INTEGRATED SYSTEMS FOR FORECASTING URBAN METEOROLOGY, AIR POLLUTION AND POPULATION EXPOSURE: FUMAPEX ACHIEVEMENTS

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INTRODUCTION

Urban air pollution is associated with significant health effects. Prediction of the health effects requires accurate modelling of emissions, meteorology, population mobility, and indoor-outdoor relationship of the pollutants. Until recently the meteorological models used for weather prediction have not accounted for the micrometeorological phenomena caused by the urban structures in densely populated areas; for forecasting the overall weather this has not been necessary. However, for forecasting the air quality within the urban areas inclusion of these phenomena is crucial. Detailed evaluations of meteorological models especially for days of extreme conditions have revealed that the traditional general meteorological models underestimate changes in the mixing height, steepness of the temperature and wind gradients, and other meteorological parameters, leading to underestimation of pollutant levels under such conditions.

Air quality modelling, linked with population exposures, is useful in two temporal scales. On the other hand, daily urban air quality is compared to air quality guidelines; short-term forecasts of air quality could therefore be used to create warning systems and targeting actions in episode situations. Usefulness of such short-term forecasts include emergency preparedness systems. On the other hand air quality models are needed for longer term urban planning, in designing transportation systems, industrial settings, and residential areas in a way that minimizes unacceptable risks to public health.

The current work presents a novel approach that integrates the latest developments in meteorological, air quality, and population exposure modelling into Urban Air Quality Information and Forecasting Systems (UAQIFS) in the context of the European Union FUMAPEX study. The suggested integrated strategy is demonstrated on examples of the systems for three Nordic cities: Helsinki and Oslo for urban air pollution episodes forecasting/assessment, and Copenhagen for urban emergency preparedness.

FUMAPEX METHODOLOGY OF IMPROVED UAQIFS, INTEGRATED FROM METEOROLOGY TO POPULATION EXPOSURE

The main aim of the FUMAPEX project is to develop, evaluate, and disseminate improved urban air quality information and forecasting systems enhancing the capabilities to successfully describe and predict air contamination episodes in cities of different European regions through improvement and integration of systems for forecasting urban meteorology, air pollution, and population exposure based on modern information technologies.

The outline scheme of the overall FUMAPEX methodology of integrating models from urban meteorology to air quality and population exposure for the improved UAQIFS is presented in Figure 1.

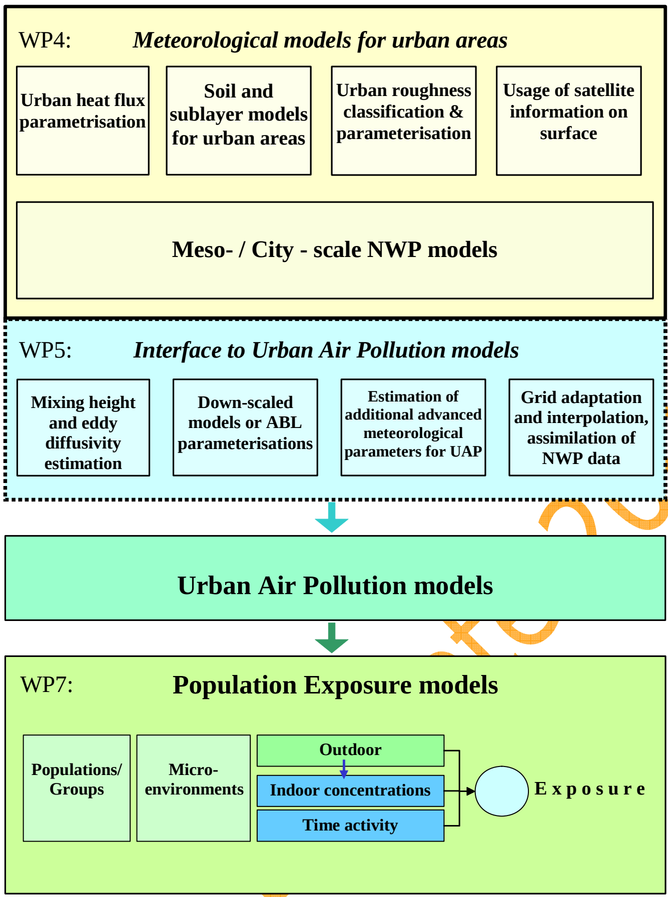

Figure 1. *Outline of the overall FUMAPEX methodology integrating models from urban meteorology to air quality and population exposure. The main improvements of meteorological forecasts (NWP) in urban areas, interfaces and integration with urban air pollution (UAP) and population exposure (PE) models for the Urban Air Quality Information Forecasting and Information Systems (UAQIFS) are mentioned on the scheme.*

Procedure of the urban air quality and health effect forecasting is divided into four integrated steps:

(i) application of national weather forecasts of the synoptic situation and meteorological fields/parameters,
(ii) down-scaling of city-scale meteorological model for urban meteorology forecast, post-processing of NWP data for UAP model inputs,
(iii) computation of pollutant concentrations, using urban dispersion modelling systems,
(iv) population (individual and collective) exposure or dose calculation, using probabilistic or deterministic models.

The improved urban-scale meteorological and air quality models are integrated in the UAQIFS (see Fig. 1) with modelling of population activity, including time spent indoors, outdoors, and in traffic, to estimate population exposures. The modelling approaches can be utilized in both short-term forecasts of air quality, combined with episode specific air quality management, and in long-term urban air quality planning.

The realisation of the system depends on the specific features of the city, its geographic and topographic location, and the climatological and air quality problems that affect the area.. In the bound of the FUMAPEX project the improved integrated UAQIFS is implemented in six target cities: Oslo (Norway), Turin (Italy), Helsinki (Finland), Castellon/Valencia (Spain), Bologna (Italy), Copenhagen (Denmark). For different target cities the developed systems are relatively different and they are realised for one of the following items:

(i) urban air quality forecasting mode,
(ii) urban management and planning mode,
(iii) public health assessment and exposure prediction mode,
(iv) urban emergency preparedness system.

METEOROLOGICAL MODELS AND INTERFACES

Following the European countries' practices of national weather forecasts, in the FUMAPEX project a unique single European meteorological model for the integrated UAQIFSs is not considered. The main strategy is to follow the existing national NWP systems and improve them for higher-resolution urban meteorology forecasting with the necessary model downscaling and interfacing with UAP model data.
Therefore, the following improvements in NWP models for the urban scale were realised for several European countries NWP models (see details in Baklanov *et al.* 2005):

(i) Model down-scaling, including increasing vertical and horizontal resolution and nesting techniques (one- and two-way nesting);

(ii) Modified high-resolution urban land-use classifications, parameterizations and algorithms for roughness parameters in urban areas based on the morphologic method;

(iii) Specific parameterization of the urban heat fluxes in meso-scale models;

(iv) Modelling/parameterization of meteorological fields in the urban sublayer;

(v) Simulation of the internal boundary layers and mixing height (MH) in urban areas.

Besides, NWP models are not primarily developed for air pollution and emergency modelling, and the results need to be designed as input to urban and meso-scale air pollution and emergency preparedness models. Therefore several interface modules for post-processing the operational NWP data (to make them suitable for UAQ models) and for calculation of additional meteorological parameters, which are not available from NWP output, but important for urban dispersion models (e.g., calculation of the urban MH based on prognostic approaches), were developed (Finardi *et al.*, 2005).

During the project progress and improved urban boundary layer parameterisations development, two possible urbanisation strategies clearly emerged: the urbanisation of the driving NWP model or the use of urban turbulence parameterisations to "correct" meteorological model results over the urban areas after its run. Both possibilities have been explored and different options have been implemented in the target cities UAQUIFS. The first choice is in principle the more scientifically sound because allows a consistent modelling of urban scale flow and turbulence and minimises the interface module task to the evaluation of dispersion parameters. On the other hand, the urbanisation of NWP revealed to be difficult due to the pre-existing structure of NWP code that has to be largely modified, it can be computationally expensive and not always feasible, due to the need of operational models to avoid the introduction of possible instabilities and limit computing time as much as possible. The second possibility corresponds to the re-computation of the structure of the boundary layer possibly implementing inside the interface module urbanised parameterisations for urban soil and surface, evaluation of the surface energy balance and of the mixing height space structure and time evolution. This realisation of this second possibility does not guarantee a full consistency of the modelled atmospheric flow, but it is much easier and cheaper to implement and in principle it has the advantage not to be connected to a particular NWP model, but it can be much easily generalised. An intermediate approach has also been verified using a small scale model describing urban flow features, to re-evaluate the urban flow starting fro the standard NWP forecast fields.

The NWP modelling systems applied in the integrated UAQIFSs in the three cities considered in this paper are described in more detail in the sections below. The different model integration strategies chosen are clearly depicted.

URBAN AIR QUALITY MODELS

Several UAP model types, including the Lagrangian, Eulerian, Hybrid Lagrangian/Eulerian, Gaussian, Trajectory, Box, and statistical approaches, have been considered within the FUMAPEX project starting from UAQIFSs and practices presently applied in different cities. The UAP models have been grouped in *four main classes* starting from their general features and from their meteorological input need, in order the kind processing of meteorological data that the interface modules have to perform (Finardi *et al*., 2004).

The first class includes *statistical models* that do not need any particular calculation from the interface system. They simply require single valued meteorological data extracted from the coupled meteorological model.

A second more numerous class of *"simple" models* includes all the approaches based on a steady-state solution of the dispersion equations. The models included in this class normally require meteorological data in a single point or possibly a vertical profile. Moreover they normally require evaluation of turbulence scaling parameters.

Even if the interface module computations required by the previous classes are quite limited and simple the extraction of 1D meteorological data representative of conditions assumed to be uniform over the whole urban area (or a relevant portion of it) is quite critical especially for large cities and for urban areas located in complex terrain.

A first class of *3D models* includes all the models based on *Lagrangian* descriptions of dispersion phenomena. These models usually need: 3D fields of average quantities like wind, temperature, humidity and possibly turbulent kinetic energy; 2D surface fields like precipitation, sensible heat flux, friction velocity and Monin-Obukhov length; 3D turbulence fields, that are usually described by wind variances and Lagrangian time scales. The turbulence describing variables have to be evaluated from mean variables, TKE or K_H, K_Z, or reconstructed from boundary layer scaling parameters.

The remaining 3D models class includes *Eulerian models*. The Eulerian dispersion coefficients (K_H, K_Z) produced by NWP models could be directly used by these air quality models. Nevertheless the direct use of dispersion coefficients calculated by NWP models is not always possible or advisable, therefore the interfaces for Eulerian models often implement capabilities to re-compute turbulence parameters from mean variables and scaling parameters. This last possibility can also allow to supplement the meteorological data provided by the NWP model with higher resolution physiographic data or even observations.

Even if all the types of models included in the previous classes are used for air quality management and forecast in urban areas only a few of them have been considered and selected for improved UAQUIFSs developed during FUMAPEX project. In brief last generation steady-state models (Helsinki and Bologna) and Eulerian Chemical Transport

Models (Oslo, Turin, and Castellon/Valencia) have been implemented into air quality forecasting system, while Lagrangian models are used for emergency preparedness systems (Copenhagen).

POPULATION EXPOSURE MODELS

Complementary approaches to exposure modelling are developed in parallel in different target cities and even within the same target cities, depending on the aspects of exposure that are of special interest locally. The FUMAPEX methodology is applied using mostly the local modelling environments and models for meteorology and air quality. Regional aspects affect e.g. the selection of target pollutants and relevant target population groups. In central European and Mediterranean areas ozone poses a much larger problem than in the Nordic areas. NO and VOC emissions are tightly associated with the generation of ozone in photochemical processes. In the Nordic countries on the other hand typical air quality problems include the spring dust situations, where PM10 concentrations are raised during dry days by resuspension of coarse particles. Vehicular traffic is recognized as the primary source of air quality problems all over Europe. Accidental or other emergency releases can include a broad spectrum of radioactive, chemical and biological harmful spices.

Main dimensions of exposure to be accounted for in population exposure modelling include (i) geography, i.e. locations where concentrations occur and populations and/or individuals are located at a given moment; (ii) mobility of persons and populations in daily, weekly, and seasonal temporal scales; and (iii) effects of indoor microenvironments, where on the other hand some of the outdoor pollution may be filtered from the air by ventilation systems and natural processes, but on the other hand indoor sources may rise the actual exposure levels much higher than the corresponding levels in outdoor air. All of these dimensions have some common and some specific effects on different pollutants that have different sources and different chemical and physical properties. Similarly different population groups may be affected differently.

Based on the computational technique the approaches can be classified into probabilistic and deterministic; based on the target population representativity the latter can be further divided into statistical and individual sub categories. Probabilistic models describe the probability distributions of the selected exposure variables within a defined target population. Deterministic models use air quality data in a geographical format, where the outdoor air concentrations are presented in a three (or two)-dimensional space and time. The statistical version of the deterministic exposure modelling allocates populations into this spatiotemporal air quality field typically using grids and population-based estimates of numbers of people residing within the grid area. The individual deterministic model uses spatial time-location-data to carry specific individuals in time and space.

The probabilistic and statistical/deterministic approaches are suitable for estimation of exposures of general population and large population sub groups. The individual deterministic model requires on the other had very detailed data on specific individuals and is thus limited to selected persons and periods. Probabilistic and individual deterministic models can be used to estimate exposures as time weighted average concentrations. The deterministic model with statistical population on the other hand can only be used to estimate the population average exposure concentration; within the model grid exposures are measured using persons x hours x concentration.