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DYNAMICS OF FIELD-ALIGNED CURRENTS DURING SUBSTORMS

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Introduction

Numerous investigations of magnetospheric disturbances show that the substorm expansion phase can begin smoothly as well as sharply [1]. The localisation of substorm centre and a character of substorm expansion phase development are determined during the preliminary phase and can be revealed a few dozen minutes before its onset T_0 [2,3]. However, there are doubts in the reality or necessity of the substorm growth phase [4]. In [5,6] it is shown that the substorm development is accompanied by the formation of zone 2 type field-aligned currents at the growth phase. In these cases, the substorms were visually related to substorms with a smooth onset of active phase. As substorms with a sharp onset of expansion phase, it is known very little about their manifestation in the magnetosphere before the onset T_0.

The purpose of this paper is to clarify if the zone 2 type field-aligned currents are always manifested before the substorm expansion phase onset which takes place at geostationary distances and whether they can be or not an indicator of the growth phase development.

Selection of Data and Analysis

The basis of experimental data are the results of geomagnetic measurements aboard geostationary satellites obtained during 1986-1987. The one-minute digital data of AE and AL – indices are also used. We selected the substorms for which the following conditions are fulfilled: a) AE-index varies weakly before the substorm expansion phase onset (T_0), and the moment T_0 is clearly determined by values of AE and AL; b) the substorm expansion phase duration is adequately determined by the AE-index curve. To calculate the field-aligned currents at geostationary distance we used an idea of the method suggested in [5] and we tested it for 4 events from [5]. From available experimental data of 1986-1987 we selected 19 events satisfying the all above conditions. For each event the average values of AE- index 1 hour before the substorm expansion phase onset as well as the time of the first maximum (or the first conditional maximum) after T_0 have been estimated. Besides, the graphs of magnetic field

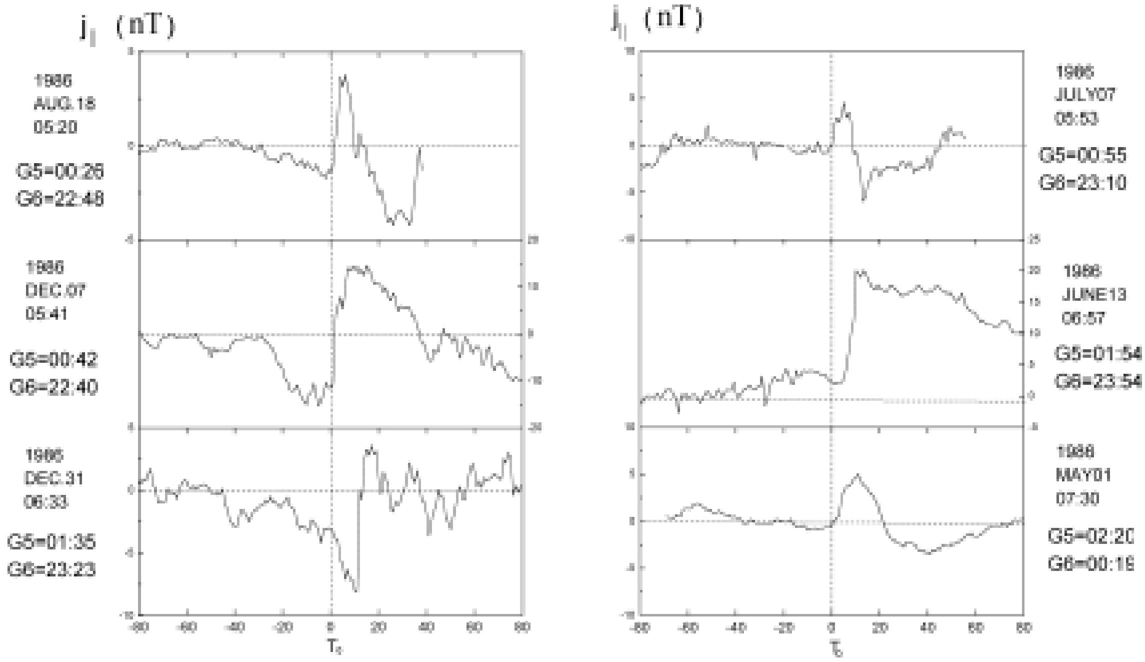

Fig.1 The field-aligned current profiles during substorms of the first (on the left) and the second (on the right) types

line slope at geostationary distances before T_0 have been constructed. We used 18 events form the paper [6] and 19 substorms we had selected. All the events were separated into two groups. 24 events were assigned to the first group for which the zone 2 type field-aligned current before the substorm expansion phase onset was observed. In 13 events of the second group the field-aligned currents were absent. Fig.1 shows the field-aligned current profiles for the substorms of the first and second types (for the events from [5] not shown). Near each graph there are date and local time of the satellite location at the time moment T0. In all events in Fig.1 the satellites were located in the midnight sector. The field-aligned current graphs for the first type substorms are presented on the left in Fig.1. One can see that the behaviour of field-aligned currents corresponds to conclusions of [6]. Graphs of field-aligned currents for the second type substorms are presented on the right in Fig.1. It is evident from the curves that there is a current wedge in the period of the expansion phase, and the zone 2 type field-aligned currents before T_0 are absent. Thus, the zone 2 type field-aligned currents before T_0 are not always observed.

The hypothesis about the influence of geomagnetic disturbance pre-history and the relation of expansion phase duration to the appearance probability of zone 2 type field-aligned currents at geostationary distances before the substorm expansion phase onset has been tested by means of the χ^2-criterion and the Student t-criterion.

To estimate the disturbance level of the preceding substorm we used the AE-index. The values of parameters for each group are following: $AE_1=154$, $\sigma^2_{01}=8176$; $AE_2=91$, $\sigma^2_{02}=1522$, and the probability of difference in the average values P>0,99. To test the qualitative relation between the geomagnetic disturbance pre-history and the appearance of zone 2 type field-aligned currents before the substorm expansion phase onset, we used χ^{2-}criterion. To separate substorms in disturbance degree we chose a conditional level of 100 nT. The geomagnetic disturbance level is assumed to be low at AE< 100 nT. We prepared the table of conjunction (Table 1).

The assumption about the dependence between studied values is justified with the probability P>0,975 . The second type substorms develop against a weakly disturbed background.

The expansion phase duration t_{fr} is supposed to be the time from T_0 to the maximum (or the first conditional maximum) in the AE-index curve. We considered 10 substorms of the first type and 13 substorms of the second type. 23 events were divided into two subgroups according to the front duration t_{fr}. The first subgroup contains events with $t_{fr} \leq t0$, the second subgroup contains events with $t_{fr} > t_0$. The values 8, 9, 10, 11, 12 min are taken as t_0, the Table 2 of conjunction is prepared for each value and χ^2 is calculated, which gives a degree of relation between the appearance probability of zone 2 type field-aligned currents before the substorm expansion phase onset (T_0) and the front duration. The maximum value of $\chi 2$ is obtained for $t_{fr} \leq 11$ min. The calculations show that at $t_{fr} > 11$ min the appearance probability of field-aligned currents at geostationary distances is the maximum one.

Table 1

Substorm type	AE<100	AE>100	Σ
2	10 (6,67)	3 (6,32)	13
1	9 (12,32)	15 (11,67)	24
Σ	19	18	37
	χ^2=5,24	P>0,975	

Table 2

Type	t_{fr}≤11	t_{fr}>11	Σ
2	13 (9,6)	0 (3,39)	13
1	4 (7,39)	6 (2,6)	24
Σ	17	6	37
	χ^2=8,2	P>0,995	

Discussion

According to [1], we consider the expansion phase onset to be sharp, if the time of the AE-index increase is smaller than the average time of expansion phase duration. For the second type substorms the duration of expansion phase is less than 13 min. Thus, the events of the second type are substorms with a sharp onset of expansion phase.

The authors of [5,6] associate the presence of field-aligned currents before the substorm expansion phase with three possible sources. Two of them are caused by typical distribution of magnetic field gradients (∇B) and plasma pressure gradients (∇P). One source is connected with the strengthening of azimuth current at the magnetosphere equator near the midnight whose divergence causes zone 2 type field-aligned current due to the magnetic field gradient of azimuth direction. The second source is the region of zone 2 and 1 large-scale field-aligned currents, the development of which is connected with the radial distribution of ∇B and the azimuth one of ∇P. The third source is the region of external plasma sheet, where the strengthening and development of plasma convection flux vortices before the substorm expansion phase onset increase.

The substorms of the second type develop against the weakly disturbed background. Maximum value of AE-index before the substorm expansion phase onset on the average is less 100 nT. It is explained by the absence (attenuation) of zone 2 field–aligned currents and convection vortices before the substorm expansion phase onset. Proceeding from three possible sources [5,6] responsible for the appearance of field-aligned currents before the moment T_0, the sole reason for field-aligned current development before the expansion phase onset for substorms with a sharp onset is, apparently, the development of thin current sheet. If we consider that the region of azimuth current strengthening is at the inner edge of the plasma sheet [7] then, as shown in the paper by Kozelova and Sakharov [8] with the rise of magnetic activity the inner edge of the current sheet is shifted to the Earth and can bee observed at a distance of 6.6 RE. Since the substorms of the first type develop against the more disturbed background then, therefore, the region of substorm centre localisation (the location of the thin current sheet) will be nearer to the Earth than for the second type substorms, and the strengthening effect of azimuth current at geostationary distances for substorms of the second type will not be observed.

In order to explain the second regularity the dynamics of angle of inclination of magnetic field lines to the magnetosphere equator for each type of substorm have been analysed. It has been obtained that for the second type substorms the angle of inclination of force lines changes less than for the first type substorms. Therefore, the change with the time of ΔB_1 determining the field-aligned current, apparently, for the substorms of the second type is negligible. Thus, the substorms of the second type apparently develop in the distant part of the magnetosphere tail. In [9] it was shown that intensifications, which are similar to substorms with a sharp onset, develop in the distant part of the magnetosphere tail.

Conclusion

From the analysis of the magnetic field data aboard geostationary satellites and of auroral indices it follows that at geostationary distances the zone 2 type field-aligned currents before the substorm expansion phase onset are not always manifested. With the increase of geomagnetic activity preceding the substorms the probability of appearance of the field-aligned currents before the expansion phase onset increases. If the duration of the front is less than 11 min, the probability of appearance of zone 2 type field-aligned currents to T_0 decreases. Apparently, it is associated with the fact that the substorm center localization region is formed in the distant part of the magnetotail .

Thus, the magnetosphere configuration during substorms with a sharp onset does not have an effect on geostationary distances. The region of near part of the magnetotail before the substorm expansion phase onset weakly reacts to changes taking place in the distant part of the tail.

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