INTERACTIVE VISUALIZATIONS OF SPATIAL AND TEMPORAL AIR POLLUTION ASPECTS FOR MONITORING AND CONTROL

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Introduction

The aim of the work presented in this paper is the design of an interactive environment for the visualization of a variety of aspects related to the problem of air pollution in industrial and urbanized areas. This task is carried out in a broader context, aiming at the integration of spatiotemporal information concerning environmental data (Project *ICAROS*, described in more detail in the next section). The ultimate purpose for designing this environment is its use by air pollution, transport and environmental specialists for policy- and decision-making, monitoring and control at urban and regional levels. The city of Brecsia, in Italy has been the pilot study for the project, which, in a following phase, is going to consider more urban cases with similar air quality problems.

The main purpose of the cartographic work within *ICAROS*, is the creation of maps that display the various aspects of air pollution in the area of interest. These maps are suggested on the basis of the various elements that interact within the physical and man-made urban environment, contributing to the atmospheric quality status. The variety of these elements suggests that apart from creating various separate maps, it will be of help to the users to develop an environment for selecting the elements they wish to display and for accessing the respective maps. Due to the nature of the problem, many of these maps display elements with values that constantly change with time (atmospheric or air quality parameters). These changes are of interest to specialists and decision-makers and therefore it is important to allow the users to interact with the spatiotemporal information mapped. This is achieved through temporal interfaces that are being developed for this purpose.

The *ICAROS* Project

The work is being developed in the context of a broader research project funded by the European Union. The *ICAROS* project - *Integrated Computational Assessment via Remote Earth Observation System* - aimed at the development of an interactive computational environment that allows the integration and assimilation of spatiotemporal environmental data deriving from different sources, including remote sensing observations, ground air-quality measurements and advanced atmospheric modelling of air pollution characteristics in urban and regional scales (Sarigiannis *et al* 1998, Sifakis *et al*, 1999). The full exploitation of ICAROS platform will contribute to the minimization of uncertainty in decision-making, regarding air pollution control and abatement in the urban environment. The ICAROS computational environment is mainly addressed to environmental- and transport-policy and decision-makers at the urban and regional levels. The typical user is the technical service of such decision-making bodies, while the final recipients of the information generated by ICAROS are the actual decision-makers.

Traditionally, urban air quality monitoring is based on ground measurements of major pollutants, such as CO, NO_x, SO_2 etc., carried out by local monitoring networks. The obtained data are valuable due to their temporal continuity and analytical character but at the same time insufficient to provide a synoptic view of the distribution of air pollution over an urban area. In parallel, urban air quality studies involve atmospheric modeling, which is also used extensively and which provides spatially and timely continuous information; its reliability, however, is heavily based on the initial conditions introduced.

Nowadays, high spatial resolution satellite sensors can serve the optical effects of the presence of polluting aerosols, because the signal recorded is directly effected by these aerosols, through scattering and absorption processes. More analytically, the linear integral of the extinction coefficient due to small airborne particles can be successfully measured and mapped if satellite optical data are radiometrically compared (Sifakis *et al* 1998, Sifakis and Soulakellis, 2000). An example of an indicator of atmospheric quality, recorded in such a way, is optical thickness.

The pilot site during the ICAROS Project was the city of Brescia, situated in the Po Valley, at the Region of Lombardia in Northern Italy. Brescia, a city of 200,000 inhabitants is the most heavily industrialized area of Northern Italy and is notorious for frequent smog episodes that considerably affect the air quality and the visibility conditions of the wider area.

Mapping Air Pollution Elements

The phenomenon of air pollution in industrial and urbanized areas involves a variety of elements which influence its development or/and are influenced by it. These elements can be divided in a number of broad categories, influencing each other in the context of the physical and human environment. For our case these broad categories are the following five: the topography of the area, the atmospheric and meteorological conditions, the polluting sources and their emissions, urban activities and finally, the air quality of the area. Each of these categories consists, as already mentioned, of a number of elements (e.g. topography can further be considered as consisting of the 3D form of the terrain, water, green areas etc.).

A matrix of interrelations has been compiled, based on relevant air pollution literature, showing the influences between all the elements (the parameters) which are involved in the problem (see Koussoulakou 1994, for a more detailed discussion of this issue). The ultimate purpose of this interrelation matrix is to define the themes of maps that have to be produced in order to assist the specialists and the decision-makers in tasks such as: informing, monitoring, evaluation, control, decision support etc.

The main purpose of the cartographic part of the work related to *ICAROS*, is the creation of such maps that display the various aspects of air pollution in the area of interest. Given the variety of the elements, their interrelations and the multitude of the available data within the project, it can be argued that apart from creating a variety of separate maps, it is of help to the users of the system to develop an environment for map themes' selection and map access.

While some of the suggested map displays seem to be rather straightforward to generate and thus require essential knowledge from the users' part, other data require more processing before their final visualization, depending on the user's needs. This is particularly the case with air quality and meteorological data, where a number of different pollutants or/and meteorological parameters are collected every few minutes in each station. A user might want to view different aspects of the spatiotemporal information that is available in the database: he/she, might, for instance want to make a selection and visualize the combined concentrations of pollutants generated by traffic emissions, for certain average times. Pragmatic reasons require, therefore, the design and creation of an interface for linking the database with the visualizations of the spatiotemporal data, according to users' selections. The purpose of the interface is mainly to allow for various selections of spatiotemporal data and to offer some options for manipulation and control of the final visualizations.

The main cartographic and visualization tasks can therefore be summarized as being the following:

1. To map the elements of interest: a number of maps are suggested and produced; these include combinations of 2D and 3D maps, (both static and animated) of various data, collected from different sources and related to the aspects mentioned above (e.g. the terrain and topography, meteorology, air quality etc.).

2. To assist the user visualize the complex phenomenon more effectively, by providing access to maps, via the suitable interface, designed on the basis of the above mentioned interrelations of physical elements.

3. To allow the users to interact with the time dependent data via suitable map interfaces.

Implementation for the area of Brescia

The maps

A variety of data (in vector, raster and alphanumeric format) are available for the city of Brescia and its surroundings. These include: **i.** Terrain information and topographical features, **ii.** Meteorological data, such as wind direction and speed, temperature, solar radiation, relative humidity etc., **iii.** Air quality data deriving from satellite sensors, such as aerosol optical thickness and **iv.** Concentrations of various pollutants (SO_2, NO_2, O_3, NO_x, CO, CO_2, CH_4), obtained from in-situ measurements. For categories (**ii**) and (**iv**) data are obtained from a network of monitoring stations, where they are collected systematically, in short time intervals, thus offering information about temporal variations of air quality and of related meteorological parameters. In order to create effective visualizations for the users a number of maps are suggested and produced, based on these data; the maps include combinations of 2D, 3D, static and animated displays of the aspects mentioned above (i.e. the terrain and topography, meteorology, urban and emission information, air quality). The maps are suggested after an analysis of the interrelations mentioned previously (see Koussoulakou, op. cit., for a more detailed discussion on the themes of urban air pollution maps). Examples of a few of these maps are shown in Fig. 1.

Access to maps

A user such as a decision maker would probably soon feel lost, if he/she had to deal with the rather large number of loose maps that are necessary for a comprehensive cartographic display of all aspects related to the problem of urban and regional air pollution in his area. In order to facilitate this task an interface for accessing available maps is developed for ICAROS users. The interface is designed on the basis of the above mentioned interrelations of physical elements and the map types that are of interest to the users due to these interrelations. On the initial menu screen a 3D map acts as the interface to the main categories of elements related to air pollution, which are indicated by labels, as the mouse moves over the different parts of the screen. By clicking on a selected category, the user is presented with screens of more detailed menus, where the separate elements within each category are accessible (or not, if there is no correlation between them). When the user selects one (or more) element(s), the program indicates the elements in different categories that are related to the one(s) selected, in order to facilitate the user view the existing interrelations. The final choice depends on the user, who can de-select the elements which are not of interest for his/her mapping purposes. In the next step the user is presented with a choice of suggested map types, according to his/her combination of elements to be mapped. An example of the interface for access to maps is shown in Fig. 2.

Interaction with spatiotemporal information

Dynamic maps are to be found among the map types proposed for visualizing the complex nature of the air pollution phenomenon. On the other hand, various spatiotemporal data concerning atmospheric and air quality parameters are collected systematically, for the purposes of the project. The temporal changes of these parameters are of interest to specialists and decision-makers and therefore dynamic maps constitute a valuable tool for their tasks. Interfaces are being developed for allowing the users to interact with the spatiotemporal information. An example of such an interface is given in Fig. 3. The concept of an active legend (Peterson, 1999) is used for generating interactive cartographic animations. In this way the user can both control the display of a temporal (or thematic) sequence of maps and examine information from individual map frames.

The software tools used for the implementation of the mapping tasks described in the previous are: *ArcInfo 8*, *ArcView 3.2*, *MapObjects v. 2.0* (all by *ESRI*) and *Visual Basic 6.0 (*by *Microsoft). Map Objects* and *Visual Basic* have been used in object oriented programming, for the creation of menus and interfaces for map access and interaction with spatiotemporal data, as described above.

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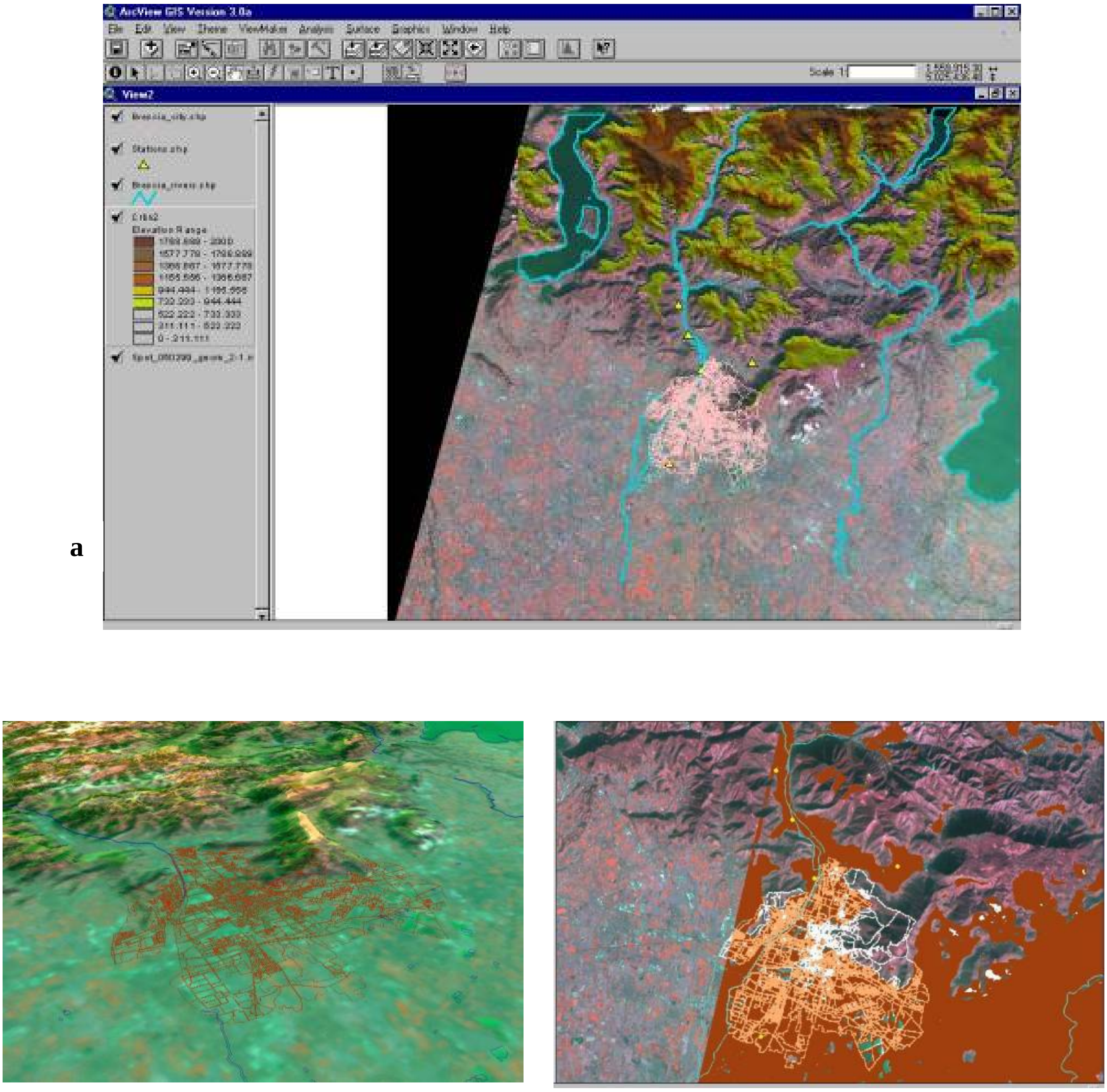

a

b

c

Figure 1. Examples of proposed map types for illustrating various air pollution aspects. Terrain and topographical features are shown in 2D and 3D displays (**a**, **b**). Air quality is indicated in **c**, by means of optical thickness, recorded with satellite sensors.

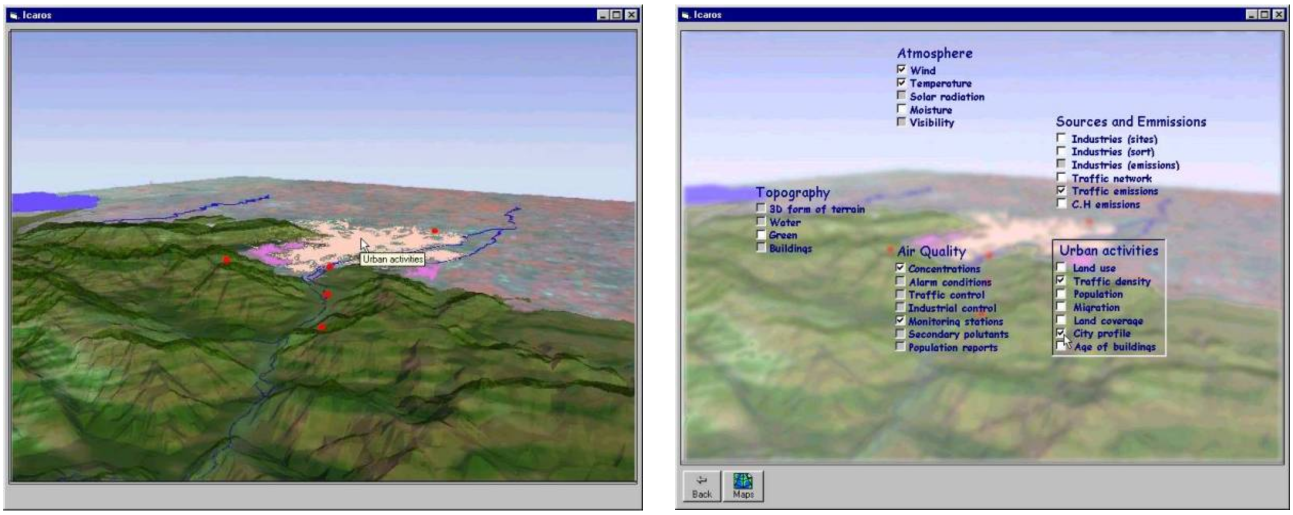

Figure 2. Interfaces for access to maps. Left, the initial menu screen: a 3D map acts as an interface to the main categories of elements related to urban air pollution. Right: more detailed menus appear for accessing data and maps of selected elements for each category.

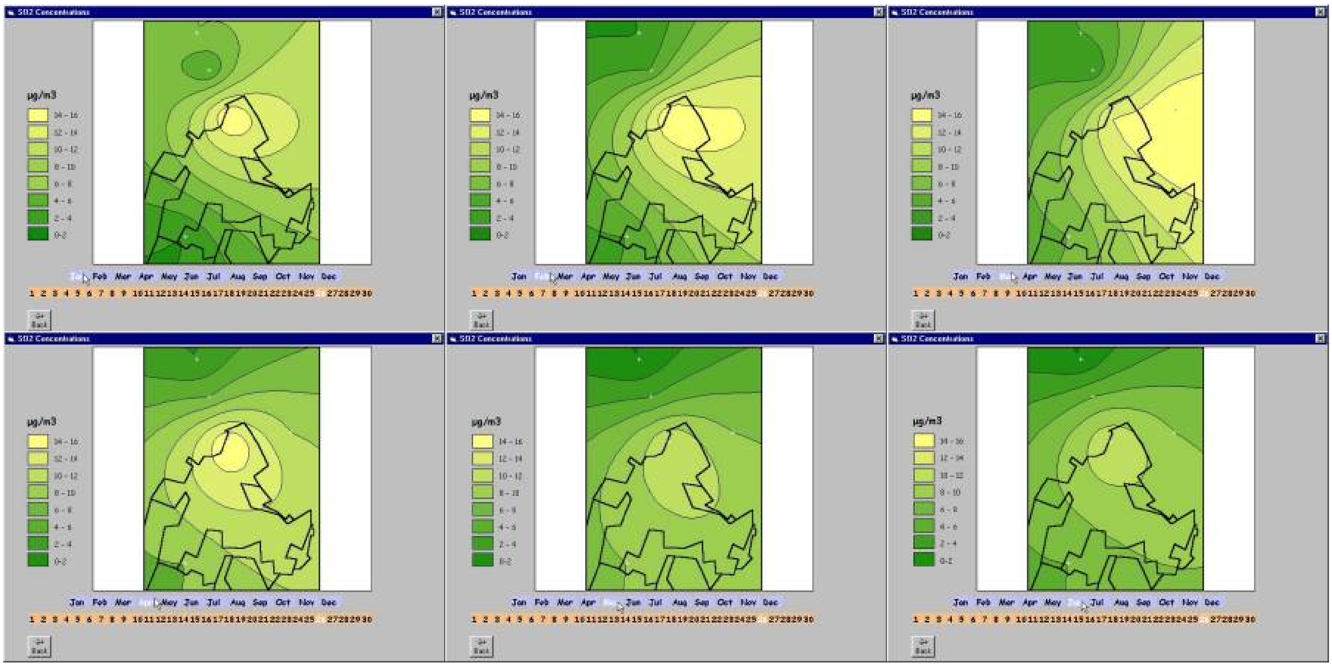

Figure 3. Snapshots from an animation of pollution concentrations. The animation is generated manually, via “mouse-over”: by moving the cursor over any date, the relevant map appears.