# Integrated Urban Air Quality Management and Information Systems

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## Abstract

One of the main elements in building an operational UAQMS is the maximisation of the benefits resulting from the usage of existing infrastructures and system components at each site. Cities prefer to make use of existing database schemes and GIS applications, and also to include internet-based environmental applications that might be available. The current paper presents practical solutions for the integration of air quality related observations and UAQMS components into a flexible, modular and user tailored system, that can either be used as a stand alone application or be combined with other systems. For this purpose, the use of wireless telecommunications channels will be discussed, for the integration of environmental observations. In addition, simple statistical tools will be presented for the analysis of time series as a first step towards the development of an operationally effective AQ forecasting module. Then, the use of public domain software will be presented for the development of internet applications for the dissemination and management of environmental information. As an extension to existing systems, public domain modules that allow for the dissemination of environmental information via SMS, WAP and e-mail will also be discussed. Last, the use of air quality modelling services will be discussed. All modules will be presented with the aid of working examples.

## Introduction

The atmospheric environment was always among the top of the priority list concerning environmental quality, not only because of its pronounced “problematic nature” but also due to the importance of air as a media preserving and supporting life, that was inherent in the collective unconscious of man. During the very early phases of organised (and urbanised) human life, the “cause-result” effect, already discussed in ancient Greek philosophy, was used as a lever for a paradigm shift towards the contemporary “source-receptor” relationship that brought into the limelight of concern the anthropogenic effect on the quality of the environment. In contemporary times, the need for managing air pollution problems was phased in urban areas at the beginning of the 60’s, and was initially addressed with a combination of regulatory – legislative actions towards lowering pollutant emissions and monitoring the quality of the urban atmospheric environment. Then, this approach was expanded to include estimations of pollutants, studies on the effect of meteorology on air quality, and forecasting air pollution with the aid of various mathematic techniques. Following the growth of atmospheric science knowledge and the extended availability of computers and supportive software, this approach was further expanded to include geographical information systems for handling all spatial related information, databases for providing a structured approach towards the data collected and computed, and various computational modules for supporting everyday environmental analysis and forecasting needs.

## The system concept

Although there was considerable progress in AQM issues, the discussion on sustainability and sustainable cities revealed an important weak point in the approach currently used: city

authorities, specialists and the public have the impression that urban air quality can effectively be managed if a set of well studied and defined steps or actions were followed as a response to a set of well studied and defined problems. This approach, however, does not take into consideration the dynamics of a city, i.e. the interactions, dependencies and limitations that go well beyond any AQM action but certainly influence the quality of the atmospheric environment. Moreover, increasing citizens' awareness on quality of life has resulted in a demand for an "interactive city", where interactions with "static infrastructures" is now being replaced with interactions with "dynamic, service providing urban infrastructures" that promote and sustain quality of life, air pollution being a major player in this issue.

**Citizen-focused environmental information**

In addition to the system concept, a new, service-related need is emerging, following the development of new types of personalised electronic information service technologies especially in the mobile phone industry: that of the citizen-centred environmental information services. These types of services have also the advantage that they are linked with quality of life indicators that can trigger citizen's reactions towards improving the urban environment, and are conceptually presented in Figure 1.

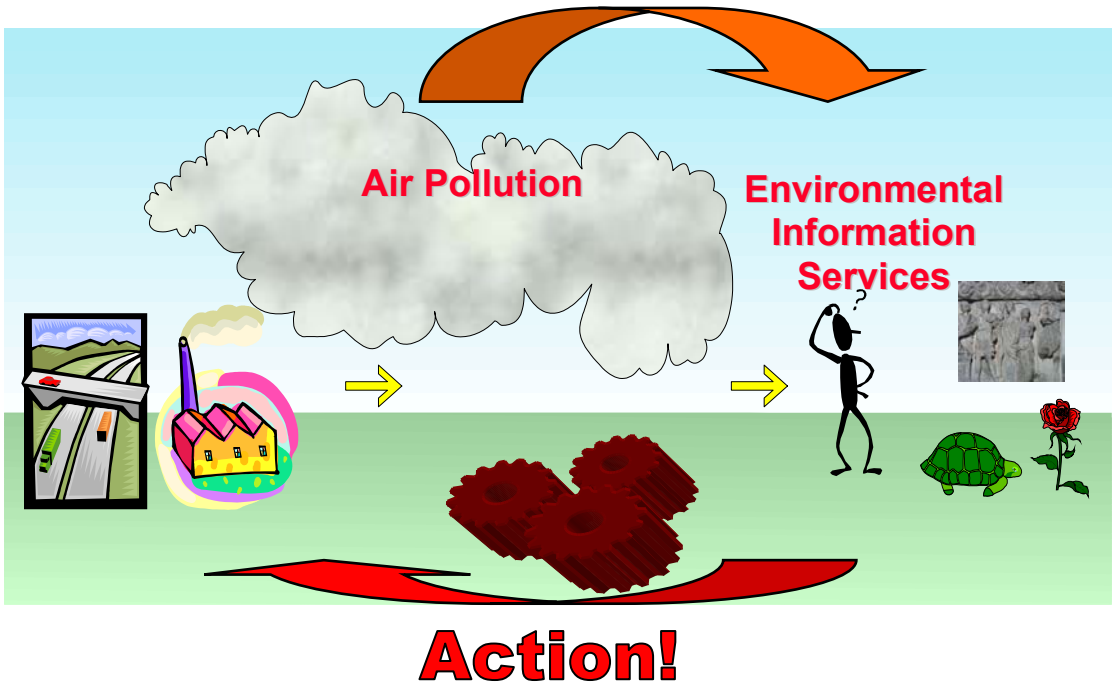


**Figure 1**. Environmental information services creating awareness and promoting self-sustained society.

The availability of these applications has also created a conceptual change, stating that the urban environment should be treated as a whole, and that managing air quality problems in a city can only be effective if an integrated, multi-domain, holistic, systematic approach is followed in urban environmental management. In this way, environmental management techniques and methods developed for coping with air quality problems have helped in the creation of a city based environmental management consensus from the citizen's point of view.

**Effective and applied UAQMS modules**

Following the above, a set of UAQMS modules are presented hereafter, aiming at demonstrating that small but well defined applications, built on the basis of "system engineering" principles, can effectively provide valuable environmental management services for both citizens and decision makers. A first step towards the successful building of such modules is a thorough examination and assessment of the user requirements, i.e., asking what the "client" of an UAQMS wants to receive as service content and functionalities. The UR phase is part of the life cycle of such systems, as presented in Figure 2.

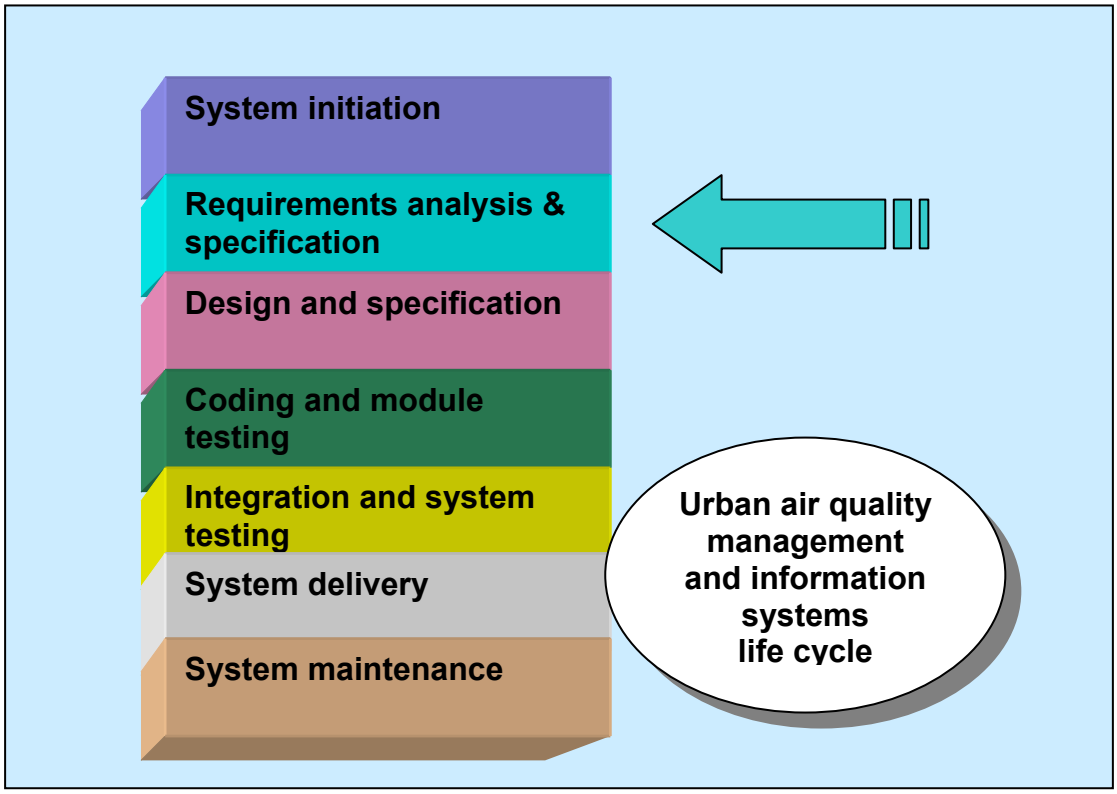


**Figure 2**. A schematic representation of the life cycle of an UAQMS.

The indented structure and functionality concept of a contemporary UAQMS is presented in Figure 3: each system module is a stand alone application that "reveals" its functionality potential as soon as it is combined with other modules, that strengthen the overall approach.

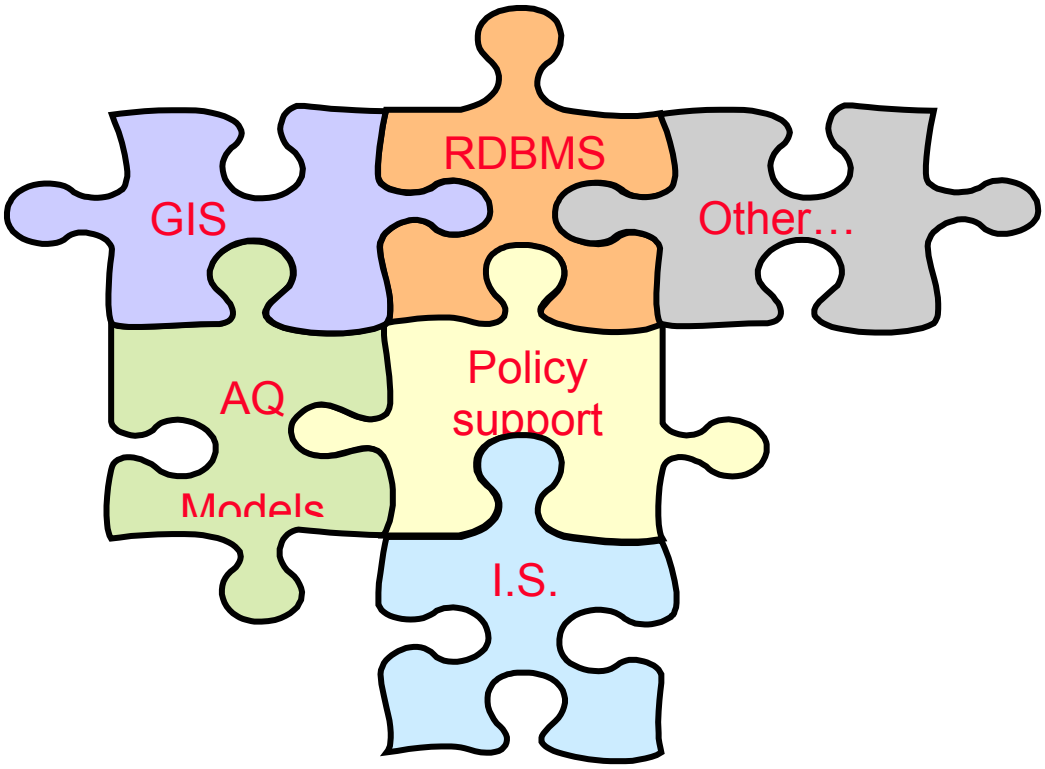


**Figure 3**. The modularity and complimentarily concept of a contemporary UAQMS. GIS=Geographical Information Systems, RDBMS=Relational Database Management System, AQ Models=Air Quality Models, I.S.=Information system module, Policy support=decision and policy making support module, Other=any additional module.

**UAQMS module examples**

In the following paragraphs some concrete examples of stand-alone modules that can be integrated into any UAQMS are presented. These examples are based on R&D work performed in the period 1996-2001, were supported by 4$^{th}$ and 5$^{th}$ FP projects of the European Union and were tested and validated on site, under pilot operation conditions. A very important aspect of all these applications is the fact that they were built using open source software, and interned-based available resources, bypassing commercial applications. In this way, it was demonstrated that efficiency can be combined with a low cost development platform, the latter being of major importance for public authorities which usually face problems in financing environmental systems.

***A Java-based air quality modelling interface***

This application was created in the framework of the IRENIE project (URL 1) and for the Athens city application site. One of the main goals of the IRENIE Athens application was to supply authorities with a tool for improved access, reporting and dissemination of air quality related data, and support urban air quality management, with the aid of model animated scenarios, towards the improvement of the decision making and policy planning process for the future. In order to promote this goal, a scenario-based air quality management scheme was developed which made use of a Java application for the visualisation of scenario results as produced by state-of–the-art air quality models and an HTML structured information system that supports navigation within the scenario parameters and the various information categories

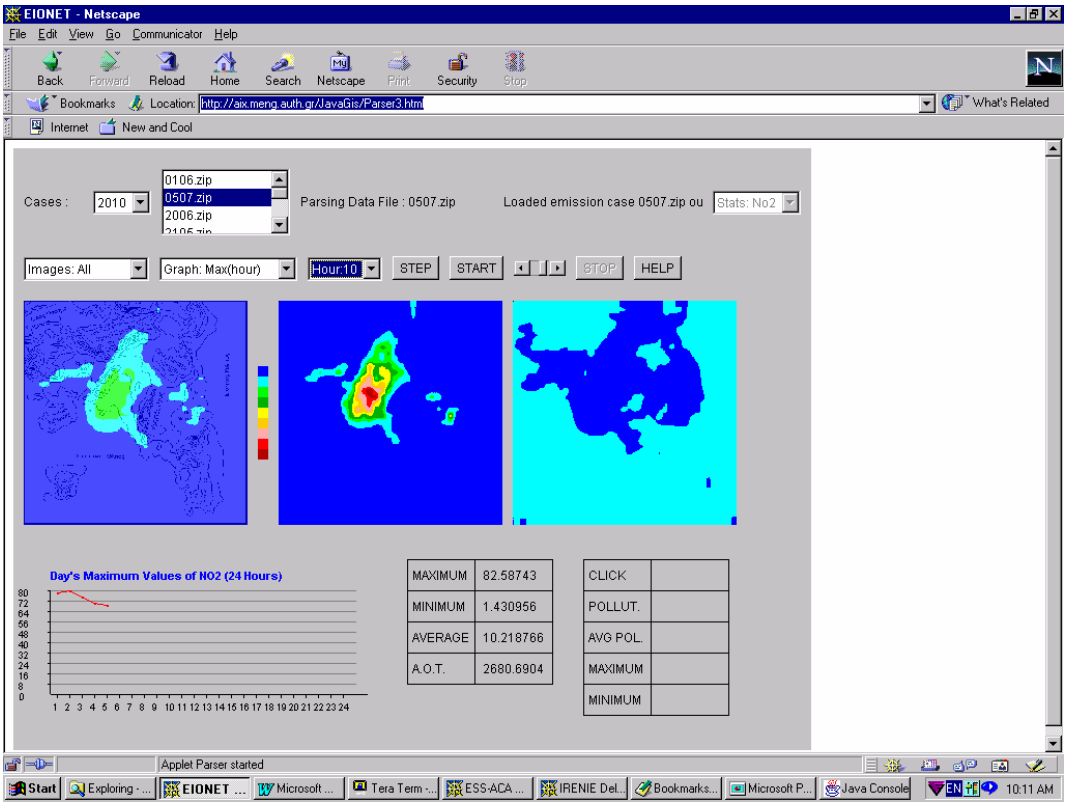


**Figure 4**. A Java-based air quality modelling interface.

(Figure 4). One of the important aspects of this module is that it allows creating images corresponding to air pollution concentration fields on the fly. Arrays are used for this purpose, where the elements represent the pixel values of the images. With the aid of the Java application, the user can visualise the air quality data resulting from the application of the selected scenarios while being able to use a set of statistical tools provided on the fly. These tools include:

-Maximum concentration plots for the selected pollutant(s).
-Accumulated Exposure over Threshold for a selected pollutant, i.e. the summing up over the time period considered the hourly concentration values exceedances over a certain time interval, which is a measure for exposure.
-At each point of the Greater Athens Area (GAA), the maximum hourly concentration over the time period considered (day) is found and the 50 highest values for the whole domain are plotted in decreasing order.
-At each point of the GAA, the user can identify the daily variation of air pollution concentration values for all the pollutants considered.

***Web-based visualisation module for environmental data time series***

In the frame of the IRENIE project, a web-based application was developed that gathers data coming from the air quality monitoring network in a web server and produces 2-dimensional graphs for one or two components per station (Figure 5). This application was tested against a heterogeneous monitoring network infrastructure that included analogue and digital data sources and networked via modem (or LAN) and wireless data nodes. The overall performance was proven very satisfactory and is now used also for assessing other types of information, like meteorological data.

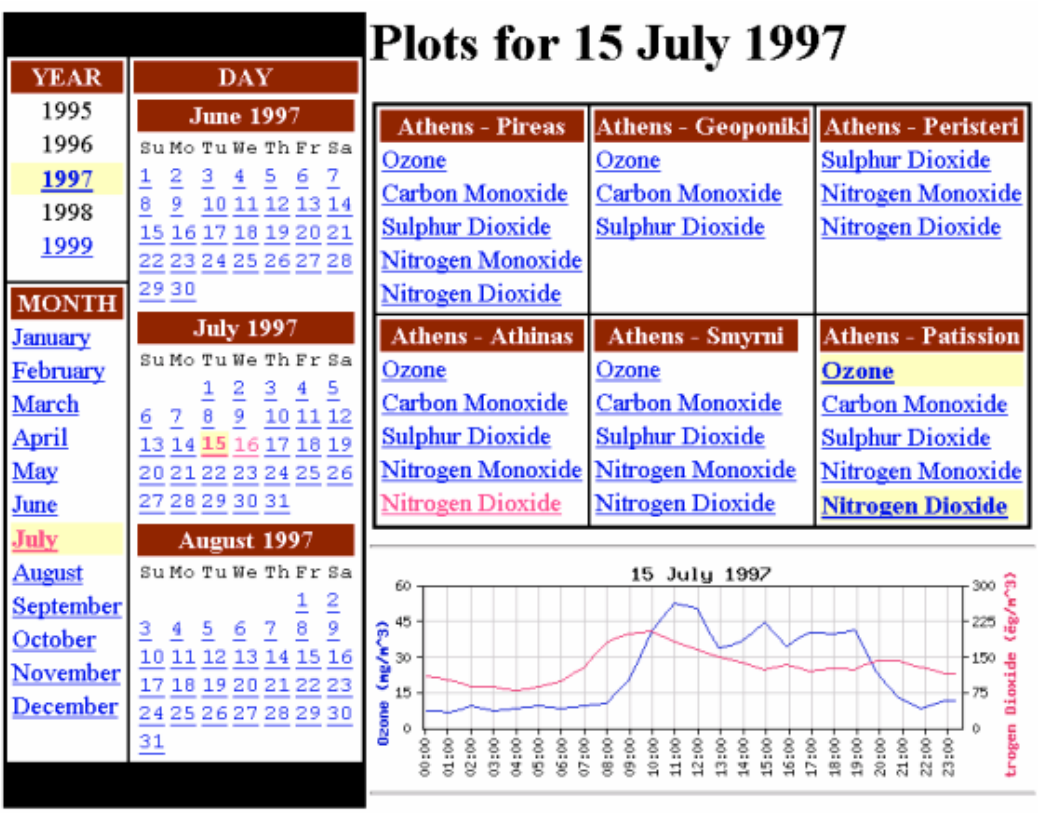


**Figure 5**. A Web-based visualisation module for environmental data time series.

***Module for the tele-transmission of environmental and energy data***

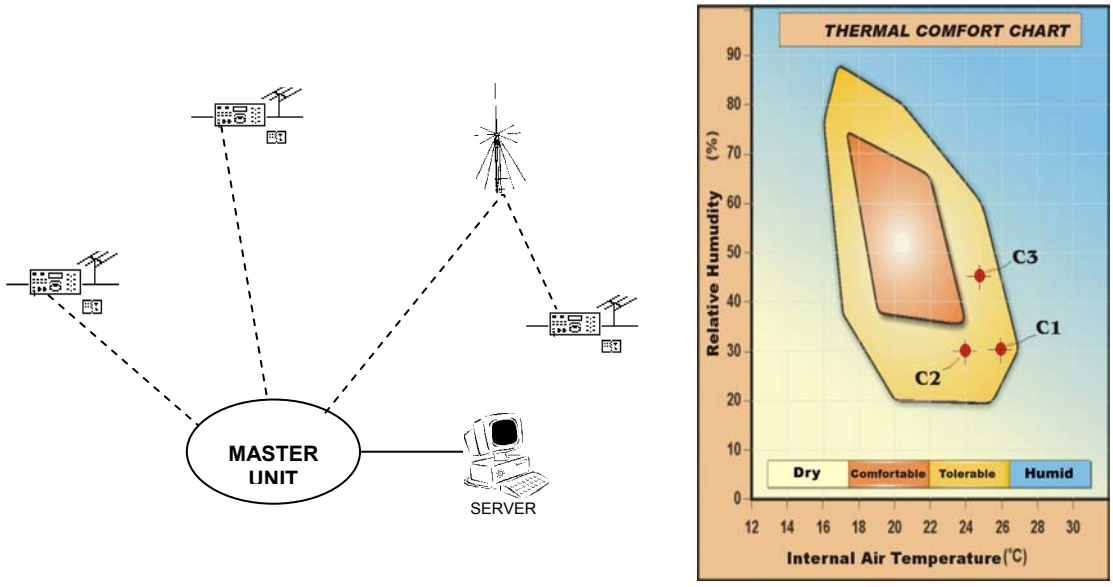


**Figure 6**. Module for the tele-transmission of environmental and energy data

Remote access to monitoring stations, located at a distance from the central processing and archiving unit is a need that becomes increasingly important in contemporary environmental as well as energy monitoring and surveillance systems. By using the wireless technologies

available, this necessity can be met and can provide a valuable tool towards the quicker and easier processing of data. One of the main advantages of such a processing system is that it complies with the need for improved reporting of environmental information, since the data are made available over the World Wide Web and are used for environmental management and public information purposes. In addition, this system provides added value to existing infrastructure, by wireless communication and web-based techniques in order to provide simple but effective telematics-based solutions, ready to be used in all fields of environmental and energy surveillance and management. In this frame, a system for retrieving climatic and air quality data recorded on remote monitoring stations was developed, supported by a national (Hellenic) funded project, that proceeds in the following manner: the sensor units conduct measurements, which are then radioed to a "master unit"; this in turn forwards the information to the central server; in case the connection between "master unit" and remote station fails, it is possible to dynamically redirect the data. In order to comply with the ETC/AQ guidelines, the data are appropriately formatted according to DEM specifications. After a primary quality control, the central server archives the data in a database, which supports the HTTP protocol and enables access to these files through the World Wide Web, thus making use of the internet, following the example of previous applications for energy management in buildings.

***Dissemination of environmental information via SMS***

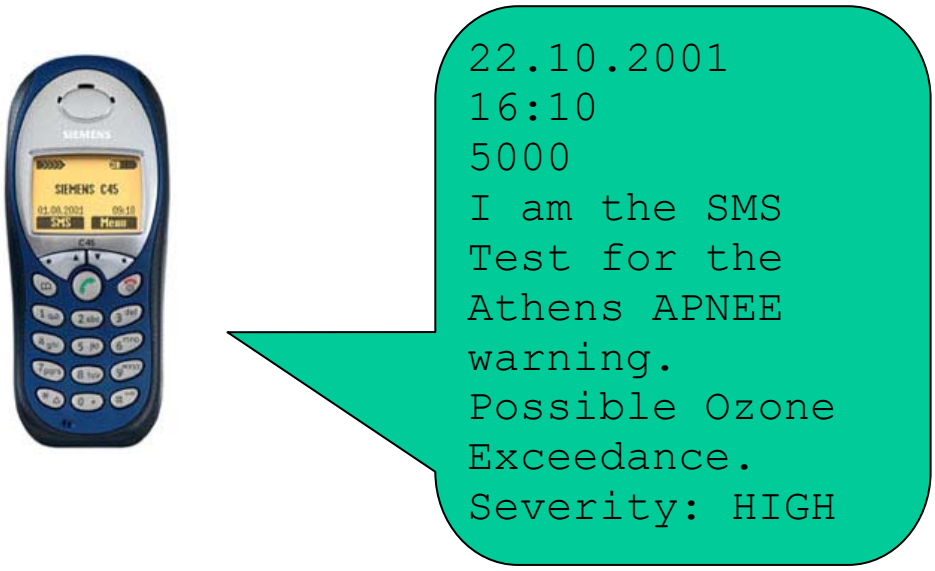


**Figure 7**. Dissemination of environmental information via SMS.

In the frame of the APNEE project an SMS application was created for providing air quality warnings (generated by an air quality forecasting module) to a list of service subscribers. This application, tested for the Athens case, contained a brief message that was automatically generated and broadcasted, when the ozone levels were expected to exceed limit values (figure 7). The SMS messages were forwarded to their destination via the web front-end of a public access service (http://mail.mycosmos.gr) which is provided by COSMOTE, one of the larger mobile telecommunication companies in Greece. A Perl script provided input and triggered a C script, which feeds the web-based SMS gateway with 2 text files, containing the message body and phone number list. A shell script, utilising the database notification trigger, executed the Perl script when a new row was inserted in the warning table.

*An air quality forecasting module*

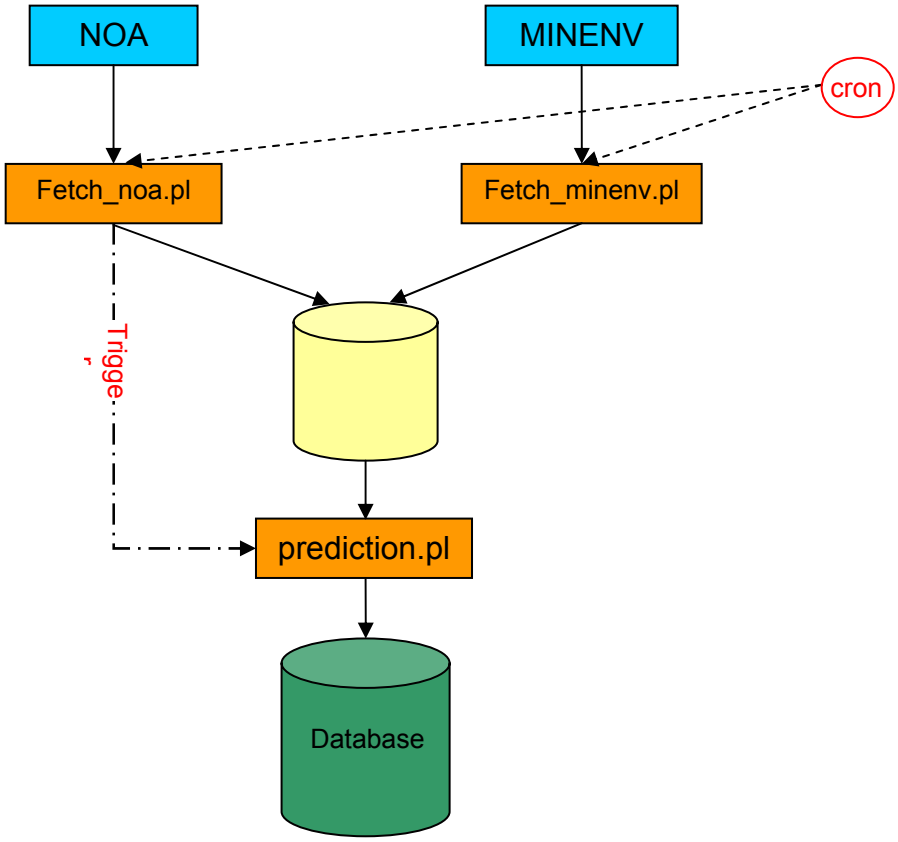


**Figure 8**. *An air quality forecasting module.*

Within the APNEE project framework, a method for daily maximum ozone prediction was been developed based on CART and regression analysis tools, in order for the citizens to be informed about the levels of the air pollutants in time. The forecasting module (FM) was used for the daily prediction of the maximum ozone concentration in the Athens basin, during the pilot operation of the system (URL 2). The FM used meteorological and air quality data in order to predict the maximum daily ozone. The meteorological data were taken by National Observatory of Athens (NOA) via the web (http://www.noa.gr/Issues/Weatheren.html, site updated every 10 minutes). The necessary data were collected every 5 minutes by a cron-driven script. The script inserted these data into a database and created averages and maximum every midnight. Similar procedure was followed in the case of the air quality data. These data were taken by Hellenic Ministry for the Environment, Physical Planning and Public Works, via the web (http://www.minenv.gr/1/12/122/12204/g1220400.html). The site is updated everyday at 14:00 and the values that were given were the daily maximum and minimum concentrations of the previous day and of the current day until 13:00. The prediction was realised via a script that ran from cron every midnight. The script fetched the data needed for the prediction from the database, produced the prediction and forwards it to the database. The performance of the FM was very promising, reaching the top values reported in related literature (Slini *et al*., 2002, Kaprara *et al.,* 2001). It is very important to underline that this module was created and operated without any interference with other

applications already available to the Ministry of Environment, using data that are available to everybody via the Internet. Thus, it was proven to be an effective and flexible module, that can produce high quality forecasts while limiting the information required as input.

## Conclusions

Urban air quality management is moving towards providing citizen-centred services that allow for the improvement of quality of life. The number of UAQMS is growing, embracing modules that are capable of providing material necessary for the compilation of environmental information services, like forecasting modules, near-real time or real time environmental information applications and visualisation modules. As many city authorities operate some kind of internet-based information systems for informing the public, UAQMS can be a valuable add-on to these systems. Nevertheless, special care should be taken for the implementation of system components in an optimized and effective way, and user requirements analysis should be exercised in advance, in order to avoid system engineering problems that may lead to additional costs and operational flaws. Last but not least, IT technologies can provide the basis for a new service-pack and provide the necessary support to a new type of electronic services.

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Slini Th., K. Karatzas and N. Moussiopoulos; Statistical analysis of environmental data as the basis of forecasting: an air quality application, *The Science of the Total Environment* **288** (2002) 227-237.

URL 1: http://www.nilu.no/irenie

URL 2: http://www.apnee.gr