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APICE

Design and evaluation of scenarios supporting coast development strategies in Marseille

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Introduction

Scenarios increase the territorial knowledge framework and provide indications to undertake environmental-addressed actions to identify objectives and interventions towards mitigation strategies as drivers for the sustainable eco-environmental growth of coast areas. From the previous tasks (WP5.2 – Assessment of air emissions sources in the Port of Marseille and future scenario), several scenarios have been designed in Marseille.

Description of the scenarios selected

The first scenario is a common scenario for each partner. It aims to evaluate the air quality for the future year by considering port and maritime traffic evolutions. For Marseille, the selected future year is 2025. Results of this scenario are used as a reference state in the following part to investigate the effectiveness of mitigation actions in term of air quality for the future year. This scenario is named "Base future 2025".

The second scenario - Common future emission mitigation scenario - is also a common scenario. It aims to highlight differences due to specificities of each studied area using a common mitigation action. The selected action is a reduction to 0.50% of the sulfur content in ship fuels during cruising and maneuvering mode with an additional reduction by 20% of $PM_{2.5}$ emissions from ships. For Marseille, this scenario is split in two parts with a first evaluation of the reduction of the fuel sulfur content for the $PM_{2.5}$ concentration and a second evaluation with both mitigation actions. These scenarios are named "Low sulfur" and "Low sulfur + PM (-20%)" respectively.

The third scenario - Individual future emission mitigation scenario - is an independent scenario for each studied area. It aims to evaluate specific mitigation actions designed according to the results of the previous APICE report about the "Identification of risk activities"[1]. For Marseille, this study has shown that emissions from ships during the hoteling phase will have a relevant contribution in total emissions and will directly impact surrounding population. Also, projected emissions forecast that the passenger activity will become a significant contributor to the total emissions in the eastern port.

According these results, a first independent scenario designed for Marseille evaluates the effect on pollutant concentrations of the on-shore power supply (OPS) solution. This action should lead to switch off the emission of ships during the hotelling phase thanks to a connection with the electrical network to supply energy. For this scenario, the mitigation action is applied to passenger ships in

[1] Assessment of air emissions sources in the Port of Marseille and future scenario – APICE report, November 2012.

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rotation between Marseille and Corsica Island. It involves one terminal (Figure 1) and three ships of the CNM Company (Figure 2). This scenario is named "OPS solution".

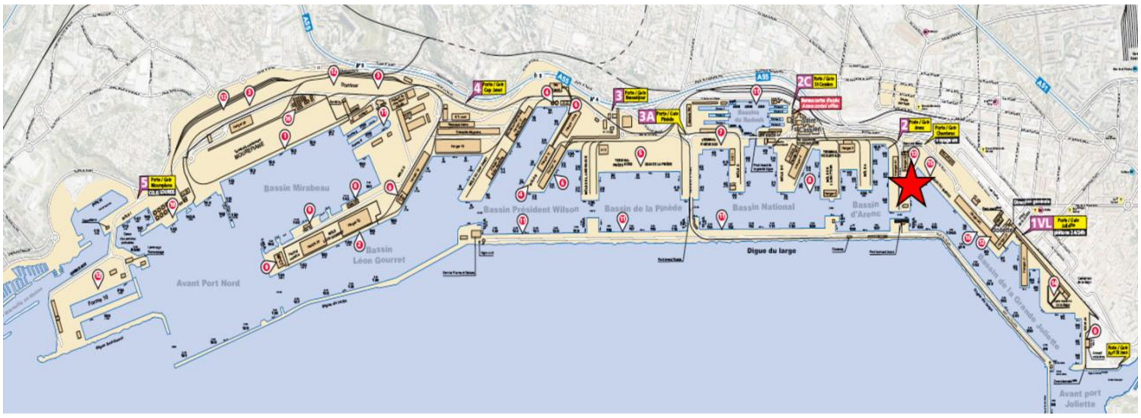

Figure 1: Eastern harbor plan and location of the terminal (red star) involved in the scenario

Figure 2: CNM ships involved in the scenario.

As cruise activity will become a significant contributor for Marseille in the eastern port by 2025, a second independent scenario evaluates the interest to build a new cruise terminal (Figure 3). The aim of this scenario is to move the current terminal cruise closer to the historical city center to allow a direct access to the places of interest. This scenario implies to extent a part of the current seawall to increase the area dedicated for the cruise calls. This scenario is named "New cruise terminal".

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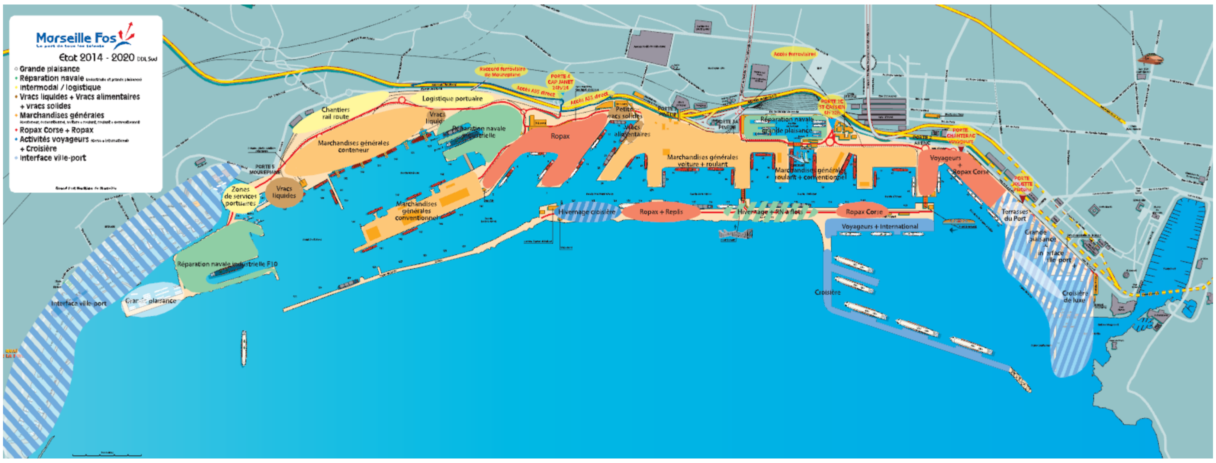

Figure 3: Eastern harbor plan with the new cruise terminal

To reduce passenger ships impact, a last independent scenario tests a modification of fuel type by using liquefied natural gas (LNG). This modification is applied to passenger and cruise ships for cruising, maneuvering and hotelling phases. This scenario is named “LNG passenger”.

Description of the set-up of the modeling system

In this study, two different modeling systems are used. The first model, CHIMERE, is an Eulerian chemical transport model accounting inorganic and organic species of primary and secondary origins. It is designed to run with spatial resolutions from 100 km to 1 km. The second model, ADMS Urban, is a Gaussian model designed to run at the scale of an urban area with finer resolutions. It provides a dispersion of pollutants released by multiple sources without particles chemistry.

The CHIMERE model is used with a spatial resolution of 3 km over the regional area (Figure 4). It uses meteorological data issue from the WRF model with the same spatial resolution and boundary conditions issue from a larger domain with a spatial resolution of 9 km. Input emissions are calculated from a local inventory over the PACA region and gridded with a spatial resolution of 3 km. The outputs are given over the APICE domain (100 x 100 km) for the first vertical layer of the model (≈ 40 m above ground level).

The ADMS Urban model is used over a domain including the Eastern port of Marseille with an adaptive spatial resolution, finer close to the main pollutant sources and over the areas including a mitigation action (Figure 4). Receptor points are computed with a height of 1.5m. Meteorological data are issue from a meteorological station located in Marseille. The main emission sources as road traffic, industry, maritime activity, are modeled as explicit sources and output from CHIMERE runs are included for the $PM_{2.5}$ background concentration.

As it is used as a reference run to evaluate mitigation actions, "Base case future run" is simulated with both CHIMERE and ADMS Urban models. The "Low sulfur" scenarios are simulated with CHIMERE model as they need to consider chemical transformation to evaluate the impact of a reduction of sulfur content in ship fuels on the final PM concentrations. As the independent scenarios consider very local mitigation actions with low emission reductions or a simple translation of emissions, the ADMS Urban model is used to allow a better evaluation of these scenarios. Table I summarizes models use for each scenario.

Table I : Modeling system used for the APICE scenarios

Scenario	Reference (2007)	Base Future (2025)	Low Sulfur	Low Sulfur + PM (-20%)	OPS solution	New cruise terminal	LNG passenger
CHIMERE	✓	✓	✓	✓			
ADMS Urban	✓	✓			✓	✓	✓

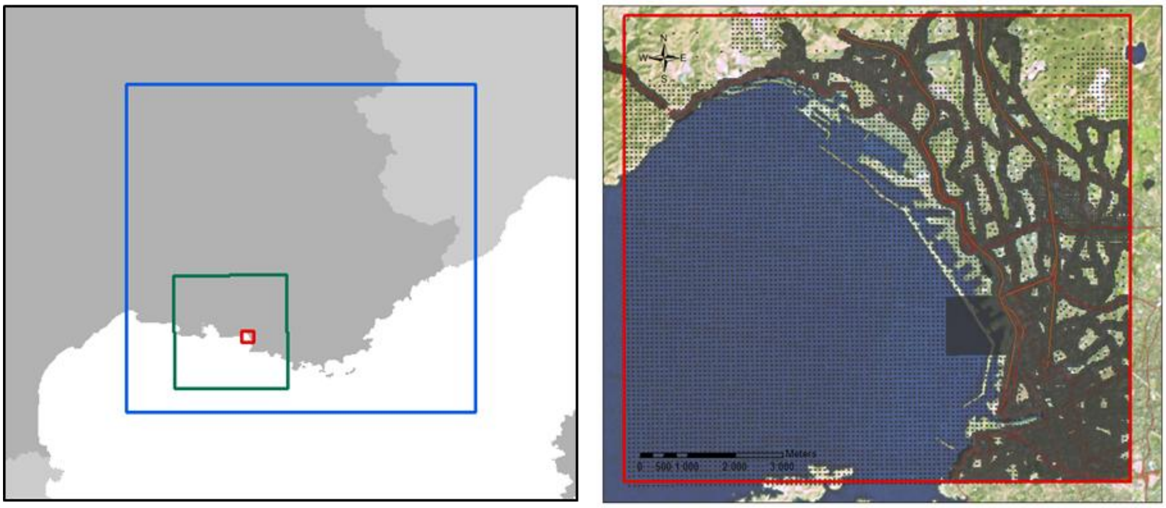

Figure 4*: Left: CHIMERE simulation area (blue), APICE domain (green) and ADMS Urban simulation area (red). Right:* ADMS Urban simulation area and receptor points (grey dots).

Description of the projected emissions for the Future Scenarios

The "Base future" scenario evaluates the air quality by considering port and maritime traffic evolutions. Future maritime traffic data are issue from Marseille port projections and are given for 2025. Data concern five activities: container, liquid bulk, solid bulk, cargo, cruise and passenger. An additional calculation provides a projection for tugs according the maritime traffic evolution. However, no data concern modification in engine type, emission factor or duration of hoteling phase. Also, no spatial data are given for additional ships. To map the future emissions, the following hypotheses are applied:

- same dimensions of ships (gross tonnage) and the same engines
- same fuel type
- same duration for the hotelling phase
- same speed for cruising and maneuvering phase
- same location of quay to load / unload
- same provenance and destination

Pollutant emissions from ship and vessel activity for this scenario are given in the Table II over the APICE domain for Marseille.

The "Low sulfur" scenario evaluates a reduction of the sulfur content in ship fuels, to reach to 0.50%, during cruising and maneuvering mode. The same emissions than for the "Base future" scenario are used with a modification of SO_2 emissions according the sulfur content. An additional reduction by 20% of primary $PM_{2.5}$ ship emissions from the "Base future" scenario is applied for the "Low sulfur + PM (-20%)" scenario. Table II gives the pollutant emissions associated to this scenario.

The first independent scenario evaluates the on-shore power supply (OPS) solution applied for one terminal and three ships of the CNM Company. The emissions of this scenario are based on the "Base future" scenario except for the emissions associated to the ships involved in the OPS scenario which are removed. Emissions of this scenario are given in Table II.

Table II: Emissions from ships and vessels activities for the different scenarios inside the APICE domain (100 x 100km^2).

Emission [Mg/year]	CO	NOx	SO_2	NMVOC	PM_{10}	$PM_{2.5}$
Reference (2007)	16 585	11 841	16 350	3 601	305	305
Base future (2025)	29 533	22 107	30 119	6 384	553	553
Low sulfur (0.5%)	29 533	22 107	4 270	6 384	553	553
Low sulfur (0.5%) + PM (-20%)	29 533	22 107	4 270	6 384	443	443
OPS solution	29 260	22 044	29 848	6 321	550	550
New cruise terminal	29 533	22 107	30 119	6 384	553	553
LNG passenger	18 993	16 914	24 743	4 093	351	351

The second independent scenario, named "New cruise terminal" evaluates the impact of a new cruise terminal building. Total emissions are the same than for the "Base future" scenario and are translated towards the new cruise terminal location for the ships concerned. Emissions of this scenario are given in Table II.

The last independent scenario, “LNG passenger” scenario, evaluates a modification of fuel type by using liquefied natural gas. As for the scenario concerning a reduction of the sulfur content, emissions are based on data using for the “Base future” scenario but are calculated with a new emission factor for passenger ships. Emissions of this scenario are given in Table II.

As discussed in a previous report about identification of present and future risks activities in terms of emissions for Marseille port, the maritime traffic projections forecast a significant increase for the emissions of this sector. Between the present time (reference year of 2007) and the future time in 2025, emissions of main pollutants as PM_{10}, $PM_{2.5}$, NO_x and SO_2 issue from maritime activity are multiplied by two over the APICE domain (Figure 5). The reduction of the fuel sulfur content lead to a reduction by 86% of SO_2 emission in comparison with the emissions of the “Base future” scenario and leads to SO_2 emissions lower than the current emissions, even if maritime traffic increases. The application of the OPS solution allows a light decrease of emissions, lower than 1% of the maritime emissions as this solution concerns only three ships even if the duration of their hotelling phases is important. However, if only hotelling emissions are considered, this action allows a gain of 0.8% and 1% for the emissions of NO_x and PM[2] respectively and a respective gain of 2.8% and 3% for NO_x and PM emissions if only the emissions of the hotelling phase inside the eastern port are considered. The last scenario, where passenger ships will use LNG fuel, leads to a reduction of 23% and 36% for NO_x and PM emissions respectively. At the APICE domain scale, this action displays the highest gain in terms of emissions.

[2] PM_{10} or $PM_{2.5}$ equally as all particulate emissions from maritime activity concern particulate smaller than 2.5µm

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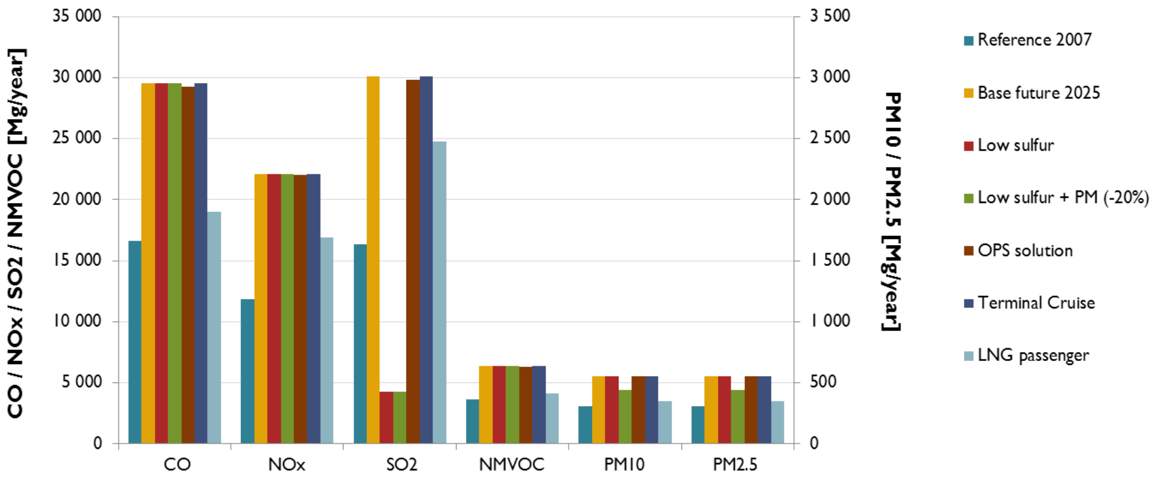

Figure 5: Graphic of emissions from ships and vessels activities for the different scenario inside the APICE domain (100 x 100km2).

Results

To evaluate the air quality under the application of mitigation actions previously described, numerical models run with meteorological conditions for both winter and summer months. The selected periods are February and August months of the year 2011. These periods have already been completed for the present time scenario to estimate the contribution of pollutant sources for the PM_{10} and $PM_{2.5}$ concentrations. Table III displays the main results of this study by summarized the contribution of maritime sector for the particles concentrations at the urban background site of "5 Avenues" and at the port site (Figure 14). As all the mitigation actions proposed in this report concerned the maritime activity, the maximal gain for the present time should not excess this contribution.

Table III : Source apportionment for the maritime activity as the percent of the total concentrations of PM2.5 and PM10 during both winter and summer period at the urban background site of "5 Avenues" and at the port site

	$PM_{2.5}$		PM_{10}	
Site position	Summer	Winter	Summer	Winter
Urban Background	9%	7%	7%	6%
Port	10%	7%	8%	6%

In the following section, the results of scenarios will be represented in the form of maps to display the difference between the “Reference”, or the “Base future” scenarios, and the mitigation actions scenarios. The main pollutants considered to evaluate the air quality for Marseille are PM and NO_2. As PM is mainly dispersed at the regional scale and NO_2 at the local scale, output from CHIMERE will display PM concentration whereas ADMS Urban output will display NO_2 concentration. A last section will present an evaluation of these scenarios for both pollutants with extractions of concentrations at two receptor sites in Marseille.

Base future scenario

$PM_{2.5}$ concentrations for the “Base future” scenario are computed during a winter and summer month (Figure 6). During the winter period, the maximal monthly concentrations are located at Marseille and its surrounding with values of 21µg/m^3. During the summer period, $PM_{2.5}$ concentrations are lower over Marseille with monthly maximal values of 13µg/m^3. This variation is due to both meteorological conditions more dispersive and lower emissions of primary particles during the summer time.

In comparison with the simulation for the present time (emissions for the year 2007), the increases of the monthly $PM_{2.5}$ concentrations are around of 2µg/m^3 for both winter and summer periods. As the winter period is the most critical period in terms of particulate concentrations, the evaluation of the mitigation actions will focus on the winter period in the following sections.

As modifications for the “Base future” scenario concern the maritime emissions, differences are mainly located over the marine areas (Figure 7), with a relative difference higher for the summer period as the background level is lower. The increases of PM_{10} and $PM_{2.5}$ concentrations are maximal inside the port areas, due to the increases of emissions of the hotelling phase. Also, ship trajectories during the maneuvering phases show significant increases. Some additional light increases are observed around the port area due to the dispersion of emissions and chemical transformations.

To evaluate the independent scenarios with low emission reductions, the “Base future” scenario is computed using ADMS Urban for both winter and summer periods. NO_2 concentrations display a significant contribution of maritime emissions inside the port area (Figure 8). However, maximal concentrations are observed on highways and heavy roads. Also, the historical city center displays a high background concentration with monthly values of around 30µg/m^3, mainly due to road traffic emissions.

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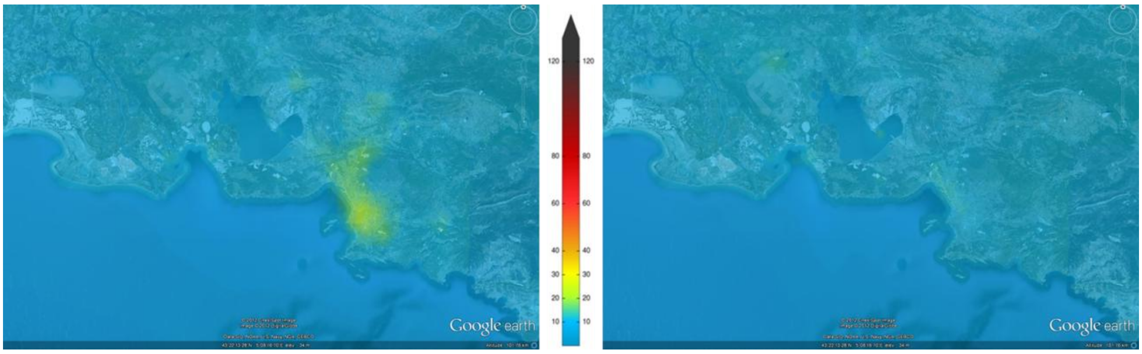

Figure 6 : $PM_{2.5}$ concentrations for the “Base future” scenario during the winter period (left) and the summer period (right).

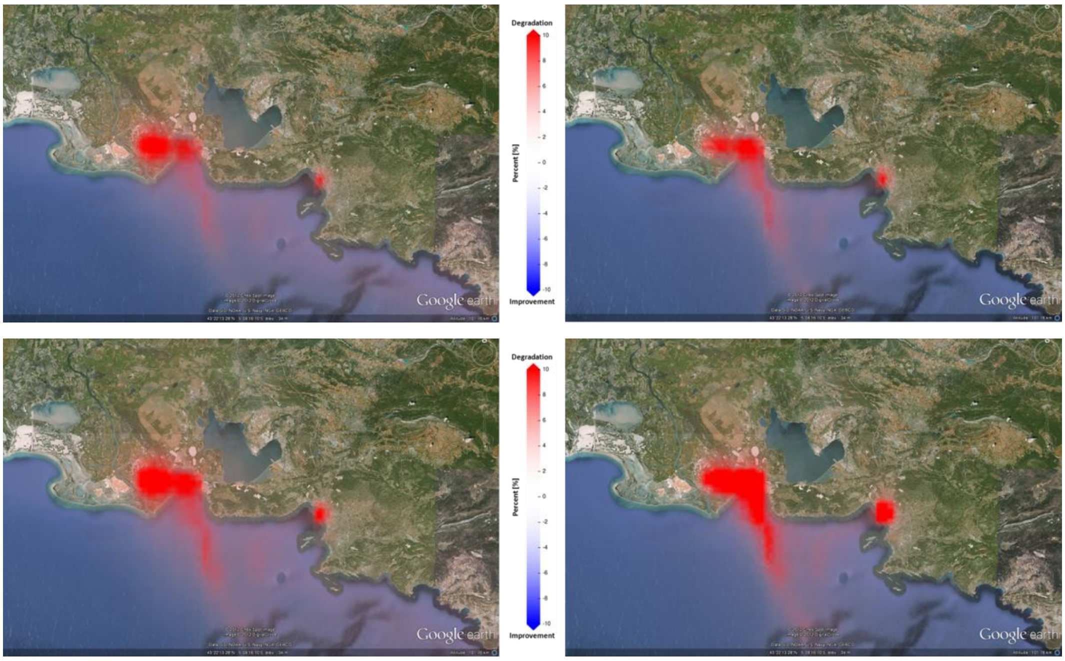

Figure 7 : Relative difference between the “Reference 2007” and the “Base future” scenarios for the PM10 (top) and PM2.5 (bottom) concentrations during the winter period (left) and the summer period (right).

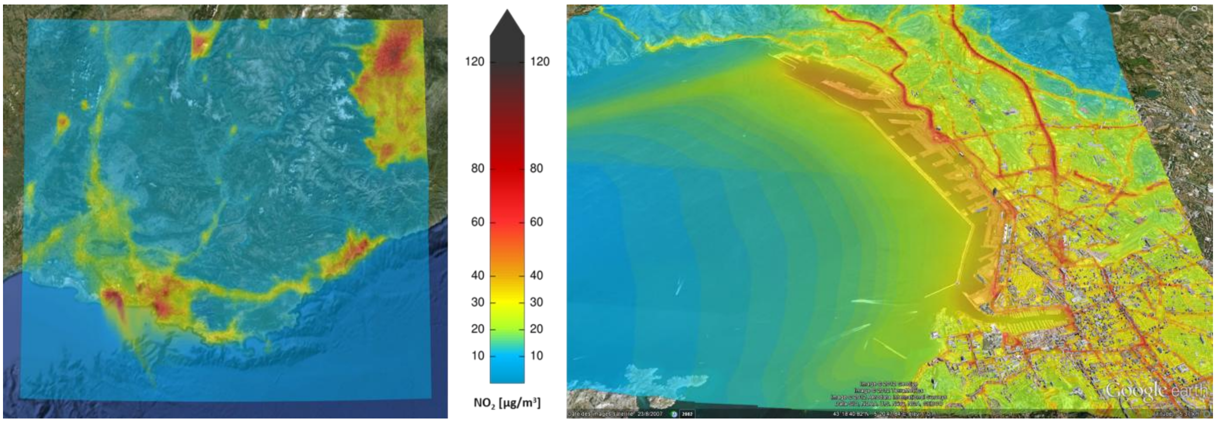

Figure 8 : NO_2 concentration for the "Base future" scenario during the winter period over the APICE domain with CHIMERE (left) and Marseille area with ADMS Urban (right).

Low sulfur

The "Low sulfur" scenario evaluates the impact of a reduction of the sulfur content in ship fuels for the $PM_{2.5}$ concentrations, by reducing the emissions of secondary aerosols precursors. This action reduces the maritime sulfur emissions which lead to a sulfate production in the atmosphere. The evaluation of the $PM_{2.5}$ decrease needs to consider chemical transformation and transport. In the Figure 9 (left side), the improvements for the $PM_{2.5}$ concentrations are not superimposed on ships trajectories or on the port area as they do not associated to a reduction of primary emissions. The improvements are mainly observed over the coastal area with an additional light decrease inside the terrestrial area. The maximal decrease over the APICE domain is 6% in comparison with the "Base future" scenario. In agreement with emissions, no reduction of NO_2 concentration is observed for this scenario.

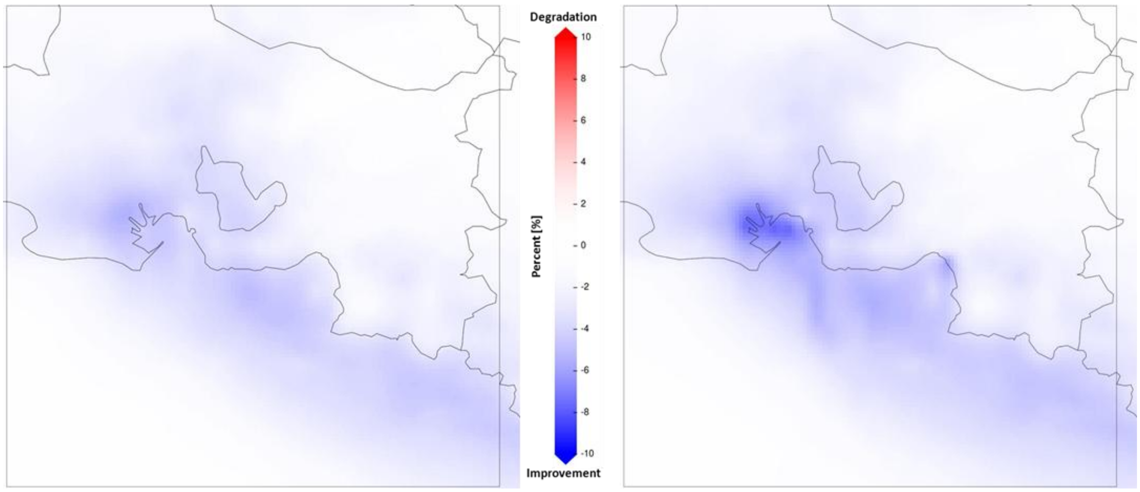

Figure 9 : Left: Relative difference between the "Base future" and the "Low sulfur" scenarios for the PM2.5 concentrations during a winter period over the APICE domain. Right: Relative difference between the "Base future" and the "Low sulfur + PM (-20%)" scenarios for the PM2.5 concentrations during a winter period over the APICE domain.

Low sulfur + PM (-20%)

The second scenario concerning the sulfur content in ship fuels considers an additional reduction of 20% for the primary $PM_{2.5}$ emissions issue from the maritime activity. The difference with the previous scenario is an additional reduction of $PM_{2.5}$ concentration associated to a decrease of primary aerosol mainly observed over the port area and along the ship trajectories (Figure 9 – right side). The maximal decrease is observed over the western part of Marseille port with a reduction by 8% of the $PM_{2.5}$ concentration in comparison with the "Base future" scenario. No reduction of NO_2 concentration is observed for this scenario.

OPS solution

The first independent scenario for Marseille is the application of the OPS solution for three passenger ships in rotation between Marseille and Corsica Island. As shown in Table II, the reduction in terms of pollutant emissions for this mitigation action is low and the evaluation of this scenario in terms of resulting concentrations needs to compute it with an urban model. The area where a significant improvement is observed is located close to the terminal involved (Figure 10). The maximal improvement in terms of monthly concentrations is $0.25 \mu g/m^3$ and $3.4 \mu g/m^3$ for $PM_{2.5}$ and NO_2 respectively. As mentioned above, ADMS Urban computes a dispersion of pollutants released without particles chemistry. The improvement for the $PM_{2.5}$ concentration only concerns the primary particles and leads to an underestimation of the real improvement associated to this action. On the other hand, the relative difference between this scenario and the "Base future" scenario displays a maximal decrease by 9.5% for the NO_2 concentration.

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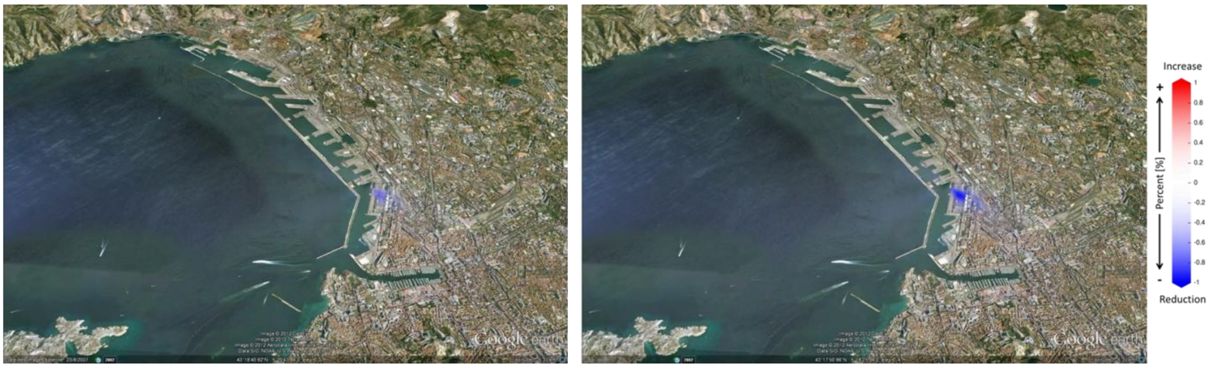

Figure 10 : Relative difference between the "Base future" and the "OPS solution" scenario for the PM_{10} (left) and $PM_{2.5}$ (right) concentrations during the winter period over the urban domain for Marseille.

New cruise terminal

This scenario evaluates the impact for the air quality of the building of a new cruise terminal closer to the historical city center to allow a direct access to the places of interest. It implies to extend a part of the current seawall to increase the area dedicated for the cruise calls and to move all cruise activities form the north part of the port to this new terminal (Figure 11). To entrance inside this new terminal, new trajectories for ships in maneuvering phase are computed. This displacement of the cruise activity leads to a decrease of concentrations in the north part of the port where cruise ships are currently located with maximal decreases by -4% and -5% of PM_{10} and $PM_{2.5}$ concentrations respectively (Figure 12). A parallel increase is computed in the south part of the port where cruise ships will be located with this scenario with maximal increases by 6% and 8% of PM_{10} and $PM_{2.5}$ concentrations respectively. This displacement also impacts concentrations around the maneuvering trajectories. The modifications expected will mainly spread over the port area and will have an impact for people working in the terminal involved.

For the NO_2 concentration, the main decreases are also located inside the old cruise terminal and spread over the north districts with some decreases between 0 and 5-6%. At the opposite, an increase is excepted over the southern part of the port due to additional emissions from the new terminal. Locally, the NO_2 concentration increases by more than 50%. Also, a small part of additional emissions is dispersed towards the city center over an inhabited area. This increase in surrounding districts does not exceed 5% of the NO_2 concentration in comparison with the "Base future" scenario.

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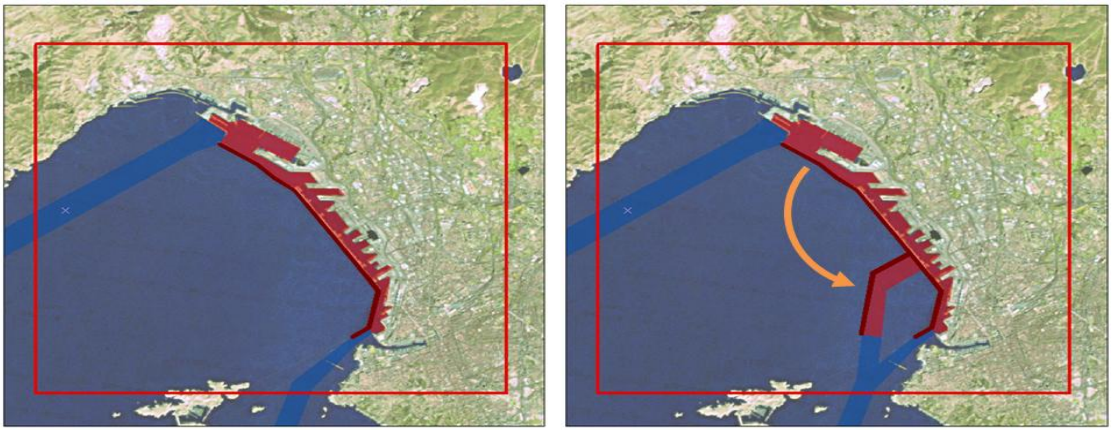

Figure 11: Location of maritime emissions (red: hotelling phase - blue: maneuvering phase) for the different scenarios (left: "Base future"; right: "New cruise terminal"). The arrow represents the displacement of activities for the "New cruise terminal" scenario.

Figure 12 : Relative difference between the "Base future" and the "New cruise terminal" scenario for the PM_{10} (left) and $PM_{2.5}$ (right) concentrations during the winter period over the urban domain for Marseille.

LNG passenger

The "LNG passenger" scenario considers a modification of the fuel type for the passenger ships which will use liquefied natural gas. As discussed in the previous part, this action displays the highest gain in terms of emissions (Table II). Emissions mainly decrease in the eastern part of the Marseille port as this scenario only concerns passenger ships. From simulation results, a significant improvement is computed inside the harbor area (Figure 13). The highest decreases of concentrations are located inside passenger terminals, with a maximal reduction by -6% and -8% of PM_{10} and $PM_{2.5}$ concentrations respectively. This mitigation action will improve the air quality for the whole people working in the harbor area. As this model does not compute chemical transformation, an additional improvement would be expected over a part of the city and for surrounding inhabitants.

An additional maximal reduction of 11µg/m^3 of the NO_2 concentrations is expected inside passenger terminals. This action displays a significant impact at the domain scale as large parts of the city show an improvement higher than 5% compared with the "Base future" scenario. This scenario leads to a decrease close to the historical city center, in the south-eastern part of the domain, and allows an improvement of the air quality over large inhabited areas. Close to the large roads, the relative contribution of this action is insignificant as concentrations surroundings are mainly determined by road traffic emissions.

In terms of concentration at the global scale, this scenario displays the highest interest.

Figure 13 : Relative difference between the "Base future" and the "LNG passenger" scenario for the PM10 (left) and PM2.5 (right) concentrations during the winter period over the urban domain for Marseille.

Synthesis

During the APICE project, two sites have been selected to run long monitoring campaigns in Marseille. These campaigns have evaluated the contribution of maritime emissions to the urban pollution and the results have been compared with source apportionment from output simulation (Table III). The first selected site is an urban background site named "5 Avenues" and located at 3 km of the port area downtown in Marseille whereas the second site is located inside the port area, close to a passenger terminal (Figure 14). To compare with the other partner areas, Table IV summarizes the evaluation of each scenario in terms of concentrations at both receptor sites.

For the scenarios simulated with CHIMERE, the evolutions for NO_2, PM_{10} and $PM_{2.5}$ concentrations at both receptor sites are similar as the spatial resolution of this model is higher than the distance between the receptor sites. On the other hand, scenarios computed with ADMS Urban display a significant difference between the receptor sites, as the mitigation actions have a direct influence on the emissions close to the port site.

At the port site, the most effective action in terms of PM_{10} and $PM_{2.5}$ concentrations reduction is the use of LNG as fuel for passenger ships (**Erreur ! Source du renvoi introuvable.**). Inside the port, this mitigation action leads to decrease PM_{10} and PM_{10} concentration by 4% and 6% respectively. This action also produces significant results for NO_2 concentration with a reduction of 27%.

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For the urban background site, the most effective action to reduce the PM_{10} and $PM_{2.5}$ concentrations is the reduction of the sulfur content in ship fuels with an additional reduction by 20% of $PM_{2.5}$ emissions from ships. Reductions expected with this action are 2% and 3% for PM_{10} and $PM_{2.5}$ respectively. As this receptor site is representative of the urban background, these results would be extended to the surroundings areas. In terms of NO_2 concentration, the most effective action is the modification of fuel type for the passenger ships which will use LNG as at the port site.

Table IV: Relative difference between the "Base future" scenario and the mitigation actions scenarios extracted at the receptor sites of "5 Avenues" (Urban background) and port site for NO_2, PM_{10} and $PM_{2.5}$ concentrations during the winter period.

Model	Scenario	Urban background			Port site		
		NO_2	PM_{10}	$PM_{2.5}$	NO_2	PM_{10}	$PM_{2.5}$
CHIMERE output	Base future (2025)*	4.64%	2.12%	2.76%	5.47%	2.43%	3.18%
	Low sulfur (0.5%)	0.28%	-1.47%	-1.85%	0.28%	-1.59%	-1.99%
	Low sulfur (0.5%) + PM (-20%)	0.29%	**-2.37%**	**-3.08%**	0.29%	-2.64%	-3.43%
ADMS output (+ PM CHIMERE background)	OPS solution	-0.61%	-0.03%	-0.04%	-1.64%	-0.11%	-0.15%
	New cruise terminal	0.14%	0.04%	0.06%	4.01%	0.54%	0.77%
	LNG passenger	**-4.78%**	-0.72%	-1.04%	**-27.25%**	**-4.21%**	**-6.00%**

** Difference with the "Reference 2007" scenario*

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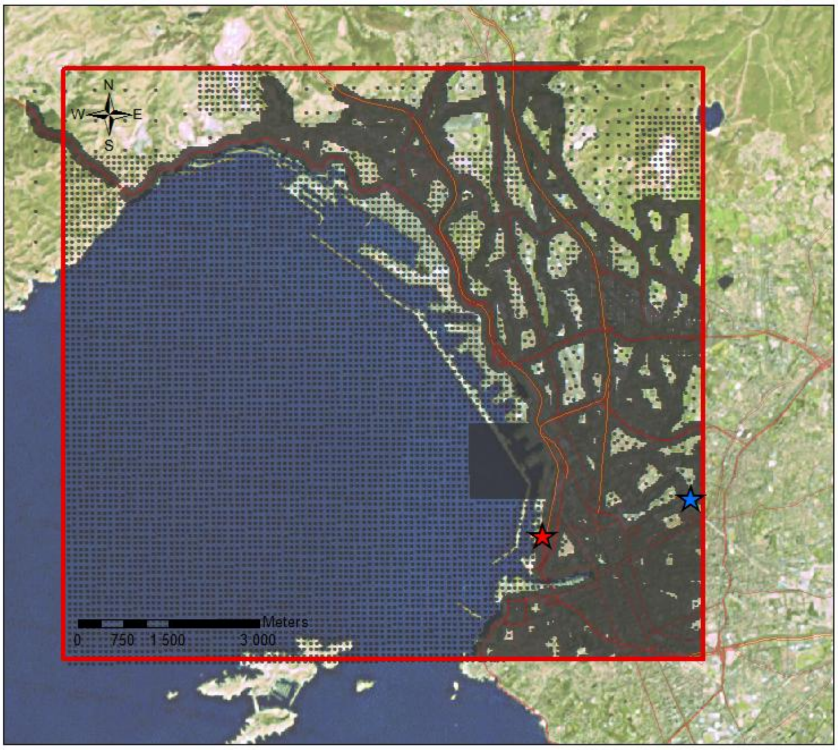

Figure 14 : Location of the urban background site of « 5 Avenues » (blue star) and of the port site (red star).

Conclusion

This study evaluated the application of mitigation actions relevant to maritime activity to reduce PM_{10}, $PM_{2.5}$ and NO_2 concentrations in Marseille. As these actions reduced emissions at large and local scales, two models have been applied: CHIMERE and ADMS Urban. In terms of $PM_{2.5}$ concentration at a large scale, the reduction of the sulfur content in ship fuels with an additional reduction by 20% of $PM_{2.5}$ emissions from ships lead to the most effective reduction. At the local scale, the use of LNG as fuel for passenger ships has shown a significant decrease for $PM_{2.5}$ concentrations. Also, the scenario relevant to a new terminal has shown that a displacement of a maritime activity without any emission reduction allowed a local improvement of air quality.

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