Possibilities of NWP Models for UAQ Forecasting and Items of the EU FUMAPEX Project

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The quality of the urban air pollution forecast and the Urban Air Quality Information and Forecasting Systems (UAQIFS) critically depends on:

- **the mapping of emissions,**
- **the UAP model, and**
- **the quality of meteorological forecast data.**

WHY to study it now ?

Meteorological fields constitute a main source of uncertainty in urban air quality (UAQ) models.

Historically, UAQ forecasting and NWP models were developed separately and there is no tradition for co-operation between the modelling groups.

This was plausible in the previous decades when the resolution of NWP and climate models was too poor for city-scale air pollution forecasting, but the situation has now changed and it is obvious that **a revision of the conventional conception of urban air quality forecasting is required**.

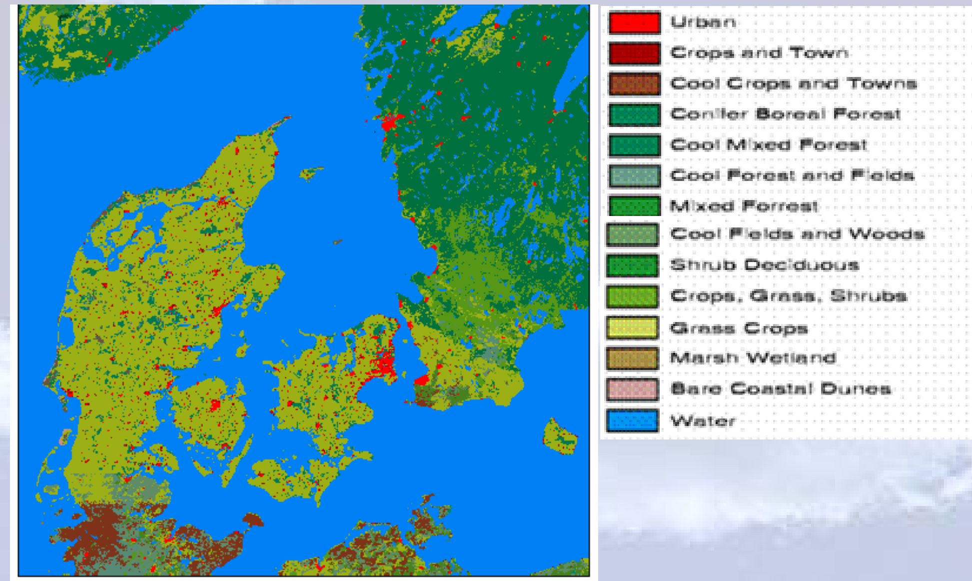
Possibilities of NWP Models for UAP forecasting

- During the last decade substantial progress in NWP modelling and in the description of urban atmospheric processes was achieved.
- Modern nested NWP models are approaching the resolution of the meso- and city-scale utilising land-use databases down to 1 km resolution or finer.
- In combination with the recent scientific developments in the field of urban atmospheric physics and the enhanced availability of high-resolution urban surface characteristics, the capability of the NWP models to provide high quality urban meteorological data will therefore increase.
- Existing operational UAP models often employ simple local measurements and meteorological pre-processors with a poor description of the temporal and spatial evolution of meteorological variables on the urban scale.
- Modern UAP models demand a lot more of additional meteorological input data, such as humidity distribution, cloud characteristics, intensity and type of precipitation, radiation characteristics etc.
- Clearly, present UAP models could greatly benefit from utilising meteorological data from NWP models to give a physically consistent basis for urban air quality forecasts.

Recent achievements:

- high resolution (up to 1.4 km horizontal resolution) numerical modelling of regional meteorological processes;
- on-line coupled meteorological and atmospheric pollution modelling;
- new algorithms for the long-lived SBLs in numerical atmospheric models;
- atmospheric chemistry and aerosol dynamics and deposition models;
- using fields of effective roughness length, satellite-based sea surface temperature and albedo in DMI-HIRLAM-E model;
- highly accurate scheme for transport and dynamics in atmospheric models.

Land-use classification and roughness simulation in DMI-HIRLAM model



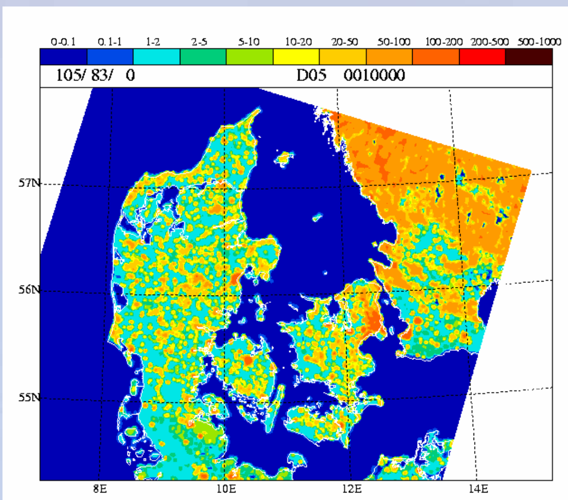
< Land-use classification over Denmark with 1 km resolution.

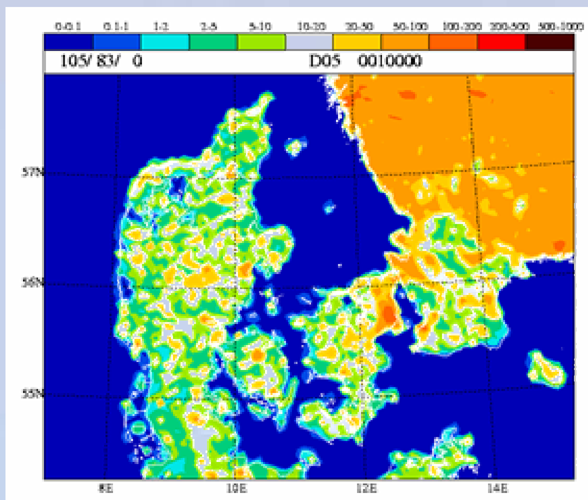
Roughness length for:

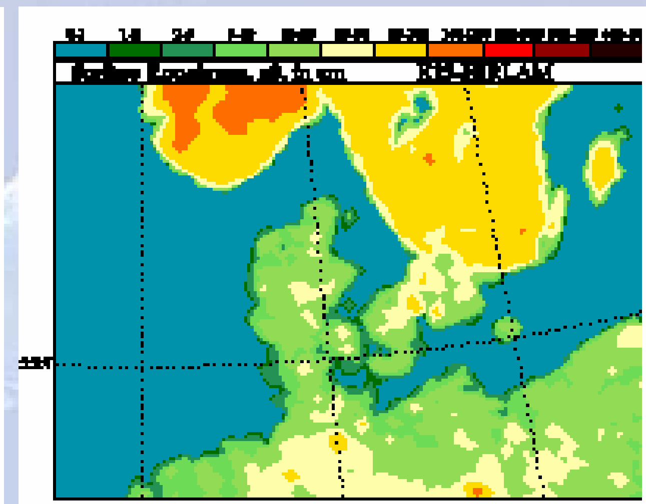
(left) I-version in 1.4 km resolution,

(centre) D-version in 5 km resolution,

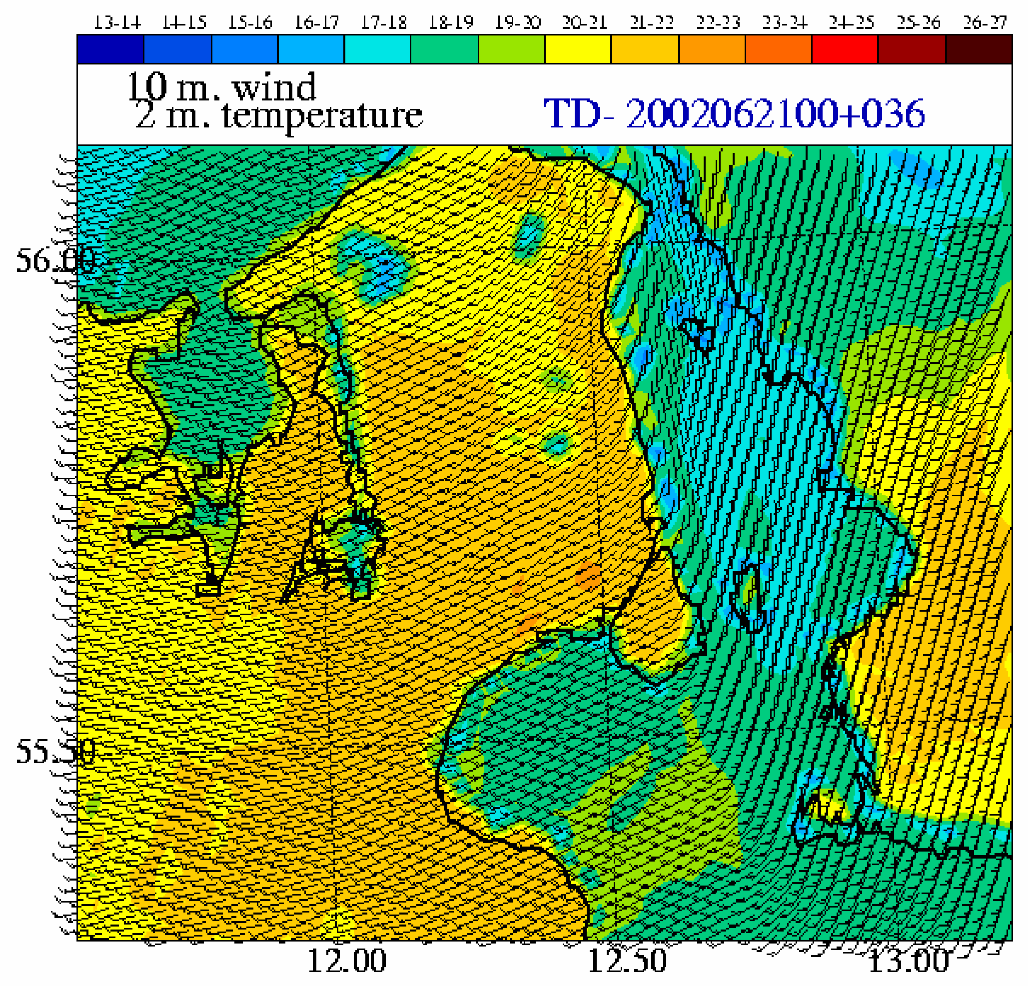
(right) E-version in 15 km resolution.

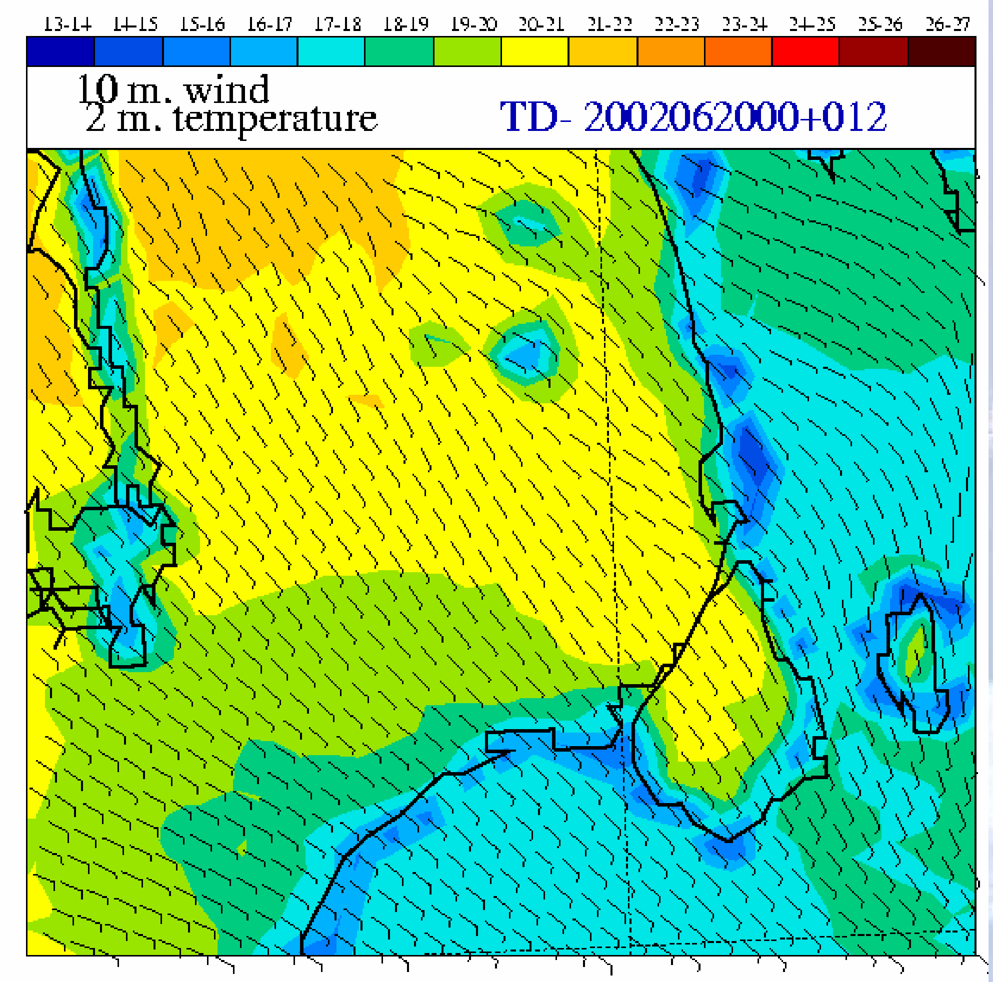






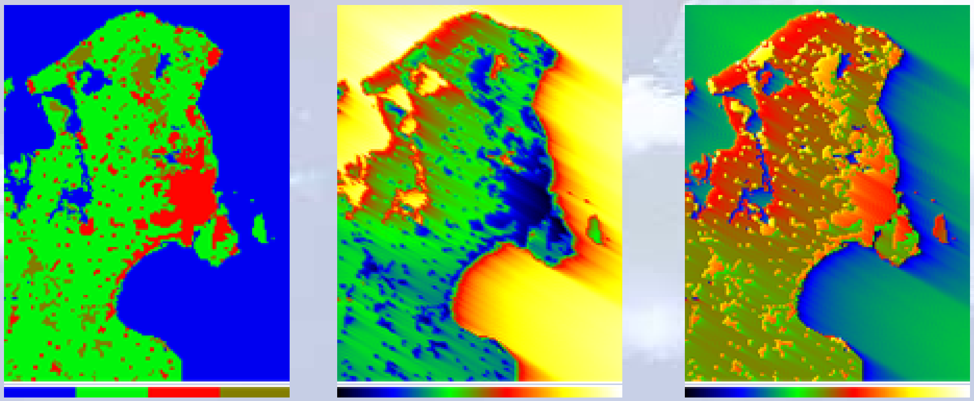
High resolution DMI-HIRLAM NWP forecast for Copenhagen area



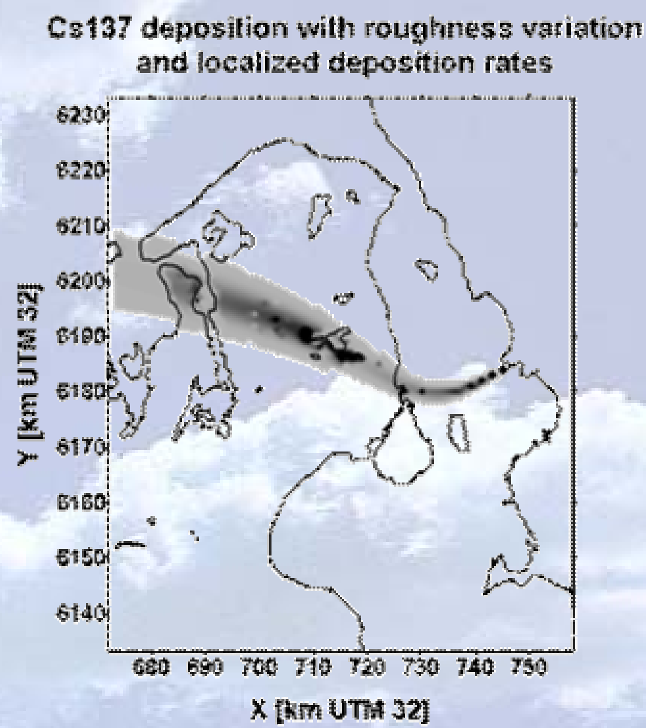


Examples of forecasted wind fields at 10-meter height and of 2-meter air temperature for the Copenhagen metropolitan area by the experimental version of DMI-HIRLAM with the horizontal resolution of 1.4 km.

HIRLAM-LINCOM-RIMPUFF simulations of a hypothetical accident at the Barsebæk NPP for the Copenhagen metropolitan area

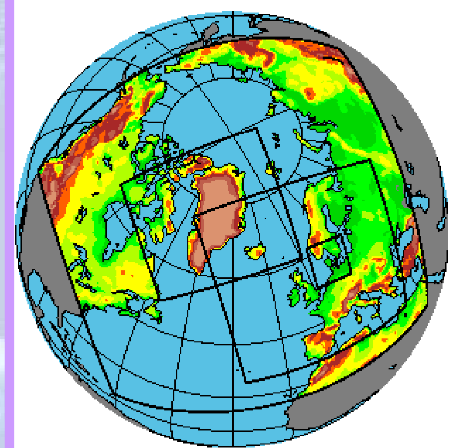


0.5 km * 0.5 km grid. left: Roughness distribution (z_0); mid: LINCOM-z_0 mean wind field (U); right: LINCOM-z_0 generated turbulence wind field (U_*).



Structure of the Danish nuclear emergency modelling system.

DMI-HIRLAM system
- *G-version: 0.45 grad*
- *E, N-versions: 0.15 grad*
- *D-version: 0.05 grad*

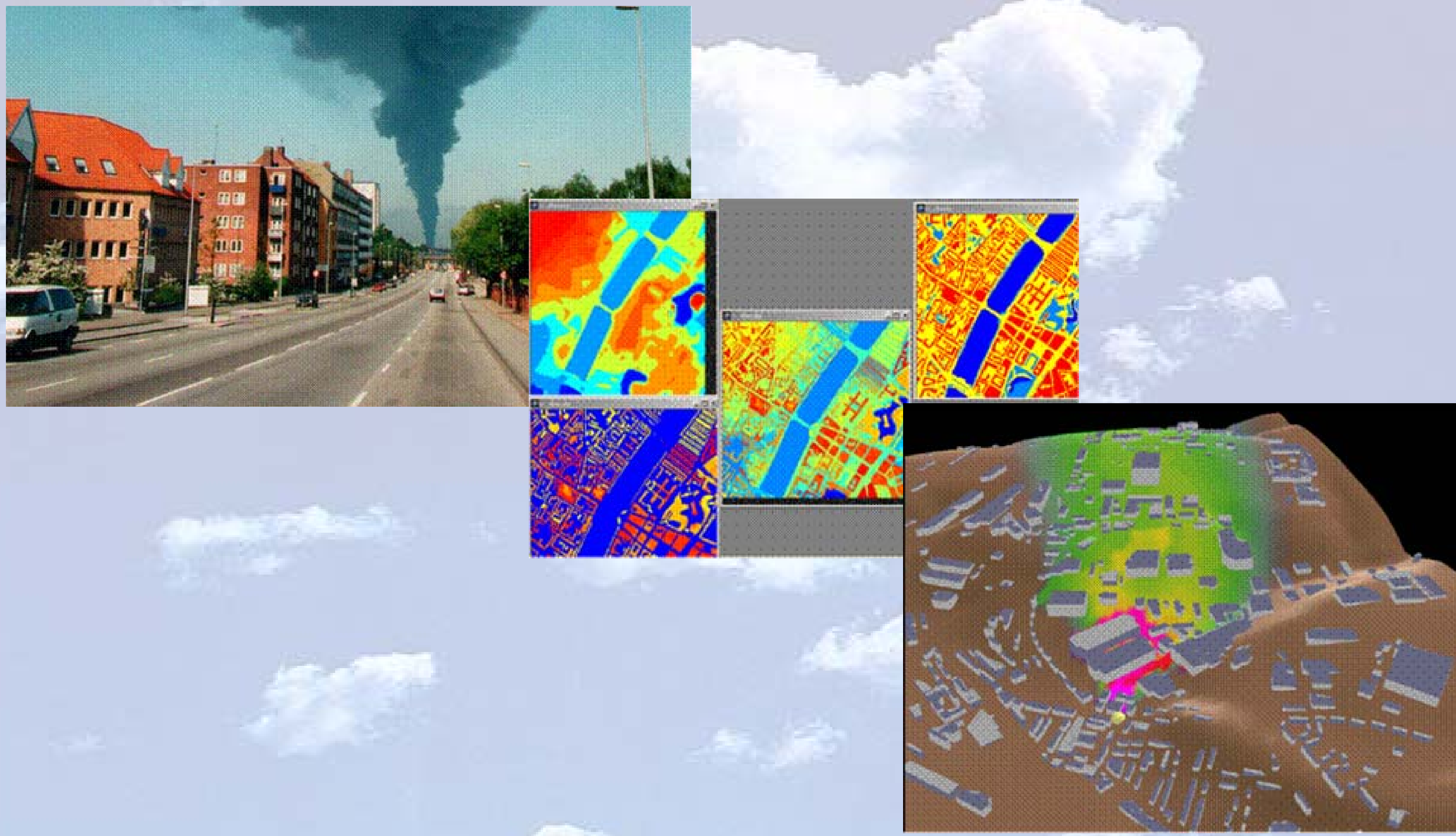


ECMWF global model

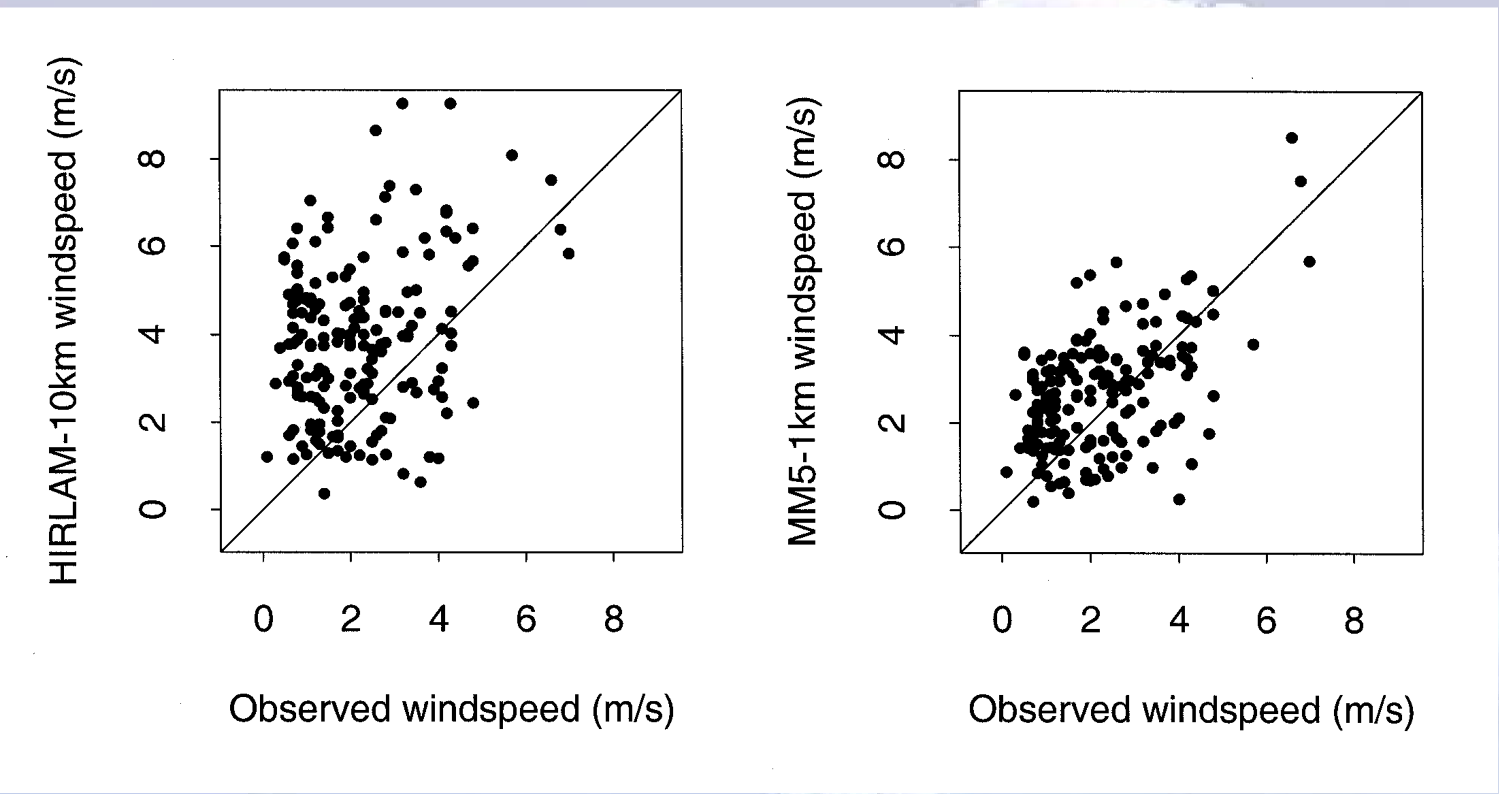
DERMA model
- ***3-D trajectory model***
- ***Long-range dispersion***
- ***Deposition of radionuclides***
- ***Radioactive decay***

ARGOS system
- ***Radiological monitoring***
- ***Source term estimation***
- ***RIMPUFF local-scale model***
- ***Health effects***

Simulation of urban accident consequences by the ARGOS/Rimpuff/UDM system

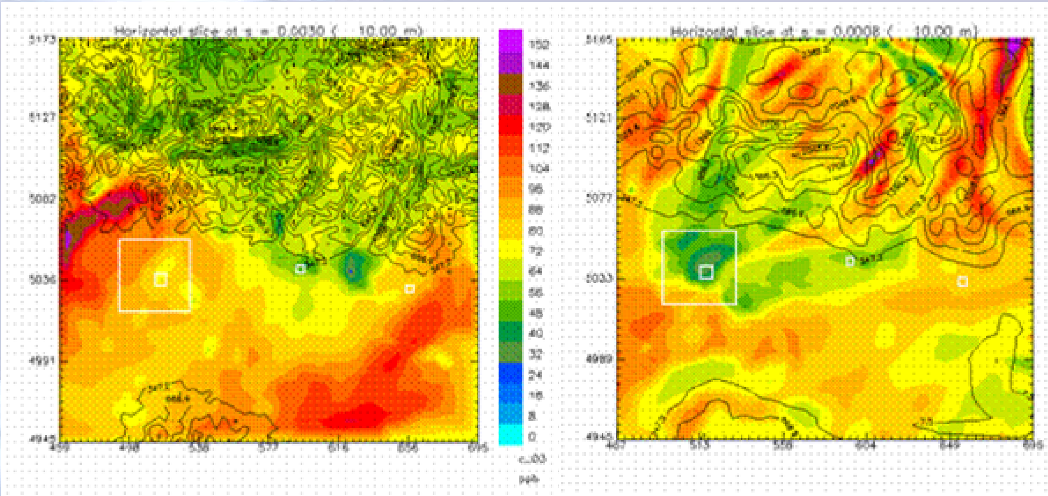


NILU-DNMI urban forecasting system for Oslo:

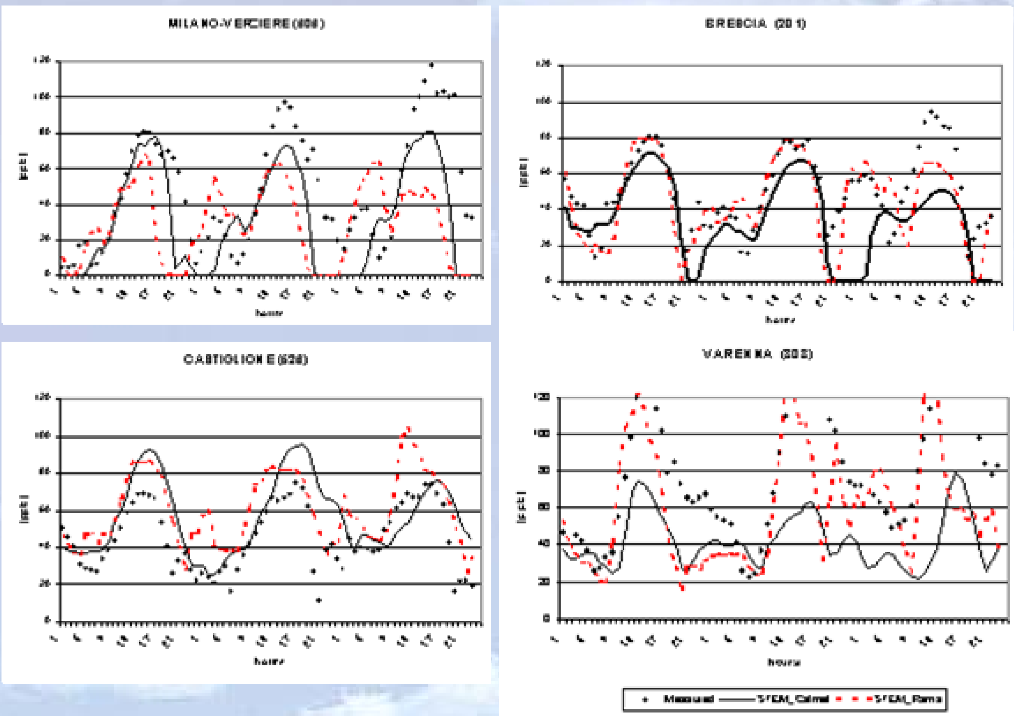


Observed and modelled wind speeds at Valle Hovin, a meteorological station in Oslo, for 22 days during the winter 1999/2000.

Sensitivity of UAP models to generated prognostic & diagnostic meteo-fields

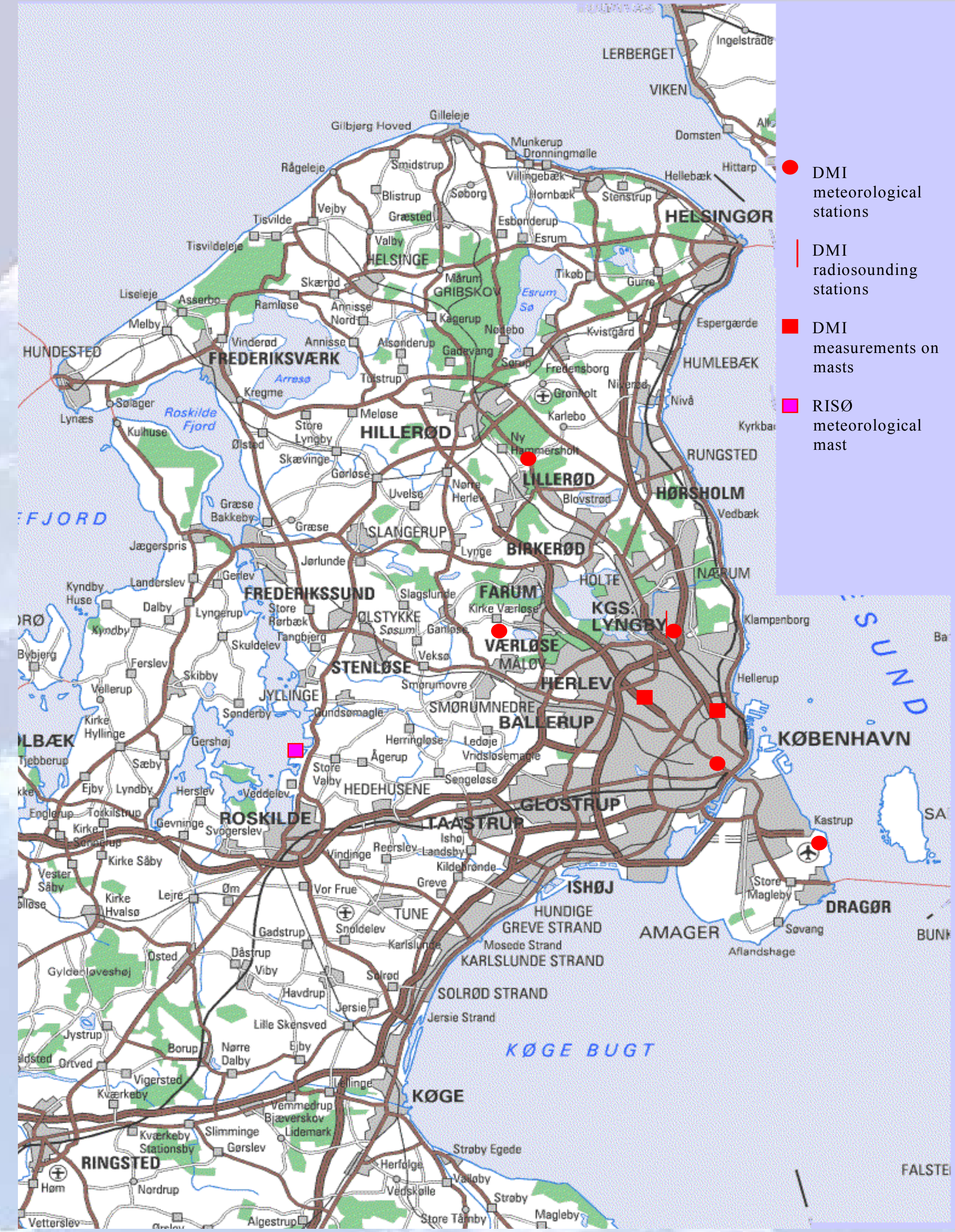


Surface O3 concentrations over the Lombardia Region obtained from CALMET+STEM-FCM (left) and RAMS+STEM-FCM (right) on June 7th 1996 at 16:00.

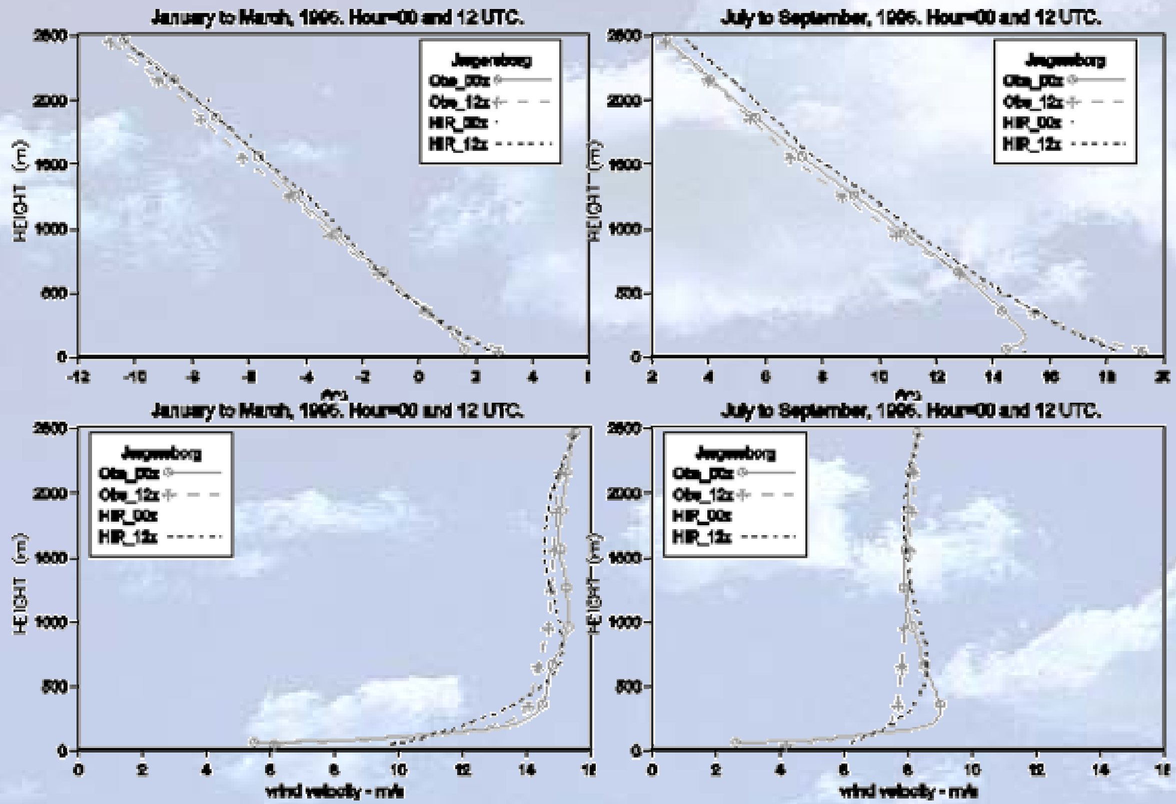


Comparison among ozone concentrations computed by CALMET+STEM-FCM (solid line), RAMS+STEM-FCM (dashed line) and observations (dotted line), for the period June 5th – 7th 1996. The plotted stations refer to Milan city (upper left), Brescia city (upper right), central Po Valley countryside (lower left) and Como Lake shore (lower right).

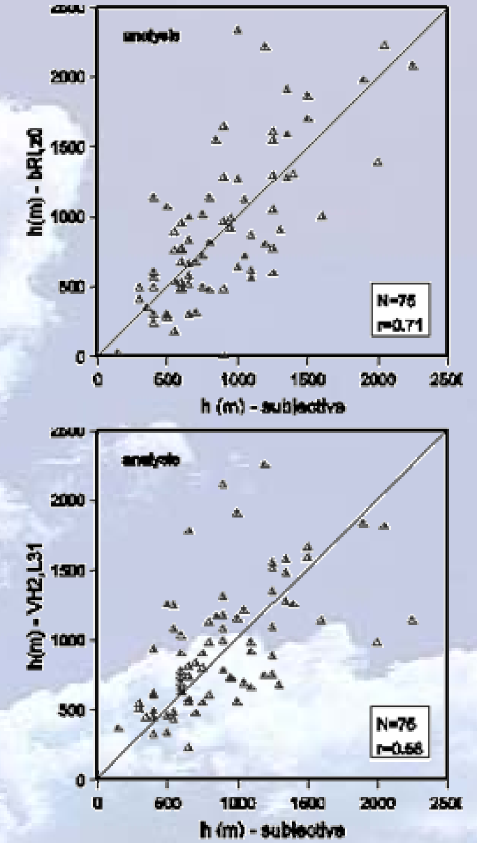
Meteorological monitoring in the Copenhagen metropolitan area



Verification of DMI-HIRLAM for Jægersborg station, Copenhagen



The mean profiles of the temperature (upper) and wind-velocity (down) at 00 and 12 UTC for the periods January to March (left) and July to September (right)

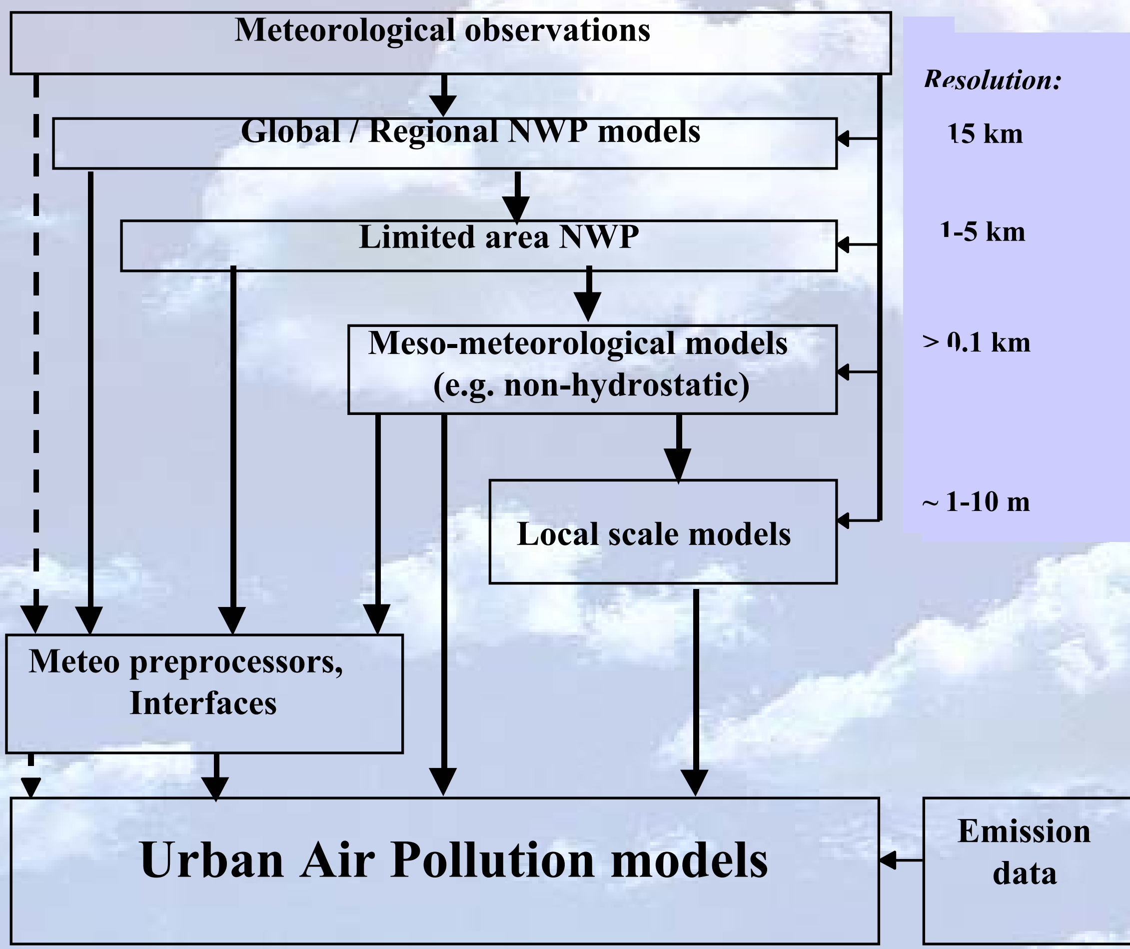


Scatter plots of the MH, measured and calculated from DMI-HIRLAM data by standard bulk Ri-method (left) and by Vogelezang-Holtslag method (right).

Shortcomings:

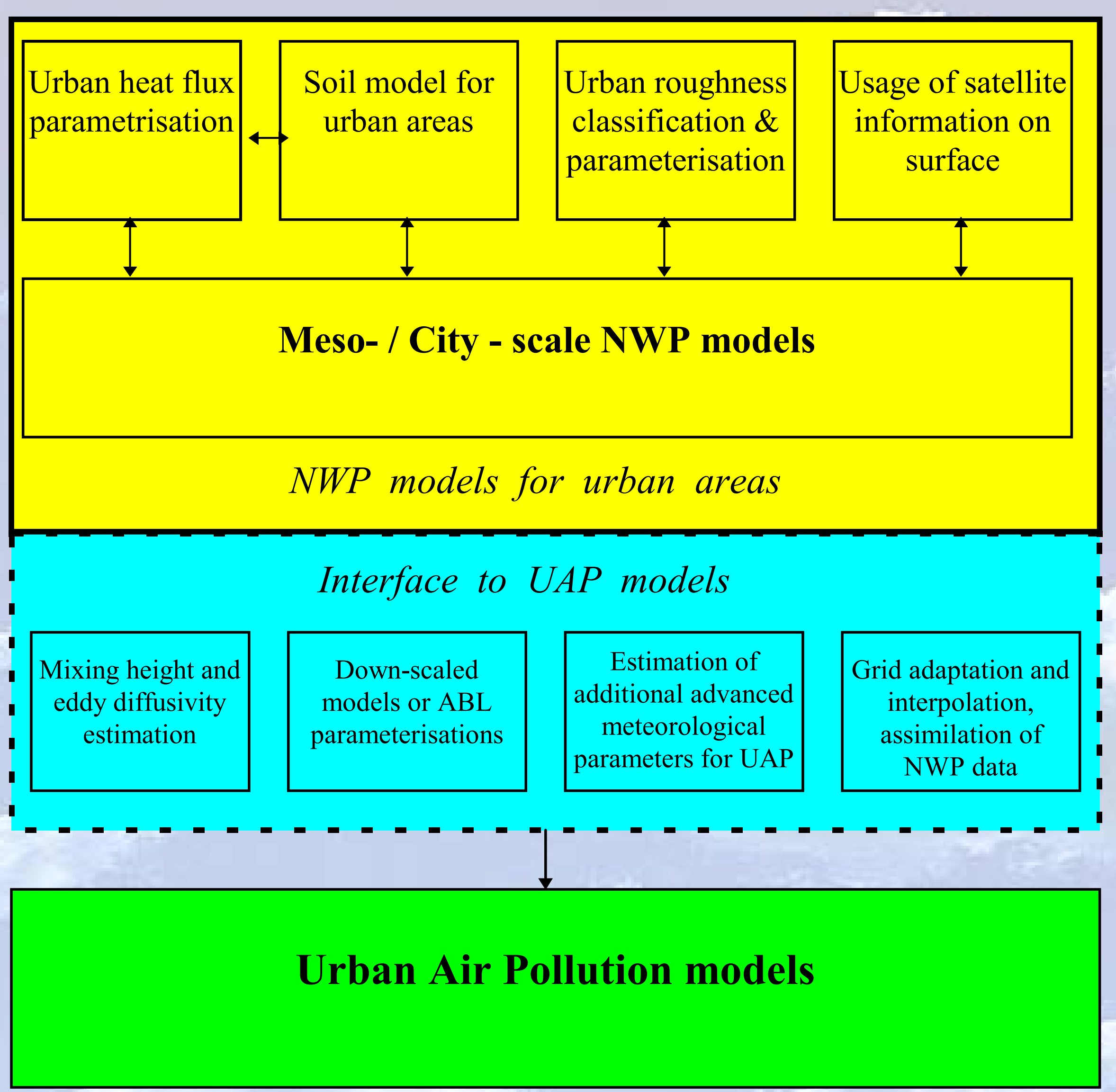
- Despite the increased resolution of existing operational NWP models, urban and non-urban areas mostly contain similar sub-surface, surface, and boundary layer formulation.
- These do not account for specifically urban dynamics and energetics and their impact on the numerical simulation of the atmospheric boundary layer and its various characteristics (e.g. internal boundary layers, urban heat island, precipitation patterns).
- Additionally, NWP models are not primarily developed for air pollution modelling and their results need to be designed as input to urban and mesoscale air quality models.

Current regulatory (dash line) and suggested (solid and dash lines) ways for systems of forecasting of urban meteorology for UAQIFS



Resolution:	*Models, e.g.:*
15 km	ECMWF HIRLAM GME
1-5 km	LM HIRLAM,
> 0.1 km	MM5, RAMS, LM
~ 1-10 m	CFD, box models

Improvements of meteorological forecasts (NWP) in urban areas and interfaces to UAP models for the Urban Air Quality Information Forecasting Systems.



Main problems to be solved:

• Nested high resolution, urban scale resolved models; coupling atmospheric mesoscale models with heterogeneous chemistry and aerosol models.

• Improvement of the urban boundary layer parameterisation, e.g. turbulent sensible and latent heat fluxes, revised roughness and land use parameters and models.

• Assimilation of surface characteristics based on satellite data and additional urban meteorological measurements for urban scale NWP models.

•A model interface capable to connect meso-scale meteorological model results to updated UAQ and atmospheric chemistry models.

• An improved urban meteorology and air pollution modelling system suitable to be applied to any European urban area on a basis of available operational weather forecast.

•Evaluation and sensitivity studies of these improvements on the meteorological input fields for UAQ models and the resulting air quality simulations.

• Testing and implementation of the improved models to urban management and emergency preparedness systems in several European cities.

European COST Action 715: URBAN METEOROLOGY
‘Meteorology Applied to Urban Air Pollution Problems’
Action period: 1999-2003
(Chairman Bernard Fisher, UK)

- WG1: Wind speed and urban dynamics (Chair M. Rotach).
- WG2: Surface energy balance and mixing height (Chair M Piringer).
- WG3: Urban air pollution episodes (Chair J. Kukkonen).
- WG4: Meteorological input data and applications (Chair M. Schatzmann).

Basel UrBan Boundary Layer Experiment (BUBLE), initiated by the Swiss COST organisation (Leader M. Rotach)

Integrated Systems for Forecasting Urban Meteorology, Air Pollution and Population Exposure

FUMAPEX

Project web-site: http://fumapex.dmi.dk

Shared-cost RTD, 2002 -2005

The Fifth Framework Programme (FP5)
Energy, Environment and Sustainable Development
Sub-programme: Environment and Sustainable Development
Key Action 4: City of Tomorrow and Cultural Heritage

Project participants

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Hamburg University, MIHU	M.Schatzmann
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Municipality of Oslo, MO	O.M. Hunnes

Scientific objectives and approach

The quality of the urban air pollution forecast and the Urban Air Quality Information and Forecasting Systems (UAQIFS) critically depends on:

(i) the mapping of emissions, (ii) the urban air pollution (UAP) models, and (iii) the meteorological data.

The quality of the meteorological data should be largely enhanced by using downscaled data from advanced numerical weather prediction (NWP) models. These different topics, as well as the application of population exposure models, have traditionally been treated in distinct scientific and administrative communities whose expertise needs to be combined to enhance the possibilities of forecasting air pollution episodes in European cities.

The main objectives of the project are thus the improvement of meteorological forecasts for urban areas, the connection of NWP models to UAP and exposure models, the building of improved UAQIFS, and their application in cities in various European climates.

The necessary steps will evolve in ten separate, but inter-linked Work Packages realised by 16 participants and 6 subcontractors. They represent leading NWP centres, research organisations, and organisations responsible for urban air quality, population exposure forecast and control, and local/city authorities from ten European countries.

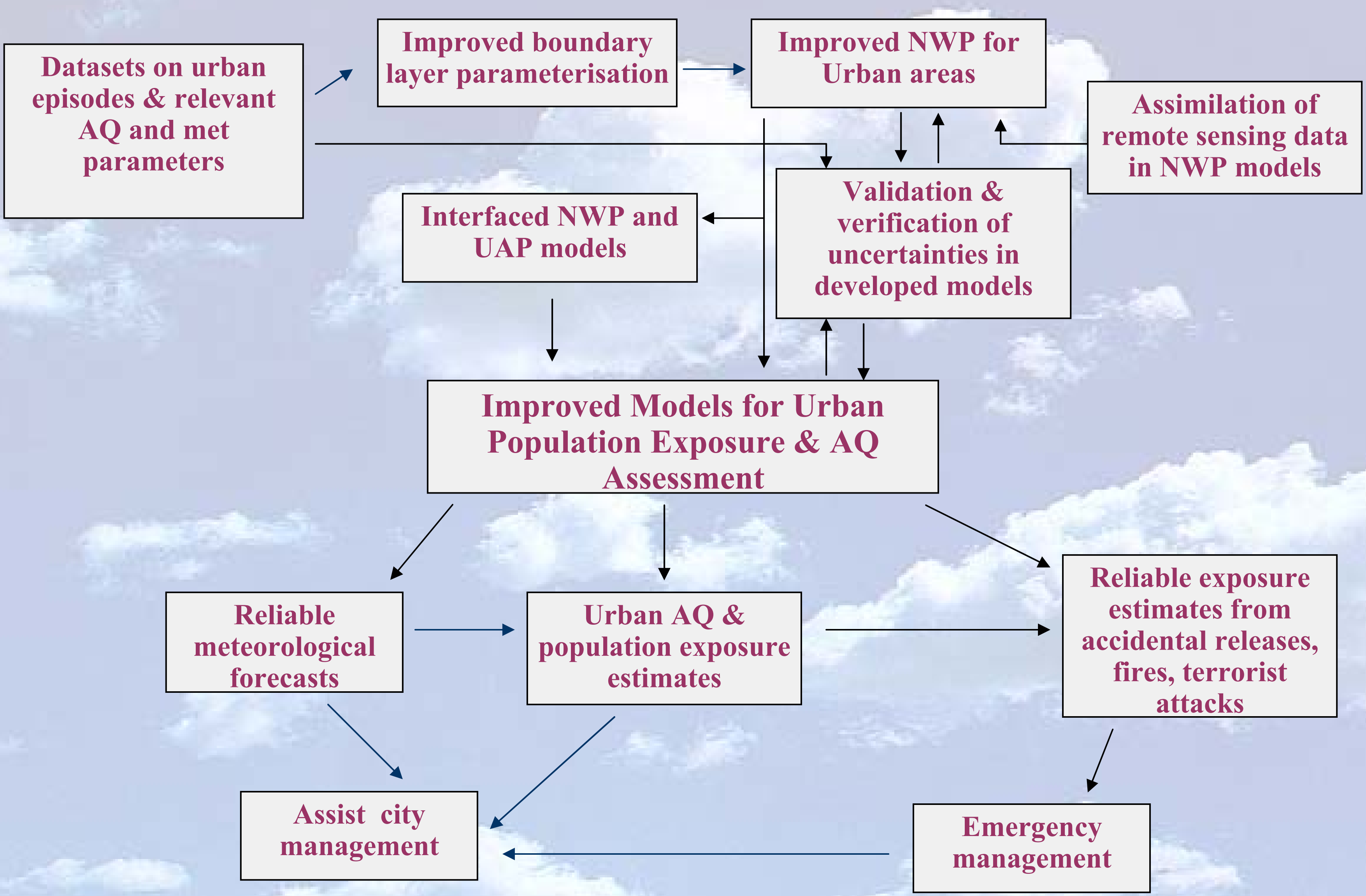
Linking of monitoring and NWP, UAP and PE modelling groups in FUMAPEX improving the UAQIFSs in Europe

- **UAP models** in operational **Urban Air Quality Information Systems (UAQIFSs)**, as a rule, use simple in-situ meteorological measurements which are fed into meteorological pre-processors. Lacking an adequate description of physical phenomena and the complex data assimilation and parameterisations of NWP models, these pre-processors do not achieve the potential of NWP models in providing all the meteorological fields needed by modern UAP models to improve the urban air quality forecasts (UAP 1998, Herrmann et al. 2000).

- Despite the increased resolution of **NWP models**, urban and non-urban areas mostly contain alike sub-surface, surface, and boundary layer formulation. These do not account for specifically urban dynamics and energetics and their impact on the numerical simulation of the atmospheric boundary layer and its various characteristics (e.g. internal boundary layers, urban heat island, precipitation patterns). Additionally, NWP models are not primarily developed for air pollution modelling and their results need to be designed as input to urban and mesoscale air quality models.

FUMAPEX:

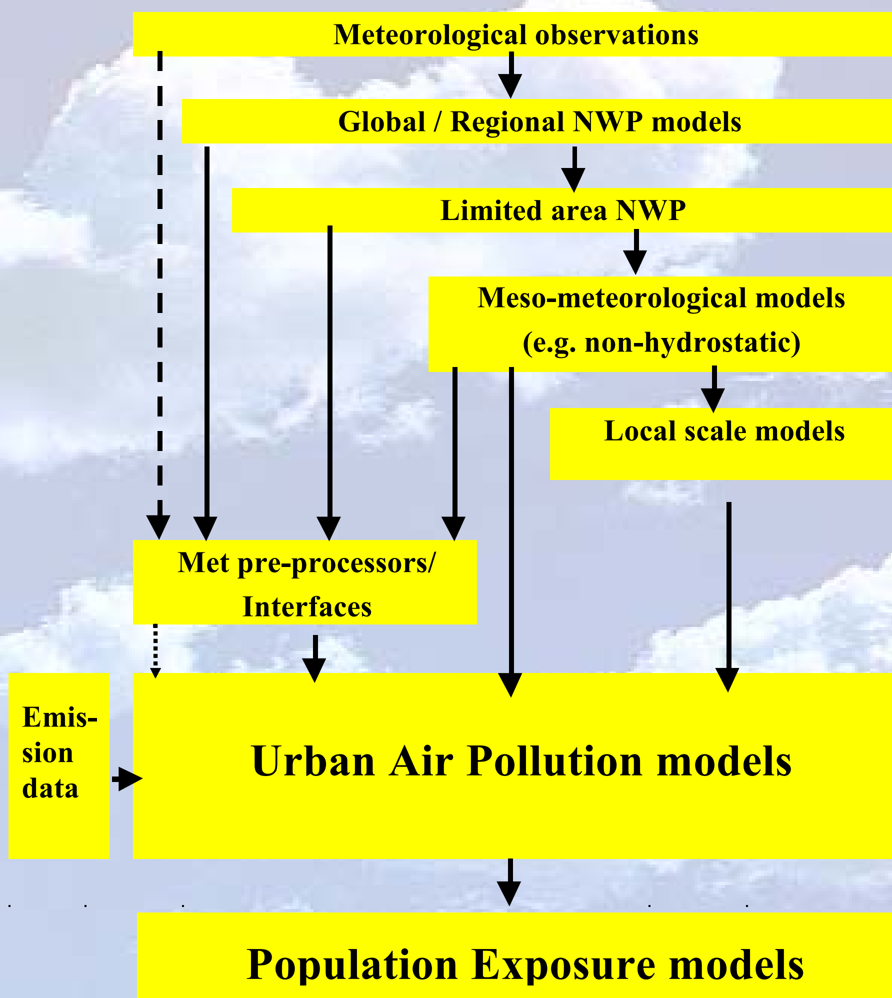
Integrated Systems for Forecasting Urban Meteorology, Air Pollution and Population Exposure



Current regulatory (dash line) and suggested (solid line) ways for systems of forecasting of urban meteorology for UAQUIFS:s.

Resolution: Models, e.g.:

≥ 15 km	**ECMWF/HIRLAM,GME**
~1-5 km	**LM, HIRLAM,**
> 0.5 km	**MM5, RAMS, LM**
~ 1-10 m	**CFD, box models**

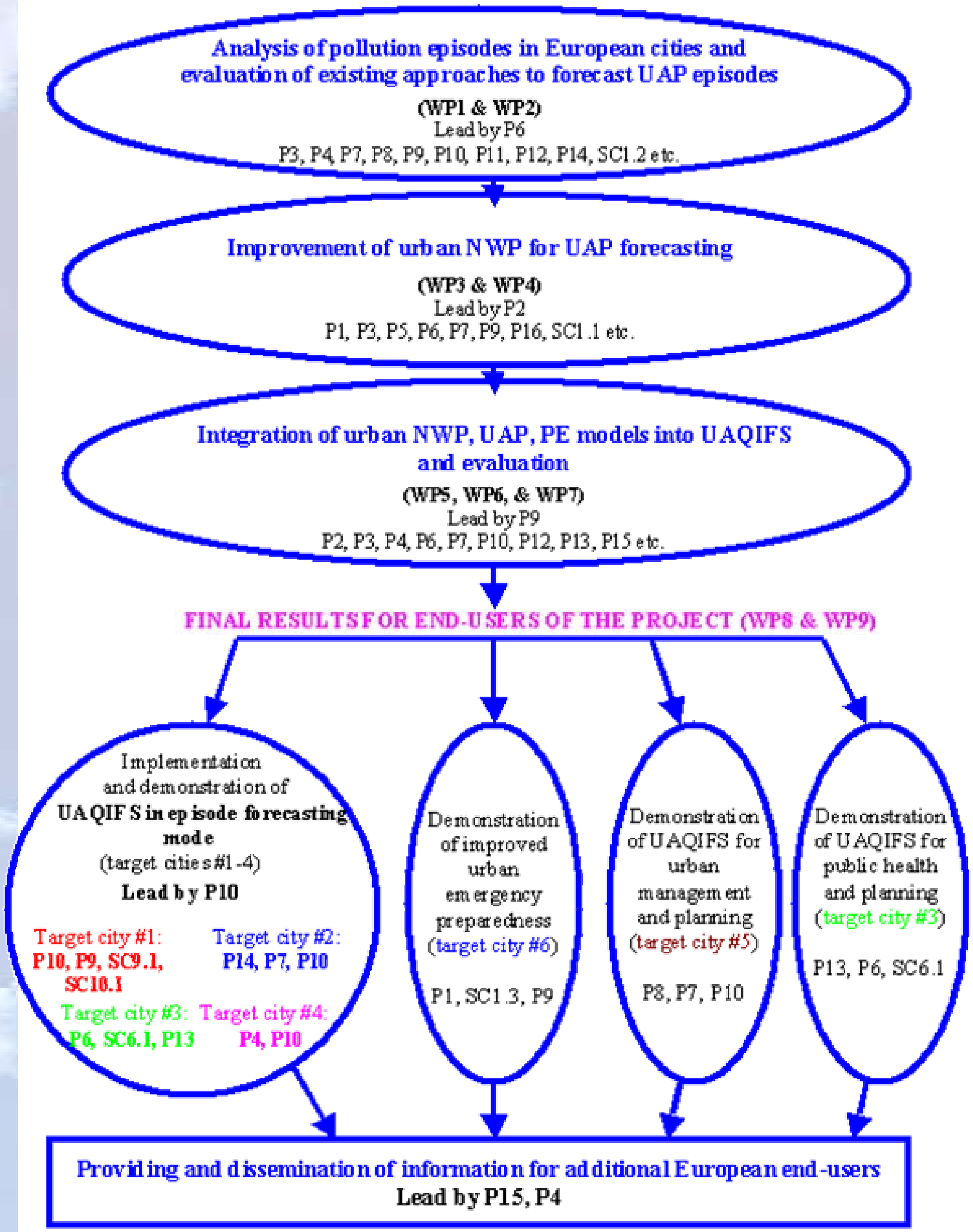


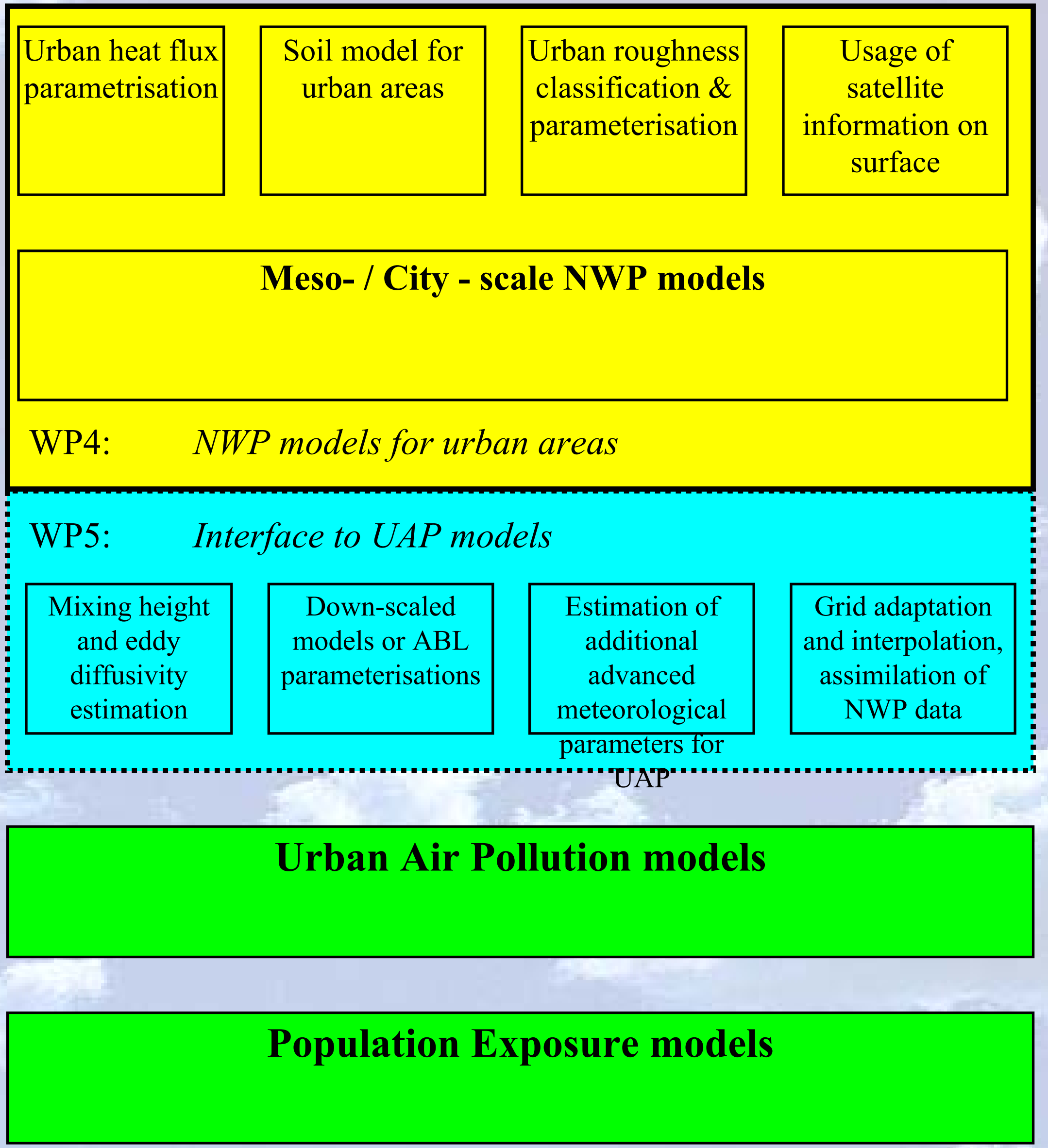
In order to achieve **the innovative FUMAPEX goal of establishing and implementing an improved new UAQIFS in four European target cities to assist sustainable urban development**, the following steps have to be achieved:

1. improve predictions of the meteorological fields needed by UAP models by refining resolution and developing specific parameterisations of the urban effects in NWP models,
2. develop suitable interface/meteorological pre-processors from NWP to UAP models,
3. validate the improvements in NWP models and meteorological pre-processors by evaluating their effects on the UAP models against urban measurement data,
4. apply the improved meteorological data to population exposure models and compare and analyse the results, and
5. successfully link meteorologists/NWP modellers with urban air pollution scientists and the ’end-users’ of UAQIFS.

In order to resolve these issues, new innovative studies are needed for the UAQIFSs that are specifically tailored to the FUMAPEX objectives:

- A **database of meteorological and chemical measurement data** for **urban air pollution episodes in European cities** will be established and **key meteorological parameters** for those episodes/climatological regions identified and classified. This will also serve for future NWP/UAP model development and validation.
- An **assessment and intercomparison** of the present simple and complex meteorological pre-processors to UAP models will be provided. The attention will be focused on the characterisation of the urban boundary layer and to the aspects more relevant to the end users needs.
- FUMAPEX will lead to the investigation and **improvement** of different **European operational weather prediction (NWP) models in urban environment** and a validation of modified NWP models on urban measurements for selected European cities and typical high pollution episodes. A study of the performance of NWP models with **higher resolution** will be provided for urban areas.
- Improved parameterisations of the **urban boundary layer in NWP models** will be established and validated, consisting of improved **urban temperature and heat flux** parameterisations (Martilli et al. 2002) and their effects on winds, turbulence, stability, and mixing height,
- The important **urban soil and surface parameterisations** (Grimmond and Oke 1999) improved by providing and validating state-of-the-art soil and roughness models for urban areas (Guilloteau & Mestayer 1999) and **scale-dependent input parameters for the obstacle resolving UAPs** required due to the new **parameterisation** of **turbulence and mixing height**, with a focus on **the relevant stable boundary layer** for urban NWP/UAP models (European regulations.
- **Improved theory and parameterisation of turbulence and mixing height, with a focus on the relevant stable boundary layer for urban NWP/UAP models** (Zilitinkevich et al. 2000, Fisher et al. 1998).
- The **extended data assimilation of surface characteristics into the urban scale NWP models** will add crucial data and thus improve the NWP models. High resolution (up to 5 m) satellite data, e.g. remotely sensed heat fluxes of urban areas (Parlow 1999), will be accommodated and assimilation algorithms developed and tested for urban areas.
- FUMAPEX will provide **improved model interfaces/meteorological pre-processors,** capable of connecting mesoscale meteorological model results and in-situ measurements to updated UAP and atmospheric chemistry models, which will incorporate the above improvements in resolution, data assimilation, and parameterisation.
- A **sensitivity study** on the relevance of the above modifications **in NWP models and meteorological pre-processors** on the detailed description of local circulation and urban meteorology will be established and validated with measurements of air pollution episodes in European cities.
- A **sensitivity study** on the relevance of the above modifications on the **performance of UAP models in UAQIFS** and validated with measurements of air pollution episodes in European cities.
- An improved urban meteorology and air pollution modelling system suitable to be applied to any European urban area on the basis of available operational weather prediction models will be established. This new UAQIFS will be implemented in selected European target cities and demonstrated with the direct participation of local authorities and other end-users.
- Linking ambient air pollution models to population time-activity to assess the true exposure levels caused by the ambient pollution.


Analysis of pollution episodes in European cities and evaluation of existing approaches to forecast UAP episodes
(WP1 & WP2)
Lead by P6
P3, P4, P7, P8, P9, P10, P11, P12, P14, SC1.2 etc.
Improvement of urban NWP for UAP forecasting
(WP3 & WP4)
Lead by P2
P1, P3, P5, P6, P7, P9, P16, SC1.1 etc.
Integration of urban NWP, UAP, PE models into UAQIFS and evaluation
(WP5, WP6, & WP7)
Lead by P9
P2, P3, P4, P6, P7, P10, P12, P13, P15 etc.
FINAL RESULTS FOR END-USERS OF THE PROJECT (WP8 & WP9)
Implementation and demonstration of UAQIFS in episode forecasting mode (target cities #1-4)
Lead by P10
Target city #1: P10, P9, SC9.1, SC10.1
Target city #2: P14, P7, P10
Target city #3: P6, SC6.1, P13
Target city #4: P4, P10
Demonstration of improved urban emergency preparedness (target city #6)
P1, SC1.3, P9
Demonstration of UAQIFS for urban management and planning (target city #5)
P8, P7, P10
Demonstration of UAQIFS for public health and planning (target city #3)
P13, P6, SC6.1
Providing and dissemination of information for additional European end-users
Lead by P15, P4

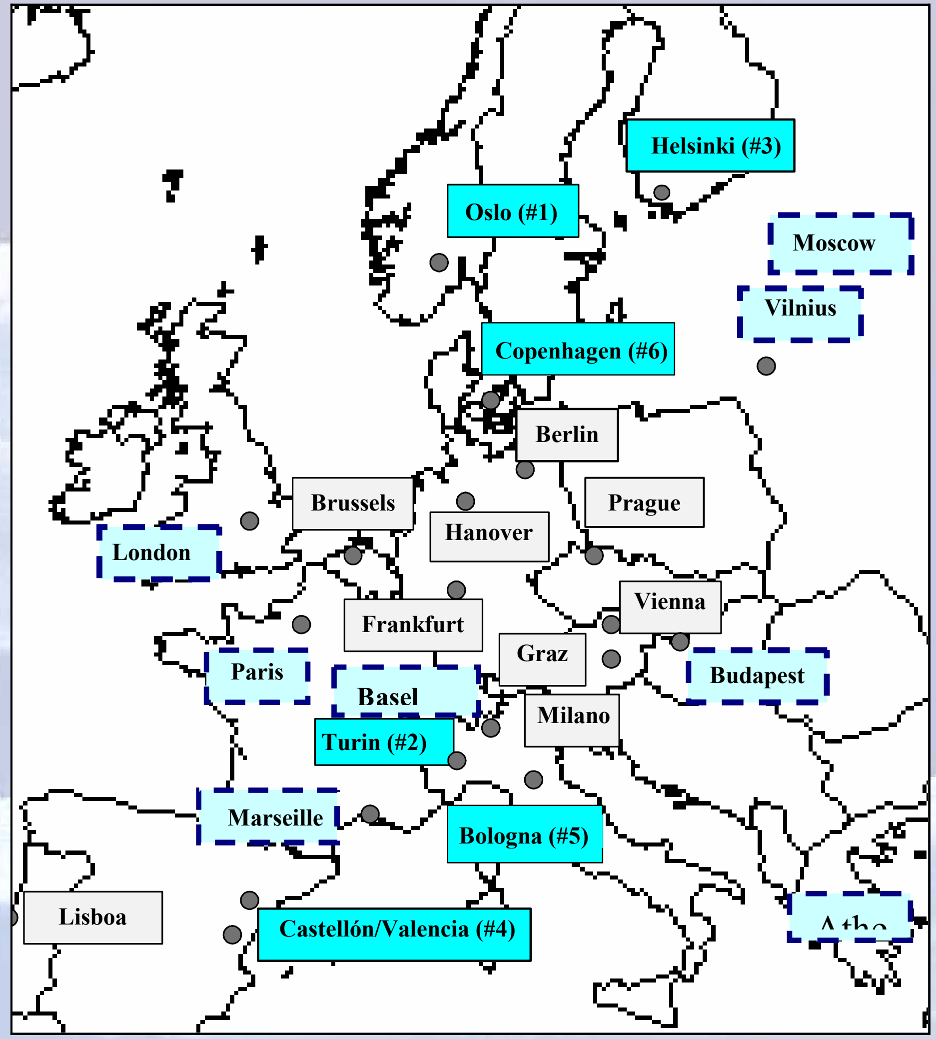


Scheme of the suggested improvements of meteorological forecasts (NWP) in urban areas and interfaces to UAP models

WP4: Improvement of parameterisation of urban atmospheric processes and urban physiographic data classification

<u>Objective</u>: Improvement of boundary layer formulations/parametrisations in NWP models and model physiographic data for urban areas and evaluation of simulation of urban meteorology in NWP models.

- ***WP4.1*** Improvement of the surface/turbulent sensible and latent heat fluxes and land-use for urban areas. Implementation and verification of the full Force-Restore soil model for urban areas.
- ***WP4.2*** Improvement of the roughness parameters of urban areas through targeted measurements of meteorological parameters in an urban area. Implementation and verification of the geometrical model for roughness parameters in urban areas.
- ***WP4.3*** Sensitivity analysis of improved parameterisations and physiographic fields on meteorological input fields for UAP models (wind fields, temperatures)
- ***WP4.4*** Assimilate surface characteristics based on satellite data into Urban Scale NWP models. Algorithms for assimilation of temperature and albedo will be developed and tested.
- ***WP4.5*** Improvement of the similarity theory for the stably stratified nocturnal urban BL and its parameterisation within NWP models.
- ***WP4.6*** Integration and validation of the results from the improved forecasting system.



Map of the selected European cities for air pollution episode analysis. The target city candidates for UAQIFS implementation in FUMAPEX are marked by a # and blue background. Potential target cities for applying the FUMAPEX technique in future are marked with a dark-blue shaded border.