thanks the Ministry of National Education in Warsaw for financial aid (PP-I-11).

REFERENCES

Brancewicz H., Dworak T. Z. 1980 *Acta Astron.* **30** , 501
Brelstoff T. 1985 *Brit. Astron. Assoc. Var. Star Section Circ.* **60**, 15
Diethelm R. 1984, *B. B. A. S. G.* Bull 72
Gaposchkin S. 1953 *Harvard Ann.* **113**, 69
Giuricin G., Mardirossian F., Mezzetti M. 1984 *Monthly Notices Roy. Astron. Soc.* **211**, 39
Glazunova L. V. 1985 *Bull. Abastumani Astrophys. Obs.* **58**, 45
— 1988, priv. commun.
Glazunova L. V., Karetnikov V. G. 1985 *Astron. Zh.* **62**, 938
Harvig V. 1981 *Publ. Tartu Obs.* **48**, 177
Horak J., Mayer P., Tremko J., Weidlich M. 1976 *Contr. Astron. Obs. Skalnaté Pleso* **7**, 39
Kizilirmak A., Pohl E. 1969 Astron. Nachr. **291**, 111
Klocok Ľ., Zverko J., Žižňovský J. 1986 *Contr. Astron. Obs. Skalnaté Pleso* **14**, 97
Kreiner J. M., Tremko J. 1987 *Contr. Astron. Obs. Skalnaté Pleso* **16**, 191
Kreiner J. M., Ziółkowski J. 1978 *Acta Astron.* **28**, 497
Kruszewski A. 1966 Adv. Astron. Astrophys. **4**, 233
Kwiek A. 1936 *Acta Astron. ser. c* **2**, 137
Manek J. 1985 *Contr. Brno* 26
Mayer P. 1987 *Bull. Astron. Inst. Czechosl.* **38**, 58
Obůrka O. 1964 *Bull. Astron. Inst. Czechosl.* **15**, 26
– 1965 *Bull. Astron. Inst. Czechosl.* **16**, 212
Paschke A. 1985 *B. B. S. A. G. Bull.* 75
Saute M., Martel M. T. 1979 *IBVS* No. 1681, 1.
Schneller H. 1929a *Beob. Zirc. Astron. Nachr.* **11**, 92
— 1929b *Astron. Nachr.* **235**, 85
— 1931 *Veröff. Univ. Sternwarte Berlin, Babelsberg* **8**, H. 6, 45
Szafraniec R. 1959 *Acta Astron. Suppl.* **3**, (part 1), 248
Woodward E. J. 1943 *Harvard Bull.* **917**, 7
Woodward E. J., Koch R. H. 1975 *Publ. Astr. Soc. Pacific* **87**, 901

THE RELATIONS BETWEEN SOLAR MOTION AND SOLAR VARIABILITY

I. Charvátová

Geophysical Institute, Czechoslovak Academy of Sciences, 141 31 Praha 4, Czechoslovakia

Received 12 December 1988

СООТНОШЕНИЕ МЕЖДУ ДВИЖЕНИЕМ СОЛНЦА И СОЛНЕЧНОЙ ПЕРЕМЕННОСТЬЮ

Описывается подход к движению Солнца вокруг центра масс солнечной системы, обьясняющий все основные черты долговременного хода солнечной активности. Результаты подтверждают прямую и постоянную взаимосвязь между обоими явлениями.

An approach to the solar motion round the barycentre of the solar system, able to explain all the main features of long-term solar variability up to the solar cycle, is described. The results confirm a continual direct connection between both the phenomena.

Key words: solar motion — long-term solar variability

1. Introduction

The solar motion round the barycentre of the solar system seems to be one of the possible origins of solar variability (Jose 1965, Landscheidt 1984, Jakubcová and Pick 1986, 1987, Fairbridge and Shirley 1987).

The time series of the positions of the Sun with respect to the barycentre [ecliptical coordinates (x, y, z) for the beginning of every year] for the time interval from 2200 BC. to 2100 AD. has been employed (Bucha et al. 1985, Jakubcová and Pick 1987). Only the outer planets were taken into consideration (J-Jupiter, S-Saturn, U-Uranus, N-Neptune, P-Pluto). The series is precise and homogeneous, in contrast to the series of solar activity. Evidence for past solar activity is largely of an indirect nature (e.g. ^{14}C in tree rings, ^{10}Be in ice cores, etc), with a lot of uncertainties. The Wolf sunspot numbers have been recorded from 1700 AD. only, with nonuniform quality. The time series of auroral and naked-eye observations are influenced by civilization factors and, therefore, considerably inhomogeneous (Křivský 1984, Schove 1983, Charvátová-Jakubcová et al. 1988).

For the first approximation to the problem, a simple approach able to explain all main features of long-term solar variability has been used. Z-coordinates of the Sun have been neglected.

2. Approach to the Problem

The solar orbit is a variable curve depending on the distribution of the planets. But, we found, it has two basic alternately repeating elements — the "loops" and the "arcs" (Fig. 1). We noticed that these elements have JS-order separations (~120°) in the epochs of prolonged high solar activity (Fig. 2a) and have chaotic separations in the epochs of prolonged minima (Fig. 2b). We found the mean duration of the solar motion round the loop to be 9·93 ± 0·2 yr, round the arc to be 9·93 ± 0·8 yr, i.e. 19·86 yr (JS-synodic period) round one pair (Charvátová 1989). The planets J + S have 93% of the mass of all the planetary system, they create the basis of solar motion.

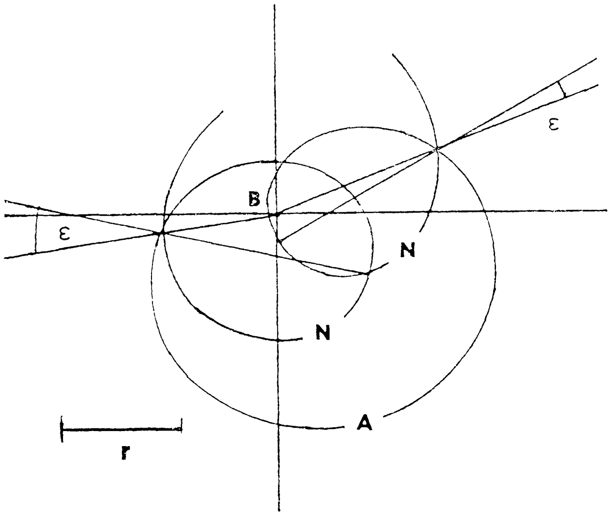

Fig. 1. The solar motion elements — the loop (N) and the arc (A); r is the solar radius.

3. The Long Periods

Two equidistant time series of the direction deviations ε (Fig. 1) and of the time deviations δ (of the differences between the respective and the mean duration of the pairs of elements) from the JS-order, caused by planets U, N, P, with a lag of 19·86 yrs were constructed for the time interval from 2200 BC. to 2100 AD.. These series can be taken as the approximate records of the long-term variability of solar motion. A conspicuous ca 180 yr (9 × 19·86) cycle is apparent in their variation, as well as a roughly 2200 yr cycle (Fig. 3). The dominant sign of the deviations ε changes always after ca 1100 yrs, near the years 1100 BC.; 0; 1100 AD..

The F-spectra of periods of both the series were computed. Besides the periods mentioned above, also the significant periods of 60 yr (3 × 120°, 3 × 19·86 yr), 90, 120 and 850 yr (great inequality of JS) were found. The dominant period of the spectra, the period of ca 180 yr, is the interval between the highest deviations of the solar motion elements from the JS-order (Fig. 3)—(Charvátová 1989).

Such a period was also detected in the Wolf numbers (e.g. Cohen abd Lintz 1974), the period of 150—200 yr,

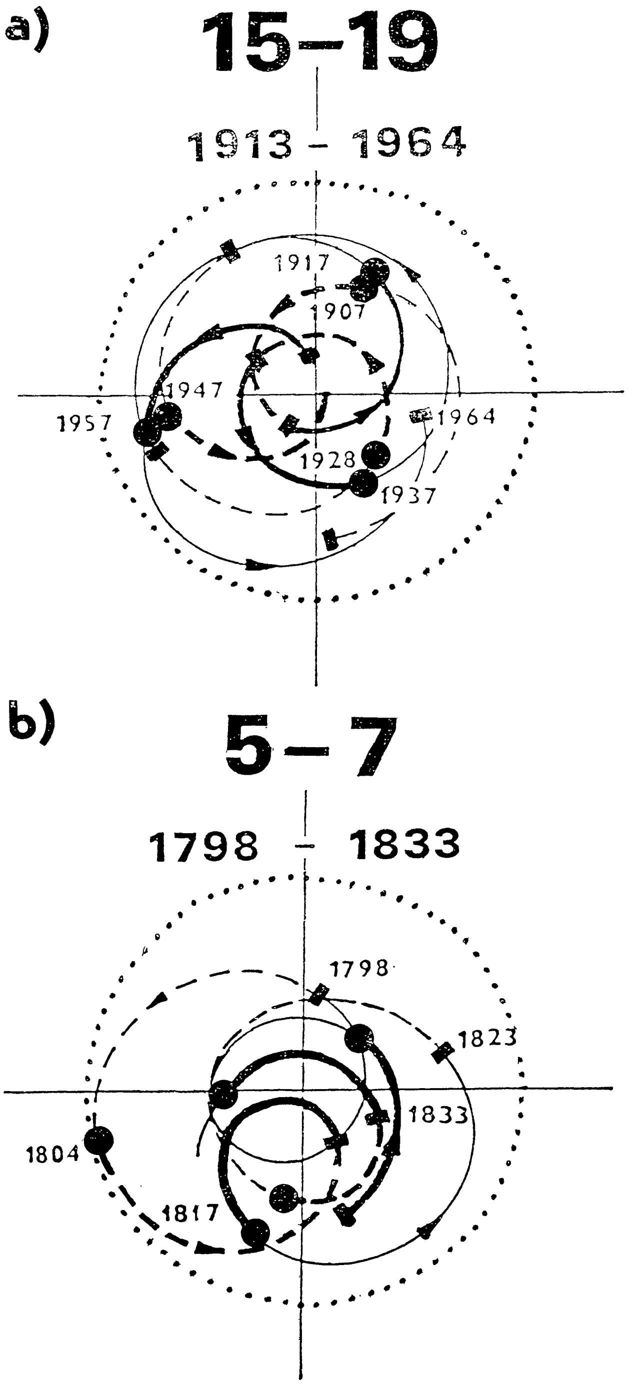

Fig. 2. The Sun's orbit during a) JS-order (cycles No. 15—19) b) chaotic (cycles No. 5—7) separation of the solar motion elements. (● — the maxima, ■ — the minima of sunspot cycles). The dotted line limits the area, in which the Sun moves.

the so-called "Suess wiggles", is the basic feature of the radiocarbon records. Nearly the same periods (60, 90, 120, 150–200, 850–950, 1000–1200, 2000 to 2400 yr) have been detected in natural records (Damon and Linick 1986, Neftel et al. 1981, Sonett 1984, Suess 1980, Stuiver 1983). Damon et al. (1988) presented the best value for the longest period—equal to 2280 yr.

4. The Prolonged Extrema

The absolute values of the deviations ε, δ are plotted in Fig. 3. The intervals of the known prolonged minima in solar activity together with the curves of ^{14}C changes are drawn in the upper part of this figure. One can see that the epochs of all known prolonged minima in solar activity coincide with the epochs of the highest deviations from the JS-order. The radiocarbon records correspond to the deviation patterns.

The basic ca 180 yr periods in solar motion, the coincidence of all known prolonged minima in solar activity with the epochs of the highest deviations from the JS-order and the similarity of their patterns, the 180 yr period found in the Wolf numbers, allow us to conclude that also the prolonged extrema in solar activity occur in basic cycle of about 180 yrs. But, there are irregularities near the years 1100 BC.; 0; 1100 AD. (Fig. 3). The natural records confirm the 2000–2400 yr maximum of solar activity in the epoch of Antiquity. At present, also in the period of small deviations ε, δ, we are probably in such a maximum (Fig. 3). Damon and Linick (1986) show "change of polarity" every 1000–1200 yrs, similarly to changes of the dominant sign of ε in solar motion every 1100 yr.

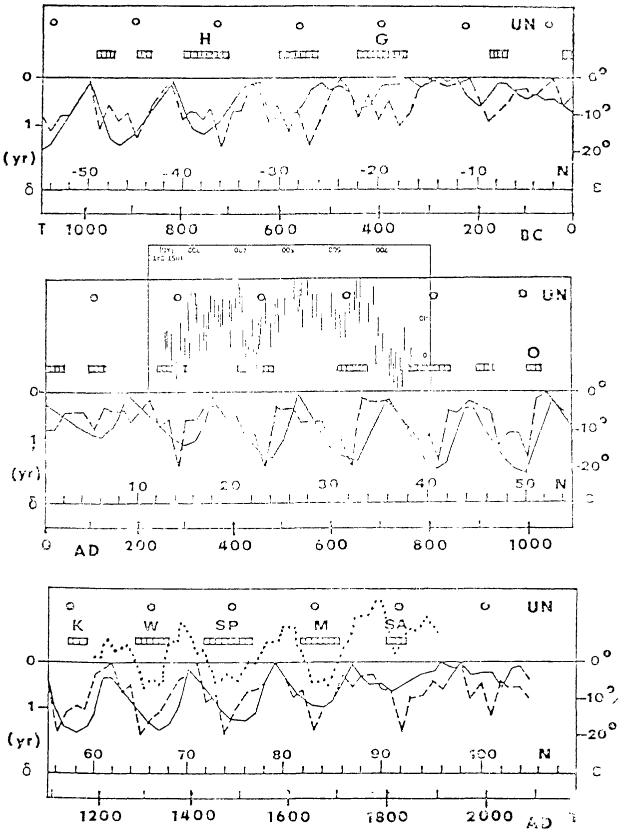

Fig. 3. The absolute values of the deviations ε (dashed line) and δ (solid line) from 1100 BC. to 2200 AD. and the intervals of the known prolonged minima in solar activity: the SA-Sabine, M-Maunder, SP-Spörer, W-Wolf, O-Oort, G-Greek, H-Homer minima in solar activity; the intervals of low solar activity in the years from 200 BC. to 950 AD. are drawn according to Schove (1983), in the years 1150-70 AD. according to Křivský (1984), in the years 610–530 BC. according to Suess (1980); the radiocarbon record (absolutely dated European oak series) for the years 200–800 AD. is taken from Bruns et al. (1980) (the inversed record due to inverse relation between ^{14}C and solar activity); for the years 1200 to 1900 AD. (dotted line) from Stuiver and Quay (1980). The circles UN denote the times of conjunction of the planets Uranus and Neptune, N is a number of the pairs of the motion elements ($T = N \times 19{\cdot}86$ yr).

5. The Shorter Periods and the Sunspot Cycle

Jakubcová and Pick (1986, 1987) computed the periods in solar motion and found that these periods are the higher harmonics of the basic period of ca 178 yr ($p_i = 178{\cdot}4/i$) and correspond to the synodic and sidereal periods of planets. The periods found by various authors in the Wolf numbers have the same properties (Jakubcová and Pick 1987, Charvátová 1988b).

In the intervals of JS-order separations of the motion elements (e.g. 1910–1960 AD., 1730–1780 AD. – Fig. 3), the sunspot cycles are high and last ca 10 yr. One can see (Fig. 2a) the maxima of these cycles near the arc-loop intersections, in the 7th to 8th years of the respective decades. The minima occur at the end of the central circular parts of the loops or of the arcs. The even cycle is created by the centrifugal, the odd by the centripetal motion of the Sun. It could explain the differences in the patterns of the even and odd cycles. The maxima of cycles coincide with the extrema of the motion characteristics, fittingly describing the motion dynamics (the rate of change of angular momentum, the acceleration, etc). The cycles of chaotic intervals are low and irregular, with prolonged extrema (Charvátová 1988b).

Charvátová and Střeštík (1988) found the dominant period in the spectra of the Wolf numbers in JS-order intervals to be 10 yrs ($\frac{1}{2}$ JS). The dominant period in the spectra of the chaotic intervals is 12 yrs (J). This result offers a physical basic for the bimodality (10 yr, 12 yr) of the sunspot cycle period distribution found by Rabin et al. (1986) and Wilson (1987), and confirms that "the 11 yr mean cycle period is nothing more than a consequence of the average behaviour of the bimodally distributed cycle periods" (Wilson 1987).

6. Conclusion

All the main features of solar variability could be explained in terms of solar motion.

Periodicities ranging from 10 to 2200 yr in solar motion, corresponding to the periodicity in solar activity, were found. A coincidence of all known prolonged extrema in solar activity with the inverse extrema of the deviations from the JS-order was demonstrated (Fig. 3) on a time interval longer than 3000 yrs. The prolonged minima in solar activity probably come in the basic, ca 180-yr cycle. Some important properties of the solar cycle itself can be explained in terms of solar motion. Our results, thus, seem to confirm a continual direct connection between solar motion and solar variability. The solar variability is probably caused by solar motion. This allows us to use our simple approach to predict solar activity, which has great influence on all terrestrial, geophysical, biological phenomena, even though the proper physical mechanism has not been discovered yet.

The next 180-yr minimum in solar activity will probably occur in 2000–2030 AD. (Fig. 3). This minimum could be shorter and milder than the medieval minima and than the Sabine minimum, because its deviations ε, δ are smaller. From 2040 AD. the JS-order separations of the motion elements will come (Charvátová 1988a). This means that high solar activity with ten-year cycles could again occur.

Acknowledgments

The author would like to thank J. Danko for computations of the positions of the Sun.

REFERENCES

Bucha V., Jakubcová I., Pick M. 1985 *Studia Geophys. et Geod.* **29**, 107

Bruns M., Münnich K. O., Becker B. 1980 *Radiocarbon* **22**, 273

Charvátová I. 1989 *Studia Geophys. et Geod.* **33**, 230

— 1988a *Adv. in Space Res.* **8**, No. 7, 147

— 1988b *Proc. of Solar Conf.* (P. Bystrica 30.5.—4.6. 1988), in press

Charvátová I., Střeštík J. 1988 *Proc. of Solar Conf.* (P. Bystrica 30. 5.—4. 6. 1988), in press

Charvátová-Jakubcová I., Střeštík J., Křivský L. 1988 *Studia Geophys. et Geod.* **32**, 70

Cohen J., Lintz P. R. 1974 *Nature* **250**, 398

Damon P. E., Linick T. 1986 *Radiocarbon* **28**, 266

Damon P. E., Cheng S., Linick T. 1988 *Proc. of 13th Radiocarbon Conf.* (Dubrovnik, June 20—25), in press

Fairbridge R. W., Shirley J. H. 1987 *Solar Phys.* **110**, 191

Jakubcová I., Pick M. 1986 *Studia Geophys. et Geod.* **30**, 224

— 1987 *Annales Geophys.* **5B**, 135

Jose P. D. 1965 *Astron. J.* **70**, 193

Křivský L. 1984 *Solar Phys.* **93**, 189

Landscheidt T. 1984 in *Solar-terr. Predictions* (Proc. of Workshop at Meudon, France, June 18.—22. 1984; Ed. P. A. Simon, G. Heckman, M. A. Shea), p. 48

Neftel A., Oeschger H., Suess H. E. 1981 *Earth Planet. Sci. Lett.* **56**. 127

Rabin D., Wilson R. M., Moore R. L. 1986 *Geophys. Res. Lett.* **13**, 352

Schove D. J. 1983 *Ann. Geophys.* **1**, 391

Sonett C. P. 1984 *Rev. Geophys. Space Phys.* **22**, 239

Stuiver M. 1983 *Radiocarbon* **25**, 219

Stuiver M., Quay P. 1980 *Science* **207**, 11

Suess H. E. 1980 *Radiocarbon* **22**, 200

Wilson R. M. 1987 *J. Geophys. Res.* **92**, A 9, 10101