



*Supplement of*

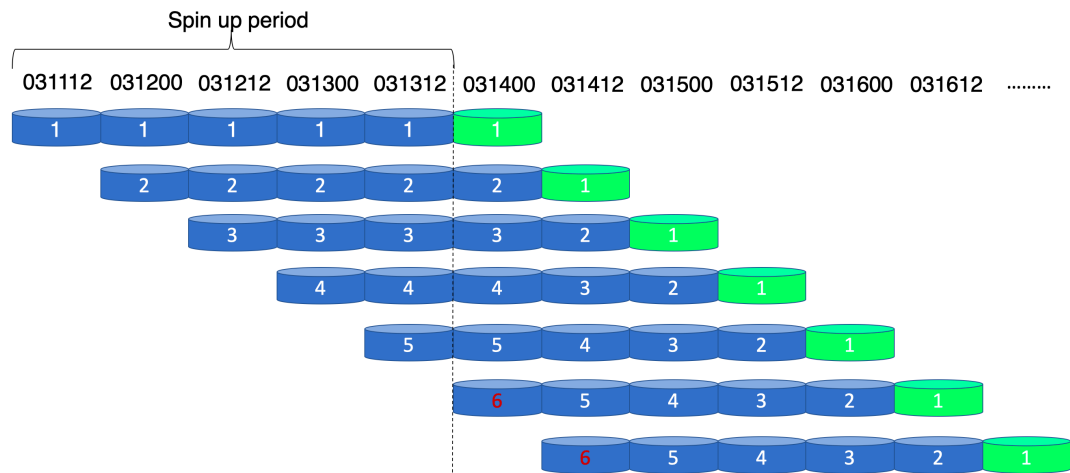
## **Improving estimation of a record-breaking east Asian dust storm emission with lagged aerosol Ångström exponent observations**

**Yueming Cheng et al.**

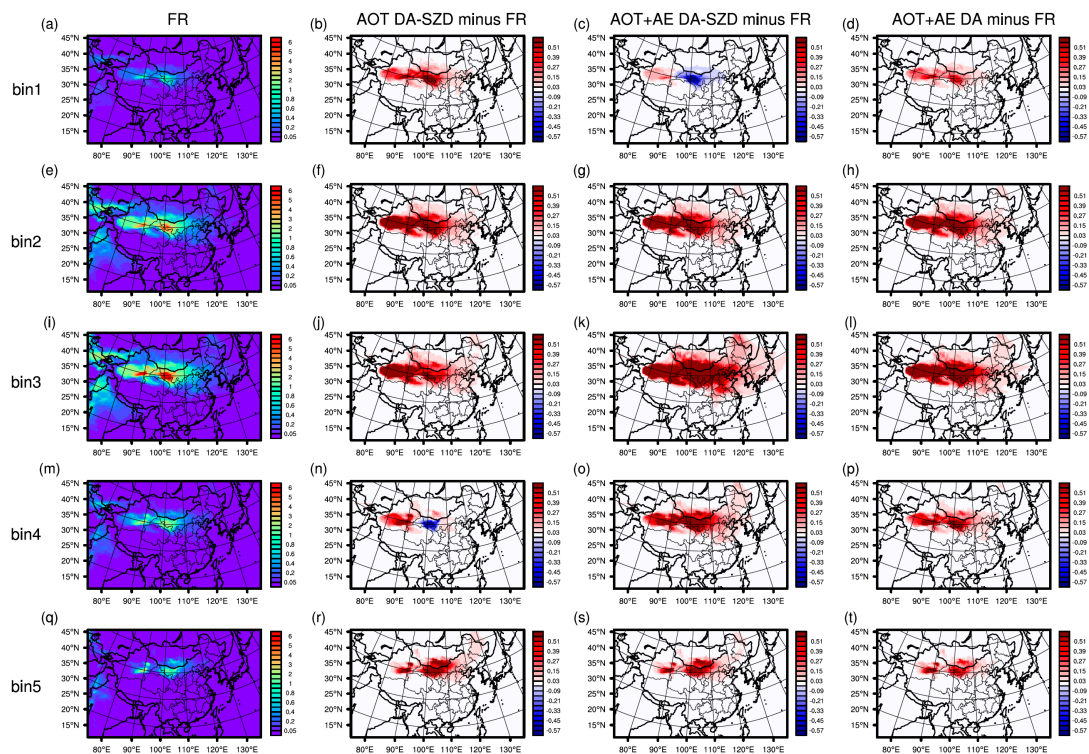
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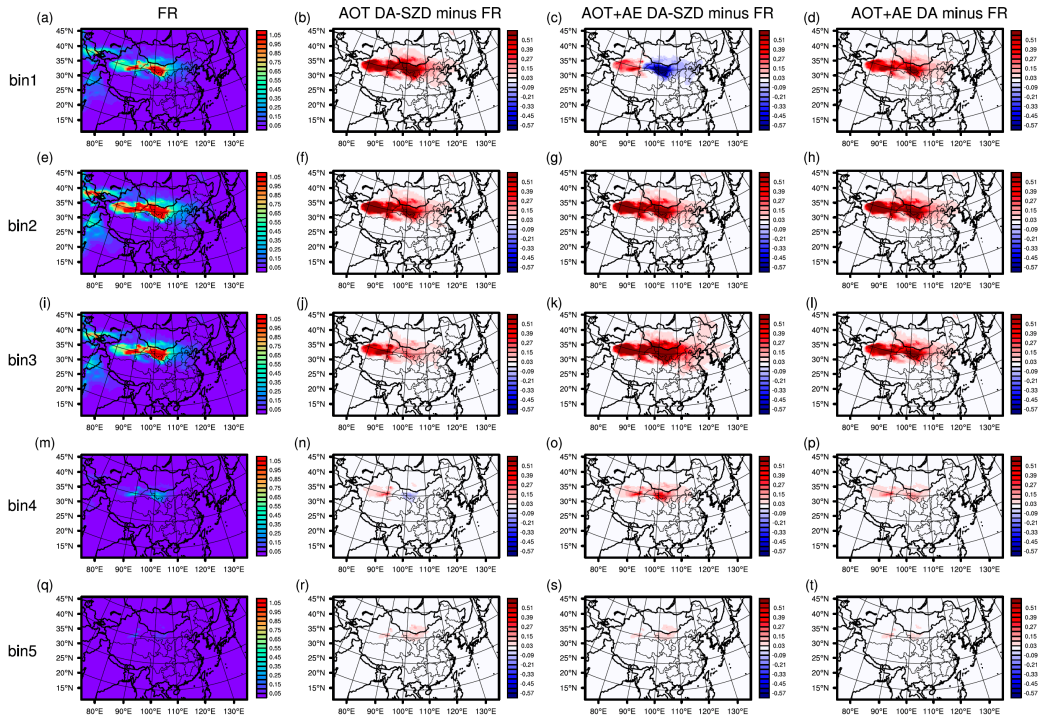
## Figures



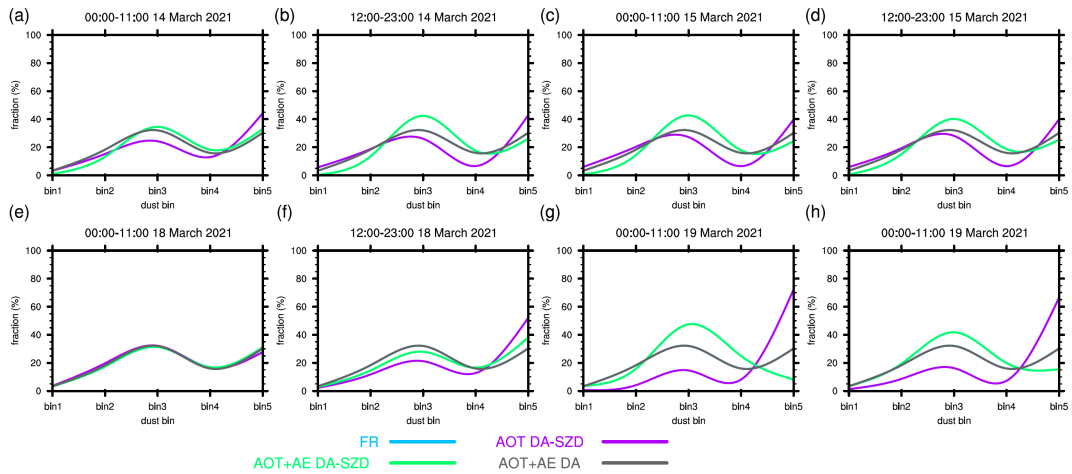
**Figure S1.** The flow chart of the Ensemble Kalman smoother system with a fixed-lag value  $N = 5$  for dust emission optimization. The number represents the time of emission optimization. The blue and green box represent the time window of emission optimization and the time window of assimilated time-lagged observations.



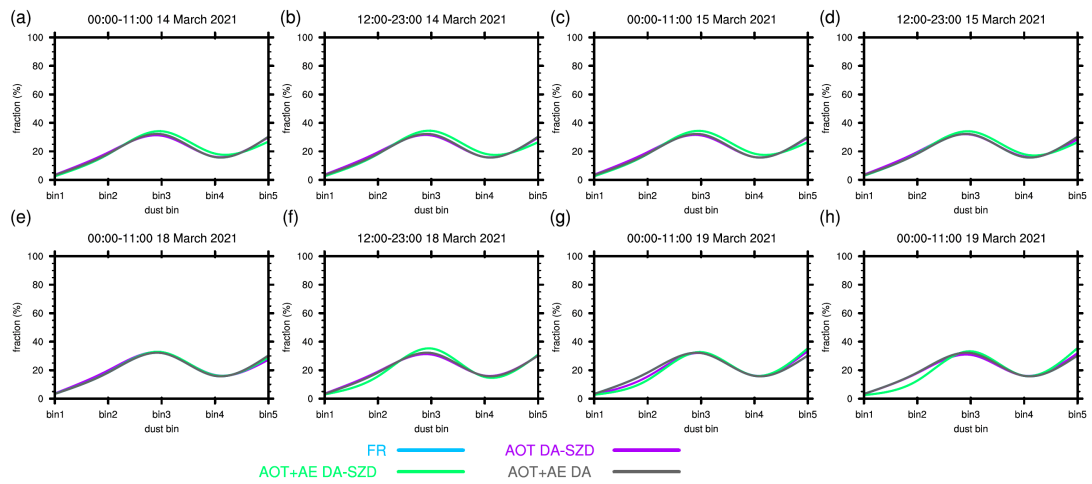
**Figure S2.** The simulated dust burden (units:  $\text{g m}^{-2}$ ) in the 5 dust size bins for FR experiment (a,e,i,m,q) during 14-17 March 2021. Difference of the dust burden between AOT DA-SZD (b,f,j,n,r), AOT+AE DA-SZD (c,g,k,o,s) and AOT+AE DA (d,h,l,p,t) experiments minus FR experiment.



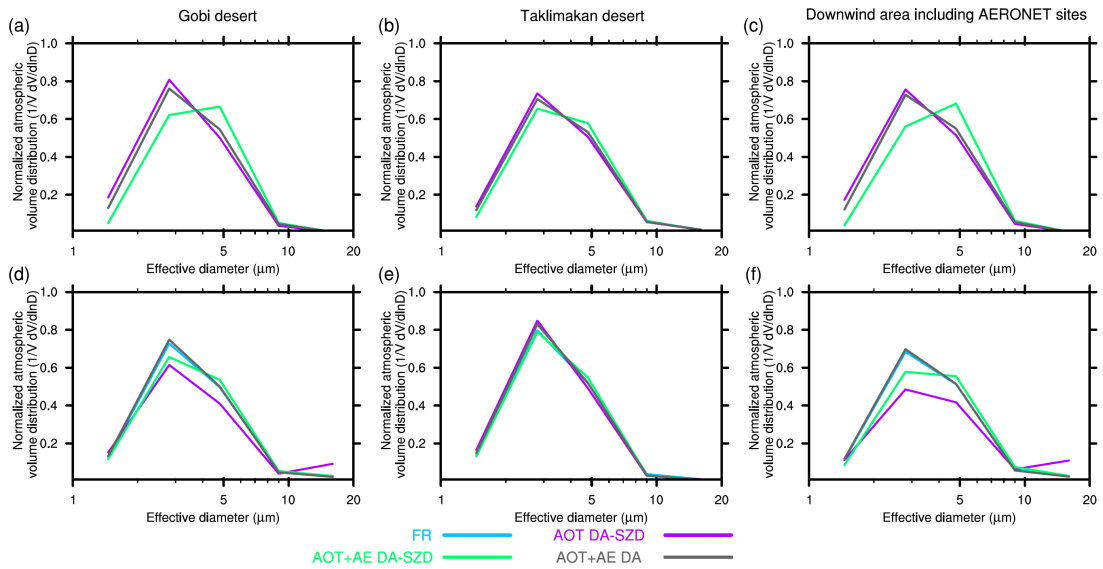
**Figure S3.** The simulated aerosol optical thicknesses (AOTs) in the 5 dust size bins for FR experiment (a,e,i,m,q) during 14-17 March 2021. Difference of the AOTs between AOT DA-SZD (b,f,j,n,r), AOT+AE DA-SZD (c,g,k,o,s) and AOT+AE DA (d,h,j,p,t) experiments minus FR experiment.



**Figure S4.** The fraction of the accumulated dust emission in each bin in Gobi desert for the four experiments during different periods.



**Figure S5.** Same as Fig. S4 but in Taklimakan desert.



**Figure S6.** Normalized atmospheric volume distribution in Gobi desert, Taklimakan desert, and downwind area including AERONET sites for the four experiments during 14-17 March 2021 and 18-23 March 2021.



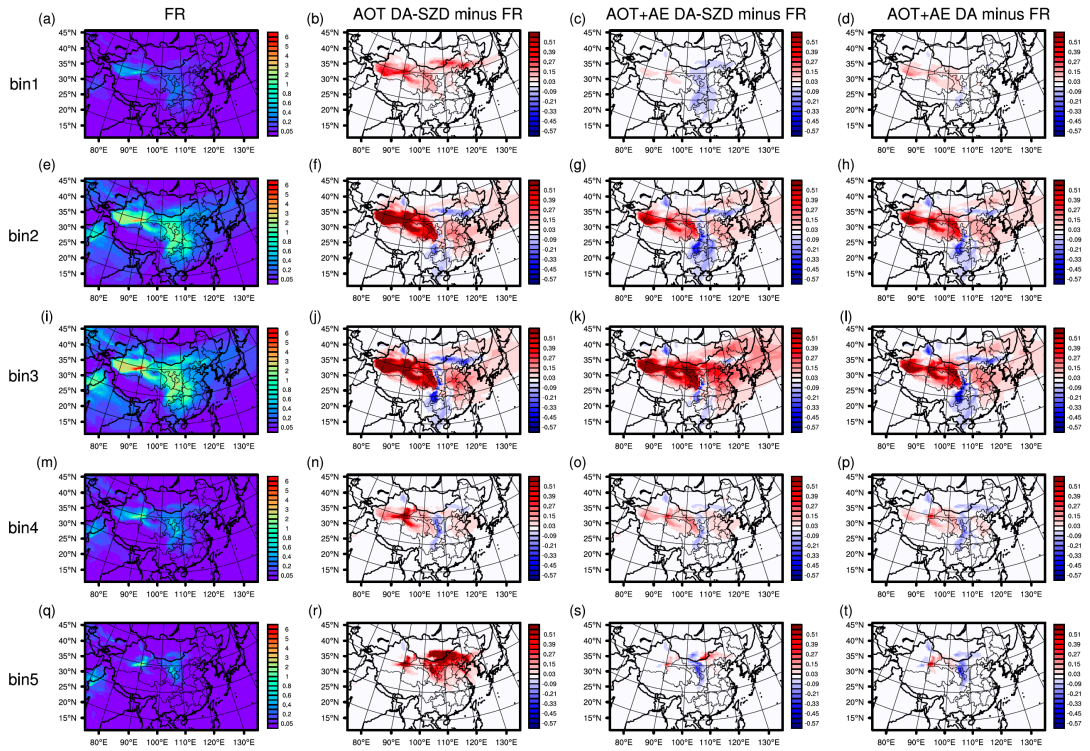


Figure S7. Same as Fig. S2 but during 18-23 March 2021.

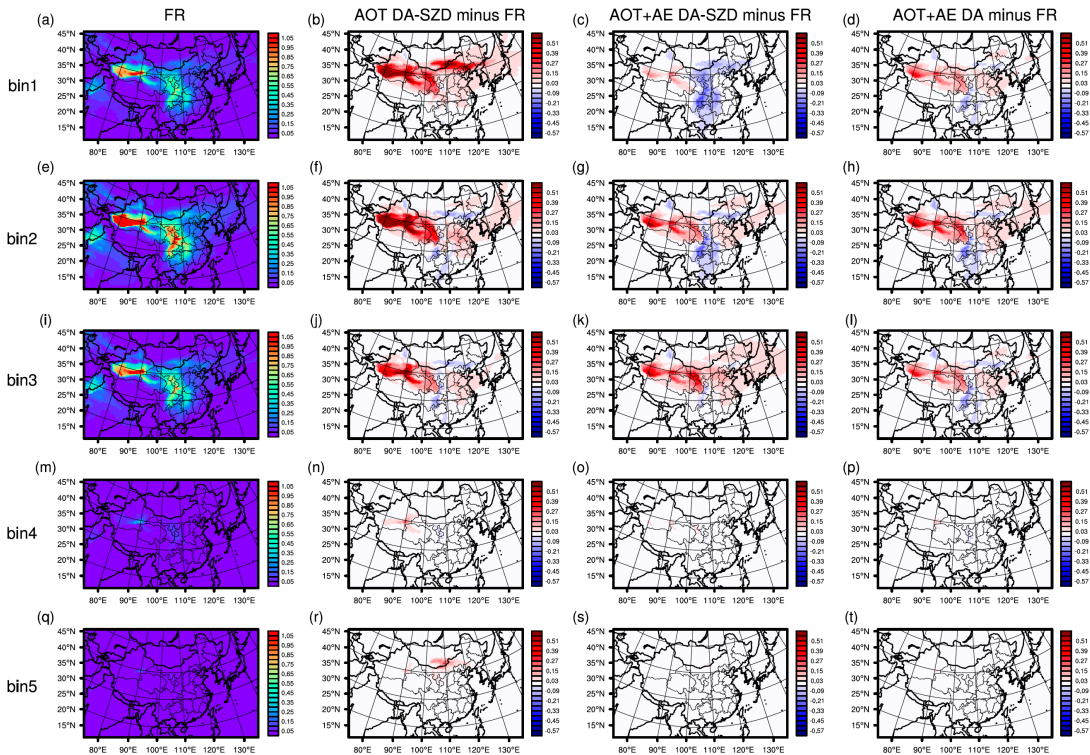
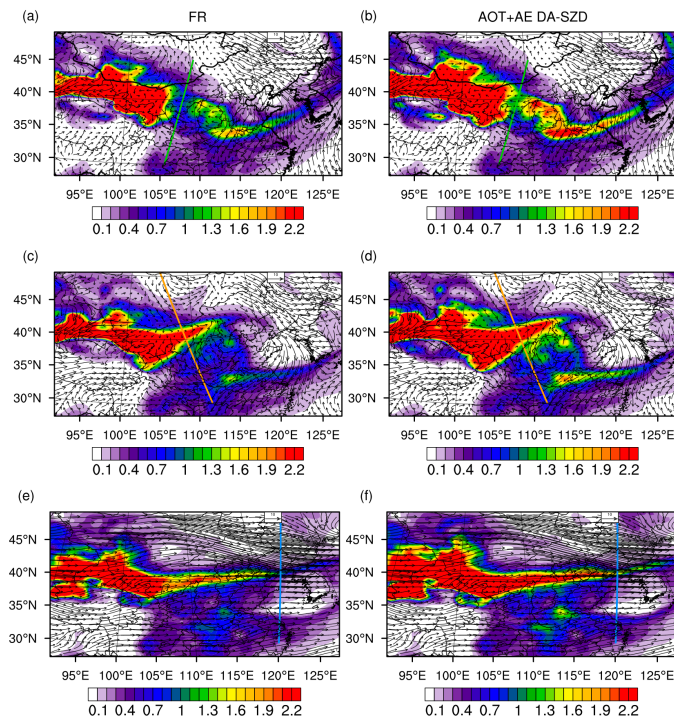


Figure S8. Same as Fig. S3 but during 18-23 March 2021.



**Figure S9.** The spatial distributions of the simulated AOTs at 550 nm at 19:00:00 (UTC) on 15 March 2021 in the FR (a) and AOT+AE DA-SZD (b) experiments. Vectors in (a-b) represent the simulated surface wind field ( $\text{m s}^{-1}$ ). (c-d) Same as (a-b) but at 06:00:00 (UTC) on 16 March 2021. Vectors in (c-d) also represent the simulated surface wind field ( $\text{m s}^{-1}$ ). (e-f) Same as (a-b) but at 18:00:00 (UTC) on 16 March 2021. Vectors in (e-f) also represent the simulated surface wind field ( $\text{m s}^{-1}$ ). The curve indicates the CALIPSO orbit paths in Fig. 11.

## Tables

**Table S1. Accumulated dust emission (units: Tg) in each dust bin for FR, AOT DA-SZD, AOT+AE DA-SZD, and AOT+AE DA experiments during 14-17 March 2021 and 18-23 March 2021 in Taklimakan desert and Gobi desert.**

14-17 March 2021	Taklimakan desert					Gobi desert				
	bin1	bin2	bin3	bin4	bin5	bin1	bin2	bin3	bin4	bin5
FR	0.47	2.62	4.59	2.28	4.33	0.71	3.93	6.88	3.43	6.50
AOT DA-SZD	0.96	5.09	8.31	4.27	7.52	1.50	5.62	8.18	3.02	13.71
AOT+AE DA-SZD	0.72	4.55	8.42	4.41	6.78	0.29	5.97	17.97	7.81	12.37
AOT+AE DA	0.81	4.47	7.82	3.89	7.39	1.10	6.07	10.61	5.29	10.03
18-23 March 2021	Taklimakan desert					Gobi desert				
	bin1	bin2	bin3	bin4	bin5	bin1	bin2	bin3	bin4	bin5
FR	0.36	1.99	3.48	1.73	3.29	0.43	2.39	4.18	2.08	3.95
AOT DA-SZD	0.66	3.60	5.90	3.04	5.06	0.15	1.27	2.96	1.95	12.51
AOT+AE DA-SZD	0.40	2.16	3.78	1.96	3.56	0.20	1.22	2.67	1.69	2.44
AOT+AE DA	0.41	2.25	3.94	1.96	3.72	0.28	1.57	2.75	1.37	2.60

**Table S2. The bias (BIAS) and root mean square error (RMSE) between simulated aerosol optical thicknesses (AOTs) for the four experiments and the observed ones from AERONET and SONET.**

BIAS	Beijing-CAMS	Beijing	Beijing_RA DI	Dalanzadgad	Beijing	Jiaozuo	Songshan	Yanqihu	Zhengzhou
FR	0.051	0.118	0.147	-0.206	0.112	-0.787	-0.276	0.249	-0.190
AOT DA-SZD	0.108	0.053	0.078	-0.063	0.101	-0.531	-0.013	-0.016	0.117
AOT+AE DA-SZD	0.111	0.044	0.067	-0.118	0.093	-0.515	-0.006	0.035	0.101
AOT+AE DA	0.111	0.052	0.077	-0.115	0.103	-0.529	0.019	-0.025	0.124
RMSE	Beijing-CAMS	Beijing	Beijing_RA DI	Dalanzadgad	Beijing	Jiaozuo	Songshan	Yanqihu	Zhengzhou
FR	0.287	0.370	0.431	0.462	0.387	0.812	0.643	0.453	0.516
AOT DA-SZD	0.343	0.310	0.308	0.256	0.292	0.552	0.643	0.286	0.527
AOT+AE DA-SZD	0.365	0.387	0.330	0.251	0.309	0.533	0.602	0.332	0.469
AOT+AE DA	0.345	0.318	0.316	0.246	0.297	0.550	0.646	0.296	0.527

**Table S3. Same as Table S2 but for Ångström Exponents (AEs).**

BIAS	Beijing-CAMS	Beijing	Beijing_RA DI	Dalanzadgad	Beijing	Jiaozuo	Songshan	Yanqihu	Zhengzhou
FR	0.225	0.205	0.211	0.056	0.195	0.295	0.230	0.288	0.200
AOT DA-SZD	0.174	0.158	0.158	0.115	0.140	0.305	0.216	0.181	0.174
AOT+AE DA-SZD	0.111	0.109	0.115	0.004	0.091	0.111	0.087	0.150	0.054
AOT+AE DA	0.195	0.189	0.194	0.071	0.171	0.252	0.189	0.256	0.157
RMSE	Beijing-CAMS	Beijing	Beijing_RA DI	Dalanzadgad	Beijing	Jiaozuo	Songshan	Yanqihu	Zhengzhou
FR	0.254	0.236	0.238	0.158	0.230	0.296	0.314	0.291	0.221
AOT DA-SZD	0.222	0.200	0.202	0.222	0.195	0.307	0.313	0.218	0.231
AOT+AE DA-SZD	0.151	0.151	0.149	0.118	0.128	0.113	0.233	0.155	0.071
AOT+AE DA	0.222	0.218	0.219	0.157	0.199	0.253	0.281	0.256	0.186