Impact assessment of biomass burning in Southeast Asia to 2019 annual average PM2.5 concentration in Thailand using atmospheric chemical transport model

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Abstract. Agricultural residues burning as a means of land preparation commonly practiced in many Southeast Asian countries causes significant deterioration of ambient air quality and public health. In this study, WRF-CMAQ Atmospheric Chemical Transport Model was used to conduct a year-round simulation (1 January - 31 December 2019) of PM2.5 spatio-temporal variation over Southeast Asia. The model utilized the Fire emission Inventory from NCAR (FINNv1.5) from National Center for Atmospheric Research (NCAR) as a biomass burning emission input. The model performance was evaluated by comparing simulated values with observed values from monitoring stations in nine major cities. The model shows acceptable performance reproducing the PM2.5 concentration with 14.9% normalized mean bias (NMB) and correlation coefficient of 0.89. After that, the simulation was conducted again with emission from FINNv1.5 turned off. The results from FINNv1.5 on and off cases were then compared to evaluate contribution of biomass burning to PM2.5 concentration in two major cities of Thailand: Bangkok and Chiang Mai. The comparison shows that biomass burning contributes to 49.1% and 13.1% of PM2.5 annual average concentration in Chiang Mai and Bangkok respectively with highest month being April for Chiang Mai (70.7% contribution) and March for Bangkok (35.5% contribution).

1 Introduction

Biomass burning (BB) of agricultural refuse for the purpose of land preparation for the upcoming plantation is widely practiced in Southeast Asian countries: mainly, Thailand, Vietnam, Myanmar, Cambodia, and Laos [1-10]. Biomass burning is in favor of cultivators as it is a costless method to clear the agricultural residue from land for faster crop rotation, control undesirable weeds, pests, and diseased crops as well as to return some nutrients to the soil [10]. Rapid release of gaseous and particulate pollutants from biomass burning significantly deteriorates ambient air quality [11-14], degrades visibility [15], and poses

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adverse health effects to humans [11, 16-18]. Biomass burning does not only influence air quality locally but also has regional and global effects as biomass burning plumes are capable of long-distance-travelling, causing transboundary pollution problem [2,11,19-20].

Particulate pollutant with size smaller than 2.5 μm (PM2.5) is known to has adverse effect to human health such as respiratory and cardiovascular diseases [21]. The annual national average of PM2.5 concentration in Thailand has been exceeding the value of WHO air quality guidelines by 5 times in the last decade [22-23]. Biomass burning plumes, both domestic and transboundary-transported, are reported as significant source of PM2.5 pollution in Southeast Asia, especially during high-burning episode toward the end of dry season, from January to April [2,22,24].

Atmospheric chemical transport modelling is a powerful tool widely used to study source apportionment, contribution assessments, and policy evaluation studies [25-26]. This study aims to assess the contribution of biomass burning in Southeast Asia to PM2.5 concentration in two major cities of Thailand: Bangkok and Chiang Mai using Weather Research and Forecasting (WRF) meteorological model coupled with Community Multiscale Air Quality (CMAQ) atmospheric chemical transport model.

2 Method

2.1 Model description – WRF and CMAQ

WRF version 4.3 was used to generate meteorological input for CMAQ version 5.3.3. CMAQ was then used to simulate PM2.5 dispersion over Southeast Asian countries. In WRF, domain was defined as 205 x 142 gridded lat-lon projection over Asia with resolution of 45 x 45 km as illustrated in figure 1. The model was set with 30 vertical sigma levels up to top of the domain pressure at 50 hPa. WRF physics settings are shown in table 1.

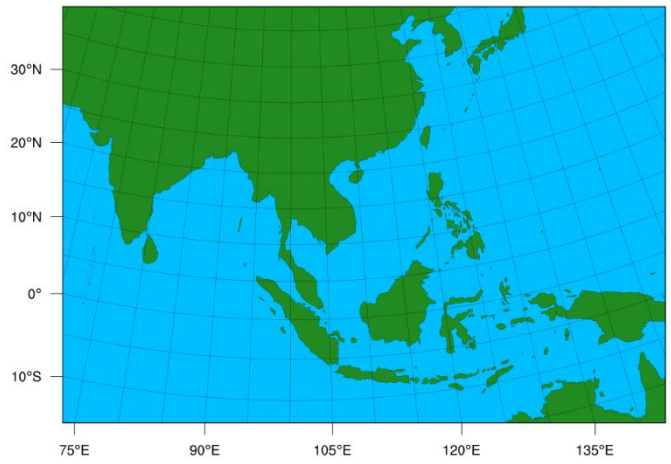

Fig. 1 WRF domain configuration.

2.2 Emission input

The Fire emission Inventory from NCAR (FINN) from National Center for Atmospheric Research (NCAR) was used as biomass burning emission input in this study. FINN utilizes satellite remote sensing data of active fires and land cover, combined with emission factors and estimated fuel loadings to estimate daily emission from biomass burning at high

resolution [27]. The MODIS data from FINN version 1.5 was used in this study. Other emission inventories used in the model are listed table 2.

In this study, the simulation was conducted in two scenarios: one with all emission inventories and one with all emission inventories but FINNv1.5 (referred to as FINNv1.5 case and BB0 case respectively). The differences between PM2.5 concentration of two scenarios thus reflected the contribution from biomass burning emission.

Table 1. Model configuration for WRF and CMAQ

WRF Configuration	
Meteorology Model	WRF v4.3
Explicit precipitation scheme	Morrison 2-moment scheme
Advection	5th/3rd-order upwind-biased (horizontal/vertical)
Longwave Radiation	RRTMG scheme
Shortwave Radiation	RRTMG scheme
Surface-layer option	MYNN surface layer
Land-surface	Noah Land-Surface Model
Planetary boundary layer scheme	MYNN 3rd level TKE scheme
Cumulus option	Grell 3D ensemble scheme
CMAQ Configuration	
Chemistry Model	CMAQ v5.3.3
Horizontal resolution	45 x 45 km
Vertical resolution	30 sigma-pressure level (with the top pressure of 50HPa)
Projection	Lambert Conformal Conic
Advection	Yamartino/WRF-based scheme, Multiscale/ACM2
Vertical diffusion	Asymmetrical Convective Model Version 2 (ACM2) [28-29] for M3DRY deposition
Gas-phase chemistry	SAPRC07tc & AERO6 with Aqueous chemistry
Dry deposition	M3DRY [30]
Wet deposition	Henry's law
Aqueous chemistry	CMAQ's standard cloud chemistry treatment (AQCHEM)
Aerosol mechanism	AERO6

Table 2. Emission inventories used in this study

Emission source	Inventory used
Anthropogenic emission	REAS version 3.2 [31] HTAP version 2.2 [32]
Biogenic volatile organic compound (BVOC) emission	MEGAN version 2.04 [33]
Sulphur dioxide emission from volcanic activity	Carn et al. [34]
Biomass burning	FINN version 1.5 [27]

2.3 Model evaluation

The simulation was conducted for a 1-year period from 1 January 2019 to 31 December 2019 with run-up period from 1 December 2018. In the purpose of model validation, simulated values from FINNv1.5 case were compared to observed values from The Acid Deposition Monitoring Network in East Asia (EANET) [35]. Annual average PM2.5 concentration from simulation of nine Southeast Asian cities, namely: Bangkok, Chiang Mai, Yangon, Mandalay, Vientiane, Phnom Penh, Jakarta, Hoa Binh, and Manila were compared to observed value individually. Normalized mean bias of simulated and observed data were then calculated to evaluate the ability of the model to reproduce spatio-temporal variation of PM2.5 over Southeast Asia.

3 Results and discussion

3.1 Model performance

Figure 2 shows comparison of simulated and observed values of annual average PM2.5 concentration of nine cities in Southeast Asia. The model shows acceptable performance with normalized mean bias of 14.9% and correlation coefficient of 0.89.

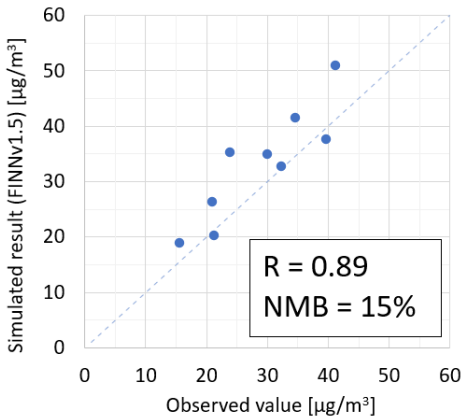

Fig. 2 Comparison of observed and simulated annual average PM2.5 concentration of nine Southeast Asian cities.

3.2 Biomass burning contribution

Figures 3 shows simulated annual average PM2.5 concentration and figure 4 shows annual average PM2.5 concentration from biomass burning alone. Figure 4 clearly illustrates that PM2.5 from biomass burning is much more severe in northern Thailand as well as Laos and Myanmar. On the other hand, central region, including Bangkok, is only mildly affected. The contribution percentages were then calculated for Bangkok and Chiang Mai using simulation result from both scenarios. Biomass burning contributes to 49.1% and 13.1% of PM2.5 annual average concentration in Chiang Mai and Bangkok respectively. Figures 5 and 6 show monthly average PM2.5 concentration and corresponding contribution from biomass burning. The PM2.5 concentration peaks in April for Chiang Mai with 70.7% contribution from biomass burning. Whereas March is the highest month for Bangkok with 35.5% contribution from biomass burning.

Chiang Mai suffers more from biomass burning than Bangkok possibly due to higher agricultural activities as well as transboundary transport from neighbouring countries. According to Thailand Pollution Control Department (PCD) [22], biomass burning in neighbouring countries is higher during March to April as the increase in hotspots can be observed by satellite.

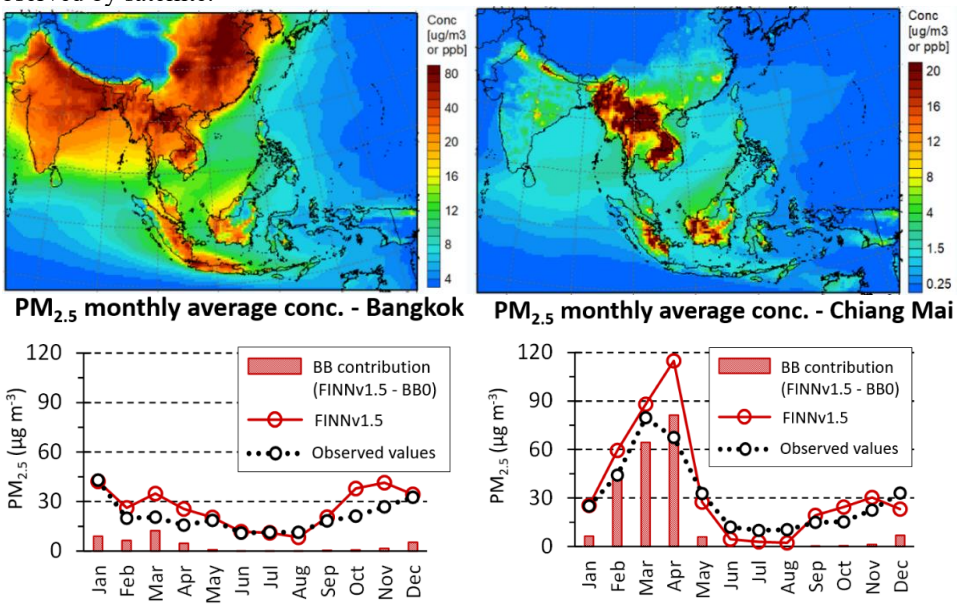

Fig. 3 (upper left) Annual average PM2.5 concentration from simulation
Fig. 4 (upper right) Annual average PM2.5 emission from biomass burning (FINNv1.5 – BB0)
Fig. 5 (lower left) Bangkok Monthly average PM2.5 concentration and contribution from BB
Fig. 6 (lower right) Chiang Mai Monthly average PM2.5 concentration and contribution from BB

4 Conclusion

Agricultural biomass burning in Southeast Asia is an on-going problem which significantly affects air quality and public health. PM2.5, one of major pollutants emitted by biomass burning, is known to cause respiratory and cardiovascular diseases and are linked to premature death. This study utilizes coupled atmospheric chemical transport model to assess contribution of biomass burning to PM2.5 concentration in Bangkok and Chiang Mai, Thailand. A WRF-CMAQ atmospheric chemical transport model was used to simulate PM2.5 pollution over Southeast Asia in the year of 2019. The simulation was conducted in two scenarios: with and without emission from biomass burning. The difference between two scenarios then provides the contribution of biomass burning to PM2.5 concentration. The result from simulation shows that biomass burning largely contributes to PM2.5 concentration in both Bangkok and Chiang Mai. Having many agricultural activities and located near neighbouring countries, Chiang Mai is severely affected as biomass burning contributes to 49.1% of annual PM2.5 concentration with highest contribution at 70.7% toward the end of dry season in April. Meanwhile in Bangkok, biomass burning only contributes to 13.1% of annual PM2.5 concentration with highest contribution in March at 35.5%. The effect is supposedly less severe due to its urban setting and lesser agricultural activities.

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