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CHARACTERISTICS OF SUBSTORMS STIMULATED BY VARIATIONS OF THE DYNAMIC SOLAR WIND PRESSURE AND MAGNETOSPHERIC CONVECTION ELECTRIC FIELD

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Introduction. The substorm explosive phase corresponds to the period of sudden release of the accumulated energy in the magnetotail and it can begin both spontaneously and under the effect of changes in outer conditions [Dmitrieva and Sergeev, 1983]. It is believed that the substorm onset is often observed in contact of the magnetosphere with shock waves or during sharp variations of solar wind dynamic pressure (Pd) [Kokubun et al., 1977, Sergeev et al., 1986], or it is accompanied by the IMF Bz-component turn to the north [Caan et al., 1975, Rostoker, 1983, Lyons 1995, 1997]. However, in the paper [Arykov and Maltsev, 2001] from the statistical analysis using the superposed epoch technique, the conclusion has been made that all substorms are spontaneous. At the same time, according to [Kozelov, Kozelova, 2002] the application of that method in studies of substorms is not quite correct. Thus, the question on the contribution of external actions to a substorm onset is still open. .

The goal of this study is the comparative analysis for the development of three sequential substorms, observed under various conditions in the solar wind (sw) on March 5, 1997, based on global ground and multisatellite data.

Data and results. We use geomagnetic digital data from ~70 high-latitude, ~20 low-latitude and equatorial stations, TV observations of aurorae at Tixie station (Φ=65.6°, Λ=194.9°) and data from five satellites: GOES 8 and GOES 9 located at 1800 UT near the noon meridian, LANL 91 and LANL 94 localized at 22-02 MLT and IMP-8 in the magnetotail with the coordinates (X_{GSM}= -27.4 R_E, Y_{GSM}= 9.1 R_E, Z_{GSM}= -18.2 R_E).

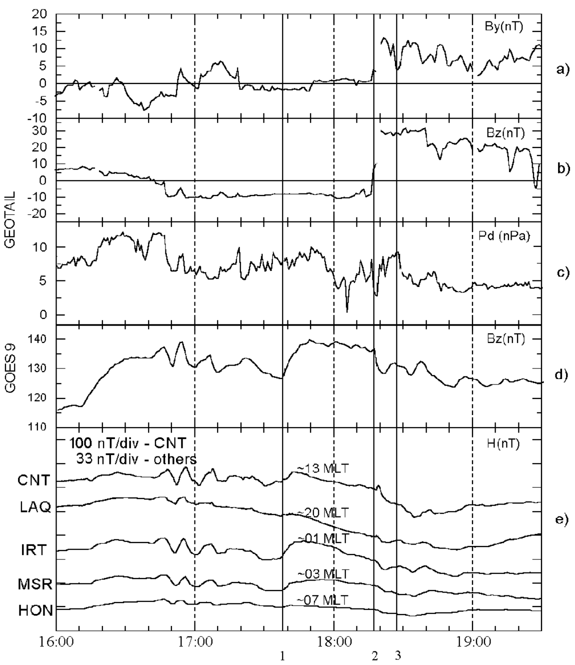

Fig. 1. Variations of the IMF By,Bz-component (a, b), sw dynamical pressure (c) from the WIND, Bz-component of magnetic field from the GOES 9 (d) and geomagnetic field H-component at the magnetic stations: Canete (CNT Φ′≈0.75°), Laquila (LAQ Φ′≈36.26°), Irkutsk (IRT Φ′≈47.3°), Moshiri (MSR Φ′≈37.28°), Honolulu (HON Φ′≈21.61°) (e) on March 5, 1997 at 1600-1930 UT.

The SW data and IMF obtained from the GEOTAIL with the coordinates (X_{GSM}= -1.32R_E, Y_{GSM}= 23.06R_E, Z_{GSM}= 8.23R_E) at 18.00 UT are presented in Fig. 1a-c. Fig. 1d,e gives magnetic field variations in the magnetosphere and at five low-latitude stations located in different MLT sectors. Figs. 2 and 3 demonstrate the magnetograms at a number of stations: in the night sector (00-03 MLT) in Fig. 2a, in the evening sector (20-21 MLT) in Fig. 3a and in the pre-noon (09-12 MLT) in Fig. 3b. Aurora dynamics at 01-03 MLT and the excitation of Pi 2 pulsations at the low-latitude stations Mondy (MON), Moshiri (MSR) and also geomagnetic field H-component variations at MSR are shown in Fig. 2b,c. Fig. 3c presents changes of total eastward current intensity at 14-18 MLT obtained from meridional chain of Greenland. The analysis of these data allowed to determine the onset of three substorms following each other at 1738-1740, 1818-1820 и 1830 UT (vertical lines 1, 2, 3 in the Figures).

Substorm 1. The expansion phase of the first substorm began at 1738-1740 UT after the prolonged (~1 hour) substorm growth phase caused by the turn of IMF Bz to the south at ~1645 UT (Fig. 1b). It was accompanied by an aurora arc brightening (Fig. 2b), Pi 2 burst and onset of low-latitude positive (Fig. 2c) and negative bays in the night sector of the auroral zone (Fig. 2a). At the dayside at latitudes Φ=73-75° (Fig. 3b, c), a short-term (~5 min) intensification of the eastward current occurs. At lower latitudes, the intensification of the eastward current in the evening sector (PEL-SOD, Fig. 3a) and the westward current in the pre-noon (PI-ES, Fig. 3b) as well in the morning sector (not shown) is observed. These field variations are similar to variations registered at the substorm growth phase (see, Fig. 3a, b) and they, probably, characterize the short-time intensification of the magnetospheric convection.

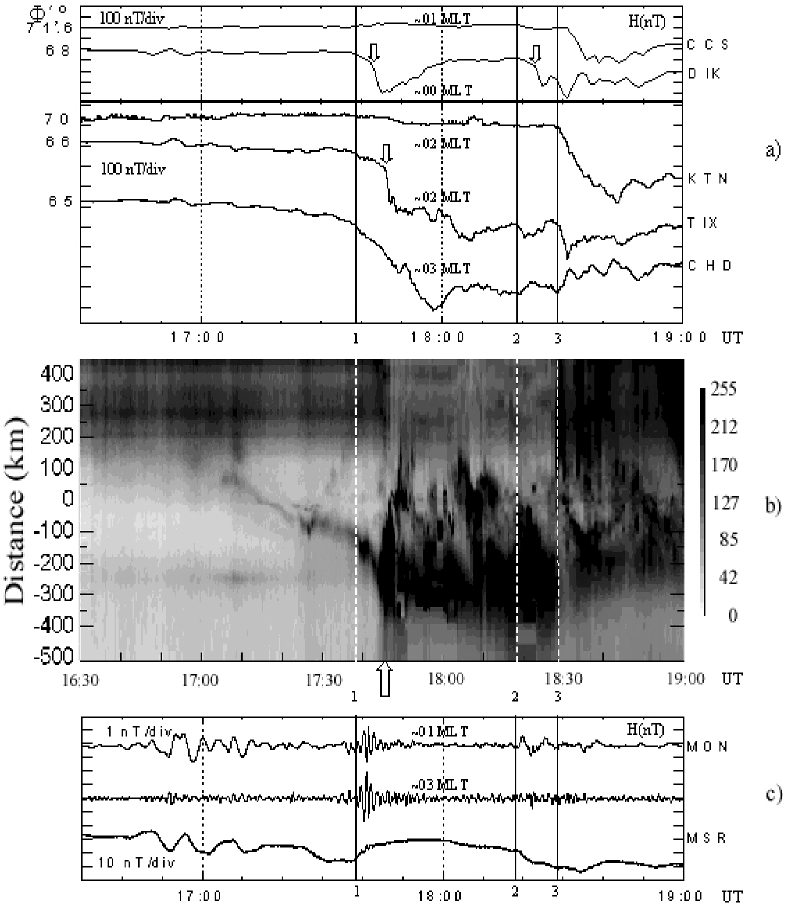

Fig. 2. H-component variations at high latitude stations (a), aurora dynamics in Tixie by keogram data (b), Pi 2 pulsations at the low-latitude stations and also geomagnetic field H-component variations at MSR (c) on March 5,1997 at 1630-1900 UT.

At 1744-1745 UT, i.e. 5-7 min after the substorm onset, a sharp intensification of the westward electrojet intensity (ΔH=300-400 nT) is observed, but only in the night sector (Dikson (DIK) и Tixie (TIX)) and extension of aurora to the pole (arrows in Fig. 2 a, b).

Thus, a substorm expansion phase development occurs in the form of two sequential stages at 1738-1744 and 1745-1750 UT. At the day magnetosphere (Fig. 1d) and at low-latitude stations (Fig. 1e), the substorm onset is accompanied with magnetic field growth practically simultaneously in all time sectors. Such field variations are similar to variations, observed during SI impulses [Araki, 1994], and are, probably, caused by a sharp compression of the magnetosphere.

Substorm 2. Before the onset of the second substorm at 1818-1820 UT, a growth phase, probably, caused by the negative IMF Bz rise, about 1800 UT (Fig. 1b) is observed. Simultaneously with the Pi 2 burst, a negative disturbance onset in H-component is observed in the 21-03 MLT sector (OUJ-MUO, Fig. 3a, DIK and TIX, Fig. 2a) followed by the new intensification of the westward jet at 1824-1825 UT in the 21-01 MLT sector (arrows in Figs. 2 a and 3 a) at Φ=67-68° (DIK and SOR) and by the simultaneous enchancement of the eastward jet at ~21 MLT at Φ=61-65° (PEL, SOD, MUO in Fig. 3a). Thus, as in the substorm 1, there is a repeated westward electrojet intensification in the night ionosphere 5-7 min after the substorm onset, but with the shift of its center to the evening sector direction and with the simultaneous enchancement of the eastward jet.

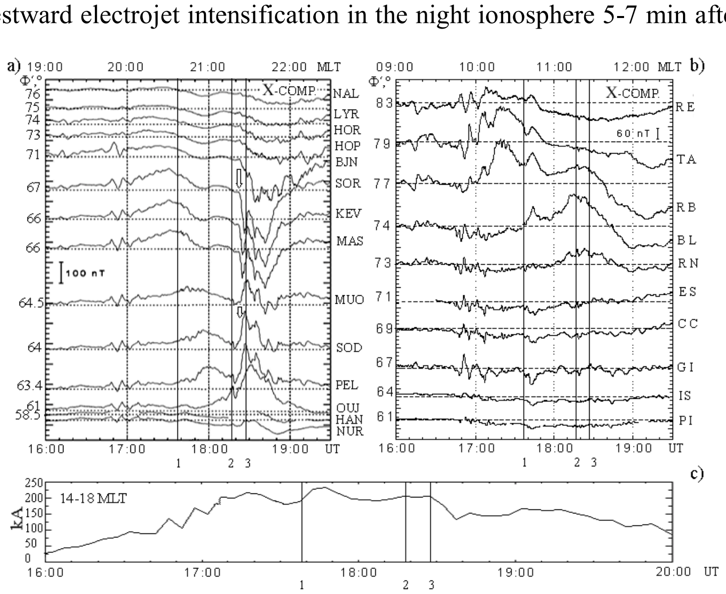

Fig. 3. Latitudinal variations in the post-noon (a) and pre-noon (b) sectors, total eastern current intensity at 14-17 MLT (c) on March 5, 1997 at 1600-2000 UT.

In other time sectors of high latitudes, the substorm onset is mainly manifested in short-term impulse variations Y(D)-component (not shown). At low-latitude stations (Fig. 1e) in all time sectors and in the magnetosphere (Fig. 1d), the H-component decrease is registered after a short-term positive ΔH impulse of maximum intensity at the equator (CNT). By GEOTAIL data, which is located near the magnetopause, the substorm onset coincides with a sharp growth of the general magnetic field, with an increase of the temperature and density of ions, with a decrease of plasma velocity (not shown) and with turn of IMF Bz to the north and the Pd increase (Fig. 1b, c). Such variations of the sw parameters and the IMF are generally classified as tangential discontinuity [Nishida, 1978]. The H-component decrease at the low-latitude station and in the magnetosphere can be associated with ring current intensification taking into account Dst-index (not shown) and also with the convection electric field direction change at ionospheric heights in connection with the turn of IMF Bz (see Kikuchi et al., 2000).

Substorm 3. The substorm begins at 1828-1830 UT with a sharp intensification of the westward electrojet in the near midnight (DIK, CCS) at Φ=68-71°, in the morning (KTN, Φ=70°) and the evening (SOR, BJN) Φ=67-71° sectors (see. Figs. 2a and 3a). In the pre-noon sector (~11 MLT) the transition from positive to negative X is observed at Φ=75-78° (BL, RB, TA in Fig. 3b). In the post-noon sector (Fig. 3c) an eastward current decrease is registered in connection with the possible westward electrojet flowing there.. The westward current intensification is accompanied by a sharp auroral luminuosity intensity increase northward of Tixie with the subsequent extension of aurorae to the equator and, possibly , to the pole (Fig. 2b). Thus, this substorm, in contrast to substorms 1 and 2 is characterized by more global intensification of ionospheric currents at higher latitudes as well. At low-latitude stations (Fig. 1e) at all MLT meridians, an H-component decrease similar to the substorm 2 is observed. The substorm onset occurs ~10 min after the IMF Bz turn to the north and it coincides with the Pd decrease at Bz>0 (Fig. 1b, c).

Magnetospheric response in the night sector. Fig. 4 a, b presents energetic electron flux variations in the different energy intervals in the inner magnetosphere at L~6.6 from satellites LANL 91 and LANL 94 in the 21-02 MLT sector. Fig. 5 illustrates variations of Bx, By and Bz-components and general field intensity B in the magnetotail at R~27 Re from IMP-8 data. It is seen from Fig. 4 that the substorm 1 onset is accompanied by the recovery of particle flux level, decreased before the substorm onset, near the midnight (LANL 94) and the field particle injection is observed after the substorm development second stage onset at ~1745 UT (is marked by an arrow). The similar recovery of a particle flux level from LANL 91 data and the particle injection after the substorm onset from LANL 94 data (Fig. 4a, b) is observed during the substorm 2. At the substorm 3 beginning the most powerful energetic particle injection into the inner magnetosphere occurs , registered by both satellites. By IMP-8 data (Fig. 5) no visible field variations in the magnetotail with the substorms 1 and 2 onsets were observed. However, during the substorm 3 onset, the impulse variations for all field components and the sharp decrease of the general field intensity (B) are registered, which usually are interpreted as a decrease or disruption of currents across the tail.

Discussion. The observation data show that the substorm 1 can be stimulated by sharp Pd variations. The ionosphere response is observed in the form of two sequential stages: simultaneously with Pd variations at the dayside and nightside and 5-7 min after in the night sector. These regularities are similar to the global character in registration of the preliminary (Pi) impulse [Kikuchi, 1986] and to the double response of aurorae to SI impulses [Vorobjev, 1974]. The time lag of the second stage in substorm development is consistent with the delay of the night plasma layer reaction to SI impulses and can be associated with the propagation time of a fast magnetosonic wave in the magnetosphere with the velocity of 700-800 km/s [Shukhtina et al, 2000]. The first stage of response, probably, reflects the short-term global compression of the magnetosphere and magnetospheric convection intensification [Kikuchi, 1986], and the second stage reflects the arrival of the fast magnetosonic wave to the night plasma layer and the instability development leading to a substorm [Safargaleev and Lyatsky, 1994].

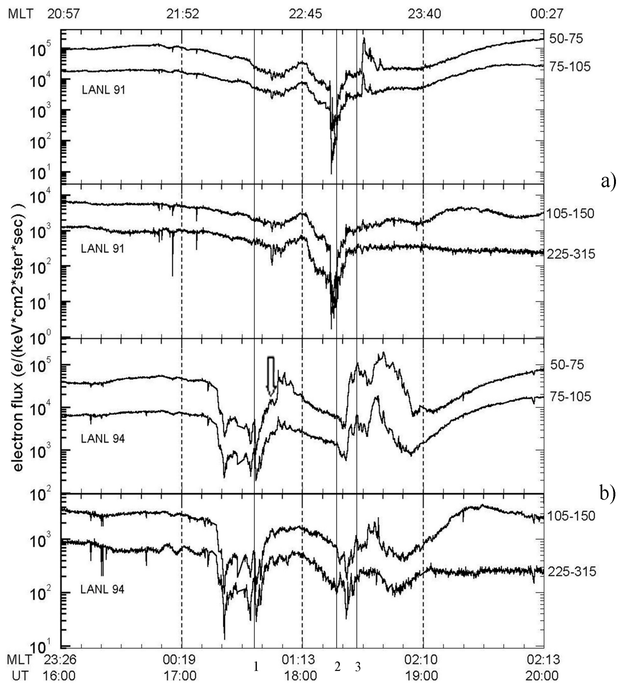

Fig. 4. Energetic electron flux variations in the different energy intervals from satellites LANL 91 (a) and LANL 94 (b) in the 21-02 MLT sector on March 5, 1997 at 1600-2000 UT.

The substorms 2 and 3 are, probably, stimulated by a tangential discontinuity in the sw. In this case, the substorm 2 can be the result of interaction of the tangential discontinuity with the magnetopause and the fast magnetosonic wave generation, i. e. according to the scenario analogous to the substorm 1 development. The substorm 3 is, probably, caused by a sharp decrease of the convection level, for example, of the one, based on the model by Lyons [1995]. The lag time ~10 min relative to the moment of Bz turn which is consistent with data of [Lyons et al., 1997]. This lag is greater by the factor of 1.5-2 than it is observed for the substorms 1 and 2. It can be explained by the smaller SW speed (V=350 km/s) in comparison with the propagation speed of fast magnetosonic wave. The sub-

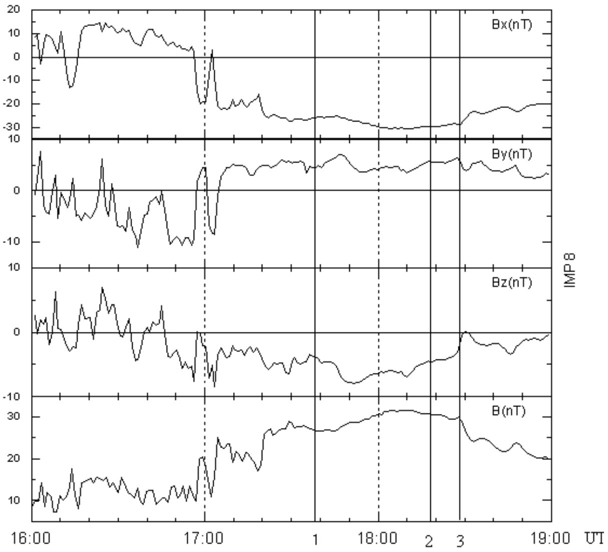

Fig. 5. Variations of Bx, By and Bz-component and total field intensity B in the magnetotail at R~27 Re from IMP-8 data on March 5, 1997 at 1600-1900 UT.

storm 3 occurs in a more distant magnetosphere region from the Earth and is of a more global character. It can be associated with different reasons, whose discussion is beyond the scope of this paper.

Conclusion. Thus, the above data show that the onsets of concrete substorms can be stimulated by both variations of SW parameters and the IMF. In this case, a triple geomagnetic response to the contact of the dayside magnetosphere with a sw inhomogeneity practically simultaneously (~1 min) and ~5 and 10 min after the contact is possible.

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