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EXPLORATIONS COSMIQUES

PROPERTIES OF MAGNETIC FIELDS IN CORONAL HOLES AND GEOEFFECTIVE DISTURBANCES IN SOLAR CYCLE 24

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Abstract

The coronal holes (CH) are sources of high-speed flows of solar wind, and, in its turn, are one of the main sources of geomagnetic disturbances. The coronal holes differ very much one from another and their geoeffectivity varies in a wide range. In this paper we implement a study to answer the question how the coronal holes characterized by different location on the Sun and by their polarity influence the geomagnetic activity. We considered 53 coronal holes observed in the period 2011-2012 of solar cycle 24, and separated them into groups by the heliolatitude and their polarity. A conclusion is made that the trans-equatorial group is the most effective one. Less, but yet sufficiently effective, are the holes of negative polarity at north latitudes and those of positive polarity at south latitudes. The much smaller number of coronal holes of opposite polarity (CH of negative polarity in south hemisphere and CH of positive one in north hemisphere) are less effective.

Key words: solar coronal holes on the Sun, positive/negative polarity of magnetic field, high-speed solar wind, geomagnetic disturbances

Introduction. The coronal holes (CH) are an important factor characterizing the solar activity. It is known that CH are the source of the high-speed solar wind, which effectively influences on the magnetosphere of Earth [1]. The coronal holes are extended regions in the solar corona where the density and temperature are lower than other places in the corona. The weak, diverging and open magnetic field lines in coronal holes extend radially outward. The high speed path of the solar wind streams out from coronal holes. The low density of the gas makes this parts of the corona appear dark in extreme-ultraviolet and soft X-ray images of the Sun, as if they were a hole in the corona [2, 3].

The investigation of the coronal holes properties and behavior is connected before all with their effects at the Earth. The studies, which are related to the coronal holes positions as well as to the flow, polarity and solar wind velocity are really very important [4]. Some models are developed for prediction of the solar wind from coronal holes [5].

The model is based on the position and the magnitude of the solar coronal holes. Some studies are proposed concerning the quantitative analysis of the quadruple component of the magnetic field [6]. By means of this method the magnetic field poles are determined and therefore the coronal holes behavior as well as their appearance and motion. It is assumed that the coronal holes position follows the magnetic field poles motion. All these and also other investigations consider before all the coronal holes, their behavior and structure or the solar wind from them. But these studies do not connect directly the coronal holes with the geophysical activity.

Generally, coronal holes are associated with fast expanding open magnetic fields and the acceleration of the high-speed solar wind [7]. The plasma properties in coronal holes and the physical processes that heat the solar corona and accelerate the solar wind are still unknown to what extent the solar wind is fed by flux tubes that remain open, and to what extent much of the mass and energy is input intermittently from closed loops into the open-field regions. Evidence for both paradigms is summarized in the works [7, 8]. Despite of the incomplete knowledge of the complex multi-scale plasma physics, however, some progress has been made toward the goal of understanding the mechanisms ultimately responsible for producing the observed properties of coronal holes [9]. The goal of the present work is to investigate the geoeffectivity of solar coronal holes in dependence on the polarity of the corresponding magnetic fields.

Data and methods. The data base for Forbush-effects and interplanetary disturbances developed in IZMIRAN [10] is used by us in order to chose events in which the coronal holes have influence on the Earth's magnetosphere. 53 events in the period 2011-2012 were chosen, such that a well recognized coronal hole was the source of geoeffectivity in each case. We considered the coronal holes with respect to their polarity and the location on the solar disk. The enumeration and location of the CH we obtained from the site [11], and the polarity was retrieved from data taken from [12]. On Figs. 1-3 are presented some representative examples of coronal holes on the Sun during the current 24th cycle passed through the central solar meridian.

The coronal hole CH435 demonstrated in Fig.1 passed through the solar central meridian on January 30 - February 1, 2011, and the related geomagnetic effect was observed on the Earth on February 4-8. This hole created a Forbush-effect of magnitude 1.5%, as well as a moderate geomagnetic storm (Kp-index was 6-, and Dst-index reached –56 nT). The maximal velocity of the solar wind was 647 km/s.

Fig.1.

The coronal hole CH474, shown in Fig.2, passed through the solar central meridian on September 1, 2011, and the related geomagnetic effect on the Earth was observed on September 4-8. This hole caused a Forbush-effect of magnitude 0.7%, and was accompanied with a small disturbance of the geomagnetic field (Kp-index was 3; Dst-index was –20 nT). The maximum velocity of the solar wind was 441 km/s.

Fig.2.

The coronal hole CH515 demonstrated in Fig. 3 passed through the solar central meridian on May 5-7, 2012, and the related geomagnetic effect was observed on the Earth on May 8-12. This hole created a Forbush-effect of magnitude 1.9%, as well as a small geomagnetic storm (Kp-index was 5-; Dst-index reached –42 nT). The maximum velocity of the solar wind was 638 km/s.

Fig.3.

Discussion of the results. We considered 53 events whose sources were coronal holes on the Sun. We found 12 coronal holes of negative polarity in the northern solar hemisphere; 16 CH of positive polarity in the southern solar hemisphere; 21 coronal holes crossing the equator (19 of them - of negative polarity, and only 2 – of positive polarity); and 4 untypical coronal holes (3 of them of negative polarity in the southern hemisphere, and one of positive polarity in the north hemisphere). The average characteristics of the cosmic ray intensity, geomagnetic activity and the interplanetary space during the studied events are presented in the Table.

Table. Average characteristics of the geomagnetic activity and the interplanetary space during studied events.

Location	N	S	Trans-equatorial	Not typical coronal holes
Polarity	-	+	-/+	+/-
Number	12	16	21	4
Forbush effect	1.01 ± 0.13	0.81 ± 0.09	1.00 ± 0.10	1.15 ± 0.25
Kp_{max}_mid	3.83 ± 0.35	3.62 ± 0.23	4.27 ± 0.21	3.16 ± 0.35
Ap_{max}_mid	29.83 ± 6.27	24.63 ± 3.71	35.52 ± 4.38	17.25 ± 3.75
V_{max}	547.3 ± 36.4	524.1 ± 15.0	572.6 ± 22.1	498.5 ± 83.9
Dst_{min}	-34.0 ± 4.6	-21.9 ± 3.3	-32.6 ± 3.8	-15.8 ± 2.4

Here the decrease of the cosmic ray intensity during Forbush effects is expressed in %. The following geomagnetic disturbance indexes are also shown in the Table: the estimated 3-hour planetary Kp-index and the daily geomagnetic planetary Ap-index. V_{max} is the maximal velocity of solar wind and Dst_{min} is the minimal value of the geomagnetic equatorial Dst index.

The results of analysis of all 53 cases of coronal holes are presented in Fig. 4. It shows the four groups on which the considered 53 coronal holes are divided.

The coronal holes of the first group are situated in the Northern hemisphere and they are of negative polarity. These holes are shown with reverse red triangles. The mean value of the maximal Kp for each of the 12 cases is 3.83. It is shown with red line.

The second group of coronal holes is situated in the Southern hemisphere with positive polarity. It is presented by blue circles. The mean value of the maximal Kp for each of the 16 cases is 3.62, respectively. It is shown with blue line.

The trans-equatorial cases which are most numerous – namely 21, are shown with green squares. The mean value of the maximal Kp for each of the 21 cases is 4.27. It is shown by green line. The remaining cases are presented by gray line. On this Figure 4 namely, it is seen clearly that the largest group which consists of trans-equatorial coronal holes, is the most geoeffective one. In this case 19 holes have negative polarity and only two – positive polarity. The result is explicable from the point of view of dynamics and topology of solar wind propagation. The negative polarity brings the negative Bz component, which is basic factor for geomagnetic storms appearance. This could be an explanation for dominance of the trans-equatorial coronal holes as a factor initiating the geomagnetic storms.

In addition, the large-scale accelerated solar wind flow increases the reconnection of the moving interplanetary magnetic field to the Earth's magnetic field. It occurs because of the great surface which is expanding from pole to pole. As a result from both factors, namely, negative interplanetary magnetic field, and large-scale solar wind shockwave, these coronal holes become most geoeffective and cause geomagnetic storms.

Fig.4.

Conclusion. We found that the most geo-effective is the trans-equatorial group, in which almost all coronal wholes are of negative polarity. Our analysis show that less (yet sufficiently) effective are the holes of negative polarity in the northern hemisphere and those of positive polarity in the southern hemisphere. There are very small numbers of coronal holes of opposite polarity (southern negative, and northern positive); their effectivity is smallest. One has to remember, however, that our study concerns a single solar cycle. We suppose that with the change of sign of the common solar magnetic field opposite results will be obtained.

It is demonstrated, also, that there is no significant difference between the groups considered, with respect to the magnitude of the Forbush-effect. Actually, the intensity of a geomagnetic storm is influenced by the sign of the B_z component of the magnetic field; on the other hand, for the Forbush effect the global interplanetary characteristics, such as the solar wind velocity, the magnitude of the common magnetic field, and dimensions of the disturbance, etc., are important.

In relation to Forbush effects, the separate groups of coronal holes do not differ by their influences. In some sense it is explicable because, before all, the interplanetary characteristics are important for the Forbush effects. Such characteristics are the solar wind velocity, flow density, the interplanetary magnetic field magnitude, as well as its disturbance. However, the sign influence and the interplanetary magnetic field Bz component value are most significant for the geomagnetic storm scaling.

The results which are obtained are yet preliminary, but they present a good base for future investigations. They give a better idea for coronal holes geoeffectiveness. At the same time, the results and conclusions which are obtained are good indicator for space weather prediction. This kind of investigations is basic for a methodology of short time (for example, 3- and 6-day) period predictions.

For the quantitatively interpretation of the influences of the considered solar factors in the ionosphere and atmosphere the operational models CORSIKA [13, 14], CORIMIA [15-18] will be used. The reported results should be taken into account in analyses related to the geomagnetic field and cosmic rays influence on the atmospheric ozone [19] and air surface temperature [20, 21].

REFERENCES

1. Tavastsherna K.S., A.G. Tlatov. In: A.V. Stepanov, E.E. Benevolenskaya, A.G. Kosovichev (Eds.) Multi-Wavelength Investigations of Solar Activity. Proceedings IAU Symposium No. 223, 2004. 2004 International Astronomical Union. DOI: 10.1017/S1743921304006039
2. Lang K.R. The Cambridge Encyclopedia of the Sun, Cambridge University Press, Cambridge, UK, 2001, 246 p.
3. Lang K.R. Sun, Earth and Sky. Springer-Verlag, Berlin-Heidelberg, Germany, 1995, 282 p.
4. Crooker, N.U. J. Atmos. Solar-Terr. Phys. 62, 2000, 1071-1085.
5. Robbins S.J., C.J. Henney, J.W. Harvey. Solar Phys., 233, No. 2. doi: 10.1007/s11207-006-0064-y. 2006.
6. Sanderson T.R., T. Appourchaux, J.T. Hoeksema, K.L. Harvey. J. Geophys. Res. 108, 2003, No. A1, 1035, doi:10.1029/2002JA009388.
7. Cranmer, S.R. "Coronal Holes", Living Reviews in Solar Physics, **6**, 2009, lrsp-2009-3. http://www.livingreviews.org/lrsp-2009-3
8. Kohl, J.L., S.R. Cranmer (Eds.), Coronal Holes and Solar Wind Acceleration, Proceedings of the SOHO-7 Workshop, Northeast Harbor, Maine, 28 Sept - 1 Oct 1998 (Dordrecht: Kluwer), ISBN 0-7923-5828-7, 1999.
9. Miralles, M.P., S.R. Cranmer, A.V. Panasyuk, M. Romoli, J.L. Kohl, Astrophys. J. Letters, **549**, 2001, L257.
10. Belov A.V. Forbush effects and their connection with solar, interplanetary and geomagnetic phenomena. Proc. 257-th of the International Astronomical Union. Ed. N. Gopalswamy and D. F. Webb. Ioannina, Greece. Volume 257, 439-450, 2009.
11. http://www.solen.info/solar/coronal_holes.html
12. http://www.solen.info/solar/old_reports/
13. Mishev A., P.I.Y. Velinov. C.R. Acad. bulg. Sci., 65, 2012, 3, 373 - 380.
14. Mishev A., P.I.Y. Velinov. C.R. Acad. bulg. Sci., 66, 10, 1457-1462.
15. Velinov P.I.Y., S. Asenovski, L. Mateev. C.R. Acad. bulg. Sci., 65, 2012, 8, 1137 - 1144.

16. Velinov P.I.Y., S. Asenovski, L. Mateev. C.R. Acad. bulg. Sci., 65, 2012, 9, 1261 - 1268.
17. Velinov P.I.Y., S. Asenovski, L. Mateev. C.R. Acad. bulg. Sci., 66, 2013, 2013, 2, 235 - 242.
18. Asenovski S., P.I.Y. Velinov, L. Mateev. C.R. Acad. bulg. Sci., 66, 2013, 6, 865 - 870.
19. Tassev Y., N. Kilifarska, D. Tomova C.R. Acad. bulg. Sci., 67, 2014, 1, 95-100.
20. Kilifarska N. C.R. Acad. bulg. Sci., 66, 2013, 2, 243 - 252.
21. Kilifarska N., V. Bakhmutov, G. Melnyk. C.R. Acad. bulg. Sci., 66, 2013, 11, 1613 - 1622.

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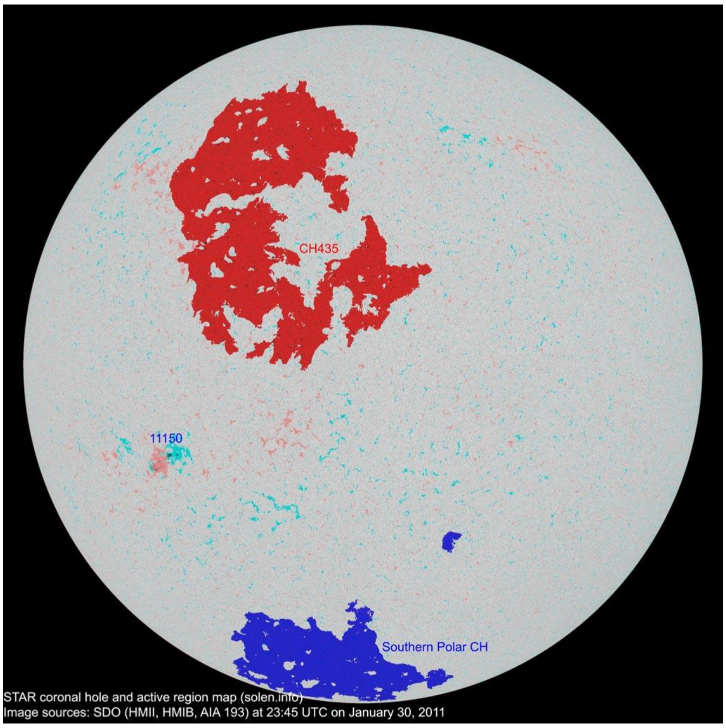

Fig.1. A case on January 30 - February 1, 2011 of a northern coronal hole of negative polarity of its magnetic field

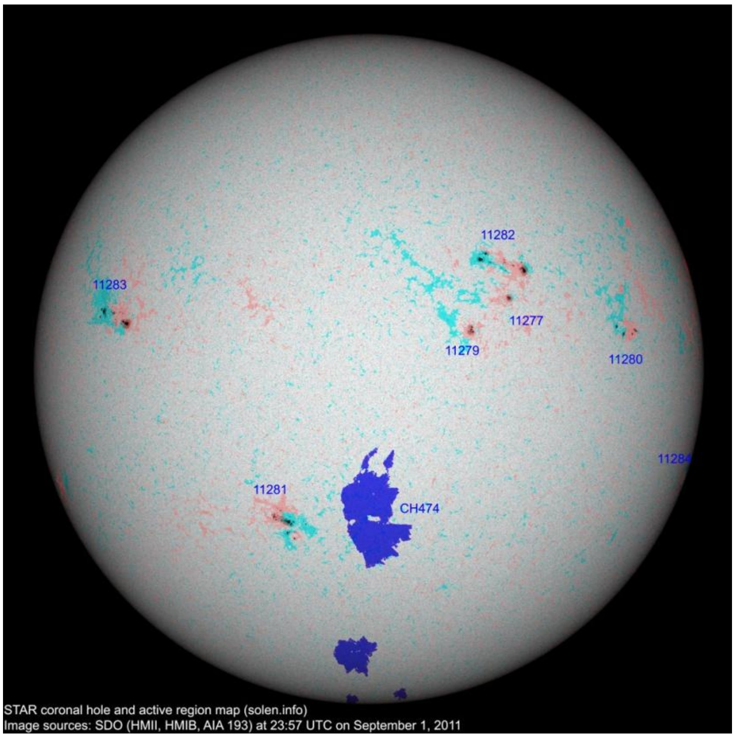

Fig.2. A case on September 1, 2011 of a southern coronal hole of positive polarity of its magnetic field

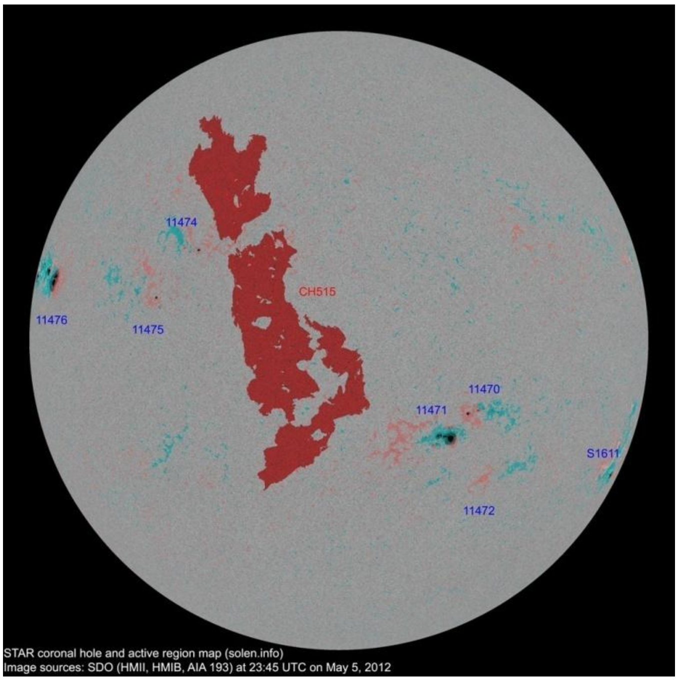

FIg.3. A case on May 5-7, 2012 of a trans-equatorial coronal hole of negative polarity of its magnetic field

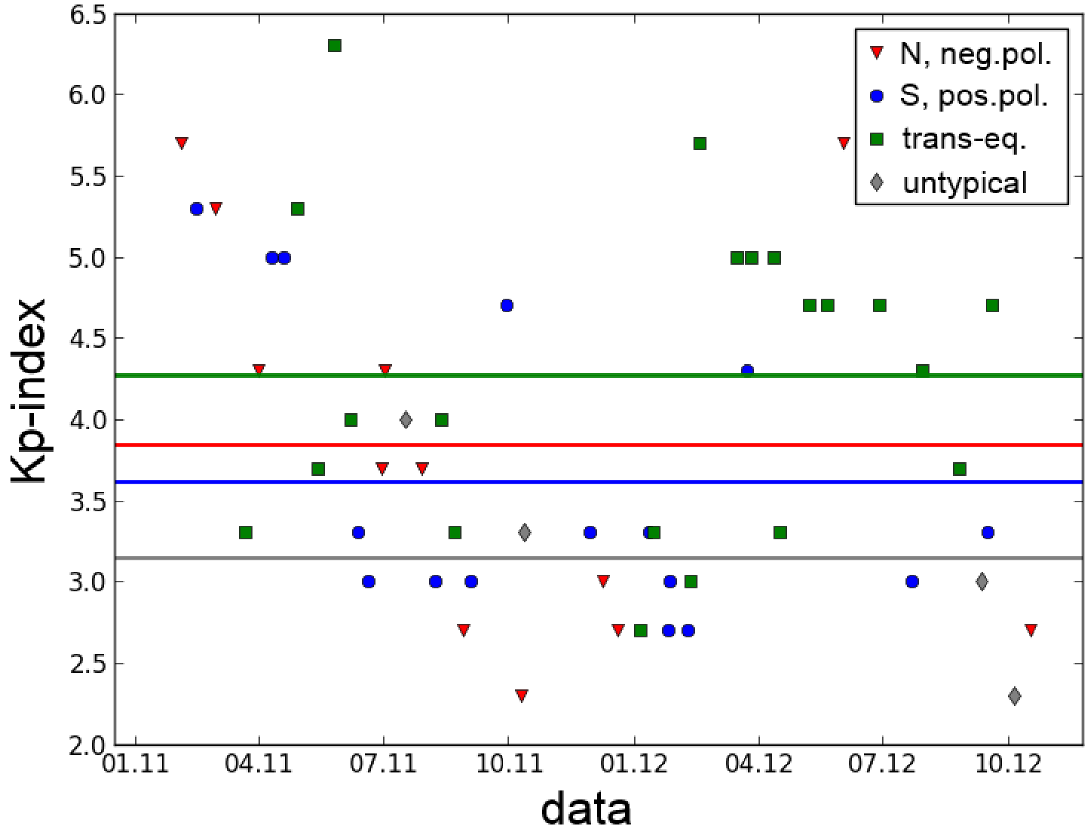

Fig.4. The average geoeffectivity of the coronal holes in different groups. The horizontal lines correspond to the average value of the Kp index for each group of coronal holes