based data service solutions were assessed: Terrascope by VITO and Earth Console by Progressive Systems. These platforms were chosen to host Jupyter Notebooks, facilitating the development and deployment of the necessary analysis tools. The presentation summarized various functionalities designed to provide convenient access to satellite data, as well as data extraction and visualisation capabilities. The assessment will include key criteria such as performance, cost-effectiveness, and spatial/temporal coverage of the data.

## DAY 3 - 2 March 2023

## Water Cal/Val

## Solvo - Advanced methods and uncertainties estimation for Ocean Color products

Constant Mazeran shared the outcomes of the activities carried out with Parbleu. R&D activities focus on Ocean Color Radiometry a technique employed to derive bio-geophysical products. The TOA signal has to be corrected for various atmospheric effects (absorption & scattering) and potential sources of contamination (sky-dome, residual sun-glint, white caps, adjacency effects in the vicinity of land, …). Standard algorithms for MERIS & OLCI have limitations as they assume ideal conditions that may not align with the complexity of real-world situations (e.g., complex waters, sun-glint, absorbing aerosols). Recognizing the need for more innovative approaches to address these challenges, a multi-pixel inversion technique was developed in Phase 1. Phase 2 will further develop and refine the OCR processor (integrating CALIOP climatology, an analytical model for aerosol transmittance, a multi-pixel inversion approach, and comprehensive uncertainty characterization). A partnership with the National Physical Laboratory (NPL) is envisaged, leveraging the CoMet toolkit. A specific case study was presented, focusing on the impact of aerosol vertical distribution on ocean color products.

## Serco - CryoSat-2/SWOT fine-scale oceanographic features

Alice Carret's presentation focused on the efforts undertaken to observe fine-scale oceanographic features, which play a crucial role in the transport and mixing of natural and anthropogenic elements within the ocean. The presentation specifically highlighted the North-Western Mediterranean Sea, known for its complex coastal and mesoscale dynamics, including the episodic penetration of the Northern Current onto the Gulf of Lion shelf. In situ instruments were used to study these complex dynamics,

with a particular focus on vertical velocity. These included moorings like JULIO, along with instruments such as Acoustic Doppler Current Profilers (ADCPs) and Vertical Velocity Profilers (VVPs), which were deployed during at-sea campaigns such as OSCAHR and FUMSECK. Several altimetry tracks from different missions, including CryoSat-2, SWOT, Jason 3, and Sentinel-3, passed over the study area. Preliminary findings were presented regarding the vertical velocities observed. The data collected using Sentinel ADCP showed significant variability in the first 50 meters, likely attributed to wave influences. A Good agreement was observed between the three different missions (Jason 3, Sentinel-3, and CryoSat-2), despite the deployment of distinct technologies. Future application to Sentinel-6 data is expected to provide better quality data in coastal areas thanks to open-burst SAR acquisitions. A prospect mentioned was the upcoming SWOT mission, which will daily pass over the JULIO mooring.

## ENEA - CO2 fluxes estimation merging satellite and in-situ data in the Mediterranean Sea

Mattia Pecci introduced the initiatives focused on CO2 flux estimation in the Mediterranean Sea. Earth system feedbacks that influence the carbon cycle result in carbon sinks absorbing approximately half of the anthropogenic CO2 emissions. It is essential to monitor exchanges between the atmosphere and the ocean to comprehend feedback mechanisms impacting climate evolution. The Mediterranean Sea is exceptional in this regard, serving as a unique climate hotspot. Therefore, there is a requirement for specialized in-situ carbon measurements. The island of Lampedusa has ideal characteristics for conducting such observations. It features simple orography, minimal local sources of pollution, is located 130 km away from the nearest continental landmass, and frequently experiences cloud-free conditions. Lampedusa hosts a permanent atmospheric observatory, which is a part of ICOS, AERONET/ACTRIS, and GAW networks. Additionally, an oceanographic observatory is in place, equipped with both above and below-water sensors. This setup constitutes one of the few ICOS sites that encompass the atmosphere and ocean domains. Continuous CO2 measurements started in 1996. Preliminary CO2 fluxes derived from models and measurements were presented. One of the forthcoming objectives involves comparing satellite-derived and in-situ CO2 ocean-atmosphere fluxes. Satellite proxies such as Sea Surface Temperature (SST), Photosynthetically Active Radiation (PAR), Sea Surface Salinity (SSS), and wind are being explored to estimate partial pressure.

## TPZ-UK - Pi-MEP Salinity Platform for Validation

Roberto Sabia introduced the SMOS Pi-MEP salinity validation and exploitation platform which lays the foundation for the forthcoming FRM4OS. The presentation covered an overview of the ESA Earth Explorer opportunity mission SMOS, focusing on the Sea Surface Salinity (SSS) product, a crucial oceanographic Essential Climate Variable (ECV). The platform represents a collaborative inter-agency effort, incorporating several satellites (SMOS/Aquarius/SMAP) and in-situ measurements (ARGO, TSG, moorings, surf drifters, marine mammals), alongside models and thematic datasets. This integrated approach enables the generation of match-up databases, providing detailed reports for each triplet (Pi-MEP Region / Satellite SSS product / In situ SSS product). The reports encompass measurement errors and

sampling effect. Furthermore, the platform offers a suite of tools for tailored validation and includes dedicated case study regions. Additionally, the presentation explored the potential relevance of the Pi-MEP Salinity Platform's activities to the PAL in the frame of the CIMR mission.

## Land Cal/Val: Part II

## TPZ-UK - ENVISAT and ERS CARD4L SAR NRB PROJECT

Kajal Haria provided an update on the ENVISAT and ERS CEOS ARD SAR NRB PROJECT, initiated in January 2022 and based on the Sentinel-1 ARD prototype. This project encompasses the development of a prototype processor, with the same gridding and Digital Elevation Model (DEM) approach employed in the Sentinel-2 mission. The rationale behind the development of the processor prototype was reiterated. This prototype seeks to fulfill the objectives of the CEOS-ARD NRB (Committee on Earth Observation Satellites - Analysis Ready Data Normalized Radar Backscatter) project, which includes both the 'Threshold' and 'Target' requirements. The presentation highlighted the successful completion of the processor development phase. Notably, the prototype has achieved 100% implementation of the CEOS-ARD NRB 'Threshold' requirements and 50% of the 'Target' requirements. The output products have been formatted as Cloud-Optimized GeoTIFFs (COGs). These products have been thoroughly reviewed, and documentation has been released. Initial assessments of the output products indicated good quality, with reasonable alignment to Sentinel-1 ARD products. The presentation discussed geolocation accuracy assessment, particularly in the context of ASAR IMS products. Various post-processing corrections were evaluated, including intermittent range bias, frameshift correction, atmospheric propagation delay correction, and azimuth bi-static delay. The application of these corrections led to a noteworthy enhancement in accuracy, particularly in azimuth bias and RMSE improvements. The recommendation to incorporate the azimuth bi-static delay within the ASAR ARD (Analysis Ready Data) processor as a bulk correction for the entire image, specifically addressing slant range time in the middle of the product, was addressed. In the medium term, the project aims to validate products using the UZH internal RTC processor.

## Highlights from discussion

- Fabrizio highlighted that the presentations covered a range of different topics but maintained a **common approach**, fostering extensive collaborations and yielding added value. He also mentioned the growing importance of meteorological support in various projects.
- Exploiting **synergies across networks** (AERONET, PGN, SKYNET, MAX-DOAS, GAW-PFR, EUBREWNET) provides mutual benefits. Many presentations showcased examples of instrument collocations (Brewer, MAX-DOAS, PFR vs Pandora) revealing improved agreements after thorough characterization and the potential for synergies between complementary sensors, e.g., CIMEL and Pandora.
- Many teams are working on aerosol optical depth (AOD) and trace gas retrievals from **ground-based lunar measurements**, optimizing settings and techniques, and making prototype products operational. This type of

measurement permits to investigate the day/night variability of aerosol and chemical species (e.g., NO2, night-time reservoir species) and is proving useful for the validation of satellite-derived products, especially from missions featuring night-time observations (e.g. EarthCare, Sentinel 3-SLSTR) or for observations at high latitudes during the polar night. The gap-filling brought in the day- and night-time series for NO2, O3, H2O, and NO3 was visible in the examples shown. These activities require exchanges and coordination within GSICS, as well as the execution of dedicated lunar field campaigns (such as the one carried out at Izana, Tenerife in 2022). Philippe Goryl proposed the organization of a dedicated discussion on lunar-related topics also involving VITO and Mark Bouvet (ESA) with the LIME project.

- The **sky-camera network** is growing with the recent addition of new sites (Davos, Valencia, Wisconsin, Sao Paolo) and with the development of algorithms to solve geometric issues and reduce interference from the Sun. The operational validation of Sentinel 3 OLCI has now been implemented as part of OPT-MPC. Several ground-based activities are being setup to prepare for the new EO missions, notably BIOMASS and CHIME, with the extension of low-cost sensor networks (StructChangeNet) or Cal/Val campaigns dedicated to UAV and airborne hyperspectral sensors (SRIX4VEG). Fabrizio emphasized that preparing for new missions (especially the Copernicus expansion missions) is a top priority. The LPVE2023 conference in ESRIN in June will be the place to follow up on the discussions at the international level. Pablo recommended including a 1-hour training session during LPVE, such as demonstration for panel characterization or UAVs.

- The importance of moving towards **FRM standards**, and the implementation of agreed practices, emerged from numerous presentations across various domains, with reference to ESA activities for AQ, SM, VEG, and DOAS. ESA is actively formulating dedicated initiatives to address these requirements, both independently and as part of CEOS WGCV.

- NPL's **CoMet toolkit** has been released and is gaining interest, but promotion within the EO community is still required. The tool provides a standardized approach for metrological rigor to various projects (now Hypernets, LIME, RadCalNet) with a recognized added value.

- The IDEAS-QA4EO contract/consortium has proved to be an **attractive framework** for the development of innovative approaches. In the short term, we have two CCNs planned. After the remaining 20 months of Phase 2, ESA plans to issue an Invitation to Tender (ITT) for a contract renewal with a likely cost reduction, depending on the outcome from the Ministerial Conference.

# IDEAS-QA4EO WS#4 on-site participants

| | Name | Affiliation | Country |
|---|---|---|---|
| 1. | Philippe Goryl | ESA-ESRIN | Italy |
| 2. | Angelika Dehn | ESA-ESRIN | Italy |
| 3. | Marin Tudoroiu | ESA-ESRIN | Italy |
| 4. | Ilias Bougoudis | Luftblick | Austria |
| 5. | Leonie Haunold | Luftblick | Austria |
| 6. | Irene Himmelbauer | TU Wien | Austria |
| 7. | Yves Govaerts | Rayference | Belgium |
| 8. | Emmanuel Dekemper | BIRA | Belgium |
| 9. | Pierre Gramme | BIRA | Belgium |
| 10. | Cedric Busschots | BIRA | Belgium |
| 11. | Juan Pablo Arroyo-Mora | NRC | Canada |
| 12. | Kari Luojus | FMI | Finland |
| 13. | Cemal Melih Tanis | FMI | Finland |
| 14. | Philippe Goloub | LOA | France |
| 15. | Oleg Dubovick | LOA | France |
| 16. | Marcos Herreras | GRASP SAS | France |
| 17. | Constant Mazeran | Solvo | France |
| 18. | Juergen Fischer | FUB | Germany |
| 19. | Jan Wevers | Brockmann | Germany |
| 20. | Martin Herold | GFZ | Germany |
| 21. | Benjamin Brede | GFZ | Germany |
| 22. | Dimitris Balis | AUTH | Greece |
| 23. | Konstantinos Michailidis | AUTH | Greece |
| 24. | Henri Diemoz | ARPA | Italy |
| 25. | Elisa Castelli | CNR-ISAC | Italy |
| 26. | Fabrizio Niro | Serco | Italy |
| 27. | Gabriele Brizzi | Serco | Italy |
| 28. | Stefano Casadio | Serco | Italy |
| 29. | Erminia De Grandis | Serco | Italy |
| 30. | Massimo Valeri | Serco | Italy |
| 31. | Noelle Cremer | Serco | Italy |
| 32. | Mattia Pecci | ENEA | Italy |
| 33. | Julian Gröbner | PMOD-WRC | Switzerland |
| 34. | Stelios Kazadzis | PMOD-WRC | Switzerland |
| 35. | Natalia Kouremeti | PMOD-WRC | Switzerland |
| 36. | Sam Hunt | NPL | UK |
| 37. | John Swinton | Telespazio | UK |
| 38. | Kajal Haria | Telespazio | UK |
| 39. | Roberto Sabia | Telespazio | UK |

## IDEAS-QA4EO WS#4 remote attendees (at least in part)

| | Name | Affiliation | Country |
|---|---|---|---|
| **40.** | Clement Albinet | ESA-ESRIN | Italy |
| **41.** | Leonardo De Laurentiis | ESA-ESRIN | Italy |
| **42.** | Alexander Cede | Luftblick | Austria |
| **43.** | Martin Tiefengraber | Luftblick | Austria |
| **44.** | Manuel Gebetsberger | Luftblick | Austria |
| **45.** | Daniel Aberer | TU Wien | Austria |
| **46.** | Pietro Stradiotti | TU Wien | Austria |
| **47.** | Sebastien Schunke | Rayference | Belgium |
| **48.** | Raymond Soffer | NRC | Canada |
| **49.** | George Leblanc | NRC | Canada |
| **50.** | Margaret Kalacska | McGill | Canada |
| **51.** | Francis Zagolski | Parbleu | Canada |
| **52.** | Sophie Coustance | CNES | France |
| **53.** | Sebastien Saunier | Telespazio | France |
| **54.** | Paola Formenti | LISA | France |
| **55.** | Grit Kirches | Brockmann | Germany |
| **56.** | Uwe Krämer | Brockmann | Germany |
| **57.** | Magdalena Smigaj | WUR | Germany |
| **58.** | Karl Segl | GFZ | Germany |
| **59.** | Helge Dämpfling | GFZ | Germany |
| **60.** | Panos Raptis | NOA | Greece |
| **61.** | MariLiza KouKouli | AUTH | Greece |
| **62.** | Giorgio di Sarra | ENEA | Italy |
| **63.** | Davide Mecoli | Serco | Italy |
| **64.** | Sabrina Pinori | Serco | Italy |
| **65.** | Alice Carret | Serco | Italy |
| **66.** | Lidia Saavedra de Miguel | Serco | Italy |
| **67.** | Raffaele Crapolicchio | Serco | Italy |
| **68.** | Alessandro Di Bella | Randstad | Italy |
| **69.** | Daniele Latini | GEO-K | Italy |
| **70.** | Filomena Catapano | RHEA | Italy |
| **71.** | Rosario Iannone | RHEA | Italy |
| **72.** | Luca Egli | PMOD-WRC | Switzerland |
| **73.** | Chris Durrell | LabSphere | USA |
| **74.** | Steve Mackin | EOSense | UK |
| **75.** | Nigel Fox | NPL | UK |
| **76.** | Bernardo Mota | NPL | UK |
| **77.** | Alexander Gruber | TU Wien | Austria |
| **78.** | Arnaud Mialon | | |
| **79.** | Daniela Meloni | | |
| **80.** | François G | | |
| **81.** | Maddie | | |
| **82.** | … | | |