PERFORMANCE OF TAPM AGAINST MM5 AT URBAN SCALE DURING GÖTE 2001 CAMPAIGN

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1. INTRODUCTION

Model performances in meteorological conditions directly influence the effects of air pollution prediction in particular in urban area with complex surface characteristics including roughness length, building characteristics, thermal properties and anthropogenic heat flux. In this study, the performances of two widely used models in air quality community, The Air Pollution Model (TAPM) (Hurley, 2005) and the PSU/NCAR fifth-generation Mesoscale Model (MM5) (Grell et al., 1995), were evaluated and compared at urban scale (a few kilometres) in the greater Gothenburg (Sweden) using the GÖTE2001 campaign data. The objectives of this study were (1) to evaluate the meteorological component of TAPM in the coastal urban environment in south-west Sweden; (2) to compare the performances of TAPM and MM5 in simulating local meteorological conditions over this urban area. Evaluation focused on simulated meteorological variables important to air quality applications: near-surface air temperature and wind, vertical temperature gradient, low wind speed situation, diurnal cycle and diurnal heating.

2. MATERIAL AND METHODS

GÖTE2001 field campaign

Gothenburg is the second largest city in Sweden with about 600 000 inhabitants. It is situated in a hilly landscape with steep sided joint aligned valleys over the Swedish south-west coast. The campaign GÖTE2001 took place in and around Gothenburg city during the period of 7–20 May, 2001. Measurement covered the Gothenburg city centre, suburban, rural areas including west coastal area (Fig. 1). The meteorological variables available during this campaign were temperature, wind speed, wind direction and humidity at near-surface level (Borne et al., 2005).

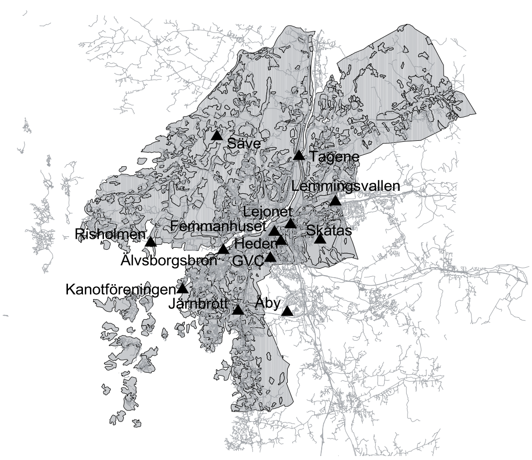

Figure 1. Positions of the measurement sites used in this study during the GÖTE2001 campaign. They are: coastal sites (Risholmen, Älvsborgsbron), urban sites (Femmanhuset, Heden, GVC, Lejonet, Skåtas, Järnbrott, Åby, Tagene) and rural site (Säve).

Methods

In order to quantitatively measure model performance, a set of statistical measures is needed to compare observations with model predictions, and to compare the statistics obtained from other model. The following measures were used in this study: mean bias error (MBE), root mean square error (RMSE), correlation coefficient (R) and one skill measure Index of agreement (IOA).

3. MODEL CONFIGURATIONS

Miao et al. (2007, 2008) showed that MM5 with MRF PBL (Planetary Boundary Layer) scheme (Hong and Pan, 1996) and Noah LSM (Land Surface Model) scheme (Chen and Dudhia, 2001) has better performance in reproducing boundary layer structure and urban effects. Based on this MM5 configurations TAPM was designed and set up accordingly for the intercomparison purpose. In this study, TAPM had four nested domains with horizontal grid resolution of 54, 18, 6 and 2 km respectively, all centred at the location (57°42´N, 11°58´E). The innermost domain consisted of 40×46 horizontal grids (N-S direction by E-W direction), which covered the area of interest, including all the GÖTE2001 campaign sites. The lowest ten of the 40 vertical levels were 10, 25, 50, 75, 100, 150, 200, 250, 300, 350 m a.g.l. (above ground level), with the highest model level at 8000 m AGL. As same with MM5, the initial and boundary conditions in TAPM were extracted from the ECMWF (The European Centre for Medium-Range Weather Forecasts) operational analysis with the spatial resolution of 0.5 degree longitude by 0.5 degree latitude and the temporal resolution of six hours. In addition, the monthly sea-surface temperature (286.2 K), the monthly deep soil temperature (282.2 K) and the monthly deep soil volumetric moisture content (0.27 m^3m^{-3}) were used in the model simulation according to the ECMWF analysis.

4. RESULTS AND DISCUSSION

Surface temperature and wind field

An examination of near-surface air temperature and wind is important for model performance because these qualities reflect the nature of the local thermal circulation influenced by mesoscale forcing, and govern contaminant distributions in air-quality models (Lee and Fernando, 2004). The simulated results on 2-m temperature and U- and V-component of 10-m wind were presented at urban, suburban, rural and coastal sites (Tabs. 1 and 2). Sample numbers for the most sites were 336 except one rural site Säve, with 112 samples due to the three-hourly interval.

Table 1. Observed and modeled 2-m temperature statistics (°C) at urban, suburban and rural sites for GÖTE2001. The number of samples is 336, except for Säve with 112 samples due to the three-hour interval.

	Järnb	Åby	Femm	Lejon	Tage	Rishol	Älvsb	GVC	Heden	Säve
MBE_MM5	-0.8	0.2	-0.8	-1.1	-1.2	-0.1	-0.6	-1.4	-0.1	0.1
MBE_TAPM	-0.1	0.8	0.0	-0.1	0.0	0.6	-0.3	-0.6	0.8	0.3
RMSE_MM5	2.37	2.40	2.84	3.11	3.00	1.86	2.54	3.02	2.38	1.92
RMSE_TAPM	2.37	2.77	2.53	2.80	2.68	1.79	1.58	2.44	2.35	2.51
R_MM5	0.83	0.82	0.76	0.77	0.78	0.77	0.75	0.82	0.82	0.90
R_TAPM	0.80	0.79	0.78	0.77	0.78	0.81	0.85	0.86	0.84	0.84
IOA_MM5	0.90	0.90	0.86	0.86	0.86	0.87	0.84	0.88	0.90	0.95
IOA_TAPM	0.89	0.88	0.88	0.87	0.88	0.89	0.91	0.92	0.90	0.91

Site abbreviations: Järnb: Järnbrott; Femm: Femmanhuset; Lejon: Lejonet; Tage: Tagene; Rishol: Risholmen; Älvsb: Älvsborgsbron.

The statistic measures for near-surface temperature showed the close agreement between models and observations (IOA>0.84). This indicates that TAPM and MM5 have comparable results in simulating the near-surface air temperature. At urban sites (Femmanhuset, Lejonet, GVC and Heden) and two coastal urban sites (Risholmen and Älvsborgsbron), TAPM performed better in terms of lower bias and RMSE, and higher R and IOA, whereas MM5 underestimated surface air temperature at urban sites.

Taking these statistic measures into account, TAPM performed much better than MM5 for 10-m wind simulation at both urban and rural sites. TAPM can predict the temporal variation of winds with IOA values ranging from 0.80 to 0.94 for U- and V-component.

Boundary layer structure

Vertical temperature gradient

The stability of lower atmosphere is characterized by vertical temperature gradient, which is often measured from instrumental mast. In this study, vertical temperature gradient is calculated by using hourly 3-m and 105-m measurement at Järnbrott mast site during 7–19 May, 2001. The comparisons of modelled vertical temperature gradient were discussed during daytime and nighttime separately (Fig. 2). Nighttime temperature gradient was able to be well predicted by two models (IOA_TAPM=0.85; IOA_MM5=0.83). However, both models failed to simulate the daytime temperature gradient. TAPM greatly underestimated daytime temperature gradient due to the overestimation of surface temperature and underestimation of daytime temperature at high altitude (105-m). The MBE for daytime temperature at 2-m was 0.10 ºC for TAPM and -0.12ºC for MM5, whereas that at 105-m was -0.89ºC for TAPM and -0.43ºC for MM5. It might be due to the local urban effects are not properly accounted for by the generic single-layer canopy scheme used, which indicates the necessary improvement in land-surface scheme in TAPM (Luhar and Hurley, 2003, Luhar et al., 2006).

Table 2. Observed and modeled U- and V-component of 10-m wind statistics (ms^{-1}) at urban, suburban and rural sites for GÖTE2001. The number of samples is 336, except for Säve with 112 samples due to the three-hour interval.

	Järnb	Åby	Femm	Lejon	Tage	GVC	Heden	Skåtas	Lemm	Älvsb	Kanot	Säve
MBE_MM5												
U	0.2	-0.1	-0.2	-0.1	0.2	-0.2	0.0	0.2	0.2	-0.1	0.8	-1.5
V	0.3	0.4	0.6	0.5	0.4	0.7	0.3	0.6	0.4	0.5	0.2	-2.7
MBE_TAPM												
U	0.2	-0.3	-0.3	-0.2	-0.1	-0.4	-0.3	-0.1	-0.2	-0.1	0.4	-0.6
V	0.2	0.3	0.5	0.5	0.3	0.4	0.2	0.4	0.3	0.4	0.0	0.5
RMSE_MM5												
U	1.69	1.85	2.09	1.54	1.72	1.64	1.56	1.69	1.70	2.78	2.82	3.67
V	1.90	1.44	1.88	1.49	1.68	1.57	1.53	1.63	1.49	2.53	3.08	4.22
RMSE_TAPM												
U	1.43	1.58	1.78	1.20	1.58	1.30	1.10	1.53	1.44	1.93	1.80	1.91
V	1.64	1.12	1.79	1.19	1.26	1.05	1.30	1.21	1.08	1.97	2.26	1.55
R_MM5												
U	0.70	0.75	0.72	0.76	0.73	0.78	0.72	0.76	0.76	0.80	0.71	0.50
V	0.62	0.76	0.71	0.71	0.72	0.74	0.66	0.70	0.69	0.71	0.57	0.14
R_TAPM												
U	0.85	0.82	0.81	0.86	0.76	0.88	0.87	0.80	0.82	0.93	0.90	0.85
V	0.71	0.82	0.74	0.81	0.83	0.86	0.71	0.79	0.79	0.85	0.69	0.81
IOA_MM5												
U	0.83	0.86	0.82	0.87	0.83	0.88	0.84	0.87	0.87	0.83	0.83	0.35
V	0.77	0.86	0.81	0.81	0.84	0.83	0.79	0.75	0.77	0.80	0.70	0.36
IOA_TAPM												
U	0.90	0.89	0.88	0.92	0.85	0.92	0.92	0.89	0.90	0.93	0.94	0.87
V	0.83	0.90	0.83	0.88	0.91	0.91	0.83	0.84	0.86	0.89	0.80	0.87

Site abbreviations: Järnb: Järnbrott; Femm: Femmanhuset; Lejon: Lejonet; Tage: Tagene; Lemm: Lemmingsvalen; Älvsb: Älvsborgsbron; Kanot: Kanotföreningen.

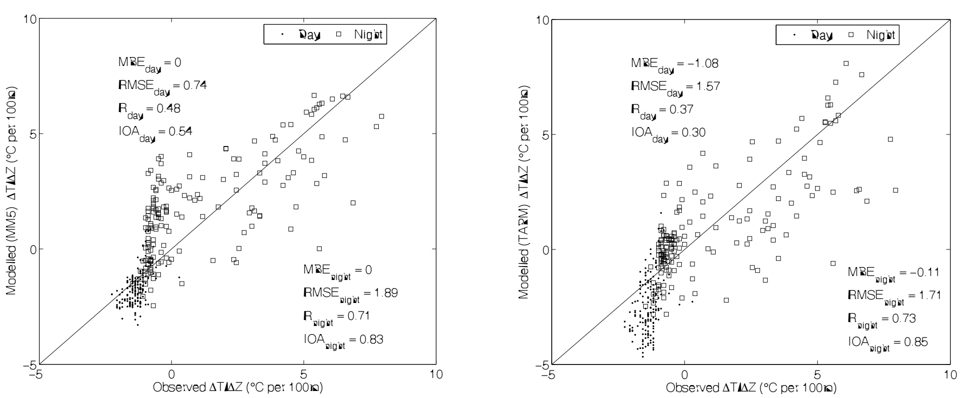

Figure 2. Observed and modelled vertical temperature gradient at Järnbrott mast site from TAPM and MM5 respectively. The results are based on hourly data of near-surface and 105-m measurements/simulations during the period from 7–19 May 2001. The temperature gradient during night hours (20:00–07:00 UTC) is denoted by square to show nocturnal temperature inversion for clarity. Statistical parameters at day and night are presented within the plot.

Low wind speed stable conditions

Many dispersion models use MOST (Monin-Obukhov Similarity Theory) in urban area by adjusting the roughness length or M–O length under very stable conditions (Craig and Bornstein, 2003). In order to examine how well this adjusting is working, we compared the frequencies of different wind levels during daytime and nighttime at urban, coastal and rural sites (Tab. 3). Results showed that the two models severely underestimate the nocturnal low wind situation (< 2 ms^{-1}) at all three sites. It indicates that the weakness of MOST under strongly stable conditions is still evident in the two models. However, the two models perform better during daytime at all wind levels. Compared with

MM5, the advantage of TAPM is the simulation at urban site and gives progressively better simulation for higher wind speed levels, which agree with earlier study (Luhar et al., 2007).

Table 3. Observed and modelled frequencies (%) of the hourly-averaged wind speed at 10-m AGL during daytime (08:00–19:00 UTC) and nighttime (20:00–07:00 UTC) at Kanotföreningen, Säve and Heden from 7 to 20 May, 2001.

			0–2 ms^{-1}	2–4 ms^{-1}	4–6 ms^{-1}	6–8 ms^{-1}	> 8 ms^{-1}
		OBS	17.9	41.1	26.2	9.5	5.4
	Day	TAPM	8.9	40.5	31.0	4.2	15.5
Kanotföreningen		MM5	7.1	22.0	38.1	12.5	20.2
(Coast)		OBS	57.1	23.2	6.0	7.7	6.0
	Night	TAPM	10.7	51.2	22.0	3.6	12.5
		MM5	9.5	36.9	34.5	8.9	10.1
		OBS	21.4	35.7	21.4	17.9	3.6
	Day	TAPM	19.6	66.1	14.3	0.0	0.0
Säve		MM5	37.5	33.9	19.6	8.9	0.0
(Rural)		OBS	64.3	23.2	3.6	7.1	1.8
	Night	TAPM	23.2	73.2	3.6	0.0	0.0
		MM5	23.2	69.6	7.1	0.0	0.0
		OBS	26.8	58.3	14.3	0.6	0.0
	Day	TAPM	22.6	61.9	15.5	0.0	0.0
Heden		MM5	39.3	29.2	22.0	9.5	0.0
(Urban)		OBS	74.4	17.9	7.7	0.0	0.0
	Night	TAPM	40.5	50.6	8.9	0.0	0.0
		MM5	33.9	64.3	1.8	0.0	0.0

Diurnal temperature variation in urban area

The urban features simulated by the two models need to be checked and compared since the interesting area is dominated by urban land use. Diurnal temperature variations including diurnal cycle and diurnal heating of surface temperature are two major characters to evaluate model performance. In this study, near-surface air temperature data at seven urban sites (Femmmanhuset, Heden, Lejonet, GVC, Järnbrott, Åby and Tagene) was used to calculate urban-averaged diurnal cycle and diurnal heat index (Fig. 3). TAPM and MM5 had similar timing at three phases of diurnal cycle. Compared with MM5, TAPM evidently overestimated the daytime temperature, which is coincided with the overestimation of daytime sensible heat flux reported by Zawar-Reza et al. (2005).

In this study, the diurnal heat index was expressed as diurnal cycle intensity (DCI), defined as the difference between daily maximum and minimum near-surface air temperatures. Figure shows that TAPM and MM5 had comparable skills in simulating diurnal heating.

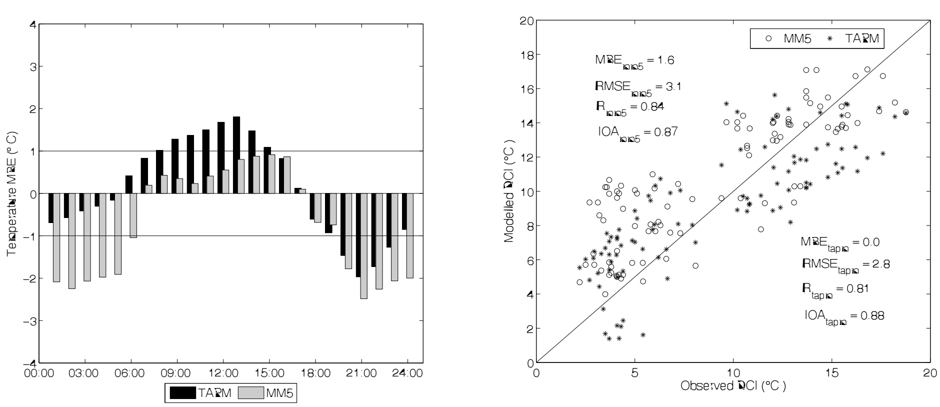

Figure 3. Comparison of diurnal cycles for near-surface air temperature mean bias error (MBE) between two models at the urban sites (left). Scatter plot of observed versus modelled diurnal cycle intensity (DCI) at urban sites (right).

5. SUMMARY AND CONCLUSIONS

This study evaluated the performances of TAPM during GÖTE2001 campaign by comparing with the results of MM5. The comparison focused on the application of models in south-west coastal urban area in high latitude and those urban scale meteorological features important to dispersion of air pollutants. It is concluded that the results from TAPM are comparable with those from MM5 at urban scale. TAPM scored higher than MM5 in simulating near-surface air temperature at urban area as well as the coastal urban area, and two models had similarly good performance in rural area. For 10-m wind simulation, TAPM had obviously better performance in all different areas. The two models were able to predict vertical temperature gradient during nighttime acceptably; whereas they failed to predict it correctly during daytime. The underestimation of daytime temperature gradient of TAPM is due to the overestimation of the surface temperature and underestimation of high altitude temperature. As well as MM5, TAPM had difficulties in correctly predicting near-surface wind under the nocturnal stagnant wind situations (< 2 ms^{-1}), which confirms the limitation of applying MOST under strongly stable conditions.

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