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Analysis of the Budapest urban heat island effect using both satellite- and ground-based temperature observations

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Human settlements, especially, the large urban areas significantly modify the environment. Atmospheric composition near urban agglomerations is highly affected mainly due to industrial activity and road traffic. Urban smog events are common characteristics of large, very populated cities. Furthermore, artificial covers and emitted energy modify the energy budget of urban regions, and thus, local climatic conditions. One of the often analyzed phenomena related to cities is the urban heat island (UHI) effect. Urban heat island is defined as the positive temperature anomaly occurring between built-in areas and their surroundings. For detailed analysis of UHI in a particular area, different approaches can be used. Here, two different techniques (ground-based and satellite-based) are applied to the Budapest agglomeration area and the results are compared.

Hourly recorded air temperature observations are available from automatically operating climatological stations of the Hungarian Meteorological Service. These ground-based observations at the weather stations provide air temperature data at standard 2 m height above surface. However, the spatial resolution of this network is not fine enough to assess the detailed spatial structure of the temperature field. In Budapest, which is the capital and the largest city of Hungary only four meteorological stations are installed due to the high costs of weather station systems and their maintenance. Because of the limited station number, this approach is not suitable for detailed evaluation of spatial UHI distribution. Moreover, the observed temperature values represent only the surrounding of the measuring points. The standard definition of UHI intensity is based on air temperature, and hence these four stations provide data sets comparable to other studies elsewhere in the world.

Remotely sensed surface temperature values are available from the measurements of the multi-spectral radiometer sensor called MODIS (Moderate Resolution Imaging Spectroradiometer), which is one of the sensors on-board satellites Terra and Aqua. They were launched to polar orbit as part of the NASA's Earth Observing System in December 1999, and in May 2002, respectively. Seven thermal infrared channels of MODIS can be applied to calculate surface temperature. Satellite Terra (Aqua) provides surface temperature fields around 09-10 UTC (12-13 UTC) and 20-21 UTC (02-03 UTC) with 1 km spatial resolution. The pixel values certainly represent larger area than the ground-based measurements. The whole agglomeration has been divided into urban and rural pixels using the MODIS Land Cover Product categories, distance from the city centre, satellite images of the Google Earth, and GTOPO-30 global digital elevation model. However, the main disadvantage of this method is that for UHI analysis, data can be used only in case of clear sky conditions, which occurs less frequently in the Carpathian basin during winter than summer.

The purpose of the present research is to analyze similarities and differences between temperature values observed by ground-based and satellite-based instruments. Monthly, seasonal and annual mean temperature values are calculated and compared for Budapest in the 21st century. In this research the surrounding of six weather stations were evaluated: two stations are located in the downtown of Budapest: Kitaibel Pál street and Lágymányos; two stations can be found in the suburbs: Újpest and Pestszentlőrinc; and two stations are in the rural region: Penc (located to the northeast from the capital) and Kakucs (to the southeast from Budapest).

On the basis of the results, the following conclusions can be drawn. (i) The mean temperature is generally higher in the downtown and lower in the rural region than in the suburbs, especially, at night-time. During day-time it is not so clear, the suburbs may be warmer than the downtown stations. (ii) Day-time/night-time satellite-based surface temperature is higher/lower than ground-based air temperature (especially, in summer/winter). This can be explained by the faster warming and faster cooling of the surface than those of the atmosphere. (iii) The satellite-based average temperature of Kakucs and Penc is highly correlated to the rural mean surface temperature.

Thus, the mean temperature of the rural region can be estimated by the average temperature of these two weather stations. Moreover, the UHI intensity can be defined as the difference between the actual temperature value and the average temperature of Kakucs and Penc. This time series are calculated from both ground-based and satellite-based temperature values. (iv) The UHI intensity shows a large temporal variability. During day-time intensity values are larger when the satellite-based method is used than the ground-based measurements. During night-time the difference between the two approaches is very small.