Enviro-HIRLAM Downscaling from Regional to Urban Scales: Meteorology and Chemistry Patterns

Alexander Mahura [1,], Roman Nuterman [2,3], Iratxe Gonzalez-Aparicio [4], Alexander Baklanov [1,5], Bent H. Sass [1]*

[1] Danish Meteorological Institute (DMI), Research and Development Department, Copenhagen, Denmark
[2] Niels Bohr Institute, University of Copenhagen (NBI-UoC), Denmark
[3] Tomsk State University (TSU), Tomsk, Russia
[4] Joint Research Center (JRC), Institute for Energy and Transport, Westerduinweg 3, NL-1755 LE Petten, The Netherlands
[5] World Meteorological Organization (WMO), Geneva, Switzerland

** Corresponding author: Alexander Mahura; ama@dmi.dk; Ph. +45-3915-7423*

Abstract

The evaluation of regional and urban meteorological and chemical patterns due to influence of the Paris metropolitan area was performed employing an urbanized version of the Enviro-HIRLAM (Environment - HIgh Resolution Limited Area Model). It is a fully online-coupled Atmospheric Chemistry Transport – Numerical Weather Prediction (ACT-NWP) modeling system developed for regional-, meso- and urban scale different environmental applications. The Paris megacity effects on formation and development of meteorological fields (for air temperature, wind speed, relative humidity, total cloud cover, boundary layer height, surface temperature) are evaluated on a diurnal cycle. Enviro-HIRLAM simultaneously with meteorological parameters simulated atmospheric transport, dispersion, deposition, and transformations of chemical species. The effects of urbanization on variability of spatio-temporal concentration patterns of selected chemical species were also studied for the Paris metropolitan area and surroundings. Results of comparative analysis based on different Enviro-HIRLAM model runs: reference/control vs. modified/urbanized are presented.

Model Downscaling Chain

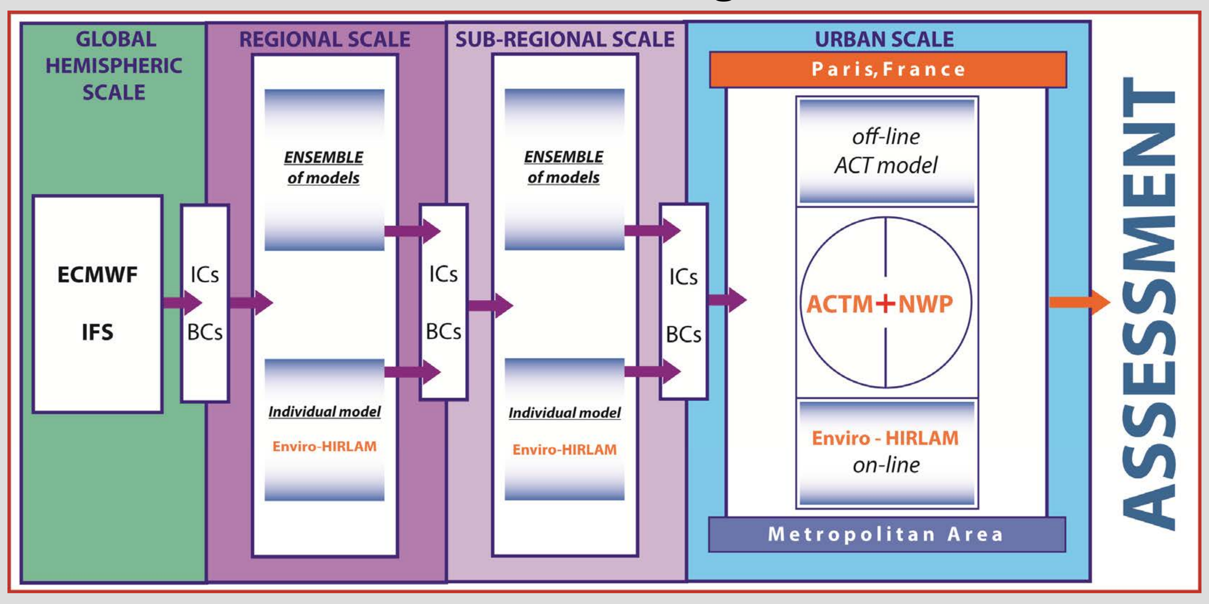


Figure 1: Downscaling chain for on-line integrated meteorology-chemistry/aerosols Enviro-HIRLAM (Environment—High Resolution Limited Area Model) model for weather and environmental applications.

The most serious air pollution events occur in cities where there is a combination of high population density and air pollution. The pollutants can lead to serious human health problems. However, European-scale air quality models are not well suited for urban forecasts, as their grid-cell is typically of the order of 5-10 km and they generally lack detailed representation of urban effects. Due to constantly increasing supercomputer power modern nested numerical meteorological and air pollution models realize model nesting/down-scaling from the global to urban scale and approach the necessary horizontal and vertical resolutions to provide weather and air quality forecasts for urban scales. This will bring a strong support for continuous improvement of the forecast modelling systems for weather and air quality in Europe, and underline clear perspectives for the future multi-scale air quality core-downstream services for end-users.

Paris Metropolitan Area & Urban Districts

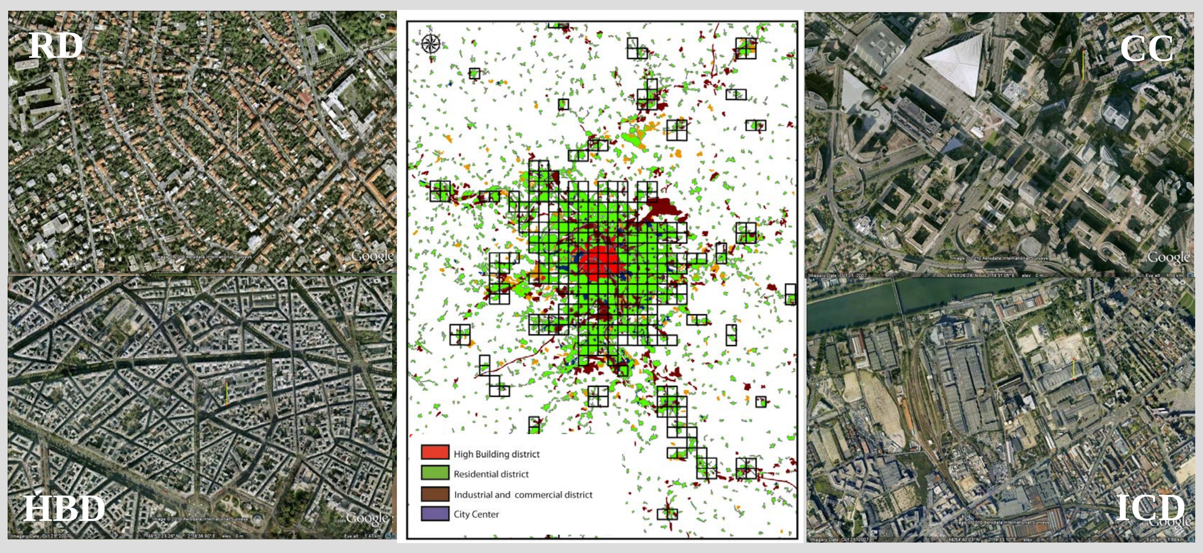


Figure 2: Paris metropolitan area: urban districts and reclassification into different urban districts based on the CORINE land-use database.

Building Effect Parameterization (BEP) & Anthropogenic Heat Flux (AHF)

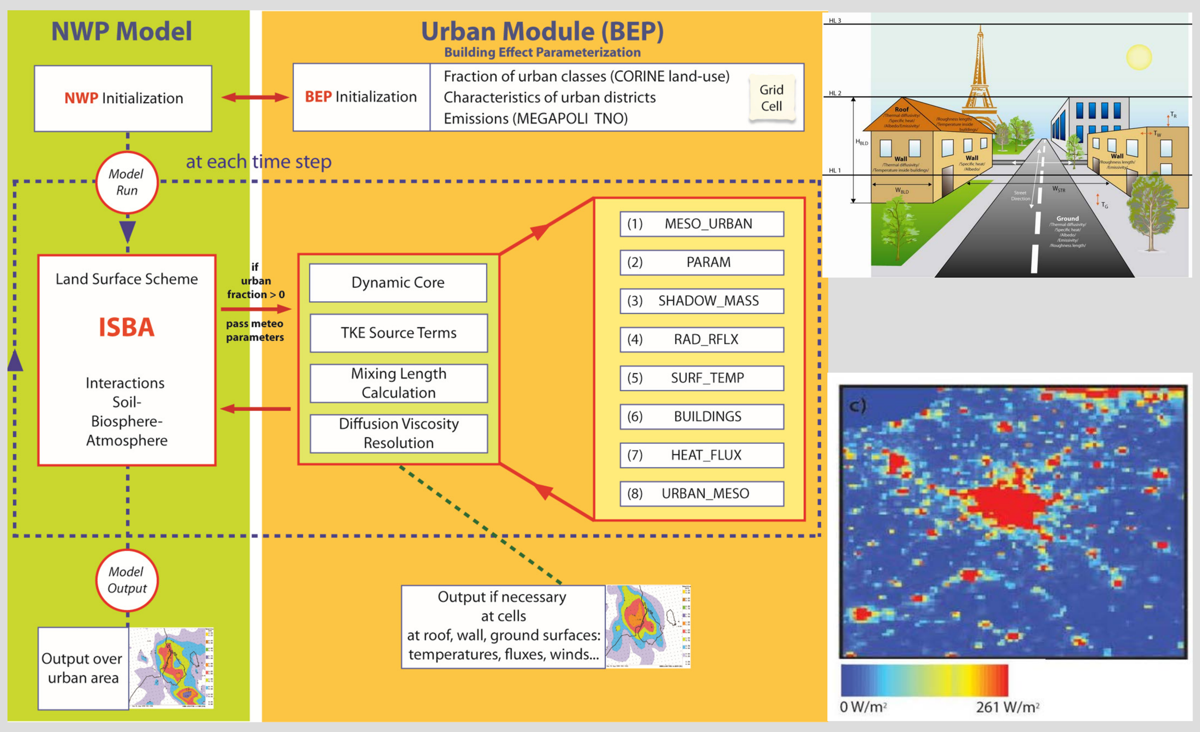


Figure 3: (right-top) Schematic representation of urban features & numerical grid in BEP urban module / HL1, HL2 – model levels; H_{BLD}, W_{BLD} – height & width of the buildings; SD, W_{STR} – street direction & width; T_G, T_W, T_R – temperatures of ground, wall & roof surfaces/; (left) General scheme of the BEP module for the model urbanization with a structure of the subroutine conception; (right-bottom) Anthropogenic heat fluxes for French urban areas (extracted from LUCY model output; Allen et al., 2011).

References

Abdul-Razzak, H., and S. J. Ghan (2000), A parameterization of aerosol activation: 2. Multiple aerosol types, J. Geophys. Res., 105 (D5), 6837–6844, doi:10.1029/1999JD901161.

Allen, L, Lindberg, F & Grimmond, S (2011), 'Global to city scale model for anthropogenic heat flux: Model and variability' Int J of Clim, vol 31, no. 13, pp. 1990-2005., 10.1002/joc.2210

Baklanov A., U. Korsholm, A. Mahura, C. Petersen, A. Gross, (2008): Enviro-HIRLAM: on-line coupled modelling of urban meteorology and air pollution. Adv. Sci. Res., 2, 41-46.

González-Aparicio I., Nuterman R., Korsholm U., Mahura A., Acero J.-Á., Hidalgo J. and Baklanov A., (2010): Land-use Database Processing Approach for Meso-Scale Urban NWP Model Initialization, DMI Sci. Report, No. 10-02, 32 p.

Korsholm U., (2009): Integrated modeling of aerosol indirect effects - develoment and application of a chemical weather model. PhD thesis University of Copenhagen, Niels Bohr Institute and DMI, Research Department.

Martilli, A., Clappier, A., Rotach, M. W., (2002): An Urban Surface Exchange Parameterization for Mesoscale Models, Boundary Layer Meteorology 104, 261-304.

Savijärvi, H. 1990: Fast Radiation Parameterization Schemes for Mesoscale & Short-Range Forecast Models. J. Appl. Met., 29, 437–447.

Unden, P., L. Rontu, H. Järvinen, P. Lynch, J. Calvo, G. Cats, J. Cuhart, K. Eerola, etc. 2002: HIRLAM-5 Scientific Documentation. December 2002, HIRLAM-5 Project Report, SMHI.

Vignati, E., Wilson, J. and Stier, P., (2004): M7: An efficient size-resolved aerosol microphysics module for large-scale aerosol transport models. Journal of Geophysical Research 109: doi: 10.1029/2003JD004485

Zakey, A. S., F. Giorgi, and X. Bi, 2008: Modeling of sea salt in a regional climate model: Fluxes and radiative forcing, J. Geophys. Res., 113, D14221, doi:10.1029/2007JD009209.

Zakey, A. S., Solmon, F., and Giorgi, F., 2006: Implementation and testing of a desert dust module in a regional climate model, Atmos. Chem. Phys., 6, 4687-4704, doi:10.5194/acp-6-4687-2006.

Zaveri, R. A., and L. K. Peters, (1999): A new lumped structure photochemical mechanism for large-scale applications, J. Geophys. Res., 104(D23), 30387–30415, doi:10.1029/1999JD900876.

Enviro-HIRLAM Downscaling (15—5—2.5 km): Meteorological & Chemical Fields

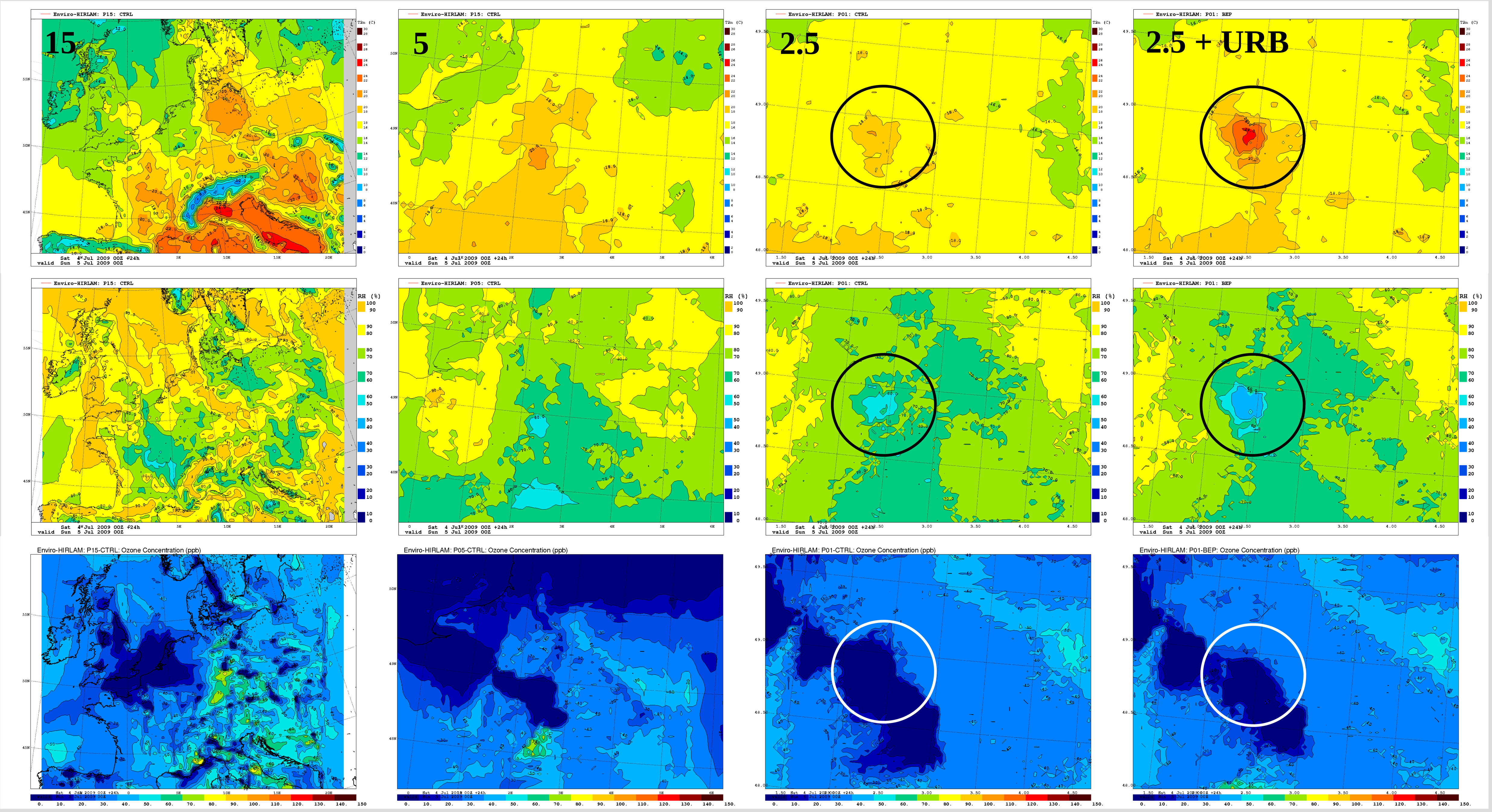


Figure 4: Enviro-HIRLAM downscaling (from left to right: CTRL 15—5—2.5 km & 2.5+URB) meteorological (top—air temperature, middle—humidity) and chemical (bottom—ozone) fields on 4 Jul 2009, 00+24 UTC.

Enviro-HIRLAM Model Components

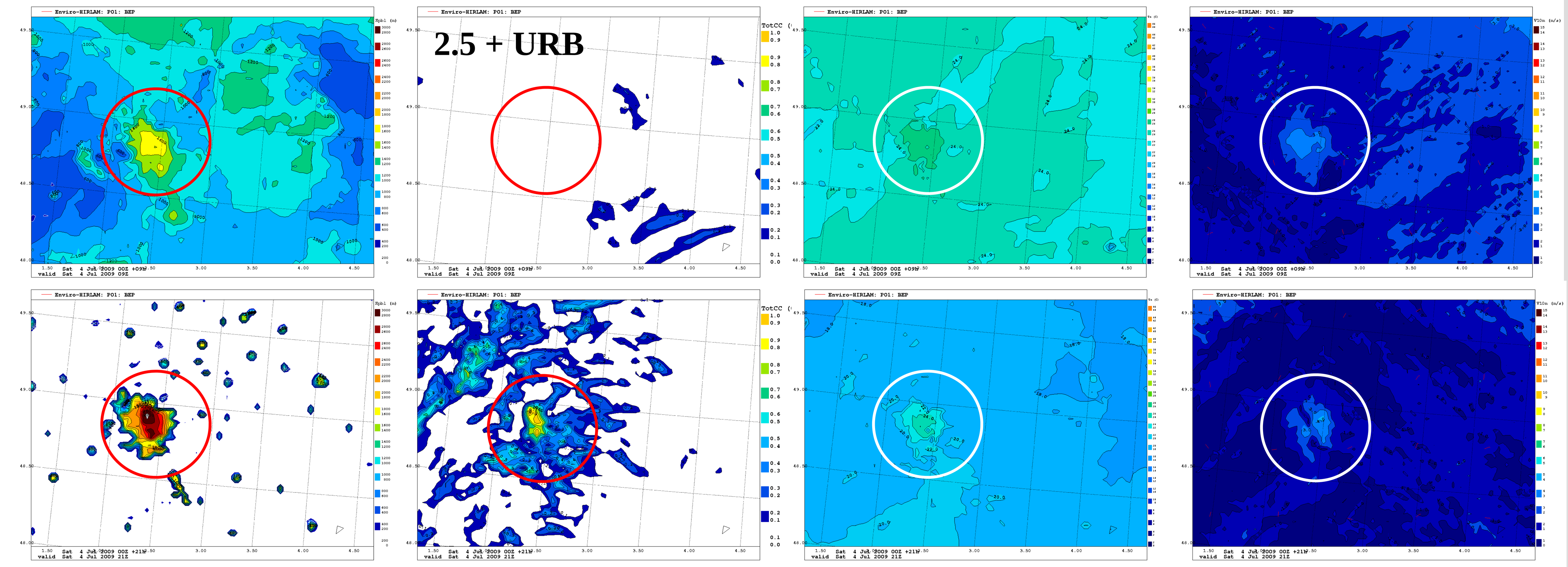
Enviro-HIRLAM (Environment—HIgh Resolution Limited Area Model) is online-coupled ACT-NWP (Atmospheric Chemistry Transport – Numerical Weather Prediction) modeling system for regional-, meso- and urban scale different environmental applications. The NWP part developed by HIRLAM consortium (*Unden et al., 2002*) is used for operational weather forecasting. The Enviro-components were mainly developed by DMI and NBI/UoC with partners from European countries (*Korsholm, 2009; Baklanov et al., 2008*). It consists of gas-phase chemistry CBMZ (*Zaveri & Peters, 1999*) and aerosol microphysics M7 (*Vignati et al., 2004*), which includes sulfate, mineral dust, sea-salt, black and organic carbon. There are modules of urbanization for land surface scheme, natural and anthropogenic emissions, nucleation, coagulation, condensation, dry and wet deposition, and sedimentation of aerosols. The Savijarvi radiation scheme (*Savijärvi, 1990*) has been improved to account explicitly for aerosol radiation interactions for 10 aerosol subtypes. The aerosol activation scheme (*Abdul-Razzak & Ghan, 2000*) was also implemented in STRACO condensation-convection scheme. The nucleation is dependent on aerosol properties and the ice-phase processes are reformulated in terms of classical nucleation theory. Model Setup includes: period to be studied; boundaries of modeling domain; selected projection; horizontal & vertical resolutions; chemical & meteorological initial & boundary conditions; emissions (anthropogenic – for EU domain - TNO-MACC for year 2009, biogenic (IS4FIRES by FMI), natural (interactive sea-salt *Zakey et al. (2008)* and mineral dust *Zakey et al. (2006)* emission modules); chemical & aerosol modules. Enviro-HIRLAM includes two-way feedbacks between air pollutants and meteorological processes. Different parts of Enviro-HIRLAM were evaluated versus ETEX-1 experiment, Chernobyl accident, urban case studies for several European metropolitan areas.

Acknowledgements

Thanks to DMI Computer Department for technical support and advice. Thanks to DMI colleagues for useful comments and discussions. The CRAY-XT5 supercomputing facilities, ECMWF boundary conditions were used in this study. The research was supported by the EU FP7 MEGAPOLI & TRANSPHORM & COST Action EuMetChem.

Temporal Variability of Meteorological Parameters over the Paris Metropolitan Area

Figure 6: Variability of (from left-to-right) boundary layer height, total cloud cover, surface temperature, wind speed on 4 Jul 2009 at (top) 09 UTC and (bottom) 21 UTC based on Enviro-HIRLAM model run at 2.5 km resolution with URB=BEP+AHF included.



Paris Influence on Urban Heat Island

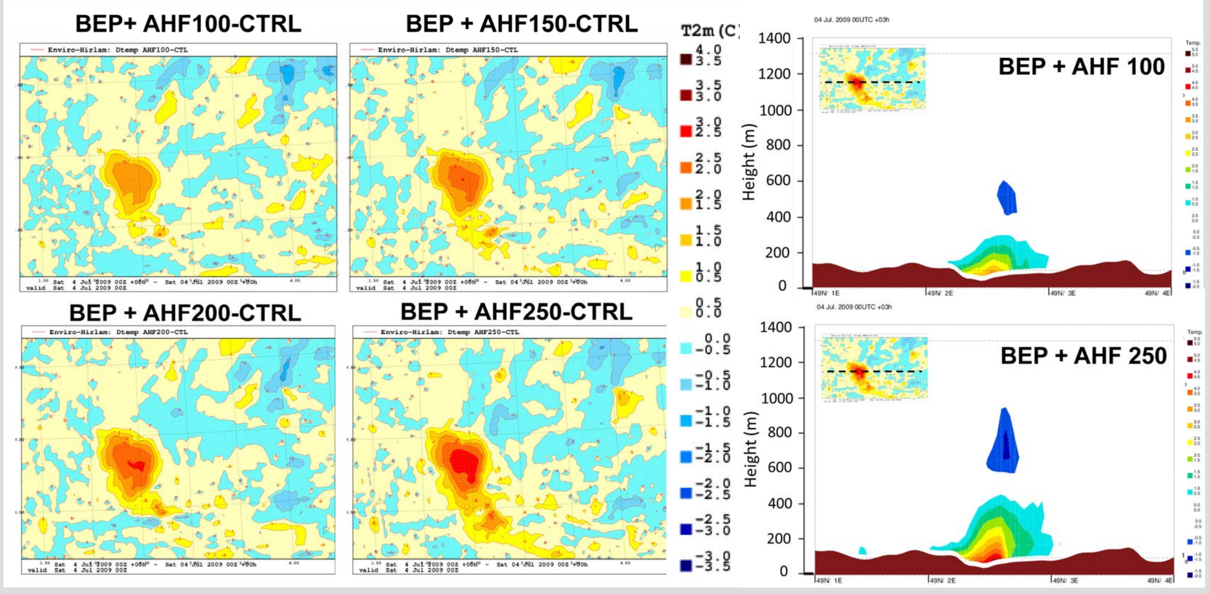


Figure 5: Difference (modified URB=BEP+AHF minus reference = CTRL run) fields for horizontal (on 4 Jul 2009, 00 UTC) and vertical (on 4 Jul 2009, 03 UTC) distribution of air temperature over the Paris metropolitan area as a function of AHF.

Concluding Remarks

In this study, the downscaling (Fig. 1) of online integrated meteorology-chemistry/aerosols Enviro-HIRLAM model was used to study effects of the Paris (megacity) metropolitan area composed of different districts (Fig. 2) on formation and development of meteorological and chemical fields through the chain of runs (CTRL run: 15 km—150x148 grids, 240 sec; 5 km—90x74 grids, 120 sec; and both CTRL&URB runs: 2.5 km—118x86 grids, 30-60-90 sec; & 2 day spin-up) and taking into account urban effects (URB run: BEP & AHF (Fig. 3) varying 100, 150, 200, & 250 W/m^2) for Jul 2009.

- **Meteorology** – *comparing URB vs. CTRL run* (Figs. 4,6) — cloud cover over megacity has increased during afternoon-night hours; PBL height increased - evening-late night hours for megacity and suburbs compared with rural areas; surface temperature increased - evening-night hours; wind speed increased - evening-late night hours; relative humidity decreased—evening-late night hours; air temperature increased, except noon;
- **Urban Heat Island** — urban effect is the strongest during evening-late night hours; and a cooling can be observed at heights above 700 m over megacity (Figs. 5-6);
- **Urban "footprint"** — can be extended up to 150 km away from urban area (Fig. 5);
- **Chemistry** — areas with low ozone concentration (titration) are less expanded from the city boundaries for the URB compared with CTRL run (Fig. 4);
- **AHF** — differences (URB vs. CTRL) for meteorological parameters became larger with increasing value of AHF, reaching largest differences at AHF=250 W/m^2 (Fig. 5).