CHANGE OF AIR TEMPERATURE IN MOSCOW DURING LAST TWO AND QUARTER CENTURIES

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Abstract

The air temperature dynamics in Moscow city has been studied at the first during last two and quarter centuries since 1779 when a first meteorological station in Moscow was found by Societas Meteorologica Palatina of Mannheim. The air temperature data in Moscow have been collected and analyzed for the total period from that time to nowadays. Some questions connected with an accuracy of old thermometers in the XVIII and the XIX centuries and with principal comparability of the air temperature measurements at different time are discussed. As a result of this analysis it is shown that three main changes of sign of the air temperature tendency in Moscow took place during last 225 years. A fall of air temperature started at the beginning of the Nineteenth century and was followed by steady long increase since the end of the XIX century. It extended during the whole last century almost monotonically and seems to become a bit slower only during last decades. A total increase of the air temperature in Moscow city consisted of nearly 1.8 ºC during last 225 years. It is connected not only with an effect of the urban “heat island” of Moscow city but with a change of background climatic conditions too. For a rural zone in Moscow region the increase of the air temperature consisted of 0.7 ºC during this period.

Key words: air temperature, secular changes of climate, global warming, urban heat island

1. INTRODUCTION AND SITES OF MEASUREMENTS

The studying of the air temperature T variability in details for long-term periods is necessary for better estimations of current global warming and for more accurate forecasting of climatic changes in future. Before the beginning of instrumental measurements the only source of our knowledge about climate in past are written annals containing some qualitative information about weather events. For conditions of Central Russia these annals were collected, e.g., by (Borisenkov and Pasetsky, 1988). However, the results of instrumental measurements, even the oldest, represent much more reliable information about climate. Hence, an analysis of total rows of instrumental measurements of T including the first ones and their verification is an important up-to-date task of climatology. As is well-known the first network of meteorological stations was Florentine one in the XVII century. However, it was limited mostly only by region of Northern Italy and existed during a short time. A second attempt to organize synchronous meteorological observations at a lot of points (almost 40) all over the world was made by Palatine Mannheim Society at the second part of the XVIII century (Kington, 1974 and others). One of the stations of that network operated in Moscow city from November of 1779 to 1797 (so that the average annual values of T are available since 1780). Unfortunately a location of Mannheim station in Moscow is unknown. However, taking into account a small area of city at the end of XVIII century (dashed figure in Fig.1) this station in any case was situated at the central part of contemporary Moscow which up-to-date bounds are marked as outer double line. After short break meteorological measurements were resumed again in 1810 at the Imperial Moscow University at the centre of Moscow (a location of it is
marked in Fig.1 by a blue pentagonal asterisk right in the city centre close to Kremlin), but shortly after they have been broken again because of invasion of Napoleon army in 1812 and terrible Moscow fire. However, several years later they have been recommenced anew – firstly at the same place and, since 1830 – at new location marked in Fig.1 by yellow four-pointed asterisk. One new meteorological station has been created at Landmark Institute (red four-pointed asterisk) in 1853 and, then, another one – at Agricultural Academy in 1879 (so-called Mikhelson Observatory that is white pentagonal asterisk in Figure 1).

Finally, Meteorological Observatory of contemporary Moscow University operates at South-Western periphery of city since 1954 (green pentagonal asterisk).

### 2. METHODOLOGICAL PROBLEMS OF THE OLDEST DATA INTERPRETATION

As for the first data of Mannheim station which were received at the end of XVIII century their reliability must be discussed. Firstly, a site of measurements is assumed to be located at the centre of contemporary Moscow city with an accuracy of 3-4 km. Secondly, a level of measurements is unknown as well as their location. Taking into account that the most of buildings in Moscow at that time were either single-storey or two-storey we can assume that this level was hardly out of limits from 1 to 4 m. At the Meteorological observatory of Moscow University air temperature is measured synchronously on two levels – 2 and 4 m – during recent years. As one can see from the Table, a difference between average annual values of air temperature on two different levels does not exceed 0.1 °C:

<table>
<thead>
<tr>
<th>Year</th>
<th>Average annual T on 2 m above ground</th>
<th>Average annual T on 4 m above ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>6.0</td>
<td>5.9</td>
</tr>
<tr>
<td>2004</td>
<td>6.2</td>
<td>6.1</td>
</tr>
<tr>
<td>2005</td>
<td>6.6</td>
<td>6.7</td>
</tr>
</tbody>
</table>

Thirdly, at the time of Mannheim network thermometers were not installed inside special boxes yet. However, Mannheim society recommended observers to mount their thermometers near Northern walls of houses or inside unheated rooms so that they were shady. As for an accuracy of thermometers used by Mannheim society it is well-known fact that almost one centenary later, at the middle of the XIX century, one of Mannheim thermometers in Prague was compared to the new thermometer and difference between them consisted of only 0.1 °C. Thus, we may conclude that the data of measurements at the XVIII century seem to be quite reliable and comparable with all results received later.

It should be noted as well that during last 225 years an air temperature was measured in Russia by use of three different scales: of de l’Isle in °D (before nearly of 1800); of Reaumur in °R (before 1870) and of contemporary ‘Sweden scale’ in °C since 1870 (i.e. Centigrade scale, suggested by Linnaeus). We recalculated all the oldest data of T using formulas:

\[ T (°C) = \frac{- (T (°D) - 150) \times 2/3}{2}, \]

\[ T (°C) = \frac{T (°R)}{5/4}. \]

Preliminary results of this work have been published by (Kurina and Lokoshchenko, 2006).

### 3. GENERAL TREND OF AIR TEMPERATURE IN MOSCOW CITY

Secular changes of air temperature in Moscow during last 225 years are shown in Fig.2. As one can see a linear trend (black line) demonstrates general tendency to warming during recent 225 years. Parabolic trend (yellow curve) indicates the main change in tendency during that time – the beginning of air temperature increase at the end of Nineteenth century. Cubical trend (green curve) shows one more significance change in general tendency: an increase of air temperature at the end of Eighteenth century, i.e. at the end of small boulder-period has been followed by its slight decrease during the most part of XIX century. Finally, a polynomial trend of the 4th degree (red curve) demonstrates three main changes during last 225 years: 1) the beginning of fall of annual values at the first part of XIX century; 2) the beginning of their increase at the end of XIX century which took place almost monotonously during whole the XX century; 3) probable deceleration of the air temperature increase during last several decades (an upward convexity of red curve close to the right edge of temporal axis). Further complication of the trend equation (increasing of mathematical power) does not lead to strong increase of significance parameter \( R^2 \) that means squared correlation co-efficient. As it is seen in Figure 3 polynomial trend of the 4th degree demonstrates a value of 37 % whereas values for trends of 5th and 6th degrees (mathematical power at their equation) are only a bit more and asymptotically approach to the value of 40 %. Hence, only three main changes really took place in general tendency of the annual air temperature in Moscow during last 225 years.

### 4. ANNUAL COURSE OF CHANGES AND AN INFLUENCE OF THE URBAN HEAT ISLAND

The annual course of the linear trend co-efficient is presented in Fig.4. As one can see a warming of Moscow climate was the strongest in winter and in spring. Notably that July is the only month for which the air temperature
Figure 2. Dynamics of average annual air temperature in Moscow city for a total period of instrumental measurements.

Figure 3. Significance of different types of the annual air temperature polynomial trend in Moscow for period 1780-2005.

Figure 4. Annual course of co-efficient value of the linear trend equation of air temperature in Moscow for period 1780-2005.
slightly reduced during last 225 years (a sign of co-efficient in July is negative unlike all other months). The annual courses of air temperature in Moscow at the XVIII and at the XX centuries are shown in Fig.5. As it is seen the total warming in Russian capital during last two centuries is significant in winter and in spring (from January to May) taking into account confidence intervals. Vice versa, in July mean value of T at the Eighteenth century was a bit more than now (the same effect was mentioned above in Fig.4). However, measurements at Moscow University represent conditions of city periphery at nearly of equal distance between the centre and margins of city (see Fig.1). As it is known an influence of the urban “heat island” is significant, especially in big cities (for Moscow it was demonstrated by Lokoshchenko and Isaev, 2003). For illustration of this effect at long-term dynamics of T the same data of Mannheim station have been compared again in Fig.6 to the data of two other stations: Balchug (which is situated right at the centre of contemporary Moscow city close to the blue asterisk on Fig.1) and Mozhaisk (small town in Moscow region). As one can see a warming in winter and in spring for last 225 years is statistically significant not only for conditions of Moscow city, but for the rural zone outside city as well. Thus, total climatic change can’t be explained only by more intensity of the urban “heat island” in time, although its influence is evident. A total increase of the annual air temperature consisted of nearly 1.8 ºC during last 225 years in Moscow city and nearly of 0.7 ºC for rural zone in Moscow region.

Acknowledgements.

Authors are much grateful to Dr. G.Peters for kindly copying of data of Mannheim station in Moscow from original volumes of Ephemerides and to Mrs. T.M.Rossinskaya for kindly given data of the air temperature measurements made in Mikhelson Observatory during period from 1879 to 1953.

References