A SERIES OF GLOBAL RADIATION AT WAGENINGEN FOR 1928–1992

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ABSTRACT

A series of daily total incoming radiation measured at Wageningen, The Netherlands, for the period 1928–1992 is described. These data are presented as *relative global radiation* (K_r), which is defined as the global radiation divided by the corresponding extraterrestrial value. Both the year-to-year variation and the mean annual cycles of K_r averaged over a year, season, month, decade (10 days), and a day are considered. Also, frequency distributions are evaluated. It is found that the maximum of K_r does not occur in June, when the solar elevation is highest, but in May. This is due partly to the west European monsoon, causing a decline of K_r in the last decade of June and second decade of July. Also, it is found that 'sunny' weather (K_r relatively large) appears to be significantly persistent in May especially. The persistence of 'cloudy weather' (K_r relatively small) is less pronounced.

KEY WORDS: solar radiation; Wageningen; The Netherlands; time series; annual and daily radiation data

1. INTRODUCTION

It is well known that solar radiation is the primary energy source for most physical and biophysical processes that take place near the Earth's surface, in the atmosphere, and in the oceans. Also, solar radiation has been recognized as an important source for renewable energy and its use for heating houses and buildings has increased significantly. For that reason, solar radiation data are required to test and calibrate meteorological models as well as for the design of houses and buildings. In many cases, statistics of the behaviour of hourly, daily, monthly, or yearly amounts of solar radiation reaching the ground are needed. For this purpose long-term records of solar radiation data are required.

Van Gulik (1927, 1929) recognized the importance of routine observations of solar radiation and set up a radiation station at Wageningen as early as 1926. He used a solarimeter manufactured by Kipp, which is based on the thermopile constructed by Moll (1913) and the work of Gorczynski (1923, 1927, 1936). An improved version of this instrument is still used nowadays.

It is the objective of this paper to present the long-term record of daily solar radiation data for 1928–1992 and to carry out some statistical analyses. Parts of the data set have been published before by Zuidhof and de Vries (1940), Reesinck and de Vries (1942), Prins and Reesinck (1946) and de Vries (1955). Also, most of the data were published in the monthly meteorological reports of the Wageningen Agricultural University. The present publication is based partly on an anonymous booklet containing daily values of the observed solar radiation at Wageningen for 1928–1976. In the current analysis also the radiation data collected during the first half of 1993 are included.

2. DESCRIPTION OF THE DATA SET

This paper is devoted to an analyses of a series of the total daily amount of *daily global radiation* or *daily incoming solar radiation* (here denoted as $K\downarrow$), i.e. the daily total of the incoming solar radiation that reaches a horizontal plane at the surface. The records of solar radiation of Wageningen, located at 51°58′N, 5°39′E, are almost uninterrupted since 1926, but in the first 2 years the data showed unexplainable deviating values. Therefore, we

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confined ourselves to the years 1928–1992. There are two major gaps in the series, notably in 1940 and 1945 owing to the Second World War. Also, in the 1980s start-up and maintenance problems of an automatic observation system occasionally caused gaps in the series. In Appendix A the periods with missing data are listed.

Prior to 1938 global radiation was measured only during the growing season, defined as the period between 21 March and 10 October. From 1938 onwards radiation data became available throughout the year.

During the entire period a Kipp solarimeter has been used to measure the global radiation. However, in course of time the design of this instrument has changed. The earliest Kipp solarimeter consisted of a Moll thermopile with an area of 1 cm^2 surrounded by two domes of glass with a diameter of 35 and 235 mm, and the space between the two domes was filled with distilled water (van Gulik, 1927; Zuidhof and de Vries, 1940). The quantity thus measured was called *water-filtered (global) radiation*. Because water absorbs most of the solar radiation with wavelengths greater than 0·85 μm, the water-filtered radiation is almost equal to PAR (photosynthetic active radiation). Since 1931 the pile of the 'normal' solarimeter has been surrounded by only one dome of glass with a diameter of 50 mm. Later versions, including those used nowadays, have two domes. We could not trace the exact date on which this double-dome type was installed at Wageningen. From 1931 to 1940 at Wageningen both the water-filtered and the unfiltered ('normal') solarimeters were installed, which allows an intercomparison. Zuidhof and de Vries (1940) concluded that the ratio water-filtered to unfiltered global radiation is fairly constant at 0·69 during the growing season. We used this conversion factor to evaluate the unfiltered global radiation for the period 1928–1931.

The solarimeter was calibrated once a year in summertime. This calibration consisted of a comparison on a clear day with an Ångström compensation pyrheliometer (Ångstrom, 1899, Zuidhof and de Vries, 1940). The latter was calibrated several times in a physical laboratorium at Utrecht (de Vries, 1955) and later on at Davos. Since the early 1980s the solarimeter is compared with a reference Kipp solarimeter, which is kept in the laboratory (if not in use for calibration). This reference instrument has been sent regularly to Davos for an absolute calibration. At present it is calibrated at the laboratory of our Department using an artificial sun.

The calibration procedure using an Ångström compensation pyrheliometer was carried out in summertime. Bener (1951) found that the calibration factor of the Kipp solarimeter is slightly dependent on temperature and solar radiation itself. Consequently, it shows an annual variation. Using Bener's results, de Vries (1955) determined mean correction factors per month (see Table I) and applied these to the data of 1946–1953. This affects primarily the wintertime data. We have applied these correction factors until August 1986. After that the Kipp CM 11 has been used, the calibration factor of which hardly depends on temperature.

An important feature is that in the course of time various radiation scales have been used. As far as we can reconstruct, at Wageningen two scales have been applied, notably the Ångström scale and the world radiation reference (WRR). It appears that WRR = 1·026 Å (Fröhlich and London, 1986). In 1981 the WRR scale was adapted as the international standard. For a detailed review the reader is referred to Fröhlich and London (1986).

Table I. Monthly correction factors for calibration of the Kipp solarimeter, derived by de Vries (1955)

Month	Correction factor
January	0·92
February	0·94
March	0·97
April	0·96
May	0·98
June	0·99
July	0·99
August	0·98
September	0·97
October	0·97
November	0·93
December	0·92

Owing to, for example, reorganizations and budget cuts the documentation of our weather station is not complete. In particular details accounting for the change from the Ångström scale to WWR are lost. Because the Ångström pyheliometer has been used for calibration up to the beginning of the 1980s, and later on a 'reference' Kipp solarimeter has been used, it is almost certain that until January 1981 the Ångström scale was used and that somewhere in the early 1980s this was changed to WRR. Unfortunately, we could not trace the exact date on which this happened. For simplicity we assumed that WRR was introduced at 1 January 1981. As a consequence, we multiplied all daily values prior to 1 January 1981 with 1·026. Probably, this modification must also be applied to the data of the early 1980s, but that is uncertain. This uncertainty means that it is not possible to distinguish trends in the present data set smaller or equal to 2·6 per cent from an actual change in the solar radiation reaching the surface.

Because the solar radiometer has to be installed outside, it is affected by 'weather and wind'. This can cause a number of measuring errors, which we could not correct because they are difficult to detect. Examples are occasions where due to snow, freezing rain, hoar-frost or rime, and rain that contains dust, the dome is covered with snow, ice, or dust. An interesting feature is that if the dome of the radiometer is covered with snow or hoar-frost, the instrument can give a value that is too high. This is due to the fact that snow and hoar-frost usually occur in winter, when the solar angle is small. Thus part of the solar radiation that is reflected by the solar shield surrounding the instrument is reflected towards the sensor by the snow or hoar-frost on the dome. The older versions of the Kipp solarimeter suffer most from this effect, because these had horizontal and flat plates. Nowadays, the shields are smaller and conical. In one of the following sections we present evidence that on days with snow the solarimeter can give an overestimation of $K\downarrow$. As noted before we did not try to make corrections for these types of errors.

At Wageningen the extraterrestrial radiation shows a significant annual variation. For that reason we will consider the *relative global radiation*, K_r, defined by

$$K_r = \frac{K\downarrow}{K\downarrow_0} \tag{1}$$

where $K\downarrow$ is the daily global radiation and $K\downarrow_0$ the corresponding extraterrestrial global radiation. The latter depends on the declination, δ, of the Sun and the geographical position (latitude). In turn, δ depends on the longitude relative to the Sun, the eccentricity of the Earth's orbit, and other factors. Note that δ varies slightly from year to year for a given day and place. We accounted for this effect. In Appendix B, $K\downarrow_0$ is listed per day, per decade (10 days), and per month for the year 1989. This allows the reader to determine the global radiation from the K_r values presented in this paper.

Also, we will consider the *average relative global radiation* over periods longer than 1 day, defined by

$$K_r^p \frac{\sum_p K\downarrow}{\sum_p K\downarrow_0}, \tag{2}$$

in which the summation is over the number of days in the period of interest. The subscript p denotes the period: p can be decade, month, winter, summer, and year. A decade is defined as a period of 10 days, except the third decade of the month; i.e. decade 1 runs from day 1 to day 10 in a month, decade 2 from day 11 to day 20, and decade 3 from day 21 until the end of the month. Furthermore, 'winter' is defined here as the period October through to March, and 'summer' as April through to September. If daily values are considered the subscript p is not used. Note that K_r can be interpreted as the mean transmittance of the atmosphere for that period.

Also, we will consider for a particular period p the mean values of K_r over all available years, i.e.

$$\overline{K_r^p} = \frac{1}{n}\sum_{j=y_b}^{y_e} K_{r,j}^p, \tag{3}$$

where $K_{r,j}^p$ is K_r^p in year j, n the number of years, and y_b and y_e are the first and last year for which data are available. Note that, because for any particular period the extraterrestrial radiation is (almost) the same for each year, equation (3) can also be used to obtain the average daily global radiation $\overline{K\downarrow^p}$:

$$\overline{K_r^p} = \frac{\overline{K\downarrow^p}}{\overline{K\downarrow_0^p}} \qquad \text{or as} \qquad \overline{K\downarrow^p} = \overline{K\downarrow_0^p}\;\overline{K_r^p} \tag{4}$$

where $\overline{K\downarrow_0^p}$ is the average extraterrestrial global radiation for period p. Because, for all periods that we will consider, $\overline{K\downarrow_0^p}$ is given in Appendix B, $\overline{K\downarrow^p}$ can be calculated from the K_r^p data presented in this paper.

3. ANNUAL VALUES

Yearly and seasonally mean values

In Figure 1 K_r^p is depicted for each year and for p of a year, winter, and summer. These data also are listed in Appendix C, where the mean values of K_r^p over the 10-year periods 1930–1939, 1940–1949, etc. also are given. It is seen that in 1959, 1976, 1989, and 1990 K_r^{year} reached high values of 0·443, 0·441, 0·436, and 0·424 respectively, which corresponds to an average of about 120 W m^{-2}. In 1966 and 1968 K_r^{year} was very low (0·330 and 0·332, corresponding to about 90 W m^{-2}). The overall annual mean of K_r^{year} is 0·385 (or 107 W m^{-2}). The summer values show a similar picture; the highest values of K_r^{summer} occurred in 1959, 1976, 1989, and 1990, with a maximum in 1959 of 0·484 (197 W m^{-2}). The minimum of 0·350 (142 W m^{-2}) was in 1968, whereas the overall mean of K_r^{summer} is 0·408 (166 W m^{-2}).

The winter figures behave somewhat differently: high values of K_r^{winter} occurred in 1949, 1972, 1973, and 1989, with a maximum of 0·383 (57 W m^{-2}) in 1949. In 1966 K_r^{winter} reached the minimum value of 0·256 (38 W m^{-2}). The overall mean of K_r^{winter} is 0·313 (46 W m^{-2}).

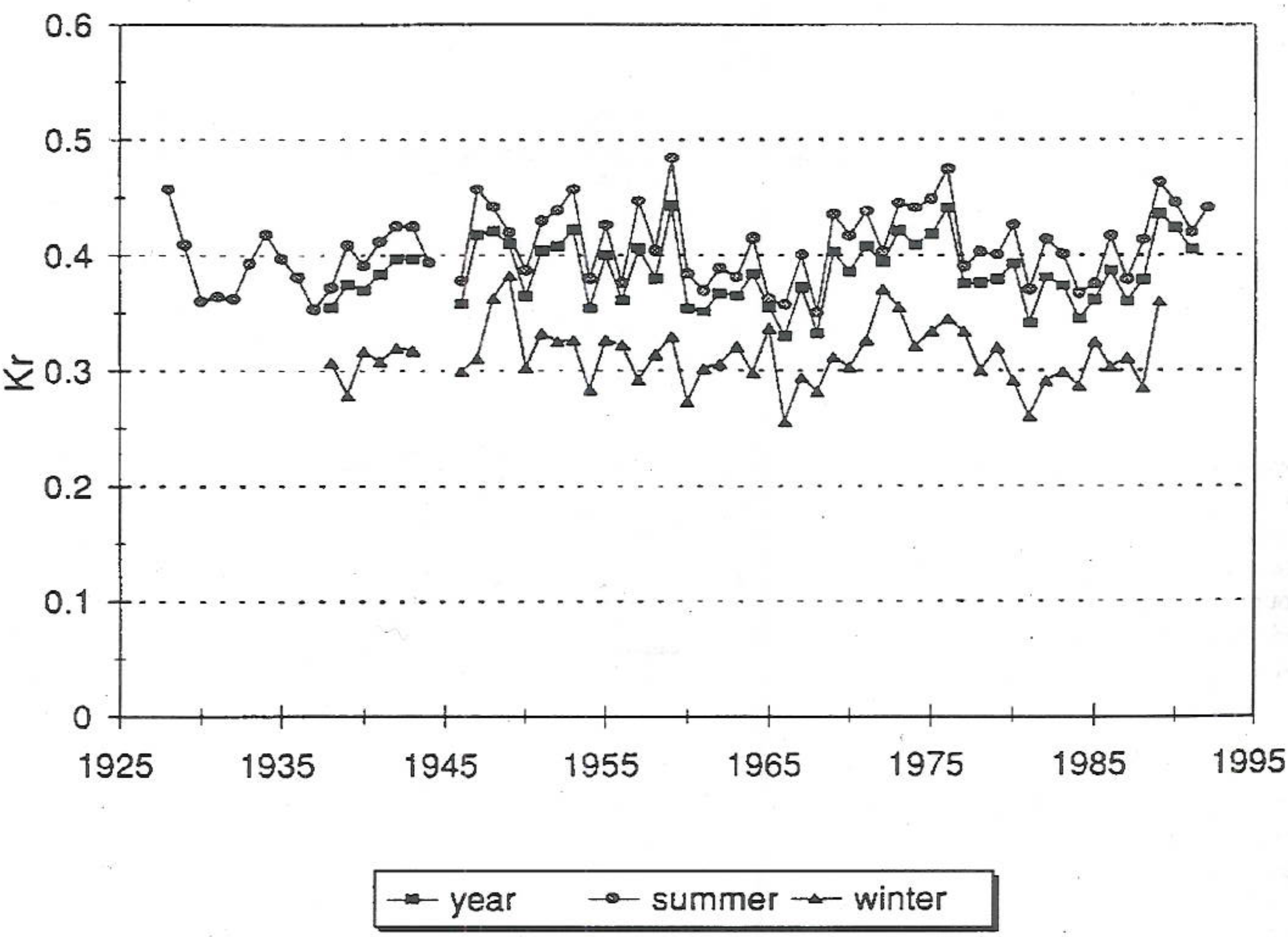

Figure 1. Annual and seasonal averaged values of K_r^p for each year, where p is year, summer, or winter

Means per month and decade

In Appendix C the values of K_r^{month} for each month and each year are listed, as well as their averages, over the whole period and over periods of 10 years. For the entire period (1928–1992) standard deviations, and minimum and maximum values also are listed. $\overline{K_r^{\text{month}}}$, $\overline{K_r^{\text{winter}}}$ and $\overline{K_r^{\text{summer}}}$ over 1928–1992 (or 1939–1992 for the winter months) are depicted in Figure 2.

In the winter months the solar angle is smallest and consequently the path length through the atmosphere of the solar rays is largest. On the other hand the contribution of diffuse radiation to the total incoming solar radiation increases with lower solar angles. Furthermore, cloudiness has an annual variation. It appears that the final effect is that K_r reaches its lowest values in the winter months. Of course at this time the solar radiation itself is at a minimum too.

On 23 June the Sun reaches its maximum elevation of about 61·5° at Wageningen. However, the average of K_r does not reach its maximum value in June or July, but in May. This is explained partly by the existence of the so-called west European monsoon. By the end of June and the beginning of July frontal systems appear to have a preferential path over western Europe. This feature also can be seen in temperature records (Jacobs and Vaags, 1986). Another reason for the dip in K_r during June and July could be that Wageningen is located far enough from the coast (approximately 100 km) for its climate can be regarded as 'continental', which is characterized by a maximum occurrence of convective clouds in the summer months.

The effect is seen more clearly in the averages over decades $\overline{K_r^{\text{decades}}}$, shown in Figure 3 (see also Appendix D, where the maximum and minimum and the standard deviation $\overline{K_r^{\text{decades}}}$ are listed). From Figure 3 it is seen that $\overline{K_r^{\text{decades}}}$ has a clear subminimum at decades 18 and 20, i.e. the last decade of June and the second decade of

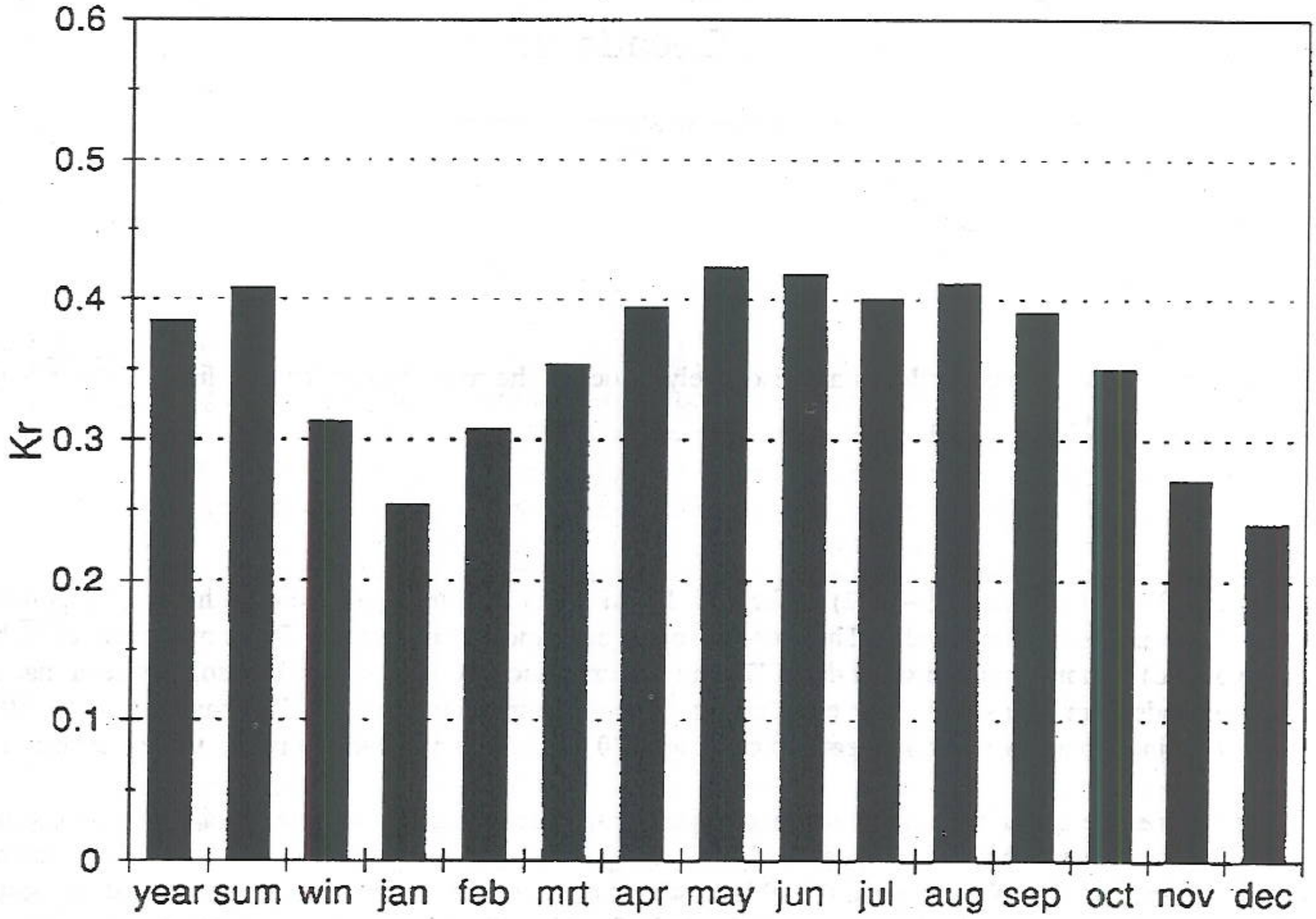

Figure 2. Annually, seasonally, and monthly averaged values $\overline{K_r^P}$, for the year, summer, winter, and each separate month

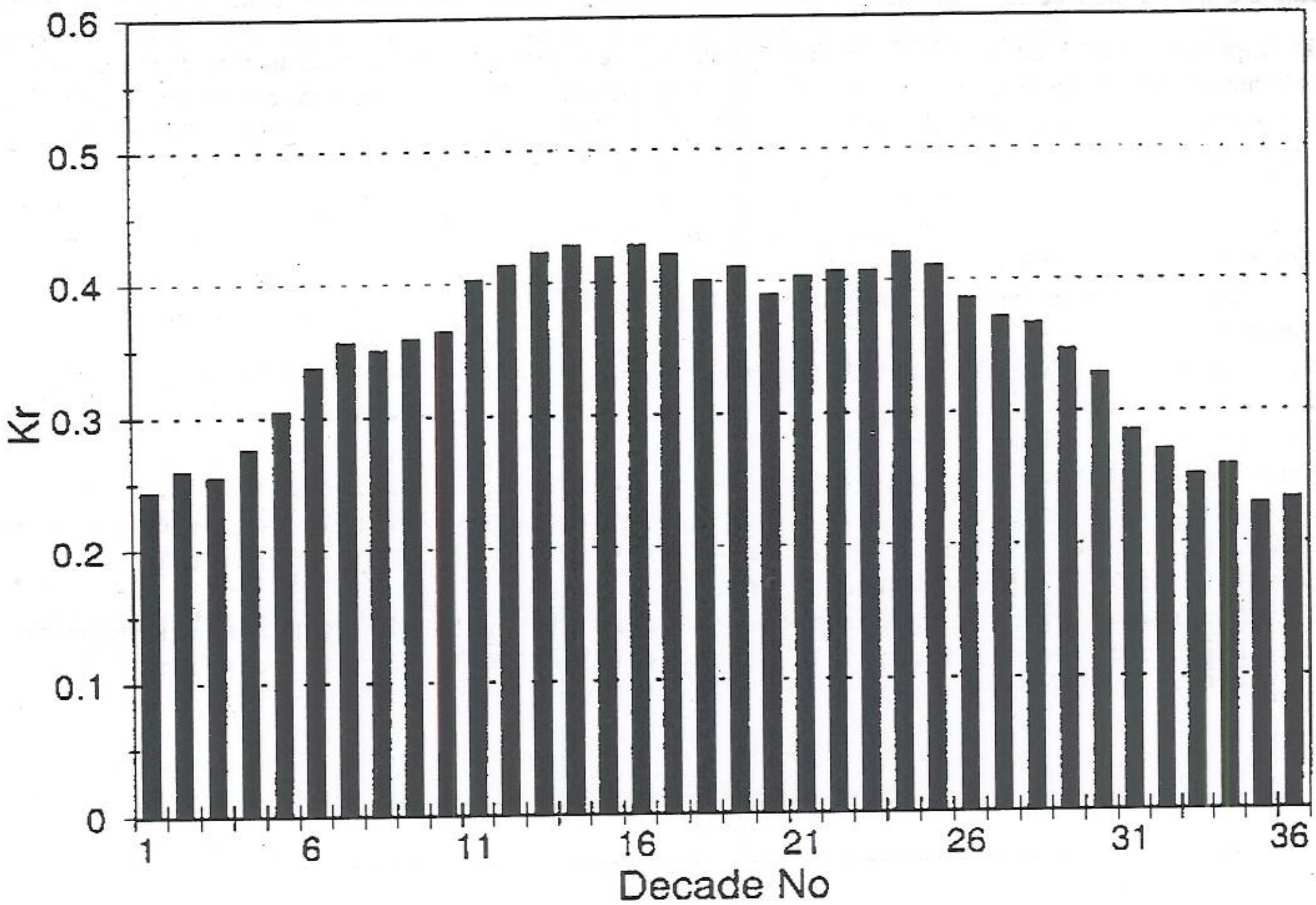

Figure 3. Averaged value of $\overline{K_r^p}$ per decade

July. Because in August convective clouds are also likely to occur, the main reason for this dip in $\overline{K_r^{\text{decades}}}$ is the west European monsoon.

Daily values

For the period 1928–1992 (or 1939–1992) $\overline{K_r}$ for each Julian day is depicted in Figure 4, with the corresponding (absolute) maximum and minimum value. These data also can be found in Appendix E. The annual curve of $\overline{K_r}$ has (as to be expected) a subminimum around day 177 (end of June) and 200 (end of July). Also, it is seen that the range of K_r extends from almost zero (on very clouded, foggy, or rainy days) during all seasons to about 0·60 in winter and 0·70 in summer, with some peaks exceeding 0·80. The scatter of the minimum values is largest in summer.

An interesting feature is that on some days in winter the absolute daily maximum values of K_r are relatively very large. On some days the maximum K_r value exceeds 0·75. As pointed out in section 2, snow on the solarimeter can cause an overestimation of K_r. We inspected the 10 largest maximum values in winter and it appears that on most of these days the weather reports indeed gave snow. It is likely therefore that the very high maximum daily values of K_r are not realistic as a result of measuring errors.

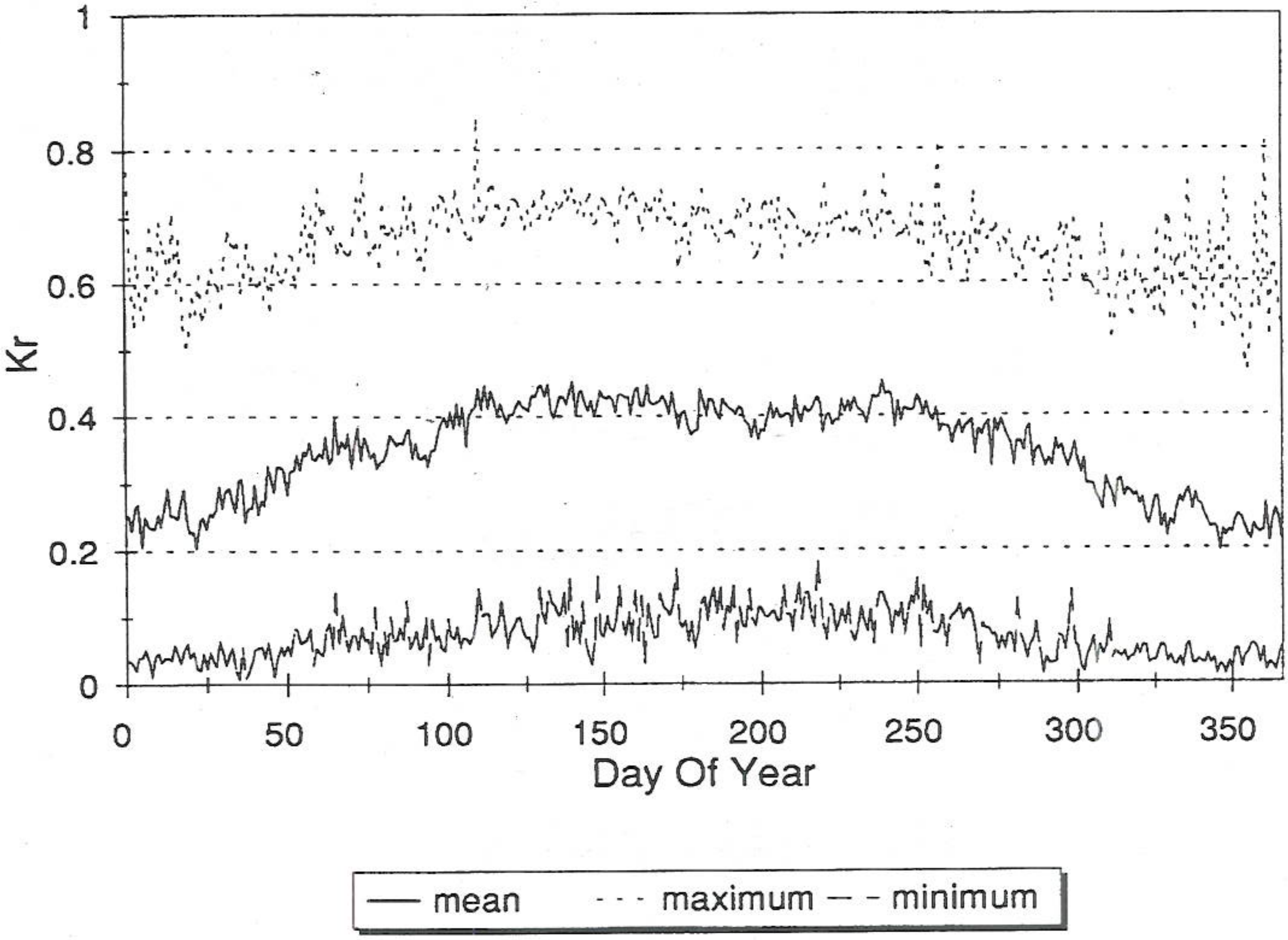

Figure 4. Daily mean, maximum and minimum value of K_r for each Julian day

4. SOME FURTHER STATISTICAL ANALYSES

Frequency distributions

For various applications a frequency distribution of K_r or K_r^p is required. Examples are the design of houses and the use of solar radiation as an energy source. For this purpose, we determine the cumulative frequency distribution for daily values of K_r. This has been done for all days in a year, winter, and summer (as defined above), and in each month. The results are shown in Table II. From this table it is seen that, for instance in May, the probability that $K_r < 0{\cdot}147$ is 5 per cent, or in May the probability is 10 per cent that $0{\cdot}484 < K_r < 0{\cdot}535$.

The cumulative frequency distributions of K_r^{year}, K_r^{winter}, K_r^{summer} and K_r^{month} are listed in Table III.

Persistence

It is well-known that most daily weather data are interrelated, i.e. often there is a kind of 'memory' in most time series of meteorological data. In this section we will pay attention to two aspects of persistence. First, we will consider the autocorrelation coefficient of the entire time series of daily K_r values, with a time shift of $i = 1, 2, 3, \ldots$ days. In order to eliminate the annual cycle, which leads to an annual cycle of the standard autocorrelation coefficient, we considered the autocorrelation ρ_i of the series of $(K_r - \overline{K_{rj}})$, where $\overline{K_{rj}}$ is the mean value of K_r for day number j (for 1 January $j = 1$, etc.). The values of $\overline{K_{rj}}$ are given in Appendix E. Because the series for 1950 through to 1959 appears to be uninterrupted, we confined ourselves to this period of 10 years. It

Table II. Cumulative frequency distribution of K_r for the period 1928–1993 (or 1939–1993 for 'winter' months). The values x are listed for which $p(K_r < x) = P$, with $P = 0{\cdot}05, 0{\cdot}1, \ldots, 0{\cdot}95$

P	Year	Summer	Winter	January	February	March	April	May	June	July	August	September	October	November	December
0·050	0·092	0·150	0·069	0·061	0·081	0·104	0·122	0·147	0·158	0·159	0·167	0·144	0·095	0·067	0·054
0·100	0·128	0·190	0·093	0·073	0·102	0·137	0·163	0·192	0·202	0·195	0·212	0·187	0·130	0·086	0·070
0·150	0·160	0·227	0·114	0·091	0·124	0·159	0·194	0·230	0·238	0·229	0·252	0·217	0·162	0·105	0·086
0·200	0·188	0·260	0·137	0·106	0·146	0·184	0·227	0·266	0·270	0·256	0·283	0·251	0·190	0·125	0·102
0·250	0·217	0·289	0·158	0·124	0·167	0·206	0·261	0·295	0·299	0·283	0·308	0·280	0·218	0·146	0·117
0·300	0·246	0·315	0·178	0·141	0·189	0·232	0·290	0·324	0·326	0·307	0·333	0·305	0·241	0·165	0·135
0·350	0·275	0·339	0·201	0·159	0·214	0·259	0·321	0·356	0·345	0·331	0·360	0·325	0·268	0·182	0·150
0·400	0·302	0·364	0·224	0·180	0·235	0·293	0·349	0·384	0·368	0·353	0·384	0·351	0·296	0·203	0·169
0·450	0·329	0·389	0·250	0·200	0·264	0·324	0·373	0·409	0·394	0·375	0·404	0·374	0·324	0·228	0·187
0·500	0·356	0·412	0·276	0·221	0·286	0·351	0·400	0·433	0·420	0·400	0·424	0·397	0·349	0·250	0·206
0·550	0·383	0·435	0·304	0·245	0·315	0·382	0·425	0·456	0·443	0·426	0·441	0·417	0·377	0·270	0·231
0·600	0·409	0·458	0·333	0·270	0·340	0·412	0·448	0·484	0·469	0·450	0·460	0·440	0·401	0·294	0·260
0·650	0·436	0·482	0·361	0·300	0·369	0·442	0·474	0·509	0·498	0·475	0·475	0·464	0·428	0·320	0·290
0·700	0·463	0·505	0·393	0·331	0·396	0·470	0·500	0·535	0·518	0·495	0·498	0·487	0·457	0·353	0·318
0·750	0·490	0·529	0·424	0·363	0·430	0·495	0·525	0·558	0·542	0·523	0·517	0·507	0·480	0·384	0·345
0·800	0·518	0·553	0·459	0·398	0·466	0·522	0·555	0·579	0·567	0·553	0·538	0·526	0·503	0·416	0·377
0·850	0·549	0·579	0·491	0·438	0·501	0·552	0·587	0·605	0·591	0·577	0·564	0·551	0·532	0·448	0·417
0·900	0·582	0·608	0·531	0·477	0·536	0·583	0·619	0·631	0·620	0·604	0·591	0·578	0·561	0·481	0·459
0·950	0·623	0·644	0·578	0·533	0·585	0·621	0·651	0·666	0·653	0·631	0·632	0·609	0·599	0·539	0·522

Table III. As for Table II, but for K_r^{year}, K_r^{winter}, K_r^{summer} and K_r^{month}

P	Year	Summer	Winter	January	February	March	April	May	June	July	August	September	October	November	December
0·050	0·038	0·358	0·267	0·180	0·255	0·268	0·304	0·328	0·335	0·331	0·337	0·316	0·261	0·185	0·177
0·100	0·352	0·363	0·282	0·189	0·260	0·289	0·324	0·354	0·351	0·335	0·353	0·327	0·285	0·206	0·192
0·150	0·355	0·370	0·286	0·197	0·271	0·296	0·329	0·370	0·365	0·338	0·363	0·339	0·291	0·222	0·196
0·200	0·359	0·376	0·291	0·210	0·274	0·300	0·337	0·387	0·370	0·350	0·374	0·350	0·300	0·231	0·201
0·250	0·363	0·380	0·297	0·219	0·278	0·315	0·348	0·390	0·378	0·354	0·380	0·351	0·319	0·245	0·217
0·300	0·367	0·386	0·300	0·224	0·286	0·326	0·356	0·398	0·391	0·368	0·385	0·361	0·325	0·249	0·218
0·350	0·373	0·391	0·302	0·234	0·290	0·330	0·364	0·403	0·396	0·373	0·392	0·369	0·333	0·255	0·220
0·400	0·375	0·397	0·304	0·235	0·295	0·336	0·367	0·408	0·406	0·378	0·397	0·379	0·343	0·259	0·226
0·450	0·379	0·402	0·308	0·244	0·298	0·338	0·381	0·412	0·412	0·401	0·401	0·387	0·346	0·264	0·233
0·500	0·382	0·407	0·311	0·247	0·302	0·350	0·385	0·423	0·417	0·404	0·402	0·397	0·352	0·270	0·238
0·550	0·386	0·412	0·317	0·252	0·304	0·353	0·400	0·427	0·425	0·414	0·409	0·404	0·358	0·278	0·245
0·600	0·394	0·417	0·320	0·260	0·308	0·354	0·417	0·435	0·437	0·422	0·412	0·406	0·362	0·282	0·248
0·650	0·398	0·420	0·321	0·262	0·312	0·364	0·422	0·441	0·439	0·424	0·432	0·408	0·366	0·286	0·253
0·700	0·404	0·426	0·325	0·267	0·320	0·383	0·430	0·445	0·445	0·428	0·436	0·413	0·374	0·292	0·257
0·750	0·407	0·435	0·327	0·277	0·328	0·403	0·445	0·455	0·456	0·439	0·444	0·425	0·378	0·295	0·261
0·800	0·409	0·441	0·332	0·298	0·337	0·408	0·450	0·460	0·461	0·440	0·449	0·431	0·398	0·311	0·271
0·850	0·419	0·445	0·335	0·308	0·345	0·424	0·473	0·471	0·469	0·453	0·456	0·441	0·402	0·327	0·279
0·900	0·422	0·453	0·354	0·342	0·367	0·433	0·489	0·497	0·479	0·469	0·481	0·454	0·411	0·333	0·301
0·950	0·437	0·462	0·367	0·358	0·391	0·454	0·502	0·530	0·510	0·486	0·512	0·473	0·450	0·354	0·337

Table IV. The conditional probabilities P_k^s and P_k^c for $k = 1$ to 5 days, for each month. ++ indicates significant persistence at level of confidence 0·001, + at 0·01, and – is not significant at 0·05

	January	February	March	April	May	June	July	August	September	October	November	December
'Sunny' days												
K_s	0·398	0·466	0·522	0·555	0·579	0·567	0·553	0·538	0·526	0·503	0·416	0·377
n	325	296	348	385	399	394	402	402	392	352	326	339
P_1^s	0·403	0·436	0·448	0·470	0·519	0·462	0·490	0·455	0·375	0·389	0·344	0·360
Significance	++	++	++	++	++	++	++	++	++	++	++	++
n	124	125	153	177	205	184	196	185	150	139	115	124
P_2^s	0·452	0·528	0·490	0·559	0·546	0·538	0·531	0·524	0·413	0·489	0·409	0·444
Significance	++	++	++	++	++	++	++	++	++	++	++	++
n	50	63	73	100	111	99	104	98	65	69	47	56
P_3^s	0·480	0·476	0·466	0·600	0·595	0·556	0·548	0·592	0·369	0·580	0·383	0·554
Significance	++	++	++	++	++	++	++	++	++	++	+	++
n	22	28	34	60	66	53	58	59	25	40	18	30
P_4^s	0·409	0·536	0·529	0·550	0·621	0·547	0·569	0·661	0·520	0·650	0·333	0·567
Significance	+	++	++	++	++	++	++	++	++	++	–	++
n	8	15	18	32	41	26	35	40	13	26	6	16
P_5^s	0·500	0·400	0·444	0·594	0·659	0·538	0·514	0·650	0·538	0·692	0·500	0·438
Significance	+	–	+	++	++	++	++	++	+	++	–	+
'Cloudy' days												
K_c	0·106	0·146	0·184	0·227	0·266	0·270	0·256	0·283	0·251	0·190	0·125	0·102
n	343	304	359	393	403	394	394	407	372	347	319	332
P_1^c	0·274	0·332	0·298	0·364	0·323	0·327	0·297	0·287	0·263	0·349	0·288	0·325
Significance	++	++	++	++	++	++	++	++	+	++	++	++
n	95	101	111	144	133	127	116	117	92	113	92	103
P_2^c	0·326	0·386	0·297	0·431	0·353	0·362	0·405	0·299	0·326	0·425	0·391	0·408
Significance	+	++	+	++	++	++	++	+	+	++	++	++
n	31	42	33	64	44	46	49	35	29	43	39	40
P_3^c	0·323	0·452	0·394	0·484	0·432	0·457	0·449	0·371	0·310	0·372	0·410	0·450
Significance	–	++	+	++	++	++	++	+	–	+	+	++
n	10	20	13	31	19	20	22	13	8	12	18	17
P_4^c	0·400	0·600	0·462	0·484	0·316	0·450	0·409	0·308	0·125	0·500	0·389	0·588
Significance	–	++	+	++	–	+	+	–	–	+	+	++
n	4	12	6	15	6	8	9	5	1	5	7	10
P_5^c	0·500	0·833	0·667	0·533	0·500	0·250	0·333	0·400	–	0·800	0·571	0·600
Significance	–	++	+	+	–	–	–	–	–	++	+	+

appears that for $i = 1$ and 2, ρ_i is respectively approximately 0·31 and 0·16. For $i > 2$, ρ_i is close to 0 (figure not shown). It can be concluded that there is persistence in the time series of K_r.

In order to investigate this further, we will pay attention to the (conditional) probability P_k^s that after $k = 1, 2, 3, \ldots$ successive 'sunny' days another 'sunny' day occurs, and P_k^c the probability that $k = 1, 2, 3, \ldots$ successive 'cloudy' days are followed by a 'cloudy' day. In this study a 'sunny' day is defined as a day with a K_r greater than K^s, the value of K_r corresponding to the 80 per cent percentile given in Table II. In the same way, a 'cloudy' day is defined by $K_r < K^c$, which is the value of K_r corresponding to the 20 per cent percentile. If there is no persistence the conditional probabilities P_k^s and P_k^c will be equal to the overall probability on a 'sunny' or 'cloudy' day, which is 20 per cent by definition. If persistence is positive the conditional probabilities will be greater than 0·20. In that case the atmosphere tends to stay in the 'sunny' (or 'cloudy') state if 'yesterday' it was in that state.

In Table IV the results of this persistence study are given. For each month, the following quantities are listed: K^s or K^c, the conditional probabilities P_k^s or P_k^c for $k = 1, 2, \ldots, 5$, and n_k^s or n_k^c, the number of events. Also, it is indicated whether P_k^s or P_k^c is statistically significantly different from 0·20 (based on the standard χ^2 test): '++' corresponds to a confidence level of 0·001, '+' to 0·01, and '–' means not significant at the 5 per cent level. It is clearly seen that the 'sunny' and 'cloudy' days are interrelated: for all months P_k^s and P_k^c are greater than 0·2. The persistence is positive and in the case of 'sunny' days this effect is the most pronounced. In May P_k increases even from 0·519 for $k = 1$ to 0·659 for $k = 5$, which implies that 'sunny' weather in May is very persistent at Wageningen. Persistence is less pronounced for 'cloudy' days, but up to k-values of about 3 it is significant for most months. Note that in general the number of events becomes rather small for $k > 3$.

5. CONCLUDING REMARKS

In this paper a series of global radiation data gathered at Wageningen (51°58′N, 5°39′E) is presented for the period 1928–1992 and the first half of 1993. Mean values of K_r, i.e. the ratio of the global radiation and the corresponding extraterrestrial radiation, are considered per day, decade (10 days), month, season, and year. It appears that on average K_r reaches its maximum in May and not, as one would expect, by the end of June. A possible explanation for this feature is the so-called west European monsoon, which occurs often at the end of June and in July. A statistical study reveals that the daily values of K_r are interrelated. It is found that the probability of a 'sunny'/'cloudy' day being followed by another 'sunny'/'cloudy' day is greater than the unconditional probability of a 'sunny'/'cloudy' day. The persistence appears to be most significant for 'sunny' days in May.

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APPENDIX A

List of periods between 1928 and 1993 for which no global radiation data are present

Year	Period or day
1928	01-01-1928 until 20-03-1928
	05-08-1928
	11-10-1928 until 31-12-1928
1929	01-01-1929 until 20-03-1929
	11-10-1929 until 31-12-1929
1930	01-01-1930 until 20-03-1930
	11-10-1930 until 31-12-1930
1931	01-01-1931 until 20-03-1931
	11-10-1931 until 31-12-1931
1932	01-01-1932 until 20-03-1932
	11-10-1932 until 31-12-1932
1933	01-01-1933 until 20-03-1933
	11-10-1933 until 31-12-1933
1934	01-01-1934 until 20-03-1934
	11-10-1934 until 31-12-1934
1935	01-01-1935 until 20-03-1935
	11-10-1935 until 31-12-1935
1936	01-01-1936 until 20-03-1936
	11-10-1936 until 31-12-1936
1937	01-01-1937 until 20-03-1937
	11-10-1937 until 31-12-1937
1938	01-01-1938 until 08-01-1938
1940	10-05-1940 until 20-05-1940
1944	11-09-1944 until 31-12-1944
1945	01-01-1945 until 30-06-1945
1963	20-01-1963

Year	Period or day
1977	17-01-1977 until 19-01-1977
1980	09-04-1980 until 11-04-1980
	13-10-1980 until 31-10-1980
1984	11-07-1984 until 14-07-1984
1987	15-04-1987
	12-06-1987
	15-06-1987 until 16-06-1987
	29-06-1987 until 30-06-1987
	02-07-1987
	14-08-1987
	09-10-1987
1988	08-03-1988
1989	21-09-1989
1990	01-01-1990
	01-02-1990 until 28-02-1990
1991	01-02-1991 until 28-02-1991
	31-03-1991
1992	02-03-1992
	18-03-1992 until 31-03-1992
	31-07-1992
	01-11-1992 until 30-11-1992
1993	01-01-1993
	01-07-1993 until 31-12-1993

APPENDIX B

Extraterrestrial radiation at Wageningen in 1989 (W m^{-2})

Day	January	February	March	April	May	June	July	August	September	October	November	December
1	77	124	206	316	413	475	482	432	341	237	141	84
2	78	126	209	320	415	476	481	429	337	233	138	83
3	79	129	213	323	418	477	480	427	334	230	136	82
4	79	131	216	327	421	478	479	424	331	226	133	81
5	80	134	220	330	423	479	478	422	327	223	131	80
6	81	136	223	334	426	480	477	419	324	220	128	80
7	82	139	227	337	428	481	476	416	320	216	126	79
8	83	142	230	341	431	482	475	414	317	213	124	78
9	84	144	234	344	433	482	474	411	313	210	121	77
10	85	147	237	347	436	483	473	408	310	206	119	77
Decade	81	135	221	332	424	479	477	420	325	221	130	80
11	86	150	241	351	438	484	471	406	307	203	117	76
12	88	153	244	354	440	484	470	403	303	200	115	76
13	89	155	248	357	442	485	469	400	300	197	113	75
14	90	158	251	361	445	485	467	397	296	193	111	75
15	92	161	255	364	447	485	465	394	293	190	109	74
16	93	164	259	367	449	486	464	391	289	187	107	74
17	95	167	262	371	451	486	462	388	286	184	105	74
18	96	170	266	374	453	486	461	385	282	181	103	74
19	98	173	269	377	455	486	459	382	279	178	101	74
20	100	177	273	380	457	486	457	379	275	175	100	73
Decade	93	163	257	366	448	485	464	393	291	189	108	4
21	101	180	277	383	459	486	455	376	272	172	98	73
22	103	183	280	386	460	486	453	373	268	169	96	74
23	105	186	284	389	462	486	451	370	265	166	95	74
24	107	189	287	392	464	485	449	367	261	163	93	74
25	109	193	291	395	465	485	447	364	258	160	92	74
26	111	196	295	398	467	485	445	360	254	157	90	74
27	113	199	298	401	468	484	443	357	251	154	89	75
28	115	203	302	404	470	484	441	354	247	151	88	75
29	117	—	305	407	471	483	439	351	244	149	87	75
30	119	—	309	410	473	482	436	347	240	146	85	76
31	122	—	313	—	474	—	434	344	—	143	—	76
Decade	111	191	295	397	467	484	445	360	256	157	91	75
Month	95	161	259	365	447	483	462	390	291	188	110	76
Year		278										
Summer		407										
Winter		148										

APPENDIX C

Monthly and yearly mean values of K_r in the period 1928–1993

Year	Year	Summer	Winter	January	February	March	April	May	June	July	August	September	October	November	December
1928	—	0·457	—	—	—	—	0·398	0·447	0·461	0·486	0·455	0·497	—	—	—
1929	—	0·409	—	—	—	—	0·365	0·458	0·373	0·420	0·427	0·405	—	—	—
Mean	—	0·433	—	—	—	—	0·382	0·452	0·417	0·453	0·441	0·451	—	—	—
1930	—	0·360	—	—	—	—	0·330	0·325	0·460	0·337	0·362	0·319	—	—	—
1931	—	0·364	—	—	—	—	0·329	0·374	0·391	0·338	0·381	0·368	—	—	—
1932	—	0·362	—	—	—	—	0·314	0·349	0·413	0·350	0·401	0·325	—	—	—
1933	—	0·393	—	—	—	—	0·349	0·374	0·391	0·401	0·432	0·414	—	—	—
1934	—	0·418	—	—	—	—	0·404	0·410	0·439	0·448	0·382	0·418	—	—	—
1935	—	0·397	—	—	—	—	0·319	0·427	0·407	0·429	0·408	0·361	—	—	—
1936	—	0·381	—	—	—	—	0·329	0·408	0·429	0·359	0·378	0·361	—	—	—
1937	—	0·353	—	—	—	—	0·237	0·391	0·396	0·352	0·364	0·351	—	—	—
1938	0·355	0·372	0·307	—	0·311	0·354	0·332	0·404	0·407	0·332	0·353	0·405	0·348	0·190	0·326
1939	0·375	0·409	0·279	0·188	0·297	0·329	0·383	0·429	0·464	0·374	0·402	0·389	0·300	0·243	0·194
Mean	0·365	0·381	0·293	0·188	0·304	0·341	0·333	0·389	0·420	0·372	0·386	0·371	0·324	0·216	0·260
1940	0·370	0·391	0·317	0·349	0·271	0·319	0·356	—	0·450	0·351	0·391	0·376	0·376	0·304	0·233
1941	0·384	0·412	0·308	0·267	0·255	0·357	0·385	0·392	0·463	0·455	0·351	0·406	0·345	0·295	0·217
1942	0·397	0·425	0·320	0·308	0·321	0·404	0·503	0·417	0·452	0·367	0·410	0·408	0·291	0·242	0·233
1943	0·397	0·425	0·318	0·298	0·277	0·437	0·449	0·483	0·353	0·466	0·386	0·408	0·251	0·270	0·255
1944	—	0·394	—	0·200	0·281	0·365	0·367	0·441	0·347	0·350	0·480	—	—	—	—
1945	—	—	—	—	—	—	—	—	—	0·425	0·363	0·436	0·361	0·174	0·201
1946	0·358	0·378	0·300	0·298	0·258	0·334	0·450	0·422	0·365	0·369	0·312	0·348	0·319	0·260	0·280
1947	0·418	0·457	0·311	0·375	0·346	0·272	0·368	0·429	0·448	0·502	0·526	0·461	0·449	0·165	0·155
1948	0·421	0·442	0·363	0·167	0·367	0·446	0·454	0·504	0·426	0·405	0·444	0·414	0·367	0·328	0·354
1949	0·410	0·420	0·383	0·355	0·337	0·463	0·448	0·355	0·428	0·450	0·436	0·408	0·399	0·362	0·226
Mean	0·395	0·416	0·328	0·291	0·302	0·378	0·420	0·430	0·415	0·414	0·410	0·407	0·351	0·266	0·240
1950	0·365	0·387	0·303	0·308	0·290	0·326	0·382	0·399	0·438	0·377	0·396	0·296	0·351	0·196	0·266
1951	0·404	0·430	0·333	0·181	0·273	0·330	0·417	0·443	0·468	0·424	0·385	0·431	0·503	0·285	0·289
1952	0·408	0·439	0·325	0·260	0·301	0·354	0·489	0·457	0·437	0·422	0·412	0·411	0·357	0·333	0·259
1953	0·422	0·457	0·327	0·195	0·299	0·428	0·490	0·464	0·419	0·427	0·483	0·477	0·336	0·258	0·274
1954	0·354	0·380	0·284	0·356	0·272	0·283	0·473	0·417	0·371	0·330	0·356	0·335	0·260	0·323	0·222
1955	0·400	0·426	0·327	0·210	0·331	0·402	0·422	0·408	0·440	0·439	0·452	0·379	0·334	0·309	0·225
1956	0·361	0·376	0·322	0·192	0·391	0·382	0·371	0·442	0·363	0·338	0·380	0·352	0·326	0·289	0·174
1957	0·406	0·447	0·292	0·252	0·256	0·338	0·497	0·491	0·504	0·424	0·401	0·323	0·352	0·209	0·219
1958	0·380	0·404	0·314	0·240	0·298	0·422	0·422	0·399	0·406	0·404	0·394	0·404	0·300	0·225	0·231
1959	0·443	0·484	0·330	0·298	0·289	0·363	0·394	0·512	0·514	0·510	0·436	0·522	0·411	0·268	0·217
Mean	0·394	0·423	0·315	0·249	0·300	0·363	0·436	0·443	0·436	0·410	0·410	0·393	0·353	0·270	0·238

APPENDIX C (*continued*)

Monthly and yearly mean values of K_r in the period 1928–1993

Year	Year	Summer	Winter	January	February	March	April	May	June	July	August	September	October	November	December
1960	0·354	0·384	0·273	0·216	0·261	0·325	0·419	0·387	0·438	0·333	0·352	0·375	0·287	0·255	0·178
1961	0·351	0·369	0·302	0·256	0·292	0·336	0·328	0·398	0·416	0·332	0·369	0·361	0·342	0·246	0·245
1962	0·367	0·389	0·306	0·246	0·303	0·338	0·323	0·354	0·458	0·369	0·401	0·429	0·343	0·217	0·313
1963	0·365	0·381	0·321	0·366	0·367	0·302	0·357	0·359	0·421	0·424	0·324	0·386	0·327	0·278	0·288
1964	0·384	0·415	0·298	0·224	0·325	0·323	0·351	0·442	0·415	0·418	0·411	0·451	0·356	0·204	0·245
1965	0·355	0·362	0·337	0·224	0·318	0·375	0·346	0·361	0·378	0·317	0·420	0·350	0·409	0·332	0·215
1966	0·330	0·357	0·256	0·262	0·229	0·254	0·297	0·425	0·366	0·314	0·379	0·350	0·283	0·272	0·218
1967	0·372	0·400	0·294	0·247	0·306	0·298	0·418	0·404	0·402	0·423	0·398	0·332	0·321	0·295	0·246
1968	0·332	0·350	0·282	0·245	0·276	0·353	0·416	0·336	0·327	0·372	0·334	0·315	0·261	0·233	0·218
1969	0·403	0·436	0·312	0·184	0·312	0·338	0·451	0·384	0·442	0·439	0·455	0·460	0·398	0·248	0·259
Mean	0·361	0·384	0·298	0·247	0·299	0·324	0·370	0·385	0·406	0·374	0·384	0·381	0·333	0·258	0·243
1970	0·386	0·417	0·303	0·219	0·303	0·351	0·324	0·424	0·511	0·362	0·450	0·407	0·309	0·293	0·248
1971	0·408	0·438	0·326	0·219	0·305	0·348	0·443	0·483	0·384	0·453	0·413	0·458	0·435	0·259	0·248
1972	0·394	0·403	0·371	0·245	0·291	0·452	0·358	0·390	0·390	0·402	0·446	0·444	0·453	0·277	0·334
1973	0·421	0·445	0·355	0·251	0·285	0·425	0·397	0·427	0·516	0·414	0·492	0·399	0·402	0·350	0·272
1974	0·409	0·441	0·321	0·234	0·374	0·353	0·511	0·437	0·470	0·378	0·472	0·369	0·365	0·255	0·200
1975	0·418	0·449	0·334	0·264	0·457	0·300	0·339	0·454	0·478	0·439	0·521	0·444	0·377	0·280	0·271
1976	0·441	0·475	0·345	0·272	0·287	0·428	0·483	0·460	0·501	0·473	0·522	0·387	0·359	0·266	0·347
1977	0·375	0·390	0·334	0·234	0·321	0·407	0·379	0·456	0·345	0·397	0·373	0·386	0·363	0·258	0·252
1978	0·376	0·403	0·300	0·244	0·337	0·292	0·473	0·398	0·412	0·393	0·401	0·330	0·318	0·319	0·261
1979	0·379	0·400	0·320	0·335	0·302	0·332	0·367	0·435	0·400	0·378	0·392	0·436	0·380	0·285	0·201
Mean	0·401	0·426	0·331	0·252	0·326	0·369	0·407	0·436	0·441	0·409	0·448	0·406	0·376	0·284	0·263

1980	0·393	0·426	0·291	0·267	0·278	0·292	0·427	0·545	0·396	0·349	0·407	0·440	—	0·291	0·220
1981	0·341	0·370	0·260	0·230	0·304	0·243	0·364	0·406	0·331	0·353	0·380	0·400	0·277	0·246	0·248
1982	0·381	0·414	0·291	0·262	0·298	0·351	0·429	0·438	0·378	0·438	0·393	0·406	0·296	0·222	0·191
1983	0·374	0·401	0·299	0·189	0·341	0·300	0·347	0·295	0·458	0·484	0·444	0·347	0·344	0·292	0·253
1984	0·345	0·367	0·287	0·209	0·260	0·348	0·434	0·302	0·370	—	0·433	0·271	0·288	0·280	0·231
1985	0·362	0·375	0·325	0·291	0·392	0·299	0·336	0·387	0·350	0·403	0·402	0·364	0·375	0·334	0·190
1986	0·387	0·417	0·303	0·235	0·339	0·296	0·299	0·448	0·472	0·404	0·443	0·413	0·365	0·283	0·211
1987	0·360	0·379	0·311	0·234	0·274	0·389	0·432	0·388	—	0·414	0·345	0·396	0·371	0·222	0·194
1988	0·379	0·413	0·285	0·176	0·312	0·286	0·526	0·465	0·369	0·337	0·437	0·350	0·325	0·339	0·193
1989	0·436	0·463	0·360	0·270	0·349	0·383	0·361	0·588	0·481	0·440	0·444	0·429	0·401	0·411	0·237
Mean	0·376	0·403	0·301	0·236	0·315	0·319	0·395	0·426	0·401	0·402	0·413	0·382	0·338	0·292	0·217
1990	0·424	0·446	—	0·221	—	0·420	0·494	0·528	0·355	0·473	0·464	0·341	0·407	0·264	0·239
1991	0·405	0·420	—	0·336	—	0·408	0·466	0·408	0·310	0·464	0·494	0·387	0·394	0·254	0·262
1992	—	0·441	—	0·253	0·316	—	0·382	0·531	0·440	0·440	0·402	0·428	0·359	—	0·254
1993	—	—	—	0·260	0·271	0·459	0·403	0·467	0·420	—	—	—	—	—	—
Mean	0·415	0·436	—												

1928–1993	Year	Summer	Winter
Mean	0·385	0·408	0·313
Standard deviation	0·028	0·033	0·026
Minimum	0·330	0·350	0·256
Maximum	0·443	0·484	0·383

APPENDIX D

Averages, standard deviation, absolute minimum, and absolute maximum K_r values per decade in the period 1928–1993

Decade		n	Mean	Standard deviation	Minimum	Maximum
January	1	54	0·244	0·066	0·139	0·384
	2	54	0·260	0·076	0·141	0·423
	3	55	0·255	0·086	0·125	0·458
February	1	53	0·277	0·075	0·128	0·488
	2	53	0·305	0·070	0·167	0·520
	3	53	0·338	0·075	0·179	0·550
March	1	55	0·357	0·077	0·166	0·551
	2	54	0·350	0·087	0·173	0·550
	3	64	0·359	0·077	0·207	0·536
April	1	64	0·364	0·088	0·201	0·602
	2	65	0·403	0·088	0·188	0·583
	3	65	0·414	0·083	0·240	0·586
May	1	65	0·423	0·080	0·218	0·606
	2	64	0·428	0·078	0·273	0·633
	3	65	0·419	0·078	0·216	0·625
June	1	65	0·428	0·084	0·262	0·655
	2	64	0·421	0·083	0·262	0·645
	3	64	0·401	0·072	0·271	0·591
July	1	65	0·411	0·076	0·270	0·619
	2	64	0·390	0·087	0·236	0·601
	3	65	0·404	0·070	0·260	0·596
August	1	65	0·407	0·065	0·277	0·617
	2	65	0·407	0·072	0·280	0·582
	3	65	0·421	0·063	0·297	0·586
September	1	65	0·411	0·067	0·256	0·592
	2	64	0·386	0·065	0·230	0·524
	3	64	0·372	0·065	0·239	0·511
October	1	64	0·367	0·076	0·165	0·560
	2	53	0·347	0·068	0·204	0·506
	3	53	0·330	0·067	0·155	0·452
November	1	53	0·286	0·063	0·163	0·484
	2	53	0·271	0·068	0·138	0·517
	3	53	0·252	0·068	0·133	0·420
December	1	54	0·259	0·075	0·080	0·445
	2	54	0·230	0·070	0·118	0·435
	3	54	0·234	0·061	0·124	0·417

APPENDIX E

Daily mean, maximum and minimum K_r values, 1928–1993

Day	Mean	Maximum	Minimum	n
1	0·254	0·770	0·036	52
2	0·231	0·612	0·033	54
3	0·266	0·537	0·021	54
4	0·271	0·646	0·041	54
5	0·206	0·568	0·041	54
6	0·252	0·547	0·052	54
7	0·237	0·594	0·034	54
8	0·235	0·686	0·011	54
9	0·234	0·613	0·044	55
10	0·255	0·587	0·047	55
11	0·237	0·695	0·032	55
12	0·266	0·653	0·040	55
13	0·294	0·638	0·040	55
14	0·253	0·606	0·036	55
15	0·254	0·704	0·060	55
16	0·248	0·587	0·045	55
17	0·269	0·668	0·031	54
18	0·293	0·538	0·053	54
19	0·244	0·506	0·061	54
20	0·228	0·523	0·040	54
21	0·230	0·579	0·050	55
22	0·204	0·555	0·024	55
23	0·246	0·615	0·021	55
24	0·251	0·546	0·047	55
25	0·233	0·558	0·024	55
26	0·257	0·601	0·049	55
27	0·252	0·624	0·036	55
28	0·263	0·602	0·026	55
29	0·297	0·596	0·065	55
30	0·264	0·564	0·050	55
31	0·289	0·636	0·029	55
32	0·294	0·679	0·046	53
33	0·278	0·663	0·056	53
34	0·258	0·656	0·020	53
35	0·306	0·661	0·007	53
36	0·308	0·587	0·057	53
37	0·243	0·610	0·009	53
38	0·264	0·661	0·018	53
39	0·265	0·604	0·034	53
40	0·300	0·628	0·053	53
41	0·255	0·596	0·055	53
42	0·276	0·606	0·057	53
43	0·267	0·577	0·038	53
44	0·328	0·626	0·064	53
45	0·305	0·561	0·033	53
46	0·288	0·624	0·012	53
47	0·326	0·648	0·040	53
48	0·325	0·606	0·057	53
49	0·322	0·602	0·044	53
50	0·284	0·618	0·058	53
51	0·319	0·643	0·044	53
52	0·321	0·642	0·082	53
53	0·345	0·594	0·083	53
54	0·321	0·620	0·061	53
55	0·349	0·674	0·064	53

Day	Mean	Maximum	Minimum
56	0·342	0·719	0·066
57	0·361	0·642	0·083
58	0·337	0·704	0·029
59	0·335	0·631	0·055
60	0·346	0·744	0·047
61	0·339	0·704	0·044
62	0·371	0·713	0·080
63	0·330	0·687	0·092
64	0·339	0·675	0·054
65	0·399	0·688	0·138
66	0·345	0·647	0·062
67	0·364	0·663	0·105
68	0·352	0·651	0·066
69	0·376	0·645	0·050
70	0·324	0·644	0·074
71	0·362	0·679	0·074
72	0·384	0·731	0·052
73	0·336	0·695	0·087
74	0·370	0·767	0·066
75	0·357	0·676	0·069
76	0·339	0·643	0·046
77	0·348	0·653	0·117
78	0·323	0·661	0·064
79	0·333	0·626	0·028
80	0·336	0·719	0·080
81	0·348	0·676	0·045
82	0·373	0·673	0·103
83	0·367	0·685	0·066
84	0·357	0·675	0·067
85	0·362	0·644	0·086
86	0·360	0·683	0·067
87	0·375	0·733	0·128
88	0·382	0·682	0·053
89	0·338	0·722	0·064
90	0·361	0·683	0·081
91	0·339	0·636	0·052
92	0·337	0·642	0·057
93	0·345	0·620	0·102
94	0·326	0·666	0·029
95	0·351	0·691	0·098
96	0·350	0·717	0·065
97	0·376	0·686	0·074
98	0·389	0·733	0·054
99	0·399	0·730	0·050
100	0·384	0·715	0·099
101	0·408	0·677	0·073
102	0·382	0·700	0·068
103	0·420	0·742	0·087
104	0·386	0·709	0·055
105	0·415	0·698	0·070
106	0·356	0·679	0·068
107	0·400	0·668	0·061
108	0·411	0·666	0·071
109	0·414	0·715	0·097
110	0·443	0·845	0·144

APPENDIX E (*continued*)

Daily mean, maximum and minimum K_r values, 1928–1993

Day	Mean	Maximum	Minimum	*n*
111	0·410	0·693	0·103	65
112	0·447	0·698	0·107	65
113	0·412	0·711	0·105	65
114	0·439	0·744	0·070	65
115	0·422	0·748	0·080	65
116	0·402	0·716	0·090	65
117	0·420	0·719	0·125	65
118	0·404	0·687	0·095	65
119	0·390	0·696	0·054	65
120	0·403	0·710	0·078	65
121	0·402	0·727	0·085	65
122	0·416	0·727	0·099	65
123	0·424	0·722	0·101	65
124	0·414	0·703	0·077	65
125	0·412	0·681	0·069	65
126	0·409	0·711	0·070	65
127	0·432	0·687	0·048	65
128	0·429	0·725	0·072	65
129	0·445	0·697	0·146	65
130	0·446	0·698	0·109	65
131	0·430	0·741	0·091	64
132	0·448	0·717	0·141	64
133	0·409	0·694	0·122	64
134	0·397	0·707	0·118	64
135	0·417	0·724	0·103	64
136	0·430	0·713	0·106	64
137	0·428	0·718	0·138	64
138	0·418	0·741	0·056	64
139	0·434	0·725	0·158	64
140	0·452	0·744	0·066	64
141	0·401	0·727	0·095	64
142	0·434	0·705	0·060	65
143	0·439	0·724	0·124	65
144	0·418	0·701	0·059	65
145	0·409	0·724	0·042	65
146	0·424	0·736	0·029	65
147	0·399	0·689	0·066	65
148	0·415	0·689	0·162	65
149	0·439	0·710	0·074	65
150	0·429	0·728	0·070	65
151	0·425	0·722	0·103	65
152	0·431	0·706	0·082	65
153	0·424	0·706	0·077	65
154	0·405	0·692	0·097	65
155	0·432	0·661	0·148	65
156	0·433	0·726	0·094	65
157	0·428	0·745	0·071	65
158	0·429	0·710	0·108	65
159	0·401	0·728	0·063	65
160	0·437	0·737	0·141	65
161	0·443	0·729	0·064	65
162	0·415	0·694	0·132	65
163	0·414	0·677	0·030	64
164	0·447	0·720	0·121	65
165	0·421	0·710	0·096	65

Day	Mean	Maximum	Minimum	*n*
166	0·417	0·708	0·068	64
167	0·419	0·728	0·070	64
168	0·421	0·692	0·136	65
169	0·431	0·741	0·114	65
170	0·419	0·713	0·110	65
171	0·402	0·699	0·102	65
172	0·436	0·693	0·116	65
173	0·406	0·721	0·173	65
174	0·380	0·625	0·092	65
175	0·403	0·634	0·083	65
176	0·409	0·684	0·095	65
177	0·387	0·691	0·063	65
178	0·371	0·642	0·093	65
179	0·377	0·715	0·052	65
180	0·379	0·703	0·079	64
181	0·440	0·709	0·119	64
182	0·421	0·742	0·130	65
183	0·399	0·681	0·094	64
184	0·427	0·710	0·123	65
185	0·422	0·686	0·143	65
186	0·405	0·674	0·104	65
187	0·395	0·660	0·143	65
188	0·425	0·694	0·079	65
189	0·416	0·674	0·117	65
190	0·411	0·673	0·105	65
191	0·408	0·680	0·147	65
192	0·401	0·667	0·061	65
193	0·415	0·710	0·115	64
194	0·410	0·698	0·086	64
195	0·392	0·727	0·083	64
196	0·387	0·705	0·142	64
197	0·368	0·719	0·097	65
198	0·394	0·636	0·086	65
199	0·365	0·642	0·115	65
200	0·379	0·652	0·111	65
201	0·377	0·717	0·100	65
202	0·397	0·722	0·099	65
203	0·419	0·689	0·107	65
204	0·396	0·724	0·109	65
205	0·412	0·677	0·092	65
206	0·397	0·729	0·095	65
207	0·399	0·635	0·147	65
208	0·403	0·652	0·104	65
209	0·402	0·711	0·103	65
210	0·382	0·706	0·076	65
211	0·431	0·701	0·120	65
212	0·398	0·686	0·150	65
213	0·390	0·653	0·095	64
214	0·413	0·678	0·135	65
215	0·405	0·668	0·137	65
216	0·409	0·676	0·102	65
217	0·417	0·658	0·083	65
218	0·429	0·668	0·182	64
219	0·418	0·683	0·127	65
220	0·374	0·713	0·088	65

APPENDIX E (*continued*)

Daily mean, maximum and minimum K_T values, 1928–1993

Day	Mean	Maximum	Minimum	*n*
221	0·400	0·749	0·064	65
222	0·403	0·667	0·118	65
223	0·385	0·687	0·115	65
224	0·394	0·695	0·076	65
225	0·393	0·696	0·092	65
226	0·425	0·701	0·110	64
227	0·405	0·676	0·090	65
228	0·422	0·707	0·120	65
229	0·406	0·681	0·078	65
230	0·428	0·675	0·062	65
231	0·412	0·684	0·079	65
232	0·407	0·670	0·114	65
233	0·404	0·701	0·096	65
234	0·388	0·738	0·078	65
235	0·411	0·696	0·110	65
236	0·430	0·688	0·058	65
237	0·427	0·664	0·113	65
238	0·428	0·703	0·136	65
239	0·453	0·675	0·136	65
240	0·432	0·762	0·121	65
241	0·435	0·699	0·108	65
242	0·431	0·707	0·073	65
243	0·383	0·692	0·107	65
244	0·422	0·668	0·098	65
245	0·392	0·673	0·119	65
246	0·412	0·673	0·071	65
247	0·408	0·685	0·108	65
248	0·407	0·669	0·130	65
249	0·408	0·719	0·118	65
250	0·430	0·691	0·156	65
251	0·421	0·657	0·052	65
252	0·400	0·718	0·145	65
253	0·419	0·626	0·102	65
254	0·398	0·629	0·121	65
255	0·392	0·608	0·076	64
256	0·412	0·682	0·072	64
257	0·374	0·804	0·082	64
258	0·386	0·670	0·101	64
259	0·383	0·699	0·053	64
260	0·382	0·663	0·093	64
261	0·358	0·617	0·101	64
262	0·378	0·675	0·104	64
263	0·391	0·652	0·118	64
264	0·372	0·656	0·094	63
265	0·384	0·675	0·106	64
266	0·388	0·598	0·110	64
267	0·394	0·662	0·100	64
268	0·340	0·736	0·074	64
269	0·379	0·641	0·026	64
270	0·371	0·684	0·090	64
271	0·384	0·693	0·081	64
272	0·392	0·663	0·080	64
273	0·324	0·676	0·070	64
274	0·394	0·675	0·073	64
275	0·374	0·687	0·048	64

Day	Mean	Maximum	Minimum	*n*
276	0·395	0·643	0·069	64
277	0·378	0·666	0·049	64
278	0·369	0·655	0·073	64
279	0·358	0·677	0·072	64
280	0·325	0·640	0·043	64
281	0·361	0·604	0·126	64
282	0·362	0·635	0·071	63
283	0·346	0·616	0·054	64
284	0·378	0·653	0·036	57
285	0·385	0·667	0·055	54
286	0·322	0·647	0·066	54
287	0·348	0·643	0·091	53
288	0·352	0·665	0·050	53
289	0·337	0·632	0·013	53
290	0·323	0·639	0·039	53
291	0·335	0·644	0·029	53
292	0·324	0·569	0·029	53
293	0·365	0·645	0·030	53
294	0·348	0·647	0·070	53
295	0·355	0·687	0·068	53
296	0·335	0·668	0·048	53
297	0·322	0·684	0·085	53
298	0·337	0·604	0·138	53
299	0·360	0·695	0·057	53
300	0·335	0·658	0·054	53
301	0·313	0·666	0·022	53
302	0·335	0·600	0·016	53
303	0·298	0·610	0·039	53
304	0·297	0·598	0·053	53
305	0·297	0·594	0·069	53
306	0·281	0·578	0·027	53
307	0·272	0·579	0·057	53
308	0·259	0·686	0·041	53
309	0·308	0·647	0·052	53
310	0·294	0·608	0·093	53
311	0·284	0·518	0·036	53
312	0·261	0·543	0·047	53
313	0·303	0·591	0·042	53
314	0·305	0·606	0·038	53
315	0·278	0·645	0·046	53
316	0·289	0·605	0·030	53
317	0·286	0·556	0·037	53
318	0·278	0·549	0·038	53
319	0·283	0·611	0·055	53
320	0·266	0·639	0·041	53
321	0·276	0·600	0·056	53
322	0·245	0·586	0·054	53
323	0·236	0·571	0·028	53
324	0·257	0·585	0·032	53
325	0·277	0·554	0·031	53
326	0·277	0·677	0·046	53
327	0·231	0·557	0·057	5
328	0·250	0·546	0·052	5
329	0·219	0·698	0·030	5
330	0·243	0·692	0·040	5

APPENDIX E (continued)

Daily mean, maximum and minimum K_r values, 1928–1993

Day	Mean	Maximum	Minimum	*n*	Day	Mean	Maximum	Minimum	*n*
331	0·235	0·592	0·026	53	349	0·228	0·692	0·031	54
332	0·258	0·626	0·025	53	350	0·223	0·550	0·019	54
333	0·278	0·638	0·037	53	351	0·243	0·537	0·050	54
334	0·267	0·577	0·022	53	352	0·251	0·621	0·050	54
335	0·283	0·636	0·053	53	353	0·246	0·547	0·022	54
336	0·290	0·751	0·059	54	354	0.233	0.487	0.038	54
337	0·258	0·651	0·027	54	355	0·221	0·468	0·044	54
338	0·282	0·526	0·027	54	356	0·213	0·529	0·057	54
339	0·268	0·666	0·034	54	357	0·237	0·578	0·057	54
340	0·265	0·605	0·030	54	358	0·227	0·718	0·050	54
341	0·249	0·553	0·028	54	359	0·224	0·560	0·028	54
342	0·241	0·582	0·043	54	360	0·227	0·611	0·050	54
343	0·231	0·688	0·028	54	361	0·268	0·811	0·017	54
344	0·235	0·573	0·036	54	362	0·210	0·521	0·029	54
345	0·231	0·644	0·012	54	363	0·242	0·622	0·025	54
346	0·197	0·651	0·026	54	364	0·259	0·625	0·017	54
347	0·229	0·530	0·023	54	365	0·247	0·571	0·038	54
348	0·218	0·755	0·012	54	366	0·212	0·523	0·054	13

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