ASSESSMENT OF SOME SUBSTORM PARAMETERS BASED ON THE MIDLATITUDE POSITIVE BAYS AND THE MPB INDEX MAXIMA

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Abstract: *Magnetospheric substorms effect on the ground magnetic field is expressed as negative bays at auroral latitudes and positive bays (MPB) at midlatitudes. In most of the cases the magnetic disturbances at high latitudes are accompanied by midlatitude positive bays. The MPB index, recently introduced by McPherron and Chu, is a measure of the field aligned currents, connected to the electrojet. The magnetic disturbances during two substorms, at 23:10 UT on 22.03.2013 and at 22:49 UT on 11.05.2015 were examined in detail. The MPB index for both events was computed by data of 16 European stations. The beginning and end of the MPB index maxima were determined, based on smoothing by moving average and by inspection of the consecutive minima before and after the MPB index maximum, calculated by the first derivative of the MPB index variations. Criteria to choose the minima of the beginning and end of the MPB index maximum have been discussed and set. Some basic substorm parameters have been determined by the MPB index. The variations in the X magnetic component series from more than 30 European stations in the range 25°-55° GMlat have been studied in the same way. Graphs of the midlatitude onset delay in reference to the first onset as a function of the longitude have been constructed and analysed.*

ОПРЕДЕЛЯНЕ НА НЯКОИ ПАРАМЕТРИ НА СУББУРЯТА ПО СРЕДНОШИРОТНИТЕ МАКСИМУМИ И МАКСИМУМИТЕ В MPB ИНДЕКСА

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Резюме: *Влиянието на магнитосферните суббури върху магнитното поле на земната повърхност се изразява във вид на минимуми в X компонентата му на авроральни ширини и максимуми на средни ширини. В повечето случаи магнитните смущения на високи ширини са съпътствани от максимуми (MPB) на средни ширини. MPB индексът, въведен наскоро от McPherron and Chu, е мярка за надлъжните токове, свързани с електроджета. Разгледани са подробно магнитните смущения по време на две суббури, в 23:10 UT на 22.03.2013г. и в 22:49 UT на 11.05.2015 г. MPB индексът за двете събития е пресметнат по данни от 16 европейски станции. Определени са началото и краят на максимума в MPB индекса след прилагане на изглаждане по метода на пълзящите средни и разглеждане на последователните минимуми преди и след максимума на MPB индекса, пресметнати по първата производна на вариациите на MPB индекса. Дискутирани са критериите за избор на началния и крайния минимуми на пика на MPB индекса. По MPB индекса са определени някои основни параметри на суббурите. По същия начин са изследвани вариациите на X компонентата на магнитното поле, определени по данни от повече от 30 европейски станции в областта от 25° до 55° геомагнитна ширина. Построени и анализирани са зависимостите на закъснението на началото на смущението на средни ширини по отношение на най-ранното смущение в зависимост от географската дължина.*

Introduction

Magnetospheric substorms are a substantial feature of the space weather. They are a considerable source of magnetic activity [1]. An electric current, originated in the tail of the magnetosphere, flows along the magnetic field lines and through the ionosphere, forming the substorm current wedge [2]. The effect of magnetospheric substorms on the surface magnetic field consists of disturbances, representing negative bays at auroral latitudes and positive bays at midlatitudes in the X component of the magnetic field. The midlatitude positive bays have been used in a number of papers for the study of substorms. The onset of the midlatitude positive bays (MPB) can be used as a sign of the beginning of the substorm expansion phase [e.g. 2, 3, 4]. Lately a new index was built, the MPB index, which represents the average horizontal power of the magnetic field at midlatitudes [4]. It can be used to determine the time of auroral expansion onset and as a measure of the substorm strength. Different kinds of maps and profiles of the temporal and spatial distribution of the magnetic disturbances have been created in the purpose to study the substorm development and to estimate some substorm parameters [e.g. 5, 6].

This study is orientated to the formation of a way to assess the beginning and end of the midlatitude positive bays (MPB) and of the peak in the MPB index associated with substorms, as well as to study the substorm expansion by the MPB onsets in a large area. Two isolated substorm events with central meridian over Europe have been chosen for the study: at 23:10 UT on 22.03.2013 and at 22:49 UT on 11.05.2015.

Data used and processing method

For the study, magnetic field data from the INTERMAGNET, IMAGE and SuperMAG databases have been used. Data from 38 midlatitude European stations and from 4 Asian stations in the range 25°-55° GMlat have been used. The following stations have been included in the study: BDV, BEL, BOX, BRZ, CLF, DUR, EBR, ESK, FUR, HAD, HLP, HRB, IZN, KIV, KRT, LVV, MNK, MOS, NGK, PAG, PEG, SFS, SPT, SUA, SUW, THY, VAL, WNG, KAR, BFO, ROE, BFE, ARS, NVS, IRT, CNH.

Two isolated substorms in non-storm conditions with central meridians over Europe have been chosen: a usual substorm, at 22:49 UT on 11.05.2015, and an expanded substorm, at 23:10 UT on 22.03.2013.

To obtain the magnetic variations at the earth surface, the main field and the mean Solar quiet magnetic variations taken away, we used the created processing tool, described in [7,8], based on the algorithm by McPherron and Chu [4]. The program was applied to process the magnetic field components registered at the stations enumerated above in order to examine the midlatitude positive bays and to determine their basic characteristics. For each of the examined substorms 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. The European MPB index was obtained by averaging the horizontal power of the magnetic field at 16 stations located in Middle Europe. In Fig. 1 the locations and the abbreviations of the station names are given. The red ellipses indicate the stations which data were used to compute the MPB index of the substorm on 22.03.2013, and the blue ones – the MPB index of the substorm on 11.05.2015.

Determination of the onset and end of the MPB index peak and X component positive bays

To determine the extrema marking the onset and end of the peaks in the MPB index and X magnetic component series associated with the examined substorms, the first derivative of these series has been computed. The derivative points intersecting the zero line from negative to positive values mark the times of data minima, and the points, intersecting the zero line from positive to negative values indicate the times of data maxima. Our experience has shown that some additional smoothing of the MPB index and X component variations was needed in order to avoid some false extrema. After the study carried out a smoothing by the use of 5 points moving averages method has been applied.

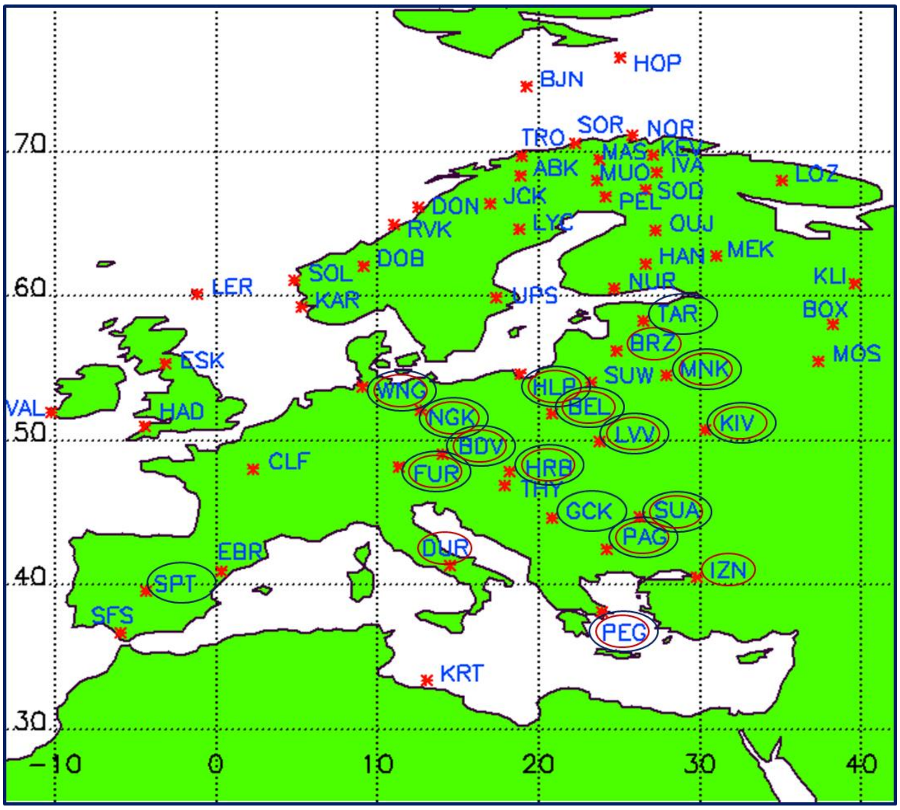

Fig. 1. Stations, used to compute the European MPB index. The red and blue ellipses indicate the stations, which data were used to obtain the MPB index of the substorms on 22.03.2013 and 11.05.2015, respectively.

Several conditions to choose the onset and end minima have been set. They can be summarized as follows:

- Criterion (1) to accept a following minimum: the ratio of the X component drop from the maximum to this minimum to the X drop to the previous minimum is greater or equal to 1.2:

  $$(X_{max}-X_{min,n})/(X_{max}-X_{min,n-1})\geq 1.2,$$

  where X_{max} is the value of the MPB maximum, $X_{min,n}$ is the n^{th} minimum earlier or later from X_{max} time, and $X_{min,n-1}$ is the $(n-1)^{th}$ minimum.
- Criterion (2): if criterion (1) is not met, but $X_{min,n}>0$, then the following check is made: the ratio of the current minimal to the maximal values is greater or equal to 0.4:
  $X_{min,n}/X_{max} \geq 0.4$
- The search for a minimum is no longer than one hour before or after the X time maximum;
- If the minimum is of a single value, it can be neglected, and the search continue;
- If the values of the consecutive ratios, described above, are steadily decreasing the search can stop;
- If $X_{min,n}>X_{min,n-1}$ and continue to increase, the search can stop.

These conditions are set to obtain the beginning and end minima of the midlatitude positive bays in the X component of the magnetic field. The same conditions are used to obtain the onset and end minima of the MPB index peak.

In Fig. 2 and Fig. 3, the determination of the onset and end minima of the MPB index peaks on 11.05.2015 and 22.03.2013, respectively, based on the enumerated above conditions, is illustrated.

The MPB index peak on 11.05.2015 has a simple form (fig.2). So, the first derivative crosses the zero line only 3 times during the peak and the extrema are easily assessed. The red vertical lines mark the onset (1) at 22:49 UT, the maximum (2) at 23:03 UT (609 nT^2), and the end of the peak (3) at 23:33 UT. The green horizontal line indicates the 2σ level (σ=61.55 nT^2). The duration of the peak from the onset to the end is 44 min., the duration at 2σ level is 22 min. and the area of the peak is 9034.

The MPB peak on 22.03.2013 has more complicated shape, including 3 consecutive maxima (Fig. 3). This example gives an idea about the difficulties to determine the onset and end of the peak, especially by computer simulations and about the need of imposing some conditions to the onset and end minima. This shape is may be connected to the strong indentation of the negative disturbanses in the X component at auroral latitudes (not presented here).

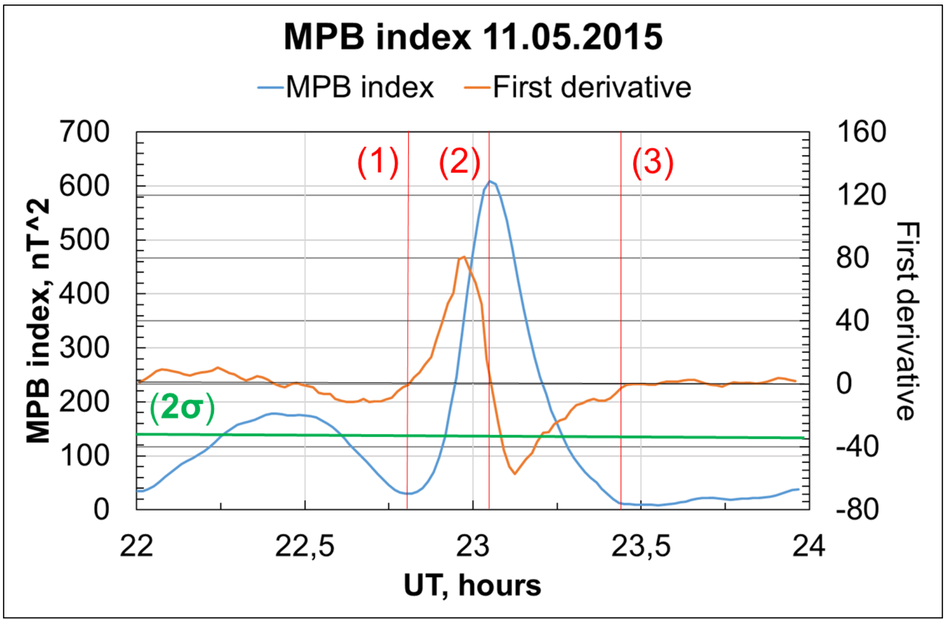

Fig. 3. Determination of the onset, max and end times of the MPB index peak on 11.05.2015: (1) onset time, 22:49 UT; (2) time of the maximum 23:03 UT, 609 nT^2; (3) end time 23:33 UT

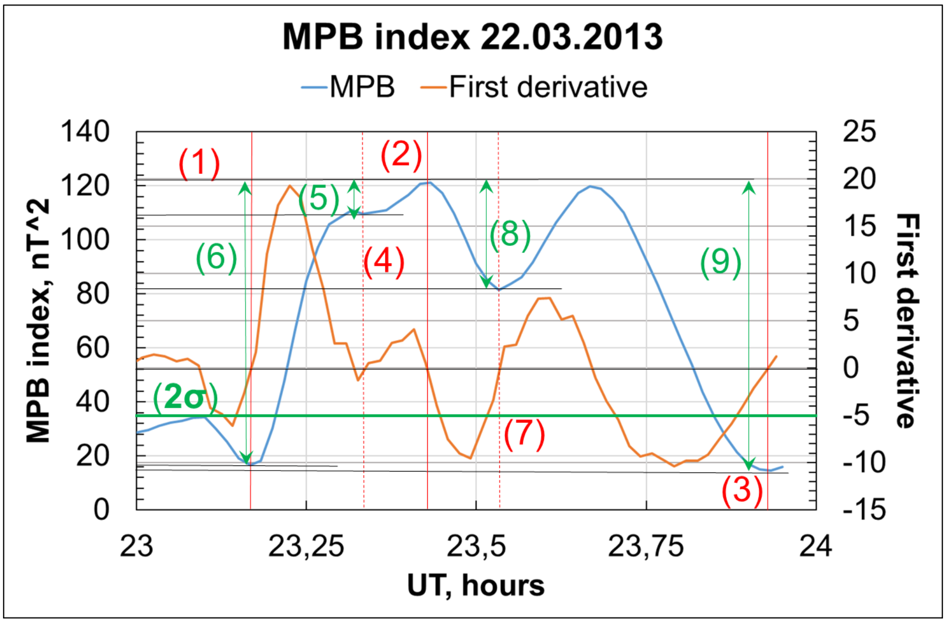

Fig. 3. Determination of the onset, max and end times of the MPB index peak on 22.03.2013: (1) onset time, 23:10 UT; (2) time of the maximum 23:26 UT, 121 nT^2; (3) end time 23:56 UT; (4) intermediate min 1; (5) drop to the intermediate min 1; (6) drop to the beginning min [(6)/(5)=9.09>1.2]; (7) intermediate min 2; (8) drop to the intermediate min 2; (9) drop to the final min [(9)/(8)=2.68>1.2].

The red vertical lines mark the determined onset (1) at 23:10 UT, maximum (2) at 23:26 UT (121 nT^2), and end of the peak (3) at 23:56 UT. Two intermediate minima at both sides of the maximum are indicated by red dotted lines numbered (4) and (7). Criterion (1) was applied for minimum (4). The differences between the maximum and minimum (4) and the onset minimum, named "drop" in the criterion definition, are marked by green arrowed lines (5) and (6), respectively. The obtained ratio of these differences, namely (6)/(5)=9.09 and meet the condition to be greater than 1.2. This result ensure that the slope of the peak continues to decrease fast and minimum (4) doesn't represent the onset of the peak. The same procedure was implemented for minimum (7). The differences ratio (9)/(8)=2.68 is greater than 1.2 and shows that minimum (7) is not the end of the MPB index peak. The green horizontal line indicates the 2σ level (σ=17.7 nT^2). The duration of the peak from the onset to the end is 46 min., the duration at 2σ level is 39 min. and the area of the peak is 3878.

Applying the specified conditions to the examined midlatitude positive bays (MPB) registered at the 42 magnetic stations during the two substorms has shown, that they are adequate to determine the onset and end of the peaks and some other peaks characteristics.

MPB onsets distribution

In an ideal case, the substorm onset occurs near local midnight, it is sharp and isolated. But in previous studies it was shown, that substorm onsets and the subsequent substorm development can be quite various and complicated [e.g., 5, 6]. In most of the cases, during the substorm there are several consecutive intensifications, resulting in several expansion onsets. Moreover, the consecutive onsets may be located at the same meridian, but they may also shift to different longitudinal sectors thus giving the expression of a westward or eastward motion of the substorm [5].

We constructed the dependence of the midlatitude onset delay in regard to the earliest onset from the degrees of longitude away from the longitude of the first onset for the examined substorms. The obtained dependences for the substorms on 11.05.2015 and 22.03.2013 are presented in Fig. 4 and Fig. 5, respectively. On the secondary y axis the onset time in UT is given, and on the secondary x axis – the geographic longitude of the stations.

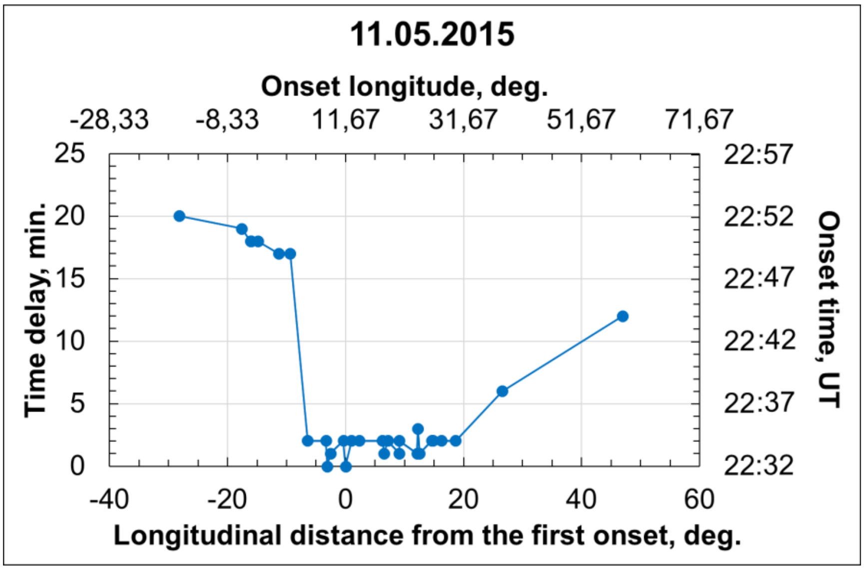

Fig. 4. Midlatitude onset delay depending on the longitudinal distance from the first onset for the substorm on 11.05.2015

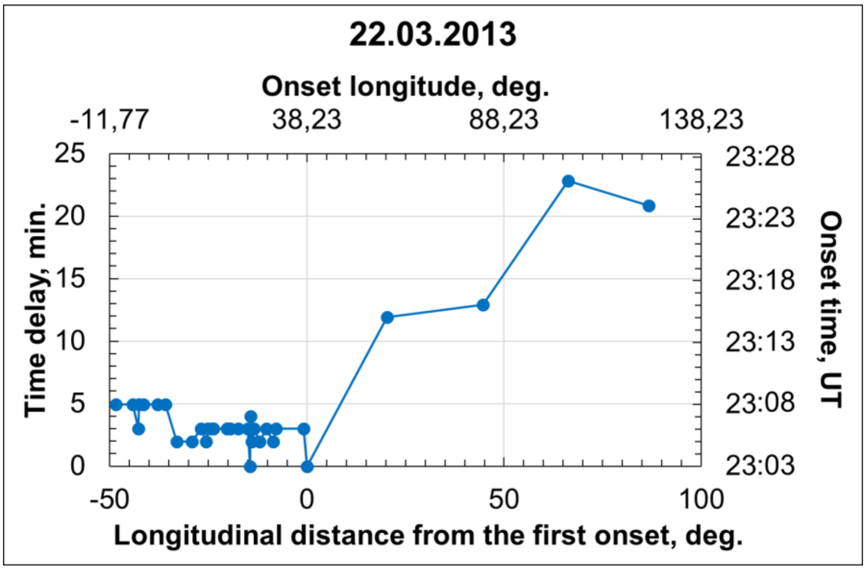

Fig. 5. Midlatitude onset delay depending on the longitudinal distance from the first onset for the substorm on 22.03.2013.

The graph of the substorm onset delay for the substorm on 11.05.2015 (fig.4) shows, that the substorm has begun first in a longitudinal area of about 30° (~0° - 30° lon.). About 15 min. later, a second onset is observed, in a different local time sector (in the range of ~ -20° to ~0° lon.). In the range from~30° to ~55° lon. a supple motion of the onset is observed for about 10 minutes, may be related to a supple movement of the eastern edge of the current wedge further to the East. This complicated substorm onset distribution is not expressed in the MPB index shape, because the MPB index is computed for the region of Middle Europe, and west Europe and Asia stations are not included in the computations by reason of the less number of magnetic stations in these regions.

In fig.5 it is seen, that the MPB onsets on 22.03.2013 were first in the range from ~5° to ~40° lon. About 2-3 min. later, one other onset is observed to the west (~ -10° - ~5° lon.). Motion of the onsets to the East is observed as well, but in this case it is not smooth. May be there are several onsets, and the eastern edge of the current wedge is propagating to the east with each onset. Such behavior is described by Clauer and McPherron [5].

Summary

The midlatituide positive bays during two substorms, on 11.05.2015 and 22.05.2015 have been studied in detail. Conditions to choose the onset and end minima of the MPB index peaks and of the MPB's have been specified. In the process of determination of the onsets and ands of the peaks it was found out, that they are adequate to determine the onset and end of the peaks and some other peaks characteristics. Thus, this way to determine the MPB's and MPB index peaks parameters may be used to develop a program for computer computation of these quantities.

The onsets distribution has been examined. It was shown that in both cases, there were two or more onsets in different longitudinal ranges, e.g. in different local time sectors.

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