



Supplement of

Intercomparison of aerosol optical depth retrievals from GAW-PFR and SKYNET sun photometer networks and the effect of calibration

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S1. Monthly calibration constants used and AOD differences attributed to calibration differences

Table S1: The monthly calibration constants for all instruments and campaigns from ILP calibration (V_{OIL}) and calibration transfer from PFR (V_{OTR}) in $\mu A \times 10^{-4}$ with their % differences at 500 nm and 870 nm.

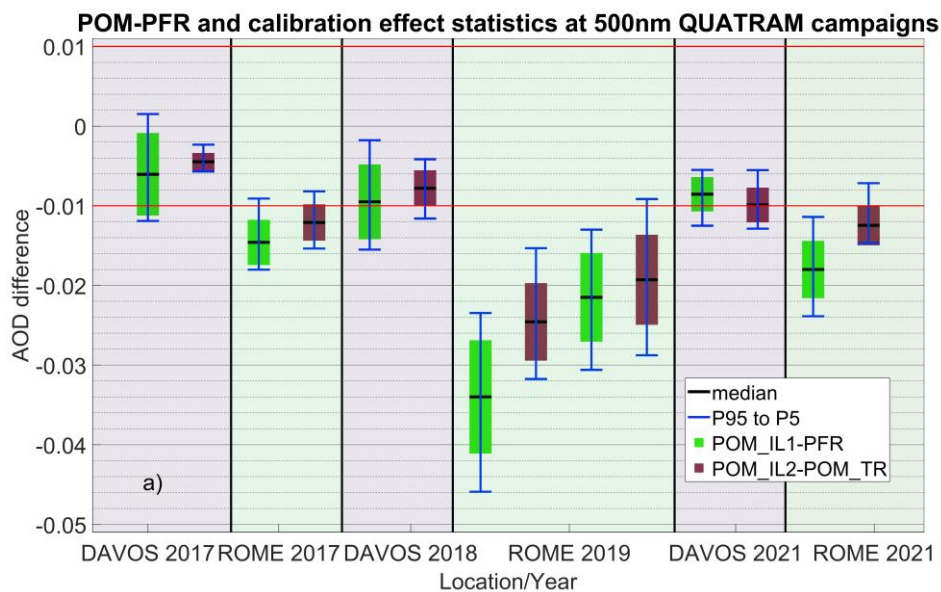
Instrument	Location	Year	Month	V_{OIL500}	V_{OIL870}	V_{OTR500}	V_{OTR870}	% difference 500 nm	% difference 870 nm
POMVDV	DAVOS I	2017	8	2.828	2.229	2.848	2.234	-0.69	-0.20
POMVDV	ROME I	2017	10	2.782	2.204	2.858	2.227	-2.67	-1.01
POMCNR	DAVOS II	2018	7	2.751	2.300	2.780	2.324	-1.05	-1.02
POMCNR	DAVOS II	2018	8	2.762	2.321	2.807	2.364	-1.60	-1.81
POMCNR	DAVOS II	2018	9	2.771	2.343	2.807	2.368	-1.28	-1.07
POMCNR	DAVOS II	2018	10	2.766	2.346	2.802	2.364	-1.27	-0.75
POMCNR	ROME II	2019	5	2.717	2.321	2.804	2.348	-3.09	-1.14
POMCNR	ROME II	2019	6	2.730	2.303	2.807	2.350	-2.73	-1.98
POMCNR	ROME II	2019	7	2.737	2.299	2.836	2.366	-3.49	-2.83
POMCNR	ROME II	2019	8	2.765	2.329	2.836	2.371	-2.51	-1.76
POMCNR	ROME II	2019	9	2.747	2.320	2.838	2.369	-3.21	-2.05
POMSPZ	ROME II	2019	5	3.062	2.174	3.134	2.203	-2.31	-1.31
POMSPZ	ROME II	2019	6	3.043	2.167	3.122	2.198	-2.53	-1.43
POMSPZ	ROME II	2019	7	3.029	2.151	3.133	2.226	-3.31	-3.36
POMSPZ	ROME II	2019	8	3.082	2.201	3.133	2.233	-1.63	-1.43
POMCNR*	ROME III	2021	9	2.686	2.250	2.754	2.308	-2.48	-2.51
POMCNR*	DAVOS III	2021	10	2.698	2.293	2.734	2.320	-1.30	-1.14

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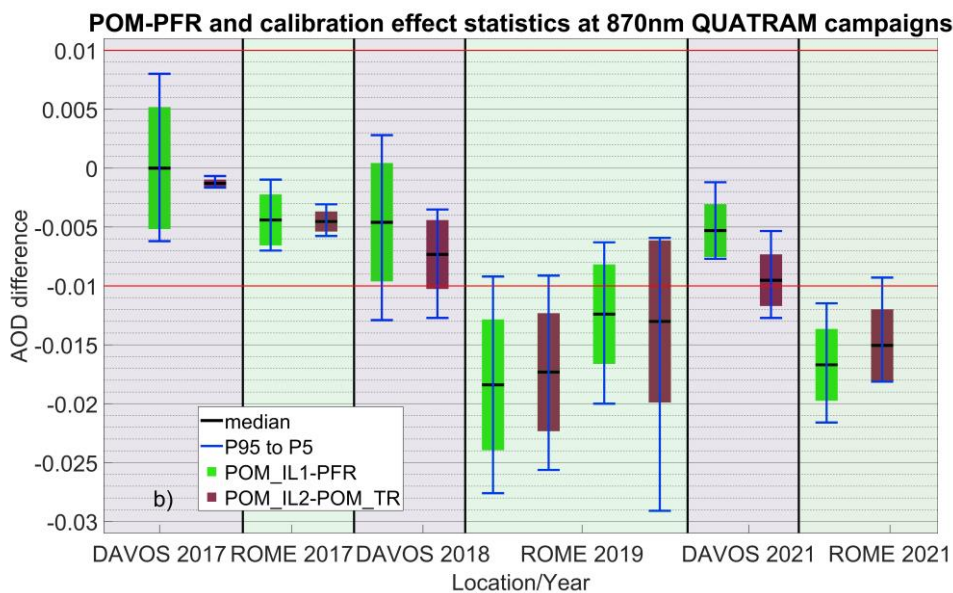
Table S2: The uncertainties % of the used reference PFR calibrations and the POM monthly calibration transfers based on the PFR at 500 nm and 870 nm. The monthly uncertainty of the calibration transfer is the square root of the sum of the square errors of the PFR calibration uncertainty and the standard deviation of the daily calibration transfers.

Instrument	Location	Year	Month	U_{PFR500} %	U_{PFR870} %	U_{TR500} %	U_{TR870} %
POMVDV	DAVOS I	2017	8	0.25	0.25	0.51	0.68
POMVDV	ROME I	2017	10	0.28	0.32	0.30	0.37
POMCNR	DAVOS II	2018	7	0.25	0.25	0.35	0.31
POMCNR	DAVOS II	2018	8	0.25	0.25	0.30	0.35
POMCNR	DAVOS II	2018	9	0.25	0.25	0.29	0.32

POMCNR	DAVOS II	2018	10	0.25	0.25	0.27	0.32
POMCNR	ROME II	2019	5	0.28	0.32	0.65	0.66
POMCNR	ROME II	2019	6	0.28	0.32	0.80	0.64
POMCNR	ROME II	2019	7	0.28	0.32	0.40	0.41
POMCNR	ROME II	2019	8	0.28	0.32	0.65	0.45
POMCNR	ROME II	2019	9	0.28	0.32	0.36	0.38
POMSPZ	ROME II	2019	5	0.28	0.32	0.62	0.63
POMSPZ	ROME II	2019	6	0.28	0.32	0.79	0.38
POMSPZ	ROME II	2019	7	0.28	0.32	0.42	0.72
POMSPZ	ROME II	2019	8	0.28	0.32	0.60	0.43
POMCNR*	ROME III	2021	9	0.37	0.39	0.43	0.48
POMCNR*	DAVOS III	2021	10	0.25	0.25	0.27	0.29



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Figure S1: Box plot of the AOD differences' statistics for all instrument comparisons during both phases of the 3 QUATRAM campaigns. The green boxes correspond to the differences between the original AOD from POMs and PFRs. The red boxes correspond to the POM AOD differences retrieved once for each calibration (ILP and transfer from the PFR) using the same post processing algorithm and inputs for ozone absorption and Rayleigh scattering. During ROME 2019 campaign on the left side are the comparisons of POMCNR (master) and on the right side POMSPZ. The black line is the median difference, the size of the boxes denotes the distance between the median and the standard deviation, while the error bars show the 5th and the 95th percentile of the AOD differences. a): 500 nm. b): 870 nm.

S2. PFR calibrations

30 Table S3: The calibrations of the PFRs that were present in the Rome phases of the QUATRAM campaigns (PFRN14 for QUATRAM I and II, PFRN01 for QUATRAM III). The last columns show the % difference of each calibration with the previous. The calibrations were performed in Davos using as reference the PFR triad used for world AOD reference. The instruments measure direct solar irradiance in mV.

Instrument: PFRN14							Difference (%)				
Year	Mo nth	Day	V0 368 nm (mV)	V0 412 nm (mV)	V0 500 nm (mV)	V0 870 nm (mV)	368 nm	412 nm	500 nm	862 nm	
2017	9	21	4.210	3.809	3.806	3.551	-	-	-	-	
2018	8	29	4.211	3.809	3.802	3.563	0.02	0.00	-0.11	0.34	
2020	6	1	4.180	3.794	3.785	3.565	-0.74	-0.40	-0.45	0.06	
Instrument: PFRN01							Difference (%)				
Year	Mo nth	Day	V0 368 nm (mV)	V0 412 nm (mV)	V0 500 nm (mV)	V0 870 nm (mV)	368 nm	412 nm	500 nm	862 nm	
2020	11	7	4.031	3.511	3.725	3.380	-	-	-	-	
2021	5	28	4.011	3.503	3.717	3.380	-0.50	-0.23	-0.22	0.00	
2022	9	6	4.006	3.493	3.712	3.376	-0.12	-0.29	-0.13	-0.12	

35 S3. Imaginary part of refractive index values

Table S4: The values used for the imaginary part of refractive index tests of section 3.2.2.1.

$\lambda(\text{nm})$	Davos			Rome		
	median-std k	median k	median +std k	median -std k	median k	median +std k
340	0.0040	0.0071	0.0186	0.0021	0.0076	0.0145
400	0.0040	0.0070	0.0189	0.0020	0.0074	0.0142
500	0.0040	0.0068	0.0194	0.0019	0.0071	0.0138
675	0.0040	0.0065	0.0204	0.0017	0.0065	0.0130
870	0.0040	0.0072	0.0204	0.0018	0.0079	0.0145
1020	0.0040	0.0078	0.0203	0.0018	0.0084	0.0135

S4. Surface albedo values

Table S5: values used for the surface albedo variation tests of section 3.2.2.1.

$\lambda(\text{nm})$	Davos			Rome		
	mean-std A	mean A	mean +std A	mean -std A	mean A	mean +std A
340	0.016	0.032	0.049	0.038	0.043	0.047
400	0.022	0.044	0.066	0.052	0.058	0.065
500	0.046	0.070	0.095	0.067	0.076	0.084
675	0.046	0.069	0.093	0.100	0.113	0.125
870	0.235	0.270	0.305	0.210	0.240	0.270
1020	0.242	0.271	0.301	0.213	0.241	0.269

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S5. Solid view angle values

Table S6: The values used for the solid view angle in $srx10^{-4}$ variation tests of section 3.2.2.1.

$\lambda(\text{nm})$	% max ΔSVA	SVA- ΔSVA	SVA	SVA+ ΔSVA
340	9.1	2.202	2.422	2.642
400	2.6	2.388	2.452	2.516
500	2.6	2.395	2.459	2.523
675	2	2.402	2.451	2.500
870	4.5	2.385	2.497	2.609
1020	3.8	2.358	2.514	2.545

S6. Total ozone column, surface pressure and inputs of the 2nd and 3rd sensitivity sub-studies

45 For section 3.2.2.2 the selected values for all the parameters are:

Total ozone column: 400 DU for both locations.

Surface Pressure: 0.85 atm for Davos and 1.02 atm for Rome.

Real part of refractive index: 1.5 for both locations and all wavelengths.

Imaginary part of refractive index, surface albedo and solid view angle are in table 6.

50 For section 3.2.2.2 the selected values for all the parameters are in table 7 below.

Table S7: The values used for the imaginary part of refractive index, surface albedo and solid view angle in $srx10^{-4}$ for the selected tests of section 3.2.2.2.

$\lambda(\text{nm})$	Davos			Rome	
	SVA- ΔSVA	median-std k	mean-std A	median k	mean - std A
340	2.202	0.0040	0.016	0.0076	0.038

400	2.388	0.0040	0.022	0.0074	0.052
500	2.395	0.0040	0.046	0.0071	0.067
675	2.402	0.0040	0.046	0.0065	0.100
870	2.385	0.0040	0.235	0.0079	0.210
1020	2.358	0.0040	0.242	0.0084	0.213

S7. Real part of refractive index sensitivity

55 Table S8: The calibration differences % between the calibration transfer from PFR and the ILP calibrations for different values of real part of refractive index.

		Davos:	Original (n=1.5)		n=1.33		n=1.5		n=1.6	
Location	Year	Rome:	Original (n=1.5)		n=1.33		n=1.5		n=1.6	
	Month		$\Delta V0\%$	$\Delta V0\%$	$\Delta V0\%$	$\Delta V0\%$	$\Delta V0\%$	$\Delta V0\%$	$\Delta V0\%$	$\Delta V0\%$
			500 nm	870 nm	500 nm	870 nm	500 nm	870 nm	500 nm	870 nm
DAVOS	2018	9	-1.28	-1.07	-1.10	-0.86	-1.28	-1.02	-1.24	-1.15
DAVOS	2018	10	-1.27	-0.75	-1.27	-0.75	-1.31	-0.75	-1.24	-0.62
ROME	2019	7	-3.49	-2.83	-3.99	-3.09	-3.49	-3.05	-3.49	-3.00
ROME	2019	8	-2.51	-1.76	-2.65	-1.72	-2.65	-1.72	-2.65	-1.72

S8. Total ozone column sensitivity

60 Table S9: The calibration differences % between the calibration transfer from PFR and the ILP calibrations for different values of total ozone column.

Davos:	Original	TOC=260 DU	TOC=300 DU	TOC=400 DU
	(TOC=300 DU)			

Location	Year	Month	Rome: Original (TOC=300 DU)		TOC=260 DU		TOC=300 DU		TOC=400 DU	
			$\Delta V0\%$ 500 mn	$\Delta V0\%$ 870 nm	$\Delta V0\%$ 500 mn	$\Delta V0\%$ 870 nm	$\Delta V0\%$ 500 mn	$\Delta V0\%$ 870 nm	$\Delta V0\%$ 500 mn	$\Delta V0\%$ 870 nm
DAVOS	2018	9	-1.28	-1.07	-1.35	-1.02	-1.28	-1.02	-1.21	-1.02
DAVOS	2018	10	-1.27	-0.75	-1.31	-0.75	-1.31	-0.75	-0.74	-0.75
ROME	2019	7	-3.49	-2.83	-3.49	-3.05	-3.49	-3.05	-3.92	-3.05
ROME	2019	8	-2.51	-1.76	-2.54	-1.80	-2.54	-1.80	-2.51	-1.80

S9. Surface pressure sensitivity

65 Table S10: The calibration differences % between the calibration transfer from PFR and the ILP calibrations for different values of surface pressure.

Location	Year	Month	Davos: Original (P=0.829 atm)		P=0.8 atm		P=0.83 atm		P=0.85 atm	
			$\Delta V0\%$ 500 mn	$\Delta V0\%$ 870 nm	$\Delta V0\%$ 500 mn	$\Delta V0\%$ 870 nm	$\Delta V0\%$ 500 mn	$\Delta V0\%$ 870 nm	$\Delta V0\%$ 500 mn	$\Delta V0\%$ 870 nm
DAVOS	2018	9	-1.28	-1.07	-1.28	-1.02	-1.28	-1.02	-1.13	-0.98
DAVOS	2018	10	-1.27	-0.75	-1.38	-0.62	-1.27	-0.75	-1.16	-0.62
ROME	2019	7	-3.49	-2.83	-3.95	-2.71	-3.49	-3.05	-3.53	-2.83
ROME	2019	8	-2.51	-1.76	-2.58	-1.76	-2.54	-1.80	-2.51	-1.80

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S10. Extensive sensitivity test inputs

Here we show the input parameter values for the third sub-study in sections 2.4.3, 3.2.2.3.

Table S11: The used values for the sensitivity tests of IRI, SA and SVA.

IRI (unitless)	SA (unitless)	SVA (sr$\times 10^{-4}$) at 500 nm	SVA (sr$\times 10^{-4}$) at 870 nm
0.0003	0.01	2.250	2.300
0.001	0.035	2.395	2.385
0.01	0.08	2.430	2.450
0.05	0.15	2.459	2.497
0.1	0.2	2.490	2.550
0.2	0.3	2.523	2.609
0.4	0.5	2.700	2.750

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S11. ILP median SSA and variability

Table S12: The monthly medians of the SSA from the Skyrad 4.2 and MRI inversions.

SSA values QUATRAM II:	SKY4.2_500 nm	SKY4.2_870 nm	MRI_500 nm	MRI_870 nm
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Location	Year	Month	Median SSA				Number of measurements
Davos II	2018	7	0.952	0.917	0.959	0.935	194
Davos II	2018	8	0.958	0.933	0.964	0.944	404
Davos II	2018	9	0.950	0.923	0.958	0.940	332
Davos II	2018	10	0.947	0.917	0.953	0.932	184
Rome II	2019	5	0.941	0.922	0.949	0.933	238
Rome II	2019	6	0.928	0.911	0.937	0.924	1215
Rome II	2019	7	0.937	0.917	0.945	0.927	1178
Rome II	2019	8	0.939	0.919	0.946	0.928	1123
Rome II	2019	9	0.932	0.921	0.940	0.929	680

85 Table S13: The monthly medians of the daily P80-P20 values for the SSA from the Skyrad 4.2 and MRI inversions. We also added the % calibration differences between the calibration transfer from the PFRs and the ILP both from Skyrad 4.2 and MRI.

SSA variability			SKY4.2_500	SKY4.2_870	MRI_500	MRI_87	SKY-TR		MRI-TR	
Location	Year	Month	nm	nm	nm	0 nm	ΔV_0	ΔV_0	ΔV_0	ΔV_0
			Median of daily P80-P20				%	%	%	%
							500	870	500	870
							nm	nm	nm	nm
Davos II	2018	7	0.0130	0.0223	0.0039	0.0073	-1.05	-1.02	-1.46	-1.21
Davos II	2018	8	0.0093	0.0170	0.0033	0.0065	-1.60	-1.81	-1.07	-4.04

Davos II	2018	9	0.0077	0.0158	0.0037	0.0052	-1.28	-1.07	-0.32	-0.43
Davos II	2018	10	0.0120	0.0203	0.0049	0.0089	-1.27	-0.75	-0.74	0.65
Rome II	2019	5	0.0093	0.0097	0.0061	0.0068	-3.09	-1.14	-2.73	-1.33
Rome II	2019	6	0.0108	0.0093	0.0060	0.0052	-2.73	-1.98	-2.51	-1.97
Rome II	2019	7	0.0087	0.0080	0.0059	0.0048	-3.49	-2.83	-3.96	-3.14
Rome II	2019	8	0.0068	0.0078	0.0053	0.0053	-2.51	-1.76	-2.69	-1.92
Rome II	2019	9	0.0121	0.0124	0.0067	0.0068	-3.21	-2.05	-2.80	-2.36

90 S12. Air mass dependence of AOD differences

Table S14: The AOD difference between the AOD from the Skyrad 4.2 inversions and the AOD from the PFR for different subsets of the air mass separately (no smaller than 2 and no larger than 1.5).

Location	Air mass	Median AOD difference		Number of data
		500 nm	870 nm	
DAVOS	≥ 2	-0.003	0.000	277
ROME	≥ 2	-0.005	0.000	201
DAVOS	≤ 1.5	0.000	0.001	443
ROME	≤ 1.5	-0.012	-0.004	743

Table S15: Least squares-linear fit of the AOD difference between the AOD from the Skyrad 4.2 inversions and the AOD from the PFR in relation to the air mass and the root mean square error (RMSE) of the fit.

Linear fit of AOD difference in relation to the air mass

Location	Wavelength (nm)	Slope	Intercept	RMSE	Number of measurements
DAVOS	500	-0.001	-0.001	0.009	1129
ROME	500	0.008	-0.022	0.010	1231
DAVOS	870	-0.001	0.002	0.004	1129
ROME	870	0.004	-0.008	0.007	1231

95 Table S16: List of abbreviations.

GAW-PFR	Global Atmospheric Watch-Precision Filter Radiometer
ESR	European Skynet Radiometers network
AERONET	Aerosol Robotic Network
WMO	World Meteorological Organization
CEReS	Center for Environmental Remote Sensing
PFR	Precision Filter Radiometer
CIMEL	CIMEL sun and sky photometer
POM	PREDE-POM sun and sky radiometer

ILP	Improved Langley Plot method
SLP	Standard Langley Plot method
FRC	Filter Radiometer Comparison
QUATRAM	Quality and Traceability of Atmospheric Aerosol Measurements
AOD	Aerosol Optical Depth
DSI	Direct Solar Irradiance
NSR	Normalized Sky Radiance
SSA	Single Scattering Albedo
sc-AOD	Scattering Aerosol Optical Depth
AE	Angström Exponent
RRI	Real part of the aerosol Refractive Index
IRI	Imaginary part of the aerosol Refractive Index
SA	Surface Albedo
TOC	Total Ozone Column
P	Surface Pressure

NO2	Nitrogen Dioxide
SVA	Solid View Angle
FOV	Field-of-View Angle
FWHM	Full-Width-at-Half-Maximum
σ	Standard Deviation
CV%	Coefficient of Variation
BRDF	Bidirectional Reflectance Distribution Function
Skyrad 4.2	Skyrad pack code version 4.2
MRI	Skyrad pack MRI version 2
DAV	Davos
ROM	Rome
