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MAGNETIC CLOUDS CONFIGURATION AND SEASONAL DEPENDENCE OF GEOMAGNETIC ACTIVITY

N.A. Barkhatov [1], E.A. Revunova [1], A.E. Levitin [2].

[1]*Nizhny Novgorod State University of Architecture and Civil Engineering, Nizhniy Novgorod, Russia*
[2]*Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Moscow-Troitsk, Russia*

Abstract. Proposed and tested on experimental data a new model of geomagnetic activity increase in intervals equinox associated with Solar wind magnetic clouds. It assumes that axial magnetic field in clouds at different times will be different projection on Earth dipole and hence have different geomagnetic effectiveness. As result of the arrangement of magnetic clouds Solar sources are primarily formed clouds with small angles of inclination of axial magnetic field in ecliptic plane. With this in mind, during equinox geomagnetic activity caused by such clouds will increase.

1. Introduction

Long-term follow geomagnetic activity revealed the existence of its semi-annual variations that occur in spring and autumn in form of peaks in long-term average values of various indices of geomagnetic activity [*Russell and McPherron*, 1973]. Now to explain the seasonal variations of the geomagnetic activity there are two main groups of hypotheses: axial hypothesis and equinox hypothesis.

Semiannual variation axial hypothesis of geomagnetic activity is related to changes in the Earth's latitude helioprojection on the Solar disk, depending on the season [*Cortie*, 1912; *Chapman and Bartels*, 1940]. Due to the tilt Sun rotation axis to the Sun-Earth line at ~ 7°, spring and autumn projection of angular distance of Earth from the Sun's equator is maximum. In these periods, Earth is more closely related to active zones, which are grouped together in redistribution of 10 to 30 degrees north and south heliographic latitudes (royal latitude). Thus, during equinox, when Earth's helioprojection latitude has maximum value, it is most likely to aim in geoeffective Solar flows from active regions. Due to this geomagnetic activity is increased (Fig. 1).

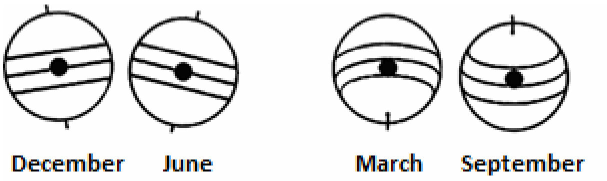

Fig. 1 Change of latitude on Earth helioprojection on Sun disk, depending on season

Equinox hypothesis of geomagnetic activity semiannual variation associated with peculiarities of impact on magnetosphere magnetized Solar wind. There are two main models of this impact - Kelvin-Helmholtz instability (Boller-Stolov model) and Russell-McPherron effect [*Boller and Stolov*, 1970; *Russell and McPherron*, 1973]. Kelvin-Helmholtz instability occurs on magnetosphere flanks and its intensity depends on daily and annual changes in angle between Earth's dipole and Solar wind flow. The maximum of the wave instability falls on the equinoxes (when the Earth's dipole is perpendicular to Solar wind flow), and the minimum - for periods solstice. It is assumed that Kelvin-Helmholtz instability observed at magnetopause, initiates geomagnetic disturbances, which are defined as semi-annual changes in geomagnetic activity [*Boller and Stolov*, 1970].

According to hypothesis proposed by Russell and McPherron, interplanetary magnetic field (IMF) should be considered objectively in the solar equatorial coordinate system (GSEQ). In turn, interaction of IMF with Earth's magnetosphere be seen in Solar magnetospheric coordinate system (GSM). These coordinate systems have a common axis X, which indicates on Sun, and Y axis and Z axis are different rotation about X axis. Since all systems have common X axis only. Consequently, value of geoeffective Bz component will change during the transition from one coordinate system to another. Thus, this hypothesis explains the semi-annual variation of geomagnetic activity as result of additional values of southern component of the IMF in terms of GSEQ in GSM [*Russell and McPherron*, 1973].

All of hypotheses seasonal dependence of geomagnetic activity take into account relative orientation of the Sun, Solar wind and the Earth's dipole only, without affecting the internal structure of the flows and their characteristics. Such geoeffective magnetic structure as clouds, unlike other plasma flows have a particular orientation in space during year and must observe a change in the projection of the axial magnetic field of cloud on the Earth's dipole. That is why in times of equinoxes and solstices magnetic clouds can cause magnetic storms of varying intensity.

Besides the magnetic clouds orientation determined by magnetic field lines sunspot groups with the most advantageous location - leading and tail spots. It also has an impact on the number of magnetic storms that occur in different seasons of the year.

In work proposes a seasonal variation model of geomagnetic activity that takes into account magnetic cloud orientation by the ecliptic plane. Under the proposed and tested hypothesis, the magnetic cloud orientation in space should be reflected in their geoeffectiveness due to changes in the values projection of axis magnetic field of clouds in the Earth's dipole during the year.

2. Annual evolution of axial projection of cloud magnetic field on Earth's magnetic dipole

The presence of magnetic clouds orientation in space allows us to study effect of different configurations of these structures on geomagnetic activity. This is possible within the framework of calculating the projection of cloud axis magnetic field (**B₀**) by geomagnetic dipole vector (**M**) as function of their relative orientation. Model calculation projections cloud axial magnetic field to Earth's magnetic dipole performed on the assumption that it coincides with rotation axis.

Calculation of projections in spherical coordinate system carried out. In this case, orientation of vectors $\mathbf{B_o}$ and **M**, predetermined polarity (90^0 - ε and θ) and azimuth angles (β and φ), respectively. During the year, vector **M** changes only angle φ, and angle θ is $\theta = 23^0$ constant. As a result, expression for vector $\mathbf{B_o}$ projection on vector **M** is as follows:

$$\mathbf{B}_{o\mathbf{M}} = \frac{\left(\mathbf{B}_o \cdot \mathbf{M}\right)}{|\mathbf{M}|} = |\mathbf{B}_o|\cos\left(\mathbf{B}_o\mathbf{M}\right) = \frac{|\mathbf{B}_o| \cdot \left(B_X M_X + B_Y M_Y + B_Z M_z\right)}{|\mathbf{B}_o||\mathbf{M}|} = \frac{\left(B_X M_X + B_Y M_Y + B_Z M_z\right)}{|\mathbf{M}|}$$

where components of cloud axial magnetic field and geomagnetic dipole define as:

$$B_X = B_o \sin\left(90^0 - \varepsilon\right)\cos\beta,\ B_Y = B_o \sin(90^0 - \varepsilon)\sin\beta,\ B_Z = B_o \cos(90^0 - \varepsilon),$$

$$M_X = M \sin\theta\cos\varphi,\ M_Y = M\sin\theta\sin\varphi,\ M_Z = M\cos\theta.$$

Fig. 2 shows the change in year average monthly values of unit vector projection of cloud axis magnetic field on geomagnetic dipole orientations for following events: $\varepsilon = 0^0$, $\beta = 90^0$ dashed line; $\varepsilon = 0^0$, $\beta = 60^0$ dotted line; $\varepsilon = 0^0$, $\beta = 30^0$ solid line; $\varepsilon = 0^0$, $\beta = 0^0$ dot-dashed line.

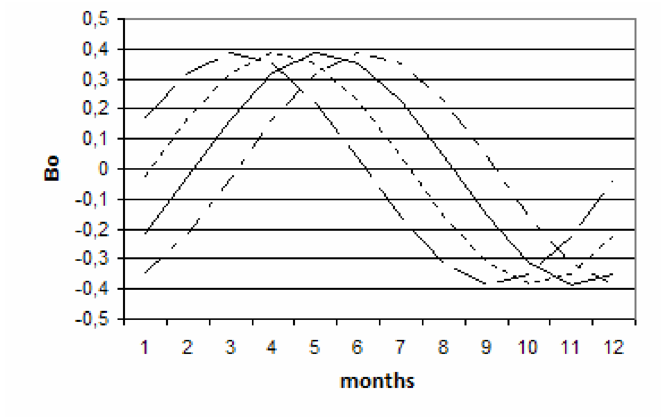

Fig. 2 Change during year average monthly values of unit vector projection of cloud axial magnetic field on geomagnetic dipole. The dashed line corresponds to the angle $\varepsilon = 0^0$, $\beta = 90^0$, the dotted line - $\varepsilon = 0^0$, $\beta = 60^0$, solid line - $\varepsilon = 0^0$, $\beta = 30^0$, dash-dot line - $\varepsilon = 0^0$, $\beta = 0^0$

According to Fig. 2 during the equinox (months 3 and 9, dashed line) maximum projection give of magnetic clouds with small values inclination angle of cloud axis to the ecliptic plane $\varepsilon = 0^0$ $\beta = 90^0$. In solstice times projection of magnetic field of such clouds on the dipole is zero. Because these clouds most often recorded in Earth's vicinity [*Bothmer and Schwenn*, 1998], then the geomagnetic activity during the equinox should be increased. During the summer solstice, the largest contribution to geomagnetic activity should provide a cloud with $\varepsilon = 0^0$ $\beta = 0^0$ (Fig. 2, dashed-dotted line). In equinox periods of projection of cloud axis magnetic field on geomagnetic dipole for such clouds is equal to zero. As the statistics observations of magnetic clouds in Earth's vicinity, such events are very rare [*Bothmer and Schwenn*, 1998] and a significant increase in geomagnetic activity they do not give. A similar analysis for different orientation of magnetic clouds was performed. He showed that by increasing the angle of inclination of cloud axis to ecliptic plane projection of the dynamics is preserved and its value increases. For clouds with an angle $\varepsilon = 90^0$ for year value of projection remains constant for all values of β: such clouds are equally geoeffective regardless of the season.

Thus, results presented in Fig. 2 show that projection of cloud axial magnetic field on the Earth's dipole varies depending on season. In solstice times greatest contribution to the geomagnetic activity should provide magnetic clouds with large values of inclination angle of cloud axis to ecliptic plane. In equinox periods in geomagnetic activity should contribute magnetic clouds any orientation.

3. Seasonal dependence of geomagnetic variations on the magnetic cloud structure

Statistical testing of this hypothesis seasonal variation of geomagnetic activity performed on the data on orientation of 52 magnetic clouds, marked by OMNI system in near-Earth space from 1980 to 2004. All events were divided into three groups according to their inclination of axis cloud to ecliptic plane ε: from 0 to 30^0, 30 to 60^0 and from 60 to 90^0. For more explicit manifestations of the contribution of each group of clouds on angle values ε, was considered the percentage of geoeffective (Dst ≤ -10 nT) and geoeffective clouds, each of angle selected range (Fig. 3, gray bars - geoeffective, black bars - not geoeffective clouds). Fig. 3 shows each range of values of ε is nearly 100%.

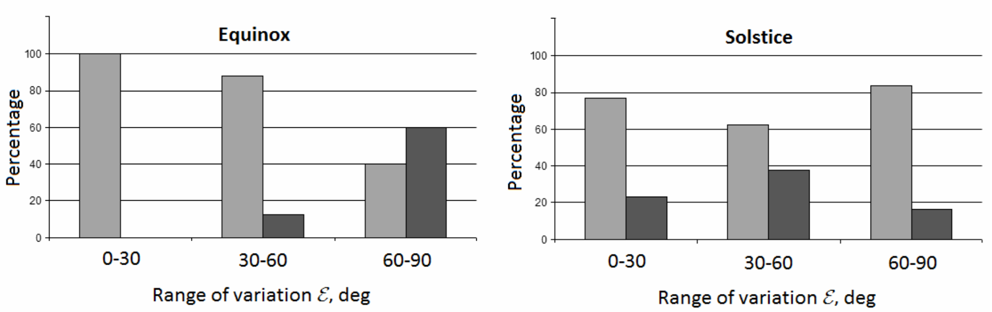

Fig. 3 Percentages groups of angle ε from 0 to 30^0, 30 to 60^0, 60 to 90^0 geoeffective (gray columns) and not geoeffective (black columns) of magnetic clouds

According to the distribution shown in Fig. 3, during equinox 40% of clouds with large inclination angles of axis to ecliptic plane were geoeffective. During solstice geomagnetic storm caused 85% of these clouds. Therefore, in solstice times clouds with large ε are indeed more geoeffective structures. During equinox 100% clouds with small values of angle ε caused storm, and in solstice - 78%. Thus, our study shows that the geomagnetic activity during equinoxes increases due to clouds of different orientation and especially clouds with low values of inclination of axis clouds to the ecliptic plane, most frequently detected in Earth’s vicinity.

4. Conclusions

Proposed and tested on real events hypothesis is the seasonal variation of geomagnetic activity, taking into account orientation in space of large-scale plasma flows, such as magnetic clouds. According to proposed hypothesis, magnetic cloud orientation in space should manifest itself in variations of geomagnetic activity, depending on season of year due to changes in projection of cloud axial magnetic field on Earth's dipole.

This study has shown that in solstice times sources of geomagnetic storms were 85% of magnetic clouds with large tilt angles (60 to 90^0), and during the equinox, only 40% of such clouds. During the solstice is not geoeffective were 20% of magnetic clouds with small angles of cloud axis inclination to ecliptic plane. During equinox, all (100%) of such clouds caused the geomagnetic disturbances. Consequently, during periods of geomagnetic activity equinox increases due to magnetic clouds with small angles of axis inclination to ecliptic plane most frequently detected in near-Earth space. In solstice times such clouds are not geoeffective structures by reducing the value of axial projection of clouds magnetic field on Earth’s magnetic dipole at such intervals, which is reflected in the reduction of level of geomagnetic activity in the summer and winter.

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