Overview of Enviro-HIRLAM developments at DMI

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and

DMI Enviro-HIRLAM team:

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The MUSCATEN Summer School
"Integrated Modelling of Meteorological and Chemical Transport Processes / Impact of Chemical Weather on Numerical Weather Prediction and Climate Modelling"

Odessa, Ukraine, 3-9 July 2011

Content

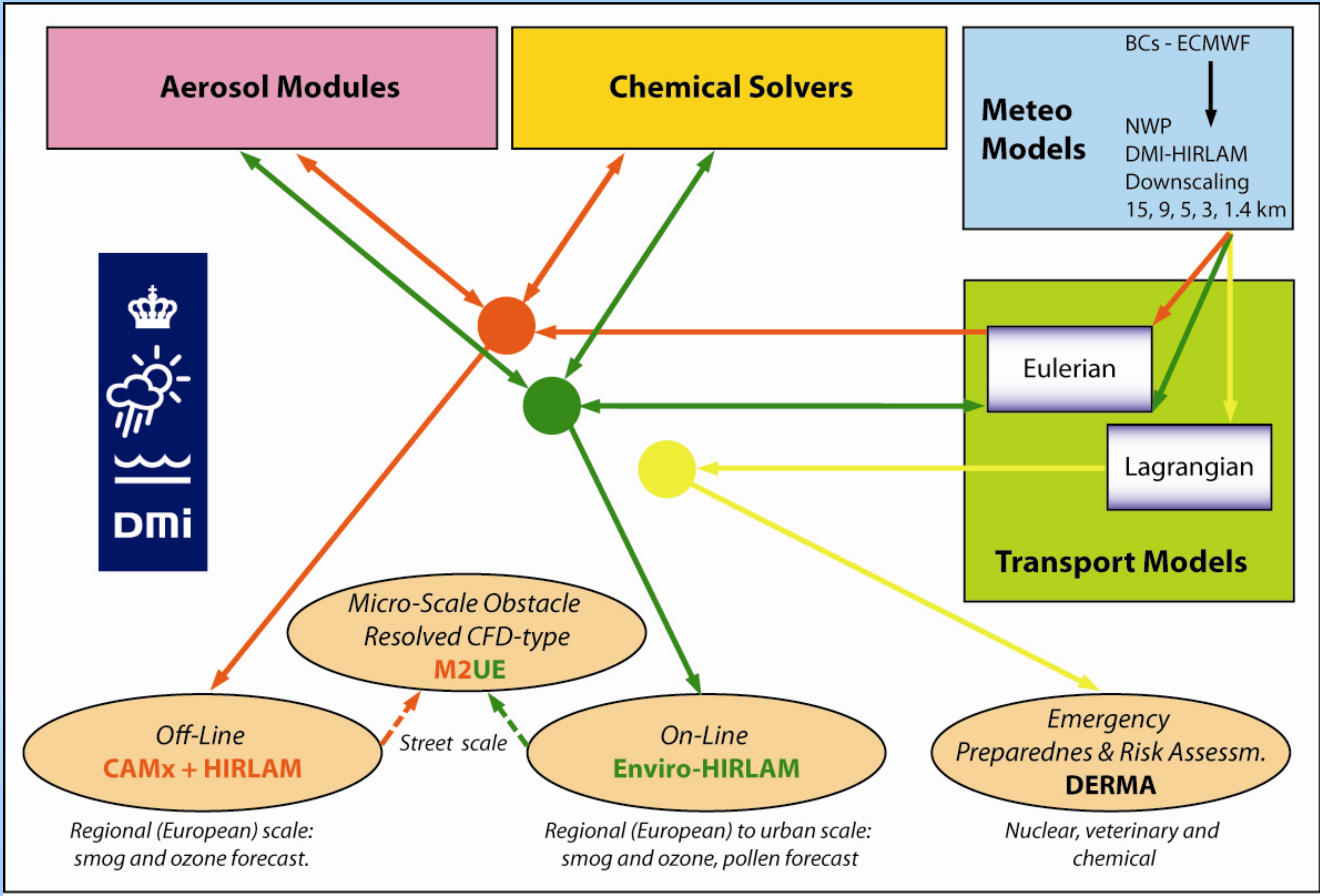
- Enviro-HIRLAM/HARMONIE online integrated ACT-NWP modelling system
- Steps of model development, versions
- Model structure overview
- Aerosol and chemistry feedbacks
- Enviro-HIRLAM community and HIRLAM Chemical Branch
- Conclusions, applications and future research

2 different tasks in HIRLAM-ACTM:

(i) improvement of HIRLAM/HARMONIE outputs for ACT modelling applications and correspondingly improvement of ACT models (for different off-line ACT models, like MATCH, SILAM, EMEP, CAMx, DERMA; DACFOS) => Interface/post-processor or coupler, e.g. OASIS4,

(ii) improvement of NWP itself by implementation of ACTMs and aerosol/gases forcing/feedback mechanisms into HIRLAM/HARMONIE (mostly by on-line integration, like in Enviro-HIRLAM/HARMONIE).

DMI Multi-Scale MetM and ACT Modelling System



*Baklanov, Mahura, Sokhi, **2011**:*
"Integrated Systems of Meso-Meteorological and Chemical Transport Models", Springer, 186 p.

HIRLAM Consortium Institutions
linking with **ECMWF**

SMHI

University International Collaboration:

Univ. Copenhagen Denmark	Univ. Tartu Estonia	Univ. Vilnuis Lithuania	RSHU Russia	Univ. Bilbao Spain	OSEU Ukraine

Currently several groups are involved:

- HIRLAM-A program of the HIRLAM consortium (HIRLAM Chemical brunch)
- Danish Meteorological Institute (A.Baklanov, U. Korsholm, A. Mahura, B.H. Sass, K.P. Nielsen, R. Nuterman, A. Zakey, etc),
- University of Copenhagen (E. Kaas, etc),
- Russian State Hydro-Meteorological University (S. Smyshlyaev, etc.)
- University of Tartu, Estonia (R. Room, etc.),
- LABELIN/University of Bilbao, Spain (I. Gonzales),
- Vilnius University and MetOffice, Lithuania (A. Mazeikis),
- Odessa State Environmental University, Ukraine (S. Ivanov, etc.).

There is an initial working group (under COST and HIRLAM-A) for HIRLAM-ACTM integration work and a sub-program for the Enviro-HIRLAM/HARMONIE development cooperation.

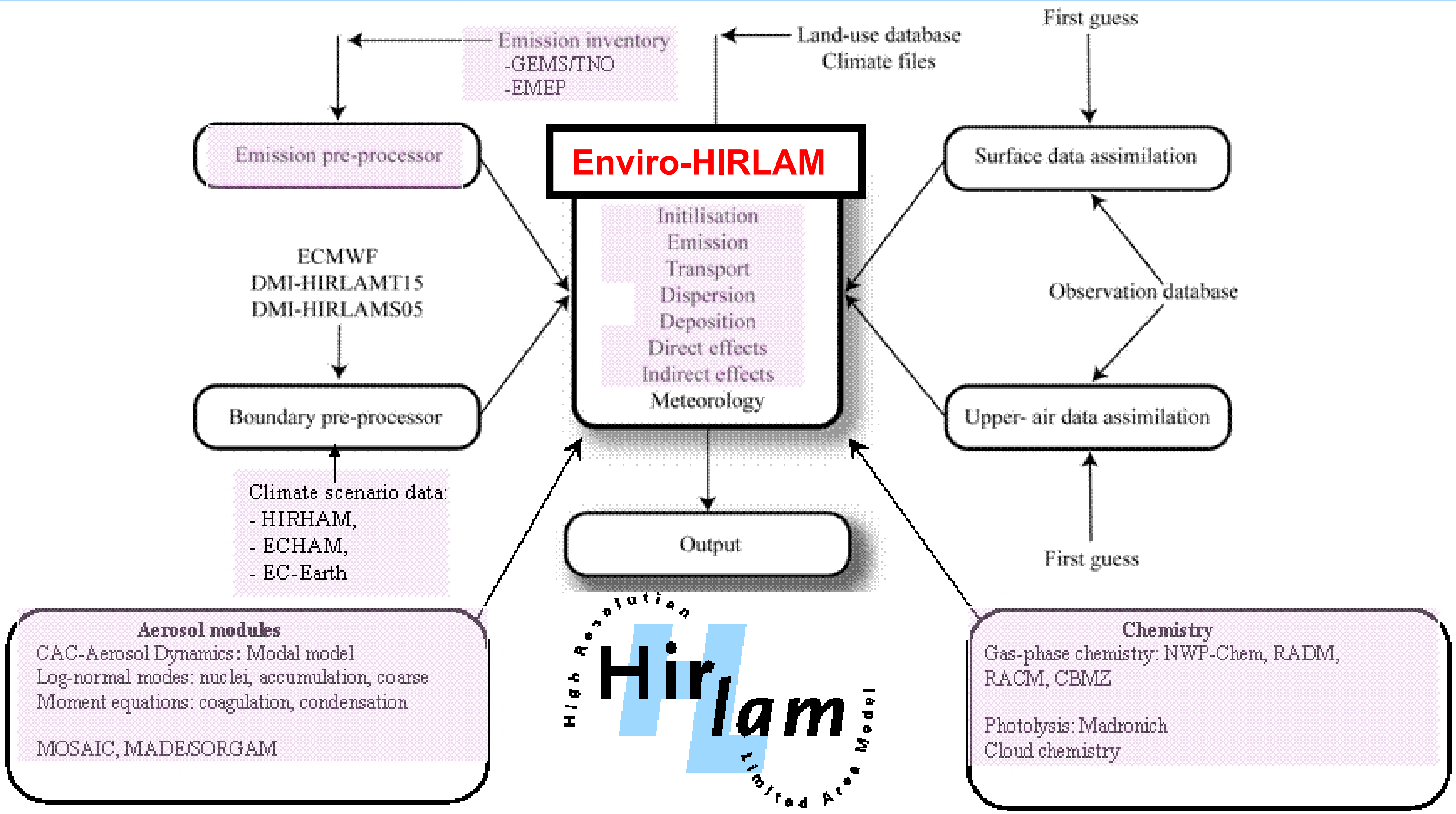
Any HIRLAM and other teams are also welcome to join the team!

Enviro-HIRLAM 10-years development history

- 1999: Started at DMI as an unfunded initiative
- Used previous experience of Novosibirsk sci. school and SMHI (A. Ekman PhD)
- 2001: Online passive pollutant transport and deposition in HIRLAM-Tracer (Chenevez, Baklanov, Sørensen)
- 2003: Aerosol model tested first as 0D module in offline CAC (Gross, Baklanov)
- 2004: Test of different formulations for advection of tracers incl. cloud water (Lindberg)
- 2005: SBL parameterisation and urbanisation of the model (funded by FP5 FUMAPEX) (Baklanov, Mahura, Peterson)
- 2005: COGCI grant for PhD study of aerosol feedbacks in Enviro-HIRLAM (Korsholm)
- 2006: Test of CISL scheme in Enviro-HIRLAM (Lauritzen, Lindberg)
- 2007: First version of Enviro-HIRLAM for pollen studies (Mahura, Korsholm, Baklanov, Rasmussen)
- 2008: New economical chemical solver NWP-Chem (Gross)
- 2008: First version of Enviro-HIRLAM with indirect aerosol feedbacks (U.Korsholm PhD)
- 2008: Testing new advection schemes in Enviro-HIRLAM (UC: E. Kaas, A.Christensen, B.Sørensen, J.R.Nielsen)
- 2008: Decision to build HIRLAM Chemical Brunch (HCB) with Enviro-HIRLAM as baseline system, Enviro-HIRLAM becomes an international project
- 2009: Integrated version of Enviro-HIRLAM based on reference version 7.2 and HCB start
- 2011: New chemistry, aerosol and radiation models version of Enviro-HIRLAM (exp)

Integrated (On-line Coupled) Modeling System for Predicting Atmospheric Composition

Enviro-HIRLAM : Environment – HIgh Resolution Limited Area Model



Started by DMI team 10 years ago (Chenevez et al, 2004; Baklanov et al, 2008; Korsholm et al, 2009)
COST-WMO (2008) model overview: the 1st European online coupled model with feedbacks
+ joined by countries of the HIRLAM Consortium → HIRLAM Chemical Branch
+ joined: Russian State HydroMet Univ, Univ Tartu, Univ Vilnus, Odessa State Envir Univ, etc.
+ close collaboration with the WRF-Chem community

Main steps of Enviro-HIRLAM realisation:

(i) model nesting for high resolutions,
(ii) improved resolving boundary and surface layers characteristics and structure,
(iii) 'urbanisation' of the NWP model,
(iv) improvement of advection schemes,
(v) emission inventories and models,
(vi) implementation of chemical mechanisms,
(vii) implementation of aerosol dynamics,
(viii) realisation of feedback mechanisms,
(ix) assimilation of monitoring data.

Enviro-HIRLAM overview

Enviro-HIRLAM can be seen as an extension to HIRLAM

Main components: Dynamical core Physical module Chemical module

Primitive equations

Radiation, clouds, precipitation, …

Semi-Lagrangian, Eulerian, semi-Lagrangian + Bott

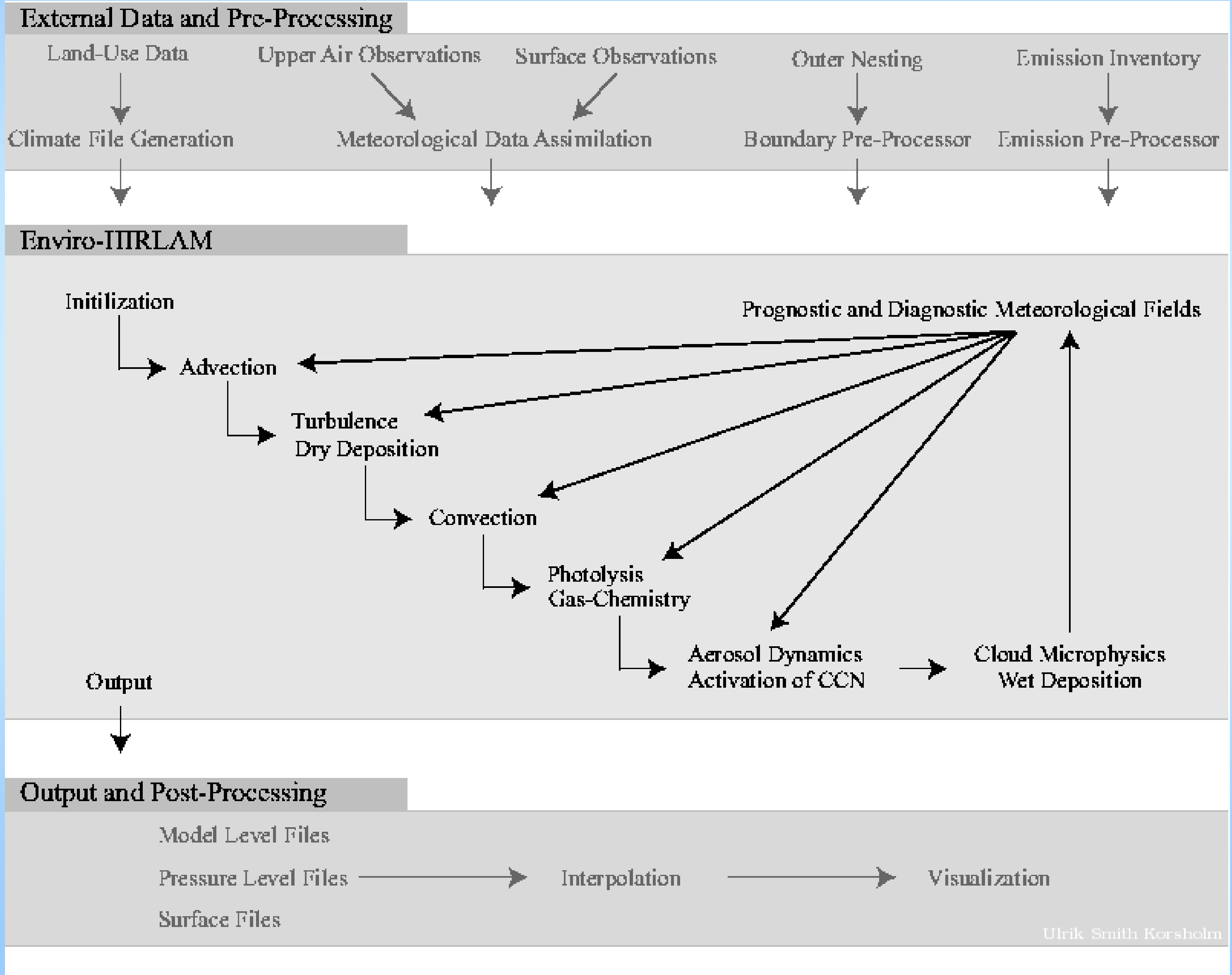
Helmholtz equation, semi-implicit adjustmnent,
4th order diffusion

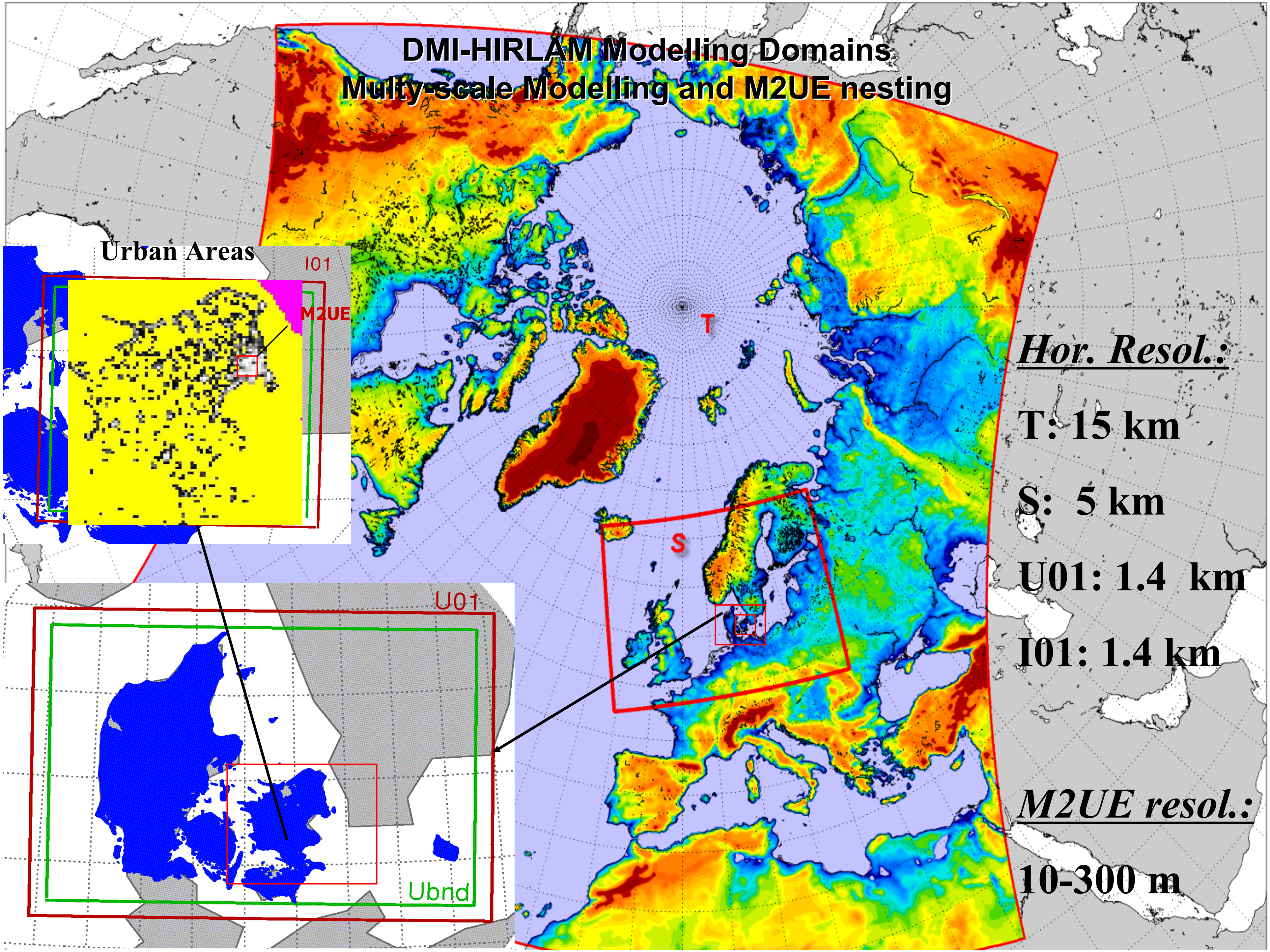
Gas chemistry
Aerosol chemistry
Aerosol equilibration
Aerosol dynamics
Deposition

Feedbacks between all modules

Prognostic equations: u, v, w, T, q, s, TKE, Ps, chemical and aerosol species

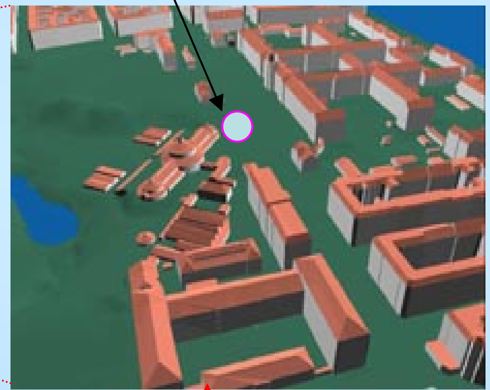
Enviro-HIRLAM overview



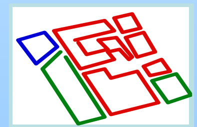

DMI-HIRLAM Modelling Domains
Multy-scale Modelling and M2UE nesting
Urban Areas
I01
M2UE
T
S
U01
Ubnd
Hor. Resol.:
T: 15 km
S: 5 km
U01: 1.4 km
I01: 1.4 km
M2UE resol.:
10-300 m

City-scale and micro-scale nested modelling in urban areas

Release site



Obstacle-resolved modelling for near-source area



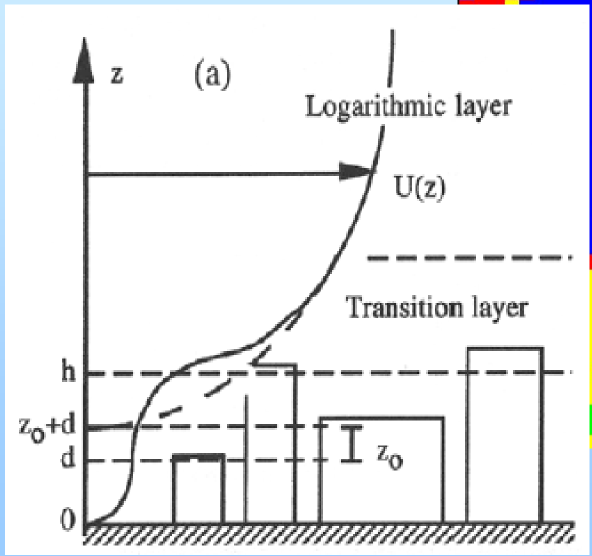
Statistical description of building characteristics

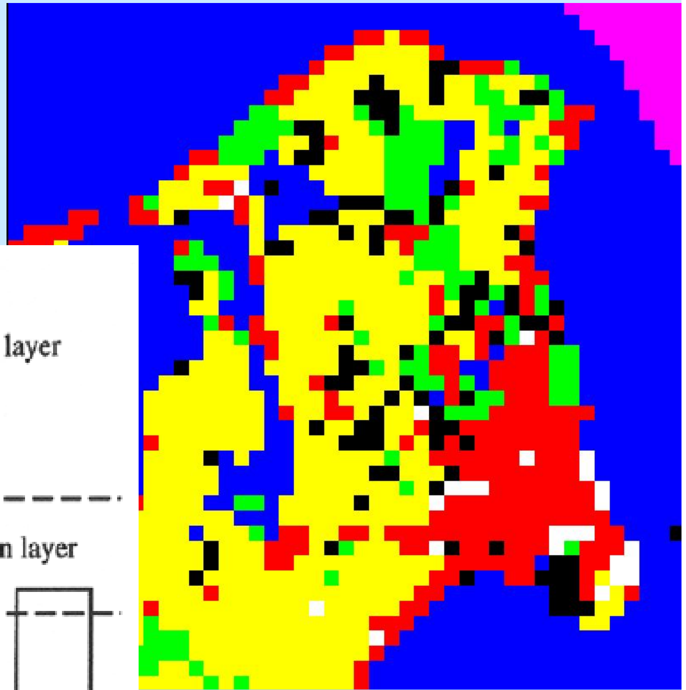
Urban Parameterisations for Enviro-HIRLAM

1. **Regional to global scales: Anthropogenic Heat Flux & Roughness – AHF+R (Baklanov et al., 2008)**
2. **Meso & city-scale: BEP - Building Effects Parameterization (Martilli et al., 2002)**
3. **Research for city-scale: SM2-U - Soil Model for Submeso Scale Urban Version (Dupont et al., 2006ab)**
4. **Obstacle-resolved approach (downscaled M2UE model, Nuterman et al., 2008)**

DMI urban parameterisation:

- Displacement height,
- Effective roughness and flux aggregation,
- Effects of stratification on the roughness,
- Different roughness for momentum, heat, and moisture;
- Calculation of anthropogenic and *storage* urban heat fluxes;
- Prognostic MH parameterisations for UBL;
- Parameterisation of wind and eddy profiles in canopy layer.





(Baklanov et al., 2008ab)

Enviro-HIRLAM model overview

- HIRLAM: High Resolution Limited Area Model: NWP model (*HIRLAM Sci. Doc., Unden et al., 2002*) , => version 7.3
- ChemBranch version: Gas-phase chemistry: NWP-Chem (*HIRLAM newsletter, No. 54, June 2008*)
- Aerosol representations, thermodynamic equilibrium, nucleation, coagulation and condensation (*Gross and Baklanov, 2004*)
- Advection: Bott *(Bott, 1989),* CISL *(Kaas, 2008)* & new LMCSL schemes
- Vertical diffusion: native CBR-TKE-1 scheme (*Cuxart et al., 2000*)
- Horizontal diffusion: Fourth order implicit
- Convection and condensation: STRACO (*Sass, 2002*)
- Aerosol and gas deposition specie dependent (*Wesely, 1989; Binkowski, 1999; Seinfeld and Pandis, 1998; Baklanov and Sørensen, 2001*)
- Emissions from inventories (GEMS-, MEGAPOLI-TNO, etc) (*TNO-report, 2007-A-R0233/B*)

Enviro-HIRLAM overview

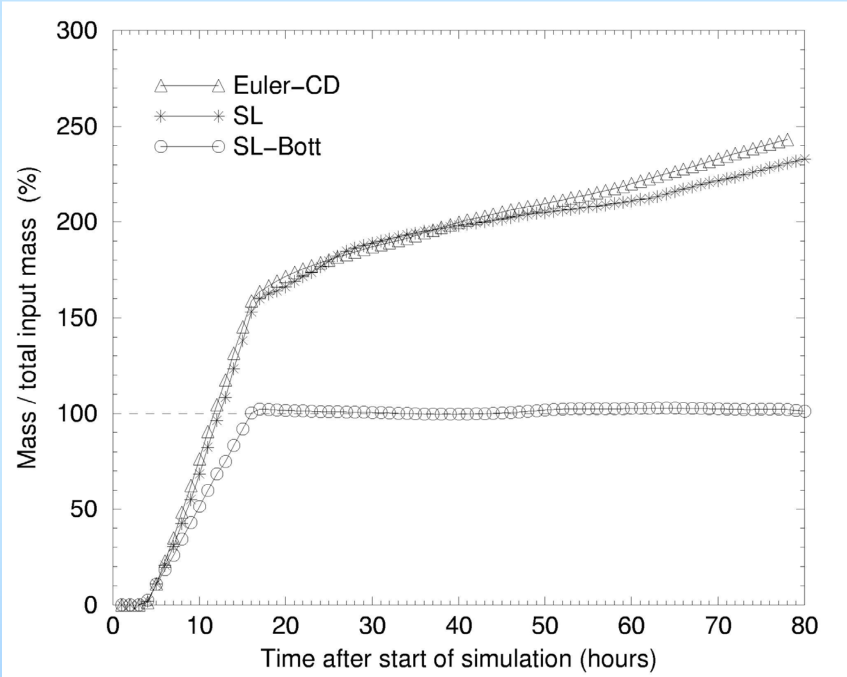
- Bott advection (*Bott, 1989*) + Easter update for tracers (*Easter, 1993*); 4th order polynomials in x and y; 2nd order polynomials in z; uses lower time step than meteorology.
- Semi-Lagrangian for meteorology
  - Mass-wind inconsistency

- Non-staggered finite differences (vertical)
- Hybrid coordinate η:

  $P = A(\eta) + B(\eta)\,P_{surface}$

  $A=0$; σ – coordinates

  $B=0$; P – coordinates
- Arakawa C grid
- Implicit 4th horizontal diffusion



Mass conservation test for ETEX release

(Chenevez 2000)

Enviro-HIRLAM overview

Convection: Modified STRACO (*Sass, 2002*)

$$\partial\psi/\partial t = (\partial\psi/\partial t\ )_{dyn} + (\partial\psi/\partial t\ )_{turb} + Q_\psi' F_\psi/F_\psi' + S_\psi$$

Ψ : species mass concentration
′ denotes a vertical average over the convective cell
S_ψ : entrainment through cloud top
Q_ψ : total concentration source
F_ψ : $\psi - \psi_e$; vertical redistribution function; lateral entrainment

Triggering: temperature perturbation, specific humidity perturbation

When triggered adiabatic lifting determines the height of the convective cell

Enviro-HIRLAM overview

Emissions -> Eulerian point sources

Particle size dependent parameterizations for dry and wet deposition

Resistance approach for dry deposition (*Wesley, 1989; Zanetti, 1990*)

Terminal settling velocity in different regimes:

- Stokes' law
- non-stationary turbulence regime
- correction for small particles

Dependent on land use classification

Below-cloud aerosol scavenging (washout); precipitation rates (*Baklanov & Sørensen, 2001*)

In and Below cloud gas scavenging follows *Seinfeld and Pandis, 1998*.

Scavenging by snow (*Maryon et al., 1996*)

Chemistry and aerosols in Enviro-HIRLAM

The **NWP-Chem mechanism**: Simplified lumped tropospheric mechanism:

- Covers most important chemical processes responsible for air pollution and aerosol formation in meso-scale models
- Advected species: no, no2, so2, co, hc, hcho, o3, ho2, hno3, h2o2, h2, h2so4, op, ho, od, ro2, rooh, (DMS, isoprene, monoterpene)

Other chemical mechanisms are testing in EnviroHIRLAM: CBMZ, GEOSext, RACM, RADM2

Aerosol module in Enviro-HIRLAM comprises a thermodynamic equilibrium model (NWP-Chem-Liquid) and an aerosol dynamics model

NWP-Aero: modal aerosol dynamics model, 3 lognormal modes, characterized by number concentration, geometric mean diameter and geometric mean standard deviation; includes nucleation, coagulation and condensation; only for Sulphur aerosols (*Baklanov, 2002, Gross and Baklanov, 2004; Korsholm, 2009*)

Two other aerosol models also tested in EnviroHIRLAM:

- sectional SALSA model (*UH and FMI*),
- modal M7 model (*Vignati, JRC; etc.*).
- also possible sectional MOSAIC (*Zaveri et al., 2007*) and - modal MADE (*Ackermann et al., 1998*) with SORGAM (*Schell et al., 2001*)

New Chemistry and Aerosols in Enviro-HIRLAM

<u>GasChem module</u>: in the current version of Enviro-HIRLAM consist of:

A) The condensed CBM gas-phase mechanism based on CBMZ (*Zaveri et al., 1999),* which is *s*implified lumped structure photochemical mechanism and most fast chemical solver (The radical balance solution technique (*Sillman, 1991*).

The chemical module has 120 reactions and 23 advected species.

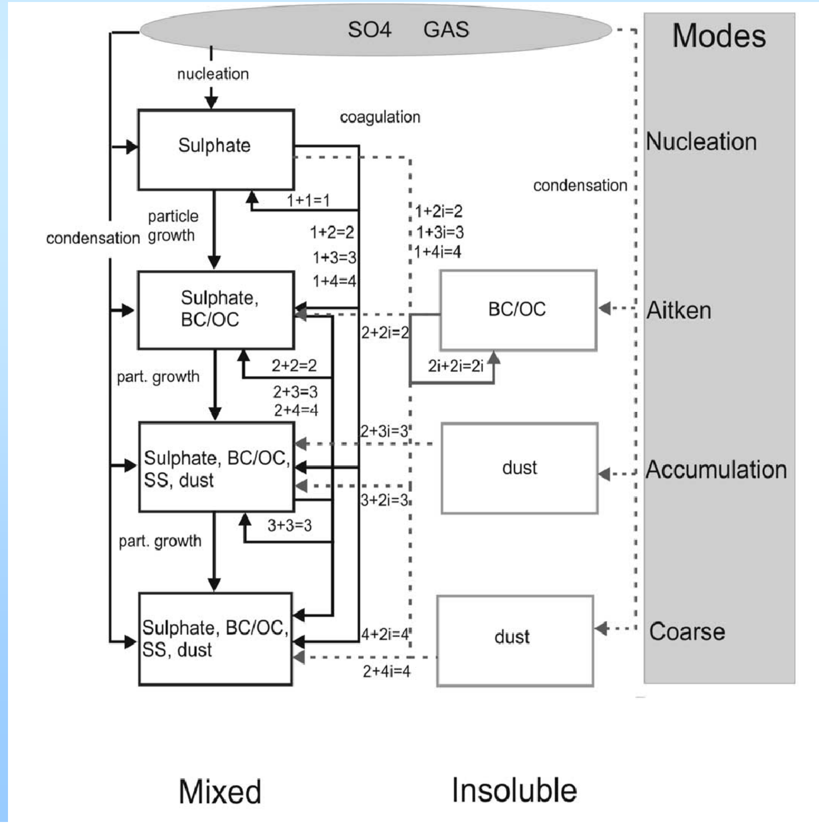
B) Photolysis rate: we setup a look-up table for J-values as a function of altitude, solar zenith angle, cloud optical depth. J-values were originally generated using programs supplied by Sasha Madronich.

<u>AeroChem module</u> in Enviro-HIRLAM consists of:

A) Thermodynamic equilibrium module HETV (Makar et al., 2003),

B) Simple aqueous-phase module

C) Aerosol dynamics module M7 (Vignati et al., 2004).



Feedback parameterisations in Enviro-HIRLAM

• Enviro-HIRLAM contains parameterizations of the ***direct, semi-direct, first and second indirect effects of aerosols***.

• Direct and semi-direct effects are realised by modification of Savijarvi scheme with implementation of a new fast analytical SW and LW (2-stream approximation) transmittances, reflectances and absorptances (Nielsen *et al*., 20010).

• Condensation, evaporation and autoconversion in warm clouds are considered fast relative to the model time step and are not treated prognostically.

• The bulk convection and cloud microphysics scheme STRACO (Sass, 1998) and the autoconversion scheme by Rasch and Kristjansson (1998) forms the basis of the parameterisation of the second aerosol indirect effect.

• As aerosols are convected they may activate and contribute to the cloud droplet number concentration, thereby, decreasing the cloud droplet effective radius affecting autoconversion of warm cloud droplets into rain drops.

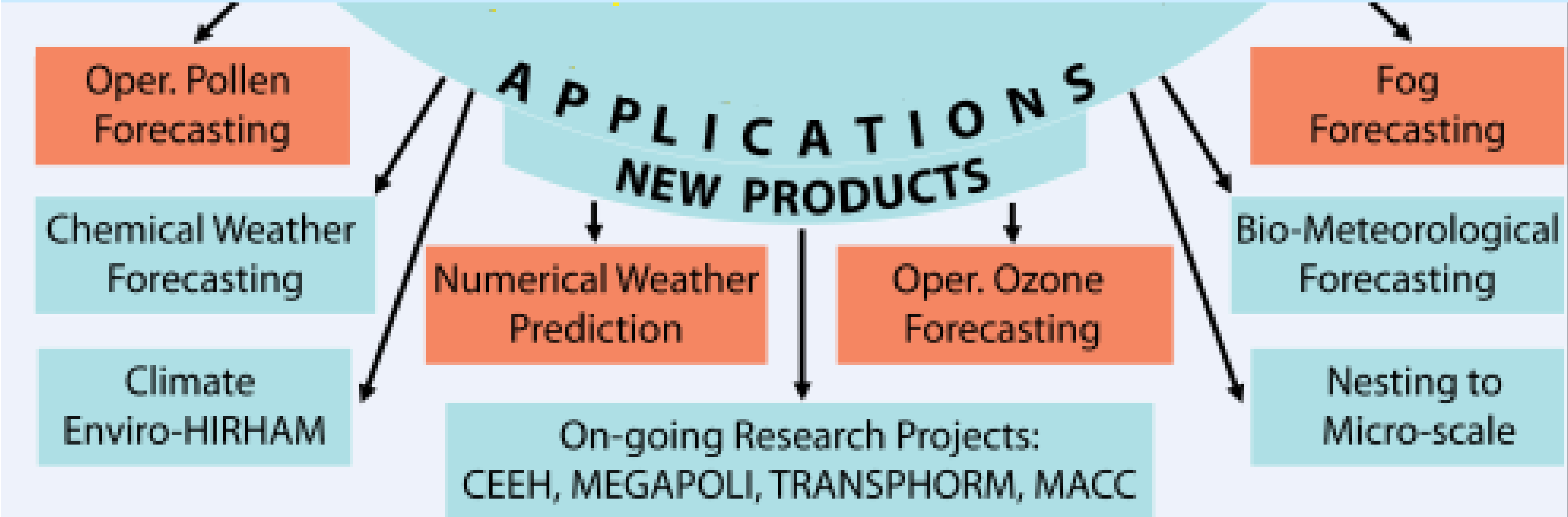
• Cloud radiation interactions are based on the cloud droplet effective radius (Wyser *et al.*, 1998).

• As it decrease warm clouds reflects more incoming short wave radiation, thereby, parameterising the first aerosol indirect effect.

• A clean background cloud droplet number concentration is assumed and the anthropogenic contribution is calculated via the aerosol scheme.

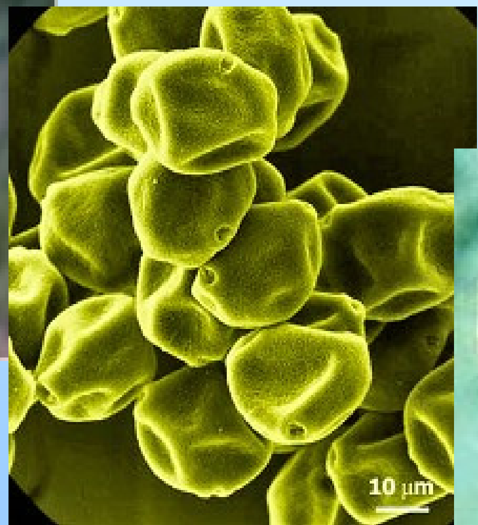
Applications of Enviro-HIRLAM

(i) chemical weather forecasting
(ii) air quality and chemical composition longer-term assessment
(iii) weather forecast (e.g., in urban areas, severe weather events, etc.),
(iv) pollen forecasting,
(v) climate change modelling (Enviro-HIRHAM),
(vi) volcano eruptions, forest fires, nuclear explosion consequences
(vii) other emergency preparedness

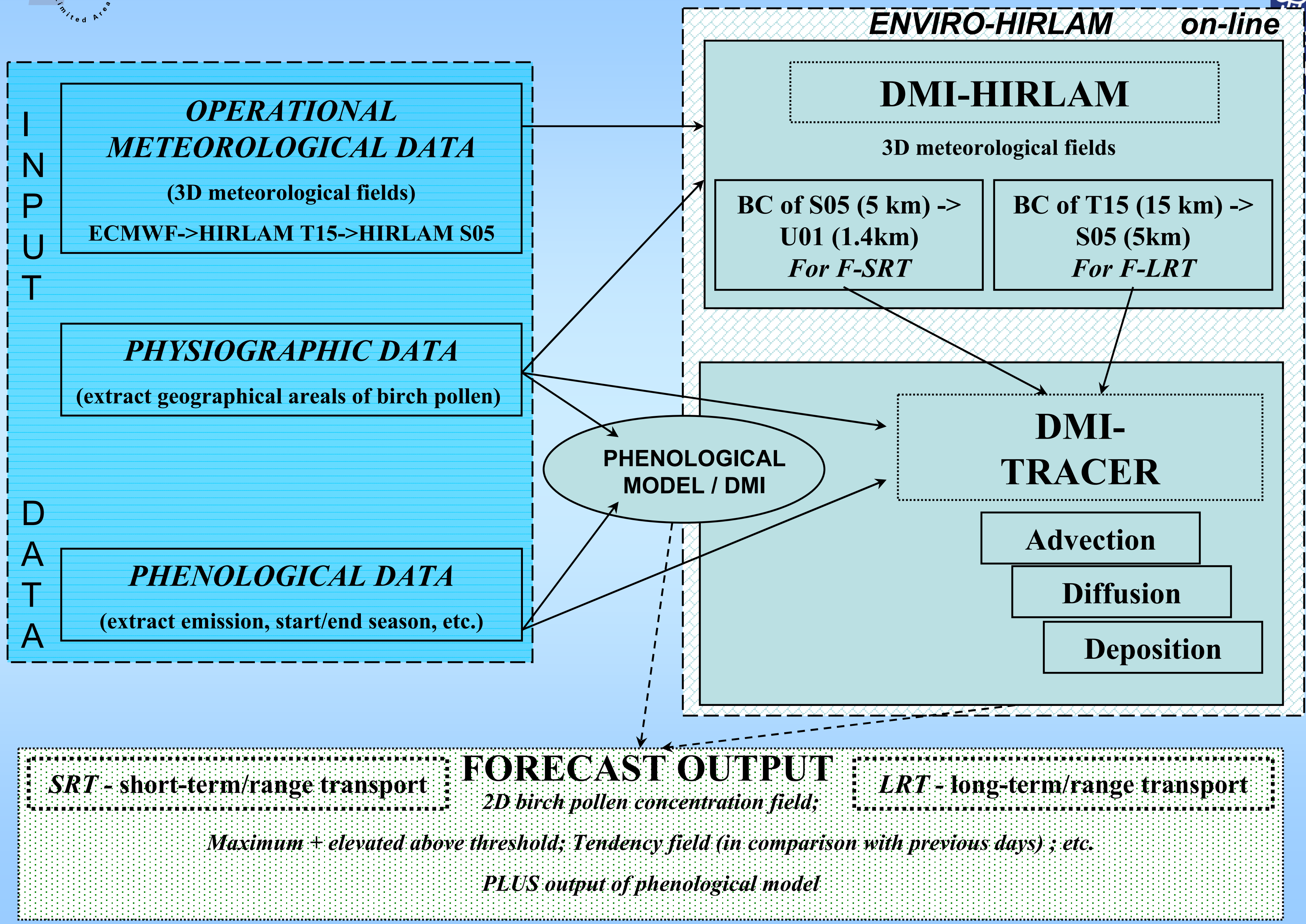


Specific Aerosols: Birch Pollen Forecasting:

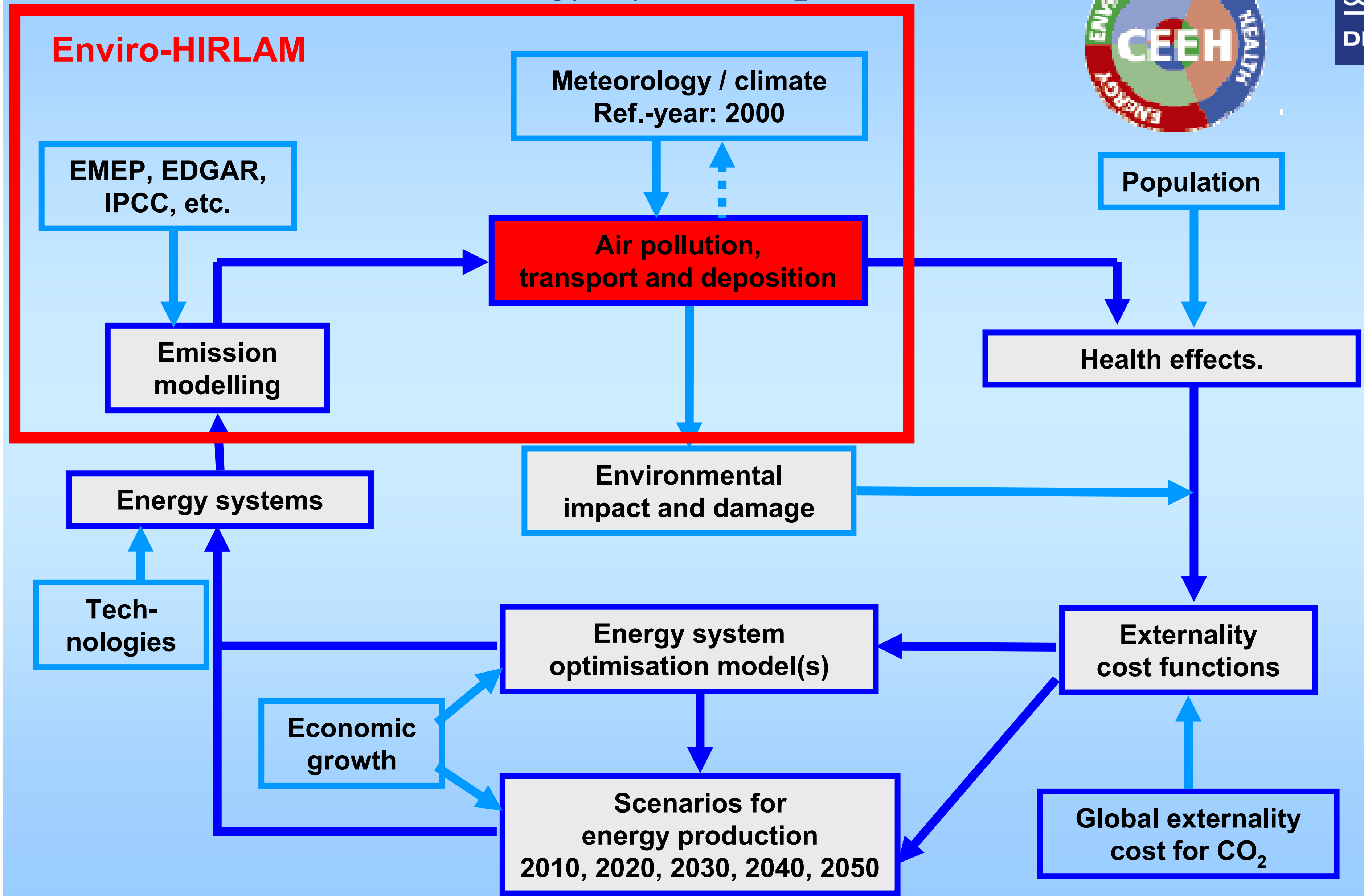
1. Specific meteorology-dependent emission,
2. Resuspension and blowing changes
3. Specific deposition mechanism
4. Chemically active as well,
5. Synergy health effects together with other pollutants
6. Special version of Enviro-HIRLAM



DMI-ENVIRO-HIRLAM for BIRCH POLLEN



CEEH modelling framework: Model Components for Energy System Optimisation



Megacities: Emissions, Impact on Air Quality and Climate, and Improved Tools for Mitigation Assessments (MEGAPOLI)

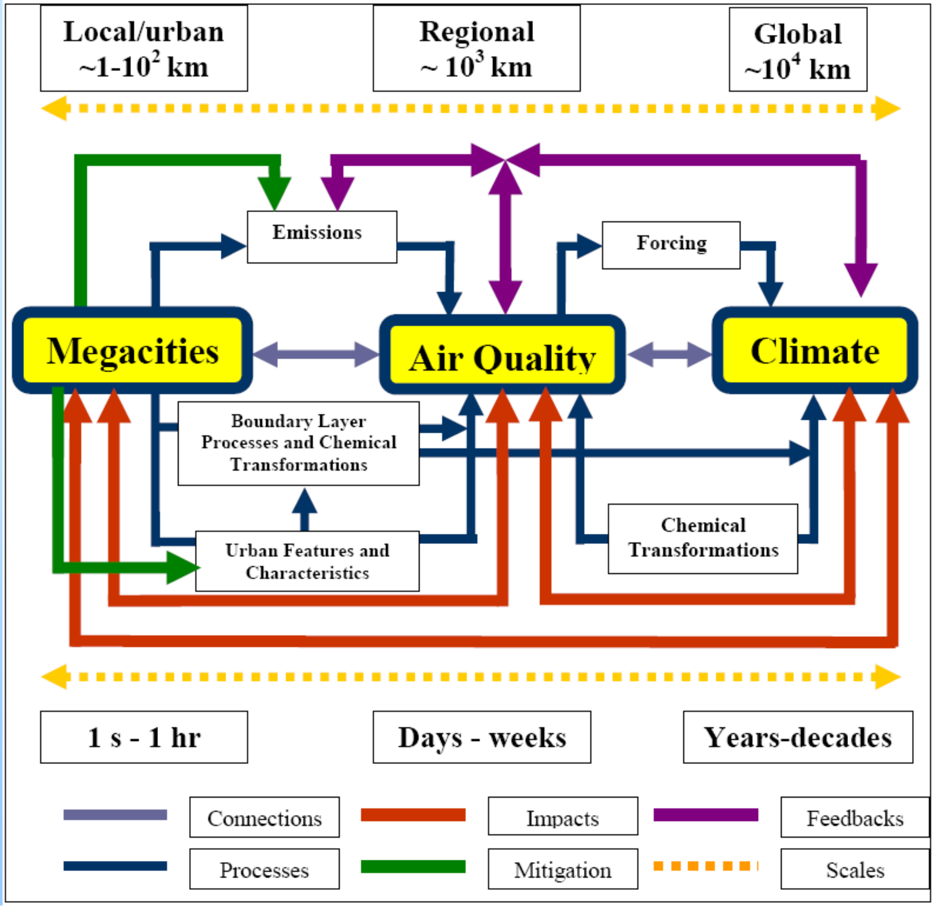
EC 7FP project for: ENV.2007.1.1.2.1.
Project duration: Oct. 2008 – Sep. 2011
27 European teams from 11 countries are involved
Coordinator: A. Baklanov (DMI)
Vice-coordinators: M. Lawrence (MPIC) and S. Pandis (FRTHUP)

(Nature, 455, 142-143 (2008), http://megapoli.info)

The <u>main aim</u> of the project is

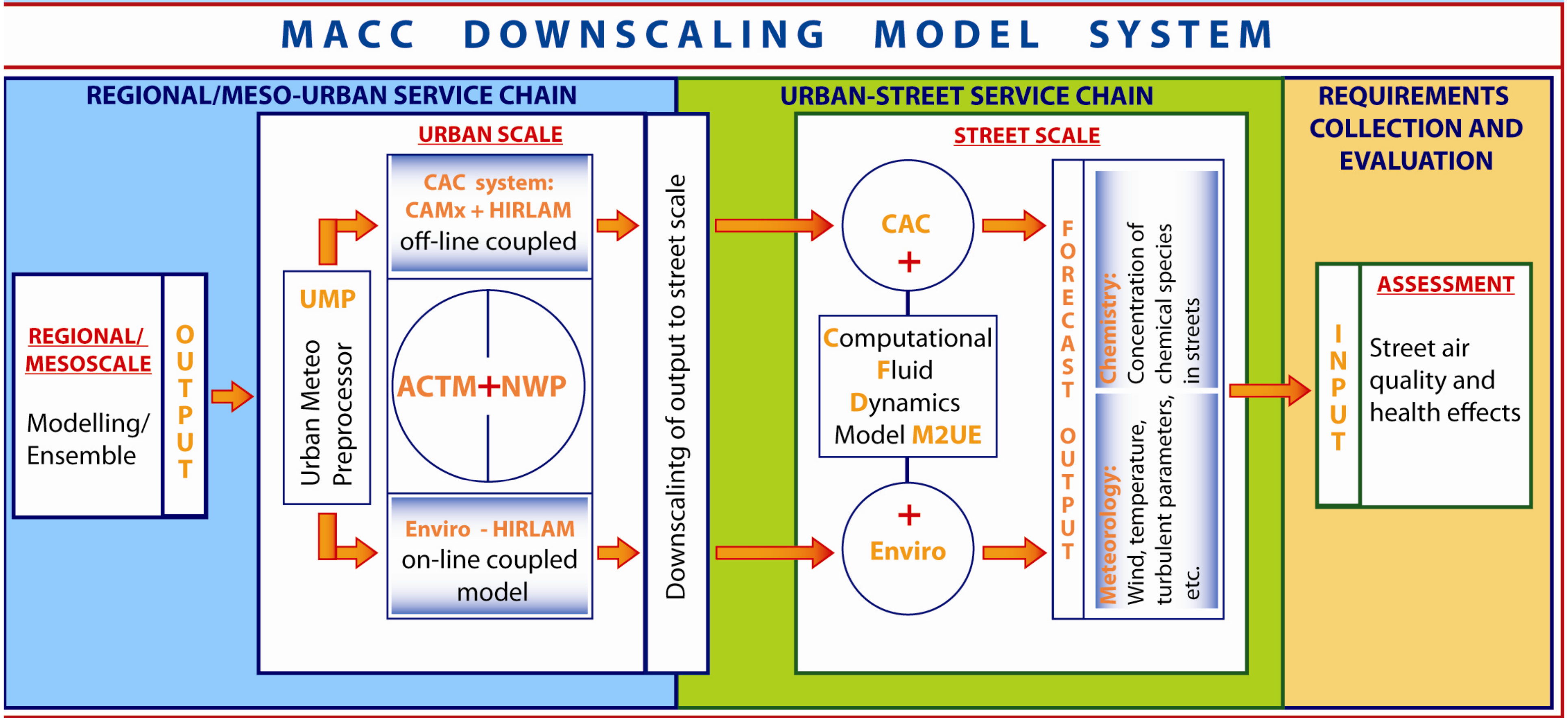
(i) to assess impacts of growing megacities and large air-pollution "hot-spots" on air pollution and feedbacks between air quality, climate and climate change on different scales, and

(ii) to develop improved integrated tools for prediction of air pollution in cities.



MACC project:

Monitoring of Atmosphere Composition and Climate



Supporting programs and projects:

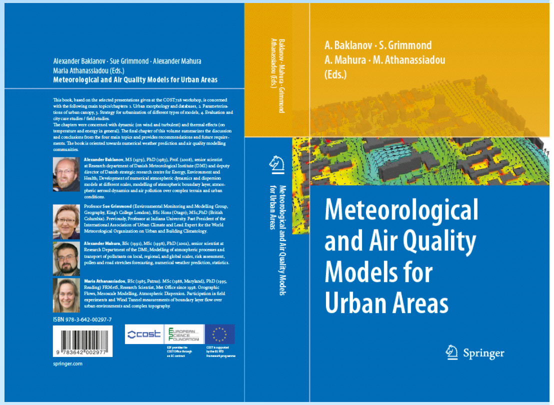
- NetFAM - Nordic Network on Fine-scale Atmospheric Modelling (http://netfam.fmi.fi/)
- MUSCATEN - Towards Multi-Scale Modelling of the Atmospheric Environment (http://muscaten.ut.ee/)
- COST728 - Enhancing Meso-scale Meteorological Modelling Capabilities for Air Pollution and Dispersion Applications
- COST ES0602 - Chemical Weather Forecasting
- New proposed COST Action EuMetChem - European framework for online integrated air quality and meteorology modelling
- CEEH - Danish Strategic Research Centre for Energy, Environment and Health (http://www.ceeh.dk)
- FP7 EC MEGAPOLI - Megacities: Emissions, urban, regional and Global Atmospheric POLlution and climate effects, and Integrated tools for assessment and mitigation (http://megapoli.dmi.dk)
- FP7 EC TRANSPHORM - Transport related Air Pollution and Health impacts – Integrated Methodologies for Assessing Particulate Matter
- FP7 EC MACC - Monitoring of Atmosphere Composition and Climate (http://www.gmes-atmosphere.eu/)
- TEMPUS - QualiMet - Development of Qualification Framework in Meteorology
- FP7 EC PEGASOS: Atmospheric chemistry and climate change interaction


RESEARCH AND DEVELOPMENT
Strategy for on-line integrated modelling
Coupling of chemical schemes
Convection and cloud microphysics
Dynamic-core
Land-surface scheme, urbanization
Aerosol chemistry
Radiation scheme, direct effects of gases and aerosols
Aerosol cloud indirect effects
Boundary layer and turbulence closure schemes
Data assimilation of chemical species
Validation (case studies and long-term evaluation)
DISSEMINATION
Publications and Presentations
HIRLAM Chemistry Branch
https://hirlam.org/trac/wiki/HirlamChemicalBranch/Introduction
Oper. versions setup for applications
Update of Enviro-HIRLAM versions
Links with boundary conditions, datasets scenarious
TECHNICAL SUPPORT
Advising and cosulting young researches
Networking MUSCATEN, TEMPUS, MEGAPOLIS
NWP+ACT integrated modelling schools
Research training weeks
SCIENCE EDUCATION
Enviro Hirlam

Collaboration with COST, WMO, NorForsk, etc.

2008 - Overview of Existing Integrated (off- and on-line) Mesoscale Systems in Europe
COST-728 / WMO Sci. Report, Geneva, Switzerland, 122p.

2009 - Meteorological and Air Quality Models for Urban Areas
Baklanov, Grimmond, Mahura, Athanassiadou (Eds),
Springer, 169p. – (ISBN 978-3-642-00297-7)



2007/2011 - Integrated Systems of Meso-Meteorological and Chemical Transport Models - workshop and book
Baklanov, Mahura, Sokhi (Eds),Springer, 242p.

2008 – Young Scientists Summer School and Workshop – 1st YSSS+W
Integrated Modelling of Meteorological and Chemical Transport Processes / Impact of Chemical Weather on Numerical Weather Prediction and Climate Modeling
Zelenogorsk (near St.Petersburg) Russia, 7-15 Jul 2008
see details at http://netfam.fmi.fi/YSSS08/

2011 – 2nd YSSS+W (MUSCATEN network + CEEH)
Odessa, Ukraine, Summer 2011

Outcome → to COST Action ES0602: Chemical Weather Forecasting (2008-2012) and new COST ES1004: EuMetChem: European framework for online integrated air quality and meteorology modelling

HIRLAM-A 2009/2010 plan:
S4.3: Coupling with atmospheric chemistry

Responsible project leaders: Tijm, Baklanov

S4.3.1: Setup of HIRLAM chemistry branch

Time: April 2009

Tasks: 1) Upgrade Enviro-HIRLAM to HIRLAM 7.2. 2) Establish the HIRLAM chemistry branch based on this Enviro-HIRLAM version.

Staff resources for 2009: Korsholm, Yang

S4.3.2: Practical course for HIRLAM-chem/Enviro-HIRLAM users/developers

Time: January 2009

Tasks: 1) Make students and new Enviro-HIRLAM developers familiar with the system

Staff resources for 2009: Korsholm, Baklanov, Mahura, Gross, Sass, Yang

S4.3.3: Inclusion of aerosol effects in HIRLAM

Time: end of 2009

Tasks:

1) Study the cloud-aerosol feedback when online chemistry modelling in HIRLAM is possible.
2) Update radiation scheme or implement a new scheme that enables the representation of the impact of aerosols the radiation directly and on cloud radiative properties

Staff resources for 2009: Korsholm, KP Nielsen, Ivarsson, Rontu, etc.

S4.3.4: Optimization of HIRLAM output for offline ACT coupling

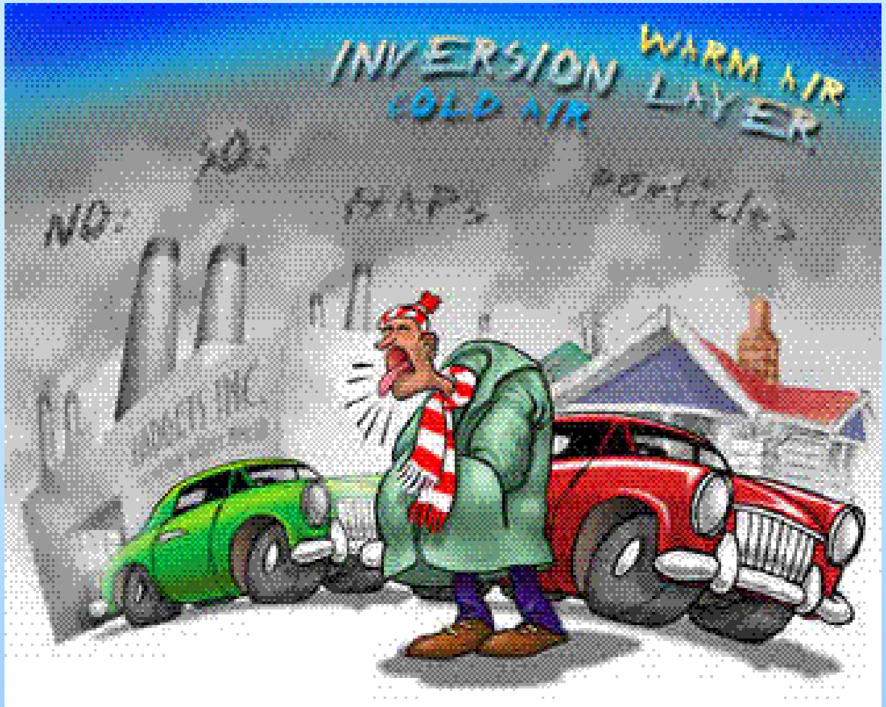
Tasks: Make extra parameters available in the HIRLAM postprocessing, if necessary.

Staff resources for 2009: Tijm, etc.

Enviro-HIRLAM/HARMONIE further work is also included into HIRLAM-B plans

Thank You !

HIRLAM Chemical Branch email list: chemical@hirlam.org



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