LuftBlick Report 2017005

ESA Ground-Based Air-Quality Spectrometer Validation Network and Uncertainties Study

AOD from Pandoras at selected wavelengths

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Document Change Record

Issue	Date	Section	Observations
1.0	31 Oct 2017	All	First draft version

Acronyms and Abbreviations

AERONET	Aerosol Robotic Network
AOD	aerosol optical depth
CCN	Contract Change Notice
FOV	field of view
mFCT	mobile field calibration tool
Pandonia	ESA Ground-Based Air-Quality Spectrometer Validation Network
s1	Pandora spectrometer 1, wavelength range 270 nm - 537 nm
s2	Pandora spectrometer 2, wavelength range 387 nm - 937 nm

1 Introduction

This report is deliverable D5 of CCN#1 [4, 3] to ESA's Pandonia project [2, 1]. This deliverable is the second part of WP3 of this CCN which concerns the determination of the aerosol optical depth (AOD) from Pandora instruments. Based on the technical report D4 by *Kreuter* [5], where suitable calibration methods were applied, the objective here is the retrieval of the AOD using these calibration results.

In this report, we will present the AOD at selected wavelengths of Pandora 128 and 129 during the CINDI2 campaign in September 2016 in Cabauw and compare them to independent AOD data from the Cimel sun photometer operated within the Aerosol Robotic Network (AERONET). The Cimel sun photometer in Cabauw has three wavelength channels for AOD measurements: 440 nm, 675 nm and 870 nm. While the wavelength range of spectrometer 2 (s2) of the Pandora instruments includes all three channels, the wavelength range of spectrometer 1 (s1) coincides only with the 440 nm channel. As a side note, another sun photometer was operated in Cabauw, a Precision Filter Radiometer (PFR) with additional wavelengths channels. However due to calibration issues, the data is not useful for the CINDI-2 period and our comparison remains restricted to the three wavelengths above.

All calibration constants (V0) obtained from four Langley type field calibrations in D4 are summarized in the table below. As we have concluded in D4 [5], the absolute calibrations from the laboratory for both instruments have systematic errors of more than 10% which is not sufficient for AOD retrievals. So here we will first consider the AOD using only the Langley results. Eventually, the absolute calibration will be used as spectral response to transfer Langley calibrations from long to shorter wavelengths.

		440 nm		870 nm	
		128	129	128	129
s1	classical Lan.	1809	1873	–	–
	weighted Lan.	1792	1811	–	–
	AOD Lan.	2022	2018	–	–
	minimum Lan.	1723	1640	–	–
s2	classical Lan.	2150	2054	1159	1074
	weighted Lan.	2067	1948	1139	1069
	AOD Lan.	2146	2018	1159	1098
	minimum Lan.	2092	1883	1144	1085

Figure 1: Numerical values of V0s (mW/m^2/nm) from report D4, Fig.7 and Fig.8. Shading of cells corresponds to magnitude.

1.1 Applicable Documents

[1] Ground-Based Air-Quality Spectrometer Validation Network and Uncertainties Study [Proposal], LuftBlick Proposal 201309A, Issue 2, 2013.

[2] ESA Ground-Based Air-Quality Spectrometer Validation Network and Uncertainties Study [Statement of Work], ENVI-SPPA-EOPG-SW-13-0003, Issue 1, Revision 3, 2013.

[3] CCN1 to ESA Ground-based Air-Quality Spectrometer Validation Network Uncertainties Study [Proposal, Proposal 201705A, Issue 2, 2017.

[4] CCN1 to ESA Ground-Based Air-Quality Spectrometer Validation Network and Uncertainties Study [Statement of Work], ESA-EOPG- MOM-SOW-1, Issue 1, Revision 1, 2017.

[5] Cede A. Tiefengraber M. Kreuter, A. ESA Ground-Based Air-Quality Spectrometer Validation Network and Uncertainties Study, LuftBlick Report 2017004: Methodologies for absolute calibration, 2017.

2 AOD at selected wavelengths

2.1 AOD time series

The AOD using the calibration constant from four field-calibration methods (classical Langley, weighted Langley, AOD Langley and minimum Langley) has been evaluated at 870 nm and 440 nm. The results for 12 selected days during the CINDI-2 campaign for both instruments and spectrometers are shown in the following figures 2 - 5.

Figure 2: AOD at 870 nm for Pandora 128 s2. Scale and labelling of axes and corresponding dates of each subplot are shown in the legend above. The classical and AOD Langley calibrations were almost identical, so the green dots are hidden behind the red ones.

Figure 3: AOD at 870 nm for Pandora 129 s2.

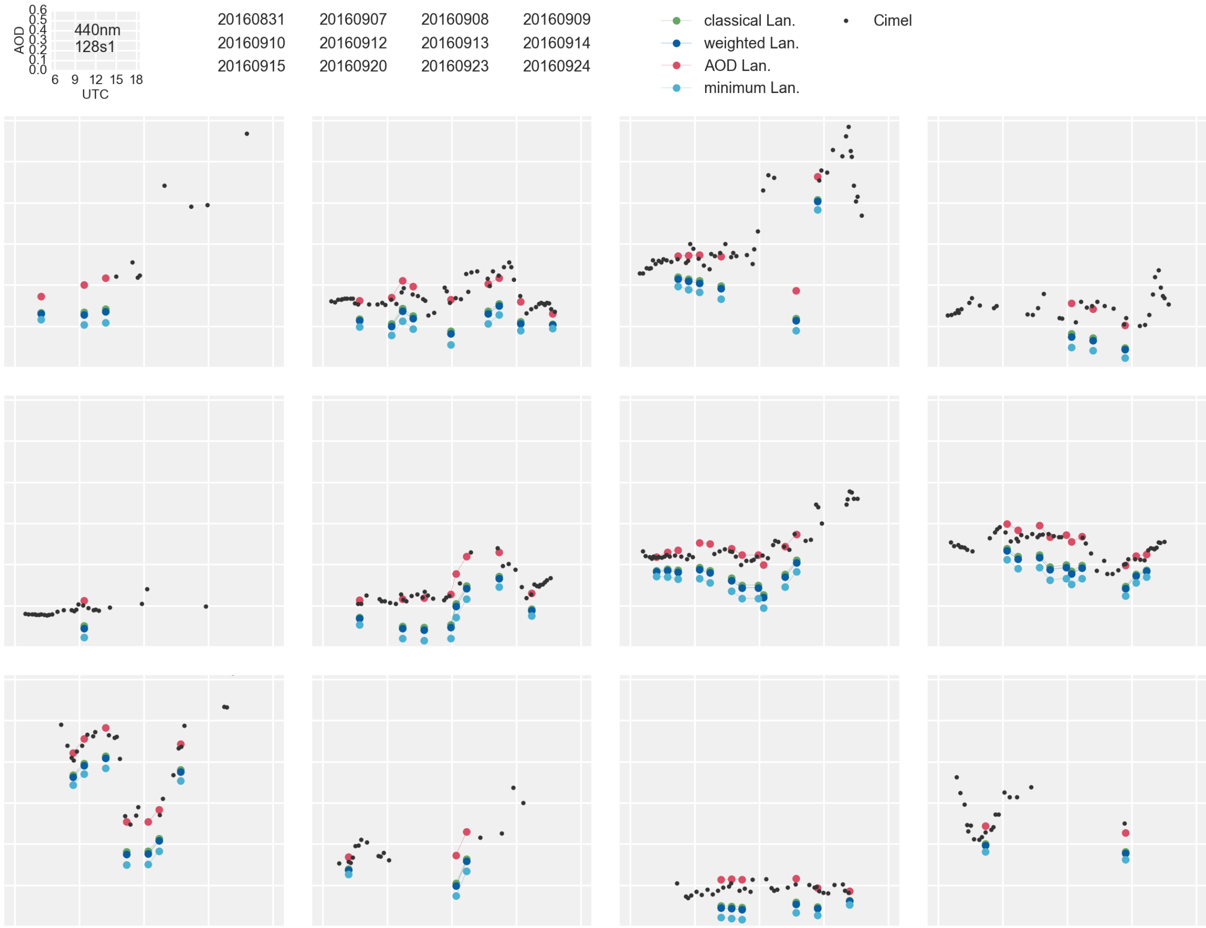

Figure 4: AOD at 440 nm for Pandora 128 s1.

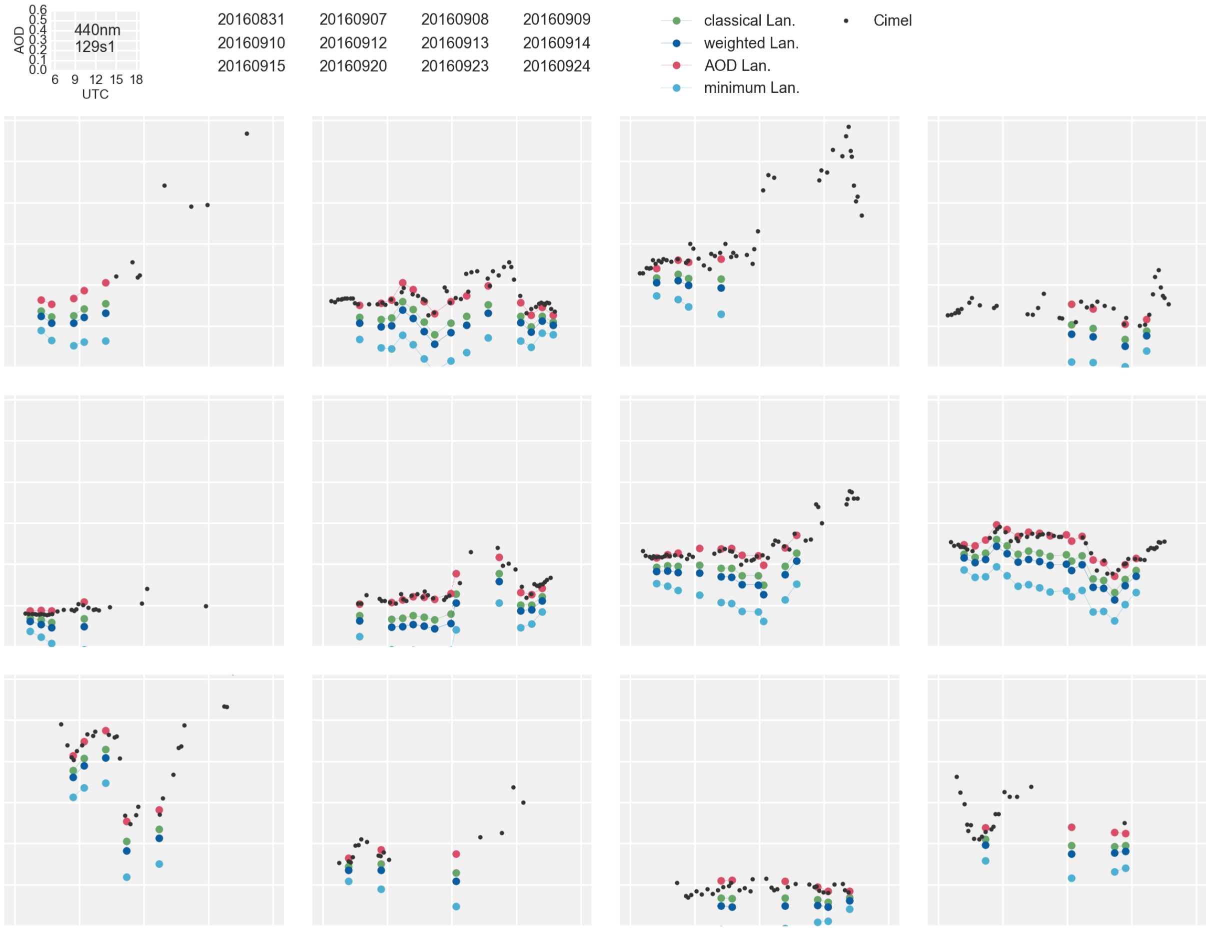

Figure 5: AOD at 440 nm for Pandora 129 s1.

2.2 AOD comparison to the sun photometer

Now we show the differences of the Pandora AOD and the Cimel sun photometer from section 2, aggregated in box plots to visualize the performance of each instrument and calibration methodology. Due to the sparse measurement schedule, the differences are computed with a time tolerance of 10 minutes between measurements.

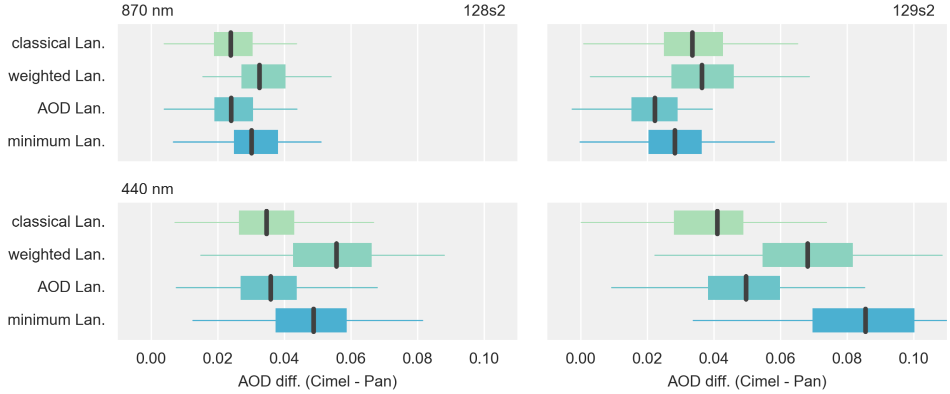

Figure 6: AOD differences of Pandora s2 and Cimel for 870 nm and 440 nm. The box plots indicate median and 25 and 75 quartiles.

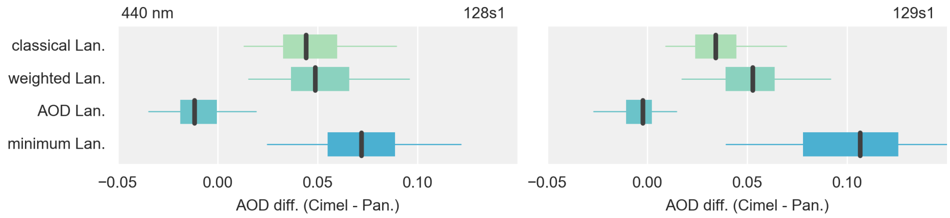

Figure 7: AOD differences of Pandora s1 and Cimel for 440 nm.

The accuracy and precision of Langley type calibration increases with wavelength (for reasons discussed in report D4 [5]). So next, we investigate the calibration approach of combining the Langley calibration at a long wavelength with the spectral sensitivity from the absolute laboratory calibration allowing the transfer of the Langley calibration to the selected shorter wavelengths. This approach is of particular relevance when aiming at retrieving the spectral AOD over the complete spectral range of the Pandora instrument. The AOD differences of the Pandoras and Cimel at 675 nm and 440 nm using the spectral response and the Langley calibration at 870 nm as a pivot are shown in Fig.8.

As we have layed out in equation 8 in D4 [5], a measurement or calibration error of the AOD results in an air mass dependent diurnal variation. The same is of course the case when considering the differences to a reference instrument and indeed it can be seen in the figures in section 2.1 that the differences are air mass dependent: small at large air masses and largest around noon. By multiplying the AOD differences $\Delta\tau_{\mathrm{aero}}$ with the air mass m, we can determine the ratio of the measurement or calibration error, $R(V/V_0)$, of the Pandoras with respect to the Cimel:

$$R(V/V_0) = \exp\left(\Delta\tau_{\mathrm{aero}} \times m\right) \approx 1 + \Delta\tau_{\mathrm{aero}} \times m \tag{1}$$

The ratio is independent of air mass and is gives a more general picture of the stability of the Pandoras. In particular, the ratio allows a direct radiometric comparison of the Pandora and Cimel instruments. The Ratios of

V/V0 of Pandora and Cimel are shown in Fig.9. Note that an AOD difference of 0.03 translates to a radiometric deviation of at least 5% (during CINDI-2, the minimum air mass was about 1.5).

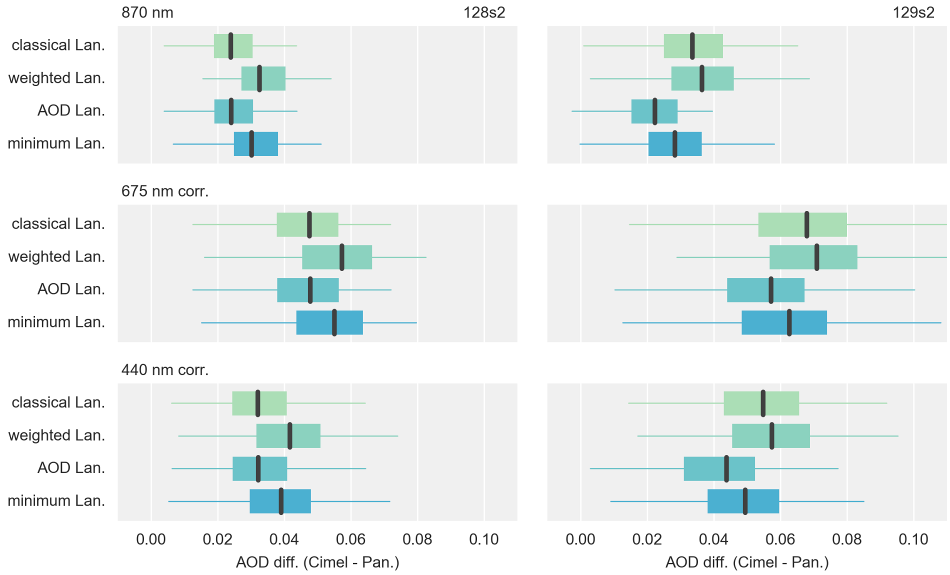

Figure 8: AOD differences of Pandora s2 and Cimel. The AOD at 870 nm is a direct result from the Langley calibrations (same as in Fig.6), the AOD at 675 nm and 440 nm has been transferred from 870 nm by applying the spectral response of the instruments.

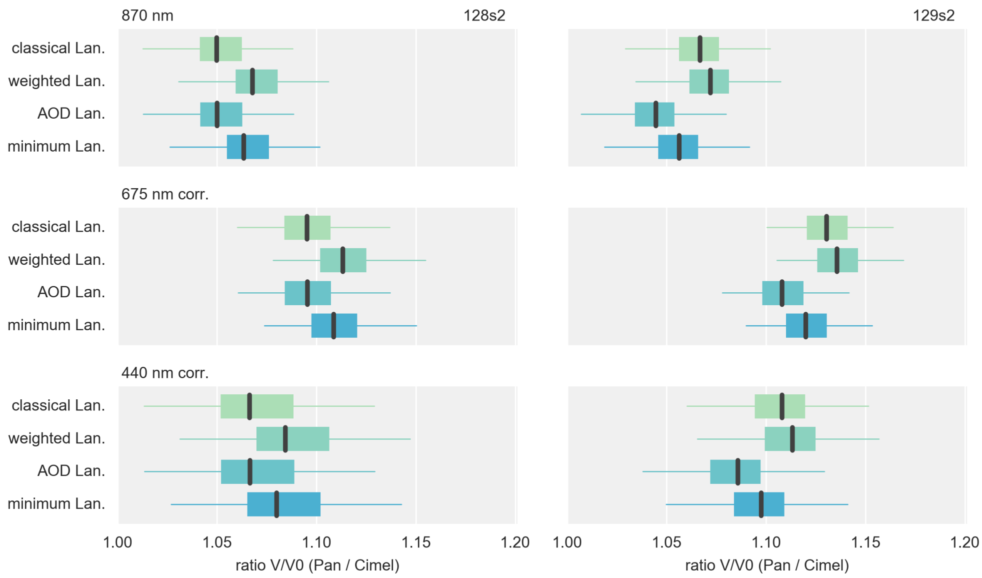

Figure 9: Ratios of V/V0 of Pandora and Cimel. The ratios are related to the AOD differences in Fig.8 by Eqn.1.

2.3 Relative stability of AOD

Besides the accuracy of the AOD, which was the focus of the previous section, we are also interested in the precision of the Pandoras instruments. The precision is related to the widths of the box plots in Fig.9. More explicitly, in Fig.10 we show the ratios of the Pandora and Cimel measurements as a time series to investigate the temporal stability of the Pandoras over the one month period during CINDI-2.

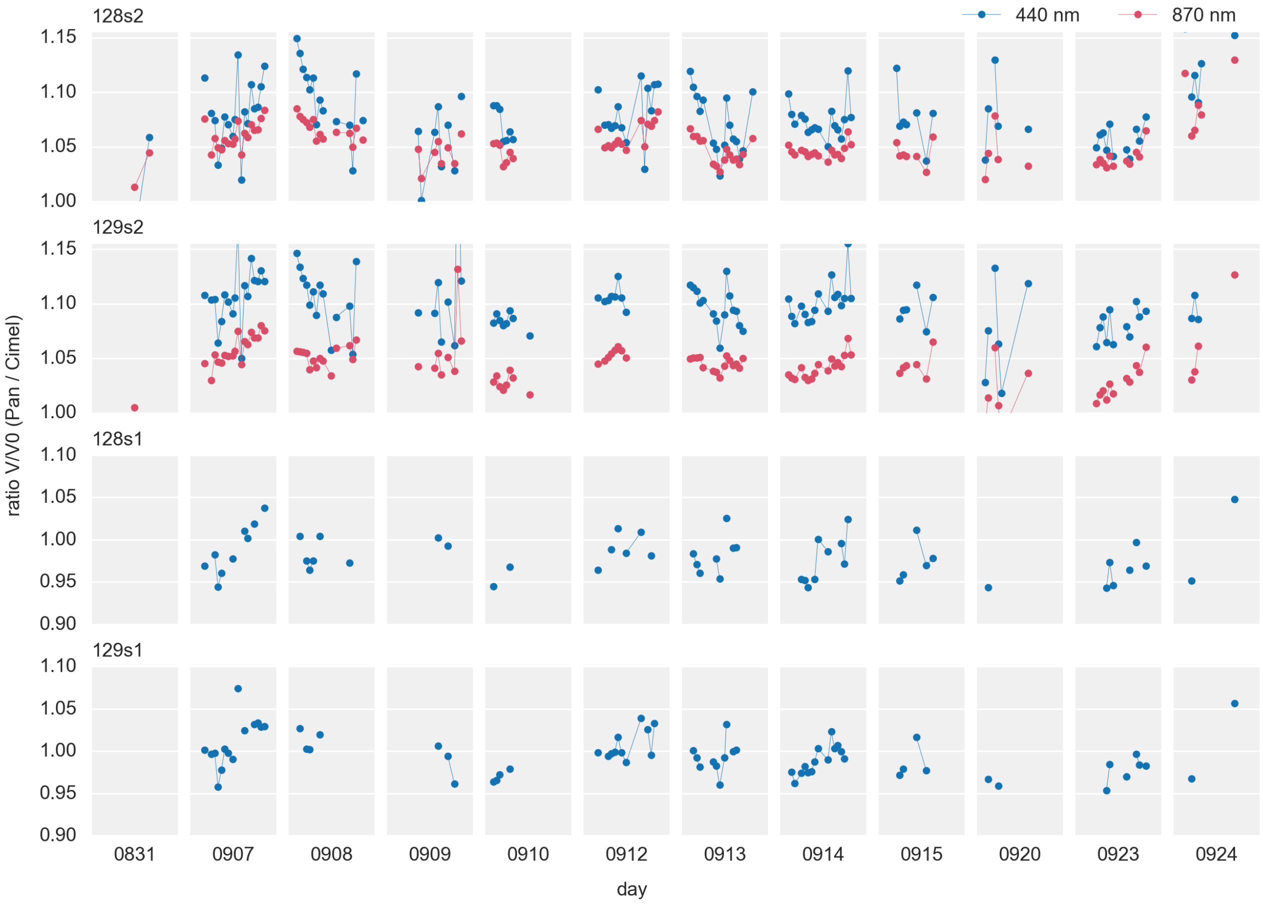

Figure 10: Ratios of V/V0 of Pandora to Cimel for all 12 selected days and all instruments and two wavelengths for the AOD Langley calibration. The time scale of each day corresponds to the scale of the figures in section 2.1

3 Discussion and Conclusions

First, we summarize the observations from the figures in section 2:

- For spectrometer s2, the AOD at 870 nm is systematically smaller than the Cimel AOD by about 0.03. Similar for all Langley type calibrations. At 440 nm, the AOD is systematically smaller than the Cimel AOD by about 0.04 and 0.06 (for Pan 128 and 129, respectively). As expected, the discrepancies between Langley type calibrations increase with wavelength.
- For spectrometer s1, the AOD at 440 nm is systematically smaller than the Cimel AOD by about 0.06, except for the AOD Langley calibration which agrees to better than 0.02.
- Overall, comparing all calibration methods, the AOD Langley method seems to achieve the best results, in particular for s1.
- Using the relative spectral response to transfer the calibration to shorter wavelengths reduces AOD differences. Ideally, the difference at all wavelengths should be the same. For Pandora 128 s2, the AOD difference at 675 nm is about 0.02 higher than at 870 nm. This implies a spectral uncertainty in the absolute calibration of Pandora 128 s2 of about 4% at 675 nm relative to 870 nm and better than 2% at 440 nm relative to 870 nm. This uncertainty is little higher for Pandora 129 s2.
- Tracking the temporal stability of the Pandora instrument against the Cimel in terms of the ratio V/V_0, shows a 1σ standard deviation of the Pandora ratio of 2% at 870 nm for spectrometer s2 of both Pandoras over the one month period. At 440 nm, the stability is 3% for all instruments .

These observations raise a few issues for discussion. First, the accuracy of the AOD shown here is not satisfactory. For this analysis, it can clearly be attributed to the very unfavourable conditions to perform Langley calibrations during CINDI-2 and we do not see any obstacles in achieving a sufficiently accurate Langley calibration after a few cloudless days with less AOD variation. In fact, for a more conclusive discussion, the calibration analysis should be done on a more suitable data set from the Pandora in e.g. Izana or Davos to allow an estimate of the optimal calibration accuracy. Note that the primary reason for choosing the CINDI-2 campaign here, was the opportunity of comparing two co-located Pandoras.

Regarding general measurement conditions we should add that the CINDI-2 campaign included some unusual challenges: Due to a tight measurement schedule with focus on trace gas slant column retrieval, the direct sun measurements were only performed intermittently with limited time for sun searches which are necessary to ensure optimal pointing accuracy with respect to the sun. Also, the sparse schedule required a larger time tolerance in the comparisons with the Cimel during which atmospheric variations may contribute to the variance. Furthermore, the instruments were mounted on a platform that was susceptible to mechanical vibrations, further reducing the pointing accuracy and possibly inducing additional noise.

The precision of the AOD, i.e. the temporal stability of 2 - 3% is slightly higher than required, but considering the above limitations, the precision is expected to improve under standard operational conditions. Also addressing this issue, last year, a "fibre guide" has been designed to minimize the movement of the optical fibre for different tracker positions which is a known source for inducing measurement uncertainty. The fibre guide is planned to be included in all future Pandora installations. The instruments at Izana and Davos have already been fitted with the guide and a preliminary analysis suggests an improvement of stability.

Any residual issues concerning the relative stability will also be addressed in the future with the current development of the mobile field calibration tool (mFCT) as a portable standard lamp for regular radiometric monitoring.

The remaining inaccuracy of the spectral response, apparent in the calibration transfer results is likely an effect of a pointing inaccuracy in combination with a wavelength dependent field of view (FOV) when measuring the FEL calibration standard in the laboratory or the direct sun. First tests, scanning over the sun by $0.5°$ (1/5 of the FOV) revealed spectral deviations in the order of up to 2% between 870 nm and 675 nm. This effect looks like an intrinsic property of the optical arrangement of the input optics and would imply an emphasized importance of the sun pointing accuracy involving regular sun searching routines.

All conclusions from this report, including insight from planned additional studies, will be summarized in a recommendation for operational AOD measurement guidelines in the final report of WP3.