Long-term Dynamics of the Urban 'Heat Island' in Moscow.

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Abstract

For the first time the long-term dynamics of the urban 'heat island' (UHI) intensity over Moscow city has been investigated for the period since 1880s till nowadays using the data of the ground meteorological network. Besides a traditional UHI maximal intensity (i.e. averaged in time difference between the air temperature in the city centre and outside the city) an additional parameter – so-called 'areal' or 'space-averaged' UHI intensity – has been suggested. It represents a value averaged both in time and in space (a difference between mean air temperature in the city area and outside the city). As it is shown the traditional UHI intensity in Moscow was nearly of 1.0 ºC at the end of the 19th century, 1.3 ºC one century ago, 1.5-1.6 ºC both in the middle, and at the end of the 20th century, and 2.0 ºC at recent years. The 'areal' or 'space-averaged' intensity was equal to 0.7-0.8 ºC both in the middle, and at the end of the 20th century whereas now, in 2010s, it is about 1.0 ºC. Thus, during several last decades a dynamics of the UHI intensity in Moscow was complicated because both its parameters changed only a bit during the second part of the XX century in spite of monotonous growth of the urban population.

1. Introduction

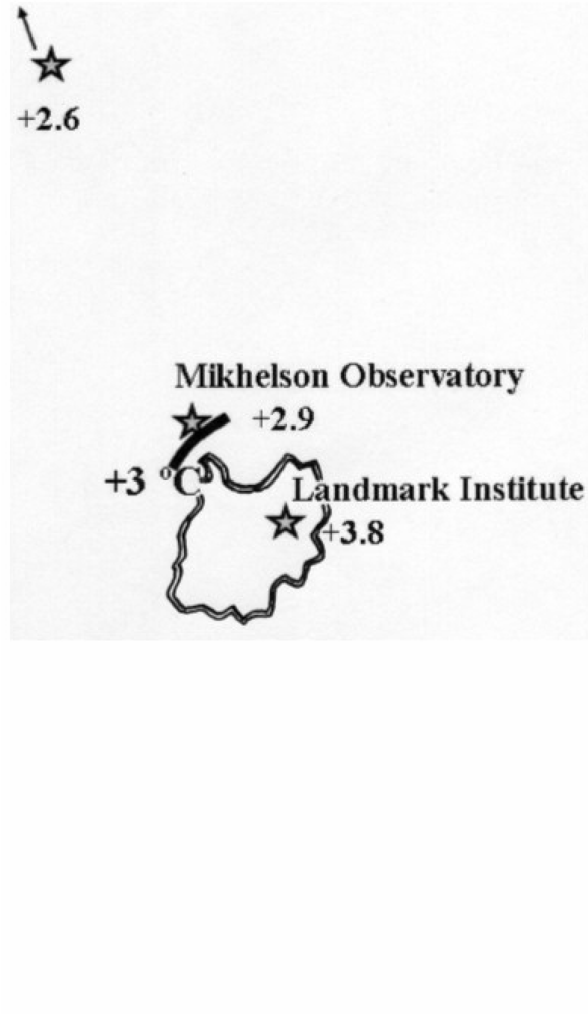
The urban 'heat island' is well-known phenomenon which was analyzed and investigated in a lot of cities all over the World since the pioneer work of Luke Howard at the beginning of the 19th century (Adamenko, 1975; Böer, 1964; Kratzer, 1956; Landsberg, 1981; Oke, 1978, etc.). The simplest and the most popular parameter is the UHI intensity ΔT as a difference between the city centre and rural zone on average in time. As a rule one station in the centre of a city and another one or several stations in surrounding rural zone outside a city are used for the UHI intensity estimation. However this value of the maximal UHI intensity strongly depends on a vicinity and data quality of only one central urban station. One more useful parameter is the 'areal' or 'space-averaged' UHI intensity ΔT_S, i.e. the intensity on average both in time and in space. It is a difference between mean T inside a city and mean T outside it. The ΔT_S may be analyzed if a lot of stations operate simultaneously both in a city area and in rural zone. Evidently a value of ΔT_S is less than usual traditional ΔT but this 'space-averaged' intensity may be important as more statistically trustworthy parameter than ΔT (especially in cases when data of the only central station in a city is doubtful, when its close vicinity was significantly changed or when the central station was displaced). Evidently, in these cases the row of the data about the UHI intensity may be non-homogeneous. The geographical reason of the 'areal' parameter is a well-known fact that a 'heat island' often represents 'plateau' form in the field of T with sharp increase of the air temperatures close to city margins (e.g., Landsberg, 1981).

The purpose of this work was to study the long-term dynamics of the UHI intensity in Moscow during last one and quarter centuries – since 1880s till nowadays – with the use of both parameters. These results were partially published in (Lokoshchenko, 2013) for the period since 1915 till 1955 and in (Lokoshchenko, 2014) for the period since 1887 till 1997; now they have been added by results of meteorological measurements during recent years.

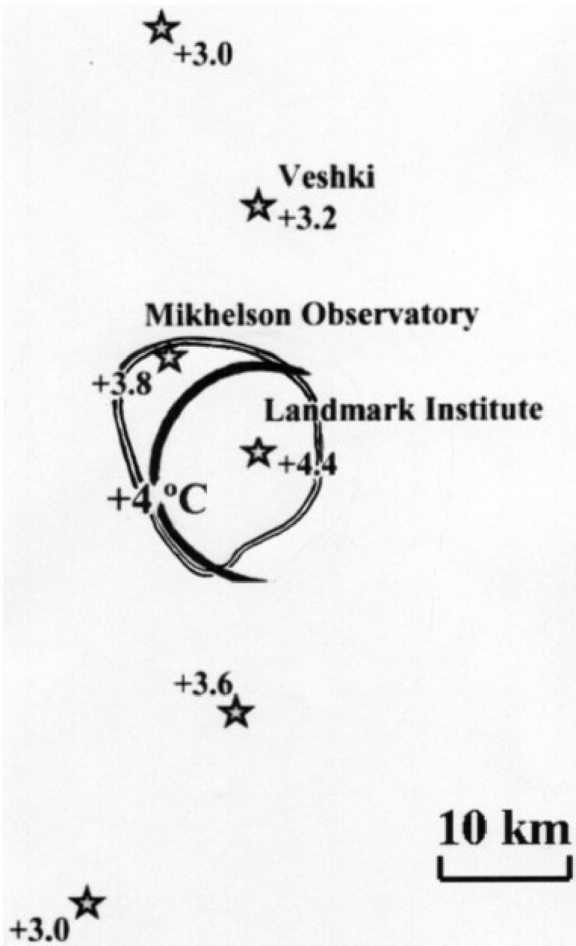
2. Main results

The urban 'heat island' intensity in Moscow city has been studied separately for five periods (Figure 1). As one can see in Fig. 1 a), at the end of the 19th century on average of three years the difference between T in Landmark institute (city centre) and Mikhelson observatory (city suburbs) was equal to 0.9 ºC whereas the difference between Landmark institute and one more station Nikol'skoye-Gorushki in the far rural zone was greater: 1.2 ºC. A single rural station is insufficient for analysis because it is unclear whether its location was representative or not. Nevertheless, we can suppose that the 'heat island' intensity at that time was nearly equal to 1.0 ºC. It is the first possible estimation of this parameter for Moscow city. Evidently only a traditional estimation of the UHI intensity with the use of only one urban station may be used.

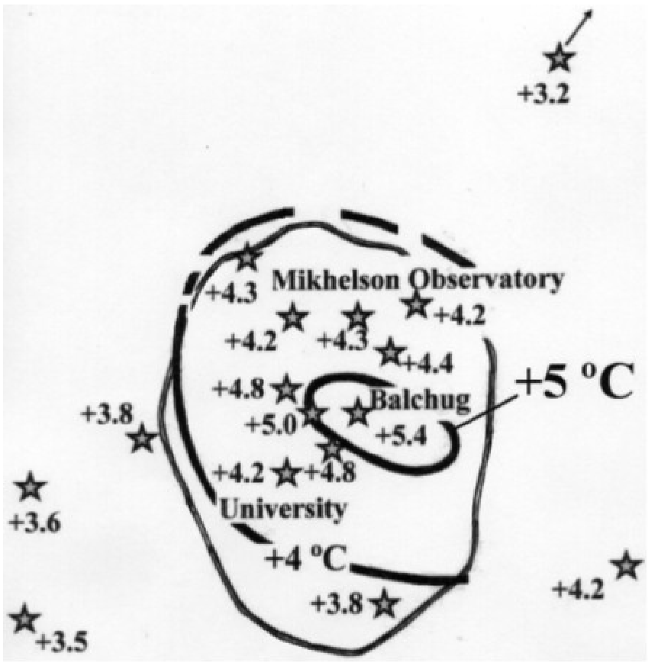
Almost thirty years later, in 1915-1916, there were already six meteorological stations in this area – two stations inside the city and four outside it (Fig. 1 b). It should be noted that for Veshki station only 23 from 24 monthly-averaged values are available, with the only exception of January, 1915. For that month the probable mean value of T was reconstructed with the account of average differences between Veshki and two other stations, Landmark Institute and Mikhelson observatory, in winter. As it is seen the +4 ºC isotherm is semi-circle and almost coincides with real Southern margin of the city during the First World War. At that time 15 meteorological stations operated in Moscow region, six of which are shown in the Figure 1 b). The mean T in the



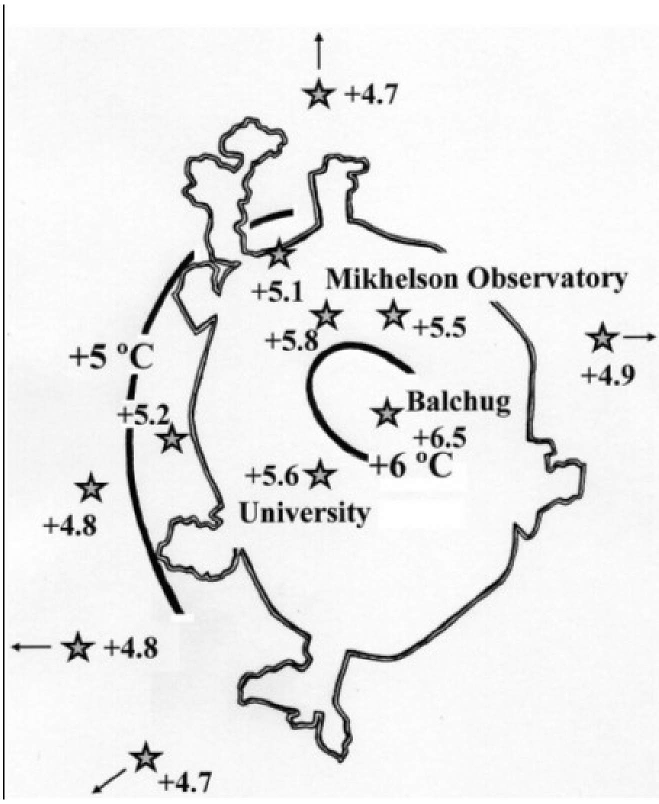
a) 1887-1889;



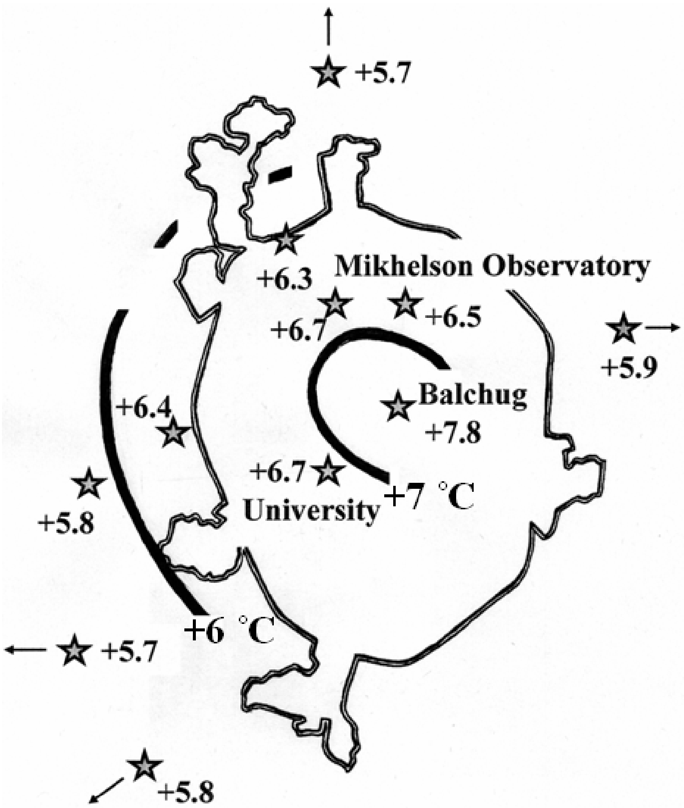
b) 1915-1916;



c) 1954-1955;



d) 1991-1997;



e) 2010-2014.

Figure 1. Dynamics of the urban 'heat island' in Moscow in time.

Double lines indicate contours of Moscow city in 1890 (a), in 1916 (b), in 1960 (c) and since 1992 till 2011 (d,e); asterisks are ground meteorological stations; bold lines are mean-annual isotherms.

rural zone outside the city during two years was in the range from +2.6 to +3.6 ºC, +3.2 ºC on average for 13 stations, except Landmark Institute and Mikhelson observatory. This scatter of values is explained both by general climatic tendency (increase from North to South) and, other than that, by influence of some local factors such as relief, closeness to open water, possible influence of small towns or villages in close vicinity of some rural stations, etc. It should be noted that correct estimation of the 'heat island' intensity is not a simple task because of non-homogeneous spatial field of T. The principal question is often – what is the real rural air temperature for the comparison with a city? Nevertheless, in our case we can see that the maximal T was equal to +4.4 ºC or, at least, only a bit higher in the city centre whereas background rural value of T was equal either to +3.0 ºC (two stations on Fig.1 at a distance of nearly 35 km both to the North and to the South from the city centre) or to +3.2 ºC with the account of all 13 rural stations in Moscow region at a distance up to nearly 100 km from the city. Thus, we can conclude that at the beginning of the 20th century the mean intensity of Moscow 'heat island' was in the range from 1.2 to 1.4 ºC (in average: 1.3 ºC).

Forty years later, as seen in Fig.1 c), 32 stations were already operating in Moscow region, including 11 stations inside present day margins of the city. At the middle of 1950s margins of Moscow were unclear: they were fixed five years later, in 1960 (mail ellipsoid in Fig.1 c). Nevertheless probably 8 from these 11 stations were really inside the city in 1954-1955, three others represented close suburbs at that time. Unfortunately, only 5 of 11 stations now remain in Moscow. Thus, in the middle of the 20th century the density of ground meteorological network in Moscow was the highest, so that the most detailed structure of the 'heat island' may be analyzed for that time. It can be seen that the 'heat island' is marked by two quasi-circle isotherms already in average of 1954-1955: +4 and +5 ºC. The closest station to the city center, Balchug, which is situated only 600 m to the South from the Kremlin, demonstrated at that time the highest air temperature: +5.4 ºC. All other urban stations represent gradual decrease of T from the centre to city margins. It should be noted that comparatively high air temperature to the East from Moscow city, as one can see on the Fig. 1 c), may be result of general Western flow in mid latitudes. The mean air temperature inside the city was +4.6 ºC basing on the data from 8 urban stations (and +4.5 ºC by the data from all 11 stations which were located inside up-to-date margins of the city). In rural zone of Moscow region the mean T was equal at that time to +3.7 ºC on average of the data from 21 stations.

Thus, as it was published in (Lokoshchenko, 2014), the value of ΔT_S in Moscow city in the middle of the 20th century was equal to 0.9 ºC whereas the traditional intensity of 'heat island' ΔT, i.e. a difference between Balchug and rural stations, was nearly equal to 1.7 ºC. However let us account now only stations which operated later, in 1991-1997 and in 2010-2014. It is necessary for more correct comparison of the UHI values during different time. Unfortunately, for the periods 1991-1997 and 2010-2014 the data only of five urban stations, including Balchug, and 10 rural stations in Moscow region are available. Thus, both parameters were recalculated on a base of reducing number of stations. As a result, for the period 1954-1955 the values of ΔT_S and ΔT are equal to about 0.7 and 1.5 ºC correspondingly.

The 'heat island' mapping on average of seven years from 1991 to 1997 may be seen in Fig.1 d). Unlike previous periods, new semi-circle isotherm +6 ºC appeared in the city centre. One more isotherm of +5 ºC may be detected close to the western city margins. As it is seen in the period of 110 years T became higher by 2.7 ºC in the city centre and nearly by 2.0 ºC or a bit more in rural zone of Moscow region.

As one can see the maximal air temperature in the city centre in 1991-1997 is equal to +6.5 ºC at Balchug station whereas in rural zone outside the city it is from +4.7 ºC to +4.9 ºC. The mean T is +5.7 ºC inside the city by the data of five urban stations and +4.9 ºC in Moscow region in average of ten rural stations. Thus, the mean 'heat island' intensity ΔT was nearly of 1.6 ºC, i.e. only 0.1 ºC higher than forty years ago. The value of ΔT_S in 1991-1997 was also increased since 1950s only a bit: 0.8 ºC. It seems to be a surprising and unexpected result with the account of continued quick growth of the city during the second part of the 20th century. As it can be seen on Fig.2, the urban population in Moscow increased from 4.84 million in 1956 to 9.07 million in 1994. Besides, the city area increased from 356 km^2 in 1955 to 940 km^2 in 1995.

Finally, at recent years (on average since 2010 till 2014), as one can see on Fig.1 e), the air temperature in Moscow became still higher: +7.8 ºC at Balchug station and from 6.3 to 6.7 ºC at other four urban stations. Thus, one more semi-circle isotherm +7 ºC appeared in the centre of Moscow. Consequent increase of the air temperature in Moscow city from one period to another during 128 years is evident in Figure 1: T became higher by half a degree from 1887-1889 to 1915-1916, by one degree from 1915-1916 to 1954-1955, by one degree from 1954-1955 to 1991-1997 and by one more degree from 1991-1997 to 2010-2014. This increase is a result both of total climate warming and of quick growth of the city. So, in the period of 128 years T became higher by 4 ºC in the city centre and nearly by 3 ºC in rural zone of Moscow region.

On a base of the same data sampling (five urban meteorological stations and ten rural ones) the values of ΔT_S and ΔT on average of five recent years are 2.0 and 1.0 ºC correspondingly. So, both parameters demonstrate a new growth after previous period of their quasi-stabilization.

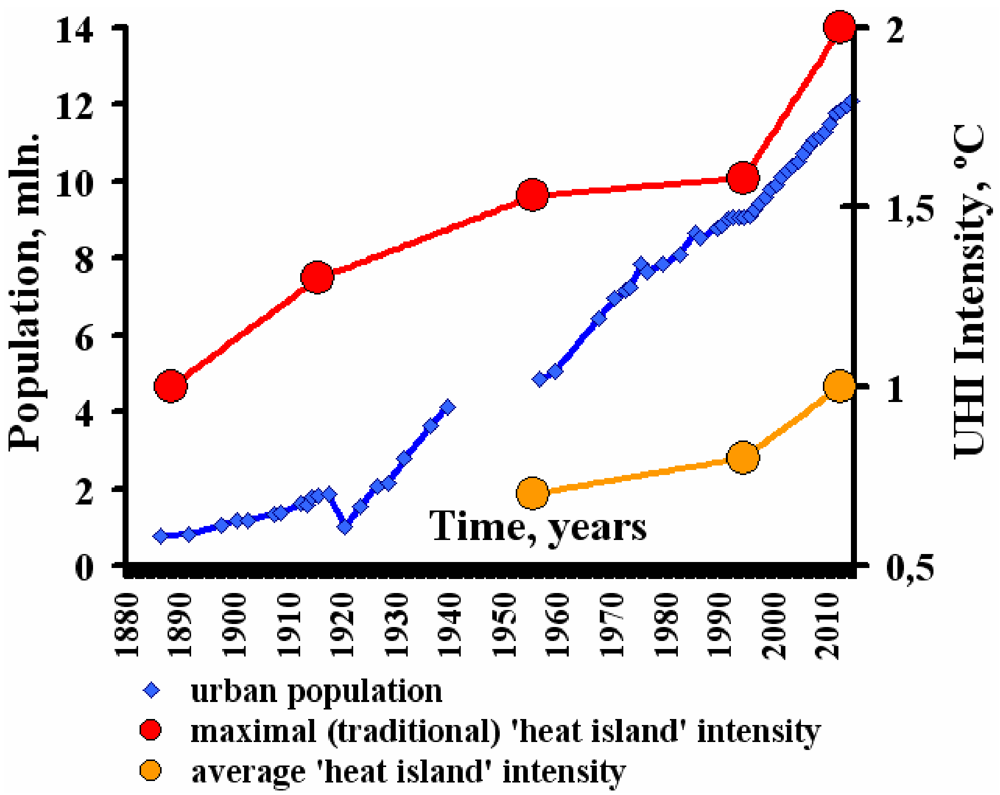


Figure 2. Dynamics of the urban 'heat island' intensity and population of Moscow city.

The results of analysis are presented on Figure 2. It demonstrates long-term dynamics of the UHI intensity in Moscow, both traditional and space-averaged one, during last 128 years. As it is seen this dynamic is complicated. During the second part of the 20th century both parameters of the UHI intensity changed only a bit whereas before and later a growth of them was quick. It should be noted that the urban population in Moscow was increasing since the mid of 1950s till nowadays monotonously with nearly the same rate.

3. Conclusions

1. The urban ‘heat island’ intensity in Moscow during last one and quarter centuries (since 1880s) became twice more: from 1.0 to 2.0 ºC.
2. The space-averaged urban ‘heat island’ intensity seems to be more reliable and trustworthy parameter than simple traditional estimation of the intensity with the use of only one central urban station. In Moscow this additional parameter increased from 0.7 to 1.0 ºC during last 60 years.
3. The dynamics of the UHI intensity is complicated and a rate of its growth is different in time as a result of influence of a lot of factors – both natural and social ones.

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