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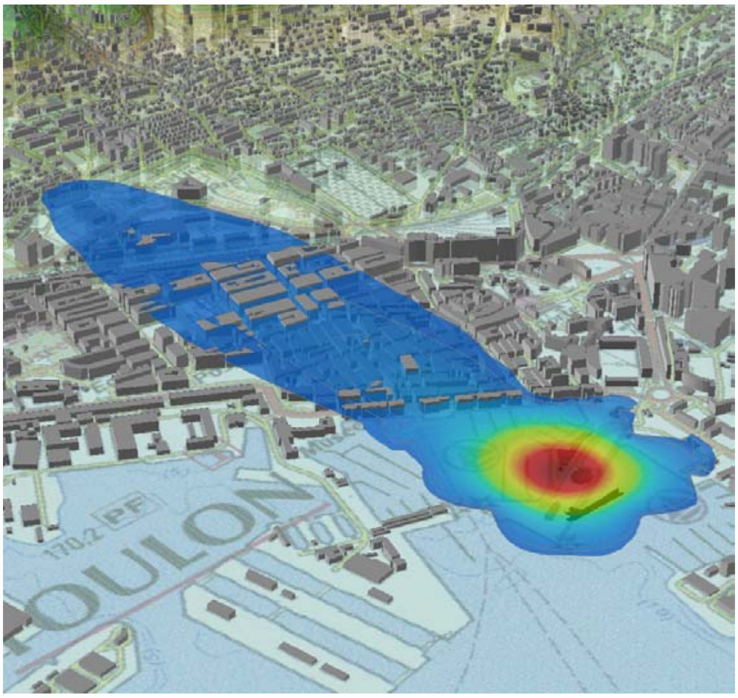

SIMPYC PROJECT

PHASE 2

ANALYSIS OF THE TERRITORY: METEOROLOGY, EMISSIONS, MODELING

CCIV Chambre de Commerce et d'Industrie du Var
SIMPYC
TOULON PROVENCE MÉDITERRANÉE

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1. PRESENTATION

1.1. PRESENTATION OF ATMO PACA

Atmo PACA is a French Approved Association of Air Quality Monitoring (AASQA). It covers the east of Bouches-du-Rhône, Var, Alpes-Maritimes, Vaucluse, Alpes-de-Haute-Provence and Hautes-Alpes departments. Atmo PACA is born from the fusion of Airmaraix and Qualitair (20th October 2006).

The monitoring of air quality on the Var department has been ensured for 1996, by Airmaraix then by Atmo PACA.

1.2. OBJECTIVES

This study is carried out at the request of Toulon Provence Mediterranée, within the framework of the SIMPYC LIFE ENVIRONMENT program.

The study concerns the commercial ports of the Toulon urban area and the urban zones which surround them, excluding the naval port. The considered areas are mainly the sector of the Toulon harbor, on the "Darse Vieille", the dock of Mourillon and the area in the vicinity of the commercial port of Brégaillon.

This work is integrated in a broader study of the port and city air quality, within the framework of the project SIMPYC, which contains three phases in order to suggest an operational air quality monitoring of the port:

- An analysis of the studied area (weather, relief, pollutant emissions, exposed population, significant establishments…),
- An air quality monitoring campaign on the area,
- The cartography and analysis of the results of this study,

1.3. SYNERGIES

A study complementary to the AirProche program was held at the same time as SIMPYC study on the downtown area of Toulon. This study was made in collaboration with the French Agency of Medical Safety of the Environment and Work (AFSSET), aiming at establishing a cartography high resolution of automobile pollution (AFSSET, 2007). The results of this complementary study have been used to consolidate the results of the SIMPYC study.

1.4. RESOURCES FOR THE STUDY

Measurement tools deployed during the program are supplemented by the numerical tools for processing data, making it possible to chart and model pollution.

1.4.1. CALCULATION OF EMISSIONS: METHOD

Methodology used to estimate the emissions of atmospheric pollutants by ships can be found in the document "Methodologies For Estimating Air Pollutant Emissions From Ships - Techne report MEET RF98, August 1998"). It is the methodology used within the framework of the ESCOMPTE program and in the PACA inventory réf.1999 maintained by Atmo PACA. A more recent European methodology was evaluated within the framework of this work, based on the document "Final Report From Entec U.K. Ltd for the European Commission - Quantification Of Emissions From Ships Associated With Ship Movements Between Ports In The European Community" (http://ec.europa.eu/environment/air/background.htm#transport) but results being close for the principal compounds studied here (NO_X, SO_2), it was not used in this first approach.

1.4.2. Calculation of pollutants dispersion: method

The system of management of air quality **ADMS-Urban** was selected to answer the aims of the study, it is based on the model of atmospheric dispersion ADMS (Atmospheric Dispersion Modeling System), used, recognized and validated internationally.

It makes it possible to take into account the simultaneous dispersion of many effluents (NO_X, CO, SO_2, VOC, Particles...), emitted by more than 4000 different sources:

- Roads and associated traffics,
- Specific and surface industrial sources,
- Diffuse sources (used in the form of land registers).

Principal data input

- **Meteorology**: Weather data at ground level, preferably measured at a one-hour frequency (Météo France format): speed and direction of the wind, temperature under shelter, nebulosity, precipitations...
- **Emissions parameters**: Localization of the sources and road sections, emission rate (hour-based or annual average daily traffic, daily profiles), roads widths and buildings heights, industrial emissions (position and characteristic of the chimneys) and diffuse (tertiary sector, VOC)...
- **Topography of the area of study**: relief and ground occupation (urban environment, average building height...),

Validation:

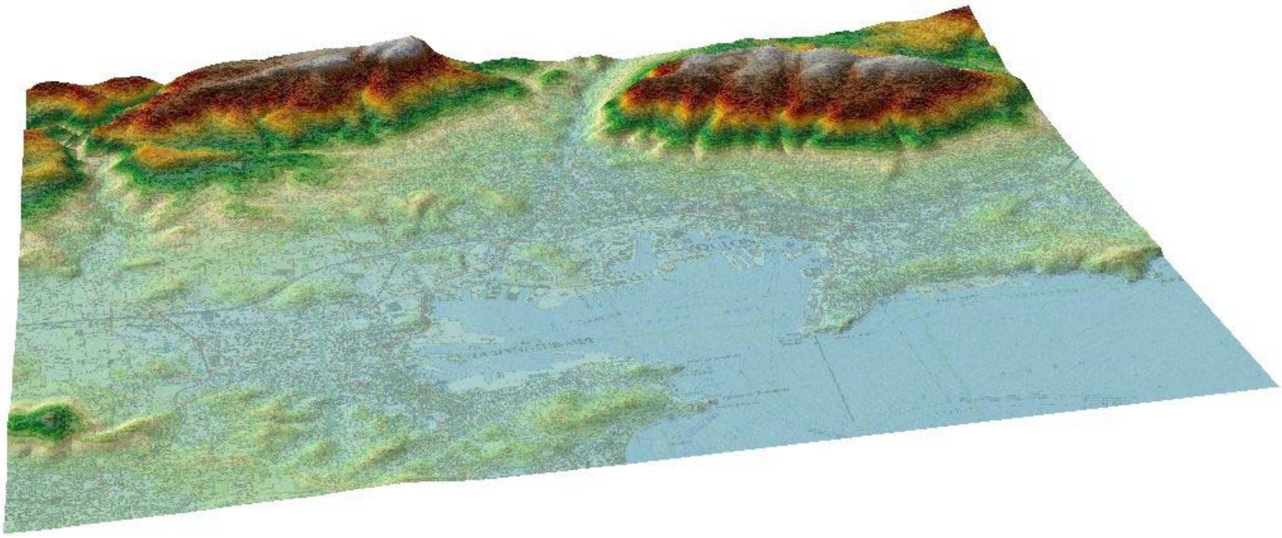
In the particular case of the city of Toulon, this model was used and validated within the framework of the project AirProche (AIRMARAIX and al., 2006). The modeled data were thus compared with the data resulting from measurements, under various environments and weather conditions (HANNA and al. 1999, INERIS 2001, NUMTECH 2006, Rouïl 2004).

2. RESULTS - DISCUSSION

2.1. RELIEF

Figure 1 represents a 3D view of the site topography. The relief of the studied area lies between 0 m and 584 m (Faron Mount).

Figure 1: Topography on the studied field



2.2. CLIMATOLOGIC TENDENCIES

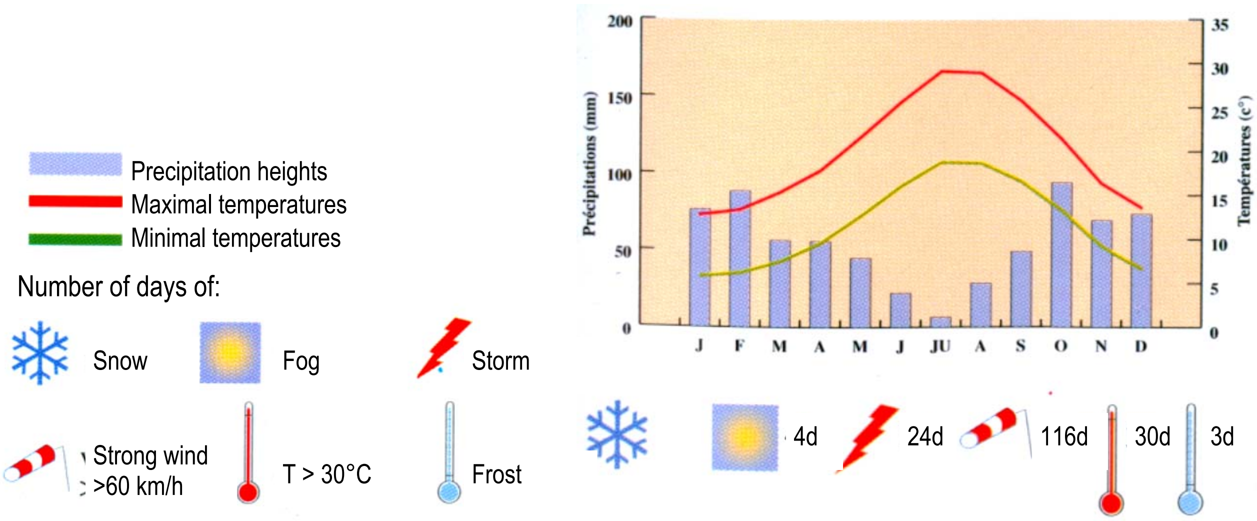
The climatologic tendencies on the city of Toulon result from the meteorological measurements taken by Météo-France from 1961 to 2000.

2.2.1. TEMPERATURES AND PRECIPITATIONS

According to the Météo-France data on the Toulon La Mitre station from 1961 to 1990, the seasonal cycle of precipitations is inversely proportional to that of the temperatures. In average over 31 years; the rainiest month is October; the hottest month is July; 116 days of winds of winds higher than 60 km/h are recorded each year. The temperature can be higher or equal to 30°C 30 days per annum. A few fog (4 days/year) and cold (3 days/year) are observed. It does not snow (Météo-France, 2007).

Figure 2: General meteorological data on the Toulon La Mitre station (Météo-France)

Averages calculated over the 30 years reference period: 1961-1990.
These are "normals" as defined by the World Meteorological Organization.

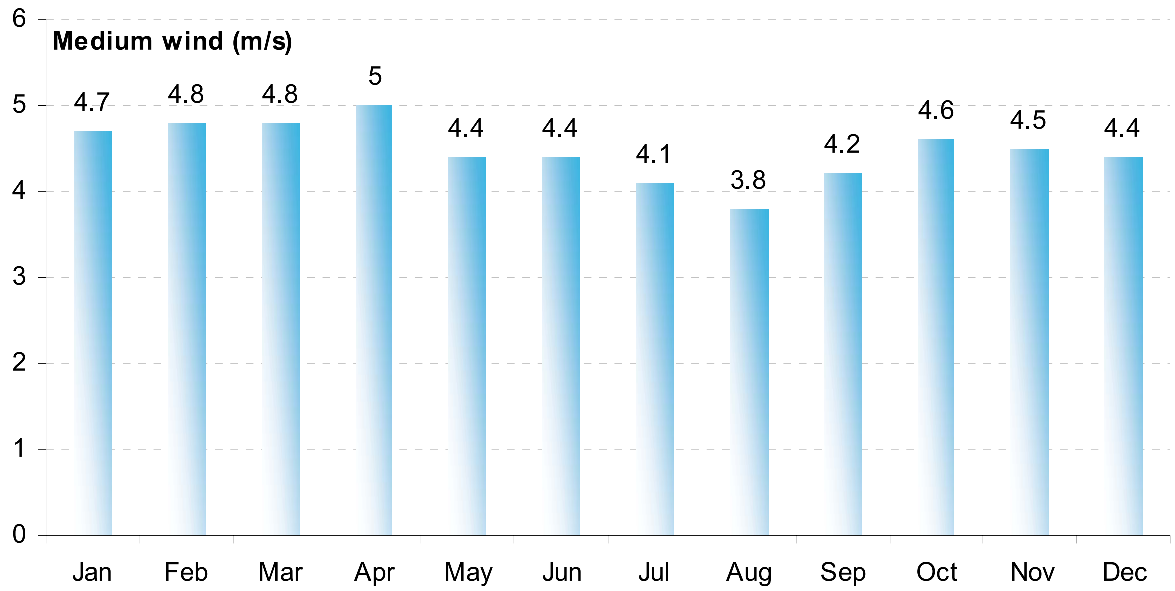


The driest year: 331 mm in 1967 (since 1946)
The rainiest year: 1086 mm in 1972
Maximum in 24 hours: 156 mm on January 16, 1978

2.2.2. Winds

According to the climatologic data of Météo-France and the data compilation from 1971 to 2000, the average wind speed over one year in Toulon La Mitre is 4.5 m/s. The figure below presents the seasonal cycle of the average wind at 10 m high. April is the windiest month with an average of 5.0 m/s; August is the less windy with 3.8 m/s. This result reinforces the very atypical character of the measurement campaign carried out for the SIMPYC program compared to the seasonal normals (AIRMARAIX 2007; SIMPYC I). August 2006, being very windy, has recorded strong winds higher than 8 m/s more than 20% of time (Mistral), carrying the average wind speed to 5.7 m/s against 3.8 m/s for the seasonal normal.

Figure 3: Seasonal wind speed cycle at Toulon La Mitre (MF) (1971-2000)



2.3. METEOROLOGY

2.3.1. PARAMETERS

The principal meteorological parameters in the context of an air pollution study are:

- Wind speed at 10m,
- Wind direction at 10m,
- Outside temperature at 2m,
- Rain height,
- Atmospheric stability.

These parameters are variable in time and space. They result from the superposition of the atmospheric phenomena on a large scale (cyclonic or anticyclonic circulation) and of local phenomena (influence of ground roughness, ground occupation and topography).

2.3.2. CHOICE OF THE REFERENCE STATION

Various criteria are taken into account in the choice of the most representative meteorological station of the studied area:

- Its geographical position: the station selected must be the nearest possible to emissions sites and it should exist no major obstacle between the station and the studied area,
- The frequency of acquisition of the meteorological data: in this case, it is important to have data on a 1-hour scale to have a good temporal representativeness of local meteorology,
- Relevance of the meteorological data.

In this context, the Météo-France meteorological station of Toulon La Mitre was retained.

2.3.3. METEOROLOGICAL ANALYSIS

Within the framework of similar studies, a period of 5 years is classically chosen. It is also the duration recommended by the US-EPA. In this case the period from 01/01/2002 to 31/12/2006 was selected.

DEFINITIONS

Calm wind:

The calm winds correspond to a wind speed null or lower than 0.9 m/s, without associated direction.

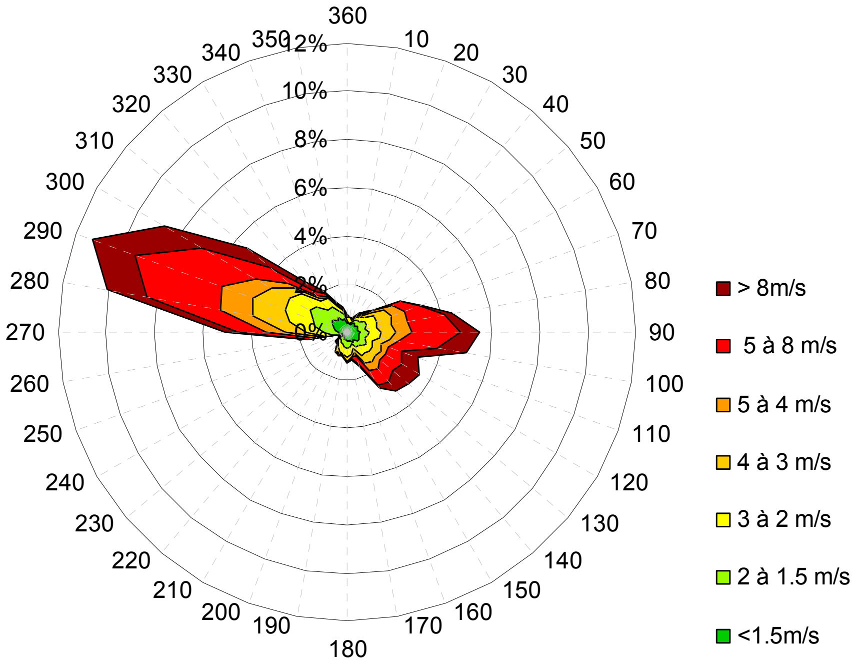
Weak wind:

The weak winds correspond to a wind speed lower than 2 m/s.

COMPASS CARD:

The figure below presents the compass card for the Toulon-La-Mitre station

Figure 4: General meteorological data on the Toulon La Mitre station (MF 2002-2006)



Major results:

The Météo France data used in this study correspond to five complete years: from 2002 to 2006. These data were measured at a 1-hour frequency for temperatures, wind speeds and wind directions.

The wind direction and speed, parameters conditioning the rejects dispersion, are represented on the figure above. The compass card was calculated from 1-hour data over the last five years. It shows that dominant winds are very mainly directed west/east, with relatively high wind speeds for west wind (Mistral).

ATMOSPHERIC STABILITY

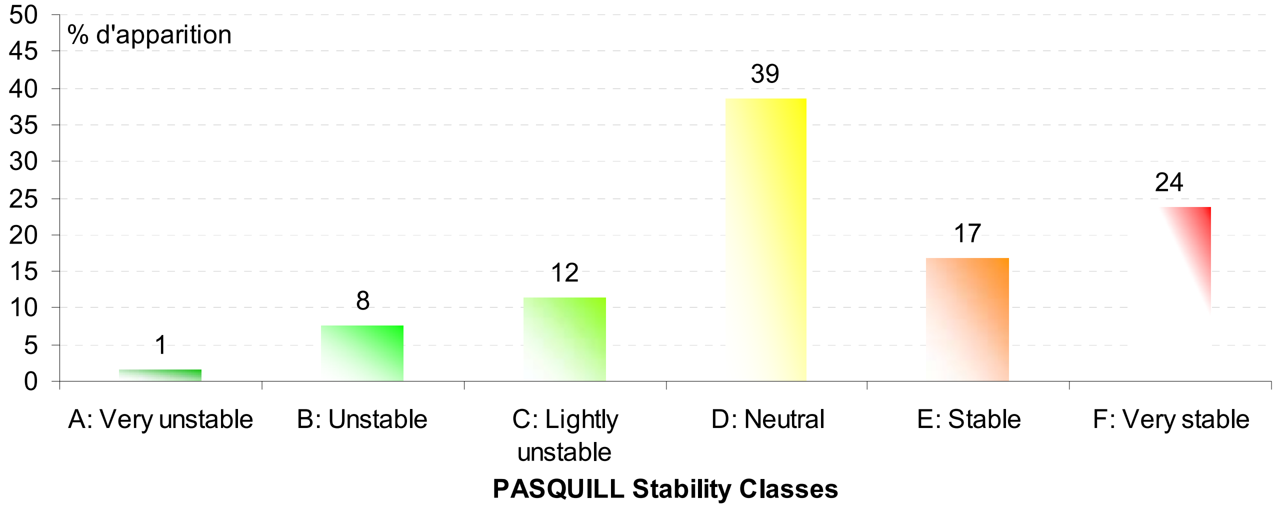
Atmospheric stability is intended to quantify the diffuse properties of the air in the low layers. It is often associated with the atmospheric thermal structure: for example, the situations of thermal inversion occur when the atmosphere is stable.

It is given by the wind speed and nebulosity, according to the method known as “Nebulosity - wind” (cf. APPENDIX 2). This method results in distinguishing six categories of atmospheric stability:

- Classify a: very strongly unstable
- Classify b: very unstable
- Classify C: unstable
- Classify D: neutral
- Classify E: stable
- Classify F: very stable

The following diagram presents the distribution of the observations according to atmospheric stability.

Figure 5: Distribution of the meteorological observations of the Toulon La Mitre station (MF) according to atmospheric stability.



The Pasquill D class is most frequently observed (39%) on the site. The dispersive conditions are overall favorable since 60% of the observations present an unstable or neutral atmosphere. However it is interesting to note that a very stable atmosphere is observed in 24 % of the cases.

2.4. EMISSIONS

2.4.1. METHODOLOGY

Methodology used to estimate the atmospheric pollutants emissions by the ships is found in the document "Methodologies for estimating air pollutant emissions from ships" Trozzi and Vaccaro (1998).

Emissions for the Greater Toulon being available for the year 2001 (Atmo PACA, AIRES platform (http://www.aires-mediterranee.org); AIRPROCHE program (AIRMARAIX et al., 2006), the sea traffic in 2001 was first considered. The 2001 to 2006 evolution was then considered for the evaluation of the current situation.

2.4.2. SEA ACTIVITIES DATA

The data of sea traffic from 1999 to 2006 were provided by the Var CCI (Chamber of Commerce and Industry). Navigation characteristics (ships type, drawing alongside time…) were provided by the harbor office and the major navigation companies Medlines and Corsica Ferries.

Table 1: Sea traffic on the Toulon harbor from 2001 to 2006

Year	TCA					Brégaillon					TOTAL
	Ferries Corsica + Sardinia	Ferries Tunisia	Ferries Algeria	Steamers	Total	Ferries Italy	Conventional freight	Various freight	Cable-laying ships	Total	
2001	384	1	0	30	**415**	0	206	0	0	**206**	**621**
2002	401	10	0	63	**474**	0	197	0	0	**197**	**671**
2003	467	7	0	54	**528**	0	44	4	158	**206**	**734**
2004	561	8	0	40	**609**	0	26	41	205	**272**	**881**
2005	622	16	17	74	**729**	151	19	4	198	**372**	**1101**
2006	603	8	8	57	**676**	154	25	0	128	**307**	**983**

Figure 6: Toulon harbor - Number of stopovers per annum from 2001 to 2006

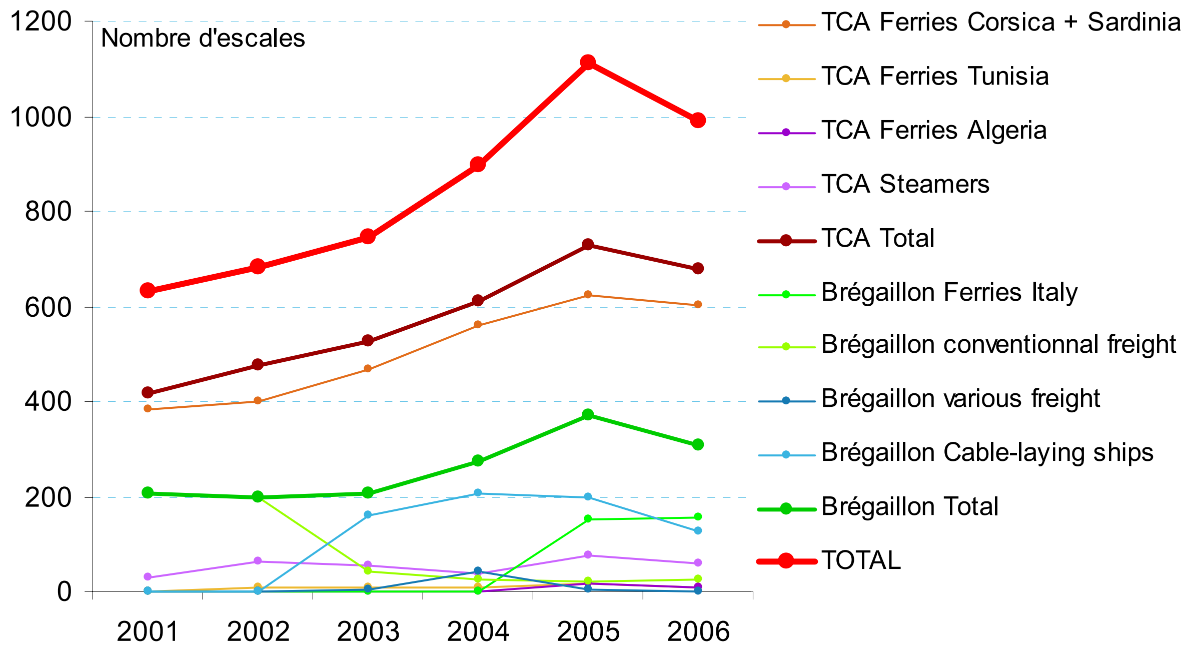


Table 2: Characteristics of the sea traffic for the two major ship-owners of the Toulon harbor

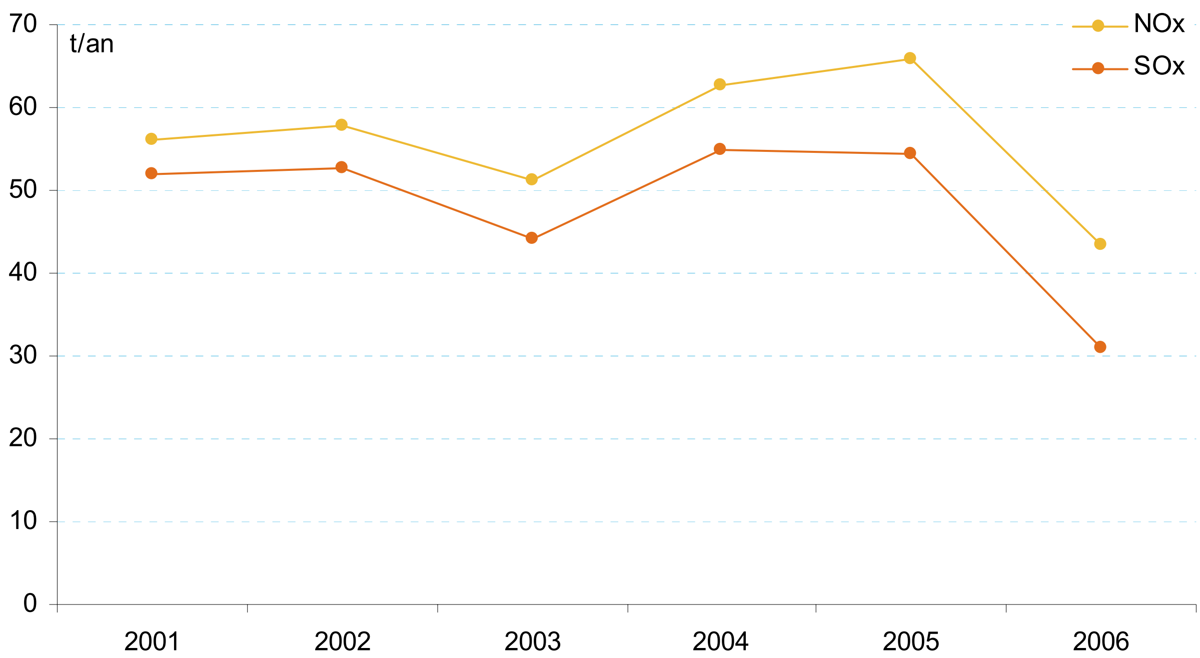
Ship-owner	Type	Capacity	Ship	Fuel	Quay	Maneuvers
Corsica Ferries	ferry: MEGA EXPRESS and MEGA EXPRESS II	1500 passengers	steamers	IFO 380 1,5% S	1h30 on average = 7h-8h15 and 20h45-22h30	30 mn: 20 mn arrival; 10mn departure
Medlines	mixed carriers	Cap. 830 passengers + trucks/trailers (2250 m in line or approximately 130 trucks of 16,5 m for example), new cars (cap.160 cars)	26 gross register tons length 186,4m width 25,6m max speed 23 knots	IFO 380	8h30 in week = 12h30-21h Tuesday and Thursday 5h30 Saturdays = 12h30-18h	45 mn

2.4.3. Emissions

Table 3: Atmospheric emissions of pollutants by sea transport (tones/an)

Year	NO_X	CO	CO_2	COV	PM	SO_X
2001	56	150	5 546	34	2	52
2002	58	151	5 632	34	2	53
2003	51	125	4 701	28	2	44
2004	63	157	5 842	35	2	55
2005	66	150	5 798	33	2	54
2006	43	84	3 317	19	2	31

Figure 7: Atmospheric emissions of pollutants of 2001 to 2006

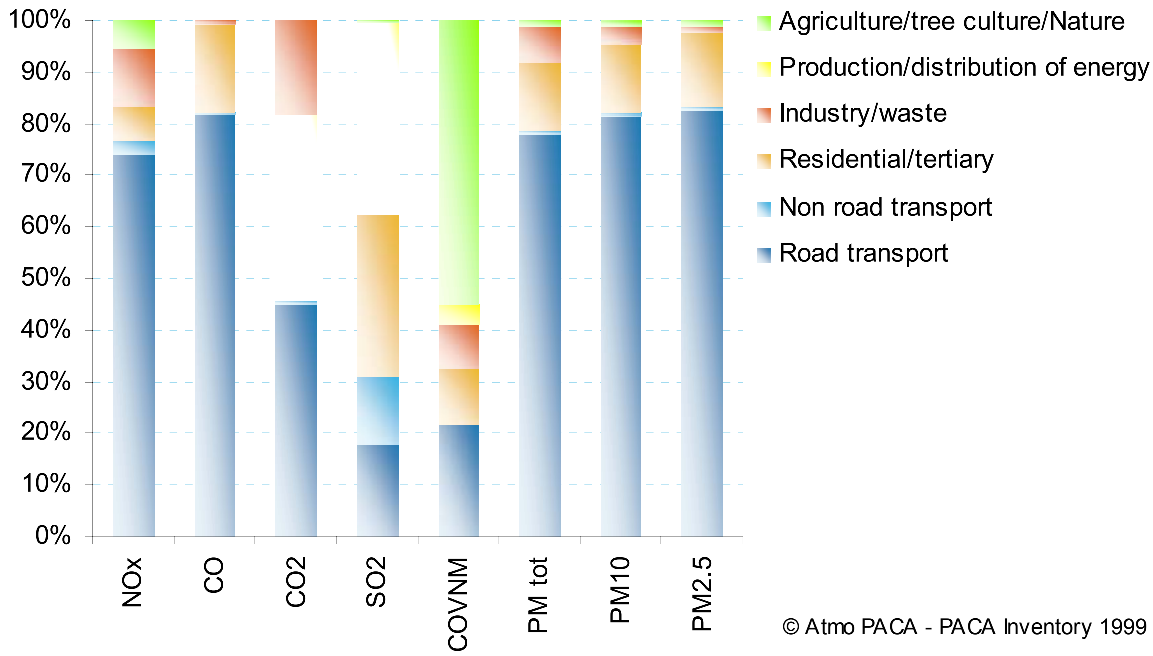


2.4.4. Comparative data

Table 4: Atmospheric pollutants emissions in the agglomeration of Toulon in 1999 (SCOT perimeter, t/an)

Emissions SCOT 1999 (t/an)	NO_x	CO	CO_2	SO_2	COVNM	PM_{total}	PM_{10}	$PM_{2.5}$
Road transport	4 464	13 758	698 734	144	2 150	305	305	274
Non road transport	159	53	13 042	105	11	3	3	3
Residential/tertiary	412	2 882	566 817	251	1 039	53	49	47
Industry/waste	680	89	279 833	296	865	27	13	5
Production/distribution of energy	0	0	0	0	391	0	0	0
Agriculture/tree culture/Nature	321	14	2 205	3	5 423	4	4	4
TOTAL	**6 036**	**16 796**	**1 560 631**	**798**	**9 879**	**392**	**374**	**332**

Figure 8: Distribution of the atmospheric pollutants emissions in the agglomeration of Toulon in 1999 (SCOT perimeter, t/an)



Annual emissions related to the sea traffic are significant on the agglomeration mainly for the sulfur dioxide (13% of the emissions of this pollutant on the agglomeration scale). However, it should be noted that these emissions are concentrated on a reduced zone of the urban space. Locally, the pollutant emissions related to the sea traffic represent a part much more significant of total emissions, particularly for nitrous oxides, sulfur dioxide and the particulate matter.

Evolution of the situation from 2001 to 2006 presents a reduction in the emissions whereas the number of stopovers increased (nearly 1000 stopovers in 2006). The passenger traffic increased more strongly than the freight traffic. Average time at pear for the traveler’s ships (ferries) is much shorter (1.5h) that time at pear for the freight ships (approximately 8.5h). In addition the ships transporting freight (carriers) emit more pollutants than the ferries (Mega Express).

2.5. MODELING THE IMPACT OF THE SEA TRAFFIC

2.5.1. INPUT DATA

This chapter presents the hypothesis of the atmospheric dispersion study, by modeling, of the atmospheric emissions of the agglomeration of Toulon. The emissions of the agglomeration are provided, at the origin, by the Escompte land register (ESCOMPTE, 2001). They were integrated in the air quality modeling system ADMS-Urban in order to estimate the NO_2 and Benzene concentrations in the air of the city (AIRMARAIX et al. 2006).

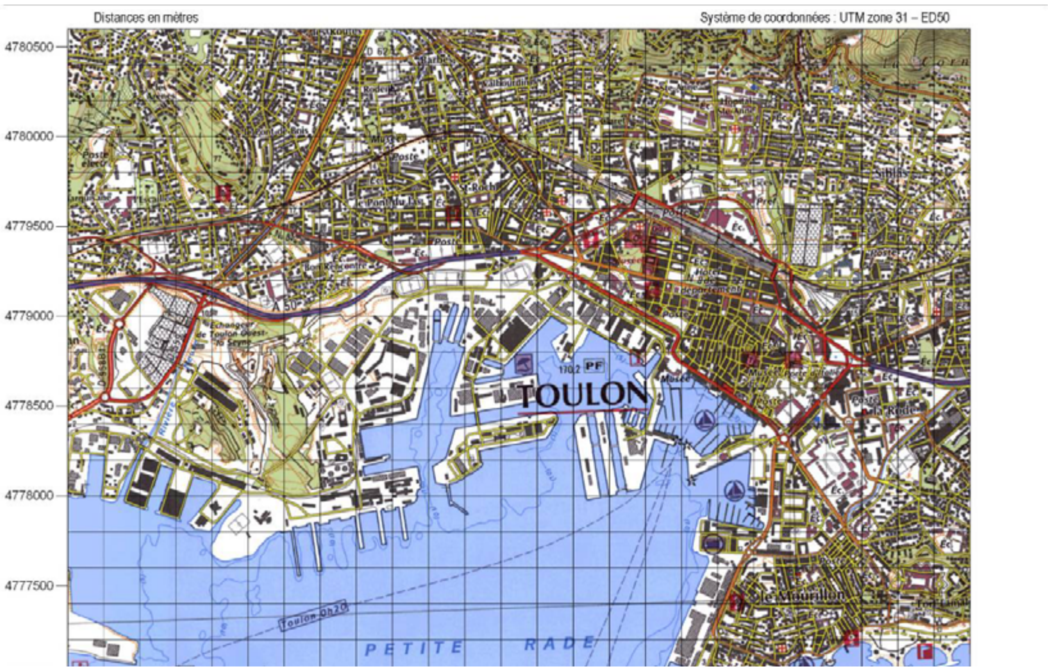
The principal sources taken into account are:

- Road traffic (principal and secondary network),
- Specific and surface industrial sources,
- Diffuse sources: emissions related to the residential and tertiary sector activities, to the biogenic sources and to the agriculture.

DEFINITION OF THE STUDIED AREA AND OF THE CALCULATION GRID

Calculations of the concentrations were carried out on a 3 x 5 km area covering the city of Toulon, and on a hundred specific points corresponding to the measuring sites.

Figure 9: Calculation grid



TOPOGRAPHY AND NATURE OF THE GROUNDS

The relief of the studied area is likely to influence the wind fields and turbulence, and thus the surface distribution of the pollutants concentrations. Topography was thus integrated in the model. The topographic field used comes from the French National Geographic Institute (IGN) data (MNT 50m). Grounds nature was represented by a constant roughness parameter on the whole area. This parameter, usually used in the atmospheric dispersion models, represents the rough nature of the obstacles occupying the ground. On the studied area, applied roughness values are 10^{-3} on the sea and 0.7 in dense urban zone.

BACKGROUND POLLUTION

Ozone background pollution measured at Atmo PACA stations was integrated in simulations. Indeed, NO_2 levels depend with photochemical reactions. The ADMS-Urban model integrates a photochemistry code (Venkatram, 1994) including the NO_2, NO, O_3 and COV chemistry (diagram with 7 reactions). It uses in particular the solar radiations data to calculate photolysis rates. This module in particular makes it possible to calculate NO_2 and O_3 concentrations starting from NO_X emissions and from a background level.

In the case of this study, ozone hourly concentrations measured in 2006 at CIOTAT station in case of west winds and at PLAN D'AUPS station for other wind directions were taken into account. As all the NO_2 and NO_X emitting sources on the agglomeration of Toulon are integrated in the land emissions register, background NO_2 and NO_X pollution was regarded as null.

SUMMARY OF THE PHENOMENA TAKEN INTO ACCOUNT IN MODELING

For this study, the physical phenomena taken into account are listed in the following table:

Table 5: Summary table of the phenomena taken into account in modeling

Physical phenomenon	Taken into account	Comments
Local meteorology	yes	Pasquill Classes in Toulon La Mitre or hourly data
Vertical description of atmospheric turbulence	yes	Analyze scale of Monin-Obukhov
Diurnal cycle of the development of the atmospheric boundary layer	yes	The hourly meteorological data are not treated independently, but by always considering the 24 previous hours
Specific treatment of the convectives weather conditions (folding back of the plumes close to the ground)	yes	"Oblique" Gaussian trajectories in convective situation
Heightening of the plumes to the emission	yes	Integral 3D trajectory model for channeled sources
Nature of the grounds	yes	Roughness height adapted to the studied area
Chemical evolution of the gas rejections in the environment	yes	Activation of the photochemical model of Venkatram (1994)
Temporal variability of the emissions	yes	Use of temporal profiles for various types of sources
Effect of topography (relief) on the dispersion of the plumes	yes	The dispersion model was coupled with FLOWSTAR fluids flowing model. This model recomputes the wind fields and turbulence in 3D on all the area

2.5.2. EMISSION SOURCES TREATMENT: AGGREATIONS DETAILS

The anthropic and biogenic emissions taken into account in modeling come from PACA regional inventory (AIRMARAIX, 2003). This emissions inventory (or registers) enables us to know the studied pollutants emissions distribution by branches of industry on the area of Toulon. This inventory is developed according to SNAP European methodology (Selected Nomenclature for Air Pollution): the emitting activities are separated in various categories described in SNAP nomenclature. This nomenclature is detailed in 3 levels, from the more general to the most precise.

The emissions register on the area of Toulon is provided in two forms:

- Sum of all the sources of emissions (except for the great point sources),
- Detail of the sources in 3 distinct data bases: surface emissions (SRF), emissions of the Great Point sources (GSP) and linear emissions.

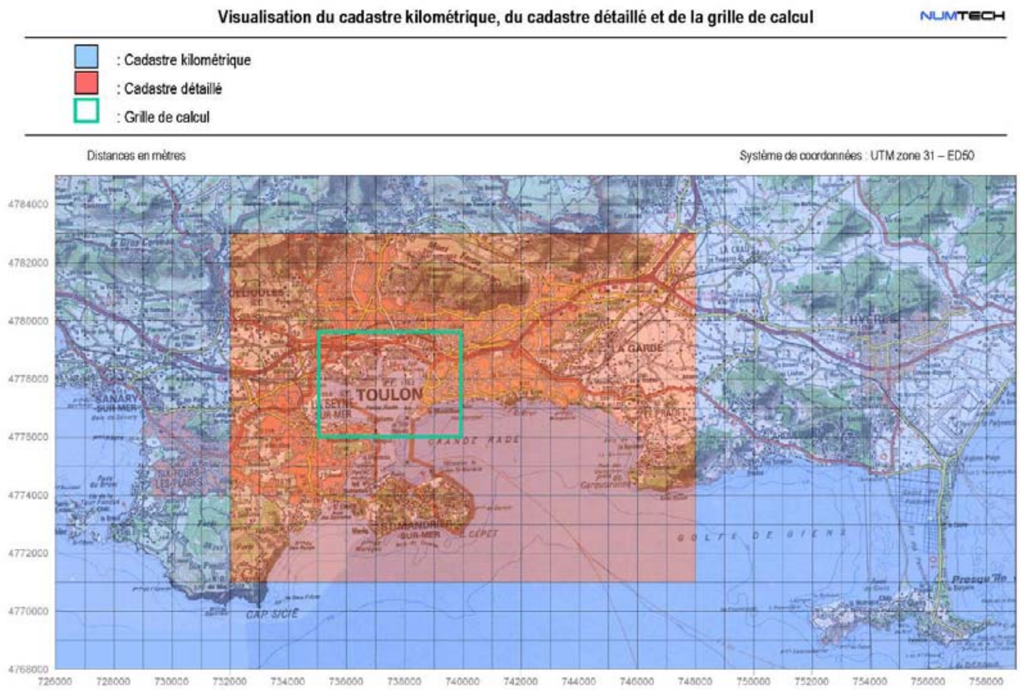
All this information was used in calculations:

- The land register was used to take into account in an exhaustive way all the emissions of the agglomeration of Toulon (17 x 33 km kilometric register).

- The sources were integrated in a detailed way on a 12 x 16 km field of in order to limit the edge effects to the limits of the calculation grid.

The various fields used in this study are localized on the figure below.

Figure 10: Visualization of the kilometric land register, the detailed land register and the calculation grid (AIRMARAIX and al., 2006)



The number of sources to be modeled being relatively important, the emissions of the sources having the same localization and especially having the same temporal profiles, were summed. Each profile is characterized by a monthly profile, a weekly profile and a daily profile.

KILOMETRIC EMISSIONS INVENTORY

Initially, all the emissions met on our studied area were modeled in ADMS-Urban in the form of a 1 km resolution inventory. Thus, each mesh of this inventory contains the totality of the emissions (road, industrial, natural, tertiary…). This inventory makes it possible to integrate into simulations all the sources which would not be modeled. Indeed, the emissions of the modeled sources are withdrawn from the emission land register. This is particularly useful for the zones located outside the detailed land register. Therefore, in order to take into account pollution coming from the outside of the studied area, the land register was carried out on a field larger than the area: 17 X 33 km (cf. Figure 10). It includes for example the emissions of the towns La Seyne-sur-Mer, Sanary-sur-Mer and Hyères.

Each mesh of the land register was modeled like a volume source of 10 m height. The emissions are regarded as uniformly distributed inside these volumes.

USE OF THE DETAILED INVENTORY

The emissions coming from the PACA land register (reference year 1999) are in the form of three distinct data bases: fixed surface emissions (SRF), emissions of the great point sources (GSP) and emissions linear.

The surface sources provided on a grid of 1km of resolution, correspond to the emissions of the residential and tertiary sectors, industrial surface, with the emissions of the biogenic sources and the secondary road traffics.

The sources of the GSP type contain the principal channeled or diffuse industrial sources. The ships moored on the Toulon Côte d'Azur harbor and the Brégaillon harbor were regarded as motionless GSP.

The linear sources characterize the principal road network (broken up on an urban network and a suburban network).

For each data base (surface, linear and GSP), the sources are gathered in several categories corresponding to the SNAP categories of activity. Each one of these categories is associated a SNAP code of nomenclature. For each SNAP code is associated an emission temporal profile (broken up into a monthly profile, a weekly profile and a daily profile). To limit the number of sources modeled in ADMS, the emissions of certain sources, characterized by the same temporal profile, were aggregated.

The data bases contain the emissions of 126 compounds. The emissions of nitrogen oxides and benzene were retained.

The data bases are provided on a field of 17 X 33 km (identical to the land register), with a resolution of 1 km for the surface sources. The sources present on a more restricted field of 12 X 16 km were extracted from these data bases in order to take into account explicitly all of the sources present on the studied area as well as the surrounding sources.

The detail of the selected emissions sources and of the aggregation work of the categories of sources is documented in the AirProche report (AIRMARAIX, 2006).

MAPS

The regular resolution is 300 m. In addition to the regular grid, the model makes it possible to add an "intelligent" grid on axes where one wishes to refine information. In this case, 5000 points of calculations were added along the principal axes (figure below).

Figure 11: Regular and "intelligent" grids for bay of Toulon

CHARACTERISTICS OF THE CHIMNEYS OF THE FERRIES

The emissions being calculated by source type, the outlet thus corresponds to an average chimney characteristic of all the ferries taken into account in this study. All the assumptions selected, in first approach, are summarized in the table below.

Table 6: Characteristics of the chimneys of the ferries

	Units	TCA	Brégaillon
Position		Cf. Figure 11	Cf. Figure 11
Height compared to the ground	m	38	38
Diameter of the chimney on the level of the ejection	m	1	1
Temperature of rejections	°C	60	60
Speed	m/s	8	8

It is important to note that we did not have access to all the characteristics of the chimneys of the ferries requested to the companies Medlines and Corsica Ferries. Thus, speeds and rejections temperatures were estimated from other similar studies and in particular one carried out by ARIA Technologies in 2006 on the Calais harbor (ARIA, 2006).

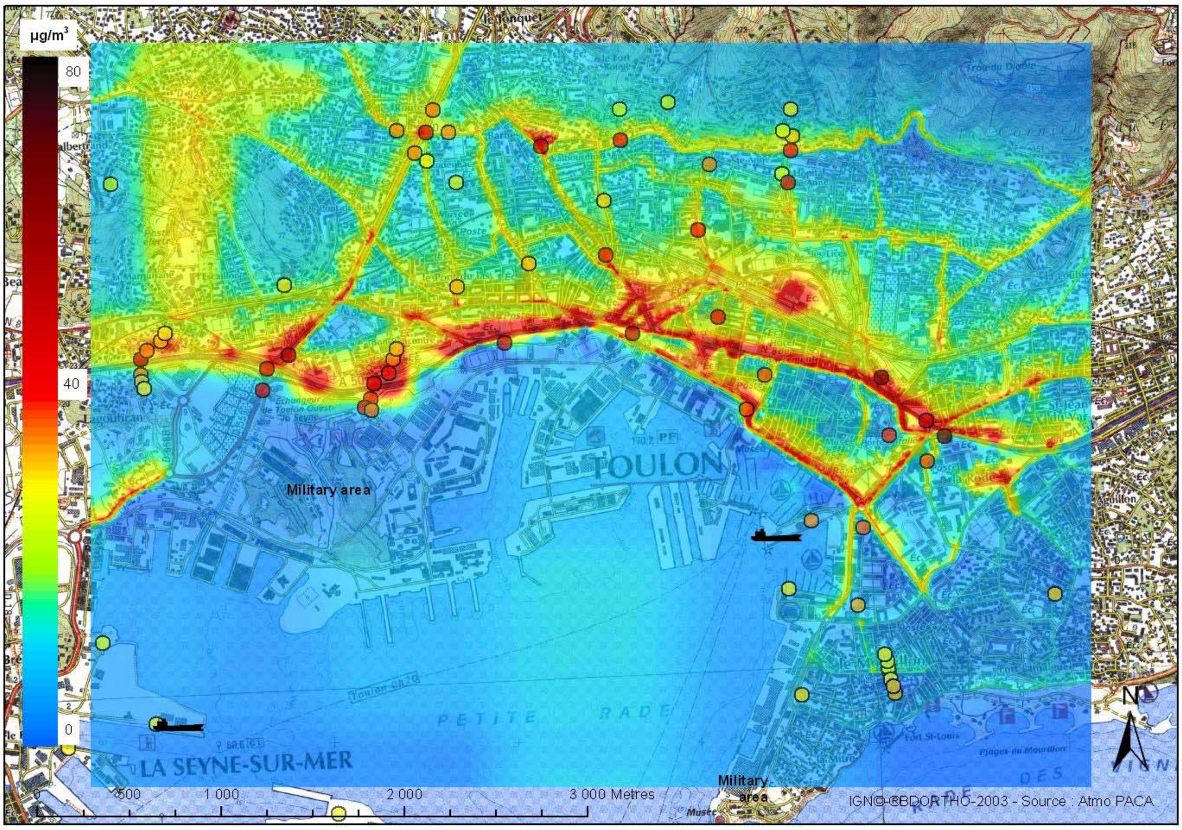
2.5.3. Modeling of a neutral situation: most frequent

The weather statistical analysis reveals that the most frequent situation is a neutral atmospheric stability. It corresponds to the D Pasquill class, which appears in 39% of the cases (cf. Figure 4, page 9). Modeling this situation does not correspond to any realistic situation; it acts of a theoretical case which makes it possible to apprehend, in first approximation, the impact of the pollutant emissions. The selected direction of the wind is of 180°; case where pollution by the ships can be more penalizing for the centre town of Toulon.

Nitrogen dioxide (NO_2)

The figures hereafter present the simulated concentrations of nitrogen dioxide in the case of a neutral atmosphere. The charts present for each pollutant the calculated concentrations (a) with the whole of the sources of emissions, (b) the emissions due to the traffic alone, (c) the emissions due to the ships alone.

Figure 12: NO_2 simulated concentrations (µg/m^3) (surface) – neutral Atmosphere and NO_2 observed concentrations (µg/m^3) (points) – 2005 annual mean (a) traffic + ships



The map above presents a “normal” standard situation for the city and ports of Toulon. Pollution by nitrogen dioxide concentrates mainly around the roads and in the very center of the city. At first sight, the influence of the harbor zones does not appear clearly. In order to distinguish the contribution of the harbor activities from the other pollution sources, simulations were made by modeling the pollution and by withdrawing alternatively one and the other pollution sources (cf. figures below). The contribution of the boats to the average NO_2 pollution level on the city seems very weak taking into consideration the other source (automobile traffic in particular).

The map above presents a first cartographic comparison measures/model. Broadly a good similarity exists between the observed concentrations and the simulated concentrations. An under estimation by the model is however noted in the districts of Mourillon and in edge of the “Petite Rade”. Concerning measurement, it is important to recall that the concentrations “observed” are in fact obtained by reconstitution of the annual means starting from measurement campaigns. Concerning the model, it is also important to recall that the simulated concentrations do not result from a real modeling but from a standard modeling approaching, at first approximation, the 2005 annual mean. In spite of these assumptions the order of magnitude and space gradients of the NO_2 concentrations seem to be respected. However on the Toulon Côte d’Azur harbor and on the Bregaillon harbor, the model seems to under estimate the concentrations measured in NO_2.

Figure 13: NO_2 simulated concentrations (µg/m^3) - neutral Atmosphere (b) traffic alone

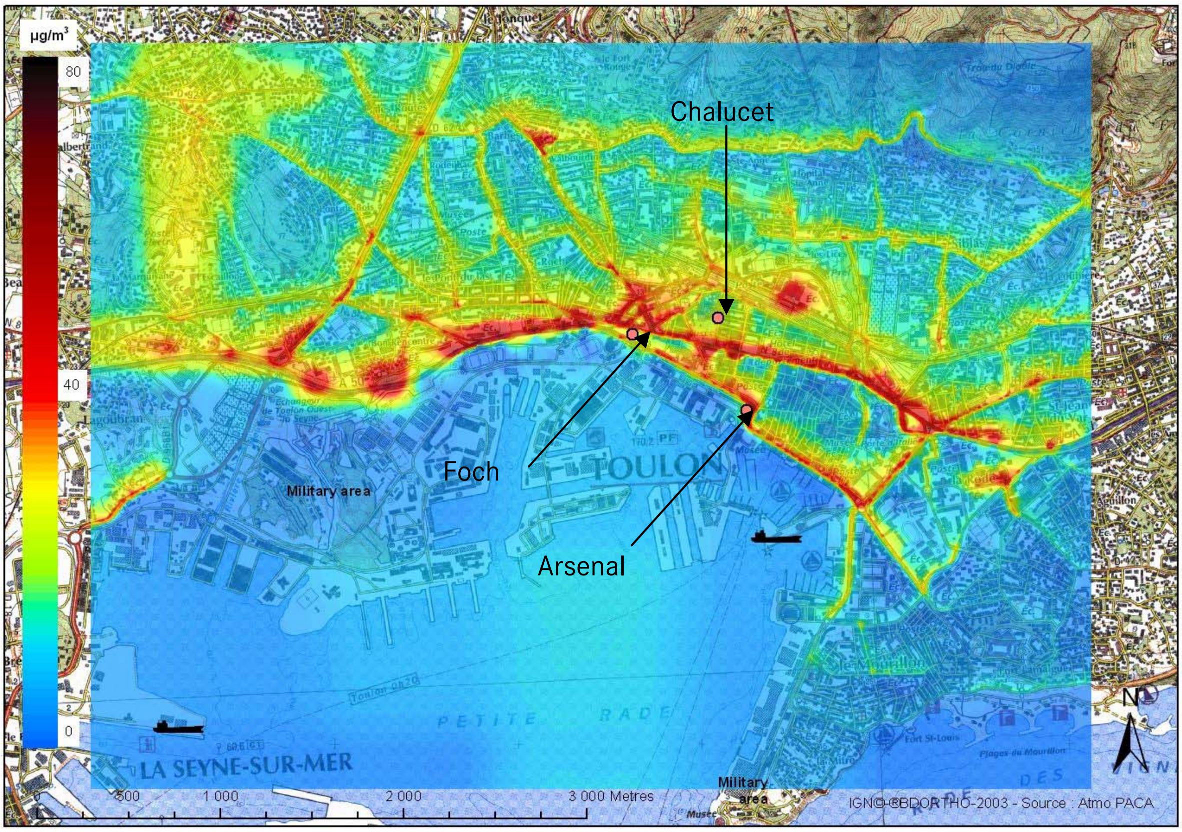
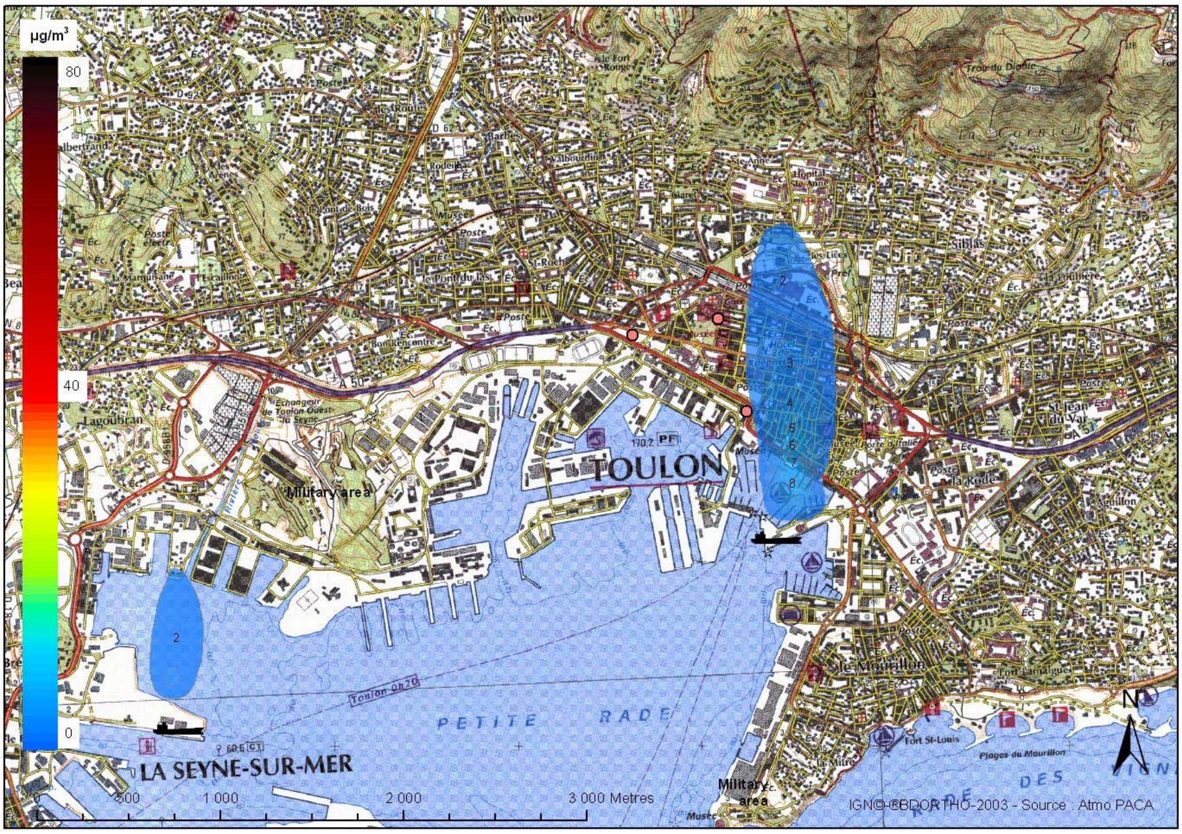
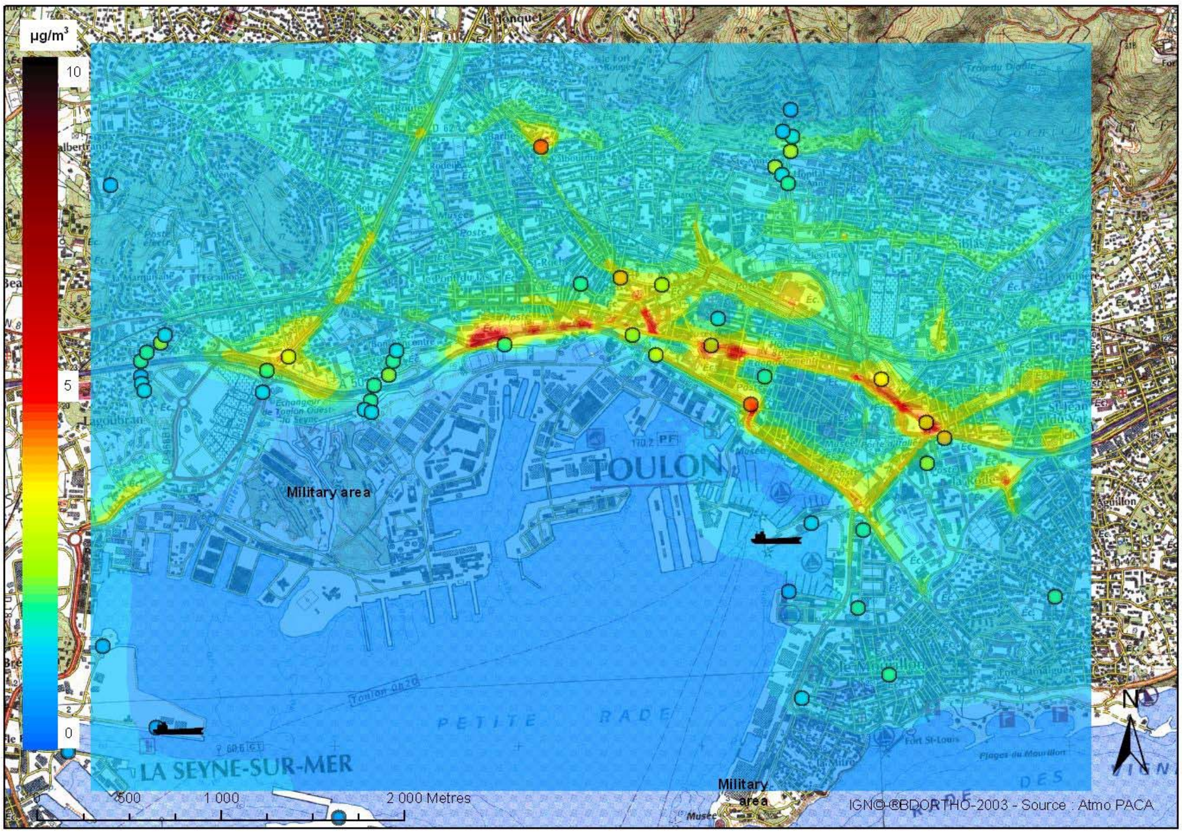


Figure 14: NO_2 simulated concentrations (µg/m^3) - neutral Atmosphere (c) ships alone



Benzene (C_6H_6)

Figure 15: C_6H_6 simulated concentrations (µg/m^3) (surface) - neutral Atmosphere and C_6H_6 observed concentrations (µg/m^3) (points) - 2005 annual mean (A) traffic + ships



The benzene levels are lower than those of NO_2, relative to their respective standards, on the port and on the town. The distribution of this pollution is very similar to that of NO_2: near to the axes with heavy traffic and the downtown area, with the harbor activity not clearly arising from the background level.

The situation is slightly different for sulphur dioxide (cf. below). In this case, the plumes resulting from the boats are distinguished slightly from the urban background level (which is itself very weak for this pollutant). The simulated and observed levels are however very low in regard to the standards on all the studied area.

The chart above presents a cartographic measures/model comparison. Broadly a good similarity exists between the observed concentrations and the simulated concentrations. The graph below illustrates the quantitative comparison between the model results and the observations of C_6H_6 on annual mean. A coefficient of correlation of 0.75 is calculated.

SULPHUR DIOXIDE (SO_2)

Figure 16: SO_2 simulated concentrations (µg/m^3) (surface) - neutral Atmosphere and SO_2 observed concentrations (µg/m^3) (points) - 2005 annual mean (a) traffic + ships

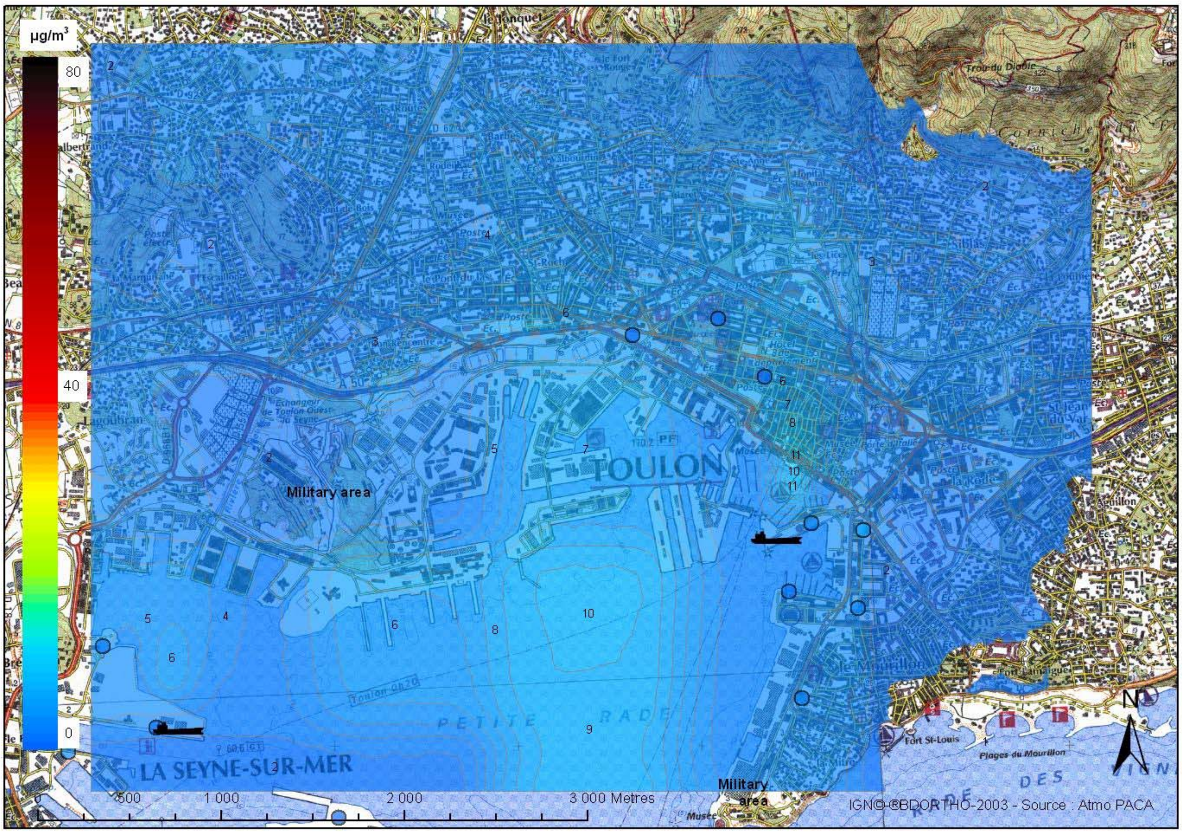


Table 7: Comparison of the annual means concentrations observed and simulated in the case of a neutral atmosphere: year 2005

Pollutants	**NO_2**		**SO_2**		**C_6H_6**	
Unit (µg/m^3)	**Observation**	**Simulation** D Pasquill class	**Observation** (SIMPYC campaign)	**Simulation** D Pasquill class	**Observation** (estimation)	**Simulation** D Pasquill class
Toulon Foch	**56**	**49**	1	4	2,8	2,8
Toulon Chalucet	40	30	2	3,9	1,9	2,1
Toulon Arsenal	34	33,6	TCA quay = 3 Breg. quay = 2	TCA quay = 3,2 Breg. quay = 2,7	4,9 (Street Anatole France)	4,1
Quality values	**40**		**50**		**2**	
Limit values **	**40**				**5**	

** The limit values for NO_2 and benzene are applicable in 2010

The table above and the preceding charts illustrate the capacity of the model to reproduce the concentrations annual means and the space gradients of the pollutants: NO_2, SO_2 and C_6H_6.

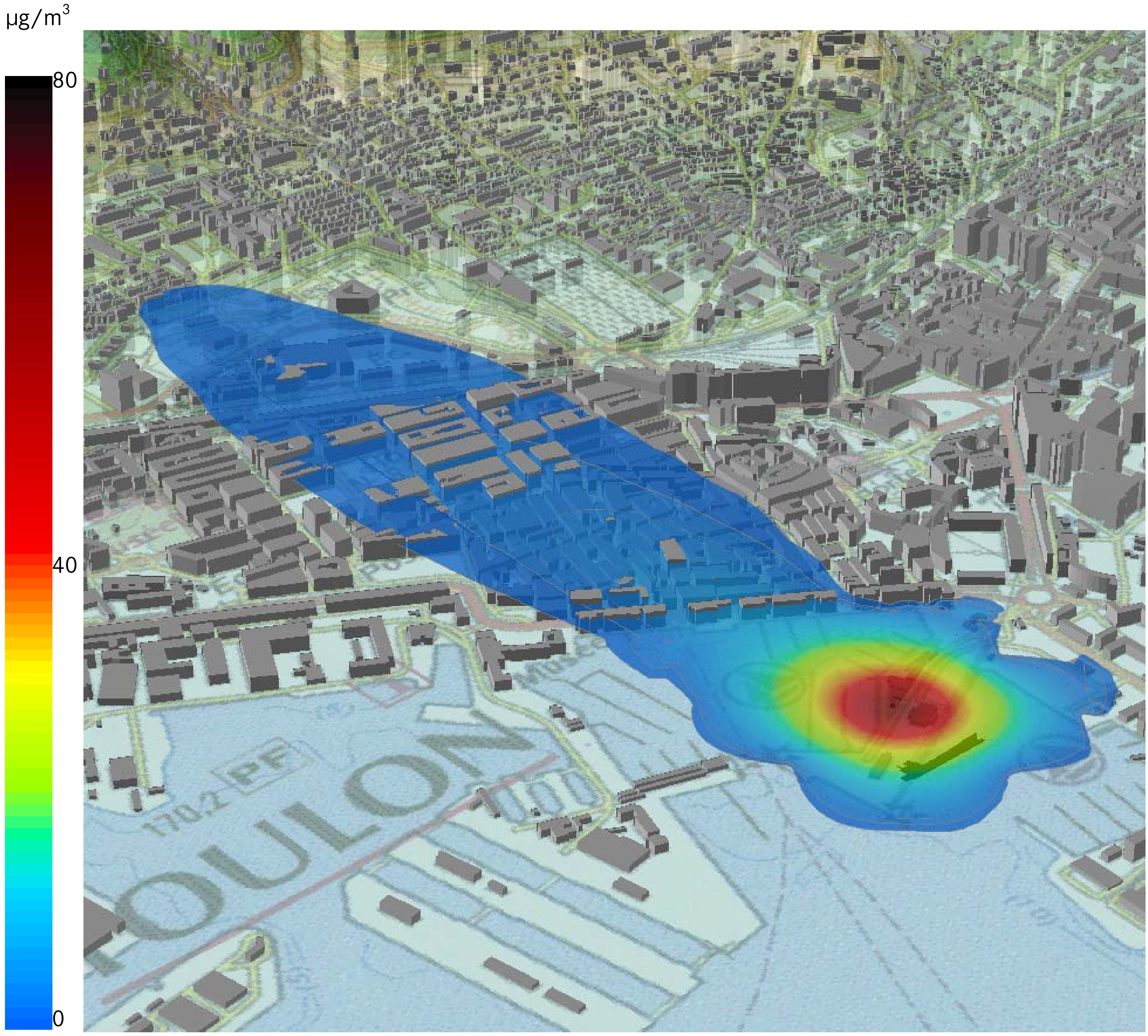
This result makes it possible to comment on the simulations carried out by isolating the emissions due to the traffic and the ships.

Figure 17: NO_2 from ferries simulated impact of the Toulon Côte d'Azur harbor (surface)

The figure above and figure 14 illustrate the impact of the ferries of the Toulon Côte d'Azur harbor in the case of a neutral atmosphere and for which the wind direction is of 180° (more penalizing case). NO_2 simulated concentrations do not exceed 8µg/m^3 (maximum) at ground level (2m). The simulated concentrations on the zones with strong density of population (city centre) lie between 2 and 7µg/m^3.

The concentrations are weak and lower than the 2010 limit value: 40µg/m^3.

Figure 18: NO_2 from ferries simulated impact of the Toulon Côte d'Azur harbor, at 40m



The figure above illustrates the impact of the ferries of the Toulon Côte d'Azur harbor in the case of a neutral atmosphere and for which the wind direction is of 180° (more penalizing case). At 40m, NO_2 simulated concentrations lie between 2 and 70µg/m^3 (maximum above the chimney exhaust). The concentrations simulated on the area with strong density of population (city centre) lie between 2 and 20µg/m^3.

It is interesting to note that the impact is more important in altitude (40 m) than at ground level (2 m). However, the concentrations remain weak and lower than the 2010 limit value (40µg/m^3) at the level of the first buildings. They however illustrate the possibility of odor embarrassment in the case of unfavorable weather situation in particular for the buildings located at the edge of the Toulon Côte d'Azur harbor.

2.5.4. MODELING OF A STABLE SITUATION: REAL CASE OF JANUARY 11, 2006

January 11, 2006 corresponds to a very stable weather situation very penalizing for air quality. The height of the boundary layer is very low, the winds are low, and the pollutants accumulate in the layers close to the ground. Atmo PACA recorded, this day, concentrations higher than the NO_2 information threshold on the stations of Toulon Foch and Toulon Arsenal. In this case, even if pollution related to the ships increases, the pollution related to the road traffic remains largely dominating: at the point where the maritime part is most important, it is 37% (cf. following page).

The figures hereafter present the nitrogen dioxide simulated concentrations in the case of a stable atmosphere. The charts present the calculated concentrations (a) with all the emissions sources, (b) the emissions due to the traffic alone, (c) the emissions due to the ships alone.

Figure 19: NO_2 simulated concentrations ($\mu g/m^3$) - stable Atmosphere - 12:00 a.m. - (a) traffic + ships

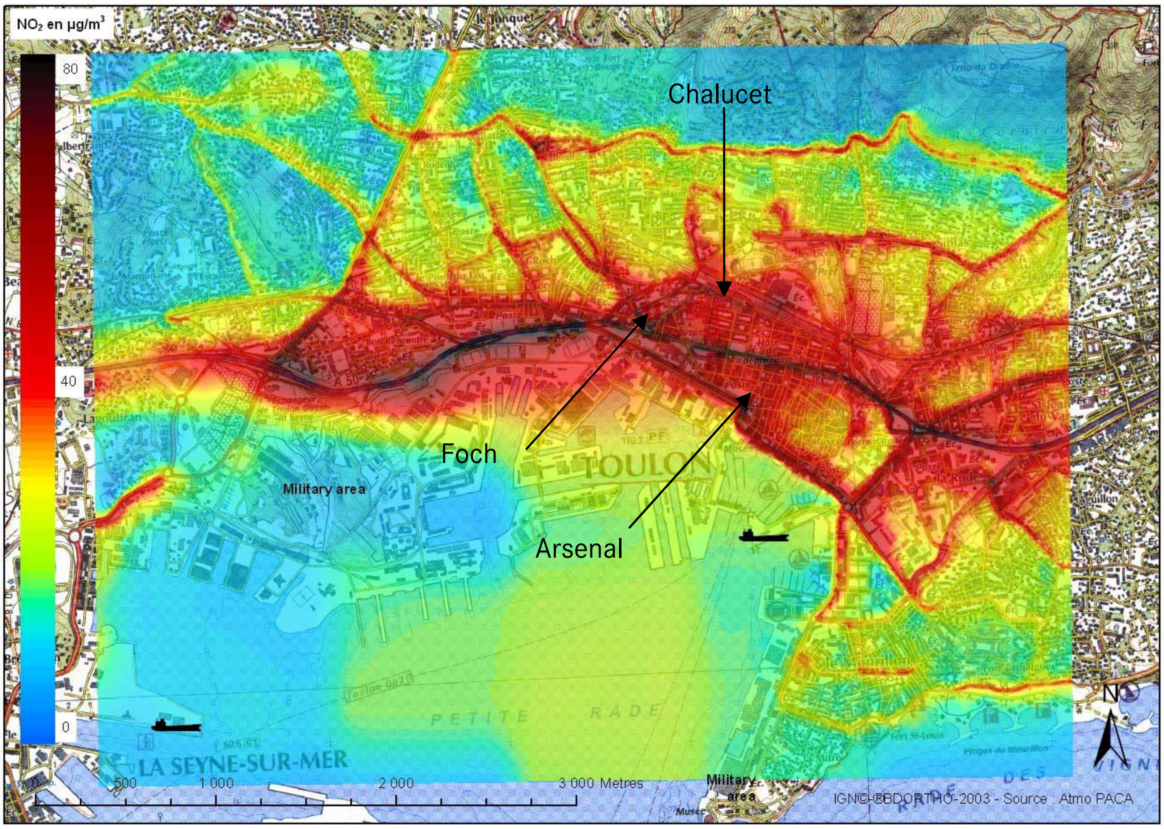


Figure 20: Measures/Model Comparison of NO_2 concentrations ($\mu g/m^3$) – 12:00 a.m.

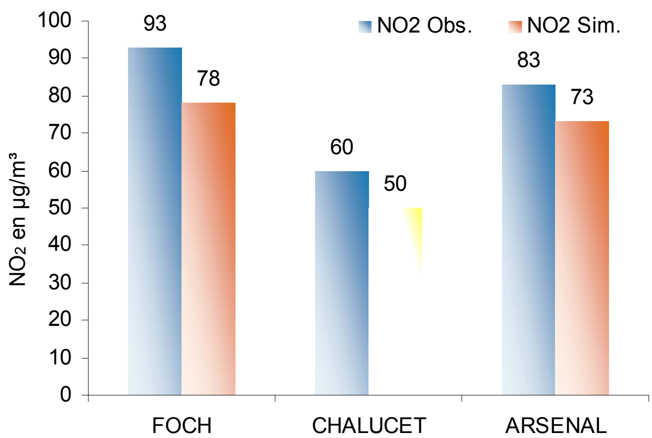
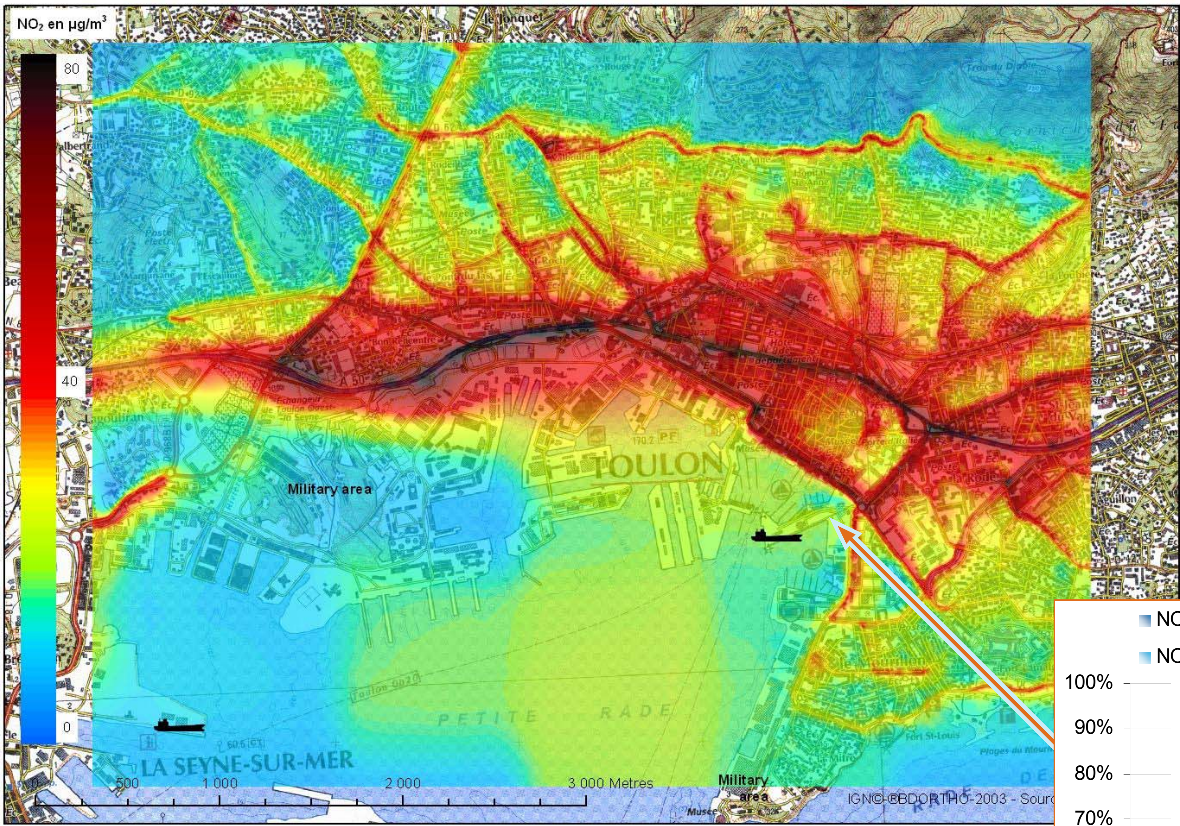


Figure 21: NO_2 simulated concentrations (µg/m^3) - stable atmosphere – 12:00 a.m. - (b) traffic alone



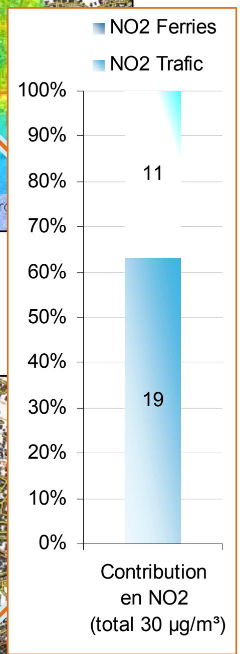
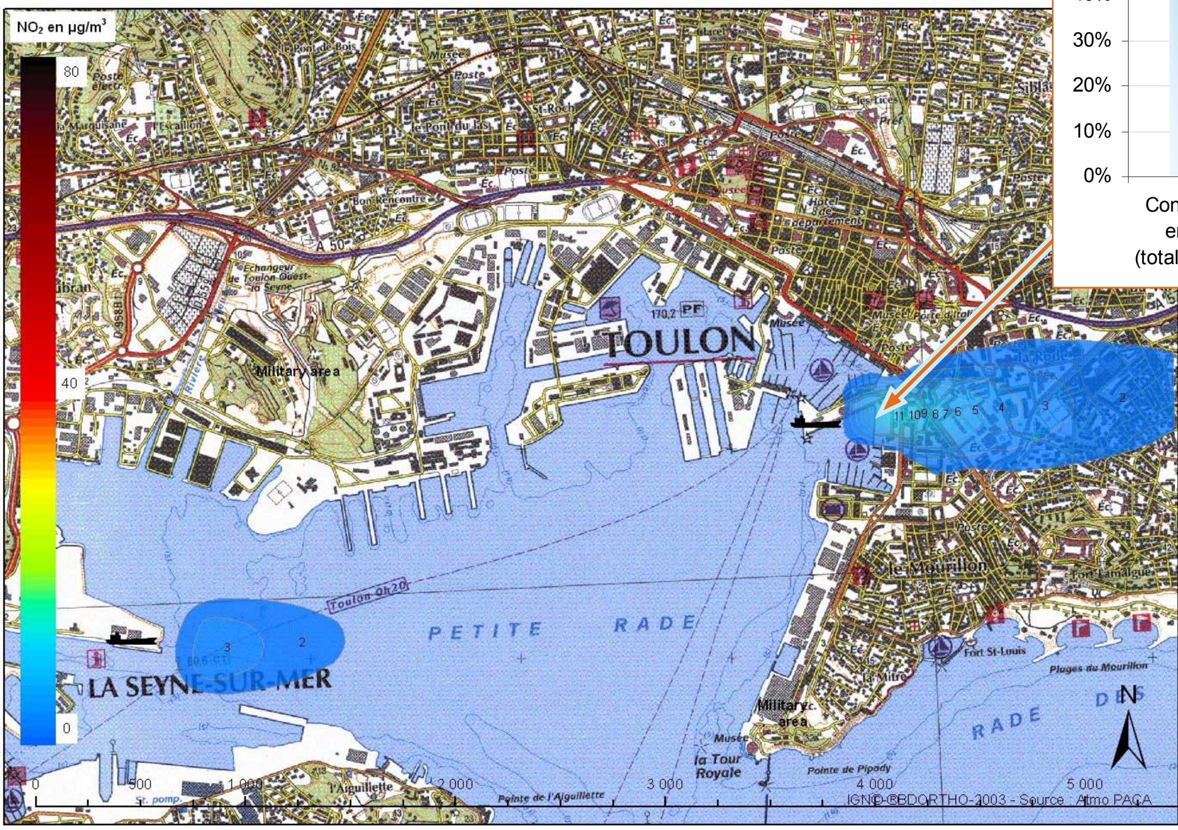


Figure 22: NO_2 simulated concentrations (µg/m^3) - stable Atmosphere – 12:00 a.m. - (c) ships alone



2.5.5. MODELING OF AN UNSTABLE SITUATION: REAL CASE OF THE SIMPYC CAMPAIGN

The figures below present the cartographies and the measurements/model correlations for the real case of SIMPYC campaign from the 8th of August to the 5th of September, 2006. The correlations factors obtained are very satisfactory since they vary from 0.81 to 0.94 according to the taking into account of measurements of the SIMPYC + AIRPROCHE campaigns or SIMPYC alone (respectively). The average model/measurements deviations expressed as a percentage vary from 16% to 9% (SIMPYC campaign alone).

Figure 23: Dispersive atmosphere: SIMPYC campaign: NO_2 simulated concentrations (µg/m^3) traffic + ships

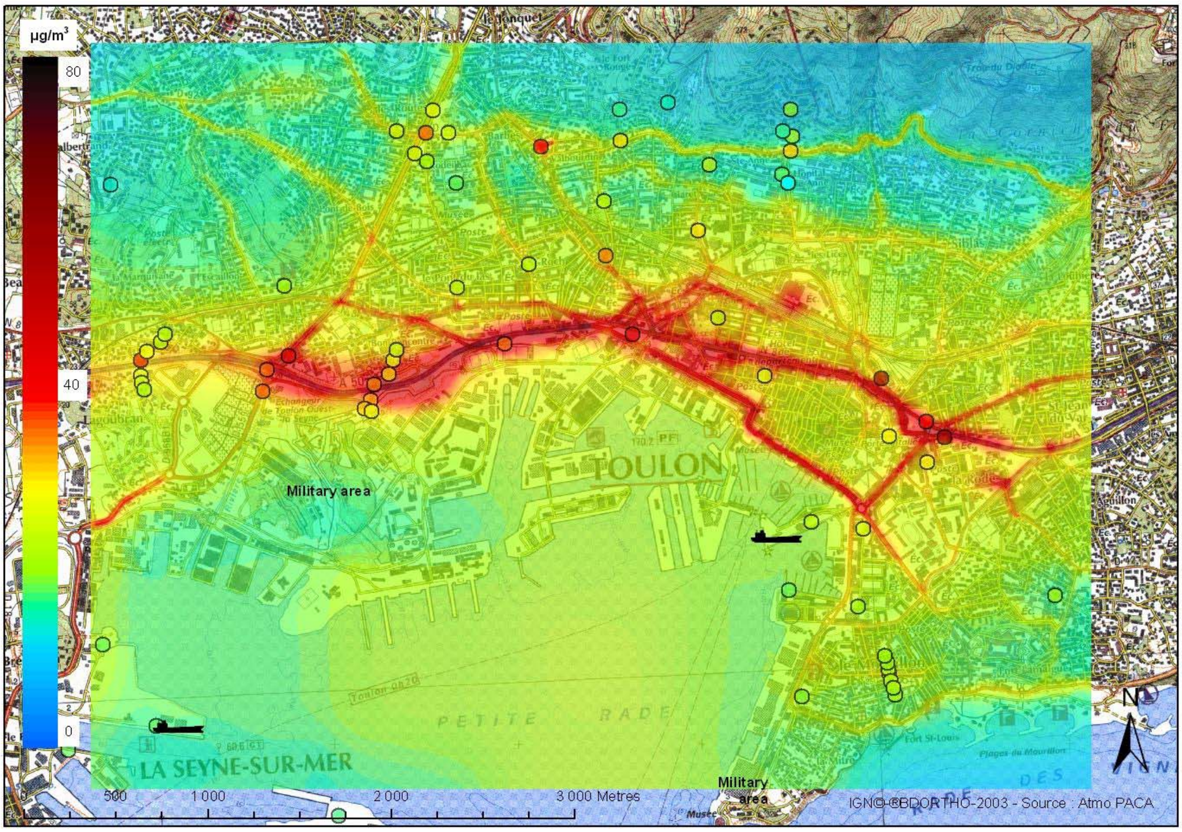
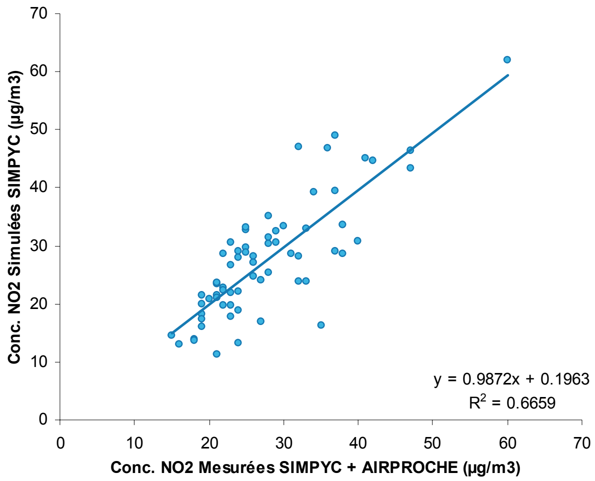


Figure 24: Correlations of the measured and simulated NO_2 concentrations (µg/m^3) (right) SIMPYC + AIRPROCHE campaigns; (left) SIMPYC campaign only



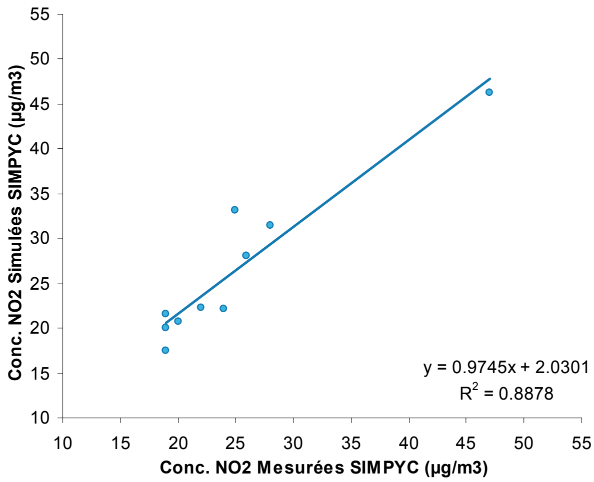


Figure 25: Dispersive atmosphere: SIMPYC campaign: SO_2 simulated concentrations (µg/m³) traffic + ships

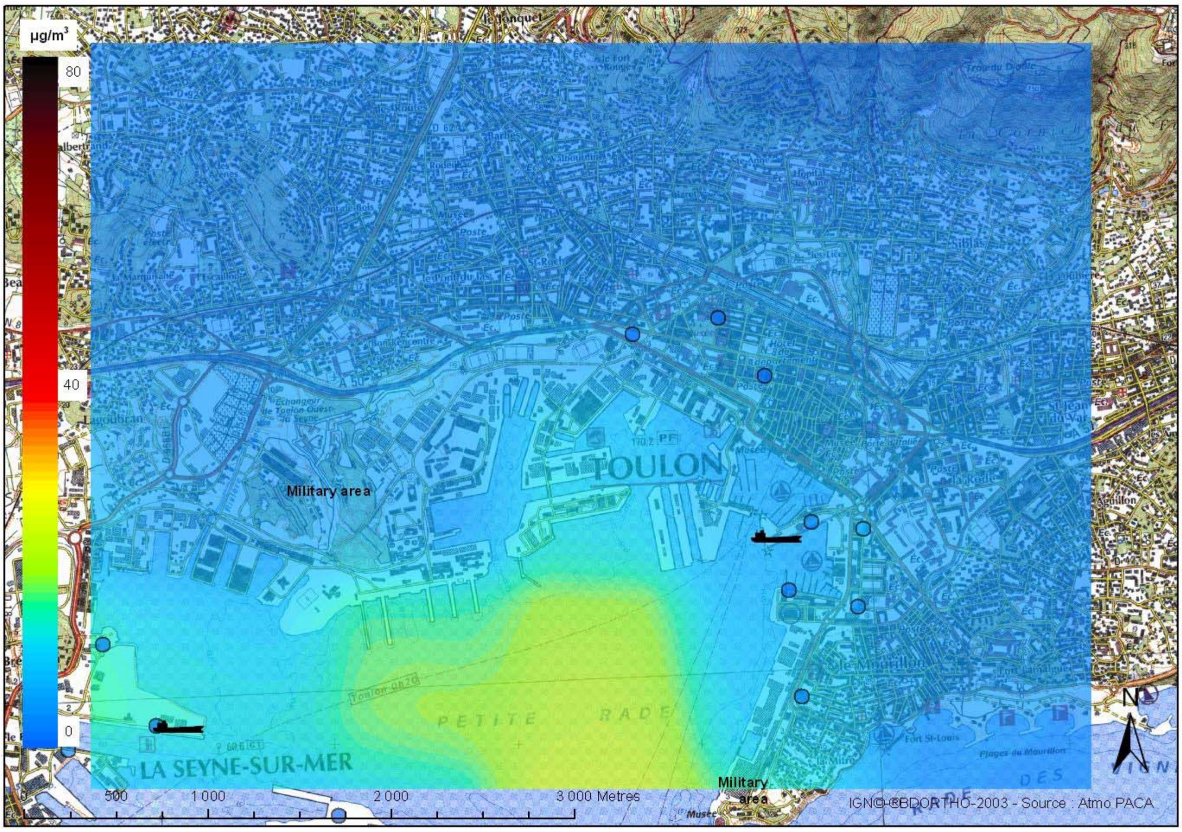
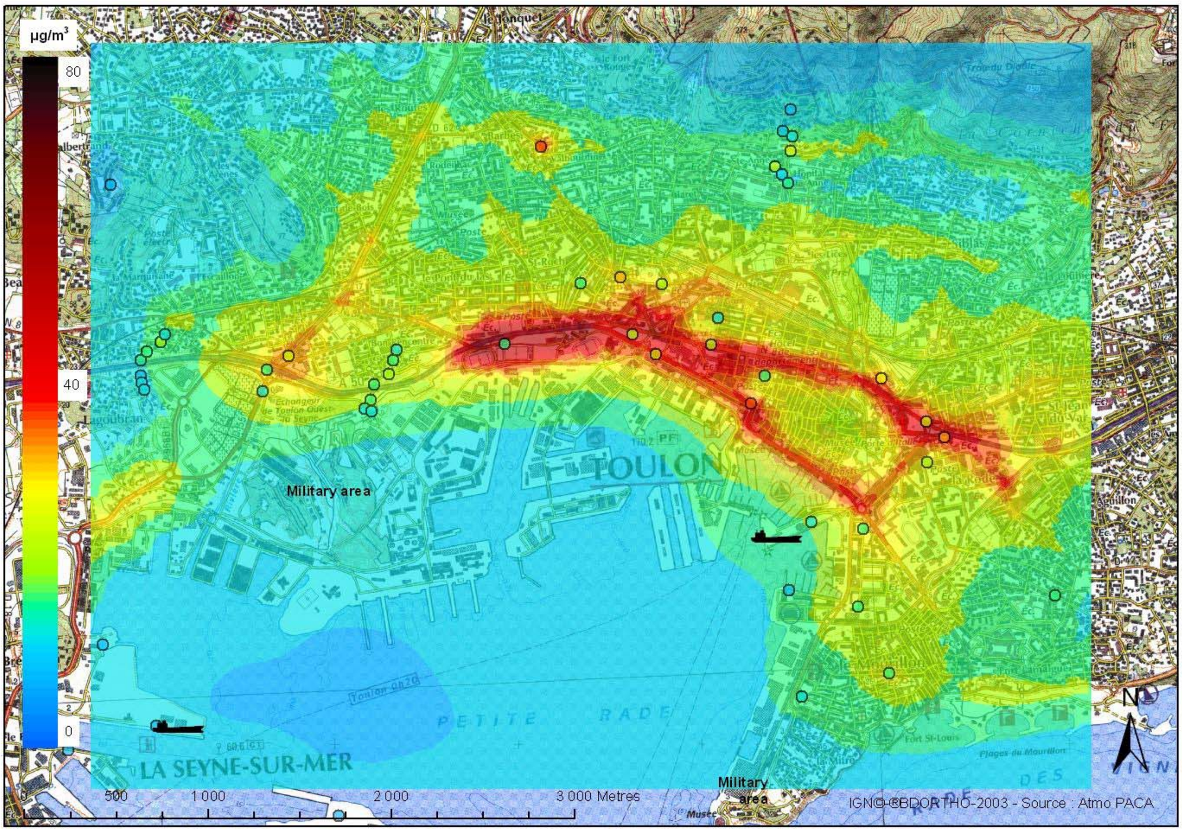


Figure 26: Dispersive atmosphere: SIMPYC campaign: C_6H_6 simulated concentrations (µg/m³) traffic + ships



3. Conclusions and Prospects

Conclusions

Three categories of atmospheric conditions are studied; neutral (most frequent), stable and unstable. The stable situation is illustrated by the real case of 11th January, 2006. The unstable period is analyzed through the real study of the SIMPYC measurement campaign (August 8 to September 5, 2006).

In the three cases the measurements/model correlations are satisfactory for the pollutants NO_2, SO_2 and C_6H_6. For the SIMPYC campaign, the variations of the simulated concentrations, compared with the concentrations measured over the period, vary from 9 to 16% for nitrogen dioxide.

For the three categories of atmospheric conditions, the contribution of the urban traffic emissions is dominating on that of the ferries of the Toulon Côte d'Azur and Brégaillon harbors.

In unstable and neutral condition, locally under the plumes, the ships contribution is about 10% of the NO_2 pollution.

In stable condition, the contribution of the ferries of the Toulon Côte d'Azur harbor can locally reach 40% of total pollution under the plume. However the hourly concentrations at ground level under the plume do not exceed 20µg/m^3 for NO_2 and the SO_2. They are lower than the 2010 limit values.

The under estimation of the NO_2 simulated concentrations inside the Toulon Côte d'Azur and Brégaillon harbors seems due to the movements induced around the maritime activity of the two port which has not been taken into account (not available for Atmo PACA), in particular the local traffic generated during the loading and unloading.

Prospects

Thanks to its participation in the SIMPYC and AirProche projects, Atmo PACA owns today, on the town of Toulon, an urban simulation model of air quality, validated for the years 2001 and 2006.

Within the framework of the follow-up of these monitoring tools, Atmo PACA continues to improve its results of high resolution urban cartography for the town of Toulon. In order to refine the results, it will be necessary to carry out a complete calculation, with a 1-hour step, of year 2006 as a whole with real meteorological data. It will also be necessary to specify certain assumptions and in particular the temperature at the emission of the ships chimneys and the emissions speed of gases at the exit of the chimney. It will also be important to have the traffic data of the vehicles inside the Toulon Côte d'Azur and Brégaillon harbors.

The modeling of the particulate matters must also be refined, in order to have reliable results for this pollutant which provoke real medical problems in the urban zones.

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5. APPENDIX 1: "NEBULOSITY-WIND" METHOD

It is the most used method because nebulosity (or index of cloud cover) is the data generally provided by the Météo-France stations. Stability is deduced starting from the parameters available (wind speed and nebulosity) according to three following steps:

1. Determination of an indicator "Iv" based on the mechanical effects and using wind measurement at 11m:

Wind (m/s)	0 <V ≤ 0.5	0.5 <V ≤ 1.5	1.5 <V ≤ 3.5	3.5 <V ≤ 5.5	5.5 <V ≤ 6.5	6.5 <V
Iv	1	2	3	4	4	6

2. Determination of an indicator of radiation "Ir" characterizing the heating effects and using the solar angle of elevation "Es", function of the day in the year and the hour in the day as well as nebulosity "N":

Es / N	night	0 ≤ Es < 15°	15 ≤ Es < 35°	35 ≤ Es < 60°	60 ≤ Es < 90°
N = 0	Ir = 5	Ir = 5	Ir = 3	Ir = 2	Ir = 1
N = 1	Ir = 5	Ir = 5	Ir = 3	Ir = 2	Ir = 1
N = 2	Ir = 5	Ir = 5	Ir = 3	Ir = 2	Ir = 1
N = 3	Ir = 5	Ir = 5	Ir = 3	Ir = 2	Ir = 1
N = 4	Ir = 5	Ir = 4	Ir = 6	Ir = 2	Ir = 1
N = 5	Ir = 4	Ir = 4	Ir = 6	Ir = 3	Ir = 2
N = 6	Ir = 4	Ir = 4	Ir = 6	Ir = 3	Ir = 2
N = 7	Ir = 4	Ir = 4	Ir = 6	Ir = 3	Ir = 2
N = 8	Ir = 6	Ir = 6	Ir = 6	Ir = 6	Ir = 3

The solar angle of elevation (in radians) can be calculated by the following relations:

With:

$$\sin Es = \sin\phi.\sin\delta s + \cos\phi.\cos\delta s.\cos\left[\frac{\pi(t-12)}{12}+\lambda\right]$$

- Φ : latitude (counted positively towards North) in radians
- λ : longitude (counted positively towards the East) in radians
- T: time in UT hour. The integer value of the hour must lie between 0 and 23h. It is possible to take into account the minutes and the seconds by taking a decimal value for T: 23.45 corresponds to a quarter to midnight.
- δS: solar angle of variation in radians can be calculated by the relation:

$$\delta s = \phi r.\cos\left[\frac{2\pi(d-dr)}{dy}\right]$$

With:

- ΦR: latitude of the tropic of Cancer in radians (23.45°=0.409 rad)
- d: Julian day: for example February 1 = day 32
- dr.: Julian day of the summer solstice: day 173
- dy: average number of day in one year = 365.25

3. Crossing of the two indicators of turbulence (mechanical turbulence: “Iv” indicator, thermal turbulence: “Ir” indicator) to obtain the PASQUILL stability class:

Iv	Ir = 1	Ir = 2	Ir = 3	Ir = 4	Ir = 5	Ir = 6
Iv = 1	A	A	B	F	F	D
Iv = 2	A	B	B	E	F	D
Iv = 3	A	B	C	E	F	D
Iv = 4	B	C	C	D	E	D
Iv = 5	C	C	D	D	D	D
Iv = 6	C	D	D	D	D	D

One finds in this step the stated principles:

- By moderate and strong wind, the atmosphere is well mixed and neutral (D),
- By weak wind and if thermal energy close to the ground is available, the natural convection can be established (A, B or C),
- Failing this the atmosphere is stable (E or F).

It is necessary to specify that this method makes it possible to have an overall estimation of atmospheric stability. It does never make it possible to have a description of the vertical structure of the atmosphere. The access to this structure (altitude and thickness of the stable layers or inversion) passes by a specific instrumentation of the site which is not carried out in routine by the meteorological centers.

6. APPENDIX 2: ADMS AND CLASSES OF STABILITIES

(Source: NUMTECH, 2007)

The meteorological preprocessor of ADMS3 Urban is based on the similarity theory and the use of the Monin-Obukhov length. For this reason the most adequate data input are the height of the boundary layer H, and the Monin-Obukhov Length (LMO), or failing this, of the data which make it possible to recompute them.

It is important to note that there is no universal data file (H-LMO), associated with each class of stability.

Indeed, by using the similarity theory, there is a continuous description of the state of the atmosphere. To the opposite by using a system of classes of stability, one obtain is a discrete description. In this second case, several weather conditions can lead to the same classification of the atmosphere; whereas in the first case, with each couple (H-LMO), there is a specific characterization of the state of the atmosphere. The consequence is that several couples (H-LMO) can correspond to the same class of stability. This is observed the following figure, where it is noted that for the neutral class of stability (D), a very great number of couple (H-LMO) can be associated. However, according to the couple chosen, the impact of dispersion will be different. For example, for this same class D, one observes that the value H can typically vary from 100 to 1000 meters. It is understood easily, that between a height of 100m and a height of 1000m, the dilution of the concentrations can be different.

Figure 27: Diagrammatic representation of the variations in the Monin-Obukhov length according to atmospheric stability