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Supplement of

Improving prediction of trans-boundary biomass burning plume dispersion: from northern peninsular Southeast Asia to downwind western North Pacific Ocean

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Section A. Model verification for modelled weather field

In the following formulas, M_i, O_i, $\bar{O}$ represent simulated value of record i, observed value of record i, mean of observed values for 1 to N. N are total number of records.

$$\text{Mean Bias (MB): MB} = \frac{1}{N}\sum_{i=1}^{N}(M_i - O_i)$$

$$\text{Mean Absolute Error (MAE): MAE} = \frac{1}{N}\sum_{i=1}^{N}|M_i - O_i|$$

$$\text{Root Mean Square Error (RMSE): RMSE} = \left[\frac{1}{N}\sum_{i=1}^{N}(M_i - O_i)^2\right]^{\frac{1}{2}}$$

$$\text{Wind Normalized Mean Bias (WNMB) : WNMB} = \frac{1}{N\times 360^\circ}\sum_{i=1}^{N}(M_i - O_i) \times 100\%$$

$$\text{Wind Normalized Mean Error (WNME): WNME} = \frac{1}{N\times 360^\circ}\sum_{i=1}^{N}|M_i - O_i| \times 100\%$$

The boundary condition data in WRF model uses the reanalysis weather data. These data are assimilated with measurement data, they are available in coarse resolution (1° × 1°). The work has hence included the observation nudging settings to improve its prediction of local area. The data used for nudging are given in Section 2. The assimilation with the default setting does not improve the prediction hourly T2 and WS, hence the subsequent effort is to adjust the area of influence of each the measuring stations. The radii of influence (RIN) for both d03 and d04 are updated to 100 km based on the average distance between the observation stations (d03: 125 km, d04: 153 km) and minimum distance between 2 stations (d03: 64 km, d04: 36 km). Although the wind direction is greatly improved with the modification of RIN, the positive bias of T2 and negative bias of WS is still apparent, especially for the LABS station. Given that the 3rd domain is of 5 km × 5 km resolution, the height of Mt. Lulin might be averaged out by the lower terrain surrounding it and the model height of Mt. Lulin is lower (2216 m, layer = 1) than its original height (2862 m). Comparison has found that model layer 4 from surface is most representative of the height of Mt Lulin (2492 m; 757 hPa). Hence with the extraction of new location of Mt Lulin, the prediction of T2 and WS are improved significantly as tabulated in Table S1. The wind profile over LABS, one of the decisive weather factors of transport, has complied well with the observation data as seen in Figure 3. The passing rate of surface cwb stations for hourly T2, WS and WD are also well above the model benchmark (60%).

Table S1: The performance of each staton for weather parameters (T2, WS, WD) in March 2013 for Thailand (TH) stations, Taiwan (TW) stations, and Lulin (LABS). *Distance given is the radius of influence in observation nudging. #Station output is extracted from the corresponding model layer of the station height in the model.

Parameter	Index	Standard	no fdda	fdda; 240 km*	fdda; 100 km*#
TH stations					
T2	MB	-1.5< x< 1.5	-0.3	-0.3	-0.3
	MAE	x< 3	2.2	2.2	2.2
WS	MB	-1.5< x< 1.5	1.2	1.2	1.2
	RMSE	x< 3	1.7	1.8	1.8
WD	WNMB	-10< x < 10	2.1	-4.0	-4.1
	WNME	x< 30	29.5	23.4	23.3
TW stations					
T2	MB	-1.5< x< 1.5	0.5	0.2	0.2
	MAE	x< 3	2.1	2.0	2.0
WS	MB	-1.5< x< 1.5	0.5	0.7	0.7
	RMSE	x< 3	1.9	1.9	1.9
WD	WNMB	-10< x < 10	-4.5	-9.9	-10.2
	WNME	x< 30	26.6	20.8	20.9
LABS					
T2	MB	-1.5< x< 1.5	1.6	2.3	**0.2**
	MAE	x< 3	2.6	2.9	**1.5**
WS	MB	-1.5< x< 1.5	-2.6	-1.9	**0.9**
	RMSE	x< 3	3.5	3.0	**2.3**
WD	WNMB	-10< x < 10	**0.3**	**-4.0**	**3.4**
	WNME	x< 30	**12.6**	**12.7**	**8.9**

Section B. Comparison of ECLIPSE and MIX anthropogenic emission

The anthropogenic dataset, ECLIPSE and MIX for year 2010 is compared in Figure S1 for peninsular SEA and in Figure S2 for the entire Asia. Figure S1 shows that ECLIPSE generated lower amount of CO and VOC and higher amount of particulate matters and NO_x over peninsular SEA compared to the MIX dataset. The ECLIPSE data give a higher total NH_3, BC, $PM_{2.5}$, NO_x, PM_{10} by 192%, 51%, 38%, 29%, 24% respectively, while lower total VOC, CO, OC, SO_2 by 40%, 23%, 22%, 20% respectively. Largest biases are observed in developing SEA countries as seen in Figure S2, such as Laos, Burma, Philippines and Timor-Leste where local data are not easily available. However, the emissions for China and Taiwan are kept unchanged due to the high confidence and quality of respective national emission inventories (Li et al., 2018).

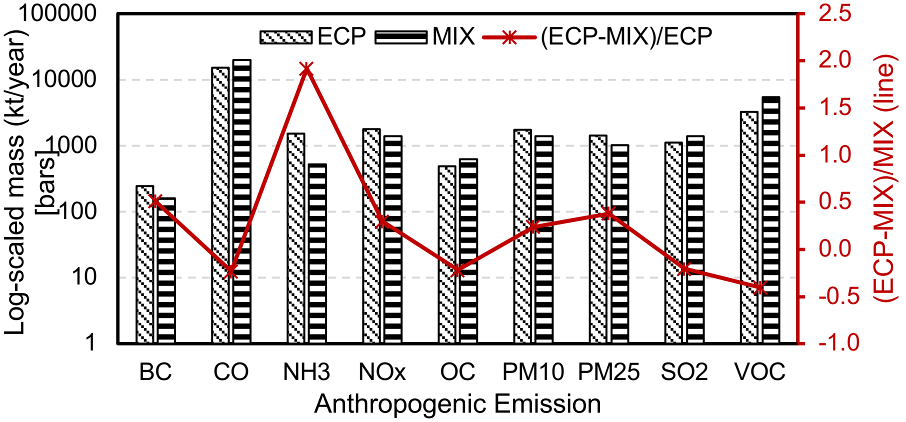


Figure S1: Comparison of total mass of emitted air pollutants (BC, CO, NH_3, NO_x, OC, PM_{10}, $PM_{2.5}$, SO_2, VOC) from anthropogenic emission inventories over peninsular SEA (including Thailand, Vietname, Cambodia, Burma and Laos) in year 2010: ECLIPSE (ECP; box with diagonal lines), MICS-ASIA (MIX; box with horizontal lines), and difference fraction between ECP and MIX ((ECP-MIX)/MIX); red line).

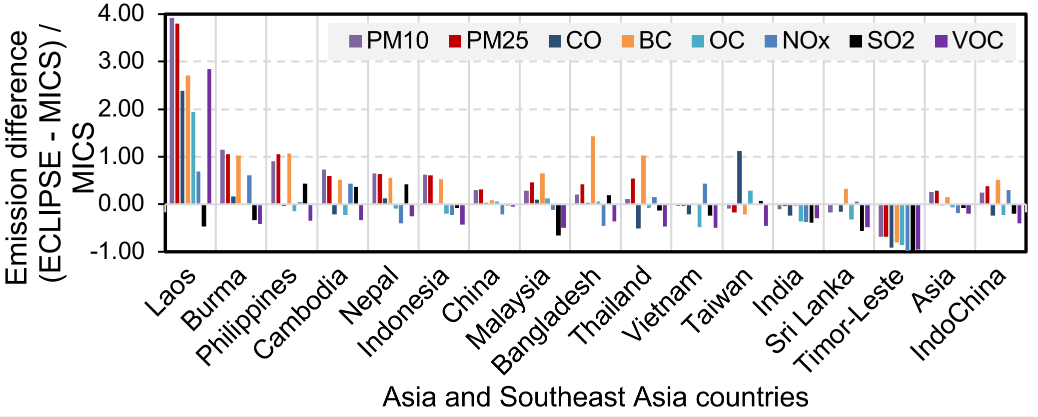


Figure S2: Comparison of 2010 ECLIPSE and MIX emission in Southeast Asia and Asia countries that are covered within d02, including Taiwan and China.

Section C. Model verification for modelled air quality

In the following formulas, M_i, O_i, $\bar{O}$ represent simulated value of record i, observed value of record i, mean of observed values for 1 to N. N are total number of records.

$$\text{Correlation Coefficient (R): R} = \frac{1}{N-1}\sum_{i=1}^{N}\left[\frac{(M_i-\bar{M})(O_i-\bar{O})}{Stdev_M Stdev_O}\right]$$

$$\text{Mean Fractional Bias (MFB): MFB} = \frac{1}{N}\sum_{i=1}^{N}\frac{M_i-O_i}{(M_i+O_i)/2}$$

$$\text{Mean Fractional Error (MFE) : MFE} = \frac{1}{N}\sum_{i=1}^{N}\frac{|M_i-O_i|}{(M_i+O_i)/2}$$

$$\underline{\text{Mean Normalized Bias (MNB): MNB} = \frac{1}{N}}\sum_{i=1}^{N}\left(\frac{M_i-O_i}{O_i}\right) \times 100\%$$

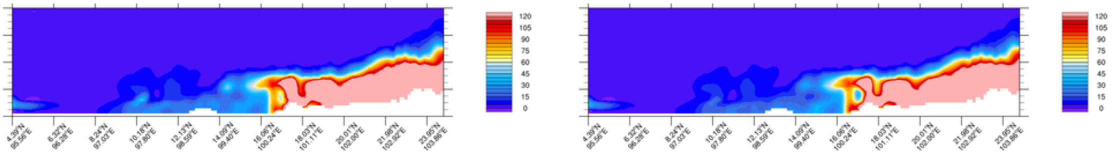
$$\underline{\text{Mean Normalized Error (MNE): MNE} = \frac{1}{N}}\sum_{i=1}^{N}\left|\frac{M_i-O_i}{O_i}\right| \times 100\%$$

Table S2: Performance of modelled chemistry field with different setting of plume rise model at other EPA stations in Taiwan and PCD stations in NT

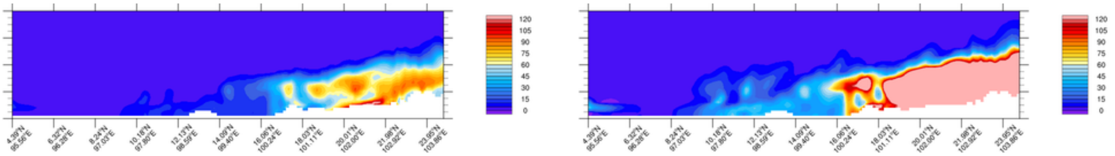
Parameter	Index	Standard	F0	F800	F2000	FWrp	IDef	IWrp	IWrp+Ec
TW stations (EPA)									
Daily PM_{10}	R	x > 0.5	0.29	0.22	0.22	0.17	0.34	0.34	0.30
	MFB	-0.35< x< 0.35	-0.53	-0.36	-0.35	**-0.26**	-0.70	-0.71	-0.79
	MFE	x< 0.55	0.66	0.60	0.60	0.58	0.74	0.75	0.81
Daily $PM_{2.5}$	R	x > 0.5	0.45	0.30	0.30	0.26	**0.48**	**0.49**	**0.46**
	MFB	-0.35< x< 0.35	**-0.21**	**-0.12**	**-0.11**	**-0.02**	-0.57	-0.58	-0.61
	MFE	x< 0.55	**0.44**	**0.43**	**0.44**	**0.44**	0.61	0.61	0.64
Hourly O_3 (>40 ppb)	R	x > 0.45	**0.65**	**0.58**	**0.58**	**0.57**	**0.55**	**0.55**	**0.61**
	MNB	-0.15< x< 0.15	**0.01**	**0.08**	**0.09**	**0.09**	**0.10**	**0.09**	**-0.01**
	MNE	x< 0.35	0.21	0.22	0.22	0.22	0.22	0.22	0.21
Hourly CO	R	x > 0.35	0.28	0.24	0.24	0.24	0.24	0.24	0.29
	MNB	-0.5< x< 0.5	**0.11**	**0.14**	**0.14**	**0.18**	**0.11**	**0.11**	**0.09**
	MNE	x< 0.5	0.55	0.55	0.55	0.56	0.56	0.56	0.56
NT Stations (PCD)									
Daily PM_{10}	R	x > 0.5	**0.75**	**0.75**	**0.76**	**0.77**	**0.83**	**0.84**	**0.84**
	MFB	-0.35< x< 0.35	-0.45	-0.45	-0.40	**-0.30**	-0.91	-0.86	-0.85
	MFE	x< 0.55	0.64	0.64	0.60	**0.50**	0.91	0.87	0.86
Hourly O_3 (>40 ppb)	R	x > 0.45	0.42	0.44	0.44	0.45	**0.47**	**0.49**	**0.49**
	MNB	-0.15< x< 0.15	-0.48	**-0.07**	**-0.04**	**-0.01**	0.27	0.22	0.23
	MNE	x< 0.35	0.74	**0.25**	**0.25**	**0.24**	0.39	0.37	0.37
Hourly CO	R	x > 0.35	**0.42**	**0.42**	**0.41**	**0.37**	**0.41**	**0.45**	**0.45**
	MNB	-0.5< x< 0.5	**-0.48**	-0.51	-0.50	**-0.48**	**-0.25**	**-0.21**	**-0.21**
	MNE	x< 0.5	0.74	0.74	0.74	0.74	0.74	0.74	0.74

Section D. Detailed comparison of vertical distribution

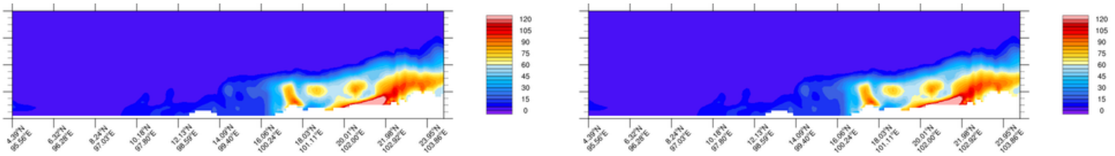
For offline methods, higher plume rise height and concentration vary positively with the initial allocated height, with increasing order of F800, F2000 to FWrp. Inline method is generally lower in amount and the near surface emission has increased with IWrp compared to IDef (Figure S3).


(a) F2000

(b) F800


(c) IDef

(d) FWrp


(e) IWrp

(f) IWrp + EC

(g) nofire

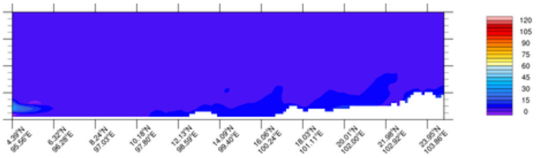


Figure S3: Comparison of vertical cross-sectional area on 19 Mar (06:00 LST) modelled by each plume rise setting with the same contour scale range (0 – 120 ug.m^{-3})

Reference:

Li, M., Klimont, Z., Zhang, Q., Martin, R. V., Zheng, B., Heyes, C., Cofala, J., Zhang, Y. and He, K.: Comparison and evaluation of anthropogenic emissions of SO2 and NOx over China, Atmos. Chem. Phys., 18(5), 3433–3456, https://doi.org/10.5194/acp-18-3433-2018, 2018.