Introduction to Integrated Modelling of Meteorological and Chemical Transport Processes

Alexander A. Baklanov
Danish Meteorological Institute, DMI, Copenhagen
alb@dmi.dk, phone: +45 39157441

Introductory lecture for

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

- Meteorological modelling,
- integration of gases and aerosols,
- on-line versus off-line,
- feedbacks,
- Enviro-HIRLAM online coupled system

Objective: what will be the basic subjects of the school, short overview of all these subjects.

School's Aim, Emphasis and Topics

The aim of this event is to join young scientists and researches of the HIRLAM community in order to elaborate, outline, discuss and make recommendations on the best strategy and practice for further developments and applications of the integrated modelling of both meteorological and chemical transport processes into the HIRLAM/HARMONIE modelling system.

The main emphasis is on fine-resolution models applied for chemical weather forecasting and feedback mechanisms between meteorological and atmospheric pollution (e.g. aerosols) processes.

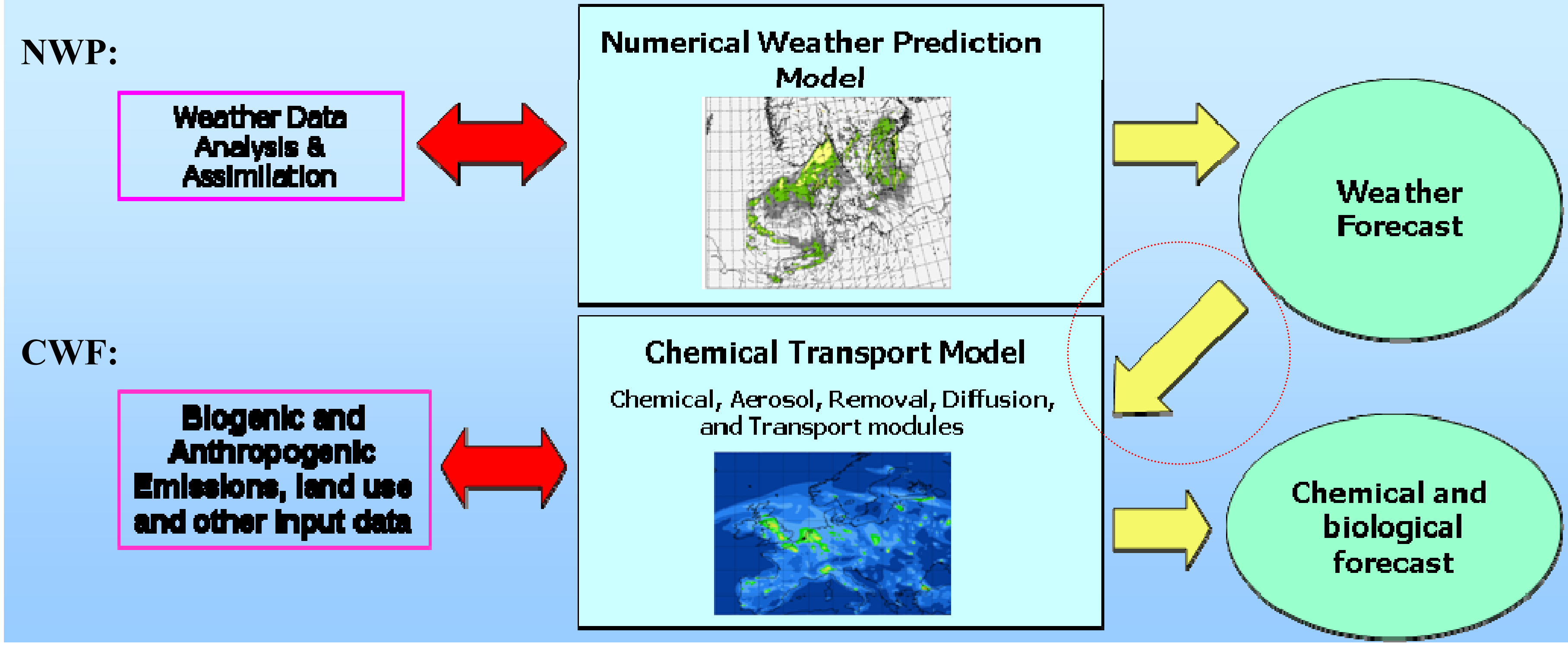
The main topics will include:

- general introduction to meteorological modelling (numerical weather prediction, parameterizations and physics, numerics, advection, land-use, radiation, clouds, aerosols, urbanization) for MM-ACTM integration;
- off-line vs. on-line meteorology-chemistry-aerosol (ACA) modelling;
- possible feedbacks and their impact from ACA on short and long time-range atmospheric circulation models; etc.

Motivation:
Physical and Chemical Weather: Off-line coupling

- Numerical Weather Prediction (Meteorological) and Air Quality Modelling – two independent problems and research communities.
- Chemical weather forecasting (CWF) - is a new, quickly developing and growing area of atmospheric modelling.

The most common simplified concept of CWF 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 (no feedbacks).



Motivation:
Physical and Chemical Weather Forecast: New concept

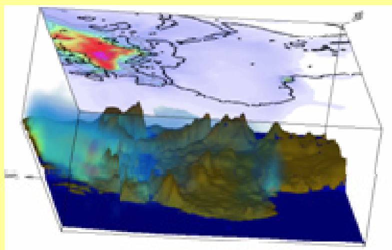
- Many experimental studies and research simulations show that atmospheric processes (meteorological weather, incl. precipitation, thunderstorms, radiation, clouds, fog, visibility and PBL structure) depend on concentrations of chemical components (especially aerosols) in the atmosphere.
- Meteorological data assimilation (in particular assimilation of radiances) depends on the chemical composition.
- Studies also show that air quality forecasts loose accuracy when CTM's are run offline.

New generation of online integrated meteorology and chemistry modelling systems for predicting atmospheric composition, meteorology and climate change is really needed.

Meteorological and Chemical Data Analysis & Assimilation & Emissions

Integrated numerical weather and *chemistry forecasting model*

Full interaction of Chemistry, Aerosols and Meteorology: radiation, clouds, etc.



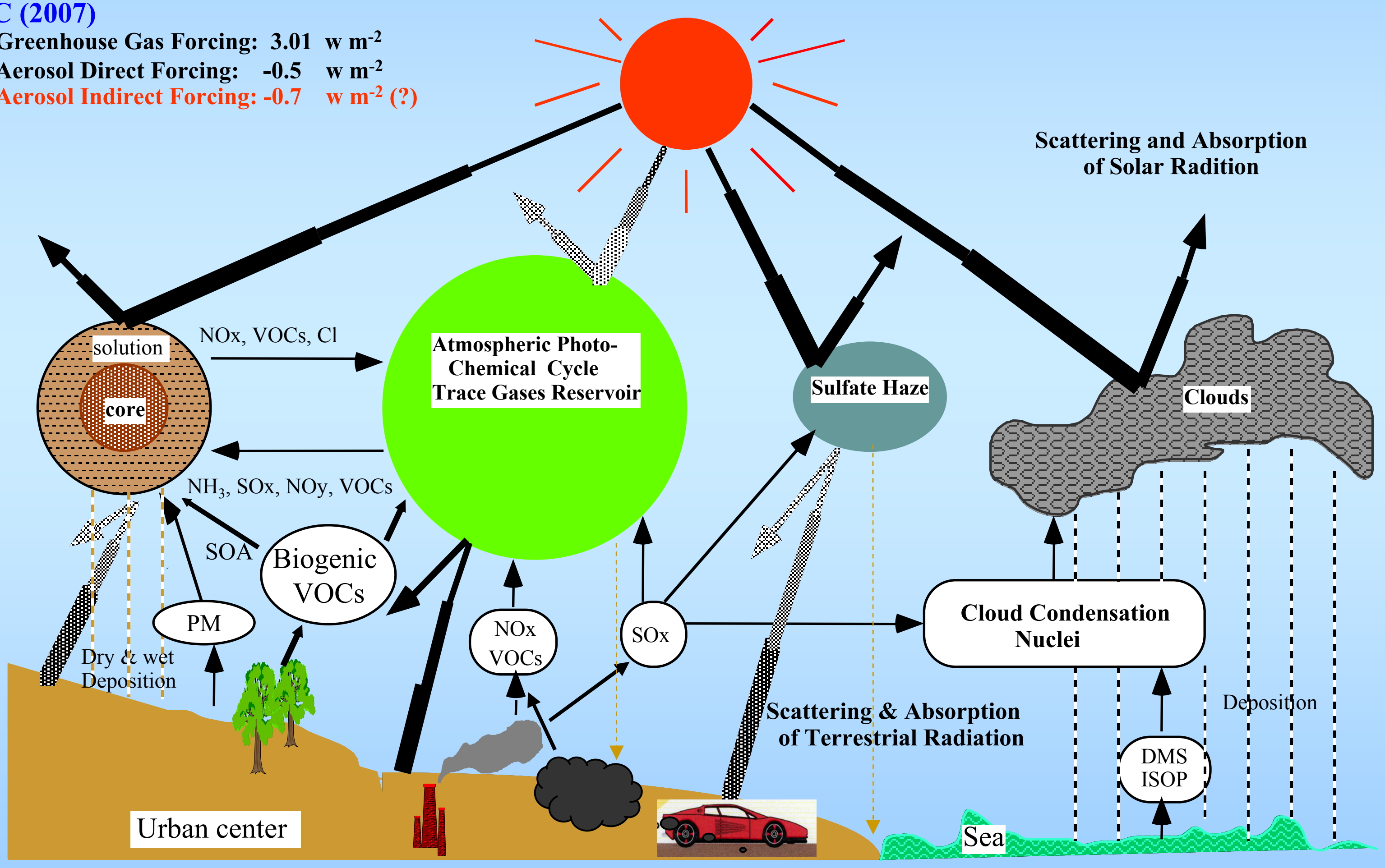
Meteorological, chemical and biological forecast

Atmosphere Interactions:

Gases, Aerosols, Chemistry, Transport, Radiation, Climate

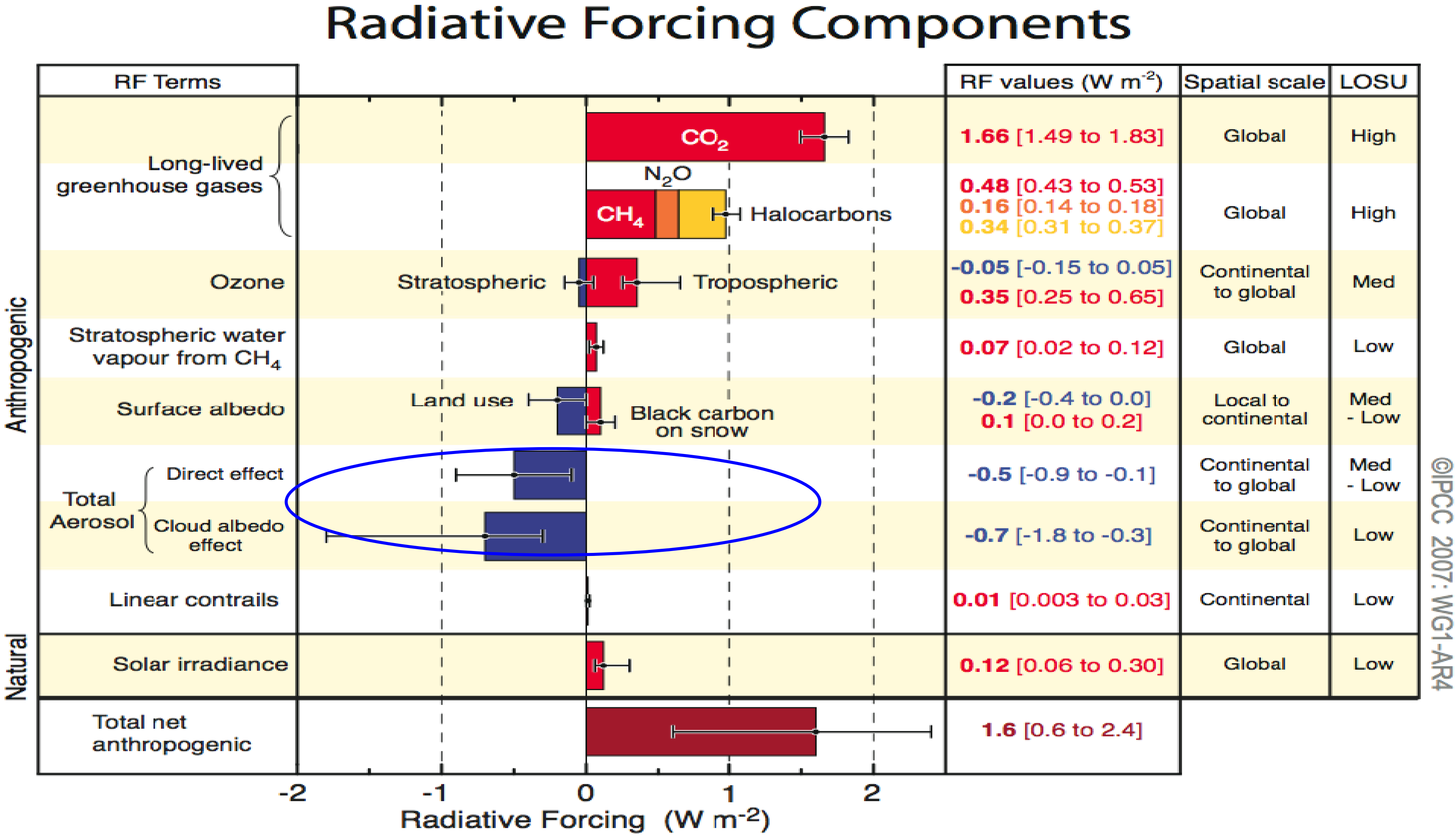
IPCC (2007)

Greenhouse Gas Forcing: 3.01 w m^{-2}
Aerosol Direct Forcing: -0.5 w m^{-2}
Aerosol Indirect Forcing: -0.7 w m^{-2} (?)



After Y. Zhang, DMI, Copenhagen, 2007

2007 IPCC Estimate of Gas and Aerosol Radiative Effects

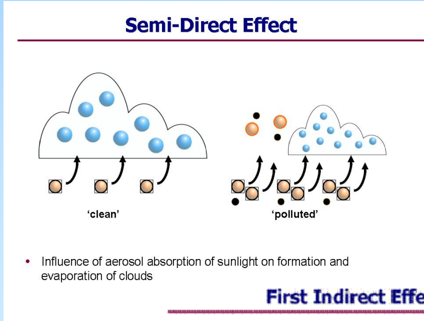


Examples of Important Feedbacks

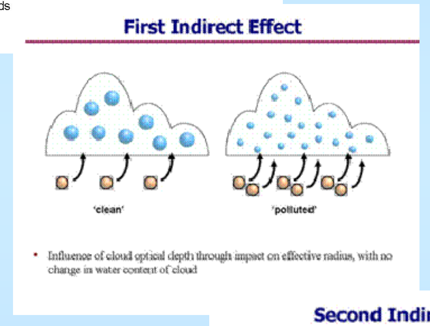
- **Effects of Meteorology and Climate on Gases and Aerosols**
  - Meteorology is responsible for atmospheric transport and diffusion of pollutants
  - Changes in temperature, humidity, and precipitation directly affect species conc.
  - The cooling of the stratosphere due to the accumulation of GHGs affects lifetimes
  - Changes in tropospheric vertical temperature structure affect transport of species
  - Changes in vegetation alter dry deposition and emission rates of biogenic species
  - Climate changes alter biological sources and sinks of radiatively active species
- **Effects of Gases and Aerosols on Meteorology and Climate**
  - Decrease net downward solar/thermal-IR radiation and photolysis (direct effect)
  - Affect PBL meteorology (decrease near-surface air temperature, wind speed, and cloud cover and increase RH and atmospheric stability) (semi-indirect effect)
  - Aerosols serve as CCN, reduce drop size and increase drop number, reflectivity, and optical depth of low level clouds (LLC) (the Twomey or first indirect effect)
  - Aerosols increase liquid water content, fractional cloudiness, and lifetime of LLC but suppress precipitation (the second indirect effect)

Motivation: Aerosol Effects on Atmospheric Processes

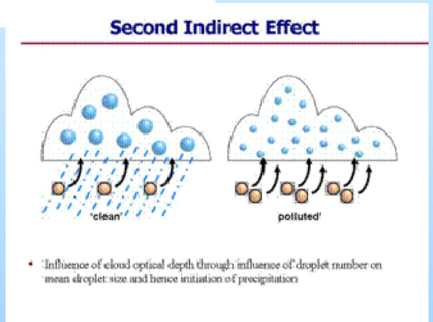
- **<u>Direct effect</u> → decrease solar/ thermal-IR radiation and visibility;**
  warming: GHGs, BC, OC, Fe, Al, polycyclic/nitrated aromatic compounds
  cooling: water, sulfate, nitrate, most OC
  (scattering, absorption, refraction, etc.)



- **<u>Semi-direct effects</u> → affect PBL meteorology and photochemistry;**



- **<u>First indirect effect</u> → affect cloud drop size, number, reflectivity, and optical depth via CCN;**



- **<u>Second indirect effect</u> → affect cloud liquid water content, lifetime, and precipitation;**

- **<u>Chain of all aerosol effects</u> (nonlinear interaction)**

⇒ **High-resolution on-line models with a detailed description of the PBL structure are necessary to simulate such effects**

⇒ **On-line integrated models are necessary to simulate correctly the effects involved 2nd feedbacks**

Definitions of integrated/coupled models

Definition 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).**

Definition 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.**

Shortcomings of existing NWP models for using in Chemical Weather Forecasting:

- Atmospheric environment modelling requires to resolve more accurately the PBL and SLs structure in NWP models (in comparison with weather forecast tasks)
- Despite the increased resolution of existing operational NWP models, urban and non-urban areas mostly contain similar sub-surface, surface, and boundary layer formulation.
- These do not account for specifically urban dynamics and energetics and their impact on the ABL characteristics (e.g. internal boundary layers, urban heat island, precipitation patterns).
- Numerical advection schemes in the meteorological part are not meeting all the requirements for ACTMs, so they should be improved and harmonized in NWP and ACT models.
- NWP models are not primarily developed for air pollution modelling and their results need to be designed as input to or be integrated into urban and meso-scale air quality models.

Advantages of On-line & Off-line modeling

On-line coupling

- Only one grid;
- No interpolation in space
- No time interpolation
- Possibility to consider aerosol forcing mechanisms
- All 3D met. variables are available No restriction in variability, no mass consistency concerns
- Possibility of feedbacks from meteorology to emission and chemical composition
- Does not need meteo- pre/post-processors
- Physical parameterizations are the same; No inconsistencies
- Harmonised advection schemes for all variables (meteo and chemical)
- Maybe more suitable for ensembles

Off-line

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

Applications of integrated models for:

(i) climate change modelling,

(ii) weather forecast (e.g., in urban areas, severe weather events, etc.),

(iii) air quality and chemical composition longer-term assessment and

(iv) chemical and biological weather forecasting

(v) Nuclear war or explosion consequences

(vi) Emergency preparedness

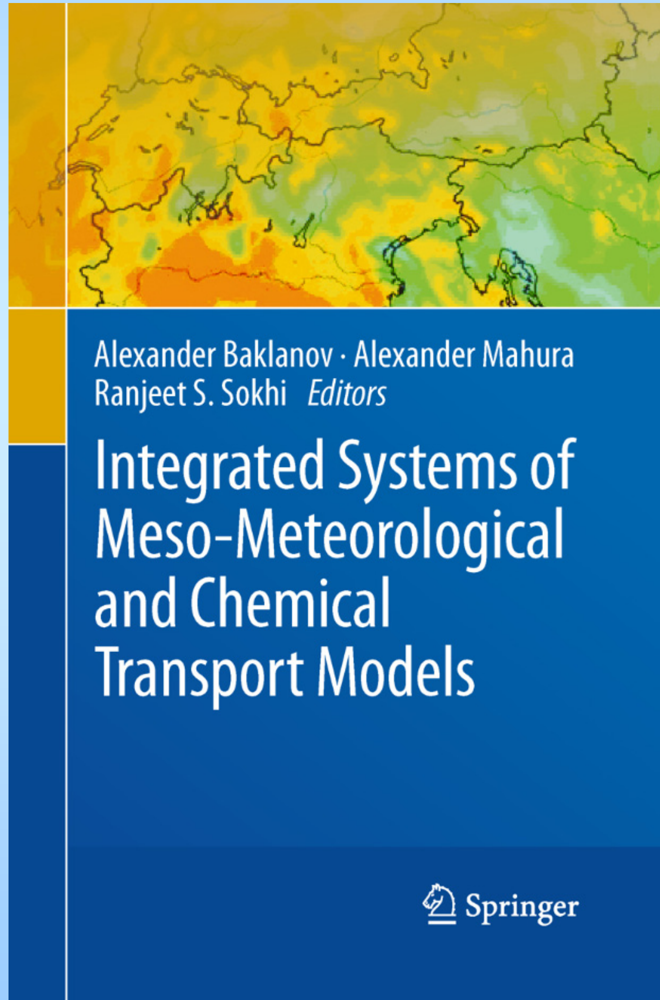
(vii) Stratospheric dynamics and cloud models

(viii) Indoor microclimate and air quality

European operational CWF models

- ***European CWF portal***: http://www.chemicalweather.eu/Domains

- ***Kukkonen et al, ACPD, 2011***: overview of 18 selected regional CWF models used in Europe: ALADIN-CAMx (Austria), CAMx-AMWFG (Greece), EURAD-RIU (Germany), Enviro-HIRLAM (Denmark and others), FARM (Italy), LOTOS-EUROS (The Netherlands), MATCH (Sweden), MM5-CAMx (Greece), MM5-CHIMERE (France and Portugal), MM5/WRF-CMAQ (Spain, UK), MOCAGE (France, Spain, Romania), NAME (United Kingdom), OPANA (Spain and others), RCG (Germany), SILAM (Finland, Estonia, Russia, Lithuania and Spain), SKIRON/Dust (Greece), THOR (Denmark), WRF-Chem (Spain and others)
- Only two of them (Enviro-HIRLAM and WRF-Chem) are online coupled
- Recently published Springer book (***Baklanov et al., 2011***) with description of main coupled ACT-MM models => 15 online =>



ISBN: 978-3-642-13979-6

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.

Online coupled or online access Atmospheric Chemistry-Meteorology models developed or applied in Europe (1)

Model/Country/References	Online coupled gas phase chemistry and aerosol	Feedback of pollutants to meteorology	Applications	Scale
BOLCHEM, Italy http://bolchem.isac.cnr.it/	SAPRC90 gas phase chemistry, AERO3 aerosol module	Direct aerosol effect on radiation	CWF; climate; Episodes	Continental to regional
COSMO-ART, Germany Vogel et al., 2009	Extended RADM gas phase chemistry, modal aerosol, soot, pollen, mineral dust	Direct aerosol effect on radiation	Episodes	Continental to regional
COSMO-LM-MUSCAT, Germany Wolke et al., 2004; Heinold et al., 2007	RACM gas phase chemistry, 2 modal aerosol models, mineral dust module	Direct aerosol effect on radiation for mineral dust	Episodes	Continental to regional
ECHAM5/6-HAMMOZ, Germany Pozzoli et al., 2008	MOZART gas phase chemistry, HAM aerosol scheme	Direct aerosol effect, indirect aerosol effect	Episodes, long term	Global
ENVIRO-HIRLAM, Denmark and HIRLAM countries Baklanov et al, 2008; Korsholm et al., 2008	NWP gas phase chemistry, modal and sectional aerosol modules, liquid phase chemistry	Direct and indirect aerosol effects	Episodes, chemical weather forecast	Hemispheric to regional and urban
IFS-MOZART (MACC/ECMWF) Flemming et al., 2009, Kinnison et al., 2007, http://www.gmes-atmosphere.eu	MOZART gas phase chemistry with updates to JPL-06, MACC aerosol scheme	Direct aerosol effect, indirect aerosol effect	Forecasts, Re-analysis, Episodes	Global
MC2-AQ, Canada (used in Polen) Kaminski et al., 2007	ADOM gas phase chemistry	none, but possible	Episodes	Regional to urban
Meso-NH, France http://mesonh.aero.obs-mip.fr/mesonh/	RACM or ReLACS gas phase chemistry, modal aerosol module	Direct aerosol effect	Episodes	Continental to regional
MESSy(-ECHAM5) , Germany Jöckel et al., 2005; http://www.messy-interface.org/	Various gas phase chemistry modules, modal aerosol module	Direct aerosol effect, indirect aerosol effect	Episodes, long term	Global

Online coupled or online access Atmospheric Chemistry-Meteorology models developed or applied in Europe (2)

Model/Country/References	Online coupled gas phase chemistry and aerosol	Feedback of pollutants to meteorology	Applications	Scale
MCCM, Germany Grell et al., 2000; Forkel & Knoche, 2006	RADM, RACM or RACM-MIM with modal aerosol module	Direct aerosol effect	Episodes, climate-chemistry	Regional
MetUM (Met Office Unified Model), UK Morgernstern et al, 2009; O' Connor et al 2010	2 tropospheric chemistry schemes, 1 stratospheric chemistry scheme. 2 alternative aerosol schemes.	Direct and indirect effects of aerosols, radiative impacts of N_2O, O_3, CH_4	Episodes, CWF, climate-chem. studies, long-range transport	Regional to Global
M-SYS (online version), Germany von Salzen and Schlünzen, 1999	RADM Gas phase chemistry, sectional aerosol module	none, but possible	Episodes	Regional to local
RegCM-Chem, Italy Zakey et al., 2006, Solmon et al., 2006	Updated GEOS-CHEM RACM, CBMZ, unimodal aerosol, sectional mineral dust, sulfur chemistry	Direct aerosol effect	Climate-chemistry	Continental to regional
RAMS/ICLAMS, USA/Greece http://forecast.uoa.gr/ICLAMS/index.php, Kallos et al. 2009, Solomos et al. 2010	Online photolysis rates. Coupled SAPRC99 gas phase, modal aerosol, ISORROPIA equilibrium and SOA, cloud chemistry.	Direct and indirect aerosol effect	Episodes, CWF, meteo-chemistry interactions	Continental to urban
WRF/Chem, US (used in UK, Spain, etc.) Grell et al., 2005; Fast et al., 2006, further references see Zhang, 2008	RADM, RACM, RACM-MIM with modal aerosol module or CBM-Z with sectional aerosol module, liquid phase chemistry	Direct aerosol effect, indirect aerosol effect	Episodes, chemical weather forecast, climate-chemistry	Continental to regional
WRF-CMAQ Coupled System, USA (used in UK) Pleim et al., 2008; Mathur et al., 2010	Gas-phase mechanisms: CB05, SAPRC-99; Modal aerosols based on the AERO5 CMAQ module	Direct aerosol effects on radiation and photolysis, indirect effect under development	Episodes to annual	Urban to Hemispheric

Courtesy of COST Action ES1004

Motivation:
Needed actions and relation to COST

- Historically Europe has not adopted a community approach to modelling and this has led to a large number of model development programmes, usually working independently.
- Besides AQ and NWP communities worked independently.

Needed: A strategic framework will help to provide a common goal and direction to European research in this field while having multiple models.

- The on-line coupling between meteorology and chemistry and the further feedback effects will be a strong research area for the next 5-10 years.

This will require enhanced dialogue and knowledge from several scientific and technological areas such numerics, physics, computer programming, chemistry, etc.

- The COST Action seems to be the best approach to integrate, streamline and harmonize the interaction between atmospheric chemistry modellers, weather modellers and end users. It will lead to strongly integrated and unified tools for a wide community of scientists and users.

New EU COST Action ES1004 EuMetChem: ’European framework for online integrated air quality and meteorology modelling’ (2011-2015)

- The COST Action will focus on a new generation online integrated ACT and Meteorology modelling with two-way interactions between atmospheric chemistry (including gas-phase and aerosols), clouds, radiation, boundary layer and other meteorological and climate processes.
- At least two application areas of the integrated modelling are planned to be considered:

  (i) improved NWP and CWF with short-term feedbacks of aerosols and chemistry on meteorological variables, and

  (ii) two-way interactions between atmospheric pollution/ composition and climate variability/change.
- 40 teams from 17 COST countries, ECMWF, WMO, US EPA, NOAA, etc.
- Working Groups:

WG1: Strategy and framework for online integrated modelling,

WG2: Interactions, parameterisations and feedback mechanisms,

WG3: Chemical data assimilation in integrated models,

WG4: Evaluation, validation and applications.

- New EGU-2011 Section AS4.25: ‘Integrated physical and chemical weather modelling with two-way interactions’, Vienna, Austria, 3-8 April 2011, see: http://meetingorganizer.copernicus.org/EGU2011/session/7498

Key science questions:

- 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 are the two-way/chain feedbacks among meteorology, climate, and air quality in the estimated effects?
- What is the relative importance of aerosol direct and indirect effects as well as of gas-aerosol interactions in the estimates on different spatial and temporal scales?
- What are the key uncertainties associated with model predictions of mentioned effects?
- How to realize chemical data assimilation in integrated models for improving NWP and CWF?
- How can simulated feedbacks be verified with available observations/datasets?

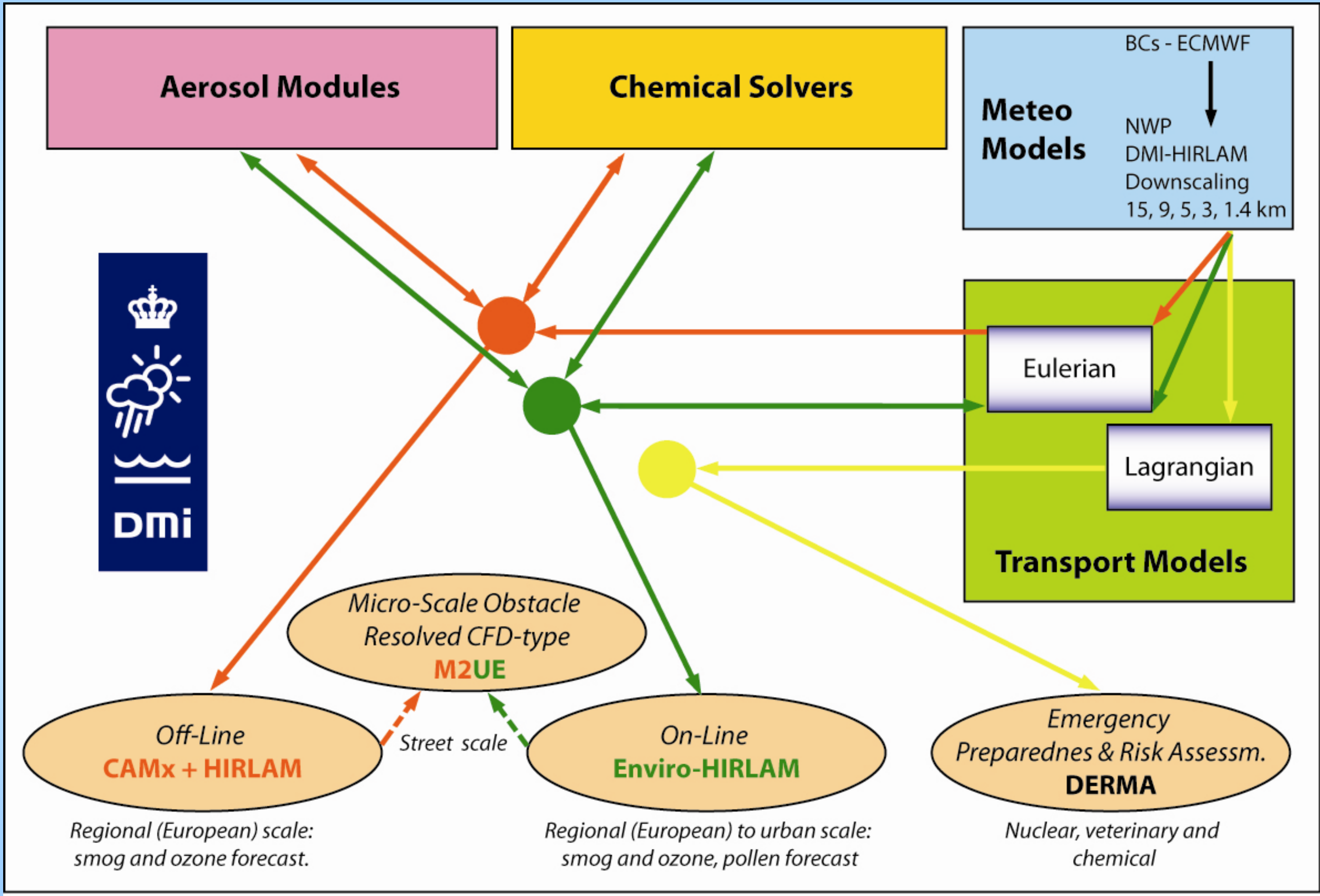
Enviro-HIRLAM/HARMONIE online integrated ACT-NWP modeling system with two-way interactions: History and current status

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.

cost

HIRLAM Consortium Institutions
linking with **ECMWF**

SMHI

International Collaboration:

Univ. Copenhagen Denmark | Univ. Tartu Estonia | Univ. Vilnius Lithuania | RSHU Russia | tecnalia Spain | OSEU Ukraine

DMI

Enviro-HIRLAM:

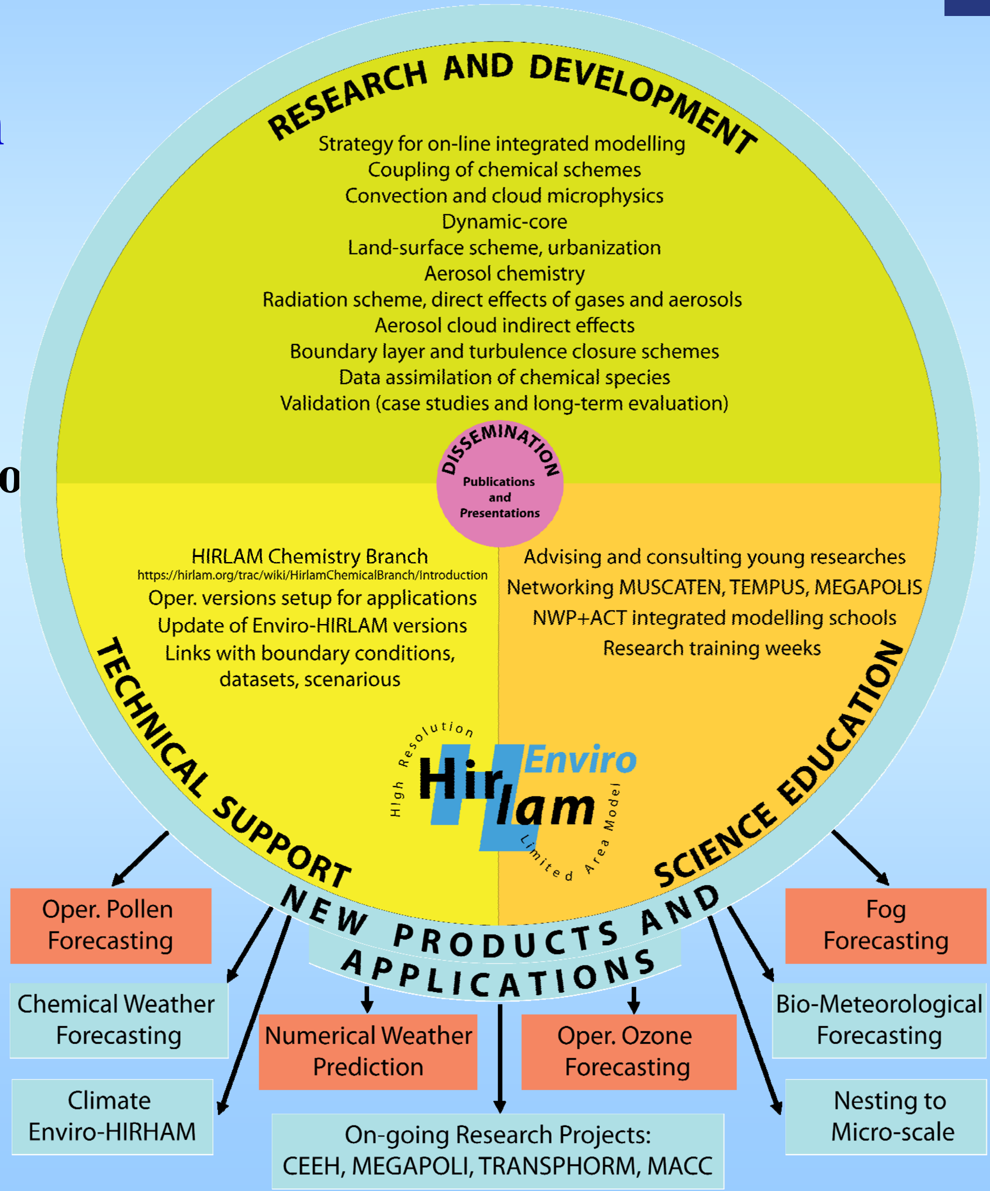
Environment – HIgh Resolution Limited Area Model

Online coupled NWP-CTM

- ➢HIRLAM Consortium Institutions
- ➢University International Collaboratio

- ➢Research and Development
- ➢Technical Support
- ➢Science Education
- ➢Dissemination

- ➢New products and Applications

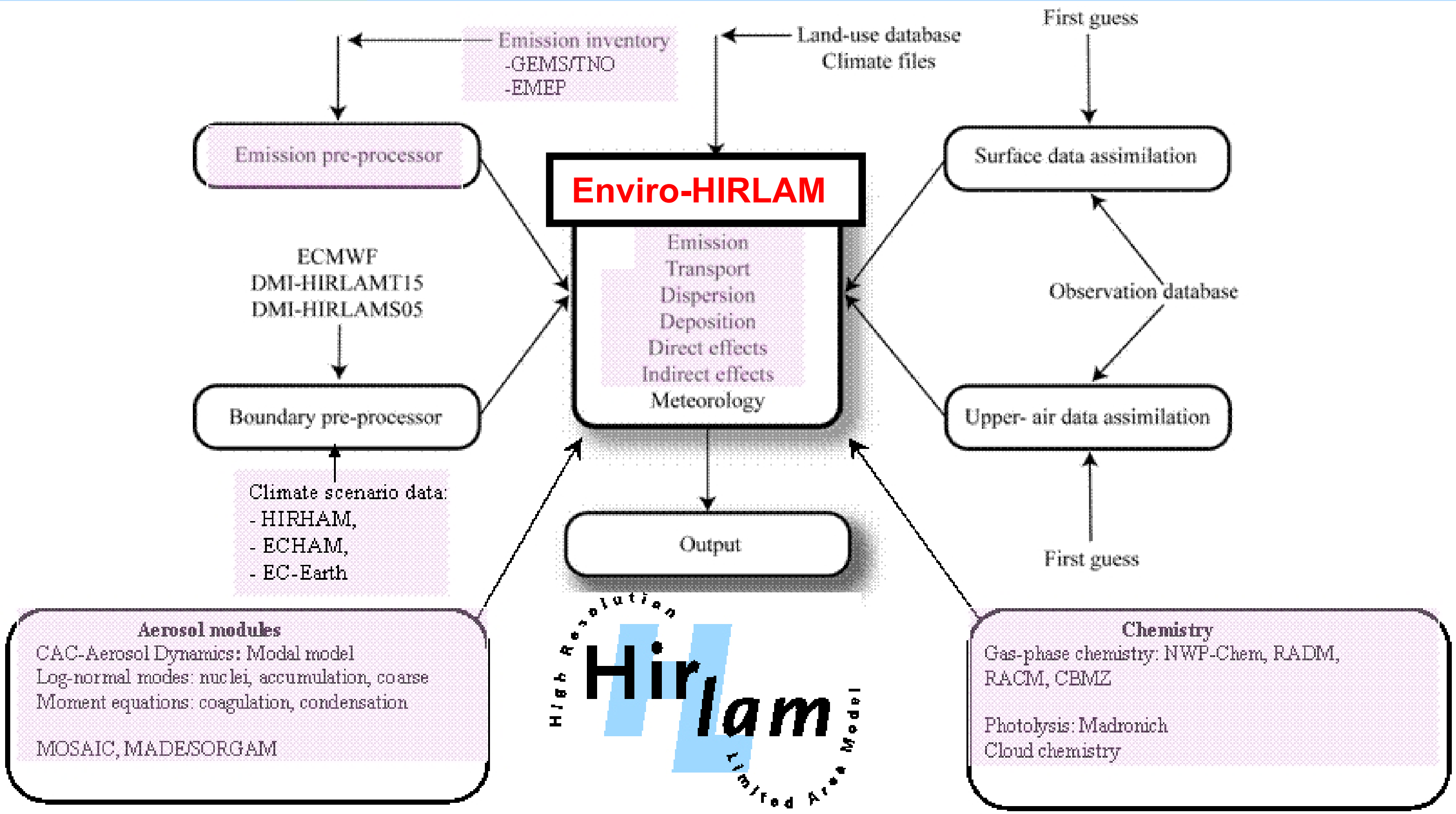


DMI-ENVIRO-HIRLAM on-line system realisation steps:

- (i) nesting of models for high resolutions,
- (ii) improved resolution of boundary and surface layer characteristics and structures,
- (ii) ‘urbanisation’ of the model,
- (iii) improvement of advection schemes,
- (iv) implementation of chemical mechanisms,
- (v) implementation of aerosol dynamics,
- (vi) realisation of feedback mechanisms,
- (vii) assimilation of monitoring data.

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)
+ joined by countries of the HIRLAM Consortium → HIRLAM Chemical Branch
+ joined: Russian State HydroMet Univ, Univ Tartu, Univ Vilnus, Odessa State Envir Univ
+ close collaboration with the WRF-Chem community

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, CISL

Helmholtz equation, semi-implicit adjustmnent,
4^{th} 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

Chemistry and Aerosols in Enviro-HIRLAM

GasChem module: 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 simplified 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.

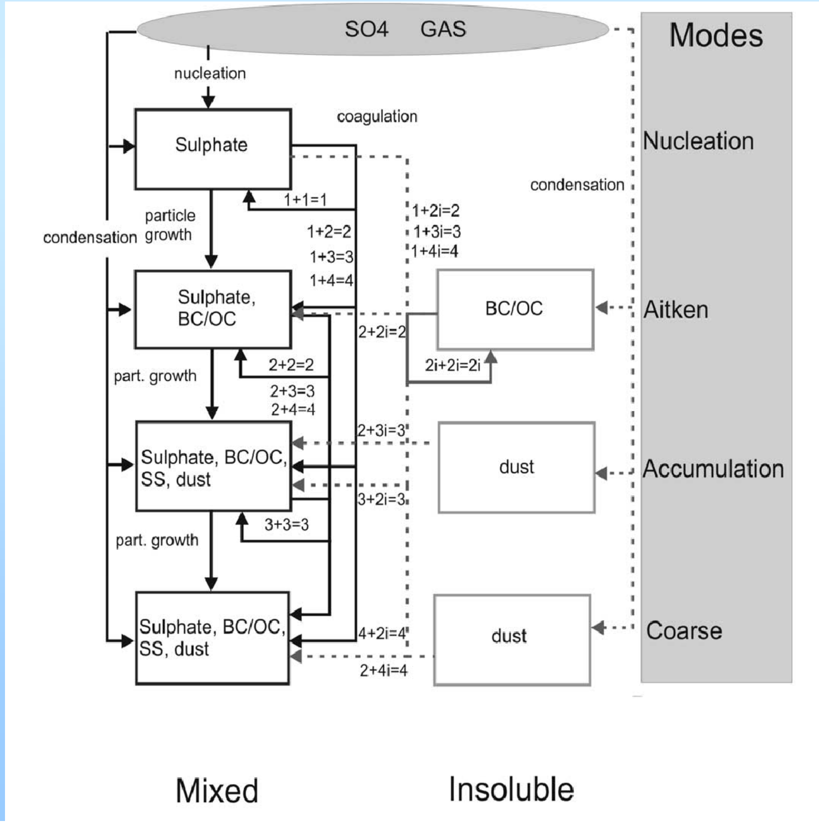
B) Photolysis rate: we setup a look-up table for J-values as a function of altitude, solar zenith angle, cloud optical depth. J-values were originally generated using programs supplied by Sasha Madronich.

AeroChem module in Enviro-HIRLAM consists of:

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

B) Simple aqueous-phase module

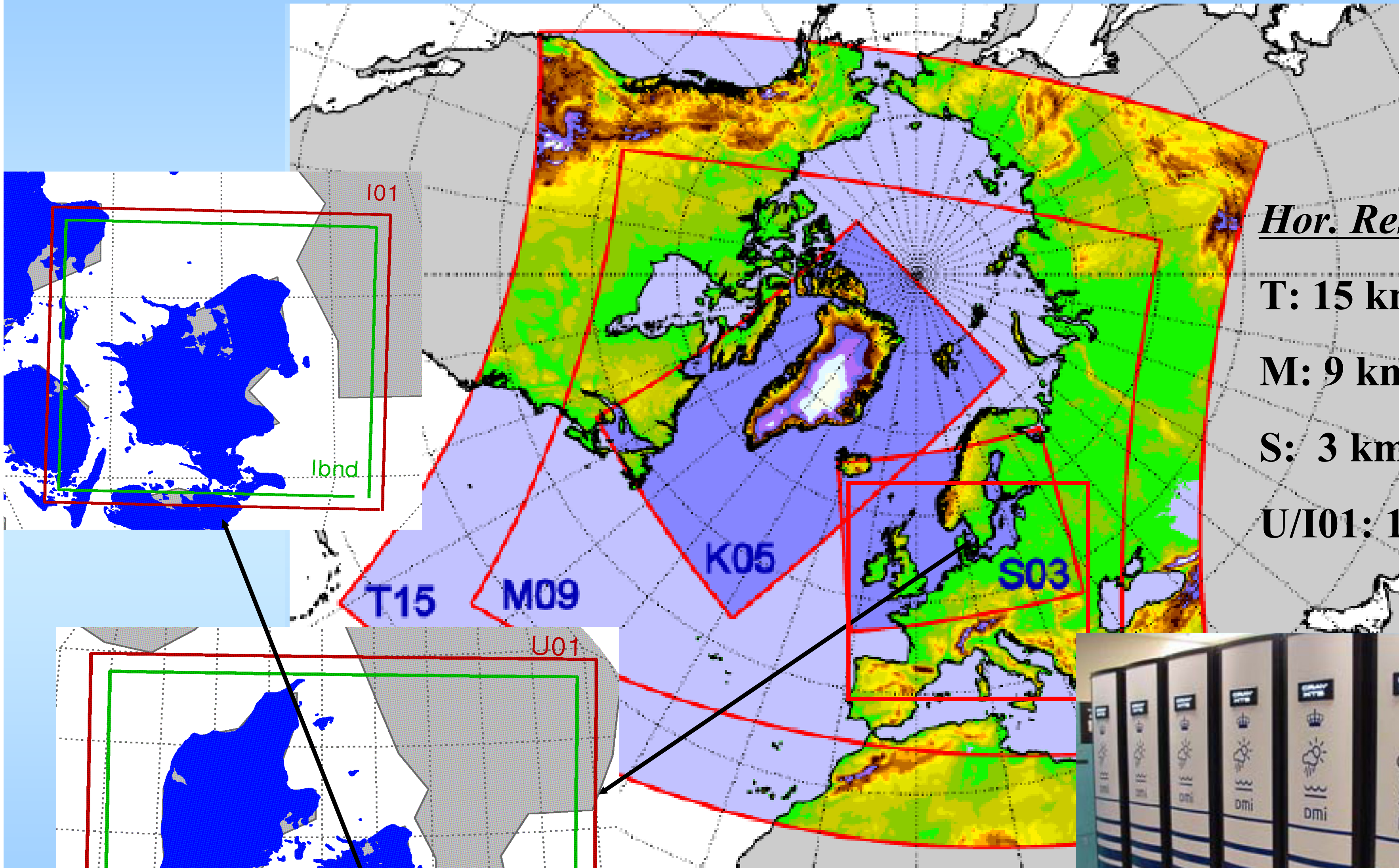
C) Aerosol dynamics module M7 (Vignati et al., 2004).



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.

DMI NWP and Enviro-HIRLAM Modeling Domains



Hor. Resol.:

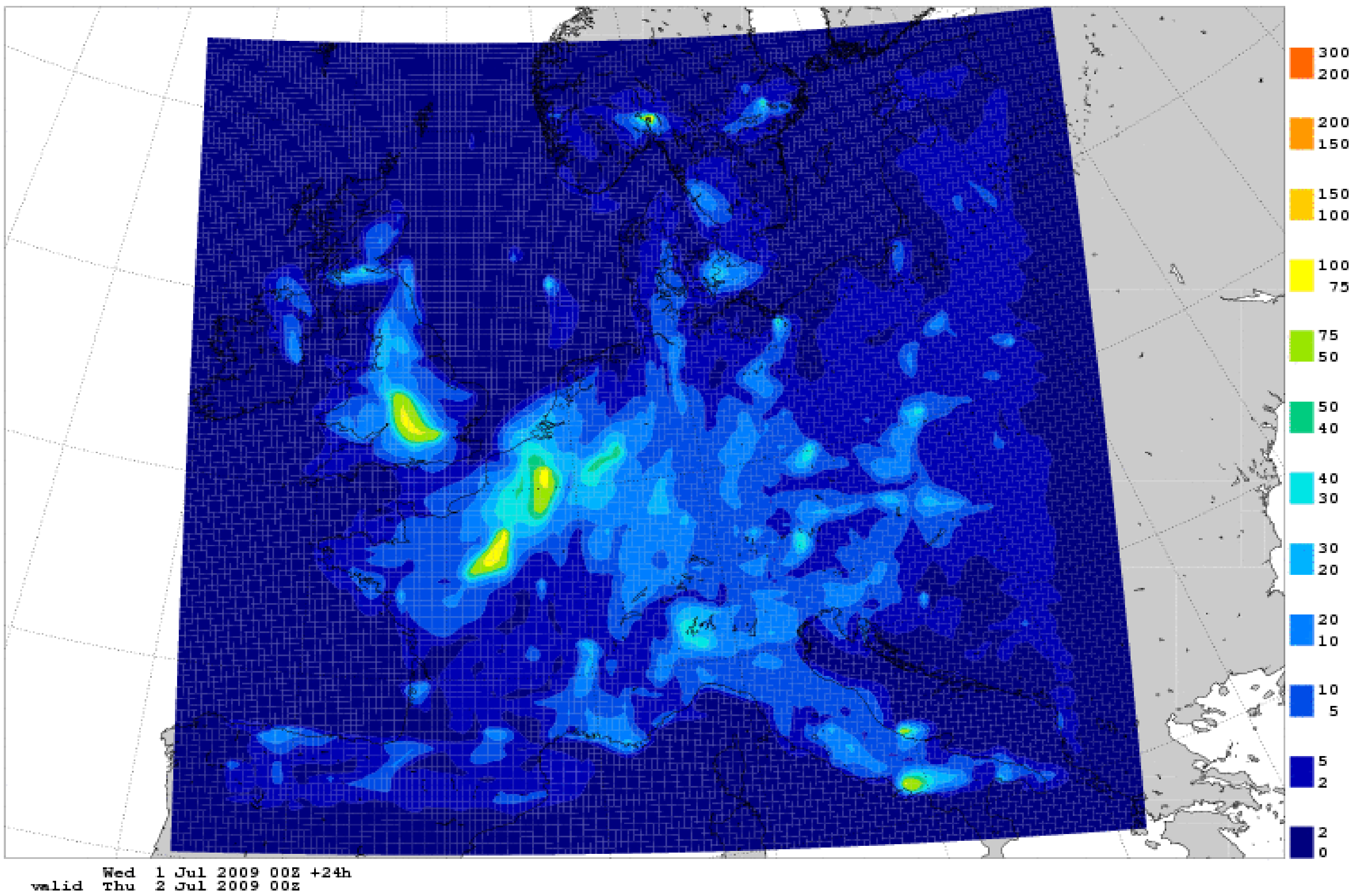
T: 15 km

M: 9 km

S: 3 km

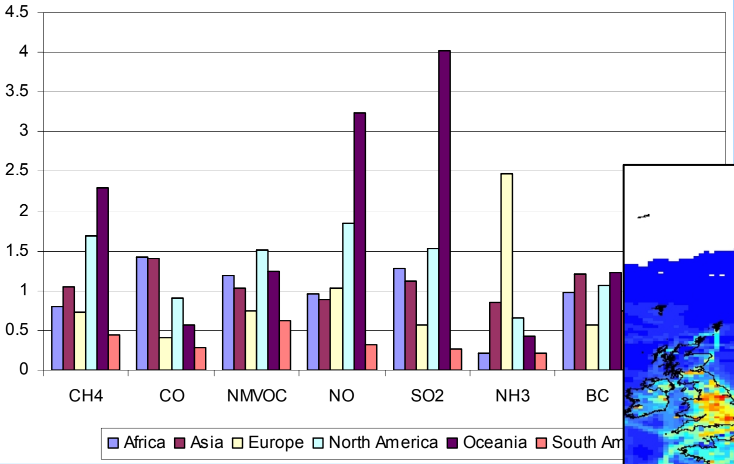
U/I01: 1.4 km

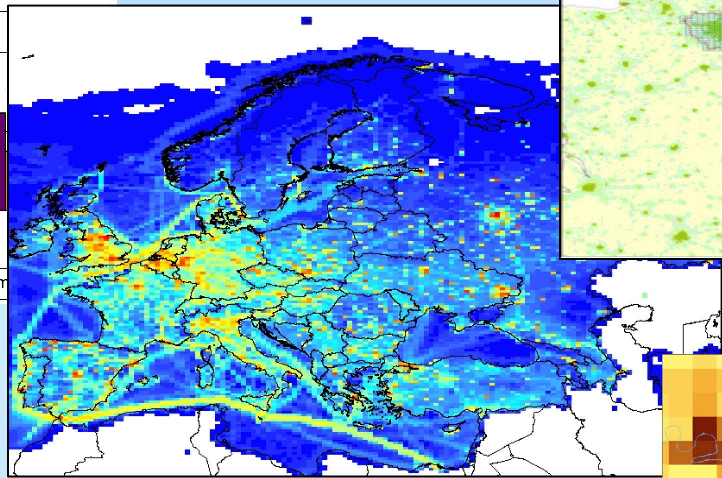
Enviro-HIRLAM NO2 concentration ($\mu g\ m^{-3}$) forecast

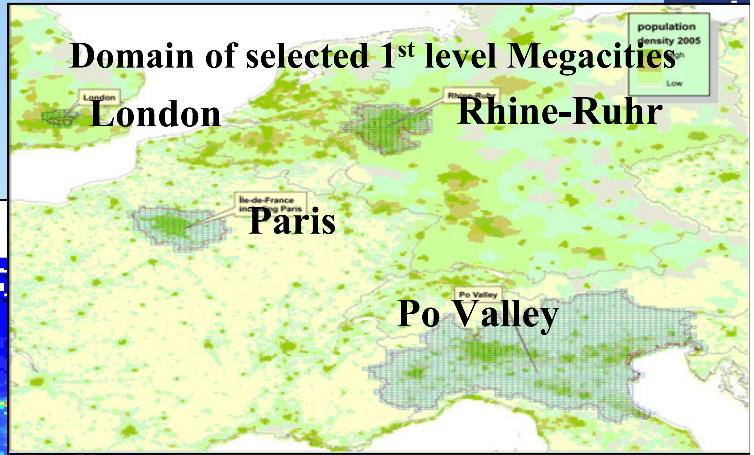


MEGAPOLI Emission Inventories

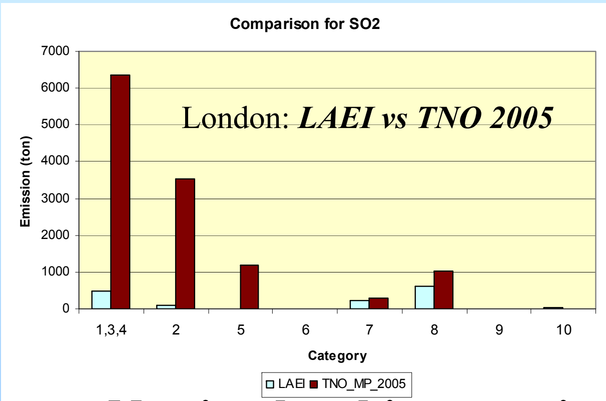
Lead by TNO Team: H. Denier van der Gone et al.



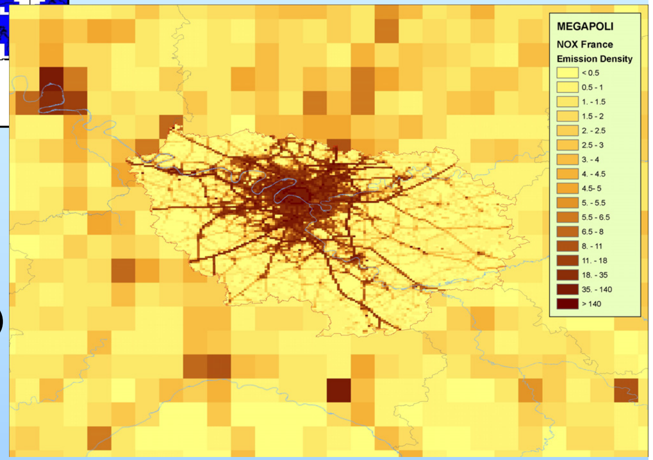




Emissions per capita in megacities (relative compared to all megacities)



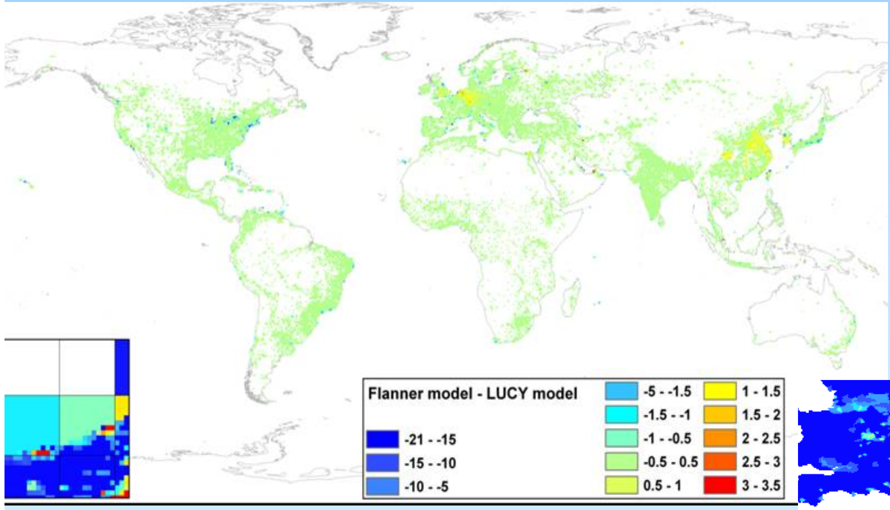
- Global emission inventory with all megacities mask
- 2005 European emission inventory (6x6 km resolution)
- Natural emissions (e.g., fire, sea salt, pollen, volcano)



- **Nesting local inventories for 4 megacities in focus (up to 1x1 km resolution)**
- **Comparison of city, national and European emissions**
- **Integration of nested emissions into multi-scale modelling chain**
- **European and megacity baseline scenarios for 2020, 2030 and 2050 (USTUTT)**

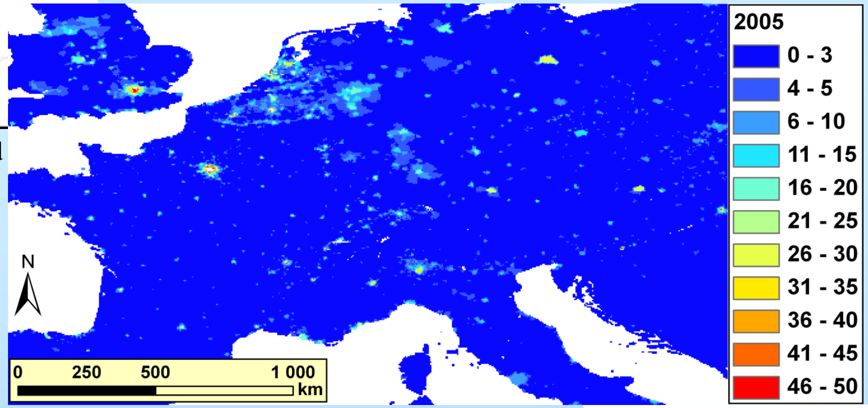
Global to City Scale Urban Anthropogenic Heat Flux

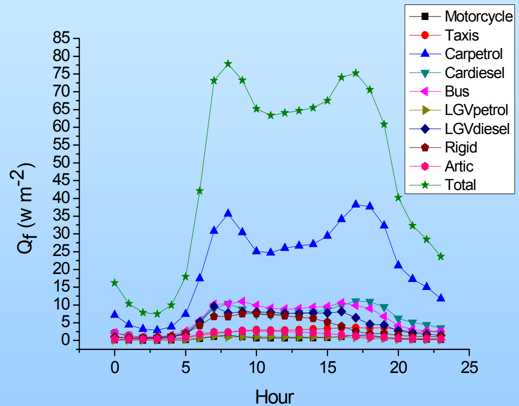
MEGAPOLI rep. D1.4: *L Allen* et al., KCL, 2010



Difference in annual average QF (W m-2) between the model presented by Flanner (2009) and LUCY (spatial resolution = 0.5°) for global urban areas.

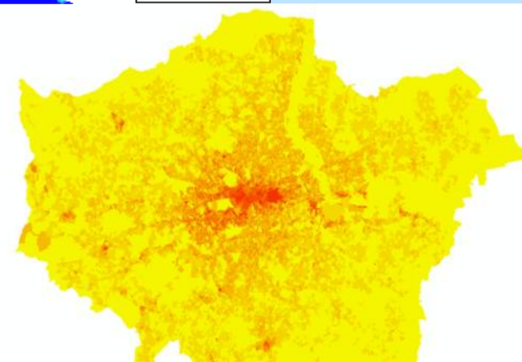
Anthropogenic heat flux (AHF) LUCY model (0.25 x 0.25 arc-minute resolution) was developed by KCL team and used to compute the AHF inventories for Europe and megacities.





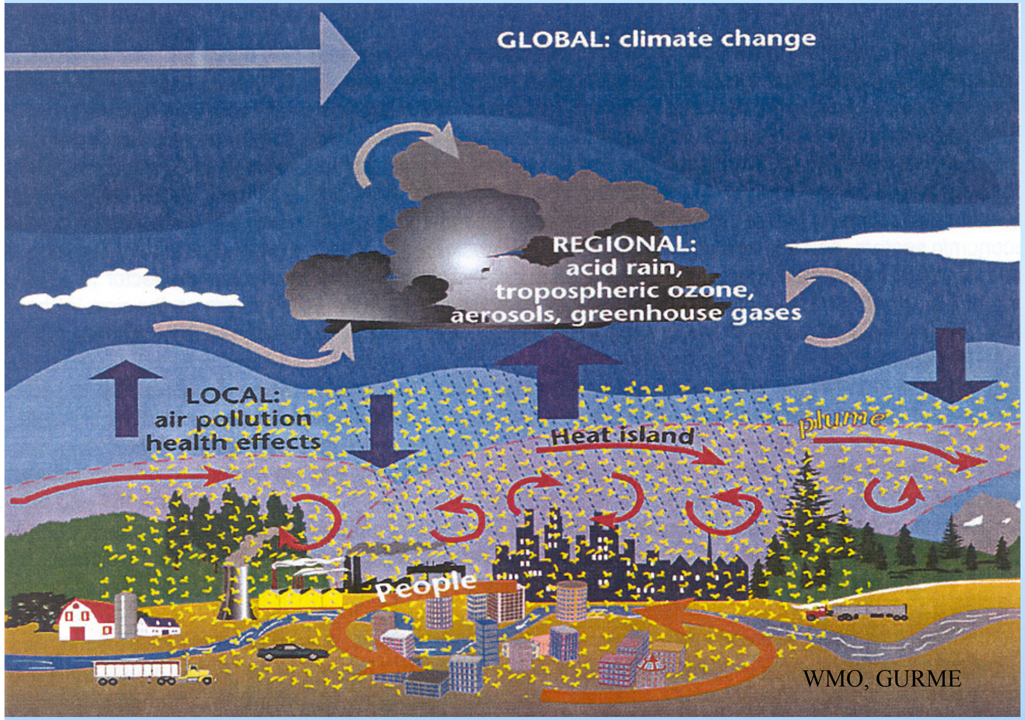
Average daily profiles of QF (w m-2) by vehicle type in London

- Multi-scale inventories/models for AHF are available for megacity, regional and global scale modelling
- Results are used in Enviro-HIRLAM for urban (Paris, etc.) and regional scale studies



QF at OA level within Greater London in 2005. Values in W m-2.

Megacities:
Urban features in focus:



- Urban pollutants emission, transformation and transport,
- Land-use drastic change due to urbanisation,
- Anthropogenic heat fluxes, urban heat island,
- Local-scale inhomogeneties, sharp changes of roughness and heat fluxes,
- Wind velocity reduce effect due to buildings,
- Redistribution of eddies due to buildings, large => small,
- Trapping of radiation in street canyons,
- Effect of urban soil structure, diffusivities heat and water vapour,
- Internal urban boundary layers (IBL), urban Mixing Height,
- Effects of pollutants (aerosols) on urban meteorology and climate,
- Urban effects on clouds, precipitation and thunderstorms.

Connections between megacities, AQ & climate:

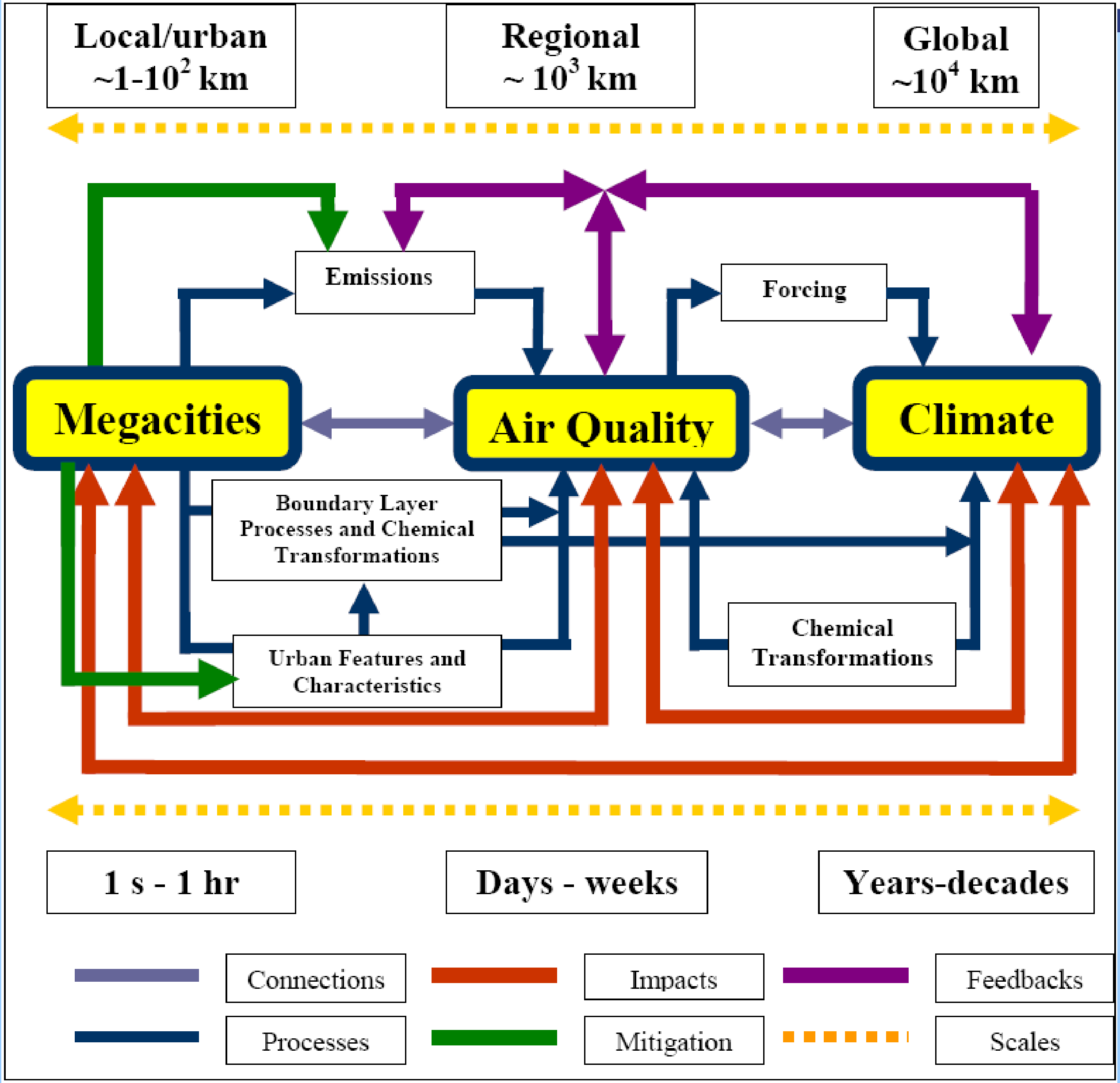
feedbacks, ecosystem, health & weather impact pathways, & mitigation routes

- Our hypothesis is that megacities around the world have an impact on air quality not only locally, but also regionally and globally and can influence the climate.

- Some of the links shown have already been considered by previous studies and are reasonably well-understood.

- However, a complete quantitative picture of these interactions is clearly missing.

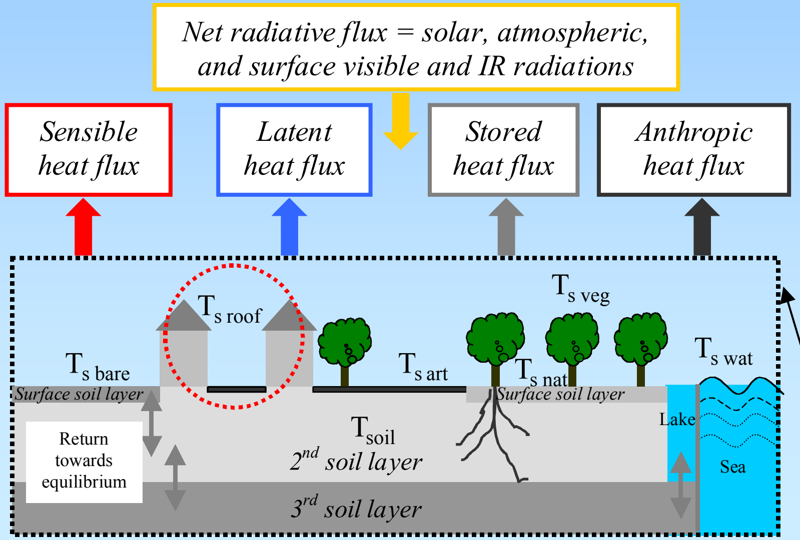
- Understanding and quantifying these missing links is the focus of MEGAPOLI.

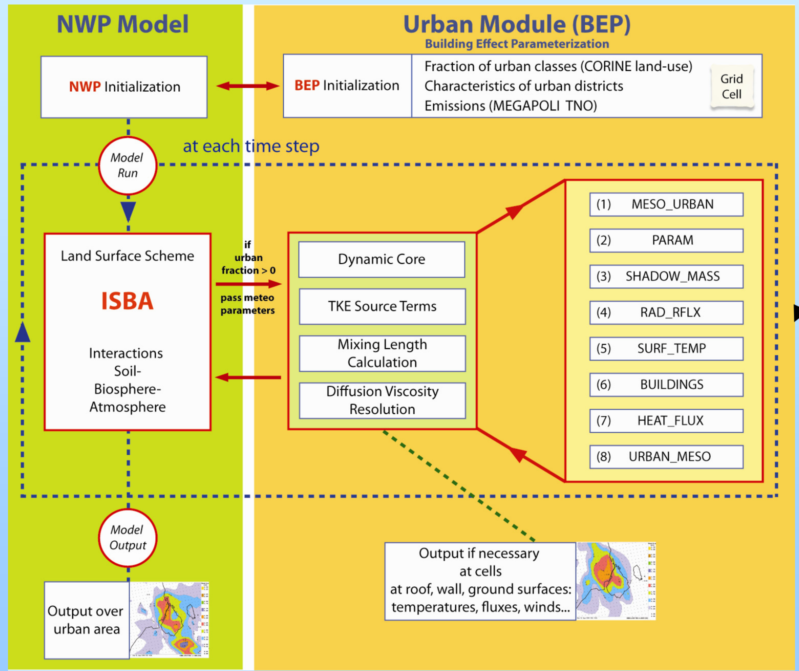


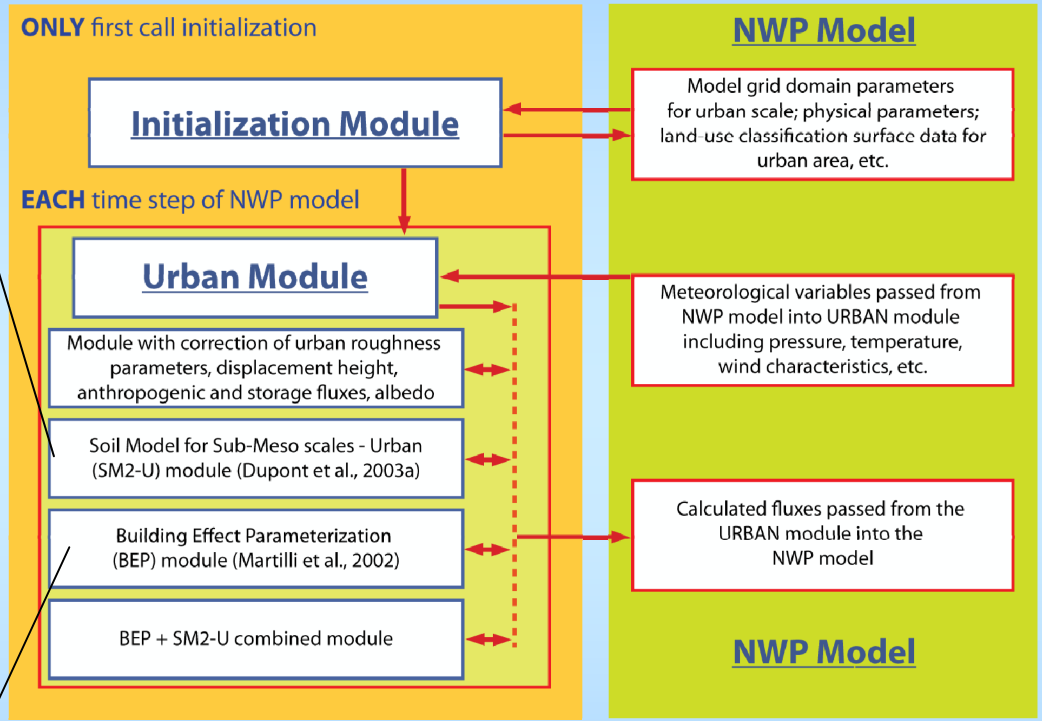
Urbanisation of NWP models:

1. Model down-scaling, including increasing vertical and horizontal resolution and nesting techniques (one- and two-way nesting);
2. Modified high-resolution urban land-use classifications, parameterizations and algorithms for roughness parameters in urban areas based on the morphologic method;
3. Specific parameterization of the urban fluxes in meso-scale models;
4. Modelling/parameterization of meteorological fields in the urban sublayer;
5. Calculation of the urban mixing height based on prognostic approaches;
6. Assimilation surface characteristics based on satellite data into Urban Scale NWP models.

Enviro-HIRLAM Urbanization

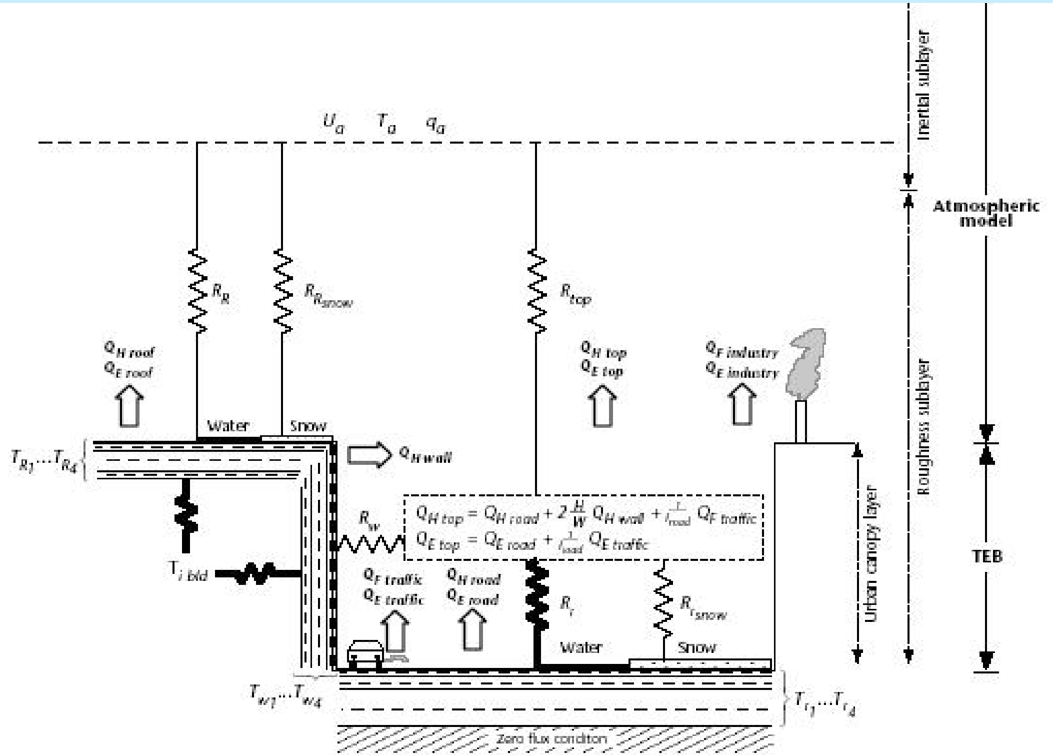




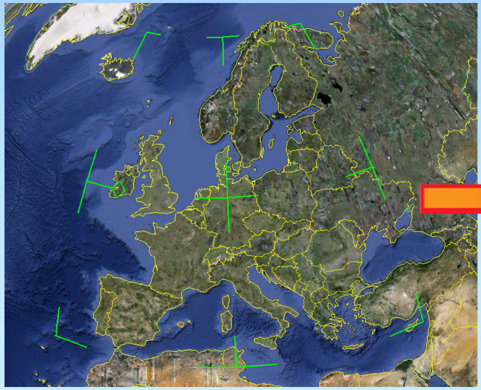


HARMONIE Urbanization – TEB scheme

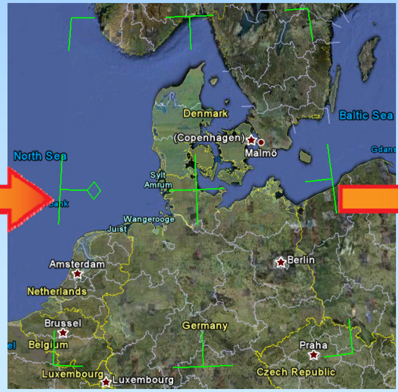
- SURFEX module (Sea/Ocean, Lakes, Vegetation/Soil/Snow, Urban)
- Town Energy Budget (TEB) scheme
- Originally in AROMA (Masson, 2000)



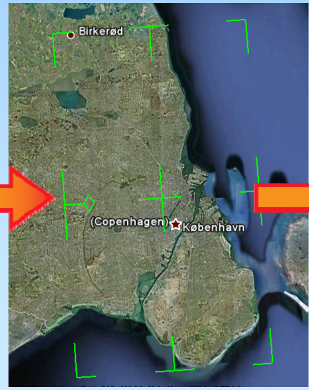
Application: MACC Core-Downstream Service for Copenhagen



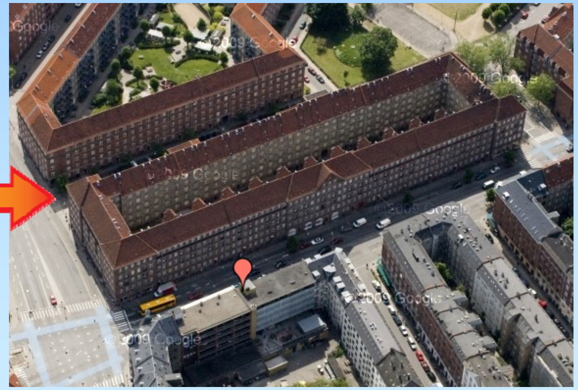
GEMS/MACC regional domain



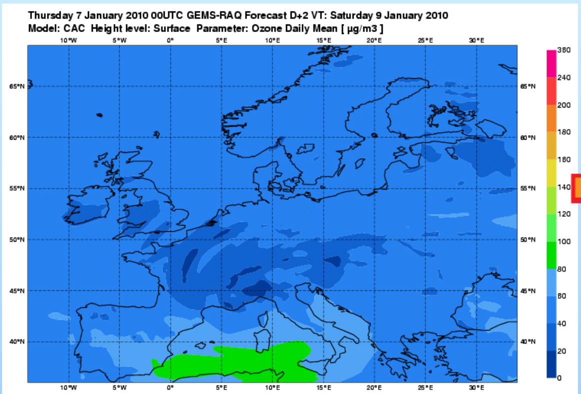
Denmark-scale domain



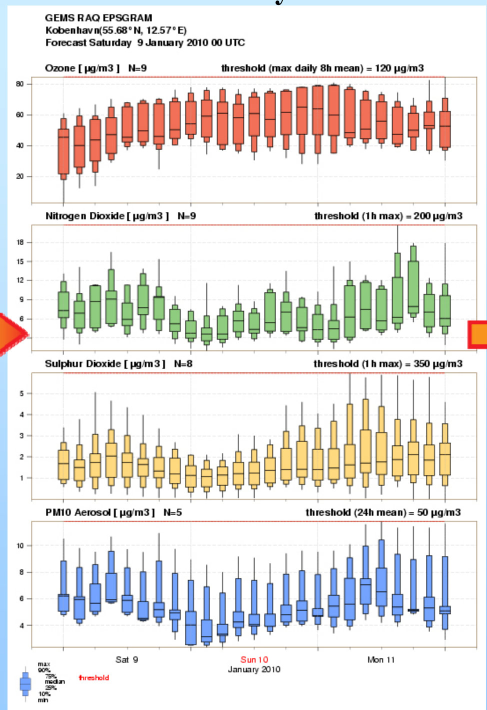
City-scale domain



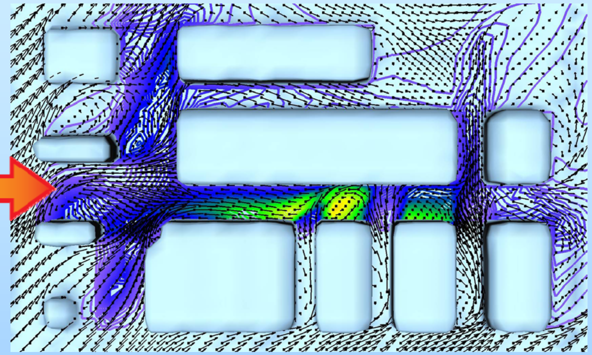
Street-scale selected domain (Jagtvej)



Example of regional-scale O_3 forecast by Chemistry-Aerosol-Cloud modeling system (from GEMS)



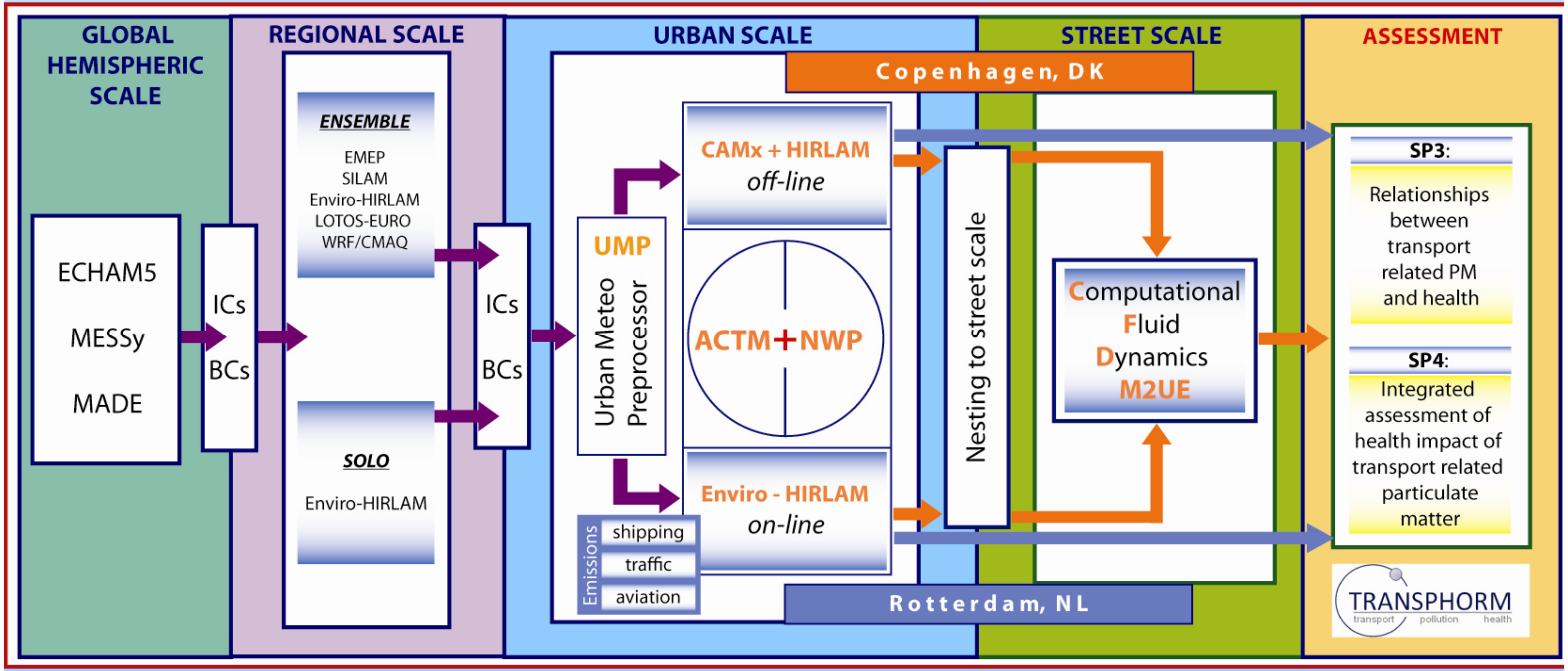
GEMS ensemble forecast for Copenhagen



Example of concentration and velocity fields for street-scale downscaling with CFD-type model M2UE (Jagtvej in Copenhagen)

Nuterman et al. (2010)

Application: TRANSPHORM
Core-Downstream Modelling Chain



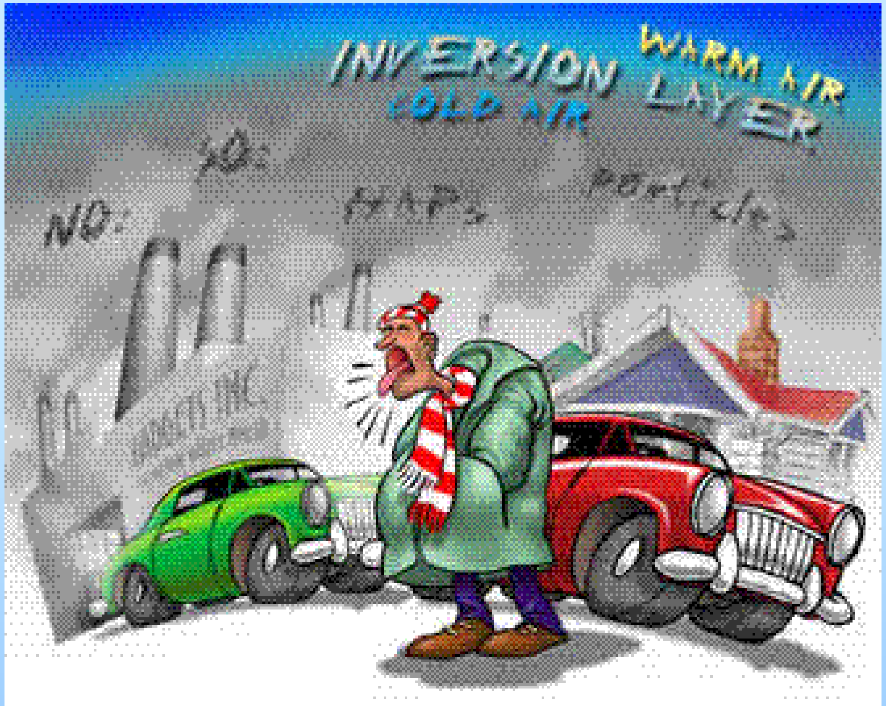
Downscaling of European-scale forecasts for the city and streets in TRANSPHORM

Conclusions

- Suggested concept - chemical weather as two-way interacted meteorological weather and chemical composition of the atmosphere => COST Action ES1004 EuMetChem.
- On-line integration of MesoMetMs and ACTMs enables:
  - *utilisation of all meteorological 3D fields in ACTMs at each time step;*
  - *consideration of feedbacks of air pollution on meteo-processes & climate forcing.*
- New generation of integrated models - not only for CWF, but also for climate change modelling, NWP (e.g., in urban areas, severe events, etc.), air quality and mitigations, long-term assessment chemical composition, etc.
- Main advantages of on-line coupling:
  - *only one grid for MMM and ACTM, no interpolation in space and time;*
  - *physical parameterizations are the same, no inconsistencies;*
  - *all 3D meteorological variables are available at each time step;*
  - *no restriction in variability of meteorological fields;*
  - *possibility to consider two-way feedback mechanisms;*
  - *does not need meteo- pre/post-processors.*
- Feedback mechanisms - important (supported by simulation results) in CWF modelling and quantifying direct and indirect effects of aerosols (and probably GHGs).
- Indirect aerosol feedbacks (based on the Paris case study): sensitivity of meteorology and chemistry, strong non-linearity, e.g. indirect effects induce large changes in NO2.

Thank You !

COST Action ES1004 Web-site:
http://eumetchem.info



Some relevant publications:

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