Towards urbanisation of the non-hydrostatic numerical weather prediction model Lokalmodell (LM)

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With a growing part of the world population living in cities and increasing air pollution abatement legislation (e.g. recently enforced European Union air quality regulations), the need for forecasts of local pollutant concentration rises. Urban air quality forecasting is investigated or operational in many large European cities also using an increasing number of nested high-resolution NWP models. This topic was also advanced in the European FP5 project FUMAPEX (Integrated Systems for Forecasting Urban Meteorology, Air Pollution and Population Exposure, 2002-2005, http://fumapex.dmi.dk) with participation of the DWD.
The urban boundary layer is characterised by a more complex structure than the rural one. Building complexes and street canyons form the urban canopy layer as part of the horizontally inhomogeneous and non-equilibrium surface boundary layer where the Monin-Obukhov similarity theory (MOST) used in most current operational NWP models is invalid and cannot reproduce the measured vertical structure of the turbulence field in the urban roughness sublayer (Rotach, 1995, Fisher et al., 2005). Initial model urbanisation steps include urbanised physiographic parameters and an anthropogenic heat source in the NWP models. Advanced measures consist of the introduction of urban surface layer schemes parameterising the urban canopy and roughness layer (e.g. Martilli et al., 2002).

First urbanisation steps were applied to the Lokalmodell LM by introducing urbanised physiographic parameters and an anthropogenic heat source (Neunhäuserer and Fay, 2005). The definition of a soil type ‘city’ along with corresponding changes of albedo, thermal conductivity and capacity according to Kinouchi et al. (2001) and of improved surface roughness, plant cover and leaf area index influence the surface heat and water budgets and the dynamics. Optionally, an anthropogenic heat source of 20 or 60W/m² was added to the surface energy balance (Best and Betts, 2004). A sensitivity study was performed for the Helsinki spring dust episode around 10 April 2002 above an enlarged and all-concrete city centre (results of LM episode evaluation and model inter-comparison for high-resolution NWP models with up to 1km resolution in Fay and Neunhäuserer, 2005; Fay et al., 2004 and 2005). The main differences in surface and 2m temperatures can be attributed to the urbanised physiographic parameters during the day while the impact of the anthropogenic heat flux rises at night (up to 7°C in surface temp compared to the non-urbanised version), partly due also to the initially assumed constant anthropogenic flux. Thus, a distinct urban heat island effect and more characteristic urban fluxes were achieved. Comparison with measurements show improved model results compared with measurements (Fig. 1 left). The components of the urban storage heat flux were also analysed separately. The change in physiographic parameters leads to a considerable shift in the partitioning of the heat fluxes during the day, with an increase of the sensible and a decrease of the latent heat fluxes reflecting urban observations. The storage heat flux is mainly negative during the day, indicating an increased energy intake of the urban texture increased soil temperature, and a slightly positive upward storage heat flux into the atmosphere for the following night (Fig. 1 middle). An added (continuous and constant) anthropogenic heat flux is generally split between sensible heat flux and storage heat flux, with the sensible heat flux prevailing during the day and warming the atmosphere and the storage heat flux dominating through the night and increasing the soil and surface temperature (Fig. 1 right).

Further sensitivity studies were performed concerning urban effects (e.g. the hysteresis loop described by Grimmond et al., 1999), refined physiographic parameters and a time-variant anthropogenic heat flux. The full results are described in Neunhäuserer et al. (2006).

The introduction of even simple urbanisation measures in LM thus leads to a distinct urban heat island effect and urbanised surface fluxes (increased Bowen ratio and heat storage). Further improvements are expected by refining these measures and by the introduction of the generalised high-resolution parameterisation scheme of LM under development at the DWD that will also be suitable for the urban canopy and roughness layer. The urban canopy layer parameterisation by Martilli et al. (2002) has recently been included into the Swiss LM version aLMo during the FUMAPEX project. Further LM studies are planned for a German government-funded research project on megacities.

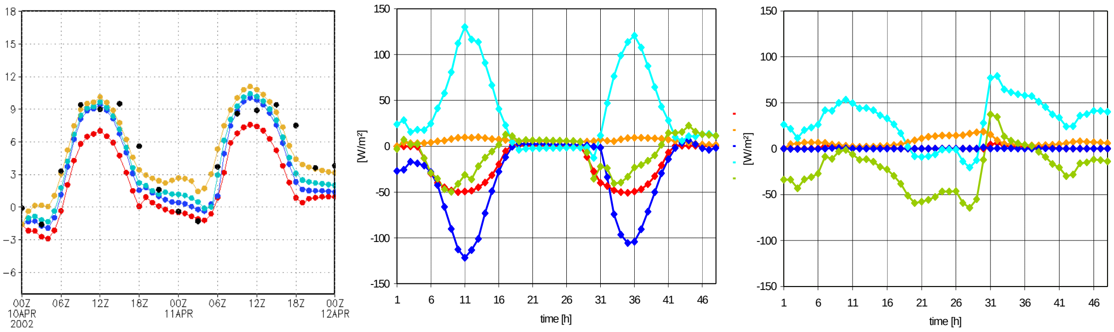

Fig. 1. Urbanised LM 1.1km, 48 time series at Helsinki,Kaisaniemi, starting 10 Apr 2002, 00UTC+00. Left: 2m temperature (°C), red=orig. LM, blue=urbanised physiographic param., turquoise=blue plus 20W/² anthropog. heat source, yellow=blue plus 60W/m². Middle: *Differences* in radiation and fluxes for case(urbanised physiographic parameters)-case(non-urb.LM). Right: *Differences* in radiation and fluxes for case(urbanised phys. param. plus 60W/m² anthrop. heat source)-case(only urbanis. phys. param.). Middle and right: red=short wave radiation, orange=long wave rad., blue=lat. heat flux, turquoise=sens. heat flux, green=storage heat flux.

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References

Best, M. and Betts, R. (2004) The impact of climate change on our cities. The 84th AMS Annual Meeting, Joint Session 5 Climate Change and Urban Areas, Seattle, WA, 15 Jan 2004.

Fay, B., L. Neunhäuserer, J.L. Palau, J.J. Dieguez, V. Oedegaard, N. Bjergene, M. Sofiev, M. Rantamäki, I.Valkama, J. Kukkonen, A. Rasmussen, A. Baklanov (2004) Model simulations and preliminary analysis for three air pollution episodes in Helsinki. FUMAPEX Report D3.3, DWD, Offenbach, Germany, 60pp.

Fay, B., L. Neunhäuserer, J.L. Palau, G. Perez-Landa, J.J. Dieguez, V. Oedegaard, G. Bonafe, S. Jongen, A. Rasmussen, B. Amstrup, A. Baklanov, U. Damrath (2005) Evaluation and inter-comparison of operational mesoscale models for FUMAPEX target cities. FUMAPEX Report D3.4, DWD, Offenbach, Germany, 110pp.

Fay, B. and L. Neunhäuserer (2005) Evaluation of very high-resolution simulations with the non-hydrostatic numerical weather prediction model Lokalmodell for urban air pollution episodes in Helsinki, Oslo and Valencia. Atm. Chem. and Phys. Discussions, 5, 8233-8284, 2005, www.atmos-chem-phys.org/acpd/5/8233/

Fisher, B., Kukkonen, J., Piringer, M., Rotach, M.W. and Schatzmann, M. (2005) Meteorology applied to urban air pollution problems: concepts from COST715. Atmos. Chem and Physics Discussions 5, pp. 7903-7927.

Grimmond, C.S.B. and Oke, T.R. (1999) Heat Storage in Urban Areas: Local Scale Observations and Evaluation of a Simple Model. J. of Appl. Met. 38, 922-940.

Kinouchi, T. and Yoshitani, J.(2001) Simulation of the urban heat island in Tokyo with future possible increases of anthropogenic heat, vegetation cover and water surface. Proc.2001 Int. Symp. on Environ. Hydraulics, 6pp.

Martilli, A., Clappier, A., Rotach, M.W.(2002) An urban surface exchange parameterisation for mesoscale models. Bound. Lay. Met., 94, 357-397.

Neunhäuserer, L., Fay, B. (2005) Towards predicting urban air pollution episodes: Introduction of urbanised parameters into the mesoscale Lokalmodell (LM) of the German Weather Service. Proceedings 5th Int. Conf. on Urban Air Quality, Valencia, Spain, 29-31 Mar 2005, 4pp.

Neunhäuserer, L., Fay, B., Raschendorfer, M. (2006) Towards urbanisation of the non-hydrostatic numerical weather prediction model Lokalmodell (LM). Submitted to Bound. Layer Met, Jan 2006.

Rotach, M.W. (1995) Profiles of turbulence in and above an urban street canyon. Atm. Environ., 29, 1473-1486.