S E S 2024
Twentieth Anniversary International Scientific Conference
SPACE, ECOLOGY, SAFETY
22 – 25 October 2024, Sofia, Bulgaria

STUDY OF THE MIDLATITUDE POSITIVE BAYS AT THE MAGNETIC STATION PANAGYURISHTE DURING THE DESCENDING PHASE OF SOLAR CYCLE 24

Veneta Guineva[1], Rolf Werner[1], Rumiana Bojilova[2], Lyubomira Raykova[1],
Atanas Atanassov[1], Dimitar Valev[1]

[1]Space Research and Technology Institute – Bulgarian Academy of Sciences
[2]National Institute of Geophysics, Geodesy and Geography – Bulgarian Academy of Sciences
e-mail: v_guineva@yahoo.com

Keywords: *magnetospheric substorms, midlatitude positive bays (MPB), intrplanetary and geomagnetic conditions, Panagyurishte magnetic station*

Abstract: *The effect of substorms at midlatitudes is manifested as specific oscillations in the magnetic field at the Earth surface: peaks in the North component X, known as midlatitude positive bays (MPB), and a systematic variation in the East component Y, consisting of a single cycle of sine wave. It was found out that the rate of substorm occurrence depends on the phase of the solar cycle and that most substotrms occur during the decending phase of the solar cycle. The aim of this work is to study the midlatitude positive bays, related to magnetospheric substorms, that were identified at the midlatitude Bulgarian magnetic station Panagyurishte during the descending phase of solar cycle 24. Therefor 255 MPB's observed in 2017, have been examined. The interplanetary and geomagnetic conditions during these substorms have been investigated. The MPB beginnings have been compared to the onsets of the same substorms, determined by SML index data. A comparison of the number of registered MPB's during different solar cycle phases has been made. It was ascertained that during the 24 SC actually most substorms occurred during the descending phase, another, smaller maximum of the number of substorms was observed during the ascending phase, and minima during the maximum and the minimum of the SC were observed.*

ИЗСЛЕДВАНЕ НА СРЕДНОШИРОТНИТЕ МАКСИМУМИ ПРИ МАГНИТНА СТАНЦИЯ ПАНАГЮРИЩЕ ПРЕЗ НИЗХОДЯЩАТА ФАЗА НА СЛЪНЧЕВ ЦИКЪЛ 24

Венета Гинева[1], Ролф Вернер[1], Румяна Божилова[4], Любомира Райкова[1],
Атанас Атанасов[1], Димитър Вълев[1]

[1]Институт за космически изследвания и технологии – Българска академия на науките
[2]Институт по геофизика, геодезия и география – Българска академия на науките
e-mail: v_guineva@yahoo.com

Ключови думи: *магнитосферни суббури, магнитни максимуми на средни ширини (MPB), междупланетни и геомагнитни условия, магнитна станция Панагюрище*

Резюме: *Влиянието на суббурите на средни ширини се проявява като специфични колебания в магнитното поле на земната повърхност: максимуми в северната компонента X, известни като магнитни максимуми на средни ширини или средноширотни максимуми (MPB), и систематично изменение на източната компонента Y, състоящо се от единичен синусов цикъл. Установено е, че честотата на поява на суббури зависи от фазата на слънчевия цикъл и най-много суббури възникват през низходящата фаза на слънчевия цикъл. Целта на тази работа е да се изследват средноширотните максимуми, свързани с магнитосферни суббури, идентифицирани при средноширотната българска магнитна станция Панагюрище през низходящата фаза на слънчев цикъл 24. Затова са разгледани 255 MPB, наблюдавани през 2017. Изследвани са междупланетните и геомагнитни условия по време на тези суббури. Началата на MPB са сравнени с началата на съответните суббури, определени по данни за SML индекса. Направено е сравнение на броя регистрирани MPB през различни фази на слънчевия цикъл. Установено е, че действително през SC 24* *най-много суббури са възникнали през низходящата фаза, още един, по-малък максимум, е наблюдаван през низходящата фаза, а през максимума и минимума на слънчевия цикъл са наблюдавани минимуми на броя суббури.*

Introduction

Magnetospheric substorms are one of the main structural parameters of space weather. The basic disturbances of the Earth's magnetosphere are in consequence of the substorms development. After the current theory, during magnetospheric substorms, a current system forms, namely the so-called Substorm current wedge (SCW) [e.g. 1, 2], by the deviation of the tail current along the magnetic field lines through the ionosphere and the formation of auroral electrojets. The auroral electrojets have been investigated since 1970s [e.g. 3, 4]. The substorm current wedge provokes disturbances in the Earth magnetic field: negative bays of the X-component at auroral latitudes and positive bays of X at midlatitudes (midlatitude positive bays – MPB), which accompany the expansion of the magnetospheric substorms [e.g. 1, 5]. The magnetic disturbances at the Earth surface have been used in lots of investigations to study the magnetospheric substorms. The midlatitude magnetic variations are a powerfull tool for the magnetospheric substorms investigation. The MPB's are a good indicator of the substorm onset [6], and the sign of Y component was used to estimate the direction of the field aligned currents at a given longitude [7].

The magnetospheric substorms may be accompanied or not by magnetic disturbances at midlatitudes. The presence and strength of the midlatitude magnetic disturbances caused by magnetospheric substorms, depend on the substorm strength, the measuring point location (distance from the substorm meridian and geomagnetic latitude), and also on the interplanetary and geomagnetic conditions. As different structures of the solar wind prevail during the different phases of the solar cycle [8], different distribution of the MPB's by number and intensity may be expected during different SC phases.

The purpose of this work is first, to verify the interplanetary and geomagnetic conditions during substorms, which caused strong MPB at the Bulgarian magnetic station Panagjurishte during the descending phase of SC 24. For this, the found out MPB's in 2017, which is in the center of the descending phase of SC 24 have been used from the Catalog of the magnetic variations at the Panagjurishte station [9, 10, 11]. This work aims also to verify the variations of the number of substorms during the different phases of SC 24 and the relative share by different MPB maximal value ranges during the ascending and descending phases of SC 24.

Data used

For the study, data from the Catalog of the magnetic variations at the Panagjurishte station (PAG) (~37° GMLat, ~97° GMLon), developed at the Space Research and Technology Institute of the Bulgarian Academy of Sciences, have been used. The catalog is available at: http://space.bas.bg/Catalog_MPB/. Data from 2017, 2012 and 2022 were examined.

The interplanetary and geomagnetic conditions have been specified by data of OMNI database of the CDA Web (https://cdaweb.gsfc.nasa.gov/) and the Catalog of large scale solar wind phenomena (http://www.iki.rssi.ru/pub/omni/catalog/).

To compare the results for the substorms by the MPB's, registered at PAG, with other results of substorms at the same time, the substorm list by Newell and Gjerloev (2011), has been used (https://supermag.jhuapl.edu/substorms/?tab=description), SML index from SuperMAG (https://supermag.jhuapl.edu/indices/) and IL index data from IMAGE database (https://space.fmi.fi/image/www/il_index_panel.php).

Interplanetary and geomagnetic conditions in the time of MPB

In 2017, 255 MPB's have been detected (Catalog of the magnetic variations at PAG [10, 11]). We examined the strongest of them, with maximum of the MPB greater than 20 nT. They are 29. Some characteristics of the MPB's and the peculiarities of the interplanetary and geomagnetic conditions at the same time are summarized in Table 1. The consecutive columns of the table are as follows: case number, date, the beginning time of MPB at PAG, MPB maximal value, MPB amplitude, observed structure in the solar wind, SYM/H index minimal value, the time of SYM/H minimum, SYM/H value at the MPB beginning time, the phase of the geomagnetic storm at the MPB beginning time (if a geomagnetic storm was developed at the same time).

In most of the cases (24), as it might be expected [8], CIR or HSS were observed in the solar wind. In only one case Slow solar wind (v<450 km/s) was detected. In all cases, geomagnetic storms developed. Taking into account, that HSS usually provoke weaker storms, than CIR, MC and Sheath, it is not surprising that 17 geomagnetic storms were weak (30 nT < SYM/H_{min} < 50 nT); 10 storms were moderate and 2 – strong.

Table 1. Interplanetary and geomagnetic conditions in the time of strong MPB's in 2017

№	date	MPB beginning time	MPB_{max} nT	Amplitude nT	Solar wind structure	SYM/H_{min} nT	Time of SYM/H_{min}	SYM/H nT	Storm phase
1	05.01.2017	23:07	24.04	36.72	ISa, HSS	-47	23:23	-40	main
2	01.02.2017	20:58	25.80	46.37	HSS	-40	22:50	-21	main
3	03.02.2017	19:39	20.15	27.04	HSS	-40	08:46	-21	Late recovery
4	17.02.2017	23:18	24.90	45.41	HSS	-41	23:57	-19	main
5	01.03.2017	18:55	20.29	29.20	CIR	-74	22:17	-33	main
6	02.03.2017	19:05	22.85	38.80	HSS	-74	22:17	-30	Late recovery
7	05.03.2017	20:05	22.48	39.47	HSS	-37	02:57/06.03	-22	main
8	08.03.2017	21:47	21.90	38.96	HSS	-32	01:00/09.03	-21	main
9	21.03.2017	18:24	20.34	41.91	CIR	-46	23:36/22.03	-28	main
10	22.03.2017	20:43	21.45	39.10	HSS	-46	23:36	-19	main
11	30.03.2017	19:56	24.09	36.23	HSS	-60	01:43/31.03	-33	main
12	31.03.2017	20:46	21.26	35.24	HSS	-48	15:33	-34	recovery
13	21.04.2017	19:05	24.00	47.60	HSS	-53	23:58/22.04	-6	main
14	27.05.2017	22:39	26.33	32.67	MC	-142	07:13/28.05	17	main
15	16.06.2017	21:58	20.66	40.48	HSS	-38	00:00/17.06	-24	main
16	16.07.2017	17:34	23.76	40.70	SHE	-67	15:51	-46	Near recovery
17	17.08.2017	22:33	28.84	28.70	HSS	-36	10:01	-25	Late recovery
18	23.08.2017	17:55	22.80	36.65	EJE/HSS	-52	12:35	-31	recovery
19	07.09.2017	22:59	22.22	43.71	IS	-146	01:10/08.09	-30	main
20	15.09.2017	21:00	22.18	46.48	HSS	-44	04:30/16.09	-26	main
21	24.10.2017	21:52	20.10	41.85	CIR	-36	22:48	-27	main
22	24.11.2017	20:17	22.70	38.56	SLOW	-33	22:39	-22	main
23	12.12.2017	19:28	22.53	34.55	HSS	-38	18:40	-33	Near recovery
24	01.03.2017	22:16	38.96	69.57	HSS	-74	22:17	-73	Max development
25	15.09.2017	19:10	34.75	58.76	HSS	-44	04:30/16.09	-12	main
26	13.10.2017	18:38	37.89	54.69	HSS	-66	00:22/14.10	-50	main
27	07.11.2017	18:09	30.60	57.68	CIR	-89	04:04/08.11	-34	main
28	17.12.2017	18:45	35.56	58.31	HSS	-34	20:30	-29	main
29	27.03.2017	19:27	50.92	82.20	CIR	-86	14:45	-49	recovery

Comparison of the obtained results with results for the same substorms by SML index

To compare the substorm results by PAG magnetic data, we used the substorm list by Newell and Gjerloev [12] from the SuperMAG database, where the SML index is used to identify substorm events. It should be taken into account, that all existing substorm onset identification techniques have limitations. By reason of the applied technique and its assumptions, there may be some differences in the identified substorms and in the determined onsets.

For our comparison, we constructed Table 2, including our data and corresponding data from the Newell and Gjerloev substorm list [12]. The columns in Table 2, are as follows: case number after Table 1, event date, substorm onset time by the substorm list, magnetic and geographic coordinates of the onset (MLT, MLAT, MLON, GLAT, GLON), station, the beginning time of the midlatitude positive bay (MPB) at PAG, the difference between the substorm onset time and the MPB beginning time (Δt), and the value of Y at PAG at the moment of the MPB maximum (YPAG).

From Table 2 it is seen, that all substorm events, identified by local (European) data, have been identified by techniques, using SML index. The time difference Δt in most cases is small, but there are also cases when Δt is much greater than expected. The MPB beginning at PAG doesn't coincide with the substorm onset, unless the substorm meridian coincide with the PAG location. In all other cases it should be nearly after the substorm onset. That means, that Δt in Table 2 is expected to be small and negative. In our previous studies [9] we have supposed, that the slightly earlier MPB beginning at PAG than the substorm onset time determined based on SML index may be due to the difficulty to estimate whether the smaller disturbances before the sharp decrease of X are the result of localized or global events in the magnetosphere, especially under disturbed conditions or when the substorms are not isolated. Later we came to the conclusion, that obtained greater differences between the determined substorm onsets and the MPB beginning at PAG in some cases are maybe result of the assumptions made and the conditions set in the processing tools of the different techniques [13]. In some cases, when the disturbance is great and spreads over a large longitudinal area the longer disturbance delay at PAG and generally over Europe may be due to the remoteness of the substorm onset.

Table 2. Comparison of the obtained beginnings of the examined MPB's with the results of identified substorms at the same time by Newell and Gjerloev (2011)

№	date	UT	MLT	MLAT	MLON	GLAT	GLON	station	MPB beginning time (this work)	Δt, min.	Y_{PAG}
1	05.01.2017	22:43	23.83	63.75	95.33	66.11	12.5	DON	23:07	-24	-6.35
2	01.02.2017	21:01	22.63	67.07	102.95	69.66	18.94	TRØ	20.58	3	-5.60
3	03.02.2017	19:29	23.88	67.35	143.28	71.16	66.83	KHS	19:39	-10	3.69
4	17.02.2017	23:21	0.74	63.82	99.02	66.4	16.98	JCK	23:18	3	-3.68
5	01.03.2017	18:37	21.22	64.77	114.46	67.97	35.02	LOZ	18:55	-18	18.97
6	02.03.2017	19:05	23.25	65.95	137.66	69.6	61.21	AMD	19:05	0	10.88
7	05.03.2017	20:08	22.17	67.8	106.21	70.54	22.22	SØR	20:05	3	-6.78
8	08.03.2017	22:01	0.13	64.41	107.29	67.37	26.63	SOD	21:47	14	-14.57
9	21.03.2017	18:43	23.42	70.64	143.28	71.16	66.83	KHS	18:24	19	11.55
10	22.03.2017	20:47	23.05	64.41	107.29	67.37	26.63	SOD	20:43	4	-7.08
11	30.03.2017	19:56	21.81	66.86	100.42	69.3	16.03	AND	19:56	0	-0.55
12	31.03.2017	20:06	0.88	67.35	143.28	71.16	66.83	KHS	20:46	-40	8.63
13	21.04.2017	19:10	21.83	68.19	109.43	71.09	25.79	NOR	19:05	5	-2.09
14	27.05.2017	22:40	1.29	64.41	107.29	67.37	26.63	SOD	22:39	1	17.65
15	16.06.2017	21:58	23.77	63.75	95.33	66.11	12.5	DON	21:58	0	-7.56
16	16.07.2017	18:18	20.59	66.65	106.46	69.46	23.7	MAS	17:34	44	-0.26
17	17.08.2017	22:16	23.88	63.75	95.33	66.11	12.5	DON	22:33	-17	6.90
18	23.08.2017	17:30	6.36	65.45	263.97	64.87	212.14	CMO	17:55	-25	14.36
19	07.09.2017	23:00	0.89	61.87	99.33	64.61	18.75	LYC	22:59	1	31.83
20	15.09.2017	20:50	5.39	66.71	197.28	71.59	128.92	TIK	21:00	10	-4.77
21	24.10.2017	21:54	0.22	65.19	105.26	68.02	23.53	MUO	21:52	2	3.86
22	24.11.2017	20:25	22.25	66.86	100.42	69.3	16.03	AND	20:17	8	-6.66
23	12.12.2017	19:35	23.82	65.95	137.66	69.6	61.21	AMD	19:28	7	3.88
24	01.03.2017	21:41	1.8	65.95	137.66	69.6	61.21	AMD	22:16	-35	-11.83
25	15.09.2017	19:12	23.75	65.95	137.66	69.6	61.21	AMD	19:10	2	9.11
26	13.10.2017	18:24	3.03	66.71	197.28	71.59	128.92	TIK	18:38	-14	-4.83
27	07.11.2017	18:26	21.05	68.19	109.43	71.09	25.79	NOR	18:09	17	17.78
28	17.12.2017	18:44	7.14	70.86	258.21	70.36	211.2	JCO	18:45	-1	-7.19
29	27.03.2017	19:23	7.46	70.64	251.13	71.32	203.38	BRW	19:27	-4	-1.32

A case with great MPB registered at PAG

The substorm development on 27.03.2017 at 19:23 UT by [12] (case 29) and its appearance at PAG are examined in detail. During this substorm, a strong MPB was registered at PAG. The maximal MPB value was 50.9 nT, and its amplitude – 82 nT. Such strong disturbances are rarely observed in Panagyurishte (42.5° N, ~37°GMLat). The interplanetary and geomagnetic conditions during the substorm are presented in Fig. 1. In the left panel, some solar wind components and geomagnetic indices are presented. The substorm time is indicated by a red vertical line. At this time, a CIR was observed in the solar wind, followed by a HSS. The CIR provoked a moderate geomagnetic storm with SYM/H_{min} = -86 nT. In the right panel of Fig. 1, the magnetic disturbances and ionospheric currents by AMPERE and SuperMAG data are shown for the times of the beginning of the examined disturbance and its development over Europe. In Fig. 2, the substorm by the SML index, by the magnetic field at BRW (left panels), by IL index and by the MPB at PAG (right panels) is presented. The substorm onset was detected in the morning sector, at the Borrow station (BRW), which is at 203°

GLon, about 180° to the East form PAG (see the upper row and the left picture of the bottom row of the right panel of Fig. 1). The beginning of the magnetic disturbance is seen at 18:32 UT at BRW (bottom left panel of Fig. 2, red vertical line). This disturbance can be detected also by SML (left upper panel in Fig. 2, red vertical line).

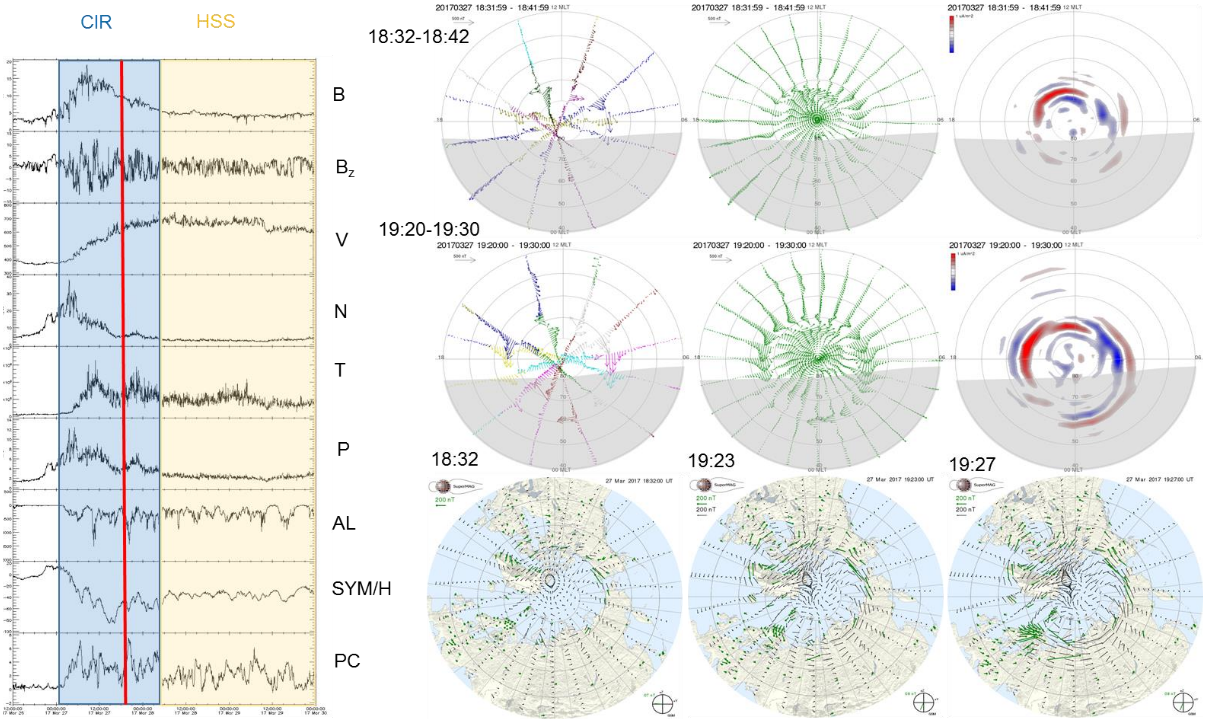


Fig. 1. Interplanetary and geomagnetic conditions during the substorm on 27.03.2017

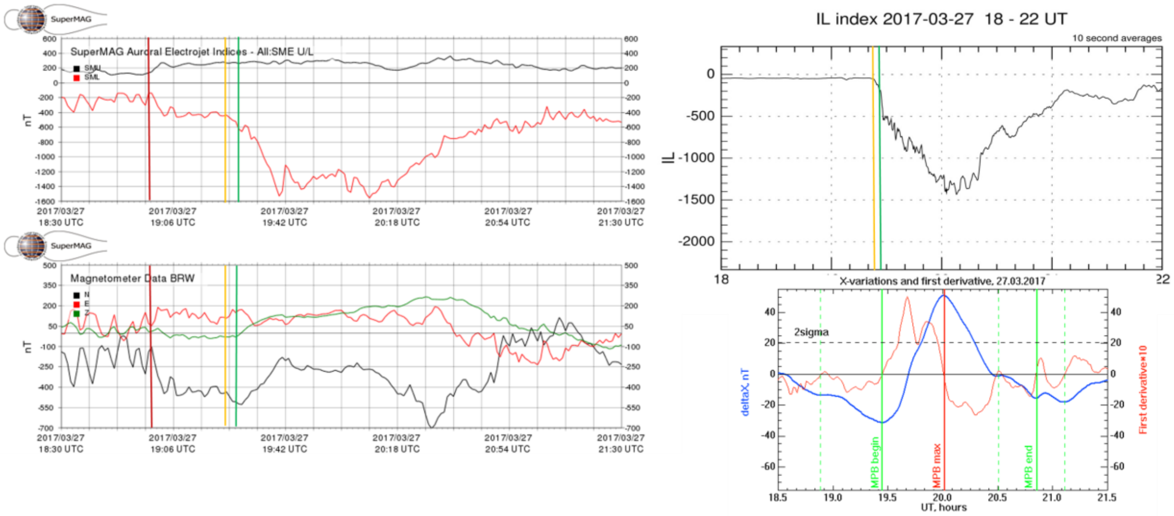


Fig. 2. Appearance of the substorm on 27.03.2017 by SML index (upper left panel), magnetic field at Barrow (BRW) station (bottom left panel), IL index (upper right panel) and MPB at Panagyurishte (PAG) (bottom right panel). The green vertical lines indicate the MPB beginning at PAG, the orange lines – the substorm onset by Newell and Gjerloev (2011), and the dark red lines – the substorm onset at BRW by eye inspection.

Later, at about 19:23 UT, a sharp westward expansion of the disturbance was observed, covering about 170 degrees of longitude, which was also observed over Europe (the middle right panel and the middle picture of the bottom right panel of Fig. 1). This development was expressed by a sharp decrease in the SML and IL indices, indicated by yellow vertical lines in the upper panels of Fig. 2. The beginning of the disturbance at PAG was observed at 19:27 UT. This time is shown by green vertical line in all panels of Fig. 2. The deviations of the magnetic field in the Northern hemisphere by SuperMAG at 19:27 UT (right picture of the right bottom panel of Fig. 1) also confirm this development.

Observed MPB at PAG during different SC phases

The variations in the number of substorms, accompanied by MPB at PAG, in the course of the SC have been studied. We dispose of PAG magnetic data since 2007, so the whole SC 24 is included in them. In Fig. 3, the number of noticeable MPB's registered at PAG from 2007 to 2022 is shown. It is seen that the maximum MPB's were observed in 2017, which is about the middle of the descending SC phase. Another, lower maximum arises during the ascending phase (2011–2012). Near the SC minima and maximum (vertical lines in Fig. 3), minima in the course of the MPB number are observed.

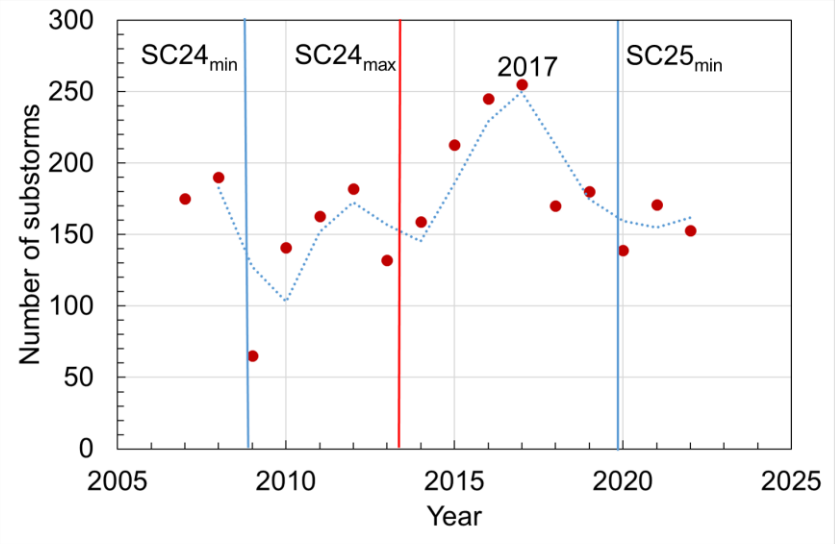
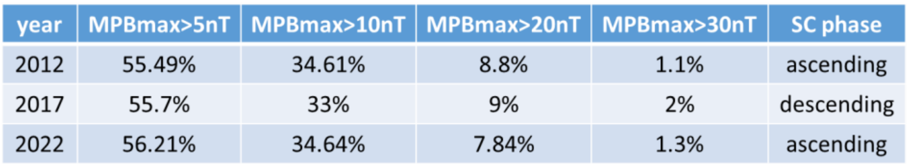


Fig. 3. Number of MPB's registered at PAG from 2007 to 2022. The solar cycle minima are marked by blue vertical lines, and the SC maximum – by red vertical line.

To study the distribution of MPB's by maximal value during years from different SC phases, the MPB's during 3 years: 2012, 2017 and 2022, have been examined. The results are presented in Table 3. It is seen, that relative share of MPB's with maxima in the range 5–10 nT is comparatively the same in the ascending and descending SC phases. The number of MPB's with maxima in the range 10–20 nT is slowly lower in the descending phase at the expense of a larger number in the intervals above 20 nT.

Table 3. Relative share of the number of MPB's for years in different phases of the SC



year	MPBmax>5nT	MPBmax>10nT	MPBmax>20nT	MPBmax>30nT	SC phase
2012	55.49%	34.61%	8.8%	1.1%	ascending
2017	55.7%	33%	9%	2%	descending
2022	56.21%	34.64%	7.84%	1.3%	ascending

Summary

The strong midlatitude positive bays (MPB) (Xmax>20 nT) registered at Panagujrishte (PAG) during the descending phase of SC 24 (in 2017) were related to substorms, developed during disturbed interplanetary and geomagnetic conditions. The obtained MPB beginning times are close to the substorm onsets determined from the SML index except a few cases.

The obtained small differences may be due to some distance of PAG station from the substorm meridian, as well as 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 presume, that the substorm onsets could be more easily and accurately determined by the midlatitude positive bays data from a global or regional set of midlatitude magnetic stations [9, 13].

The obtained greater differences between the determined substorm onsets and the MPB beginning at PAG in some cases can be obtained during very strong, prolonged, extended substorms, developed over a large area in longitude, when the substorm onset location is far from PAG, and the disturbance reaches PAG in some longer time interval.

The obtained greater differences between the onsets and the PAG MPB's maybe also the result of the applied processing techniques and their assumptions. It should be taken into account, that all existing substorm onset identification techniques have limitations. The contributions of stations far from the substorm meridian, in such cases may lead to significant discrepancies between the substorm onset, determined by global (SML) and regional (IL, European MPB index) indices. Hence, all results have to be verified for every concrete case.

The highest number of MPB's is recorded during the descending phase of the solar cycle, another, lower maximum is observed during the ascending phase of the solar cycle, and minima in the number of MPBs occur around the SC minimum and maximum. The relative number of MPB in the interval 5–10 nT is preserved in the years of the ascending and descending phase, while in the interval 10–20 nT the number of MPB is slightly lower during the descending phase. On the other hand, the number of MPBs with a maximum above 20 nT is higher during the descending phase.

Acknowledgements: We acknowledge the substorm timing list identified by the Newell and Gjerloev technique, the SMU and SML indices (Newell and Gjerloev, 2011); and the SuperMAG collaboration (Gjerloev et al. 2012). The authors are grateful to the creators of the databases AMPERE (https://ampere.jhuapl.edu/), IMAGE (http://space.fmi.fi/image/), OMNI (https://cdaweb.gsfc.nasa.gov/) and the solar wind large-scale phenomena catalog (http://www.iki.rssi.ru/omni/) for the opportunity to use them in this work.

References:

1. McPherron, R. L., (1972). Substor related changes in the geomagnetic tail: The growth phase, Planet. Space Sci., Vol. 20, No. 9, pp. 1521–1539, DOI: 10.1016/0032-0633(72)90054-2.
2. McPherron, R. L., C. T. Russell, M. Aubry, (1973). Satellite studies of magnetospheric substorms on August 15, 1968, 9: phenomenological model for substorms, J. Geophys. Res., Vol. 78, No. 16, pp. 3131–3149, DOI: 10.1029/JA078i016p03131.
3. McPherron, R. L., C. T. Russell, M.G. Kivelson, P.J. Coleman, Jr., (1973b). Substorms in space: The correlation between ground and satellite observations of the magnetic field, Radio Sci., Vol.8. No.11, pp. 1059–1076, DOI: 10.1029/RS008i011p01059.
4. Kisabeth, J. L., G. Rostoker, (1974). The expansive phase of magnetospheric substorms: 1. Development of the auroral electrojets and auroral arcs configuration during substorm, J. Geophys. Res., Vol.79, No7, pp.972–984, DOI: 10.1029/JA079i007p00972.
5. Kepko, L., R. L. McPherron, O. Amm, S. Apatenkov, W. Baumjohann, J. Birn, M. Lester, R. Nakamura, T.I. Pulkkinen, V. Sergeev, (2014). Substorm current wedge revisited, Space Sci. Rev., Vol.190, pp. 1–46, DOI: 10.1007/s11214-014-0124-9.
6. McPherron, R. L., X. Chu, (2017). The midlatitude positive bay and the MPB index of substorm activity, Space Sci. Rev., Vol. 206, pp. 91–122, DOI: 10.1007/s11214-016-0316-6.
7. Meng, C.-I., Akasofu, S.-I., (1969). A study of polar magnetic substorms. 2. 3-dimensional current system, J. Geophys. Res., Vol. 74, pp. 4035–4053, DOI: 10.1029/JA074i016p04035.
8. Koala, S., Bere, W. P., Sawadogo, Y., Ki, I. and Zerbo, J. L., (2023). Distributions and Structure of the Solar Wind during Solar Cycles 23 and 24, International Journal of Geosciences, Vol.14, pp. 813–826, DOI: 10.4236/ijg.2023.149043
9. Guineva, V. H., R. Werner, A. M. Atanassov, R. Ts. Bojilova, L. N. Raykova, D. T. Valev, (2023a). Determination of the parameters of midlatitude positive bays caused by magnetospheric substorms, Proceedings of the Fifteenth Workshop "Solar Influences on the Magnetosphere, Ionosphere and Atmosphere", Primorsko, Bulgaria, 05 - 09 June 2023, pp. 56–63, DOI: 10.31401/ws.2023.proc, https://www.spaceclimate.bas.bg/ws-sozopol/pdf/Proceedings2023.pdf
10. Guineva, V., R. Werner, I. Despirak, N. Klejmenova, A. Lubchich, P. Setsko, A. Atanassov, R. Bojilova, L. Raykova, D. Valev, (2023b). Results from the bulgarian-russian project on investigation of the geomagnetic disturbances propagation to mid-latitudes and their interplanetary drivers identification for the development of mid-latitude space weather forecast, Proceedings of the Nineteenth International Scientific conference SES2023, 24-26.10.2023, Sofia, Bulgaria, pp. 47–56, http://space.bas.bg/SES/archive/SES%202023_DOKLADI/1_Space%20Physics/2_Guineva.pdf
11. Guineva, V., R. Werner, I. Despirak, N. Klejmenova, A. Lubchich, P. Setsko, A. Atanassov, R. Bojilova, L. Raykova, D. Valev, (2023c). Basic results from the project "Investigation of the geomagnetic disturbances propagation to mid-latitudes and their interplanetary drivers identification for the development of mid-latitude space weather forecast", Proc. 46th Annual seminar "Physics of Auroral Phenomena", 13-17 march 2023, Apatity, Russia, pp. 23–29, http://pgia.ru/seminar/archive/
12. Newell, P. T., Gjerloev, J. W., (2011). Substorm and magnetosphere characteristic scales inferred from the SuperMAG auroral electrojet indices, J. Geophys. Res., Vol. 116, A12232, DOI:10.1029/2011JA016936.
13. Guineva, V. H., R. Werner, A. M. Atanassov, R. Ts. Bojilova, L. N. Raykova, D. T. Valev, (2024). Analysis of substorms related to strong MPB at Panagjurishte station in 2022, Proceedings of the Sixteenth Workshop "Solar Influences on the Magnetosphere, Ionosphere and Atmosphere", Primorsko, Bulgaria, 03 - 07 June 2024, pp. 56–63, DOI: 10.31401/ws.2024.proc