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Determination of the Parameters of Midlatitude Positive Bays Caused by Magnetospheric Substorms

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6. Abstract.

Magnetospheric substorms are an important feature of the space weather. Apart of the variety of phenomena that they provoke, they influence the magnetic field at the Earth surface. Negative X-bays at auroral latitudes and positive bays in the X magnetic component at midlatitudes known as midlatitude positive bays (MPB) are observed. The study of the MPB development serves in the investigation of the solar-magnetosphere coupling during the substorm progress. At the Space Research and Technology Institute of the Bulgarian Academy of Sciences, the magnetic variations at Panagjurishte were calculated, based on data by the Bulgarian magnetic station Panagjurishte (PAG) with the main goal to determine the variations related to the substorm activity (MPB) and estimate the MPB main parameters. In this work we described the development of a processing tool to determine the beginning and end of the MPB registered at PAG. The tool is based on smoothing by moving average and by inspection of the consecutive minima of the X-component before and after the MPB maximum, calculated by the first derivative of the X variations. The MPB amplitude was obtained by the difference between the MPB maximum and the X value at the MPB beginning. Criteria to choose the minima of the beginning and end of the MPB have been specified. A minima find algorithm has been worked out and applied to specific cases. All results were made available to the scientific community by a created catalog, described also in this paper.

Keywords: *midlatitude positive bays (MPB), catalog of magnetic variations, MPB parameters*

7. Introduction

Substorms are a typical phenomenon, associated with many processes in the magnetosphere and ionosphere, summarized by Akasofu (2004). During magnetospheric substorms, a big amount of energy is released from the magnetospheric tail into the ionosphere and inner magnetosphere [Akasofu, 1968]. Magnetospheric substorms are the cause for the major disturbances in the Earths magnetic field. As it is well known, at auroral latitudes negative bays in the X (North) magnetic component at ground are observed [Akasofu, 1964]. It is also known, that during large magnetospheric substorms the negative bays at auroral latitudes are accompanied by positive bays in the X component at midlatitudes. [Akasofu, 1968; McPherron et al., 1973]. Moreover, a systematic variation of the Y (East) component is observed in the same time. First, the presence of MPB was explained with low latitude return currents of the westward electrojet [Akasofu et al., 1965]. Later, the positive bays were associated to the upward field-aligned currents [Meng and Akasofu, 1969]. The accepted theory at present is, that the midlatitude positive bays are the result of a current system, namely the Substorm Current Wedge (SCW) [McPherron, 1972; McPherron et al., 1973]. SCW is formed, when the tail current is deviated along the magnetic field lines through the ionosphere. The magnetic variations at midlatitudes during substorms have been used as tools for the study of magnetospheric substorms by a lot of authors. MPB's appear a good indicator of substorm onset [e.g. Hones et al., 1971; Mende et al., 1972; McPherron, 1972; McPherron and Chu, 2017]. The sign of the Y component can be used to deduce whether the direction of the field aligned currents is down or up in the ionosphere at the longitude of a given station [Meng and Akasofu, 1969]. A method to determine the geomagnetic longitude of the auroral substorm onset was worked out [Rostoker et al., 1980, Sergeev and Tsyganenko, 1980]. Thus, the study of the midlatitude positive bays and the estimation of their parameters can be very useful in the magnetospheric substorms research.

At the Space Research and Technology Institute of the Bulgarian Academy of Sciences, an original catalog of the magnetic variations at Panagjurishte is developed, based on data by the Bulgarian magnetic station Panagjurishte (PAG) (~37° GMLat, ~97° GMLon), as one of the tasks of a bilateral project Bulgaria – Russia. The catalog is available at: http://space.bas.bg/Catalog_MPB/. The objectives of this work are to create a processing tool to determine automatically the basic parameters of the midlatitude positive bays registered at PAG and to use it to complete the Panagjurishte station catalog of the magnetic variations.

8. Content of the catalog of the magnetic variations at Panagjurishte and envisaged additions

In Fig.1, the structure of the catalog, which went through several modifications (e.g. Guineva et al., 2021a, Guineva et al., 2021b) is presented.

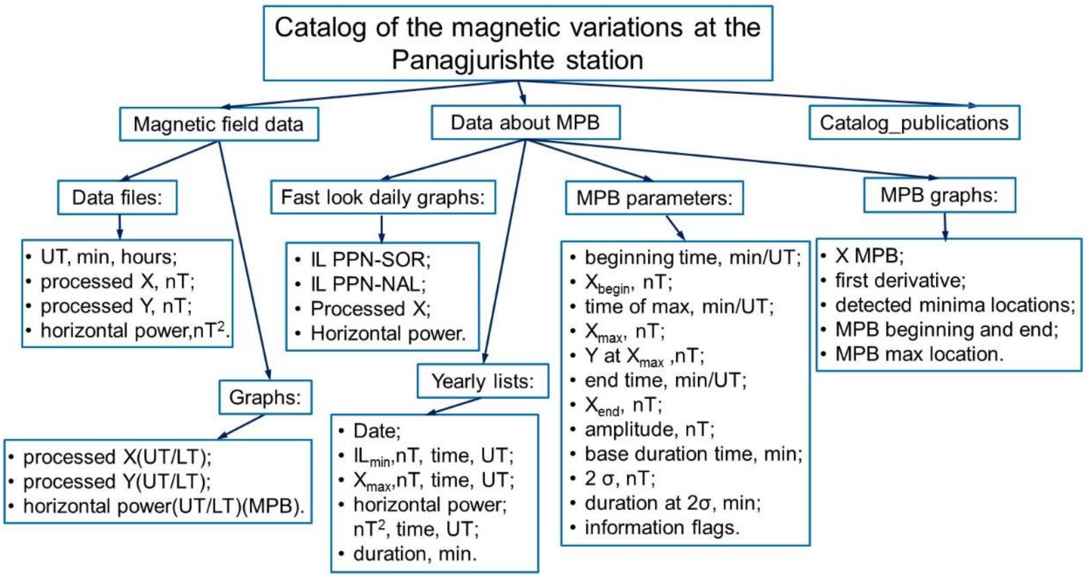

Fig.1. Scheme of the structure of the Catalog of the magnetic variations at the Panagjurishte station.

In the present variant, the catalog comprises three main sections: Magnetic field data, Data about MPB, and Catalog publications. In the section Magnetic field data, the processed X and Y magnetic components and the computed horizontal power of the magnetic field at PAG (subsection Data files), as well as their graphics (subsection Graphs), from 2007 to 2022, are stored. The processing procedure, based on the algorithm by McPherron and Chu [2017] with some new developments is described in Werner et al. (2021a), and Werner et al. (2021b). The second section, Data about MPB, consists of four subsections: Fast look daily graphs, Yearly lists, MPB parameters and MPB graphs. Fast look daily graphs comprises combined graphics, including the IL index, computed for the IMAGE PPN-SOR and PPN-NAL magnetometer station chains, the X-component variations and the horizontal power of the magnetic field. The Yearly lists include data about the cases in which noticeable variations (midlatitude positive bays - MPB) are observed at the time of the substorms, verified by the IL index. In the sections Fast look daily graphs and Yearly lists are uploaded data and graphs from 2007 to 2022. The present work is intended to develop a processing tool to determine automatically the parameters of the MPB's and to create graphs of the MPB's presenting the minima and maxima illustrating the beginning and the end of the MPB's. The data in the sections MPB parameters and MPB graphs were determined based on the procedure described in section 5 of the paper. They are preliminary in the sense of later procedure improves. Section Catalog publications grants access to the papers, describing the catalog or using data from it for some study.

4. Data used

To determine the basic MPB parameters, data from sections Yearly lists and Magnetic field data of the Catalog have been used. Yearly lists are created for the evening sector (18-24 UT) which corresponds roughly to the night sector in LT at Panagjurishte (21-03 LT). They cover cases, meeting the following conditions: the minimal value of the IL index for the PPN-NAL chain in the negative bay exceeds -200 nT (IL_{min}< -200 nT), the negative bay duration at 2σ is greater than 10 minutes and at PAG station a maximum of the X component near the time of the IL minimum, which is g reater than 5 nT, is obtained. From the Yearly lists, the date of the respective case, the maximum of the X component and the time of this maximum are used. From Magnetic field data section, data about the X variations during the day of the respective case are used.

5. Processing procedure to determine the beginning and end of the MPB

The processing procedure consists of several parts: determination of the extrema locations of the X variations, elaboration of criteria to locate the beginning and end of the MPB, application of these criteria to determine the beginning and end of the MPB, determination of other parameters of MPB and creation of files with numerical data about the parameters of every MPB and graphics with MPB.

5.1. Determination of the minima of the X variations development

The minima determination passes through two steps:

Step 1: Smoothing of the data series of the processed X component by 5 points moving average which enables the elimination of some false extrema originating by noise, and facilitates the further computations.

Step 2: Computing the first derivative to obtain the extrema locations (the crossings of the zero line). The crossing from negative to positive values indicates a minimum, and from positive to negative values – a maximum. The beginning and end of the MPB's coincide with a X minimum before and after the MPB maximum, respectively, which are not always the first ones before or after the maximum. We have implemented a search procedure for a minimum in the time interval from 90 minutes before the moment of the X maximum to 90 minutes after it. This interval ensures the evaluation of the correct locations of the beginning and end of MPB. It was estimated based on tests with several years data from PAG.

5.2. Criteria to locate the beginning and end of MPB

To the beginning and end of a MPB, a minimum before and after the MPB maximum, respectively, is assigned. As this may not be the first minimum before or after the MPB maximum, criteria to choose the minima locating the beginning and end of the MPB have been worked out and applied. The following two criteria were taken.

Criterion (1) concerns two consecutive minima: n^{th} and $(n+1)^{th}$. To assume that the n^{th} minimum is not the beginning or end of MPB, the following condition has to be met: the ratio of the X drop from the maximum to the current, $(n+1)^{th}$ minimum to the X drop to the previous minimum is greater or equal to a constant c:

$$\text{ratio}_n = (X_{max}-X_{min,n+1})/(X_{max}-X_{min,n}) \geq c, \quad (1)$$

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, $X_{min,n+1}$ is the $(n+1)^{th}$ minimum and c is a constant. This criterion was introduced by McPherron and Chu (2017). They used c = 1.25. Based on tests of the MPB's registered at PAG, we have chosen 1.20 for the ratio boundary. If condition (1) is met, the n^{th} minimum is not taken as the beginning or end of the MPB, and the check-up continues.

Criterion (2): if criterion (1) is not met, but $X_{min,n} > 0$, then the following check is made: the ratio of the n^{th} minimal value to the maximal one is greater or equal to 0.4:

$$X_{min,n}/X_{max} \geq 0.4 \quad (2)$$

This criterion was accepted based on empirical studies of the PAG data.

If this condition is met, the n^{th} minimum is not taken as the beginning or end of the MPB, and the search continues.

5.3. Determination of the MPB parameters

The following parameters were determined and included in the data file for each detected midlatitude positive bay:

- Beginning time (the time of the MPB beginning, in min., and in hh:mm, UT);
- Xbegin (the value of X at the time of the beginning in nT);
- Time of max (the time of the maximal X value, in min., and in hh:mm, UT);
- Xmax (the maximal value of X in nT);
- Y at Xmax (the value of Y at the time of Xmax in nT);
- Endtime (the time of the MPB end, in min., and in hh:mm, UT);
- Xend (the value of X at the time of the MPB end in nT);
- Amplitude (the amplitude of the MPB, equal to the difference Xmax-Xbegin in nT);
- Base duration time (the MPB duration at the base, equal to endtime-beginning time in min.);
- 2sigma (the 2σ value in nT, computed for the whole day data);
- Duration at 2 sigma (the MPB duration at 2σ level in min.).

5.4. Creation of MPB graphics

For every MPB, a graphic was created. The graphic is designed to give as much as possible visual information about the event. In Fig.2, an example of such graphic is given, for the case of the MPB at 23:05 UT (beginning) on 22.03.2013. In Fig.2, the variations of the X component of the magnetic field are drawn in blue colour. The first derivative of X is drawn by red continuous line. The 2σ level is given by a dotted black line with inscription "2σ" over it. The MPB maximum location is shown by dark red vertical line. The locations of all detected minima are also shown, by green dotted vertical lines. The locations of the minima of the beginning and end of MPB are given by green continuous vertical lines. The maximum, beginning and end of the MPB are indicated by inscriptions, as well. The time interval, in which the graphic is constructed, covers all detected minima in the time range ±90 min. from the MPB maximum. If this range continue in the next day, data from it are used, too, in the computations and drawings. For example, in the presented case MPB is found 7 min. after midnight, and two more minima are detected after it.

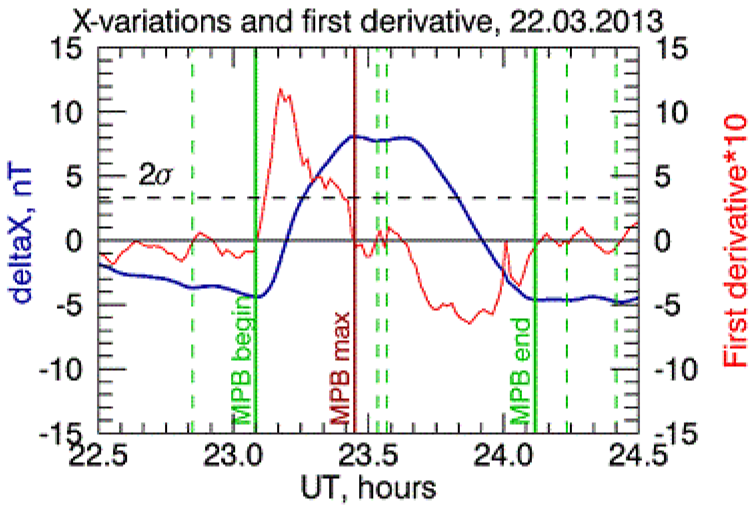

Fig.2. Example of a MPB graphic for a substorm: substorm at 23:05 UT on22.03.2013.

6. Comparison with other authors results

Some of the obtained MPB beginnings were compared with the substorm onsets by Newell and Gjerloev (2011), Forsyth et al. (2015), and Ohtani and Gjerloev (2020), determined from SML index. The results are presented in Table 1. In the consecutive columns the number of the event, the date, the substorm onset times by Newell and Gjerloev (2011), Forsyth et al. (2015), and Ohtani and Gjerloev (2020), the MPB beginning time determined by us, the difference between our result and the results of the other authors in min., and the geomagnetic longitude of the substorm meridian, determined in the cited papers. For more clarity, the results by different authors are given in different colours. The results by Newell and Gjerloev (2011) are written in blue colour, the ones by Forsyth et al. (2015) – in green colour, and the ones by Ohtani and Gjerloev (2020) – in red colour.

From the column next to the last it is seen, that the MPB beginnings at PAG, determined in this work, are close to the substorm onsets. Taking into account, that the substorm meridians are also close to the longitude of Panagjurishte (at maximum distance of about 15°), the results appear reasonable. It is well known, that the beginning of MPB's can be used as indicator of the substorm onset [e.g. Hones et al., 1971; Mende et al., 1972; McPherron, 1972; McPherron and Chu, 2017]. As substorm onset, the time of the earliest beginning of MPB is taken, and the longitude of the station of this MPB is accepted as the substorm meridian. The negative bays in the auroral zone may sometimes precede this onset, and if this is the case, Clauer and McPherron (1974) suppose that the disturbances in the auroral zone, before the onset at midlatitudes are the appearance of small localized disturbances in the magnetosphere, which have no effect at midlatitudes. In our cases, the reason for later MPB beginning may be also the fact, that the station PAG, although near the substorm meridian, howsoever is located at some degrees apart.

Table 1. Some substorm onset times estimated by SML index, and the MPB beginnigs, obtained in this work.

№	date	Substorm onset time (Newell and Gjerloev, 2011)	Substorm onset time (Forsyth et al., 2015)	Substorm onset time (Ohtani and Gjerloev, 2020)	MPB beginning time (this work)	Δt, min.	GMlon (PAG: ~97° GMlon)
1	02.01.2015	22:11	22:11		22:05	-6	107.29, 114.46
2	04.01.2015	22:36	22:26		22:35	-1, 9	106.15, 106.15
3	05.01.2015	-	21:32		21:21	-11	104.95
4	08.01.2015	-	21:49	21:54	21:54	-5, 0	108.61, 106.46
5	25.01.2015	23:11	23:09	23:05	23:09	-2, 0, 4	100.42, 114.46, 106.46
6	31.01.2015	22:52	22:36		22:41	-11, 5	107.29, 114.46
7	21.02.2015	23:09	-	23:04	23:09	0, 5	109.43, 114.46, 106.21
8	17.03.2015	22:56	-		23:05	9	115.13
9	26.03.2015	23:22	23:16	23:11	23:26	4, 10, 15	95.33, 114.46, 100.42
10	03.04.2015	23:32	23:26		23:19	-13,-7	106.21, 101.82
11	26.12.2015	21:23	20:58		21:03	-20, 5	109.62

More interesting are the cases, when the determined MPB beginning at PAG is some earlier than the sumbtorm onsets, estimated by auroral zone data. We tried to find an explanation of such cases. In most of the cases, the substorms are not isolated. If several consecutive substorms develop, the conditions in the time between them cannot quieten down, and there are magnetic disturbances between the substorm disturbances. In that sort of cases, it is difficult to estimate whether the smaller disturbances between the substorms are the result of localized or global events in the magnetosphere. We assume that the onsets, determined by MPB beginnings, can help to resolve this problem. In Fig.3, an example is given for the event on 03.04.2015, for which the MPB beginning at PAG is earlier than the substorm onsets, determined by Newell and Gjerloev (2011) and Forsyth et al. (2015) (see Table 1). In the left panel of Fig.3, the IL index, computed for the IMAGE PPN-NAL chain, is presented. It is seen, that after 20 UT, two consecutive substorms develop. The examined event is the second one, preceded by a substorm at about 21:12 UT. The blue vertical line shows the sharp decrease of the IL index at 23:32 UT. This time coincides with the substorm onset, determined by Newell and Gjerloev (2011). The red vertical line indicates the obtained MPB beginning time at PAG. It would be difficult to set a boundary at that time, especially by a processing procedure.

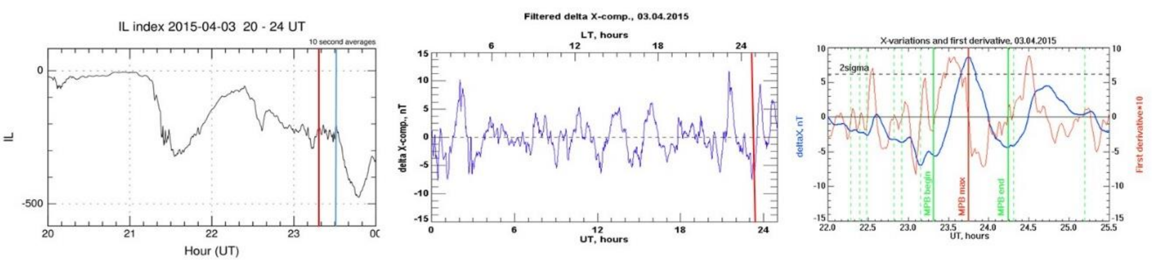

Fig.3. Example of a case when the determined MPB beginning at PAG is earlier than the substorm onsets estimated by auroral zone data. In the left panel, the IL index by the IMAGE PPN-NAL chain is given, the central panel presents the obtained X variations for the day, and the right panel is the MPB graphic for the event.

In the central panel, the variations of the X component on 03.04.2015 are given. The red vertical line points at the MPB beginning for the event under examination. The right panel is the MPB graphic for this case (its appearance is described in section 5.3). The MPB beginning is clearly seen, it coincides with the first minimum before the MPB maximum. Maybe the disturbances after 23:19 UT are provoked by the beginning of the global magnetospheric disturbances.

After McPherron (1972) MPB is a good indicator of the substorm onset, it is coincident with the auroral expansion and less sensitive to interference from small details in the electrojet.

We suppose that the beginning of global magnetospheric disturbances as the substorm current wedge (SCW) is, and respectively the substorm onset, is easily determined by the midlatitude positive bays beginnings.

7. Results and conclusions

- A program tool to compute automatically the parameters of the midlatitude positive bays, registered at Panagjurishte station was developed, including application of criteria to locate the beginning and end minima of the midlatitude X positive bays (MPB);
- The program was tested on different cases of MPB from 2015 and 2013;
- The content and design of the MPB graphs and the MPB parameters files were specified;
- The obtained MPB beginning times are close to the substorm onsets determined from the SML index by Newell and Gjerloev (2011), Forsyth et al. (2015) and Ohtani and Gjerloev (2020). Some of them are later than the substorm onsets, and the others are earlier than the substorm onsets, determined based on the SML index. We suppose that this is due to small scale magnetospheric perturbations, superimposed on or border the global disturbances. We came to the conclusion, that the substorm onsets are more easily and accurately determined by the midlatitude positive bays data from a global or regional set of midlatitude magnetic stations.

The processing of all yearly lists and the addition of the MPB images and MPB data files in the MPB Catalog are forthcoming.

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