INTERANNUAL VARIABILITY OF GLOBAL RADIATION AT WAGENINGEN

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ABSTRACT
A spectral analysis of the 12-monthly running means of the global radiation ratio $K_r$ observed at Wageningen (52°N, 6°E) showed significant QBO, QTO (Quasi-biennial and Quasi-triennial Oscillations) and higher periodicities, with the strongest peak at ca.22 years but none at the solar cycle (11 years). All these are probably due to similar periodicities in cloudiness. © 1997 by the Royal Meteorological Society. Int. J. Climatol., Vol. 17, 1487–1493

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KEY WORDS: The Netherlands, Wageningen; global radiation; spectra; oscillations.

INTRODUCTION
Solar radiation is the main energy source for physical and biological processes at the Earth’s surface, in the atmosphere and in the oceans. Long-term records of solar radiation are required for many purposes. At Wageningen, The Netherlands, routine observations started as early as 1926 and data are published in the monthly meteorological reports of the Wageningen Agricultural University. Recently, De Bruin et al. (1995) (henceforth referred to as BHW) published a series of the global radiation at Wageningen for 1928–1992 and presented detailed results for the seasonal variation (e.g. maximum in May rather than end of June). Regarding long-term behaviour, mean values over 10-year periods (1930–1939, 1940–1949, etc.) were given and it was mentioned that the radiation reached high values in 1959, 1976, 1989, and 1990 and very low values in 1966 and 1968, and plots of annual values were shown. The global radiation could show variations due to many causes, e.g. changes in the solar input (11 year or longer periodicities), changes in the atmospheric parameters affecting transmission of solar radiation (cloudiness, aerosol), etc. If the atmospheric parameters have some periodicities (e.g. El Niño relationships), these could be, reflected in global radiation. In this paper, a spectral analysis of the long-term series of global radiation is attempted at Wageningen in order to detect if any significant periodicities exist.

DATA
The total daily amount of ‘daily global radiation’ or ‘daily incoming solar radiation’, i.e. the daily total of the incoming solar radiation that reaches a horizontal plane at the surface, has been measured at Wageningen (51°58’N, 5°39’E), The Netherlands, almost uninterrupted since 1926 but more reliably since 1928 onwards. A detailed scrutiny and comparison of the earlier data was made by BHW (see also references therein), who applied appropriate normalizing factors and obtained a homogeneous series of daily global radiation for 1928–1992 and

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expressed it as a fraction \( K_r \) of the corresponding extraterrestrial global radiation (solar constant modified, taking into account declination \( \delta \) of the sun on each day and the geographical latitude of Wageningen, see details in BHW). From the daily means of \( K_r \), the monthly, seasonal (summer, defined as April through to September; winter, defined as October through to March) and yearly means were calculated and presented in Appendix C of BHW. In the present analysis, these values are used.

**PLOTS**

Figure 1 shows a plot of \( K_r \) values for a sample interval 1950–1959. Figure 1(a) refers to the monthly values, which show a large seasonal variation (range 0.18–0.52), whereas other periodicities, if any exist, are hidden. Figure 1(b) shows the summer (S) and winter (W) values. Even here, the seasonal variation is substantial (range 0.28–0.48). Figure 1(c) shows the running means over two consecutive values of summer and winter, i.e. 12-monthly means, centred 6 months apart (S+W, W+S, and so on). The seasonal variation is now eliminated and other, longer period variations are visible. The same is true for Figure 1(d), which shows the annual means (January–December).

Figure 2 shows plots of seasonal (summer, winter) and yearly means of \( K_r \) for the whole period 1928–1992. Figure 2(a and b) shows the summer (S) and winter (W) means (one value per year). During 1944–1945, data for some months were missing and the summer and winter values have been interpolated as shown by the crosses. Figure 2(c) shows the summer, winter, summer, winter, sequence with a large seasonal variation, and Figure 2(d) shows their running means over two consecutive values, with seasonal variation eliminated. Figure 2(e) shows the annual (January–December) means. Figure 2(f) shows 3-yearly (six values) running means of SWSW sequence, centred 6 months apart (two values per year). If these are subtracted from the 12-monthly (two semester) running means of Figure 2(e), the residues designated as (12–36) are shown in Figure 2(g) and represent short-term fluctuations (1–3 years) only. Figure 2(h) shows the 11-yearly running means of the SWSW sequence. Figure 2(i) shows the sunspot numbers, with sunspot minima marked by the vertical lines. As can be seen, Figure 2(h) shows roughly a 22-year cycle.

![Sample plot of global radiation ratio](image-url)
SPECTRAL ANALYSIS

To detect periodicities, all these series were subjected to a power spectrum analysis, using MESA (maximum entropy spectral analysis, Burg, 1967; Ulrych and Bishop, 1975), which detects periodicities much more accurately than the conventional BT method (Blackman and Tukey, 1958). Similar to the lag parameter $m$ in BT, MESA has a parameter called LPEF (length of the prediction error filter), which can be chosen. With low LPEF, only low periodicities are resolved. Larger LPEF resolve larger periodicities, even those approaching the data length, but the errors are larger, and low periodicities show peak-splitting. An LPEF of ca.50 per cent of the data length is generally adequate and was used in the present analysis.

The MESA has a drawback, namely, the power estimates are not reliable (Kane and Trivedi, 1982). Hence, MESA was used only to identify the possible periodicities $T_k$, which were then used in the expression:

$$f(t) = A_0 + \sum_{k=1}^{n} [a_k \sin(2\pi t/T_k) + b_k \cos(2\pi t/T_k)] + E$$

$$= A_0 + \sum_{k=1}^{n} r_k \sin(2\pi t/T_k + \phi_k) + E$$

where $f(t)$ is the observed series and $E$ the error factor. A multiple regression analysis (MRA; Bevington, 1969) was then carried out to obtain the best estimates of $A_0$, $(a_k, b_k)$ and their standard errors, by a least-square fit. From

Figure 2. Plots of $K_r$ for 1928–1992. (a) Summer (S), (b) winter (W), (c) S,W,S,W in succession, (d) running means of S, W, (e) annual, (f) 3-yearly running means, (g) 12-monthly minus 3-yearly means (12 – 36), (h) 11-yearly running means, (i) sunspots
these, $r_k$ and their standard error $\sigma$ (common for all $r_k$ in this methodology) can be calculated and any $r_k$ exceeding $2\sigma$ would be significant at a 95 per cent (a priori) confidence level.

Figure 3 shows the amplitudes of the various periodicities obtained by MESA for each series. Figure 3(a) shows spectra of the SWSW series of Figure 2(c). As can be seen, many peaks are observed but none significant at the $2\sigma$ limit (hatched portion), indicating a high level of noise. When this series is smoothed by evaluating running averages over two successive values ($S + W$, $W + S$, etc., as in Figure 2(d)), the spectra of the smoothed series were as shown in Figure 3(b), the noise level is reduced considerably (smaller $2\sigma$ limit) and several

![Figure 3. Amplitudes of the periodicities detected by maximum entropy spectral analysis of the various series, (a) S,W,S,W in succession, (b) running means of S, W, (c) summer (S), (d) winter (W), (e) annual, (f) 3-yearly, (g) 12-monthly minus 3-yearly means (12 – 36), (h) 11-yearly, (i,j,) 1938–1963 and 1964–1989 series of the running means of S,W](image-url)
periodicities that were insignificant in Figure 3(a) become significant, the most prominent being a 22-year peak. Figure 3(c) shows the spectra for summer (S) value series (one value per year as in Figure 2(a)), Figure 3(d) for winter (W) values (Figure 2(b)) and Figure 3(e) for annual values (Figure 2(e)). The summer (S) spectra have QBO (Quasi-biennial oscillation) at 2.05 and 2.36 years, which are absent in the winter (W) spectra. On the other hand, peaks at ca.3.40, 3.95, 5.9 and 24 years appear in both summer and winter spectra.

Figure 3(f) shows spectra for the 3-yearly means. As expected, lower periodicities are wiped out and peaks at 5.3, 7.4, 13.0 and 22.3 (the most prominent one) are seen. If the 3-yearly means are subtracted from the 12-monthly means, the spectra of the residues (12 − 36) of Figure 2(g) are shown in Figure 3(g) and show only lower periodicities, most prominently at 2.05 and 3.39 years.

Figure 3(h) shows the spectra for the 11-yearly means of Figure 2(h). Here, peaks at only 13.9 and 22.6 years are seen.

How persistent are these peaks? For example, if the interval 1928–1992 is divided into two roughly equal parts, would the same spectra be seen? Figure 3(i and j) shows the spectra for the 12-monthly running means (S + W, W + S, etc, of Figure 2(d)) for 1938–1963 and 1964–1989. Peaks at (1.81 − 2.02), (3.33 − 3.53), (5.1 − 5.5) and (16.4 − 18.0) years are common to both these intervals; but a peak near 9 years is seen only in the first half. Thus, slight changes of spectral characteristics with time do seem to occur. Overall, however, many peaks seem to be genuine. The peaks in the latter half seem to shift towards lower periods (2.02 to 1.81, 3.53 to 3.33 and 18.0 to 16.4; 5.1 to 5.5 is an exception).

Two atmospheric phenomena known to have QBO and/or QTO are the low-latitude stratospheric winds (Reed et al., 1961), available from 1951 onwards only, and the ENSO phenomena. For ENSO, the indices used are the Tahiti (T) minus Darwin (D) atmospheric pressure difference (T-D) (Parker, 1983; Meteorological Data Reports), and the equatorial eastern Pacific sea-surface temperature SST (Angell, 1981; and further private communication). Figure 4 shows the spectra for 1951–1990. Figure 4(a) for the global radiation shows QBO peaks at 2.04 and 2.30 years, a QTO peak at 3.37 years and small peaks at 1.79 and 5.7 years. Figure 4(b) for the
50 hPa wind (Pawson et al., 1993) shows a strong peak at 2–34 years, a smaller peak at 2.73 years and a still smaller peak at 1.97 years (all QBO). Figure 4(c and d) shows spectra for (T-D) and SST, respectively, which are similar to each other as expected (both are components of ENSO) and show the most prominent peak at 4.8 years, a smaller but significant peak at ca.3.50 years (QTO) and small peaks in the QBO region (Kane, 1992). Some of these are similar to the peaks in the global radiation and suggest a possible relationship between the global radiation and these phenomena.

CONCLUSIONS AND DISCUSSION

The monthly means of the global radiation recorded at Wageningen (52°N, 6°E), The Netherlands, during 1928–1992 have a strong seasonal variation. If this is eliminated by calculating 12-monthly running means, several significant periodicities are revealed, from QBO (Quasi-biennial Oscillations, 2–3 years), QTO (Quasi-triennial Oscillations, 3–4 years) to higher periodicities, with the strongest periodicity at ca.22 years, but none at the solar cycle (11 years). Some of the peaks in the global radiation seem to match with peaks in the spectra of 50 hPa low-latitude zonal wind and the ENSO phenomena (El Niño–Southern Oscillation).

The extraterrestrial global radiation varies very little during a solar cycle, only ca.0.2 per cent or less (Lean and Rind, 1994), although larger changes of up to ca.1 per cent over longer intervals could be inferred from some other evidence (Frohlich, 1987; Reid, 1987, 1991). In the present investigation, the amplitudes were of the order of 0.02 in a mean K_r value of ca.0.40, i.e. ca.5 percent, and hence could not be of extraterrestrial origin. For the USA, Angell et al. (1984) reported variations in cloudiness and sunshine, and Angell and Korshover (1987) studied the relationship with the El Niño phenomenon. Angell (1990) showed that there was a high, negative correlation (−0.86) between annual cloudiness and sunshine duration. Recently Kane and Gobbi (1995) studied the spectral characteristics of USA cloudiness and found significant QBO as well as other periodicities near 4.2, 7.5 and 11–14 years, some of which matched with the periodicities of the ENSO phenomena. The 12-monthly running means of the surface-to-500-hPa precipitable water obtained from radiosonde data at several locations (Elliott et al., 1991) also showed QBO and decadal effects (Kane, 1996). Thus, the periodicities obtained in this investigation of global radiation at Wageningen could be due to similar, long-term periodicities in cloudiness, reported in Kane and Gobbi (1995).

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