The 90-day Oscillation of the Jovian Great Red Spot

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Abstract

The purpose of this contribution is to study the possible existence of the 90-day longitude oscillation of Jupiter's Great Red Spot (GRS) which had been discovered in the 1960s over long time intervals. Additionally, further possible periodicities in the longitudinal motion of the GRS in the 40 to 400 day range are considered.

Introduction

In 1968, Solberg [1] reported the discovery of an oscillation in the longitudinal position of the GRS having a period of about 90 days. Later investigations [2-6] by Solberg and Reese resulted in a mean period of 89.9 days and a mean amplitude of 0.8° as improved estimates of the oscillation parameters for the years 1962 to 1971. This result had been reached by measuring photographs with a mean error of about 0.15° in jovigraphic longitude.

The 90-day oscillation had been supposed by Molesworth as early as 1905 [7]. Later observations of the phenomenon have been published, e.g. by McKim for the apparitions 1973 and 1974 [8,9]. McKim found periods of about 97/90 days and amplitudes of 2°/circa 1°. Further references are given in [8].

Within the scope of the JUPOS programme [10], 1600 longitude positions of the GRS centre in 1878-1912 and 2100 positions in 1968-1994 have been collected to date. Almost all of them have been obtained by central meridian timings. Naturally, such observations are subject to a mean error in the 1° to 3° range. JUPOS also includes observations of the International Jupiter Voyager Telescope Observations Programme (IJVTOP), a project which was initiated at the time of the Voyager encounters.

This JUPOS data set has been analysed in order to search for periodic variations regarding the longitudinal position of the GRS.

Method

The appropriate numerical technique used here for retrieving discrete periodicities has been described by Deeming [11] and is based on the calculation of two functions: periodogram and spectral window (for detailed formulae and how to deduce them, see Deeming's paper). The frequency f shown on the abscissa of both functions we define here as the reciprocal of oscillation period P, $f = 1/P$, where P is measured in days. If a significant periodicity attributable to a certain period is present in the data, then the periodogram displays a so-called "genuine" peak situated at the same period (or frequency). Moreover, the complete spectral window peak pattern, centred at zero frequency, is superimposed on the periodogram starting from each genuine peak. This phenomenon is called aliasing. To search for periodicities present in the data, one must carefully examine both periodogram and spectral window and distinguish genuine peaks from aliases and periodogram "noise" as well.

The intensity of a peak means its height in the periodogram or spectral window, respectively. Under the assumption that a genuine peak is caused by a (near-) sinusoidal oscillation, its intensity can be regarded as a good estimate for the oscillation's amplitude.

To start the periodicity search analysis from an optimum data base, all GRS observations have been processed according to the following criteria:

(1) Observers whose positional estimates turned out to scatter by more than about 2° (i.e. 30% of all observers and 10% of all observations), observers who contributed less than 4 positions in

an apparition, apparent outliers as well as temporally isolated observations (altogether five positions only) were disregarded. This procedure has been performed graphically for each apparition.

(2) Most of the 1000 observations before 1894 are concentrated in the three apparitions 1879/80, 1880/81 and 1881/82. For the time periods 1883-1893, 1908-1912 and 1968-1970 too few observations were reported. Hence, these years were excluded. - 600 GRS positions of 17 observers in 1879-82, 600 positions of 10 observers in 1894-1907 and 1750 positions of 50 observers in 1971-1993 remained for further analysis.

(3) All JUPOS longitudes relate to ephemerides of the geometrically illuminated disc of Jupiter. Owing to stronger limb darkening present at the planet's terminator, these values become systematically falsified. To correct this phase effect, the quantity $0.12 * \phi$, whereby ϕ is the Jovian phase angle of observation time, has been added to all original longitudes [12].

(4) Systematic errors attributable to individual observers have been estimated in order to reduce all data to a nominal observer.

(5) In the long-term, the GRS moves distinctly in system II longitude. However, the method by Deeming [11] presupposes that data are not affected by a long-term trend. To satisfy this condition, a linear least square fitting line for each Jovian apparition has been computed, and the difference of each observation from that linear fit has been derived. This procedure safely eliminates periodicity components having periods of more than about 400 days. - It should be noted that a linear fit seems too rough an approximation in the case of some apparitions. However, a reduction using more complicated fitting functions is beyond the scope of this contribution.

Discussion of results

First, data have been analysed over long time intervals. Figure 1 shows the periodogram sections of interest. Distinct peaks at about 73, 90 and 116 days can be clearly recognised. In all probability, the peak situated at 90 days is a genuine one and the two neighbouring ones are "aliases" produced by spectral window peaks due to Jupiter's synodic period of 400 days. Since there is a gap of about one hundred years between the sampling intervals examined, with high certainty the 90-day oscillation is a long-enduring component in the Great Red Spot's movement.

There arises the question whether period and amplitude of the oscillation are constant over time, or not. To this end, the time intervals to be analysed have to be as short as possible. Since the number of observations analysed in each case must not be too small, the sampling intervals must not be too short. Test calculations demonstrate that computations over six Jovian apparitions, i.e., more than six years, are the optimum choice. In the case of a sufficient number of observations, additional computations over four or five apparitions have been performed.

As the main result, the aforementioned peak at a period of 90 days occurs in all computations and its position does not depend much on the choice of sampling intervals. The 116-day alias near the turn of the century is higher than the 90-day peak in only four out of 11 computations (Figure 1a). Table 1 and Figure 2 show the temporal development of the 90-day component. An oscillation with a period between 70 and 140 days also occurs in 1879/80. In the two following apparitions no significant periodicities have been found.

Next, a starting epoch of the 90-day oscillation near the middle of each sampling interval has been computed such that its probable progress over the epochs 1894-1907 and 1971-1993 can be reconstructed (Table 1). Upon dividing the time difference between the last and first oscillation by the number of intervening ones, one gets a long-term average of the oscillation period. From 1894 to 1907 it amounts to 89.81 days, and from 1971 to 1993 to 89.78 days. Figure 3 shows the phase diagram corresponding to the former sampling interval, whereby all observation are reduced to the period of the 90-day peak in Figure 1a (90.09 days).

Also of interest are peaks between periods of 155 and 240 days occurring in the periodograms of 1971 to 1993 (Table 2, Figures 1c and 1d). A 225-day periodicity seems to have existed over the last couple of years. Figure 4 shows the corresponding phase diagram. Most of these peaks cannot be explained as aliases for plausible reasons. It is noticed that, generally, the peaks in the 155 to 240 day range and the 90-day peak are mutually distinct (see column "Identification" of Tables 1 and 2).

To be able to identify genuine peaks having a period of more than 40 days, in the accompanying spectral window peaks with periods greater than 20 days must be considered. In this range only significant spectral window peaks at 400 days occur which correspond to one synodic revolution of Jupiter, i.e., they are produced by gaps in the planet's visibility due to successive solar conjunctions. Thereby aliases are placed in the immediate neighbourhood of genuine peaks, and periodogram analysis has been straightforward in this respect.

Concluding remarks

It should be emphasised that these results are to be considered as a first step to reveal periodic variations in the longitudinal movement of the GRS over long time periods, in particular with respect to the 90-day oscillation. A larger database of the JUPOS programme is expected to improve the reliability of future analyses considerably, and carefully obtained visual amateur observations seem to be appropriate for that purpose. Furthermore, other data which cover past decades are hardly available.

Acknowledgements

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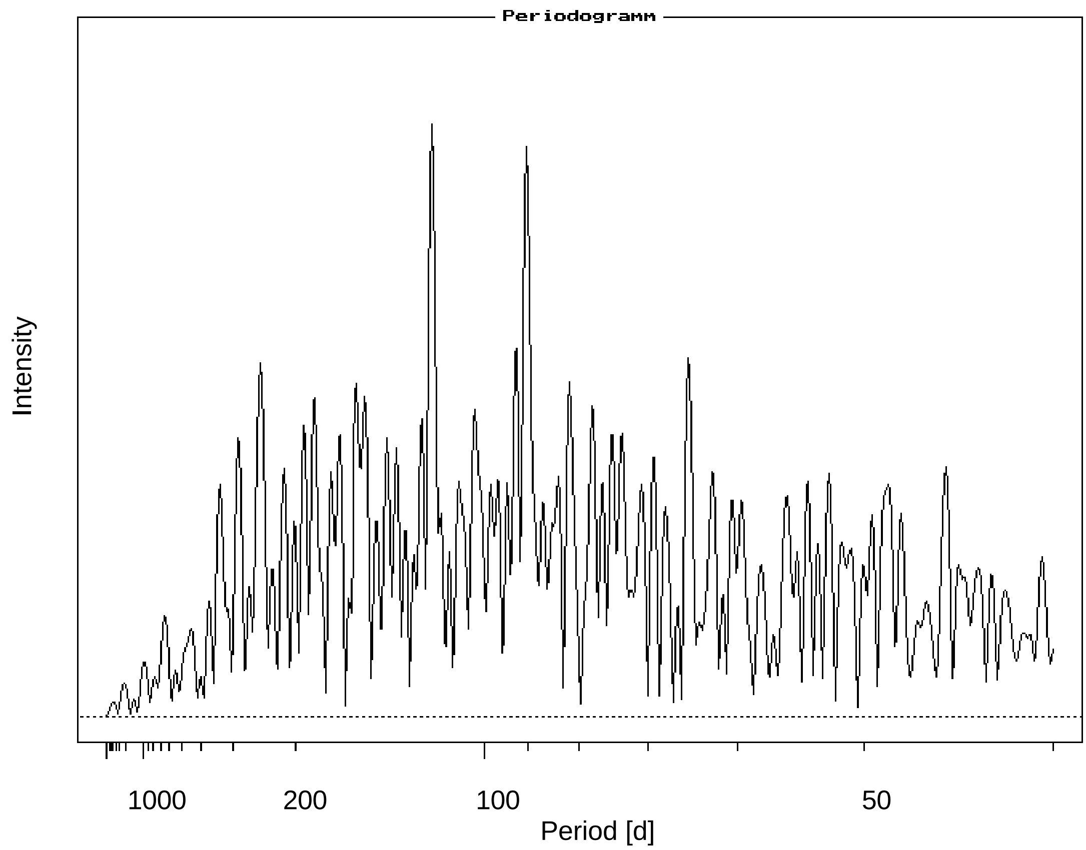
Interval	Opp	CMT	Date	No. of Osc.	24 ...	Period [d]	Amplitude [°]	Identification
1894/95-1897/98	4	176	1896,7	0	13794	92,32	1,12	certain
1894/95-1898/99	5	308	1897,9	5	14246	91,42	0,83	certain
1894/95-1900	6	335	1898,1	6	14341	91,56	0,80	certain
1895/96-1901	6	330	1899,0	9	14610	89,51	0,68	certain
1896/97-1902	6	346	1899,9	13	14966	89,35	0,68	certain
1897/98-1903/04	6	341	1900,5	16	15235	89,51	0,60	certain
1898/99-1904/05	6	343	1901,5	20	15590	89,28	0,64	certain
1900-1905/06	6	268	1903,5	28	16305	89,44	0,68	moderate
1901-1906/07	6	274	1904,2	31	16575	90,03	0,87	moderate
1902-1906/07	5	229	1904,8	33	16756	90,26	0,76	moderate
1903/04-1906/07	4	172	1905,5	36	17027	90,40	0,87	moderate
1965/66*)	1	-	1966,0	-	-	-	1,00	-
1964/65-1966/67*)	3	-	1966,0	-	-	90,60	-	-
1963/64-1968/69*)	6	-	1966,6	0	38312	89,90	0,80	-
1962-1969/70*)	8	-	1966,6	27	40740	89,98	0,76	-
1962-1971*)	9	-	1967,1	30	41008	89,89	0,77	-
1971-1974/75	4	307	1973,1	38	41725	89,59	0,39	uncertain
1971-1975/76	5	452	1974,1	42	42083	89,13	0,45	uncertain
1971-1976/77	6	511	1974,5	44	42259	88,91	0,46	uncertain
1972-1977/78	6	487	1975,8	49	42710	90,17	0,45	uncertain
1973-1978/79	6	616	1976,8	53	43072	90,69	0,50	uncertain
1974-1979/80	6	634	1977,4	55	43251	90,85	0,72	moderate
1975/76-1980/81	6	585	1978,2	59	43612	91,25	0,81	certain
1976/77-1982	6	504	1979,5	64	44067	91,16	0,79	certain
1977/78-1983	6	479	1980,1	66	44248	89,83	0,93	certain
1978/79-1984	6	416	1980,8	69	44517	89,62	0,98	certain
1979/80-1985	6	340	1982,8	77	45237	89,78	0,90	certain
1980/81-1986	6	384	1985,0	86	46039	88,97	0,58	certain
1982-1987/88	6	447	1986,3	92	46571	88,82	0,50	moderate
1983-1988/89	6	508	1987,3	96	46931	89,05	0,47	moderate
1984-1989/90	6	597	1987,9	98	47109	89,07	0,45	moderate
1985-1990/91	6	614	1988,2	99	47201	89,10	0,42	uncertain
1986-1991/92	6	592	1988,7	102	47466	90,34	0,41	uncertain
1987/88-1992/93	6	526	1989,7	106	47825	90,82	0,40	uncertain
1988/89-1992/93	5	409	1990,4	108	48007	90,40	0,38	uncertain
1989/90-1992/93	4	284	1991,2	112	48367	90,66	0,41	uncertain

Tab. 1: Numerical results regarding the 90-day peak. "Opp" is the number of Jovian apparitions during "Interval", "CMT" the number of analysed positional observations and "Date" the arithmetic mean of observational times. "No. of osc." is the running count of the mean oscillation starting at Julian Date "24..." (zero epochs are arbitrarily defined), "Period" corresponds to the peak's position in the periodogram and "Amplitude" is its intensity. "Identification" denotes to what extent the peak can be considered as genuine. Sampling intervals labelled by *) contain results from the literature [1-6].

Interval	Period [d]	Amplitude [°]	Identification
1971-1974/75	-	-	-
1971-1975/76	-	-	-
1971-1976/77	224	0.6	certain
1972-1977/78	230	0.6	certain
1973-1978/79	235	0.7	certain
1974-1979/80	237	0.8	certain
1975/76-1980/81	238	0.8	moderate
1976/77-1982	154	0.8	uncertain
1977/78-1983	204	0.6	uncertain
1978/79-1984	203	0.6	uncertain
1979/80-1985	191	0.8	moderate
1980/81-1986	-	-	-
1982-1987/88	180	0.5	moderate
1983-1988/89	211	0.4	uncertain
1984-1989/90	216	0.4	moderate
1985-1990/91	219	0.5	certain
1986-1991/92	220	0.5	certain
1987/88-1992/93	225	0.6	certain
1988/89-1992/93	225	0.5	certain
1989/90-1992/93	228	0.6	certain

Tab. 2: Parameters of significant, possibly genuine peaks between periods of 400 and 100 days. Columns are designated as in Table 1.



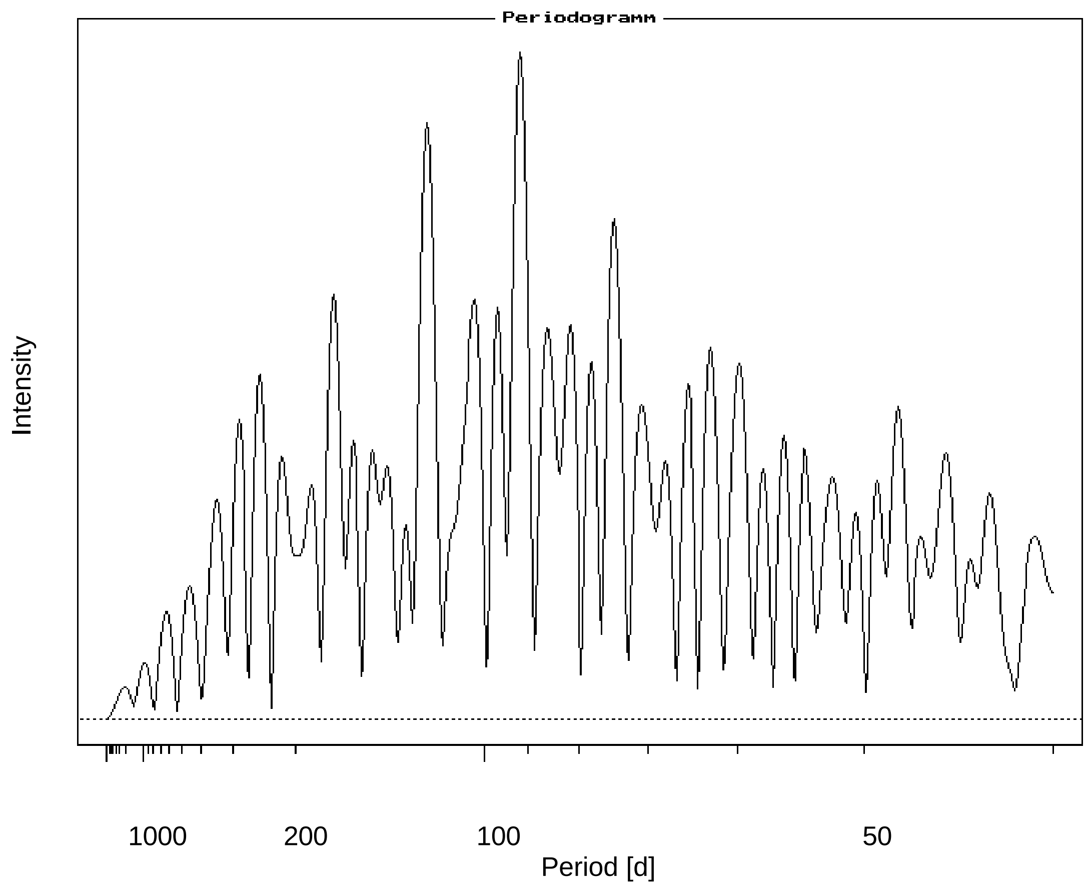
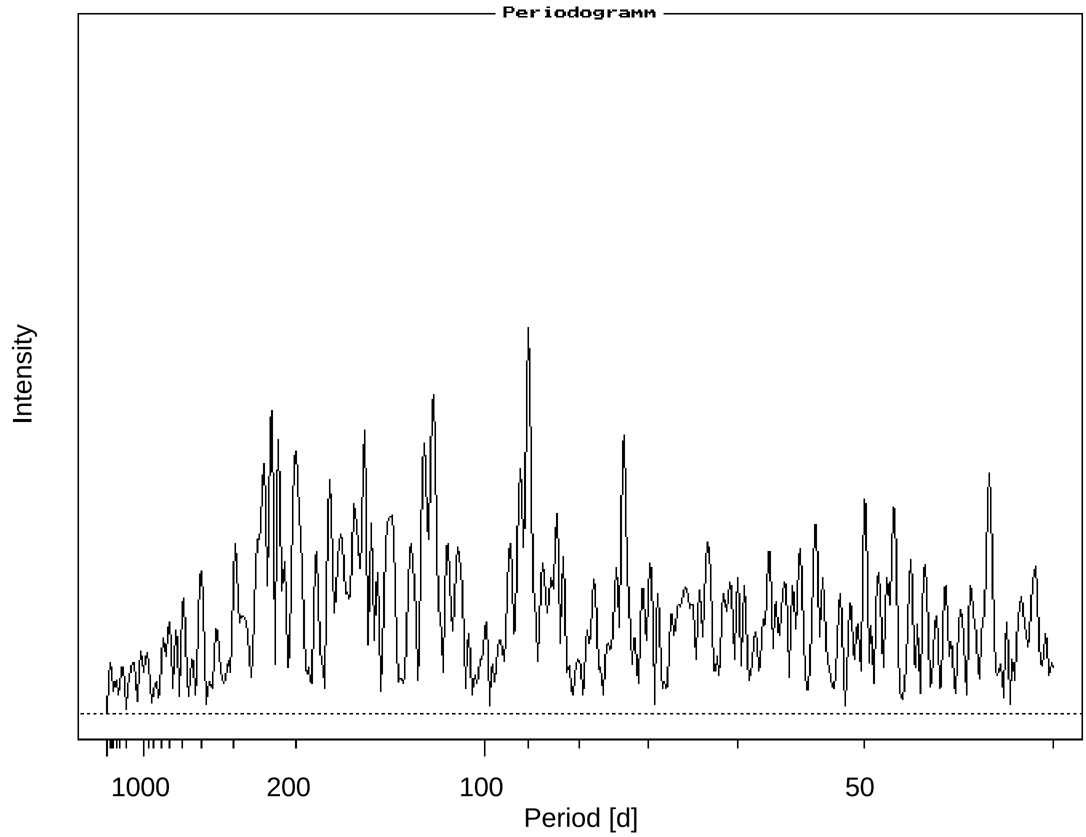


Fig. 1a/b: Periodograms of years 1894-1907 (a), 1894-1900 (b). Abscissas display period measured in days. The maximum value on all ordinates is 0.8°.



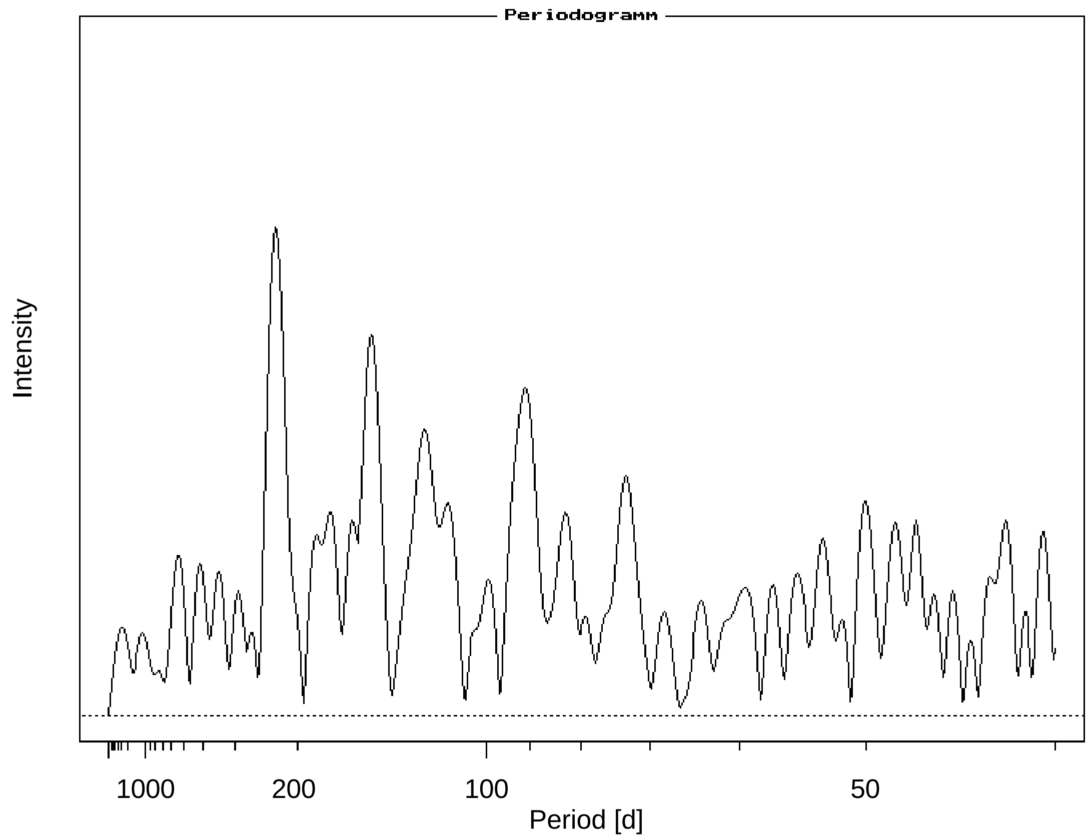
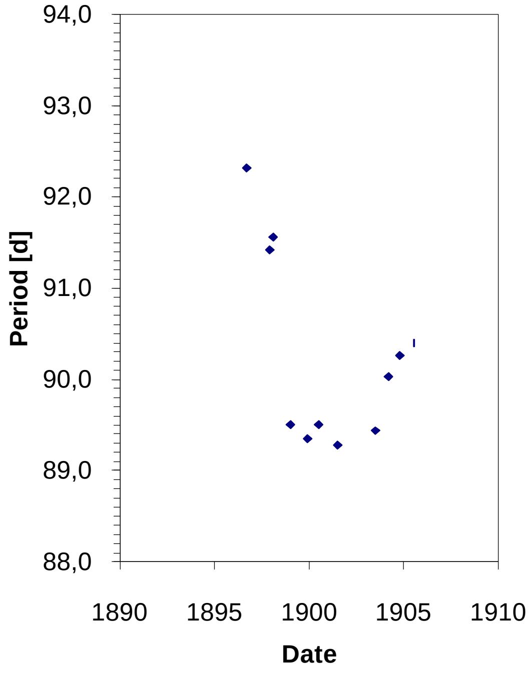


Fig. 1c/d: Periodograms of years 1971-1993 (c) and 1987-1993 (d). Abscissas display period measured in days. The maximum value on all ordinates is 0.8°.



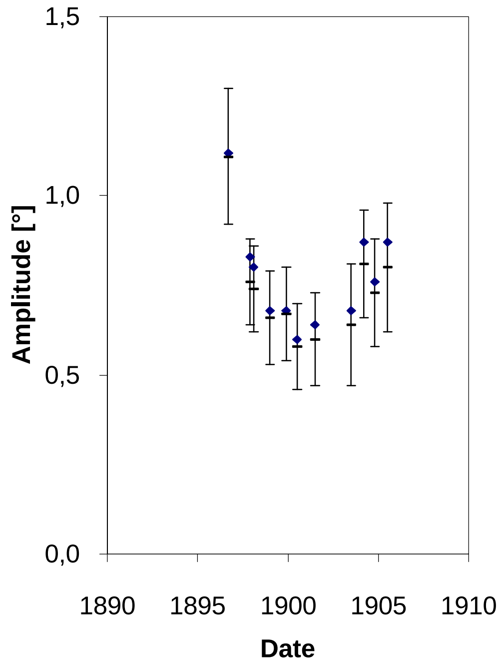


Fig. 2a/b: Period in days and amplitudes in degrees of the 90-day oscillation in the years 1879-1907 (see also Table 1). Points show intensities of periodogram peaks and crosses display results from regression computations performed with a sinusoidal function of the corresponding period.

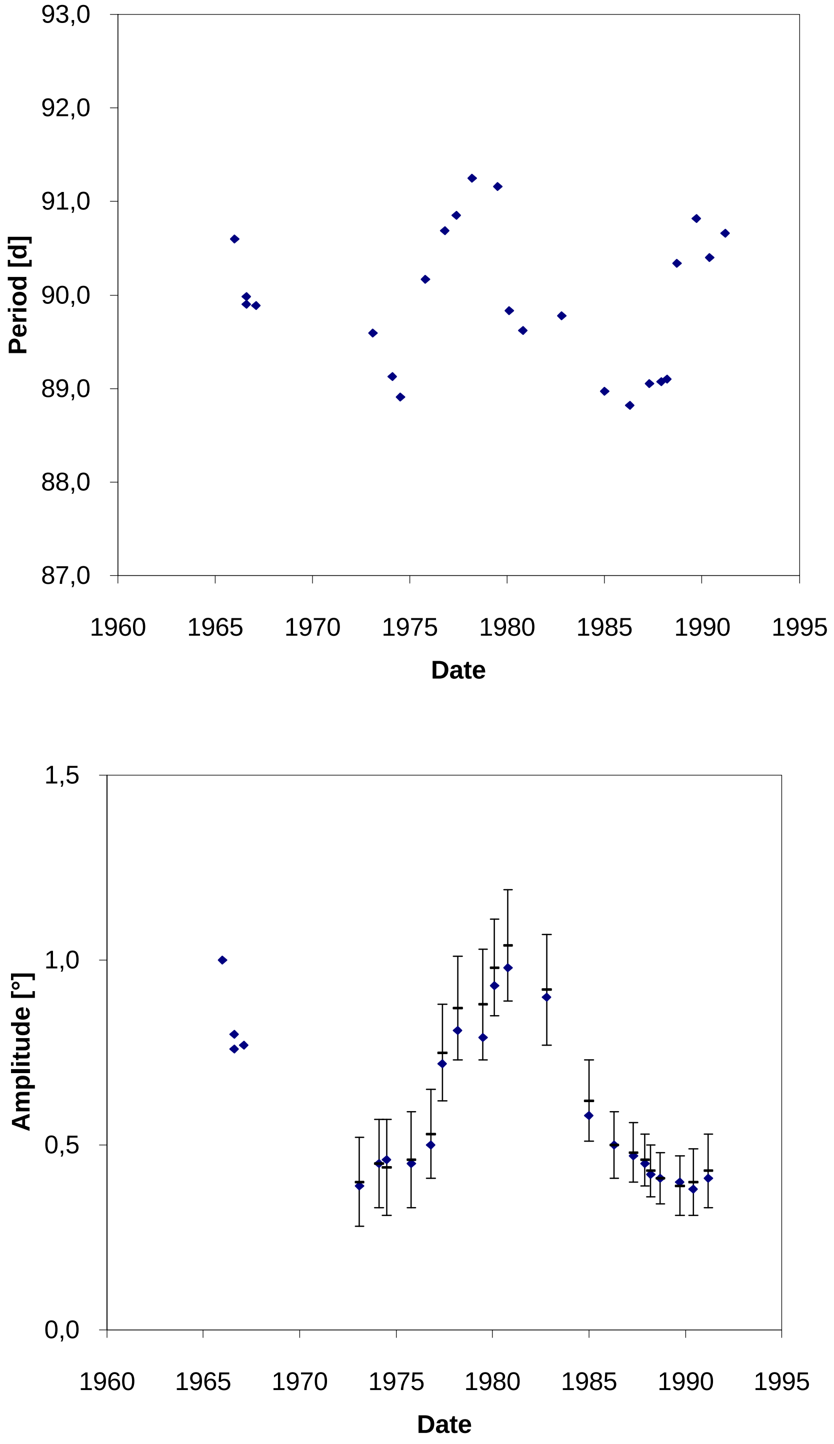


Fig. 2c/d: Period in days and amplitudes in degrees of the 90-day oscillation in the years 1971-1993 (see also Table 1). Points show intensities of periodogram peaks and crosses display results from regression computations performed with a sinusoidal function of the corresponding period.

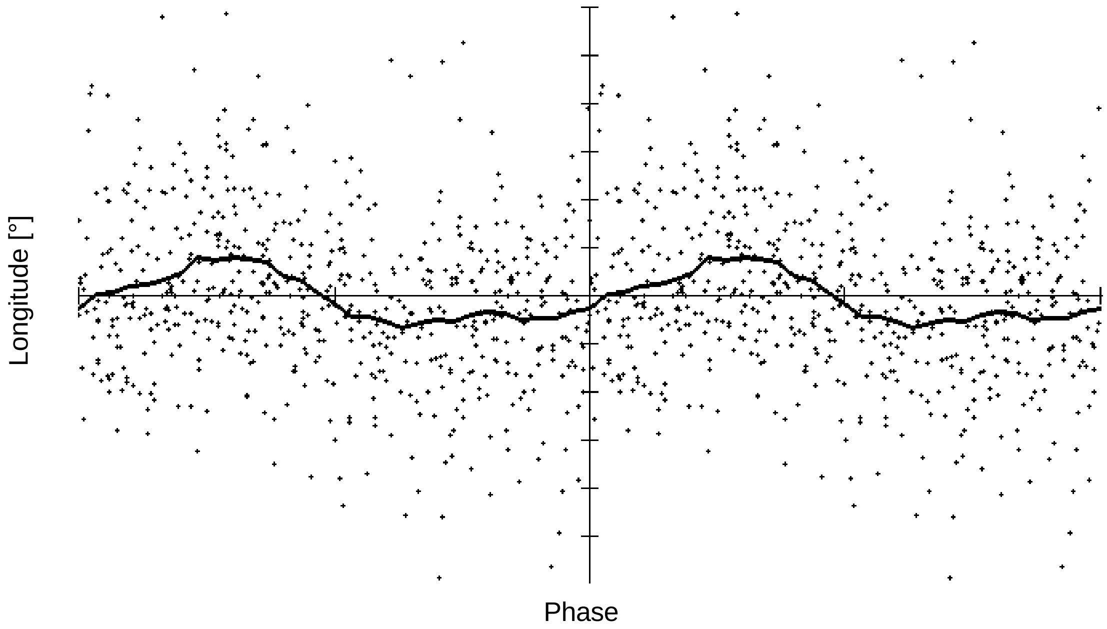


Fig. 3: Phase diagram of the years 1894-1907 at a period of 90.09 days. The polygon connects arithmetic positional means computed every three days and each covering 15 days. The phase ranges from -1 (left) to +1 (right), i.e., two complete epochs are displayed. On the ordinate the jovigraphic longitude is marked in 1° steps. The mean error of a single observation has been estimated as 1.8° and the amplitude of the sinusoidal oscillation as 0.65° ± 0.10°.

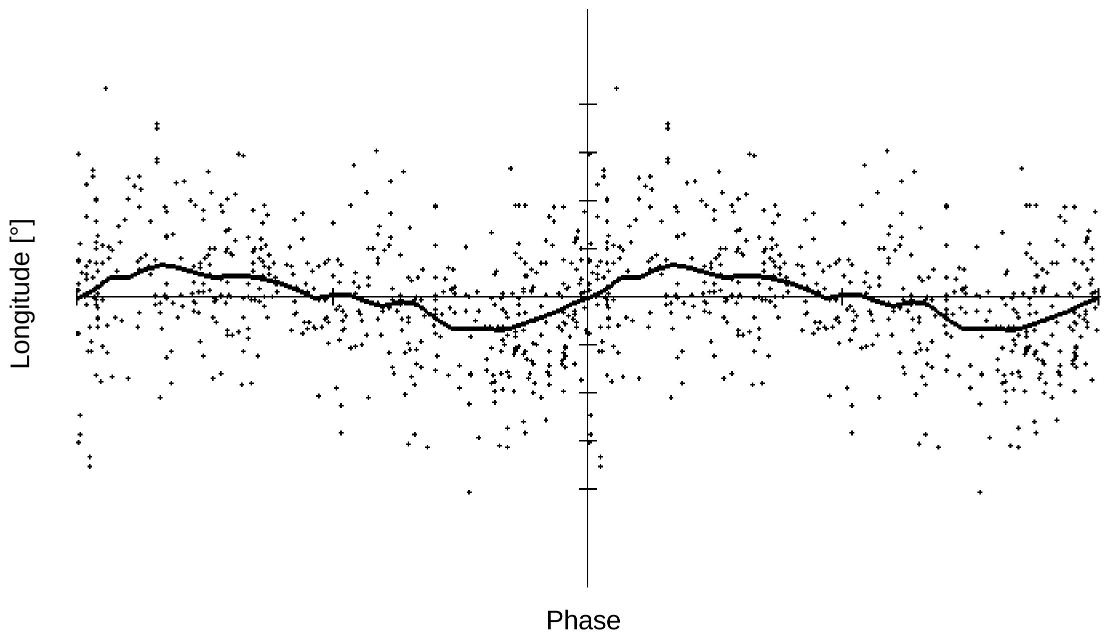


Fig. 4: Phase diagram of the years 1987-1993 at a period of 225.0 days. The polygon connects arithmetic positional means computed every 7.5 days and each covering 21 days. The mean error of a single observation has been estimated as 1.2° and the amplitude of the sinusoidal oscillation as 0.60° ± 0.10°.