DANISH METEOROLOGICAL INSTITUTE

SCIENTIFIC REPORT

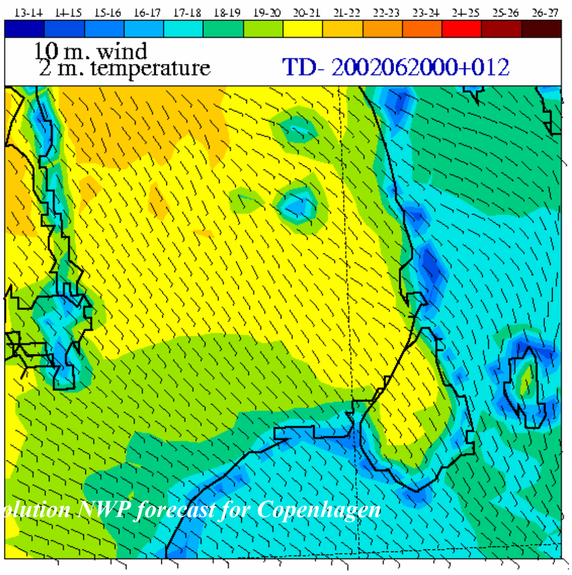
03-12

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

FUMAPEX

EVK4-CT-2002-00097

http://fumapex.dmi.dk



Project Kick-off Meeting and First Progress Report

Alexander Baklanov (Editor)

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Participant's information:

Contractors:

No	Partner Full Name	Coun-try	Partner code	Competence	Leads WP	Contributes to WP
P1	Danish Meteorological Institute	DK	DMI	NWP and air pollution forecasting	4, 10	1,3,5,9
P2	German Weather Service	D	DWD	NWP and dispersion modelling	3	1, 4-6, 10
P3	Hamburg University	D	MIHU	Obstacle resolving scale parameterisation	-	1,4,5
P4	Centro De Estudios Ambientales Del Mediterrano	ES	CEAM	Meso-scale effects on UAP	9	1,3,4,5,8,9
P5	Ecole Centrale de Nantes	F	ECN	Parameterisation of urban canopy	-	4,5
P6	Finnish Meteorological Institute	FIN	FMI	Analysis of UAP episodes, modelling	1	4-9
P7	ARIANET Consulting	I	ARIA-NET	Scale-interaction of NWP & UAP models	5	1,2,5,6, 8-10
P8	Environmental Protection Agency of Emilia Romagna Region	I	ARPA	Implementation and end-use of UAQIFS	-	1-3,5, 8, 9
P9	The Norwegian Meteorological Institute	NO	DNMI	NWP and operational UAQIFS modelling	6	1,3,4,5,8,9
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P12	INSA CNRS-Universite-INSA de Rouen	F	CORIA	Urban meteorology, UAP measurements	-	1,2,4,6,8
P13	Finnish National Public Health Institute	FIN	KTL	Population exposure method development	7	6, 8, 9, 10
P14	Environmental Protection Agency of Piedmont	I	ARPAP	Implementation and end-use of UAQIFS	-	1,5-6, 8-9
P15	Environment Institute - Joint Research Center	I	JRC EI	UAQIFS information dissemination	9	1,6,7,8
P16	Swiss Federal Institute of Technology	CH	ETH / EPFL	Urban parameterisation, UAP measurements	-	1,3,4,5

Subcontractors:

No	Partner Full Name	Country	Partner code	Competence	Contributes to WP
SC1.1	Brockmann Consult	D	BC	New theory & parameterisations	4, 5
SC1.2	Université catolique de Louvain	B	UCL	Measurement data for Brussels and verifications	1,4,7
SC1.3	Danish Emergency Management Agency	DK	DEMA	Project end-user for emergency preparedness in Copenhagen	8,9
SC6.4	Helsinki Metropolitan Area Council	FIN	YTV	Implementation and end-use of UAQIFS in Helsinki	6-9
SC9.5	Norwegian Traffic Authorities	NO	NTA	Implementation and end-use of UAQIFS in Norwegian cities	6,8,9
SC10.6	Municipality of Oslo	NO	MO	Implementation and end-use of UAQIFS in Oslo	6,8,9

1 OVERALL OF KICK-OFF MEETING

The EU project "Integrated Systems for Forecasting Urban Meteorology, Air Pollution and Population Exposure" (FUMAPEX) (http://fumapex.dmi.dk) is recently initiated by 16 organizations from 10 European countries and is coordinated by DMI. The ***main objectives*** of the project are the improvement of meteorological forecasts for urban areas, the connection of numerical weather prediction (NWP) models to urban air pollution (UAP) and exposure models, the building of improved Urban Air Quality Information and Forecasting Systems (UAQIFS), and their application in cities in various European climates.

FUMAPEX was formally accepted by the European Commission as contract No. *EVK4-CT-2002-00097*, which was duly signed on 9 October 2002. The project thus accordingly officially started on 1 November 2002 for three years. The present document presents the minutes of the first meeting by the entire FUMAPEX consortium and a first progress report.

The kick-off meeting of the FUMAPEX project was held at the Danish Meteorological Institute in Copenhagen, Denmark, on November 28 – 29, 2002. The aim of the 1st FUMAPEX meeting was to activate the interactions between the partners involved and identify issues, which required action in order for the project to progress smoothly according to the EU contract – here the description of work (DoW) document. Having the partners giving scientific presentation, highlighting the main activities relevant for FUMAPEX at their home institution, did this in combination with a set of Work Package Plan presentations by the WP leaders. For more details, see the meeting agenda and the abstract compilation. The total number of participants was 39.

1.1 Kick-off meeting program

The FUMAPEX kick-off Meeting,
Danish Meteorological Institute, Lyngbyvej 100, Copenhagen

Wednesday, November 27, evening: Arrival to the Mermaid Hotel, Copenhagen
Thursday, November 28: (partners, subcontractors, end-users)

09:30 - 09:40 Welcome to the participants (Leif Laursen, DMI)

09:40 - 09:50 FUMAPEX Project Introduction (Alexander Baklanov)

09:50 - 12:00 Current status and planned activities for FUMAPEX: Presentations of each contractor and main subcontractors (with coffee break app. 10:40 - 11:00):

P1	Danish Meteorological Institute	Niels W. Nielsen,
P2	German Weather Service	Barbara Fay
P3	Hamburg University	Michael Schatzmann
P4	Centro De Estudios Ambientales Del Mediterrano	Millan M. Millan
P5	Ecole Centrale de Nantes	A. Coppale /P. Mestayer/
P6	Finnish Meteorological Institute	Jaakko Kukkonen
P7	ARIANET Consulting	Sandro Finardi
P8	Env. Prot. Agency of Emilia Romagna Region	Marco Deserti
P9	The Norwegian Meteorological Institute	Erik Berge / Norvald Bjergene
P10	Norwegian Institute for Air Research	Leiv H. Slordal / Bruce Denby
P11	University of Hertfordshire	Ranjeet S. Sokhi
P12	INSA CNRS-Universite-INSA de Rouen	Alexis Coppalle
P13	Finnish National Public Health Institute	Otto Hänninen
P14	Environmental Protection Agency of Piedmont	Roberta De Maria
P15	Environment Institute - Joint Research Center	Andreas Skouloudis

P16	Swiss Federal Institute of Technology	Yves-Alain Roulet
SC1.1	Uppsala University	Sergey Zilitinkevich
SC1.2	Université catolique de Louvain	A. Baklanov /Guy Schayes/
SC1.3	Danish Emergency Management Agency	Lars Henrik Jakobsen /S.C. Hoe/
SC6.1	Helsinki Metropolitan Area Council	Ari Karppinen /Paivi Aarnio/
SC9.1	Norwegian Traffic Authorities	Pål Rosland

12:00 - 13:00 Lunch

13:00 - 18:00 Continue the presentations. Discussion of the Working Program and project co-ordination and defining/making break out task groups
(with coffee break app. 15:00 - 15:20)

19:00 Official Dinner in the restaurant of the Mermaid Hotel

Friday, November 29: (only the partners and the Commission with Eric Ponthieu)

09:00 - 09:10 Welcome to the participants — Anne Mette Jørgensen, DMI

09:10 - 09:25 Introduction from the Commission — Eric Ponthieu

09:25 - 09:35 Short introduction of each FUMAPEX participant

09:35 - 10:00 The main goals and work plan of FUMAPEX — Alexander Baklanov

10:00 - 10:30 Coffee break

10:30 - 12:00 Short presentations of WP1 - WP10 (WP leaders):

WP1: Analysis and evaluation of air pollution episodes in European cities	J. Kukkonen
WP2: Evaluation of different existing approaches to forecast UAP episodes	R.S. Sokhi
WP3 Testing the quality of different operational meteo-forecasting systems for urban areas	B. Fay
WP4: Improvement of parameterisation of urban atmospheric processes and physiographic data	A. Baklanov
WP5: Development of an interface between urban-scale NWP and UAP models	S. Finardi
WP6: Evaluation of the suggested UAQIFS to the uncertainties of input data for UAP episodes	N. Bjergene
WP7: Development and evaluation of population exposure models in combination with UAQIFS's	M. Jantunen
WP8: Implementation and demonstration of improved UAQIFS	L.H. Slørdal
WP9: Providing and dissemination of relevant information	A. Skouloudis
WP10: Project management and quality assurance	A. Rasmussen

12:00 - 13:00 Lunch

13:00 - 14:30 Presentations of the four groups of WP's by the Group Co-ordinators:

Group I (WP1-WP2):	Jaakko Kukkonen
Group II (WP3-WP4):	Barbara Fay
Group III (WP5-WP7):	Norvald Bjergene / Erik Berge
Group IV (WP8-WP9):	Leiv Håvard Slørdal

14:30 - 15:00 Coffee break

14:30 - 15:30 Discussion of the Working Program and project management

15:30 - 16:00 Cluster activities, 6FP and related projects — Ranjeet Sokhi

16:00 - 18:00 Informal discussions; Group meetings; Meeting of the Co-ordination Board

1.2 Welcome speech from DMI Research Director Dr A.M.Jørgensen

Good morning ladies and gentlemen. I am pleased to welcome you here in Copenhagen to the FUMAPEX kick-off meeting, and I am pleased to get the opportunity to address you today.

Air pollution and other environmental issues are of concern to all of us, and therefore monitoring, forecasting and research are of the utmost importance. Furthermore, air pollution does not respect national borders, so international collaboration on these issues is important.

At DMI we have a long experience in environmental monitoring, modelling and forecasting. Our activities include weather and climate modelling and modelling atmospheric dispersion, transformation and deposition of pollutants.

The DMI weather forecasting model system is called DMI-HIRLAM. This model system is run operationally for Denmark (5 km horizontal resolution), Europe (15 km resolution), and the North Atlantic region as DMI is also issuing forecasts for Greenland.

A substantial amount of work of our scientists has been put into improving the physical parameterisations of the HIRLAM forecasting system. Of relevance to you in particular, I can mention that two specific components were developed recently and tested for operational use: a revision to the surface flux parameterisation and improved parameterisations of the stably stratified boundary layer height.

As mentioned, DMI has a long tradition of work on many aspects concerning air pollution, both nationally and internationally.

Besides dealing with common air pollution modelling problems, such as smog and ozone arising from emissions from industry, power plants, house warming and urban traffic, DMI works on nuclear emergency and pollen forecasting, and participates in international projects on airborne dispersion of foot-and-mouth disease virus and in several projects on nuclear emergency preparedness.

We were proud to note that among 28 models from most European countries, USA, Canada and Japan, which contributed to model validations based on the European Tracer EXperiment a few years ago, our model called DERMA was emphasised as very successful.

DMI participates in a number of EU COST Actions, and in this connection methods for modelling of atmospheric boundary layer height utilised for real-time dispersion modelling were developed.

An automatic computerised system has been developed providing real-time high-resolution forecast data derived from the DMI-HIRLAM system to ARGOS and RODOS for local and regional-scale atmospheric dispersion modelling.

You have a lot of work to do today in planning your project more in detail.

I hope that the collaboration in the FUMAPEX project will be fruitful and I wish you a pleasant stay in Copenhagen.

1.3 Project overview and structure

Problems to be solved

Most major European conurbations experience severe short-term pollution episodes that are harmful to the environment and to human health, especially for children and the elderly. The European Environment Agency evaluated that more than 40 million people, living in 115

major urban areas in Europe, are exposed to pollutant levels that exceed the reference levels stated by the World Health Organisation. EU Air Quality Directives and national regulatory legislation were introduced to abate these adverse effects.
In order to diminish or prevent critical concentration levels, abatement action (such as traffic reduction) should be planned at least one or two days in advance. Often no effective action can be imposed because no or only inadequate forecasting models exist. In some European cities, early warning systems like Urban Air Quality Information and Forecasting Systems (UAQIFS) are already employed. They need to be improved, verified, supplemented by population exposure models, and then implemented more widely in Europe for providing better protection of human and environmental health in cities and urbanised regions with an ever-increasing part of the population

Main Objectives
The main aim of the project is to develop, evaluate, and disseminate improved UAQIFS enhancing the capabilities to successfully describe and predict air pollution episodes in cities of different European regions through improvement and integration of systems for forecasting urban meteorology, air pollution, and population exposure based on modern information technologies.
The improvement of urban meteorological forecasts will also provide information to city management regarding additional **hazardous or stressing urban climate** (e.g. urban runoff and flooding, icing and snow accumulation, high urban winds or gusts, heat or cold stress in growing cities and/or a warming climate). All these factors will have implications on the quality of urban life, energy consumption and street maintenance programs. Moreover, the availability of reliable urban scale weather forecasts could be of relevant support for the emergency management of fires, accidental toxic emissions, potential terrorist actions etc.
The improved forecast techniques can be used in two ways: Firstly, **short-term episode forecasts** for the next few days. Secondly, as an **integrated modelling system for long-term air quality management** to predict future episodic pollution levels, taking into account estimated trends in local traffic and other emissions. In both cases the modelling system can be employed to evaluate alternative scenarios and to develop efficient strategies to reduce emissions, pollution levels, and population exposure (PE) to prevent health consequences in a cost-effective way.
The project will proceed through the steps given below, each of which can be considered as a separate **objective** providing valuable **results**:
1.CATALOGUING AIR POLLUTION EPISODES WITH A FOCUS ON RELEVANT METEOROLOGICAL VARIABLES.

- Identification and classification of various types of air pollution episodes in cities located in different European climatic and geographic regions.
- Key pollutants relevant to EU Air Quality Directives and the Daughter Directives (EC/96/62; EC/99/30) will be selected for the investigation of different regions/city characteristics.
- Classification of meteorological conditions leading to pollution episodes and identification of the more relevant meteorological parameters to define these conditions in various European climatic regions.
- Compilation and critical analysis of existing datasets of concentration and meteorological data measured during air pollution episodes in different European climatic and geographic regions.

2. IMPROVEMENT OF THE QUALITY OF URBAN METEOROLOGICAL FORECASTING FOR URBAN AIR POLLUTION AND POPULATION EXPOSURE MODELS

- Improvement of urban weather forecasts adapting NWP modelling systems to the urban scale and to the forecast of key meteorological parameters for pollution episodes. A hierarchy of NWP models from large scale Global Circulation Models to high resolution mesoscale (non-hydrostatic) models to local-scale obstacle-resolving meteorological models will be employed.
- Improvement of boundary layer formulations/parameterisations and physiographic data description for urban areas.
- Development of assimilation techniques to introduce satellite remote sense data in NWP models.
- Development of interfaces to connect NWP to UAP models.

3. VERIFICATION OF THE IMPROVED NWP, UAP, AND PE MODELS

- Evaluation of these improved urban meteorological forecast models based on urban air pollution episode data in 1.
- Estimation of the sensitivity of UAP models to uncertainties in meteorological input data.
- Evaluation of the impact of the improved output of the UAQ models on simulations of an urban population exposure (PE) model.

4. APPLICATION OF UAQIFS AND EMERGENCY SYSTEMS, DISSEMINATION

- Integration of the improved NWP, UAP and PE models into UAQIFSs. Implementation of the new improved UAQIFS in air quality forecasting mode to be applied in four target cities, in urban management or public health and planning mode in one selected target city, and of the emergency preparedness system in one selected target city. The selection of target cities will take into account different orographic, climatic, and pollution characteristics, as well as socio-economic and socio-cultural structures, characteristic of different parts of Europe.
- Involvement of end users in the definition of the information required from the UAQIFS. Different location end-users will collaborate with modellers to define content and format of needed forecasts and warnings, and the strategy of data dissemination to decision-makers, authorities and to the public.
- Demonstration of the new UAQIFS for selected episodes in each of the four selected target cities with the direct participation of local authorities and other end-users. Additionally, the improved high-resolution NWP forecasting will be implemented and demonstrated in an urban emergency preparedness system.
- Demonstration of an UAQIFS enhanced with a built-in population exposure model.
- Dissemination of the improved UAQIFS to other interested regional and local authorities, management bodies, or research institutions in Europe.

The necessary steps will evolve in ten separate, but inter-linked Work Packages (Figure 1) realised by 16 partners 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 eleven European countries.

Expected impacts

The main impact of FUMAPEX will be improved, validated, inter-compared, and accessible UAQIFS implemented in an increasing number of European cities. Forecast and prevention of the worst air pollution episodes in large cities according to air quality directives will lead to an improved quality of human life and of the environment.

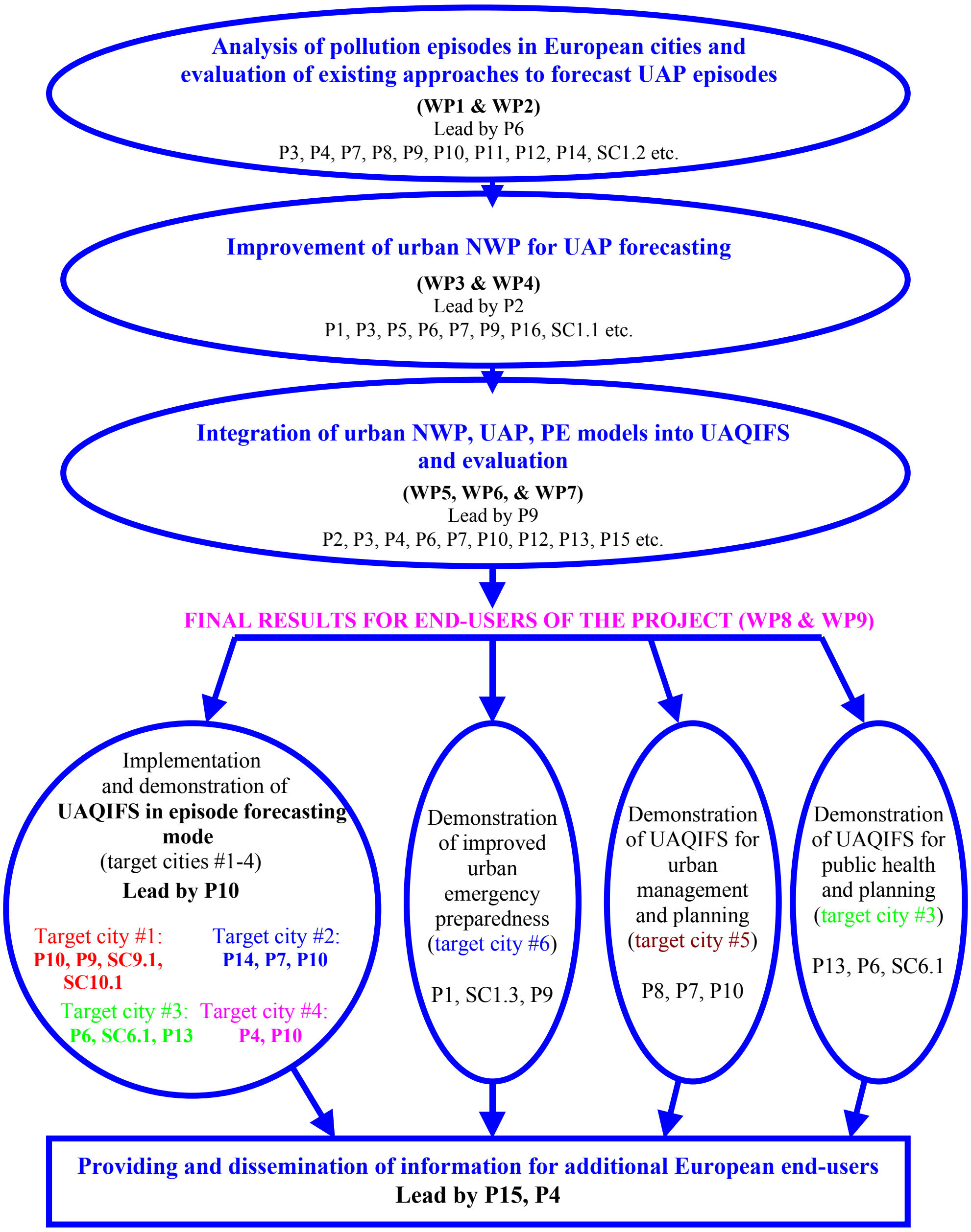

Figure 1. FUMAPEX Work Packages, Participants, their interconnection and the horizontal organisation of the consortium, including several WP groups (NWP: Numerical Weather Prediction, UAP: Urban Air Pollution, PE: Population Exposure; Target city candidates: #1 – Oslo, #2 – Turin, #3 – Helsinki, #4 – Valencia/Castellon, #5 – Bologna, #6 - Copenhagen).

Additional impacts are the potential use of improved weather and pollution forecasts for emergency management (fires, accidental emissions) and for long-term air quality management (scenario studies, emission abatement strategies, sustainable city life). Linking scientists and administrators of different specialisation will also lead to speed-up and innovation in related urban research and application addressed by FP5 (e.g. urban climate, sustainable transport, environment, health).

Work Packages Structure

WP 1 Analysis and evaluation of air pollution episodes in European cities (leaded by J. Kukkonen, FMI)
WP 2 Assessment of different existing approaches to forecast UAP episodes (leaded by R.S. Sokhi, UH)
WP 3 Testing the quality of different operational meteorological forecasting systems for urban areas (leaded by B. Fay, DWD)
WP 4 Improvement of parameterisation of urban atmospheric processes and urban physiographic data classification (leaded by A. Baklanov, DMI)
WP 5 Development of interface between urban-scale NWP and UAP models (leaded by S. Finardi, Arianet)
WP 6 Evaluation of the suggested system (UAQIFS) to uncertainties of input data for UAP episodes (leaded by N. Bjergene, DNMI)
WP 7 Development and evaluation of population exposure models in combination with UAQIFS's (leaded by M. Jantunen, KTL)
WP 8 Implementation and demonstration of improved Urban Air Quality Information and Forecasting Systems (leaded by L.H. Slørdal, NILU)
WP 9 Providing and dissemination of relevant information (leaded by A. Skouloudis, JRC)
WP 10 Project management and quality assurance (leaded by A. Rasmussen, DMI).

1.4 Kick-off meeting conclusions

Working program

The working program was discussed and prepared. The Description of Work (DoW) with necessary details, additions and corrections was accepted as the FUMAPEX working program. Each WP leader presented a more detailed WP working program, which will be available on the project web-page: fumapex.dmi.dk.

A key objective of the kick-off FUMAPEX meeting was to identify gaps in knowledge and potential bottlenecks, which might hinder the progress of the project. Two of the important issues to emerge were:

- The design of an effective format of project model intercomparison and verification studies for WP2-6;
- The choice of cities and episodes for the model intercomparison and verification in different WPs.

Coordination Board

The Project Coordination Board, which includes the project coordinator, EC scientific officer and WP leaders (and, if necessary, can involve additional end-users and external experts), was established on the kick-off meeting.

Project Secretariat

FUMAPEX secretariat program and detailed project plan were discussed. FUMAPEX will be managed at four levels of interaction: 1) The co-ordinator and FUMAPEX secretariat, 2) The Project Board, 3) The WP leaders, 4) Annual contractor's Meetings.

The co-ordinator Alexander Baklanov (alb@dmi.dk) established a "FUMAPEX Secretariat function" at DMI including the project manager Alix Rasmussen(ar@dmi.dk), economical adviser Lotte Christiansen (lc@dmi.dk) and secretary Bente Elise Andersen (bea@dmi.dk).

2 STATUS REPORTS FROM THE PARTNERS

Participant 1 (P1) - DMI

DMI (Partner 1, Co-ordinator)
Danish Meteorological Institute
Meteorological Research Department

Partner team members:
Dr. Alexander Baklanov, FUMAPEX co-ordinator, WP4 leader,
Mr. Alix Rasmussen, WP10 leader,
Drs. Niels Woetmann Nielsen, Bjarne Amstrup, Jens Havskov Sørensen, Karina Lindberg, Allan Gross
Subcontractors:
SC1.1: University of Uppsala (MIUU), Prof. Sergej Zilitinkevich (see a separate report)
SC1.2: Université catolique de Louvain (UCL), Prof. Guy Schayes
SC1.3: Danish Emergency Management Agency (DEMA), Mr. Steen C. Hoe

High-Resolution Meteorological and Dispersion Modelling in DMI

Introduction

DMI team recent activity and achievements:

- high resolution (up to 1.4 km horizontal resolution) numerical modelling of regional meteorological processes;
- using fields of effective roughness length, satellite-based sea surface temperature and albedo in DMI-HIRLAM-E model;
- new algorithms for the SBL mixing height in atmospheric models;
- on-line coupling of meteorological and atmospheric pollution models;
- DMI modelling for emergency preparedness and the ARGOS system.

The growth of computer power (new NEC-SX6 supercomputer) and the implementation of grid nesting techniques allowed the DMI NWP system to approach the resolution of the city-scale (Sattler, 1999; Sass, 2002; Rasmussen et al., 1999; Baklanov et al., 2002). The Danish operational NWP system consists of several nested models named DMI-HIRLAM 'G', 'N', 'E' and 'D', where the high resolution model 'D', covering an area around Denmark, has 4.6 km horizontal grid and uses boundary values from the large scale model 'E'. Last two years, DMI started to run operationally during limited summer periods an experimental version of DMI-HIRLAM over the Zealand Island, including the Copenhagen metropolitan area, with the horizontal resolution of 1.4 km. The vertical resolution of the operational DMI-HIRLAM is 40 vertical levels and of an experimental version was increased up to 52 vertical levels. Examples of forecasted wind fields at 10 meter height and of 2 meter air temperature for the Zealand Island and the Copenhagen metropolitan area are presented in Figure 1.

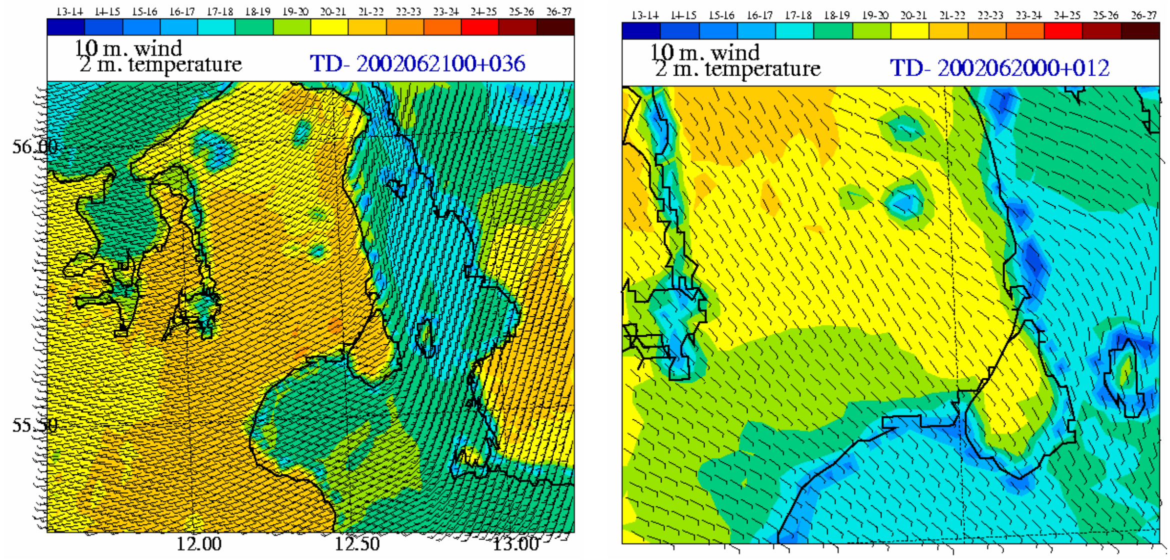

Figure 1. One example of forecasted wind fields at 10-meter height and of 2-meter air temperature for the Copenhagen metropolitan area by the experimental version of DMI-HIRLAM with the horizontal resolution of 1.4 km.

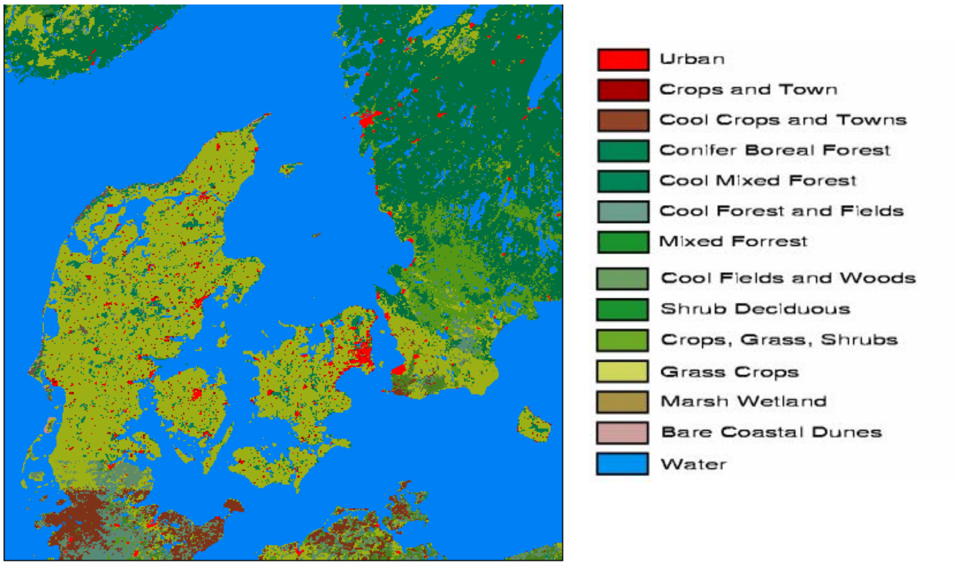

Figure 2. Land-use classification over Denmark and south Sweden from GLCC- and KMS-data for the DMI-HIRLAM-D model with 1 km resolution (Sattler, 1999). The complete legend has 21 types of land/sea including one class of urban areas.

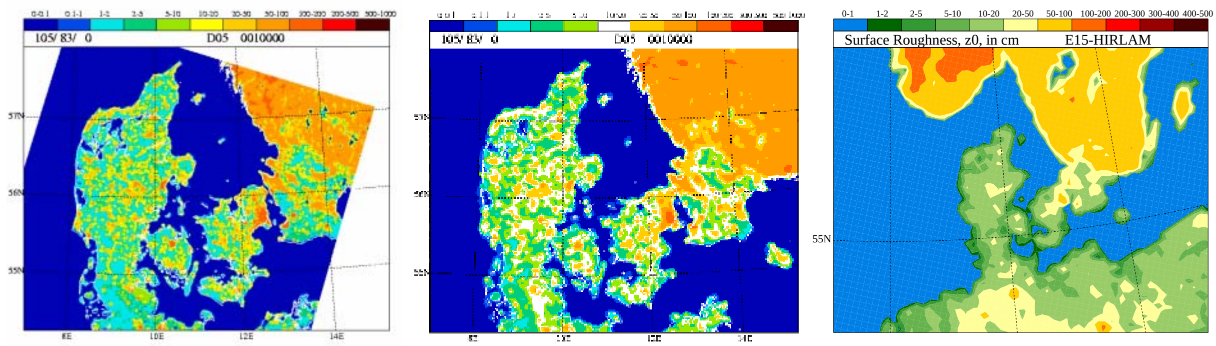

Figure 3. The simulated roughness length (z_0) for Denmark from the high resolution physiographic data for DMI-HIRLAM: (left) experimental version in 1.5 km resolution, (centre) D-version in 5 km resolution, and (right) E-version in 15 km resolution.

For the urban scale results of existing NWP models will only be reliable when refined databases for external parameters with 1km resolution or finer are also provided and used (Baklanov et al., 2002). Utilising land-use databases down to 1 km resolution or finer, models can reach a detailed description of surface features, including the identification of urban areas. The DMI-HIRLAM model uses a land-use classification with 1 km resolution from GLCC- and KMS-data (Figure 2). The database describes 21 types of landcover/sea including a separate class of urban areas (Sattler, 1999). Each grid cell includes a percentage of different classes in the cell, thus urban areas are presented differently in a city centre and suburb territories. Correspondingly, the surface parameters in NWP models, like the albedo, surface fluxes and roughness length (z_0) are simulated from the high resolution physiographic data. Figure 3 shows the roughness length, simulated in different DMI-HIRLAM versions: for Denmark in 1.4 km (left) and 4.6 km (centre) resolutions, and for the European territory in 15 km resolution (right).
A new flux aggregation technique, suggested by Risø NL in cooperation with DMI (Hasager et al., 2002: SAT-MAP-Climate Report), was realized in the DMI-HIRLAM model for non-urban areas for the moment. It is planned to extend the approach for the urban canopies as well (we need experimental data to verify the parameterisations for urban areas).

Pre-processing from NWP to air pollution models.
Several DMI atmospheric pollution models utilise 3D meteorological data from NWP forecast or analysis based on DMI-HIRLAM or ECMWF modelling systems. Therefore necessary interfaces for different pollution models were elaborated for reading of meteorological field from NWP model in suitable formats and computing grids, and calculation of additional meteorological characteristics important for the dispersion models.
The PBL height, for example, is one of the important characteristics for UAP models and is already included in the DMI-HIRLAM model as an output field.
MH calculation is also realised at DMI as a module in the pre/post-processor from NWP-to-AP model (e.g. DERMA, DACFOS). Different methods are included in the library (Sørensen and Rasmussen, 1996; Baklanov, 2001, Zilitinkevich & Baklanov, 2002).
Previously they were not prepared specially for urban areas, so verification of the MH methods for urban conditions and extension on the non-homogeneous and non-stationary cases are needed. Preliminary analysis of different methods (Baklanov, 2002) gives the following general suggestions concerning the applicability of 'rural' methods of the MH estimation for urban areas:
For estimation of the daytime MH, applicability of common methods is more acceptable than for the nocturnal MH.
For the convective UBL the simple *slab models* (e.g. Gryning and Batchvarova, 2001) were found to perform quite well.
The formation of the nocturnal UBL occurs in a counteraction with the negative 'non-urban' surface heat fluxes and positive anthropogenic/urban heat fluxes, so the applicability of the common methods for the SBL estimation is less promising.
The determination of the SBL height needs further developments and verifications versus urban data. As a variant of the methodics for SBL MH estimation the new Zilitinkevich *et al.* (2002) parameterisation can be suggested in combination with a prognostic equation for the horizontal advection and diffusion terms (Zilitinkevich and Baklanov, 2002).
Meso-meteorological and NWP models with modern high-order non-local turbulence closures give promising results (especially for the CBL), however currently the urban effects in such models are not included or included with great simplifications (Baklanov *et al.*, 2001).

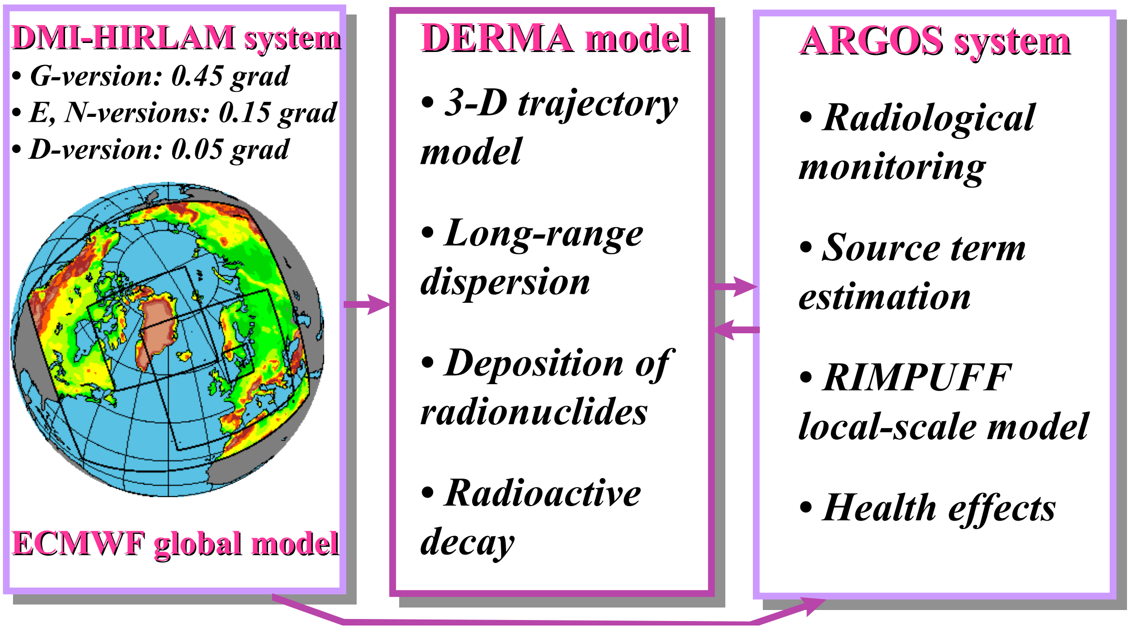

Figure 4. Structure of the Danish nuclear emergency preparedness long-range modelling system.

On-line coupling of the NWP and atmospheric pollution models

DMI develops an on-line coupled NWP - atmospheric pollution model, for which the Eulerian air pollution model is an integral part of the meteorological DMI-HIRLAM model. The first step of the integrated system is the HIRLAM-Tracer (*Chenevez et al., 2002a,b*). In order to improve the advection scheme the fourth-order Bott algorithm for tracer advection has been implemented in the semi-Lagrangian version of DMI-HIRLAM. Due to its practically perfect mass conservation properties and its low computational cost, this method turns out to be efficient for simulations of transport of pollutants in the atmosphere. Further improvements of this integrated model will include deposition and chemical transformation or radioactive decay processes in order to be employed to air pollution forecasting.

***Emergency preparedness system in Denmark**, DMI participation and responsibilities.*

The Danish Emergency Response Model of the Atmosphere (DERMA) is used for the real-time modelling of possible contamination and consequences (cf. Figure 4). The model is developed at the Danish Meteorological Institute (DMI) mainly for nuclear emergency preparedness purposes. DERMA is a 3-D Lagrangian long-range dispersion model using a puff diffusion parameterisation, particle-size dependent deposition parameterisations and radioactive decay (*Sørensen, 1998; Sørensen et al., 1998; Baklanov and Sørensen, 2001*). Earlier comparisons of simulations by the DERMA model vs. the ETEX experiment involving passive tracers gave very good results. 28 institutions from most European countries, USA, Canada and Japan contributed to the real-time model evaluation. Based on analyses from the first experiment, the DERMA model was emphasised as being very successful (*Graziani et al., 1998*). In general, the DERMA model can be used with different sources of NWP data, including the DMI-HIRLAM and ECMWF NWP models with different resolution.

The main objective of the DERMA model is to predict the atmospheric transport, diffusion, deposition and radioactive decay of a radioactive plume within a range from about 20 kilometres from the source up to the global scale. For shorter distances the RIMPUFF local-scale model developed by the Risø NL (*Mikkelsen et al., 1997*) can be used. Both models are parts of the Danish Nuclear Preparedness System ARGOS (*Hoe et al., 2000*).

Recently, the Danish nuclear emergency preparedness decision-support system, the Accident Reporting and Guidance Operation System (ARGOS) (*Hoe et al., 2000*), has been extended with the capability of real-time calculation of regional-scale atmospheric dispersion of radioactive material from accidental releases. This is effectuated through on-line interfacing with the DERMA model, which is run at DMI.

For local-scale modelling of atmospheric dispersion, ARGOS utilises the Local-Scale Model Chain (LSMC) (*Mikkelsen et al., 1997*), which makes use of high-resolution DMI-HIRLAM NWP model data provided by DMI four times a day under operator surveillance covering Denmark and surroundings.

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.

DMI contribution in the FUMAPEX study

DMI is the project co-ordinator and co-ordinates work packages # 4 and 10. In addition P1 will contribute to the following work packages: WP3, WP5 and WP6. The main objective for P1 will be to contribute: (WP3) into the validation of the HIRLAM model analysis and forecasts during urban air pollution episodes in Europe; (WP4) to improve the urban effects and boundary layer parameterisations in the DMI-HIRLAM model with a higher resolution (meso-scale version); and (WP5) to develop different elements of an interface from urban NWP to UAP models (estimation of mixing height, surface fluxes, velocity fields, cloud and precipitation parameters). DMI-HIRLAM will be coupled with an Eulerian air pollution model.
The improvement and validation will especially focus on the forecast of wind velocity and wind direction in the urban atmospheric boundary layer, but other parameters important for the urban air pollution, e.g. stability, mixing height, heat-fluxes etc., will also be considered.
Proposed work for the nocturnal urban boundary layers (UBL) will include (see also the SC1.3 report) the following phases (WP4 and WP5):
- theoretical analysis and improvement of the similarity theory for the stably stratified UBL, and non-local transport properties of the SBL, and of the turbulent fluxes of heat and momentum in the extreme cases of strong stability,
- tests and verification of developed theories and parameterisations for urban conditions using data from measurements, more sophisticated turbulence closure numerical models,
- implementation and validation of new approaches and parameterisations in urban, meso-scale numerical models and atmospheric dispersion.

P1 will participate (WP6) in a substantial uncertainty analysis of meteorological parameters important in urban air-pollution episodes for NWP models, and an estimation of the importance of the uncertainty of the meteorological input to the total uncertainty of the UAP models. The improved high-resolution NWP forecasting will be provided to demonstrate the emergency preparedness system ARGOS for the target city of Copenhagen (WP8).

DMI team plans for FUMAPEX:

- validation of the HIRLAM model analysis and forecasts during urban air pollution episodes in Europe;
- urban effects and sublayer parameterisations in the DMI-HIRLAM model with a higher resolution (details are below);

- mixing height estimation for the nocturnal urban boundary layer,
- elements of an interface from urban NWP to UAP models,
- DMI-HIRLAM coupling/integration with an Eulerian air pollution model,
- uncertainty analysis of meteorological parameters for NWP and UAP models,
- improved high-resolution NWP forecasting will be provided to demonstrate an emergency preparedness system for the target city of Copenhagen.

Three levels of complexity (or phases) of the NWP 'urbanization':

1. Simple corrections of the surface roughness for urban areas (e.g., following to Grimmond and Oke, 1999) and heat fluxes (adding the additional urban heat flux, e.g., via heat/energy production/using in the city and albedo change) within the existing (non-urban) physical parameterisations of the surface layer in the model with higher resolution and improved land-use classification.
2. Improvement and realization of a new flux aggregation technique, suggested by Risø NL in cooperation with DMI (Hasager et al., 2002: SAT-MAP-Climate Report) for urban areas. This module was realized in the DMI-HIRLAM model for non-urban areas for the moment. However, the approach can be extended for the urban canopies as well (we need experimental data to verify the parameterisations for urban areas).
3. Implementation of special physical parameterisations/submodel for the urban sub-layer into the NWP model. In the FUMAPEX project we plan to realize at least two different urban submodels/modules in HIRLAM and in MM5:
   (i) urban surface exchange parameterisation, developed by our Swiss partner (the model description in: Martilli, 2001; Martilli et al., 2002),
   (ii) SM2-U urban soil submodel, developed by our French partners (Patrice Mestayer, Sylvain Dupont etc.).

Subcontractor SC1.2: Université catolique de Louvain (Prof. Guy Schayes)

Contributes to WP1, WP4 and WP6.
WP1: Preparation of air pollution data and identification of urban air pollution episodes for the Brussels area.
WP4, WP6: Analysis and simulation with TVM mesoscale model of the ESCOMPTE campaign, testing of various urban schemes. Making sensitivity runs in order to test the key parameters acting on the urban boundary layer characteristics. In case the model does not resolve the small-scale characteristics of the urban surface, hence these must be parameterised. Using idealised cities (circular shape and surface characteristics, roughness heat flux and other parameters depending only the distance from the centre) allows to derive more easily the main characteristic dependence of the external meteorological parameters. SC1.2 plans to focus on the mixing height problems, but other related factors (roughness, surface flux, anthropogenic flux, etc.) will also be investigated. Various met pre-processors and/or surface formulations (taking into account the non-resolved surface) from other groups will be tested in this frame. Finally, the model will be applied to the real Brussels area with the use of a coupled photochemical module. This work is very important for a possible practical implementation of the improved UAQIFS for the Brussels urban area on further steps.

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Subcontractor SC1.1 (Prof. S. Zilitinkevich)

Recent Developments in Boundary Layer Physics Relevant to Weather, Climate and Pollution Dispersion Modelling

S.S. Zilitinkevich
Department of Earth Sciences, Meteorology, Uppsala University, Villavägen 16, SE-752 36, Uppsala, Sweden, E-mail <sergej@met.uu.se>

With contributions from:
I.N. Esau and *A.-S. Smedman,* Uppsala University, Sweden
V. Perov and *K.-I. Ivarsson,* Swedish Meteorological & Hydrological Institute, Sweden

P.-E. Johansson, Defence Research Establishment, Sweden
T. Soomere, Institute of Marine Systems, Tallinn Technical University, Estonia
A. Baklanov, Danish Meteorological Institute, Copenhagen, Denmark
J.C.R. Hunt, University College London, UK
J.C. King, British Antarctic Survey, UK
D. Lalas, National Observatory of Athens, Greece
E. Akylas and *M. Tombrou,* University of Athens, Greece
P. Calanca, Swiss Federal Institute of Technology, Switzerland
D.V. Mironov, Alfred Wegener Institute for Polar and Marine Research, Germany
J. Rost, University of the Freiburg, Germany
A.A. Grachev, University Colorado, USA
C.W. Fairall, NOAA / Environmental Technology Laboratory, USA
T. Elperin, N. Kleeorin and *I. Rogachevskii,* Ben-Gurion University of the Negev, Israel
V. Gryanik, Institute of Atmospheric Physics, Russia
V. N. Lykosov, Institute of Numerical Mathematics, Russia
V. Maderich, Institute of Mathematical Machine and System Problems, Ukraine

1. Introduction

Along with other measures needed to further improve modelling and forecasting of the urban climate and air quality, it is proposed to modify current operational models accounting for new developments in physics of atmospheric planetary boundary layers (PBLs). This paper shortly presents recent relevant works performed at the Meteorology Programme, Uppsala University in co-operation with a number of groups in Europe and USA. These works address the following problems: (i) PBL thickness, h; (ii) turbulent fluxes at the lower and upper boundaries of the PBL (the surface layer and the entrainment zone); (iii) turbulent fluxes within PBLs calculated through turbulent closures or alternative approaches; (iv) air-sea fluxes.

2. The effect of internal waves on turbulent transport in stable stratification

Summary: *Third-order fluxes due to internal gravity waves are included in a turbulence closure for stable PBLs. The key points are Eq. (7) for wave-induced fluxes from the PBL outer boundary to the stratified, non-turbulent free flow, and Eq. (8) – revised velocity and temperature profiles in the surface layer, This new theory incorporates the free-flow Brunt Väisälä frequency N in the surface-layer scaling. At N=0 it reduces to the classical Monin-Obukhov (MO) theory.*

Until the recent time the concern of the traditional theory of the atmospheric stable PBLs was the nocturnal PBL. It develops after sunset on the background of a neutrally stratified residual layer, which keeps memory of the daytime mixing, caused by the velocity shear and/or convection. The residual layers separate the nocturnal PBLs from the stably stratified free flow, thus preventing propagation of internal gravity waves (IGW) throughout the lover atmosphere. As a result, the nature of turbulence in nocturnal PBLs is basically local. The nocturnal PBLs are well described by traditional theories, such as local or semi-local[1] turbulence closures or similarity theories (Monin and Obukhov, 1954; Nieuwstadt, 1962)

Things are principally different in the *long-lived* stable PBLs placed immediately below the stably stratified free flow. Here, the PBL as a whole and its near-surface ("constant-flux") sub-layer are affected by the vertical transport of the kinetic energy and the squared density fluctuations, caused by the vertical propagation of IGW [Zilitinkevich and Calanca, 2000;

[1] Here, the term "semi-local closure" is applied to the diffusion-approximation of the third-order fluxes.

Soomere and Zilitinkevich, 2002; Zilitinkevich, 2002a (henceforth referred to as Z-2002)]. A new non-local theory briefly presented below predicts that the surface-layer turbulence is generally dependent on the free-flow Brunt-Väisälä frequency, *N*. The surface layer represents approximately one tenths of the PBL. So it is separated from the free atmosphere by its upper nine tenths comprising hundreds of metres. Traditional concepts fail to explain so distant links.

The key point in the new approach is the inclusion of the third-order wave-induced fluxes in a turbulence-closure scheme. The latter is rather simple as concerns its true-turbulence part, but principally advanced due to explicit parameterisation of the transport properties of the IGW. To the best of the author's knowledge this has been done for the first time in Z-2002, where this new approach has been applied to the surface layer. This model allowed explaining why and when well-developed turbulence could exists at very large, supercritical Richardson numbers; and why and how the turbulent Prandtl number increases with increasing stability. It also allowed indicating the limits of applicability of the classical theories. In strong free-flow stratification, results from the new theory are confirmed by atmospheric data, whereas the classical, local theory fails (see Figure 1)[2].

To demonstrate the basic idea of the new turbulence-IGW closure approach, consider the problem by the example of the surface (constant-flux) layer within the long-lived PBL. The model employs budget equations for the turbulent kinetic energy, $E_K = \frac{1}{2}\left(\overline{u'^2 + v'^2 + w'^2}\right)$ (henceforth, TKE), and for the squared fluctuation of potential temperature, $E_P = \frac{1}{2}\overline{\theta'^2}$:

$$\vec{\tau} \cdot \frac{\partial \vec{u}}{\partial z} \approx u_*^2 \frac{\partial u}{\partial z} = -F_b + \varepsilon + \frac{\partial F_{KE}}{\partial z}, \quad -F_{\theta s} \frac{\partial \theta}{\partial z} = \varepsilon_\theta + \frac{\partial F_{PE}}{\partial z}. \tag{1}$$

Here, $\vec{\tau}$ and $\vec{u} = (u, v)$ are the wind-velocity and momentum-flux vectors; u_* is the friction velocity; F_b is the buoyancy flux: $F_b = \beta F_{\theta s}$ where $\beta = g / T_0$ is the buoyancy parameter, *g* is the acceleration due to gravity, T_0 is a reference value of the absolute temperature and $F_{\theta s}$ is the vertical turbulent flux of potential temperature at the surface; ε and ε_θ are the dissipation rates; $F_{KE} = \frac{1}{2}\overline{\left(u'^2 + v'^2 + w'^2\right)w'} + \rho_0^{-1}\overline{p'w'}$ and $F_{PE} = \frac{1}{2}\overline{\theta'^2 w'}$ are the third moments representing vertical fluxes of the energy (TKE + normalised pressure, $\rho_0^{-1} p'$, where ρ_0 is the reference density) and the squared temperature, respectively. The *x*-axis is aligned with the near-surface wind; hence $\vec{u} = (u, 0)$ and $\vec{\tau} = (\tau_s, 0)$. The fluxes $\vec{\tau}\left(u_*^2, 0\right)$ and $F_b = \beta F_{\theta s}$ are height-constant in the surface layer (in the PBL they become unknown variables).

For the dissipation rates, the conventional Kolmogorov closure hypotheses are

$$\varepsilon = \frac{E_K^{3/2}}{l_E} = \frac{E_K}{t_E}, \quad \varepsilon_\theta = \frac{E_P}{t_\theta}, \tag{2}$$

[2] Notice that very strong stratification in the free flow (in the thermocline) is an inherent feature of upper mixed layers in the sea or lakes. The new approach could very naturally be extended to these layers.

where l_E is the turbulent length scale, and $t_E = l_E / E_K^{1/2}$, $t_\theta \sim t_E$ are the time scales.

In the stably stratified surface layer, E_K and E_P are height-constant:

$$E_K = C_K \,|\, \tau \,| \approx C_K u_*^2 , \quad E_P = C_P \frac{F_\theta^2}{|\, \tau \,|} \approx C_P \theta_*^2 , \tag{3}$$

where $\theta_* = -F_{\theta s} / u_*$, $C_K \approx 5$ and $C_P \approx 0.3$ are empirical constants (e.g., Figures 75, 76 in Monin and Yaglom, 1971).

For the length and time scales, alternative asymptotic formulas are known: $l_E \sim z$, $t_E \sim z / E^{1/2} \sim z / u_*$ close to the surface, and $l_E \sim E^{1/2} / (\beta \partial \theta / \partial z)^{1/2} \sim L$, $t_E \sim L / u_*$ at some distance from the surface – in the so-called *z*-less stratification layer. Interpolation between the above asymptotes for t_E^{-1} yields

$$\frac{1}{t_E} = C_{t1} \frac{u_*}{z} + C_{t2} \frac{u_*}{L} , \quad \frac{1}{t_\theta} = C_{t3} \frac{u_*}{z} + C_{t4} \frac{u_*}{L} , \quad L = -\frac{u_*^3}{F_b} , \tag{4}$$

where, C_{t1}, C_{t2}, C_{t3}, C_{t4} are dimensionless coefficients, and L is the Monin-Obukhov length. Then the dissipation rates become

$$\varepsilon = C_K C_{t1} \frac{u_*^3}{z} \left(1 + \frac{C_{t2}}{C_{t1}} \frac{z}{L} \right) , \quad \varepsilon_\theta = C_P C_{t3} \frac{\theta_*^2 u_*}{z} \left(1 + \frac{C_{t4}}{C_{t3}} \frac{z}{L} \right) . \tag{5}$$

In the traditional turbulence closures, the third-order fluxes are either neglected (local approach) or expressed through the quasi-local turbulent-diffusion approximation: $F_{KE} \sim E^{1/2} l_E \partial E_K / dz$, $F_{PE} \sim E^{1/2} l_E \partial E_P / dz$, which provides only minor corrections to the local approach. In this context, the contribution to F_{KE} and F_{PE} from the IGW was never considered. Applying the linear theory of IGW to the non-turbulent free flow allows to determine F_{KE} and F_{PE} at the PBL outer boundary ($z = h$+0):

$$F_{KE} \,|_{z=h} \sim l^2 \lambda N^3 , \quad F_{PE} \,|_{z=h} \sim \beta^{-2} l^2 \lambda N^5 , \tag{6}$$

where l and λ are the wave amplitude and length, and N is the free-flow Brunt-Väisälä frequency (Thorpe, 1973; Carruthers and Hunt, 1986; Soomere and Zilitinkevich, 2002). We assume that the IGW are excited by turbulent disturbances at the PBL outer boundary. Then, to the first approximation, the typical wavelength is proportional to the PBL depth, *h*; and the typical wave amplitude λ – to the turbulent length scale at z = *h*–0, that is to $E^{1/2} / N \sim u_* / N$, where $N = (\beta \partial \theta / \partial z) |_{z>h}$ is the free-flow Brunt-Väisälä frequency. Taking F_{KE}, F_{PE} = 0, which is justified over land[3], and using the finite-difference approximation, $\partial F / \partial z = (F_h - F_0) / h$, the flux-divergence terms in the budget eqautions, Eq. (1), become

[3] In the atmospheric PBL over the sea/lake, the near-surface flux of kinetic energy from wind to waves should be taken into account.

$$\frac{\partial F_{KE}}{\partial z} = C_{WK} u_*^2 N \,, \quad \frac{\partial F_{PE}}{\partial z} = C_{WP} \frac{u_*^2 N^3}{\beta^2} \,, \tag{7}$$

where C_{WK} and C_{WP} are dimensionless coefficients to be determined empirically.
Allying the closure scheme (1)-(7) to the surface layer yields the wind and temperature gradients essentially dependent on the free-flow stability:

$$\frac{\partial u}{\partial z} = \frac{u_*}{kz}\left[1 + C_u\left(1 + C_{uN}\mathrm{Fi}\right)\frac{z}{L}\right], \quad \frac{\partial \theta}{\partial z} = \frac{\theta_*}{k_T z}\left[1 + C_\theta\left(1 + C_{\theta N}\mathrm{Fi}^3\right)\frac{z}{L}\right], \quad \mathrm{Fi} = \frac{LN}{u_*}. \tag{8}$$

Here, k, k_T, C_u, C_θ, C_{uN} and $C_{\theta N}$ are combinations of the dimensionless constants appeared in Eqs. (2)-(4), (7); and Fi is an inverse Froude number, which quantifies the non-local effect of the free-flow stability on the surface-layer turbulence.

Taking Fi = 0, Eq. (8) reduces to the familiar Monin-Obukhov-theory statement that the "slope factors", $s_u = (kL/u_*)\partial u/\partial z - L/z$ and $s_\theta \equiv (k_T L/\theta_*)\partial \theta/\partial z - L/z$, are universal constants: $s_u = C_u$=2.1 and $s_\theta = C_\theta$=3.2 (e.g, Högström, 1995). Thus, the classical theory is justified in the atmospheric nocturnal PBL. However, data from measurements in the long-lived PBL shown in Figure 1 exhibit strong dependence of s_θ and C_θ on Fi, as predicted by Eq. (8), in striking contrast with the classical theory.

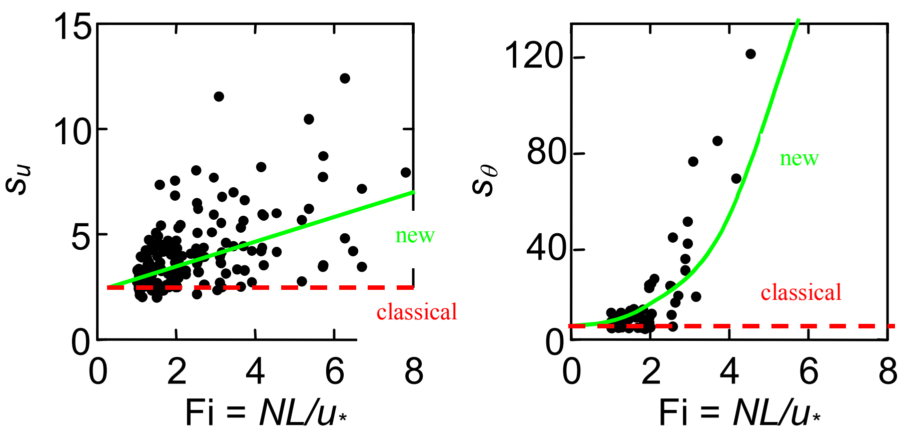

Figure 1. Experimental data (from Zilitinkevich and Calanca, 2000) and theoretical predictions for the slope factors $s_u \equiv (kL/u_*)\partial u/\partial z - L/z$ and $s_\theta \equiv (k_T L/\theta_*)\partial\theta/\partial z$ as dependent on the inverse Froude number Fi. Solid lines are plotted after Eq. (8): $s_u = C_u + C_u C_{uN}\mathrm{Fi}$, $s_\theta = C_\theta + C_\theta C_{\theta N}\mathrm{Fi}^3$; dashed lines, after the classical theory: $s_u = C_u$=constant, $s_\theta = C_\theta$=constant (C_u=2.1, C_θ=3.2, $C_{uN} = C_{\theta N}$= 0.3).

Using the surface layer model based on Eq. (8), an advanced surface flux calculation technique has been developed (Zilitinkevich et al, 2002b) and implemented in the Swedish version of the weather prediction model HIRLAM (Perov and Zilitinkevich, 2000; Perov et al, 2001). Statistical analysis demonstrated generally improved forecasts, especially in cold calm weather typical of the Northern Scandinavia in winter. The same technique supplemented by an improved roughness-length scheme for the water surface (Zilitinkevich at al., 2001) is implemented in the Ukrainian coupled atmosphere – lake – water quality model IMMSP (Maderich et al., 2002).

For further application to modelling of pollution dispersion in long-lived stable PBLs, the above closure will be extended using appropriate momentum- and thermodynamic-energy equations (instead of the surface-layer approximation: $|\vec{\tau}| = u_*^2 =$ constant, $F_b = \beta F_{\theta s} =$ constant), implemented in operational models and validated against experimental and LES data.

3. PBL depth in stable stratification

Summary: *The key point is Eq. (9) for the equilibrium stable PBL depth h_E. It is applicable to PBLs in both atmosphere and hydrosphere, and accounts for all essential damping factors:*

(i) the earth's rotation (the Coriolis parameter f – always important),

(ii) the buoyancy flux at the PBL inner boundary (F_{bs} – dominant factor in the nocturnal PBLs),

(iii) the free-flow stability (N – essential or even dominant factor in long-lived stable PBLs, always dominant factor in the ocean),

(iv) baroclinicity (geostrophic shear Γ – often important but newer considered before).

The depth, *h*, of the turbulent boundary layer is one of its most fundamental properties required in a number of practical problems within environmental sciences. Physical processes controlling *h* in the atmosphere and the ocean are basically similar. Experimental studies of PBLs are much easier and cheaper in the atmosphere. Good knowledge about *h*, especially in stable stratification, is strongly required in air-pollution modelling. Indeed, shallow stable PBLs cause the most dangerous air-pollution events. Thus meteorological studies of the PBL depth are very strongly motivated. They represent the concern of many international conferences, projects and specialised field campaigns (e.g., Siebert et al., 1998, 2000). In the last years, this problem was further developed accounting for the non-local IGW-induced transports (see Section 2.1) and baroclinicity.

The earlier models focused on the equilibrium stable PBL depth h_E as dependent on the intensity of turbulence (characterised by u_*) and suppressing effects of the earth's rotation: $h_E \sim u_* / |f|$, where *f* is the Coriolis parameter (Rossby and Montgomery, 1935), and the near-surface buoyancy flux: $h_E \sim u_*^2 \, |fF_b|^{-1/2}$ (Zilitinkevich, 1972). Kitaigorodskii and Joffre (1988) considered the suppressing effect of the free flow Brunt-Väisälä frequency *N* and applied the depth scale u_* / N to measure h_E in the atmosphere. The effect of *N* on the maximum depth of the oceanic PBL evolving against the stably stratified thermocline was recognised earlier by Pollard et al. (1973). They derived an equation $h_E \sim u_* / |Nf|^{1/2}$. Zilitinkevich et al. (2002a) (henceforth: Z-et-al-2002) demonstrated that the same equation is applicable to the steady-state, near-neutral PBL, where *N* becomes a controlling factor of the TKE losses due to the radiation of IGW from the PBL outer boundary [cf. Eq. (6)].

A general formulation for the equilibrium, stable PBL depth can be derived from the following scaling reasoning. The Ekman eqautions dictate an inherent PBL depth scale: $h_* \sim |K_* / f|^{1/2}$. Here, K_* is the eddy-viscosity scale estimated as $K_* \sim u_T l_T$, where u_T and l_T are the turbulent velocity and length scales. In the barotropic, stable PBLs, $u_T \sim u_*$. Then taking appropriate length scales, namely, $l_T \sim h_E$ in the truly neutral PBL, $l_T \sim L = -u_T^3 / F_b$ in the surface-flux dominated PBL, and $l_T \sim u_T / N$ in the free-flow-stability dominated PBL the above quoted Rossby-Montgomery, Zilitinkevich, and Pollard et al. formulations are immediately obtained. Interpolating between the reciprocals, $l_T^{-1} \sim \sum_i l_{T,i}^{-1}$, a general formulation becomes

$$h_E = C_R \frac{u_*}{|f|}\left(1 + \frac{C_R^2 C_{uN}}{C_S^2}\mu_N + \frac{C_R^2}{C_S^2}\mu\right)^{-1/2}. \qquad (9a)$$

where $\mu = u_* |fL|^{-1}$ and $\mu_N = N|f|^{-1}$ are internal- and external-stability parameters, receptively, whereas $C_R \approx 0.5$, $C_S \approx 0.6$ and $C_{uN} \approx 0.3$ are empirical dimensionless constants (Z-et-al-2002). Eq. (9a) is consistent with the non-local closure model, Section 2.1, so that C_{uN} in Eqs. (8) and (9a) is one and the same constant.

Zilitinkevich and Esau (2002b) have derived a modified, baroclinic-PBL scale for the turbulent velocity:

$$u_T^2 = \frac{u_*^2}{1 - \mathrm{C}_0 \mathrm{Ri}^{-1/2}} \approx u_*^2\left(1 + C_0 \mathrm{Ri}^{-1/2}\right) = u_*^2\left(1 + C_0 \mu_\Gamma\right), \qquad \mu_\Gamma = \frac{\Gamma}{N} = \mathrm{Ri}^{-1/2}, \qquad (10)$$

where $\mathrm{Ri} = (N/\Gamma)^2$ is the Richardson number based on the free-flow Brunt-Väisälä frequency N and the geostrophic-velocity shear Γ, μ_Γ is the parameter of baroclinicity, and $C_0 \approx 0.67$ is an empirical constant estimated in *op. cit.* through LES. Then, the equilibrium baroclinic PBL depth equation analogous to Eq. (9a) reads:

$$h_E = C_R \frac{u_*}{|f|}\left(1 + C_0 \mu_\Gamma\right)\left(1 + \frac{C_R^2 C_{uN}}{C_S^2}\mu_N + \frac{C_R^2}{C_S^2}\mu\right)^{-1/2}. \qquad (9b)$$

In non-steady regimes, the actual PBL depth *h* differs from the equilibrium depth h_E:

$$\frac{dh}{dt} = \begin{cases} w_h - C_E |f| (h - h_E) \\ w_h + w_e \end{cases} \qquad (11)$$

Here, the upper line is a relaxation equation (e.g., Mahrt, 1981), which describes collapsing or slowly evolving PBLs; the lower line is an entrainment equation which describes rapidly growing PBLs (e.g., Kato and Phillips, 1969; Kraus, 1977; Zilitinkevich et al., 1979; Kanta and Clayson, 2000); w_h is the large-scale vertical velocity at $z = h$; w_e is the entrainment rate; and $C_E \approx 1$ is an empirical constant.

Barotropic and baroclinic versions of the equilibrium PBL depth equation, Eqs. (9a) and (9b), and the relaxation version of Eq. (11) have been validated against atmospheric and LES data by Z-et-al-2002, Zilitinkevich and Baklanov (2002) and Zilitinkevich and Esau (2002b). In their principal features, these new models are applicable to all range of stably stratified geophysical PBLs.

4. PBL bulk resistance and heat/mass transfer laws in stable stratification

<u>Summary</u>: *The resistance and heat/mass transfer laws express the surface fluxes through the governing external parameters of the PBL. The dimensionless coefficients A, B, C and D in these laws were traditionally considered as single-valued functions of one argument, namely,*

$\mu = u_* / fL$, where L is the MO length. The new theory disclosed that A, B, C and D depend in the steady state on the three arguments, namely μ, $\mu_N = N/f$, and $\mu_\Gamma = \Gamma / N$, and in non-steady states, on these three and one more argument, h/h_E. This new development rehabilitates the resistance laws as a practical tool for use in numerical modelling. As an example, Figure 2 and Eq. (13) present new theoretical prediction on A and B supported by LES. Sections 2-4 present a closed turbulence-parameterisation package for stable PBLs.

The classical resistance law expresses the geostrophic drag coefficient C_g and the cross-isobaric angle α_0 through the PBL governing parameters:

$$A = \ln\left(C_g \mathrm{Ro}\right) - \frac{k}{C_g}\cos\alpha_0 , \qquad B = \mp \frac{k}{C_g}\sin\alpha_0 . \tag{12}$$

Here, $k \approx 0.4$ is the von Karman constant, *A* and *B* are dimensionless coefficients, *f* is the Coriolis parameter, Ro $= G/|f| z_{0u}$ is the surface Rossby number, and z_{0u} is the surface roughness length for momentum. On the r.h.s. of Eq. (12b), minus is applied to the Northern Hemisphere and plus to the Southern Hemisphere. In the atmospheric PBL, $C_g = u_*/G$ is the ratio of the friction velocity u_* to the near-surface geostrophic velocity *G*, and α_0 is the angle between that surface stress and the geostrophic wind[4].

Equations (12) for the neutral PBL, with *A* and *B* supposed to be universal constants, were derived by Rossby and Montgomery (1935) from a turbulence closure model and later by Kazanski and Monin (1961) from a similarity-theory reasoning. An overview of further studies of the atmospheric-neutral-PBL resistance law is given by Hess and Garratt (2002a,b).

Zilitinkevich et al. (1967), Gill (1967), and Zilitinkevich and Chalikov (1968) extended Eq. (12) to stratified PBLs with the only difference that *A* and *B* became functions of the internal stability parameter $\mu = u_* |fL|^{-1}$. Since then, the PBL was traditionally considered as neutral when μ is zero or very small. In the seventies and early eighties, much work focused on theoretical and experimental determination of the coefficients *A* and *B* and similar coefficients *C* and *D* in the heat and mass transfer laws (henceforth, "scalar resistance laws") supposed to be single-valued functions of μ. However, empirical relationships of this type showed so wide spread of data that any interest in practical application of the resistance laws gradually decayed.

Recently Zilitinkevich et al. (1998b) and Zilitinkevich and Esau (2002a) have found that the coefficients *A*, *B*, *C* and *D* depend not only on μ but also on the Brunt-Väisälä frequency *N* in the free flow, which involves the external stability parameter $\mu_N = N|f|^{-1}$. Next, Zilitinkevich and Esau (2002c) have extended the resistance laws accounting for the effect of baroclinicity on the PBL turbulence [cf. Eq. (10)].

These developments rehabilitate the resistance laws as a precise physical theory. In particular, they explains wide spread of empirical data on *A* and *B* and a seemingly paradoxical disagreement between atmospheric and LES, DNS or lab-experiment estimates of *A* and *B* in neutral PBL. Indeed, numerical or lab models deal with the truly neutral PBLs

[4] The same law can be applied to the upper PBL in water reservoirs. Then C_g represents the ratio of u_* to the surface-drift-current velocity, whereas α_0 is the angle between the wind stress and the surface drift current. Thus Eq. (12) could be quite useful in modelling of air-sea/lake interaction. Even more useful could be resistance laws for scalars: heat and moisture in the air or heat and salt in water.

($\mu = 0$ and $\mu_N = 0$), whereas atmospheric PBLs treated as neutral ($|\mu| << 10$) are in fact strongly affected by the free-flow stability (with typical value of the external stability parameter $\mu_N \sim 10^2$). For such "conventionally neutral" PBLs, the new theory predicts

$$A = \ln(a_0 + \mu_N) - a_1 \mu_N^{1/2}, \qquad B = b_0 + b_1 \mu_N \qquad (a_0, a_1, b_0, b_1 = \text{constant}). \tag{13}$$

Thus the above disagreement becomes only natural (see Figure 2).

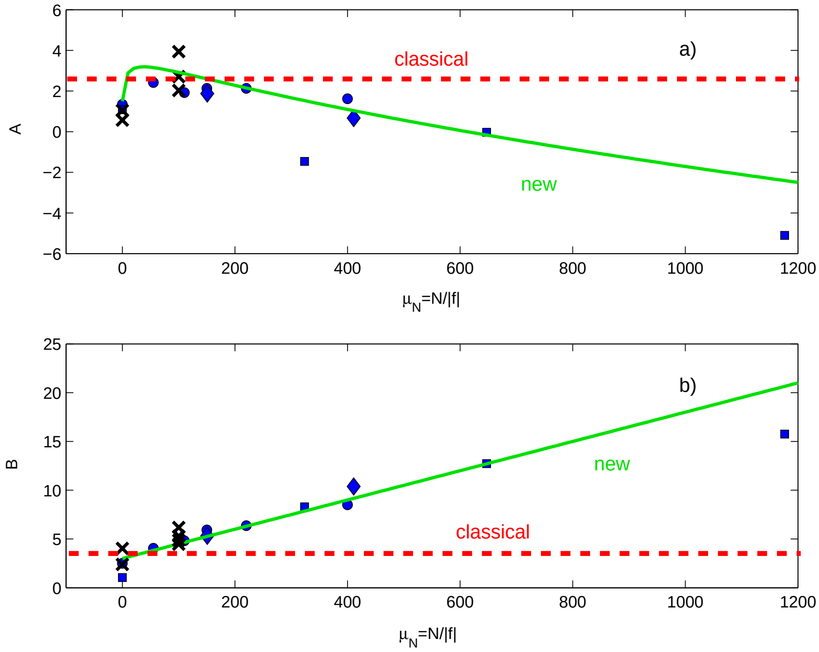

Figure 2. The resistance-law coefficients *A* and *B* versus the imposed-stability parameter μ_N in the conventionally neutral PBL (Zilitinkevich and Esau (2002a,c): the curves – after non-local theory, Eq. (13); circles (Ro=10^6), diamonds (Ro=$1.47*10^7$) and squares (Ro=$2.6*10^8$) – new LES; crosses – earlier LES (Mason and Thomson, 1987; Moeng and Sullivan, 1994; Sullivan et al., 1994; Lin et al., 1997). The classical, local theory assumed *A*,*B* = constant, which is evidently wrong.

The new theory has been systematically validated through LES. It transforms the resistance laws into a practically useful element of atmospheric modelling. It is also allows to apply the resistance laws to the sea or lakes. Here, the role of μ_N is absolutely dominant because of the very strong static stability typically observed in the thermocline. It is not surprising that up to now the resistance laws were never used in air-sea interaction modelling. The generalised laws provide a physically grounded parameterisation for (i) turbulent fluxes of momentum and scalars at the sea/lake bottom, and (ii) surface drift-current velocity and direction, and the temperature, salinity and other scalar increments in thin films at the water surface. The latter is required in a number of practical problems, e.g., in modelling of transport and dispersion of oil spots.

5. Near-surface friction and heat/mass transfer in convective PBLs

Summary: The key point is the effect of the PBL-scale eddies ("convective-wind" circulations), which generate additional friction in the surface layer and strongly enhance the surface fluxes. This effect was totally disregarded in classical theories (such as the

Monin-Obukhov similarity theory or traditional closures, e.g., those of the Mellor-Yamada type). The very concept of the "minimum friction velocity" U_* (shown in Figure 3) is absolutely outside the classical theory. U_* is a sort of friction velocity that appears in the convective surface layer, when the mean wind diminishes to zero and the classical theory assumes $u_* = 0$. This new theory incorporates the PBL depth h in the surface-layer scaling (confer the incorporation of the free-flow Brunt-Väisälä frequency N in the surface layer scaling in stable stratification).

In the majority of atmospheric GCMs, the near-surface convective mixing processes are considered in the spirit of the Prandtl (1932) and Obukhov (1946) theory of convection and the Malkus (1954) and Priestley (1954) heat transfer law ($\mathrm{Nu} \sim \mathrm{Ra}^{1/3}$, where Nu and Ra the Nusselt and Rayleigh numbers respectively). These classical theories are based on the concepts of (i) universally chaotic turbulence and (ii) local correspondence between turbulent fluxes and mean gradients. The turbulent fluxes in the atmospheric surface layer are usually parameterised through the Monin-Obukhov similarity theory or down-gradient turbulence closures, disregarding non-local mechanisms and gross features of PBLs.

Numerous observational and LES studies performed in the last decades allowed to recognise that the above local-transport models break down in strong convection. This is caused by the semi-organised structures embracing the convective PBL, namely, narrow buoyancy-driven plumes surrounded by wider areas with weaker motions of the opposite sign. The surface layer feeds the plumes through the PBL-scale convergence flow patterns. These can be treated as internal boundary layers of basically radial geometry strongly affected by the buoyancy forces. Generally, convergence flows superimpose on mean wind. In calm weather they yield their own velocity shears characterised by the "minimum friction velocity" (Businger, 1973). As a result, the turbulent mixing and the heat/mass transfer in the surface layer are strongly facilitated depending on the PBL depth and the surface roughness length.

Stull (1994) and Beljaars (1995) applied different scaling hypotheses to parameterise the contribution from large-scale convective structures to the near-surface mixing. In the Beljaars scheme, the Deardorff convective velocity scale $w_* = (F_b h)^{1/3}$ is used to measure the typical wind velocity in the near-surface convergence flow patterns (following Deardorff, 1972). Then a standard Monin-Obukhov type flux calculation scheme is modified by replacing the mean wind velocity $u(z_1)$ at the first model level $z = z_1$ by the sum $u(z_1) + w_*$. The Beljaars scheme has been successfully employed in the European weather prediction model ECMWF and the Hamburg climate model ECHAM. Advanced theoretical models of the buoyancy-driven convergence flow patterns in the convective surface layer have been developed by Schumann (1988), Sykes et al. (1993) and Zilitinkevich et al. (1998a). Comparison of different model predictions with atmospheric data is shown in Figure 3. Similar revisions of the classical convective heat/mass transfer law has been perfumed in engineering fluid mechanics (see Siggia, 1994). All the above models involve the Deardorff velocity scale w_* dependent on the PBL depth *h*. Thus *h* is included in the surface layer scaling. An advanced prognostic equation for *h* is considered below in Section 6.

Oceanographic aspects of the non-local heat/mass transfer at the sea surface and bottom still did not attract much attention. The time is ripe to make up for this deficiency The above recent developments could be immediately employed to derive non-local resistance laws for both upper and bottom convective PBLs in water reservoirs (cf. similar strategy for the stable PBL briefly discussed in Section 4).

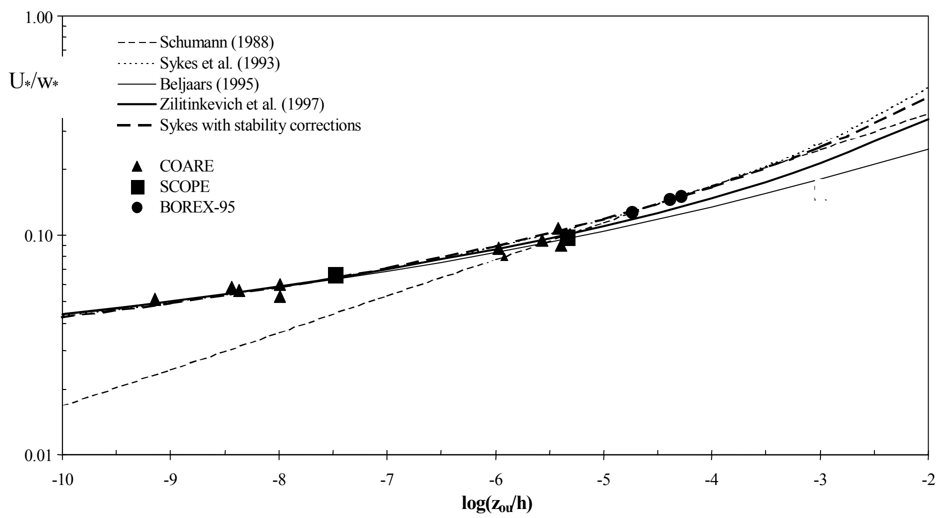

Figure 3. Dimensionless "minimum friction velocity" U_* / w_* versus dimensionless roughness length z_{0u} / h, after theoretical models and field data (Akylas et al., 2001). Traditional local theories overlook generation of U_* by large-scale coherent eddies.

6. Convective PBL depth

<u>Summary</u>: *The key point is a generalised prognostic equation for the convective PBL depth, applicable to atmospheric, laboratory and (in basic features) oceanic convective layers. The proposed approach needs validation through atmospheric, lab, LES and oceanographic data. The convective PBL depth, h, is required in the surface flux calculation techniques (Section 5). It is also required in modern non-local convective closures (Section 7).*

The convective PBLs in the atmosphere and the ocean represent well-mixed layers developing against stable stratification in the free flow. Considering their bulk features, such as the PBL depth, conservative parameters (e.g., potential temperature) could be taken depth-constant within the PBL, except for close vicinities of the PBL inner and outer boundaries. Accordingly the turbulent fluxes are approximated by linear functions of height. In this "slab model", the surface buoyancy flux F_{bs} is the basic driving force for the PBL turbulence, together with the surface friction, characterised by the friction velocity u_*, and the baroclinic shear Γ. An advanced theory of the convective surface layer underlying the surface-flux calculation technique is briefly presented in Section 5. As mentioned above it involves the PBL depth *h*.

The fluxes due to entrainment at the PBL outer boundary are expressed through the increments of appropriate parameters at the PBL outer boundary, e.g.,

$$F_{bh} = \Delta b dh / dt , \tag{14}$$

where F_{bh} and Δb are the flux and the increment of the buoyancy. Calculation of these fluxes requires knowledge about the PBL depth as dependent on time and horizontal coordinates.

Prognostic equations for the convective PBL depth *h* and the buoyancy increment Δb are derived through term-wise integrating of the TKE-budget and the thermodynamic-energy equations over the PBL. Here, the convective-PBL scaling (based on *h* and w_*) is used to parameterise the vertical profiles of the TKE *E* and its dissipation rate ε (Deardorff, 1972). Zilitinkevich (1991) accounted for the energy losses due the radiation of IGW from the PBL outer boundary to the stratified free flow (cf. Eq. 6a). By this means, he refined the *h*- and

Δb-equations and validated them against data from numerous lab models of the shear-free penetrative convection. More recently he extended the derivation to geophysical PBLs accounting for the baroclinic shear and the difference in the spectrum of IGW in the nature and in lab experiments, where the wave lengths are limited by the width of experimental tanks (Report on SFINCS – EC Contract ENV4-CT97-0573, 2001; available at Dept. of Earth Sci., Uppsala Uni., Sweden). The h- and Δb-equations for barotropic geophysical PBL are

$$\frac{dh}{dt} = w_h + \frac{C_1 w_*}{C_2 + \mathrm{Ri}_1 + \sqrt{\mathrm{C}_1 C_3}\,\mathrm{Ri}_1 \mathrm{Ri}_2^{3/4}}, \qquad \frac{d}{dt}\left(\tfrac{1}{2} N^2 h^2 - h\Delta b\right) = F_{bs}, \tag{15}$$

where C_1, C_2 and C_3 are empirical constants, $Ri_1 \equiv h\Delta b / w_*^2$ and $\mathrm{Ri}_2 \equiv \tfrac{1}{2}(Nh/w_*)^2$ are Richardson numbers based on the buoyancy increment and the free-flow Brunt-Väisälä frequency, respectively.

7. Turbulent fluxes in the interior of convective PBLs

Summary: A large number of alternative convective turbulence closures of different complexity have been proposed. No consensus is achieved, which obviously indicates that no one theory is sufficiently advanced. It is the author's opinion that the most constructive way to model convective turbulent flows is to consider separately the large-scale coherent structures ("convective wind") – which must be resolved, and the small-scale truly chaotic part of the turbulent spectrum – which could be parameterised using local, traditional type of the sub-grid scale closure.

Principal difficulties with turbulence closures for convective flows are clearly seen by the example of the potential temperature flux. Its conventional expression $F_\theta = \overline{w'\theta'} = -K_H(\partial\theta/\partial z)$, where K_H is the eddy conductivity, is justified when the turbulent mixing length is much less than the length scale of heterogeneity of the mean flow. This is not true in convective flows, which are strongly affected by large-scale semi-organised structures with pronounced asymmetry between up- and down-draughts. In such flows, F_θ in not necessarily proportional to the mean gradient $\partial\theta/\partial z$. The latter could be of the same sign as F_θ (counter-gradient transport) or equal to zero (no relation between F_θ and $\partial\theta/\partial z$). To make the eddy-conductivity concept applicable to convective PBLs, a counter-gradient γ_H was introduced (Budyko and Yudin, 1946; Priestley and Swinbank, 1947; Deardorff, 1972):

$$F_\theta = -K_H(\partial\theta/\partial z - \gamma_H). \tag{15}$$

Troen and Mahrt (1986) developed the first practically sound version of the counter-gradient-correction closure. They employed a Deardorff-type counter-gradient $\gamma_H \propto F_{\theta s}/w_s h$ based on the generalised velocity scale $w_s = \left(u_*^3 + 0.28 w_*^3\right)^{1/3}$ together with the eddy conductivity $K_H \sim t_* \sigma_w$ based on empirical profile-functions for the time scale t_* and the vertical velocity variance σ_w.

More recently Holtslag and Moeng (1991) extended the above formulation with due regard to the third order turbulent-transport term in the TKE budget equation, using results from the Moeng and Wyngaard (1989) LES of the convective PBL. By this means the potential temperature flux within the PBL, $F_\theta(z)$, was expressed through the PBL bulk parameters h and $F_{\theta s}$ and empirical functions $\sigma_w(z)$ and K_H(z). These closures are conceptually very similar to the so-called KPP closure proposed recently for use in oceanographic modelling (Large et al., 1994).

It is usually assumed that the counter gradient term $K_H\gamma_H$ in Eq. (15) represents the contribution from large eddies to the potential temperature flux. Frech and Mahrt (1995) recognised that the large-eddy flux is not immediately related to the small-scale eddy conductivity K_H and, moreover, not necessarily directed counter to the gradient. They decomposed the vertical flux $F_\psi = \overline{w'\psi'}$ of a quantity ψ into the small-scale (down-gradient) and the large-scale (generally non-gradient) contributions, $F_\psi = -K_\psi \partial\psi/\partial z + \overline{w'\psi'}_L$, and proposed empirical parameterisations for $\overline{w'\psi'}_L$.

Berkowicz and Prahm (1979) and Fiedler (1984) proposed an integral closure: $F_\psi = -\int_0^\infty W_\psi(z,z')(\partial\psi/\partial z)dz'$, where W_ψ is a weight function (a sort of turbulent transport velocity). Stull (1988) proposed a discrete closure of the same type, which involved a so-called "transilient matrix" playing the same role as the above weight function and also subjected to empirical estimation.

Wyngaard (1983) and Wyngaard and Brost (1984) have found that the vertical diffusion of a passive scalar through the atmospheric convective PBL is a superposition of the bottom-up and the top-down diffusion due to buoyancy-driven plumes (up-draughts) compensating down-draughts, respectively. They also recognised that up-draughts are narrower and stronger than downdraughts. This asymmetry is characterised by the skewness, $S_w = \overline{w'^3}/(\overline{w'^2})^{3/2}$. Using the above concept, Wyngaard and Weil (1991) have derived an expression for the counter-gradient: $\gamma_\psi = S_w \sigma_w \tau_L (\partial^2\psi/\partial z^2)$, where τ_L is a Lagrangian integral time scale.

It is understood that the non-local transports are controlled by the third moments. In most higher order closures (Zeman, 1975; Zeman and Lumley, 1976; Andre, 1976; Moeng and Randall, 1984; Kurbatskii, 1988; Lykossov, 1990; Canuto et al., 1994) these moments are determined from appropriate budget equations, whereas the forth moments are expressed through quasi-normal (Gaussian) approximation, following the Millionshchikov (1941) hypothesis. Canuto et al. (1994) performed the most systematic derivation of this kind.

Zilitinkevich et al. (1999) and Mironov et al. (1999) developed a non-Gaussian, turbulent advection + diffusion model for the third moments and applied it to derive an integral non-local closure for the convective heat flux.

Of the above non-local closures, all those which are comparatively simple and practically useful (Troen and Mahrt, 1986; Holtslag and Moeng, 1991; Large et al., 1994) require the predetermined surface buoyancy flux $F_{\theta s}$ and convective PBL depth h. Thus modern turbulence closure schemes for convective PBLs should be employed in combination with (i) the surface-layer flux-profile relationships or the PBL bulk resistance laws (Section 5) and (ii) a convective PBL depth equation (Section 6).

In future work, a promising strategy of applied modelling of convective PBLs could be based on a combination of analytical investigation of typical sizes and other basic features of the most energetic eddies (Elperin et al., 2002) and comparatively low-resolution LES. The latter should focus on resolving only the energetically dominant eddies with a properly parameterised small-scale turbulence.

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Participant 2 (P2) - DWD

DWD (German Weather Service)
Business Area Research and Development

Partner team:
Barbara Fay, WP3 leader
Lina Neunhäuserer, project scientist

Matthias Raschendorfer (parameterisation), Ulrich Schättler (data interpolation), Thomas Hanisch (numerical experiments), Andreas Klein, Van Tan Nguyen (programming, external parameters)

1. Introduction

The German Weather Service (Deutscher Wetterdienst, DWD) is the national meteorological service. Its research and operational activities relevant to FUMAPEX include numerical weather prediction, air pollution modelling and expertise, and emergency systems.

The DWD has a long experience in ***numerical weather prediction*** developing stand-alone NWP systems including data assimilation and parameterisation. The current operational NWP model suite consists of the Global Model (GME) and the non-hydrostatic Lokal Model (LM), now under development by **COSMO (Consortium of Small Scale Modelling, meteorological services of Germany, Italy, Greece, Switzerland, Poland)**. A workstation version of the predecessor mesoscale forecast model is operational in 9 national meteorological services in Europe, Asia, and South America.

The central task in ***air pollution modelling*** is providing forecasts for the **national nuclear emergency system** for guidance to federal and regional government bodies. The operational system developed comprises a **trajectory model**, a **Lagrangian particle dispersion model (LPDM)** and a **mixing height pre-processor** based on the results of the NWP models on different scales. For chemistry dispersion research, a trajectory box model and a three-dimensional Eulerian ozone forecast model using LM data and the RADM chemistry code were developed, applied, and evaluated. A primary goal for improving especially the emergency and air quality work is the provision of more highly resolved model simulations for which LM input data with increased resolution and adapted parameterisations are needed.

These will also bridge the gap in input data for a range of local-scale dispersion models at the DWD which are employed for **climatological expertise** and at the moment use only measure-ment-based meteorological pre-processors, but not NWP data. These models comprise Gaussian plume models, a local LPDM, and the urban climate model MUKLIMO-3.

2. High-resolution meteorological and dispersion modelling in FUMAPEX

Some recent and future activities at the DWD include:

- introduction of prognostic turbulence scheme of level 2.5 closure after Mellor and Yamada (1974), Raschendorfer (1999).
- pre-operational testing of new 7 layer soil model
- pre-operational testing of prognostic cloud ice scheme
- pre-operational testing of increased resolution for NWP models
- pre-operational testing of emergency system for chemical accidents (local to regional scale)
- participation in European radioactivity preparedness projects (from ETEX to ENSEMBLE)
- preliminary urban episode modelling in COST715.

NWP modelling:

DWD developed and since 2000 operates a stand-alone NWP model chain comprising the Global Model with about 60km mesh size (triangular grid), 31 vertical levels, and full data assimilation. It provides initial and boundary values to the nested non-hydrostatic Lokal Model (LM) with 7km and 35 levels operational resolution for central and western Europe.

The growth of supercomputer power (new IBM RS6000) will allow increased resolution for both GME and LM models. The **pre-operational LM** version has 43 vertical levels and 2.8km horizontal resolution and will be run for nowcasting purposes for Germany, while the area of the operational 7km version will be extended across most of Europe.

In FUMAPEX, horizontal and vertical resolution of the LM may now be increased as desired after the finalisation of the **1-way self-nesting version of LM** by L. Neunhäuserer. This version was already distributed to P8 and the partners of the COSMO consortium.

Preliminary modelling of two stable winter inversion episodes for Oslo and Helsinki was performed in the framework of COST715 with a **2-way interactive LM nesting version** which is under research in the COSMO.

A **research high-resolution version of the LM (the LLM)** was developed at the DWD (Herzog et al., 2002a and b). It has 100m resolution, 39 layers up to 3km height, 3D turbulent fluxes, and parameteristion of subgrid-scale turbulence including the prognostic fully 3D TKE equation. The model is driven by local measurements (also LM-derived input data), uses subgrid-scale land use and opography databases and is at the moment applied for the rural environment of the East German DWD research observatory Lindenberg. P8 was interested in using the model for Bologna applications but the intended application had to be suspended for resource reasons.

For the application of these LM-versions for the urban scale, external parameters with 1km resolution or below are needed. **High-resolution external parameter fields** were already calculated, with the simulated roughness length (z_0) in Fig. 1. z_0 not only shows much more detail (valleys etc.), but also decreases with increasing resolution, because the subscale orographic influence decreases with increased NWP model resolution, whereas the portion of the plant cover stays approximately the same. However, with the 1.1km resolution map in Fig. 1 the limitations of using the common 1km x 1km data base become apparent: z_0 appears too low especially in mountainous areas due to the absent roughness in the sub-grid scale of the database which has a resolution close to the accuracy of the calculated field (Baklanov et al., 2002).

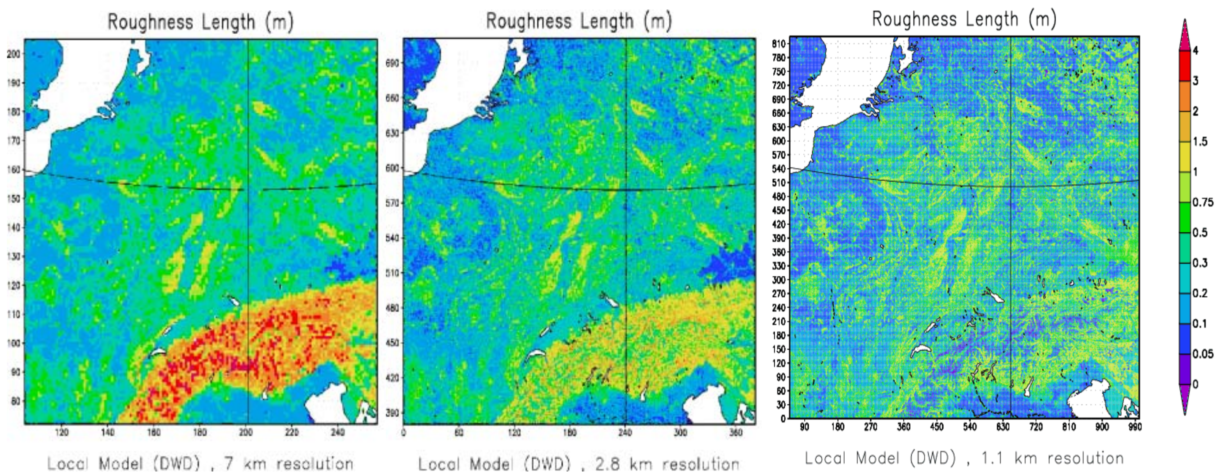

Fig 1. DWD LM (Lokal Model) simulation of the roughness length in 7, 2.8, and 1.1 km resolution (all based on a 1km x 1km database).

Interfaces from NWP to air pollution models:

Dispersion models often need input fields not directly provided as NWP model output. The mixing height (MH) is such a parameter important for many UAP models. It is calculated in an operational post-processing module to the LM and the results are provided a.o. to the German emergency preparedness system.

The scheme uses a Richardson number approach. MHs (see Fig. 2) were calculated for different seasons and weather situations and compared to radiosoundings and MHs calculated from various other methods (mechanical, parcel, slab, encroachment) recommended in the COST710 final report , WG2 (Fisher at al, 1998) showing the generally high quality of the DWD approach. The largest systematic underestimations (20 to 30%) compared to estimated radiosounding MHs and wind profiler measurements occur in unstable and convective conditions caused by a too weak development of the boundary layer in these situations (Fay et al.,1997). Similar results are obtained e.g. by P1 (DMI) (Baklanov et al., 2002).

In FUMAPEX, research will focus on urban conditions including problems of the nocturnal boundary layer height.

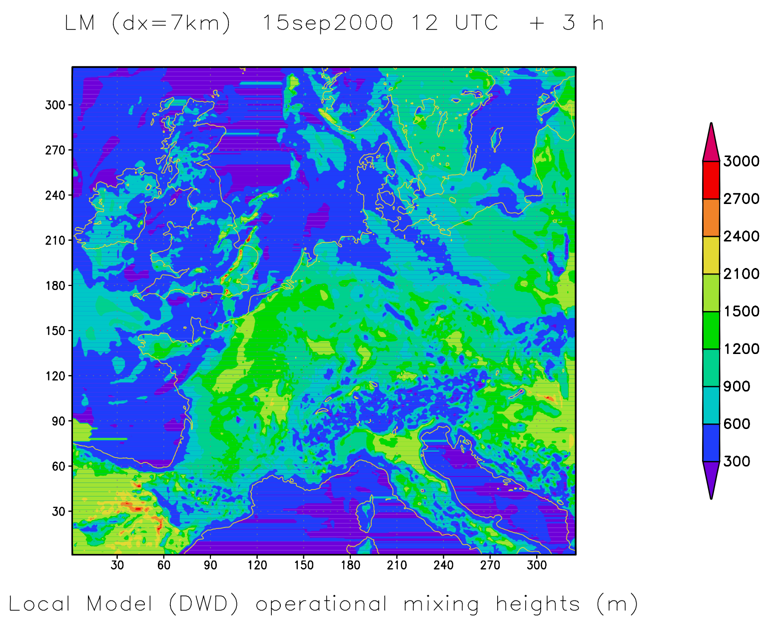

Fig. 2. DWD Lokal Model LM operational mixing height [m] calculations for central/western Europe, here for 15 Sep 2000, 15UTC.

Radioactivity emergency preparedness system in Germany:

The German radioactivity preparedness system consists of two main sub-systems:

The emergency system run on the German federal level by the DWD includes radioactivity measurements and emergency model calculations performed with DWD models. Initial fast information is provided from the fully 3D trajectory model TRAJ (Kottmeier and Fay, 1998), detailed concentrations and dispersion information are calculated with the Lagrangian particle dispersion model LPDM (Fay et al.,1995). These models took part in the European emergency projects ETEX, RTMOD, and ENSEMBLE and always ranged amongst the best (Glaab et al., 1998). For support of the emergency authorities of the individual German federal states for accidents in their own or neighbouring states, a modified version of the European emergency system development RODOS is partly operated at the DWD which uses LM input data and the mixing heights described above, and also follow-up calculations with the DWD's LPDM for the medium and long distance.

The use of high resolution LM input data for the emergency system and for the models applied in the system is a standing request by the system end users, and the adaptation and evaluation of the LM data and the dispersion models to the urban environment is a relevant improvement concerning the numerous conurbations in Germany.

3. DWD contribution to FUMAPEX

The DWD contributes to **FUMAPEX** with the aim of developing and testing **a model system suitable for forecasting meteorology for air pollution episodes** in order to **provide high-resolution input data to their own dispersion models and for dissemination** to federal and regional agencies. This will involve adapting, improving, and validating the LM NWP model and meterological interfaces/pre-processors for higher resolution and the urban environment.

The DWD co-ordinates WP 3 (Testing the quality of different operational meteorological forecasting systems for urban areas) and participates in WP 4 to 6 which are all concerned with NWP modelling and pre-processors. The contributions in WP1 are concerned with the choice of suitable cities / episodes for the modelling work (questionnaire and Helsinki meeting representation), and in WP10 for project management and quality assurance.

WP3 (9PM):
The main tasks of DWD are the co-ordination of the activities in WP3 and (following the DoW):
WP3.1: the overview of the different NWP modelling systems participating in FUMAPEX, including the description of the GME/LM model chain
WP3.2: the design of the model comparison study for the different cities/episodes
WP3.3/4: NWP model comparison and evaluation of the partners' model systems for the target cities/episodes.
The self-nesting LM version was finalised by L. Neunhäuserer and distributed to P8 (ARPA/SMR, Italy).

WP4 (6PM):
P2 will work on the improvement of boundary layer parameterisations for the urban scale in the LM model:
External and physiographic parameters, turbulence parameterisation, and surface fluxes in the LM will be adapted for the urban environment starting with simple improvements and later investigating the options already included in the DWD's new prognostic turbulence parameterisation scheme.
Partner P16 will be supported in implementing their state-of-the-art urban turbulence parameterisation into the LM (LM documentation was transferred to P16.)

WP5 (4PM):
For all LM grid points, DWD operationally calculates and disseminates LM mixing heights. In WP5, P2 will test the modified LM results from WP3 and WP4 for the calculation of mixing heights for cities and focus on their improvement, validation, and intercomparison for the urban environment in co-operation with other partners (especially P1, P8).
The present MH was transferred to P8 who will implement and test it against CALMET results and measurements.

WP6 (2PM):

DWD will contribute to the sensitivity study by carrying out LM simulations with increasing resolution and studying the impact of the modified meteorological fields on the selected air quality models (trajectories, LPDM) which are used in the German radioactivity emergency systems described above (approach similar to P1) .

Projects most relevant to FUMAPEX:

- COST715, Meteorology applied to urban air pollution problems, 1998 – 2004: Preliminary tests of high resolution external parameters, LM model, and mixing heights.
- COSMO – LM-model development.

Further related project:
Evaluation of daily ozone forecasts (with the photochemistry model based on LM) for summer 2000 by cluster analysis to determine typical chemical scenarios, German research project AFO2000 and EUROTRAC-2.

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Participant 3 (P3) - MIHU

Meteorological Institute, University of Hamburg
Centre for Marine and Atmospheric Research

1. Partner Description

The Meteorological Institute of Hamburg University (MIHU) has a permanent staff of 13 scientists and employs in addition about 35 research workers funded by external sources. Together with the Max-Planck-Institute for Meteorology and several other institutes of Hamburg University (Oceanography, Geophysics, etc.) we form the Centre for Marine and Atmospheric Research (ZMAW) which is one of the leading centres for climate and environmental research in Germany. The institute has access to most up-to-date computers including the NEC SX-6 Super Computer of the German Climate Computer Centre with which we share the building. As the only meteorological institute in Germany, we operate a laboratory with several boundary layer wind tunnels equipped with advanced instrumentation (Laser Doppler Velocimetry, Image Processing, Fast Flame Ionisation Detectors etc.)

The group which participates in FUMAPEX is active in the field of Urban Air Pollution Meteorology since many years. Specialty is the generation of quality data sets suitable to test the accuracy of urban air pollution models or specific parameterisations used in the models. In addition meso- and obstacle-resolving micro-scale models are developed and applied.

Principal personnel involved
Michael Schatzmann, Prof., Director in Charge of the Institute, tel. +49-40-42838-5090, fax: +49-40-42838-5452, e-mail: schatzmann@dkrz.de,
NN (to be employed).

2. Potential Role of Partner 3 (MIHU) within FUMAPEX

The task of partner P3 is to contribute mainly to work packages WP4 and WP5 and to evaluate urban air pollution(UAP) -model inputs and results. The new European regulations, as they are expressed in the air quality guideline (96/92/EC), require the prediction of local peak values (high percentiles) at specific points (hot spots) within an urban conurbation. Those hot spots are normally found in and around city centres in street canyons with heavy traffic loads. To determine pollutant concentrations in such environments, local-scale, obstacle-resolving models need to be applied. To drive these models, input data representative for the local environment of the hot spot are needed. These input data for urban air pollution models are either provided by weather forecast models or they are transferred from measurements taken at routine synoptic stations outside the cities.

Both methods have their limitations. It is presently unknown how accurate the input data for UAPs applied in city environments are. P3 will contribute to fill this gap in knowledge. P3 will participate in the discussion on which parameters are the most important during critical air pollution episodes in European cities (WP1). P3 will contribute to improvements in the parameterisations for obstacle-resolving models and will provide data for the validation of such models. Furthermore, P3 will provide data which allow to improve the roughness parameterisations for urban areas (WP4). P3 will analyse data measured simultaneously over a period of at least one year at an airport and at a city monitoring station both at an above roof and street canyon position. The deliverable is a dataset which can be used to evaluate the quality of existing data transfer methods (WP5). Since NWPs and other methods deliver input data at best with a spatial resolution of 1 km x 1 km, additional investigations will be made concerning the extent of local variability of UAP input parameters within such an area, thereby contributing to WP6.

Subsequently an example of MIHUs ongoing work on model validation at the local scale is given. This example is presented in order to raise awareness for the specific problems which will be encountered by FUMAPEX when dealing with local scale problems.

3. Model validation at the local scale

Validation comprises a direct comparison between model results and data. As will be shown below, validation of local scale models is not trivial: Data generated in field or laboratory experiments and results from model simulations exhibit systematic differences. To simply compare them with each other is often inappropriate. Special model validation strategies that reflect the particular features of urban canopy layer flows are needed. In the remainder of this section these differences between measurement and calculation will be explained and quantified using the example of data collected at a street canyon monitoring station.

The differences between numerical model results and data are demonstrated using the example of a small area source that continuously discharges a passive tracer into a street canyon (Fig. 1). The figure shows the instantaneous concentrations (in excess above background) as a function of time at the same receptor point and under identical steady-state ambient conditions as they might be found (a) in a field experiment, (b) in a wind-tunnel experiment, or (c) in a numerical simulation with full turbulence parameterisation.

(a) Field experiments: High-resolution field measurements usually provide highly intermittent signals, i.e. periods of zero concentration (in excess above ambient) are interspersed with non-zero fluctuating concentrations. It is to be expected that the intermittency of the signal depends largely on the turbulence structure within the canyon and the instantaneous wind direction fluctuations. If the concentration versus time trace varies as shown in Fig. 1 (top), long averaging times are required in order to produce a meaningful time-mean-value. It is anticipated that the commonly used 10 min or 30 min measurement cycles are not long enough. Longer averaging times, however, are not usually feasible since the meteorological conditions continuously change during the diurnal cycle. The conclusion is that the repeatability of field results is poor and that large error bars should be attached to time-averaged concentrations determined in field situations as described.

(b) Laboratory experiments: When the same dispersion problem is modelled in a wind tunnel, the concentration signal presented in Fig. 1 (centre) is obtained. If all main similarity parameters were matched properly in the small-scale simulation, the time series should resemble that of the field test, but intermittency due to low frequency wind direction variations might be reduced in a ducted flow with insufficient width. Therefore, time-mean concentration maxima determined in laboratory experiments may be larger than those obtained in the field. An important advantage of wind tunnel measurements in comparison to field tests, however, is that the boundary conditions can be carefully controlled, and that numerous repetitions of the same case can be made in order to determine the inherent variability of the dispersing cloud characteristics.

(c) Numerical model results: Finally, at the bottom of Fig. 1, the concentration versus time trace as obtained from a common grid model is displayed. Provided that the model considers turbulent fluctuations only in parameterised form, in case of constant boundary conditions, it delivers a stationary concentration value. In contrast to the experimental data, this value represents not only a time-mean but also a space-mean concentration representative of the characteristics of the volume of a grid cell.

The example shows that field or laboratory experiments in comparison with the numerical simulations represent distinctively different realities. To compare the results with each other resembles the proverbial comparison of apples with oranges if these fundamental differences are not properly taken into account.

The common approach to solve the problem is to average over the measured concentration time series (c = f (t) in Fig. 1, top), thereby applying the same averaging period as is used in the derivation of the assumed (quasi-) steady ambient conditions (e.g., 30 min). However, as will be subsequently shown, concentration mean values based on 30 min averaging intervals are not long enough to obtain representative results. If one compares several half-hourly concentrations measured under nearly identical ambient conditions at the same monitoring stations, differences are found which can be as large as an order of magnitude.

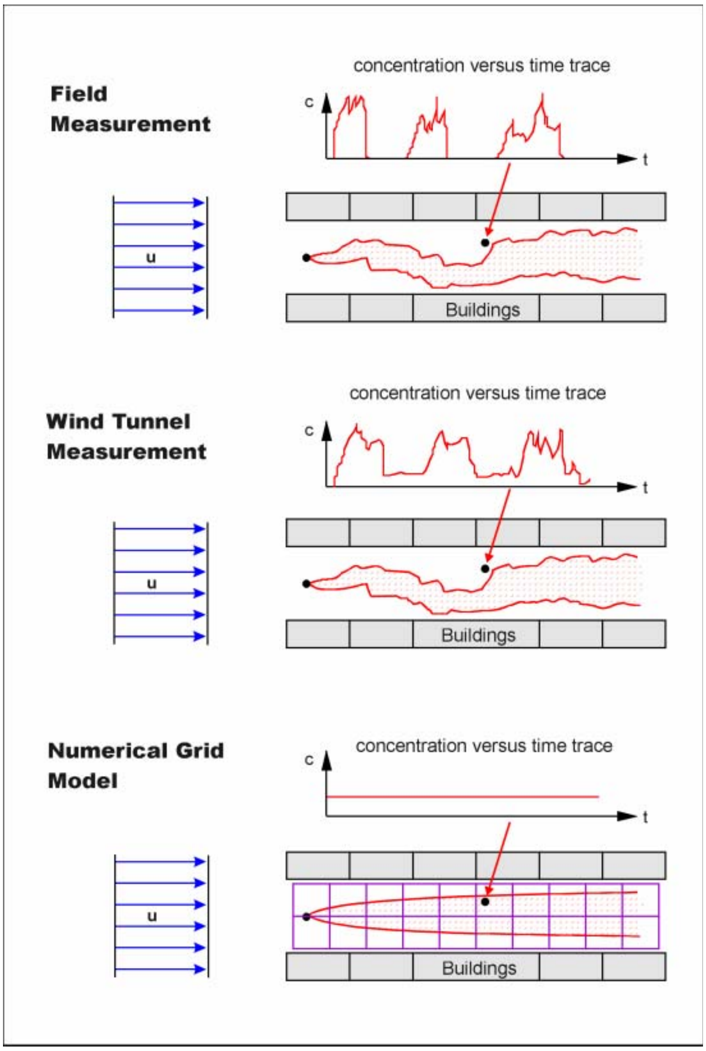

Fig. 1: Comparison of concentration (in excess above ambient) versus time traces typical for field measurements (top), wind tunnel measurements (centre) and numerical model results (bottom) after Schatzmann and Leitl (2002).

This is demonstrated in Fig. 2 using the example of data taken over a full year at the street monitoring station Goettinger Strasse in Hanover/Germany by the Lower Saxony State Agency for Ecology (NLÖ 1994, 1995). Shown are normalised concentrations $c^* = C\, u_{ref}\, H/(Q/L)$ as a function of wind direction, with C the 30-min averaged measured concentrations at the location of the monitoring station, u_{ref} the wind velocity taken in a measurement height of 100 m, H a characteristic height of the buildings surrounding the street canyon, and (Q/L) the total strength (kg/(m s)) of parallel line sources representing the traffic lanes. Values obtained during low traffic and low wind periods were omitted since under those conditions neither the line source concept nor the assumed neutral stratification are justified.

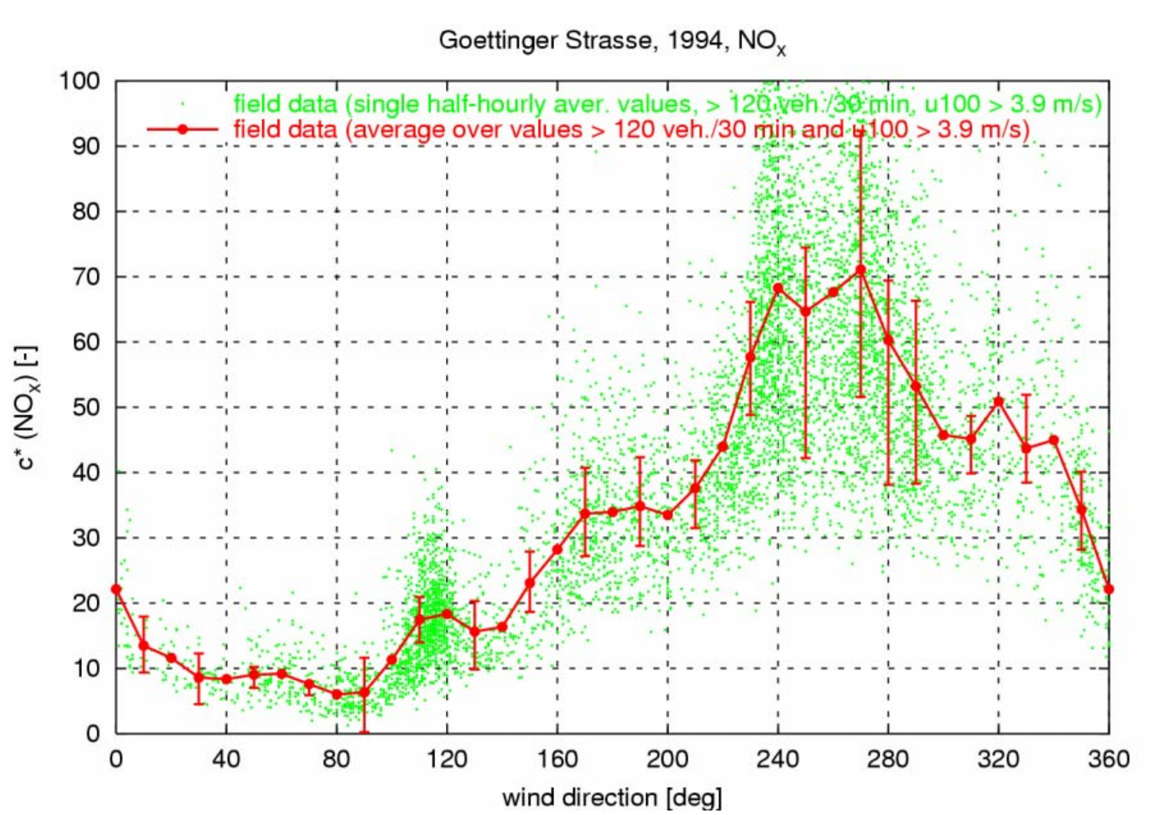

Fig. 2: Normalized half-hourly mean concentration values as a function of wind direction measured in situ over the period of one year at the street monitoring station Goettinger Strasse in Hanover/Germany (NLÖ 1994, 1995). The error bars were determined in corresponding wind tunnel experiments, see text.

In theory, all points shown in Fig. 2 should fall onto a single curve, but in reality this is not the case. . The scatter of data points is caused by the fact that averaging periods of 30 min are simply not long enough to derive representative mean values from strongly fluctuating and intermittent concentration time series. To average over longer time intervals is not however an option since both the meteorological and the traffic conditions continuously change.

The hypothesis that mean concentrations obtainable in urban dispersion experiments are only random samples and not suitable for validation purposes has been verified in corresponding wind tunnel experiments. In a 1:200-scale model of the same site the concentrations at the position of the monitoring station were measured using a Fast Flame Ionisation Detector with a frequency response of approximately 400 Hz. This high resolution in time enabled time series to be collected which were subsequently split into intervals of different length and averaged.

Under the assumption of equal prevailing wind velocities in both the field and wind tunnel, all processes in the wind tunnel are 200 times (=scale factor) faster than in reality. This means averaging intervals of 30 min in the field correspond only to 9 s in the laboratory. Of course, 9 s is much too short to achieve repeatable concentration means.

The amount of scatter inherent to short-time averages has been quantified. The difference between the maximum and minimum short time mean value (different depending on wind direction) is in the range of scatter of the data points in Fig. 2.

The large scatter of data points (small dots) shown in Fig. 2 supports the statement that the common 30 min-mean concentrations measured inside the urban canopy layer have the character of random samples only. Depending on the wind direction, the variability between seemingly identical cases can be large. To simply increase the sampling time does not solve the problem, since in the real world the meteorological conditions continuously change. The data points scatter even more than suggested by the wind tunnel results. The reason for this is that in reality the assumption of constant meteorological conditions is already poor for 30 min intervals. To simply increase the sampling time would not solve but worsen the problem since over periods longer than 30 min a systematic trend in meteorological conditions has to be expected.

These findings indicate that for locations within the urban canopy layer which are usually exposed to highly fluctuating and intermittent concentrations, single measurements are not representative. Secondly, these findings demonstrate that the common belief the uncertainty of field data would be mainly related to the inaccuracy of the instruments may well be false. And thirdly it can be concluded that field experiments in urban areas should always be accompanied by corresponding boundary layer wind tunnel experiments. This only marginally increases the total costs of the experiments, and if carried out effectively may fill gaps in the field data and provide substantial help in the analysis and interpretation of these data.

With respect to the validation of micro-scale, obstacle resolving flow and transport models, special strategies need to be applied. In view of the arguments detailed before, it does not make sense to simply compare the results from such models, usually obtained under steady-state conditions, with field data from urban sites, which are random samples from a largely varying ensemble. Another discrepancy results from the fact that present state-of-the-art computers are still not capable enough to allow simulations with sufficiently large domain sizes and geometrical resolutions.

To test the quality of obstacle resolving models in a comprehensive way, data sets are needed which are of the same complexity as can be handled by the model. Such data were made available in the data bank CEDVAL (Leitl, 2000, and http://www.mi.uni-hamburg.de/cedval). The speciality of this data bank is that it provides measurements which were taken under steady-state boundary conditions in idealized obstacle arrays of increasing complexity. The CEDVAL-data are presently in use world-wide. They provide the means for basic model testing which should be done before the model is exposed to data from real sites (as those shown in Fig. 2).

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Participant 4 (P4) - CEAM

Fundación CEAM
Observed O_3 Cycles in the Western Mediterranean

Partner team members:
Millán M. Millán; Jose Luis Palau; José Jaime Diéguez; Gorka Pérez-Landa and Enrique Mantilla.

Introduction

A very extensive set of experimental/historical data (meteorological and air quality measurements) is available for the Castellón coastal area, situated on the Mediterranean coast of the Iberian Peninsula. This dataset is the result of various EC-funded projects (MECAPIP, RECAPMA, SECAP, BEMA, and RECAB) in conjunction with the commitment of the local authorities to the surveillance and control of air quality in the area. This commitment has been expressed through two initiatives: the set-up and support of an air-quality monitoring network; and the design of a project to elaborate tropospheric Ozone analysis and forecasting in the Valencian Community (Castellón-València-Alicante region).

On the basis of the forementioned studies, the air quality network in the Valencian Community has been optimized for all major cities and sorrounding areas. Monitoring stations measure SO_2, NO_x, O_3, CO, particles and meteorological parameters – wind speed and direction, temperature, radiation, pressure and relative humidity. The network is connected in real time to a central processing unit in València, and CEAM is the partner in charge of validating (data quality assurance) and exploiting the air quality data.

This dataset has enabled CEAM to characterise a typology of situations for understanding the behaviour of tropospheric Ozone in the Western Mediterranean basin. We have applied this typology since the start of the Ozone Analysis and Forecasting Campaign in 2000. In this project (the first of its kind in Spain and carried out in cooperation with the regional government) an information sheet is broadcast in the media each day[•] (from April to September) with: (a) a summary of the Ozone values during the last 24 hours; (b) an analysis of the Ozone situation and (c) a forecasting of its expected evolution taking into account the weather forecast. The established procedure is heuristic; it is based both in a summary of the scientist's a priori knowledge and in the experience obtained through the routine observation of the phenomenon. Thus, both the regional authority and CEAM are end-users of the data.

[•] http://www.cma.gva.es/cidam/emedio/aire/contaminacion_atmosferica/previozono_2002.htm
http://www.gva.es/ceam

Background

The MECAPIP - *(1988 – 1991) Meso-meteorological cycles of air pollution in the Iberian Peninsula* - and RECAPMA - *(1990 – 1991) Regional cycles of air pollution in the west central Mediterranean area* - projects showed that stacked layer systems 2-3 km deep and more than 300 km wide form along the Spanish Mediterranean coast, with the most recent layers at the top and the older ones near the sea (1), (2). These act as a reservoir for aged pollutants to re-enter land the next day, and tracer experiments have shown that turnover times are from 2 to 3 days (3). Recent data analyses have also shown a diurnal pulsation of the Tramontana/Mistral wind regime; this can transport new pollutants into the area (background concentrations of 50-60 ppb of O_3 of continental European origin) which are added to local emissions and re-circulated within the coastal breezes in eastern Iberia for periods of more than five days (5).

The transport of photooxidants inland was also documented during the RECAPMA and SECAP - *(1992 – 1995) South European cycles of air pollution* - projects, and the latter project identified some interregional and long-range transport in each of the main Mediterranean basins (2), (3).

The evidence collected to date from urban monitoring networks shows that air quality problems in southern Europe are governed by meteorological processes with marked diurnal cycles and space scales of tens of km (4,9,10). The study of tall-stack plume dispersion in several regions of Spain started in 1979, i.e., after the EC's Remote Sensing Campaign in Turbigo (Italy). Mobile units equipped with COSPEC (Correlation SPECtrometer) remote sensors were used to track plumes by measuring the SO_2 burdens. Using two of these plumes as tracers of opportunity (one located beside the coastal city of Castellón and the other inland, 80 km from the coast), some experimental/numerical studies have been carried out to show the mesoscale effects on the daily evolution of the wind field in the Castellón region (6,7,8). The results obtained indicate that diurnal formation of the Iberian thermal low is associated with: the convergence of surface winds from the coasts towards the interior of the peninsula, a 90-180º change in wind (plumes) directions during the day (8,11), and high levels of O_3 along the Spanish Mediterranean coast (7,11).

Regional flux measurements and modelling are presently being carried out within the RECAB - *(2000 - 2003) Regional assessment and modelling of the carbon balance within Europe* -project. The availability of aircraft and tower flux measurements is allowing us to calibrate and validate the soil/vegetation/atmosphere transfer schemes recently included in meteorological mesoscale models. Results to date show that the behaviour of surface fluxes in the whole Iberian Peninsula (including downwind of the coastal regions) has a strong influence on the properties of the Boundary Layer over the Spanish Mediterranean coast.

Ground-level concentrations in the Castellón-València areas

In the Valencian Community the notable coastal distribution of both the main population and the industrial areas, and therefore of the emissions, and the atmospheric dynamics, very conditioned by a geographic situation and an orography which favour mesoscale circulations, combine in a way that more or less guarantees the presence of pollutants throughout the entire territory. Differentiated and characteristic patterns exist depending on relative position with respect to the emission sources, distance to the coast, and altitude. Figure 1 shows the annual averages of the concentrations registered at the automatic stations of the regional Air Quality Monitoring Network for NO, as representative of the primary pollutants, and O_3, as representative of the secondary pollutants.

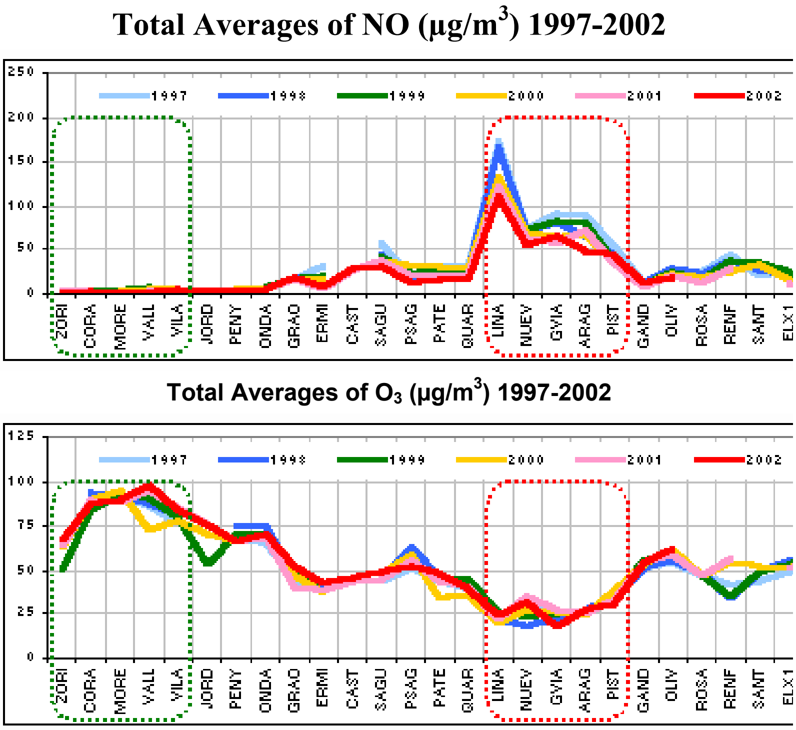


Figure 1: NO and O_3 annual averages (Automatic air quality network, arranged from North to South).

Within the site groups, urban coastal sites with high traffic density (red square), and inland rural areas with low population (green square) stand out. They represent extreme and opposite behaviours; the former with the highest levels of primary pollutants like NOx, SO_2 and CO, and the latter with very low levels of these primary pollutants, but, on the other hand, with the highest levels of secondary pollutants like O_3.

In urban areas the pollution is preferentially related to the continuous traffic emissions (figures 1, 2a). The seasonal pattern (figure 2b) there shows increasing levels in the autumn and winter months. In rural areas far removed from urban sites the pollution is preferentially related to secondary pollutants (figures 1,2c), products of photochemical reactions during the transport of the air mass from its sources. The seasonal pattern shows increasing levels in the spring and summer months (figure 2d).

Both types of sites also represent the two extremes in the habitual transport path of the air mass for a large part of the year. During spring and summer, when anticyclonic conditions dominate over the Iberian Peninsula, with low winds, strong insolation, and frequent formation of the Iberian thermal low, the circulations are governed by mesoscale processes. In this period the daily breeze cycles, coupled with up-slope winds, carry the air masses over all the Community territory. Under these dynamics the numerous river valleys transversal to the coast channel the air mass loaded with coastal emissions towards inland areas (1,3,4). Along this typical path, five characteristic site types can be distinguished according to their daily O_3 pattern (figure 2): mountain top (MT), upper valley floor (UVF), intermediate valley (VF), high coastal (HC), and coastal (C) sites. Urban sites can also be distinguished, and of these, urban downtown (U) are clearly different from peripheric urban sites downwind (PU).

Taking as reference the latest European directives (1999/30/CE for SO_2, NO_x, PM10 and Pb, 2000/69/CE for CO and C_6H_6, and 2002/3/CE for O_3), figures 2 and 3 show significant O_3 exceedances at all site types except the urban sites, and, complementarily, NO_x exceedances are only significant at urban sites with high traffic density.

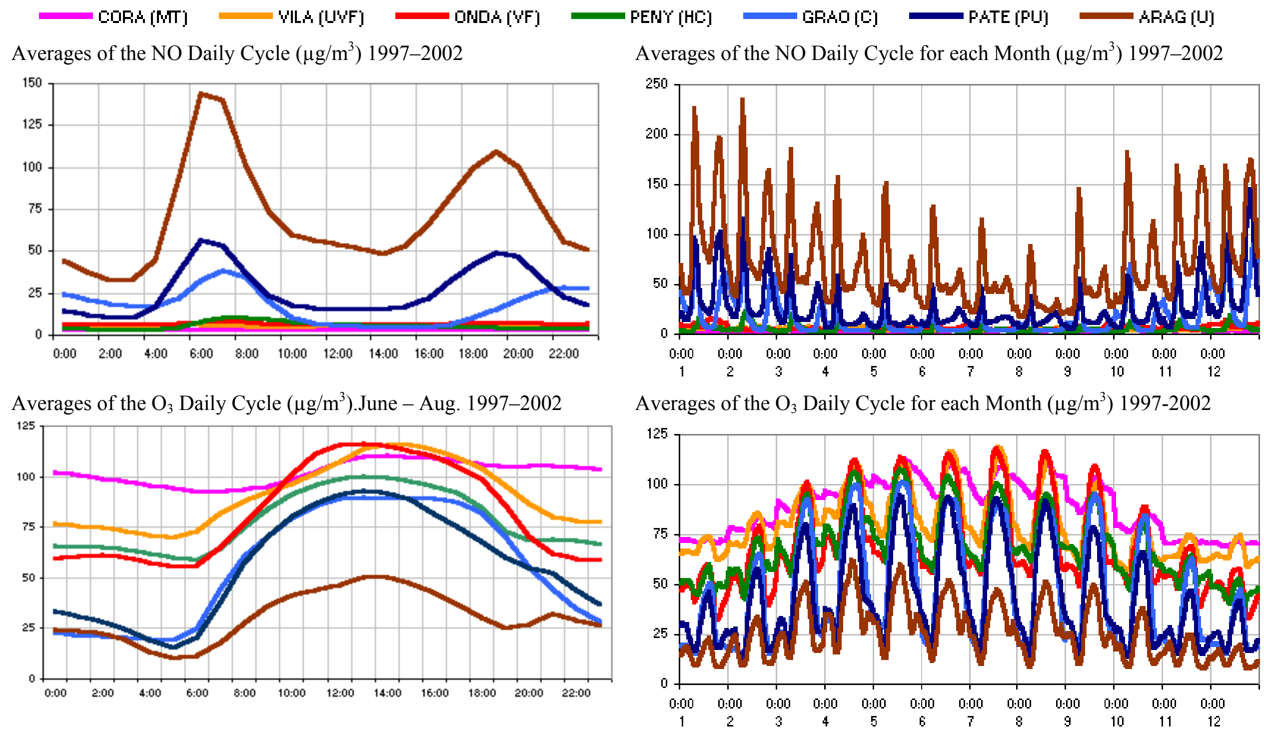


Figure 2: (a) and (b), averages of the NO daily cycles (annually averaged day, and averaged day for each month). (c) and (d), averages of the O_3 daily cycles (averaged day from June to August, and average day for each month).

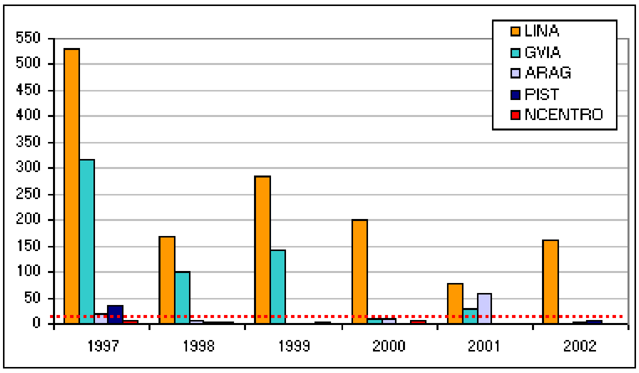


Figure 3a. Number of exceedances of the NO_2 1h-limit value for protection of human health (200 µg/m^3): 18 times

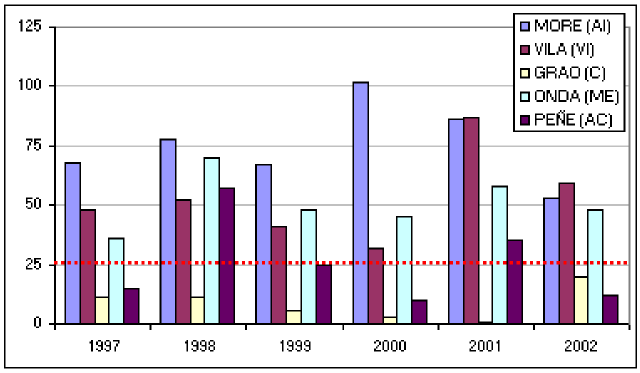
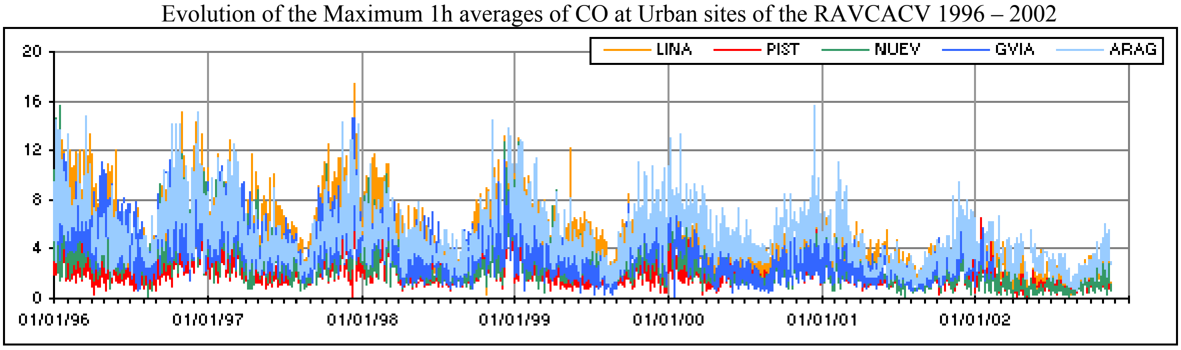
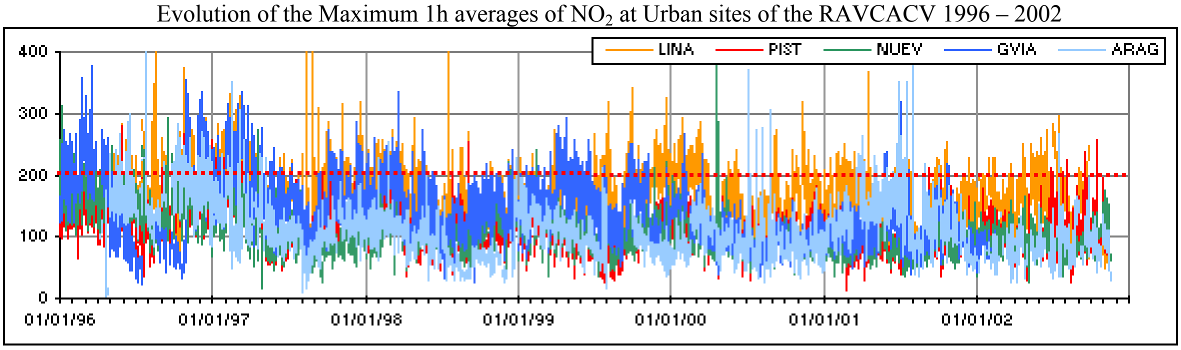


Figure 3b. Number of exceedances of the O_3 8h-average target value for protection of human health (120 µg/m^3): 25 times

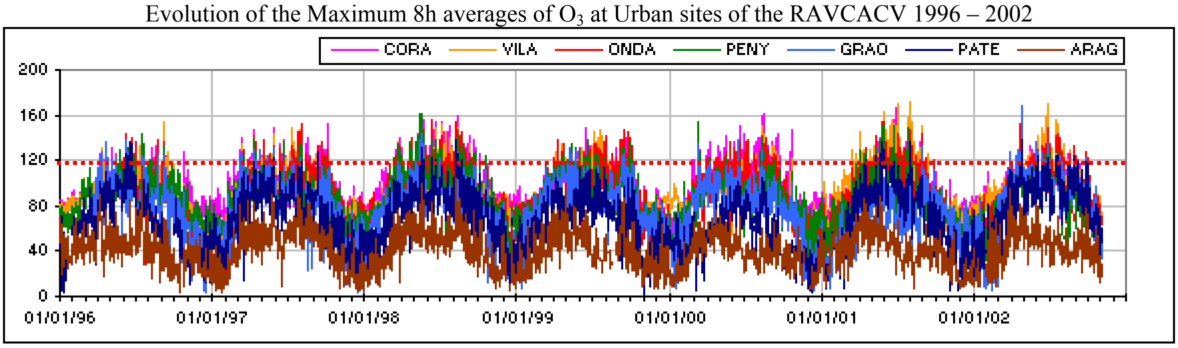
Evolution of the Maximum 1h averages of CO at Urban sites of the RAVCACV 1996 – 2002



Evolution of the Maximum 1h averages of NO_2 at Urban sites of the RAVCACV 1996 – 2002



Evolution of the Maximum 8h averages of O_3 at Urban sites of the RAVCACV 1996 – 2002



Figures 4a,b,c. Interannual evolution of the CO, NO_2 and O_3 averages (vertical scales are expressed in $\mu g/m^3$).

Conclusions

Reiterative experimental results evidence that non-local (mesoscale) effects strongly determine flows at urban scales.When modelling, the interaction between different scales must be reproduced. Grid nesting, domain configuration, and horizontal and vertical resolution are key parameters to describe wind flows for air pollution forecasting purposes and must be set up properly.

NO_2 hourly limit value exceedances show a decreasing tendency over the last six years (figures 3a and 4b). This is not the case, however, for tropospheric ozone (figure 3b). These tendencies are connected with the evolution in the concentration:

- (a) for primary compounds the maximum 1-hour averages decrease smoothly during the period 1997 – 2002 (as is clearly shown in the interannual CO evolution, figure 4a), and
- (b) for ozone the maximum 8-hour averages remain at more-or-less invariable levels (figure 4c).

In the case of ozone, the target value for protection of human health was exceeded systematically, and almost every day, between March and September at the following three station types: MT (mountain top), UVF (upper-valley floor) and VF (valley floor). The latter station type (VF), like the one located in the city of Onda (15 km inland from the city of Castellón), is especially relevant because of the large population living in this site type (around 1.000.000 people; approximately 20% of the entire population of the Castellón-València-Alicante regions).

Tasks within the FUMAPEX project

Results to date show that in Western Mediterranean conurbations the problems associated with exceedances of the EU air pollution legislation and the WHO guidelines are linked not only to short-term pollution episodes but also to their high temporal recurrence.

The results expected from FUMAPEX should allow CEAM, as an end-user of the air quality data, to further refine the processes to protect public health in the Castellón/València region during the above-described chronic episodes. In this sense, the FUMAPEX methodology and expected results will be supported by previous utilization of the experimental results obtained from the aforementioned European projects and from the air quality data of the Regional Government of València.

Within the FUMAPEX project, CEAM aims to improve and expand the appropriate regionalization of the numerical simulation systems in order to, on the one hand, make the prediction tools more reliable (taking advantage of the contributions from the different project partners on the subject of numerical simulation model parameterisations) and, on the other, increase the control and forecasting range to different pollutant species (such as O_3, NO_x, CO, CO_2, etc.).

Our study area is centred on the Castellón conurbation and extends 400 km north to Barcelona and 200 km south towards València. Around this Mediterranean coast site there is a variety of mixed industries including ceramic factories, nitrogen fertiliser plants, refineries, and a power station. Additional features that make this an interesting area for air pollution studies are:

- It is an industrialized conurbation that is broadly considered to be a representative experimental site in the Western Mediterranean basin with respect to photochemical processes, and it presents meteorological-orographic coupling between urban and regional air pollution problems.
- A very large set of experimental/historical data on both meteorology and atmospheric pollution is available, which makes the characterisation of the links between urban and regional processes very feasible.
- Local authorities are very conscious of the new air quality directives (requirements) and, as end-users and decision-makers, are strongly involved, in cooperation with CEAM, in the development of an air quality information and forcasting system in the Castellón/València region.

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Participant 5 (P5) - ECN

Laboratoire de Mécanique des Fluides UMR 6598 CNRS - Ecole Centrale de Nantes, France

Urban soil models for NWP models

1. Partner team members:
Patrice G. Mestayer and Isabelle Calmet
with Nathalie Long and Sylvie Leroyer and a post-doc.

2. SM2-U urban soil model
The basis of the proposed work in FUMAPEX is the ECN software chain for high resolution simulations of the urban atmosphere (Fig. 1):
(1) DF Map analyzes the urban numerical data bases to generate physiographic data (roughness parameters, surface cover modes) integrated at the hectometric resolution,
(2) The physiographic data are input to the submeso soil model SM2–U, which provides gridded roughness length, surface temperature, and surface specific humidity, which are used by SUBMESO as lower boundary forcing parameters.

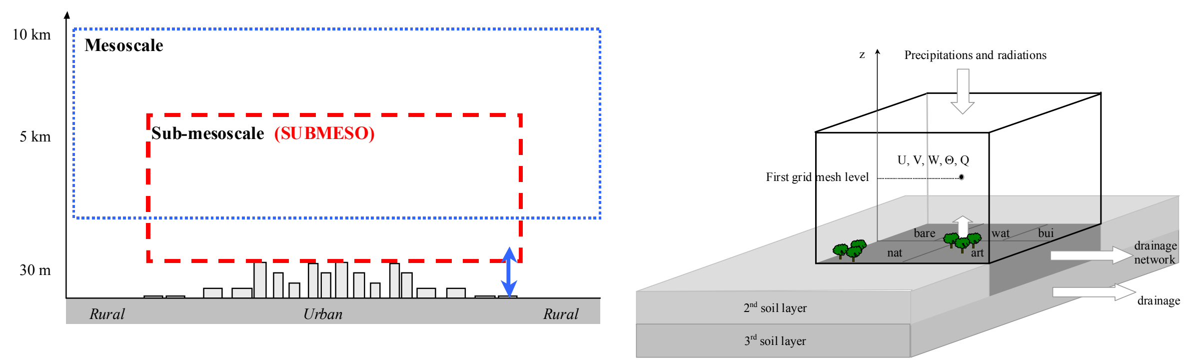

Figure 1. Structure and simulation domains of the ECN software chain for high resolution simulations of the urban atmosphere.

SM2-U is a force-restore soil model computing the surface temperature T_s and specific humidity q_s , such as :

$\partial T_s/\partial t = CTG_s - (2p/t)(T_s - T_{soil})$,
G_s = Ground flux ; t = 24 h.

From DF Map data, for each surface cell SM2-U specifies the percentages of occupation by FIVE different cover types : bare grounds, natural grounds, artificial surfaces, water bodies, buildings, and the percentage of coverage by vegetation over the natural and artificial grounds.

Water budget
Within each cell SM2-U computes the water budget of each of the 5 cover modes according to their coverage percentage, balancing precipitation with surface evaporation and vegetation transpiration, accounting for the water transfers between the surfaces and the soil (Fig. 2). The model output is the cell-averaged specific humidity (plus vapour and drainage fluxes).

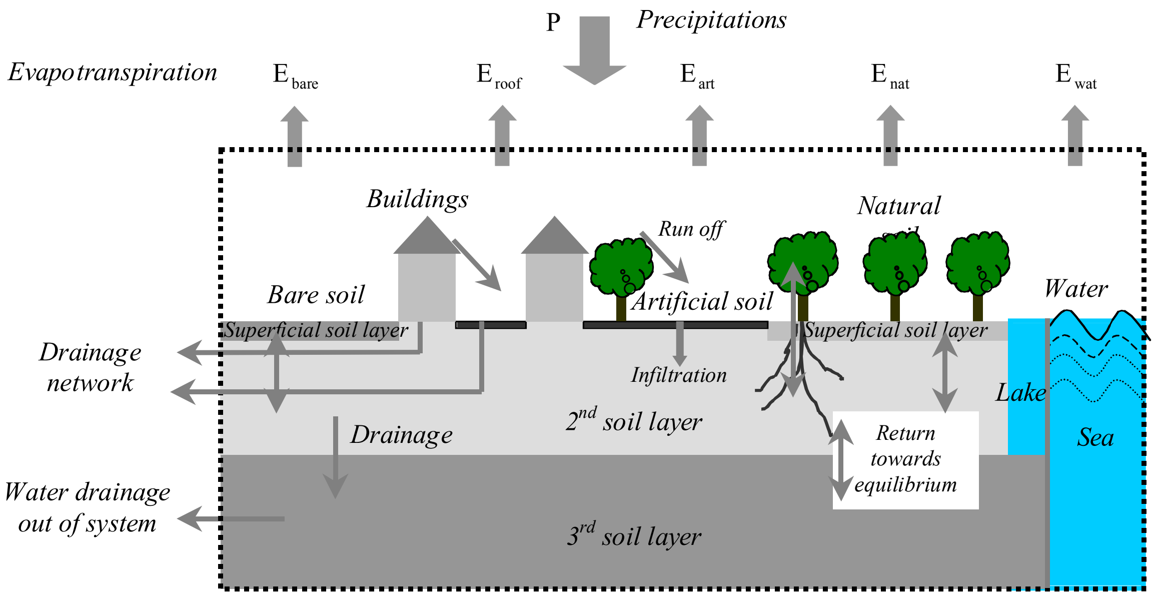

Figure 2. SM2-U water budget.

Energy budget
Within each cell SM2-U computes the energy budget of each of the 5 cover modes according to their coverage percentage, balancing the net radiation with the heat fluxes, accounting for the transfers to soil layers. The buildings/roofs cover mode receives a special modeling for canopy.
The model output is the cell-averaged temperature (plus the heat fluxes).

Canopy modelling in SM2-U:

- The heat storage by building materials is modeled by adding wall volumes and heat capacities to those of the (street) artificial cover surfaces,
- The effects of radiative trapping by street vertical surfaces and of surface mutual shadowing is modeled by an effective albedo (Fig. 3) parameterized on the basis of Masson's (2000) computations.

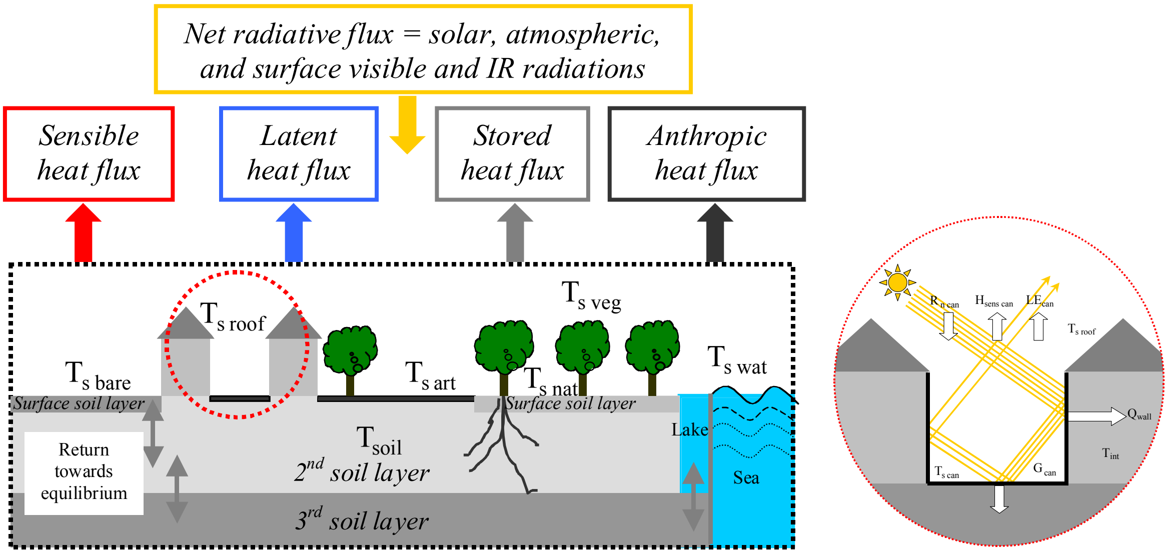

Figure 3. SM2-U energy budget.

3. UBL/CLU, Marseille an associated project of ESCOMPTE

During 6 weeks in June-July 2001, the project used the ESCOMPTE experimental set-up and completed it over the Marseille area (Fig. 4), to document :
* UBL 4D dynamics,
* urban canopy thermodynamics,
* visible and TIR remote sensing : ground cover modes, surface temperatures, heat fluxes.

Figure 4. UBL/CLU-Escompte experimental set-up.

4. Content of the ECN contribution

The ECN group will contribute to WP 4, 5 and 6.

For WP4:

Based on the most recent developments, a full Force-Restore soil model is to be constructed for urban areas, computing the thermodynamic and radiative exchanges between the atmosphere and the ground, taking into account the artificial surfaces, the buildings, the drainage systems, and the impact of radiative trapping (buildings in streets induce mutual shadowing and multiple radiative refraction) - a major cause of the “urban heat island”. This model will be made available to all participants for adaptation to their model systems.

ECN will provide methods and software for computing the physiographic and roughness parameters (roughness length and displacement height) of urban areas including the areas with a noticeable to large density of buildings, and to construct the spatial distributions (maps) of these parameters on the model computational grids.

For WP6 :

ECN will participate in the WP6 uncertainty analysis by using the developed models to drive a sensitivity analysis of NWP-model computations (wind, turbulence and pollutant concentration fields) with respect to the sophistication of urban ground description for a selection of cities where urban databases are available and a selection of meteorological conditions (identified air pollution episodes). A large part of this sensitivity analysis will be conducted from simulations of the ESCOMPTE and CLU-Escompte experimental campaigns over the area of Marseille during June and July 2001.

The data of the ESCOMPTE data base are already available to the participants in the experiment, including the ECN research group, and they will be publicly available by the end of the spring 2003. This exceptional set of data will therefore be incorporated in FUMAPEX for model validation and sensitivity analysis.

Conclusion

ECN will derive from the study results a series of simplified improved parameterisations adapted to the NWP-models and a series of requirements for running the NWP-models over urban areas.

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Participant 6 (P6) - FMI

Finnish Meteorological Institute

1. The FMI and YTV teams in FUMAPEX

FMI: Doc. Jaakko Kukkonen, Dr. Ari Karppinen, Prof. Sylvain Joffre, Lic.Phil. Leena Partanen, Ms. Minna Rantamäki, Mr. Ilkka Valkama
YTV (Helsinki Metropolitan Area Council): Lic.Tech. Tarja Koskentalo, Dr. Anu Kousa

2. Content of the FMI contribution

FMI (Participant 6) co-ordinates WP 1 (Analysis of pollution episodes in European cities) and participates in all WP's from 4 to 9. The largest amount of resources are spent to WP1 and WP7 (exposure modelling).

WP1. The main objectives of FMI will be (the following is a quote from DoW):
(a) prepare datasets of concentration and meteorological data measured during air pollution episodes in different European climatic and geographic regions;
(b) identify and classify various types of air pollution episodes in cities located in different European climatic and geographic regions;
(c) identify the key meteorological parameters leading to air pollution episodes in various European climatological regions;
(d) evaluate the influence of practical measures taken in order to control air pollution episodes;
(e) evaluate the performance of Urban Air Pollution (UAP) Models and Information Systems in terms of meteorological conditions during air pollution episodes.

WP4 and WP5. FMI will participate including theoretical analysis and improvement of the similarity theory for the stably stratified PBL and of the turbulent fluxes of heat and momentum in extremely stable atmospheric conditions, and developing meteorological pre-processors and interfaces between NWP models and UAP Models.

WP6 and WP8. P6 will evaluate and implement UAP models in an example city (Helsinki Metropolitan Area), in close co-operation with the local city authorities (Helsinki Metropolitan Area Council, YTV).

WP7. FMI will work in close cooperation especially with the National Public Health Institute in Finland (KTL), for the development and evaluation of population exposure models in combination with UAQIFS's. National cooperation between FMI, KTL and YTV is in progress within the project HEAT (see section 4 below).

3. Previous work

The most relevant previous projects:
1. COST 715, Meteorology applied to urban air pollution problems, 1998 – 2004.
2. Air Pollution Episodes: Modelling Tools for Improved Smog Management – APPETISE, EU, 2000 - 2002.

Previous relevant publications that can be utilised in FUMAPEX:

WP1. Tasks (a), (b) and (c) (see above): Sokhi et al. (2002), Kukkonen et al. (2001), Piringer and Kukkonen (2002), Kukkonen et al. (2002). Task (d): Mäkelä et al (1997, 1998), Railo (1997). Task (e): Berge et al. (2002), Piringer and Kukkonen (2002), Kukkonen et al. (2002).

WP4 and WP5: Karppinen et al. (2000, 2001).

WP6 and WP8: E.g., Kousa et al. (2001).

WP7. Kousa et al. (2002).

4. Ongoing related work

1. Environmentally viable electronic city - ENV-e-CITY, 2002 - 2003. Information Society Technology, Content, Multimedia Tools and Markets: e-Content. Funding from European Union. http://lhtee.meng.auth.gr/~kostas/ENV-e-CITY/
2. Optimised Expert System for Conducting Environmental Assessment of Urban Road Traffic – OSCAR, 2002 – 2004. European Union, City of Tomorrow, Improving the quality of urban life. Funding from European Union.
3. Source apportionment of urban airborne particles and polycyclic aromatic hydrocarbons in Europe – SAPPHIRE, 2002 – 2004. City of Tomorrow, Improving the quality of urban life. Funding from European Union.
4. Health Effects caused by Urban Air Pollution for the Transport System Plan Scenarios in Helsinki Area – HEAT, 2002 – 2004. Academy of Finland. http://www.fmi.fi/research_air/air_18.html
5. Improved modelling tools for air quality forecasting, applying deterministic and neural network models – FORECAST, 2002 – 2004. Academy of Finland.

More project descriptions are available at http://www.fmi.fi/research_air/air_9.html

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Participant 7 (P7) - ARIANET

ARIANET s.r.l.
Environmental Consulting

Partner team members:
Dr. Sandro Finardi, Dr. Giuseppe Calori and Dr. Camillo Silibello,

Content of the ARIANET contribution

The main objective for ARIANET (Participant 7) is the construction of a modelling system suitable for forecasting meteorology and air pollution episodes in urban areas. The models have to be able to perform forecasts for the ground level concentrations of the more relevant passive and reactive pollutants, such as SO_2, NO_2, CO, PM10, O_3 and Benzene. The major air quality problems in the target city of Turin are sketched in Tables 1-3, which show that the EU standards for NO_2, O_3 and PM10 are presently exceeded.

Table 1 Table 2

O_3	Exceedances of 180 µg/m^3 hourly averages		
Station	**1999**	**2000**	**2001**
Borgaro	88	150	224
Druento	18	156	121
Lingotto	20	46	72
Pino Torinese	102	130	91
Vinovo	10	104	147

NO_2	Exceedances of 200 µg/m^3 hourly averages		
Station	**1999**	**2000**	**2001**
Consolata	20	27	4
Lingotto	4	2	2
Gaidano	30	31	9
Rebaudengo	45	47	30
Rivoli	41	150	36

Table 3

PM10	Exceedances of 50 µg/m^3 daily averages
Station	**2001**
Consolata	186

The proposed forecasting system is based on a prognostic non-hydrostatic model which will downscale results of a NWP model to the urban scale and drive an Eulerian atmospheric chemistry model. The UAP modelling system will be applied simultaneously to the city of Turin and to the whole Piedmont Region. The domain nesting approach will allow to better take into account the effect of sources located outside the computational urban domain, and to describe air pollution processes dominated by scales larger than the city scale, like photochemical smog. The tentative domains size and location is depicted in Figure 1.

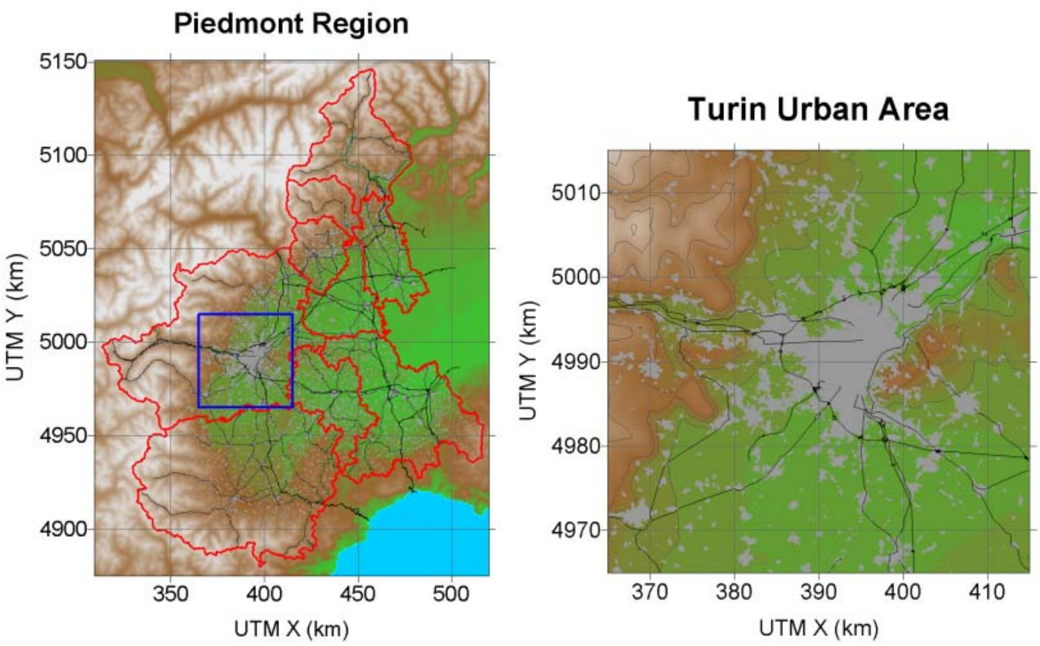

Figure 1: Nested computational domains.

The building and implementation of the forecasting system will be done in collaboration with Participant 14 (ARPA Piemonte). The scheme of the projected modelling system is described in Figure 2, where the modules already developed and applied for case studies in Piedmont Region are indicated.

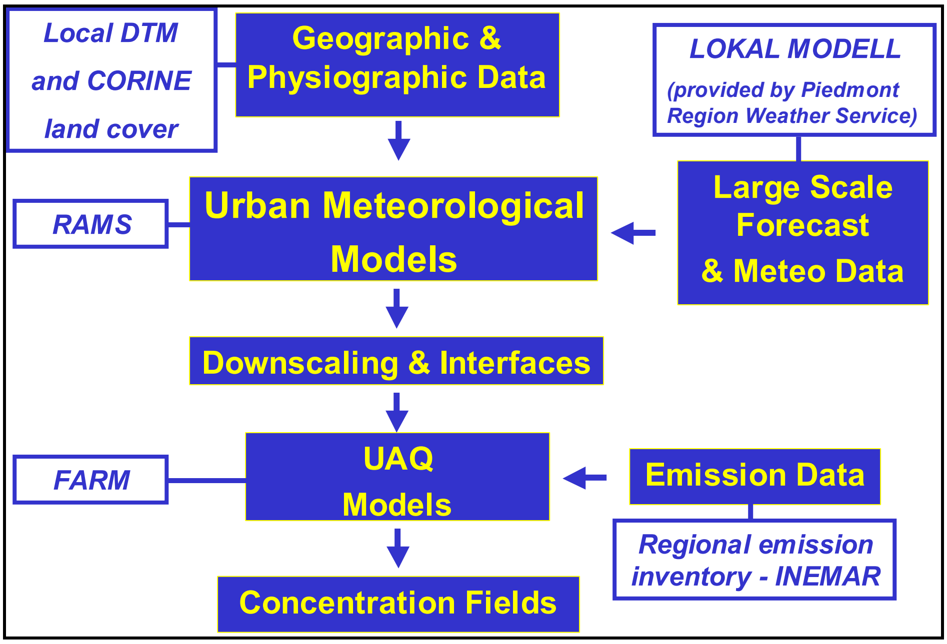

Figure 2: Scheme of the different elements composing the UAQIFS for Turin city. In white background are indicated the modules already available and applied over the Turin region.

ARIANET (Participant 7) co-ordinates WP 5 (Development of interface between urban-scale NWP and UAP models) and participates in WP's 1, 2, 6, 8, 9 and 10. The largest amount of resources are spent to WP5, WP6 and WP8.

WP1. ARIANET will contribute to the identification of air pollution episodes and to the classification of the most important meteorological parameters for Italian cities located, like Turin, inside the Po valley.

WP2. ARIANET will participate to define and analyse the meteorological input and pre-processing needed by atmospheric chemistry models. The possible approaches to properly model the needed variables will be evaluated.

WP5. ARIANET will co-ordinate the activities concerning the improvements of meteorological pre-processors and the development of model interfaces to connect NWP model results to UAP models input needs. An interface module to connect the prognostic meteorological model to the atmospheric chemistry model, will be developed and tested

WP6 and WP8. The sensitivity of the UAP model to meteorological field variations will be investigated. The proposed modelling system will be then implemented and verified on selected pollution episodes occurred in the city of Turin. ARIANET will execute this task in close co-operation with the local city authorities and Partner 14 (ARPAP).

WP9. P7 will finally contribute to the dissemination of the project results.

Previous related experience
The most relevant previous projects:
3. COST 710, Harmonisation of the Pre-processing of Meteorological Data for Atmospheric Dispersion Models, 1996 – 1998.
4. COST 715, Meteorology applied to urban air pollution problems, 1998 – 2004.

5. EUROTRAC2, Subprojects SATURN and CAPMAN.

ARIANET acquired a long experience in model integration and in the application meteorological models to drive atmospheric dispersion models (Finardi et al. 2000, Silibello et al., 2001). ARIANET has been involved in the development of modelling systems aimed to support environmental agencies to perform regional and urban scale air quality assessment studies (Finardi et al, 2002; 2003), and co-operates at the execution of integrated air quality assessments.

Ongoing related projects

1. **MINNI.** Development/Integration of a modelling system for the simulation of pollutants concentration and deposition on national scale, to support the ENEA/Environmental Ministry program on “Climate change and transboundary pollution”. Performance of model simulations to compute hourly concentrations and depositions for a whole year, applying the mesoscale meteorological model RAMS ant the atmospheric chemistry model FARM. Founded by a contract from ENEA/Bologna.
2. Support of Piedmont Region Environmental Protection Agency (ARPAP) to the analysis of winter and summer pollution episodes through the application of different modelling techniques. The simulation of a summer ozone episode with the atmospheric chemistry model FARM driven by diagnostic meteorology is presently ongoing, while the a project to verify the use of meteorological fields produced by LOKAL MODELL (available at the Regional Weather Service of Piedmont Region) to drive O_3 simulations is foreseen for the next year. This project is founded by a contract from ARPA Piedmont.
3. Diagnostic reconstruction of the wind field over the Turin Province territory. The project is aimed to build a 3D analysis of wind field over a domain covering 125x105 km^2, with an horizontal resolution of 1 km. The data set, that will cover a period of 1 year, will be used to support environmental impact assessment activities.

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Participant 8 (P8) - ARPA

ARPA (Environmental Protection Agency of the Emilia Romagna Region Italy)

Partner team members:

Dott. Marco Deserti, head of the Environmental meteorology unit of the ARPA meteorological service (team Leader);
Dott. Giovanni Bonafè, Dott. Enrico Minguzzi, Dott. Michele Stortini, technical staff members of the environmental meteorology unit.
Dott. Barbara Ramponi, administrative secretary.

ARPA description

ARPA stands for Agenzia Regionale per la Prevenzione e l'Ambiente dell'Emilia-Romagna (regional agency for health prevention and environmental protection in the Emilia-Romagna region) and it was fully operational in the regional area since May 1st 1996. ARPA's functions and activities cover all the questions concerning environmental and collective prevention. ARPA is an agency of the regional government having its own administrative, accounting and technical autonomy. Functions, activities and tasks of ARPA (indicated in detail in regional Law n. 44 of April 19th 1995) are mainly of technical and scientific nature and concern the areas of environmental control, support and analysis, land planning and research. ARPA employ about 1000 employees. (http://www.arpa.emr.it/inglese.htm)
Concerning the specific task of air quality evaluation and management, ARPA’s activities are:

- air quality monitoring;
- meteorological observations, analysis and forecasts,
- air quality modeling,
- air pollution forecast,
- public information on air quality,
- technical support for environmental planning.

Status report

In the Emilia Romagna region, the concept of an Urban Air Quality Information and Forecasting Systems (UAQIFS) was introduced by ARPA. The development of such systems requires connections among several activities involved in air pollution evaluation and management, following this scheme:

Basic information are organized in data bases containing:
- Geographical data
- Emission inventory
- Air quality data
- Meteorological data

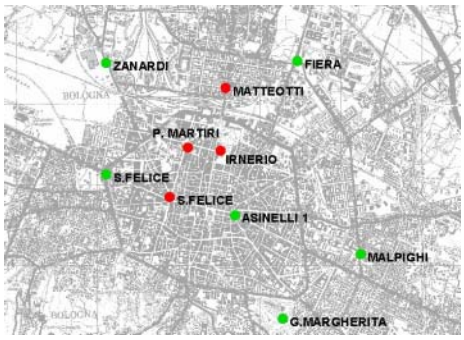
Specific pre-processors provide input information to Air quality models. The pre-processors are:
- A meteorological pre-processor
- An emission pre-processor

Air quality models are:
- Forecast models
- Urban area model
- regional photochemical model

Information to public and to several end users are provided via an internet/intranet web service. The WEB facilities are available through the official air quality website of the Emilia Romagna region. Periodic reports, such as the annual report on air quality, are written and published on the web sites of local authorities (provinces, municipalities).
Emilia Romagna region, province and municipality of Bologna, are involved in the FUMAPEX project as main stakeholders of ARPA's activity.
Air quality information are used by the ARPA's environmental epidemiology unit to evaluate population exposure and inform population and health authorities about pollution effects as well.

Some additional information about key elements of the UAQIFS are then provided:

Emission inventory: The present emission inventory for the Emilia Romagna region refers to 1990 (data disaggregated from CORINAIR'90 Italian national inventory). The upgrading to 1998 at a spatial resolution of 5 x 5 km^2 is ongoing (June 2003). The local emission inventory for Bologna is available at a spatial resolution ranging between 1 x 1 km^2 outside the town and 0.5 x 0.5 km^2 inside the town.



Air quality data: the air quality monitoring network covers the whole regional domain, with about 100 stations. The stations are located mainly in urban areas, the detail on Bologna urban area, where 6 stations (marked in green) are located, is shown in figure. A suburban (M.te Cuccolino) and a rural (S.Pietro Capofiume) background stations are located near Bologna.

Meteorological data: the meteorological network used to provide basic information to meteorological pre-processor includes both standard meteorological synoptic stations and Emilia Romagna regional stations. Three upper air stations are located at S.Pietro Capofiume, Udine and Milano Linate. The Emilia Romagna meteorological network is completed by two meteorological radars. A network of urban meteorological stations located in the nine main towns is under implementation. Some experimental measurements campaigns where carried out to study the influence of Bologna urban area on local meteorological conditions. Heat island mapping, surface fluxes measurements and SODAR vertical profiling were performed in rural and urban locations during summer and winter typical conditions (see the COST 715 report, to be published, for more details). The results of the study will provide basic information for the design of an urban meteorological network in the Emilia Romagna region and to improve meteorological pre-processors running on daily basis to estimate SEB and MH.

Meteorological models

The hydrostatic Limited Area Model (LAM) LAMBO provides operationally 72 hours forecasts over Italy. The model runs since 1993 with two mesh resolutions, the finest horizontal grid-size is 0.125 degrees, about 20 km (Paccagnella et al., 1994).

The Italian version of the non-hydrostatic Lokal Modell (LM) meteorological model started operational running at ARPA-SMR in 2001. Its development was first organised as an internal project of the German Weather Service (DWD), and it is now carried on by the Weather Services of Germany, Switzerland, Italy, Greece and Poland through the COSMO consortium. LM is intended to be used as a flexible tool for specific tasks of weather services as well as for various scientific applications on a broad range of spatial scales, ranging from meso-α (50 km) down to meso-γ scales (50 m), where non-hydrostatic effects play an essential role. These include operational weather forecasting in COSMO states, nowcasting, transport and deposition of chemical and radioactive pollutants, but also the study of small scale atmospheric processes, boundary layer turbulence, details of atmosphere-orography interaction, local effects on climate.

Meteorological pre-processor: a meteorological pre–processor, based on the mass-consistent model CALMET (Scire et al., 1995) and feeded with observed meteorological data, runs daily to compute hourly fields of 3-D wind and temperature, together with micrometeorological parameters, over the Po valley with a 5 km horizontal grid spacing (Deserti et al. 1999).

Air quality models are: two statistical forecast models, an urban area model and a regional photochemical model.

ARPA operates two statistical models to forecast ozone and PM_{10} pollution at several monitoring sites of the Emilia – Romagna region.

The ozone model called OLMO (Ozone Linear MOdel) forecasts the maximum daily ozone peak for the next two days. The PM_{10} model called PIOPPO (Pm10 Pollution POlynomial model) forecasts daily average for the next two days. Both models use meteorological forecast and surface observed concentration as input data.

The ADMS-URBAN (CERC) and IMPACT (Aria Tecnology) urban air quality models were employed to carry out AQ studies in Bologna. ARPA is presently testing both models in order to select an urban air quality modelling system, to be employed for future local scale studies.

The photochemical Eulerian model CALGRID was applied to analyse at regional scale intense pollution episodes, with different emission scenarios.

Information and reporting: The air quality official website of the Emilia Romagna region http://www.liberiamolaria.it/ provides daily information about:

- Air quality real time data
- Ozone and PM10 forecasts
- Summary of the last ten days and annual exceedances data;
- General information on pollutants health effects and suggestions,

- Information about emission reduction actions, such as traffic limitations.

A detailed report about meteorological conditions during peak pollution episodes is available at the ARPA –SMR web (http://www.arpa.emr.it/smr/).

Content of the ARPA contribution
The main objective of P8 is to improve its UAQIFS for predicting and simulate air pollution in Bologna, Italy (one of the target cities), in close co-operation with other local authorities.

The large amount of resources (12 man months) of P8 will be spent mainly on WP8 (Implementation and demonstration of improved Urban Air Quality Information and Forecasting Systems - UAQIFS)
The main activities of P8 in WP8 will be (following the DoW)
8.1 The determination of the information required by the UAQIFS of ARPA, with details on meteorological data input required to run ARPA's air quality models (the statistical forecast models, the urban area model and the regional photochemical model);
8.2 The selection of episodes for demonstration of the UAQIFS on Bologna and Emilia Romagna;
8.3 The application and demonstration of the existing UAQIFS to the selected episodes;
8.4 The application and demonstration of the new UAQIFS's to the selected episodes. The models will be used to simulate the selected air pollution episodes. The sensitivity of the calculated concentration levels to changes in the NWP model design -regarding spatial resolution, length of forecast and assimilation of urban meteorological observations- will be investigated.

The local authorities will be involved in system evaluation and testing, through public meetings and distribution of FUMAPEX reports.

P8 will also participate in WP3 (Testing the quality of different operational meteorological forecasting systems for urban areas) (3 man months)
The main activities of P8 in WP3 will be (following the DoW)
3.1 To provide information about ARPA's forecasting systems to be used in the overview of the different forecasting systems in Europe;
3.2 To design the comparison study;
3.3 To perform the parallel runs and to analyse the results. The analysis will be carried out comparing two different NWP models running on a daily base, the LAMBO-CALMET model and the LM model, with the observation data set available for Bologna.

ARPA will be involved in WPs 1, 2, 5, 6, 9 too, providing all basic information belonging to it and necessary or useful to realize the project.
Moreover the population exposure models results could be evaluated and demonstrated in co-operation with the ARPA environmental meteorology unit.

Some previous related projects

COST 715, Meteorology applied to urban air pollution problems, 1998 – 2004;

MAAM project, Air quality modelling in Bologna metropolitan Area, 1997-2000;

CTN_ACE Italian National Topic Center on Atmosphere, Climate and Emissions, 1999-2001;

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Participants 9 (P9) - DNMI and 10 (P10) - NILU

Institutions and team members:
Norwegian Meteorological Institute (met.no, Partner 9), Erik Berge[1], Norvald Bjergene, Knut Helge Midtbø and Frank Tveter.
Norwegian Air Research Institute (NILU, Partner 10), Leiv Håvard Slørdal, Bruce Denby
Norwegian Traffic Control Authority (Subcontractor of Partner 9), Pål Rosland
Municipality of Oslo (Subcontractor of Partner 10), Ingrid Myrtveit
[1]Presently at Kjeller Vindteknikk

1 Introduction

The Norwegian FUMAPEX team consists of the Norwegian Meteorological Institute (met.no) and the Norwegian Air Research Institute (NILU) as partners, and the Norwegian Traffic Control Authorities and the Municipality of Oslo as subcontractors. Met.no and NILU have developed an urban forecasting system for air quality sponsored by the Norwegian Traffic Control Authorities. The results from the forecasting system are utilized daily by the Municipality of Oslo, which issues the air quality forecasts and warnings in Oslo during the winter season.

Air pollution in Norwegian cities is first of all a wintertime problem related to stable inversion conditions and weak winds. Peak PM_{10} concentrations around 150 $\mu g/m^3$ (24 hour average) and NO_2 levels of around 300 $\mu g/m^3$ (hourly average) are recorded nearly every winter in Oslo and other Norwegian cities. An example of an episode of peak air pollution is given in Fig. 1.

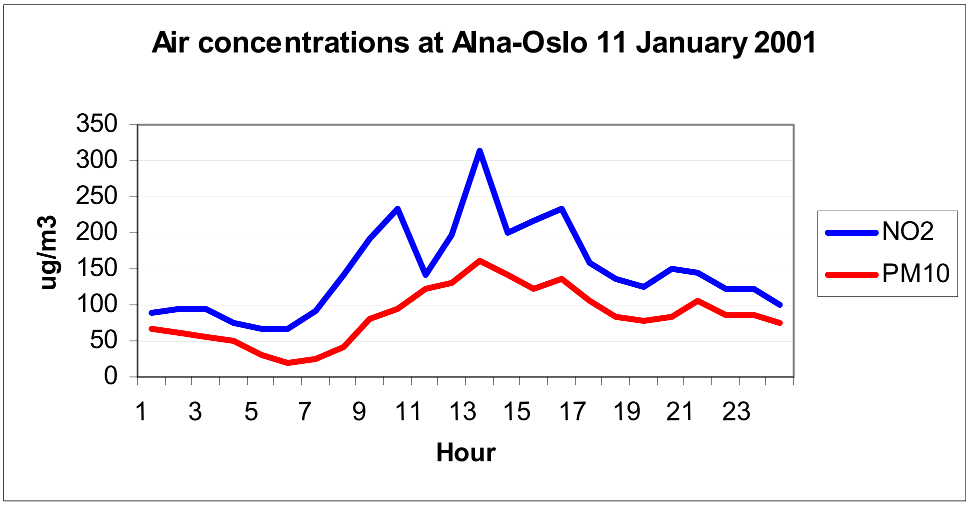


Figure 1. Measurements from a "severe NO_2 case" 11 January 2001.

In 1999 an operational urban forecast model for air quality and meteorology was established for the two larger cities in Norway, Oslo and Bergen. The aim of the model was to forecast the PM_{10} and NO_2 levels on days of peak air pollution, and thereby assist the local authorities in issuing forecast and applying traffic restrictions in order to reduce the emissions. The results from the forecast model were distributed electronically in the morning to the local authorities in charge of the air quality forecasting.

During the first winter 1999/2000 the model was run approximately 20 times when peak air pollution was expected from the forecasted weather. Since the winter 2000/2001 the model has been operated daily for Oslo for the period 1. Nov. to 1.Mai. From the last winter (2001/2002) the model was also run daily for Drammen (a neighbouring city of Oslo), and during peak air pollution events for the cities Bergen, Trondheim and Stavanger.

2 Meteorological models

HIRLAM is the operational NWP-model at met.no. A version with 10 km horizontal resolution (HIRLAM10) is run two times per day for NW-Europe, and the initial- and boundary conditions for the meso-scale meteorological simulations for Oslo are obtained from this version of HIRLAM. The meso-scale model applied is the non-hydrostatic MM5. This model is applied in a two-way nested mode, coupling two model domains with horizontal grid resolutions of 3 km and 1 km. The inner domain (with 1 km resolution) is shown in Fig. 2. The source code of MM5 is open software

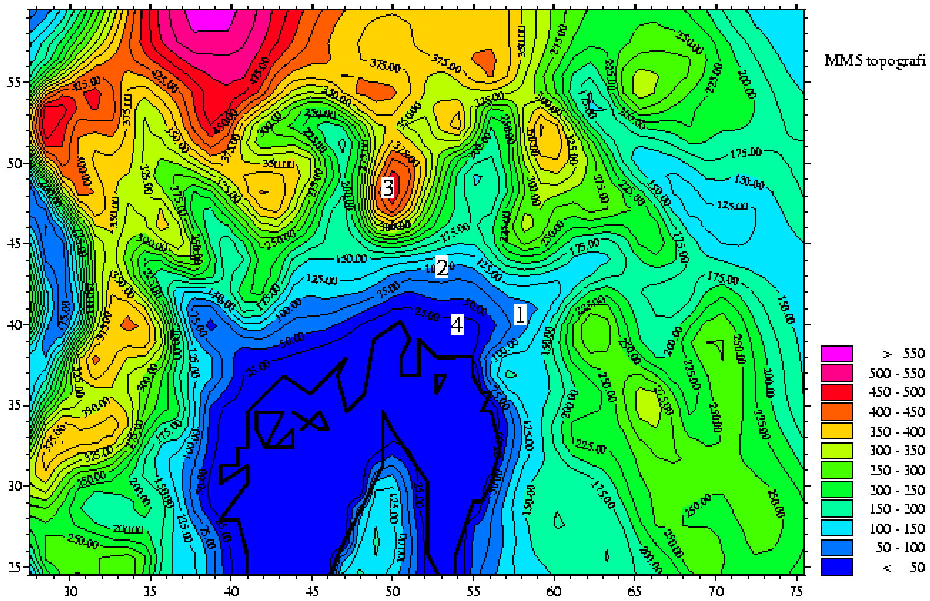


Fig. 2. Model topography of MM5 – 1km resolution. The numbers 1-3 indicate meteorological stations, while 4 is close to the city centre.

developed at NCAR/Penn State Univeristy, USA. The model has been modified to fit into met.no's meteorological forecasting system.

3 The Air Quality model

AirQUIS/Episode is the Air Quality Information System of NILU. The model applies a meteorological pre-processor that extracts the needed input information from MM5 and then feeds the required dispersion parameters to the AQ-model. The model calculates both average grid value concentrations (typically 1km*1km), and sub-grid receptor point concentrations close to individual sources.

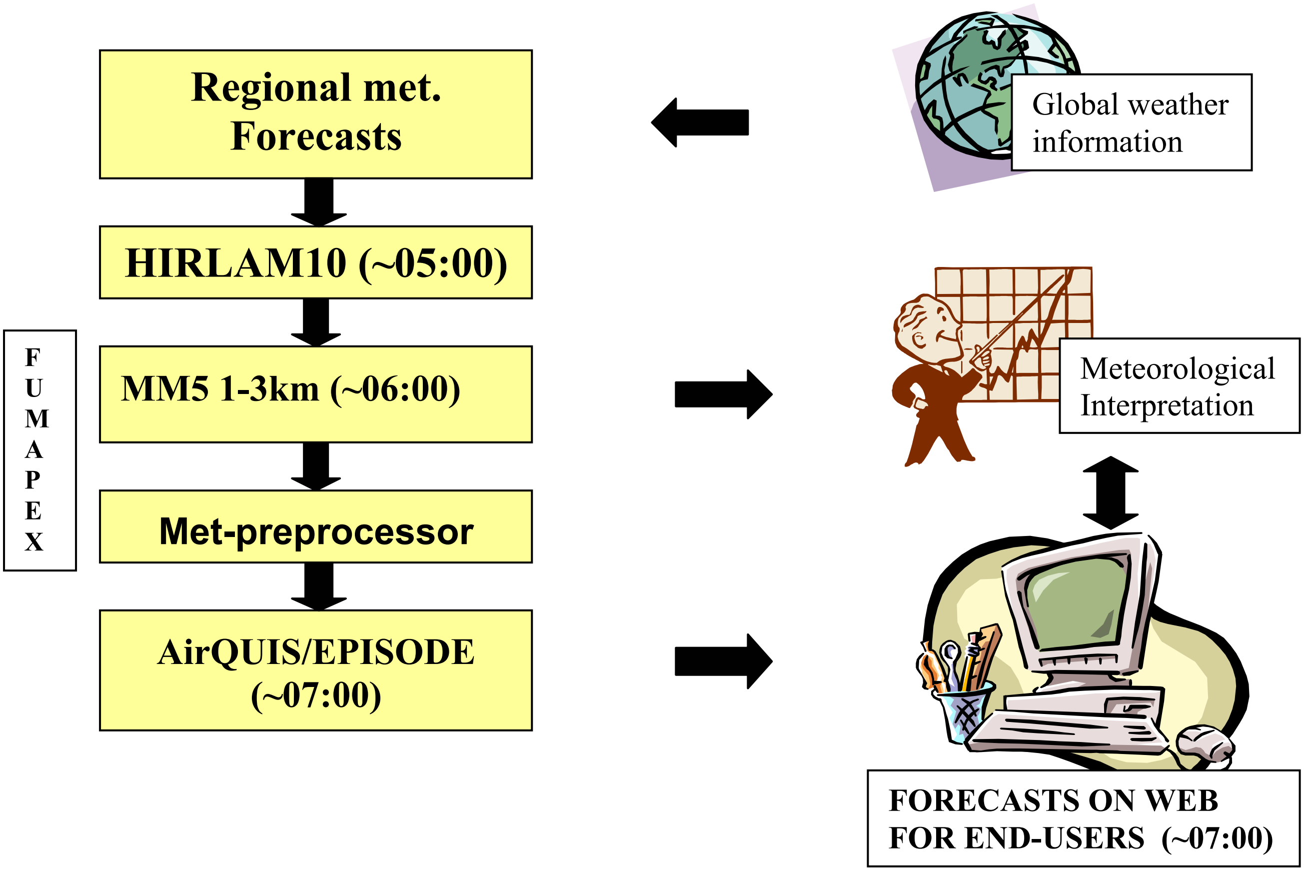
4 Operational urban forecasting system

An overview of the forecasting system for Oslo is given in Fig. 3. The prognostic model is operated in the following way:

(1) The HIRLAM10 is run during the night (+48 hours starting at 00 UTC) based on input from global and regional models. It is run on the national super computer and finishes at ~05 local winter 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 +24 to +48 hours since the local forecasts first of all is needed for the nest day. Runs are performed on a local Linux-cluster (20 processors), and it is finished at ~06 LT.
(3) A meteorological pre-processor extracts the MM5 information needed by AirQUIS. AirQUIS is then run for Oslo (alos +48 to +48 hours) on a dedicated PC. The AQ-forecasts are finished around 07 LT.
(4) The quantitative forecast for the NEXT day is distributed to the end-user by a WEB-page. All information for Oslo is available at about 07 local winter time.

(5) The end-users (the Municipality of Oslo and the local traffic control authorities) receive the quantitative forecast and issues a public forecast for the next day at about 07:30 LT.

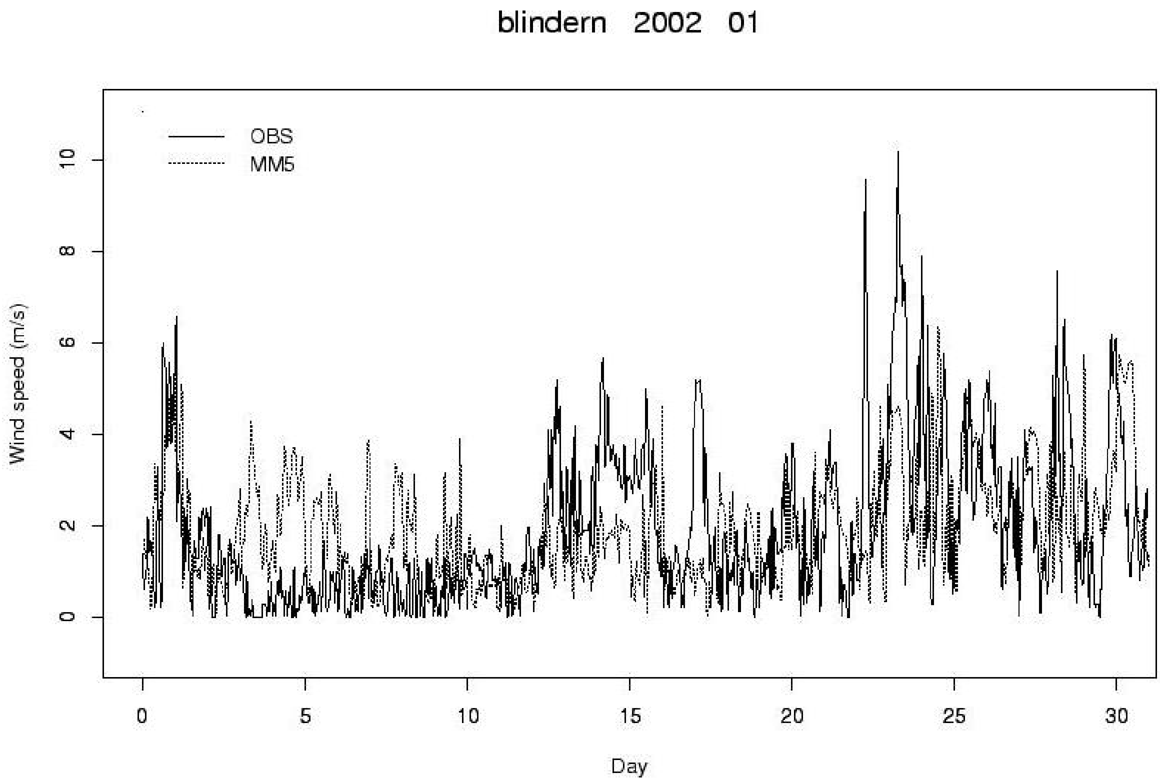
Fig. 3. The operational forecast model for Oslo.



The FUMAPEX activity at met.no and NILU will be concentrated around the MM5/fine-scale meteorological modelling and the meteorological pre-processor for the air quality model.

5 Examples from recent analysis for Oslo.

For the last winter (2001/2002) more comprehensive studies of the modelling results in the Oslo region were performed. Based on 6 months of daily fine-scale meteorological forecasts the MM5 climate of Oslo was evaluated (Berge and Køltzow, 2002, Jablonska et al., 2002). A comparison of the wind predictions and observations at 25 m height for the station Valle Hovin and Blindern is given in Fig. 4 (respectively position 1 and 2 in Fig. 2). The higher wind speed levels at Valle Hovin than at Blindern are for some periods well captured by the MM5 model. This indicates that the circulation patterns resolved by MM5 clearly could be important for the urban scale modelling in Oslo. Qualitatively, the predicted wind speeds follow the observational pattern. But during some periods the differences are large. The frequency distribution of wind directions are also reasonable well represented by the model (not shown), however large discrepancies may occur at certain instances. Wind speeds are generally slightly too high on average, in particular the frequency of wind speeds below 2 m/s is lower in the model than what is observed. The 2 m temperature predictions had a bias of less than 1°C during the winter season 2001/2002. But the temperature inversion at Valle Hovin was overestimated with approximately 0.7°C in the lowest 25 meters.



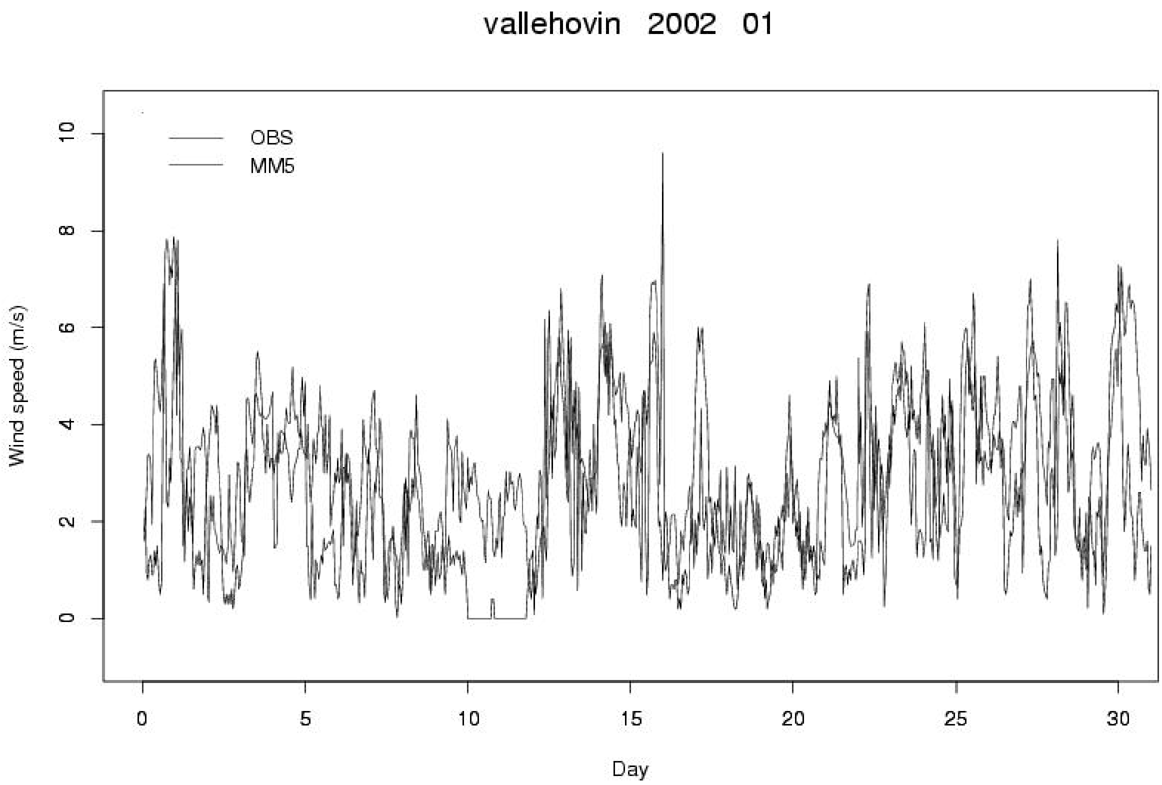


Fig. 4. Observed (full line) and modelled (dotted line) hourly wind speed for January 2002 at the stations Valle Hovin and Blindern (stations 1 and 2 respectively in Fig. 2).

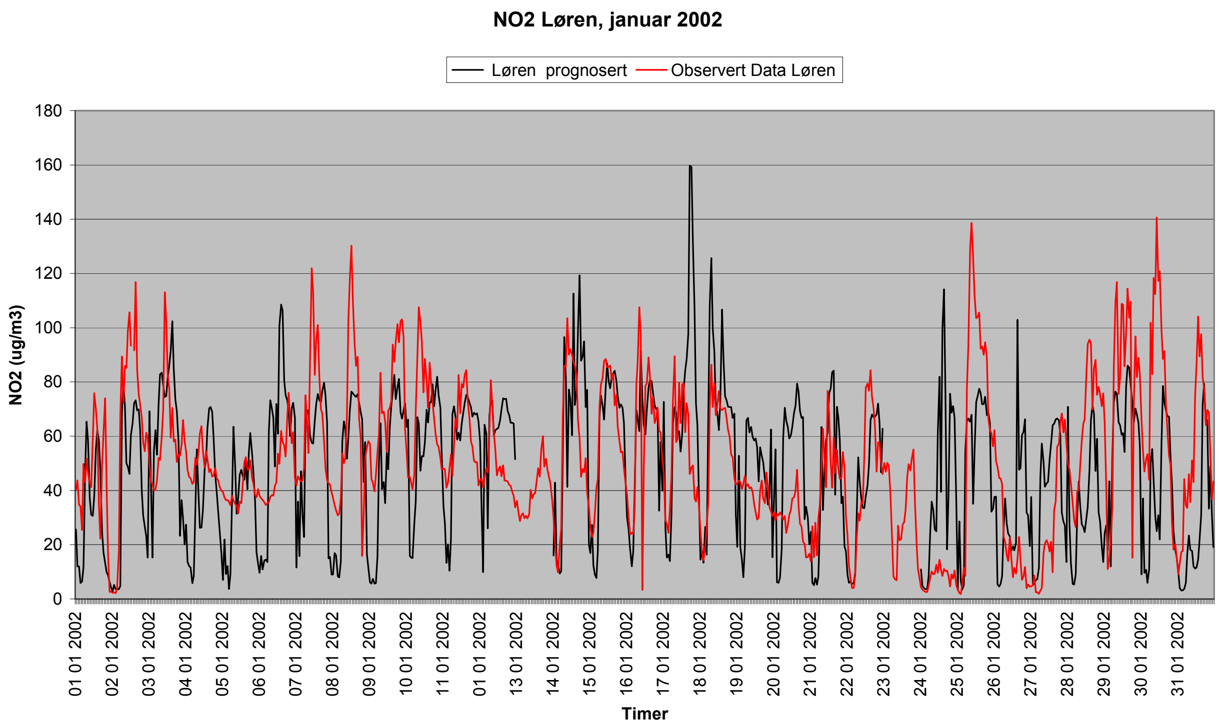


Figure 5. Observed (red) and modeled (black) NO_2 at the station Løren, for January 2002.

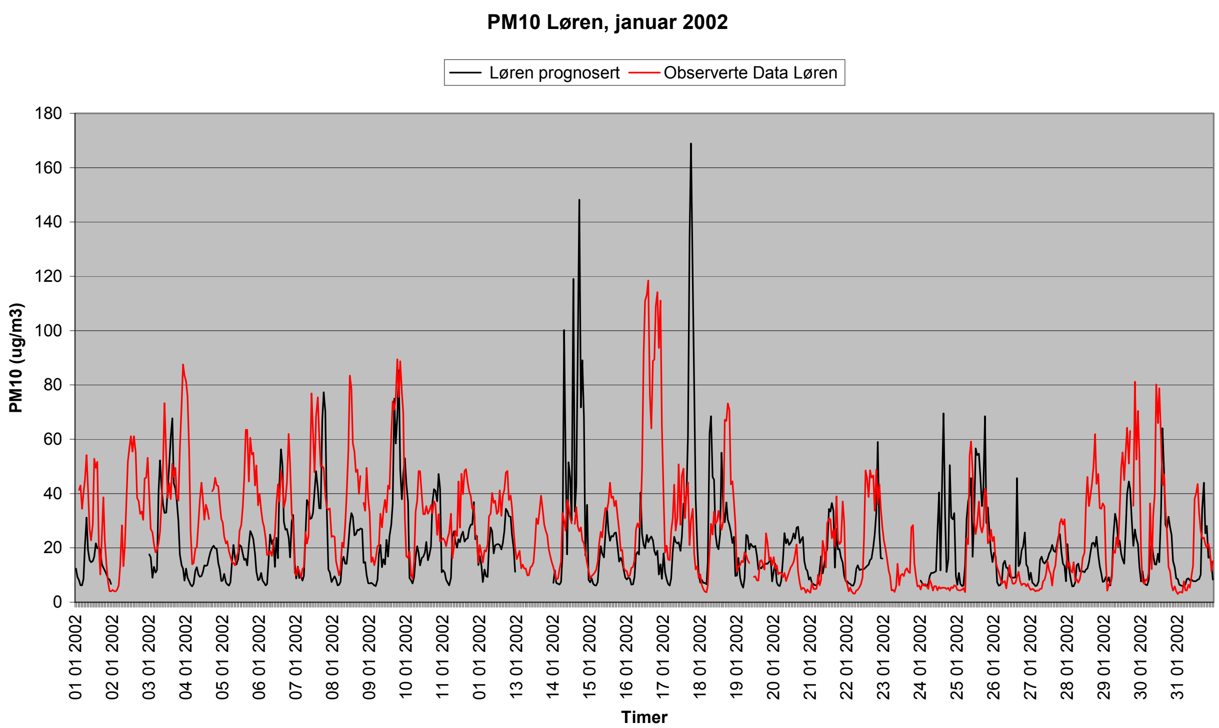


Figure 6. Observed (red) and modeled (black) PM_{10} at the station Løren, for January 2002.

In Figs. 5 and 6 examples on hourly observed and modelled concentrations of NO_2 and PM_{10} are presented for a street station in Oslo. The figures show that for some of the episodes the model results fit well the observations. In other cases the differences are large. The discrepancies between modelled and measured wind and stability may be substantial at a particular time as exemplified for wind in Fig. 4. This can often explain the differences between modelled and observed concentrations. Furthermore, there are also considerable uncertainties in how to make use of the meteorological data in the air quality calculations. This topic, together with the improvement of the quality of the NWP-data, constitutes an important part of the FUMAPEX work plan. Met.no and NILU will mainly be involved with these issues in the FUMAPEX project.

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Participant 11 (P11) - UH

University of Hertfordshire

1. UH team members

Professor Ranjeet S Sokhi (Project Manager)
Postdoctoral Research Fellow – to be employed soon
Dr Lakhumal Luhana – urban air quality modelling
Ms Lia Fragkou – mesoscale modelling
Visiting Researchers:
Professor Dick van den Hout, TNO (air quality policy)
Dr Douglas R Middleton, UK Met Office (urban meteorology)

2. Content of the UH contribution

UH (Participant 11) co-ordinates WP 2 (**Assessment of different existing approaches to forecast UAP episodes**) and participates in all WP's except WP3 as shown below. The largest amount of resources are devoted to WP2.

Workackage No[5]	Workpackage title	UH Contribution Manmonths
WP 1	**Analysis and evaluation of air pollution episodes in European cities**	**2**
WP 2	**Assessment of different existing approaches to forecast UAP episodes**	**6**
WP 3	**Testing the quality of different operational meteorological forecasting systems for urban areas**	**0**
WP 4	**Improvement of parameterisation of urban atmospheric processes and urban physiographic data classification**	**2**
WP 5	**Development of interface between urban-scale NWP and UAP models**	**4**

WP 6	**Evaluation of the suggested system (UAQIFS) to uncertainties of input data for UAP episodes**	**3**
WP 7	**Development and evaluation of population exposure models in combination with UAQIFS's**	**1**
WP 8	**Implementation and demonstration of improved Urban Air Quality Information and Forecasting Systems**	**1**
WP 9	**Providing and dissemination of relevant information**	**1**
WP 10	**Project management and quality assurance**	**1**
	TOTAL	**21**

WP2. The main objectives of this work package as stated in the DoW will be:

(a) To identify and collate the current approaches for characterising the urban boundary layer in UAP models relevant to End Users.

(b) To classify the met-pre-processors/approaches according to scientific formulation, complexity, input data, output information, pre-processing requirements, type of model and application for urban air pollution assessment.

(c) To evaluate these current met-pre-processors and approaches and identify areas of improvement.

Methodology for WP2

The outcomes of this work package will provide the initial basis regarding the currently employed meteorological approaches for characterising the urban atmospheric boundary layer. It will lay the foundations for subsequent work packages especially in relation to areas that require improvement.

WP2.1 Collation and examination of selected models used for urban air pollution assessment in diagnostic and forecasting mode. A key criteria of selecting the models will be the relevance and need for End Users. The models will be classified according to the approaches used to describe atmospheric dispersion such as Eulerian, Lagrangian, Gaussian, Box, statistical, CFD.

WP2.2 Met-pre-processor schemes used by these models will be categorised and examined in relation to scientific formulation, complexity, input data, output information, pre-processing requirements and type of model and application.

WP2.3 Different met pre-processors will be compared by running simpler UAP models with existing datasets for episodic conditions. The outputs will be examined for pollutants such as CO, NOx and PM10. This work will build upon the contribution of WP1.

UH Contribution to other Work Packages

WP1. UH will participate by providing data and analysis for episodes of relevance to European cities. UH is already collaborating with FUMAPEX partners in COST 715 WG3 on the meteorology of air pollution episodes and this will feed directly into this WP.

WP4 and WP5. UH will provided input on urban meteorological parameterisation schemes evaluated in WP2. Analysis of the meteorological inputs for different classes of UAP models, as defined by WP2 results. This will feed into WP5.

WP6. Sensitivity analysis of improved meteorological preprocessors for use in UAP models.

WP7. Assist in the demonstration of exposure models to end users in the UK.

WP8. Assist in the demonstration of UAQIFS to end users in the UK.

WP8. To undertake dissemination activities such as presentation of results to end users and to major international conferences including Urban Air Quality and publication of joint papers in peer-reviewed journals.

WP10. Project management activities.

3. Previous work

The most relevant previous projects:

1. WG3 of COST 715, Meteorology applied to urban air pollution problems, 1998 – 2004.
2. Development of GAMMA-MET – a meteorological preprocessor for urban air quality modelling 1998- continuing.
3. Improvement of surface roughness treatment in urban air quality models 1998-continuing.

4. Ongoing related work

1. Optimised Expert System for Conducting Environmental Assessment of Urban Road Traffic – OSCAR, 2002 – 2004. European Union, City of Tomorrow, Improving the quality of urban life. Funding from European Union.
2. Source apportionment of urban airborne particles and polycyclic aromatic hydrocarbons in Europe – SAPPHIRE, 2002 – 2004. City of Tomorrow, Improving the quality of urban life. Funding from European Union.
3. Cluster of European Air Quality Research (CLEAR) – consists of six FP5 projects (City of Tomorrow).

More information on research projects is available on:
http://www.herts.ac.uk/natsci/Env/Research/ASRG/

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Participant 12 (P12) - CORIA

CORIA

Partner team members:

Pr. Alexis Coppalle , M. Talbaut, C. Philippe (PhD)

Introduction

The CORIA team is working on atmospheric pollution since several years. The research is focused on dispersion and chemical transformations of pollutants at local scale, the emphasis being on urban air pollution. The team has experiences on plume dispersion modelling, gained with several studies on the impact of sulphur dioxide emitted by refineries or power plants (participation in a LIFE project, collaborations with refinery companies and the pollutant monitoring network of Haute Normandie AIR NORMAND). Theoretical modelling has been performed on reactive plumes with the application to NO-NO2 conversion in thermal power station emissions (collaboration with Electricité de France). The team worked on modelling of photo-chemistry pollution episodes and on the assessment of abatement strategies (in the case of Rouen city with AIR NORMAND and in the case of Paris, project supported by the PRIMEQUAL French research program). The participant is now taking a great interest in urban meteorology and the observation of turbulent fluxes in the urban atmosphere. He has participated to the CLU-ESCOMPTE observation campaign in the Marseille city (France). In the field of air pollution, the CORIA laboratory, on beneath of A. Coppalle, is in constant contact with management centres and end-users. The CORIA has a lot of collaborations with the pollutant monitoring networks in France, as for example the AIR NORMAND network and the 'Laboratoire Central de la Qualité de l'air' of the French environmental ministry. He will manage dissemination of the project results in France to the scientific community, management centers and end-users.

Status report

The CORIA will contribute to **WP1,2,4,6,** and **9**.

WP1 : P12 will perform the analyse of pollution episodes occurring over Paris and Marseille. The study will be carried out with the help of the pollutant observations provided by monitoring stations existing in France, and the meteorological data from the European Centre for Medium-Range Forecasts.
WP2 Examination of the current meteorological pre-processors available in operational models, which are used for air pollution assessment.
WP4 Contribution to the development of improved urban meteorological pre-processors. The CORIA participation to several observation campaigns of urban meteorology and turbulent mixing above roof level, for example the CLU-ESCOMPTE campaign over Marseille city, will be useful to the other partners. The data obtained in theses experiments will be useful to assess the boundary layers parameterisations and the new meteorological pre-processors which will be developed in the FUMAPEX project (**WP3, WP4** and **WP5**).
WP6 : Evaluation of improvements given by the meteorological pre-processors, (developed in WP4 and WP5), on the operational dispersion model predictions. Among the operational models, which are suitable for regulatory purposes, the Gaussian plume model is widely used to determine point or line source impact. Recently, 'new generation' Gaussian models have been developed (as for example AEROMOD in USA). It is well recognised that they give more accurate results compared with models, which used the Pasquil's stability classification. The improved models need, for routine applications, input meteorological data provided by the pre-processors developed through actions WP4 and WP5. Calculations of point or line source impacts will be performed with such 'new' Gaussian plume model. Collaborations with P9 is intended to apply the meteorological MM5 model to provide wind field over the studied cases.
WP9 : P12 will finally contribute to the dissemination of the project results in France to the scientific community, management centres and end-users.
WP8 : It is intended to make several applications of the new Urban Air Quality Model Systems, developed in the FUMAPEX project, to the case of Paris urban area. This will depend on the availability of the pollution data at the time these applications will be performed.

Previous related experience and ongoing work

The most relevant projects to FUMAPEX :

- COST715, Meteorology applied to urban air pollution problems, 1998 – 2004:
- EUROTRAC2, Subprojects SATURN.
- City delta: model inter-comparison exercise organized by Ispra JRC in the framework of CAFE program (DGXI)

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Participant 13 (P13) - KTL

KTL (Finnish National Public Health Institute)
Department of Environmental Health
Laboratory of Air Hygiene

Partner team members:
Prof. Matti Jantunen, Head of the Laboratory of Air Hygiene, FUMAPEX Work package (WP7) leader,
Ms. Anna-Maija Piippo, secretary,
Ph.D. Sari Alm, *Ph.D.* Kimmo Koistinen, *Lic.Tech.* Päivi Aarnio, Ms. Tuulia Rotko, Mr. Otto Hänninen

Probabilistic Exposure Modelling in KTL

Introduction

Besides other environmental effects, ambient air pollution has been connected to population mortality and other serious health effects (e.g. Pope et al, 1993, 2002). The ambient pollution can cause these effects only to the extent that the pollution and the people meet. This is also one of the definitions of the term *exposure*, depicted in figure 1.

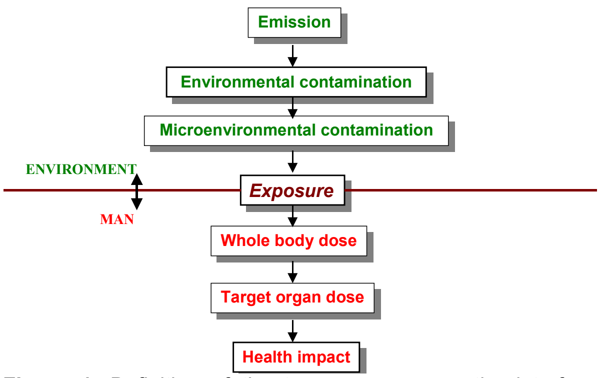

Figure 1. Definition of the term *exposure* as the interface between man and the environment.

Ambient pollutant concentrations vary substantially both in time and in space, and the population moves around in the varying pollutant field daily. Besides the spatial and temporal variation of the ambient air quality, maybe the most significant factor differentiating personal exposures from outdoor air quality is the fact that typically over 85% of the population time in western societies is spent indoors. The building envelope and air exchange systems restrict penetration of pollutants indoors and creates partially closed compartments, in which indoor emissions can raise the concentrations orders of magnitude higher than outdoors.

Since the '80ies, personal exposures have been measured in numerous studies to find out the relationship of ambient pollution levels and personal exposures (e.g. Alm et al. 1994, Janssen et al. 1999). EXPOLIS study, conducted in six European cities in 1996-97 was one of the first international population based personal exposure studies (Jantunen et al. 1998). The following section introduces shortly some of the basic concepts and findings of the personal exposure studies.

Exposure and dose. Inhalation exposure is measured as the concentration of the pollutant in the air in the vicinity of the subject. When the pollutant is inhaled, part of it is retained within the lung, forming the lung dose. Due to the biochemical, immunological and physiological activities the pollutant is then removed from the lung and is potentially transported to other sensitive organs, causing target organ dose.

The amount of pollutant entering the body and retaining there is a function of both the immediate concentration (exposure level) and the physical activity level of the subject. Higher physical activity levels lead to increased oxygen demand and thus higher inhalation rates. Most health effects are functions of the target organ dose.

Time activity. Urban citizens spend most of their time in indoor environments. Time activity is typically measured using questionnaires and/or diaries. The physical activity level of a person is typically low indoors. Figure 2 shows time activity data of adult Helsinki citizens in 1996-97 measured using a structured 48-hour diary with 15-minute time resolution in the EXPOLIS study.

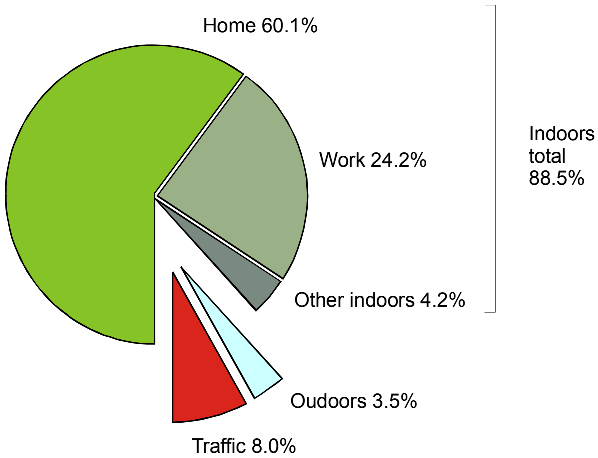

Figure 2. Population time activity in Helsinki 1996-97 (EXPOLIS data, 48-hour diary data for 201 subjects).

Microenvironments. One approach used to handle spatial variability in concentrations and to describe time activity is to classify the environments a subject visits into microenvironments. The classic definition of a microenvironment states that it is an environment where the concentration of the pollutant in question can be considered to be homogeneous.

In the probabilistic modelling approach a microenvironment is defined as a group of environments for which the distribution of concentrations in time (for a specified averaging time) can be described using a single probability distribution.

Effective penetration. Ambient pollutants enter indoors together with air via the air exchange system. Parts of the ambient pollutants are removed by the air filters (if any), the building envelope and removal processes in the indoor air, such as deposition. The (average) ratio of the indoor concentration of ambient origin and outdoor concentration is called the effective penetration factor.

When the ambient concentrations are used to estimate exposures, the effective penetration rates should be taken into account. Figure 3. visualises the effective penetration factors for PM2.5 in Helsinki (Hänninen et al. 2002b).

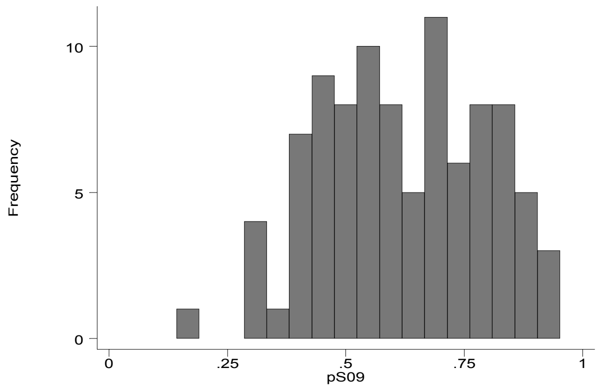

Figure 3. Effective penetration factors for PM2.5 in Helsinki 1996-97 (n=98, 2-night measurements, mean=0.64, sd=0.2).

Personal exposures versus ambient concentrations. The findings about the health effects of air pollution are mainly based on epidemiological studies using ambient fixed station concentration measurements as exposure measures. The method assumes that on the population level, the ambient originating fraction of the personal exposures is correlated to the concentrations observed in the fixed monitoring stations. Then, if an association is found between the ambient levels and health, this must be caused by the fraction of personal exposures that correlates with the fixed stations. The better the correlation is between the exposures and the fixed station concentrations, the easier it is to observe also the potential connection with the health effect.

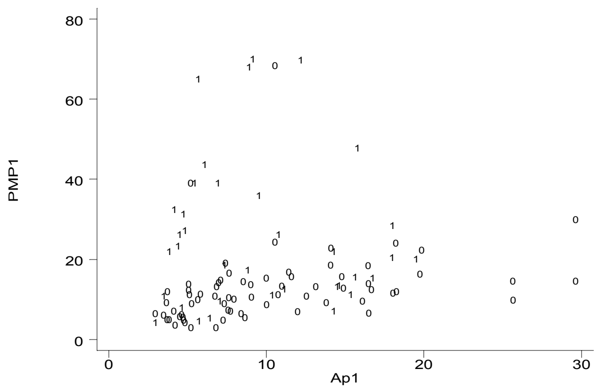

Figure 4. Relationship of personal day-time exposures (y-axis) and corresponding ambient PM2.5 concentrations (x-axis) in Helsinki 1997 (n=105, 2-day measurements). Symbol 1 indicates ETS-exposure reported by the subject.

A lot of the effort spent in exposure studies has been focused on looking at the relationships of personal exposures and ambient concentration levels. This relationship for 105 adults in Helsinki 1997 is shown in Figure 4. It can be seen from the graph that a part of the large variation of exposures around the ambient level is explained by ETS exposures, but that a lot of variation still remains unexplained. Mean exposure is 16.5 μg m^{-3} while the corresponding ambient concentration is only 10.1 μg m^{-3}.

Probabilistic modelling. Exposure models are typically divided into three main classes; deterministic, statistical and probabilistic. Probabilistic models are called also *stochastic* in some contexts. Deterministic models use physical equations to describe causal relationships between model variables. Input data in a deterministic model describes individuals and thus also the model outputs are deterministically assigned to them. Probabilistic models use the same physical equations but describe the inputs as probability distributions instead of fixed values for specified individuals. Thus the probabilistic model inputs describe populations, not individuals, and the same applies to the model outputs.

Traditionally exposures, especially in occupational settings, but also in environmental issues, were assessed using point estimates calculated with conservative assumptions. In the case of this maximum exposure level falling far below harmful effects this approach is sufficient. In reality, however, often at least parts of the general population are in danger and the need to know more about the distribution of population 's exposures arises.

The situation is similar in city planning. We want to compare health – among many other – effects of alternative policy options. The differences between real-world policy options hardly ever have any effect on conservative point estimates of exposures, but do have some effects on population time activity and spatial distribution of both the population and pollutant concentrations. To be able to compare the policy options, we need to develop methods to model population exposure distributions in the competing future scenarios.

Theoretically it would be possible to calculate an hour-to-hour description of the outdoor pollutant field in a city, to enter the location of each of the population member for each 15 minutes into the model and to model the indoor concentrations deterministically using mass-balance description of the air exchange system of each building in the city. Practically speaking, a lot of data from such a model is still missing and it is not sure that collecting the data would be an effective solution.
Random sampling of different populations like buildings for penetrations and people for time activity might prove to be the most efficient solution. Statistical random sampling techniques can be combined into deterministic concentration models in many different ways and probabilistic penetration and population time activity modelling is one of them.

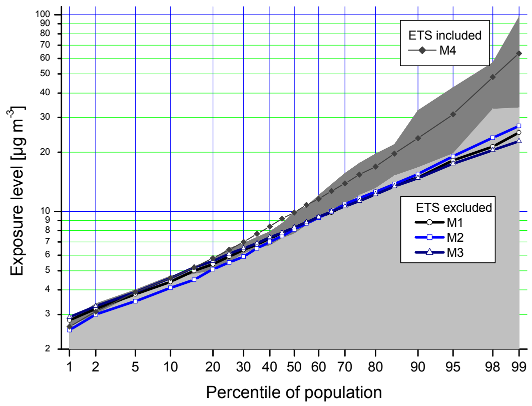

Figure 5. Comparison of observed and simulated $PM_{2.5}$ exposure distributions in Helsinki. The filled gray areas represent the observed exposures, and lines the model outputs.

Probabilistic microenvironment based exposure modelling framework has been developed together by RIVM and KTL and the model has been applied on PM_{10} and $PM_{2.5}$ exposures in Dutch and Finnish set-ups (Kruize et al. 2002, Hänninen et al. 2002a). Figure 5 compares the model results with observed personal exposures in Helsinki (Hänninen et al. 2002b). The match between the simulation model and the observed exposures is good, and it probably can be said that the model describes the overall shape of the population distribution quite well.

Exposure research in KTL

Previous related work

LIILA. The national Children and Traffic (LIILA) -study conducted by KTL in 1990-91 was one of the first personal exposure studies in Europe. Since then the exposure assessment has been one of the key areas in environmental health research in KTL in epidemiology, toxicology and exposure science.

ULTRA. During the '90ies KTL co-ordinated two European Union funded international exposure focused studies. The Unit of Epidemiology co-ordinated the ULTRA studies, in which the health indicators of adult asthmatics (ULTRA I) and cardiovascular patients (ULTRA II) were monitored and their relationships with their personal exposures and home indoor concentrations were studied. These studies identified the exposure characteristics, like time pattern, leading to health responses.

EXPOLIS. The Laboratory of Air Hygiene co-ordinated the Air Pollution Exposure in European Cities -study, in which air pollution exposures of random population samples to main air pollutants were measured in six European cities (Athens, Basle, Grenoble, Helsinki, Milan and Prague). The studied pollutants were $PM_{2.5}$, elemental composition of $PM_{2.5}$ (30 elements), NO_2, CO and VOCs (volatile organic compounds, over 300 compounds in some samples, 30 target compounds quantified from all samples). Besides personal exposures, the corresponding concentrations were measured also in the main microenvironments (home and workplace) of each subject. A large exposure questionnaire and time activity diary was collected from the exposure measurement subjects and from another random questionnaire-only population sample in each of the cities. The data were compiled as an international exposure database, which has been extensively used to analyse determinants of personal exposures.

Related on-going projects

HEAT. The Academy of Finland funded study Health Effects caused by Urban Air Pollution for the Transport System Plan Scenarios in Helsinki area (HEAT) is co-ordinated by the Finnish Meteorological Institute and the main partners YTV and KTL are the same as in FUMAPEX. In the HEAT study the traffic emissions are evaluated and the $PM_{2.5}$, NO_2, and NO_x concentrations modelled for the transport system plan scenarios. Exposure to $PM_{2.5}$ and NO_2 will be modelled and the methods to assess population exposures developed further.

HEARTS (Health Effects and Risk of Transport Systems)is an European Union funded project co-ordinated by WHO, Regional Office for Europe, European Centre for Environment and Health, in which all the health effects of traffic are modelled. In this study the health effects include, besides air pollution, also those of accidents and noise.

INDEX. The Indoor Exposures -study is funded by EU Directorate General (DG) Health and Consumer Protection and the study is co-ordinated by the EU Joint Research Centre, Ispra, Italy. This study conducts a comprehensive literature review of indoor pollutants to rank the potential health risks of them and to prepare for future development of guidelines and control strategies for indoor pollution in Europe.

EEF. The European Exposure Factors –project is funded by the European Chemical Industry Council (CEFIC). Exposure related factors from European countries are collected in this project. The results are published as an exposure factor source book and as an internet-based database to support exposure assessments in various set-ups.

EXPOLIS-INDEX (Human Exposure Patterns for Health Risk Assessment: Indoor Determinants of Personal Exposures in the European EXPOLIS Population in Athens, Basle, Grenoble, Milan, Helsinki, Oxford and Prague) study is also funded by the European

Chemical Industry Council (CEFIC). This study is co-ordinated by the University of Basle. The focus is in time activity and VOC exposures.

KTL, Department of Environmental Health was nominated a special grant for **Centre for Environmental Health Risk Analysis**. In this work the epidemiological and toxicological risk assessment processes are developed towards a unified approach by comparing the current state of art risk assessments of dioxins (based on toxicology) and particulate matter (based on epidemiology).

KTL contribution in the FUMAPEX study

KTL participates in FUMAPEX work packages 6-10, co-ordinating WP7, *Development and evaluation of population exposure models in combination with UAQIFS's*. The minor contribution in work packages 6, 8, 9, and 10 allows for integration to the UAQIFS's and demonstration, evaluation and dissemination of the exposure modelling techniques.

Work package 7: Exposure modelling

KTL has developed a probabilistic modelling technique together with RIVM (The Dutch Institute for Public Health and the Environment). A probabilistic model has been developed and validated for fine particles ($PM_{2.5}$). In the FUMAPEX WP7 the needed interface is built to connect the probabilistic population exposure model to the dispersion models.

The exposure modelling techniques are developed in tight collaboration with FMI and YTV using Helsinki Metropolitan area as the development environment. Other partners participating in this work package are University of Hertfordshire and the Environment Institute of Joint Research Centre.

KTL will apply the probabilistic modelling technique on population exposures. The 4-dimensional dispersion model outputs (hourly time series of concentrations in 3-dimensional spatial space) are sampled using a stratified sampling scheme to create the outdoor concentration distributions corresponding to exposures in different microenvironments. For the indoor microenvironments the pollution penetration is modelled probabilistically. Population time activity is also probabilistically modelled to create the exposure distribution for the target population.

FMI and YTV have used a statistical approach to model population locations during fixed hours of day (a time-window approach) in the EXPAND model. FMI will develop further the deterministic techniques for exposure modelling.

The next paragraphs discuss shortly exposure modelling related issues.

Averaging time. The current model has been evaluated for 24-hour $PM_{2.5}$ exposures. Longer and especially shorter averaging time modelling would require changes to the time activity model, e.g. redefinition of the microenvironments.

Seasonal effects. The current model has been built for assessing exposure distributions over a one-year period. In FUMAPEX the focus is in forecasting short-term (up to 1 week) episode situations, and thus the time activity model, must be season (and working day versus holiday) specific.

Sub populations. The current *EXPOLIS* model has been tested for working age population. Other sub populations, like children and elderly, are potentially in the higher risk during an air pollution episode. The exposure model must be separately developed for selected sub populations.

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Participant 14 (P14) - ARPAP

ARPAP: Environmental Protection Agency of Piedmont – Italy
Responsible for implementation and end-using of UAQIFS for the city of Turin, Italy

Partner team members:
dr. Francesco Lollobrigida Head of ARPAP Centre for Air Pollution Modelling
dr. Mauro Maria Grosa Coordinator of the Piedmont region Air Pollution Monitoring Network
dr. Roberta De Maria Component of ARPAP Centre for Air Pollution Modelling
dr. Monica Clemente Component of ARPAP Centre for Air Pollution Modelling

Air Quality Management in Piedmont region

Air Monitoring Network

The Piedmont Air monitoring Network is managed by ARPAP. It includes 68 stations, with 23 stations in Turin metropolitan area monitoring ambient air concentration of sulfur dioxide, carbon monoxide, nitrogen oxides, benzene, ozone and PM10. A dedicated hardware-software system has been developed since 2000 in order to obtain standardized data validation in whole region.

Regional Emission Inventory

Piedmont Regional Administration developed an emission inventory based on CORINAIR metodology. It includes over 100 point sources(power plants, main industrial plants), the main roads as line sources, and other sources classified as "area" ones. Area sources are aggregated according to their nature (local traffic, heating, local industial activities etc.) in SNAP (Selected Nomenclature for Air Pollution)categories.

Meteorological monitoring network

The Piedmont meteorological monitoring Network is managed by the Regional Weather Service.
It includes 52 meteorological stations, 3 synop station, 4 radiosonde station. A wind profiler will be installed during 2003 in Turin metropolitan area.
ARPA have cooperated with Regional Weather Service since 2000 in relation to air quality problems .
A daily bulletin is released by Regional Weather Service for Turin metropolitan area in order to support
air quality forecasting under a qualitative point of view.
Geographical dataset

A geographical dataset is available for whole Piedmont region. It provides two kinds of information:

the geo-referenced terrain heights (orography) and land use. The latter is needed to determine the roughness parameters of surface terrain, while orography is needed to describe the presence of complex terrain ,that characterized both regional territory and Turin metropolitan area

Air quality modelling integrated system

An integrated system for diagnostic air quality modelling is available. The system was provided by partner 7(ARIANET) within the specific regional project " Air quality integrated assessment by means of air pollution models over Piedmont territory"
The system includes at present time:
a specific module(Emission Manager) which prepares emissive input for 3D lagrangian and eulerian models;
a diagnostic meteorological model (MINERVE) that construct 3D wind and temperature fields, together with a separated module for computing turbulent parameters;
a gaussian air quality model (ARIA Impact) ;
a lagrangian particle air quality model (SPRAY);
an eulerian photochemical model (FARM)

Besides, Piedmont Regional Weather Service participates in the working group which deals with italian version of the non-hydrostatic meteorological model Lokal Model (LM).

Applications

Scenario analysis and environmental impact assessment

ARPAP performed a study about traffic induced pollution episodes in relation to highway leading to Frejus Tunnel, in the north-western part of Piedmont, at the border with France. The study simulated air pollution before and after the closure(owing to the accident of 23nd March 1999) of the other main tunnel that connects Italy and France, the Monte Bianco one. Air pollution due to a hypothetical accident inside the Frejus tunnel was also simulated. Besides, ARPAP usually performs simulation of air quality changes due to new considerable emissive sources as power plants

Air quality assessment (96/62/CE)
Air Quality assessment is usually achieved through the knowledge of data recorded at the air monitoring stations. Unfortunately those values are representative of an area just closeby the mentioned stations. Yet, the use of regression curves for correlating pollutants recorded at certain stations with emission data, to other areas where stations do not exist enables to construct a map where concentrations of pollutants are estimated with reliable accuracy..
This metodology has been used to classify every municipality in Piedmont in relation to carbon monoxide, nitrogen dioxide, benzene and PM10 concentrations in ambient air. The classification is based on long-period reference values provided for these pollutants by 1999/30/CE and 2000/69/CE Directives.

Urban air quality modelling
A winter pollution episode (28 th-31st January 2000, for a total of 96 hours) was simulated for carbon monoxide and nitrogen oxides. in an area of 80 x 80 km^2 surrounding the city of Turin. Above one thousand of emissive sources was considered on the base of regional emission inventory.

The air quality modelling integrated system described above was used and the outputs of the lagrangian model SPRAY were compared with data provided by air quality monitoring stations , with good results

Guidelines for air quality modelling

ARPAP participated in the working group of National Thematic Centre fo Atmosphere, Climate and Emissions which developed National Guidelines for the application of air quality models.

Guidelines are inclusive of a full description of all the models which are nowadays available and recommended, so that a user is able to choose a model accordingly to the situation the model has to be applied, the results that are needed, the level of complexity the problem requires.

Photochemical pollution modelling

ARPAP planned a simulation of a photochemical pollution episode in the Piedmont Region using the diagnostic meteorological model MINERVE coupled with the eulerian dispersion model FARM, according to the air quality modelling integrated system described above.

A test of interfacing the outputs of the non-hydrostatic meteorological model Lokal Model with FARM is also planned.

ARPAP contribution in the FUMAPEX study

The main objective of ARPAP is to improve its air quality modelling integrated system as regarding air quality forecasting in the metropolitan area of Turin, that is one of the target cities ; all the activities will be performed in close co-operation with both Regional Weather Service and local authorities. With the latter public meetings will be organized.

Therefore the largest amount of resources (12 man months) will be spent on WP8 (Implementation and demonstration of improved Urban Air Quality Information and Forecasting Systems).

The other main contributions are in WP5-Development of an interface between urban-scale NWP and UAP models(6 man months) and WP6 Evaluation of the suggested UAQIFS to the uncertainties for UAP episodes(7 man months).

ARPAP also partecipates in WP1 – Analysis and evaluation of air pollution episodes in European cities,providing air quality data and statistics for Turin metropolitan area (3 man months), and WP 9 Providing and dissemination of relevant information)

Selected relevant publications

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Participant 15 (P15) – JRC EI

JRC EI: Environment Institute - Joint Research Center – European Commission
Responsible for the Dissemination Work Package 9 (WP9).

Partner team leader:
Dr. Andreas N.Skoudoudis

Specific WP9 Progress Outline:
During this period was set out the framework for the dissemination and publicity activities of the FUMPAEX project. The dissemination and use plan has identified the steps of dissemination work and defining the time scales.

FUMAPEX dissemination will mainly happen on two different levels: the European and the local level. This dissemination plan focuses on European wide dissemination activities, whereas local dissemination work will be undertaken by the different application sites. The dissemination work will be implemented in two phases: the preparatory phase and the dissemination phase.

At the beginning of the dissemination phase, general information about the project will be distributed via a project brochure and the web site. Later, as tangible results become available, dissemination work will focus on presenting the FUMPEX demonstrations at the different application sites, mainly via regular project newsletters, scientific articles, press releases, conferences and workshops.

The target groups of FUMAPEX dissemination work, the specific information requirements and the corresponding preferred dissemination tools and media have been defined. The primary target group are large European cities (more than 250.000 inhabitants) which are considered to be potential users of a Decision Support System to be developed in FUMAPEX. Secondary target groups are national and regional government decision makers and research institutions in European countries. Dissemination at the level of the application sites will be targeted for local users, interest groups, other institutions, associations with professional interests. FUMAPEX results will also be made accessible to multiplier organisations at international, national and local level, who are able to support FUMAPEX in its dissemination work. According to specific information requirements of the target groups, the appropriate dissemination tools and dissemination channels have been selected.

Apart from the project web site, which will provide general and specific up-to-date information about FUMEPAX, the project newsletter will be the key dissemination tool. It will regularly report the upcoming results of the project applications and will be distributed amongst local and national decision makers and other target groups. Other dissemination tools are a project brochure, conference presentations, scientific reports and project reports and deliverables.

In order to deliver information, provided in the above mentioned dissemination tools, the project will mainly make use of dissemination media such as E-mail, the Internet, direct mailings (Post/fax) and traditional media if necessary (Newspapers, Specialised Magazines, TV, Radio). Very important media for delivering information about FUMAPEX will be workshops and conferences.

The preparatory phase, will be completed through issuing various documents, dissemination target groups on the European and the local level, their information needs and multipliers have been defined.

Objectives of Dissemination Activities:
This dissemination plan only defines the wider framework of how the dissemination of the FUMAPEX results will be implemented, since sufficient flexibility is required to allow activities to occur on an ad-hoc basis and enable local project managers to develop their own local dissemination strategies with their specific priorities. In order to ensure the quality of dissemination activities and a high degree of effectiveness and satisfaction of target groups during the project, it is necessary to regularly update the definition of the dissemination tasks and to monitor their implementation on a regular basis.

Throughout the duration of the project the following monitoring activities will be realised and co-ordinated DG-JRC. The specific monitoring activities will include:

- The FUMAPEX stakeholder database as well as the list of upcoming seminars and conferences throughout Europe, where FUMAPEX results may be presented, will be updated previous to major dissemination activities.
- A brief feedback form will be added to newsletters and on the web page.
- The use of the FUMAPEX project web page will be examined, by analysing web statistics (number of hits) and comments.
- Create a registered users section for promoting the visitors to register
- For project partners encourage to register scientific publications and dissemination events where FUMAPEX is mentioned or worth to be mentioned.
- At FUMAPEX dissemination events a questionnaire form will be distributed amongst the participants, asking for feedback on the usefulness of the events.
- Informal feedback will be encouraged and taken into account.
- The implementation of all significant dissemination activities at the European level, as indicated in the dissemination plan, will be monitored on a target-group-specific basis. This will allow the project to get a differentiated overview of how well the target groups are reached during the project.
- Local applications sites will be asked to give a regular report (every six months) on the local dissemination activities.

Deliverables:
1. The project web sites (http://fumapex.dmi.dk and http://fumapex.jrc.cec.eu.int)
2. Project presentation through the project brochure
3. First newsletter

4. Users' Database (initiation)
5. Events' Registry (initiation)
6. Publications Registry (initiation)

Next Items:
1. Dissemination of Newsletter
2. Preparation of first year's workshop
3. Select and Monitoring results to be reported of and
4. Completion of:
   - Users' Database
   - Events' Registry
   - Publications Registry.

Participant 16 (P16) – ETH/EPFL

Swiss Federal Institute of Technology in Lausanne
Laboratory of Air and Soil Pollution

Partner team members:
Dr. A. Clappier, Dr. M. Rotach, Mr. C. Muller

Development and test of urban parameterizations for Mesoscale model.

1 .Introduction

The Laboratory of Air Pollution (LPAS: Laboratoire de Pollution de l'Air et des Sols) at the Swiss federal Institute of Technology in Lausanne (EPFL)

During the last 10 years, the EPFL group contributed to improve the speed and the precision of several numerical techniques (transport algorithms, Clappier, 1998; massive parallelisation, Martin M. et al., 1999). It used the California Institute Technology air quality model (CIT), the Thermal Vorticity Mesoscale Model (TVM, Thunis and Clappier, 2000), the METPHOMOD model (Perego, 1999) to simulate the air quality over different cities (Athens, Clappier et al., 2000, Milan, Martilli et al. 2003, Madrid, Palacios et al. 2002, Grenoble, Couach, 2002). Two models have been developed for specific module developments: 1) A mesoscale wind model adapted for urban areas (Finite Volume Model, FVM, Clappier et al., 1996, Martilli et al., 2002). 2) A pollutant transport model designed to study the coupling between different gas phase chemical mechanism, the aerosol formation and the solar radiation (Transport Air Pollution Model, TAPOM).

The Institute for Atmospheric and Climate Research (IAC) at the Swiss federal Institute of Technology in Zürich (ETHZ)

The investigation of the flow and turbulence structure over urban surfaces has been a research focus for many years in the boundary layer research group lead by Mathias Rotach, at the Institute for Atmospheric and Climate Research ETH (IAC-ETH). In the Zürich Urban Climate Program the vertical divergence of momentum flux in an urban RS was for the first time systematically investigated (Rotach, 1991; 1993a) and other characteristics of RS turbulence (namely the local scaling hypothesis) were worked out (Rotach 1993b; 1994, 1995). These results have later been used to investigate the influence of the RS turbulence structure on the dispersion of passive pollutants (Rotach et al. 1996, Rotach and de Haan 1997, de Haan and Rotach, 1998; Rotach 1997a,b; 1999, 2001; de Haan et al. 1998, 2001). In a recently finished TMR network (TRAPOS – Optimisation of modelling methods for street level pollution), the research group was 'responsible' for the investigation of the meteorological input for those models (e.g., Kastner-Klein et al. 2000, 2001, Kastner-Klein and Rotach 2001). Last but not least is the head of the boundary layer group, the Swiss representative in the Management Committee of COST 715 as well as the chairman of its working group 1 on 'the urban wind field' (Rotach et al. 2000). The ongoing research project BUBBLE ('Basel UrBan Boundary Layer Experiment') is co-ordinated by M. Rotach and the collaboration between the two Swiss groups is already established and strong.

2. Urban parameterization research in EPFL.

2.1 Previous related work

The FVM model was used to develop and test a new urban turbulence parameterization. Since the aim of the simulations is to reproduce the pollutant dispersion, the model domain starts at the street level (where a main part of the pollutants are emitted). The city is represented as a series of buildings of the same size, located at the same distance one from the others (street size) but with different heights (i. e. the building density is function of height). Depending on the building height and the vertical model resolution, several grid levels can be defined below the roof height. The method consists in introducing the momentum, energy and TKE equations, solved by the mesoscale model; extra terms representing the impact of the buildings surfaces (roof, walls and street). For every grid cell, it is possible to define several street directions, and the results are averaged over all the street directions in the grid cell. This new urban parameterization was tested in 1D, 2D and 3D, in order to quantify the improvement on air quality simulations (Martilli et al., 2002, Martilli, 2002, Martilli 2003, Martilli et al. 2003b).

2.2. Related on-going projects.

FVM and TAPOM are now currently used to simulate air pollution episodes over several cities: Basel (Switzerland), Bogota (Colombia), Mexico City (Mexico). In most of the cases the parameterization module developed by Martilli et al. (2002) improves the simulated results. In urban areas, the parameterization slows down the wind speed and increases the temperature (see figure 1 and 2).

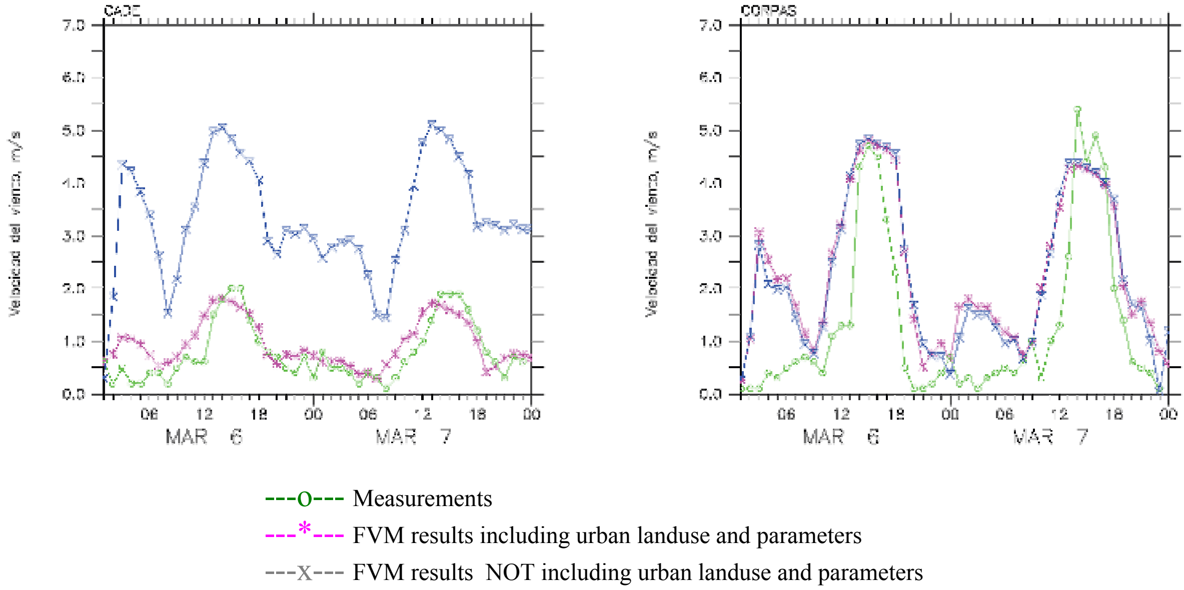

Figure 1: Wind speed measured and simulated with and without the urban parameterization over Bogota city. The left figure shows the results in an urban area and the right figure, the results in a rural area. In the rural area, the wind speed reaches 5 m.s^{-1} in the afternoon and there is no difference between the two simulations. In the urban area, the wind speed reaches only 2 ms^{-1} in the afternoon. The simulation without urban parameterization overestimates the wind speed while the simulated results obtained with the urban parameterization are in better agreement with the measurements.

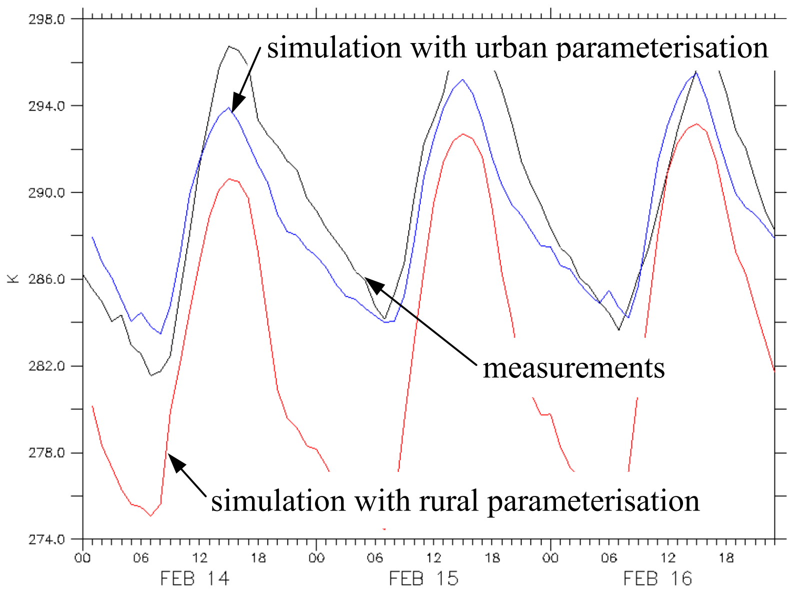

Figure 2: Temperature measured and simulated with and without the urban parameterization over Mexico City. The simulation without the urban parameterization underestimates the temperature.

3. EPFL contribution in the FUMAPEX study.

WP4: The LPAS main task will be to introduce the urban turbulence parameterisation module developed at the EPFL into the LM the HIRLAM model.

WP1: The LPAS and the IAC will provide the measurement data obtained over Basel (CH) obtained during the BUBBLE campaign.

WP3: The LPAS and IAC will evaluate the quality of the improvement obtained with the new turbulent parameterisation using the LM and HIRLAM model for some specific pollution episodes.

WP5: The LPAS will write an interface between the LM and HIRLAM models to run the air quality model TAPOM. This model will be used to simulate the gas phase species over one the selected European cities. The effects of the new urban parameterisation will be intensively tested and validate using the BUBBLE and other data.

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Appendix 1. Overview of FUMAPEX Models

Fumapex NWP, AQ and PE Models

Collated by Sandro Finardi

1 Introduction

Information concerning meteorological models, air quality models, interface modules and pre-processors that will be used in the frame of FUMAPEX project is needed by different WP leaders to better define, program and coordinate the WP activities. This document gathers basic data concerning model features and modelling activities to be shared inside the FUMAPEX community. The information provided regards only models that are actually used for building UAQIFS, i.e coupled NWP+UAP models, or applied/improved/verified inside a specific WP program. The aim of this document is to give a first picture of the model park that will be used in FUMAPEX and to help WP leaders to better define the needs that will have to be covered by WPs activities.

The first part of the document reports models and modelling activities as described by FUMAPEX partners. The last part attempts to quickly resume the different used models grouping then in tables.

2 Models and Modelling activities description

2.1 Partner 1 (DMI) with Subcontractor 1.3 (DEMA) models

The main objective for DMI (P1) will be to contribute: (WP3) into the validation of the DMI-HIRLAM model analysis and forecasts during urban air pollution episodes in Europe; (WP4) to improve the urban effects and boundary layer parameterisations in the DMI-HIRLAM model with a higher resolution (city-scale version); and (WP5) to develop different elements of an interface from urban NWP to UAP models. General strategy for this work is described in (Baklanov et al., 2002). The improved high-resolution DMI-HIRLAM forecasting will be provided by DMI together with the Danish Emergency Management Agency (DEMA) to demonstrate an emergency preparedness system ARGOS for the target city of Copenhagen (WP8). Therefore the considered dispersion models for FUMAPEX are mostly emergency preparedness models for nuclear or other biological or chemical species.

2.1.1 NWP and other Meteorological Models

Model name: DMI-HIRLAM (several versions, see Fig. 1; see also: dmi.dk, Sass et al., 2002)

Prognostic/Diagnostic: Prognostic

Hydrostatic/non-hydrostatic: Hydrostatic (a non-hydrostatic version is under development by the HIRLAM consortium)

Vertical coordinate system, horizontal grid-type: terrain influenced hybrid vertical co-ordinate; spherical rotated horizontal co-ordinates.

Domain size: five different versions (four nested operational versions (G, N, E, D): from the Northern hemisphere up to the scale of Denmark, see **Figure**

1a; one experimental city-scale version (L): Danish cities (incl. Copenhagen/Øresund area) ~400 km, see **Figure 1b**).

Horizontal and vertical resolution: horizontal resolution: down to 1.4 km, vertical resolution: 40 vertical levels with a highest resolution ~30 m (from 2004 it will be 60 levels).

Spatial resolution of available topography and land-use: the existing version: 1 km resolution database, can be increased up to 250 m.

Used boundary and initial conditions: ECMWF or larger area DMI-HIRLAM forecasts; data assimilation from the WMO GTS observation net and NOAA ATOVS AMSU-A data.

Nesting procedures: separate runs with boundary conditions from a larger area DMI-HIRLAM version or ECMWF model.

For how long time-periods can the model be operated (Forecast length and CPU limitations etc.):

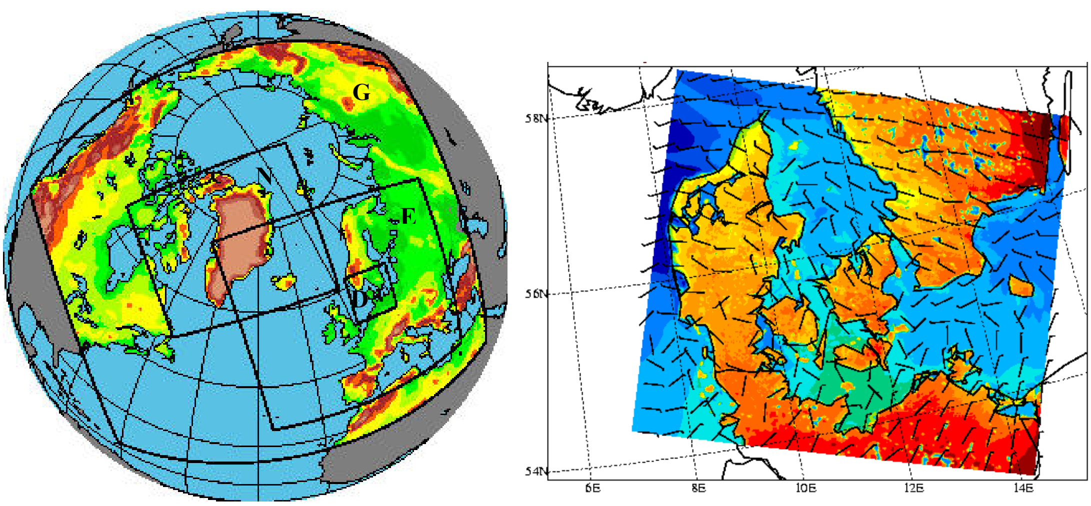
different versions with 18, 36, 54 and 60 hrs forecasts.

Possibilities for assimilations of meteorological observations, and experience with assimilation:

3D-VAR assimilation system.

Briefly name the physical packages used (PBL, Cloud, Radiation and Surface energy schemes etc):

Vertical diffusion: Prognostic turbulent kinetic energy and diagnostic mixing length. Explicit moisture and cumulus clouds: STRACO, cloud microphysics based on Sunquist, convection with moisture convergence closure (modified KUO). Radiation: Fast algorithm based on Savijärvi with separate treatment of SW and LW radiation. Surface: Land and sea. Three soil layers over land. Prognostic equations for snow depth, surface and sub-surface temperature and soil moisture. Analysed SST's over sea (see dmi.dk; Sass et al., 2002; Unden et al., 2002).



a b

Figure 1. DMI-HIRLAM NWP system domains: a) four nested operational versions (G, N, E, D), b) experimental city-scale (1.4 km resolution) version (L) for the Danish territory.

Data format of the meteorological output from the NWP-model: the WMO GRIB format

Platform: Unix

Programming language: FORTRAN

2.1.2 Air Quality Model

For general items:

Models name: The Danish Emergency Response Model of the Atmosphere (DERMA) (Sørensen, 1998; Sørensen et al., 1998, Baklanov and Sørensen, 2001).

Type of model: Lagrangian Puff.

Domain size: any area around the word as given by the NWP model used, but not less than 50 km.

Spatial resolution: the same as the NWP model in use.

Temporal resolution: one hour output resolution, period ~ week(s).

Pollutants: radionuclides (or other biological or chemical species).

Platform: Unix.

Programming language: FORTRAN.

Application: Emergency preparedness.

Emissions: point source type (area and line sources are described by sequences of point sources).

Pollutants and chemistry: : radionuclides (or other biological or chemical species)

Passive/Reactive: active (deposition and radioactive decay are included).

Modelled chemical species: up to e.g. 15 radionuclides (from a list of ~300 nuclides or other biological or chemical species).

Types of reactions considered: radioactive decay, effects of aerosol size distribution.

Meteorological requirements:

Input meteorological variables, specifying their dimensions (1D, 2D or 3D) and time resolution:

3D, currently 1 hourly.

Turbulence and stability parameters (specify if computed internally or needed as input):

Computed internally.

Additionally for the Copenhagen area:

Models name: The Accident Reporting and Guidance Operation System (ARGOS) (Hoe et al., 1999, 2002), which is developed by the Danish Emergency Management Agency (DEMA) and the Prolog Development Center. ARGOS includes the Local-Scale Model Chain (LSMC) (Mikkelsen et al., 1997; Mikkelsen et al., 1984), which is developed at the Risø National Laboratory for local-scale modelling of atmospheric dispersion.

Type of model: Lagrangian Puff dispersion model and linearized Eulerian flow model.

Domain size: any area around the word, less than ~100 km.

Spatial resolution:

Temporal resolution:

Pollutants: radionuclides (or other biological or chemical species).

Platform: PC

Programming language: FORTRAN.

Application: Emergency preparedness.

Emissions: point source type (area and line sources are described by sequences of point sources).

Pollutants and chemistry: : radionuclides (or other biological or chemical species)

Passive/Reactive: active (deposition and radioactive decay are included).

Modelled chemical species: many radionuclides (from a list of ~300 nuclides or other biological or chemical species).

Types of reactions considered: radioactive decay.

Meteorological requirements:

Input meteorological variables, specifying their dimensions (1D, 2D or 3D) and time resolution:

3D or in-situ measurements.

Turbulence and stability parameters (specify if computed internally or needed as input):

Similarity-scaling parameterisation.

For research purposes only:

Models name: the HIRLAM-Tracer model (Chenevez et al., 2002).

Type of model: Eulerian model integrated with the DMI-HIRLAM NWP model.

Domain size: any area around the word, the same as the NWP model in use

Spatial resolution: up to 1.4 km horizontal resolution, and 31–40 vertical levels

Temporal resolution: one hour output resolution, up to ~6 days simulation

Pollutants: any biological or chemical species (chemically passive for the moment).

Platform: UNIX

Programming language: FORTRAN.

Application: Air pollution research.

Emissions: any gridded type.

Pollutants and chemistry: : any gridded type

Passive/Reactive: passive for the moment (deposition, chemical mechanism (RACM) and aerosol model are realised as separate modules, but not included in the model yet).

Modelled chemical species: any biological or chemical species.

Types of reactions considered: radioactive decay.

Meteorological requirements:

Input meteorological variables, specifying their dimensions (1D, 2D or 3D) and time resolution:

on-line integrated with the DMI-HIRLAM NWP modelling system.

Turbulence and stability parameters (specify if computed internally or needed as input):

The CBR turbulence scheme.

<u>Further air pollution models at DMI (not directly used in FUMAPEX):</u>

- The DACFOS modelling system for operational ozone forecasting (Kiilsholm, 2000),
- the Kalman filter model for ozone forecasting (Chenevez and Jensen, 2001),
- the MOON air chemistry model, based on the RACM2 mechanism (Gross, 2000),
- the Cloud Aerosol Chemistry (CAC) model (ELCID report, under development),
- the pollen forecast model (Rasmussen, 2002),
- CFD 3D local-scale model (Baklanov 2000).

2.1.3 Meteorological pre-processors

- LSMC pre-processor (a part of the ARGOS system)
- RODOS met-pre-processor (Mikkelsen et al., 1997)
- Mixing Height calculation methods library (Sørensen et al., 1996; Baklanov, 2001; Ziltinkevich and Baklanov, 2002)
- Interface between the DERMA and ARGOS modelling systems (Sørensen, 2003)

2.1.4 Existing Interface

Name: Integration Interface for the DERMA model - ARGOS System (Sørensen, 2003) and other operation air quality forecast models (e.g., DACFOS). Transport of passive pollutants is on-line integrated into the DMI-HIRLAM model for research purposes.

General purpose interface or tailored on specific models: Emergency preparedness, ozone forecast models.

Meteorological and air quality models names: DMI-HIRLAM and DERMA.

Space interpolation: linear.

Change of coordinate grid system: no.

Meteorological input variables/fields:

3-D: horizontal wind components, temperature, specific humidity,

2-D: precipitation, surface pressure, surface temperature, friction velocity, surface sensible heat flux

Supplementary external variables/fields:

2-D: Land-use classification, roughness, surface geopotential

Variables interpolated or re-estimated (e.g. vertical velocity on a new grid system):

vertical velocity, geopotential heights.

Computed output variables/fields (e.g. dispersion coefficients, wind variances, boundary layer depth):

instantaneous concentration, time-integrated concentration, wet deposition, dry deposition, total deposition.

Platform: UNIX

Programming language: FORTRAN

2.1.5 Exposure Models

Name: The ARGOS system includes an exposure model and a food-chain module for calculation of the radioactive population exposure (Hoe et al., 1999, 2002).

Type: -

Platform: PC.

Programming language: FORTRAN and C++.

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2.2 Partner 2 (DWD) models

2.2.1 NWP models

Model name: LM (Lokalmodell) of DWD, version LM2.19 identical LM3.1 (COSMO) in Feb 03 refer to Quarterly Report of the operational NWP-models of the DWD at www.dwd.de/en/FundE/Veroeffentlichung/Quarterly/Quarterly.htm, further development in the European research consortium COSMO, information and news under www.cosmo-model.org.

Prognostic/Diagnostic: Prognostic

Hydrostatic/non-hydrostatic: non-hydrostatic.

Vertical coordinate system, horizontal grid-type: hybrid terrain-following system (eta co-ord.), operational: 35 layers covering all of the atmosphere, 10 layers in lowest 1500m above model orography, higher resolution tested. Horizontal grid: rotated spherical grid, mesh size 0.0625° (~7km) operational , Arakawa C-grid, higher resolution tested.

Domain size:

Horizontal and vertical resolution:

Spatial resolution of available topography and land-use: mean orography derived from GTOPO30 data set (30''x30'') of USGS, prevailing soil type from DSMdata set (5'x5') of FAO, land-fraction, veg cover, root depth , leaf area index from CORINE data set of ETC/LC (250m). Roughness length from GTOPO30 and CORINE.

Used boundary and initial conditions: initial and boundary values from DWD's operational global model GME.

Nesting procedures: 2way interactive nest model based on LM (of MM5 nesting type) not operational, 1way self-nesting under development.

For how long time-periods can the model be operated (Forecast length and CPU limitations etc.): LM operational for 48h forecast (~ 1h CPU on IBM), longer periods possible.

Possibilities for assimilations of meteorological observations, and experience with assimilation: Continuous data assimilation by nudging, analysis available every hour (DWD's own analysis group), but no participation in FUMAPEX

Briefly name the physical packages used (PBL, Cloud, Radiation and Surface energy schemes etc):

Subgrid scale turbulence;

Surface layer parameterisation;

Grid scale clouds and precipitation;

Longwave and shortwave radiation;

Soil model;

Cumulus paramerisation;

Terrain and surface data.

Data format of the meteorological output from the NWP-model: GRIB files, edition 1.

Platform:

Programming language:

Model name: LLM (LES LM), Herzog et al. (2002) research high resolution LM at the DWD, based on LM1.10 version, driven by local measurements (or LM-derived input data). Under discussion to be used by P8

Prognostic/Diagnostic: Prognostic LES

Hydrostatic/non-hydrostatic: non-hydrostatic.

Vertical coordinate system, horizontal grid-type: hybrid terrain-following system (eta co-ord.). Horizontal grid: rotated spherical grid, Arakawa C-grid.

Domain size:

Horizontal and vertical resolution: 100m horizontal resolution, 15 levels in lowest 200m, 39 layers up to 3km height.

Spatial resolution of available topography and land-use:.

Used boundary and initial conditions:

Nesting procedures:

For how long time-periods can the model be operated (Forecast length and CPU limitations etc.):

Possibilities for assimilations of meteorological observations, and experience with assimilation:

Briefly name the physical packages used (PBL, Cloud, Radiation and Surface energy schemes etc): 3D turb. fluxes of TKE, parameterisation of subgrid-scale (SGS) turbulence after Mason and Brown (1999) : prognostic LES- scheme.

Data format of the meteorological output from the NWP-model: GRIB files, edition 1.

Platform:

Programming language:

2.2.2 Air Quality Model

Dispersion models used operationally at DWD and intended for sensitivity studies of modified met. fields and parameterisations in WP6.1:

Models name: **MUKLIMO (Microscale Urban Climate Model)** (Sievers (1996)

Type of model: Eulerian, 3D stream function/vorticity method, non-hydrostatic.

Domain size: any area around the word as given by the NWP model used, but not less than 50 km.

Spatial resolution: street resolution.

Temporal resolution: only climatological application.

Pollutants: passive tracers.

Platform:

Programming language:

Application: determine reaction of atmospheric variables on changes in model area simulating episodes for climatological expertise.

Emissions:

Pollutants and chemistry: :

Passive/Reactive: passive

Modelled chemical species:

Types of reactions considered:

Meteorological requirements:

Input meteorological variables, specifying their dimensions (1D, 2D or 3D) and time resolution:

Turbulence and stability parameters (specify if computed internally or needed as input):

Models name: **Trajectory model TM**

Type of model: 2nd order accuracy, interpolation 1st order in time, 3rd order in space. Free choice of start levels, traj. fully 3D, on constant model or pressure surfaces.

Domain size:

Spatial resolution: same horizontal and vertical resolution of LM.

Temporal resolution:

Pollutants:

Platform:

Programming language:

Application:

Emissions:

Pollutants and chemistry:

Passive/Reactive:

Modelled chemical species:

Types of reactions considered:

Meteorological requirements:

Input meteorological variables, specifying their dimensions (1D, 2D or 3D) and time resolution: interface using LM-GRIBs.

Turbulence and stability parameters (specify if computed internally or needed as input):

Models name: **Lagrangian Particle Dispersion Model LPDM**

Type of model: Calculation of 105 to 106 trajectories of tracer particles based on LM output data, fully operational interface using LM-GRIBs (mean wind and superimposed turbulent fluctuations (TKE, Monte Carlo method)). Dry and wet deposition, sedimentation, convective mixing, radioactive decay.

Domain size:

Spatial resolution: same horizontal and vertical resolution as LM

Temporal resolution:

Pollutants: passive tracers

Platform:

Programming language:

Application:

Emissions:

Pollutants and chemistry:

Passive/Reactive: passive.

Modelled chemical species:

Types of reactions considered:

Meteorological requirements:

Input meteorological variables, specifying their dimensions (1D, 2D or 3D) and time resolution: interface using LM-GRIBs.

Turbulence and stability parameters (specify if computed internally or needed as input):

2.2.3 Meteorological pre-processors

The following pre-processors used operationally at DWD are intended for sensitivity studies of modified met. fields and parameterisations in WP5

Name: Mixing Height Module MH

Computational scheme (e.g. M-O similarity theory): based on Richardson number approach (gradient Ri no.) deducted from diagnostic turbulence scheme (former LM version) , level 2.5 after Mellor and Yamada (1982), current prognostic LM turb. to be included. Twice daily operational MHs for all LM grid points. Validated research options include different parcel/slab/encroachment methods and mechanical MH according to COST710 final report, WG 2 (Fisher et al.(1998)).

Data requirement (list and features of input data):

List of output variables:

Platform:

Programming language:

Name: Mixing Height Module MH

Computational scheme (e.g. M-O similarity theory): based on Richardson number approach (gradient Ri no.) deducted from diagnostic turbulence scheme (former LM version) , level 2.5 after Mellor and Yamada (1982), current prognostic LM turb. to be included. Twice daily operational MHs for all LM grid points. Validated research options include different parcel/slab/encroachment methods and mechanical MH according to COST710 final report, WG 2 (Fisher et al.(1998)).

Data requirement (list and features of input data):

List of output variables:

Platform:

Programming language:

2.2.4 Existing Interface

General purpose interface or tailored on specific models: fully operational interface between LM and TM.

Meteorological and air quality models names:

Space interpolation:

Change of coordinate grid system:.

Meteorological input variables/fields: use of LM-GRIBs

Supplementary external variables/fields:

Variables interpolated or re-estimated (e.g. vertical velocity on a new grid system):

Computed output variables/fields (e.g. dispersion coefficients, wind variances, boundary layer depth):

Platform:

Programming language:

General purpose interface or tailored on specific models: fully operational interface between LM and LPDM.

Meteorological and air quality models names:

Space interpolation:

Change of coordinate grid system:

Meteorological input variables/fields: use of LM-GRIBs, mean wind and superimposed turbulent fluctuations (TKE, Monte Carlo method).

Supplementary external variables/fields:

Variables interpolated or re-estimated (e.g. vertical velocity on a new grid system):

Computed output variables/fields (e.g. dispersion coefficients, wind variances, boundary layer depth):

Platform:

Programming language:

2.2.5 References

Doms, G., Schättler, U. (1999): The nonhydrostatic limited-area model LM, part1: scientific documentation. R&D Dep. of DWD, 169p.

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Kottmeier, C., Fay, B. (1998): Trajectories in the Antarctic lower troposphere. Jour. Geophys. Res. 103, D9, 10947-10959.

Raschendorfer, M. (1999): The new turbulence parameterization of LM
Quarterly Report of the Operational NWP-Models of the DWD, No 19, 3-12, May 1999

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2.3 Partner 4 (CEAM) models

2.3.1 NWP models

Model name: RAMS (Regional Atmospheric Modeling System) 4.3.0.

Prognostic/Diagnostic: Diagnostic

Hydrostatic/non-hydrostatic: Non-hydrostatic.

Vertical coordinate system, horizontal grid-type: Sigma terrain following coordinate system with Arakawa-C horizontal grid.

Domain size: Nested-grid configuration with four domains centred over the Castellon coastal area (100x100 grids spaced at 40.5, 13.5, 4.5 and 1.5).

Horizontal and vertical resolution:

Horizontal grid lenght of the inner domain, 1.5 km; vertical, 60 levels with geometric streching increased with height to the top located at 14000 m (20 levels in the first 1000 m)..

Spatial resolution of available topography and land-use: 30'' in lat-lon files.

Used boundary and initial conditions: NCEP Reanalysis database. ECMWF is desirable, but currently we do not dispose of this information, could any partner provide it to us?.

Nesting procedures: Four domains nested with a ratio of 3.

For how long time-periods can the model be operated (Forecast length and CPU limitations etc.): with the above configuration we run four days of simulation in three days of CPU time.

Possibilities for assimilation of meteorological observations, and experience with assimilation: Nudging type of four-dimensional data assimilation scheme with observational data. The technique combines the analysis nudging and the observational nudging schemes.

.

Briefly name the physical packages used (PBL, Cloud, Radiation and Surface energy schemes etc): Surface fluxes momentum, heat and water vapour are computed from similarity theory of Louis. Prognosis of energy and moisture in soils layers, vegetation and canopy air. Parameterisation of subgrid mixing is based on Mellor and Yamada which employs a prognostic turbulent kinetic energy. Radiation package is based in Chen and Cotton and the cumulus parameterisation is the modified Kuo parameterisation..

Data format of the meteorological output from the NWP-model: Different options for the output. GRADS format seems to be more workable although VIS5d or ASCII formats are also available

Platform: LINUX.

Programming language: FORTRAN

2.3.2 Air Quality Model

Models name: **HYPACT (Hybrid Particle and Concentration Transport Model).**

Type of model: Hybrid (combines both the Lagrangian and Eulerian dispersion schemes) driven by RAMS NWP model..

Domain size: The model domain can extend from an area as small as an industrial plant site to hundreds of kilometres (up to the size of the RAMS domain)

Spatial resolution: Resolution equal to or greater than the maximum local atmospheric grid resolution.

Temporal resolution: Must be less than or equal to the RAMS analysis file frequency, and greater than or equal to the discrete timestep used to update particle velocities and positions. Time covered by simulations, any (as given by the NWP model).

Pollutants: CO, NO, NO2, NOx, PM10, SO2, etc.

Platform: UNIX/LINUX

Programming language: FORTRAN

Application: HYPACT allows assessment of the impact of one or multiple sources emitted into highly complex local weather regimes, including mountain/valley and complex terrain flows, land/sea breezes, urban areas, and other situations in which the traditional Gaussian-plume based models are know to fail.

Emissions: Sources, species and emission scenarios can either be managed through the namelist, or through database files
Sources can be single or multiple, instantaneous, continuous, or time varying for any of the specified species. Source geometry can include point, line area and volume sources of various orientations. The number of particles released is limited only by available memory.

Pollutants and chemistry: Without chemistry scheme

Passive/Reactive: Passive

Modelled chemical species:

Types of reactions considered:

Meteorological requirements:

Input meteorological variables, specifying their dimensions (1D, 2D or 3D) and time resolution: The 2-D or 3-D wind and turbulence fields are provided by RAMS NWP model for diagnostic applications..

Turbulence and stability parameters (specify if computed internally or needed as input): Computed internally

Models name: **Comprehensive Air Quality Model with Extensions (CAMx) Version 3.1.**

Type of model: 3-D Eulerian.

Domain size: Following NWP model

Spatial resolution: Following NWP model with nesting capability.

Temporal resolution: Following NWP model.

Pollutants: CO, NO, NO_2, O_3, SO_2, VOC.

Platform: LINUX

Programming language: FORTRAN

Application: 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, and aerosol processes. This system constitutes a state-of-the-art tool that allows for integrated assessment of gaseous and particulate air pollution over many scales ranging from urban to regional.

Emissions:

Gridded sources: Low-level Point, Mobile, Area/Non-road Mobile, and Biogenic Area

Non-gridded sources: Elevated Point Sources

Pollutants and chemistry:

Passive/Reactive: Reactive

Modelled chemical species: CB IV (Gery *et al*, 1989) or SAPRC99 (Carter, 2000; Dodge, 2000).

Types of reactions considered: gas-phase, aerosols.

Meteorological requirements:

Input meteorological variables, specifying their dimensions (1D, 2D or 3D) and time resolution: 3-D: Winds, Temperatures, Pressure, Water Vapor, Cloud Cover, and Rainfall.

Turbulence and stability parameters (specify if computed internally or needed as input): Vertical Diffusivity needed as input.

2.3.3 Meteorological pre-processors

This will be defined as soon as possible (as the photochemical model).

2.3.4 Existing Interface

General purpose interface or tailored on specific models: fully operational interface between RAMS and HYPACT

General purpose interface or tailored on specific models: generates CAMx meteorological input files from RAMS output files.

Meteorological and air quality models names: RAMS and CAMx.

Space interpolation: State variables (temperature, moisture, and cloud cover) are located at the cell center (horizontal and vertical). Vertical diffusion is also carried at horizontal cell center but on the vertical layer interfaces.

Wind components are carried at the horizontal cell interfaces. Wind components *u* and *v* are staggered from each other.

Change of coordinate grid system: Arakawa-C grid , no change between models.

Meteorological input variables/fields:

Supplementary external variables/fields:

Variables interpolated or re-estimated (e.g. vertical velocity on a new grid system):

Computed output variables/fields (e.g. dispersion coefficients, wind variances, boundary layer depth): Vertical Diffusivity

Platform: LINUX

Programming language: FORTRAN

2.3.5 References

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. Journal of Geophysical Research, 94, 925-956.

Carter, W.P.L., 2000. Programs and Files Implementing the SAPRC-99 Mechanism and its Associates Emissions Processing Procedures for Models-3 and Other Regional Models. January 31, 2000.

Dodge, M.C., 2000. Chemical oxidant mechanisms for air quality modeling: critical review. Atmospheric Environment, 34, no. 12-14, 2103-2130

2.4 Partner 6 (FMI) models

2.4.1 NWP models

Model name: HIRLAM (Finnish version).

Prognostic/Diagnostic: Prognostic

Hydrostatic/non-hydrostatic: The HIRLAM reference version maintained by the international HIRLAM project is hydrostatic. HIRLAM version 4.6.2 is hydrostatic; it has been in operative use since November 15th, 1999. HIRLAM version 5.2 is also hydrostatic; this new HIRLAM version will be taken into operative use in spring 2003.

Within the international HIRLAM project, a non-hydrostatic version has been developed, based on code written in Tartu university (Rõõm, 2001). The nonhydrostatic code is also available for FMI.

Vertical coordinate system, horizontal grid-type: Hybrid-vertical coordinate system. In both FMI versions, horizontal grid-type is staggered Arakawa-C-grid and implementation is a rotated coordinate with south pole at longitude/latitude 0/-30°.

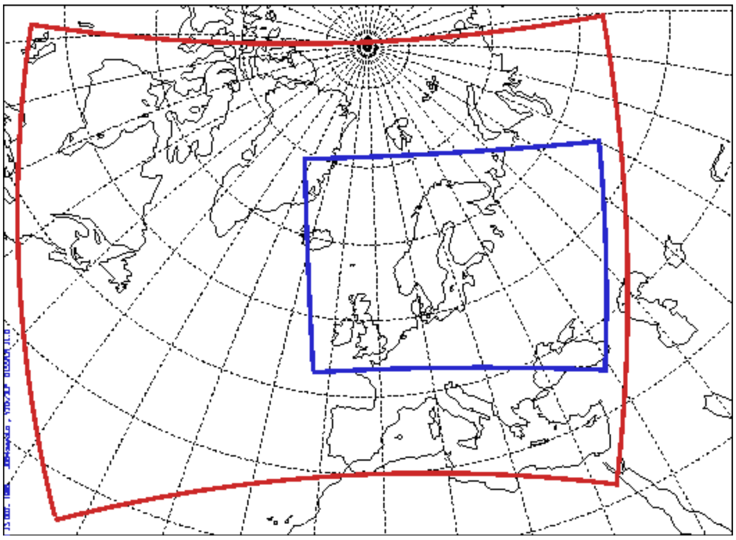

Figure 1. Approximate model domains used for the HIRLAM versions ENO 4.6.2 (smaller) and ATA 4.6.2 (larger) (Eerola 2000). The domain of the latest reference version 5.2 is approximately the same as the larger domain shown in the figure.

Domain size: see **Figure 1**.

Horizontal and vertical resolution:

Horizontal resolution (version 4.6): ATA (0,4o) 44 km and ENO (0,2 o) 22 km

Horizontal resolution (version 5.2): (0,3 o) 33 km

Vertical resolution (version 4.6): ATA and ENO 31 layers

Vertical resolution (version 5.2): 40 layers

.

Spatial resolution of available topography and land-use: Orography height derived from the GTOPO30" data base. Other physiography fields are based on several data bases with variable resolutions.

Used boundary and initial conditions: In the operational implementation a Davies-Kållberg relaxation scheme is applied for the staggered grid used. ECMWF lateral boundary fields are used for the largest integration area.

Nesting procedures:

For how long time-periods can the model be operated (Forecast length and CPU limitations etc.): Operational model is integrated to +54 hours.

Possibilities for assimilations of meteorological observations, and experience with assimilation:

Version 4.6: optimal interpolation with normal model initialization

Version 5.2: Three-dimensional variational data assimilation with digital filter initialization

.

Briefly name the physical packages used (PBL, Cloud, Radiation and Surface energy schemes etc):

HIRLAM version 4.6.2

PBL: turbulence based on TKE and a diagnostic length scale

Clouds and condensation: microphysics using cloud condensate as a prognostic variable (modified Sundqvist scheme), convection based on Kuo-type closure

Radiation: fast radiation scheme with LW and SW radiation handled separately based on (Savijärvi, 1990)

Surface: Hirlam simple surface parametrization scheme (Eerola 2000)

HIRLAM version 5.2

PBL: turbulence based on TKE and a diagnostic length scale (Cuxart et al, 2000)

Clouds and condensation: microphysics using cloud condensate as a prognostic variable (modified Sundqvist scheme), convection based on Kuo-type closure (Sundqvist et al., 1989, Kuo 1974)

Radiation: fast radiation scheme with LW and SW radiation handled separately based on Savijärvi, 1990

Surface: ISBA scheme with five surface subtypes in each grid square (Navascués et al., 2002)

.

Data format of the meteorological output from the NWP-model: Grib-format

Platform:

Programming language:

2.4.2 Air Quality Model

General:

Models name: CAR-FMI and OSPM

Described at http://www.fmi.fi/research_air/air_14.html and European Topic Center, Model Documentation System.

UDM-FMI

http://www.fmi.fi/research_air/air_13.html

MATCH (Mesoscale Atmospheric Transport and Chemistry Model)

http://www.smhi.se/sgn0104/miljo/match/match.htm

2.4.3 Meteorological pre-processors

Name: MPP-FMI

http://www.fmi.fi/research_air/air_12.html

2.4.4 Existing Interface

Brief description of the interface of to the NWP-model.

CAR-FMI is linked to HIRLAM through FMI:s RealTime database querydata interface and metPostProc program which deals with the following issues:
Meteorological data reading.
Conversion of cumulative values to instant values (for example heat and momentum fluxes).
Calculation of atmospheric boundary layer parameters not provided (for example Monin-Obukhov mixing depth).
Construction of meteorological time-series for CAR-FMI

2.4.5 Exposure Models

Name: EXPAND.

Kousa, Anu, Jaakko Kukkonen, Ari Karppinen, Päivi Aarnio, Tarja Koskentalo, 2002. A model for evaluating the population exposure to ambient air pollution in an urban area. Atmospheric Environment **36**, pp. 2109-2119.

Kousa, Anu, 2002. PM2.5 and NO2 exposure assessment of urban population in the Helsinki metropolitan area and other European urban areas. University of Helsinki, Academic Dissertation, Faculty of Science, Department of Physical Sciences. http://ethesis.helsinki.fi/julkaisut/mat/fysik/vk/kousa/

.

Platform:

Programming language:

2.4.6 References

Cuxart, J., P. Bougeault, and J. L. Redelsberger, 2000: A turbulence scheme allowing for mesoscale and large-eddy simulations. Quart. J. Roy. Met. Soc., 126, 1 30.

Berge, E., Karppinen, A., Kukkonen, J., Køltzow, M.Ø., Slørdal, L.H., 2002. Simulations of wintertime inversions in northern European cities by use of NWP-models. In: Piringer, M. and Kukkonen, J. (eds.), Proceedings of the workshop 3 and 4 October 2001, Toulouse, France. COST Action 715, EUR 20451, European Commission, Brussels, pp. 75 - 88.

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

Fisher, B E A, J. Kukkonen and M. Schatzmann, 2001. Meteorology applied to urban air pollution problems COST 715. International Journal of Environment and Pollution, Vol. 16, Nos. 1-6.

Karppinen, A, J. Kukkonen, T. Elolähde, M. Konttinen, T. Koskentalo and E. Rantakrans, 2000. A modelling system for predicting urban air pollution, Model description and applications in the Helsinki metropolitan area. Atmos. Environ. 34-22, pp 3723-3733.

Karppinen, A, J. Kukkonen, T. Elolähde, M. Konttinen and T. Koskentalo, 2000. A modelling system for predicting urban air pollution, Comparison of model predictions with the data of an urban measurement network. Atmos. Environ. 34-22, pp 3735-3743.

Karppinen, A., S. M. Joffre and J. Kukkonen, 2000. The refinement of a meteorological preprocessor for the urban environment. International Journal of Environment and Pollution, Vol. 14, Nos. 1-6, pp. 565-572.

Karppinen, A., Härkönen, J., Kukkonen, J., Aarnio, P. and Koskentalo, T., 2002. Statistical model for assessing the portion of fine particulate matter transported regionally and long-range to urban air. Scandinavian Journal of Work, Environment & Health, 24 , (in print).

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Kousa, A., J. Kukkonen, A. Karppinen, P. Aarnio, T. Koskentalo, 2001. Statistical and diagnostic evaluation of a new-generation urban dispersion modelling system against an extensive dataset in the Helsinki Area. Atmos. Environ., Vol 35/27, pp 4617-4628.

Kousa, Anu, Jaakko Kukkonen, Ari Karppinen, Päivi Aarnio, Tarja Koskentalo, 2002. A model for evaluating the population exposure to ambient air pollution in an urban area. Atmospheric Environment 36, pp. 2109-2119.

Kuo, H. L., 1974: Further Studies of the Parameterization of the Influence of Cumulus Convection on Large-Scale Flow. J. Atm. Sci., 31, 1232-1240.

Kukkonen, Jaakko, Esko Valkonen, Jari Walden, Tarja Koskentalo, Ari Karppinen, Ruwim Berkowicz and Raimo Kartastenpää, 2000. Measurements and modelling of air pollution in a street canyon in Helsinki. Environmental Monitoring and Assessment 65 (1/2):371-379.

Kukkonen, Jaakko, Esko Valkonen, Jari Walden, Tarja Koskentalo, Päivi Aarnio, Ari Karppinen, Ruwim Berkowicz and Raimo Kartastenpää, 2001. A measurement campaign in a street canyon in Helsinki and comparison of results with predictions of the OSPM model. Atmos. Environ. 35-2, pp 231-243.

Kukkonen, Jaakko, Jari Härkönen, Jari Walden, Ari Karppinen and Kaisa Lusa, 2001. Evaluation of the dispersion model CAR-FMI against data from a measurement campaign near a major road. Atmos. Environ. 35-5, pp. 949-960.

Kukkonen, Jaakko, Jari Härkönen, Ari Karppinen, Mia Pohjola, Harri Pietarila and Tarja Koskentalo, 2001. A semi-empirical model for urban PM10 concentrations, and its evaluation against data from an urban measurement network. Atmos. Environ. 35, pp. 4433-4442.

Kukkonen, Jaakko, Jari Härkönen, Jari Walden, Ari Karppinen and Kaisa Lusa, 2001. Validation of the dispersion model CAR-FMI against measurements near a major road. International Journal of Environment and Pollution, Vol. 16, Nos. 1-6.

Kukkonen, J., Partanen, L., Karppinen, A., Walden, J., Kartastenpää, R., Aarnio, P., Koskentalo, T. and Berkowicz, R., 2003. Evaluation of the OSPM model combined with an urban background model against the data measured in 1997 in Runeberg Street, Helsinki. Atmospheric Environment 37 (8), pp. 1101-1112.

Navascués, B., Ayuso J., J. and Rodríguez, E., 2002. The new HIRLAM surface analysis. SRNWP/HIRLAM Workshop on Surface Processes, Turbulence and Mountains Effects. Instituto Nacional de Meteorologia, Madrid 22-24 October 2001. HIRLAM Workshop Report, January 2002, pp. 37-44.

Piringer, M. and Kukkonen, J. (eds.), 2002. "Mixing height and inversions in urban areas", Proceedings of the workshop 3 and 4 October 2001, Toulouse, France. COST Action 715, EUR 20451, European Commission, Brussels, 113 pp.

Pohjola, M A, Pirjola, L, Kukkonen, J, Kulmala, M. 2003. Modelling of the influence of aerosol processes for the dispersion of vehicular exhaust plumes in street environment. Atmospheric Environment 37 (3), pp. 339-351.

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

Savijärvi, H., 1990: Fast radiation parameterization schemes for mesoscale and short-range forecast models. J. Appl. Meteor., 29, 437-447.

Sundqvist, H., E. Berge, and J. E. Kristjánsson, 1989: Condensation and Cloud Parameterization Studies with a Mesoscale Numerical Weather Prediction Model. Mon. Wea. Rev., 117, 1641-1657.

Sokhi, R.S., Luhana, L., Kukkonen, J., Berge, E., Slördal, L.H. and Finardi, S., 2002. Analysis of Air Pollution Episodes in European Cities. In: Piringer, M. and Kukkonen, J. (eds.), Proceedings of the workshop 3 and 4 October 2001, Toulouse, France. COST Action 715, EUR 20451, European Commission, Brussels, pp. 65 - 74.

Tiitta, P., T. Raunemaa, J.Tissari, T. Yli-Tuomi, A. Leskinen, J. Kukkonen, J. Härkönen and A. Karppinen, 2002. Measurements and Modelling of PM2.5 Concentrations Near a Major Road in Kuopio, Finland. Atmospheric Environment 36, pp. 4057-4068.

Öttl, D., J. Kukkonen, R.A. Almbauer, P.J. Sturm, M. Pohjola and J. Härkönen, 2001. Evaluation of a Gaussian and a Lagrangian model against a roadside dataset, with focus on low wind speed conditions. Atmos. Environ. 35, pp. 2123-2132.

2.5 Partner 7 (ARIANET) and Partner 14 (ARPAP) models

2.5.1 NWP models

Model name: RAMS (Regional Atmospheric Modeling System) Version 4.4 (Pielke et al., 1992; Walko and Tremback, 2002)

Prognostic/Diagnostic: Prognostic

Hydrostatic/non-hydrostatic: Non-hydrostatic.

Vertical coordinate system, horizontal grid-type: Sigma terrain following coordinate system(also called z*) with Arakawa-C horizontal grid.

Domain size: Optional. For FUMAPEX application nested-grid configuration with two target domains (**Figure 2**)centred over Turin city (40x40 km^2) and Piedmont Region (212x276 km^2). A larger outer domain will be defined to optimise the connection with the larger scale driving model.

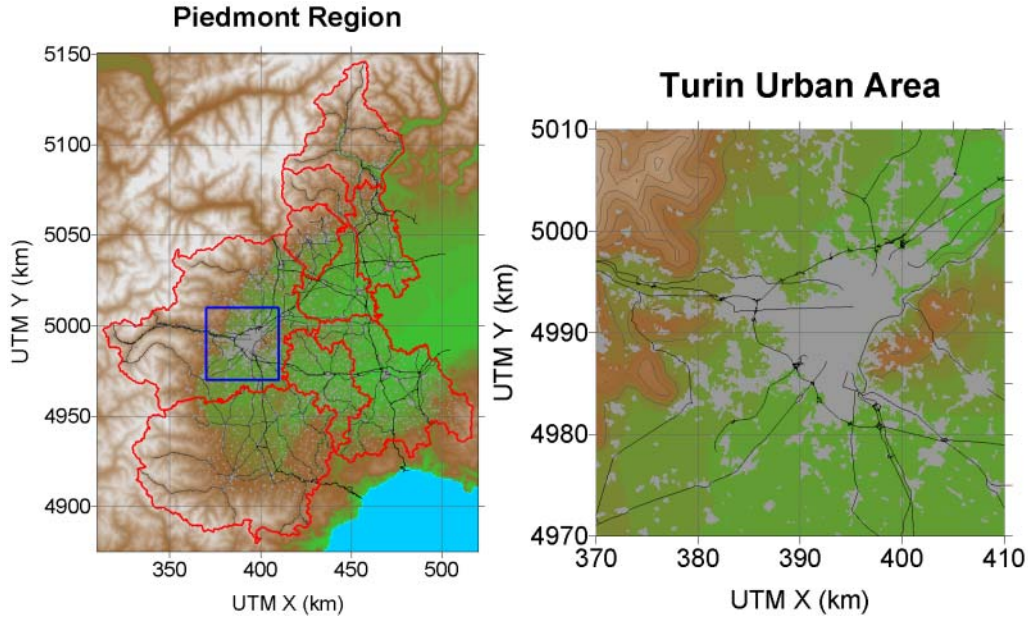

Figure 2. Model computational do mains covering Piedmont Region (left) and Turin city area (right).

Horizontal and vertical resolution:

Optional. Horizontal grid spacing will be respectively 1, 4 and 16 km for the three nested grids. 30 vertical levels with geometric stretching increased with height.

Spatial resolution of available topography and land-use: topography is available with 5"*7.5" resolution over Italy and 30'' (GTOPO30 database) elsewhere. Land-use is available with 250 m resolution over EU countries+Switzerland and 30" (GLCC database) elsewheres.

Used boundary and initial conditions: ECMWF Analyses/Forecasts. Lokal Modell, to be implemented. The operational forecasts of the Italian version of Lokal Modell (LAMI) will be made available by the Regional Weather Forecast Service of Piedmont Region. The main features of LAMI are described in section 2.6.

Nesting procedures: Two way nesting.

For how long time-periods can the model be operated (Forecast length and CPU limitations etc.): Optional, limited by available computer resources and boundary driving information. For Turin application 48 hours simulation is foreseen.

Possibilities for assimilation of meteorological observations, and experience with assimilation: Nudging type of four-dimensional data assimilation scheme with observational data. The nudging is based on 3D fields produced by RAMS Isentropic Analysis (ISAN) pre-processor.

Briefly name the physical packages used (PBL, Cloud, Radiation and Surface energy schemes etc): Surface fluxes momentum, heat and water vapour are computed from similarity theory of Louis. Prognosis of energy and moisture in soils layers, vegetation and canopy air. Parameterisation of sub-grid mixing is based on Mellor and Yamada 2.5 scheme. Radiation package is based in Chen and Cotton work and the cumulus convection parameterisation is a modified Kuo parameterisation.

Data format of the meteorological output from the NWP-model: RAMS specific portable coded ASCII format. Extraction of selected variables from the standard output file to different formats (e.g. GRADS, VIS5d, or user defined format) can be performed with RAMS post processor.

Platform: LINUX.

Programming language: FORTRAN 90

2.5.2 Air Quality Model

General:

Models name: FARM (Flexible Air quality Regional Model) (Silibello and Calori, 2003).

Type of model: FARM is an Eulerian model that accounts for the transport, chemical conversion and deposition of atmospheric pollutants. The code has been originally derived from STEM-II (Carmichael et al., 1991;). A nested grid version supporting PMI parallel computation is currently under development.

Domain size: Optional. Horizontal domains coincident with the meteorological driver domains (Figure 2).

Spatial resolution: Optional. Horizontal resolution chosen to minimise grid differences with the meteorological driver. It has been applied with horizontal resolutions down to 1x1 km^2. Terrain following stretched vertical grid system. Variable vertical resolution.

Temporal resolution: Usually applied with hourly averaged meteorological and emission input data. The computational time-step is defined by advection/diffusion and chemical reaction computation needs.

Pollutants: SO2, CO, NO, NO2, O_3, VOC, PM_{10}, $PM_{2.5}$ and others (see *modeled chemical species* for details)

Platform: PC (WINDOWS), LINUX.

Programming language: FORTRAN77, FORTRAN90.

Application: Regional and Urban scale photochemical episodes analysis (Calori et al., 1998; Silibello et al., 2001).

Emissions: FARM can consider time-varying (normally specified on hourly basis) emissions, from both diffuse (specified on a regular grid) and point sources (related to individual stacks).

Pollutants and chemistry: FARM models transport and diffusion, transformation of chemical species by gas- and aerosol-phase chemistry, dry and wet removal of pollutants.

Passive/Reactive: Reactive.

Modelled chemical species: The number of species depends on the activated chemical mechanism (see below) e.g. 51 species are considered if the SAPRC-90 scheme is used.

Types of reactions considered: FARM model can be configured with the following different gas-phase chemical mechanisms: SAPRC-90, SAPRC-99, CBM-IV/99. Such schemes have been implemented using the Flexible Chemical Mechanism (FCM) software (Kumar et al., 1995).

Meteorological requirements:

Input meteorological variables, specifying their dimensions (1D, 2D or 3D) and time resolution:

Data: 3D gridded hourly values of pressure, temperature, humidity (optionally water vapour and liquid water content), wind speed and direction. 2D hourly values of precipitation, cloud cover, cloud bottom heigh. For diagnostic calculations the required wind and temperature fields can be produced with the mass consistent model MINERVE (Aria Tec., 2002).

Turbulence and stability parameters (specify if computed internally or needed as input).

Stability: 3D gridded hourly values of horizontal and vertical diffusivities. For diagnostic calculations or in case only average quantities fields are available the dispersion parameters can be evaluated by the meteorological pre-processor SURFPRO (Silibello, 2002)

2.5.3 Meteorological pre-processors

Name: SURFPRO (SURrface-atmosphere interFace PROcessor)

Pre-processor for air pollution models. Starting from topography, land-use and gridded standard meteorological data, it provides gridded fields of turbulence scaling parameters as well as 3D fields of horizontal and vertical diffusivities and 2D fields of deposition velocities for a given set of chemical species. It can take into account water bodies and terrain slopes.

Computational scheme (e.g. M-O similarity theory): M-O similarity theory (Holtslag and van Ulden, 1983; Hanna et al., 1985; Paine, 1988; Scire et al., 1998, Scire et al., 1990).

Data requirement (list and features of input data):

1) geo-referenced topography and land-use (2D fields);
2) wind speed and direction (3D field);
3) air temperature (3D field);
4) relative humidity (3D field);
5) precipitation (2D field);
6) surface pressure (2D field);
7) global radiation (1D), optional;
8) net radiation (1D), optional;
9) sea (lake) surface temperature (1D), if needed;

10) snow cover flag, optional;
11) climate index (dry/normal/wet), optional.

List of output variables: 2D/3D gridded fields of the variables described in the following table

Output Variables

Variable	**Units**
roughness lenght	m
Albedo	
Bowen ratio	
leaf area index	
anthropogenic heat flux	W m^{-2}
soil heat flux parameter	
total radiation	W m^{-2}
net radiation	W m^{-2}
sensible heat flux	W m^{-2}
friction velocity	m s^{-1}
Monin-Obukhov lenght	m
convective scale velocity	m s^{-1}
mixing height	m
PGT stability class	{1 .. 6}
horiz. and vertical diffusivities	m2 s^{-1}
deposition velocities of selected species	m s^{-1}

Platform: PC (WINDOWS), LINUX.

Programming language: FORTRAN 77, FORTRAN 90

2.5.4 Existing Interface

General purpose interface or tailored on specific models: Meteorological pre-processor interface to connect a prognostic meteorological model output to meet the input requirements of an Eulerian photochemical. Taylored on RAMS and FARM (Silibello et al., 2001).

Meteorological and air quality models names: RAMS and FARM.

Space interpolation: The two models can operate on the same horizontal grid system (rotated polar stereographic coordinates) but they use different vertical coordinates. Interpolation are performed in vertical.

Change of coordinate grid system:

Horizontally: none.

Vertically: From a normalized sigma_z in RAMS to a pure terrain following coordinate system in FARM.

Meteorological input variables/fields:

3-D: Horizontal wind components, temperature, relative humidity, horizontal and vertical diffusivities

2-D: Precipitation, cloud cover, surface pressure

Supplementary external variables/fields:

2-D: topography, land-use classification

Variables interpolated or re-estimated (e.g. vertical velocity on a new grid system):

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

Computed output variables/fields (e.g. dispersion coefficients, wind variances, boundary layer depth):

Direct use of modelled and parameterised meteorological variables from the meteorological model. Unavailable or non effective variables have to be substituted with alternative parameterisations (e.g. horizontal diffusivities or dry deposition velocities). The development of this task is expected from FUMAPEX ativities.

Platform: PC (Windows) or LINUX

Programming language: FORTRAN

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2.6 Partner 8 (ARPA-SMR) models

2.6.1 NWP models

Model name: **Lokal Modell - LAMI**.

Prognostic/Diagnostic: Prognostic

Hydrostatic/non-hydrostatic: Non-hydrostatic

Vertical coordinate system: hybrid sigma coordinate, normalized with "standard" pressure in order to obtain levels of constant-height.

Horizontal grid type: rotated spherical grid.

Domain size: present operational domain covers Italy and central Mediterranean (1900 x 1600 km).

Horizontal and vertical resolution: operational mesh size 0.0625° (~7km), Arakawa C-grid, 35 layers covering all of the atmosphere (10 layers in lowest 1500m).

Spatial resolution of available topography and land-use: mean orography derived from GTOPO30 dataset (30" x 30") of USGS; land use and other soil parameters from Corine data set of ETC/LC (250 m).

Used boundary and initial conditions: initial and boundary values from DWD's operational global model GME; non-operational option to use ECMWF model output.

Nesting procedures: 1-way self nesting.

For how long time-periods can the model be operated (Forecast length and CPU limitations etc.):

presently operational for 72h forecast (~ 1h CPU on IBM SP4).

Possibilities for assimilation of meteorological observations, and experience with assimilation:

operational continuos data assimilation by nudging of GTS plus some Italian local data.

Briefly name the physical packages used (PBL, Cloud, Radiation and Surface energy schemes etc):

Grid scale clouds and precipitation: cloud water condensation/evaporation by saturation adjustment; bulk parameterisation for precipitation formation; optional cloud ice scheme.

Cumulus paramerisation: mass-flux convection scheme (Tiedke)

Radiation: δ-two stream radiation scheme (after Ritter and Geleyn); cloud-radiation feedback.

Subgrid scale turbulence: diagnostic K-closure at hierarchy level 2; optional level 2.5 scheme with prognostic TKE

Surface layer parameterisation: constant flux layer parameterisation; optional scheme with laminar-turbulent roughness layer

Soil model: 3 layers model, including transpiration, snow and interception storage.

Data format of the meteorological output from the NWP-model: GRIB files.

Platform: Unix

Programming language: Fortran 90

2.6.2 Air Quality Model

General:

Models name: OLMO (Ozone Linear MOdel) (documentation available at: http://www.arpa.emr.it/smr/Sapernedipiu/ozono.asp, forecasts daily available during summer period at: http://www.arpa.emr.it/ozono/).

Type of model: statistical (linear regression).

Domain size: 11 points (including a point on the target city Bologna) over a ≈240*120km area.

Spatial resolution: 1D model.

Temporal resolution: in the present version, the model forecasts ozone daily maxima for days d+1 and d+2.

Pollutants: O_3.

Platform: Unix.

Programming language: FORTRAN.

Application: daily ozone forecasts during summer period for population information purposes.

Emissions: no emissions.

Pollutants and chemistry:

Passive/Reactive: “implicit” chemistry (statistical model).

Modelled chemical species: O_3.

Types of reactions considered: no reactions (statistical model).

Meteorological requirements:

Input meteorological variables, specifying their dimensions (1D, 2D or 3D) and time resolution:

in the present version (2002), forecasted daily T_{MAX} over several station-points (1D).

Turbulence and stability parameters (specify if computed internally or needed as input):

in the present version, no turbulence and stability parameter needed.

Models name: PIOPPO (Pm10 Pollution POlynomial model) (forecasts daily available during winter period at: http://www.liberiamolaria.it/previsioni.asp).

Type of model: statistical (linear regression).

Domain size: 13 points (including a point on the target city Bologna) over a ≈240*120km area.

Spatial resolution: 1D model.

Temporal resolution: in the present version, the model forecasts PM_{10} daily averages for days d+0, d+1 and d+2.

Pollutants: PM_{10}.

Platform: Unix.

Programming language: FORTRAN.

Application: daily PM_{10} forecasts during winter period for population information purposes.

Emissions: no emissions.

Pollutants and chemistry:

Passive/Reactive: “implicit” chemistry (statistical model).

Modelled chemical species: PM_{10}.

Types of reactions considered: no reactions (statistical model).

Meteorological requirements:

Input meteorological variables, specifying their dimensions (1D, 2D or 3D) and time resolution:

in the present version (2002), forecasted daily T_{MIN}, wind velocity and total precipitation over several station-points (1D).

Turbulence and stability parameters (specify if computed internally or needed as input):

in the present version, no turbulence and stability parameter needed.

Models name: ADMS-Urban.

Type of model: Three dimensional quasi-Gaussian model nested within a trajectory model.

Domain size: urban area.

Spatial resolution: 500*500 m.

Temporal resolution: resolution 1 hour, covered period 1 year.

Pollutants: SO_2, CO, NO_2, NO, PM_{10}, TSP, VOC, benzene, any passive/generic.

Platform: PC.

Programming language: FORTRAN.

Application: Long term urban air quality assessment and scenario analysis taking into account the full range of emission source types including: road traffic, industrial, commercial and domestic emissions.

Emissions: Sources can be single or multiple, continuous, or time varying for any of the specified species. Source geometry can include point, line, area and volume sources.

Pollutants and chemistry:

Passive/Reactive: Reactive.

Modelled chemical species: Generic Reaction Scheme (NO_X, O_3, VOC).

Types of reactions considered: Dry.

Meteorological requirements:

Input meteorological variables, specifying their dimensions (1D, 2D or 3D) and time resolution:

Hourly 1-d wind and reciprocal of Monin-Obukhov length.

Turbulence and stability parameters (specify if computed internally or needed as input):

Computed internally.

Models name: CALGRID.

Type of model: Eulerian.

Domain size: Regional domain, 450*370 km over the Po valley.

Spatial resolution: 5 Km and 11 vertical levels.

Temporal resolution: 1 hour, 1 year.

Pollutants: O_3, NO, NO_2, VOCs, SO_2, other photochemical pollutants.

Platform: Unix.

Programming language: FORTRAN.

Application: Simulation of reactive pollutants dispersion and transformation on regional scale.

Emissions: Emissions are provided, for each emitted species, as mass per time unit for every grid cell for the area sources and for every stack for point sources.

Pollutants and chemistry:

Passive/Reactive: Reactive.

Modelled chemical species: SAPCR90.

Types of reactions considered: Dry photochemical.

Meteorological requirements:

Input meteorological variables, specifying their dimensions (1D, 2D or 3D) and time resolution:

Hourly 3-d wind and temperature fields.

Turbulence and stability parameters (specify if computed internally or needed as input):

Hourly 2-d fields of Mixing height, Monin-Obukhov length (L), PGT class, friction velocity (u*), convective scale velocity (w*).

2.6.3 Meteorological pre-processors

Name: CALMET-SMR (Deserti et al. 2001)

Computational scheme (e.g. M-O similarity theory): Holtslag & Van Ulden scheme

Data requirement (list and features of input data):

T and horizontal wind profiles (at least 1 profile every 12h); surface data: T, wind, total and low cloud cover, cloud types, relative humidity, precipitation, surface pressure

List of output variables: 3D fields of: 3D wind and temperature; 2D fields of: mixing height, Monin-Obukhov length, friction velocity, convective velocity scale, Pasquill-Gifford stability classes

Platform: Unix

Programming language: FORTRAN

2.6.4 Existing Interface

General purpose interface or tailored on specific models: interface tailored on specific models.

Meteorological and air quality models names: fully operational interface between LM and OLMO

Space interpolation: no interpolation, just point extractor.

Change of coordinate grid system:

Meteorological input variables/fields:

in the upgraded version 2003: wind and precipitation.

Supplementary external variables/fields:

temperature calculated by a Kalman filter, using ECMWF forecasts and observations (Cacciamani – de Simone, 1992)

Variables interpolated or re-estimated (e.g. vertical velocity on a new grid system):

Computed output variables/fields (e.g. dispersion coefficients, wind variances, boundary layer depth):

Platform: UNIX.

Programming language: FORTRAN

General purpose interface or tailored on specific models: interface tailored on specific models.

Meteorological and air quality models names: fully operational interface between LM and PIOPPO

Space interpolation: no interpolation, just point extractor.

Change of coordinate grid system:

Meteorological input variables/fields: wind and precipitation.

Supplementary external variables/fields:

temperature calculated by a Kalman filter, using ECMWF forecasts and observations (Cacciamani – de Simone, 1992)

Variables interpolated or re-estimated (e.g. vertical velocity on a new grid system):

Computed output variables/fields (e.g. dispersion coefficients, wind variances, boundary layer depth):

Platform: UNIX.

Programming language: FORTRAN

Meteorological and air quality models names: meteorological pre-processor CALMET and Eulerian 3D model CALGRID are fully compatible

2.6.5 References

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2.7 Partner 9 (met.no) and Partner 10 (NILU) models

2.7.1 NWP models

Model name: **MM5** (Dudhia et al. (1993), Grell et al. (1994), see also http://www.mmm.ucar.edu/mm5/).

Prognostic/Diagnostic: Prognostic

Hydrostatic/non-hydrostatic: Non-hydrostatic

Vertical coordinate system, horizontal grid-type: Normalized pressure (sigma) in the vertical, polar stereographic projection in the horizontal, Arakawa B-staggering of the horizontal wind.

Domain size: Optional. Presently for the Oslo application (see Berge et al., 2002, Berge and Køltzow, 2002): 231 km * 198 km outer nest, 77 km * 66 km inner nest.

Horizontal and vertical resolution: Optional. Presently 3 km and 1 km for outer and inner nest for Oslo application. 17 layers in the vertical. It is not recommended to use less than 0.5 km resolution.

Spatial resolution of available topography and land-use: 0.5 km * 0.9 km at 60°N.

Used boundary and initial conditions: HIRLAM and ECMWF analysis and/or prognosis.

Nesting procedures: Two-ways nesting.

For how long time-periods can the model be operated (Forecast length and CPU limitations etc.):

Optional, but limited by available computer resources and boundary fields. For the Oslo application 48 hours simulations following the output of HIRLAM10 is used. Simulations up to 10 days using ECMWF would in principle be possible.

Possibilities for assimilations of meteorological observations, and experience with assimilation:

Assimilation package available with MM5, but it has not yet been tested by met.no.

Briefly name the physical packages used (PBL, Cloud, Radiation and Surface energy schemes etc):

Present Oslo application:

PBL: MRF-scheme (Hong and Pan, 1996), GSPBL-scheme (Ballard 1991, Shafran, 2000).

Explicit moisture: Simple ice (Dudhia, 1993),

No cumulus cloud scheme employed due to fine horizontal resolution.

Radiation: Cloud radiation scheme (see Dudhia, 1993, Grell et al. 1994).

Surface scheme: Five layer soil model Dudhia (1996).

Data format of the meteorological output from the NWP-model: GRIB, MM5 specific format, met.no specific format

Platform: Most computers, Workstations, Linux PC's, Supercomputers with MPP

Programming language: FORTRAN

Model name: **HIRLAM** (Kallén, 1996, Undén, 2002), see also http://www.met.no).

Prognostic/Diagnostic: Prognostic

Hydrostatic/non-hydrostatic: Hydrostatic

Vertical coordinate system, horizontal grid-type: Terrain following (sigma) with gradually transition to pressure in the vertical, spherical rotated horizontal coordinates, Arakawa C grid, staggering of the wind.

Domain size: Optional. Presently one version with 10 km resolution (HIRLAM10) covering NW Europe is used to drive the MM5 model in an operational environment. A 5 km version is also run for southern Norway.

Horizontal and vertical resolution: Optional. Presently 10 km and 5 km. 31 layers in the vertical. It is not recommended to use less than approximately 10 km resolution in complex topography and during rigorous convection due to non-hydrostatic effects.

Spatial resolution of available topography and land-use: Topography and land-use (fraction of land, fraction of lakes, fraction of sea ice, fraction of bare land, fraction of low vegetated land, fraction of forest) derived from databases with data in horizontal resolution 30" (approximately 0.9km).

Used boundary and initial conditions: Presently HIRLAM50 (50km resolution) provides boundary conditions for the 10 km version. Within short time ECMWF forecasts will be used directly on the boundaries.

Nesting procedures: One-way nesting.

For how long time-periods can the model be operated (Forecast length and CPU limitations etc.):

Optional, but limited by available computer resources and boundary fields. Presently run up to 60 hours.

Possibilities for assimilations of meteorological observations, and experience with assimilation:

Assimilation employed by HIRLAM 3D-variational system for variables in the free atmosphere (Vignes, 1999). 2m temperature and relative humidity are analyzed (optimum interpolation) and used as predictor for temperature and water content in the surface and the subsurface layers. Data for SST, snow depth and sea ice are derived weekly from a subjective analysis of synop observations and satellite pictures.

Briefly name the physical packages used (PBL, Cloud, Radiation and Surface energy schemes etc):

Presently:

Vertical diffusion: Based on a drag coefficient formulation, monin-Obukhov similarity theory (Louis, 1979)

Explicit moisture and cumulus clouds: Sundqvist scheme, prognostic cloud water.

Radiation scheme: Based on Savijarvi, two spectral bands, short-wave and long-wave.

Surface scheme: Three layers, surface types land and sea, prognostic calculation of surface and subsurface temperature and water content.

In near future:

PBL: Prognostic turbulent kinetic energy, diagnostic length scale (TKE-l).

Explicit moisture and cumulus clouds: STRACO, based on Sundqvist, puts special emphasis in achieving gradual trasition between the two regimes.

Surface scheme: ISBA, aggregation of fluxes approach, based on Avissar and Pielke (1989).

Data format of the meteorological output from the NWP-model: GRIB, felt (met.no specific format)

Platform: Linux PC's, SGI Supercomputers with MPP

Programming language: FORTRAN

2.7.2 Air Quality Model

General:

Models name: EPISODE (Slørdal et al., 2003; Walker et al., 1999; Grønskei et al., 1993; European Topic Center, Model Documentation System).
This is the Air Dispersion Model within the PC-based Air Quality Information System, AirQUIS (Bøhler and Sivertsen, 1998; http://www.nilu.no/aqm/). The 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, 2002).

Type of model: Eulerian grid model with use of embedded subgrid line and point source Gaussian models for near source treatment.

Domain size: Optional. To reduce computation time this model system has mostly been applied for urban areas, covering a horizontal domain of typically 25 x 25 grid squares and a limited number of vertical levels, i.e. 3 to 6. However, recent applications have been performed with larger grid domains and with up to 10 vertical levels.

Spatial resolution: Eulerian model: Horizontally down to 1x1 km. Vertically, variable resolution of about: 20 m and upwards.

Temporal resolution: Mostly used on hourly averaged input data, but with much less temporal timestep applied in the Eulerian grid model, and in the subgrid puff-model.

Pollutants: CO, NO, NO_2, NOx, PM_{10}, $PM_{2.5}$.

Platform: PC (WINDOWS, 98, 2000, NT, XP).

Programming language: FORTRAN, (compiled as a Dynamic Link Library (DLL) for application in AirQUIS' Visual Basic (VB) environment).

Application: Estimating urban background concentration levels, and near source concentrations from road transport and individual stacks.

Emissions: Yearly on 1x1km resolution (transformed to hourly values by use of time-variation functions).

- Hourly line source emissions based on ADT, vehicular composition, time variation functions, etc. for each line source segment.
- Area sources, and point source emissions based on either consumption data with related emission factors, or direct emissions information.

Pollutants and chemistry: Photochemical $NO_2/NO/O_3$ equilibrium for fine scale applications (hor. res. of ~ 1 km) with subgrid models applied. If only the Eulerian grid model is applied a simplified EMEP-chemistry is applied.

Passive/Reactive: Reactive.

Modelled chemical species: 45 photchemical species if the simplified EMEP-chemistry is applied.

Types of reactions considered: Dry and wet photochemical if the simplified EMEP-chemistry is applied.

Meteorological requirements:

Input meteorological variables, specifying their dimensions (1D, 2D or 3D) and time resolution:

Data: Gridded hourly wind speed and direction, precipitation, cloud cover, land cover (if available), solar radiation (if available), surface layer ΔT-values (if available), surface layer turbulence (σ_v and σ_w) values (if available), h_{mix}-values (if available). All of the above data can either be given a measurement (hourly values) or as gridded (hourly) values from a meteorological model (for example MM5). For diagnostic calculations the required wind field have also been produced by use of simpler diagnostic models, i.e MATHEW (Sherman, 1978; Foster et al., 1995; Slørdal, 2002).

Turbulence and stability parameters (specify if computed internally or needed as input).

Stability: PG classes or M-O scheme applied for calculating surface layer values of friction velocity ($u*$), temperature scale ($\theta*$), Monin-Obukhov length (L), convective velocity scale ($w*$), and profiles of turbulence [σ_v (z) and σ_w(z)]. Computed internally, based on the meteorological input data and the applied meteorological pre-processor. If measurements of σ_v (z) and σ_w(z) exists, these values can be applied directly.

2.7.3 Meteorological pre-processors

Name: METPRO (Bøhler, 1996)

Computational scheme (e.g. M-O similarity theory): M-O similarity theory (Ulden and Holtslag, 1985; Holtslag and de Bruin, 1988 and Gryning et al., 1987)

Data requirement (list and features of input data):

1) Location (latitude and longitude ; degree) include surface roughness.
2) Wind Speed (m/s) plus height at which measured.
3) Wind direction (degree)
4) Ambient Temperature (degree C)

and either:

5) Time (Year, Month, Date, Hour)
6) Cloud cover (Octa or Deca)
7) Global Radiation (W/m2)

or

5') Temperature difference between two heights within the surface layer

List of output variables: Friction velocity (u*), temperature scale (θ*), Monin-Obukhov length (L), convective velocity scale (w*), [thereby giving estimates of the surface momentum flux, (τ_0) and the surface sensible heat flux, (H_0),] the mixing height (h_{mix}), and the vertical profile functions of the surface layer wind, temperature and turbulence parameters (σ_v and σ_w).

Platform: PC or UNIX Workstation

Programming language: FORTRAN 90

2.7.4 Existing Interface

General purpose interface or tailored on specific models:
A meteorological pre-processing interface is translating/interpolating the model output of MM5 (and thereby also HIRLAM10 data, which first is transferred to MM5 format and grid) so as to meet the input requirements of the AirQUIS/EPISODE modelling system.

Meteorological and air quality models names: MM5/HIRLAM10 and AirQUIS/Episode.

Space interpolation: The two models are defined with as equal spatial and temporal resolution as possible to avoid use of extensive interpolation.

Change of coordinate grid system:

Horizontally: From the polar stereographic projection in MM5, to the EPISODE grid defined in UTM-coodinates.

Vertically: From a normalized pressure (sigma) in the vertical (see MM5 description) to a terrain following σ-transform (transforming from the Cartesian height z) in EPISODE. The model layers are defined approximatly at the same physical heights.

Meteorological input variables/fields:

3-D: Horizontal wind components, temperature, specific humidity

2-D: Precipitation, surface pressure, surface temperature, friction velocity, surface sensible heat flux

Supplementary external variables/fields:

2-D: Land-use classification, surface roughness

Variables interpolated or re-estimated (e.g. vertical velocity on a new grid system): The vertical velocity in the Air Quality Model is recalculated based on the gridded horizontal wind field from the Meteorological Model and the implicit AQM-requirement of a mass consistent flow field.

Computed output variables/fields (e.g. dispersion coefficients, wind variances, boundary layer depth):

Presently: To this point the meteorological input required by the Air Dispersion Model has just been extracted from MM5 as if these were observed values.

In the context of FUMAPEX: Direct use of modeled and parameterized meteorological variables from the meteorological model will be investigated in order to optimize the description of the dispersion conditions.

Platform: PC or UNIX Workstation.

Programming language: FORTRAN

2.7.5 Exposure Models

Name: AirQUIS.

Type: Simply relating a stationary population distribution based on information of inhabitants related to geographical position of home adresses with the calculated outdoor concentrations in these building points.

Platform: PC (WINDOWS, 98, 2000, NT, XP).

Programming language: Visual Basic.

2.7.6 References

About AirQUIS: http://www.nilu.no/aqm/

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2.8 Partner 11 (UH)

2.8.1 NWP models

Model name: **MM5**.

Prognostic/Diagnostic: Prognostic

Hydrostatic/non-hydrostatic: Non-hydrostatic (MM5 version 3)

Vertical coordinate system, horizontal grid-type: Terrain following sigma coordinate (Sigma surfaces near the ground closely follow the terrain, and the higher-level sigma surfaces tend to approximate isobaric surfaces).

Horizontal grid-type: Arakawa B-grid type

Domain size: variable.

Horizontal and vertical resolution: variable. The model vertical resolution is defined by a list of values between zero and one that do not necessarily have to be evenly spaced. Commonly the resolution in the boundary layer is much finer than above, and the number of levels may vary from ten to forty, although there is no limit in principle.

Spatial resolution of available topography and land-use: 1-degree, 30-, 10-, 5-, and 2-minitues, including 30-second resolutions.

Used boundary and initial conditions:

Nesting procedures: Multiple-nest capability.

For how long time-periods can the model be operated (Forecast length and CPU limitations etc.):

Possibilities for assimilations of meteorological observations, and experience with assimilation: Four-Dimensional Data Assimilation (FDDA): this is a method of nudging model towards observations or analysis. This scheme may be used for:

- Dynamical initialization (pre-forcast period)
- Creating 4D meteorological datasets (e.g., for air quality model)
- Boundary conditions (outer domain nudged towards analysis).

.

Briefly name the physical packages used (PBL, Cloud, Radiation and Surface energy schemes etc):

- Precipitation physics
    - Cumulus parameterisation schemes:
        - Anthes-Kuo
        - Grell
        - Kain-Fritsch
        - Fritsch-Chappell
        - Betts-Miller
        - Arakawa-Schubert
    - Resolvable-scale micro physics schemes:
        - Removal of supersaturation
        - Hsie's warm rain scheme
        - Dudhia's simple ice scheme
        - Reisner's mixed-phase scheme
        - Reisner's mixed-phase scheme with graupel
        - NASA/Goddard microphysics with hail/graupel
        - Schultz mixed-phase scheme with graupel
- Planetary boundary layer process parameterization
    - Bulk formula
    - Blackadar scheme
    - Burk-Thompson (Mellor-Yamada 1.5-order/level-2.5 scheme)
    - Eta scheme (Janjic, 1990, 1994)
    - MRF scheme (Hong and Pan 1996)
    - Gayno-Seaman scheme (Gayno 1994)
- Surface layer precess parameterization
    - fluxes of momentum, sensible and latent heat
    - ground temperature prediction using energy balance equation
    - variable land use catagories (defaults are 13, 16 and 24)
    - 5-layer soil model
    - OSU land-surface model (V3 only)
- Atmospheric radiation schemes
    - Simple cooling
    - Dudhia's long- and short-wave radiation scheme

- NCAR/CCM2 radiation scheme
- RRTM long-wave radiation scheme (Mlawer et al., 1997)

Data format of the meteorological output from the NWP-model: MM5 Version 3 file format

Platform: Unix workstations, Crays/IBM's, PC running Linux

Programming language: FORTRAN 77, FORTRAN 90

2.8.2 Air Quality Model

General:

Models name: **PEARL**.

Type of model: Box.

Domain size:

Spatial resolution: horizontal: 1x1 km, vertical: averaged.

Temporal resolution: hourly to annual.

Pollutants: CO, NO, NO_2, NOx, PM10.

Platform: PC, WINDOWS 98, 2000.

Programming language: FORTRAN 90.

Application: Urban background, ground level from road transport sources.

Emissions: annual on 1x1km resolution.

Pollutants and chemistry:

Passive/Reactive: Reactive.

Modelled chemical species:

Types of reactions considered: empirical or Generic Reaction Scheme for NO_2.

Meteorological requirements:

Input meteorological variables, specifying their dimensions (1D, 2D or 3D) and time resolution:

Data: hourly wind speed and direction, precipitation, solar radiation, cloud cover, land cover (if available), ambient temperature.

Turbulence and stability parameters (specify if computed internally or needed as input).

Stability: PG classes or M-O scheme, needed as input.

General:

Models name: **CMAQ**.

Type of model: Eulerian.

Domain size: Variable.

Spatial resolution: variable.

Temporal resolution: hourly.

Pollutants: CO, NO, NO_2, NOx, PM10.

Platform: Unix workstations, PCs rumming Linux..

Programming language: FORTRAN 77, FORTRAN 90.

Application: assessment tool designed to support air quality modelling applications ranging from regulatory issues to science inquiries on atmospheric science processes.

Emissions: co-ordinate-based hourly elevated point source, gridded hourly emissions for low point, area, motor vehicle, anthropogenic and biogenic sources.

Pollutants and chemistry: atmospheric transport, deposition, cloud mixing, emissions, gas- and aqueous-phase chemical transformations, and aerosol dynamics and chemistry.

Passive/Reactive: Reactive.

Modelled chemical species:

Types of reactions considered: gas- and aqueous-phase chemical transformations, and aerosol chemistry.

Meteorological requirements:

Input meteorological variables, specifying their dimensions (1D, 2D or 3D) and time resolution:

Time-dependent and time-independent 2-D and 3-D meteorological data:

- Time Dependent 3-D meteorological data: cloud water mixing ratio (kg/kg), water vapour mixing ratio (kg/kg), air temperature (K), pressure (Pascal), total density of air (kg/m3), U-wind (m/s), V-wind (m/s), W-wind (m/s), etc.

- Time dependent 2-D meteorological data: air density at surface (kg/m3), PBL height (m), sensible heat flux (watts/m2), latent heat flux (watts/m2), net radiation (watts/m2), total cloud fraction (fraction), etc.

- Time independent 2-D variables: pressure difference between top and surface (Pascal), total Jacobian at surface (m), etc.

- Time independent 3-D variables: density of reference atmosphere (kg/m3), temperature of reference atmosphere (K), pressure of reference atmosphere (Pascal), etc.

Turbulence and stability parameters (specify if computed internally or needed as input): M-O length scheme.

2.8.3 Meteorological pre-processors

Name: GAMMA-MET

Computational scheme (e.g. M-O similarity theory): M-O similarity theory

Data requirement (list and features of input data):

1) Location (latitude and longitude ; degree) include surface roughness.
2) Time (Year, Month, Date, Hour)
3) Cloud cover (Octa or Deca)
4) Global Radiation (W/m2)
5) Wind Speed (knots) plus height at which measured.
6) Wind direction (degree)
7) Ambient Temperature (degree C)

For more detailed option, GAMMA-MET needs:

1) Temperature profile at a different height (for MOB)
2) Cloud base height

List of output variables:.

Platform:

Programming language:

2.8.4 Existing Interface

Name: The Meteorology-Chemistry Interface Processor (MCIP)

General purpose interface or tailored on specific models:

Linking between CMAQ and MM5. MCIP programme deals with the following issues:

- Data format translation,
- Conversion of units of parameters,
- Diagnostic estimations of parameters not provided,
- Extraction of data for appropriate window domains, and
- Reconstruction of meteorological data on different grid and layer structures

Meteorological and air quality models names MM5 and CMAQ.

Space interpolation: horizontal interpolation is provided to generate higher resolution data than the input meteorological data.

Change of coordinate grid system: Generate the co-ordinate dependent meteorological data to the generalised co-ordinate for CMAQ.

Meteorological input variables/fields: predicted surface and PBL parameters, or MM5 profile data, e.g., temperature, humidity and momentum together with the surface landuse data.

Supplementary external variables/fields:

Variables interpolated or re-estimated (e.g. vertical velocity on a new grid system):

Computed output variables/fields (e.g. dispersion coefficients, wind variances, boundary layer depth):

dry deposition velocities, PBL parameters (e.g., boundary layer depth), etc..

Platform: Unix workstations, PC running Linux.

Programming language: FORTRAN

2.8.5 Exposure Models

Name: PEM-UH.

Type: Empirical based on Time Activity data.

Platform:

Programming language:

2.8.6 References

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3 Resuming tables.

The following tables simply resume the meteorological, air quality and exposure models that are going to be used in the different workpackages that build Fumapex activities. For each model a few major features are cited to simply identify the model type. A last table gives a quick view of meteorological and air quality model that are coupled and joined by an interface module.

Fumapex Meteorological Models

Partner	Model	hydrostatic	Non-hydrostatic	Presently operational
P1 (DMI)	DMI-HIRLAM (DK version)	√		√
P2 (DWD)	LOKAL MODELL (LM)		√	√
P2 (DWD)	LES LM		√	
P4 (CEAM)	RAMS		√	
P6 (FMI)	HIRLAM (FIN version)	√		√
P7 (ARIANET) P14 (ARPAP)	RAMS		√	
P8 (ARPA)	LOKAL MODELL (LAMI)		√	√
P9 (met.no) P10 (NILU)	HIRLAM (N version)	√		√
P9 (met.no) P10 (NILU)	MM5		√	√
P11 (UH)	MM5		√	

Fumapex Air Quality Models

Partner	Model	Model type	Application
P1 (DMI)	DERMA	Lagrangian Puff	Emergency preparedness
P1.3 (DEMA) P1 (DMI)	ARGOS	Lagrangian Puff	Emergency preparedness
P1 (DMI)	HIRLAM-Tracer	Eulerian	Air Pollution Research
P2 (DWD)	TM	Trajectory	Emergency preparedness, episodes
P2 (DWD)	LPDM	Lagrangian Particle	Emergency preparedness, Episodes
P4 (CEAM)	HYPACT	Hybrid Lagrangian/Eulerian	
P4 (CEAM)	CAMx	Eulerian Chemistry	Episodes simulation
P6 (FMI)	CAR-FMI OSPM	Road and Street canyon models	
P6 (FMI)	UDM-FMI	Urban Gaussian	
P6 (FMI)	MATCH	Eulerian Chemistry	
P7 (ARIANET) P14 (ARPAP)	FARM	Eulerian Chemistry	Episodes simulation
P8 (ARPA)	OLMO PIOPPO	Statistical (linear regression)	Air Quality Forecast
P8 (ARPA)	ADMS-Urban	Three dimensional quasi-Gaussian model	Long Term Urban Air Quality Assessment
P8 (ARPA)	CALGRID	Eulerian Photochemical	Regional Scale Episodes simulations
P9 (met.no) P10 (NILU)	EPISODE	Eulerian	Urban Air Quality
P11 (UH)	PEARL	Box	Urban Air Quality
P11 (UH)	CMAQ	Eulerian Chemistry	Episodes simulation

Fumapex Exposure Models

Partner	Model
P1.3 (DEMA)	ARGOS
P6 (FMI)	EXPAND
P9 (met.no) P10 (NILU)	AirQUIS
P11 (UH)	PEM-UH

Fumapex NWP-UAQ Model Interfaces

	Meteorological model Type		
Air Quality Model Type	**Hydrostatic**	**Non-hydrostatic**	**Diagnostic**
Statistical		*X*	
Box		*X*	
Road and Street canyon models	*X*		
Urban Gaussian	*X*		
Trajectory		*X*	
Lagrangian Puff	*X*		
Lagrangian Particle		*X*	
Eulerian Chemistry	*X*	*X*	*X*

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Scientific Reports

Scientific reports from the Danish Meteorological Institute cover a variety of geophysical fields, i.e. meteorology (including climatology), oceanography, subjects on air and sea pollution, geomagnetism, solar-terrestrial physics, and physics of the middle and upper atmosphere.

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