Supplement of Atmos. Meas. Tech., 11, 925–938, 2018
https://doi.org/10.5194/amt-11-925-2018-supplement

Atmospheric Measurement Techniques
Open Access

Supplement of

Collocation mismatch uncertainties in satellite aerosol retrieval validation

Timo H. Virtanen et al.

Correspondence to: Timo H. Virtanen (timo.h.virtanen@fmi.fi)

DIST	Δt: 0.10 h				Δt: 0.25 h				Δt: 0.50 h			
(deg)	R	τ_{ADV}	τ_{AERO}	N	R	τ_{ADV}	τ_{AERO}	N	R	τ_{ADV}	τ_{AERO}	N
0.05	0.926	0.215	0.199	92	0.914	0.220	0.197	139	0.897	0.226	0.199	168
0.10	0.885	0.226	0.189	118	0.904	0.241	0.201	189	0.906	0.241	0.201	222
0.15	0.939	0.222	0.188	126	0.927	0.237	0.198	203	0.929	0.238	0.197	237
0.20	0.936	0.218	0.184	133	0.938	0.230	0.195	210	0.934	0.233	0.194	248
0.30	0.942	0.217	0.183	138	0.939	0.230	0.195	218	0.934	0.232	0.194	256
0.40	0.946	0.214	0.180	141	0.945	0.226	0.192	222	0.941	0.230	0.193	261
0.50	0.944	0.212	0.178	144	0.944	0.224	0.190	226	0.942	0.228	0.191	265
0.60	0.943	0.212	0.178	144	0.945	0.225	0.192	227	0.943	0.229	0.193	266
0.70	0.942	0.211	0.178	144	0.944	0.224	0.192	227	0.942	0.227	0.193	266
1.00	0.942	0.208	0.178	144	0.941	0.221	0.192	227	0.938	0.225	0.193	266
DIST	Δt: 1.00 h				Δt: 1.50 h				Δt: 2.00 h			
(deg)	R	τ_{ADV}	τ_{AERO}	N	R	τ_{ADV}	τ_{AERO}	N	R	τ_{ADV}	τ_{AERO}	N
0.05	0.882	0.228	0.202	189	0.875	0.229	0.199	196	0.868	0.234	0.199	203
0.10	0.894	0.249	0.206	256	0.893	0.249	0.204	265	0.888	0.251	0.203	273
0.15	0.921	0.249	0.204	273	0.920	0.248	0.201	284	0.915	0.250	0.201	293
0.20	0.929	0.243	0.201	285	0.929	0.242	0.198	296	0.916	0.246	0.197	307
0.30	0.923	0.243	0.201	294	0.922	0.246	0.201	308	0.916	0.249	0.199	319
0.40	0.935	0.241	0.201	300	0.935	0.244	0.201	314	0.926	0.248	0.200	326
0.50	0.934	0.239	0.199	304	0.936	0.244	0.201	320	0.925	0.250	0.201	333
0.60	0.937	0.239	0.201	305	0.936	0.245	0.202	321	0.926	0.250	0.203	334
0.70	0.936	0.238	0.201	305	0.935	0.244	0.202	321	0.925	0.249	0.203	334
1.00	0.933	0.236	0.201	305	0.934	0.241	0.202	321	0.924	0.247	0.203	334

Table S1: Dependence of the AOD correlation coefficient R, the average AOD of the matching cases for AATSR (τ_{ADV}) and for AERONET (τ_{AERO}), and the number of matches N on the sampling parameters d and Δt, as shown in Fig. 4.

DIST	Δt: 0.10 h				Δt: 0.25 h				Δt: 0.50 h			
(deg)	R_σ	σ_{ADV}	σ_{AERO}	N_σ	R_σ	σ_{ADV}	σ_{AERO}	N_σ	R_σ	σ_{ADV}	σ_{AERO}	N_σ
0.05	NaN	NaN	NaN	0	NaN	NaN	NaN	0	NaN	NaN	NaN	0
0.10	0.475	0.057	0.018	7	0.207	0.044	0.016	16	0.340	0.047	0.019	21
0.15	0.101	0.052	0.018	35	0.021	0.044	0.019	77	0.019	0.055	0.020	113
0.20	0.216	0.061	0.022	71	0.256	0.059	0.021	142	0.150	0.066	0.021	185
0.30	0.141	0.066	0.023	105	0.292	0.065	0.023	191	0.201	0.069	0.023	231
0.40	0.265	0.069	0.025	122	0.382	0.068	0.024	203	0.342	0.072	0.025	243
0.50	0.198	0.072	0.026	132	0.393	0.071	0.028	218	0.348	0.075	0.028	258
0.60	0.188	0.077	0.027	136	0.380	0.075	0.029	221	0.367	0.078	0.029	260
0.70	0.280	0.079	0.030	141	0.406	0.076	0.030	225	0.395	0.079	0.029	263
1.00	0.358	0.080	0.031	144	0.476	0.077	0.030	225	0.461	0.080	0.030	263
DIST	Δt: 1.00 h				Δt: 1.50 h				Δt: 2.00 h			
(deg)	R_σ	σ_{ADV}	σ_{AERO}	N_σ	R_σ	σ_{ADV}	σ_{AERO}	N_σ	R_σ	σ_{ADV}	σ_{AERO}	N_σ
0.05	NaN	NaN	NaN	0	NaN	NaN	NaN	0	NaN	NaN	NaN	0
0.10	0.258	0.054	0.020	26	0.392	0.061	0.018	28	0.304	0.063	0.018	30
0.15	0.021	0.067	0.022	142	0.056	0.066	0.020	148	0.022	0.066	0.020	156
0.20	0.284	0.070	0.023	224	0.235	0.070	0.021	238	0.179	0.071	0.022	248
0.30	0.353	0.072	0.024	272	0.348	0.072	0.023	288	0.253	0.074	0.023	300
0.40	0.505	0.076	0.026	283	0.507	0.077	0.025	297	0.470	0.079	0.026	309
0.50	0.473	0.078	0.028	298	0.475	0.079	0.026	314	0.462	0.080	0.027	327
0.60	0.476	0.082	0.029	301	0.467	0.083	0.027	320	0.461	0.084	0.028	333
0.70	0.511	0.084	0.030	305	0.488	0.084	0.028	321	0.491	0.086	0.028	334
1.00	0.572	0.085	0.030	305	0.551	0.086	0.028	321	0.558	0.087	0.028	334

Table S2: Dependence of the AOD variability correlation coefficient R_σ, the average spatial standard deviation of AOD over the matching cases for AATSR (σ_{ADV}) and for AERONET ($\sigma_{\mathrm{AERO}}^{\mathrm{NEAR}}$), and the number of matches N_σ on the sampling parameters d and Δt, as shown in Fig. 6. Here we have applied the thresholds $N_{\mathrm{ADV}} > 2$ and $N_{\mathrm{NEAR}} > 2$.

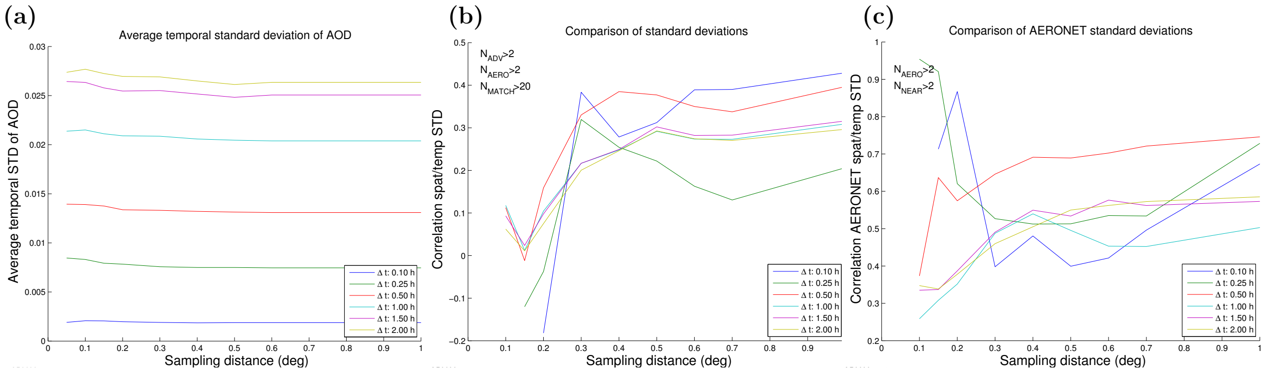

Figure S1: **(a)** Dependence of the standard deviation of AERONET AOD observations within the temporal sampling window on the sampling parameters. **(b)** Correlation between the temporal variability of AERONET AOD and the spatial variability of AATSR AOD (for collocated matches) as function of the sampling distance for various temporal sampling window sizes. Here we have required that the number of samples for AATSR and AERONET is at least 3 and the number of remaining matches is at least 20. **(c)** Same as (b), but for the spatial variability from nearby AERONET sites.

Date	Time		ΔAOD	AATSR			AERONET			MODIS		
	AATSR	MODIS		N	AOD	STD	N	AOD	STD	N	AOD	STD
06/03	15:30	16:50	0.04	124	0.11	0.065	9	0.07	0.004	31	0.06	0.041
06/08	15:46	15:30	0.02	110	0.30	0.086	20	0.29	0.031	45	0.40	0.063
06/30	15:40	16:30	0.04	118	0.12	0.095	26	0.08	0.016	35	0.06	0.051
07/11	15:37	16:15	0.00	103	0.43	0.084	24	0.43	0.035	89	0.51	0.078
07/14	15:27	16:45	0.06	79	0.11	0.080	30	0.05	0.010	34	0.04	0.038
07/19	15:44	-	0.13	27	0.73	0.139	8	0.60	0.128	-	-	-
07/22	15:34	15:55	-0.00	125	0.42	0.069	30	0.42	0.038	82	0.53	0.063
07/27	15:50	16:15	0.01	78	0.06	0.033	35	0.05	0.011	81	0.06	0.032
07/30	15:41	16:45	-0.01	101	0.09	0.051	34	0.10	0.017	23	0.12	0.044
08/02	15:31	15:35	0.05	119	0.21	0.112	28	0.16	0.050	47	0.27	0.089
08/07	15:47	-	-0.07	18	0.47	0.178	3	0.54	0.084	-	-	-
08/10	15:37	-	0.15	46	0.25	0.149	19	0.10	0.014	-	-	-

Table S3: Daily comparison of AATSR, AERONET, and MODIS results averaged over the whole study area, as shown in Fig. 7. 'Time' shows the AATSR overpass time and the corresponding value for the nearest MODIS Terra orbit with data. ΔAOD= $\tau_{\mathrm{AATSR}} - \tau_{\mathrm{AERO}}$, N is the number of valid pixels (AATSR and MODIS) or the number of sites with data at the overpass time (AERONET), 'AOD' is the AOD averaged over the whole area, and 'STD' is the standard deviation of AOD in the area. The AERONET data is first averaged over a one hour time window centered at the overpass time. For MODIS we use a single Terra orbit closest in time to the AATSR overpass.

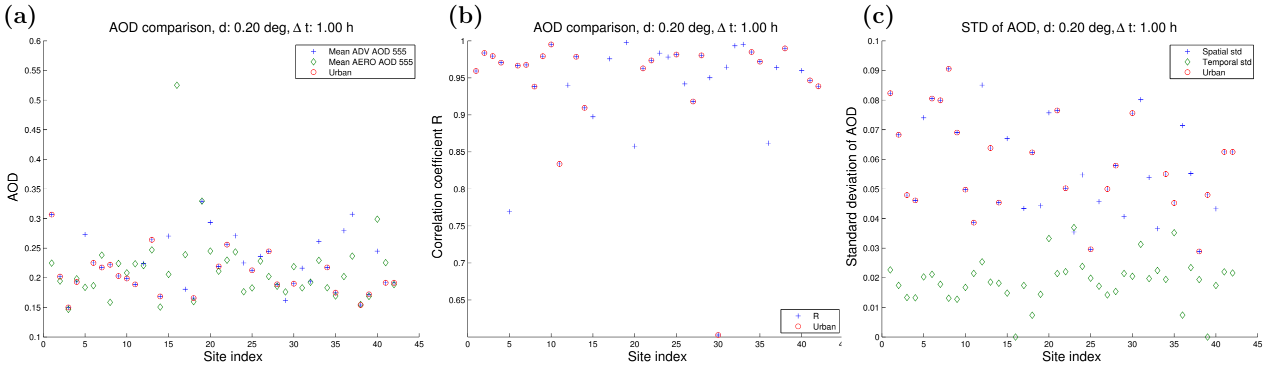

Figure S2: Comparison of AOD and standard deviation of AOD between AATSR and AERONET does not differ systematically between urban and rural sites. The urban sites are marked with red circles. **(a)** Average AATSR and AERONET AOD for individual sites over the study period. **(b)** The correlation coefficient R between AATSR and AERONET AOD for individual sites. For one of the sites (DRAGON_Padonia) the AOD correlation coefficient is particularly low (0.6) for the selected sampling parameters (d=0.2°, $\Delta t = 1$ h), but not necessarily for other sampling parameters. **(c)** The average spatial standard deviation of AOD for AATSR and the corresponding temporal standard deviation of AERONET AOD for individual sites.

Ind	Site name	URB	N_m	AATSR AOD	AATSR σ	AERO AOD	AERO σ	R	$\Delta\tau$
1	DRAGON_ABERD	1	9	0.31	0.08	0.22	0.02	0.96	0.08
2	DRAGON_ANNEA	1	8	0.20	0.07	0.19	0.02	0.98	0.01
3	DRAGON_ARNCC	1	10	0.15	0.05	0.15	0.01	0.98	0.00
4	DRAGON_ARNLS	1	7	0.19	0.05	0.20	0.01	0.97	-0.01
5	DRAGON_Aldino	0	13	0.27	0.07	0.18	0.02	0.77	0.09
6	DRAGON_BATMR	1	10	0.23	0.08	0.19	0.02	0.97	0.04
7	DRAGON_BLDND	1	11	0.22	0.08	0.24	0.02	0.97	-0.02
8	DRAGON_BLLRT	1	8	0.22	0.09	0.16	0.01	0.94	0.06
9	DRAGON_BLTCC	1	8	0.20	0.07	0.22	0.01	0.98	-0.02
10	DRAGON_BLTNR	1	8	0.20	0.05	0.21	0.02	1.00	-0.01
11	DRAGON_BOWEM	1	11	0.19	0.04	0.22	0.02	0.83	-0.03
12	DRAGON_BTMDL	0	9	0.22	0.09	0.22	0.03	0.94	0.00
13	DRAGON_Beltsville	1	10	0.26	0.06	0.25	0.02	0.98	0.02
14	DRAGON_CLLGP	1	10	0.17	0.05	0.15	0.02	0.91	0.02
15	DRAGON_CLRST	0	10	0.27	0.07	0.21	0.01	0.90	0.06
16	DRAGON_CPSDN	0	1	NaN	NaN	0.53	0.00	NaN	NaN
17	DRAGON_EDCMS	0	14	0.18	0.04	0.24	0.02	0.98	-0.06
18	DRAGON_ELLCT	1	3	0.17	0.06	0.16	0.01	NaN	0.01
19	DRAGON_EaglePoint	0	4	0.33	0.04	0.33	0.01	1.00	-0.00
20	DRAGON_Edgewood	0	14	0.29	0.08	0.25	0.03	0.86	0.05
21	DRAGON_Essex	1	13	0.22	0.08	0.21	0.02	0.96	0.01
22	DRAGON_FLLST	1	12	0.26	0.05	0.23	0.02	0.97	0.03
23	DRAGON_FairHill	0	13	0.27	0.04	0.24	0.04	0.98	0.03
24	DRAGON_KentIsland	0	10	0.22	0.05	0.18	0.02	0.98	0.05
25	DRAGON_LAUMD	1	5	0.21	0.03	0.18	0.02	0.98	0.03
26	DRAGON_MNKTN	0	10	0.24	0.05	0.23	0.02	0.94	0.01
27	DRAGON_OLNES	1	12	0.24	0.05	0.20	0.01	0.92	0.04
28	DRAGON_ONNGS	1	10	0.19	0.06	0.19	0.02	0.98	0.00
29	DRAGON_PATUX	0	9	0.16	0.04	0.18	0.02	0.95	-0.01
30	DRAGON_Padonia	1	7	0.19	0.08	0.22	0.02	0.60	-0.03
31	DRAGON_Pasadena	0	8	0.22	0.08	0.18	0.03	0.96	0.03
32	DRAGON_PineyOrchard	0	7	0.19	0.05	0.19	0.02	0.99	0.00
33	DRAGON_Pylesville	0	9	0.26	0.04	0.23	0.02	1.00	0.03
34	DRAGON_SPBRK	1	12	0.22	0.06	0.18	0.02	0.98	0.03
35	DRAGON_UMRLB	1	8	0.17	0.05	0.17	0.04	0.97	0.01
36	DRAGON_WSTFD	0	8	0.28	0.07	0.20	0.01	0.86	0.08
37	DRAGON_Worton	0	8	0.31	0.06	0.24	0.02	0.96	0.07
38	GSFC	1	9	0.15	0.03	0.15	0.02	0.99	-0.00
39	MD_Science_Center	1	3	0.17	0.05	0.17	0.00	NaN	0.00
40	SERC	0	6	0.24	0.04	0.30	0.02	0.96	-0.05
41	UMBC	1	10	0.19	0.06	0.23	0.02	0.95	-0.03
42	UMBC_temp	1	10	0.19	0.06	0.19	0.02	0.94	0.00
	Average	0.6	9.0	0.22	0.06	0.21	0.02	0.94	0.03
	Aver. (urban)	1.0	9.0	0.20	0.06	0.20	0.02	0.94	0.02
	Aver. (non-urban)	0.0	9.0	0.25	0.06	0.24	0.02	0.94	0.04

Table S4: AOD comparison between AATSR and individual AERONET sites in the study area for the study period. Column 'URB' is 1 for urban sites, 0 for non-urban sites. Column 'N_m' gives the number of matches i.e. the number of AATSR overpasses in cloud-free conditions. For AATSR we show the average AOD and the average spatial standard deviation. For AERONET we show the average AOD and the average temporal standard deviation. Column 'R' shows the correlation coefficient for the collocated AOD values, and $\Delta\tau$ shows the average difference in AOD. The averages over the columns are calculated for all sites, for the 25 urban sites, and for the 17 non-urban sites, respectively. The sampling parameters used in this comparison are d=0.20 °, Δt=1.00 h.

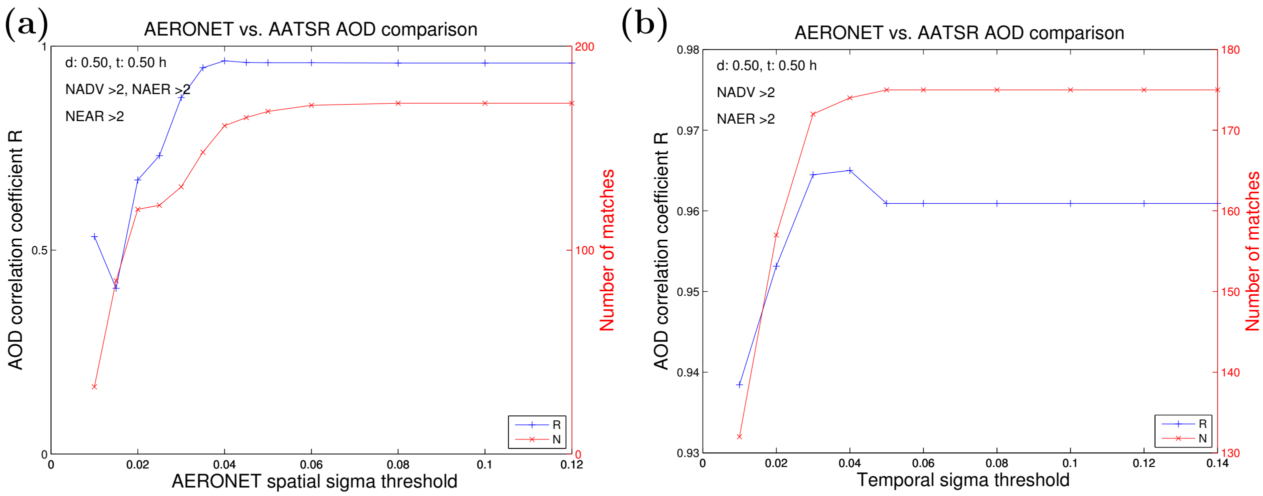

Figure S3: **(a)** Effect of spatial standard deviation threshold from AERONET data on the AOD correlation R. The blue line shows the AOD correlation coefficient R (left y-axis) and the red lines shows the number of remaining matches N (right y-axis) after the threshold has been applied. **(b)** Effect of temporal standard deviation threshold on the AOD correlation R. Here we have required that the number of samples is at least 3 when calculating the standard deviations.

N_{ADV}	N	R	N_{AERO}	N	R	σ_{RTOA}	N	R	N_{NEAR}	N	R
0	248	0.934	0	248	0.934	0.002	0	NaN	0	235	0.930
1	247	0.934	1	203	0.957	0.004	15	0.976	1	218	0.944
2	236	0.935	2	164	0.960	0.005	47	0.927	2	190	0.942
3	224	0.927	3	125	0.964	0.006	94	0.923	3	170	0.949
4	216	0.940	4	75	0.958	0.007	157	0.944	4	137	0.946
5	205	0.960	5	32	0.952	0.008	191	0.946	5	113	0.964
6	186	0.971	6	27	0.970	0.010	237	0.946	6	88	0.971
7	174	0.972	7	26	0.968	0.012	246	0.939	7	64	0.975
8	153	0.974	8	25	0.981	0.014	246	0.939	8	37	0.975
9	120	0.974	9	24	0.979	0.016	247	0.937	9	29	0.978
10	90	0.973	10	23	0.979	0.018	247	0.937	10	18	0.975
11	69	0.966				0.020	248	0.934			
12	39	0.945									

Table S5: The AOD correlation coefficients R and number of matches N when various thresholds are applied as shown in Fig. S4. Sampling distance is $d = 0.2°$ and $\Delta t = 0.5h$. Columns N_{ADV}, N_{AERO}, and N_{NEAR} give the lower thresholds for the corresponding parameters, while column σ_{RTOA} gives an upper threshold.

N_{ADV}	N_σ	R_σ	N_{AERO}	N_σ	R_σ	σ_{RTOA}	N_σ	R_σ	N_{NEAR}	N_σ	R_σ
0	265	0.325	0	265	0.325	0.002	0	NaN	0	265	0.325
1	265	0.325	1	219	0.224	0.004	1	NaN	1	263	0.397
2	262	0.393	2	178	0.267	0.005	40	0.843	2	260	0.389
3	259	0.415	3	138	0.248	0.006	145	0.583	3	256	0.364
4	259	0.415	4	83	0.407	0.007	205	0.578	4	247	0.334
5	258	0.411	5	33	0.226	0.008	241	0.541	5	241	0.313
6	256	0.362	6	28	0.260	0.010	251	0.413	6	239	0.312
7	255	0.361	7	27	0.288	0.012	265	0.325	7	237	0.309
8	254	0.355	8	26	0.394	0.014	265	0.325	8	236	0.307
9	252	0.347	9	25	0.408	0.016	265	0.325	9	236	0.307
10	249	0.347	10	24	0.308	0.018	265	0.325	10	234	0.317
11	248	0.343				0.020	265	0.325			
12	245	0.321									

Table S6: The AOD variability correlation coefficients R_σ and number of matches N_σ when various thresholds are applied as shown in Fig. S5. Sampling distance is $d = 0.5°$ and $\Delta t = 0.5h$. Columns N_{ADV}, N_{AERO}, N_{NEAR}, and σ_{RTOA} give the thresholds as explained in Table S5.

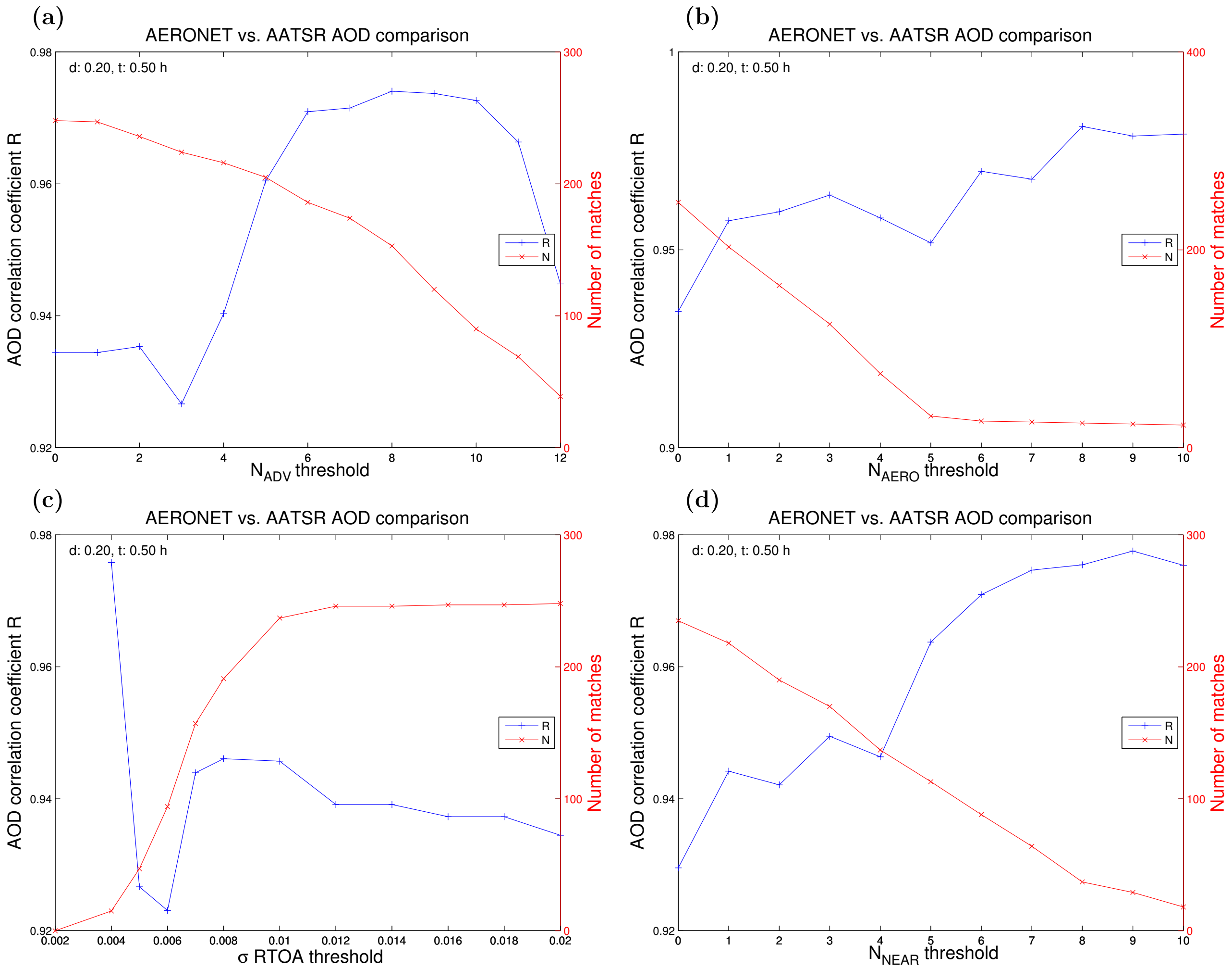

Figure S4: Effect of N_{ADV}, N_{AERO}, σ_{RTOA}, and $N_{\mathrm{AERO}}^{\mathrm{near}}$ thresholds on AOD comparison. The blue lines show the correlation coefficient (left y-axis) while the red lines show the number of matches between AATSR and AERONET (right y-axis). Sampling distance is $d = 0.2°$ and $\Delta t = 0.5h$. The numerical data is shown in Table S5.

Thresholds				AOD		Std of AOD	
N_{ADV}	N_{AERO}	N_{NEAR}	σ_{RTOA}	N	R	N_σ	R_σ
2	0	0	0.008	239	0.963	239	0.589
2	0	0	0.006	143	0.951	143	0.672
2	0	2	0.006	141	0.951	141	0.668
2	2	0	0.006	110	0.975	110	0.558
2	2	2	0.006	108	0.975	108	0.545
4	0	0	0.006	143	0.951	143	0.672

Table S7: Mixed thresholds optimized to improve AOD variability correlation for sampling parameters $d = 0.5°$, $\Delta t = 0.5$ h. Columns N_{ADV}, N_{AERO}, N_{NEAR}, and σ_{RTOA} give the thresholds as explained in Table S5. Column R shows the correlation coefficient between AATSR and AERONET AOD data, N is the number of matches for the AOD comparison, R_σ is the correlation between the AOD standard deviations in the sampling area calculated from AATSR and AERONET data, and N_σ is the corresponding number of matches. (N and N_σ are not necessary always the same since a minimum number of nearby sites is always required for calculating σ_{AOD}.)

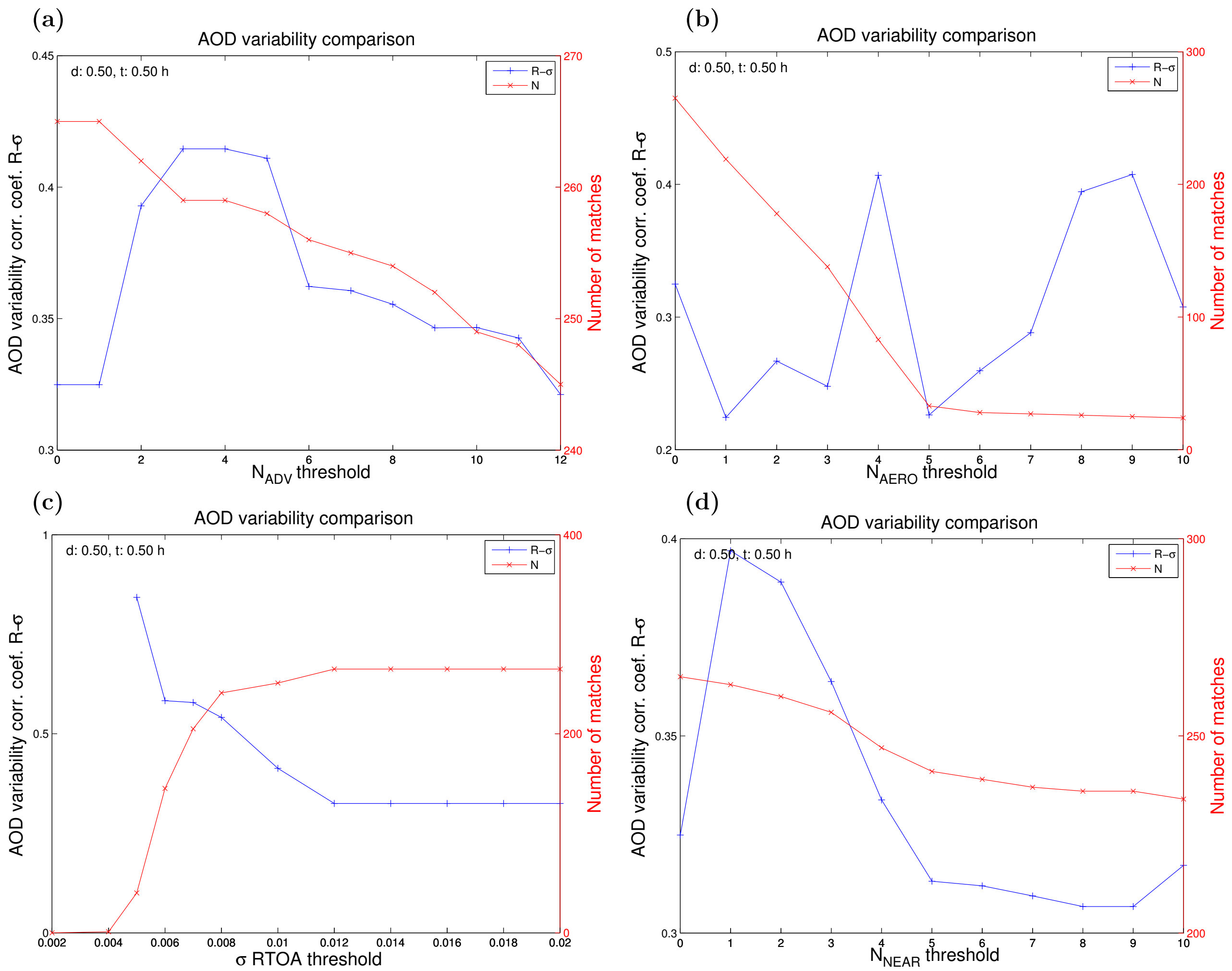

Figure S5: Same as Fig. S4, but for AOD variability (σ_{AOD}) comparison. Here we use a larger sampling radius $d = 0.5°$, and $\Delta t = 0.5h$. The numerical data is shown in Table S6.

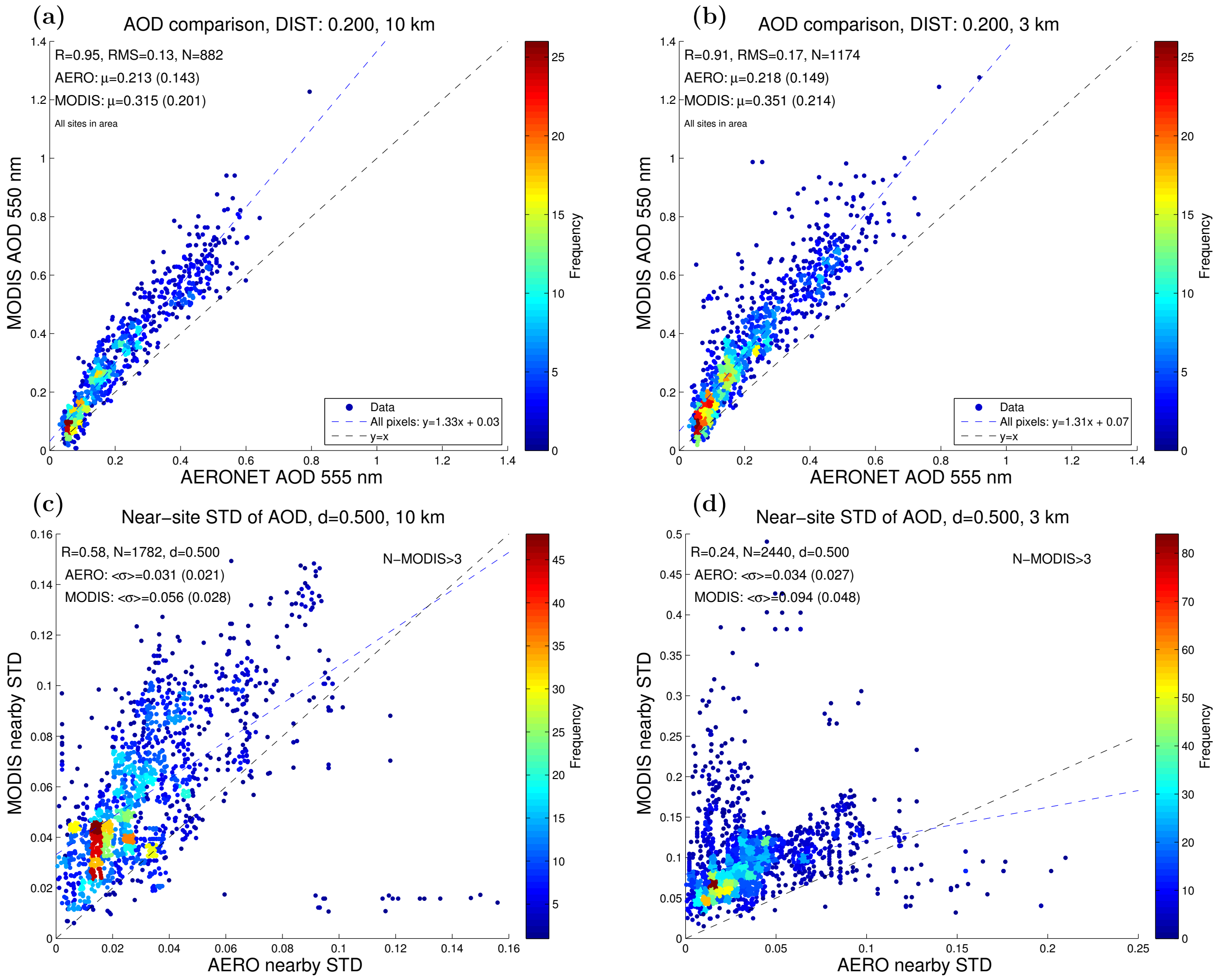

Figure S6: **(a)** Scatter plot of MODIS AOD against AERONET AOD with sampling distance 0.2° for the MODIS 10 km product. **(b)** The same for the 3 km product. **(c)** AOD variability scatter plot for the 10 km product with $d = 0.5°$ and the threshold $N_{\text{MODIS}} > 3$. **(d)** The same for the 3 km product.

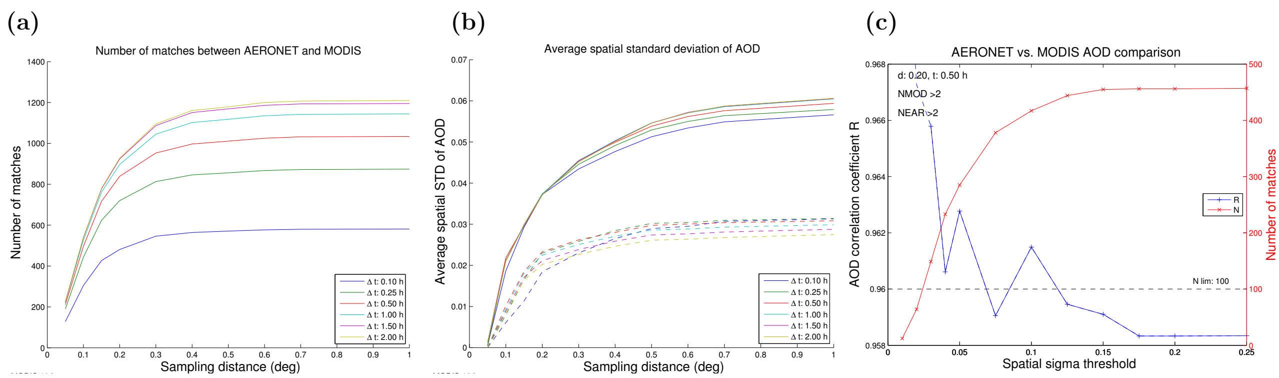

Figure S7: **(a)** Effect of sampling distance on the number of matches with AERONET for the MODIS 10 km product. **(b)** Dependence of the average standard deviation of AOD within the sampling area on the sampling distance. The solid lines are for MODIS, the dashed lines for AERONET. The colors indicate the different temporal sampling windows. **(c)** Effect of the AOD standard deviation threshold on the MODIS AOD comparison. Matches with MODIS AOD standard deviation higher than the threshold are removed. The AOD correlation coefficient R is then calculated for the remaining matches N.

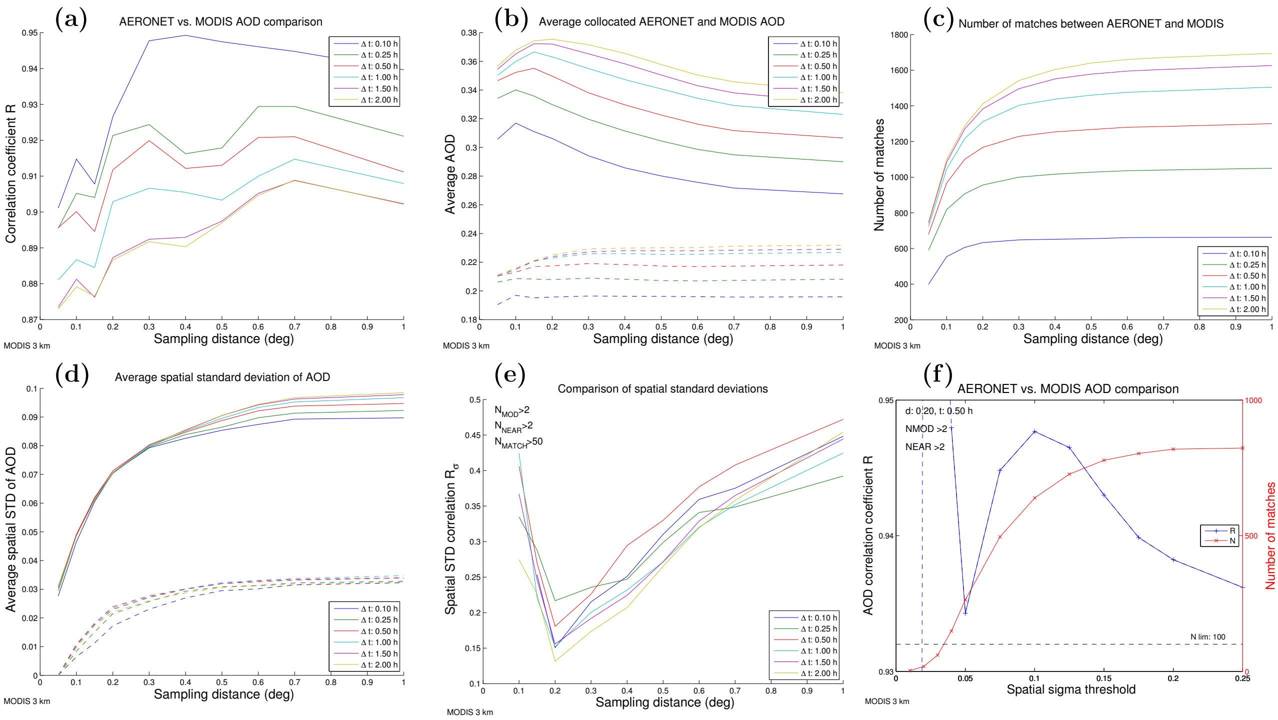

Figure S8: Effect of sampling distance on the MODIS 3 km AOD retrievals. For details, see Fig. 9 and Fig. S7.

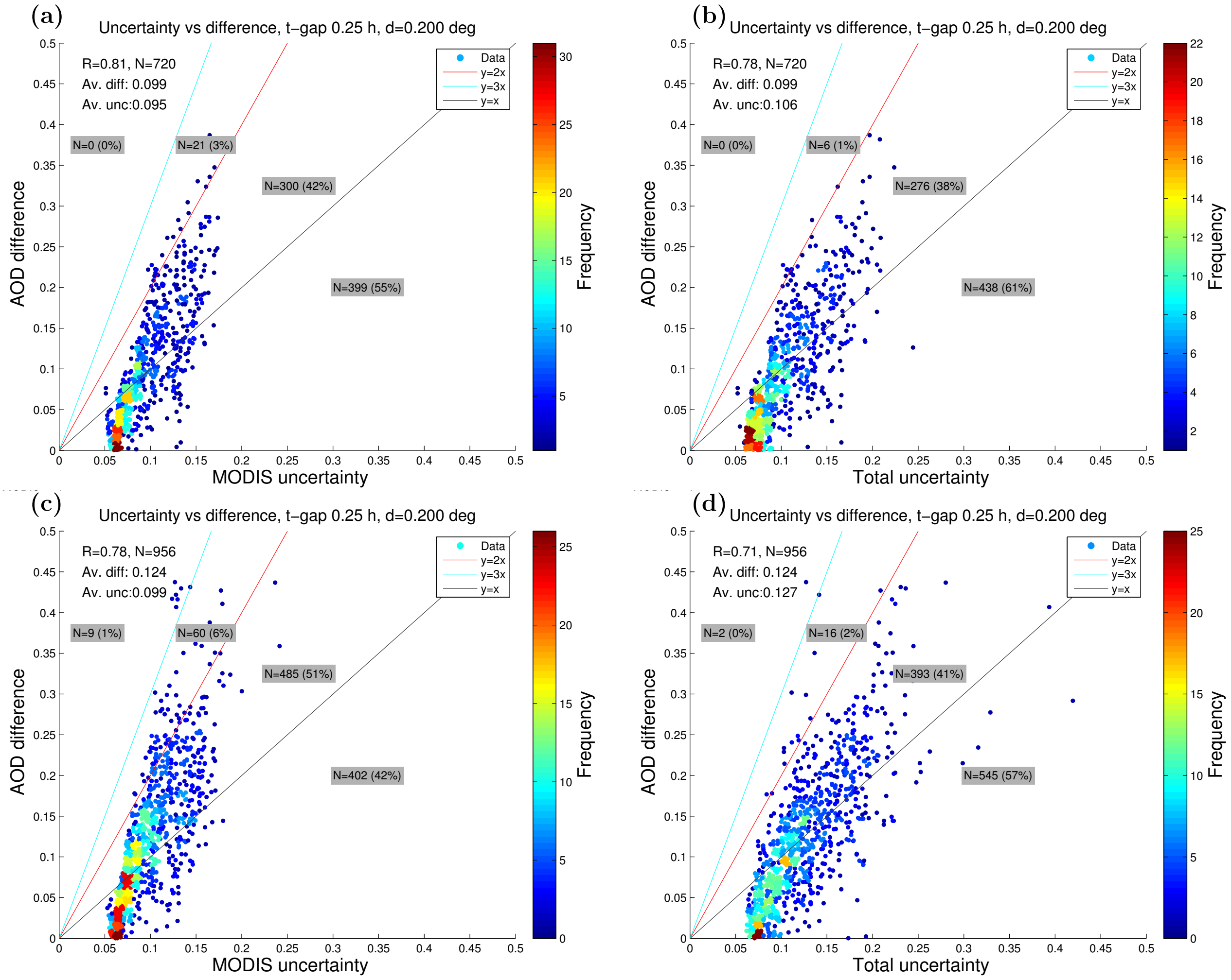

Figure S9: Scatter plot of MODIS AOD uncertainty against AOD error (difference to AERONET) for the MODIS 10 km product (top row) and the MODIS 3 km product (bottom row). Here we have used the 'expected error' values for the MODIS uncertainty. The colored lines correspond to different values of the coverage factor k (see Sect. 4.4). In the left panels we have used only the AOD uncertainties, while in the right panels the collocation mismatch uncertainty obtained from the MODIS data is included in the total uncertainty.

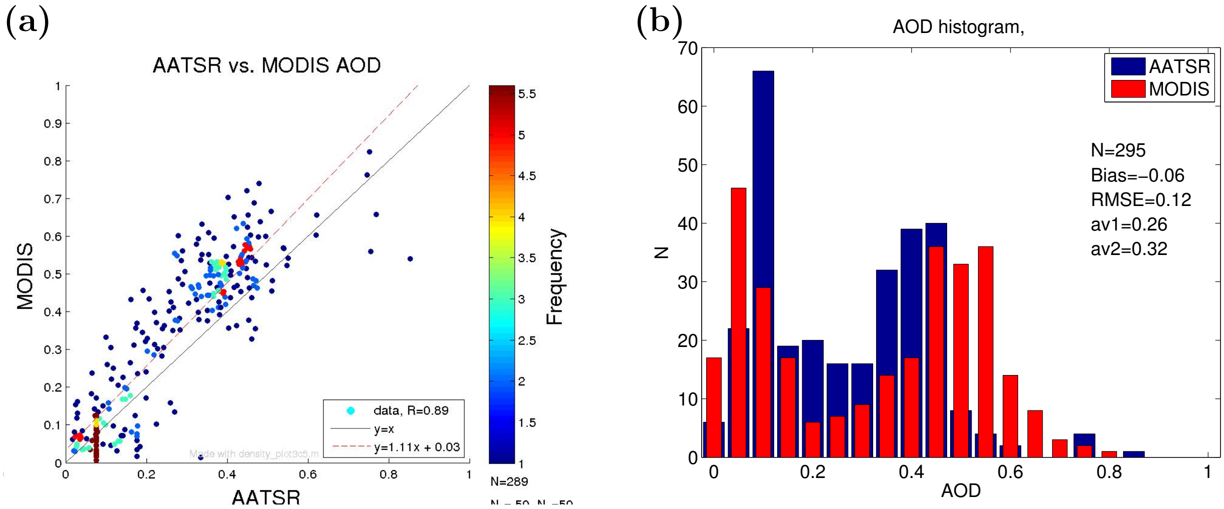

Figure S10: Comparison of collocated AATSR ADV and MODIS 10 km AOD values at 555 nm for the DRAGON 2011 campaign. The MODIS data has been resampled to the AATSR 0.1° grid. **(a)** Scatter plot of collocated AATSR and MODIS AOD values. The text inset shows the correlation coefficient R=0.89. **(b)** AOD histogram for AATSR and MODIS comparison. The average MODIS AOD of the collocated cases is 0.06 higher than AATSR AOD.