Understanding inter-site temperature differences at the KNMI terrain in De Bilt (the Netherlands)

Theo Brandsma
Royal Netherlands Meteorological Institute (KNMI), PO Box 201,
3730 AE De Bilt, the Netherlands, Tel: +31 302206911, Fax: +31 302210407,
theo.brandsma@knmi.nl

ABSTRACT

From May 2003 through June 2005 a field experiment was carried out at the KNMI terrain in De Bilt. At five sites, including the operational site, temperature and wind speed were measured at a height of 1.5 m every minute, using identical instruments. The temperature differences between the sites have been studied in connection with the wind speed differences and operationally measured weather variables. During the experiment (in October 2004) a renovation of the nature area just west of the operational temperature screen took place. The renovation introduced an inhomogeneity in the temperature time series at the operational site. The inter-site temperature differences are largest in summer and smallest in winter. Except for the most enclosed site, these temperature differences have opposite signs for daily maximum and minimum temperatures. As could be expected, the magnitudes of the differences strongly depend on the weather conditions. The understanding of these dependencies is an important condition for improving the homogenization of daily temperature series.

INTRODUCTION

Temperature measurements are often an object of debate. Questions arise whether the measurements are representative for the area that the stations are supposed to represent, or whether the temperature time series are homogeneous enough to allow studies of climate trends and climate variability. Meteorologists mostly emphasize the first question while climatologists are generally more concerned about the second question.

In this context, thermometer exposure and siting are important. WMO (1996) states: “In order to achieve representative results when comparing thermometer readings at different places and at different times, a standardized exposure of the screen and, hence, of the thermometer itself is also indispensable. For general meteorological work, the observed temperature should be representative of the free air conditions surrounding the stations over as large an area as possible, at a height of between 1.25 and 2 m above ground level. The height above the ground level is specified because large vertical temperature gradients may exist in the lowest layers of the atmosphere. The best site for the measurements is, therefore, over level ground, freely exposed to sunshine and wind and not shielded by, or close to, trees, buildings and other obstructions." From this statement it is obvious that sheltering, and changes in sheltering due to e.g. growth of trees or relocation are undesirable for air temperature measurements.

The present study aims at quantifying the possible effects of sheltering on temperature measurements. These effects have been studied at the local scale of the KNMI-terrain in De Bilt in a two-year experiment by comparing five different sites. Other causes that may affect temperature series, e.g., urbanization and reclamation of land, are not taken into account. The effect of urbanization on the temperature series of the De Bilt is discussed in Brandsma *et al*. (2003).

This paper summarizes some of the results of the experiment in De Bilt. An extensive description of the instrumental setup and calibration can be found in Brandsma (2004) that presents the results of the first year of the measurements.

BACKGROUND AND METHODOLOGY

Background

The particular exposure problems in De Bilt are illustrated in Figure 1. The figure shows the location of the operational thermometer screen De Bilt 260 (DB260) at the instruments field of KNMI. The first problem originates from the lines of trees that run from south of DB260 to north-northeast. The present height of the trees

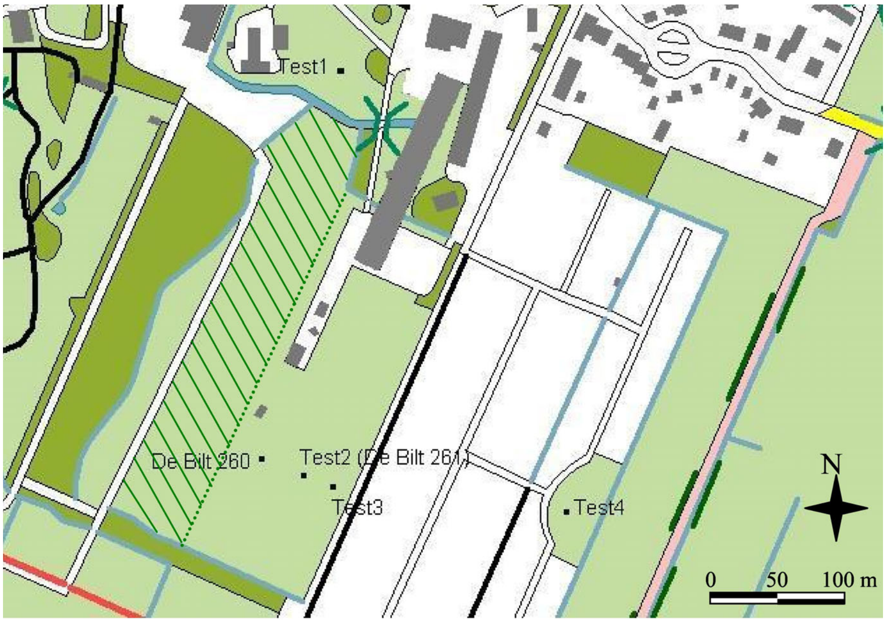

Figure 1: Location of the operational site (DB260) and the 4 parallel sites (Test1-Test4) at the KNMI terrain in De Bilt. Light green is grass cover and dark green trees. The white area that runs from mid bottom to top right consists mainly of vegetable gardens. The KNMI buildings are in gray (left from the vegetable gardens). The green hatched area represents a nature area.

varies from about 20 to 30 meter. Because the thermometer screen at DB260 is amply within the range of 8-12 times the obstacle height, local effects may affect the temperature measurements. The predominant southwesterly flow further attributes to this problem. In addition, in 2–3 years before the start of the experiment, the area west of DB260 (the green hatched area) had been transformed into nature. During the period May 2003–September 2004 the bushes in the nature area had heights up to 2 to 3 m at a distance of only 12 m from DB260, thus creating an extra shelter effect. In October 2004 the nature area has been renovated completely (see Figure 2), introducing an inhomogeneity in the measurements during the experiment.

The second problem deals with long-term homogeneity. At 27 August 1951 the operational thermometer screen was moved from location Test1 to the current DB260 location. It is known that this relocation, combined with a change in screen type and a minor relocation on 16 September 1950, caused a jump downwards in the maximum temperatures, especially in the summer. The change in screen type was accompanied by parallel measurements. We digitized and analyzed these data and found that the screen transition partly explains the downward dump in summer maximum temperature. Unfortunately, no parallel measurements were performed for the relocation, making it difficult to correct for the jump, especially for the daily series. Moreover, since the relocation in 1951 the height of the line of trees increased considerably. The height of the line of trees varied at that time between 5 and 25 m, indicating a gradual growth of the trees between

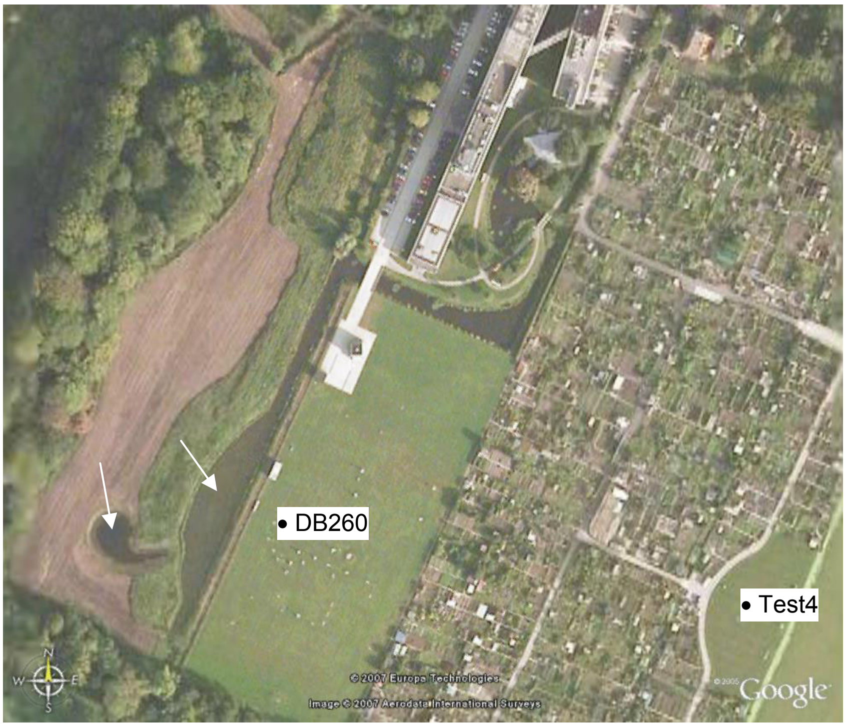

Figure 2: Aerial photo of the measurement field after the renovation of the nature area west of DB260 in October 2004. The arrows point to two new bodies of water.

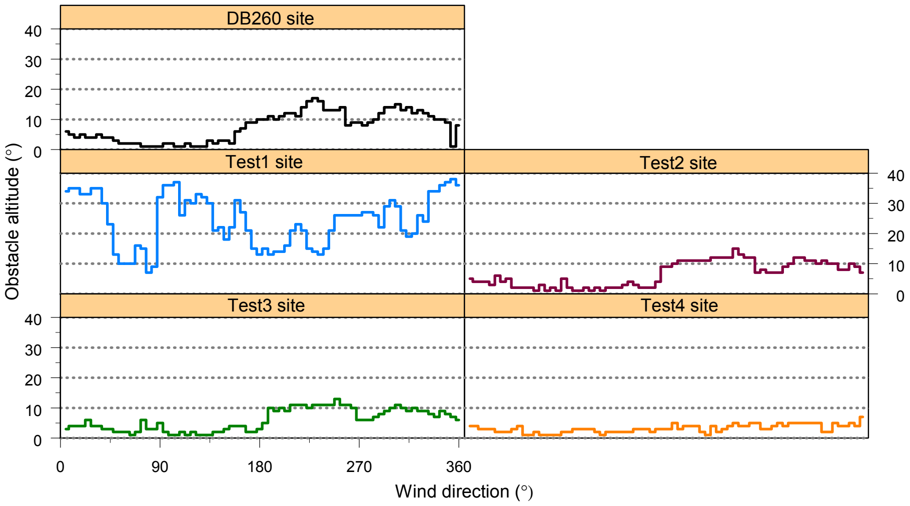

Figure 3: Obstacle altitude as a function of wind direction at the operational site DB260 and the 4 parallel locations.

that time and present.

Figure 1 shows the position of the current operational site DB260 and the four selected experimental parallel locations indicated by TestN (N = 1,…,4). Test1 is located at the historical operational site; Test2 (the current back-up site) is situated 30 m from DB260 at 118°, and Test3 at 50 m from DB260 at 118°. Test4 is situated about 220 m east of DB260 near the operational wind mast, which measures wind direction and speed at 20 m height.

Besides the large barrier of trees that runs from south of DB260 to north-northeast, there is also a shallow barrier between the vegetable gardens and the KNMI terrain (see Figure 1). The distance of Test3 to the barrier equals 23 m (perpendicular to the barrier). The barrier consists of a 2 m high permeable fence. Behind the fence, there are garden houses with a height of 2–3 m scattered over the vegetable gardens.

Figure 3 shows the obstacle altitude for each site. The figure clearly shows that Test1 is the most enclosed location and Test4 the most open location. This is also reflected in the annual cycle of the percentage of shade hours (not shown). During winter, Test1 is in the shade for almost the whole day, while for Test4 this only happens for a small fraction (< 13%) of the day.

Instrumental setup

All 5 locations are equipped with identical instruments and sensors. Figure 4 shows the instruments at DB260. Air temperature is measured at 1.5 m above ground level in naturally ventilated KNMI multi-plate radiation shields. The stan-

Figure 4: Instruments at the operational site DB260. To the left the KNMI multi-plate radiation shield for measuring temperature and to the right the cup anemometer. Both instruments operate at 1.5 m above ground level. The 4 parallel locations are equipped with the same instruments.

dard measurement uncertainty of the sensors is 0.1°C but this is reduce to about 0.03°C by correcting the data with the calibration curves.

Wind speed is measured at each site with cup anemometers on top of a pole (see Figure 4) at the same height as the air temperature measurements (1.5 m). The anemometers are situated at a distance of 4 m northeast of the thermometer-screens. The standard uncertainty of the sensors is 0.5 m/s. As for temperature, a higher accuracy was obtained by correcting the measurements with the calibration data.

Besides the experimental temperature and wind speed measurements also the following operational 10-minute measurements at the KNMI terrain are stored and used: wind direction, actual total cloud cover and total cloud cover in the last 30 minutes (both with ceilometer), air pressure reduced to mean sea level, precipitation duration, mean precipitation intensity, direct radiation, diffuse radiation, global radiation, grass minimum temperature at 10 cm, and horizontal visibility.

Methodology

The differences between the 5 locations are studied by comparing the air temperature differences ΔT(SiteX – Test4), where SiteX stands for the Test1, Test2, Test3 and DB260 sites. Test4 is used as the reference site. This site is likely not affected by the renovation of the nature area and is also a candidate future operational location. In this paper we focus on the monthly mean temperature differences between the 5 locations from May 2003 – June 2005 and on the diurnal temperature cycle differences. Special attention is given to the impact of the renovation of the nature area.

RESULTS

Maximum temperature. Figure 5 shows the monthly means of the daily maximum temperature differences Δ*T*. The temperature differences are largest in the summer half year and may amount to 0.4-0.5°C for Test1 and DB260 (summer 2003). Before the renovation of the nature area in October 2004, Δ*T* for DB260 and Test 1 are comparable, while after the renovation DB260 is close to Test2 and Test3. Keep in mind that that the temperature at Test1 and the reference Test4 are probably not affected by the renovation.

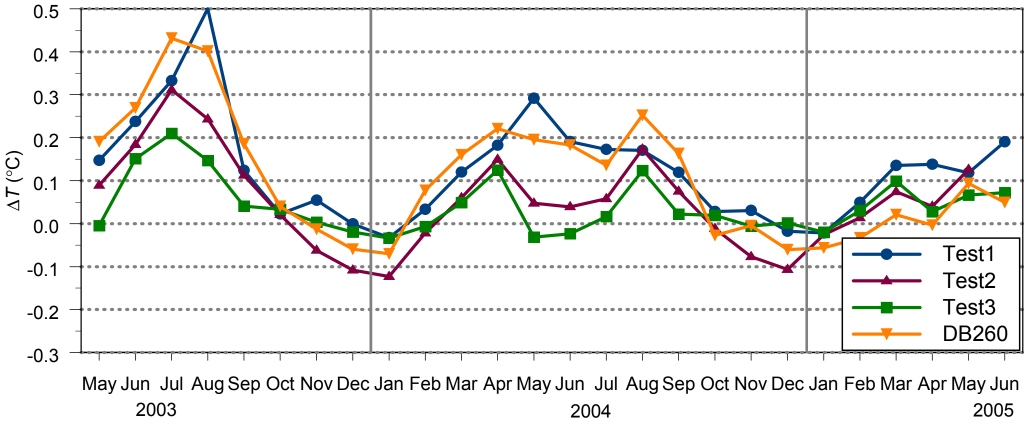

Figure 5: Monthly means of the daily maximum temperature differences Δ*T* between SiteX and Test4 for the period May 2003–June 2005.

Minimum temperature. Figure 6 shows the monthly means of the daily minimum temperature differences Δ*T*. Compared to Figure 5 it is noteworthy that the sign of Δ*T* changed, except for Test1. Test1 is warmer than Test4, both in the maximum and minimum temperature, where the relative warmth is largest for the minimum temperature. After de renovation, Δ*T* for DB260, Test2 and Test3 are all close to zero. This suggests that the renovation influenced all of these three sites.

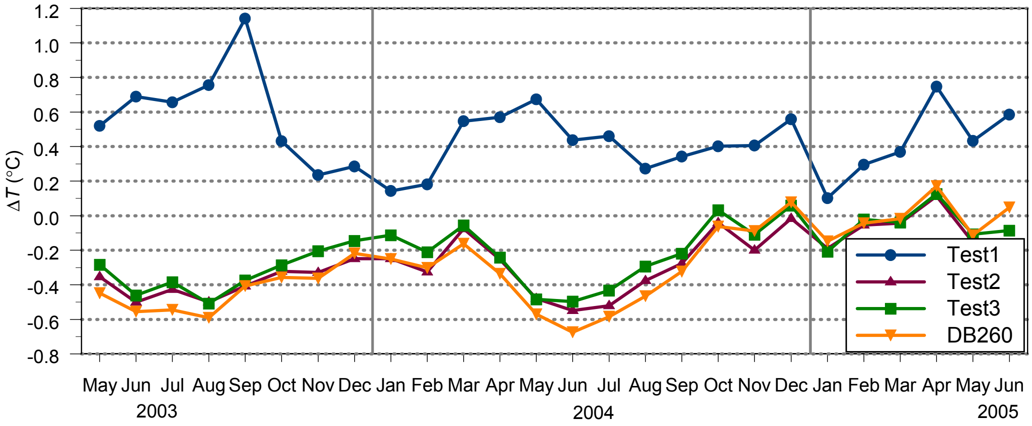

Figure 6: Same as Figure 5 but now for daily minimum temperature

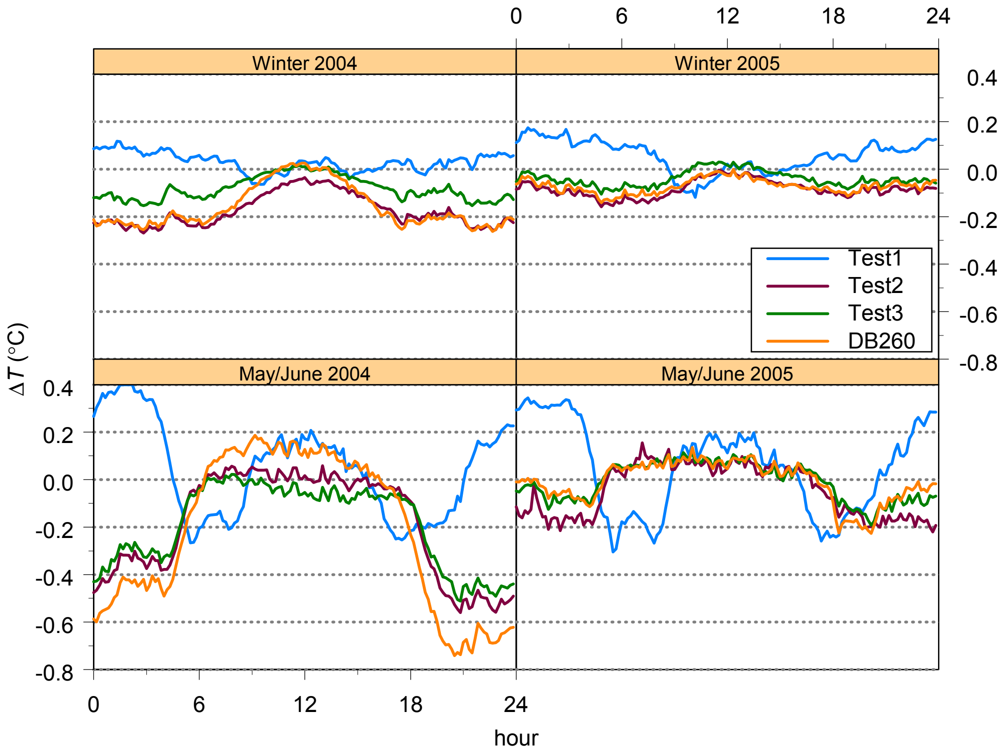

Figure 7: Mean diurnal temperature cycle differences between SiteX and Test4 for (a) winter 2004 (DJF), (b) winter 2005 (after the renovation), (c) May-June 2004, and May-June 2005 (after the renovation).

Diurnal temperature cycle differences. Figure 7 presents the mean diurnal temperature cycle differences between siteX and Test4. Note the behavior of Test1, especially in the summer, during sunrise and sunset. Because the site is in the shade during sunrise and sunset, temperatures at these times are lower than that of the other sites. Note also the decrease in the diurnal cycle differences with respect to Test4 for DB260, Test2 and Test3 after the renovation (especially for the May/June period). After the renovation, the diurnal cycle differences for DB260, Test2 and Test3 are almost identical, especially during daytime.

Diurnal temperature cycle differences as a function of windspeed and cloudiness. Figure 8 presents the mean diurnal temperature cycle differences between siteX and Test4 in summer for 4 combinations of windspeed W and cloudiness N (cloud cover fraction). The figure clearly shows that the inter-site temperature differences strongly depend on the prevailing weather conditions. Low windspeed and clear-sky condition results in large inter-site temperature differences while large windspeed and cloudy conditions result minimize the differences.

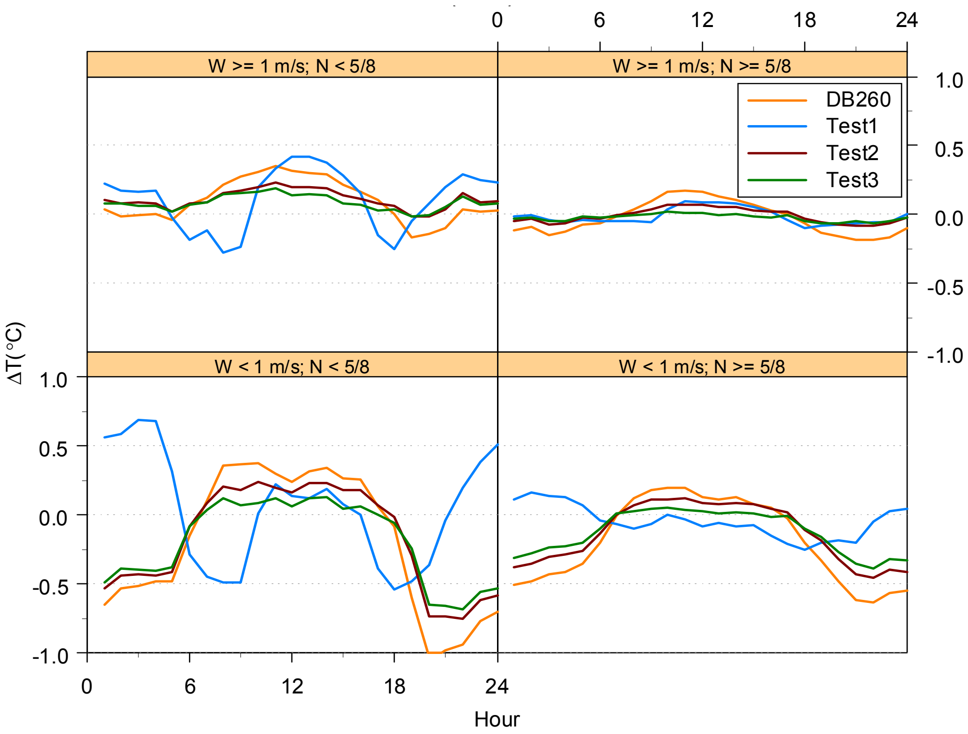

Figure 8: Mean diurnal temperature cycle differences between SiteX and Test4 for the summers (JJA) of 2003 and 2004 (before the renovation) for four combinations of windspeed *W* and cloud cover *N* (fraction of cloud cover) as indicted on top of each panel.

DISCUSSION AND CONCLUSIONS

In this study we quantified the possible effects of sheltering on temperature measurements at the KNMI-terrain in De Bilt. It appeared that, especially in summer, these effects may have the same order of magnitude as the long-term temperature trend (about 1.0°C/100yr in De Bilt). However, for most sites the inter-site temperature differences for maximum and minimum temperature have opposite signs. The net effect on the daily mean temperatures (not shown) is, therefore, small. In practice, the largest inhomogeneities in mean temperature series may be anticipated in case of relocations from very enclosed sites (like Test1) to more open sites (the other sites). The renovation of the nature area, close to the operational site DB260, had a significant effect on the temperature.

The results indicate that the magnitude of the inter-site temperature differences strongly depends on windspeed and cloud cover. In case of homogenization of daily temperature series, it is important to take this into account. A complication may be that for windpeed the largest effects on inter-site temperature differences occur in the range 0.0-1.0 m/s at screen level. In practice (a) windspeed is mostly not measured at screen level but at heights of 10-20 m (during stable nights, windspeeds at these heights are uncoupled from those at screen height), and (b) the measurement error for small windspeeds is large. The first problem may be solved by installing additional anemometers at screen height at locations important for climate monitoring. The second problem may largely be met by the introduction of sonic anemometers.

Improvement of our understanding of inter-site temperature differences may enable the modeling them. In case of De Bilt there are certain aspects that are likely important and should be studied further. First, the non-uniformity of the KNMI-terrain may affect downstream sites by daytime advection. Especially the vegetable gardens seem to have energy balances different from those of the surrounding grassland. This results in different Bowen ratios (sensible heat flux/latent heat flux). Second, local stability differences are most important during nighttime stable conditions (small wind speeds, clear sky) when inversions develop, causing low temperatures near the ground. Differences in wind speed between the locations may then cause different strengths of the inversion, resulting in higher temperatures at the location with the larger wind speed. Third, screen ventilation differences are especially important during the day when radiation errors increase with decreasing wind speed. Fourth, small sky-view factors restrict radiation. This is mainly important at the Test1 location. Fifth, local differences in soil type and groundwater levels between the locations may affect the energy balance and may cause differences in observed temperatures. It is known that at the Test4 site groundwater levels are shallower than at the other sites. Especially in dry summers this may result in local differences in the Bowen ratio. Finally, instrumental errors may play a role, though these are minimized here by the calibration procedures.

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