An anthropogenic and biogenic emission model over Madrid area for photochemical mesoscale models by using Landsat satellite data

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Abstract

A critical element in the description of atmospheric chemistry is an accurate spatial and temporal inventory of the different compounds. Some of them are passive \( \text{(SO}_2 \) and others are very reactive \( \text{(NO}_x, \text{VOC}'\)s). The anthropogenic emissions are usually accounted following the CORINAIR and EPA methodologies. In this paper, we present an accurate point, line and area emission distribution over the Madrid mesoscale urban area which includes a geometrical surface of 80 x 100 km with 2000 m resolution. A special part of the inventory is that which is produced by the traffic. We have considered different types of vehicles with different emission factors for different running conditions and for different pollutants. The \text{VOC}'s emissions are mainly taken from the traffic and we have not considered those from four main sources: running losses, hot soak losses, diurnal losses and refueling losses. Finally, the residential and industrial facilities are also modelled following the different methodologies for accounting the emission factors. For accounting the biogenic hydrocarbon emissions produced by the different vegetation canopy environments we are using data from the thematic mapper Landsat-5 satellite which has a 30-m resolution and by using a Bayesian algorithm we are able to cluster the different spectral signatures into several groups which can be identified as a different land-use type. The land-use classification is also used in the Photochemical Transport Models for accounting the updraft and downdraft momentum, heat and vapour fluxes and for the deposition modules for accounting the canopy resistance. We have used fourteen land-use types \(^{16}\) and an adaptive scheme for different number of land-use types. The emission module has been tested by using the Photochemical Transport Module NUFOMO for sensitivity and validation analysis.
1. Introduction

Emission inventories are one of the most critical modules in urban photochemical air quality models. The uncertainty of emission estimations for different pollutants is an important source of errors in the Air Quality Models. Because of this, research in the last decades of this subject has been increased. The research on emission models started around 1970's with Böttger et al. (1978) and Zimmerman (1979) and continued during the 80's with the CORINE and EPA 4-year updating emission inventory programs. The NAPAP report and the Andreani-Aksoyoglu and Keller (1994) report and Lamb et al. (1993) are important contributions in the scientific literature to the knowledge of the algorithms and methodologies to understand the emission from natural and anthropogenic sources. The emission inventory described in this contribution comprises the inventory and localization of emission data of both industrial and non-industrial sources in a mesoscale area in Spain. The area is located in the central part of the nation and it is identified with an autonomous region called Madrid Community. The Madrid Area includes the nation capital and this city forms the 75% of the total population. We have included anthropogenic and biogenic emissions. The objective of this inventory is to provide a modelling module into the Integrated Air Quality System (NUFOMO, Numerical Photochemical Model) which is continuously interrelated to the transport and deposition modules of the Photochemical Model. Anthropogenic emissions can be described by using the algorithms included into the EPA and CORINE reports. This inventory model is focused on mesoscale areas -in our case the Madrid area but it can be extended immediately to other areas with compared scales.

The numerical photochemical models require continuous information of the total (and grid) input of pollutants into the atmosphere every very short time steps. This information is only achieved by precise emission inventory models with high quality algorithms to calculate emission factors. At the moment, we do not have European or national programs to achieve this type of information however information for wider spatial and temporal resolution is already available for national and European scales. Increased interest has been shown in recent years on the quantification of the emissions from the biosphere and the consequences on the changes on the physical and chemical properties of the Earth's atmosphere and uptake of trace gases of biota. Neglecting the natural hydrocarbon emissions in air pollution models leads to inaccurate estimations of pollutant concentrations and to ineffective pollutant reduction strategies based on a reduction of anthropogenic hydrocarbons only (Chameides et al.). Our emission model EMIMA takes into account all above points and underlines the attention on the high spatial (250 m x 250 m) and temporal resolution. The model comprises two coupled information systems: Individual Emission Inventory System and the Collective Emission Inventory system. For a realistic strategy to reduce the emission of the predominant air pollutants such as sulfur dioxide, nitrogen oxides ($NO_x$) and volatile organic compounds ($VOC$), it is necessary to know
the types of the sources as well as their emission rates with some confidence and to predict their future levels.

2. Methodology

Taken into account above general considerations, we have used a numerical photochemical model to qualify and if possible quantify our emission inventory model EMIMA. The numerical photochemical model NUFOMO includes 33 species and 78 chemical reactions including $NO_2$ reactions, Ozone cycle, inorganic reactions, photochemical reactions, sulfur reactions and organic reactions. This model provides a complete information about the distribution of the different chemical compounds at different grid points and at different predicted times. The model needs a high resolution emission inventory (spatial and temporal) and this information is provided by EMIMA. This is an emission model of atmospheric pollutants in a domain centered in the Madrid metropolitan area following the CORINE methodology. The pollutants which have been taken into account in the actual version of the model (2.0) are: $SO_2$, $NO_2$ and anthropogenic and biogenic VOC’s (isoprene and monoterpenes). The model domain comprises an area of 80 km x 100 km with 5.108.144 people and more than 2.000.000 vehicles. The number of towns is 210. The city of Madrid (capital of the nation) with more than 3.000.000 people is the main source of anthropogenic emissions and its influence is key for understanding the atmospheric environment of the area. The time resolution is un hour and the source classification is: line, point and area. The output used in this contribution is 2 km x 2 km for being used in the numerical photochemical air quality system (NUFOMO). We are able to obtain the total emission per pollutant in the whole domain at a day or during a number of day (usually the photochemical models run for 4-5 days). It is also possible to obtain the emission per grid cell per pollutant per hour.

The Area sources consider emissions from small industries, tertiary, domestic consumption, biogenic emissions and urban/suburban traffic. The line emissions consider the emissions from the national roads in the Area (six and one important secondary road in the South) and the two Road Rings in Madrid City (M-30 and M-40). Six types of vehicles and five types of fuel are considered. Finally, the point emissions consider the emissions of the big industries with more than 100 TmSO$_2$/year.

The emission model EMIMA considers 14 types of land use which are also used in the mesoscale meteorological model MEMO and the resistance deposition model DEPO included into the NUFOMO system. The land use types are: caudiceus forest, perennial forest, mixed forest, olive, garden, bush, vineyard, fruit, pasture ground, rice, dry land, inland water, urban land, suburban land.

Emissions from road traffic are computed following:
where \( E \) is the emitted pollutant in g., \( n \) is the number of travelling vehicles of each type, each hour, \( r \) is the mean distance travelled by vehicle in kms, \( c \) is the mean consumption by vehicle in l/km and \( f \) is the emission factor for each pollutant in g/l. The value of \( n \) is based on yearly averaged data and then distributed equally on each day. This number is corrected with a time dependent factor using information from the Traffic Department of Madrid City. For August, 15, 1991 (the day that the photochemical model was using) the factor \((f_{cnv})\) is given as:

\[
\begin{align*}
1.240, & \quad 1.430, \quad 1.240, \quad 1.260, \quad 0.950, \quad 0.740, \quad 0.490, \quad 0.510, \quad 0.530, \quad 0.540, \quad 0.620, \\
0.870, & \quad 1.110, \quad 1.320, \quad 1.290, \quad 1.150, \quad 0.770, \quad 0.780, \quad 0.770, \quad 1.010, \quad 1.150, \quad 1.250, \quad 1.530, \\
1.460.
\end{align*}
\]

Isoprene emissions depend strongly on the light and on the temperature. The effects of these two parameters are critical on the parameterization of the emission factors for isoprene and monoterpenes. Increasing temperature from 25°C to 30°C can cause a 70% increase in isoprene emissions and doubling the available photosynthetically active radiation (PAR) can increase isoprene emissions by 100%. The \( \alpha \)-pinene and the sum of other monoterpenes, the emission rate does not depend on the light (they are emitted during day and night). It is considered to depend only on the temperature.

The suburban areas are modelled assuming 10% grass coverage and 10% tree coverage with the same value for oak, other deciduous and coniferous trees. Emissions in mixed forests are calculated as 50% perennial forest and 50% caduceus forest. When we have olive, garden, bush, vineyard and fruit, we consider them agricultural lands. The rest of land use types are considered with no biogenic emissions.

### 2.1 Land use classification: LANDSAT-5 data

The land use classification is obtained using the information provided by the LANDSAT-5 satellite. The methodology to obtain this information is described in [15]. The methodology involves the following procedures:

- Linear Transforms of multispectral images, involving the bands 1-5 and 7. Tasseled Cap and Principal Component.
- To obtain terrain samples from the original image for the training of the classifier.
- To compute the two first principal components from a list of training samples.
- To cluster the samples into classes.
- To complete the total classification of the multispectral image starting with a classified list of terrain samples.

This methodology has been compared with hand-made maps and by sensitiv-
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ity analysis by using the integrated air quality system NUFOMO for land use sensitivity\textsuperscript{16} with satisfactory results. Fig. 1 shows a comparison of percentages between both systems with obvious advantages for the automatic technique. The advantage of using remote sensing information is important because of the extraordinary man power involved on hand-made land use classification.

![Comparison of percentages between both systems](image)

Fig. 1 Comparison between land use types on the Madrid Area and those obtained through the Landsat-5 satellite data.

3. Results and Discussion

The emissions for August, 15th, 1991 are calculated for $SO_2$, $NO_x$, $VOC$'s (anthropogenic) and Isoprene (biogenic). Also, monoterpenes are evaluated. Fig. 2 shows the anthropogenic VOC emission for the Area domain. It is clear how the VOC's emissions from the traffic appear in accordance with the factor given by the Traffic Department of Madrid. At 12h00 (LST) high emission are seen because it is a holiday on the middle of August which is a typical vacation month. Later 18h00 (LST) a reduction of the traffic produces the corresponding reduction in the VOC's emissions. Finally, at 23h00 the strongest emissions are appearing because the movility of population on a typical very hot day at night. During the maximum intensities new emission areas are appearing in the surrounding areas.
Fig. 2 Anthropogenic VOC emission on August, 15th, 1991 (holiday) in the Madrid Area.

Fig. 3 shows the hourly evolution of the total emissions in the Area of Madrid. Isoprene emissions appear to be an important contributor to the total emission budget. The photochemical activity on this latitude trigger the production of secondary pollutants ($O_3$ and $PAN$), so that, new locations of forest areas will affect extraordinary to the equilibrium in the Area.
Fig. 3 Hourly evolution of the total emissions in the Madrid Area.

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