Solar and Stellar Variability: Impact on Earth and Planets
Proceedings IAU Symposium No. 264, 2009
A. G. Kosovichev, A. H. Andrei & J.-P. Rozelot, eds.

doi:10.1017/S1743921309992821

The non-radial propagation of coronal streamers in minimum activity epoch

Andrey G. Tlatov and Valeria V. Vasil'eva

Kislovodsk Mountain Station, The Central Astronomical Observatory of RAS at Pulkovo, 357700, Box-145, Gagarina st., 100, Kislovodsk, Russia
email: tlatov@mail.ru

Abstract. We have analyzed the shape of the solar corona using the data of daily observations with Mark-3/4 (1980-2008) and SOHO/Lasco-2 (1996–2008) telescopes. The angles of deviation of coronal rays from the radial direction $\Delta\theta$ vary cyclically, reaching the maximum deviation towards the solar equator at the minimum of the solar activity. At the minimum of the 24-th cycle of activity, the $\Delta\theta$ angles were smaller than they were at the minimum of the 22-nd and 23-rd cycles.

We also analyzed of the solar structure corona during eclipses for minimum activity from 1870 till 2008. We examined changes in the index, which characterizes the angle of large coronal streamers to the equatorial plane. It has been shown that the index has been smoothly changing during the last 140 years. The maximal value of an index was during 17–19 activity cycles. The minimal values are reached in the end of 19 centuries and at the present time.

We consider the relations between the angles of deviation of coronal rays at the minimum of activity, the parameters of the global magnetic field of the Sun, and the amplitude of the subsequent cycle of activity, and discuss the hypothesis that the variations of the inclination of coronal rays may affect the parameters of the solar wind and the indices of geomagnetic perturbations at the minima of the solar activity cycles.

Keywords. Sun: corona, activity, fundamental parameters

1. Overview

The solar corona structure corresponds to the configuration of solar magnetic fields. Since the magnetic field of the Sun is subjected to cyclic variations, the corona shape also changes cyclically. The coronal rays are distinctive structures in the solar corona, which propagate at a small angle to the radial direction from the Sun and display the electron density in K-corona enhanced by the factor of 3 to 10. The angle $\Delta\theta$ (Figure 1a) that describes the deviation of the rays from the radial position varies with the phase of the solar cycle Kim *et al.* (2004) and the latitude Eselevich & Eselevich (2002). The regular observations with the SOHO/LASCO and Mark III/IV coronagraphs at the Mauna Loa solar observatory make it possible to analyze the structure of the solar corona from 1980. In order to determine the inclinations of coronal rays, we developed a technique of the identification of coronal streamers in two-dimensional images of the corona obtained with SOHO/LASCO-2 and Mark III/IV in automatic mode. The analysis of the SOHO/Lasco-2 data for 1996–2008 indicates that the inclination angle $\Delta\theta$ varies with the 11-year cycle of the activity, reaching the maximum values at the minimum of the activity. Figure 1b presents the monthly averages for the inclination, averaged along the entire limb. The coronal rays at the minimum of the activity and the phases of the decline are, as a rule, turned towards the solar equator. These conclusions are also confirmed by the analysis of the structure of the solar corona at the heights $1.2-2.5R$ based on the MLSO MarkIII/IV data. Figure 1c presents the angle $\Delta\theta$ for the latitude zone $\pm 30^o$ in the time interval

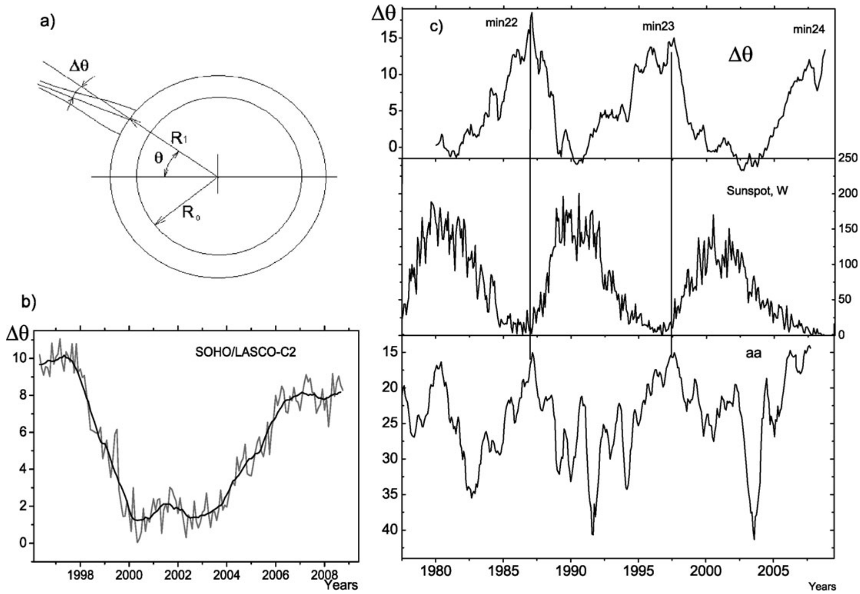

Figure 1. a) The determination of inclination angles for coronal rays. b) The monthly-averaged deviation from the radial direction $\Delta\theta$ derived from the SOHO/Lasco-2 data. The envelope curve averaged from 12 points is also presented. c) The comparison between the deviations of coronal rays $\Delta\theta$ according MLSO- MarkIII/IV data, the Wolf indices for the solar spots W and the geomagnetic index aa. The data are smoothed with a sliding window technique for 6 months.

1980–2008. At the minimum of the 22-nd cycle of the solar activity, the angle $\Delta\theta$ was around 18.2^o, at the minimum of the 23-rd cycle it was 14.7^o, while at the minimum of the 24-th cycle about 9^o. This Figure presents the graph of the deviation angle in comparison with sunspot index W and the index of geomagnetic perturbations aa. The non-radial propagation of the solar wind may explain the relationship between geomagnetic indices detected during the minima of activity and the amplitude of a subsequent solar cycle Ohl (1966). Indeed, the relation between the amplitude of the angles $\Delta\theta$ at the minima of the 22-th - 24-th cycles is close to that for the index of the large-scale magnetic field of the Sun in these times Tlatov (2009), and this field is one of prognostic indices of the solar activity.

We can also test changes deviations of coronal streamers from the radial direction for over 100 years (Figure 2). You can use the catalogs of solar eclipses Loucif & Koutchmy (1989), Vsekhsvyatsky *et al.* (1965). Let us introduce index γ that characterizes the angle between high-latitude boundaries of the large coronal streamers at a distance of $2R$. The γ index is the sum of the angles at the eastern and western limbs: $\gamma = \gamma_N + \gamma_S$. In fact, the γ index is a simpler version of the corona flattening indices Nikolskiy (1955) but it is calculated at height R above solar limb.

2. Implications

The awareness of the variations of the angles $\Delta\theta$ and γ with the phase of a cycle is important for theoretical models describing the structure of the corona and the geometry of the magnetic field above the solar limb Wang (1996). The applied aspect of the studies for the deviations of coronal streamers, along with the plasma flows in the solar wind, is also of great importance, since the deviation may affect the geo-efficiency of the solar wind impact. The presence of long-term trends in the solar corona structure can be caused

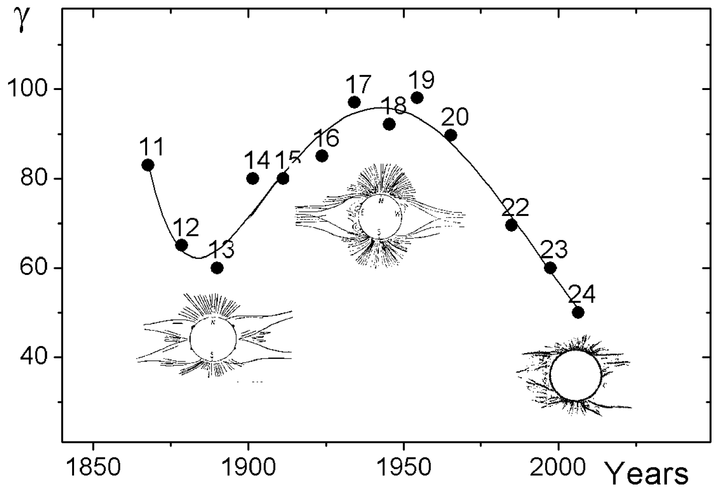

Figure 2. Distribution of parameter γ for the structure of the corona of the minimal type. Numbers of activity cycles are given. The shape of the solar corona to cycles 13,19 and 24 are present.

by changes in the configuration of the global magnetic field of the Sun. The non-radial propagation of the solar wind may explain the relationship between geomagnetic indices detected during the minima of activity and the amplitude of a subsequent solar cycle (Ohl, 1966). Indeed, the relation between the amplitude of the angles at the minima of the 22-th - 24-th cycles is close to that for the index of the large-scale magnetic field of the Sun in these times, and this field is one of prognostic indices of the solar activity. Thereby, we may suggest a link between the large-scale magnetic field and the deviation of coronal rays towards the equator, which in turn affects the level of geomagnetic indices at a solar minimum as well as solar-terrestrial relations.

Thus, analysis of the corona shape has revealed a long-term modulation of the global magnetic field of the Sun (Figure 1b; 1c; 2). Possibly, there exists a secular modulation of the global solar magnetic field which is most pronounced during the solar activity minimum epoch.

References

Eselevich, V. G. & Eselevich, M. V. 2002, *Solar Phys.*, 208, 5

Kim, G.-D., Makarov, V. I., & Tlatov, A. G. 2004, *International Journal of Geomagnetism and Aeronomy*, 5, 2, GI2011

Loucif, M. L. & Koutchmy, S. 1989, *ApJS*, 77, 44

Nikolskiy, G. M. 1955, *Astron. Lett.*, 160, 11

Ohl, A. I. 1966, *Solnycnye Danie*, N9, 84

Tlatov, A. G. 2009,*Solar Phys.*, in pres

Vsekhsvyatsky, S. K., Nikolsky, G. M., Ivanchuk, V. I., Nesmuanovich, A. T., Ponomarev, E. A., Rubo, G. A., & Cherednichenko, V. I. 1965, *The Solar Corona and Corpuscular Emission in Interplanetary Space* (Kiev Univers. Press, Kiev), 293 pp

Wang, Y.-M. 1996, *Apj*, 456, L119