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FEATURES OF OCCURRENCE OF THE GEOMAGNETIC FIELD SEASONAL VARIATIONS IN THE NORTHERN PART OF ARMENIA

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Abstract. This research deals with the study of seasonal variations of the Earth's magnetic field using the changes in the intensity of its diurnal variations. The initial data were recorded at the Bavra and Gyulagarak observation points of the total intensity of the geomagnetic field vector (Republic of Armenia). A comparison is made between the variations identified from the data registered at these points and the variations that appear in the data from the magnetic observatory Chambon-la-Foret (France), which is close in latitude. They are also compared with geomagnetic variations identified using the global geomagnetic activity indices. The comparison results show that, according to geomagnetic observations, annual variations are distinguished, caused by the ionospheric current system and expressed by the maximum intensities of diurnal variations in the summer months and minimums in the winter season. According to the geomagnetic activity indices, semi-annual variations of magnetospheric sources with characteristic maxima during the spring and autumn equinoxes are distinguished. Comparison of solar-diurnal variations between the Bavra and Gyulagarak station data showed the similarity of their amplitudes in the summer. However, the duration of the maximum intensity period of diurnal variations at Gyulagarak station data is one month longer than that of the maximum intensity period of diurnal variations at the corresponding data from Bavra station. The revealed temporal characteristics of seasonal variations in the geomagnetic field are consistent with existing ideas about geomagnetic variations due to the influence of external sources. Comparison between the annual variations revealed by observations on the territory of Armenia and the ones according to the data registered at the Chambon-la-Foret observatory showed a similarity of the main characteristics of the studied variations. The noted circumstances can be considered as a scientific justification for the feasibility of creating a magnetic observatory in Gyulagarak.

Keywords: geomagnetic field, seasonal variations, geomagnetic activity indices, magnetosphere.

Introduction

It is known that the sources of geomagnetic variations are processes that occur both in the interior of our planet and in its ionosphere and magnetosphere. In the second case, the variations are associated with the impact of the solar wind on the Earth's magnetic field; besides, the intensity of variations caused by the influence of external sources varies depending on local time, season of the year, as well as on the activity of processes occurring on the Sun.

Annual and semiannual variations are traced in seasonal geomagnetic activity. The first of them (annual) are well reflected in the intensity of diurnal variations, which maximum amplitudes are observed in the summer months, the minimum amplitudes - in the winter months. The mechanism of this regularity is related to the dependence of the intensity of variations on the duration of the solar illumination period, which in its turn, depends on the season of the year [*Yacob, Rao,* 1966; *Takeda,* 2002; *Santarelli et al.,* 2007]. Studies presented in [*Vestine,* 1954], showed that annual changes in *Sq*(*H*)[1] variations should be attributed to processes occurring in the ionosphere. However, in later works (see, for example, [*Olsen*, 1996]) it was shown that diurnal and annual *Sq*(*H*) variations are also affected by electric currents flowing in the magnetosphere.

The studies of geomagnetic disturbance presented in [*McIntosh*, 1959] revealed in values of *K*-index and global K_p- and a_p-indices both the annual component of seasonal variations with pronounced summer maximum and winter minimum and the semi-annual component responsible for the characteristic maxima during the equinoxes. The study of the physical causes of these variations leads the author of the above work to the conclusion that the cause of annual changes is the dynamo processes occurring in the atmospheric layer.

Three hypotheses based on two factors - the very properties of the solar wind flowing around our planet and its interaction with the Earth's magnetosphere can be proposed to explain the semi-annual variations, distinguished mainly by series of geomagnetic activity indices.

The first hypotheses describing the mechanism of occurrence of the semi-annual variations is called axial. According to it, during the equinoxes, when the Earth is in high heliographic latitudes, its magnetic field is most affected by solar disturbances [*Cliver*, *Svalgaard*, *Ling*, 2004; *Cortie*, 1912]. A possible mechanism of the enhanced effect of the Sun on the Earth's magnetic field in this case is due to the high probability of capturing a large number of solar wind ions by the magnetic field of our planet when its magnetosphere is symmetrical relative to the Sun – Earth line [*Malin, Winch, Işıkara,* 1999]. Enhanced effect of solar sources on the Earth's magnetosphere during the equinoxes is reflected in the time series of variations in the global geomagnetic activity indices D_{st} by the appearance of spring and autumn peaks.

According to the second hypothesis, called equinoctial, the semi-annual geomagnetic activity is associated with a change in strength of the solar wind interaction with the Earth's magnetosphere, depending on the change in the angle between the axis of the geomagnetic dipole and the Sun – Earth line [*McIntosh*, 1959].

The third hypothesis, based on the Russell – McPherron effect (*RMP*)[2], explains the occurrence of semi-annual variations by the properties of the solar wind. According to this hypothesis, the semi-annual and diurnal variations in geomagnetic activity are caused by the direction of the effective southern component of the interplanetary magnetic field (IMF): when the southern component is directed inside the Parker spiral, the spring maximum of magnetic disturbance is observed, when in the opposite direction (out) - autumn maximum [*Russell*, *McPherron*, 1973].

Estimating the contribution of all phenomena in the observed values of geomagnetic activity, the authors of [*Cliver*, *Kamide*, *Ling*, 2000] attribute semi-annual variations of geomagnetic activity mainly to the *RMP*- effect. Since this effect depends both on the inclination of the rotation axis of the Sun and the inclination of the Earth's dipole relative to the ecliptic plane, it can be considered as combining axial and equinox effects. Besides, in the mentioned work it is noted that most of semi-annual variations are the result of the equinox effect associated with a change in the angle between the solar wind flow direction and the axis of the Earth's dipole. During solstices, adherence efficiency in the Sun – Earth system decreases.

[1] The accepted designation *Sq*(*H*) comes from the English ***S****olar* ***q****uiet* ***H****orizontal component of the geomagnetic field.*

[2] The abbreviation *RMP* is derived from the names of scientists who discovered this effect [*Russell, McPherron*, 1973].

When conducting studies aimed at identifying and studying local anomalies of the secular trend in Armenia [*Simonyan, Ohanyan, Khachatryan*, 2011, 2012], according to the average daily values of the modulus of geomagnetic field *T* obtained from the regular observations, seasonal variations of the geomagnetic field were identifies as one of the secondary effects. Moreover, the maximum intensity values of these variations turned out to be clearly confined to the summer months, while the winter months differed in the minimum values of their intensity. To explain the mechanism of the revealed features of annual variations in the frameworks of existing ideas requires a more detailed analysis of the obtained results. This is the subject of the present work.

The used data and analysis

The authors studied the seasonal and diurnal variations from the observations of the module of geomagnetic field total intensity *T*, carried out at two geomagnetic observation stations located in the northern part of Armenia – Gyulagarak (40.96° N, 44.47° E) and Bavra (41.12° N, 43.81° E). Peculiarities of the tectonic structure of the research area and physical properties of rocks that can influence the formation of seasonal variations have been previously studied in detail in [*Gabrielyan, Sargsyan, Simonyan*, 1981]. Since the 90s of the last century, MMP-203 proton *T*-magnetometers have been operating at Gyulagarak and Bavra stations, with a sensitivity of 0.01 nT, and an absolute accuracy of ±1 nT; *T* values are recorded every 5 minutes.

For analysis, we used the observation data for 2008, which is the minimum year in the current 24th cycle of solar activity and therefore is of great interest to study. Previously, the authors studied the dynamics of *Sq*-variation and the equivalent ionospheric current for the period corresponding to this year [*Soloviev et al*., 2019]. The selected time interval has the most qualitative and continuous series of observations [*Simonyan et al.*, 2011, 2012]. The hourly average values of geomagnetic field were calculated by simple averaging of the initial 5-minute observations, the monthly average values were similarly calculated from the hourly average values.

The results of processing the initial data of Gyulagarak and Bavra stations are displayed on the time maps shown in the top row in Fig. 1. Their analysis shows a clear increase in the field values from the beginning of the considered year to its end. This is probably due to the increase in the contribution of the secular trend observed at the research area during the year. The seasonal variations in the intensity of the hourly average values of the observed magnetic field of the Earth in this figure are poorly distinguished against the prevailing field values of secular variations.

The annual trend caused by the secular trend and the background value of the geomagnetic field typical for the region and determined on the basis of the global *IGRF*[1] model for each month at points corresponding to the coordinates of the observation stations (see Fig. 1, *bottom row*) were eliminated from the obtained data.

[1] https://www.ngdc.noaa.gov/IAGA/vmod/igrf.html

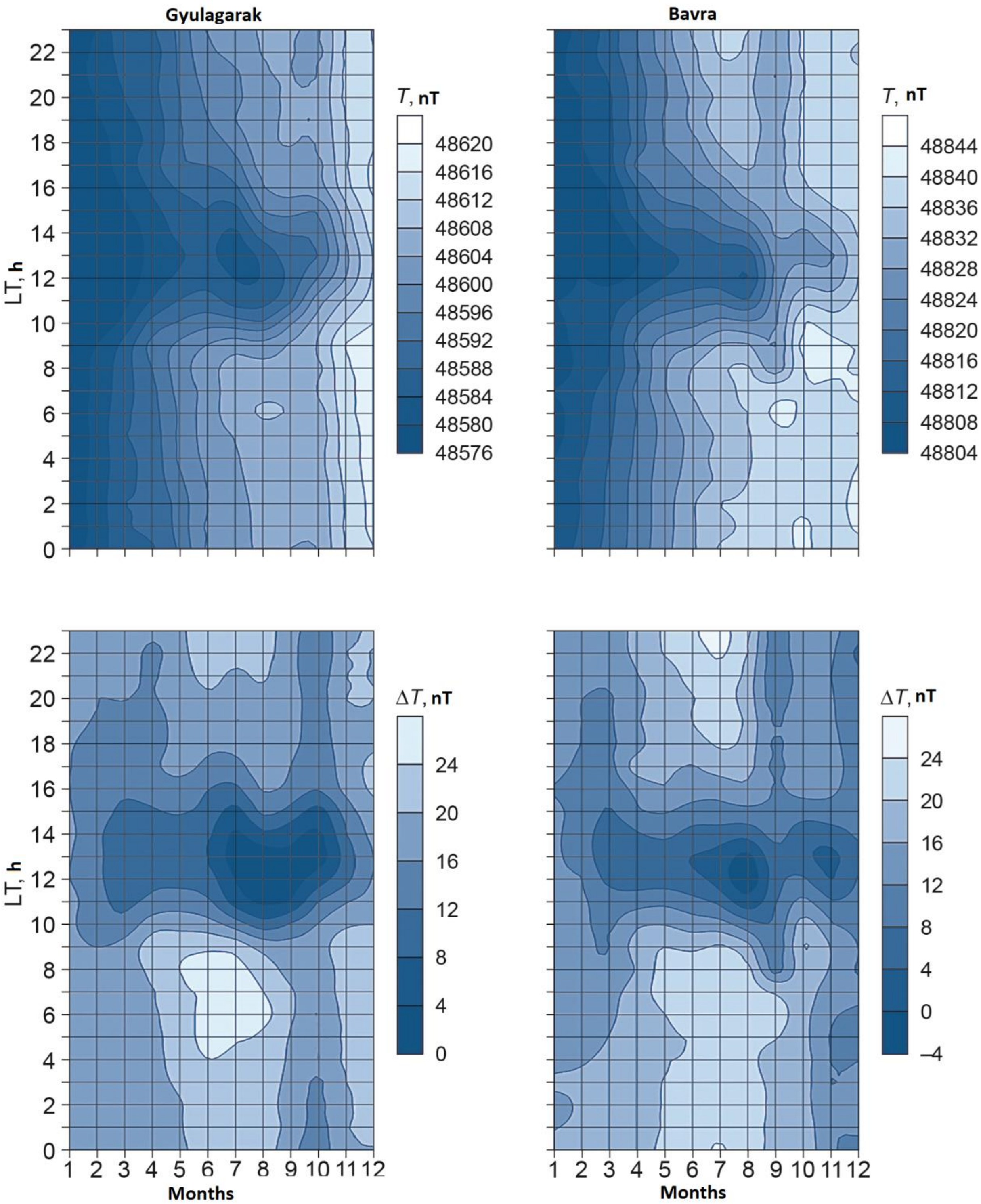

Fig. 1. Data of 2008 on Gyulagarak (*left*) and Bavra (*right*) stations. Seasonal and diurnal variations according to the data from the regular geomagnetic field observations before (*top plots*) and after (*bottom plots*) the elimination of the regional field and the secular variation trend calculated from the monthly averaged field values. The horizontal axis is the months of the year; the vertical axis is the time within the day; time step is Δt=1 hour

Comparison of the maps shown in the top and bottom rows in Fig. 1, shows that seasonal and diurnal variations are more clearly distinguished after eliminating the regional field and trend of a secular trend from the monthly average values. In both cases, midday minima are clearly distinguished in the central (in time) part of the maps. The dependence of the intensity of diurnal variations on the season of the year is easily traced by months displayed on the horizontal scale. The deepest peak of diurnal variations (with a natural minimum in the interval of 11:00–13:30 LT) was observed in August (see Fig. 1, *bottom row*). When examining the August maps vertically, it can be seen that during this month, diurnal variations represent the whole range of changes - from minimum to maximum.

According to the data of both stations, there is a clear minimum of the intensity of diurnal variations occurring in December – January. It is reasonable to assume that the revealed annual changes in the intensity of diurnal variations can be associated not only with the ionospheric current system, since there was no data selection on the geomagnetic disturbance rate in the study of the dependence of diurnal variations on the season of the year. The elimination of the effect of disturbances caused by sources of magnetospheric origin on the ionosphere in this case is difficult. In addition, there are some differences between the seasonal variations identified in two locations, which may be caused by the structural features of the upper layers of the earth's crust of the research area. So, if the maximum intensity values of diurnal variations according to the Bavra station are in July – September, then according to the Gyulagarak station this maximum is slightly stretched and covers the July – October period. Due to the fact that at the Gyulagarak station the period of maximum intensity of diurnal variations is longer than at the Bavra station, it can be assumed that seasonal variations at the Gyulagarak station contain an induction component (associated with electrical induction).

Comparison with data from the nearest observatory and magnetic activity indices

Fig. 2 similarly represents data from the near-latitude observatory of Chambon-la-Foret (France) for the studied 2008 year[1] for a comparative analysis of the revealed variations.

Comparing Fig. 1 and 2, it is easy to verify that there is no significant difference between annual variations detected at three different locations - at the stations Gyulagarak, Bavra and at the Chambon-la-Foret observatory. It is worth noting that the maximum intensity values of diurnal variations according to the Chambon-la-Foret observatory cover the May – August period, i.e. correspond exactly to the *J* season of Lloyd calendar. The minimum values of the intensity of solar-diurnal variations for all three stations occur in season *D* according to Lloyd calendar (November – February). In addition, it is easy to find (see Fig. 2, *right*) that the structure of spots characterizing the extreme values of diurnal variations at the Chambon-la-Foret location is much smoother, which is obviously associated with high accuracy of observatory data.

To assess the possible effect of magnetospheric disturbance on seasonal variations revealed by direct observations, we considered a series of values of a_p and D_{st} indices, the first of which is a linearized version of quasi-logarithmic K_p-indices, the second determines ring current disturbance[2].

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[1] *Magnetic databank*. doi:10.18715/BCMT.MAG.DEF. *Last access* 20.08.2019.

[2] http://www.wdcb.ru/stp/data/geomagni.ind/

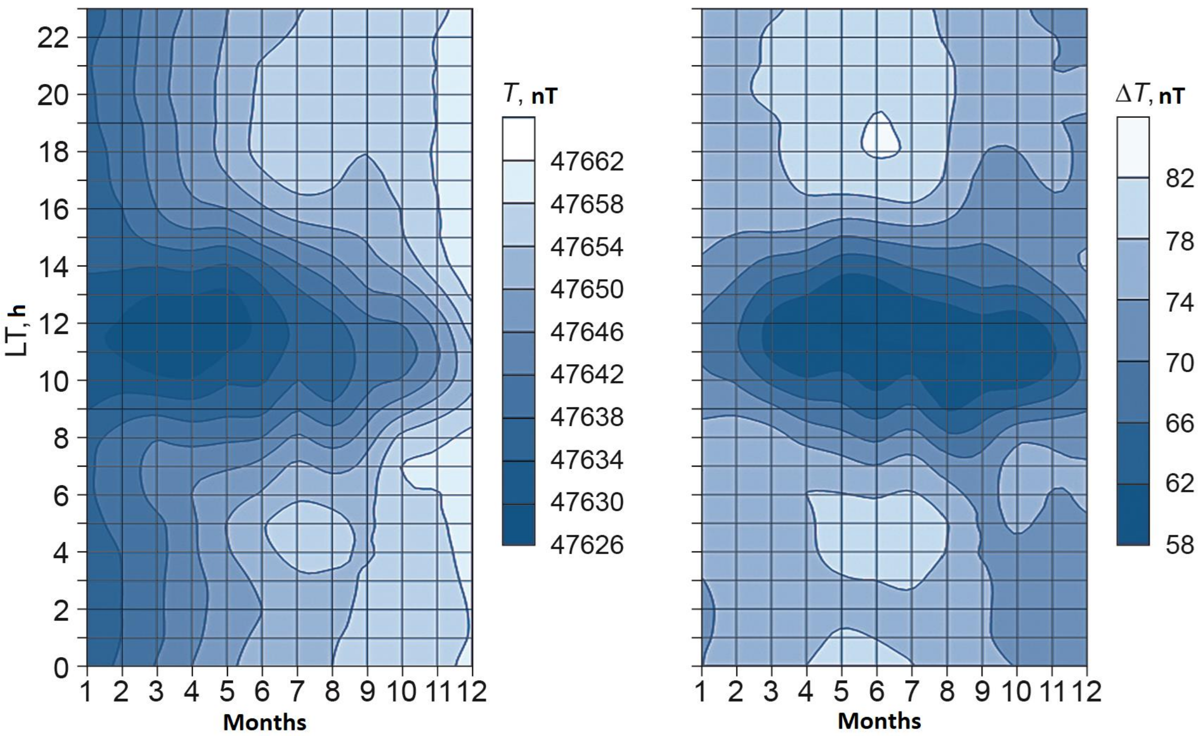

Fig. 2. Data for 2008 on Chambon-la-Foret (CLF, France) magnetic observatory. Seasonal and diurnal variations according to the data before (*left*) and after (*right*) the elimination of the trend due to the secular variation and background/regional value of the observed field. The horizontal axis is the months of the year; the vertical axis is the time within the day; time step is Δt=1 hour

It is known that the timing of geomagnetic activity indices is carried out in accordance with the international time UT, which differs from the local time LT used in the description of observations for 4 hours – LT=UT+4. With this in view, in order to ensure temporal comparability of series of indices with series of observational data, correction of the presentation time of activity indices was performed.

Seasonal and diurnal variations presented in Fig. 3 are constructed according to the data for different periods: top row is for 2008; bottom - according to averaged data for 1960–2010. The plots constructed using the monthly average indices were calculated for each hour within the day in the case of D_{st}-indices (right in the row) and for each three-hour interval in the case of a_p-indices (left in the row).

Insignificant false foci observed on the plots by a_p- indices, for example, between 15 and 18 hours LT in September – October (see Fig. 3, *on the left*), have no physical meaning, since they appeared due to insufficient temporal resolution of the source data while constructing the contour line. To ensure phase comparability of the studied indices, D_{st}-indices in Fig. 3 are presented with a minus sign. Analysis of Fig. 3 shows that diurnal variations in presented values of a_p-indices are weakly expressed against the sharp maximum of semi-annual variations during the spring equinox and are distinguished by a small relative minimum observed from August to the end of the year. As expected, the diurnal variations are practically absent on the presented values of D_{st}-indices.

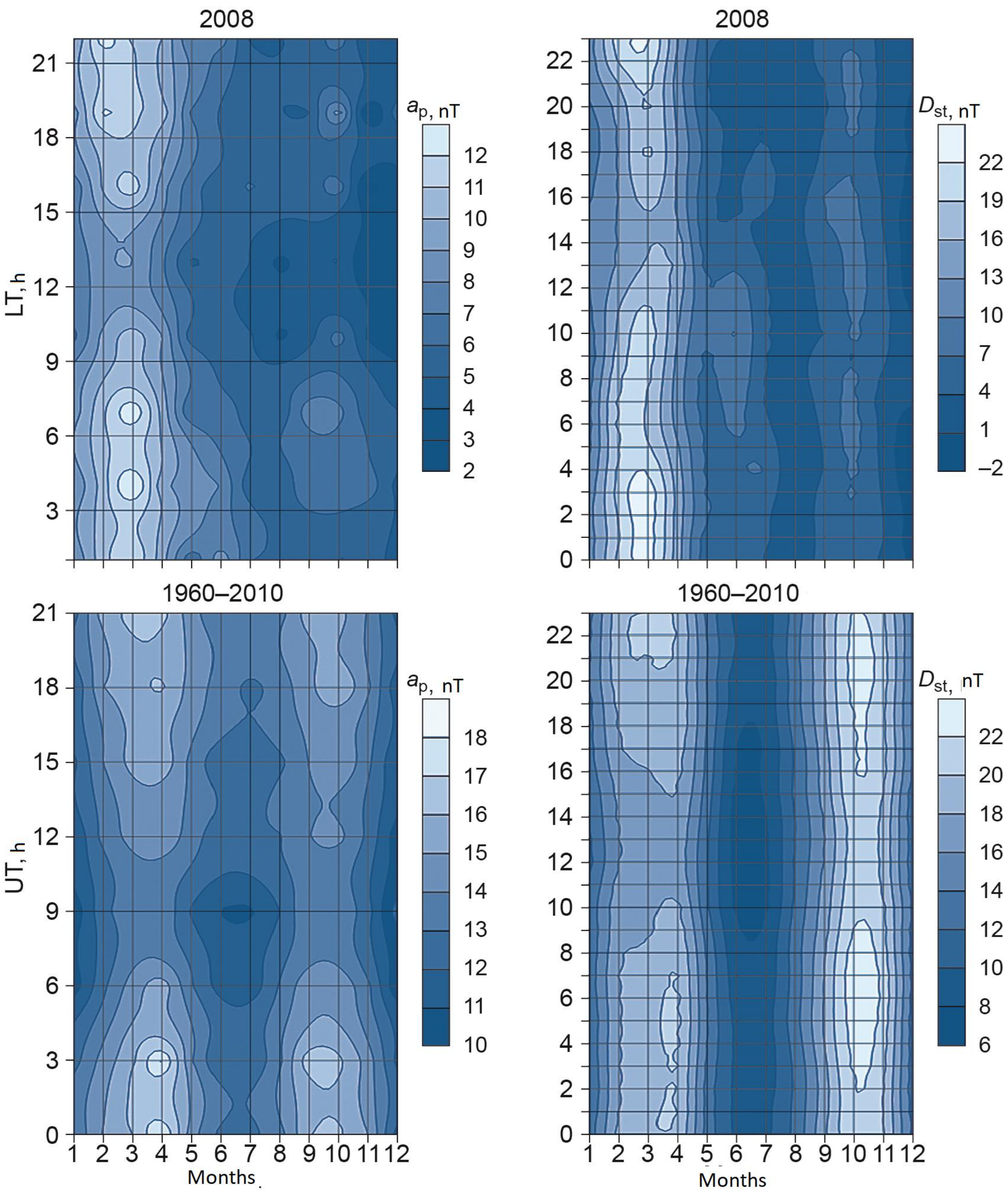

Fig. 3. Seasonal and diurnal variation plots according to the monthly averaged global geomagnetic activity indices a_p (*left*) and D_{st} (*right*) for 2008 (*top plots*) and for the 1960–2010 period (*bottom plots*). Plots were made using the 3-hour a_p values and hourly D_{st} values

Thus, for the studied 2008, in addition to the global semi-annual variations of magnetospheric origin, the ionospheric activity is also traced by the a_p-index, whereas the variations of magnetospheric origin are reflected in the purest form by the D_{st}-index. In general, clear spring maximum that is clearly visible in Fig. 3, is the main characteristic feature of the semi-annual component of seasonal variations.

Since the phase of semi-annual variations, depending on the studied year, can move from spring to autumn and vice versa [*Mursula*, *Tanskanen*, *Love*, 2011], the observed features of occurrence of external variations were studied by the indices averaged over the fifty-year period of 1960–2010. Data for both seasons *E* are clearly visible in the plots (see. Fig. 3, *bottom row*). Note that diurnal variations of a_p-indices are traced with the clearly distinguished seasonal variations, while semiannual variations of magnetospheric origin again prevail in D_{st}-indices.

Conclusions

The authors analyzed the measurement data of the module of geomagnetic field full vector, performed at the Gyulagarak and Bavra stations (Republic of Armenia) in order to identify and study the characteristics of seasonal variations appearing in changes of intensity of diurnal variations.

A comparative analysis of the annual variations traced on the territory of Armenia with the variations recorded according to the Chambon-la-Foret observatory (France) and the global geomagnetic activity indices a_p and D_{st} is carried out.

It turned out that according to geomagnetic observations, the annual component prevails in seasonal variations with a characteristic maximum in the summer season and with a minimum intensity of diurnal variations in winter. In the indices of geomagnetic activity, on the contrary, semi-annual variations prevail with the maximum values of geomagnetic activity during season *E* according to the Lloyd's calendar. Moreover, diurnal variations of the ionospheric origin are also distinguished by a_p-indices, while magnetospheric processes reflected in D_{st}-indices are caused by changes in the solar wind parameters and the conditions of its interaction with the Earth's magnetosphere, which depend on the change in the position of our planet relative to the Sun during the year. In this case, the geomagnetic activity manifested in annual variations in the intensity of the diurnal course is due to processes occurring in the ionosphere. Obviously, the ionospheric activity, reflected in the variations of the geomagnetic field observed on the Earth's surface, is an artifact of the total geomagnetic activity variations, manifested in the indices of global geomagnetic activity in the form of semi-annual variations.

Comparison of diurnal variations according to the Gyulagarak and Bavra stations showed that their amplitudes are almost the same in the summer months, but the period of the maximum intensity of the solar-diurnal variations at the Gyulagarak station is extended towards the autumn months.

Comparison of annual variations revealed by observations in the territory of Armenia with annual variations according to the data of the Chambon-la-Foret observatory (France) demonstrated the similarity of the main characteristics of the studied variations. In addition, the high quality of observatory data was manifested in the smooth nature of the revealed structures of variations.

Physically meaningful values and the dynamics of geomagnetic variations identified by the Gyulagarak station data, the consistency of the detected temporal characteristics with existing ideas about geomagnetic variations of external sources, as well as variations identified in the Chambon-la-Foret high-precision magnetic observatory data, can be considered as a scientific justification for expediency of creating a magnetic observatory in the village Gyulagarak.

It should be noted that in 2019 the construction of two non-magnetic pavilions necessary for registration of variations and absolute values of the magnetic field was completed at the Gyulagarak station. Through joint efforts of the Institute of Geophysics and Engineering Seismology after A. Nazarov of the National Academy of Sciences of the Republic of Armenia and the Geophysical Center of the Russian Academy of Sciences (GC RAS), the observatory is being equipped with a set of magnetometric equipment of INTERMAGNET standard[1]. Continuous subminute observations of the magnetic field vector module are already being submitted to the Analytical Center of the geomagnetic data on the basis of the GC RAS and are being processed using the MAGNUS hardware-software system [*Gvishiani et al.*, 2016; *Gvishiani et al.*, 2018, 2019].

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[1] See http://intermagnet.org

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