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ISOLATED SUBSTORMS ACCORDING TO MAGNETIC MEASUREMENTS AT TIXIE DURING MINIMUM SOLAR ACTIVITY

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Abstract. A catalog of isolated substorms in 2016–2020 has been compiled from data on the H component of the geomagnetic field, obtained at Tixie. From the catalog data, it has been found that during this period changes in the number of substorms and the number of sunspots are well approximated by quadratic functions with minima at the end of 2017 and in the middle of 2019 respectively; during the year, disturbances more often occurred during solstices; within 24 hours, substorms more often occurred at local midnight. The intensity and duration of substorm disturbances, the duration of their expansion phase do not show a noticeable dependence on the time of occurrence; however, from average values of these parameters in hourly ranges, it has been found that the intensity takes lower values around 0–3 MLT; in the midnight sector, the duration of disturbances and the duration of their expansion phase are shorter than those in the dawn sector. Compared to the data from mid-latitude stations [Chu et al., 2015], the average duration of substorms and the duration of their expansion phase are longer.

Keywords: substorm, geomagnetic variations, fluxgate magnetometer.

INTRODUCTION

Substorms are one of the most vivid manifestations of magnetospheric disturbances [Akasofu, 1964]. Their origin and development are intimately connected with the auroral oval [Feldstein, 1963; Khorosheva, 1962], which is a projection of the magnetospheric plasma and boundary layers onto the ionosphere [Sergeev, Tsyganenko, 1980]. According to [Akasofu, 1964], the substorm expansion phase begins with a brightening of an equatorial discrete arc and usually lasts for ~30 min during which auroras intensify and expand in both polar and azimuth directions. The recovery phase lasting for an hour or more is associated with a decrease in auroral activity. The substorm growth phase [McPherron, 1970] starts when the interplanetary magnetic field (IMF), frozen into the solar wind plasma, with the southward component reaches the magnetosphere and reconnects at the dayside magnetopause. Statistical studies have shown that substorms do occur mainly under conditions of southward IMF (e.g., [Kamide et al., 1977]).

Substorms are classified as isolated and recurrent [Sandhu et al., 2019], yet there is no consensus among researchers on this classification [Liou et al., 2013]. A brief definition of isolated substorms is given in [Liou et al., 2013]: isolated substorms are substorms with an interval of at least 3 hrs between two consecutive onsets. Study of isolated substorms allowed identification of the substorm growth phase during which a large amount of energy from the solar wind is accumulated in the magnetosphere [Sergeev, Tsyganenko, 1980]. Sergeev et al. [2012] have noted that observations with improved space and ground networks, as well as comprehensive statistical studies, have significantly extended the understanding of the magnetotail dynamics at the onset of a substorm; thus, the occurrence of substorms is an area of active research. It is emphasized that observations of the beginning of the substorm expansion phase provide key information for understanding substorms and open up new directions for further research. Another characteristic of substorms, the occurrence rate, is mentioned in [Newell et al., 2013] as an alternative and possibly more proper approach to addressing the question of what causes geomagnetic variations on different time scales.

Using previously compiled catalogs of substorms, various scientific teams have carried out comprehensive statistical studies of substorms. Borovsky et al. [1993] have estimated probabilities of random and periodic magnetospheric substorms, using particle injection observations from three geostationary satellites. Seasonal and cyclic dynamics of substorms according to IMAGE magnetic measurements have been discussed by Tanskanen [2009]. Newell et al. [2013], using SuperMAG data on substorms, have examined solar-cyclic, seasonal, and diurnal variations of substorm onset. In [Chu et al., 2015; McPherron, Chu, 2018] based on a large amount of statistical data using the mid-latitude positive magnetic bay index (*MPB* index), developed by the authors, the regularity of occurrence of magnetospheric substorms in solar cycle, seasons, during the day, depending on solar wind conditions has been analyzed, and the main characteristics of three substorm phases have been investigated. Vorobjev et al. [2016, 2018], using the catalog of isolated substorms compiled at the Polar Geophysical Institute of the Russian Academy of Sciences, have studied the effect of solar wind plasma parameters on characteristics of isolated substorms.

The purpose of this work is to compile a catalog of isolated substorms from magnetic measurements at the auroral station Tixie during weak solar activity, to determine the rate of their occurrence, and to analyze some regularities of variations in the intensity and duration of substorms.

1. DATA

The magnetic station of the Yu.G. Shafer Institute of Cosmophysical Research and Aeronomy SB RAS, located in Tixie Bay (corrected geomagnetic latitude of 66° and longitude of 197°), is part of the Yakutsk meridional chain of geophysical stations. It is one of the high-latitude observation stations of MAGDAS [Baishev et al., 2013] and SuperMag [Gjerloev et al., 2012]. Variations in the geomagnetic field horizontal *H*, *D* and vertical *Z* components are recorded by a fluxgate magnetometer MAGDAS-9 with a 1 s time resolution in the range of ±70000 nT up to 0.1 nT.

From Tixie data on the geomagnetic field *H* component for 2016–2020, a catalog of isolated substorms has been compiled. It includes 91 events.

When selecting the data, the following conditions were taken into account: the development of an *H*-component disturbance in the sector 12–22 UT, or 20–06 MLT of the Tixie station; the duration of the disturbance no longer than 180 min; an *H*-component deviation of at least 80 nT [Tanskanen, 2009]; disturbances of the auroral index *AL* in the time interval considered; absence of noticeable disturbances in the data on the *Dst* index before the selected events; absence of *H*-component disturbances before the selected event for at least three hours. According to these criteria, substorms were selected visually.

The time taken for the geomagnetic field *H* component to decrease during corresponding disturbances of the *AL* index was assumed as the onset of substorms. No account has been given to the substorm growth phase due to the difficulty of determining its beginning from the *H* component; therefore, the duration of the entire substorm considered includes the expansion and recovery phases. The end of the entire substorm was defined as the end of the recovery phase — the time when the negative magnetic bay disappeared and the *H* component returned to the quiet level. For the beginning of the substorm expansion phase we took the time of a sharp decrease in the *H* component by 25–30 nT for 3–5 min; and for its end, the moment when the *H* component was minimum.

Annual sunspot numbers have been taken from the database of the World Data Center for Solar-Terrestrial Physics of the Geophysical Center of the Russian Academy of Sciences, Moscow [http://www.wdcb.ru/stp/data/solar.act/sunspot/]; 1 min values of the geomagnetic auroral indices *AU*, *AL* from the database of NASA's Space Physics Data Center [https://spdf.gsfc.nasa.gov/pub/data/omni/]; data on the low-latitude *Dst* index and preliminary information about the auroral indices for 2019 and 2020, from the website of the World Data Center in Kyoto, Japan [https://wdc.kugi.kyoto-u.ac.jp/wdc/Sec3.html].

2. INTERANNUAL, DAILY, AND SEASONAL VARIATIONS IN SUBSTORM NUMBERS

Figure 1 illustrates annual variations in the number *n* of isolated substorms in Tixie compared to the sunspot number R_a. The variations are seen to not exhibit any noticeable regularity during this period; nevertheless, they can be approximated by a second-degree polynomial function with a minimum at the end of 2017, the correlation coefficient r=0.66. In this short period, R_a variations demonstrate a clear regularity and are also approximated by a quadratic function with a minimum in mid-2019 and r=0.99. It is impossible to talk about cyclic variation in *n*, using such material; note, however, that the smallest number of substorms is observed approximately 1.5 years before solar minimum. Newell et al. [2013] have obtained that the occurrence rate of substorms is maximum at the descending phase of solar cycle, whereas Tanskanen [2009] has found a weak correlation between substorm and sunspot numbers. That said, according to the data on mid-latitude positive magnetic bays, substorms most often occur during the descending phase of solar cycle [McPherron, Chu, 2018].

Figure 2 displays distributions of the isolated-substorm number *n* as measured at the Tixie station during the day (late dusk, midnight, and dawn sectors according to MLT of Tixie) (*a*) and during the year (*b*).

In the selected sector 20÷06 MLT, isolated substorms occur more often during midnight hours (22÷01 MLT), and further in the dawn sector the rate of their occurrence gradually decreases. This time of occurrence of substorms is well known [Akasofu, 1964] and agrees with the results of statistical definitions of this parameter from satellite measurements [Liou et al., 2001; Frey et al., 2004]. Using mid-latitude data, McPherron, Chu [2018] have shown that substorm activity has two characteristic intervals between onsets of activations —

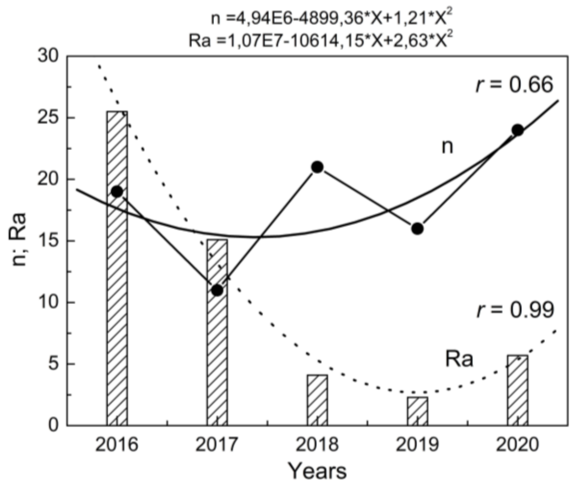

Figure 1. Variations in the number of isolated substorms *n* as measured at the Tixie station (black dots connected by segments) and in the sunspot number R_a (histogram) in 2016–2020: *r* designates correlation coefficients between experimental data and polynomial approximation functions; solid and dotted lines are curves of approximation functions for *n* and R_a respectively

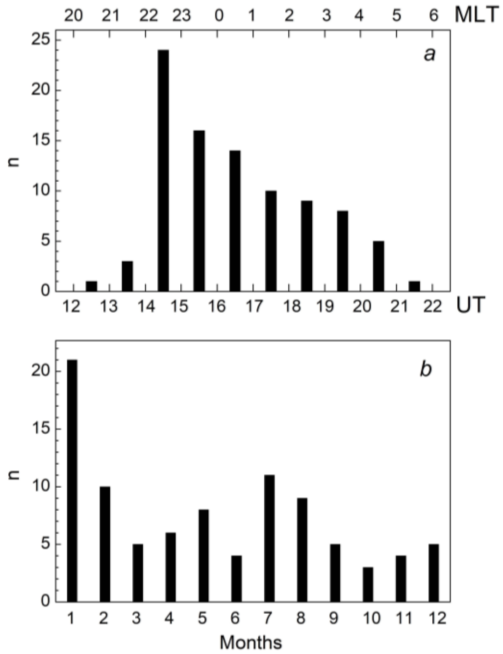

Figure 2. Variations in the number of isolated substorms *n* at Tixie: during the day (late dusk, midnight, and dawn sectors at MLT of Tixie) (*a*); during the year (*b*)

45 and 170 min; and as substorm activity increases, a longer period becomes dominant. A shorter time interval, according to the authors, corresponds to the interval between activations of auroras.

As follows from the histogram in Figure 2, *b*, during the year isolated substorms most often occur during solstices, and in winter the number of substorms is noticeably higher than in summer. A similar result was discussed in [Tanskanen, 2009]. Nevertheless, we should make it clear that our results are a reflection of the selected actual data and they should be considered as preliminary due to small statistics. There might also be methodological effects — isolated substorms were selected during fairly quiet periods. Newell et al. [2013] have found that a maximum number of substorms occur during equinoxes — October and March. According to [Chu et al., 2015; McPherron, Chu, 2018], where the mid-latitude *MPB* index is analyzed, the occurrence rate of substorms is also maximum during equinoxes and minimum during solstices.

3. SUBSTORM INTENSITY AND DURATION VARIATIONS

Figure 3 on the left shows time distributions (late dusk, midnight, and dawn sectors at MLT of the Tixie station) of a decrease in the magnetic field horizontal component *dH* (*a*), which characterizes the substorm intensity, duration *dT* (*c*), and the duration of the substorm expansion phase *dt* (*e*); on the right are variations in hourly means of these parameters <*dH*> (*b*), <*dT*> (*d*), and <*dt*> (*f*).

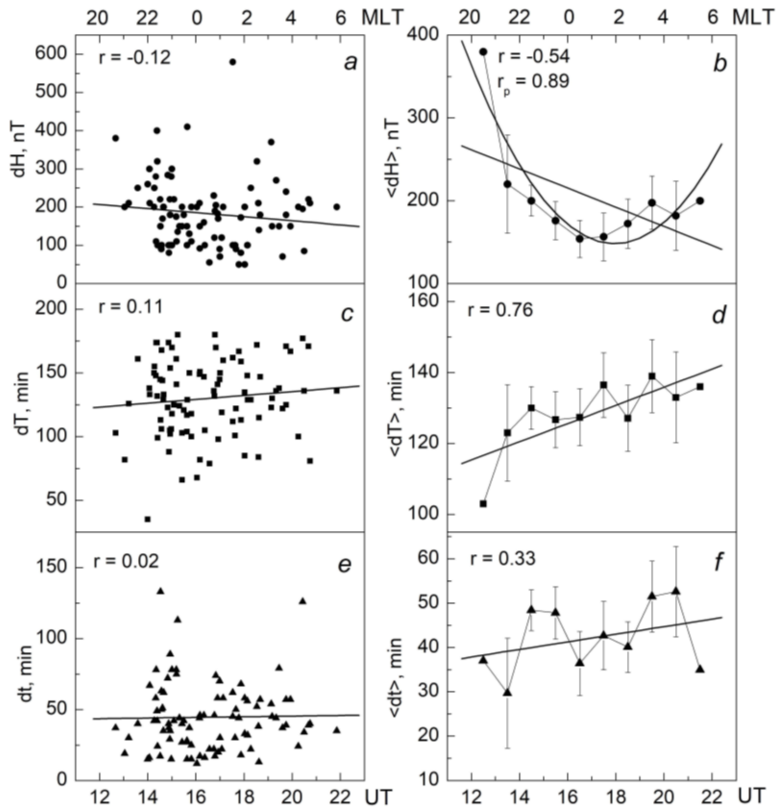

Figure 3. Time distributions (late dusk, midnight, and dawn sectors at MLT of the Tixie station) of a decrease in the magnetic field horizontal component *dH* in Tixie (*a*), substorm duration *dT* (*c*), and duration of the substorm expansion *t* phase *dt* (*e*), as well as variations in hourly means of these parameters <*dH*> (*b*), <*dT*> (*d*), and <*dt*> (*f*); vertical segments are standard deviations of means; r and r_p are the correlation coefficients between experimental data and their linear and quadratic approximations (straight lines and parabola) respectively; along the top X-axis is the local magnetic time for Tixie

The distributions of *dH*, *dT*, and *dt* indicate that a decrease in *H* (substorm intensity) and durations of a substorm and its expansion phase do not exhibit a noticeable dependence on the time of occurrence of substorms; this is also evidenced by low correlation coefficients *r* between the experimental data and their linear approximations, given in the top left corner of each panel. The *dH*, *dT*, and *dt* values are generally in line with the values of similar parameters for the *IL* index, determined from IMAGE magnetic measurements in the auroral region [Tanskanen, 2009].

However, from the data on hourly means of substorm parameters it can be observed that in the midnight sector, compared to the dawn sector, a decrease in the magnetic field *H* component is more significant, whereas durations of a substorm and its expansion phase are shorter. A decrease in <*dH*> from late dusk and midnight to dawn hours in a linear approximation is not very convincing, although r=–0.54, especially since the extreme points in this distribution represent isolated cases. With a quadratic approximation of the data on <*dH*>, the parabola vertex is located on the time axis around 00–03 MLT (according to experimental data, around 23–02 MLT) and r_p=0.89. The mean duration of substorms <*dT*> (*d*) occurring during the dawn hours is longer (to 25 min) than that of substorms in the late dusk and midnight hours. The same regularity, albeit to a lesser extent, is seen in the mean duration of the substorm expansion phase <*dt*> (*f*), but this substorm characteristic has a fairly wide data spread at the time of interest. The means obtained for the entire array of events (128 min and 42 min) are almost twice as long as the mean durations of the entire substorm and its expansion phase, determined from *MPB* (50 min and 21 min respectively) [Chu et al., 2015].

CONCLUSION

According to magnetic measurements at the Tixie auroral station, we have first compiled a catalog of isolated substorms for 2016–2020. This is the main result of the work.

For the events included in the catalog, we have examined their statistical distributions and some regularities. We have found out that variations in the number of isolated substorms in Tixie and the sunspot number are well approximated by quadratic functions with minima at the end of 2017 and in the middle of 2019 respectively, i.e. the smallest number of substorm disturbances is observed approximately 1.5 years before solar minimum; during the year, the number of substorms is maximum during solstices; during the day, substorms more often occur at local midnight, and in the dawn sector their number gradually decreases. The intensity of isolated substorms, their duration, as well as the duration of their expansion phase do not show a noticeable dependence on the time of occurrence of the disturbances considered. However, from the data on hourly means of substorm parameters we have found that their duration and the duration of their expansion phase are shorter in the midnight sector compared to the dawn sector, and the intensity is lower around 0–3 MLT. The mean durations of substorms and their expansion phase as compared with the results obtained for mid-latitude stations [Chu et al., 2015] are longer.

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