Report on the outcomes of a Short-Term Scientific Mission[1]

Action number: CA21119

Grantee name: Stefan-Marius Nicolae

Details of the STSM

Title: **Knowledge transfer for optical and spectral calibration of PANDORA instrument in aerosol remote sensing applications**

Start and end date: 01/01/2025 to 23/10/2025

Description of the work carried out during the STSM

The online training parts of the STSM were carried out through online Teams meetings, facilitating proper communication between the trainee and the trainers (LuftBlick). The points that were brought up in the training were basic operation principles of the instrument, potential sources of uncertainties coming from the instrument's hardware and the propagation of said uncertainties through the processing chain associated with the PANDORA instrument. All of these points were put in the context of the aerosol retrieval, highlighting the importance of wavelength, radiometric and optical calibration for the instrument.

The on-site training included 3 days of laboratory calibration measurements, in which the trainee was walked through the entire measurement procedure for standardised calibration measurements. These measurements included the optical alignment of the instrument, followed by the radiometric, spectral response, wavelength and, finally, stray light calibration measurements.

For the radiometric part, a certified standardised incandescent lamp was used, and the emission spectrum was measured with the PANDORA instrument (see Fig. 1), in order to determine the instrument's sensitivity across the entire UV-VIS spectrum. By utilizing the certificate of calibration of the lamp and a standardized measurement procedure, the arbitrary units of the instrument's spectral response are converted to absolute units (absolute units are measured in $W/m^2/nm$, and are only available for direct-sun measurements, as the multiple scatterings for zenith-sky measurements provide too much uncertainty regarding the fraction of diffuse light measured, thus lowering the signal-to-noise ratio significantly). Then, the spectral response and wavelength calibrations were performed using spectral emission lamps (with discrete emission lines) and by measuring the spectra with the PANDORA instrument, at different temperatures, thus providing a baseline for the nominal wavelength separation of the spectrometer. Finally, the stray light calibration was done using a tuneable laser at different wavelengths, whose output was measured with the instrument. This step corrects for, and removes

[1] This report is submitted by the grantee to the Action MC for approval and for claiming payment of the awarded grant. The Grant Awarding Coordinator coordinates the evaluation of this report on behalf of the Action MC and instructs the GH for payment of the Grant.

unwanted optical effects inside of the spectrometer (such as diffuse light hitting the CCD sensor and producing false readings across the entire spectral range, when only a thin line should be observed).

The laboratory calibration is then followed by an on-field calibration, in which reference extraterrestrial spectra are used to validate the laboratory calibration. In order to do this, strong features of the Sun's reference spectrum (e.g. Fraunhofer lines) are correlated with the measured signal from the instrument, ensuring proper spectral calibration. At this point, the radiometric calibration is also validated with respect to the reference spectra and is noted as a calibration parameter for the instrument. To prevent unwanted instrumental drift, this routine is run often as an automated procedure, ensuring both the spectral and radiometric consistency of the instrument. If significant drifts are to be seen, a field calibration can be performed using radiometric (continuous spectrum) or spectral (discrete lines) lamps. In severe cases, this triggers more investigation by the network operator, who can flag the need for a full overhaul of the instrument (disassembly, repair, and/or laboratory calibration).

Furthermore, field of view (FOV) tests are also performed in the field. These consist of automatic routines for Sun tracking, which slightly modify the viewing angle of the instrument relative to the Sun and checking the measured signal. This helps with validating the instrument's proper optical alignment (as a theoretical FOV is known for the direct Sun measurements), ensuring the diffuse and stray light entering the instrument is kept at a minimum (in order not to introduce spectral artefacts and increase signal-to-noise ratios in zenith-sky or moon measurement modes) and determining its position and rotation around the three orthogonal axes (for proper Sun tracking).

All of the aforementioned activities were done under the constant surveillance of trained personnel from LuftBlick, and with the appropriate safety gear for both the trainer and the trainee. Additionally, on-site training also featured possibilities for the trainee to ask questions and get answers regarding related topics, such as logistical management, instrument handling and operational workflows for the PANDORA instrument network.

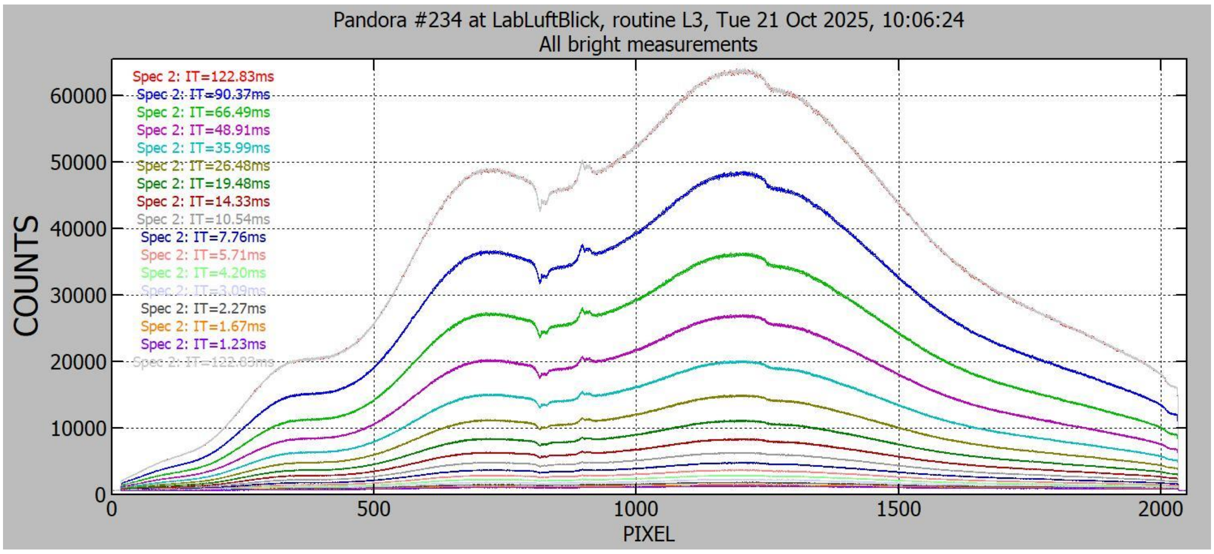

Fig. 1 - Spectral response of the PANDORA instrument for a continuous spectrum incandescent lamp, used to determine the radiometric calibration constants and to correct for unwanted per-pixel spectral behaviour (e.g. higher than usual sensitivity)

After the initial 3 days of laboratory measurements, the remaining on-site time has been used to show the trainee how these standardised measurements are then used in the calibration software for deriving the laboratory calibration constants specific to the PANDORA instrument. All of this knowledge was put into the context of the aerosol optical depth retrieval, with particular attention to the handling of aerosol-related products in the PANDORA processing chain.

One such important point to note is that the retrieved aerosol optical depth values are obtained by subtracting the contribution of major and minor absorbers (trace gases such as NO_2, O_3, and others) from the corrected spectral signal measured. In other words, if any instrument-related spectral feature is still present in the corrected data (which should be instrument-agnostic in theory), then the fitting algorithm will consider that feature as coming from aerosol-related processes in the atmosphere, thus providing erroneous data about the AOD. As such, the PANDORA instrument (used for AOD measurements) is particularly sensitive to calibration parameters and instrumental drift. For this reason, automatic routines have been implemented to ensure a stable behaviour of the instrument with time and ongoing developments are being done at LuftBlick to better characterize and prevent the unwanted spectral features present in the measured data.

Description of the STSM main achievements and planned follow-up activities

The STSM has achieved its planned goals and expected outcomes, as the trainee has had hands-on experience in the laboratory performing the calibration measurements on a PANDORA-type instrument. Furthermore, the calibration measurements were used to obtain the calibration constants used for operational data acquistion and processing. Lastly, the characteristics of the aerosol optical depth retrieval procedure have been presented to the trainee, and have been linked, from beginning to end, with the importance of the calibration measurements performed in the laboratory.

As such, the primary goal of providing the trainee with more knowledge into the calibration procedures implemented at a network-level has been thoroughly accomplished. Moreover, the networking activities performed during this STSM have extended the possibility of collaborations between the training personnel and the trainee. One such possibility is mirroring the processing chain done by the network on the local hardware resources of the trainee's organization, providing the possibility of near real-time data availability for the measurement station.

Additionally, the transfer of expertise contributes to a better understanding of the entire data flow, from the physical processes in the data acquisition procedure, to the processing chain implemented on a network level, and, finally, to the end-user web platforms that are available for data downloading and visualization. This has directly helped with the HARMONIA deliverable D4.2 *"Establish a collaboration platform among scientists and instrument manufacturers aiming on instrument hardware improvement, linked with retrieval algorithms, towards improvement of aerosol retrieval accuracy"* and the specific Research Coordination Objective "*Homogenization of existing aerosol optical properties from different networks through establishing an expert team aiming to:*

- Provide documentation on calibration standardization, recommendations towards harmonization of metadata formats, real-time retrievals and optimization of standard operation procedures.

-Identify and report the different networks' retrieval uncertainties and assess the limitations on their use", through providing the foundation for a collaboration medium in which researchers responsible with the operational use of the equipment and scientists ensuring proper calibration and instrumental performance can exchange information and communicate accordingly.

For HARMONIA deliverable D3.2 *"Define the needs of stakeholders, assess the adaptation of photometry aerosol products to increase the usefulness and applicability"*, possibilities of ensuring high quality data through future long- and short-term comparisons with dedicated photometry data products (such as AERONET data) were also discussed, for continuous assessment of data quality resulting from the PANDORA measurements. Through this operational activity, the needs of stakeholders were targeted, with the intention of increasing the usefulness and applicability of the PANDORA instrument and its aerosol-related products to the current global research direction of aerosol products, specifically regarding aerosol optical depth.

Taking all of the above points into consideration, this STSM proves to have been a successful endeavour in the context of the proposed goals and expected outputs established in the proposal. In addition to the objectives stated in the proposal, additional points of discussion naturally occurred within the timespan of the STSM, such as logistical management of the Pandonia Global Network (PGN), possible directions of development for the retrieval algorithms and instrumentation and inherent limitations of the measurement principle. The above discussion helped both the training institution and the trainee to have a more complete perspective on the entire data acquisition chain and fostered collaboration between the two entities.