H13-255
SIMULATION OF SO_2 EPISODES EXCEEDING EU REGULATIONS IN THE INDUSTRIAL AREA OF LE HAVRE WITH THE MM5, SWIFT AND SPRAY MODELS

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Abstract: The industrial zone of Le Havre in the River Seine Estuary (France) is characterized by the presence of several major sources of SO_2 emissions, with several refineries and a large power plant. The air quality in the area is under the supervision of the AIR NORMAND Air Quality Management Board, which operates an extended network of automatic stations. There were a large number of SO_2 episodes during year 2007 when observed concentrations were above regulatory limits: this situation has driven the Regional Authority for Industry Research and Environment (DREAL) to undertake the detailed numerical simulation of all episodes, in order to determine with precision the emission reductions that had to be imposed to comply with EU regulations.

The simulation of all the 77 episodes observed during year 2007 was performed, with a very high spatial resolution (down to 100m) and a time step of 15mn for averaged SO_2 concentrations, using full 3D simulation tools. The SO_2 emissions from all the main stacks of the "Top 3" industrial sources were defined on an hourly basis. A sequence of nested mesoscale meteorological models (MM5 + NSWIFT) was used to represent the flow over the Seine Estuary, and a 3D Lagrangian Dispersion model (SPRAY) was used to simulate the time dependent SO_2 concentration distributions.

The paper presents the comparisons between model results and measurements and the model evaluation conclusions, and focuses on the difficulties of high-resolution micro-meteorological modelling in weak winds and stable conditions in an Estuary situation, with topographic and sea breeze effects.

A subset of the episodes for which the quality of the results was fairly good was selected and the results of the simulations for these cases have been actually applied to the computation of optimal emission reductions.

Key words: *Air quality management system, source emissions control, meteorological modelling, lagrangian dispersion modelling.*

INTRODUCTION
During year 2007, in Le Havre's industrial area and surrounding, 77 periods presented SO_2 observations exceeding the European Commission regulations about mean daily concentration (threshold : 125µg/m^3/day max) and/or mean hourly concentration (threshold : 350 µg/m^3/h max). Four sensors in the area were concerned. This fact urged the local Industry authority DREAL to consider emissions reduction plans using a dispersion model validated over these episodes.

The domain main characteristics are:
- a wide estuary extended by the river Seine,
- a 100m high cliff along the north border of the estuary,
- the city of Le Havre,
- and the two industrial zones : Le Havre on the western side and Notre Dame de Gravenchon on the eastern side.

The total area of interest is then 45x21km wide.

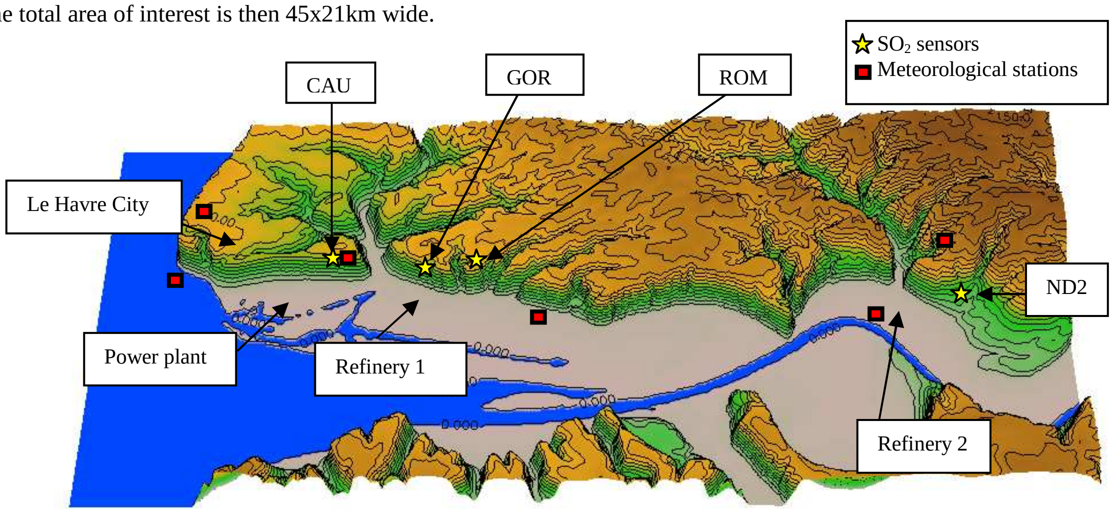


Figure 1: Topography of the domain – Origin: IGN (French National Geographic Institute) - 100m resolution. Yellow stars represent the referenced SO_2 sensors

THE MODELS

The simulations where performed taking into account the top three plants accounting for 90% of the total SO_2 emissions. These sites have provided us with their hourly SO_2 emission rates for every episode: 47 chimneys were taken into account.

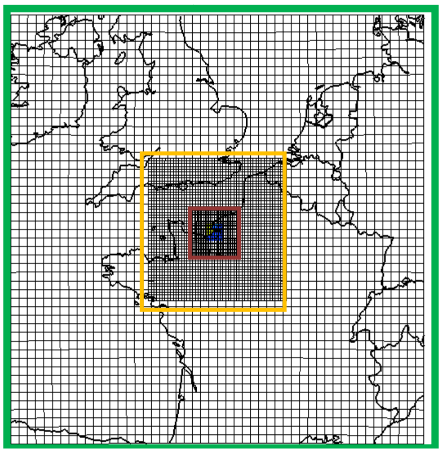
Meteorological analysis was performed starting from the data provided by the AIR NORMAND monitoring network, the French Meteorological Office local stations, MM5 meteorological model and the SWIFT diagnostic model. SWIFT is a non divergent interpolation model, derived from the MINERVE model, taking into account large scale model outputs together with local meteorological measurements.

Simulation of the pollutant dispersion evolution was processed by the SPRAY 3D non steady state lagrangian dispersion model. Meteorological fields produced by MM5/SWIFT are used by SPRAY as an input.

DOMAINS DEFINITION

Regarding meteorological modelling, two separate approaches have been followed:

- A classical nested approach using MM5 and SWIFT to take into account large scale as well as smaller scale effects. The MM5 model was used with three nested domains from 27km resolution to 3km resolution. SWIFT was then configured with a nested approach: a 400m resolution domain using as meteorological inputs the smaller scale MM5 output and a 100m resolution domain using as inputs the previous SWIFT outputs and the local meteorological stations (cf. Figure).
- A simpler approach, using only SWIFT supplied with local meteorological measurements.



Domaine	Résolution
MM5 - D1	27 Km
MM5 - D2	9 Km
MM5 - D3	3 Km
NSwift 1	400 m
NSwift 2	100m

Figure 2: Nested domains used to run MM5 simulation together with NSWIFT nested approach

For each episode, the two approaches have been computed and the one giving the best results taken into account.

For the dispersion simulation, the SPRAY model was run using a 100m resolution domain. To reduce the computing time, three domains were considered: one covering Le Havre zone for episodes that only concern the western sensors, another covering Notre dame de Gravenchon zone for episodes that only concern the ND2 sensor, and a global domain including both areas for situations that concern sensors from both sides.

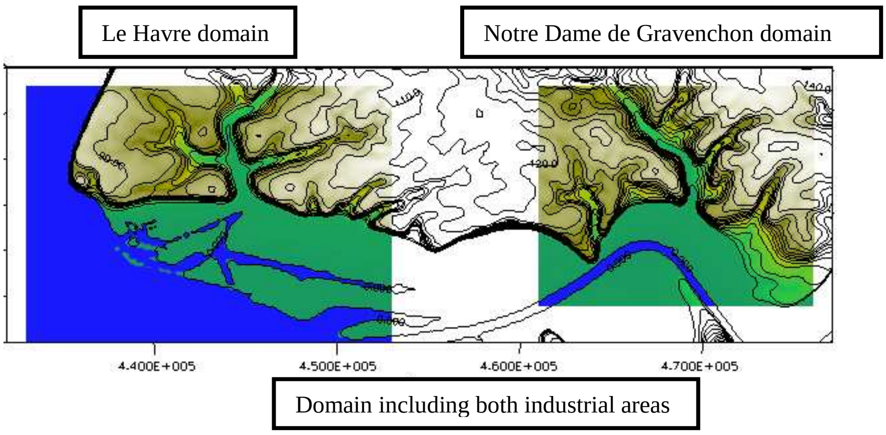


Figure 3: Domains used for the dispersion simulations using the SPRAY lagrangian model.

DATA ANALYSIS

Measurements from the four SO_2 sensors have been analysed for the whole period, focusing on concentration values higher than 100µg/m^3 in order to identify particular weather conditions leading to high concentration measurements. As shown in Figure 4, most sensors presented high concentrations for moderate to high wind speeds. On the opposite, the CAU sensor, situated on the western part of the domain, presented high concentration for low and moderate wind speeds.

In each case, concentration roses signatures are typical: ROM and GOR measured high levels of concentrations for winds coming from Le Havre refinery, TAN for winds coming from Notre Dame de Gravenchon refinery. Only the CAU sensor is not that well signed, presenting wind directions coming from the North East: as those winds are associated with low wind speeds, relationship with a precise industrial plant is hazardous.

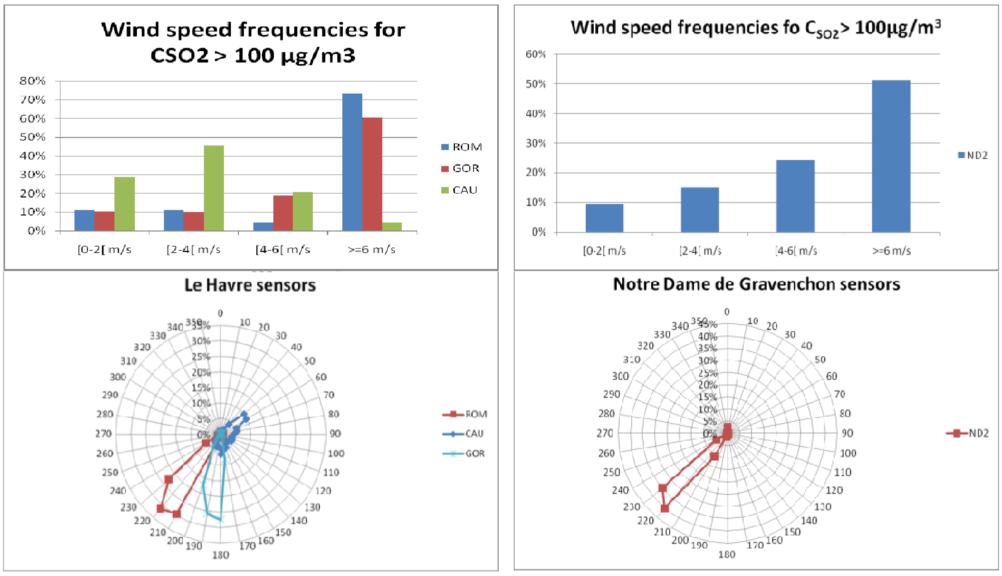


Figure 4: Concentration roses and wind histograms for concentration measurements higher that 100µg/m3.

VALIDATION METHODOLOGY

The scores described in the well Model Validation Kit (Hannah, 1991) have been used in order to evaluate the model performances. As only high concentration values are of interest, scores have been calculated for concentration measures higher than 100µg/m^3. This prevents the scores from being distorted by low concentration values.

In a point to point comparison and for short term simulations, the sensitivity of the scores to the chosen modelled concentration reference point is very high. In our case, this situation is worsened by the short distances between the emissions and the sensors (about 2 km): at such distances, the plume's width is low and the concentration gradient in the crosswise direction is high. On the other side, the meteorological sensor from the French Meteorological Office has a direction measurement precision of +/- 5°. At a 2km distance, such an error on the wind direction can introduce a 180m error on the plume centreline, to be compared to the 100m resolution of the simulation. The same influence can be underlined for the wind speed precision: the French Meteorological Office provided us with wind speeds at a precision of +/- 0.5 m/s. At 2km from emissions, this error can introduce a delay or a lead of 15mn on the plume transport. To smooth this phenomenon, the scores presented here have been calculated taking into account the best point among the 4 corners of the cell containing the sensor + the interpolated value at the sensor place at times T and T+/- 15mn.

MODEL RESULTS

Notre Dame de Gravenchon domain

The model results for the episodes related to Notre Dame de Gravenchon (western side) are very good as shown in Table 1. For this particular domain, only two episodes where simulated with difficulty, due to very low wind speeds. During these episodes, the two meteorological stations close to the ND2 sensor presented uncorrelated wind directions and low wind speeds associated with stable atmospheres the meteorological models were not able to reproduce.

Table 1: Scores at ND2 sensor for episodes that only concerned the Notre Dame de Gravenchon domain.

	Optimum	ND2
Correlation coefficient	100%	56%
FB	0 %	-12%
MG	1.	0.9
FA2	100%	91%

Le Havre domain

Most episodes impact the GOR sensor and only few episodes impact the ROM and CAU sensors. The scores obtained for these episodes are summarized in the table below. The results obtained at the GOR and ROM sensors are quite correct but the CAU sensor is not well simulated.

Table 2: Scores at GOR, ROM and CAU sensors for episodes that only concerned the Le Havre domain

	Optimum	GOR	ROM	CAU
Correlation coefficient	100%	59%	52%	27%
FB	0 %	5%	5%	-111%
MG	1.	1.	1.	0.5
FA2	100%	86%	86%	31%

A detailed observation of the nearest meteorological data at the top and at the bottom end of the cliff show in many occasions highly uncorrelated wind directions, as presented in Figure 5. This vertical wind shear is associated with low winds. The model hardly shows the wind vertical structure as none of the estuary measurements delivers any vertical wind information. This is the case of most episodes related to the CAU sensor.

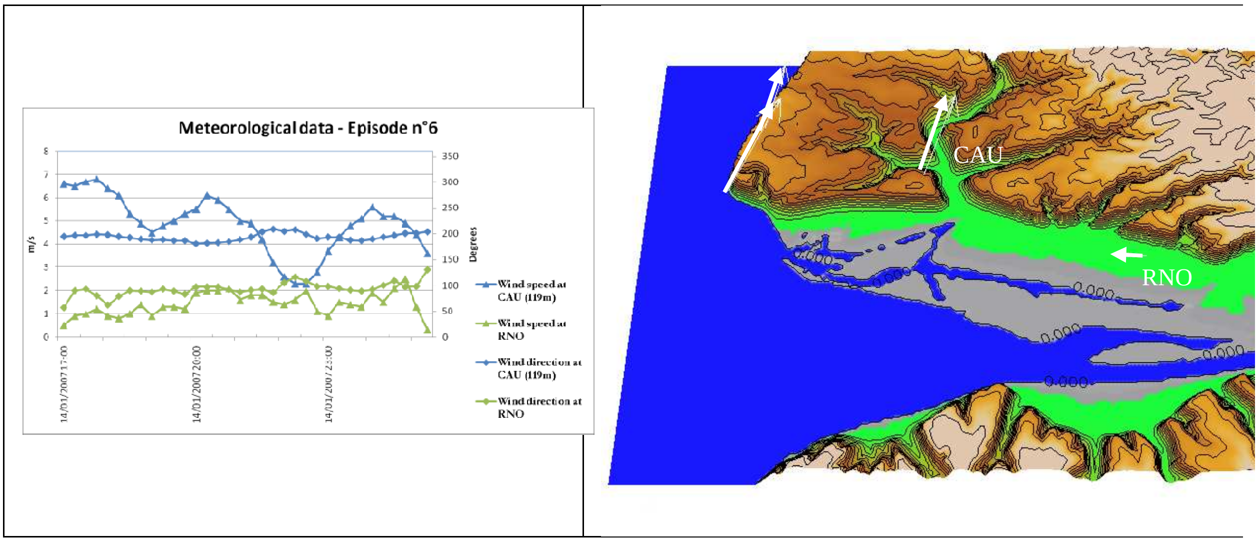


Figure 5: Episode presenting vertical wind direction divergence between the bottom and the top of the cliff

Whole domain

9 episodes involve all studied sensors. The global results are presented in Table 3. In 3 cases out of 9, the wind is well established and each domain plume impacts a limited number of close sensors. For these cases, the model performances are good.

The 6 other episodes correspond to very low wind speed, disorganized wind directions, very stable conditions associated with fog. The latest episodes (4 days) correspond to the 2007 Christmas period where the whole North of France was concerned with high pollution peaks: in Paris, the ATMO air quality indicator reached a 10/10 level. For these cases, the model performances are poor: further work should be done to better represent the meteorological and turbulence fields.

Table 3: Scores at GOR, ROM and CAU sensors for episodes that only concerned the whole domain

	Optimum	ND2	GOR	ROM	CAU
Correlation coefficient	100%	-24%	34%	-6%	3%
FB	0 %	-71%	-15%	-68%	-150%
MG	1.	0.5	0.7	0.7	0.2
FA2	100%	70%	58%	48%	13%

EMISSION REDUCTION SCENARIOS

Regarding the model results, a subset of the episodes was chosen among the previous episodes, retaining those which best represent the sensors observations. Simulations were done taking into account the reduction emission scenario as planned for 2015. The contribution of each chimney to the concentration calculated at the sensors position was determined. The model error was reported on time series plots (green bars) to ensure a better interpretation of the results together with the maximal threshold (red line).

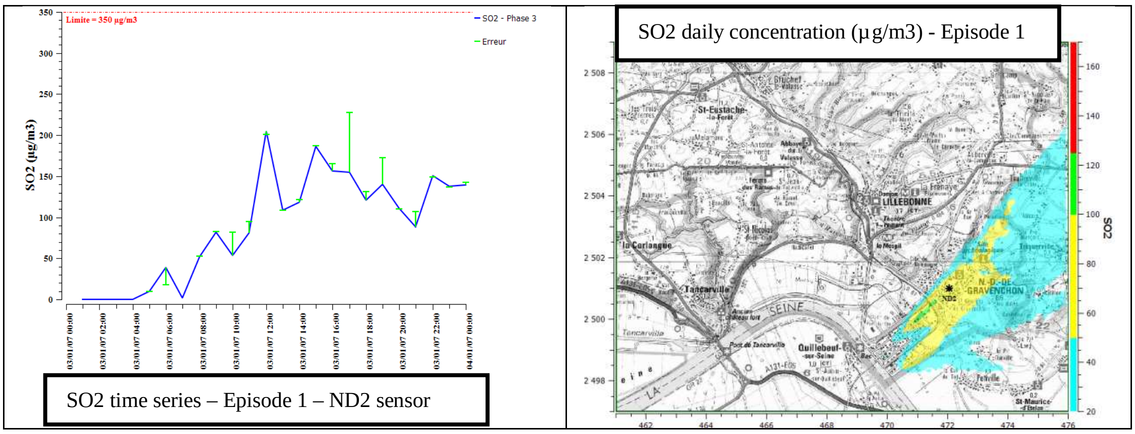


Figure 6: Example of provided outputs for episode 1 after emission reductions

As a conclusion of this part of the study, only one episode still presents concentration values exceeding the European limit. The study of each chimney contribution has revealed points where emission efforts should be made to optimise the SO_2 impact.

CONCLUSION

For this site particular case, the meteorological situations leading to high concentrations observations are frequent due to the presence of the cliff, the Seine estuary, together with big industrial plants. In this case, the use of 3D meteorological and dispersion models using a proper turbulence parameterisation can provide an appropriate quantified answer to emission scenario studies. Looking at each chimney influence is also important as its contribution is not necessarily proportional to its emission rate.

Further work on models is recommended in order to better simulate very stable weather conditions associated with low wind speeds, as for 2007 Christmas episode.

REFERENCES

Hanna, S.R., Strimaitis, D.G. and Chang, J.C. 1991: Hazard Response Modeling Uncertainty (a Quantitative Method). Vol. I: User's Guide for Software for Evaluating Hazardous Gas Dispersion Models'. Sigma Research Corporation, Westford, Ma.