Modelling Snow in the City

Evaluation and Investigation of the Affects of Snow on Urban and Rural Microclimate

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In Short

- Evaluation of urban LES and snow scheme coupling
- Investigation of snowfall and snowpack effects on UHI and vice-versa
- Investigation of urban-rural circulation patterns in Berlin

Urban areas account for approximately 55% of the human population and this number continues to grow [1]. The most distinct effects of the urban environment on living conditions are the urban heat island (UHI), surface roughness modification and increased aerosol emissions from traffic, industry and households. With the ever-increasing threat global environmental and climatic change, cities must adapt for the benefit of those who reside within.

Building-resolving simulations are commonly used to investigate the urban environment, its surroundings and the impact its effects has on daily life. Typically, these models use Reynolds-Averaged-Navier-Stokes (RANS) methods to fully parameterize turbulence. Recent advances in computing power allow for the use of the large-eddy simulation (LES) technique, which explicitly resolves the bulk of the turbulence spectrum. LES models are more accurate but consume more compute time than their RANS counterparts.

In 2015 the German Federal Ministry of Education and Research (BMBF) announced a first call for project proposals with the goal of developing a new and highly efficient urban climate model (UCM). The LES code PALM developed at the Leibniz University Hannover met the goals of the call especially well. PALM runs effiently on desktop computers with a few cores, but also scales exceptionally well to parallel computing architectures with thousands of processor cores.

We designed the project "Model-based city planning and application in climate change" (MOSAIK) (project web page at http://uc2-mosaik.org) that has been funded by BMBF from June 2016 to August 2019 as module A within the framework Urban Climate Under Change ([UC]^2) (see offical web page at http://uc2-program.org). The main goal of MOSAIK was to develop a proper UCM, with PALM as its model core, named PALM-4U (PALM for urban applications, read: PALM for you).

With the second phase of the [UC]^2 (from September 2019 to August 2022) the BMBF is pursuing the goal of further developing PALM-4U into a product that meets the needs of municipalities and other practitioners. Following the main specification of the BMBF announcement, the central goal of MOSAIK-2 is the further development of PALM-4U as a tool for practical applications by local authorities as well as for scientific applications.

One of these tools is the surface snow scheme developed within the land surface and building surface models (LSM and BSM, respectively). While many robust numerical snow schemes exist, most are primarily focused on synoptic (e.g., [2,3]), mesoscale (e.g., [4,5]) or non-urban (e.g., [6–8]) applications. Furthermore, there are many studies detailing the affects of snow on the UHI in cold weather cities (e.g., [9–11], etc.), though few of these studies use robust numerical modelling. Those studies that do use robust numerical models tend to have simplified atmosphere (e.g., [12]), urban canopy (e.g., [13]) and/or snow model representations (e.g., [14]). Additionally, the domains of studies using microscale modeling of urban areas focus on neighborhoods and subsections of cities. To our best knowledge, no study or LES code to date has used a domain that spans an entire urban area and the surrounding rural areas at the 1 - 10 m scale.

[12] stated the need for improvements on anthropogenic heat flux, thermal parameters in winter, snow cover in spring and evapotranspiration in future UHI studies. Furthermore, [15]) state there is a lack of studies that provide sufficient validation with experimental data, which make many of these studies impractical for local authorities. PALM-4U has the capability to address these concerns.

The goals of this project are twofold: 1) evaluate the snow model using observations from measurement campaigns conducted in the city of Berlin and 2) understand the feedback processes between snow, the urban heat island and the corresponding circulation with rural surroundings. Of specific interest are how the UHI affects snow accumulation in urban areas vs. rural areas, how snow in rural areas and a warm city affect the urban thermal plume circulation, and how anthropogenic building heat affects snowpack persistence in the city and, by association, the urban thermal plume circulation.

To evaluate the snow scheme, we will conduct eight simulations of the city of Berlin, using combi-

nations of prescribed snow precipitation and snowpacks. Evaluation will be performed against the Intensive Observation Period (IOP). During the IOP, project partners from 3DO took various measurements with respect to meteorological and air pollution aspects, building the basis for model evaluation. We are most concerned with snow cover.

A constant snow precipitation rate will be prescribed to assess the accumulation rate of snowpacks in urban and rural settings. This will provide a comprehensive analysis of the accumulation rates and the impact of the UHI on snowfall.

We will investigate the impact of snow on the UHI and the urban thermal plume circulation by running simulations where the there is no snow coverage in the city, while the rural surroundings are mantled by a snowpack of uniform depth. The snowpack thickness is important for these simulations because if the snowpack melts in the rural settings, the surface thermal and radiative properties change dramatically.

The final simulations will be used to determine the magnitude of snow melt due to anthropogenic building heat flux. Comparing simulations with building heat flux on and off to each other will reveal the impact of anthropogenic heat flux on snowpack persistence and the urban thermal plume circulation.

These large, resource-intense runs must be conducted to capture the urban-rural interaction and the Berlin domain offers an excellent opportunity to do so.

WWW

http://uc2-program.org/

More Information

[1] Nations, U., *The World's Cities in 2016 - Data Booklet* **Technical Report ST/ESA/SER.ATech. rep. United Nations**, Department of Economic and Social Affairs (2016).

[2] Ducharne, A. et al., *J. Geophys. Res.* **105(D20)**, 24823-24838 (2000) doi:10.1029/2000JD900328

[3] Koster, R. et al., *J. Geophys. Res.* **105(D20)**, 24809-24822 (2000) doi:10.1029/2000JD900327

[4] Dutra, E. et al., *J. Hydromet.* **11(4)**, 899-916 (2010)

[5] Oleson, K. et al., *Technical description of version 4.0 of the Community Land Model (CLM)* **Tech. Rep.**(2010)

[6] Bartelt, P. et al., *Cold Reg. Sci. Technol.* **35**, 123-145 (2010)

[7] Gelfan, A. N. et al., *J. Hydromet.* **5(5)**, 785-803 (2004)

[8] Vionnet, V. et al., *Geosci. Model Dev.* **5**, 773-791 (2012) doi:10.5194/gmd-5-773-2012

[9] Kłysik, K., Fortuniak, K., *Atmos. Environ.* **33(24-25)**, 2885-2895 (1999) doi:10.1016/S13522310(99)001314

[10] Kim, H.-Y., Baik, J.-J., *J. Appl. Met.* **44**, 591-605 (2005) doi:10.1175/JAM2226.1

[11] Gedzelman, S. D. et al., *Theo. Appl. climatol.* **75(1-2)**, 29-42 (2003) doi:10.1007/s00704-002-0724-2

[12] Karsisto, P. et al., *Q. J. R. Meteorol. Soc.* **142**, 401-417 (2016) doi:10.1002/qj.2659

[13] Lemonsu, A. et al., *J. Appl. Met. and Clim.* **49(3)**, 346-362 (2010)

[14] Yang, J., Bou-Zeid, E., *J. Appl. Met. and Clim.* **57(6)**, 1309-1320 (2018)

[15] Brozovsky et al., *Renew. Sus. Energy Rev.* **138**, 110551 (2021) doi:10.1016/j.rser.2020.110551

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