Using GIS for Impact Analysis from Industries Installation

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Abstract—**This paper presents a simulator that analyzes the impacts of the pollutants emission of a new industry insertion on a specific region (in our studies, at Rio Grande City – Brazil). This simulation calculates the pollutants concentration in the atmosphere, using CALPUFF non-stationary Gaussian model integrated to GIS. The goals are to assist people and responsible entities in the evaluation and air quality control.**

Keywords-social simulation; pollutants dispersion; air quality control; CALPUFF.

I. INTRODUCTION

The problems created by excessive emission of pollutants are not recent and they had significantly increased due the fast industrial growth. An alternative is to take some preventive measures by knowing the risk of the installation of a new industry on a region.

Using computational tools is an alternative to predict risks. by this way, these tools can create new possibilities for the control of air quality, because the simulations are able to predict the concentration of pollutants in the atmosphere.

In this context, the Geographic Information Systems (GIS) are emerging as robust tool, helping to organize and to have a better understanding about the results, because they have methods/objects to view, manipulate, synthesize and edit the georeferenced data [1].

In Thomasi et al. [2], GIS is used to evaluate the dispersion radius of total suspended particles and to analyze the potential risk of contamination of coastal ecosystems near to the industrial zone in Rio Grande city (Brazil), using the stationary model ISC [3]. However, a non-stationary model [4] provides a more realistic evaluation because the meteorological factors are under flotation most of the time.

The main goal of this study is to analyze the pollutants emission impacts of a new industry insertion in a specific region (in our studies, in Rio Grande City – Brazil). We are developing a simulation that calculates the pollutants concentration in the atmosphere, using the CALPUFF non-stationary Gaussian model [4] together to GIS [1]. It allows to view the damage size in areas near to the industry operations.

The paper is organized as follows: Section II presents the basic concepts of air pollution, the dispersion phenomenon and the requirements to air quality control. In Section III the tools used to implement the simulator are described. In Section IV is shown complete modeling of the simulator and the results. Finally, Section V presents the conclusions and future works.

II. POLLUTANTS EMISSION IN THE ATMOSPHERE

A. Atmospheric Pollution

Chemicals, even toxics, are not necessarily considered atmospheric pollutants, because to cause damage they have to reach a certain concentration. In this way, an atmospheric pollutant is any form of matter, that a given quantity, exceeds the limits (defined by a control agency), and it transforms the air improper [4] [5].

Therefore, the atmospheric pollution occurs when the air contaminants injure the well-being and health of people, and it cause harm to the environment [5].

B. The Dispersion Phenomenon

The dispersion mechanisms of pollutants in the atmosphere are governed by fluctuations in wind fields and turbulence [6].

The main meteorological factors that influence the atmospheric dispersion phenomenon are wind, temperature, high and low pressure and terrain. The meteorological factors in the region can contribute in a positive or negative way in the mixing of contaminants with clean air. These factors could cause a quick or slow dispersion pollutants.

According to Saraiva and Krusche [7], the main damaging weather conditions to the pollutants dispersion in our study region are: high pressure associated with light winds, low temperature and high humidity.

C. Air Quality

The air quality standards are a control strategy used to indicate the maximum concentration of pollutants that could be issued to preserve the health and well-being of the population, flora, fauna and the environment in general [5].

The pollutants group responsible for controlling air quality, basing to their frequency in the environment, is composed of: sulfur dioxide (SO_2), particulate matter (PM), carbon monoxide (CO), ozone (O_3) and nitrogen dioxide (NO_2). In this work only SO_2, CO and NO_2 are considered to evaluate the emission of air quality.

Excessive exposure to pollutants causes damage. Therefore, the great importance of the emissions control is to preserve the life quality of people and also the environment preservation [4]. According to the resolution of CONAMA – The Brazilian National Environmental Council [5], there are specific levels of emissions that are allowed, ranging from the lowest level of "attention" to the higher level of "emergency", as shown in Table 1.

TABLE I. STANDARDS OF AIR POLLUTION BY BRAZILIAN NATIONAL ENVIRONMENTAL COUNCIL (CONAMA).

	LEVELS		
Parameters	**ATTENTION**	**ALERT**	**EMERGENCY**
Sulfer Dioxide - SO_2 ($\mu g/m^3$) - 24h	**≥ 800**	**≥ 1.600**	**≥ 2.100**
Carbon Monoxide - CO ($\mu g/m^3$) - 8h	**≥ 17.000**	**≥ 34.000**	**≥ 46.000**
Nitrogen Dioxide - NO_2 ($\mu g/m^3$) - 1h	**≥ 1.130**	**≥ 2.260**	**≥ 3.000**

III. USED TOOLS

This section describes the tools used to develop the simulator. These tools were chosen because of their availability, documentation, generation and manipulation of maps interatively.

A. MATLAB

The MATLAB [8] is a programming language with several libraries that allow us to perform a series of scientific calculations, statistics, solution of linear differential equations, engineering calculations, etc. Moreover, it has specific libraries to work with neural networks, filtering, bioinformatics, telecommunications, imaging, digital signal processing, automation, GIS and others.

In this work, to automate the processes of file management, data import, creation, manipulation and presentation of maps and their respective layers, we have chosen the GIS library (called "mapping toolbox"). This library was also important to perform post-processing data of the CALPUFF model and results analysis

B. Mapping Toolbox

The mapping toolbox [9] is a library of specific functions that allow us analyzing geographic data, create and manipulate maps. It imports both vector and raster type data. It also has support to the most common file formats, such as shapefile, GeoTIFF and DEM SDTS. In addition, it is possible to import data from WMS servers (Web Map Service). Thus, the developer can customize his application in subsection, side view, intersection and other methods.

The toolbox features allow us to develop customized solutions for various geographic problems. Some of these features allow that different layers data can be easily manipulated and presented in the same map.

Other features that also deserve attention are those that allow you to convert different types of coordinates, facilitating the use of data from different sources and to allow you to save all creation and manipulation of files that can later be analyzed by users of GIS software.

C. GIS - Geographic Information System

The GIS (Geographic Information Systems) [1] are softwares that manage, view and manipulate geographic data computationally. They allow that each set of data can be presented in different layers.

The layers are composed by a set of features of geographic objects. These objects have an infinite variety of shapes, but they can be represented basically by three different shapes: polygons, lines or points. Polygons represent things that have limits such as countries, states, cities or lakes. Lines represent narrow things such as streets, roads, rivers or railroads. Points are used to small things such as buildings, hotels, schools, fire hydrants or poles. The union of polygons, lines and points generates the vector data.

Therefore, GIS are used for better understanding the patterns, relationships and trends in the data. Many times, those information are not obvious to find in databases.

IV. THE PROPOSED SIMULATOR

This section presents a complete simulator modeling that uses a non-stationary model of pollution dispersion. The non-stationary models can be Eulerian, Lagrangian and Gaussian [10]. The Eulerian and Lagrangian models have a high computational cost due because they need to solve complex equations. It requires parallelization to obtain a satisfactory response time. On the other hand, the Gaussian models do some simplifications that it allows a faster response, making it attractive for real time applications.

This work uses the CALPUFF non-stationary Gaussian model that allows the prediction of risks caused by one or more industries in a specific period of time, varying the weather conditions in space and time [11].

Calpuff model is recommended by U.S. EPA (Environment Protection Agency) due to be working with a micro-region and it can handle complex three-dimensional wind fields. It is easy to setup and run for point sources with multiple parameters.

The Gaussian models do not have accuracy when we use a complex topography or emissions near the ground. In our experiments, these factors are not relevant because the simulated region has a flat terrain and their emission sources have a certain distance from the ground. The work aims to develop a tool to help the community and responsible entities in decision-making, visualization and evaluation of possible risks caused by the emission of pollutants from industries, without the concerned of accuracy.

The proposed simulator integrates the Gaussian CALPUFF model to MATLAB in order to automate their execution. The Matlab Mapping Toolbox saves and presents the output data in a vector layers and it can be manipulated in GIS softwares.

A. The Modelling of Proposed Simulator

In this stage of the project, the goal of the simulator is to predict what will be the risks in a specific region by the pollutants emission caused by the insertion of one or more industries. The result of the simulation is a layer with georeferenced points containing the concentration of certain pollutants. The simulator calculates the pollutants concentration resulting from one or more emissions.

The simulator is divided in two modules: CALPUFF model execution and maps' manipulation. According to the flow diagram, shown in Figure 1, the basic inputs to start the

 ISBN: 978-1-61208-178-6

simulation are: the shape file containing the map of the interesting region and the output shape file names. The simulation returns the files with georeferenced points.

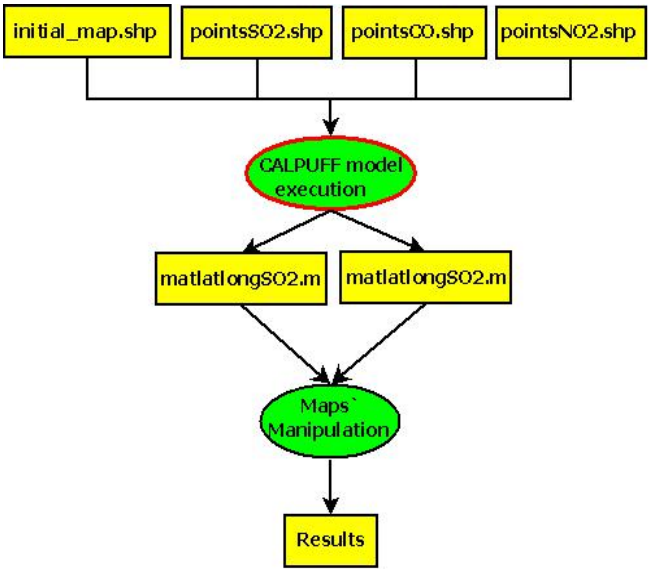

Figure 1. Data Flow Diagram to use the CALPUFF non-stationary Gaussian model.

In the CALPUFF model execution stage, all the settings and procedures for their execution are made and these steps are explained in greater details later. The output of this module has two georeferenced matrices containing latitude, longitude and pollutants concentration in the points. These matrices will be the inputs of the next step (maps manipulation) and they have the function of read, write, manipulate and present the vector files. Three structures are created, one for each pollutant to control the air quality: SO_2 (sulfur dioxide), CO (carbon monoxide) and NO_2 (nitrogen dioxide), containing the attributes shown in Table II. The elements of these structures are filled with the input values. After this procedure, three layers are created, one for each pollutant, which are the simulator output files.

TABLE II. STRUCTURE OF THE POINTS

Attribute	Type	Description
Geometry	*string*	Geometry of the point;
BoundingBox	[2x2 *double*]	Extreme of the point;
X	[1xN *double*]	X coordenates set in the point;
Y	[1xN *double*]	Y coordenates set in the point;
POLLUTION	*double*	Calculted pollution level by Gaussian model;
LOCAL_X	*double*	X coordinate of the location of the center point;
LOCAL_Y	*double*	Y coordinate of the location of the center point;

The last step of the simulation is to present the results, as shown in the Figure 2. The pollutants shape file is superimposed on the map of the interesting region, providing a better interface to analyze the results. In this map, the colored points refer to calculated concentration degree of the model. The Figure 3 is showing the value of the concentration pollution of each pollutant in µg/m^3.

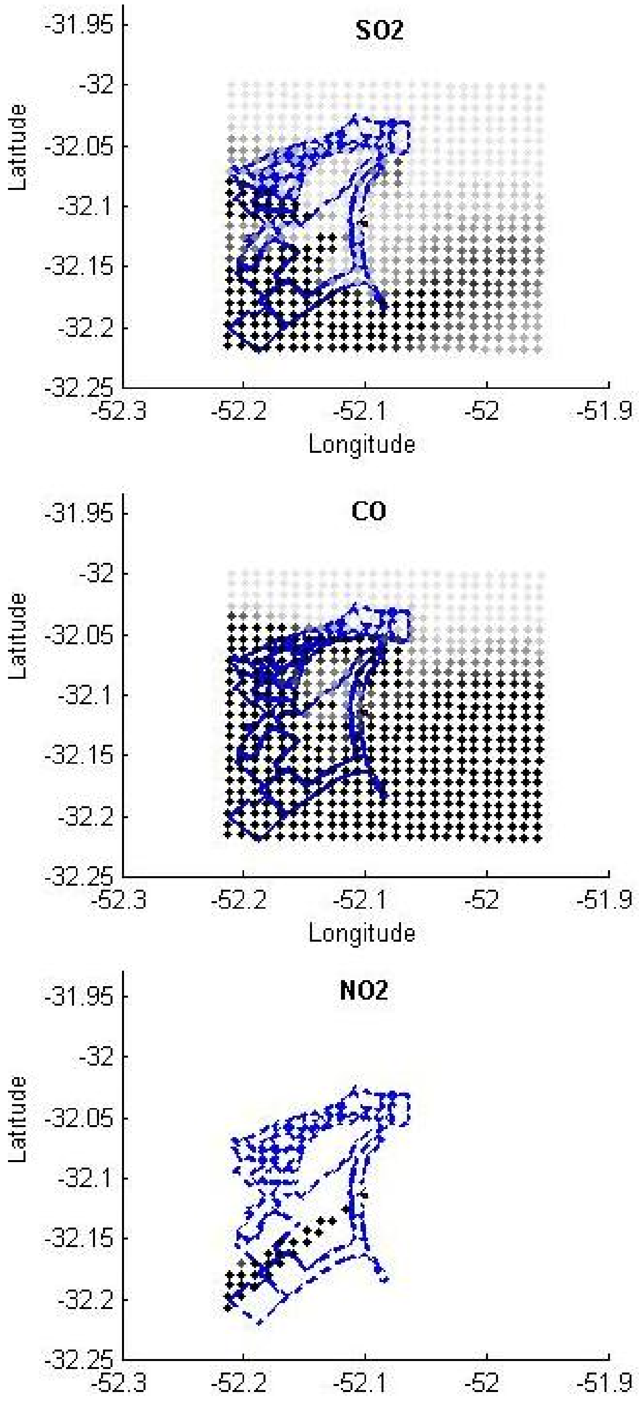

Figure 2. Results presentation.

B. *Propagation Model of Pollution*

The chosen model for the pollutants propagation in the atmosphere is the CALPUFF non-stationary Gaussian model. It is a puff Gaussian model used to simulate continuous puffs of pollutants emitted by a source to receivers according to the wind flow in the environment [12].

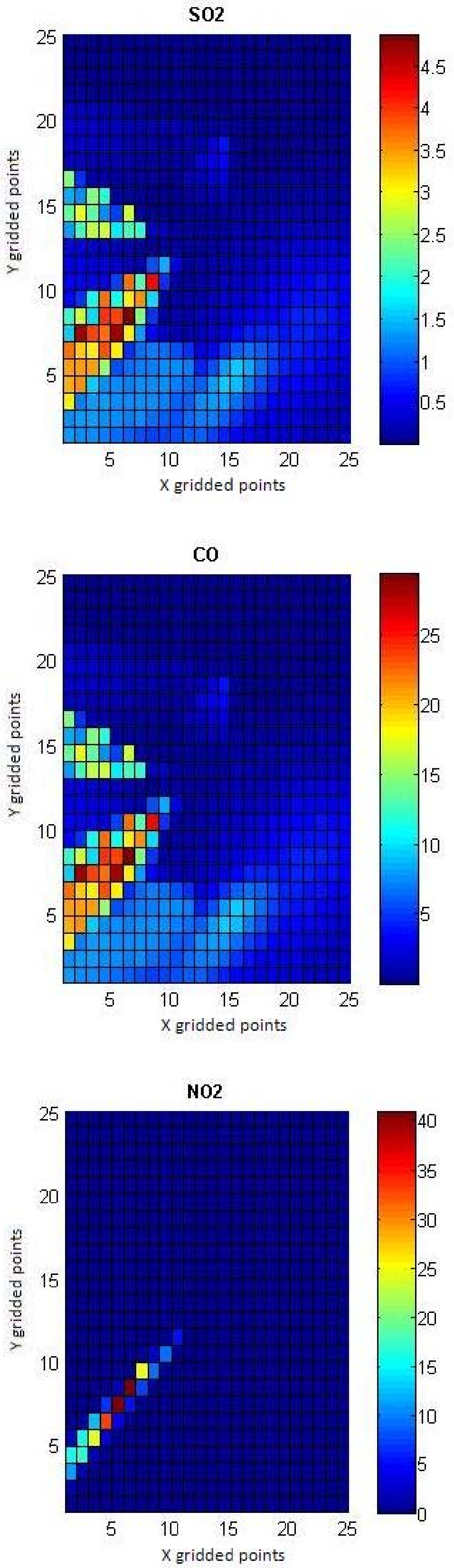

Figure 3. Georeferenced bidimensional arrays.

The plume, in these models, is represented by a set of discrete puffs of polluting material [6], as shown in Figure 4.

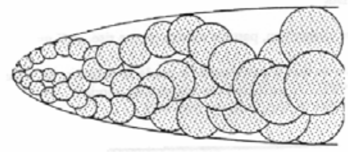

Figure 4. Representation of the plume in CALPUFF model

The puffs mass is dispersed according to a Gaussian distribution. The transport is made according to the trajectory of its mass center and the local wind vector speed [6].

The wind changes every hour, changing also the puffs path to the wind flow. While the puff is transported in the air, its pollutant concentration decreases. If the puff finds out other receptor, a new pollutant material is increased to it [12].

The Equation (1) is the basic equation to provide the contribution of a puff on a receiver [4]. To discover the total concentration of a receiver, it is necessary to add the concentration of neighborhood puffs of a particular receiver.

$$C = \frac{Q}{2\pi\sigma_x\sigma_y} g \exp\left[-d_a^2/\left(2\sigma_x^2\right)\right] \exp\left[-d_c^2/\left(2\sigma_y^2\right)\right] \quad (1)$$

where C is the ground-level concentration (g/m^3), Q is the pollutant mass (g) in the puff, σ_x is the standard deviation (m) of the Gaussian distribution in the along-wind direction, σ_y is the standard deviation (m) of the Gaussian distribution in the cross-wind direction, σ_z is the standard deviation (m) of the Gaussian distribution in the vertical direction, d_a is the distance (m) from the puff center to the receptor in the along-wind direction, d_c is the distance (m) from the puff center to the receptor in the cross-wind direction, g is the vertical term (m) of the Gaussian equation, [2].

C. Related works

In this subsection, we present some works that use CALPUFF in different domains. In Zhou et al. [13] is calculated the fraction of particulate matter emitted by power plants, using the CALPUFF model to estimate the risks for which the population is submitted to be exposed to these pollutants. MESOPUFF II method is used for simulation of chemical transformations. The dry deposition is modeled to gases and particles and the wet deposition for liquid precipitation. The internal plume increases are calculated as a function of some effects, as vertical wind shear and floating feather.

Levy et al. [14] make the assessment of emissions by power plants. It uses the NOAA'S RCU2 model to generate climatological data, spatial and temporal inputs to the CALMET grid. Simulation results compare the emission sources, in order to find the most polluted.

 ISBN: 978-1-61208-178-6

In Barsotti et al. [15], the CALMET is used to generate three-dimensional fields (wind and temperature) and two-dimensional (friction velocity, Obukhov length, atmospheric boundary layer height and so on). This work presents a CALPUFF based model called VOL-CALPUFF to simulate the launch, the transport and the volcanic ashes deposition.

D. CALPUFF Model Execution

The CALPUFF model execution in the simulator is responsible for setting up all files and parameters needed to run the model. With this analysis, is possible to observe the entire operation of the system.

Initially, the terrain configurations are made based in a file that has the *x* and *y* coordinates of all terrain and elevation. To obtain these information is necessary to run the TERREL.

TERREL is a preprocessor to create the terrain elevation data from multiple databases to a grid specified by the user [4]. This preprocessor has a control file where the scanned files are assigned. According to the flow diagram in Figure 5, the first thing is to obtain the terrain and topography grid, using files available in WebLakes [16]. The next step is to configure these files as input to the control file terrel.INP. Once that is done you can run the module *runTerrel*. This preprocessor provides as output a formatted file containing the coordinates in UTM X, Y and Z (elevation of the land).

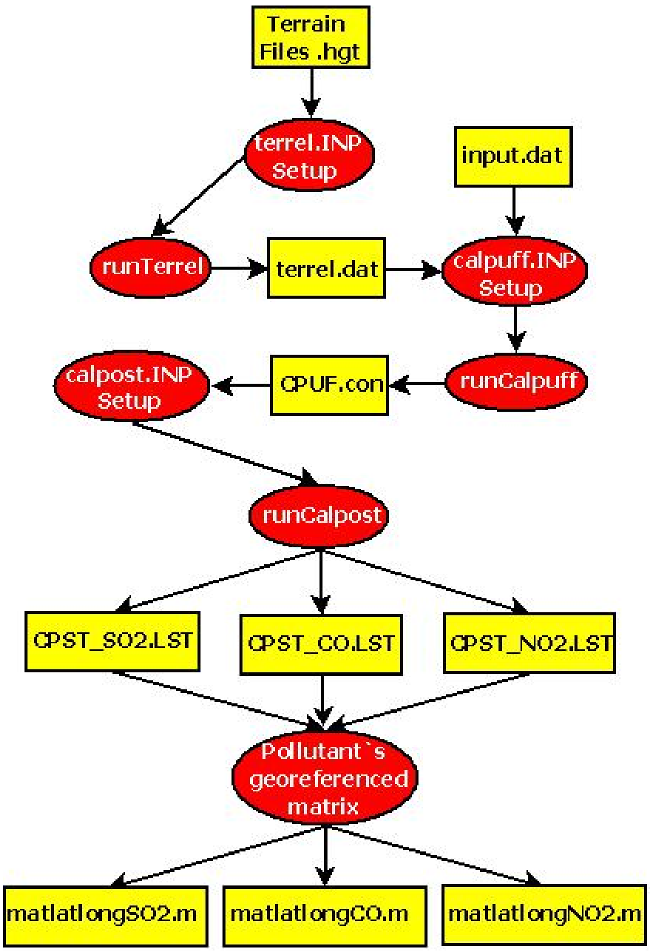

Figure 5. Steps of CALPUFF model execution

After obtaining the characteristics of the terrain, the next module is responsible for the configuration of the control file of the CALPUFF model. In this module, two files are needed as input: the terrain file (terrel.dat) and the region weather setting file (input.dat). The terrain file is provided from the preprocessor TERREL and the region weather file is a formatted file containing: day, month and year of data, simulation hours (1-24 hours), wind direction in degrees, air temperature (° C), Pasquill stability class [4] and the planetary boundary layer height (m). With these inputs and the configured control file calpuff.INP, it is possible to run the execution module of the CALPUFF (runCalpuff). This module generates its output as a binary file (*conc.dat*) that contains an average grid of pollutants concentrations, which were simulated in a period of time.

To calculate the concentrations, the conc.dat file must be executed in CALPOST postprocessor [4]. For that, firstly, the calpost.INP configuration module should be setted with the runCallpuff. After it, the runCalpost should be executed to the number of species issued. In this work, we have issued three species: SO_2, CO and NO_2. As output files are provided cpst_so2.LST, cpst_co.LST cpst_no2.LST and these files provide the concentration values in each grid point.

The last step is the creation of the georeferenced matrices that have the concentrations and converted UTM coordinates to latitude and longitude coordinates for each gridded point.

E. Simulation Scenario

We have chosen the industrial zone in Rio Grande city, in southern Brazil, to evaluate the model. The city has a large number of industries which emit a large quantity of pollutants in the atmosphere.

The simulator allows the user customizes the industry features to be inserted, according to their emission profile. The following features can be modified according to the desired simulation scenario: latitude and longitude, elevation, height and diameter of the stack, speed and temperature of the pollutant output and emission rates of pollutant source.

In our tests, the industry is located at latitude 52.1045S and longitude 32.1167 W. In Figure 6 are shown the neighborhood map of the Rio Grande city, highlighting the industrial zone. This region has the following characteristics: void elevation, because it is situated at sea level; 30 meters of stack height; 5 meters of stack diameter; output speed 5m/s; output temperature 195.3°C; and the following emission rates: 7.4 de SO_2, 44.39 de CO e 88.78 de NO_2, all in g/s.

The meteorological data in the simulator are: wind direction and speed, air temperature, and Pasquill stability class [4]. All these data were captured by the meteorological station at Universidade Federal do Rio Grande (FURG).

The used data correspond to a period of 24 hours in a day, with a propitious situation for pollutant dispersion, because these data present low pressure, light winds and medium temperatures.

F. Results Analysis

According to the scenarios described earlier, this section will analyze the consequences from emissions of the pollutants SO_2, NO_2 and CO in accordance with current legislation [4].

 ISBN: 978-1-61208-178-6

The chosen model (CALPUFF) provides the greatest values of pollutants concentration in a specific period. The highest values are compared with the data in Table I, that presents tolerable limits defined by law in Brazil, CONAMA [5].

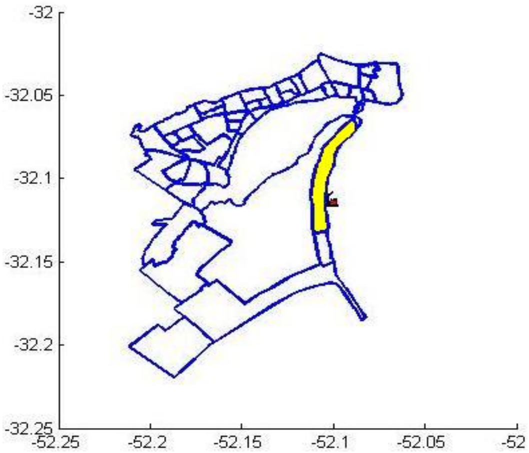

Figure 6. Industrial zone and industry location

The Figures 2 and 3 present the results of pollutants concentration to the SO_2 emissions (in 24 hours), the CO emissions (8 hours) and NO_2 emissions (1 hour).

According to the simulated results, the concentration of CO reached 28.019 mg/m³, the SO_2 reached 4.8623 mg/m³ and NO_2 reached 40.8490 mg/m³. Basing in Table I data, these values do not indicate a problem, because they do not even reach the lower limit (attention level). However, this is a hypothetical simulation in order to test the applicability of the proposed tool, because we had simulated just 24 hours and considered a single emission source. In real situations, the industrial interesting region has many industries with more than one source operating in continuous periods of time. Moreover, the effects of air pollution are cumulative. In this way, we believe that a simulation with a long period and many emission sources will create an attention level (or a worse situation).

Although the related work presented in subsection C helps in calculating the concentration of pollutants, both use the CALPUFF associated with complex weather forecasting models that have high computational cost.

Our results offer an estimate that is not so accurate due to the CALPUFF simplifications, but it allows application's real-time execution.

Furthermore, this paper presents graphic results that can be easily understood. The application allows saving the results generated in vectorial files. The application helps people and responsible entities in risk's evaluation using GIS software.

V. CONCLUSION AND FUTURE WORKS

This paper presented a simulator that use the CALPUFF non-stationary Gaussian model integrated with GIS. The idea is to analyze the air quality when new industries are inserted in a specific region.

As showed in section IV, the CALPUFF model is very complex to execute, but it presents complete data about pollutant dispersion.

Historically, the Rio Grande city (Brazil) has problems with air pollution and few works explore this scenario. The second reason to choose this region is because we live here and we believe that computational tools could help a better understanding about environmental problems and improve the people lives.

Our initial tests, using a hypothetical situation, just help to analyze how the CALPUFF model processes the data. As further work, we will execute the model for a long period (probably two years) and many emission sources (more than twenty). This new scenario will present a more realistic situation, and more comparisons will be done.

ACKNOWLEDGMENT

We thank FAPERGS (Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul – Brasil) for funding research and development. Grant Number 10/0049-7.

This is a multidisciplinar project. Therefore, we will like thank you the Dr. Jonas Carvalho, to help in the understanding of CALPUFF model and the initial data of the meteorological station of Rio Grande.

REFERENCES

[1] Câmara, G., Casanova, M.A., Hemerly, A., Medeiros, C.M.B. and Magalhães, G., “Anatomia de Sistemas de Informação Geográfica”, Curitiba, Editora SAGRES, p. 205, 1997.

[2] Thomasi, C. D., Nunes, G., Tolego, R., Jugueiro, M., Teixeira, P., Adamatti, D. F. and Tagliani, C., ”Um sistema para previsão de impactos gerados pela instalação de indústrias e sua influência sobre ecossistemas costeiros no extremo sul do Brasil”, In: III WCAMA 2011, pp. 1455-1464 Natal / RN, 2011.

[3] EPA - Environmental Protection Agency, ”User´s guide for the industrial source complex (ISC3), dispersion models volume II – Description of model algorithms”, p. 128, 1995.

[4] Scire, J.S., Strimaitis D.G. and Yamartino, R.J. “A user’s guide for the CALPUFF dispersion Model (Version 5)”, Earth Tech. Inc. 196 Baker Avenue, Concord MA 01742, p. 521, 2000.

[5] Conselho Nacional de Meio Ambiente (CONAMA), “Resolução N.º 003”, Brazil, 28/Jun/1990.

[6] Moraes, M. R., “Ferramenta para a Previsão de Vento e Dispersão de Poluentes na Micro-escala Atmosférica”, PhD. Thesis, Universidade Federal de Santa Catarina, UFSC, p. 166, Brasil, 2004.

[7] Saraiva, L. B. and Krusche, N., “Condições Atmosféricas Favoráveis à concentração de Poluentes em Rio Grande, RS”, resumos do II Congresso em física da camada limite planetária e modelagem de processos de dispersão. Santa Maria, RS. v.1. p.14. 2001.

[8] MathWorks, “MATLAB - Introduction and Key Features”, available: www.mathworks.com/products/matlab/description1.html accessed in: 28 Nov. 2011.

[9] MathWorks, “Mapping Toolbox Introduction and Key Features”, Available: www.mathworks.com/products/mapping/description1.html accessed in: 28 Nov. 2011.

[10] Vilhena M. T.,Carvalho J. C. and Moreira D. M., “Tópicos em turbulência e modelagem da dispersão de poluentes na camada limite planetária”, Porto Alegre, Editora da UFRGS, p. 260, 2005.

[11] Vallero D. A. “Fundamentals of air pollution”, Civil and Environmental Engineering Department Pratt School of Engineering Duke University Durham, North Carolina, p. 967, 2008.

[12] EPA – United States Environmental Protection Agency, “A Comparison of CALPUFF with ISC3”, Office of Air Quality Planning and Standards Research Triangle Park, NC 27711, EPA-454/R-98-020, p. 50, december 1998.

[13] Zhou Y., Levy J.I., Hammitt J.K. and Evans J.S., “Estimating population exposure to power plant emissions using CALPUFF: a case

study in Beijing, China", Atmospheric Environment, 37, pp. 815–826, 2003.

[14] Levy, J.I., Spengler, J.D., Hlinka, D., Sullivan, D. and Moon, D., "Using CALPUFF to evaluate the impacts of power plant emissions in Illinois: model sensitivity and implications", Atmospheric Environment 36, pp. 1063–1075, 2002.

[15] Barsotti, S., A. Neri, and J. S. Scire, "The VOL-CALPUFF Model for Atmospheric Ash 1 Dispersal: I. Approach and Physical Formulation", Istituto Nazionale di Geofisica e Vulcanologia, Journal of Geophysical Research, Pisa, Italy, p. 113, 2008.

[16] Lakes Environmental Software. Available: http://www.weblakes.com, acessed in: 28 Nov. 2011.