Megacities impact on air quality and climate: model integration and model ‘bridging’ in context of the MEGAPOLI project

Alexander A. Baklanov
Danish Meteorological Institute,
DMI, Research Department, Lyngbyvej 100, Copenhagen, DK-2100, Denmark
alb@DMI.dk, phone: +45 39157441

In cooperation with
MEGAPOLI, Enviro-HIRLAM, COST728 and COST ES0602 consortiums

ARPA-ARIANET Seminar,
Milan, Italy, 29 May 2009
Overview

• MEGAPOLI overview
• Integrated ACT-NWP modelling
• Chemical weather forecasting: new concept
• Aerosol feedbacks
• Urbanization of models
• Multi-scale effects from megacities
• Enviro-HIRLAM online coupled system
• First results from Paris study
• Conclusions and further research
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

27 European research organisations from 11 countries are involved.
Coordinator: A. Baklanov (DMI)
Vice-coordinators: M. Lawrence (MPIC) and S. Pandis (FRTHUP)

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

The main aim 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.
### MEGAPOLI Partners:

<table>
<thead>
<tr>
<th>Nr</th>
<th>Beneficiary name</th>
<th>short name</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Danish Meteorological Institute</td>
<td>DMI</td>
<td>Denmark</td>
</tr>
<tr>
<td>2</td>
<td>Foundation for Research and Technology, Hellas, University of Patras</td>
<td>FORTH</td>
<td>Greece</td>
</tr>
<tr>
<td>3</td>
<td>Max Planck Institute for Chemistry</td>
<td>MPIC</td>
<td>Germany</td>
</tr>
<tr>
<td>4</td>
<td>ARIANET Consulting (SME)</td>
<td>ARIANET</td>
<td>Italy</td>
</tr>
<tr>
<td>5</td>
<td>Aristotle University Thessaloniki</td>
<td>AUTH</td>
<td>Greece</td>
</tr>
<tr>
<td>6</td>
<td>Centre National de Recherche Scientifique (incl. LISA, LAMP, LSCE, GAME, LGGE)</td>
<td>CNRS</td>
<td>France</td>
</tr>
<tr>
<td>7</td>
<td>Finnish Meteorological Institute</td>
<td>FMI</td>
<td>Finland</td>
</tr>
<tr>
<td>8</td>
<td>Joint Research Center, Ispra</td>
<td>JRC</td>
<td>Italy</td>
</tr>
<tr>
<td>9</td>
<td>International Centre for Theoretical Physics</td>
<td>ICTP</td>
<td>Italy</td>
</tr>
<tr>
<td>10</td>
<td>King’s College London</td>
<td>KCL</td>
<td>UK</td>
</tr>
<tr>
<td>11</td>
<td>Nansen Environmental and Remote Sensing Center</td>
<td>NERSC</td>
<td>Norway</td>
</tr>
<tr>
<td>12</td>
<td>Norwegian Institute for Air Research</td>
<td>NILU</td>
<td>Norway</td>
</tr>
<tr>
<td>13</td>
<td>Paul Scherrer Institute</td>
<td>PSI</td>
<td>Switzerland</td>
</tr>
<tr>
<td>14</td>
<td>TNO-Built Environment and Geosciences</td>
<td>TNO</td>
<td>The Netherlands</td>
</tr>
<tr>
<td>15</td>
<td>UK MetOffice</td>
<td>MetO</td>
<td>UK</td>
</tr>
<tr>
<td>16</td>
<td>University of Hamburg</td>
<td>UHam</td>
<td>Germany</td>
</tr>
<tr>
<td>17</td>
<td>University of Helsinki</td>
<td>UHel</td>
<td>Finland</td>
</tr>
<tr>
<td>18</td>
<td>University of Hertfordshire – Centre for Atmospheric and Instrum. Research</td>
<td>UH-CAIR</td>
<td>UK</td>
</tr>
<tr>
<td>19</td>
<td>University of Stuttgart</td>
<td>USTUTT</td>
<td>Germany</td>
</tr>
<tr>
<td>20</td>
<td>World Meteorological Organization</td>
<td>WMO</td>
<td>Switzerland (Int.)</td>
</tr>
<tr>
<td>21</td>
<td>Charles University, Prague</td>
<td>CUNI</td>
<td>Czech Republic</td>
</tr>
<tr>
<td>22</td>
<td>Institute of Tropospheric Research</td>
<td>IfT</td>
<td>Germany</td>
</tr>
<tr>
<td>23</td>
<td>Centre for Atmospheric Science, University of Cambridge</td>
<td>UCam</td>
<td>UK</td>
</tr>
<tr>
<td>WP No.</td>
<td>Title</td>
<td>Lead Participant(s)</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>------------------------------------------------------------</td>
<td>--------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Emissions</td>
<td>P. Builtjes, H. Denier van der Gon</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Megacity Environments: Features, Processes and Effects</td>
<td>S. Grimmond, I. Esau</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Megacity Plume Case Study</td>
<td>M. Beekmann, U. Baltensperger</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Megacity Air Quality</td>
<td>N. Moussiopoulos</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Regional and Global Atmospheric Composition</td>
<td>J. Kukkonen, A. Stohl</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Regional and Global Climate Effects</td>
<td>W. Collins, F. Giorgii</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Integrated Tools and Implementation</td>
<td>R. Sokhi, H. Schlünzen</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Mitigation, Policy Options and Impact Assessment</td>
<td>R. Friedrich, D. van den Hout</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Dissemination and Coordination</td>
<td>A. Baklanov, S. Pandis, M. Lawrence</td>
<td></td>
</tr>
</tbody>
</table>

**Work Packages (WPs) structure & integration**

- **WP1:** Emissions
- **WP2:** Megacity features
- **WP3:** Megacity Plume Case Study
- **WP4:** Megacity Air Quality
- **WP5:** Regional and Global Atmospheric Composition
- **WP6:** Regional and Global Climate Impacts
- **WP7:** Integrated Tools and Implementation
- **WP8:** Mitigation, Policy Options and Impact Assessment
- **WP9:** Dissemination and Coordination
European population distribution & megacities in focus

Managers for megacities:
- Paris (Beekmann, CNRS)
- London (Sokhi/Grimmond, UH/KCL)
- Ruhr (Friedrich/Lawrence, US/MPIC)
- Po Valley (Finardi, ARIANET)
- Istanbul (Incecik, ITU)
- Moscow (Baklanov, DMI)
Megacity Characteristics, Pollution & Emission

(Butler et al., Atmos. Env., 42 (2008) 703–719)

(Megacity pollution index (MPI))

New TNO Emission for MEGAPOLI:
• Complete Pan-European inventory at ~ 6x6 km for 2005 completed
• Next focus: nesting local inventories for 5 megacities at the highest resolution:
  - London: Detailed inventory available at 1x1 km for 2004, upgrade to 2005 underway
  - Paris, Po Valley, Ruhr Region, Istanbul: underway
• Improved Global emission inventory for 2005 underway
• Future emission and mitigation scenario underway

(TNO: Denier van der Gon et al.)
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 will be the focus of MEGAPOLI.
One-way: 1. NWP meteo-fields as a driver for ACTM (off-line);
   2. ACTM chemical composition fields as a driver for R/GCM (or for NWP)

Two-way: 1. Driver + partly feedback NWP (data exchange via an interface with a limited time period: offline or online access coupling, with or without second iteration with corrected fields);
   2. Full feedbacks chains included on each time step (on-line coupling)
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 feedback chains are available. We will use this definition as on-line coupled modelling.
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 2-way 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.
Chemical weather forecast: common concept

- 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 benefits from the ACTM) and not considering the feedback mechanisms.
Chemical weather forecast: new concept

• 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.
• 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).
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/developers

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


WG2 outcome => COST Action ES0602: Chemical Weather Forecasting (2008-12)
<table>
<thead>
<tr>
<th>Model name</th>
<th>On-line coupled chemistry</th>
<th>Time step for coupling</th>
<th>Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOLCHEM</td>
<td>Ozone as prognostic chemically active tracer</td>
<td></td>
<td>None</td>
</tr>
<tr>
<td>ENVIRO-HIRLAM</td>
<td>Gas phase, aerosol and heterogeneous chemistry</td>
<td>Each HIRLAM time step</td>
<td>Yes</td>
</tr>
<tr>
<td>WRF-Chem</td>
<td>RADM+Carbon Bond, Madronich+Fast-J photolysis, modal+sectional aerosol</td>
<td>Each model time step</td>
<td>Yes</td>
</tr>
<tr>
<td>COSMO LM-ART</td>
<td>Gas phase chem (58 variables), aerosol physics (102 variables), pollen grains</td>
<td>Each LM time step</td>
<td>Yes (*)</td>
</tr>
<tr>
<td>COSMO LM-MUSCAT (***)</td>
<td>Several gas phase mechanisms, aerosol physics</td>
<td>Each time step or time step multiple</td>
<td>None</td>
</tr>
<tr>
<td>MCCM</td>
<td>RADM and RACM, photolysis (Madronich), modal aerosol</td>
<td>Each model time step</td>
<td>(Yes) (***</td>
</tr>
<tr>
<td>MESSy: ECHAM5</td>
<td>Gases and aerosols</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>MESSy: ECHAM5-COSMO LM (planned)</td>
<td>Gases and aerosols</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>MC2-AQ</td>
<td>Gas phase: 47 species, 98 chemical reactions and 16 photolysis reactions</td>
<td>Each model time step</td>
<td>None</td>
</tr>
<tr>
<td>GEM/LAM-AQ</td>
<td>Gas phase, aerosol and heterogeneous chemistry</td>
<td>Set up by user – in most cases every time step</td>
<td>None</td>
</tr>
<tr>
<td>Operational ECMWF model (IFS)</td>
<td>Prog. stratos passive O3 tracer</td>
<td>Each model time step</td>
<td></td>
</tr>
<tr>
<td>ECMWF GEMS modelling</td>
<td>GEMS chemistry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GME</td>
<td>Progn. stratos passive O3 tracer</td>
<td>Each model time step</td>
<td></td>
</tr>
<tr>
<td>OPANA=MEMO+CBMIV</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* ) 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 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-IR radiation and visibility
  - Processes needed: radiation (scattering, absorption, refraction, etc.)
  - Key variables: refractive indices, ext. coeff., SSA, asymmetry factor, AOD, visual range
  - Key species: **cooling**: water, sulfate, nitrate, most OC
    **warming**: BC, OC, Fe, Al, polycyclic/nitrated aromatic compounds

- **Semi-direct effect** - Affect PBL meteorology and photochemistry
  - Processes needed: PBL/LS, photolysis, met-dependent processes
  - Key variables: T, P, RH, Qv, WSP, WDR, Cld Frac, stability, PBL height, photolysis rates, emission rates of met-dependent primary species (dust, sea-salt, biogenic)

- **First indirect effect** — Affect cld drop size, number, reflectivity, and optical depth via CCN
  - Processes needed: aero. activation/resuspension, cld. microphysics, hydrometeor dynamics
  - Key variables: int./act. frac, CCN size/comp., cld drop size/number/LWC, COD, updraft vel.

- **Second indirect effect** - Affect cloud LWC, lifetime, and precipitation
  - Processes needed: in-/below-cloud scavenging, droplet sedimentation
  - Key variables: scavenging efficiency, precip. rate, sedimentation rate

- **All aerosol effects**
  - Processes needed: aero. thermodynamics/dynamics, aq. chem., precursor emi., water uptake
  - Key variables: aerosol mass, number, size, comp., hygroscopicity, mixing state

⇒ High-resolution on-line models with a detailed description of the PBL structure are necessary to simulate such effects
⇒ Online integrated models are necessary to simulate correctly the effects involved
1. Off-line integrated urbanised UAQIFS in FUMAPEX (Baklanov et al., ACP, 2006, 2008)


3. Simplified urban models for emergency preparedness: e.g. ARGOS (Hoe et al., 2007; Baklanov et al., JER 2008)
Enviro-HIRLAM
Integrated (on-line coupled) modeling system structure for predicting the atmospheric composition

On-line integrated new generation system with feedbacks: urbanised EnviroHIRLAM
(Baklanov et al., ASR 2008, Korsholm et al., HN 2009)
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
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 recently joining the development team:
- University of Tartu, Estonia (R. Room, etc.),
- 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!
DMI-HIRLAM Modelling Domains
Multi-scale Modelling and M2UE nesting

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

- Obstacle-resolved modelling for near-source area
- Statistical description of building characteristics
- Release site
Release position sensitivity study: Results for Copenhagen area

Near surface velocity field and isosurfaces of concentration:
10 m difference of release position ● (left and right)

Baklanov and Nuterman, ASR, 2009
Up-scaling of modelling

- MEGAPOLI: megacity effects on larger scales pollution and climate
- Street => City => Region => Global
- Different approaches:
  - 2-way nesting
  - unregular grid concentration over megacities
  - Parameterisations to larger scale
  - Inner BC, assimilation, ..
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., ACP 2006, 2008
The effects of urban aerosols on the urban boundary layer height, $h$, could be of the same order of magnitude as the effects of the urban heat island ($\Delta h$ is about 100-200 m for stable boundary layer).

Baklanov et al., JER, 2008
Sensitivity of ARGOS dispersion simulations to urbanized DMI-HIRLAM NWP data

A local-scale plume from the $^{137}$Cs hypothetical atmospheric release in Hillerød at 00 UTC, 19 June 2005 as calculated with RIMPUFF using DMI-HIRLAM and visualised in ARGOS for the Copenhagen Metropolitan Area (DEMA and DMI study).

Baklanov et al., JER, 2008
Enviro-HIRLAM model description 1, Overview

• Gas-phase chemistry: NWP-Chem (HIRLAM newsletter, No. 54, June 2008)
• Aerosol representations, thermodynamic equilibrium, nucleation, coagulation and condensation (Gross and Baklanov, 2002)
• Advection: Bott (Bott, 1989) and CISL (Kaas, 2008) schemes
• Vertical diffusion: native CBR-TKE-1 scheme (Cuxart et al., 2000)
• 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)
Model description 2, Chemistry and aerosols

The **NWP-Chem mechanism**: Lumped tropospheric mechanism based on newest chemical knowledge

- Covers most important chemical processes responsible for air pollution and aerosol formation in meso-scale models
- Adveled species: NO, NO2, SO2, CO, HC, HCHO, O3, HO2, HNO3, H2O2, H2, H2SO4, OP, HO, OD, RO2, ROOH, (DMS, isoprene, monoterpene)

3 other chemical mechanisms available in EnviroHIRLAM: RACM, RADM, CBMZ

**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 (*Whitby and McMurry, 1997; Gross and Baklanov, 2004*)

2 other aerosol models also available in EnviroHIRLAM:
- sectional MOSAIC (Zaveri et al., 2007) and
- modal MADE (Ackermann et al., 1998) with SORGAM (Schell et al., 2001)
The first aerosol indirect effect

\[ r^3_{\text{eff}} = \frac{3L}{4\pi \rho_{\text{wat}} kN} \]  
(Wyser et al. 1999)

\[ \Delta N_{\text{cont}} = 10^{8.06} \text{conc}^{0.48} \]
\[ \Delta N_{\text{sea}} = 10^{2.24} \text{conc}^{0.26} \]

(Boucher & Lohmann, 1995)

Polluted airmass has more aerosols => hence more cloud droplets

<table>
<thead>
<tr>
<th></th>
<th>k</th>
<th>N \ [m^{-3}]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine</td>
<td>0.81</td>
<td>10^8</td>
</tr>
<tr>
<td>Cont.</td>
<td>0.69</td>
<td>4 \times 10^8</td>
</tr>
</tbody>
</table>
Model description 4, Aerosol feedbacks

The second aerosol indirect effect

Rasch - Kristjansson condensation scheme in STRACO

Auto-conversion: \( F(q_l, \rho_{\text{air}} / \rho_{\text{wat}}) N^{1/3} H(r - r_c) \)

- \( r \) : droplet volume radius; \( r = r_{\text{eff}} \cdot \rho_{\text{air}} \)
- \( r_c \) : critical value below which no auto-conversion takes place; 5 \( \mu \text{m} \)
- \( \rho_{\text{air}} \) : air density
- \( q_l \) : in-cloud liquid water mixing ratio

Korsholm et al., HN, 2008
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
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. False peak due to off-line coupling.

Korsholm et al., AE, 2008
Domain covering 665 x 445 km around Paris, France,

Case study days: 2005-06-28 - 2005-07-03,

Emission data from TNO-GEMS (year 2003, now modified for 2005),

300 s time step, NWP-Chem chemistry (18 species), DMI urbanisation scheme,

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 runs with urban and aerosol indirect effects.
Results 1: Aerosol effects on 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 4° C
wind changes up to 3-6 m/s

Korsholm et al., 2009
Results 2: PBL height

Reference - Perturbation (in 100 m)

00 UTC

Changes in PBL height quite large (up to 900 m !)

12 UTC

Korsholm et al., 2009
Results 3: NO2 concentrations

Vertical NO₂ 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).

Reference – Perturbation

Day-time (2005-06-29 +036; 12 UTC) and night-time (2005-06-29 +048; 00 UTC) reference - perturbation NO₂ concentration (μg m⁻³)

Korsholm et al., 2009
Scientific questions still to be 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?
Major Upcoming MEGAPOLI Research:

- Two field campaigns in Paris (July 2009 and January/February 2010)
- Further emissions database and future scenario development
- Continued model development from urban to global scale, analysis and interactions
- Bringing it together with integrated modelling and mitigations scenarios
- Modelling to quantify feedbacks among megacity air quality, local and regional climate, and global climate change
- Assessing different mitigation options to reduce health impacts of megacity emissions
Relevant publications:

Thank You!

MEGAPOLI web-site: megapoli.info

Contact e-mail: Alexander Baklanov <alb@dmi.dk>