Annual Report 2021: OHP/France and (IZO) Tenerife/Spain

ACTRIS Annual Report 2021

Observatoire de Haute-Provence (OHP)/France and Tenerife (IZO)/Spain

(January-December 2021)

Prepared by

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

Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center

Abstract

PFR instruments, designed 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 measurements of AOD. Under ACTRIS-CARS (Center for aerosol remote sensing), 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 Precision Filter Radiometer (PFR) was installed at OHP/France and the Tenerife/Spain (IZO) based infrastructure (PFR/tracking system) has been updated/upgraded. This annual report presents the aerosol optical depth (AOD) comparisons at seven wavelengths between 340 nm and 1020 nm and the retrieved Ångström Exponent between PFR and Cimel instruments at the ACTRIS stations of OHP/France and IZO/Spain as well as some results from the Fifth Filter Radiometer Campaign (FRC-V) held in October 2021.

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 380 nm which was reduced to 88% for 340 nm, while the correlation coefficient was higher than 0.999 at all compared wavelengths. The comparison of the daily mean pressure values used by the PFR and Cimel instruments showed an average difference of 1.23 ± 0.83 hPa, while the daily mean difference between the AERONET ozone climatology and the ozone value of OMI overpass used by WORCC was 1.5 ± 14.90 DU. It was observed that the effect of NO_2 optical depth on the AOD retrieval for the PFR wavelengths (not accounted for in the WORCC retrieval), using the AERONET O_3 and NO_2 climatology showed that the observed offsets showed negligible changes. The Ångström Exponent comparison between PFR (AE 367-862 nm) and Cimel (AE 440-870 nm) showed a correlation of 0.942 and the percentage of their differences within ±0.1 and between 0.1 and 0.2 were found to be $approximately$ 69% and $approximately$ 22%, respectively.

For OHP station, the annual comparison of PFR AOD with Cimel AOD showed that the percentage of AOD differences within the WMO uncertainty limits are mostly above 99% for all wavelengths longer than 380 nm while it is reduced to 80% for 380 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 is found to be within 0.01 at all wavelengths longer than 440 nm and within 0.02 at 380 nm for the two Cimel reference instruments that operated at OHP in 2021. The average difference between the daily mean measured pressures used by PFR and CIMEL instruments respectively was 0.13 ± 2.10 hPa while the difference between the AERONET ozone climatology and the ozone value of OMI overpass used by WORCC was 5.7 ± 21.4 DU. When the NO_2 is accounted for using the AERONET climatology, the effect on the comparison results were non negligible but relatively low (up to 0.005 in AOD) for wavelengths shorter than 675 nm, however, when the AERONET O_3 and NO_2 climatology was used, the observed offsets did not show any more significant changes. The Ångström Exponent comparison between PFR (AE 367-862 nm) and Cimel (AE 440-870 nm) showed a correlation of 0.837 and the percentage of their differences within 0.1 and between 0.1 and 0.2 were found to be approximately 65% and $a$pproxiametly 29%, respectively.

The FRC-V results include the comparison of the four Cimel instruments with the PFR-TRIAD at six wavelengths between 380 nm and 1020 nm. The comparisons were found to be within the WMO limit and the correlation was found to be above 0.99 for all the four instruments at all wavelengths.

1. Introduction

PMOD/WRC maintains the world reference AOD standards/triad of precision filter radiometers (PFR) being the Central Calibration Laboratory for aerosol optical depth under the WMO's Global Atmosphere Watch Program (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 WORCC and annually reporting on the AOD traceability of all CARS-ACTRIS calibrated sun-photometers at the three calibration sites to WORCC.

Izaña 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.

The Fifth Filter Radiometer Comparison (FRC-V), which was delayed for one year due to COVID-19 pandemic, was held from September 27 to October 25, 2021, at PMOD/WRC. PMOD/WRC (46° 49' N, 9° 51' E, 1590 m above sea level) is situated in Davos, Switzerland where in autumn the solar observations are limited to zenith angles smaller than about 78° (from about 7:15 to 16:15 hours CET) and the monthly average sunshine duration in September and October is 173 and 156 hours, respectively with the average AOD being 0.053 at 500 nm. During the FRC-V comparison period, there were eleven days with at least 4 hours of sunshine which were used for comparing the participating instruments. Instruments from different AOD global networks participated in the campaign and three reference instruments from the CARS-ACTRIS (Aerosol, Clouds and Trace Gases Research Infrastructure) facility also participated. The aim of the whole activity was to initiate action towards homogenization of the AOD measurements on a global scale. The comparison protocol was formulated according to the WMO recommendations. Measurements of each instrument were compared to the WORCC Precision Filter Radiometer (PFR) reference triad. The three CIMEL sun and sky scanning radiometers operated within AERONET-Europe-ACTRIS network and one CIMEL operated within AERONET-Europe network were used in this analysis whose details are provided in Table A1.

2. Activities

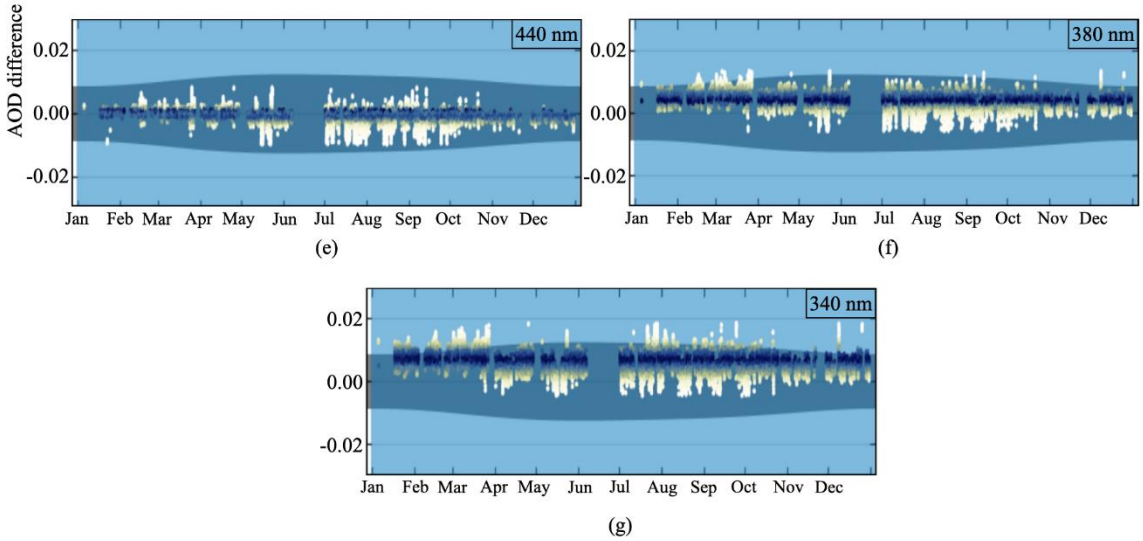
- A new PFR was installed at CARS site of OHP/France which is functional since 2020 (Picture 1a).
- Hardware and software updates and upgrades have been performed at the IZO, site, including a new PFR calibrated instrument, and solar tracker software and hardware updates and improvements (Picture 1b).
- FRC-V held in 2021 which provided an opportunity to compare the measurements from different networks with an aim for harmonization.
- This annual report provides the AOD comparison analysis of the two CARS/ACTRIS sites (OHP, France and IZO, Spain) with the Cimel instruments that operated at these sites in 2021 as well as the results from the FRC-V.

Picture 1: a) Ohp, France ACTRIS calibration site, b) IZO, Spain ACTRIS calibration site

3. Results and Discussion

3.1 Annual comparison at IZO

The operation of the PFR during 2021 was within the WORCC quality management limits, 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 22882 synchronized measurements, within ±1min, were compared in the period from January,1 to December, 31, 2021. 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 380 nm. The agreement is reduced to 88.5% for 340 nm, however accounting for the Angstrom extrapolation uncertainty the differences are within the uncertainty of the PFR AOD. The correlation coefficient for all compared wavelengths is higher than 0.999. 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 3rd degree Gaussian distribution and is presented in Figure 2a. To investigate the origin of the small offset of 500 nm (0.003), 675 nm (0.002) and 380 nm (0.004) as well as the offset at 340 nm (0.007), the contribution of the differences in trace gases concentrations and pressure used in AOD retrieval of PFR and Cimel was investigated.



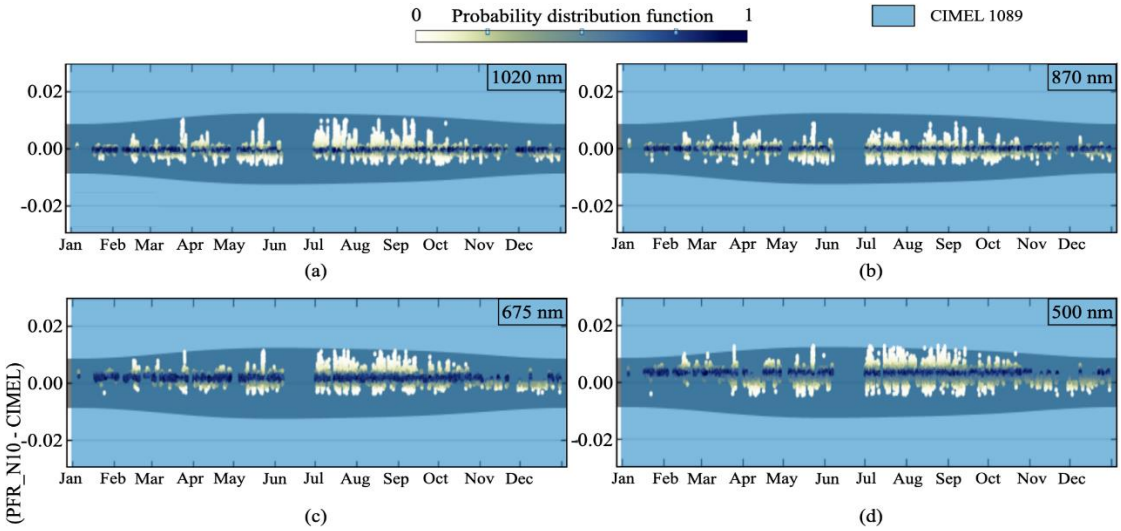


Figure 1: Time series of AOD differences (PFR-Cimel) at 7 Cimel wavelengths (colored dots). The dark gray area shows the WMO limits at local noon of each day. The colors of the dots follow the probability distribution function of the AOD differences.

Table 1: AOD Comparison results of PFR and Cimel operated at Izaña observatory in 2021.

	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.
IZO: PFR_N10 and Cimel#1089									
1020.0	0.000	-0.002	0.003	100.0	0.99	0.60	0.13	0.01	1.000
861.6	0.000	-0.002	0.002	100.0	1.01	0.01	0.12	0.01	1.000
675.0	0.002	-0.001	0.006	100.0	1.00	-1.81	0.17	0.01	1.000
500.5	0.003	-0.001	0.007	99.9	1.00	-2.86	0.21	0.02	0.999
440.0	0.000	-0.004	0.002	99.9	1.02	-0.43	0.15	0.01	1.000
380.0	0.004	0.000	0.009	99.2	1.02	-5.65	0.20	0.02	1.000
340.0	0.007	0.001	0.012	88.5	1.02	-8.14	0.26	0.03	0.999

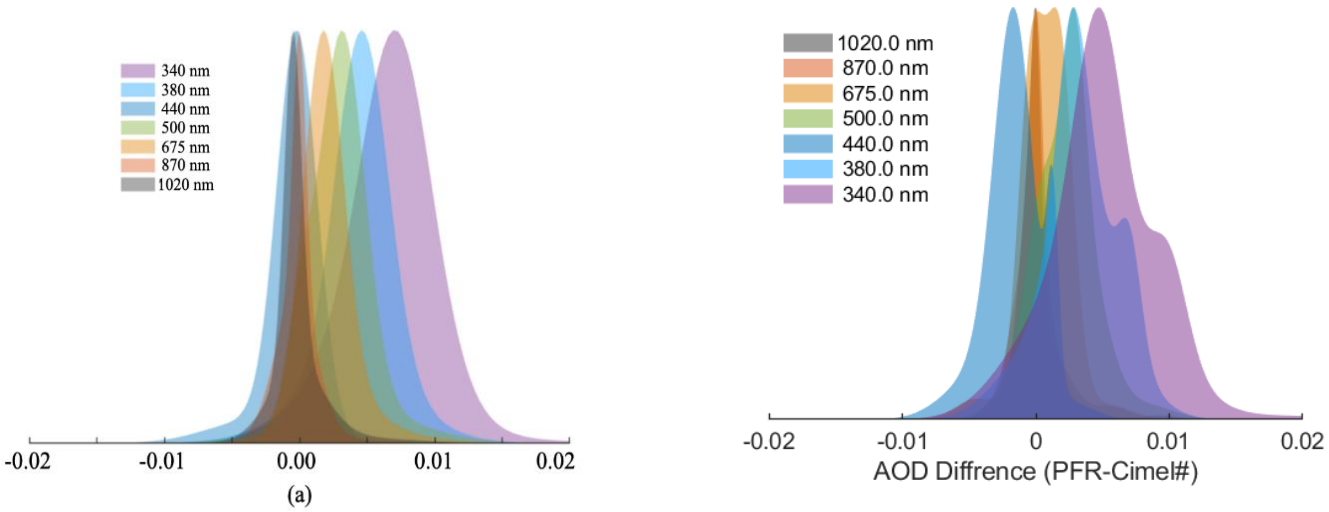


Figure 2: Normalized to maximum distribution of AOD differences at 7 Cimel wavelengths (a) WORCC trace gases and (b) including AERONET NO_2 climatology.

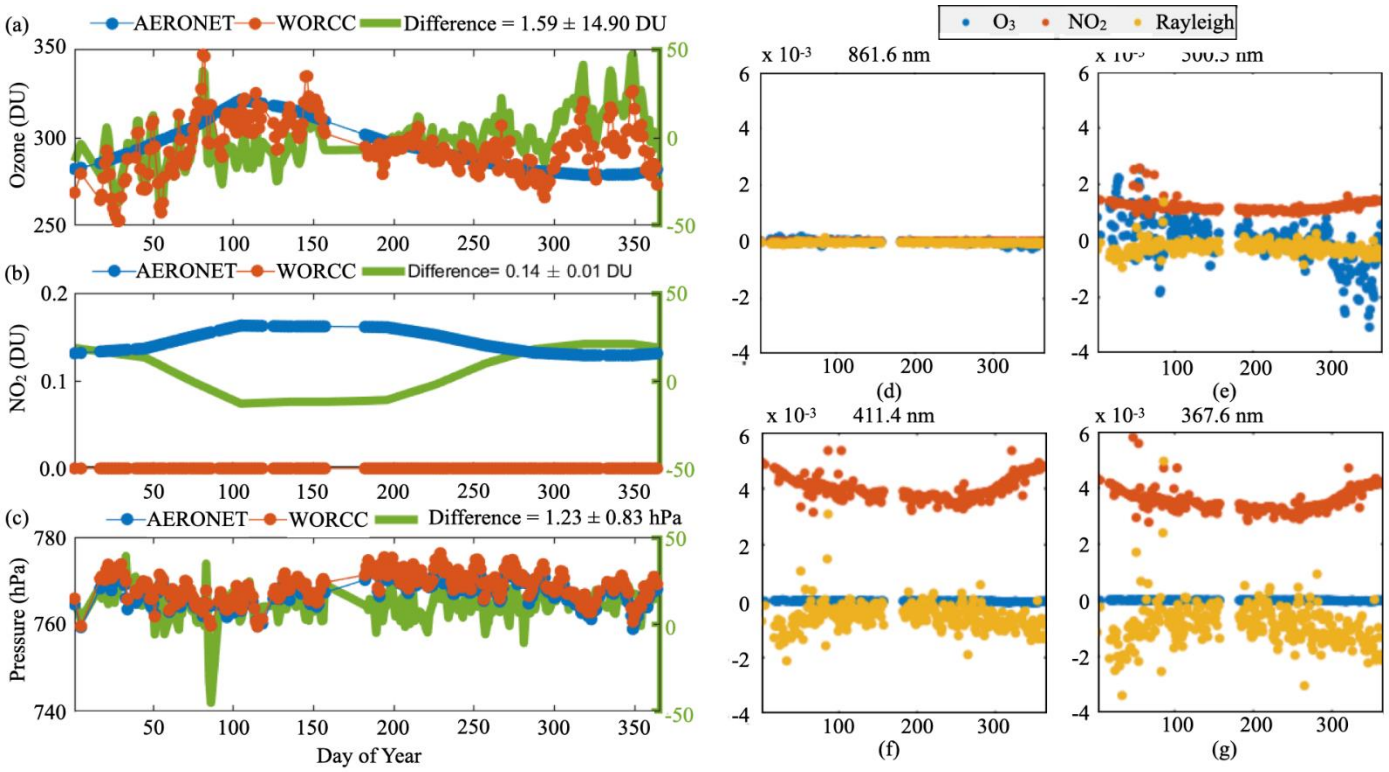


Figure 3: Daily mean (a) ozone, (b) NO_2 and (c) pressure values used for the AOD retrievals for PFR (WORCC) and Cimel (AERONET) and the right axis and green lines shows their differences (CIMEL-PFR). (d-g) Differences in the optical depth of O_3, NO_2, and Rayleigh for the PFR wavelengths using the 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 1.23 ± 0.83 hPa while the difference between the AERONET ozone climatology and the ozone value of OMI overpass used by WORCC is 1.5 ± 14.9 DU. The effect on the AOD retrieval for the PFR wavelengths (Figure 3) is mostly significant for the NO_2 optical depth since it is not accounted for in the WORCC retrieval. AOD median differences between Cimel and PFR for 2021 for 3 different options for the concentration of O_3, NO_2 and atmospheric pressure is presented in Table 2. The effect on the comparison results when accounting for the NO_2 using the AERONET climatology is significant for wavelengths shorter than 675 nm, reducing the AOD differences by 0.003, 0.002, 0.002 and 0.001 at 340 nm, 380 nm, 440 nm and 500 nm respectively. While using the AERONET O_3 and NO_2 climatology the observed offsets do not show any more significant changes. The spread of the AOD differences is unaffected by the small differences in O_3 and pressure and the low NO_2 values observed at Izaña.

Table 2: AOD median differences between Cimel and PFR at IZO in 2021 for 3 different options for the concentration of O3, NO2 and atmospheric pressure.

Wavelength (nm)	WORCC O_3 and Pressure Values			WORCC O_3 and Pressure Values NO_2 AERONET Climatology			WORCC Pressure Values O_3, NO_2 AERONET Climatology		
	Median	Spread (k=2)	% within WMO limits	Median	Spread (k=2)	% within WMO limits	Median	Spread (k=2)	% within WMO limits
1020	0.000	0.003	100.0	0.000	0.003	100.0	0.000	0.003	100.0
870	0.000	0.002	100.0	0.000	0.002	100.0	0.000	0.002	100.0
675	0.002	0.003	100.0	0.002	0.003	100.0	0.002	0.003	100.0
500	0.003	0.004	99.9	0.002	0.004	100.0	0.002	0.004	100.0

440	0.000	0.003	99.9	-0.002	0.003	99.4	-0.003	0.003	99.3
380	0.004	0.004	99.2	0.003	0.004	99.9	0.002	0.005	99.9
340	0.007	0.006	88.5	0.004	0.006	96.2	0.004	0.006	96.5

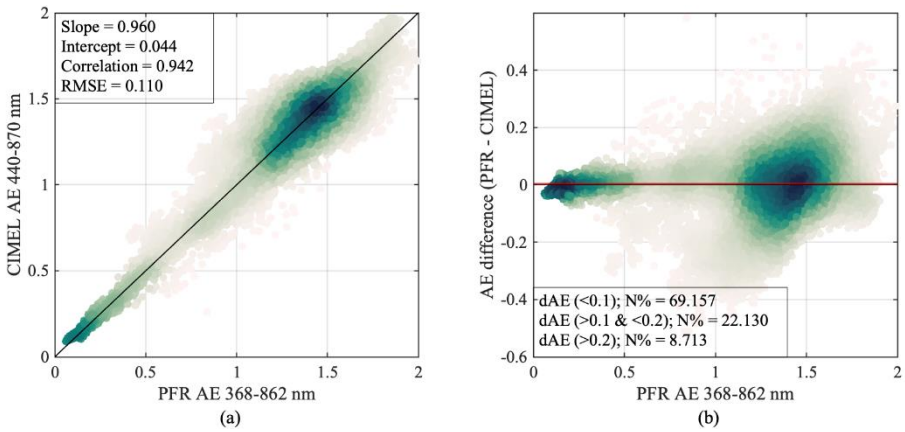


Figure 4: (a) Comparison of Ångström Exponent of PFR (367-862 nm) and Cimel (440-870 nm) and (b) variation of PRF and Cimel AE difference with PFR AE for IZO. dAE is the difference in AE and N% represent the percentage of data as out of the total data.

Figure 4a presents the PFR AE (367-862 nm) which is compared with the Cimel AE (440-870 nm) for IZO station and the correlation between them is found to be 0.942 with the RMSE being 0.110. Figure 4b presents the variation of the difference between PFR and Cimel AE as a function of the PFR AE. It can be observed that the percentage of the differences within 0.1 is ~ 69% and that between 0.1 and 0.2 is ~ 22%. While percentage of the differences beyond 0.2 is about ~ 9%.

3.2 Annual comparison at OHP

The PFR N14 was functional at OHP in 2021 from January 01 to September 24 while two Cimel instruments (Cimel#1141 and Cimel#1143) were operated during this period namely Cimel#1141 from January 01 to April 20 and after September 21 and Cimel#1143 from April 21 to September 20. PFR N14 was calibrated on August 29, 2018 at PMOD/WRC before installation at OHP in 2020 and the calibration was done with respect to the PFR reference triad. In total 4629 synchronized measurements were compared between PFR N14 and the two Cimel instruments in the period from January to September 2021. The comparison results are presented in Table 2 based on the two Cimel instruments. The percentage of AOD differences within the WMO uncertainty limits are above 99% for all wavelengths above 380 nm for Cimel#1141 while it is reduced to 80% for 380 nm. For Cimel#1143, it is above 98% for all wavelengths above 440 nm and reduces to 85% for 380 nm. While at 340 nm, the agreements are found to be below 50% for both the Cimels. 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 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 3. The data gap between February 23 to April 7 results from cleaning issues due to scarce visits to the station during the COVID related restrictions. This led to careful filtering and elimination of a number of data on days with weak signal due to deposition of dirt on the PFR instrument. The PFR was cleaned after the first week of April after which the signals as well as the comparisons are good. Figure 6 presents the frequency distribution of the AOD difference between the PFR and Cimel#1141 and Cimel#1143. The average AOD

difference uncertainty is found to be within 0.01 at all wavelengths longer than 440 nm and within 0.02 at 380 nm for both the Cimels.

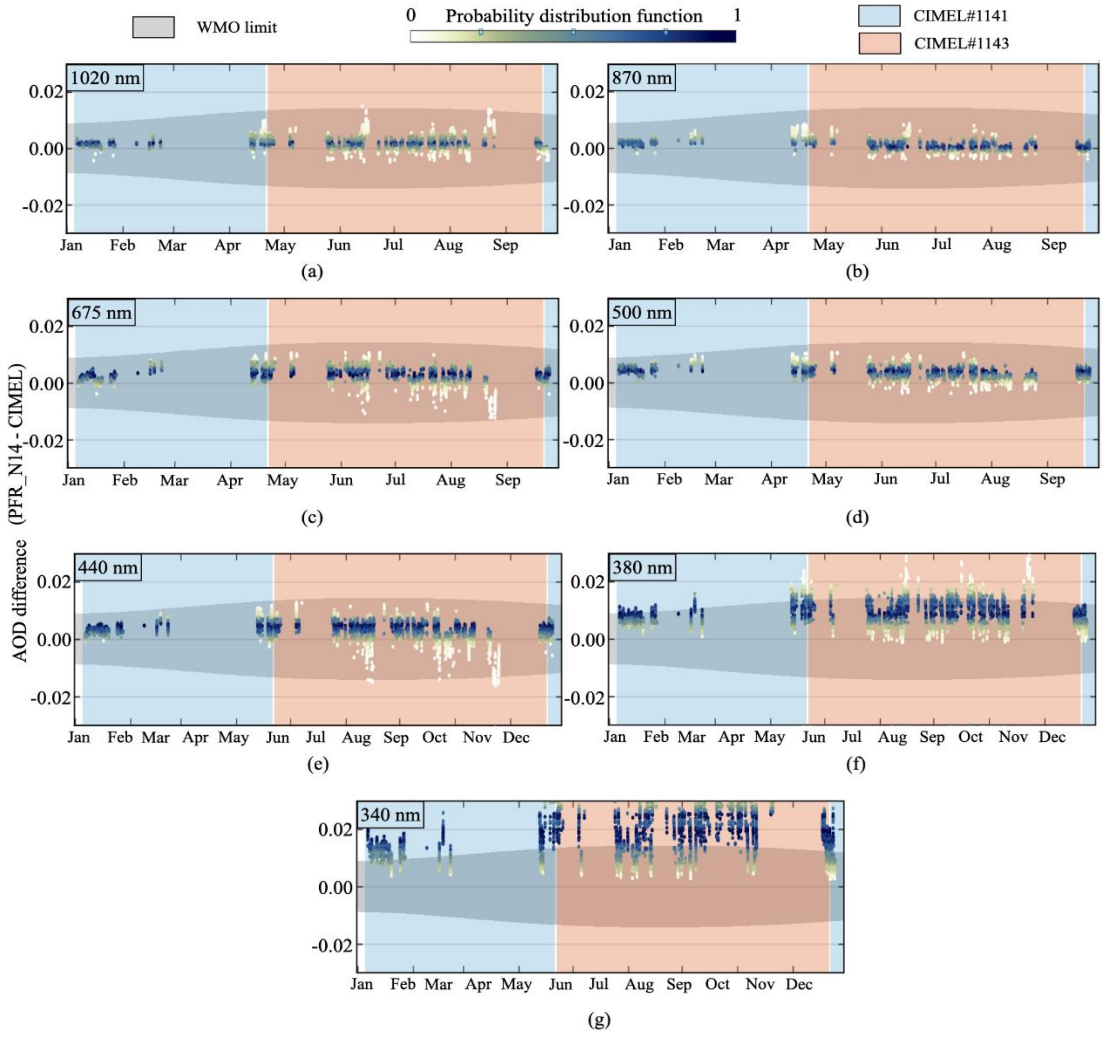


Figure 5: Comparison of PFR N14 and Cimel#1141 and Cimel#1143 from January to December 2021 at OHP station.

Table 3: AOD Comparison results of PFR and Cimel operated at OHP in 2021.

	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.
OHP: PFR_N14 and Cimel#1141									
1020.0	0.001	-0.002	0.005	99.8	0.962	-0.757	0.0159	0.387	0.979
861.6	0.002	0.000	0.007	100	0.934	-1.129	0.0117	-0.355	0.988
675.0	0.004	0.001	0.007	100	0.963	-2.891	0.0080	0.350	0.994
500.5	0.005	0.002	0.009	99.8	0.997	-5.176	0.0057	0.384	0.997
440.0	0.004	0.001	0.010	99.8	0.991	-3.979	0.0063	0.501	0.997
380.0	0.007	0.001	0.016	80.4	0.988	-6.382	0.0079	0.771	0.995
340.0	0.012	0.003	0.024	21.4	0.957	-8.965	0.0081	0.938	0.994
OHP: PFR_N14 and Cimel#1143									
1020.0	0.002	-0.002	0.006	98.7	1.011	-2.255	0.0050	0.242	0.996
861.6	0.001	-0.002	0.004	99.4	1.014	-1.440	0.0030	0.198	0.998
675.0	0.004	0.001	0.009	98.8	1.008	-4.864	0.0040	0.294	0.997
500.5	0.003	-0.001	0.007	99.0	1.018	-4.974	0.0030	0.309	0.999
440.0	0.004	-0.005	0.009	96.4	1.031	-7.425	0.0020	0.438	0.998
380.0	0.007	-0.006	0.015	85.4	1.030	-10.500	0.0030	0.720	0.997
340.0	0.020	0.003	0.035	13.6	0.967	-13.312	0.0057	1.200	0.992

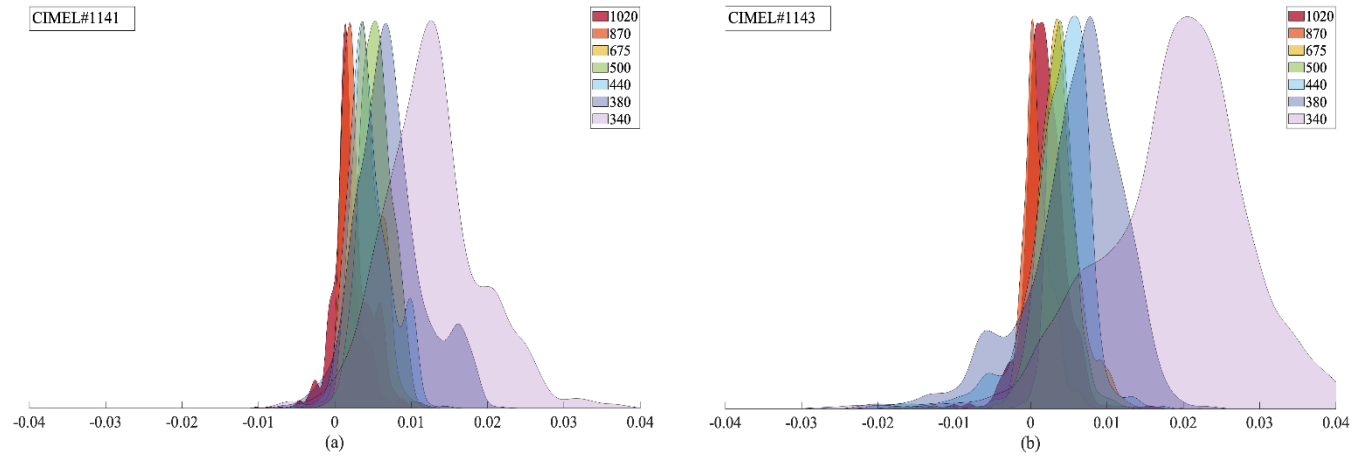


Figure 6: Frequency distribution of PFR and Cimel (a) 1141 and (b) 1143 AOD difference.

Figure 7 (a-c) 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 0.13 ± 2.10 hPa while the difference between the AERONET ozone climatology and the ozone value of OMI overpass used by WORCC is 5.7 ± 21.4 DU. Figure 7 (d-g) presents the 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.

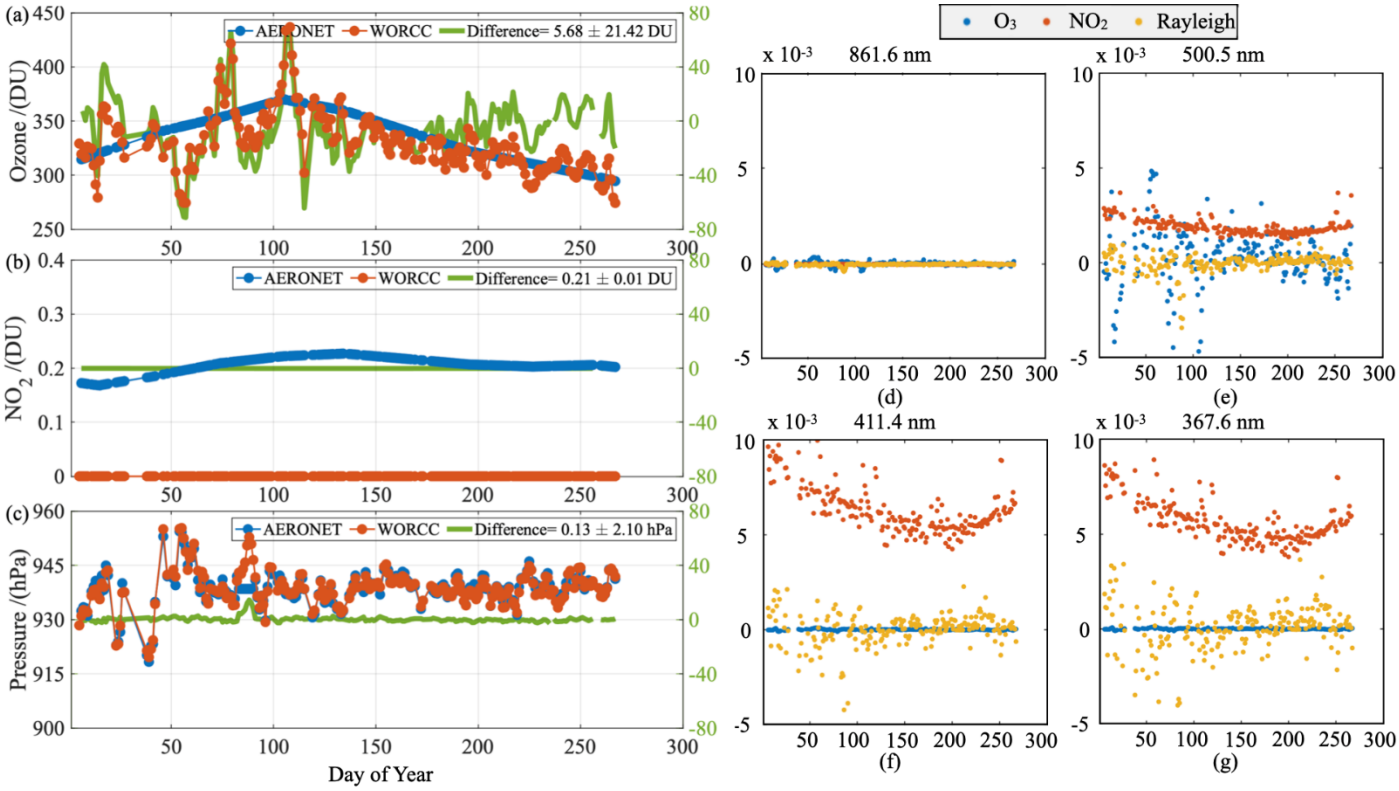


Figure 7: Daily mean (a) ozone, (b) NO_2 and (c) pressure values used for the AOD retrievals for PFR (WORCC) and Cimel (AERONET) and the right axis and green lines shows their differences. (d-g) Differences in the optical depth of O_3, NO_2, and Rayleigh for the PFR wavelengths using the AERONET and WORCC ($OD_{AERONET}$ - OD_{WORCC}).

The effect on the AOD retrieval for the PFR wavelengths (Figure 7 (d-g)) is mostly significant for the NO_2 optical depth since it is not accounted for in the WORCC retrieval. AOD median differences between Cimel and PFR for 2021 for 3 options (1: WORCC O_3 and Pressure Values, 2: WORCC O_3 and Pressure Values with NO_2 AERONET Climatology and 3: WORCC Pressure Values with O_3 and NO_2 AERONET Climatology) are presented in Table 4. When the NO_2 is accounted for using the AERONET climatology, the effect on the comparison results were significant for wavelengths shorter than 675 nm, leading to a reduction in the AOD differences by 0.004, 0.003, 0.002 and 0.001 at 340 nm, 380

nm, 440 nm and 500 nm respectively. However, when the AERONET O_3 and NO_2 climatology was used, the observed offsets do not show any more significant changes.

Table 4: AOD median differences between Cimel and PFR at OHP in 2021 for 3 different options for the concentration of O_3, NO_2 and atmospheric pressure.

Wavelength (nm)	WORCC O_3 and Pressure Values			WORCC O_3 and Pressure Values NO_2 AERONET Climatology			WORCC Pressure Values O_3, NO_2 AERONET Climatology		
	Median	Spread (k=2)	% within WMO limits	Median	Spread (k=2)	% within WMO limits	Median	Spread (k=2)	% within WMO limits
1020	0.002	0.004	99.7	0.002	0.004	99.6	0.003	0.004	99.6
870	0.001	0.003	100	0.001	0.003	100.0	0.001	0.003	100
675	0.003	0.005	99.7	0.003	0.005	99.7	0.003	0.005	99.7
500	0.004	0.004	99.9	0.003	0.004	100.0	0.003	0.004	100
440	0.004	0.006	98.4	0.002	0.006	97.9	0.002	0.006	97.9
380	0.010	0.007	62.7	0.007	0.008	87.0	0.007	0.008	90.5
340	0.020	0.018	7.1	0.016	0.017	20.9	0.016	0.018	23.3

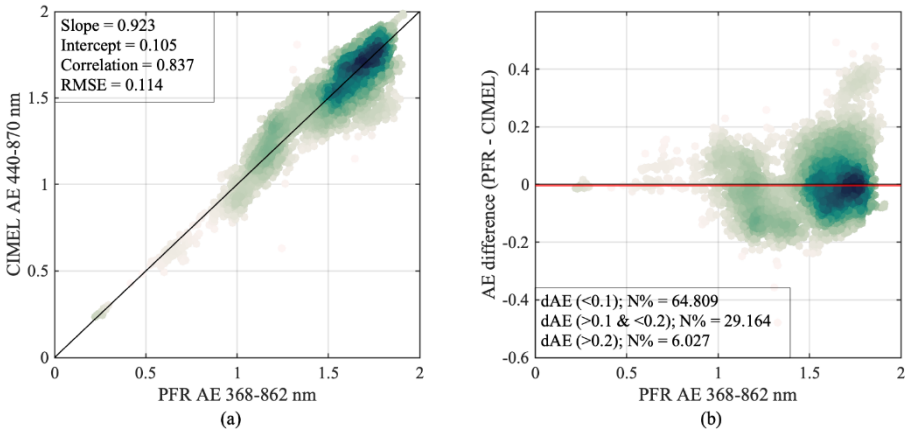


Figure 8: (a) Comparison of Ångström Exponent of PFR and Cimel and (b) variation of PRF and Cimel AE difference with PFR AE. dAE is the difference in AE and N% represents the percentage of data as out of the total data.

Figure 8a presents the PFR AE (367-862 nm) which is compared with the Cimel AE (440-870 nm) and the correlation between them is found to be 0.837 with the RMSE being 0.114. Figure 8b presents the variation of the difference between PFR and Cimel AE as a function of the PFR AE. It can be observed that the percentage of the differences within 0.1 is ~ 65% and that between 0.1 and 0.2 is ~ 29%. While the percentage of differences beyond 0.2 is ~ 6%.

3.3 FRC 2021

During the intercomparison days, AOD at 500 nm varied from 0.02 up to 0.1, which can be considered normal values for the area. Table 5 shows the comparison statistics if the AOD difference during the intercomparison days. The correlation was found to be above 0.99 at all wavelengths for the four Cimel instruments. The detailed comparison result of the four Cimel instruments at six wavelengths between 380 nm and 1020 nm with the PFR-TRIAD are presented in Table 6. The comparisons are found to be within the WMO limit and the correlation is found to be above 0.99 for all the four instruments at all wavelengths.

Table 5: FRC-V inter comparison statistics for four CIMEL instruments.

Wavelength (nm)	368/380	400/440	500 ± 3	865 ± 5
AOD Diff Median ±1σ *(10^{-3})	-2.9 ± 1.1	-2.7 ± 2.4	-5.1 ± 2.2	-1.2 ± 1.1
Correlation Coefficient (min, max)	0.994, 0.998	0.985, 0.999	0.997, 0.999	0.973, 0.998

Table 6: FRC comparison statistics for the four Cimel instruments for each wavelength (380 nm – 1020 nm).

Instrument	Median ±1σ	Percentile (5, 95)	Correlation Coefficient	Linear Fit (Slope, Intercept)	Number of Data	% Within WMO limits
380 nm						
CIM_CH_1270	-0.003 ± 0.001	-0.005, -0.001	0.998	1.025, -0.005	417	100
CIM_UL_1091	-0.003 ± 0.002	-0.005, 0.002	0.995	1.004, -0.003	2336	100
CIM_UV_1	-0.003 ± 0.002	-0.006, -0.001	0.994	1.008, -0.003	1506	100
CIM_IZ_1219	-0.001 ± 0.006	-0.005, 0.002	0.998	1.017, -0.002	2256	100
400 nm						
CIM_CH_1270	+0.000 ± 0.001	-0.001, 0.002	0.999	1.033, -0.001	413	100
CIM_UL_1091	-0.002 ± 0.001	-0.003, 0.001	0.997	1.013, -0.002	2333	100
CIM_UV_1	-0.004 ± 0.002	-0.008, -0.001	0.985	0.968, -0.003	1507	100
CIM_IZ_1219	-0.005 ± 0.002	-0.008, -0.002	0.994	1.013, -0.006	2244	100
500 nm						
CIM_CH_1270	-0.001 ± 0.001	-0.002, -0.000	0.999	1.014, -0.002	415	100
CIM_UL_1091	-0.005 ± 0.001	-0.006, -0.003	0.997	0.984, -0.004	2327	100
CIM_UV_1	-0.006 ± 0.001	-0.007, -0.004	0.997	0.975, -0.005	1505	100
CIM_IZ_1219	-0.006 ± 0.002	-0.007, -0.003	0.998	0.991, -0.005	2244	100
675 nm						
CIM_CH_1270	-0.002 ± 0.001	-0.002, -0.001	0.998	0.971, -0.001	414	100
CIM_UL_1091	-0.003 ± 0.001	-0.005, -0.002	0.996	0.936, -0.002	2333	100
CIM_UV_1	-0.004 ± 0.001	-0.006, -0.002	0.991	0.912, -0.002	1505	100
CIM_IZ_1219	-0.004 ± 0.002	-0.007, -0.003	0.997	0.930, -0.003	2244	100
870 nm						
CIM_CH_1270	+0.000 ± 0.000	-0.001, 0.001	0.996	1.009, 0.000	411	100
CIM_UL_1091	-0.001 ± 0.000	-0.002, 0.000	0.997	0.965, 0.000	2336	100
CIM_UV_1	-0.002 ± 0.001	-0.003, 0.000	0.973	0.931, -0.001	1507	100
CIM_IZ_1219	-0.003 ± 0.001	-0.004, -0.001	0.998	0.955, -0.002	2244	100
1020 nm						
CIM_CH_1270	-0.001 ± 0.001	-0.001, 0.001	0.992	1.045, -0.001	412	100
CIM_UL_1091	+0.000 ± 0.001	0.000, 0.001	0.994	0.997, 0.000	2327	100
CIM_UV_1	-0.000 ± 0.001	-0.002, 0.001	0.963	0.977, 0.000	1505	100
CIM_IZ_1219	-0.001 ± 0.002	-0.002, 0.001	0.997	0.992, -0.001	2244	100

4. Conclusions

This annual report presents the AOD measurements and the retrieved Ångström Exponent as observed by the PFR installed at ACTRIS-CH station of OHP/France and IZO/Spain. The AOD comparison between the PFR-98-N-010 and master Cimel #1089 for IZO during 2021 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_N14 with Cimel#1141 and Cimel#1143 AOD showed good agreement for all wavelengths longer than 380 nm. Similar to IZO, the inclusion of NO_2 climatology into the AOD retrievals significantly improved the comparisons. The FRC-V comparison result between four Cimel instruments and the PFR-TRIAD at six wavelengths between 380 nm and 1020 nm showed excellent agreement with the comparisons being within the WMO limit and the correlation above 0.99.

Appendix

Table A1: Description of CIMEL instruments used for FRC-V

Instrument Name	Network	Institute (Country)
CIM_CH_1	AERONET-Europe-ACTRIS	LOA, University of Lille (France)
CIM_UL_1270	AERONET-Europe	LOA, University of Lille - PMOD/WRC (France/Switzerland)
CIM_UV_1219	AERONET-Europe-ACTRIS	University of Valladolid (Spain)
CIM_IZ_1091	AERONET-Europe-ACTRIS	AEMET, Izaña Atmospheric Research Center (Spain)

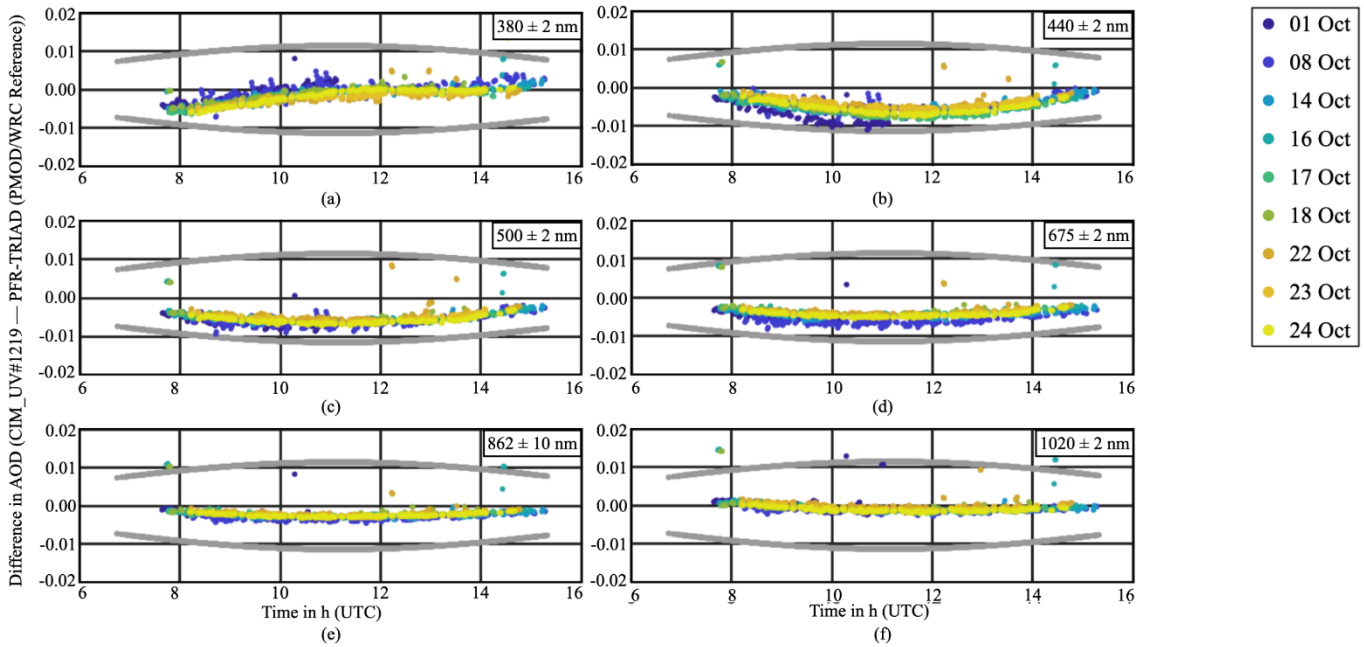


Figure 9: Comparison of AOD of CIM_UV#1219 with PFR TRIAD at (a) 380 nm, (b) 440 nm, (c) 500 nm, (d) 675 nm, (e) 862 nm, and (f) 1020 nm at PMOD/WRC, Davos.

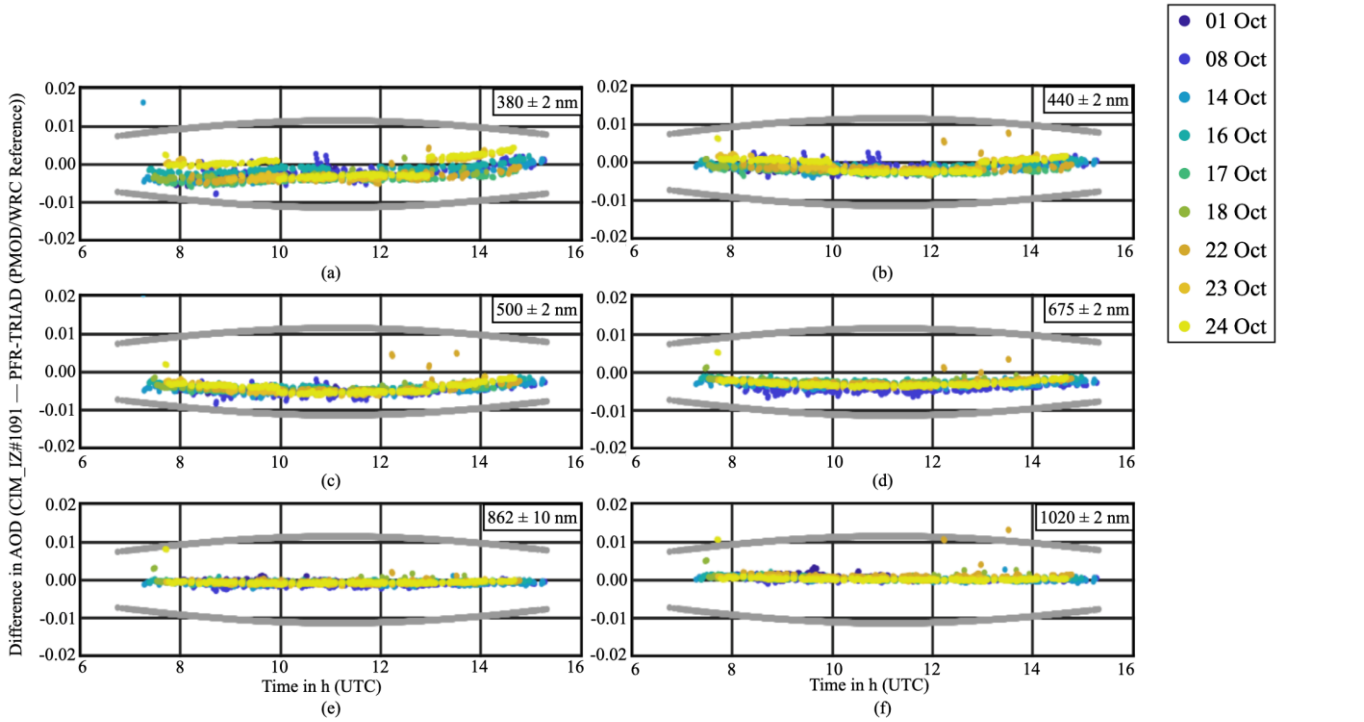


Figure 10: Comparison of AOD of CIM_CH#1 with PFR TRIAD at (a) 380 nm, (b) 440 nm, (c) 500 nm, (d) 675 nm, (e) 862 nm, and (f) 1020 nm at PMOD/WRC, Davos.

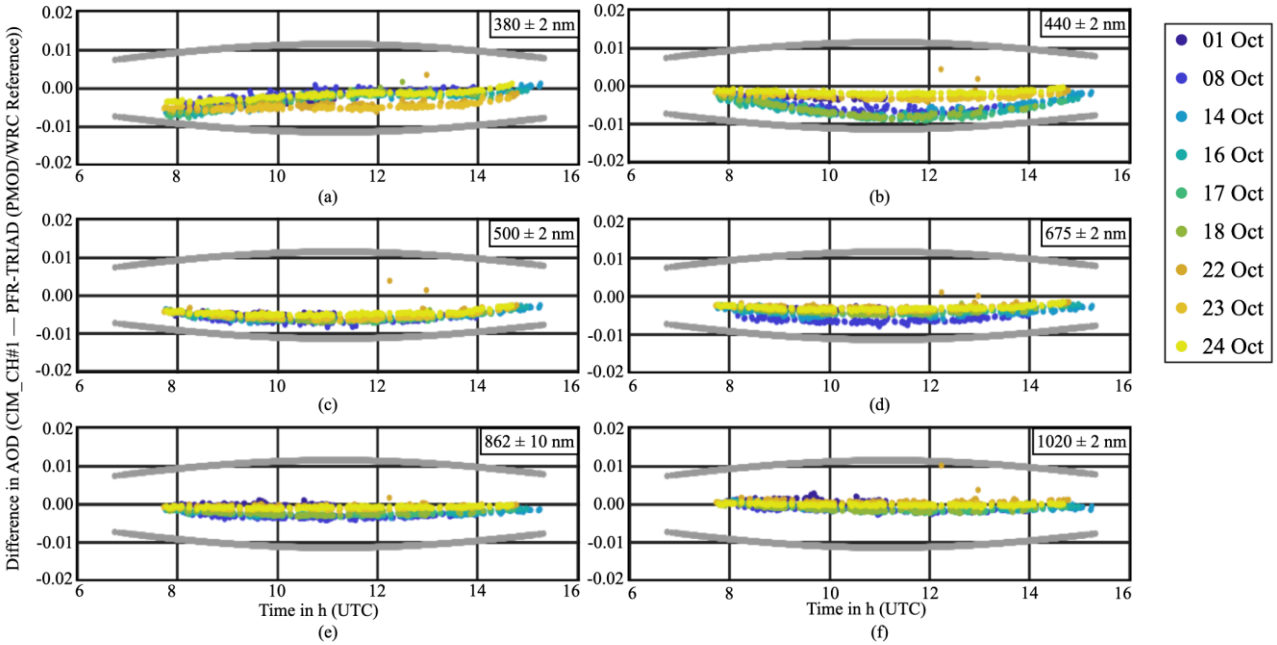


Figure 11: Comparison of AOD of CIM_IZ#1091 with PFR TRIAD at (a) 380 nm, (b) 440 nm, (c) 500 nm, (d) 675 nm, (e) 862 nm, and (f) 1020 nm at PMOD/WRC, Davos.

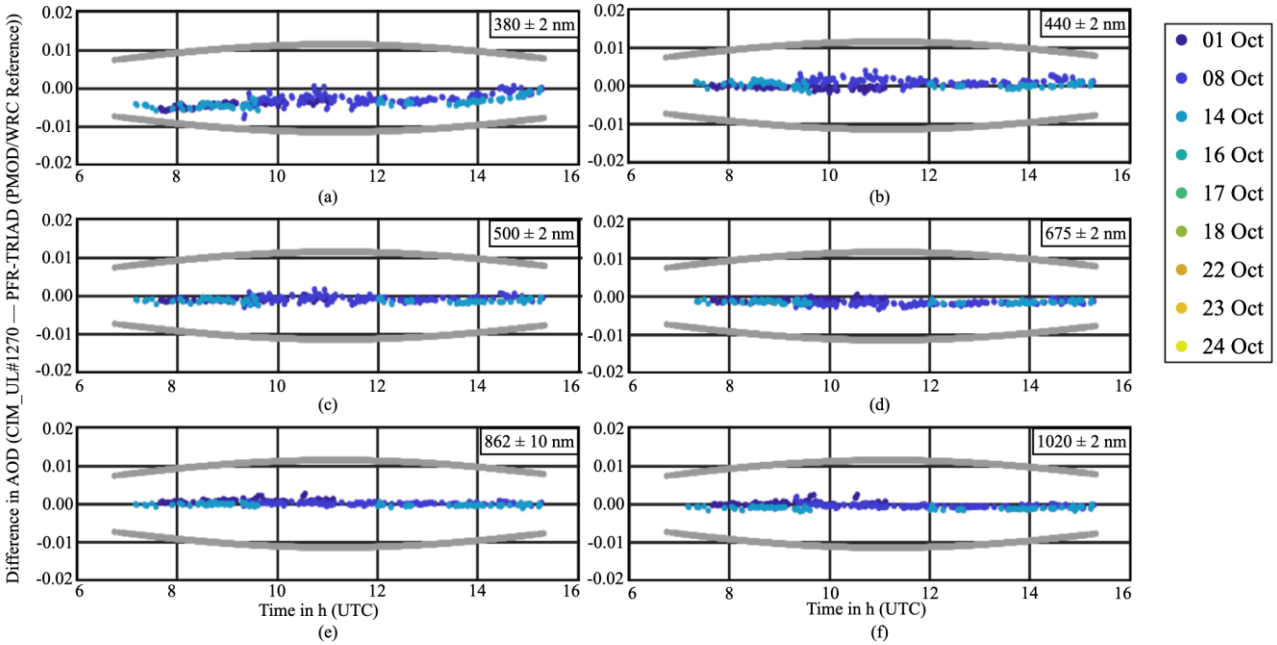


Figure 12: Comparison of AOD of CIM_UL#1271 with PFR TRIAD at (a) 380 nm, (b) 440 nm, (c) 500 nm, (d) 675 nm, (e) 862 nm, and (f) 1020 nm at PMOD/WRC, Davos.

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.