Annual Report 2022: IZO/Spain, OHP/France and VLD/Spain

ACTRIS Annual Report 2022

Izaña (IZO) Tenerife/Spain, Observatoire de Haute-Provence (OHP)/France and University of Valladolid (VLD)/Spain

(January-December 2022)

Prepared by

A. Masoom, N. Kouremeti, J. Gröbner, S. Kazadzis

Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center

Abstract

PMOD/WRC aims at standardization and homogenization of AOD reference scales and improving the calibration, processing algorithms and consistent long-term measurements of AOD. Under Center for aerosol remote sensing (CARS) - Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS), PMOD/WRC aims to establish the traceability link between the ACTRIS measured AOD to the GAWPFR reference operated by PMOD/WRC on behalf of the WMO. With this aim, a new PFR was installed at VLD/Spain, the PFR at CARS site of OHP/France and IZO/Spain were exchanged during 2022 in May and September, respectively. For IZO, hardware improvements also took place including data logger, cables exchange as well as PFR holders. This annual report presents the AOD comparison analysis at seven wavelengths between 340 nm and 1020 nm between PFR and CIMEL instruments at the three CARS-ACTRIS sites of Izaña (IZO) in Spain, Observatoire de Haute-Provence (OHP) in France and University of Valladolid (VLD) in Spain.

The annual comparison results of PFR and CIMEL AOD at IZO showed that the percentage of AOD differences within the WMO uncertainty limits were above 99% for all wavelengths longer than 340 nm and the correlation coefficient was higher than 0.999 at all compared wavelengths. The uncertainty in the AOD difference was mostly within 0.01 at all wavelengths above 380 nm while it was within 0.02 at 380 nm and 340 nm. The average difference of the daily mean pressure and ozone values used by the PFR and the CIMEL was -1.1 ± 0.7 hPa and 1.9 ± 9.9 DU, respectively. For OHP station, the annual AOD comparison of PFR with CIMEL showed that the percentage of AOD differences within the WMO uncertainty limits were mostly above 99% for all wavelengths longer than 440 nm while it was above 80% for all wavelengths except 340 nm. The correlation coefficient was found to be greater than 0.9 for all compared wavelengths for the CIMEL instruments. The average AOD difference uncertainty was found to be mostly within 0.02 at all wavelengths longer than 340 nm. The average difference of the daily mean pressure and ozone values used by the PFR and the CIMEL was 1.02 ± 1.16 hPa and 2.96 ± 16.56 DU, respectively. At VLD, the percentage of AOD differences within the WMO uncertainty limits were mostly above 99% for all wavelengths above 440 nm and above 90% for all wavelengths except 340 nm and the correlation coefficient was found to be greater than 0.99 for all compared wavelengths. The average AOD difference uncertainty was found to be within 0.02 at all wavelengths longer than 340 nm and within 0.03 at 340. The average difference of the daily mean pressure and ozone values used by the PFR and the CIMEL was 0.86 ± 1.21 hPa and 1.75 ± 12.40 DU, respectively. For all the three stations, it was observed that the effect of NO_2 optical depth on the AOD retrieval was mostly significant since it is not accounted for in the WORCC retrieval.

1. Introduction

Physical Meteorological Observatory in Davos - World Radiation Centre (PMOD/WRC) maintains the world reference aerosol optical depth (AOD) standards/triad of precision filter radiometers (PFR) being the Central Calibration Laboratory for AOD under the Global Atmosphere Watch Program of World Meteorological Organization (WMO) (Kazadzis et al., 2018a). PFR instruments, designed and manufactured at PMOD/WRC, are used for performing accurate and reliable measurements for long-term AOD observations based upon the recommendations by WMO. PMOD/WRC aims at standardization and homogenization of AOD reference scales and improving the calibration, processing algorithms and consistent long-term measurement. Under CARS (Calibration of Aerosol Remote Sensing) - ACTRIS (Aerosol, Clouds and Trace Gases Research Infrastructure), PMOD/WRC aims to establish the traceability link between the ACTRIS measured AOD to the WMO reference. This collaboration aims for developing a Standard Operational procedure and a real time support to the traceability of ACTRIS calibration sites to the WMO reference Triad according to ISO 17025, issue calibration certificates to demonstrate formal metrological traceability of ACTRIS AOD reference radiometers to the WMO AOD reference maintained by World Optical Depth Research and Calibration Center (WORCC) and annually reporting on the AOD traceability of all CARS-ACTRIS calibrated sun-photometers at the three calibration sites to WORCC.

Izaña (IZO) Tenerife, Spain (28.3° N, 16.5° W, 2401m) is a Langley calibration site for the WORCC PMOD/WRC since 2002. The link of the transfer standard PFR to the designated WMO AOD reference (PFR-Triad) maintained by WORCC PMOD/WRC is described in Kazadzis et al. (2018a). Within the ACTRIS project, WORCC provides a

traceability link to the WMO AOD reference though AOD comparison of the PFR transfer standard to the master CIMEL instrument which is for calibration of field CIMEL instruments of AERONET. The Observatoire de Haute-Provence (OHP) (43.93° N, 5.71° E, 680 m above sea level) is situated in southeast France on a plateau at 650 m altitude near the town of Forcalquier. The PFR was installed in 2020 at OHP and has been functional since then. Valladolid (41.66° N, 4.71° W, 705.0 m) is located in northwestern part of Spain in North-Central Iberian Peninsula. A new PFR was installed at University of Valladolid in June 2022 and is functional since then.

2. Activities

- A new PFR was installed at CARS site of Valladolid/Spain in June 2022 (Picture 1a).
- The PFR at CARS site of OHP /France was exchanged in May 2022. The data acquisition system arrived damaged, one month delay to exchange it. It is in normal operation from June.
- The PFR at CARS site of Izanã/Spain was exchanged in September 2022. Hardware improvements have also taken place (data logger and cables exchange as well as PFR holders).
- This annual report provides the AOD comparison analysis of the three CARS-ACTRIS sites (IZO-Spain, OHP- France and VLD-Spain) with the CIMEL instruments that operated at these sites in 2022.

Picture 1: a) VLD, Spain ACTRIS calibration site

3. Results and Discussion

3.1 Annual comparison at IZO

The operation of the PFR during 2022 was according to the WORCC quality management procedures, without any significant problems. During this period one master CIMEL was operated by AEMET. The protocol followed for the comparison of the AOD values at the wavelengths of CIMEL is described in detail in the document WORCC_ACTRIS_AOD_TracabilityProtocol_v1.0. In total 18442 synchronized measurements, within ±1min, were compared in the period from January 01 to September 23 in 2022. The comparison results are presented in Table 1. The percentage of AOD differences within the uncertainty limits defined by WMO, are above 99% for all wavelengths longer than 340 nm. The agreement is slightly reduced to 98.4% for 340 nm. The correlation coefficient for all compared wavelengths is higher than 0.94. The time series of the AOD differences at the 7 compared wavelengths are presented in Figure 1 along with the WMO recommended limits (dark shaded area). While the distribution of the AOD differences at each wavelength has been simulated with a 2nd – 8th degree Gaussian distribution and is presented in Figure 2. The AOD difference is mostly within 0.01 at all wavelengths above 380 nm while it is within 0.02 at 380 nm and 340 nm.

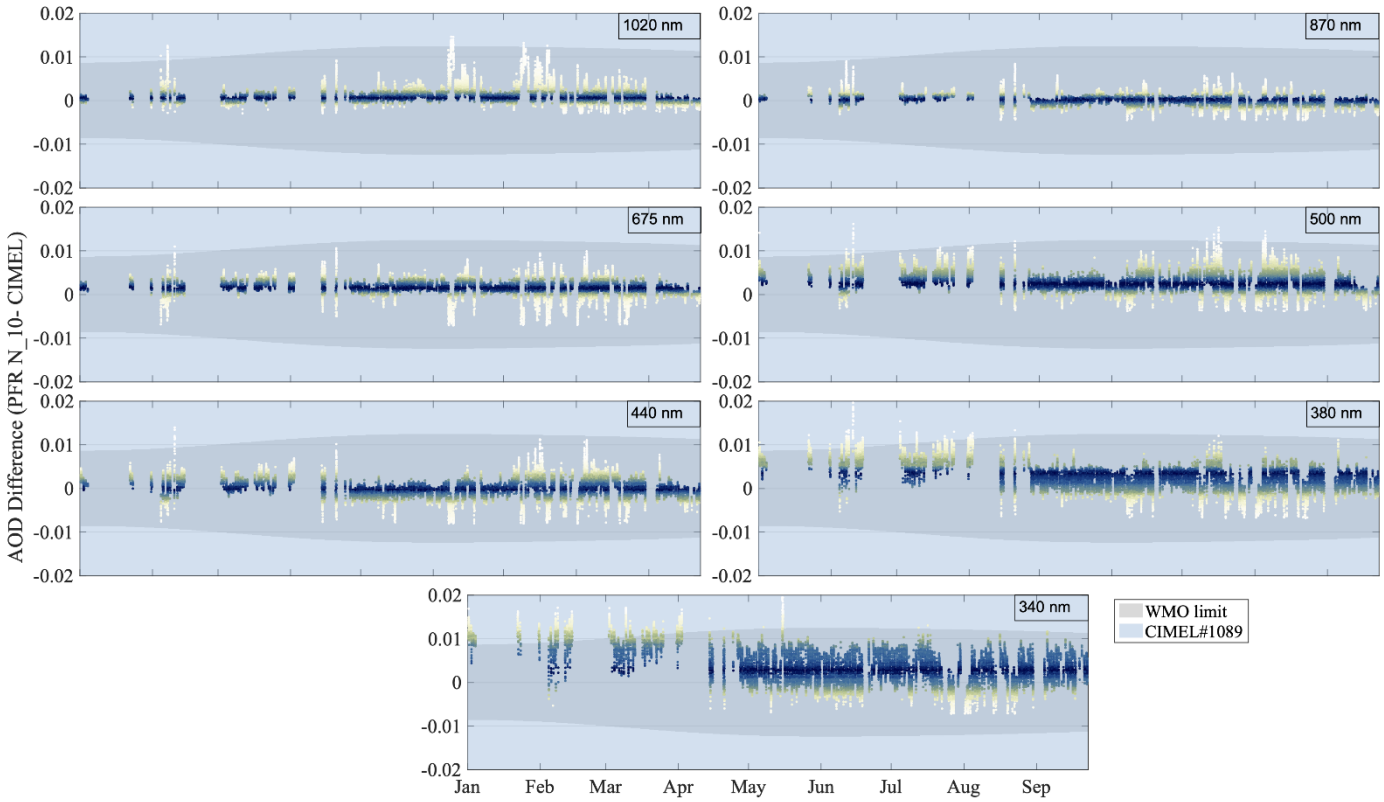

Figure 1: Time series of AOD differences (PFR-Cimel) at 7 Cimel wavelengths (colored dots). The dark gray area shows the WMO limits at local noon of each day.

Table 1: AOD Comparison results of PFR and Cimel operated at Izaña observatory in 2022.

	AOD Difference (CIMEL - PFR)				AOD linear regression results				
Exact wavelength (nm)	Median	5th percentile	95th percentile	within WMO limits (%)	Slope	Intercept ($x10^{-3}$)	Slope Uncertainty ($x10^{-3}$)	Intercept Uncertainty ($x10^{-3}$)	Correlation Coeff.
1020.0	0.001	-0.001	0.009	99.8	0.896	0.000	0.007	0.000	0.938
861.6	0.000	-0.003	0.003	100.0	0.951	0.000	0.006	0.000	0.962
675.0	0.001	-0.005	0.005	100.0	0.858	-0.001	0.008	0.000	0.939
500.5	0.002	-0.002	0.008	99.9	0.815	0.000	0.007	0.000	0.949
440.0	-0.002	-0.007	0.003	99.8	0.945	0.002	0.003	0.000	0.990
380.0	0.000	-0.006	0.008	99.7	0.834	0.000	0.005	0.000	0.964
340.0	0.001	-0.007	0.010	98.4	0.880	-0.002	0.005	0.000	0.971

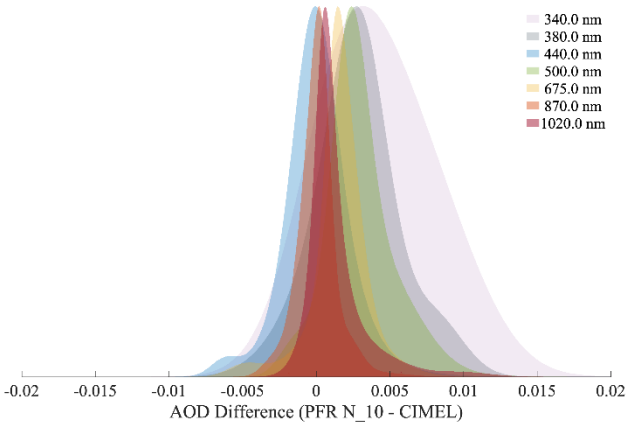

Figure 2: Normalized to maximum distribution of AOD differences at 7 Cimel wavelengths using WORCC trace gases and including AERONET NO_2 climatology.

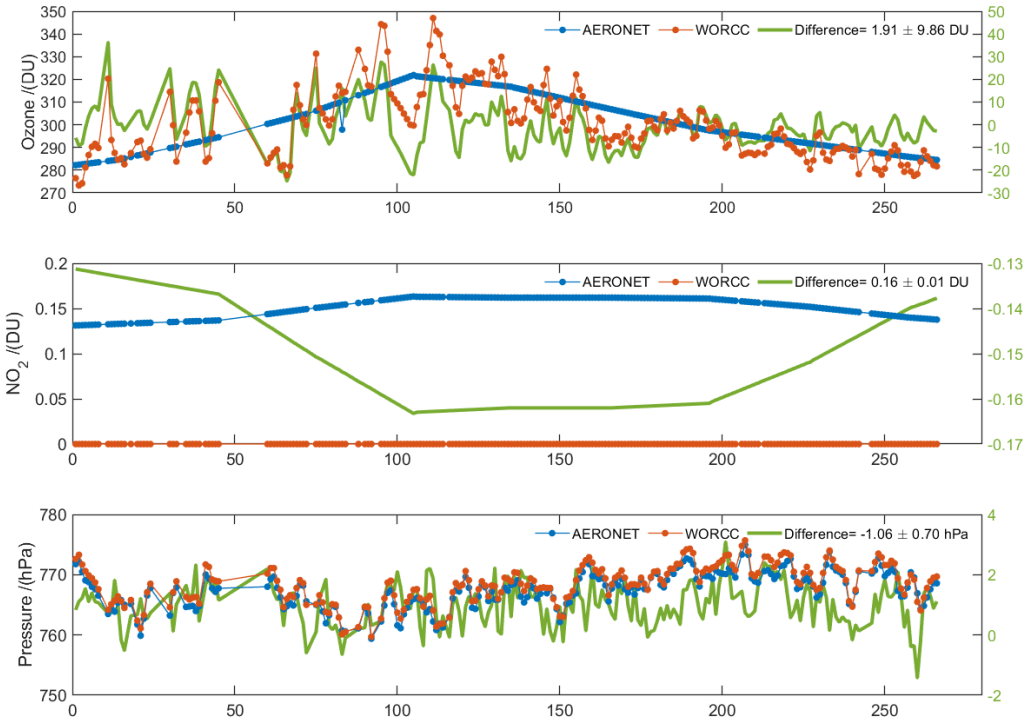

Figure 3: Daily mean ozone, NO_2 and pressure values used for the AOD retrievals for PFR (WORCC) and Cimel (AERONET) and the right axis and green lines shows their differences (CIMEL - PFR).

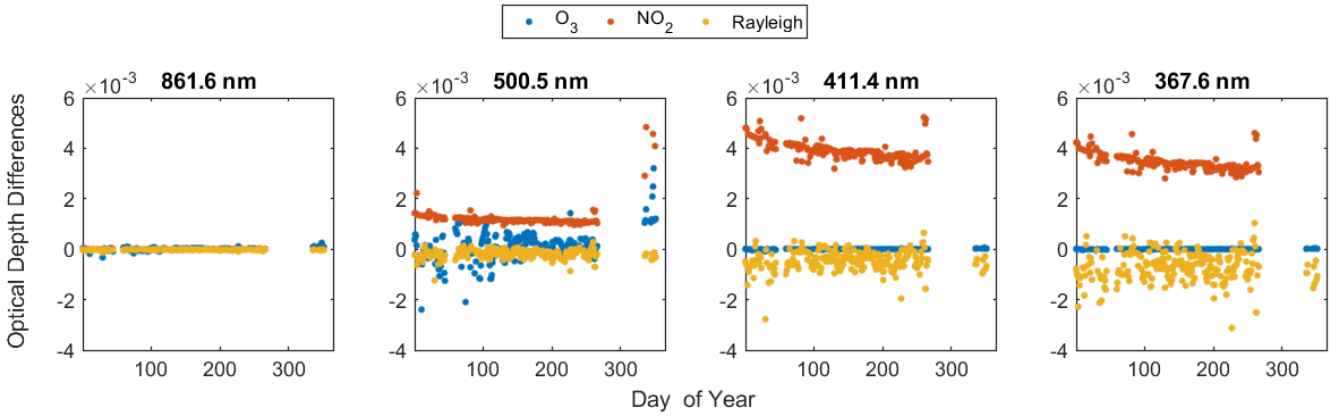

Figure 4: Differences in the optical depth of O_3, NO_2, and Rayleigh for the PFR wavelengths using the AERONET and WORCC ($OD_{AERONET}$ - OD_{WORCC}).

In Figure 3, the daily mean values of the atmospheric ozone (O_3), nitrogen dioxide (NO_2) and pressure used by both instruments are presented along with their differences. The average difference of the measured pressure is -1.1 ± 0.7 hPa while the difference between the AERONET ozone climatology and the ozone value of OMI overpass used by WORCC is 1.9 ± 9.9 DU. The effect on the AOD retrieval for the PFR wavelengths (Figure 4) is mostly significant for the NO_2 optical depth since it is not accounted for in the WORCC retrieval.

3.2 Annual comparison at OHP

The PFR N26 was functional at OHP in 2022 from May to December while three CIMEL instruments (CIMEL #1143, CIMEL #1265 and CIMEL #1141) were operated during this period namely CIMEL #1143 from May 30 to September 28 CIMEL #1265 on September 29 and CIMEL #1141 from October 04 to December 31. In total 4667 synchronized measurements were compared between PFR N26 and the three CIMEL instruments in the period from May to December 2022. The comparison results are presented in Table 2. The percentage of AOD differences within the WMO uncertainty limits are above 99% for all wavelengths above 440 nm and above 80% for all wavelengths except 340 nm. The

correlation coefficient was found to be greater than 0.9 for all compared wavelengths for the CIMEL instruments. Figure 5 presents the time series of the AOD differences between the PFR and CIMEL at 7 compared wavelengths. The AOD comparison meets the WMO traceability criteria (represented by the grey shaded area) at all wavelengths longer than 380 nm as is also interpreted from Table 2. Figure 6 presents the frequency distribution of the AOD difference between the PFR and CIMEL. The average AOD difference uncertainty is found to be mostly within 0.02 at all wavelengths longer than 340 nm.

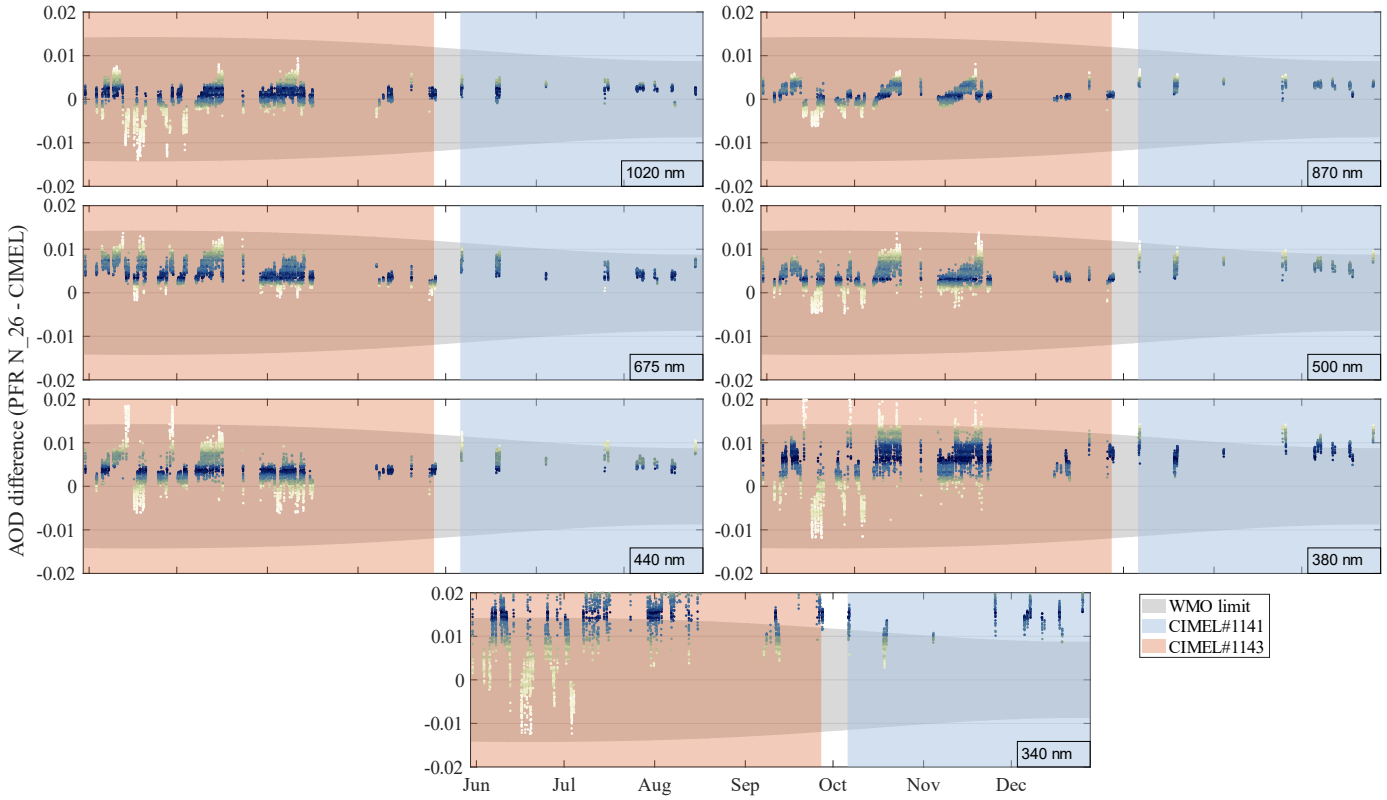

Figure 5: Comparison of PFR N26 and Cimel for 2022 at OHP station.

Table 2: AOD Comparison results of PFR and Cimel at OHP in 2022.

	AOD Difference				AOD linear regression results				
Exact wavelength (nm)	Median	5th percentile	95th percentile	within WMO limits (%)	Slope	Intercept ($x10^{-3}$)	Slope Uncertainty ($x10^{-3}$)	Intercept Uncertainty ($x10^{-3}$)	Correlation Coeff.
1020.0	0.997	-0.009	0.006	99	1.039	-2.921	0.860	0.061	0.997
861.6	0.998	-0.004	0.005	100	1.021	-3.064	0.736	0.059	0.998
675.0	0.992	0.001	0.011	100	0.996	-6.127	0.752	0.076	0.992
500.5	0.998	-0.002	0.010	99	1.009	-5.330	0.594	0.082	0.998
440.0	0.996	-0.003	0.015	94	1.016	-7.215	0.650	0.107	0.996
380.0	0.996	-0.007	0.021	83	1.019	-7.235	0.596	0.117	0.996
340.0	0.995	-0.006	0.043	25	0.974	-10.777	0.855	0.194	0.995

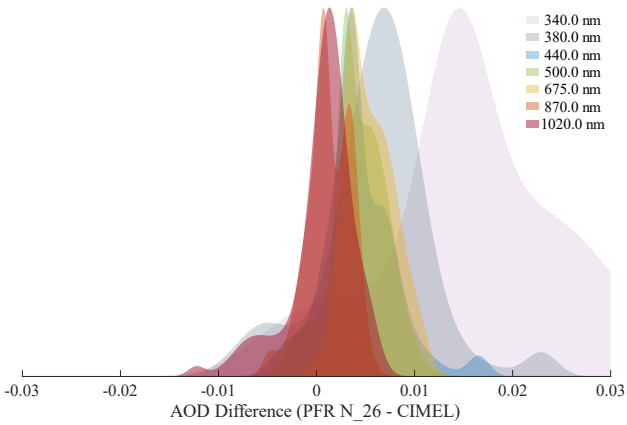

Figure 6: Frequency distribution of PFR and Cimel AOD difference.

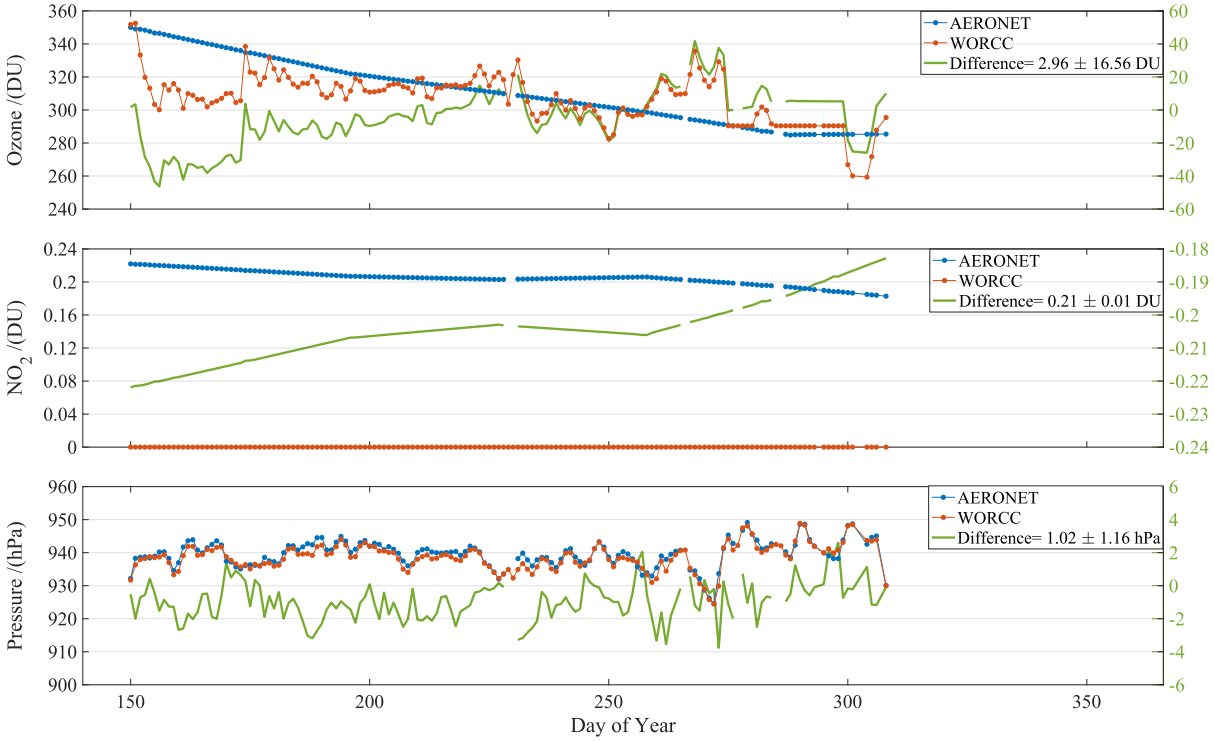

Figure 7: Daily mean ozone, NO_2 and pressure values used for the AOD retrievals for PFR (WORCC) and Cimel (AERONET) at OHP and the right axis and green lines shows their differences.

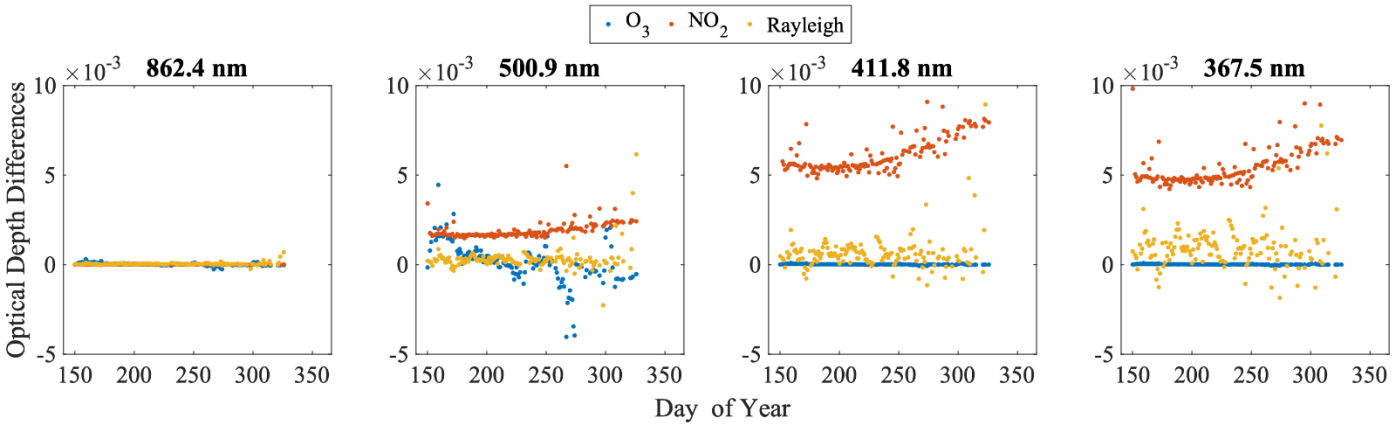

Figure 8: Differences in the optical depth of O_3, NO_2, and Rayleigh for the PFR wavelengths using the AERONET and WORCC ($OD_{AERONET}$ - OD_{WORCC}).

Figure 7 presents the daily mean values of the atmospheric ozone (O_3), nitrogen dioxide (NO_2) and pressure used by PFR and Cimel instruments along with their corresponding differences at OHP station. The average difference of the measured pressure is 1.02 ± 1.16 hPa while the difference between the AERONET ozone climatology and the ozone value of OMI overpass used by WORCC is 2.96 ± 16.56 DU. Figure 8 presents their effect on the AOD retrieval for the PFR wavelengths which is mostly significant for the NO_2 optical depth since it is not accounted for in the WORCC retrieval. The optical depth differences are more pronounced for NO_2 at lower wavelengths.

3.3 Annual comparison at VLD

The PFR N14 was functional at VLD in 2022 from June to December and only one CIMEL instrument (CIMEL #942) was functional during this period. In total 127 days and 9181 synchronized measurements were compared between PFR N14 and CIMEL #942 in the period from June to December 2022. The comparison results are presented in Table 3. The percentage of AOD differences within the WMO uncertainty limits are mostly above 99% for all wavelengths above 440 nm and above 90% for all wavelengths except 340 nm. The correlation coefficient was found to be greater than 0.99 for all compared wavelengths for the CIMEL instrument. Figure 9 presents the time series of the AOD differences between the PFR and CIMEL at 7 compared wavelengths. The AOD comparison meets the WMO traceability criteria (represented by the dark shaded area) at all wavelengths longer than 340 nm as is also interpreted from Table 3. Figure 10 presents the frequency distribution of the AOD difference between the PFR and CIMEL #942. The average AOD difference uncertainty is found to be within 0.02 at all wavelengths longer than 340 nm and within 0.03 at 340.

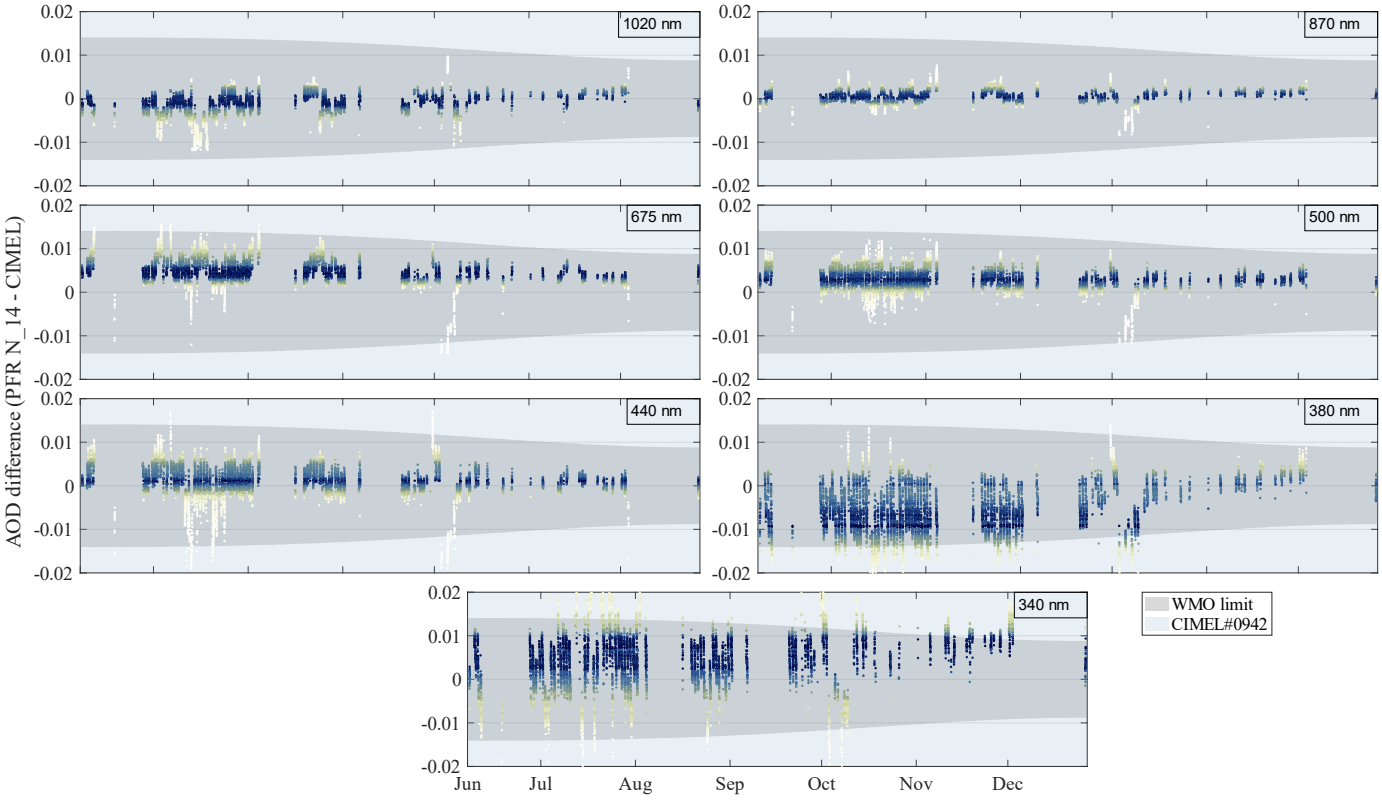

Figure 9: Comparison of PFR N14 and CIMEL#942 for 2022 at VLD station.

Table 3: AOD Comparison results of PFR and CIMEL operated at VLD in 2022.

	AOD Difference				AOD linear regression results				
Exact wavelength (nm)	Median	5th percentile	95th percentile	within WMO limits (%)	Slope	Intercept ($x10^{-3}$)	Slope Uncertainty	Intercept Uncertainty ($x10^{-3}$)	Correlation Coeff.
1020.0	-0.001	-0.009	0.003	99	1.041	-0.679	0.384	0.032	0.998
861.6	0.001	-0.002	0.004	100	1.010	-1.239	0.262	0.024	0.998
675.0	0.005	0.000	0.012	98	0.981	-4.970	0.384	0.043	0.999
500.5	0.003	-0.003	0.008	100	1.000	-3.608	0.284	0.044	0.999
440.0	0.002	-0.010	0.009	97	1.006	-4.363	0.376	0.066	0.998
380.0	-0.006	-0.017	0.006	91	1.029	2.364	0.415	0.084	0.999
340.0	0.005	-0.010	0.028	78	1.005	-3.978	0.438	0.097	0.999

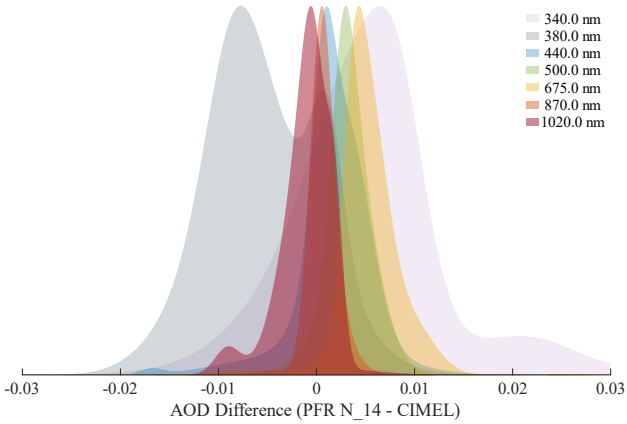

Figure 10: Frequency distribution of PFR and CIMEL AOD difference.

The effect of NO_2 on the AOD retrieval for the PFR wavelengths is presented in Table 4. NO_2 optical depth is not accounted for in the WORCC retrieval. When the NO_2 is accounted for using AERONET climatology, the comparison results improved for wavelengths larger than 500 nm and 340 nm. While at 440 nm and 380 nm, the results were found to deteriorate for VLD station.

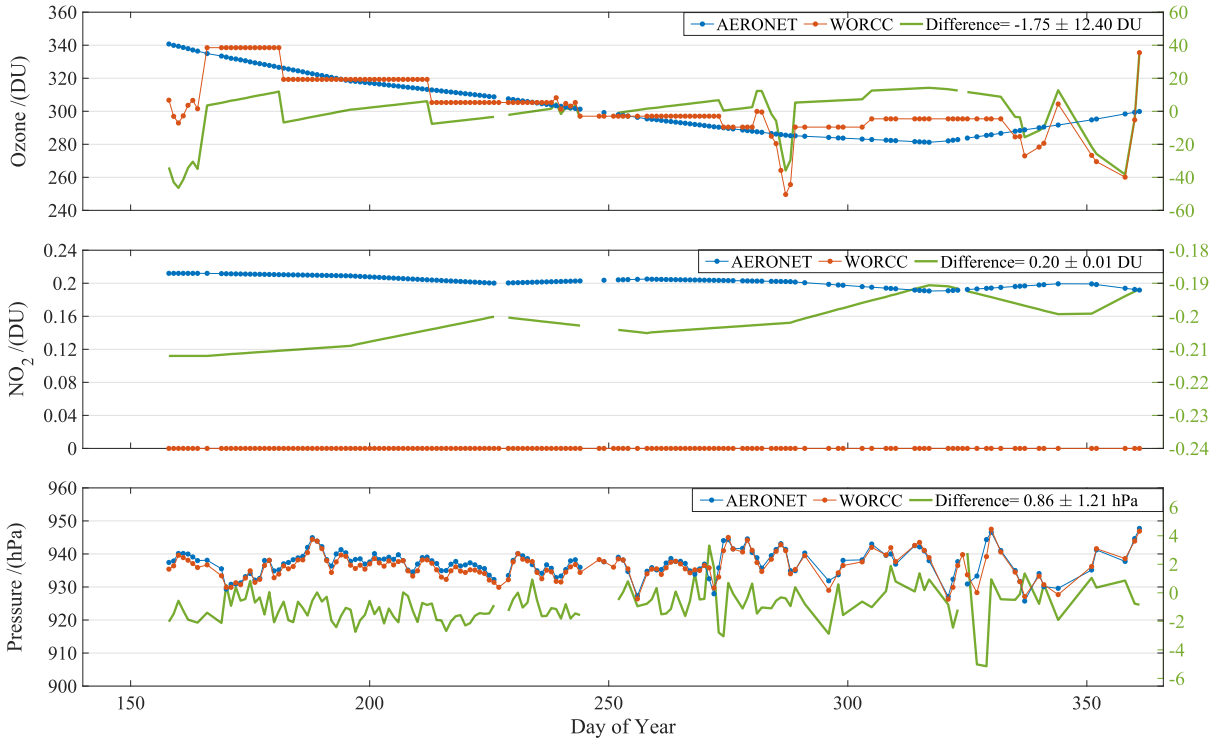

Figure 11: Daily mean ozone, NO_2 and pressure values used for the AOD retrievals for PFR (WORCC) and CIMEL (AERONET) and the right axis and green lines shows their differences (CIMEL-PFR).

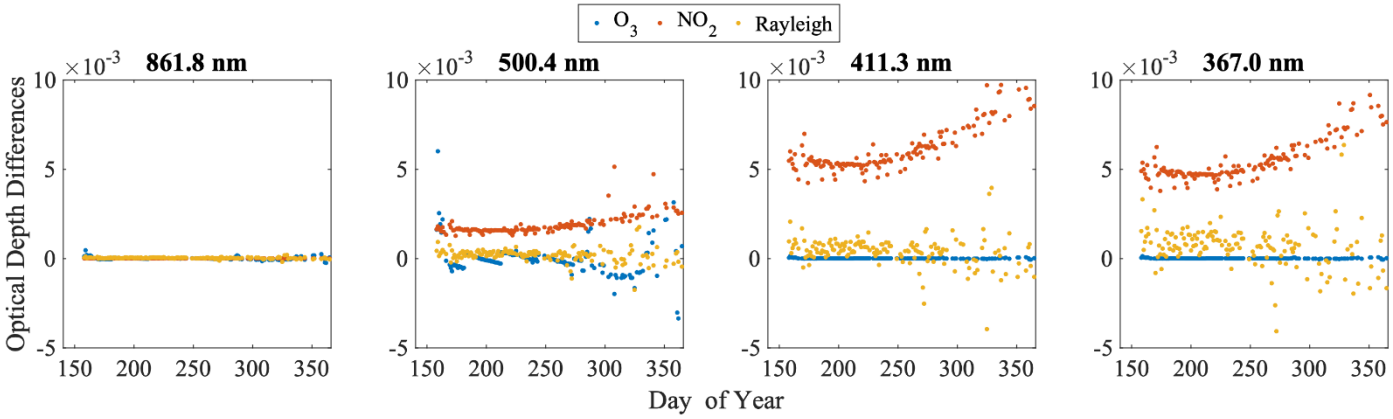

Figure 12: Differences in the optical depth of O_3, NO_2, and Rayleigh for the PFR wavelengths using the AERONET and WORCC ($OD_{AERONET}$ - OD_{WORCC}).

Figure 11 presents the daily mean values of the atmospheric ozone (O_3), nitrogen dioxide (NO_2) and pressure used by PFR and CIMEL instruments along with their corresponding differences at OHP station. The average difference of the measured pressure is 0.86 ± 1.21 hPa while the difference between the AERONET ozone climatology and the ozone value of OMI overpass used by WORCC is 1.75 ± 12.40 DU. Figure 8 presents their effect on the AOD retrieval for the PFR wavelengths which is mostly significant for the NO_2 optical depth since it is not accounted for in the WORCC retrieval. The optical depth differences are more pronounced for NO_2 at lower wavelengths.

4. Conclusions

This annual report presents the comparison of the AOD measurements of PFRs installed at the three CARS-ACTRIS stations of IZO-Spain, OHP-France and VLD-Spain with the CIMEL instruments. The AOD comparison between the PFR-98-N-010 and master CIMEL#1089 for IZO during 2022 showed an excellent agreement between the retrievals. The NO_2 climatology should be taken into account in order for the AOD differences to reflect possible differences in the calibration procedures of the networks. According to the WMO traceability criteria, Cimel#1089 AOD retrievals at 340 nm, 380 nm, 440 nm, 500 nm, 675 nm, 870 nm and 1020 nm are traceable to WORCC and to the WMO AOD reference, since more than 95% of the differences are within ±(0.005+0.001/airmass) when accounting for the NO_2 absorption. For OHP station, the annual comparison of PFR_N26 with CIMEL#1143 and CIMEL#1141 AOD showed good agreement for all wavelengths longer than 380 nm and the AOD difference uncertainty was mostly within 0.02 at all wavelengths longer than 340 nm. The comparisons at VLD were traceable to the WMO uncertainty limits with the AOD differences mostly above 99% for all wavelengths above 440 nm and above 90% for all wavelengths except 340 nm and the average AOD difference uncertainty was found to be within 0.02 at all wavelengths longer than 340 nm and within 0.03 at 340. The analysis of the effect of pressure, ozone and NO_2 on AOD retrievals showed that for all the three stations, the effect was mostly significant for the NO_2 optical depth since it is not accounted for in the WORCC retrieval.

References

Kazadzis, S., Kouremeti, N., Nyeki, S., Gro ̈bner, J., Wehrli, C., 2018. The world optical depth research and calibration center (worcc) quality assurance and quality control of gaw-pfr aod measurements. Geoscientific Instrumentation, Methods and Data Systems 7, 39–53. URL: https://gi.copernicus.org/articles/7/39/2018/, doi:10.5194/gi-7-39-2018.