UPPSALA URBAN HEAT ISLAND - HOMOGENIZATION OF MEAN TEMPERATURE

Hans Bergström, January 2021
hans.bergstrom@met.uu.se

As the urban area of Uppsala has grown considerably during the last century, a false warming trend is expected in the temperature series. Moberg and Bergström (1997) estimated this urban heat x§island effect on a seasonal basis using a set of 10 homogenised temperature series and found that the annual mean temperature had increased by 0.47 °C since 1861 due to the urbanisation effect.

The homogenization was repeated in Bergström and Moberg (2002) using the same set of 10 stations, but now on a monthly basis. The analysis was made using the Standard Normal Homogeneity Tests (SNHT) for trends and single shift (Alexandersson, 1986; Alexandersson and Moberg, 1997). The exact dates for breakpoints of shifts and for starting and ending points of trend sections as estimated by the SNHT, were observed to vary somewhat between individual months, although the overall appearance was qualitatively the same for neighbouring months. As there were no true reasons to vary the dates of inhomogeneities between months with similar behaviour, the same time points were used for groups of months with a similar character of inhomogeneities. These dates were determined from tests on average temperatures for selected groups of months, and were, whenever possible, also chosen to coincide with relocations of the site.

The results of the homogeneity tests are presented in Figure 1. A significant positive trend for the months March to August started in 1868 and ended in 1925, while the positive trend did not start until 1926 and ended in 1952 for the months November to February, and was completely absent for the months September and October. An abrupt negative jump occurred for the summer months June to August in 1952 and seems to be connected to the relocation of the observation site from the old observation house to Rackarberget. Possibly the reason for this jump was that the old screen was changed to a freshly white painted Stevenson screen, but this could not be the whole truth as the next site movement in the middle of August 1959 back to the Observatory Park was followed by an almost as large positive jump in 1960. Finally another positive jump occurred in the months March to October in 1981, which may have been caused by the building of new houses west and southwest of the observation site.

Except for the jumps in 1952 and 1960, other jumps and trends may be related to the growth of the urban area, although the effects were not the same during all parts of the year. The urban warming seems to have affected the spring and summer months first, then the winter months, and last the autumn months September and October which were not affected until 1981 in connection with the building of new blocks on the western outskirts of Uppsala. The total effect of the urbanisation and also other inhomogeneities has caused the annual mean temperature to be 0.53 °C too high after 1981. As can be seen from Figure 2, there is also an annual variation, with a maximum in spring and summer and the highest value, 0.95 °C, in March, while a minimum is found in the autumn with the lowest value, 0.17 °C, in September. A comparison with the corresponding corrections for Stockholm used in Moberg et al., (2002) shows a similar annual cycle but with the highest value, 1.37 °C, in May and the lowest value, 0.24 °C, in October. The total correction on the annual mean temperature is 0.77 °C for Stockholm.

Homogeneity tests with SNHT on the difference of monthly mean temperature series for Stockholm (Moberg et al., 2002) and Uppsala, also suggest a shift in the Uppsala temperature around 1854, close to September 1853 when the site was moved from the Old Astronomical Observatory in the

city centre to the new one just outside the city limits. An early urban heat island effect can thus be assumed to have affected the Uppsala temperatures before that date, and we have chosen to correct the early part of the series to correspond to the conditions that prevailed in the Observatory Park during the 1850s and 1860s. In that way the homogenized Uppsala temperature series should be as representative as possible of the rural conditions around Uppsala. Monthly mean values of the different corrections used to homogenise the Uppsala temperatures are given in Figure 1. The corrections were applied with specific daily values, which were obtained through interpolation between the monthly values.

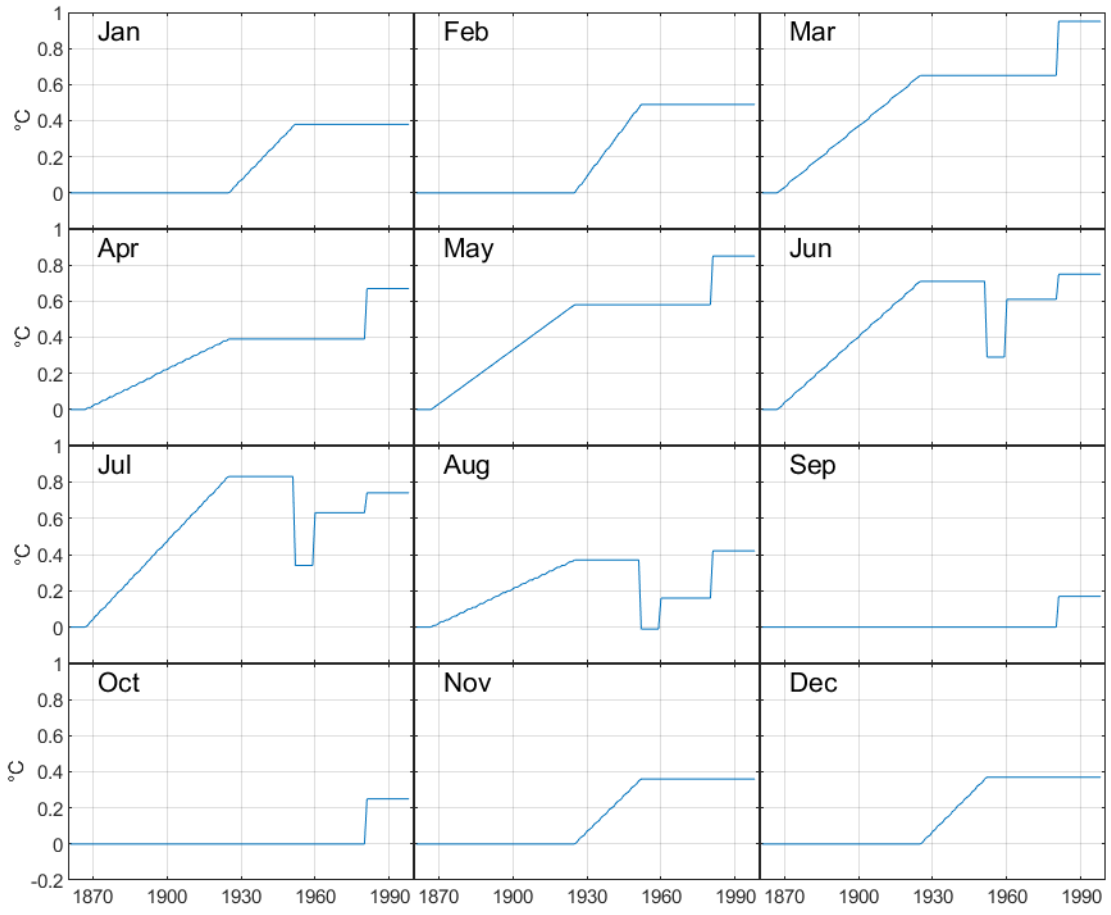

Figure 1: Monthly values of corrections for the urban heat island for Uppsala 1861–1997.

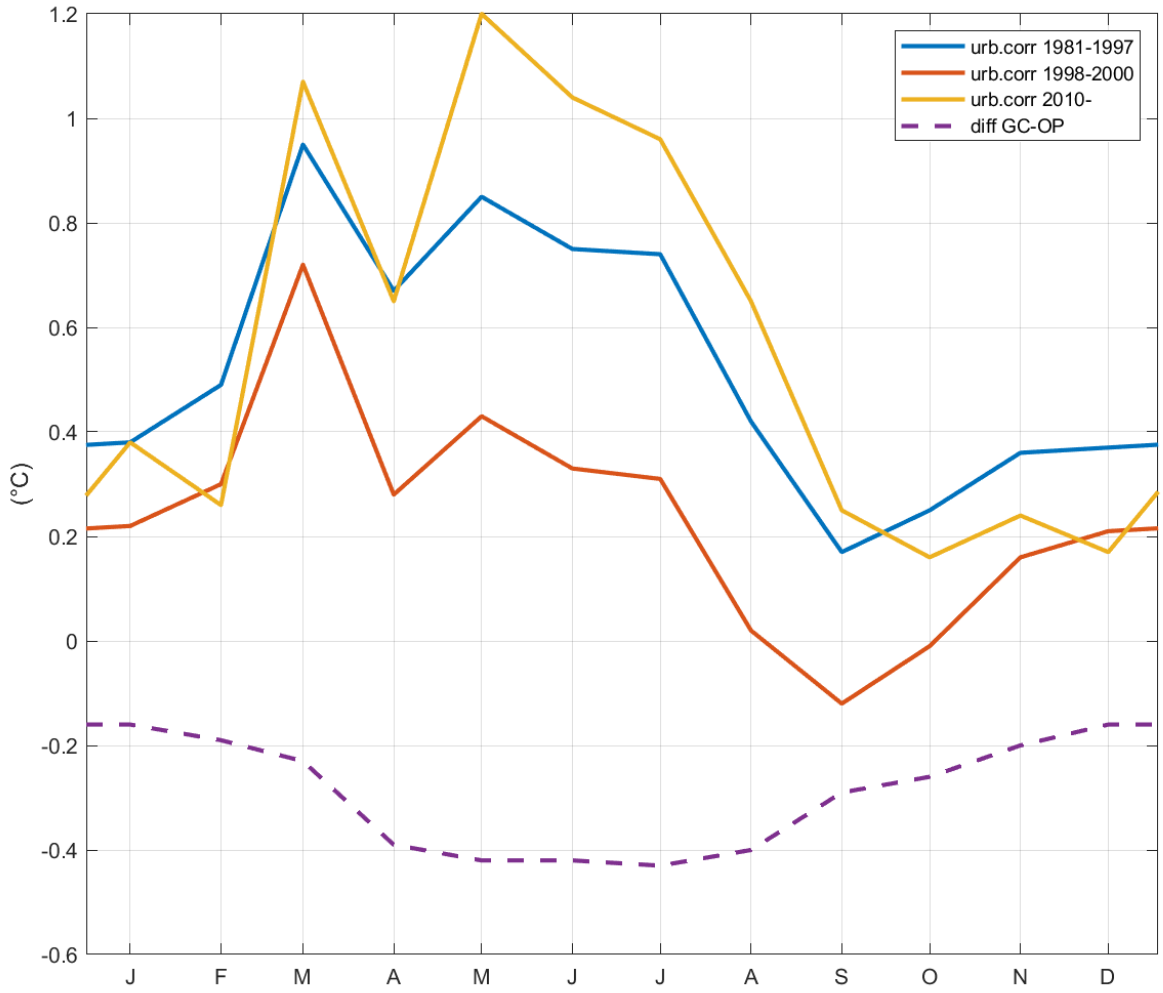

Figure 2: Annual variation of corrections for urban heat island according to different homogeneity tests. The results are based on monthly values.

In January 1998 the observational site was moved from the Observatory Park about 1.4 km southwards to a site close to the Geocentre, somewhat more distant from the city centre and thus likely less affected by the urban heat island.

To check this temperature was from January 1998 to September 2000 also measured at the Observatory Park. The results show that the annual average temperature was 0.3°C lower at the Geocentre than at the Observatory Park with an annual cycle showing larger differences during summer and smaller differences during winter (Figure 2, dashed line). Thus the urban heat island effect on the annual average temperature decreases from 0.53°C, earlier found for the Observatory Park, to 0.24°C at the Geocentre. The annual cycle, as given by monthly averages, of urban heat island corrections for these two periods are shown in Figure 2.

The urban heat island effects at the Geocentre was however soon after 1998 affected by changes in the urban area surrounding the site. New houses were built, both close to the site and more distant, especially south of the site. Also large areas close to the measurement site were converted from grass covered parks to car parking spaces, covered with asphalt or gravel, likely changing the local radiation climate.

To investigate the urban heat island changes, the observations taken at the Geocentre were compares with observations made at Marsta, 9 km north of Uppsala. Marsta is located in an agricultural area with mostly fields and only some smaller forested areas and a few houses and villages. The measurements are taken in an open field area with at least 500 m to the closest forests. Almost no changes have occurred during the measurement period which started about 1950.

As can be seen in Figure 1 all months had unchanged urban heat island corrections from 1981-1997 according to the earlier homogenization. For this reason the differences between temperatures in Uppsala, corrected for the urban heat island, and temperatures at Marsta are expected to be constant during this period. Manual observations were made at Marsta until May 1997.

From June 1994 observations were also available from a 30 m high meteorological tower at Marsta. There is however quite a lot of periods with data losses of the tower data, and also the aim was primarily to get high quality profile data and focus was not on high accuracy of the absolute temperature. This made it difficult to use the tower data for the purpose of investigating the Uppsala urban heat island. In May 2011 the tower system was updated, and from that date also the absolute temperature is of high enough accuracy to be used to estimate the urban heat island.

Thus data from 1981-1997 and from 2011-2020 have been used to investigate the changes of the urban heat island effects on the temperature observations taken at the Geocentre. Monthly average differences between the temperature measured at the Geocentre and at Marsta were calculated, and the results are shown by the markers in Figure 3. Of course there is quite a lot of scatter between the individual months, but no or just a very small trend may be observed. The observed average difference is 0.71°C for the period 1981-1997, and 0.76°C for the period 2011-2020. A difference which cannot be judged as significant.

Correcting measured temperature data from Uppsala for the urban heat island, we get the average difference 0.17°C for the period 1981-1997. This is a reasonable difference in general agreement with the expected decrease in temperature with growing distance northward from Lake Mälaren. Using the correction data for 1997 for the Observatory Park and also correct for the observed difference between the Observatory Park and the Geocentre, result in the average difference 0.53°C for the period 2011-2020. This much larger difference suggests that the urban heat island correction has increased with about 0.3-0.4°C during the period 2000-2010.

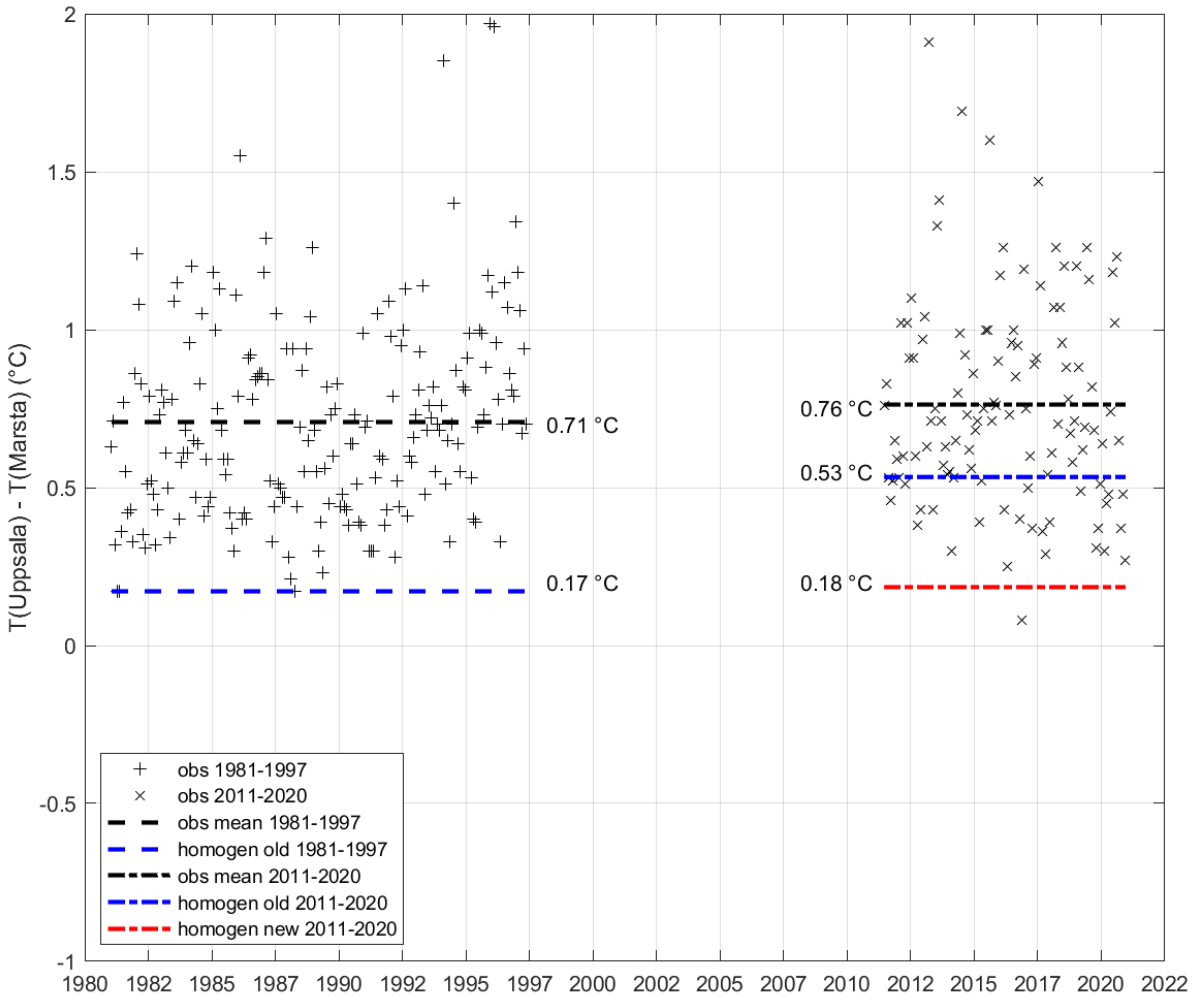

Figure 3: Difference between temperatures measured at the Geocentre in Uppsala and at Marsta.

We know from the homogenization made for the period 1861-1998 that there is a large annual variation, giving differences between corrections based on monthly averages. Thus to update the urban heat island corrections for the period after 2010 monthly average differences have been used. Results showing the observed monthly average temperature differences between Uppsala and Marsta are shown in Figure 4. Without any corrections the monthly average temperatures are typically between 0.5 and 1 °C higher in Uppsala with a maximum during summer and during winter, with a minimum during spring and autumn. After correcting for the urban heat island the differences for the period 1981-1997 decreases on the average 0.53 °C, and the summer maximum is more a late summer/early autumn maximum, while the autumn minimum becomes very small. Using the same correction for the period 2011-2020 the average difference remains high showing corrected temperatures in Uppsala to be 0.53 °C higher than at Marsta, indicating an increased urban heat island effect at the Geocentre. Based on the difference between the urban heat island corrected monthly temperatures 1981-1997, assumed to be correct according to the previous corrections, and the monthly average temperatures resulting from using the same correction for the period 2011-2020, a set of new corrections are estimated which should be valid for the period 2011-2020. Using these updated corrections gives a result for 2011-2020 very similar to the result for 1981-1997, see Figure 4.

It is assumed that the transition from the urban heat island corrections estimated to be valid at the Geocentre 1998 occurred from 2000 to 2010, after which the new correction estimated from the averages 2011-2020 are supposed to be valid. The resulting monthly corrections are plotted in Figure 5 for the period 1990-2020. The decreased correction following from moving the observational site from the Observatory Park to the Geocentre in January 1998 is clearly seen for all months. The growing urban heat island effects results in increased corrections for all months except February and December. Typically the increased monthly values are small during the whole winter, with maximum increased corrections during the summer months. This is not surprising in view of the changes in radiation climate due to the increased areas with artificial surfaces surrounding the Geocentre observation site. Both due to new buildings and, but maybe to a higher degree due to the very much increased areas with parking spaces.

The monthly averages of the corrections used to homogenise the temperature observations made in Uppsala are given in *Table 1*. The corrections, after having been interpolated to daily values, are subtracted from the daily mean temperatures to obtain the homogenised series.

The urban heat island effect on the annual average temperature is estimated by annually averaging the monthly corrections. The results are shown in Figure 6. As written above the homogenisation is made so that the resulting average temperatures should represent the conditions outside the urban area, taken to be represented by the conditions at the new astronomical observatory in the Observatory Park 1853-54. This was then outside the built up urban area to the west of central Uppsala.

The temperature observations were taken at the Observatory Park from September 1853. Before that the observations were taken at the Old Astronomical Observatory (the Celsius Observatory) located in the city centre. Although Uppsala was then a small city an urban heat island effect should anyhow have been existing. The corrections before 1853-54 was arrived at comparing with the observations taken at Stockholm Observatory.

From 1868 an urban heat island effecting the temperatures were found with a trend from 1868 to 1925 for the months March to August. When this trend ended a trend was instead detected for the winter months November to February 1925-1952. An annual trend thus occurred during the whole period 1925-1952. From 1952 the temperature observations were made at Rackarberget a few hundred metres from where the observations had been previously taken. This affected the urban effects during the summer months June-August, reducing the correction. In August 1959 the observational site was again moved, now back to the Observatory Park. This resulted in an increased correction for the summer months June-August. Next the corrections for the months March to October increased in 1981. This was likely due to that new urban housing areas were built around this time at Ekeby and Flogsta about a kilometre southwest of the observation site.

The next change of the urban heat island corrections occurred when the observation site was moved to the new Geocentre in 1998. But already a few years later building activity in this new area made the urban effect to increase to levels of the same magnitude or even slightly above those found at the Observatory Park. From 2011 to 2020 the urban effects seems to have been stable at the same level, the annual urban heat island effect then being 0.58 °C.

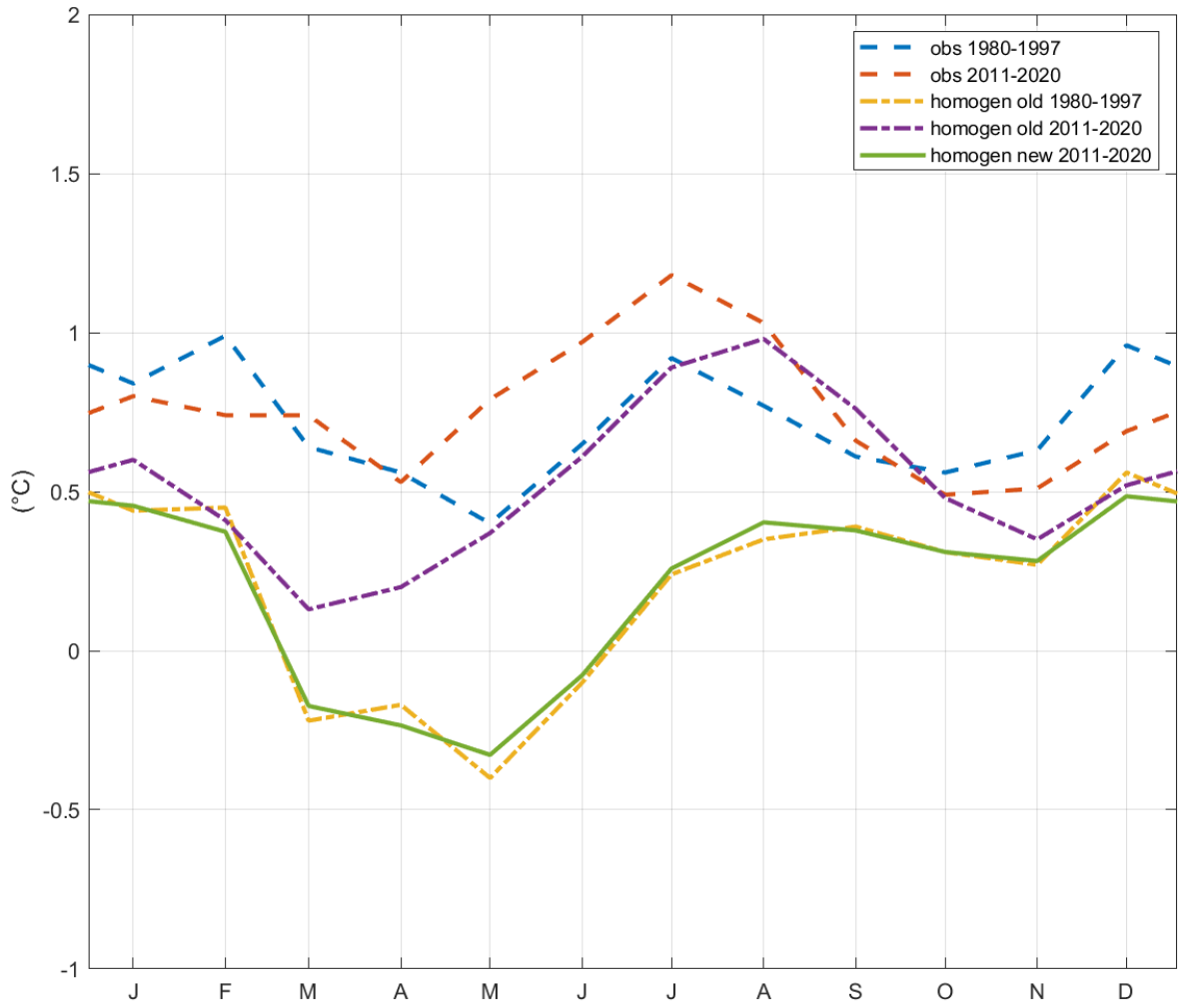

Figure 4: Temperature differences between Uppsala (Observatory Park 1981-1997, Geocentre 2011-2020) and Marsta.

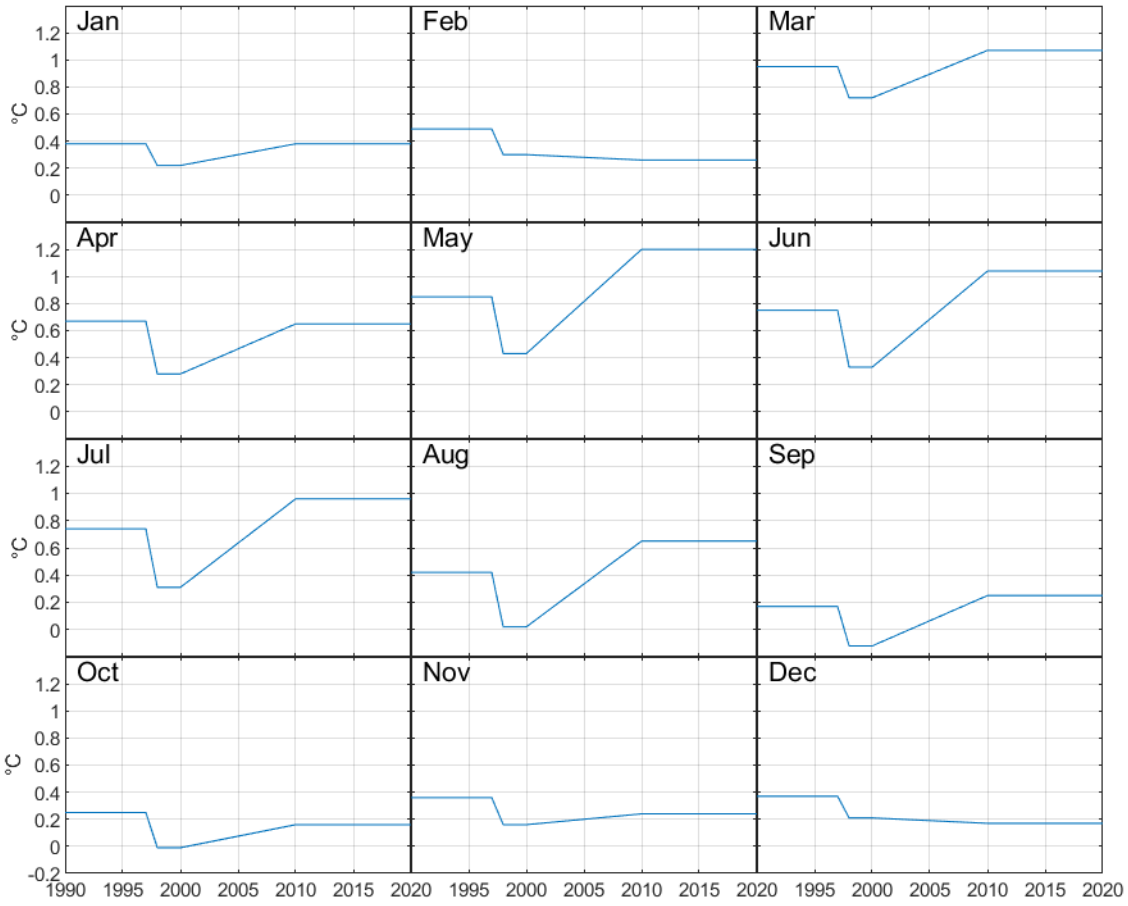

Figure 5: Monthly values of corrections for the urban heat island for Uppsala 1990-2020.

Table 1: Monthly values used to correct the Uppsala temperature series for inhomogeneities. For columns giving one year in the heading, the numbers given are the corrections used from that year onwards. For columns with trend sections, the first and last values of the linearly changing corrections are given. A dash (–) indicates the use of the same corrections as an earlier period. The corrections, after having been interpolated to daily values, are subtracted from the daily mean temperatures to obtain the homogenised series.

	1722	1853	1854	Trend section 1868-1925	Trend section 1926-1952	1952	1960	1981	1998	Trend section 2000-2010	2011
J	0.11	-	0.00	-	0.00-0.38	-	-	-	0.22	0.22-0.38	-
F	0.47	-	0.00	-	0.00-0.49	-	-	-	0.30	0.30-0.26	-
M	0.66	-	0.00	0.00-0.65	-	-	-	0.95	0.72	0.72-1.07	-
A	0.55	-	0.00	0.00-0.39	-	-	-	0.67	0.28	0.28-0.65	-
M	0.27	-	0.00	0.00-0.58	-	-	-	0.85	0.43	0.43-1.20	-
J	0.15	-	0.00	0.00-0.71	-	0.29	0.61	0.75	0.33	0.33-1.04	-
J	0.11	-	0.00	0.00-0.83	-	0.34	0.63	0.74	0.31	0.31-0.96	-
A	0.03	-	0.00	0.00-0.37	-	-0-01	0.16	0.42	0.02	0.02-0.65	-
S	0.08	0.00	-	-	-	-	-	0.17	-0.12	-0.12-0.25	-
O	0.19	0.00	-	-	-	-	-	0.25	-0.01	-0.01-0.16	-
N	0.24	0.00	-	-	0.00-0.36	-	-	-	0.16	0.16-0.24	-
D	0.22	0.00	-	-	0.00-0.37	-	-	-	0.21	0.21-0.17	-

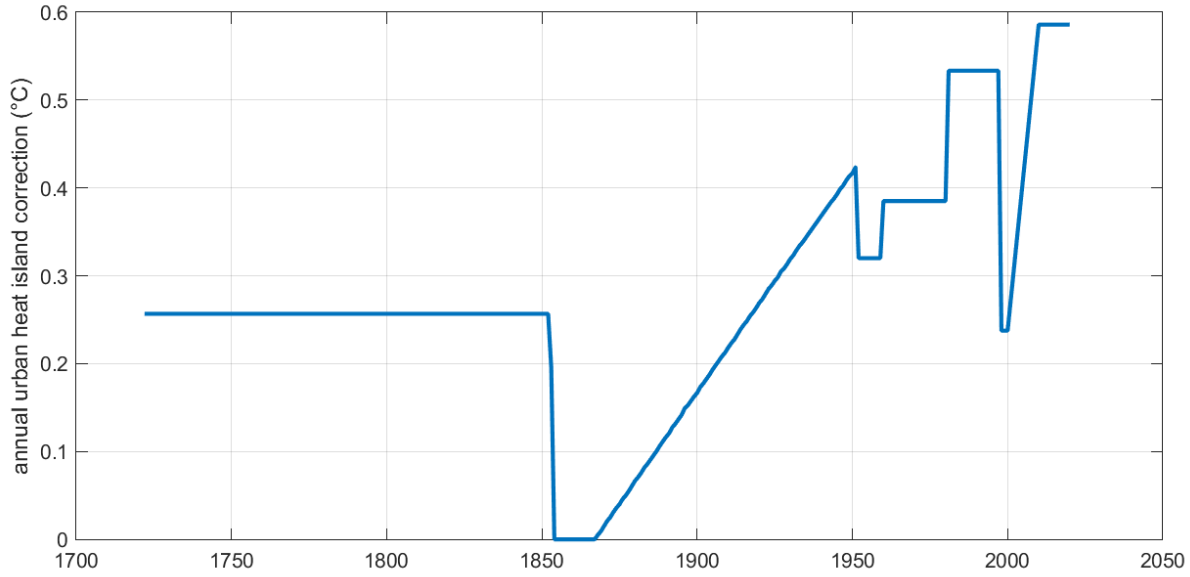

Figure 6: Annual values, estimated from the monthly values given in Table 1, used to correct the Uppsala temperature series for inhomogeneities during the period 1722-2020.

The magnitude of the increased urban heat island effects on the temperature data from Uppsala (Geocentre site) presented above were estimated comparing with data from Marsta, 9 km north of Uppsala. To support these results similar comparisons were made between Uppsala temperature data and temperature observations taken at four additional sites. These sites were Sala (54 km west of Uppsala), Risinge (50 km northeast of Uppsala, Bromma (58 km south of Uppsala), and Uppsala Airport (Ärna) (5 km north of Uppsala).

The comparisons are presented in Figure 7 where the monthly differences between the two periods 2011-2020 and 1981-1997 are shown. These differences were calculated by first correcting the Uppsala temperature data for the urban heat island using the results presented for the period 1981-1997 in Bergström and Moberg (2002). Using the same correction also for the period 2011-2020 will make it possible to estimate the increased urban heat island effect for this latter period. For both periods the temperature difference between Uppsala and the other sites were estimated. Then the differences between the two periods of these differences between sites were calculated for each month.

The results using data from Marsta are shown by the thicker line in Figure 7. Results using data from Sala, Risinge and Bromma for the comparison show the same general behaviour as regards the annual variation. With a maximum during summer and a minimum during winter. While the results from Uppsala airport deviates from all the other. With only a few kilometres between Marsta and Uppsala airport this is not expected, and as three other more distant sites in the region show similar results as Marsta, it is likely that there is something suspicious with the temperature data from Uppsala airport. Unknown what, but maybe connected to that this site being located close to or even within a grove with some buildings, and that it is also about 1 km from built up Uppsala urban areas.

The general agreement comparing temperature differences between Uppsala and Marsta, and three other sites in the region, supports the use of Marsta data to adjust the urban heat island correction of the temperature observations taken at the Geocentre in Uppsala. The small differences regarding the exact numbers are not surprising in regard of the distances being of the order 50 km between Uppsala and the three more distant sites. As Marsta is only 9 km from the Geocentre it may be argued that these results should be more representative for the adjustment of the urban heat island effect.

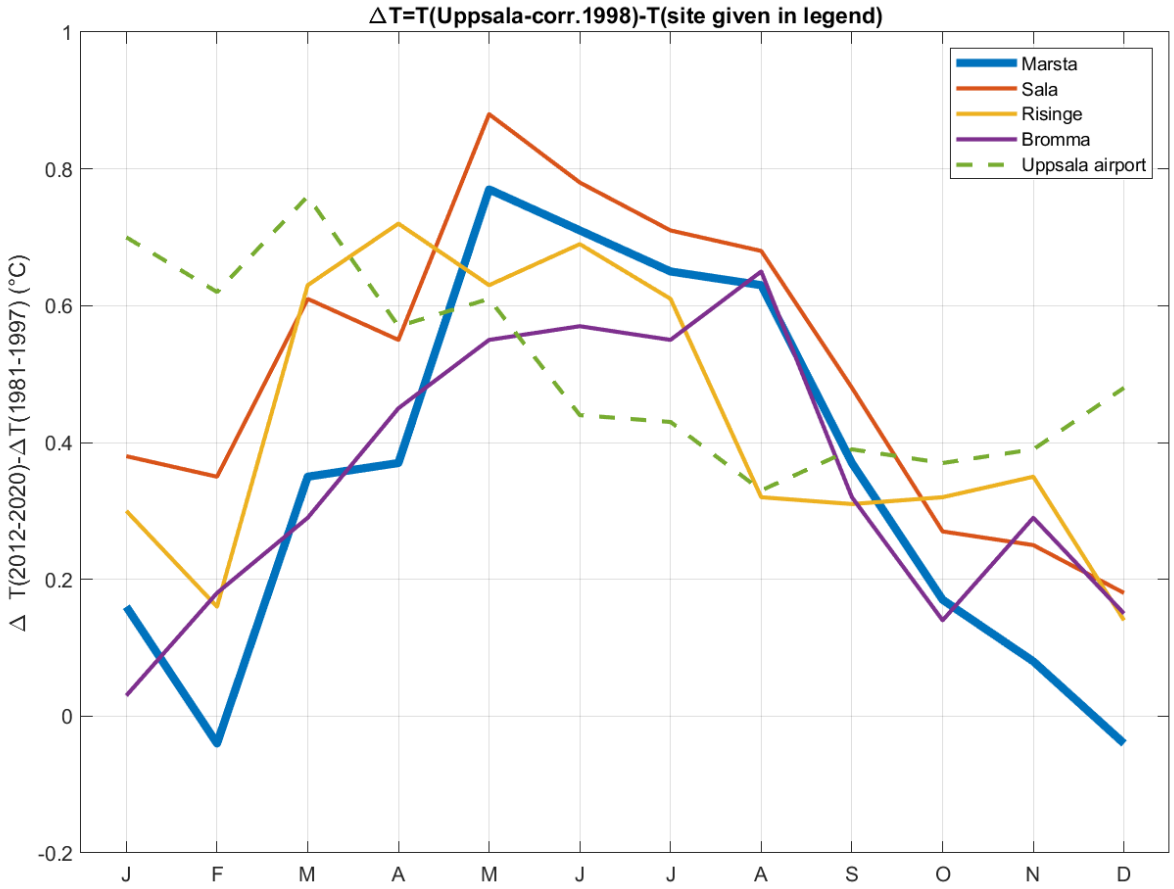

Figure 7: Change between period 2012-2020 and period 1981-1997 of monthly average temperature differences between Uppsala and five other sites in the region.

References

Alexandersson, H.: 1986, 'A Homogeneity Test Applied to Precipitation Data', *Int. J. Clim.* **6**, 661–675.

Alexandersson, H. and Moberg, A.: 1997, 'Homogenization of Swedish Temperature Data. Part I: Homogeneity Test for Linear Trends', *Int. J. Clim.* **17**, 25–34.

Bergström, H. and Moberg, A.: 2002, 'Daily Air Temperature and Pressure Series for Uppsala (1722-1998)', Climatic Change, **53**, 213-252.

Moberg, A. and Bergström, H.: 1997, 'Homogenization of Swedish Temperature Data. Part III: The Long Temperature Records from Stockholm and Uppsala', *Int. J. Clim.* **17**, 667–699.

Moberg, A., Bergström, H., Ruiz Krigsman, J., and Svanered, O.: 2002, 'Daily Air Temperature and Pressure Series for Stockholm (1756–1998)', *Clim. Change*, this volume.