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FUMAPEX

Improved UAQIFSs implemented and applied in the target cities

Edited by Leiv Håvard Slørdal

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Edited by Leiv Håvard Slørdal; Norwegian Institute for Air Research (NILU).

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Contents

List of Contributors

Chapter 2

Authors: Susanne Lutzenkirchen(1), Ingrid Myrtveit(1), Pål Rosland(2), Leiv Håvard Slørdal(3), Viel Ødegaard(4) and Norvald Bjergene(4)

(1) City of Oslo Health and Welfare Agency
(2) Norwegian Road Traffic Authorities
(3) Norwegian Institute for Air Research (NILU)
(4) Norwegian Meteorological Institute (met.no)

Chapter 3

Authors: Ari Karppinen(1) ,Jaakko Kukkonen(1) ,Ilkka Valkama(1), Mari Kauhaniemi(1), Minna Rantamäki (1), Anu Kousa(2) and Otto Hänninen(3)

(1) Finnish Meteorological Institute
(2) Helsinki Metropolitan Area Council
(3) Finnish National Public Health Institute

Chapter 4

Authors: José Jaime Diéguez, Jose Luis Palau, Gorka Pérez-Landa, Ariel Stein and Millán Millán

Fundacion CEAM

Chapter 5

Authors: Sandro Finardi (1), Roberta De Maria (2), Francesco Lollobrigida (2), Giuseppe Calori (1), Alessio Dallura (1), Monica Clemente (2), Cinzia Cascone (2)

(1) ARIANET Consulting
(2) ARPAP - Environmental Protection Agency of Piedmont

Chapter 6

Authors: Marco Deserti(1), Giovanni Bonafè(1), Enrico Minguzzi(1), Michele Stortini(1), Suzanne Jongen(1), Vanes Poluzzi(2), Linda Passoni(2);

Environmental Protection Agency of Emilia – Romagna Region(ARPA):
(1) Hydro meteorological Service (SIM)
(2) Bologna Provincial Department (ARPA BO)

Chapter 7

Authors: Steen Hoe (1), Alexander Baklanov (2) and Jens Havskov Sørensen (2)

(1) Danish Emergency Management Agency (DEMA)
(2) Danish Meteorological Institute (DMI)

List of Contributing Institutions

Chapter No.	Home page	Name of Organisation
2		Public Health Authority, Municipality of Oslo Maridalsveien 3, NO-0178 Oslo
		Norwegian Traffic Authorities P.O. Box 8142 Dep, NO-0033 Oslo
		Norwegian Institute for Air Research P.O. Box 100, NO-2027 Kjeller
		The Norwegian Meteorological Institute P.O. Box 43 Blindern, NO-0313 Oslo
3		Finnish Meteorological Institute P.O. Box 503, FIN-00101 Helsinki
		Helsinki Metropolitan Area Council P.O. Box 521, FIN-00520 Helsinki
		Finnish National Public Health Institute Mannerheimintie 166,FIN-00300 Helsinki
4		Centro De Estudios Ambientales Del Mediterrano C/ Charles Darwin, 14 – Parque Tecnológico de Paterna, ES-46980 Valencia
5		ARIANET Consulting Via Gilino n. 9, IT-20128 Milano
		Environmental Protection Agency of Piedmont
6		Environmental Protection Agency of Emilia - Romagna Region
7		Danish Emergency Management Agency Datavej 16, DK-3460 Birkeroed
		Danish Meteorological Institute Lyngbyvej 100, DK-2100 Copenhagen Ø

Executive summary

A major goal of the FUMAPEX project has been to improve the performance of Urban Air Quality Information and Forecasting Systems (UAQIFSs) presently applied in various urban areas in Europe. The scientific focus has been both on improving the meteorological forecast data that are applied in the UAQIFS and to optimise the coupling interface between the meteorological and the air quality model. Furthermore, various elements of population exposure assessments have been included in the forecasting procedures to enhance the applicability for the end-users. The scientific improvements have then been evaluated through implementation in different UAQIFSs with subsequent testing and demonstration in six European target cities. In order to ensure a wide applicability of the project achievements, differences in orographic-, climatic-, and pollution characteristics in various parts of Europe have been used as selection criteria when deciding on target cities. The goal has not just been to improve the air quality forecast, but also to ensure that the UAQIFSs contain the necessary functionality for a proper dissemination of the forecasts to specific end-users and the public in general. For this reason several end-users have been directly involved in the project, both as partners and as sub-contractors.

The demonstration activity has been defined as a separate Work Package (WP8) within the FUMAPEX project. The present report (deliverable 8.2) gives a detailed technical description of each of the UAQIFS that has been implemented in the following target cities:

- The city of Oslo, Norway.
- The Helsinki metropolitan area, Finland.
- The Castellón area, Spain.
- The city of Turin, Italy.
- The city of Bologna, Italy.
- The Copenhagen metropolitan area, Denmark.

It should be noted that while the five first cities in the above list are describing operational day to day urban air quality forecast systems, the UAQIFS for the Copenhagen Metropolitan area is an emergency preparedness system. This system primarily focuses on accidental releases of radioactive materials. Moreover, the UAQIFS for Bologna is also an urban management system and therefore this system is focused both on short-term forecasts and long-term assessments.

As seen from the descriptions of the UAQIFSs, differences in topographic-, climatic-, and pollution- characteristics within the various target city areas clearly have lead to differences in methodical approach. An example is the use of hydrostatic NWP models (variants of the HIRLAM model) in the target cities surrounded by practically flat terrain like Copenhagen and Helsinki, whereas non-hydrostatic mesoscale circulation models (RAMS, MM5, LAMI) are applied in more complex terrain areas like Oslo, Turin, Bologna and Valencia/Castellón.

At present most of the boundary layer parameterisations applied in the meteorological models and the meteorological pre-processors are based on traditional Monin-Obukhov similarity theory. However, as part of the project activities in FUMAPEX

Work Package 4 and 5, urban effects are now being introduced into these traditional schemes, thereby improving model performance in urban areas.

The UAQIFS descriptions also reveal that there is a clear north-south difference in that the UAQIFSs are focused on predicting (mostly wintertime) episodes of NO_2 and PM_{10} in the northern cities (Helsinki and Oslo) while summertime ozone forecasts are of equal importance for the southern cities (Valencia/Castellón, Turin and Bologna). Since larger (regional) spatial scales are of importance for successfully forecasting the summertime episodes, larger modelling domains are generally needed within the southern city UAQIFSs.

In order to ensure a proper dissemination of the forecasted air quality information the end-users of the project have been heavily involved in designing the practical aspects of the forecast procedure. Therefore, in addition to the technical description, a description of the applied forecast procedure is also presented for each target city in the present report.

Acknowledgement

This report is part of work package 8 of the FUMAPEX project, which has been funded by the European Commission under the FP5 EESD programme Key Action City of Tomorrow.

1. Introduction

A major goal of the FUMAPEX project has been to improve the performance of Urban Air Quality Information and Forecasting Systems (UAQIFSs) presently applied in various urban areas in Europe. The scientific focus has been both on improving the meteorological forecast data that are applied as input to the UAQIFS and to optimise the coupling interface between the meteorological and the air quality model. Furthermore, various elements of population exposure assessments have been included in the forecasting procedures to enhance the applicability for the end-users. The scientific improvements have then been evaluated through implementation in different UAQIFSs with subsequent testing and demonstration in six European target cities. In order to ensure a wide applicability of the project achievements, differences in topographic-, climatic-, and pollution characteristics in various parts of Europe have been used as selection criteria when deciding on target cities. The UAQIFSs developed and installed in the different target cities reflect local experience and modelling expertise to provide an effective support to the management of local air pollution priorities.

The goal has not just been to improve the air quality forecast, but also to ensure that the UAQIFS contain the necessary functionality for a proper dissemination of the forecasts to specific end-users and the public in general. For this reason several end-users have been directly involved in the project, both as partners and as sub-contractors. One of the major achievements of the FUMAPEX project is the development of user oriented UAQIFSs, tailored for practical use, implementing state of the art meteorological, air quality and exposure modelling, and introducing elements of urbanisation.

The demonstration activity has been defined as a separate Work Package (WP8) within the FUMAPEX project. The present report (deliverable 8.2) gives a detailed technical description of each of the UAQIFS that has been implemented in the following target cities:

- The city of Oslo, Norway.
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It should be noted that while the five first cities in the above list are describing operational day to day urban air quality forecast systems, the UAQIFS for the Copenhagen Metropolitan area is an emergency preparedness system. This system primarily focuses on accidental releases of radioactive materials. Moreover, the UAQIFS for Bologna is also an urban management system and therefore this system is focused both on short-term forecasts and long-term assessments. The long-term assessment is done for a 6-12 months period for actual and future emissions of pollutants.

In addition to the six target cities, there has also been some additional WP8 activity in London and Paris.

In order to ensure a proper dissemination of the forecasted air quality information the end-users of the project have been heavily involved in designing the practical aspects of the forecast procedure (see FUMAPEX deliverable 8.1). Therefore, in addition to the technical description, a description of the applied forecast procedure is also presented for each target city in the following sections. To facilitate readability all of the sections have been structured as consistently as possible. However, because of differences both in methods and in system operationality, some nonconforming features will be found in the text layout.

2. The UAQIFS for the city of Oslo, Norway

Authors: Susanne Lutzenkirchen[(1)], Ingrid Myrtveit[(1)], Pål Rosland[(2)], Leiv Håvard Slørdal[(3)], Viel Ødegaard[(4)] and Norvald Bjergene[(4)]

[(1)] City of Oslo Health and Welfare Agency
[(2)] Norwegian Road Traffic Authorities
[(3)] Norwegian Institute for Air Research (NILU)
[(4)] Norwegian Meteorological Institute (met.no)

2.1 Technical description of the new UAQIFS

The basis for the UAQIFS in Oslo is a combined model consisting of the Meteorological Institute's meteorological model MM5 and NILU's dispersion model AirQUIS. The model runs are performed at met.no. The final AQ forecast is distributed to the public by the City of Oslo Health and Welfare Agency (end-user). These forecasts are issued every day during the winter season from about 1 November until 1 May. In the period from May to October the air quality in Oslo is generally good, and therefore AQ-forecasts are not issued on an operational day-to-day basis during this period.

2.1.1 Meteorological models and computer system

The meteorological forecast system applied in the Oslo UAQIFS consists of the operational regional NWP model HIRLAM (Undén, 2002) and the mesoscale (non-hydrostatic) meteorological model MM5 (Dudhia, 1993, 1996; Grell *et al.*, 1994). Documentation on MM5 is available at http://www.mmm.ucar.edu/mm5/. This model system is off-line coupled with the UAP model AirQUIS (AirQUIS, 2005) through a meteorological pre-processor interface program.

Norwegian Meteorological Institute (met.no) provides meteorological forecasts for Norway, Northern-Europe and the adjacent ocean areas. The HIRLAM models with resolution 20 km (HIRLAM20) and 10 km resolution (HIRLAM10) are run in operational mode, HIRLAM 20 is run four times a day. HIRLAM10 results are applied as initial and boundary conditions for the MM5 model (Berge *et al.,* 2002), version 3.4 of the non-hydrostatic Fifth-Generation Mesoscale Model (MM5) used to simulate the small-scale circulations generated by local topography and open water bodies.

The MM5 48h forecast provides the authorities with information in time to implement practical details and inform the public of eventual restrictions (abatement actions). The operational MM5 configuration consists of an outer 3 km horizontal resolution grid and an inner mesh with 1 km horizontal resolution, covering a quite large area around Oslo. The 1 km grid has 76 * 67 grid points. Both integration areas have 17 vertical layers (9 below 1500m). The MM5 model has several different options for physical parameterisation schemes. Operationally a first order turbulence closure scheme (Hong and Pan, 1996) is applied, combined with a 5-layer soil model with prescribed land-use dependent soil moisture. Resolved convection is parameterised including ice phase. Cumulus and shallow convection are not parameterised. Topography and land-use are collected from the U.S. Geological Survey (USGC). At

60° north this data has a 0.5km * 0.9km horizontal resolution, thereby allowing a horizontal grid resolution down to 1 km. In Figure 2.1 the topography for the inner mesh is shown and Table 2.1 describes different land-use categories in use with their physical properties.

Table 2.1: Land-use categories in MM5, with prescribed values of different physical properties.

Land-use category	Albedo (%)	Surface emissivity (fraction)	Soil moisture (fraction)	Roughness length (cm)	Description
1	18	0.88	0.10	100	Urban and built-up land
2	23	0.92	0.60	5	Dry land cropland and pasture
5	23	0.92	0.40	5	Cropland/grassland mosaic
6	20	0.93	0.60	20	Cropland/woodland mosaic
8	25	0.88	0.20	10	Shrub land
11	17	0.93	0.60	50	Deciduous broadleaf forest
12	15	0.93	0.60	50	Deciduous needle leaf forest
14	12	0.95	0.60	100	Evergreen needle leaf forest
15	14	0.94	0.60	50	Mixed forest
16	8	0.98	1.00	0.01	Water bodies
18	14	0.95	0.70	40	Wooded Wetland
24	70	0.95	0.95	5	Snow or ice

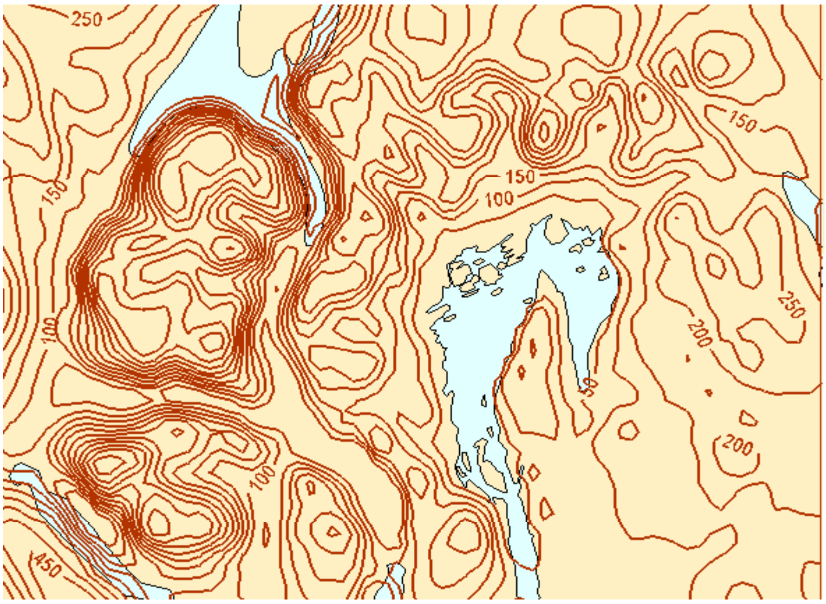


Figure 2.1: Topography for the MM5 domain covering the Oslo region (contour interval 50meter).

As part of FUMAPEX WP6 different parameterisation schemes for turbulent exchange of heat and momentum between the surface and the atmosphere were tested on a strong inversion episode. The MM5 model's tendency to overestimate the inversion strength close to the ground motivated the study. Neither of the MM5 parameterisation schemes tested proved to be the cause of the problem. It was concluded that the chosen scheme by Hong and Pan (1996) made a proper representation of the boundary layer process in this case, simulating no turbulent exchange between the surface and the atmosphere. Furthermore, it was shown that an increase in vertical resolution from the third level above the ground and upward could not improve the simulations (Ødegaard et al., 2005).

The snow cover is playing an important role in pollution dispersion in northern cities. The snow traps and stores dust along the roads and releases large amounts in short periods during spring. In addition the snow cover modifies the surface albedo and is thus crucial in the radiative balance and in building up inversions. In FUMAPEX WP4 the possibilities of assimilating snow cover observations from satellite into MM5 was investigated (Eastwood et al., 2004). By combining satellite observations with surface observations and terrain information in a proper assimilation procedure it will be possible to achieve a snow cover field of sufficiently high resolution for model initialisation.

2.1.2 The meteorological interface module

A meteorological pre-processing interface is translating the model output of MM5 so as to meet the input requirements of the AirQUIS modelling system. The pre-processor takes care of the following tasks:

- *Horizontal and vertical interpolation of the meteorological variables from the MM5 grid to the AirQUIS grid.*

  In the present version of the Oslo UAQIFS, the horizontal model domain of AirQUIS is defined as a subset of the 1 km^2 MM5 model domain, with identical fields of topography and land use classification in order to avoid the use of horizontal interpolation. Vertically MM5 applies a terrain following coordinate, defined from an idealized hydrostatic pressure-distribution (Dudhia, 1993). In AirQUIS a similar, but not identical, terrain following $\sigma-$coordinate has been implemented (Slørdal et al., 2003). However, since the two models are applying identical fields of topography, the model layers can be defined approximately at the same physical heights, thus avoiding vertical interpolation as well.

- *Meteorological input variables transferred from MM5:*
  - 3-D: Horizontal wind components, temperature;
  - 2-D: Precipitation, relative humidity, cloud cover, ground temperature, dew-point temperature, topography, land-use classification, and surface roughness.

Note that the vertical velocity applied in AirQUIS is recalculated based on gridded horizontal wind fields from MM5 and the physical requirement of mass consistent (divergence-free) wind fields.

In the original forecast version the meteorological input required by AirQUIS were just extracted from MM5 as if these were observed values available in the model grid system. The dispersion parameters for the air quality forecast were then calculated in a separate interface program using traditional Monin-Obukhov similarity theory following the methods of van Ulden and Holtslag (1985), (Bøhler, 1996; Slørdal *et al.,* 2003). Utilizing this theory in combination with the meteorological data extracted from MM5, quantities like the PBL height, the vertical profile functions in the surface layer, and the vertical eddy diffusivity (K_z) were estimated.

An important part of the FUMAPEX project has been to review and improve this interface program between MM5 and AirQUIS in order to describe the dispersion conditions more consistently, thereby assuring an optimum use of the meteorological information available within the MM5 model. The modifications that have been tested are:

1. Direct application of the MM5 estimated surface fluxes of momentum, heat, and moisture, to estimate dispersion parameters like PBL height, vertical profile functions of the turbulence parameters (σ_v and σ_w) and the vertical eddy diffusivity K_z.
2. Direct application of the MM5 estimated PBL height and vertical eddy diffusivities (for either momentum or heat) in the dispersion model.
3. Same as point 2 above, but with application of other choices of turbulence schemes (including higher order closure) optionally available as part of the MM5 package.

Of these alternatives, the direct use of the MM5 estimated eddy diffusivities and PBL height (points 2 and 3 above) represent the closest coupling of the two model systems and should therefore be the preferred method. If improved "urbanisation" or "topographical" parameterisations are later incorporated into the NWP model, the effect of these parameterisations will directly influence the air quality forecast, and need not be "re-programmed" in the interface module.

The metrological pre-processor is run either on a PC or a UNIX Workstation, and the programming language is FORTRAN.

2.1.3 The air quality modelling system, AirQUIS

The air quality forecast is made by the PC-based Air Quality Information System, AirQUIS (Bøhler and Sivertsen, 1998; Slørdal *et al.*, 2003; AirQUIS, 2005). This system has been developed at NILU over the last years and has been applied for estimating urban Air Quality in several cities (Laupsa and Slørdal, 2003; Wind et al., 2003). The combination of functionalities for emission inventory and numerical modelling within an operable and functional GIS platform makes AirQUIS an effective UAQIFS tool.

The AirQUIS emission inventory module contains data such as fuel consumption, emission factors, physical description of stacks and processes, traffic load etc. Estimates of hourly emissions of the different air quality components are then calculated by application of the emission model. The emission data are split into three separate categories. These are:

- **Point source emissions:** Include emissions from industrial plants or large factories.
- **Line source emissions:** Include all emissions from road traffic. In the calculations only roads with annual daily traffic (ADT) above a user defined limit value are included as line sources. The emissions from the roads with lower ADT are treated as area sources.

- **Area source emissions:** Include both stationary sources that are too small to be regarded as point sources as well as road traffic emissions from roads with ADT below a given user defined limit.

The method applied to calculate the PM_{10} emissions from traffic induced re-suspension takes into account the effect of vehicle composition, traffic speed and, during the winter season, the percentage of vehicles with studded tyres, on each road segment. Since practically no particles are resuspended when the roads are wet, hourly data on relative humidity, dew-point temperature and precipitation within the modelling area have been included as input to the emission model.

The dispersion model within AirQUIS (EPISODE) is a Eulerian grid model with use of embedded subgrid line and point source Gaussian models for near source treatment (Slørdal et al., 2003). The model estimates urban background concentration levels, and near source concentrations from road transport and individual stacks. Air Quality forecasts are made for NO_2, PM_{10}, and $PM_{2.5}$.

At present deposition (dry or wet) is not explicitly included as a sink term in these calculations. Tests performed with inclusion of deposition for PM_{10} revealed that this process had negligible effect on the calculated ambient concentration levels within the urban area (Slørdal et al., 2004).

The regional background is taken into account by applying climatological values of NO_2, O_3, PM_{10}, and $PM_{2.5}$ at the open model boundaries

Presently AirQUIS treats PM_{10}, and $PM_{2.5}$ as inert species. The contribution from secondary aerosols is assumed to be included in the applied climatological background. For the prediction of NO_2, however, AirQUIS makes use of the photo-stationary state assumption, i.e. an instantaneous equilibrium is assumed between the following three reactions:

$$NO_2 + h\upsilon \xrightarrow{k1} NO + O \ ,$$

$$O + O_2 + M \xrightarrow{k2} O_3 + M \ ,$$

$$O_3 + NO \xrightarrow{k3} NO_2 + O_2 \ .$$

The steady-state assumption implies that NO_X (the sum of nitrogen oxides) and O_X (oxidants) are conserved, where NO_X and O_X are defined as:

$$[NO_x] = [NO] + [NO_2] \ , \quad \text{and} \qquad [O_x] = [O_3] + [NO_2].$$

By these assumptions the three components NO, NO_2 and O_3 can be found by the solution of a second-degree equation in O_3. During wintertime in Nordic cities this is a rather good approximation to the real situation. However, when the solar UV-radiation is stronger, either because of a more southern location or in summer, a net ozone formation could take place even in urban areas a certain distance away from the main emission sources. Thus, the assumption of conservation of O_X and NO_X is then not valid and a more detailed chemical description is needed.

In the Oslo UAQIFS AirQUIS is applied on a 1 km resolution grid for the area covering the 22 km x 18 km city region. The model domain (with topography and main road network depicted) is shown in Figure 2.2.

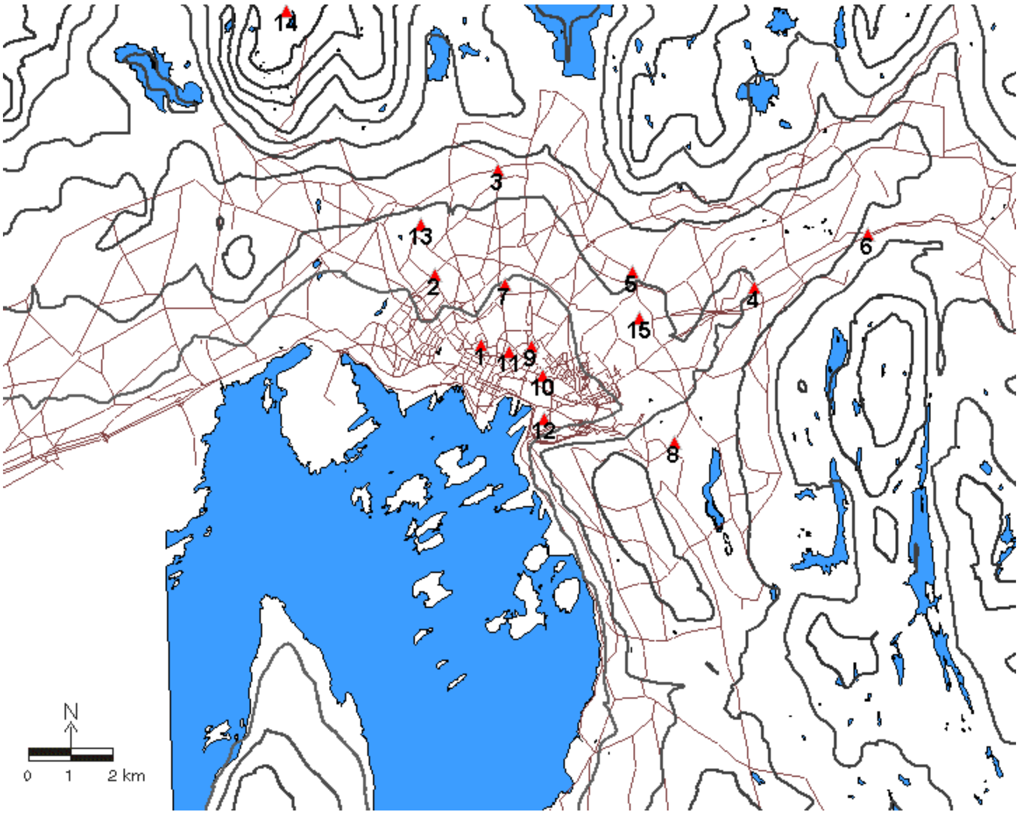


Figure 2.2: AirQUIS model domain for the city of Oslo. The topography is given with thick dark contour lines (50 m equidistance) and the main road network is indicated with thin lines. The available AQ and met. measurement stations are depicted with numbered red triangles. (AQ-stations numbered 1 to 12, and met. stations 13 to 15).

The Oslo UAQIFS also contains a population exposure module (Laupsa and Slørdal, 2003). This module, which is an integrated part of AirQUIS, combines the calculated outdoor concentration levels with information on the geographical distribution of the city inhabitants. The applied population distribution is stationary and is based on information on the number of people living in each of the buildings within the city area. The application of the sub-grid line source model makes it possible to estimate more detailed concentration levels in receptor points in the vicinity of the major road network. These receptor points are placed in the geographical positions of buildings located close to the main road network (within a distance less than 200 – 500 m from the road). In AirQUIS these receptor points are termed "building points". An example of a "building point" concentration distribution is shown in Figure 2.3. The colour coding indicates outdoor concentration level (in µg/m^3) estimated at each building position. The near road exposure levels are thus obtained simply by combining the information on building inhabitants with the estimated outdoor "building point" concentration. Exposure levels for inhabitants living in buildings located farther away from the main road network, i.e. buildings not defined as an individual receptor points, are defined as the Eulerian grid point concentrations (urban background) for the grid cells hosting the buildings. In this way an exposure level is estimated for the total population.

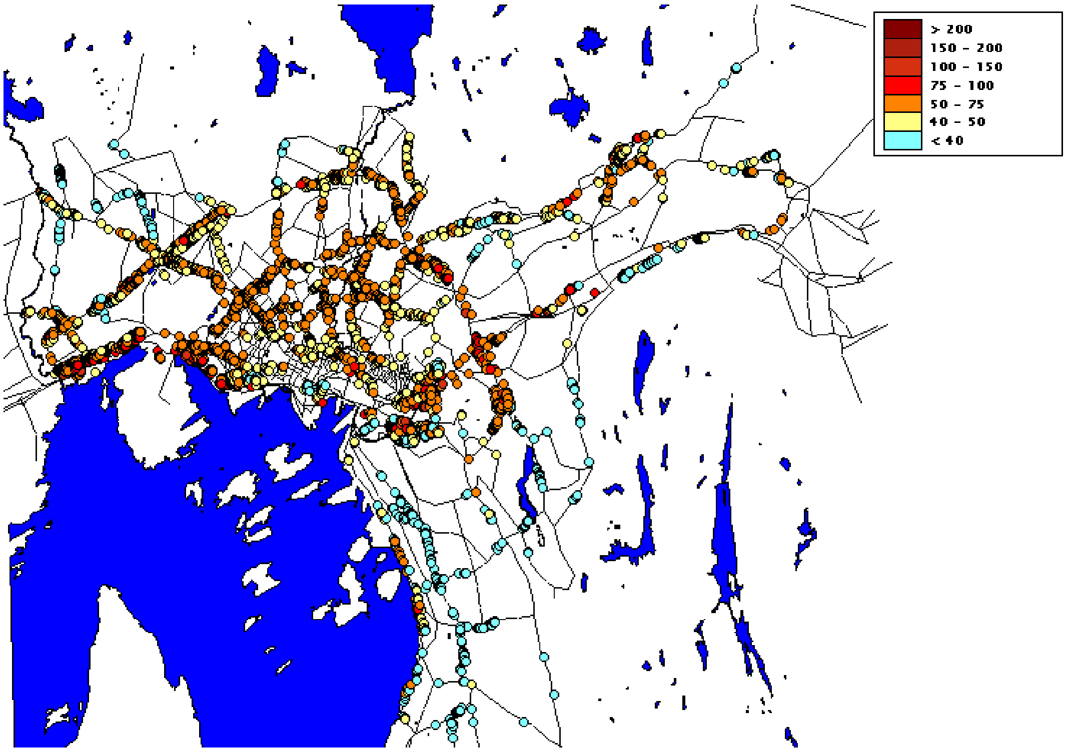


Figure 2.3: Example of hourly concentration distribution of PM10 in the selected "building points" (µg/m³).

In the air quality forecast the exposure estimates are employed as an aid when assessing the forecasted air quality. The air quality is defined in four classes: good, moderate, poor and very poor. The concentration limits defining the various air quality classes are presented for the compounds NO_2 (hourly average), PM_{10} (daily average) and $PM_{2.5}$ (daily average) in Table 2.2 below.

Table 2.2: Concentration levels defining the AQ classes for NO_2, PM_{10} and $PM_{2.5}$.

Air Quality (description)	**NO_2 (Hourly) (µg/m³)**	**PM_{10} (Daily) (µg/m³)**	**$PM_{2.5}$ (Daily) (µg/m³)**
Good	0 - 100	0 - 35	0 - 20
Moderate	100 - 150	35 - 50	20 – 35
Poor	150 - 200	50 - 100	35 - 60
Very poor	> 200	> 100	> 60

By combining the forecasted concentration levels (calculated both in “building points” and in the model grid system) with the population distribution, the number of inhabitants exposed within the various Air Quality classes can be estimated. An example of such an exposure forecast is presented in Table 2.3 below.

Table 2.3: Example of forecasted population exposure.

Air Quality description	**NO_2 Number of persons exposed**	**PM_{10} Number of persons exposed**	**$PM_{2.5}$ Number of persons exposed**
Good	491 926	352 636	408 764
Moderate	13 374	105 565	96 234
Poor	554	45 255	856
Very poor	0	2 398	0

In the Oslo UAQIFS it has been decided that at least 20 000 inhabitants need to be exposed to a certain air quality class, in order to define the general air quality for the next day as belonging to this class. In the example presented in Table 2.3, poor, moderate and good air quality is thus expected with regards to PM_{10}, $PM_{2.5}$ and NO_2, respectively. In this case the overall air quality can be forecasted as poor, with an additional description of pollution type, and where (and possibly when) to expect the worst conditions.

Based on the above model results, monitoring data (air quality and meteorology) and experience, the person responsible for the air quality forecast at the Oslo Public Health Agency (end-user) formulates an air quality bulletin that is published on the Internet for the general public. An example of such a bulletin is presented in the next Chapter.

AirQUIS is run on a PC (WINDOWS, 98, 2000, NT, and XP), and the programming language is Visual Basic (VB). The dispersion model (EPISODE) is programmed in FORTRAN 90 and compiled as a Dynamic Link Library (DLL) for application within the AirQUIS' VB environment.

2.1.4 The operational forecast procedure

The forecast model is operated in the following way (see also Figure 2.4):

(1) The HIRLAM10 is run every morning (for a 00- 48 hours prognosis) on the national super computer based on input from global and regional models. This run is finished at about 04:30 local time (LT).

(2) Initial and boundary values from HIRLAM10 are utilized to run the fine-scale meteorological model MM5 (1 km resolution) for the Oslo region for the period 00 to +48 hours. This simulation is performed on a local Linux-cluster (40 processors), and is finished at about 05:30 LT.

(3) A meteorological interface extracts the MM5 information needed by AirQUIS. AirQUIS is then run for Oslo (00 to +48 hours) on a dedicated PC. The AQ-forecast is finished around 06:30 LT.

(4) The (quantitative) AQ and MM5 forecast (e.g. model output plots) and the duty forecasters interpretation and comments to the MM5 results for the next day are distributed to the end-user by a WEB-page. All information for Oslo is available at about 07:00 – 07:30 LT.

(5) The end-user, (Public Health Authority, the Municipality of Oslo) receives the quantitative forecast and issues a public forecast for the next day at about 07:30 LT. The forecast is described in more detail in Section 2.2.

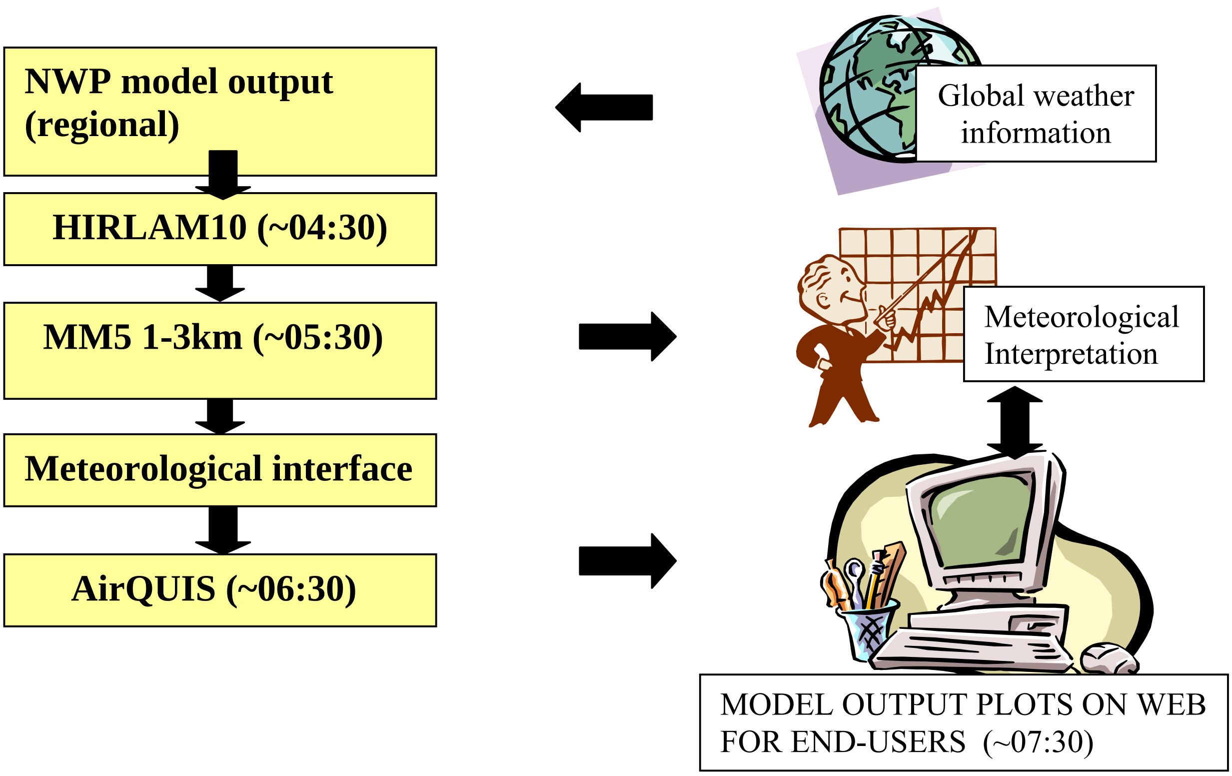


Figure 2.4: The existing operational forecast model for Oslo.

2.2 Description of the forecasting procedure as performed by the end-users

During the FUMAPEX project some changes and additions have been incorporated in the forecasting procedure for the UAQIFS used in Oslo, Norway. This updated procedure is described below.

- **Model:** The results from the combined meteorological and air quality model has to be ready at 7:30 a.m. local time at the latest. The results from MM5 and AirQUIS are made available on the Internet for the End-Users. In addition, the End-User also receives model output from HIRLAM10 on e-mail.
    - **Meteorological data**: The results from the MM5 model include surface data of wind, temperature, precipitation and prognostic vertical profiles (wind, temperature, relative humidity) for every three hours from 0 to + 48 hours ahead. Precipitation data is displayed for every 0,1 mm. Additionally meteograms, containing information about wind, pressure, temperature, precipitation and cloud cover, are available for five locations in Oslo. Furthermore, there is a file containing explanatary comments to the model results, written by the duty forecaster at met.no.
    - **Air pollution data**: The AirQUIS model calculates the concentrations of NO_2, PM_{10} and $PM_{2,5}$ for every hour at the monitoring stations in the city. At street stations both the value at the real monitoring location and the corresponding mirror point at the opposite side of the street are estimated. The data is available in an easy-to-read table on the Internet site. Moreover, the model also gives maps of the air quality situation in the city (24 maps of hourly concentration for NO_2 and 1 map each for daily concentrations of PM_{10} and $PM_{2.5}$).
    - **Exposure**: The AirQUIS model calculates the total human exposure for each forecasting class. Exposure is taken into account when defining the forecasting class for the city. In Oslo more than 20.000 persons must be expected exposed above a given class for this class to be forecasted. A national guideline for carrying out urgent measures (if applicable in a city) is also referring to this number of exposed people. The four forecasting classes used are defined in Table 2.4 below.
- **Forecasting** (example shown below in Figure 2.5): Based on the model results, monitoring data (air quality and meteorology) and experience, the person responsible for the forecast at the Oslo Public Health Agency (end-user) formulates a subjective air quality forecast for today and tomorrow.
    - **Content of the forecast**: Time variations for NO_2, PM_{10} and $PM_{2,5}$ are determined for yesterday, today and tomorrow. These graphs apply for the city as a whole. Therefore, forecasting classes are based on the estimated number of people exposed. The forecast includes one graph showing the variation in the pollution level for these three days. This graph is based on the component (NO_2, PM_{10} or $PM_{2,5}$) with the highest concentration level for every hour. Furthermore, the air quality forecasts include a text explaining when and where the pollution is expected to be highest in the city, which areas the air quality is supposed to be good, the health effects in the different forecasting classes, and which sources that are believed to

be the main contributors to the pollution. If the air pollution is high, the forecast includes a request to the public to take actions to contribute to a lower pollution level. If the calculated air quality maps are assumed to give a realistic picture of the expected air pollution, one or more maps are published with the forecast.

- **Publishing**: The forecast is published at 8:30 a.m. (Monday to Friday) and 9:30 a.m. during weekends and on holidays during winter season i.e. end of October through April. The forecast is available in newspapers, on the Internet (pages on air quality and in connection with weather forecasts), and is broadcasted on the local radio. Moreover, the forecast and information on the status at the monitoring stations is available as email and SMS. Internet sites on air quality (in Norwegian):

  www.hev.oslo.kommune.no (Oslo)

  www.luftkvalitet.info (national site for all Norwegian cities)

Table 2.4 National forecasting classes for local air quality.*

Level	NO_2 (µg/m³)	PM_{10} (µg/m³)	$PM_{2,5}$ (µg/m³)	Health effects
Good	< 100	<50	< 25	No health effects
Moderate	100 - 150	50 - 100	25 - 50	Asthmatics may experience health effects in these areas, especially during physical activities.
Poor	150 - 200	100 - 150	50 - 100	Asthmatics and people with serious heart- and bronchial diseases should avoid longer outdoor stays in areas with high air pollution.
Very poor	> 200	> 150	> 100	Asthmatics and people with serious heart- and bronchial diseases should avoid areas with very high air pollution. Healthy people may experience incidentally irritations in the muscular membrane and unpleasantness.

* A forecasting class is based on expected maximum levels for one of the three components during each hour.

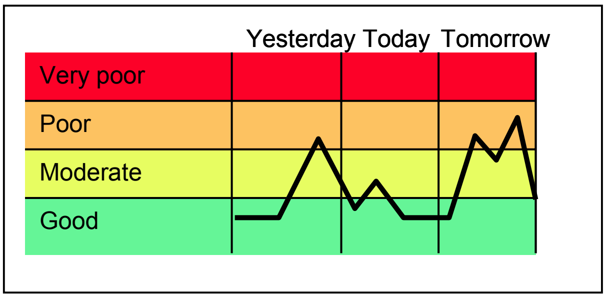
Forecast of air quality

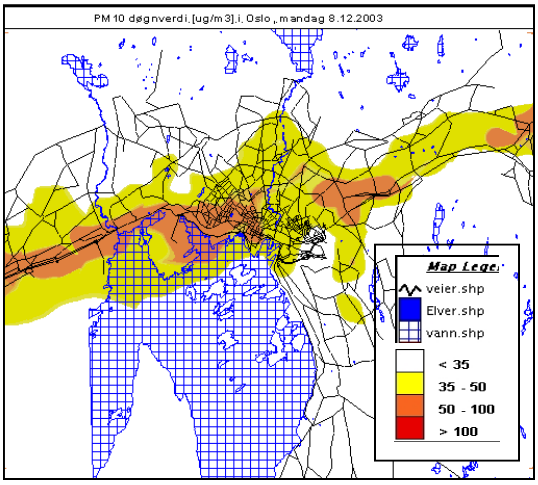
Oslo Public Health and Welfare Agency

Forecast for Oslo:

- The air quality was **moderate** Sunday, December 7th, at 9 a.m. The air quality is expected to be **moderate** within Ring road 2 and along the main roads in the morning. It is dust resuspension and wood burning that cause pollution. The air quality is expected to be **good** in other parts of the city.

- Forecast for Monday, December 8th. The air quality is expected to be **poor** to **very poor** along the main roads. The highest concentrations can be expected during rush hours. The air quality is expected to be **moderate** within Ring road 3 and in greater distance to the main roads. It is dust resuspension and exhaust that cause pollution. The air quality is expected to be **good** in other parts of the city.





Level	Health Effects
Good	No health effects
Moderate	Asthmatics may experience health effects in these areas, especially during physical activities.
Poor	Asthmatics and people with serious heart- and bronchial diseases should avoid longer outdoor stays in areas with poor air quality.
Very poor	Asthmatics and people with serious heart- and bronchial diseases should avoid areas with very poor air quality. Healthy people may experience incidentally irritations in the muscular membrane and unpleasantness.

Figure 2.5 Example of an air quality forecast for Oslo (8th of December 2003)

2.3 References

AirQUIS 2005. URL: http://www.nilu.no/aqm/

Berge, E., Walker, S-E., Sorteberg, A., Lenkopane, M., Eastwood, S., Jablonska, H.I. and Køltzow, M.Ø. (2002) A real-time operational forecast model for meteorology and air quality during peak air pollution episodes in Oslo, Norway. *Water, Air and Soil Pollution Focus, 2*, 745-757.

Berge, E. and Køltzow, M.Ø. (2002). Winter climate of Bjørvika, Oslo, described by MM5. Oslo, The Norwegian Meteorological Institute (Research Report no. 142). (in Norwegian)

Bøhler, T. (1996) MEPDIM. The NILU Meteorological Processor for Dispersion Modelling. Version 1.0. Model description. Norwegian Institute for Air Research, Kjeller (NILU TR 7/96).

Bøhler, T. and Sivertsen, B. (1998) A modern Air Quality Management system used in Norway. Norwegian Institute for Air Research, Kjeller (NILU F 4/98).

Dudhia, J. (1993) A nonhydrostatic version of the Penn State/NCAR mesoscale model: Validation tests and simulation of an Atlantic cyclone and cold front. *Mon. Wea. Rev., 121,* 1493-1513.

Dudhia, J. (1996) A multi-layer soil temperature model for MM5. Preprints, The sixth PSU/NCAR Mesoscale Model Users Workshop, 22-24 July 1996, Boulder, Colorado. pp. 49-50.

Eastwood, S., Ødegaard, V. and Midtbø, K.H (2004) Algorithms for assimilation of snow cover, FUMAPEX D4.3. URL: http://glwww.dmi.dk/f+u/luft/eng/fumapex/Index/index_docu.html

Grell, G., Dudhia, J., and Stauffer, D. (1995) A Description of the Fifth-Generation PENN STATE/NCAR Mesoscale Model (MM5). Boulder, Colorado, National Center for Atmospheric Research. (NCAR Technical Note, NCAR/TN-398+STR).

Hong, S.-Y. and Pan H.-L. (1996) Nonlocal boundary layer vertical diffusion in a medium range forecast model. *Mon. Wea. Rev., 124*, 2322-2339.

Laupsa, H. and Slørdal, L.H. (2003) Applying model calculations to estimate urban air quality with respect to the requirements of the EU directives on NO_2, PM_{10} and C_6H_6. *Internat. J. Environ. Pollut.*, *20*, 309-320.

Slørdal, L.H., Solberg, S., and Walker, S.E. (2003) The Urban Air Dispersion Model EPISODE applied in AirQUIS$_{2003}$. Technical description. Norwegian Institute for Air Research, Kjeller (NILU TR 12/03).

Slørdal, L.H., Laupsa, H., Wind, P., and Tarrasón, L. (2004) Local and regional description of Particulate Matter in the Oslo. Joint MSC-W & NILU Technical Report. Oslo, Norwegian Meteorological Institute (MSC-W Technical Report 5/2004).
URL: http://www.emep.int/publ/reports/2004/emep_technical_5_2004.pdf

Undén, P. (ed.) (2002) HIRLAM-5 Scientific Documentation. Norrköping, Swedish Meteorological and Hydrological Institute.

van Ulden, A.P. and Holtslag, A.A.M. (1985) Estimation of Atmospheric Boundary Layer parameters for Diffusion Application. *J. Appl. Meteorol., 24*, 1196-1207.

Wind, P., Tarrason, L., Slørdal, L.H., Solberg, S., Denby, B., and Walker, S.E. (2003) Further development of a modelling system able to link hemispheric-regional and local air pollution. Joint MSC-W & NILU Note. Oslo, Norwegian Meteorological Institute (MSC-W# Technical Report 2/2003) URL: http://www.emep.int/publ/reports/2004/mscw_note_2_2003.pdf

Ødegaard, V., D'Allura, A., Baklanov, A., Dieguez, J., Fay, B., Finardi, S., Glaab, H., Hoe, S.C., Millan, M., Mahura, A., Neunhauserer, L., Palau, J.L., Perez, G., Slørdal, L.H., Stein, A. and Havskov Sørensen, J. (2005) Study of sensitivity of UAP forecasts to meteorological input. Oslo, Norwegian Meteorological Institute (met.no report 13/2005). URL: http://met.no/english/r_and_d_activities/publications/2005/13_2005/report13.2005.pdf

3. The UAQIFS for the Helsinki Metropolitan Area, Finland

Authors: Ari Karppinen(1) ,Jaakko Kukkonen(1) ,Ilkka Valkama(1), Mari Kauhaniemi(1), Minna Rantamäki (1), Anu Kousa(2) and Otto Hänninen(3)

(1) Finnish Meteorological Institute
(2) Helsinki Metropolitan Area Council
(3) Finnish National Public Health Institute

3.1 Technical description

The FMI-UAQIFS system API-FMI, Air Pollution Information and Forecasting System for disseminating real-time and forecasted air pollution information to the public has been updated during the FUMAPEX project. Emission modelling, dispersion modelling for fine particles and exposure modelling have been completely revised.

Air pollution forecasting is divided into two steps:

(i) Application of the weather forecasts of the synoptic situation and meteorological parameters.

(ii) Computation of pollutant concentrations, using statistical methods and the urban dispersion modelling systems CAR-FMI and regional background models - this part of the forecasting system which is most relevant for FUMAPEX activities will be described in more detail in Section 3.1.2.

The statistical methods are based on regression analysis of measured concentrations and meteorological parameters. These correlations have been derived from measurements in the Helsinki metropolitan area. Air pollution forecasts are made for the compounds SO_2, NO_x, and CO. During 2003-2005 also neural network based forecasting procedures for NO_2, $PM_{2.5}$, and PM_{10} have been extensively tested in the Helsinki area (e.g. Niska et al, 2005).

In addition a Meteorological Air Quality Index (MAQ), an application for forecasting of air pollution episodes during Northern European wintertime weather conditions, has been implemented during 2002-3. The application is based on evaluating the air pollution potential from the HIRLAM forecast and the result is then presented as a single index value (i.e. the MAQ index). The most important parameters in determining the index value are the occurrence and strength of surface inversion and wind speed near the surface. The air quality forecast was made for the next day (i.e. from +24 to +48h from the time of the HIRLAM forecast). The MAQ is used by duty forecasters at the FMI for evaluating the air quality situation inside the Helsinki Metropolitan Area. Verification of the MAQ index has been conducted during 2003-4 against the observed NO_2 concentrations in Lahti, Turku and the Helsinki Metropolitan Area. Results show, that although problems in the HIRLAM model boundary layer modelling decrease the accuracy of the predictions, the MAQ index follows the general NO_2 concentration accumulation relatively well.

3.1.1 Meteorological model

Since November 2004, the operational NWP model at FMI has been HIRLAM (High Resolution Limited Area Model) version 6.2.1, which is also the current HIRLAM reference version maintained by the international HIRLAM project. Currently, the model produces four daily 54-hour regional and mesoscale forecasts.

HIRLAM is a hydrostatic, prognostic numerical weather model, which has hybrid coordinate system in the vertical and staggered Arakawa-C-grid in the horizontal (Eerola, 2000). In the implementation the South Pole is rotated at longitude/latitude 0/-30°. Within the international HIRLAM project, a non-hydrostatic version has been developed, the code being written in Tartu University, Estonia (Rõõm, 2001). This nonhydrostatic version is also available for FMI, but is not operational.

The horizontal resolution of HIRLAM RCR is 22 km at 60°N and the resolution of the HIRLAM MBE is 9 km, both models having 40 vertical levels (Figure 3.1).

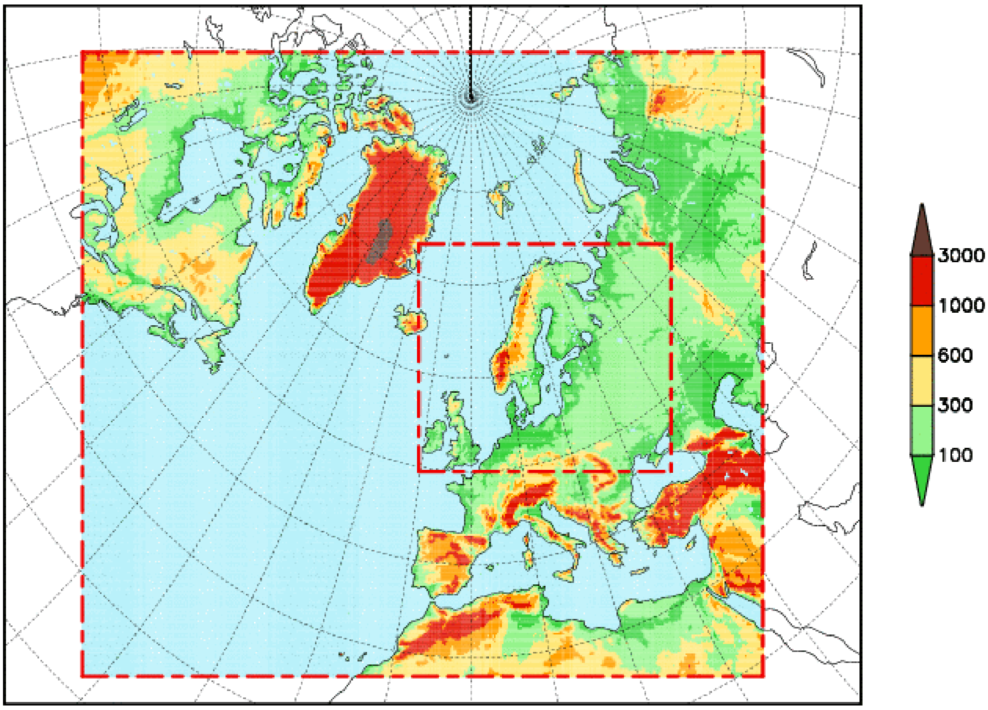


Figure 3.1: Approximate model domains used for the HIRLAM MBE(smaller) and RCR(larger).

In the operational implementation a Davies-Kållberg relaxation scheme applied for the staggered grid is used. The lateral boundary fields for the largest integration area are obtained from ECMWF. Inside HIRLAM a one-way nesting procedure is used.

During the FUMAPEX project an evaluation of the performance of the operative HIRLAM model was performed (Rantamäki et al., 2005ab) during the selected FUMAPEX episodes. The performance of the newest operational HIRLAM version in predicting the temperature inversion was found to be satisfactory.

3.1.2 The air quality forecast system

The new UAQIFS in the Helsinki Metropolitan Area (Helsinki, Vantaa, Espoo, Kauniainen) is based on FMI's local scale dispersion model CAR-FMI (Contaminants in the Air from a Road) (Härkönen et al., 1996; Härkönen, 2002). In this system the air quality forecast is directly linked to the operational HIRLAM through FMI's Real-Time Database.

The interface between CAR-FMI and HIRLAM is a query-data interface. The meteorological post processing is done by the metPostProc program, which deals with the reading of the meteorological data and the conversion of cumulative values to instant values (e.g. heat and momentum fluxes). The meteorological input data for the CAR- FMI includes wind speed, (m/s), wind direction, inverse Obukhov length (1/m), mixing height (m), temperature (K), global radiation intensity (W/m^2), relative humidity (%), and ambient pressure (mbar). Most of the atmospheric boundary layer parameters are obtained directly from HIRLAM; the missing parameters are processed with a simple postprocessor based on Monin-Obukhov theory.

CAR-FMI computes the concentrations of carbon monoxide (CO), nitrogen monoxide (NO), nitrogen dioxide (NO_2), nitrogen oxides (NO_x), ozone (O_3), and exhaust fine particle matter ($PM_{2.5}$). The model uses a general solution of the Gaussian diffusion equation for a finite line source for the dispersion of the gaseous pollutants (Härkönen, 2002). The structure of the emission model is independent on emitted compounds. The emission model includes motor emissions for CO, NO_x, and $PM_{2.5}$. Exhaust emission as a function of the average driving speed is fitted separately for six different vehicle categories. The height of which the emissions are released is 1.0 m above the road. The chemical transformation model contains basic reactions for nitrogen oxides, oxygen and ozone. The transformation uses discrete parcel method, which considers that the emissions and the background air are uniformly mixed in the air parcels. The size of the reaction volume is dependent on the receptor location (Härkönen et al, 1997).

The schematic diagram of the modelling process of CAR-FMI is shown in Figure 3.2. The input information includes the size and location of the region of interest, detailed information of the roads investigated, location of the roads and the average traffic speed, volume, and composition on the roads in question. In addition, the model needs as an input the information about the average temporal variation of traffic volumes, meteorological and background concentrations, and emissions.

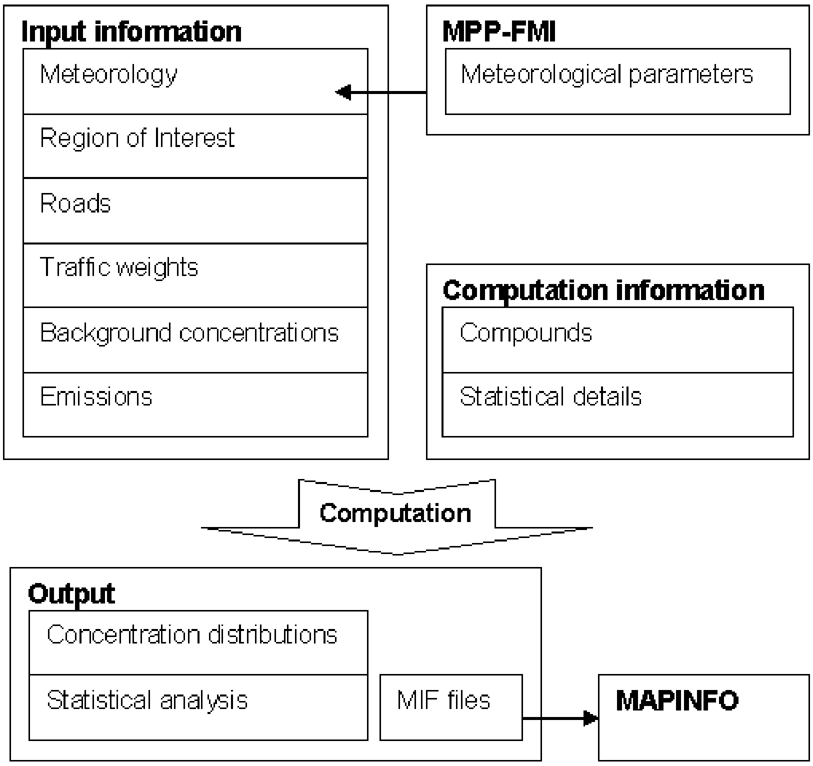


Figure 3.2: The general flow of CAR-FMI. MPP-FMI is meteorological pre-processing, which is replaced by the direct HIRLAM-interface in operative forecasting use; MIF is file format that enables the results of CAR-FMI model to be presented with MapInfo software (GIS, Geographical Information System).

The model requires also input information about the pollutants coming outside of the study area, i.e. background concentrations. The background data used in the model can be statistically modelled from on-site background measurements or it can be based on regional scale model calculations.

The operative air quality forecast is at the moment based on the calculated CO and NOx concentrations – an example of the forecasted spatial distribution of the air quality index is presented in Figure 3.3.

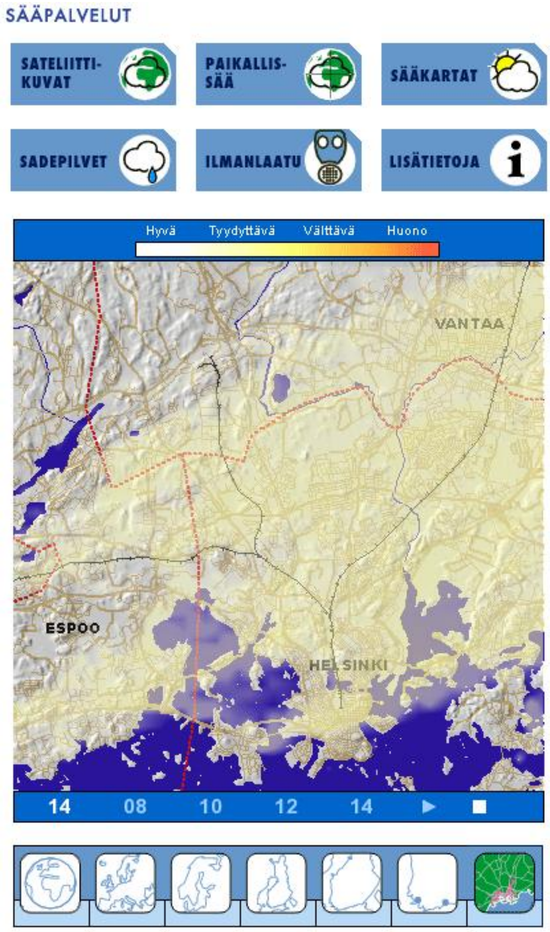


Figure 3.3: An example of the forecasted air quality index (based on modelled CO and NO2 concentrations) for Helsinki Metropolitan area.

3.1.3 Population exposure modelling

Ambient air pollution, especially fine particulate matter ($PM_{2.5}$), has been associated to excess mortality and morbidity at the current urban levels. Air pollution is an additional risk factor that increases the statistical probability of death and other adverse health effects caused primarily by cardio-vascular and respiratory diseases. Most of the epidemiological studies have been based on air pollution concentrations at fixed ambient air quality monitoring sites. However, the measurement data from these stations does not necessarily represent areas beyond their immediate vicinity, as the concentrations of pollutants in urban areas may vary by orders of magnitude on spatial scales varying from tens to hundreds of metres. Therefore there is a need to model the population exposures to pollutants.

We have developed a mathematical model, EXPAND (EXposure model for Particulate matter And Nitrogen oxiDes), for the determination of human exposure to ambient air pollution in an urban area (Kousa et al., 2002; Kousa et al, 2005). The model can be used to evaluate the spatial and temporal variation of the average exposure of the urban population to ambient air pollution in different microenvironments. In this new version we have updated our earlier time activity model, the time-microenvironment activity data, and we have used more detailed traffic data (besides cars and buses also trains, trams, metro, pedestrians, and cyclists). Also the indoor/outdoor ratios are included in the model.

We obtained the information on the location of the population from the data set collected annually by the municipalities of the Helsinki metropolitan area. This data set contains data on the dwelling houses, enterprises and agencies located in the area. The data set provides geographic information on the total number and age distribution of people living in a particular building or the total number of people working at a particular workplace. The information on the location of people in shops, restaurants and other recreational activities is based on this data set. The location of people in traffic is evaluated using the computed traffic flow information; this information is available separately for buses, cars, trains, trams, metro, pedestrians, and cyclists for each street/rail section on an hourly basis. However, this information does not identify individual persons. The time-microenvironment activity data is based on the time use survey by Statistics Finland. The time activity data were collected from 813 randomly selected over 10-year old inhabitants in the Helsinki metropolitan area. For our model the time-activity of the population was divided into four main categories: home, workplace, traffic, and other activities.

Home co-ordinates are combined with the information on the number of inhabitants at each building and the time spent at home during the day. Correspondingly, for the workplace co-ordinates the number and age distribution of the personnel, and the time spent at the workplace are combined. The population activities at other locations (shops, cinemas, theatres, opera, libraries, restaurants, cafes, pubs etc.) are also evaluated using statistical information of leisure time. The number of persons in traffic is evaluated based on the predicted traffic flows. In the case of buses, trains, metro, trams and also pedestrians and cyclists, the number of persons and the time they spend in each street/rail section is estimated using the traffic-planning model EMME/2. In the case of private cars the EMME/2 model predicts the number of cars; we assumed that the number of passengers in each car is equal to the average value in the area i.e. 1.2. Also Indoor/Outdoor ratio is included in the model. I/O ratio data is based on the results of the Expolis study (Hänninen et al., 2004). I/O ratio 0.59 ($PM_{2.5}$) and 0.71 (NO_2) are used for buildings and 1 for traffic (both $PM_{2.5}$ and NO_2).

In the model the $PM_{2.5}$ concentrations are interpolated on to a rectangular grid. The data regarding population activities (number of persons * hour) is also transformed to the same grid. Finally the interpolated concentrations and the population activities are combined to form the estimate of the population exposure. The GIS system is subsequently utilised in the post-processing and visualisation of this information.

As an example, we present some results for an inversion-induced episode day when the high concentrations were mainly caused by the local vehicular emissions (the 22nd of September 2002). The inversion-induced episode occurred in the evening starting about 3 p.m. In Figure 3.4 the evaluated population exposure from 7 to 8 p.m. is presented. At this hour many people have already returned home from their workplaces, but due to the meteorology the $PM_{2.5}$ concentrations are relatively high. For comparison in Figure 3.5 the evaluated exposure from 10 to 11 a.m., when the morning rush hours are over and people are mostly at work, is presented.

We can see a clear difference in the magnitude and the spatial distribution of the population exposures during these two hours. During the evening episode hour the total population exposure is over 2.5 times higher than during the daytime. However, from 10 to 11 a.m. the maximum exposures in the area are higher than from 7 to 8 p.m. due to the fact that the time-microenvironment activity is “concentrated” in the many working places in the city centre.

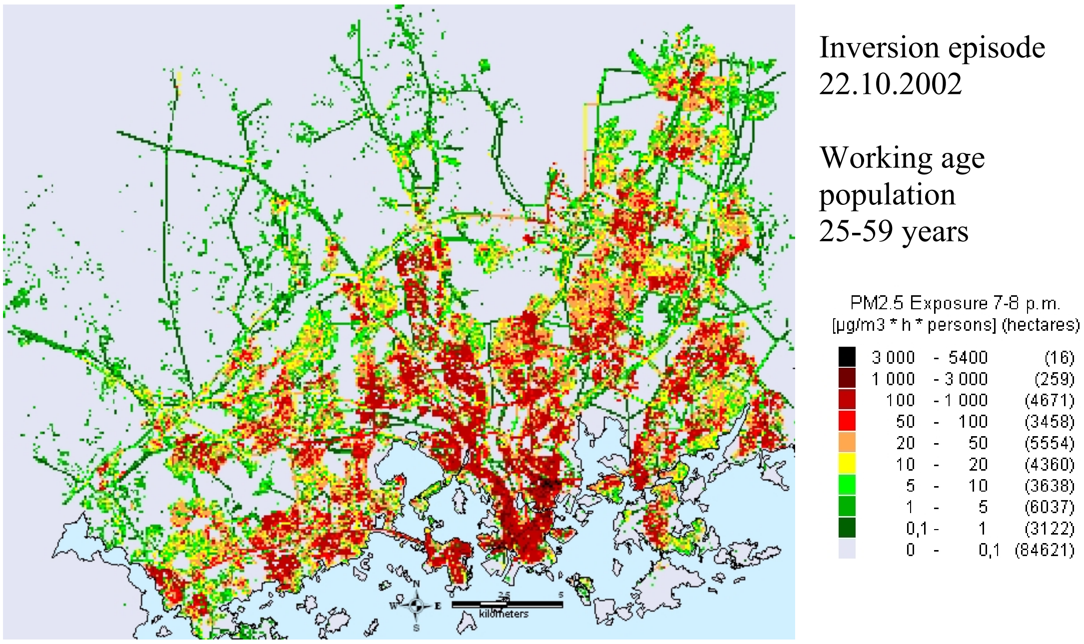


Figure 3.4: Spatial distribution of the $PM_{2.5}$ exposures of the working age population (25-59 years) on the inversion-induced episode day at 7-8 p.m.

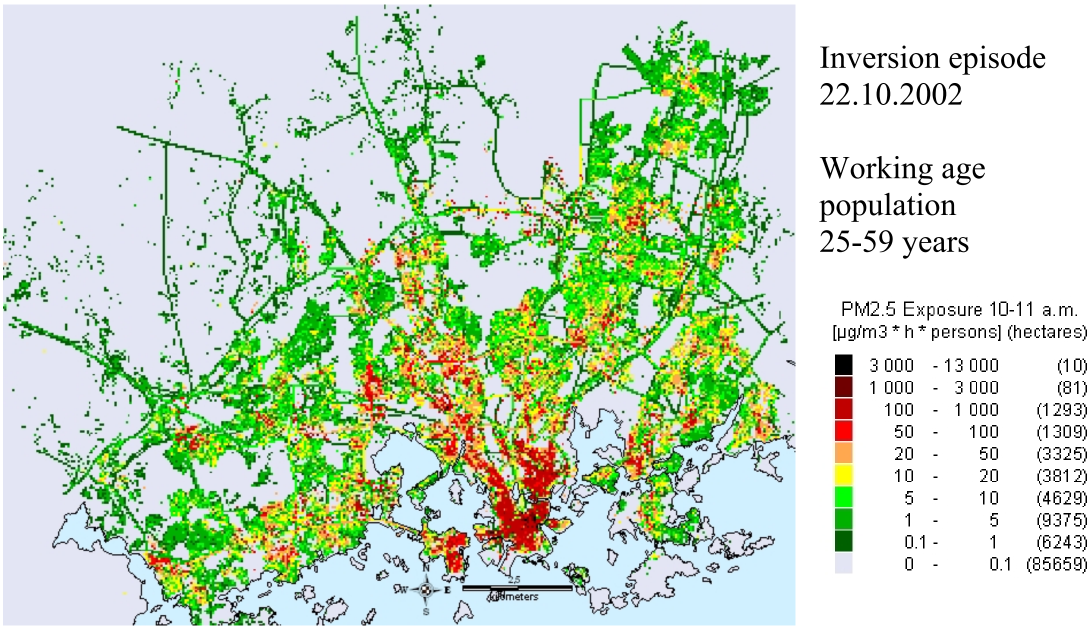


Figure 3.5: Spatial distribution of the $PM_{2.5}$ exposures of the working age population (25-59 years) on the inversion-induced episode day at 10-11 a.m.

The results demonstrate that the model can distinguish the temporal and spatial variation of the population exposures. The numerical results on population exposure can be interpreted based on the variation of the time-microenvironment activities and the meteorological parameters. The GIS techniques are indispensable for the presentation of the results that illustrate, e.g., the most problematic areas and time periods.

3.2 Description of the forecasting procedure as performed for/by the end-users

Monitoring and modelling data on air quality and population exposures to air pollution are used in the Metropolitan area on different levels. Most air quality management actions and decisions are taken in the long run to prevent air quality problems; only a limited number of means are available for the city authorities in episode situations. Forecasting of the episode air quality, however, is important for communicating to the public and giving recommendations especially for the susceptible population groups and in setting optimal interventions for traffic and industrial emissions in the worst cases. The ultimate target of the air quality management actions, including both long-term planning and reactions to short-term episodes, is to minimise public health risks caused by population exposures to air pollution.

Air quality forecasts and warnings in case of possibly occurring peak pollution episodes produced by the Finnish Meteorological Institute (FMI) are forwarded to the Helsinki Metropolitan Area Council (YTV) on a continuous basis. The warnings are distributed to the public by YTV as the end-user.

The map-based air quality forecast is at the moment distributed only to a commercial cable network (www.welho.fi) along with several weather forecast products. The forecast is run completely automated, connected directly to the weather forecast schedules, thus it is being updated 4 times a day. However, this automatic operative forecast does not yet include all the new components developed during the FUMAPEX project.

During year 2006 the operative forecasting system will be updated to include all the improvements of the at the present non operative modelling system:

i. Air quality index based on not only the gaseous pollutants but also the predicted $PM_{2.5}$ and PM_{10} concentrations.

ii. Forecast for regional transport (SILAM, HILATAR).

iii. Forecasted daily exposures for $PM_{2.5}$ and NO_2.

3.3 References

Eerola, K. (2000) The new operational HIRLAM at the Finnish Meteorological Institute. *HIRLAM Newsletter,* No. 35, 36-43.

Hänninen, O.O., Alm, S., Katsouyanni, K., Künzli, N., Maroni, M., Nieuwenhuijsen, M.J., Saarela, K., Sram, R.J., Zmirou, D. and Jantunen, M.J. (2004) The EXPOLIS study: implications for exposure research and environmental policy in Europe. *J. Expo. Anal. Environ. Epidemiol., 14,* 440-456.

Härkönen, J., Valkonen, E., Kukkonen, J., Rantakrans, E., Lehtinen, K., Karppinen, A. and Jalkanen, L. (1996) A model for the dispersion of pollution from a road network. Helsinki, Yliopistopaino, Finnish Meteorological Institute (Publications on air quality, 23).

Härkönen J., Walden J. and Kukkonen, J. (1997) Comparison of model predictions and measurements near a major road in an urban area. *Int. J. Environ. Poll., 8*, 761-768.

Härkönen, J. (2002) Regulatory dispersion modelling of traffic-originated pollution. Helsinki, Yliopistopaino (Finnish Meteorological Institute Contributions, 38).

Kousa, A., Aarnio, P., Kukkonen, J., Riikonen, K., Alaviippola, B., Kauhaniemi, M., Karppinen, A., Elolähde, T. and Koskentalo, T. (2005) Refinement of a deterministic population exposure model, and its application for predicting the exposures of $PM_{2.5}$ in Helsinki in 2002, In: *Proceedings of the 5th International Conference on Urban Air Quality, Valencia, 29-31 March 2005.*

Kousa, A., Kukkonen, J., Karppinen, A., Aarnio, P. and Koskentalo, T. (2002) A model for evaluating the population exposure to ambient air pollution in an urban area. *Atmos. Environ., 36,* 2109-2119.

Niska, H., Rantamäki, M., Hiltunen, T., Karppinen, A., Kukkonen, J., Ruuskanen, J. and Kolehmainen, M. (2005) Evaluation of an integrated modelling system containing a multi-layer perceptron model and the numerical weather prediction model HIRLAM for the forecasting of urban airborne pollutant concentrations. *Atmos. Environ., 39,* 6524–6536.

Rantamäki, M., Pohjola, M.A., Tisler, P., Bremer, P., Kukkonen, J. and Karppinen, A. (2005a) Evaluation of two versions of the HIRLAM numerical weather prediction models during an air pollution episode in Southern Finland. *Atmos. Environ., 39,* 2775-2786.

Rantamäki, M., Gregow, E., Valkama, I. and Karppinen, A. (2005) Are current operative NWP-models able to provide the meteorological conditions for regulatory air quality models in Finnish episodic conditions? In: *Proceedings of the 10th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Sissi, Crete, 17-20 October, 2005*, pp. 463-467.

Rõõm, R. (2001) Nonhydrostatic adiabatic kernel for HIRLAM. Part I. Fundamentals of nonhydrostatic dynamics in pressure-related coordinates. HIRLAM Technical Report No. 48.

4. The UAQIFS for the Castellón area, Spain

Authors: José Jaime Diéguez, Jose Luis Palau, Gorka Pérez-Landa, Ariel Stein and Millán Millán

Fundacion CEAM

4.1 Technical description of the new UAQIFS

Previozono is performed by CEAM for the DGCA (Regional Air Quality Service) of the regional government which is the organism in charge of the regional air quality management, and is in fact our end-user. The old UAQIFS was described in deliverable 8.1 (Guidelines of output from UAQIFSs as specified by end-users, chapter 4) as result of the tasks performed in Workpackage 8 (within the FUMAPEX project).

The new UAQIFS, developed within the FUMAPEX project, is based on the old system "Previozono" which was the program for ozone forecasting and public information in the Valencia Region during the last five years. The improvement developed within the FUMAPEX project, consists of developing a new module to complement the old "Previozono" system[1] (Figure 4.1). This new module consists of two coupled numerical models: a photochemical model (CAMx) and a meso-meteorological model (RAMS). Meteorological fields produced by the RAMS model

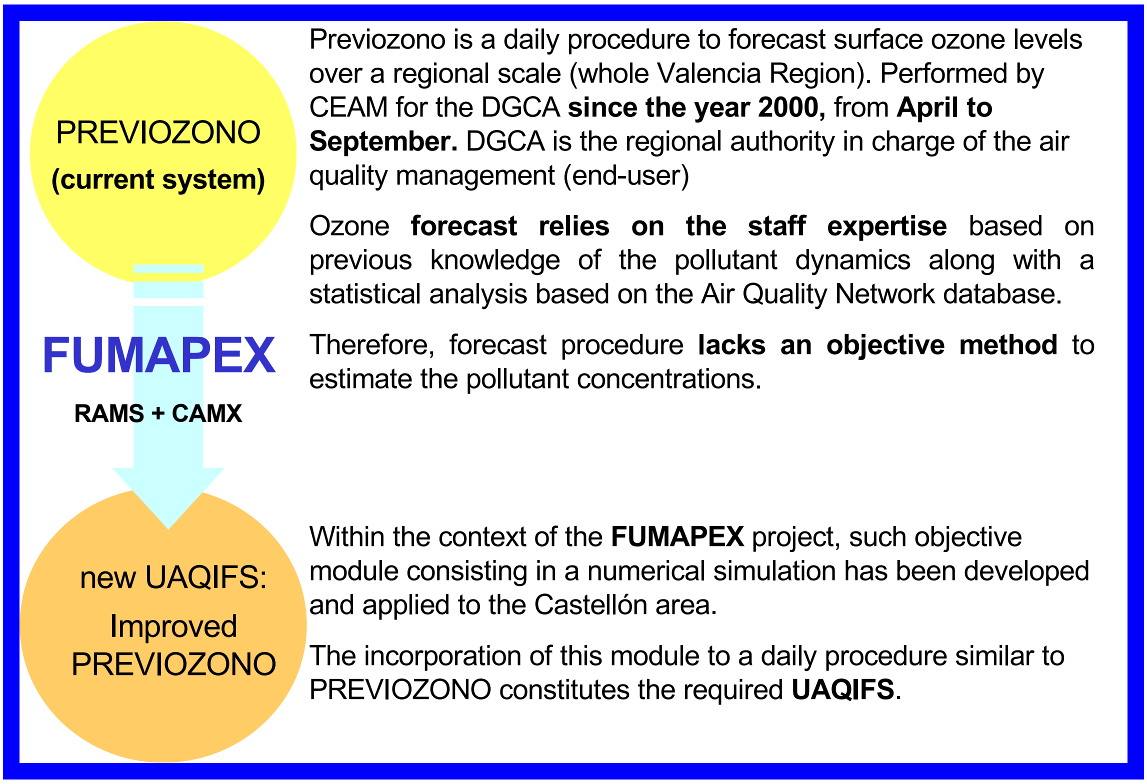


Figure 4.1: UAQIFS developed for the Castellón area as an improvement of the old forecasting procedure "previozono".

[1] "Previozono" forecast relied on the staff expertise and lacked an objective method to estimate ozone concentrations (more details report nº D8.1 of FUMAPEX project).

along with primary pollutant emissions data are coupled to the CAMx photochemical simulation.

The photochemical model is run for a coarse grid covering the Iberian Peninsula and a finer grid including the forecast target area. Emission inventories based on EMEP data for the Iberian Peninsula serve as a basis for the photochemical model to calculate the pollutant background concentrations. These pollutant levels are in turn used as boundary conditions for the finer grid. Furthermore, detailed emission inventory data and nested meteorological fields from RAMS at the fine grid are used to estimate the ozone levels for the Castellón area. The model output is in turn interpreted by the expert staff as an intermediate step for the formulation of the daily forecast.

4.1.1 Meteorological model

The simulations of version 4.3.0 of the Regional Atmospheric Modeling System (RAMS - Pielke et al., 1992) were performed in prognostic mode. The turbulence parameterisation used is a TKE level 2.5 scheme (Mellor and Yamada, 1982). Surface layer fluxes are obtained with the Louis (1979) scheme. The short-wave and long-wave radiation parameterisation applied is a full-column two-stream single-band radiation scheme (Chen and Cotton, 1983). The LEAF-2 soil-vegetation model calculates the sensible, latent and soil heat fluxes exchanged with the atmosphere, using prognostic equations for soil moisture and temperature (Walko et al., 2000).

Each simulation is initialised at 12 GMT hours each day according to the configuration options presented in Table 4.1. The domains configuration, consist of four nested domains centred over the area of interest. Thus, the inner domain covers the Castellón region with a grid length of 1.5 km, enabling to representation of the main orographic features (see Figure 4.2).

Table 4.1 Configuration of the meso-scale meteorological model RAMS.

Horizontal grid-type	Arakawa-C staggered grid
Vertical coord. system	Terrain-following height coordinate system (σ-surfaces)
Initialisation of Boundary Conditions	ERA Reanalysis database (ECMWF)
Domain Configuration	121x101, 182x155, 146x156, 146x155 cells
Grid Length	40.5, 13.5, 4.5 and 1.5 km
Vertical Configuration	45 levels. Thickness of 1st level: 30 m
SST	NOAA image
Land Use Database	CORINE (Iberian Pen.)+ PELCOM (Eur.)+ USGS (Rest) at 30''
Soil Texture	Homogeneous initialisation: Clay Loam
Soil Moisture	Homogeneous initialisation: 0.21 cm3/cm3
Surface fluxes	Louis similarity theory
PBL parameterisation	Mellor and Yamada level 2.5
Radiation package	Chen and Cotton
Cumulus parameteris.	Kuo modified, applied only in domains 1 and 2.
Land Surface Model	LEAF-2

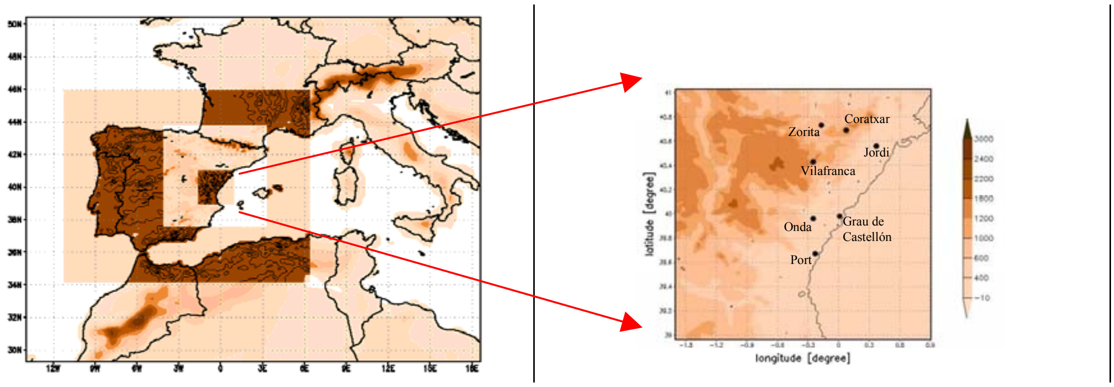


Figure 4.2: RAMS meteorological model domains. Configuration consists of four nested domains centred over the Castellón area.

4.1.2 Air quality model

The **C**omprehensive **A**ir quality **M**odel with e**x**tensions (CAMx) is a photochemical dispersion model that allows for an integrated "one-atmosphere" assessment of gaseous and particulate air pollution over many scales ranging from urban to super-regional (Environ, 2003). This system constitutes a state-of-the-art tool for regional-scale simulations of photochemical smog, visibility and fine particulates. CAMx is a three-dimensional Eulerian chemical transport model that accounts for horizontal and vertical advection, eddy diffusion, gas-phase chemical transformations, emissions, cloud mixing, aqueous-phase chemical reactions, and aerosol processes. This model solves the pollutant continuity equation for each chemical species on a system of nested three-dimensional grids.

CAMx version 4.03 has been implemented using the area preserving flux-form advection solver of Bott (1989) and K-theory parameterisation for vertical diffusion based on the Mellor and Yamada (1982) and Helfand and Labraga (1988) algorithms. The meteorological data used for this simulation have been obtained as output fields from the Regional Atmospheric Modelling System (RAMS) (Pielke, 1992). A detailed description of the equations and algorithms of each component of CAMx are given in Environ (2003). Following is a description of the horizontal and vertical resolution, chemical mechanism, meteorological pre-processor, and emissions that have been implemented to simulate ozone formation in the area of Castellón in the Western Mediterranean basin.

Two horizontal nests using a Lambert Conformal geographical projection have been defined for the simulation (Figure 4.3). The two-way photochemical nesting capability of CAMx has been used for this simulation. This feature allows CAMx to be run with coarse grid spacing over a wide regional domain in which high spatial resolution is not particularly needed, while within the same run, applying fine grid nests in areas where high resolution is needed. For this application, the first nest covers the entire Iberian Peninsula with a resolution of 12 km and a dimension of 108x92 cells. The second nested domain has a 4-km horizontal resolution, 38x83 cells, and encompasses the Valencian Community (VC). The vertical resolution of both grids is 30 sigma-p layers. These layers directly correspond to the lowest 30 layers of the RAMS simulation.

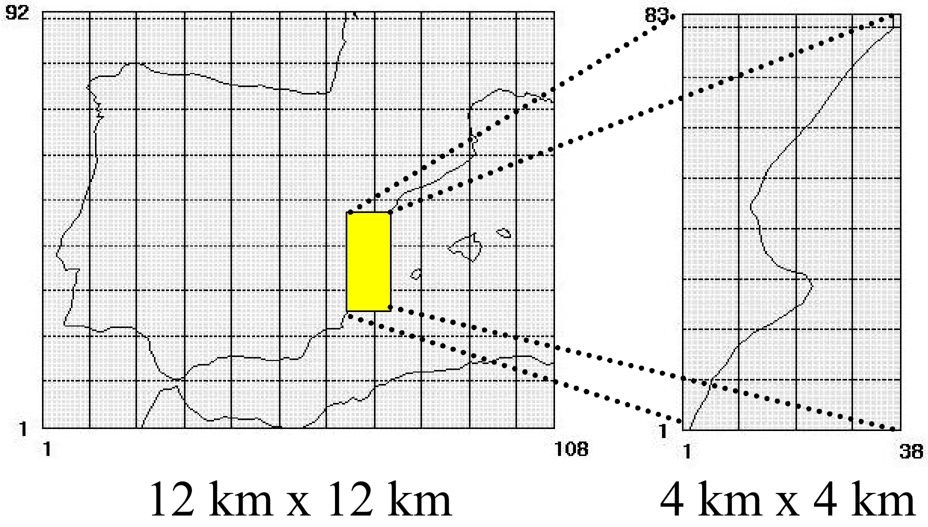


Figure 4.3: Description of photochemical model domains.

Table 4.2: Configuration of the photochemical model CAMx.

Horizontal grid-type	Lambert Conformal geographical projection
Vertical coord. System	Terrain-following height coordinate system (σ-surfaces)
Domain Configuration	108x92, 38x38 cells
Nesting	2-way
Grid Length	12 and 4 km
Vertical Configuration	30 levels. Thickness of 1st level: 30 m
Chemical mechanism	Carbon Bond IV
Meteorology preprocessor	RAMSCAMx
Vertical diffusion	K-theory parameterisation
Emissions Domain 1	EMEP
Emissions Domain 2	Local estimation

4.2 Description of the forecasting procedure as performed for/by the end-users

Flow chart (Figure 4.4) shows the step-by-step daily procedure of the new UAQIFS for the Castellón area. Dashed square indicates the old system "Previozono"; at the top right the new modelisation phase added to the former previozono procedure.

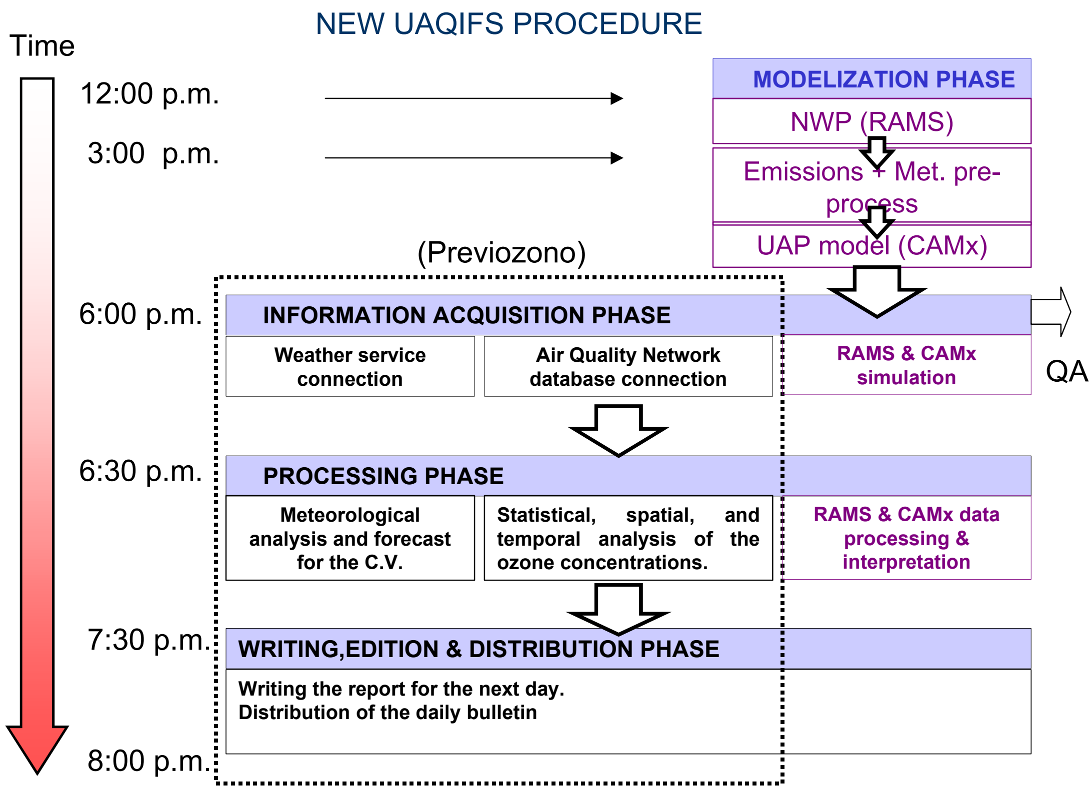


Figure 4.4: Flow chart showing the step-by-step daily procedure of the new UAQIFS for the Castellón area.

The new module added to the proviozono procedure provides new useful information available for the expert in charge of the forecast (meteorological and photochemical simulations for the different domains).

Thus, the new UAQIFS is structure in four phases or steps: (1) The modelisation phase, (2) the information acquisition phase, (3) the processing phase, and (4) the edition and distribution phase. Time arrow at left of the flow chart (Figure 4.4) represents the timing. End-user establishes as a requirement the hour when the forecasting report for the next 24 hours must be released (20:00 h.).

The first phase ("modelisation phase") begins at 12:00 p.m., and it includes meteorological, emissions and photochemical simulations.

Meteorological simulation is used as input for the photochemical model. Furthermore, simulated meteorological fields are analysed by the expert during the processing phase. At 3:00 p.m., the photochemical simulation begins. Simulated ozone concentrations are presented following a colour scale corresponding to the **Air Quality Index** (AQI) defined for ozone public information, Figure 4.5. Use of an AQI based on legal reference values laid down in the directive 2002/3/EC is a requirement of the regional authorities.

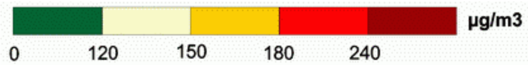


Figure 4.5: Air Quality Index (AQI) and colours defined by the end-user.

At 6:00 p.m. both numerical simulations (meteorological and photochemical) are available and the following phase begins.

During the second phase (information acquisition phase), the expert collects and digests the information processed during the first phase. Besides, expert gathers (a) data from the air quality network registered during the last seven days (from 6:00 p.m. on the forecasting day), and (b) meteorological charts from three different operational meteorological models (HIRLAM, from INM, Spain; GFS & MASS, from METEOSIM, Spain; and BRACKNELL, from Wetterzentrale, Germany). This last information is collected to allow an "operational" comparison of the meteorological forecast performed by RAMS and by those four models. Meteorological charts are found through the CEAMET web page (http://www.ceam.es/ceamet/).

Data from the air quality network, analysed by the expert, include both meteorology and ozone concentrations at 10 meter above the ground. Measurements are recorded each 10 minutes

The third phase (processing phase) begins at 6:30 p.m. when all the abovementioned information is available and it corresponds to the beginning of the expert's forecast. During the forecasting procedure, (a) analysis of the meteorological and photochemical simulations, and (b) validation and analysis of the experimental data available, are the previous steps for performing a final forecast bulletin for the following 24 hours.

Finally, at 7:30 p.m., during the edition and distribution phase, an ozone daily report is uploaded to the web site http://www.cth.gva.es/cidam/emedio/atmosfera/index.htm. Results (analysed for the last 24-hours period and forecast for the next 24 hours) are presented attending to the **zonification** map established on the Castellón region as a direct consequence of the Directive 1996/62/EC (Figure 4.6).

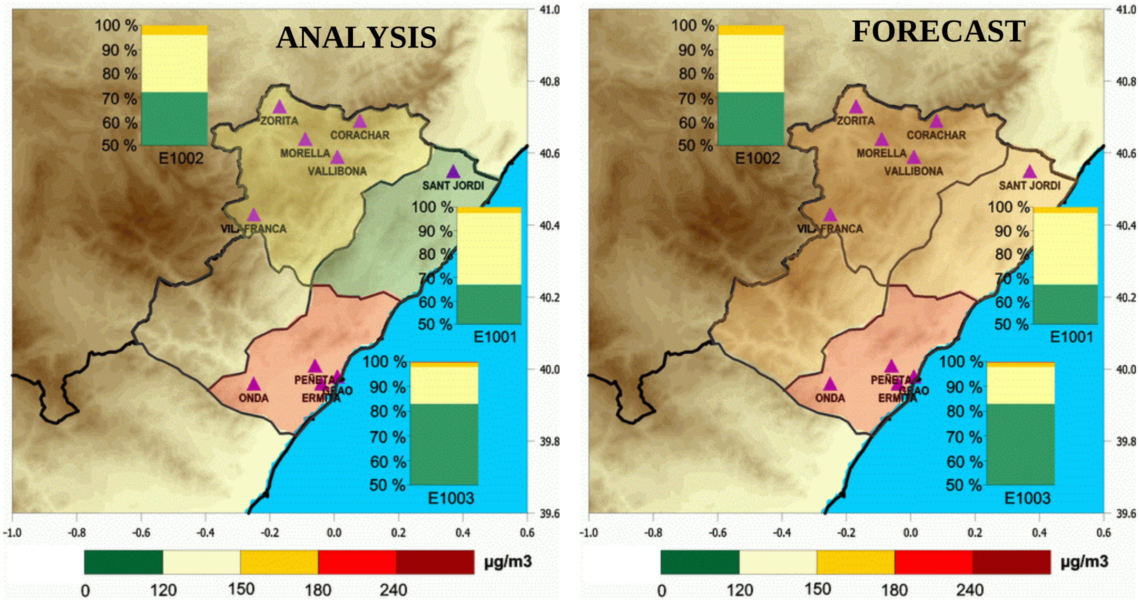


Figure 4.6: Forecast of ozone concentrations on the zonification map. This forecast bulletin is uploaded each day on the web site. Colour scale corresponds to the AQI.

Ozone daily report includes (Figure 4.7): (a) an analysis of the ozone concentrations during the last 24 hours (reporting the hourly maximum and 8-hours maximum of the concentrations during the present day, because forecast is uploaded at 8:00 p.m.); (b) an analysis of the current situation regarding meteorology and ozone levels; (c) a meteorological forecast chart for the next day; (d) a forecast for the next day regarding meteorology and ozone concentrations on the different geographical areas within the Castellón region (zonification); (e) a brief summary of the ozone forecast for the following 24 hours; and (f) some recommendations to the population (if an ozone exceedance is forecasted); (g) AQI for the different zones (zonification) within the Castellón region; and (h) the statistical significance of both the forecasted ozone concentrations for the next 24 hours and the last 24-hours ozone concentration levels, Figure 4.6, to illustrate (from a statistical point of view) if the present (and forecasted) ozone concentrations within each zone are "usual" levels or not (to prevent unnecessary social alarms).

Final note: This new UAQIFS and the updated ozone daily report will be operational in the near future on the aforementioned web site. At present, the old previozono report is available on the web page:

http://www.cth.gva.es/cidam/emedio/atmosfera/index.htm.

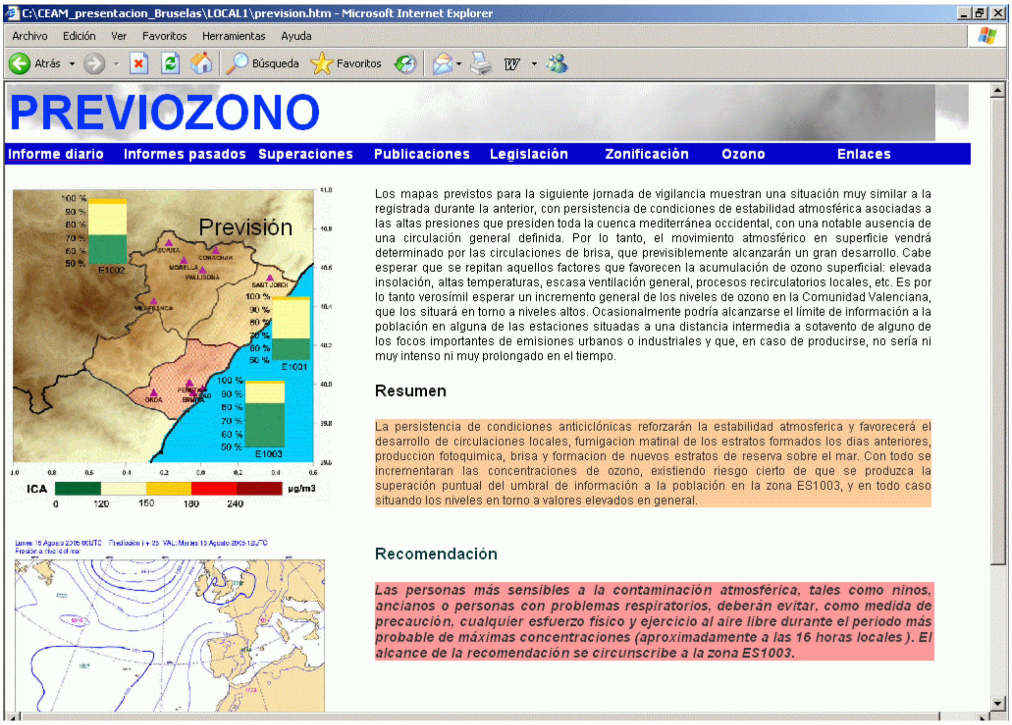


Figure 4.7: Forecast bulletin uploaded each day on the web site.

4.3 References

Bott, A. (1989) A Positive Definite Advection Scheme Obtained by Nonlinear Renormalization of the Advective Fluxes. *Mon. Wea. Rev., 117*, 1006-1015.

Chen, C. and Cotton, W.R. (1983) A one-dimensional simulation of the stratocumulus-capped mixed layer. *Bound. Layer Met., 25,* 289-321.

Environ (2003) User’s guide. Comprehensive Air Quality Model with Extensions (CAMx) Version 4.00. Novato, California, ENVIRON International Corporation.

Environmental Protection Agency (1994) Guidance on Urban Airshed Model (UAM) Reporting Requirments for Attainment Demonstration. Research Triangle Park, W.C., EPA (EPA-454/R-93-056).

Finardi, S. (Ed), Baklanov, A., Batchvarova, E., Clappier, A., Fay, B., Joffre, S., Karppinen, A., Kitwiroon, N., Slørdal, L.H., Sokhi, R.S. and Stein, A. (2004) Guidelines for the construction of the interfaces from operational NWP models to different types of UAP models. Deliverable 5.1 of the EC FUMAPEX project, Milan, Italy.

Gery M.W., Whitten, G.Z., Killus, J.P. and Dodge, M.C. (1989) A photochemical kinetics mechanism for urban and regional scale computer modeling. *J. Geophys. Res.*, 94, 12925-12956.

Guenther, A.B., Hewitt, C.N., Erickson, D., Fall, R., Geron, C., Graedel, T., Harley, P.C., Klinger, L., Lerdau, M., McKay, W.A., Pierce, T., Scholes, B., Steinbrecher, R., Tallamraju, R., Taylor, J. and Zimmerman, P.R. (1995) A global model of natural volatile organic compound emissions. *J. Geophys. Res., 100,* 8873-8892.

Guenther, A.B., Zimmerman, P.R., Harley, P.C., Monson, R.K. and Fall, R. (1993) Isoprene and monoterpene emission rate variability: Model evaluations and sensitivity analyses. *J. Geophys. Res.*, *98*, 12609-12617.

Helfand, H.M. and Labraga, J.C. (1988) Design of a Nonsingular Level 2.5 Second-Order Closure Model for the Prediction of Atmospheric Turbulence. *J. Atmos. Sci., 45*, 113-132.

Louis, J.F. (1979) A parametric model of vertical eddy fluxes in the atmosphere. *Bound. Layer Met., 17*, 187-202.

Martín, F., Palacios, M., Cabal, H., Gómez, M., Domínguez, J., Sánchez, I., Salazar, M. J. and Salvador, R. (1998) Anthropogenic emission inventory around the city of Burriana (Valencia) Final Report CIEMAT no 11320-96-11-F1PE-ISP.

Mellor, G.L. and Yamada, T. (1982) Development of a Turbulence Closure Model for Geophysical Fluid Problems. *Rev. Geophys. Space Phys*., *20*, 851-875.

Mellor, G. L. and Yamada, T. (1982) Development of a turbulence closure model for geophysical fluid problems. *Rev. Geophys. Space Phys., 20*, 851-875.

Millán, M.M., Mantilla, E., Salvador, R., Carratala, A., Sanz, M.J., Alonso, L., Gangoiti, G. and Navazo, M. (2000) Ozone Cycles in the Western Mediterranean Basin: Interpretation of Monitoring Data in Complex Coastal Terrain. *J. Appl. Met., 39*, 487-508.

Millán, M.M., Salvador, R., Mantilla, E. and Kallos, G. (1997) Photooxidant dynamics in the Mediterranean basin in summer: Results from Eurpean reserarch projects, *J. Geophys. Res., 102,* 8811-8823.

Pielke, R.A., Cotton, W.R., Walko, R.L., Tremback, C.J., Lyons, W.A., Grasso, L.D., Nicholls, M.E., Moran, M.D., Wesley, D.A., Lee, T.J. and Copeland, J.H. (1992) A Comprehensive Meteorological Modeling System – RAMS. *Meteorol. Atmos. Phys., 49,* 69-91.

Sun, P., Chock, D.P. and Winkler, S.L. (1994) An Implicit-Explicit Hybrid Solver for a Systemof Stiff Kinetic Equations. *J. Comp. Phys., 115,* 515-523.

Walko, R. L., Band, L. E., Baron, J., Kittel, T. G. F., Lammers, R., Lee, T. J., Ojima, D., Pielke Sr., R. A., Taylor, C., Tague, C., Tremback, C. J. and Vidale, P. J. (2000) Coupled atmospheric-biophysics-hydrology models for environmental modeling. *J. Appl. Met., 39*, 931-944.

5. The UAQIFS for the city of Turin, Italy

Authors: Sandro Finardi [(1)], Roberta De Maria [(2)], Francesco Lollobrigida [(2)], Giuseppe Calori [(1)], Alessio Dallura [(1)], Monica Clemente [(2)], Cinzia Cascone [(2)]

[(1)] ARIANET Consulting
[(2)] ARPAP - Environmental Protection Agency of Piedmont

5.1 Technical description of the new UAQIFS

The UAQIFS developed for the city of Torino within the FUMAPEX Project is based on a modelling system whose main constituents are the meteorological model RAMS and the ARIANET's chemistry transport model FARM. The system is intended to forecast pollutants such as suspended particulate matter PM_{10}, nitrogen dioxide, ozone, carbon monoxide, sulphur dioxide and benzene, in order to give to the local administrations and the population the information required by the present Italian legislation. In the meanwhile, a "lighter" version of this prototype system is being made operational at ARPAP, providing air quality forecasts for the two main cities of the Piemonte Region, Torino and Novara. This latter system directly uses meteorological forecasts from the Italian version of the Lokal Modell (LAMI) without performing prognostic meteorological downscaling.

The air quality forecasts will be issued every day to the population by local administrators.

Both the above UAQIFSs previously cited are described in the following, outlining – where relevant - the differences between the two systems.

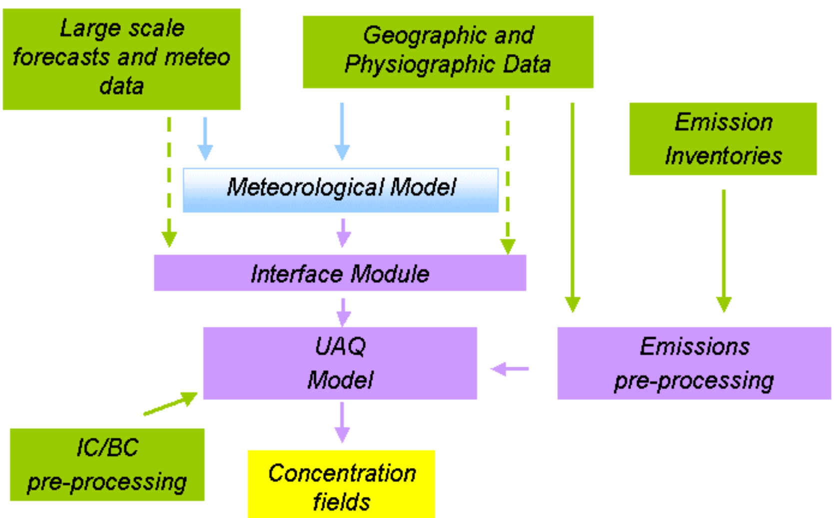


Figure 5.1: Torino's UAQIFS architecture. The prototype system (developed in the FUMAPEX Project) is comprehensive of the meteorological model; in the operational system meteorological forecasts and geographycal/-physiographic data are directly used by the interface module (following green dashed lines).

In order to better clarify the systems' architecture, Figure 5.1 shows the main components of both the prototype and the operational UAQIFS: an emission pre-processing system, downscaled meteorological forecasts (by means of either the prognostic non-hydrostatic meteorological model or the diagnostic space and time interpolation of the forecasted meteorological fields), an IC/BC pre-processing system, the Eulerian atmospheric chemistry model and an interface module, connecting meteorological and air quality models.

The forecasting systems have been built and tested in a PC/LINUX environment. All the models and interface modules are written in FORTRAN90, while the operational procedure is written in tcl/tk scripting language. The only off-line module was originally the emissions processor, e.g. for the FUMAPEX test case simulations the emissions have been taken from a data base prepared in advance. The integration of emission processing in the operational UAQIFS is planned for November 2005, to possibly allow future connection of emissions with forecasted meteorological fields.

5.1.1 Meteorological models

5.1.1.1 Prototype UAQIFS

The meteorological forecasts in the prototype system for the Torino city are provided by the prognostic non-hydrostatic meteorological model RAMS, (Pielke et al., 1992; Walko and Tremback, 2002; Cotton et al., 2003), which downscales ECMWF forecasts available at ARPAP with 0.5° degrees space resolution and 6 hours time resolution. In the configuration employed for test cases the model runs to give 72h weather forecasts.

RAMS uses horizontal rotated polar stereographic coordinate system and vertical sigma z coordinates, and implements *two-way nesting* technique.

Table 5.1: RAMS computational domain features.

Computational grid	**1**	**2**	**3**
Horizontal resolution	16 km	4 km	1 km
Grid points (nx*ny*nz)	75x75x35	56x72x35	52x52x35
Δt	30 sec	15 sec	5 sec
Minimum Δz	50 m	50 m	50 m
Domain top	23 km	23 km	23 km

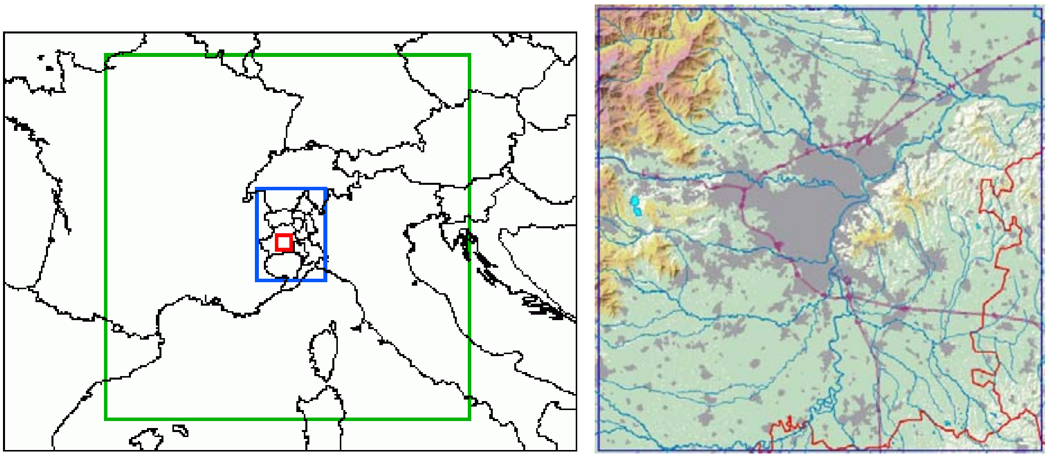


Figure 5.2: Torino prototype UAQIFS nested computational domains (left). The major road network and urbanised area are depicted on the metropolitan area domain (right).

In order to take into account the geographic and meteorological features of the Torino area, located at the western limit of the Po River valley and clustered between the Alps and a range of hills, RAMS is used to downscale the weather forecasts to a scale and resolution suitable to describe local topography, surface cover and urban area effects on the atmospheric circulation. This can be obtained through the application of a 3 level grid nesting, with horizontal resolution of 16, 4 and 1 km. The model configuration is resumed in Table 5.1, while the three computational domains are sketched in Figure 5.2. Topographic data used by the meteorological model have been derived from the U.S. Geological Survey (USGS) global data sets called GTOPO30, having a space resolution of 30''. The land use data have been obtained from the European dataset called CORINE land cover, having a resolution of 250 m. Figure 5.3 and Figure 5.4 respectively shows topography and land use of the Torino urban area.

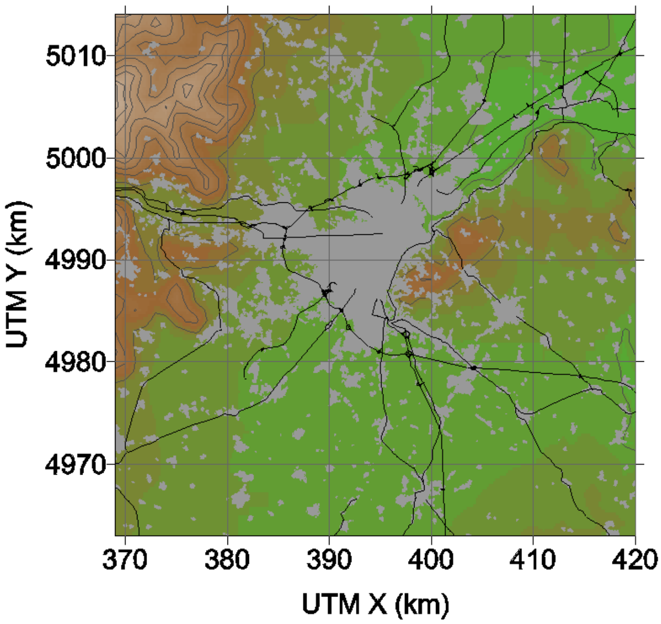


Figure 5.3: Topography of the RAMS inner domain covering the Torino urban area. Urbanised areas are indicated in grey colour, black lines correspond to major extra urban road network.

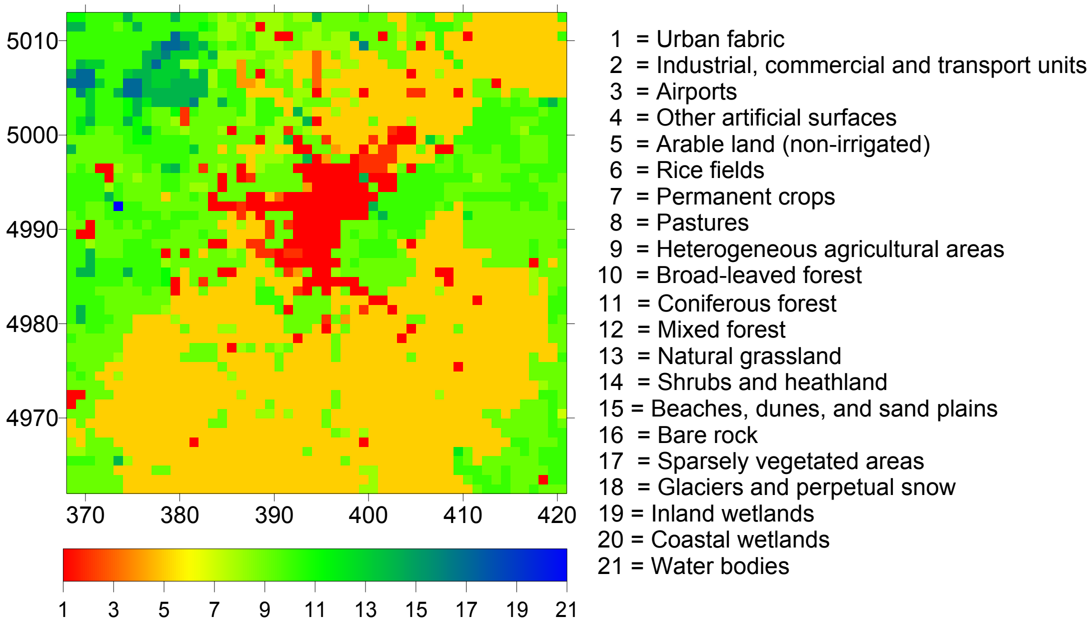


Figure 5.4: Land use of the RAMS inner domain covering the Turin urban area. Information elaborated from the CORINE land cover database.

5.1.1.2 Pre-operational UAQIFS

Due to limited computational power availability, the meteorological forecasts in the pre-operational UAQIFS implemented at ARPAP are not obtained by prognostic downscaling but are provided by the non-hydrostatic prognostic model LAMI (Italian version of DWD Lokal Modell), running at ARPA SMR and available on a daily basis at ARPAP as member of the European consortium COSMO (http://www.cosmo-model.org/cosmoPublic).

LAMI's computational domain covers Italy and the central Mediterranean area (1900 x 1600 km), with horizontal mesh size of 0.0625° (~7 km); it uses rotated spherical horizontal coordinates and terrain-following hybrid sigma vertical coordinates with 35 layers covering the whole atmosphere. The 3D forecasted meteorological fields are available at ARPAP with a time resolution of 3 hours, while surface fields are available with hourly frequency.

The operational procedure running the UAQIFS provides extraction of LAMI's meteorological data over three nested domains; the external one (covering the Piemonte Region with an horizontal grid size of 4 x 4 km) and the one centred on the Torino urban area (1 km horizontal resolution) correspond to grid 2 and 3 of the prototype system applied in the FUMAPEX project. Besides, another high-resolution domain (1 km horizontal resolution) is located over the Novara area, at the neighbourhood of the Lombardia region. *Table 5.2* resumes the three domains major features. Their location and geographic characteristics are depicted in Figure 5.5.

Table 5.2: Operational system's computational domain features.

Computational grid	**1**	**2**	**3**
Horizontal resolution	4 km	1 km	1 km
Grid points (nx*ny)	56x72	52x52	45x69

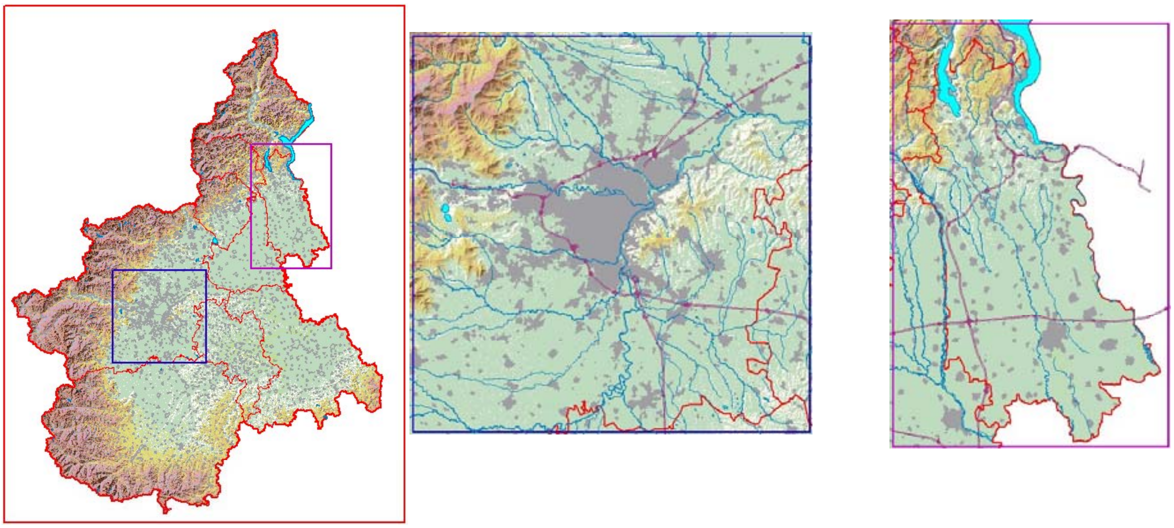


Figure 5.5: Operational system computational domains: the regional domain, with 4 km horizontal resolution and the two nested subdomains (left), respectively the Torino urban area domain (centre) and the Novara urban area domain (right).

Even if the operational version of LAMI provides 78h meteorological forecasts, the operational modelling system is presently configured to supply 48h air quality forecasts.

5.1.2 The meteorological interface module

The meteorological interface implemented in the modelling system is made by the GAP/SURF*PRO* modules (Calori et al., 2005; Finardi et al., 2005) used to connect meteorological models with the chemical transport model FARM.

GAP (*Grid AdaPtor*) is a grid interpolation tool, which is responsible for the vertical and horizontal interpolation of 2D and 3D atmospheric fields from any meteorological model source grid to the FARM's target grids (horizontal UTM32 projections and vertical terrain following coordinates). The input grid cartographic projection system is assumed to be unknown and grid points are identified by their latitude, longitude and height above surface level. The meteorological fields, which are transferred by GAP to SURFPRO, are the following:

- 3D: horizontal wind components, temperature, humidity;
- 2D: precipitation, cloud cover, surface pressure.

The vertical wind component w is recalculated from the gridded horizontal wind field applying the continuity equation to obtain a mass consistent wind field.

The calculation of turbulence scaling parameters in the Torino UAQIFS is carried out inside the meteorological processor SURF*PRO* (SURFace atmosphere interface *PRO*cessor, Silibello 2002), which is based on the surface energy budget method and Monin-Obukhov similarity theory (Van Ulden and Holtslag, 1985).

Starting from topography (obtained from the meteorological model through GAP), land-use (CORINE Land cover data, 250 m resolution) and gridded average meteorological variables (e.g. wind, temperature and humidity), SURFPRO provides 2D gridded fields of turbulence scaling parameters (i.e. roughness length, sensible heat flux, friction velocity, Monin-Obukhov length, mixing height and convective velocity scale) as well as 3D fields of horizontal and vertical diffusivities and 2D fields of dry and wet deposition velocities for the set of chemical species needed by FARM. When computing radiation and energy budget, the processor takes into account water bodies, terrain slopes and related solar shading effects.

During the FUMAPEX Project some new parameterisations - aimed at improving the description of the urban meteorology and dispersion - have been introduced inside an upgraded version of the interface module called SURF*PRO*3 (Finardi et al., 2005):

1. Diagnostic schemes to calculate the mixing height based on Richardson number evaluation;
2. Prognostic scheme to calculate the mixing height, keeping into account advection effects like IBL growth, integrating the formulation proposed by Gryning and Batchvarova (1996) and Zilitinkevich and Baklanov, (2002);
3. Urban heat storage calculation, implementing the Objective Hysteresis Model proposed by Grimmond and Oke (1999, 2000 and 2002).

The prototype UAQIFS with the improved interface module has been tested on a winter episode, demonstrating how improvements of the urban layer modelling and consequent enhancement of the description of dispersion conditions can be obtained introducing urban parameterisations in the interface module.

5.1.2.1 Prototype UAQIFS

The meteorological interface made by the GAP/SURF*PRO* modules is used to connect the meteorological model RAMS with the chemical transport model FARM. RAMS provides meteorological fields at the target resolutions described in Table 5.1 on its horizontal rotated polar-stereographic and vertical sigma z coordinates. The consistency of meteorological fields over the 3 nested grids is guaranteed by the two-way nesting computational technique. These data are interpolated by gap to the FARM's target grid (horizontal UTM32 and vertical terrain following). Near the ground and in the central part of the computational domain (not far from the projection pole) the modification imposed on the input fields demonstrated to be very limited.

5.1.2.2 Pre-operational UAQIFS

In addition to the pre-processing meteorological module GAP/SURF*PRO* the pre-operational Torino UAQIFS implements a tool to convert LAMI fields from GRIB to netCDF format, and the module TINT to interpolate data in time from the LAMI temporal resolution of 3 hours to 1 hour resolution for each computational domain. The time interpolated fields are then given as input to the GAP/SURF*PRO* modules, that interpolates meteorological fields from the LAMI grid system to the target grids described in *Table 5.2* and Figure 5.5 and prepares the input data necessary to the transport and dispersion model.

5.1.3 The emission pre-processing system, Emission Manager

Data from different emission inventories, as shown in Figure 5.6, have been integrated to set up the database needed by the Emission Manager module to prepare the emissive input needed to perform atmospheric dispersion and chemistry simulations:

- The European scale EMEP inventory, outside Italy;
- The national Italian inventory CORINAIR, at provincial resolution;
- The high-resolution inventory of Piemonte and Lombardia Region, with municipality detail.

Two types of sources are presently considered in the Torino UAQIFS systems: the major point sources located inside the region (several hundreds) and area sources, including all other emissions scattered on the territory.

The pre-processing system Emission Manager allows the estimation of hourly emission rates by applying to the input database the following procedures, as resumed in Figure 5.7:

- Space disaggregation, taking into account thematic layers with different level of information according to the resolution of the input database (e.g. CORINE land use cover, built-up areas and road networks from regional cartography)
- NMVOC (non-methane hydrocarbon) speciation, related to point, line and area sources, by means of speciation profiles specific for different emissive activity
- Activity-specific modulation patterns, to perform time disaggregation.

In order to better represent the time activity modulations, particularly as regards traffic related emissions (one of the most important sources in the Torino target domain), traffic data from local authorities have been collected and elaborated with the aim of reproducing more accurately local emission patterns. Figure 5.8 illustrates the estimated hourly CO emission fields, reconstructed on the three simulation domain in the Torino prototype UAQIFS at 8 UTC of a working day.

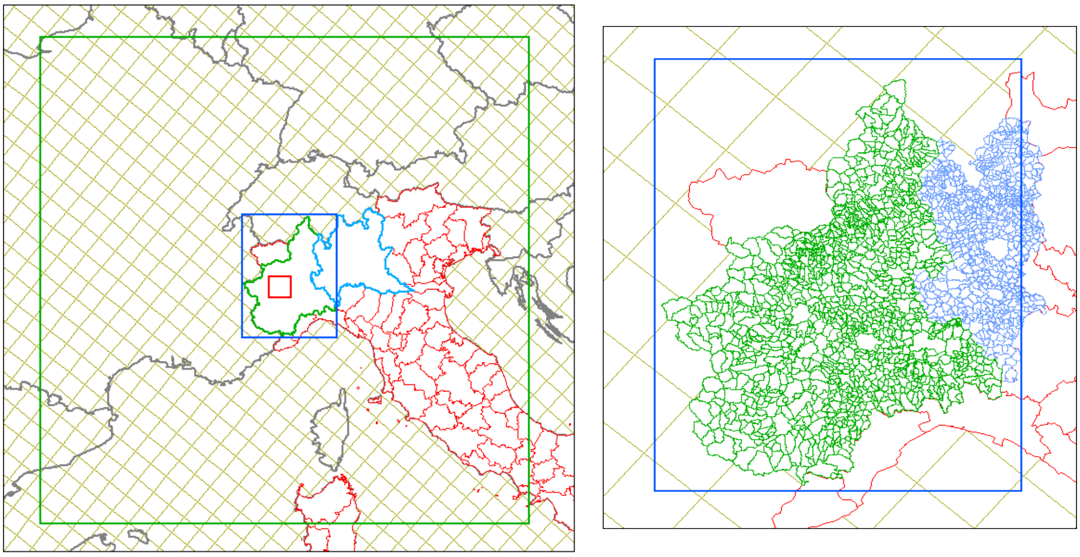


Figure 5.6: Detail comparison for the database emission inventories used to estimate hourly emissions in the Torino UAQIFS: EMEP, Italian, Piemonte and Lombardia Region inventories in the external domain (left) and in the regional one (enlarged, right).

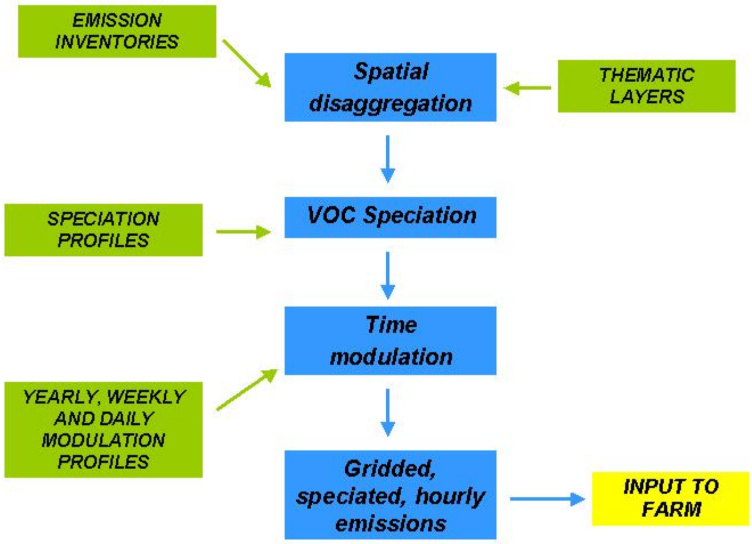


Figure 5.7: Emission Manager flow chart: the pre-processor performs firstly a spatial disaggregation, then applies the VOC speciation and finally the time modulation in order to obtain gridded, speciated and hourly emissions.

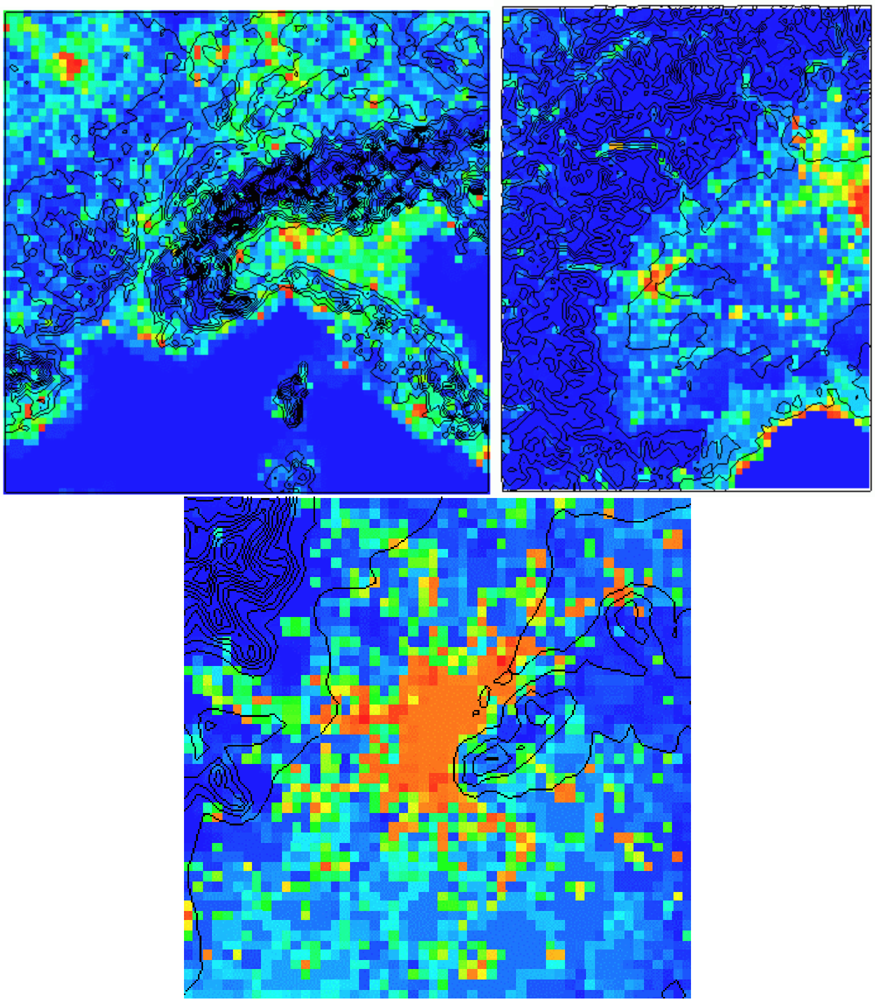


Figure 5.8: CO diffuse emission hourly fields on the three simulation domains in the Torino prototype UAQIFS.

5.1.4 The initial and boundary conditions

In the Torino prototype UAQIFS the boundary conditions for the air quality model have been obtained by EMEP simulation fields, while initial concentration fields have been reconstructed by objective analysis of EMEP background fields and local observations over Piemonte Region.

In the pre-operational system, boundary conditions are supplied by the continental prognostic runs of the Chemical Transport Model CHIMERE (PREV'AIR service, daily supplied by INERIS and available at ARPAP) (Bessagnet et al., 2004; http://prevair.ineris.fr). As regards initial conditions, the use of the Regional air quality monitoring network data is foreseen in order to adjust the previous day forecasted concentration fields.

5.1.5 The chemistry air quality model, FARM

FARM (Flexible Air quality Regional Model) is a three-dimensional Eulerian model that accounts for the transport, chemical conversion and deposition of atmospheric pollutants implemented inside the two Torino UAQIFS. The code has been originally derived from STEM (Centre for Global and Regional Environmental Research, Univ. of Iowa; Carmichael et al., 1986; Chang et al., 1990; Carmichael et al., 1991; Carmichael et al., 1998; Silibello et al., 2001). Major features of the model include:

- Emission of pollutants from area and point sources, with plume rise calculation and mass assignment to vertical grid cells.
- Three-dimensional transport by advection and turbulent diffusion.
- Simple or detailed cloud module.
- Transformation of chemical species by gas-phase chemistry, with flexible mechanism configuration.
- Aerosol modelling through modal approach.
- Dry removal of pollutants dependent on local meteorology and land-use.
- Wet removal through precipitation scavenging processes.
- Possibility of one- or two-way nesting with an arbitrary number of computational grids.
- Interface with a complete modelling system for multiscale air quality simulations.

The gas-phase chemical mechanism used for Torino UAQIFS is SAPRC-90 (Carter, 1990); the system procedure employs two-way nesting on the three simulation grids in the prototype system and in each of the two target domains (Torino and Novara) in the pre-operational one.

An example of NO2 concentration fields over Piemonte Region and Torino metropolitan area is given in Figure 5.9.

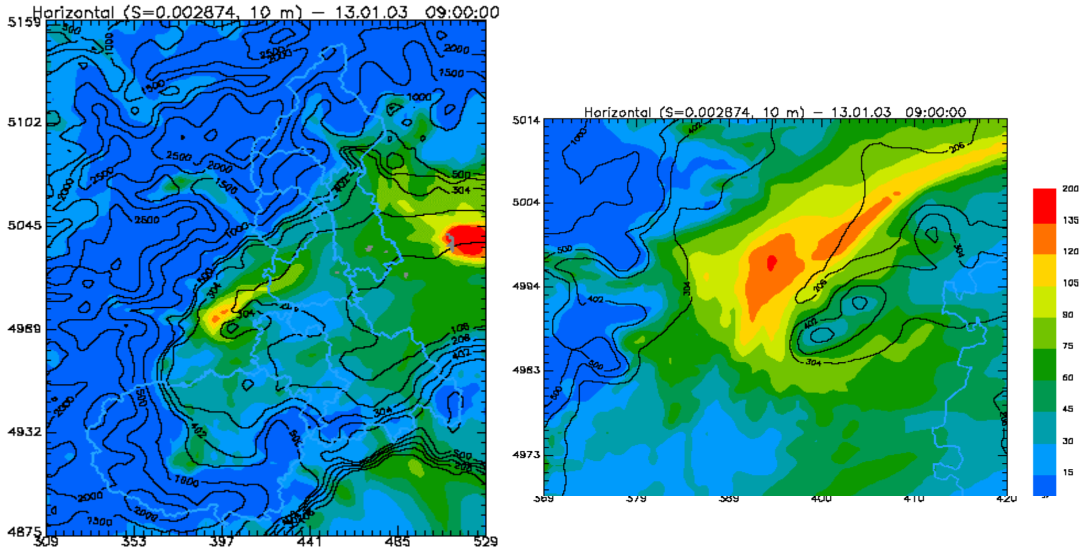


Figure 5.9: NO_2 ground level concentrations over Regione Piemonte (left) and Torino metropolitan area (right). 13/01/2003 09:00.

5.1.6 The pre-operational forecasting procedure

The pre-operational forecasting procedure, illustrated in Figure 5.10, is made by the following steps:

a. The emissive input is prepared off-line in advance. The operational emission processing implementation is planned for November 2005, and it will be scheduled at previous time to provide emissions before the start of the air quality forecast procedure.

b. The LAMI forecasts (for a 00-72 hours prognosis) are made available at ARPAP by ARPA SMR at 01:00 local solar time (LST).

c. The meteorological interface module extracts, data from LAMI output fields and performs time and space interpolation over each of the three nested domains (Piemonte Region, Torino and Novara cities); sub-sequently it produces turbulence scale parameters, dispersion coefficients and deposition velocities.

d. Air quality data from the regional monitoring network are available at 01:00 LST; they are extracted from the regional database and can be used to correct the previous day air quality forecast in order to adjust the initial conditions (not yet operational on October 24, 2005).

e. The continental run of the CHIMERE model (Prev'Air service daily supplied by INERIS) is made at ARPAP at 04:30 LST.

f. Air quality initial and boundary conditions are prepared from concentration fields extracted from CHIMERE fields and air quality data from the regional monitoring network.

g. The chemical transport model FARM starts running around 05:00 LST and produces results for the first simulated day (today) at about 09:00.

h. The first day simulation results are post-processed and Air Quality information (00 to +24 hours) are made available to the public at 09:30 LST.

i. The FARM model run finishes its second day simulation at 13:00 LST.

j. The final post-processing is performed and Air Quality information (+24 to +48 hours) are made available to the public at 13:30 LST.

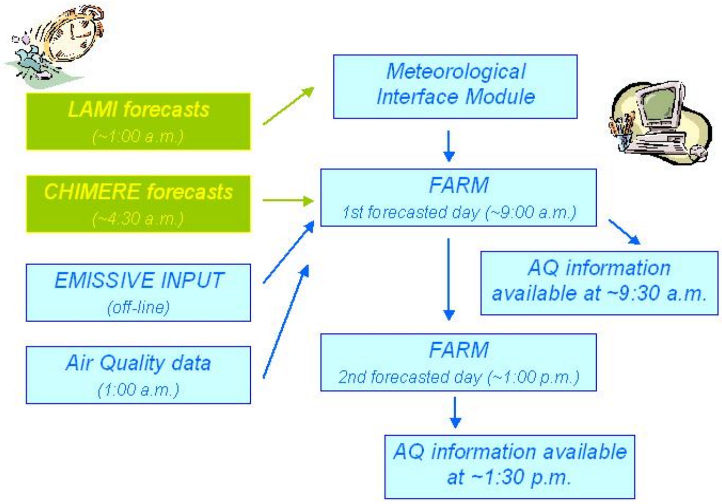


Figure 5.10: The pre-operational Torino UAQIFS forecasting procedure.

5.2 Description of the forecasting procedure as performed for/by the end-users

The forecasted pollutants include carbon monoxide, sulphur dioxide, nitrogen oxides, ozone, benzene, particulate PM_{10} and $PM_{2.5}$. At each grid point compliance with limit values foreseen by EU and Italian legislation are verified and maps with possible exceedances are eventually produced.

The air pollution concentrations are then used to calculate the forecasted AQI (Air Quality Index) on defined areas (e.g. the Torino metropolitan area), referred to +24 and +48 hours in the pre-operational system. AQI represents a conventional index aimed to:

i. Inform the population on air quality.

ii. Support the identification of the most critical environmental parameters.

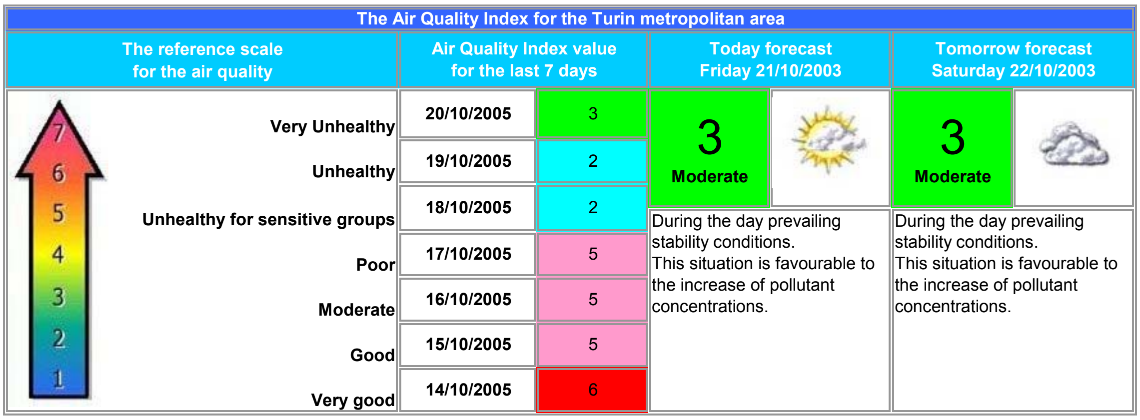
iii. Estimate the risk related to population exposure.

The partial indexes referred to the most critical pollutants affecting the Torino metropolitan area (NO_2, PM_{10} and O_3) are calculated by comparing the forecasted values to the correspondent legislation target values (200 µg/m^3 NO_2 hourly average threshold value for health protection, 50 µg/m^3 PM_{10} daily average value for health protection and 120 µg/m^3 O_3 8-hours running average limit value for health protection); finally the two higher partial indexes are averaged to obtain the AQI. *Table 5.3* shows the correspondence between the computed index value, the numeric index and colour and the air quality description.

The computed AQI is updated on the web as soon as the new forecast is available (at the end of the first day, and of the second day of the FARM simulation). The table containing the updated AQI appears as in Figure 5.11, with the indication about the previous days value and some short information regarding the meteorological forecasts for +24 and +48 hours.

Table 5.3: Air Quality Index in the metropolitan area of the Torino city: air quality description and correspondent colour and numeric index.

COMPUTED INDEX VALUE	NUMERIC INDEX	AIR QUALITY DESCRIPTION
0-50	1	*Very Good*
51-75	2	*Good*
76-100	3	*Moderate*
101-125	4	*Poor*
125-150	5	*Unhealthy for sensitive groups*
151-175	6	*Unhealthy*
>175	7	*Very Unhealthy*



The Air Quality Index for the Turin metropolitan area						
The reference scale for the air quality	Air Quality Index value for the last 7 days		Today forecast Friday 21/10/2003		Tomorrow forecast Saturday 22/10/2003	
Very Unhealthy	20/10/2005	3	3 Moderate		3 Moderate	
Unhealthy	19/10/2005	2				
Unhealthy for sensitive groups	18/10/2005	2	During the day prevailing stability conditions. This situation is favourable to the increase of pollutant concentrations.		During the day prevailing stability conditions. This situation is favourable to the increase of pollutant concentrations.	
Poor	17/10/2005	5				
Moderate	16/10/2005	5				
Good	15/10/2005	5				
Very good	14/10/2005	6				

Figure 5.11: The forecasted information about Air Quality Index for the Torino metropolitan area as provided with the pre-operational UAQIFS.

A prototype web site has been realized by ARPAP (end-user) for the information dissemination based on a WebGis System; maps are not static but the user is enabled to enlarge them and to add/remove cartographic information (e.g. major roads network, highways, rivers) in order to have a better look at the area influenced by concentrations. Moreover, cartographic details change with map resolution, as it is depicted in Figure 5.12. Information presently available on the web site are limited to air quality concentrations regarding the 13^{th} – 15^{th} January 2003 episode studied in the FUMAPEX project and they are not available to the public, as the web site is still under construction and presently password protected; a further example of the information produced is available at the following web address:

http://www.aria-net.it/FUMAPEX_demosys/

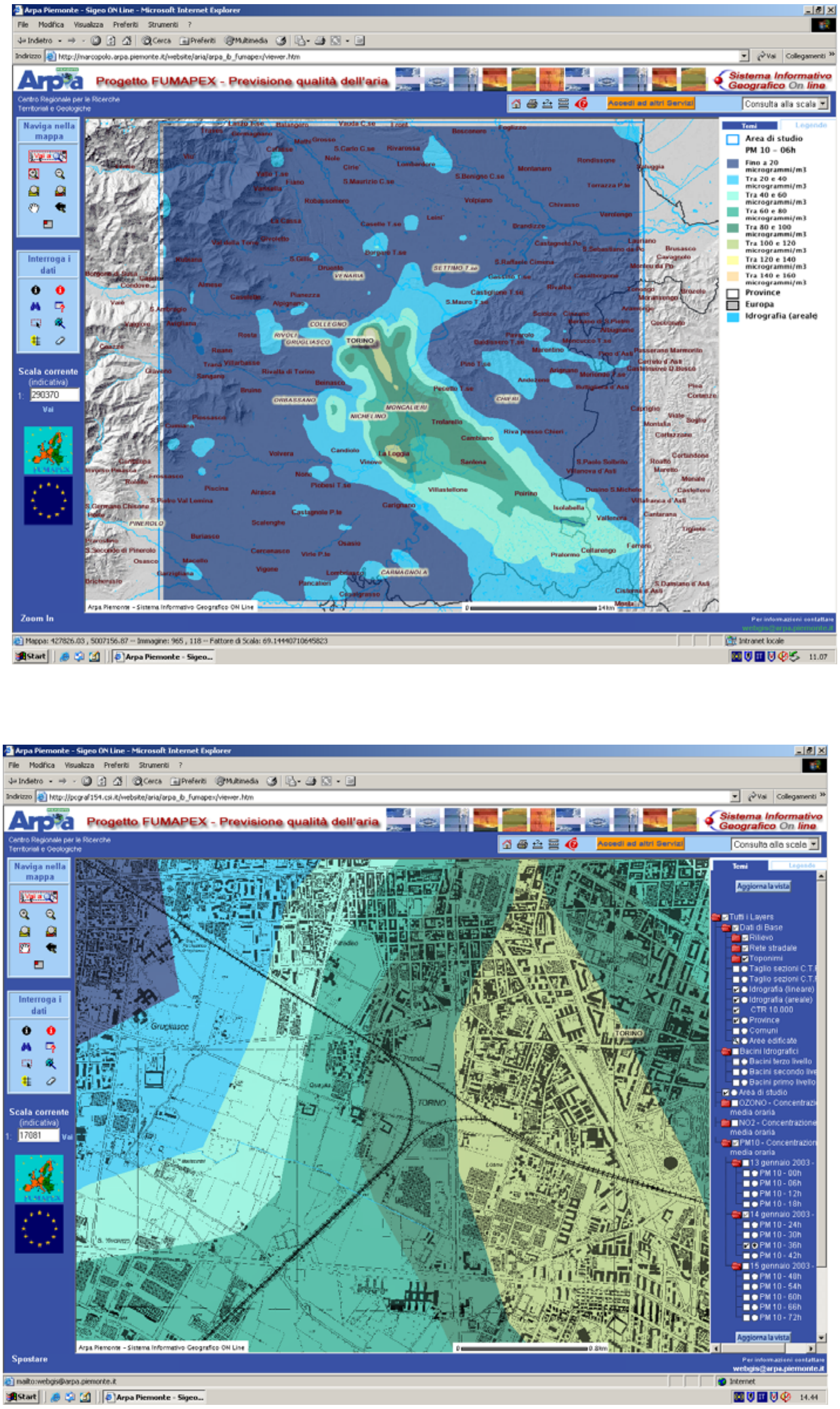


Figure 5.12: Information as it appears on the prototype web site realized by ARPAP in the FUMAPEX Project: PM10 concentrations at +36 forecasted hour in the January 2003 episode in the inner domain (upper) and enlarged in the Torino area (lower)

5.3 References

Bessagnet, B., Hodzic, A., Vautard, R., Beekmann, M., Cheinet, S., Honoré, C., Liousse, C. and Rouil, L. (2004) Aerosol Modelling with CHIMERE – Preliminary evaluation at continental scale. *Atmos. Env., 38*, 2803-2817.

Calori, G. and Silibello, C. (2004) FARM (Flexible Air quality Regional Model) Model formulation and user manual. ARIANET Report, Milan, Italy.

Carmichael, G.R., Peters, L.K. and Saylor, R.D. (1991) The STEM-II Regional Scale Acid Deposition and Photochemical Oxidant Model-I. An Overview of Model Development and Applications. *Atmos. Environ., 25A*, 2077-2090.

Carmichael, G.R., Peters, L.K. and Kitada, T. (1986) A second generation model for regional scale transport / chemistry / deposition. *Atmos. Environ., 20*, 173-188.

Carmichael, G.R., Uno, I., Phadnis, M.J., Zhang, Y. and Sunwoo, Y. (1998) Tropospheric ozone production and transport in the springtime in east Asia. *J. Geophys. Res., 103*, 10649-10671.

Chang, Y.-S., Carmichael, G.R., Ueda, H. and Kurita, H. (1990) Diagnostic evaluation of the components of the STEM-II model. *Atmos. Environ., 24A*, 2715-2731.

Cotton, W.R., Pielke, R.A., Walko, R.L., Liston, G.E., Tremback, C.J., Jiang, H., McAnelly, R.L., Harrington, J.Y., Nicholls, M.E., Carrio, G.G. and McFadden, J.P. (2003) RAMS 2001: Current Status and Future Directions. *Meteorol. Atmos. Phys., 82*, 5-29.

Finardi, S. (Ed.), Baklanov, A., Clappier, A., Fay, B., Joffre, S., Karppinen, A., Ødegård, V., Slørdal, L.H., Sofiev, M., Sokhi, R.S. and Stein A. (2005) Improved interfaces and meteorological pre-processors for urban air pollution models. Deliverable 5.2-3 of the EC FUMAPEX project. Milan, Italy.

Grimmond, C.S.B. and Oke, T.R. (1999) Heat storage in urban areas: observations and evaluation of a simple model. *J. Appl. Meteorol., 38,* 922-940.

Grimmond, C.S.B. and Oke, T.R. (2000) Heat fluxes and stability in cities. Mixing Heights and Surface Energy Budget in Urban Areas: Proc. COST 715 Expert Meeting, Antwerp, Belgium, European Commission (Rep. EUR 19447) [Available online at http://www.cordis.lu].

Grimmond, C.S.B. and Oke, T.R. (2002) Turbulent heat fluxes in urban areas: observations and a local-scale urban meteorological parametrization scheme (LUMPS). *J. Appl. Meteorol., 41,* 792-810.

Gryning, S-E. and Batchvarova, E. (1996) A model for the height of the internal boundary layer over an area with an irregular coastline. *Bound. Layer Met., 78,* 405-413.

Pielke, R.A., Cotton, W.R., Walko, R.L., Tremback, C.J., Lyons, W.A., Grasso, L.D., Nicholls, M.E., Moran, M.D., Wesley, D.A., Lee, T.J. and Copeland, J.H. (1992) A Comprehensive Meteorological Modeling System – RAMS. *Meteorol. Atmos. Phys., 49*, 69-91.

Silibello C. (2002) SURF*PRO* (SURrface-atmosphere interFace *PRO*cessor) User's guide. Report Arianet.

Silibello, C., Calori, G., Pirovano, G. and Carmichael, G.R. (2001) Development of STEM-FCM (Flexible Chemical mechanism) modelling system – Chemical mechanisms sensitivity evaluated on a photochemical episode. In: *Proceedings of APMS'01 International Conference Paris, 9-13 April 2001.*

Van Ulden, A.P. and Holtslag, A.A.M. (1985) Estimation of Atmospheric Boundary Layer parameters for Diffusion Application. *J. Appl. Meteorol., 24,* 1196-1207.

Zilitinkevich, S. and Baklanov, A. (2002) Calculation of the height of stable boundary layers in practical applications. *Bound. Layer Met., 105,* 389-409.

Walko, R.L. and Tremback, C.J., RAMS - Regional Atmospheric Modeling System Version 4.3/4.4. Introduction to RAMS 4.3/4.4. Boulder, Colorado (ATMET Report). URL: www.atmet.com/html//docs/rams/ug44-rams-intro.pdf

6. The UAQIFS and urban management and planning system for the city of Bologna, Italy

Authors: Marco Deserti[(1)], Giovanni Bonafè[(1)], Enrico Minguzzi[(1)], Michele Stortini[(1)], Suzanne Jongen[(1)], Vanes Poluzzi[(2)], Linda Passoni[(2)];

Environmental Protection Agency of Emilia – Romagna Region(ARPA):
[(1)] Hydro meteorological Service (SIM)
[(2)] Bologna Provincial Department (ARPA BO)

6.1 Technical description of the new UAQIFS

The AQ modelling system of Bologna was significantly improved during the Fumapex project. The new UAQIFS and urban management and planning system is a multi-scale CTM, which consists of a statistical pollution model, called OPPIO, and a Chemical Transport Model (CTM), called NINFA. The necessary meteorological input is provided by a numerical weather prediction model (NWP) and adapted to the desired input format by a new meteorological interface module.

The unified multi-scale CTM NINFA is since October 2005 operative, producing daily numerical fields of pollutants over the northern part of Italy.

The statistical pollution model OPPIO was changed in order to predict pollution levels for a set of points corresponding to air quality stations.

The ARPA Hydro meteorological Service (ARPA-SIM) uses the NINFA data, the statistical forecast and other information to formulate a subjective air quality forecast. ARPA communicates the air quality forecasts (PM_{10} and Ozone) each day to local authorities and informs the population through their website. During winter, local authorities decide to stop traffic if high pollution levels are predicted. All above mentioned model runs are performed at ARPA-SIM.

The need to apply a multi-scale CTM in the northern part of Italy to forecast urban air quality in Bologna and most of the other Po Valley cities, is explained by the features of the pollution episodes, often observed in this area. During a winter “Po Valley type” pollution episode, high PM_{10} pollution levels are simultaneously observed in the whole area, producing an urban background concentration that is roughly half of the peak pollution inside the city centre. During summer, ozone peaks are observed in sub-urban and rural areas. Both winter- and summer Po Valley type pollution episodes are caused by air stagnation during stable, high-pressure periods (ref: D1.2 Fumapex report). Almost all PM_{10} and ozone episodes are of “Po Valley type” and causes frequent exceedances of the reference levels.

In the Bologna UAQUIFS, the urban effect is considered by downscaling the background concentration estimated by the CTM to roadside level. This can be done in the following two ways:

- In the forecast mode, the statistical model (OPPIO), which uses data of urban stations, formulates the subjective forecasts.

- In the urban planning mode, the downscaling is realized by applying an urban dispersion model (ADMS). ADMS takes into account the additional pollution emitted by local sources and simulates the most important chemical reactions.

6.1.1 Meteorological models

The prognostic model: LAMI

ARPA-SIM, as member of the European research consortium COSMO (http://www.cosmo-model.org/), provides daily two runs of the prognostic model LAMI, the Italian version of the non-hydrostatic limited area model Lokal Modell (LM; Steppeler, 2003). LAMI was initially designed at DWD. It became operationally in Italy since June 2003.

LM, applying suitable parameterisation schemes, takes a variety of sub grid scale physical processes into account. The most important schemes in the operational version are:

- The precipitation formation scheme, with 4 prognostic variables for condensate water: cloud water and ice, precipitating water, snow (Baldauf, 2004).
- Second order turbulence closure, with prognostic TKE (level 2.5 in the notation of Mellor and Yamada, 1982); effects of sub grid scale condensation and evaporation are included, and the impact of sub grid scale thermal circulations is taken into account.
- Refined surface layer parameterisation (TKE-based surface transfer scheme), including a laminar boundary layer for the sub grid scale turbulence.
- The mass flux convection scheme (Tiedke, 1989), with closure based on moisture convergence.
- The δ-two-stream radiation scheme (8 spectral intervals) with full cloud radiation feedback (Ritter, 1992).
- The soil model with two layers (Jacobsen, 1982) and monthly climate values applied to a third layer; transpiration, snow and interception storage are included.

More detailed and regularly updated information on LM numerics and physics are available on the COSMO website in the documentation page: (www.cosmo-model.org/public/documentation) and in the newsletter section (www.cosmo-model.org/public/newsLetters.htm)

In the operational configuration, the model runs on a domain covering Italy and the central Mediterranean (1900 x 1600 km, Figure 6.1). The horizontal grid uses Arakawa C-grid and spherical rotated coordinates, with a mesh size of 0.0625° (~7km,). In the vertical, terrain-following hybrid sigma coordinates are applied, with 35 layers covering most of the atmosphere: there are 10 levels in the lowest 1500m; the model top is set at 30 hPa. (ref D.3.XX).

LAMI's mean orography is derived from the GTOPO30 data set (30''x30'') of USGS, prevailing soil type from the DSM data set (5'x5') of FAO, land-fraction, veg. cover, root depth and leaf area index from the CORINE dataset of ETC/LC (250m), and roughness length from the GTOPO30 and CORINE dataset. Boundary- and initial conditions for surface parameters are provided by DWD's operational global model GME (icosahedral-hexagonal grid with a mesh size of ~60km), initial conditions for non-surface variables are calculated through a continuous assimilation cycle (Figure 6.2).

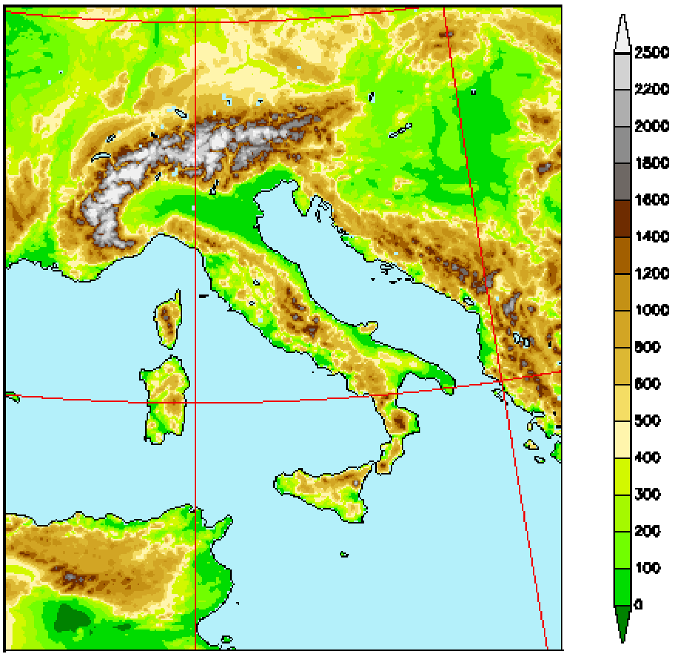


Figure 6.1: LAMI operational domain of integration

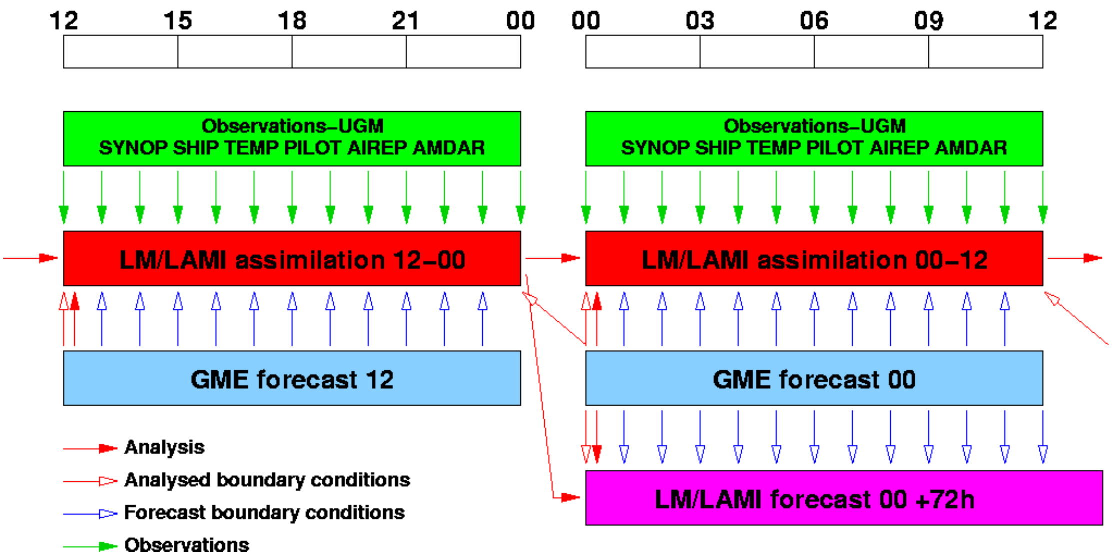


Figure 6.2: Flow diagram of the LAMI assimilation cycle.

The analysis dataset: LAMA

High resolution meteorological fields are not only required for short-term forecasts, but also for long-term assessment of air quality, the evaluation of effectiveness of emission reduction policy and a-priori estimation of pollution increase due to specific new sources. In these applications, long time series of surface- and upper level atmospheric parameters are often required, together with estimations of fields which are not currently measured, such as turbulence intensity and boundary layer height. These data must finally compose a complete description of the atmosphere, as much as possible self-consistent and close to observations.

In the Fumapex project, an extended dataset of high-resolution meteorological analysis has been produced, by storing and archiving hourly fields from the LAMI assimilation cycle (Figure 6.2). In practice, the analysis is therefore produced by a long term hind-cast integration of LAMI, continuously forced by local observations and with boundary conditions from the DWD global analysis; the result is supposed to be the best compromise between the self-consistency of the meteorological model and the accuracy of local observations.

The LAMA dataset covers the operational domain of LAMI (Figure 6.1), with hourly data starting from 1st April 2003 (the dataset is updated every day). To allow the largest possible variety of applications, all relevant model parameters are stored, including 10 3-D fields (on 35 model levels) and almost 30 surface and bulk fields. Some very important turbulent parameters, friction velocity, boundary layer height, Monin-Obukhov length, which are not included in LAMI output, have been estimated in the post-processing phase by means of parametric schemes.

The meteorological pre-processor CALMET-SIM

At ARPA-SMR a mass-consistent meteorological diagnostic pre-processor was implemented as well (Deserti *et al.*, 2001).

CALMET processes data measured by the standard meteorological surface stations (temperature, wind, total and low cloud cover, cloud types, relative humidity, precipitation, surface pressure) of the synop- (~20 stations over Northern Italy) and other local networks (~20) and upper air data from 4 radio soundings. Wind and temperature are interpolated on the model grid and corrected to take into account some local scale effects (slope flows, orographic blocking) and a set of parametric schemes (Holtslag and Van Ulden, 1983)

In the operational configuration, CALMET is run every morning with the observations of during the previous day; its domain covers the whole Po Valley (450 x 260 km), with a horizontal resolution of 5 km and 10 vertical terrain-following levels from the surface up to 2500 m. The output includes hourly values of 3D wind and temperature, as well as 2D fields of mixing height, Monin-Obukhov length, friction velocity, convective velocity scale and Pasquill-Gifford stability classes.

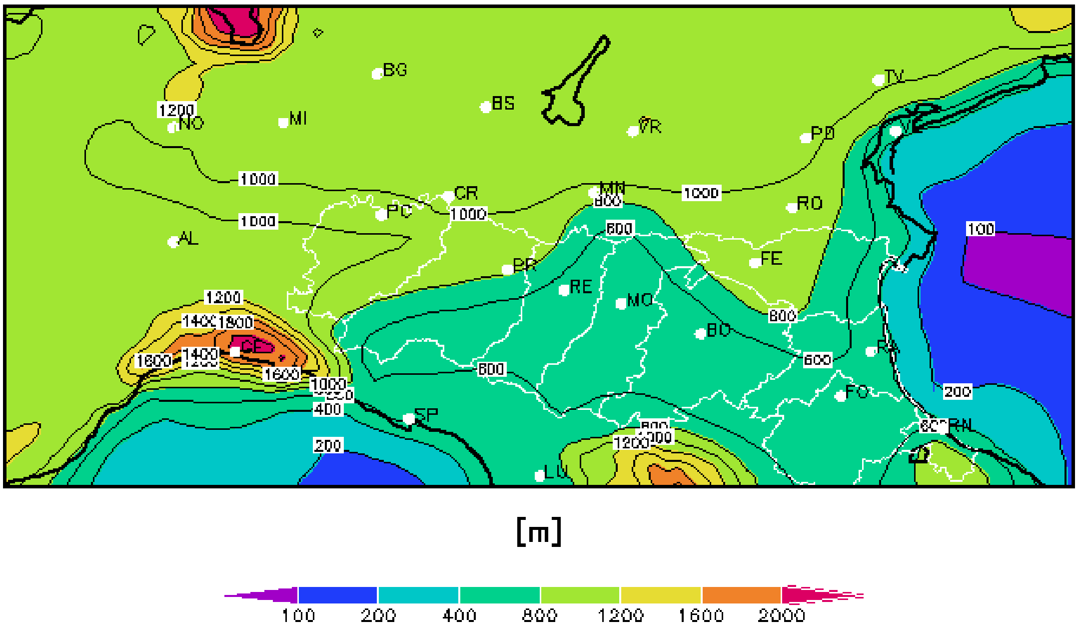


Figure 6.3: *An example from CALMET-SIM dataset (maximum mixing height estimated for 17/11/2005)*

The two datasets (LAMA and CALMET) are therefore “overlapping”, since they both describe the same meteorological conditions. In the first stage of the project, it was thought that LAMA would replace CALMET. Afterwards it was found that both datasets could be useful, since their strengths and deficiencies are complementary. CALMET fields are more affected by inconsistencies, but have smaller systematic errors. Moreover, the pre-processor is much easier to run and modify, which allows the production of longer time series (10 years are presently available) and to correct model schemes to describe specific conditions, such as urban areas: urban observations, for example, are much easier to introduce in CALMET than in LAMA.

6.1.2 The regional air quality modelling system, NINFA

NINFA (North Italian Network to Forecast Aerosol pollution) is an integrated tool to simulate atmospheric pollutant concentrations. NINFA (Figure 6.4) is based on the regional version of the CHIMERE chemical transport model (Bessagnet et al., 2004) and driven by the meteorological model LAMI (*see below*). The model runs daily at ARPA-SIM and provides concentration maps of PM_{10}, Ozone, and NO_2 for the previous day (hind cast) and the next two days (forecast).

CHIMERE chemical model

CHIMERE is a multi-scale Eulerian CTM, primarily designed to produce daily forecasts of ozone, aerosols and other pollutants and for long-term simulations, used in emission control scenarios. The scale on which it is able to operate can range from continental (several thousands of km) to urban (100-200 km) with resolutions ranging from 1-2 km to 100 km. CHIMERE describes the most important phenomena affecting atmospheric pollutants: emission, diffusion, transport, chemical reactions and depositions. The model uses the chemical scheme MELCHIOR (Lattuati, 1997) for the gas phase, and it includes an additional module to describe aerosols (see model documentation at: http://euler.lmd.polytechnique.fr/chimere).

In the NINFA system, the CHIMERE integration domain covers the whole northern part of Italy (Figure 6.5): this allows the model to take into account local scale circulations, which strongly affect the transport and dispersion of pollutants in the Po Valley (*Dosio et al.,* 2002). The horizontal resolution is relatively coarse (10 km), in order to allow the use of homogeneous emission inventories and meteorological data on the whole domain, and to avoid unreasonable long computing times.

The meteorological interface

In order to build CHIMERE meteorological input files starting from the LAMI output, a suitable interface was constructed: hourly values of temperature, wind, pressure, humidity, cloud cover, surface fluxes and soil wetness are directly passed to CHIMERE; cloud water content, mixing height and friction velocity are recalculated with parametric schemes. For the hind cast (i.e. previous day) NINFA simulation, fields from the LAMI assimilation cycle are used; for the forecast simulation, LAMI forecast from 00Z integration are used.

Emissions and boundary conditions

Emission input data are based on the Italian National Inventory of the year 2000 and prepared by the CTN-ACE (www.inventaria.sinanet.apat.it). The inventory covers the Northern part of Italy and describes PM, VOC, NH_3, NO_x, SO_x, and CO emissions from all anthropogenic sources (industrial, transports, civil, etc.) with a resolution of 5 km. PM emissions are divided in two classes (< 2.5 μm and between 2.5 and 10 μm), while VOC data are split in 199 species according to the speciation profiles suggested by UK-NAEI (*AEAT* 2002). The biogenic emission inventory was built by the CHIMERE developing group (*Guenther* 1997, *Simpson et al.* 1999). Point sources and biogenic emissions depend also on meteorological conditions such as atmospheric stability.

Pollutant concentrations at the boundaries of the CHIMERE integration domain are provided by the air quality modelling system PREV'AIR (www.prevair.org), also based on CHIMERE, but driven by the meteorological model MM5. It is run daily at INERIS (www.ineris.fr) on a domain covering most of Europe with a horizontal resolution of 50 km. The two modelling systems are therefore rather similar and can be integrated introducing only limited inconsistencies; in operational use, three dimensional hourly concentrations of 23 gaseous and 47 aerosol species estimated by PREV'AIR are used as input for NINFA, for both the hind cast and forecast simulations.

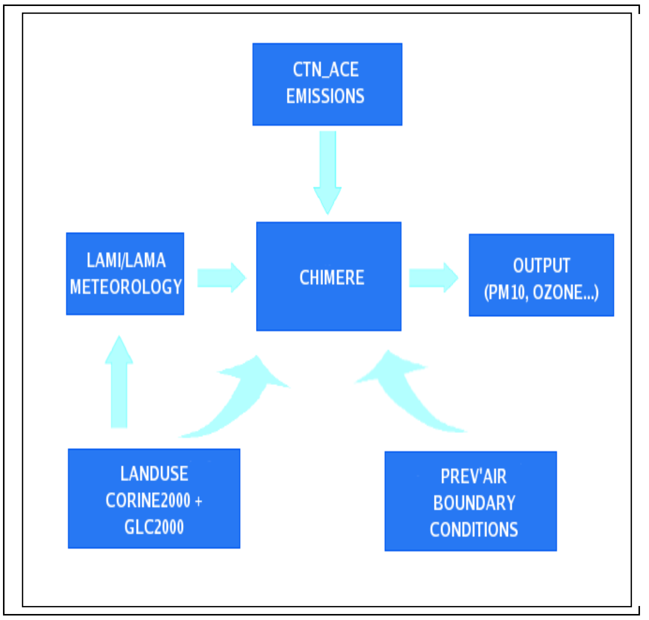


Figure 6.4: The NINFA modelling system components

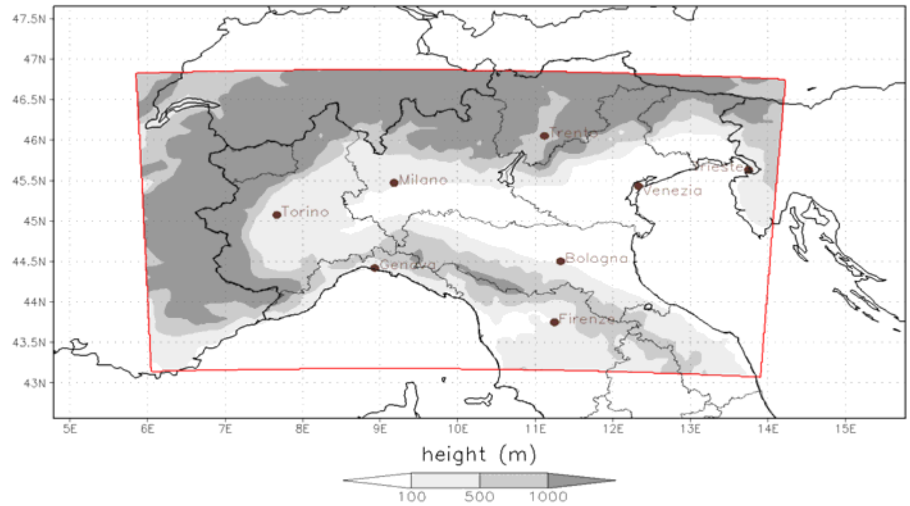


Figure 6.5: The NINFA integration domain

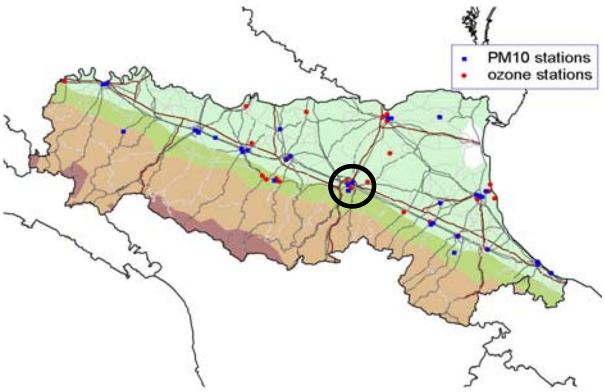
6.1.3 The statistical pollution model, OPPIO

OPPIO (Ozone and PM10 Polynomial Inference based on Observations) is the collective name of 4 statistical linear regressive pollution models.

In the present operational configuration, Ozone daily maxima and PM_{10} daily average concentrations are predicted for today (d+0) and the two following days (d+1 and d+2). Forecasts are issued on a set of 22 points (Figure 6.6) corresponding to the air quality monitoring stations of Emilia Romagna. Most stations are located in urban sites (street and urban background). 3 points in the target city of Bologna are included. To take into account the strong annual cycle of Ozone and PM_{10} observed in Northern part of Italy, different models are used during summer (April-September) and winter (October-March) months.

The regression models are fitted using two full years of observations, validated on an independent dataset and used for daily forecasts. Predictors are separately chosen for each point, among a set including: previous day concentration, average concentration of weekday, maximum- and minimum temperature, average wind speed and precipitation amount (Stortini, 2003, Deserti et al., 2002).

By default, meteorological predicted variables are taken from LAMI simulations, but the operator can choose also to use temperatures from the outputs of the ECMWF meteorological model Kalman-filtered (Cacciamani & de Simone 1992, Costa & Selvini 2002) or from subjective forecasts.



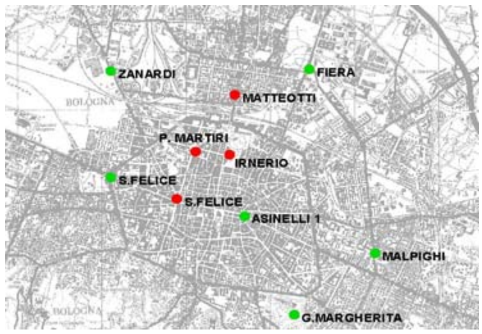


Figure 6.6: Left, the locations of the monitoring stations used by the OPPIO statistical model, the circle indicates the Bologna urban area. The stations in Bologna are indicated in the left part of the figure.

6.1.4 The operational forecast procedure

Daily air quality forecasts at ARPA-SIM can, in principle, be produced at any time, using the best information available at the moment. The operational issuing time has been scheduled at noon (the latest possible time for end users), in order to allow forecasters to use the largest number of support products.

Operational time schedule (hours are local time; times in italic refers to the summer season)

03.30 (*04.30*): data from the continental CTM Prev'air (INERIS) are available; Prev'air provides boundary conditions for the NINFA run and a first forecasting tool.

07.00 (*08.00*): most information from the meteorological models are available; they include forecast maps from ECMWF and LAMI and analysed maps from Calmet.

10.00 (*11.00*):	NINFA forecasts are available and published on the web; maps from other European CTM models are also available on the web.
11.00:	validated pollution data from the ARPA AQ monitoring network are available. The statistical model (OPPIO) can be run.
11.15:	the ARPA-SIM meteorological forecast bulletin is available; the operator starts producing the air quality bulletin.
12.00:	air quality bulletin is issued and published on the WEB.

6.1.5 Computer systems

Due to the large number of grid points (234x272), LAMI is the most time-consuming among the operational models run at ARPA-SIM. The main operational simulations are run on the IBM-SP4 system hosted by CINECA (Inter-university consortium for supercomputing in North-eastern Italy), and require ~ 1h CPU time for a 3 days forecast. Additional simulations are run at ARPA-SIM on a Linux parallel system with 44 Intel processors: these simulations are identical to the former and are mainly used as a backup in case of failure or delay of CINECA runs. A 3-day forecast on this platform requires ~ 2.5h.

The LAMA dataset is built simply by storing data from the continuous assimilation cycle of the backup LAMI simulations; due to the large number of data to be archived, a mass storage system with an overall capacity of ~ 3 TeraBytes has also been installed at ARPA-SIM.

Unlike LM, CHIMERE code is not yet implemented on parallel systems. Nevertheless, thanks to the limited size of the operational grid (64x41 points), NINFA daily forecasts can be run on a single processor in a reasonable time: a 4 days simulation requires ~ 5h on an Intel-Xeon 3GHz processor. The release of the first MPI version of CHIMERE, which is scheduled for the first months of 2006, will allow substantial changes in the operational suite, eventually including an increase in model resolution to 5 km.

6.2 Description of the forecasting procedure as performed by the end-users

During the FUMAPEX project, the Provincial authorities defined agglomerations and zones in Emilia - Romagna (Council Directive 96/62/EC) as shown in Figure 6.7. The forecasting procedure was updated in order to provide an air quality forecast for each agglomerate and is described below.

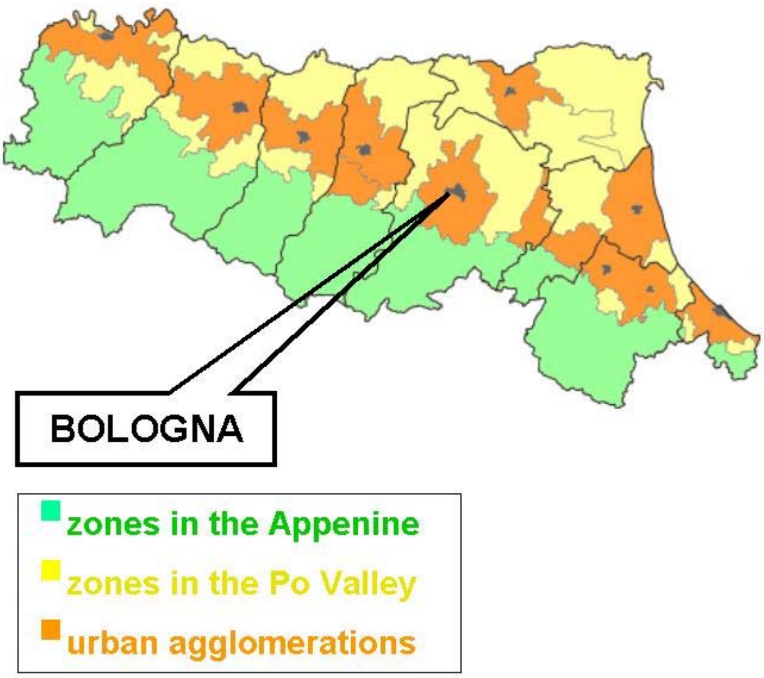


Figure 6.7: Agglomerates and zones in the Emilia-Romagna region (Council Directive 96/62/EC)

The person responsible for the forecast at the ARPA-Hydro meteorological Service formulates a subjective air quality forecast for today, tomorrow and the day after tomorrow. The procedure starts at 11:00-11:20 and stops at 11:40-12:00 and follows below mentioned steps:

1. Retrieval of the pollution data (ozone and PM_{10}) of the previous days. These data are measured by the regional monitoring network (Figure 6.8) and checked and validated (at 9:30-10:30 AM) by the ARPA technicians;
2. Run the statistical forecast model OPPIO (Ozone and PM_{10} Polynomial Inference based on Observations) and generate the automatic forecast (pollution levels for each agglomerate and zone, both for ozone and PM_{10});
3. Check the automatic statistical forecast, check the predictors of the statistical model, eventually modifying them (e.g. filling the missing data, Figure 6.10), re-run the model (options 1 to 11 in Figure 6.9);
4. Produce the definitive forecast, integrating the forecast issued by the statistical model with additional information: concentration maps produced by various chemical transport model (Figure 6.11): NINFA, PREV'AIR, EURAD; numerical weather predictions issued by LAMI (Figure 6.12); textual meteorological bulletin written and published daily by ARPA-SIM (options 20 to 24 in Figure 6.9);

5. Transform the forecast table in forecast maps;
6. Publish the maps on the web (Figure 6.13).

The maps published on the web are the daily mean PM_{10} and the daily maximum ozone forecasts for today, tomorrow and the day after tomorrow. PM_{10} is forecasted for the 12 urban agglomerations in Emilia Romagna; ozone is forecasted for the 12 agglomerations and the other 18 zones in which the region is divided.

Even in case of missing observed pollution data or missing numerical weather predictions, the subjective forecast (maps) is emitted anyway, using the best available information.

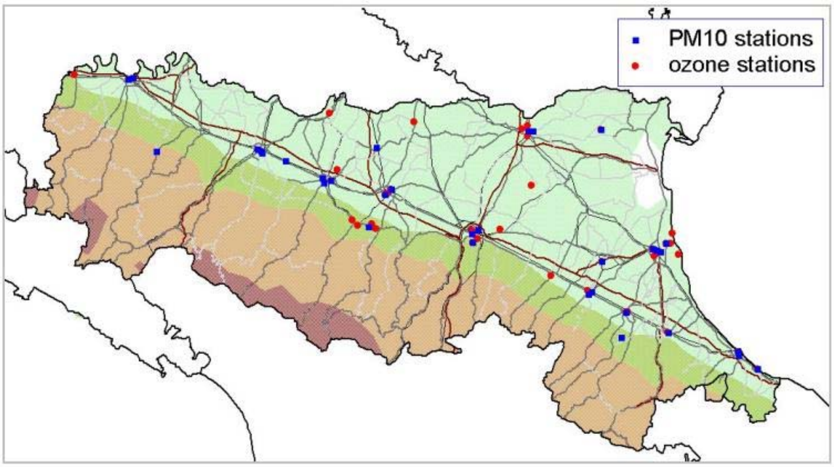


Figure 6.8: The Emilia Romagna regional monitoring network

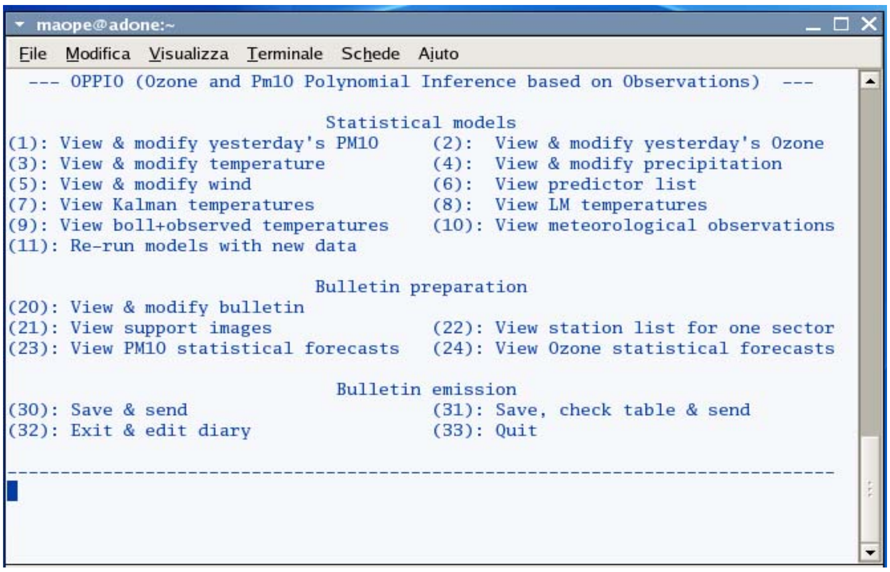


Figure 6.9: Menu of the options available for the forecaster during the forecasting procedure

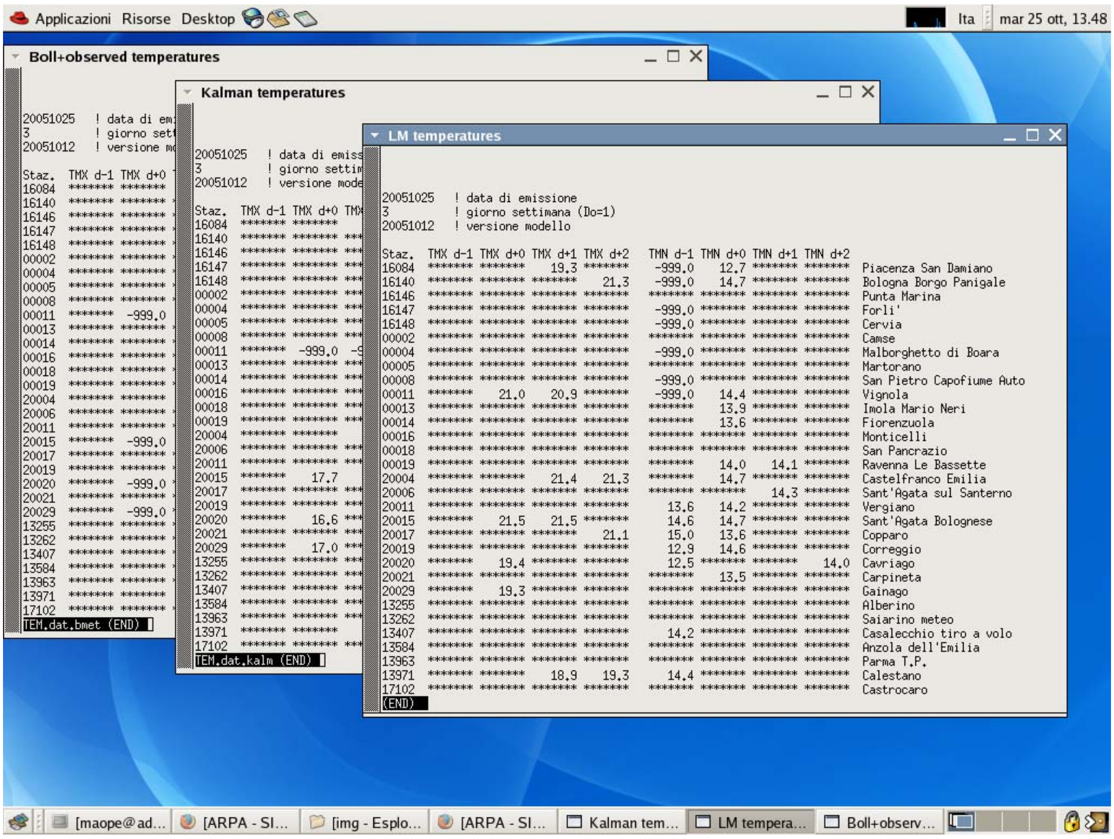


Figure 6.10: Tables of some of the predictors used by the statistical model. The forecaster can check the predictors, eventually modifying them.

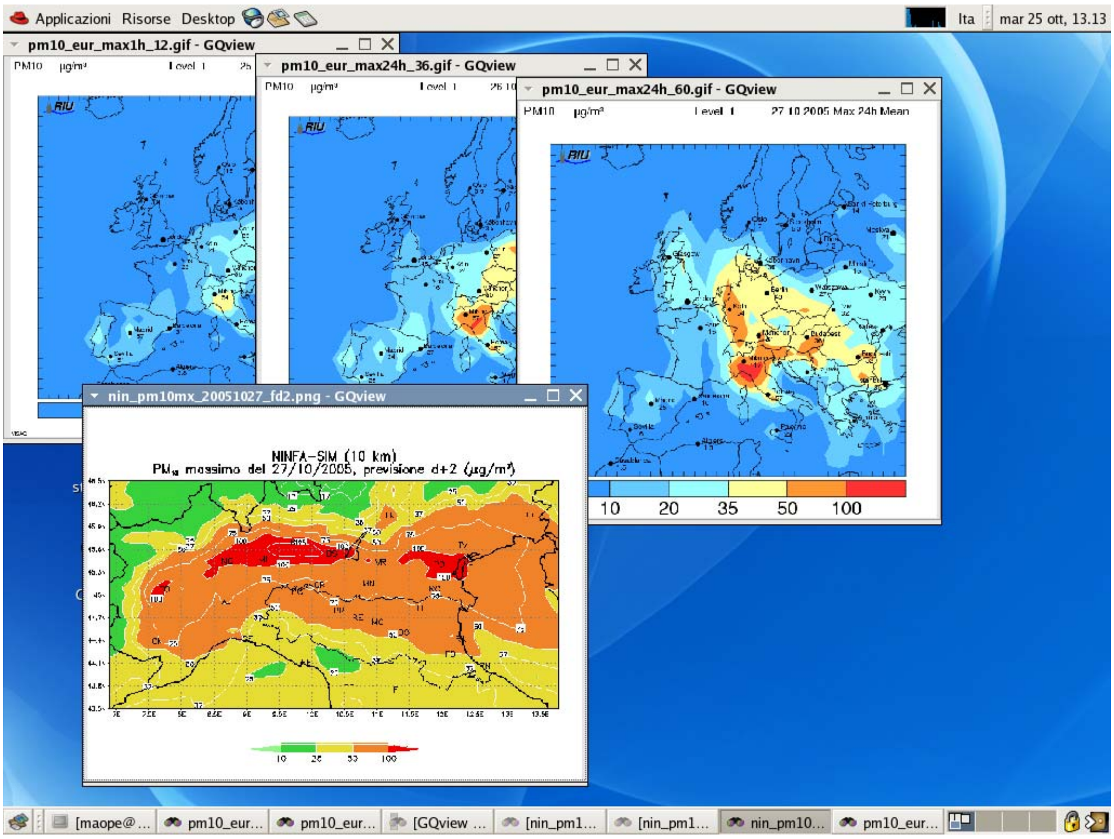


Figure 6.11: Some of the predicted concentration maps available to the forecaster as additional information.

Air quality forecasts are used in winter to take short-term abatement actions according to the 3rd Regional Agreement on Air Quality. This agreement was signed on October 3rd 2006 by the Regional Government of Emilia Romagna, the Provincial Authorities and the main Municipalities and starts in January 7th 2006. It establishes to stop traffic on Thursdays during winter, if high pollution levels are predicted and the PM10 pollution level exceeded 50 μg/m^3 during the previous days (Saturday, Sunday and Monday). The action is focused in particular on PM10 pollution management and is aimed to reach the target values.

During summer, when high ozone pollution levels are frequently observed and predicted in Italy, air quality forecasts are used to inform the population about the health risk.

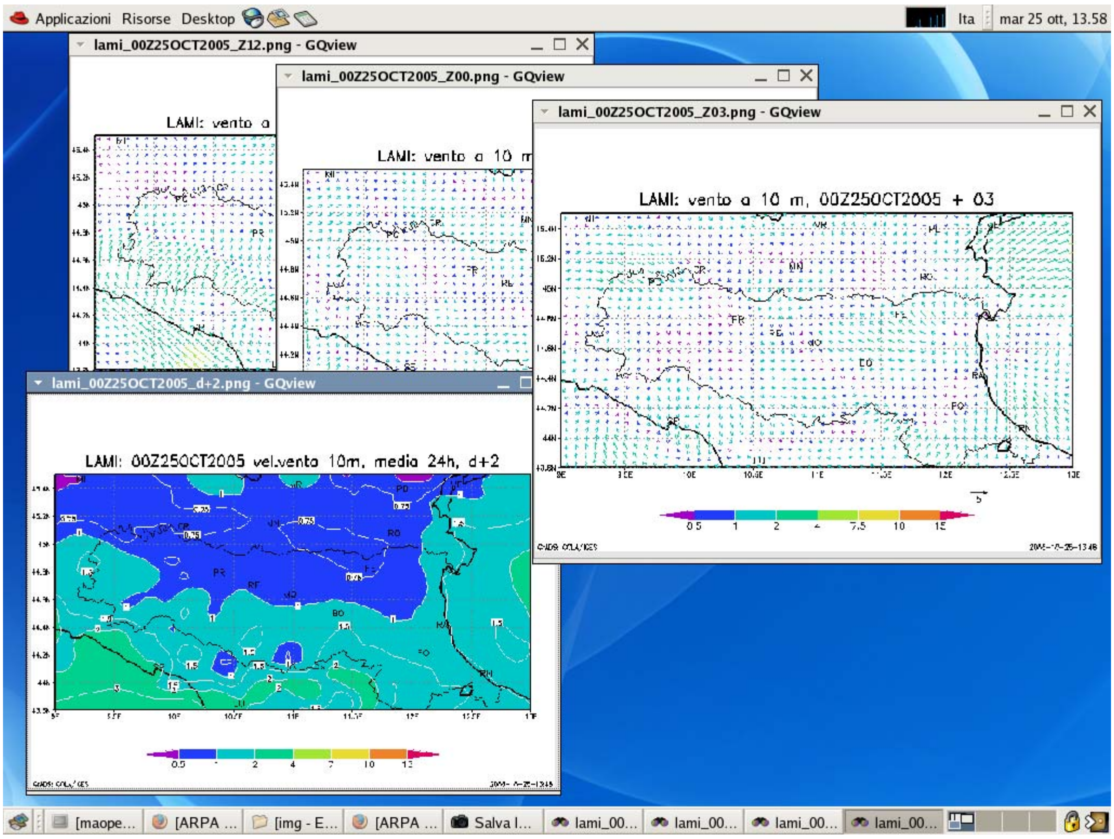


Figure 6.12: Some of the meteorological forecast maps available to the forecaster as additional information.

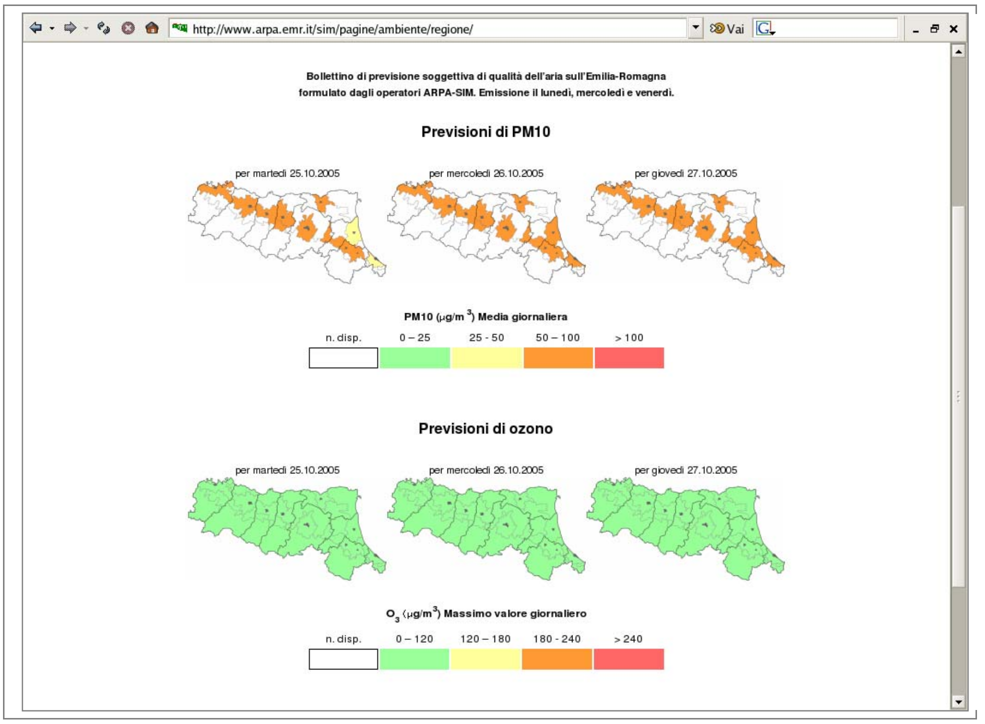


Figure 6.13: The pollution forecast (PM_{10} and ozone) for the region Emilia-Romagna, as published on the website

6.3 Description of the procedure for urban planning and population exposure assessment, test cases

Once a year long-term runs of the NINFA modelling system are performed in order to make an assessment of the ozone, NO2 and PM10 pollution levels in the region Emilia - Romagna. In the long term hind cast runs the LAMA data set, previously described, provides the meteorological input for NINFA. The NINFA hind cast results are compared with the pollution levels measured at the monitoring stations, in order to establish if the calculations of the modelling technique satisfy the required accuracy (an accuracy of 50 % is requested by the EC Directives1999/30/EC and 2002/3/EC). An example is shown in Figure 6.14.

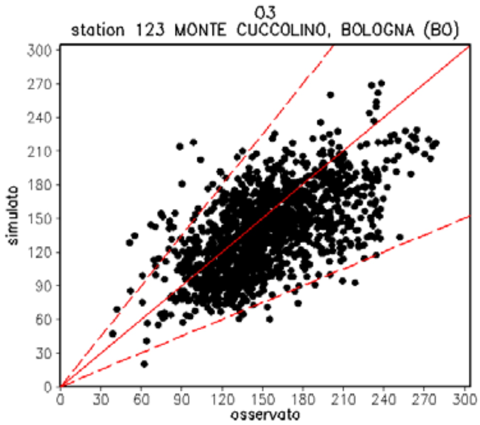


Figure 6.14: Comparison between the hourly averaged ozone concentrations measured at the Bologna Monte Cuccolino monitoring station (X axis) and the calculated values (Y axis). Red dotted lines indicate the ±50 % interval.

The hourly values calculated by the long-term runs are processed to produce maps that indicate the zones where reference pollutants levels are exceeded. An example of maps of ozone exceedances during the 2003 summer period is shown in Figure 6.15.

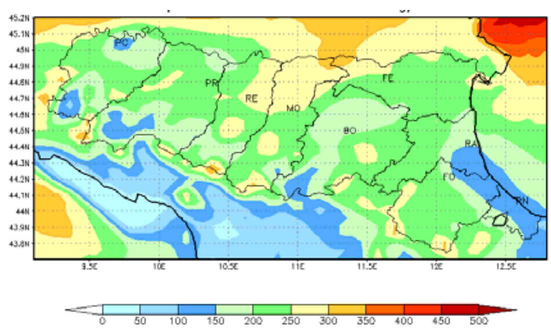
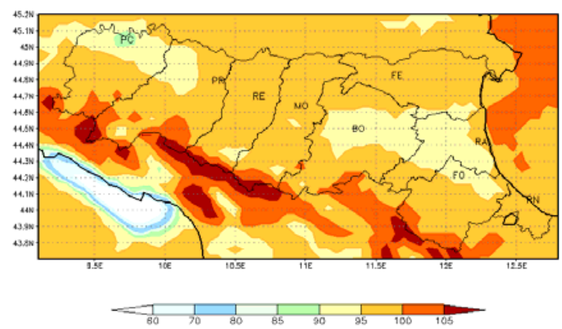
	
Number of exceedances of the ozone threshold (1 hour average > 180 μg/m^3) during the 2003 summer period.	Number of exceedances of the ozone limit for protection of human health (8 hour average > 120 μg/m^3) during the 2003 summer period.

Figure 6.15: Figure text presented in the figure.

In the urban agglomerations, where pollutant levels exceed their limits, it is necessary to simulate the pollution in more detail and to evaluate different scenarios to reduce it. For urban management and planning, pollution simulations are done with the Advanced Gaussian ADMS – Urban model (CERC, 2003). For the Bologna urban area, ADMS was used to simulate the pollution in the Bologna S. Felice district (Figure 6.16) for a period of 1 year (April 2003 - April 2004). The technical description of the urban model is given in section 6.3.1.

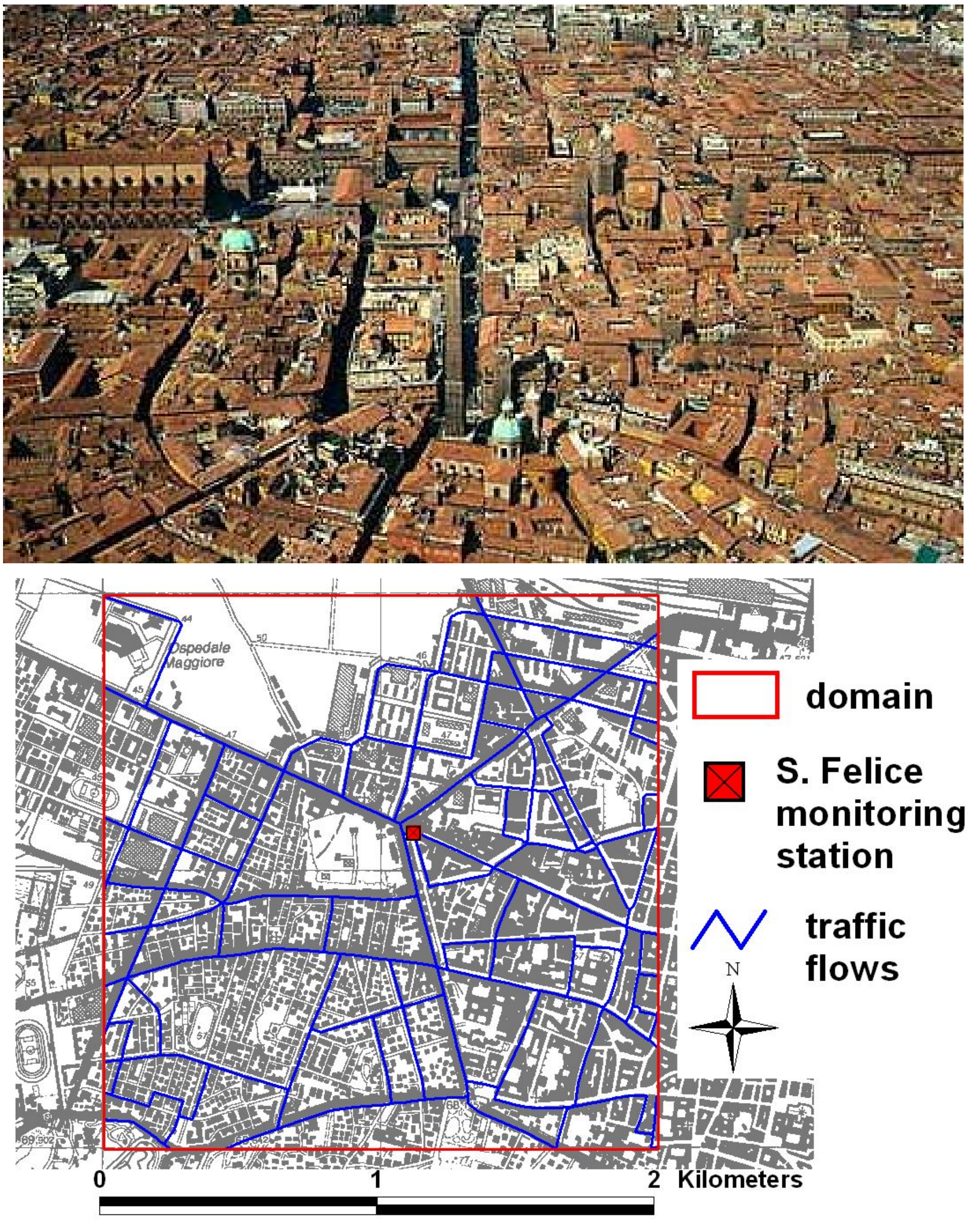


Figure 6.16: The Bologna modelling domain (2 Km x 2 Km) at 50 m horizontal resolution. The picture in the upper part of the figure shows a photo of the area.

In order to establish if the calculations satisfied the required accuracy (the accuracy required by EU Directive 99/30/EC is 30% for the NO2 annual average and 50% for the PM annual average), simulated annual average pollutant concentrations were compared with measurements of the air quality monitoring stations. Table 6.1 shows an example of this comparison.

Table 6.1: *Results of the urban model for the 1-year run at the S. Felice monitoring station: good agreement between simulated and observed mean values of PM10, NO2 annual mean is slightly overestimated, both indexes are within the error range (30%) required by EU Directive 99/30/EC.*

	NO_2 annual mean µg/m³	**NO_2** 18th highest hourly value µg/m³	**PM_{10}** annual mean µg/m³	**PM_{10}** 35th highest daily value µg/m³
*simulated*_S. Felice	68	195	48	68
*observed*_S.Felice	*52*	*123*	*42*	73

The detailed pollution fields, as seen in Figure 6.17, provide a basic pollution scenario. They show the most critical situations and their relation with the pollution sources. Next to that, they can be used to estimate the effectiveness of emission reduction actions such as traffic limitations or changes in the traffic distribution insight the area.

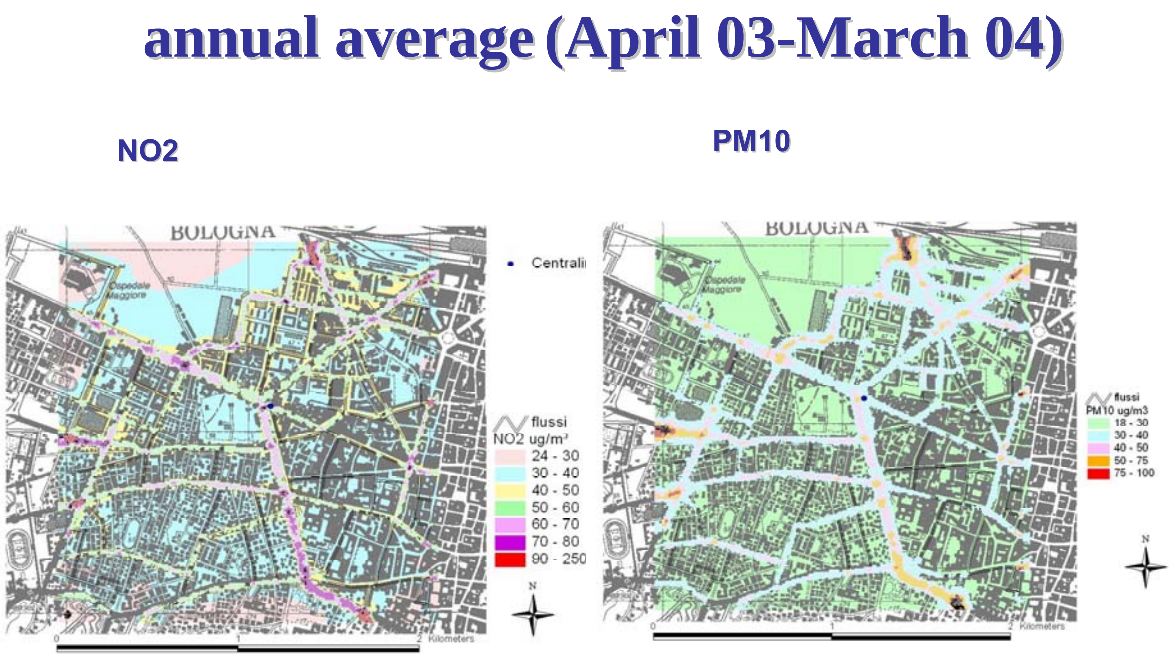


Figure 6.17: Average NO2 and PM10 pollution fields

The urban pollution data from ADMS provide also the outdoor concentration data for population exposure assessment, as described in report D7.4. An example of the NO2 outdoor concentration levels in 333 children houses + 2 schools calculated by the urban model in the S. Felice district in Bologna is shown in Figure 6.18.

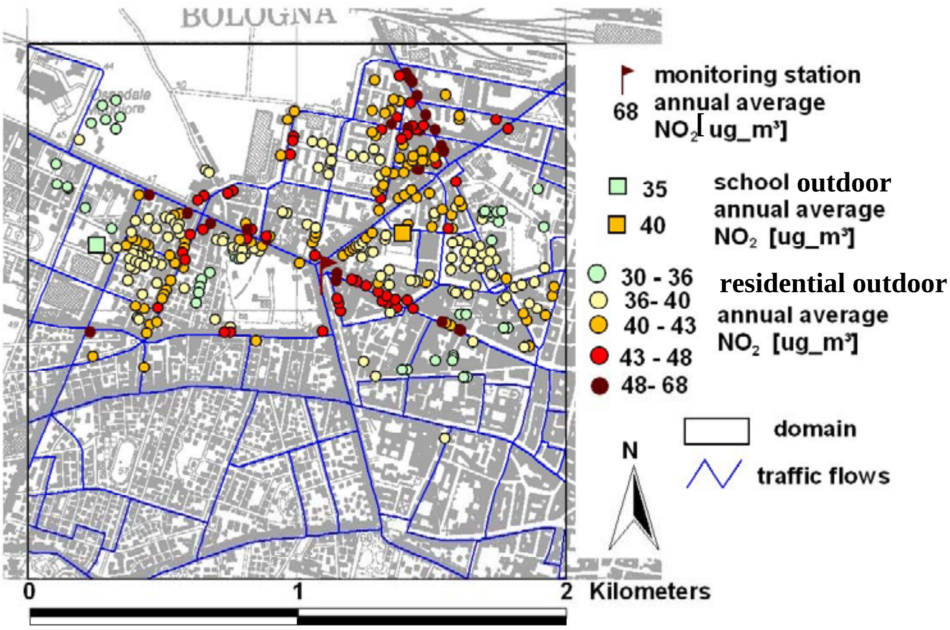


Figure 6.18: NO2 outdoor concentration levels in 333 children houses + 2 schools calculated by the urban model in the S. Felice district in Bologna

6.3.1 Technical description of the urban management and planning system, the Atmospheric Diffusion Model for Urban planning ADMS-Urban

The Advanced Gaussian ADMS – Urban model (CERC, 2003) allows to simulate industrial, domestic and road traffic emission sources in urban are. It includes the OSPM street canyon model (Hertel et al, 1990), suitably adjusted to incorporate the meteorological input profiles. The chemistry is modelled by a simple chemical reaction scheme to describe the photochemical cycle of nitrogen oxides and ozone, and a scheme to describe the sulphate chemistry.

In the Bologna implementation, detailed traffic emissions on 213 road links are estimated from traffic flows (source: Bologna Municipality) and emissions factors. The vehicles are split in a number of categories, including cars, motorcycles and buses. The choice of this division is based on several information sources, among which the ACI (Automobile Club Italia) and the PSC (Bologna Municipality Structural Strategic Plan) data on circulating vehicles.

The emission factors were derived from the Corinair 2000 inventory for gases and the TNO (Netherlands Organisation for Applied Scientific Research) inventory for PM_{10} (cold starts, brake wear, tire wear and road abrasion).

Emission time-varying profiles are calculated from the Bologna PSC data.
Meteorological input can be provided both by CALMET-SIM and LAMA. The urban background concentrations are calculated by the NINFA modelling system.

A scheme of the model implementation for Bologna is shown in Figure 6.19:

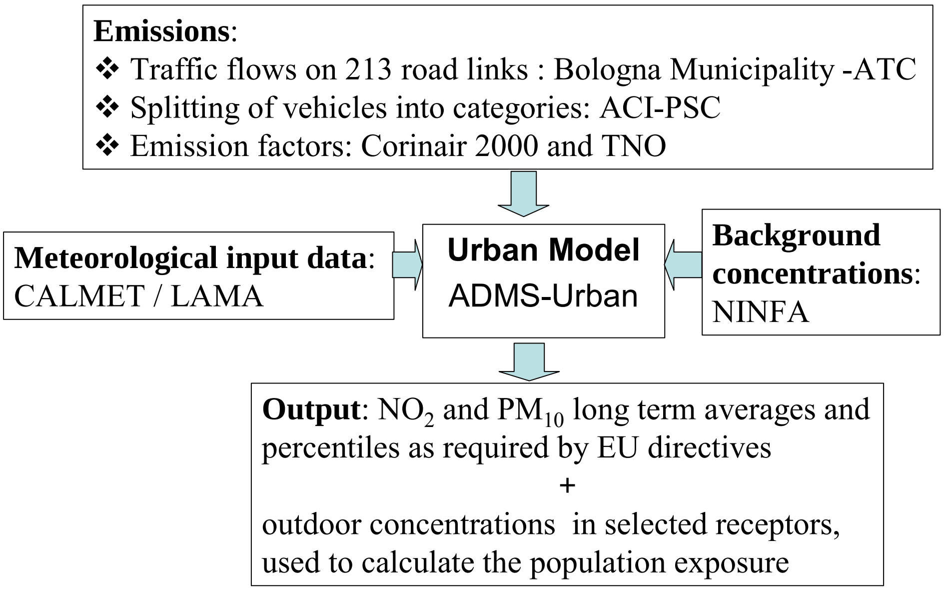


Figure 6.19: Configuration of ADMS urban for the Italian city Bologna

6.4 References

Passant, N.R. (2002) Speciation of UK emissions of non-methane volatile organic compounds. Abingdon, AEA Technology (AEAT/ENV/R/0545).

Baldauf, M. and Schulz, J.P. (2004) Prognostic precipitation in the Lokal Modell of DWD. *COSMO Newsletters, No 4,* 177-180.

Bessagnet, B., Hodzic, A., Vautard, R., Beekmann, M., Cheinet, S., Honoré, C., Liousse, C. and Rouil, L. (2004) Aerosol modelling with CHIMERE: preliminary evaluation at the continental scale. *Atmos. Environ.*, *38,* 2803-2817.

CERC (2000) ADMS 3 & ADMS-Urban 1.6 Technical Specification. User Guide. Cambridge, CERC.

CERC (2003) ADMS-Urban User Guide (Version 2.0). Cambridge, CERC.

Deserti, M., Cacciamani, C., Golinelli, M., Kerschbaumer, A., Leoncini, G., Savoia, E., Selvini, A., Paccagnella, T. and Tibaldi, S. (2001) Operational meteorological pre-processing at Emilia-Romagna ARPA Meteorological Service as a part of a decision support system for Air Quality Management. *J. Environ. and Poll., 16,* 571-582.

Dosio, A., Galmarini, S. and Graziani, G. (2002) Simulation of the circulation and related photochemical ozone dispersion in the Po plains (northern Italy): comparison with the observations of a measuring campaign. *J. Geophys. Res., 107*, 8189.

Guenther, A. (1997) Seasonal and spatial variations in natural volatile organic compound emissions, *Ecol. Appl., 7*, 34–45.

Hertel, O., Berkowicz, R. and Larssen, S. (1990) The Operational Street Pollution Model (OSPM). In: *Proceedings, 18th International technical meeting of NATO/CCMS on Air Polution Modelling and its Application. Vancouver, Canada,* pp. 741-749.

Holtslag, A.A.M. and van Ulden, A.P. (1983) A simple scheme for daytime estimates of the surface fluxes from routine weather data. *J. Clim. Appl. Meteor.*, *22,* 517-529.

Jacobsen, I. and Heise, E. (1982) A new economic method for the computation of the surface temperature in numerical models. *Contrib. Atmos. Phys.*, *55,* 128-141.

Lattuati, M. (1997) Impact des emissions européennes sur le bilan d'ozone troposphérique à l'interface de l'Europe et de l'Atlantique Nord: apport de la modélisation lagrangienne et des mesures en altitude. Ph.D. Thesis, Université Pierre et Marie Curie, Paris, France.

Mellor, G.L. and Jamada, T. (1982) Development of a turbulence closure model for geophysical flow problems. *Rev. Geophys. Space Phys., 20*, 831-857.

Ritter, B. and Jelen, J.F. (1992) A comprehensive radiation scheme for numerical weather prediction models with potential applications in climate simulations. *Mon. Wea. Rev., 120,* 303-325.

Simpson et al. *(*1999) Inventorying emissions from nature in Europe. *J. Geoph. Res., 104,* 8113.

Steppeler, J., Doms, G., Schättler, U., Bitzer, H. W., Gassmann, A., Damrath, U. and Gregoric, G. (2003) Meso-gamma scale forecasts using the nonhydrostatic model LM. *Meteorol. Atmos. Phys.*, *82,* 75-96.

Steppeler, J., Doms, G., Schättler, U., Bitzer, H.W., Gassmann, A., Damrath, U. and Gregoric, G (2003) Meso-gamma scale forecasts using the nonhydrostatic model LM. *Meteorol. Atmos. Phys.*, *82,* 75-96.

Tiedtke, M. (1989) A comprehensive mass flux scheme for cumulus parameterisation in large scale models. *Mon. Wea. Rev., 117*, 1779-1799.

7. The emergency preparedness system for the city of Copenhagen, Denmark

Authors: Steen Hoe [(1)], Alexander Baklanov [(2)] and Jens Havskov Sørensen [(2)]

[(1)] Danish Emergency Management Agency (DEMA)
[(2)] Danish Meteorological Institute (DMI)

7.1 Technical description of the Operational Emergency Modelling for Danish cities

The Danish nuclear emergency preparedness involves the Accident Reporting and Guidance Operational System (ARGOS), developed by the Danish Emergency Management Agency (DEMA) and collaborators (Hoe et al., 1999, 2002). The overall ARGOS system consists of various parts as depicted in Figure 7.1.

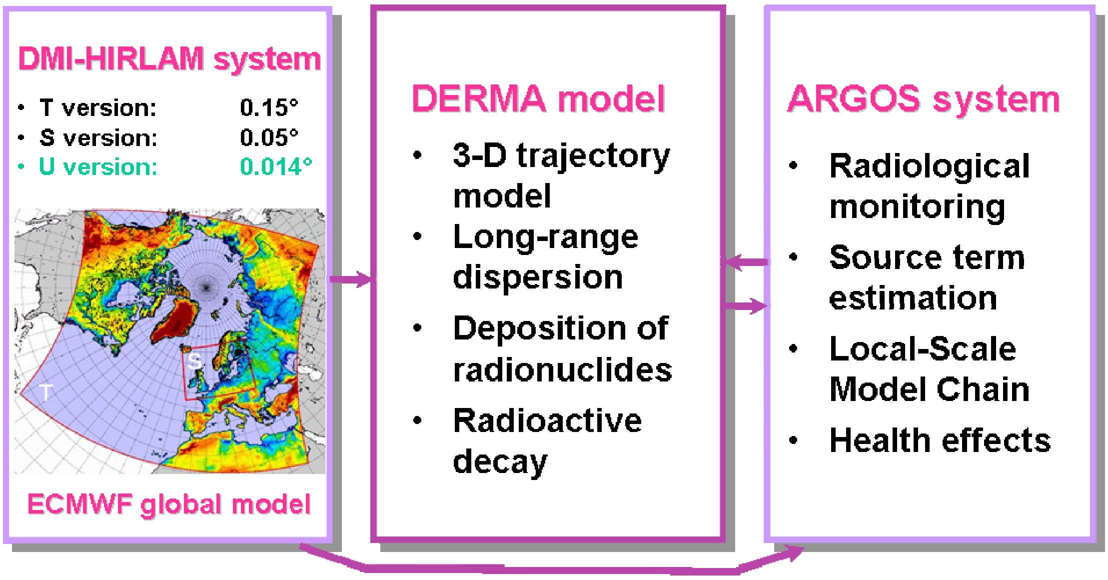


Figure 7.1: Structure of the Danish nuclear emergency modelling system.

The ARGOS system utilises meteorological forecast data for the prediction of contamination, doses and other consequences on local and European scales. In Denmark such data are provided by the Danish Meteorological Institute (DMI) four times a day. The 3-d data, which are transferred online to DEMA, are operationally extracted with 5 km (or experimentally 1.4 km) horizontal resolution forecasting up to 54 hours ahead. For Denmark the recent Danish operational NWP system (Sass *et al.*, 2002) consists of two nested models named DMI-HIRLAM-S05 and -T15, with horizontal resolutions of about 5 and 15 km, respectively. The vertical resolution of the operational versions is given by 40 levels, but for tests it has been increased to 60 vertical levels. Within the FUMAPEX project for the urban version of the ARGOS system, DMI also runs several experimental versions of DMI-HIRLAM over Denmark and the Zealand island, on which the city of Copenhagen is located, with a horizontal resolution of 1.4 km and improvements of parameterisations of the urban sublayer processes and the urban physiographic data classification (cf. Baklanov *et al.* (2005a,b)).

In order to meet the input requirements of the ARGOS system, a meteorological pre-processing interface is translating and interpolating the NWP model output. The Local Scale Model Chain (LSMC) (Mikkelsen *et al*., 1997) comprises a meteorological pre-processor, which calculates deposition and stability parameters and wind fields based on the data provided by the DMI-HIRLAM model. These data are pre-processed and interpolated to yield data input fields for the RIMPUFF local-scale dispersion model of ARGOS. Typically the fields are interpolated to a grid spacing of about 1 km or finer. The wind fields are interpolated either with the linearised flow model LINCOM (Mikkelsen et al., 1997; Astrup et al., 1996) or by $1/r^2$ weighting. In order to provide a more detailed wind field near the source, LINCOM is only used out to about 15 km from the source. The mixing height, which is one of the important characteristics for UAQ models, is included in the NWP output data or calculated separately by methods suitable for urban conditions (Sørensen et al., 1996; Zilitinkevich and Baklanov, 2002; Baklanov, 2002). However, the mixing height calculation may also be realised by the LSMC using different methods.

The local-scale atmospheric dispersion model system LSMC (already mentioned above), is used in ARGOS for the calculation of actual and forecasted ground-level air concentrations, wet and dry deposition, and ground-level gamma dose rates on short and medium range scales (up to about 100 km from the source). It includes the atmospheric local-scale dispersion model RIsø Mesoscale PUFF model (RIMPUFF) developed at the Risø National Laboratory (Mikkelsen *et al*., 1984, 1997). At distances greater than about 20 kilometres from the source, the DMI long-range atmospheric dispersion model, the Danish Emergency Response Model of the Atmosphere (DERMA), can be used (Sørensen, 1998; Sørensen *et al*., 1998; Baklanov and Sørensen, 2001). Source terms for specific events, reactors and release categories are defined in the ARGOS database. Presently the nuclide database contains 361 radionuclides. The result of the forecast includes nuclide specific air concentrations, ground contamination and gamma doses.

RIMPUFF is a fast puff diffusion code suitable for real-time simulation of puff and plume dispersion using meteorology changing in space and time. The model is provided with a puff splitting feature to deal with plume bifurcation and flow divergence due to channelling, and slope flow and inversion effects in non-uniform terrain. In RIMPUFF the puff diffusion processes are controlled by local turbulence levels, either provided directly from on-site measurements, or via pre-processor calculations. RIMPUFF is equipped with standard plume rise formulas, inversion and ground level reflections, as well as gamma dose algorithms.

DERMA is a three-dimensional Lagrangian long-range dispersion model using a puff diffusion parameterisation, particle-size dependent deposition parameterisations and radioactive decay. Earlier comparisons of simulations with the DERMA model versus the ETEX experiment involving passive tracer measurements gave very good results (Graziani *et al*., 1998). The DERMA model can be used with different sources of

NWP data, including the DMI-HIRLAM limited-area and the ECMWF global NWP models with various resolutions. The main objective of DERMA is the prediction of the atmospheric transport, diffusion, deposition and decay of a radioactive plume within a range from about 20 kilometres from the source up to the global scale. DERMA is run on operational computers at DMI. The integration of DERMA in ARGOS is effectuated through automated on-line digital communication and exchange of data. The calculations are carried out in parallel for each NWP model to which DMI has access, thereby providing a mini-ensemble of dispersion forecasts for the emergency management.

In order to consider the micro-scale processes in urban areas (e.g., the dispersion of the released substance in a separate street canyon or around a block of buildings), a further level of nesting/downscaling can be included with usage of local-scale obstacle-resolving urban models, which have to carefully resolve the geometry of each building, e.g. the UK Urban Dispersion Model (UDM) (Brook et al., 2003). Such potential for local-scale urban simulation in the ARGOS system is considered by Thykier-Nielsen and Roed (2005).

Due to the focus of the Copenhagen system on emergency preparedness, calculation of the population exposure in ARGOS has considerable specifics. First, mostly potential radioactive releases are considered, thus the individual and collective doses for population exposure (corresponding to the deterministic-individual and deterministic-statistical approaches in Baklanov et al. (2005)) are calculated for the acute phase and long-term effects. In a general sense the total doses to man for different groups of the population (e.g., adult, children, elderly) may be calculated based on the contributions of inhalation, external exposure, and ingestion (Figure 7.2).

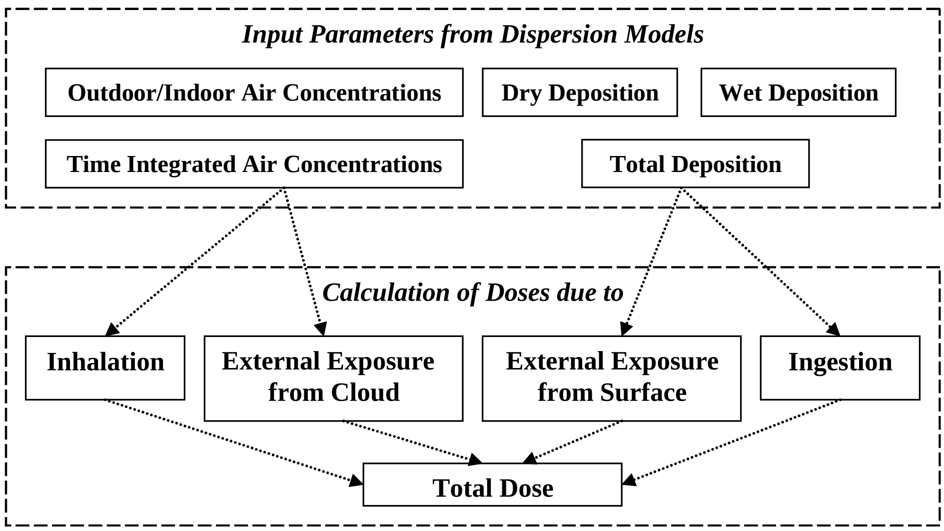


Figure 7.2: General scheme of individual dose calculations for different groups of the population from radioactive airborne contamination in the ARGOS system.

Inhalation exposures and body depositions are estimated for subjects passing through the radioactive cloud. The deposition fields are further used to calculate soil contamination and effects of accumulation in crops and the human food chain.

As inputs for the dose calculation the air concentration and deposition fields are necessary. Time integrated air concentration fields are important to calculate doses due to inhalation and external exposure from the passing radioactive cloud. The total deposition fields are important to calculate external exposure from the deposited radioactivity and doses due to ingestion. Moreover, the deposition patterns are important to calculate contamination of soils (due to deposition although there are radioactive decay and some removal from the upper layers) and crops (through interception during contaminated cloud passage and uptake from soil). The radionuclide intake through the food chains occurs by direct consumption of contaminated crops, and by indirect consumption of animal milk/meat.

ARGOS calculates external doses separately for adults and children. Effective doses, inhalation doses, thyroid doses and doses avertable by shielding are calculated. The dose calculations can be carried out by different methods including gamma dose rate measurements, air concentrations of specific radionuclides, from estimated external gamma doses, and modelling of food chain effects (Hoe et al., 2000):

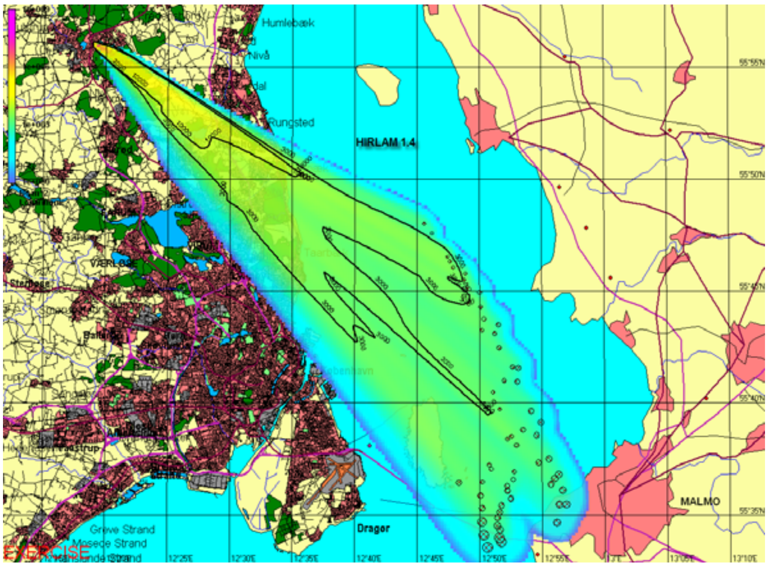
- From multiple gamma dose rate measurements in a selected time interval, a simple integration can be performed.
- From air concentration measurements of specific radionuclides measured during the plume passage, the total outdoor Committed Effective Dose from inhalation can be calculated for both adults and children.
- The total external gamma dose received during the plume passage can be estimated by adding the gamma dose from the plume and the gamma dose from the deposited activity on the ground.
- The Food Dose Module (ARGOS FDMT 2.0) (Hoe et al., 2000) can be applied.

Urban surface data bases, implemented into ARGOS, have resolutions up to 2 m resolving individual buildings. Population databases in the current version of ARGOS have much poorer resolution, but it will be essentially improved for Danish cities soon.

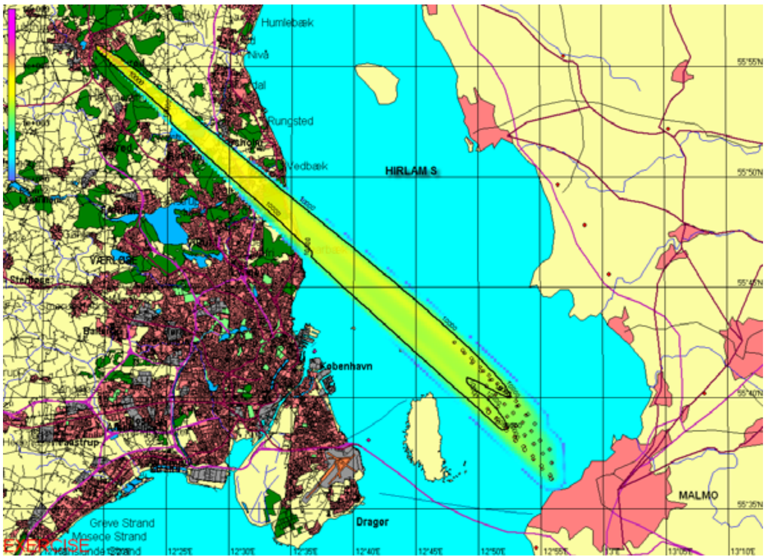
7.2 Description of the operational procedure as performed for/by the end-users

In case of an accident or other type of emergency the ARGOS system provides air concentration, deposition, gamma dose fields, and total doses for the population. This information will be available to decision makers. The first ARGOS forecast is usually available 15-30 minutes after the information about the event was received.

To demonstrate the improved ARGOS system for the Copenhagen metropolitan area, let us consider a hypothetical dirty bomb scenario, as described by Sohier and Hardeman (2004), with radioactive releases from the town of Hillerød close to Copenhagen city. The source was Cs-137 released at a constant rate of 10^{11} Bq/s within 15 minutes. The information about the source term for a dirty bomb scenario is a very uncertain issue. In this sensitivity study we consider a unit release of ^{137}Cs as an example. It could be considered as the first stage of forecasting for later adaptation when relevant data about the release strength become available. For the situation considered on, June 19, 2005, the hypothetical release took place from 00:00 to 00:15 UTC. In Figure 7.3 the corresponding local-scale plume from the hypothetical atmospheric release of ^{137}Cs, as calculated by RIMPUFF/ARGOS using meteorological data from the urbanised U01 and operational S05 DMI-HIRLAM models and visualised by ARGOS, is shown for the Copenhagen metropolitan area.

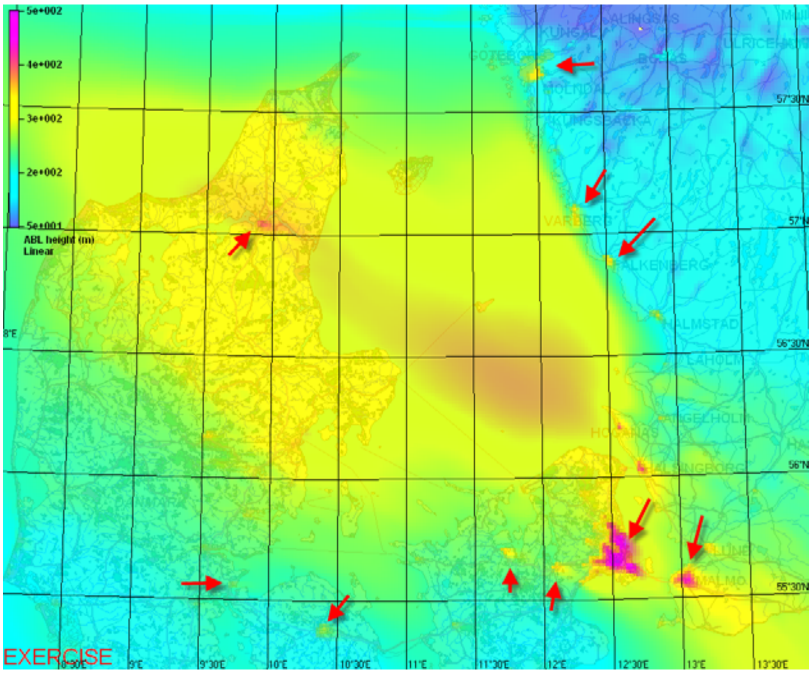


a

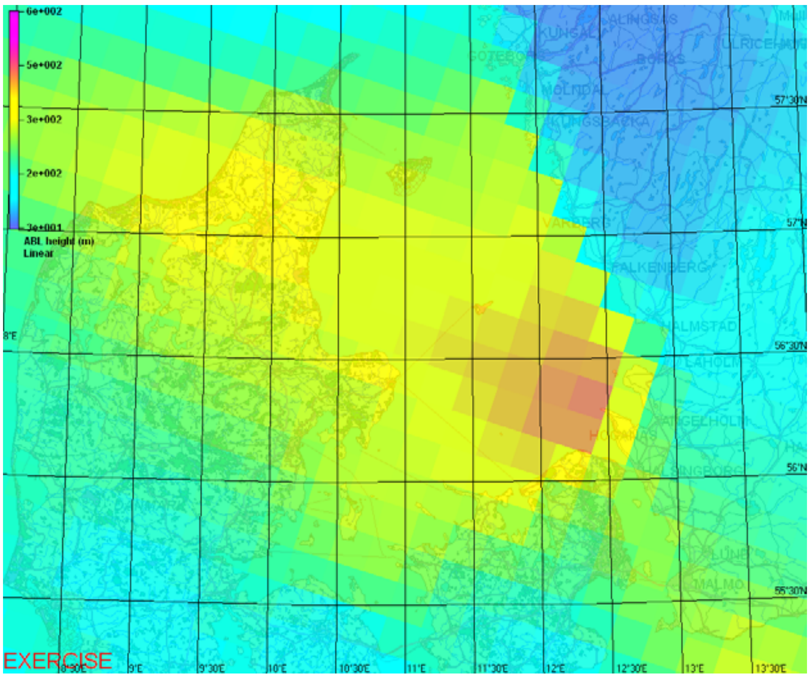


b

Figure 7.3: *A local-scale plume from the ^{137}Cs hypothetical atmospheric release in Hillerød at 00 UTC, 19 June 2005 as calculated with RIMPUFF using DMI-HIRLAM and visualised in ARGOS for the Copenhagen Metropolitan Area. Cs-137 air concentration for different DMI-HIRLAM data: a) urbanised U01, 1.4 km resolution, b) operational S05, 5 km resolution.*



a



b

Figure 7.4 The mixing height for a large part of Denmark as calculated from different versions of DMI-HIRLAM: a) urbanised U01, b) operational T15 . Main cities are shown by arrows.

250 m resolution land orography data were used for the ARGOS simulations. Figure 7.4 shows the differences in the mixing heights, simulated for the two versions of DMI-HIRLAM (urbanised U01 and operational S05) and considered in the above ARGOS simulations. The urban heat island effect, considered by the urbanised

version U01, on MH over Copenhagen, Malmö and other Danish and Swedish cities (marked by arrows) is very visible in Figure 7.4a. The mixing height considerably affects the air concentration and deposition levels of the contaminants.

The sensitivity of the dispersion pattern on the meteorological data (operational non-urbanised 5-km S05 and city-scale 1.4-km urbanised U01) is large: the differences in dispersion, as seen in Figure 7.3, lead to different levels of contamination over the city areas and to different areas contaminated by the plume.

Finally, the sensitivity of the population exposure (doses) to the urban improvements in the DMI-HIRLAM model, used for the ARGOS simulations, has been studied. One example of the simulations is presented in Table 7.1. As can be seen, the doses for populations of different towns and areas of Copenhagen are very different for the non-urbanised operational S05 (lower table) and for urbanised 1.4-km resolution U01 (upper table).

Table 7.1: The population doses, calculated by ARGOS for the hypothetical release considered, based on the non-urbanised operational S05 (lower table) and the urbanised 1.4-km resolution U01 (upper table).

U01 1.4 km modified/urbanised

Community	Collective	Potential	Expected
Lyngby-Taarbæk	4.97	0.00231	0.00224
Søllerød	3.65	0.00274	0.00267
Gentofte	3.51	0.00121	0.00118
Birkerød	2.72	0.003	0.00292
Hørsholm	1.89	0.00186	0.00181
Karlebo	1.29	0.00155	0.00151
Hillerød	1.02	0.000667	0.000648
Tårnby	0.912	0.000512	0.000497
Allerød	0.396	0.000411	0.0004
København Ø	0.00734	2.11e-006	2.05e-006
København S	0.000114	2.5e-008	2.43e-008
København C	7.07e-006	6.29e-009	6.11e-009

S05 5 km non-modified

Community	Collective	Potential	Expected
Hørsholm	10.1	0.0101	0.00978
Birkerød	7.16	0.00797	0.00774
Søllerød	7.82	0.00597	0.0058
Karlebo	1.09	0.00132	0.00128
Lyngby-Taarbæk	0.345	0.000162	0.000157
Allerød	8.43e-015	4.35e-019	3.65e-019

The collective doses for populations of different towns and areas of Copenhagen are very different for the non-urbanised operational S05 and for urbanised 1.4-km resolution U01 due to the urban effects considered, i.e. 10.1 and 1.89 (in relative units) for Hørsholm, and 7.16 and 2.72 for Birkerød.

7.3 References

Baklanov, A. (2002) The mixing height in urban areas – a review. In: *Mixing heights and inversions in urban areas*, COST Action 715. EC Publication (EUR 20451) pp. 9-28.

Baklanov, A. and Sørensen, J. H. (2001) Parameterisation of radionuclide deposition in atmospheric dispersion models. *Phys. Chem. Earth., 26*, 787–799.

Baklanov, A., Mestayer, P., Clappier, A., Zilitinkevich, S., Joffre, S., Mahura, A. and Nielsen, N.W. (2005a) On the parameterisation of the urban atmospheric sublayer in meteorological models. *Atmos. Chem. Phys. Discuss., 5*, 12119-12176.

Baklanov, A., Sørensen, J.H., Hoe, S.C. and Amstrup, B. (2005b) Urban meteorological modelling for nuclear emergency preparedness. (NKS Conference on Radioactive Contamination in Urban Areas, May 7-9, 2003, Risø, Roskilde, Denmark), *J. Envir. Radioact.* In press.

Baklanov, A., Hänninen, O., Slørdal, L.H., Kukkonen, J., Sørensen, J.H., Bjergene, N., Fay, B., Finardi, S., Hoe, S.C., Jantunen, M., Karppinen, A., Rasmussen, A., Skouloudis, A. and Sokhi, R.S. (2005c) Integrated systems for forecasting urban meteorology, air pollution and population exposure. *Atmos. Chem. Phys. Discuss., 6,* 1867-1913. URL:http://www.atmos-chem-phys.org/acpd/6/1/ http://www.copernicus.org/EGU/acp/acpd/6/1867/acpd-6-1867.pdf

Brook, D.R., Felton, N.V., Clem, C.M., Strickland, D.C.H., Griffiths, I.H., Kingdon, R.D., Hall, D.J. and Hargrave, J.M. (2003) Validation of the Urban Dispersion Model (UDM). *Int. J. Environ. Poll., 20*, 11-21.

Finardi S. (Ed.), Baklanov, A. Clappier, A., Fay, B., Joffre, S., Karppinen, A., Ødegaard, V., Sørdal, L. H., Sofiev, M., Sokhi, R.S. and Stein, A. (2005) Improved interfaces and meteorological pre-processors for urban air pollution models. Deliverable 5.2-3 of the EC FUMAPEX project, Arianet, Milan, Italy.

Graziani, G., Klug, W. and Moksa, S. (1998) Real-Time Long-Range Dispersion Model Evaluation of the ETEX First Release. Luxenbourg, Joint Research Centre, EU.

Hoe, S., Sørensen, J.H. and Thykier-Nielsen, S. (1999) The Nuclear Decision Support System ARGOS NT and Early Warning Systems in Some Countries around the Baltic Sea. In: *Proceedings of the 7th Topical Meeting on Emergency Preparedness and Response, September 14–17, 1999, Santa Fe, New Mexico, USA.*

Hoe, S., Müller, H. and Thykier-Nielsen, S. (2000) Integration of dispersion and radioecological modelling in ARGOS NT. In: *Proceedings of IRPA 10, Tenth International Congress of the International Radiation Protection Association, Hiroshima, Japan, May 14-19, 2000.*

Hoe, S.C., Müller, H., Gering, F., Thykier-Nielsen, S. and Sørensen, J. H. (2002) ARGOS 2001 a Decision Support System for Nuclear Emergencies. In: *Proceedings of the Radiation Protection and Shielding Division Topical Meeting, April 14–17, 2002, Santa Fe, New Mexico, USA.*

Mikkelsen, T., Thykier-Nielsen, S., Astrup, P., Santabárbara, J.M., Sørensen, J.H., Rasmussen, A., Robertson, L., Ullerstig, A., Deme, S., Martens, R., Bartzis, J.G. and Päsler-Sauer, J. (1997) MET-RODOS: A Comprehensive Atmospheric Dispersion Module. *Radiat. Prot. Dosim., 73* 45–56.

Mikkelsen, T., Larsen, S.E. and Thykier-Nielsen, S. (1984) Description of the Risø puff diffusion model. *Nucl. Tech.*, *67*, 56–65.

Erhardt, J. and Weiss, A. (eds.) (2000) RODOS: Decision support system for off-site nuclear emergency management in Europe. Final project report. EC DG Research, EURATOM (EUR 19144 EN).

Sass, B.H., Nielsen, N.W., Jørgensen, J.U., Amstrup, B., Kmit, M. and Mogensen, K.S. (2002) The operational DMI-HIRLAM system – 2002 version. Copenhagen, Danish Meteorological Institute (DMI Technical Report 02–05).

Sohier, A. and Hardeman, F. (2005) Radiological Dispersion Devices: Are we prepared? (NKS Conference on Radioactive Contamination in Urban Areas, May 7-9, 2003, Risø, Roskilde, Denmark), *J. Envir. Radioact.* In press.

Sørensen, J. H. (1998) Sensitivity of the DERMA Long-Range Dispersion Model to Meteorological Input and Diffusion Parameters. *Atmos. Environ., 32,* 4195–4206.

Sørensen, J.H., Rasmussen, A. and Svensmark, H. (1996) Forecast of Atmospheric Boundary Layer Height Utilised for ETEX Real-time Dispersion Modelling. *Phys. Chem. Earth, 21*, 435–439.

Sørensen, J. H., Rasmussen, A., Ellermann, T. and Lyck, E. (1998) Mesoscale Influence on Long-range Transport; Evidence from ETEX Modelling and Observations. *Atmos. Environ., 32*, 4207–4217.

Thykier-Nielsen, S. and Roed, J. (2005) Dispersion as a consequence of detonation of a dirty bomb in an urban area. (NKS Conference on Radioactive Contamination in Urban Areas, May 7-9, 2003, Risø, Roskilde, Denmark), *J. Envir. Radioact.* In press.

Zilitinkevich, S. and Baklanov, A. (2002) Calculation of the height of stable boundary layers in practical applications. *Bound. Layer Meteorol.*, *105*, 389-409.

8. Concluding remarks

In this report the various UAQIFSs that have been implemented in the six FUMAPEX target cities, have been described. In Table 8.1 an overview of the model elements of the different UAQIFSs is presented.

Table 8.1: Overview of the applied models within the target city UAQIFSs.

Target City	Met. model	Met. Pre-processor	AQ model
Oslo, Norway	met.no-HIRLAM (hydrostatic NWP model) / MM5 (non-hydrostatic mesoscale model)	METPRO	Eul: AirQUIS /EPISODE Gaus: Subgrid line- and point-source models
Helsinki, Finland	FMI-HIRLAM (hydrostatic NWP model)	MPP-FMI / SILAM-PP / HIRLAM turbulence parameterisation	Eul: HILATAR Lagr: SILAM Gaus: CAR-FMI/OSPM UDM-FMI
Castellon area, Spain	RAMS (non-hydrostatic mesoscale model)	RAMS generates CAMx input	Eul: CAMx
Turin, Italy	RAMS/LAMI (non-hydrostatic mesoscale model)	SURFPRO	Eul: FARM/CHIMERE
Bologna, Italy	LAMI (non-hydrostatic mesoscale model)	CALMET-SMI	Stat: OPPIO Gaus: ADMS-Urban Eul: NINFA/CHIMERE
Copenhagen, Denmark	DMI-HIRLAM (hydrostatic NWP model)	LSMC pre-proc. RODOS met-pre-proc. H_{mix} Calculation Library	Lagr: DERMA and ARGOS

As seen from Table 8.1 differences in topographic-, climatic-, and pollution-characteristics within the various target city areas clearly have lead to differences in methodical approach. An example is the use of hydrostatic NWP models (variants of the HIRLAM model) in the target cities surrounded by practically flat terrain like Copenhagen and Helsinki, whereas non-hydrostatic mesoscale circulation models (RAMS, MM5, LAMI) are applied in more complex terrain areas like Oslo, Turin, Bologna and Valencia/Castellón.

At present most of the boundary layer parameterisations applied in the meteorological models and the meteorological pre-processors are based on traditional Monin-Obukhov similarity theory. However, as part of the project activities in FUMAPEX Work Package 4 and 5, urban effects are now being introduced into these traditional schemes, thereby improving model performances in urban areas.

The UAQIFS descriptions of the preceding sections have also revealed that there is a clear north-south difference in that the UAQIFSs are focused on predicting (mostly wintertime) episodes of NO_2 and PM_{10} in the northern cities (Helsinki and Oslo) while summertime ozone forecasts are of equal importance for the southern cities (Valencia/Castellón, Turin and Bologna). Since larger (regional) spatial scales are of importance for successfully forecasting the summertime episodes, larger modelling domains are needed within the southern city UAQIFSs.

Since the UAQIFS for the Copenhagen Metropolitan area is an emergency preparedness system, this system primarily focuses on accidental releases of radioactive materials. This difference in scope has clearly influenced the modelling choice and system set-up for this UAQIFS.

The end-users of the project have been heavily involved in the writing of this report. This end-user involvement has also been essential in order to promote further application of the scientific achievements within FUMAPEX beyond the three-year project period. The implementation of similar systems in other cities will benefit considerably from the experience gathered through the implementation, testing and demonstration exercise performed in FUMAPEX.

Norwegian Institute for Air Research (NILU)
P.O. Box 100, N-2027 Kjeller, Norway

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ABSTRACT
The major goal of the FUMAPEX project has been to improve the performance of Urban Air Quality Information and Forecasting Systems (UAQIFS) presently applied in various urban areas in Europe. The scientific focus has been on improving the meteorological forecast data that are applied as input to the UAQIFS. The scientific improvements have subsequently been demonstrated in six European target cities as part of the project. The demonstration activity was defined as a separate Work Package (WP8) within FUMAPEX. The present report (deliverable 8.2) gives a detailed technical description of each of the six target city UAQIFSs. i.e. Oslo (Norway), Helsinki (Finland), the Castellon/Valencia region (Spain), Turin (Italy), Bologna (Italy), and Copenhagen (Denmark).

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Forbedrede varslingsystemer for luftkvalitet implementert og anvendt i utvalgte Europeiske byer

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Urban	Air quality	Forecasting systems

ABSTRACT (in Norwegian)
Hovedmålet i prosjektet FUMAPEX har vært å forbedre systemene som i dag benyttes for luftkvalitetsvarsling i ulike Europeiske byer. Det forskningsmessige fokus har vært rettet mot forbedringer i de meteorologiske prognosedataene som brukes som inngangsdata til luftkvalitetsvarselet. De forskningsmessige resultatene er deretter, som en del av prosjektet, blitt demonstrert i seks utvalgte europeiske byer. Demonstrasjonsaktiviteten ble definert som en egen arbeidspakke (arbeidspakke 8) i FUMAPEX. Den foreliggende rapport (leveranse 8.2) gir en detaljert teknisk beskrivelse av varslingssystemene i de seks utvalgte byene, d.v.s. i Oslo (Norge), Helsinki (Finland), Castellon (Spania), Torino (Italia), Bologna (Italia) og København (Danmark).

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