Atmospheric Pollution Research 9 (2018) 133–145

Contents lists available at ScienceDirect

Atmospheric Pollution Research

journal homepage: http://www.journals.elsevier.com/locate/apr

Modified biomass burning emission in modeling system with fire radiative power: Simulation of particulate matter in Mainland Southeast Asia during smog episode

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ARTICLE INFO

Article history:
Received 2 April 2017
Received in revised form
11 August 2017
Accepted 14 August 2017
Available online 24 August 2017

Keywords:
Biomass burning emission
Particulate matter
Southeast Asia
Air quality model
Fire radiative power

ABSTRACT

The uncertainty in biomass burning emissions are large in many regions due to high variation of fire characteristics, limitation of fire data and uncertainty in factors calculation. The simulations in Mainland Southeast Asia (MSEA), using Fire Inventory from NCAR (FINN) as the biomass emissions that is estimated by using emission factors, fuel consumption and burned area based on land use/land cover (LULC) type, found great overestimation of PM in dense biomass burning area. This study developed the method to solve the uncertainty of biomass burning emission by air quality modeling system using Fire Radiative Power (FRP) to modify FINN. The modeling system WRF-CMAQ is applied to simulated PM in MSEA during smog episode in March 2012. Results from simulation were compared to both satellite and ground-based observations. The comparison of simulated PM with modified FINN by FRP ($PM_{FINN\text{-}FRP}$) showed generally good agreement and the modeling system captured most of the important observed features. The comparison of PM in source region found greatly improvement of simulated PM. Simulated $PM_{FINN\text{-}FRP}$ are in factor of two of the observations more than 70% and spatial correlation with the observation are greater than 0.8.

1. Introduction

Smog is a major air quality problem in Mainland Southeast Asia (MSEA) that people in this region have faced for long time. The monitoring data from Pollution Control Department in northern Thailand revealed that PM10 concentration had continuously exceeded the daily National Ambient Air Quality Standard (NAAQS) of 120 μg/m^3 every year during 2000–2016. Peak daily average concentration of PM10 was higher than 400 μg/m^3. Most of particulate problems usually occur during February–April in which dominated source of PM10, biomass burning due to forest fires and agricultural residue burning, are at their peak (Reid Jeffrey et al., 2013). The smog has several adverse impacts on human health and atmospheric visibility in local area and also impacting on regional air quality, biogeochemical cycles, climate and the hydrological cycle (Chen et al., 2017; Crutzen and Andreae, 1990; Lee et al., 2017).

There are a few studies on pollutant dispersion from biomass burning in MSEA during smog episodes, specifically in source region. Most research works investigated long-range transport of biomass burning from Indochina that could be transported to East Asia through subtropical westerlies and Asian monsoon, and some studies reported significant influence of biomass burning emission on air quality in downwind areas (Chuang et al., 2015; Dong and Fu, 2015a, b; Fu et al., 2012; Huang et al., 2013; Lin et al., 2013). The contribution of biomass burning in downwind regions could be as high as 20–50% on CO, 10–30% on O_3 and 20–70% on PM2.5 (Huang et al., 2015). Most numerical simulation studies were conducted during field campaign of NASA in 2006 when was the low smog period (Fu et al., 2012; Huang et al., 2013).

Quantitative and temporal profiles of biomass burning emissions are highly uncertain and difficult to be estimated, resulting in the input accuracy for air quality models. Many studies showed the uncertainty of emission estimation due to the difficult-to-avoid

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Peer review under responsibility of Turkish National Committee for Air Pollution Research and Control.

http://dx.doi.org/10.1016/j.apr.2017.08.002
1309-1042/

inaccuracies of data, such as burned area, fuel loading, burning efficiency, burning duration and emission factors (French et al., 2011; van der Werf et al., 2006; van der Werf et al., 2010; Zhang et al., 2012). Application of biomass burning emission inventories in air quality models found large uncertainties. There are a few studies currently working on the evaluation of biomass burning emission inventory. Most of the work evaluated CO which is a typical species or tracer for biomass burning sources. Application of the Fire Locating and Modeling of Burning Emissions (FLAMBE) found large overestimate in Southern Russia, Southeast Asia and Taiwan (Chuang et al., 2015; Fisher et al., 2010). Simulation of CO in Southeast and East Asia using FLAMBE expressed that the largest discrepancy between modeled and observed data occurred in northern Thailand, FLAMBE overestimated the peak episodes by a factor of 2–3 (Huang et al., 2013). In contrast, the CO concentrations which were simulated from Global Fire Emissions Database (GFED) emissions underestimated by 200–300 ppbv during the peak periods. The comparison between CO estimated from FLAMBE and GFED revealed that FLAMBE's predictions were 7.89 and 11.63 times higher than that of GFED in March and April 2006 in Southeast Asia, respectively (Fu et al., 2012). Emission of different fire inventory is divergent in each region. Globally, The Global Fire Assimilation System(GFAS) and Fire Inventory from NCAR (FINN) show higher estimates for the months of February, March, April and May while GFED has higher estimates for the months of July, August and September. In boreal North America, GFAS and GFED emissions are considerably higher than FINN emissions. Estimated emissions for Central Asia and Southeast Asia were highest in FINN and considerably lower for GFAS and GFED; while equatorial Asia and Australia showed relatively low emission estimates by FINN (N Andela et al., 2013).

According to uncertainty of biomass burning emission, some studies try to increase the quality of quantification of the simulation results by adjust quantity of biomass burning emission in air quality modeling system. For example, a sensitivity test for the FLAMBE emissions was performed by multiplying FLAMBE with numerical factors of 1.0, 0.5, 0.25, 0.125, and 0.0, which were then used as inputs for the simulations. The comparisons with the observations in Taiwan found that biomass burning emission should be multiplied by 0.25 (Chuang et al., 2015). GFAS calculates biomass burning emission by assimilating FRP obtained from the MODIS instruments onboard the Terra and Aqua satellite (Giglio, 2013). For application of GFAS, a global enhancement of the particulate matter emissions by 3.4 is recommended. The factor was obtained by proportion between observed Aerosol Optical Depth (AOD) using satellite data and AOD estimation from air quality model using GFAS (Kaiser et al., 2012). Simulated tropospheric NO_2 concentration had better agreement with the observed NO_2 when FINN NO_x emissions where reduced by a factor of 2.2 in South Asia (Jena et al., 2015). The discrepancy between model results and the observation were corrected by adjusting emissions based on the assumption that emission errors in the model are systematic. The modelling system need to decrease biomass burning emissions in the FLAMBE inventory by a factor of 0.5 over Southern Russia and by a factor of 0.4 over Southeast Asia (Fisher et al., 2010).

FINN is a fire emission with high temporal/spatial resolution, global coverage, and the number of species estimated. It is developed specifically for modeling atmospheric chemistry and air quality at scales from local to global. Quantity of FINN emission agrees reasonably well with other inventories on a global scale, but locally or regionally the differences can be a factor of two or higher. The results of FINN application are being critically evaluated with models and observations whenever possible (Wiedinmyer et al., 2011). From PM estimation by FINN revealed that the PM concentration in dense biomass burning area in MSEA was 2 times higher than observed concentration during smog episode in March 2012 (Vongruang et al., 2017). Due to large uncertainty of biomass burning emission estimation, this study developed a new method to adjust quantity and decrease uncertainty of biomass burning emission by using fire radiative power applying with FINN inventory. FINN calculates emissions as the function of estimated burned area, emission factors and biomass loading factor based on MODIS land use/land cover (LULC) type. Although, fires that appear in same LULC could have vast difference in their fire power. Therefore, this study using FRP to adjust burn biomass loading for appropriate of each fire point. This study focus on PM that is main air pollution problems during smog episode in MSEA. Case study selection of PM episode in MSEA was described in section 3.1. Simulation results of PM using FINN inventory and theirs uncertainty are discussed in section 3.2. Development of modifying FINN with FRP (FINN-FRP) is described in section 3.3. Finally, evaluation FINN-FRP using WRF-CMAQ (Weather Research and Forecasting/Community Multiscale Air Quality) modeling system is in section 3.4.

2. Methodology

2.1. Emissions

2.1.1. Anthropogenic emissions and biogenic emissions

Anthropogenic emission used in this study is the Southeast Asia Composition, Cloud, Climate Coupling Regional Study (SEAC4RS) emission (Lu and Streets, 2012). The SEAC4RS emissions inventory is regional anthropogenic emission data set prepared for the NASA SEAC4RS field campaign and for the Asia region based on year 2012. The main sources of these emissions are industrial, power plants, transportation, and residential. The inventory mainly includes gaseous pollutants, primary aerosols and their precursors, such as SO_2, CO, NO_x, NMVOC, CH_4, CO_2, PM10, PM2.5, BC and OC. SEAC4RS emissions provide a fine spatial resolution of $0.1^\circ \times 0.1^\circ$. Moreover, these emissions develop of a new emission inventory for Southeast Asia using a technology-based methodology and update of the Asia emission estimates using updated emission factors and new energy use data reflecting the year 2012. The previous simulation using SEAC4RS emissions found that modeling system can calculate ambient concentrations reasonable well comparing with other anthropogenic emission inventories in Southeast Asia (Amnuaylojaroen et al., 2014). SEAC4RS provides the yearly emission. Temporal allocation profile used the seasonal and diurnal allocate fractions following Olivier et al. (2005). The modeling system using this fraction can simulate ambient concentrations well comparing to the observation in many studies (In Hwan Lee, 2012; Wang et al., 2010). Biogenic emissions are generated by the Model of Emissions of Gases and Aerosols from Nature (MEGEN). MEGAN uses leaf area index, plant functional types, and meteorological conditions from WRF simulations. MEGAN has been applied in many studies over East Asia and demonstrated its good estimation of natural emission (Guenther et al., 2006).

2.1.2. Biomass burning emissions

The Fire Inventory from NCAR (FINN) and modified FINN with fire radiative power were employed to examine biomass burning emission. FINN provides daily, 1-km resolution, global estimates of the trace gas and particle emissions from open burning of biomass, which includes wildfire, agricultural fires, and prescribed burning and does not include biofuel use and trash burning. The uncertainty in the FINNv1 emission estimates are about a factor of two; but, the global estimates agree reasonably well with other global inventories of biomass burning emissions (Wiedinmyer et al., 2011). FINN was developed by bottom-up approach using each fire