Evaluation of Meteorological Condition During 2005 Haze Episode In Klang Valley Using Mesoscale Model MM5

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***Abstract*--** **Haze pollution has become a transboundary problem to the South East Asian region, especially Malaysia, Indonesia and their adjacent countries. Meteorological condition, particularly temperature, is severely affected during the haze episode which occurred between 1 August 2005 and 15 August 2005 in Klang Valley, Malaysia. This paper reports on the use of MM5 modelling system to predict the hourly temperature distribution during the haze period. Meteorological simulation was conducted to spatially and temporally analyse the temperature distribution during haze episode in Klang Valley. Domain resolution of 27km, 9km, 3km and 1km (innermost) have been employed for this study. Urban areas in Klang Valley experience higher temperature during the haze episode simulation. Highest daily maximum temperature for each day was recorded during late afternoon. Evaluation of the model performance was also conducted with a measured data through a range of statistical measures. The model tends to under predict the temperature distribution of the simulation period. The paper discusses the spatial and temporal distribution of temperature during the haze episode in Klang Valley and also the model performance in predicting the meteorological condition of the study area.**

***Index Term*--** **MM5, Atmospheric Modelling, Urban meteorology, Haze**

I. INTRODUCTION

Urban air quality is becoming increasingly affected by pollution from neighbouring jurisdiction. Haze is one of the major transboundary problems that plague the Southeast Asian regions in the past 15 years. This air pollution problem could directly or indirectly affect human health, environment and economic in the region respectively.

The most basic form of air pollution is haze, where tiny particles (submicron size) in the air cause significant visibility reduction, due to the effectiveness of the particles in scattering and absorbing sunlight [1]. Haze can be formed either by direct emission of haze-causing particles into the air, or by transformation of gaseous emissions into particles [2]. Transboundary air pollution happened when these fine particles are dispersed and transported via wind, depending on the speed and direction of the wind itself.

Major sources of fires in Southeast Asian region include forestland conversion that involves uncontrolled use of fire to prepare the land for agricultural purposes. Land clearing by fires, especially in Indonesia, has caused this transboundary air pollution problem over the past decades. When El Nino phenomenon hit the Southeast Asian region with its drier condition, haze from forest and bush fires had gotten worse and this becomes an intensifying challenge for the neighbouring countries to overcome. Annually, several hundred million hectares of the world's forest and vegetation are destroyed by wildfires and intentional fires for land use system management [3]. Smoke haze due to uncontrolled forest fire during dry season in Southeast Asia has become a problem almost annually, specifically for countries such as Indonesia, Malaysia, Brunei, southern Thailand and Singapore. The most severe and damaging fire episode hit the region during the El Nino drought of 1997-1998 [4]. Most parts of Malaysia, Indonesia, southern Thailand, Singapore, southern Philippines and Brunei were relentlessly affected during the worst haze episode from July to October 2007. Many researchers [5-9], have reported the cause and effects of haze over the past years. Uncontrolled fires were detected in the peat areas of Sumatra Island during the severe 1997 haze episode [3]. The air quality in those affected areas remained at hazardous level, with certain locations such as Sarawak, Malaysia recorded an Air Pollution Index (API) peak value of 849. Since there was less rainfall recorded during the haze occurrence, affected areas experience much warmer condition during the period.

Another recent onset of regional smoke haze in Southeast Asia occurred at the beginning of August 2005 [4]. Areas such as Malaysia, Indonesia and southern Thailand were badly affected by the haze. During this period, enormous peat conversion fires, vegetation fires and slash-and-burn agricultural activities were reported to have taken place on the Sumatra Island of Indonesia. Although the problems of fire-related haze in Southeast Asia region have frequently been addressed, there are very few systematic studies on the effect of haze in this densely

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populated area. Many studies [10-12], through inadequate and inconsistent data have reported that the effects of haze can escalate to a serious level over time.

This study analyzes the meteorological condition and distribution of Klang Valley area during the August 2005 haze episode using the Fifth Generation Mesoscale Model (MM5) from PSU/NCAR [13]. There have been very few applications of this system for meteorological studies in urban areas in Malaysia. Performance of the model for predicting hourly temperature of the area was also being evaluated in this paper. This particular study does not consider the performance of the modelling system under extreme episodic conditions which will be the focus of future investigations.

II. METHODOLOGY

The PSU/NCAR mesoscale model is a limited-area and non-hydrostatic model with terrain-following coordinates, multi-scale, capable of interface with actual weather forecast models (Global Circulation Model) and contains explicit cloud schemes and soil parameterization [14]. The MM5 model is the most widely used meteorological model for providing the meteorological information although other meteorological models are also available for this purpose. The MCIP module (Meteorology-Chemistry Interface Processor) converts and adjusts the MM5 output that can be use together with Sparse Matrix Operation Kernel Emission (SMOKE) model and Community Multiscale Air Quality (CMAQ) model. This module performs an analysis of the MM5 output to ensure mass conservation between MM5 and other air quality modelling system. The initial meteorological conditions were obtained from NCEP FNL (Final) Operational Global Analysis data for the appropriate time periods [15]. Fig. 1. shows you a schematic of the MM5 modeling system.

Four domains were used for this study. The mother domain with the resolution 27km covers most of the Peninsular Malaysia; second domain with 9km resolution covers Selangor and Negeri Sembilan states; third domain with 3km resolution covers northern region of Negeri Sembilan; finest domain with 1km resolution will cover the study area of Klang Valley as shown in Fig. 2.

Meteorological simulation was done for the period of 6-10 August 2005, typically reflecting the peak haze episode that occurred during that time. In this study, meteorological fields are simulated from 00:00 UTC 6 August to 00:00 UTC 11 August 2005, and fields of 72h, excluding the data employed to stabilize the initial simulation were analysed.

The results of MM5 model were compared and validated with measured data from two meteorological stations located within the study domain of Klang Valley, which are Petaling Jaya and Subang Jaya. Meteorological data from the two stations were provided by the Malaysian Meteorological Department (MMD). Careful selection of the monitoring stations is very crucial as the predictions by the model provides for the mean values of the grids with a resolution of 1 km x 1 km and not precisely for a certain receptor point. Monitoring station provides good spatial coverage of the inner domain and is not affected by any significant source within 25m of the monitors which may initiate local bias. However, local influences on any given monitoring station cannot be ruled out as monitoring station represents a point measurement and cannot fully represent the pollution climate of the surrounding area [16].

It is necessary to carry out a qualitative evaluation of the influence of dense meteorological data on the meteorological field of the target area. To understand the assessment impact quantitatively, we conducted statistical analyses to further quantify the agreement between the simulated values (P) and the measured data from MMD (O). Model performance statistics included the observation and prediction mean, deviation, correlation coefficient, Normalized Mean Square Error (NMSE), Fractional Bias (FB), and Factor of Exceedance (FOEX).

- *The Correlation Coefficient (CC)*

$$\mathrm{CC} = \frac{\sum_{j=1}^{m}\sum_{i=1}^{n} y_{O,i,j}\, y_{P,i,j}}{\sqrt{\sum_{j=1}^{m}\sum_{i=1}^{n} y^2_{O,i,j} \sum_{j=1}^{m}\sum_{i=1}^{n} y^2_{P,i,j}}}$$

- *The Normalized Mean Square Error (NMSE)*

$$\mathrm{NMSE} = \frac{\overline{(C_P - C_O)^2}}{\overline{C_P{}^2}}$$

- *The Fractional Bias (FB)*

$$\mathrm{FB} = \frac{\overline{C_P} - \overline{C_O}}{0.5(\overline{C_P} + \overline{C_O})}$$

- *The Factor of Exceedance (FOEX)*

$$\mathrm{FOEX} = \left[\frac{N_{(P_i > M_i)}}{N} - 0.5\right]100$$

C_p is predicted concentration and C_o is the observed/measured value. The overbar refers to the average over all hourly values. CC and NMSE provide a measure of the correlation of the predicted and measured time series of hourly results. FB represents a measure of the agreement between the mean predicted and observed hourly values and hence perfect agreement between two data set is indicated when FB=NMSE=0. The Factor of Exceedance (FOEX) is a useful measure of the extent of over-under prediction. If

FOEX is equal to -50% then all points lie below the y = x line of the scatter diagram, i.e. all the modelled results are under predicted and vice versa. If FOEX equals 0% then one observes optimum distribution of data where there are half under- and half over-predictions [16].

III. RESULT AND DISCUSSION

A) MM5 simulation results

Fig. 3 shows the simulation results for 8th August 2005. The simulated result was analysed to investigate the spatial and temporal distribution of the temperature during the haze episode of 2005. The highest daily temperature recorded was 33.93°C. Several locations were in the range of high temperature such as Shah Alam, Petaling Jaya and Kuala Lumpur. Most locations such as Kajang and Seri Kembangan recorded temperature of the range between 29.74°C and 31.94°C. Klang Valley recorded temperature of around 30°C to 33°C. Haze episode occurred during the simulation period, which contributes to a much higher temperature recorded on hourly basis. However, much higher daily temperature was recorded on the 10th August 2005, where the temperature recorded was 34.14°C for Kuala Lumpur as shown in Fig. 4 temperature distribution for this simulation day was very distinguished, as more locations are in the range of high temperature. Sepang, Kajang, Gombak, Shah Alam, Putrajaya recorded high temperature during the simulation period.

Temporal analysis was also conducted for the simulation of haze period. Fig. 5 showed the temporal distribution of MM5 simulation for 6-10 August 2005. From the figure, we can see that on the 8th August 2005, the highest daily temperature was recorded at 08:00:00 UTC or 4.00pm local time with the temperature of 33.93°C. On the 9th August, the highest daily temperature recorded was 33.90°C, also at 4.00pm local time. However, simulation on the 10th August 2005 recorded the highest maximum daily temperature of 34.14°C at 3.00pm local time. This result is in sync with the haze episode which started to elevate on the 10th August 2005 and reached its peak on the 11th August 2005 as reported [17-18].

Based on the spatial and temporal analysis of the simulations, Klang Valley experienced a much higher temperature during haze episode compared to normal days. This is due to the prolonged dry season in the region, coupled with direct influence of south-westerly wind [19]. Klang Valley and together with several other parts of the country experienced short-term mild to severe haze episodes from mid-May until mid-October 2005. The land and forest fire in Riau Province of Central Sumatra, Indonesia were the primary cause of transboundary haze which was aggravated by the stable atmospheric conditions during the period. Due to its geographical position, large-scale industrial and commercial activities, densely populated areas and high vehicular traffic, with prevailing winds generally weak in this area and low rain frequency, Klang Valley encountered a much warmer condition as the condition of haze worsened [20-23]. The effect of urban heat island, which is a well known problem for major cities and urban areas, is also contributing to the resulting high temperature during the haze [24]. Overall, for temperature distribution assessment, MM5 produces reliable meteorological simulations [25-27] for its diurnal variation and the minimum temperatures at those sites.

Analysis of Correlation Coefficient (CC) was conducted to validate the simulated results with field data provided by the Malaysian Meteorological Department (MMD). Data from two MMD monitoring stations within the study area was used to validate the model. Results from the analysis showed that the correlation between simulated results and observed data is high, which is 0.73 for Subang Jaya station and 0.72 for Petaling Jaya station as shown in Fig. 6 and Fig. 7. Results showed that the modelled result is reliable and can be use for further analysis. To further confirm the reliability of the modelled result, evaluation of the model performance was also conducted and discussed later in this paper.

B) Model performance evaluation

The results of the statistical comparison are shown in Table 1 for the simulation period. The correlation for the simulation period is satisfactory for both meteorological stations. Other studies have also produced the same range of correlation coefficient values for meteorological simulations at different locations as well [15, 28]. The normalized mean square errors (NMSE) are low, indicating good performance of the model. Fractional Bias (FB) is low but indicates that the model under-predict for both meteorological stations as shown in Fig. 8. This is further confirmed by the FOEX with negative value of 12.8% and 30.99% for the simulation. Even though the predicted meteorology from the grids is generally consistent, differences sometimes occur among sites because of the sensitivity of various MM5 physics options to the horizontal grid spacing [29]. Overall, the statistical measures confirm the adequacy and reliability of the model for predicting meteorological distribution, in this case ground temperature distribution of the study area.

IV. CONCLUSION

Haze pollution has become a regional problem especially in South East Asia region, where land clearing by fire is still a common practice among farmers of this region. This study simulates the 2005 haze episode which occurred in Malaysia using the MM5 model and attempted to spatially and temporally analyse the temperature distribution during the haze episode. Findings showed that daily maximum temperature distribution during haze episode is much higher compared to other normal days, especially in places of urban characteristics. Several locations experienced higher than normal ground temperature. Sudden temperature changes can be a great discomfort not only to the people living in areas affected by haze, but also to the surrounding environment as well.

Utilization of the meteorological model is a good way to spatially and temporally analyse the meteorological distribution, especially for certain cases such as haze. Related environmental agencies often depend on data from continuous air quality monitoring system (CAQM) to determine the air quality status and meteorological condition during haze episode. However, the data obtained from the CAQM only gives the average value for the said parameter (e.g. specific pollutant or meteorological parameter) and representative for one location. On the other hand, meteorological model or any other air quality model can provide spatial and temporal distribution of the desired parameter to be analysed. Overall the result indicates an acceptable agreement between observed and modelled data. MM5 can also be integrated with other emission and chemical transport model, thus expanding its usage to not only on meteorological prediction, but for further studies on air quality as well, especially in Malaysia.

V. LIMITATION OF WORK

Lack of observation data from the ground monitoring stations hindered this study from making a better validation of the results obtained from the simulation. A more comprehensive study can be done to see the temperature distribution between different locations during certain haze episode, provided more ground stations data are available for further analysis.

VI. ACKNOWLEDGMENT

This project is funded by the Ministry of Higher Education of Malaysia under the Fundamental Research Grant Scheme (FRGS). We are thankful to the Malaysian Meteorological Department (MMD) for providing the meteorological data needed for this study. We would like to thank the Department of Environment Malaysia for providing us with useful information for the purpose of this study.

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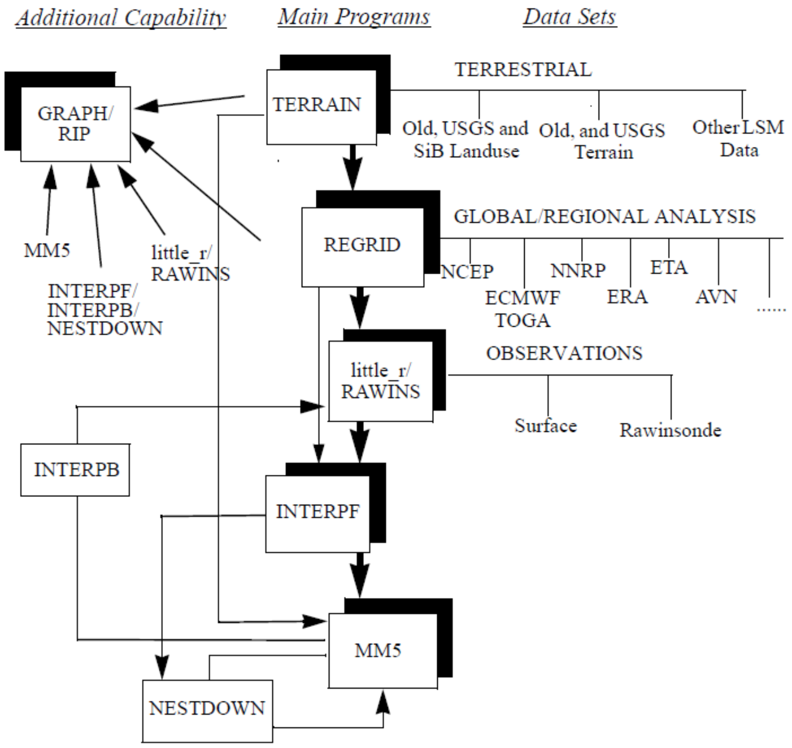

Fig. 1. Schematic diagram of MM5 modeling system

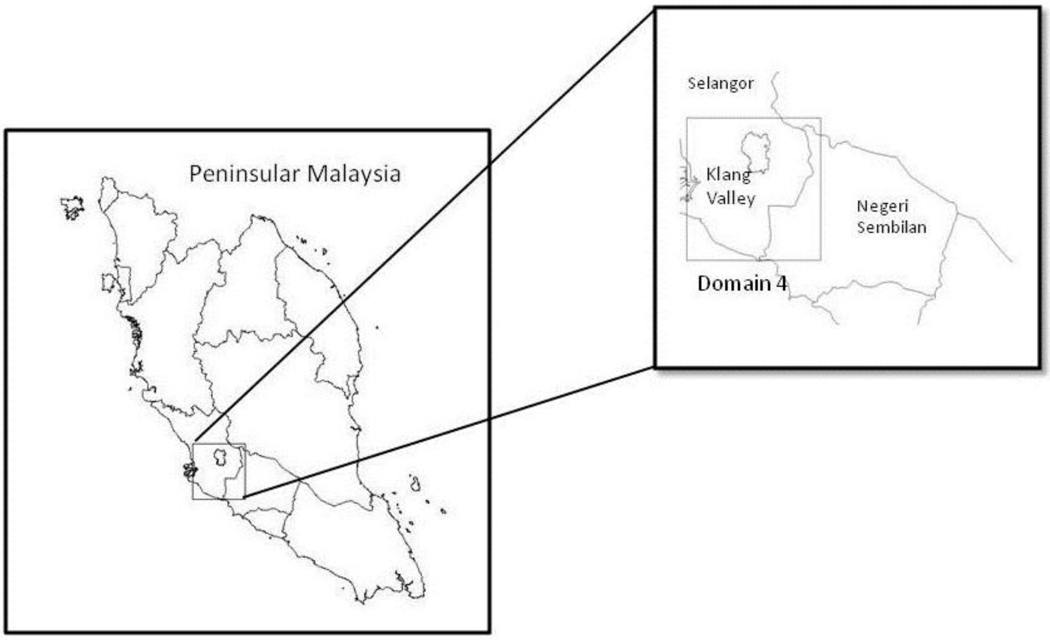

Fig. 2. Domain set up of MM5. Domain 4 (1km x 1km) comprises of Klang Valley area.

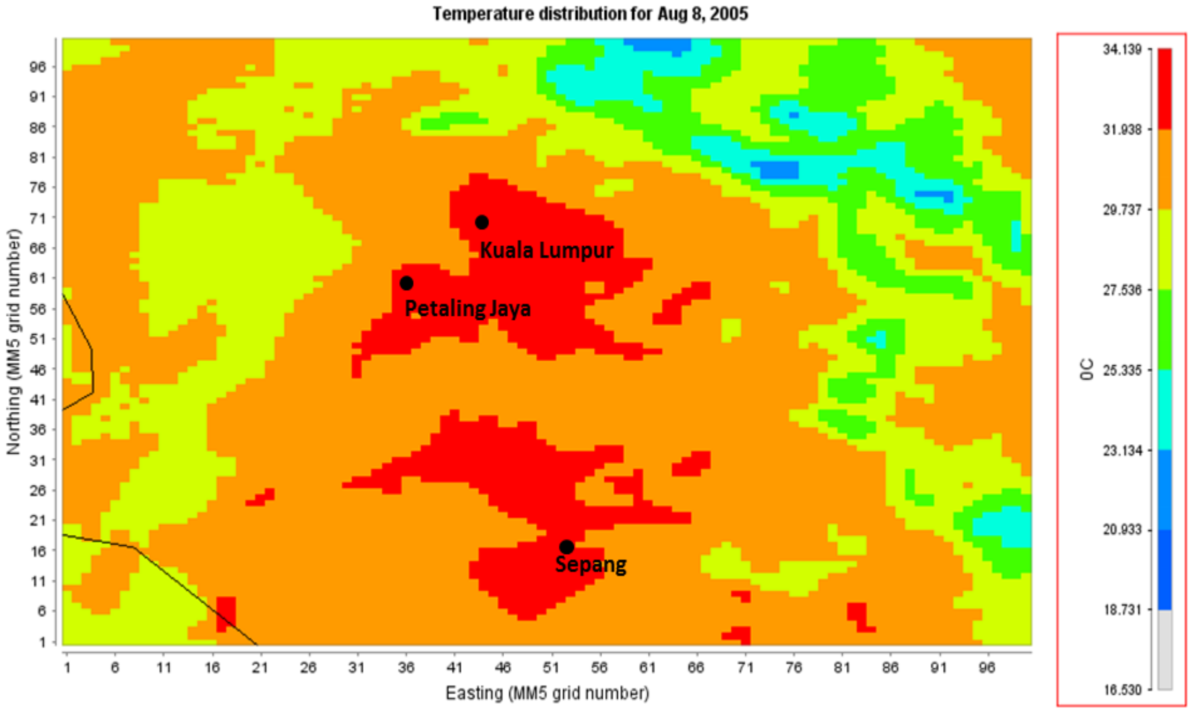

Fig. 3. Temperature distribution of MM5 simulation for 8 August 2005 at 08:00:00 UTC

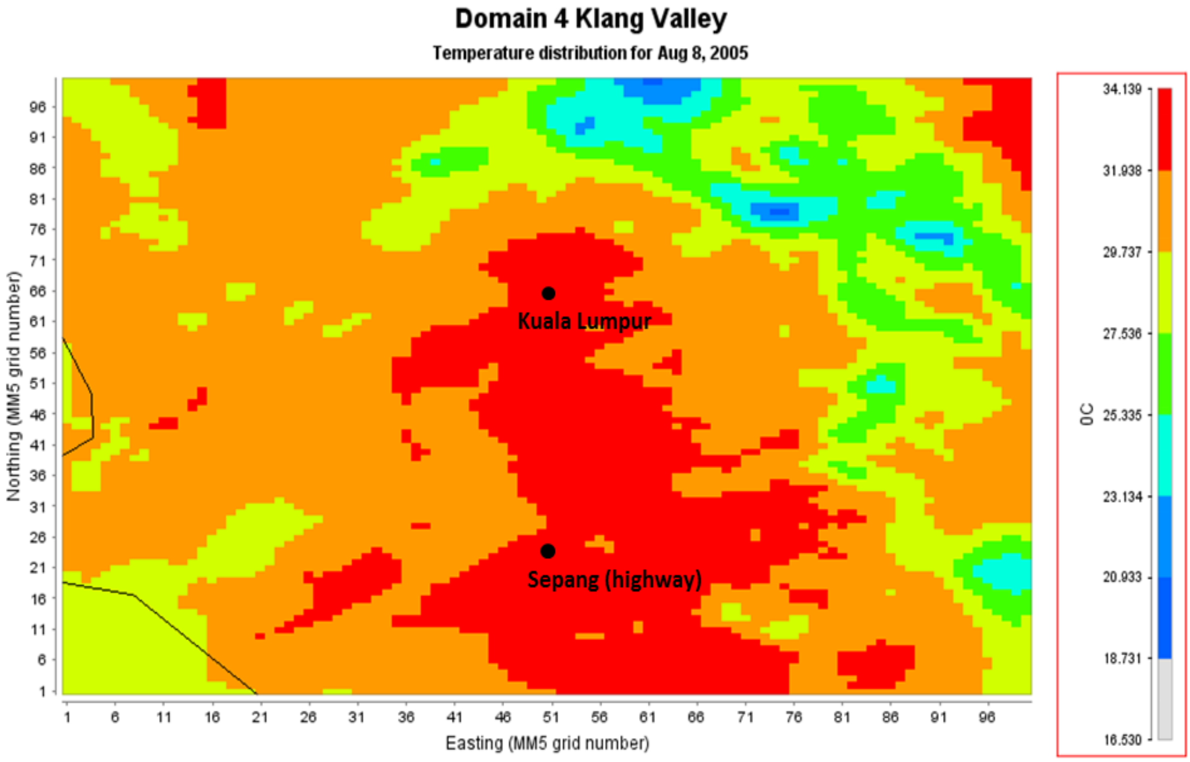

Fig. 4. Temperature distribution of MM5 simulation for 10 August 2005 at 07:00:00 UTC

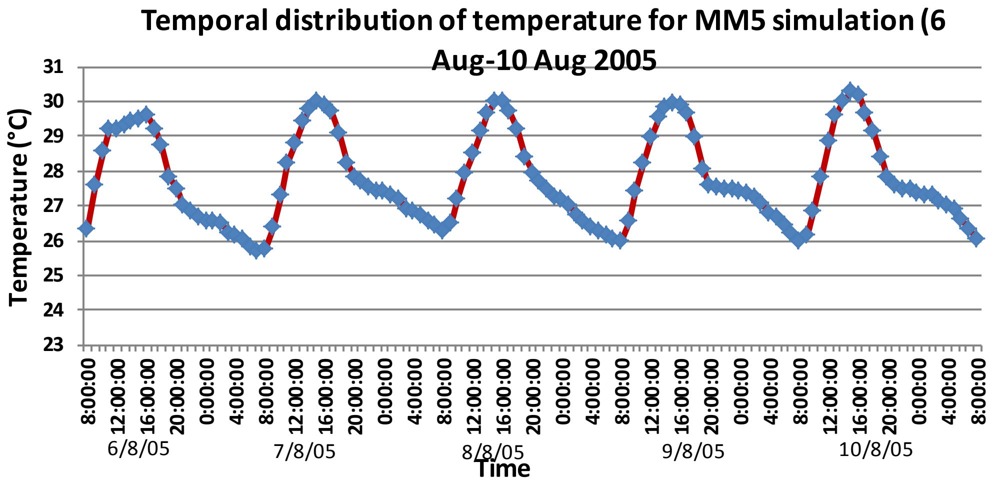

Fig. 5. Temporal distribution of temperature for simulation of haze episode using MM5

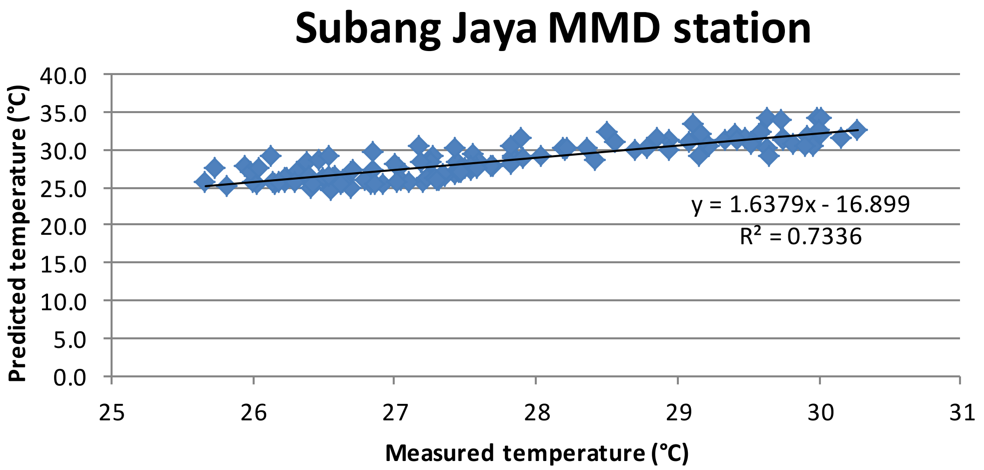

Fig. 6. Analysis of Correlation Coefficient (CC) between predicted data and observed data from MMD station Subang Jaya

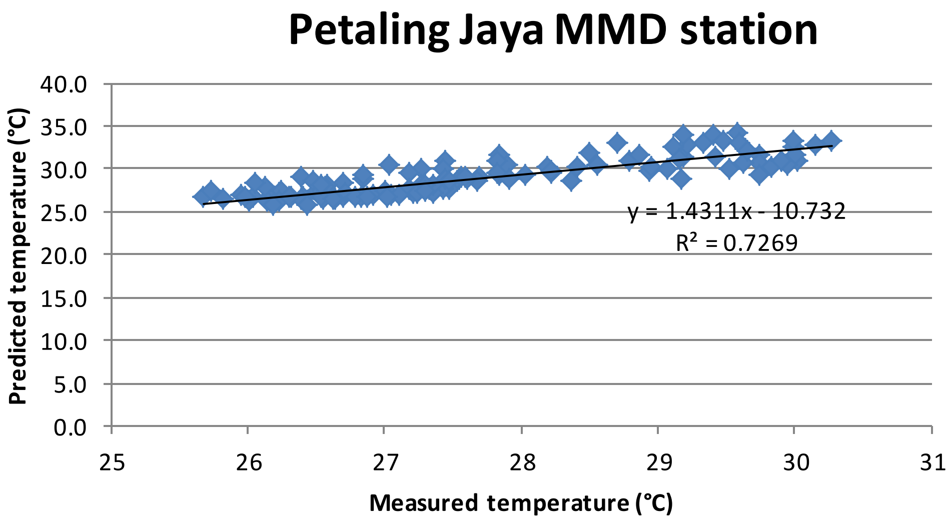

Fig. 7. Analysis of Correlation Coefficient (CC) between predicted data and observed data from MMD station Petaling Jaya

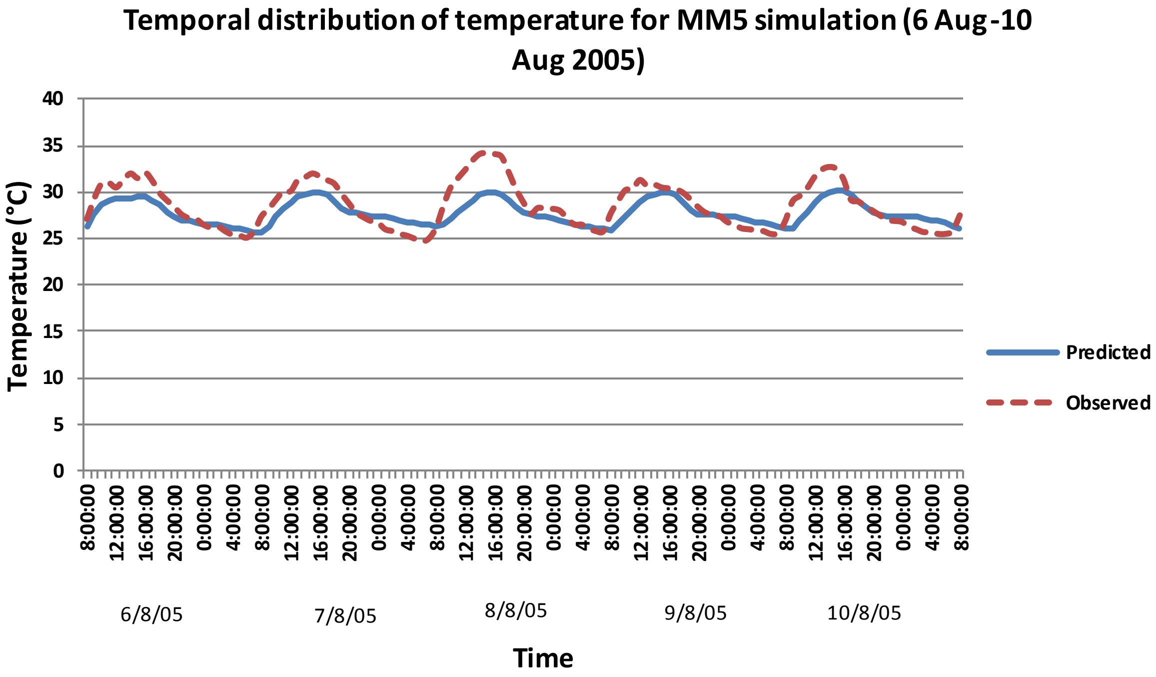

Fig. 8. Temporal distribution of temperature for predicted result and observed data from MMD station Subang Jaya

TABLE I
STATISTICAL MEASURES FOR MM5 FOR 6-10 AUGUST 2005 SIMULATION

Parameter	MMD Stations	CC	NMSE	FB	FOEX
Temperature (°C)	Subang Jaya	0.73	0.004	-0.03	-12.8
	Petaling Jaya	0.72	0.004	-0.02	-30.99

Abbreviations: Correlation Coefficient (CC), Normalized Mean Square Error (NMSE), Fractional Bias (FB), Factor of Exceedance (FOEX)