# Urbanization in Atmospheric Modeling with High Spatial and Temporal Resolution

*Alexander Mahura* [1,*], *Sylvie Leroyer* [2], *Patrice Mestayer* [2], *Alexander Baklanov* [1], *Claus Petersen* [1]

*2 Ecole Centrale de Nantes (ECN), BP 92101, F-44321, Nantes, France*
*1 Danish Meteorological Institute (DMI), Lyngbyvej 100, DK-2100, Copenhagen, Denmark*

*(*Author for correspondence: E-mail: ama@dmi.dk; Phone: +45-3915-7423; Fax +45-3915-7400 )*

## Abstract

The large-eddy simulations (LES) employing the atmospheric model SUBMESO (derived from the Advanced Regional Prediction System model) coupled with the Soil Model for SubMeso scales Urbanized version (SM2-U; composed with 3 soil layers and a canopy layer) were carried out during winter months (Dec, Jan, and Feb). The selected area of interest is the Copenhagen metropolitan area (Island of Zealand). The land use classes, including related to urban areas, were derived from the CORINE dataset (based on 40 different types of surfaces over Europe, resolution of 250 m) providing a better representation of orography and identification of urban surface features. The selected modeling domain (118 x 124 grid points) has a resolution of 1.4 x 1.4 km. For each grid cell, the classification is represented by 7 types of surfaces.

In our study, the SUBMESO+SM2-U model was run in a climatological mode with monthly typical averaged meteorological variables in the selected model domain. To perform such simulations, as input, a set of characteristics was extracted from the climate generation files produced for the HIRLAM model as well as from climatological data (city of Copenhagen and other cites located in the domain). The surface oriented data included also types of soil, vegetation above natural and artificial surfaces, water, buildings and artificial surfaces, and a set of water content related characteristics in different soil layers, etc. The meteorological oriented data included air temperature, direction and velocity components for wind, relative humidity, surface and sea surface temperatures, salinity, soil and deep soil water contents, pressure, roughness.

An analysis of the winter diurnal variability of the surface temperatures and fluxes was performed for different types of surfaces/covers and districts of the Copenhagen urbanized area.

## Introduction

In urban areas, in contrast with rural areas, the urban boundary layer is more complex, and hence, it requires a special treatment. The surface energy balance in urban areas includes the storage, sensible, and latent heat fluxes, plus the anthropogenic heat flux. Experimental studies showed that within the city itself there are differences between different districts. The LES can be employed as a numerical substitute or research tool in studies of surface and urban boundary layer development, and its properties and characteristics, etc.

In our study, we used the SUBMESO atmospheric model, non hydrostatic model, derived from the Advanced Regional Prediction System (ARPS; *Xue et al., 1995*) coupled with Soil Model for Sub-Meso scales Urbanized version (SM2-U; *Dupont at el., 2006ab*) to investigate the monthly and diurnal variability of the net radiative, sensible, and storage heat fluxes and temperatures for different types of covers/surfaces and urban districts. It was done on example of the simulations in the model domain covering the Danish island of Zealand and surroundings (including Copenhagen metropolitan area, Fig 1; *Mahura et al., 2009*).

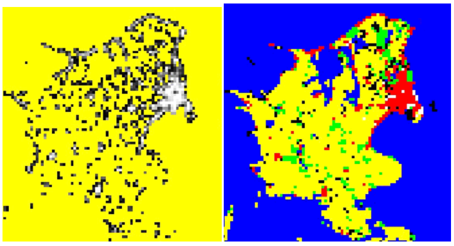

**Fig 1.** Modeling domain and land-use classification of the CORINE dataset - * (left) presented type of the bat surface, PTS (black-white scale is from the lowest to the highest values); (right) dominated type of surfaces, DTS (red – bat; white – art and vega, yellow – bare, green – vegn, black – nat, blue – eau).

## Land Use Classification, Urban Districts and its Characteristics

Land use covers/surfaces:

- BARE — bare soil without vegetation;
- NAT— bare soil located between sparse vegetation elements;
- VEGN — vegetation over bare soil;
- VEGA — vegetation over paved surfaces (trees on road side),
- ART — paved surfaces between sparse vegetation elements,
- BAT — building/ roofs & walls; and
- EUA — water surfaces.

| Characteristic<br>Surface type | Max | Avg. | StD | PTS | DTS |
|---|---|---|---|---|---|
| VEGN | 100 | 4.03 | 13.30 | 12.74 | 2.74 (401) |
| VEGA | 79 | 0.29 | 2.89 | **1.48** | **0.08 (12)** |
| NAT | 100 | 3.25 | 10.95 | 12.07 | 1.83 (268) |
| ART | 100 | 0.15 | 2.65 | **0.54** | **0.12 (18)** |
| BARE | 100 | 23.48 | 37.12 | 29.78 | 21.79 (3189) |
| BAT | 100 | 3.17 | 12.70 | 9.54 | 2.25 (329) |
| EAU | 100 | 65.62 | 45.67 | 75.49 | 70.74 (8279) |

**PTS** (presented type of surface) – percentage of cells from total number of cells in domain where, at least, a fraction of surface type is presented.
**DTS** (dominated type of surface) – percentage of cells from total number of cells in domain where a fraction of selected surface type is the highest compared with other types; values given in brackets are number of cells with this type in the model domain.

**Tab 1.** Distribution of surface types and its characteristics (in %) in the model domain based on classification of the CORINE dataset (*CORINE, 2000*).

Urban districts: (Fig. 2)

- CC — city center;
- HBD — high buildings districts;
- ICD — industrial commercial district,
- RD — residential district; and
- RA — rural/ non-urban area (if no BAT-type in grid cell).

Districts morphology (BDTopo database & DFMap software):

- aspect ratios (height vs. width) are 1.78, 0.9, and 1.125 for CC/ HBD, ICD, and RD, respectively;
- average heights of buildings are 15.8, 10.7, and 7.3 m;
- average surfaces are 1500, 1223.6, and 263.3 $m^2$;
- artificial and building roof surfaces were assumed made of asphalt and slite with tile (sheet metal – for ICD).

## Urban Modeling

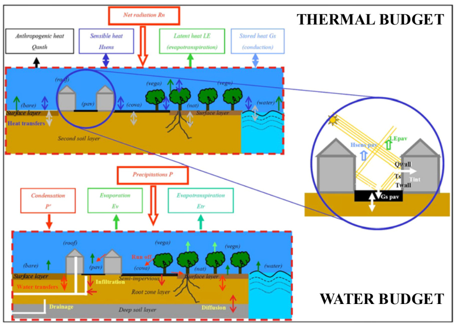

**Fig 3.** Schematic representation of SM2U: the upper box shows the processes modeled in the energy budget part, with a zoom on the in-street radiation and heat storage processes due to building walls; the lower box shows the modeled water transfer processes. The black brackets indicate the different possible tiles within one grid mesh. Precipitation is a model input while the net radiation is computed by the model from the incoming global and atmospheric radiation inputs (*Fig from Dupont at el., 2006ab*).

SM2-U (Fig 3) — urban extension of the force-restore model of *Noilhan & Planton (1989)*. It is composed with 3 soil layers and a canopy layer. In each cell at the ground, 7 types of surfaces are defined by their characteristics. The horizontal exchanges inside the urban canopy are not considered except radiation reflections and water runoff from saturated surfaces. Surface temperature and humidity of the ground surface types are obtained from force-restore equations and exchanges with the soil layers. For buildings and water surfaces temperature evolution, a simple conduction equation is used, without force-restore process, but including exchanges through two layers of materials. Important processes like radiative trapping inside the street canyon are parameterized by an effective albedo of the street. Energy and water budgets are performed for each type of surface in order to deduce the heat and moisture fluxes to be set at the interface between canopy and atmosphere. The surface dynamical influence is represented through roughness lengths and displacement heights. An example of the simulation results is shown in Fig. 4.

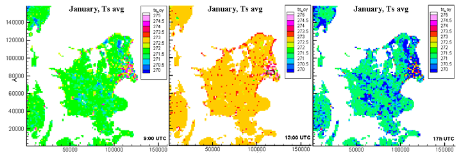

**Fig 4.** Schematic January surface temperature (deg K) simulated using SM2-U urban module for the Copenhagen metropolitan area /averaged over 7 types of surfaces/ at (left) 09:00, (middle) 13:00, and (right) 17:00 UTCs

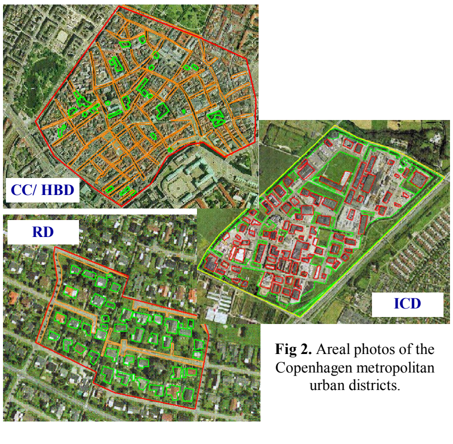

**Fig 2.** Areal photos of the Copenhagen metropolitan urban districts.

## Results

Summary results are shown in Figs 5 and 6. During winter months, among different types of surfaces, the lowest **net radiative flux** is for artificial surfaces (abs. min. -69 W/$m^2$ in Dec). For CC/HBD, on a diurnal cycle, this flux is negative during Dec-Jan, but beginning Feb it becomes positive between 09-13 h; moreover, a daily mean flux is the lowest (-47 W/$m^2$) - in Dec. For ICD, on a diurnal cycle, there are always periods showing positive flux, but duration of such periods is the shortest (08-14 h) during Dec-Jan compared with Feb; moreover, a daily mean flux is the lowest (-7 W/$m^2$ ) in Dec.

The **mean sensible heat flux**, for CC/HBD is negative only in Dec reaching up to -36 W/$m^2$ during late evening hours (and a daily mean of -29 W/$m^2$); and although a daily mean is negative in winter, in Jan it becomes shortly positive at 11-12 h. For ICD, on a diurnal cycle, the positive flux can occur between 08-15 h.

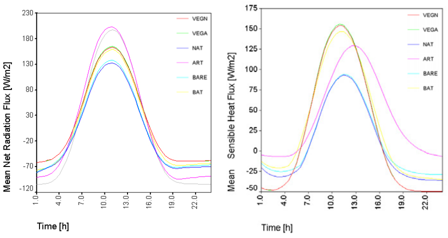

**Fig 5.** Diurnal cycle variability of the (left) net radiative and (right) sensible heat fluxes (in W/$m^2$) for different types of surfaces.

The **mean storage heat flux**, for the CC/ HBD is always negative during Dec-Jan reaching -33 W/$m^2$ at night, and it becomes positive in Feb between 8.5-9 h. For ICD, on a diurnal cycle, this flux is always negative only in Dec reaching -29 W/$m^2$ at night. For RD, the pattern is similar, although reaching higher value -32 W/$m^2$ in Dec. The monthly and diurnal cycle variability for RA grid cells show patterns very similar to RD.

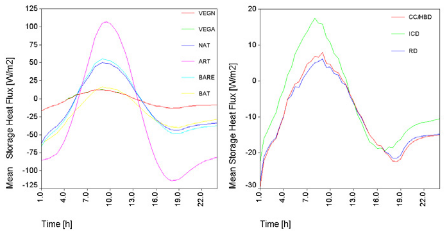

**Fig 6.** Diurnal cycle variability of the storage heat fluxes (in W/$m^2$) for different types of surfaces (left) and urban districts (right).

## Applicability

The results of this study are applicable for investigation of temporal and spatial variability of various meteorological and derived variables over urbanized areas; for improvements in the land use classification and climate generation properties, distinguishing and selection of types of urban districts and their properties; testing and verification of NWP models performance over high resolution model domains, and especially over the urbanized areas.

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