Search for relationship between duration of the extended solar cycles and amplitude of sunspot cycle

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Duration of the extended solar cycles is taken into the consideration. The beginning of cycles is counted from the moment of polarity reversal of large-scale magnetic field in high latitudes, occurring in the sunspot cycle n till the minimum of the cycle $n + 2$. The connection between cycle duration and its amplitude is established. Duration of the "latent" period of evolution of extended cycle between reversals and a minimum of the current sunspot cycle is entered. It is shown, that the latent period of cycles evolution is connected with the next sunspot cycle amplitude and can be used for the prognosis of a level and time of a sunspot maximum. The 24th activity cycle prognosis is made. The found dependences correspond to transport dynamo model of generation of solar cyclicity, it is possible with various speed of meridional circulation. Long-term behavior of extended cycle's lengths and connection with change of a climate of the Earth is considered.

1 Introduction

Duration of activity cycle is an important parameter necessary for understanding of the solar cyclicity. In order to define the sunspots cycle length, as a rule, the moments of a sunspots minimum are used. Average duration of sunspots cycle duration is near ~ 11 years, but it can vary from ~ 8 till 15 years. There is a relation between the length of the sunspots cycle and its amplitude: $W_{\max} = 379.9(\pm 64.5) - 24.959(\pm 58)\, L$, where L and $W_{\max}$ show the length and maximal Wolf number (Chistaykov 1997). At the same time the duration of a sunspots cycle can be different from the duration of an activity cycle (Harvey 1992) and the duration of a large-scale magnetic fields cycle (Makarov et al. 2003).

For the description of time responses of a solar magnetic cycle it is possible to use the moments of a polarity reversal of a large-scale magnetic field. In the paper (Makarov et al. 2003) was shown, that the drift speed of boundary polarity reversal line to poles depends on the sunspots area sum in current cycle. The time between an epoch of a minimum and the moments of a polarity reversal on poles also depends on amplitude of the current sunspots cycle (Makarov et al. 2003).

In this paper the connection between the moments of a polarity reversal of a large-scale magnetic field in polar areas and the amplitude of the next cycle of activity is investigated. Along with that long-term changes of duration of large-scale magnetic field cycles and their link with long-term variations of activity and a climate are surveyed.

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2 Duration of the extended activity cycles

Evolution of a large-scale magnetic field in various latitudes can be investigated on series of synoptic Hα charts. The polarity boundary lines of magnetic field are represented on these charts. As markers of neutral lines the optical observations data are used. These are observations of filaments, channels of filaments or prominences. Today summarized number of Hα charts covers the period since 1887 up till now. It was created by different authors (McIntosh 1979; Makarov, & Sivaraman 1989; Vasilieva 1998) and the work over the creation of the number of Hα charts is still going on at Kislovodsk Solar Station (www.solarstation.ru).

The distribution of a large-scale magnetic field has a specific organization in the latitude called zone structure. During the epoch close to a sunspots maximum there is a change of a sign of a large-scale magnetic field on poles. The time of the disappearance of the polar protuberances corresponds to this moment.This moment is important for the formation of the new magnetic fields of the Sun.

Let's consider the time interval between the time of a polarity reversal according to the data of Hα maps and the following moment of a solar activity minimum $\Delta T_{\rm R} = T^{n+1}_{\rm min} - T^{n}_{\rm H\alpha}$. Table 1 shows the moments of a polarity reversal presented on Hα charts, taken from paper (see Makarov & Makarova 1996) for N = 12–22 cycles and supplemented by cycles 23, 24.Reversal on poles in northern and southern hemispheres occurs during the various moments of time. In case of single-fold polar magnetic field reversals the moment for a hemisphere where it passed later was chosen. In some cycles, three-fold reversal polar field was observed. In case of thrice-repeated moments of polarity reversals $T_{\rm H\alpha}$ instanced in Table 1 are taken. Also in

Table 1 Duration of time intervals between the polarity reversal of large-scale magnetic field $T_{\mathrm{H}\alpha}$, received from the time of polarity reversals from Hα synoptic maps. Also numbers of activity cycles N, years of minimum $T_{\min}$ and the moments the reversal of dipole components of large scale magnetic field T_{dip} are presented.

N (cycle)	T_{min} (yr)	$T_{\mathrm{H}\alpha}$ (yr)	$T^{n+1}_{\min}-T^{n}_{\mathrm{H}\alpha}$	$T^{n+2}_{\min}-T^{n}_{\mathrm{H}\alpha}$	T_{dip} (yr)
11	1867.2	1872.3			
12	1878.9	1883.4	6.6	17.3	
13	1889.6	1895.0	5.9	18.3	1893.2
14	1901.7	1908.4	6.7	18.6	1905.8
15	1913.6	1918.6	5.2	15.2	1916.3
16	1923.6	1928.5	4.9	15.1	1927.0
17	1933.8	1940.1	5.3	15.7	1936.5
18	1944.2	1950.2	4.1	14.2	1947.3
19	1954.3	1959.5	4.1	14.7	1957.2
20	1964.9	1971.5	5.2	17	1968.6
21	1976.5	1981.8	5.0	15.3	1979.9
22	1986.8	1991.8	5.0	14.6	1990.4
23	1996.4	2001.7	4.6	15.7	1999.7
24	2007.6(?)	–	5.8	–	–

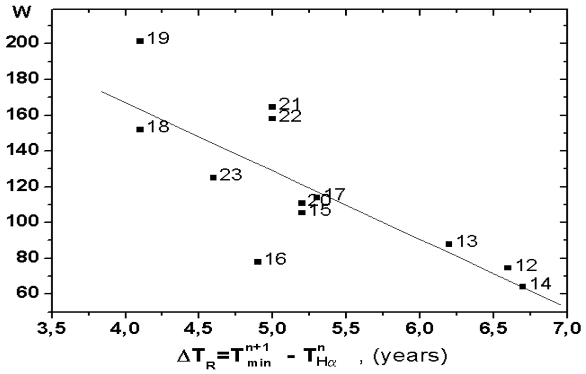

Fig. 1 Amplitude of the sunspots index as the function from duration of the time interval ΔT_{R} between the polarity reversal moments of a large-scale magnetic field in a cycle n and a minimum of a cycle of activity $n+1$.

the table one can see the rm results concerning the time reversal of dipole components T_{dip} of a large-scale magnetic field according to the article (Makarov et al. 2003) . Time of a sunspot activity minimum and amplitude of Wolf's numbers were taken from www.ngdc.noaa.gov/stp.

In Fig. 1 The link between an interval with amplitude of the next sunspot cycle is presented. Function of regression can be expressed as

$$W^{n+1}_{\max} = 320(\pm 51) - 38.2(\pm 9.6)\cdot \Delta T_{\mathrm{R}},\ \ r = 0.78. \quad (1)$$

Apparently, that the shorter the time interval ΔT_{R} is, the higher is the amplitude of the next sunspots cycle. There is also a connection (Fig. 2) between the duration from the polarity reversal moment in cycle n and the moment of a sunspot maximum $T^{n+1}_{\max}$ in a new cycle $\Delta T_2 = T^{n+1}_{\max} - T^{n}_{\mathrm{H}\alpha}$ with amplitude of a new sunspot cycle which can be presented as:

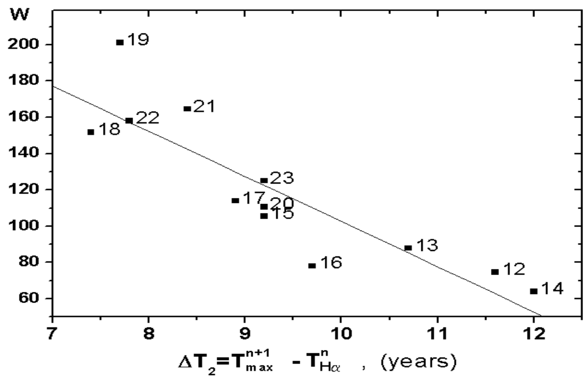

Fig. 2 Amplitude of the sunspots index as a function from the time interval ΔT_2 between the moments of the polarity reversal in a cycle n and a maximum of a cycle of activity $n+1$.

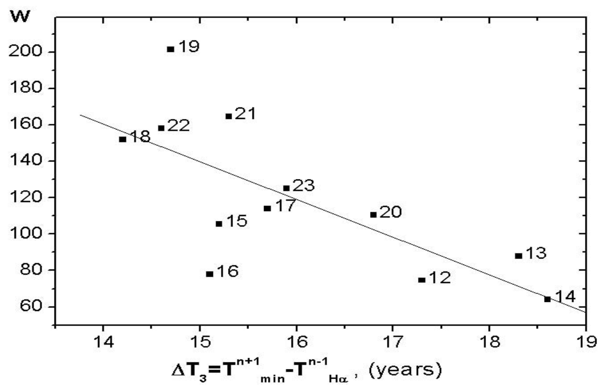

Fig. 3 Amplitudes of the sunspots cycles as a function from the overall duration of extended activity cycles ΔT_3 , counted from the moment of the polarity reversal in a cycle $n-1$ before a minimum of a sunspots cycle $n+1$.

$$W^{n+1}_{\max} = 352(\pm 40) - 24.9(\pm 4.3)\cdot \Delta T_2,\ \ r = 0.87. \quad (2)$$

It is possible to introduce additional time interval, equal to an interval between the moment of a polarity reversal of a large-scale magnetic field $T_{\mathrm{H}\alpha}$ in a cycle n and the moment of a sunspots minimum of a cycle $n+2$: $\Delta T_3 = T^{n+2}_{\min} - T^{n}_{\mathrm{H}\alpha}$. This period varies from 14.2 years for the 18th cycle till 18.6 years for the 14th activity cycle (see Fig. 3). Between the amplitude of a sunspot cycle and an interval there is the following relationship:

$$W^{n+1}_{\max} = 450(\pm 101) - 20.7(\pm 6.4)\cdot \Delta T_3,\ \ r = 0.72. \quad (3)$$

Between the interval ΔT_2 and the duration of the interval ΔT_R there is a link:

$$\Delta T_2 = 1.1(\pm 1.3) + 1.54(\pm 0.24)\cdot \Delta T_{\mathrm{R}},\ \ r = 0.88, \quad (4)$$

where time intervals are expressed in years (Fig. 4).

As it known, the length of sunspots cycles has the correlation with the changes of the surface temperature of the Earth in comparison with their amplitude (Friis-Christensen & Lassen 1991; Lockwood & Fröhlich 2007). Let's consider the link between the length of large-scale

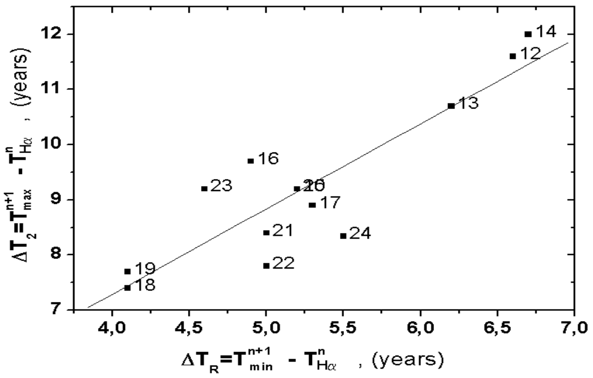

Fig. 4 Connection between the time interval of a polarity reversal and a minimum of activity $\Delta T_{\rm R}$ with an interval between a polarity reversal and approach of a maximum of sunspots activity ΔT_2.

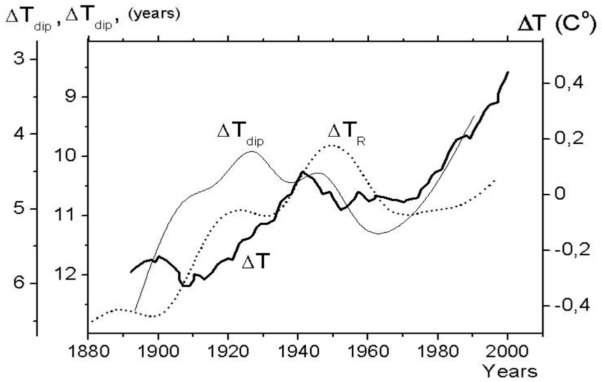

Fig. 5 Change of duration of the time intervals of large-scale magnetic field reversals $\Delta T_{\rm dip}$ (solid line) and $\Delta T_{\rm R}$ (dashed line) during the period of 1880-2000 and variations of the Earth surface temperature ΔT (bold solid line).

magnetic field cycles and long-term temperature changes of the Earth's ΔT according to the data (Lockwood & Fröhlich 2007). In Fig. 5 changes of duration of the period $\Delta T_{\rm R}$ and also duration of cycles dipole components of a large-scale magnetic field $\Delta T_{\rm dip}$ and a surface temperature of the Earth's are presented. To draw $\Delta T_{\rm R}$ and $\Delta T_{\rm dip}$ smoothed curves the procedure of build-up of a B-spline was applied. We can see the data fit. Decrease of length of large-scale magnetic field cycles of the Sun influences a heliosphere and possibly, changes of the Earth climate.

3 Conclusion

The discovered links between the time intervals counted off the moment of a large-scale magnetic field reversal and the amplitude of the next sunspot cycle show that the solar activity cycle has longer duration, than an 11-years sunspot cycle. Equations (1)–(3) show the presence of the connection between the duration of an "extended" cycle (Wilson et al. 1988) beginning from the polarity reversal moment in polar areas of the Sun and the amplitude of activity of the following sunspots cycle.

Thus the time interval ΔT_3 can be interpreted as the duration of the extended activity cycle. The time interval $\Delta T_{\rm R}$ between the polarity reversal and a minimum of activity in $n+1$ can be regarded as the "latent" period of evolution of an extended solar cycle. This time interval can be used for the prognosis of the amplitude of the next sunspot cycle.

If to accept that minimum of 24th cycle of activity has come in 2007.6 the amplitude of 24th cycle can be estimated as $98(\pm 27)W$. The ratio (4) enables to estimate the approach of a maximum of a new cycle of activity. Maximum of 24th activity cycle is expected in $2011.7(\pm 0.7)$ years.

It should be pointed out that the correlation (3) shows that during the period of deep minima of activity, for example during Maunder minimum, the duration of an interval ΔT_3 is close to 22 years, in other words, that is duration of the extended activity cycle during this period strives for the duration of a solar magnetic cycle.

Determination of the role of the moment of a polarity reversal in polar areas and duration of the activity cycle of about 15–18 years corresponds to a transport dynamo model of generation of solar cyclicity with the closed meridional circulation (Tlatov 1995, 1997; Choudhuri et al. 1995). Probably, changes in duration of the extended activity cycle in the interval of 14–18 years are linked with the drift speed of a generation wave at the bottom of the convective zone, and at the same time it is a variable quantity which can be calculated from parameter ΔT_3, varies in limits $v \sim 1.3$–1.7 m/s.

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References

Chistaykov, V.F.: 1997, *Solar Cycle and Climate Oscillations*, Dalnauka, Vladivostok, p. 154
Choudhuri, A.R., Schüssler, M., Dikpati, M.: 1995, A&A 303, L29
Harvey, K.L.: 1992, in: K.L. Harvey (ed.), *Solar Cycle*, ASPC 27, p. 335
Friis-Christensen, E., Lassen, K.: 1991, Sci 254, 698.
Lockwood, M., Fröhlich, C.: 2007, Proc. Royal Society A, doi:10.1098/rspa, 1
Makarov, V.I., Sivaraman, K.R.: 1989, SoPh 119, 35
Makarov, V.I., Makarova, V.V.: 1996, SoPh 163, 267
Makarov, V.I., Tlatov, A.G., Sivaraman, K.R.: 2003, SoPh 214, 41
McIntosh, P.S.: 1979, *Annotated Atlas of H-alpha Synoptic Charts*, NOAA, Boulder
Tlatov, A.G.: 1996, R&QE 39, 794
Tlatov, A.G.: 1997, ARep 41, 448
Vasil'eva, V.V.: 1998, in: V.I. Makarov (ed.), *New Cycle of Activity of the Sun: Observational and Theoretical Aspects*, p. 213
Wilson, P.R., Altrock, R.C., Harvey, K.L., Martin, S.F., Snodgrass, H.B.: 1988, Nature 333, 748