GIS-based Hotspot and Cold Spot Localization in Olomouc Depend on Geofactors

Jan Geletic

Abstract—**Air temperature is for a long time one of meteorological variables that are in interesting continuously monitored by general and professional public. Especially urban climate is characterized by very strong temporal and spatial variability. This difference is primarily related to the specific areas in the city, such as industrial sites, parks, lakes, roads, squares or dense areas. Due to the uneven distribution of these elements is possible that a combination of several elements can accumulate negative impacts of extreme phenomenon, which may have an strong impact on society living in the city.**

Most studies of city climate often describe only urban heat island and spatial variability of air temperature. In the city already exists hot spots and cold spots. The aim of this paper is determine the key factors that influence the creation and intensity of these phenomena in Olomouc. Using GIS tools (multi-criterial model) define areas inclinable to these phenomena and determine relationship between the observed elements. The analysis of these elements can lead to the possibility of such an early warning of inhabitants before the emergence of local dangerous meteorological phenomena (formation of black ice, fog, poor air quality, high temperature, etc.) or to improve urban planning.

Index Terms—**Hot spot, cold spot, GIS, geostatistical modeling.**

I. Introduction

Due to anthropogenic climate change heat waves are expected to occur more frequently in the future, which might cause adverse health effects for urban population. Especially the combination of high temperatures and poor air quality impinges on the well-being of man. This accentuates need for assessing the health risks of residents regarding air pollutants and anomalously high summer air temperatures. However, comprehensive information on the spatial and temporal distribution of air temperature in cities is presently difficult to obtain since only few measurement sites exist. In order to identify hot spots and cold spots with high health risks for different groups of urban population, was used the measurement of purpose station network MESSO (MEtropolitan Station System in Olomouc). This network is primarily used to determine the differences between urban and suburban climate. Measurements were carried out since 2009 at 18 locations, but due to the construction of the network data is not homogeneous. Since 2010 continuously measured 8 automatic stations and 16 data loggers.

Manuscript received November 26, 2012; revised January 28, 2013

Jan Geletic is with Department of geography, Faculty of Science, Palacky University in Olomouc, Czech Republic (e-mail: author@ boulder.nist.gov).

Several locations were selected to examine spatial influences such as topography, building density, vegetation and traffic on air temperature. The findings permit the detection of urban environmental variables that contribute to both temperature enhancement and poor air quality. Those variables were used as spatial predictors for the identification of possible hot spots inside and outside the area of field measurements. The zones of enhanced risks of high air temperature were detected by means of GIS based on geostatistical modeling. These areas were mainly identified in the inner city, which is characterized by a dense building structure and heavy traffic.

Heat-related illnesses such as heat strokes or heat exhaustion occur most frequently during heat wave episodes and are likely to increase as climate change continues [1].

Areas with poor air quality and enhanced thermal load are not distributed uniformly in urban areas but appear as hot spots with different spatial extents [2]-[6].

Measurements indicate that the hot spots in combination with poor air quality in cities primarily bind on street with dense traffic [2], [7]. Especially in street canyons are characterized by large ratios between height and width, which reduces circulation and allows the accumulation of substances overheated microparticles [3], [8].

Temperature anomalies and overheating of specific areas (urban heat islands) are direct consequences of building structure and heat capacities of the surface materials. The highest temperatures occur in districts with a dense building structure, a high degree of surface sealing and anthropogenic heat release. In general, these circum-stances are associated with inner cities. Rural areas generally show lower temperatures as they are mostly covered by green spaces, water bodies and a sparser building structure [5], [6], [9].

Cold spots, which in summer days often bind to the waterlogged areas, lakes and parks, may show temperature differences to around to a few degrees. For example, in Bigmingham was the difference in temperature between the city center and city park 7°C [10]. This high temperature difference can cause many health complications.

II. Area of Investigation

The city of Olomouc is located in the Hornomoravsky uval (lowland) and the eastern part rise massif Nizky Jesenik (highland). This area is a large approximately 170 km^2 and has about 125,000 inhabitants (31.12.2011). The climate is continental (the average temperature in January is -2.2°C, in July 19.0°C, the average annual temperature is 8.9°C) and the average annual rainfall is 570.1 mm [11]. The prevailing wind directions are northwest and southwest.

Olomouc is a city of historic buildings and distinct remains of fortification. Around the fortification were moat (now Mlynsky potok) and the river Morava. Under the city walls are today four parks.

Western and south-western parts of the city are characterized by panel housing, while the northern and north-eastern parts consist mainly of family houses. Industrial areas are mainly concentrated in the western and south-western parts of the city.

III. Instrumentation and Data Handling

A. Data Temperature

Air temperature data was measured at intervals of 10' and 30' on 24 locations in Olomouc and its vicinity. MESSO station network was consisted of 7 automatic stations Fiedler-Mágr and supplemented by 16 dataloggers (Fourier Microlog, Proges Plus Thermo Track PC). The stations were classified as urban and suburban (15 stations were urban and 9 suburban).

B. GIS Data

The main dataset sources used for GIS analysis were CORINE Land Cover 2006 [12] and landuse. Landuse data was used from OpenStreet Maps database, because obtain all building and it is free. Digital elevation model has spatial resolution 10 meters [13]. Cartographic and geostatistical data processing was carried out in the programs ArcGIS for Desktop 10.1 (Esri) and Project R.

Data with a high number of categories, such as landuse, had to be processed and subsequently divided into the same categories. Therefore, it was assigned to each type of landuse code CORINE Land Cover to be uniformly processed data [14]. This procedure has been reduced 57 previous values of landuse to 16 CORINE categories. The result is a layer of land cover with maximum possible resolution 2 m.

Additional data entering into the analysis were traffic intensity in Olomouc [15], rivers and streams, roads, railroads, the height of buildings (without roofs) and slope. These data were assigned parameterized value affecting air temperature and were considered the interaction between the individual parameters. For example, the higher is the location of traffic or the higher the building, the higher the value of the parameter [16]-[18].

IV. Methods

Effect of spatial variables of the air temperature is quantified using centroids, which represent measurement points. Around these points were created buffer zones with a radius of 100, 200, 400 and 800 meters. Buffer zones were used in order to quantify impact of different elements in the far area on the formation of air temperature. The maximum size of buffer zone (800 m) was chosen because in the city are between stations small distances (300-1000 m). The strongest influence of factors that affect the temperature of the air is always located closest centroid. Factor dependence on the distance from the centroid can be considered as linear [19]. The remaining data were interpolated using a multi-criterial linear model with spatial resolution 2 m.

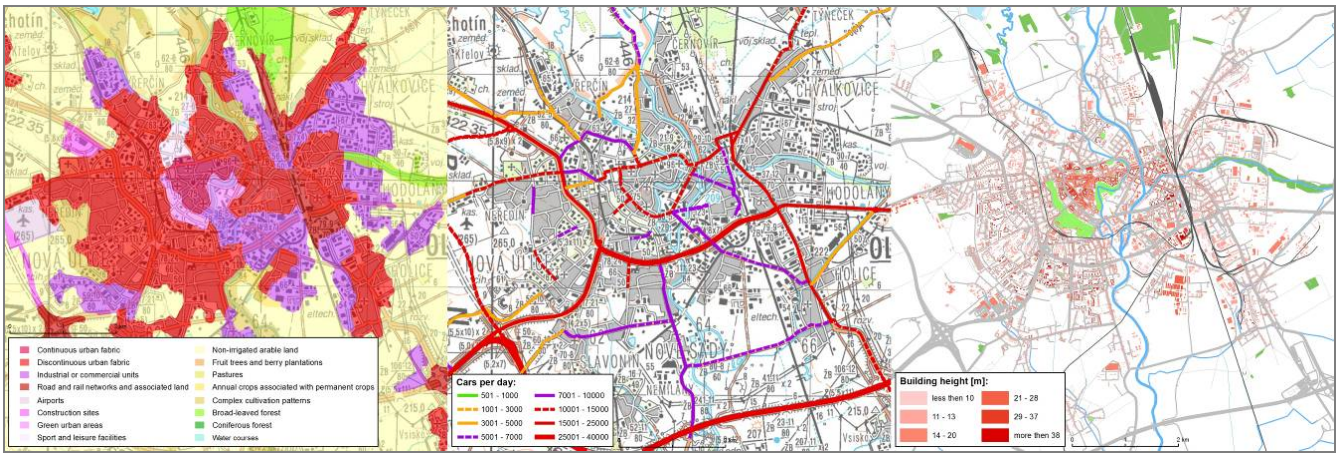

Fig. 1. Example of the input data (CORINE Land Cover 2006, traffic density in Olomouc city and building height)

V. Results

In this analysis were correlated 16 different influencing variables with average air temperature. The buffer sizes for the best correlations vary between 100 and 200 m, depending on the predictors. Thus indicate a stronger impact of urban structures on air temperature in the close vicinity.

The results of correlation of the various factors are shown in Fig. 2. As the picture clearly shows the most significant role in the creation of urban climate has urban character, building heights, traffic intensity and distance from water courses and bodies. An important role is also played by parks and forests, respectively, the density and height of the trees.

The most significant hot spots are demonstrably bind to the city center (town squares, narrow streets, building height), industrial areas and surprising railway station. Most clearly stand out shopping and logistics centers, which is mainly a large parking places in the vicinity of these centers. Type of the active surface is practically only one - the concrete, and thus gives rise to overheating and accumulation of hot air.

During heat waves is here possible place for creating a poorly ventilated area with very high temperatures, which can have negative effects on customer centers. Significant occurrence of hot spots in industrial complexes is caused by a complex combination of size, height and number of buildings. The greater number of buildings causes the greater accumulation of warm air. Other parts of the city, like panel houses districts and residential areas are not susceptible to forming hot spots.

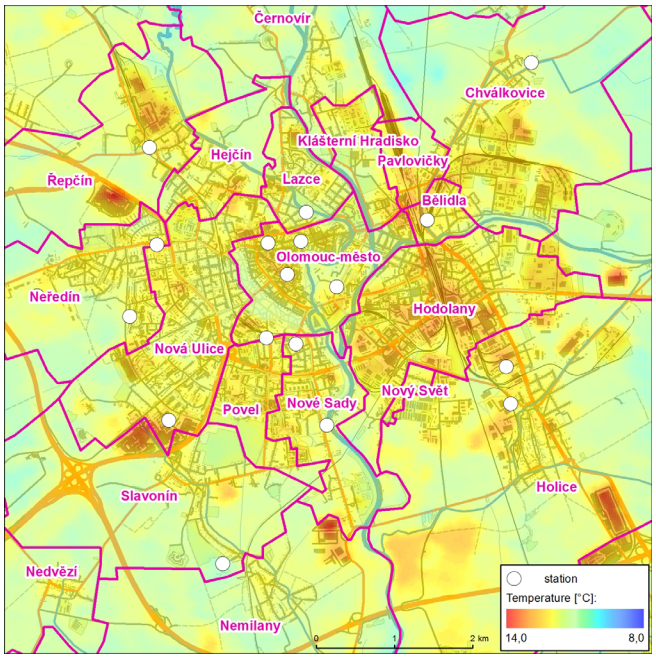

Fig. 2. Average air temperature interpolated by multi-criterial linear model for year 2011

The most significant cold spots are linked to city parks, alluvial forests (north of Olomouc, national protected area Litovelske Pomoravi), around rivers (Morava and Mlynsky potok) and lakes (Podebrady). Even in the scale of Olomouc is noticeable cooling effect of water bodies and city greenery.

Multi-criterial linear model working only with parameters for geographical and spatial factors and how is possible to see in Table I, all suburban stations have lower model temperature as real. On the other hand, stations near the city center (for example CMSE, KRAK, ENVE) have higher temperatures. Here are three possibilities: as first, the model parameters are not correct. Second, that exist other factor, which is important for each station (probably SkyView factor for each day in year or synoptic situation). Only automatic station in city center, DOMI, was well predicted. Third possibility is dependence on special geographical (or other) factor, which is out of 800 m or his part in buffer zone is too small and can be taken like unimportant (for example larger forest or field with vegetation).

Model results confirm that the air temperature in the city is primarily dependent on local factors, which are found in the surroundings of measuring point. However, some stations may also be affected by more extensive services, which can affect the entire region, or a major part. Because is very important urban planning. Without parks, gardens or other city greenery and areas with cooling effects will temperature in the city rising.

TABLE I: ANNUAL AVERAGE TEMPERATURE MEASURED BY MESSO IN 2011*

Station ID	Type[1]	Temperature	Model Value
BOT_PedF	U	12,9	11,4
BYST	S	9,6	8,7
DOMI	U	12,8	13,0
ENVE	U	10,3	11,4
JUTA	U	10,2	12,5
KOPE	S	12,4	10,4
LETO	S	12,6	10,9
HORK	S	9,1	8,8
HODO	U	9,7	10,4
BOT_PrF	U	9,4	10,1
KOJE	U	9,5	9,7
CMSE	U	10,1	12,8
CHVA	U	9,4	11,3
KRAK	U	10,6	11,0
NEMI	S	9,9	9,7
HOLI	U	11,3	11,6
PRAZ	U	10,0	10,8
EINS	U	9,9	10,7
HORL	U	10,2	11,2
VTYN	S	9,6	9,5

* One automatic station is far from Olomouc and three stations were broken.

[1]U – Urban, S - suburban

ACKNOWLEDGEMENTS

This paper was prepared within the project 205/09/1297 "Multilevel analysis of urban and suburban climate on the example of medium-sized cities" with financial support of the Czech Republic Grant Agency.

REFERENCES

[1] C. Koppe, S. Kovats, G. Jendritzky, and B. Menne, *Heat waves: Risks and responses*, Copenhagen, 2004.

[2] S. Weber, "Spatio-temporal covariation of urban particle number concen-tration and ambient noise," *Atmospheric Environment*, vol. 43, no. 34, pp. 5518-5525, 2009.

[3] W. Beckröge, "Windfeld," In A. Helbig, J. Baumüller, and M. J. Kerschgens, eds., *Stadtklima und Luftreinhaltung*, Berlin, pp. 53-94, 1999.

[4] H. Taha, "Urban climates and heat islands: albedo, evapotranspiration and anthropogenic heat," *Energy and Buildings*, vol. 25, pp. 99-103, 1997.

[5] T. R. Oke, *Boundary layer climates*, New York, 1987.

[6] P. Dobrovolný and K. Jelínek, "Detekce tepelného ostrova města Brna s využitím družicových dat. 50," let geografie na Přírodovědecké fakultě Univerzity Palackého v Olomouci, Olomouc, 10-11th June, 2009.

[7] C. Monn, V. Carabias, M. Junker, R. Waeber, M. Karrer, and H. U. Wanner, "Small-scale spatial variability of particulate matter < 10 mm (PM10) and nitrogen dioxide," *Atmospheric Environment.*, vol. 31, no. 15, pp. 2243-2247, 1997.

[8] S. Weber and K. Weber, "Coupling of urban street canyon and backyard particle concentrations," *Meteorologische Zeitschrift*, vol. 17, no. 3, pp. 251-262, 2008.
[9] J. Unger, "Intra-urban relationship between surface geometry and urban heat island. Review and new approach," *Climate Research*., vol. 27, pp. 253-264, 2004
[10] C. J. Tomlinson, L. Chapman, J. E. Thornes , C. J. Baker, "Derivation of Birmingham's summer surface urban heat island from MODIS satellite images," *Internation Journal of Climatology*, vol. 32, no. 2, pp. 214-224, 2012
[11] M. Tomáš and M. Vysoudil, "Teplotní *a* srážkové poměry Olomouce," *Zprávy Vlastivědného muzea v Olomouci*, vol. 301, pp. 69-91, 2011.
[12] European Environment Agency (EEA). *CORINE land cover project*, Commission of the European Communities, 1995.
[13] Český úřad zeměměřičský a katastrální (ČÚZK). *Digitální model reliefu České republiky 4. generace (DMR 4G)*, 2012.
[14] H. Merbitz, M. Buttstädt, S. Michael, W. Dott, and C. Schneider, "GIS-based identifi cation of spatial variable s enhancing heat and poor air quality in urban areas," *Applied Geography*, vol. 33, pp. 94-106, 2012.
[15] Ředitelství silnic a dálnic (ŘSD), *Celostátní sčítání dopravy 2010 - intenzity dopravy v České republice*, 2011.
[16] L. Pirjola, T. Lähde, J. V. Niemi, A. Kousa, T. Rönkkö, P. Karjalainen, J. Keskinen, A. Frey, and R. Hillamo, "Spatial and temporal characterization of traffic emissions in urban microenvironments with a mobile laboratory," *Atmospheric Environment*, vol. 63, pp. 156-167, 2012.
[17] S. Schubert, S. Grossman-Clarke, and A. Martilli, "A Double-Canyon Radiation Scheme for Multi-Layer Urban Canopy Models," *Boundary-Layer Meteorology*, vol. 145, no. 3, pp. 439-468, 2012.
[18] F. Chen, H. Kusaka, R. Bornstein *et al.*, "The integrated WRF/urban modelling system: development, evaluation, and applications to urban environmental problems," *International Journal of Climatology*, vol. 31, no. 2, pp. 273-288, 2011
[19] G. Ketzler, "Vergleichende Untersuchungen der Temperaturverhältnisse in Städten unter besonderer Berücksichtigung der Temperaturänderungsraten," *Aachener Geographische Arbeiten*, vol. 31, 1997.

J. Geletic was born in 25. 8. 1986 in Ostrava. He graduated from mathematical high school in 2005 and later graduated from Palacky University, Department of Geoinformatics (2010). He is interesting in geoinformatics, geostatistics and modeling natural phenomenon (landslides, flood-modeling, etc.). His dissertation focuses low-scale climate modeling (topoclimate). He wants to describe important effects of the geographical factors shaping the climate of the city and sorroundings.