Intercomparison of AOD retrievals from GAW-PFR and SKYNET sun photometer networks and calibration effects

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1. 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_{0IL}) and calibration transfer from PFR (V_{0TR}) in $\mu Ax10^{-4}$ with their % differences at 500 nm and 870 nm.

Instrument	**Location**	**Year**	**Month**	**V_{0IL500}**	**V_{0IL870}**	**V_{0TR500}**	**V_{0TR870}**	**% difference 500 mn**	**% 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
POM11	ROME II	2019	5	3.062	2.174	3.134	2.203	-2.31	-1.31
POM11	ROME II	2019	6	3.043	2.167	3.122	2.198	-2.53	-1.43
POM11	ROME II	2019	7	3.029	2.151	3.133	2.226	-3.31	-3.36
POM11	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

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
POM11	ROME II	2019	5	0.28	0.32	0.62	0.63
POM11	ROME II	2019	6	0.28	0.32	0.79	0.38
POM11	ROME II	2019	7	0.28	0.32	0.42	0.72
POM11	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

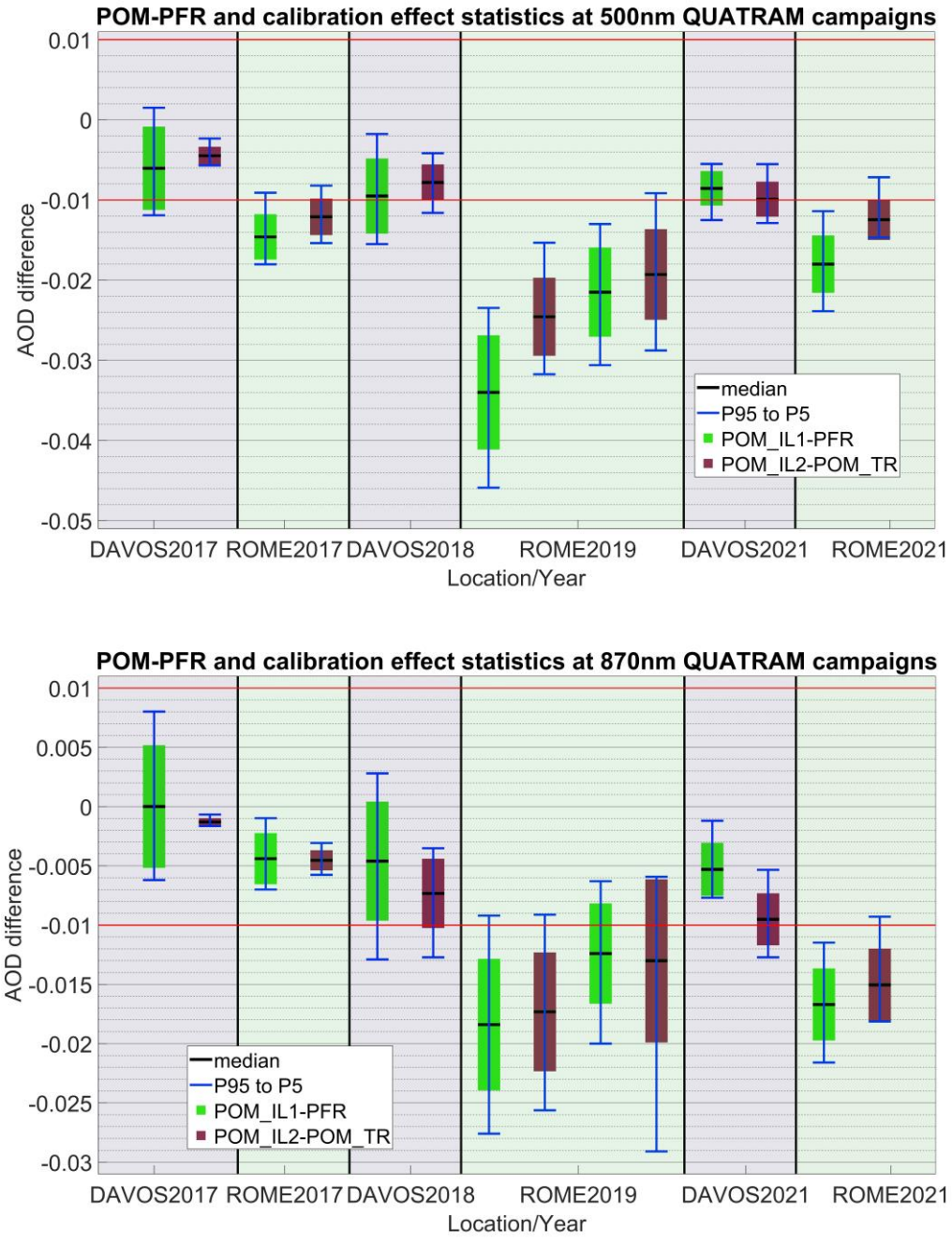

Figure S1: Box plot of the AOD differences' statistics for all instrument comparisons during both phases of the 3 QUATRAM campaigns. The green boxes correspond to the differences between the original AOD from POMs and PFRs. The red boxes correspond the POM AOD differences retrieved once for each calibration (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 POM11. 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. Top: 500 nm. Bottom: 870 nm.

2. PFR calibrations

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	**Month**	**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	**Month**	**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

3. 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.

	Davos			Rome		
λ(nm)	**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

4. Surface albedo values

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

	Davos			Rome		
λ(nm)	**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

5. 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.

λ(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

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

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.

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.

		Davos		Rome	
λ(nm)	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

7. Real part of refractive index sensitivity

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**	
		Rome:	**Original (n=1.5)**		**n=1.33**		**n=1.5**		**n=1.6**	
Location	**Year**	**Month**	**ΔV0% 500 mn**	**ΔV0% 870 nm**	**ΔV0% 500 mn**	**ΔV0% 870 nm**	**ΔV0% 500 mn**	**ΔV0% 870 nm**	**ΔV0% 500 mn**	**ΔV0% 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

8. Total ozone column sensitivity

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=300 DU)		TOC=260 DU		TOC=300 DU		TOC=400 DU	
		Rome:	Original (TOC=300 DU)		TOC=260 DU		TOC=300 DU		TOC=400 DU	
Location	**Year**	**Month**	**ΔV0% 500 mn**	**ΔV0% 870 nm**	**ΔV0% 500 mn**	**ΔV0% 870 nm**	**ΔV0% 500 mn**	**ΔV0% 870 nm**	**ΔV0% 500 mn**	**ΔV0% 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

9. Surface pressure sensitivity

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

		Davos:	Original (P=0.829 atm)		P=0.8 atm		P=0.83 atm		P=0.85 atm	
		Rome:	Original (P=1 atm)		P=0.97 atm		P=1 atm		P=1.02 atm	
Location	**Year**	**Month**	**ΔV0% 500 mn**	**ΔV0% 870 nm**	**ΔV0% 500 mn**	**ΔV0% 870 nm**	**ΔV0% 500 mn**	**ΔV0% 870 nm**	**ΔV0% 500 mn**	**ΔV0% 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

10. 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 ($srx10^{-4}$) at 500 nm**	**SVA ($srx10^{-4}$) 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

11. 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**	
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

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 nm**	**SKY4.2_870 nm**	**MRI_500 nm**	**MRI_870 nm**	**SKY-TR**		**MRI-TR**	
Location	**Year**	**Month**	**Median of daily P80-P20**				**ΔV_0 % 500 nm**	**ΔV_0 % 870 nm**	**ΔV_0 % 500 nm**	**ΔV_0 % 870 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

12. 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

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