ENVIRONMENTAL INFORMATION SYSTEM FOR ANALYSIS AND FORECAST OF AIR POLLUTION (APPLICATION TO SANTIAGO DE CHILE)

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ABSTRACT

In Santiago de Chile and other cities in Chile, air pollution is a dramatic problem. An Environmental Information System (EIS) based on air quality models is extremely valuable in order to support users in governmental administrations and industry with forecasting and operative decision-making as well as short to long-term regional planning. Using a model-based EIS for air pollution it is possible (i) to study complex source/receptor relationships, (ii) to optimize air pollution abatement strategies either locally or in a larger region, and (iii) to forecast the air quality for urban and industrial regions. The paper presents issues of a joint project of Universidad Catolica de Chile and GMD FIRST which objectives are the exchange of know how in the fields of EIS design and the use of air quality models, the installation of a model-based EIS for air pollution for Santiago de Chile including the acquisition of necessary input data, the study of the particularities of the Santiago region and the demonstration of the functionality of the EIS in terms of analysis and forecast of air pollution.

INTRODUCTION

The city of Santiago (33.5ºS, 70.8ºW) is located in a basin bounded by the high Andes (4500 m altitude on average) in the central part of Chile. To the east, a lower parallel mountain range to the west (1500 m altitude on average), and two east-to-west mountain chains to the north and south of the basin respectively. Nearly one third of the population of Chile (i.e., about five million people) lives in the metropolitan area of Santiago. Thus private and public transportation, domestic and industrial energy consumption and other activities are brought together and large emissions of pollutants take place (see Table 1). The average meteorological conditions are unfavorable for the dispersion of air pollutants in the basin, especially during fall and winter (Aceituno, 1988). These stagnant anticyclonic conditions are further intensified in fall and winter by the presence of sub-synoptic features such as the coastal-lows (Rutllant and Garreaud, 1995). In spring and summer, the relatively larger insolation determines an increase in the depth of the mixed layer counteracting the accumulation of pollutants. Nonetheless, actinic fluxes are also increased during spring and summer accelerating the occurrence of a great deal of photo chemical reactions.

Chilean environmental authorities have through the years established monitoring networks for assessing the air quality of Santiago. Especial attention has been paid to health effects. The concentrations of pollutants in Santiago frequently exceed Chilean and international air quality standards. Therefore, an attainment plan has been established (CONAMA-RM, 1997). This plan considers a number of long-term measures intended to prevent and curb the air pollution problems of Santiago and surrounding areas. In addition, a number of short-term measures are put in place in wintertime when the air quality standards of inhalable particulate matter (PM10) are exceeded. Until 1998, authorities were not allowed to apply these measures unless the air quality observed in the monitoring stations exceeded the standards.

The law was changed in 1998, making it possible to apply preventing measures according to the predictions of forecast tools. Hereto, the forecast tool used is a statistical model that takes the tendencies in the measurements, the emission patterns and the meteorological situations into account (REF Norma de PM10). Other statistical models are now being developed (Cassmassi, 1999). Numerical models, which describe emissions, transport, chemistry and deposition processes of the atmospheric constituents have not been applied yet for forecasting air pollution events. This type of models have been applied so far as diagnostic tools, mainly as an input for establishing cost-efficient long-term pollution control measures.

Source	PM	CO	NO_x	VOC	SO_2
Stationary	3	4	11	1	17
Mobile	2	225	30	22	3
Other	37	16	3	39	1
Total	42	245	44	62	21

Table 1. Emissions of particulate matter (PM), carbon monoxide (CO), reactive nitrogen oxides (NO_x), volatile organic compounds (VOC), and sulfur dioxide (SO_2) in Santiago. Unit: 10^3 tons per year. Source: CONAMA-RM, 1997.

In the near future, photochemical pollution will also require of environmental information systems with prognostic and diagnostic capabilities. The system we describe (DYMOS) might contribute in this respect, broaden up the available battery of modeling tools. The first steps towards the implementation of this tool are presented.

DISPERSION MODELING IN SANTIAGO

In Chile, the models most frequently applied for environmental assessments are Gaussian models developed by the Environmental Protection Agency of the United States. The majority of such applications consider the dispersion of pollutants in the surroundings of stationary sources, mainly within the intensive copper mining industry. These tools are, of course, inadequate for assessing the severe air pollution problems that affect Santiago. Such urban and regional air pollution problems involve several spatial and temporal scales for which local, mesoscale and synoptic transport patterns must be considered. Chemical and physical transformations occurring within these temporal and spatial scales must also be taken into account for such problems.

In the 80's and in the first half of the 90's, several initiatives, mostly developed within the universities, approached different aspects of the dispersion of pollutants in Santiago. Some work was made in describing the meteorological features that control the dispersion of pollutants in the area (Ruttlant and Garreaud, 1995; Ulriksen, 1993). A few attempts were made for implementing models to assess the dispersion of quasi-inert tracers such as carbon monoxide (Ulriksen, Rosenbluth and Muñoz 1992).

Since the mid 90's, under the National Commission for the Environment (CONAMA), strong efforts have been made for establishing emission inventories, meteorological and air quality networks. Air quality data has been monitored regularly ever since in Santiago (see Figure 1). The air quality stations have been placed to assess, mainly, health effects due to air pollution in Santiago. Also, several monitoring campaigns have been made (e.g., Artaxo, 1998). In addition, a network of meteorological stations has been put in place. The meteorological network (ca. 22 stations) was designed to capture meso-scale meteorological features induced by complex topography in the area.

A complete emission database has been developed for the Metropolitan area of Santiago (REF CONAMA RM). All this data begins to make it possible the meaningful modeling of applications for meso and regional scale problems. An information system that includes a dispersion model for inert tracers has been applied for assessing the dispersion of CO and PM10 on the urban scale. Also, a meso-scale meteorological model has been implemented for Santiago (CENMA, 1999). A first attempt to assess the regional distribution of, mainly, oxidized sulfur by means of a transport model fed with meteorological fields calculated by a limited area model has been recently presented (Gallardo et al., 1999; Robertson et al., 1999). Also, at

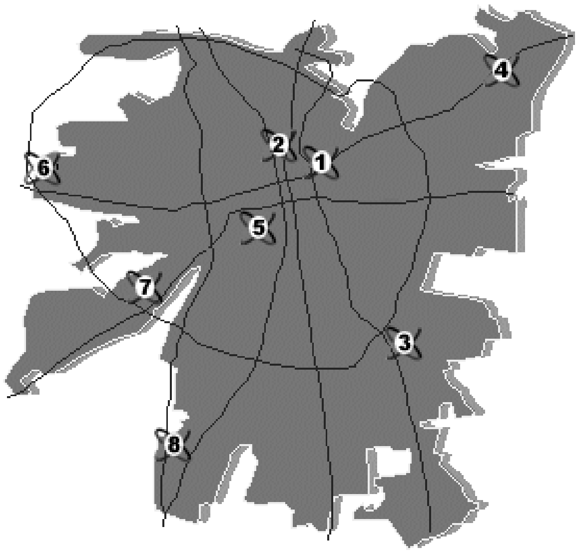

Figure 1. City of Santiago (33.5ºS, 70.8ºW) and location of the monitoring stations. Source: Servicio de Salud Metropolitano del Ambiente (SESMA).

the University of Chile a regional meteorological model, which may provide useful input data for dispersion applications, has been implemented (Garreaud, pers. communication).

It must be pointed out that the majority of the ongoing modeling efforts and initiatives are strongly linked to international cooperation agreements. This helps in creating the required local know-how in atmospheric chemistry, meteorology and informatics for approaching the increasing demands for reliable environmental modeling applications in Santiago and elsewhere in Chile. In the next section, a modeling system (DYMOS) designed to assess photochemical processes is presented. This tool, that has the necessary functionalities for simulation, prediction and visualization of air pollution, must be considered as complementary to the available models and as a contribution that enlarges the battery of tools for decision making and research in atmospheric modeling in Chile.

THE DYMOS SYSTEM

At GMD FIRST the DYMOS system has been developed (Sydow et al. 1998), a parallelly implemented air pollution simulation system for mesoscale applications. DYMOS consists of different meteorology/transport models for different application purposes including an air chemistry model for the calculation of photochemical oxidants like ozone. The core of the model system is formed by a hydrostatic mesoscale Eulerian model with a low vertical resolution for fast operational forecast tasks (enhanced version of REWIMET, Heimann, 1985) and a non-hydrostatic mesoscale Eulerian model with a high vertical resolution and complex parameterization facilities (enhanced version of GESIMA, Kapitza and Eppel, 1992). In addition, Eulerian and Lagrangian transport models are included within DYMOS. The air chemistry model CBM-IV (Gery, Whitten, and Killus, 1988) is dealing with 34 species in 82 reaction equations for simulating the photochemical processes in the lower atmosphere.

Using the DYMOS system, analyses can be performed regarding winter smog (high concentrations of inert pollutants), summer smog (high concentrations of ozone and other photochemical oxidants), and single components (e.g. heavy metals, benzol, radioactive or antigenic substances). In addition to providing a dynamic emission source for the smog forecast simulations, traffic flow modeling has become a research field within DYMOS in its own right. Emphasis is put on the analysis of critical states in urban traffic systems. Due to the research work with basic character carried out in DYMOS, a foundation has been set for further, more applied projects.

Various case studies of summer smog conditions in urban areas have been carried out using the DYMOS system. The Department of Environment of the Berlin state government and the Ministry for Environment of the state Brandenburg commissioned summer smog analyses for the results of the FLUMOB measuring campaign carried out in July 1994. Greenpeace commissioned an analysis of the influence of emissions caused by traffic in Munich on the ozone concentration in the Munich area. The analysis was performed for a typical mid-summer day in 1994. Within the subproject PATRIC the DYMOS system coupled with an Petri-net-based traffic flow model was used to analyze the traffic induced air pollution of the City of Budapest.

In order to inform the public about ozone concentrations, the DYMOS system is currently in use for the operational daily forecast of near surface ozone concentrations in the Berlin-Brandenburg region (Mieth, Unger, and Sydow, 1998). In cooperation with the Department of Environment of the Berlin state government, the Institute of Meteorology of the Free University of Berlin and Inforadio Berlin, the predicted concentrations are presented as raster images for defined day times and as MPEG movie for the whole day and can be found on the WWW (http://www.first.gmd.de/ozon/).

DYMOS SYSTEM IN CHILE: FIRST STEPS

The first steps towards the implementation of a set-up of the DYMOS system for simulating and visualizing atmospheric pollution in Santiago have started to be taken.

In order to apply the system DYMOS to forecast the level of pollutants in the Metropolitan region of Santiago, it has been judged to be necessary, according to the experience with DYMOS, to divide this area into a network of square grids, each of them with an area of 4 km^2. After this, it is necessary to provide three kinds of data for each grid: static data (elevation), slowly varying data (land use) and rapid varying data (emission and meteorological information).

The set-up considers a domain of 54 km in the east-west direction and by 86 km in the north-south direction. Initially, the vertical resolution is not specified. It includes 1.161 grids-points of 2x2 km^2, covering the urban area of Santiago. This area was chosen in a first step because that is the area for which data is available. In a second phase, for photochemical simulations probably a larger domain would be required, one considering and the big mountains around the city, because they will certainly affect the calculations, at least when calculating the meteorological fields.

The static data and the slowly varying data were determined by using satellite photographs of the domain. They were obtained from the “Remote Perception Center” of the Catholic University of Chile. From them, and for each grid, an average elevation and the percentage of water, meadows, forest, suburban and urban area were computed.

As we mentioned before, the rapid varying data includes emissions and meteorological information. Emission data of nitrogen oxides (NO_x), carbon monoxide (CO) and volatile organic compounds (VOC) from industries, houses and vehicles are included. Annual averages have been provided by the metropolitan branch of CONAMA, CONAMA RM, (REF CONAMA-RM). On the basis of this information, we are now working on estimating emissions per day and per month. The Transportation Engineering Laboratory of the Catholic University of Chile is providing information about vehicle emissions in several places in Santiago. By applying a transportation model, ESTRAUSS, to these data, it is possible to obtain an estimate of vehicle emissions in every street in Santiago.

Meteorological data to initialize the model, i.e. air temperature, winds, cloud-coverage, etc. will be obtained from the observations provided by the meteorological network of the Santiago basin and by the European Center for Medium-Range Weather Forecasts (ECMWF).

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