"Physics of Auroral Phenomena", Proc. XXXIII Annual Seminar, Apatity, pp. 95 - 98, 2011

Polar Geophysical Institute

SOLAR WIND RECURRENT PHENOMENA IN 23-th MINIMUM

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Abstract. The prolonged minimum of solar activity (SA) in the end of 23-th solar cycle is continuing now. Very low level of SA and geomagnetic disturbance is observed in the beginning of 2010. The phase of sunspot minimum is suitable for investigation of long-lived phenomena of SA, especially heliosphere plasma layer (HPL) and connected with him sector structure of interplanetary magnetic field (IMF) on the Earth's orbit. Recurrence of fast solar wind (SW) flows is the feature of regular phenomena, connected with equatorial and near-equatorial coronal holes (CHs) in minimal phase of SA. Namely these CHs are producing high-speed SW in immediate proximity to HPL. Absence of sporadic phenomena of SA (such as flares, coronal mass ejections and filaments) allows us to study SW and plasma parameters (data Wind) in the near-Earth cosmic space in quiet condition on the Sun. For these purposes the interval of Carrington rotations №2052-2091 (from January, 2007 till January, 2010) is defined. Fractal dimension calculations help us to estimate structural variations on intervals, which are lasting about a week or more. Such intervals have been named "activity impulses" in classical works of M.N. Gnevyshev and A.I. O'l. In an initial phase of a minimum these activity impulses have concrete manifestations: the high-speed recurrent streams of SW from equatorial and near- equatorial CHs. Impulses are separated by the regions of sector structure transition boundaries in according with heliosphere plasma layer intersection. It allows us to investigate long-lived phenomena of SA and to explain changes by means of transformations of general solar magnetic field, large-scale magnetic fields and local photospheric magnetic fields in minimum. Comparison with solar maps, such as WSO source surface field, WSO photospheric magnetic field and coronal holes, helps us in SW flows – to recognize reliable source on the solar disk. A brief summary includes:

1. Fast solar wind streams from local equatorial coronal holes of minimum generate activity impulses.
2. Recurrence and variability of activity impulses are caused by heliophysical reasons, such as large-scale magnetic field transformations and reorganization of CHs in near-equatorial belt of the Sun.
3. Effect of the helio-projection of the Earth on the solar disk in yearly motion is seen in the preferred polarity of sector structure in Carrington rotations, which including equinoctial points.
4. Fractal dimension calculations confirm the plasma layer transitions on the Earth's orbit.
5. Low geomagnetic activity exists in minimum. The growth over quiet level is produced by activity impulses.
6. The duration of 23-th minimum is connected with the reaching of SA secular minimum, such as in the beginning of the twentieth century.

1. Introduction

Recurrent phenomena in the geomagnetic disturbance were studied actively since 30-th years of the XX century [1-3], in IGY period and after formation of Data Centers A and B. The connection of 27-days magnetosphere recurrence phenomena with sources on the Sun is investigated statistically [4] and specifically on large quantity of examples. First of all, the role of high-speed solar wind (SW) streams as the reasons of the geomagnetic activity growth was recognized. Then high-speed streams of SW have been in turn classified on types depending on sources on the Sun and in accordance with SW parameters on the Earth orbit. These parameters were measured by cosmic instruments in near-Earth space, and subsequently in a heliosphere by means of Ulysses, INTERBOL, Mars - Odysseus missions.

Characteristic examples of sporadic flare events (connected with active regions (AR) on the Sun) and also with coronal mass ejections – possess individual signs, their generation originates from solar AR's. Time of AR life is estimated as one Carrington rotation or several ones sometimes. Presence of so-called active longitudes on the Sun promotes to AR "reproduction" in places of their former existence. It complicates a situation in addition, but their repeatability concerns with AR life only. All these phenomena are the sporadic events.

The expressed repeatability of the recurrent events allocated in separate type is estimated in many Carrington rotations of the Sun [5]. Recurrent phenomena are generated from long-living SW streams from coronal holes. This concept is today the basic. However, nature of CHs as sources of fast SW it is not understood up to the end – problem in solar physics is not closed, since the mechanism of SW generation from CH is not established. The localization of CHs on a disk is studied: polar CHs in minima of solar activity became the most known experimental fact. Variations of CHs in average and low heliolatitudes are in a studying stage nowadays. We study the reasons of their occurrence and migrations, fast changes of contrast and borders of CHs and properties of SW streams from CHs too.

In our Institute this theme is considered in works of V.N. Obridko about large-scale fields on the Sun [6], of K.I.Nikolskaja about CHs in a cycle [7-8], E.I.Mogilevsky and T.E.Valchuk about fractal research of sources and qualities of SW [9].

It is known that the recurrent flows are the most expressed on a decrease branch of solar cycles. The purpose of the present work is to study recurrent SW events in the last minimum of SA. The solar origin of recurrence and SW parameters in near-Earth cosmic space, especially sector structure of IMF shows us the connection between solar and heliospheric phenomena.

2. Data and calculations

For interpretation the picture of last minimum we choose the data representing a near-Earths cosmic space: plasma parameters and an interplanetary magnetic field in SW (data Wind; SOHO, University of Maryland), the data about sector structure (SS) IMF (ACE). Geomagnetic disturbance was estimated by Ap index. Solar parameters are presented as follows: coronal pictures by LASCO SOHO; MDI magnetograms and solar disc in soft X-ray EIT SOHO; solar spots on a disk in continuum (SOHO); and also synoptic charts of photospheric magnetic field and charts of source surface field WSO; and also cards of CHs in Fe XIV line NSO Sacramento Peak for addition of a dynamic transformation of CHs in CR 2052-2091 in 23-th minimum in years 2007-2010.

Fractal calculations were made on all period of a minimum (except for time intervals of data absence – from hours up to several days). The Higuchi method allows us to estimate fractal dimension (FD) of SW plasma, as the characteristic of SW plasma flow structure. FD characteristics and the synoptic analysis (based on the concrete examination of data set about sources of SW on the solar disk) can supplement each other. FD variations were calculated by means of the sliding window lasting 6 hours with the 3-sentry step; the similar technique was applied in [9].

3. IMF polarity and SW flows

The IMF sector structure transformations are valuable factors of solar minimum. It is necessary to consider that SS is the reflection in SW a large-scale magnetic field of the Sun. Taking into account the helio-projection of our Earth on the solar disk making 7 degrees above and below relatively solar equator in equinoxes affects in primary polarity: S – spring equinoxes in CRs № 2054, 2068, 2081 and N – autumn equinoxes in CRs 2061, 2074 and 2088 accordingly in 2007, 2008 and 2009. In [5] four-sector structure is presented as the basic feature in the descending and minimum phase of solar cycle. The current minimum №23 reveals the following: 4 sectors of IMF in CRs 2052-2059 are transformed to two-sector structure in CRs 2060-2069; in beginning of CR 2070 the occurrence of positive SS is not positive sector display, but only variations near heliosphere plasma layer, when SW velocity is low. In 2007, from CR 2060, the two-sector structure is presented as steady phenomenon in the next Carrington rotations. The steady sector boundary (September 1, 2007, (–/+) transition) exists as the most stable up to 2009. In an autumn equinox 2008 positive SS remains only on September, 15 and 16. Positive sector IMF is steady, and up to CR 2080 it is connected with a fast stream of positive polarity. It is necessary to notice that from CR 2060 up to CR 2079 the crossing of HPL occurs on steady boundary of two fast streams – in negative and positive polarity of IMF.

In 2009 the stability of large-scale solar magnetic fields in near-equatorial belt of the Sun decreases a little. It is visible on reduction of speed and loss of structural features of streams. There is ample evidence that large-scale magnetic field in equatorial belt of the Sun is transformed. The line of polarity section of source surface field is approached to Sun equator; HPL reaches the most flattening.

Geomagnetic disturbance is represented as weak geomagnetic storms and active periods. Geomagnetic activity in 2009 gets the least in minimal phase of SA.

Nevertheless in 2007, when high-speed impulses of activity are expressed distinctly, the arrival of co-rotation regions, following after HPL crossing, causes geomagnetic activity. We will study these situations in consecutive change of CRs of the Sun for the purpose of identification of high-speed SW stream sources from unipolar areas of magnetic fields on the solar disk

4. Fractal dimension variations in front of fast SW streams in HPL transitions

In the beginning 2007 in an explicit form data of the SW speed and plasma concentration are very like from CR 2052 up to CR 2057. It shows the saving of structure and characteristics of long-living areas of polarity on the Sun. These areas remain in the specified CRs in the beginning of 2007.

We will consider the steady boundary of HPL transition (from negative polarity to positive) in the beginning of CRs. After HPL transition the fast SW stream is generated from near-equatorial CH of positive polarity. Fractal dimension variations show the functions similar to each other in general features, two samples are on Fig.1. The co-rotation region (CIR) in the case of fast SW flow near HPL gives fractal dimension values $1.2 < FD < 1.4$, that is appreciably lower than typical $FD \sim 1.5$ in HPL transition.

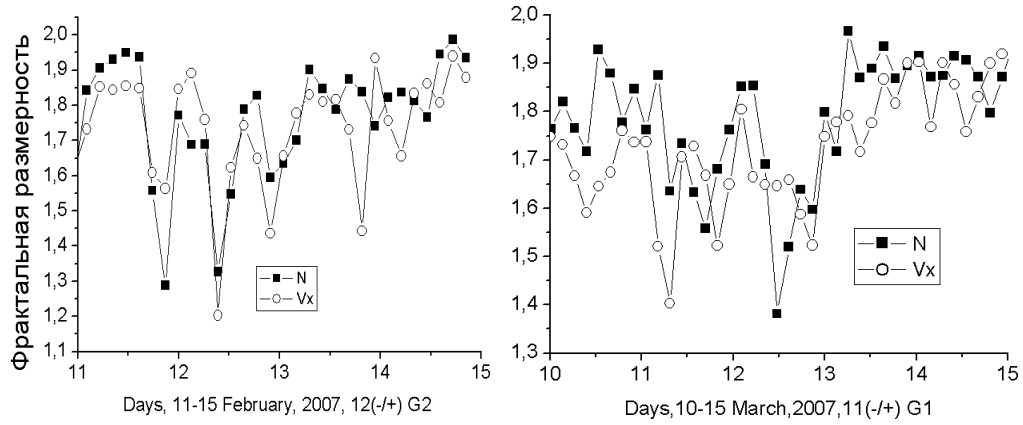

Fig. 1

The CIR area near HPL is typically shown by sharp descending of FD value, a sign of formation multi-layered current sheets inside HPL. FD of a high-speed stream from CH equals 1.7 < FD < 2.0. The fast stream follows HPL transition in positive sector of IMF. In August 2007, 24 and 25.08 from (+) sector IMF a little trace remains: only variations (– / +) and (+ / –). FD values changes rather essentially (though FD=1.5), but it speaks only about immersing in HPL, without its crossing. The dividing line on the synoptic chart of WSO source surface field proves a true situation. In CR 2060 HPL is not crossed, though HPL has the bend very close to dividing line, fig. 2.

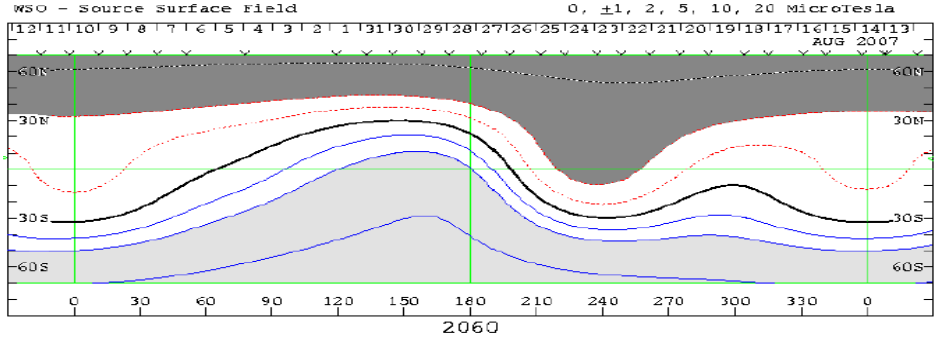

Fig. 2

5. Conclusions

1.Geomagnetic activity in solar minimum is caused by co-rotating SW stream (CIR). CIR arises at distribution of high-speed solar wind streams from CHs of minimum phase – CHs of near-equatorial localization. They settle down on background large-scale magnetic fields (data MDI) and are visible on the Sun disk in a soft X-ray (LASCO - the Sun corona; images SOHO EIT, 284A). Recurrent «activity impulses» are provided by these long-lived CHs of solar minimum.
2. The shape of heliosphere plasma layer (HPL) is reflected in IMF sector structure variations. HPL is long-living phenomenon of SA, which is the most regular in a minimum.
3. In equinoxes we may look the preferred polarity of that solar hemisphere, on which helio-projection of the Earth is realized. It is maximal in an equinox, about 7˚.
4. Solar spots of the beginning of new 24-th cycle are weak and have the high-altitude layout. They have no influence on position HPL in minimum.
5. Bends of HPL, flattening to an ecliptic plane, pass in the minimum through low-latitude "old" solar spots, which actually are on the boundary between large-scale background magnetic fields of different polarities.

Acknowledgement. The study was supported by Russian Foundation for Basic Research, grant НШ-4573.2008.2.

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