MODELLING PM_{10} DISPERSION FROM ROAD TRAFFIC AND INDUSTRY IN LJUBLJANA BASIN

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Abstract: Ljubljana has unfavourable geographical location in the basin, almost entirely surrounded by high hills. Winds in the basin are often weak and situations with temperature inversion are very frequent therefore many PM_{10} daily limit value exceedances were observed in year 2011. The Directive 2008/50/EC (EU, 2008) requires Member States to adjust or provide new air quality plans in order to comply with air quality standards for over-polluted area in near future. This is why it is necessary to provide the action plan for PM_{10} pollution reduction in Ljubljana. Firstly, it is important to determine sources of PM_{10} particles and its spatial distribution. In the present study traffic emissions as the major local emission source were estimated with NEMO pollution model. The map of important point sources in Ljubljana was prepared as well as emissions from these sources were estimated. This detailed emissions database was then introduced into CALPUFF/CALMET modelling system coupled with meso-scale meteorological model ALADIN. Correlation between observed and simulated PM_{10} concentrations was examined for year 2011, while for some selected episodes also more detailed evaluations of simulated and observed temporal evolution of PM_{10} concentrations was performed to enhance our understanding about strengths and deficiencies of the selected modelling system. Major focus was on the model ability to represent dispersion under calm conditions related to the local temperature inversion.

Key words: *Ljubljana basin, CALPUFF, ALADIN, traffic pollution, industry pollution, meso-scale meteorology, air quality.*

INTRODUCTION

Air quality measurements in Ljubljana (the capital city of Slovenia) show frequent winter time PM_{10} exceedances. PM_{10} particles in the air are measured at three air-quality stations in Ljubljana basin: Bežigrad (S1), Tivolska - Vošnjakova (S2) and Zadobrova (S3). First two stations are located in the city centre: station S2 is placed near a major city road and the station S1 is placed a little further from another nearest major road for about 300 m with some buildings barrier around. Station S3 is located in east suburb at the distance 400 m outside of motorway ring. Many exceedances of daily PM_{10} limit value were measured in year 2011 at all three stations (Table 1). There is also the fourth station in modelling domain of Ljubljana. Station Vnajnarje (S4) is located at the top of the hill above the basin near the east edge of the modelling domain. Station S4 is usually above temperature inversion and so the observed pollution at this station is not highly correlated with measurements in the basin. Nevertheless, data from station S4 could be useful for preparing estimation of temperature inversion intensity and influence of the long-range pollution transport.

Table 1. Measurements of PM_{10} in 2011.

Value / Station	S1	S2	S3	Limit value
Annual PM_{10} concentration [μgm^{-3}]	32	44	37	40
Maximum daily PM_{10} concentration [μgm^{-3}]	167	134	191	50
Number of exceedances of limit PM_{10} daily value	63	94	69	35

The calm wind dispersion conditions problem at the basin bottom in Ljubljana city is similar to the equal problem of Graz city in Austria. An interesting modelling experiment was prepared in Graz city where influence of increased ventilation on air quality was verified (Oettl, 2008a). Oettl prepared two calculations with GRAL model (Oettl, 2008b) with the same emission data and with different wind and terrain conditions. In the first case original meteorological data and the real topography in Graz were taken into account whereas the second case was calculated for Graz as flat terrain and with meteorological data from Vienna. The simulation results suggest that emissions near the ground in the first experiment cause about 3-4 times higher air pollution levels than in the second case with Vienna data. Oettl considers that the EU air quality directives lead to strong disadvantages between regions with good or bad dispersion conditions for providing effective action plans of PM_{10} pollution reduction.

MODEL CONFIGURATION

Modelling air quality assessment for regulatory purposes must be prepared for entire year period in order to capture the most unfavourable dispersion conditions. Inhomogeneous meteorological 3D fields are the most important for suitable air pollution simulation on complex terrain. Meso-scale meteorological model computational intensity is usually too high for modelling applications in local scale, therefore calculation approach for situation categorization with characteristic days may be effective (Žabkar and Ivančič, 2012). More common approach used for simulating the local scale meteorological conditions in air quality applications is to calculate the 3D meteorological fields by a mass consistent diagnostic wind field model (Sherman, 1978).

In this study air pollution simulations were prepared with CALPUFF modelling system which consists of diagnostic wind field model CALMET (Scire et al., 2000a) and non-steady-state Lagrangian puff model CALPUFF (Scire et al., 2000b). CALMET modelling system is proved to be particularly suitable to work over complex terrain in fine-scale (Scire and Robe, 1997) where processes such as stagnation, inversion, recirculation, fumigation conditions, valley channelled winds and calm wind conditions must be taken into account (Scire et al., 2000b). CALMET is a meteorological model which includes a diagnostic wind field generator containing objective analysis and parameterized treatments of slope flows, kinematic terrain effects, terrain blocking effects and a divergence minimization procedure, as well as a micrometeorological model for overland and over water boundary layers.

Wind field initialization for CALMET model should necessary contain vertical meteorological profile data. Since radio-sounding measurements in Ljubljana are carried out once daily, while the lowest temporal resolution required by CALMET is 14 hours for radio-sounding measurements, these measurements were not included in simulations. Initialization diagnostic model using data from meso-scale meteorological model such as MM5 or WRF (Gualtieri, 2010) is the second option to introduce quality vertical development of atmosphere. The third option is that vertical data are taken from the nearest airport which are measured during aircrafts landing and takeoff. This option could be also potentially very useful for meso-scale data assimilation in numerical weather prediction models (Strajnar, 2012) and could also be part of second mentioned option in the future.

Coupling CALPUFF modelling system with operational meso-scale model ALADIN was being presented in previous study where different CALMET initializations were tested (Ivančič et al., 2011). First guess filed for CALMET calculation in current study was taken from ALADIN hourly predictions, therefore phenomena such as synoptic scale forcing, meso-scale circulations and temperature inversions could be taken into account. Meteorological observations from ground stations S1, S3 and S4 with local meteorological conditions description were introduced in step 2 of CALMET calculation. Wind observations at station S2 are exposed to street canyon canalization, therefore station S2 observations are not representative for our calculation. CALMET/CALPUFF simulations were performed in domain with 125 × 125 horizontal points and 200 m horizontal resolution. Vertical atmosphere structure was represented by 22 vertical levels from 0 to 3000 m altitude and near the ground vertical resolution of 20 m.

SIGNIFICANT PM_{10} EMISSION SOURCES

PM_{10} particles emission in urban location could be distributed in three groups: industry sector emissions, road traffic emissions and emissions resulting the burning of small furnaces for heating needs of individual buildings. Important role could also play long range transport of dust from other area in vicinity and foreign countries.

Industry sector emissions were introduced in CALPUFF model as point sources and road traffic emissions were introduced as area but not as line source (Popovic, 2009). Volume and area sources suggested by Popovic for road traffic pollution modelling should be determined in the way that the source width and length should be equal. This instruction can be applied for pollution modelling on several roads but not for entire city because of dealing with nearly hundred roads. An example of introducing area road sources for CALPUFF modelling in our study is shown in Figure 1. There can be found some papers published from other authors that are also using CALPUFF for road traffic emissions dispersion modelling (Mangia et al., 2011, Puliafito et al., 2011).

Figure 1. Roads were introduced as area sources in CALPUFF. As an example there is the motorway intersection in the south-western part of Ljubljana city.

There is no heavy industry placed in Ljubljana region. The industry sector in Ljubljana can be characterized with 2 thermal power plants and 14 no-energetic sector industry plants which together represent 187 point sources. Positions of all 16 units are shown on the left part of Figure 2. Both thermal power plants have installed continuous emission measurements providing real data which are introduced in model calculation. No-energetic sector emissions were estimated on the base of periodical emission measurements and entire year continuous operation was assumed for this sector. Plume rise for each point source was estimated on the base of exhausted plume temperature and exhausted plume velocity.

Ljubljana city is located in the centre of Slovenia and it is important intersection of European roads E61, E70 and E71. In CALPUFF road traffic emissions were introduced as 612 area sources and 3 groups which are represented in the middle part of Figure 2: highways (red), important local and regional roads (blue) and major city roads (orange).

Figure 2. Main PM_{10} emissions sources in Ljubljana. Left: important energetic and industry plants. Middle: important roads. Right: good network of district heating system reduces emissions from domestic heating sources (TETOL, 2013).

Exhaust road traffic emissions have been estimated using the Network Emission Model (NEMO) developed by the Graz University of Technology (Rexeis and Hausberger, 2005). Traffic emissions were calculated on the basis of annual average daily traffic with information from traffic counters, traffic road patterns and emission factors for different types of vehicles. Averaged daily cycle was also estimated. Future emissions from traffic until 2020 can be also predicted with model NEMO (Rexeis and Hausberger, 2009) on the base of expected development EURO vehicle classes in future years. Estimation of non-exhaust particle emissions such as resuspension, emissions from tyres and breaks was prepared with a simple assumption: ratio between exhaust and non-exhaust emissions were taken into account in range of 1:1.

Ljubljana city is well covered by the network of district heating system inside the motorway ring (Figure 2: right part). Therefore pollution made by sector of domestic heating sources is reduced in this area where also stations S1 and S2 are located. Station S3 is located in the north-eastern suburb of Ljubljana where no district heating system exists and where domestic sources may have a significant impact at this station.

RESULTS AND DISCUSSION

Calculation of PM_{10} pollution was prepared for the industry sector sources and for the road traffic sector sources. Figures below represent annual PM_{10} concentration spatial distribution (Figure 3) and maximum daily PM_{10} concentration (Figure 4). Both figures have the same colour scale (not absolute) for air pollution: red colour is for the limit value, blue colour for the lower threshold value, yellow colour for the upper threshold value and green colour for 3 % of annual limit value. Calculated PM_{10} concentrations as a consequence of the road traffic emissions are much higher than calculated industry sector pollution: calculated annual mean PM_{10} value in point with maxima for industry sector is 5 μgm^{-3} and for traffic sector 84 μgm^{-3} (Figure 3). The highest concentrations were calculated in the centre of the city and on all four highway intersections.

Short validation of observed and modelled data is shown in Figure 6 with scatter plot (left) and quintile plot (right). Daily PM_{10} limit exceedances were measured frequently in winter time, therefore observed and modelled concentrations time series were plotted for the episode of cold part of the year. Time series of concentrations for January and February 2011 are shown in the Figure 6 and time series for November and December 2011 in Figure 7. Comparison of measured and modelled PM_{10} values was prepared for all three stations at the basin bottom (S1, S2, S3) and observed PM_{10} values from station S4 are represented in Figure 6 and Figure 7.

Vertical mixing of air pollution in the basin bottom is suppressed by temperature inversion so the result is accumulation of air pollution under inversion. Situations with entire day persisting temperature inversion were determinate on the base of temperature difference between S1 and S4. Increased concentrations were observed and modelled for days with continuous inversion: 1st, 2nd, 6th, 14 -19th January and 4-11th February (Figure 6) and 12-19th November, 27th November to 3rd December, 7th, 8th, 21-27th December (Figure 7). Good correlation between observed and modelled data was noticed for these days with inversion. Significant peak of observed concentrations also appeared on New Year days 1st and 2nd January, shown in Figure 6, when fireworks could be recognized as important source (Bolte, 2011).

Processes as precipitation with wet deposition and change of atmospheric stability from stable to neutral with better vertical mixing properties could clean particle pollution from lower atmosphere and correlation between observed and modelled values of these processes which can be seen in Figure 6 and 7. Cleaning of atmosphere related to precipitation was detected on 4th, 20-22nd, 28th January, 4th, 23rd November and 3rd, 10th, 13th, 16th December (Slovenian Environment Agency, 2011). It is very interesting that strong precipitation does not necessarily cause wet deposition with decrees of pollution which could be seen on 11th, 12th January, 4th, 15th, 16th February and 15th, 17th December when modelled and observed PM_{10} concentrations stay high although precipitations were observed on these days (Slovenian Environment Agency, 2011).

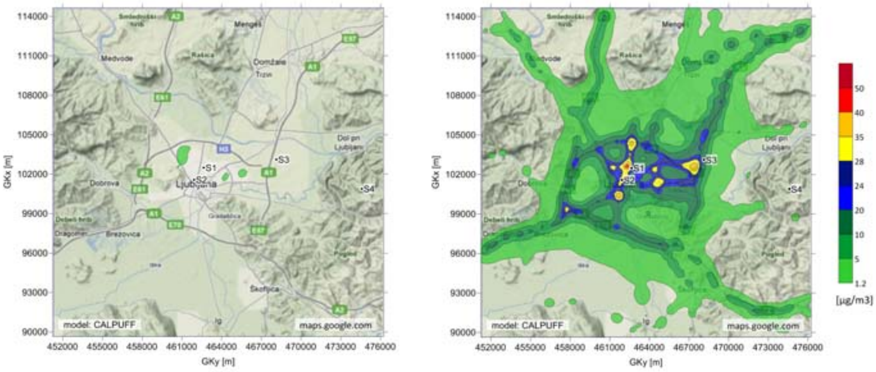

Figure 3. Annual PM_{10} concentration in Ljubljana: industry sector pollution (left) and road traffic pollution (right).

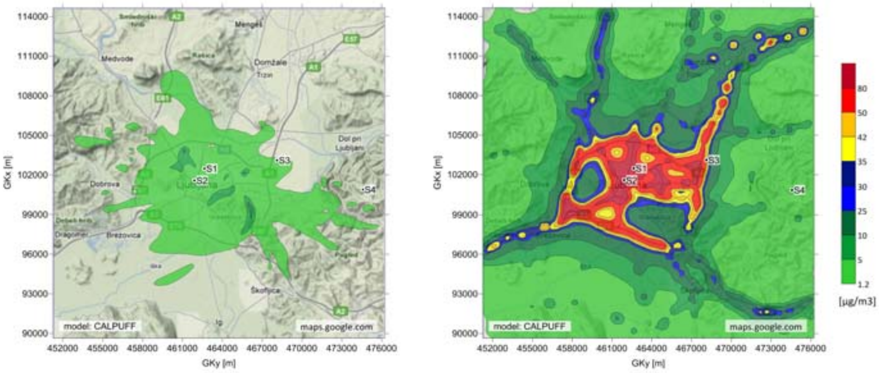

Figure 4. Maximum daily PM_{10} concentration in Ljubljana: industry sector pollution (left) and road traffic pollution (right).

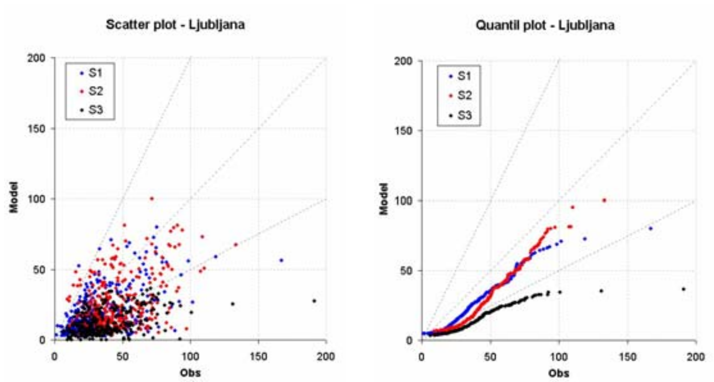

Figure 5. Scatter and quintile plot comparison of daily observed and modelled PM_{10} concentrations in Ljubljana for the year 2011.

It is possible to find significant difference between measured and modelled PM_{10} concentrations in station S3 on 16-19th January, 3-11th February and 20-27th December when temperature inversions were observed. Significant difference can be also observed on the right site of Figure 5. Station S3 is located outside of motorway ring where district heating system network does not exist. Emissions from domestic heating sources could be recognized as important local source for pollution on station S3 and were not taken into account in current study.

Station S4 is located in the eastern part of Ljubljana at hill top more than 300 m above the basin bottom. This station is usually situated above temperature inversion so the observed high PM_{10} concentrations at this location are probably not a consequence of emission sources from Ljubljana city. It was documented that Sahara dust had a strong influence on PM_{10} pollution in Slovenia on 7th November (Bolte and Koleša, 2012) what can also be seen in Figure 7. It is possible to conclude that situations with higher observed PM_{10} pollution on station S4 should be recognized as a consequence of long range transport (end of January and end of February in Figure 6 and 17-19th November in Figure 7).

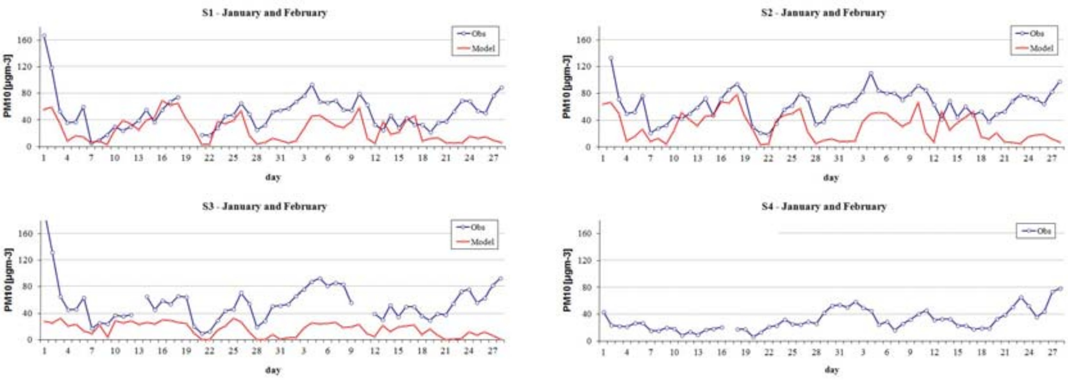

Figure 6. Comparison of observed and modelled PM_{10} concentrations in January and February 2011.

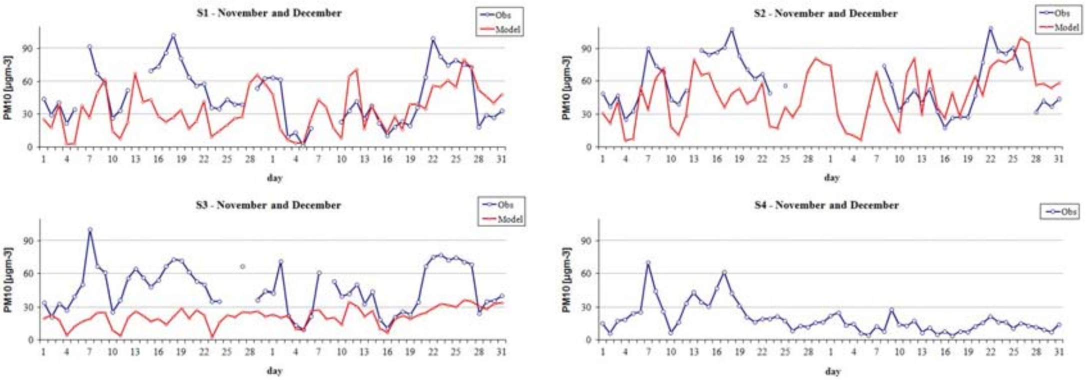

Figure 7. Comparison of observed and modelled PM_{10} concentrations in November and December 2011.

CONCLUSION

Ljubljana has unfavourable geographical location in the basin with weak wind and frequent temperature inversions especially in winter time. The observed and modelled high PM_{10} concentrations are correlated with situations of temperature inversions which was shown in this study. A correlation in cleaning situations such as wet deposition with precipitation and atmosphere destabilization was found. Calculations were prepared with CALMET/CALPUFF model system coupled with meso-scale meteorological model ALADIN. Complex phenomena such as synoptic scale forcing, slope winds and temperature inversions were well simulated with ALADIN/CALMET meteorological system. Calculation of PM_{10} pollution was prepared with only daily traffic cycle and with continuous industry sector operation. Therefore almost no dynamics of emission were considered in calculation and so weather dynamics play the most important role in air pollution modelling.

The case of study was determination of PM_{10} sources in Ljubljana region and their influence on air quality. Energetic and industry sectors have already installed filters and cleaning devices so the pollution from these sectors is well controlled. New, lower emission limits will come with implantation of 2010/75/EU directive (European Commission, 2010) after 2016 which leads in additional reduction of industry sector emissions. Road traffic emissions were recognized as the most important source of PM_{10} pollution. Solutions for reduction of these sources must be founded in future. Ljubljana city also took place at international project CIVITAS ELAN (CIVITAS Initiative, 2013) as a member where action plans such as cleaner and efficient public transport, new cycling roads and city centre closure were prepared for creating a more sustainable urban mobility culture.

Some other possible sources were determined but not modelled such as pollution from fireworks, transport of Sahara dust and long range pollution transport from other countries. District heating system network is not available in the south part of Ljubljana city and outside of motorway ring where domestic heating systems may play an important role. These PM_{10} emissions could be reduced by a district heating system network expansion to those parts of the city.

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