SAMAA : a software for air quality modelling and analysis

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ABSTRACT

In order to provide to decision makers an operational tool to help define mitigation measures and to anticipate their qualitative and quantitative effects on air quality. ACRI-ST has developed a user friendly integrated modeling system called SAMAA (System for Air Modeling And Analysis), including a GIS based emission module called AIREMIS. This system allows to simulate air pollution events at medium and regional scale in order to better understand the evolution of air pollution in cities and their surroundings, and to improve air quality by selecting efficient emission control strategies.
SAMAA is a PC software that is very innovative because of its underlying GIS, its modular approach, and its user-friendly interface. The emission computations reflect the European state of the art in emission estimation, and respect user requirements for an acceptable computation time.
The AIREMIS emission module was designed to be used in a modelling system. As a consequence, it calculates local and hourly emissions of primary pollutants. It makes use of bottom-up European methodologies for all source types. Its user interface, has been defined in term of user specifications (functionality, scenarios management) jointly with two French Air Quality Survey Networks, which now use SAMAA as a decision making tool for air quality management and engineering studies. The emission module AIREMIS is presently under implementation on the city of Bogota (Colombia).
In this paper, the details of the system are described and some applications are presented as illustrations of emission inventory (input data inventory, adaptation to local specificities) used in an air quality modeling system.

INTRODUCTION

In France, air quality condition is under the responsibility of 39 regional Air Quality Survey Networks whose management team is shared between national and local authorities, industries representatives and environmental public associations. Their role is to survey pollutant concentration levels, if possible to anticipate short term trends, to transmit the information and awareness to the public and to evaluate the impact of development strategies on air quality.
In order to accomplish their prospective role, two of these Air Quality Survey Networks (Air Pays de la Loire and Atmo Auvergne) decided to support the development of a friendly tool dedicated to understand causes for air pollution events and to identify and assess actions to reduce the impact of development decisions.
As end users of the tool, they were waiting for a tool having the following characteristics:

- A user friendly interface for non scientist

- A unique system allowing to make all the modeling study from the beginning to the end
- An emission calculation adapted to realize prospective or/and development scenario studies
- An emission calculation dedicated to photo chemical and dispersion modeling activities
- A GIS based system

Filling these characteristics and adding new ones (modularity, state of the art methodologies), ACRI-ST has designed and developed an innovative integrated software to simulate atmospheric air quality conditions under real or potential emissions scenarios. This software is called SAMAA (Software for Air Quality Modelling and Analysis). It is currently used as a decision making tool dealing with short and middle term project and is also very useful for event analysis.

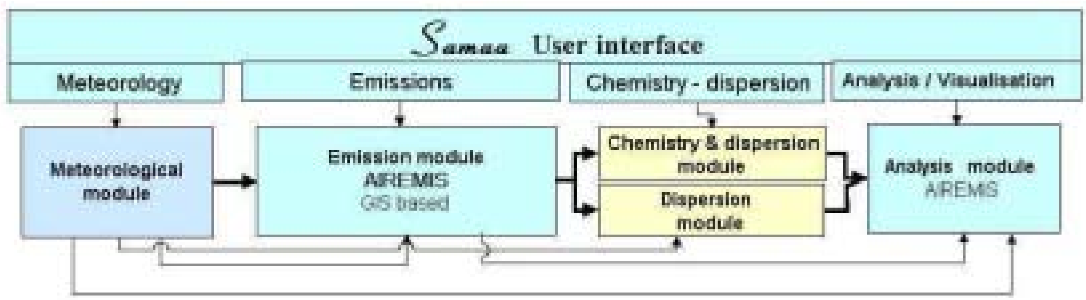
The mailing list of SAMAA allows the users to specify their needs and their comments and to keep aware of what is done concerning SAMAA.

SYSTEM DESIGN OF SAMAA

Structure of SAMAA

SAMAA is a GUI based "platform" designed for managing the different steps of air quality studies (initialization and parameterization of pollutants emission, meteorological computations, dispersion and chemistry computations, results analysis).
Emission calculations is the critical aspect of such a platform. A dedicated GIS based emission model (AIREMIS) was designed, with which a meteorological model, a photochemical model and a dispersion model can be interfaced. This structure, presented in figure 1, allows to use the platform with other meteorological, chemistry or dispersion models than those included in the main version (CALMET, CALGRID, CALPUFF), just by developing specific converters.

Figure 1. Structure of SAMAA



The whole system offers also powerful graphical capabilities for result display. The development of the "platform" in the frame of a GIS gives the opportunity to :
- manage emission data that are used downstream in the system (parameterization and processing of geo-referenced data)
- visualize results of the five different modules (wind and temperature maps, emission maps, concentration maps)

After the adaptation of the platform to a study domain, the Data Base contains all the meta-data emission information necessary to run the system on any day of the year.

Meanwhile during each simulation, the user can modify emission parameters (for instance fleet composition for traffic prospective studies or industrial characteristics for impact assessment), in order to evaluate the effect of these modifications on the concentration fields.

The emission module AIREMIS

The emission model AIREMIS (developed by ACRI-ST) computes emissions of different primary pollutants (NO_x, SO_2, CO, NMCOV, PS, CH_4) for various sources :

- transports (road and air),
- production and services,
- residential heating,
- and natural environment (vegetation and soil) on any kind of emission geometric (segment, surface, point).

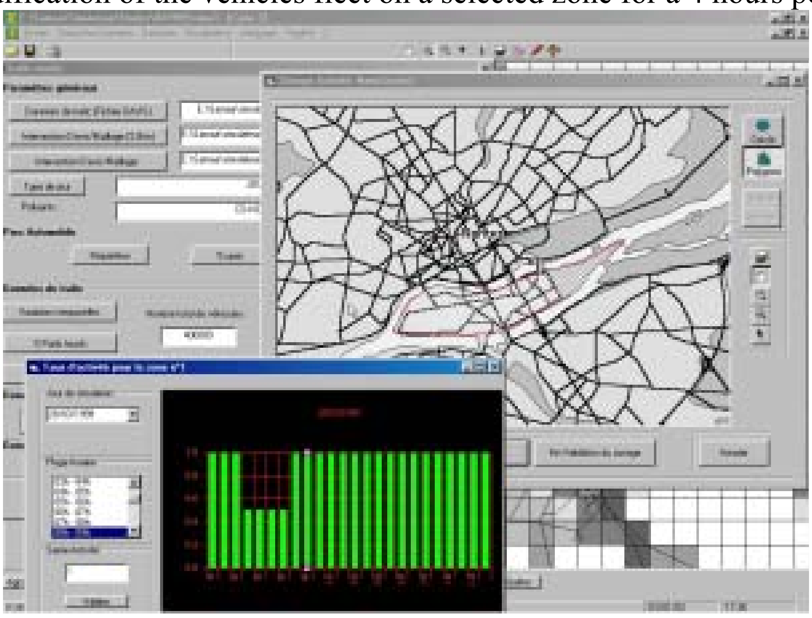
For each emission category, the calculation methodologies were selected considering the following two criteria:

- the state of the art in emission calculations
- the adaptability to available data

The emission were dedicated to be used for chemical and dispersion modeling, and all these methodologies had to be adapted to local and hourly scale.

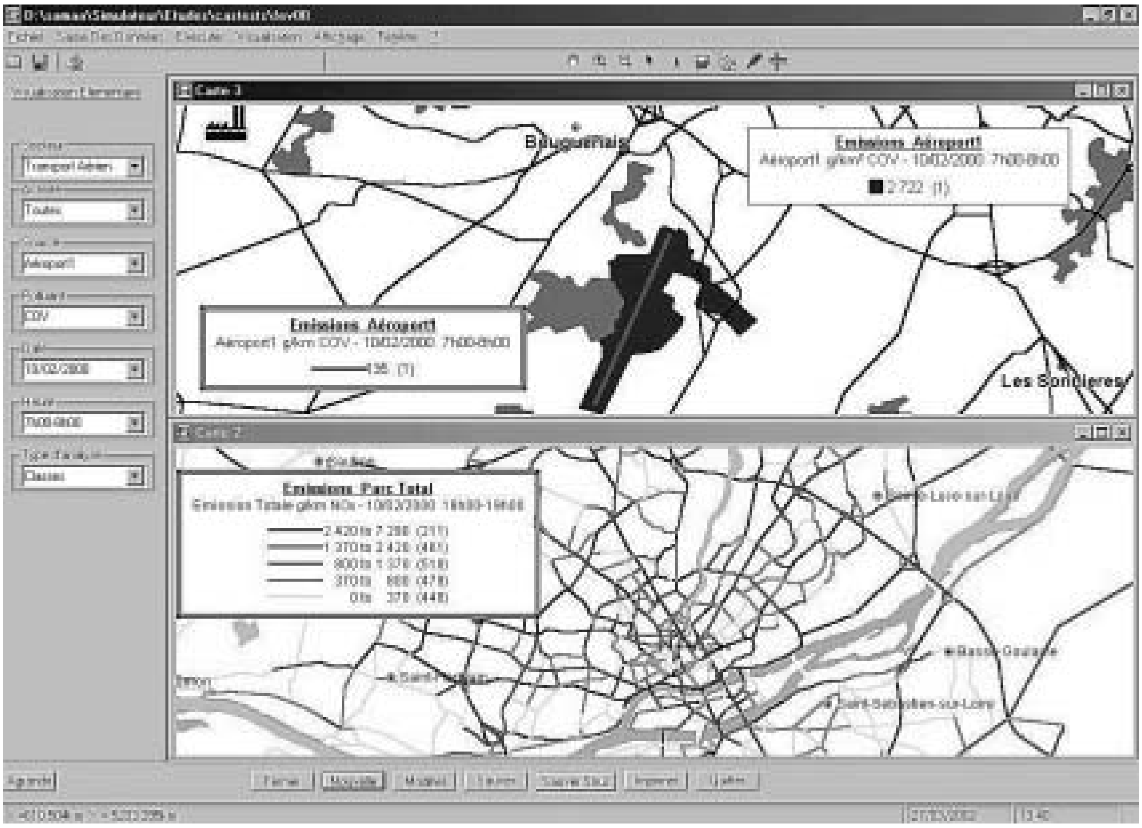
The calculation of emissions linked with *Road Transport* is processed following a system that adapts the COPERT III Methodology (André M. and al., [1]) to local scale and hourly time step and makes use of output from a traffic model and statistical road traffic counting data. The car type distribution, ratio of heavy vehicles by type of road, the fuel characteristics, and temporary variations can be tuned via the interface. Figure 2 presents the interface allowing to modify fleet vehicles composition on a selected zone over a chosen period of time. For each type of road the traffic flow variations during the simulation period is computed by using hourly (by type of day), weekly and monthly variations. These are obtained by a statistical processing of the road traffic counting data.

Figure 2. Example of the road traffic emission interface
modification of the vehicles fleet on a selected zone for a 4 hours period



The emissions linked to *Air Traffic* include airplane emissions on land operations, during take off and landing, up to a 1000-meter (3280 feet) altitude. The applied methodology is based on an adaptation to an hourly scale and airport data of the MEET Methodology (Fitzerald P. and al., [2]), specialized in air traffic. Emissions are considered as depending on the park breakdown, the number of planes that take off and land every hour, and the duration of each phase. Hourly and weekly variation of air traffic are specified by the user.

Figure 3. Visualization of Air and Road traffic hourly results

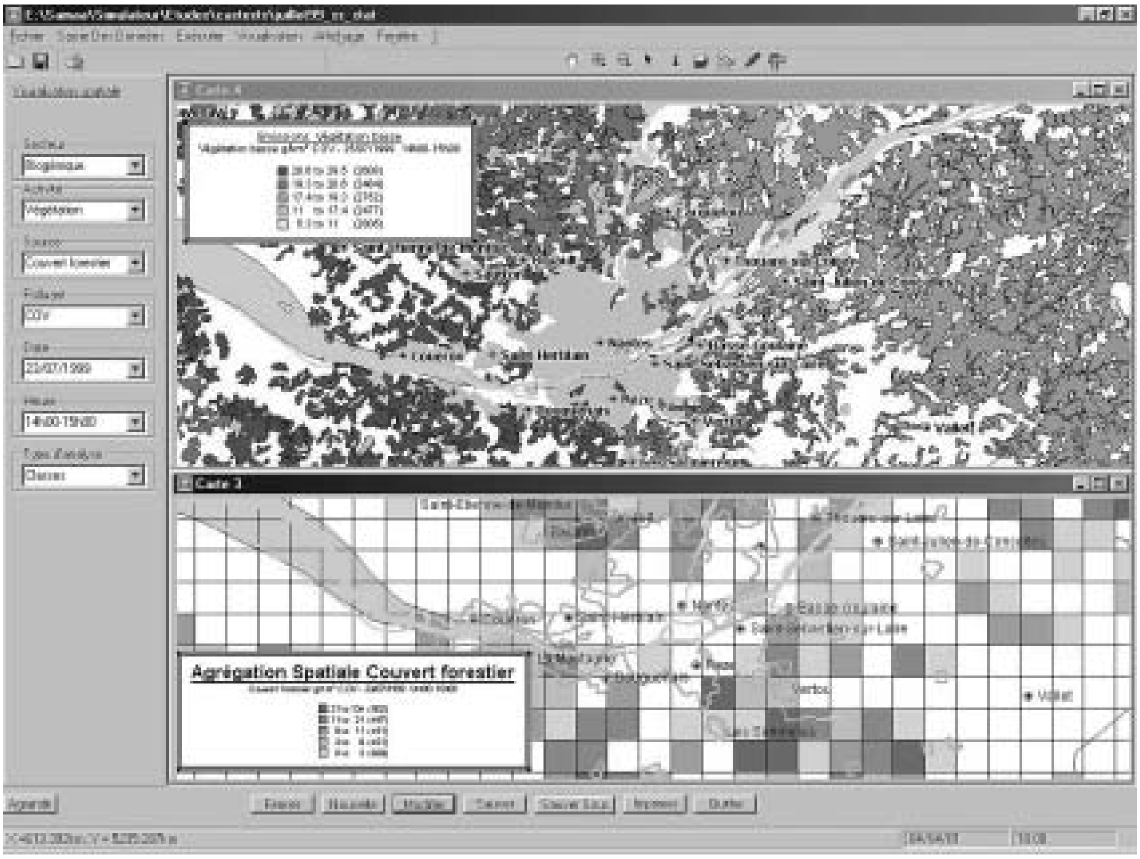


The emissions linked to *'Production & Services'* activities are calculated for different economy industries ('energy extraction / transformation', 'retail establishments', 'services' and service industry heating.). Methodology applied consists in calculating an annual flux for each pollutant and then breaking it down to the hourly rate for the simulation period depending on the industry's activity during the year. The different calculation methodologies of flux per year defined in CORINAIR (Unece/emep task force [3]) are proposed depending on the information and data available. The choice of one of these procedures depends on the availability of information for each source.

The emissions linked to *Residential Heating* are processed per unit area as diffuse sources. Methodology entails several phases applied to surface corresponding to statistical units used for population census and to associated 'habitat' data (number and size of flats etc.). Hourly emission variations are directly linked to temperature variations computed by the meteorological module.

The calculation of emissions linked to the *Natural Environment* takes into account several sources (forest areas, low vegetation, and soils). VOC emissions are calculated considering the different types of forest and low vegetation. The respective calculation methodologies, which depend on the CORINAIR Methodology (UNECE/EMEP task force [4]), are based on an emission factor, on the density of foliar biomass, and on an environmental factor dependent on temperature and PAR (Photosynthetically Active Radiation). NO emissions from soils are also calculated for wetlands, as well as for forests, grasslands and croplands. The emissions of NO are calculated following the methodology employed in the EPA's BEIS (Biogenic Emissions Inventory System v2.0, Pierce E. [5]). Hourly variations are linked to the variations in temperature and PAR calculated by the meteorological module. Figure 4 presents the visualization and analysis interface of SAMAA for biogenic emissions.

Figure 4. SAMAA visualization of calculated natural emissions – elementary and aggregated results



Meteorological model

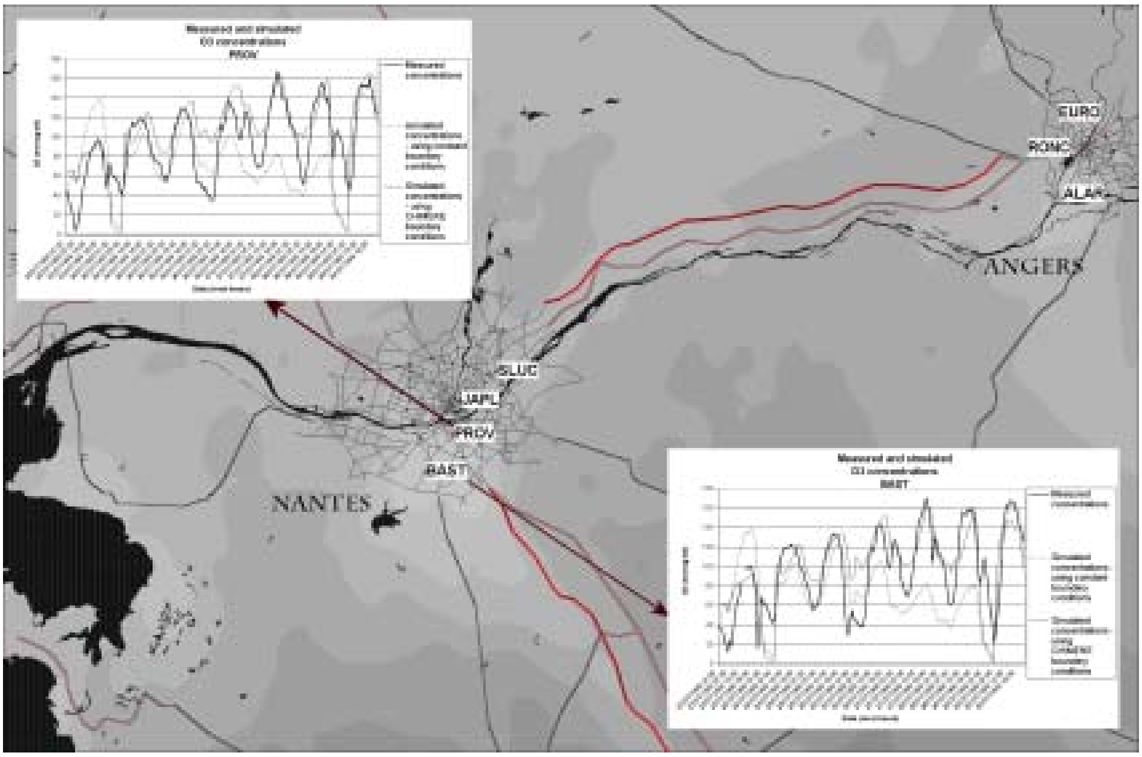
The meteorological model computes meteorological field that are used by the emission model and by the dispersion/photochemical model. CALMET, a public domain software developed by Earth Tech (Scire J.S. and al. [6] [7]) is the meteorological model that is used for the first version of SAMAA; however, because the system has been developed in a modular way, any other meteorological model may be interfaced by changing the specific converters. The meteorological model requires input that are meteorological observations and/or computations at larger scale. The data used in the present applications of SAMAA come from ARPEGE and ALADIN models from Meteo France and COAMPS and NOGAPS models (Haack T. [8]) from FNMOC, distributed by the Master Environmental Library (MEL).

Photochemical model

The photochemical model CALGRID (Yamartino R.J. and al. [9]) allows to simulate dispersion and evolution of pollutants using the results of meteorological and emission modules; however, likewise the meteorological model, any other photochemical model could be interfaced (providing compatibility between chemical description in emission and photochemical model).

As recommended during the validation step of SAMAA, the boundary conditions must be taken into account precisely. As a consequence, SAMAA has recently been interfaced with a photochemical continental model running daily on Europe, called CHIMERE Continental (Vautard R.and al. [10], Menut L. and al. [11]) developed by a French laboratory working on Meteorology ans air quality (Laboratoire de Météorologie Dynamique - LMD), that provides the hourly concentrations values on the European gridded domain. The outputs are used to create initial and hourly boundary conditions (border, top) on the limit of the SAMAA regional domain. Figure 5 shows that the results are improved using these boundary conditions.

Figure 5. O3 concentrations on the region of Nantes. Impact of taking into consideration CHIMERE Continental outputs as boundary conditions



Dispersion model

The puff dispersion model allows to simulate the dispersion of puffs from several types of sources (punctual, linear, surface) using the results of the meteorological and emission modules. CALPUFF, a public domain software developed by Earth Tech Inc. (Scire J.M. and al. [12] [13]) has already been implemented in the current version.

Visualisation module

The visualisation module allows to generate maps through the underlying GIS. The hourly outputs of the emission module can be visualised on the emitting object or on the cells of the calculating grid. The user can also choose to make a integration or a mean of the values over several hours (up to 24). The outputs from the meteorological, dispersion and chemical models are plotted as rasters and the created images, geolocalised automatically, can be overlaid to maps (especially those created by the AIREMIS emission model).

VALIDATION OF THE MODEL

The LCSQA (Laboratoire Central de Surveillance de la Qualité de l'Air) is a French public entity which role is to assist the national air quality survey networks in their air modelling activities. As a part of this entity, the department of chemistry and environment of the Ecole des Mines de Douai was in charge of the following and the evaluation of the implementation of whole modelling system SAMAA. In particular, the validation step of the simulator was performed under their expertise.

SAMAA has been validated on two 3-day simulations: the first one was dedicated to evaluate the "chemical processing" and the second to the "dispersion processing".

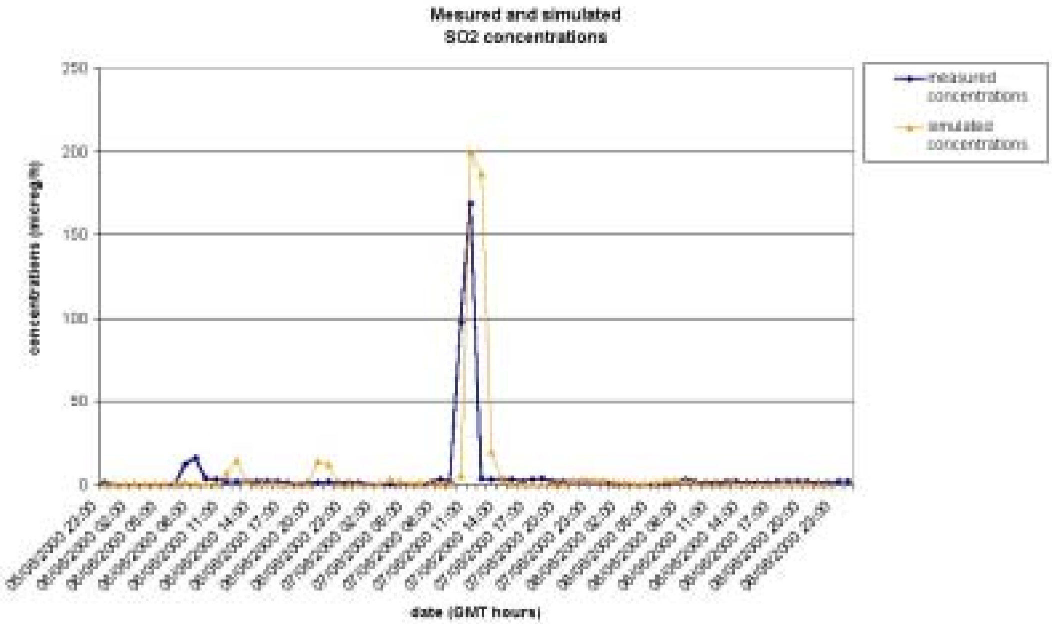
Each of these exercises was split into tuning and validation steps. These four test cases were performed using various functionalities of SAMAA:

- Meteorological conditions simulation based of data from the French national meteorological organism
- Hourly emissions calculation using the available data (road traffic, industries, residential heating and vegetation)
- GIS visualisation of the results

The concentration values calculated by SAMAA were confronted to the measured values of the local automatic observation station of the air quality survey network. The expert of the LCSQA has estimated that the performances of the system (photochemical and dispersion processing) give expected accuracy.

The industrial plumes computed with the dispersion module were well simulated and the concentration levels were coherent. This result is shown in figure 6.

Figure 6. Comparison between measured concentrations and simulated values calculated with SAMAA (dispersion study) during an industrial air pollution event



Concerning the results of the photochemical processing the identified differences between model and measures were understood (meteorological inputs, boundary condition etc.). The audit recommendations were to take into account of the boundary conditions more precisely using vertical profiles of pollutants on the borders of the domains. This has been done using the continental model CHIMERE outputs as boundary conditions as shown Figure 5.
The user SIG interface of SAMAA has been evaluated by the LCSQA, using the simulator on the city of Lille (France) for which there exists a lot of available data. The conclusion of the study was that the interface is friendly and useful.

APPLICATIONS OF SAMAA AND AIREMIS

Application of SAMAA

The version of SAMAA used by the air quality survey network of the city of Nantes (AIR PAYS DE LA LOIRE) was run on a 160*180 km^2 domain (100*110 Mi^2). It is now used by the engineers of the network as a decision management tool at regional and urban scale.
A recent French legislation imposes on large and middle sized cities having an Air Protection Plan, in which local authority have to describe their coming development program in term of impact on air quality. Within this scope, the emission module AIREMIS was used for the urban traffic plan, in order to study three traffic scenarios : one corresponding to the present state of the traffic, two were prospective scenarios (for year 2010) for the coming traffic network, with and without a new composition of the vehicles fleet.
The system SAMAA (dispersion processing) was also used by the air quality survey network in order to define the correct location to deploy automatic measurement stations around an industrial plant. The sulfur dioxide plume was simulated for various meteorological configurations. Now the air quality network is adapting SAMAA on the zone of Angers town (100*100 km^2) that belongs to its surveyed domain.

The air quality survey network of Clermont Ferrand (ATMO AUVERGNE) was also implied in the conception of SAMAA. It choose to use SAMAA as an research tool on air pollution, focussing attention to the effects of emission and meteorological conditions on photochemical phenomena of the domain.

Application of AIREMIS

A mathematical air quality system is being developed for the city of Bogota (Colombia), aiming to supply a tool able to facilitate the decision-making process for the environmental authorities. The photo-chemical model, used in the system, developed by the EPFL (Ecole Polytechnique Fédérale de Lauzanne) and called TAPOM, requires as input data the results of the emission inventory, which must be adapted to the requirements of this model. This means that the spatial and temporal distribution of the emissions must be in agreement with the selected domain for the simulation, and the spatial and temporal resolution of the mesoscale model. As a consequence, the emission module AIREMIS was adapted to the city of Bogota.

The selected domain includes an area of 212 km by 212 km, with cells of 4 km by 4 km each. Additionally, in order to fulfil the simulated episode requirements, the emissions over a two-day period of important ozone pollution were calculated (this corresponds to february 6th and 7th, 2000) with a time resolution of one hour. After the data classification and calculation, AIREMIS generates punctual, linear and areal emission results, for each source and for each pollutant. Thanks to a dedicated converter those values can then be used in the photo-chemical model TAPOM.

It is important to remember that the accuracy of the results obtained are proportional to two main aspects: (i) the precision of the collected information, and (ii) the adjustments that still need to be done in order to adapt AIREMIS to the special needs of Bogota.

Mobile sources of emissions

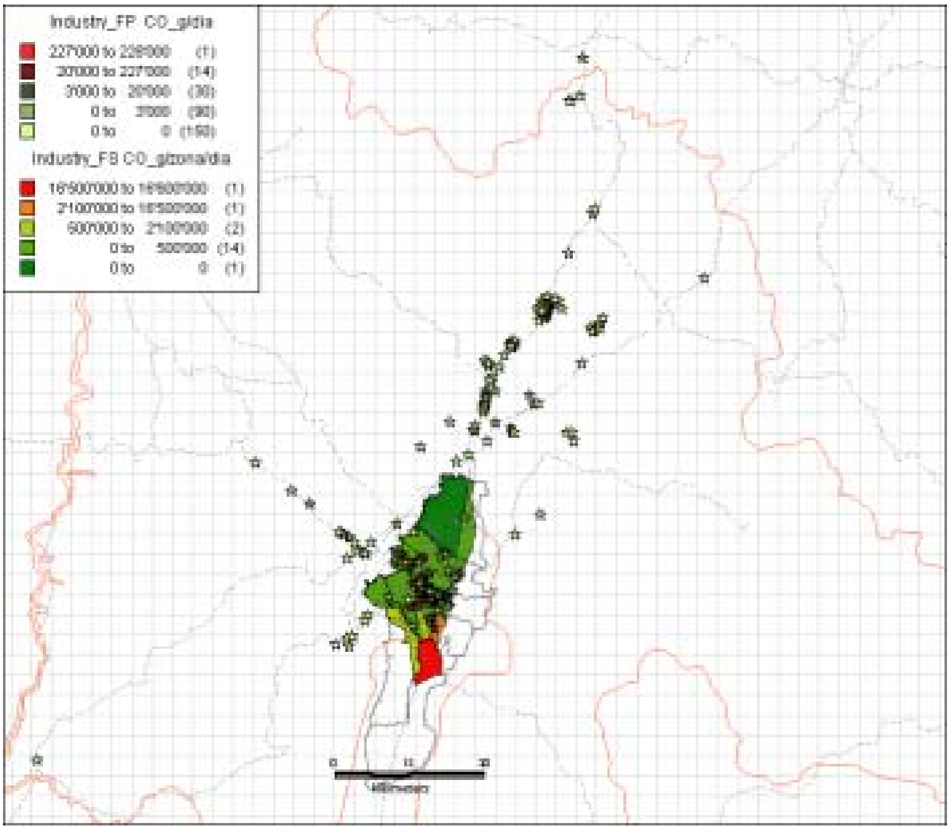
AIREMIS calculates the vehicular emissions based on three groups of basic information over the chosen domain: the georeferenced street network, the fleet, and the temporal variations of car circulation and parking. With the number of vehicles per hour circulating on each segment of the street network and their average speed, AIREMIS calculates the emission for each hour and on each segment of the network.
The street network used on Bogota is made of 2500 segments. The fleet and the temporal evolution were evaluated by running a traffic model on the basis of cars counting campaigns done on several hours and days in the main streets of the city.
The fleet composition of Bogota had to be adapted to the European COPERT III categories. As first approach it was assume that the oldest vehicles of Bogota (before 1972) were equivalent in terms of emission to the 1972 European categories. Fuel characteristics (sulphur ratio for instance) was adapted through the interface to the case of Bogota.

Spatial aggregation of results can be made by overlaying the street network together with the grid. AIREMIS create theses intersections and calculates the emission over each cell. This aggregation allows to identify the critical zones of the domain in terms of traffic emissions hour after hour.

Fixed sources of emissions

An inventory of the industrial sources has been done in Bogota. The aim of this inventory was to obtain for each source of high or middle importance, the type of industry, the location, temporal evolution of the activity and information allowing to calculate annual emission, such as production or fuel consumption data. About 4820 sources were inventoried inside the urban perimeter by a local company, including very small sources.
It was then necessary to identify if each sources had to be taken into account as individual punctual sources (such as important industrial plants), or as aggregated areal sources (weak and numerous sources such as dry cleaning shops). At this level of the work, the Data Base contains 285 punctual sources and 19 areal sources of emission on which emissions from small sources were distributed. Figure 7 presents the location of these punctual and areal sources over the region of Bogota, and the daily CO emissions values for the simulated day.

Figure 7. CO industrial emission over the domain.
Punctual sources (g/day) and areal sources (g/zone/day)



Air traffic emissions

As well as the road traffic emissions, AIREMIS calculates the air traffic emissions based on 3 groups of information: the geographical location of the runway and the airport, the aerial fleet and the number of aerial operations per day. All the necessary information were supplied by the Airport and stored in the Data Base.

CONCLUSIONS

SAMAA is a PC software that is very innovative because of its underlying GIS, its modular approach, and its user-friendly interface; it is the result of more than 6 man-years of research and development. The emission computations reflect the state of the art European experience, and respect user requirements for an acceptable computation time.

SAMAA has been used successfully as a decision making tool for the cities of Nantes, and is used as a research tool on pollution events on the city of Clermont Ferrand. Although AIREMIS is still under adaptation to the case of cities with non European characteristics (vehicles park, effect of height on emission factors) it has been proved as a good tool to manage and calculate hourly emissions of big urban areas such as the 7-million-inhabitant Bogota.

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KEYWORD
Emission
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