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A METHODOLOGY TO ESTIMATE THE MPB PARAMETERS

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Abstract. The midlatitude positive bays (MPB) represent a mark of the development of substorms at auroral latitudes. To have a knowledge of their parameters could serve as a tool to obtain more information about the magnetospheric substorms onset and progress. In the purpose to enable the study of the various phenomena related to the substorm disturbances and their propagation to mid-latitudes, an original catalog of the variations of the magnetic field at midlatitudes at the Bulgarian station Panagyurishte (PAG) was created for the period 2007 - 2022. The MPB parameters are part of this catalog. To estimate the MPB parameters, a special methodology was worked out. The beginning and end of the MPB's were determined, based on smoothing by moving average and by inspection of the consecutive minima before and after the MPB maximum, calculated by the first derivative of the X component of the magnetic field variations. Criteria to choose the minima of the beginning and end of the MPB have been discussed and set. For each specified case, a graphic of the positive bay with some parameters marked in it, and a file with the determined parameters and some flags, giving information about the concrete positive bay, have been created. These results can be accessed in the Catalog of the magnetic variations at the Panagyurishte station, located on the website of the Space Research and Technology Institute, BAS, Bulgaria (http://space.bas.bg/Catalog_MPB/).

Introduction

Magnetospheric substorms, as one of the basic characteristics of the space weather, govern a range of disturbances in the Earth magnetosphere. The modern understanding is, that during magnetospheric substorms, a current system forms, namely the so-called Substorm current wedge (SCW) [e.g. *McPherron*, 1972; *McPherron et al.*, 1973a], by the deviation of the tail current along the magnetic field lines through the ionosphere and the formation of auroral electrojets, in the east and west direction. The auroral electrojets have been studed since the 1970s [e.g. *McPherron et al.*, 1973b; *Kisabeth and Rostoker*, 1974]. The substorm current wedge produces the main disturbances in the Earth magnetic field. At the Earth surface, negative bays of the X-component at auroral latitudes and positive bays of X at midlatitudes, called midlatitude positive bays (MPB) are observed. These disturbances arise during the expansion of the magnetospheric substorms [e.g. *McPherron*, 1972; *Kepko et al.*, 2014]. The magnetic disturbances at the Earth surface have been used in a number of studies of the magnetospheric substorms. The midlatitude magnetic variations can serve as a powerful tool in the investigation of magnetospheric substorms. By way of example, the midlatitude positive bays are a good indicator of the substorm onset [*McPherron and Chu*, 2017], and the sign of the Y component was used to appreciate the direction of the field aligned currents at a given longitude [*Meng and Akasofu*, 1969].

Due to the possibility of using mid-latitude magnetic disturbances in the study of magnetospheric substorms for an even better understanding of the ongoing phenomena and determination of substorm parameters, a catalog of the magnetic variations at the Bulgarian Panagyurishte station was created for the time interval 2007 – 2022 [*Guineva et al.*, 2023a; 2023b; 2023c]. The parameters of the detected midlatitude positive bays are part of the catalog. The purpose of this work is to describe the methodology developed to determine the MPB parameters and to present some examples.

Description of the methodology of the MPB parameters estimation

To assess the MPB parameters, a special methodology has been developed. It covers several steps: determination of the minima and maxima in the vicinity of the MPB maximum, determination of the MPB beginning and end, determination of some additional parameters, concerning the MPB's, and determination of several flags, releted to the peculiarities in the estimation of the MPB parameters.

Determination of the minima and maxima in the vicinity of the MPB maximum

The first step of the determination of the MPB parameters is the determination of the extrema around the MPB maximum. This is the preliminary process needed to estimate the MPB beginning and end. It was described in *Guineva et al.* [2023]. First, a smoothing of the daily X data series by 5 points moving average is accomplished in order to avoid some small false minima and maxima and to facilitate the procedure. After that the first derivative is computed to obtain the extrema positions. Minima in the time interval ±90 min. from the MPB maximum have been taken under

consideration. This time interval was obtained experimentally with the data from 2013 and 2015. In case if to the end of the day there were less than 90 min., the minima search continues in the next day data.

Determination of the beginning and end of the midlatitude positive bays

To determine which minima before and after the MPB maximum can be accepted for beginning and end of the MPB, two criteria have been developed and applied, described in detail in *Guineva et al.* [2023a].

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

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

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 accepted as the beginning or end of the MPB, and the check-up continues.

When criterion (1) is no more satisfied, but $X_{min,n} > 0$, the second criterion, Criterion (2) is applied. It consists in the following check: whether the ratio of the n^{th} minimal value to the maximal one is greater or equal to 0.4:

$$Xmin,n/Xmax \geq 0.4 \quad (2)$$

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

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

In the MPB data files, the beginning and end times of the MPB were included in two formats: in min., and in hh:mm, UT, as well as the values of X at these moments (X_{begin} and X_{end}).

Other parameters, included in the MPB data file

In order to get a more complete picture of each particular midlatitude positive bay, in addition to the MPB beginning and end times, several other parameters concerning the MPB, are included in the data file. These are the value X_{max} and the time of the maximum, the value of Y at the time of X_{max}, the amplitude of the MPB, equal to the difference X_{max}-X_{begin}, the base duration time (the MPB duration at the base, equal to end time-beginning time in min.), the 2σ value, computed for the whole day data, and the MPB duration at 2σ level.

Flags about the peculiarities in the MPB beginning and end determining

To get an idea at a glance, from the MPB data files, about the peculiarities of determining the MPB beginning and end, several flags have been introduced that are included at the end of the files. The flags concern the determining of the MPB beginning (flagbegin), the determining of the MPB end (flagend), and the stability of the MPB maximum (flagxcheck). The flags have the following meanings:

flagbegin=0 – the beginning meets the conditions set;

flagbegin=1 – there is not found a minimum in the 90 min. interval before the MPB maximum; as MPB beginning the boundary of this interval is taken;

flagbegin=2 – only one minimum was found before the maximum and it is taken as MPB beginning;

flagbegin=3 – the last ratio $(X_{max}-X_{min,n+1})/(X_{max}-X_{min,n}) \leq 1.2$, but $X_{min,n}/X_{max} > 0.4$. In this case the last minimum $X_{min,n+1}$ time is taken as MPB beginning;

flagbegin=4 – the last ratio $(X_{max}-X_{min,n+1})/(X_{max}-X_{min,n}) > 1.2$. Then the time of the last minimum $X_{min,n+1}$ is taken as MPB beginning.

The meaning of the values of flagend is the same as for flagbegin:

flagend=0 – the end meets the conditions set;

flagend=1 – there is not found a minimum in the 90 min. interval after the MPB maximum; as MPB end the boundary MPB_{max}+90 is taken;

flagend=2 – only one minimum was found after the maximum and it is taken as MPB beginning;

flagend=3 – the last ratio $(X_{max}-X_{min,n+1})/(X_{max}-X_{min,n}) \leq 1.2$, but $X_{min,n}/X_{max} > 0.4$. In this case the last minimum $X_{min,n+1}$ time is taken as MPB end;

flagend=4 – the last ratio $(X_{max}-X_{min,n+1})/(X_{max}-X_{min,n}) > 1.2$. Then the time of the last minimum Xmin,n+1 is taken as MPB end.

The flagxcheck flag gives information about the stability of the MPB maximum or whether there are two consecutive maxima at less than 30 min. from each other.

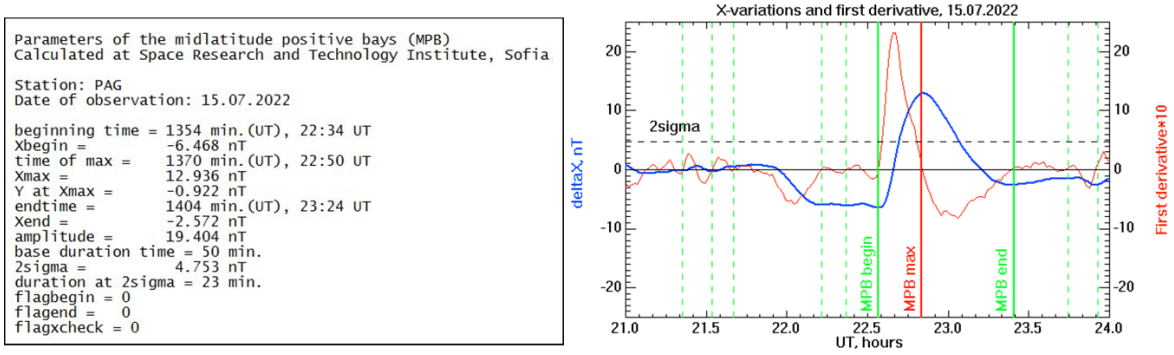
flagxcheck=0 – the maximum keeps its position after the smoothing;

flagxcheck=1 – the maximum moved from its initial position.

It is seen, that a given case is "normal", is the flags values are 0 or 2, i.e. the MPB boundaries meet the conditions set, or there is only one minimum in the searched interval, respectively. Otherwise, there were some peculiarities in the assessment of the boundaries, which have to be taken into account when considering such cases.

Presentment of the midlatitude positive bays in the created catalog

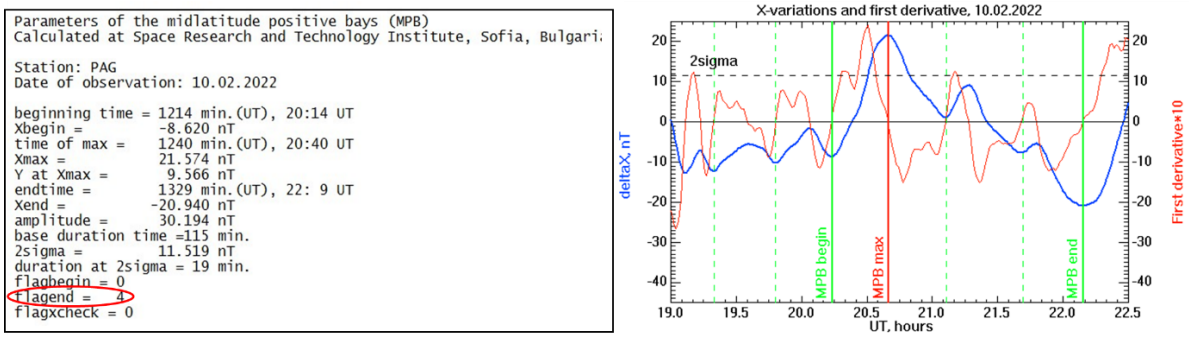
In the catalog of the variations of the magnetic field at midlatitudes at the Bulgarian station Panagyurishte, the midlatitude positive bays are presented by a file, containing the parameters and flags, described above, and by a graphic, in which some parameters have been indicated. In Fig. 1a, b, an example of MPB data file and graphic is presented. The example is for the MPB at 22:34 UT on 15.07.2022. From the data file it is seen, that all flags are 0. So, the accepted beginning and end satisfy the applied criteria. In this case, the first minima before and after the MPB maximum coincide with the beginning and end of the MPB. The substorm meridian is not far from PAG, at little distance to the East. In Fig. 1b, the variations of the X component of the magnetic field are drawn by blue continuous line, and the first derivative of X is drawn by a red 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 the beginning and end of MPB are given by green continuous vertical lines. The locations of all detected minima are also shown, by green dotted 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.



a) b)

Figure 1. Appearance of a MPB parameters data file (a) and of a MPB graphic (b). Example for the MPB at 22:34 UT on 15.07.2022.

In Fig. 2a, b, an example, when there was a peculiarity in the determining of the MPB end occurred. This is the substorm on 10.02.2022 at 20:14 UT. In this case flagend = 4 (Fig. 2a). This means that the last ratio $(X_{max}-X_{min,n+1})/(X_{max}-X_{min,n})>1.2$. The last minimum was taken as MPB end and it is seen that this decision was correct (Fig. 2b).



a) b)

Figure 2. MPB data file (a) and MPB graphic (b) during the substorm on 10.02.2022 at 20:14 UT. In this case there were a peculiarity in the determining of the MPB end.

Results and conclusions

A methodology to determine the parameters of the midlatitude positive bays has been worked out. A program tool to compute automatically the MPB parameters, registered at Panagjurishte station was developed, including application of the criteria to locate the beginning and end minima of the midlatitude X positive bays. The program was tested and adjusted on different cases of MPB from 2015 and 2013. The provided visual inspection showed that the MPB

parameters were set correctly. The content and design of the MPB graphs and the MPB parameters files were specified. Special flags have been included in the data files in order to give an idea about the peculiarities in the determining the parameters of the relevant MPB.

The yearly lists from 2007 to 2022 were processed and the MPB images and data files were uploaded in the Catalog of the magnetic variations at Panagjurishte (http://space.bas.bg/Catalog_MPB/).

The obtained MPB beginning times were compared with the substorm onsets determined from the SML index by *Newell and Gjerloev* [2011], *Forsyth et al.* [2015] and *Ohtani and Gjerloev* [2020]. It was found out that in most of the cases the other authors detected also a substorm presence over Europe. The MPB beginning times are close to the onsets of the corresponding substorms, determined from the SML index. Some of them are later than the substorm onsets, and the others are earlier than the substorm onsets.

The obtained differences may be due to some distance of PAG station from the substorm meridian, but this cannot explain these differences in all cases. We suppose that sometimes the discrepancy between the obtained MPB beginning times and the substorm onsets by the SML index can be due to the complicated conditions, when some smaller magnetic perturbations just before the sharp decrease of X are related to the beginning of the global magnetospheric 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.

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