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Calibration

Heimann radiation thermometers

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1. Introduction

In the past years radiation thermometers have been employed by KNMI to measure the sky temperature at various locations in the Netherlands and the surface temperature at the Cabauw research station. The instruments used are of the type Heimann KT15-85D. These instruments measure the radiation from on object at a wavelength around 10 μm and, assuming and emissivity of 1, convert this to a temperature. The sky looking instruments have a K6 lens with a narrow field of view of 3° and are sensitive to the wavelength band 9.5-11.6 μm. The surface temperature is measured from two different heights, 4 m and 213 m. The lower instrument has a M6 lens that has a field of view of 40° and is sensitive to the 8-14 μm band, whereas the upper instrument is like the sky looking ones. The instruments are mounted inside a box that is held at a temperature of approximately 35 °C.

In an earlier study (unpublished internal note) questions were raised on the calibration of the instruments and on their sensitivity to changes in body temperature. Although the temperature of the box is controlled, changes of several degrees Celsius may occur due to solar heating of the box. In order to get more insight in their behaviour, two instruments were sent back to the local representative for inspection. The representative stated that the problems were caused by moisture that had affected the electronics. The instruments were repaired and again calibrated by the manufacturer. Their behaviour was again checked at the KNMI by procedures described below. Also other instruments were successively recalled from the field and checked. This note explains the calibration procedures that were used and summarizes the characteristics of the checked instruments.

2. Calibration procedures

2.1 Calibration with the Galai black body (Fig.1)

The Galai black body is a disc of 5 cm diameter that is provided with a high emissivity coating. To further enhance the emissivity the surface has concentric grooves. According to the manufacturer the emission coefficient is at least 0.98. A Platinum resistance thermometer senses the temperature of the emitting body. Temperature control is by means of a Peltier device. A closed water circuit cools the hot side of the Peltier element. In this way a low temperature of at least –35 °C can be reached. In order to prevent dew formation on the black body, an aluminium cylinder (length 50 mm, diameter 45.5 mm) was placed between the black body and the thermostatted box. This cylinder was flushed with N_2 at a flow rate of 0.5 l/min. The distance between the front surface of the lens of the Heimann and the black body is 79 mm. The aluminium cylinder also prevents external radiation from reaching the black body. Since the emission coefficient is lower than 1, external radiation could be reflected into the Heimann and influence the reading. Aluminium has a low emission coefficient, therefore contributes little. It was found that by inserting the cylinder, the emission coefficient of the black body was increased by about 0.02. For the moment being, it is assumed that the emission coefficient of the black body including the cylinder is unity. Experiments to be discussed below will show that this is a reasonable assumption.

2.2. Temperature of the Galai black body

In the initial experiments, doubts were raised on the temperature measurement of the Galai. Therefore, the temperature of the black body was independently measured by insertion of a small thermocouple in one of the grooves; by having laid the wires in the same groove for a complete turn, care was taken to prevent conduction errors. Also, the black body's surface

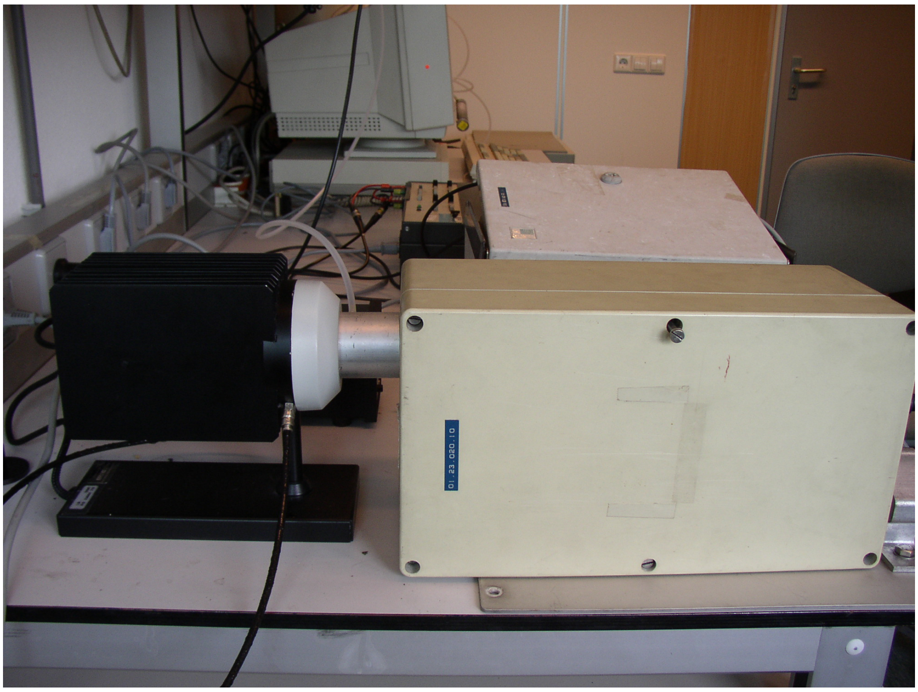

Fig.1. Calibration set-up using the Galai black body (left). The Heimann is inside the thermostatted box on the right. In between the aluminium cylinder.

was isolated from the surroundings by means of a cotton plug. Temperature measurement was done by means of a Campbell 21X datalogger. A considerable difference between the reading of the Galai and the thermocouple was found (Fig.2). It was assumed that the latter was correct.

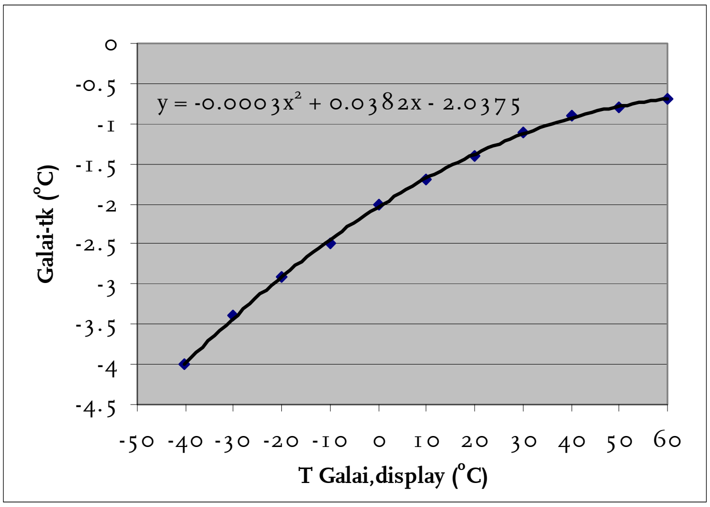

Fig.2. Temperature difference between the Galai display the thermocouple, with regression curve.

2.3. Calibration using the climate chamber

Inside a closed surface the radiation density only depends on the temperature, and thus is independent of the characteristics of the surface. This statement is based on the second law of thermodynamics. If we now create a small hole in the surface, this hole will act as a black body. Based on this idea, a climate chamber of the KNMI's calibration laboratory was adapted. The chamber measures 80 cm at every side, has stainless steel walls and is temperature and humidity controlled. An aluminium cylinder of 60 mm length and 36.4 mm diameter is stuck through the mantle of the chamber as a viewing port for the Heimann. An optical absorber is placed inside the chamber in the field of view of the Heimann. This was deemed necessary since otherwise the Heimann could look at itself by reflection from the opposite wall. The absorber is constructed out of 3 rectangular plates of 40 cm at the equal sides welded together in such a way that they form a hat. Radiation that is emitted by the Heimann enters the hat and is sent back into the same direction, but displaced, after 3 reflections. Since the inner surface of the hat is painted black, the over-all reflection coefficient is estimated to be less than 1%.

3. Comparison of calibrations

Two instruments (nr.10 and nr.23) were repaired and re-calibration by Heimann. Thereafter, instrument nr.10 was checked against both the Galai black body and the climate chamber, nr.23 against the Galai only.

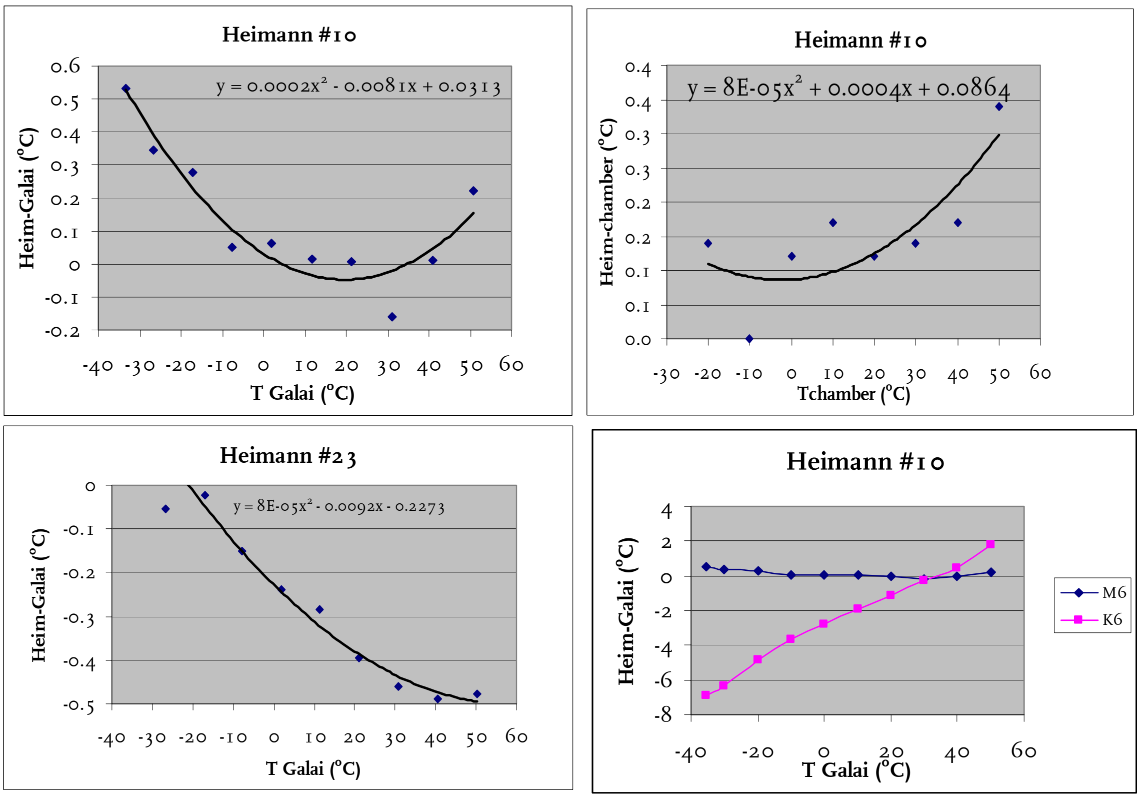

Fig.3. Above and below left: difference between the reading of the Heimann and the Galai black body or climate chamber, after repair. Below right: effect of lens type. The Galai temperature has been corrected.

Fig.3 shows the results. It is seen that the differences are almost always between +/-0.5 °C. This is a very satisfactory agreement. Moreover, it confirms that the effective emission coefficient of the Galai in the present set-up can indeed be assumed equal to 1.
Regarding the temperature compensation, our findings were less favourable. Opening the thermostatted box changed the temperature of the Heimann, and it was found that the

instrument's reading also changed, in spite of an unaltered blackbody temperature. For instrument nr.10 the sensitivity was –0.05(that means, an apparent change of -0.05 °C per °C change of the Heimann body temperature), and regarding nr.23 the sensitivity was – 0.14. In contrast, the manufacturer's specifications suggest a temperature sensitivity of 0.007 only. The reason for this discrepancy is still not clear. The manufacturer calibrated the instruments at 30 °C, we at 35 °C. Thus, the differences as shown in Fig.3 should be corrected for this temperature difference. After correction, the agreement is still in the +/- 05 °C bracket.
In another test of the temperature sensitivity, instrument #10 and the Galai radiator were placed inside the climate chamber. The set-up is thus as shown in Fig.1, be it that the aluminium cylinder was not purged with N_2 and the box housing the Heimann was open. The temperature of the chamber was varied between 0 and 50 °C, while the relative humidity was less than 7.5%. The temperature of the Galai was kept constant at 21.4 °C . In Fig. 4 it is shown that around 35 °C the temperature sensitivity is about 0.06, which confirms the earlier (but somewhat less accurate) result.

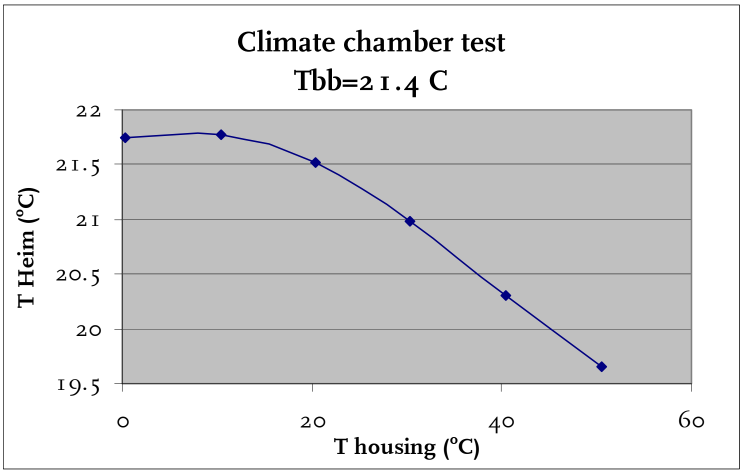

Fig.4. Temperature sensitivity of Heimann#10

4. Effect of lens type and dirt

As noted above, two lens types with different viewing angles were employed, K6 en M6. Heimann nr. 10, which is fitted with lens M6, was also calibrated with lens K6. The difference is large (Fig.3, below and right). Thus, the calibration is only valid for a specific lens type. According to the manufacturer, also an interchange with the same type of lens may affect the calibration, although little effect was found in an earlier study by van Lammeren in 1995.
The effect of dirt on the lens was investigated by comparing the calibrations of instrument #12 with a dirty lens and a new, clean lens. The Galai black body was used as radiation source. It was found that dirt has a considerable effect (Fig.5). Dirt not only accumulates on the front side of the lens, but may also deposit on the backside, in spite of a o-ring between lens and fitting. Therefore, it is advised to inspect and (if necessary) also clean the rear side of the lens with alcohol. Since dirt may enter the inside of the instrument, there is a risk that other components are affected as well. Indeed, some dirt was found inside this instrument. After cleaning, the instrument was again calibrated. A small difference with the foregoing calibration was found (Fig.5). More importantly, the inside cleaning had a favourable effect on the temperature sensitivity, which was now negligible.

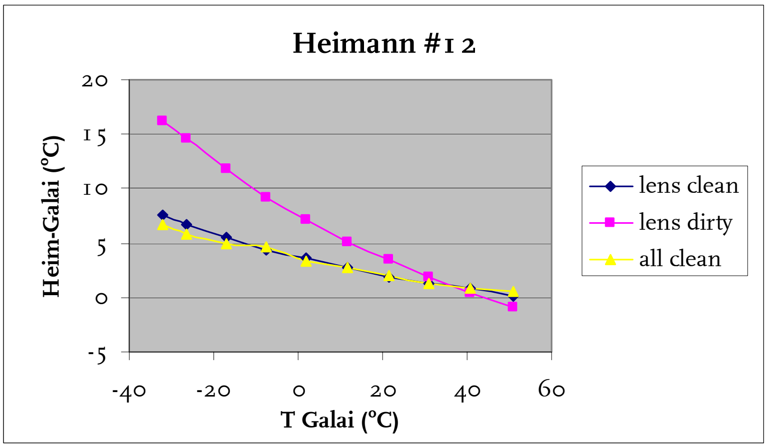

Fig. 5. Effect of dirt.

5. Calibration results
In Table 1 the instrument numbers (KNMI) are given and their measuring location. The results of the calibration are represented by a second order fit:

$$T(Heim) - T(Galai) = a_0 + a_1 T(Heim) + a_2 T^2(Heim),$$

where T(Heim) is the instrument reading and T(Galai) the corrected black body temperature. The temperature coefficient tc (the change of T(Heim) as a fraction of the change of house temperature) was measured at 20 and −20 °C. The instruments were calibrated in the condition as they came from the field, so no cleaning was done. Fig.6 gives the results in graphical form.

Table1. Calibration results

Heimann#	Location	lens	a0	a1	a2	tc@20°C	tc@-20°C
12	Gilze	K6	4.80	-0.144	0.00113	0.04	0.05
14	Spare	K6	4.83	-0.180	0.00140	0.07	0.08
15	Deelen	K6	8.52	-0.275	0.00186	0.08	0.10
16	Cabauw2m	M6	3.94	-0.136	0.00115	0.05	0.05
17	Antartica	K6	8.56	-0.300	0.00222	0.07	0.12
19	Cabauw sky	K6	4.50	-0.145	0.00092	0.05	0.04
20	Cabauw sky	K6	5.74	-0.182	0.00143	0.05	0.09
21	Volkel	K6	4.71	-0.155	0.00119	0.06	0.08
22	Cab. 213m	K6	4.02	-0.147	0.00116	0.06	0.07
272	Eindhoven	K6	1.59	-0.021	0.00001	0.06	0.11
273	De Bilt	K6	5.16	-0.181	0.00153	0.03	0.03

It is seen that all but one instrument measures a too high temperature. The discrepancy increases with decreasing temperature and can reach up to 10 °C or more. Instrument nr.272, being the only favourable exception, has a higher noise level than the other instruments.
In case of measurement of the cloud base height, these results indicate that such height is underestimated. The surface temperature measurements at the Cabauw station are a few degrees Celsius too high.

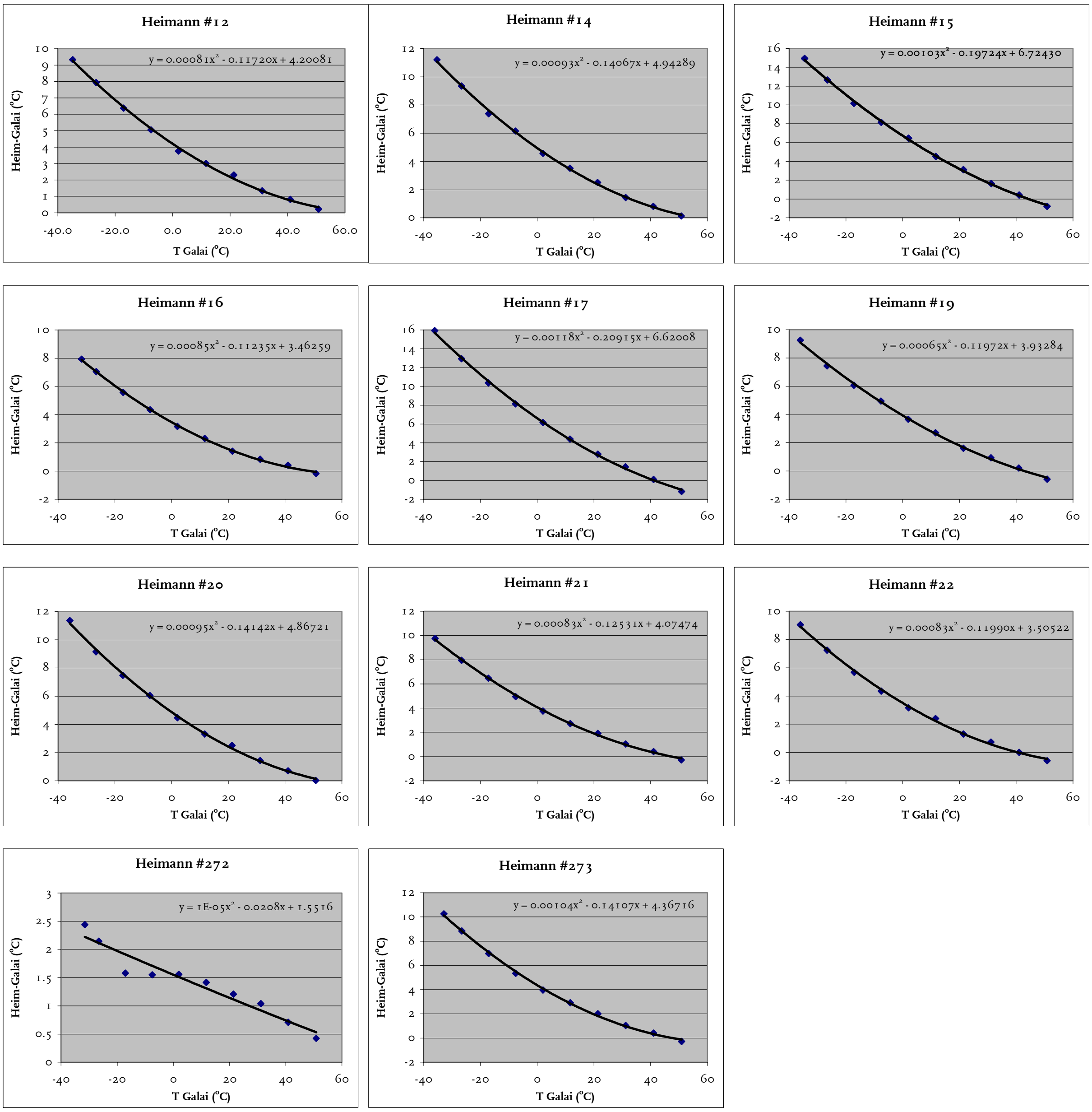

Fig. 6. Calibration results. Note that the abscissa is here the corrected Galai temperature, which leads to regression coefficients that are different from the calibration coefficients of Table 1.

6. Previous calibrations and field comparisons

Previous calibrations at the KNMI were done with a black body that consisted out of a vessel filled with water provided with a conical intrusion at the side. The Heimann is looking into this intrusion that effectively act as a black body. The temperature of the water was varied between room temperature and 50 °C , thus no information was gained on the low temperature behaviour. The tests done in 1993 revealed that the Heimann reading was generally within 1 °C of the black body temperature, while the difference increased with increasing temperature. This in contrast to Fig.6, which shows that the difference decreases. It was also recognised that the temperature compensation was not perfect; for a specific instrument a sensitivity of 0.13 was found. This instrument was thereupon sent back and repaired. Later calibrations with the water vessel were done in 1998. The differences were then often larger than in 1993, while a decreasing as well as increasing difference was found. Primarily test with the Galai black body were also done and showed the pattern as found nowadays, but these results were discarded since the emission coefficient of the Galai was not trusted, partly because of dew of ripe formation at lower temperatures. Tests with the Galai were continued in 2000, but now in the dry climate chamber. This did not change the general picture that the Heimann readings were too high, while the difference was decreasing with increasing temperature. It is important to note that the temperature of the Galai was not suspected at that time, so care should be exercised in comparing these results with the present ones. Also lenses may have been replaced, which can have some effect on the calibration. After 2000, no calibrations were done till the recent ones.

Several inter-comparisons were done in the past, in which a number of sky-looking instruments were located at the same site. Recent tests of this kind are:

1. June/July 2001, before the BBC1 campaign, 11 instruments
2. October 2001, after BBC1, 7 instruments
3. April 2002, in the framework of Cloudnet 2002, 5 instruments.

All test were done at De Bilt. The last inter-comparison is of limited use since some uncertainty exists on the relevant instrument numbers. Thus, only inter-comparisons before and after BBC1 will be discussed. The differences between the instruments were plotted

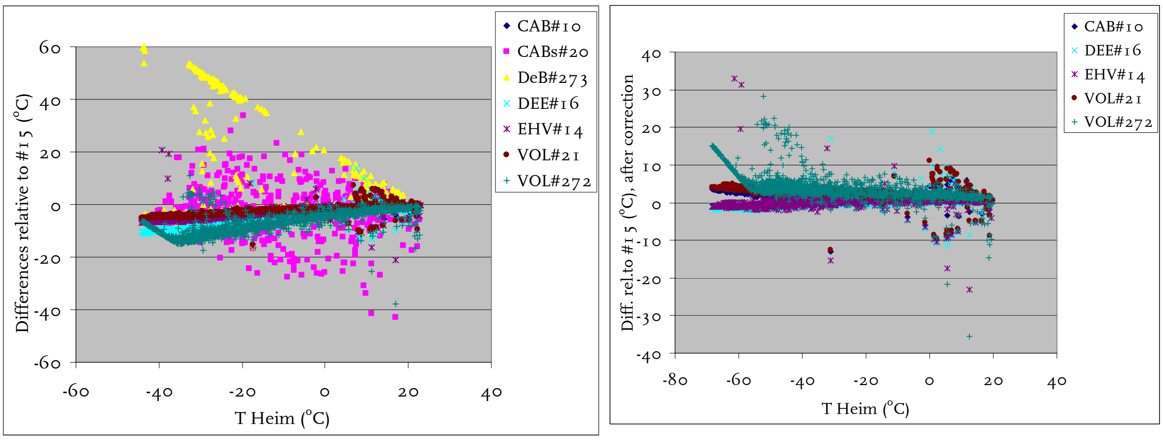

Fig. 7. Comparison of sky-looking Heimann infrared thermometers after the BBC1 experiment. In the right hand figure the data have been corrected, and data of Heimann #20 and #273 sets were omitted. Data represent 10 min averages.

taking one instrument as a reference. In Fig. 7 the results are shown for the comparison found in this report. Two instruments (#20 and #273) were so much different from the other ones that they were left out of the corrected plot. It is seen that correcting the data brings the instruments closer together, although differences of many degree C remain. The "tail" of instrument #272 at the lowest temperatures is an artefact caused by different cut-off levels of the instruments. Note also the extended temperature range to the negative, after correction. However, the data below −40 °C must be regarded as less accurate because the calibration curve has been extrapolated into that region.

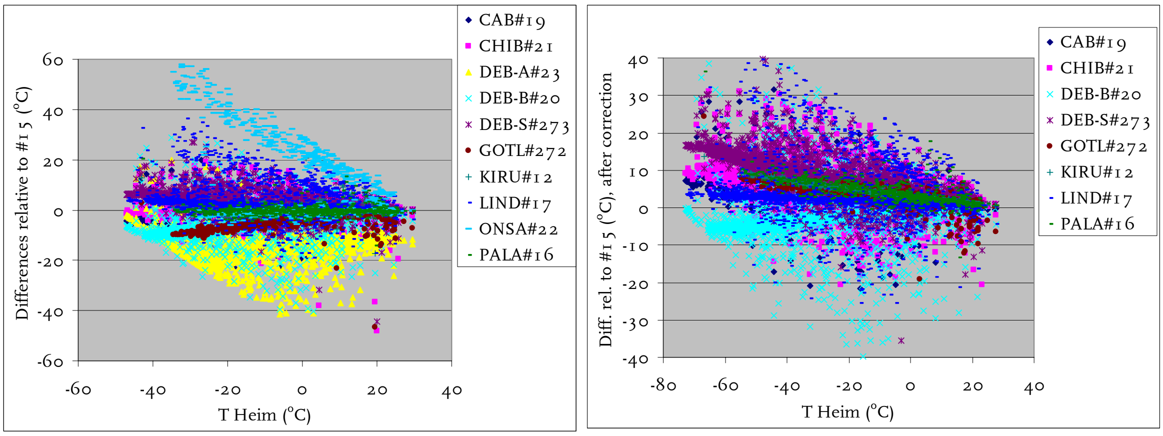

Fig.8. Like Fig.7, but before BBC1. In the right hand figure the data of Heimann #22 and #23 were omitted.

The inter-comparison before BBC1 shows more scatter than the one after, and correcting the measurements does not bring an improvement (Fig.8).

Summarizing the results of previous work, one may say that
-the temperature compensation was questioned from the beginning on
-doubts on the calibration already existed since many years
-inter-comparisons revealed considerable differences, and some instruments were completely out of calibration

7. Conclusions and recommendations

-The climate chamber with the provision of an absorber can be employed as a black body radiator. The temperature of the chamber is standardised according to ISO procedures.
-The Galai black body may be used as a secondary radiator. Since its temperature measurement was found to be in error, it is advised to check it regularly. The Galai has the advantage over the climate chamber of ease-of-use, and it can attain lower temperatures.
-It is recommended to consider Heimann nr. 10 as reference instrument and, using this instrument, compare the Galai black body with the climate chamber every year.
-The lens types K6 and M6 are not to be changed without re-calibration.
-Lenses have to be cleaned on both sides with alcohol. If cleaning is neglected, substantial errors may occur.
-Almost all Heimann instruments that were checked by us exhibit a positive deviation that increases with decreasing temperature. Errors of 10 °C or more are no exception.
-Two instruments that were anew adjusted by the manufacturer were found to agree within 0.5 °C with our calibration. However, their temperature dependency was not improved.
-Because of the temperature dependency, the Heimann radiation thermometers have to be thermostatted.

Acknowledgement
Harry Carolus carried out the majority of the calibrations. Rinus Rauw and Harry took care of demounting and mounting the instruments on their locations. Rob van Krimpen did the climate chamber calibrations. Ed Worrell put attention to the effect of dirt inside the instrument. They all are thanked for their input.