Royal Netherlands
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Homogenization of daily temperature data of the five principal stations in the Netherlands (version 1.0)

Theo Brandsma

De Bilt, 2016 | Technical report; TR-356

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Table of contents

Foreword

Homogeneous time series of daily Tn, Tx and Tmean are indispensable for climate change and variability studies. The present study describes the homogenization of the 20th century daily mean, minimum and maximum temperatures (Tmean, Tn, Tx) of the five principal stations in the Netherlands. For the investigated stations, it is known that there have been major relocations that caused inhomogeneities. In addition, for station De Bilt the relocation was accompanied by a major change in thermometer screen. The existence of parallel data makes it possible to correct for the inhomogeneities.

The study is a logical follow-up of the recent standardization of data and methods for calculating daily Tn, Tx and Tmean for the five principal stations (Brandsma et al., 2013). The standardized series are measured series and serve as the source for calculating the homogenized series. The homogenized series presented here are not only the source for climate change and variability studies but also for calculating extremes like cold- and heat waves and their communication.

The new series are a step forward because they allow a realistic comparison of mean and extreme temperatures from the beginning of the 20th century up till now. For the stations considered, they give a consistent picture of climate change both in space and time.

1 Introduction

1.1 Problem description

Meteorological time series may become inhomogeneous for reasons such as relocations of stations and/or instruments, slow or abrupt changes in the environment and changes in instruments and measurement practices. For climate change and variability studies, it is important to deal with these potential sources of inhomogeneities and obtain homogenized datasets.

The daily temperature series of the five principal station in the Netherlands have known inhomogeneities due to relocations. De Bilt, also experienced a change from a large pagoda screen, open at the bottom, to a Stevenson screen. In most cases parallel observations have been made that facilitate correction of the series for the inhomogeneities.

Nowadays, many studies are being undertaken that homogenize time series before calculating trends and variability (Venema et al., 2012). Homogenization is then mostly done in a statistical way by calculating corrections from mutual comparisons of stations. This report deals with the homogenization of the daily minimum, maximum and mean temperatures (Tn, Tx, Tmean) in the Netherlands using parallel measurements. An existing technique called percentile matching will be used to obtain a baseline version 1.0 of the homogenized daily temperatures for The Netherlands.

For the Netherlands two time series of homogenized monthly Tmean have already been constructed. The first series is the monthly Tmean series of De Bilt. In that series corrections have been made for changes in instruments, relocations and urban heat island (Brandsma et al., 2003, Brandsma and Van der Meulen, 2007). The second series is the so-called Central Netherlands Temperature (CNT, Schrier et al., 2011). This series is a composition of 5-8 stations located in the central part of the Netherlands. Each of the stations is homogenized using statistical comparison with neighboring stations.

The homogenized monthly series are useful for studying the long-term trends in Tmean in the Netherlands. However, in practice we are not only interested in changes in Tmean but also in Tn and Tx and for smaller time scales as well. The construction of such series is the topic of the present study.

1.2 Scope and objectives

The objective of this study is to obtain homogenized daily temperature time series of Tn, Tx and Tmean of the five principal stations in the Netherlands. The homogenization improves the suitability of the series for climate change and variability studies, not only for average but also for daily extreme values.

We restrict ourselves to the five principal stations: 1. Den Helder/De Kooy, 2. De Bilt, 3. Groningen/Eelde, 4. Vlissingen, and 5. Maastricht/Beek. These five stations have long time series with hourly temperatures and have been used in several KNMI publications. For the Bilt the 1901-2015 period will be considered, for the other stations the 1906-2015 period. The study focuses on the known large inhomogeneities due to relocations and, in case of De Bilt, also on to the change of pagoda screen to Stevenson screen.

The homogenized series presented here will be the source for climate change and variability studies and for calculating extremes like cold- and heat waves and their communication. For Tmean, the existing homogenized monthly series (De Bilt and CNT) remain available for climate research. The latter series have been corrected for more inhomogeneities than the series presented here.

1.3 Structure of the report

Chapter 2 describes the data sources and the homogenization technique and how it is applied to each of the five series. Chapter 3 presents results of the homogenization. The corrections will be presented and the homogenized series will be compared with the original series and with each other. For Tmean the series will be compared with the existing homogenized monthly series. Also some relevant statistics will be presented for each station separately and for the Netherlands as a whole. Chapters 4 and 5 present a discussion and a summary and conclusions.

2 Data and methods

In this chapter we first describe the data and parallel data used for calculating the homogenized time series of Tn, Tx and Tmean. Thereafter, the homogenization technique is explained in detail.

2.1 Data

The data to be homogenized consists of the daily operational Tmean, Tn and Tx data of the five principal stations of KNMI (see Figure 1): De Kooy (235), De Bilt (260), Eelde (280), Vlissingen (310) and Maastricht (380). The operational data of De Bilt starts in 1901 and for the other series in 1906. Brandsma et al. (2013) standardized the data and methods for calculating Tn, Tx and Tmean for those stations. Tn and Tx always apply to the 0-0 UTC interval. Tmean is always the mean of the hourly temperatures T1, T2,…,T24, where the index refers to hours UTC.

The following major relocations took place:

1. De Kooy started on 1 August 1972 and is a continuation of Den Helder. Den Helder wat located along the North-Sea dike on the Western edge of the city of Den Helder whereas De Kooy is located in an exposed location on the airport on the SE edge of Den Helder about 1 km from the Wadden Sea.
2. De Bilt experienced a change from a large pagoda screen to a Stevenson screen on 16 September 1950 (Figure 2) and a relocation on 27 August 1951 of about 300 m Southward from a sheltered location to an exposed location.
3. Eelde started in 1951 and is a continuation of Groningen. Groningen was a city location whereas Eelde is located in an exposed location on the airport 10 km South of Groningen.
4. Vlissingen was temporally located in Souburg from 1947-1958. Vlissingen is an exposed location in the harbor along the water of the Westerschelde and Souburg was an exposed airport location located land-inward at 1.8 km NNW of Vlissingen.
5. Maastricht was first situated in the city of Maastricht until 1950 an then relocated to an exposed location on Beek airport in 1951 about 9 km NE of Maastricht. Ground level of Beek airport is about 65 m higher than that of Maastricht. In addition, temperature measurements in Maastricht were taken at 20 m above ground level. This strongly deviates from the standard measurement height of 2.2 m of that time.

Figure 1 shows the locations of the above stations. The details of the stations are presented in Table 1.

For De Kooy, Eelde, Vlissingen and Maastricht parallel observations were made at the time of the relocation enabling the homogenization of the series (in Table 1). These observation were also part of the standardization in Brandsma et al. (2013). For the relocation in De Bilt in 1951 no parallel observations have been made because the relocation was unforeseen and after the relocation the old location was disturbed due to building activities in the neighborhood of the former screen. Therefore, data of Eelde (before the relocation and screen change and thereafter) has been used for the homogenization of the series (see Section 2.2).

Table 1: Details of the stations shown in Figure 1.

Station	LAT (N)	LON (E)	ALT (m)	Operational Period	Overlap	Current name (WMO nr.)
Den Helder / De Kooy	52.967 52.924	4.750 4.785	4.4 0.5	1906/07-1972/07* 1972/08-present	1961-1970 (10 yr)	De Kooy (235)
De Bilt	52.101	5.177	2.0	1901-present	1946-1949 and 1952-1955**	De Bilt(260)
Groningen / Eelde	53.217 53.125	6.550 6.586	2.1 3.5	1906-1950 1951-present	1946-1951 (6 yr)	Eelde (280)
Vlissingen / Souburg	51.442 51.467	3.596 3.583	8.0 -0.5	1906-present*** 1947-1958	1958/05–1962 (~5 yr)	Vlissingen (310)
Maastricht / Beek	50.850 50.910	5.693 5.768	49.4 114.0	1906-1950 1951-present	1946-1952 (7 yr)	Maastricht (380)

* Gap from September 1944 – May 1945: not filled in.
** Station Eelde used as alternative for missing overlap.
*** Gap from October 1944 – July 1945: not filled in. Gap from 1947-1958: filled in with Souburg.

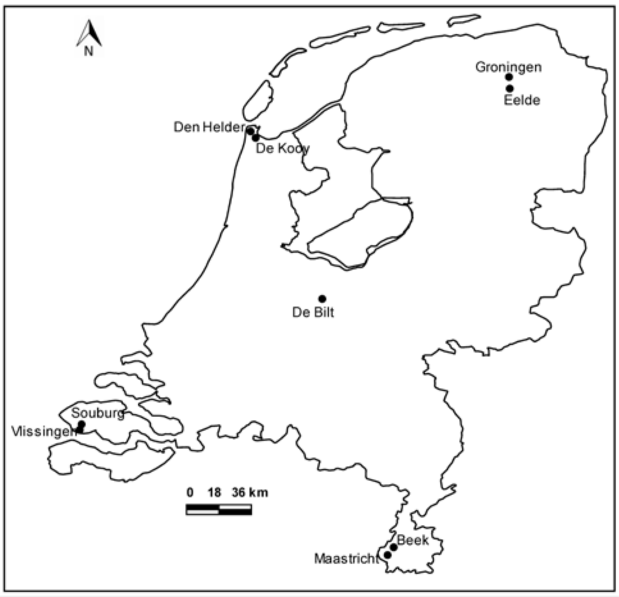

Figure 1: Situation of the five principal stations, Den Helder/De Kooy, Groningen/Eelde, De Bilt, Vlissingen and Maastricht/Beek.

Figure 2: Screen change in De Bilt on 16 September 1950. On the left the old pagode screen and on the right the new Stevenson screen.

2.2 Methodology

2.2.1 Parallel data

The parallel data enable the homogenization of temperature series. Figs. 3-7 present the time series of the monthly mean temperature differences ΔT (old-new). For De Bilt, Eelde is used as a reference. This means that ΔT is calculated as $\Delta T_1 - \Delta T_2$, where ΔT_1 equals the temperature differences De Bilt – Eelde before the relocation and the screen change (1946-1949), and ΔT_2 the temperature difference thereafter (1952-1955).

The figures have in common that Tn is generally most affected by the relocation/ screen change with the largest ΔTn in summer. ΔTx of stations Den Helder/De Kooy, Vlissingen and De Bilt shows a clear seasonal cycle whereas for the Groningen/Eelde and Maastricht/Beek the seasonal cycle is almost absent. The coastal stations are affected by the seasonal cycle of the temperature of the sea which lags behind the land temperature. Note that the relocation from the city of Groningen to the airport Eelde hardly affects Tx while the relocation of the city of Maastricht to the airport Beek affects both Tn and Tx. The reason for this discrepancy is that, firstly, the deviating measurements height of Maastricht (20 m above ground level). Secondly, the Beek location is about 60 m higher than the Maastricht location and much more exposed, causing a temperature bias of about 0.4°C.

For De Bilt note the sometimes large differences between adjacent months. This results from the lack of real parallel measurements for this station and stresses the importance of smoothing the individual monthly values.

Schrier et al. (2011) show monthly Tmean temperature differences for Den Helder/De Kooy, Groningen/Eelde and Maastricht/Beek similar to the ones presented here.

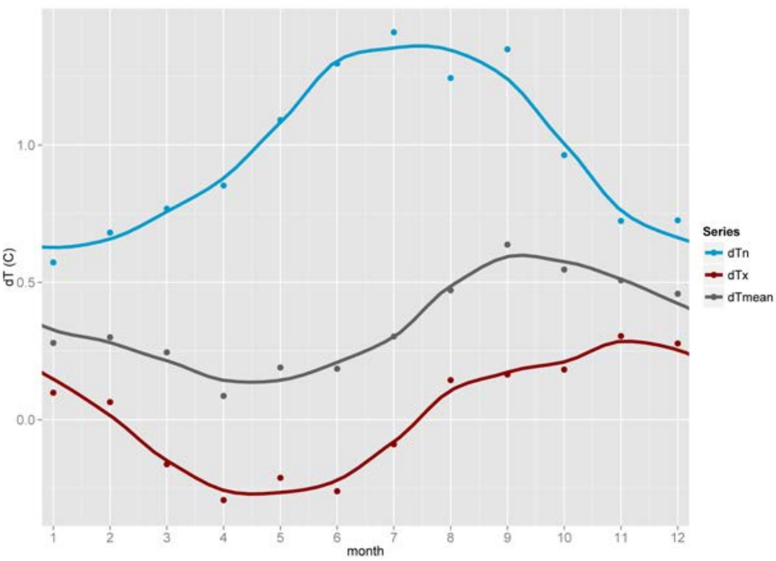

Figure 3: Mean monthly temperature differences (Den Helder – De Kooy) in the overlapping period 1961-1970. The smooth curves are the result of a loess fit (Cleveland, 1979) and use the SOND values before and the JFMA values after JF...D.

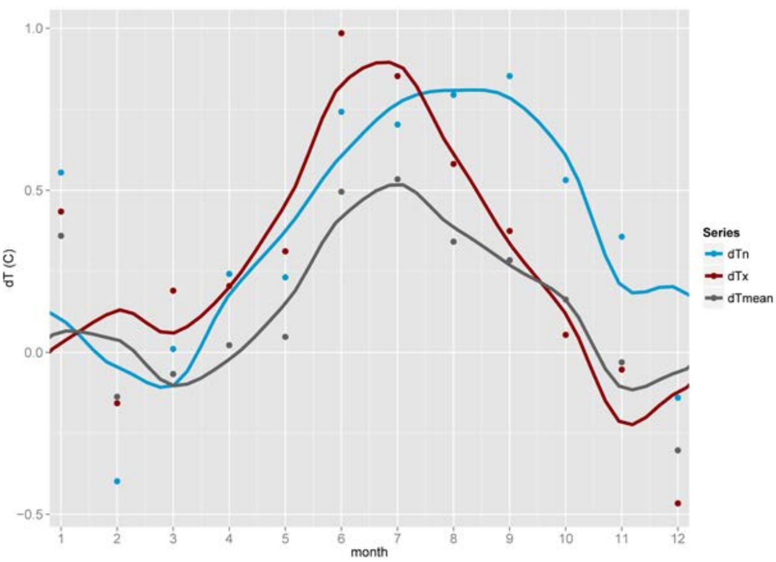

Figure 4: Mean monthly temperature differences (De Bilt_old – De Bilt_new), see text for details. The smooth curves are the result of a loess fit (Cleveland, 1979) and use the SOND values before and the JFMA values after JF...D.

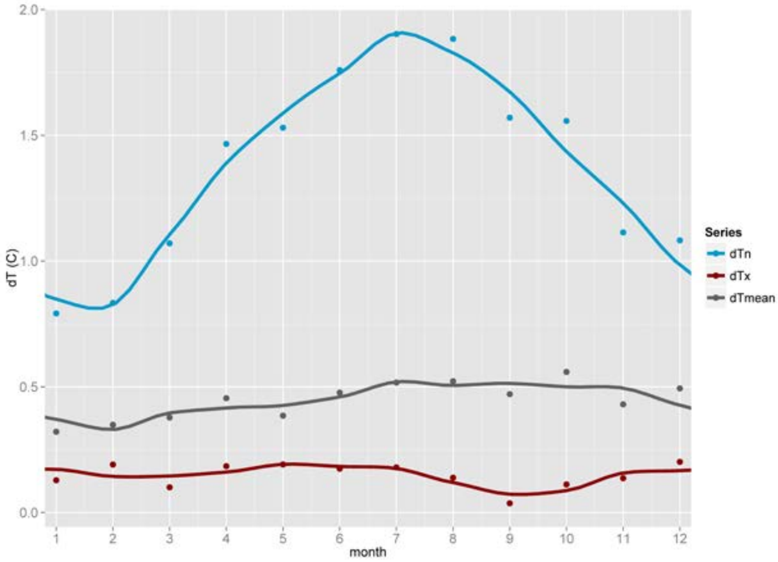

Figure 5: Mean monthly temperature differences (Groningen – Eelde) in the overlapping period 1946-1951. The smooth curves are the result of a loess fit (Cleveland, 1979) and use the SOND values before and the JFMA values after JF...D.

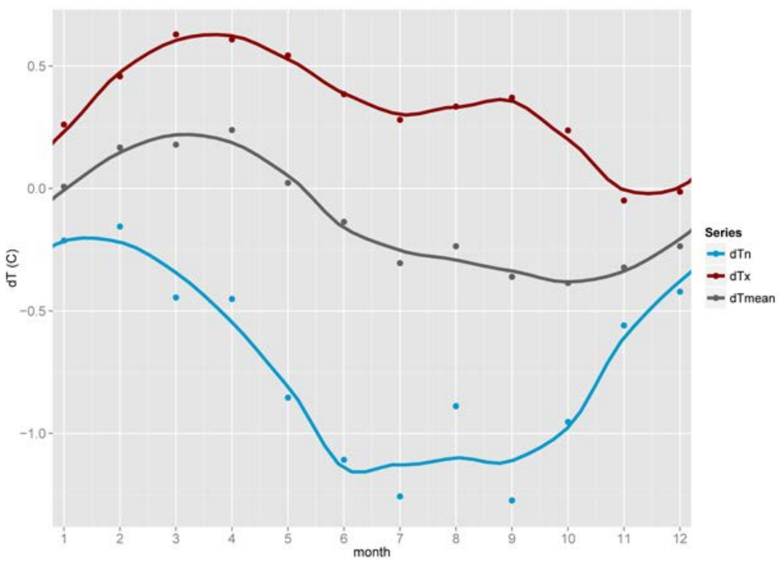

Figure 6: Mean monthly temperature differences (Souburg – Vlissingen) in the overlapping period May 1958- December 1962. The smooth curves are the result of a loess fit (Cleveland, 1979) and use the SOND values before and the JFMA values after JF...D.

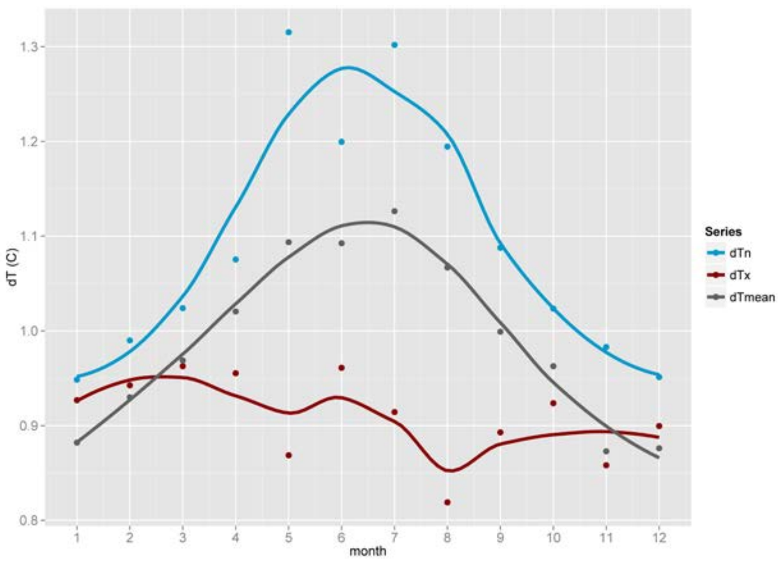

Figure 7: Mean monthly temperature differences (Maastricht – Beek) in the overlapping period 1946-1952. The smooth curves are the result of a loess fit (Cleveland, 1979) and use the SOND values before and the JFMA values after JF…D.

2.2.2 *Method*

As a rough homogenization of the temperature series, it would be possible to use the smoothed monthly mean ΔTn, ΔTx and ΔTmean from Figs. 3-7 and use these to correct the series before the relocation. However, this may result in large errors for individual months as ΔT may vary strongly from year to year, dependent on the weather conditions. An important improvement considered here, is to compare the temperature distributions of the daily Tn, Tx and Tmean for both locations and derive corrections from the differences of the distributions. This accounts not only for changes in the mean but also for changes in the shape of the distribution.

The method is known as percentile matching (also known as quantile matching) and has been used in other countries as well (Kuglitsch et al., 2009; Trewin, 2013). As an example, Figure 8 shows the distributions of Tn for both Groningen and Eelde in the month of July. The figure shows a clear difference between the city station Groningen and the rural airport station Eelde. It is also obvious that the low temperatures differ more from each other than the high temperatures. Figure 9 shows the percentiles [5,10,…,95] of Tn distributions in Figure 8. The difference between these percentiles in Figure 10 can then be used to correct the Groningen temperatures (percentile matching).

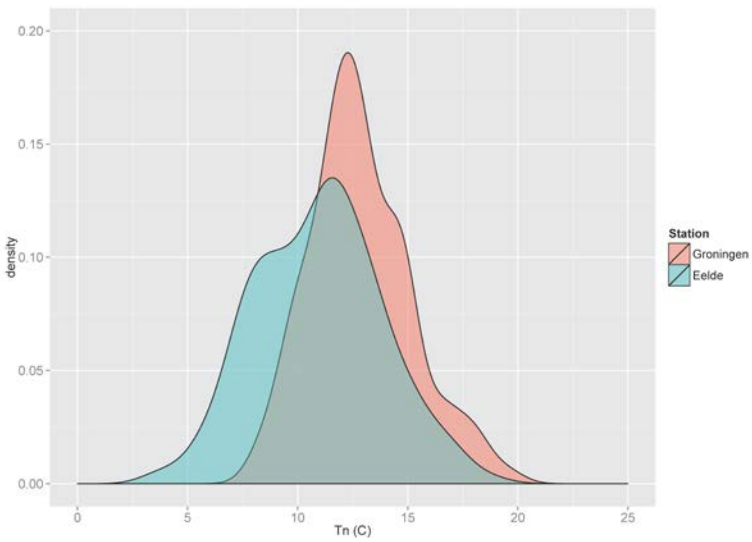

Figure 8: Densities of the July daily minimum temperatures of Groningen and Eelde in the overlapping period 1946-1951.

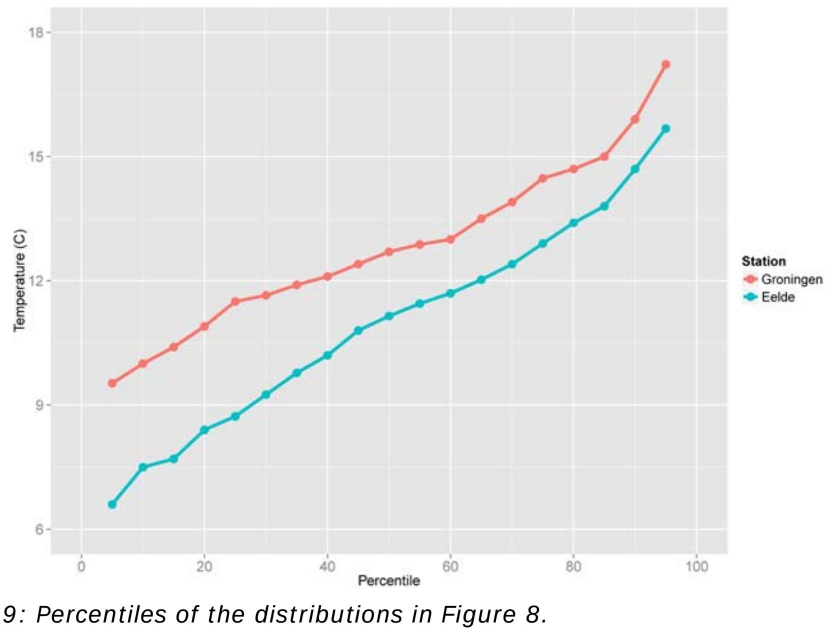

Figure 9: Percentiles of the distributions in Figure 8.

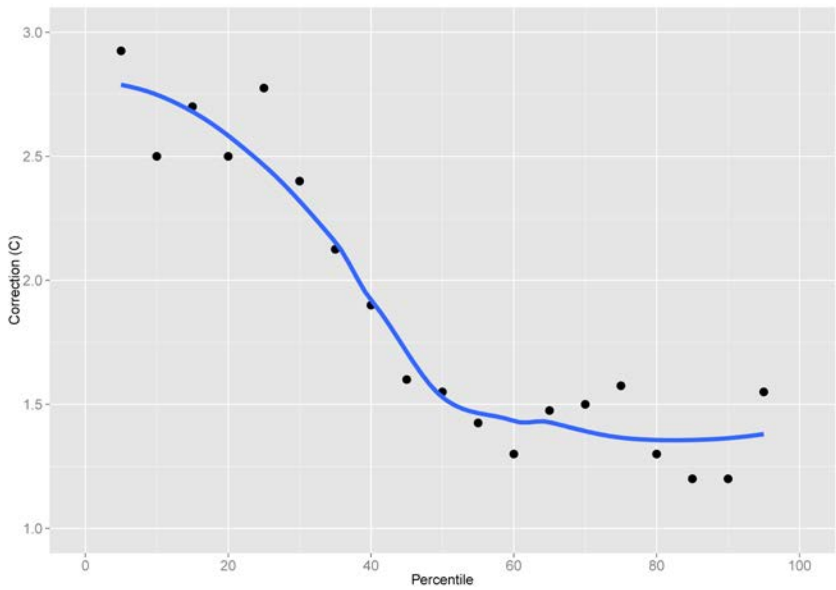

Figure 10: Tn correction derived from the percentile difference in Figure 9. The smooth curve is the result of a loess fit (Cleveland, 1979).

Figure 10 shows that the lowest Tn (smallest percentiles) needs a much larger correction than the highest Tn (largest percentiles). The reason is that Tn differences between a city (Groningen) and a rural (Eelde) station depend on the weather. For clear and calm days the differences are large whereas for cloudy and windy days the differences are small. In July low Tn corresponds, on average, to clear and calm weather whereas high Tn corresponds to cloudy and windy weather.

The correction procedure is applied for Tn, Tx and Tmean separately and can be summarized as follows:

1. Calculate for each month the sample percentiles [5,10,...,95] (Hyndman and Fan, 1996) of the daily temperatures for the old and new situation in the overlapping period
2. Calculate for each month the difference between the percentiles (old – new) calculated in step (1)
3. Smooth the differences calculated in step (2)
4. Smooth for each percentile the values calculated in step (3) between the months (adding ND before and JF behind JF...D)
5. Correct the old series by subtracting for each month the correction found in step (4) as a function of percentile.

The 5 and 95 percentiles are taken as the upper and lower limit, respectively. It was found that for the given number of days these are reasonable limits. For the final correction, temperature values more extreme than the limits are corrected using corrections of the nearest limit, so beyond the limits the correction remains constant. The smoothing is done using a so-called loess smoother (Cleveland, 1979). Using a mixture of cross-validation and expert opinion we determined a span of 0.6 (family = Gaussian and degree=2).

3 Results

In this chapter we first present the corrections for the individual stations together with a comparison of the measured and homogenized series. Thereafter, we compare the annual Tn, Tx and Tmean averaged over the five series (H5) with the individual station series. Finally, we show the effect of the homogenization on the number of cold- and heat waves in the Netherlands and the ten highest and lowest daily values per station. The figures and tables are grouped together at the end of the report in the appendix.

3.1 Individual stations

3.1.1 *Den Helder/De Kooy*

Figs. 11-13 show the corrections for Den Helder/De Kooy, for Tn, Tx and Tmean, respectively. All figures show corrections clearly varying with percentile and time of the year. For Tn the corrections are always positive with the largest values (up to 2.6°C) for the smallest percentile in summer. In winter Tn corrections are generally small and decrease with increasing percentile. For Tx the corrections are much smaller than for Tn and are mostly positive for small percentiles and mostly negative for large percentiles. Tmean is a mixture of Tn and Tx. In general the corrections reflect the more maritime character of the Den Helder location compared to the De Kooy location.

As an example, Figure 14 compares the homogenized series with the measured series for the annual mean values of Tn, Tx and Tmean (first column) and the annual minimum (n added) and maximum (x added) of the daily Tn, Tx and Tmean (second and third column). The effect of the homogenization is clearly visible, but most pronounced for Tn. Apparently Tn is most sensitive to the relocation away from the seas.

3.1.2 *De Bilt*

Figs. 15-17 show the corrections for De Bilt (compared with Eelde) for Tn, Tx and Tmean, respectively. Again all figures show corrections varying with percentile and time of the year. For Tn the largest corrections (up to 1.0°C) are in summer mostly for the lower percentiles, caused by the relocation to the more exposed location (see Brandsma, 2011). The corrections are generally small in winter. For Tx large positive corrections (up to 1.9°C) are found in summer for the largest percentiles. This is mainly a result a combination of the pagoda which was open at the bottom and affected by reflected sunlight and the enclosed location till 1951. Corrections for Tmean vary between -0.3 and 1.1°C.

Figure 18 compares the homogenized series with the measured series. Txx is strongest affected by the homogenization. Note that for most variables the homogenization results in increased temperature trends in the 1901-2015 period.

3.1.3 *Groningen/Eelde*

Figs. 19-21 show the corrections for Groningen/Eelde, for Tn, Tx and Tmean, respectively. The variation with percentile and time of the year is again evident. The corrections of Tn are always positive with the largest values (up to 2.8°C) in summer for the smallest percentiles due to the relocation of the sheltered city location to the exposed airfield location. For Tx the corrections are nearly zero for a large part of the temperature distribution. Only for the smallest and largest percentiles, the correction become larger than zero. For Tmean the corrections are always positive and vary between 0.1 and 0.7°C. The corrections reflect the difference between a city station and a rural station (see e.g. Brandsma and Wolters, 2012).

Figure 22 compares the homogenized series with the measured series. The effect of the homogenization is an increase in trends for all variables.

3.1.4 Vlissingen

Figs. 23-25 show the corrections for Souburg/Vlissingen, for Tn, Tx and Tmean, respectively. The figures are similar to the figures for Den Helder/De Kooy comparison but the corrections have an opposite sign. The reason is that here we compare the more inland station Souburg with the coastal station Vlissingen, while earlier we compared the coastal station Den Helder with the more inland station De Kooy. The corrections for Tn are largest in summer for the smallest percentiles (up to -2.5°C. For Tx the corrections are largest around March and around August for the largest percentiles (up to 1.6°C). For Tmean the corrections vary between -0.8 and 0.9°C.

Figure 26 compares the homogenized series with the measured series. The trends are hardly affected by the homogenization, which results directly from Souburg being operational only in the 1947-1958 period.

3.1.5 Maastricht/Beek

Figs. 27-29 show the corrections for Maastricht/Beek, for Tn, Tx and Tmean, respectively. The corrections for all variables are positive (between 0.5 and 1.5°C) and vary relatively little within the year. Only for the largest percentiles there is a clear seasonal pattern with the largest values in summer. Most of the time the corrections are close to 1.0°C. As for Groningen/Eelde, the corrections reflect the difference between a city stations and a rural stations. The difference with Groningen/Eelde is the relatively high situation of the thermometer screen in Maastricht (decreasing the diurnal temperature range) and the height difference between Maastricht and Beek (see Table 1).

Figure 30 compares the homogenized series with the measured series. The effect of the homogenization is a clear increase of the temperature trends for all variables.

3.2 Mean daily H5 temperatures

The homogenized daily temperatures of the five principal stations (H5) are used to calculate a mean daily Tn, Tx and Tmean for the Netherlands. This is of interest for climate change and variability studies. Figs. 31-33 compare the homogenized smoothed annual means of Tn, Tx and Tmean of H5 with the individual stations[1].

It is of interest to note the similarity between the trend lines of H5 for Tn, Tx and Tmean. Their shape is similar and the difference between the begin and end values of the trend lines is close to 1.8°C for all three variables. Note that the homogenized series give a consistent picture of the trends both in space and time.

Figure 34 compares the homogenized Tmean of H5 and De Bilt with the existing homogenized monthly Tmean series: De Bilt_m and CNT. The differences in trends between the 4 series are negligible. This strengthens the confidence in the known temperature trends in the Netherlands.

3.3 Cold- and heat waves

Cold- and heat waves are traditionally calculated with the daily temperature data of De Bilt[2]. They are mainly used by KNMI in communication to arouse the awareness

[1] Before the calculation, missing values in the homogenized daily series have been infilled using the corresponding daily values of the nearest reference station corrected with the climatological difference (on a monthly level) between the station of interest and the reference station.

[2] A cold wave is defined as a period with at least 5 consecutive days with Tx < 0°C of which at least 3 days with Tn < -10°C. A heat wave is defined as a period with at least 5 consecutive days with Tx ≥ 25°C of which at least 3 days with Tx ≥ 30°C.

of the public of the severity of an extreme cold or warm period. Outside KNMI, long-term changes in the occurrence of cold- and heat waves have also been used to make statements about climate change. However, inhomogeneities in the measured series make them unsuitable for such purposes.

We recalculated the number of cold- and heat waves for the 1901-2015 period using the homogenized daily temperature data of De Bilt. Figure 35 shows the number of cold waves per year for the measured and homogenized series. The total number of cold waves equals 33 both for the measured and homogenized series. Incidentally the length of a cold wave may change by a day but that did not result in more or less waves.

Figure 36 shows the number of heat waves per year for the measured and homogenized series. Due to the effect of the homogenization on summer Tx, there is a strong decrease in the number of heat waves before 1950. The total number of heat waves decreases from 40 for the measured series to 24 for the homogenized series.

3.4 Daily extreme values

Tables 2-6 compare the highest and lowest daily Tn, Tx and Tmean values before and after the homogenization. It is obvious that in many cases the homogenization results in a reshuffling of the extreme values. The magnitude of the changes in extremes are a reflection of the corrections (see corresponding figures) for the highest and lowest percentiles in summer and winter.

4 Discussion

In this report we used the percentile-matching method for homogenizing the daily temperatures of the five principal stations in the Netherlands. This statistical homogenization method preserves the statistical distribution of the temperatures. This implies that on average the correction of extreme values is taken care of. On individual days however, the real correction may differ from the one applied. Nonetheless, there is ample reason to use the homogenized series instead of the measured series. The latter are mostly not suitable for climate trend and variability studies, where the precise correction for individual days is mostly of minor importance.

Methods for homogenizing daily temperature data are only starting to be developed and are strongly dependent on the available data. The corrections presented here are statistical but flexible in the sense that they may vary with temperature and season. The current initial homogenized version is denoted version 1.0 and serves as a baseline version.

Future improvements to the current version 1.0 are possible by taking into account weather variables other than temperature. Although temperature indirectly accounts for other weather variables, it is far from perfect. For instance, the same low nighttime temperatures in winter may be caused by (a) strong advection of cold air or by (b) clear-sky and windless nights. It is known that corrections in case of (a) are mostly close to zero whereas corrections in case of (b) may become quite large. The same holds for high daytime temperatures in summer, which may be caused by advection of warm air of by clear-sky and windless days.

Temperature trends in the comparison period may affect the corrections resulting from the percentile method. This may need some attention in future studies. In the present study, however, temperature trends in the comparison periods may be considered negligible.

The study here was restricted to the most important known inhomogeneities, major relocations and a major screen change in De Bilt. There are however other known inhomogeneities that may need correction. For instance, the lowering of the thermometer screen from 2.2 m to 1.5 m around 1960, other known minor relocations and urban effects. For Tmean, the monthly CNT series and the homogenized monthly De Bilt series show that these corrections are much smaller than the corrections applied here.

5 Summary and conclusions

In this report we homogenized the daily Tn, Tx and Tmean temperatures of the five principal stations in the Netherlands. The percentile-matching method was used to correct the stations for major relocations in the past and, for De Bilt, also for a major screen change.

The homogenized series show clear changes in long-term trends with respect to the measured series. In most cases there is an increase in the trends. A well-known inhomogeneity around 1951 in the Tx series of De Bilt is removed as a result of the homogenization. The highest Tx values before 1951 were at maximum about 1.9°C too high. This resulted in a strong increase in the positive trend of annual maximum Tx values after homogenization.

A comparison of the annual mean temperatures of the five individual stations with their mean (H5) demonstrated that the homogenization yielded a consistent picture of climate change both in space and time. The series are also consistent with the existing monthly homogenized Tmean series (De Bilt_m and CNT).

Cold- and heat waves in the Netherlands have so far been calculated using the measured data of De Bilt. By using the homogenized daily temperatures of De Bilt, the number of heat waves in the 1901-2015 period decreases from 40 to 24 while the number of cold waves remains the same at 33.

KNMI will use this version 1.0 of the homogenized daily Tn, Tx and Tn for public communication and for all their products: calculating climate trends and variability, cold- and heat waves and other extremes. De Bilt_m and CNT will remain available for climate research and for comparison. Several improvements to the current version may be possible and may result in slight adaptions of version 1.0. In conclusion, the new series are a step forward because they allow a realistic comparison of mean and extreme temperatures from the beginning of the 20th century up till now.

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A. Appendix

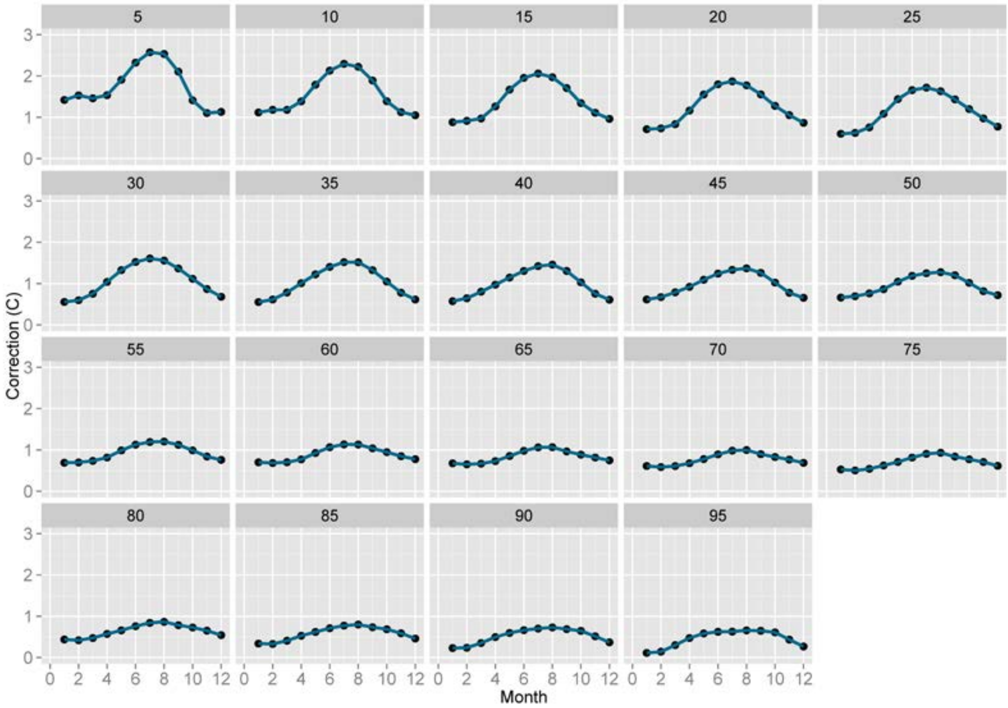

Figure 11: Tn correction Den Helder - De Kooy for each month and percentile.

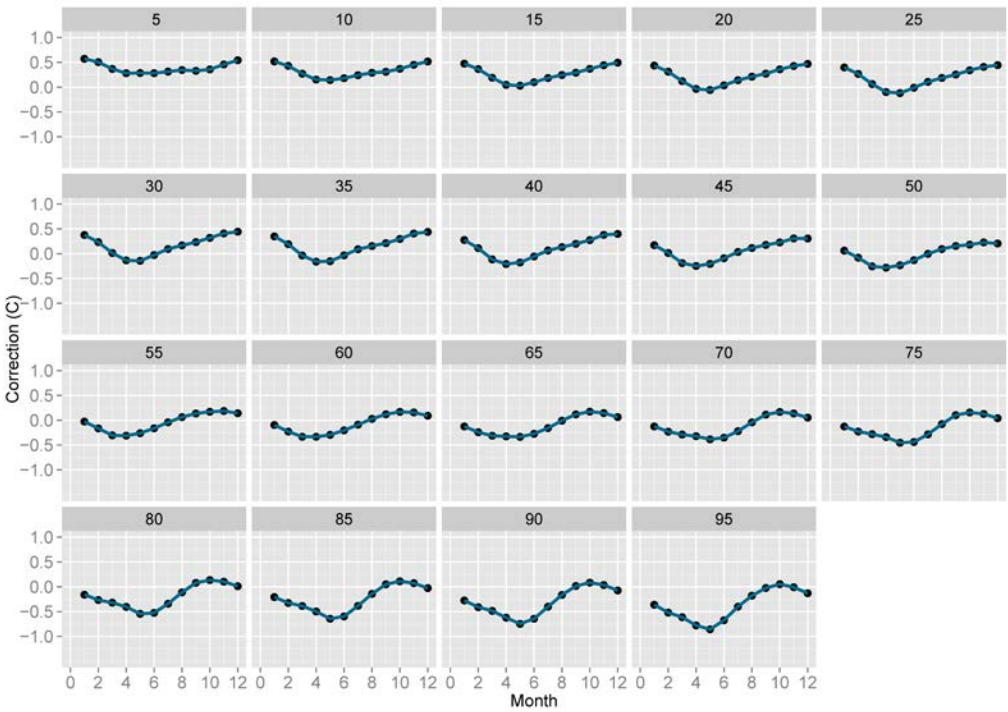

Figure 12: Tx correction Den Helder - De Kooy for each month and percentile.

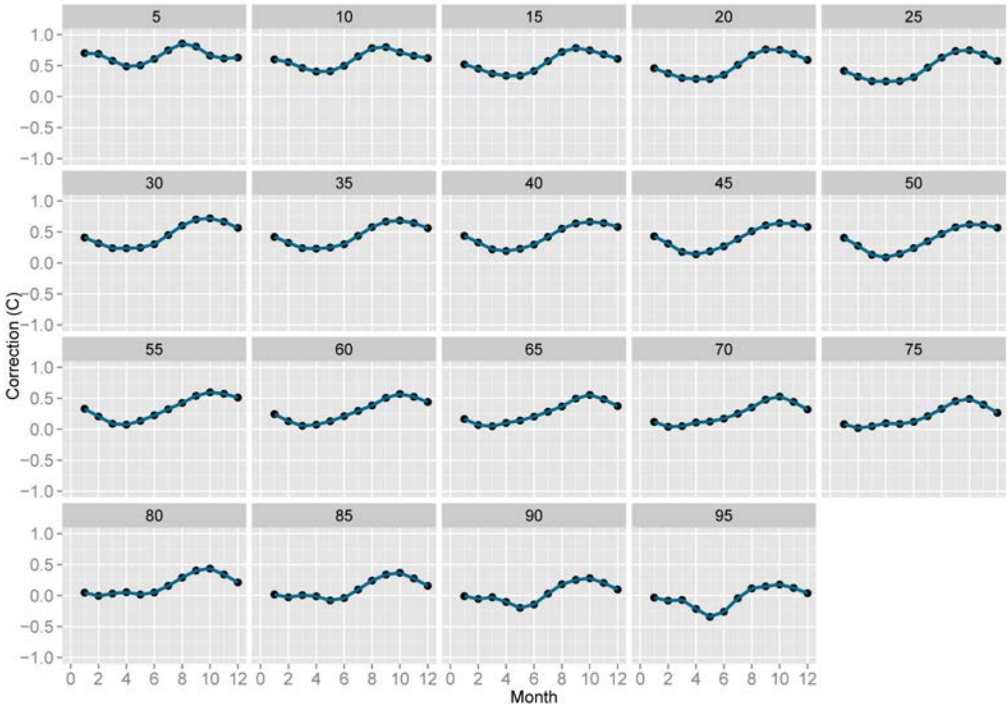

Figure 13: Tmean correction Den Helder - De Kooy for each month and percentile.

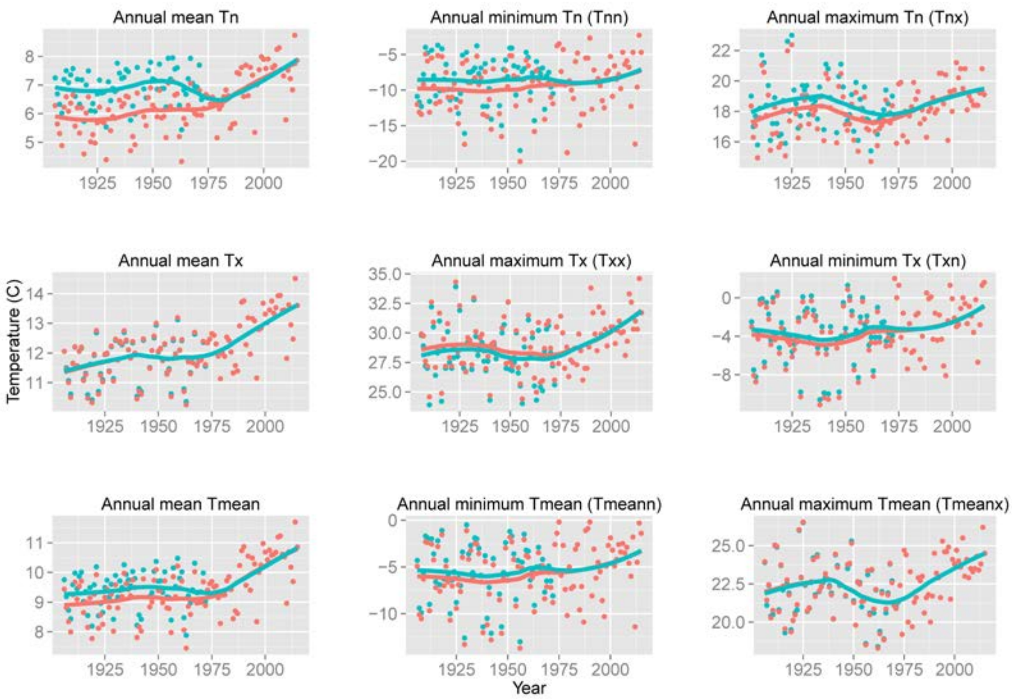

Figure 14: Comparsion of Tn, Tx and Tmean before (bluegreen) and after (redorange) homogenization for Den Helder/De Kooy 1906-2015.

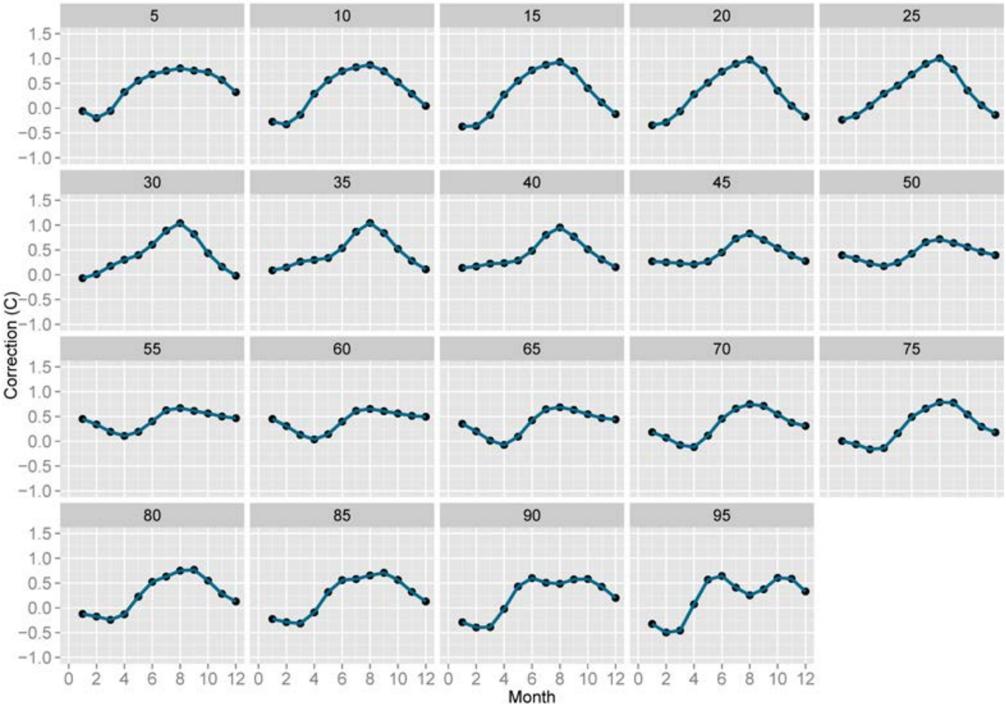

Figure 15: Tn correction De Bilt (old – new) each month and percentile.

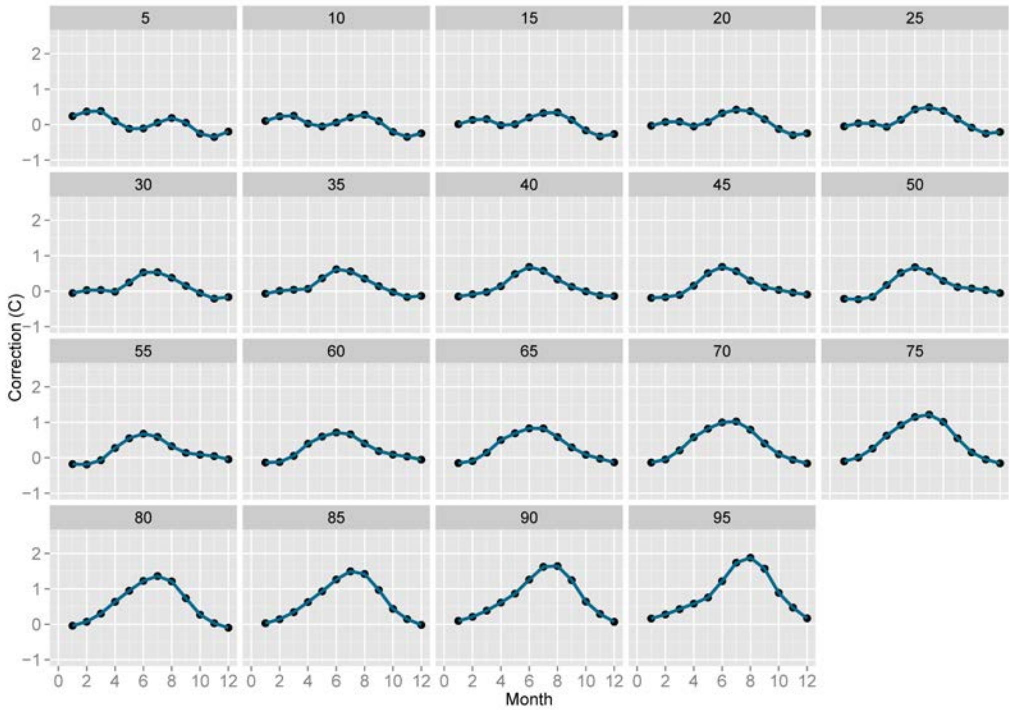

Figure 16: Tx correction De Bilt (old – new) each month and percentile.

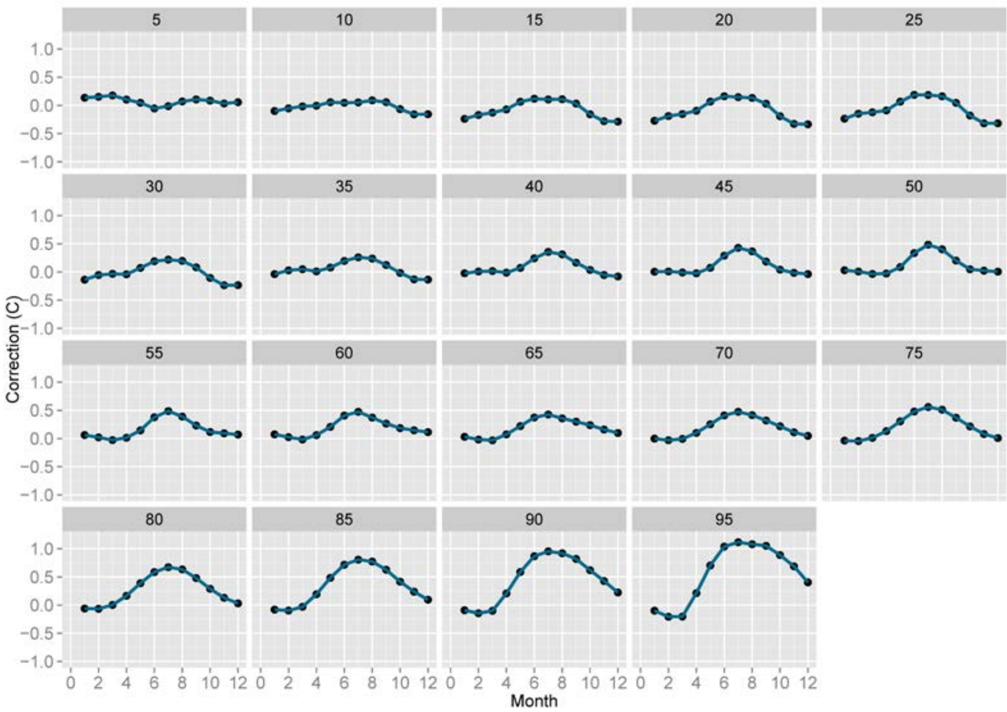

Figure 17: Tmean correction De Bilt (old – new) each month and percentile.

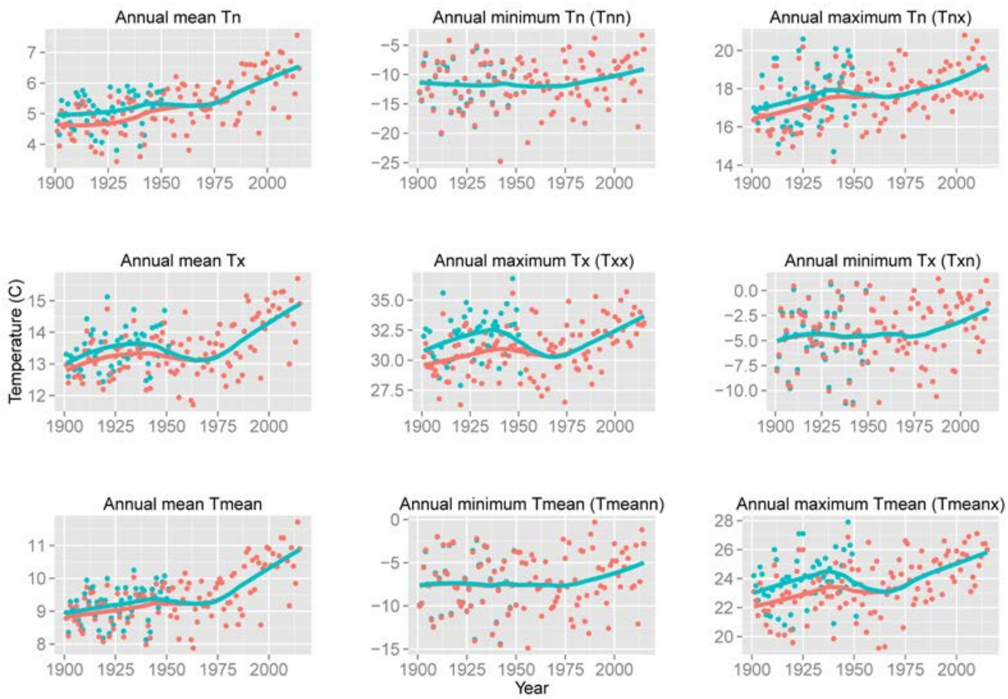

Figure 18: Comparsion of Tn, Tx and Tmean before (bluegreen) and after (redorange) homogenization for De Bilt 1901-2015.

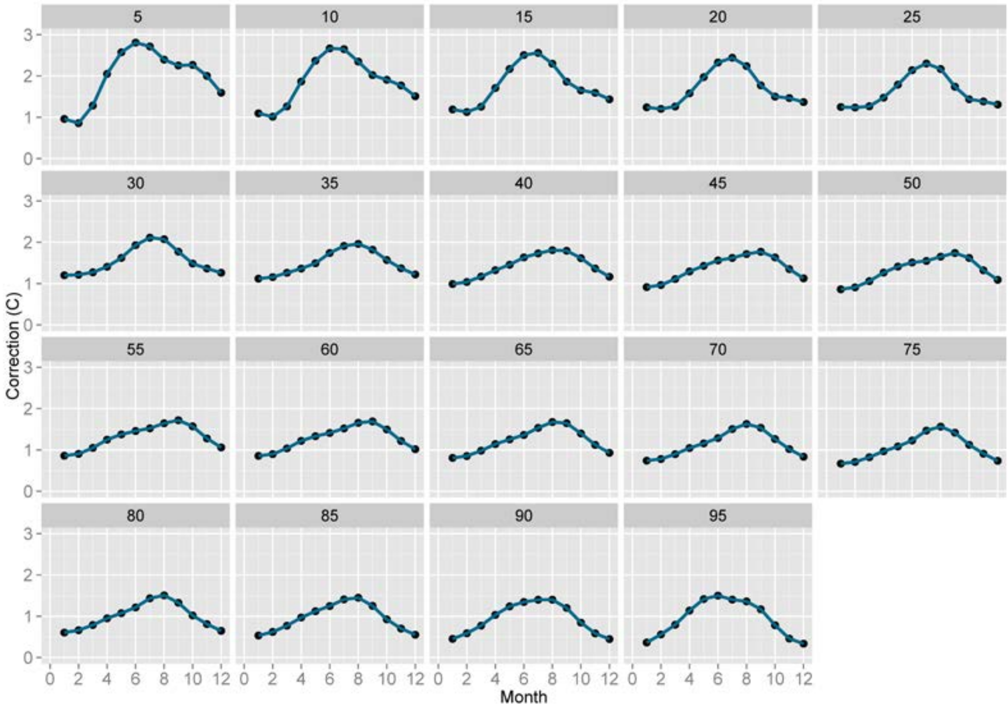

Figure 19: Tn correction Groningen - Eelde for each month and percentile.

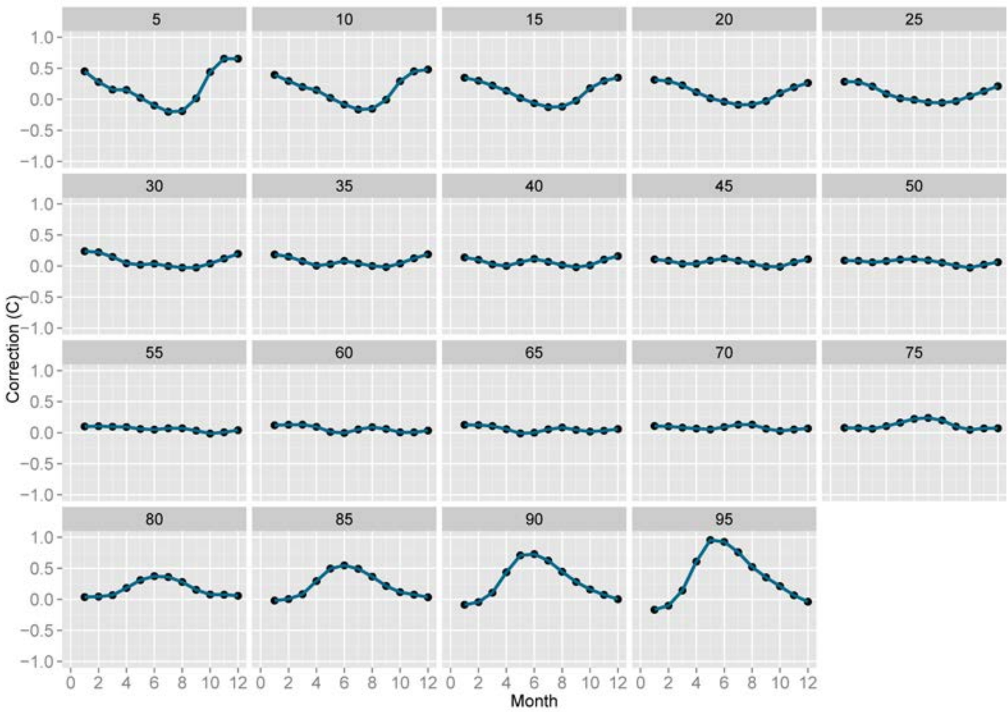

Figure 20: Tx correction Groningen - Eelde for each month and percentile.

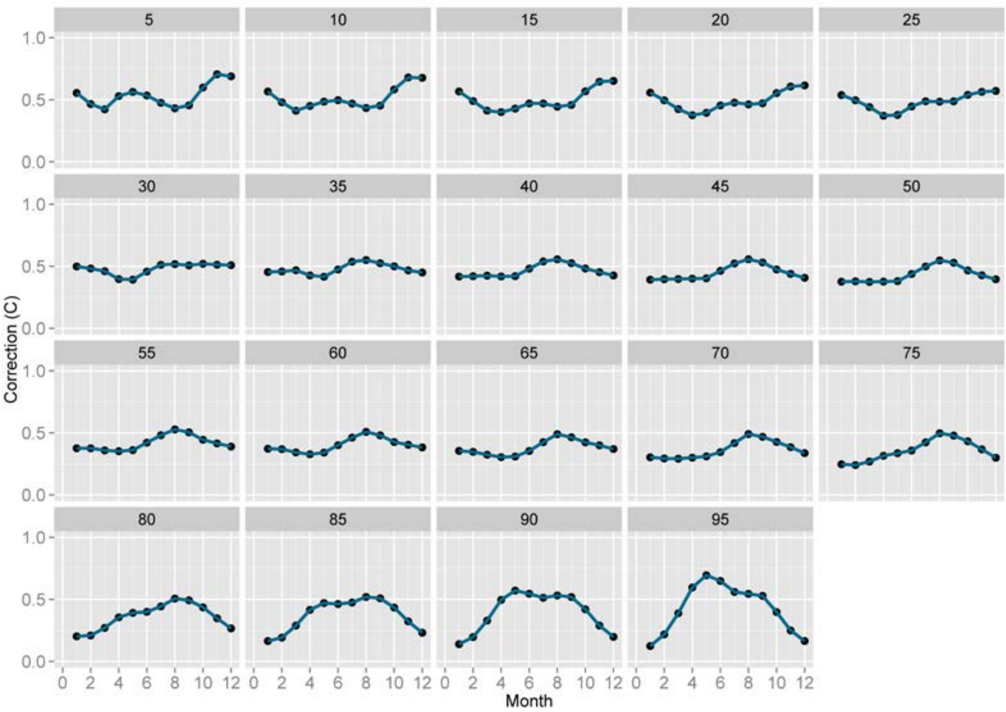

Figure 21: Tmean correction Groningen - Eelde for each month and percentile.

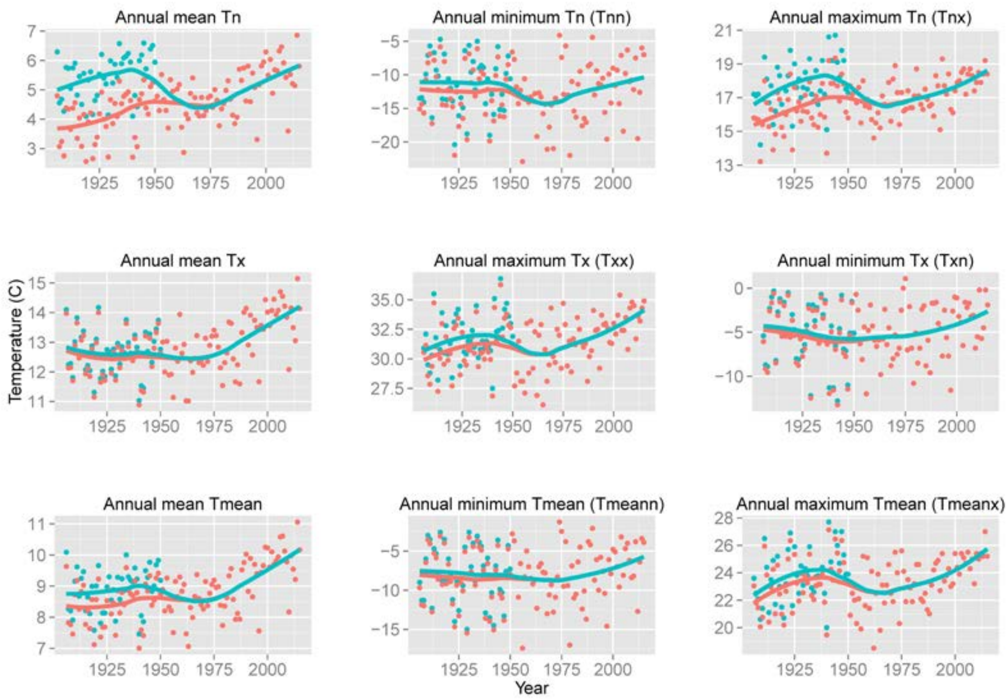

Figure 22: Comparsion of Tn, Tx and Tmean before (bluegreen) and after (redorange) homogenization for Groningen/Eelde 1906-2015.

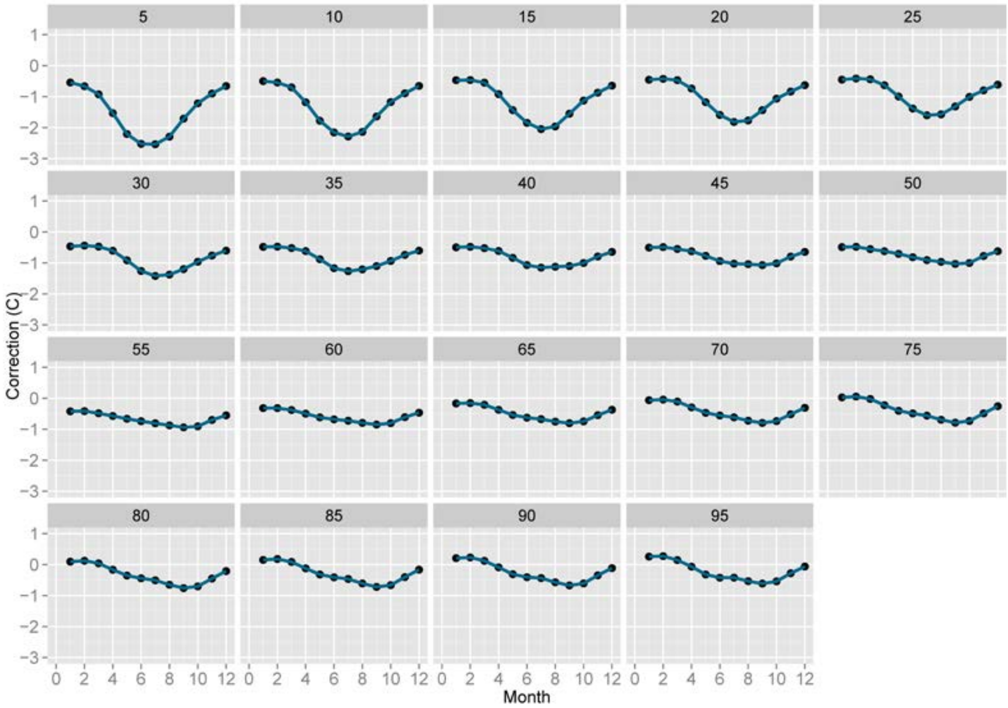

Figure 23: Tn correction Souburg - Vlissingen for each month and percentile.

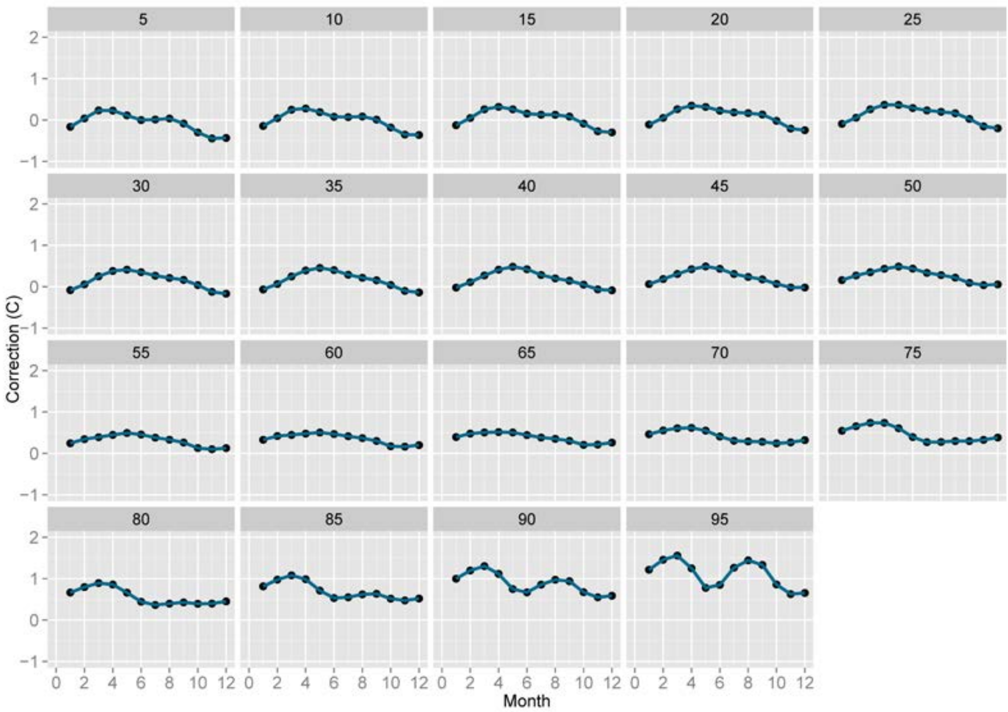

Figure 24: Tx correction Souburg - Vlissingen for each month and percentile.

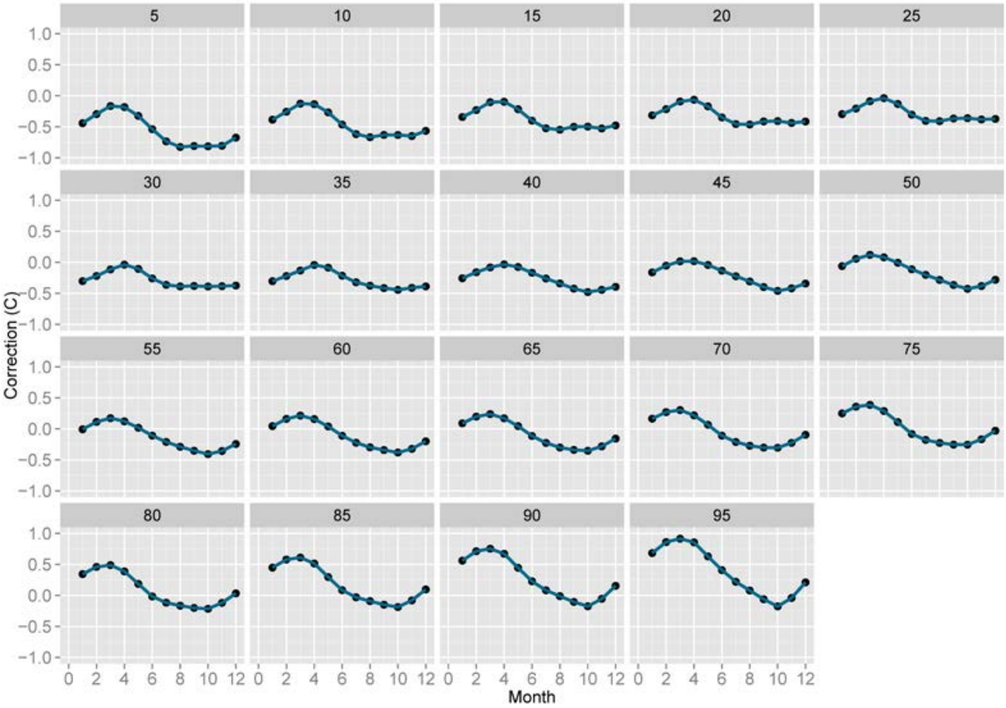

Figure 25: Tmean correction Souburg - Vlissingen for each month and percentile.

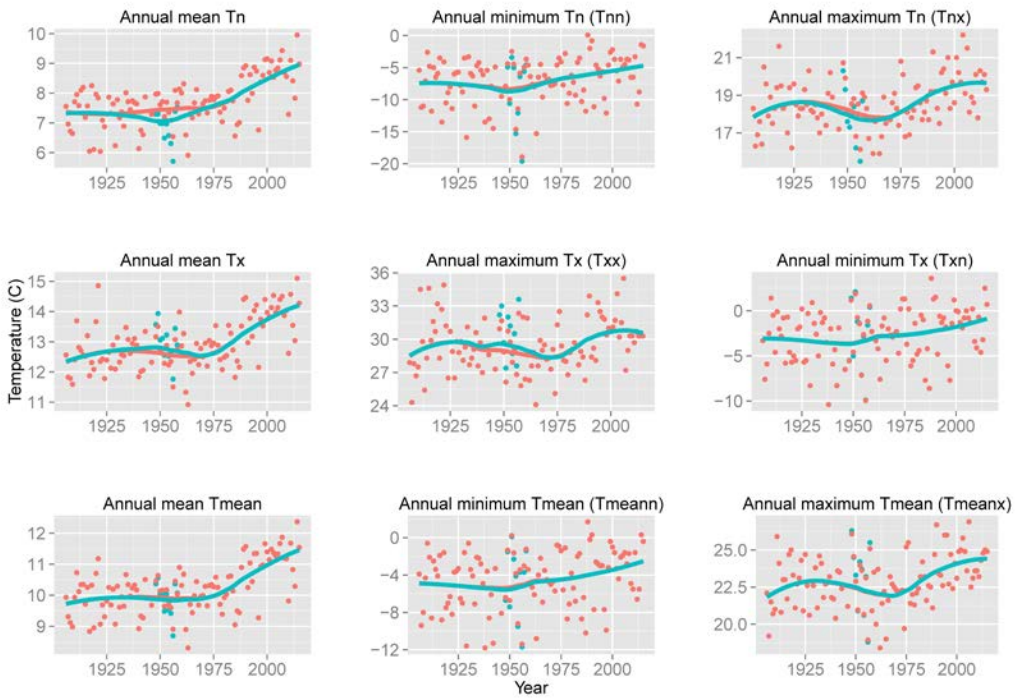

Figure 26: Comparsion of Tn, Tx and Tmean before (bluegreen) and after (redorange) homogenization for Souburg/Vlissingen 1906-2015.

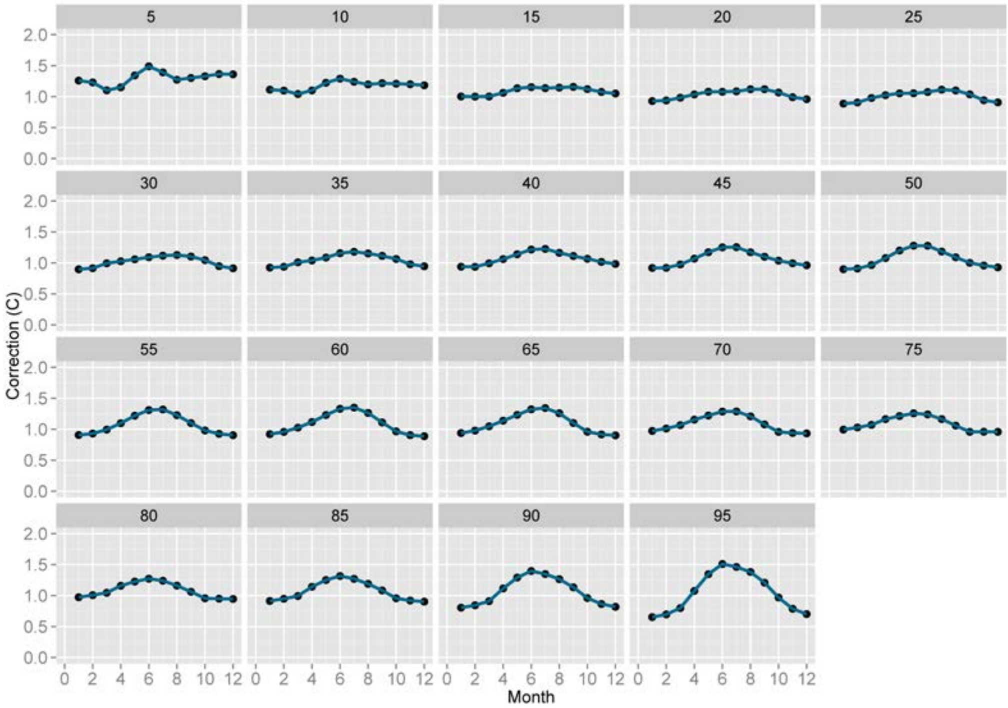

Figure 27: Tn correction Maastricht - Beek for each month and percentile.

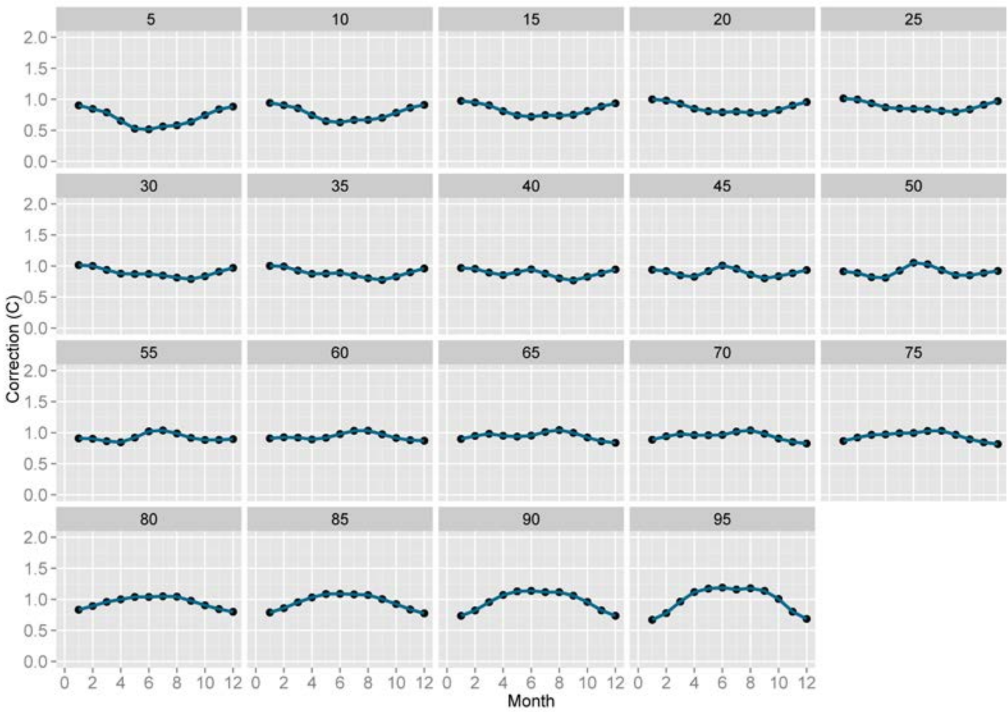

Figure 28: Tx correction Maastricht - Beek for each month and percentile.

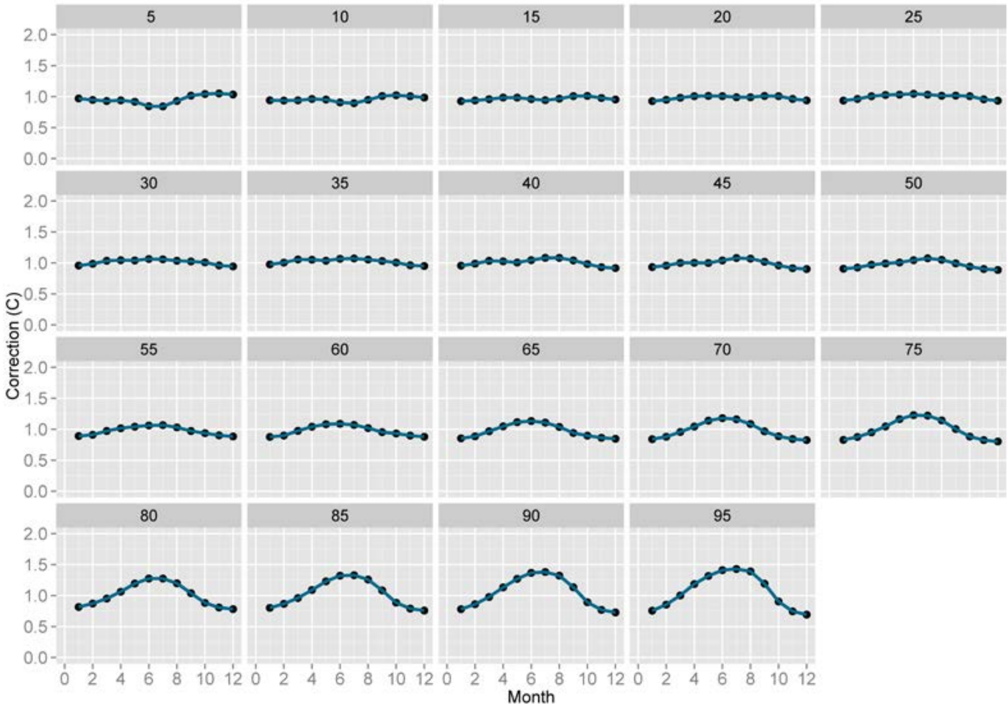

Figure 29: Tmean correction Maastricht - Beek for each month and percentile.

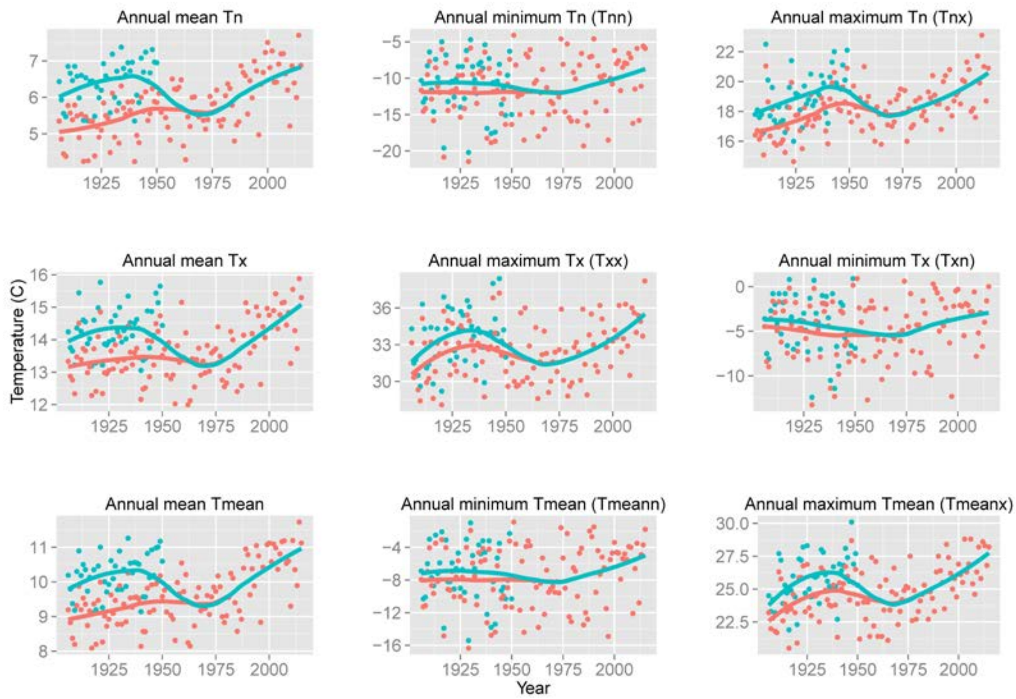

Figure 30: Comparsion of Tn, Tx and Tmean before (bluegreen) and after (redorange) homogenization for Maastricht/Beek 1906-2015.

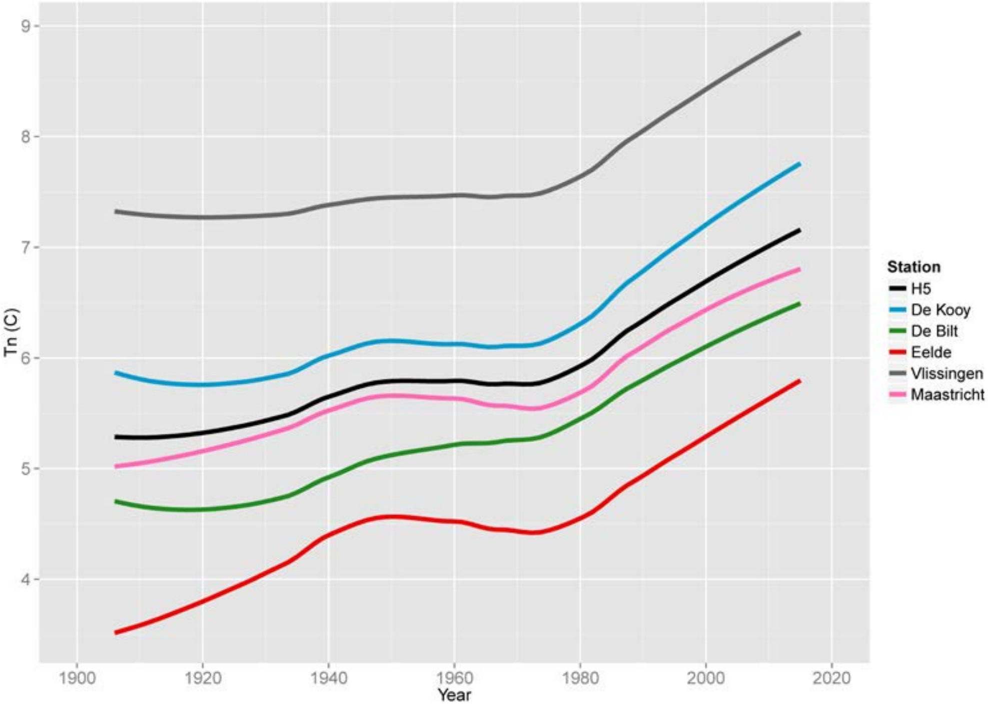

Figure 31: Comparison of homogenized smoothed annual mean Tn of the individual stations and their mean (H5) in the 1906-2015 period. The curves are the result of a loess fit (Cleveland, 1979).

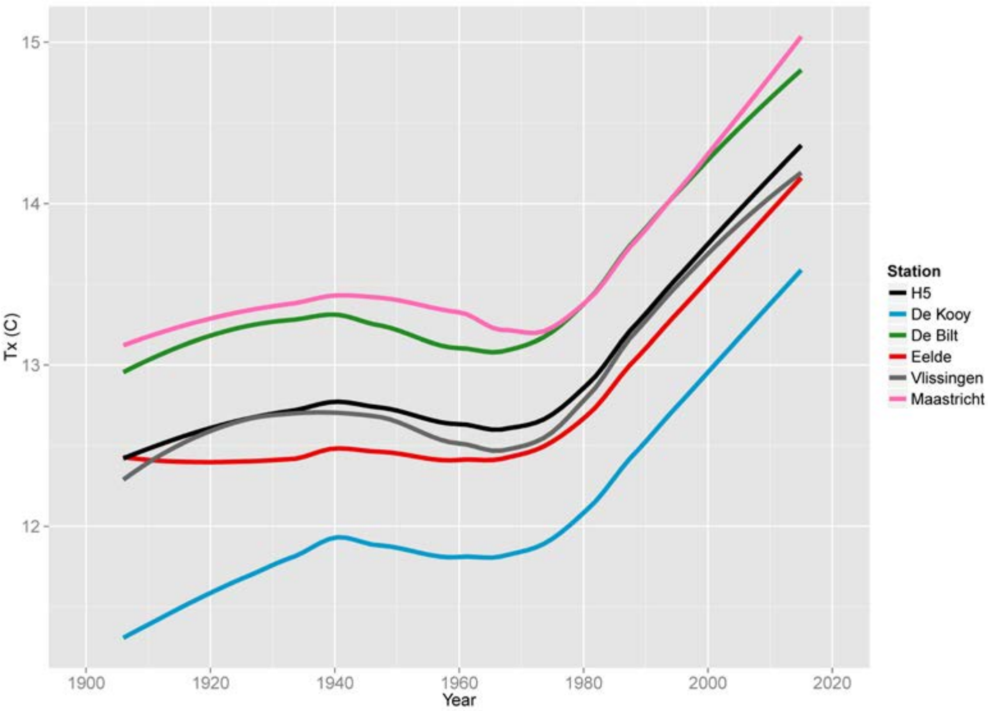

Figure 32: Comparison of homogenized smoothed annual mean Tx of the individual stations and their mean (H5) in the 1906-2015 period. The curves are the result of a loess fit (Cleveland, 1979).

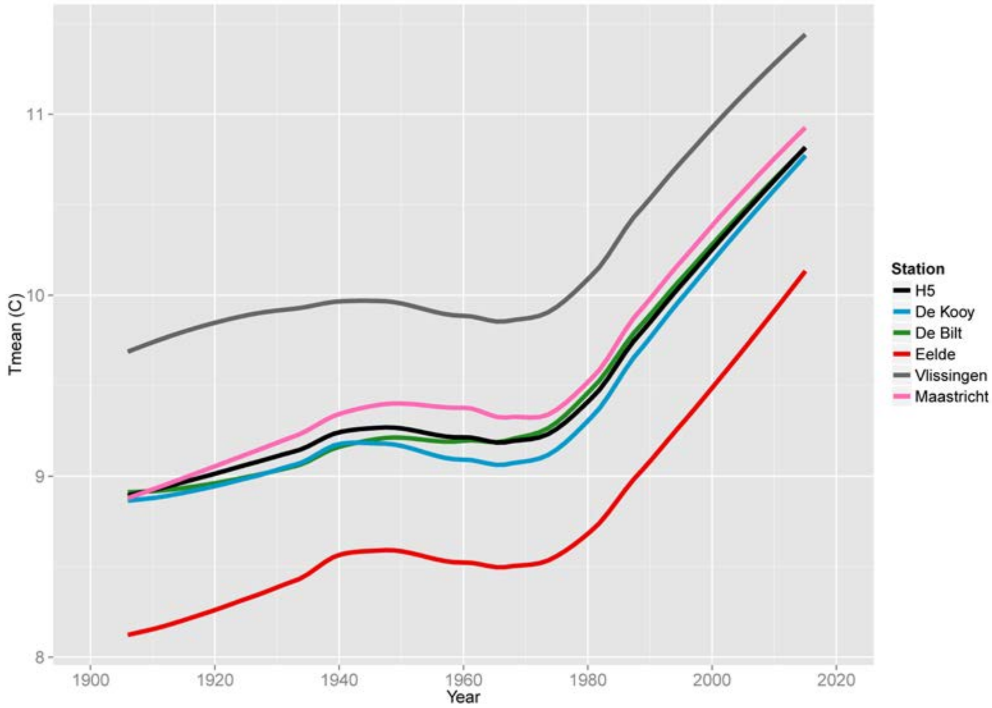

Figure 33: Comparison of homogenized smoothed annual mean Tmean of the individual stations and their mean (H5) in the 1906-2015 period. The curves are the result of a loess fit (Cleveland, 1979).

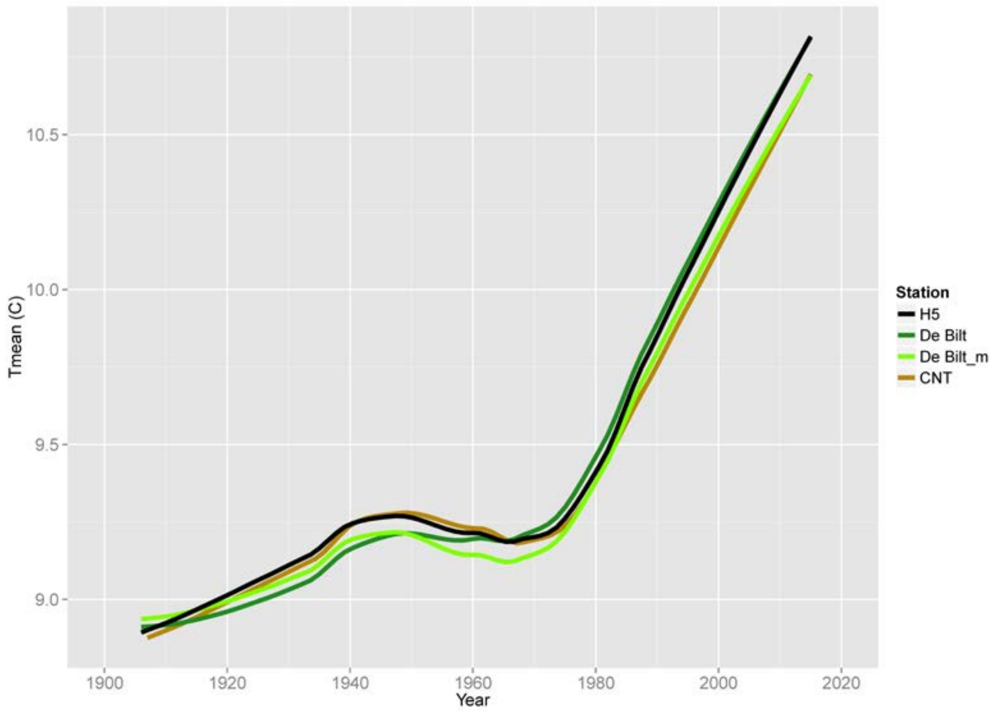

Figure 34: Comparison of homogenized smoothed annual Tmean of H5, De Bilt, De Bilt_m (homogenized monthly) and the monthly Central Netherlands Temperature (CNT) in the 1906-2015 period. The curves are the result of a loess fit (Cleveland, 1979).

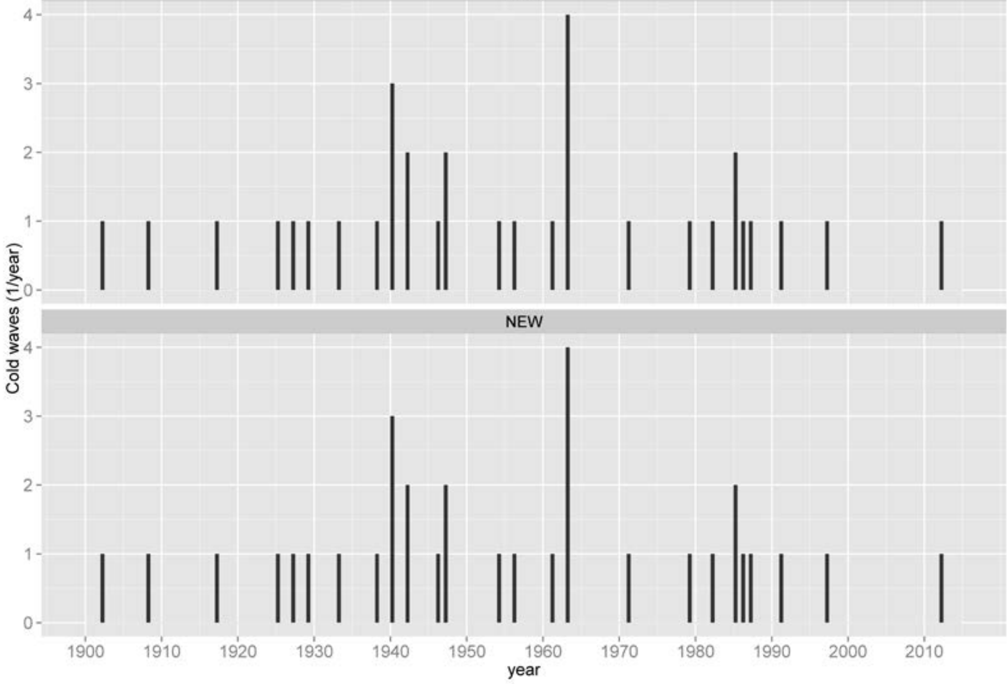

Figure 35: Number of cold waves per year in De Bilt for the measured data (OLD) and the homogenized data (NEW) 1901-2015.

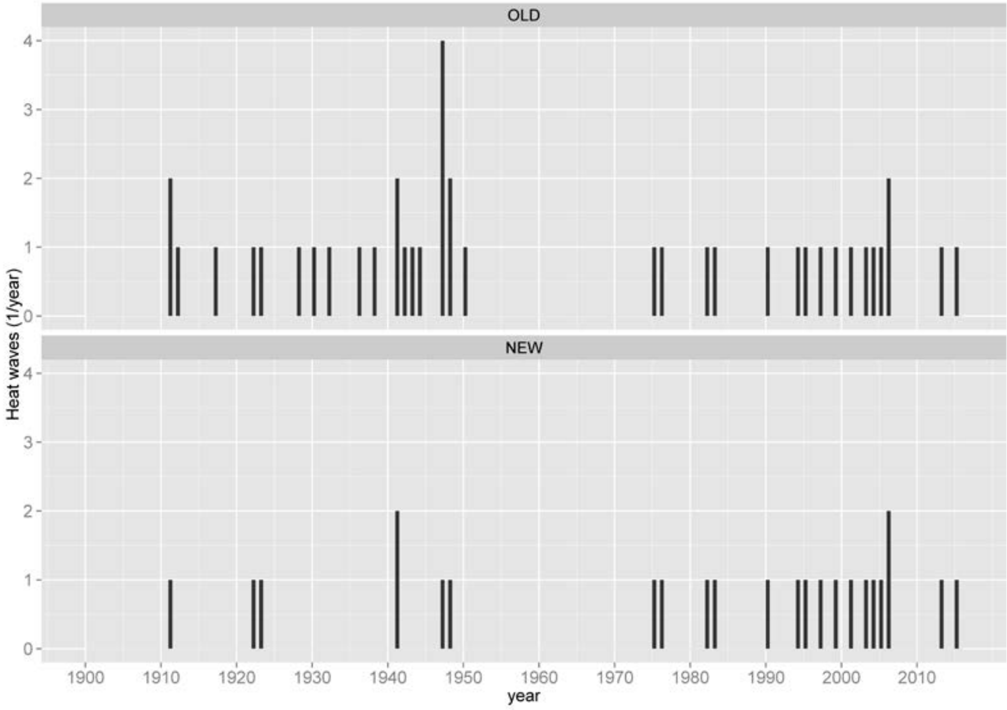

Figure 36: Number of heat waves per year in De Bilt for the measured data (OLD) and the homogenized data (NEW) 1901-2015.

Table 2: Ten highest and lowest daily values of Tn, Tx and Tmean for Den Helder/De Kooy (1906-2015).

Ten highest daily values (°C)											
New		Old		New		Old		New		Old	
yyyymmdd	Tn	yyyymmdd	Tn	yyyymmdd	Tx	yyyymmdd	Tx	yyyymmdd	Tmean	yyyymmdd	Tmean
19250722	22.4	19250722	23.0	20140719	34.6	20140719	34.6	19250722	26.5	19250722	26.5
19230713	22.0	19230713	22.6	19230712	34.3	19230712	33.9	20140719	26.2	20140719	26.2
20020729	21.2	19110812	21.7	19900804	33.8	19900804	33.8	19230713	26.0	19230713	26.0
19110812	21.0	19230711	21.6	20090820	33.3	20090820	33.3	19230710	25.5	19230710	25.5
19230711	21.0	19110813	21.2	19320820	33.0	19320820	32.8	20040809	25.5	20040809	25.5
20040809	20.8	19120713	21.2	19900803	32.8	19900803	32.8	19940712	25.3	19490905	25.3
20060725	20.8	20020729	21.2	19490905	32.6	19490905	32.6	19490905	25.2	19940712	25.3
20140723	20.8	19110809	21.1	19110728	32.6	20100709	32.6	19450715	25.1	19450715	25.1
19120713	20.6	19410711	21.1	20100709	32.6	19110728	32.2	19110728	25.0	19110728	25.0
19110813	20.5	19480728	21.1	19250722	32.3	19940804	32.2	19940804	25.0	19940804	25.0
Ten lowest daily values (°C)											
New		Old		New		Old		New		Old	
yyyymmdd	Tn	yyyymmdd	Tn	yyyymmdd	Tx	yyyymmdd	Tx	yyyymmdd	Tmean	yyyymmdd	Tmean
19560216	-20.0	19790101	-18.8	19381220	-11.1	19381220	-10.6	19560216	-13.7	19560216	-13.0
19790101	-18.8	19560216	-18.5	19420121	-10.6	19420121	-10.0	19290211	-13.3	19290211	-12.6
19290215	-17.6	20120204	-17.6	19400202	-10.4	19400202	-9.9	19420126	-12.8	19420126	-12.1
20120204	-17.6	19290215	-16.1	19470107	-10.4	19290211	-9.8	19420121	-12.5	19420121	-11.8
19290211	-16.7	19790102	-16.0	19290211	-10.3	19470107	-9.8	19420122	-12.4	19290215	-11.7
19470224	-16.5	19790128	-15.8	19420122	-10.2	19420122	-9.6	19290215	-12.4	19420122	-11.7
19790102	-16.0	19790105	-15.3	19420120	-9.9	19420120	-9.3	19470107	-12.1	19381220	-11.4
19470304	-16.0	19290211	-15.2	19400119	-9.2	19400119	-8.6	19381220	-12.0	19470107	-11.4
19630204	-15.8	19470224	-15.0	19400201	-9.1	19400201	-8.6	19420120	-11.8	20120204	-11.4
19790128	-15.8	19850105	-15.0	19381222	-9.0	19381222	-8.5	20120204	-11.4	19420120	-11.1

Table 3: Ten highest and lowest daily values of Tn, Tx and Tmean for De Bilt (1901-2015).

Ten highest daily values (°C)											
New		Old		New		Old		New		Old	
yyyymmdd	Tn	yyyymmdd	Tn	yyyymmdd	Tx	yyyymmdd	Tx	yyyymmdd	Tmean	yyyymmdd	Tmean
20040809	20.8	20040809	20.8	20060719	35.7	19470627	36.8	20100702	27.1	19470627	27.9
20100702	20.5	19250722	20.6	19470627	35.6	20060719	35.7	20060719	26.9	19470628	27.6
19250722	20.2	20100702	20.5	19900804	35.3	19110728	35.6	19470627	26.9	19230713	27.1
20080728	20.1	19410711	20.1	20030807	35.0	19900804	35.3	19750808	26.6	19250722	27.1
19720721	20.0	20080728	20.1	19760703	34.9	19470628	35.2	19940724	26.6	20100702	27.1
19750805	19.8	19230710	20.0	20100709	34.4	20030807	35.0	19470628	26.6	19230711	26.9
19410711	19.7	19470627	20.0	20030716	34.3	19110810	34.9	19570630	26.5	20060719	26.9
19720719	19.6	19720721	20.0	19570630	34.2	19760703	34.9	20040809	26.5	19750808	26.6
20060720	19.6	19750805	19.8	19940724	34.1	19230711	34.8	19760627	26.4	19940724	26.6
20130802	19.6	19480728	19.7	19590709	34.0	19230713	34.7	20130802	26.4	19230710	26.5
Ten lowest daily values (°C)											
New		Old		New		Old		New		Old	
yyyymmdd	Tn	yyyymmdd	Tn	yyyymmdd	Tx	yyyymmdd	Tx	yyyymmdd	Tmean	yyyymmdd	Tmean
19420127	-24.7	19420127	-24.8	19420126	-11.4	19381220	-11.3	19560216	-14.9	19560216	-14.9
19420126	-23.3	19420126	-23.4	19560201	-11.2	19420126	-11.2	19420126	-14.5	19420126	-14.4
19560216	-21.6	19560216	-21.6	19381220	-11.1	19560201	-11.2	19420127	-14.5	19420127	-14.4
19120203	-19.9	19120203	-20.1	19870114	-10.6	19381219	-10.6	19290214	-14.1	19560201	-14.0
19560215	-19.5	19560215	-19.5	19420121	-10.4	19870114	-10.6	19420121	-14.0	19290214	-13.9
20120204	-18.9	19290214	-18.9	19381219	-10.4	19420121	-10.2	19560201	-14.0	19420121	-13.9
19290214	-18.7	20120204	-18.9	19290214	-10.1	19081229	-9.8	19420122	-13.6	19420122	-13.5
19850108	-18.3	19850108	-18.3	19420122	-9.8	19290214	-9.7	19290211	-13.5	19290211	-13.3
19630118	-18.2	19630118	-18.2	19420120	-9.6	19420122	-9.6	19381219	-13.4	19381219	-13.3
19560217	-18.0	19290212	-18.1	19081229	-9.6	19781231	-9.5	19381220	-13.4	19381220	-13.3

Table 4: Ten highest and lowest daily values of Tn, Tx and Tmean for Groningen/Eelde (1906-2015).

Ten highest daily values (°C)											
New		Old		New		Old		New		Old	
yyyymmdd	Tn	yyyymmdd	Tn	yyyymmdd	Tx	yyyymmdd	Tx	yyyymmdd	Tmean	yyyymmdd	Tmean
19440824	19.3	19440824	20.7	19440823	36.3	19440823	36.8	19410710	27.1	19410710	27.7
19940727	19.3	19410710	20.6	20030812	35.4	19110728	35.5	20140719	27.0	19410712	27.3
20140719	19.2	19410711	20.5	20030807	34.9	20030812	35.4	19410712	26.7	19440823	27.0
19410710	19.2	19410712	20.1	20150702	34.9	19410712	35.1	19440823	26.5	19470628	27.0
19410711	19.1	19230714	19.8	20090820	34.8	20030807	34.9	19470628	26.4	20140719	27.0
19720719	18.9	19440823	19.8	19110728	34.7	20150702	34.9	19230713	26.3	19230713	26.9
20140720	18.9	19470723	19.8	19750810	34.7	20090820	34.8	19410711	26.3	19410711	26.9
19720720	18.8	19110729	19.4	20030808	34.5	19470628	34.7	19230714	26.2	19230714	26.8
19820714	18.7	19410709	19.4	20100709	34.5	19750810	34.7	19110728	25.9	19110728	26.5
20040810	18.7	19470628	19.4	19410712	34.3	19320820	34.5	19750810	25.6	19450715	26.0
Ten lowest daily values (°C)											
New		Old		New		Old		New		Old	
yyyymmdd	Tn	yyyymmdd	Tn	yyyymmdd	Tx	yyyymmdd	Tx	yyyymmdd	Tmean	yyyymmdd	Tmean
19560216	-22.9	19560216	-22.9	19420126	-13.3	19420126	-12.8	19560216	-17.4	19560216	-17.4
19790105	-22.0	19790105	-22.0	19290211	-12.5	19290211	-12.2	19790105	-17.0	19790105	-17.0
19231231	-22.0	19790104	-21.5	19560201	-12.0	19560201	-12.0	19290211	-15.5	19790104	-15.2
19790104	-21.5	19680109	-21.1	19381220	-12.0	19970102	-11.6	19790104	-15.2	19290211	-15.0
19680109	-21.1	19560215	-21.0	19970102	-11.6	19381220	-11.3	19420126	-15.1	19970102	-14.6
19560215	-21.0	19710101	-21.0	19400202	-11.6	19400202	-11.3	19231231	-14.7	19420126	-14.5
19710101	-21.0	19231231	-20.4	19420121	-11.5	19560216	-11.2	19970102	-14.6	19231231	-14.0
19680112	-20.2	19680112	-20.2	19470107	-11.5	19420121	-11.0	19290215	-14.4	19290215	-13.9
19680113	-20.2	19680113	-20.2	19560216	-11.2	19470107	-11.0	19420121	-14.4	19420121	-13.8
19790102	-19.9	19790102	-19.9	19290215	-10.9	19790105	-10.8	19400213	-14.0	19560201	-13.8

Table 5: Ten highest and lowest daily values of Tn, Tx and Tmean for Souburg/Vlissingen (1906-2015).

Ten highest daily values (°C)											
New		Old		New		Old		New		Old	
yyyymmdd	Tn	yyyymmdd	Tn	yyyymmdd	Tx	yyyymmdd	Tx	yyyymmdd	Tmean	yyyymmdd	Tmean
20040809	22.2	20040809	22.2	20060719	35.5	20060719	35.5	20060719	26.9	20060719	26.9
19180822	21.6	19180822	21.6	19220523	34.9	19220523	34.9	19900803	26.7	19900803	26.7
20060727	21.5	20060727	21.5	19150608	34.6	19150608	34.6	20060726	26.2	19480728	26.3
20060726	21.4	20060726	21.4	19110728	34.5	19110728	34.5	19480728	26.1	20060726	26.2
19900803	21.3	19900803	21.3	20030806	34.1	20030806	34.1	19940724	26.0	19470816	26.0
19970812	21.0	19970812	21.0	19110722	33.9	19110722	33.9	19950801	26.0	19940724	26.0
20010825	21.0	20010825	21.0	19900803	33.9	19900803	33.9	19470816	25.9	19950801	26.0
20060722	21.0	20060722	21.0	19220524	33.4	19470816	33.6	19110722	25.9	19110722	25.9
19750808	20.8	19750808	20.8	19940724	33.3	19570706	33.6	20030806	25.8	20030806	25.8
19480728	20.7	19110812	20.5	20060718	33.3	19220524	33.4	19110809	25.5	19110809	25.5
Ten lowest daily values (°C)											
New		Old		New		Old		New		Old	
yyyymmdd	Tn	yyyymmdd	Tn	yyyymmdd	Tx	yyyymmdd	Tx	yyyymmdd	Tmean	yyyymmdd	Tmean
19560221	-18.9	19560221	-19.6	19381220	-10.4	19381220	-10.4	19381220	-11.8	19381220	-11.8
19290212	-15.9	19290212	-15.9	19560201	-9.9	19560201	-9.9	19290212	-11.6	19560201	-11.7
19290214	-15.7	19560214	-15.8	19381219	-9.5	19381219	-9.5	19290214	-11.6	19290212	-11.6
19630118	-15.3	19290214	-15.7	19870114	-8.6	19870114	-8.6	19560201	-11.4	19290214	-11.6
19560214	-15.1	19530207	-15.3	19290214	-8.3	19290214	-8.3	19420121	-11.3	19420121	-11.3
19530207	-14.6	19630118	-15.3	19420121	-8.3	19420121	-8.3	19381219	-10.9	19381219	-10.9
19290213	-14.5	19560219	-14.6	19420122	-8.0	19420122	-8.0	19420122	-10.8	19420122	-10.8
19420122	-14.5	19560223	-14.6	19850116	-7.7	19850116	-7.7	19630118	-10.8	19630118	-10.8
19560219	-13.9	19290213	-14.5	19970102	-7.7	19970102	-7.7	19870114	-10.2	19870114	-10.2
19560223	-13.9	19420122	-14.5	19070123	-7.6	19070123	-7.6	19290211	-9.9	19560202	-10.1

Table 6: Ten highest and lowest daily values of Tn, Tx and Tmean for Maastricht/Beek (1906-2015).

Ten highest daily values (°C)											
New		Old		New		Old		New		Old	
yyyymmdd	Tn	yyyymmdd	Tn	yyyymmdd	Tx	yyyymmdd	Tx	yyyymmdd	Tmean	yyyymmdd	Tmean
20120819	23.1	20120819	23.1	20150702	38.2	19470627	38.4	20030812	28.8	19470627	30.1
20100702	21.7	19110730	22.5	19470627	37.2	20150702	38.2	20060719	28.8	20030812	28.8
20050624	21.3	19490905	22.1	19440823	36.8	19440823	38.0	19470627	28.7	20060719	28.8
19110730	21.0	19430801	22.0	20060719	36.3	19210728	36.9	20120819	28.6	20120819	28.6
19570704	21.0	20100702	21.7	19940804	36.2	19320819	36.6	19940804	28.4	19940804	28.4
20130802	21.0	19230714	21.4	20030812	36.2	19110728	36.3	20130802	28.3	19250722	28.3
20150704	20.9	19420829	21.3	19590709	36.0	20060719	36.3	20100702	28.2	20130802	28.3
19490905	20.9	20050624	21.3	20090820	36.0	19110723	36.2	20150704	28.2	19230713	28.2
19970824	20.8	19470627	21.1	19760716	35.9	19940804	36.2	20150702	28.0	20100702	28.2
20060726	20.8	19470729	21.1	19860803	35.9	20030812	36.2	20060726	27.6	20150704	28.2
Ten lowest daily values (°C)											
New		Old		New		Old		New		Old	
yyyymmdd	Tn	yyyymmdd	Tn	yyyymmdd	Tx	yyyymmdd	Tx	yyyymmdd	Tmean	yyyymmdd	Tmean
19290214	-21.4	19290214	-20.2	19290214	-13.2	19560201	-12.7	19290214	-16.3	19290214	-15.4
19170203	-20.8	19170203	-19.6	19560201	-12.7	19290214	-12.4	19970101	-14.9	19970101	-14.9
19850108	-19.3	19850108	-19.3	19400122	-12.3	19970101	-12.3	19170203	-14.8	19560201	-14.4
19400122	-18.9	19560216	-18.5	19970101	-12.3	19400122	-11.4	19400122	-14.8	19170203	-13.9
19420127	-18.7	19970102	-18.5	19381219	-11.4	19381219	-10.5	19560201	-14.4	19400122	-13.8
19560216	-18.5	19630118	-18.0	19381220	-10.5	19630118	-10.4	19420122	-14.4	19560223	-13.8
19970102	-18.5	19560223	-17.9	19630118	-10.4	19560223	-10.0	19420121	-14.3	19630118	-13.8
19381223	-18.3	19400122	-17.6	19560223	-10.0	19870112	-9.9	19560223	-13.8	19850108	-13.5
19420126	-18.3	19560224	-17.6	19870112	-9.9	19790101	-9.7	19630118	-13.8	19420122	-13.4
19290213	-18.2	19970101	-17.5	19420121	-9.8	19381220	-9.6	19290212	-13.5	19420121	-13.3