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Contributed Paper

Dispersion of Particulate Matter (PM10) from Forest Fires in Chiang Mai Province, Thailand

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Abstract

This research investigates the factors affecting dispersion of particulate matter (PM10) released from forest fires in Chiang Mai province during March 9-13, 2007 and 2008. Atmospheric initial and boundary conditions for this area were generated by the mesoscale model, MM5. Dispersion of the PM10 at the resolution of 1 square kilometer was performed by the air pollution model, CALPUFF.

Atmospheric stability over Chiang Mai is clearly indicated by the temperature inversion and wind velocity shown on Skew-T diagrams derived from the MM5. Dispersion of the PM10 over Chiang Mai vicinity was found to depend on atmospheric stability, wind direction and velocity and its topography. The simulated PM10 concentrations in Chiang Mai were 161-401 $\mu g/m^3$ during March 9 – 13, 2007 and 32 – 80 $\mu g/m^3$ during March 9 – 13, 2008 consistent with the observed values. The PM10 affected areas in Chiang Mai were defined according to the concentrations of the air pollutant.

Keywords: particulate matter, dispersion, CALPUFF Model, Chiang Mai.

1. Introduction

One of the main problems of megacities is air pollution problem. Chiang Mai, the largest city in mountainous northern Thailand, is a growing city of total area 20, 107 km^2 with 69.92% forest [1].

In March 2007, there were severe air pollution problems due to high concentration of particulate matter with diameters less than 10 micrometers (PM10) mostly released from high activities of open burning and forest fires in Chiang Mai and surrounding areas. Vinitketkumnuen *et al.,* [2] found that a high concentration of air pollutants including PM10 in the city adversely affects human health and visibility. Due to high cost air pollution instrumentation, PM10 concentrations can only be measured at a few specific locations in Chiang Mai; namely at Yupparaj Wittayalai School, Province of Chiang Mai Government Center and Puping Palace. In order to cope up and manage air pollution problem, it is necessary to approximate the amounts of fine dusts distributed in the city.

Research works on air pollution have been underway in highly populated and industrialized cities. Air pollutions models have come to play an important role on reliable estimation of pollutant concentrations. Some of air pollution models commonly used worldwide are California Mesoscale Puff Model (CALPUFF), Simulation of Air pollution From Emissions Above Inhomogeneous Regions (SAFE AIR), Industrial Source Complex (ISC3), and Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT). Song *et al.* [3] used the CALPUFF model to simulate dispersion of PM10 in Beijing in the winter, from 1 January to 20 February 2000, and found that the PM10 concentration was consistent with the observed value of 188 $\mu g/m^3$. Yang *et al.* [4] revealed from the CALPUFF outputs that about 46% of PM10 was transported from Mentougou to Beijing during April 1-7, 2004. Choi and Fernando [5] simulated the PM10 dispersion from forest fires in Yuma/San Luis area along the U.S./Mexico border under the simulated atmospheric conditions and found that the fires plume did not disperse much and thus mostly affected the areas near the sources.

This research work aimed to analyze the dispersion of PM10 according to atmospheric conditions during the dry season in Chiang Mai by the CALPUFF air pollution model and the mesoscale weather model, MM5.

2. MATERIALS AND METHODS

High spatial resolution weather variables such as temperature, pressure, wind, humidity and precipitation were required as input data to the CALPUFF model. The mesoscale meteorological model, MM5 was selected to generate high spatial resolution weather data of Chiang Mai for the CALPUFF input during March 9-13, 2007 and 2008.

2.1 The Fifth-Generation NCAR / Penn State Mesoscale Model (MM5) and atmospheric input data

MM5 is a limited-area, nonhydrostatic, terrain-following sigma-coordinate model designed to simulate or predict mesoscale atmospheric circulation. The model is supported by several pre- and post-processing programs, which are referred to collectively as the MM5 modeling system. The MM5 modeling system software is mostly written in Fortran, and has been developed at Penn State and NCAR as a community mesoscale model with contributions from users worldwide. Chotamonsak and Kreasuwun [6] used MM5 to simulate depression 23W over the Gulf of Thailand and found that simulated rains were comparable with reported rains of 197-200 mm/24 hr at Prachuab Kriri Khan Province during 24-25, 2003. In this research the MM5 was employed to simulate high spatial resolution of 3 km grid weather variables e.g. temperature, pressure, humidity and wind to serve as atmospheric input to the CALPUFF along with the PM10 emission rate from forest fires.

The MM5 was performed using nested domains, starting from parent domain of 27 km grid resolution, with subdomains consisting of 9 km grid resolution and 3 km grid resolution as shown in Figure 1. Final analysis data (FNL) downloaded from the National Center for Atmospheric Research (NCAR) provided initial and boundary conditions for the MM5.

2.2 California Mesoscale Puff Model (CALPUFF)

Dispersion and concentrations of PM10 were generated from California Mesoscale Puff (CALPUFF) air pollution model. The CALPUFF is an advanced non-steady-state meteorological and air quality modeling system developed by Atmospheric Studies

Group (ASG) scientists. The model has been adopted by United State Environmental Protection Agency (US EPA) in its Guideline on Air Quality Models as the preferred model for assessing long range transport of pollutants and their impacts on Federal Class I areas and on a case-by-case basis for certain near-field applications involving complex meteorological conditions [7].

The CALPUFF modeling system consists of three main components and a set of pre and post processing programs. The main component of the modeling system is CALMET (a diagnostic 3-dimensional meteorological model), CALPUFF (an air quality dispersion model), and CALPOST (a postprocessing package) [8].

The meteorological data from MM5 was incorporated as initial data to CALMET. CALMET was set at eleven vertical layers 0, 20, 50,100, 200, 500, 1000, 1500, 2000, 2500, 3000, 3500 m. CALMET automatically interpolated MM5 model grid system to its own grid. CALMET output and emission rate from forest fires were used as input to CALPUFF.

Emission rate can be estimated from relation of emission factor, fuel load, combustion efficiency and time [9]. The PM10 emission factor of 13 for deciduous trees was assumed in this study as indicated in Table.1.

Table1. Emission factor, Fuel load, Combustion efficiency [9].

Fuel	Fuel load(kg/m2)	Combustion efficiency	Emission Factor(g/kg)						
			Co_2	CO	CH_4	NMHC	PM2.5	PM10	NO_x
Shrub	1	0.8	1477	82	4	9	9	10	7
Resinous	8.6	0.25	1627	75	6	5	10	10	4
Deciduous	1.75	0.25	393	128	6	6	11	13	3
Eucalyptus	3.9	0.25	1414	117	6	7	11	13	4

3. RESULTS AND DISCUSSION

Outputs from the air pollution model CALPUFF and the mesoscale meteorological model MM5 were analyzed and compared with stational observation.

3.1 PM10 observation and hot spots.

The highest level of the PM10 in Chiang Mai was observed to take place in March as displayed in Figure 1.

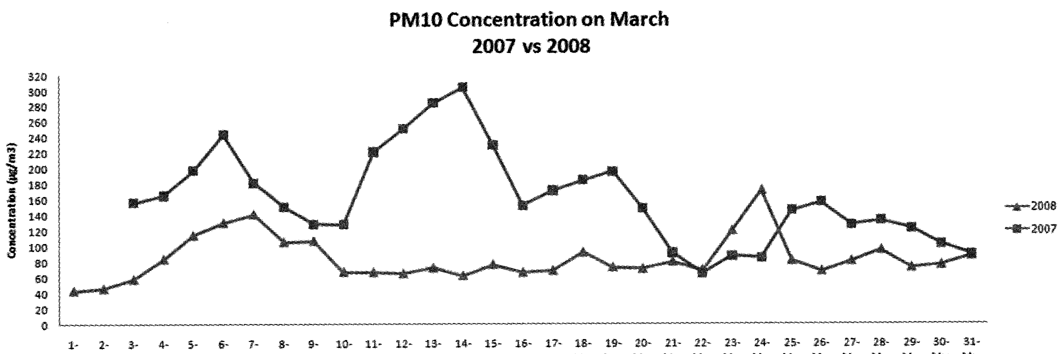


Figure 1. Time series of observed 2007 and 2008 PM10 concentrations in March at Province of Chiang Mai Government Center site [10].

During the same time of each year, open burnings and forest fires in the city always reach their peak activity ,i.e., in March as indicated from extensive numbers of hot spots from satellite images as shown in Figure 2. (a) and (b).

(a)

(b)

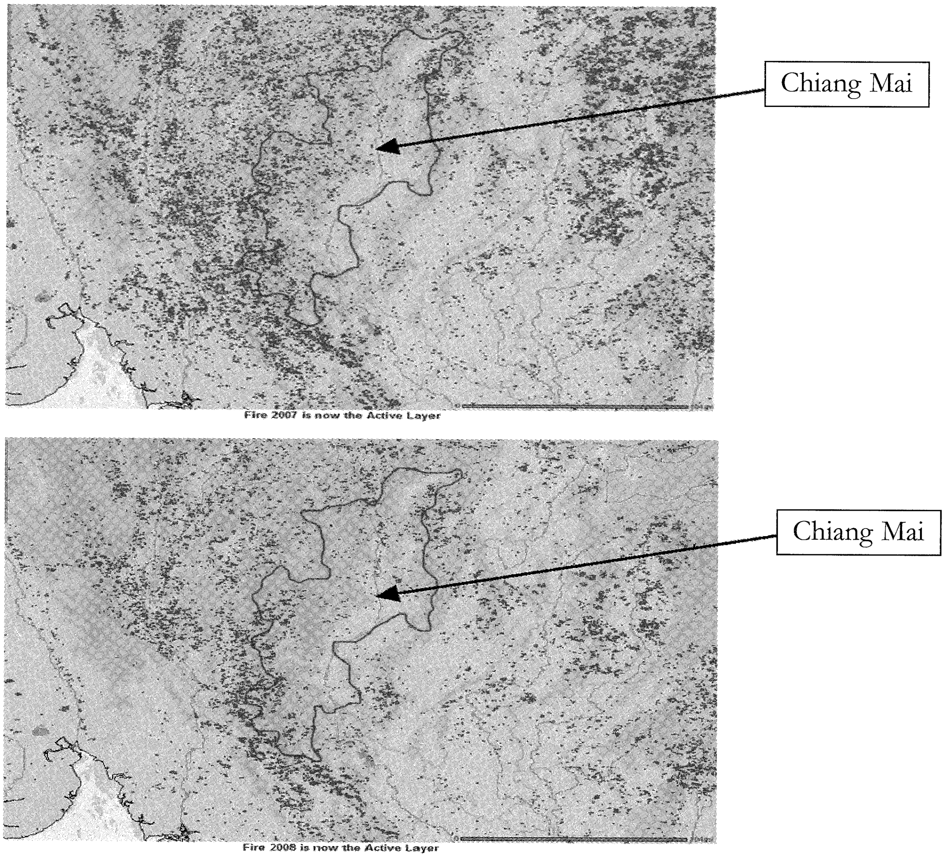


Figure 2. Hot spots in March (a) 2007(b) 2008 [11].

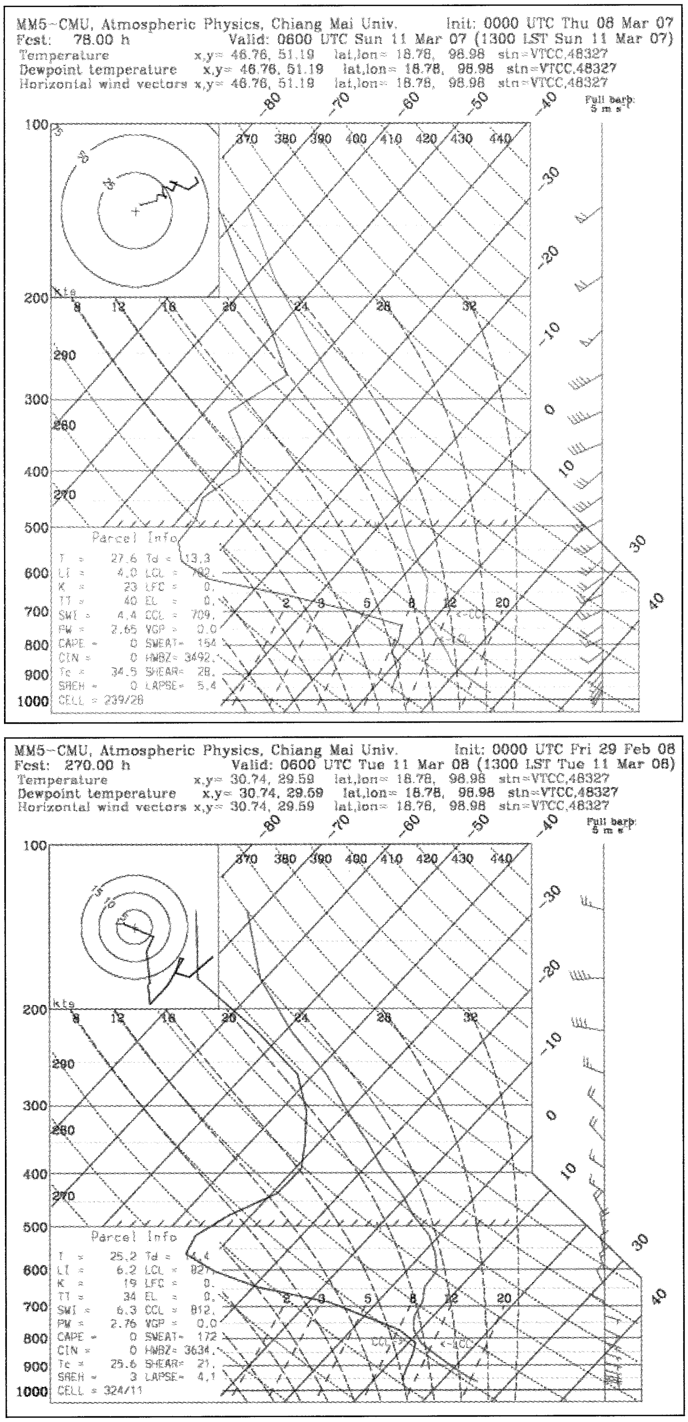
3.2 SKEW-T DIAGRAMS

Representatives of generated Skew-T diagram from the MM5 during March 9-13, 2007 and March 9-13, 2008 are displayed in Figures 3(a) and (b), respectively.

The profile of environmental temperature (the red line) in the Skew-T

diagrams derived from the MM5 output as shown in Figures 3(a) and (b) indicates the strong stability of the lower atmosphere between 0.6 – 1.2 km resulting in the very stable atmosphere that inhibits the atmospheric upward movement. The upward distribution of dew point temperature is signified by the blue line in the Skew-T diagrams. Humidity is estimated from the difference between the profiles of environmental temperature and the dew point temperature. When the dew point temperature is approximately the same as the environmental temperature, the air is very humid and rain is likely to form, provided with other favorable atmospheric variables. However, if the two variables are more than 4°C, it is unlikely to rain [12]. Particulate matter can be efficiently removed by rain. Aerosols and PM10 are unlikely to either dispersed upward or blown away from the basin by weak low-level wind as indicated from wind barbs at the right hand side of Skew-T diagrams. Low-level inversion and weak wind with no rain in the vicinity of Chiang Mai basin is the favorable condition for air pollutants built up in the basin.

A Skew-T diagram for March 11, 2008 is shown as a representative in Figure 3(b). Atmospheric stability at 1.5 - 2.0 km, calm wind with slightly chance of rain was expected during these days. The PM10 is most likely



(a)

(b)

Figure 3. Skew-T diagram at lat 18.78 lon 98.98 (a) on March 11, 2007. (b) on March 11, 2008.

trapped in Chiang Mai basin. Air pollution problem was likely to take place with this kind of atmospheric condition when the PM10 emission was high. These results correspond well with Kreasuwun *et al.*, [13] even though the studied domain is slightly different.

3.3 Outputs from CALPUFF

The PM10 concentrations from the CALPUFF are comparable with observation at the Province of Chiang Mai Government Center site during March 9-13, 2007 and March 9-13, 2008 as presented in Figure 4. These results were agreed with Kreasuwun *et al.,* [13]. The simulated and the observed PM10 concentrations are in the good accordance. It is noted that the observation is made at a single point location, while the CALPUFF estimates the average value of the PM10 over 1-km^2 grid cell. Other possible errors may be due to lack of information on emission rate input such as emission factor, combustion efficiency as well as fuel load.

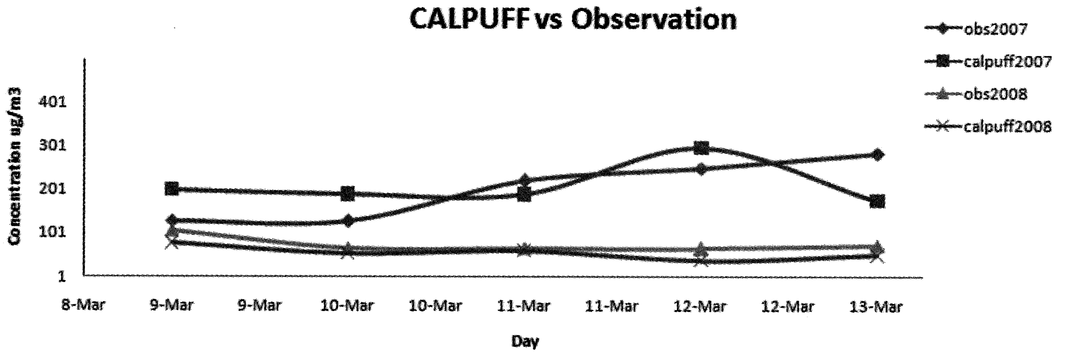


Figure 4. Calculated and observed PM10 concentrations at the Province of Chiang Mai government Center site during March 9-13, 2007 and 2008.

3.3.1 Wind and PM10 dispersion in 2007 and 2008

Wind and PM10 dispersion during March 9-13, 2007 and March 9-13, 2008 were simulated by CALMET and CALPUFF as representative in Figures 5 and 6. Dispersion of the PM10 in Chiang Mai during 9-13 March 2007 and 9 -13 March 2008 according to atmospheric stability, topography and wind velocity. Calm to moderate, west and southwest wind of 0.1-5.0 m/s distributed the PM10 in Chiang Mai basin during March 9-13 2007 as shown in Figure 5(a). The PM10 mostly dispersed nearby the burning areas and moved along with the light wind as shown in Figure 5(b).

Wind velocities in Chiang Mai during 9-13 March 2008 varied considerably from day to day. Southeast wind played a role on PM10 transport in Chiang Mai on March 11, 2008 as shown in Figure 6(a). Consequently the expansive PM10 dispersion shapes along with associated winds as shown in Figure 6(b).

(a)

(b)

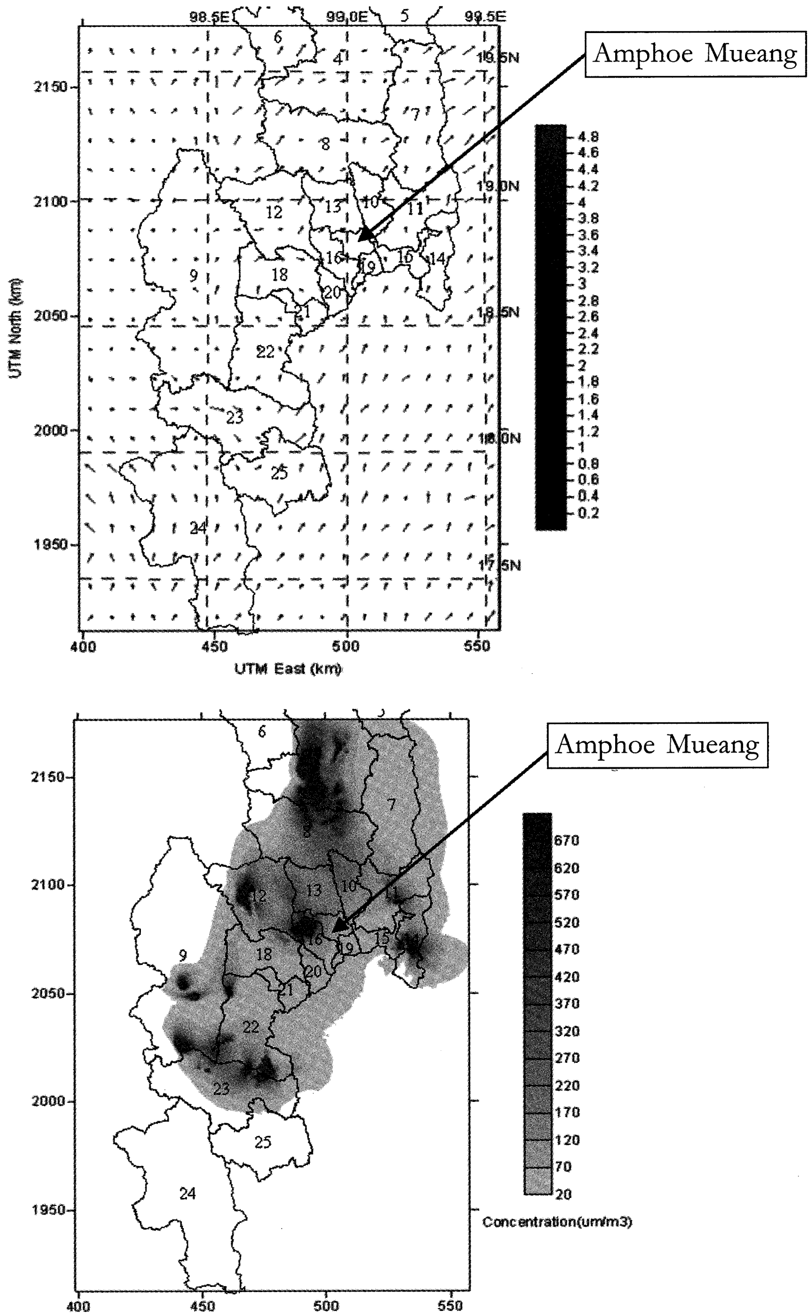


Figure 5. (a) 24-h average wind speed and direction at 5 m on March 11, 2007. (b) Affected area and 24-h average PM10 concentrations at 5 m on March 11, 2007. Numbers in the figures denote the subdistricts in Chiang Mai as follows 4 = Chiang Dao, 7 = Phrao, 8 = Mae Taeng, 9 = Mae Chaem, 10 = San Sai, 11 = Doi saket, 12 = Samoeng, 13 = Mae Rim, 14 = Mae On, 15 = San Kamphaeng, 16 = Hang Dong, 17 = Mueang, 18 = Mae Wang, 19 = Saraphi, 20 = San Patong, 21 = Doi Lo, 22 = Chom Thong, 23 = Hot, 24 = Om Koi, 25 = Doi Tao.

(a)

(b)

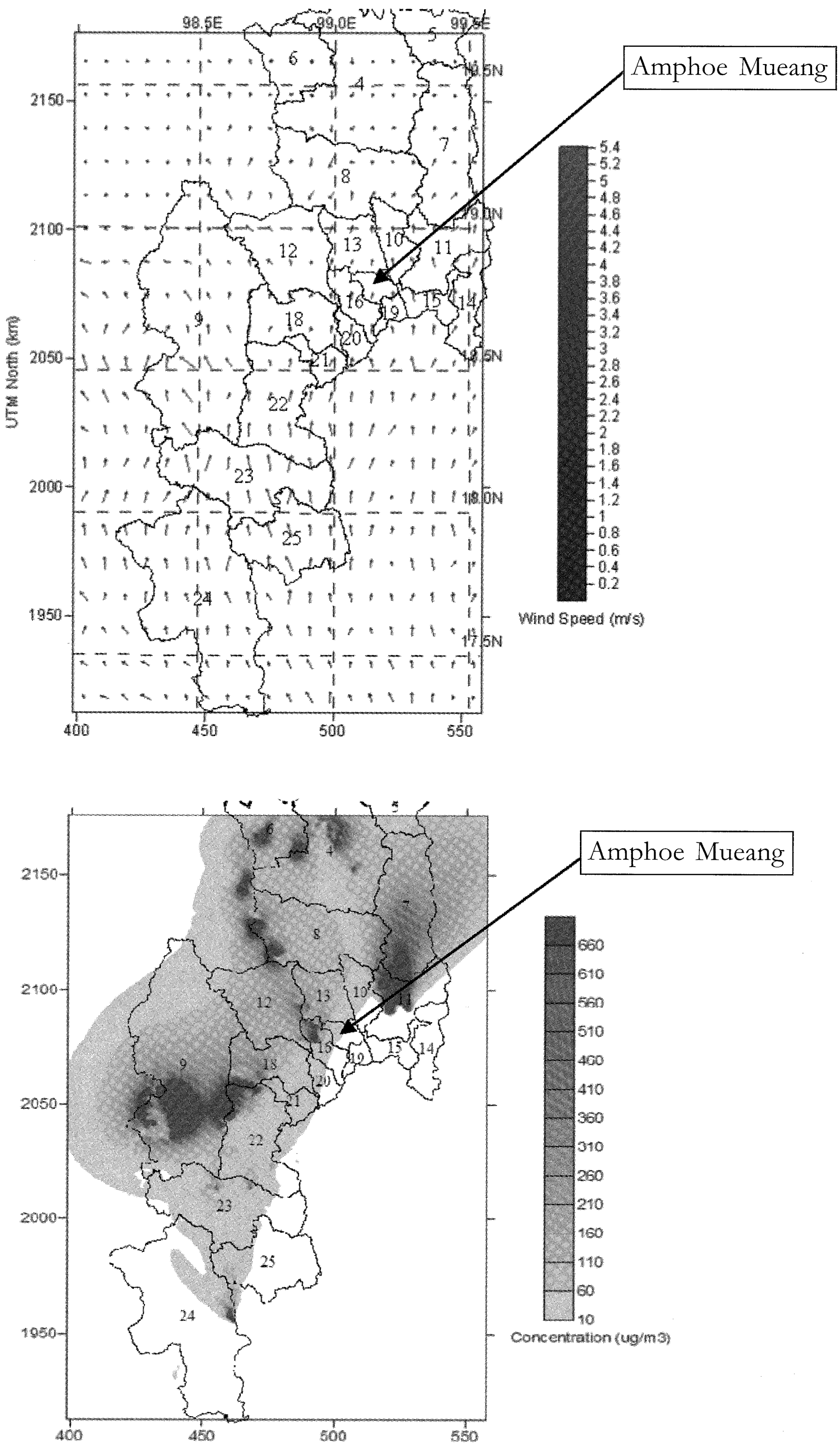


Figure 6. (a) 24-h average wind speed and direction at 5 m on March 11, 2008. (b) Affected area and 24-h average PM10 concentrations at 5 m on March 11, 2008. (refer to Fig. 5 for figure notation)

4. Conclusions

The PM10 concentration in Chiang Mai significantly depends on burning and forest fire activities, while the PM10 dispersion is considerably affected by atmospheric features such as atmospheric stability, temperature inversion caused by high pressure system and wind velocity. The results of this study including the affected areas could be potentially used in planning and mitigation policy to help control the level of the future PM10.

5. Acknowledgements

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