METEOROLOGY No. 148, 2011

Upgrade of SMHI's meteorological radiation network 2006-2007

Effects on direct and global solar radiation

Thomas Carlund

Front:
Upper row: Old pyranometer with ventilator (left) and old pyrheliometer on solar tracker (right).
Lower row: New pyranometer with ventilator (left) and new pyrheliometers, sunphotometer and shaded pyranometers and pyrgeometer on solar tracker (right) .
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ISSN: 0283-7730

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Summary

The radiation network of SMHI was modernized in 2006-2007. Old measurements were closed down after 6-18 months of parallel operation of new and old measurements. This study reports the results of the comparison mainly between the old and new global and direct solar radiation measurements.

On average the agreement between old and new measurements was good. The network average of ratios of whole period values was for global radiation 0.997 and for direct radiation 1.009. None of these results are significantly different from one at a level of confidence of 90 %.

Despite the fairly good agreement some systematic differences between the old and new measurements were found. The differences are mainly thought to be caused by a difference in the apparent directional response between the old and new pyranometers and different viewing geometries in the old and new pyrheliometers. Functions to correct old global and direct radiation have been developed. These should be used to increase the homogeneity in Swedish solar radiation data from 1983and onwards, especially for monthly data.

A new measurement method and new instruments for determination of sunshine duration were introduced in the upgraded network. A more detailed study comparing sunshine duration measurements by pyrheliometers in the old network and by contrast sensors in the modernized network, probably based on 1-minute or even instantaneous data, needs to be done in the future.

Sammanfattning

SMHIs strålningsnät moderniserades 2006-2007. Innan de äldre mätningarna upphörde genomfördes parallella mätningar med både ny och gammal utrustning under 6-18 månader. Här rapporteras resultaten av jämförelsen mellan de gamla och de nya mätningarna av i huvudsak globalstrålning och direktstrålning.

I genomsnitt var överensstämmelsen god mellan de gamla och de nya mätningarna. Medelvärdet av förhållandet mellan de gamla och nya mätningarna, baserat på tidsintegrerade värden från hela den tillgängliga jämförelseperioden vid respektive station, var 0,997 för globalstrålning (12 stationer) och 1,009 för direktstrålning (3 stationer). Inget av dessa resultat är signifikant skilda från 1 vid en signifikansnivå av 90 %.

Trots den goda överensstämmelsen identifierades ett par systematiska skillnader mellan de gamla och de nya mätningarna. Dessa skillnader antas i huvudsak bero på skillnad i öppningsvinkel mellan gamla och nya pyrheliometrar (mäter direktstrålning) samt skillnad i den riktningsberoende responsen mellan gamla och nya pyranometrar (mäter globalstrålning). Korrektionsfunktioner för dessa systematiska skillnader har utvecklats. Dessa bör tillämpas för att korrigera de äldre mätningarna (1983-2007) för att förbättra homogeniteten i framförallt månadsvärden av strålningsdata.

Vid moderniseringen av strålningsnätet genomgick även de automatiska mätningarna av solskenstid en betydande förändring. Preliminära jämförelser av solskenstid från gammal och ny mätmetod ger i nuläget svårtydda resultat. En mer detaljerad studie av solskenstidsmätningarna, baserad på minut- eller t.o.m. momentanvärden, måste därför göras i framtiden.

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1 Background

Since the 1950s SMHI has been operating an observation network for solar radiation. For the early measurements sunshine recorders of Campbell-Stokes type and Moll-Gorczynski/Kipp & Zonen pyranometers with chart recorders were used. All these measurements required manual evaluation. In the early 1980s there was a major network upgrade and the radiation measurements were automized for the first time. The official start of this network was 1983-01-01 and most of these stations were in operation until 2007-12-31. During 2005-2007 the most recent upgrade of SMHI's radiation network was made. This report presents the results of a comparison between parallel measurements taken 2006-2007 by the former ("old") and the latest ("new") network.

2 The meteorological radiation network of SMHI

As mentioned above, SMHI's first automatic meteorological radiation network started in 1983. Description of this network and some measurement results can be found in Josefsson (1987), Persson (1999 and 2000). In the following, this network will be called the old network. Only a brief description will be given here.

The old radiation network consisted of 12 stations. All these stations had the same basic setup with pyranometers and suntracking pyrheliometers. Pyranometers are used for the measurement of total solar irradiance on a horizontal surface, often, and in the following, called global radiation/irradiance, *G*. Pyrheliometers are used for the measurement of direct normal solar irradiance, *I*, in the following just called direct radiation/irradiance. Also sunshine duration, *SD*, was measured by the pyrheliometers. From the beginning all stations were also equipped with standard meteorological measurements of air temperature (2 m), relative humidity (2 m), wind direction and speed (10 m). Initially, five of the stations were also equipped with (battery compensated) pyrgeometers for the measurement of downward longwave irradince, *L*. Due to financial constraints the standard meteorological observations had to be closed at several sites during the 1990s. Due to the lack of a blackbody or reference pyrgeometers the field pyrgeometers were never calibrated. There were also frequent troubles with the batteries. This resulted in unknown but anticipated high uncertainty. For this reason, the pyrgeometer measurements were also closed in the late 1990s.

SMHI's new radiation network from 2007 is divided into two station types, namely "advanced" stations and "simple" stations. There are three advanced (by SMHI measures) stations. The rest of the stations are simple stations and among these there are three subsets of stations with different measurement programs. A map of the current radiation network is shown in Figure 1 and a list of the stations and their measurement programs is given in Table 1.

Economic priorities only permitted three of the new stations to be equipped with sun trackers. Therefore, direct irradiance measurements are only performed at the sites, Kiruna, Norrköping and Visby. On the other hand, compared to the old network the measurement program was extended at these stations. These advanced stations now also measure diffuse (solar) irradiance, *D*, longwave irradiance, *L*, and spectral transmission at four wavelengths. The spectral transmissions are then used to calculate aerosol optical depth, *AOD*.

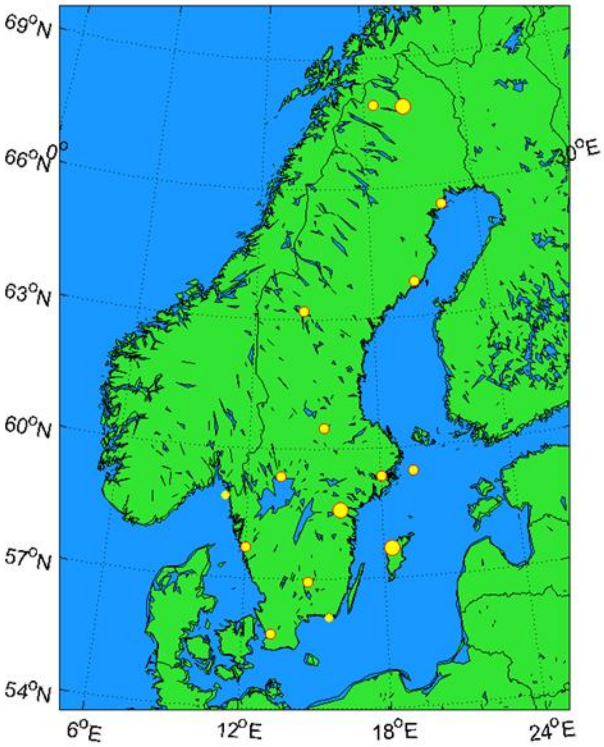

Figure 1. Map of the meteorological radiation network of SMHI 2010.

Currently, there are 13 simple stations in the new network and at all these sites at least sunshine duration is measured. At 11 of these stations also global irradiance is measured, as well as air temperature and relative humidity at the location of the radiation instruments. Two of the simple stations, Tarfala and Svenska Högarna, were extended to include longwave irradiance measurements.

Measurements at all 12 locations in the old network continue in the new network at exactly the same places as were used before. The locations of the radiation stations were measured by GPS when the new instruments were installed or were taken from internet based high resolution map services (e.g. eniro.se, hitta.se). The numbers for latitude, longitude and altitude given in Table 1 therefore differs slightly from the less accurate values given in earlier publications.

2.1 Instruments

2.1.1 Data acquisition

In the old network data were collected and preprocessed by means of a microprocessor controlled automatic logger, TAFS 8001 by ASEA (also called ASEA-ADAT 1).

At the new simple stations Vaisala MAWS QML201 loggers are used. These loggers were calibrated over a wide ambient air temperature range prior to installation. While the data acquisition system at all the old stations were placed indoors at room temperature the Vaisala logger at a new simple station is placed in a weather tight enclosure outdoors. At the three new advanced stations the data acquisition is performed by an Agilent 34970A multimeter with a 34901A multiplexer unit. These units are controlled by a PC on which the measurement program, a LabView application developed by Jan-Erik Karlsson at SMHI, runs. As at the old stations, the data acquisition hardware is placed indoors at room temperature.

Table 1. Stations in the meteorological radiation network of SMHI 2010.

Station	**Lat. (°N)**	**Long. (°E)**	**Alt (m.ö.h.)**	**Type**	**Parametrar**	**Position**	**Old station**
Tarfala	67.911	18.607	1144	E+	*SD, G, L, T, RH*	*G*	
Kiruna	67.842	20.410	424	A	*SD, G, L, I, D, AOD, P, T, RH*	*R*	*SD, G, I*
Luleå	65.544	22.111	32	E	*SD, G, T, RH*	*R*	*SD, G, I*
Umeå	63.811	20.240	23	E	*SD, G, T, RH*	*R*	*SD, G, I*
Östersund	63.197	14.480	374	E	*SD, G, T, RH*	*R*	*SD, G, I*
Borlänge	60.488	15.430	164	E	*SD, G, T, RH*	*R*	*SD, G, I*
Svenska Högarna	59.442	19.502	10	E+	*SD, G, L, T, RH*	*G*	
Karlstad	59.359	13.472	46	E	*SD, G, T, RH*	*G*	*SD, G, I*
Stockholm	59.353	18.063	30	E	*SD, G, T, RH*	*R*	*SD, G, I*
Nordkoster	58.892	11.004	33	S	*SD*	*G*	
Norrköping	58.582	16.148	43	A	*SD, G, L, I, D, AOD, P, T, RH*	*R*	*SD, G, I*
Göteborg*)	57.708	11.992	30	E	*SD, G, T, RH*	*R*	*SD, G, I*
Visby	57.67 3	18.345	49	A	*SD, G, L, I, D, AOD, P, T, RH*	*R*	*SD, G, I*
Växjö	56.927	14.731	182	E	*SD, G, T, RH*	*G*	*SD, G, I*
Karlskrona	56.109	15.587	10	S	*SD*	*R*	
Lund	55.714	13.212	85	E	*SD, G, T, RH*	*R*	*SD, G, I*

Explanation
A = Advanced station
E = Simple station
E+ = Simple station with longwave radiation
S = Sunshine duration station

SD = Sunshine duration
G = Global radiation
L = Longwave radiation
I = Direct radiation
D = Diffuse radiation
AOD = Aerosol optical depth
P = Air pressure
T = Air temperature (measured at radiation instrument level)
RH = Relative humidity (measured at radiation instrument level)

G = Ground level (2m)
R = Roof

*) From March 2011 The Göteborg station has a new location: 57.688 °N, 11.980 °E, 94 m altitude.

2.1.2 Reference instruments

Since the 1980s SMHI has three pyrheliometers which have participated at IPCs (International Pyrheliometer Comparisons, held every five years in Davos, Switzerland) and thus transfer the WRR (World Radiometric Reference) to the solar radiation observations. The three instruments are Å-171, PMO-6 #811108 and AHF-AWX #33393. The Ångström compensation pyrheliometer Å-171 was the working standard during the 1980s and 1990s. In the late 1990s the absolute pyrheliometer PMO-6 measurements were automized and since then this has been the primary working standard at SMHI. AHF-AWX was purchased in 2003 and this instrument participated for the first time at an IPC in 2005. The AHF-AWX is actually an absolute pyrheliometer designed for all-weather operations. It was therefore supplied with a CaF_2 (calcium fluoride) apperture window. However, both at IPCs in Davos and during calibration measurements at SMHI in Norrköping the AHF-AWX has so far been operated in windowless mode.

The three standard pyrheliometers are, or have been, used to calibrate “field reference” pyrheliometers and pyranometers at SMHI. These field reference instruments were then used to calibrate the field instruments for the whole radiation network. The only exception is the Norrköping station where the field instruments are calibrated directly against the absolute pyrheliometers since 2007. The field reference instruments for the old network were

Eppley NIP #20919E6	Direct normal irradiance
Kipp & Zonen CM11 #810132	Diffuse irradiance
Kipp & Zonen CM10 #800080	Global irradiance 1
Kipp & Zonen CM11 #820134	Global irradiance 2

And the field reference instruments for the new network are

Kipp & Zonen CH1 #990233	Direct normal irradiance 1
Kipp & Zonen CH1 #030347 CaF_2	Direct normal irradiance 2
Kipp & Zonen CM21 #031118	Diffuse irradiance 1
Kipp & Zonen CM21 #051527	Diffuse irradiance 2
Kipp & Zonen CM21 #000716	Global irradiance 1
Kipp & Zonen CM21 #051513	Global irradiance 2

2.1.3 Field instruments

For the solar radiation measurements in the old radiation network Eppley NIP pyrheliometers were used for the direct (normal) solar radiation and Kipp& Zonen CM11 pyranometers were used to measure the global radiation. (From 2000 some failing Eppley NIPs were replaced by Kipp & Zonen CH1s at some stations.) In the modernized network the the new pyrheliometers are Kipp & Zonen CH1s and the new pyranometers are of the model Kipp & Zonen CM21. Tables 2 and 3 specify which pyrheliometers and pyranometers were used at the 12 old and new stations during the comparison period.

In Table 2 and 3 also the responsivities are given which were determined before the comparison period, denoted pre-calibration, and after the comparison period, denoted post-calibration. In the old network the instrument responsivities were realized by an amplifier cirquit in which a potentiometer had to be tuned manually prior to operation. The amplifier cirquit boards were checked after the old stations were closed and the responsivities that actually had been applied are given in the fourth column of Table 2 and 3.

Since the majority of the stations in the new network are not equipped with suntrackers and pyrheliometers another type of instrument had to be introduced for the measurement of sunshine duration. As new sunshine duration instrument the Kipp & Zonen CSD1 and CSD2 sensors were initially chosen. This type of instrument gives an analog output signal which should be an approximation of the direct irradiance. It was also assumed to have a fairly good behaviour at low solar elevation angles which frequently occur in Sweden.

Unfortunately, there were lots of troubles with the CSD1 and CSD2 instruments originally purchased. For this reason they were replaced by new instruments of the model CSD3 during 2008-2010. The view geometry of the CSD3 is the same as for the CSD1 and CSD2 so the measurement characteristics have not improved. But with the use of a glass cylinder instead of a plastic one it is easier to keep the instrument clean and free from scratches. Hopefully, it will also be of a much more weather tight construction.

For the measurements of longwave irradiance, which are made at five stations in the new network, the Kipp & Zonen CG4 pyrgeometer is used. But since there were no longwave irradiance observations in the old network there are no comparison results to report here.

Sunshine duration and longwave radiation are not discussed further in this report.

2.2 Calibration

All radiation calibrations are performed outdoors using the sun as the radiation source, i.e. under the same measurement conditions as experienced in the field during sunny days. Calibrations are limited to the summer half year due to the requirement of relatively high solar elevations.

In most cases the pre- and post-calibration results were very similar both at the old and new stations which is also indicated by the “Pre/Post R ratio” columns in Table 2 and Table 3. The largest difference between pre- and post-calibration was found at the old station in Norrköping. At this station the pre calibration of the pyranometer and the pyrheliometer were not made according to normal practice (see below). Instead of connecting these instruments to the reference and calibration measurement system in Norrköping, data directly from the automatic station were compared with data on global and direct radiation from the reference system. It was then found that the responsivities applied in the pyranometer and pyrheliometer amplifier cirquits needed to be reduced by 1.6 % and 1.3 %, respectively. Unfortunately, the amplifier cirquits were adjusted by the double amounts by mistake. However, this did not become clear until the data from the automatic station in Norrköping before and after the calibration adjustment were re-examined during this study.

2.2.1 Pyrheliometer calibration

In relative terms, pyrheliometers (currently) are the most accurate solar radiation instruments and they are also the easiest ones to calibrate. The field reference pyrheliometers are compared to some of the standard pyrheliometers. At these calibrations instantaneous readings from the various instruments are compared. Then, field pyrheliometers are calibrated through comparison with the field reference pyrheliometer(s), or even against an absolute pyrheliometer, under clear sky conditions. While measurements taken at all available solar elevations are investigated, only the measurements taken at solar elevations higher than 35° are taken into account in the calculation of the average pyrheliometer responsivity. In the calibrations for the old network hourly, or sometimes even daily, reference and field instrument data were used. In the calibrations for the new network 1-minute mean values are used. The 1-minute data makes it easier to sort out unstable measurement conditions/periods and the higher time resolution also gives a more detailed picture of e.g. any solar elevation and/or temperature dependence of the sensitivity.

Table 2. Pyrheliometers used during the comparison period at the old and new stations. Also given are the pre-calibration and post-calibration responsivities for each instrument. Unit for responsivities (R) is $\mu V/Wm^{-2}$.

Station	**Old pyrheliometer**	**R pre-cal**	**R pre-cal used in amplifier cirquit**	**R post-cal**	**Pre/Post R ratio**	**New pyrheliometer**	**R pre-cal**	**R post-cal**	**Pre/Post R ratio**
Kiruna	NIP#20924	8.86	8.86	8.89	0.997	CH1#050403	9.85	9.85	1.000
Luleå	NIP#25737	8.68	8.73	8.61	1.014	-	-	-	-
Umeå	NIP#20910	8.71	8.74	8.82	0.991	-	-	-	-
Östersund	NIP#20917	8.86	8.89	8.81	1.009	-	-	-	-
Borlänge	NIP#20912	8.75	8.81	8.70	1.013	-	-	-	-
Karlstad	CH1#010249	10.84	10.86	10.84	1.002	-	-	-	-
Stockholm	CH1#990224	10.12	10.13	10.12	1.001	-	-	-	-
Norrköping	NIP#20920	8.89	8.79	8.87	0.990	CH1#990226	10.94	10.97	0.997
Göteborg	NIP#25736	8.47	8.52	8.50	1.002	-	-	-	-
Visby	NIP#20922	8.98	9.00	8.96	1.004	CH1#050402	9.78	9.77	1.001
Växjö	NIP#20921	8.55	8.58	8.55	1.004	-	-	-	-
Lund	CH1#010251	10.77	10.78	10.80	0.998	-	-	-	-

Table 3. Pyranometers used during the comparison period at the old and new stations. Also given are the pre-calibration and post-calibration responsivities for each instrument. Unit for responsivities (R) is $\mu V/Wm^{-2}$.

Station	**Old pyranometer**	**R pre-cal**	**R pre-cal used in amplifier cirquit**	**R post-cal**	**Pre/Post R ratio**	**New pyranometer**	**R pre-cal**	**R post-cal**	**Pre/Post R ratio**
Kiruna	CM11#820138	5.48	5.47	5.45	1.004	CM21#051493(G) CM21#051488(D)	11.08 10.95	11.09 10.96	0.999 0.999
Luleå	CM11#810252	5.70	5.72	5.72	1.000	CM21#051519	11.11	11.09	1.002
Umeå	CM11#850756	4.58	4.58	4.60	0.996	CM21#051521	10.47	10.45	1.002
Östersund	CM11#924592	4.47	4.48	4.48	1.000	CM21#051516	10.55	10.53	1.002
Borlänge	CM11#820130	4.59	4.60	4.56	1.009	CM21#051515	10.96	10.92	1.004
Karlstad	CM11#850752	4.90	4.89	4.90	0.997	CM21#051517	10.84	10.83	1.001
Stockholm	CM11#820072	4.43	4.43	4.44	0.997	CM21#051514	11.10	11.08	1.002
Norrköping	CM11#850745	4.50	4.43	4.52	0.981	CM21#051487(G) CM21#051485(D)	11.00 11.58	11.01 11.59	0.999 0.999
Göteborg	CM11#820071	4.49	4.50	4.49	1.002	CM21#051522	11.09	-	-
Visby	CM11#850769	4.59	4.56	4.61	0.989	CM21#051490(G) CM21#051491(D)	10.95 10.99	10.97 11.00	0.998 0.999
Växjö	CM11#820139	5.27	5.29	5.31	0.996	CM21#051520	11.83	11.76	1.006
Lund	CM11#820131	4.60	4.60	4.62	0.996	CM21#051518	10.46	10.42	1.004

2.2.2 Pyranometer calibration

There exist several calibration methods for pyranometers. For shaded pyranometers the “alternating sun-and-shade” method (ISO 9846 (1993), also called “shade-unshade” or “sun disk” method) is commonly used. This method was used for the diffuse reference CM11 before 1996. The extended shade-unshade method (ISO 9846, Annex C) is used for the diffuse reference CM21s from 2006 and later. Earlier, the shade-unshade method was sometimes used also for the global reference CM11s and CM10.

Between 1996-2004 the so called pseudo-composite method was used to calibrate the global reference pyranometers as well as the diffuse reference CM11. For more details, see Persson, 2000. Today, the reference global CM21s are calibrated both with the component sum method and the pseudo-composite method. The results from these two methods always agree within 0.2 %.

In the pre-calibrations a mix of results from the component sum method and the comparison method was used. For the component sum method the Eppley NIP #20919 was the reference pyrheliometer and the Kipp & Zonen CM11 #810132 was the shaded reference pyranometer in the calibrations of the old CM11s. For the pre-calibrations of the new CM21s the Kipp & Zonen CH1 #990233 pyrheliometer and the shaded CM21 #031118 were used as refererences. For the comparison method the CM10 #800080 was used as reference for the CM11 calibrations, while CM21 #000716 was the reference for CM21 calibrations.

In the pre-calibration evaluations hourly mean values were used and the resulting responsivities were calculated as the mean of the values from stable hours when the average solar elevation was >35°. The length of a calibration period was typically 1-2 weeks.

In the post calibrations of all the CM11s and the CM21s from the new simple stations mainly the component sum method was used. The same reference instruments were used as in the pre-calibrations of the (new) CM21s with the addition of the CH1 #030347 (CaF2) pyrheliometer and the shaded CM21 #051527 pyranometer as secondary references in the component sum calibrations. This means that the post-calibrations were made using the same references for both the old CM11s and the new CM21s.

New calibration evaluation software had also been developed for the updated data acquisition and measurement platform in use at the time for the post-calibrations. Instead of hourly means now 1-minute mean data from clear stable minutes when the solar elevation was >35° were used. Requirements on a stable sunny minute are that direct irradiance must be higher than a direct irradiance threshold and diffuse irradiance must be lower than a diffuse irradiance threshold. Both the direct and diffuse irradiance thresholds are functions of solar elevation. In addition the 1-minute standard deviation of the direct irradiance must be <1 Wm^{-2}.

At the new advanced stations the pyranometers are calibrated on-site by means of the alternate method (Forgan, 1996; WMO cimo-guide 2008). In this case the station pyrheliometer is the reference instrument. At the annual station visit, which is made as close to the summer solstice as possible, the pyranometers for diffuse and global radiation are swapped. Clear sky 1-minute data at similar solar elevations from before and after the pyranometer exchange are combined so that responsivities for both pyranometers can be calculated. As at the calibrations in Norrköping only results from minutes when the solar elevation is >35° are used in the calculation of the average (constant) responsivity to be used in the forthcoming measurements.

As in all radiation measurements it is of vital importance that pyrheliometer windows and pyranometer domes are perfectly clean during the measurements that will be used in the calibration analysis. This is no problem in Norrköping. However, it was a problem in Kiruna and Visby during the pre-calibrations in 2007. At that time the maintenance and instrument cleaning was not performed on a daily basis. And when just selecting all the stable clear sky calibration data that were found the spread in the calibration results from different days was disturbingly large. The pre-calibrations therefore had to be re-analysed keeping only data from days when cleaning was performed (in the morning). This resulted in more stable calibration results but at the same time the amount of available data was strongly reduced. Since 2009 the maintenance should be performed on all working days also in Kiruna and Visby and the calibration results have improved.

For the new CM21s the agreement between pre- and post-calibration was always within 1 %. A brief investigation of the precision in CM21 calibrations in Norrköping with the current (2010) calibration routines has been made. Calibration results for the two ventilated pyranometers CM21 #000716 and CM21 #051513 were calculated for 10 half month periods during April-September 2010. The pyranometers were calibrated by the component sum method using two reference instrument combinations: 1) CH1 #990233 together with shaded and ventilated CM21 #031118, and 2) CH1 #030347CaF2 together with shaded and ventilated CM21 #051527. There was no significant trend or change found between 2009 and 2010 in any of the reference or test instruments. The standard deviation of ten calibration results varied between 0.09 – 0.24 % for the four combinations of reference and test instruments. The largest spread was for CM21 #000716 when it was calibrated against CH1 #030347CaF2 and CM21 #051527. Naturally, this instrument combination also produced the largest deviation of 0.44 % of any single calibration result from the mean. In practice, the average of the results from the two reference groups is used and in that case the maximum difference of any individual calibration result from the mean was reduced to 0.35 %. Based on these findings the precision (not the total uncertainty) of the current CM21 calibrations is estimated to be within ±0.5 % at 95 % level of confidence. The precision in the pre-calibrations of the CM11s and the CM21s is not known but most probable they were less precise than the current CM21 calibrations. Only in one case, the difference between pre- and post-calibrations for the CM21s in the new network exceeded 0.5 %. Also this is taken as an indication that that estimated calibration precision of ±0.5 % is a realistic figure.

One drawback in the pre-calibrations of the CM21s was that the new radiation stations were installed before the reference and calibration system and measurement platform in Norrköping was upgraded. For this reason the field CM21s could not be ventilated during the calibration measurements. Thermal offset correction based on nighttime pyranometer and pyrgeometer thermopile signals was applied. However, later daytime pyranometer thermal offsets determined by capping experiments showed that the applied offset correction for the unventilated CM21s was too weak. This result is also supported by the findings of Reda, et al. (2005), who reported significant differences between nighttime net IR sensitivities compared to net IR sensitivities derived by blackbody characterization of pyranometers and daytime net IR sensitivities derived from the difference between sun and shade calibration versus component sum calibration of an unventilated pyranometer. In the original pre-calibration analysis of the (unventilated) CM21s the following pyranometer offset correction was applied:

$$\text{Offset} = 0.037 * \text{netIR} \quad [\text{Wm}^{-2}] \qquad (1)$$

Where netIR is the pyrgeometer thermopile output in Wm^{-2}. In Figure 2 results of the capping experiment on one ventilated (left panel) and one unventilated CM21 is shown. Plotted is also the derived nighttime net IR sensitivity. While the difference between the capping offset and the nighttime derived offset function is small for the ventilated pyranometer the difference is very large for the unventilated instrument. Therefore, the pre-calibrations of the CM21s were re-evaluated with the following offset correction applied:

$$\text{Offset} = 0.090 * \text{netIR} \quad [\text{Wm}^{-2}] \qquad (2)$$

With the offset correction in Equation 2, the responsivities became 0.3-1.0 % higher than when the equation 1 was used. The pre-calibration responsivities for the CM21s given in Table 3 were calculated with the offset correction according to Equation 2.

Attention!

In this report, the global radiation results from the new stations have been recalculated with the pyranomter sensitivities given in Table 3. However, in the original raw data telegrams/files from the radiation network the responsivities derived with offset correction according to equation 1 were used and reported at the simple stations.

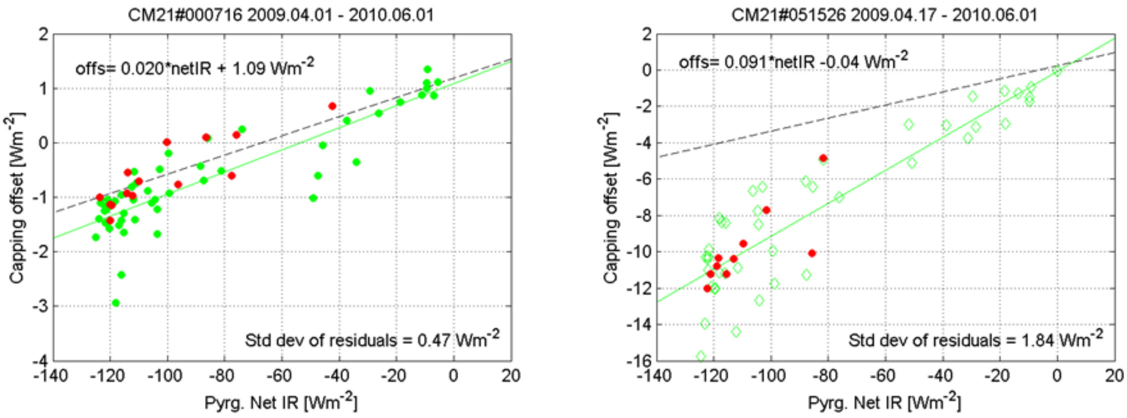

Figure 2. Daytime pyranometer offsets determined by capping experiments.CM21#000716 was operated in a SMHI3-ventilator, CM21#051526 was operated with the original Kipp&Zonen radiation screen. Green dots= daytime pyranometer offsets determined by capping. Green line= linear fit of (green) capping offset points. Red dots= daytime pyranometer offsets determined by capping when dT(air)/dt>1.5 K/h. Black dashed line= offset function determined from nighttime pyranometer and pyrgeometer data. The majority of the capping data points were taken in calm conditions.

3 Data used for the comparison

The basic dataset used for the comparison consists of quality assured hourly values from the 12 stations with both old and new measurements. For the old network the old operational quality assurance routine (“Solrutinen”,VMS based) was used. For the new stations, preliminary quality assurance routines developed by Thomas Carlund were applied. The new quality assurance routines are based on routines developed for the Baseline Surface Radiation Network (BSRN) by Long and Dutton (2002), adjusted to fit the measurement program at the Swedish stations and tuned to Swedish climatological limits.

Only the hourly values that were classified as “properly measured” both in the old and the new network for each specific parameter were used for the comparison. Therefore, in the cases when daily and monthly values are compared these values may not represent the complete daily or monthly totals. Since the old quality assurance routine was developed for hourly data only, and the new routines are mainly designed for 1-minute data, an attempt to compare the old and new routines (on the same data set) has not been made.

At the majority of stations, the time period for the parallel measurements was from June 2006 until December 2007. Unfortunately, some of the old stations broke down beyond repair in advance. This was the case in Stockholm (ended August 2006), Göteborg/Gothenburg (ended October 2006) and Karlstad (ended April 2007). Luckily, the new stations were installed early at these sites and data from March-May 2006 could also be used for Stockholm and Göteborg. The new advanced stations in Kiruna and Visby were not installed until late 2006 which limited the comparison to 2007 only.

At the old stations in Umeå and Östersund errors were found in the global radiation data around midsummer. Both the direct and global radiation measurements were offset corrected by the average night-time signals. However, from a solar radiation point of view there is no night-time in northern Sweden around midsummer. The solar elevation never gets below -6° which is set as the limit defining night-time. During the summer period tabulated values for the offset had to be used. These tabulated values were based on the night-time results during spring. What caused the old QA routine to assign erroneous global radiation offset values in Umeå and Östersund is currently not known. In the following analysis the erroneous global radiation offset values +5 Wm^{-2} (Umeå) and +3 Wm^{-2} (Östersund) have been replaced with the more correct values -1 Wm^{-2} and -3.5 Wm^{-2}, respectively. The effect of the errors was that the corrected global radiation values from the old stations became 6 Wm^{-2} (Umeå) and 6.5 Wm^{-2} (Östersund) higher than the original reported values during about 90 days around midsummer. For the direct radiation in Kiruna there was a similar kind of offset error but since the error in this case was small, about 2 Wm^{-2}, it has not been corrected for.

An overview of the magnitude of monthly totals of the radiation variables during the comparison period at each station is shown in Figure 3. Note that the plotted monthly irradiation values are not complete monthly values, since only the data points flagged as properly measured at the same time both in the old and in the new network that are included in these monthly values. Generally, winter values of solar radiation in Sweden are very small which makes the comparison more noisy during this time of the year. In summer the higher solar elevations and longer days result in much higher irradiance and irradiation values which make the comparison more robust.

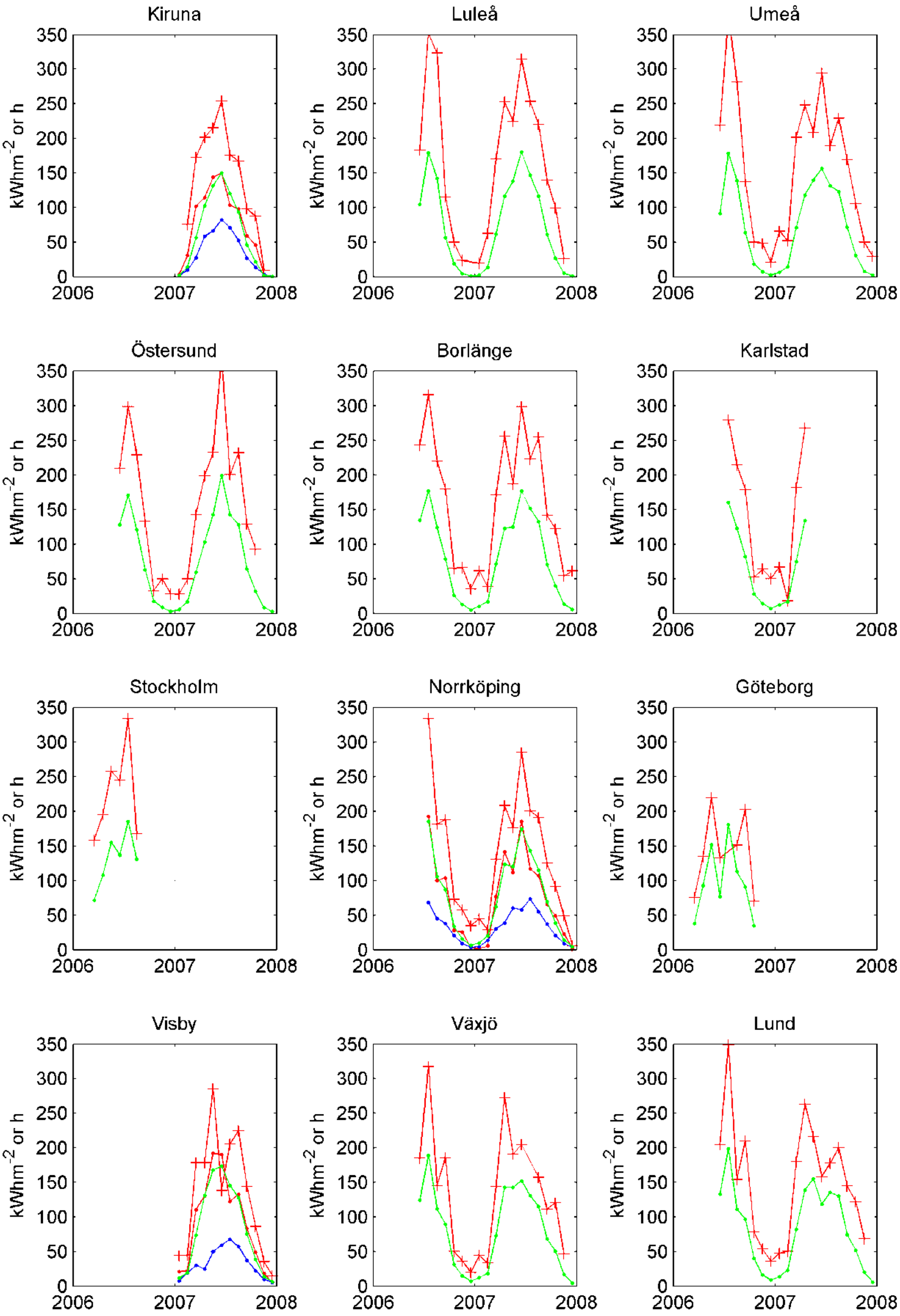

Figure 3. Monthly totals (irradiations) of the variables direct radiation (red line with dots), global radiation (green), diffuse radiation (blue) and sunshine duration (red line with plus signs) during the comparison period measured by the new stations. (100 kWhm^{-2} *= 360 MJm*$^{-2}$*.)*

4 Results

4.1 Direct radiation

4.1.1 Comparison of old and new direct radiation measurements

Firstly, monthly sums and hourly mean values of direct radiation from the old and the new stations in Kiruna, Norrköping and Visby have been compared. Ratios of monthly direct irradiation from the old (I_{old}) and the new (I_{new}) stations are presented in Table 4 and plotted in the upper row of Figure 4. At all three stations the direct radiation values integrated over the whole period are slightly higher for the old measurements. In Kiruna and Visby the differences are less than 1 %. In Norrköping, the difference is larger but close to the calibration error found in the pyrheliometer measurements from the old station. Another feature is that the (monthly) ratios appear to be more stable in Kiruna and, especially, Visby than in Norrköping. The reason for this is currently not known. By correcting for the calibration error in Norrköping one can conclude that the ratios for high irradiance months are generally within 1 % at all sites.

The slightly higher direct irradiance values measured by the old stations also show up in the comparison of hourly values. The graphs in the middle row in Figure 4 show differences in hourly mean direct irradiance for all hours when I>10 Wm^{-2} either at the old or at the new station. An approximate interval that covers 95 % of the differences is between -5 Wm^{-2} and +10 Wm^{-2}, when the old station in Norrköping is corrected for its calibration error.

A third type of analysis of direct irradiance data has been made for hourly clear sky, or more correctly clear sun, data. The criteria for a clear sun hour are that the sunshine duration must be 60 minutes, direct irradiance must be >400 Wm^{-2} and the diffuse irradiance must be <150 Wm^{-2}. Furthermore, only hours when the solar elevation in the middle of the hour was >5° were considered. Taking the sum of all clear sun hours from the old and new stations there is just a small positive bias in the old measurements compared to the new ones (~0.2 % in Kiuna and Visby). As described above calibrations of pyrheliometers are made in clear sun condition when the solar elevation is >35°. It is therefore encouraging to see that the ratio of the old over the new measurement values under these conditions is very close to one both in Kiruna and Visby. The pre-calibration of the old pyrheliometer in Norrköping was not done in the same way as ordinary calibrations of field pyrheliometers. Instead daily totals of direct radiation, from both clear and partly cloudy skies, were used to derive the pre-calibration responsivity. This is supposed to partly be the reason why the direct radiation differs most in Norrköping for the clear sun hours even if a correction for the 1.3 % calibration error at the old station would be made.

Finally, there appear to be a small dependence with solar elevation. A careful look at the graphs in the bottom row of Figure 4 reveals that the ratio of old to new direct irradiance (NIP/CH1) slightly increases with decreasing solar elevation.

Table 4. Ratios of monthly accumulated direct radiation (=sum(Iold)/sum(Inew)), monthly accumulated direct radiation (kWhm-2) and number of hourly values available in each month of the comparison.

Month	Kiruna	Norrköping	Visby
200608	-	1.0184 99.9 600	-
200609	-	1.0193 103.8 630	-
200610	-	1.0255 27.9 661	-
200611	-	1.0204 25.4 574	-
200612	-	-	-
200701	1.0123 3.1 675	1.0333 1.9 624	1.0039 20.8 684
200702	1.005 30.9 594	1.0285 5.3 600	1.0047 21.9 568
200703	1.0068 101.8 665	-	1.0033 110.6 636
200704	1.0094 114.3 650	1.0094 141.3 579	1.0043 130.4 431
200705	1.0042 144.0 732	1.0164 111.3 632	1.0019 192.0 670
200706	1.001 150.1 656	1.0112 185.1 650	1.0045 189.9 667
200707	1.0038 103.3 669	1.0128 116.5 683	1.0055 122.3 694
200708	1.013 97.7 656	1.0136 106.6 649	1.0052 132.9 657
200709	1.0124 59.0 636	1.0167 65.3 654	1.0044 83.4 641
200710	1.0161 45.7 658	1.0188 48.8 668	1.0083 49.2 711
200711	1.0021 2.6 631	1.0215 23.0 671	1.0122 18.2 666
200712	-	1.0282 2.2 687	1.0112 5.4 686
Whole period	1.0069 852.5 7895	1.0150 1064.2 9562	1.0044 1076.9 7711

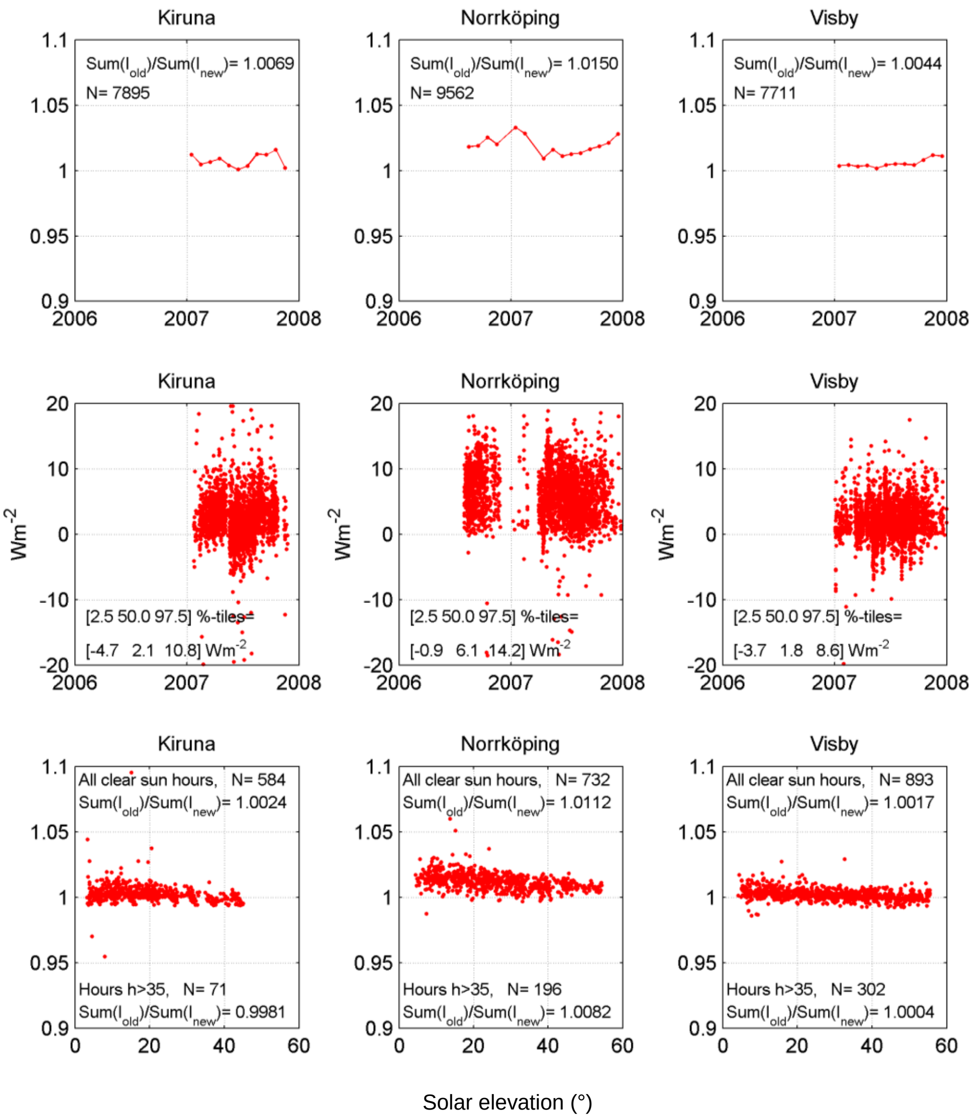

Figure 4. Top row: Monthly direct irradiation ratios, I_{old}/I_{new}, at the three stations under study. $Sum(I_{old})/Sum(I_{new})$ is the ratio of the total direct irradiation values integrated over the whole comparison period for the old and the new stations respecitely.
Middle row: Difference in hourly mean direct irradiance, $I_{old}-I_{new}$, for hours with $I>10$ Wm^{-2}.
Bottom row: Ratio of hourly mean direct irradiance, I_{old}/I_{new}, versus solar elevation for clear sun conditions.

4.1.2 Possible corrections of “old” direct radiation data

There are many sources of errors influencing meteorological radiation measurements. Factors influencing the accuracy of measurements are among others spectral selectivity, non-linearity, response time/signal delay, thermal and electrical offsets, temperature dependence, viewing geometry, tilt angle, pointing or levelling accuracy, calibration uncertainty and data acquisition errors. From field measurement data it is difficult, or even impossible, to isolate and accurately quantify the effect of any single error source.

Nevertheless, in the following some attempts have been made to quantify a few apparently systematic differences found in the comparison data, both for the direct radiation and in section 4.2.2 for the global radiation.

As shown above, under other than near ideal calibration conditions (clear sky, high and stable direct irradiance, high solar elevation) the old Eppley NIP pyrheliometers seem to give slightly higher readings than the new Kipp & Zonen CH1 pyrheliometers. This is also in line with the findings by Michalsky et al. (2011). Over a 10 month period a large number of commercial pyrheliometers were compared to a group of three electrical-substitution cavity radiometers. All test instruments were calibrated against a group of four (un-windowed) electrical-substitution cavity radiometers around 45° solar elevation. The study was a “blind” analysis and the instruments were not identified until after all the results had been calculated (and submitted for publication). Among others, it was found that the groups of Eppley NIP pyrheliometers especially under all sky and passing cloud conditions gave higher readings than both the reference group and the group of CH1 pyrheliometers. Since the instrument identities were not known during the analysis any causes for the found differences were not discussed by Michalsky et al.

One explanation to the fact that the Eppley NIPs give higher readings in some conditions is probably their slightly larger field of view compared to the CH1s (as well as the cavity radiometers). Under conditions with larger contribution from circumsolar irradiance than during calibration situations the Eppley NIPs simply measure more radiation. Other factors such as e.g. difference in spectral response, non-linearity, and tilt angle dependence may also contribute to the found difference but these effects are thought to be smaller. And since the pyrheliometers were mounted side by side on the same tracker the difference in pointing accuracy should also be small. Possibly, there could also be a small offset effect that differ between the two pyrheliometer types. At a few simple capping experiments of pyrheliometers at SMHI the tested CH1 pyrheliometers were found to have a very low (thermal) offset, normally <1 Wm^{-2}. On the other hand, the offsets in the investigated Eppley NIPs were estimated to ≥ +5 Wm^{-2} in most clear sky cases. However, the results varied considerably between different Eppley NIPs and any conclusive results have not been possible to derive.

4.1.2.1 Solar elevation dependence

A simple function to correct for the slight solar elevation dependent difference between the NIPs and the CH1s under clear sun conditions (from bottom row of Figure 4) has been derived. To reduce the effect of any calibration errors, the clear sun $I_{old}/I_{new} = I_{NIP}/I_{CH1}$ data points in the lower row of Figure 4 have here been normalised with the average ratio for the points between 40°-50° solar elevation at each station. The combined result from all three stations is shown in Figure 5. For solar elevations h<43° a simple linear function has been fitted to the data and the result is

$$\left(\frac{I_{old}}{I_{new}}\right)_{norm} = -0.000167h + 1.0072, h < 43^{\circ} \qquad (3)$$

This relation should be valid for Swedish average turbidity conditions (mean $\mathrm{AOD}_{500nm} \approx 0.10$) and solar elevation and temperature range. From this, the solar elevation corrected direct irradiances measured by an old/Eppley NIP pyrheliometer, $I_{old,hcorr}$ become

$$I_{old,hcorr} = \frac{I_{old}}{-0.000168h + 1.0071}, h < 43^{\circ} \qquad (4)$$

In the calibrations of the field reference Eppley NIP #20919 against SMHI’s absolute pyrheliometers there is a clear (and approximately linear) solar elevation dependence of the sensitivity, with increasing sensitivity for decreasing solar elevation (not shown here). In the calibrations of the field reference CH1s the solar elevation dependence, if any, is much smaller. This supports the idea that a solar elevation correction should be applied to the old pyrheliometer measurements.

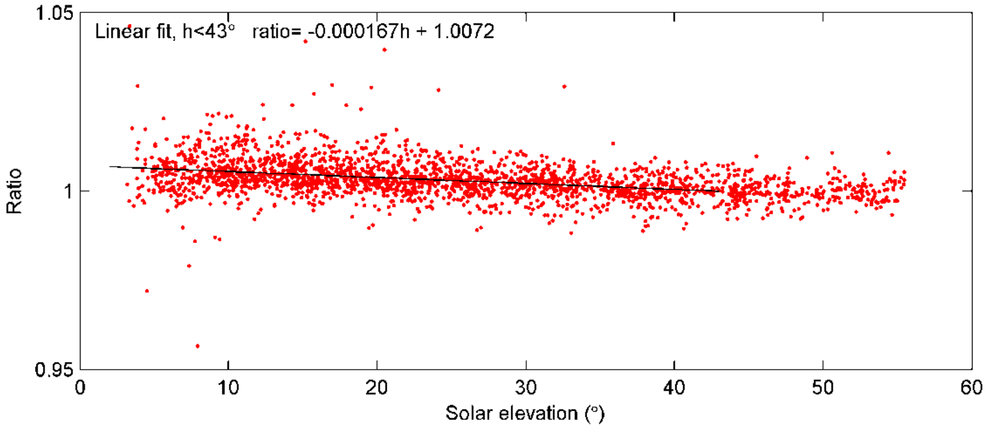

Figure 5. The normalised ratio of $I_{old}/I_{new} = I_{NIP}/I_{CH1}$ *derived from hourly direct irradiance values versus solar elevation at minute 30 of each hour. Only clear sun hours are analysed.*

4.1.2.2 Temperature dependence

Since the air temperature to some degree is correlated with solar elevation, at least on a seasonal basis, any difference in temperature dependence could explain part of the solar elevation dependence in Figure 5. But there is no “extra” temperature dependence found in the ratio of the old over new direct radiation measurements. In Figure 6, the normalised ratio $I_{old,hcorr}/I_{new}$ has been plotted versus ambient air temperature. From these results it is concluded that, at least for the interval -5°C to +25°C, conditions under which the majority of the Swedish measurements take place, there is no significant temperature dependence in the investigated data.

According to calibration certificates from Kipp & Zonen for instruments from 2001 and later CH1 pyrheliometers seem to have very individial temperature dependence of the sensitivty. In Figure 7 this temperature dependence have been plotted for eight of SMHIs CH1 pyrheliometers. For some instruments the sensitivity decreases with temperature and for others it increases. The temperature sensitivity averaged over all the CH1s is however small and within 0.3 % over the whole temperature interval -20°C to +50°C. From this, i.e. the results shown if Figure 6 and Figure 7, it is concluded that it is neither possible nor needed to derive any general temperature correction of the the older pyrheliometer measurements to make them better comparable to the new ones.

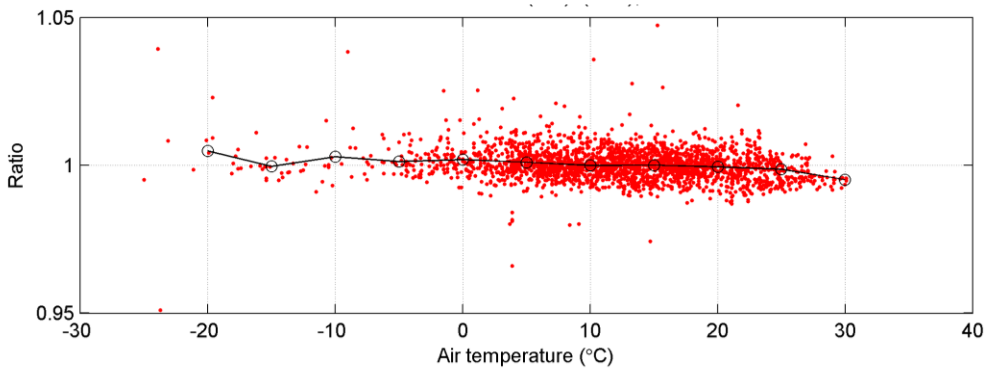

Figure 6. Normalised and solar elevation corrected ratio $I_{old,hcorr}/I_{new}$ *versus air temperature. Black line with circles is average result for 5 °C intervals.*

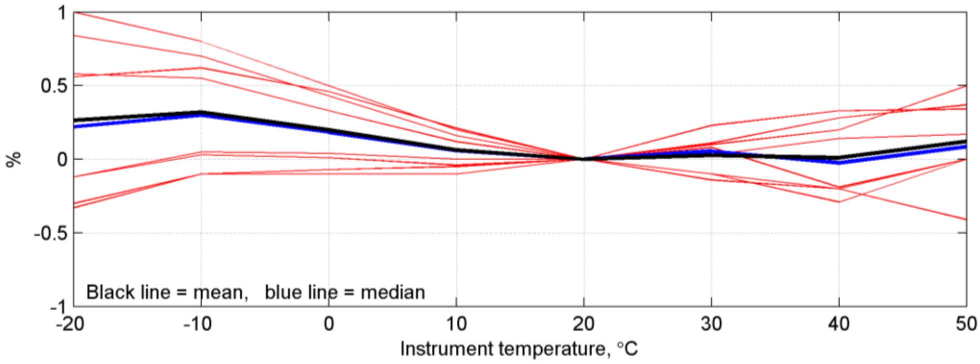

Figure 7. Temperature dependence of the sensitivty for eight of SMHI's CH1 pyrheliometers according to the calibration certificates from Kipp & Zonen. Plotted lines indicate the relative devition from the sensitivity at 20 °C.

4.1.2.3 Field of view dependence

As mentioned earlier, the difference between Eppley NIPs and Kipp & Zonen CH1s is more pronounced under conditions with thin clouds or passing clouds in front of the sun when the relative amount of circumsolar radiation seen by a pyrheliometer increases compared to the clear sun conditions. To derive a measure of the circumsolar radiation a "direct radiation clearness index" has been calculated for each hourly direct irradiance value. Here, the direct radiation clearness index, K_I, has been calculated as

$$K_I = \frac{I_{old,hcorr}}{I_{max,clear}} \qquad (4)$$

where $I_{max,clear}$ is an estimated maximum clear sky direct irradiance. To derive $I_{max,clear}$ SMARTS2 (Gueymard, 1995) calculations were performed at 1° solar elevation intervals from 0° to 60° which were stored in a lookup table. Execpt for the solar elevation/zenith angle other input parameters for the SMARTS2 calculations were fixed. Constant input parameters with influence on the calculation of direct (broadband) irradiance were: Air pressure at station level p = 950 hPa (a typical value for Kiruna), Ångström turbidity coefficient β = 0.020, Ångström wavelength exponent α = 1.3, single scattering albedo ω = 0.95, asymmetry parameter gg = 0.8, precipitable water w = 0.2 cm and total ozone O_3 = 350 DU. The maximum SMARTS2 wavelength range 280-4000 nm was used. The actual $I_{max,clear}$ values used to calculate K_I were then linearly interpolated from the SMARTS2 direct irradiance lookup table.

The dependence of (normalised) $I_{old,hcorr}/I_{new}$ on K_I has been studied and the results from all the three investigated stations are plotted in Figure 8. For $K_I \geq 0.7$ there is no significant deviation from 1 in the $I_{old,hcorr}/I_{new}$ ratio. For $K_I < 0.7$ $I_{old,hcorr}/I_{new}$ increases with decreasing K_I which is in line with the assumed increasing contribution (in relative terms) of circumsolar irradiance to the measured direct irradiance value. This type of analysis would work better for data with higher resolution in time. But since hourly values is the highest time resolution of quality assured data from the old network only hourly data have been studied here.

The black plus signs and the blue diamonds in Figure 8 are mean and median values respectively of $I_{old,hcorr}/I_{new}$ at 0.05 intervals. The values of the piecewise linear approximation for $K_I \leq 0.7$, black line in Figure 8, are given in Table 5.

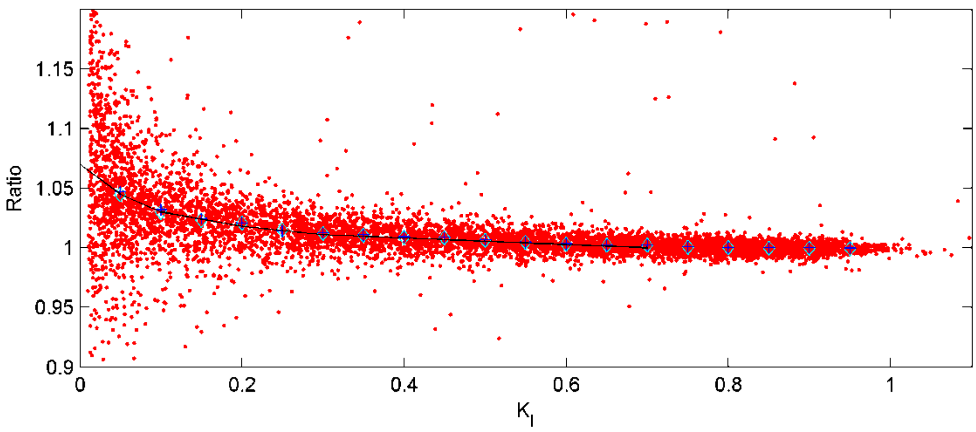

Figure 8.The normalised ratio of $I_{old,hcorr}/I_{new}$ *versus direct irradiance clearness index* K_I*. The black plus signs and the blue diamonds are mean and median values of* $I_{old,hcorr}/I_{new}$ *at 0.05 intervals.The black line is a piecewise linear approximation to the data for* K_I *<0.7.*

Table 5. Data points for the piecewise linear approximation to the normalised ratio of $I_{old,hcorr}/I_{new}$ *versus* K_I *(black line in Figure 8).*

K_I	$I_{old,hcorr}/I_{new}$
0.00	1.070
0.05	1.045
0.10	1.030
0.20	1.018
0.30	1.011
0.70	1.000

4.1.2.4 Application of corrections

The data from the old stations have been re-evaluated applying the corrections for solar elevation and field of view dependence in I_{old}. The result is presented in Figure 9. The red lines with dots are the same as in the top row of Figure 4. The black lines with plus signs are the resulting mothly I_{old}/I_{new} ratios with corrections applied to I_{old}. On the total/annual values the magnitude of the I_{old} corrections is in the order of 0.5 % and on average the I_{old}/I_{new} ratios were brought closer to one in all three cases.

The above described corrections to make I_{old} better compareable with I_{new} are rather small. But since the corrections are meant to reduce systematic errors they should be applied, in particular for studies analysing long-term changes/variation in direct solar radiation.

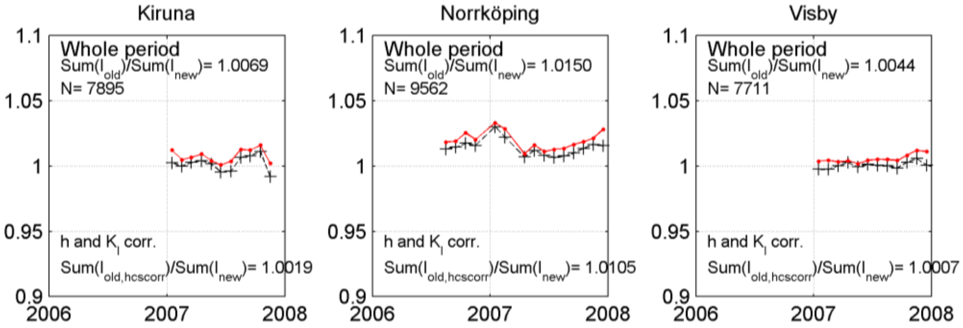

Figure 9. Monthly direct irradiation ratios, I_{old}/I_{new}, at the three stations under study. $Sum(I_{old})/Sum(I_{new})$ is the ratio of the total direct irradiation values integrated over the whole comparison period for the old and the new stations respecitely.This figure is the same as the top row of Figure 4 with the addition of the results derived with corrected I_{old}.

4.2 Global radiation

4.2.1 Comparison of old and new global radiation measurements

Monthly sums and hourly mean values of global radiation from the 12 old and new stations have been compared. Ratios of monthly global irradiation from the old and the new stations, G_{old} /G_{new}, are given in Table 6 and plotted in Figure 10. Also the ratio of the total values integrated over the whole comparison period (Sum(G_{old})/Sum(G_{new})) are given both in Table 6 and in the graphs of Figure 10. At eleven of the twelve stations the ratio of the total global irradiation is within 1±0.01. The largest difference is found in Kiruna where the old station gave about 1.2 % lower total global irradiation than the new station. The average of all total ratios is 0.9974 and the standard deviation is 0.0053. The standard deviation of the mean is 0.0015. For a 90 % confidence interval the coverage factor from Student's t-distribution for 12-1=11 degrees of freedom is 1.80. The upper limit for a 90 % confidence interval of the mean ratio then becomes 0.9974+1.80·0.0015 = 1.0001. One is therefore (with a tiny margin) covered by this interval and the average of the total ratios is therefore not significantly different from one at a 90 % level of confidence.

It is currently not understood why the measurements agree so well in Norrköping despite the fact that according to the calibration results the old station was using a 1.9 % too low pyranometer sensitivity which should lead to an overestimation of the global radiation measurements. Correcting for this suspected error would give 1.6 % lower total global irradiation from the old station compared to the new one. While a correction for the erroneous sensitivity applied to the old pyrheliometer measurements gave a very good agreement with the new measurements this is apparently not the case for the pyranometer measurements. The deviating results between the pyrheliometer and pyranometer measurements in Norrköping can not be explained but are thought to be caused by the non-standard calibration procedure and the following sensitivity adjustment of the amplifier cirquit in the old station.

Naturally, individual monthly global irradiation ratios scatter a lot more than the total global irradiation ratios, especially for winter months. The agreement during summer is normally within 1 % while the measurements can differ 5 % or more during November to January. But one should keep in mind that the global irradiation during these autumn-winter months is very low. Even in southern Sweden the global irradiation during November, December and January summed together is generally less than 5 % of the annual global irradiation.

Table 6. Ratios of monthly global irradiation (=sum(G_{old})/sum(G_{new})), monthly accumulated global radiation (kWhm^{-2}) and number of hourly values available in each month of the comparison.

Month	Kiruna	Luleå	Umeå	Östersund	Borlänge	Karlstad	Stockholm	Norrköping	Göteborg	Visby	Växjö	Lund
200603	-	-	-	-	-	-	0.9859 71.3 743	-	1.0043 38.0 379	-	-	-
200604	-	-	-	-	-	-	0.9928 107.5 718	-	1.0042 92.6 718	-	-	-
200605	-	-	-	-	-	-	0.9925 154.8 742	-	1.0012 151.9 740	-	-	-
200606	-	0.9974 104.5 400	1.0032 91.2 421	0.9881 127.8 526	0.9961 134.4 528	-	0.9944 136.6 505	-	0.9985 76.3 263	-	0.9988 124.3 518	1.0023 132.8 510
200607	-	0.9972 179.0 690	1.0003 178.1 711	0.9888 171.0 733	0.9966 176.3 736	0.9912 160.1 612	0.9928 185.1 710	1.0026 185.2 724	1.0028 180.3 739	-	1.0019 188.6 732	1.0037 198.8 726
200608	-	0.9944 141.8 728	0.9956 138.9 724	0.9899 120.7 735	0.9921 123.7 738	0.9909 122.6 669	0.9937 130.7 732	1.0035 105.6 618	0.9990 112.5 737	-	0.9980 111.8 733	1.0008 111.4 735
200609	-	0.9945 56.6 689	1.0019 63.9 693	0.9911 63.1 695	0.9888 78.9 695	0.9932 81.7 694	-	0.9932 86.7 650	1.0002 90.5 695	-	0.9946 89.3 694	1.0061 96.3 695
200610	-	0.9999 18.9 690	1.0169 18.3 629	0.9957 17.7 676	0.9865 26.0 694	0.9963 27.9 692	-	0.9952 33.8 690	1.0039 34.3 691	-	0.9986 31.3 693	1.0032 40.0 693
200611	-	1.0301 4.3 689	1.0675 7.0 694	1.0090 8.8 690	0.9996 13.0 692	1.0128 14.3 693	-	0.9952 15.2 657	-	-	1.0008 14.7 687	1.0284 16.0 692
200612	-	0.9914 0.8 722	1.0539 2.1 740	1.0191 2.7 743	1.0216 5.2 742	1.0424 7.1 744	-	1.0253 6.0 577	-	-	1.0107 7.1 744	1.0422 8.7 742
200701	0.9962 1.8 676	1.0155 2.1 672	1.0769 6.0 744	1.0044 5.6 728	1.0047 10.3 743	1.0253 12.3 744	-	1.0006 9.9 664	-	1.0176 11.3 684	1.0031 12.2 712	1.0255 13.5 743
200702	0.9994 14.0 601	1.0048 13.7 615	1.0273 14.5 617	0.9902 17.1 605	0.9905 17.0 617	0.9978 16.9 608	-	1.0014 20.2 630	-	1.0017 19.3 568	0.9983 18.2 617	1.0073 23.0 618
200703	0.9853 56.4 665	0.9997 61.9 738	1.0067 70.7 735	0.9922 59.7 700	0.9837 71.5 739	0.9987 74.4 737	-	0.9999 62.2 697	-	0.9934 73.6 640	0.9945 73.0 741	1.0006 82.2 741
200704	0.9876 102.8 652	1.0029 116.4 716	1.0059 117.7 720	0.9944 103.0 711	0.9909 122.8 717	0.9989 133.6 719	-	1.0028 113.4 632	-	0.9985 131.1 646	0.9963 142.9 720	0.9991 138.9 720
200705	0.9872 131.4 734	1.0054 138.3 733	1.0030 139.7 741	0.9917 142.4 742	0.9937 124.7 740	-	-	1.0023 119.9 641	-	0.9998 167.9 675	0.9989 143.0 743	0.9995 155.0 741
200706	0.9862 149.9 654	1.0001 180.3 719	0.9967 156.4 543	0.9893 198.7 718	0.9920 176.7 716	-	-	1.0033 174.0 670	-	1.0017 173.5 669	1.0008 152.0 700	1.0015 118.4 568
200707	0.9884 120.3 675	0.9977 147.0 743	0.9970 131.2 700	0.9894 142.3 739	0.9939 151.5 744	-	-	1.0080 143.4 699	-	1.0053 145.3 703	1.0034 131.0 744	0.9992 135.2 737
200708	0.9876 93.5 658	0.9963 116.5 740	1.0039 122.8 741	0.9919 127.9 739	0.9940 132.9 743	-	-	1.0061 115.0 668	-	1.0043 127.5 661	0.9984 115.2 743	0.9996 130.5 741
200709	0.9891 46.0 640	0.9985 61.1 689	1.0126 71.5 713	0.9928 64.2 690	0.9919 70.6 695	-	-	1.0060 69.7 666	-	0.9977 75.5 644	0.9940 68.2 695	1.0019 73.9 689
200710	0.9902 21.3 659	0.9998 26.4 740	1.0288 30.3 744	0.9938 31.8 726	0.9861 40.0 744	-	-	1.0000 38.2 676	-	0.9892 38.4 715	0.9881 50.6 743	1.0009 51.7 735
200711	0.9891 1.4 630	0.9938 4.8 718	1.0372 7.8 719	1.0079 8.3 718	1.0137 13.3 718	-	-	0.9952 14.3 680	-	0.9975 13.3 666	0.9964 17.1 718	1.0201 20.0 716
200712	0.9329 0.4 673	0.9674 0.9 743	1.0924 2.3 743	1.0077 2.8 743	1.0638 5.9 743	-	-	1.0248 4.3 687	-	1.0123 6.2 689	0.9925 4.6 741	1.0375 5.2 722
Whole period	0.9876 739.1 7917	0.9989 1375.3 13174	1.0037 1370.4 13072	0.9910 1415.6 13357	0.9932 1494.5 13484	0.9959 650.8 6912	0.9925 655.2 4150	1.0028 1317.0 11958	1.0015 776.5 4962	1.0006 983.0 7960	0.9985 1495.0 13418	1.0026 1551.3 13272

In Figure 11, the monthly G_{old}/G_{new} ratios have been averaged over all (available) stations for each month. The ratios are stable and slightly below 1 during the summer half year. The average of the April through September ratios is 0.9974. For months around mid-winter the G_{old}/G_{new} ratios increases to about 1.02 for January and December.

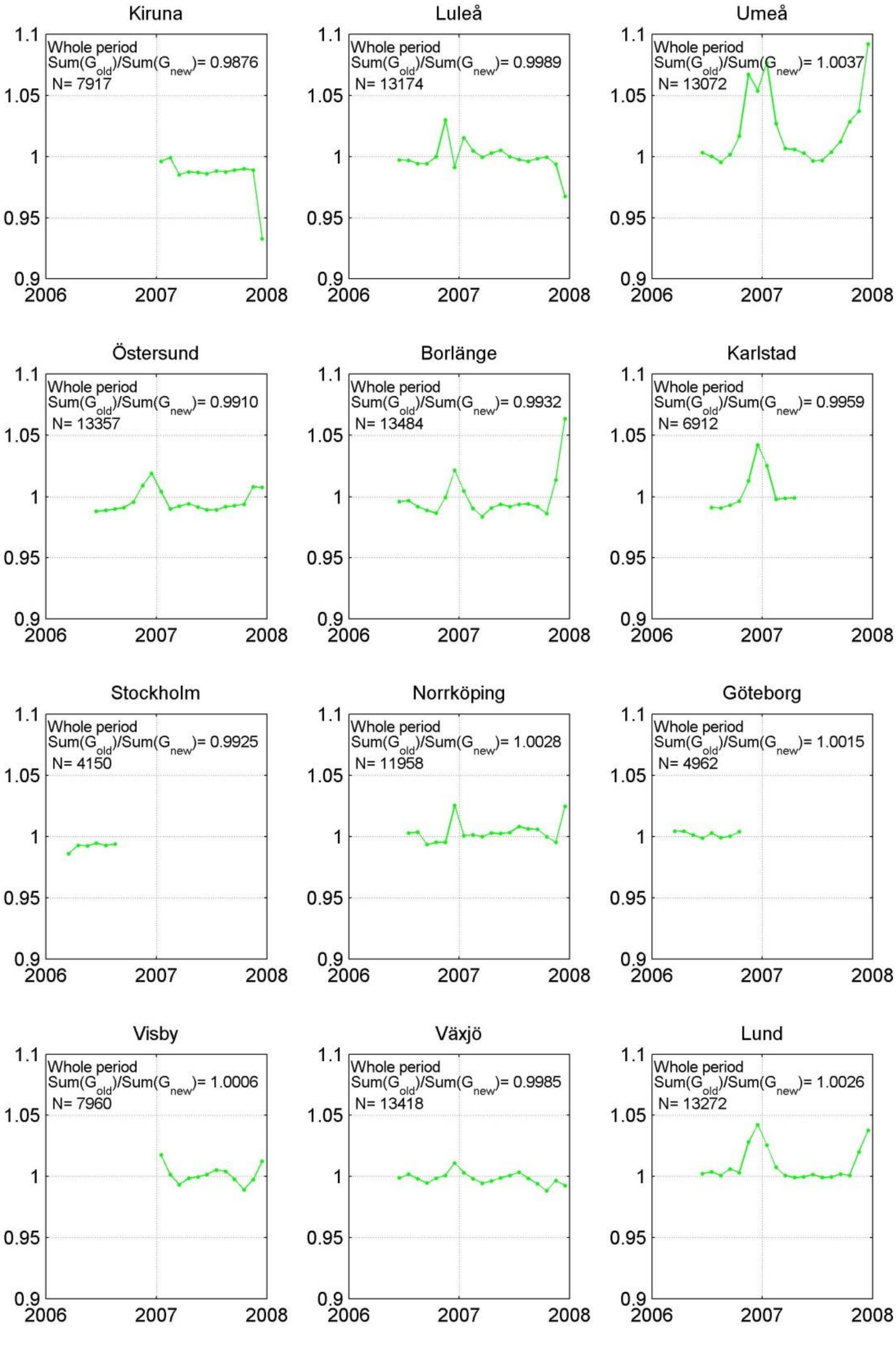

Figure 10. Monthly global irradiation ratios, G_{old}/G_{new}, at the twelve stations under study. $Sum(G_{old})/Sum(G_{new})$ is the ratio of the total global irradiation values integrated over the whole comparison period for the old and the new stations respectively.

Despite the very low global radiation around mid-winter there is one feature found that helps explaining the common higher global radiation values at the old stations during this time of the year. In Figure 12 the ratios of hourly mean global irradiance, G_{old}/G_{new}, for clear sun hours have been plotted versus solar elevation. (The requirements for an hour to be classified as a

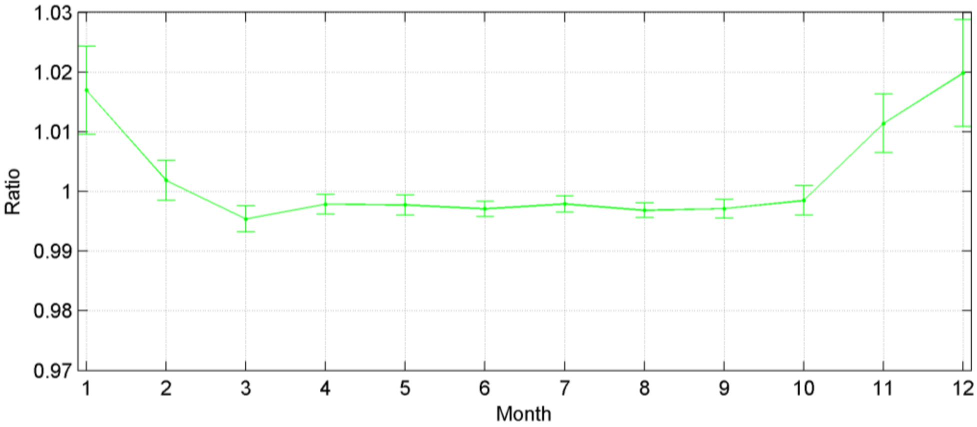

Figure 11. Monthly mean global irradiation ratios G_{old}/G_{new} *averaged over all (available) stations. Error bars indicate one standard deviation of the means.*

clear sun hour are the same as for the direct radiation comparison: I>400 Wm^{-2}, D<150 Wm^{-2} and SD=60 minutes.) In most cases there is a slight decrease in G_{old}/G_{new} ratio for decreasing solar elevations from around 50° down to 20-15°. Then from 15-10° towards even lower solar elevations the G_{old}/G_{new} ratio increases markedly. (These results are studied in more detail below.) For clear sun conditions at solar elevations h>35°, which is close to normal calibration conditions, the average ratios G_{old}/G_{new} are in all cases within 1±0.010 except in Kiruna. The average ratio over all stations for clear sun hours and h>35° is 0.9981 (std. dev.= 0.0050).

There is no apparent solar elevation dependence in the G_{old}/G_{new} ratio for cloudy skies. Figure 13 is the same as Figure 12 but for overcast conditions. Requirements on an hour to be classified as overcast are that SD<0.1 minute, I<3 Wm^{-2} and G>50 Wm^{-2}. The 50 Wm^{-2} limit on global radiation was set to reduce noise in the ratio for low irradiance hours. Generally, the total irradiation ratio for cloudy skies is very close to the ratio for clear sky and solar elevation h>35° at each station. The average Sum(G_{old})/Sum(G_{new}) ratio for cloudy skies over all stations is 0.9980, i.e. almost exactly the same value as for clear skies and h>35°.

The solar elevation dependent G_{old}/G_{new} ratio for clear skies can partly explain the variation in monthy mean ratios over the year. It could also lead to a systematic difference between the old and new measurements with latitude. In Figure 14 the total global irradiation ratios, Sum(G_{old})/Sum(G_{new}) for the whole comparison period, have been plotted versus station latitude. The picture is rather noisy but if any, there is a decreasing trend in the G_{old}/G_{new} ratio ratio with increasing latitude. This is in line with the clear sky results since the relative contribution of global radiation under solar elevations angles in the range 10°-30° increases with latitude.

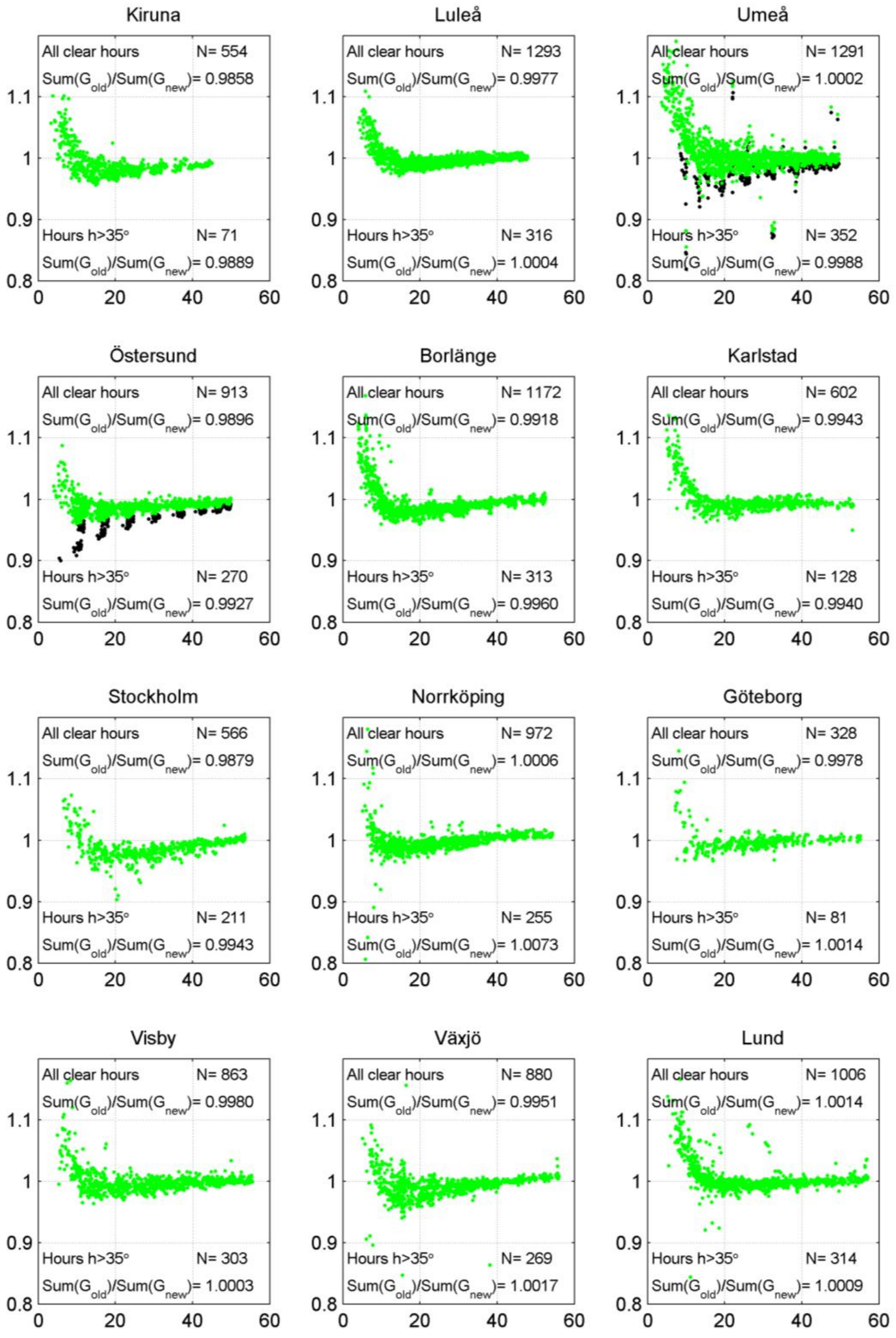

Figure 12. Hourly global irradiance ratios, G_{old}/G_{new}, for clear sun hours at the twelve stations under study. (See text for description of clear sun hour.) Black dots represent results using original data from the old stations in Umeå and Östersund where erroneous tabled offset values were used during summer months when the nights never get dark in northern Sweden.

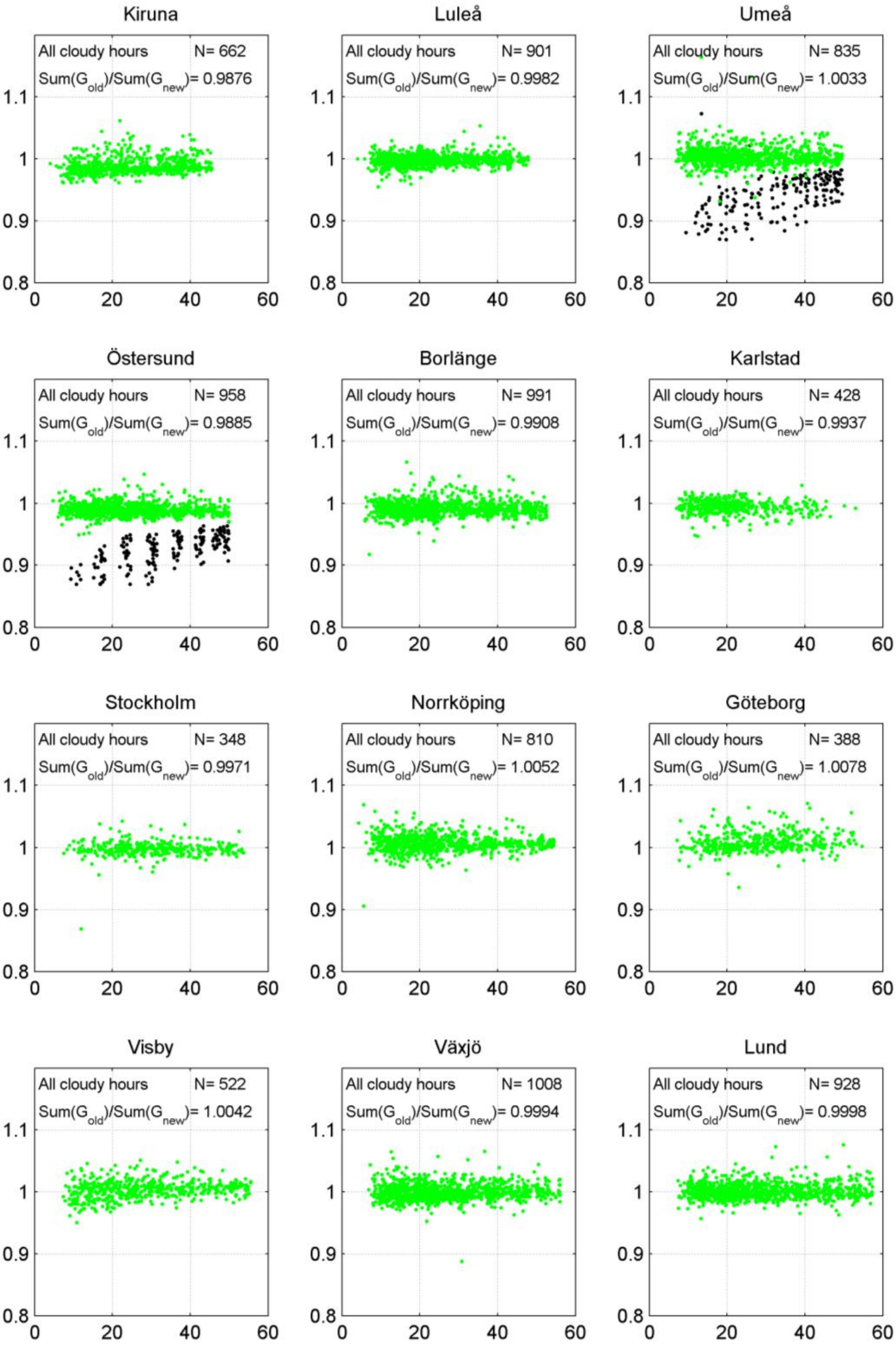

Figure 13. Hourly global irradiance ratios, G_{old}/G_{new}, for overcast hours at the twelve stations under study. (See text for description of an overcast hour.) Black dots represent results using original data from the old stations in Umeå and Östersund where erroneous tabled offset values were used during summer months when the nights never get dark in northern Sweden.

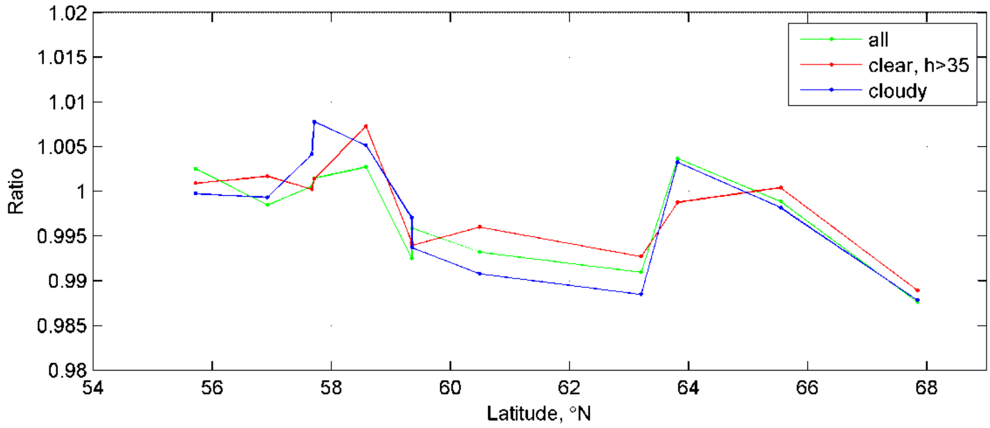

Figure 14. Total global irradiation ratios, Sum(G_{old})/Sum(G_{new}) for the whole comparison period, versus station latitude and for different cloud conditions as indicated by the legend.

4.2.2 Possible corrections of “old” global radiation data

In the field measurements several types of measurement errors affect the result. Among others thermal and electrical offset errors, temperature dependence, non-linearity, non-ideal spectral and directional responses are all affecting the measurement results. In this case, the main contributor to the solar elevation dependent G_{old}/G_{new} ratio under clear sun conditions is believed to be a difference in directional response between the CM11 and the CM21 pyranometers.

4.2.2.1 Temperature dependence

In the subtask project “Solar radiation and pyranometry” in the Solar Heating and Cooling Programme of the International Energy Agency during (IEA) the 1980s several pyranometer types were characterised by different laboratories (Wardle 1996). According to these results the sensitivity of a CM11 pyranometer could vary as much as ±3 % over the interval -25°C to +35°C. It was also shown that the temperature dependence may change over time. But the results of the temperature characterisation differ considerably between laboratories and perhaps the main conclusion is that, at least during the 1980s, it was very difficult to accurately measure temperature sensitivities of pyranometers.

In the same way as for the pyrheliometers any difference in temperature sensitivity between the old and new pyranometers used by SMHI have been investigated. In Figure 15 the normalised ratio for cloudy hours has been plotted versus air temperature. The ratios from cloudy hours were used to reduce the effect of directional response differences, based on the fact that the radiance distribution under cloudy sky is less anisotropic than is the case under clear skies. As for the pyrheliometers any systematic difference in temperature sensitivity between the old and the new instruments was not found. Over the temperature interval -10°C to +25°C in Figure 15, there is only minor deviations (<0.003) from 1 in the average result for 5°C intervals.

According to calibration certificates from Kipp & Zonen for instruments from 2001 and later CM21 pyranometers seem to have very individual temperature dependence of the sensitivty. In Figure 16 this temperature dependence have been plotted for 26 of SMHIs CM21 pyranometers. For some instruments the sensitivity decreases with temperature and for others it increases. The temperature sensitivity averaged over all the CM21s is however rather small and within 0.5 % over the whole temperature interval -20°C to +50°C. Even though the sensitivity on average is

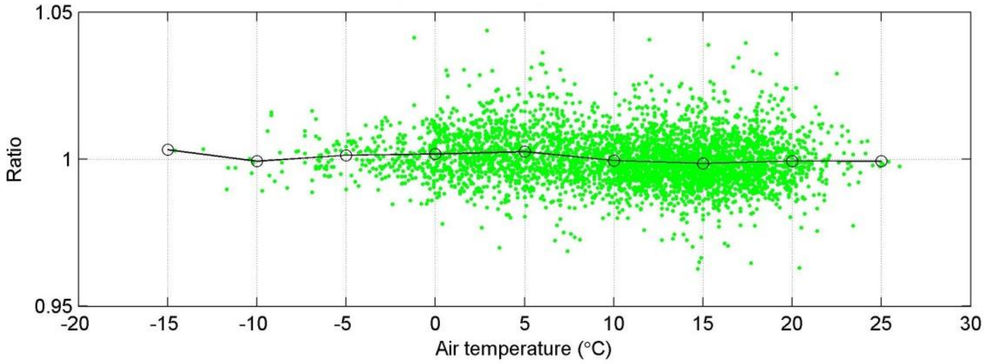

Figure 15. Normalised G_{old}/G_{new} for cloudy hours versus air temperature. Black line with circles is average result for 5 °C intervals.

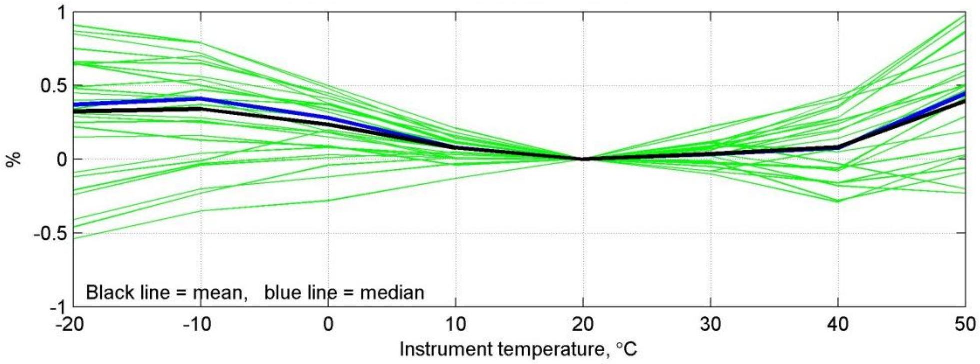

Figure 16. Temperature dependence of the sensitivty for 26 of SMHI's CM21 pyranometers according to the calibration certificates from Kipp & Zonen. Plotted lines indicate the relative deviation (%) from the sensitivity at 20 °C.

higher at temperatures below zero compared to the reference temperature 20°C, there are still several instruments with lower sensitivity at freezing temperatures.

From the results shown if Figure 15 and Figure 16, it is concluded that it is neither possible nor needed to derive any general temperature correction of the older pyranometer measurements to make them better comparable to the new ones.

4.2.2.2 Directional response

Due to the dependence on solar elevation found for clear sun hours the pyranometer's directional response have been studied in more detail. Firstly, pyranometer response have been investigated separately for CM11/CM10 and CM21 pyranometers. Relative responses of four (ventilated) field reference pyranometers at the main station in Norrköping were calculated for the mainly cloudfree day 2009-06-01 and the results are plotted in Figure 17. The reference values of global irradiance were calculated from direct irradiance (CH1 #990231) and diffuse irradiance (CM21 #031118, ventilated and offset corrected by net-IR dependent function from capping experiments). The green line is the apparent directional response ($G/(I\sin(h)+D)$) relative to the average response at solar elevations >35° for each instrument derived from data which have been corrected. for thermal offset by the function determined by capping experiments (see section on pyranometer calibration above). The black lines are the same but in this case the test pyranometers were only corrected for their average nighttime signals.

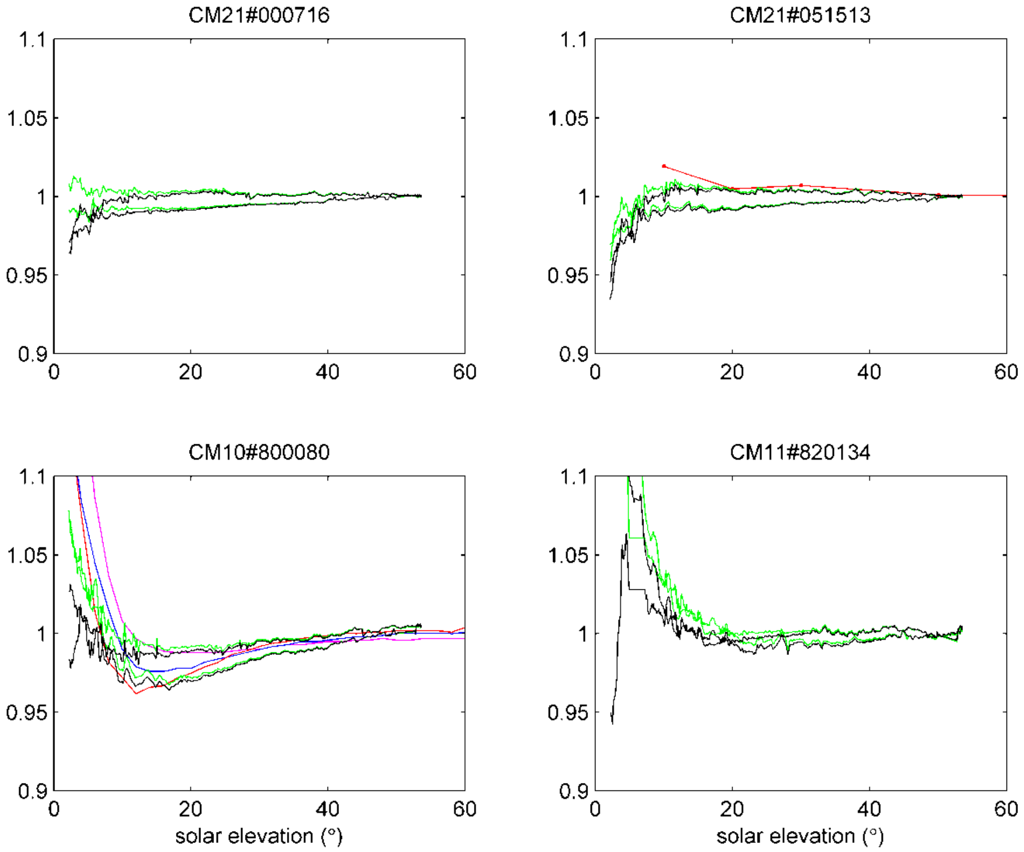

Figure 17. Relative pyranometer responsivity, for the clear sky day 2009-06-01 in Norrköping. For green lines the test pyranometers were corrected for thermal offset as a function of pyrgeometer thermopile signal. For black lines the test pyranometers were corrected by their mean night-time signals. Reference responsivity is the mean resposivity for all minutes when the solar elevation was >35°. Reference values of global irradiance were measured by a pyrheliometer (CH1 #990233) and a shaded pyranometer (CM21 #031118). All pyranometers were ventilated. For CM21 #051513, the directional response given by the manufacturer for 180° azimuth angle has been plotted in red. For CM10 #800080 the directional response for three azimuth angles measured in laboratory by SP (Borås, Sweden) in an IAE project during the mid 1980s. Magenta line: 90° azimuth, blue line: 180° azimuth and red line: 270° azimuth.

(This is the “offset correction” that was used at all the old stations and that is used at the new simple stations.) For CM21 #051513 also the directional response for 180° azimuth angle given in the calibration certificate from the manufacturer is plotted in red. For CM10 #800080 the directional response, measured in laboratory at SP (SP Technical Research Institute of Sweden) in the mid 1980s, is plotted for three different azimuth angles. (Any laboratory measurements of CM21 #000716 and CM11 #820134 do not exist.)

During the analysed day 2009-06-01 the air temperature (at instrument level) varied from 10 °C at sunrise to 25 °C at solar noon. In the afternoon the maximum temperature of 27 °C was registered and at sunset the temperature had fallen to 17 °C. Except for half an hour around 24° solar elevation in the afternoon the absolute value of the temperature change (*dT/dt*) was <3°C/h. Over this limited temperature range the difference in temperature sensitivity between reference and test instruments should be within 0.5 % for the CM21s according to manufacturer specifications (see Figure 16 above). From the analysis of (normalised) G_{old}/G_{new} during cloudy hours versus air temperature (Figure 15 above) there is no systematic difference in temperature dependece between CM11 and CM21 pyranometers.

The temperature change affect all pyranometers in the same direction and the error should be of the same magnitude for CM11 and CM21 pyranometers, according to their specifications from the manufacturer. The spectral properties of the CM21 and CM11 domes and detectors should also be similar. Also the difference in non-linearity should be a minor factor according to the specifications. Based on these assumptions and the fact that the field and laboratory results for CM10 shown in Figure 17 agree well, the apparent difference in directional response between the CM21s and the CM10/CM11 in Figure 12 and Figure 17 is thought to be, to a major part, a true directional response difference.

Finally, the dependence of normalised G_{old}/G_{new} for clear sun hours on solar elevation has been studied and the results from all the twelve investigated stations are plotted in Figure 18. The hourly G_{old}/G_{new} values have here been normalised with the average ratio at each station for solar the elevation range 43°-47° to reduce the effect of any calibration errors. The yellow-red diamonds in Figure 18 are median values of the normalised G_{old}/G_{new} at 1° intervals. The values of the piecewise linear approximation, black line in Figure 18, are given in Table 7.

While the average sensitivity of the CM11s in clear sun conditions is slightly higher compared to the CM21s for solar elevations >45° it decreases for lower angles down to about 15° where the CM11 sensitivity on average is 1.15 % lower relative to the CM21s. For even lower solar elevations there is a strong increase in G_{old}/G_{new}. At 5° solar elevation the scatter is very large in the data and the normalised G_{old}/G_{new} varies between +1 % and +15 % with mean and median values close to 7.5 %.

This type of analysis would work better for data with higher resolution in time. But since hourly values is the highest time resolution of quality assured data from the old network only hourly data have been studied here.

The above described correction to make G_{old} better compareable with G_{new} is on average small. But since the correction is meant to reduce systematic errors it should be applied, in particular for studies analysing long-term changes/variation in monthly, seasonal as well as annual global radiation.

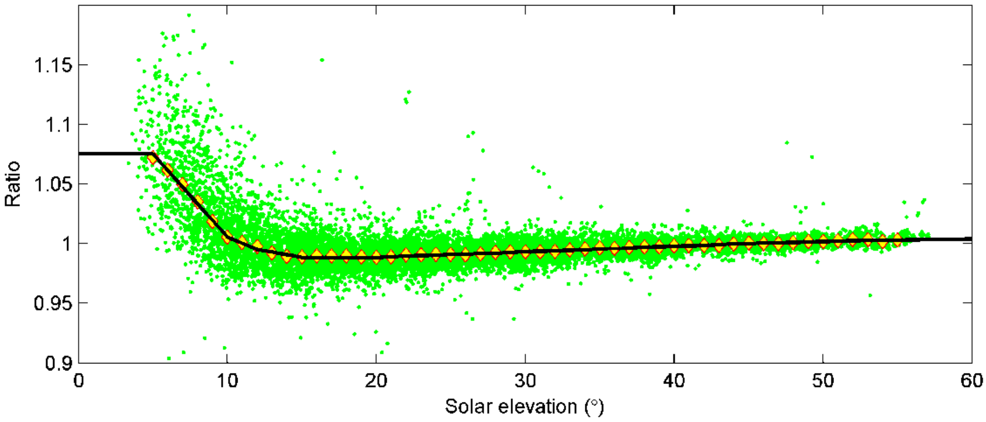

Figure 18. Normalised ratio of hourly G_{old}/G_{new} for clear sun hours versus solar elevation. The yellow-red diamonds are median values of G_{old}/G_{new} at 1° intervals. The black line is a piecewise linear approximation to the data.

Table 7. Data points for the piecewise linear approximation to the normalised ratio of G_{old}/G_{new} for clear sun hours versus solar elevation (black line inFigure 18).

Solar elevation (°)	G_{old}/G_{new}
0	1.0750
5	1.0750
10	1.0054
12	0.9950
15	0.9885
20	0.9885
45	1.0000
50	1.0018
60	1.0038

4.2.2.3 Application of correction

The data from the old stations have been re-evaluated applying the correction for solar elevation/directional response dependence in G_{old} under clear sun conditions according to the piecewise linear function given in Table 7. How much of the calculated correction that really should be applied was (linearly) weighted by the measured sunhine duration for each hour. For 60 minutes of sunshine duration the full correction was applied and for 0 minutes of sunshine no correction was applied.

The result is presented in Figure 19. The green lines with dots are the same as in the top row of Figure 10. The black lines with plus signs are the resulting mothly G_{old}/G_{new} ratios with correction applied to G_{old}. On the total/annual values the magnitude of the G_{old} corrections is in the order of 0.2 % and on average the $G_{old,corr}/G_{new}$ ratios for the whole period were brought closer to one in 7 of 12 cases. The mean $G_{old,corr}/G_{new}$ ratio, i.e. averaged over the whole comparison period and over all stations, is 0.9993. (For uncorrected data the ratio was 0.9974.) At some stations, but not all, the variation in monthly G_{old}/G_{new} is nicely smoothed out over the year in the corrected data. At a few stations, e.g. Kiruna and Lund, there are only very small improvements or even increased wintertime variation in the $G_{old,corr}/G_{new}$.

The improvement of the agreement between $G_{old,corr}$ and G_{new} becomes clearer when the results are studied month by month for the whole network. In Figure 20 monthly G_{old}/G_{new} and $G_{old,corr}/G_{new}$ have been averaged over all stations for each month. The green line with dots is the same as in Figure 11 for uncorrected data and the black line with plus signs is the nework monthly average $G_{old,corr}/G_{new}$. For the all network average the improved agreement between $G_{old,corr}$ and G_{new} is evident all year around.

The above described correction to make G_{old} better compareable with G_{new} are rather small. But since the correction is meant to reduce systematic errors it should be applied, in particular for studies analysing long-term changes/variation in global solar radiation.

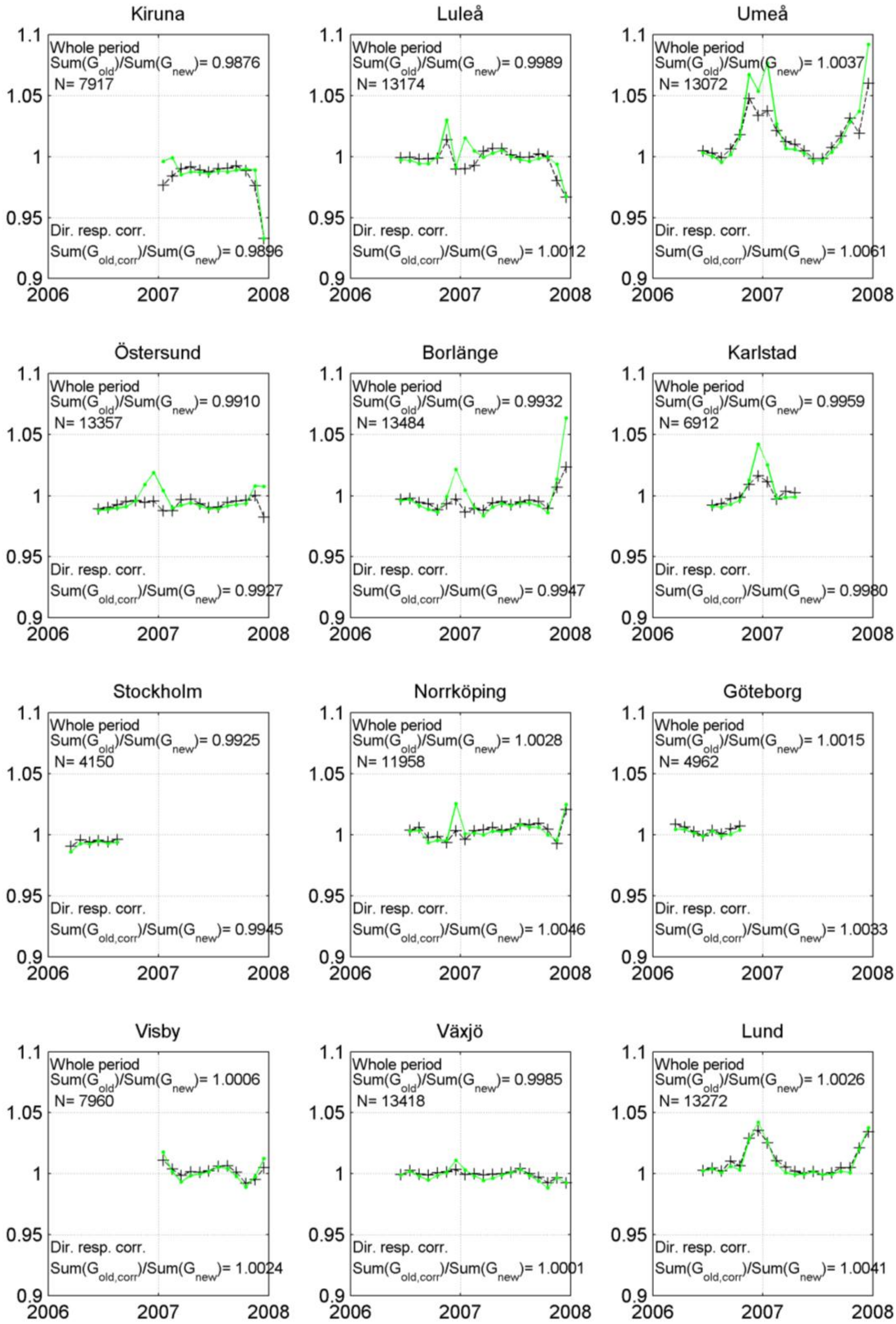

Figure 19. Monthly global irradiation ratios, G_{old}/G_{new}(green lines) and $G_{old,corr}/G_{new}$(black +lines), at the twelve stations under study. Sum(G_{old})/Sum(G_{new}) and Sum($G_{old,corr}$)/Sum(G_{new}) are the ratios of the total global irradiation values integrated over the whole comparison period.

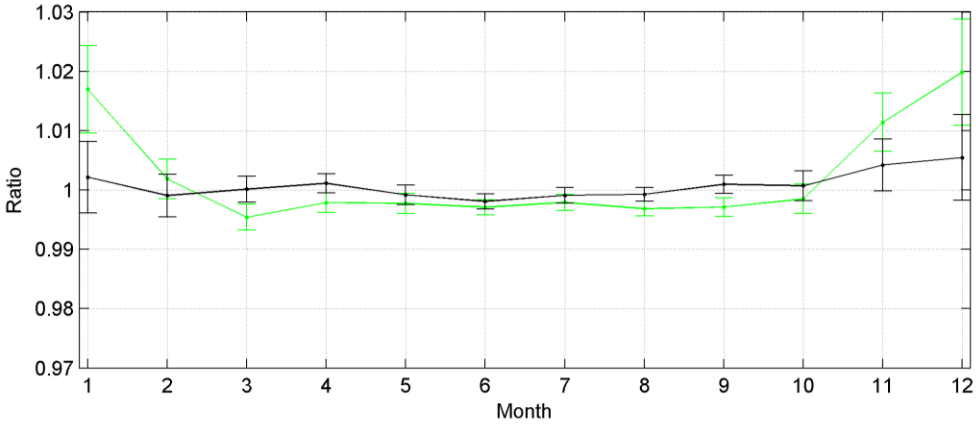

Figure 20. Monthly mean global irradiation ratios G_{old}/G_{new} (green) and $G_{old,corr}/G_{new}$ (black +lines) averaged over all (available) stations. Error bars indicate one standard deviation of the means.The standard deviations of the corrected data were only noticeably reduced for January, November and December.

4.3 Diffuse radiation

4.3.1 Comparison of old and new diffuse radiation data

In the old network diffuse irradiance (D) was not measured but calculated from hourly mean global (G) and direct (I) irradiance according to

$$D = G - I\sin(h) \qquad (5)$$

To get the horizontal part of the direct irradiance, $I\sin(h)$, the solar elevation value, h, was calculated for the midpoint of each hour (i.e. at XX:30:00). In addition to measurement uncertainty originating from two instruments (for hours when $I>0$) the method itself introduces further uncertainty. Especially under varying cloud conditions, the solar elevation for the midpoint of the hour might not be representative for the time when the direct irradiance was actually measured during the hour. In the long run, this extra uncertainty is mainly of a random nature but there seem also to be a small systematic effect. An average of ten investigated days from February to June, all with some amount of direct radiation, gave a positive bias of 0.5 % comparing D calculated from hourly values of G and I with D based on 1-minute data. If overcast days are included the effect on annual values is estimated to +0.2 to +0.4 % at the Swedish stations. For individual hours the error occasionally can exceed ±10 $\mathrm{Wm^{-2}}$.

Results of comparisons of monthly and hourly diffuse radiation data from the old (D_{old}) and the new/upgraded (D_{new}) stations are shown in Figure 21. It is clear that the old and new diffuse radiation measurements do not agree as well as the direct and global radiation measurements, at least not in relative terms. (The average annual D/G ratio varies between 0.45 (Visby) and 0.59 (Kiruna) at the Swedish radiation stations.) Considering all the three stations the difference between the old and new measurements is within 10 $\mathrm{Wm^{-2}}$ for about 95 % of the cases. The bias is very small for Norrköping but significantly negative for Kiruna (-3.1 % / -3.2 $\mathrm{Wm^{-2}}$) and positive for Visby (+1.6 % / +1.6 $\mathrm{Wm^{-2}}$). The negative bias in Kiruna is mainly explained by the fact that the global radiation was lower and the direct radiation was slightly higher at the old station compared to the new one. In Norrköping both I_{old} and G_{old} were reading too high. To a large extent these errors cancelled out in the calculation of D_{old}. In Visby the agreement between the old and the new measurements was good both for the direct and global radiation.

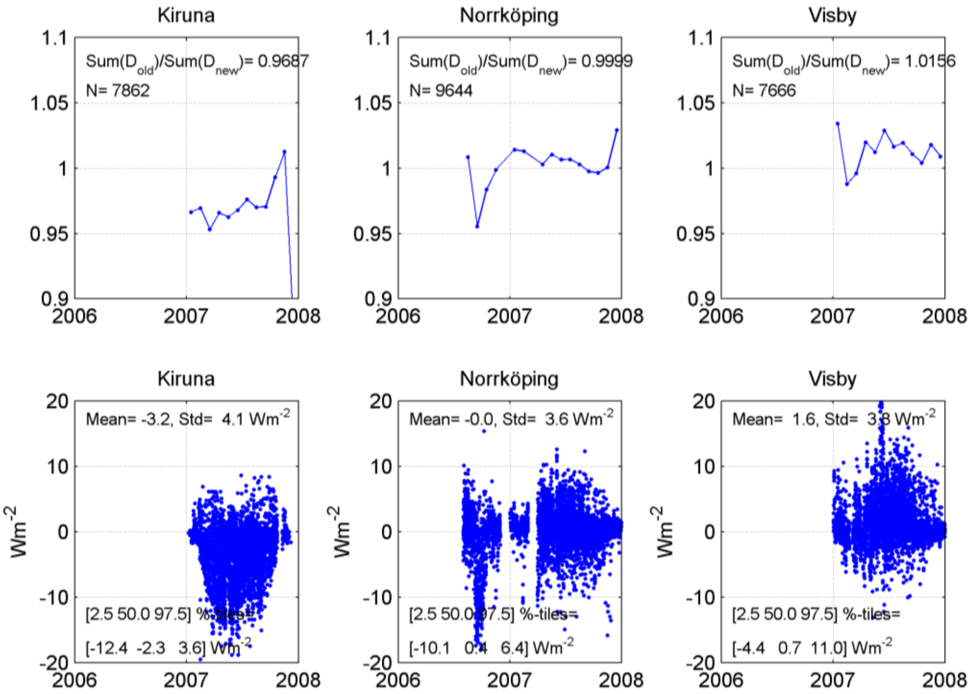

Figure 21. Top row: Monthly diffuse irradiation ratios, D_{old}/D_{new}, at the stations Kiruna, Norrköping and Visby. Sum(D_{old})/Sum(D_{new}) is the ratio of the total diffuse irradiation values integrated over the whole comparison period for the old and the new stations respectively.
Bottom row: Difference in hourly mean diffuse irradiance, D_{old}-D_{new}, for hours with D>5 Wm^{-2}.

However, as mentioned in the calibrations section (2.2.2), during the first 1-2 years (2007-2008) there were significant problems with deposition (dirt) on the instruments due to insufficient maintenance at the Visby station. On average, dirt on the pyrheliometer windows reduced the direct irradiance from the old and new stations more or less to the same extent, and the same holds for the pyranometer measurements. But pyrheliometers are more sensitive to unclean windows than the effect is of unclean domes on pyranometers. This means that the direct irradiance is much more underestimated than global irradiance at times with unclean instruments. Therefore, when calculating D from G and I the diffuse irradiance will be overestimated. This is thought to be a major cause of the comparatively high D_{old} values in Visby during 2007.

Diffuse irradiance/irradiation calculated from the new measurements of G_{new} and I_{new} , here called DGI_{new}, have also been compared to the measured D_{new}. The resulting monthly diffuse irradiation ratios are shown in Figure 22. For the whole comparison period the agreement is within ±1 % in Kiruna and Norrköping, which is considered to be a fairly good result. But in Visby, the diffuse irradiation (DGI_{new}) calculated from (hourly) global and direct radiation again is significantly higher than the measured diffuse (D_{new}). A significant part of this bias is thought to be an effect of the insufficient maintenance.

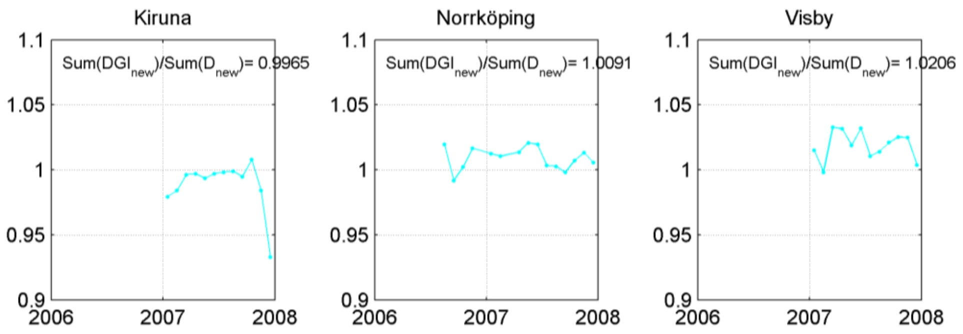

Figure 22. Monthly diffuse irradiation ratios, DGI_{new}/D_{new}, at the three stations under study. DGI_{new} is diffuse radiation calculated from hourly means of G_{new} and I_{new} .

The proposed corrections of the old pyranometer and pyrheliometer measurements appear not to result in any improvement of the old diffuse radiation data. Partly, Figure 23 shows the same result as are shown in the upper graphs of Figure 21. What is added in Figure 23 are the $D_{old,corr}/D_{new}$ ratios, where $D_{old,corr}$ is the diffuse radiation calculated from $G_{old,corr}$ and $I_{old,corr}$ described above. Except during winter $D_{old,corr}$ becomes higher than D_{old}. In winter the effect of the corrections of old global and direct radiation is small in Norrköping and Visby while $D_{old,corr}$ becomes lower in Kiruna. Due to the suspected calibration errors and/or maintenance problems and the fact that there are only three new stations with diffuse radiation measurements it is not possible to say whether the proposed corrections of old global and direct radiation measurements generally result in more accurate diffuse radiation values or not.

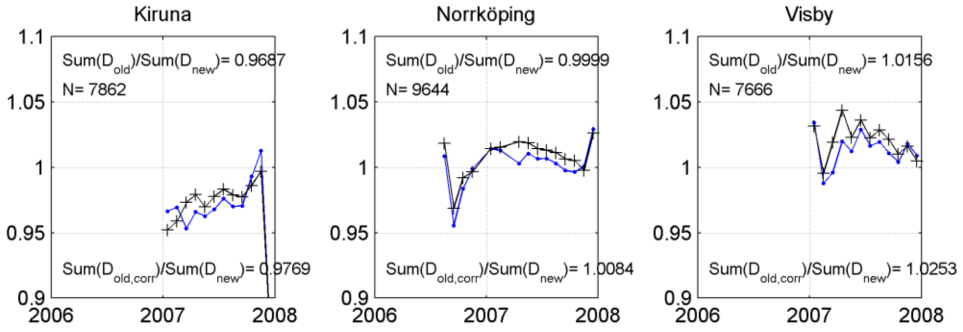

Figure 23. Monthly diffuse irradiation ratios, D_{old}/D_{new}(blue lines) and $D_{old,corr}/D_{new}$(black +lines), at the three stations under study. Sum(D_{old})/Sum(D_{new}) and Sum($D_{old,corr}$)/Sum(D_{new}) are the ratios of the total diffuse irradiation values integrated over the whole comparison period.

5 Summary and conclusions

The Swedish meteorological radiation network was modernized in 2006-2007. The old measurements were closed down after 6-18 months of parallel operation of new and old measurements. This study mainly reports the results of the comparison between the old and new global radiation (12 stations) and direct radiation (only 3 stations) measurements.

In general, the agreement between the old and new measurements of direct and global radiation is considered to be good. The differences in total irradiation values integrated over the whole comparison period were in all cases less than 1.5 % at individual sites both for global and direct radiation. Naturally, the difference between monthly values varied more, with small differences/good agreement during summer (±1.5 %) and, especially for global radiation, much larger differences during winter. The network average of ratios of whole period values was for direct irradiation $I_{old}/I_{new} = 1.009$ and for global irradiation $G_{old}/G_{new} = 0.997$. None of these results are significantly different from one at a level of confidence of 90 %. Both for global and direct radiation the differences between the old and new measurements were well within the uncertainties estimated for the old measurements at a "good station" by Persson (2000).

Despite the fairly good agreement some apparently systematic differences between the old and the new measurements were found. Functions to correct old direct and global radiation data are proposed, and these could be used to increase the homogeneity in Swedish solar radiation data from 1983 and onwards, especially for monthly data.

The difference in field of view between the old and the new pyrheliometers is thought to be an important factor behind the difference in direct radiation. Correction functions for hourly data dependent on solar elevation and "direct radiation clearness index" have been developed.

For the global radiation a systematic difference was found in the directional response between the old and the new pyranometers. A function to correct the old measurements for this difference has been developed. While the network *average* difference between the old and new measurements was reduced with the correction applied, the results were not improved at every single station. An explanation for this may be that the directional response is, at least partly, individual for each pyranometer. Also, there is always some error/difference in levelling of the instruments. In several of the old pyranometers the bubble level was broken and these instruments were levelled using an "external" bubble level which most probable resulted in less accurate levelling. These facts are thought to be the main explanations why the apparent directional response differences varies slightly among the stations (Figure 12) and why the applied correction does not result in improved agreement between the old and new measurements at all stations.

Diffuse radiation was briefly compared at the three stations where diffuse radiation measurements are carried out in the new network. In absolute numbers the difference between the old and new diffuse radiation data is similar to the differences in direct and global radiation. But in relative terms the differences are larger. For the summer half year the differences of monthly diffuse irradiation were within ±4 %.

There are some lessons to be learned from the radiation network upgrade to learn, especially for the future work at SMHI. Perhaps this could also be of some interest/use to other agencies operating a radiation network or station. Even though they are all more or less obvious, they are listed here:

- Calibrate all instruments and measurement equipment in a standardized and a properly documented way.

- An upgrade of a measurement network should start at/with the reference station in order to get instruments properly tested and calibrated before deployment at new or upgraded field sites.
- Ventilate at least pyranometers and pyrgeometers. Even though dew or frost is less common on pyrheliometer windows it is of course benificial to ventilate and/or (slightly) heat pyrheliometer windows as well.
- Make sure radiation instruments always are kept clean (and, of course, free from dew or frost).
- An average climate value derived from measurements (of the same quality) from multiple stations in a region is much more accurate and probably more representative than a value from a single station. For studies of longterm regional climate variations and/or changes it is therefore important to have a network of sufficient density to keep uncertainties as low as possible.

A new measurement method and new instruments for determination of sunshine duration were introduced in the upgraded radiation network. Compared to the old stations, where sunshine duration was measured in the most correct way through the use of pyrheliometers, the uncertainty in sunshine data from the "contrast sensors" in the new network has increased considerably. Still, there was a fairly good agreement in monthly and yearly values from 2007. However, at the three advanced stations both methods are still in use and for 2008-2010 the differences have increased (with the contrast sensors overestimating the annual sunshine duration of about 5 %). The reason for this change over time during 2007-2010 is currently not understood. A more detailed study comparing sunshine duration measurements from pyrheliometer and contrast sensor, probably based on 1-minute or even instantaneous data, needs to be done in the future.

There are still a few issues connected to the radiation network upgrade that need to be completed. Some issues regarding loss of data needs to be solved. Also, quality assurance procedures need to be operationalized.

Nevertheless, with new and better instrumentation, improved ventilation of pyranometers, new and more detailed calibration routines and enhanced and documented maintenance it is strongly believed that the data quality has increased at the individual stations, both in high time resolution data as well as for monthly and yearly integrated values, after the upgrade of SMHI's radiation network.

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ISSN 0283-7730