Meteorological and Air Quality Models for Urban Areas

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Editors

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Introduction to the Problem and Aims

Alexander Baklanov

Urban features essentially influence atmospheric flow and microclimate, strongly enhance atmospheric turbulence, and modify turbulent transport, dispersion, and deposition of atmospheric pollutants (e.g., Piringer et al., 2007). Increased resolution in numerical weather prediction (NWP) models allows for a more realistic reproduction of urban air flows and air pollution processes, however most of the operational models still do not consider, or consider very poorly, the urban effects. This has triggered new interest in model development and investigation of processes specific to urban areas. Recent developments performed as part of the European project FUMAPEX on integrated systems for forecasting urban meteorology and air pollution (Baklanov et al., 2002, 2005), the US EPA and NCAR communities for MM5 (Dupont et al., 2004; Bornstein et al., 2006; Taha 2008), WRF models (Chen et al., 2006), and other relevant studies (see e.g. Baklanov and Grisogono, 2007) have shown many opportunities in the "urbanization" of weather forecasting and atmospheric pollution dispersion models.

Atmospheric models for urban areas have different requirements (e.g. relative importance of the urban boundary layer (UBL) and urban surface sublayer (USL) structure) depending on:

(i) the scale of the models (global, regional, city, local, micro, etc.);
(ii) the functional type of the model, e.g.:

- Forecasting or assessment type of models,
- Urban or regional climate models,
- Research meso-meteorological models,
- Numerical weather prediction models,
- Atmospheric pollution models (city-scale),
- Emergency preparedness models,
- Meteo-preprocessors (or post-processors).

A wide range of approaches have been taken to incorporating urban characteristics. In addition there are a wide range of processes which includes: characteristics of the urban canopy sublayer, components of urban surface energy balance (net radiation, sensible and latent heat fluxes, storage heat flux, etc.), and water transport. This results in a wide range of models (e.g., Brown and Williams, 1998; Oke et al., 1999; Grimmond and Oke, 1999; Kusaka et al., 2001; Masson, 2000; Dupont, 2001; Martilli et al., 2002). Most urban NWP or meso-meteorological models modify the existing non-urban approaches (e.g., the Monin-Obukhov similarity theory, MOST) for urban areas by parameterisation or finding proper values for the effective roughness lengths, displacement height, and heat fluxes, including the anthropogenic heat flux, heat storage capacity, albedo and emissivity change, etc. The main limitation is when there is a need to resolve meteorological profiles within the urban canopy, where the MOST assumption of a constant flux surface layer is invalid. This is obviously important as it is a layer into which pollutants are emitted and in which people live. The sophistication of urbanization within research mesoscale models has increased during the last 10 years, starting with the work of Brown and Williams (1998), which included urban effects in their TKE scheme. Masson (2000) then included a detailed canyon energy balance scheme into his surface energy balance equation. Martilli et al. (2002) expanded on the work of these two studies to include effects from canyon walls, roofs, and streets in each prognostic PBL equation. A similar, but less complex urbanization scheme has been developed by Kusaka et al. (2001). A drawback to these advanced urbanization schemes is that they require detailed (i.e., on scale of a few 10 s of meters) urban morphological data, including land use and land cover, surface roughness, building thermal characteristics, and anthropogenic heat fluxes.

The urban canopy models, modules and parameterisations which are available are very different in terms of the sophistication of process descriptions, computing resources required and in the associated difficulties in implementing in numerical meso-scale models. Many publications consider separate aspects of urban features but none provide a complete picture of the necessary algorithms and steps required. Proceeding from the above, the *main aim* of the COST Action 728 (http://cost728.org) workshop on "Urbanisation of meteorological and air quality models" (May 3–4, 2007, UK Met Office, Exeter, UK) was to discuss and make recommendations on the best practice and strategy for urbanisation of different types of meteorological and air quality models.

International organising committee of the workshop included: Maria Athanassiadou (UK Met Office, responsible local organiser), Alexander Baklanov (Danish Meteorological Institute, responsible for scientific program), Bob Bornstein (San Jose State University, USA), Peter Clark (UK Met Office), Stefano Galmarini (Joint Research Centre, Italy), Sven-Erik Gryning (Risø NL, Denmark), Alberto Martilli (CIEMAT, Spain), Ranjeet Sokhi (University of Hertfordshire, UK), Sergej Zilitinkevich (Helsinki University, Finland). The workshop program and list of participants are listed in Appendices 1 and 2.

This workshop is a logical continuation of the Sessions and Round Table Discussion entitled "Urban sub-layer parameterisations in meteorological, climate and environmental models" of the 6th International Conference on Urban Climate (ICUC6) in Göteborg, Sweden, June 12th–16th 2006 (ICUC, 2006). The main focuses of the Section, which included 22 oral presentations, were:

– Urban physiographic data classification and utilisation of surface satellite data,
– Parameterisations and models of urban soil/heat, roughness sublayer and internal boundary layers,
– Urbanisation of meso-meteorological and numerical weather prediction models,
– Urban sublayer models, parameterisations and meteo-preprocessors for urban air quality and emergency preparedness models,
– The incorporation of urban effects into regional climate models.

An outcome from the Round Table was to build a world-wide working group on "Model urbanization strategy" and to organise a workshop associated with COST 728. The Round Table discussions were summarised by A. Baklanov, J. Ching, A. Martilli and V. Masson and published in the COST 728 "Model urbanisation" report (COST728, 2007). With increasing numbers of users simulating at the meso-scale (or higher resolution) it becomes increasingly necessary to include some urban characteristics and therefore parameterisations in their models.

This volume, based on the presentations given at this workshop, is concerned with the following *main topics*:

1. Urban morphology and databases,
2. Parameterisations of urban canopy,
3. Strategy for urbanization of different types of models,
4. Evaluation and city case studies/field studies.

The workshop was oriented towards NWP and air quality modelling. Presentations were concerned with dynamic (on wind and turbulent) and thermal effects (on temperature and energy in general). Most of the papers presented at the workshop are published in this volume. However the following were not available for this volume but PowerPoint presentations are also available at the workshop web-site (http://www.cost728wg1.org.uk):

- Dirk Schuttemeyer "The present setup for the urban experiment in Bonn, Germany";
- Omduth Coceal "Turbulence statistics from DNS and LES – implications for urban canopy models" (Coceal and Belcher, 2004; Coceal et al., 2006, 2007);
- Valery Masson "CAPITOUL experiment: first experimental results and parameterization" (Hidalgo et al., 2008; Masson et al., 2008);
- Fei Chen "Advancing the multi-scale urban modelling in the community mesoscale WRF model: current status and future plan" (Chen et al., 2004, 2006; Lo et al., 2006);
- Bob Bornstein "Urbanization of US meso-scale models" (Otte et al., 2004; Bornstein et al., 2006).

The final chapter of this volume summarizes the discussion and conclusions from the four main topics and provides recommendations and future requirements.

Cutting across the main topics, issues of concern and major interest arise:

- Which variables do we need to model (and to what degree of precision) for which applications (air quality, emergency response, urban climatology, weather forecast, etc.). For example,
  - Do we need values within the canopy or only whole surface fluxes?
  - Do we need good turbulence fluxes?
  - For dispersion applications, do we need mean concentrations or also the variances?
- What is the best way to evaluate the capability of the parameterizations to model the relevant variables i.e.,
  1. urban measurement campaigns,
  2. wind tunnel experiments,
  3. role of the CFD/LES models.
- What ways could the parameterizations improved (if needed):
  - For dynamics: porosity models, dispersive stress, role of CFD/LES models,
  - For energy: need for building energy models.

References

Baklanov, A., S. Joffre, and S. Galmarini (Eds.), 2005: "Urban Meteorology and Atmospheric Pollution (EMS-FUMAPEX)". *Atmos. Chem. Phys.*, Special Issue 24. http://www.atmos-chem-phys.net/special_issue24.html

Baklanov, A., A. Rasmussen, B. Fay, E. Berge, and S. Finardi, 2002: Potential and shortcomings of numerical weather prediction models in providing meteorological data for urban air pollution forecasting. *Water, Air Soil Poll.: Focus*, 2 (5–6): 43–60.

Bornstein, R., R. Balmori, H. Taha, D. Byun, B. Cheng, J. Nielsen-Gammon, S. Burian, S. Stetson, M. Estes, D. Nowak, and P. Smith, 2006: Modeling the effects of land-use land cover modifications on the urban heat island phenomena in Houston, Texas. SJSU Final Report to Houston Advanced Research Center for Project No. R-04-0055, 127 pp.

Brown, M. and M. Wiliams, 1998: An Urban canopy parameterization for Mesoscale Meteorological Models. AMS 2nd Urban Environment Symposium, Albuquerque, NM USA.

Chen, F., H. Kusaka, M. Tewari, J.-W. Bao, and H. Hirakuchi, 2004: "Utilizing the coupled WRF/LSM/urban modeling system with detailed urban classification to simulate the urban heat island phenomenon over the greater Houston area", Paper 9.11, American Meteorological Society Fifth Symposium on the Urban Environment, 23–27 August 2004, Vancouver, British Columbia.

Chen, F., M. Tewari, H. Kusaka, and T.L. Warner, 2006: Current status of urban modeling in the community Weather Research and Forecast (WRF) model. Sixth AMS Symposium on the Urban Environment, Atlanta GA, January 2006.

Coceal, O. and Belcher, S.E., 2004: A canopy model of mean winds through urban areas. *Q. J. Roy. Meteor. Soc*. 130: 1349–1372.

Coceal, O., A. Dobre, and T.G. Thomas, 2007: Unsteady dynamics and organized structures from DNS over a building canopy. *Int. J. Climatol*. 27: 1943–1953.

Coceal, O., T.G. Thomas, I.P. Castro, and S.E. Belcher, 2006: Mean flow and turbulence statistics over groups of urban-like cubical obstacles. *Bound.-Layer Meteorol*. 121: 491–519.

COST728, 2007: Overview of the urban sublayer/exchange parameterizations in meso-meteorological and air pollution models. Report of the WG1 COST728, available from: http://cost728.org

Dupont, S., 2001: Modelisation Dynamique et Thermodynamique de la Canopee Urbaine: Realisation du Modele de Sols Urbains pour SUBMESO, Doctoral thesis, Universite de Nantes, France.

Dupont, S., T.L. Otte, and J.K.S. Ching, 2004: Simulation of meteorological fields within and above urban and rural canopies with a Mesoscale Model (MM5). *Bound.-Layer Meteorol.*, 113: 111–158.

Grimmond, C.S.B. and Oke, T.R., 1999: Heat storage in urban areas: observations and evaluation of a simple model. *J. Appl. Meteorol.*, 38: 922–940.

Hidalgo, J., G. Pigeon, and V. Masson, 2008: Urban-breeze circulation during the CAPITOUL experiment: Observational data analysis approach, *Meteorol. Atmos. Phys.*, 102(3–4): 223–241.

ICUC, 2006: 6th International Conference on Urban Climate, June 12–16, 2006, Goteborg, Sweden, Proceedings. ISBN-10:91-613-9000-1.

Kusaka, H., H. Kondo, Y. Kikegawa, and F. Kimura, 2001: A simple single-layer urban canopy model for atmospheric models: Comparison with multi-layer and SLAB models. *Bound.-Layer Meteorol.* 101: 329–358.

Lo, J., A.K.H. Lau, J.C.H. Fung, and F, Chen, 2006: Investigation of enhanced cross-city transport and trapping of air pollutants by coastal and urban land-sea breeze circulations. *J. Geophys. Res.*, 111, D14104, doi:10.1029/2005JD006837.

Martilli, A., A. Clappier, and M.W. Rotach, 2002: An urban surface exchange parameterisation for mesoscale models. *Bound.-Layer Meteorol.* 104: 261–304.

Masson, V., 2000: A physically-based scheme for the urban energy budget in atmospheric models. *Bound.-Layer Meteorol.* 98: 357–397.

Masson, V., L. Gomes, G. Pigeon, C. Liousse, V. Pont, J.-P. Lagouarde, J. Voogt, J. Salmond, T. Oke, J. Hidalgo, D. Legain, O. Garrouste, C. Lac, O. Connan, X. Briottet, and S. Lachérade, 2008: The Canopy and Aerosol Particles Interactions in TOulouse Urban Layer (CAPITOUL) experiment. *Meteorol. Atmos. Phys.*, 102(3–4): 135–157.

Oke, T.R., R. Spronken-Smith, E. Jauregui, and C.S.B. Grimmond, 1999: Recent energy balance observations in Mexico City. *Atmos. Environ.*, 33: 3919–3930.

Otte, T.L., A. Lacser, S. Dupont, and J.K.S. Ching, 2004: Implementation of an urban canopy parameterization in a mesoscale meteorological model. *J. Appl. Meteor.*, 43: 1648–1665.

Baklanov and Grisogono (eds.), 2007: Atmospheric boundary layers: nature, theory and applications to environmental modelling and security. Springer Publishers, 241, doi:10.1007/978-0-387-74321-9.

Piringer, M., S. Joffre, A. Baklanov, A. Christen, M. Deserti, K. De Ridder, S. Emeis, P. Mestayer, M. Tombrou, D. Middleton, K. Baumannstanzer, A. Dandou, A. Karppinen, and J. Burzynski, 2007: The surface energy balance and the mixing height in urban areas – activities and recommendations of COST Action 715. *Bound.-Layer Meteorol.* 124: 3–24.

Taha, H., 2008: Sensitivity of the urbanized MM5 (uMM5) to perturbations in surface properties in Houston Texas. *Bound.-Layer Meteorol.*, 127: 193–218.

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