Overview of European Research in Online Coupled NWP & ACT Modeling with Two-Way Interaction

Alexander Baklanov, Ulrik Korsholm (*Danish Meteorological Institute*), Ranjeet R. Sokhi (*University of Hertfordshire, UK*), Georg Grell (*NOAA, USA*)

In cooperation with COST728, HIRLAM and MEGAPOLI consortiums

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Content

- General thoughts on meteorological and chemical weather forecast as a joint problem
- COST Action 728 overview of European online coupled NWP-ACT models;
- EC 7FP project MEGAPOLI “Megacities: Emissions, urban, regional and Global Atmospheric POLlution and climate effects, and Integrated tools for assessment and mitigation”
- Enviro-HIRLAM online integrated modelling system: an application
- Conclusions and future research

Chemical weather forecast: common concept

- Chemical weather forecasting (CWF) - is a new, quickly developing and growing area of atmospheric modelling. Possible due to
  1. Quick growing supercomputer capability and operationally available NWP data as a driver for atmospheric chemical transport models (ACTMs)
  2. Realization of the importance of the interactions between different earth system components
  3. Possible importance of chemistry for meteorological data assimilation (provide better optimal initial state of the atmosphere
- 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 (no feedbacks, limited in scope with respect to (2) and (3)).

Chemical weather forecast: new concept

- Many experimental studies and research simulations show that atmospheric processes depend on concentrations of chemical components (especially aerosols) in the atmosphere.
- Meteorological data assimilation (in particular assimilation of radiances) depend on the chemical composition
- Studies also show that air quality forecasts loose accuracy when ACTM's are run "offline"

Therefore:

- It may be advantages to run ACTMs online, considering the two-way interactions
- CWF should include not only health-effecting pollutants (air quality components) but also GHGs and aerosols effecting climate, meteorological processes, etc.

New generation of 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).

Definitions of integrated/coupled models

Definitions of off-line models:

• separate CTMs driven by <u>meteorological input data</u> from meteo-preprocessors, measurements or diagnostic models,

• separate CTMs driven by analysed or forecasted meteodata from <u>NWP archives or datasets</u>,

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

Definitions of on-line models:

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

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

Advantages of On-line & Off-line modeling

On-line coupling

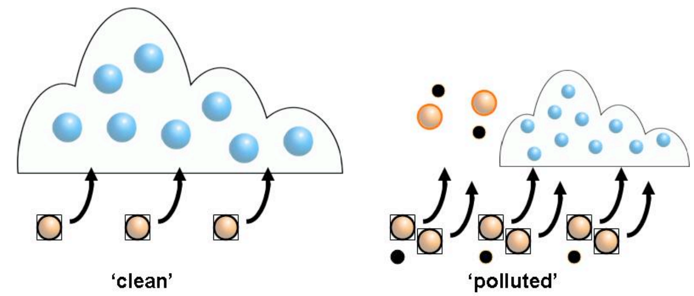
- Only one grid;
- No interpolation in space
- No time interpolation
- Possibility to consider aerosol forcing mechanisms
- All 3D met. variables are available No restriction in variability, no mass consistency concerns
- Possibility of feedbacks from meteorology to emission and chemical composition
- 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;

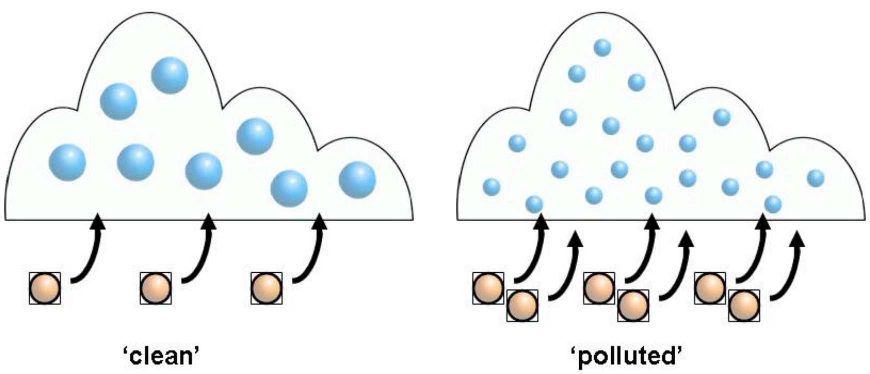
Aerosol direct and indirect effects

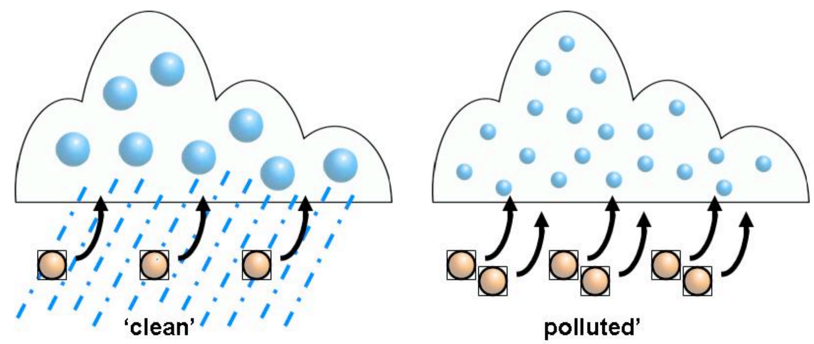
Semi-Direct Effect



Aerosol direct effect

Direct and semi-direct effects are caused through the direct interaction of aerosols with radiation

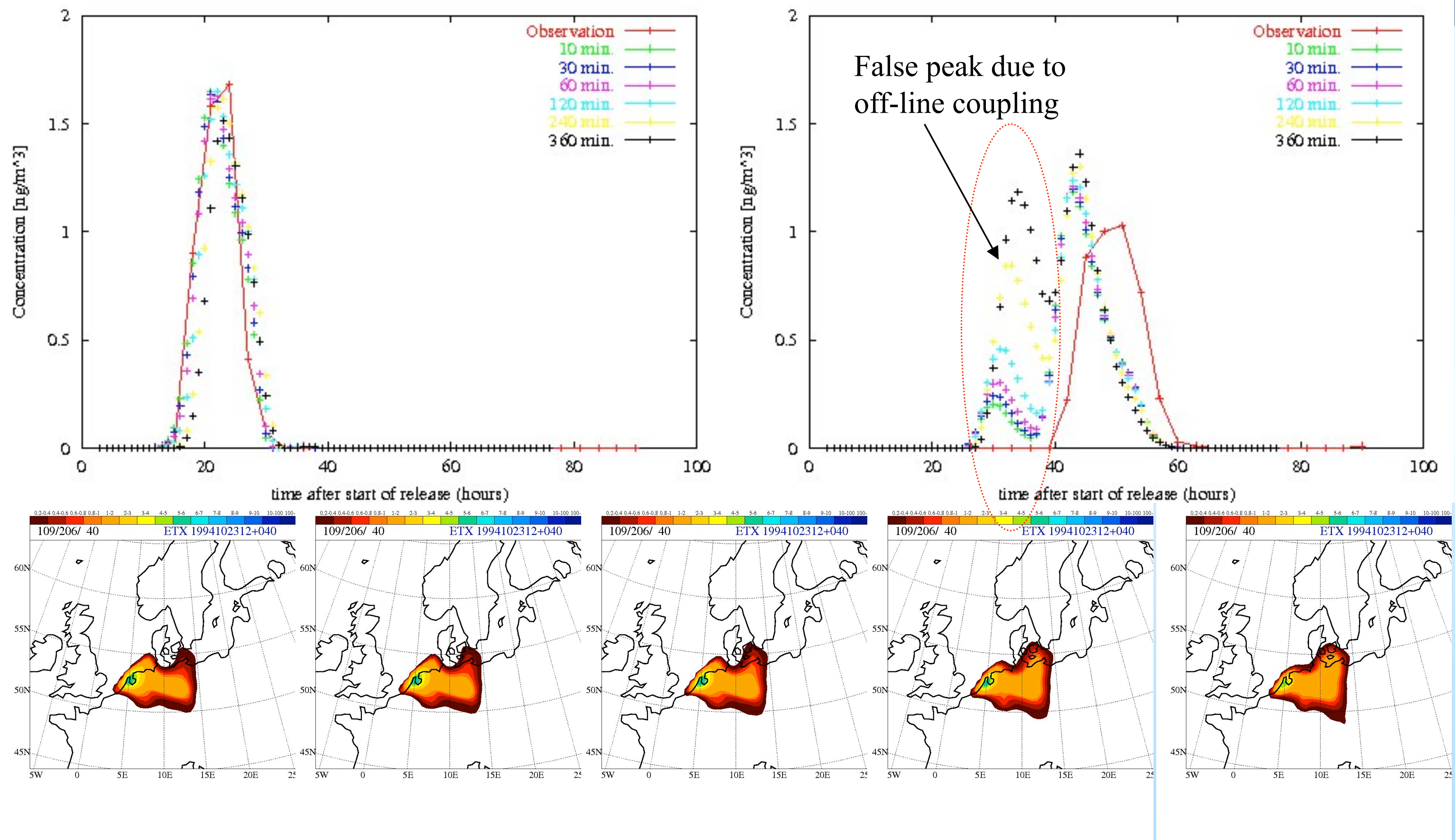




Indirect effects are caused from the interaction of aerosols with cloud microphysics (through Cloud Condensation Nuclei)

Þ High-resolution on-line integrated models with a detailed description of the PBL, microphysics, and chemical composition are necessary to simulate such effects.

ETEX1: ON-LINE/OFF-LINE COMPARISON



Top: concentration as function of time at F15 and DK02 for different coupling intervals: 30, 60, 120, 240, 360 minutes. Bottom: concentration after 36 hours with the same coupling intervals

Korsholm et al., AE, 2009

COST-728: MESOSCALE METEOROLOGICAL MODELLING CAPABILITIES FOR AIR POLLUTION AND DISPERSION APPLICATIONS

Working Group 2: Integrated systems of MetM and CTM/ADM: strategy, interfaces and module unification (http://cost728.org)

The overall aim of WG2 is to identify the requirements for the unification of MetM and CTM/ADM modules and to propose recommendations for a European strategy for integrated mesoscale modelling capability.

NWP Communities Involved:
- HIRLAM, COSMO, ALADIN/ AROME, UM communities
- MM5/WRF/RAMS users/dev-s

Tasks/Sub-groups:
1. Off-line models and interfaces
2. On-line coupled modelling systems and feedbacks
3. Model down-scaling/ nesting and data assimilation
4. Models unification and harmonization

1. COST-728 / WMO, 2007: **"Overview of existing integrated (off-line and on-line) mesoscale systems in Europe" published by WMO, Geneva, 122p.**
2. COST-728 / NetFAM workshop **on "Integrated systems of meso-meteorological and chemical transport models", Copenhagen, Denmark, 21-23 May 2007. Springer (in press). Web-site: http://netfam.fmi.fi/Integ07/**

WG2 outcome => COST Action ES0602: Chemical Weather Forecasting (2008-12)

1. NetFAM school and workshop "Integrated Modelling of Meteorological and Chemical Transport Processes / Impact of Chemical Weather on Numerical Weather Prediction and Climate Modelling" in Zelenogorsk, 7-15 July 2008, on http://netfam.fmi.fi

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	Gas phase chemistry generated by Kinetic Preprocessor (KPP), Madronich+Fast-J photolysis, bulk, modal, and 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 (MM5-Chem)	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 NWP-ACT models in Europe

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

- At the current stage most of the online coupled models do not consider all feedback mechanisms (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.

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. Megacities and regional hot-spots air quality and climate

Project duration: Oct. 2008 – Sep. 2011

27 European research organisations from 11 countries are involved. Also US participation (10 groups).

Coordinator: A. Baklanov (DMI)

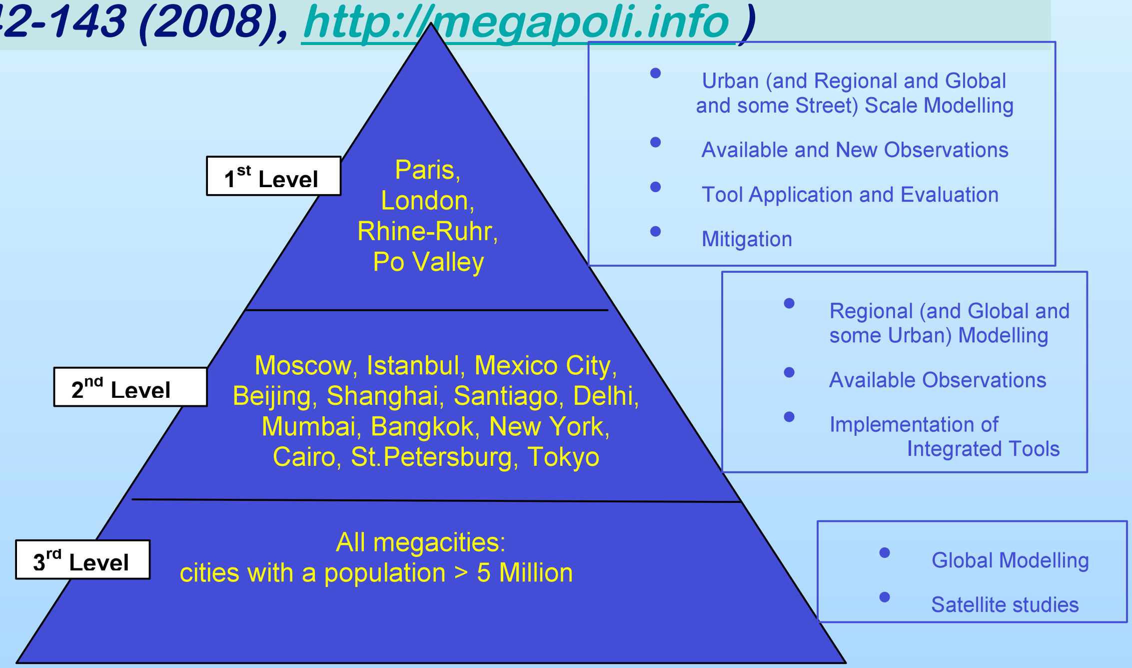
Vice-coordinators: M. Lawrence (MPIC) and S. Pandis (FRTHUP)

(see: 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

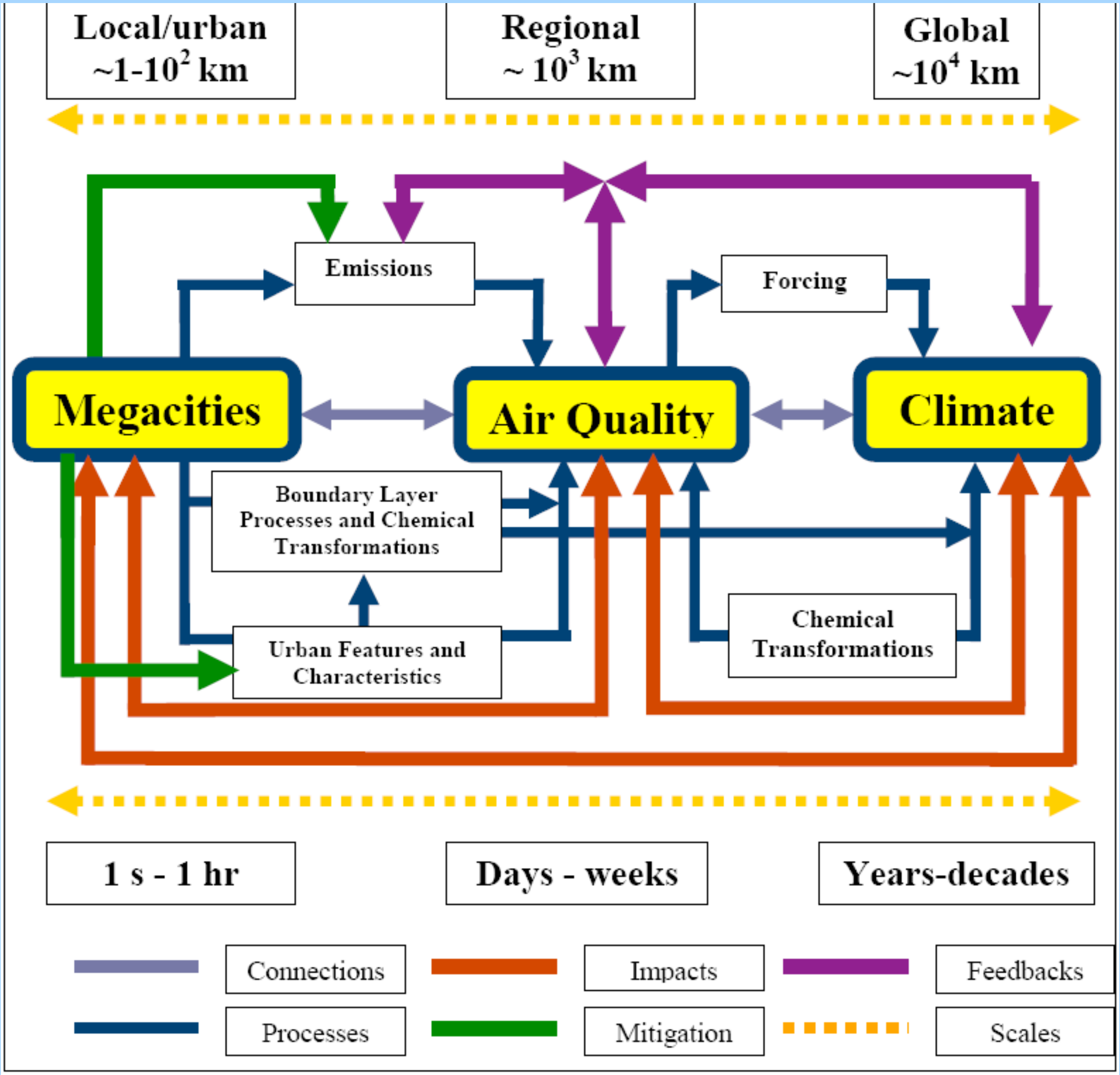
(ii) to develop improved integrated tools for prediction of air pollution in cities.



Connections between megacities, air quality and climate:

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

- Science - nonlinear interactions and feedbacks between emissions, chemistry, meteorology and climate
- Multiple spatial and temporal scales
- Complex mixture of pollutants from large sources
- Scales from urban to global
- Multiple sources and emission mixtures



MEGAPOLI Paris Campaign Objectives

Provide new experimental data to better quantify sources of primary and secondary carbonaceous aerosol in a large agglomeration and its plume

Four major tasks for Paris study

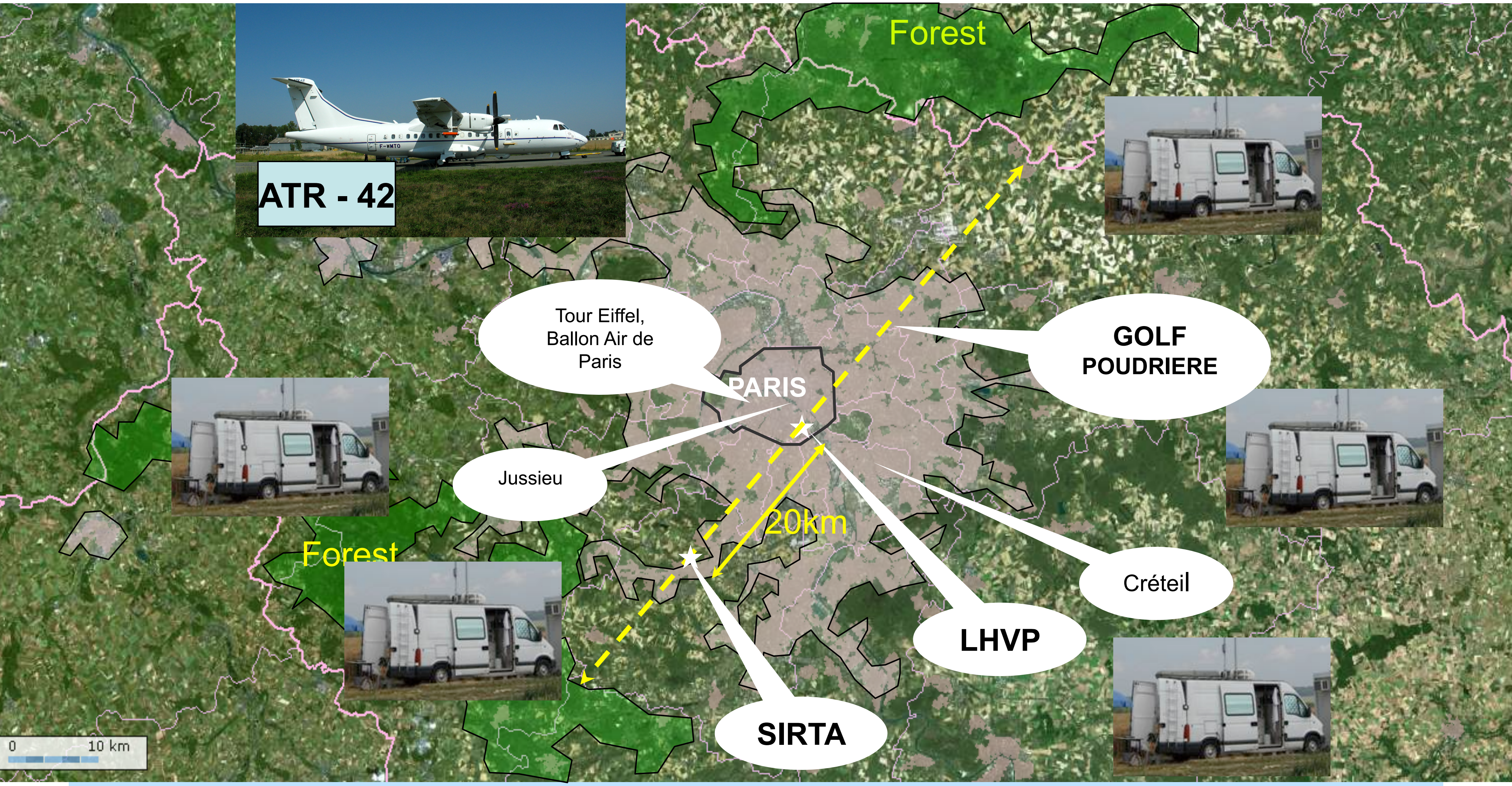
- **Document aerosol composition and properties variability**
- **Source apportionnement**
- **Quantify SOA build-up in urban area and plume**
- **Integrated data set for Model evaluation and improvement**

Summer campaign – 1-31 Jul 2009

Winter campaign – Jan-Feb 2010

30 research institutions from France and other European countries, both MEGAPOLI Teams and Collaborators

More details: Matthias Beekmann, Leader of CNRS Team



3 primary sites => full in situ measurements / + met at SIRTA.

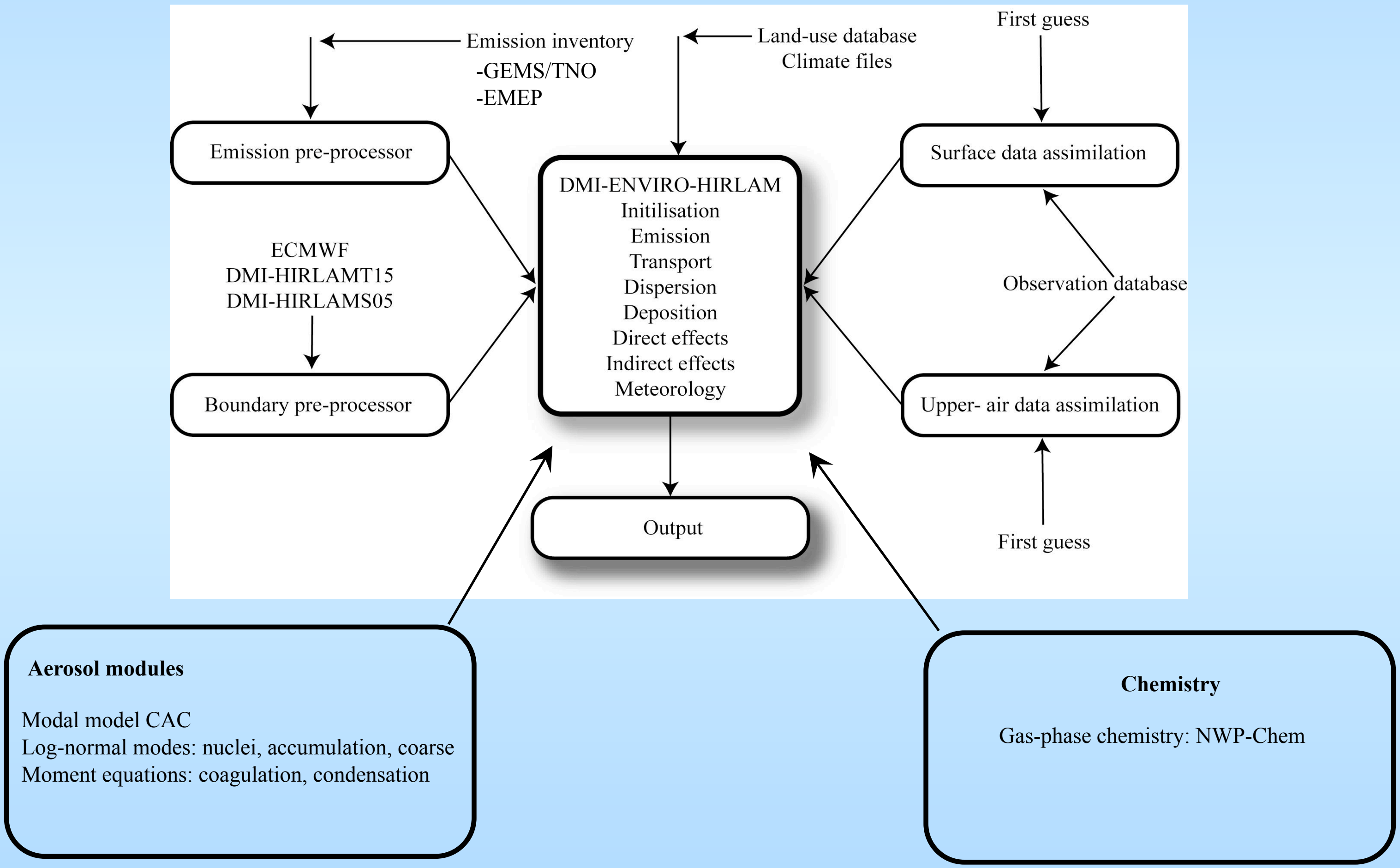
3 secondary sites => lidar and spectrospcopic measurments / or in some situ

3 mobile labs => full in situ measurements (PSI + MPI) + Univ Duisburg

1 mobile lab => lidar measurements (CEA) **1 mobile lab** => MAXDOAS (MPI)

1 aircraft ATR-42 => full in situ measurements (SAFIRE, CNRS, MPI)

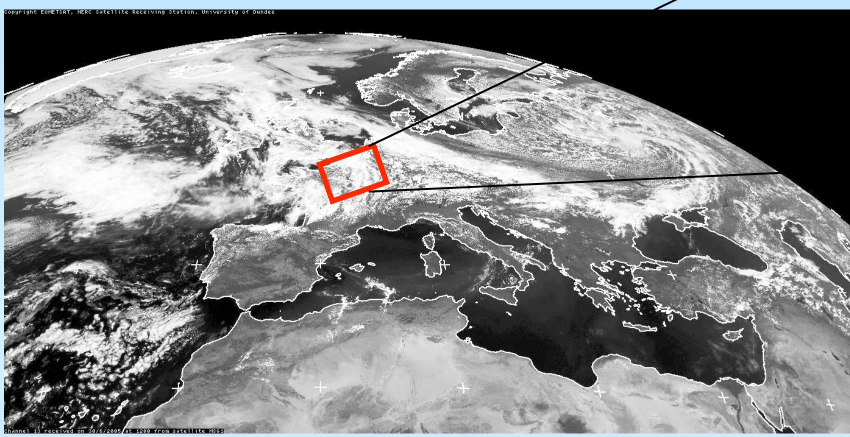
First version of online coupled Enviro-HIRLAM modelling systems, showing the components of a forecast



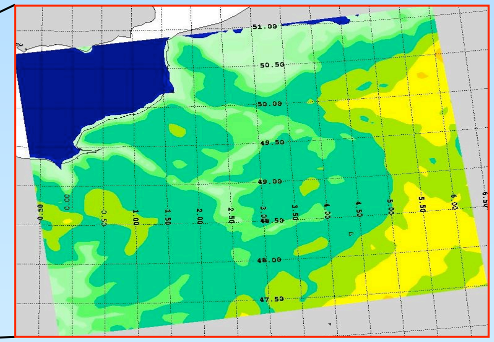
Korsholm, Baklanov, Gross, Mahura (2008)

ENVIRO-HIRLAM sensitivity study for Paris: First and Second indirect feedbacks of aerosols

Korsholm et al., 2009



MSG1 satellite image 2005-06-30, 12 UTC



445 km

665 km

Horizontal resolution: 0.05º x 0.05º
Vertical resolution: 40 levels
Model top: 10 hPa

- Domain covering 665 x 445 km around **Paris, France**,
- Case study days: **2005-06-28 - 2005-07-03**,
- 300 s time step, NWP-Chem chemistry (18 species),
- CAC-aerosol mechanism: homogeneous nucleation, condensation, coagulation
- Aerosols consists of H2O, HSO4-, SO4--, two log-normal modes: nuclei, accumulation
- Accumulation mode aerosols used as CCN's (Boucher & Lohmann, 1995)
- Case with low winds, convective clouds, little precipitation
- Reference run without feedbacks, Perturbed run with first and second indirect effects.

Enviro-HIRLAM research team:

<u>Many institutions are involved</u>:

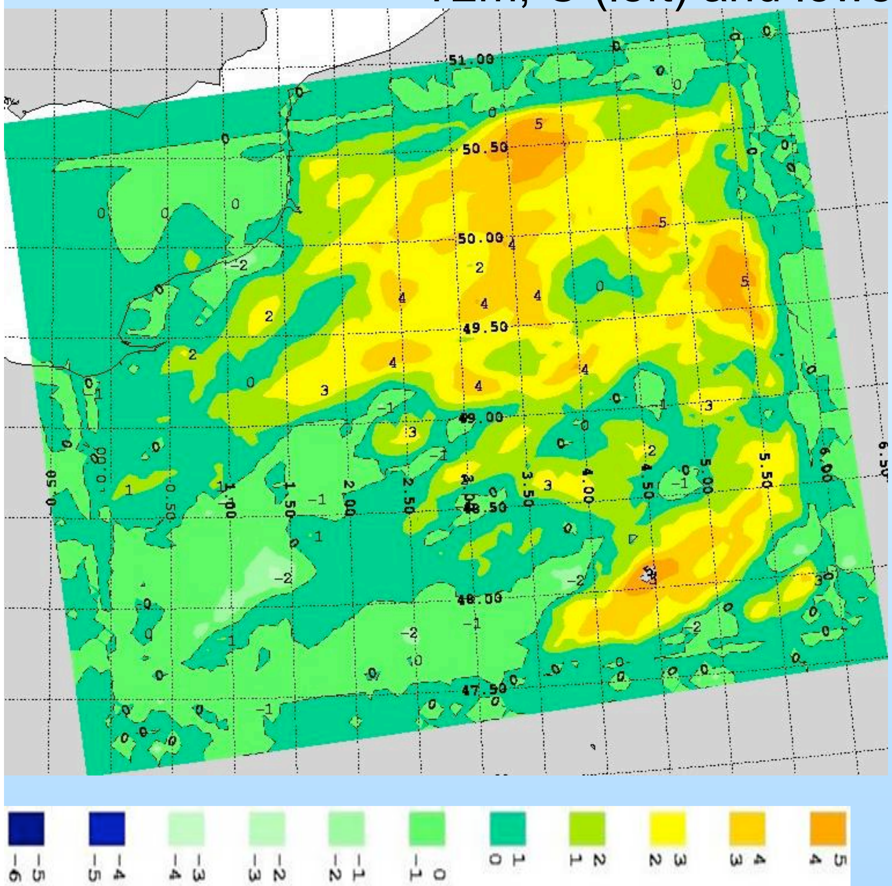
- Danish Meteorological Institute (A. Baklanov, U. Korsholm, A. Mahura, R. Nuterman, B.H. Sass, K.P. Nielsen, etc),
- University of Copenhagen (E. Kaas, etc),
- Russian State Hydro-Meteorological University (S. Smyshlyaev, etc.)
- HIRLAM-A program of the HIRLAM consortium,
- University of Tartu, Estonia (R. Room, etc.),
- Vilnius University, Lithuania,
- Odessa State Environmental University, Ukraine,
- Finnish Meteorological Institute and Helsinki University.

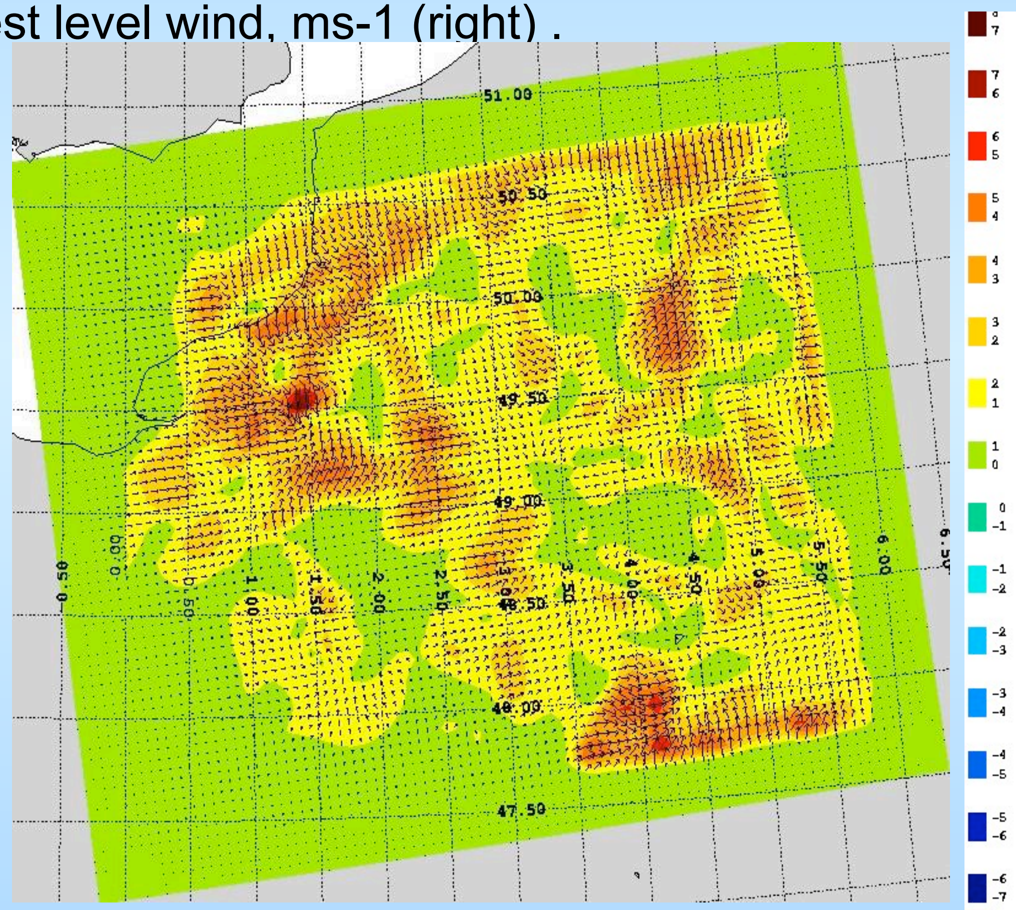
The HIRLAM international Chemical brunch, where Enviro-HIRLAM is considered as the baseline system, was organized in 2008.

<u>Any HIRLAM and other groups are also welcome to join the team!</u>

Results 1: Meteorology

Day-time (2005-06-29 +036; 12 UTC) difference (reference - perturbation) of T2m, C (left) and lowest level wind, ms-1 (right) .





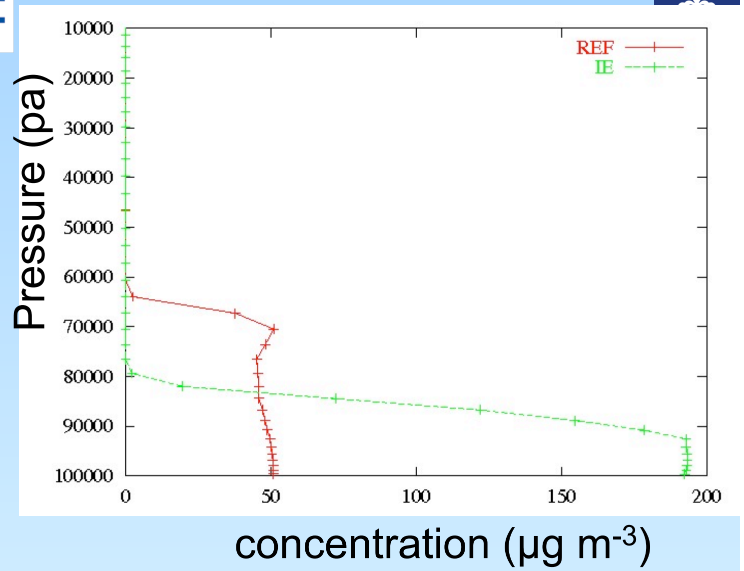
Surface temperature changes are up to 4º C

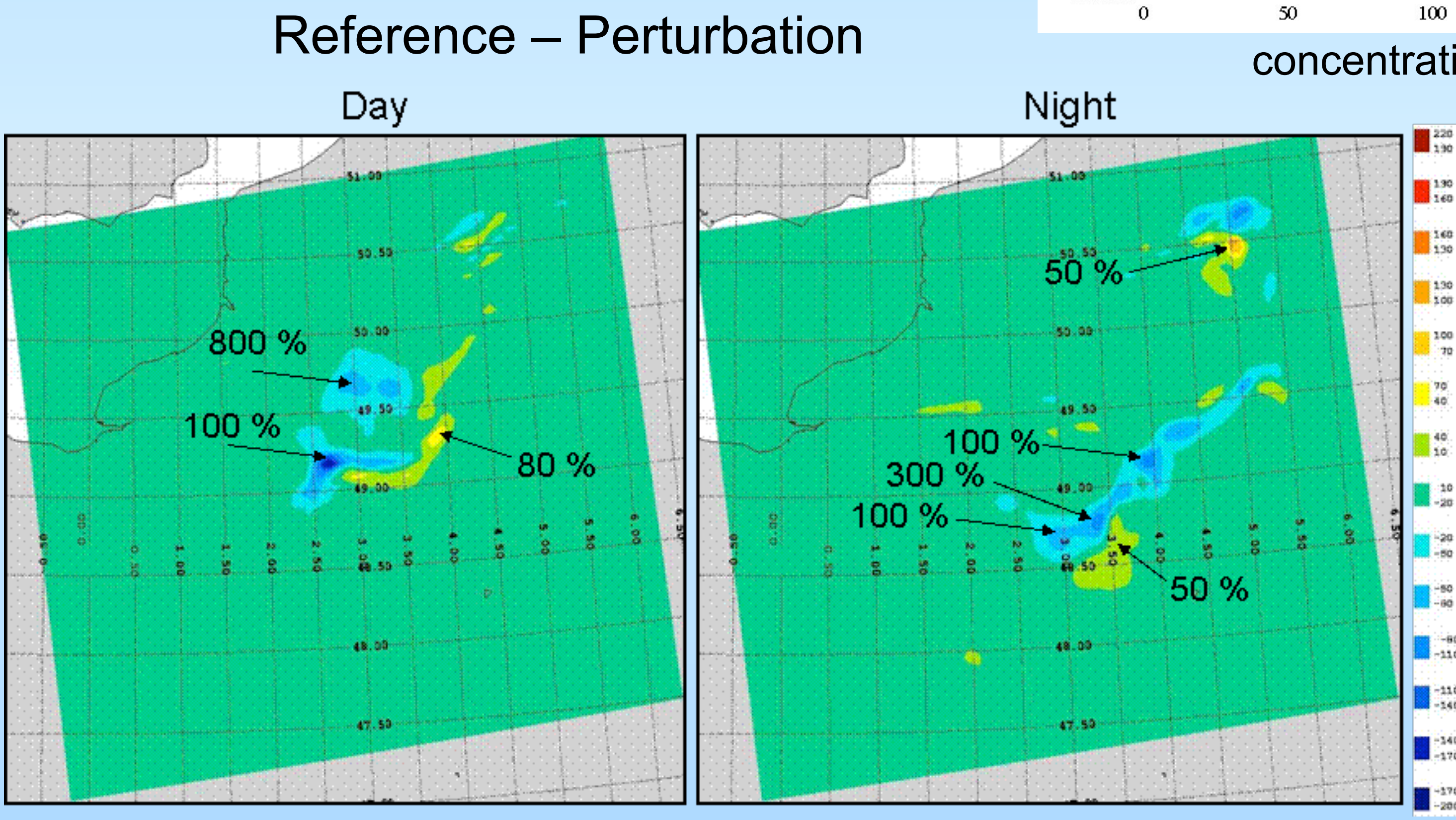
wind changes up to 3-6 m/s

Korsholm et al., 2009

Results 2: NO2 concentrations

Vertical NO_2 profile in point of maximum increase (49.2N;2.7E) during daytime 2005-06-29 +036; 12 UTC for the reference simulation (red) and the simulation including the indirect effects (green)

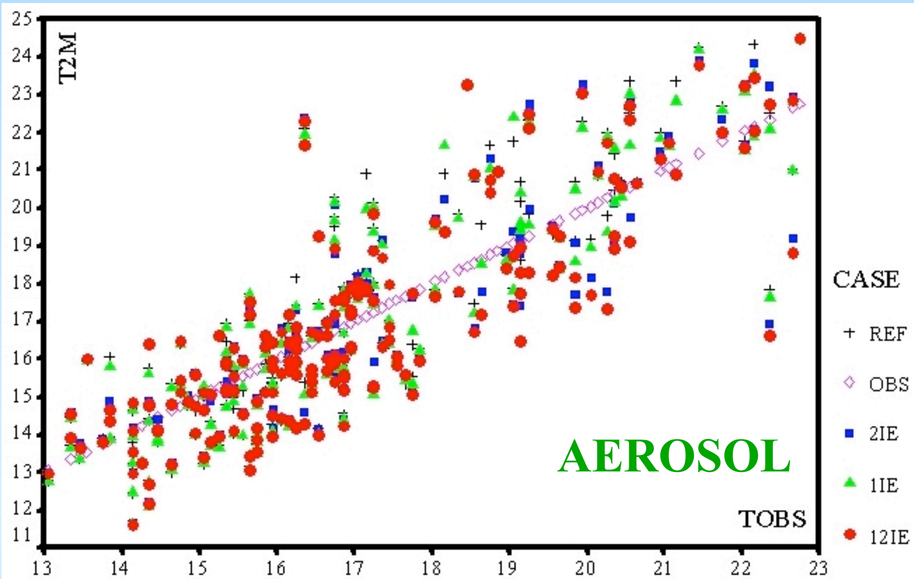


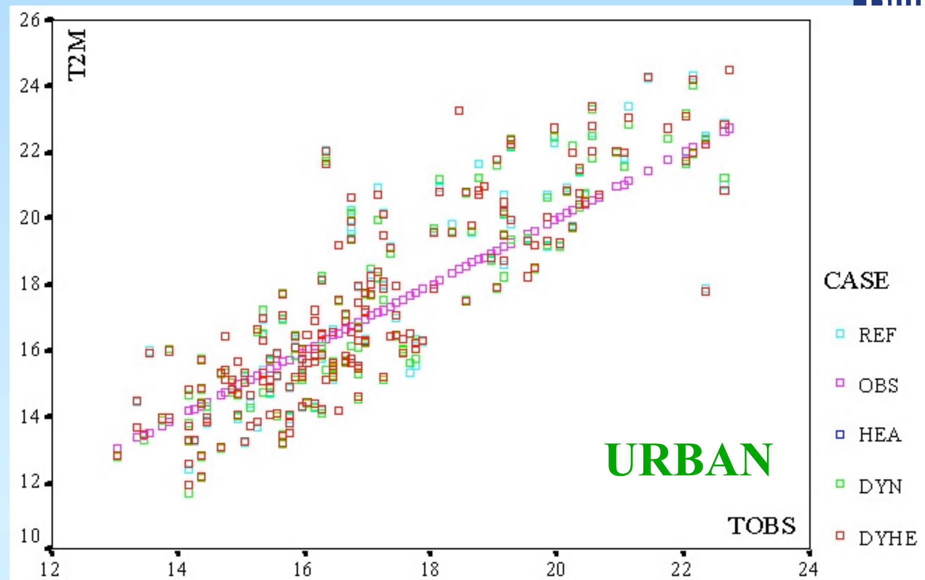


Day-time (2005-06-29 +036; 12 UTC) and night-time (2005-06-29 +048; 00 UTC) reference - perturbation NO_2 concentration (µg m^{-3})

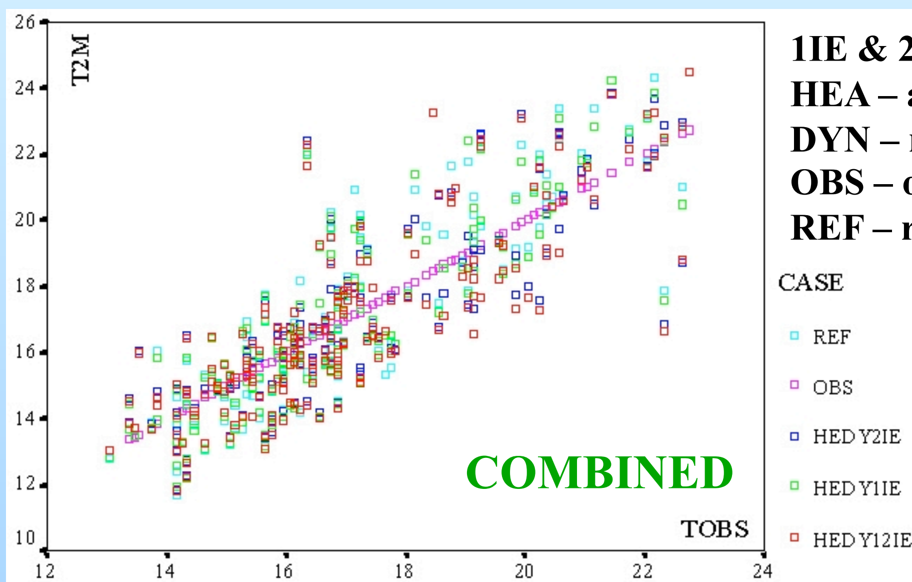
Korsholm et al., 2009

Paris Runs – Aerosol vs. Urban Effects - 1





Parameter	Global Cor
DYN	0,856
HEA	0,857
DYN+HEA	0,857
2IE	0,831
1IE	0,852
12IE	0,821
DYN+HEA+1IE	0,855
DYN+HEA+2IE	0,829
DYN+HEA+1IE+2IE	0,820
REF	**0,855**



1IE & 2IE – 1st & 2nd indirect effects
HEA – anthropogenic heat flux
DYN – roughness
OBS – observations
REF – reference run / non-modified

Korsholm et al., 2009

Applications of Enviro-HIRLAM for:

(i) chemical weather forecasting

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

(iii) pollen forecasting,

(iv) air quality and chemical composition longer-term assessment,

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

(vi) volcano eruptions, nuclear explosion consequences,

(vii) other emergency preparedness modelling.

CONCLUSIONS

- The new concept: the chemical weather as two-way interacted meteorological weather and chemical composition of the atmosphere.
- On-line integration of MMMs and CTMs enables the utilisation of all meteorological 3D fields in ACTMs at each time step and the consideration of the feedbacks of air pollution on meteorological processes and climate forcing.
- New generation of integrated models => not only for the chemical weather forecasting, but also for climate change modelling, weather forecasting (e.g., in urban areas, severe weather events, etc.), air quality analysis and mitigations, long-term assessment chemical composition, etc.
- Main advantages: (i) Only one grid for MMM and ACTM, no interpolation in space and time, (ii) Physical parameterizations are the same, no inconsistencies; (iii) All 3D meteorological variables are available at the right time at each time step; (iv) No restriction in variability of meteorological fields; (v) Possibility to consider two-way feedback mechanisms; (vi) Does not need meteo- pre/post-processors.
- A number of on-line coupled MMM and ACTM model systems in Europe. However, many of them were not built for the meso-meteorological scale, most of them 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.
- Indirect aerosol feedbacks (based on the Paris case study): strong sensitivity of chemistry, strong non-linearity, fist indirect effect is much smaller than second one, indirect effects induce large changes in NO2.
- We can conclude that feedback mechanisms could be important in accurate CWF modelling and quantifying direct and indirect effects of aerosols, this is supported by the simulation results.

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