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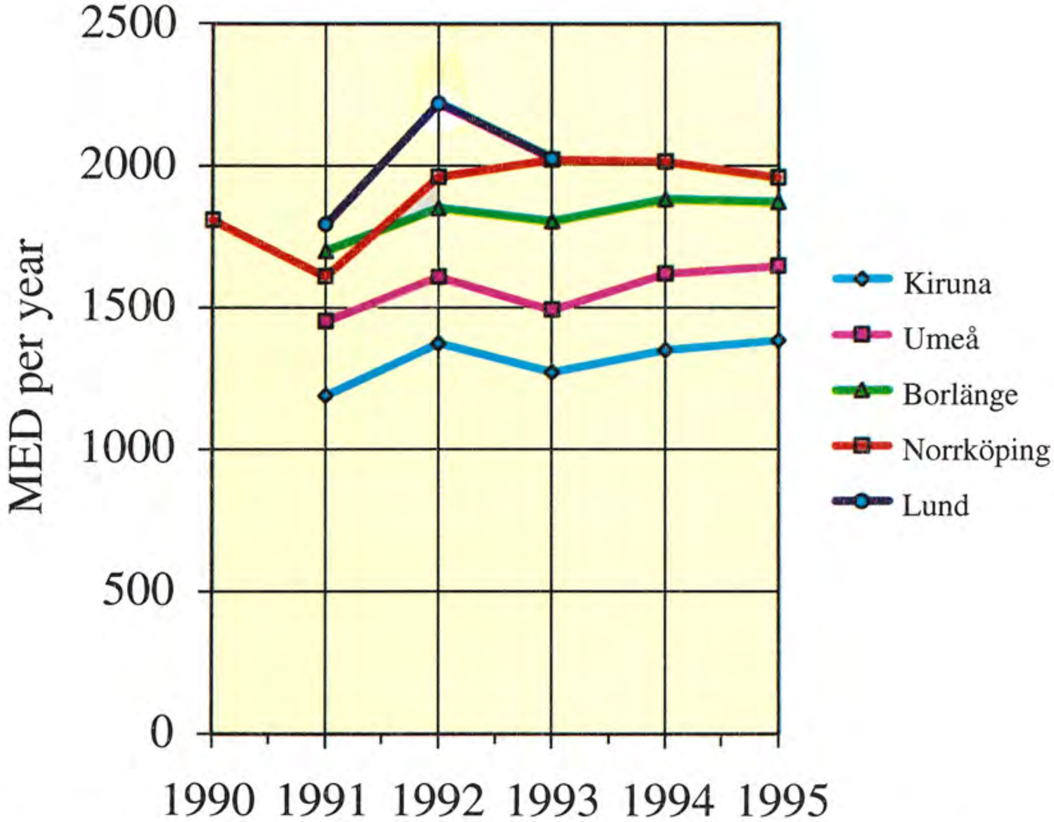

Five years of solar UV-radiation monitoring in Sweden

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Abstract/Sammandrag

A network of five stations measuring the solar UV-radiation has been operated for about five years. Data are presented as plotted time-series of monthly and yearly values for the sites. A general climatology can be deduced from these data. Daily and hourly maximum values are shown for each month as indicators of the potential extreme exposure levels. The large annual variation at high latitudes is easily seen in the data set. This illustrates the importance of the solar elevation on the level of the UV-irradiance. Influence of cloud variation and of larger changes in ozone is also detectable. A few examples of the daily variation also show the strong solar elevation dependence of the UV-irradiance.

The quantity and unit of the UV-radiation in this presentation is CIE-weighted irradiance expressed as MED (minimum erythemal dose), where one MED equals 210 Jm^{-2} . The values have been re-computed to refer to the international intercomparison of broad-band meters in Helsinki in 1995. In the following named WMO-STUK 1995 scale.

As will be seen there are many sources of error and detailed studies are prevented by the large uncertainty connected with these data. Due to the short period of the record and the low accuracy no attempt to study trends is done.

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Summary

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Acknowledgment

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1 Introduction

In 1980 SMHI was contacted by the Swedish Radiation Protection Institute (SSI). A project was initiated with the goal of estimating the levels of hazardous solar ultraviolet radiation in Sweden. The project was finalized with a report including maps with modelled monthly average estimates of damaging ultraviolet radiation based on spectral measurements and meteorological data, Josefsson (1986).

The results of the previous project did not give any details of the natural variation of the ultraviolet radiation. In particular, the temporal variation both on the short term and on the long term was unknown. Also the ongoing depletion of the stratospheric layer of ozone increased the interest of knowing the variations of ultraviolet radiation. A pilot project testing a commercially available UV-radiometer started in 1989, Josefsson (1989), followed by a project for the monitoring of the natural ultraviolet radiation in a small Swedish network in 1990. Five of the existing stations of the SMHI solar radiation network were selected to be equipped with radiometers for UV-measurements. The instruments were put into operation during 1990 or early 1991.

At the time of initiating this project there were not many instruments for monitoring UV on the market. The selected radiometers have shown to inherit technical malfunctioning as well as physical limitations regarding the attainable accuracy. In particular the UV-A radiometers. During the years a lot of interruptions in the records have occurred as well as complete break-downs of the sampling.

A number of sources of inaccuracy will give a substantial final uncertainty in the data. There is also problems connected with the calibration of the radiometers. These problems will be further discussed in following sections. Despite these draw-backs there is some useful information to be extracted from the data-set. A general climatology could be presented, such as typical yearly variation and extreme values.

2 Network

In the table below the stations are listed by latitude as well as the period of available data. The station number is according to the WMO station code. The dates for the start and end of available data is on the format year-month-day (yymmdd). It should be noted that there are many short periods of missing data. Data have been inserted in these gaps and for some of the months of start of the record by using a rough relation between UV and the global radiation that is measured at each site. This was done to get a complete data set to study.

Table 2.1 Stations and period of record.

Station	Number	Latitude	Longitude	Start	End
Kiruna	2045	67.83°N	20.43°E	901008	951231
Umeå	2283	63.82°N	20.25°E	910417	951231
Borlänge	2749	60.48°N	15.43°E	910411	951231
Norrköping	2071	58.58°N	16.15°E	900426	951231
Lund	2627	55.72°N	13.22°E	901024	940606

3 Instruments, units and calibration

3.1 Model 500 sunburning meter

The radiometer that has been used during these years are the Model 500 sunburning meter from Solar Light Co. Basically it is similar to the so called Robertson-Berger meter. However, there are some differences. The cosine response is fundamentally different. This is probably due to the difference in the phosphorus layer which is used to convert the UV to visible radiation. The recording unit is another difference which has caused a lot of problems with communication and hence loss of data. In late 1992 a Solar Light Model 501 instrument was bought. This instrument has the advantage to be temperature stabilized and hence reducing one of the larger uncertainties. This instrument has been used as reference and for special observations. It has also participated in international intercomparisons at Izaña in 1993, Koskela (1994) and in the WMO-STUK broad-band intercomparison in Helsinki in 1995.

All instruments were initially calibrated by the manufacturer. At arrival they were intercompared and differences were noted. These differences were reduced by adjusting the output signal. This intercomparison before the instruments were put into the field was used to relate all instruments to each other. If something happens out in the field it is almost impossible to detect if the change is less than 10%.

The calibration problems can be illustrated by the result of an intercomparison between two units, Figure 3.1.1. The ratio of daily values as recorded in Norrköping by the Solar Light Model 501 #922 and Solar Light Model 500 #230 (roughly temperature corrected) and using the manufacturers calibration. These instruments that are supposed to measure the same quantity differ a lot. It is worth noting that the difference not only show a solar elevation dependence but there is also a large scatter for each solar elevation.

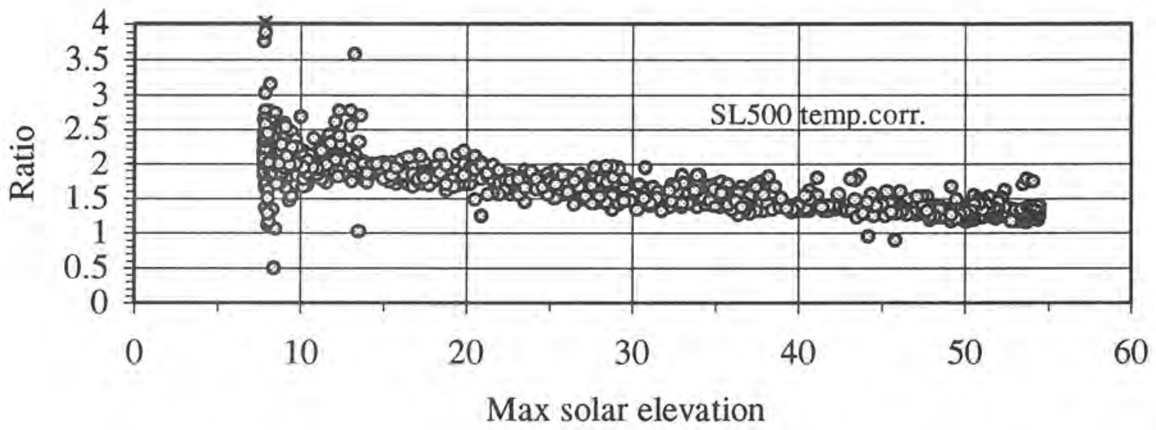

Figure 3.1.1 Ratio of daily values of Solar Light Model 501 #922 over Model 500 #230 recorded in Norrköping 1992 Nov. to 1995 Dec. (not continuously) as a function of the solar elevation around noon. The Model 500 values are roughly corrected for temperature dependence hour by hour.

Another example is from the calibration of the Solar Light Model 501 #922 instrument by use of a sophisticated and accurate spectroradiometer during very good conditions in June 1995, Figure 3.1.2. Also in this case there is a scatter of a couple of percent as well as a solar elevation dependence. A plausible explanation to the scatter and solar elevation dependence is differences in the spectral responsivity and in the directional responsivity.

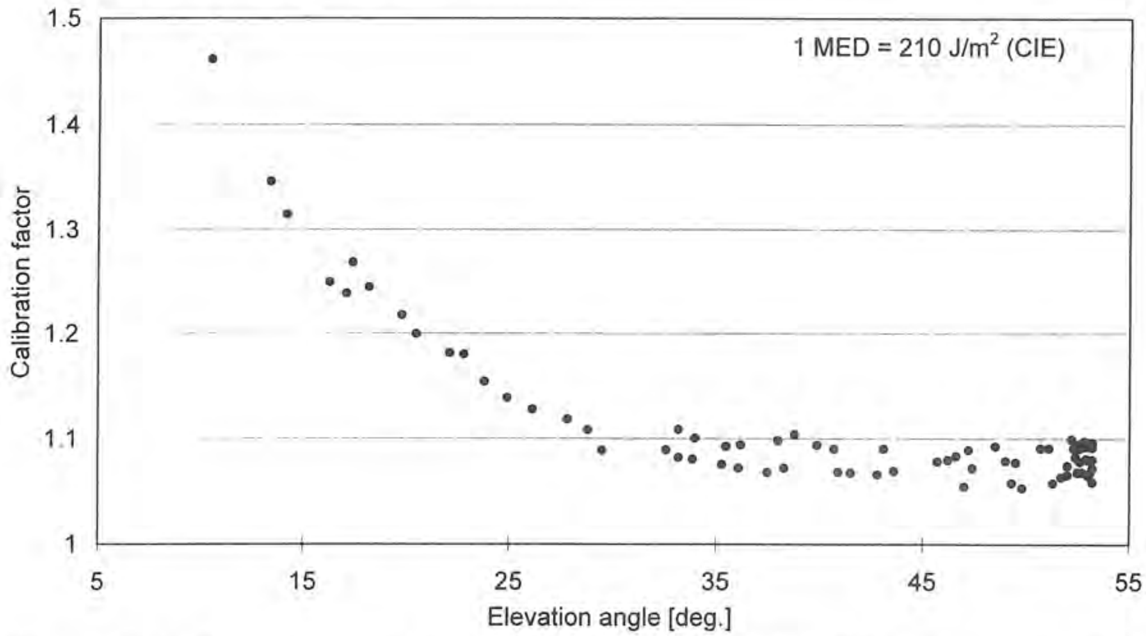

Figure 3.1.2 The calibration factor of Solar Light Model 501 #922 as measured at the WMO-STUK 1995 intercomparison in Helsinki. The reference data are cosine corrected, K. Leszczynski pers.comm.

The calibration of broad-band filter instruments is a difficult task. There is not only the lack of stable and reliable references, the instruments themselves have characteristics that will give variation in the results of a calibration. Although the manufacturer tries to build identical instruments, there are considerable differences in the characteristics of this type of radiometers, e.g. Jokela et al. (1991), DeLuisi et al. (1992). The spectral responsivity varies among instruments and it is often temperature dependent. Most of the temperature dependence can be eliminated by post-correction of the data if the temperature of the instrument is known or if it can be estimated. But, there will remain an uncertainty due to non-reproducible temperature gradients in the instrument and to the fact that the output of an instrument is proportional to the convolution of the spectrum of the radiation source and the spectral responsivity. Therefore, due to the remaining difference in the spectral responsivity the ratio of the outputs from two instruments will vary depending on the spectral distribution of the radiation source. For example, if the sun is used, the measured ratio of two instruments will be dependent on factors changing the solar spectral distribution, such as the solar elevation and the amount of total ozone. Use of a halogen lamp as radiation source will introduce radiation of wavelengths shorter than 290 nm and correspondingly the spectral responsivity of the instruments for those wavelengths will affect the result. The ratio of the instrument outputs may be surprisingly different using the sun and the halogen lamp, respectively. This problem is much smaller for the temperature stabilized instruments than for the non-stabilized. Another complication is the differences in the directional responsivity. The same type of instruments usually have similar characteristics but when broad-band instruments are compared with or calibrated using a spectroradiometer their different directionality has to be accounted for.

The calibration of the instrument in this network are traceable to the standards of an international recognized institute of standards (e.g. NIST, PTB) in a chain as below. However, they will be claimed to refer to the WMO-STUK international inter-comparison of 1995.

- 0 - *international recognized institute of standards*

- 1 - *Bentham DM 150 spectroradiometer from University of Innsbruck*

- 2 - *WMO-STUK intercomparison 1995, Solar Light 501 #922*
cosine corrected Bentham DM 150

- 3 - *intercomparison between Solar Light 501 #922 and Solar Light 500 #230*

- 4 - *network instruments intercompared to Solar Light 500 #230*

From this it can be understood that uncertainty is added in each of these step and when comparing data from two networks independently calibrated one has to be aware of the additional uncertainty. Presently, there is much efforts put into this field of the scientific community to improve calibration methods and to establish international references to reduce the uncertainty.

Table 3.1 Factors applied to records to get comparable data.

		I	II	III
Station	**Instrument number**	**Versus #423** **MED=250 Jm^{-2}**	**#230 vs #922** **MED=210 Jm^{-2}**	**WMO-STUK** **cosine corr**
Kiruna	#430	0.7556	1.17	1.083
Umeå	#424	0.7669	1.17	1.083
Borlänge	#427	0.7824	1.17	1.083
Norrköping	#230	0.9399	1.17	1.083
	#230	0.9399	1.3	1.083
Lund	#429	0.7375	1.17	1.083

In Table 3.1 Column **I** shows the factor that was applied from the original inter-comparison. At that time all values referred to instrument #423 and to a MED corresponding to 250 Jm^{-2}. The discrepancy seen in the factor of instrument #230 was caused by a change in the manufacturer calibration method. The two lines of Norrköping refer to two separate periods. the first one 1990-1992 and the other one 1993-1995.

The factor in column **II** emanates from the intercomparison between instruments #230 and #922 (Solar Light Model 501). The last column **III** gives the factor which converts from output of instrument #922 to the WMO-STUK 1995 scale using the cosine corrected values of the reference spectroradiometer. Whether one should use the cosine corrected values or not is debatable. This because the correction always will introduce some uncertainty depending of the applied method. It should be remembered that the cosine error for many instruments is of the order 10%. The advantage using a correction for this error is that the corrected values probably will be closer to the 'true' values which is an advantage for those using the data.

All the different corrections normally varies with the solar elevation as well as the total ozone. However, the applied factors are constants. They have been selected to representative for solar elevations larger than 30°. Therefore at low solar elevations as in the winter and in the morning and evening there will be an offset from the WMO-STUK 1995 scale. One of the reasons for not applying variable corrections is of course that the instruments have not been fully characterized, which makes this method impossible to utilize.

The results presented in this report are all referring to the WMO-STUK intercomparison in Helsinki 1995 with a cosine corrected reference. This would make the results more useful as they can be compared with data recorded by other instruments that are traceable to this intercomparison. The UV-radiometers used in this network have a spectral responsivity that tries to mimic the erythemal response of fair skinned people. There is an international recommendation to use the so called CIE-action spectrum for erythema for this purpose. Therefore, the unit used for the measured UV-irradiance was chosen to be MED per hour, per day, per year etc., where one MED (Minimum Erythemal Dose) is the CIE-weighted irradiance of 210 Jm^{-2}.

$$\mathbf{1\ MED = 210\ Jm^{-2}}$$

Except for the temperature correction all data has only been multiplied straight forward by factors as previously described. There is no factor depending on solar elevation, total ozone etc. Therefore, knowing the temperature and the applied factors the raw signal can be retrieved. A course correction for the improper cosine response is included in one of the factors because of the intercomparison to the cosine corrected reference spectroradiometer of the WMO-STUK intercomparison. However, as the cosine error presumably differ between the different radiometers and types of instruments this correction will probably not be very exact.

Recalling that 1 MED corresponds to 210 Jm^{-2} CIE-weighted irradiance it is possible to convert to other definitions of MED. One should remember, as noted above, that the results mainly represents the WMO-STUK 1995 scale for higher solar elevations.

3.2 Model 500 UV-A meter

These meters with a similar design as the sunburning units have a filter-detector combination giving a response in the UV-A spectral region. However, they have proved to change their responsivity dramatically over the years. Sometimes radiometers notably degrade during the first months of operation and then sets at a specific level. These units have shown a considerable degradation for more than two years and slightly slower afterwards. The responsivity has decreased by a factor 4 since the start. This will make interpretation of the data very uncertain. Trying to estimate the course of the responsivity of the individual meters will be connected with uncertainties of a magnitude that one could as well model the UV-A using the available global radiation.

The change of the responsivity is illustrated by plotting the daily ratio between the UV-A radiometer output and the global radiation, Figure 3.2.1. The latter one is measured at all stations and the uncertainty of daily values is within a few percent.

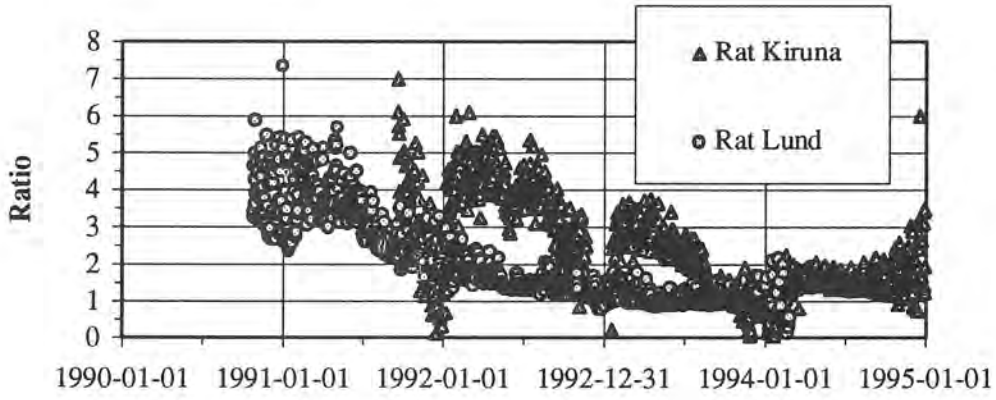

Figure 3.2.1 Ratio of daily values of Solar Light Model 500 UV-A Meter over global radiation recorded in Kiruna and Lund as a function of the time. Plotted to illustrate the decrease of the responsivity of the UV-A meters.

4 Uncertainties

UV-radiometers are far from ideal in the sense of recording the UV-irradiance. Beside of the intended response for UV they also have some response (change of voltage, resistance etc.) to variations in other environmental quantities. To reduce the inaccuracy it is important to achieve knowledge how the instrumental response is affected by different environmental factors. Such studies are called characterization and includes the instrument and its data acquisition system.

Many of these dependencies of the instrumental response are negligible for some instruments but may be of considerable magnitude for others. The following list is compiled to present the most important ones for a the UV-broad-band radiometers in this network. The list is not arranged to reflect any opinion of the magnitude of different sources of uncertainty. They often varies in complex way.

- *Directionality* (cosine and azimuth). The response depends of the angle of incidence of the radiation.

- *Non-linearity*. The response shows a non-linear dependence of the intensity of the radiation.

- *Spectral dependency*. The spectral response of an instrument varies or is different from the intended one.

- *Temperature dependency*. The response depends of the temperature.

- *Change of responsivity with time*. This is sometimes called ageing. Filters may change their properties permanently when exposed to radiation and humidity. The electronics and detectors may also change their characteristics which will affect the overall responsivity.

- *Offset and interference.* Many data acquisition systems also have characteristics that will affect the measurements. There is a noise level that should be known not mixing it with low level irradiance. Closely related to this is the existence of electrical offsets in the system. If there is no radiation the signal should be almost zero (= noise level) but some systems will produce a small signal that may be either positive or negative if voltage is measured. Normally it is negligible and can be corrected for but at low levels of irradiance it is significant.

Some characteristics such as ageing and temperature dependence are factors that may be caused by changes in other characteristics of an instrument such as spectral responsivity and non-linearity.

The overall uncertainty in these types of measurements with non-temperature stabilized broad-band UV-radiometers have been estimated, Leszczynski et al.(1994) to be ± 19 % and to be ± 11 % for the Solar Light Model 501 temperature stabilized instrument. All numbers in these paragraphs are 2σ estimates. As the presented data are roughly corrected for the temperature dependence it is plausible to assume that the overall uncertainty will be somewhere in between. These numbers are of course estimates for high solar elevations; cf. Figures 3.1.1 and 3.1.2.

Much of the presented uncertainty is systematic. Comparing data from different periods for single station will only introduce the random part of the uncertainty. This so called precision of the measurements is better, although it is not easy to state a specific number, a rough estimate would be less than ± 10% for the presented records. Intercomparing data from different stations will probably give a precision slightly larger than ± 10 %.

5 Data processing

To understand some of the difficulties it can be of interest to follow the data flow from the station to the final data base.

At the station the signal of the instrument is sampled many times an hour to get an hourly value. These values are collected once an hour along with other meteorological parameters by modems and telephone lines to a computer disk at SMHI in Norrköping. Once a month data, including the UV, from the solar radiation stations are extracted from the disk. These hourly raw UV-data are processed to remove offsets, temperature corrected (using the measured air-temperature), and inter-related to one instrument. Missing data are roughly replaced by a simple model using the global irradiance which is available from the same site. The processed hourly data are stored as monthly files along with indicators telling if the values are computed or measured.

Another program summarize the hourly values into daily and monthly values which are stored as separate files. These files are imported into Excel spread sheets where the daily and hourly data are converted to the WMO-STUK 1995 scale. The results presented in the following sections are based on these data.

6 Results

The primary data from the stations are hourly values. In this report most presentations use various types of monthly values. In Figure 6.1 all the monthly values for all stations are plotted from 1990 to the end of 1995. These monthly as well as the yearly values are also given in Table 6.1 and 6.2 in the Appendix. The most apparent feature is the typical yearly course; extremely low values in the winter and higher in the summer time. One should also note the steep increase and decrease in the spring and in the autumn. In the summer there is some difference in the maximum values that more or less is a function of the latitude.

It is not easy to quantitatively say which year is the worst or the best from these graphs. There are some months that more clearly deviates from the typical pattern than other do. An example of a month with a low value is June 1991 and one with a high value is July 1994.

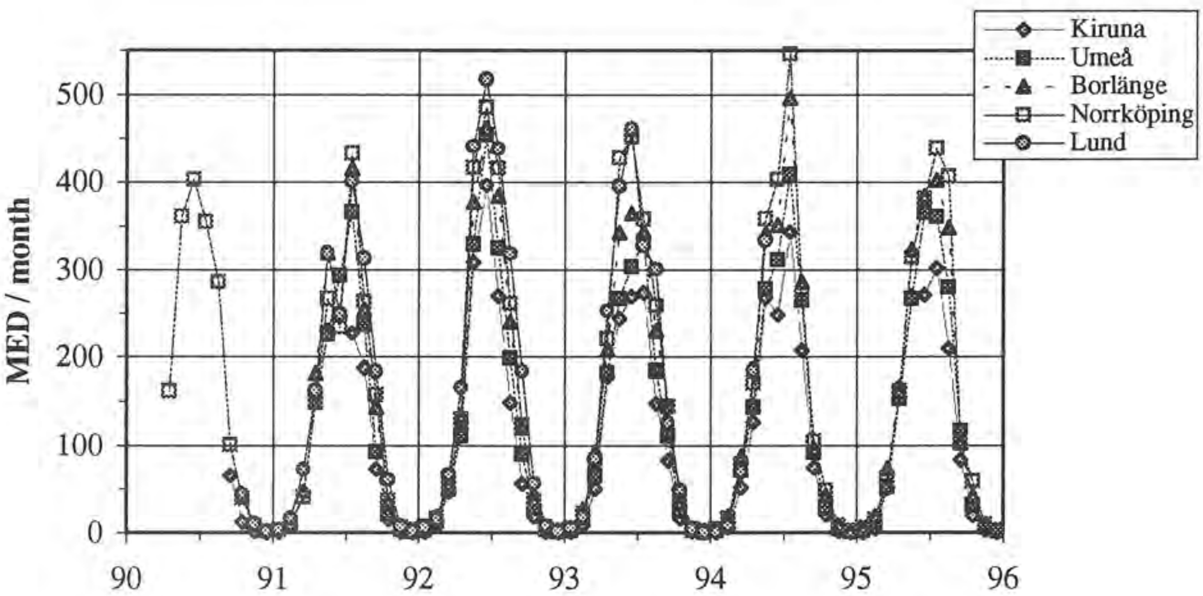

Figure 6.1 Monthly values from the five stations of the Swedish network. Unit: MED/month. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

In Figure 6.2, tracking the recorded yearly sums, the latitudinal dependence is more clear than in Figure 6.1. In Kiruna, the northernmost site, there is roughly some 1300 MED per year whilst in the southern sites Lund and Norrköping there is about 2000 MED. So in one year there is about 35% less UV in the north compared with the south of Sweden. Compared to the previous mapping, Josefsson (1986), the north-south gradient is less. For yearly values that study gave 50% less DUV in the north compared with the south. Here, one must note that the previous study calculated ultraviolet radiation that was weighted by the ACGIH action spectrum which is displaced towards shorter wavelengths compared to the CIE action spectrum. Consequently, the earlier data will show a stronger dependence on the solar elevation or latitude than the present study. Therefore, there is no contradiction.

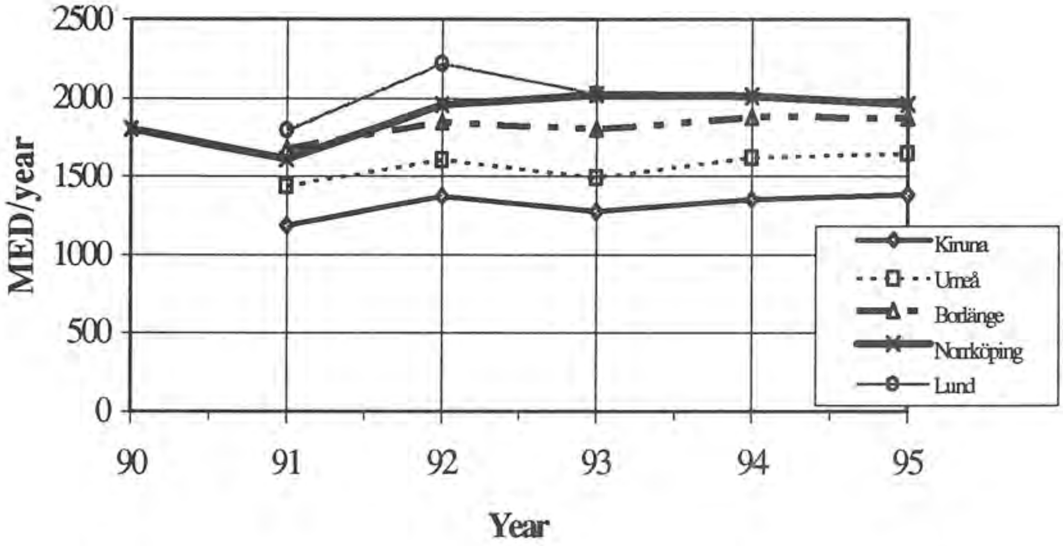

Figure 6.2 Yearly values from the five stations of the Swedish network. Unit: MED/year. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

The range of variation during this short record is roughly 20%. The lowest value can be found in 1991 a year with the thickest ozone layer within this period. There is no year which clearly could be given the attribute as the one with the highest UV within this short period. The whole period 1992 to 1995 has shown very low values of total ozone. It would have been interesting to have more data from the 1980-ties because during that decade the ozone was more abundant in our part of the world.

The following graphs are compiled in an appendix. There are three sets of similar figures presented. The first group, Figures 6.3-6.7, show all the monthly values with one graph for each station. The next group, Figures 6.8-6.12, use the same type of presentation but the presented values are maximum daily values for each month. The third and last group, Figures 6.13-6.17, shows the maximum hourly value for each month and station. The graphs are arranged in the same order. The values are given as bars representing individual years starting with 1990 (if measurements were taken that year) and ending with 1995. The shadings should be the same throughout all the figures to make intercomparison easier as well as the scales of each group of graphs.

An important difference between the three groups is that the monthly values represent the full month but the maximum values only represent one single day of a month of that specific year. Naturally, this day will in most cases be a clear day. During spring and autumn the day will probably be in that part of the month that is closest to the solar summer solstice. The amount of ozone have a less prominent role. The monthly values representing the full month will heavily depend on the cloudiness of the specific months and partly on the amount of total ozone. For the spring and autumn months the cloud and ozone situation at the part of the month that is closest to the solar summer solstice will, as mentioned above, highly influence the monthly value.

Comparing monthly values of Kiruna and Umeå, Figure 6.3 and 6.4, show that the monthly values very much show the same inter-annual pattern for the summer half year. This despite the large distance between the sites, 450 km. One exception is July of 1991. Even Borlänge, Figure 6.5, show a similar inter-annual variation as Kiruna. In this case the distance is as large as almost 900 km. The two southernmost stations Norrköping and Lund (short series) present a slightly different pattern. If this is a sign of a stationary different UV-radiation climate of the two regions is not yet to be stated.

As mentioned the figures showing maximum values represent one day each. These groups give an indication of the potential of high UV-exposure (irradiance) levels for each month of the year at each site. For example at Kiruna, Figure 6.8, one can expect daily values around 15 MED to occur in the months of May to August. But, there has not been any daily values above 20 MED observed during the latest five years. At Umeå and Borlänge, Figures 6.9 and 6.10, daily values above or around 20 MED per day have been observed around the summer solstice. Further south in Norrköping and Lund, Figures 6.11 and 6.12, in most years there are daily values exceeding 20 MED in June and July. There have even been observed such high values in May and August along with thin layer of ozone.

In Kiruna the highest hourly values of the month are recorded in the period May to July. The magnitude is between 2 and 2½ MED. In Umeå the maximum hourly value may exceed 2½ MED. The maximum hourly value recorded in Borlänge are above 2 MED from May to August. The highest recorded value is not far from 3 MED. Further south in Norrköping the level 3 MED was exceeded almost every summer and values above the level 2 MED are found from May to August. There are even two years with maximum hourly values above 2 MED in April. In Lund the 2 MED level has been exceeded also in September and values close to 3 MED has been observed both in May and August.

The daily course of average hourly values for each month of 1991 in Kiruna is shown in Figure 18 and Figure 19. The last graph is an enlargement of the first one. This to make the winter months observable. Another reason is to show the steep increase/decrease during the morning/evening. The unit is mMED per hour. On the average the noon-time UV-radiation was roughly 100 times larger in the summer compared to the November and January average. In December the sun is below the horizon most of the month (polar night). From late May to mid of July the sun is above the horizon in Kiruna (midnight sun). Despite this the UV-irradiance is below detection with these meters at midnight. Even for the maximum hourly values of each month during 1991 in Kiruna, Figure 20 and Figure 21, the UV-irradiance is below detection limit at midnight. For an individual year as in these graphs the cloudiness will affect the different months strongly. Therefore it is not possible to tell which month that is typically the most sunny. However, it is clear that during the period of the midnight sun the UV-radiation during the 'night' is very low. Another piece of information of interest for the UV-radiation is the duration of snow-cover. This because the snow reflects much of the UV. In 1991 there was snow on the ground until the 1st of May and in the autumn the snow returned in the beginning of October. This could be one reason why the values of April is not far from the August values.

A set of data from 1994 and Norrköping was selected to illustrate the daily variation in the south of Sweden. These data were recorded by the Solar Light Co. Model 501 temperature stabilized instrument. The Figures 22, 23 and 24 show the hourly average

UV-radiation for each month of 1994. The curve shapes are very similar to the corresponding curves of Kiruna. But, the level of irradiance around noon is much higher. The number of days with snow-cover in Norrköping during 1994 were 23, 28 and 14 days in January, February and March respectively. In November and December there were 1 and 4 days.

7 Conclusions

The used radiometers have shown several technical problems over the years. This in combination with high inaccuracy will limit the usefulness of the available data. The measurements of UV-A have been regarded as useless. But, the records of the sunburning UV can be used to retrieve a rough climatology, which may be useful for many applications. In particular since the data now are referring to an internationally recognized scale for UV.

In summary, regarding the daily and hourly maximum values, it seems that in the winter half-year (i.e. between the equinoxes) the UV-irradiance level can be regarded as low. Consequently, at that time of the year it is hard to get sunburned in Sweden. For most fair skinned people the risk of burning season starts in late March and ends in late September.

From the data showing the daily variation it is evident that the UV is less than 1 MED for the hours before about 7 and after 16 all the year around. Note, that this is valid for Swedish normal time. For the period with daylight saving time the time should be adjusted by one hour.

Typically, the highest values of the day always occur around noon. The highest UV radiation values of the year are found close to the summer solstice within a month or so. On average there is a slight shift towards a later date. This is due to the typical yearly course of the total ozone, with high values in the spring and lower in the autumn.

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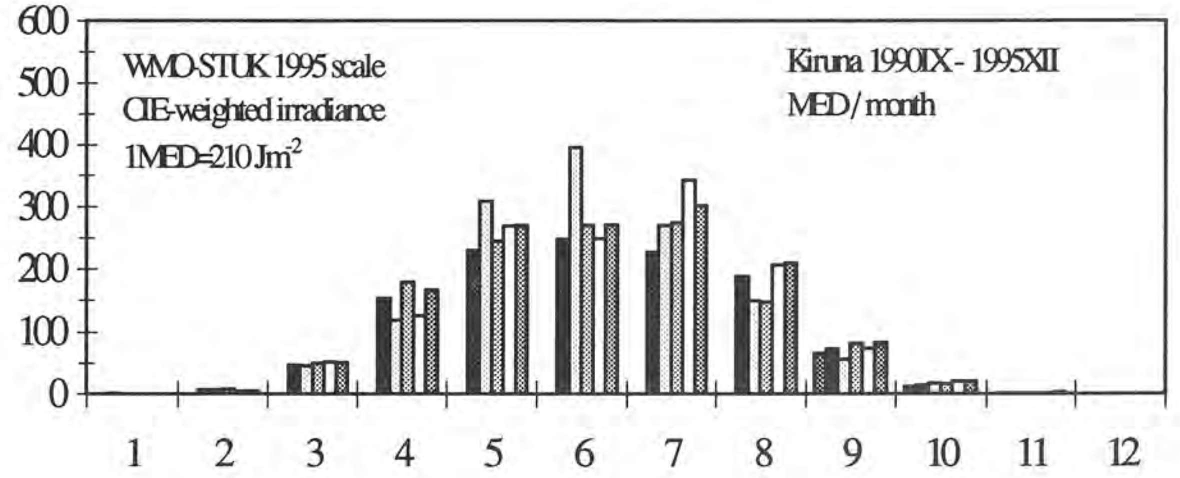

Figure 6.3 Monthly values from the station in Kiruna. The individual years are consecutively presented by different shaded bars, where 1991 has the darkest shade. Unit: MED/month. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

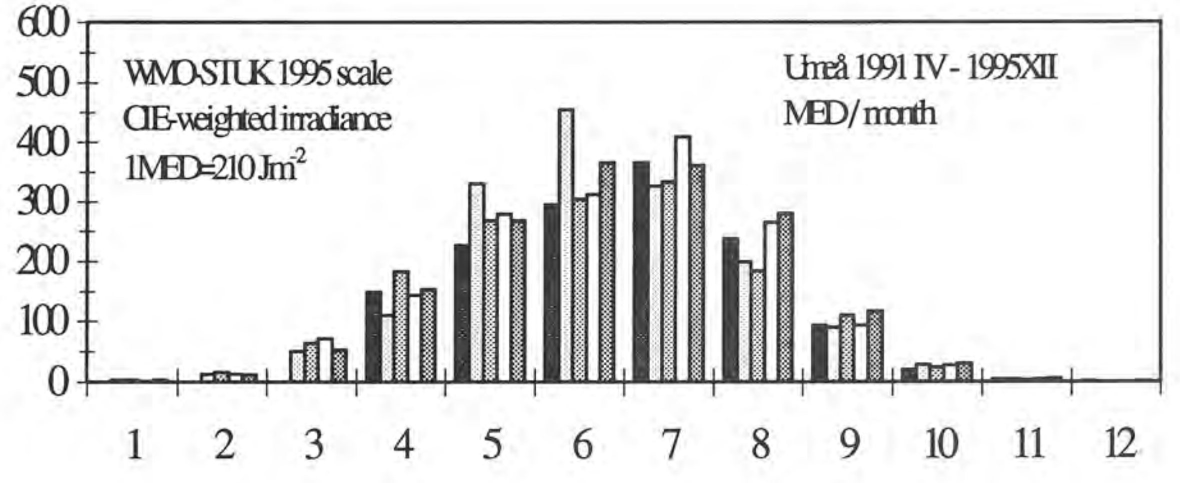

Figure 6.4 Monthly values from the station in Umeå. The individual years are consecutively presented by different shaded bars, where 1991 has the darkest shade. Unit: MED/month. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

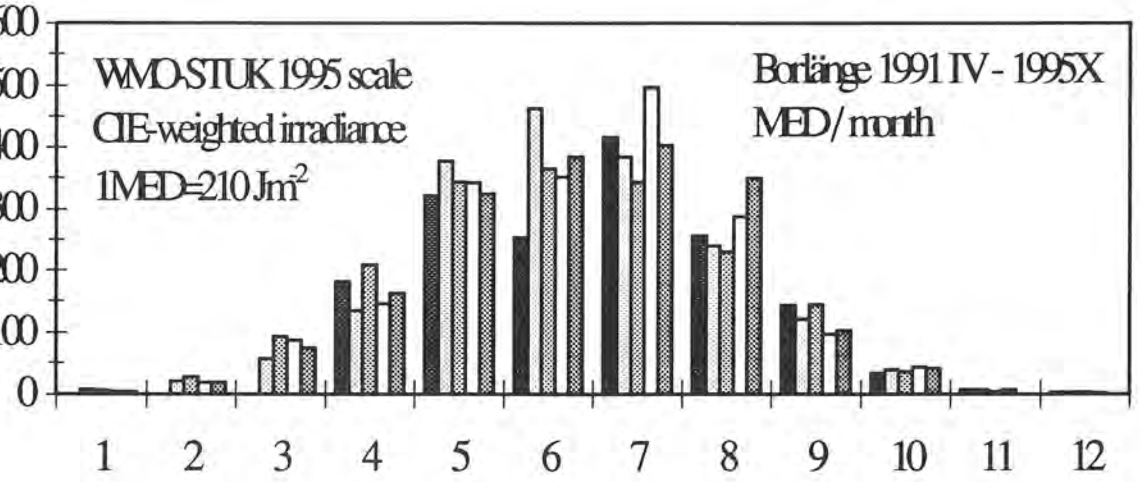

Figure 6.5 Monthly values from the station in Borlänge. The individual years are consecutively presented by different shaded bars, where 1991 has the darkest shade. Unit: MED/month. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

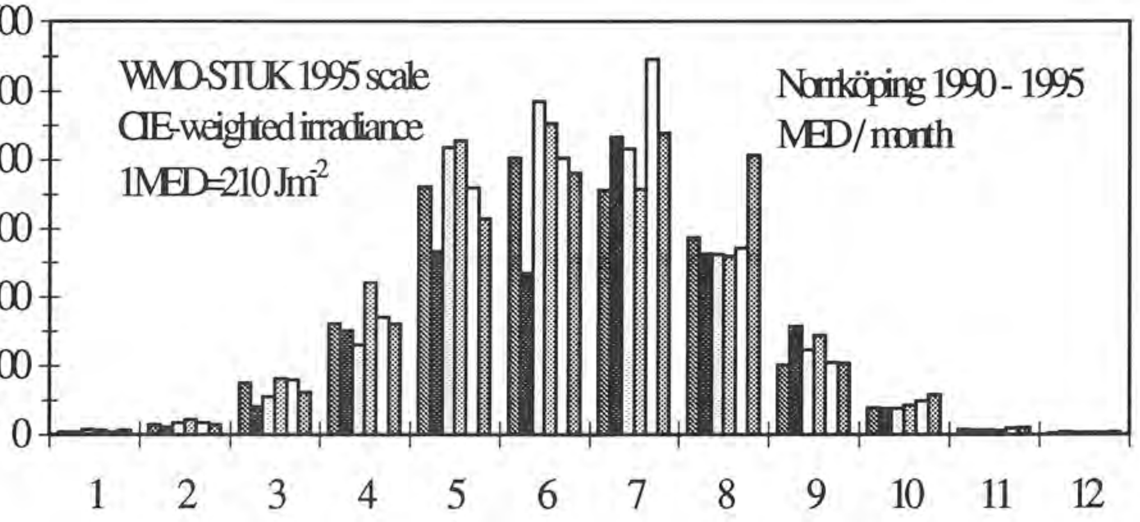

Figure 6.6 Monthly values from the station in Norrköping. The individual years are consecutively presented by different shaded bars, where 1991 has the darkest shade. Unit: MED/month. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale

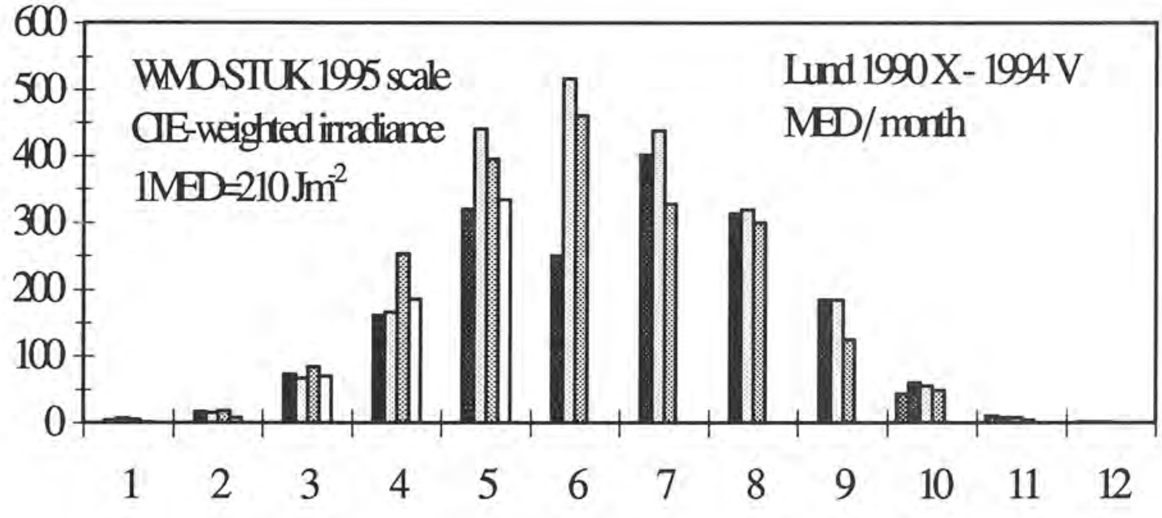

Figure 6.7 Monthly values from the station in Lund. The individual years are consecutively presented by different shaded bars, where 1991 has the darkest shade. Unit: MED/month. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale

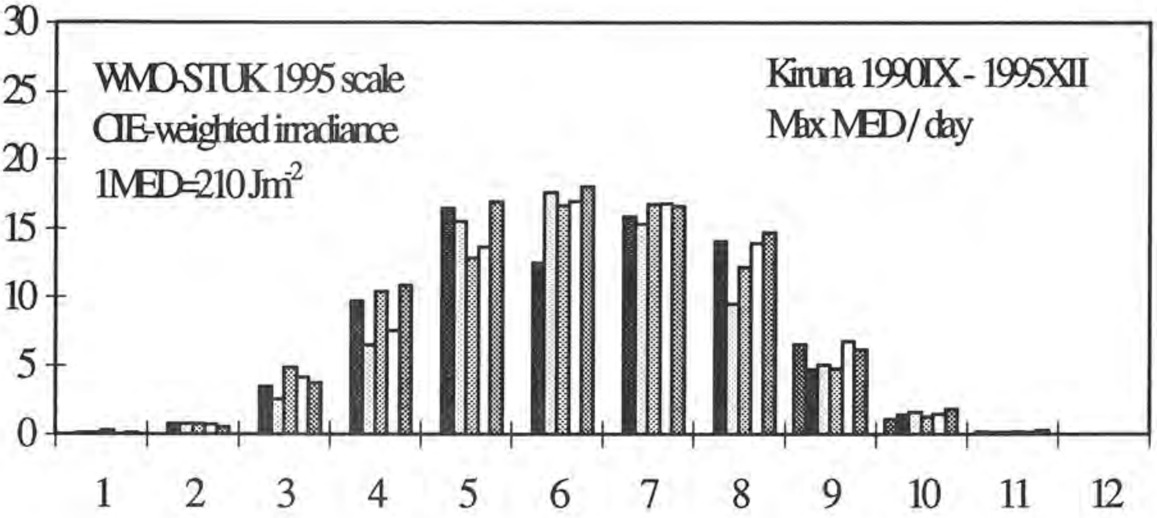

Figure 6.8 The maximum daily value of each month of each year from the station in Kiruna. Data of individual years are consecutively presented by different shaded bars, where 1991 has the darkest shade. Unit: Max MED/day. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

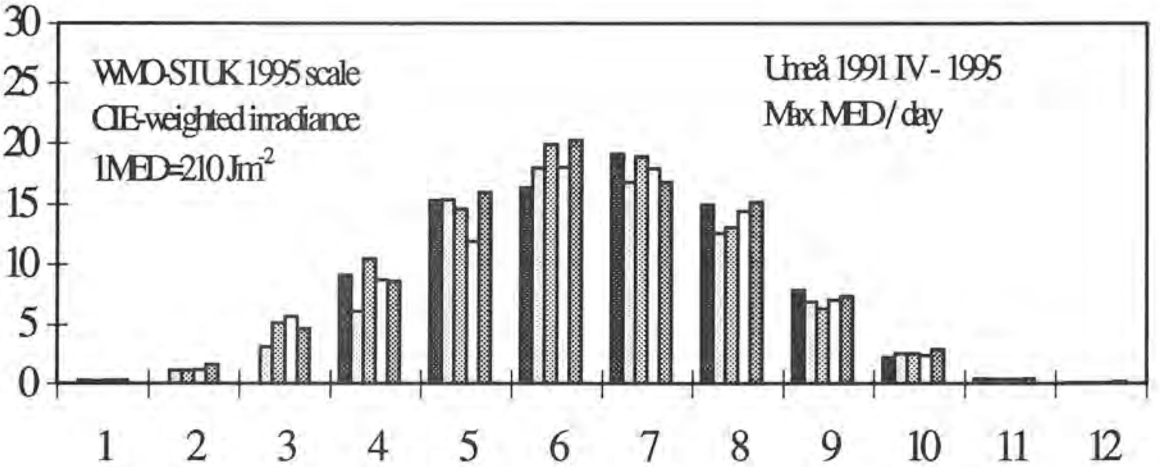

Figure 6.9 The maximum daily value of each month of each year from the station in Umeå. Data of individual years are consecutively presented by different shaded bars, where 1991 has the darkest shade. Unit: Max MED/day. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

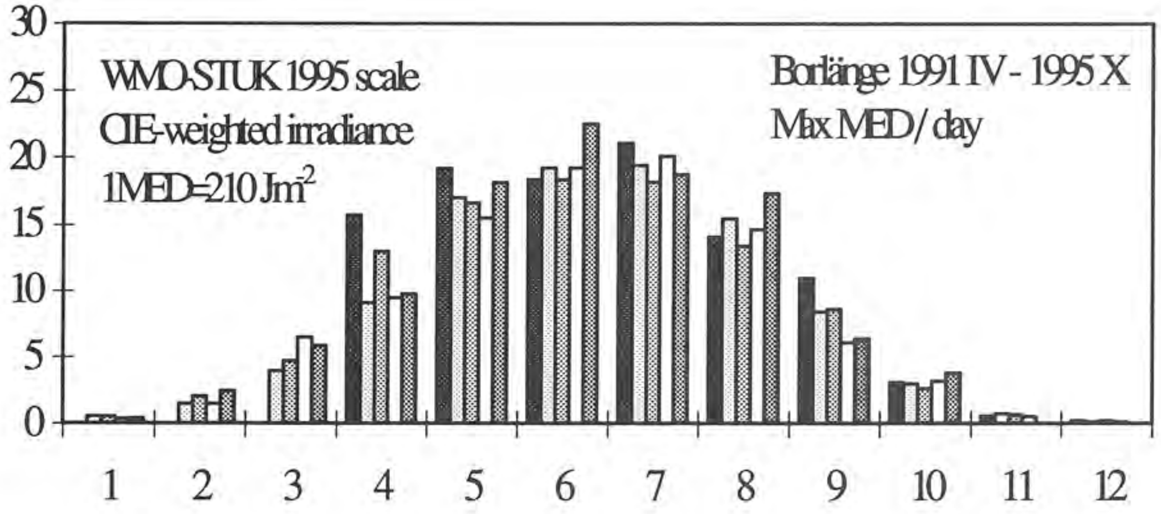

Figure 6.10 The maximum daily value of each month of each year from the station in Borlänge. Data of individual years are consecutively presented by different shaded bars, where 1991 has the darkest shade. Unit: Max MED/day. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

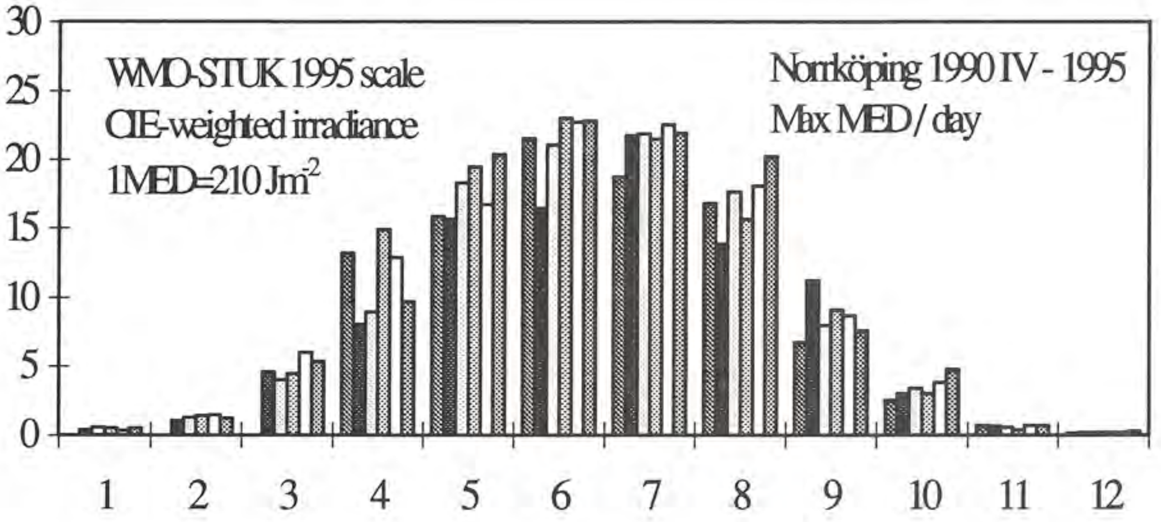

Figure 6.11 The maximum daily value of each month of each year from the station in Norrköping. Data of individual years are consecutively presented by different shaded bars, where 1991 has the darkest shade. Unit: Max MED/day. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

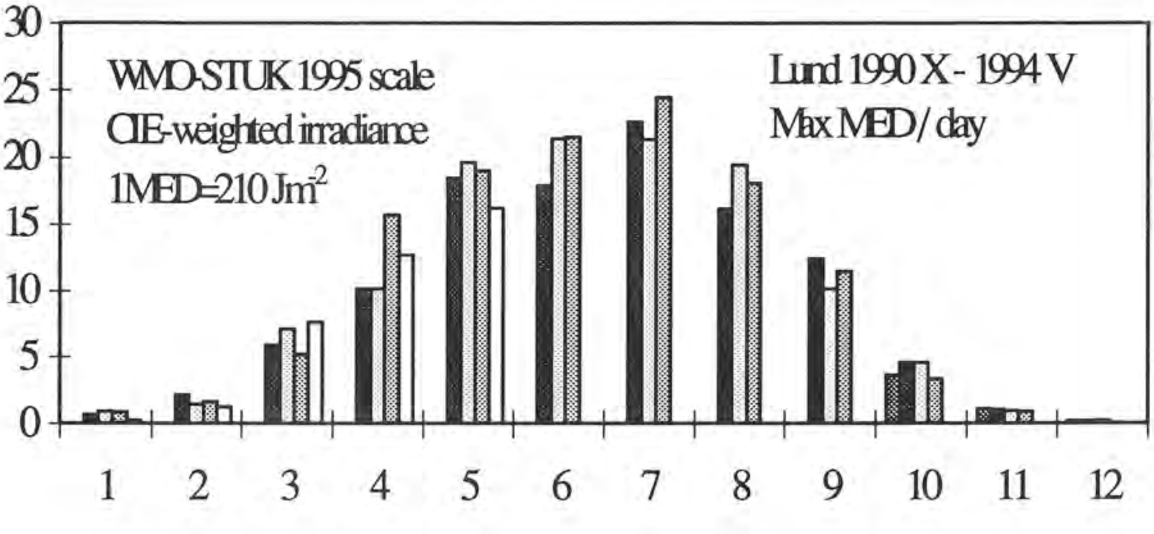

Figure 6.12 The maximum daily value of each month of each year from the station in Lund. Data of individual years are consecutively presented by different shaded bars, where 1991 has the darkest shade. Unit: Max MED/day. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

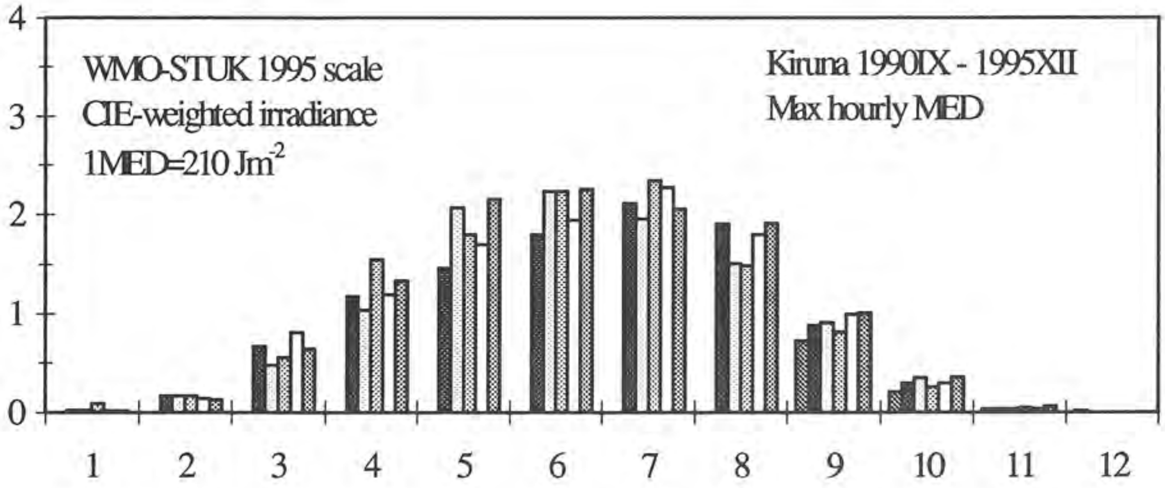

Figure 6.13 The maximum hourly value of each month of each year from the station in Kiruna. Data of individual years are consecutively presented by different shaded bars, where 1991 has the darkest shade. Unit: Max MED/hour. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

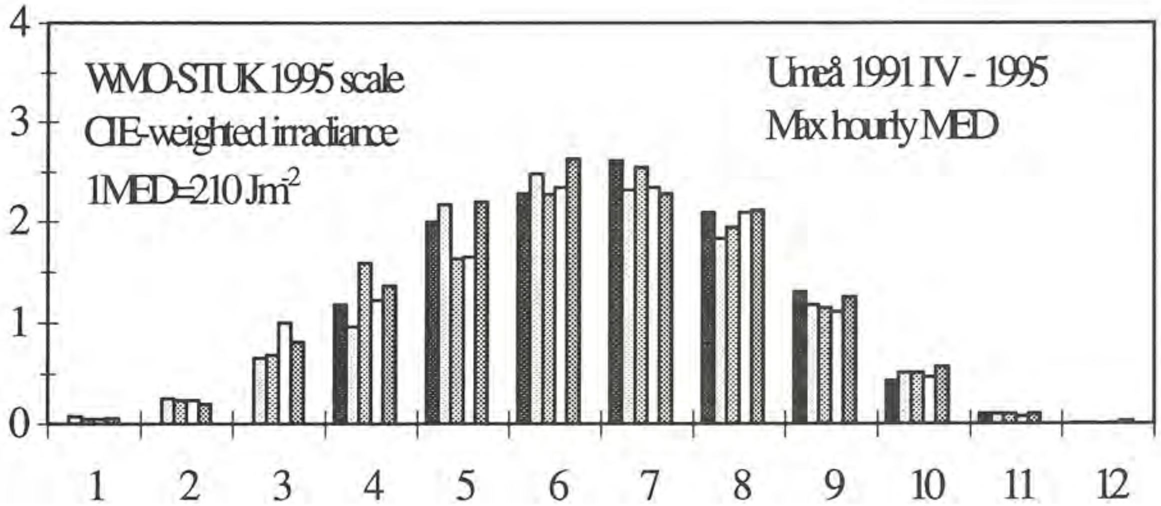

Figure 6.14 The maximum hourly value of each month of each year from the station in Umeå. Data of individual years are consecutively presented by different shaded bars, where 1991 has the darkest shade. Unit: Max MED/hour. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

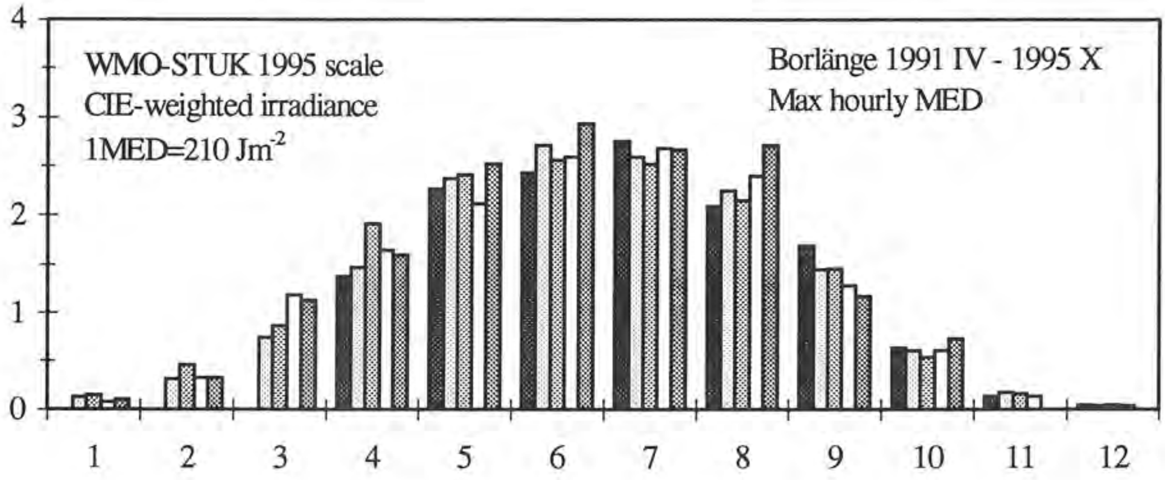

Figure 6.15 The maximum hourly value of each month of each year from the station in Borlänge. Data of individual years are consecutively presented by different shaded bars, where 1991 has the darkest shade. Unit: Max MED/hour. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

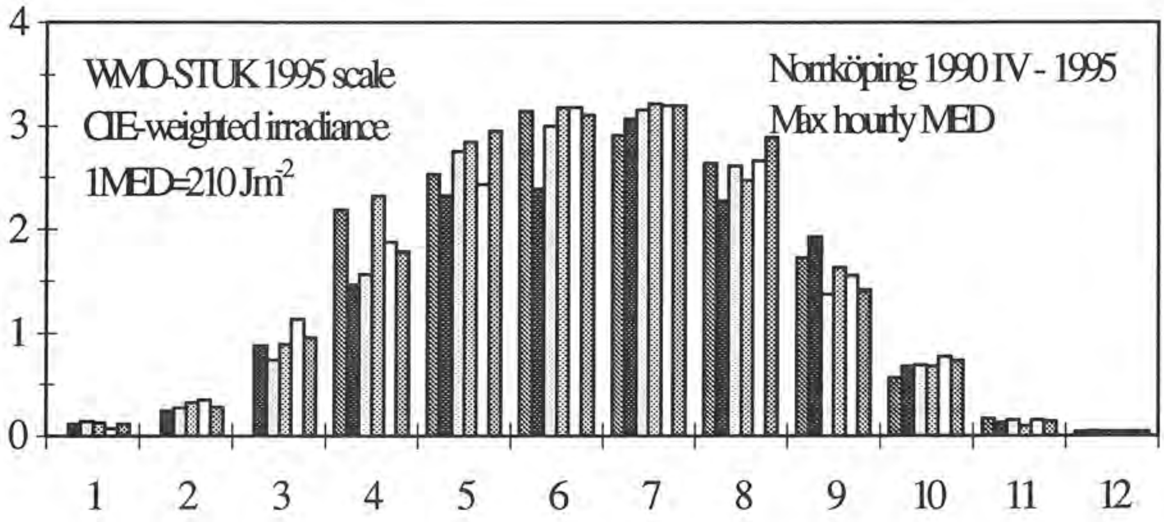

Figure 6.16 The maximum hourly value of each month of each year from the station in Norrköping. Data of individual years are consecutively presented by different shaded bars, where 1991 has the darkest shade. Unit: Max MED/hour. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

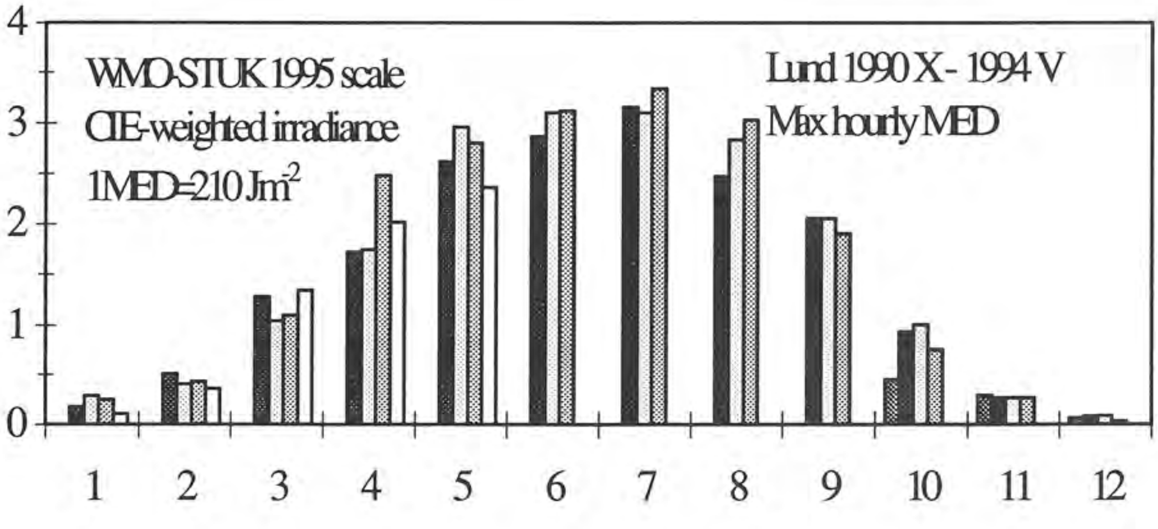

Figure 6.17 The maximum hourly value of each month of each year from the station in Lund. Data of individual years are consecutively presented by different shaded bars, where 1991 has the darkest shade. Unit: Max MED/hour. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

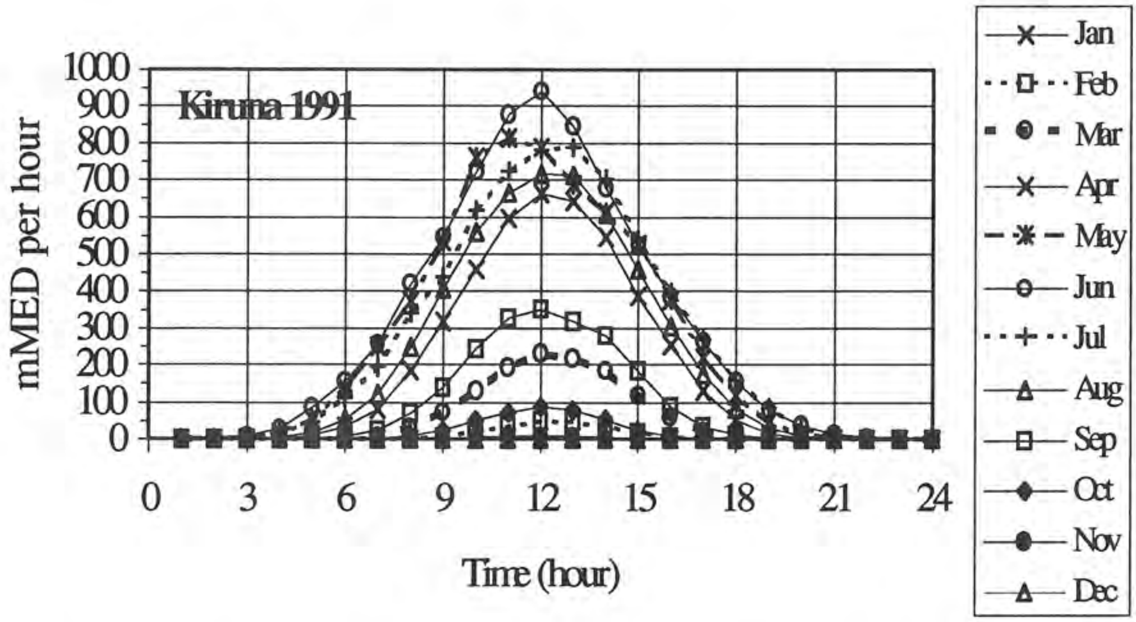

Figure 6.18 Average hourly values of each month during 1991 from the station in Kiruna. Data of individual months are presented by different lines and symbols. Unit: mMED/hour. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

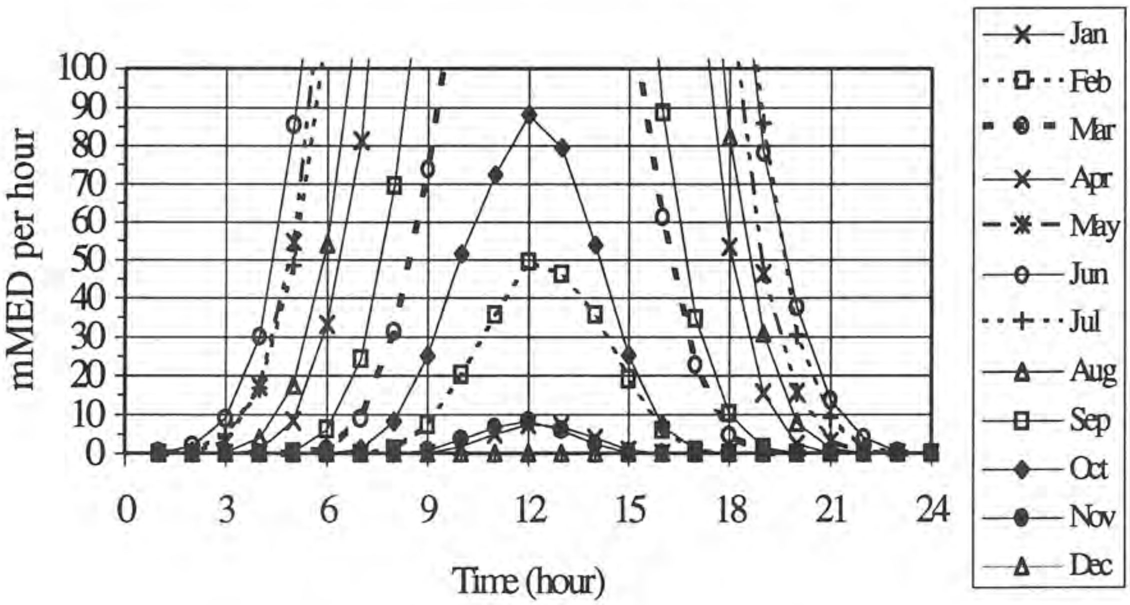

Figure 6.19 Enlargement of the lower part of Figure 6.18. Average hourly values of each month during 1991 from the station in Kiruna. Data of individual months are presented by different lines and symbols. Unit: mMED/hour. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

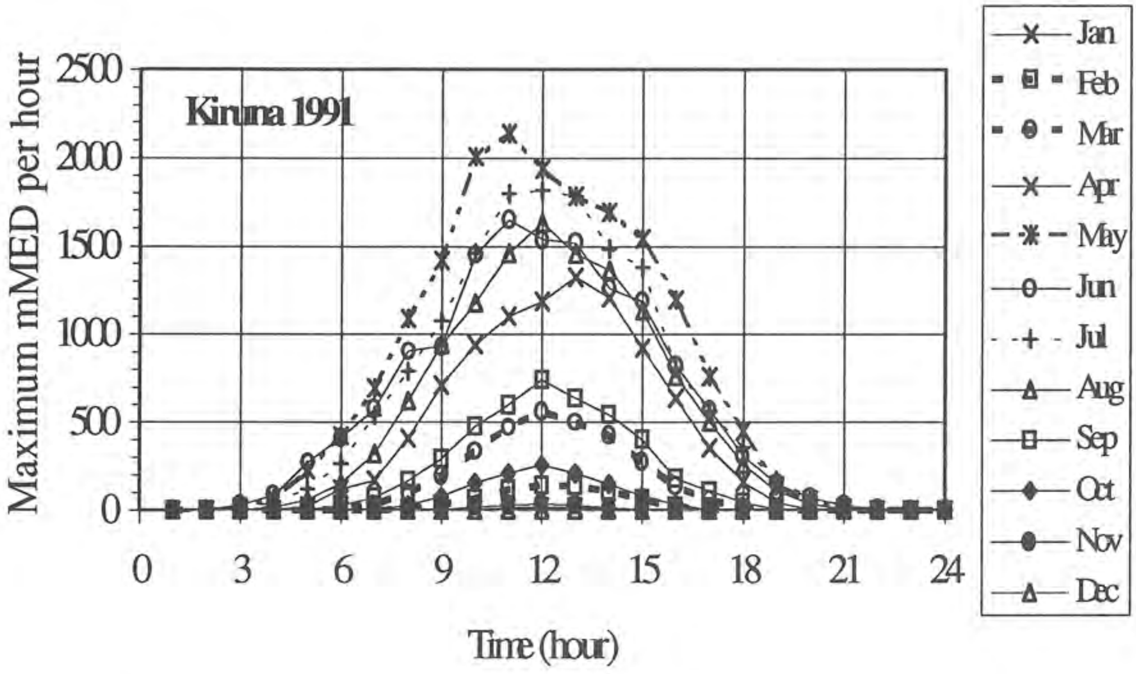

Figure 6.20 Maximum hourly values of each month during 1991 from the station in Kiruna. Data of individual months are presented by different lines and symbols. Unit: mMED/hour. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

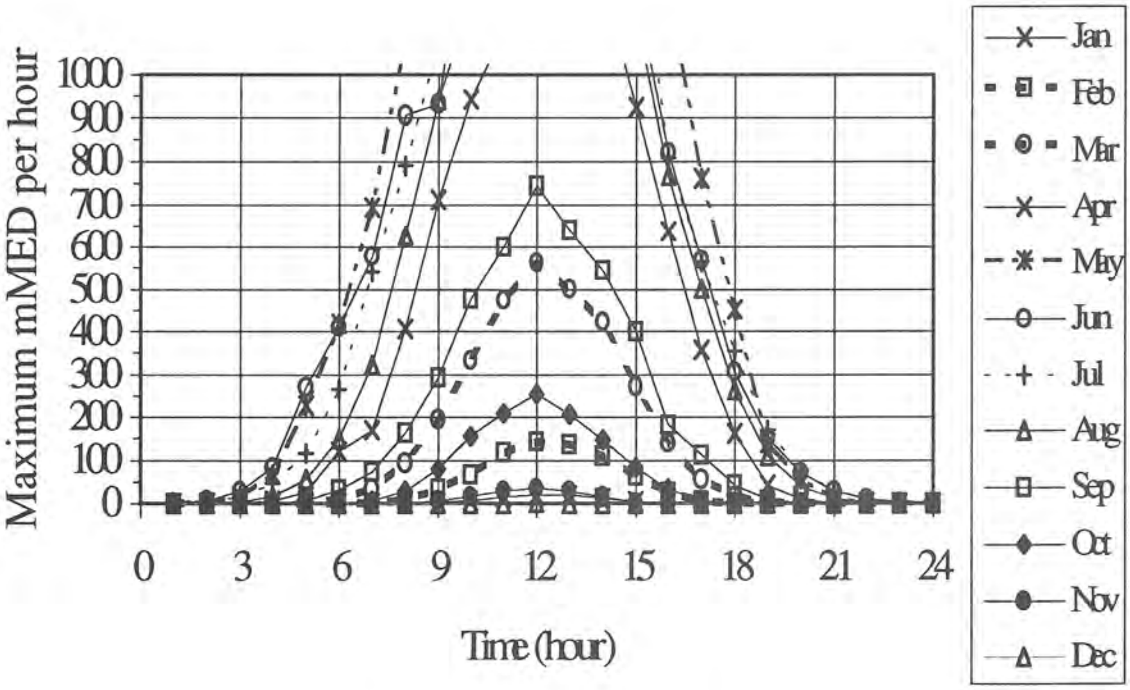

Figure 6.21 Enlargement of the lower part of Figure 6.20. Maximum hourly values of each month during 1991 from the station in Kiruna. Data of individual months are presented by different lines and symbols. Unit: mMED/hour. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

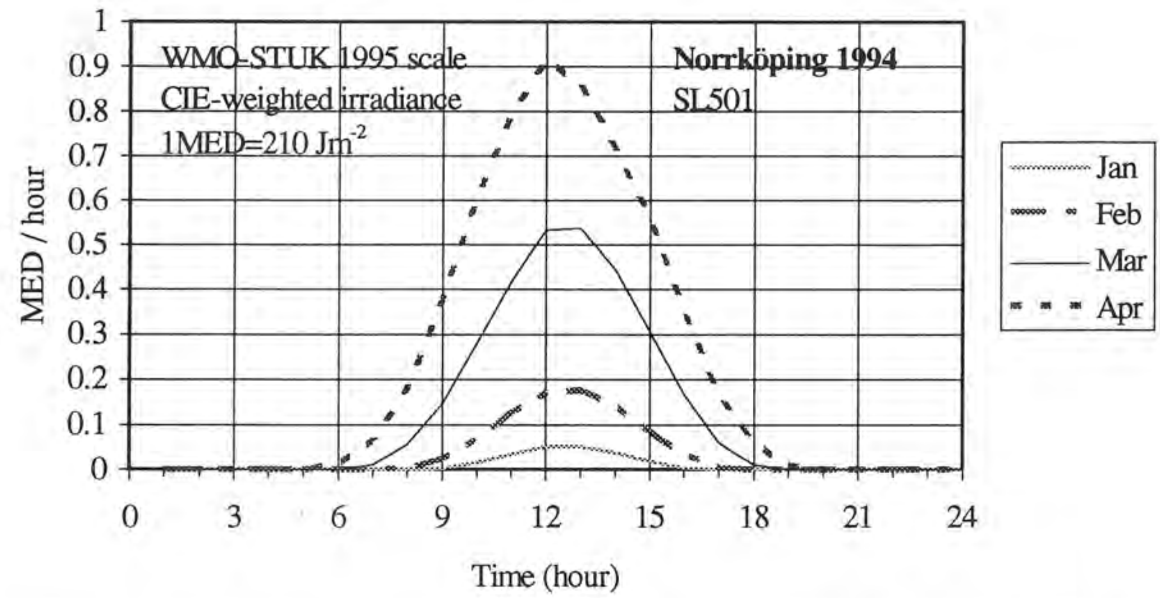

Figure 6.22 Average hourly values of the months January to April of 1994 from the station in Norrköping recorded by Solar Light Model 501 #922. Data of individual months are presented by different lines. Unit: MED/hour. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

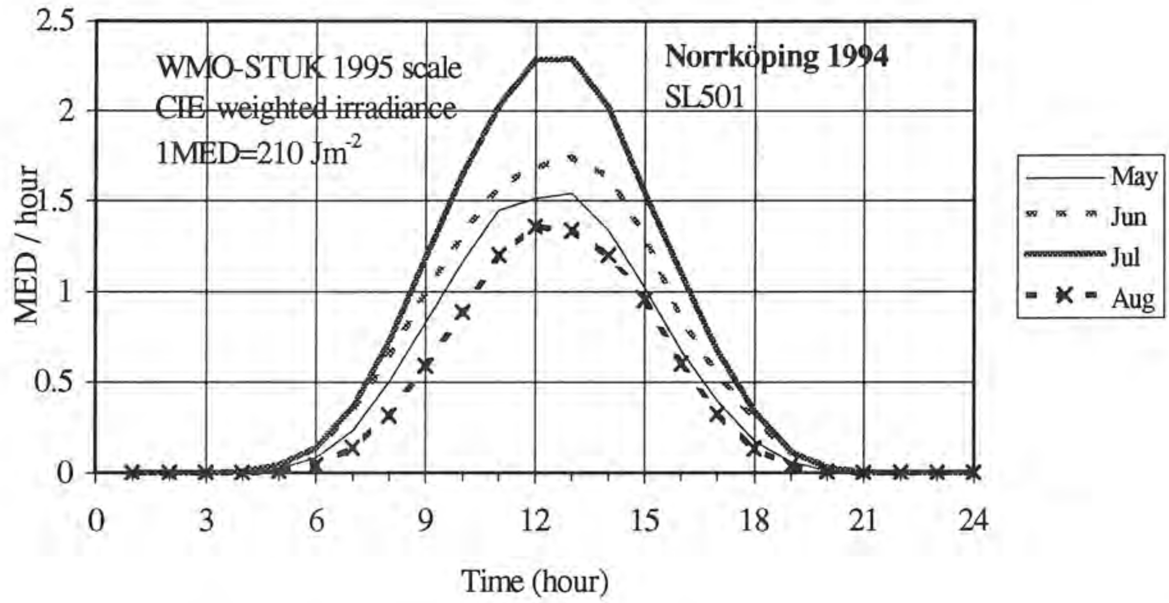

Figure 6.23 Average hourly values of the months May to August of 1994 from the station in Norrköping recorded by Solar Light Model 501 #922. Note the shift of scale compared to Figure 6.22 and Figure 6.24. Unit: MED/hour. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

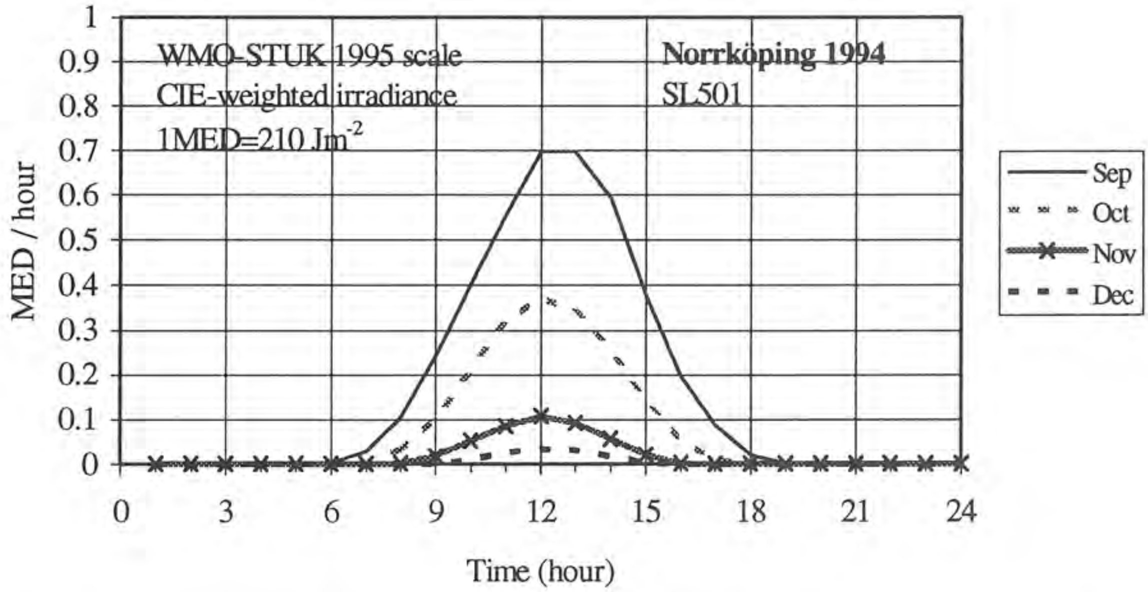

Figure 6.24 Average hourly values of the months September to December of 1994 from the station in Norrköping recorded by Solar Light Model 501 #922. Data of individual months are presented by different lines. Unit: MED/hour. MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

Table 6.1 Yearly values (MED/year). MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

Year	**Kiruna**	**Umeå**	**Borlänge**	**Norrköping**	**Lund**
1990				1807.2	
1991	1188.2	1450.8	1697.9	1608.8	1791.5
1992	1372.0	1607.7	1849.1	1959.0	2217.0
1993	1270.9	1491.9	1802.1	2019.6	2023.7
1994	1348.5	1618.8	1880.7	2013.7	
1995	1382.4	1645.7	1870.3	1956.5	

Table 6.2 Monthly values (MED/month). MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

Year	Month	Kiruna	Umeå	Borlänge	Norrköping	Lund
90	1					
90	2					
90	3					
90	4				161.40	
90	5				360.92	
90	6				402.54	
90	7				354.51	
90	8				286.33	
90	9	65.61			100.84	
90	10	12.61			39.48	43.94
90	11	1.46			7.70	10.50
90	12	0.18			1.31	1.66
91	1	0.95			3.79	3.94
91	2	7.26			11.16	16.69
91	3	46.38			40.76	72.40
91	4	153.46	148.75	181.89	150.62	161.62
91	5	229.96	226.01	319.88	267.45	319.34
91	6	246.82	293.70	251.98	234.06	249.46
91	7	226.99	365.33	414.95	432.38	400.75
91	8	187.61	236.48	254.98	263.93	313.50
91	9	72.87	92.68	143.31	157.41	183.88
91	10	14.96	20.83	33.88	37.42	60.71
91	11	0.96	3.81	7.11	6.47	7.49
91	12	0.00	0.94	3.26	3.37	1.70
92	1	0.66	3.23	6.83	7.12	6.07
92	2	7.12	13.34	19.17	17.06	15.27
92	3	46.29	49.81	56.74	55.01	66.51
92	4	118.56	110.85	134.22	129.94	165.23
92	5	309.07	328.99	377.56	416.71	440.51
92	6	396.47	453.79	462.04	484.83	516.97
92	7	270.20	325.03	383.69	416.22	438.15
92	8	148.37	199.09	240.38	261.77	318.29
92	9	56.26	89.55	120.08	123.25	184.47
92	10	18.02	29.74	38.57	37.79	55.90
92	11	1.03	3.85	7.44	6.59	8.27
92	12	0.00	0.49	2.33	2.71	1.36

continues next page

Table 6.2 (cont.) Monthly values (MED/month). MED= Minimum Erythemal Dose corresponding to 210 Jm^{-2} CIE-weighted irradiance, WMO-STUK 1995 scale.

Year	Month	Kiruna	Umeå	Borlänge	Norrköping	Lund
93	1	0.62	2.27	5.32	6.11	5.39
93	2	8.43	16.43	27.18	21.75	18.55
93	3	50.06	64.86	92.61	81.28	84.31
93	4	178.03	182.11	208.36	220.39	252.80
93	5	244.20	267.09	342.61	427.76	394.81
93	6	269.53	303.81	364.50	451.84	460.56
93	7	273.81	332.11	343.79	357.72	328.17
93	8	146.98	184.17	230.32	259.38	300.52
93	9	81.99	110.57	145.16	144.44	125.49
93	10	16.04	25.60	35.01	42.22	48.57
93	11	1.22	2.62	4.79	4.32	4.33
93	12	0.00	0.20	2.37	2.41	0.24
94	1	0.22	2.10	4.46	4.24	0.89
94	2	5.79	13.79	19.10	16.66	7.83
94	3	51.99	71.40	87.14	78.72	69.74
94	4	126.75	143.36	145.68	170.64	184.92
94	5	268.96	277.97	341.47	358.32	333.96
94	6	248.58	311.52	351.41	402.66	
94	7	342.78	408.55	496.00	546.39	
94	8	207.26	264.89	286.56	271.78	
94	9	74.08	92.14	96.24	104.71	
94	10	20.36	28.42	42.94	48.18	
94	11	1.72	4.05	7.70	8.93	
94	12	0.00	0.58	2.07	2.51	
95	1	0.33	2.29	4.61	5.66	
95	2	4.71	11.10	19.08	15.01	
95	3	51.03	52.37	73.57	62.65	
95	4	166.22	152.69	162.29	161.36	
95	5	270.12	267.44	323.61	314.68	
95	6	271.78	365.31	383.83	380.94	
95	7	302.59	360.35	402.33	438.48	
95	8	209.95	280.12	348.30	406.56	
95	9	82.92	116.22	102.65	103.69	
95	10	19.93	31.15	41.17	59.01	
95	11	2.58	5.51		9.60	
95	12	0.19	1.10		3.25	

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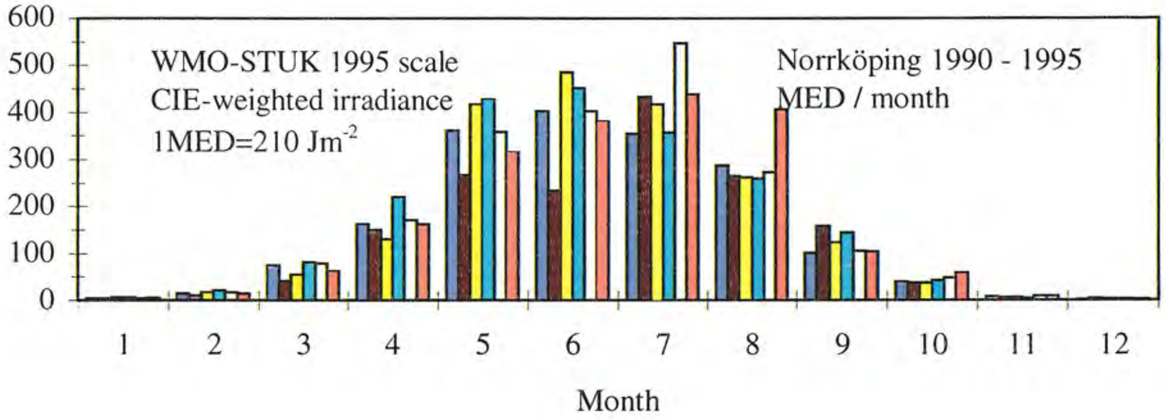

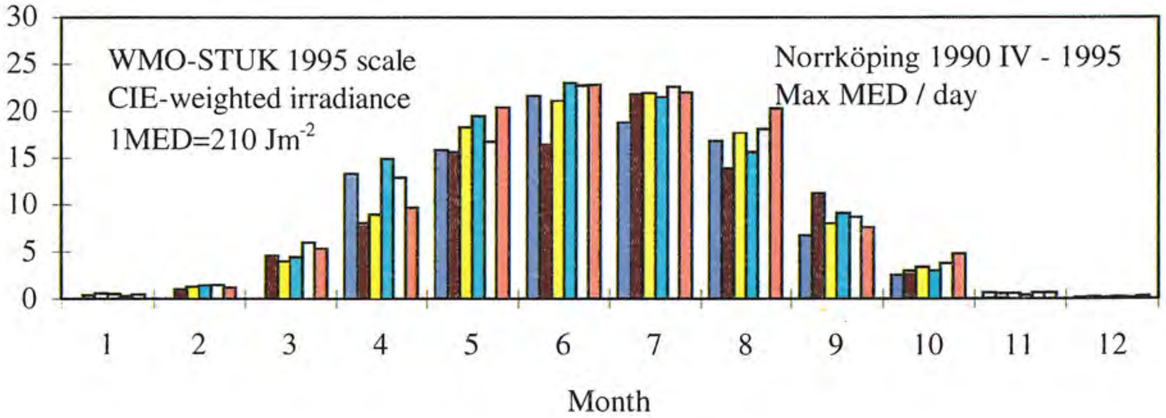

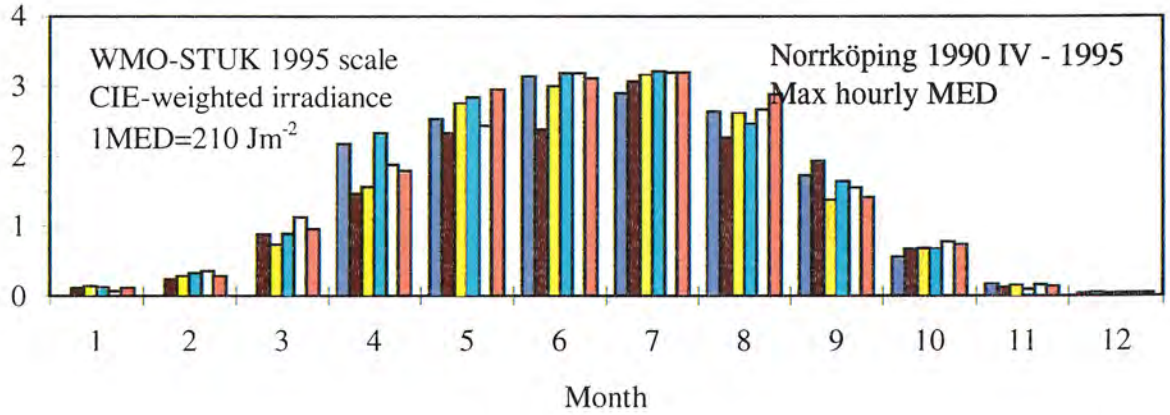

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