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Polar Magnetic Field Reversals of the Sun in Maunder Minimum

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Abstract. A possible scenario of polar magnetic field reversal of the Sun during the Maunder Minimum (1645–1715) is discussed using data of magnetic field reversals of the Sun for 1880–1991 and the ^{14}C content variations in the bi-annual rings of the pine-trees in 1600–1730 yrs.

Key words. Sun: cycle—magnetic field—maunder minimum.

1. Introduction

Topology and polar magnetic field reversals for 1880–1991 were described in the papers (Makarov & Sivaraman 1989; Makarov 1994). In this paper we continue to discuss a possible scenario of polar magnetic field reversal of the Sun in the Maunder Minimum (1645–1715). Preliminary result has been published in the paper (Makarov & Callebaut 1999).

2. Observational data

The data on polar migration of solar magnetic fields were obtained on the basis of H-alpha magnetic synoptic charts for 1880–1991 using Kodaikanal, Kislovodsk and Italian observations, and Atlas of H-alpha charts (Mclntosh 1979; Makarov & Fatianov 1980; Makarov & Sivaraman 1989; Makarov 1994). The Wolf numbers were taken from Jones (1955), Hoyt & Schatten (1998) and Makarov & Makarova (1996). We used ^{14}C content variations in the biannual rings of the pinetrees in 1600–1730 yrs (Kocharov *et al.* 1995).

3. Results

A comparison of H-alpha magnetic charts with the Stanford magnetographic observations shows that the pattern of the largescale magnetic fields can be derived with greater accuracy than can be inferred from magnetograms (Duval *et al* 1977; Makarov & Tlatov 1999). Thus, H-alpha charts represent data for investigation of global properties of large-scale magnetic fields during many solar cycles when magnetographic observations are not available.

The poleward migration rate of the magnetic fields, V (ms^{-1}), depends on the solar activity. To quantify this we take as an independent variable quantity the sum of the

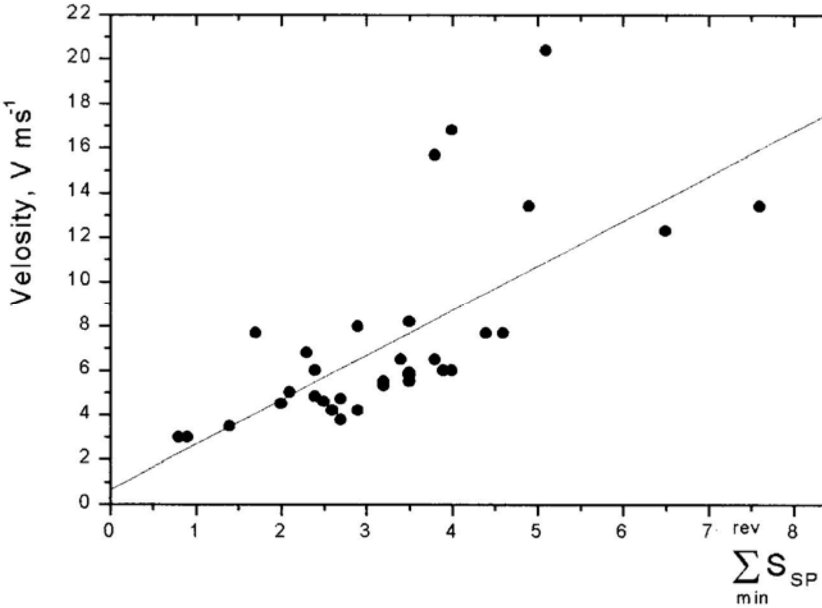

Figure 1. Poleward migration rate, V (ms^{-1}), of the magnetic field vs the sum of the yearly mean Wolf numbers $\sum_{min}^{rev}$ W(t) from a minimum of the solar activity to polar magnetic field reversal for 1880–4991 yrs.

yearly mean Wolf number $\sum_{min}^{rev}$ W(t) starting at a minimum activity, min, up to polar magnetic field reversal, rev, or the Wolf number maximum, $W_{max.}$ We found that the poleward migration rate of the magnetic fields according to Fig. 1 is:

$$V(\mathrm{ms}^{-1}) = 0.7 + 0.015\Sigma_{\min}^{\mathrm{rev}} W(t); \quad \text{or} \quad V(\mathrm{ms}^{-1}) \approx 0.7 + 0.06 W_{\max}.$$

One can see that the value V (ms^{-1}) at very low solar activity is about 0.7 ms^{-1}. In those cycles the latitude zones of magnetic field migrate to the poles during more than 20 yrs and this process determines length of a solar cycle. But according to Beer *et al.* (1998) the magnetic cycles persisted throughout the Maunder Minimum. As the intensity of the solar cycle determines the poleward migration rate it also determines which latitude of the zonal boundary will reach. The higher W(t), the higher the latitúde which is reached. According to Makarov & Callebaut (1999) the minimum intensity of solar cycle for polar magnetic reversal requires the $\sum_{min}^{rev}$ W (t) ≈ 200, or W_{max} ≈ 40 ± 10. According to Hoyt & Schatten (1998), Nagovitsyn (1997) W_{max} has been significantly less than 40 during 1640–1715.

4. Discussion

According to Ribes *et al.* (1993) in the Maunder Minimum the active regions were observed only near the equator. This fact of long occurrence of the sunspots near the equator is unique. In the normal solar cycles active regions practically do not emerge in a zone of ±5° around the equator. The occurrence of active regions during a long time near the equator of the Sun may be taken to testify as a case of a "long

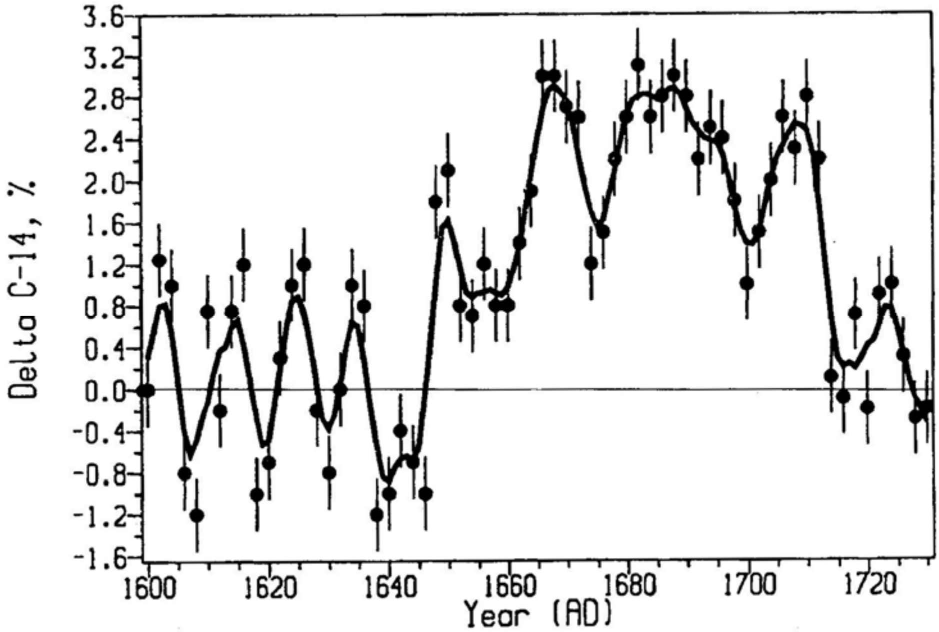

Figure 2. ^{14}C content variations in the bi-annual rings of the pine-trees from South Urals for AD 1600–1730. (By courtesy of Kocharov *et al.* 1995).

solar cycle". This version of a "long solar cycle" is confirmed by the study of the ^{14}C content variations in the bi-annual rings of the pine-trees from South Urals over AD 1600–1730, Kocharov *et al.* (1995) (Fig. 2). In fact, ^{14}C content shows the cycle length to be about 20 yrs in 1640–1715 in accordance with poleward migration rate.

According to Waldmeier (1957), solar activity on a branch of growth of a century cycle dominates in the northern hemisphere, and on a branch of decay in the southern hemisphere. Actually, in 1672–1704 practically no sunspots were observed in the northern hemisphere (Ribes & Nesme-Ribes 1993). At such low activity of the Sun in the northern hemisphere polar magnetic field reversal was possible only in the southern hemisphere. In this epoch the structure of the magnetic field of the Sun was of a "monopole" type, i.e: both poles of the Sun had the same polarity. Such state of solar magnetic field was repeatedly observed in 1955–1982 yrs (Makarov 1984). In 1705 the Wolf number increased and became sufficient for polar magnetic field reversal and hence the structure of a magnetic field was restored.

5. Conclusion

In Maunder Minimum, poleward migration rate of magnetic fields was about 0.7 ms^{-1} and solar cycle length was about 20 yrs. The minimum strength of solar cycle, $W_{max} \approx 40 + 10$, is required for polar magnetic field reversal. We used these results to show that probably polar magnetic field reversal in Maunder Minimum occurred in the one hemisphere.

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