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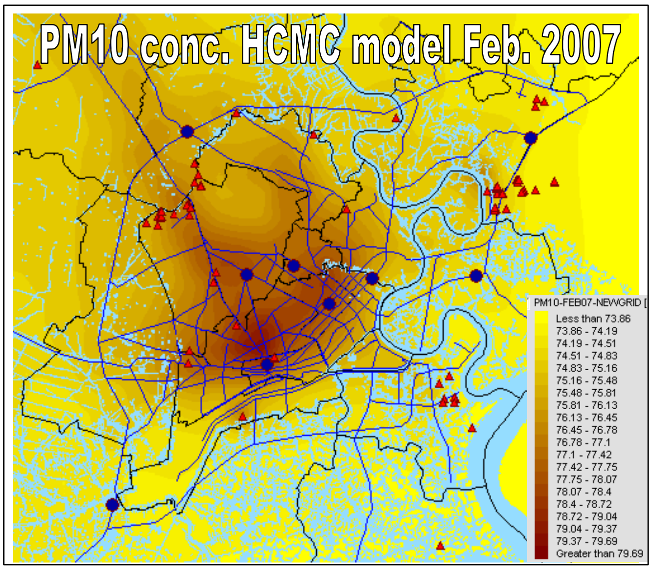

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Emission Inventory and Air Quality Modelling in Ho Chi Minh City, Vietnam

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Abstract:
The Ho Chi Minh City Environmental Protection Agency (HEPA) under DONRE is operating an air quality monitoring and assessment system in Ho Chi Minh City (HCMC). The data collected through the automatic monitoring and telemetric network is being quality controlled and transferred for storage in the AirQUIS database. An automatic air quality index (AQI) generator provides AQI values for traffic and for urban background microenvironments to be displayed daily on electric board and the information website.

Emission inventory has been done in HCMC for the last three years to collect the information as the database for the air pollution dispersion models, AirQUIS, which have been installed at HEPA. This system is based on the integrated GIS based air quality management and information system developed by the Norwegian Institute for Air Research (NILU). Up to now, the information 141 main roads in HCMC have been collected by traffic counting using students and cameras. Information at more than 200 factories in the industrial areas around HCMC has also been collected as part of the emission inventory based on templates provided by the AirQUIS system.

Air pollution dispersion models have been operated and tested for application in HCMC. Concentration estimates will also be used to evaluate different source's relative importance to the total exposure, impact assessment and to perform optimal abatement planning.

The first results from the full application of the system are presented in the paper.

Keywords: Emission Inventory, Air quality models, air quality monitoring and dissemination.

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1 INTRODUCTION

The air pollution situation in Ho Chi Minh City (HCMC) is being monitored automatically at nine monitoring stations located in different microenvironments in the city. Data and information is being transferred to a GIS based database and planning tool based on the NILU developed AirQUIS system. The key features of the system is the integrated approach that enables the user in a user friendly way to not only access measured data quickly, but also use the data directly in the assessment and in the planning of actions. The demand of the integrated system to enable monitoring, assessment, planning and forecasting has been and will be increasing in the future.

Air quality and meteorological data are being collected and quality controlled on a daily basis. Statistical programmes are available for quality control and data assessment. The system also includes an automatic air quality index (AQI) generator. AQI information is provided on the Ho Chi Minh City Environmental Protection (HEPA) Website daily.

Air pollution dispersion models have also been installed as part of AirQUIS for HCMC (Sivertsen and Dam, 2006). Templates and routines for emission inventories are presently being applied to collect emission data and the first model estimated have been presented. In the near future concentration estimates will be used to evaluate different source's relative importance to the total exposure, impact assessment and to perform optimal abatement planning.

2 THE AIR QUALITY IN HCMC

A brief summary of the air quality in HCMC is presented in the following. Continuous measurements of selected air pollution indicators have been undertaken since 2000. One main objective of the monitoring programme has been to evaluate compliance relative to national and international standards and limit values. The present air quality standards for Vietnam (TCVN 5937 – 2005) are shown in Table 1.

Table 1: The air quality standard values for Vietnam as given in TCVN 5937 – 2005.

STT	***Component***	**TCVN 5937 – 2005**			
		1h	**8h**	**24h**	**Annual**
1	CO (mg/m^3)	30	10	-	-
2	TSP (µg/m^3)	300	-	200	140
3	PM10 (µg/m^3)	-	-	150	50
4	O_3 (µg/m^3)	120	-	80	-
5	NO_2 (µg/m^3)	200	-	-	40
6	SO_2 (µg/m^3)	-	-	125	50

SO_2 is not a major air pollution problem in HCMC. None of the limit values have been exceeded for SO_2. Typical annual average concentrations are measured between 20 and 30 µg/m^3.

Hourly CO concentrations seldom exceeded the limit value of 30 mg/m^3, while the 8-hour average limit value of 10 mg/m^3 was frequently exceeded near the roads and in streets of HCMC (Sivertsen et.al 2004).

2.1 PM_{10} concentrations

Suspended particulate matter represents the largest problem in HCMC. The annual average PM_{10} limit values are exceeded at all measurement sites as seen in Figure 1.

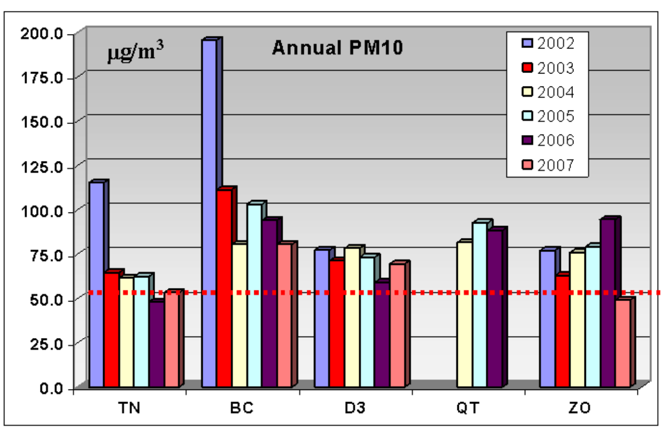

Figure 1: Annual average PM_{10} concentrations measured at 5 sites from 2002 to 2007

Daily average concentrations also exceeded the national limit value proposed for Vietnam at 150 µg/m^3. Even at the urban background stations the 24-hour average concentrations are exceeded during more than 1 % of the time.

2.2 NO_2 and ozone

Annual average NO_2 concentrations were only exceeded at the roadside stations in HCMC. Measurements performed with passive samplers indicated that the NO_2 concentrations sharply decrease with the distance from the street or road. Only about 50 m away from the street the concentrations are half the level measured at the sidewalk (Sivertsen, 2003, Sivertsen et.al 2005b).

There is also a clear diurnal variation in NO_2 concentrations with peak values in the morning and late afternoon rush hour. It is also evident that the highly turbulent daytime boundary layer in HCMC efficiently dilutes the NOx emitted from cars at the surface.

Ozone in the lower part of the atmosphere (in the troposphere) is one of the most wide spread global air pollution problem today. In and around urban areas, relatively large gradients of ozone can be observed. Near strong emission sources of NOx, where there is an abundance of NO, ozone is “scavenged” as it reacts with NO to form NO_2. As a result the ozone concentrations are often low in busy urban centres and higher in suburban and adjacent rural areas.

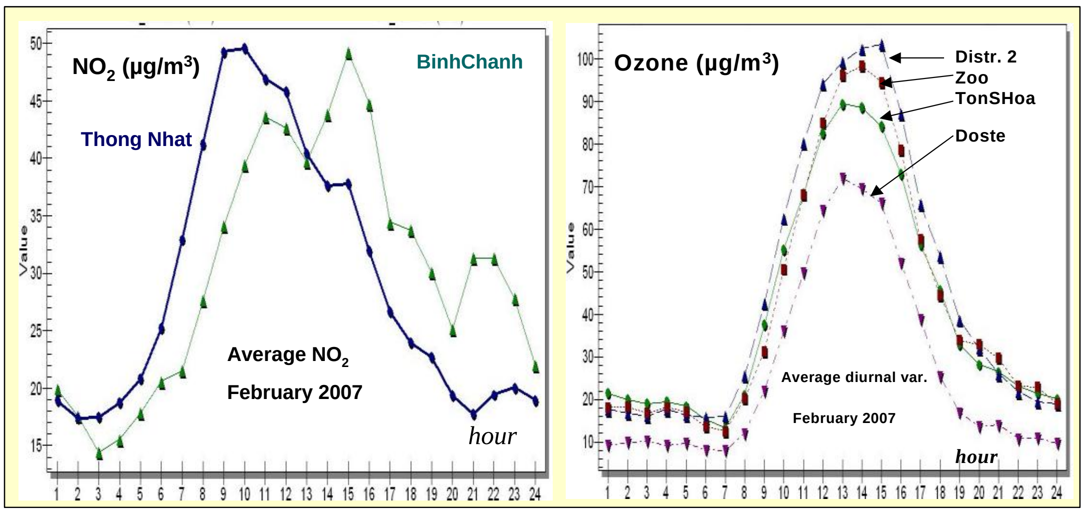

Figure 2: Average diurnal variation of NO_2 and Ozone at different sites in HCMC during February 2007.

The highest ozone concentrations measured in the HCMC network is thus found at the regional background stations. Daytime hourly concentrations may easily exceed 120 µg/m^3 in the dry season. The average daytime concentration for the month of February 2007 was about 100 µg/m^3 at the background stations, as seen in Figure 2. The daytime hourly concentrations inside the city and close to roads seldom exceeded 100 µg/m^3. The limit value of 120 µg/m^3 was exceeded during 8 % of the time from 1 October 2006 to 1 April 2007 at the regional background (District 2) and one urban background station (Zoo). Close to a busy road at Doste the exceedance was 1.2 % of the time.

2.3 Air Quality Index (AQI) generated daily

Daily values of the Air Quality Index (AQI) have been established in AirQUIS based on the present air quality standards for Vietnam (TCVN 5937 – 2005) as shown in Table 1. The generated AQI values are being transferred every day to the information board near Binh Thanh marked in the city centre of HCMC (Sivertsen et.al, 2004).

The AQI estimated for the preceding day is also presented on an Internet page for HEPA. A test site was developed by NILU based on the measurement programme. This site was based on the AirOnline development at NILU and was shown to HEPA in September 2004. Today, AQI information is provided on the Ho Chi Minh City Environmental Protection (HEPA) Website www.hepa.gov.vn daily.

From August 2006, the AQI and air quality information for the last week in HCMC is being published every Friday in the SGGP, the second largest Vietnamese newspaper.

3 EMISSION INVENTORY DATA

The main sources of air pollution in HCMC are originating from traffic. There are more than 3 million motorcycles and 0.35 million of all kinds of other vehicles officially registered in HCMC (Statistical office in HCMC, 2006). Many of the trucks and buses are old, and use obsolete technology, while the majority of the motorcycles, cars and vans are relatively new, but tend to use old technology and have no pollution control devices.

Performing an emission inventory for HCMC has therefore concentrated on developing a good database for traffic emissions. In the analyses presented in this report all available sources were tested and installed into the new version of AirQUIS. The total number of sources is:

- 141 line sources and roads
- 210 stacks with a total of 155 industries
- An almost complete set of area sources for traffic emissions based on information on population distributions in the Wards of HCMC

3.1 Collecting Methods

There is a limited budget to do emission inventory in HCMC included in the HEPA annual budgets. The methods used to collect the emission data both from traffic and industry are therefore basically based on the low cost methods like using students to collect line source data by manual counting or using camera to record the traffic flow and then count the number of vehicle later.

For point sources like factories, especially stacks, HEPA has combined the inventory task with the inspection task. It means that whenever HEPA organizes the inspection trip to a factory, there will be a questionnaire to collect the emission data to fill in.

3.2 Line Sources

Traffic represents the main sources to air pollution in Ho Chi Minh City. Templates and methodologies for traffic counting and line source emission estimates were given to HEPA during Mission 3 and 4. (Sivertsen et.al. 2003)

The traffic counting was undertaken by HEPA staffs and students. For each road or line source, the counting took place in the same street over the whole 24 hours of the day. Each hour, it was sufficient to count over about 30 minutes. There were 3 different groups of 6 persons. Each group was in charge of 8 hours of a day. And within a group, 3 persons were in charge of 1 direction of the road. Vehicles were divided into 5 group types:

- Heavy trucks (carry over 3 tons) or Coaches over 25 seats
- Light trucks (carry less than 3 tons) or Van from 9-25 seats
- Cars 4-9 seats
- Buses
- Motorbikes

The line sources inventory, on the first stage, focus on the main road, highway, national and provinces connecting road.

The annual average daily traffic (ADT) can then be estimated taking into account the total number of hours in a typical day. The chart has been made available to the HEPA staffs in excel to simplify the estimate of ADT numbers. The daily, weekly and seasonal variation in the traffic density was indicated in other tables. Emission estimates are based on emission factors collected from European and Asian studies, and modified to be relevant for HCMC.

From 2007, instead of using many students to do traffic counting, HEPA used camera to capture the traffic flow and counts the vehicles later in office which use less manpower and more precise.

Photo 1. Using camera to capture the traffic flow (*Source: HEPA, 2007*)

3.3 Point Sources

Information on industries; type, location, production rates etc has been collected by HEPA. Some of the required parameters for the stacks may be difficult to collect and emission factors for different industries have most often not been available.

General data from the NILU developed AirQUIS system was therefore used to give advice in order to get the most important physical parameters and help to estimate missing information. The production time variations depend on the demand of the product. However, time variation has been difficult to get and will probably be uncertain. In the HEPA studies we have therefore so far not used any time variation applied to the point sources.

The principle of modelling emissions from point and area sources is very simple. For consumption data the emission rates (Q) will be calculated as:

Q = Consumption x "Consumption Emission Factor"

If emission data for the sources is available as initial input, there is of course no such calculation.

A total of 155 industries with coordinates have been collected by HEPA. 210 stacks have been identified with 30 processes together with consumption data given as ton per year. More stacks are under verification. The validity period for most of these stacks is from 2003 to 2006. The fuels included are: fuel oil, coal and heavy diesel oil. Some of the main point sources are given as triangles in Figure 6.

3.4 Area sources

The area sources includes waste burning, resuspended dust and "rest traffic" i.e. traffic on small roads that is not counted for in the main road system traffic density database. To improve the quality of area source estimates population distributions for each ward within every District of HCMC was obtained.

For District 1 in the central part of HCMC the data looks as shown in Figure 3. This information was used to estimate the number of kilometres driven on the small roads and streets within each ward and the emission factors were further used to estimate the total emission rate of NOx as shown in Figure 3.

Area, Population of regions HCMC				
No	**Name of District and Ward**	**Area(Km2)**	**Population (people)**	**NOx emission**
	HCMC area	**2094.34**	**5 250 257**	(kg/yr)
I	**District 1**	**7.72**	**226 735**	
1	Ward Ben Nghe	2.49	21 429	4443
2	Ward Ben Thành	0.93	21 257	2694
3	Ward Cô Giang	0.36	23 915	1885
4	Ward Cau Kho	0.34	20 584	1577
5	Ward Cau Ong Lanh	0.23	17 959	1132
6	Ward Đa Kao	1	23 528	3092
7	Ward Nguyen Thái Bình	0.49	19 441	1788
8	Ward Nguyen Cư Trinh	0.76	25 914	2968
9	Ward Pham Ngu Lao	0.49	22 636	2082
10	Ward Tan Dinh	0.63	30 072	3136

Figure 3: Area, population and estimated NOx emission rates in 10 wards located in District 1 of HCMC

These data may also be used to distribute the human generated emissions of particles as area sources. However, more basic information on activities, vehicles, fuel types and emission factors will have to be obtained in order to arrive at a reliable area source emission estimate.

3.5 Meteorological data

Meteorological data are important as part of a complete air quality monitoring system. Local meteorological data have to be collected to explain the importance and impact of the different sources in an area and to understand the air quality measured.

An Automatic Weather Stations (AWS) has been operated in the central part of HCMC at the Doste station located in District 3. Data are collected every hour of wind speed and wind directions as well as temperatures, vertical temperature gradients, radiation, relative humidity and pressure. The data are being transferred to a computer via wireless communication.

As input data to the modelling of air pollution concentrations in HCMC we have selected one month of data from February 2007. The wind frequency distribution (wind rose) as well as the diurnal variation of atmospheric stability is presented in Figure 4.

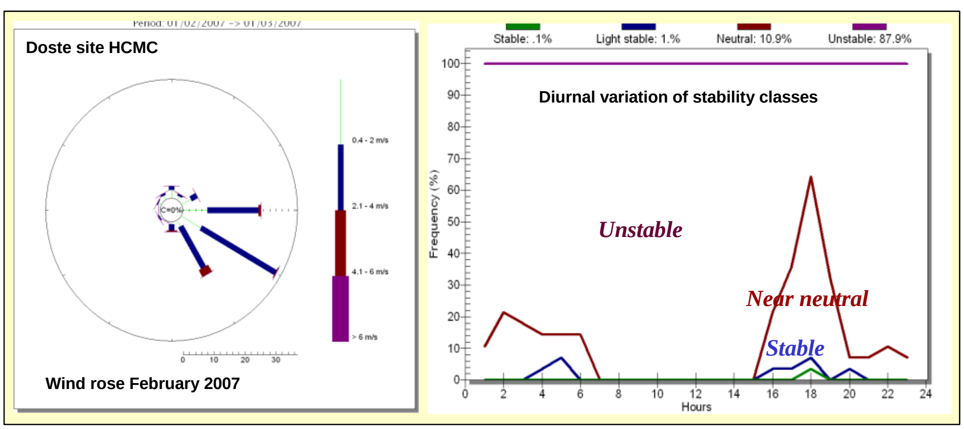

Figure 4: Wind frequency distributions and diurnal variation of atmospheric stability classes measured at the 30 m tower at Doste station in HCMC.

During February 2007 there was a prevailing wind from east-southeast ±45 degrees. The wind speed was most often between 2 and 4 m/s at the top of the 30 m tower. Unstable atmospheric conditions prevailed during 87 % of the time, which is quite typical for the dry season at latitudes of HCMC. Near neutral and stable atmospheric conditions most frequently occurred after sunset in the late afternoon and during nighttime hours. The total frequency of these cases was only 13 % of the time.

4 MODELLING

4.1 The model

The AirQUIS-EPISODE model was used in these studies in HCMC. It is the main dispersion model used in the PC-based Air Quality Information System AirQUIS2003 (Bøhler and Sivertsen, 1998), which has been developed at NILU during recent years. The AirQUIS-EPISODE model is a combined 3D Eulerian/Lagrangian air pollution dispersion model for urban and local-to-regional scale applications (Slørdal, Walker and Solberg, 2003). The model is typically used to calculate air pollution concentration in cities and urban areas from several simultaneous emission sources such as road traffic, domestic (home) heating and industry. The model calculates ground level hourly average concentrations as gridded values (using one or more user defined grids) and/or at individually placed receptor points.

4.2 Modelling Results –

Concentration distributions of NOx and PM_{10} have been generated for the month of February 2007, which was selected as the test period. The results were compared with hourly and monthly concentrations of PM_{10} at two sites; Binh Chanh (BC) and District 2 (D2) and with NOx concentrations at four sites, BC, D2, Zoo (ZO) and Doste (DO).

4.3 PM_{10} concentrations

PM represents the main air pollution problem in HCMC. The first verification of the dispersion models have been undertaken in order to generate concentration distributions for PM_{10} over the whole city area.

The monthly average concentrations of PM_{10} measured and model estimated are compared at two sites and presented in Table 2.

Table 2: Monthly average PM_{10} concentrations for February 2007 from measurements and model results at Binh Chanh and District 2 stations in HCMC.

Site	Monthly aver PM_{10}	
	Measured	Modelled
BinhChanh	74.6	86.6
District 2	63.4	75.1

The model seems to slightly over estimate the monthly average concentrations at both sites. If we look at hourly concentrations throughout the month in Figure 5 there seems to be a good correlation between observed and model estimated PM_{10} concentrations.

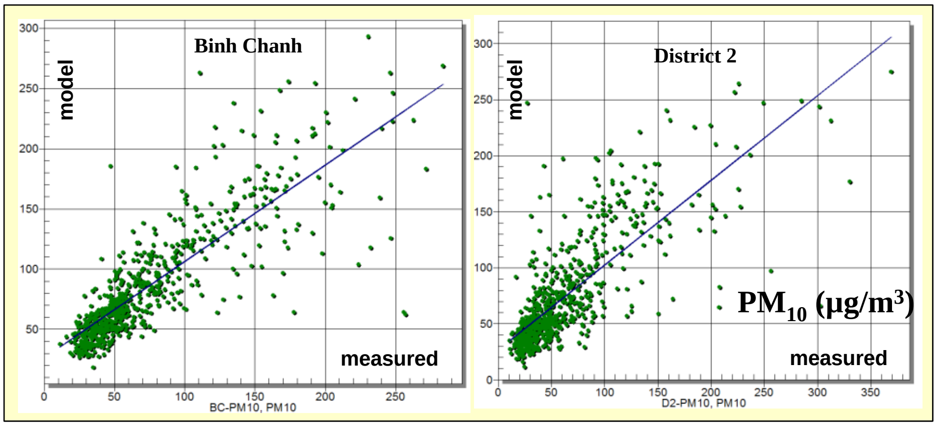

Figure 5: Model estimated PM_{10} concentrations versus measured concentrations at two sites in HCMC, February 2007.

The correlation coefficient for BinhChanh was 0.84, for District 2 0.77.

The average diurnal variation of PM_{10} at the two sites are also well reflected in the model, even if the model predicts both a morning and an afternoon peak, while the measurements only show a morning peak.

The monthly average PM_{10} concentrations generated by the dispersion model is presented in Figure 6. The triangles indicate positions of some major point sources and the blue circles indicate measurement sites and the blue lines indicates main roads where traffic counting have been performed.

The average PM_{10} concentrations represent gridded kilometre scale average concentrations. For this reason the results indicates fairly small gradients over the city varying between 73 and 80 µg/m^3. When analysing variations from hour to hour at specific receptor points the variation in concentrations are much larger, typically varying from 10 to 350 µg/m^3.

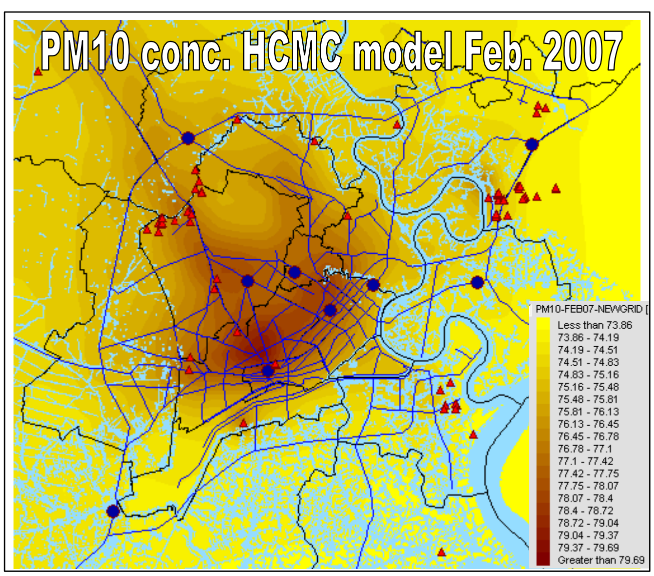

Figure 6: Model estimated concentrations of PM_{10} over HCMC for the month of February 2007.

The model estimated PM_{10} concentration distributions for February 2007 seem to reproduce measurement data well.

4.4 NOx concentrations

Modelling NOx concentrations in HCMC is still not so successful as the PM_{10} modelling results. Table 3 shows the measured and model estimated NOx concentrations for February 2007 at 4 sites in HCMC.

Table 3: Monthly average PM_{10} concentrations for February 2007 from measurements and model results at four sites in HCMC

	Measured NOx	Model NOx
BC	75.3	185.3
D2	23.5	30.1
ZO	26.6	84.0
DO	129.5	267.7

The model estimated concentrations are overestimated at all stations. The best result is found at District 2, which a regional background station, not strongly influenced by traffic. The other three sites are all influenced by traffic on roads passing close to the measurement station.

Analyses of model-estimated concentrations versus wind directions shows high short-term peak concentrations whenever it is blowing from the street. This indicates that the initial dilution of pollution around the moving traffic is not well enough reflected in the model. The vertical dilution of the emissions from the ground level traffic sources may also be under estimated in the model.

In order to verify these assumptions we have run the model for a period, 15 to 28 February 2007, when it was always blowing away from the street running northwest of the Zoo station. The NOx concentrations during this period was due to emissions far away from the station, and ranged between 15 and 30 $\mu g/m^3$ only.

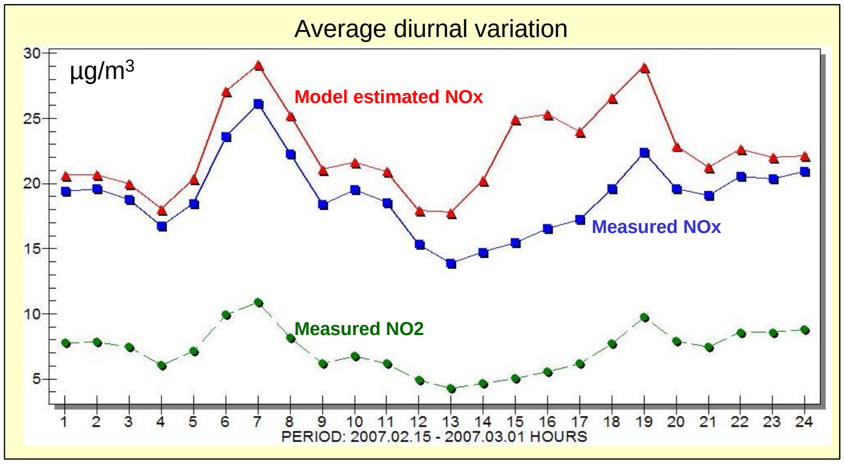

Figure 7: Average diurnal variation of measured NOx and NO_2 compared to model estimated NOx concentrations at the Zoo station during 15 to 28 February 2007.

The average diurnal variation of NOx at Zoo is well reflected in the model as shown in Figure 7. The model still slightly overestimates the measured concentrations. We thus believe that it may also be necessary to evaluate the emission factors used for NOx.

The significant overestimate in the monthly average concentrations as shown in Table 3 at Binh Chanh and Doste are both due to some very high singular peak values occurring when the measurements are directly impacted by transport of pollution from the closest road. Before the model is to be further applied for NOx, modifications will have to be implemented in order to account for the near road effects.

5 RELATIVE IMPORTANCE OF SOURCES

The relative importance of the different sources contributing to the exposure in HCMC may be estimated combining the concentration distribution with the population distribution. So-called person weighted contributions of PM_{10} exposures from three different source categories; traffic, industry and other sources are being performed for HCMC.

When the most important sources are identified it will be possible to further estimate the impact of reduction measures. Air quality action plans will be developed based on modelling the exposures for the different actions identified in order to reduce the impact.

6 CONCLUSIONS AND FUTURE WORK

The first model tests for HCMC have shown that the AirQUIS models are performing well for PM_{10} emissions. One reason for this is that the regional background of PM_{10} plays an important role on the kilometre scale concentration distribution. The spatial distributions of PM_{10} will be further studied in order to understand the model performance better. Further studies of emission factors and the influence of varying the emission factors are also needed.

For NOx calculations, the model has proven to be very sensitive to traffic emissions along roads close to the receptor points. The model generally overestimates the concentrations at the receptor points. We have prepared a schedule for further testing and modification of model input data, emission factors and the effects of initial turbulence along the traffic stream. We believe that the model for NOx and NO_2 impact in HCMC will perform satisfactory in the near future, and that this again can be used for impact assessment and planning.

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