SEASONAL MODULATION AND TEMPORAL DISTRIBUTION OF MIDLATITUDE POSITIVE BAYS OBSERVED AT THE PANAGYURISHTE GEOMAGNETIC OBSERVATORY DURING SOLAR CYCLE 23/24 AND 24/25 TRANSITIONS

Lyubomira Raykova, Veneta Guineva, Rolf Werner

Space Research and Technology Institute, Bulgarian Academy of Sciences, Stara Zagora, Bulgaria
E-mail: heiti456@gmail.com

Keywords: *midlatitude positive bays; substorm current wedge; solar minima; solar wind; SYM-H*

Abstract: *Midlatitude positive bays (MPBs) serve as ground-based indicators of the Substorm Current Wedge (SCW) during magnetospheric substorms. This study analyzes the seasonal modulation and temporal distribution of MPB events recorded at the Panagyurishte observatory during 13-month intervals centered around the December solar minima in 2008 (Cycle 23/24) and 2019 (Cycle 24/25). MPB events were identified between 18:00 and 24:00 UT using 1-minute X-component magnetic data. Monthly occurrence peaks in March and September–October, consistent with the Russell–McPherron effect. Within the selected time window, beginning times are most frequent between 20:00 and 22:00 UT. Analysis using the Solar Wind Large-Scale Phenomena Catalog (http://www.iki.rssi.ru/omni/) and the SYM-H index from the OMNI database (https://cdaweb.gsfc.nasa.gov/) indicates that slow solar wind is the largest classified category in both intervals (>53%), while no-storm and recovery-phase cases together account for most MPBs.*

СЕЗОННА МОДУЛАЦИЯ И ВРЕМЕВО РАЗПРЕДЕЛЕНИЕ НА MPB, НАБЛЮДАВАНИ В ГЕОМАГНИТНАТА СТАНЦИЯ ПАНАГЮРИЩЕ ПРИ ПРЕХОДИТЕ МЕЖДУ СЛЪНЧЕВИТЕ ЦИКЛИ 23/24 И 24/25

Любомира Райкова, Венета Гинева, Ролф Вернер

Институт за космически изследвания и технологии, Българска академия на науките, Стара Загора, България
E-mail: heiti456@gmail.com

Ключови думи: *MPB; токов клин на суббурята; слънчев минимум; слънчев вятър; SYM-H*

Резюме: *MPB служат като наземни индикатори за токовия клин на суббурята (SCW). Изследвани са сезонното и времевото разпределение на MPB, регистрирани в геомагнитната обсерватория Панагюрище през два 13-месечни интервала около слънчевите минимуми през декември 2008 г. (цикли 23/24) и декември 2019 г. (цикли 24/25). Събитията са идентифицирани между 18:00 и 24:00 UT по едноминутни данни за X-компонентата на магнитното поле. Месечното разпределение има максимуми през март и септември–октомври, в съгласие с ефекта на Ръсел–Макферон. В разглеждания часови интервал началните моменти са най-често между 20:00 и 22:00 UT. Анализът с Каталога на структурите в слънчевия вятър и индекса SYM-H от OMNI показва, че бавният слънчев вятър е най-голямата класифицирана категория и през двата периода (над 53%), а случаите извън буря и във фазата на възстановяване, взети заедно, обхващат повечето MPB.*

Introduction

Geomagnetic storms result from enhanced coupling between the solar wind and Earth's magnetosphere. Coronal mass ejections (CMEs), associated with solar magnetic activity, are an important source of such disturbances. They often originate in active regions with complex magnetic field structures, and some are associated with erupting solar prominences [Temmer, 2026; Sammis et al., 2000; Gopalswamy et al., 2003].

Magnetospheric substorms produce transient disturbances that can be recorded by ground-based magnetometers. As a substorm develops, part of the current in the magnetotail is diverted along magnetic field lines into the ionosphere. This forms the Substorm Current Wedge (SCW), a current system associated with the auroral electrojets [McPherron, 1972; McPherron et al., 1973a]. The SCW has been studied since the 1970s [McPherron et al., 1973b; Kisabeth and Rostoker, 1974].

During the substorm expansion phase, the SCW produces different geomagnetic signatures depending on the station's latitude: a sharp negative deflection in the X-component at auroral latitudes and a positive deflection at midlatitudes. The latter is known as a midlatitude positive bay (MPB) and is recorded in the horizontal component of the magnetic field [McPherron, 1972; Kepko et al., 2014; Guineva et al., 2021; Guineva et al., 2024a,b; Guineva et al., 2025]. MPBs are therefore useful indicators of substorm onset and, in some cases, may provide a more reliable indication of it than the global SML index [McPherron and Chu, 2017].

In this work we carry out a comparative analysis of the seasonal and monthly distribution of the MPB occurrence during SC23 and SC24 minima at the midlatitude station Panagyurishte in the time interval 18:00–24:00 UT, depending on the solar-wind structures and geomagnetic storm/non-storm conditions.

Data and Event Selection Criteria

This study uses 1-minute X-component magnetic field data from the Panagyurishte (PAG) station (37° N geomagnetic latitude, 97° E geomagnetic longitude), which is well situated for observing midlatitude positive bays (MPBs). Events were identified between 18:00 and 24:00 UT using the Station Catalog's "Monthly lists" and "Magnetic field data," following Guineva et al. (2023). Selection required a distinct X-component maximum at PAG coincident with, or close in time to, a minimum in the auroral IL index. Only events with an MPB amplitude exceeding 5 nT and IL below −200 nT were retained. The associated high-latitude negative bay was also required to last at least 10 minutes at a 2σ deviation threshold. The analysis considers both MPB amplitude and the peak X-component value (Xmax). For the study, the MPB amplitudes and Xmax were divided into groups by their values as follows: 5-10 nT, 10-20 nT and greater than 20 nT.

For each MPB, the SYM-H time series was examined to determine whether a geomagnetic storm was present and, if so, whether the event occurred during its initial, main, or recovery phase. Solar-wind conditions were classified using the Solar Wind Large-Scale Phenomena Catalog as slow (SWslow) or fast (SWfast) solar wind, heliospheric current sheet (HCS), corotating interaction region (CIR), Ejecta (EJE), magnetic cloud (MC), or sheath region (SHE). Together, these classifications describe the geomagnetic and solar-wind conditions associated with the observed MPBs.

Results

The comparison covers monthly occurrence, the distribution by the MPB amplitude, the peak X-component deviation (Xmax), and the MPB beginning time, followed by geomagnetic and solar-wind classifications. Amplitude is the rise from the X value at the beginning of a bay to its peak; it can therefore exceed Xmax if the beginning value is negative.

MPB occurrence increases near both equinoxes (Fig. 1). The autumn maximum falls in September in 2008–2009 and October in 2019–2020; both distributions also show a March maximum. This pattern is consistent with semiannual modulation associated with the Russell–McPherron effect.

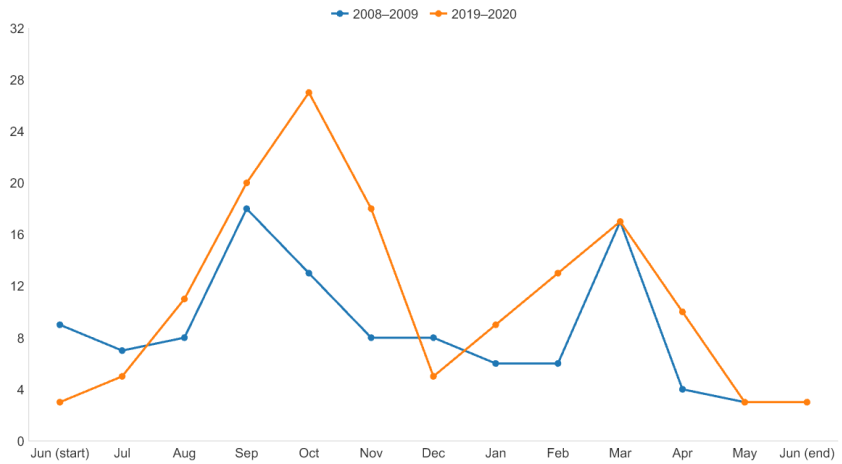


Fig. 1. Monthly distribution of MPB events in 2008–2009 and 2019–2020

The 10–20 nT amplitude bin contains the most events in both intervals (Fig. 2) with maxima in September/October and March. In 2008–2009, it includes 12 events in September and 12 in March; in 2019–2020, it includes 12 in October and 11 in March. Events above 20 nT are less frequent.



Fig. 2. Comparison of MPB amplitude distributions for the periods 2008–2009 and 2019–2020

The 5–10 nT Xmax range is the largest category in both periods (Fig. 3). It also shows maxima in March and September/October. It reaches 13 events in March 2009 and 18 in October 2019; the 2019–2020 interval also has 15 events in November 2019.

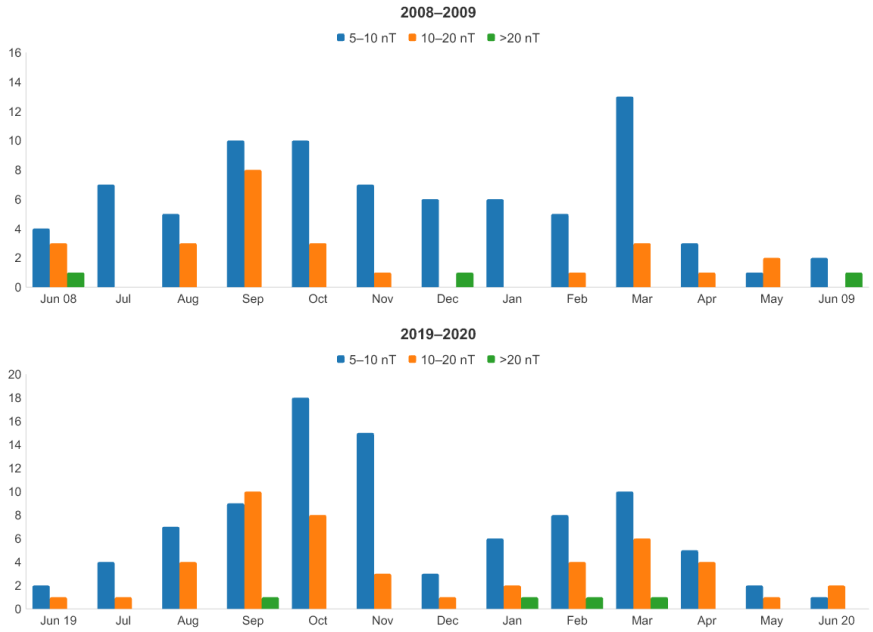


Fig. 3. Monthly distribution of peak X-component deviation (Xmax) in 2008–2009 and 2019–2020

Within the selected 18:00–24:00 UT window, 20:00–22:00 UT is the most frequent two-hours beginning-time bin (Fig. 4) for both time periods. In 2008–2009, it contains 10 March and 9 September events. The 2019–2020 pattern is less uniform: 18:00–20:00 UT starts increase in September–October, while the 22:00–24:00 UT bin is prominent in November.



Fig. 4. Distribution of MPB beginning times (UT) in 2008–2009 and 2019–2020

No-storm cases account for 69% of MPBs in 2008–2009 and 42% in 2019–2020 (Fig. 5). In the second interval, no storm remains the largest single category, although storm-associated cases collectively are more frequent. Recovery-phase cases account for 18% and 36%, respectively, compared with 8% and 17% during the main phase. The initial phase represents 5% in each interval.

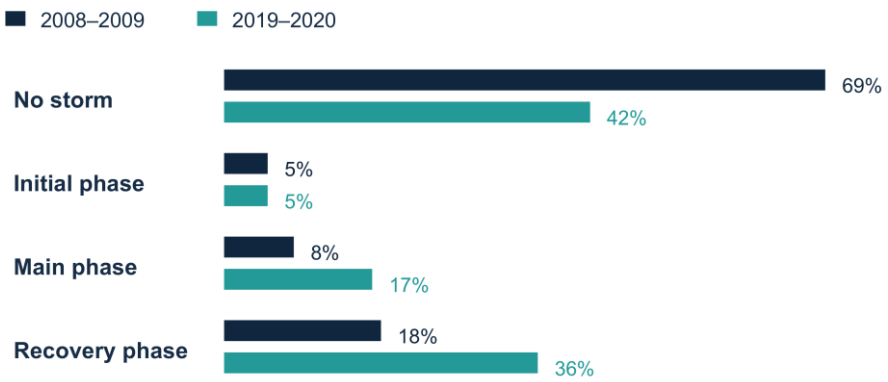


Fig. 5. MPB occurrence by geomagnetic-storm phase in 2008–2009 and 2019–2020.

Slow solar wind is the largest classified structure in both intervals (Fig. 6): 64.8% in 2008–2009 and 53.1% in 2019–2020. Fast solar wind accounts for 21.3% and 23.8%, respectively. CIR contributes 9.3% in the first interval, whereas HCS contributes 12.9% in the second. These shares describe the conditions associated with detected MPBs.

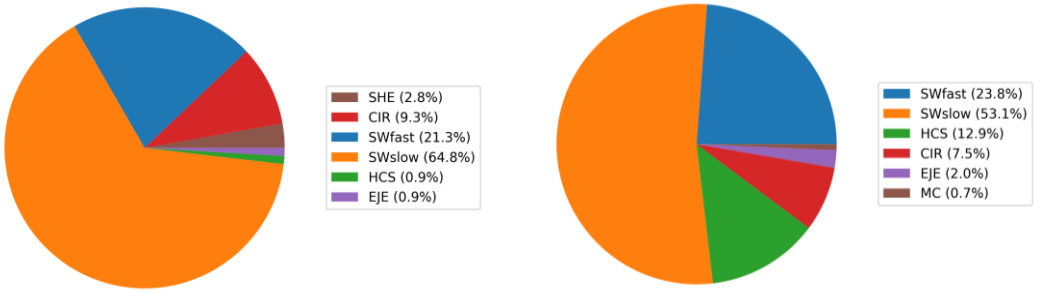


Fig. 6. Distribution of solar-wind structures during MPB events (left: 2008–2009; right: 2019–2020)

Conclusion

The MPB occurrence during SC23 and SC24 minima at the midlatitude station Panagyurishte has been studied in the time interval 18:00 -24:00 UT, corresponding to the midnight MLT interval. In both studied intervals of solar minima the MPB occurrence and behavior are similar.

MPB occurrence peaks in March and again around September–October in both studied 13 months intervals confirming the Russel-McPherron effect. Amplitudes of 10–20 nT and Xmax values of 5–10 nT dominate in the amplitude and Xmax distributions, respectively. In both studied periods the Russel-McPherron effect is also well expressed in these distributions.

The most frequent beginning-time interval is 20:00–22:00 UT and the Russel-McPherron effect for this time period is observed as well.

The classification by solar-wind structures shows slow wind as the largest category (64.8% in 2008–2009; 53.1% in 2019–2020).

In the storm-phase tables, no-storm cases 69% (2008–2009) and 42% (2019–2020) and recovery-phase cases 18% (2008–2009) and 36% (2019–2020) are the largest parts.

Acknowledgements

We acknowledge the SuperMAG collaboration (Gjerloev et al. 2012). The authors are grateful to the creators of the databases SuperMAG (https://supermag.jhuapl.edu/), IMAGE (http://space.fmi.fi/image), OMNI (https://cdaweb.gsfc.nasa.gov/), INTERMAGNET (http://intermagnet.org/) 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. Temmer, M. CME Observations from Sun to Impact on Geospace. In: N. Gopalswamy, D. Banyś, S. Gadimova (eds.), Proceedings of the United Nations/Germany Workshop on the International Space Weather Initiative, Springer Proceedings in Physics, Vol. 431, 2026, pp. 3–13. DOI: 10.1007/978-981-95-1121-1_1.
2. Sammis, I., F. Tang, H. Zirin. The Dependence of Large Flare Occurrence on the Magnetic Structure of Sunspots. Astrophysical Journal, Vol. 540, No. 1, 2000, pp. 583–587. DOI: 10.1086/309303.
3. Gopalswamy, N., M. Shimojo, W. Lu, S. Yashiro, K. Shibasaki, R. A. Howard. Prominence Eruptions and Coronal Mass Ejection: A Statistical Study Using Microwave Observations. Astrophysical Journal, Vol. 586, 2003, pp. 562–578. DOI: 10.1086/367614.
4. McPherron, R. L. Substorm related changes in the geomagnetic tail: The growth phase. Planetary and Space Science, Vol. 20, No. 9, 1972, pp. 1521–1539. DOI: 10.1016/0032-0633(72)90054-2.
5. McPherron, R. L., C. T. Russell, M. Aubry. Satellite studies of magnetospheric substorms on August 15, 1968: 9. Phenomenological model for substorms. Journal of Geophysical Research, Vol. 78, No. 16, 1973a, pp. 3131–3149. DOI: 10.1029/JA078i016p03131.
6. McPherron, R. L., C. T. Russell, M. G. Kivelson, P. J. Coleman Jr. Substorms in space: The correlation between ground and satellite observations of the magnetic field. Radio Science, Vol. 8, No. 11, 1973b, pp. 1059–1076. DOI: 10.1029/RS008i011p01059.
7. Kisabeth, J. L., G. Rostoker. The expansive phase of magnetospheric substorms: 1. Development of the auroral electrojets and auroral arcs configuration during substorm. Journal of Geophysical Research, Vol. 79, No. 7, 1974, pp. 972–984. DOI: 10.1029/JA079i007p00972.
8. Kepko, L., R. L. McPherron, O. Amm, S. Apatenkov, W. Baumjohann, J. Birn et al. Substorm current wedge revisited. Space Science Reviews, Vol. 190, 2014, pp. 1–46. DOI: 10.1007/s11214-014-0124-9.
9. Guineva, V., R. Werner, I. Despirak, R. Bojilova, L. Raykova. Mid-latitude positive bays during substorms by quiet and disturbed conditions. Comptes rendus de l'Académie bulgare des Sciences, Vol. 74, No. 8, 2021, pp. 1192–1200. DOI: 10.7546/CRABS.2021.08.11.
10. Guineva, V. H., R. Werner, A. M. Atanassov, R. Ts. Bojilova, L. N. Raykova, D. T. Valev. 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", 2023, pp. 56–63. DOI: 10.31401/WS.2023.proc.
11. Guineva, V., R. Werner, R. Bojilova, L. Raykova, A. Atanassov, D. Valev. 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", 2024a, pp. 56–63. DOI: 10.31401/WS.2024.proc.08.
12. Guineva, V., R. Werner, R. Bojilova, L. Raykova, A. Atanassov, D. Valev. Study of the Midlatitude Positive Bays at the Magnetic Station Panagyurishte during the Descending Phase of Solar Cycle 24. Proceedings of the Twentieth Anniversary International Scientific Conference "Space, Ecology, Safety" (SES 2024), 2024b, pp. 48–54.
13. Guineva, V. H., I. V. Despirak, R. Werner, A. A. Lubchich, L. Raykova, R. Bojilova. The Geomagnetic Midlatitude Effects of the Supersubstorms during May 10–12, 2024 Superstorm. Proceedings of the Seventeenth Workshop "Solar Influences on the Magnetosphere, Ionosphere and Atmosphere", 2025, pp. 92–109. DOI: 10.31401/WS.2025.proc.14.
14. McPherron, R. L., X. Chu. The midlatitude positive bay and the MPB index of substorm activity. Space Science Reviews, Vol. 206, 2017, pp. 91–122. DOI: 10.1007/s11214-016-0316-6.