Maps of the Spatial Distribution of the Variations in the X and Y Components of the Magnetic Field at European Midlatitudes During Substorms: A Case Study

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1. Abstract

The goal of this work is to present the utility of maps of the magnetic field components variations to define the characteristics of the magnetospheric substorms appearance at midlatitudes. To study the spatial distribution of the magnetic field components variations during substorms, an isolated substorm in non-storm conditions, the substorm on 22 March 2013 at ~23:07 UT with central meridian over Europe has been chosen. Magnetic field data from INTERMAGNET, SuperMAG and IMAGE databases have been used. The X and Y variations due to the substorm were computed for 56 stations based on the developed programs. Maps of the spatial distribution and latitudinal and longitudinal profiles of the magnetic variations have been created and some characteristics as the line of sign conversion latitude, the central meridian, the longitudinal and latitudinal extent of the midlatitude positive bays (MPB) and the latitudinal and longitudinal dependence of the variations at three times with maxima during the maximal development of the substorm have been estimated. The central meridian is near PAG (~37°MLAT, ~97°MLON): it is at ~84°MLON during the first part of the substorm and at ~106° MLON in the final stage. The sign conversion latitude is in the range 60°-67°MLAT, the latitudinal extent – from 46° to 53°, and the longitudinal extent – from 60° to 140° during the stage of the maximal development of the substorm. These results are typical for expanded substorms.

Keywords: magnetospheric substorm, midlatitude positive bay (MPB), perturbations maps

2. Introduction

Magnetospheric substorms are an important element of the space weather. During magnetospheric substorms, a considerable release of energy from the magnetospheric tail into the ionosphere and inner magnetosphere occurs [Akasofu, 1968]. They are the main reason for the specific disturbances of the magnetic field on the Earth surface. According to the present-day view, a current system forms, namely, the substorm current wedge (SCW) [McPherron et al., 1973]. At auroral latitudes, negative bays in the X component are observed, driven by the westward electrojet, and at midlatitudes, positive bays in the X magnetic component are seen, associated with the field aligned currents. The magnetic variations at midlatitudes can be used to study the magnetospheric substorms. For example, in a number of papers the onset of the midlatitude positive bays (MPB) has been used as indicator of the beginning of the substorm expansion phase [e.g. Mende at al., 1972, McPherron and Chu, 2017], the sign of the Y component was used by Meng and Acasofu [1969] to set the direction of the field aligned currents, a method to determine the geomagnetic longitude of the auroral substorm onset was worked out [Rostoker et al., 1980, Sergeev and Tsyganenko, 1980]. Different kinds of maps of the spatial or temporal distributions and profiles of the magnetic variations at midlatitudes have been constructed to determine some substorm parameters [e.g. Clauer and McPherron, 1974, Pothie et al., 2015].

In this work the magnetic field variations at midlatitudes during substorms have been examined based on maps of the spatial distribution and latitudinal and longitudinal profiles of the magnetic variations on the Earth surface. An isolated substorm in non-storm conditions, the substorm on 22 March 2013 at ~23:07 UT with central meridian over Europe has been chosen for the study. The constructed maps and profiles have been used to estimate some characteristics of the substorm as the line of sign conversion latitude, the central meridian, the longitudinal and latitudinal extent of the midlatitude positive bays (MPB) and the latitudinal and longitudinal dependence of the variations at chosen times of the substorm development.

3. Data

Magnetic field data from the databases INTERMAGNET, SuperMAG, and IMAGE have been used. Data from 53 European stations at auroral and midlatitudes and from 6 Asian stations have been used for the study of the magnetic disturbances due to the examined substorm. The following stations have been included in the study: BDV, BEL, BOX, BRZ, CLF, DUR, EBR, ESK, FUR, GUI, HAD, HLP, HRB, IZN, KIV, KRT, LER, LVV, MNK, MOS, NGK, NUR, OUJ, PAG, PEG, SFS, SPT, SUA, SUW, THY, UPS, VAL, WNG, ABK, BJN, DOB, HAN, HOP, IVA, JCK, KAR, KEV, LYC, LOZ, MAB, MEK, MUO, NOR, PEL, RVK, SOL, TRO, SOR, ARS, NVS, IRT, CNH, YAK, MGD.

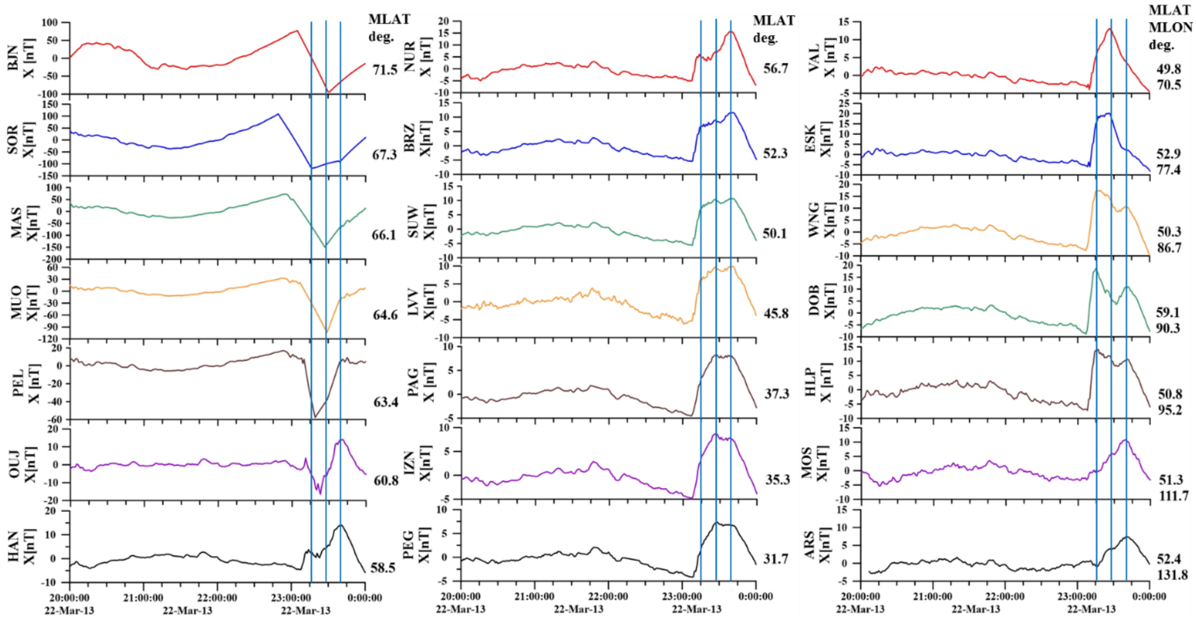
4. Processing method

For the data processing, we applied the developed by us program for computing the perturbations of the magnetic field components on the earth surface, described in more detail in Werner et al. (2021a) and Werner et al. (2021b). The program tool is based on the McPherron and Chu algorithm (McPerron and Chu, 2017) and some new developments. In general, the main field and the mean Solar quiet magnetic variations are removed. The program was designed to process the magnetic field data from the Bulgarian station Panagjurishte (PAG) since 2007. Here it was applied to process the magnetic field components registered at a number of stations in order to examine the behavior of the magnetic field in a large area during a selected substorm event. Data for 25 consecutive days centered on the substorm day have been used. The variations of the X, Y components and the horizontal power have been computed.

5. Results

5.1.X component variations

In Figure 1 the variations of the X component of the magnetic field at different stations from 20 to 24 UT on 22.03.2013 are given. In panels a) and b) the result for chosen stations from the PPN-NAL IMAGE chain and its prolongation at midlatitudes is presented, and in panel c) – the X component variations at stations at different longitudes are shown. The station names are written at the left side of the graphs, and the magnetic coordinates – at the right side. Three typical times of the substorm development, at which maxima at some of the midlatitude stations were observed, namely 23:16 UT, 23:27 UT and 23:40 UT, have been selected to be used for the maps of the distribution and the profiles of the X and Y magnetic components construction. These times are shown by blue vertical lines in the graphs of Figure 1.



a) b) c)

Figure 1. *a), b): X magnetic variations during the substorm at ~23:07 UT on 22.03.2013 at chosen stations from the IMAGE PPN-NAL chain and its prolongation at midlatitudes (MLON interval 96°-108°); c) X magnetic variations at different longitudes. The blue lines indicate the chosen typical times of the substorm development.*

5.2.Maps of the X and Y components variations

Maps of the X and Y magnetic components spatial distribution at the selected times have been constructed. In Figure 2 the abbreviations of the names and the locations of the stations from which data for the maps creation have been used, are shown. The rectangular frame indicates the area for which the maps were constracted: 38°÷68° geogr. lat. and -5°÷35° geogr. lon.

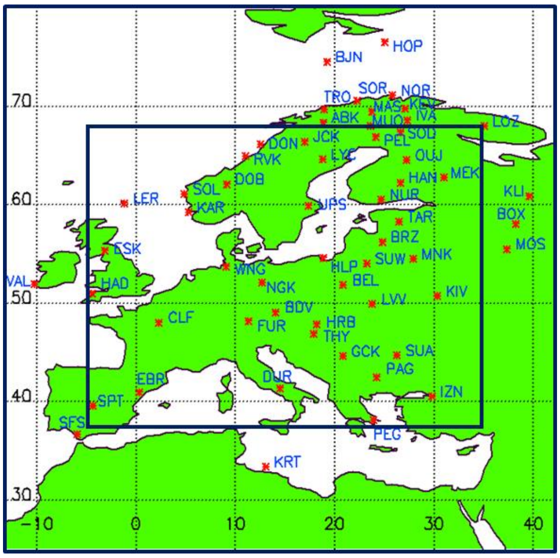


Figure 2. *Stations, used to compute the distribution of the magnetic variations on the Earth surface. The rectangular frame in the figure indicates the region for which maps of the spatial distribution of X and Y are constructed.*

The spatial distributions of the X and Y variations at the three chosen moments during the substorm development are presented in Figure 3, in the upper and lower panels, respectively. In the maps of the X magnetic variations (upper panels in Figure 3) the sign conversion boundary is clearly expressed. It is seen in the range 65°-68° geographic latitude or at about 60°-65° MLAT.

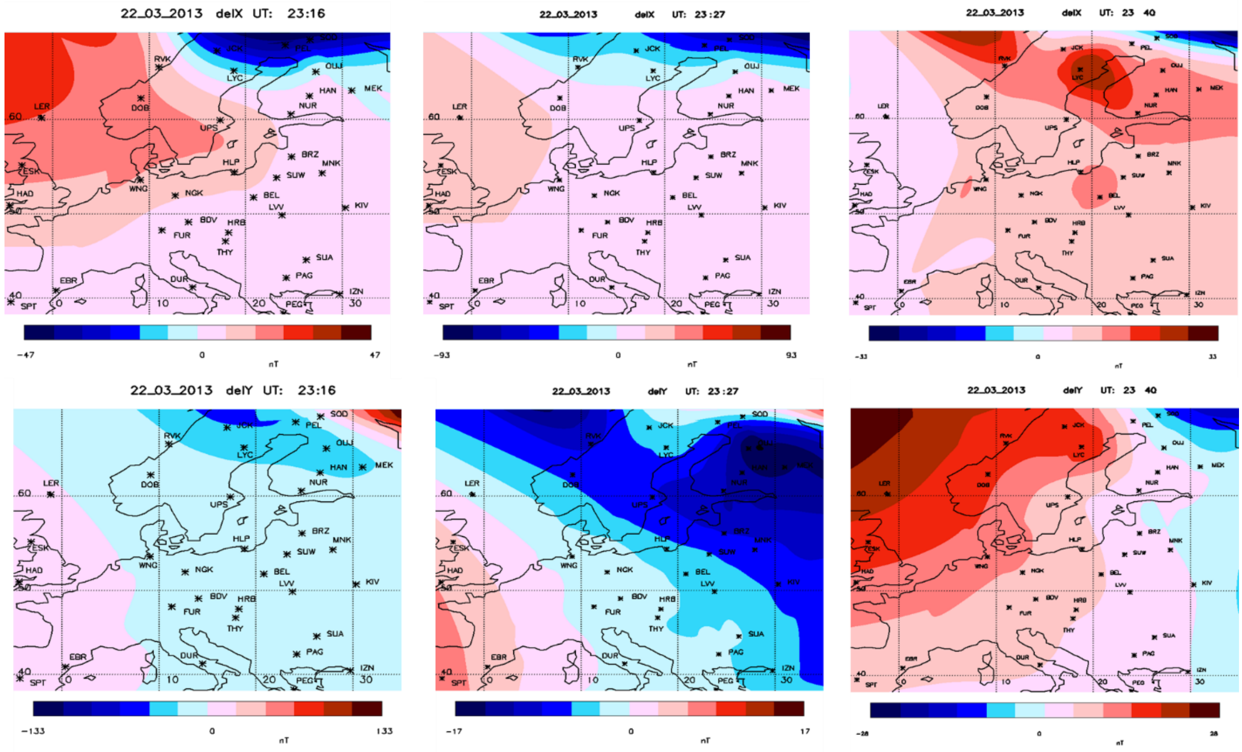


Figure 3. *Maps of the X (up) and Y (down) magnetic variations at the three chosen moments of maxima in X during the substorm development.*

In the maps of the Y magnetic variations (lower panels in Figure 3) the central meridian of the substorm arises, close to the sign conversion in Y.

5.3.Profiles of the X and Y variations

To examine the behavior of the midlatitude positive bays in more detail and over a larger area latitudinal and longitudinal profiles of the X and Y variations have been constructed. They are the dependences of the values of X or Y obtained from the examined stations at the three chosen times from the geomagnetic latitude/longitude. In view of the difference of the profiles at different longitudes/latitudes the data were distributed in groups pertained to the following intervals by geomagnetic longitude: 60°-80° MLON, 80°-95° MLON, 95°-100° MLON, 100°-105° MLON, and 105°-115° MLON to construct the latitudinal profiles and to the following intervals by geomagnetic latitude: 14°-30° MLAT, 30°-40° MLAT, 40°-50° MLAT, 50°-55° MLAT, 55°-60° MLAT to construct the longitudinal profiles. Data from all examined European and Asian stations are used. The obtained profiles are presented in Figure 4, namely: the upper panels display the latitudinal profiles of the X variations for the chosen times, the middle panels show the longitudinal profiles of the X variations, and the bottom panels – the longitudinal profiles of the Y variations. The data from every interval are drawn by markers with different form and colour. The extent of the positive bays is determined by two levels: where the X variations become 0 nT (0 nT boundary), and where they reach 5 nT (5 nT boundary), presented in the two upper panels of Figure 4 by black and blue vertical lines, respectively. The interception of the 0 line in the X latitudinal profiles where the negative X bays turn into positive ones, gives the sign conversion latitude (upper panel in Figure 4. The interception of the 0 line of the Y variations longitudinal profile points the central meridian of the substorm. It is indicated by red vertical line in the bottom panels of Figure 4.

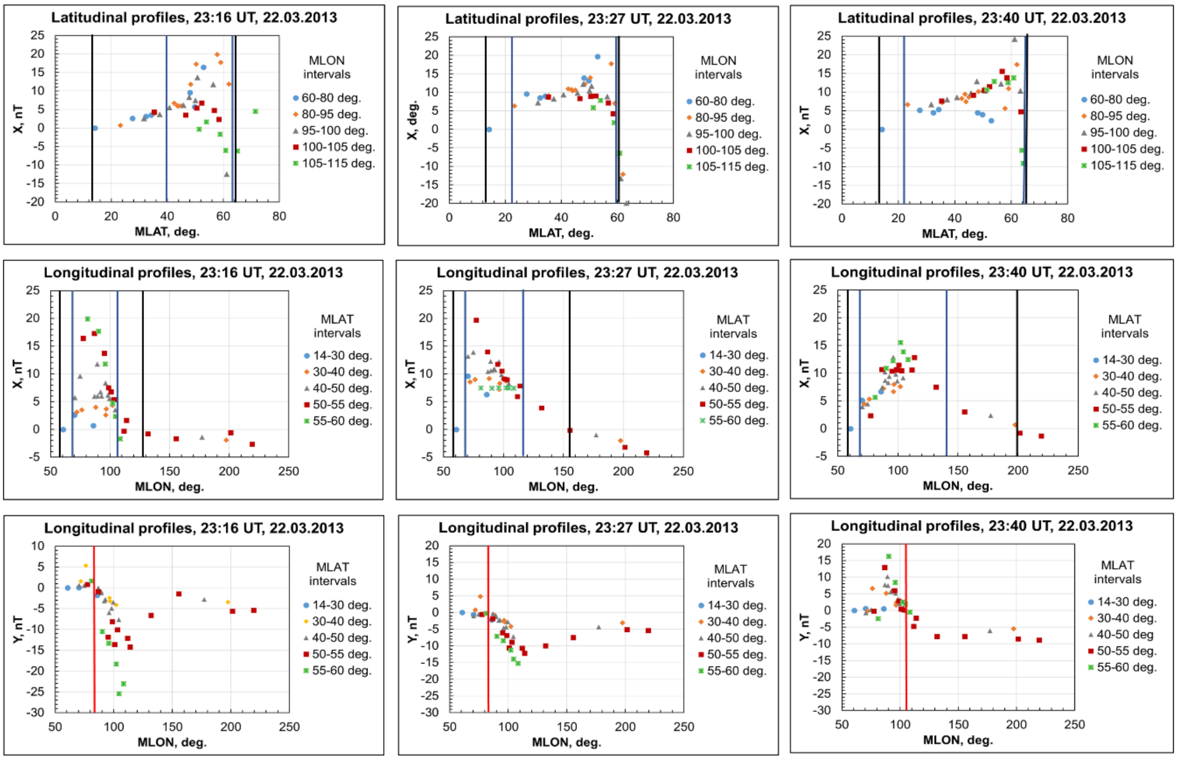


Figure 4. *Latitudinal and longitudinal profiles for given intervals, listed in the panels. The vertical blue lines indicate the latitudinal and longitudinal extent of MPB at the limit of 5 nT, and the black ones – the limit of 0 nT. The vertical red lines point out the location of the central meridian of the substorm.*

The results of the profiles examination are summarized in Table 1. In the rows from up to down the following quantities are given: the boundaries of the MPB presence by geomagnetic latitude, the latitude of the maximum value of the MPB and the interval of latitudes for the maxima in the different longitudinal intervals, the latitudinal extent of the MPB, the MPB boundaries by geomagnetic longitude, the longitude of the MPB maximal value, the longitudinal extent of MPB, and the geomagnetic longitude, where the Y variations cross the 0 line and from positive become negative.

From the upper panels of Figure 4 it is seen, that the latitudinal dependence of the X variations is as follows: after the sign conversion latitude X increases to the lower latitudes, reaches a maximum close to it, and decreases gradually. This confirms our previous results about the behavior of the MPB amplitude from the sign conversion latitude to lower latitudes (Guineva et al., 2021a, b). It is seen also, that the maximal value of X variations is located at different latitude for the different longitudinal intervals.

Table 1. *Results for the MPB latitudinal and longitudinal limits to 0 nT (black colour) and to 5 nT (blue colour), for the location of the maximal value and the central meridian of the substorm*

UT:	23:16	23:27	23:40
MLAT limits	~14°-67° ~40°-65°	~14°-60° ~23°-60°	~14°-63° ~23°-63°
Max at	58°(51°-59°)	53°(53°-58°)	61°(56°-62°)
Lat. extent	~53°(~25°)	46°(~37°)	~49°(~40°)
MLON limits	~60°-120° ~70°-104°	~60°-156° ~70°-120°	~60°-200° ~70°-140°
Max at	~82°	~82°	~102°
Long. extent	~60° (~34°)	~96°(~50°)	~140°(~70°)
Y_0	~84°	~84°	~106°

The latitudinal and longitudinal extent increase during the chosen interval of substorm development, which is during the substorm expansion phase.

In longitudinal direction, maximal variations are observed near the substorm meridian.

Development of the substorm to the West resulting from the westward electrojet progress is observed.

6. Conclusions

The development of the substorm at ~23:07 UT on 22.03.2013 is presented in detail. Maps of the X and Y magnetic components in the range 38°÷68° geographic latitude, -5°÷ 35° geographic longitude, as well as longitudinal and latitudinal profiles for 3 moments of the substorm development: 23:16 UT, 23:27 UT (max. development) and 23:40 UT have been constructed.

By the use of the maps and the profiles, the following the following parameters were estimated: the central meridian of the substorm, the sign conversion latitude, the longitudinal and latitudinal extent. The central meridian is near PAG (~37°MLAT, ~97°MLON): it is at ~84°MLON during the first two chosen times and at ~106° MLON at the third time. The sign conversion latitude is in the range 60°-67°MLAT, the latitudinal extent – from 46° to 53°, and the longitudinal extent – from 60° to 140° during the stage of the maximal development of the substorm.

Similar results were obtained in previous investigations of expanded substorms.

In latitudinal direction, after the sign conversion latitude X increases fast to the lower latitudes, reaches a maximum, and after decreases gradually. This confirms our previous results about the behavior of the MPB amplitude from the sign conversion latitude to lower latitudes.

In longitudinal direction, maximal variations are observed near the substorm meridian.

The latitudinal and longitudinal extent increase during the chosen time interval of the expansion phase of the substorm.

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