

Table S1. Key parameterization schemes adopted in the WRF-Chem simulation

Parameterization	Scheme
Surface layer	Revised MM5
Land surface	Unified Noah
Radiative transfer (SW)	RRTMG
Radiative transfer (LW)	RRTMG
Boundary layer	Yonsei University (YSU)
Cumulus option	Grell 3D
Microphysics	Morrison 2-moment
Dust emissions	GOCART
Aerosol chemistry	GOCART/RACM

Table S2. Statistical scores ( $R^2$ , MB, and RMSE) were calculated for daily AOD time series from WRF-Chem, MERRA-2, and CAMS for AERONET AOD observations.

Sites/Scores	WRF-Chem			CAMS			MERRA-2		
	$R^2$	MB	RMSE	$R^2$	MB	RMSE	$R^2$	MB	RMSE
Beijing	0.593	0.242	0.550	0.600	0.176	0.767	0.537	0.030	0.684
Dhaka	0.478	0.445	0.635	0.505	-0.009	0.529	0.462	-0.161	0.516
Kanpur	0.278	0.341	0.470	0.459	-0.069	0.432	0.483	-0.223	0.456
Lumbini	0.535	0.506	0.591	0.780	0.002	0.404	0.742	-0.217	0.415
Karachi	0.257	0.341	0.470	0.535	-0.364	0.467	0.279	-0.019	0.299
Langtang	0.572	-0.001	0.021	0.837	0.044	0.064	0.890	0.133	0.192
Qoms	0.411	-0.051	0.168	0.872	0.029	0.088	0.462	0.011	0.083
Namco	0.398	0.037	0.044	0.575	-0.006	0.030	0.775	-0.021	0.031
Mezaira	0.137	0.193	0.274	0.451	-0.149	0.275	0.543	0.223	0.377
Dushanbe	0.425	0.241	0.292	0.556	-0.195	0.267	0.436	-0.037	0.207

Table S3. The formula used for calculating statistical scores ( $R^2$ , MB, and RMSE)

RMSE	MB	$R^2$
$\sqrt{\frac{\sum_{i=1}^N (M_i - O_i)^2}{N}}$	$\frac{1}{N} \sum_{i=1}^N (M_i - O_i)$	$\frac{1}{N-1} \sum_{i=1}^N \left( \frac{M_i - m}{\sigma_M} \right) \left( \frac{O_i - o}{\sigma_o} \right)$

Here, the metrics calculated, with  $N$ ,  $M_i$ ,  $O_i$ ,  $m$ ,  $o$ ,  $\sigma_M$ , and  $\sigma_o$  are the number of observation and model data, model value, observed value, model mean, observed mean, and standard deviation model/observed, respectively