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A HIGH RESOLUTION MODELLING SYSTEM – THE A86 WEST AIR QUALITY SURVEY SYSTEM
O. Sanchez, F. Dugay, P. Pernot

Abstract: In the Ile de France region, road traffic is of major concern with regard to air pollution: EU air quality limit values are exceeded for several pollutants like NO\textsubscript{2}, PM10 and even benzene at roadside along busy streets. In the frame of the Duplex A86 tunnel project which will allow completing the A86 beltway around Paris, AIRPARIF has been assigned by the French state to assess air quality outside the tunnel. The first section of the tunnel (5 km long) between Rueil-Malmaison and Vaucresson was put into service the 26th of June 2009; the second one between Vaucresson and Versailles, 6 km long will be opened to traffic in almost 2 years. In order to fulfill this objective, an air quality survey system has been set-up using 2 types of tools. First, intensive measurement campaigns have been set up around the tunnel for background impact assessment with special focus around ventilation stacks and ends of the tunnel. Secondly, a modelling system integrating background concentrations from a regional air quality system based on the CHIMERE model (IPS/LISA/INERIS) coupled with the short-range dispersion model CALPUFF (ASG from TRC) has been set up in order to provide near real-time air quality information for the main road traffic pollutants on a 200 km\textsuperscript{2} area in the western part of the agglomeration of Paris. During the set-up phase, the gaussian air dispersion model ADMS-Urban (CERC) has also been tested. The concentration maps for NO\textsubscript{2}, PM10, PM2.5, benzene and CO are accessible via the following web site http://www.obsairvatoire-a86ouest.fr. The complete report concerning the evaluation of the modelling system is available in French on the AIRPARIF website.

Keywords: near real-time modelling system, regional and high resolution model coupling, evaluation against monitoring campaign.

MODELLING SYSTEM DESCRIPTION

Study domain description

The study domain is located in the western part of the agglomeration of Paris (fig. 1 and 2). The north-eastern part of the domain is very close to the high density centre of the Paris agglomeration. Therefore, this specific area is characterized by dense urban fabric but it contains also some huge industrial units. Located in the Seine valley, the terrain elevation is almost 20 meters high. The centre part of the domain is dominated by a discontinuous urban fabric, woodland and green urban areas. This area contains for example the cities of Versailles, Vaucresson and Garches and is crossed by two important road infrastructures: the A13 and the A86 in the south motorways that are almost respectively 150 000 veh/day and 100 000 veh/day. The southern and western part which is further from the center of the agglomeration is dominated by forest, agriculture and loose urban fabric. The last 2 areas cover a 200 m high plateau.

Modelling system design

The pollutants assessed by the modelling system are NO\textsubscript{2}, CO, PM10, PM2.5 and benzene. The modelling system has been designed considering the main features of the study domain. In order to take into account the rugged terrain especially in the north-east of the domain which is a key area regarding the tunnel end and ventilation stacks, the heterogeneous land-use and the vicinity of the Paris agglomeration, the MM5 meteorological model (NCAR) is used to provide 3D meteorological patterns at high resolution: a new 1.6 km resolution domain has been added within the regional meteorological forecast system. Furthermore, as it is located at the periphery of the agglomeration, strong concentration gradients are observed within the modelling domain: on annual mean, the NO\textsubscript{2} concentration in La Défense monitoring station close to the north-east corner of the domain is almost 36 µg/m\textsuperscript{3}, while in the Garches station, located 6 km southern from the previous, it is 24 µg/m\textsuperscript{3} and in the rural areas, close to 10 µg/m\textsuperscript{3}. In order to take into account those gradients and potential incoming pollutants, a methodology coupling background concentration forecasts and measurements has been set-up to provide accurate background concentration to the high resolution air dispersion models. Two air dispersion models have been evaluated, the non steady-state lagrangian puff model CALPUFF and the steady-state Gaussian model ADMS-Urban. Concentrations and air quality index maps are presented on the web site using the CITEAIR index which accounts for background and roadside pollution.

Emission modelling over the study domain

Two types of emission data are distinguished in the modelling system. First, traffic emissions are estimated on an hourly basis using outputs from the HEAVEN system developed within the framework of a European project. It calculates near-real time traffic emissions based on real-time traffic counts (fig. 2). Almost 500 traffic counts are used each hour to calculate traffic fluxes over the 20 000 roads network. Within the study domain, 2 500 traffic segments are used to estimate traffic emissions. Emissions from the tunnel, at ends and at ventilation stacks are also evaluated using NO\textsubscript{2}, CO and visibility measurements performed inside the tunnel by COFIROUTE. The other emissions are taken from the Ile de France regional inventory. It contains surface emissions on a 1 km resolution grid and point emissions corresponding to the major industrial plants. Those emissions are treated on a daily basis, since diurnal variations are taken from day-type temporal profiles.
Background concentration evaluation

The methodology used to evaluate background concentrations is based on a linear coupling between regional background forecasts from both ESMERALDA, the 3 km resolution regional forecast system and the low resolution national forecast system PREV’AIR (INERIS), and the AIRPARIF background monitoring network. This correction of the regional concentrations over the Ile de France region uses urban, suburban and rural monitoring stations located, if possible, close to the study domain (fig. 4). For CO and PM2.5, all the monitoring stations are used by the correction module, as only few stations exist. For benzene, the correction uses linear regression coefficients calculated for NO₂ background concentration correction.

High resolution dispersion model set-up

The two models used within the project have several differences that can influence significantly the results. The main differences are the following:

1. First, the meteorological processing is slightly different. In the CALPUFF version of the system, the meteorological model CALMET (ASG from TRC) is completely coupled with the 3D meteorological model MM5. This model calculates 3D meteorological fields and 2D boundary layer parameters accounting for topography and land-use characteristics. In the ADMS-Urban, the meteorological processor that is used is FLOWSTAR. The model takes into account local topography and calculates gridded wind fields from surface meteorological data at a single point location. The 3D calculations from CALMET are therefore significantly more precise, as the MM5 simulation is at 1.67 km resolution.

2. Then, CALPUFF is a lagrangian non steady-state model while ADMS-Urban is a Gaussian steady-state model. Considering the size of the study domain, the steady-state aspect of the Gaussian model could be a limitation especially in case of pollutant accumulation episodes. Another difference between the two models is the way the urban environment is taken into account: ADMS-Urban accounts for street canyon, using the OSPM module while it is not the case with CALPUFF. Nevertheless, within the study domain, no street canyon has been taken into account.

3. Thirdly, in order to take advantage of the 4 processors XEON workstation, CALPUFF is run with no chemical transformation: all the sources are split between 4 groups that are run independently. The equilibrium between NOₓ and NO, NO₂ is then evaluated using a correlation function between NOₓ and NO₂ optimised at each time step with data from traffic and background monitoring stations (fig. 5). On the other hand, ADMS-Urban is run sequentially and the GRS (Generic Reaction Set) chemical mechanism is used to evaluate NO₂ concentrations. Three calculation domains are used in the ADMS-Urban version of the modelling system for size limitation reasons.

Finally, the main difference between the two versions of the modelling system is the way background concentrations are taken into account by high resolution dispersion models:

- In ADMS-Urban, background concentrations are considered as incoming into the study domain as expressed in fig. 5. Depending of the origin of winds, the incoming pollutant concentration is evaluated as the mean value of seven grid meshes. This value is then used homogeneously over the whole domain.

- Within the CALPUFF version of the modelling system, 2D concentration fields are used to take into account pollutant gradients and accumulation processes. Furthermore, double counting is considered by subtracting local contribution (evaluated from high resolution modelling) to these 2D fields. The resulting concentrations are then added to the high resolution model outputs.

MODELLING SYSTEM EVALUATION

The evaluation of the modelling system has to consider the 3 sets of modelled data that are used to produce real-time concentration fields, that is meteorological fields, background concentration datasets and local concentration outputs from the two high resolution models. In order to validate the system outputs, two monitoring campaigns performed in 2007 and 2009 before the Duplex A86 putting into service have been used.

Monitoring campaign

The two monitoring campaigns lasted 6 weeks, corresponding to 3 passive sampling series. Almost 106 passive samplers (illustrated in orange fig.7) were used over the study domain: 48 background sites at 2 km resolution with 2 focuses at 400 m resolution at the ends of the first section of the tunnel, at Rueil-Malmaison and Vaucresson. Those passive samplers measuring benzene and NO₂ allow getting an accurate spatial distribution of benzene and NO₂ concentrations. Furthermore, 4 temporary automatic stations were used (cabin icon), two in Rueil-Malmaison close to one end of the tunnel, and two at the other end, at Vaucresson and Marne-la-Coquette. At the Rueil-Malmaison end, the first automatic station was set-up very close to ventilation stacks and almost 200 m far from the toll area at “Stade du Vert-Bois” (ETU2). The second station was located further from the tunnel end, almost 800 m from the toll area at “avenue Marmontel” (LABO2). At the Vaucresson tunnel end, the first automatic station was located “allée du college” (ETU1) close to the ventilation stack.
and 200 m from the tunnel end and the A13 motorway. The second automatic station was set at “Stade de la Marche” 800 m from the tunnel end (ETU5) and in the same configuration against A13 motorway. In addition to those temporary automatic monitoring stations, two permanent stations (sensor head icon) monitoring NOx are located within the study domain, the Garches station, 600 m from the A13 motorway located in the eastern part of the domain and the Versailles station located in the centre. All temporary automatic samplers measured NOx, PM10 and CO. PM2.5 was only measured at two sites, the closest to the tunnel ends ETU2 and ETU1. They allow getting very accurate pollutant temporal variations.

Evaluation of the meteorological model outputs

Only MM5 outputs have been evaluated against measurements from the Météo-France ground measurement stations (RADOME network). Three meteorological variables were evaluated, i.e. 10 m wind speed and direction and 2 m temperature. In the figure 9, the monitoring stations used for evaluation are presented. As MM5 is used for weather forecasting, the evaluation has been performed over the +12H and +36H forecasts corresponding to the current use of the near real-time modelling platform. Regarding wind directions, two monitoring stations are quite interesting considering their localization. Trappes, the closest station from the study domain is a synoptic station while Achères, located in the north of the study domain is influenced by the Seine valley. In figure 9, both modelled and measured wind roses are presented for the 2007 campaign. They illustrate the airflow channelling by the Seine valley: while at the Trappes station the wind direction distribution varies between SSW and W directions, at Achères station, the wind rose indicates that the wind blows mainly from the WSW direction. This phenomenon is well reproduced by the regional model. This effect was also noticed during the 2009 campaign with measured prevailing winds from WNW at Trappes station and from WSW at Achères. Those results confirm that a high resolution model is required in order to get relevant meteorological data.

In figure 10, some statistical parameters are presented for wind direction, wind speed and 2 m temperatures. The biases for wind direction are almost smaller than 10° except for the station of Melun at which temporal evolutions are quite unstable compared to other stations. From the bar graph, it is also pointed out that uncertainties (biases and gross errors) in wind direction have been more important during the 2009 campaign than during the 2007 one. This is due to the differences in meteorological conditions that have been recorded between the 2 campaigns. Actually, during the 2009 campaign, wind speeds were significantly lower than during the 2007 one leading to an increase of model and measurement uncertainties. The wind direction gross errors which are generally between 25° and 40° are consistent with other meteorological systems for 12h to 36h forecasts. In Grimit and Mass [2], absolute circular biases vary between 40 and 45°.

Considering wind speeds, some discrepancies between monitoring stations are noticed: wind speed biases are generally positive and below 1 m/s except at airport stations, where they are negative indicating model under-estimation. Those results are due to airport terrain features. Actually, the two major airports Orly and Roissy are located close to the Paris agglomeration. They are therefore considered partly in the meteorological model as “urban” or “suburban” land-use which is not consistent with low roughness length of those open areas with very few obstacles. Biases at Trappes and Achères stations are increased between the two campaigns. Time series analyses indicate that this bias is more important at night during stable and low wind speed atmospheric conditions. Following Hanna et al., those uncertainties are commonly admitted and result in wind speed RMSE that range between 2 and 3 m/s [3]. The lowest biases are recorded at the Montsouris station in the city of Paris. During the two campaigns, wind speed error standard-deviations were close to 1.5 m/s and RMSE, below 2 m/s except for airport stations.

The analyses of 2 m temperatures time series point out the capacity of the model to reproduce on average, good temporal evolutions of ground temperatures. Nevertheless, the analysis of time series graphs reveals that over the 2 campaigns, some particular periods are not modelled as good: it is the case at the beginning of February 2007 and at the end of February 2009. Those differences between modelled and measured temperatures referred to daily temperature range: the model tends to overestimate the daily minimum and underestimate the maximum. Two main hypotheses can explain such behaviour of the model. It could be a badly modelled cloud coverage that would be for example overestimated by the model (fig.11). Soil parameters related to humidity or temperatures could also have a great impact on ground radiative budget. From the bar plots (fig.10), the biases over all the stations are close to -1 °C in 2007 and -1.5 °C in 2009.
Those biases are consistent with biases observed at wintertime in other studies [1]. These increases in temperature biases between the 2 campaigns have a direct impact on RMSE values that go up from 2°C in 2007 to 2.4°C in 2009. All the meteorological analyses performed on the modelling system show a good agreement of the model with the measurements: calculated statistical parameters are within the range usually reported in bibliography. Even though some uncertainties inherent with meteorological forecasting exist, their impact on final concentration fields will be significantly reduced as measured and modelled concentrations are coupled in order to reduce biases and error variability.

**Evaluation of background concentrations**

The evaluation of background concentrations has been performed considering both the outputs of the 2 regional forecast systems and the corrected associated fields. Those analyses performed using measurements from the AIRPARIF monitoring network, illustrate the impact of the correction on real-time background concentration estimation. In the following, the results are detailed for NO₂, PM10 and PM2.5 which are of major concern in the Ile-de-France region. Results from regional systems are in green and results from corrected concentrations are in blue.

For NO₂, the monitoring stations used for the evaluation are the surrounding stations of the study domain: 4 urban, 3 suburban and 1 rural station.

From the bias bar plot, the regional system Esmeralda tends to underestimate NO₂ of the study domain: 4 urban, 3 suburban and 1 rural station. where the bias is +7 µg/m³ between the 2 campaigns.

In the following, the results are detailed for NO₂ concentration estimation. In the following, the results are detailed for NO₂ background concentrations.

**Evaluation of the modelling system output concentrations**

In the following, the results are detailed for NO₂, PM10, PM2.5 and benzene and for the two dispersion models, CALPUFF and ADMS-Urban. In order to sum-up the time series analyses, the comparisons of the two dispersion models are based on bias and RMSE at the 4 automatic stations. The detailed results for all the statistical indicators are available in the report.

For NO₂, the CALPUFF version biases generally range from -5 µg/m³ and +5 µg/m³, except at “Avenue Marmontel” in 2009 where the bias is +7 µg/m³ (fig. 14). Those values are consistent with NO₂ background concentration biases.
From fig. 15, it emerges that the hourly mean NO$_2$ concentrations are better reproduced by the local model than by the regional one, especially at rush hours. The bias of the CALPUFF version is generally closer to zero than the ADMS-Urban one except at “allée du collège” in 2007 and at “Stade de la Marche” in 2009. Analyses of error standard-deviation and RMSE confirm the better behaviour of the CALPUFF version of the system: error variability of NO$_2$ concentrations calculated by CALPUFF is lower, for all the stations and all the campaigns.

In Fig. 16, are presented scatter plots of modelled and measured concentrations by passive samplers. From this figure, it emerges that the CALPUFF version reproduces much better spatial heterogeneities than the ADMS-Urban one. These differences in concentration results are linked to background concentration treatment by the two versions: the ADMS-Urban version doesn’t take into account concentration gradients over the whole domain unlike the CALPUFF. The three isolated points correspond to a particular site which undergoes atypical emission due to tunnel building site in 2007. In 2009, modelled and measured concentrations at that site were consistent. Results for PM10 and PM2.5 concentrations are quite similar. PM2.5 biases and PM10 RMSE are presented in fig. 17. PM10 RMSE for the CALPUFF version ranges from 2 µg/m$^3$ to 4 µg/m$^3$. A slight increase is noticed between 2007 and 2009, due to less favourable meteorological conditions.

In 2007, PM10 RMSE of the ADMS-Urban version are higher than those of the CALPUFF version. In 2009, they are almost equivalent: even if the bias of ADMS-Urban is lower, its error variability is higher. Between the two campaigns, PM2.5 biases are significantly different: from positive in 2007, they become negative in 2009 for both of the system versions. However, the CALPUFF version bias is always closer to zero than the ADMS-Urban one. The differences between the two versions of the system are illustrated in the time series of fig. 18. In the Calpuff version, biases are almost constant for all the period. The ADMS-Urban version behaviour is worse especially during the high concentration period halfway through the campaign.

The system underestimation is partly due to the low number of stations used for concentration correction and also to measurements themselves, as over the 2009 campaign significant discrepancies were noticed: among the stations used for correction, relative differences above 25 % were registered between Gennevilliers and Bobigny stations.

Benzene concentrations have been evaluated against passive sampler measurements. Benzene concentrations from the regional model cannot be corrected, it is the most uncertain pollutant. The scatter plots for the two versions of the modelling system and the two monitoring campaigns are presented in fig. 19. In 2007, the two versions tend to underestimate the measurements. The absolute value of the Calpuff bias is less important than the ADMS-Urban one. On the contrary, in 2009, the ADMS-Urban version of the system performs better than the Calpuff version.

CONCLUSION

The A86 West air quality survey system is an innovative and unique modelling system: it couples several air quality assessment devices, that is to say regional forecast systems, measurements from the permanent monitoring network and high-resolution dispersion model. It has been evaluated on intensive monitoring campaigns set-up in 2007 and 2009 for impact assessment of the tunnel. The system has been developed in a modular way and several enhancements are planned in near future. Furthermore, it is also planned to adapt the existing system for airport and industrial zone air quality assessment.

REFERENCES