



Supplement of

Validation of ceilometer aerosol profile retrievals using sun–sky photometer and balloon-borne in situ measurements

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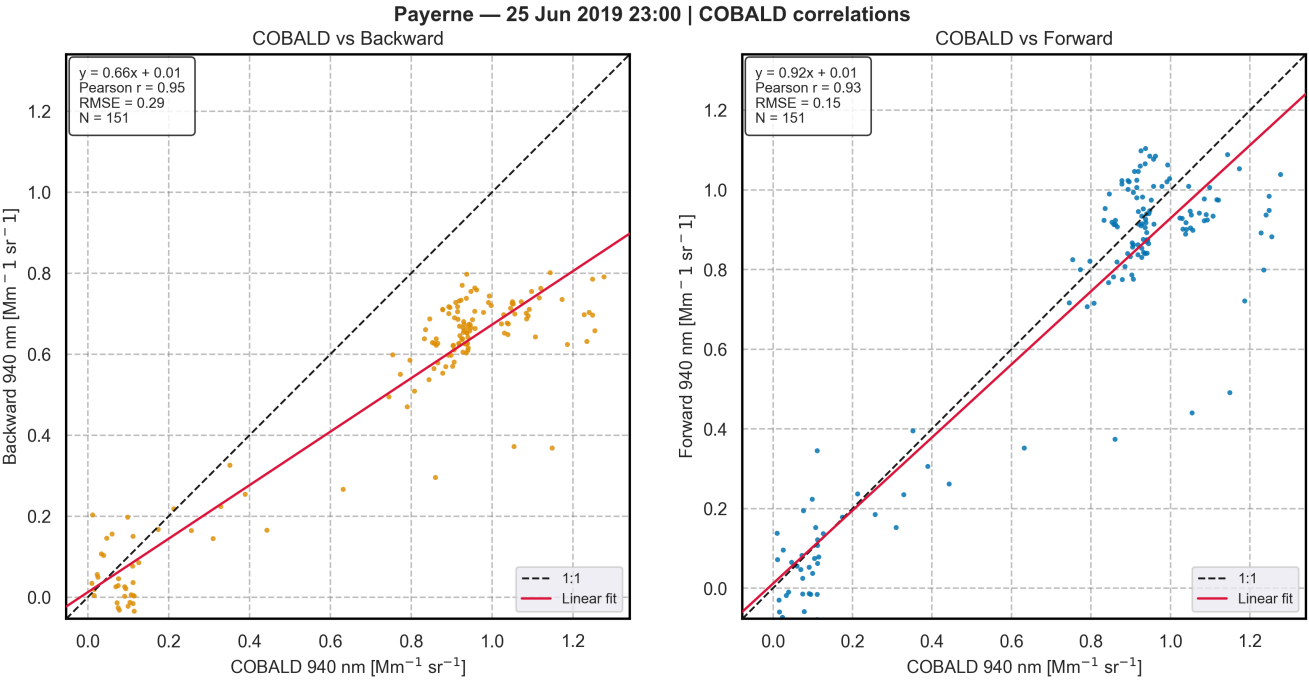


Figure S1. Scatter comparison of the ceilometer aerosol backscatter coefficient at 940 nm against the COBALD sonde at Payerne on 25 June 2019.

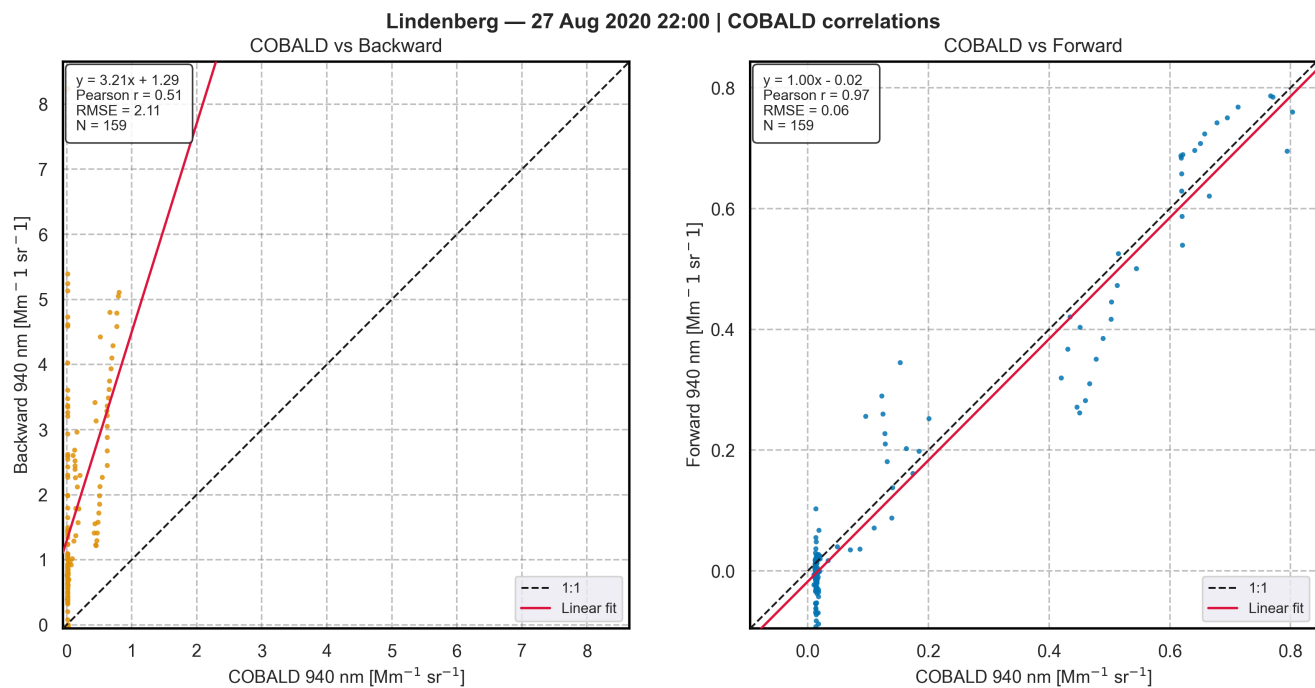


Figure S2. Scatter comparison of the ceilometer aerosol backscatter coefficient at 940 nm against the COBALD sonde at Lindenberg on 27 August 2020

Klett Backward vs GRASP — backscatter coefficient

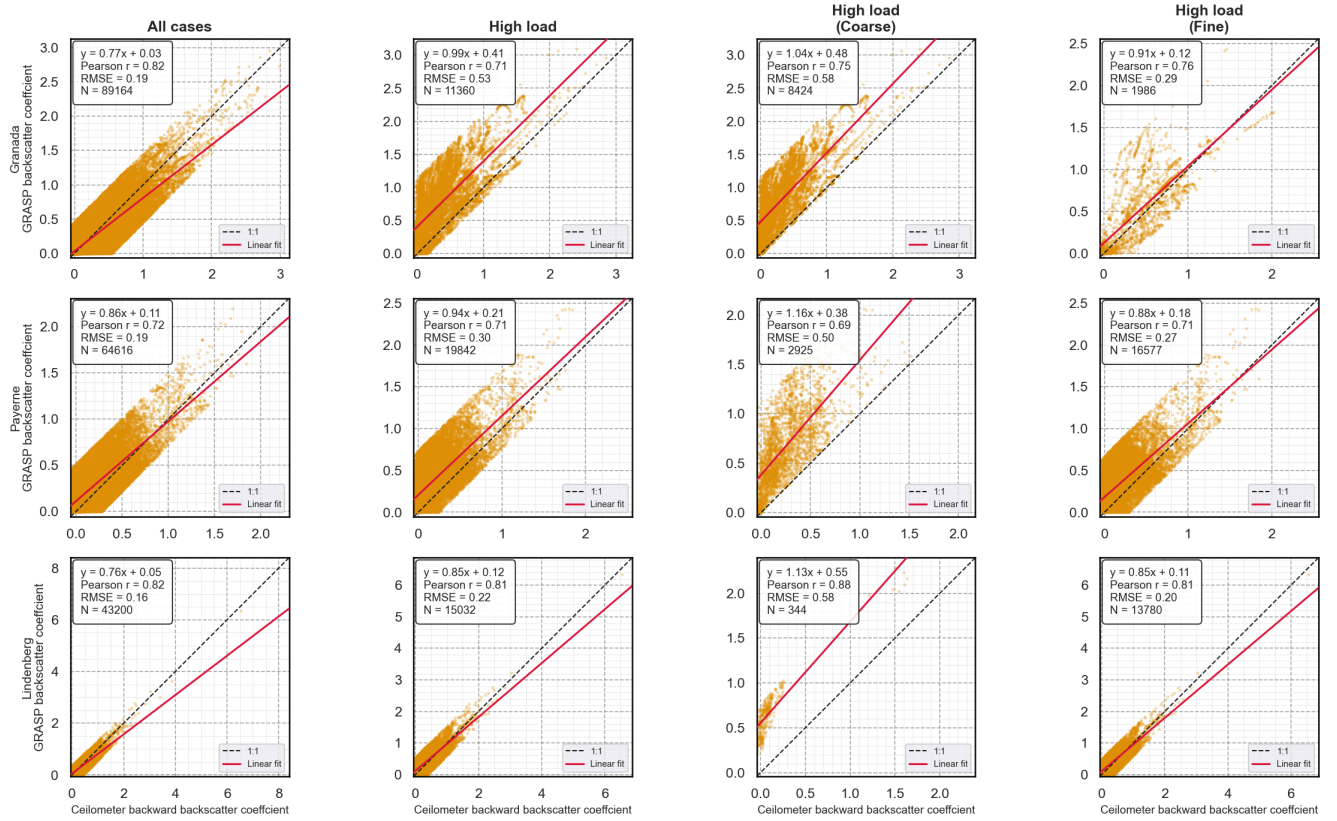


Figure S3. Scatter comparison of the ceilometer backscatter coefficient (Klett Backward) vs. GRASP at Granada (top), Payerne (middle) and Lindenberg (bottom), for all cases, high aerosol load, high-load coarse particles and high-load fine particles. The same 10–90 percentile filtering used in the profile comparison was applied.

Klett Forward vs GRASP — backscatter coefficient

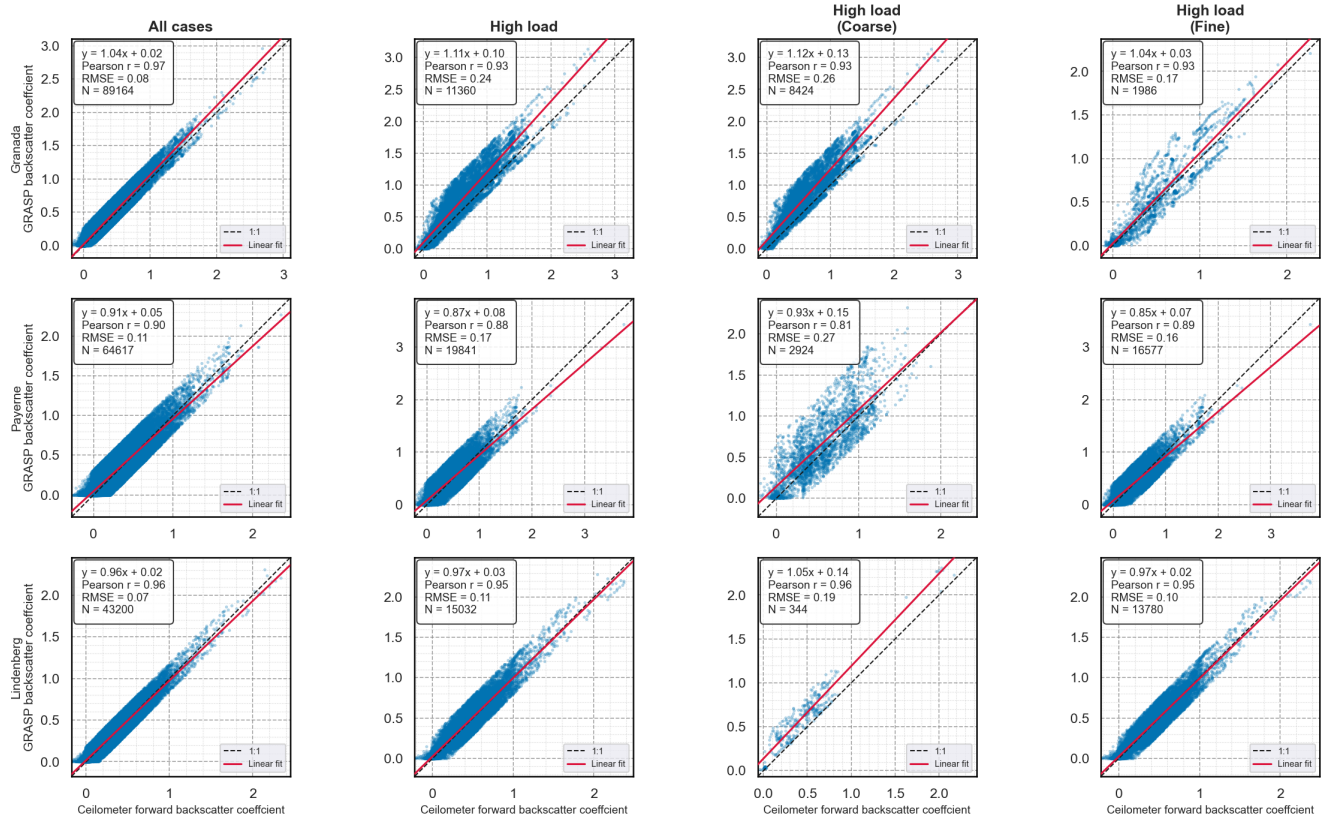


Figure S4. Scatter comparison of the ceilometer backscatter coefficient (forward) vs. GRASP at Granada (top), Payerne (middle) and Lindenberg (bottom), for all cases, high aerosol load, high-load coarse particles and high-load fine particles. The same 10–90 percentile filtering used in the profile comparison was applied.

Klett Backward vs GRASP — extinction

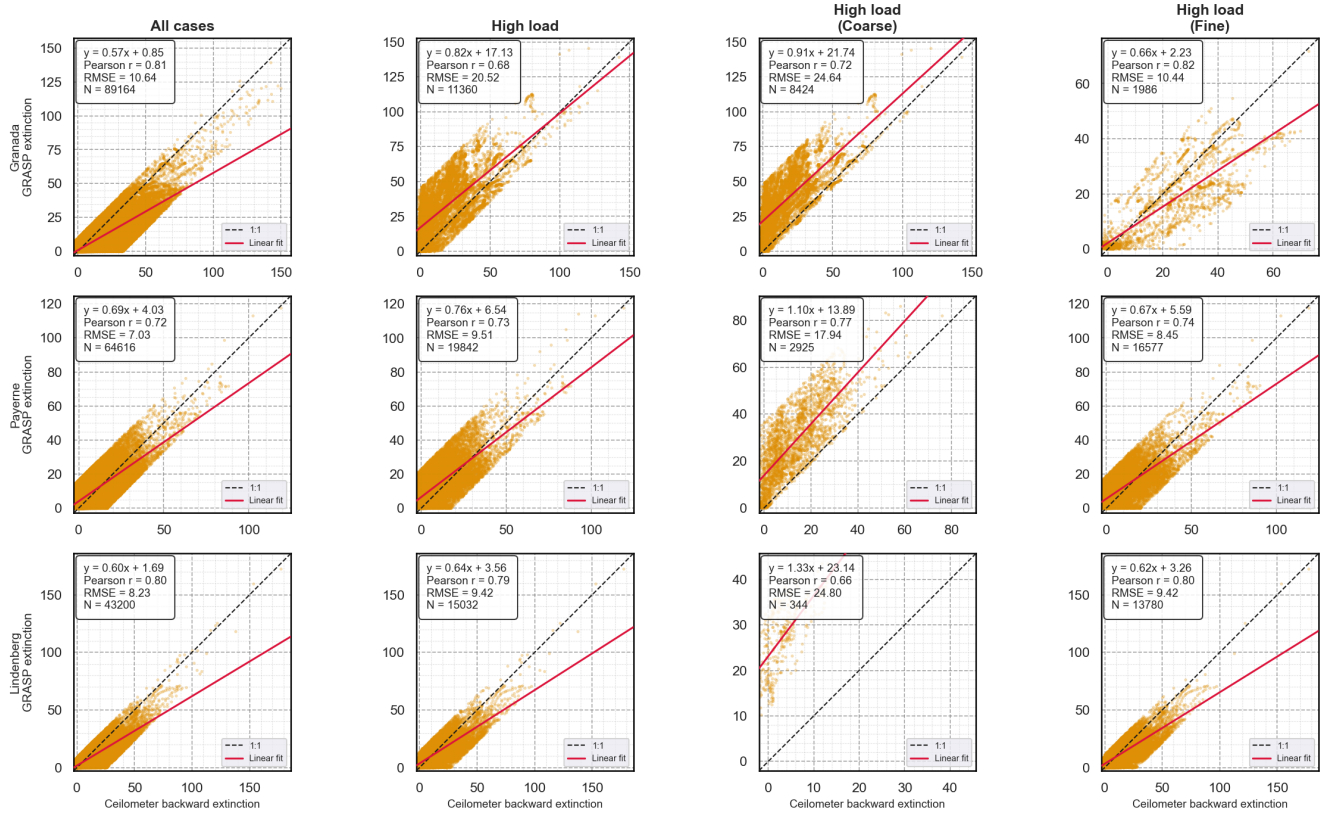


Figure S5. Scatter comparison of the ceilometer extinction (Klett Backward) vs. GRASP at Granada (top), Payerne (middle) and Lindenberg (bottom), for all cases, high aerosol load, high-load coarse particles and high-load fine particles. The same 10–90 percentile filtering used in the profile comparison was applied.

Klett Forward vs GRASP — extinction

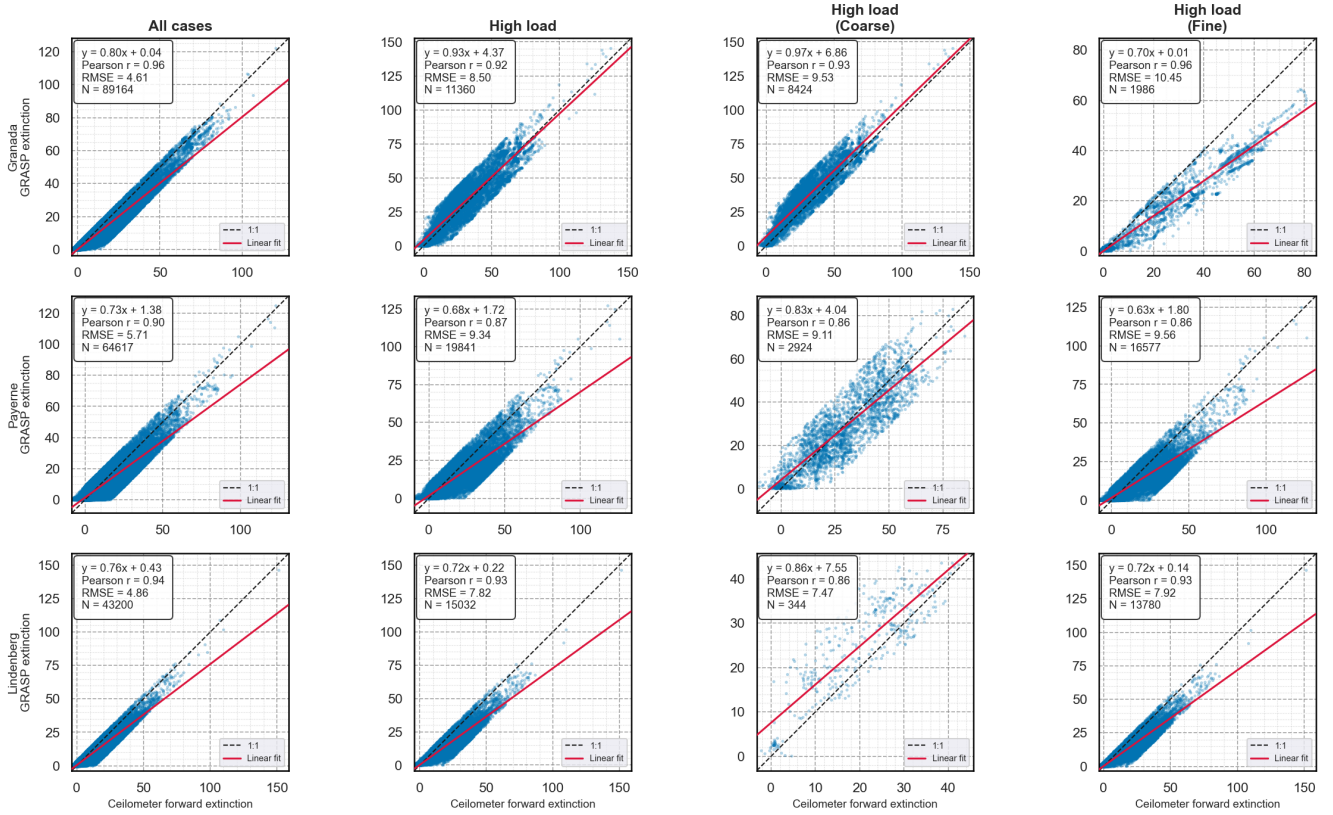


Figure S6. Scatter comparison of the ceilometer extinction (forward) vs. GRASP at Granada (top), Payerne (middle) and Lindenberg (bottom), for all cases, high aerosol load, high-load coarse particles and high-load fine particles. The same 10–90 percentile filtering used in the profile comparison was applied.

Ceilometer AOD₁₀₆₄ vs AERONET AOD₁₀₆₄ — Backward

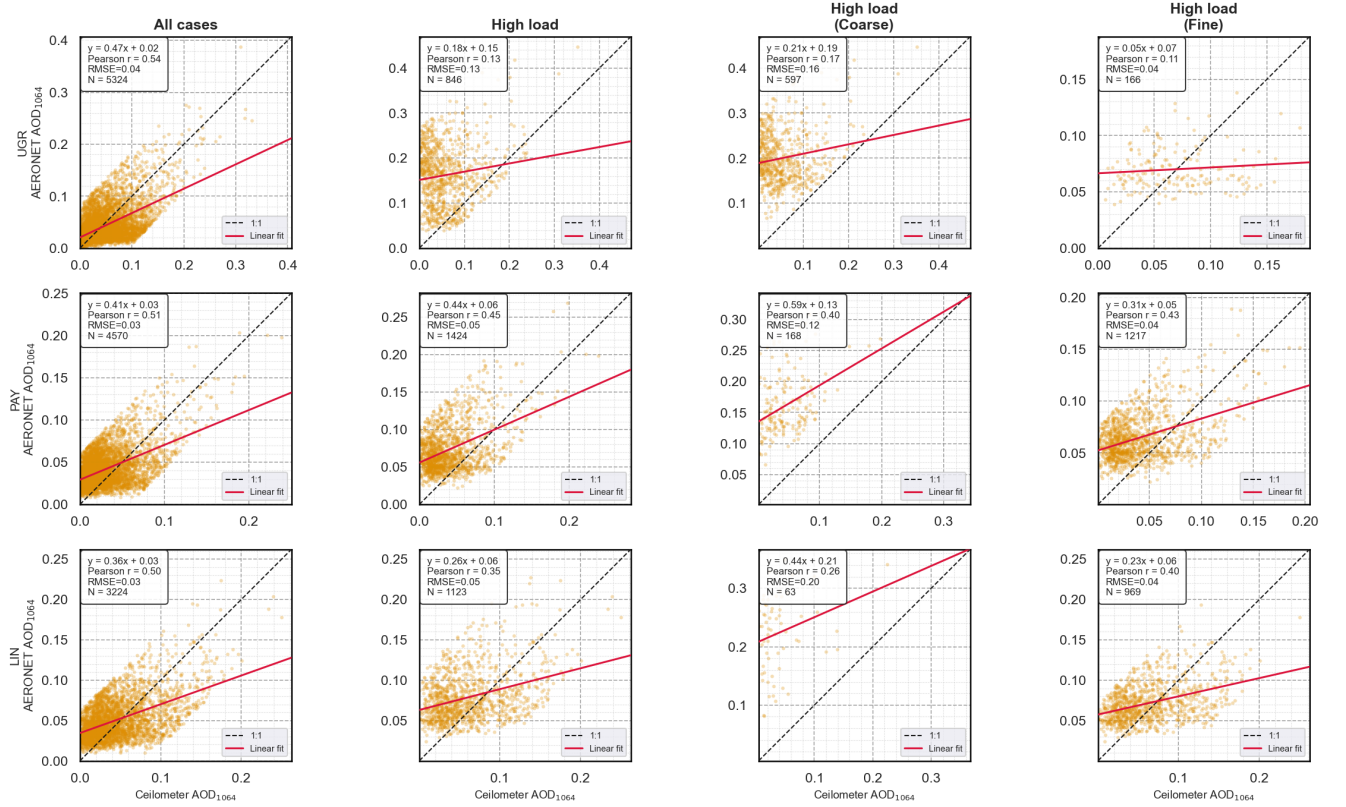


Figure S7. Scatter comparison of ceilometer-derived AOD at 1064 nm (Klett backward) vs. AERONET AOD at Granada (Top), Payerne (middle) and Lindenberg (bottom), for all cases, high aerosol, high-load coarse particles and high-load fine particles. The same 10–90 percentile filtering used in the profile comparison was applied.

Ceilometer AOD₁₀₆₄ vs AERONET AOD₁₀₆₄ — Forward

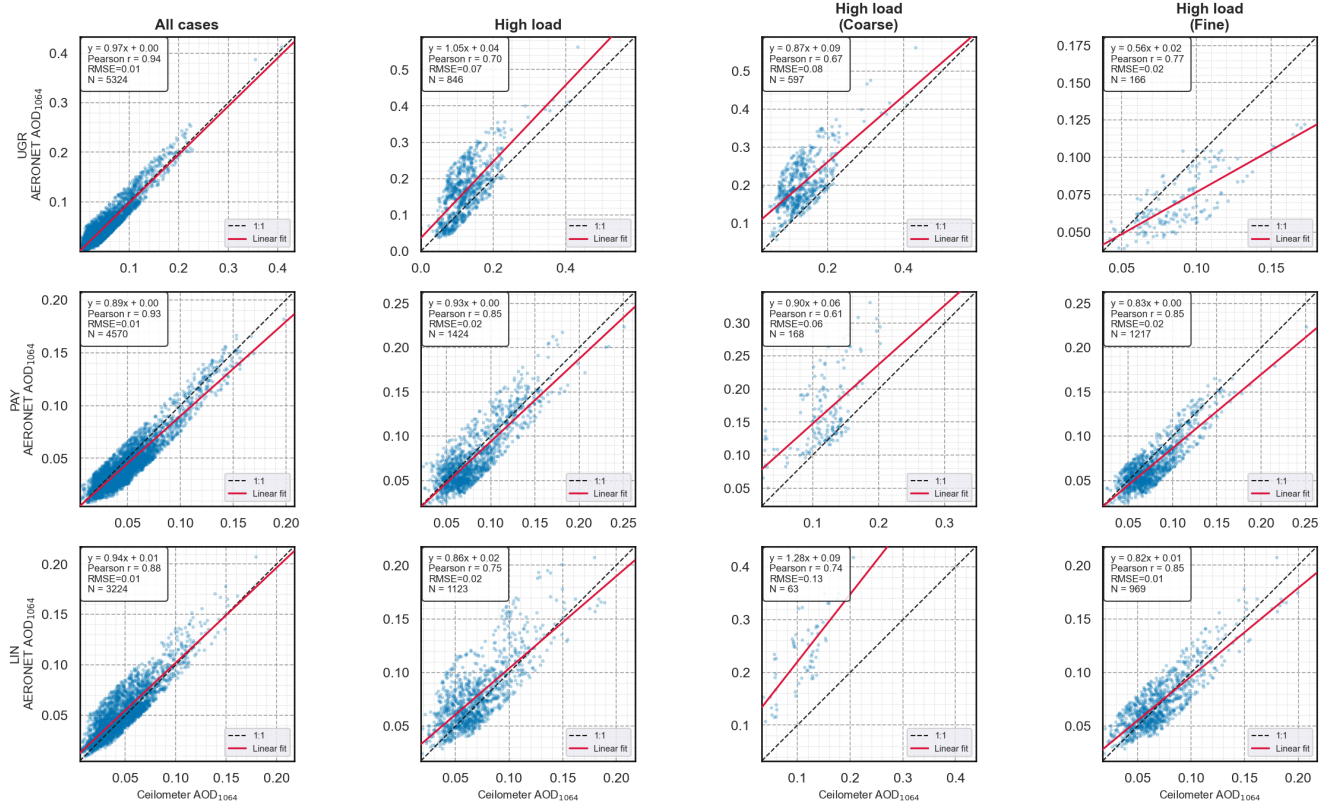


Figure S8. Scatter comparison of ceilometer-derived AOD at 1064 nm (Forward) vs. AERONET AOD at Granada (Top), Payerne (middle) and Lindenberg (bottom), for all cases, high aerosol, high-load coarse particles and high-load fine particles. The same 10–90 percentile filtering used in the profile comparison was applied.

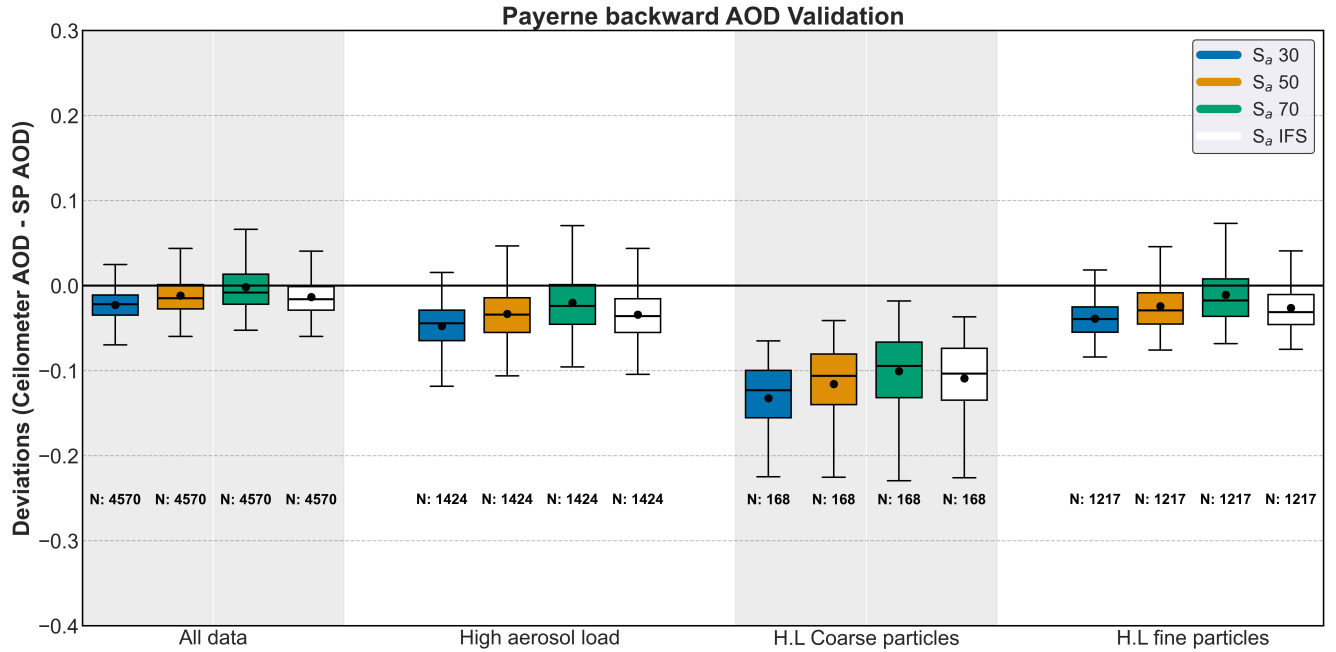


Figure S9. Deviations between ceilometer-derived AOD and AERONET sun-sky photometer AOD at Payerne for the backward (Klett–Fernald) retrieval, evaluated under four lidar ratio configurations: fixed values of 30, 50 and 70 sr and the daily variable IFS–CAMS estimate (S_a IFS). From left to right: all cases, high aerosol load, high-load coarse particles and high-load fine particles. The whiskers of each box show the interquartile range, the dot and black line inside the boxes represent the mean and median respectively, and N shows the number of integrated profiles used.

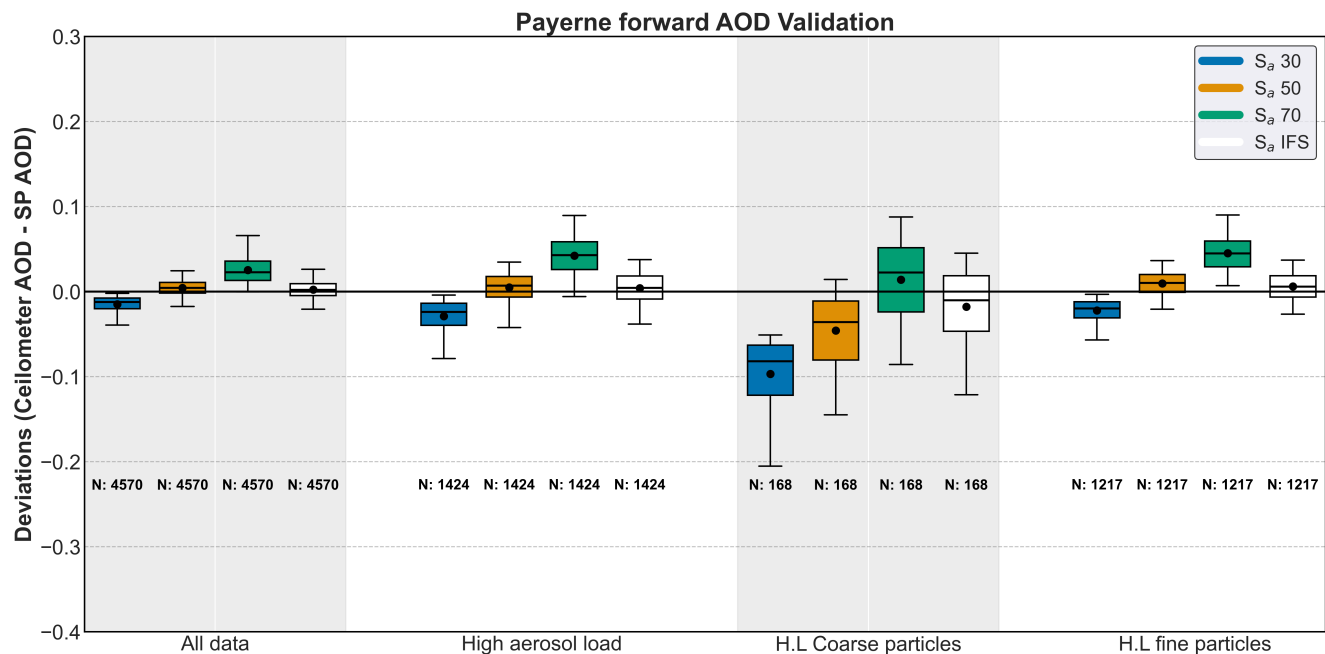


Figure S10. As in Fig. S9, but for the forward iterative retrieval at Payerne.

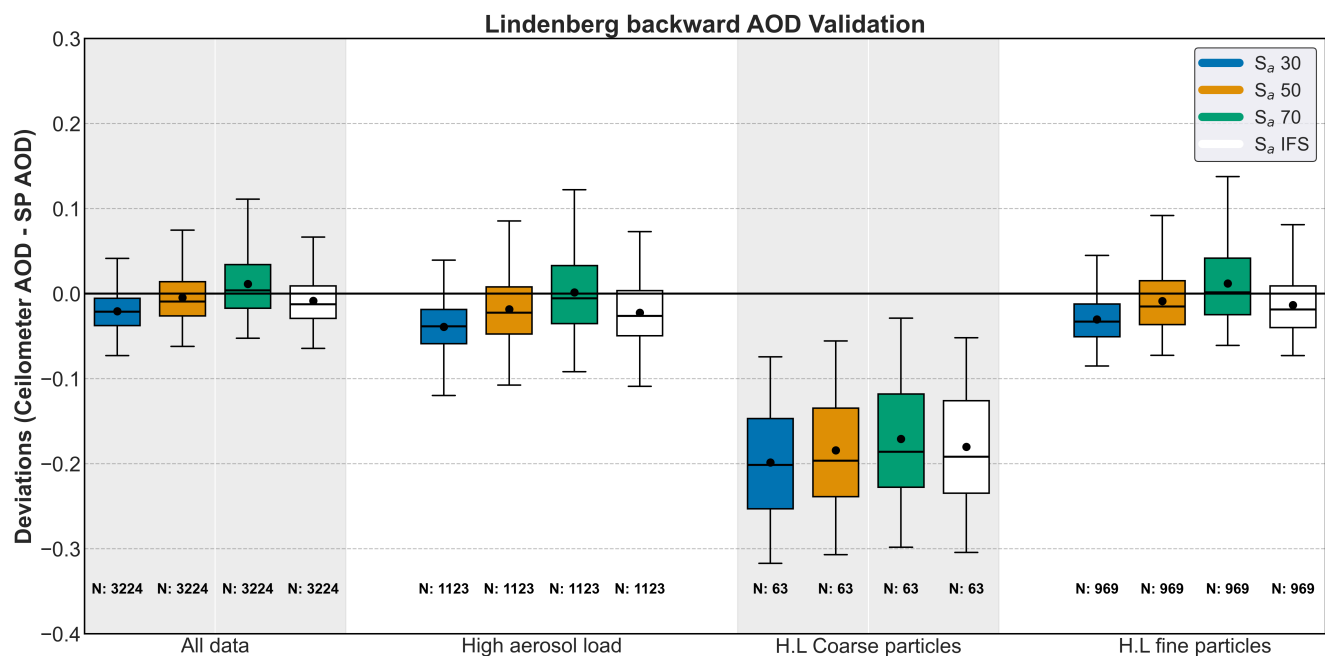


Figure S11. As in Fig. S9, but for the backward retrieval at Lindenberg.

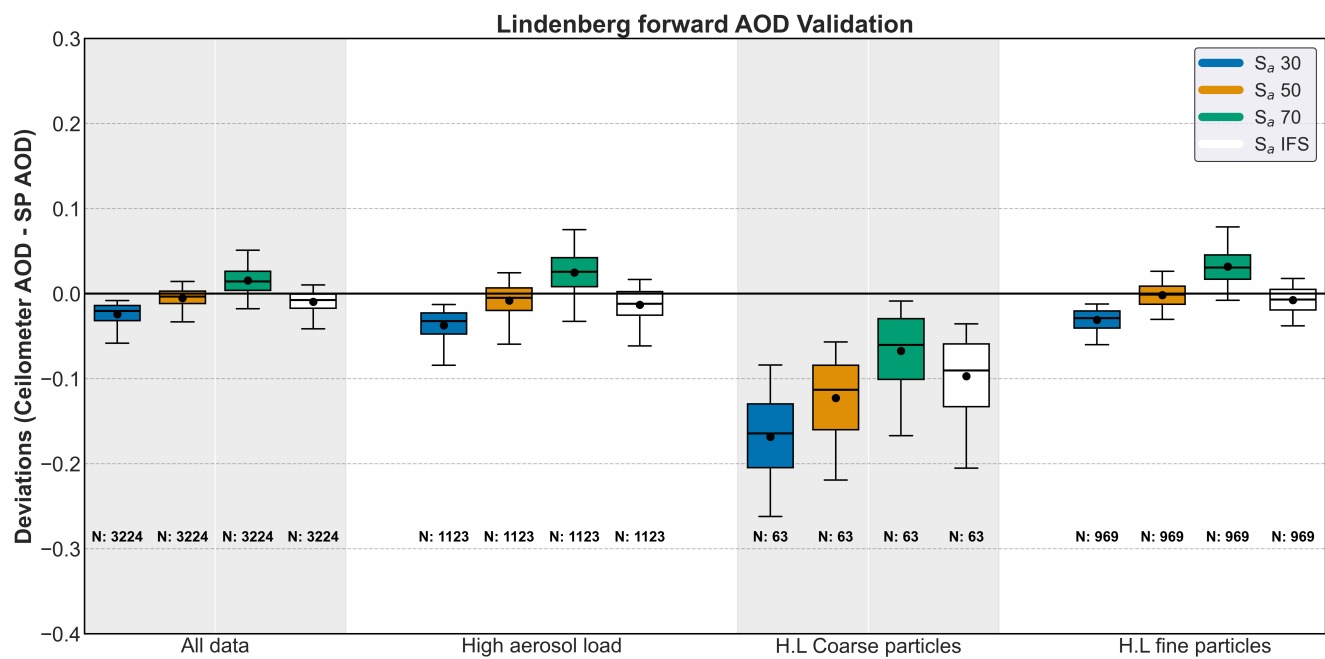


Figure S12. As in Fig. S9, but for the forward iterative retrieval at Lindenberg.

Table S1. Mean and standard deviation (with relative values in parentheses) and RMSE of the AOD deviation between the backward retrieval and AERONET at Granada, for four lidar ratio configurations (fixed values of 30, 50 and 70 sr and the IFS–CAMS daily estimate) under different aerosol load and particle mode conditions.

Lidar Ratio	Mean (%)	STD (%)	RMSE
<i>All data</i>			
LR 30	−0.012 (−13.7%)	0.029 (64.0%)	0.031
LR 50	0.006 (34.0%)	0.035 (95.0%)	0.035
LR 70	0.021 (76.9%)	0.041 (121.1%)	0.047
LR IFS	0.003 (21.6%)	0.033 (85.3%)	0.033
<i>High aerosol load</i>			
LR 30	−0.123 (−71.5%)	0.069 (23.8%)	0.141
LR 50	−0.103 (−56.5%)	0.076 (34.9%)	0.128
LR 70	−0.086 (−43.3%)	0.083 (44.1%)	0.119
LR IFS	−0.093 (−50.3%)	0.077 (37.6%)	0.120
<i>H.L Coarse particles</i>			
LR 30	−0.165 (−81.1%)	0.060 (15.5%)	0.175
LR 50	−0.147 (−71.1%)	0.067 (22.5%)	0.161
LR 70	−0.131 (−62.3%)	0.074 (28.4%)	0.150
LR IFS	−0.132 (−63.3%)	0.073 (27.6%)	0.151
<i>H.L Fine particles</i>			
LR 30	−0.026 (−32.9%)	0.030 (41.8%)	0.040
LR 50	−0.002 (3.8%)	0.041 (61.6%)	0.041
LR 70	0.020 (36.4%)	0.049 (77.8%)	0.053
LR IFS	−0.005 (−1.7%)	0.040 (58.8%)	0.040

Table S2. Mean and standard deviation (with relative values in parentheses) and RMSE of the AOD deviation between the forward retrieval and AERONET at Granada, for four lidar ration configurations (fixed values of 30, 50 and 70 sr and the IFS–CAMS daily estimate) under different aerosol load and particle mode conditions.

Lidar Ratio	Mean (%)	STD (%)	RMSE
<i>All data</i>			
LR 30	−0.018 (−38.2%)	0.016 (17.6%)	0.024
LR 50	0.001 (5.8%)	0.012 (29.1%)	0.012
LR 70	0.021 (54.1%)	0.019 (44.4%)	0.029
LR IFS	0.001 (0.6%)	0.013 (31.6%)	0.013
<i>High aerosol load</i>			
LR 30	−0.094 (−53.2%)	0.052 (14.9%)	0.108
LR 50	−0.043 (−18.9%)	0.050 (26.6%)	0.066
LR 70	0.023 (25.4%)	0.053 (40.7%)	0.058
LR IFS	0.000 (5.7%)	0.043 (27.1%)	0.043
<i>H.L Coarse particles</i>			
LR 30	−0.126 (−61.2%)	0.046 (9.8%)	0.134
LR 50	−0.070 (−32.8%)	0.047 (17.8%)	0.085
LR 70	0.003 (5.3%)	0.057 (28.6%)	0.057
LR IFS	−0.006 (0.5%)	0.053 (25.9%)	0.053
<i>H.L Fine particles</i>			
LR 30	−0.020 (−26.9%)	0.011 (12.9%)	0.022
LR 50	0.018 (25.9%)	0.017 (23.2%)	0.024
LR 70	0.060 (88.2%)	0.027 (35.7%)	0.066
LR IFS	0.012 (18.7%)	0.017 (25.3%)	0.021

Table S3. Mean and standard deviation (with relative values in parentheses) and RMSE of the AOD deviation between the backward retrieval and AERONET at Payerne, for four lidar ration configurations (fixed values of 30, 50 and 70 sr and the IFS–CAMS daily estimate) under different aerosol load and particle mode conditions..

Lidar Ratio	Mean (%)	STD (%)	RMSE
<i>All data</i>			
LR 30	−0.023 (−51.4%)	0.019 (38.6%)	0.030
LR 50	−0.012 (−23.5%)	0.024 (57.8%)	0.027
LR 70	−0.002 (1.8%)	0.029 (73.9%)	0.029
LR IFS	−0.013 (−27.8%)	0.023 (55.2%)	0.027
<i>High aerosol load</i>			
LR 30	−0.047 (−62.6%)	0.029 (26.8%)	0.055
LR 50	−0.033 (−41.6%)	0.033 (39.6%)	0.047
LR 70	−0.020 (−22.2%)	0.038 (50.5%)	0.043
LR IFS	−0.034 (−43.8%)	0.032 (37.9%)	0.046
<i>H.L Coarse particles</i>			
LR 30	−0.132 (−81.8%)	0.045 (11.3%)	0.140
LR 50	−0.116 (−71.3%)	0.047 (17.2%)	0.125
LR 70	−0.101 (−61.7%)	0.050 (22.5%)	0.112
LR IFS	−0.109 (−67.4%)	0.048 (19.3%)	0.119
<i>H.L Fine particles</i>			
LR 30	−0.039 (−58.4%)	0.023 (29.2%)	0.045
LR 50	−0.024 (−35.1%)	0.029 (42.9%)	0.038
LR 70	−0.011 (−13.6%)	0.036 (54.6%)	0.037
LR IFS	−0.026 (−38.4%)	0.028 (41.1%)	0.038

Table S4. Mean and standard deviation (with relative values in parentheses) and RMSE of the AOD deviation between the forward retrieval and AERONET at Payerne, for four lidar ration configurations (fixed values of 30, 50 and 70 sr and the IFS–CAMS daily estimate) under different aerosol load and particle mode conditions..

Lidar Ratio	Mean (%)	STD (%)	RMSE
<i>All data</i>			
LR 30	−0.015 (−33.8%)	0.010 (13.2%)	0.018
LR 50	0.004 (13.2%)	0.009 (22.9%)	0.010
LR 70	0.026 (63.9%)	0.016 (33.3%)	0.030
LR IFS	0.002 (6.8%)	0.010 (24.5%)	0.011
<i>High aerosol load</i>			
LR 30	−0.029 (−35.7%)	0.019 (14.2%)	0.034
LR 50	0.005 (11.3%)	0.018 (24.9%)	0.018
LR 70	0.042 (64.2%)	0.022 (36.5%)	0.048
LR IFS	0.004 (7.6%)	0.018 (24.1%)	0.018
<i>H.L Coarse particles</i>			
LR 30	−0.097 (−57.3%)	0.042 (10.9%)	0.105
LR 50	−0.046 (−24.7%)	0.042 (19.4%)	0.062
LR 70	0.014 (13.3%)	0.046 (29.2%)	0.048
LR IFS	−0.018 (−7.4%)	0.045 (25.5%)	0.048
<i>H.L Fine particles</i>			
LR 30	−0.022 (−31.9%)	0.013 (13.2%)	0.026
LR 50	0.010 (17.6%)	0.014 (23.3%)	0.017
LR 70	0.045 (73.1%)	0.020 (34.5%)	0.049
LR IFS	0.006 (10.8%)	0.016 (23.9%)	0.017

Table S5. Mean and standard deviation (with relative values in parentheses) and RMSE of the AOD deviation between the backward retrieval and AERONET at Lindenberg, for four lidar ratio configurations (fixed values of 30, 50 and 70 sr and the IFS-CAMS daily estimate) under different aerosol load and particle mode conditions.

Lidar Ratio	Mean (%)	STD (%)	RMSE
<i>All data</i>			
LR 30	−0.021 (−37.1%)	0.024 (43.7%)	0.032
LR 50	−0.005 (−3.0%)	0.031 (64.1%)	0.032
LR 70	0.011 (30.3%)	0.039 (82.6%)	0.040
LR IFS	−0.008 (−11.5%)	0.030 (59.4%)	0.031
<i>High aerosol load</i>			
LR 30	−0.039 (−47.1%)	0.033 (35.3%)	0.051
LR 50	−0.018 (−18.8%)	0.041 (51.5%)	0.045
LR 70	0.002 (8.0%)	0.050 (65.5%)	0.050
LR IFS	−0.022 (−24.7%)	0.039 (47.5%)	0.045
<i>H.L Coarse particles</i>			
LR 30	−0.199 (−88.2%)	0.064 (9.9%)	0.209
LR 50	−0.184 (−81.8%)	0.068 (14.6%)	0.196
LR 70	−0.171 (−75.2%)	0.071 (18.8%)	0.185
LR IFS	−0.180 (−80.2%)	0.066 (13.7%)	0.192
<i>H.L Fine particles</i>			
LR 30	−0.030 (−41.0%)	0.028 (37.1%)	0.042
LR 50	−0.009 (−9.7%)	0.038 (53.6%)	0.039
LR 70	0.012 (20.0%)	0.047 (67.7%)	0.049
LR IFS	−0.013 (−16.8%)	0.036 (49.5%)	0.038

Table S6. Mean and standard deviation (with relative values in parentheses) and RMSE of the AOD deviation between the forward retrieval and AERONET at Lindenberg, for four lidar ratio configurations (fixed values of 30, 50 and 70 sr and the IFS–CAMS daily estimate) under different aerosol load and particle mode conditions..

Lidar Ratio	Mean (%)	STD (%)	RMSE
<i>All data</i>			
LR 30	−0.024 (−45.8%)	0.013 (12.1%)	0.027
LR 50	−0.005 (−8.9%)	0.011 (20.7%)	0.013
LR 70	0.016 (34.1%)	0.016 (30.7%)	0.022
LR IFS	−0.010 (−18.0%)	0.012 (20.0%)	0.015
<i>High aerosol load</i>			
LR 30	−0.037 (−45.8%)	0.019 (13.0%)	0.042
LR 50	−0.008 (−7.4%)	0.020 (22.6%)	0.021
LR 70	0.025 (37.4%)	0.024 (33.8%)	0.035
LR IFS	−0.013 (−14.5%)	0.018 (21.2%)	0.023
<i>H.L Coarse particles</i>			
LR 30	−0.168 (−73.2%)	0.049 (5.9%)	0.175
LR 50	−0.123 (−53.8%)	0.045 (10.5%)	0.131
LR 70	−0.067 (−29.7%)	0.043 (16.5%)	0.080
LR IFS	−0.097 (−44.6%)	0.045 (15.8%)	0.107
<i>H.L Fine particles</i>			
LR 30	−0.031 (−42.1%)	0.013 (11.3%)	0.033
LR 50	−0.002 (−1.0%)	0.014 (19.8%)	0.014
LR 70	0.032 (46.8%)	0.021 (30.0%)	0.038
LR IFS	−0.008 (−10.0%)	0.015 (20.5%)	0.016