TEMPORAL EVOLUTION OF SNOW COVER AND THE URBAN HEAT ISLAND IN PRAGUE

LUBOŠ TŮRKOTT, VERA POTOPOVÁ, DITA HIŘMANOVÁ
Department of Agroecology and Biometeorology, Czech University of Life Sciences Prague, Kamýcká 129, Praha-6 Suchdol 165 21, Czech Republic, turkott@af.czu.cz

The Urban Heat Island (UHI) is a phenomenon of many centres of big cities and it is an unintentional climatic change caused by modifications of surface and atmosphere in urban space. In the article, a data sheet was used and mean monthly air temperatures in 1961 – 2011 were applied. The analysis was performed at the urban climatologic station Praha Karlov and climatologic station Praha Ruzyně situated on the outskirts of the city in the seasons and in months with snowing in particular (November, December, January, February and March). The Urban Heat Island Magnitude (UHIM) had the highest increasing trend 1.20 °C/100 years in summer, 0.79 °C/100 years in spring, 0.37 °C/100 years in autumn, and a decreasing trend -0.07 °C/100 years in winter. Having analysed selected months, the increasing trend concerned all months except December with the decreasing trend. The number of days with snow cover in the period 1921/1922 – 2010/2011 and the number of days with snowing in the period 1960/1961 – 2010/2011 at the urban climatological station Praha Karlov were used. The highest value of 102 days of the number of days with snow cover was calculated in the period 1969/1970 and the lowest value was 4 days in the period 1989/1990. Similarly, the highest number of days with snowing was 70 days in the period 1969/1970 and the lowest number was 19 days in the period 2006/2007. The increase of the number of days with snowing was also determined in March in particular as well as the decrease of days with snow cover in December and February.

Keywords: Urban Heat Island, snow cover, temperature, Prague

INTRODUCTION

The urban climate is shaped not only by the character of active surface but also atmosphere pollution and waste heat produced by human activities (Rožnovský et al., 2010). Temperature distribution in urban areas is highly affected by the urban radiation balance. Solar radiation incident on the urban surfaces is absorbed and then transformed to sensible heat. Most of the solar radiation impinges on roofs, and the vertical walls of the buildings, and only a relatively small part reaches the ground level (Santamouris et al., 2001). Active urban surface is created by mostly building elements, which serve as heat accumulators and then as heat sources. Absence of green plants and water-filled areas does not allow active cooling of the environment with evapotranspiration; urban climate then becomes significantly warmer in comparison with the outskirts. This phenomenon is called the Urban Heat Island (UHI). In mathematic terms, its intensity (UHIM) can be expressed as the difference between the air temperature in town (Urban) and the air temperature of its outskirts (Rural) and it is $\Delta T_{U\text{-}R}$ (°C) (Vez et al., 2000). The UHI intensity depends on the city expansion. Martinez et al. (1991) describes the increase of the UHI intensity in Madrid, Spain and Kim-Baik (2002) describe a similar situation in Seoul, South Korea. The UHI does not concern only big cities, but urbanization is also happening in smaller towns; even its outskirts are affected by industrial zones and depot areas. Hinkel et al. (2003) links the increase of inhabitants in Barrow, Alaska and the increase of the UHI intensity in winter in particular. The average UHIM was 2.2 °C over the 4-month winter period 1 December 2001 to 31 March 2002, with the maximum monthly UHIM of 2.4 °C occurring in January. This suggests a causal relation such that urbanization has resulted in warmer winter air temperature, which, in turn, contributes to early snowpack melt-out. Snow cover is yet another meteorological factor influenced by the UHI. The presence of snow cover is a precondition for the formation of a sufficient volume of both surface and ground water. In excessive amounts, however, it leads to considerable difficulties for the national economy (Tolasz et al., 2007).

Generally, maritime areas in Europe have lower water reserves in the snow cover in winter compared with continental ones.

At its maximum, snow covers most of eastern and northern Europe, as well as the Alpine region, but this area shrinks back during spring and by the end of May, only upland regions have snow cover. Across most of Western Europe, snowfall and snowmelt are minor components of the water balance (Arnell, 1999). The ongoing climate change, which is demonstrated by the temperature increase, has and will have influence on the snow cover evolution.

However, as first noted by Groisman et al. (1993) and more recently by Räisänen (2007), the snow cover response to global warming is complicated by projected increases in precipitation, particularly over high latitudes. The snow cover response to warming could therefore vary with latitude and elevation, with potential for increased accumulation in high latitudes and high elevations where increases in precipitation are sufficient to offset reductions in the length of the accumulation season (Brown and Mote, 2009). Snow cover over North America has increased in the fall half of the year but decreased in the spring (Brown 2000); snow cover trends in China exhibit strong regional variations (Yang et al. 2007) despite widespread warming, glacier wasting, and permafrost thawing (Li et al. 2008). Snow depth trends over northern Eurasia show contrasting increases in the northeast and decreases in the west (Popova 2007). The snow cover evolution is significantly influenced by atmospheric circulation. Several studies demonstrate that climatic impact of the Eurasian snow cover is not limited by regional scale: interannual land-surface snow anomalies in this region can influence interannual variability of the winter mode of the Arctic oscillation (AO) (Gong et al., 2004). It has been revealed that snow cover variations during winter in northern Eurasia are associated with monsoon rainfall in Southeast Asia (Krenke et al., 2001), as well as tropical Pacific and Atlantic sea-surface temperature anomalies in spring (Ye and Bao, 2001). Tolasz et al. (2007) states that at low elevations, January has the highest number of days with snow cover (around 12), while at the highest elevations in mountain areas, days without snow cover are almost an exception between January and March in the Czech Republic.

MATERIALS AND METHODS

The meteorological data set from climatological stations Praha Karlov (1921 – 2011) and Praha Ruzyně (1961 – 2011) was used for the analysis. The station Praha Karlov is an urban climatologic station and Praha Ruzyně is situated on the outskirts of the city. The mean monthly air temperature from the Praha Ruzyně station was adjusted to the altitude of the Praha Karlov station according to Nosek (1972). The value of the vertical temperature gradient for selected months was applied according to Smolík and Stružka (1959).

In the first step, the urban heat island magnitude (UHIM) ΔT_{K-R} (°C) was calculated as the difference in monthly air temperature in Praha Karlov and Praha Ruzyně. UHIM linear trends for months November, December, January, February and March in the period of 1961 – 2011 were stated according to Vez et al. (2000). In the following step, temporal evolution of the number of days with snow cover (DSC) in the period 1921 – 2011 and the number of days with snowing (SD) in the period 1961 – 2011 in Praha Karlov was analysed as well as the number of days with snow cover in Praha Ruzyně in 2000 – 2011. Then the linear trends of the evolution of these characteristics were calculated.

The period from November to March was used for this analysis.

RESULTS AND DISCUSSION

The linear trends of the Urban Heat Island Magnitude (UHIM) for Praha Karlov (1921 – 2011) have been analysed. The estimation of linear slope of a trend in the time series of the UHIM, the nonparametric Kendal-Theil method was applied. Temporarily, UHIM has a strong seasonal cycle with the highest values between June and August. The seasonal analysis (not displayed) reveals higher UHIM intensities in the summer and the lowest intensity in winter. The most pronounced increasing trend of UHIM was observed in the summer (1.20 °C/100-yr), spring (0.79 °C/100-yr), and autumn (0.37 °C/100-yr). UHIM shows a statistically not significant decreasing trend in the winter (-0.07 °C/100-yr). Coefficients of determination (R^2) are listed in the same order 0.3736, 0.2455, 0.0619 and 0.0016. The yearly UHIM was increased by 0.57 °C/100-yr and R^2 achieved 0.1765. Beranová and Huth (2003) reached similar results in their research of the Prague UHIM using the dataset from the Praha Klementinum station. At the Praha Klementinum, the highest UHIM was determined in autumn (1.6 °C/100-yr), and then in the spring and summer (1.5 °C/100-yr); and the lowest in the winter (0.3 °C/100-yr). The yearly UHIM increase was 1.2 °C/100 years.

When analyzing the months with snow cover and snowing (November, December, January, February and March) in detail, the UHIM trends were increasing in all months except for December when the trend was decreasing (Fig. 1). Therefore, we can conclude that excessive snowfall in the early winter tends to reduce the absorbed solar radiation in winter by increasing the surface albedo, thus resulting in persistence of colder temperatures (Potopová et al. 2016).

In Praha Karlov, the mean number of SD in the period 1961 – 2011 was 11.3 in January, 9.8 in February, 9.3 in December, 6.5 in March and 4.1 in November. The highest number of SD in the cold period November – March was 70 days (1969/1970). On the contrary, the lowest number of SD was 19 days in the cold period of 2006/2007, with the following distributions: 3 days in November, 2 days in December, 8 days in January, 2 days in February and 4 days in March. The absolutely highest number of SD was in December with 27 days (2010) with precipitation out of which 26 days were with snowing.

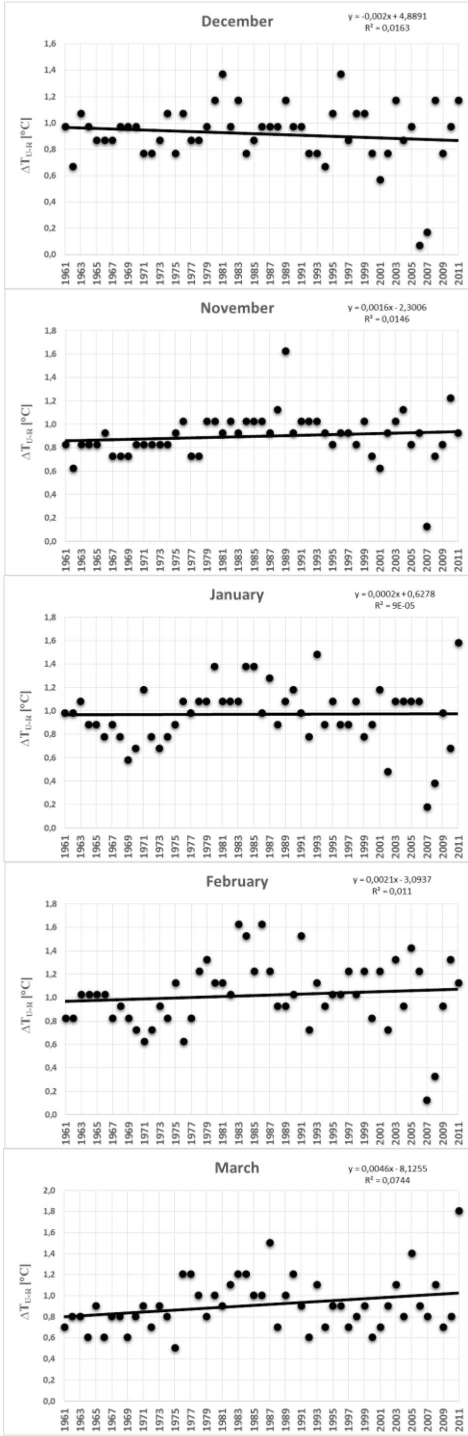

Figure 1. The urban heat island magnitude (UHIM) and the linear trends of UHIM at the Praha Karlov station in the period 1961 – 2011.

There was a decreasing trend in the number of DSC at the Praha Karlov in the period 1921– 2011. The lowest number of DSC was recorded in 1989/1990 (4 days) and 1991/1992 (5 days). However, the highest number of DSC was in 1969/1970 (102 days) and 1939/1940 (90 days). Months with all days with snow cover were recorded in December of 1969 and 2010, January of 1929, 1940, 1941, 1963, 1970, 1979 and 2006, February of 1929, 1942, 1947, 1956, 1963 and 2010. At the Praha Ruzyně, the DSC analysis was performed in the period 2000 – 2011. As shown in the Fig. 3, the highest number of DSC in the cold period was in 2005/2006 (80 days) and 2009/2010 (76 days).

On the contrary, the lowest number of DSC was 11 (15) for the period 2006/2007 (2007/2008). Months with all DSC were the same at the Praha Ruzyně and Praha Karlov in the period 2000 – 2011. The total number of DSC was higher at the Praha Karlov in the past 6 cold seasons.

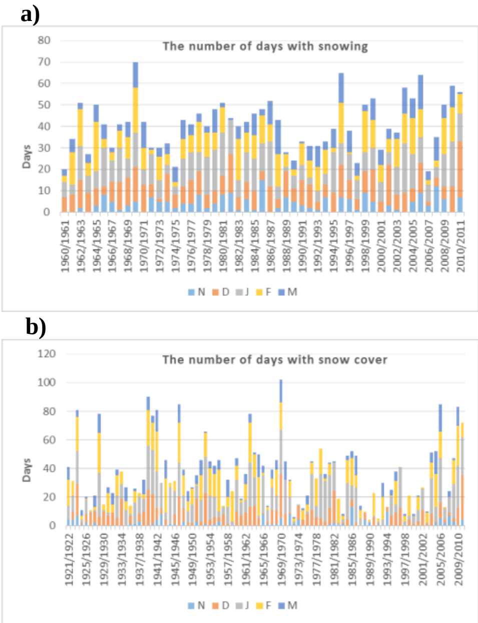

Figure 2. a) The number of days with snowing (1960 – 2001) and **b)** the number of days with snow cover (1921 – 2001) in the cold period (November – March) at the Praha Karlov climatological station.

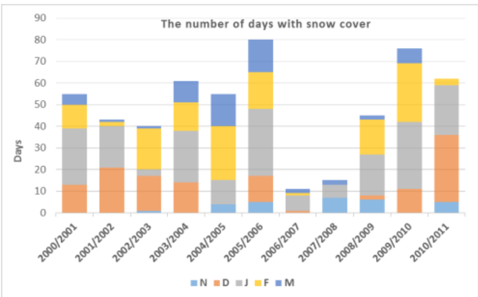

Figure 3. The number of days with snow cover (2000 – 2001) in the cold period (November – March) at the Praha Ruzyně climatological station.

Using the linear analysis of DSC, the decreasing trend of the occurrence of these days was identifiend in December, February and March. The greatest decrease DSC -0.4 days/10-yr was calculated for December, -0.2 days/10-yr for February and -0.1 days/10-yr for March.

During 1991–2015, DSC shows a statistically significant decreasing trend in the southern lowland and western hilly areas and slightly increasing trend but not statistically significant in the eastern part of the Czech Republic (Potopová et al., 2016). In the Czech Republic, accumulations of years with significantly below average DSC were recorded in the early 1960s, mid 1980s, late 1990s, and most of the 2000s.

Falarz (2004) states that during the last 50 years, outside the mountains, the snow cover duration displays a slight decreasing trend in Poland, which is, however, neither spatially differentiated nor statistically significant. The highest trend (-1.2 days/10-yr) in the decrease of DSC in winter took place in the town of Pułavy in eastern Poland; in Gdynia in northern Poland on the coast of the Baltic Sea, it was -0.8 days/10-yr as well as in Kalisz in central Poland.

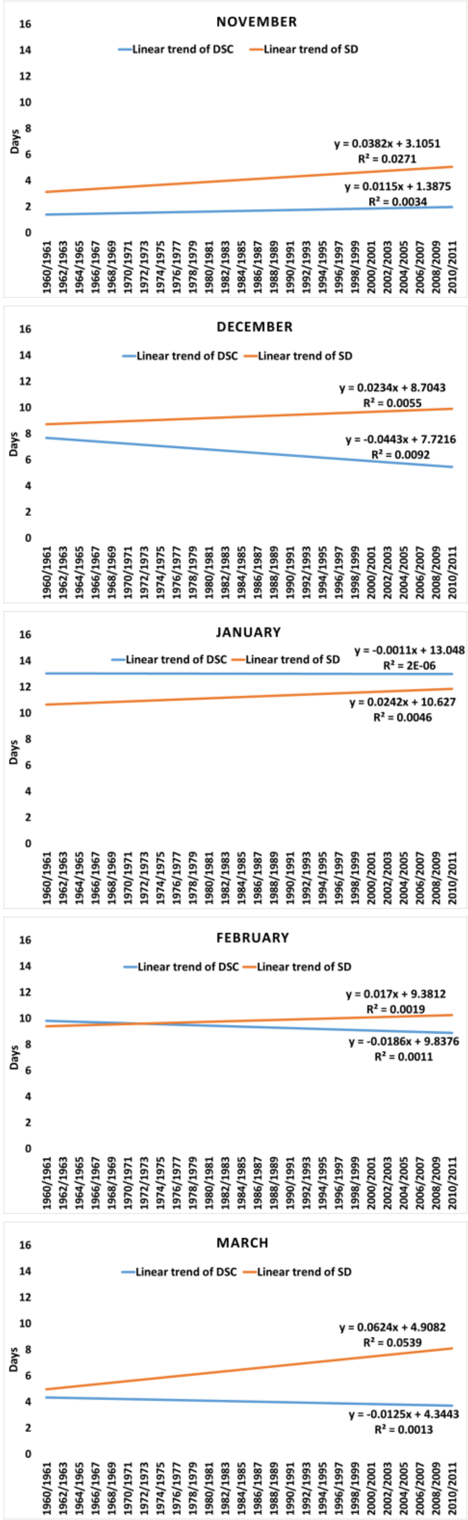

Figure 4. The linear trends of DSC and SD at the Praha Karlov station in the period 1960 – 2001.

The results show the increasing number of SD in Praha Karlov in 1961 – 2011, although this increases was not statistically significant. The highest trend of SD was in March and November. However, similar studies show prevailing decrease number of SD with great spatial variability (Serquet et al. 2011, Vries et al. 2014).

CONCLUSION

Linear trends of UHIM with the highest value 1.2 °C/100-yr were determined in summer, while the lowest value of -0.07 °C/100-yr was determined in winter. The annual UHIM was 0.57 °C/100-yr at Praha Karlov compared with Praha Ruzyně.

We may assume that UHIM is partially caused by accumulation of solar energy in building elements and its subsequent radiation as well as anthropogenic heat released to the environment through heated buildings, car traffic etc.

When analysing UHIM in the cold period in detail, the decrerasing trend was determined in December, which may be the reason for the decreasing trend of the number of DSC despite the increasing value of the trend of SD. In Praha Karlov, the number of SD increased in all the analysed months. The highest increase was in March and the lowest in February.

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