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OPERATIONAL PLATFORM FOR SURVEY AND FORECAST OF LOCAL AIR QUALITY OF THE BERRE'S AREA: METHODS, RESULTS AND PERSPECTIVES

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Abstract: AIRFOBEP is the regional air quality agency in charge of the survey of the air pollution over the Etang de Berre region, which is one of the two main industrial areas in France. From several years, AIRFOBEP has decided to develop an operational automated platform which routinely monitors and forecasts air pollution over its territory. This paper discusses the operational tools associated with particle matter (PM10) and sulfur dioxide (SO_2). The particularity of these tools is that the evaluation of the pollution associated with each pollutant is based on local air dispersion modelling (ADMS4 and ADMS-Urban for SO_2 and PM10, respectively) to account for numerous local emission sources, considering a large simulation domain. A description of each tool which has been developed will be given. An overall view of the performance of the system in terms of ground-level concentration prediction will also be shown.

***Key words:** air quality modelling, operational pollutant monitoring , data assimilation, ADMS models suites.*

1. INTRODUCTION

The Etang de Berre region is one of the two main French industrial areas and it is located in the Bouches-du-Rhône department, in the south-east of France. In particular, the border of the salt water lake is surrounded by several sources of pollutant ranging for example from agricultural activities, chemical industries, refineries and road transports, thus leading to the release of various pollutants damaging for human health and the environment (Figure 4b).

AIRFOBEP is the regional air quality agency in charge of the monitoring of air pollution over the Etang de Berre area, including the western part of the Bouches-du-Rhône department (Figure 4a). Its missions consisted of both monitoring in real-time the majority of air pollutants that may impact human health and environment (see Figure 4a for the location of SO_2 and PM10 measurements), and forecasting air quality over the whole Etang de Berre region. In particular, air quality forecasts are designed both to inform populations about the air quality which is expected in the next few days and to take preventive measures of reduction of pollutant emissions associated with industries located on the border of the salt water lake. From several years ago, AIRFOBEP has decided to develop an operational numerical platform to perform daily forecasts of air pollution at local scale over the whole Berre domain. This platform provides automated predictions of concentrations of O_3, NO_2, SO_2 dioxide and PM10 which are based on local dispersion simulations which may be coupled to mesoscale photochemical simulation.

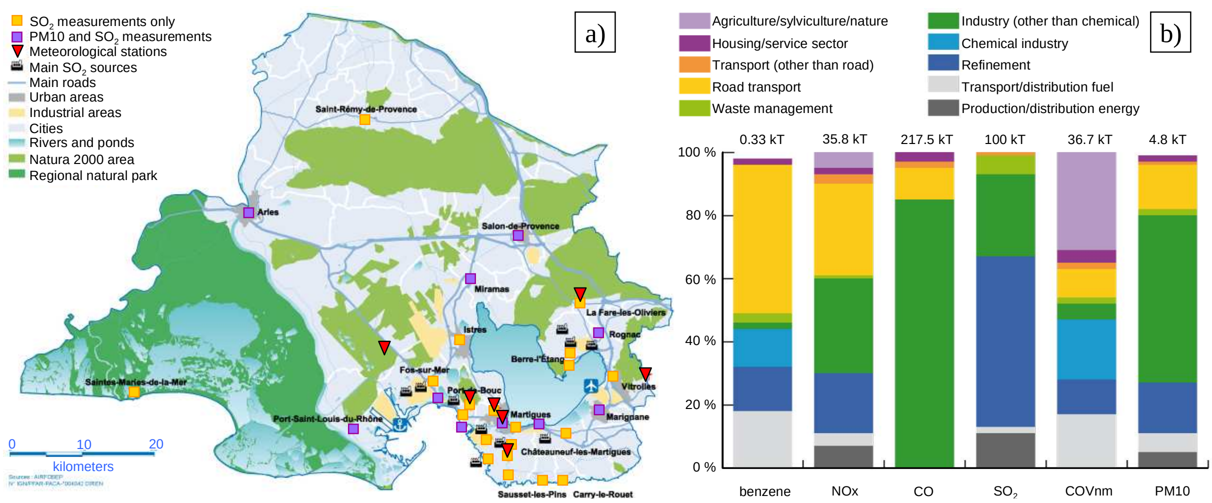

Figure 4. Main sources of pollutant release for the Etang de Berre region : (a) Geographical domain of the Etang de Berre region. Air quality monitoring and meteorological stations are reported as well. (b) Sectorial distribution of pollutant release (adapted from AIRFOBEP©).

The present work is related to operational applications associated with SO_2 and PM10. We focused on the following points:

- The specific approaches developed for the operational monitoring and the forecast of each pollutant. In particular, a specific approach has been developed to account for background pollution for PM10 while data assimilation methods have been used to incorporate chemical measurements to correct SO_2 dispersion plumes prediction.
- The performances of each application in terms of ground-level concentration predictions, focusing both on mean annual concentrations and on simulation of peaks and regulatory values.

The paper is structured as follows. In section 2, the methodology which is used for PM10 prediction and monitoring will be described and an overall view of the performances of this operational tool will be given. The section 3 is as the section 2 but concerns the application associated with SO_2 pollution. Some conclusions and perspectives will be drawn in section 4.

2. MONITORING AND FORECASTING PM10 POLLUTION OVER THE ETANG DE BERRE REGION

In this section, we will focus on the application which has been developed to monitor and predict PM10 concentrations over the Etang de Berre region. First, a brief overview of the main functionalities of this tool will be given. Then, more details about the methodology which has been used to determine background PM10 concentrations that are used for dispersion simulations will be presented. Finally, some quantitative evaluation of the results provided by this application will be shown.

2.1 General overview of the platform

In 2008, AIRFOBEP deployed an operational platform to monitor PM10 over the Berre region (Figure 4a). This platform has two main functions:

- Providing daily PM10 concentration forecasts for the present and the following day (D and D+1, respectively).
- Providing daily analysis for the day before (D-1) by taking into account observations from D-1.

For each application, the computation of PM10 concentrations is performed using the ADMS-Urban model (McHugh *et al*., 1997; Carruthers *et al*., 2000). The simulation domain has been subdivided into three different grids that used variable and intelligent gridding (Figure a). Such a methodology allows one to optimise the computation time keeping a very fine horizontal resolution in the vicinity of roads and point sources of PM10. The emissions that are used for dispersion simulations are derived from an inventory that was realized in 2001. This inventory contains data for each type of source including point source (chimneys), lines (roads), areas and volumes and finally natural and anthropogenic sources. Note that point sources as well as natural and anthropogenic sources are common to the three simulation domains. The meteorology is derived from RAMS forecasts conducted at 1 km grid-spacing over the Berre region (Cotton *et al*., 2003) for the predictions at D and D+1, and surface station observations to generate analyses at D-1. Background pollution used for dispersion simulations is determined from a statistical method based on measurements provided by the AIRFOBEP network. This point will be further detailed in the section 2.2. The results of the dispersion simulations are then bias-corrected at each measurement station and the results are interpolated on a regular grid of 200 x 200 m^2. Note that the bias has been established by comparing past predictions and observations from 2007 and 2008 and is a function of both the value of concentration which has been predicted and the month. Maps that are generated for D-1 also include PM10 observations that have been incorporated using the *kriging of innovations* method (Blond *et al*., 2003).

An example of the results provided by the platform is presented on Figure b. A full description of the PM10 platform is given at *http://www.airfobep.org/docs/Modelisation_PM_Rapport_2008_ecran.pdf*. Daily operational results are available at: *http://previsions.airfobep.org/*.

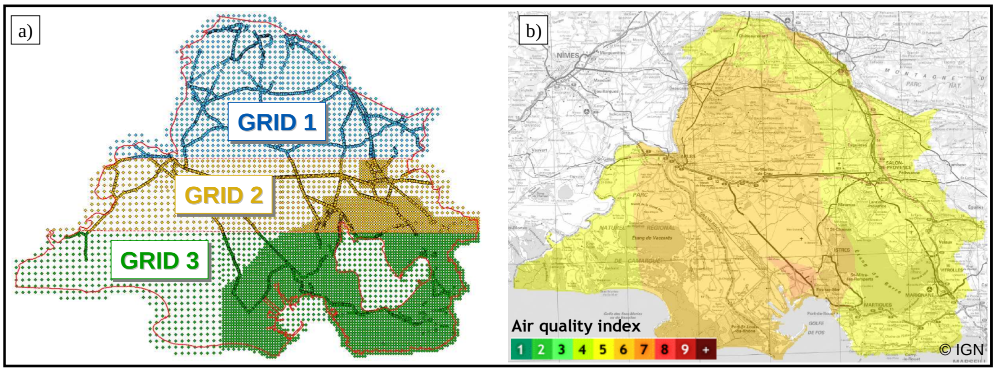

Figure 2. Overview of the platform developed for PM10 monitoring: (a) Simulation domains used for ADMS-Urban and (b) air quality index (AQI) as deduced from the mean daily concentration of PM10 for the 1st July 2009. The scale is the one used for the French *ATMO index* (sources: NUMTECH, SIMALIS and AIRFOBEP©).

2.2 Details about the determination of background PM10 concentrations

An important part of PM10 pollution is attributed to long range transport of particles. Actually, this kind of pollution is not taken into account in the emission inventory that is used to perform ADMS-Urban simulations. Preliminary studies showed that using the available inventory only led to underestimations of observed PM10 concentrations, thus suggesting that a background concentration of PM10 is needed to improve the results of dispersion simulations. For this, a statistical methodology has been developed to define homogeneous (over the simulation domain) and daily background PM10 concentrations using measurements arising from the AIRFOBEP network. We can commonly define the measured concentration (C) as:

$$C = C_f + E + N$$

Where C_f is the actual background concentration, E the contribution of different emission sources and N the noise which may be associated with errors of measurement or concentration fluctuations due to atmospheric turbulence.

Here we will give a brief description of each of the following step of the statistical methodology which has been developed to define C_f: the suppression of the term *N*, the determination of the tendency of C_f as well as the constant derived from its time integration and finally the application of a *step-by-step* method to define hourly background concentrations.

Suppression of the term *N*

By definition, the arithmetic mean of the term *N* tends towards zero so that performing a moving average over a time period which is long enough (here, 24 hours) allows one to define the average of *C* as the average of C_f plus the average of *E*.

Determination of both the tendency C_f and its constant of integration C_0

The determination of the tendency of C_f is based on the following hypothesis: "if C_f varies, this variation is observed for every measurement station of the AIRFOBEP network. Therefore, observations at different stations are likely to be correlated if this variation is more important than the local impact associated with some emission sources". We proceeded as follows:

- Computing the correlation coefficient R^2 for each couple of station over 13 hour periods and determining the number (*Ns*) of stations correlated with $R^2 \geq 0.6$ at least with *K* other stations (here, $K = 4$).
- If $Ns < K$, the tendency of C_f is considered as null so that C_f remains constant.
- If $Ns > K$, the tendency of C_f is then the average of concentration tendencies associated with each station correlated with $R^2 \geq 0.6$ at least with *K* other stations.

Doing this, and by summation, it is possible to determine the value of C_f minus its constant of time integration, C_0. C_0 has both to be positive and smaller than the minimum concentration (*C*) observed between every station (C_{min}). Comparing C_{min} and the tendency of C_f over the period of interest, it is possible for each hour to determine the value of C_0 using the mean between the minimum and the maximum values it may have.

Application of a *step-by-step* method

Using continuously the method previously described (i.e. over an infinite time period) may lead to strong errors in the estimation of C_f. To overcome this problem, a step-by-step method has been applied using finite time intervals of 200 hours that are defined to provide two values of C_f for each time step (actually, the second half of a given time interval corresponds to the first half of the following). The final value is then a weighted mean of these two values.

2.3 Quantitative evaluation of the results

The quantitative evaluation of the results concerns the period ranging from the 1st January 2009 to the 31st December 2009. The Table 1 displays the results obtained for two of the ten measurement stations (chosen as the stations for which the PM10 platform succeeds the best and the worst) as well as the average results taking into account all stations, for mean and maximum daily concentrations prediction at D-1[1]. The Table 2 presents the bias for mean and hourly maximum daily concentrations prediction at D-1 as a function of concentration values.

Table 1. Quantitative evaluation of simulations results at D-1 for the period ranging from the 1st January 2009 to the 31st December 2009.

Variable	Station of measurement	Observed mean (µg.m^{-3})	Predicted mean (µg.m^{-3})	Bias (µg.m^{-3})	NMSE (%)	AQI good prediction (%)
Daily mean concentration	MILE (Best prediction)	27.91	27.95	-0.06	17.3	44
	PSLV (Worst prediction)	33.97	29.96	-4.07	37.3	36
	Mean over all stations	31.17	30.35	-0.66	20.69	41
Daily hourly maximum concentration	SLPV (Best prediction)	49.81	36.23	-14.3		
	PSLV (Worst prediction)	69.13	35.71	-35.21		
	Mean over all stations	56.14	36.26	-21.07		

Table 2. Quantitative evaluation of simulations results at D-1 for the period ranging from the 1st January 2009 to the 31st December 2009. The first (resp. last) three rows are associated with mean daily (resp. hourly) concentrations.

Concentration classes (µg.m^{-3})	0-9	10-19	20-29	30-39	40-49	50-64	65-79	80-99	100-124	>124
Number of observed	1	56	124	109	53	22				
Number of predicted		75	113	92	48	23				
Mean bias (µg.m^{-3})	2.33	0.38	-1.1	-0.87	-1.37	-1.82				
Number of observed	3481	18302	22800	18445	10391	6658	2063	874	293	234
Number of predicted	1925	22055	27245	26822	12567	7412	818			
Mean bias (µg.m^{-3})	7.86	4.42	3.04	0.65	-3.91	-10.49	-24.58	-41.62	-63.84	-113.9

Concerning daily mean concentrations, results are satisfying with more than 41 % of good predictions and at worst a bias of –4.07 µg.m^{-3} (station PSLV). In general, daily hourly maximums are underestimated for every measurement station with a mean bias of –21.07 µg.m^{-3}. The station PSLV, for which the mean observed maximums are the largest (69.13 µg.m^{-3}) exhibits the largest mean bias with –35.21 µg.m^{-3}. Looking at the distribution of the bias as a function of concentration values

[1] The calculations concerning quantitative evaluation of results at D and D+1 are still under process. Also, note that the prediction at D-1 used for the evaluation does not include observations kriging.

(Table 2), it is shown that mean daily concentrations lower (resp. greater) than 20 µg.m^{-3} are generally overestimated (resp. underestimated). In the same way, observed hourly concentrations lower (resp. greater) than 40 µg.m^{-3} are overestimated (resp. underestimated). Note that the platform was not able to predict observed hourly concentrations greater than 80 µg.m^{-3}.

3. MONITORING AND FORECASTING SO_2 POLLUTION OVER THE ETANG DE BERRE REGION

In this section, the platform developed for SO_2 monitoring will be briefly described. More details about original methodologies that have been developed to correct SO_2 plumes direction and assimilate SO_2 observations for D-1 analyses generation will be given. As the platform is still under development, any quantitative results will be shown.

3.1 General overview of the platform

The platform which is currently operational for SO_2 monitoring over the Etang de Berre region has two main functionalities :

- Providing daily SO_2 concentration forecasts for the present and the following days (D, D+1 and D+2, respectively).
- Providing daily analysis for the day before (D-1) by taking into account observations from D-1 and uncertainties related to wind direction and emission rates.

For each application, the computation of SO_2 concentrations is performed using the ADMS model (Carruthers, 1994) in its version 4.1. Ten different grids are used for the dispersion calculation (Figure a), each grid corresponding to an industrial site of the Berre area. The largest grid uses a horizontal mesh of 1000 m while small squared grids (5 x 5 km^2) centred on emission sources have a 100 m horizontal resolution. Finally, intermediate domains of 10 x 10 km^2 centred on emission sources with a horizontal mesh of 250 m are used to smooth the structure of plumes that overlap different simulation grids. The emission rates associated with each industrialist and used for the simulation are considered as constant with time. The meteorology is derived from observations for D-1 simulations and numerical weather forecasts interpolated to meteorological stations for D, D+1 and D+2. Note that different meteorological conditions are attributed to each simulation grid as a function of its geographical location. Maps that are generated for D-1 also include correction of plumes direction and SO_2 observations that have been incorporated using geostatistical interpolation methods. This last point is still under development and will be discussed in section 3.3. An example of the results provided by the platform is presented on Figure b. Daily operational results are available at: *http://previsions.airfobep.org/*.

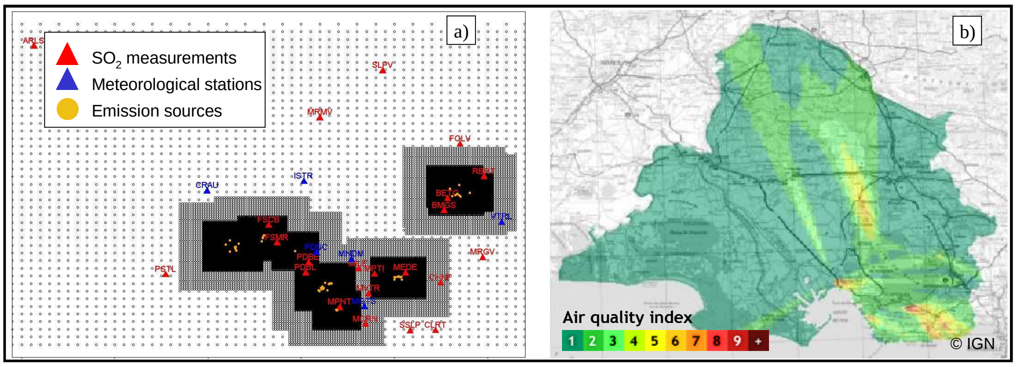

Figure 3. Overview of the platform developed for SO2 monitoring: (a) Simulation domains used for each of the ten industrials and (b) air quality index as deduced from the max hourly concentration of SO_2 for the 30th June 2009 at 10UTC. The scale is the one used for the French *ATMO index* (sources: NUMTECH, SIMALIS and AIRFOBEP©).

3.2 Correcting plume direction and emission rates for D-1 analyses

The methodology which is described here only concerns the generation of analyses at D-1 and is applied to the hourly maps of predicted concentrations projected onto the largest grid. This methodology is intended to account for uncertainties related to wind direction and emission rates that are two variables that may strongly impact the results of Gaussian plume dispersion models and leading to poor performances. The methodology may be described as follows:

- An ensemble of angles of rotation Φ_i ranging from –20° to 20° (by 1°) is defined.
- For each Φ_i, the concentration field which is associated with each industrialist is rotated. For each industrialist, the centre of the rotation is defined as the barycentre of the location of its emission sources. When the rotation has been applied to the ten industrialists, the ten concentration fields are then summed.
- In the same way, the uncertainty related to emission rates is taken into account defining a correction factor *f* (applied to emission rates) ranging from 50 % to 150 % of the standard rates used for ADMS simulations.
- For each combination of Φ_i and *f*, a concentration field is then obtained. The field that best matches SO_2 observations is then conserved and used for the following step, that is the incorporation of SO_2 measurements.

3.3 Assimilation of past observations for D-1 analyses

The last step of the generation of hourly concentration analyses consisted of assimilating SO_2 measurements into two-dimensional concentration fields that have been obtained after applying corrections of plumes direction and emission rates. The so-called kriging of innovations method is currently used. It is based on linear combinations of model errors at each surface station used for SO_2 measurements. The corrections are directly applied at the location of measurements using a range (radius) of influence of 1 km to account for the fact that SO_2 observations are representative of the local scale.

The Figure displays an example of the impact of wind and emission rates corrections as well as the influence of the kriging of innovations for a particular case-study. As initial errors between ADMS results and some measurements were large (more than 150 µg.m^{-3}, see Figure a), the influence of these differences is clearly shown when applying wind and emission rate corrections (Figure b). In particular, the concentration field which is produced does not exhibit very large values in the vicinity of the FSMR and MEDE sensors. The application of the kriging method (Figure c) also led to further improvements as the predicted values at VTRL (on the right border of the Figure c) are close to the observed ones while the results at the surrounding sensors (BETG and BMGS) have not been deteriorated. Nevertheless, the application of innovations kriging to daily predictions sometimes led to unrealistic results, suggesting that this method is not fully applicable to Gaussian plume models results.

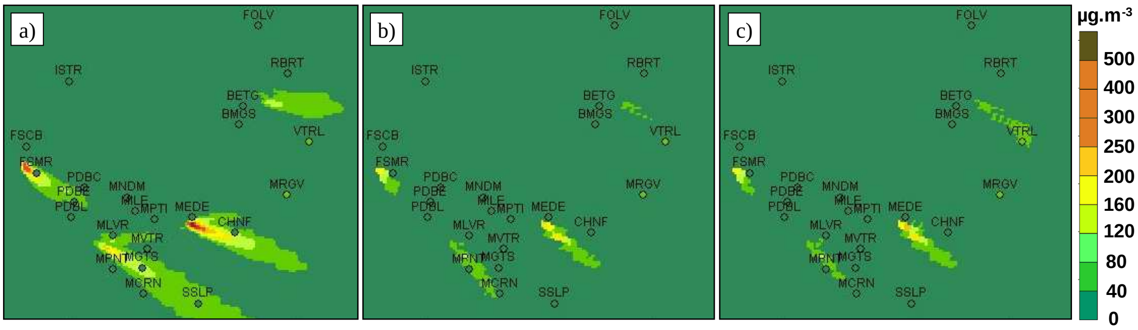

Figure 4. Example of the generation of SO_2 analyses at D-1: Hourly concentration (µg.m^{-3}) derived from (a) raw ADMS simulations, (b) ADMS simulations with wind and emission rates corrections and (c) ADMS simulations with wind and emission rates corrections, and kriging of innovations. The values at each measurement station is also reported with colored circles.

4. CONCLUSIONS AND FUTURE WORK

In this study the automated platforms used by AIRFOBEP to monitor and forecast PM10 and SO_2 concentrations over the Etang de Berre region were presented. The results provided by the PM10 platform showed a very good agreement with ground stations measurements, in particular thanks to a specific methodology developed to account for historical errors of the system (application of a bias) and background PM10 pollution that is not taken into account in standard emissions inventories. Nevertheless, the current PM10 platform still exhibits a strong negative bias in comparison with large PM10 concentrations. The automated platform associated with SO_2 concentrations prediction is currently operational but developments are still under process to generate analyses at D-1 accounting for both uncertainties related to wind direction and emission rates, and local SO_2 measurements that have to be assimilated in concentration fields. The method of innovations kriging does not seem to be fully applicable to this platform in its current form and a different data assimilation technique that may be applied to discontinuous fields such as SO_2 plume fields is probably needed. In particular the following developments may be envisaged for the SO_2 platform:

- The correction applied to plumes direction is currently identical for each industrialist. It is planned to assess the impact of applying individual corrections that may differ between industrialists.
- Taking into account the spatial direction when applying kriging of innovations. Such a methodology may bring valuable improvements for discontinuous concentrations fields that exhibit anisotropic structures.
- Finally, it is planned to develop a statistical module that will provide, on demand, quantitative assessments of SO_2 predictions. Actually, such a quantitative evaluation module already exists for the platforms that have been developed for PM10, O_3 and NO_2 monitoring.

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