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Gerard van der Schrier

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The Construction of a Central Netherlands Temperature

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Abstract

The Central Netherlands Temperature record (CNT) is a monthly daily mean temperature time series that is representative for a region in the centre of the country, i.e., excluding the coast, north and south. It has been constructed to study large-scale temperature changes and facilitate comparisons with climate models, which resolve similar scales.

From 1906 onwards temperature observations in the Netherlands have been sufficiently standardised to construct a high-quality series. Long time series have been constructed by merging nearby stations, using the overlap periods to calibrate the differences. These long time series have been subjected to a homogeneity analysis. Significant breaks and trends have been corrected. Many, but not all, breaks correspond to changes in the observations that are documented in the station metadata.

The current version of the Central Netherlands Temperature (CNT4,6) is constructed as the unweighted average of four stations until 1950 (De Bilt, Winterswijk/Hupsel, Oudenbosch/Gilze-Rijen and Gemert/Volkel), and six stations afterwards (Deelen and Eindhoven added to the previous stations). The RMS difference with the observed temperature at De Bilt is 0.11°C for annual means, and 0.07°C with the De Bilt series that has been homogenised using physical methods. The trend is slightly lower than the trend in the De Bilt series over the last 60 years.

The CNT data are available at www.knmi.nl and are updated monthly.

Samenvatting

De Centraal Nederland Temperatuur reeks (CNT) is een tijdreeks van maandgemiddelde daggemiddelde temperatuur, representatief voor een gebied in het midden van het land, d.w.z, niet voor de kust, het noorden en het zuiden. Deze reeks is geschikt om grootschalige temperatuurveranderingen te bestuderen en te vergelijken met klimaatmodellen, die soortgelijke schalen representeren.

Sinds 1906 zijn de temperatuurwaarnemingen in Nederland voldoende gestandaardiseerd om een tijdreeks van hoge kwaliteit te kunnen maken. Lange tijdreeksen zijn samengesteld uit nabijgelegen stationswaarnemingen, waarbij overlappende periodes gebruikt zijn om de verschillen te ijken. Deze lange reeksen zijn vervolgens op discontinuïteiten en trends gecontroleerd, en indien nodig daarvoor gecorrigeerd. Veel, maar niet alle, discontinuïteiten komen overeen met gedocumenteerde veranderingen in de metadata.

De huidige versie van de Centraal Nederland (CNT4,6) is gedefinieerd als het ongewogen gemiddelde van vier stations tot en met 1950 (De Bilt, Winterswijk/Hupsel, Oudenbosch/Gilze-Rijen en Gemert/Volkel) en zes stations vanaf 1951 tot heden (dezelfde plus Deelen en Eindhoven). De standaardafwijking met de waargenomen temperatuur in De Bilt is 0,11°C in het jaargemiddelde, en 0,07°C met de op fysische grondslag gehomogeniseerde De Bilt reeks. De trend is iets lager dan de De Bilt reeksen over de afgelopen 60 jaar.

De CNT is beschikbaar op www.knmi.nl en wordt maandelijks bijgewerkt.

Contents

1. Data

Instrumental temperature observations started in the Netherlands in 1706. Many more temperature records became available in the next two centuries. Because of lack of standardisation in observation procedures, instruments and observation screens, the construction of a homogeneous record for this period is an immense task, which we will not undertake here. An older reconstruction has been described in Labrijn (1945), this series is available from www.knmi.nl.

In 1906 a new climatological network was installed, which was largely employing a type of Stevenson screens. A notable exceptions was De Bilt, where up to 1950 temperature was measured in a large thermometer screen (the 'Pagoda'). From 1906, the observation practice was also highly standardised. Main stations recorded hourly observations of temperature, while secondary stations recorded three times daily the temperature and its maximum and minimum value over the previous period. From these data accurate estimates of daily main temperature can be determined (van der Hoeven, 1992). Around 1950 a new synoptic network (operated by the Weather Forecast Division) was added to the climatological network (operated by the Climate Division of KNMI). Around 1990 a gradual transition was made to a single, fully automated, observation network.

It is the aim of this study to analyse the quality of the long monthly mean temperature records for the period 1906–2008 and find corrections for inhomogeneities based on a statistical analysis. We will construct long homogeneous monthly mean records and construct from these a Central Netherlands Temperature record (CNT). Our major analysis tool will be a statistical intercomparison of records based on the approach by Alexandersson and Moberg (1997) and by Easterling and Peterson (1995).

The locations of the observing stations are shown in figure 1, while the records analysed in this study are specified in table 1.

Following van der Hoeven (1992), daily mean temperatures were computed from records with 5 observations per day (indicated by a G in table 1): T_1, T_2 and T_3 are observations at 8, 14 and 19 hr respectively, and T_x and T_n the daily maximum and minimum temperature. From each of these observations an estimate of the daily mean temperature was constructed using the amplitude of the diurnal cycle as

$$T_{24}^{(i)} = T_i - C_i(T_x - T_n)\,. \qquad (1.1)$$

Figure 1: Map of the Netherlands showing the station locations.

The coefficients C_1, C_2, C_3, C_x and C_n were obtained from a comparison with 24 hourly observations of T and of T_x and T_n in De Bilt in the period 1961-1970. In order to account for the annual variations in the the times of sunrise and sunset, the values of C_i were computed for each of the 36 decades of the year separately. Finally, these five estimates of the daily mean temperature were averaged to give a best estimate:

$$T_{24} = (T_1 + T_2 + T_3 + T_x + T_n - (T_x - T_n)(C_1 + C_2 + C_3 + C_x + C_n))/5, \quad (1.2)$$

Stevenson huts were used in all stations until about 1990 (except for De Bilt 1901–1950), in Maastricht up to 1945 he screen was at 20 m above ground on top of a tower on a building. From about 1990 gradually a new fully automated observing system was introduced using small multi-plate thermometer screens. According to Brandsma and van der Meulen (2008), this latter transition has a negligible effect on monthly mean temperatures. The changes in De Bilt will be discussed later.

Climatological Records (H-records based on 24 hourly observations; G-records based on 5 observations per day)				
Station	Record	Period	Missing Data	Filled from
De Bilt	D001 H	1901–1970		
Den Helder	D002 H	1906–1970	Sep 1944–May 1945	Hoorn
Vlissingen	D003 H	1906–1970	1918–1930, 1944–1945	Excluded from analysis
Eelde	D004 H	1946–1970		
Beek	D005 H	1946–1970		
Groningen	D006 H	1906–1951		
Maastricht	D007 H	1906–1952		
De Kooy	D009 H	1961–1970		
Winterswijk	D020 G	1906–1990	Nov 1944	De Bilt
Hoorn	D029 G	1906–1990	Nov 1947–Apr 1948	Den Helder
Oudenbosch	D032 G	1906–1992		
Gemert	D033 G	1906–1990		
Sittard	D145 G	1906–1948	Apr-Aug 1940, Nov 1944-Feb 1945	Maastricht
Gilze-Rijen	D132 G	1953–1970		
Twenthe	D146 G	1947–1970		
Synoptic Records based on 24 hourly observations				
Station	Record	Period	Missing Data	Filled from
Den Helder	235	1971–Jul 1972		
De Kooy	235	Aug 1972–2008		
Schiphol	240	1951–2008		
De Bilt	260	1951–2008		
Soesterberg	265	1953–2007		
Leeuwarden	270	1951–2008		
Deelen	275	1951–2008	Many months 1951–1957	De Bilt, Winterswijk
Eelde	280	1951–2008		
Hupsel	283	1990–2008		
Twenthe	290	1971–2008		
Rotterdam	344	1957–2008		
Gilze-Rijen	350	1971–2008		
Eindhoven	370	1951–2008	May, Jun 1952	Gemert
Volkel	375	1953–2008		
Beek	380	1971–2008		

Table 1: Records analysed in this study.

2. Construction of long records

From the station data described in table 1 we constructed long, continuous records. This implied filling missing data using nearby stations, and joining records of nearby stations using the overlap periods.

Most records in table 1 were complete. Den Helder and Sittard had 9 missing months, Winterswijk 1 missing month, while Hoorn had 6 missing months. Deelen and Eindhoven had missing records in the 1950s. These missing data were filled with adjusted data from nearby stations (see table 1). The record from Vlissingen appeared to be too incomplete to be useful for this study. We tested all records for outliers, but found none.

We constructed 8 long records covering the period 1906—2008, merging the records with records from nearby stations (see table 2). The older parts of these merged records were adjusted to the recent parts using overlapping observation periods. The monthly adjustment factors were smoothed with a 5-point quasi-gaussian filter. The statistical accuracy of these monthly adjustment factors is about 0.1°C. For the transition Winterswijk to Hupsel the overlapping period was only 10 months, which is too short for a reliable estimate of the adjustment factors. Therefore we used a 10-yr overlap of both time series with Deelen to determine the adjustments.

The smoothed adjustment factors are shown in figure 2. We see in this figure that the adjustment factors are all negative, meaning that the recent stations are cooler than the older stations. Therefore it is necessary to apply adjustments to the merged records.

In addition to the 8 long records starting in 1906, we used Hoorn until 1990 and 6 records starting after 1946 for further analysis of the recent 50-yr observation period. These records are also shown in table 2.

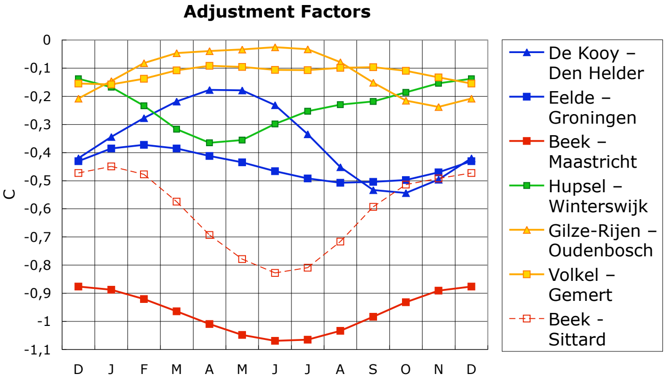

Figure 2: Adjustment factors.

Station	Records	Period	Transition	Overlap
De Bilt	D001+260	1901–2008	Jan 1971	
Den Helder/De Kooy	D002+235	1906–2008	Aug 1972	1961–1970
Groningen/Eelde	D004/006+280	1906–2008	Jan 1946	1946–1951
Maastricht/Beek	D005/007+380	1906–2008	Jan 1946	1946–1952
Winterswijk/Hupsel	D020+283	1906–2008	Jan 1991	Mar–Dec 1990
Hoorn	D029	1906–1990	No suitable follow-up	
Oudenbosch/Gilze-Rijen	D032+350	1906–2008	Jan 1993	1988–1992
Gemert/Volkel	D033+375	1906–2008	Jan 1991	1990
Sittard/Beek	D145+380	1906–2008	Jan 1946	1946–1948
Twenthe	D146+290	1946–2008	Jan 1971	
Schiphol	240	1951–2008		
Soesterberg	265	1953–2008		
Deelen	275	1951–2008		
Rotterdam	344	1957–2008		
Eindhoven	370	1951–2008		

Table 2: Long composite records used for break and trend analysis.

3. Difference time-series

It is instructive to analyse in some detail the general characteristics of the difference time-series in the Netherlands. As an example, we consider the 9 long records in the period 1906–1948. Each record was compared with the average of the other 8 records. The correlations between the monthly mean target records and the reference records were high and ranged from 0.95 for Den Helder to 0.99 for more centrally located stations.

In figure 3 we show the standard deviations of the difference-series for averages over 1, 3, 6 and 12 months. We see that De Bilt, which is situated in the centre of the Netherlands, has the lowest standard deviations in its difference time-series. These standard deviations range from 0.16°C for monthly averages to 0.07°C for annual averages. Stations in the north and in the south have the highest standard deviations. This is related to the fact that temperature anomaly fields show primarily gradients in the NNW-SSE direction. Such anomaly fields are natural and primarily related to anomalies in the atmospheric circulation. This is illustrated in figure 4, which shows the deviations of the annual mean station anomalies from the reference anomalies. A nice example was 1947, which was a year with exceptional circulations. In this year Maastricht and Sittard had the warmest temperature anomaly differences, while Den Helder had the coldest relative anomalies. The other stations showed intermediate positions.

Running standard deviations provide another interesting source of information. Figure 5 shows 11-yr standard deviations of annual mean temperature differences from the reference temperature. We see that these standard deviations may vary considerably with time. For example, Sittard has a broad maximum around 1920, which is related to the warm bias around that year (see also figure 4). Gemert has a very pronounced peak around 1950, which is related to a very significant break in that period (for details see section 5.4).

De Bilt has low standard deviations for the whole observation period with modest peaks around 1948 and 1976. For De Bilt two different records are available for the period 1951-1970: a 'climatological record' with low standard deviations and a 'synoptic record', which is based on synoptic observations at the same location. This 'synoptic record' has much higher standard deviations, which amounts to a higher noise level. The origin of this higher noise level is unclear, but we will not use this record in the following analysis.

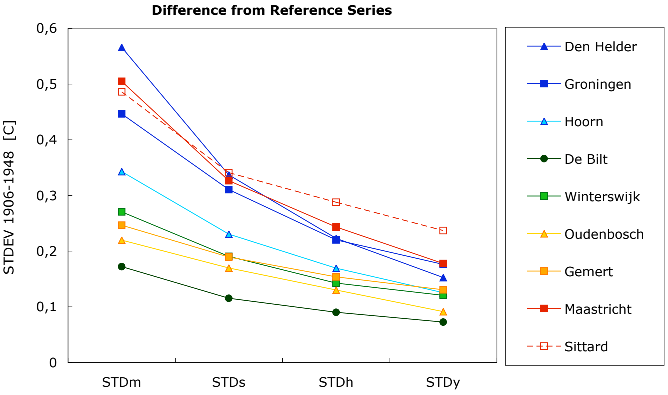

Figure 3: Standard deviations from reference time-series for averaging periods of 1, 3, 6 and 12 months. The colour codes of the stations vary from blue in the north, to green in the Centre and red in the south. The symbols used are triangles in the west, circles in the Centre and squares in the east of the country. The relatively low standard deviations for De Bilt are related to the central location of this station and an absence of inhomogeneities. The relatively large standard deviations for Sittard are related to a warm bias around 1920 and a cold bias in the 1930s (see figure 4).

Soesterberg and Twenthe also show high noise levels, which extend to the end of the 1980s. For Soesterberg this is surprising given its central location. The high deviations from the reference temperature may be related to the environment, a relatively dry sandy region. Not shown are the stations Gilze-Rijen and Volkel, which also have high noise levels until 1988. Around 1990, the noise levels of all stations (except for Beek) are significantly reduced. This may be related to improved observation practices and the transition to an automated network.

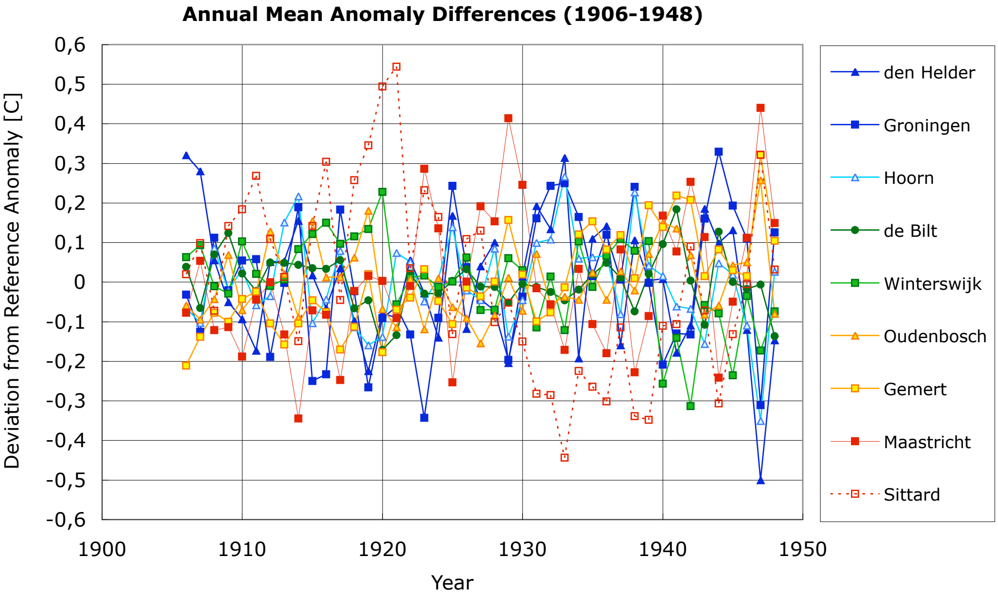

Figure 4: Deviations of station anomalies from reference anomalies for annual averages.

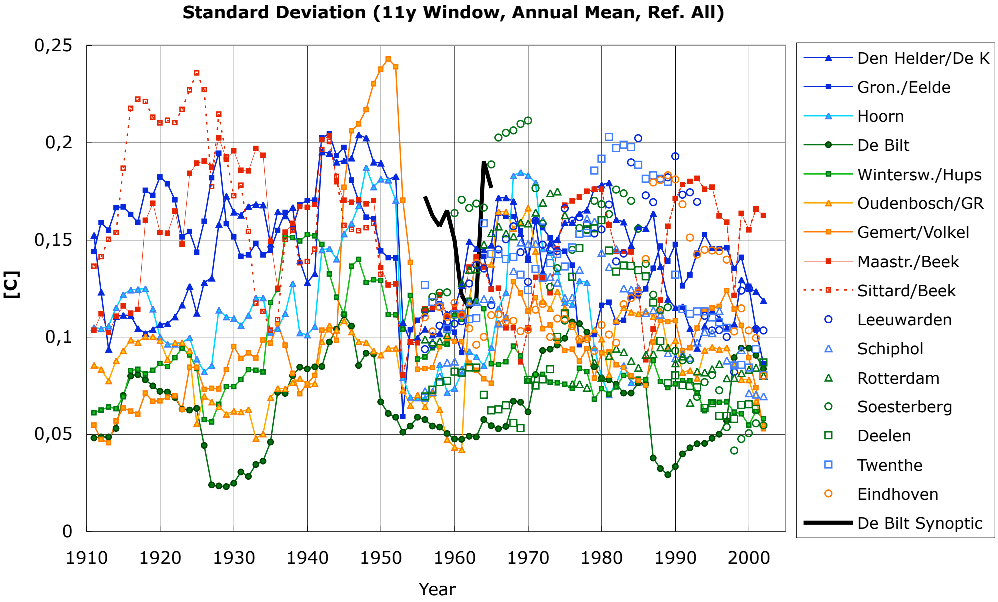

Figure 5: 11-yr running standard deviations of annual mean difference time-series. The mean of all stations serves as reference station.

4. Homogeneity tests

The homogeneity tests in this study are based on Easterling and Peterson (1995) and on Alexandersson and Moberg (1997). In these methods the target time series is compared with a break-free reference time series, which is constructed from nearby stations. In the present application the difference time-series consists of annual values of averages over 1, 3, 6, and 12 months. The 95% significance value of a potential break in the target time series can be expressed as the ratio of this value and the residual standard deviation, which is obtained as the standard deviation of the difference time series, after removal of the break from the target time series. This ratio depends on the length of the difference time series. It is shown in figure 6 for the single break test values reported by Alexandersson and Moberg (1997). Similar test values can be obtained for linear trends (not shown).

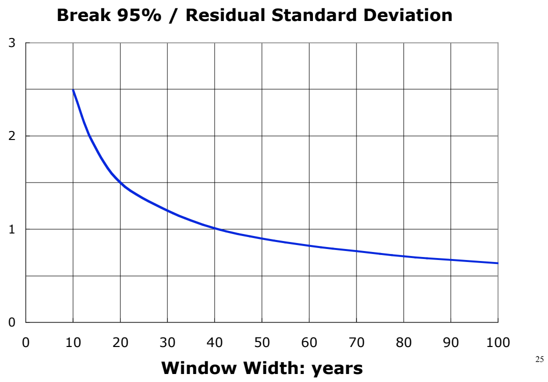

Figure 6: Critical levels for single breaks. Derived from Alexandersson and Moberg (1997), Table AI, p. 31.

The magnitude of the breaks which can be detected at the 95% confidence level appears to depend on both the window width and the residual standard deviation. If we combine the results from the figures 3 and 4, we see that for more centrally located stations, breaks around 0.1°C in the annual means can be detected at the 95% significance level, if we use a window width of about 40 years. For shorter averaging periods (e.g., 3 months) and/or smaller windows (e.g., 20 yr) the breaks have to be larger to be detectable at the 95% significance level.

In practice the following test procedure gave the most consistent results. We started with a test of the annual averages of all records using all stations as reference station and using moving windows between 20 years and 40 years. Next we focussed on a specific significant break in a target record, retained only break-free and suitably located stations as reference station and repeated the break test. We then checked the metadata of the station for possible changes in the observation practice. If such changes occurred near the time at which the break was provisionally detected, we adopted the month of such changes as the time of the break. Otherwise January was used as the time of the break. Next we determined the 12 break values for each month of the year. These monthly break-values were then smoothed with a 5-point quasi-gaussian filter, in order to obtain a smooth annual cycle of the break. This smoothed cycle was then used to correct the target time-series. This procedure was repeated for all breaks. A similar procedure was used to detect and correct significant trend differences using the test values for trends by Alexandersson and Moberg (1997).

Some aspects of the test procedure are illustrated in the figures 7 and 8. Figure 7 shows the running break amplitudes for the centre of a moving window of 24 yr, before any correction has been applied. Plotted are the running difference between the second 12-yr mean and the first 12-yr mean in the moving 24-yr window. For each target series all other records are used as reference series. We see that the absolute values of all maxima and minima of the break amplitudes are modest (i.e., less than about 0.2°C). Only Gemert and Sittard have an annual mean negative break of about 0.4°C. The significance of these running breaks can be illustrated by dividing the running breaks by their 95% significance levels. These are shown in figure 8. Sharp peaks greater than unity indicate the presence of a well-defined significant break. The break in Gemert in 1950 is the best example. From the metadata for this station it follows that this break is related to a complete re-instalment of this station in October 1949 (cf. section 5.4).

The 95% significance levels are different for each station and depend also on the choice of reference stations and on the window width. Therefore, a relatively small break in the record of De Bilt can be significant because the residual standard deviation for De Bilt is small, while a larger break in Maastricht can be not significant, because Maastricht has a larger residual standard deviation.

Around 1950, three more records (Hoorn, De Bilt, and Winterswijk) show significant breaks, although these are smaller and not as well defined as the one in Gemert. For the period around 1950, four break-free records remain, to serve as reference station (Den Helder, Groningen/Eelde, Oudenbosch and Maastricht/Beek). These records are thus used to repeat the break tests for this period, and to estimate the annual cycle of the break amplitudes. This exercise is described briefly in the following sections.

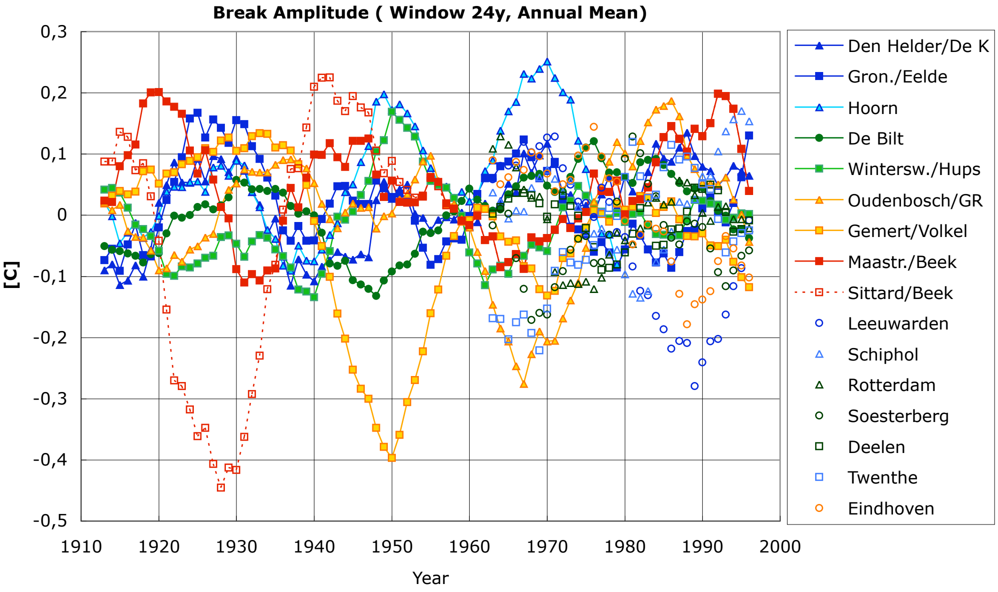

Figure 7: Break amplitudes in 24-yr running windows of annual mean station temperature compared with the average of all other stations.

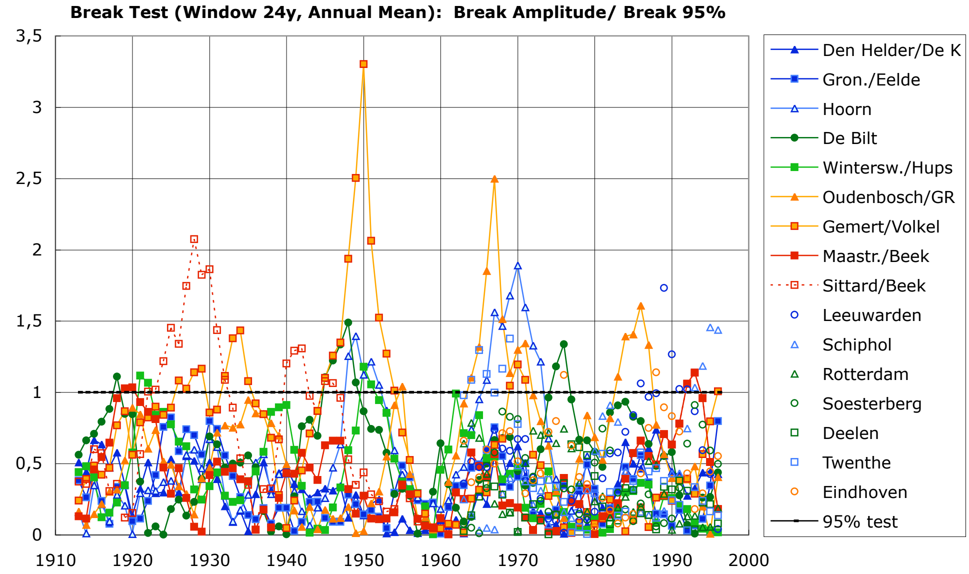

Figure 8: Break significance associated with figure 7, a value of one indicates that the break is significant at 95%.

5. Breaks and trends in individual records

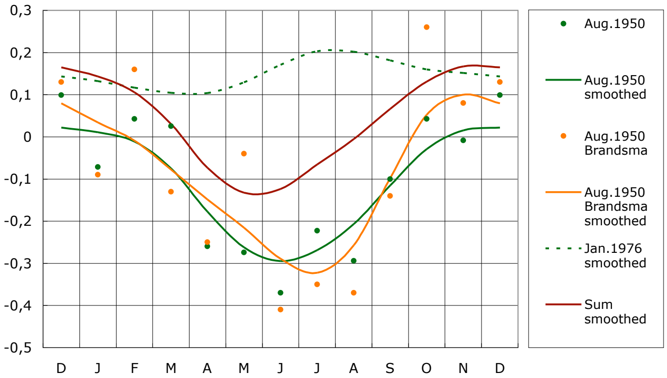

Figure 9: Breaks at De Bilt (temperature before minus after the break in °C).

5.1 De Bilt

In the record of De Bilt we detected two significant breaks: one near 1950 and one near 1976. The break near 1950 was clearly associated with the replacement of the large thermometer screen (the so called 'Pagoda') by a Stevenson screen in August 1950. For the quantification of this break we used Den Helder, Groningen/Eelde, Oudenbosch and Maastricht/Beek as reference stations. The monthly break values were determined as the difference between the averages of the difference time-series over 1951-1965 and 1935-1949. These values are shown in figure 9. A smoothed annual cycle was obtained by filtering the monthly values with a 5-point quasi-gaussian filter with weight factors 0.09, 0.24, 0.34, 0.24, and 0.09. This filter is equivalent with seasonal smoothing, but avoids aliasing. This smoothed cycle is also shown in figure 9. For comparison we include break estimates by Brandsma (personal communication), who used 13 stations as reference station, but only 3 years of data before and after the break. These monthly estimates are noisier than the present estimate, which is probably due to the short period of the difference time-series. We estimate the accuracy of the present break estimates to be about 0.1°C.

For the second break the metadata provide no information, and we placed this break in January 1976. We used Rotterdam, Schiphol, Deelen and Gemert as reference station and the smoothed correction factors are also shown in figure 9. We see that this second correction partly compensates the correction for 1950. This implies that together the two corrections have a fairly modest impact on the long-term trends in the record of De Bilt.

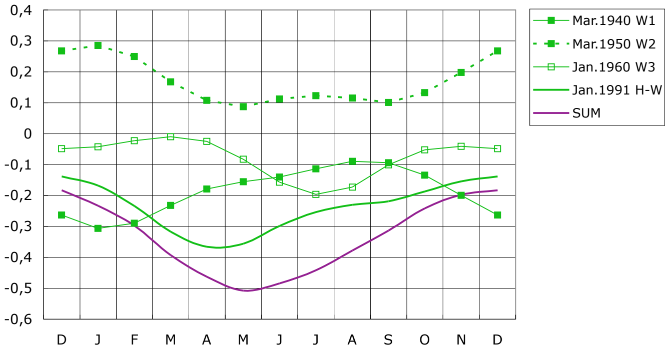

Figure 10: Breaks at Winterswijk [°C].

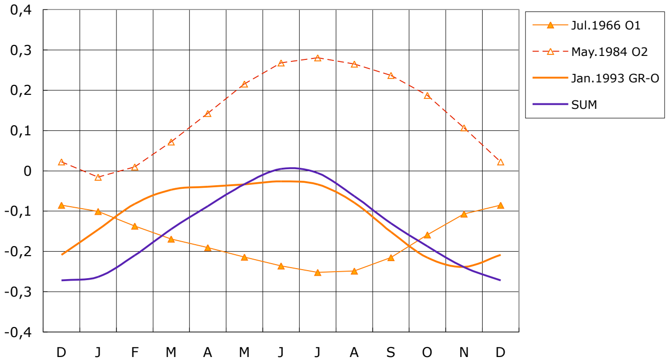

Figure 11: Breaks at Oudenbosch [°C].

5.2 Winterswijk/Hupsel

For Winterswijk we detected significant breaks near 1940, 1950 and 1960. These breaks corresponded to documented changes in the observing system in March 1940 and March 1950. The break in 1960 was placed in January. We used Groningen/Eelde, Maastricht/Beek and the corrected series of De Bilt as reference stations and the difference between 10-yr periods to estimate the breaks. The smoothed breaks are shown in figure 10. The sum of the breaks implies a modest correction on the long-term trends in the temperature in Winterswijk.

5.3 Oudenbosch/Gilze-Rijen

Oudenbosch had a break in July 1966, which was likely to be related to a 1400 m displacement of the station to the south. Around May 1984 another break was detected, but the precise date was less clear (see figure 11). Rotterdam, Deelen, Gemert and the corrected record of De Bilt were used as reference stations. The two breaks compensate each other to a large extent, and have together only a small impact on the long term trend of this station.

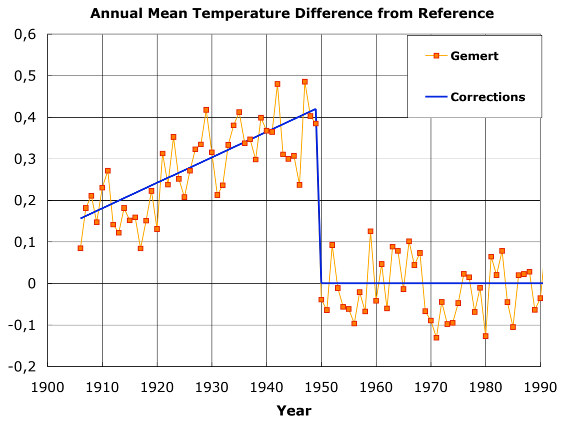

Figure 12: Trend and break in the annual mean temperature differences at Gemert [°C].

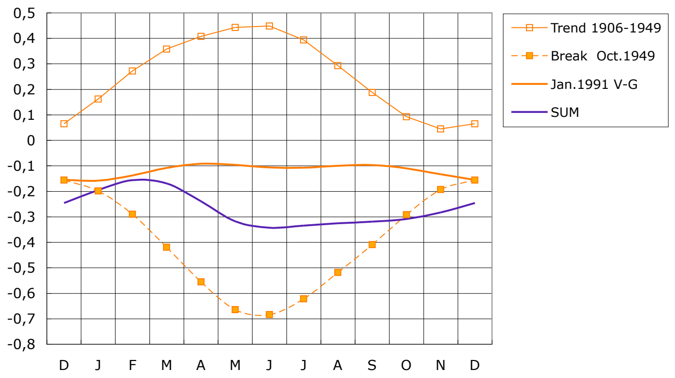

Figure 13: Smoothed seasonal cycle of the amplitudes of the total trend and the break at Gemert [°C].

5.4 Gemert/Volkel

As mentioned before, Gemert had a large break in October 1949, when the station was renovated. In the period 1906–1949 the record shows a significant positive trend relative to the reference stations Oudenbosch, De Bilt and Winterswijk. This trend was likely to have been due to a gradual growth of the vegetation at this station until the re-instalment in 1949 (see the figures 12 and 13). Both the trend and the break have been corrected for in the homogenised time series.

5.5 Deelen and Rotterdam

No breaks were detected in Deelen and Rotterdam.

5.6 Soesterberg and Twenthe

Because of the high noise levels of the records of Soesterberg and Twenthe, no attempts were made to find and correct the breaks in these records.

5.7 Eindhoven

Significant breaks were detected in Eindhoven in 1969 and 1988 (See figure 14). The metadata provided no information on the possible origin of these breaks. The net impact of the breaks on the long-term trends in Eindhoven is small. De Bilt, Winterswijk/Hupsel, Oudenbosch/GR and Gemert/Volkel were used as reference stations.

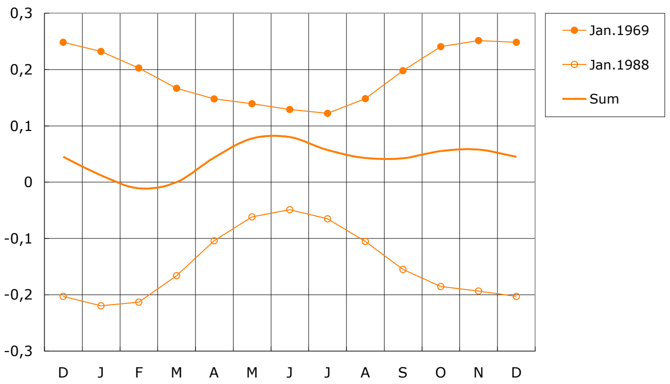

Figure 14: Smoothed annual cycle of breaks at Eindhoven [°C].

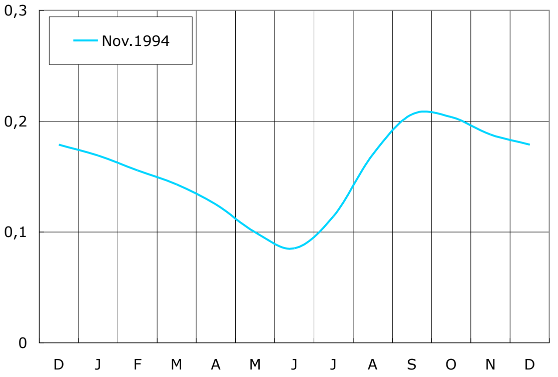

Figure 15: Smoothed annual cycle of breaks at Schiphol (Amsterdam Airport) [°C].

5.8 Schiphol

Schiphol showed a significant break in November 1994, which corresponded with a displacement of the station to a new location (runway 19R) on the airport. (See figure 15). Rotterdam, De Bilt and Deelen were used as reference stations.

5.9 Maastricht, Sittard and Beek

Maastricht and Sittard showed significant breaks relative to each other in the period 1920 to 1930. Comparison with De Bilt, Winterswijk, Oudenbosch and Gemert showed that Sittard was much more inhomogeneous than Maastricht. Therefore we did not correct Sittard. Maastricht had a break in 1920. The metadata do not give information in this year.

The transition to Beek caused a considerable cooling, as Beek is located on an exposed plateau and Maastricht in the valley below it. Beek had a break (relative to the same 4 central stations) in September 1993. This break may be related to a change in the type and position of the temperature screen. The breaks in Maastricht/Beek are shown in figure 16. The accuracy of these break estimates is less than those for the more centrally located station, because the position of Maastricht and Beek gives rise to a higher level of natural variability in their difference time-series.

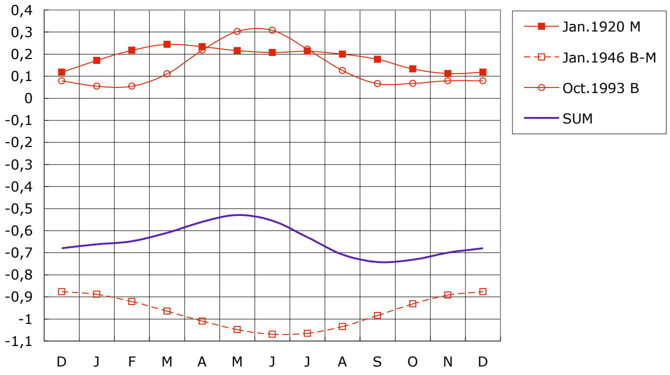

Figure 16: Smoothed annual cycle of breaks in Maastricht/Beek.

5.10 Den Helder, De Kooy, Leeuwarden and Hoorn

In the period 1909–1947, the variability of Den Helder and Hoorn is quite similar, indicating that both records were homogeneous in this period. Den Helder showed a negative break in January 1909, when the station was moved to a position on the North Sea dike. The amplitude of this break cannot be estimated accurately because of the short period of parallel observations. Den Helder is likely to be homogeneous until 1972, when the station was moved to De Kooy. Comparison with other stations indicates that De Kooy was homogeneous until present except for a period around 1989. The break in this period is difficult to quantify, because the nearest station Leeuwarden showed a large significant break in the same year. Hoorn showed significant breaks in 1948, and in 1973 and 1977. Again it was difficult to estimate the magnitude of these breaks.

5.11 Groningen and Eelde

Groningen and Eelde showed no large significant breaks. Because of the remote position of these stations, the existence of smaller breaks cannot be excluded.

6. The Central Netherlands Temperature (CNT)

Climate models compute meteorological variables at a typical scale of 100 km. Local effects caused by vegetation, small lakes and changes in altitude are not resolved by the models. To compare the model output to observations, these need to be defined at a similar scale. The Central Netherlands Temperature record (CNT) has been designed to meet this demand.

The CNT is based on the homogenised time series constructed in the preceding section. The coastal series from Den Helder/De Kooy, the northerly series from Groningen/Eelde and the southerly series from Maastricht/Beek were found to deviate too much from the more centrally located stations to form a sensible mean (cf. figure 3). Starting in 1951, Deelen and Eindhoven were added to the set of stations. Data from the airports of Amsterdam (Schiphol) and Rotterdam were not included in the CNT because these stations are situated relatively close to the sea and may have been affected by building activities. The CNT is therefore representative for the area between the cities of Utrecht, Arnhem, Breda and Eindhoven.

We first attempted to define weighing factors proportional to the inverse standard deviation of the homogenised time series with respect to the weighted mean of the other time series, using an iterative procedure. This resulted in the version that was used in Kattenberg (2008). Later research showed that large uncertainties on the weighing factors warrant a more robust definition in which all stations are weighed equally. The current definition of the CNT is therefore the straight average of the corrected monthly mean temperatures of De Bilt, Winterswijk/Hupsel, Oudenbosch/Gilze-Rijen and Gemert/Volkel until 1950, afterwards these stations plus Deelen en Eindhoven. This version is referred to as CNT4 until 1950 and CNT6 after this. A (small) correction was applied to CNT4 until 1950, in order to account for the transition from 4 to 6 reference stations. The combined series 1906-now is called the CNT4,6.

The differences with the previous definition, CNT2,7, are slight, see figure 17 and table 3. The standard deviation of the difference is 0.04°C for the annual mean, 0.07°C for individual months. The homogenised De Bilt temperature has an RMS difference with the CNT4,6 of 0.07°C in the annual mean, 0.2°C for individual months.

The trends in these time series are shown in table 4. The CNT4,6 has slightly higher trends (less than 5% higher) than those reported in Kattenberg (2008) for CT2,7. The trends are about 10% lower than the trends in De Bilt. The difference is reduced somewhat by the homogenisation, which includes an estimate of the urban heat advection to De Bilt (Brandsma *et al.*, 2003). It is not clear what causes the differences in trends. Note that the differences between the various series are still much smaller than the random errors on the trends.

All corrections in the station records and in CNT have been made relative to the most recent stations. CNT4,6 is extended every month using new observations of De Bilt, Hupsel, Gilze-Rijen, Volkel, Deelen and Eindhoven. The updated series is available from www.knmi.nl and climexp.knmi.nl, the individual homogenised series are available on request.

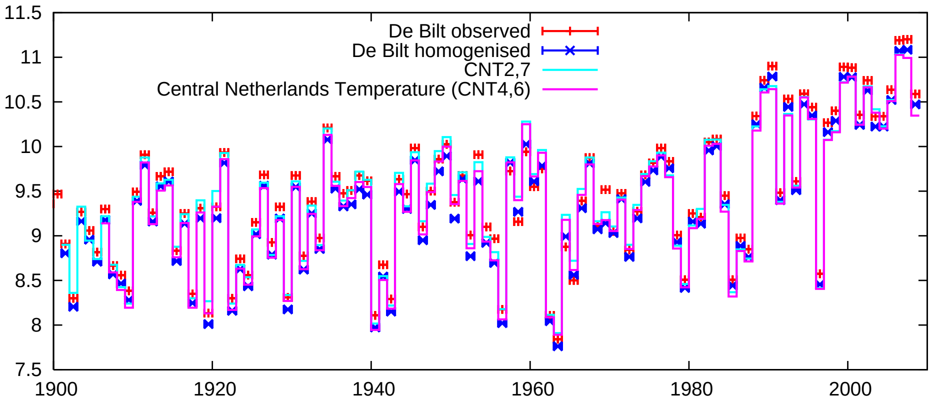

Figure 17: Annual mean temperatures of the actual observations at De Bilt, the De Bilt homogenised series (Verbeek, 2003; Kattenberg, 2008), the CNT2,7 (Kattenberg, 2008) and the current CNT4,6 described in this report.

	bias [°C]			rms difference [°C]		
	CNT2,7	$T^{\mathrm{hom}}_{\mathrm{DeBilt}}$	T_{DeBilt}	CNT2,7	$T^{\mathrm{hom}}_{\mathrm{DeBilt}}$	T_{DeBilt}
annual	0.04±0.01	0.03±0.01	0.30±0.02	0.04±0.01	0.07±0.01	0.11±0.02
DJF	0.05±0.01	0.03±0.02	0.55±0.03	0.05±0.01	0.13±0.01	0.14±0.02
MAM	0.06±0.01	0.03±0.02	0.38±0.02	0.05±0.01	0.10±0.01	0.13±0.02
JJA	0.02±0.01	0.02±0.02	0.11±0.03	0.06±0.01	0.13±0.02	0.17±0.03
SON	0.04±0.01	0.04±0.02	0.16±0.03	0.04±0.01	0.13±0.02	0.16±0.03
Jan	0.05±0.01	0.02±0.04	0.96±0.04	0.06±0.01	0.19±0.02	0.19±0.03
Feb	0.05±0.01	0.02±0.04	0.16±0.04	0.07±0.01	0.20±0.03	0.21±0.03
Mar	0.02±0.01	0.00±0.03	0.60±0.03	0.06±0.01	0.16±0.02	0.17±0.03
Apr	0.07±0.01	0.03±0.03	0.21±0.03	0.06±0.01	0.16±0.02	0.18±0.03
May	0.09±0.01	0.05±0.03	0.34±0.04	0.07±0.01	0.18±0.03	0.20±0.02
Jun	0.02±0.01	0.01±0.03	0.07±0.04	0.06±0.01	0.16±0.02	0.23±0.03
Jul	-0.00±0.01	0.00±0.03	0.17±0.04	0.07±0.01	0.16±0.02	0.21±0.04
Aug	0.04±0.02	0.05±0.04	0.09±0.04	0.09±0.01	0.20±0.02	0.20±0.03
Sep	0.01±0.01	0.03±0.04	-0.09±0.05	0.06±0.01	0.19±0.03	0.23±0.04
Oct	0.04±0.01	0.04±0.03	0.20±0.03	0.06±0.01	0.17±0.02	0.17±0.03
Nov	0.06±0.01	0.05±0.04	0.36±0.04	0.06±0.01	0.18±0.02	0.21±0.03
Dec	0.04±0.01	0.04±0.04	0.52±0.04	0.07±0.01	0.20±0.03	0.21±0.03

Table 3: Bias and root mean square differences of the CNT2,7, homogenised De Bilt temperature and observed De Bilt temperature with the CNT4,6. The errors represent the 95% confidence interval, determined using a bootstrap method.

	regression against $T^{(3)}_{\mathrm{global}}$				linear trend [°C/100yr]			
1950–2008	CNT4,6	ΔCNT2,7	$\Delta T^{\mathrm{hom}}_{\mathrm{DeBilt}}$	$\Delta T_{\mathrm{DeBilt}}$	CNT4,6	ΔCNT2,7	$\Delta T^{\mathrm{hom}}_{\mathrm{DeBilt}}$	$\Delta T_{\mathrm{DeBilt}}$
annual	2.3±0.8	-0.10±0.03	0.18±0.10	0.23±0.15	2.6±1.0	-0.12±0.04	0.28±0.11	0.34±0.18
DJF	2.3±2.0	-0.13±0.04	0.25±0.14	0.28±0.17	3.4±2.6	-0.15±0.06	0.35±0.18	0.43±0.21
MAM	2.9±1.0	-0.09±0.03	0.15±0.12	0.20±0.17	3.1±1.4	-0.11±0.05	0.22±0.16	0.27±0.22
JJA	2.1±1.2	-0.08±0.06	0.11±0.17	0.21±0.21	2.5±1.4	-0.15±0.06	0.26±0.19	0.35±0.25
SON	1.7±1.2	-0.07±0.05	0.18±0.17	0.22±0.25	1.5±1.4	-0.09±0.06	0.29±0.20	0.32±0.29
1906–2008	CNT4,6	ΔCNT2,7	$\Delta T^{\mathrm{hom}}_{\mathrm{DeBilt}}$	$\Delta T_{\mathrm{DeBilt}}$	CNT4,6	ΔCNT2,7	$\Delta T^{\mathrm{hom}}_{\mathrm{DeBilt}}$	$\Delta T_{\mathrm{DeBilt}}$
annual	1.7±0.5	-0.09±0.02	0.06±0.06	0.05±0.08	1.3±0.4	-0.08±0.02	0.05±0.05	0.01±0.07
DJF	1.1±1.4	-0.07±0.04	0.06±0.09	0.23±0.10	1.1±1.2	-0.06±0.03	0.01±0.08	0.20±0.09
MAM	1.8±0.6	-0.10±0.03	0.09±0.07	-0.01±0.10	1.3±0.6	-0.09±0.03	0.06±0.06	-0.06±0.08
JJA	2.1±0.7	-0.12±0.04	0.13±0.10	-0.15±0.14	1.6±0.6	-0.12±0.03	0.16±0.08	-0.21±0.11
SON	1.8±0.8	-0.04±0.04	-0.03±0.11	0.14±0.14	1.3±0.6	-0.05±0.03	-0.03±0.08	0.13±0.11

Table 4: Trends in the CNT4,6, and in difference with the old CNT2,7, the homogenised De Bilt temperature and the observed De Bilt temperature. Trends are defined as regressions against the global mean temperature (HadCRUT3) with a 3-yr running mean (as in Kattenberg, 2008) and as linear trends. The errors represent the 95% confidence interval, assuming the residuals are normally distributed.

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