Numerical simulations for biomass burning aerosol transport in northern Thailand

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Abstract. This paper presents the evaluation of a numerical biomass burning aerosol transport simulation system developed for northern Thailand. The simulation system is composed of the Weather Research and Forecasting model coupled with Chemistry (WRF-Chem) employing its best physics options, global gridded analyses from the NCEP FNL (Final) Operational Global Analysis data, global emission data from the REanalysis of the TROpospheric chemical composition over the past 40 years (RETRO) and the Emission Database for Global Atmospheric Research (EDGAR), and biomass burning emission data from the Brazilian Biomass Burning Emissions Model (3BEM). The simulated hourly averaged particulate matters with diameters less than 10 micron (PM10) at 5-km resolution covering the 3-month period of February – April of 2015 were evaluated using measurements from 13 ground stations distributed in northern Thailand. Results show that the numerical biomass burning aerosol transport simulation system can predict the times when hourly averaged PM10 dry mass concentrations are high and low well. Simulations are negatively biased for concentrations above 200 μg/m^3 and are slightly positively biased otherwise. The simulations have good utility for concentrations above 100 μg/m^3 and are useful for all concentration ranges.

1. Introduction

Air pollution caused by agricultural burning and forest fires is one of the most crucial environmental issues in the northern region of Thailand [1-3]. During the dry season, the smoke haze situation severely affects the air quality in many areas in northern Thailand, including the provinces of Chiang Mai, Chiang Rai, Mae Hong Son, Lampang, Lamphun, Phrae, Nan, and Phayao [4], resulting in adverse health consequences [1]. The level of particulates matter (PM) concentrations in these provinces have been automatically measured at the Air Quality Monitoring (AQM) stations administered by the Pollution Control Department (PCD) of Thailand [5]. During the smoke and haze period, the levels of particulate matters with diameters less than 10 micron (PM10) measured at provincial stations rise above the standard level, i.e, 120 μg/m^3, set by PCD mostly in February and March of each year [6].

To better understand the impacts of biomass burning aerosols in northern Thailand, an accurate numerical biomass burning aerosol transport simulation system is required. Such system can provide details about the amounts and coverages of biomass burning aerosols as a function of time. Such

information is useful for mitigating the impacts. Although it is a very important problem with big public impacts in northern Thailand, previous studies concerning biomass burning aerosol transport simulations in northern Thailand do not exist.

The main goal of this paper is to develop and evaluate a numerical biomass burning aerosol transport simulation system for northern Thailand. [7] has found the best physics options of the Weather Research and Forecasting (WRF) model for high-resolution weather forecasting for Thailand and nearby regions and has shown that the weather forecasts agree well with satellite observations. [8] and [9] have employed the WRF model to simulate and forecast near surface wind speeds and directions at 65 and 90 m above ground for wind stations in northeastern Thailand, respectively, and has shown that simulations and forecasts agree well with ground measurements.

The WRF model coupled with Chemistry (WRF-Chem) [10-11] is employed in this study. The biomass burning emission data from the Brazilian Biomass Burning Emissions Model (3BEM) [12] are used. Simulated hourly averaged PM10s covering a period of 3 months in year 2015 were evaluated using measurements from 13 ground stations distributed in northern Thailand.

Section II describes the method employed in this study, including details about ground measurements and the numerical biomass burning aerosol transport simulation system used in this study. Section III shows the results. Section IV summarizes and concludes the paper.

2. Methodology

2.1. Ground Measurements

Hourly-averaged dry mass concentrations of PM10 employed in this study were collected by 13 PCD ground stations in northern Thailand. Figure 1 shows the study area and locations of the 13 ground stations. The PM10 concentrations are generally high in February and March of each year, which is in the cold season and the air is dry. In addition, the biomass burning activities in the 2 months are very active. The biomass burning is an agricultural practice for preparing the soil for the coming rainy season and a new rice planting season [13].

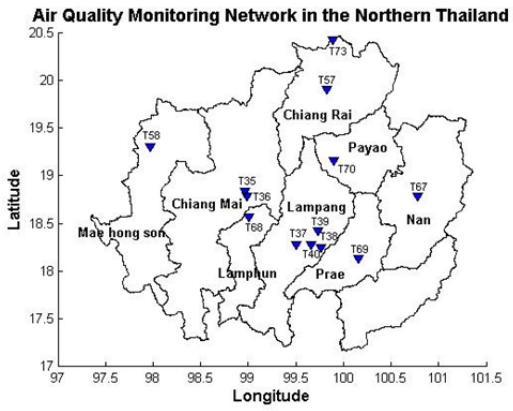

Figure 1. Locations of 13 ground stations in northern Thailand empoyed in this study.

Figure 2. Two co-centered WRF domains employed in this study.

2.2. The Numerical Biomass Burning Aerosol Transport Simulation System

To simulate the biomass burning aerosol transport in this study, WRF-Chem version 3.5.1 was employed. The WRF domain configurations are composed of 2 domains co-centered at 18.97°N and 99.4°E as shown in the Figure 2. The domains were selected such that domain 2 covers northern Thailand. The domains 1 and 2 have 99x99 and 120x120 grid points with 15 and 5 km resolutions, respectively. Both domains have 45 terrain-following levels extending to 50 mb. WRF physics options employed in this study follow those successfully used in [7-9]. The 1-degree gridded NCEP Final

Analysis every 6 hours were used as initial and boundary conditions for the WRF model. The global emission data from the REanalysis of the TROpospheric chemical composition over the past 40 years (RETRO) and the Emission Database for Global Atmospheric Research (EDGAR) [12], and the daily biomass burning emission data from 3BEM were used in this study.

The biomass burning aerosol transport for the study area was simulated continuously starting from January 30th and to April 30th of 2015 to ensure that chemical variables in the model integrate through the period. The 3BEM emission data were fed into the simulations daily. Simulations for the first 2 days were treated as a spin-up period and were not used. WRF-Chem simulated PM10 at 5-km resolution were used in this study. To compute PM10 at the ground stations, horizontally linear interpolation followed by vertically linear interpolation between neighboring levels were used.

3. Results

Table 1 shows mean errors (E[Simulations – Observations]; MEs), root mean square errors (RMSEs), and correlation coefficients (CCs) of simulated hourly averaged PM10 dry mass concentrations (μg/m^3) for each ground station during February–April, 2015. MEs for most stations except stations T35, T36, and T40, are less than 3 μg/m^3. The station with maximum RMSE is T58. Correlations between simulations and observations are quite good for most stations, where CCs are ranged from 0.4 to 0.69.

Since values of hourly averaged PM10 dry mass concentrations cover a wide range, Table 2 shows MEs and RMSEs of simulated hourly averaged PM10 dry mass concentrations for all 13 ground stations during February–April, 2015 computed separately for different concentration ranges divided using observations. RMSEs shown in boldface are those below the minimum of the concentration range listed in the first column, which indicate good utility. Simulated PM10 dry mass concentrations are useful for all ranges and have good utility for concentrations above 100 μg/m^3. Simulations are slightly positively biased for concentrations below 200 μg/m^3 and are negatively biased otherwise.

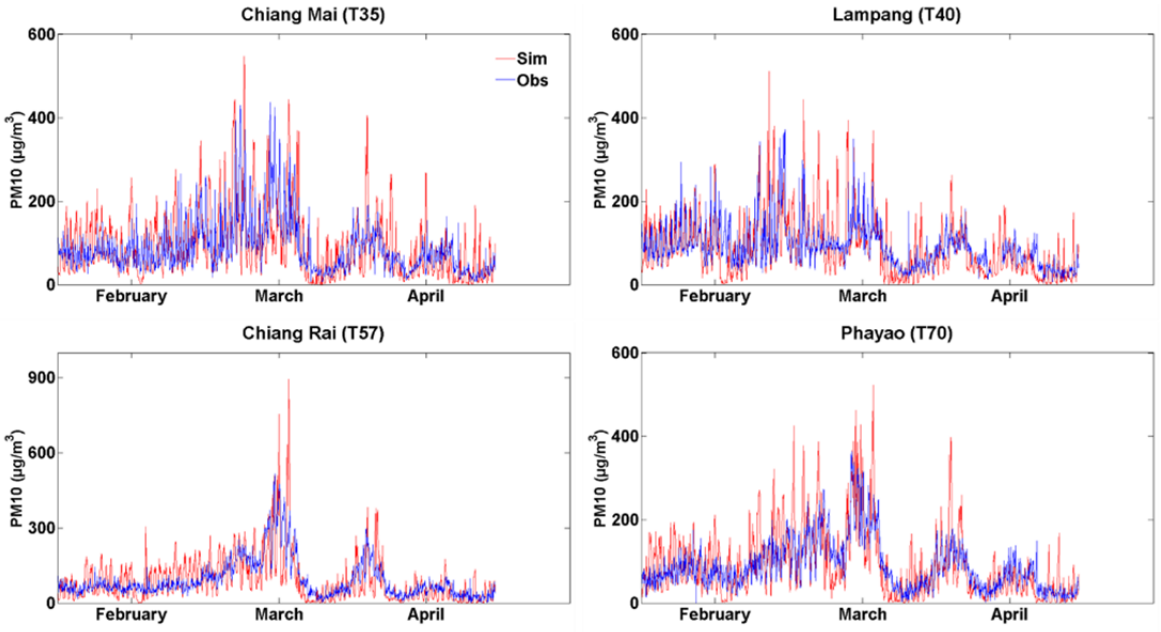

Figure 3. Comparisons of simulated (red) and observed (blue) hourly averaged PM10 dry mass concentrations (μg/m^3) for 4 ground stations during February–April, 2015.

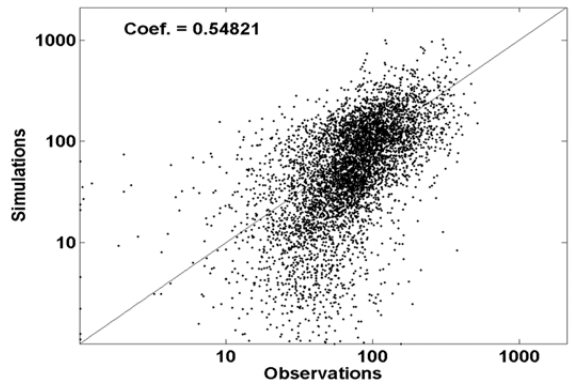

Figure 4. Scatterplots between simulated and observed hourly averaged PM10 dry mass concentrations (μg/m^3) for all 13 ground stations during February–April, 2015.

Figure 3 compares simulated and observed hourly averaged PM10 dry mass concentrations for the 4 ground stations for the full 3-month period of February-April 2015. PM10 concentrations from the end of February to the middle of March at most stations are relatively high and exceed the value of 50 μg/m^3, which is a threshold for polluted air quality according to the World Health Organization [14]. Simulated PM10 concentrations can predict lows and highs of observed PM10 concentrations quite well for all stations for the full 3 months.

Figure 4 shows scatterplots between simulated and observed hourly averaged PM10 dry mass concentrations for 13 ground stations for the full 3-month period of February-April 2015. Simulations agree well with observations. The overall correlation coefficient between simulations and observations is 0.55. The scatterplot is consistent with results shown in Table 2, that is, simulations are biased lower than observations for observed concentrations below 200 μg/m^3, and are biased higher otherwise.

Table 1. MEs (E[Simulations – Observations]), RMSEs, and CCs of Simulated Hourly Averaged PM10 Dry Mass Concentrations (μg/m^3) for Each Ground Station during February–April, 2015

Stations	ME	RMSE	CC
T35	5.97	78.76	0.41
T36	-5.05	67.25	0.50
T37	2.46	76.93	0.44
T38	2.91	50.91	0.60
T39	1.01	63.72	0.63
T40	-3.16	63.09	0.52
T57	-2.70	74.19	0.64
T58	2.45	130.20	0.58
T67	2.52	91.86	0.43
T68	2.90	69.26	0.40
T69	-2.20	53.79	0.53
T70	2.68	59.59	0.69
T73	0.83	92.97	0.64

Table 2. MEs (E[Simulations – Observations]) and RMSEs of Simulated Hourly Averaged PM10 Dry Mass Concentrations (μg/m^3) for all 13 Ground Stations during February–April, 2015 for Different Observed Concentration Ranges

Range (μg/m^3)	ME	RMSE
0-100	3.06	54.61
100-200	2.76	**95.72**
200-300	-28.67	**168.71**
300-400	-72.78	**201.40**
>500	-148.00	**214.16**

Boldface: RMSEs below the minimum listed in column 1, indicating good utility.

4. Summary and Conclusions

A numerical biomass burning aerosol transport simulation system developed to be used for northern Thailand is evaluated. The system is composed of the WRF-Chem model with its best physics options, global gridded analyses from the NCEP Final Analysis used for initial and boundary conditions, the RETRO and EDGAR global emission data, and the 3BEM biomass burning emission data. Simulated hourly averaged PM10 dry mass concentrations at 5-km resolution for the full 3-month period of February-April 2015 were evaluated using measurements from 13 ground stations distributed in northern Thailand. The numerical biomass burning aerosol transport simulation system can simulate the times of highs and lows of hourly averaged PM10 dry mass concentrations well. Simulations have small positive biases for concentrations below 200 μg/m^3 and have negative biases for concentrations above 200 μg/m^3. The numerical biomass burning aerosol transport simulation system can provide useful simulated hourly averaged PM10 dry mass concentrations for all ranges of observed concentrations. The simulations have good utility for concentrations above 100 μg/m^3.

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References

[1] Wiwanitkit V 2008 PM10 in the atmosphere and incidence of respiratory illness in Chiangmai during the smoggy pollution *Stoch. Environ. Res. Risk. Assess.* **22** 437–440.

[2] Amnauylawjarurn T, Kreasuwun J, Towta S and Siriwitayakorn 2010 Dispersion of particulate matter (PM10) from forest fires in Chiang Mai province, Thailand *Chiang Mai J. Sci.* **37(1)** 39-47.

[3] Kanabkaew T 2013 Prediction of hourly particulate matter concentrations in Chiang Mai, Thailand using MODIS aerosol optical depth and ground-based meteorological data *EnvironmentAsia* **6(2)** 65-70.

[4] Sooktawee S and Humphries U W 2015 Visualization and interpretation of PM10 monitoring data related to causes of haze episodes in Northern Thailand *App. Envi. Res.* **37(2)** 33-48.

[5] Chantara S PM10 and its chemical composition: a case study in Chiang Mai, Thailand, air quality - monitoring and modeling *accessed February 18, 2017*, available at http://www.intechopen.com/books/air-quality-monitoring-and-modeling/pm10-and-its-chemical-composition-acase-study-in-chiang-mai-thailand.

[6] Sirimongkonlertkul N, Upayokhin P, and Phonekeo V 2013 Multi-temporal analysis of haze problem in Northern Thailand: a case study in Chiang Rai province *Kasetsart J. (Nat. Sci.)* **47** 768-780.

[7] Surussavadee C and Aonchart P 2013 Evaluation of WRF physics options for high-resolution weather forecasting in Tropics using satellite passive millimeter-wave observations *Proc. IEEE Intern. Geosc. Remote Sens. Symp.* 2013 (Melbourne, Australia) p 2262-2265.

[8] Surussavadee C 2017 Evaluation of WRF Near-Surface Wind Simulations in Tropics Employing Different Planetary Boundary Layer Schemes *Proc. of 8th Int. Renewable Energy Congress* (Amman, Jordan) p 1-4.
[9] Surussavadee C 2017 Evaluation of Tropical Near-Surface Wind Forecasts Using Ground Observations *Proc. of 8th Int. Renewable Energy Congress* (Amman, Jordan) p 1-4.
[10] Grell G A, Peckham S E, Schmitz R. McKeen S A, Frost G, Skamarock W C and Eder B 2005 Fully coupled "online" chemistry within the WRF model *Atmos. Environ.,* **39** pp. 6957–75.
[11] Fast J D, Gustafson Jr W I, Easter R C, Zaveri R A, Barnard J C, Chapman E G, Grell G A and Peckham S E 2006 Evolution of ozone, particulates, and aerosol direct radiative forcing in the vicinity of Houston using a fully coupled meteorology–chemistry–aerosol model *J. Geophys. Res.* **111** D21305.
[12] Freitas S R, Longo K M, Alonso M F, Pirre M, Marecal V, Grell G, Stockler R, Mello R F and Sanchez Gacita M 2011 PREP-CHEM-SRC 1.0: a preprocessor of trace gas and aerosol emission fields for regional and global atmospheric chemistry models *Geosci. Model Dev.* **4** 419433.
[13] Duc H N, Bang H Q and Quang N X 2016 Modelling and prediction of air pollutant transport during the 2014 biomass burning and forest fires in peninsular Southeast Asia *Environ. Monit. Assess.* **188** 188:106.
[14] World Health Organization (WHO) 2006 WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: Summary of risk assessment WHO/SDE/PHE/OEH/06.02.