Introductory presentation on Integrated NWP-ACT modelling and ENVIRO-HIRLAM project

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NetFAM-DMI Practical Course

"Environment - HIgh Resolution Limited Area Model (**Enviro-HIRLAM**)"

Copenhagen, Denmark, 26-31 January 2009

Danish Meteorological Institute (DMI), Research Department

Enviro-HIRLAM Course's Aim, Emphasis & Topics

- The course is oriented on students, young scientists and researches who are working or planning to work with the Enviro-HIRLAM system
- The aims of this event are:

  - to learn the current Enviro-HIRLAM model code, main developments in the system, and Enviro-HIRLAM research program;

  - to choose main topics of your research with Enviro-HIRLAM further development and its applications;

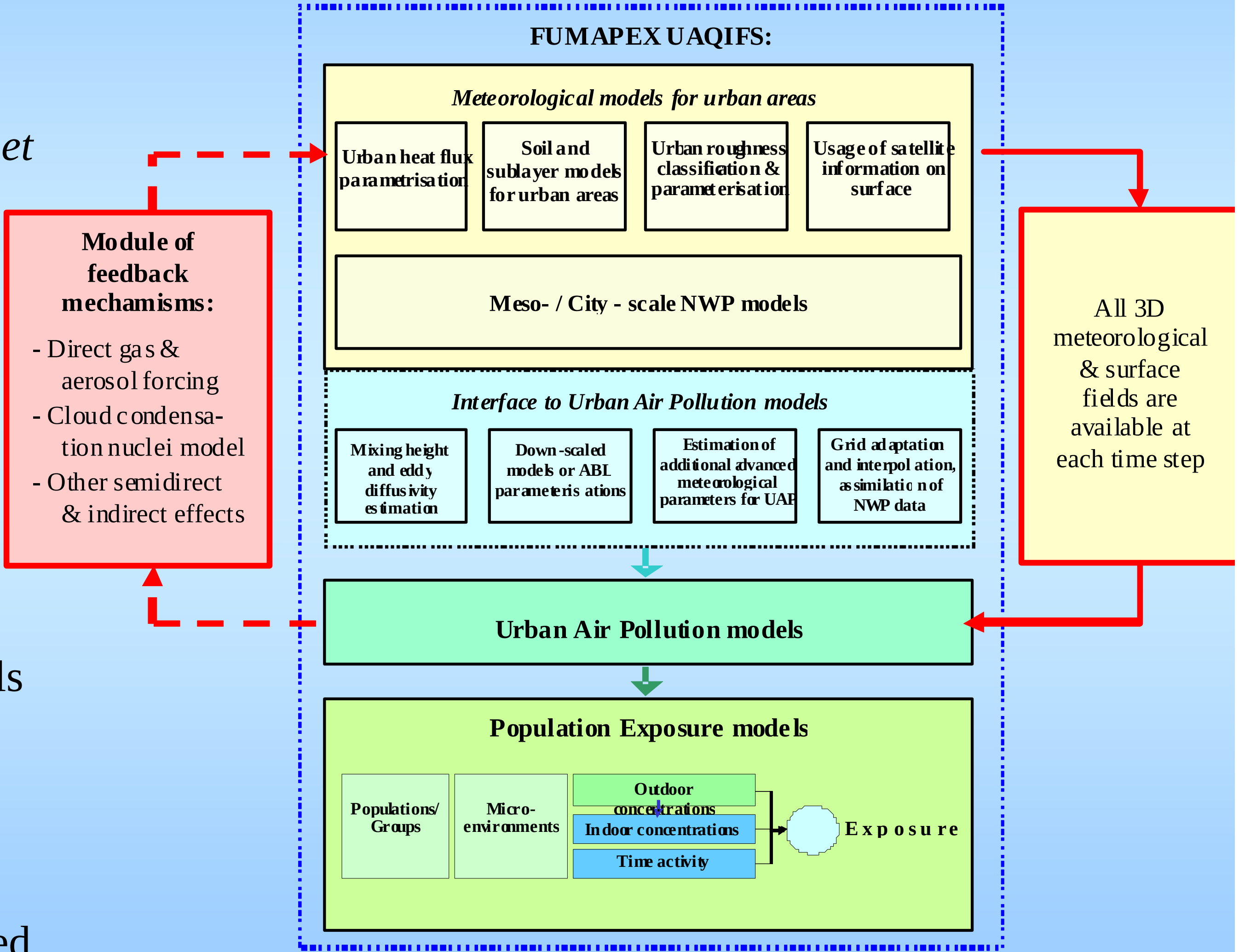
  - to discuss individually (or by small groups) concrete scientific tasks for your further research with Enviro-HIRLAM .
- We proceed from the assumption that main theoretical knowledge for Enviro-HIRLAM was already presented on the NetFAM Summer School on Integrated Modelling held in July 2008 (Zelenogorsk, Russia) and all the participants refreshed your general knowledge/ basics from lectures on the web-site: http://netfam.fmi.fi/YSSS08/SS/school_prese.html

Chemical weather forecast: the main concepts

- Chemical weather forecasting (CWF) - is a new quickly developing and growing area of atmospheric modelling.
- Possible due to quick growing supercomputer capability and operationally available NWP data as a driver for atmospheric chemical transport models (ACTMs).
- The most common simplified concept includes only operational air quality forecast for the main pollutants significant for health effects and uses numerical ACTMs with operational NWP data as a driver.
- Such a way is very limited due to the off-line way of coupling the ACTMs with NWP models (which are running completely independently and NWP does not get any benifits from the ACTM) and not considering the feedback mechanisms.
- Many experimental studies and research simulations show that atmospheric processes (meteorological weather, including the precipitation, thunderstorms, radiation budget, cloud processes and PBL structure) depend on concentrations of chemical components (especially aerosols) in the atmosphere.
- Therefore ACTMs have to be run together at the same time steps using online coupling and considering two-way interaction between the meteorological processes, from one side, and chemical transformation and aerosol dynamics, from other side.
- Complete new concept and methodology considering the chemical weather as two-way interacted meteorological weather and chemical composition of the atmosphere.
- CWF should include not only health-effecting pollutants (air quality components) but also GHGs and aerosols effecting climate, meteorological processes, etc.
- Strategy of new generation online integrated meteorology and ACT modelling systems for predicting atmospheric composition, meteorology and climate change (as a part of and a step to Earth Modelling Systems).

Different types of integrated urban air quality integrated models

1. Off-line integrated urbanised UAQIFS in FUMAPEX (*Baklanov et al., 2006, 2008, ACP*)
2. On-line integrated new generation system with feedbacks: urbanised EnviroHIRLAM (*Chenevez etal 2004, Baklanov et al. 2008, Korsholm 2009*)
3. Simplified urban models for emergency preparedness: e.g. ARGOS (*Hoe et al., 2007*) ➔ Urban preprocessors are needed



Definitions of integrated/coupled models

Definitions of off-line models:

• **separate CTMs driven by meteorological input data from meteo-preprocessors, measurements or diagnostic models,**

• **separate CTMs driven by analysed or forecasted meteodata from NWP archives or datasets,**

• **separate CTMs reading output-files from operational NWP models or specific MetMs with a limited periods of time (e.g. 1, 3, 6 hours).**

Definitions of on-line models:

• **on-line access models, when meteodata are available at each time-step (it could be via a model interface as well),**

• **on-line integration of CTM into MetM, when CTM is called on each time-step inside MetM and feedbacks are available. We will use this definition as on-line coupled modelling.**

Implementation of the feedback mechanisms into integrated models:

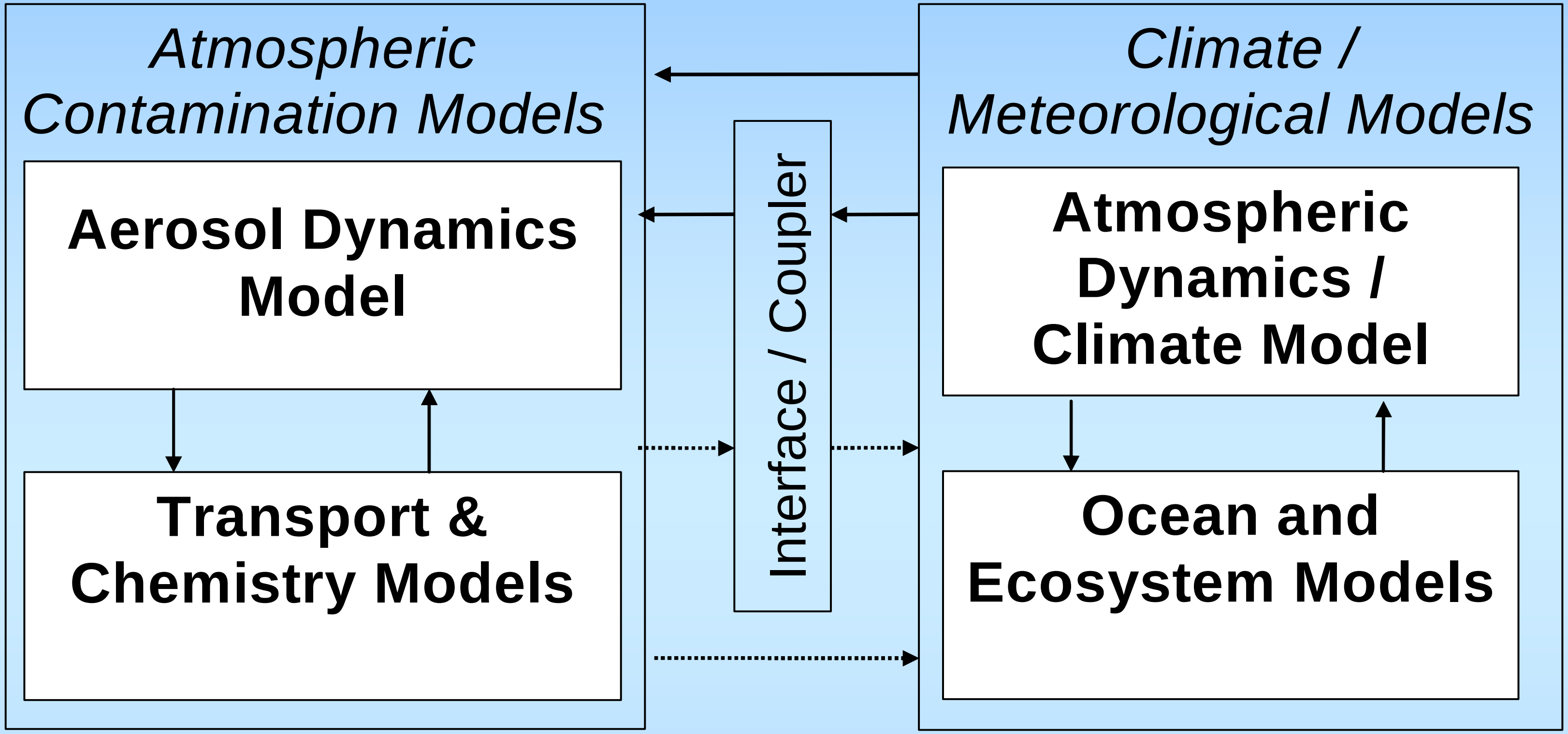
One-way integration (off-line):

- 1. Simplest way (no aerosol forcing): Climate/NWP meteo-fields as a driver for CTM (this classical way is used already by most of air pollution modellers);
- 2. CTM chemical composition fields as a driver for Regional/Global Climate Models (including the aerosol forcing on meteo-processes, it could also be realized for NWP or MetMs).

Two-way integration:

- 1. Driver + partly aerosol feedbacks, for CM or for NWP (data exchange in both directions with a limited time period coupling: off-line or on-line access coupling, with or without second iteration with corrected fields);
- 2. Two-way/chain full feedbacks included on each time step (on-line coupling/integration).

Integrated Atmospheric System Model Structure



One-way: 1. Meteo-fields as a driver for ACTM; 2. Chemical composition fields as a driver for R/GCM (or for NWP)

Two-way: 1. Driver + partly feedback (data exchange); 2. **Full feedbacks included on each time step (on-line coupling)**

Advantages of On-line & Off-line modeling

On-line coupling

- Only one grid;
- No interpolation in space
- No time interpolation
- Physical parameterizations are the same; No inconsistencies
- Harmonised advection schemes for all variables (meteo and chemical)
- Possibility to consider aerosol forcing mechanisms
- All 3D met. variables are available at the right time (each time step); No restriction in variability of met. fields
- Possibility of feedbacks from meteorology to emission and chemical composition
- Does not need meteo- pre/post-processors

Off-line

- Possibility of independent parameterizations;
- Low computational cost (if NWP data are already available and no need to run meteorological model);
- More suitable for ensembles and operational activities;
- Easier to use for the inverse modelling and adjoint problem;
- Independence of atmospheric pollution model runs on meteorological model computations;
- More flexible grid construction and generation for ACT models,
- Suitable for emission scenarios analysis and air quality management.

Non-European Union countries experience

- from America: the US EPA and other US and Canadian institutions (see WRF-Chem; Grell et al., 2005; (GATOR-MMTD: Jacobson, 2005, 2006; Byun and Schere, 2006; GEM-AQ: Kaminski et al., 2005; etc.);
- from Russia, e.g. one of the first experience in on-line coupling atmospheric pollution models and meteorological models in the Novosibirsk scientific school (Marchuk, 1982; Penenko and Aloyan, 1985; Baklanov, 1988), for example for modelling of active artificial/anthropogenic impacts on atmospheric processes;
- from Japan: integrated chemical weather forecasting systems, using the Earth Simulator CFORS (Uno et al., 2003, 2004), CHASER (Takigawa et al., 2007), etc.

Characteristics of On-line coupled MetM - CTMs in Europe

Model name	On-line coupled chemistry	Time step for coupling	Feedback
BOLCHEM	Ozone as prognostic chemically active tracer		None
ENVIRO-HIRLAM	Gas phase, aerosol and heterogeneous chemistry	Each HIRLAM time step	Yes
WRF-Chem	RADM+Carbon Bond, Madronich+Fast-J photolysis, modal+sectional aerosol	Each model time step	Yes
COSMO LM-ART	Gas phase chem (58 variables), aerosol physics (102 variables), pollen grains	each LM time step	Yes (*
COSMO LM-MUSCAT (**	Several gas phase mechanisms, aerosol physics	Each time step or time step multiple	None
MCCM	RADM and RACM, photolysis (Madronich), modal aerosol	Each model time step	(Yes) (***
MESSy: ECHAM5	Gases and aerosols		Yes
MESSy: ECHAM5-COSMO LM (planned)	Gases and aerosols		Yes
MC2-AQ	Gas phase: 47 species, 98 chemical reactions and 16 photolysis reactions	each model time step	None
GEM/LAM-AQ	Gas phase, aerosol and heterogeneous chemistry	Set up by user – in most cases every time step	None
Operational ECMWF model (IFS) ECMWF GEMS modelling	Prog. stratos passive O3 tracer GEMS chemistry	Each model time ste Each model time step	 Yes
GME	Progn. stratos passive O3 tracer	Each model time step	
OPANA=MEMO+CBMIV		Each model time step	

*) Direct effects only; **) On-line access model; ***) Only via photolysis

On-line integrated meso-scale models

(WMO-COST728, 2008, see: www.cost728.org)

- At the current stage most of the online coupled models do not consider feedback mechanisms or include only direct effects of aerosols on meteorological processes (like COSMO LM-ART and MCCM).
- Only two meso-scale on-line integrated modelling systems (WRF-Chem and Enviro-HIRLAM) consider feedbacks with indirect effects of aerosols.

Aerosol feedbacks to be considered

- **Direct effect** - Decrease solar/thermal-infrared radiation and visibility:
  - Processes involved: radiation (scattering, absorption, refraction, etc.);
  - Key variables: refractive indices, extinction coefficient, single-scattering albedo, asymmetry factor, aerosol optical depth, visual range;
  - Key species: - cooling: water, sulphate, nitrate, most OC;
    - warming: BC, OC, Fe, Al, polycyclic/nitrated aromatic compounds;
- **Semi-direct effect** - Affect PBL meteorology and photochemistry:
  - Processes involved: PBL, surface layer, photolysis, meteorology-dependent processes;
  - Key variables: temperature, pressure, relative and water vapour specific humidity, wind speed and direction, clouds fraction, stability, PBL height, photolysis rates, emission rates of meteorology-dependent primary species (dust, sea-salt, pollen and other biogenic);
- **First indirect effect** (so called the Twomey effect) – Affect clouds drop size, number, reflectivity, and optical depth via CCN or ice nuclei:
  - Processes involved: aerodynamic activation / resuspension, clouds microphysics, hydrometeor dynamics;
  - Key variables: int./act. fractions, CCN size/compound, clouds drop size / number / liquid water content, cloud optical depth, updraft velocity;
- **Second indirect effect** (also called as the lifetime or suppression effect) - Affect cloud liquid water content, lifetime and precipitation:
  - Processes involved: clouds microphysics, washout, rainout, droplet sedimentation;
  - Key variables: scavenging efficiency, precipitation rate, sedimentation rate.

Scientific hypotheses/questions still to be tested/addressed

(formulated on COST-NetFAM workshop in Copenhagen, May 2007)

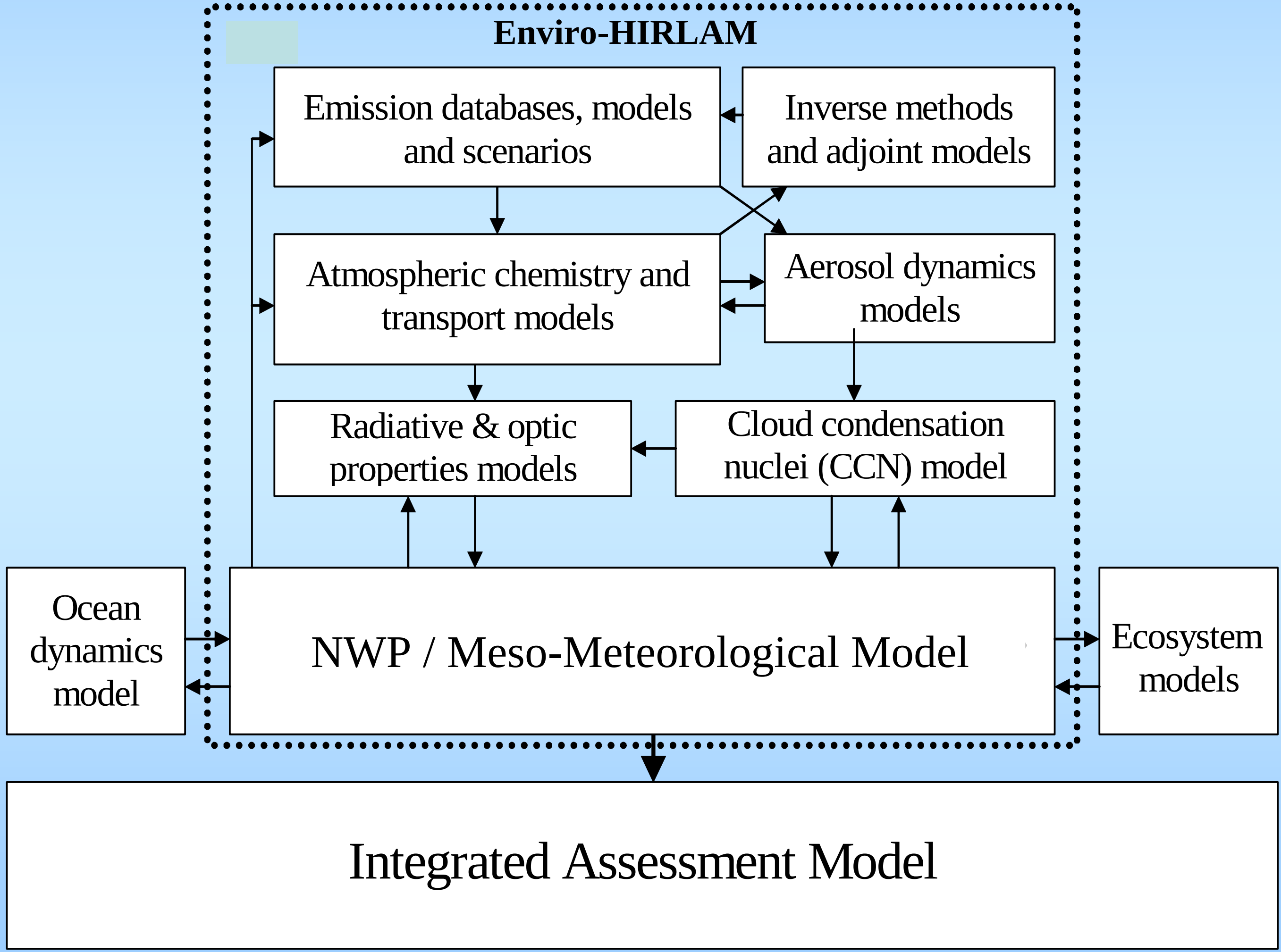
- **Hypothesis**
  - **Feedback mechanisms are important in accurate modeling of NWP/MM-ACT and quantifying direct and indirect effects of aerosols.**

  => *the answer is 'Yes, they can be very important'*

- **Key questions** *(still waiting for answers)*
  - **What are the effects of climate/meteorology on the abundance and properties (chemical, microphysical, and radiative) of aerosols on urban/regional scales?**
  - **What are the effects of aerosols on urban/regional climate/meteorology and their relative importance (e.g., anthropogenic vs. natural)?**
  - **How important the two-way/chain feedbacks among meteorology, climate, and air quality are in the estimated effects?**
  - **What is the relative importance of aerosol direct and indirect effects in the estimates on different time and space scales?**
  - **What are the key uncertainties associated with model predictions of those effects?**
  - **How can simulated feedbacks be verified with available datasets?**

Enviro-HIRLAM

New integrated (on-line coupled) modeling system structure for predicting the atmospheric composition



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) implementation of chemical mechanisms,

(vi) implementation of aerosol dynamics,

(vii) realisation of feedback mechanisms,

(viii) assimilation of monitoring data.

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 (K.Lindberg)
- 2005: 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 (currently there are several versions of the model code)

Plan for DMI-ENVIRO-HIRLAM development and applications

(2005 -2010), PI - ALB

1. DMI-HIRLAM related continued (2005 – 2007), after FUMAPEX:

URBANIZATION (Responsible persons - ALB, AMA, CP)

- DMI module (cont. cooperation with S. Zilitinkevich, HU, Finland), (involved NWN)
- SM2_U module (cont. cooperation with ECN, France), (involved NWN, KSA)
- BEP module (cont. cooperation with EPFL, Switzerland), (involved NWN, KSA)
- High resolution HIRLAM output for Urban ARGOS (cooper. DEMA, RISØ), (involved JHS)

ISBA LSS and PHYSICS PARAMETRIZATIONS (PR – AMA, involved NWN, BHS, KSA, ALB)

LUC and CGF FOR HIGH RESOLUTION MODELLING (RP – KSA, involved AMA, USN, AGR, AR)

ABL HEIGHT PARAMETRIZATIONS (RP – ALB, involved NWN, AMA)

2. Environment Integrated Modelling related (DMI, COGCI, COST728):

- **SI-CISL advection scheme** (2005-2006), (RP – KLI, involved USN, EK)
- **AEROSOLS** (2005 – 2007), (RP – USN, involved ALB, AGR)
- **POLLEN** (2005 – 2007), (RPs – AR, AMA, ALB, cooper. FMI)
- **CHEMISTRY** (2006 – 2008), (RP – AGR, involved ALB, USN)
- **RISK** (incl. Enviro-RISKS project) (2005 – 2008), (RP – ALB, involved JHS, AMA, AR, AGR, USN; cooper. RISØ)
- **FEEDBACKS** (2007 – 2009), (RP – USN, involved ALB, AGR)

3. Data assimilation /Ph.D. Student/ (2008 – 2010), (involved XYH, ALB, JHS, AGR)

Enviro-HIRLAM research team:

Currently 4 institutions are working:

- Danish Meteorological Institute (A.Baklanov, U. Korsholm, A. Gross, A. Mahura, B.H. Sass, K.P. Nielsen, etc),
- University of Copenhagen (E. Kaas, etc),
- Tomsk State University (R. Nuterman, etc.),
- Russian State Hydro-Meteorological University (S. Smyshlyaev, etc.)
- HIRLAM-A program of the HIRLAM consortium (HIRLAM Chemical brunch).

Teams willing to join the development team:

- University of Tartu, Estonia,
- Belgium Royal Meteorological Institute,
- Vilnius University, Lithuania,
- Odessa State Environmental University, Ukraine.

There is an initial working group (under COST728 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!

Applications of Enviro-HIRLAM for:

(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.),

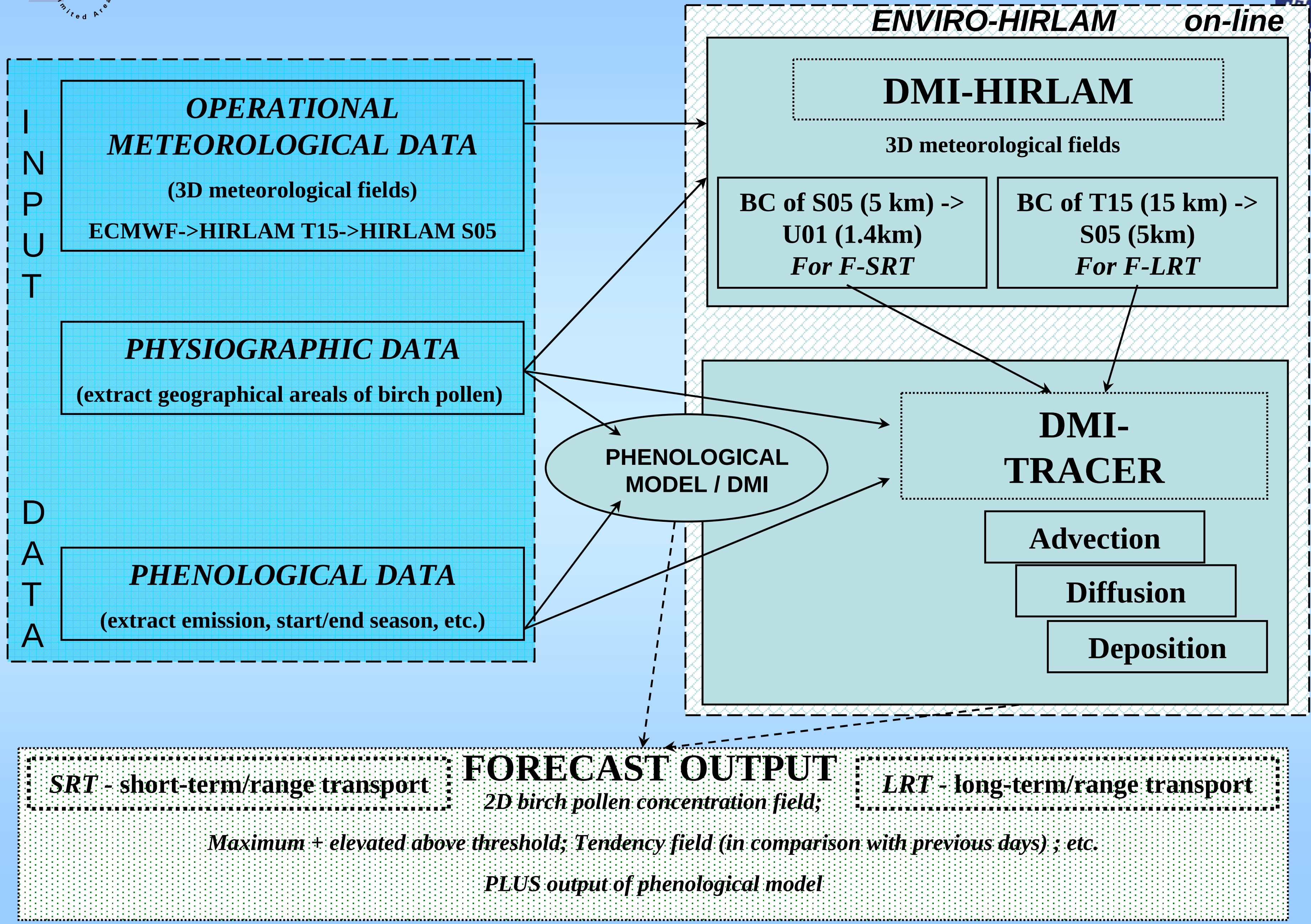
(iv) pollen forecasting,

(v) climate change modelling (Enviro-HIRHAM),

(vi) volcano eruptions, nuclear explosion consequences

(vii) Other emergency preparedness

DMI-ENVIRO-HIRLAM for BIRCH POLLEN



Further work with Enviro-HIRLAM development

There are a number of outstanding issues which will be dealt with in the future, e.g.:

- Enviro-HIRLAM to be optimized to the new CRAY-XT5 at DMI (this work is going),
- the model will be updated to HIRLAM version 7.2,
- will be implemented and available on the chemical branch of HIRLAM,
- all modules/models from diff. vers. to be tested in the reference version of EnviroHIRLAM
- improvement and validation of the direct and indirect aerosol effects,
- implementation of the gas feedback mechanisms,
- implementation and parallelization of a new advection scheme,
- updates for the gas-phase chemistry and aerosol modules, their validation,
- in MEGAPOLI it is planed to test EnviroHIRLAM with the aerosol model from University of Helsinki,
- improved representation of PBL and SL, further 'urbanization' of the model,
- a new mass conservative horizontal diffusion scheme will be implemented,
- heterogeneous chemistry will be expanded, implemented and validated,
- data assimilation for the chemical compounds to be implemented,
- expansion of the HARMONIE system to include the Enviro-HIRLAM chemistry and aerosol features and feedbacks,
- Climate version of the Enviro-HIRLAM => Enviro-HIRHAM (based on newest HIRLAM version)
- ……

These would be a joint effort for the Enviro-HIRLAM developers and HIRLAM consortium.

HIRLAM-A: Two different tasks in HIRLAM-ACTM

(i) improvement of HIRLAM outputs for ACT modelling applications and correspondingly improvement of ACT models (for different off-line ACT models, like MATCH, SILAM, EMEP, CAC, DERMA; DACFOS),

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

Some joint actions

- Opening the HIRLAM Chemical branch with implementation of the latest version of EnviroHIRLAM for further development work for all interested members
- Joint work with HIRLAM-A team improving the cloud/microphysics and radiation modules
- Continuity equation (advection) scheme improvement (CISL, other schemes tests) and schemes intercomparison/validation
- Exercise for off-line (and on-line) ACTMs linked with HIRLAM (considering feedbacks with EnviroHIRLAM version)
- Requirements from ACTM community to HIRLAM outputs and improvements
- Web-place for ACTM-HIRLAM integration group (public part)

HIRLAM-A 2009 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.

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

SEVENTH FRAMEWORK PROGRAMME

DMI

New EC 7FP project for: ENV.2007.1.1.2.1. Megacities and regional hot-spots air quality and climate

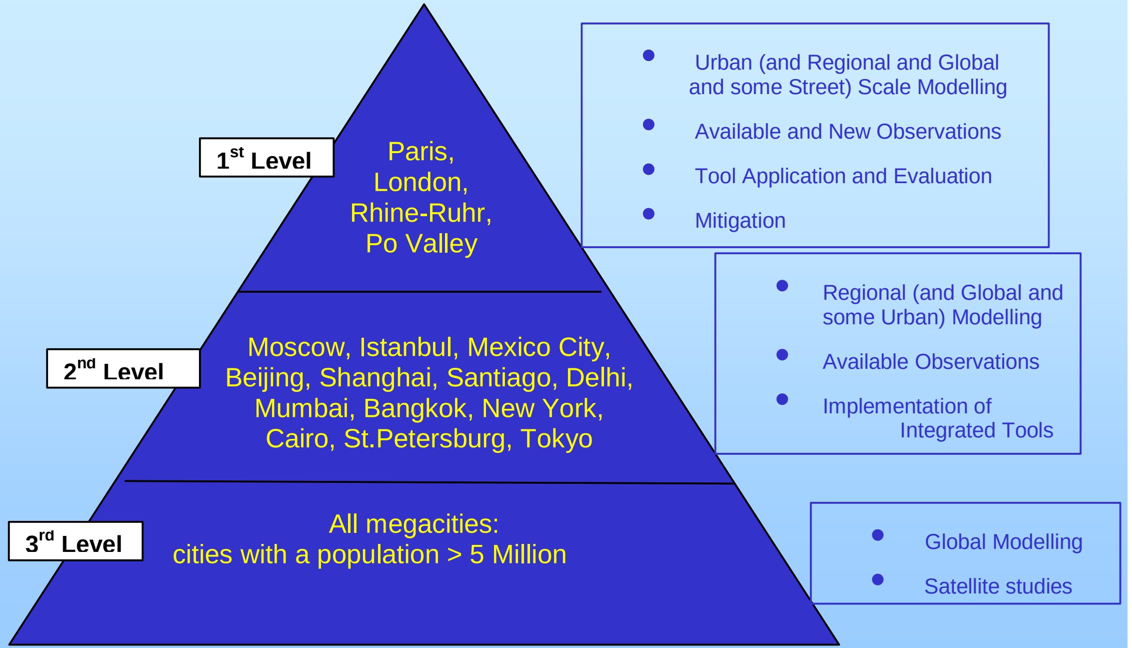
Project duration: 2008 - 2011 years
28 European research organisations from 12 countries are involved.
Coordinator: A. Baklanov (DMI)
Vice-coordinators: M. Lawrence (MPIC) and S. Pandis (FRTHUP)

(see: Nature, 455, 142-143 (2008), doi:10.1038/455142b)

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

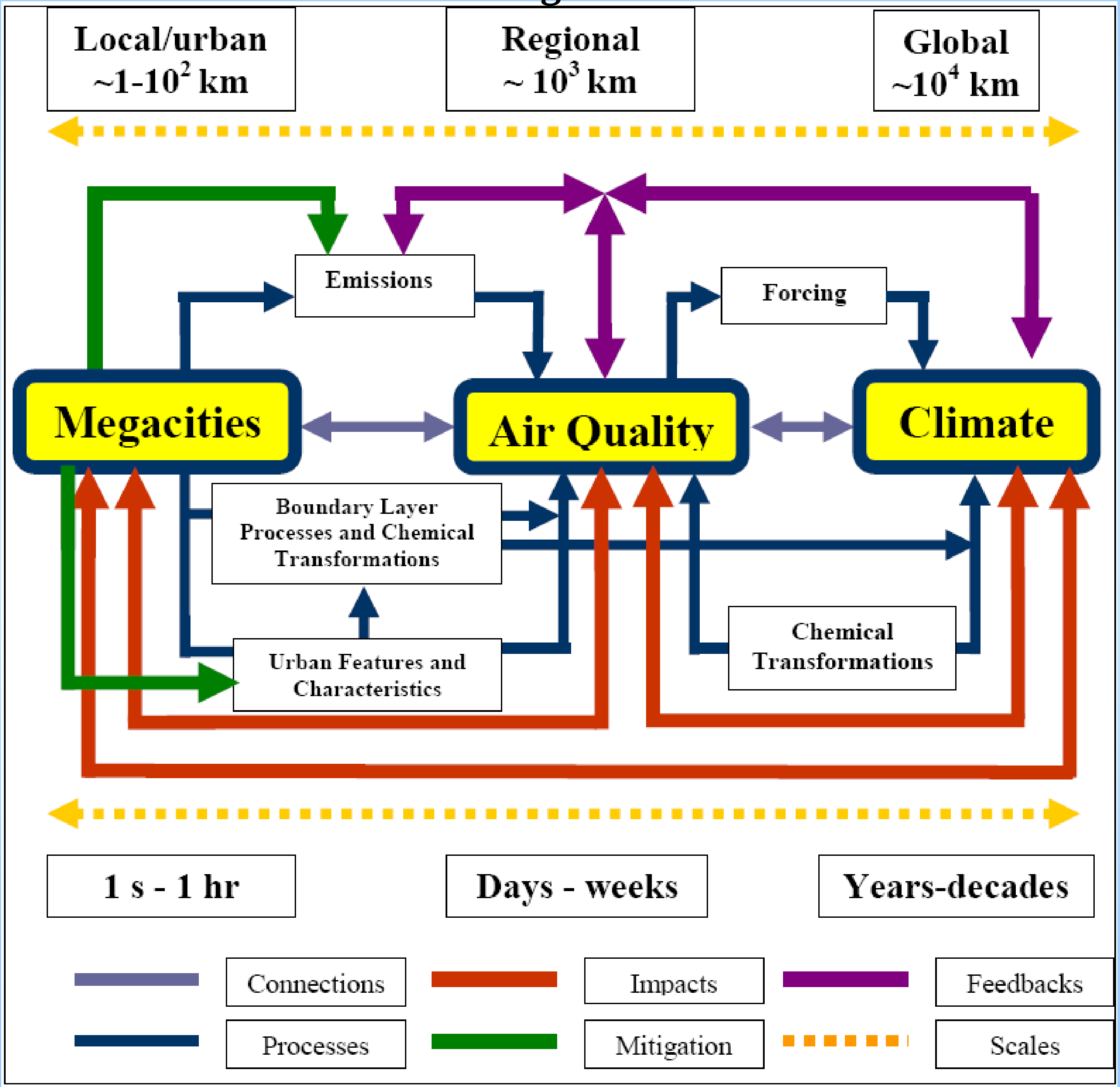
(i) to assess impacts of growing megacities and large air-pollution "hot-spots" on air pollution and feedbacks between air quality, climate and climate change on different scales, and

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



Connections between megacities, air quality and climate:

main feedbacks, ecosystem, health and weather impact pathways, and mitigation routes



Recommended Publications:

- Baklanov A., 2008: Integrated Meteorological and Atmospheric Chemical Transport Modeling: Perspectives and Strategy for HIRLAM/HARMONIE. *HIRLAM Newsletter*, 53: 68-78.
- Korsholm U.S., A. Baklanov, A. Gross, A. Mahura, B.H. Sass, E. Kaas, 2008: Online coupled chemical weather forecasting based on HIRLAM – overview and prospective of Enviro-HIRLAM. *HIRLAM Newsletter*, 54.
- Korsholm U. (2009) Integrated modeling of aerosol indirect effects - develoment and application of a chemical weather model. PhD thesis University of Copenhagen and DMI.
- Baklanov A., U. Korsholm, A. Mahura, C. Petersen, A. Gross, 2008: ENVIRO-HIRLAM: on-line coupled modelling of urban meteorology and air pollution. *Advances in Science and Research*, 2, 41-46
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- Baklanov, A., P. Mestayer, A. Clappier, S. Zilitinkevich, S. Joffre, A. Mahura, N.W. Nielsen, (2008) Towards improving the simulation of meteorological fields in urban areas through updated/advanced surface fluxes description. *Atmospheric Chemistry and Physics*, 8: 523-543.
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- Baklanov, A. and U. Korsholm: 2007: On-line integrated meteorological and chemical transport modelling: advantages an prospective. In: ITM 2007: Air Pollution Modelling and its Application, pp. 21-34.
- WMO-COST, 2007: Overview of Existing Integrated (off-line and on-line) Mesoscale Meteorological and Chemical Transport Modelling Systems in Europe, WMO GAW Report No. 177, Joint Report of COST Action 728 and GURME, 107 pp. Available from: http://www.cost728.org
- COST-NetFAM, 2008: Integrated systems of meso-meteorological and chemical transport models, Materials of the COST 728/NetFAM workshop, DMI, Copenhagen, 21-23 May 2007, 183 pp. Available from: http://www.cost728.org

Thank You !

Acknowledgements:

DMI: http://dmi.dk
COST728: www.cost728.org
COGCI: http://www.cogci.dk
FUMAPEX: www.fumapex.dmi.dk
MEGAPOLI: http://megapoli.dmi.dk
HIRLAM-A: http://hirlam.org
COST-EC0602: http://www.chemicalweather.eu
NetFAM: http://netfam.fmi.fi