ON THE VARIABILITY OF THE SOLAR INTEGRAL RADIATION CONSTITUENTS

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The results of spectral analysis of series of observations of the equatorial and polar diameters, as well as of series of satellite observations of the S_0 variations during 1975-1987 presented in papers by Laclare (1987), Delache (1988) and Delache et al. (1988) confirm with confidence the presence of an 11-year modulation in the Sun's radiation and diameter, and consequently, in the effective temperature of the photosphere. The same conclusion has been drawn with regard to the "1000th" and "320th" daily periodicities.

With regard to the manifestation of a 22-year periodicity in solar and terrestrial processes, there are no final, generally accepted conclusions, in spite of a great number of investigations performed. It should be noted that Gilliland (1981), in his analysis of all basic long-period series of observations of diameter variations, has not found any substantial evidence in favor of the existence of a 22-year modulation.

Let us consider now the results of papers by Vasilyev and Rubashev (1971- 1972), where combined processing of the Greenwich and Rome series of observations of the solar radius have been made. Due to the presence in the observational data of these Observatories of non-eliminated errors (the random error for the Rome series is about 0.024" ± 0.01") and the existence of opposite tendencies in individual regions of the temporal series, the smoothing of the initial data using the third differences has been performed, after which an average curve has been plotted for the period in common (from 1876 to 1937). Therefore, on the temperal variation of the radius thus synthesized, there are three maximums and three minimums with the mean interval of 21 years. Spectral analysis of the synthetic dependence $R_{\odot}(t)$ yielded the basic period (according to split components) of 21.6 years with the magnitude of 0.20". The presence of a constituent with the period of 10.8 years and magnitude of 0.03" should also be noted. There are no traces of the 76-year constituent anywhere.

Although one of the two observation series of $R_{\odot}$ (the Greenwich one), which have been included in the statistical analysis made by Vasilyev and Rubashev (1971, 1972), served as the main one in many combinations of series used for statistico-harmonic analysis by Gilliland (1981), the conclusions drawn in these two investigations concerning the constituents of the radius variations with the periods of 22 to 76 years are quite opposite. The impression is that the results of the analysis are under a strong influence of the order of priority of the variation periods. Thus, Gilliland states that when the 76-year period is extracted, the greater part of the variability in the measured series of the radius values is withdrawn. Also important are the depth of averaging of the series data and the deliberate selection of the series combination. This is indicated by the spread from 56.9 to 99.7 years in the period sought for with various combinations (20 combinations) of series. It is regrettable that the successful (in our opinion) combination of the Greenwich and Rome series has been used in the series analysis to reveal only the 11-year constituent.

The periods of combinations averaged over 20 series constituted 76 ± 8 years, with the phases of maximums at 1911 ± 4 years and at 1987 ± 9 years, with the magnitude equal to 0.4" ± 0.1".

Coming back to the hypothesis of the manifestation in the radius variations of periodicities which are multiples of the basic variation, one can suppose that the 76-year periodicity is a 7-fold one of the 10.86-year variation. The difference from the 10.56-year period can be easily explained by the slow variation of the basic period of the solar activity cycle (SAC) with time. The acceptance of this hypothesis must result in rejecting the 76-year variation as it is, and in changing the method of analysis of observation series, viz., the singling out (after the withdrawal of the trend [secular] variation) of the 11-year and 22-year variations, and later the harmonics of the 11-year variation. The delay of −0.8 ± 1.1 years between $R_{\odot}$ and W_Z found from 5 series (1860-1940) is apparently important for the analysis.

Let us consider now the graphic presentation of the above-mentioned periodic constituents of the radius variations on the temporal scale from 1967 to 1986 (Fig. 1), together with the results of direct measurements at Greenwich, Belgrade and CERGA Observatories. The smooth, slightly bent curve (the 76-year constituent) and the 11-year constituent superimposed on it (readings from the left-hand scale) are presented according to Gilliland's (1981) data. The other two smooth curves with the minimum in 1979 represent the main result of the statistical analysis performed by Vasilyev and Rubashev (1971, 1972). The 22-year constituent of the Sun's radius variations has been obtained from the data of the Greenwich and Rome (Campidoglio) series and is presented here by two sinusoidal curves with different amplitudes. The curve denoted by the triangles has the mean amplitude for the 1876-1937 period, whereas the second curve (dash-dot) has an amplitude characteristic for the period from 1911 to 1924, when the 22-year variation had the maximum span (~ 0.43"). The phase of the variation is characteristic of considerable uncertainty.

Before we pass on to the consideration of the $\Delta R(t)$ dependences presented in Fig. 1, one should clarify the circumstances relevant to certain changes in the Greenwich ΔR_{Gr} taken from the paper by Fröhlich and Eddy (1984), who processed the data from Greenwich Observatory concerning the solar diameter observations. The authors of this work made an interesting attempt to relate the changes in the radius and those of the Sun's luminosity (to which we will return). As follows from the conclusions made by Fröhlich and Eddy, they felt the presence of some long-period variation which was close to that 76-year variation which was found by Gilliland (1981), or coinciding with the 22-year one. However, its phase, which determines the coincidence of maximum values in the variation of $\Delta R_{\odot}$, with a maximum in the luminosity value (the solar constant) and the maximum of relative solar spot numbers, was obviously outside the scope of the understandable relationships between the above-mentioned solar parameters. Recently, C. Fröhlich informed us that in the course of processing of the Greenwich data, namely, in the calculation of the dependence $\Delta R(t)$, an accidental change of the sign might have taken place, which reverses the sign of the deviations from the mean value. In Fig. 1, the Greenwich dependence $\Delta R_{Gr}(t)$ is presented in the corrected form, and as can be clearly seen, it correlates very well not only with the direct measurement data, but also can be fairly well described by the 22-year (average) variation. However, the variation of the direct measurement data distinctly indicates the influence of the 11-year constituent superimposed upon the upward part of the 76-year variation, and the contribution of the latter is not manifested.

If one compares the 11-year variation (see Fig. 1) with the variations of the annual mean data of direct observations, one can easily see the contribution of the 11-year variation. If one supposes that the amplitude of the presented 11- and 22-year variations corresponds to the period under consideration (1979), then the "mean" 22-year variation, and not the "maximum" one should be introduced in the calculation. In this case, the measured value of $\Delta R_{\odot}$ for 1979 will be entirely determined by these two constituents.

The presence of several series and the restoration of the sign of deviations of ($\Delta R_{\odot}$) found from the Greenwich series of the horizontal diameter make it possible to derive common annual mean values of the $R_{\odot}$ variations, which will, in all probability, be more representative than this or that individual series. The period from 1967 to 1974 is represented only by deviations from the operational mean value ($\bar{R}_{\odot}$ = 959.50") obtained from the Greenwich series (see Table 1).

The following obvious conclusions can be drawn from the data presented:

– The 76-year variation in the period from 1967 to 1987 is not revealed in the data of observations; the data of the middle series (see Table 1) will doubtless be made more precise after the facsimile from the initial information is obtained.

– The basic and comparable contributions to the radius variability yield the 11- and 22-year variations.

– The presence can easily be seen (Fig. 1) of harmonics with periods of 2 and 4 years; the 4-year period is revealed up to 1979 only, and the 2-year one, after 1980 only. This is possibly due to the combined contribution of the 11- and 22-year variations (to be more precise, 10.8 and 21.2 years) forming a certain mean 16-year periodicity. In this case, the 4- and 2-year variations can be regarded as the 4th and 8th harmonics of such a mean variation.

– Measurements of the horizontal diameter made at Greenwich Observatory have not lost their significance for the analysis of phenomena on the Sun, since they contain data having precision characteristics conforming to the level of the latest ground-based diameter measurements.

Table 1
Annual mean radius variations obtained by averaging three series of observations: at the Observatories of Greenwich for 1967-1985; Belgrade for 1977-1986; and CERGA for 1975-1986 (in arc sec).

Year	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
ΔR	0.09	0.24	0.17	0.08	–0.01	0.03	0.07	–0.03	0.22	0.02

Year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
ΔR	–0.03	–0.1	–0.33	–0.12	–0.14	–0.17	–0.04	–0.1	–0.005	+0.05

Precision measurements of the total solar radiation flux (the solar constant, S_0) carried out for almost 10 years on the NIMBUS-7 and SMM satellites (Hickey et al., 1988; Mecherikunnel et al., 1988), as well as measurements of the latitudinal distribution of the Sun's limb brightness from 1983 to 1987 (Kuhn et al., 1988) have opened up the possibility of justification of the selection and numerical confirmation of one of a number of proposed relationships between the variations of luminosity, temperature and radius of the Sun.

The most justifiable, physically, is the relationship $(\Delta L/L) = 4(\Delta T/T) + 2(\Delta R/R)$ (Spiegel, Weiss, 1980), which is the sum of the first terms of the series expansion of the basic law of absolute radiometry and which makes it possible (with the sufficiently large time of data averaging) to estimate the contribution of the variations of temperature and radius to changes in the Sun's luminosity. Since the luminosity variations have been obtained with a high level of accuracy and the accuracy of the annual mean measurements of the solar diameter is also high enough, it is possible, making use of the above-presented relationship, to calculate the variations of the effective temperature of the photosphere and to compare them with the measurements of Kuhn et al. (1988).

Combining the data from the NIMBUS-7 and SMM satellites, it has become possible to provide sufficient data on the luminosity variation for the period from 1979 to 1987. Data on the radius variation have been taken from the Greenwich series of the horizontal diameter measurements (Fröhlich, Eddy, 1984) and the CERGA Observatory series (Delache et al., 1988).

The results of calculations performed agree very well with the temperature variation at heliolatitudes 26.5°, 29° and 32°. The ΔS_0 data have a temporal variation close to the calculated data for ΔT_{eff}^{φ} for the heliolatitude belt from 26.5° to 29° over the entire time interval (1983-1987) provided with sufficient information (Kuhn et al., 1988).

The extrapolation of the temporal variation of the heliolatitudinal dependences ΔT_{eff}^{φ} for 1979, taking into account the calculated data for 1980-1983, makes it possible to estimate the variations of $T_{eff}^{\odot}$ in the 11-year cycle (~ +2.2K) and to single out the variations of $T_{eff}^{\odot}$ connected with the 22-year cycle (~ +0.7K). Fig. 2 shows the calculated variations of T_{eff}^{φ} and L^{φ} in the latitudinal belt from 20° to 32° in the 11-year solar activity cycle (SAC).

The results obtained make it possible to state that there are processes influencing the luminosity and acting in phase or counterphase (or a phase close to it). Above all, this is relevant to annual mean variations of the effective temperature of the photosphere and solar diameter variations, whose contribution in the course of SAC No. 21 is estimated approximately as 0.2% and −0.1%, respectively, which leads to $\Delta L/L = 0.1\%$ or $\Delta L = 1.37\ W/m^2$ in SAC. It is obvious that the contribution of the latitudinal belts to the total radiation flux changes substantially in SAC. On the decreasing branch of the 11-year SAC, the basic contribution to the luminosity is made by the near-equatorial region (± 20°) of the Sun. On the increasing branch, the zones with $\varphi > 20°$ make the greatest contribution.

Completing our brief excursion to the area of interrelationships between L, R and T_{eff}, it should be noted that measurements on the NIMBUS-7 satellite yielded during their first 6 months of work the mean value of $S_o = 1376 \pm 0.73\ W/m^2$. Later Hickey et al. (1988) reduced this value, but the data of Fig. 1 show that in 1979, an abrupt decrease of the Sun's diameter took place ($\Delta R_\odot \approx 0.37''$) which was accompanied by the corresponding growth of T_{eff}. It is possible that Hickey et al. considered that the data of the initial stage of measurements were not reliable enough and introduced the reduction. The actual value of S_o for 1979 is very important for the agreement between the data of NIMBUS-6 and NIMBUS-7. The confirmation of a higher S_o value for 1979 would be very important for the estimation of the efficiency of the mechanism of solar-terrestrial relations through the channel of the solar constant variations.

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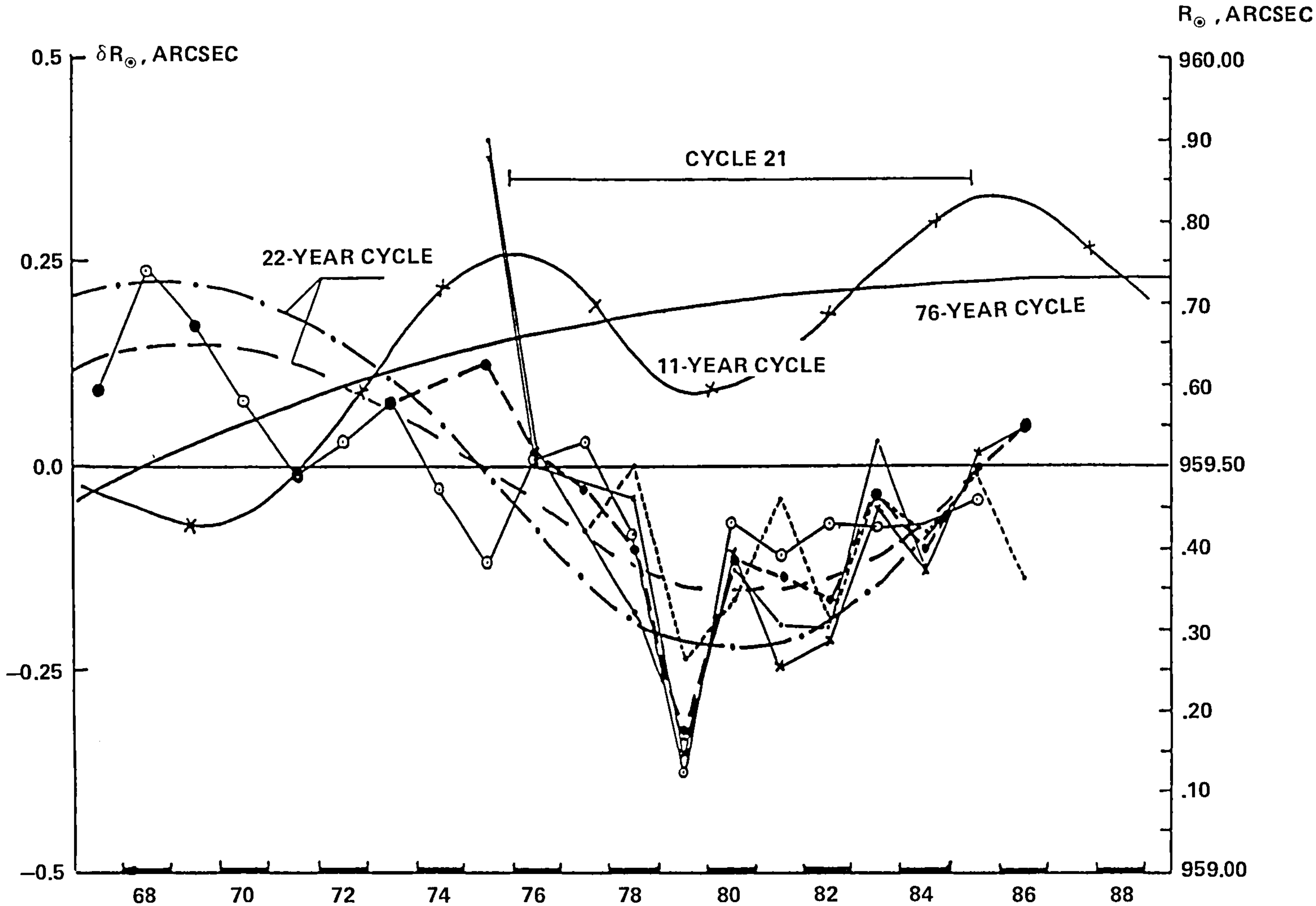

Figure 1. Temporal variations of the Sun's radius from the latest measurement data and periodic constituents of the radius variation from the results of spectral analyisis of long period observation series of the Sun's angular diameter.

} from the data of Gilliland (1981); }Vasilyev, Rubashev (1971); Fröhlich, Eddy; Laclare (1987); Delache et al. (1988); Ribes et al. (1988); the mean dependence.

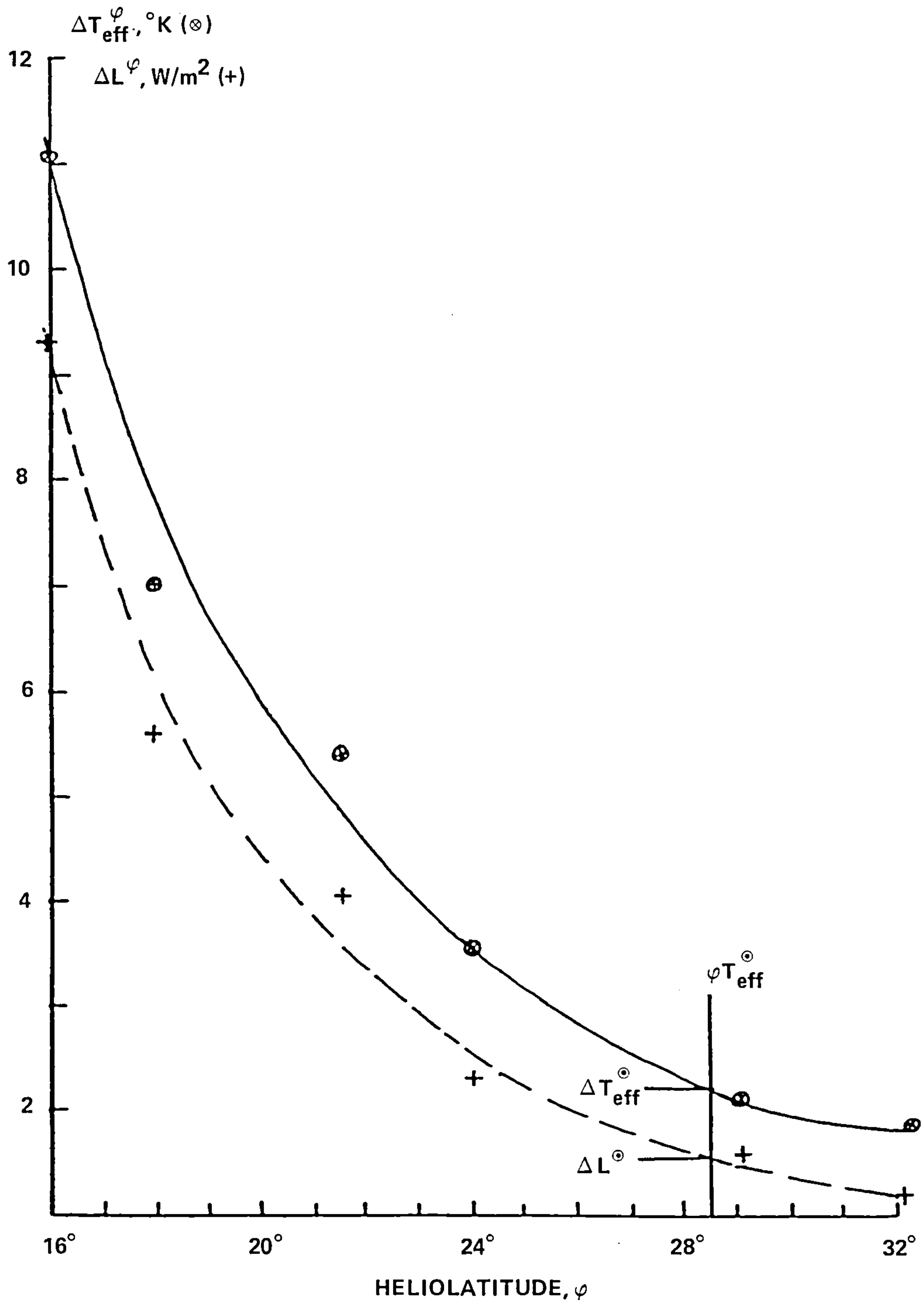

Figure 2. Increments of effective temperature (⊗), and luminosity (+) of the photosphere at different heliolatitudes in phase of maximum solar activity (SA) (1979) relative to the phase of minimum SA (1986). The values of T_{eff}^{φ} and L^{φ} have been obtained using the data of Kuhn et al.(1988).