Royal Netherlands
Meteorological Institute
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Effects of lowering thermometers screens in the Netherlands around 1960

T. Brandsma

De Bilt, 2022 | Technical report; TR-400

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Corrigendum

Page 9-10

"Each 10-min value is the mean of five 12-sec temperature samples in the last minute of the 10-min interval."

Must read

"Each 10-min value is the mean of fifty 12-sec temperature samples in the 10-min interval."

Contents

Summary

As a result of a new WMO regulation, KNMI lowered its thermometer screens around 1960 from 2.20 to 1.50 m above ground level. The present study analyses parallel air temperature measurements in screens at the two heights in De Bilt in the period 2017–2019. The results are compared with results of two one-year comparisons at KNMI stations De Bilt and Witteveen in the 1950s.

We found an increase in the diurnal temperature range on 1.50 m compared to 2.20 m, with a slight increase in daily maximum temperatures and a somewhat larger decrease in daily minimum temperatures. The effect on the mean daily temperatures is negligible. The effect of the lowering of the screen on annual minimum temperatures is a decrease of about 0.2°C, while the effect on annual mean maximum temperature is an increase of about 0.1.°C. In general, the differences in 2.20 and 1.50 m air temperature show a seasonal cycle with the largest values in summer and the smallest in winter.

It is argued that there is a real effect on temperature of the lowering of thermometer screen in the Netherlands around 1960. The effect is small and depends on wind speed. Therefore, it is not feasible to correct the time series of all five principal stations in the Netherlands. The added value of the present study is that it gives an estimation of the order of magnitude of the temperature differences due to the lowering of the thermometer screens.

Chapter 1

Introduction

Thermometer screens are used in meteorology and climatology to minimize environmental effects of, for instance, precipitation and radiation on the temperature sensor. Although international guidelines have been specified to obtain uniformity in the measurements [10], no standard thermometer screen has been defined. This includes the choice between natural or artificial ventilation. Consequently, many different designs of thermometer screens are in use in the world, each with its own specific characteristics. Also the height of the screen above ground level may vary from country to country, generally within the WMO prescribed measurement height of 1.25–2.0 m above ground level. This report focuses on the effects of a change in temperature screen height in the Netherlands on the measured temperatures. The effects of changes in screen type in the Netherlands have been discussed elsewhere [3, 6, 2].

1.1 Background

Around 1960, KNMI reduced the thermometer screen height in the Netherlands from 2.20 m to 1.50 m[1] above ground level. Figure 1.1 shows the situation at the KNMI operational field in De Bilt just after lowering the thermometers screens. Table 1.1 present the transition dates for the five main stations in the Netherlands.The reason for the lowering of the screens, was a new WMO regulation prescribing a measurement height of 1.25–2.0 m above ground level. For KNMI, an additional reason for lowering the the measurement height was the need of stairs to make observations in the 2.20 m screen. Measuring at 1.50 m removed this need.

[1] Screen height equals the height above ground level of the temperature sensor inside the screen.

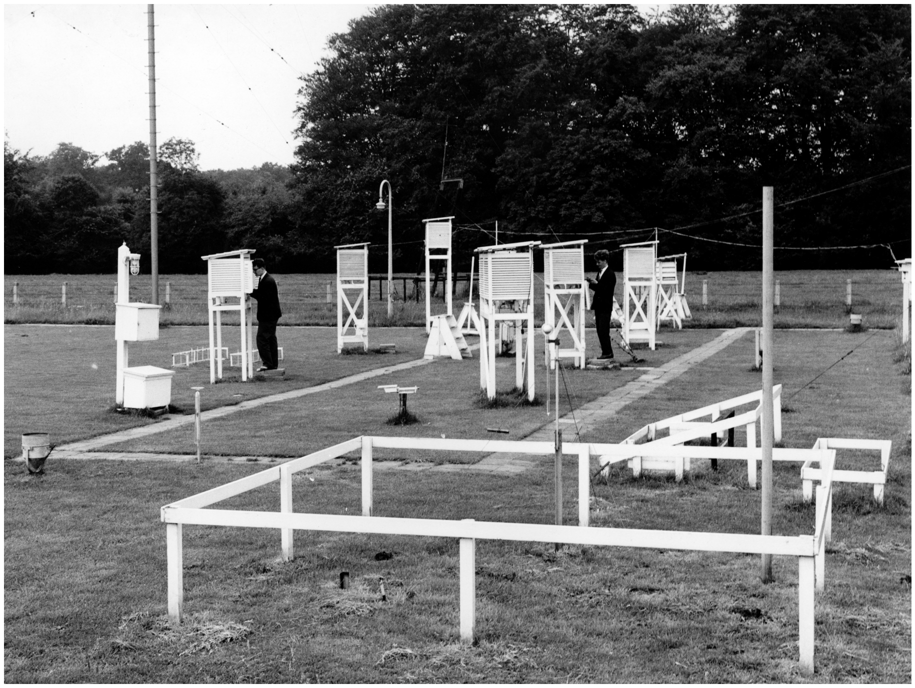

Figure 1.1: Situation of the thermometer screens on the KNMI operational field just after the lowering of the thermometer screens from 2.20 m to 1.50 m in 1961. In the back a 2.20 m screen is still visible together with the stairs.

Station	Transition date (yyyymmdd)	Current name (WMO nr.)
Den Helder/De Kooy	19611124	De Kooy (06235)
De Bilt	19610629	De Bilt(06260)
Groningen/Eelde	19590731	Eelde (06280)
Vlissingen	19611003	Vlissingen (06310)
Maastricht/Beek	19610414	Maastricht (06380)

Table 1.1: Transition dates for lowering thermometer screens from 2.20 to 1.50 m for the five principal KNMI stations.

In anticipation of the lowering of the screens, two 1-year comparison studies were performed:

1. A comparison in De Bilt lasting from May 1952–April 1953 (Appendix B).

2. A comparison in Witteveen lasting from August 1958–July 1959 (Appendix C.

Both studies showed an increase in the diurnal temperature range on the 1.50 m screen height compared to 2.20 m, with a slight increase in daily maximum temperatures and a somewhat larger decrease in daily minimum temperatures. The effect on the mean daily temperatures was negligible.

Sparks [9] and Parker [7] brought together data on the effect of thermometer (screen) height on observed temperature, and through several studies demonstrated that the lower screens produce greater diurnal ranges than higher screens. They also showed that the increase in range was largest in midsummer and smallest in winter. No averages for daily temperatures were given. Sparks concluded that differences in temperature measurement due to differences in screen height may occur even though heights are within the range specified in WMO publications.

Recently a intercomparision study was undertaken at the KNMI test field in De Bilt, comparing three different thermometer screens (an old pagode, a Stevenson screen, and the current KNMI multi-plated screen) using modern sensors and calibrations. For one of the screens (KNMI multi-plated) measurements were made at both 2.20 and 1.50 m. This report analyses three years of these measurements (2017–2019) and compares its results with the earlier studies.

1.2 Objective and scope

In 2016 KNMI presented homogenized daily temperature series of the five principal stations[1]. The homogenization focused 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 study mentioned the lowering of the thermometer screen from 2.2 m to 1.5 m around 1960 as another known source of inhomogeneities that might need correction. The objective of this report is assess the need for this correction. We will study the climatological differences of parallel temperature measurements at 2.20 m and 1.50 m in the Netherlands. In addition, the dependence of these differences to the weather conditions will be addressed. The study focuses on the parallel measurement in the 2017–2019 period. The earlier measurements in De Bilt and Witteveen are presented in appendix B and C and discussed in the main text.

Chapter 2

Instruments, data and methods

2.1 Instrument setup

In September 2016 KNMI started an experiment on its test field in De Bilt comparing three thermometer screens: a pagode, a Stevenson and a KNMI multi-plated screen. Since 1901 these three screens have consecutively been used as operational thermometer screens: the pagode to 15 September 1950, the Stevenson from 16 September 1950–25 June 1993, and the KNMI multi-plated screen from 26 June 1993 till present. Figure 2.1 shows the screens at the KNMI test field in De Bilt. In front a cup anemometer is shown, measuring wind speed at 2.20 m above ground level. The KNMI multi-plated screen measures temperatures at both 2.20 and 1.50 m above ground level.

Temperature in all screens was measured using platinum resistance thermometers, Pt-500. These sensors are in use at all KNMI automatic weather stations in the Netherlands. The sensors and the test field were subject to the same management and maintenance as the stations and sensors in the operational network. An exception is the calibration of the Pt-500, which was done before, during and after the experiment.

On the test field all other relevant meteorological variables were being measured like humidity, wind direction, radiation, cloudiness, precipitation, visibility.

2.2 Data and methods

Data

In this study we used the measurements from the 3-year period January 2017 to December 2019. The measurements apply to 10-min temperature data. Each 10-min value is the mean of five 12-sec temperature samples in the last

Figure 2.1: Situation of the thermometer screens on the KNMI test field in De Bilt. The KNMI multi-plate screen (KNMI schotel) is double and measures at both 2.20 and 1.50 m above ground level. The measurements of the multi-plated screens are the subject of the present study. The anemometer is at 2.20 m above ground level and is used in the analysis of this report. Photograph is taken in Northerly direction.

minute of the 10-min interval. The daily maximum, minimum, and mean temperatures (Tmean, Tn, Tx) were calculated as, respectively, the mean, minimum and maximum of all 144 10-min measurements in a day running from 0:00–0:00 UTC. Note that Tn and Tx used here differ slightly from the regular climatological values. The latter use the daily extremes of the 1-minute averaged values updated every 12 seconds.

All temperature sensors were calibrated in the KNMI calibration lab. Appendix A describes how the resulting calibration values were used to correct the sensors values. This reduces the measurement uncertainty from about 0.1°C to 0.01°C. Note that this not standard practice for operational sensors at KNMI.

Methods

In the study we compare the temperature differences (2.20 m - 1.50 m) for Tmean, Tn and Tx (ΔTmean, ΔTn, ΔTx). The differences are compared at a monthly and daily level. In addition, diurnal cycle differences are considered and the dependence of temperature differences to wind speed and cloudiness is investigated. In all cases the corrected 10-minute temperature values are the basis for the derived daily or monthly values.

For the calculation of the statistical significance of monthly mean values calculated from daily values it is often necessary to take into account the serial correlation of the daily values. The method used here is described below [4, 5].

For n independent observations $x_1, x_2, ..., x_n$ the standard error of the mean $se_{\overline{x}}$ is defined as:

$$se_{\overline{x}} = \frac{s}{\sqrt{n}} \tag{2.1}$$

where s is the sample standard deviation.

As daily meteorological observations are usually not independent $se_{\overline{x}}$ has to be multiplied by a factor resulting in a corrected standard error $se^*_{\overline{x}}$:

$$se^*_{\overline{x}} = f\, se_{\overline{x}} \tag{2.2}$$

where the factor f is defined as:

$$f = \sqrt{\left(\frac{1+\rho}{1-\rho}\right)} \tag{2.3}$$

where ρ is the auto-correlation coefficient.

Chapter 3

Results

3.1 Time series

Figure 3.1 shows monthly values of rainfall, wind speed, cloudiness and temperature in the observation period. There is strong variation from month to month, which is common in the Netherlands.

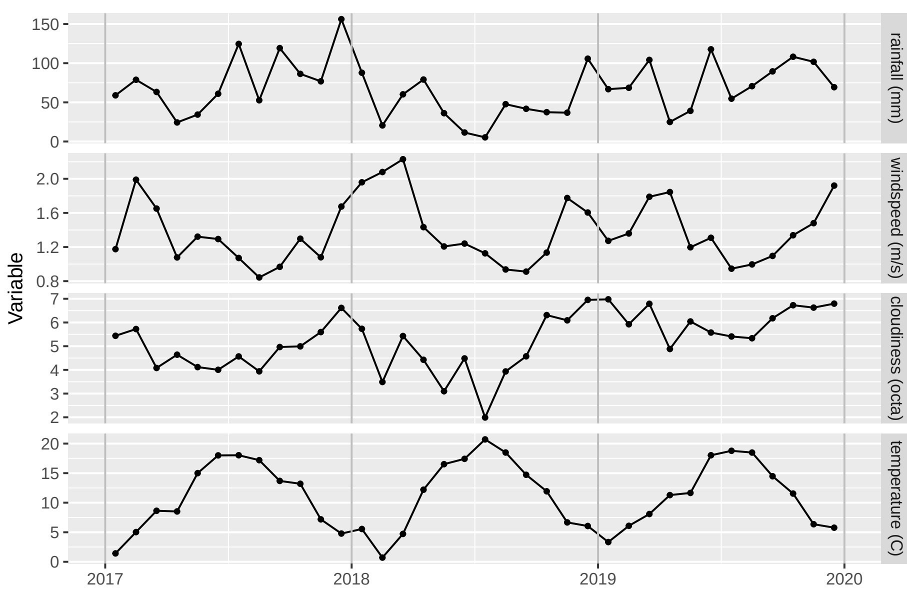

Figure 3.1: Monthly values of relevant weather variables in the observation period 2017–2019. Wind speed (2.20 m) and temperature (1.50 m) are from the experimental site (Figure 2.1), rainfall and cloudiness are from the nearby backup sensors at the test field (De Bilt 06261).

Figure 3.2 shows the monthly temperature differences between the screen at 2.20 and 1.50 m. ΔTx is negative but small (of the order of the measurements uncertainty of operational temperature measurements of 0.1°C). ΔTn is positive and mostly larger than the measurement uncertainty. It varies from 0.08°C in December 2017 to 0.36°C in July 2019. ΔTmean is slightly positive but mostly smaller than the operational measurement uncertainty. Note also the year-to-year variability of the temperature differences. This stresses the need for multi-year comparisons.

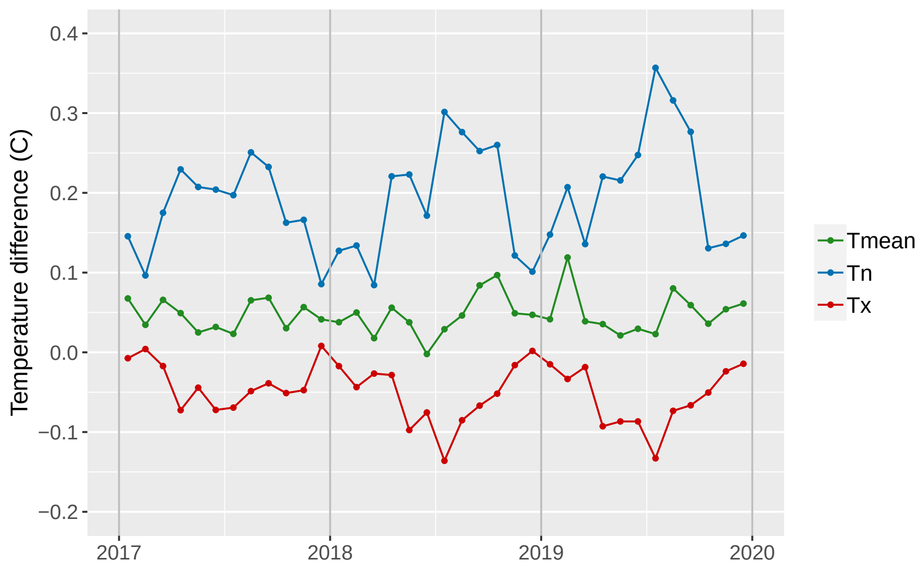

Figure 3.2: Monthly differences between temperatures in the screens (2.20 m – 1.50 m) in the observation period 2017–2019.

3.2 Seasonal cycle of temperature differences

Figure 3.3 shows for each month the spread of the daily temperature differences using boxplots. Mainly for Tn there may be large daily differences. In July 10% of the difference values are larger than 0.57°C.

Figure 3.4 shows the monthly mean temperature differences. Although ΔTn and ΔTmean are small, they are mostly significantly different from zero. In summer ΔTn is up to about 0.3°C whereas for ΔTx the most extreme value are also in summer and vary around 0.1°C. The mean temperature differences vary around 0.05°C. Note the large standard errors for ΔTn compared to ΔTx

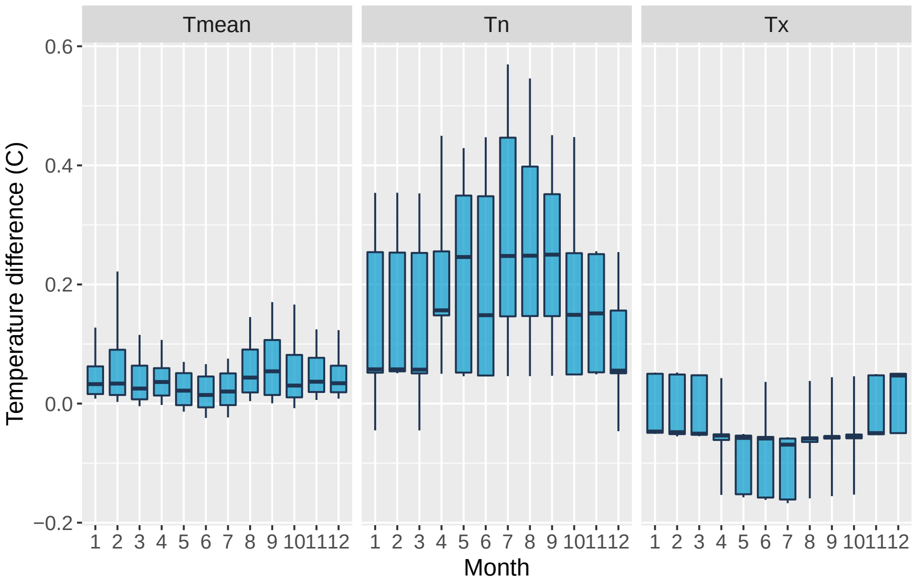

Figure 3.3: Boxplots of daily temperature differences between temperatures in the screens (2.20 m – 1.50 m) in the observation period 2017–2019. The lower and upper boundaries of the box correspond with the 25 and 75th percentile, respectively, the whiskers correspond with the 10 and 90th percentiles and the horizontal line is the median. The distribution of the temperature differences may sometimes cause the whiskers and/or median to coincide with the upper or lower boundary of the box.

and ΔTmean. Table 3.1 summarizes the monthly mean temperature differences.

3.3 Diurnal cycle of temperature differences

Figure 3.5 shows the diurnal temperature cycles per season and the differences in cycles between the two measurements heights. The temperature differences are rather constant during the day and the night. Around sunrise and sunset – when the energy balance changes sign – also the sign of the temperature differences changes. The diurnal temperature range of the temperature differences is largest in summer and smallest in winter. In spring it is slightly larger than in autumn.

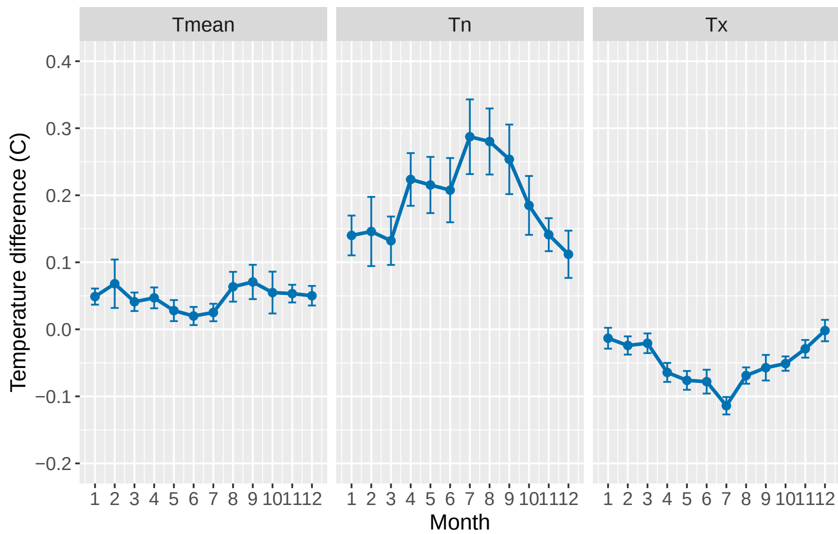

Figure 3.4: Monthly mean temperature differences between temperatures in the screens (2.20 m – 1.50 m) in the observation period 2017–2019. The error bars present the 2xse* values.

month	ΔTmean	ΔTn	ΔTx
1	0.05	0.14	–0.01
2	0.07	0.15	–0.02
3	0.04	0.13	–0.02
4	0.05	0.22	–0.06
5	0.03	0.22	–0.08
6	0.02	0.21	–0.08
7	0.03	0.29	–0.11
8	0.06	0.28	–0.07
9	0.07	0.25	–0.06
10	0.05	0.18	–0.05
11	0.05	0.14	–0.04
120	0.05	0.11	–0.00
year	0.05	0.19	–0.05

Table 3.1: Monthly mean differences (°C) between temperatures in the screens (2.20 m – 1.50 m) in the observation period 2017–2019.

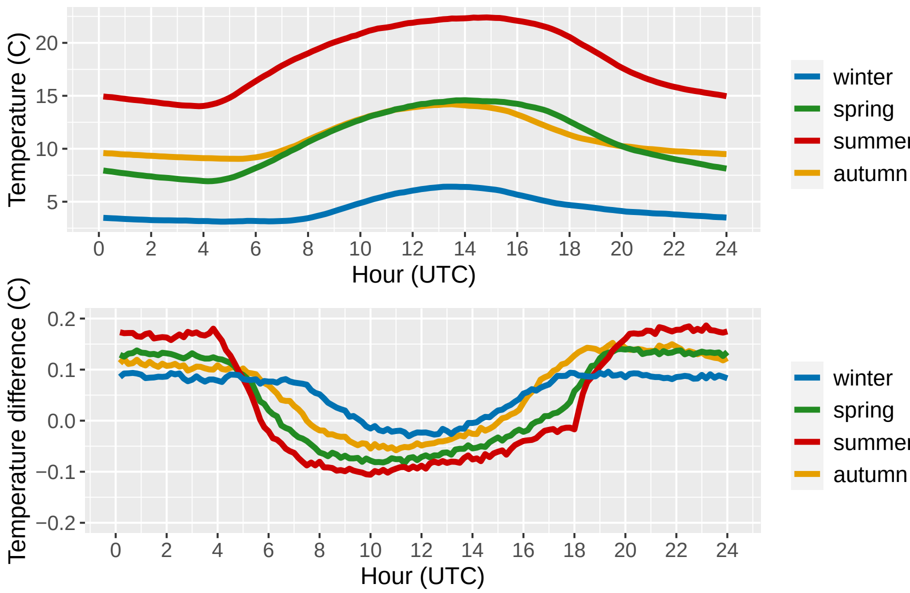

Figure 3.5: Diurnal temperature cycle at 1.50 m for each season (top) and the differences between the diurnal cycles in the screens (2.20 m – 1.50 m) (bottom) in the observation period 2017–2019. Temperatures are at 10-min intervals. Winter is DJF, spring MAM, summer JJA, autumn (SON).

3.4 Dependence on cloudiness and wind speed

Cloudiness and wind speed are the main variables influencing the vertical temperature profile near the ground. During the night, clear-sky and calm conditions create stable conditions near the ground. The resulting strong positive temperature gradient, causes higher temperatures at 2.20 m compared to 1.50 m. During the day it is the other way around. Clear-sky and calm conditions then cause lower temperatures at 2.20 m compared to 1.50 m.

For this study we determine the dependence of ΔTn and ΔTx on cloud cover and wind speed in summer. Summer is selected because in that time of the year the screen differences are largest.

Figures 3.6 and 3.7 show the ΔTn and ΔTx as a function of wind speed for three cloud cover categories. For ΔTn the figure shows a strong relationship with wind speed for low wind speeds (< 1 m/s). The effect of cloudiness is small. For ΔTx there is no notable effect of both wind speed and cloudiness.

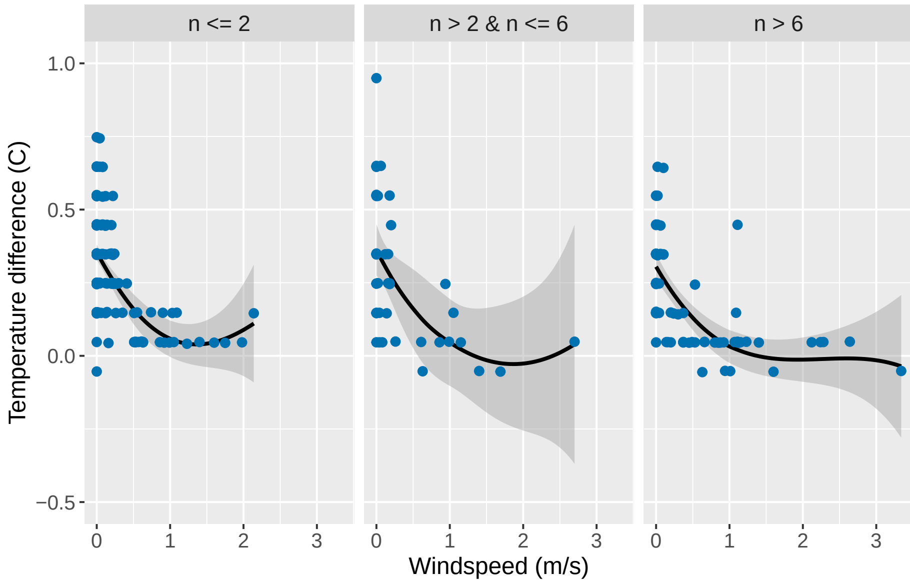

Figure 3.6: Dependence of ΔTn on wind speed for three cloudiness categories in the observation period 2017–2019 in summer (JJA). Cloud cover (n) and wind speed apply to the moments of occurrence of Tn. Cloud cover is in octas. A loess fit with a two times standard error band (in grey) is added.

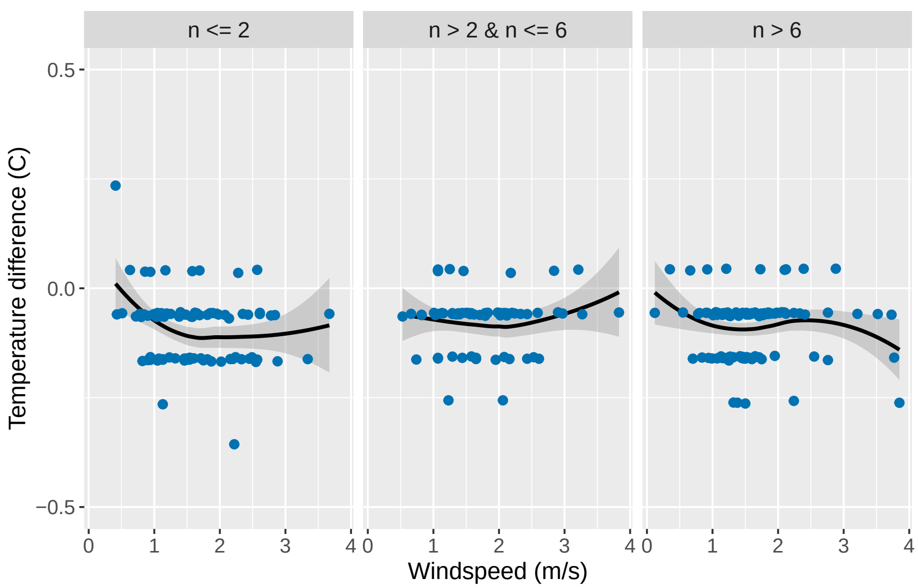

Figure 3.7: See 3.6 but now for ΔTx.

Chapter 4

Discussion and conclusion

The results of the 2017-2019 comparison are in line with the earlier comparisons in De Bilt and Witteveen (Appendix B and C) and international findings. Note that the earlier comparisons for De Bilt and Witteveen are for one year only and with a larger measurements uncertainty than the 2017-2019 comparison. For reasons mentioned in chapter 1, we have somewhat less confidence in the old parallel measurements in De Bilt than in the other measurements.

In general, there is an increase in the diurnal temperature range on 1.50 m compared to 2.20 m, with a slight increase in daily maximum temperatures and a somewhat larger decrease in daily minimum temperatures. The effect on the mean daily temperatures is negligible. Table 4.1 compares the annual mean differences for three comparisons in the Netherlands. The effect of the lowering of the screen on Tn is decrease of about 0.2°C, while the effect on Tx is an increase of about 0.1°C. For the recent three-year comparison the table shows the variation between years.

These effects of the screen lowering are small compared to the long-term trends in Tn and Tx of about 2°C in the Netherlands (1901–present)[1]. Cor-

Experiment	ΔTmean	ΔTn	ΔTx
De Bilt (2017–2019)	0.05	0.19	–0.05
	[0.05, 0.05]	[0.18, 0.21]	[–0.06, –0.04]
De Bilt (May 1952–Apr 1953)		0.16	–0.17
Witteveen (Aug 1958–Jul 1959)		0.18	–0.08

Table 4.1: Summary of annual mean mean temperature differences (°C) between temperatures in the screens (2.20 m – 1.50 m) in for the three experiments. The values in square brackets give the lower and upper values in the three individual years.

rection for the transition of the screen height would slightly increase the long-term trend in Tn and slightly decrease the trend in Tx.

In addition, the seasonal temperature differences are small compared to most of the corrections used in the homogenization of the five principal stations in the Netherlands[1]. For Tn in summer, these differences depend on wind speed at measurement height. In theory one would also expect a relationship with with wind speed and probably cloudiness for Tx. However, the ΔTx values are apparently too small to show this relationship.

If needed, the present results for the De Bilt can be used (with caution due to the relocation in 1951) tot correct the daily Tn and Tx time series of De Bilt for the transition to the 1.50 m thermometer screen. However, for the other four principal stations we do not have parallel measurements for the screen height change. Especially for the coastal stations, we expect smaller effect of the screen lowering due to the higher wind speeds. For these stations, the effect of the screen lowering can also not be estimated from nearby stations because (a) all stations have the transition around 1960, and (b) the magnitude of temperature effects is relatively small.

In conclusion, there is an effect on temperature of the lowering of thermometer screen in the Netherlands around 1960. The effect is small and it is probably not feasible to correct the time series of all five principal stations. The present study allows for the estimation of the order of magnitude of the temperature effects.

Acknowledgements

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Appendix A

Calibration results

Figure A.1 shows the calibration curves of the four sensors used in the experiment at the KNMI test field. Only two of them (muliplate22 and multiplate15) are used in the current study. The calibration curves have been determined in the KNMI calibration lab. They have been obtained before, during and after the study period 2017–2019.

The figure shows different calibration curves for the individual sensors but for each sensor there is hardly any difference between the curves for the different calibration dates. Therefore, for each sensor the mean of the three calibration curves was used to correct the measured temperatures in the 2017-2019 period. The corrected temperature equals the measured temperature plus the correction. Corrections for intermediate temperatures were obtained by linear interpolation.

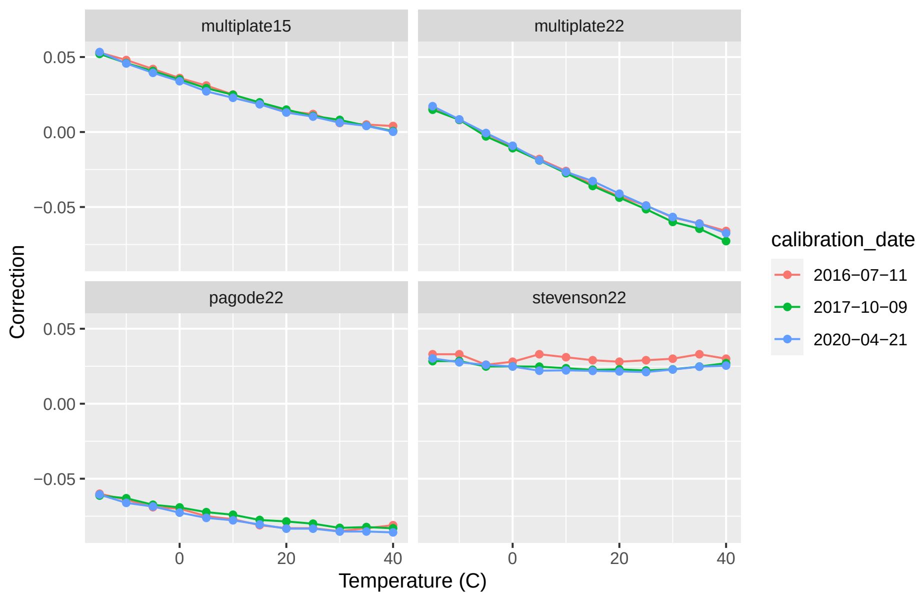

Figure A.1: Calibration curves of the sensors used in the experiment at the KNMI test field for three dates (yyyy-mm-dd). The curves for multiplate15 (screen at 1.50 m) and multiplate22 (screen at 2.20 m) were used to correct the temperatures in the present study.

Appendix B

Comparison in De Bilt 1952–1953

From May 1952–April 1953 an experiment took place at the KNMI measurement field, comparing the (then) operational temperature measurements at 2.20 m above ground level with measurements at 1.50 m above ground level. The reason for this experiment was a WMO technical regulation stating: "Air temperature at synoptic surface land stations, aeronautical meteorological stations and climatological stations should be measured at a height of between 1.25 and 2.0 meters above ground level".

Three-times a day readings were done of the dry bulb thermometers and the minimum and maximum thermometers. In addition, hourly temperatures were derived from thermograph readings. The experiment was restricted to working days.

In an internal document Rijkoort [8] wrote about the screen height comparison. He was not satisfied with the quality of the measurements. He mentions: (1) wrong interpretation of strip charts, (2) the three-times a day measurements at 1.50 m were made by another observer, and (3) the observation time of the third observation at 1.50 m deviated from the standard observation time. Standard observation times were 8, 14, en 19 local time, corresponding to 7:40, 13:40 and 18:40 UTC, respectively. In contrast to the regular observation at 19 hours, the third observation at 1.50 m was done at 16 hours local time.

Rijkoort concluded that a lowering of measurement from 2.20 m to 1.50 m would:

1. Increase the amplitude of the diurnal temperature cycle by about 0.25°C (probably stronger in summer than in winter).

2. Hardly or not affect the daily mean temperatures.

3. Decrease the daily minimum temperature by about 0.15°C and increase the daily maximum temperature by about the same amount.

The measurements of this comparison are archived at KNMI (A-297; De Bilt, Vergelijking temperatuur 1.50 m/2.20 m hoogte, Mei 1952–April 1953). We digitized these measurements and analysed the daily minimum (Tn) and maximum (Tx) temperature values (8–8 local time).

Figure B.1 shows the boxplot of the daily temperature differences for each month. Table B.1 summarises the mean monthly temperature differences. Given a measurement uncertainty of about 0.1°C, the temperature differences are small. This supports the decision of KNMI to lower the thermometer screen from 2.20 m to 1.50 m.

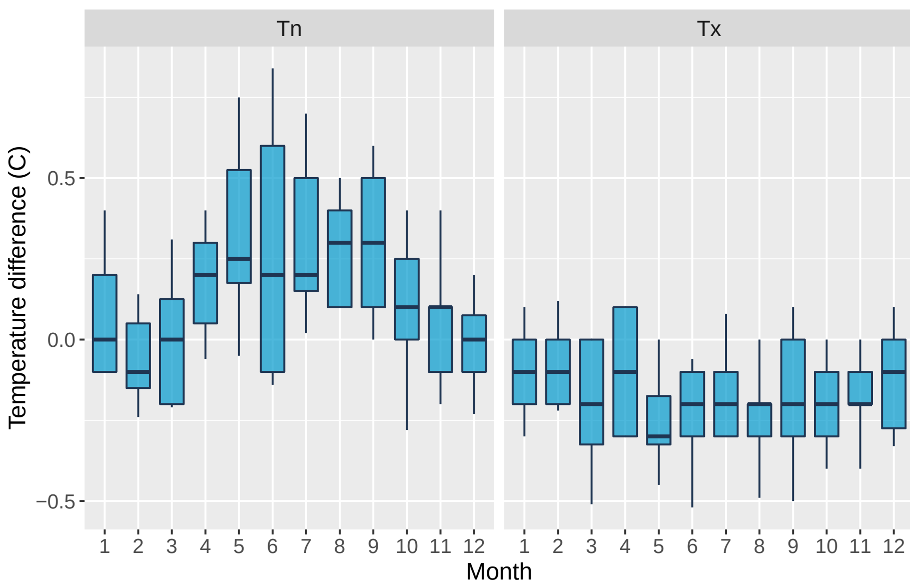

Figure B.1: Boxplots of daily (8–8) Tn and Tx temperature differences between temperatures in the screens (2.20 m – 1.50 m) in the observation period May 1952–April 1953. See Figure 3.3 for an explanation of the boxplot.

month	ΔTn	ΔTx
1	0.08	–0.09
2	–0.06	–0.04
3	–0.00	–0.20
4	0.17	–0.13
5	0.33	–0.26
6	0.24	–0.24
7	0.33	–0.16
8	0.31	–0.24
9	0.28	–0.15
10	0.12	–0.20
11	0.09	–0.18
12	–0.01	–0.17
year	0.16	–0.17

Table B.1: Monthly mean differences (°C) between temperatures in the screens (2.20 m – 1.50 m) in the observation period May 1952–April 1953.

Appendix C

Comparison in Witteveen 1958–1959

From August 1958–July 1959 another screen height comparison experiment took place at KNMI station Witteveen in the Northeast of the Netherlands (Figure C.1). Witteveen was chosen for the experiment because it was considered the most enclosed KNMI station, situated in a forested area. It was known that the temperatures differences between heights tend to decrease with increasing wind speed. In Witteveen wind speed would be the lowest of all stations thus providing an upper boundary for the effect of decreasing screen height from 2.20 to 1.50 m.

Ten Kate described the results in an internal note. His conclusions were:

1. Tx is 0.1°C lower at 2.20 m compared to 1.50 m.

2. Tn is 0.2–0.3°C higher at 2.20 m compared to 1.50 m.

Strangely, no mention is made of the earlier measurements in De Bilt (Appendix B).

The written measurements are archived at KNMI (A-297; Witteveen August 1958/July 1959, Vergelijking temperatuur in Stevenson hutten op 2.20 en 1.50 m hoogte). Only Tn and Tx (19–19 local time) were presented (also in the weekend). We digitized these measurements and analysed the daily Tn and Tx values.

Figure C.2 shows the boxplot of the daily temperature differences for each month. Table C.1 summarises the mean monthly temperature differences. Given a measurement uncertainty of about 0.1°C, the temperature differences were considered small. This was seen as support for the decision of KNMI to lower the thermometer screen from 2.20 m to 1.50 m.

Figure C.1: Thermometer screens at 1.50 m (front) and 2.20 m (back) above ground level at KNMI station Witteveen at 9 September 1958. Photograph taken in west-southwesterly direction

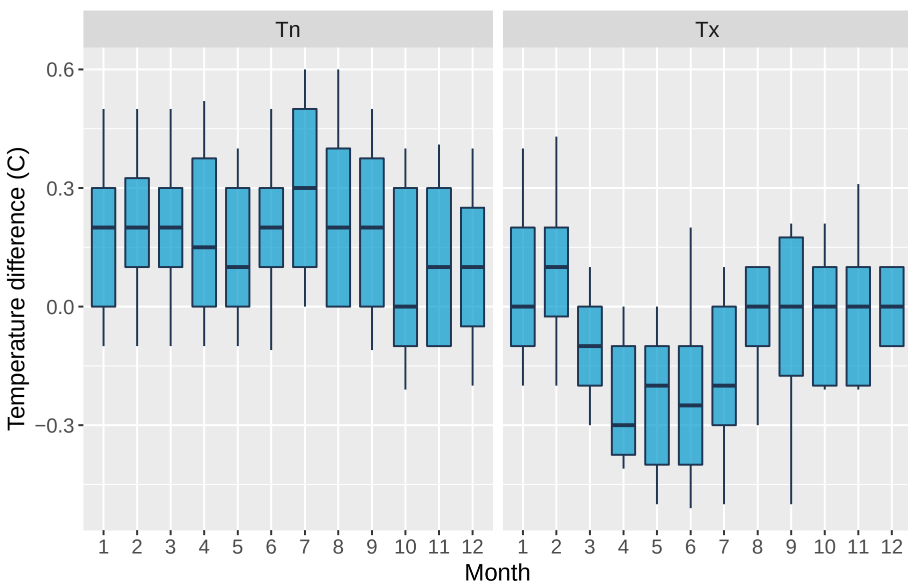

Figure C.2: Boxplots of daily (19–19) Tn and Tx temperature differences between temperatures in the screens (2.20 m – 1.50 m) in the observation period August 1958–July 1959. See Figure 3.3 for an explanation of the boxplot.

month	ΔTn	ΔTx
1	0.21	0.03
2	0.21	0.12
3	0.19	–0.10
4	0.22	–0.23
5	0.15	–0.21
6	0.21	–0.23
7	0.29	–0.21
8	0.22	–0.04
9	0.16	–0.06
10	0.10	–0.04
11	0.15	0.02
12	0.08	0.00
year	0.18	–0.08

Table C.1: Monthly mean differences (°C) between temperatures in the screens (2.20 m – 1.50 m) in the observation period August 1958–July 1959.

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