Multi-model simulations of springtime dust storms in East Asia: Implications of an evaluation of four commonly used air quality models (CMAQ, CAMx, CHIMERE, and WRF-chem)

Supplementary Materials

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1 Comparison of wind speed with different land surface schemes in WRF

The modeling results showed the wind speed of two schemes changed similarly while their differences often appeared near the extreme values and generally larger than measurements (Fig. S1). The mean root mean square error (RMSE) between two schemes and measurements were 1.52 m/s (for Noah-MP scheme) and 1.61 m/s (for Pleim-Xiu scheme) respectively and the differences could not pass the significance t-test. Their correlation coefficients were both 0.8, passing the significance test at 0.01 level. These comparisons showed close results between two schemes, however, the Noah scheme had a larger standard deviation showing higher dispersion than PX scheme. Therefore in the following study, the physical parameterization schemes used in the WRF model were WRF Double-Moment 6-class microphysics scheme, the Rapid Radiative Transfer Model for GCMs (RRTMG) longwave and shortwave radiation scheme, Pleim-Xiu scheme for surface layer and land-surface scheme, ACM2 (Pleim) boundary layer scheme, and Grell-Devenyi ensemble cumulus scheme.

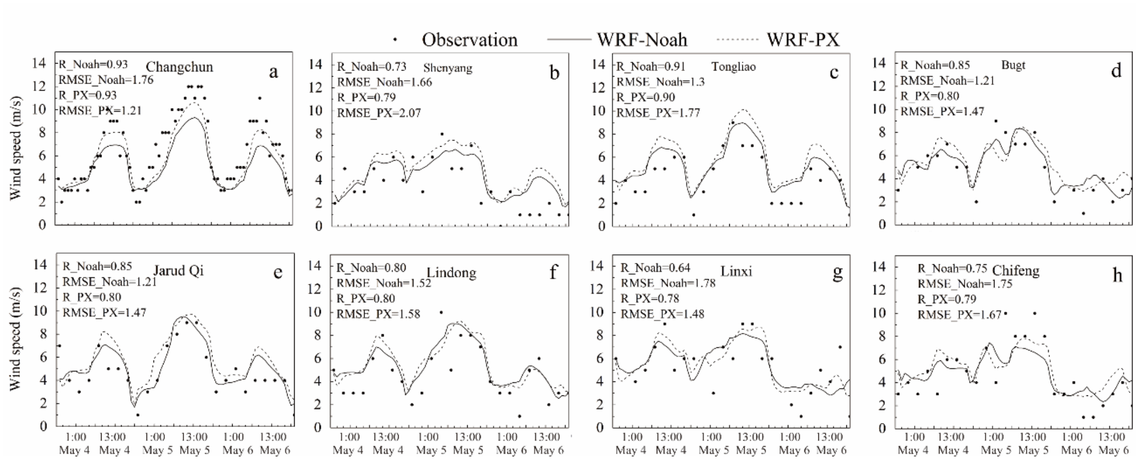

Figure S1. Wind speed hourly variations and the correlation coefficient between observation and WRF simulation with land surface scheme of Noah and Pleim-Xiu respectively wind speed in each sites (WRF-Noah indicated the simulating results with Noah land surface scheme while WRF-PX indicated the results with Pleim-Xiu, the observation wind speed were hourly data in Changchun station while in other sites were available every 3 h.)

2 Dust mask in CAMx model

The dust mask map used in CAMx, which is similar to the dust source map, only has two values: 0 indicating no erodible dust potential while 1 dust emitting capacity in the grid cell. Dust flux will be calculated with the clay fraction-dependent vertical-to-horizontal dust flux ratio (Fig. S2a). However, no dust erodible area was recorded for the region of Northeastern China in this dust mask file (Fig. S2b). Therefore, no further evaluation was conducted for the dust emission scheme in CAMx.

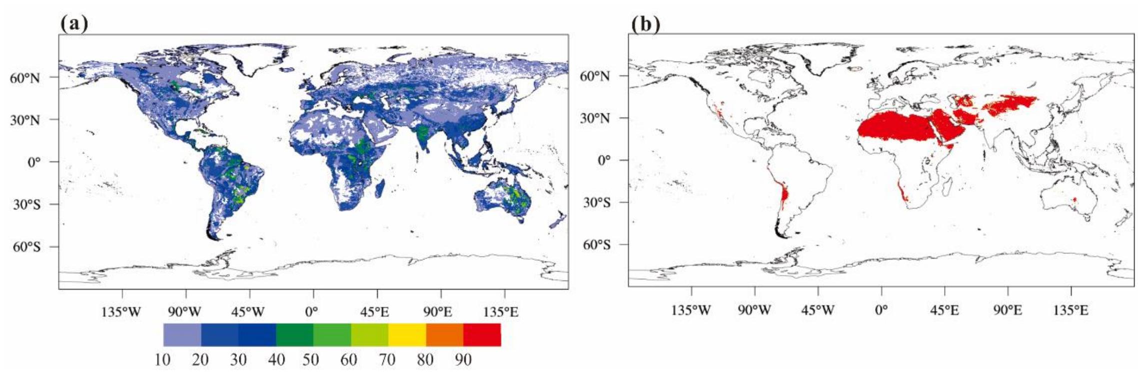

Figure S2. The global distribution of clay fraction (%) in top 4.5 cm soil layer (**a**) and dust mask (**b**).

3 Inter-model Comparisons

The correlation coefficients, biases and errors between simulations with each dust scheme and observations in four sub-areas are quite different. Generally, the simulations performed the best in the sub-area of CTA while showed lowest CORR in NWA. For the 12 simulations, UOC_Shao2011 (s11 in Table S2) yielded the highest CORR values, of up to 0.82, among the four dust schemes in WRF-Chem, and the UOC_Shao2011 simulation with dust source map G12_0.1_seasonal (g12 in Table S2) showed the strongest correlation of all. CHIMERE and CMAQ yielded CORR values ranging from 0.43 to 0.76, with good correlations in all three areas. Although the CORRs of WRF-Chem with GOCART were the lowest among all schemes, that combination yielded very low NSDs and RMSEs, showing that simulated concentrations were closer to the measurements. AFWA yielded relatively low NSDs and RMSEs in CTA and NEA, but the highest values in sub-area SWA. UOC_Shao2011 in CTA and NEA yielded the highest deviations. The NMBs and NMEs of the WRF-Chem simulations were lower in the CTA and SWA sub-areas than in the other two sub-areas. Finally, CHIMERE yielded the lowest NMB (near zero) and an NME <75%, while the NMB and NME for CMAQ were slightly larger.

Table S1 Statistic parameters for each simulation

Region	Parameter	chem_gocart_g01	chem_gocart_k08	chem_gocart_g12	chem_afwa_g01	chem_afwa_k08	chem_afwa_g12
CTA	CORR	0.27	0.46	0.64	0.73	0.63	0.79
	RMSE	245.76	291.63	191.67	291.52	237.43	169.07
	NMB	-0.18	1.13	0.12	1.34	0.92	0.38
	NME	79.11	160.16	66.45	146.88	116.00	64.81
	BIAS	-46.64	160.16	1.48	208.02	129.50	49.12
	NSD	0.36	1.09	0.48	2.62	1.32	1.33
SWA	CORR	0.21	0.15	0.35	0.38	0.17	0.46
	RMSE	101.37	129.51	89.26	186.82	111.39	112.87
	NMB	0.06	0.41	0.26	1.24	0.23	0.54
	NME	71.66	45.91	62.71	142.18	70.43	79.06
	BIAS	1.84	45.91	22.55	130.20	26.86	52.59
	NSD	0.89	1.71	1.14	3.74	1.21	2.48
NEA	CORR	0.28	0.49	0.71	0.53	0.53	0.78
	RMSE	188.16	229.21	136.18	200.94	242.70	110.43
	NMB	-0.72	1.59	-0.24	0.99	1.55	-0.03
	NME	76.59	155.32	57.13	135.47	180.73	52.07
	BIAS	-93.81	155.32	-37.37	103.45	154.54	-9.10
	NSD	0.04	0.96	0.17	1.23	1.76	0.50
NWA	CORR	0.30	0.10	0.33	0.19	0.17	0.42
	RMSE	34.10	206.11	35.79	155.95	192.70	39.83
	NMB	-0.55	5.35	0.35	3.58	4.54	0.34
	NME	63.31	173.97	70.81	374.11	464.72	74.77
	BIAS	-18.91	173.97	14.42	119.80	147.57	15.32
	NSD	0.24	48.62	1.28	38.74	70.17	2.47

Region	Parameter	chem_s11_g01	chem_s11_k08	chem_s11_g12	chim_ierod3	cmaq	cmaq_agland
CTA	CORR	0.68	0.76	0.76	0.73	0.77	0.71
	RMSE	534.95	210.93	232.37	179.84	232.18	303.64
	NMB	-0.17	-0.07	1.56	0.10	0.16	0.45
	NME	126.11	68.59	72.02	63.72	68.61	84.86
	BIAS	61.35	-49.36	-22.97	4.61	7.49	60.39
	NSD	12.24	1.63	2.43	1.04	2.31	3.89
SWA	CORR	0.42	0.47	0.46	0.51	0.45	0.43
	RMSE	127.89	97.92	92.97	104.79	151.89	191.91
	NMB	-0.63	-0.51	1.25	0.34	0.59	0.94
	NME	77.00	69.43	65.40	68.83	87.60	110.08
	BIAS	-20.24	-66.08	-53.47	31.60	56.07	92.57

	NSD	3.32	0.44	0.82	3.42	4.20	5.87
NEA	CORR	0.60	0.78	0.81	0.62	0.71	0.67
	RMSE	227.96	319.06	266.62	156.00	143.50	139.10
	NMB	0.97	0.54	2.24	-0.53	-0.19	-0.05
	NME	95.36	134.61	102.22	66.09	68.48	66.53
	BIAS	-12.75	75.70	39.01	-62.59	55.05	56.91
	NSD	3.28	8.02	6.09	0.16	0.12	0.21
NWA	CORR	0.53	0.38	0.47	0.37	0.44	0.42
	RMSE	48.11	80.28	59.02	47.32	76.51	79.05
	NMB	1.29	0.29	5.14	0.20	1.78	1.77
	NME	79.03	160.88	90.34	81.64	190.27	187.65
	BIAS	-3.60	41.08	11.83	11.33	32.97	51.26
	NSD	7.97	19.68	11.53	3.72	5.72	6.61

The calculation of the threshold velocity (u_{*t}) is based on dust particle size, following Shao and Lu (2000) (SL) in the present CMAQ version. According to the source code, the dust is divided into 4 particle sizes depending on soil texture types, namely coarse sand, fine-medium sand, silt, clay. Table S2 provides the values of u_{*t} from SL scheme and constants in earlier CMAQ version. It shows significant differences between these two methods, and considering the main erodible land-use types are cropland and barren land in Northeastern China, the u_{*t} from SL is generally 1~3 times larger than the constant u_{*t} except the soil texture of silt. This would lead to large discrepancies when calculating the dust horizontal flux.

Table S2 Threshold friction velocity (m s^{-1}) from Shao and Lu scheme and constants in earlier CMAQ version

Mean mass median particle diameter (m)	Description	Shao and Lu, 2000	u_{*t} constants		
			shrubland	shrubgrass land	barren land/cropland
6.90×10^{-4}	Coarse sand	0.427	0.34	0.34	0.23
2.10×10^{-4}	Fine-medium sand	0.250	0.47	0.47	0.24
1.25×10^{-4}	Silt	0.214	0.22	0.22	0.71
2.00×10^{-6}	Clay	0.910	0.42	0.42	0.29

References

Shao, Y. and Lu, H.: A simple expression for wind erosion threshold friction velocity, J. Geophys. Res. Atmos., 105(D17), 22437–22443, doi:10.1029/2000JD900304, 2000.