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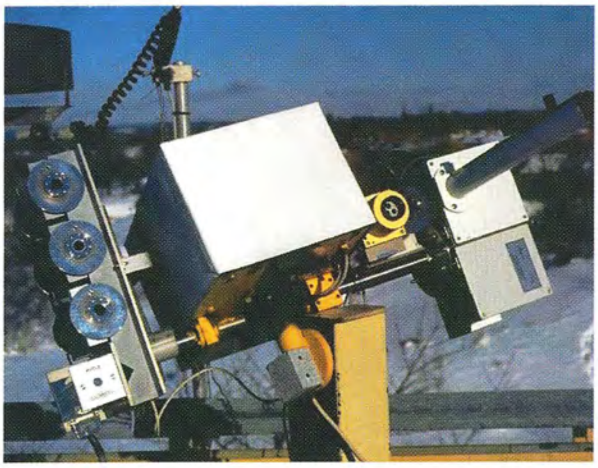


Measurements of Solar Radiation in Sweden 1983-1998

Thomas Persson

Cover photos

Pictures from the solar radiation station of SMHI in Norrköping.

Upper left: The diffuse reference pyranometer with its tracking shade disk.

Upper right: Solar tracker of the automatic radiation station with a field pyrheliometer (upper instrument) and occasionally also a direct illuminance instrument, belonging to the IDMP (International Daylight Measurement Programme).

Lower left: Solar tracker of the radiation research and calibration station carrying 3 field pyrheliometers and the absolute cavity radiometer PMO-6 #811108 to the left and a 3-channel sunphotometer (368, 500, 778 nm) and a spectroradiometer (300 – 1100 nm) to the right .

Lower right: Ventilated pyranometer (left) and pyrgeometer (right) of the automatic radiation station.

Photo: Thomas Persson

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Measurements of solar radiation in Sweden 1983-1998.

Abstract/Sammandrag

Since 1983 an automatic solar radiation network of 12 stations is operated by SMHI. At all 12 stations direct solar irradiance (Eppley NIP pyrheliometers) and global irradiance (Kipp & Zonen CM10/CM11 pyranometers) are measured continuously. Together with general network information and uncertainty analyses, results of the radiation measurements during 1983 – 1998 are presented in this report.

The resulting quality controlled database consists of yearly, monthly, daily and hourly values of direct (normal) solar and global radiation together with the diffuse sky radiation and sunshine duration, *SD*. E_d has been calculated from the hourly values of E_b and E_g. Observed air temperature (2-m), relative humidity, wind direction and wind speed are available in the hourly radiation database, as well.

Generally, the uncertainty of 6-minute and hourly values of direct and global radiation has been estimated to 3 % and 4 % (at 95 % confidence level), respectively. The precision of annual values has been estimated to 2 % for both quantities.

The solar radiation climate in Sweden varies a lot, both in time and space. The dominating factors influencing the solar radiation climate are the latitudinal location and the prevailing cloud conditions.

Key words/sök-, nyckelord

Solar radiation climate, global radiation, direct solar radiation, radiation measurements, measurement uncertainty.

Supplementary notes/Tillägg

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Contents

1 Introduction

Solar radiation is the fundamental driving force behind weather and climate. It is also a vital parameter for agriculture and forestry and it is an important renewable energy resource. Ever since IGY, the International Geophysical Year, 1957-58, data on global radiation from around a dozen sites in Sweden has been collected by SMHI (Swedish Meteorological and Hydrological Institute). However, since 1983 an enlarged radiation-measuring programme is in operation, with more measured parameters, increased sampling frequency, better time resolution of the stored data and, in especial, increased accuracy, compared to the earlier measurements.

The high quality solar radiation database of SMHI is considered most useful both for climate studies and for model development and validation. Solar radiation data are also needed in other fields, such as solar energy, agriculture and forestry.

Measured radiation data for the years 1961-1971 has been published in Measurements of solar radiation in Sweden, SMHI (a). For the period 1972-1982, daily values of global radiation and duration of bright sunshine in Stockholm have been published in *Månadsöversikt över väder och vattentillgång i Sverige*, SMHI (b). From 1983 monthly values of global radiation and duration of bright sunshine from the present network have been published in *Väder och Vatten*, SMHI(c). In a comprehensive report by Josefsson (1987), monthly values of global radiation and sunshine duration from all Swedish stations during the period 1908-1986 have been published. Maps of yearly and monthly mean values of global radiation and sunshine duration during the reference period 1961-1990 are presented in *National Atlas of Sweden – Climate, lakes and rivers* (1995).

The present report is the first one in a new series of yearbooks, presenting results of solar radiation measurements in Sweden. Even though solar radiation data for 1983-1986 have been published earlier, results from all the years 1983-1998 are summarised here, in order to get data from the whole period of the present network published in the same series of reports. In this first issue, the ambition has been to give a more detailed description of the radiation network, the measurements and the data quality, beside the presentation of the pure measuring results. It has been considered useful to potential radiation data users from other disciplines to get an overview of some basic features of the radiation conditions and climate in Sweden.

Abbreviations of radiation and meteorological quantities used in the following are:

E_g	global radiation, also called global irradiance (Wm^{-2})
H_g	global irradiation (Whm^{-2})
E_b	direct (normal) solar radiation, also called direct irradiance (Wm^{-2})
H_b	direct irradiation (Whm^{-2})
E_d	diffuse (solar) radiation, also called diffuse irradiance (Wm^{-2})
H_d	or diffuse irradiation (Whm^{-2})
E_l	atmospheric (downward) long-wave radiation
SD	sunshine duration

T	air temperature
RH	relative humidity
WD	wind direction
WS	wind speed
h	solar elevation
UTC	Universal time, coordinated (formerly known as Greenwich Mean Time, GMT).

It is recommended by WMO (1996) that irradiance quantities should be denoted by an E and suitable subscripts. The direction (downward, ↓, or upward, ↑) of fluxes should also be noted, but since only downward fluxes are considered in this work, the arrows have been omitted. To be consistent, the direct solar radiation abbreviation E_b is also based on the E letter notation for irradiance, instead of using S as recommended by WMO.

2 The SMHI solar radiation network

A map and a list of the Swedish solar radiation network of SMHI 1998 are presented in Figure 2.1 and Table 2.1 respectively. The network of 1998 is very much the same as when it started in 1983. The only difference concerning radiation measurements is that from the beginning there was a station located in Gunnarn, Västerbottens län (64.96° N, 17.70° E), which during 1986/87 was moved to Borlänge. Due to lack of funding, collocated measurements of air

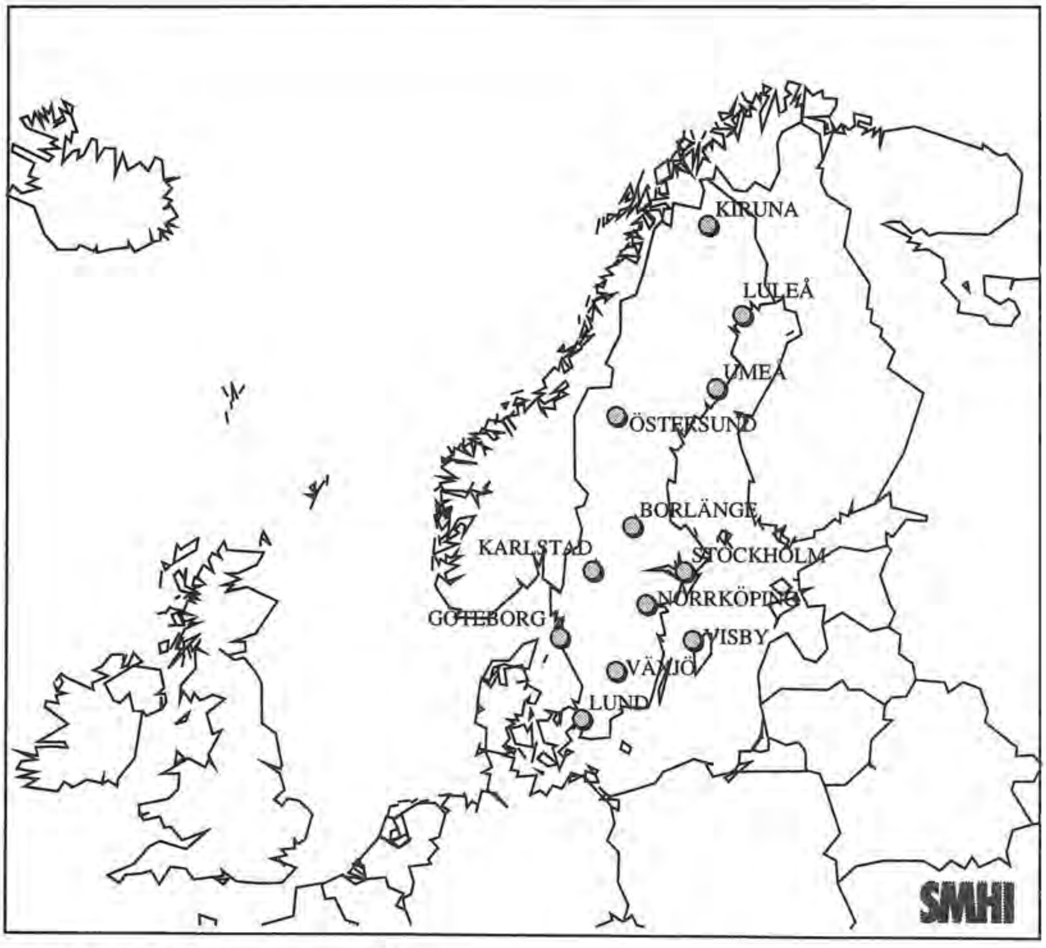

Figure 2.1. The solar radiation network of SMHI.

Table 2.1. Location of and measured quantities at the stations in the solar radiation network of SMHI 1998.

Station	Latitude (^{o} N)	Longitude (^{o} E)	Altitude (m.a.s.l.)	Radiation Quantities	Other met. quantities
Kiruna	67.83	20.43	408	E_b, E_g, SD	T, RH
Luleå	65.55	22.13	17	E_b, E_g, SD, E_l	-
Umeå	63.82	20.25	10	E_b, E_g, SD	T, RH
Östersund	63.20	14.50	376	E_b, E_g, SD	T, RH,
Borlänge	60.48	15.43	140	E_b, E_g, SD, E_l	T, RH, WD, WS
Karlstad	59.37	13.47	46	E_b, E_g, SD	T, RH, WD, WS
Stockholm	59.35	18.07	30	E_b, E_g, SD, E_l	T, RH, WD, WS
Norrköping	58.58	16.15	43	E_b, E_g, SD, E_l	T, RH, WD, WS
Göteborg	57.70	12.00	15	E_b, E_g, SD	-
Visby	57.67	18.35	51	E_b, E_g, SD	T, RH, WD, WS
Växjö	56.93	14.73	182	E_b, E_g, SD	T, RH, WD, WS
Lund	55.72	13.22	73	E_b, E_g, SD, E_l	T, RH, WD, WS

temperature, relative humidity, wind direction and speed, which from the beginning were performed at all stations, have ceased at some sites. Instead of replacement or reparation of the temperature, humidity and wind sensors at breakdowns, these instruments have been taken out of operation when malfunctioning.

The radiometers are placed on top of approximately 4 - 15 m high roofs at all stations, except in Växjö and Karlstad, where they are placed on a ground based platform. The T and RH sensors are placed on the ground (i.e. 2 m above) near the building housing/keeping the radiometers. The only exception is Norrköping where T and RH sensors are mounted on the measuring platform on the roof of SMHI. When possible, the 10 m wind masts have been placed on the ground. However, in Kiruna, Borlänge, Stockholm and Göteborg, the wind masts were sited on top of roofs as long as the wind measurements were working there.

Norrköping is the main station in the radiation network. There, a separate radiation measuring system is run, besides the ordinary automatic station. This continuously operating system collects 1-minute mean data of E_b, E_d, E_g, and E_l together with calibration data from reference radiometers and radiometers to be calibrated. Also, measurements of atmospheric turbidity and aerosol optical depth are carried out with this system.

Besides the automatic solar radiation stations, SMHI operates a small network equipped with Campbell-Stokes heliographs measuring sunshine duration. This network is not considered in the current report. Monthly data have been compiled and published by Josefsson (1987) and are regularly published in the SMHI publication *Väder och Vatten*.

2.1 Measured and computed radiation quantities

Global (horizontal) radiation, E_g, and direct normal solar radiation, E_b, (hereafter only denoted direct radiation or direct irradiance) are measured at all twelve stations in the radiation network.

Global radiation is measured with Kipp & Zonen CM11 pyranometers. These instruments are all ventilated. The reason for this is mainly to prevent rime on the dome, but the ventilation has also proved to keep the instrument relatively free from snow, dew and raindrops. Further, the zero offset signal uncertainty is strongly reduced when the instruments are ventilated. The ventilators have been developed and built at SMHI.

Direct solar radiation is measured with Eppley NIPs (Normal Incidence Pyrheliometer) mounted on automated suntrackers. The tracking is passive, meaning that the tracker points to the sky where the sun should be according to the solar position as given by an algorithm. The pointing of the tracker has been improved by introducing angular resolvers. To have high pointing precision the tracker has to be carefully mounted and the clock of the station must be accurate.

The direct solar radiation is used to determine the sunshine duration. By recommendation of the Commission for Instruments and Methods of Observation (CIMO), the sunshine duration is the time when the direct solar radiation, as measured by a pyrheliometer, is larger than 120 Wm^{-2}. This is to get a good correspondence with measurements performed with the Campbell-Stokes heliograph, which is an older instrument type used for recording sunshine duration.

The diffuse solar radiation, E_d, is computed from the global and the direct irradiance by using the definition

$$E_d = E_g - E_b \cdot \sin(h) \qquad (2.1)$$

where h is the solar elevation. Only hourly values of diffuse radiation are calculated regularly. In these calculations of E_d, the solar elevation at the midpoint of the hour has been used.

At five of the stations, also the atmospheric (downward) longwave radiation, E_l, is measured. It is measured with ventilated Eppley PIR pyrgeometers. Problems with this kind of instrument have caused large gaps in the record. The instrument is equipped with a battery, which has to be exchanged now and then. If not, the measured values will be erroneous. This is usually seen as a decrease in the measured radiation. One must note that many of these erroneous data are not rejected from the database. They have been included in the database, although in error, because they seem to inherit some information about the variation of E_l. The long-wave data are also affected by the lack of an accurate calibration procedure. This is why results from these measurements are not published here. Work on comparing the field pyrgeometers with a reference instrument, an Eppley PIR modified and calibrated according to Philipona et al. (1995), has recently started. Hopefully, results of the longwave radiation measurements can be published later.

2.2 Network status

At the start in 1983, the automatic solar radiation network of SMHI was one of the most modern and extensive/complete radiation networks in the world. Still today, it is one of the densest, though not most accurate, networks measuring direct irradiance with pyrheliometers continuously. Ever since the start of this network, instruments, data collection equipment and methods have been the same. This, together with the fact that all the radiometers have been calibrated regularly throughout the period, guarantees homogeneity in the collected data. On the other hand, this also means that all the measuring and data acquisition equipment today is old.

Considering the age of the network together with the relative complexity of suntracking pyrheliometer measurements, the amount of missing data has been acceptable, except for the last two years. Figure 2.1 shows that most years, averaged over all stations, the mean percentage of calculated or corrected data in the yearly total E_g and E_b is below 5 %. Often, severe problems at only a few stations largely contribute to the amount of missing data.

However, at the start there were initial problems at several stations. During the last years, problems have arisen at most stations simply due to the natural ageing of the equipment. The amount of missing direct irradiance data in 1998 is huge, over 10 %. This was to a large extent caused by moist which penetrated into the pyrheliometer in Kiruna already sometime in May, and then stayed throughout the year. This led to erroneous measurements during the whole eight-month period. Unfortunately, this was not discovered until the yearly data compilation and final control in early 1999.

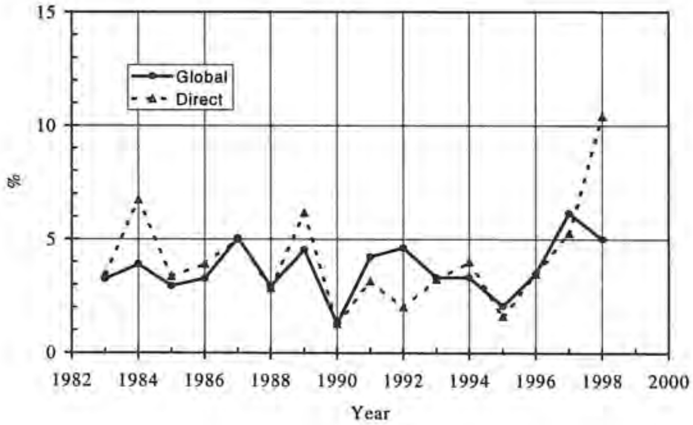

Figure 2.1. Percentage missing data in the determination of yearly total global radiation and direct irradiance. Mean of all 12 stations.

3 Data archive

Measured data at the solar radiation stations are automatically collected once every hour by the observation data central at SMHI in Norrköping. Data with the highest resolution in time, regarding global radiation, direct irradiance and sunshine duration, are 6-minute mean values. From the 6-minute values, hourly mean values of E_g and E_b together with hourly total sunshine duration are calculated. Then, E_d is calculated from the hourly values of E_g and E_b. All 6-minute data are stored on tapes but these data have *not* been quality controlled or completed when missing.

The quality control, correction and completion of missing data are mainly performed on the hourly data. Missing and erroneous data are replaced by calculated values from a model developed by Josefsson, described and validated in Davies, et al. (1988). The model calculations are based on cloud observations from the nearest synop station where manual cloud observations are made. (A synop station is a meteorological observing station performing and reporting weather observations every third or every sixth hour at 00:00 UTC, 03:00 UTC, etc.). From the controlled and corrected hourly database daily, monthly and yearly values are computed. Finally, daily and monthly values are inspected manually.

The automatic quality control of hourly values is very simple. It is based upon the extraterrestrial radiation $E_{g,0} = (E_{b,0}/R^2)\cdot\sin(h)$. The value used for the solar constant, $E_{b,0}$, is 1367 Wm^{-2}. R is the current Sun-Earth distance expressed in AU (astronomical units). The control consists of three small parts:

Control 1
I) If $E_g > 0.9\ E_{g,0}$, E_g is flagged erroneous.
ii) If $0.8\ E_{g,0} \leq E_g < 0.9\ E_{g,0}$, E_g is flagged suspect.
iii) If $E_g < 0.8\ E_{g,0}$, E_g is flagged correct.

Control 2
If $E_b = 0$ and $E_g > 0.5E_{g,0}$, both E_b and E_g are flagged suspect.

Control 3
If $E_d < 0$, both E_b and E_g are flagged suspect.

The hourly database is built up of monthly data files (ASCII format), one for each station. The structure of these data files is as follows:

Column	Parameter	Unit
1	Date	-
2	Hour (1-24, LST)	-
3	Temperature (2 m)	0.1°C
4	Relative Humidity	%
5	Wind direction	°
6	Wind speed	0.1 m/s
7	Global radiation	0.1 Wm^{-2}
8	Diffuse radiation	0.1 Wm^{-2}
9	Direct irradiance	0.1 Wm^{-2}
10	Sunshine duration	0.1 min
11	Longwave radiation	0.1 Wm^{-2}
12	Quality indicator	-

All variables are stored as integers and decimals are omitted by using a factor of ten when appropriate. There is always at least one blank delimiting the variables. The time (hours) is given in LST, Local Standard Time (= SNT, "svensk normaltid"), which is UTC + 1^h. 1 indicates the first hour of each day. This hour includes the period $00^h00^m00^s$ to $00^h59^m59^s$.

The last number, the quality indicator of each hourly record, is used to indicate the origin or the quality of the given variables. The quality indicator is a number consisting of nine digits each one corresponding to the nine variables in the record. The digits are given in the same order as the variables in the record. For example, the first one represents the temperature and the last one the downward longwave radiation. The value of each digit indicates the origin or the quality of the corresponding variable, according to the following list:

Indicator	Status of the variable	
1	Measured value	Accepted values in the quality controlled database
2	Measured value from nearby site	
3	Interpolated value	
4	Computed or corrected value	
7	Suspect value	
8	Erroneous value	
9	Missing value	

Normally, the indicator should read 1, representing a measured and after quality control accepted value. If data have been rejected or are missing, they have been replaced by some method indicated by the numbers 2, 3 or 4. The values 7 and 8 of the quality indicator should normally not be present in the data set, since these values indicate possible problems, which should have been corrected during the revision of data. However, the quality control of the longwave radiation has sometimes indicated suspect or erroneous values and there is yet no method to correct or replace these values. It was decided that they might be of interest although they are not correct.

4 Units, calibration and uncertainties

The basic unit for the irradiance (radiant flux density) quantities is Wm^{-2}. For time integrated irradiance values, i.e. radiant energy per unit area, the term is radiant exposure or irradiation, which is expressed in Whm^{-2} or Jm^{-2} ($1\ Whm^{-2} = 3600\ Jm^{-2} \Rightarrow 1\ kWhm^{-2} = 3.6\ MJm^{-2}$). In the hourly radiation database the values could be interpreted either as hourly mean values of irradiance in Wm^{-2}, or as hourly values of irradiation in Whm^{-2}. All the measured values refer to the World Radiometric Reference, WRR.

Connected with all radiation measurements, there are many sources of uncertainties and errors, which have a negative influence both on the accuracy of calibrations and measurements. Sources of uncertainty of radiation instruments are:

- Directional dependent responsivity (pyranometers)
- View geometry (pyrheliometers)
- Temperature dependence (especially below -20 °C for the SMHI sensors)
- Nonlinearity
- Spectral dependence
- Degradation

- Response time
- Inexact alignment (pyrheliometers) or levelling (pyranometers)
- Data acquisition errors.

Yet two sources of uncertainty must be added to the above factors, which are of great importance to continuous field measurements and the resulting dataset. These two error sources are:

- Improper maintenance and
- Missing data.

These latter two error sources are mostly neglected when measurement uncertainties are presented. Indeed, at a very well maintained and supervised station possible errors due to deposits on the instrument domes and windows can be neglected. But most field stations throughout the world are thought *not* to be that well maintained. As will be shown, this holds for the radiation stations of SMHI as well, though they all are only exposed to the relative clean air over Sweden.

A measurement site must be chosen with great care to make sure that the horizon is close to totally free (i.e. free from any obstruction above the plane of the sensor surface of a horizontally mounted pyranometer), or at least that it will not change with time. For instance in valleys of mountain districts it is impossible to find a site on ground with a totally free horizon. Still, it can be very valuable to perform radiation measurements at such a site. (See WMO (1983) or WMO (1996) for full site requirements and mounting instructions.)

4.1 Uncertainty estimation method

Unfortunately, in reality all measurements have errors. These errors are the differences between the measured and the true values. Furthermore, the total error is usually expressed in terms of two components: a fixed or bias error, β, and a random (precision) error, ε. For a measured value, x_m, one has

$$x_m = x + \Delta x = x + \beta + \varepsilon \qquad (4.1)$$

where x is the true value and Δx is the total error. In the following, the assessments of irradiance measurement uncertainties are done through analysis of instrument comparison and calibration results. The evaluation of the total uncertainty of measured irradiance/irradiation values generally follows the recommendations given in ISO TC30 SC9 (1987) and EAL-R2 (1997), hereafter referred to ISO TC30 SC9 and EAL-R2.

The total relative uncertainty, *U*, is (ISO TC30 SC9) calculated as

$$U = B + t_{95}S \qquad (4.2)$$

where B is the estimated maximum total bias error (@95 % confidence level) in relative units, *S* is the total experimental standard deviation of x in relative units and t_{95} is Student's statistical parameter at the 95 % confidence level. When large samples ($N \geq 30$) can be used to derive all individual random error sources, t_{95} could be given the value 2.0. In other cases, t_{95}

depends on the number of degrees of freedom, ν_p, calculated from the Welch-Satterthwaite formula as given in for example ISO TC30 SC9.

When using the uncertainty model in equation 4.2, with B>0 the true confidence level is actually higher than 95 %. This way to calculate and express a single number of the total uncertainty of a measurement is also referred to as the U_{ADD} or linear addition method (e.g. in ISO TC30 SC9). Typically, for bias and random uncertainty limits of 95 % coverage, U_{ADD} is considered to have coverage of approximately 99 %.

The type of uncertainty depends on the considered time-scale. For instance, when daily mean calibration results (or measured data) of *field* radiometers are studied over a month or a year, the scatter in the results could be seen as random on a daily basis. To a large extent, the daily scatter just reflects the differing measuring conditions, which influence the results since the field instruments are all affected by the error sources listed above. But when studying 1-minute values during an hour with fairly constant measuring conditions, the daily uncertainty could instead be seen as a bias. For example, 300 1-minute values from one and the same day do not scatter about $300^{1/2} \approx 17$ times more than the daily values considered as randomly scattered on a monthly or yearly basis. Hence, the random uncertainties are divided into daily, hourly and either 1-minute or 6-minue random uncertainties, depending on the time-scale under consideration.

In accordance with recommendations in ISO TC30 SC9, uncertainty values derived by a statistical analysis of repeated measurements are classified as random uncertainties, while systematic uncertainty values are estimated by non-statistical methods.

To calculate the proper random uncertainty on the 1-minute and hourly level, calibration results for a given time-scale are normalised with the corresponding calibration results for the next longer time-scale. That is, 1-minute results are divided by the hourly mean value of the considered hour. Then the (experimental) standard deviation of the normalised 1-minute values is calculated. In the same way hourly values are normalised by the daily average before the standard deviation of normalised hourly values from several days is calculated. The tiny contribution of the 1-minute random uncertainty ($S_{1\text{-}minute}/n^{1/2}$) to the uncertainty of an hourly mean value is also subtracted. Daily mean calibration results have not been normalised before calculation of standard deviation. Hence, monthly variation or some other inter-annual variation is included in the daily random uncertainty.

The model function of any measuring result is in this work always a simple product or quotient of independent variables, suffering from some degree of uncertainty. Again according to ISO TC30 SC9 and EAL-R2, for symmetrical uncertainty limits, the individual bias and random uncertainties, B_i and S_i, of the individual error sources are summed up using the root-sum-square (RSS) method, *i.e.*

$$B = \sqrt{\sum B_i^{\,2}}\,, \qquad (4.3\text{ a})$$

$$S = \sqrt{\sum S_i^{\,2}} \qquad (4.3\text{ b})$$

and the total relative uncertainty is given by Equation 4.2.

4.2 Reference instruments

All calibrations of the field radiometers in the network are performed at SMHI in Norrköping. The reference instruments, both pyrheliometers and pyranometers, are maintained by the Research and Development department of SMHI, which also is responsible for the Regional Radiation Centre of WMO, located in Norrköping.

4.2.1 Reference pyrheliometers

Both secondary standard pyrheliometers and a first class field pyrheliometer are used as reference pyrheliometers at SMHI. A secondary standard pyrheliometer is an instrument of high precision and stability whose calibration factor is derived from primary standard pyrheliometers. A first class pyrheliometer has lower accuracy and precision than a secondary standard pyrheliometer. (For details regarding the pyrheliometer classification see WMO, 1996.) The secondary standard and field pyrheliometers will be treated separately in the following.

4.2.1.1 Secondary standard pyrheliometers

All the radiometers in the network are calibrated against the reference pyrheliometers of SMHI. Every fifth year two of these reference instruments are compared with the World Standard Group (WSG) of pyrheliometers maintained by Physikalisches Meteorologisches Observatorium Davos/World Radiation Center (PMOD/WRC). The WSG is used to realise the World Radiometric reference (WRR). Figure 4.1 is a block diagram of the transfer of WRR to the field radiometers of SMHI. In this figure it can be seen that there are only a few steps in the transfer of WRR from WSG to the SMHI field radiometers, which of course is a great advantage.

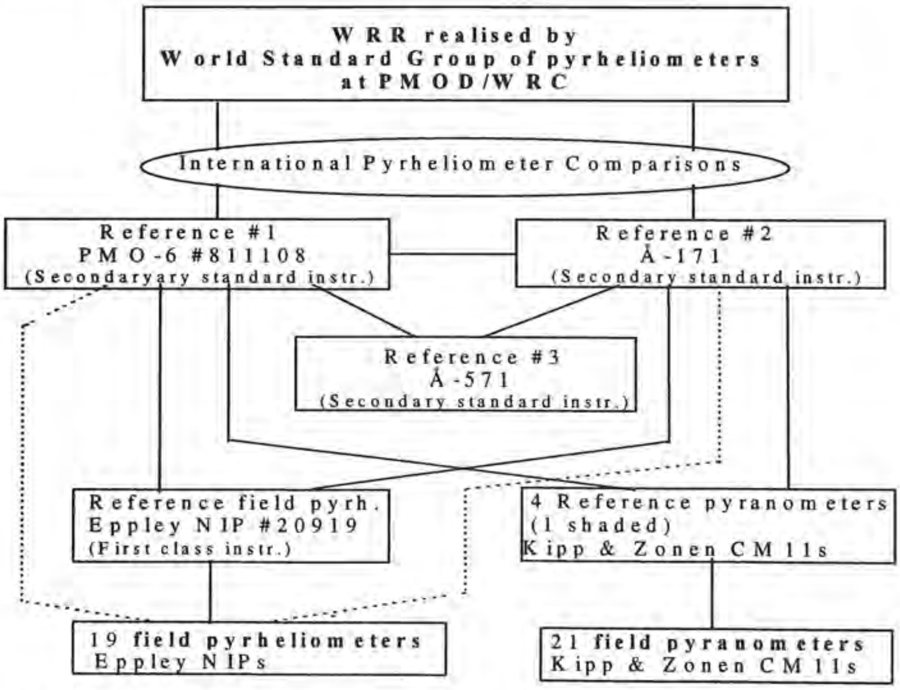

Figure 4.1. Block diagram of the transfer of WRR to the SMHI field radiometers. The dotted lines just indicate that the transfer often goes directly from the reference pyrheliometers to the field pyrheliometers and not via the field reference instrument.

Fortunately, the reference pyrheliometers of SMHI have shown to be both very accurate and stable. Some results from the 8th International Pyrheliometer Comparisons, IPC-VIII, held during September-October 1995 in Davos, Switzerland, are shown in Figure 4.2 (from IPC-VIII, 1996). The results for the absolute cavity radiometer PMO-6 #811108 (secondary standard) and the Ångström compensation pyrheliometer Å-171 (secondary standard) are plotted. Each point represents the mean value of a 21-minutes measuring series, consisting of 7 instantaneous values for PMO-6 and 14 instantaneous values for Å-171. The mean deviation from the irradiance values determined by WSG were only 110 ppm for PMO-6 and 330 ppm for Å-171 when the calibration factors determined at IPC-VII in 1990 were used. The corresponding standard deviations of the instantaneous values were 0.095 % for PMO-6 and 0.293 % for Å-171.

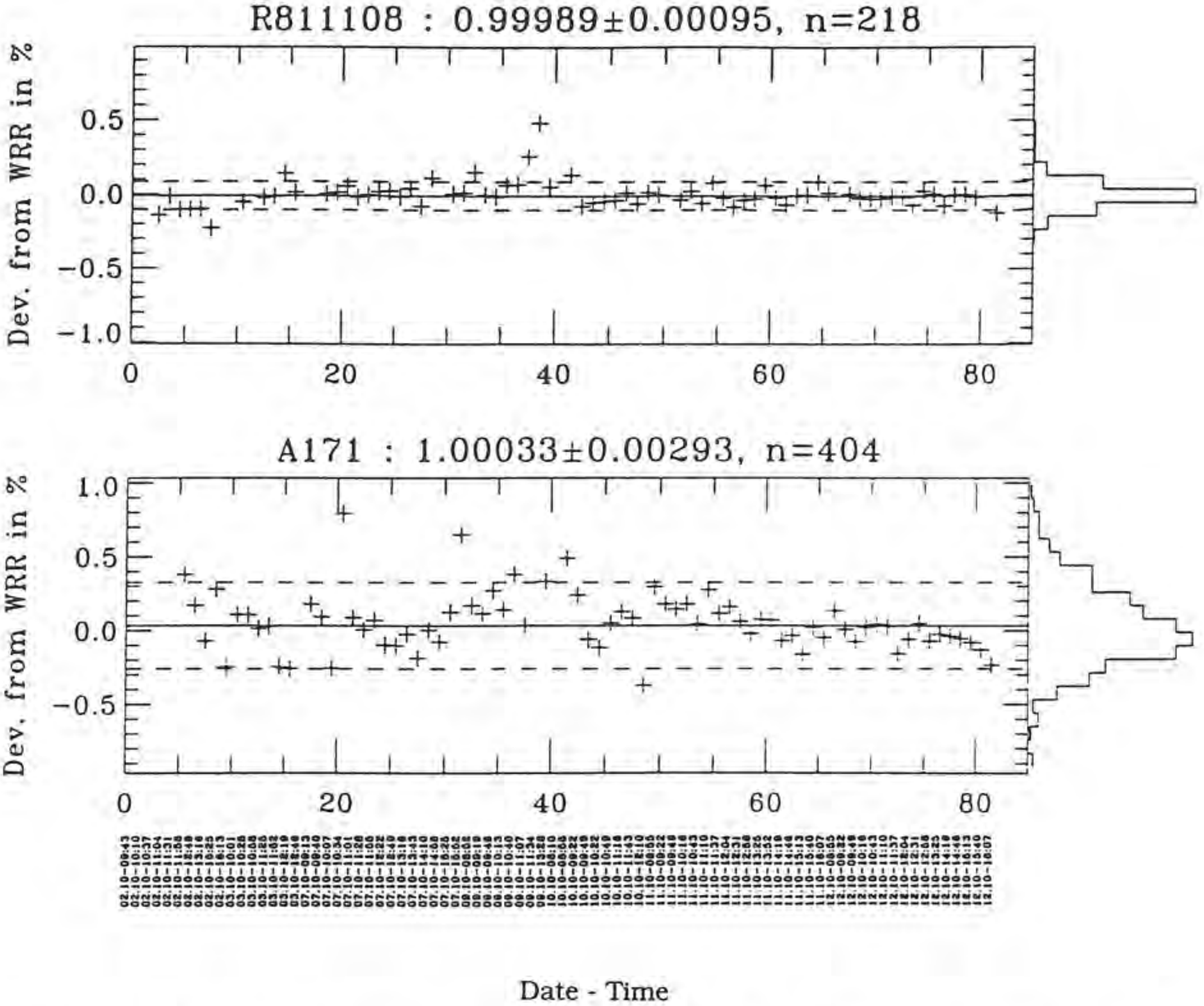

Figure 4.2. Graphical representation of the results at IPC-VIII for the SMHI pyrheliometers PMO-6 #811108 (upper) and Å-171 (lower). Each point represents the mean value of a 21-minutes measuring series, consisting of seven instantaneous values for PMO-6 and fourteen instantaneous values for Å-171. Note the frequency histograms on the right hand side. (From IPC-VIII, 1996.)

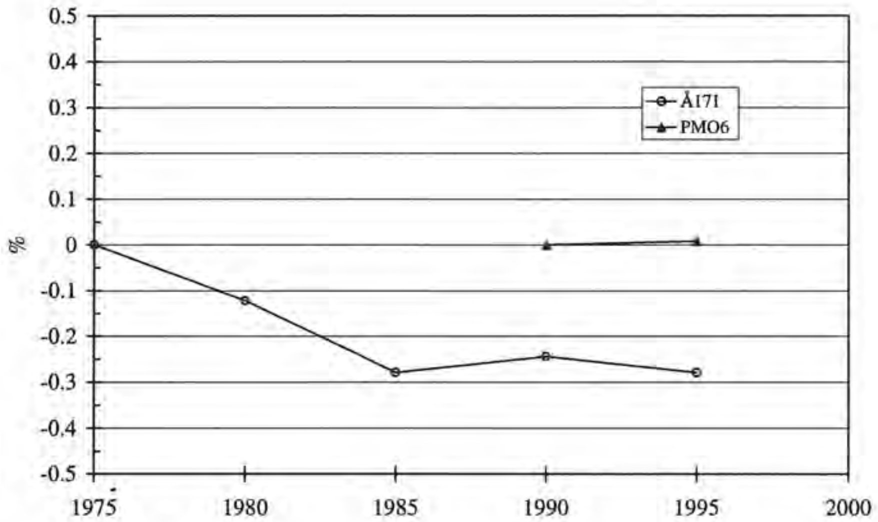

Figure 4.3. Percentage deviation of subsequent calibration results relative the first IPC calibration result for the SMHI radiometers Å-171 and PMO-6 #811108.

The responses of the secondary standard pyrheliometers of SMHI have proved to be very stable with time. In Figure 4.3 results for the SMHI radiometers from several IPCs are shown. Plotted is the percentage deviation of subsequent relative the first IPC calibration result for Å-171 and PMO-6 #811108, respectively. Clearly, the change in response over a five year period normally is very small (< 0.1 %). The PMO-6 #811108 participated for the first time at IPC-VI in 1985. However, during IPC-VII in 1990 some adjustments of the electronics were made, leading to a change of the original calibration of March 1984. For this reason, the resulting calibration of PMO-6 at IPC-VII is taken as the original one in Figure 4.3.

Note that the seasonal or daily uncertainty fluctuations of secondary standard pyrheliometers PMO-6 and Å-171 are small but not exactly known. From comparisons between radiometer pairs within WSG at PMOD/WRC, the standard deviation of daily average ratios normally is < 0.07 % (IPC-VIII). In case of the PMO-6 and Å-171, the daily and seasonal random uncertainties are accounted for in the estimates of the bias uncertainties of the respective instrument.

Every year, the two reference pyrheliometers are compared with each other and with the reference field pyrheliometer Eppley NIP #20919 at SMHI in Norrköping. Often, they are also used to calibrate the ordinary field pyrheliometers directly.

National Pyrheliometer Comparisons (NPCs) are held in Norrköping once between the IPCs. At these comparisons the radiometers PMO-6 #811108 and Å-171 of SMHI and the Eppley HF #15744 of the Swedish National Testing and Research Institute (SP) are compared. At such occasions and at regular comparisons at SMHI both before and after IPC-VIII a bias of about 0.25 % between Å-171 and the two absolute radiometers (Å-171 showing the lower values) have occurred in 1995 to 1998. The difference is not yet explained, but it might be due to the fact that the auxiliary measuring equipment used for the Å-171 in Norrköping is not exactly the same as at IPCs in Davos.

In fact, the observed difference in the Å-171 measurements is of the opposite sign to what one would expect. The differing view geometry between the Ångström pyrheliometer and the cavity radiometers affects the results since the atmospheric conditions on average are not the same in Norrköping as in Davos. Approximate calculations of the circumsolar contribution to the total irradiance measured by PMO-6 and Å-171 have been performed with the SMARTS2 model (Gueymard, 1995). These results indicate that, due to its larger aperture angle, Å-171 should measure a somewhat higher (about 0.1 % at airmass 2) E_b in Norrköping than PMO-6, when the calibration constants determined at IPCs in Davos are used for both instruments.

4.2.1.2 Field reference (first class) pyrheliometer

a) Calibration methodology

A calibration factor, C_{NIP}, of a field pyrheliometer of SMHI is calculated as

$$C_{NIP} = \frac{E_{b,ref}}{V_{NIP}} \tag{4.4}$$

where $E_{b,ref}$ is the direct solar irradiance (Wm^{-2}) measured by a reference pyrheliometer and V_{NIP} is the output voltage (mV) from the calibrated field pyrheliometer. Figure 4.3 is a plot of achieved calibration factors for the reference field pyrheliometer, Eppley NIP #20919, determined through comparison with Å-171 during 1995-1996. The points represent one 6-minute mean value each, all measured during different days. The measurements were taken at solar elevations ranging from 9° to 53° and the range of the direct irradiance was 450 - 965 Wm^{-2}, about 80 % of the cases exceeding 700 Wm^{-2}. The standard deviation in these 6-minute values of calibration constants is rather low, namely $S(C_{NIP,6\text{-}minute})$ = 0.29 %.

b) Bias uncertainties of field reference pyrheliometer; B_{A171} and $B_{NIP,C\text{-}mean}$.

The bias and random uncertainties of WRR are very small and have here been considered as negligible, compared to the uncertainties of the SMHI radiometers. For uncertainty estimation, a bias, B_{A171} = 0.30 %, in Å-171 is still allowed after correction by the 0.25 % difference from the cavity radiometers, as mentioned above.

The uncertainty of the mean calibration factor of a reference NIP is estimated from the data in Figure 4.3. The uncertainty of the mean calibration factor of the reference NIP #20919 from the 69 individual calibration results in Figure 4.3 is only $0.29/69^{1/2}$ = 0.03 %. This value is doubled giving $B_{NIP,C\text{-}mean}$ = 0.06 %, to get coverage at the 95 % confidence level of a possible bias in the mean calibration factor, due to the limited amount of calibration data.

c) Random uncertainties of field reference pyrheliometer; $S_{NIP,1\text{-}minute}$, $S_{NIP,1\text{-}hour}$ and $S_{NIP,1\text{-}day}$.

From comparisons with the PMO-6 #811108, the normalised 1-minute random uncertainty of the NIP #20919 irradiance measurement, $S_{NIP,1\text{-}minute}$, is assumed to be equal to the observed standard deviation of the derived calibration factor of normalised 1-minute data, i.e.

$$S_{NIP,1\text{-}minute} = S\left(\frac{C_{NIP,1\text{-}minute,i,j}}{C_{NIP,1\text{-}hour,i}}\right) \quad \text{for} \begin{Bmatrix} i = 1, 2, ..., n_h. \\ j = 1, 2, ..., n_{m,i}. \end{Bmatrix}, \tag{4.5}$$

where $S(\ldots)$ stands for the standard deviation of the expression within the parenthesis, n_h is the number of hours and $n_{m,i}$ is equal to the number of minutes of the i^{th} hour. In this way the result $S_{NIP,1\text{-}minute}$ = 0.25 % was achieved. The measured values by PMO-6 are instantaneous irradiance values, one value every second minute. The one-minute values of the NIP #20919 are averages of about 10 readings evenly spread over a whole minute. Therefore, the instantaneous values of the PMO-6 are not exactly the same as 1-minute averages, not even if they are taken in the middle of a minute as in this case. There is also the small random uncertainty of the PMO-6 itself contributing to the total scatter in C_{NIP}. However, as a matter of precaution, no attempt to remove these uncertainties from the C_{NIP} before the calculation of $S_{NIP,1\text{-}minute}$ has been made.

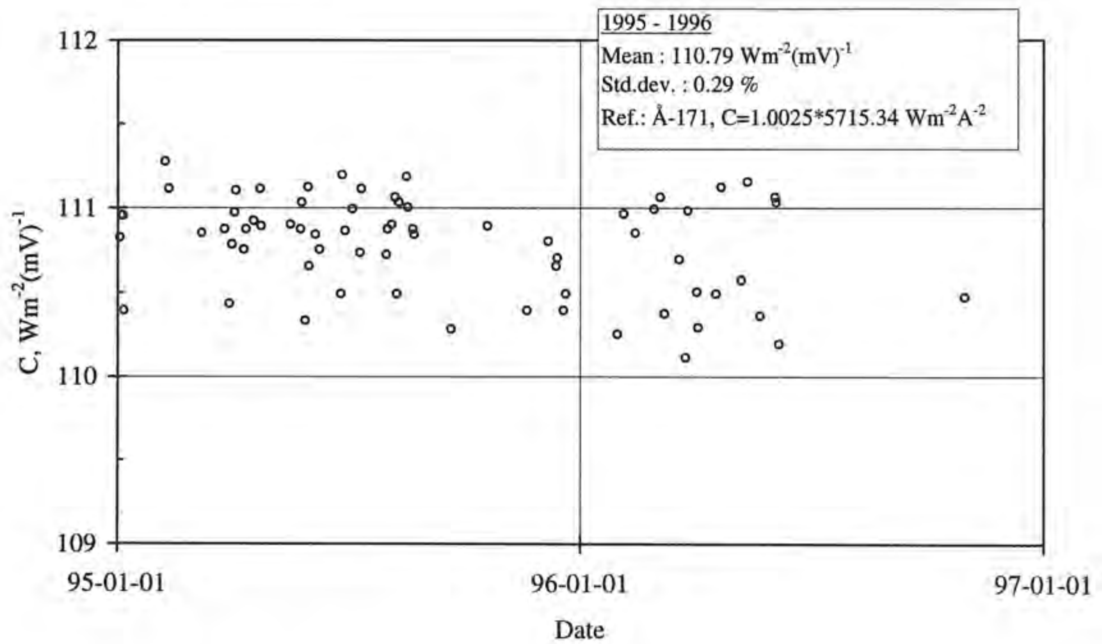

Figure 4.3. Example of calibration factors for the reference field pyrheliometer, Eppley NIP #20919, determined through comparison with Å-171 during 1995-1996. Each point represents a 6-minute mean value.

Taking the 0.25 % random uncertainty of NIP #20919 for 1-minute values, the random uncertainty for 6-minute mean values, $S_{NIP,6\text{-}minute}$, is approximated to $0.25/6^{1/2} = 0.10$ %. In the same way, the random uncertainty of 6-minute mean values of Å-171 is, from the results of IPC-VIII, approximated to $S_{Å171,6\text{-}minute} = 0.29/6^{1/2} = 0.12$ %.

The hourly random uncertainty, $S_{NIP,1\text{-}hour}$, for the field reference NIP was calculated as

$$S_{NIP,1\text{-}hour} = \sqrt{S\left(\frac{C_{NIP,1\text{-}hour,i,j}}{C_{NIP,1\text{-}day,i}}\right)^2 - \left(S_{NIP,1\text{-}minute}/\sqrt{n}\right)^2} \tag{4.6}$$

From 23 samples of hourly mean values of C_{NIP} from four different days in April, May or June using PMO-6 #811108 as reference, the resulting hourly random uncertainty of the NIP #20919 was calculated to $S_{NIP,1\text{-}hour} = 0.12$ %.

As mentioned above, daily mean C_{NIP} values have not been normalised by any yearly, seasonal or monthly averages. Probably there is some inter-annual variation in daily averages of C_{NIP}, but there should not be any noticeable yearly random variation. The change in long-term mean responsivity is thought to be slow and monotonic or discontinuous, as could be the case after an instrument repair. The random uncertainty component of the longest time interval here considered, *i.e.* the daily standard deviation, was calculated as

$$S_{NIP,1\text{-}day} = \sqrt{S(C_{NIP,1\text{-}day})^2 - (S_{NIP,1\text{-}hour}/\sqrt{n_h})^2 - (S_{NIP,1\text{-}minute}/\sqrt{n_m})^2}\,. \qquad (4.7)$$

In the present calculations $n_h = 6$ and $n_m = 6 \cdot 30 = 180$. Finally, the daily random uncertainty of the NIP #20919 was computed to $S_{NIP,1\text{-}day} = 0.23$ %. However, the $S_{NIP,1\text{-}day}$ calculations were here based on only six daily averages of calibration factors of the NIP ($C_{NIP,1\text{-}day}$). Again, the days were days of April, May or June and the PMO-6 #811108 was used as reference. Note that $S_{NIP,1\text{-}day} > S_{NIP,1\text{-}hour}$. This is quite in line with the author's experience of pyrheliometer calibration measurements all year around in Sweden.

The range of scatter of the *mean* calibration values taken at different days of comparisons with PMO-6 is approximately the same as with Å-171 as reference. From the regular calibrations of the reference field pyrheliometer, using Å-171 as reference, the standard deviation of 6-minute values, $S(C_{NIP,6\text{-}minute})$, is as mentioned 0.29 %. The random uncertainties of Å-171 and NIP #20919 at the 6-minute level, random errors in the data acquisition system as well as the assumed daily and hourly random uncertainties of the NIP contribute to this number. Since the data acquisition system always is the same during calibration and operational measurements at the main station in Norrköping, the data acquisition system uncertainties are included in the respective radiometer uncertainties. To check the individual random uncertainties derived for the NIP #20919 using PMO-6 as reference, and the random uncertainties of the Å-171 from IPC-VIII, a theoretical value of $S(C_{NIP,6\text{-}minute})$, $S_t(C_{NIP,6\text{-}minute})$, could now be calculated.

$$S_t(C_{NIP,6\text{-}minute}) = \sqrt{S_{NIP,1\text{-}day}{}^2 + S_{NIP,1\text{-}hour}{}^2 + S_{NIP,6\text{-}minute}{}^2 + S_{A\text{-}171,6\text{-}minute}{}^2} = 0.30\ \%\,.$$

Indeed, $S_t(C_{NIP,6\text{-}minute}) = 0.30$ % is very close to the experimental $S(C_{NIP,6\text{-}minute}) = 0.29$ %, achieved using Å-171 as reference, thus adding reliability to the random uncertainty derivations made above.

d) Student's statistical parameter, t_{95}

Since the amount of available average daily and hourly calibration data at present is not large enough to permit the number of samples to be 30 or more in all calculations of the experimental standard deviations, the t_{95} must be determined. Inserting the values given above for the daily, hourly and 1-minute random uncertainties of the reference NIP, with corresponding individual degrees of freedom of 5, 22 and 500, respectively, into the Welch-Satterthwaite formula (ISO TC30 SC9), gives $\nu_p = 13.8$. For 13 degrees of freedom, $t_{95} = 2.160$ (tabulated value).

e) Total uncertainty of field reference pyrheliometer

Finally, the total uncertainty of 1-minute, 6-minute and hourly mean values of E_b, measured under calibration conditions (i.e. clear sky, high direct irradiance, perfect alignment, modest air temperature, well-cleaned window) with the reference field pyrheliometer Eppley NIP #20919 are, with the aid of the expression

$$U_{NIP,time\text{-}interval} = B_{Å171} + B_{NIP,C\text{-}mean} + t_{95}\sqrt{S_{NIP,1\text{-}day}^{\;2} + S_{NIP,1\text{-}hour}^{\;2}/n_h + S_{NIP,1\text{-}minute}^{\;2}/n_m}\,, \qquad (4.8)$$

estimated to $U_{NIP,1\text{-}minute}$ = 1.1 %, $U_{NIP,6\text{-}minute}$ = 1.0 %, $U_{NIP,1\text{-}hour}$ = 0.9 % and $U_{NIP,1\text{-}day}$ = 0.9 %, respectively. Here n_h and n_m are the number of hours and minutes that are spanned by the considered time-interval. In the $U_{NIP,1\text{-}day}$ estimate, n_h = 6 was used. In table 4.1, the uncertainty estimates above are summarised. Since only two bias terms have been considered, the bias terms where here directly added, in accordance with the recommendations in ISO TC30 SC9.

Table 4.1. Bias, random and total uncertainties of the reference pyrheliometers PMO-6 #811108, Å-171 and Eppley NIP #20919 under calibration conditions (i.e. clear sky, high direct irradiance, perfect alignment, modest air temperature, well-cleaned window).

Type of uncertainty	PMO-6 #811108	Å-171	Eppley NIP #20919
Bias			
Reference			
$B_{PMO\text{-}6}$	≤ 0.15 % *)		
$B_{Å171}$		0.30 % *)	0.30 %
Mean C uncert.			
$B_{NIP,\,C\text{-}mean}$			0.06 %
Random (1 S)			
1-minute (noise)	0.10 % (IPC-VIII)	0.29 % (IPC-VIII)	
$S_{NIP,1\text{-}minute}$			0.25 %
6-minute (noise)	$0.10/3^{1/2} = 0.06$ %	$0.29/6^{1/2} = 0.12$ %	
$S_{NIP,6\text{-}minute}$			$0.25/6^{1/2} = 0.10$ %
1-hour (meas. cond.)	$0.10/30^{1/2} = 0.02$ %	$0.29/60^{1/2} = 0.04$ %	
$S_{NIP,1\text{-}hour}$			0.12 %
1-day (meas. cond.)	0 % 1)	0 % 1)	
$S_{NIP,1\text{-}day}$			0.23 %
Total ($B + t_{95}S$)	$U_{PMO6,\,1\text{-}min}$ = 0.4 % $U_{PMO6,\,6\text{-}min}$ = 0.3 % $U_{PMO6,\,1\text{-}hour}$ = 0.2 %	$U_{Å171,\,1\text{-}min}$ = 0.9 % $U_{Å171,\,6\text{-}min}$ = 0.5 % $U_{Å171,\,1\text{-}hour}$ = 0.4 %	$U_{NIP,\,1\text{-}min}$ = 1.1 % $U_{NIP,\,6\text{-}min}$ = 0.9 % $U_{NIP,\,1\text{-}hour}$ = 0.9 % $U_{NIP,\,1\text{-}day}$ = 0.8 %

*) *Estimate*

1) *All uncertainties due to the influence from differing atmospheric conditions between Davos and Norrköping are put into the bias term. The bias term is also estimated to include a small but unknown daily uncertainty.*

Due to its window, a field pyrheliometer does not see any direct solar radiation of wavelengths longer than 4 µm. For this reason, there is a small solar elevation dependence in the responsivity of a field pyrheliometer since the amount of transmitted infrared radiation varies with the pathlength through (and the water vapour amount in) the atmosphere. So far there has unfortunately not been enough data collected to quantify this effect.

4.2.2 Reference pyranometers

The reference and the field pyranometers have all been the same since the start of the current radiation network of SMHI in 1983. The instruments are all Kipp & Zonen CM10 or CM11 secondary standard pyranometers. Except for the name, the CM10 and CM11 models are of identical instrument type. Only the reference pyranometer No.1 is a CM10 and all the other SMHI pyranometers are CM11s. Therefore, uncertainty terms connected with pyranometer measurements will all be indexed by the subscript *CM11* in the following, even though they refer to the CM10 instrument as well.

4.2.2.1 Calibration methodology

Before 1996 the reference pyranometers were calibrated using the alternating sun-and-shade method, also called the sun-disk method. (For a description see e.g. ISO, 1993.) From 1996 the reference pyranometers are calibrated using the so-called pseudo-composite method. This latter method only requires a well-calibrated pyrheliometer as a reference to calibrate one unshaded (E_g) and one shaded (E_d) pyranometer. Further, continuous measurements of E_g and E_d do not have to be interrupted for special calibration measurements.

The calibration is made in two steps. First, for overcast skies when $E_g = E_d$, the global/diffuse instrument sensitivity ratio, r_o, is determined as

$$r_o^* = \frac{V_g}{V_d} \qquad (4.9)$$

where V_g and V_d are 1-minute mean or hourly mean voltage readings of the global and diffuse (shaded) pyranometers, respectively. The * superscript indicate individual or momentaneous values. To get reliable statistics on r_o^*, only voltage readings from instants when E_g exceeds 70 Wm^{-2} are taken into account. The constant r_o value that is used in the following clear sky calibration calculations is achieved by putting the sums of the selected V_g and V_d values into (4.9), i.e.

$$r_o = \frac{\sum V_g}{\sum V_d}\,. \qquad (4.10)$$

The second step is to determine the calibration factor for the global pyranometer, $C_{CM11,Global}$, during selected clear days through

$$C_{CM11,Global}^* = \frac{E_b \cdot \sin(h)}{V_g - r_o \cdot V_d} \qquad (4.11)$$

where E_b is the direct solar radiation and h is the solar elevation. For simplicity, in the evaluation of the final calibration factors (constants) of the SMHI reference pyranometers, time integrated values of the clear sky calibration data, $E_b \cdot \sin(h)$, V_g and V_d, are used in (4.11), i.e.

$$C_{CM11,Global} = \frac{\sum E_b \cdot \sin(h)}{\sum V_g - r_o \cdot \sum V_d} \quad . \tag{4.12}$$

The resulting constant is very close to an irradiance weighted $C_{CM11,Global}$. The individual r_o^* and $C_{CM11,Global}$ are calculated and controlled to derive statistics of the calibration uncertainties and to check for outliers. Finally, the calibration factor for the shaded (diffuse) pyranometer becomes

$$C_{CM11,Diffuse} = r_o \cdot C_{CM11,Global} \quad . \tag{4.13}$$

An irradiance value measured by a pyranometer then simply is

$$E_g = C_{CM11} \cdot V_g \tag{4.14}$$

or

$$E_g = \frac{V_g}{R_{CM11}} \tag{4.15}$$

where V_g is the output voltage from the pyranometer. Sometimes the responsivity factor, R_{CM11} (= 1/ C_{CM11}), is used instead of C_{CM11}. Evidently, the unit of C_{CM11} is Wm^{-2}/V and the unit of R_{CM11} is instead V/Wm^{-2}.

The scatter of the individual calibration factors (1-minute mean values) for the reference 1 pyranometer, Kipp & Zonen CM10 #800080, from the calibration in spring 1996 is shown in Figure 4.4. Eppley NIP #20919 simultaneously calibrated by Å-171 on 6-minute mean level, was used as reference for the direct component and the diffuse reference pyranometer Kipp & Zonen CM11 #810132 (tracking disk) was used to measure the diffuse component. The measurements were taken during the period from 1996-03-25 to 1996-06-07 at solar elevations ranging from 22° to 54°. The standard deviation of the derived 1-minute values of the calibration constant, $S(C_{CM11,Global})$ of the CM10 #800080 is 0.59 %.

4.2.2.2 Bias uncertainties of pyranometer measurements

a) Bias uncertainty of reference; $B_{Å171}$

Since the Å-171 pyrheliometer was used as reference to derive the calibration factor of the reference 1 pyranometer, the estimated worst case bias in Å-171, $B_{Å171}$ = 0.30 % (paragraph 4.2.1), must be included as a bias uncertainty of the reference pyranometer as well.

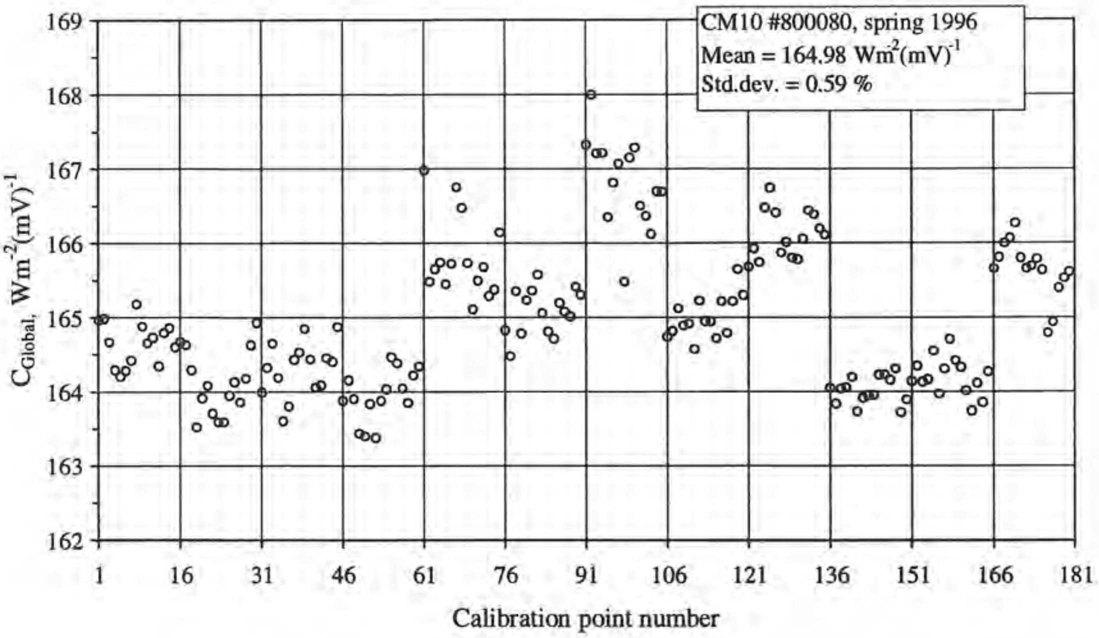

Figure 4.4. Calibration factors for the SMHI reference 1 pyranometer, CM10 #800080, during spring of 1996, determined through pseudo-composite method using Eppley NIP #20919 simultaneously calibrated against Å-171, together with the shaded CM11 #820132, as reference. Each point represents a 1-minute mean value. The data consists of 15 points measuring series taken at twelve different days. Solar elevation range: 22°- 54°.

b) Bias uncertainty of mean C_{CM11}; $B_{CM11,C\text{-}mean}$

Even though the a final C_{CM11} is not an arithmetic mean value of the individual calibration points such as those presented in Figure 4.4, there is a bias uncertainty, $B_{CM11,C\text{-}mean}$, introduced by using a relatively small sample. As a matter of precaution, the experimental standard deviation of the mean values of C_{CM11} for each day (15 points per day) is calculated. The result is 0.57 %, which is only marginally smaller than the 0.59 % for the 1-minute mean values. The standard deviation of an average, S_m, is equal to the standard deviation, S, of the individual values used to derive the average value, divided by the square root of the number of values in the sample, n. To get coverage at 95 % confidence S_m is then multiplied by t_{95}. Finally, with S = 0.57 %, n = 12 and t_{95} = 2.201 for 11 degrees of freedom, $B_{CM11,C\text{-}mean}$ is estimated to

$$B_{CM11,C\text{-}mean} = 2.201 \cdot \frac{0.57}{\sqrt{12}} = 0.36 \text{ \%}.$$

c) Systematic zero offset uncertainties; $B_{CM11,CG,offs,c}$, $B_{CM11,CD,offs,c}$ and $B_{CM11,CG,offs,o}$

A significant source of uncertainty in pyranometer measurements is caused by the varying zero offset signal. The zero offset is mainly composed by three components: 1) An assumed constant electronic offset in the measuring system. 2) Net thermal radiation induced offset. 3) Offset induced by change in ambient temperature.

All radiation measurements at SMHI are corrected for the mean dark signals measured during the night before and after a day. This is assumed to cancel the effect of any electronic offset in the measuring system. If the net thermal radiation would be constant during the 24 hours of a day, also the offset caused by this effect would be totally removed. For some overcast days this may closely be the case. But normally, there is a difference in the net thermal radiation during night and day. The change in offset due to changes in ambient temperature is in this work assumed to be a random effect and is thus considered to be included in the random uncertainty analysis below.

According to McArthur (1998) the response to (+)200 Wm^{-2} net thermal radiation is +7 Wm^{-2} for a ventilated Kipp & Zonen CM11 pyranometer. The net long-wave (thermal) radiation has been studied with the aid of pyrgeometer measurements of the downwelling long-wave irradiance, E_l, and the pyrgeometer body temperature, T_{pyrg}. The net long-wave irradiance of a pyranometer, Q_l, was approximated by

$$Q_l = E_l - \sigma T_{pyrg}^{\ 4} \tag{4.16}$$

where σ is Stefan-Boltzmann's constant.

It has been found that for clear days, the difference in Q_l between day and night often is –35 to –70 Wm^{-2} Assuming a linear response to the net thermal irradiance, this results in additional offset values during daytime of about –1.2 to –2.5 Wm^{-2}, which are not corrected for. If there would have been clouds present for some times during the night, the offset difference would have been even larger. Hence, during clear days and clear sky calibration conditions relative bias errors due to insufficient zero offset correction of E_g, $B_{CM11,G,offs,c}$, and E_d, $B_{CM11,D,offs,c}$, of approximately (-)0.4 % and (-)3.1 %, respectively, are assumed to exist.

During overcast days (and nights) the difference in Q_l between day and night is much smaller. An average difference of –20 Wm^{-2} is not thought to be an underestimation and it would give an additional zero offset value of less than 1 Wm^{-2}. Thus, a bias uncertainty due to insufficient offset correction of both E_g and E_d under overcast conditions, $B_{CM11,offs,o}$, is approximated to (-)1.0 %.

The systematic erroneous offset correction of both E_g and E_d pyranometer measurements, especially under clear skies, also affect the derivation of the (linear) calibration constants, $C_{CM11,Global}$ and $C_{CM11,Diffuse}$. On the other hand, the global/diffuse voltage ratio under overcast, r_o, should not be significantly affected. This is partly because of the small net thermal radiation stress under overcast skies and partly because the two instruments are exposed to the same measuring conditions, which they are supposed to respond to equally.

Consider an ideal clear sky calibration case when E_d = 0.2 E_g, i.e. r_oV_d = 0.2 V_g, and $C_{CM11,ideal}$ = 1 implying that $E_b\sin(h)$ = 0.8 V_g (from Equation 4.11). In this case one has

$$C_{CM11,ideal} = \frac{E_b \sin(h)}{V_g - r_o V_d} = \frac{0.8V_g}{V_g - 0.2V_g} = 1$$

Now consider a somewhat more realistic case with the bias terms $B_{CM11,G,offs,c}$ = -0.4 % and $B_{CM11,D,offs,c}$ = 3.1 % taken into account. In this case, for a $C_{CM11,real}$ one has

$$C_{CM11,real} = \frac{0.8V_g}{0.996 \cdot V_g - 0.2 \cdot 0.969 \cdot V_g} = \frac{0.8}{0.8022} = 0.997,$$

that is, $C_{CM11,real}$ is 0.3 % smaller than $C_{CM11,ideal}$. Hence one gets yet another bias term due to, on the average, insufficient zero offset correction of the clear sky calibration data. This bias term of 0.3 % is denoted $B_{CM11,C,offs}$. Since this bias uncertainty is of the same sign as all the terms $B_{CM11,G,offs,c}$, $B_{CM11,D,offs,c}$ and $B_{CM11,offs,o}$, it is simply added to these latter uncertainties, giving $B_{CM11,CG,offs,c}$ = 0.7 %, $B_{CM11,CD,offs,c}$ = 3.4 % and $B_{CM11,CG,offs,o}$ = 1.3 %, which are the terms to be used in the total uncertainty calculations.

d) *Systematic clear – overcast sky difference;* $B_{CM11,c\text{-}o,c}$, $B_{CM11,c\text{-}o,o}$ *and* $B_{CM11,D,c}$

Apart from the zero offset difference, there are other systematic uncertainties introduced by the different measuring conditions under clear and overcast skies. Due to non-linearity effects there is a small difference in the response of the pyranometers, especially in the unshaded one, between clear (E_g =500-830 Wm^{-2}) and overcast (E_g =70-250 Wm^{-2}) calibration conditions. For Kipp & Zonen CM11 pyranometers the difference in response at 100 Wm-2 relative to the response at 500 Wm^{-2} is (-) 0.6 %, McArthur (1998) and Wardle *et al.* (1996). This effect is mainly influencing an unshaded global irradiance measuring pyranometer, while the range and variation of diffuse irradiance is much less than for E_g and hence the variation in response due to non-linearity is much less for a shaded pyranometer.

Further, the diffuse sky radiance distribution differs systematically under clear and cloudy skies. The unique and non-ideal directional response of each real pyranometer, see further discussions below, results in yet another bias term. Assume that both pyranometers have responsivities to (diffuse) irradiance equal to unity under overcast skies, i.e. $R_{G,o} = R_{D,o} = 1$. Then, under clear skies let the pyranometers have the responsivities $R_{G,c}$ = 0.994 and $R_{D,c}$ = 0.998, a 0.4 % difference, to the clear sky diffuse irradiance. These estimated values have been chosen after simple studies of mean responsivity to isotropic radiation for some typical Kipp & Zonen CM11 directional responsivities. Further, the relative sky radiance from directions having large angles of incidence is assumed to be higher under a clear sky than under an overcast sky.

In the calibration equations 4.11-13 one should rather have used the (unknown) voltage ratio for the diffuse clear sky, r_c, instead of the ratio r_o valid under overcast skies. To estimate r_c in this case, both the non-linearity of the unshaded pyranometer and the directional dependent clear-overcast difference described above are taken into account. If added, the two factors would lead to a maximum biased r_c of $r_c \approx (1 - 0.006 - 0.004)r_o = 0.99r_o$. Hence, r_o could be considered to be biased by $B_{CM11,ro}$ = 1.0 %.

However, the bias term influencing the calibration of the unshaded pyranometer under clear skies never exceeds $B_{CM11,c\text{-}o,c}$ = 0.25 %. This is because the E_d/E_g ratio never exceeds 1/5, or $E_b \cdot \sin(h)/E_g \geq 4/5$, in Swedish clear sky calibration conditions and the possibly biased diffuse part is subtracted from E_g in the denominator on the right hand side of (4.11-12). ([Biased diffuse part of G]/[Direct horizontal part of G] = (0.01·0.2)/0.8 = 0.0025.)

The maximum bias uncertainty of a pyranometer (unshaded) measurement in clear sky calibration conditions, due to an assumed clear/cloudy sky response difference, was estimated to one fourth of the 1 % total bias of this effect. To get an estimate of the influence of this uncertainty under overcast sky (and as a matter of precaution), the mean calibration constant for a clear sky is in this case assumed to be biased toward the cloudy sky response by only one tenth of the 1 % difference, i.e. 0.1 %. (This would be the case if the E_d / E_g ratio under clear sky calibration always was ≈1/10.) Therefore, in the worst case, a global irradiance value from an overcast situation could be biased by $B_{CM11,c\text{-}o,o}$ = 0.90 %, due to the use of a clear sky calibration factor. But hopefully, the clear/overcast sky response difference is somewhat overestimated.

Unfortunately, the influence of the systematic clear-overcast difference on measurements by a shaded pyranometer of the diffuse irradiance under clear skies is even worse than the 0.90 % under overcast. The calibration factor of the shaded pyranometer, $C_{Diffuse}$, is according to Equation 4.13 equal to $C_{Diffuse} = r_o \cdot C_{Global}$. The total bias uncertainty of a E_d measurement due to the clear-overcast difference, $B_{CM11,D,c} = B_{CM11,ro} + B_{CM11,c\text{-}o,c}$, is therefore 1.25 %.

e) Uncertainty of mean r_o; $B_{CM11,r\text{-}mean,c}$, $B_{CM11,r\text{-}mean,o}$ and $B_{CM11,r\text{-}mean,D}$

The standard deviation of r_o, $S_{r,h}$, determined from hourly values of V_g and V_d normalised with the daily mean values, is about 0.80 %. As mentioned above, r_o is not an arithmetic mean value of the $r_{o,i}$ values. For simplicity, the uncertainty in r_o due to limited amount of experimental data is yet estimated as if it would be an arithmetical average. Since only 50 to 80 hourly values of V_g and V_d are used to determine r_o, the (bias) uncertainty, $B_{CM11,r\text{-}mean}$ ($= 2S_{r,h}/n^{1/2}$), of an observed mean r_o would be about 0.20 %.

In analogy with the influence of the r_oV_d uncertainty discussed above, in the clear sky calibration case when $E_d / E_g \leq 1/5$, only one fourth of $B_{CM11,r\text{-}mean}$ must be taken into account. Thus an estimation of total uncertainty of pyranometer calibration due to these effects results in the bias term $B_{CM11,r\text{-}mean,c}$ = 0.05 %. The uncertainty value to take into account in an overcast case is 90 % of $B_{CM11,r\text{-}mean}$, leading to the bias term $B_{CM11,r\text{-}mean,o}$ = 0.18 %.

As in the two preceding cases the calibration of a diffuse pyranometer is affected twice by a mean r_o uncertainty. Due to the calibration method used for the shaded pyranometer, Equation 4.13, the bias in clear sky E_d measurements due to the uncertainty of the mean r_o, $B_{CM11,r\text{-}mean,D}$, is the sum of $B_{CM11,r\text{-}mean}$ and $B_{CM11,r\text{-}mean,c}$. Therefore, $B_{CM11,r\text{-}mean,D}$ = 0.25 %.

4.2.2.3 Random uncertainties of pyranometer measurements

The 1-minute, hourly and daily random uncertainties of a pyranometer are calculated in the same way as the random uncertainties of a NIP pyrheliometer were calculated in the preceding paragraph. Likewise, the total random uncertainty is considered to be made up of three components of different time-scale, 1-minute, hourly and daily random uncertainties. Also in this case, no attempt has been made to remove the contribution from the small random uncertainties of the reference instruments to the resulting pyranometer uncertainties.

a) 1-minute noise; $S_{CM11,1\text{-}minute,c}$ and $S_{CM11,1\text{-}minute,o}$

From calibrations of the global radiation reference pyranometer CM10 #800080 against PMO-6 during several hours from three clear sky days, the normalised $S_{CM11,1\text{-}minute,c}$ of the determined calibration factors was 0.32 %. Additional to this number, there is also a small contribution from the random uncertainty of the PMO-6 as well as from the shaded pyranometer. But as a matter of precaution, due to the fact that the random uncertainty of PMO-6 is very small and that the subtracted signal from the shaded pyranometer is only a minor part of the total E_g signal, the calculated $S_{CM11,1\text{-}minute,c}$ = 0.32 % is considered to originate only from the CM10 #800080.

The 1-minute experimental standard deviation in r_o, $S_{r,1\text{-}minute}$, for a couple of hours during one day has been found to be 0.56 %. Since the pyranometers under consideration are of the same type, their individual contribution to this total noise is assumed to be equal. Hence, the normalised 1-minute random uncertainty (noise) of pyranometer measurements under overcast conditions, $S_{CM11,1\text{-}minute,o}$, is assumed to be $S_{r,1\text{-}minute}/2^{1/2}$ = 0.40 %. This is somewhat higher than the $S_{CM11,1\text{-}minute,c}$ = 0.32 % valid under clear sky conditions, which is considered to be a fairly realistic result due to the lower global radiation under overcast situations. $S_{CM11,1\text{-}minute,o}$ is also assumed to be valid for a shaded pyranometer under clear skies.

b) Hourly random uncertainty including uncertainty due to directional dependent response; $S_{CM11,1\text{-}hour}$

A significant source of error in pyranometer measurements is the directional dependent responsivity of the instruments. It can be split into two components, the azimuth, R_{Az}, and the cosine response, R_{cos}. The latter, R_{cos}, is here defined as the responsivity to beam irradiance, E_b, with angle of incidence, Z_{pss} to the plane of the sensor surface, i.e.

$$R_{cos} = \frac{V}{E_b \cos Z_{pss}}. \tag{4.17}$$

As earlier, V is the output voltage of the calibrated pyranometer. For an ideal pyranometer, R_{cos} would be equal for all Z_{pss}. In practice, instrument receiving surfaces may not always be perfectly levelled. Therefore, the exact Z_{pss} is not known and Z_{pss} is approximated by the solar zenith angle, Z. Often, R_{cos} is normalised for example by $R_{cos}(Z = 55°) = R_{cos}(h = 35°)$ as in this report. If the solar elevation, h, is used instead of Z, sine expressions instead of cosine expressions show up in the equations. For modern and accurately levelled pyranometers, the responsivity dependence on azimuth angle, Az, of the incident beam is much smaller than the dependence on Z. For improperly levelled instruments, the situation becomes rather complex, as will be demonstrated.

At SMHI pyranometer calibrations are only made at times when the solar elevation is higher than 20° ($Z < 70°$). However, even in the solar elevation range $20°<h<35°$ the cosine response of any high quality pyranometer such as a Kipp & Zonen CM11 or CM21 could differ significantly from an ideal response. This could be studied by using the horizontal component of the measured direct irradiance, E_b, and compare it with the same component as retrieved from the global and diffuse irradiance measurements, figure 4.5. In this figure, three examples of the approximate ($Z \approx Z_{pss}$), irradiance weighted (E_b not constant with Z), relative cosine response (normalisation by daily average response at $h = 35°$, $R_{@35°}$) versus solar elevation for Kipp & Zonen CM10/CM11 pyranometers are shown. Evidently, above $h = 35°$ the relative cosine response is very close to ideal, i.e. close to unity. But already at $h = 20°$ the cosine response could be about 3 % off from the ideal one. Mostly the directional response deviates even more from the ideal one for lower solar elevations. Below $h = 5°$ the signals are very small, which explains in the large noise in that region.

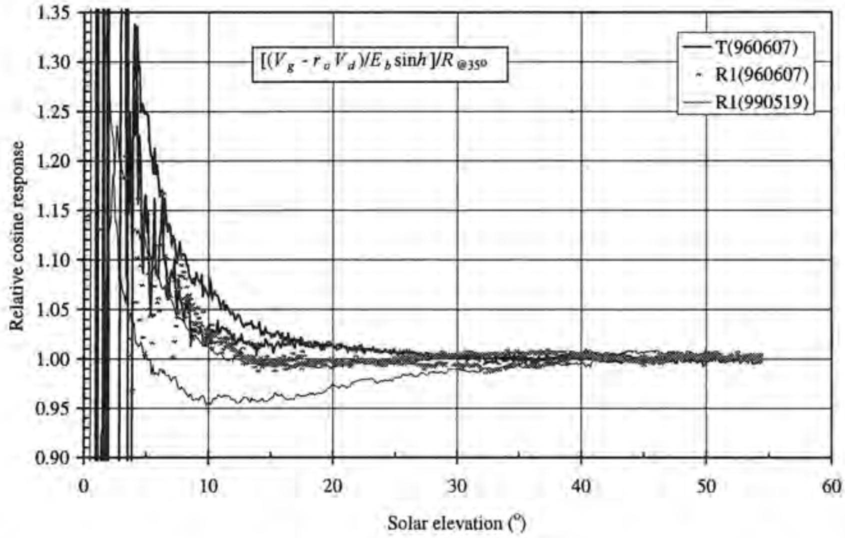

Figure 4.5. Approximate, irradiance weighted, relative cosine response versus solar elevation for the pyranometers Kipp & Zonen CM11 #820134 (T) on 1996-06-07 and Kipp & Zonen CM10 #800080 (R1) on 1996-06-07 and 1999-05-19. The reference direct irradiance was measured by Eppley NIP #20919 continuously calibrated against PMO-6 #811108 during most times of the days. The shaded reference pyranometer was in all three cases the Kipp & Zonen CM11 #820132.

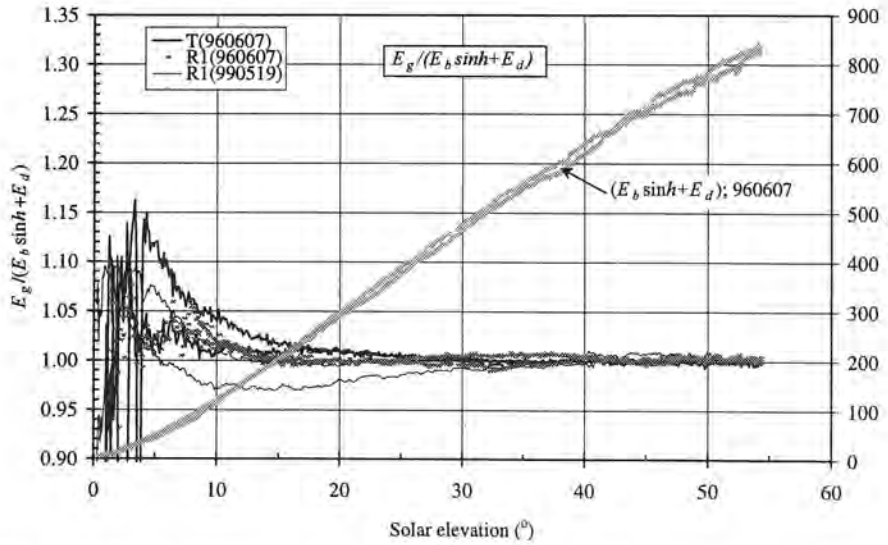

Figure 4.6. The ratio $E_g/(E_b \cdot sin(h)+E_d)$ versus solar elevation. The pyranometers and the dates for the measurements are the same as in Figure 4.5. E_g was measured using a constant calibration factor throughout the days. On the right hand y-axis the component sum of E_g, $E_b \cdot sin(h)+E_d$, for the day 1996-06-07 is plotted.

With decreasing solar elevation the diffuse part of the global radiation becomes relatively larger and larger. In turn, this somewhat reduces the error of an E_g measurement caused by the non-ideal response to the direct solar radiation at low solar elevations. This is seen when comparing the graphs in Figure 4.5 and Figure 4.6. The ratio of E_g, measured using a constant calibration factor, to the component sum $E_b \cdot \sin(h) + E_d$, measured with a pyrheliometer and a shaded pyranometer, is plotted in Figure 4.6. Assuming $E_b \cdot \sin(h) + E_d$ to be closer to the true global irradiance, it is clear that for solar elevation less than about 20° the deviation from ideal pyranometer behaviour is apparently less in Figure 4.6 than in Figure 4.5.

Similar results of the approximate relative cosine response for the CM10 #800080 have earlier been found by L. Dahlgren, presented in Wardle *et al.* (1996), pp 57-86.

In both Figures 4.5-6, data for the reference pyranometer CM10 #800080 (R1) from two days are plotted. The behaviour of this instrument is quite different on the two days. On 1996-06-07 the relative cosine response was very close to ideal for all $h > 15°$, both before and after noon. On 1999-05-19, however, the behaviour was close to ideal for solar elevations higher than about 12° before noon, but in the afternoon the behaviour starts to deviate significantly from the ideal already around $h = 33°$. According to a pyranometer characterisation in 1985 by L. Liedquist at the Swedish National Testing and Research Institute, SP, the azimuthal dependence in response of the CM10 #800080 is small. For example, the relative response range at 70° angle of incidence for 12 different azimuth planes was found to be less than 0.3 %. Instead it is probably a small difference in the levelling of the R1 pyranometer that causes the apparent difference in the cosine response between the two dates.

This clearly illustrates the great importance of having a pyranometer very accurately levelled when measuring global radiation, especially at solar elevations below 35°, which indeed is very common on the latitudes of Sweden. Accordingly, this also demonstrates the difficulty to determine and use one single solar elevation dependent calibration function, $C_{CM11}(h)$, to take the directional dependency into account in routine field measurements at stations where the instruments are changed routinely and not calibrated in situ. If mounted in a slightly different way than at the calibration, the $C_{CM11}(h)$ is no longer valid. In other words, and which is very well known, global radiation under is much more accurately measured by using a suntracking pyrheliometer together with a shaded (tracking disk) pyranometer (Wardle et al. 1996, Michalsky et al. 1999). A shaded pyranometer measuring only the diffuse sky irradiance is much less sensitive to levelling errors than an unshaded one.

In this work, uncertainties introduced by a directional dependent responsivity or calibration factor, are put into the hourly random uncertainty term. Normalised hourly values of C_{CM11} for three different pyranometers (CM10 #800080 being one of them) from hours with average solar elevations evenly distributed from 20° to 50° have been studied. The pseudo composite method, using PMO-6 #811108 as reference for the direct irradiance and the shaded CM11 #810132 for the diffuse irradiance, was used. Similarly to the expression in equation 4.6, the hourly random uncertainty of E_g measurements under clear skies, $S_{CM11,1\text{-}hour,c}$, is calculated as

$$S_{CM11,1\text{-}hour,c} = \sqrt{S\left(\frac{C_{CM11,h\text{-}mean}}{C_{CM11,@35}}\right)^2 - \left(\frac{S_{CM11,1\text{-}minute,c}}{\sqrt{60}}\right)^2}, \qquad (4.18)$$

where $C_{CM11,h\text{-}mean}$ is hourly mean values of C_{CM11} and $C_{CM11,@35}$ is the average C_{CM11} between 34°< h <36°, for each particular day analysed. For 36 hourly values analysed, measured by three different pyranometers, the result $S_{CM11,1\text{-}hour,c}$ = 0.96 % was found.

With an accurately levelled pyranometer, as seemed to be the case for CM10 #800080 during spring of 1996, $S_{CM11,1\text{-}hour,c}$ could be considerably lower than the 0.96 % achieved above. For hourly data from CM10 #800080 only during the spring of 1996, the resulting hourly random uncertainty instead became $S_{CM11,1\text{-}hour,c,96}$ = 0.37 %. This value will be used for the calculation of the daily random uncertainty, $S_{CM11,1\text{-}day}$, from the data presented in Figure 4.4.

As stated earlier, $S_{r,h}$ = 0.80 %. Again assuming that the contributions from the two pyranometers to this number are equal, the hourly random uncertainty under overcast skies, $S_{CM11,1\text{-}hour,o}$, is calculated to

$$S_{CM11,1\text{-}hour,o} = \sqrt{\frac{0.80^2 - 2 \cdot 0.40^2 / 50}{2}} = 0.56\,\%.$$

It was here assumed that the number of analysed values each hour were only 50 instead of 60, because some outliers have been removed. Since the hemispheric sky radiance roughly is isotropic in overcast conditions, the effect of the non-ideal cosine response for angles of incidence above 65° becomes much less than under clear skies. This is main the reason why $S_{CM11,1\text{-}hour,o}$ was found to be smaller than $S_{CM11,1\text{-}hour,c}$.

The hourly random uncertainty for global radiation measurements under overcast skies ($S_{CM11,1\text{-}hour,o}$) is also assumed to be valid for diffuse irradiance measurements by the shaded pyranometer under both clear and overcast skies.

c) *Daily random uncertainty;* $S_{CM11,1\text{-}day}$

If the mean of each 15-point series in Figure 4.4 is approximated as an hourly value, the standard deviation is only marginally reduced from 0.59 % to 0.57 %. Precision errors from four different instruments, i.e. Å-171, NIP #20919, a shaded reference pyranometer and the CM10 #800080 reference pyranometer to be calibrated, contribute to the 0.59 % and 0.57 % standard deviation. In order not to underestimate the daily random uncertainty of the CM10 #800080, the contributions from the NIP and the shaded pyranometer to the total standard deviation of the points in Figure 4.4 are neglected. The 0.57 % total random uncertainty of the approximated hourly values of C_{CM11} in Figure 4.4, should then be the root-square sum of $S_{A171,6\text{-}min}$ (= 0.12 % from paragraph 4.1.1), $S_{CM11,1\text{-}day}$, $S_{CM11,1\text{-}hour,96}$, $S_{CM11,1\text{-}minute}/15^{1/2}$. With all other terms known, a daily random uncertainty of the CM10 #800080, due to different measuring conditions, now can be estimated to

$$S_{CM11,1\text{-}day} = \sqrt{0.57^2 - 0.12^2 - 0.37^2 - 0.32^2 / 15} = 0.41\,\%.$$

All the pyranometer measurements are corrected for the mean dark offset signal during nights. There could be both some systematic and random difference between the nighttime and daytime offsets as well as a (random) daytime offset variation due to rapid temperature changes, long-wave irradiance changes or rapid changes of the global radiation itself. These random effects are taken to be included in the daily random uncertainty. The bias uncertainty due to these effects was dealt with in the preceding paragraph.

The daily random uncertainty of global radiation measurements, due to varying measuring conditions, is assumed to be the same under overcast and clear sky conditions.

d) *Student's statistical parameter, t_{95}*

For the pyranometer uncertainty calculations made above, the number of degrees of freedom, derived with the aid of the Welch-Satterthwaite formula, is $\nu_p \approx 50$. Therefore, $t_{95} = 2.00$ is applied in the following total uncertainty estimations.

4.2.2.4 Total uncertainty of pyranometer measurements

a) *Clear sky*

The total uncertainty in a single 1-minute, 6-minute, hourly and daily mean value of global radiation, measured by a reference pyranometer *under calibration conditions* (i.e. pyranometer calibrated against secondary standard pyrheliometer, clear sky, high global radiation, solar elevation of 20° or higher, modest ambient air temperature and well-cleaned dome) are, with the aid of the expression

$$U_{CM11,time\text{-}interval} = \sqrt{B_{A171}^2 + B_{CM11,C\text{-}mean}^2 + B_{CM11,CG,offs,c}^2 + B_{CM11,c\text{-}o,c}^2 + B_{CM11,r\text{-}mean,c}^2} +$$

$$+ t_{95}\sqrt{S_{CM11,1\text{-}day}^2 + S_{CM11,1\text{-}hour,c}^2 / n_h + S_{CM11,1\text{-}minute,c}^2 / n_m}\,, \qquad (4.19)$$

estimated to $U_{CM11,1\text{-}minute,c}$ = 3.1 %, $U_{CM11,6\text{-}minute,c}$ = 3.0 %, $U_{CM11,1\text{-}hour,c}$ = 3.0 %, and $U_{CM11,1\text{-}day,c}$ = 2.0 %, respectively. Here n_h and n_m are the number of hours and minutes that are spanned by the considered time-interval. In the $U_{CM11,1\text{-}day}$ estimate, $n_h = 6$ was used. In Table 4.2, the above uncertainty estimates are summarised.

b) *Overcast*

Under an overcast sky the global radiation is strongly reduced. In absolute numbers the uncertainty is lower, but in relative numbers it could be either higher than or more or less the same as under clear skies.

The total uncertainty of 1-minute, 6-minute, hourly and daily means of E_g under *overcast* calibration conditions ($E_g > 70$ Wm^{-2}) are with the aid of the expression

$$U_{CM11,time\text{-}interval} = \sqrt{B_{A171}^2 + B_{CM11,C\text{-}mean}^2 + B_{CM11,CG,offs,o}^2 + B_{CM11,c\text{-}o,o}^2 + B_{CM11,r\text{-}mean,o}^2} +$$

$$+ t_{95}\sqrt{S_{CM11,1\text{-}day}^2 + S_{CM11,1\text{-}hour,o}^2 / n_h + S_{CM11,1\text{-}minute,o}^2 / n_m} \qquad (4.20)$$

estimated to $U_{CM11,1\text{-}minute,o}$ = 3.3 %, $U_{CM11,6\text{-}minute,o}$ = 3.1 %, $U_{CM11,1\text{-}hour,o}$ = 3.1 % and $U_{CM11,1\text{-}day,o}$ = 2.6 %, respectively.

As in the clear sky case, n_h and n_m are the number of hours and minutes that are covered by the considered time-interval. In the $U_{CM11,1\text{-}day}$ estimate, $n_h = 6$ was used. Note that in the end, the 1-minute, 6-minute and hourly total uncertainties for an unshaded pyranometer where found to be virtually the same under clear as under overcast skies. In table 4.2, the above uncertainty estimates are summarised.

c) Uncertainty of diffuse irradiance measurements

The total uncertainty in a single 1-minute, 6-minute, hourly and daily mean value of diffuse irradiance, measured by a shaded reference pyranometer *under clear sky calibration conditions* (i.e. pyranometer calibrated against secondary standard pyrheliometer, high global radiation, solar elevation of 20° or higher, modest ambient air temperature and well-cleaned dome) are, with the aid of the expression

$$U_{CM11,D,time\text{-}interval} = \sqrt{B_{A171}^2 + B_{CM11,C\text{-}mean}^2 + B_{CM11,CD,offs,c}^2 + B_{CM11,D,c}^2 + B_{CM11,r\text{-}mean,D}^2} +$$

$$+ t_{95}\sqrt{S_{CM11,1\text{-}day}^2 + S_{CM11,1\text{-}hour,o}^2 / n_h + S_{CM11,1\text{-}minute,o}^2 / n_m} \quad (4.21)$$

estimated to $U_{CM11,D,1\text{-}minute} = 5.3$ %, $U_{CM11,D,6\text{-}minute} = 5.1$ %, $U_{CM11,D,1\text{-}hour} = 5.1$ % and $U_{CM11,D,1\text{-}day} = 4.6$ %.

As in the two preceding cases, n_h and n_m are the number of hours and minutes that are covered by the considered time-interval. In the $U_{CM11,D,1\text{-}day}$ estimate, $n_h = 6$ was used. Clearly the clear sky diffuse irradiance uncertainties are higher than the global irradiance uncertainties under both clear and overcast skies. Mainly because of the lower zero offset uncertainty under overcast, the diffuse irradiance uncertainty is believed to be close to the global irradiance uncertainty under overcast.

d) Discussion of pyranometer uncertainty estimates

In the present study uncertainties have been expressed in relative units only. The soundness of this could certainly be discussed. Relative units were chosen beforehand, because they were considered to be easier measures to understand, directly giving a qualitative feeling for the proportions of the measurement errors, also to people not very familiar with radiation measurements.

For low irradiances, especially diffuse irradiance under clear skies, the relative unit is probably not the best choice. But, the uncertainties considered so far in this report are associated with relatively high values of direct, diffuse and global radiation and they are therefore assumed to be realistic.

According to the uncertainty analysis in this chapter, some conclusions now can be drawn regarding the uncertainty of reference pyranometer measurements during calibration conditions at SMHI:

- The total uncertainty of a global radiation value is more or less the same under clear skies ($h < 20°$) and overcast skies. It is slightly larger than 3 % for 1-minute to hourly mean values. If only measurements from times when $h > 35°$ are considered in the clear sky case, uncertainties are significantly smaller, about 2 %.

- The total uncertainty of clear sky diffuse irradiance measurements using a shaded Kipp & Zonen CM11 pyranometer is slightly larger than 5 %. This is significantly higher than the uncertainty of reference measurements of global radiation.

- The uncertainty of hourly mean values of E_g and E_d is not much smaller than the uncertainty of 1-minute values. However, the uncertainty of daily mean values is clearly reduced, by about 0.5 %, compared to the uncertainty of hourly values.

- For time intervals of a day (here approximately 6 hours) or shorter the total bias uncertainties amount to about 1/3, 1/2 and 2/3 of $U_{CM11,1\text{-}minute,c}$, $U_{CM11,1\text{-}minute,o}$ and $U_{CM11,D,1\text{-}minute}$, respectively.

The resulting pyranometer uncertainty estimates do only partly agree with the findings in Wardle et al. (1996). In their report simple models for the absolute uncertainty of pyranometer measurements where suggested. For a 10-minute mean value of E_g from a ventilated premium pyranometer, such as a Kipp & Zonen CM11 of SMHI, the total uncertainty could be approximated as

$$U = 30\sqrt{\frac{E_g}{1000}} \qquad (4.22)$$

where U is the total absolute uncertainty in Wm^{-2} at 95 % confidence level, and E_g is the measured global radiation value. According to Wardle et al. (1996) the uncertainty of 1-minute and hourly mean values then should be approximately 150 % and 75 % of the 10-minute values.

For an hourly value of 500 Wm^{-2} the relative total uncertainty becomes 3.2 %, according to Wardle et al., which is close to the $U_{CM11,1\text{-}hour,c}$ of 3.0 % derived in the present work. But for both higher and lower E_g values, and especially for mean E_g values of shorter averaging periods, the uncertainty estimates derived in this work are significantly smaller than those given by Wardle et al. From the otherwise very comprehensive and detailed report by Wardle et al., it is not fully understood how the authors arrived at the final total uncertainty estimates.

By performing uncertainty analysis as in this report, a lot of knowledge about pyranometer uncertainties is gained. However, there could still be some important sources of uncertainty that have been overlooked. This question especially arises if one consider the target accuracy for radiation measurements within the global Baseline Surface Radiation Network (BSRN), McArthur (1998), and Ohmura (1998). For example the BSRN target accuracy of diffuse irradiance measurements is 5 Wm^{-2}. For a clear sky diffuse irradiance of 80 – 90 Wm^{-2} and with the $U_{CM11,D,1\text{-}minute}$ = 5.3 %, this would mean that the BSRN target accuracy is reached by the diffuse reference pyranometer of SMHI. If this really is the case is however doubtful, considering the somewhat inaccurate tracking shade disk mount used and that no net thermal radiation offset correction is made. Further, from considerations in for example paragraph 4.2.2.2 d), the pseudo-composite method is not thought to be the optimal method for calibrating a shaded (reference) pyranometer. Any random zero offset uncertainty has not been taken into account exclusively. Especially under broken cloud conditions the varying zero offset should be a significant source of error.

Table 4.2. Bias, random and total uncertainties of the global reference pyranometer (Kipp & Zonen CM10 #800080) and the diffuse reference pyranometer (Kipp & Zonen CM11 #810132) under calibration conditions (i.e. clear sky —high direct irradiance, $h \geq 20°$, modest air temperature, well-cleaned dome; overcast—$G > 70$ Wm^{-2}; diffuse clear sky—$D < 70$ Wm^{-2}).

Type of uncertainty	Global Clear sky	 Overcast	Diffuse Clear sky
Bias			
Reference (Å-171)			
$B_{Å171}$	0.30 %	0.30 %	0.30 %
Bias in average C			
$B_{CM11,C\text{-}mean'}$	0.36 %	0.36 %	0.36 %
Zero offset			
$B_{CM11,CG,offs,c}$	0.7 %		
$B_{CM11,CG,offs,o}$		1.3 %	
$B_{CM11,CD,offs,c}$			3.4 %
Clear/overcast diff.			
$B_{CM11,c\text{-}o,c}$	0.25 %		
$B_{CM11,c\text{-}o,o}$		0.90 %	
$B_{CM11,D,c}$			1.25 %
Bias in average r_o			
$B_{CM11,r\text{-}mean,c}$	0.05 %		
$B_{CM11,r\text{-}mean,o}$		0.18 %	
$B_{CM11,r\text{-}mean,c}$			0.25 %
Random (1 S)			
Daily			
$S_{CM11,1\text{-}day}$	0.41 %	0.32 %	0.41 %
1-hour			
$S_{CM11,1\text{-}hour}$	0.96 %	0.56 %	0.56 %
1-minute (noise)			
$S_{CM11,1\text{-}minute,c}$	0.32 %		
$S_{CM11,1\text{-}minute,o}$		0.40 %	0.40 %
Total			
$U_{CM11,1\text{-}min}$	3.1 %	3.3 %	5.3 %
$U_{CM11,6\text{-}min}$	3.0 %	3.1 %	5.1 %
$U_{CM11,1\text{-}hour}$	3.0 %	3.1 %	5.1 %
$U_{CM11,1\text{-}day}$	2.0 %	2.6 %	4.6 %

4.3 Field measurements

No comparisons between reference radiometers and operating radiometers at any solar radiation station has been made in the field, with the exception of the well-maintained station in Norrköping. At these comparisons of 6-minute and hourly values under clear skies the disagreement between the field and reference instruments has always been less than 1.5 % for pyrheliometers and less than 2.5 % for pyranometers.

For the other eleven stations, the uncertainties of the measurements are probably considerably higher than at the Norrköping station. There are several reasons for this. What in this context is a relatively small source of uncertainty, valid for both the E_b and E_g measurements, is the fact that the measuring equipment is not the same as during calibration, since the radiometers are not calibrated on site. The increase of the bias uncertainty due to errors in the data acquisition system is thought to be less than 0.5 %.

In the following sections the measuring problems will be discussed separately for pyrheliometers and pyranometers.

4.3.1 Field pyrheliometers

In the current radiation network of SMHI, the field pyrheliometers have most of the time been calibrated directly against Å-171. However, because of short calibration periods, a few days, their mean calibration factors have not been determined as accurately as for the reference field pyrheliometer. It is estimated that the bias and total uncertainties for the field reference for 6-minute and hourly values in Table 4.1 should be increased by 0.3 % (bias) to be valid as the lowest possible inaccuracy for the field measurements of E_b (in cloudless conditions).

The calibration records of the Eppley NIPs show that the field pyrheliometers have been very stable so far. Normally a drift is seen as a decrease of sensitivity. The difference in calibrations before and after the NIPs have been operating at a station has always been less than 1 %. Most exceptions occur when pyrheliometers start to leak and then get their aperture window resealed. Before 1996 this only happened at one of the twelve stations approximately once every second year. From 1996 problems with leaking NIPs have become more frequent.

The rather simple trackers used in the network have shown to be reliable. Tracking problems have become somewhat more frequent during the last years due to ageing. However, in most cases either the trackers point fairly accurate (within 1°) towards the sun or they are pointing totally wrong. So, when a tracker stops working properly it can at least be discovered quickly, and hopefully soon be repaired. Therefore, under cloudless conditions the error in E_b due to misalignment of the pyrheliometer is normally very small, approximately less than (-)0.5 %. In case of thin and/or broken clouds in front of or close to the solar disk, these errors increase strongly.

The major source of error in the field measurements of E_b is improper maintenance. As soon as there is a gap in the maintenance various deposits, either dry dust or wet deposition of dirty rain or both, start to accumulate on the aperture window. However, if the rain is relatively clean it could also have a positive effect as it helps flushing off older contamination from the window.

At certain stations some periods have been detected when the instrument windows have not been cleaned at all. Such periods may have lasted for several weeks. It is often during the summer holiday period that the maintenance has been neglected. But, also at other times of the year there have been gaps in the maintenance at some stations.

The quality of the maintenance has changed from time to time and from station to station. The only station that with certainty has been well maintained throughout the years is the Norrköping station. At all the other stations the quality of the maintenance have probably varied considerably between very good and none at all from time to time. A thorough investigation has to be done to identify truly good and bad measuring periods in the data records. This has not yet been possible. This could possibly be done through a detailed turbidity analysis of the E_b measurements for example.

Even though most stations are located at places with mostly relatively clean air considerable amounts of pollution have accumulated on some NIP windows. This has been found when the instruments have been returned to the main station for calibration. In the worst case ever found the deposits on the window reduced the measured irradiance by 13 %! With this extreme value excluded, the observed reduction has been 0 - 6 %.

For E_b measurements, deposits on the pyrheliometer window always reduce the radiation measured. Based on recorded data of E_b, estimates of the atmospheric aerosol content, or turbidity, have been made. Such analyses are very sensitive to measurement errors. The resulting turbidity data from all stations during the whole measuring period, 1983-1998, do not indicate that there have been any station with large measuring errors during a longer period of time (a couple of months). Moreover, compared to the very well-attended Norrköping station the mean climatological turbidity values derived for the rest of the stations are well in line with the expected south-north gradient (Persson, 1999). However, the selection criteria for the accepted turbidity data may very well mask some of the effect of un-cleaned windows. However, at present it is assumed that error in E_b of as much as 6 % due to improper maintenance luckily are rare. But such large errors are still temporarily present in direct solar radiation data.

An overall estimate of the uncertainty of field pyrheliometer measurements is given in section 4.4.

4.3.2 Field pyranometers

The pyranometers in the solar radiation network have throughout the period mainly been calibrated by comparison to the reference 1 pyranometer (Kipp & Zonen CM10 #800080). In the calibrations, only measurements from times when the solar elevation has been higher than 20° have been taken into account. The limited duration of the calibration periods, 1 – 8 weeks, may give an additional small bias in a derived calibration factor. Therefore, the bias ($[\Sigma B_i^2]^{1/2}$) and total uncertainties given in Table 4.2 for the reference pyranometer have to be further increased by approximately 0.3 % to give an estimate of the lowest possible uncertainty of the field pyranometers. The total bias uncertainty of the E_g measurements then becomes equal to 1.2 % and 2.0 % for clear sky and overcast, respectively.

Instead of the pointing errors associated with direct irradiance measurements, errors in global radiation measurements are introduced because of the non-ideal directional response and small but significant levelling errors in the mounting of the pyranometers at a measuring site. For daily, monthly and yearly global radiation data, the directional errors not only result in random uncertainties as assumed in paragraph 4.2.2, but also in systematic uncertainties of the irradiation (or average irradiance) values. Examples of the effect of non-ideal directional (cosine + azimuth) response of a pyranometer, similar to the type used in the solar radiation network of SMHI, are shown in Figures 4.5-6.

As already mentioned, the directional errors are usually quite large, 1-15 % (for $E_g/[E_b \cdot \sin(h)+E_d]$, Figure 4.6), at low solar elevations. A global radiation value measured by an unshaded pyranometer could either be higher or a lower than what is measured by a pyrheliometer together with a shaded pyranometer. But, low solar elevation results in low global radiation and the contribution from such periods to a daily value fortunately becomes rather small. For totally clear days during the summer in Norrköping, the fraction of the daily total global radiation (global irradiation), associated with low solar elevation, is of course small.

For the range of h not considered in the uncertainty analysis of Chapter 4.2.2, i.e. solar elevations less than 10° and between 10° and 20°, the fractional contribution to a daily value of E_g is only about 2 % and 7 %, respectively. So, even if an average directional error of 5 % is assumed during these times, which is an overestimate between $10° \leq h \leq 20°$, the additional error in the daily global irradiation is only about 0.5 %. Of course, this number increases markedly in winter and, to a somewhat smaller extent, when convective clouds develop before noon and disappear (diminish) in the afternoon/evening on a summer day. For a clear day around midwinter in southern Sweden, the uncertainty of daily global irradiation due to the directional errors could probably be about 10 %. No attempt to correct for this effect has been made.

Sweden covers about 13° in latitude. Therefore the frequency of a certain solar elevation changes from north to south over the country. This in turn leads to different influences of the directional errors of pyranometers in northern and southern Sweden. In Figure 4.7 (a, b), distributions of the relative frequency of 5° solar elevation intervals during one year are plotted. As seen, the relative frequency of low solar elevations is much higher in Kiruna, the northernmost station in the radiation network, than in Lund, the southernmost station. Consequently, the contribution of global radiation measured when $h < 20°$ to the yearly sum of E_g is higher in the north. In Kiruna 25 % of the yearly sum of E_g in 1996 was measured under such conditions. In Lund, this number is only 17 %, Figure 4.7 (c, d).

Again, assume that the pyranometers in the solar radiation network have a constant cosine error of 5 % for all solar elevations < 20° (overestimate in the range 10 - 20°) and that the sky is clear 65 % (overestimate) of this time. Then the total error in the yearly sums of E_g, due only to these directional errors, should be less than 0.8 % in Kiruna and 0.6 % in Lund. Further, these errors should not vary much from year to year. Hence, the precision of yearly global irradiation values is only slightly reduced by the directional dependent response of the pyranometers.

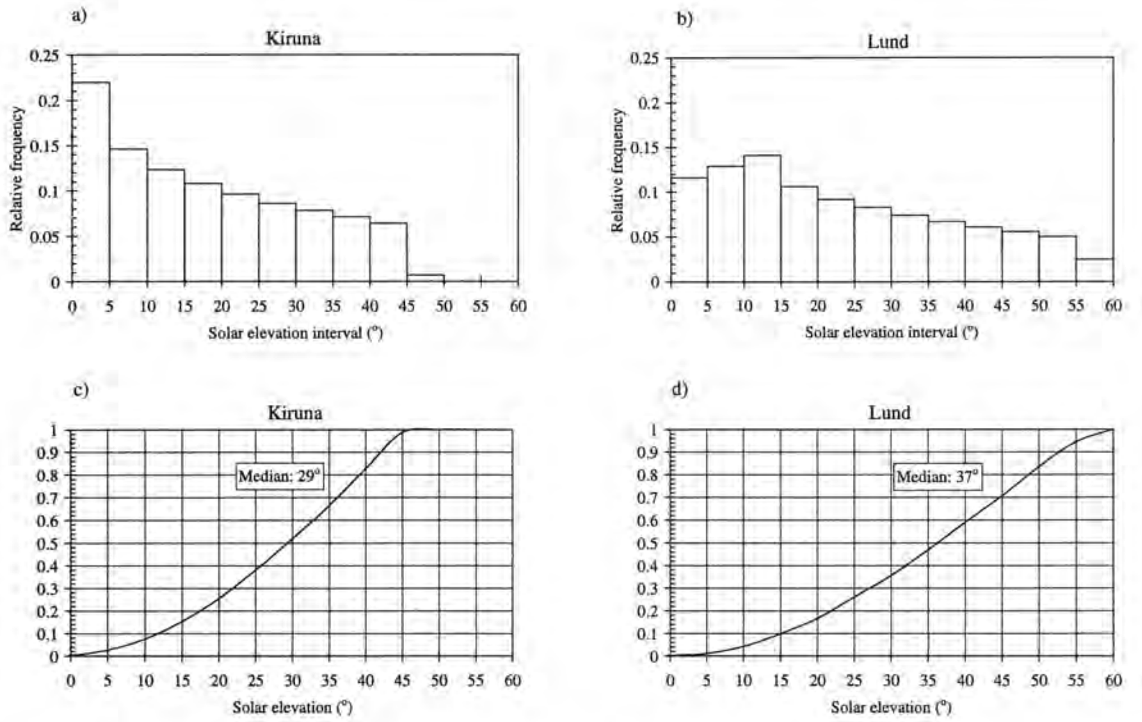

Figure 4.7. Upper: Relative frequency distribution of solar elevations (5 ° intervals) above the horizon during a year in a) Kiruna and b) Lund. Lower: Cumulative distribution of time integrated global radiation at solar elevations >0 ° 1996 in c) Kiruna and d) Lund.

Poor maintenance is a serious problem for all radiation measurements. The occasions and places where the pyranometers have not been properly attended are the same as for the pyrheliometer measurements. However, the effect of various deposits on the dome of a pyranometer is not as strong as the effect is on a pyrheliometer window. Neither does it always result in a radiation loss, even if that most often is the case.

Deposits on a pyranometer dome are thought to scatter the radiation mainly in the forward direction. Because the distance between the outer dome and the sensor surface is rather small, most of the scattered radiation of a dust like deposit hits the sensor surface anyway. Rime on the dome could even result in a strong increase of the measured E_g. Due to the ventilation and the slight heating of the air blown on the domes, development of rime on the domes of the SMHI pyranometers is very rare.

Unfortunately, there have been no tests of the effect of deposits on pyranometer domes performed at SMHI. A maintenance experiment has been made at KNMI in De Bilt, the Netherlands, reported by Kuik (1997). During a period of six months the maximum reduction of global radiation measured with an unattended and ventilated pyranometer was about 7 % for daily values, and 4 % for monthly values. Normally, the radiometers in the Swedish solar radiation network are cleaned at least once a week. However, gaps in the maintenance of 2 – 5 weeks have occurred every now and then at some stations, especially during summer. Therefore, it is concluded that additional errors due to improper maintenance of up to about 4 % may exist in the hourly and daily global radiation databases, and errors of 3 % in the monthly global radiation database. (Of course, even the 4 % could be to small if some bird has left its trademark on a pyranometer dome. Fortunately, this has happened only a couple of times.) But still, it is thought that the effect of deposits on the domes only rarely exceeds 2 %.

To ensure proper maintenance, i.e. cleaning of the windows and domes 3 times per week or more at all stations, and to perform calibration checks in the field would be the easiest and most effective way to reduce the uncertainties of the Swedish solar radiation measurements.

An overall estimate of the uncertainty of field pyranometer measurements is given in section 4.4.

4.3.3 Missing data

In the full hourly radiation database missing or erroneously measured values are replaced by calculated values. It is indicated in the database whether a radiation value is properly measured, calculated or, in a few cases, even manually estimated. The radiation model, which uses manually observed cloudiness from the nearest synop stations as input, is briefly described and validated in Davies et al. (1988).

The errors introduced in yearly and monthly data are thought to have increased during the last years. The reasons for this are both a slight increase of missing data and the reduction of manual (cloud) observation stations, which leads to longer distances between a malfunctioning radiation station and the closest cloud observing synop station. Due to erroneous cloudiness and general limitations in the model, single hourly values can be totally wrong. However, a validation of the model gave a mean bias error of only 2 % for hourly values of both E_g and E_b. Root mean square error of E_g and E_b was 29 % and 40 %, respectively. A restriction is that the cloud observations taken as input must have been performed at or very close to the radiation station. (Davies et al. 1988).

The average amount of missing data from the solar radiation network has been checked and is shown in Figure 2.1. The average amount of missing data for all stations during 1983-1998 was 3.7 % for E_g and 4.1 % for E_b. Assuming that for one particular station as much as 10 % of a yearly irradiation value is replaced by calculated values, the final contribution to the (systematic) error of the yearly value would on the average only be roughly 0.2 %, if the cloud observations were made on site.

Radiation stations and manually synop stations are co-located only at two sites, in Luleå and Östersund (1998). Not having the radiation stations co-located with synop stations, increases the errors caused by malfunctioning measurements or data transmission. The actual effect of missing data is basically unknown. Therefore it can only be roughly estimated. It is estimated that, replacement of missing data by calculated values is here estimated to only seldom have introduced errors of more than 1 % in a yearly irradiation value. The errors in individual monthly values for months with severe measuring problems can be several percent. But normally, the influence of missing data on monthly irradiation values is expected to be less or equal to 2 %.

4.4 Summary of uncertainties of the field measurements

When monthly or yearly irradiation values are considered, the random uncertainties originating from the varying measuring conditions more or less cancel out and become negligible. Instead it is the remaining systematic (bias) uncertainties that become crucial. These are listed and summed up in Table 4.3.

Table 4.3. Summary of uncertainties of monthly and yearly irradiation data.

Source of uncertainty	Monthly values			Yearly values	
	E_g		E_b	E_g	E_b
	Summer	Winter			
Improper maintenance	3 %	3 %	6 %	1 %	2 %
Directional errors	1 %	7 %	0.5 %	0.8 %	0.5 %
Response drift	1 %	1 %	1 %	1 %	1 %
Bias uncertainty of perfect field measurements	1.2 %	1.2 %	0.7 %	1.2 %	0.7 %
Missing data	2 %	2 %	2 %	1 %	1 %
Data acquisition error	0.5 %	0.5 %	0.5 %	0.5 %	0.5 %
Total uncertainty, $[\Sigma B_i^2]^{1/2}$	**4.1 %**	**8.0 %**	**6.5 %**	**2.3 %**	**2.6 %**
Total uncertainty for well maintained station	2.8 %	7.5 %	2.4 %	2.1 %	1.7 %
Total uncertainty without missing data	3.6 %	7.8 %	6.2 %	2.1 %	2.4 %
Total uncertainty for a good station (i.e. well maintained, a minimum of missing data)	1.9 %	7.2 %	1.4 %	1.8 %	1.4 %

To get an estimate of the effect of possible improper maintenance on yearly radiation values, it has been assumed that the maximum effect were valid every third month. During the rest of the year the instrument windows and domes were supposed to be well cleaned.

All individual bias uncertainties in Table 4.3, except the uncertainty due to improper maintenance, could be either positive or negative. However, a drift in calibration is mostly caused by a decrease in sensitivity, leading to too small measured values.

Since instrument calibrations are not performed during midwinter, a temperature dependence bias might also exist. This could be a significant effect during very cold periods. But since this wintertime bias is not known it has been omitted. Except for the total uncertainty of a cold winter month irradiation value it is thought that the exclusion of any temperature bias have not lead to dramatically underestimated uncertainties.

Obviously, recapitulate lower part of Table 4.3 if necessary, one would gain enormously in accuracy of the radiation measurements if proper maintenance could be guaranteed at the field stations. It would have the strongest impact on the accuracy of the direct solar radiation measurements, but also the quality of the important global radiation measurements would be significantly enhanced.

Likewise, but to a somewhat smaller extent, a reduction of the rather common instrument and data transmission failures would increase the quality of the resulting radiation data collected by SMHI.

In general, the total uncertainty of a single 6-minute or hourly mean value of direct solar radiation from a field station can not be guaranteed to be better than about 8 %. However, a total uncertainty of 3 % or better is assumed to be valid most times when clouds are not closer than 7° from the solar disk. For properly working field measurements of E_b (well-cleaned window, well aligned, response drift after latest calibration ≤ 0.3 %, cloud-free 7° around the solar disk, $E_b \geq 600$ Wm^{-2}) the total uncertainty of both 6-minute and hourly values is estimated to 1.5 % at the 95 % confidence level.

The total uncertainty of a single 6-minute or hourly mean value of global radiation measured at a field station when $h > 20°$ can not be guaranteed to be better than 6 %. However, the uncertainty is normally assumed to be about 4 % for the field measurements. For properly working field measurements of E_g (well-cleaned dome, response drift after latest calibration ≤ 0.3 %, $h > 20°$, $E_g > 200$ Wm^{-2}) the total uncertainty of both 6-minute and hourly values is estimated to 3.5 % at the 95 % confidence level. If the sky is clear and $h \geq 35°$ as well, the uncertainty decreases to about 2.5 %.

Beside the total uncertainty the precision of the measurements is an important characteristic, especially for time series analyses and trend studies. The precision is equal to the total *random* measurement uncertainty. Hence, in reality the precision is always better than the total uncertainty, since there is always some bias uncertainty present.

The precision of the field measurements of global and direct radiation is not exactly known. For a single monthly or yearly irradiation value, the uncertainties in Table 4.3 are all considered as systematic. But, when considering many years of data, major parts of the uncertainties instead turn into random uncertainties. By reducing the range of some of the individual uncertainty terms for yearly values of G and I in the upper half of Table 4.3, it is estimated that the precision of annual G and I are both about 2 %, or slightly better.

Proper maintenance would be the single most effective way to reduce the uncertainty of the radiation measurements performed by SMHI. Though this is very well known problem, improper maintenance during certain periods or at certain stations is a problem that most solar radiation networks all over the world suffer from.

5 Results

From the start of the current radiation network in 1983 and onwards an extensive solar radiation database has been built up at SMHI. As large efforts have been put into regular calibration and instrument maintenance the database may be considered to have a much higher quality than older solar radiation data. The central part of this homogeneous database consists of hourly, daily, monthly and yearly values of global, direct and diffuse radiation and sunshine duration at 12 sites for the period 1983-1998. Also 6-minute mean values of E_g, E_b and SD have been collected throughout the whole period. These latter data have not been quality controlled or refined in any way, but consists of raw data that are stored on tapes.

Since such a large amount of data has been collected from the solar radiation, selected results from the Swedish solar radiation measuring program will be presented graphically in this section, with only short comments. In the Appendix, full tables of monthly and yearly global, direct and diffuse irradiation and sunshine duration are given.

To give an idea of how the radiation conditions varies over a day at the darkest and brightest times of the year, some 1-minute data from the main station in Norrköping have been plotted in Figure 5.1. In this graph, solar irradiances, E_b, E_d and E_g, together with the longwave downward irradiance from four different days are shown.

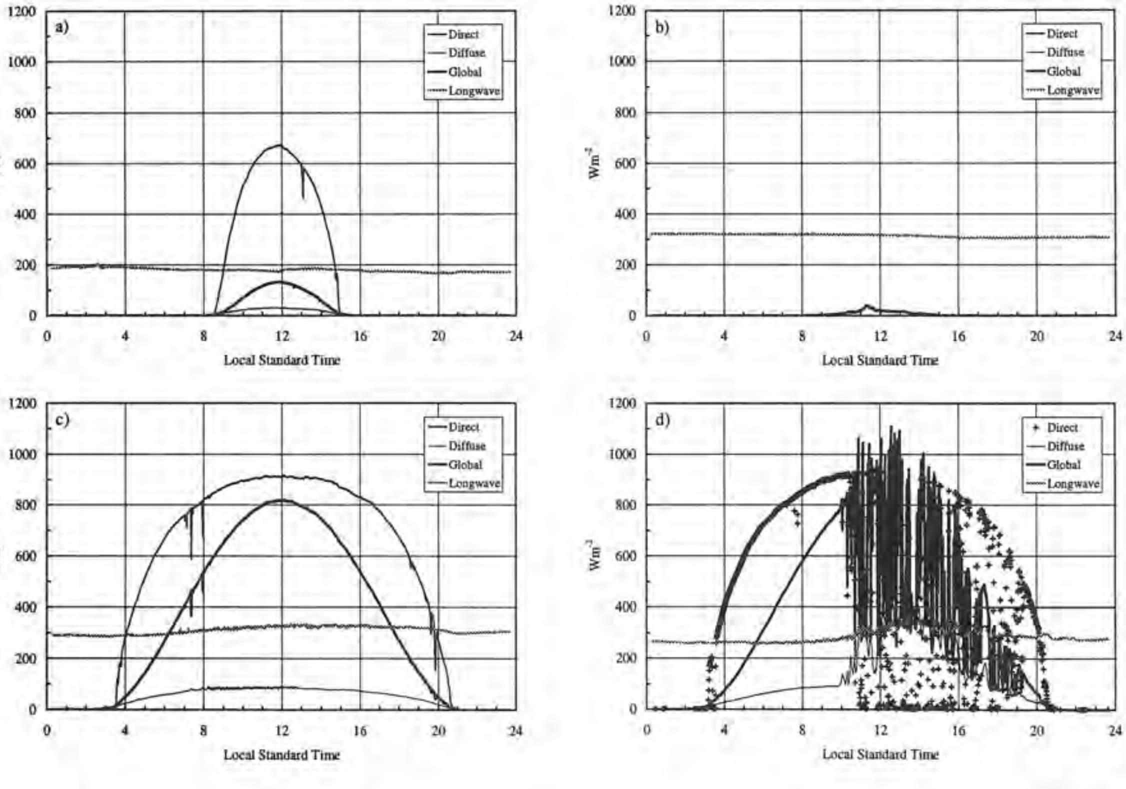

Figure 5.1. Examples of solar and atmospheric longwave irradiances reaching the Earth's surface. The measurements of 1-minut mean values were taken in Norrköping, 58.58 °N, 16.15 °E. a) A cloudless winter day (1996-12-19). b) A cloudy winter day (1996-12-11). c) A cloudless summer day (1995-07-12). d) A summer day with broken (convective) clouds (1996-06-14). During the days in a), c) and d) the atmospheric turbidity was close to the local climatological average.

The figure clearly shows the seasonal dependence as well as the dependence on cloudiness experienced in Sweden. In almost all cases clouds strongly reduce global and direct radiation, while they enhance diffuse and, in especial, longwave radiation. However, a broken cloud layer can, during short time intervals, also strongly enhance both E_d and E_g, as seen in Figure 5.1 d). At such occasions the clouds, lying close to the sun without shading it, act as reflectors of the solar radiation. Not plotted in the figure are measurements from a totally overcast summer day (which actually do occur every now and then in Sweden). Even during summer with a really dense cloud layer over the measuring site the global irradiance can be less than 50 Wm^{-2} at noon.

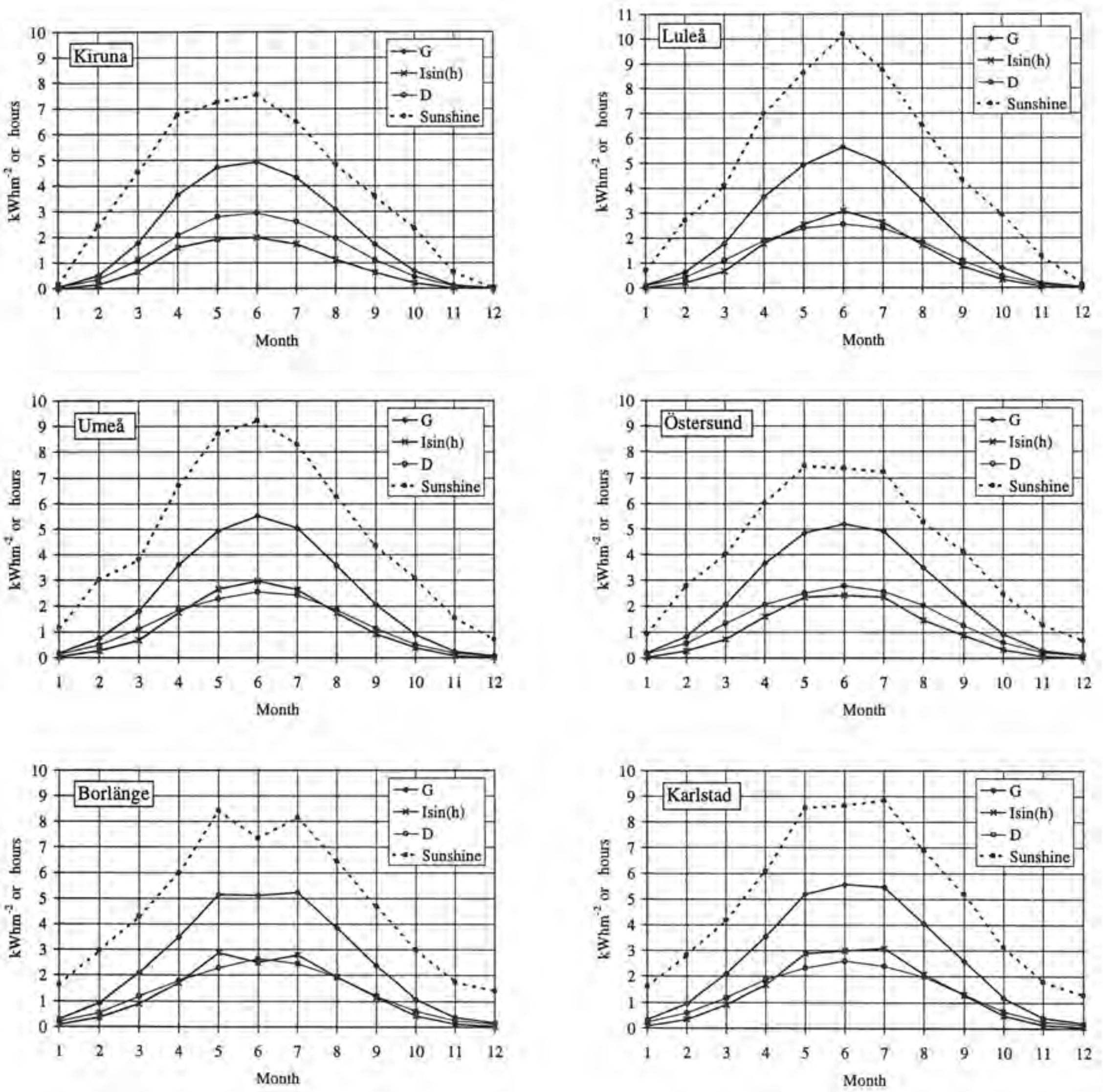

Figure 5.2. Mean daily sums 1983-1998 of global irradiation, direct horizontal irradiation ($I\cdot\sin(h)$), diffuse irradiation (kWhm^{-2} per day) and duration of sunshine (hours per day) at the six northernmost Swedish solar radiation stations.(For Borlänge the averaging period is only 1987-1998.) Here the letter I instead of E_b is used for direct radiation.

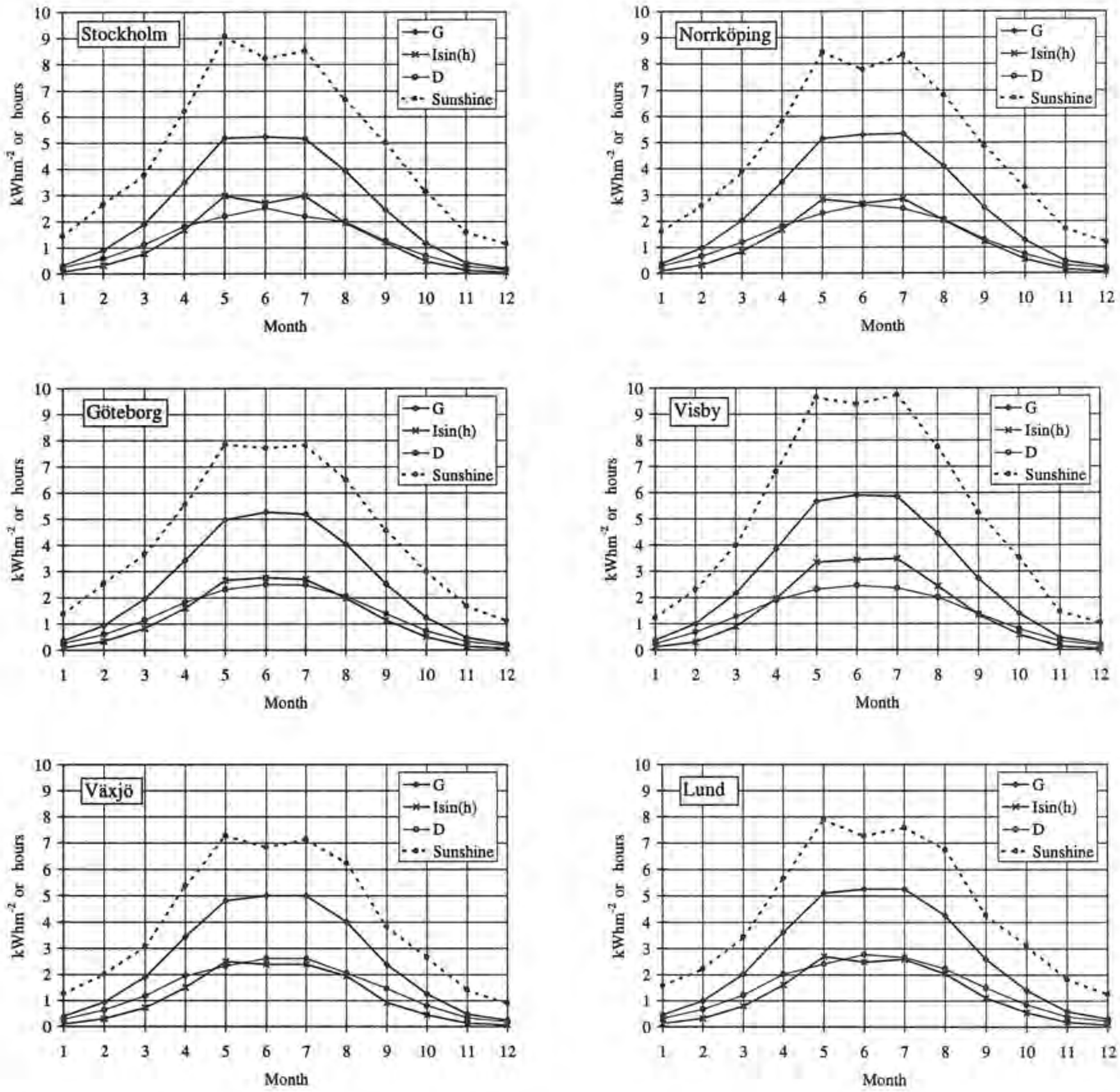

Figure 5.3. Mean daily sums 1983-1998 of global irradiation, direct horizontal irradiation ($I \cdot \sin(h)$), diffuse irradiation (kWhm^{-2} per day) and duration of sunshine (hours per day) at the six southernmost Swedish solar radiation stations. Here the letter I instead of E_b is used for direct radiation.

The large seasonal variation of solar radiation in Sweden is clearly demonstrated in Figures 5.2-3. For each month average daily sums of E_g, $E_b\sin(h)$ (i.e. direct *horizontal* radiation), E_d (i.e. H_g, $H_{b,h}$ and H_d) and *SD* are plotted for the period 1983-1998. Here, the direct horizontal irradiation instead of direct normal irradiation has been plotted to make the comparison between the direct and diffuse solar radiation components of the global radiation easier. During most of the year, the diffuse irradiation somewhat exceeds the direct irradiation over a horizontal surface. However, in May, June and July the direct component of the global radiation is the larger one at most stations, except in Kiruna, Östersund, Växjö and Lund.

The highest mean daily duration of sunshine, during the period of consideration, was about 10.2 hours for June in Luleå. Accordingly, at the three northernmost stations, the sunshine duration peaks in June. But at all the other stations June has been rather cloudy, relative to May and/or July. This is also seen in the direct radiation.

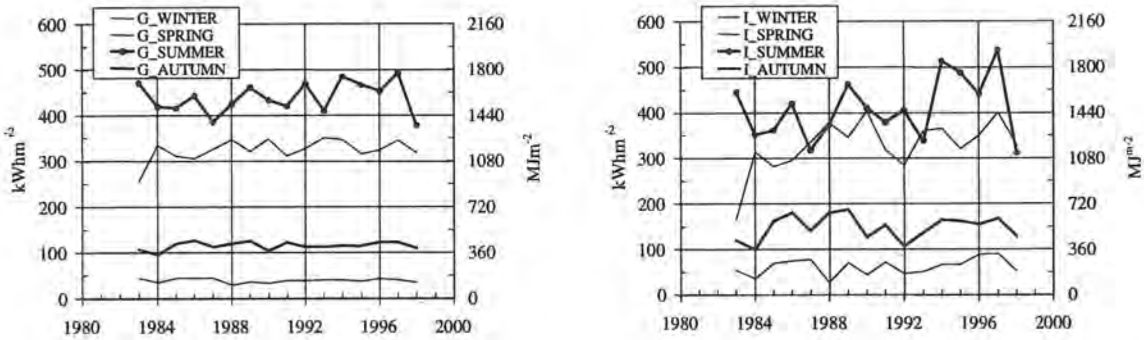

Figure 5.4. Mean seasonal sums of global radiation (left) and direct normal radiation (right) at the Swedish solar radiation stations 1983-1998.

In Figure 5.4, the monthly values have been averaged over all stations and summed up for the seasons and plotted versus time. Here, winter spans the period December-February, spring March-May, summer June-August and autumn September-November. Following this seasonal division, almost half of the yearly global irradiation is received during summer in Sweden. A large portion is also received in spring, but the global irradiation is always higher in summer than in spring. The seasonal variation of direct irradiation is also very large, but for individual years the value received during a relative cloudless spring can be higher than those received during a cloudy summer. Since the direct radiation is more sensitive to cloudiness, the year to year variation is larger than the variation in global radiation.

The current division of the seasons in Figure 5.4, which is not symmetrically divided around the summer solstice, leads to a large difference in solar radiation between spring and autumn. For the same reason, when taking a closer look at the daily mean values in Figure 5.2-3, one sees that both E_g and E_b are often higher in August and September than in April and March at most stations. However, at the northern stations in Kiruna, Luleå and Östersund the conditions are reversed. There, the radiation is higher in spring. Since this is seen in the direct as well as in the global radiation, a clearer sky and drier atmosphere are the major parts of the explanation to this. But, also the higher albedo of the snow-covered ground around the stations should contribute to the higher global radiation in springtime.

Finally, results of yearly time integrated radiation parameters will be presented. As already shown, there is a large difference in incoming solar irradiance between different parts of Sweden. On the average, the highest mean yearly global irradiation during the period 1983-1998, 1041 $kWhm^{-2}$ (3746 MJm^{-2}), was measured in Visby, located on the coast on the island of Gotland in the Baltic Sea. The lowest mean yearly global irradiation is found in Kiruna, which is an inland site and the northernmost station. It amounted to 779 $kWhm^{-2}$ (2808 MJm^{-2}), 25 % less than in Visby (Figure 5.5). On the whole, with a few exceptions, there is a clear dependence on latitude in global radiation. This demonstrates the high importance of solar elevation to global radiation.

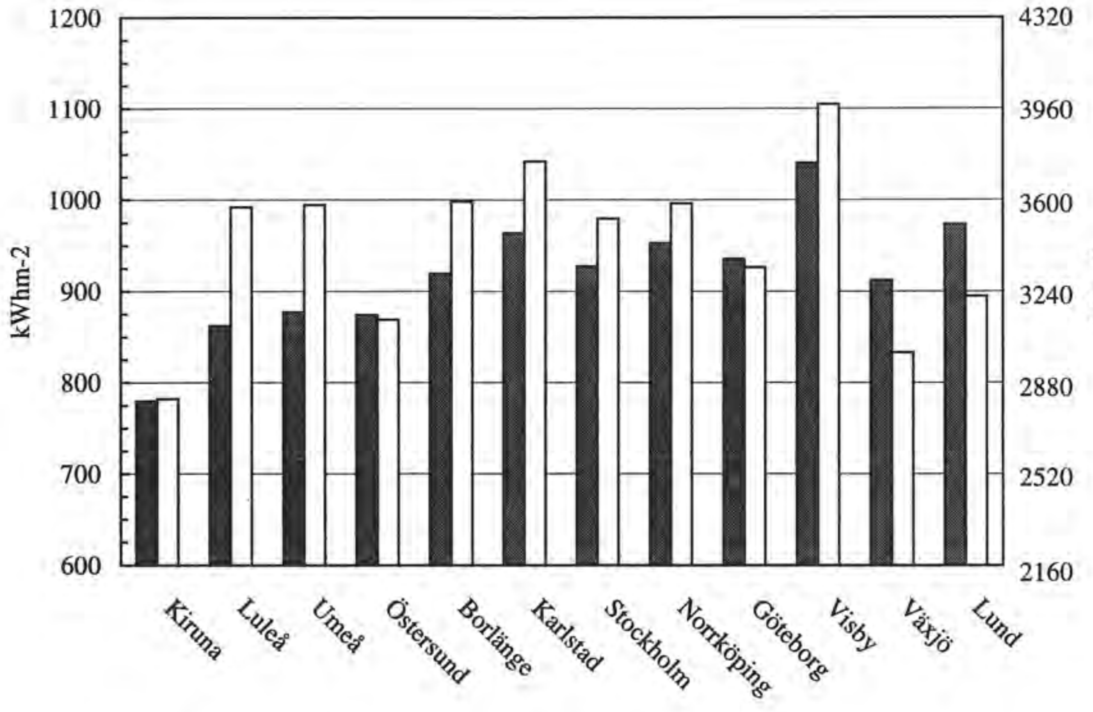

Figure 5.5. Mean yearly global irradiation, H_g, (grey) and direct irradiation, H_b, (white) 1983-1998 at the Swedish solar radiation stations, from north (Kiruna) to south (Lund).

Another major factor influencing the solar radiation climate is the prevailing cloud conditions. The average cloud conditions, and therefore the location of a station in relation to its distance from sea or big lakes, are of great importance. Differing cloudiness in Kiruna and Visby is also a large contributor to the difference in solar radiation between the two sites. The effect of different cloud conditions on E_g is very clear when comparing the station in Växjö, an inland site in southern Sweden, and the coastal station in Visby. Even though only 0.72° in latitude separates the stations (Visby being the northernmost of the two stations), the mean difference in yearly total global radiation is 12 %.

The largest difference in mean yearly total direct irradiation is also between the stations in Kiruna (2857 MJm^{-2}) and Visby (4001 MJm^{-2}). The analysis of the E_b measurements, though, shows a much weaker dependence on latitude than is the case for E_g. The distribution of sunshine duration at the stations is very similar to the distribution of direct radiation, Figure 5.4. Naturally, this is not very astonishing since the time of bright sunshine duration is derived from the E_b measurements. The mean sunshine duration during 1983–1998 in Kiruna was 1418 hours and in Visby 1894 hours (Figure 5.6).

At all sites there is a large year to year variation. The yearly range of variation of the global irradiation at each station is about 150 $kWhm^{-2}$, or approximately 15 %.

In the time series of yearly H_g, there exist clear increasing trends at all stations during the period 1983-1997. The trends are all dramatically diminished when the year 1998 is taken into account. For the first fifteen years the strongest linear trend of +9.3 %/decade was found for Göteborg and the weakest, +4.6 %/decade, for Karlstad. The average linear trend in global

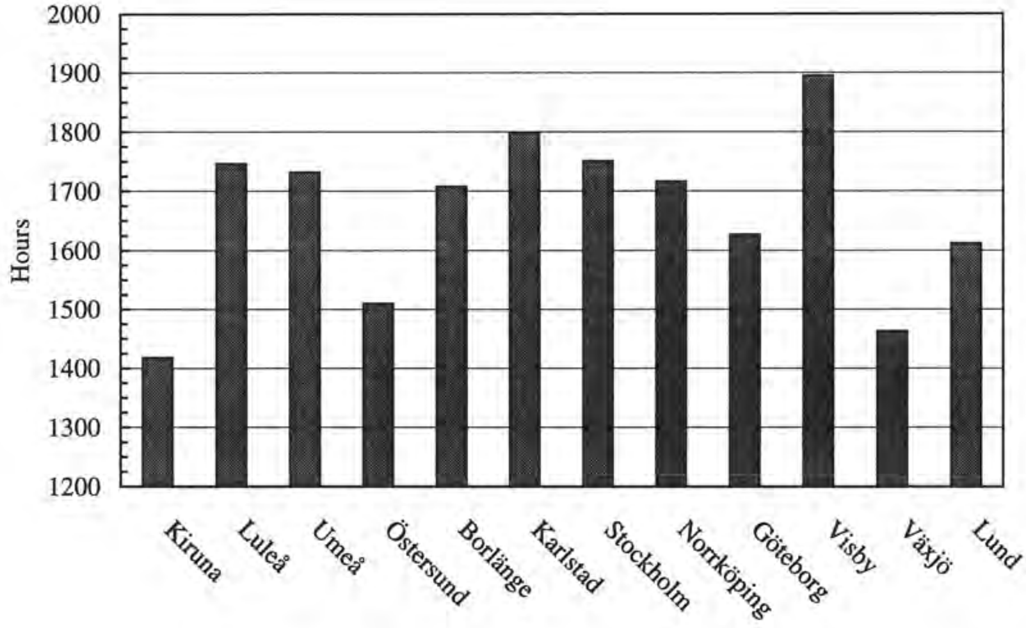

Figure 5.6. Mean yearly sums of sunshine duration 1983-1998 at the Swedish solar radiation stations, from north (Kiruna) to south (Lund).

radiation for all stations during the period 1983-1997 is +7.2 %/decade, Figure 5.7. By using a Student's t-test it is confirmed that the existence of a positive (linear) trend in E_g during 1983-1997 is statistically significant even at the 99 % confidence level. But, taking also the year 1998 into account the trend is only 4.0 %/decade. At 95 % confidence level, this trend is not significantly different from zero. The positive trend found for global radiation is even more pronounced in the direct solar radiation. The linear trend in mean yearly H_b for all stations during 1983-1997 amounts to +19 %/decade (Figure 5.8). The trend for this period is statistically significant at the 99 % confidence level. If the year 1998 is included the trend is reduced to +13 %/decade, which is not significantly different from zero at the 95 % confidence level.

The trend in solar radiation is mainly explained by a decrease in cloudiness, especially during the summer half year, for the same period. In Figure 5.9, time series of yearly mean total cloud cover at 12 cloud observing stations evenly distributed all over Sweden are shown. The correlation between yearly global irradiation and mean total cloud cover during the summer half year (April – September) is as high as 0.92 for the years 1983-1998. The correlation between yearly global irradiation and yearly mean total cloud cover is somewhat lower, namely 0.83. The approximated linear trend in mean total cloud cover for the summer half year is - 7.4 %/decade. Indeed, the relative decrease in summer cloudiness is very close to the relative increase in yearly global irradiation during the years 1983 – 1997.

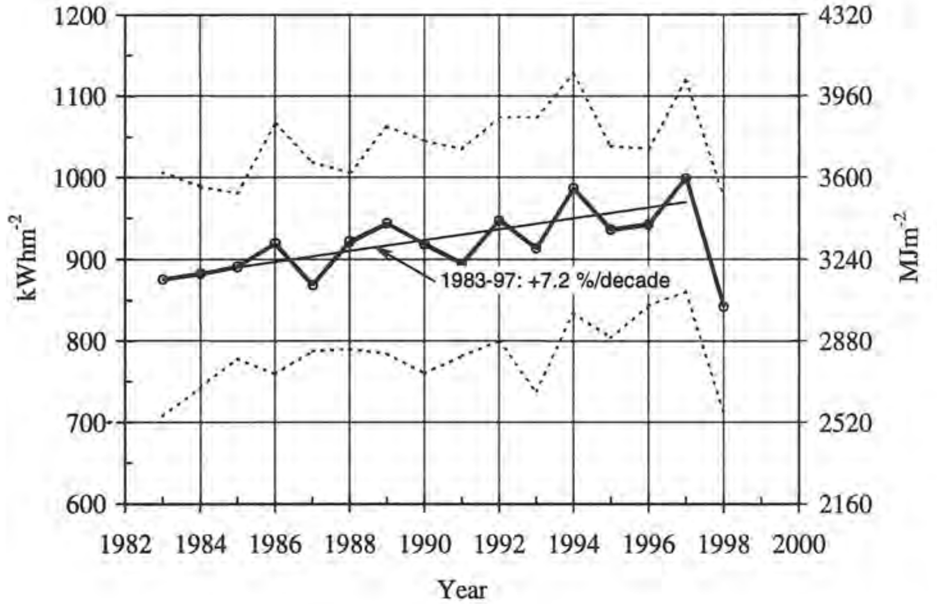

Figure 5.7. Mean yearly sums of global radiation at the Swedish solar radiation stations 1983-1998 (thick line). The thin line represents the linear trend in G (+7.2 %/decade) for the period 1983-1997. Also indicated are the maximum and minimum yearly sums of global radiation at any station in the network (dashed lines).

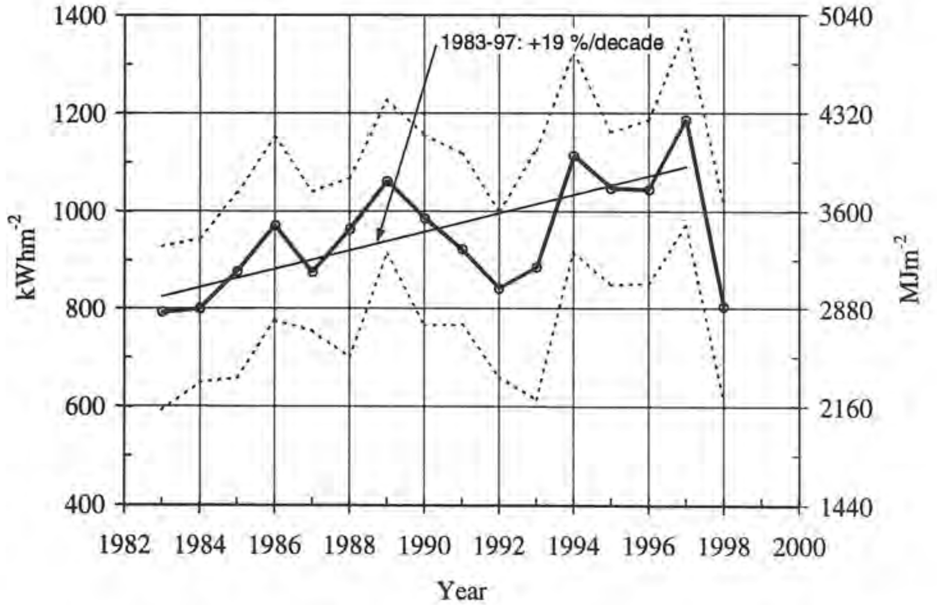

Figure 5.8. Mean yearly sums of direct solar radiation at the Swedish solar radiation stations 1983-1998 (thick line). The thin line represents the linear trend in I (+19 %/decade) for the period 1983-1997. Also indicated are the maximum and minimum yearly sums of I at any station in the network (dashed lines).

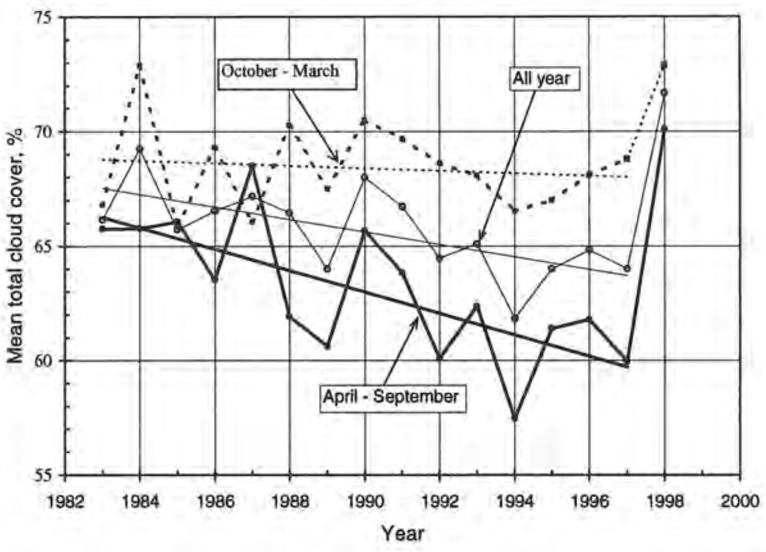

Figure 5.9. Time series 1983-1998 and linear trends 1983-1997 of yearly mean total cloud cover (thin), mean total cloud cover during April-September (thick) and during October-March (dashed).

Also the amount of aerosols in the atmosphere influence the trends, at least in the direct solar radiation (the direct effect). During the first 2-3 years, E_b was markedly decreased by the high turbidity resulting from the volcanic eruption of El Chichon in April 1982. Also the major eruption of Mt. Pinatubo in June 1991 largely effected the direct solar radiation over Sweden in 1992 - 93, and also, to some extent, in 1994.

Trends in solar radiation have been reported on before. Studies of global radiation in Europe, e.g. Ohmura (1988), Russak (1990), and Abakumova et al. (1996), have shown decreasing trends from the late 1950s to the late 1970s. Thereafter a slight recovery has been reported, which as far as the Swedish radiation stations are concerned, more or less has lasted throughout the period from 1983 to 1997.

6 Conclusions

From the start of the current solar radiation network of SMHI in 1983 and onwards, a quality controlled database consisting of yearly, monthly, daily and hourly values of direct and global radiation together with the diffuse sky radiation and sunshine duration, *SD* has been built up. In most cases, observed air temperature (2-m), relative humidity, wind direction and wind speed are available in the hourly radiation database, as well. Also 6-minute mean values of E_b and E_g have been collected throughout the period. So far, these data are only stored on tapes. To extract the 6-minute data and build up an easily accessed 6-minute radiation database are important tasks in the (near) future. These are very valuable data, especially useful for aerosol, cloud forcing and satellite remote sensing studies.

The solar radiation climate in Sweden varies a lot, both in time and space. The dominating factors influencing the solar radiation climate are the latitudinal location and the prevailing cloud conditions. Both these factors are the main reasons for the largest difference in yearly irradiation between two stations. On the average, the highest mean yearly global irradiation, H_g, and direct irradiation, H_b, during the period 1983-1998, 1041 kWhm^{-2} (3746 MJm^{-2}) and

1111 $kWhm^{-2}$ (4001 MJm^{-2}) respectively, was measured in Visby, located on the coast on the island of Gotland in the Baltic Sea. The lowest mean yearly H_g and H_b is found at the inland site and the northernmost station Kiruna. There, H_g amounted to 779 $kWhm^{-2}$ (2808 MJm^{-2}) and H_b to 794 $kWhm^{-2}$ (2857 MJm^{-2}), which is 25 % and 29 % less than in Visby, respectively. Even lower values could be expected in the mountains at the Norwegian border.

The effect on global radiation of different cloud conditions is very clear when comparing the station in Växjö, an inland site in southern Sweden, and the station in Visby. Even though only 0.72° in latitude separates the stations (Visby being the northernmost of the two stations), the yearly global irradiation is on average 12 % less in Växjö. In this case even lower values could be expected on the western side of "Sydsvenska höglandet".

At all stations there is a large year to year variation of incoming solar radiation. The difference between the highest and lowest yearly global irradiation at each station is 15 %, or more.

Looking at the fifteen year period 1983-1997, there are statistically significant increasing trends in the time series of mean yearly H_g (+ 7.2 %/decade) and H_b (+ 19 %/decade). These are both largely reduced and not statistically significant when also the last year, 1998, is taken into account. The variation in radiation is mainly explained by a corresponding variation in cloudiness during the same period.

Under favourable measuring conditions (clear skies, $h > 20°$, well-cleaned instruments) the uncertainty of the Swedish solar radiation measurements is low, for 6-minute and hourly mean values about 1.5 % for E_b and 3.5 % for E_g. However, uncertainty analysis has shown that the inaccuracy of any single value in the hourly or monthly database is much higher than these numbers. Generally valid uncertainty, at the 95 % confidence level, of 6-minute and hourly values is estimated to 3 % for direct irradiance and to 4 % for global irradiance. The total uncertainty of yearly values of H_g and H_b has been estimated to 2.3 % and 2.6 %, respectively. Major parts of these uncertainties are considered to be random, if many years of data are considered. Hence, the precision is not much better than the total uncertainty. The precision of the annual values is estimated to about 2.0 % for both global and direct radiation.

To guarantee proper maintenance at the field stations, i.e. cleaning of the windows and domes 3 times per week or more, and to reduce the amount of erroneous or lost data would have a dramatic and positive impact on the accuracy of the measurements and on the quality of the resulting Swedish solar radiation databases.

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APPENDIX

TABLES OF MONTHLY AND YEARLY GLOBAL IRRADIATION, DIRECT (NORMAL INCIDENCE) SOLAR IRRADIATION, DIFFUSE IRRADIATION AND DURATION OF BRIGHT SUNSHINE.

KIRUNA
(67.83° N, 20.43° E)

DIRECT IRRADIATION, H_b (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	0.0	21.0	70.6	43.6	75.0	114.9	111.0	78.6	44.2	25.2	8.7	0.0	592.8
1984	0.9	19.8	65.3	88.4	142.2	127.4	55.3	73.5	59.5	15.6	8.1	0.0	656.0
1985	3.2	50.5	61.6	146.1	127.7	107.9	146.1	91.1	49.0	45.3	5.7	0.0	834.2
1986	1.3	30.6	55.2	119.6	60.5	203.9	144.2	67.1	49.6	33.6	9.9	0.0	775.5
1987	3.4	39.4	78.6	131.3	140.2	66.1	165.0	81.3	35.2	39.5	12.1	0.0	792.0
1988	2.2	14.9	49.6	180.4	152.9	72.8	83.5	47.1	49.3	42.3	5.2	0.0	700.1
1989	0.4	31.0	71.1	117.6	125.0	188.2	137.2	100.4	93.1	45.9	3.8	0.0	913.7
1990	1.8	19.3	83.2	163.2	107.1	158.7	78.0	56.8	58.7	30.5	8.4	0.0	765.7
1991	1.2	56.1	87.1	169.6	129.2	101.0	93.3	99.9	88.4	25.0	2.6	0.0	853.6
1992	1.0	12.4	52.4	48.7	162.2	195.1	79.5	46.3	28.0	33.6	1.5	0.0	660.7
1993	0.8	21.4	68.3	101.9	105.9	74.9	104.3	46.1	55.3	32.5	2.9	0.1	614.2
1994	2.1	29.7	61.8	102.1	149.4	100.6	192.2	122.3	89.3	68.7	10.1	0.0	928.3
1995	0.1	17.9	67.0	158.5	140.4	121.3	121.6	108.8	103.9	51.0	7.0	0.0	897.5
1996	3.4	40.5	109.9	95.1	229.5	116.3	88.3	159.8	72.0	27.6	8.4	0.0	950.8
1997	4.2	36.9	93.6	158.6	120.4	185.4	154.8	140.8	43.2	23.7	9.1	0.0	970.6
1998	2.91	18.8	100.09	116.25	-99	-99	-99	-99	-99	-99	-99	-99	612*)

*) *Calculated value.*

GLOBAL IRRADIATION, H_g (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	1.0	14.0	53.8	81.8	110.9	147.8	134.5	100.6	38.6	20.3	4.5	0.3	708.1
1984	1.6	14.8	58.5	102.6	151.8	151.3	101.3	92.4	49.9	14.8	3.9	0.4	743.2
1985	1.9	17.3	52.6	125.0	143.8	137.8	135.9	92.4	45.7	21.8	3.5	0.4	778.0
1986	1.4	15.2	49.3	106.4	105.1	175.9	140.5	86.5	51.6	22.8	3.9	0.4	758.9
1987	1.9	15.4	54.8	115.9	160.9	118.7	162.0	89.7	43.8	19.9	3.9	0.2	787.1
1988	1.5	12.3	50.5	130.7	162.6	163.8	123.4	73.1	47.9	20.0	3.3	0.3	789.4
1989	1.2	13.0	50.7	91.5	138.9	160.6	136.8	102.2	62.8	22.9	2.9	0.3	783.9
1990	1.5	11.2	56.1	117.1	136.5	151.7	120.3	90.5	52.9	18.1	3.4	0.4	759.6
1991	1.6	16.5	54.3	123.3	144.5	130.6	124.8	101.5	60.8	19.1	3.4	0.4	780.9
1992	1.6	13.1	54.7	95.2	169.8	188.5	129.3	79.3	38.9	25.8	3.2	0.3	799.7
1993	1.7	14.6	56.0	112.6	134.2	127.7	128.5	79.2	58.3	21.0	3.2	0.4	737.3
1994	1.8	14.4	53.7	104.7	155.7	131.5	164.3	116.6	59.1	27.8	4.1	0.3	834.2
1995	1.3	11.3	51.6	120.2	148.4	127.5	143.8	108.3	62.3	24.2	3.9	0.5	803.2
1996	2.1	15.6	62.0	100.9	189.0	143.2	132.1	119.5	56.4	18.4	3.6	0.3	843.2
1997	1.9	14.7	58.5	121.3	154.2	176.0	147.1	118.3	46.9	17.6	3.5	0.4	860.3
1998	1.5	12.1	57.6	105.1	137.0	130.4	120.7	74.7	50.8	18.5	3.9	0.4	712.5

KIRUNA
(67.83° N, 20.43° E)

DIFFUSE IRRADIATION, H_d (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	1.0	10.9	35.9	63.6	74.5	91.9	81.2	67.1	25.0	15.2	3.6	0.3	470.3
1984	1.5	11.8	41.2	67.1	84.1	87.9	76.8	62.2	31.1	12.1	3.3	0.4	479.5
1985	1.7	10.0	35.7	66.7	84.1	86.0	69.6	54.7	30.7	13.5	3.2	0.4	456.2
1986	1.4	10.8	34.5	59.0	77.5	77.6	73.0	59.8	36.5	16.1	3.1	0.4	449.6
1987	1.8	9.1	34.9	65.8	95.3	88.4	87.1	56.4	32.1	11.9	2.8	0.2	485.8
1988	1.4	9.8	37.2	60.3	91.4	130.5	85.5	54.8	32.1	12.4	2.9	0.3	518.6
1989	1.2	9.0	31.7	47.5	81.7	75.7	76.2	59.7	33.6	14.6	2.6	0.3	433.9
1990	1.4	8.6	34.1	53.5	89.4	74.7	81.6	65.5	33.0	12.6	2.8	0.4	457.4
1991	1.5	9.1	29.7	57.0	86.2	84.5	81.7	58.5	33.4	14.6	3.2	0.4	459.8
1992	1.6	11.4	39.4	75.0	90.6	89.8	89.0	59.9	29.7	19.2	3.1	0.3	509.0
1993	1.7	11.3	36.1	71.8	83.8	90.4	77.3	60.3	40.1	15.5	3.0	0.4	491.6
1994	1.7	10.4	36.2	63.1	83.6	83.2	70.2	62.1	31.1	13.5	3.3	0.3	458.7
1995	1.3	9.1	33.8	59.3	85.6	71.0	87.2	63.6	30.8	13.5	3.4	0.5	459.0
1996	2.0	10.3	32.4	64.0	84.8	87.5	87.4	52.0	34.4	13.2	2.9	0.3	471.3
1997	1.6	9.7	33.0	58.2	95.9	85.9	72.3	60.6	33.3	13.5	2.7	0.4	467.0
1998	1.3	9.5	32.0	60.5	-99	-99	-99	-99	-99	-99	-99	-99	473*)

*) *Calculated value*

SUNSHINE DURATION, *SD* (Hours).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	0.0	62.0	140.0	88.0	153.0	209.0	211.0	161.0	80.0	56.0	30.0	0.0	1190.0
1984	0.0	50.0	155.0	188.0	262.0	230.0	100.0	139.0	108.0	35.0	21.0	0.0	1288.0
1985	10.0	116.0	123.0	243.0	221.0	189.0	244.0	152.0	86.0	92.0	15.0	0.0	1491.0
1986	2.6	68.9	106.1	193.8	111.7	332.5	242.7	115.8	90.3	65.9	25.0	0.0	1355.3
1987	11.1	86.8	159.4	227.0	234.2	123.0	282.5	138.9	57.3	82.5	29.1	0.0	1431.8
1988	7.4	41.1	113.0	285.9	274.5	242.3	181.3	80.3	90.6	84.1	13.7	0.0	1414.3
1989	1.2	67.1	126.0	185.4	214.5	311.6	228.7	174.4	154.3	88.4	11.0	0.0	1562.6
1990	5.6	48.0	150.0	260.0	195.4	255.1	148.9	111.1	107.6	59.3	24.2	0.0	1365.3
1991	4.0	118.5	153.9	270.3	212.9	185.8	165.8	171.1	160.0	59.0	9.9	0.0	1511.2
1992	2.0	41.9	124.6	106.7	307.0	353.8	156.7	103.6	57.4	94.1	5.1	0.0	1353.0
1993	0.0	67.1	143.5	191.0	204.4	137.4	180.5	88.1	106.8	75.4	9.8	0.0	1203.9
1994	6.9	76.9	118.1	172.1	245.5	180.7	308.5	204.5	151.7	119.7	27.6	0.0	1612.3
1995	0.0	42.4	121.1	254.0	230.0	208.9	217.0	184.1	166.8	90.0	19.9	0.0	1534.3
1996	12.1	93.9	185.5	152.7	343.9	192.5	145.5	256.7	127.2	50.3	20.3	0.0	1580.5
1997	12.8	79.9	159.4	235.4	184.1	295.2	251.0	235.9	75.9	45.8	23.0	0.0	1598.4
1998	6.8	38.6	165.4	186.1	201*)	173*)	157*)	79*)	104*)	58*)	24*)	0	1192*)

*) *Calculated value*

LULEÅ
(65.55° N, 22.13° E)

DIRECT IRRADIATION, H_b (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	4.3	19.3	65.9	62.9	99.6	152.2	157.9	140.3	43.6	34.7	13.1	0.9	794.6
1984	3.0	21.5	84.2	105.5	184.0	162.3	99.7	115.5	54.3	15.3	8.7	1.3	855.3
1985	12.4	44.8	64.1	152.7	138.2	168.0	184.7	93.3	72.3	58.5	10.8	1.5	1001.2
1986	4.3	50.3	29.8	125.8	109.5	224.9	172.7	72.6	74.9	53.1	16.4	2.3	936.5
1987	11.3	42.1	66.4	143.2	164.8	142.3	171.2	106.7	40.5	34.4	16.2	1.9	940.9
1988	3.5	14.4	18.7	190.9	204.5	214.9	163.0	81.2	63.1	67.7	24.4	3.0	1049.2
1989	4.7	35.6	66.1	100.0	181.9	215.8	177.4	119.1	106.2	51.7	13.0	3.8	1075.6
1990	5.1	31.7	95.6	139.2	180.1	209.8	137.7	112.7	51.2	39.6	19.2	3.7	1025.5
1991	9.1	46.0	65.7	148.3	138.8	142.9	167.8	114.9	81.8	36.7	5.9	1.4	959.3
1992	9.0	15.7	37.8	74.0	160.2	222.3	110.9	49.2	37.4	48.6	4.0	0.6	769.7
1993	2.6	24.2	71.3	126.3	149.1	129.6	164.2	83.9	87.4	54.6	7.7	0.5	901.2
1994	7.6	60.1	73.6	111.5	185.3	169.9	236.7	157.4	109.5	76.7	21.7	1.1	1211.0
1995	7.7	27.8	69.8	131.3	154.9	179.1	186.4	180.6	126.3	59.5	30.4	1.5	1155.1
1996	13.8	49.2	107.4	111.7	227.3	174.5	134.4	198.6	111.5	38.5	18.9	1.2	1187.0
1997	9.3	32.1	105.5	146.1	115.2	230.7	176.4	194.0	82.3	37.6	17.6	0.8	1147.7
1998	7.9	26.1	86.5	136.5	151.3	153.6	136.2	50.3	70.8	33.8	6.5	0.7	860.1

GLOBAL IRRADIATION, H_g (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	3.5	17.6	55.8	83.4	131.1	172.3	163.1	124.8	42.9	22.9	6.6	1.2	825.2
1984	3.0	17.8	66.0	101.8	174.4	168.2	131.4	111.9	50.6	14.8	5.3	1.0	846.2
1985	4.7	21.0	55.4	128.6	149.1	170.7	158.7	101.9	58.5	27.9	5.1	1.2	882.7
1986	2.8	21.8	40.4	106.1	128.0	195.5	157.5	90.0	59.6	25.9	5.0	1.1	833.8
1987	4.1	19.5	52.2	120.4	151.4	148.3	152.6	100.1	43.8	20.5	5.3	0.9	819.1
1988	2.7	14.6	45.7	132.0	164.1	179.3	162.7	90.7	53.1	28.9	7.1	1.3	882.2
1989	3.4	15.5	49.7	89.0	156.9	176.6	159.7	109.3	68.5	26.0	4.1	1.3	859.8
1990	2.9	15.2	61.7	110.1	167.3	175.8	144.4	108.2	47.8	22.0	5.8	1.1	862.3
1991	3.6	18.8	52.0	112.7	132.8	142.9	163.8	116.2	64.4	21.8	4.4	1.2	834.5
1992	4.0	16.5	48.7	96.4	167.0	201.4	142.8	79.3	46.6	32.2	4.6	1.1	840.6
1993	3.6	18.6	60.7	118.6	153.5	157.1	154.6	98.3	68.5	29.6	5.0	0.9	868.8
1994	3.8	23.2	56.4	102.7	164.0	165.3	185.3	132.6	67.2	31.8	6.1	1.0	939.4
1995	3.3	14.2	51.7	115.6	145.2	168.3	167.4	134.0	76.4	27.3	8.1	1.3	912.8
1996	4.0	20.2	65.8	105.8	175.1	158.1	148.7	138.3	70.0	21.0	5.9	1.1	913.9
1997	3.7	17.3	61.0	117.9	145.1	182.7	157.2	136.6	57.8	21.4	5.5	0.8	906.9
1998	2.8	15.3	57.4	110.9	137.5	145.0	134.0	79.9	57.5	22.2	4.1	0.9	767.4

LULEÅ
(65.55° N, 22.13° E)

DIFFUSE IRRADIATION, H_d (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	3.2	14.3	37.0	54.6	79.0	90.0	82.2	59.8	28.5	15.6	5.3	1.2	470.6
1984	2.8	13.9	40.6	57.4	80.6	84.5	79.7	61.0	31.3	11.9	4.5	0.9	469.1
1985	3.8	13.4	35.2	64.3	80.4	83.5	67.6	61.6	34.6	15.7	4.2	1.2	465.4
1986	2.6	13.1	31.7	54.1	73.4	78.3	73.5	56.9	34.0	13.9	3.5	1.0	435.8
1987	3.3	11.8	33.8	60.5	69.7	75.2	67.5	50.6	30.1	11.9	3.4	0.9	418.7
1988	2.4	11.9	39.8	51.4	64.6	70.2	76.9	54.5	32.5	15.3	4.9	1.2	425.7
1989	3.0	9.7	28.5	48.3	68.2	69.1	70.3	57.3	31.8	15.0	3.1	1.2	405.5
1990	2.6	9.4	33.8	51.7	80.1	68.3	77.2	57.9	31.1	13.8	4.0	1.0	430.9
1991	3.1	11.6	31.0	49.8	65.3	71.3	77.4	63.0	36.0	14.0	3.8	1.2	427.4
1992	3.4	13.6	37.0	63.0	83.2	83.8	84.9	56.0	33.1	20.7	4.1	1.1	483.9
1993	3.4	14.5	37.9	63.7	80.2	90.1	71.0	60.0	37.8	18.2	4.1	0.9	481.8
1994	3.3	12.7	34.5	54.3	75.5	80.0	68.0	59.4	29.9	14.3	4.0	0.9	436.7
1995	2.8	9.7	30.3	58.2	70.4	76.0	72.5	54.6	32.4	14.3	5.2	1.3	427.7
1996	2.9	12.1	34.2	58.5	62.1	70.4	80.3	47.8	32.5	12.5	4.1	1.0	418.5
1997	3.1	11.8	30.5	57.4	85.4	66.9	67.4	50.2	30.8	14.1	3.4	0.8	421.8
1998	2.2	10.9	32.8	55.8	64.5	66.6	66.2	55.2	32.7	14.4	3.5	0.8	405.5

SUNSHINE DURATION, *SD* (Hours).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	13.0	50.0	125.0	122.0	193.0	282.0	293.0	249.0	79.0	75.0	44.0	1.0	1526.0
1984	4.0	58.0	167.0	202.0	352.0	295.0	170.0	214.0	101.0	32.0	23.0	4.0	1622.0
1985	32.0	107.0	125.0	257.0	239.0	296.0	302.0	177.0	132.0	108.0	29.0	3.0	1807.0
1986	13.5	106.7	63.1	198.5	192.2	376.3	292.0	122.4	122.4	100.1	42.3	8.3	1637.8
1987	31.8	91.1	130.6	242.9	275.1	251.8	273.6	169.5	72.3	66.2	37.1	7.2	1649.2
1988	12.2	43.5	48.3	298.2	324.7	342.7	289.8	142.3	110.7	133.3	65.7	10.6	1821.9
1989	16.8	71.2	112.1	167.6	289.4	349.8	287.5	206.0	170.5	93.5	37.2	13.6	1815.2
1990	17.2	59.7	164.3	223.9	298.7	327.8	239.8	198.5	95.8	74.9	48.7	13.1	1762.5
1991	30.9	98.3	116.3	234.0	210.9	243.0	267.2	220.3	143.2	79.5	19.4	2.1	1665.2
1992	35.5	48.4	90.9	153.0	302.0	408.4	214.9	102.9	74.7	114.4	15.5	0.0	1560.5
1993	4.7	77.7	151.7	225.3	278.2	229.1	280.0	150.9	147.8	120.2	21.6	1.5	1688.9
1994	24.8	130.8	130.7	188.1	307.2	288.2	387.0	276.3	180.9	136.9	55.8	3.3	2110.1
1995	24.8	59.5	119.2	208.1	249.9	299.7	301.7	288.7	214.2	109.6	76.0	4.4	1955.5
1996	40.3	103.2	180.6	183.0	335.7	281.1	228.3	315.2	179.5	69.4	45.7	3.4	1965.5
1997	27.8	64.8	180.1	225.8	188.8	373.4	290.3	319.7	129.0	70.2	35.6	2.8	1908.3
1998	20.1	51.4	131.8	222.5	238.4	248.4	223.7	80.2	131.5	70.8	18.0	1.2	1438.0

UMEÅ
(63.82° N, 20.25° E)

DIRECT IRRADIATION, H_b (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	7.6	37.8	50.6	46.5	92.7	137.9	177.8	146.4	48.1	35.8	24.9	3.9	809.9
1984	8.2	15.7	92.5	117.8	191.3	138.0	109.3	148.6	32.0	29.0	11.0	2.9	896.2
1985	22.9	47.2	49.5	131.2	131.5	170.9	180.3	97.4	112.2	63.5	22.3	8.2	1037.0
1986	10.7	59.8	31.8	115.9	150.6	222.9	151.7	58.6	73.6	55.7	23.5	3.6	958.4
1987	21.3	48.5	81.7	133.9	156.9	118.1	180.8	93.7	60.3	28.9	16.5	5.7	946.2
1988	2.4	9.2	9.6	171.7	199.6	206.3	151.1	83.8	69.0	72.4	38.7	10.8	1024.7
1989	15.1	42.3	52.4	88.4	207.3	165.5	130.2	100.2	113.8	68.2	17.5	9.9	1010.8
1990	7.0	25.5	100.2	122.8	172.9	192.8	117.0	112.6	47.6	64.5	24.4	9.3	996.5
1991	11.5	51.9	53.4	136.5	118.8	148.8	166.0	112.1	80.6	31.5	13.6	6.2	930.8
1992	12.3	19.6	38.8	52.2	165.1	224.0	111.5	66.8	55.6	36.1	6.9	2.8	791.6
1993	8.0	39.5	80.1	133.9	141.5	122.7	127.9	61.9	78.7	58.9	9.2	4.1	866.3
1994	14.0	80.1	94.0	112.2	194.5	156.7	252.3	150.4	87.7	75.0	24.4	8.6	1249.9
1995	14.6	34.6	45.4	130.9	169.5	167.0	179.3	168.0	98.8	69.8	28.9	11.0	1117.9
1996	15.3	64.2	103.6	120.1	185.1	146.8	124.9	167.9	99.9	49.0	18.3	6.4	1101.4
1997	20.0	35.1	101.7	147.5	168.0	226.2	212.5	197.3	98.8	36.9	15.2	7.0	1266.1
1998	15.0	30.1	80.2	154.9	161.1	125.3	120.3	68.7	84.7	47.8	10.8	8.2	907.0

GLOBAL IRRADIATION, H_g (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	5.0	22.9	54.9	82.0	121.2	160.7	161.9	130.5	48.0	24.8	10.0	2.5	824.4
1984	4.9	17.3	69.5	106.7	176.2	153.5	132.8	125.8	45.2	18.9	6.4	1.6	858.8
1985	7.4	24.6	52.7	120.8	132.1	168.0	167.0	96.7	72.9	31.2	8.0	2.6	884.0
1986	4.7	26.2	40.8	104.1	146.9	192.3	152.1	79.8	63.2	27.6	8.1	2.0	847.8
1987	7.1	23.8	58.1	116.3	149.5	147.0	168.9	97.7	50.1	20.2	6.9	2.3	847.9
1988	3.3	15.4	44.4	130.7	168.5	179.8	157.7	89.9	57.3	32.6	10.3	2.6	892.3
1989	5.7	17.5	46.4	81.5	168.5	184.5	170.0	103.4	73.2	32.5	6.4	2.6	892.0
1990	4.3	16.9	64.2	108.5	160.0	171.9	133.0	112.9	50.1	30.8	8.0	2.4	863.0
1991	4.9	23.0	47.2	112.3	129.7	148.4	160.9	116.4	62.9	21.8	6.8	2.5	837.0
1992	5.9	19.0	49.1	85.6	173.6	208.8	147.7	95.2	54.4	30.3	6.6	2.3	878.6
1993	5.8	23.0	63.0	114.5	145.2	148.4	142.1	89.8	68.5	29.2	5.7	1.9	836.9
1994	5.8	28.5	63.2	106.6	169.2	153.7	194.0	134.3	65.8	31.9	7.7	2.0	962.5
1995	5.0	18.9	47.3	110.4	147.3	164.0	165.2	133.2	73.8	32.8	9.9	2.9	910.6
1996	5.2	25.8	69.2	111.7	162.4	153.1	142.4	141.6	71.3	26.1	6.8	2.2	917.8
1997	6.3	19.6	65.8	120.8	157.1	182.0	174.7	140.7	70.4	26.2	6.4	2.2	972.2
1998	5.5	18.2	58.6	118.8	145.2	137.7	135.8	91.9	61.6	28.7	6.8	2.2	811.0

UMEÅ
(63.82° N, 20.25° E)

DIFFUSE IRRADIATION, H_d (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	4.3	15.6	39.3	60.2	71.8	82.5	68.1	61.0	31.7	16.5	7.1	2.3	460.4
1984	4.3	14.5	39.8	53.6	72.8	82.3	74.5	56.0	32.8	12.3	5.1	1.5	449.3
1985	5.4	15.1	37.3	63.4	64.8	76.6	73.4	51.9	33.6	17.0	5.6	2.3	446.4
1986	3.9	14.7	30.7	54.5	71.5	72.3	71.9	53.1	37.0	14.3	5.2	1.8	431.1
1987	5.3	14.0	33.8	59.4	69.9	82.7	76.1	56.7	28.3	12.0	4.8	2.1	445.1
1988	3.1	13.3	41.4	54.8	68.0	71.4	78.2	50.8	32.7	16.3	6.2	2.1	438.3
1989	4.3	9.9	28.2	44.2	65.7	98.5	100.1	57.7	33.1	16.6	4.7	2.1	465.1
1990	3.8	11.9	33.5	52.2	72.8	71.8	74.9	61.9	34.2	16.0	5.2	1.9	440.1
1991	4.0	13.5	29.9	52.7	72.4	68.4	75.8	62.7	35.2	14.8	5.4	2.3	436.9
1992	4.8	15.2	35.4	62.3	84.2	85.0	86.6	61.2	32.7	21.7	5.7	2.2	497.0
1993	5.1	15.3	36.5	53.6	69.3	80.9	74.1	60.9	40.6	16.3	4.5	1.7	458.9
1994	4.6	13.2	32.9	56.1	73.5	73.1	62.4	62.1	34.4	13.4	5.2	1.6	432.4
1995	3.7	12.9	33.1	52.8	63.5	73.7	72.6	56.9	37.1	16.7	6.5	2.4	431.7
1996	3.8	13.9	36.2	58.7	69.6	78.1	77.4	60.5	35.6	14.0	4.9	1.9	454.5
1997	4.7	13.7	35.5	57.6	74.7	60.0	61.4	45.7	35.6	17.8	4.2	1.9	412.7
1998	3.9	13.0	33.2	52.7	68.2	70.2	72.5	58.8	30.4	16.9	5.4	1.9	427.0

SUNSHINE DURATION, *SD* (Hours).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	17.0	89.0	98.0	101.0	177.0	247.0	307.0	248.0	88.0	77.0	63.0	1.0	1513.0
1984	19.0	36.0	181.0	209.0	344.0	247.0	178.0	246.0	58.0	55.0	29.0	10.0	1612.0
1985	60.0	101.0	91.0	224.0	231.0	295.0	297.0	166.0	195.0	120.0	53.0	22.0	1855.0
1986	25.7	117.2	56.8	181.8	253.4	359.1	245.0	102.9	125.3	97.6	52.0	12.0	1628.7
1987	64.2	101.7	149.4	227.0	254.0	212.5	285.4	150.2	93.5	56.3	35.3	18.9	1648.5
1988	8.2	28.2	24.4	277.0	322.6	335.8	264.9	135.0	116.7	128.7	94.2	39.7	1775.4
1989	41.0	79.2	87.8	145.9	320.6	249.6	212.3	173.3	187.0	118.5	44.1	32.6	1691.8
1990	20.4	51.5	167.1	201.5	278.8	300.8	203.9	201.7	87.1	115.9	57.7	29.6	1716.0
1991	30.9	104.4	85.7	226.5	187.4	231.5	268.7	201.2	139.8	69.8	39.7	24.4	1610.1
1992	44.4	58.0	88.1	117.1	313.8	408.7	210.4	126.7	103.9	91.2	25.4	2.4	1590.1
1993	23.9	110.2	159.5	228.2	236.2	212.3	218.8	114.4	140.1	114.7	24.9	17.5	1600.6
1994	43.5	160.8	157.2	189.0	324.0	249.2	403.0	261.7	147.0	123.9	60.4	32.0	2151.7
1995	41.9	71.9	81.4	212.3	274.0	281.5	296.7	269.1	166.5	120.7	69.4	38.3	1923.3
1996	39.7	121.2	172.8	203.9	290.4	247.3	209.9	298.4	156.9	87.0	42.7	21.7	1891.9
1997	55.5	71.8	166.6	229.3	253.6	343.8	313.9	301.0	148.6	58.1	28.1	21.7	1992.0
1998	33.6	60.3	123.7	245.0	251.3	204.0	194.4	111.8	136.2	87.7	24.0	26.8	1498.9

ÖSTERSUND
(63.20° N, 14.50° E)

DIRECT IRRADIATION, H_b (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	5.1	18.7	38.7	37.9	80.9	120.3	140.6	90.7	43.5	28.2	9.5	3.4	617.4
1984	6.2	27.2	68.7	90.5	127.3	123.5	114.7	84.4	21.4	20.4	20.8	3.3	708.4
1985	12.6	38.4	50.1	131.9	142.3	118.0	109.1	96.7	60.6	25.4	27.6	4.4	817.3
1986	12.7	55.3	70.0	107.5	149.1	174.2	121.1	48.3	63.6	59.3	25.3	3.2	889.5
1987	11.8	48.2	107.4	99.2	124.3	56.0	148.2	85.9	64.5	42.1	9.7	3.7	800.8
1988	5.9	15.3	50.3	154.8	186.5	208.5	133.5	96.1	74.6	47.6	22.5	8.6	1004.3
1989	8.0	40.9	84.0	106.1	152.8	198.7	164.0	105.9	104.0	45.1	20.8	6.9	1037.2
1990	10.2	29.4	59.8	114.1	176.8	167.8	121.1	99.2	33.4	57.9	8.3	8.9	886.8
1991	13.7	53.4	41.0	151.9	108.5	84.4	170.7	102.2	67.3	25.6	10.7	3.5	832.8
1992	6.4	15.6	38.8	72.5	142.5	167.1	99.3	60.0	80.8	24.5	4.3	3.7	715.5
1993	6.1	33.9	72.5	127.2	121.3	119.3	79.4	94.5	86.4	40.2	7.9	6.6	795.2
1994	9.2	65.0	98.3	127.2	158.0	103.0	212.5	93.1	94.8	47.6	13.4	9.4	1031.5
1995	18.3	42.6	58.4	84.8	129.6	111.8	137.2	99.5	81.1	50.5	23.5	11.2	848.5
1996	23.4	57.8	113.1	124.5	126.0	118.1	132.4	148.8	122.8	41.8	21.9	10.4	1040.9
1997	15.3	41.2	69.4	106.4	152.8	175.8	210.4	141.4	61.0	39.0	14.5	5.0	1032.1
1998	8.5	33.5	87.7	111.3	178.3	92.6	90.8	80.0	87.6	54.5	11.0	12.0	847.8

GLOBAL IRRADIATION, H_g (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	4.7	19.2	53.6	73.5	117.8	153.5	164.5	109.9	50.6	27.0	8.7	3.0	786.0
1984	6.6	22.9	69.4	101.8	150.1	151.3	147.8	107.6	41.6	19.6	8.5	2.6	829.7
1985	7.0	25.2	60.3	123.8	146.6	162.5	136.4	107.1	57.5	24.0	10.6	3.2	864.1
1986	6.1	26.6	63.0	110.0	154.5	178.1	143.6	81.8	65.6	33.1	10.5	2.7	875.6
1987	7.8	24.0	73.0	105.5	145.8	111.4	156.0	100.9	62.7	27.7	6.8	2.5	823.9
1988	5.2	20.8	58.0	130.0	167.8	190.5	141.7	103.4	63.7	29.7	9.8	3.1	923.6
1989	5.5	20.7	64.5	92.2	148.6	180.0	160.6	109.1	74.2	29.6	8.5	3.0	896.4
1990	5.5	21.1	57.7	108.6	159.7	164.9	137.3	113.4	47.4	31.6	7.4	3.0	857.5
1991	5.7	25.4	51.1	117.8	139.5	128.5	167.2	121.8	65.7	26.8	8.0	2.9	860.5
1992	5.7	20.5	56.3	102.7	165.7	189.6	143.3	92.6	74.3	29.6	7.3	3.2	890.9
1993	6.4	23.5	69.3	122.1	134.1	154.5	129.4	110.8	73.9	28.7	7.2	3.2	863.0
1994	6.5	29.2	74.0	118.8	164.1	141.1	188.9	109.4	69.7	33.2	9.0	3.3	947.2
1995	6.5	24.2	59.5	114.7	145.5	148.1	154.8	111.1	65.8	31.4	10.2	3.8	875.6
1996	7.7	27.3	75.6	114.8	141.4	143.1	155.5	128.2	81.5	25.9	8.8	3.4	913.3
1997	6.3	22.1	66.7	117.8	156.5	170.1	182.6	124.4	63.7	28.2	7.5	2.7	948.5
1998	5.5	21.3	67.1	100.5	169.7	126.5	128.0	100.3	66.5	32.8	7.7	3.2	828.9

ÖSTERSUND
(63.20° N, 14.50° E)

DIFFUSE IRRADIATION, H_d (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	4.2	15.7	41.1	56.5	76.5	89.3	87.0	65.9	35.3	20.2	7.5	2.8	502.0
1984	6.1	17.4	46.7	61.0	83.5	83.1	85.0	66.6	33.5	14.9	6.1	2.4	506.2
1985	5.9	17.7	43.6	64.6	70.0	96.5	78.4	59.9	36.9	17.8	7.2	3.0	501.6
1986	5.0	15.6	40.8	62.9	75.2	82.8	78.5	59.7	41.3	18.9	7.2	2.5	490.4
1987	6.8	14.1	40.5	63.0	83.0	82.9	76.5	61.9	39.6	16.6	5.4	2.3	492.6
1988	4.7	17.8	41.5	60.7	70.2	78.3	74.4	57.7	35.2	18.9	7.3	2.6	469.0
1989	4.8	12.9	35.6	48.6	70.2	71.0	75.9	60.2	35.9	18.3	6.2	2.6	442.3
1990	4.6	15.6	39.4	58.2	71.1	77.4	75.7	66.0	35.4	17.5	6.5	2.6	469.7
1991	4.6	15.2	37.4	51.8	84.7	84.5	75.4	72.4	40.9	20.4	6.7	2.7	496.7
1992	5.1	17.3	41.9	69.4	89.1	95.6	89.0	63.2	42.6	23.1	6.7	3.0	546.0
1993	5.8	16.3	44.6	63.2	71.8	89.4	85.4	64.4	42.3	19.6	6.1	2.8	511.7
1994	5.7	16.0	42.7	63.5	83.5	87.2	72.9	65.5	34.5	21.2	7.5	2.8	503.0
1995	5.0	15.6	41.5	77.7	78.1	87.2	81.4	64.5	36.0	18.8	7.0	3.2	515.8
1996	5.4	16.4	39.0	60.5	79.0	80.4	86.0	57.9	38.5	15.6	6.1	2.9	487.7
1997	5.0	14.5	44.7	70.7	78.6	74.8	72.0	57.9	42.0	19.2	5.8	2.4	487.7
1998	4.6	14.7	38.5	53.7	78.4	76.3	78.6	62.4	32.9	18.4	6.4	2.6	467.4

SUNSHINE DURATION, *SD* (Hours).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	13.0	50.0	83.0	77.0	156.0	211.0	246.0	164.0	100.0	68.0	27.0	13.0	1208.0
1984	7.0	62.0	135.0	179.0	222.0	207.0	193.0	144.0	43.0	42.0	52.0	8.0	1296.0
1985	29.0	85.0	93.0	202.0	232.0	212.0	182.0	161.0	106.0	50.0	61.0	10.0	1423.0
1986	34.4	104.0	133.7	169.5	242.4	285.1	198.1	86.2	106.5	104.1	60.9	9.6	1534.5
1987	28.9	89.6	183.1	163.4	204.8	101.2	223.7	134.2	115.5	79.9	23.1	12.1	1359.6
1988	14.3	37.3	103.5	232.5	290.3	319.2	225.9	154.9	125.3	89.8	55.9	27.2	1676.0
1989	23.8	75.3	136.9	167.3	236.8	293.8	254.5	183.1	168.0	77.1	50.1	21.9	1688.8
1990	25.7	61.8	110.0	188.3	268.1	267.3	203.4	169.0	57.9	105.7	20.4	28.0	1505.6
1991	34.7	103.6	71.8	240.1	180.1	140.1	274.6	192.3	120.1	53.0	32.8	11.9	1455.1
1992	23.0	42.8	91.1	144.7	274.0	305.8	183.5	115.4	161.1	59.1	13.7	11.6	1425.9
1993	20.4	83.0	139.5	228.1	208.9	200.9	142.3	155.8	147.7	82.3	21.4	25.1	1455.4
1994	30.1	133.1	176.0	210.4	260.7	171.4	335.6	166.6	149.9	87.0	37.1	32.7	1790.5
1995	53.5	80.4	98.6	148.1	197.4	192.4	231.5	172.4	133.7	88.2	51.9	35.4	1483.5
1996	62.1	108.6	178.3	199.8	199.9	194.1	208.8	252.0	189.1	75.9	51.2	31.9	1751.6
1997	40.8	79.3	119.3	172.2	239.0	280.0	332.6	229.2	107.1	72.7	30.4	16.6	1719.1
1998	19.8	59.4	141.6	161.5	279.3	146.7	151.1	135.4	136.8	91.3	25.4	35.2	1383.3

BORLÄNGE
(60.48° N, 15.43° E)

DIRECT IRRADIATION, H_b (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	-	-	-	-	-	-	-	-	-	-	-	-	-
1986	-	-	-	-	-	-	-	-	-	-	-	-	-
1987	18.1	31.6	59.3	84.9	107.7	44.4	183.0	94.3	103.3	29.9	15.7	15.0	787.3
1988	4.0	8.2	52.0	134.3	205.1	154.6	117.3	107.8	90.2	65.3	46.2	24.0	1008.9
1989	22.4	51.4	67.3	75.2	191.3	191.1	193.0	106.6	112.9	79.8	34.0	17.4	1142.4
1990	16.2	15.1	87.2	104.8	199.2	146.4	121.1	112.7	42.3	70.3	37.9	18.0	971.2
1991	32.9	46.3	41.5	115.4	154.7	70.7	195.0	115.4	109.9	35.4	20.3	13.3	950.8
1992	18.2	26.1	37.6	68.6	171.9	185.9	134.3	83.0	66.7	24.5	7.6	9.4	833.9
1993	14.6	53.0	97.0	113.0	161.7	128.2	98.5	89.2	87.2	49.9	9.6	12.4	914.2
1994	20.6	62.3	85.2	100.1	188.9	134.2	239.2	147.7	67.7	71.1	28.7	15.3	1160.9
1995	21.8	61.5	60.0	94.7	156.4	132.9	155.2	172.5	62.8	58.8	25*)	23.6	1025.1
1996	31.1	71.2	118.3	135.8	114.6	149.5	131.1	158.7	83.1	10.6	23.0	24.7	1051.6
1997	31.9	55.8	131.4	175.5	139.0	177.9	213.2	157.6	109.7	56.7	17.3	9.0	1274.8
1998	28.9	45.8	86.7	74.1	171.9	85.0	100.3	90.1	88.2	43.8	13.9	13.7	842.3

*) *Calculated value.*

GLOBAL IRRADIATION, H_g (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	-	-	-	-	-	-	-	-	-	-	-	-	-
1986	-	-	-	-	-	-	-	-	-	-	-	-	-
1987	10.3	29.3	64.6	110.5	147.9	94.7	176.0	102.5	75.0	26.4	10.3	6.0	853.5
1988	4.7	18.3	60.7	118.3	171.8	172.7	142.7	112.8	70.0	35.9	16.4	6.6	930.6
1989	9.4	23.5	56.1	79.5	170.2	177.1	177.1	118.1	81.6	40.6	11.9	6.9	951.7
1990	8.4	17.4	66.7	100.6	167.5	158.5	136.7	115.7	51.8	36.5	13.5	6.0	879.2
1991	11.9	26.2	47.7	108.9	159.3	120.8	176.2	118.4	82.3	28.5	11.0	6.3	897.4
1992	11.0	24.9	51.1	89.4	178.6	195.1	159.7	108.0	65.4	31.1	10.0	5.5	929.7
1993	10.5	32.1	77.7	111.6	157.9	154.5	137.1	103.1	76.9	30.4	7.3	5.1	904.1
1994	9.3	31.4	69.3	100.8	173.0	153.2	199.6	131.5	59.2	37.8	12.2	4.6	981.8
1995	9.1	27.5	58.1	95.7	152.4	149.7	165.9	148.0	56.9	34.1	13.7	4.6	915.6
1996	9.6	32.7	77.5	116.9	131.2	170.5	149.6	138.9	76.5	29.9	10.8	6.2	950.3
1997	11.3	24.2	80.3	132.5	142.3	174.6	188.0	132.9	84.3	36.1	8.9	4.1	1019.7
1998	10.1	27.0	66.0	88.3	165.1	119.7	134.4	104.2	70.3	32.3	10.8	5.3	833.5

BORLÄNGE
(60.48° N, 15.43° E)

DIFFUSE IRRADIATION, H_d (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	-	-	-	-	-	-	-	-	-	-	-	-	-
1986	-	-	-	-	-	-	-	-	-	-	-	-	-
1987	-	-	-	-	-	69.2	76.6	56.9	33.6	17.4	7.7	4.5	-99
1988	4.3	16.2	41.9	55.5	59.9	84.3	80.6	59.0	34.2	19.5	9.3	4.5	469.1
1989	6.6	12.3	31.5	45.6	66.9	72.4	70.7	64.6	36.2	18.5	7.3	5.2	437.8
1990	6.3	13.9	35.9	49.9	65.0	76.2	71.3	59.8	35.8	18.2	7.7	4.4	444.4
1991	7.8	16.0	31.9	56.1	77.0	83.4	69.1	61.4	38.3	18.7	7.9	5.1	472.5
1992	8.5	18.8	37.2	55.8	81.1	85.3	82.7	65.0	38.3	23.8	8.7	4.7	509.7
1993	8.4	19.7	42.6	56.3	71.4	83.5	80.6	59.6	43.4	18.3	5.7	3.9	493.5
1994	6.6	16.6	38.8	53.9	72.0	81.6	65.7	57.1	-99	-99	-99	-99	-99
1995	6.4	13.1	36.1	52.6	71.4	75.8	80.7	61.2	33.2	17.9	-99	-99	-99
1996	5.5	16.8	35.3	56.1	71.2	87.0	78.3	59.5	27.8	-99	7.2	4.1	-99
1997	7.4	12.6	35.6	52.1	70.2	75.3	71.7	52.8	41.7	22.1	6.1	3.3	450.7
1998	6.1	16.6	37.6	54.3	72.1	72.4	79.6	59.8	33.8	20.5	8.6	4.1	465.4

SUNSHINE DURATION, *SD* (Hours).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	-	-	-	-	-	-	-	-	-	-	-	-	-
1984	-	-	-	-	-	-	-	-	-	-	-	-	-
1985	-	-	-	-	-	-	-	-	-	-	-	-	-
1986	-	-	-	-	-	-	-	-	-	-	-	-	-
1987	30.9	59.6	114.4	151.9	173.9	78.3	283.4	148.9	154.7	58.7	36.7	36.2	1327.7
1988	9.3	16.8	96.0	213.2	326.6	250.2	200.0	179.5	143.1	116.3	90.6	59.4	1701.0
1989	51.8	95.4	109.3	131.9	292.6	294.2	290.7	180.5	181.0	127.2	75.1	43.9	1873.6
1990	39.1	32.3	146.3	171.5	298.6	235.2	189.9	181.1	72.3	122.0	73.4	42.9	1604.6
1991	74.6	80.0	71.4	203.4	238.7	132.5	305.9	202.5	185.5	63.9	53.2	48.8	1660.4
1992	57.0	72.3	87.4	131.0	312.8	334.3	237.3	155.8	129.1	52.7	21.9	37.7	1629.3
1993	50.2	124.2	188.7	206.6	274.5	219.2	172.4	153.9	152.0	96.7	26.7	34.7	1699.8
1994	49.4	113.6	150.1	178.1	293.7	215.7	382.2	248.0	111.6	117.2	63.4	38.3	1961.2
1995	47.6	101.3	98.2	152.2	251.1	213.7	258.7	272.7	100.0	100.8	75.0	67.0	1739.0
1996	62.9	122.7	186.5	228.5	188.4	246.6	210.0	269.6	142.9	83.6	45.2	56.9	1843.8
1997	71.3	95.4	213.5	255.0	215.6	279.4	335.3	253.5	174.9	98.0	34.8	18.1	2044.9
1998	56.5	84.3	138.5	134.3	263.0	142.9	161.5	146.1	137.3	76.5	28.1	35.2	1404.3

KARLSTAD
(59.37° N, 13.47° E)

DIRECT IRRADIATION, H_b (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	17.0	56.2	44.3	42.2	64.0	152.6	174.6	171.7	62.5	51.8	32.9	9.6	879.6
1984	19.8	12.3	87.1	111.0	118.6	117.6	150.8	137.3	65.2	44.0	19.3	9.2	892.2
1985	22.8	48.5	46.6	89.9	151.2	146.0	169.0	100.6	110.8	72.9	29.2	16.5	1004.1
1986	14.9	71.8	39.6	103.5	149.5	211.1	129.2	84.1	156.4	58.6	29.4	12.1	1060.2
1987	35.1	50.5	97.1	128.9	134.6	68.7	182.6	86.0	122.2	35.9	24.1	18.1	983.9
1988	6.1	3.5	61.4	131.5	192.9	196.9	126.2	123.4	93.8	50.3	44.3	22.4	1052.6
1989	18.9	45.4	62.0	96.2	201.5	214.2	181.1	109.0	113.2	70.9	30.2	22.4	1165.0
1990	13.9	14.2	101.4	123.1	218.4	159.9	154.9	130.9	54.0	58.5	39.4	15.8	1084.3
1991	24.7	34.8	30.0	128.7	189.3	107.5	196.7	112.9	117.4	47.7	23.5	14.4	1027.5
1992	17.7	28.1	51.2	77.5	181.7	201.0	152.0	84.8	71.8	26.6	10.6	11.1	914.1
1993	10.8	38.6	96.5	122.1	193.9	174.8	113.2	106.7	97.3	62.0	2.4	11.3	1029.6
1994	19.7	50.7	84.6	105.2	220.0	166.0	251.5	123.6	66.6	73.8	34.0	13.3	1208.8
1995	24.5	50.8	64.7	109.2	161.7	133.8	176.0	219.7	66.8	63.2	30.4	30.8	1131.4
1996	19.4	68.0	119.7	120.3	90.0	137.8	172.3	170.1	128.6	43.1	20.6	19.5	1109.4
1997	35.4	57.5	144.2	168.1	144.9	183.3	230.7	158.3	122.4	77.3	15.9	2.8	1340.7
1998	30.4	30.1	97.2	0.0	176.8	109.4	121.7	89.7	59.1	43.1	17.7	15.9	791.1

GLOBAL IRRADIATION, H_g (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	10.5	32.5	55.0	74.7	117.9	170.9	177.7	148.4	67.0	37.5	15.6	5.7	913.2
1984	11.2	22.7	76.3	109.9	150.8	155.8	169.2	137.0	65.5	34.9	10.6	4.6	948.5
1985	10.6	31.2	54.4	104.9	160.6	167.4	167.8	115.3	81.5	41.2	13.3	6.6	954.7
1986	10.4	35.9	48.5	104.9	156.8	193.1	160.7	111.9	98.0	37.9	13.1	5.7	976.9
1987	14.2	31.7	75.6	116.8	144.8	129.1	178.6	105.5	83.3	30.8	13.3	7.6	931.4
1988	5.4	16.9	63.0	112.4	174.4	186.3	145.7	122.3	73.3	33.6	16.1	7.6	956.9
1989	9.4	24.0	51.9	94.2	170.8	190.4	172.1	117.5	81.5	39.9	12.2	6.9	970.8
1990	8.0	17.3	68.5	110.4	180.7	167.1	157.6	126.1	65.6	35.9	15.4	6.2	958.8
1991	10.9	24.3	43.3	116.8	171.3	139.2	180.2	121.8	87.7	34.3	12.3	8.1	949.9
1992	11.6	24.9	58.7	95.0	179.3	202.7	170.3	109.2	76.5	30.8	10.7	6.5	976.3
1993	12.6	26.7	78.5	114.4	181.5	180.6	144.0	115.7	82.3	36.2	5.9	5.6	983.9
1994	10.7	32.6	71.2	111.1	191.7	171.8	208.4	126.6	65.8	39.7	14.2	5.3	1048.9
1995	10.6	26.8	58.5	106.4	156.5	147.4	163.5	160.8	63.6	37.3	14.5	8.6	954.3
1996	9.1	33.8	79.2	113.3	122.7	160.0	171.8	143.6	88.2	32.5	11.4	6.7	972.3
1997	12.5	25.4	83.7	126.6	150.6	179.4	193.9	137.7	90.5	42.1	10.2	3.9	1056.5
1998	11.5	23.3	68.7	85.4	166.4	130.1	152.9	110.3	66.8	35.8	12.3	6.3	869.6

KARLSTAD
(59.37° N, 13.47° E)

DIFFUSE IRRADIATION, H_d (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	8.1	18.7	38.6	53.7	80.2	80.4	77.6	58.9	41.8	22.8	10.0	4.7	495.4
1984	8.5	19.8	44.5	54.0	84.4	85.7	87.4	66.3	36.5	21.8	7.4	3.6	519.7
1985	7.7	19.9	35.9	61.4	75.5	80.3	70.3	63.1	37.7	22.0	8.5	4.8	487.1
1986	8.3	17.8	34.5	57.5	73.2	70.0	83.9	70.0	34.1	20.5	7.8	4.4	482.0
1987	9.6	19.2	41.4	54.9	69.5	87.5	74.5	61.8	34.4	19.1	9.0	5.6	486.4
1988	4.7	16.0	41.0	49.4	67.1	72.4	72.2	58.5	34.9	20.5	8.9	5.3	450.8
1989	6.9	13.4	27.5	49.2	62.7	68.7	70.8	62.7	34.9	19.3	7.9	4.5	428.5
1990	6.1	13.9	30.8	49.7	63.2	75.0	72.8	59.8	43.2	19.5	8.9	4.5	447.4
1991	7.3	16.5	31.2	54.0	69.9	76.9	68.6	64.7	39.2	20.1	8.1	6.6	463.1
1992	9.1	18.2	38.5	54.8	75.5	83.6	80.5	64.7	46.5	22.6	8.8	5.4	508.1
1993	11.1	17.4	41.4	54.0	71.5	81.1	79.0	63.7	41.8	19.8	5.6	4.4	490.7
1994	7.9	20.0	39.6	59.4	71.0	80.5	65.0	60.9	39.2	17.9	8.9	4.0	474.1
1995	7.3	15.0	33.1	55.8	67.3	71.2	65.3	48.9	36.7	19.4	9.3	5.5	434.8
1996	6.1	17.7	35.7	56.9	73.9	81.7	74.0	54.8	37.3	19.3	7.7	4.7	469.6
1997	7.7	12.7	32.1	48.0	71.2	76.3	63.3	55.4	41.0	21.6	7.6	3.6	440.2
1998	6.8	16.1	34.2	85.4	70.9	68.2	81.8	65.1	42.8	23.7	9.2	4.7	508.9

SUNSHINE DURATION, *SD* (Hours).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	46.0	120.0	86.0	87.0	160.0	280.0	313.0	292.0	120.0	102.0	79.0	29.0	1714.0
1984	50.0	29.0	145.0	197.0	195.0	208.0	271.0	249.0	113.0	73.0	46.0	23.0	1599.0
1985	58.0	98.0	81.0	145.0	246.0	269.0	264.0	176.0	179.0	136.0	62.0	42.0	1756.0
1986	33.2	120.2	72.9	172.9	248.1	335.9	220.5	149.0	226.9	102.3	57.9	30.8	1770.5
1987	88.3	91.2	169.1	213.4	215.4	130.4	289.6	138.5	191.2	72.8	50.6	46.5	1696.9
1988	15.6	8.8	107.0	208.2	308.6	315.0	220.3	200.6	154.1	92.3	86.0	54.4	1770.9
1989	44.7	86.0	101.3	157.2	319.1	337.3	288.4	182.5	180.3	115.7	64.7	52.4	1929.7
1990	31.9	30.9	161.3	199.1	328.2	260.2	244.1	215.1	92.8	98.2	75.1	34.9	1771.8
1991	53.1	66.2	53.5	222.7	281.3	170.9	314.6	205.0	198.8	89.3	54.5	48.5	1758.5
1992	53.4	75.3	109.9	145.3	332.4	360.8	267.7	161.1	138.2	52.5	33.0	42.1	1771.6
1993	40.6	87.1	178.9	230.1	329.3	288.2	190.8	182.9	165.2	113.1	6.7	32.7	1845.6
1994	48.1	98.3	146.4	188.9	342.6	272.0	406.5	215.6	124.3	117.0	70.8	31.4	2062.0
1995	56.9	90.3	105.8	178.8	257.2	222.9	280.7	336.8	108.0	107.3	61.7	71.6	1878.1
1996	37.6	111.9	187.3	205.8	152.5	224.0	265.5	288.6	192.7	74.0	38.8	45.6	1824.2
1997	75.1	99.5	224.8	250.1	237.6	300.5	352.3	264.6	188.6	124.6	34.4	6.0	2158.0
1998	58.3	58.7	141.3	116.5	283.8	171.9	197.6	155.4	116.7	82.3	36.4	37.5	1456.4

STOCKHOLM
(59.35° N, 18.07° E)

DIRECT IRRADIATION, H_b (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	9.0	48.3	37.3	54.2	109.9	139.4	175.1	161.1	58.5	47.0	30.3	8.6	878.7
1984	16.3	16.8	66.6	112.3	138.4	115.1	113.6	114.2	54.9	35.9	16.3	8.5	808.9
1985	15.4	50.5	43.2	101.8	174.9	129.4	129.7	94.5	89.4	59.3	19.5	17.2	924.7
1986	10.1	47.5	53.4	84.8	208.0	187.5	149.6	66.6	122.9	50.1	23.3	8.4	1012.2
1987	31.4	63.6	100.4	115.3	118.5	69.3	169.8	79.9	97.3	42.8	21.2	13.4	922.8
1988	1.9	4.3	46.3	120.4	212.4	137.5	128.7	97.3	118.3	72.2	47.2	25.9	1012.3
1989	24.0	48.0	44.4	89.2	208.4	183.2	177.1	111.3	107.8	56.7	21.2	15.7	1086.7
1990	10.3	15.0	100.9	132.9	189.6	175.9	117.0	131.1	41.3	48.0	28.3	14.5	1004.9
1991	22.8	26.9	35.6	115.4	122.7	92.1	188.8	119.3	115.1	39.8	8.7	8.7	896.0
1992	23.7	24.5	38.6	57.5	198.8	192.5	145.0	90.4	63.4	26.2	12.0	8.1	880.7
1993	14.5	30.4	62.0	124.1	192.1	147.6	103.2	89.9	90.1	48.4	3.5	8.7	914.6
1994	18.3	51.4	75.2	106.1	210.3	171.5	261.9	106.9	71.3	71.7	35.2	11.8	1191.8
1995	18.3	42.7	49.1	111.2	144.5	158.1	181.0	194.0	80.7	63.5	28.0	32.3	1103.5
1996	17.1	54.9	86.1	152.4	128.8	132.1	149.0	174.3	112.3	52.1	18.0	24.8	1101.7
1997	35.3	48.2	128.1	147.7	172.4	177.0	194.0	158.9	99.6	62.7	18.5	3.0	1245.6
1998	12.6	20.9	75.3	46.5	176.0	97.5	122*)	99.4	83.8	49.6	18.0	8.4	810.0

*) *Calculated value*

GLOBAL IRRADIATION, H_g (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	8.6	33.0	52.1	78.7	141.3	158.4	173.4	140.5	62.7	36.3	15.5	5.7	906.1
1984	9.4	19.3	64.8	111.9	152.4	142.3	137.3	120.6	56.6	26.6	10.6	4.3	856.0
1985	10.8	32.9	49.4	97.8	163.9	153.7	144.9	111.6	74.2	39.6	12.3	6.2	897.2
1986	7.1	32.7	53.1	97.1	173.2	175.4	157.9	97.4	88.0	34.4	12.2	5.0	933.6
1987	13.9	32.0	70.8	114.7	133.7	114.5	164.0	99.7	80.9	35.2	13.0	6.1	878.6
1988	3.9	15.4	54.7	109.9	176.4	154.9	148.3	112.6	85.0	42.4	17.2	7.8	928.4
1989	10.8	21.7	46.2	98.5	180.6	177.7	167.7	120.8	81.7	37.3	11.8	6.7	961.4
1990	7.7	18.4	71.7	115.4	162.2	174.6	136.7	130.0	53.3	35.3	13.4	5.3	923.9
1991	11.4	20.9	40.9	110.1	134.1	123.2	176.7	124.7	87.5	34.8	9.9	7.1	881.3
1992	12.7	26.5	54.2	86.6	191.8	199.6	164.5	118.4	71.3	35.4	11.3	6.1	978.3
1993	11.7	24.5	63.7	116.2	180.7	163.9	138.8	111.2	78.0	34.2	6.5	4.6	933.9
1994	9.4	28.7	62.8	108.8	178.1	167.6	208.7	115.2	63.6	40.3	15.1	5.1	1003.3
1995	10.7	26.2	52.8	102.1	150.3	160.0	173.9	149.8	63.6	40.4	13.8	9.4	952.9
1996	8.0	28.5	65.4	125.4	140.5	158.5	149.7	147.9	82.0	33.4	11.0	7.3	957.5
1997	13.3	23.7	78.7	117.8	153.9	167.6	180.5	141.5	76.9	37.7	10.6	3.6	1005.7
1998	9.4	21.2	60.3	89.8	158.0	119.6	143.1	113.6	71.3	34.7	11.5	5.0	837.5

STOCKHOLM
(59.35° N, 18.07° E)

DIFFUSE IRRADIATION, H_d (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	7.3	20.8	38.4	50.7	77.8	77.9	72.9	57.2	38.9	22.9	10.4	4.8	480.0
1984	7.2	15.3	39.6	54.2	75.8	77.2	73.2	62.0	32.8	16.8	8.0	3.4	465.5
1985	8.6	20.2	32.2	49.6	66.0	79.0	74.8	64.6	38.8	23.9	8.7	4.4	470.7
1986	5.8	20.6	33.6	56.6	59.0	70.3	74.2	63.8	38.5	19.4	8.0	4.1	453.8
1987	9.5	16.3	34.7	59.4	68.2	76.8	73.6	60.3	40.2	22.0	8.9	4.6	474.4
1988	3.7	14.4	37.5	51.0	61.6	77.0	78.2	63.2	36.1	21.6	9.3	5.0	458.5
1989	7.4	10.9	30.3	56.1	66.0	75.4	69.1	63.9	37.1	21.1	8.4	5.0	450.7
1990	6.3	15.0	34.7	52.9	62.5	76.2	71.2	63.3	37.5	21.5	8.5	3.8	453.3
1991	8.1	14.5	27.2	55.9	70.4	75.0	70.2	63.5	38.7	22.7	8.5	6.1	460.8
1992	9.1	20.2	39.2	57.0	76.7	84.9	82.1	70.0	44.4	27.4	9.0	5.2	525.2
1993	9.4	17.8	39.7	53.4	72.2	80.5	80.2	66.1	41.4	21.1	5.8	3.7	491.1
1994	6.6	15.7	35.2	57.2	65.1	73.2	62.7	61.8	35.1	19.2	9.4	3.9	445.1
1995	8.4	16.1	34.2	50.0	72.1	70.0	73.9	50.4	31.4	22.4	9.3	5.9	444.0
1996	5.4	15.7	35.0	53.1	70.5	81.3	66.9	58.8	38.1	18.2	7.9	4.6	455.5
1997	8.2	12.7	32.5	49.8	62.5	69.0	72.4	60.8	37.2	21.6	7.1	3.3	437.0
1998	7.4	15.8	34.7	67.7	63.8	67.2	72*)	61.9	35.4	20.5	8.4	4.2	458.9*)

*) *Calculated value*

SUNSHINE DURATION, *SD* (Hours).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	24.0	118.0	82.0	109.0	228.0	268.0	301.0	284.0	126.0	99.0	75.0	29.0	1743.0
1984	44.0	43.0	128.0	210.0	258.0	220.0	191.0	202.0	99.0	70.0	41.0	23.0	1529.0
1985	37.0	106.0	81.0	172.0	306.0	233.0	231.0	172.0	177.0	127.0	39.0	42.0	1723.0
1986	24.2	100.3	99.2	152.4	329.3	306.6	258.6	125.4	189.7	89.1	46.7	21.6	1743.1
1987	80.2	111.8	175.1	206.1	190.7	126.9	275.8	134.4	154.6	90.9	47.0	35.1	1628.5
1988	5.7	11.1	85.7	190.8	337.8	232.6	238.9	166.4	190.9	136.8	93.4	61.3	1751.4
1989	55.6	87.1	79.1	168.6	329.4	301.9	284.3	190.2	177.8	98.9	55.6	36.4	1864.8
1990	26.6	35.5	168.3	232.6	303.5	286.1	192.9	221.2	76.3	91.5	57.2	35.0	1726.8
1991	56.6	50.7	61.8	211.4	194.6	173.9	306.2	212.0	196.2	82.4	24.0	34.1	1603.8
1992	73.4	65.4	90.5	113.8	358.1	344.9	267.8	178.4	136.6	62.1	34.0	32.1	1757.1
1993	50.6	74.1	125.8	226.3	333.0	250.8	184.6	166.8	157.9	94.8	9.0	24.5	1698.1
1994	43.1	96.0	130.4	196.4	325.0	275.3	423.9	190.4	120.0	117.3	72.7	29.5	2019.9
1995	44.7	80.1	87.2	179.1	245.9	264.2	305.3	307.8	125.9	117.4	57.2	73.2	1888.1
1996	37.4	99.1	142.8	253.4	217.4	218.6	232.7	302.1	175.5	91.5	40.5	55.9	1866.9
1997	78.3	83.7	203.0	229.0	261.1	290.7	326.9	280.2	160.1	104.4	35.9	7.0	2060.4
1998	28.7	40.3	128.0	131.2	283.5	157.0	201.4*)	165.6	138.0	85.5	38.0	20.2	1417.2

*) *Calculated value*

NORRKÖPING
(58.58° N, 16.15° E)

DIRECT IRRADIATION, H_b (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	2.6	2.2	23.8	48.2	85.9	156.1	177.4	155.3	68.6	54.6	36.4	13.2	824.2
1984	15.5	14.4	76.8	112.1	118.0	115.6	145.7	118.2	54.9	31.1	23.1	10.3	835.6
1985	16.7	46.7	27.8	77.4	155.1	105.9	133.8	85.1	98.0	72.1	26.0	6.8	851.6
1986	10.0	58.4	65.1	70.6	196.2	193.8	131.2	83.4	139.6	67.3	29.2	10.6	1055.4
1987	27.0	69.8	98.8	117.2	132.4	66.4	151.5	80.9	108.7	50.0	29.5	22.5	954.6
1988	3.6	12.5	60.5	112.1	201.8	147.0	113.5	118.1	111.5	54.7	52.1	27.8	1015.1
1989	24.6	41.1	42.7	101.3	193.8	176.2	190.2	110.9	96.2	61.9	27.8	18.1	1084.7
1990	12.6	20.3	102.8	120.8	186.7	155.2	124.6	131.4	41.3	60.9	30.7	12.4	999.7
1991	33.7	37.8	39.0	118.7	157.5	79.4	180.8	116.4	122.3	43.4	12.6	11.6	953.1
1992	25.1	27.3	48.6	65.7	200.3	187.1	145.5	87.1	69.6	31.1	10.9	11.5	909.8
1993	20.6	29.8	64.0	121.8	195.0	158.5	103.1	101.8	92.9	51.9	2.0	6.1	947.3
1994	17.9	40.7	83.1	114.2	204.6	165.0	256.4	110.7	71.5	72.9	34.1	16.2	1187.3
1995	34.7	38.8	52.2	116.3	135.8	137.3	176.4	204.0	56.9	71.0	30.9	27.9	1082.0
1996	14.6	52.3	79.6	139.3	78.7	122.6	146.5	178.7	118.9	52.9	17.7	25.5	1027.2
1997	44.2	53.5	146.7	142.2	148.1	154.8	206.5	161.2	104.1	75.8	16.3	5.8	1259.1
1998	31.1	22.5	89.1	64.6	162.9	108.4	118.4	108.7	66.1	48.5	18.7	8.2	847.0

GLOBAL IRRADIATION, H_g (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	10.9	34.1	52.7	74.2	126.3	172.9	184.3	146.8	68.8	42.6	17.8	7.3	938.1
1984	11.3	22.2	69.8	112.1	143.2	158.8	169.5	126.1	62.0	29.9	12.9	5.4	923.1
1985	12.0	34.4	46.0	91.3	163.3	141.0	157.3	112.2	78.5	44.5	15.2	6.5	902.1
1986	9.8	33.5	59.1	89.6	176.0	180.6	156.6	108.2	93.2	41.8	15.3	6.5	970.0
1987	14.7	35.3	72.7	112.1	142.1	117.2	165.3	100.3	80.7	36.5	14.7	8.5	900.2
1988	5.5	20.6	65.0	106.9	176.8	164.5	142.4	125.3	84.5	38.1	19.6	9.3	958.3
1989	11.9	24.6	47.7	108.3	177.9	175.1	175.3	122.0	79.3	41.1	14.1	7.7	984.8
1990	9.8	21.5	76.3	113.7	174.1	168.7	146.9	133.6	58.4	39.9	14.9	6.3	964.0
1991	14.4	26.1	45.1	116.6	144.7	119.3	176.4	123.3	91.3	36.2	11.3	8.4	913.1
1992	13.7	26.7	53.7	92.1	189.4	194.6	165.9	116.8	73.2	35.8	11.3	8.3	981.5
1993	14.1	26.3	68.4	117.8	181.9	174.0	137.5	118.2	77.1	37.5	6.5	5.9	965.3
1994	10.4	28.7	70.8	114.5	177.8	169.1	207.8	118.8	66.4	42.6	15.9	6.9	1029.7
1995	13.3	26.6	58.2	106.6	148.0	146.7	171.5	159.1	57.6	45.4	16.1	8.9	958.0
1996	9.4	32.1	67.6	122.8	114.3	156.5	152.1	151.0	85.8	36.6	12.3	8.2	948.5
1997	15.6	27.9	86.2	120.2	153.5	166.5	187.3	147.3	83.8	42.1	11.5	4.7	1046.6
1998	12.5	22.0	69.8	81.7	161.2	132.9	145.7	123.1	69.3	38.9	12.7	6.6	876.5

NORRKÖPING
(58.58° N, 16.15° E)

DIFFUSE IRRADIATION, H_d (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	10.3	31.7	42.2	50.1	78.1	80.1	80.5	65.8	40.6	26.6	11.3	5.7	523.0
1984	9.1	18.6	41.1	54.2	78.0	90.3	85.4	64.4	37.4	21.3	9.0	4.3	513.0
1985	9.5	22.6	35.4	53.9	74.2	77.5	80.4	69.6	39.2	24.5	10.3	5.7	502.7
1986	8.4	18.5	35.0	56.6	66.3	69.6	81.9	64.0	36.1	21.2	9.5	5.2	472.2
1987	10.6	17.0	36.9	55.2	67.3	78.9	81.5	59.8	35.2	20.9	8.9	5.8	478.0
1988	5.0	17.4	42.4	52.3	65.6	78.7	78.0	63.6	37.2	22.6	10.3	6.2	479.1
1989	8.2	14.6	31.0	57.6	71.4	78.0	71.5	66.8	40.1	22.5	9.7	5.7	477.0
1990	7.9	16.5	37.7	55.6	72.8	78.4	76.7	66.9	41.5	22.5	9.6	4.9	491.0
1991	9.2	16.4	29.2	59.6	61.9	77.5	73.5	63.5	40.6	23.1	9.0	7.1	470.7
1992	9.8	19.6	34.3	58.6	72.9	82.9	82.0	71.4	43.6	25.8	9.2	7.0	516.9
1993	10.9	19.5	42.6	54.8	73.0	80.9	79.1	67.0	38.4	23.4	6.2	5.3	501.0
1994	7.6	18.2	39.3	58.4	68.1	78.0	63.0	60.7	37.4	20.6	10.2	5.1	466.5
1995	8.4	17.5	38.1	50.7	73.7	68.4	72.3	53.1	34.8	24.6	10.5	5.8	457.7
1996	6.9	19.4	38.6	56.0	74.4	84.6	71.3	57.4	38.3	20.5	8.9	5.4	481.6
1997	8.8	15.3	32.5	52.7	74.1	77.7	72.8	63.2	40.9	21.1	8.1	4.0	471.0
1998	7.3	16.1	37.6	49.6	71.6	73.9	78.6	65.9	40.5	24.5	9.3	5.7	480.6

SUNSHINE DURATION, *SD* (Hours).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	38.0	110.0	72.0	98.0	180.0	282.0	318.0	279.0	124.0	112.0	83.0	37.0	1733.0
1984	41.0	33.0	145.0	199.0	218.0	210.0	249.0	202.0	93.0	60.0	56.0	27.0	1533.0
1985	37.0	96.0	50.0	130.0	272.0	190.0	225.0	161.0	151.0	137.0	52.0	16.0	1517.0
1986	25.2	108.2	120.8	119.7	305.4	297.2	229.7	143.3	205.1	117.4	57.4	25.6	1754.9
1987	66.3	116.0	167.9	202.3	200.3	119.0	253.0	132.9	166.9	96.4	58.5	54.5	1634.1
1988	9.4	25.8	106.4	179.0	318.8	245.0	195.1	191.9	178.0	101.4	97.1	63.3	1711.3
1989	54.7	72.7	70.8	178.0	305.8	292.3	291.7	195.7	163.1	107.9	62.7	43.1	1838.4
1990	30.3	42.9	172.0	201.5	299.2	257.4	203.7	233.4	74.3	108.4	57.6	29.2	1709.8
1991	73.2	68.1	64.0	205.1	230.5	146.3	293.3	206.1	208.8	85.1	31.4	39.9	1651.8
1992	68.4	63.3	102.5	126.8	351.5	328.4	259.9	171.8	130.3	63.2	28.8	42.5	1737.5
1993	67.3	68.3	122.2	215.1	330.2	255.4	181.2	183.2	155.7	95.7	4.9	16.6	1695.8
1994	39.8	74.4	140.9	206.1	316.5	263.4	405.0	191.0	119.4	117.7	70.5	40.7	1985.3
1995	72.9	69.8	90.1	178.9	222.7	216.8	287.5	318.1	92.4	126.5	62.0	63.6	1801.2
1996	29.4	87.8	130.5	220.7	143.6	203.2	230.7	289.1	186.4	90.3	32.7	55.9	1700.2
1997	88.0	88.8	222.7	210.4	235.1	251.9	329.3	291.5	172.4	123.1	30.7	12.7	2056.6
1998	56.8	41.0	140.5	108.8	258.8	171.8	185.9	182.8	111.9	87.6	35.0	21.2	1402.1

GÖTEBORG
(57.70° N, 12.00° E)

DIRECT IRRADIATION, H_b (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	8.2	52.0	32.9	37.2	57.2	141.9	153.7	127.0	59.0	40.5	34.4	11.8	755.7
1984	12.8	17.6	77.8	111.7	126.3	106.0	143.5	115.4	64.2	31.5	21.5	8.5	836.8
1985	26.3	50.7	36.0	64.2	149.5	103.5	120.9	74.8	73.8	53.0	29.3	6.9	788.8
1986	14.8	77.5	35.2	83.6	119.4	198.6	114.7	112.8	108.0	54.0	25.4	8.6	952.5
1987	21.5	48.2	86.0	99.2	134.0	57.2	115.1	78.4	89.0	44.9	12.2	20.2	805.9
1988	4.3	8.9	41.5	111.4	179.6	166.5	79.0	84.5	76.1	59.0	44.0	24.3	879.1
1989	11.1	18.0	48.3	105.7	184.4	209.5	178.9	93.5	112.2	46.5	38.0	15.4	1061.6
1990	7.2	30.8	90.4	108.0	188.5	126.8	168.3	131.1	66.7	60.1	30.0	18.5	1026.4
1991	27.6	39.0	39.8	109.4	182.9	72.1	173.3	119.2	99.2	64.1	15.5	12.4	954.4
1992	20.2	26.0	42.6	56.4	176.8	193.3	127.1	75.0	65.3	47.5	13.1	9.9	853.0
1993	13.9	30.4	70.2	126.5	151.8	164.3	74.3	97.6	68.3	54.1	6.3	8.9	866.6
1994	19.7	34.5	60.8	91.9	188.1	140.2	226.9	118.6	46.3	62.1	25.7	6.9	1021.9
1995	28.0	36.9	74.7	107.2	134.8	131.5	156.6	217.1	70.5	45.4	29.9	22.8	1055.5
1996	15.6	51.1	109.9	110.2	78.4	125.7	176.6	153.5	114.5	30.2	13.6	21.3	1000.5
1997	28.2	38.1	106.2	147.0	124.1	169.5	191.5	166.2	109.5	72.1	21.1	12.8	1186.4
1998	28.9	15.9	88.5	50.5	158.9	108.6	114.6	90.4	46.6	40.6	15.0	16.7	775.1

GLOBAL IRRADIATION, H_g (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	10.3	34.4	46.3	78.3	110.9	164.6	171.7	133.5	73.3	35.2	16.2	7.2	881.8
1984	11.9	20.3	69.6	109.5	150.1	141.7	168.2	127.4	67.0	32.6	12.9	6.2	917.5
1985	13.3	31.5	49.2	84.0	159.3	135.6	150.4	112.4	70.3	40.8	16.9	5.9	869.5
1986	11.6	41.2	46.4	95.0	143.6	179.0	148.4	123.4	87.0	37.5	14.9	6.6	934.5
1987	13.1	29.7	69.7	101.5	142.7	107.8	143.1	100.9	78.5	37.4	12.7	9.4	846.5
1988	6.4	20.7	50.1	103.8	173.5	177.3	128.3	118.2	74.4	39.9	18.4	9.1	919.9
1989	8.9	18.5	51.9	104.1	168.1	189.2	170.7	111.6	84.6	36.4	16.6	7.7	968.2
1990	8.1	23.5	69.5	110.0	168.4	154.0	161.9	127.7	70.2	38.2	15.6	7.9	955.0
1991	13.1	25.9	43.9	111.4	167.9	124.8	176.5	132.6	84.5	45.8	13.2	8.3	947.9
1992	13.1	24.2	52.5	88.1	178.9	205.8	172.3	111.1	80.3	40.8	12.7	7.6	987.3
1993	12.2	24.7	69.3	122.6	162.6	180.7	119.1	114.2	71.8	38.7	9.3	6.4	931.5
1994	11.4	29.5	62.1	106.3	181.4	159.1	200.9	128.5	60.5	40.7	14.9	5.9	1001.4
1995	13.2	24.3	63.6	108.3	147.9	148.1	160.1	167.0	67.7	35.5	16.7	8.8	961.1
1996	9.7	29.5	76.8	117.9	107.9	157.4	180.8	142.1	90.9	34.3	12.1	8.3	967.6
1997	12.2	25.2	79.0	120.2	141.2	173.5	179.7	146.6	89.1	42.8	13.1	6.5	1029.1
1998	14.0	18.8	72.8	81.8	163.0	130.2	143.7	110.2	59.9	35.0	13.6	8.1	851.1

GÖTEBORG
(57.70° N, 12.00° E)

DIFFUSE IRRADIATION, H_d (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	8.9	20.3	33.0	59.0	77.2	77.7	81.4	65.5	48.0	22.6	9.7	5.6	508.7
1984	9.9	15.6	39.9	50.5	77.7	76.9	84.6	67.3	38.8	22.8	9.1	5.1	498.3
1985	9.3	18.7	33.8	50.3	73.3	74.8	79.6	69.9	39.2	25.3	11.4	5.0	490.5
1986	9.3	20.5	32.9	55.0	76.3	61.1	81.2	63.6	41.0	20.3	9.4	5.4	476.0
1987	9.7	16.5	37.7	51.6	67.2	73.6	77.1	59.1	40.5	22.5	10.4	6.7	472.5
1988	5.7	18.2	34.9	48.4	71.3	77.1	81.2	71.9	41.3	22.5	10.1	5.8	488.5
1989	7.1	13.9	32.4	51.4	64.5	66.9	67.2	63.6	37.3	21.2	9.9	5.7	441.0
1990	6.9	14.5	33.7	55.8	63.2	78.0	66.6	60.5	41.3	20.9	10.0	5.5	456.8
1991	8.3	16.2	27.2	55.8	65.2	81.6	74.3	69.5	40.2	25.0	10.0	6.7	479.9
1992	9.7	17.0	35.0	58.5	74.5	84.9	96.5	68.2	50.9	25.2	10.0	6.3	536.7
1993	9.6	16.6	40.3	57.7	75.2	83.3	75.8	64.3	43.0	22.8	8.2	5.2	501.9
1994	8.0	20.7	38.0	59.8	76.2	75.3	70.6	65.9	40.2	21.2	10.0	5.0	490.8
1995	8.7	14.9	33.4	56.1	72.4	69.5	70.1	52.4	39.0	20.8	10.7	5.9	453.8
1996	7.2	15.8	34.8	62.6	66.0	82.4	77.7	59.7	42.1	25.2	9.3	5.6	488.3
1997	7.3	15.3	39.3	48.4	72.5	73.6	72.7	57.8	43.5	21.9	9.1	4.8	466.3
1998	8.7	14.6	39.2	55.3	73.6	68.0	76.8	63.0	39.0	22.1	10.9	5.9	476.9

SUNSHINE DURATION, *SD* (Hours).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	20.0	116.0	66.0	81.0	120.0	254.0	295.0	236.0	113.0	86.0	80.0	33.0	1500.0
1984	33.0	40.0	146.0	196.0	234.0	209.0	242.0	223.0	122.0	65.0	52.0	21.0	1583.0
1985	68.0	103.0	59.0	109.0	271.0	179.0	202.0	130.0	120.0	105.0	60.0	16.0	1422.0
1986	31.7	151.3	72.3	143.3	212.4	305.9	197.7	189.6	175.5	96.6	54.9	23.9	1654.9
1987	50.3	87.6	145.0	176.4	206.0	101.2	202.5	124.8	150.1	92.1	29.0	49.9	1414.9
1988	11.2	19.3	72.9	181.1	296.2	280.0	145.7	149.7	135.7	107.4	82.6	52.1	1533.9
1989	26.2	36.7	87.5	178.9	285.9	327.3	266.3	155.8	184.4	78.1	82.1	32.4	1741.6
1990	19.3	59.9	151.4	178.6	284.4	208.5	257.1	224.2	107.6	106.3	57.1	40.6	1695.1
1991	60.4	73.5	65.8	199.3	278.6	126.9	287.2	221.7	168.6	125.7	37.0	43.5	1688.2
1992	60.8	66.6	91.7	116.9	313.9	349.1	246.1	140.7	139.1	99.1	38.5	36.2	1698.8
1993	41.5	70.2	134.3	236.4	268.8	274.3	134.3	168.0	118.9	96.5	19.8	24.3	1587.3
1994	48.3	67.0	110.9	170.8	312.2	215.7	377.2	210.2	81.6	101.1	56.3	16.9	1768.1
1995	61.1	69.2	117.9	186.9	215.6	209.3	254.0	345.3	124.7	85.2	53.0	48.7	1770.9
1996	35.4	82.4	174.6	198.9	141.7	214.2	278.2	261.5	179.1	59.6	26.8	44.4	1696.6
1997	53.1	69.1	182.4	214.4	200.3	267.6	310.2	286.7	184.9	110.7	43.4	25.6	1948.4
1998	56.9	38.3	142.3	93.4	255.3	176.4	187.5	147.6	82.7	71.2	31.5	38.1	1321.2

VISBY
(57.67° N, 18.35° E)

DIRECT IRRADIATION, H_b (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	9.6	41.8	40.6	48.0	82.2	166.3	210.4	175.3	59.7	54.1	20.8	11.1	919.8
1984	10.7	21.9	72.7	116.7	152.7	136.9	160.4	142.7	66.7	36.5	19.9	6.9	944.6
1985	6.2	29.4	23.0	87.6	164.0	140.8	163.4	102.3	97.6	71.2	23.3	15.4	924.1
1986	2.1	36.7	80.5	88.1	214.5	209.6	164.3	115.5	135.4	66.3	28.8	9.3	1151.1
1987	5.6	53.5	80.5	135.3	136.0	132.8	180.8	104.7	113.3	64.4	21.8	11.3	1039.9
1988	2.6	7.4	55.9	115.0	236.4	167.2	125.7	136.3	105.9	55.7	32.7	26.8	1067.4
1989	28.0	47.2	52.9	103.0	258.9	203.6	216.5	116.2	111.3	56.9	20.2	12.6	1227.2
1990	12.0	26.2	112.0	152.9	214.1	192.4	142.0	165.7	44.3	60.3	22.7	11.1	1155.9
1991	32.2	12.4	50.6	139.2	168.6	139.2	238.0	129.5	125.4	57.9	10.2	13.9	1117.2
1992	22.0	21.4	45.1	82.1	214.4	211.6	171.5	112.0	71.6	29.1	8.2	11.1	1000.1
1993	19.7	24.9	59.1	145.2	222.2	185.4	142.3	144.7	110.2	64.1	2.3	4.6	1124.6
1994	12.2	31.2	78.5	109.6	235.3	242.4	291.9	130.1	71.5	73.8	36.5	11.7	1324.6
1995	14.5	41.3	52.9	142.4	165.2	169.0	195.3	186.0	73.5	79.1	21.5	20.7	1161.3
1996	15.3	49.4	99.1	167.9	78.3	157.2	189.2	189.9	116.0	42.8	22.4	16.2	1143.5
1997	48.8	53.5	145.5	140.0	191.9	199.8	213.7	184.9	103.1	66.4	14.5	7.4	1369.3
1998	14.9	29.3	84.3	97.2	189.5	123.0	159.0	128.1	94.1	58.4	17.8	15.1	1010.8

GLOBAL IRRADIATION, H_g (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	10.7	32.6	57.5	88.9	147.9	179.8	200.4	150.2	66.9	46.5	16.9	8.3	1006.5
1984	9.3	25.6	69.9	120.5	168.2	160.6	172.3	138.2	69.5	35.8	13.2	5.3	988.3
1985	11.9	30.7	53.1	97.3	175.2	162.8	176.6	117.8	82.5	47.1	17.5	8.1	980.6
1986	9.6	33.0	67.4	108.4	188.6	188.6	177.0	127.3	99.0	44.6	15.6	6.9	1066.0
1987	12.6	34.1	76.6	128.2	150.5	159.1	179.8	123.6	87.9	44.1	14.7	7.6	1018.7
1988	5.8	20.2	63.0	109.5	192.0	173.0	151.4	137.5	85.3	40.7	17.1	10.1	1005.6
1989	14.0	29.8	56.6	114.7	204.0	182.7	190.3	124.7	85.5	40.2	13.1	7.1	1062.8
1990	10.1	25.5	80.0	130.6	184.6	187.1	150.9	148.5	62.9	43.8	15.1	6.3	1045.4
1991	14.7	19.9	51.2	130.3	163.5	150.2	206.2	134.8	97.3	44.9	12.7	9.2	1034.9
1992	13.7	27.2	60.7	103.2	202.6	209.8	185.5	133.9	79.0	37.8	12.2	8.4	1074.0
1993	15.9	23.7	64.2	130.5	197.4	193.2	167.3	137.8	87.1	43.6	7.4	5.8	1073.9
1994	10.0	28.3	72.1	119.6	192.5	203.4	224.7	132.9	71.4	47.3	17.9	6.8	1126.8
1995	11.2	29.5	57.5	115.9	169.1	173.8	183.3	151.1	73.0	49.5	14.6	8.5	1036.8
1996	9.1	32.0	79.9	137.3	125.3	173.5	173.8	154.9	89.8	37.2	14.3	7.8	1034.9
1997	17.2	30.1	90.0	119.9	176.2	190.0	192.7	156.3	84.7	43.9	12.8	5.5	1119.3
1998	10.6	26.2	71.6	98.4	172.1	144.9	170.3	132.4	84.6	42.7	14.5	8.2	976.6

VISBY
(57.67° N, 18.35° E)

DIFFUSE IRRADIATION, H_d (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	9.1	21.0	40.8	63.6	99.9	77.8	72.9	57.3	41.4	30.0	12.6	6.9	533.2
1984	7.7	19.6	41.6	59.3	79.8	80.1	78.2	63.3	38.9	24.7	9.6	4.4	507.0
1985	10.8	22.9	43.4	52.8	81.2	76.9	78.5	64.8	42.3	26.1	12.4	6.2	518.3
1986	9.3	23.2	37.3	64.0	66.0	67.1	78.2	64.6	42.6	23.1	9.7	5.7	490.8
1987	11.7	19.5	45.8	58.7	72.2	78.3	76.2	68.4	38.8	23.6	10.0	6.1	509.4
1988	5.5	18.3	41.4	51.8	58.1	75.6	81.1	63.0	40.4	23.5	10.9	6.6	476.2
1989	9.4	18.2	36.3	62.0	58.4	64.0	66.8	64.3	38.0	22.1	9.4	5.5	454.1
1990	8.1	18.5	36.5	56.1	63.7	72.2	67.5	59.7	44.4	24.8	10.7	5.0	467.1
1991	9.5	16.8	30.0	59.7	68.9	69.0	68.2	65.3	41.1	24.8	10.7	7.3	471.1
1992	10.0	21.2	42.5	60.4	76.7	81.9	83.7	71.6	46.4	28.7	10.5	7.0	539.6
1993	12.6	17.9	40.0	55.9	71.2	81.0	82.0	60.7	40.3	24.8	7.0	5.1	498.5
1994	8.0	20.5	40.2	63.5	60.0	59.8	56.3	63.0	41.0	24.4	11.0	5.3	452.9
1995	9.1	18.8	36.5	47.5	75.0	72.6	71.2	54.9	41.8	24.8	10.7	5.9	468.7
1996	6.5	19.1	42.1	55.1	81.9	78.6	62.9	53.9	41.2	23.7	10.1	5.8	481.0
1997	8.8	16.5	34.5	51.4	67.7	70.1	71.6	59.4	41.2	24.5	9.6	4.6	459.9
1998	7.9	17.9	40.5	49.4	66.2	75.6	78.2	62.0	42.7	24.5	11.0	6.3	482.1

SUNSHINE DURATION, *SD* (Hours).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	26.0	90.0	88.0	110.0	223.0	293.0	335.0	303.0	121.0	116.0	53.0	35.0	1793.0
1984	28.0	49.0	133.0	220.0	283.0	244.0	270.0	241.0	120.0	79.0	49.0	17.0	1733.0
1985	12.0	60.0	49.0	155.0	303.0	251.0	281.0	182.0	158.0	133.0	46.0	36.0	1666.0
1986	5.1	68.7	140.8	167.0	338.4	323.5	270.5	195.9	207.4	113.0	60.3	23.2	1913.7
1987	20.1	94.8	149.7	231.3	215.9	221.2	292.6	183.8	181.4	126.5	42.1	26.7	1786.1
1988	7.0	19.6	98.0	189.0	358.2	278.0	232.7	218.4	172.8	103.1	66.2	57.3	1800.2
1989	64.7	100.3	92.1	190.2	391.8	318.5	337.5	201.0	184.7	96.8	46.6	28.6	2052.8
1990	29.4	57.8	182.1	261.6	327.8	305.6	222.9	267.9	78.2	115.1	42.9	24.1	1915.4
1991	71.6	27.4	82.4	242.8	253.5	221.8	381.5	229.4	209.0	112.8	25.9	45.4	1903.5
1992	62.1	52.6	107.4	158.4	372.3	366.7	312.4	214.7	143.3	69.0	20.9	36.4	1916.2
1993	64.8	56.2	113.1	259.8	378.2	297.2	242.4	236.0	177.3	119.5	6.2	11.0	1961.8
1994	30.0	54.6	125.1	198.7	347.7	348.9	457.7	223.2	125.7	125.4	78.1	28.7	2143.6
1995	31.9	75.5	89.3	224.4	267.4	267.3	320.1	299.1	121.1	144.5	46.2	44.5	1931.2
1996	30.3	89.0	161.4	276.2	140.4	257.1	277.6	307.2	182.8	78.2	48.7	39.2	1888.3
1997	91.6	90.8	223.5	211.8	286.5	310.3	344.9	331.0	171.7	109.1	29.7	18.2	2219.0
1998	30.3	53.6	145.9	164.9	290.0	199.7	251.7	208.0	164.2	102.6	38.4	37.8	1687.2

VÄXJÖ
(56.93° N, 14.73° E)

DIRECT IRRADIATION, H_b (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	9.7	51.4	37.0	41.5	37.3	121.8	168.0	160.5	55.9	28.4	31.5	10.8	753.7
1984	9.7	12.9	69.4	24.8	111.9	76.2	115.5	119.9	48.5	32.1	21.0	7.1	648.9
1985	22.6	42.1	13.4	44.0	99.9	75.8	126.6	71.7	70.9	57.1	29.9	5.2	659.1
1986	9.7	76.0	54.6	67.2	151.3	190.2	101.9	105.1	98.3	54.7	24.7	7.2	940.9
1987	26.8	50.3	100.1	105.1	120.6	54.5	85.6	67.7	70.9	38.7	9.2	24.7	754.0
1988	0.2	11.2	45.0	125.6	182.0	132.4	82.4	96.0	78.9	52.6	49.4	23.1	878.7
1989	11.0	21.6	34.0	98.6	203.4	166.3	125.3	101.2	87.0	42.5	29.3	10.6	930.8
1990	4.2	18.0	80.9	128.5	173.1	111.7	130.1	134.8	43.2	24.3	21.1	8.8	878.7
1991	22.6	23.0	32.4	92.6	143.2	46.8	171.9	86.9	82.7	47.5	9.2	7.8	766.5
1992	27.7	19.3	37.4	57.4	174.2	193.5	136.9	82.3	70.4	42.1	9.2	10.4	860.8
1993	19.0	22.3	44.1	127.6	186.5	149.9	74.9	81.5	64.3	41.6	1.7	5.2	818.3
1994	11.3	27.7	42.3	86.3	158.3	127.2	231.8	99.6	36.6	57.5	29.6	10.1	918.2
1995	26.1	25.3	43.0	91.9	107.8	133.7	165.7	193.8	48.6	51.1	24.0	23.9	934.9
1996	19.5	38.4	71.9	145.4	44.4	121.0	116.8	142.8	0.0	23.5	12.5	24.0	760.2
1997	43.0	34.7	113.0	113.0	119.9	152.8	131.1	165.0	93.7	71.6	20.7	8.3	1066.7
1998	24.0	15.6	83.1	52.0	144.7	99.8	89.3	80.9	48.3	39.9	6.9	8.2	692.6

GLOBAL IRRADIATION, H_g (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	10.4	34.9	49.9	76.9	107.6	165.4	180.7	141.5	68.9	35.6	19.0	8.8	899.5
1984	10.9	21.9	71.2	110.5	142.0	130.7	150.7	129.4	61.7	33.7	13.8	6.4	882.8
1985	14.6	35.7	39.6	86.0	154.1	128.0	149.7	105.3	70.8	46.3	17.4	7.0	854.5
1986	11.0	42.6	52.7	89.0	151.9	178.0	143.1	120.7	83.2	39.5	14.3	6.6	932.4
1987	15.2	32.4	73.9	107.3	133.3	107.8	129.3	96.3	70.9	37.4	11.0	9.4	824.2
1988	4.9	19.7	59.4	113.6	166.8	162.9	128.2	118.7	71.6	37.9	19.7	9.7	913.1
1989	8.9	20.1	44.8	112.1	178.4	166.2	162.1	118.7	79.0	36.3	15.2	7.7	949.4
1990	7.3	21.8	68.3	118.3	162.3	149.7	150.7	134.9	61.2	38.4	16.7	7.2	936.6
1991	13.8	24.0	45.3	108.5	147.2	99.6	177.8	116.8	82.1	42.2	11.9	7.8	877.0
1992	15.0	23.3	52.7	91.8	182.0	201.4	171.4	112.2	76.8	40.6	11.7	8.5	987.3
1993	13.7	23.5	55.8	121.7	170.9	164.3	125.7	113.9	67.6	33.9	7.2	6.3	904.5
1994	10.4	25.4	59.9	104.4	157.8	151.0	202.7	120.2	57.4	41.5	17.0	7.1	954.7
1995	13.9	22.6	52.1	99.3	146.7	146.5	166.5	159.3	58.3	42.7	17.1	10.7	935.6
1996	11.7	31.0	66.9	129.8	93.3	154.2	143.3	141.7	87.9	35.9	11.5	10.2	917.4
1997	16.7	23.8	78.7	105.9	140.0	163.9	166.0	149.1	85.9	44.0	12.6	5.7	992.2
1998	13.8	19.1	71.8	79.6	157.1	131.7	133.7	112.0	61.3	36.7	13.6	7.8	838.3

VÄXJÖ
(56.93° N, 14.73° E)

DIFFUSE IRRADIATION, H_d (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	8.7	19.9	34.7	54.3	85.5	91.7	81.9	56.0	44.1	26.5	12.8	7.2	523.3
1984	9.3	18.3	43.3	96.9	75.0	85.1	82.3	63.8	39.2	23.3	9.8	5.4	551.7
1985	10.8	24.5	33.8	63.0	95.7	84.1	77.9	66.6	40.6	28.3	10.9	6.2	542.3
1986	9.3	20.9	32.2	56.3	65.6	66.0	82.4	64.1	40.5	21.0	8.8	5.5	472.8
1987	10.6	18.2	36.9	52.9	63.6	74.2	80.5	60.4	39.9	24.7	9.1	5.8	476.7
1988	4.9	16.4	41.7	49.3	63.2	81.4	79.6	67.4	35.3	22.2	9.9	6.4	477.5
1989	6.9	14.2	30.7	60.1	62.8	69.7	89.1	62.4	40.3	22.6	10.0	6.3	475.0
1990	6.6	16.6	35.9	54.0	66.3	82.4	79.9	62.6	42.6	31.1	12.5	5.9	496.5
1991	9.7	17.7	31.9	62.2	67.5	74.1	77.6	69.9	44.3	26.0	9.9	6.6	497.4
1992	10.0	17.8	37.6	61.0	78.6	85.0	89.3	66.1	45.6	25.9	9.7	7.1	533.8
1993	10.1	17.7	37.8	54.5	62.1	75.4	81.1	70.6	39.0	22.0	6.9	5.5	482.7
1994	8.1	18.0	41.8	59.8	71.3	78.0	68.8	66.1	40.3	22.5	11.1	5.6	491.4
1995	9.5	16.4	35.0	53.8	83.8	69.5	70.9	55.2	37.6	25.6	12.1	7.5	476.8
1996	8.0	20.7	39.3	56.5	66.7	81.4	77.8	63.7	87.9	28.4	9.0	7.0	546.2
1997	9.2	14.5	33.9	50.3	71.3	71.6	85.3	61.0	46.3	22.8	8.0	4.6	478.9
1998	9.0	14.8	37.7	52.3	73.8	73.1	84.1	68.0	39.0	23.9	12.2	6.7	494.5

SUNSHINE DURATION, *SD* (Hours).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	26.0	101.0	68.0	79.0	124.0	221.0	299.0	268.0	101.0	55.0	74.0	30.0	1446.0
1984	23.0	27.0	127.0	168.0	199.0	134.0	199.0	215.0	82.0	61.0	49.0	18.0	1302.0
1985	51.0	90.0	21.0	88.0	224.0	139.0	212.0	127.0	110.0	111.0	54.0	10.0	1237.0
1986	19.0	121.2	93.8	112.2	236.4	302.0	184.0	197.6	165.4	89.8	45.0	17.5	1583.9
1987	63.2	86.4	167.4	186.3	175.3	94.4	153.3	118.1	115.7	80.7	20.4	41.0	1302.0
1988	0.5	19.3	76.5	196.5	284.8	220.5	152.4	161.3	122.3	95.4	84.5	48.0	1462.0
1989	24.4	36.7	52.3	178.8	308.8	263.8	192.0	159.2	141.1	73.3	57.4	23.0	1510.8
1990	8.5	36.2	132.4	211.5	263.0	192.8	214.9	222.9	77.8	78.0	56.1	21.6	1515.7
1991	46.7	43.0	59.6	168.3	214.4	87.2	284.9	162.6	137.6	93.5	20.7	24.1	1342.5
1992	73.5	45.0	81.0	119.5	311.0	354.0	258.6	157.3	135.4	83.7	23.7	34.4	1677.0
1993	56.0	52.7	84.3	229.9	270.5	247.8	136.3	148.5	109.2	75.2	4.6	13.2	1428.2
1994	20.9	47.2	77.6	162.6	259.6	208.0	393.3	180.9	70.7	99.3	66.0	21.4	1607.6
1995	49.9	47.5	72.5	159.8	214.9	217.2	268.3	312.7	81.9	94.4	42.0	52.6	1613.8
1996	38.0	68.0	112.1	246.9	86.2	208.4	196.6	230.4	149.2	44.5	22.5	49.1	1451.9
1997	78.3	54.8	172.7	165.5	187.3	227.5	239.2	293.8	158.9	111.2	34.7	16.2	1739.9
1998	44.0	32.1	129.5	103.2	242.8	157.9	151.5	133.3	80.3	70.1	16.4	19.8	1181.1

LUND
(55.72° N, 13.22° E)

DIRECT IRRADIATION, H_b (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	8.9	46.6	37.9	47.8	52.9	134.9	169.7	144.5	57.2	42.2	32.6	16.0	791.1
1984	14.2	11.3	61.6	105.7	126.1	85.2	114.2	78.4	56.9	36.0	21.5	10.0	721.2
1985	31.7	55.8	9.6	50.7	153.8	110.9	131.9	101.9	65.2	56.0	33.6	4.8	805.7
1986	14.4	68.6	51.5	63.8	148.6	176.5	131.3	112.3	90.7	53.9	25.9	11.5	948.8
1987	31.1	40.8	94.6	79.0	115.8	64.3	105.7	82.0	85.9	63.7	6.2	16.4	785.3
1988	4.6	18.7	53.1	102.4	195.2	119.5	94.5	87.3	73.0	58.4	46.0	20.2	872.8
1989	19.2	22.0	43.6	108.4	181.6	148.2	130.8	115.1	110.1	52.2	51.1	18.2	1000.4
1990	5.1	31.7	78.8	142.8	191.9	110.6	150.8	140.1	65.1	53.5	39.1	19.1	1028.4
1991	39.3	27.1	42.7	88.8	146.9	53.1	154.2	96.7	92.9	52.2	12.7	15.0	821.7
1992	23.6	17.8	41.2	55.2	182.4	197.8	148.8	85.6	83.7	42.4	18.2	11.9	908.6
1993	24.8	23.3	54.7	128.9	160.7	146.2	84.8	88.3	45.7	53.6	8.3	10.3	829.5
1994	12.8	25.5	56.1	98.2	144.8	118.2	221.1	123.2	36.6	55.7	23.9	14.6	930.6
1995	29.2	25.0	62.2	106.4	158.6	140.7	171.6	196.0	58.4	55.0	44.2	28.0	1075.2
1996	19.7	35.4	76.1	142.0	68.4	113.5	117.6	154.1	111.3	40.5	16.5	30.7	925.7
1997	39.1	40.8	105.5	114.5	120.5	152.5	160.4	166.0	88.8	70.8	27.9	14.6	1101.4
1998	35.3	20.4	100.5	54.7	157.2	115.9	79.2	77.6	50.2	33.2	22.8	24.5	771.3

GLOBAL IRRADIATION, H_g (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	12.1	38.1	51.7	83.6	115.9	169.9	186.0	144.8	74.1	41.4	20.1	11.6	949.0
1984	13.5	20.6	67.2	120.1	155.3	133.8	156.0	113.1	70.7	38.1	16.1	8.5	912.9
1985	18.7	37.6	42.5	91.5	168.0	146.9	159.9	124.6	75.3	45.1	20.4	6.4	937.0
1986	13.9	42.9	48.2	95.6	159.0	175.1	166.0	134.1	82.2	41.8	17.2	8.4	984.3
1987	18.2	31.7	77.2	101.6	136.7	119.0	140.6	113.8	84.3	50.9	12.3	9.5	895.8
1988	8.1	23.8	63.4	109.9	182.7	157.1	142.9	122.3	73.6	42.5	20.3	9.4	955.9
1989	12.2	20.8	55.6	118.1	191.7	182.0	170.5	125.3	93.1	42.7	22.5	10.5	1045.1
1990	8.5	28.6	69.2	132.6	172.4	158.4	161.1	138.3	72.8	42.1	19.9	10.2	1013.9
1991	16.9	27.0	57.3	104.1	153.6	111.6	161.4	129.1	86.6	47.0	15.2	10.4	920.1
1992	14.9	22.8	56.0	98.1	188.1	206.7	184.0	119.5	88.3	43.6	17.0	10.5	1049.4
1993	17.0	24.5	66.6	131.1	172.9	173.6	121.9	121.7	61.8	42.5	13.2	8.0	954.8
1994	11.7	26.1	61.2	121.1	158.9	156.8	208.1	134.5	61.9	45.2	18.3	8.6	1012.5
1995	15.6	23.3	62.3	107.7	162.8	164.8	187.2	166.9	67.9	46.4	20.6	12.7	1038.3
1996	12.1	32.0	65.7	132.0	107.3	151.1	155.8	151.6	94.6	43.8	14.1	11.7	971.7
1997	17.3	29.9	77.9	105.0	141.0	169.9	171.8	158.3	87.4	46.2	16.6	8.2	1029.4
1998	17.8	21.9	79.0	90.0	165.0	147.7	131.3	116.2	71.8	35.5	17.8	10.8	904.8

LUND
(55.72° N, 13.22° E)

DIFFUSE IRRADIATION, H_d (10^3 Whm^{-2}).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	10.4	24.5	36.0	58.9	83.5	87.5	83.5	64.9	48.5	27.2	13.0	9.1	547.0
1984	10.9	17.3	43.1	63.4	81.0	84.5	86.3	69.9	44.8	25.8	11.5	7.1	545.7
1985	13.0	22.6	38.3	65.6	74.1	81.0	83.3	67.9	45.9	26.3	13.4	5.7	537.1
1986	11.2	22.1	28.5	63.1	71.9	71.5	86.7	73.0	40.6	23.6	11.2	6.6	509.9
1987	12.5	19.6	40.5	59.4	70.9	78.8	77.6	69.6	45.4	28.8	10.9	6.9	520.8
1988	7.2	18.2	41.9	57.8	70.3	85.0	86.4	73.3	40.8	23.6	10.8	6.3	521.6
1989	8.4	14.3	36.9	61.6	83.8	95.7	94.4	63.1	44.6	24.8	12.5	7.8	547.8
1990	7.6	19.2	37.4	57.3	65.9	90.6	74.2	62.6	43.5	25.5	11.5	7.2	502.3
1991	9.6	19.4	38.2	59.2	70.8	80.0	71.9	75.5	43.4	29.4	12.3	8.1	517.7
1992	10.3	17.6	38.4	68.3	77.5	85.7	91.8	70.5	49.1	28.8	13.0	8.7	559.6
1993	12.0	17.4	43.0	62.1	79.5	84.8	72.9	74.1	41.5	26.2	11.2	6.5	531.1
1994	9.0	18.9	37.6	69.4	74.9	84.4	77.2	68.0	45.4	26.7	13.0	6.3	531.0
1995	10.3	16.5	36.3	53.4	71.5	81.1	85.7	61.0	41.6	28.0	11.0	8.5	504.8
1996	8.6	22.4	36.2	59.2	69.2	80.4	85.6	68.4	46.0	29.6	10.7	7.2	523.3
1997	10.5	18.3	36.5	50.4	72.1	80.9	78.5	68.7	48.1	24.5	10.5	6.1	505.1
1998	10.6	16.0	37.6	60.8	75.2	78.8	84.7	73.9	47.8	24.5	13.3	7.0	530.3

SUNSHINE DURATION, *SD* (Hours).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1983	20.0	101.0	73.0	106.0	111.0	239.0	310.0	277.0	114.0	81.0	71.0	44.0	1548.0
1984	39.0	30.0	124.0	203.0	241.0	165.0	201.0	154.0	102.0	72.0	48.0	23.0	1402.0
1985	71.0	107.0	21.0	103.0	275.0	193.0	225.0	187.0	105.0	105.0	68.0	10.0	1470.0
1986	33.6	128.5	85.1	121.3	249.1	283.2	224.0	206.5	141.2	96.5	51.3	32.2	1652.5
1987	65.5	71.8	157.3	151.8	191.1	121.4	191.2	147.1	151.3	132.8	15.2	38.2	1434.8
1988	13.6	37.1	101.8	174.4	317.2	208.4	175.7	158.0	127.6	108.3	80.7	43.7	1546.6
1989	43.5	42.5	80.2	199.8	313.9	281.6	249.4	190.3	186.2	91.7	98.5	37.9	1815.6
1990	13.4	66.6	141.6	236.1	288.4	203.5	236.2	237.2	108.0	106.5	72.6	42.1	1752.3
1991	80.7	48.7	79.4	161.1	229.6	102.1	257.3	190.8	157.7	111.4	33.2	46.7	1498.8
1992	61.4	42.8	88.4	122.7	312.5	361.0	274.8	170.4	160.4	82.0	48.3	39.1	1763.8
1993	68.0	49.0	105.5	235.7	295.1	256.5	150.6	158.7	82.1	95.9	23.8	27.5	1548.4
1994	29.4	45.7	98.9	188.4	236.0	201.4	382.7	220.5	74.3	99.5	54.3	31.3	1662.5
1995	63.1	48.4	101.2	178.2	262.7	232.4	289.6	323.7	109.1	108.5	77.1	56.4	1850.3
1996	38.1	67.2	123.7	248.8	124.2	196.7	194.5	276.9	180.4	78.8	34.4	63.9	1627.7
1997	75.9	75.9	166.8	174.1	193.0	246.9	265.3	307.1	157.8	107.4	51.8	28.7	1850.7
1998	64.0	42.5	159.0	109.6	271.3	189.7	136.2	135.3	92.7	63.5	46.2	52.4	1362.6

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