PLENARY SESSIONS

ASSESSMENT OF AIR QUALITY IN CYPRUS
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URBAN AIR QUALITY IN EUROPE: THE POLICY RESPONSE
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OPPORTUNITIES FOR BETTER INTEGRATION OF THE LOCAL AIR QUALITY MANAGEMENT AND THE IPPC REGIMES TO IMPROVE AIR QUALITY
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REGIONAL INTEGRATED AIR QUALITY MANAGEMENT: AN EXAMPLE FROM THE CALIFORNIA REGIONAL PM_{10}/$PM_{2.5}$ AIR QUALITY STUDY (CRPAQS)
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CAN AIR QUALITY MODELLING IMPROVE EMISSION INVENTORIES?
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FACILITATING ADVANCED URBAN METEOROLOGY AND AIR QUALITY MODELING CAPABILITIES WITH HIGH RESOLUTION URBAN DATABASE AND ACCESS PORTAL TOOLS
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TWENTY YEARS OF RESEARCH AND APPLICATIONS IN IDENTIFYING, TRACKING AND MAPPING THE SPATIAL DISTRIBUTION OF AIR POLLUTION OVER URBAN AREAS USING SATELLITE REMOTE SENSING
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TWENTY YEARS OF RESEARCH AND APPLICATIONS IN IDENTIFYING, TRACKING AND MAPPING THE SPATIAL DISTRIBUTION OF AIR POLLUTION OVER URBAN AREAS USING SATELLITE REMOTE SENSING

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ABSTRACT
We describe our research in air pollution mapping using remote sensing since 1984. High spatial resolution satellites, originally not addressing atmospheric peering, have been used to retrieve information on the spatial distribution of aerosols. The basic method developed allows relative retrieval between "polluted" and "reference" images, neglecting contribution from possible surface reflectance changes. Attempts were made to isolate the "noise" due to surface variations. Pilot trials using SPOT/Landsat data took place over Toulouse and Athens. During various projects satellite data were combined with numerical models and ground measurements to optimize the siting of ground based monitoring networks (Athens, Milan). The ICAROS-NET project developed an innovative system for managing air quality and associated health risks. Full scale experiments (Munich, Budapest) indicated that it is the first time that pollution particles have been detected from space with such precision. Latest research addresses the operational use of moderate and moderate-to-high spatial resolution satellites for urban pollution monitoring. We are also testing the capability of satellites to distinguish between aerosols of different sizes.

1. INTRODUCTION

There is currently a pressing request from both scientists and decision-makers at all policy levels for reliable, spatial, timely and comparable information on urban air quality and associated indicators. In most cities this information is derived by ground based measurements of major pollutants. Such measurements provide timely point information on the concentration and nature of the pollutants but the spatial continuity is as of yet missing. On the other hand, atmospheric modelling, which is also extensively used in air quality studies, provides spatially and timely information but its reliability is heavily based on ground measurements and inventoried data. This lack of spatial and comparable-between-different-cities data leads to an increasing demand for exploitation of satellite data, which provide spatial measurements allowing geographically synoptic and physically synthetic views of pollution. Satellite data are also flexible to integrate with other monitoring tools.

There is a paradox in that, whilst remote sensing from space has a history of some forty years and has been recognised as an operational monitoring tool in many environmental fields; no satellite-based indicator is yet routinely used in air pollution monitoring. The reason seems to be that while some of the first operational satellites launched already in the sixties were oriented to meteorological observations (e.g., TIROS) the first applications tackled land or sea parameters rather than the atmosphere. Later, meteorological satellites, such as Meteosat, GOES and NOAA, regularly provided data on temperature profiles and wind speed/direction, which are closely associated to pollution phenomena yet only a very small number of instruments (e.g., on board Nimbus-7 and NOAA satellites) provided data directly related to atmospheric chemistry. Unfortunately, no sensor in orbit could directly measure pollutant concentrations in the boundary layer with a resolution satisfying urban studies. In the early eighties there was still no operational atmospheric monitoring by commercial satellite sensors. In fact there was no satellite sensor addressing air pollution per se in orbit until 1999 (i.e., MOPITT). Finally, satellite based indicators directly associated to air pollution have not been systematically compared with results obtained by conventional monitoring and numerical modelling techniques.

A variety of satellite sensors are destined to observe the Earth at spatial scales depending on their orbital and optical characteristics: (i) those with spatial resolution of tens of kilometres are considered of "low spatial resolution" (LSR) and address global scale observations, (ii) those with spatial resolution of few kilometres are considered of "moderate spatial resolution" (MSR) and address observations of continental scale, (iii) those with spatial resolution of hundreds of metres are considered of "moderate-to-high spatial resolution" (MHSR) and address observations of regional scale, (iv) those with spatial resolution of tens of metres are considered of "high spatial resolution" (HSR) and address local scale observations, (v) those with spatial resolution of few metres are considered of "very high spatial resolution" (VHSR) and address detailed observations at a local scale.

With respect to the gaseous atmospheric pollutants, only LSR sensors (such as TOMS, MOPITT, SCIAMACHY), which do not address urban pollution problems. Concerning the particulate atmospheric pollutants there are sensors from all the previous categories. This paper describes our attempts and innovative research in the area of air pollution mapping since 1984 using satellite data mainly of categories (ii), (iii) and (iv). These satellites, particularly those with HSR, did not originally address atmospheric peering but we have succeeded in using their data as source for qualitative first, then quantitative information on the spatial distribution of pollution in terms of satellite-based indicators, such as the columnar aerosol optical thickness (AOT).

2. FIRST STUDIES

In 1984 we started reviewing the state-of-the-art in air pollution monitoring by remote sensing. Air pollution in Athens (Greece) was, in this context, remotely sensed using ground based colour photography (Sifakis and Karpodinis 1986). The air pollution phenomenon in the area of Athens is known as “nephos”, meaning “cloud” a name that underlines its visible character, visibility impairment being due to high burdens of fine aerosols while a yellowish-brown colour of the cloud is due to NO_2. We tested the capabilities of SPOT satellite images to locate pollution palls and their spread over Athens by visual photointerpretation on printed colour composites; the results were comparable to those obtained by simple ground-based photography 20 years earlier (Sifakis 1991). A comparison of the obtained results with those from previous studies using bioindicators showed remarkable similarities (Sifakis 1995). Field surveys showed that the peaks on the pollution maps corresponded to scattered stationary emission sources associated to industrial activity (Sifakis 1992). SPOT-1 satellite data were processed, in a similar way, over the city of Toulouse (in southern France) to detect plumes of industrial origin (Sifakis 1988). On the basis of photointerpretation only two or three levels of pollution densities could generally be distinguished. This allowed, however, obtaining unique views of the particulate pollution cloud over the examined cities. Especially for the case of Athens, where an experience on pollution dispersion already existed from modelling simulations, it was the first time that such a synoptic picture based on a real measurement was obtained.

During feasibility studies we selected multitemporal Landsat and SPOT images covering the two aforementioned areas so that pollution levels were representative (i.e., typical low, moderate and high pollution conditions). The selection of the images was based on available pollutant concentration measurements and on image quality and cloud cover. We examined the images to locate pollution palls and map their dispersion over the two areas. This first approach can be considered as qualitative approximation of dense pollution, yet quantitative information on tenuous phenomena remained challenging. The optical atmospheric effects engendered by aerosols in HSR imagery were then quantitatively evaluated to map pollution plumes (Sifakis et al. 1990). Athens was the first site allowing an overall validation of satellite-based air pollution measurements through comparison with ground stations. The latter measured particulate concentrations by “TSP” and “Black smoke” methods. Black smoke concentrations were three times higher in the city-centre, while TSP concentrations were slightly higher in the industrial area; this was in agreement with satellite observations, sensitive to non-black particles, showing that their main burden was confined to the industrial district west of the city centre. Trend analysis showed a decline of black smoke while TSP remained stable, which implied an increase of non-black particles (Sifakis 1995).

3. METHODOLOGY

The aerosol optical thickness (AOT) is the main parameter retrieved by satellite directly correlated to air pollution in terms of particulate load (Cachoro and Tanre 1997). The “contrast reduction” principle (Middleton 1952), implemented using satellite data by Tanre et al. (1988), was first applied by Sifakis and Deschamps (1992) to retrieve AOT values over an urban site. The methods developed allow a relative AOT retrieval between a “polluted” and a “clean of pollution” satellite image used as reference image. The assessed AOT is thus relative to pollution-free conditions and, since optical effects by aerosols are virtually determined within the first kilometer(s) of the ground (Fraser et al. 1983), it is associated to air quality. The first code was the DTA (Differential Textural Analysis) applicable to high spatial resolution satellite data recorded in the visible spectrum (Sifakis and Deschamps 1992). The second code, SMA (Satellite Mapping of Aerosols) (Sifakis et al. 1998), is applicable to high spatial resolution data recorded in the visible and in the thermal infrared spectrum, such as Landsat data. Information from the thermal band is used in this code to screen radiometric variations due to other than atmospheric effects that may have arisen in the compared images. A third code, the SIPHA (Satellite Image Processing for Haze and Aerosol Mapping) allows the quantification of AOT over land, snow and sea (Sifakis and Soulakellis 2000). All these codes use the radiative transfer equation to quantify AOT from one or a combination of the following optical atmospheric effects: (i) the “blurring effect”, which arises in the visible and near infrared spectrum and is linked to scattering/backscattering of radiation by particles, (ii) the “screening effect”, which emerges in visible wavelengths as an attenuation of the observed reflectance by strong light absorbers (e.g., soot particles) or over bright underlying targets (e.g., snow), (iii) the "opacity effect", which results in a veiling of the images engendered in the thermal infrared due to the attenuation by particles, (iv) the "dark target effect", which appears over clear water in the infrared spectral bands and is due to the backscattered radiation by the particles.

All previous codes follow a common basic procedure; this consists of radiometric comparison of multi-temporal satellite data sets of the same area acquired by the same sensor during different pollution conditions, allowing to assess variations of the magnitude of the optical atmospheric effects. The main steps of the procedure are:

(a) Selection of a reference image, which determines the accuracy of the results and requires the consultation of existing ground-based pollution or meteorological measurements.
(b) Pre-processing of the images in order to render them radiometrically comparable. This includes an absolute calibration (transformation of digital numbers to apparent reflectance) applied to all but the thermal infrared bands, and in a geometrical control with subsequent correction in order to super-impose the images on a map. The images, where necessary, are corrected with least-square regression, and the values of the pixels are resampled according to the nearest-neighbour algorithm. This choice aims at maintaining intact the pixels distribution pattern without altering their raw radiometric values. For the same reason, no stretching or other contrast enhancement techniques are applied to the histograms of the images prior to the main processing.
(c) Application of one of the codes for AOT retrieval. AOT is calculated inside cells including a number of pixels automatically selected on a pixel-by-pixel basis through the use of a simple "homogeneity" criterion without any a-priori information (Paronis and Sifakis 2003).
(d) Approximation of the aerosol scattering coefficient by dividing columnar AOT by the appropriate scale length that is, under well-mixed conditions, the mixing height. Satellite information is thus normalised to reflect air quality in terms of ground level aerosol load (Sarigiannis et al. 2005). This height is so far calculated from meteorological data, based either on in situ observations or on meteorological models. We recently approximated the mixing height with the use of a digital elevation model combined with AOT maps without involving any other external meteorological information or measurement (Sifakis et al. 2006).
(e) Representation of the results in a map format. The presence of clouds and/or land cover changes produce patches of missing values therefore satellite derived pollution maps can be improved with the use of a geostatistical interpolation method using a universal kriging in order to obtain reasonable estimates for missing values (Kanaroglou et al. 2002).

The codes assume a uniform particle size distribution and composition and neglect bidirectional reflectance. Spectral bands at around 550 nm are used to retrieve AOT values. A new code is under development, using multispectral information to estimate particle size by assessing the Angstrom coefficient.

4. RESULTS FROM VARIOUS PROJECTS

A LIFE-Environment EC project (1995-1997) on the "optimisation of the network of air pollution measuring stations" provided the first opportunity for real scale application in Athens. The ICAROS (Integrated Computational Assessment via Remote Observation System) project (1998-2000) allowed combining satellite data with numerical models and ground based measurements. The synthesised information was applied to the optimal planning of urban and industrial infrastructure in Lombardy; the results successfully compared to those obtained by conventional methodology. The EUROBIONET LIFE-Environment project (1999-2002) allowed comparing satellite images with bioindication measurements in order to provide objective guidance when choosing the optimal location to install the natural indicator network (Sifakis 2006). The ICAROS-NET project (2001-2005) has developed an innovative system for monitoring and managing urban air quality and the related health risks (Sarigiannis et al. 2004). It used various satellite sensors to monitor the concentration of harmful particles in the air, caused by heavy industry, traffic and household heating systems. Four pilot trials were completed in Athens, Milan, Munich and Budapest (Schaefer et al. 2002). Results from the pilot studies indicated that it is the first time that fine pollution particles have been detected from space with such accuracy and precision. The RETROPOLIS project (2001-2002) allowed a retrospective mapping of the aerosol pollution evolution in Athens using HSR satellites. It produced a worldwide first spatially detailed diachronic urban pollution picture (Sifakis and Sarigiannis 2005).

Latest research addresses the operational use of MSR (AVHRR, MSG) and MHSR (MERIS, MODIS) data in urban pollution monitoring. PM_{10} data measured at ground level showed considerable correlation with AOT retrieved by AVHRR 1st spectral band (Retalis et al. 2003) and by MERIS 5th spectral band (Retalis and Sifakis 2004). We are also testing the capability of various satellite data to distinguish between aerosols of different sizes in urban atmospheres. Another project aims at the evaluation of aerosol and ozone photochemical models using in situ sensors and lidar techniques in conjunction with satellite observations.

5. CONCLUSIONS

The review presented in this paper is part of going research, which was driven by the initial hypothesis that satellites with resolutions from high to moderate can be integrated into operational schemes of air quality monitoring in order to interpolate ground-based point measurements and to complement models in the case of missing/unreliable emission data. The main strength of these satellite observations is their capacity to provide spatially resolved information at local level, not their frequent temporal coverage. Their use is expected to considerably extend the spatial coverage of information on air pollution using data fusion. Satellites can also track the dispersal of pollution at extended distances, which allow to link local sources to their regional effects with objectivity, and independently from any ground measurement. Finally, analysis of satellite based pollution maps has shown qualitative and quantitative changes of aerosol pollution in urban areas over time, and allowed to draw conclusions on the evolution of particulate pollution effectively complementing other existing methods.

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ASSESSMENT OF AIR QUALITY IN CYPRUS

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ABSTRACT

The objectives of this project were to determine the air pollution situation in Cyprus and to compare it with EU limit values, to investigate the spatial pollutants distribution in different zones over the whole of Cyprus, to determine the temporal variation and to find out the main sources of pollutants. The sources and their emissions were investigated by implementing an emissions inventory. The spatial distribution was determined with a diffusive sampling programme including 250 sampling sites which were distributed over one year. For the evaluation interpolation methods and a Neural Network model were used. The vertical pollutants distribution was investigated by tethered balloon soundings in two cities. For recording the temporal pollutants variation different monitoring stations and PM_{10} samplers had been operated in urban and rural sites. Besides some local problems around industrial plants the pollution problems are concentrated in the inner cities with high traffic load, traffic and poor ventilation. Measures to improve the air quality have been suggested.

1. INTRODUCTION

During the years 2002 to 2004 a project with the title "Preliminary Assessment of Ambient Air Quality in Cyprus" was carried out. To reach the objectives of the project, to determine the temporal and the spatial distribution of the air pollutants and the assessment of its results, the work was broken down in detailed tasks. The tasks of the assessment part were the following:

- Emissions inventory
- Measurements of pollutants in different zones of Cyprus using Diffusive and Active Sampling techniques and continuous measurements
- Determination of pollutants transport by measuring the vertical structure of the pollutant plume of Nicosia and Limassol and continuous ground level wind measurements
- Calculation of complete concentration fields over Cyprus using measurement results and modeling
- Overall evaluation and recommendations using the results of measurements and modeling

These tasks should be worked on by surveys, by more than one years extensive measurements, by statistical modeling based on the numerous measurement results and surveys and finally by recommendations to improve the air quality where necessary.

2. METHODOLOGY

2.1 Emissions Inventory

The emissions inventory was aiming to the collection and processing of appropriate data for the estimation of air pollutants emissions from different sources. Usually, much of this information is available through the databanks of EUROSTAT, but for Cyprus this was not the case. This was the first time that a systematic and coherent inventory was performed here. Some data were available from different departments, but this had been collected for other purposes. Apparently, the work performed within the framework of this project is a first good approximation and has set the basis for continuous improvement and update of the developed database. The air pollution sources being considered in this project are treated as linear, point and area sources. The considered point and area sources are boilers including industrial furnaces, dry cleaners, hotel industries, domestic heating in hospitals etc., petrol stations, air crafts at the air ports, agriculture activities and a lot of quarries. The last ones are registered, but their diffusive Particulate Matter (PM) emissions could not be quantified till now. All the emissions have been calculated as daily (24h) and annual loads, finally summarized in 1x1 km grids over Cyprus.

2.2 Spatial distribution of air pollutants determined by diffusive sampling

The spatial pollutants distribution has been determined by diffusive sampling at 250 sites in Cyprus over one year for the compound NO_2 and at 85 sites for SO_2 and VOC, especially Benzene. The sites were divided in 15 categories and annual averages as well as seasonal pollutant averages have been calculated from the sampling results. Firstly, the spatial distribution had been calculated by weighed interpolation. But, much better results could be achieved using a neural network methodology in which the emissions inventory and the population density was also worked in. The results are presented as complete concentration fields in pollutant maps.

2.3 The temporal variation of air pollutants determined by continuous monitoring

In addition to the stations of the Cyprus monitoring network three mini and two multi-component stations had been in operation over a total time period of 14 months, from July 2002 until August 2003. For some of them the site has been changed after half of the time. All stations were equipped with monitoring instruments for ozone (O_3) and nitrogen oxides (NO, NO_2, NO_X). Further, instruments for measuring the concentrations of carbon monoxide (CO) and sulphur dioxide (SO_2) were installed in the multi-component stations. Also, meteorological parameters had been measured at most of the stations. The mini stations (O_3 and NO, NO_X, NO_2) were positioned at rural background sites, e.g. on the highest point of Cyprus the Mount Olympus in order to determine the overall pollutants transport. The data evaluation was carried out regarding several aspects. Also PM10 and PM2.5 samplings had been carried out at many sites. The results of this programme are presented by Kleanthous et al. (2007).

2.4 Vertical distribution of air pollutants and wind systems determined by tethered balloon soundings

The wind systems of Cyprus had been investigated by evaluating data of the Cyprus Meteorological Service. In addition to this, vertical profiles of meteorological parameters and pollutants concentrations were determined by tethered balloon soundings during winter and summer campaigns in Nicosia as an inland site and in Limassol, a site influenced by land-sea breezes. The results of these investigations are presented by Baumbach et al. (2007). To preserve the ventilation of the cities and the high traffic zones is an important milestone within the efforts for an improved air quality.

2.5 Recommendations for Air Quality Assessment and Improvement

Based on all results of the project air quality measures have been proposed distinguished in

- Administrative, planning and management measures
- Technical measures to reduce the emissions at the sources
- Educational measures.

3. RESULTS AND DISCUSSION

3.1 Emissions Inventory

The overall annual air pollutants emissions in the Greek (GCC) and Turkish (TCC) Cypriot Communities for the reference year 2001 are listed in Table 1.

Table 1. Overall annual air pollutants emissions of all investigated sources in Cyprus.

Pollutants Sources	NO_X tn/yr	CO tn/yr	VOC tn/yr	PM tn/yr	SO_2 tn/yr
Boilers	11747	221	515	1655	39932
Dry cleaners	31	8	211	8	334
Hotels	21.6	6.3	0.25	2.2	91.1
Domestic heating	65.6	98.1	3.82	39.2	1666
Agriculture	19.5	29.2	1.1	11.7	498
Petrol stations	-	-	736.4	-	-
Aircrafts	258	64.5	2.613	90.2	18.29
Traffic only exhausts	13256	39549	8271	667	7078

The boilers include the power plants which are the main sources for NO_x and SO_2. The other important source for NO_x and the main source for CO and Volatile Organic Compounds (VOC) is the traffic, especially in the cities. Particulate Matter (PM) is emitted from industries (boilers with their combustion processes), from vehicle exhausts and from wild waste burning or forest fires. Since the dryness of the country resuspension of natural soil and of road dust plays an important role within the PM emissions. But such diffusive emissions could not be quantified within the emissions inventory. Their contribution to the PM_{10} load of the air was investigated by ambient air PM samplings and analyses (Kleanthous et al. 2007).

3.2 Spatial distribution of air pollutants determined by diffusive sampling

As an example of the results of the determining the spatial pollutants distribution the NO_2 map is shown in Figure 1. It has been calculated with neural network model, based on diffusive sampling, emissions inventory with plume dispersion modeling and population density. As an another example the benzene distribution in a city shall be depicted in Figure 2. This map was only calculated by interpolation, not by Neural Networking. It can be seen that the evaluation by means of Neural Network results in a much better resolution and plausibility than the interpolation between sampling points. But the most polluted zone in the inner city in this case in Nicosia can also be recognised by the depiction from the easier method of interpolation. Compared to the conditions in other European cities the benzene concentrations referred to the number of moving vehicles were high in Cyprus cities. This was because of the relatively low number of vehicles with EURO 2 standard and higher at that time.

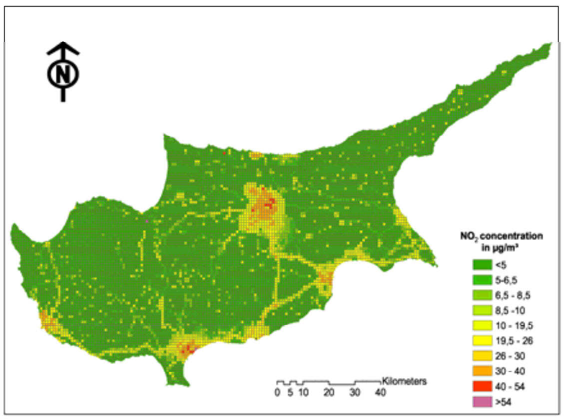

Figure 1. NO_2 distribution calculated with neural network model, based on diffusive sampling and emissions inventory.

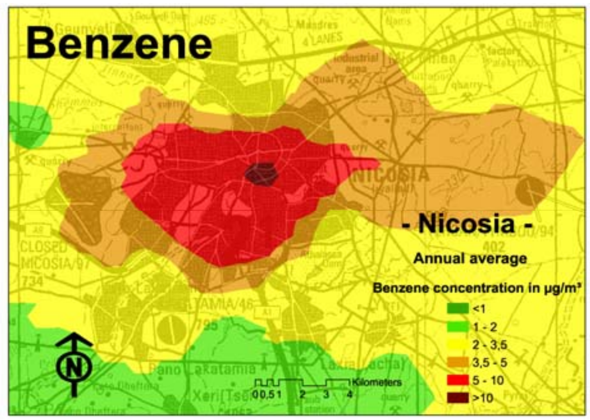

Figure 2. Mean annual interpolated benzene distribution in Nicosia.

3.3 The temporal variation of air pollutants determined by continuous monitoring

The results of continuous monitoring had been evaluated by different modes. To recognize regularities in the pollutant behavior the depiction of average diurnal courses gives a representative impression. As examples the average diurnal courses of NO_x in urban areas during winter season and weekdays are shown in Figure 3a on the one hand. There is a great influence of traffic behavior on the NO_x courses. On the other hand ozone shows in summer months a site-typical behavior, see Figure 3b. On the Mount Olympus (1952 m asl) nearly now diurnal course can be observed. That means, the overall ozone concentration is nearly not influenced by daily meteorological and anthropogenic cycles respectively activities. But in the cities the ozone concentrations

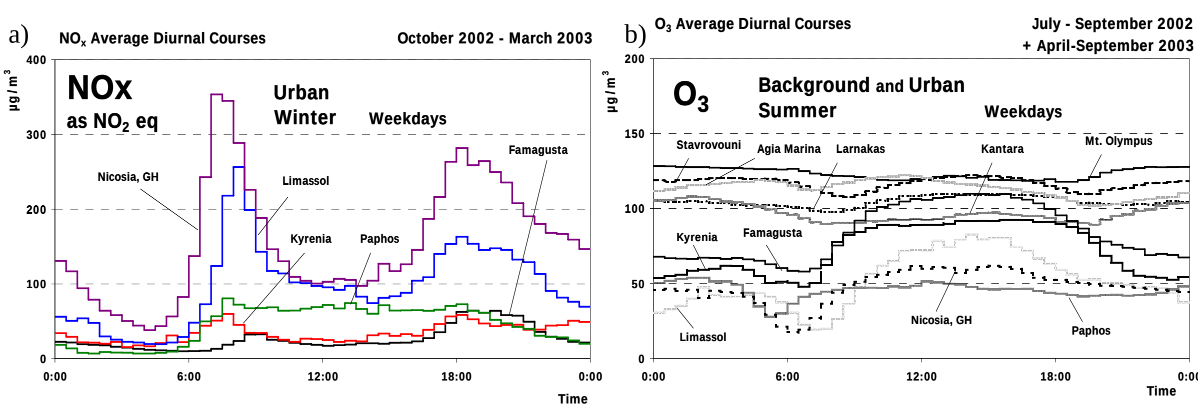

Figure 3. Average diurnal courses: a) NO_x at urban monitoring sites during winter season on weekdays
b) O_3 at background and urban monitoring sites during weekdays in summer season.

are much lower, especially during night. This is due to the ozone depletion by NO_x emissions which are concentrated in the cities below the nocturnal surface inversions. The balloon soundings showed the same result (Baumbach et al. 2007). Above these layers ozone is preserved in the so called "Ozone reservoir layer"(Baumbach and Vogt, 2003). Therefore at the mountain sites no nocturnal ozone decrease takes place (see Fig.4). With other words: The average ozone values are lower in the cities, but the air is not better there because the ozone is consumed by other pollutants in high concentrations (NOx and VOC). So, if there is no nocturnal ozone decrease on the mountains it can be stated that this is an indicator for fresh air. In Limassol it could be observed that the nocturnal Mountain wind transports fresh air into the city, indicated by a nocturnal ozone increase peak (Baumbach and Pfeiffer, 2004).

4. CONCLUSIONS

As result of all the measurements carried out in the project it can be stated that the most affected sites in Cyprus are: high traffic zones in the cities, bad ventilated city areas with traffic influence, Residential areas influenced by close traffic zones, Surrounding areas of power plants and cement factories and some special industries, Neighborhood of quarries, Sites affected by uncontrolled burning: surrounding areas of wild waste burning and of field or bush fires. To improve the air quality different measures have been recommended in the project. The realization of such measures has different time scales. Not all measures can be realized immediately because of costs or other reasons. But some measures could be implemented at once. In the following the recommended air quality improvement measures are classified in short, medium and long term improvement activities, classified according the responsibilities. For improving the air quality in the inner cities of Cyprus the measures have been proposed: 1. Introduction of air quality and urban climate aspects into the city planning of all cities in Cyprus: No development plan should be decided without an air quality and climatic experts opinion which considers the ventilation of the cities and of high traffic roads 2. Studies for the design of integrated traffic systems for each major city of Cyprus including modern traffic management systems 3. Initial set up of bus systems with high frequent servicing (and priority lanes and traffic lights) in the major cities and as interconnection between the cities. For Nicosia the installation of a combined trolley bus system has been proposed (electric driving in the city, diesel operation outside the city) 3. Establishing of school bus systems 4. Extending of pedestrian areas 5. Promotion of cycle ways 6. Planting of bushes and hedgerows at the edges of fields 7. For existing bad ventilated roads in the cities, the traffic emissions have drastically to be reduced (by the measures mentioned above) 8. Drastically emissions reduction in bad ventilated inner cities by closing them for traffic (not closed for electric trolley buses): e.g. inner cities of Larnaca, Kyrenia and Makarios Avenue in Nicosia etc.

5. ACKNOWLEDGEMENTS

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URBAN AIR QUALITY IN EUROPE: THE POLICY RESPONSE

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ABSTRACT

The Clean Air for Europe (CAFE) programme compiled the latest knowledge on the impacts of air pollution and developed policy responses to complement implementation of existing legislation and other activities related to air pollution abatement. The resulting 2005 Thematic Strategy on Air Pollution (the Strategy) has been later accompanied by the Thematic Strategy on Urban Environment addressing environmental problems of urban areas.

The Strategy sets interim objectives for improvement of human health and environment through improvement of air quality up to year 2020. It identifies the most important sources and their abatement potential. Need for specific measures at the community and the international level is outlined such as vehicle emission standards, shipping and the revision of the national emission ceilings directive. In parallel, activities to support more effective implementation are being prepared.

The Commission has jointly with the Strategy proposed a new Directive for ambient air quality and cleaner air for Europe, which is currently in the co-decision process. It includes elements such as new $PM_{2.5}$ environmental standards and flexibility to address compliance with existing limit values.

1. INTRODUCTION

Air pollution has been subject to action taken at the national and the EU/international level for several decades. In the last 15 years a number of different legal community instruments have been developed to address emissions at source, fuel quality as well as to set the ambient air quality standards[1]. These are only the most direct actions in a vast arsenal of measures which enable air pollution abatement that includes information exchange, research, development of emission inventories, air quality models and measurement standards, assessment of air quality and human exposure, and the development of non-technical measures such as urban transport planning.

Despite significant improvements, serious air pollution impacts persist. The Community's Sixth Environmental Action Programme (6th EAP) called for the development of a thematic strategy on air pollution with the objective to attain '*levels of air quality that do not give rise to significant negative impacts on, and risks to human health and the environment*'. Impacts on public health are particularly significant in the urban areas due to stronger pressures on the environment and larger public exposure. For those, 6th EAP had called for a strategy '*contributing to a better quality of life through an integrated approach concentrating on urban areas*' and to contribute '*to a high level of quality of life and social well-being for citizens by providing an environment where the level of pollution does not give rise to harmful effects on human health and the environment and by encouraging sustainable urban development*'.

As it is impossible to present all activities which could be considered as the 'policy response' in a few pages, the paper is limited to the presentation of the Thematic Strategy on Air Pollution, the Thematic Strategy on Urban Environment, and the new Air Quality Directive. It is important to note at least three additional relevant activities, which are the fight against climate change, the Global monitoring for environment and security programme (GMES), and the environment and health action plan. While the latter aims to coherently address the impacts of a number of physical and chemical stressors including air pollution on human health, GMES aims to make use of the extensive in-situ and remote air quality monitoring by providing EU-wide air quality assessment service. Better assessment leads to better understanding of the local and regional air quality situation and facilitates planning and implementation of the most cost-effective abatement on a local, regional and EU scale.

Today we also understand better the linkages between the climate change and air pollution. By reducing the radiative forcing the air pollution has been in the last decades to some extent shielding our planet against the effects of climate change. On the other side, a number of measures that aim at reduction of greenhouse gas emissions such as improving energy efficiency represent a typical win-win situation with the air pollution policy and importantly reduce the implementation cost of each of the policies.

[1] See References

2. THEMATIC STRATEGIES

Following its communication on the Clean Air for Europe programme (CAFE), the Commission has examined whether current legislation is sufficient to achieve the 6th EAP objectives by 2020. This analysis looked at future emissions and impacts on health and the environment and has used the best available scientific and health information. It showed that significant negative impacts will persist even with effective implementation of current legislation. Fine particles $PM_{2.5}$ and to a lesser extent ozone have been identified as principal pollutants which need to be addressed.

According to the CAFE impact assessment modelling using the energy scenarios available at the time, in 2020 even the use of all available technological solutions would not deliver in full the 6th EAP objectives. Based on the thorough assessment of the scope and costs of currently known technological solutions for air pollution abatement, the Commission's Communication on a ***Thematic Strategy on Air Pollution*** (COM(2005) 446) therefore recommended interim objectives for the protection of health and the environment from air pollution to be attained by 2020 relative to the position in the year 2000, among others:

- 47% improvement in premature mortality (expressed as life years lost over the whole population) due to exposure to fine particulate matter (PM2.5) in air [3.62 million life years lost in 2000 roughly equivalent to 350,000 deaths];
- 10% improvement in acute deaths from exposure to ozone from [20,000 cases in 2000];

These objectives by themselves have no legal force, but they serve as a benchmark when developing and adopting measures which have legal force.

Accompanied by a comprehensive impact assessment, the Strategy proposed a range of measures, among others:

- The air quality Proposal to combine the existing air quality legislation (see chapter below).
- Revision of the national emissions ceilings directive 2001/81/EC. It currently establishes annual mass limits to be attained by 2010 for each Member State's emissions of nitrogen oxides, sulphur dioxide, volatile organic compounds and ammonia and does not specify the means of attaining these emissions reductions. The revision that will be available by mid-2007 would potentially establish national emission caps on for the year 2020 and include primary/direct emissions of fine particles $PM_{2.5}$.
- New measures to reduce exhaust emissions from cars and vans in two stages (EURO 5 & 6, addressing particle and NO_x emissions respectively) have been already adopted by legislator. Preparatory work is underway to develop new tailpipe limits for heavy duty engines (EURO VI). Proposal is expected in 2007. Heavy duty vehicles account for a third of all road transport emissions of NO_x in 2020 where transport will comprise up to half of all NO_x emissions from land based sources.
- Review of the directive on IPPC (integrated pollution prevention and control) to potentially include (i) intensive cattle farming activities; wider range of pig and poultry installations; (ii) industrial combustion plant in the power range of 20-50 Mega Watts which are currently outside the scope. The review is expected to finish in late 2007.
- Ship emissions will represent more than half of total emissions of sulphur dioxide and nitrogen oxides in the EU in 2020. In its conclusions on the ship emissions strategy, the Council invited the Commission to pursue action at the International Maritime Organisation to tackle emissions of NOx from international shipping by imposing stricter standards on ships' engines. If progress is unsuccessful, the Council invited the Commission to look at the feasibility of establishing Community measures.
- Other measures to reduce exhaust emission from domestic boilers and in particular ammonia emissions from agriculture.
- Last but not least, measures in research to improve our understanding of air pollution, its impacts on health and environment, and to develop new technological solutions which will reduce anthropogenic emissions in air.

The main conclusion of the ***Thematic Strategy on Urban Environment*** (COM(2005) 718) was the recognized importance of national and EU support to the local authorities to adopt the integrated approach to the urban environmental management. Voluntary technical guidance on the integrated management, drawing on experiences and good examples as well as appropriate references to the legislation was chosen as the most appropriate and instrument at EU level, as the potential EU legislation could probably not appreciate appropriately the diversity of local implementation.

To address the most important contributor to the urban environmental pressures the EU Guidance on sustainable urban transport plan has been developed in a similar fashion. It provides practical recommendations for making an appropriate analysis of the situation and gives the list of potential measures, linking them to the expected benefits in terms of air pollution, congestion and noise. Challenged by the constant increase in urban mobility the transport plans should represent the cornerstone of every air quality plan developed by the European cities, if improvement in air quality is to be achieved in a sustainable manner.

The last major initiative launched by the urban strategy has been to further develop the networking between the cities with an aim to support exchange of best practices, efficient use of resources through joined exercises and capacity building. On a EU level, further research under the FP7 and explicit references to the urban environmental performance including in the use of EU cohesion/structural funds has been promoted.

3. AIR QUALITY DIRECTIVES

The ambient air quality is regulated at the EU level by the Council Directive 96/62/EC on ambient air quality assessment and management, referred to as the Air Quality Framework Directive and its 4 daughter directives 1999/30/EC, 2000/69/EC, 2002/3/EC, and 2004/107/EC.

Their implementation has revealed 2 main issues that needed to be addressed by the Commission when launching the Strategy:

- The fine particles $PM_{2.5}$ are not yet covered by the environmental objectives. The Directive 1999/30/EC includes general references to monitoring of $PM_{2.5}$,, but this provision has not been well implemented
- There are widespread exceedances of limit values for particulate matter PM_{10} (in 2005 40% of all air quality zones for daily PM10 limit value, 17% for annual, in all countries except Ireland). Reasons for exceedance are complex, from strong increase in urban traffic in recent years, late planning and weak implementation of local/regional measures, to late introduction of community measures (such as vehicle emission standards EURO 5/6, EURO VI). Some measures such as reductions of emissions under national emission ceilings directive have also not delivered enough, contributing to high regional background concentrations and transboundary pollution.

The Strategy was accompanied by a **directive Proposal on ambient air quality and cleaner air for Europe** (COM(2005) 447). The proposal merges existing air quality directives except 4th daughter directive and the Exchange of Information Decision. It has three key elements, the last two of which specifically address non-compliance problems:

- Introduce two new air quality objectives for fine particulate matter in ambient air ($PM_{2.5}$): a limit value and an exposure reduction target requiring improvement of $PM_{2.5}$ concentration in urban areas by 20% between 2010 and 2020. It also provides explicit requirements for monitoring $PM_{2.5}$ and to the limited degree its chemical speciation
- the possibility of discounting natural sources such as sea spray for the purpose of assessing compliance
- under certain conditions, granting of time extensions to meet air quality standards in specific areas (PM_{10} up to 2010, NO_2 up to 2015)

Granting time extensions is linked to strict conditions which include demonstration of implementation of all related community legislation, and the assessment on an updated air quality plan by the Commission. The Commission will assess the rationale for any such request and whether all possible measures have been considered, and that the levels of ambition and implementation are adequate to ensure compliance with the limit values by the new date. Possibility to discount natural sources is an extension of the already existing provision to discount for natural events such as Sahara dust, acknowledging for example that these contributions, which are beyond control of the Member States, can be quite significant particularly in arid and coastal areas.

The most important innovation is the national exposure reduction target for $PM_{2.5}$. Its assessment is based on urban background monitoring which should be set in a way to proxy the population exposure in urban areas. It is expected to drive more cost-efficient measures with larger benefits in terms of reducing the population exposure as compared to the setting of an ambitious $PM_{2.5}$ limit value, which could focus the efforts in improving the situation to hot-spots. The accompanying $PM_{2.5}$ limit value is however still proposed to prevent unduly high exposure in some areas and to a larger extent ensure social equity.

The Council and the European Parliament have deliberated on the proposal in the first reading. The Council common position expressing the political agreement between the Member States is expected in April 2007. It follows closely the original Commission proposal. Due to several differences between the Council and the Parliament on some of the future solutions the directive will go into the second reading during 2007. If an agreement is reached, the directive will enter into force in 2007.

CONCLUSIONS

It is evident that it is the Member States, their regional and local governments as well as the industry that implement the EU policy response presented above. Technological measures such as vehicle emission reductions can and must be complemented by national, regional and local measures that include sustainable land use and transport planning, environmental zones, incentives for faster renewal of the fleet or domestic appliances, change to cleaner sources and individual local solutions. The Commission facilitates the implementation by providing guidance, organises networks to promote exchange of best practices, supports production of common standards and services, and monitors compliance with the obligations under the EU legislation.

The Commission is also constantly re-evaluating the situation and trying to ensure that all related EU policies pursue the objectives of the 6^{th} EAP and the more specific targets of the Thematic Strategy on Air Pollution.

ACKNOWLEDGMENT

The CAFE programme as well as the preparation of the Thematic Strategy on Urban Environment has been extensive collaborative exercises. CAFE alone included a public consultation with more than 10000 responses, over 100 meeting with stakeholder representatives from the Member States, NGOs and industry federations, consultants, and a number of organisations, most notably UN-ECE CLRTAP, World Health Organisation (WHO) and the European Environment Agency (EEA).

The Commission gratefully acknowledges all contributions.

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For general information and an exhaustive list of the existing related EU legislation see http://ec.europa.eu/environment/air/index_en.htm

OPPORTUNITIES FOR BETTER INTEGRATION OF THE LOCAL AIR QUALITY MANAGEMENT AND THE IPPC REGIMES TO IMPROVE AIR QUALITY

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ABSTRACT
This paper investigates the process of Local Air Quality Management (LAQM) in English and Welsh local authorities experiencing poor air quality arising from industrial emissions and the integration between LAQM and the Integrated Pollution Prevention and Control (IPPC) Regime. This study shows that the Environment Agency and local authorities were working in partnership in implementing LAQM and IPPC. However, inconsistent patterns of communications between local authorities and the Environment Agency were revealed in the case study research. This research identified a new area of investigation for the Environment Agency moving away from point sources to a fuller consideration of the importance of fugitive source. The paper concludes with recommendations for future practices in LAQM related to industrial emissions.

1. INTRODUCTION
This paper examines the implementation of the regime to control ambient air quality, i.e. Local Air Quality Management (LAQM), in English and Welsh local authorities experiencing poor air quality arising, at least in part, from industrial emissions. Specific attention is given to industrial sources because the system of industrial pollution control (particularly in England) has been established for over 100 years with clearly defined responsible bodies i.e. shared between the Environment Agency of England and Wales and local authorities. Thus, it allows an examination of a relatively new regime, LAQM, within the scope of an established system. This research focused on the first round of air quality review and assessment[1].

The primary legislation regarding the LAQM is part IV of the Environment Act 1995. The Act also anticipated the EU Framework Directive 96/62/EEC on Ambient Air Quality Assessment and Management (Council of the European Union, 1996a), which requires the introduction of legally binding air quality standards and assessment procedures to maintain and improve air quality within Member States. In the UK, it is the local authority who has the statutory powers to conduct a review and assessment of air quality and to declare an Air Quality Management Area (AQMA) where necessary (sections 82 and 83 of the 1995 Act) (HM Government, 1995). Within one year of the declaration, and in parallel with ‘Further Assessment’ work, the authorities should develop an air quality action plan setting out how they intend to achieve the Objectives. In carrying out their reviews and assessments, and preparing the action plan, local authorities undertake consultation with statutory consultees such as the Environment Agency. Local authorities are now in the third round of review and assessment and over 200 local authorities across the UK currently have AQMAs.

Another main feature of the Environment Act 1995 was the establishment of one Environment Agency for England and Wales, and a separate one for Scotland called the Scottish Environmental Protection Agency (SEPA), responsible for the control of air, water, and land pollution. The Environment Agency’s functions that are specifically related to air pollution control are its industrial pollution control and being one of the statutory consultees in the National Air Quality Strategy. Section 81 of the Environment Act 1995 states that whilst exercising its pollution control functions, the Environment Agency is to have regard to the Strategy. This means that when the Environment Agency determines the authorisation limits for an industrial process, they must take into account the air quality standards and objectives. Being a statutory consultee, the Environment Agency is obliged to contribute to achieving the AQOs and, therefore the Environment Agency needs to work together with the local authorities.

Responsibilities for controlling industrial installations are shared between the Environment Agency (the Scottish Environment Protection Agency in Scotland) and local authorities. The European Council Directive 96/61/EEC on Integrated Pollution Prevention and Control (Council of the European Union, 1996b) is currently being implemented in the UK by the Pollution Prevention and Control (PPC) Act 1999 and associated regulations (HM Government, 1999). An industrial installation requires site specific permits which consider the characteristics of each industrial plant, location and state of the local environment. To obtain a permit, the installation must ensure that pollution from industry is minimised through the use of Best Available Technique (BAT)[2] subject to an assessment of costs and benefits. It is essential that the local

[1] The first round ended in 2003 whilst the second round finished in 2005.
[2] Defined as ‘the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing in principle the basis

authorities in their review and assessment work and the regulator of an industrial installation evaluate the extent of any contribution the installation might make to the pollution burden in an AQMA in order to determine the most appropriate measures to include in an air quality action plan.

2. METHODOLOGY

Data are drawn from questionnaire survey and case study research. Questionnaires were sent by mail to 105 local authority officers, responsible for implementing the LAQM regime in areas considered affected by industrial sources, and Environment Agency officers (Process Industries Regulation Inspectors) where such authorities were located. Five local authorities were selected for case studies. The selection was based on responses given to the questionnaire survey where local authorities were asked about the relative impacts of different air pollution sources to local authority. Case study authorities reported major or minor impacts from industrial installations which then contribute to air pollution problems. The questionnaire survey provided a broad picture of LAQM practice in local authority areas affected by industrial sources whilst case studies covered a more limited number of authorities but in more depth, in order to understand the relationship between local authorities and the Environment Agency and to investigate how to further integrate the LAQM and IPPC regimes.

3. RESULTS AND DISCUSSION

In general, the Environment Agency makes contributions to LAQM through the industrial activities they regulate. Both the Environment Agency and the local authorities hold substantial information about national and local air quality, with regards to emissions from prescribed industrial processes. The Environment Agency can provide data from Part A /A1 installations, whilst local authorities have detail data on local emissions from A2 and B installations.

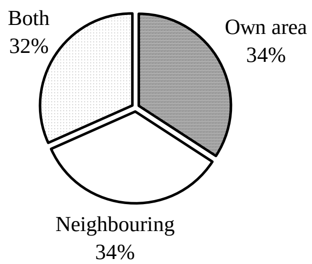

Figure 1. Locations of significant industrial sources affecting local authorities as advised by Technical Guidance 4 Pollutant Specific Guidance (n=69)

Of the 105 local authorities contacted, an overall response rate of 67% was achieved. Fifty-five percent of survey participants stated that they had significant industrial source(s) within their local authority area, or were being affected, regardless of location of the industry. Figure 1 illustrates the categories of locations of significant industrial source(s) affecting a local authority as advised by Technical Guidance 4 Pollutant Specific Guidance (DETR *et al*, 2000). Details for each pollutant are presented in Table 1. Very few authorities had significant industrial source(s) for benzene, 1,3-butadiene, carbon monoxide or lead. Other pollutants mentioned were cadmium and volatile organic compounds.

The majority of survey participants worked with the Environment Agency at the area level, which indicated that local authorities see the area office as their first point of contact. This is in line with the area officers' responsibility for the day-to-day management of the environment and to meet the needs of the local community. Around 80% of survey participants asked the Environment Agency officers to provide information on type of pollutants and this was followed by the number of authorities requiring total emission data. Only 40% of local authorities requested information on monitoring and modelling from the Environment Agency.

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for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a while' (Regulation 3(1) of the PPC Regulations).

Table 1. Location of significant industrial sources based on advice given in Technical Guidance 4 Pollutant Specific Guidance $^{(n=37)}$

Pollutant	Percentage		
	Within local authority	Neighbouring authority	Both
Benzene	5	0	3
1,3-butadiene	0	0	0
Carbon monoxide	5	3	3
Lead	11	3	0
Nitrogen dioxide	22	22	24
Particles	27	14	22
Sulphur dioxide	27	22	14
Other	3	3	3

From the questionnaire surveys sent to the Environment Agency officers, all regional and area offices stated that they provided information to local authorities in relation to industrial installations regulated by the Agency. Every regional office stated that the most common type of information requested by local authorities were the types of pollutants and the total emissions whilst all area offices provided information on types of pollutants to local authorities, followed by total emissions data (82%), monitoring (36%) and modelling data (46%). Over 80% of regional offices stated that they would conduct modelling and work with industry if an industrial source was believed to contribute to an AQO exceedence. Two thirds of them would inform the affected local authorities and 50% would ask the industry concerned to conduct air quality modelling. Nearly all area offices worked with industry if an industrial source was believed to give rise to the AQO exceedence. In addition, they informed affected local authorities and conducted modelling themselves and/or required industry to do it. These questionnaire findings were supported by evidence from one case study authority in the South West Region. The local authority based their AQMA declaration and boundary designation according to the Environment Agency's modelling results, which predicted a maximum of 125 exceedences of the SO_2 15-min objective.

Case studies have highlighted relatively good collaboration between local authorities and the Environment Agency. The air pollution problem from a particular point source, a cellophane factory at South West Region, was recognised early and had led to an early dialogue between both parties. A distinctive feature of this collaboration is the utilisation of very useful resources that the Environment Agency has at their disposal. The Regional Environmental Data Unit of the Environment Agency carried out modelling related to the point source, the results of which were then incorporated into the local authority's review and assessment report. Another authority in Kent also identified an SO_2 problem from a power station located in the neighbouring district. The Environment Agency Southern Region office acted rapidly to issue the Council with a statement that no power generating facilities would be permitted to cause an SO_2 exceedence. The Thames Region office also issued a similar statement for a London Borough authority. These rapid responses were due to the Environment Agency's policy regarding power stations as the sole cause of an exceedence of the SO_2 objectives. There was no need for local authorities to declare AQMAs in such cases as the Environment Agency altered their authorisations to ensure achievements of the objectives (AQM, 2000).

In the case of other case study authorities, collaboration was not established at the beginning of the LAQM process, but regular communication and co-operation have since resulted in an improved working relationship and agreements to revise licensing conditions of the industrial sources. These authorities experienced PM_{10} problems from Environment Agency regulated processes (cement works and waste management facilities). Initially, there was reluctance at the area office level in all three cases to acknowledge the PM_{10} problems although at regional level, the problem of fugitive emissions emanating from waste management facility was already recognised. The use of the Environment Agency resources or quick response as in the case of SO_2 problems was not reported by these case study authorities. Late recognition of the problem delayed the Review and Assessment work as local authorities had no powers to enforce any conditions on the sources of AQMA declarations.

4. CONCLUSIONS

This research investigates the level of co-operation and liaison between local authorities and the Environment Agency as the two key actors in industrial pollution control with regards to the LAQM process. The Environment Agency already assisted central government in the preparation of guidance documents related to IPPC and LAQM regimes. Further direction and involvement in preparing specific review and assessment guidance (both technical and policy) for local authorities with air pollution problems from industrial emissions would prove to be useful. It would enable the Environment Agency to link their two functions and identify areas for improvement or where there is an overlap in responsibilities. This specific guidance could enhance collaboration between the two enforcing authorities. Inconsistent patterns of communications between local authorities and the Environment Agency revealed in the case study research whereby the Environment Agency officers' interest in air quality issues appears to determine the pattern can be avoided by providing training to area officers about the LAQM process, the Environment Agency's responsibilities, its importance especially with regards to industrial pollution control, and the support that they can offer to local authorities. This research also identified a new area of investigation for the Environment Agency moving away from point sources to a fuller consideration of the importance of fugitive source. It would also be invaluable for the Environment Agency or central government to lead or commission research on such unregulated pollution sources with 'negligible' thermal output capacity, with the aim of re-classification of industrial installations, for instance A2 installations and waste management facilities responsible for AQMA declarations, into A1 installations.

5. ACKNOWLEDGEMENTS

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REGIONAL INTEGRATED AIR QUALITY MANAGEMENT: AN EXAMPLE FROM THE CALIFORNIA REGIONAL $PM_{10}/PM_{2.5}$ AIR QUALITY STUDY (CRPAQS)

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ABSTRACT

The 14-month-long (December 1999- February 2001) Central California Regional $PM_{10}/PM_{2.5}$ Air Quality Study (CRPAQS) acquired speciated $PM_{2.5}$ measurements at 38 sites representing urban, rural, and boundary environments in the San Joaquin Valley (SJV) air basin. It was found that $PM_{2.5}$ and NH_4NO_3 concentrations decrease rapidly as altitude increases, confirming that topography influences the ventilation and transport of pollutants. Concentrations of organic matter differed substantially between urban and rural areas. UNMIX and Positive Matrix Factorization (PMF) were applied to chemically speciated $PM_{2.5}$ measurements from 23 CRPAQS sites to estimate source contributions. Source factors included marine sea salt, fugitive dust, agriculture-dairy, cooking, secondary sulfate and nitrate, gasoline and diesel exhaust, and residential wood combustion (RWC) emissions. Secondary ammonium nitrate and RWC accounted for over 70% of $PM_{2.5}$ mass during the wintertime high $PM_{2.5}$ period. Chemical Mass Balance (CMB) source apportionment was done for high $PM_{2.5}$ episodes during winter 2000/2001 at the Fresno supersite.

1. INTRODUCTION

The California Regional $PM_{10}/PM_{2.5}$ Air Quality Study (CRPAQS) is a multiyear effort to understand the causes of elevated particulate matter (PM) concentrations and to evaluate ways to reduce them in central California (Watson et al., 1998). The SJV is one of the largest $PM_{2.5}$ and PM_{10} non-attainment areas in the United States ($PM_{2.5}$ and PM_{10} are particles with aerodynamic diameters less than 2.5 and 10 micrometers [µm], respectively). Previous studies (Chow et al., 1996; 1999) have shown that winter PM concentrations were primarily in the $PM_{2.5}$ size fraction, while during the remainder of the year PM_{10} consisted of nearly equal parts of $PM_{2.5}$ and PM_{coarse} (PM_{10} minus $PM_{2.5}$). Surface wind speeds during winter in the SJV are very low, often <1 m/s, and surface wind directions are variable. Surface transport distances estimated from these wind speeds are insufficient to account for the mixing of non-urban ammonia (NH_3) emissions with urban nitrogen oxides (NO_x) emissions for the formation of secondary ammonium nitrate (NH_4NO_3). These observations suggest that PM concentrations in the SJV are determined by regional-scale interaction of source emissions, chemical transformation, vertical mixing, horizontal transport, and deposition.

2. METHODOLOGY

To better assess the source-receptor relationships, CRPAQS established a comprehensive aerosol monitoring network consisting of 38 sites of eight site-types defined by environmental characteristics around the sites, i.e., 18 community exposure sites, 11 emissions source-dominated sites, 9 visibility sites, 11 intra-basin gradient sites, 2 vertical gradient sites, 1 intra-basin transport site, 6 inter-basin transport sites, and 7 boundary/background sites (one site could be in multiple categories). This network covered a region ~600 km long by 200 km wide and is described by {Chow, 2006 17211 /id}. Sampling took place from 2 December 1999 through 3 February 2001, including an annual program between 1 February 2000 and 31 January 2001. Sampling was also conducted during winter Intensive Operating Periods (IOPs) that were selected based on forecasts of high $PM_{2.5}$ between 15 December 2000 and 3 February 2001. The annual program included every-sixth-day 24-hr sampling at three anchor sites—Fresno Supersite (FSF, Watson et al., 2000), Angiola (ANGI), and Bakersfield (BAC)—and at 35 satellite sites. Winter IOPs included five times/day 3-8 hr samples for 15 days at the five anchor sites—Bethel Island (BTI), Sierra Nevada Foothills (SNFH), FSF, ANGI, and BAC—and daily 24-hr sampling for 13 days at 25 satellite sites.

The speciated $PM_{2.5}$ data were analyzed by multivariate receptor models, UNMIX and Positive Matrix Factorization (PMF) for source apportionment (Chen et al., 2007). UNMIX and PMF require the chemical profiles of the contributing sources to be relatively constant within a source type but differ substantially between source types. The CRPAQS $PM_{2.5}$ dataset meets these requirements because area and mobile source profiles are reasonably consistent throughout the SJV (i.e., not site-specific, and there is a large expected variability between source contributions by sampling time and location. Emission factors and chemical profiles of the area and mobile sources are expected to differ between seasons. Motor vehicle cold starts are more prevalent during the winter. Wood stoves and fireplaces are only used during winter, while agricultural burning and wildfires are more prevalent during warm non-winter periods. To ensure uniformity of source profiles, the UNMIX and PMF analyses were limited to 23 "within-valley" sites. The low $PM_{2.5}$ (February to October) and high $PM_{2.5}$ periods (November and December) contain 929 and 670 samples, respectively.

IOP samples used for the CMB at Fresno were analyzed for specific $PM_{2.5}$ organic compounds in addition to elements, ions, and carbon fractions {Chow, 2006 18705 /id;Rinehart, 2006 16945 /id}. CMB source profiles in CMB were obtained from emission tests on vehicle exhaust, wood burning, and cooking specific to fuels and operating conditions in California. These profiles have been integrated into a documented data base with other recent profiles (Chow et al., 2006c) and are being incorporated into the U.S. EPA's SPECIATE data base (Pechan, 2006).

3. RESULTS AND DISCUSSION

Annual-average $PM_{2.5}$, based on four quarterly averages at 14 of the 38 CRPAQS sites, exceeded the U.S. annual $PM_{2.5}$ National Ambient Air Quality Standard (NAAQS) of 15 µg m^{-3}. Most of these exceedances occurred in the southern SJV at urban sites such as Fresno (23 µg m^{-3}), Visalia (VCS; 22 µg m^{-3}), and Bakersfield (26 µg m^{-3}), and also at the regional transport Angiola site (18.7 µg m^{-3}). The $PM_{2.5}$ concentration decreased rapidly towards the higher elevation valley boundary. Three sites in Bakersfield (residential Bakersfield residential site, urban Bakersfield central site, and inter-basin gradient Edison [EDI] site, all ~118 m above MSL) reported consistently high annual $PM_{2.5}$ concentrations of 24–28 µg m^{-3}, despite the fact that each site represents different micro-environments. Tehachapi (TEH2), an inter-basin transport site, located ~50 km to the southeast of Edison at 1229 m above MSL, recorded an annual-average $PM_{2.5}$ concentration of 7.3 µg m^{-3}. The stable atmosphere surrounding the Sierra Nevadas and coastal mountains prevents precursor gases and PM released in the SJV from rapidly dispersing. This is especially true for the southern SJV because the elevation of the valley floor generally increases from north to south as far as Fresno and descends south of Fresno. The five most northwestern sites in this network, located at Bodega Bay, Bethel Island, San Francisco, Sacramento, and Stockton, all have elevations less than 10 m above MSL. Marine air enters the SJV through the Carquinez Straits east of the San Francisco Bay area, leading to the lower $PM_{2.5}$ in the northern valley.

CRPAQS confirmed several results from previous SJV studies (e.g., Chow et al., 1993; 1996). $PM_{2.5}$ consists mainly of NH_4NO_3 and carbonaceous material. Ammonium sulfate $(NH_4)_2SO_4$ and crustal material are minor components of $PM_{2.5}$. During summer, a nearly-uniform organic carbon (OC) distribution was observed between the Sierra Nevada and the coastal mountains (Figure 1a). Average OC concentrations at most sites were between 6 and 8 µg m^{-3}. EC showed a similar pattern. Within the SJV, summertime nitrate was <4 µg m^{-3}, decreasing to <1 µg m^{-3} at the elevated mountain sites (Figure 1b). Nitrate in the southern SJV was much higher during winter, with the highest average concentration of ~18 µg m^{-3} observed at BAC (Figure 1d). Elevated nitrate were not limited to urban areas. The rural Helm site in central Fresno County (55 m above MSL), ~41 km to the west of FSF, reported a nitrate concentration of ~12 µg m^{-3}, close to levels found in the Fresno area (14–16 µg m^{-3}). Average nitrate was even higher at Angiola, approaching 18 µg m^{-3}. However, nitrate concentrations decreased rapidly with site elevation and location outside the SJV. The MOP site (832 m above MSL in the Mojave Desert) reported < 1 µg m^{-3} nitrate during both summer and winter. Widespread NH_4NO_3 is the major contributor to wintertime basin-wide $PM_{2.5}$ episodes.

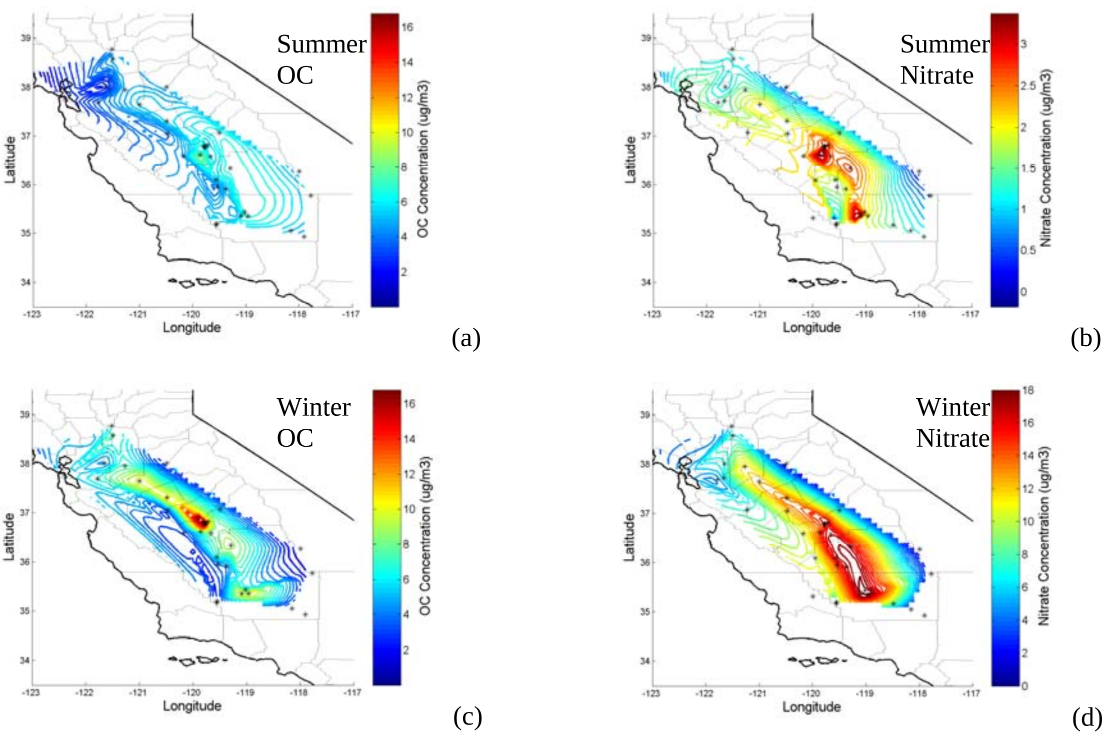

Figure 1. Spatial and seasonal variation of nitrate and OC concentration during CRPAQS.

In contrast with nitrate, no appreciable increases of EC or OC were detected at rural sites, such as Bethel Island, Helm, and Angiola (Figure 1c) in winter. While nitrate increased from 2.5 μg m^{-3} (summer) to 12 μg m^{-3} (winter) at Helm, the OC concentration remained between 3 and 5 μg m^{-3}. This is consistent with a weak source of primary PM emissions in the rural areas. OC concentrations of 7 μg m^{-3} or higher were found at the urban sites Modesto (M14), Sacramento (S13), Fresno, and Bakersfield. EC usually tracked with OC, which exacerbated urban PM pollution already enhanced by NH_4NO_3. $PM_{2.5}$ water-soluble potassium (K^+), a prominent marker for RWC emissions, averaged 0.58 and 0.04 μg m^{-3} during winter and summer, respectively, at the Fresno residential site. At Bakersfield, K^+ concentrations were 0.34 and 0.09 μg m^{-3} during winter and summer, respectively, while the corresponding average ratios of soluble to total K were 0.87 and 0.45, respectively. It is evident that RWC caused elevated winter OC and EC concentrations in the urban areas.

By applying the UNMIX "OVERNIGHT" option to evaluate all possible combinations of species, 6-factor and a 7-factor solutions were found for the non-winter low $PM_{2.5}$ and wintertime high $PM_{2.5}$ periods, respectively, using common species NO_3^-, NH_4^+, total ammonium (T-NH_3 = NH_3 + NH_4^+), Na^+, K^+, OC, EC2, EC, TC, and Si, and an additional species OC1 for the high_$PM_{2.5}$ period only. PMF included 27 species that were above lower quantifiable limits (LQL) for at least 50% of the samples plus the eight thermal carbon fractions. Eight-factor solutions were determined by PMF with the robust mode for both the high and low $PM_{2.5}$ periods. The median *Q* values were 20858 (low $PM_{2.5}$ period) and 18964 (high $PM_{2.5}$ period), compared to ideal values of 31586 (low $PM_{2.5}$ period) and 22780 (high $PM_{2.5}$ period).

Based on source markers, seven common factors resolved by UNMIX and PMF for the high $PM_{2.5}$ period are: 1) marine (Na^+); 2) fugitive dust (Si); 3) agriculture-dairy (T-NH_3, OC); 4) cooking (K^+, OC, EC); 5) secondary aerosol (NO_3^-, NH_4^+, OC); 6) motor vehicle (OC, EC2, EC); and 7) residential wood combustion (K^+, Cl^-, OC1, OC, EC). The extra factor from PMF contains a high zinc (Zn) content and could be related to brake and tire wear. For the low $PM_{2.5}$ period, the six common factors are 1) marine; 2) fugitive dust; 3) agriculture-dairy; 4) cooking; 5) secondary aerosol; and 6) motor vehicle exhaust. The additional two factors from PMF are Zn and another secondary aerosol factor featuring $(NH_4)_2SO_4$. Annual average $PM_{2.5}$ concentrations are well explained within ±1% by both UNMIX and PMF factors. Secondary aerosol, RWC, and vehicle contributions account for ~90% of the $PM_{2.5}$ mass during the high $PM_{2.5}$ period if the Zn factor is classified as a mobile source contribution. UNMIX and PMF yielded similar source contribution estimates that are qualitatively consistent with those of Magliano et al. (1999) and Schauer and Cass (2000) for winter 1995. The portion of $PM_{2.5}$ from secondary aerosol and RWC are much lower for the non-winter (low $PM_{2.5}$) period while the portions due to fugitive dust and marine aerosol are larger compared to the winter period.

CMB sensitivity tests verified that organic compounds markers can help distinguish contributions from gasoline exhaust, diesel exhaust, and cooking by increasing the differences between their source profiles. However, organic markers were not needed to estimate the wood burning contribution. Organic markers did not appear to separate hardwood and softwood contributions, even though there are noticeable differences between their source profiles. The influential species in the source profiles were as expected: Al and Si for paved road, benzo(ghi)perylene , coronene, and indeno[123-cd]pyrene for gasoline vehicles, the EC2 thermal fraction for diesel vehicles, K^+, levoglucosan, and syringaldehyde for hardwood combustion, EC for softwood combustion, and cholesterol for cooking.

For the 51 samples collected in Fresno, RWC was the largest contributor to measured $PM_{2.5}$ (29-31%). Harwood and softwood combustion accounted for 16-17% and 12-15% of $PM_{2.5}$, respectively, although the uncertainty of the softwood contribution was large. Secondary NH_4NO_3 represented 31-33% of $PM_{2.5}$. Motor vehicle exhaust contributed only 9-15% of $PM_{2.5}$. The gasoline-vehicle contribution (3-10%) was comparable to the diesel-vehicle contribution (5-6%). The cooking contribution did not depend on cholesterol, which was not detected in most samples, and was variable, ranging from 5-19% of $PM_{2.5}$. Figure 2 compares the estimated major source contributions to $PM_{2.5}$ during Fresno winter episodes. The CMB, UNMIX, and PMF reach the best agreement for secondary NH_4NO_3 that account for 31 – 33% of $PM_{2.5}$ mass. This also agrees with Schauer et al (2000). There are more deviations in the estimates of burning and cooking contributions.

4. CONCLUSIONS

CRPAQS set up a comprehensive ambient network to investigate the causes of elevated particulate matter (PM) concentrations and to identify dominate sources in central California. This study analyzes the spatial and temporal variations of major $PM_{2.5}$ species. Such an analysis would not be achieved without the design and operation of CRPAQS network. This study also reports preliminary results from the receptor modeling, estimates the source contributions to $PM_{2.5}$, and compares those between different models and previous results. All these information can be used to refine long-term monitoring networks for air quality research and management.

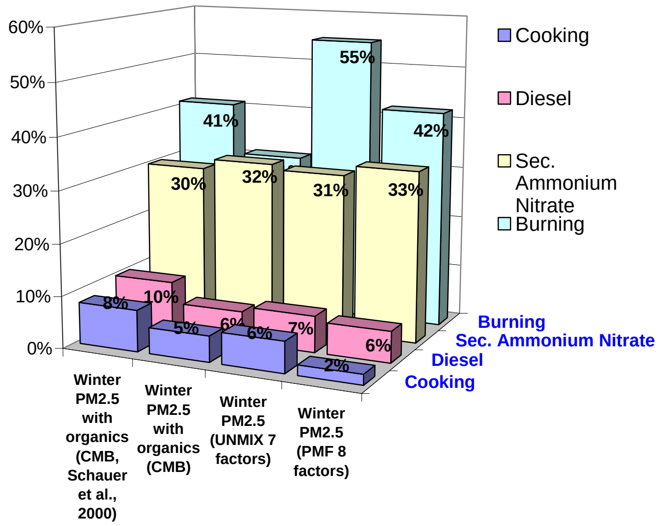

Figure 2. Comparison of source contribution estimated for $PM_{2.5}$ during Fresno winter episodes 2000 – 2001.

5. ACKNOWLEDGEMENTS

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CAN AIR QUALITY MODELLING IMPROVE EMISSION INVENTORIES?

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ABSTRACT
In this paper we present the results of air quality modelling applications using different emission inventories available for Portugal (INERPA, EMEP and LOTOS). These applications were performed with the CHIMERE model, forced by MM5 meteorological fields, over the Portuguese domain. Simulations included testing the different national totals of the emission inventories with their distinct spatial disaggregation, and also temporal profiles used for time disaggregation. The evaluation model exercise indicates no significant discrepancies between the direct applications of the three emission inventories. Globally, is the national inventory (INERPA) application that implies the lowest bias. Nevertheless, it was found an overestimation of PM values for Porto agglomeration, which can be related to a less correct spatial disaggregation in this northern region of Portugal. Sensitivity tests using different road traffic temporal profiles show their influence on the air quality results, mainly regarding traffic hot spots and urban areas.

1. INTRODUCTION

Emission inventories are a vital component of environmental decision-making process providing information on atmospheric emissions by sources and removals by sinks. There are various applications for emission inventories such as compliance verification of national and international legislation, atmospheric modelling and air quality assessment and as a background scenario for the development and monitoring of plans and measures. Therefore emission inventories should be as accurate as possible in order to provide a solid base for air quality decision-making. Nevertheless, the air quality modelling community widely acknowledges that are considerable uncertainties in the emission inventories used for modelling, and they cause part of the errors in the model results. Inventories can also be used in combination with air quality models in order to diagnose emission uncertainties. In Portugal, the Institute for the Environment is in charge of the annual national emission inventory, which is sent to the UNFCCC and to the UN-ECE according to international commitments. Since late 2005 efforts have been made aiming to improve the national inventory (INERPA) through the development of an emission model providing a higher detail (municipality) level of the spatial allocation of emissions and a suitable temporal disaggregation of emissions per sector. Besides this national inventory, other sources of inventories for Portugal are available, like EMEP (Vestreng *et al.*, 2005) and LOTOS (Visschedijk and Denier van der Gon, 2005). In this paper, the main goal is to evaluate the accuracy of each inventory and to identify the key sources of uncertainty, through air quality modelling validation for Portugal.

2. METHODOLOGY

The air quality modelling applications were performed with the CHIMERE chemistry-transport model (Schmidt *et al.*, 2001), forced by the MM5 meteorological fields, over Portugal with a 10 x 10 km^2 grid, and a horizontal dimension of 290 km x 580 km (Monteiro *et al.*, 2007). The simulations were carried out for 2004 summer (1 June - 31 September), regarding gaseous and particulate pollutants, and using the most updated annual emission inventories (2003 year). The Institute for the Environment elaborates the INERPA inventory using activity data from several official providers, according to the legal bindings institutionalised by the National System. Emission values from these inventories are considered official data and are used to verify the accomplishment of international obligations such as those coming from the UE ceiling directive and the UN_ECE long-range transboundary air pollution convention (CLTRAP). Total emissions per NFR source category are thereafter allocated to territorial units (municipalities) using surrogate indicators such as fuel sales, human population, agricultural area and livestock population. The EMEP emission inventory was obtained through the interactive EXPERT database available via Internet and updated by June 2006, with totals/sectors and as gridded emissions (0.5º x 0.5º long-lat) estimated by the EMEP Centres (Meteorological Synthesizing Centres - West and East), which are generally made by completing and correcting/substituting the officially reported data. The LOTOS emission inventory results from a combination of the TNO emission database (with high resolution: 0.25º x 0.125º long-lat) and the CAFE baseline emissions for 2000. For each source category and each country, the country totals of the TNO emission database are scaled to those of the CAFE baseline emissions. Large point source emissions were not included in these applications, because not all the inventories integrated in this study had available data. Simpson *et al.*, (1999) methodology was adopted to calculate biogenic emissions with the CHIMERE model. Time disaggregation was obtained by application of monthly, weekly and hourly profiles from the University of Stuttgart (GENEMIS, 1994). A road traffic urban hourly profile measured in a field campaign in Portugal in the scope of the SAPPHIRE European Project (EVK4-2002-00089) was also tested. Spatial disaggregation was applied for each inventory separately, applying an interpolation method and GIS software to the original inventory grid in order to obtain a regular grid of 10 x 10 km^2, according to the simulation domain resolution. Concerning the INERPA inventory, two different levels of spatial disaggregation were considered: the municipality, available in the original spatialisation, and the sub-municipality. This last one was obtained by further disaggregating the municipality level by population (census) data. Simulations included testing the different emission inventories with their distinct spatial disaggregation, and also the temporal profiles used for time disaggregation.

3. RESULTS AND DISCUSSION

In Figure 1a is presented the comparison between the total emission values (sum of all area source activities) estimated by each inventory, and for each pollutant, considering only the Portuguese territorial area. The major differences are obtained for the LOTOS database, which estimates are significantly lower (20-30%) than EMEP and INERPA, mainly regarding PM emissions (50%). The similarity between the EMEP and INERPA totals is explained by the correction/revision made of the expert EMEP inventory by the officially reported data (INERPA). The analysis by pollutant activity shows that the major discrepancies between inventories are registered for road transport (more than 30%), as shown as example in Figure 1b.

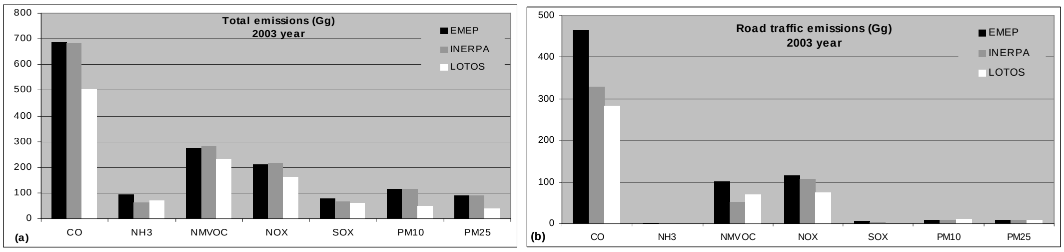

Figure 1. Comparison of the total (a) and road transport (b) emissions for each inventory, by pollutant specie.

Modelling results were compared to monitoring data from the air quality networks, composed by 39 stations for O_3 (22 background and 11 traffic) and 31 for PM_{10} (12 background and 14 traffic). Before testing the different emissions inventories, a sensitivity test to the spatial disaggregation of INERPA national inventory, using the original municipality values and its disaggregation to sub-municipality degree was performed. The statistical analysis is presented in Table 1, for background stations, which are more representative of the used model grid (10 x 10 km^2). Concerning O_3, the Root Mean Square Error (RMSE) and the systematic error (BIAS) analysis suggests that the further spatial disaggregation performed introduced more errors to the emission inventory, namely for the urban area, where the RMSE and BIAS differences are bigger. However, regarding PM_{10}, there are no significant differences between the two inventories results. The BIAS analysis indicates that when the sub-municipality spatial disaggregation is applied, the rural and suburban PM emissions decrease, in opposition to the increase in urban areas (where more population exist). Since there is an overall tendency for emissions underestimation (bias negative), it is expectable that model performance is reduced in rural areas and improved in urban zones, when the INERPA disaggregated inventory is used.

Table 1. Validation of CHIMERE simulations, using different spatial disaggregation of INERPA inventory, and considering the average of each background station type.

	O_3 ($\mu g.m^{-3}$)				PM_{10} ($\mu g.m^{-3}$)			
Station zone	RMSE		BIAS		RMSE		BIAS	
	INERPA disaggregated	INERPA original	INERPA disaggregated	INERPA original	INERPA disaggregated	INERPA original	INERPA disaggregated	INERPA original
Rural	28.88	25.32	-13.24	-9.58	16.81	16.71	-13.13	-13.01
Suburban	33.12	29.00	-12.70	-8.93	34.85	37.15	-9.82	-8.80
Urban	37.26	24.71	-23.19	-4.70	25.54	25.84	-7.15	-8.31

$\text{bias} = \frac{1}{N}\sum_i (M_i - O_i)$ $\text{RMSE} = \frac{1}{N}\sum_i |(M_i - O_i)|$ N is the number of samples, Oi are observations and M_i are model predictions

Tables 2 and 3 show the statistical parameters obtained for the three emission inventory simulations, for O_3 and PM_{10}, respectively. For both pollutants, there are no significant discrepancies between the RMSE values for each inventory application, indicating that higher resolution in the emission inventory do not necessarily mean better model performance. The negative values of BIAS suggest that there is an overall tendency for underestimation of ozone precursors and PM emissions. In fact, the more negative bias is attributed, in both Tables, to the LOTOS inventory that presents the lower emission values (see Figure 1), in opposition to INERPA that shows the higher emissions for NO_x, VOC, and PM, and consequently inferior bias. Nevertheless, regarding PM_{10} results, there is a particular overestimation over Porto region (LEC, VNT, ERM stations) when the INERPA (original) inventory is used. Moreover, the absolute errors are also higher and the correlation coefficient lower comparatively to the others emissions inventory, for this particular area, indicating spatial disaggregation problems. The similar correlation factor (CF) found for the three applications, and regarding O_3 and PM_{10} results, is explained by the same temporal emission disaggregation (seasonal, diurnal and hourly) applied to each annual inventory.

Table 2. Statistical parameters obtained for each simulation, for O_3 background stations.

				RMSE (μg.m^{-3})			BIAS (μg.m^{-3})			CF (correlation factor)		
Zone	Long	Lat	Station	EMEP	LOTOS	INERPA*	EMEP	LOTOS	INERPA*	EMEP	LOTOS	INERPA*
Rural	-8.6	40.8	AVA	25.57	29.99	24.13	-7.91	-12.49	-6.04	0.81	0.79	0.82
Rural	-8.5	39.3	CHA	31.77	33.72	30.22	-15.40	-19.71	-14.30	0.65	0.67	0.69
Rural	-8.9	39.9	ERV	18.40	19.48	18.40	2.84	1.43	2.08	0.76	0.73	0.76
Rural	-7.3	40.2	FUN	28.01	29.63	28.54	-19.52	-21.61	-20.06	0.64	0.63	0.63
Suburban	-8.5	41.3	CAL	23.11	23.81	24.45	-10.32	-10.92	-11.93	0.86	0.87	0.86
Suburban	-8.7	40.6	ILH	20.12	21.57	20.19	1.49	-1.12	1.52	0.80	0.78	0.79
Suburban	-9.1	38.6	PP	25.24	23.70	25.81	-8.57	-8.35	-0.48	0.73	0.77	0.72
Suburban	-8.6	41.3	VNT	24.58	25.19	25.72	5.55	7.18	-2.91	0.66	0.66	0.60
Urban	-8.9	38.5	ARC	24.42	22.40	26.18	2.52	-3.57	2.65	0.68	0.69	0.65
Urban	-9.1	38.7	BEA	21.82	21.17	23.10	-2.42	-0.30	2.99	0.72	0.73	0.72
Urban	-8.5	41.2	ERM	24.99	24.53	26.24	-3.59	0.94	-7.10	0.75	0.78	0.74
Urban	-8.4	40.2	IGEO	22.86	26.18	22.47	-8.79	-12.61	-8.53	0.80	0.78	0.81
Urban	-9.2	38.7	LAR	23.09	22.01	23.67	-5.56	-1.12	1.15	0.70	0.71	0.70
Urban	-8.4	41.3	LAT	32.35	34.03	33.45	-20.40	-21.60	-20.98	0.84	0.84	0.83
Urban	-9.2	38.8	LOU	21.72	23.06	22.78	-2.38	-3.81	-1.43	0.74	0.71	0.71
Urban	-9.3	38.7	MARQ	22.90	23.34	22.04	-3.53	-0.13	-1.70	0.71	0.69	0.73
Urban	-9.3	38.8	MEM	19.81	19.88	19.31	-1.19	-0.78	0.08	0.71	0.70	0.73
Urban	-9.1	38.8	OLI	22.75	22.94	24.03	-0.79	-1.86	3.48	0.72	0.73	0.72
Urban	-9.2	38.7	REB	24.12	23.56	23.52	-7.59	-4.45	-6.06	0.71	0.70	0.71
Urban	-9.2	38.7	RES	31.23	28.38	28.62	-18.15	-11.47	-15.10	0.64	0.62	0.68
Urban	-8.5	41.3	STIR	24.86	25.94	25.79	-9.15	-10.13	-10.57	0.87	0.88	0.87
Average				**24.46**	**24.98**	**24.70**	**-6.33**	**-6.50**	**-5.39**	**0.74**	**0.74**	**0.74**

*original

Table 3. Statistical parameters obtained for each simulation, for PM_{10} background stations.

				RMSE (μg.m^{-3})			BIAS (μg.m^{-3})			CF (correlation factor)		
Zone	Long	Lat	Station	EMEP	LOTOS	INERPA*	EMEP	LOTOS	INERPA*	EMEP	LOTOS	INERPA*
Rural	-7.3	40.2	FUN	20.48	20.65	20.46	-16.11	-16.28	-16.13	0.56	0.55	0.58
Suburban	-8.5	41.4	CAL	28.29	29.76	26.48	-23.73	-25.28	-21.82	0.65	0.65	0.67
Suburban	-8.6	41.2	LEC	25.65	23.95	40.23	-21.28	-19.61	**33.86**	0.79	0.78	0.75
Suburban	-8.7	41.3	VNT	26.12	25.16	33.74	-23.13	-22.15	**15.86**	0.75	0.75	0.70
Urban	-8.6	41.2	ERM	25.82	24.76	38.37	-21.62	-20.53	**37.31**	0.69	0.69	0.66
Urban	-9.2	38.7	LAR	24.90	29.85	18.96	-18.08	-23.62	-9.38	0.65	0.65	0.66
Urban	-8.4	41.3	LAT	28.67	29.87	24.19	-24.06	-25.25	-19.05	0.76	0.76	0.67
Urban	-9.2	38.8	LOU	21.95	26.91	21.68	-16.77	-22.34	-16.30	0.62	0.62	0.63
Urban	-9.3	38.7	MARQ	25.00	28.24	22.85	-18.45	-22.24	-15.16	0.48	0.45	0.48
Urban	-9.4	38.8	MEM	15.70	18.15	14.98	-12.51	-15.62	-11.36	0.58	0.62	0.60
Urban	-9.1	38.8	OLI	20.43	20.43	20.43	-15.18	-15.18	-15.18	0.86	0.86	0.86
Urban	-9.2	38.8	REB	29.33	34.68	27.29	-20.36	-26.85	-17.35	0.52	0.52	0.52
Average				**24.36**	**26.03**	**25.81**	**-19.27**	**-21.25**	**-4.56**	**0.66**	**0.66**	**0.65**

*original

Two different hourly profiles were applied to the road transport emissions within the INERPA inventory simulation: a European averaged profile and an urban hourly profile obtained in field measurements made in Portugal (see Figure 2). Table 4 shows the correlation factor and errors found for each profile model application. There are no differences found concerning background stations, but there is an improvement in model performance, regarding traffic sites, when the Portuguese (measured) road transport profile is used.

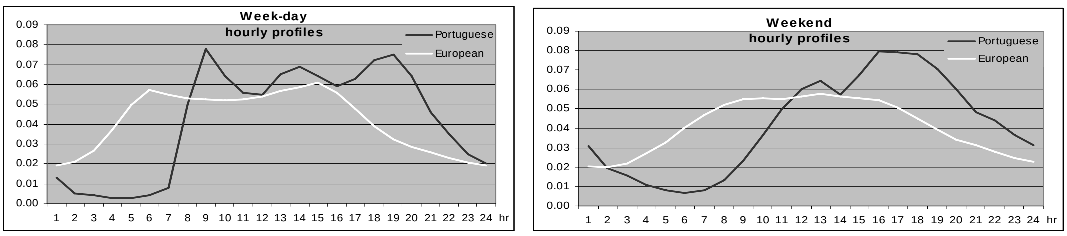

Figure 2. Comparison of the European and Portuguese road transport hourly profiles, for weekdays and weekend.

Table 4. Validation of CHIMERE simulations, using INERPA inventory, with different Hourly Profiles (HP), considering the average for background and traffic stations.

	O_3				PM_{10}			
Station zone	CF		RMSE ($\mu g.m^{-3}$)		CF		RMSE ($\mu g.m^{-3}$)	
	European HP	Portuguese HP	European HP	Portuguese HP	European HP	Portuguese HP	European HP	Portuguese HP
Background	0.74	0.74	25.93	25.80	0.66	0.66	27.05	27.00
Traffic	0.64	0.65	25.55	25.12	0.63	0.66	29.95	29.48

4. CONCLUSIONS

Because of the widespread use of inventories for policymaking, planning, and research purposes, it is important to know the quality of the inventories and that any shortcomings in the inventories could be identified and prioritised for improvement. The work presented here intends to evaluate the available emission inventories for Portugal through air quality modelling validation, in order to identify their weakness and strengthens and the key sources of uncertainty that can be targeted for reduction via additional data collection and research. The evaluation model exercise, against observed data, shows no significant discrepancies between the direct applications of the three emission inventories. This similarity, already verified on the total emission values, proves that higher resolution in the emission inventory do not mean necessarily better model performance, indicating that spatial disaggregation of an emission inventory should be performed carefully, otherwise could be an additional source of uncertainty. The model results point out to an overall tendency for emissions underestimation that could be emphasised by the point sources omission. This underestimation is more notorious with the LOTOS inventory, and less with INERPA, which presents, in average, less systematic errors. Nevertheless, the range of uncertainty varies with locals and pollutants. The analysis of results provided clues for improving emission inventories. It is found, for instance, that exists a probably overestimation of the INERPA inventory concerning emissions of particulate matter on Porto region, emphasized when transformed in air quality values. A less correct spatial disaggregation could be the reason for that. Sensitivity tests with road traffic temporal profiles shows to have a certain influence on the air quality results, in what concerns traffic and urban stations, confirming that the Portuguese average profile is more adequate for these specific areas. Future work will involve testing this methodology with other air quality modelling systems and analysing each emission source category. The development and assessment of an emission inventory ensemble will also be the focus of future work.

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FACILITATING ADVANCED URBAN METEOROLOGY AND AIR QUALITY MODELING CAPABILITIES WITH HIGH RESOLUTION URBAN DATABASE AND ACCESS PORTAL TOOLS

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ABSTRACT

Information of urban morphological features at high resolution is needed to properly model and characterize the meteorological and air quality fields in urban areas. We describe a new project called National Urban Database with Access Portal Tool, (NUDAPT) that addresses this need. NUDAPT is designed to produce gridded fields of urban canopy parameterizations to improve urban meteorological simulations given the availability of new high-resolution data of urban buildings and land use. An important core-design feature is the utilization of Portal technology to enable NUDAPT to be a "Community" based system. Sensitivity studies showing air quality simulations driven with outputs from urban meteorology preprocessors using advanced urban descriptions are described.

1. INTRODUCTION

Current data and modeling tools are limited in their capability to perform accurate air quality assessments in urban areas that contain highest and most vulnerable population densities. Advanced treatments of high resolution urban morphological features for meteorological, air quality and human exposure modeling systems will be needed for future urban applications (OFCM 2005). In response, a new project called National Urban Database with Access Portal Tool (NUDAPT) has been launched. The initial NUDAPT prototype is a new project sponsored by the United States Environmental Protection Agency (USEPA) and involves collaborations and contributions from many groups from federal and state agencies, and from private and academic institutions. NUDAPT will produce gridded outputs of urban parameters capable of driving current (Dupont et al., 2004, Otte et al, 2002, Chen et al., 2006, Ching et al., 2004) and future advanced urban meteorological and air quality models Additionally, ancillary information such as gridded population, energy usage and traffic will be incorporated so as to encourage and facilitate linkages to air quality and human exposure models. We incorporate portal technology to enable NUDAPT to be a "Community" based system, an important core-design feature. Web-based portal technology will facilitate data retrievals and handling based on data federation concepts. Houston Texas will serve as NUDAPT's initial prototype; it will feature advanced urban canopy implementations of the MM5 as well as WRF; thus serving to demonstrate the NUDAPT features, including scope of the data and processing methodologies for an eventual extensibility to all other cities.

2. APPROACH

In this paper, we describe a prototype of an operational template that can be extended to provide an eventual nation-wide capability that will serve a broad user community engaged to develop and drive powerful new and advanced atmospheric transport and dispersion and air quality modeling tools. (Already, the value of using high resolution urban data in meteorological and air quality simulations has been demonstrated from sensitivity studies based on mesoscale modeling system that incorporate urban canopy parameters, Dupont, et al., 2004; Ching et al., 2004; and Chen et al., 2006). This will provide a strategic implementation to both the modeling and decision support communities requiring appropriate modeling tools to support the assessments and applications needed to help reduce health risk from exposure to poor air quality. Further, it addresses homeland security in regard to transport and dispersion of toxic releases.

We have selected Houston, the fourth largest city in the USA, to serve as the initial prototype for demonstrating the NUDAPT features. A set of lidar-derived building data for Houston is available for unrestricted use (Figure 1), as are several derived products, and sets of air quality data available from major intensive field studies. Houston has active emissions management programs to address its poor air quality and associated health effects. The NUDAPT prototype will include: (1) primary data sets such as (three-dimensional building and geo-morphological data, roads and their linkages;(b) activity data including census data, traffic, and industrial outputs, (c) land surface characteristics data; (2) derived daughter products including model specific UCPs, diurnal gridded population data, gridded anthropogenic energy inputs, and gridded traffic emissions; and (3) selected illustrative examples of model outputs and analyses to demonstrate a range of applications possible. This initial prototype will be available in Fall 2007 and will feature advanced urban implementations; in MM5 (Ching et al, 2004) and WRF (Chen et al., 2006) and other modeling systems.

3. FEATURES OF NUDAPT

a: Morphology databases and urban canopy parameters

An important feature of NUDAPT is the provision to incorporate urban structure data and their derivative urban parameters that can be used by mesoscale meteorology models. For example, the urbanized version of MM5, makes use of UCPs introduced to building and vegetation influences on the drag, the partitioning of the surface energy budget components, and the generation of turbulence of the flow in the surface boundary layer. The set of UCPs listed in Table 1 (8 of which vary with height) used in the Dupont modeling system (Dupont et al., 2004) has been calculated for each grid in the modeling domain (Burian et al., 2004). The data to derive this set of UCPs were primarily from airborne based LiDAR system that collects data for Digital Elevation Model (DEM) and Digital Terrain Model (DTM). Differencing the digital elevation and terrain signals provides the buildings and tree information, an example of which is shown in Fig. 1a. High altitude aircraft and municipal property data provide information to complement the LiDAR database. Such data and the derived UCPs (example shown in Figure 1b) are incorporated into the Houston Prototype.

Geospatial databases similar to that used in Houston that consist of detailed building and other urban morphological structures imagery information at resolutions of order 1 m are being acquired for 133 urban centers in the USA. This is in response to the Homeland Security Infrastructure Program (HSIP); the Nunn-Lugar-Dominici Act (Defense Against Weapons of Mass Destruction Act of 1996) established a project by which DOD was tasked to help respond to chemical, biological and nuclear (CBN) incidences in the 133 urban centers. These data (together with the National Map Project of the US Geological Survey) provide the foundation for a national scale database. Of course, even higher resolution descriptions of building data exist. In principle, the NUDAPT can incorporate such data if it can be made available.

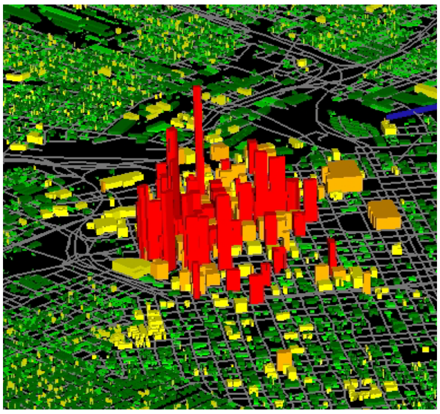
b Relevant Ancillary data

Data obtained from NUDAPT are expected to improve meteorological fields for air quality, homeland security, and planning purposes. NUDAPT will also provide a service by including links to other sources of data that we anticipate will be of high utility. Such information will include various activities and land-use data such as roads and their linkages, and activity data including census data, traffic, industrial outputs, and land surface characteristics data from which gridded products useful for models will be derived. In addition, NUDAPT will include gridded population data for the USA, e.g., day-night populations, indoor-outdoor populations, sensitive population groups and population mobility matrix. Such data are being generated for the prototype at latitude-longitude (lat-long) coordinates with a spatial resolution of 250 m. Other derived daughter products include model specific urban canopy parameters, gridded anthropogenic energy inputs and gridded traffic emissions. Selected illustrative examples of model outputs and analyses will be also available to demonstrate a range of applications possible.

c. NUDAPT Design concept

NUDAPT will become a two level framework, in the form of a web-enabled database that provides ready access to the various datasets, both primary or source data and processed data to users. The first level of the framework is the primary data and includes the high resolution building data. Access to this level will be granted for those interested in creating new or modified UCP datasets. The second level provides unrestricted access; users can query the database for relevant data, retrieve data in a form that can be readily assimilated into models such as MM5, and submit model results for further analysis. The database is federated, i.e., the database will act as a repository for multiple, heterogeneous datasets that all adhere to a consistent format and metadata specification. This framework allows for analysis by the scientific community by providing an efficient means of sharing observed and modeled data. The community provides the means for detailed analysis and knowledge integration. The data-sharing concept in NUDAPT can facilitate researcher efforts to improve models of the urban environment. For example, a researcher wishes to compare their model results with another simulation that used a different set of UCPs. This is easily accomplished by a query to the database, retrieval of the model run of interest, and analysis accomplished at the user end. Once researchers utilize these UCPs in their modeling, more knowledge integration will occur through enhanced model evaluations leading to improved models.

Datasets will either reside on the NUDAPT portal server or where available for public download elsewhere, the portal will provide a link to facilitate the appropriate download. Because the site is expected to act as a data repository rather than an active transaction-heavy database, there does not appear to be a need to utilize database software to manage the datasets in question. Instead the datasets will exist as stand-alone files in the file system. The initial Prototype will use the ArcGIS 9.2 server that provides the desired functionality needed to handle both vector and raster data formats.



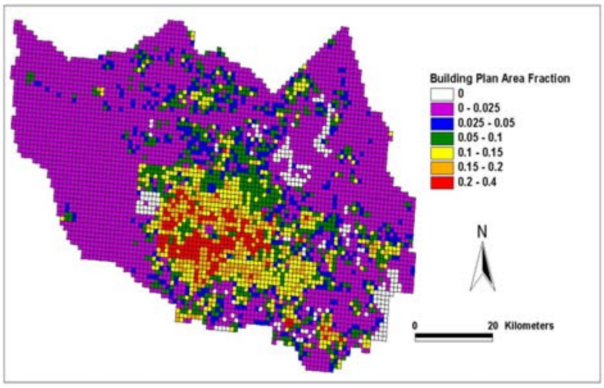


Fig. 1(a) Left: Three dimensional building data derived from airborne lidar platform for 1x1 km section of downtown Houston. (b) Right: Building plan area density, an example of a UCP for Harris County (Houston Metropolitan area) (cf Table 1)

4. DISCUSSION AND SUMMARY

Initial sensitivity studies of air quality (and other) applications using outputs of advanced meteorological models that incorporates data such as to be available from NUDAPT are being performed. Figure 2 contrasts the mixed layer simulations from MM5 with and without UCP. The urban area of Houston is categorized with one urban land use category in the standard version of MM5. Figure 3 illustrates the sensitivity of CMAQ to MM5 versions with and without detailed urban canopy feature. In this instance, significant differences are seen, serving as a motivation for advancements in urban modeling.

The development of NUDAPT represents a promising resource to stimulate addressing of many of the emerging problems in urban areas. NUDAPT provides a platform for accessing and developing data and for sharing information with the user community. Primary data in NUDAPT will include physical and morphological data prepared and collected under various conventional and unconventional systems. The preparation of NUDAPT daughter products which are closely directed to urban gridded modeling applications will need to consider various map projections that are used in typical meteorological and air quality modeling applications. Due to the multiple scales of the applications that will potentially be used in various studies, it is important that the NUDAPT include methodologies for re-projecting and re-gridding these daughter products that conserves their properties of the features for generalized applications. Currently, a database for Houston Texas is serving as the NUDAPT prototype. Eventually, the goal for NUDAPT is to be extended to all major urban areas within the United States; ultimately, there is nothing to preclude this concept to extend beyond the USA.

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Table 1: Gridded UCPs from lidar-derived building and vegetation data for urbanized MM5 model.

Canopy UCPs:	Building UCPs:	Vegetation, Other UCPs:
Mean canopy height	Mean building height	Mean vegetation height
Canopy plan area density	Standard deviation of building height	Vegetation plan area density
Canopy top area density	Building height histograms	Vegetation top area density
Canopy frontal area density	Building wall-to-plan area ratio	Vegetation frontal area density
Roughness length	Building height-to-width ratio	Mean orientation of streets
Displacement height	Building plan area density	Plan area fraction surface covers
Sky view factor	Building rooftop area density	Percent directly connected impervious area
	Building frontal area density	Building material fraction

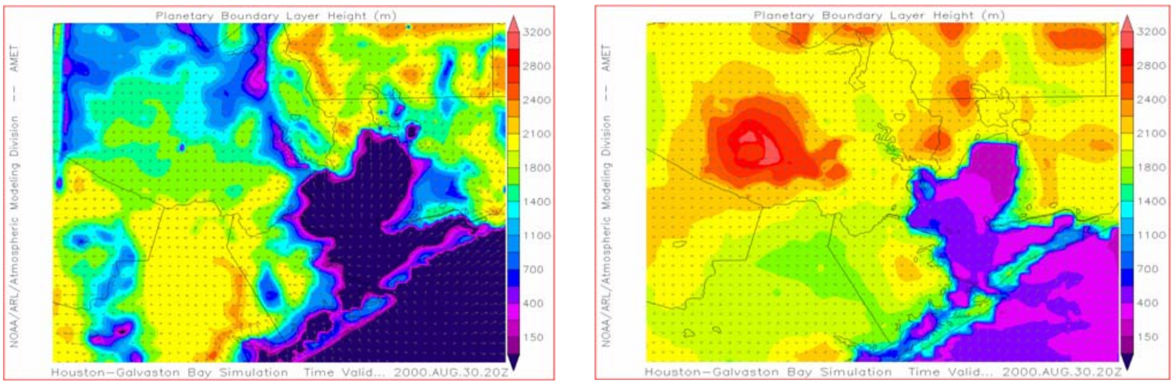

Figure 2. Simulations of mixed layer heights size for 2100 GMT, August 30, 2000. MM5 with UCP (left) and standard version of MM5 (right) at 1 km grid.

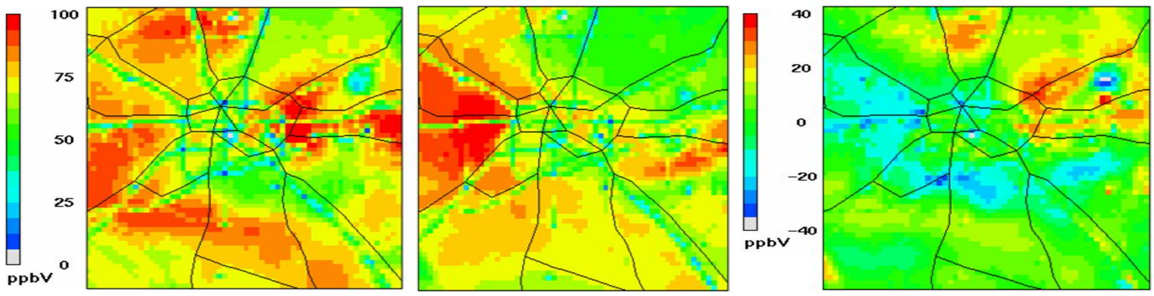

Figure 3: Simulations of surface ozone using CMAQ driven by UCP (left) and No-UCP (center) versions of MM5 (see Figure 2). Differences are shown on right panel.

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