Indonesian Journal of Earth Sciences, Vol. 04, No. 1 (2024), A1035

P-ISSN: 2798-1134 | E-ISSN: 2797-3549 | DOI: 10.52562/injoes.2024.1035

Indonesian Journal of Earth Sciences

https://journal.moripublishing.com/index.php/injoes

| Research Article |

Assessment of Seasonal Distribution and Characterisation of Geomagnetic Storm Occurrence during Solar Cycles 21–24

Moses Audu [1,*], Francisca Okeke [2], Tikyaa Emmanuel [1], Jam Terkaa [1], Peter Onoja [1], Inyope Thankgod [1]

[1]*Department of Physics, Joseph Sarwuan Tarka University, P.M.B. 2373, Nigeria*
[2]*Department of Physics and Astronomy, University of Nigeria, P.M.B. 410001, Nigeria*
* *Correspondence: audu.moses@uam.edu.ng*

Received: 06 May 2024 / Accepted: 14 June 2024 / Published: 18 June 2024

Abstract: Geomagnetic storms (GMSs) are an important space weather phenomenon that poses serious threats to the advancement of space technology, power transmission lines, oil pipelines, and other infrastructure. This study investigates seasonal patterns of GMSs due to recent reports on the prominence of large storms (Dst ≤ -50 nT) during equinox conditions. Hourly Dst index data provided by the World Data Center, Kyoto, Japan, for solar cycles 21–24 (1976–2019) were employed. Storm occurrences in each solar cycle considered were identified using the minimum Dst value. The identified storms were categorized and analyzed statistically. Results revealed that storm occurrence varied from month to month, season to season, and solar cycle to solar cycle based on storm categories. Furthermore, the observed seasonal distribution of GMS occurrence decreases in the following order: autumn, spring, winter, and summer. This indicates that equinox conditions are more likely to have GMSs, consistent with the Russell-McPherron effect, compared to solstice conditions. The findings suggest that the distribution and characterization of storm occurrence vary seasonally due to solar activity. The insights on storm occurrence, distribution, and characterization may serve as a guide to space scientists to avert the impacts of GMSs while exploring space.

Keywords: Geomagnetic storm, Dst index, seasonal distribution, space weather, solar cycle

INTRODUCTION

Geomagnetic storms (GMSs) are a crucial space weather phenomenon that threaten the advancement of space technology, power transmission lines, oil pipelines, and other infrastructure. Studies on the impacts of space weather phenomena on both space- and ground-based technology and infrastructure have been carried out worldwide over the years (Wu et al., 2016; Daglis et al., 2019; Mandea & Chambodut, 2020).

Several authors have extensively discussed the sources and impacts of GMSs (Gonzalez et al., 1994; Parashar et al., 2011; Rathore et al., 2012; Rathore et al., 2014; Watari, 2017; Chapman et al., 2020; Reyes et al., 2021). Solar drivers such as coronal mass ejections (CMEs) and co-rotating interaction regions (CIRs) have been identified as sources of geomagnetic activity (Borovsky & Denton, 2006; Watari, 2017; Doha & Wathiq, 2019). The strength of GMSs, measured by the magnitude of the disturbed storm time (Dst) index, ranges from +100 nT to < -600 nT. The Dst index measures storm intensity, while indices such as Kp and Ap are used to assess global geomagnetic activity (Kane, 2014; Chapman et al., 2020). Generally, GMSs are classified based on the magnitude of the Dst index into moderate (-100 < Dst ≤ -50 nT), intense (-200 < Dst ≤ -100 nT), severe (-350 < Dst ≤ -200 nT), and great storms (Dst ≤ -350 nT) (Gonzalez et al., 1994; Parashar et al., 2011; Joshua et al., 2018). Some authors also consider weak storms (-50 < Dst ≤ -30 nT) (Gustavo, 2014; Wu et al., 2016; Shadrina, 2017; Kevser, 2021). Several researchers have used the Dst index in the study of GMSs (Parashar et al., 2011; Doha & Wathiq, 2019; Reyes et al., 2019; Reyes et al., 2021). Data on the Dst index reported by the World Data Center in Kyoto, Japan, are available in the following resolutions: hourly, daily, weekly, 27 days, and yearly.

It has long been established that, on average, geomagnetic activity is higher during equinoxes than during other seasons. This is due to the Russell-McPherron effect (Joshua et al., 2018). Thus, most studies on the seasonal variation of GMSs have considered only the equinoxes (Rashmi et al., 2013). However, to investigate the seasonal variation of GMSs holistically, it is important to study storm occurrence in all seasons (spring, summer, autumn, and winter). Besides, it was recently reported that the prominence of GMSs during equinoxes is mostly associated with large storms (Dst ≤ -50 nT) (Gustavo, 2014). Therefore, more studies on the seasonal variation of GMSs are needed. This study aims to address this gap by studying storm occurrence in all seasons and ascertaining earlier findings on the prominence of large storms during equinoxes. Large storms are those with Dst ≤ -50 nT, categorized as defined earlier.

Several studies have examined the variation of GMSs (Le et al., 2013; Rashmi et al., 2013; Love et al., 2015; Ptitsyna & Tyasto, 2017; Christian, 2018; Reyes et al., 2019; Reyes et al., 2021). GMSs during solar cycle 23 (Parashar et al., 2011; Rathore et al., 2012; Rashmi et al., 2013), solar cycle 24 (Watari, 2017), solar cycles 21–23 (Reyes et al., 2019; Reyes et al., 2021), and solar cycles 23 and 24 (Sawadogo et al., 2022), among others, have been assessed, with significant results observed. Sawadogo et al. (2022) observed higher storms during solar cycle 23 compared to solar cycle 24, attributing their results to the influence of intense solar magnetic fields on magnetospheric energy transfer.

To better understand the causes of seasonal variation of GMSs, the axial hypothesis, equinoctial hypothesis, Russell-McPherron hypothesis, and solar illumination hypothesis have been proposed. The mechanisms for these hypotheses are based on excitation and modulation of the parameters involved in geomagnetic activity (Svalgaard et al., 2002).

In our earlier study, we investigated GMS occurrence and its classification based on the phases of the solar cycle. In this study, we considered GMS occurrence and its categories based on seasonal distribution from 1976 to 2019 (solar cycles 21–24). The specific objectives were to: (i) determine the monthly and seasonal distribution of GMSs; (ii) compare the total GMSs in each solar cycle; and (iii) compare GMSs in spring, summer, autumn, and winter based on storm categories during solar cycles 21–24. This will enable us to confirm the Russell-McPherron effect and the recent report that the prominence of GMSs during equinoxes is mostly associated with large storms (Dst ≤ -50 nT).

The seasons considered in this study are equinox conditions (spring and autumn) and solstice conditions (summer and winter). The months in each season are: spring (March, April, and May), summer (June, July, and August), autumn (September, October, and November), and winter (December, January, and February). This study hopes to provide scientific insight into the seasonal distribution of storm occurrence based on storm classes, contributing to the understanding of space weather phenomena and the earlier findings on the seasonal variation of GMSs.

DATA & METHODS

Solar cycles 21–24 have features and parameters similar to those of other cycles (Joshua et al., 2018). The start and end years and months of solar cycles 21–24 are: 1976-03 to 1986-09, 1986-09 to 1996-08, 1996-08 to 2008-12, and 2008-12 to 2019-12, respectively. Solar minimums for solar cycles 21–24 were observed in 1976, 1986, 1996, and 2008, while solar maximums were recorded in 1979, 1986, 1996, and 2008, respectively. The lengths of solar cycles 21–24 are 10.5, 9.9, 12.3, and 11.0 years, respectively.

This study employed Dst index data of hourly resolution, provided by the World Data Center, Kyoto, Japan. The magnitude of the Dst index measured the strength of GMSs as stated earlier. The data was obtained from the OmniWeb website (www.omniweb.gsfc.nasa.gov) (World Data Center for Geomagnetism, 2015). Detailed information about the Dst index can be obtained from the World Data Center for Geomagnetism, Kyoto, Japan. The period under investigation covers solar cycles 21–24 (1976–2019).

Large storms (Dst ≤ -50 nT) were considered in this study. Storm occurrence in each solar cycle was identified as the minimum value of Dst during the main phase of a GMS, as observed on the storm profile. Hourly Dst values were used to create the storm profile. Based on the large storms (Dst ≤ -50 nT) considered in this study, a storm is said to occur if the Dst ≤ -50 nT. From the storm profile, the observed storm is then categorized based on the minimum Dst value. The identified storms were then counted and categorized based on the storm classification stated earlier. Descriptive statistics were then employed. The identified storms (GMSs) in each month (M), year (A), and season (S) in each solar cycle were computed using Equations 1–3, respectively.

$$M = \sum_{i=1}^{n} GMSs_i \qquad (1)$$

$$A = \sum_{i=1}^{12} \bar{M}_{s\,i} \qquad (2)$$

$$S = \sum_{i=1}^{4} D_{s_i} \tag{3}$$

where *n* is the number of storms in each month.

Subsequently, total storms in each season were determined from the monthly values. Finally, a statistical test (Student's t-test) was performed at the 0.05 level of significance to compare the total storms observed in each solar cycle and to identify any differences in the distribution of GMS occurrences in cycles 21–24.

RESULTS & DISCUSSION

Comparison of Monthly and Seasonal Distribution of GMSs in Solar Cycles 21–24

Figure 1 presents the monthly mean variation of geomagnetic storms (GMSs) during solar cycle 21. Moderate storms were observed in all months, with relatively high occurrences in December and May, and the lowest occurrences in February and August. Intense storms were observed in all months except July, with the highest and lowest occurrences in November and June, respectively. Severe storms were recorded from January to April, and from July to September.

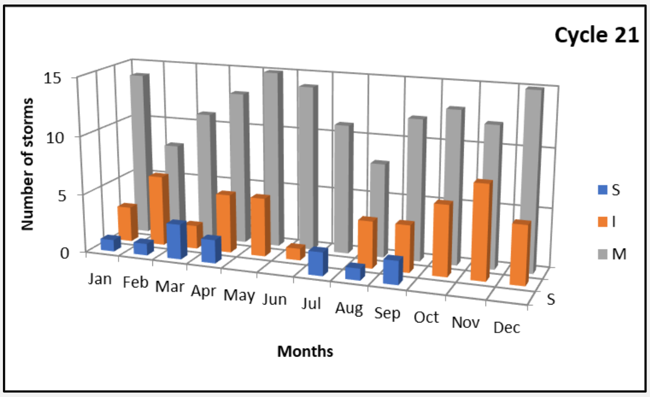

Figure 1. Monthly mean variation of GMSs during solar cycle 21.

In Figure 2, moderate storms were almost of the same magnitude across all seasons (26.7%, 22.6%, 25.3%, and 25.3%). Intense storms observed during spring, summer, autumn, and winter were 24.5%, 10.2%, 36.7%, and 28.6%, respectively, while severe storms were 41.7%, 25.0%, 16.7%, and 16.7%, respectively. The highest and lowest intense storms were observed in autumn and summer, respectively, while the highest severe storms were recorded in spring. Thus, the total number of storms during cycle 21 in spring, summer, autumn, and winter were 27.1%, 19.8%, 27.5%, and 25.6%, respectively. This indicates a higher number of storms during the equinoxes (spring and autumn) than during the solstices (summer and winter) in cycle 21.

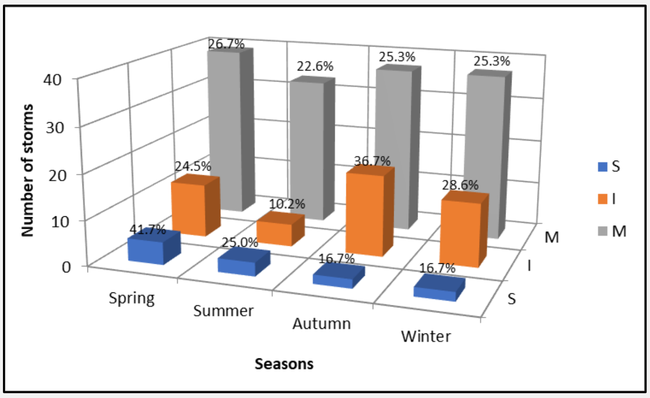

Figure 2. Comparison of seasonal variation of GMSs during solar cycle 21.

From Figure 3, moderate and intense storms were recorded in all months. Moderate storms were high in January, May, August, and December but low in April, June, and November. Intense storms were high in August and September but low in May and December. Severe storms were recorded from February to June and from September to November, while great storms were recorded only in March and November.

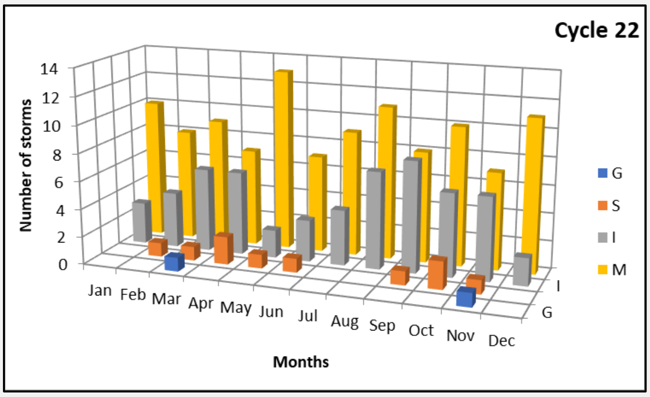

Figure 3. Monthly mean variation of GMSs during solar cycle 22.

The comparison of seasonal variation of GMSs during solar cycle 22 is illustrated in Figure 4. Moderate storms observed in spring, summer, autumn, and winter were 26.4%, 24.5%, 22.7%, and 26.4%, respectively, depicting more moderate storms in spring and winter than in summer and autumn. Intense and severe storms tended to be higher during the equinoxes (spring and autumn) compared to the solstices (summer and winter), while great storms were not observed during the solstices. Thus, the total number of storms during cycle 22 in spring, summer, autumn, and winter were 26.8%, 23.5%, 27.9%, and 21.8%, respectively. This implies a higher number of storms in spring and autumn (equinoxes) than in summer and winter (solstices) during cycle 22.

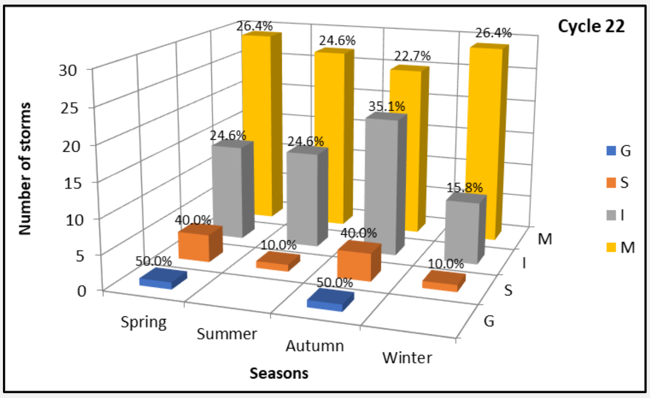

Figure 4. Comparison of seasonal variation of GMSs during solar cycle 22.

From Figure 5, moderate storms were recorded in all months, with the highest and lowest occurrences in March and August, respectively. Intense storms were also observed in all months, with the highest occurrences in August, October, and November, and the lowest in December. Severe storms were observed from April to May and from July to November, while four great storms were recorded in March (spring), and October and November (autumn), which are equinoctial months.

It can be seen from Figure 6 that the highest and lowest moderate storms were observed in spring (29.9%) and summer (16.8%). The highest and lowest intense storms were recorded in autumn (39.6%) and winter (11.3%), respectively. Severe storms were very high in spring and autumn but low in summer, with no storms in winter. Great storms were recorded only in spring (25.0%) and autumn (75.0%). Therefore, the total number of storms during cycle 23 in spring, summer, autumn, and winter were 28.3%, 19.0%, 30.7%, and 22.0%, respectively, indicating that the total number of storms during cycle 23 was higher during the equinoxes than during the solstices.

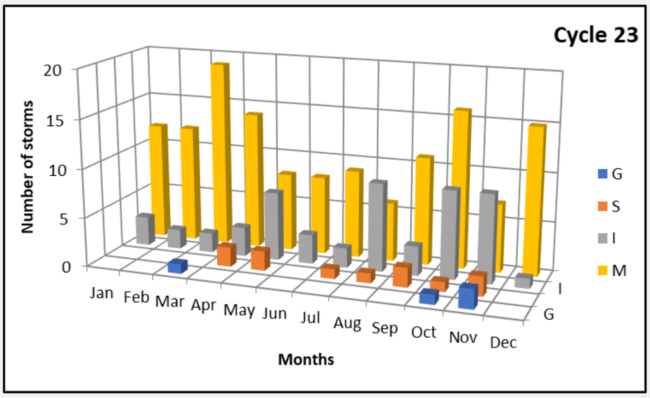

Figure 5. Monthly mean variation of GMSs during solar cycle 23.

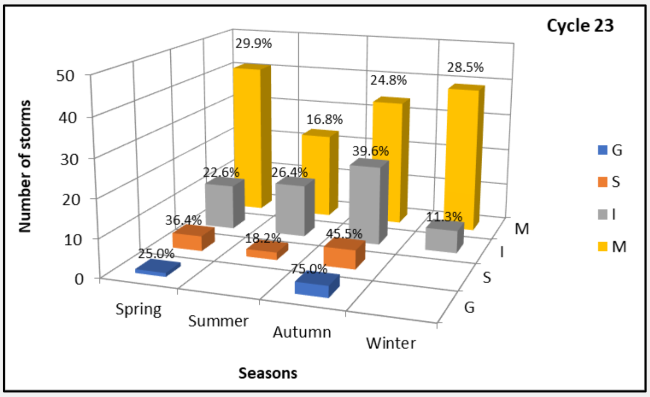

Figure 6. Comparison of seasonal variation of GMSs during solar cycle 23.

In Figure 7, moderate and intense storms were recorded in all months. Moderate storms were high in all months except January, June, and December, while intense storms were relatively low in all months except October. Severe storms were observed only in March and June, with no great storms observed in cycle 24.

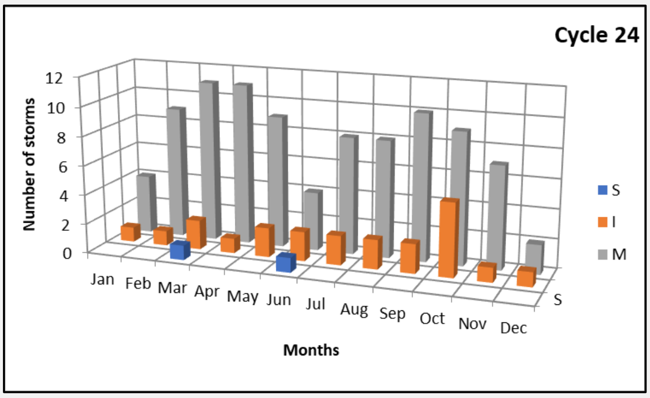

Figure 7. Monthly mean variation of GMSs during solar cycle 24.

From the comparison of seasonal variation of GMSs during solar cycle 24 (Figure 8), moderate storms tended to decrease in the following order: spring, autumn, summer, and winter. Intense storms decreased as follows: autumn, summer, spring, and winter, while severe storms were observed only in spring and summer. Thus, the estimated percentage of storms during cycle 24 in spring, autumn, summer, and winter were 31.9%, 23.3%, 29.3%, and 15.5%, respectively. This indicates higher storms during the equinoxes than during the solstices in cycle 24.

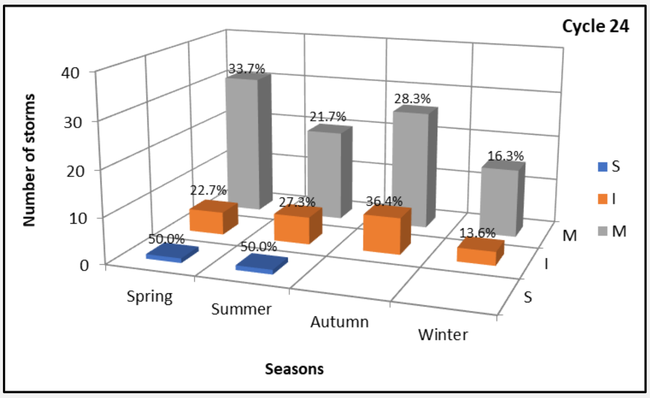

Figure 8. Comparison of seasonal variation of GMSs during solar cycle 24.

Comparison of Total Storms in Solar Cycles 21–24 Based on Storm Classification

For the period under study, the total GMSs observed in each solar cycle were classified as follows: for cycle 21, 207 storms were observed, classified into moderate (146), intense (49), and severe storms (12). In cycle 22, 179 storms were recorded, grouped into moderate (110), intense (57), severe (10), and great storms (2). For cycle 23, 205 storms were observed, categorized into moderate (137), intense (53), severe (11), and great (4) storms. In cycle 24, 116 storms were observed, classified into moderate (92), intense (22), and severe (2) storms. This implies that GMS occurrence differs from one solar cycle to another. It is clearly evident that among the solar cycles considered, cycle 24 recorded the lowest number of storms. According to Reyes et al. (2021), this depicts the weak nature of cycle 24 among the solar cycles on record, and we equally attribute this result to the same weak nature. This is in line with the findings of Sawadogo et al. (2022).

Furthermore, we performed a statistical test to compare the total storms recorded in each solar cycle using a Student's t-test. The Student's t-test was employed because of its advantages over other statistical tests (Mishra et al., 2019). We assumed that the variances of the two solar cycles to be compared are equal. Monthly averages of total storms observed in cycles 21–24 were compared with each other using a Student's t-test. The statistical test indicates that differences exist between solar cycles 21 and 22, solar cycles 21 and 23, solar cycles 21 and 24, solar cycles 22 and 23, solar cycles 22 and 24, and solar cycles 23 and 24. Thus, the null hypothesis that no difference exists between two solar cycles was rejected. The observed differences are significant at the 0.05 level, except between cycles 21 and 23. This indicates that the total storms observed differ from one solar cycle to another. Thus, the statistical test suggests that the distribution of GMS occurrence varied from one solar cycle to another, confirming our earlier observation.

Comparison of GMSs in Spring, Autumn, Summer, and Winter during Solar Cycles 21–24

To ascertain the total number of storms recorded in each season (spring, autumn, summer, and winter) based on storm categories, we considered the storms recorded in each solar cycle. The GMSs recorded in cycles 21–24 during spring were 56, 48, 58, and 37, respectively. This shows that storms were higher in cycle 23 during autumn than in other cycles. Similarly, during summer, we observed 41, 42, 39, and 27 storms in cycles 21–24, respectively, indicating more storms in cycle 22 during summer compared to other cycles. The storms recorded in cycles 21–24 during autumn were 57, 50, 63, and 34, respectively, implying that cycle 23 recorded more storms during autumn than other cycles. The storms recorded in cycles 21–24 during winter were 53, 39, 45, and 18, respectively, showing that more storms were observed in cycle 21 during autumn than in other cycles. We further classified these storms into moderate, intense, severe, and great storms for each cycle as shown in Figures 9-12.

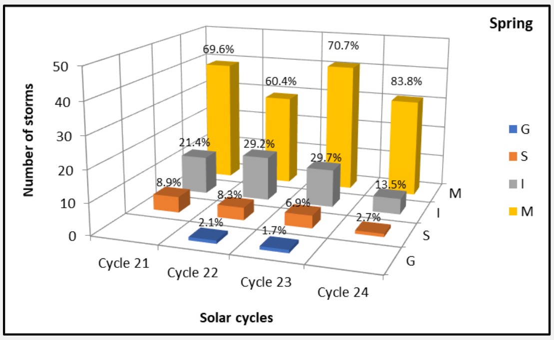

Figure 9. Comparison of GMSs in Spring during solar cycles 21 – 24.

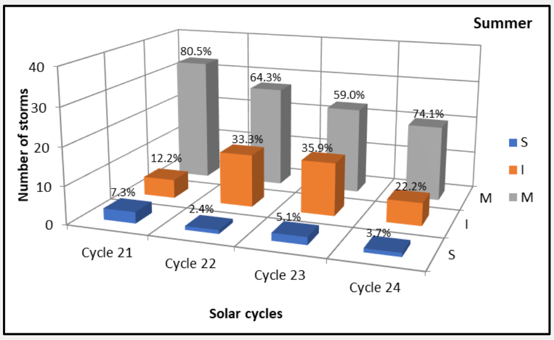

Figure 10. Comparison of GMSs in Summer during solar cycles 21 – 24.

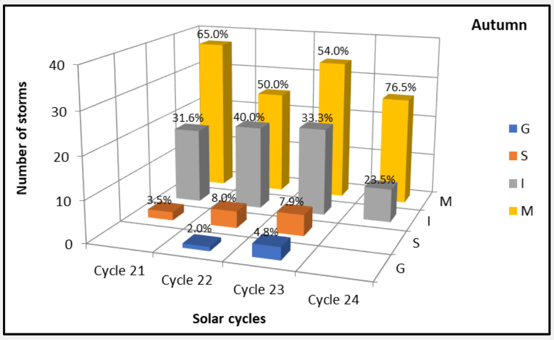

Figure 11. Comparison of GMSs in Autumn during solar cycles 21 – 24.

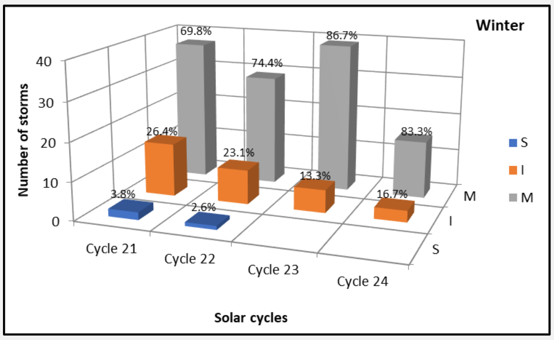

Figure 12. Comparison of GMSs in Winter during solar cycles 21 – 24.

Considering the GMSs in spring, summer, autumn, and winter, it is evident that the observed storms decrease in each solar cycle based on storm classification into moderate, intense, severe, and great storms (Figures 9-12). This suggests that moderate storms are the most frequently occurring storms, while great storms are the least frequent. We observed great storms in cycles 22 and 23 during spring and autumn only, which are equinoctial conditions. This suggests that equinox conditions are periods to expect more storms and storms with higher intensity (Dst ≤ -350 nT), which could be very dangerous to astronauts, space scientists, and space technology and infrastructure.

From the foregoing, it is clear that in cycles 21–24, moderate storms were dominant and had the highest percentage compared to intense, severe, and great storms. Moderate storms were observed in all months and seasons, indicating that among the large storms considered, moderate storms were the most frequently occurring. However, moderate storms varied from month to month and season to season depending on the solar cycle. Similarly, intense storms were recorded in all months (except July of cycle 21) and seasons, and they also varied based on the solar cycle. Severe storms were observed in most months, depending on the solar cycle, and in all seasons in cycles 21–24 except in autumn and winter of cycle 24.

During the period under study, great storms were observed in cycle 22 (March and November) and cycle 23 (March, October, and November), which are all equinoctial conditions. This suggests the months and seasons in which great storms may probably occur, serving as a guide to space scientists while exploring space weather phenomena. This suggests that we could possibly predict the seasons when great storms may occur.

Generally, our findings show that GMSs varied from month to month, season to season, and solar cycle to solar cycle based on storm categories. However, we were unable to predict the number of storms that may be expected per month or season in each solar cycle. We recommend further studies to ascertain that. The observed monthly and seasonal variation of GMSs could be attributed to solar activity, which influences geomagnetic activity. According to Watari (2017), solar activity controls the intensity and severity of magnetic storms.

Furthermore, the total storms recorded during cycles 21–24 in spring, summer, autumn, and winter were 199, 149, 204, and 155, respectively. This suggests more storms during equinoxes compared to solstice conditions. The high storms in equinoxes were attributed to enhanced geomagnetic activity due to increased coupling of the solar wind with the magnetosphere (Rashmi et al., 2013), known as the Russell-McPherron effect. The result of this study is in line with findings on GMSs during solar cycle 23 (Parashar et al., 2011; Rathore et al., 2012; Rashmi et al., 2013), solar cycle 24 (Watari, 2017), and cycles 21–23 (Reyes et al., 2019; Reyes et al., 2021) reported earlier.

These findings confirm earlier reports that geomagnetic activity was higher during equinoxes using large geomagnetic storms compared to solstices (e.g., Gustavo, 2014). Besides the prominence of large storms during equinoxes, we also observed great storms (Dst ≤ -350 nT) in cycles 22 and 23 during equinoxes only, indicating a higher probability of occurrence of great storms during equinoxes (spring and autumn). Furthermore, the findings of this study suggest that the seasonal distribution of geomagnetic storm occurrence decreases in the following order: autumn, spring, winter, and summer.

We recommend that GMSs in solar cycle 25 be assessed to ascertain the prominence of large storms (Dst ≤ -50 nT) during equinoxes as well as the order of GMS occurrence (autumn, spring, winter, and summer) observed in this study. This may help us better understand space weather phenomena during this solar cycle.

The implication of the observed seasonal distribution of GMSs suggests that the impacts of storms on satellites and other space communication devices, as well as astronauts, may be relatively high during equinoxes, especially in March (spring), October, and November (autumn), where great storms (Dst ≤ -350 nT) were observed. This may pose a serious threat to the advancement of space technology, as well as the lives and activities of astronauts in space. The results of this research will benefit society tremendously in understanding space weather phenomena.

CONCLUSION

The following conclusions were drawn from this study: For the period under study, storm occurrence varied from month to month, season to season, and solar cycle to solar cycle based on the categories of storms. GMS occurrence decreases monthly and seasonally in the following order: moderate, intense, severe, and great storms. Similarly, the seasonal distribution of geomagnetic storm occurrence decreases in the following order: autumn, spring, winter, and summer. The findings of this study suggest that equinox conditions are more likely to have more geomagnetic storms, consistent with the well-known Russell-McPherron effect, while winters tend to present more storms than summers.

ACKNOWLEDGMENT

The authors appreciate the World Data Center Kyoto Japan for providing the Dst index data used for this study. The authors also thanked the anonymous reviewers for their valuable comments, suggestions, and contributions that have improved the quality of this study, and the editorial team for their good work.

REFERENCES

Borovsky, J. E., & Denton, M. H. (2006). Differences between CME-driven storms and CIR-driven storms. *Journal of Geophysical Research*, *111*(A7). https://doi.org/10.1029/2005JA011447

Chapman, S. C., Horne, R. B., & Watkins, N. W. (2020). Using the index over the last 14 Solar cycles to characterize extreme geomagnetic activity. *Geophysical Research Letters*, *47*(3), e2019GL086524. https://doi.org/10.1029/2019GL086524

Christian, O. C. (2018). A statistical analysis of sunspot and CME parameters for the solar cycle 23. *Physics and Astronomy International Journal*, *2*(4), 300–308. https://doi.org/10.15406/paij.2018.02.00103

Daglis, T., Konstantakis, K. N., & Michaelides, P. G. (2019). Solar events and economic activity: evidence from the US telecommunications industry (1996–2014). *Physica A: Statistical Mechanics and its Applications*, *534*, 120805. https://doi.org/10.1016/j.physa.2019.04.041

Doha, A., & Wathiq, A. (2019). Large geomagnetic storms drive by solar wind in solar cycle 24, *Journal of Physics: Conference Series*, *1234*, 012004. https://doi.org/10.1088/1742-6596/1234/1/012004

Gonzalez, W. D., Joselyn, J. A., Kamide, Y., Kroehl, H. W., Rostoker, G., Tsurutani, B. T. and Vasyliunas, V. M. (1994). What is a geomagnetic storm? *Journal of Geophysical Research*, *99*, 5771. https://doi.org/10.1029/93JA02867

Gustavo, A. M. (2014). Solar cycle and seasonal distribution of geomagnetic storms with sudden commencement. *Earth Science Research*, *3*(1), 50–55. https://doi.org/10.5539/esr.v3n1p50

Joshua, B. W., Oladipo, O. M., Adamu, J. L., Adebiyi, S. J., & Ikubanni, S. O. (2018). Correlation between sunspot number and geomagnetic storm. *Equity Journal of Science and Technology*, *5*(1), 157-161.

Kane, R. P. (2014). Evolution of solar indices during the maximum of solar cycle 24. *Indian Journal of Radio and Space Physics*, *43*, 151–155.

Kevser, K. (2021). Mathematical analysis of 08 May 2014 weak storm. *Mathematics problems Engineer*, *2021*(1), 9948745. https://doi.org/10.1155/2021/9948745

Le, G.-M., Cai, Z.-Y., Wang, H.-N., Yin, Z.-Q., & Li, P. (2013). Solar cycle distribution of major geomagnetic storms. *Research in Astronomy and Astrophysics*, 13, 739–748. https://doi.org/10.1088/1674-4527/13/6/013

Love, J. J., Rigler, E. J., Pulkkinen, A., & Riley, P. (2015). On the lognormality of historical magnetic storm intensity statistics: Implications for extreme-event probabilities. *Geophysical Research Letters*, *42*(16), 6544–6553. https://doi.org/10.1002/2015GL064842

Mandea, M., & Chambodut, A. (2020). Geomagnetic Field Processes and Their Implications for Space Weather. *Survey Geophysics*, *41*, 1611–1627. https://doi.org/10.1007/s10712-020-09598-1

Mishra, P., Singh, U., Pandey, C. M., Mishra, P., & Pandey, G. (2019). Application of student's t-test, analysis of variance, and covariance. *Annals of Cardiac Anaesthetia*, *22*(4), 407-411. https://doi.org/10.4103/aca.ACA_94_19

Parashar, K. K., Rathore, B. S., Kaushik, S. C., Kapil, P., & Gupta, D. C. (2011). Classification and study of geomagnetic storms during Year 1996-2010. *International Journal of Pure and Applied Physics*, *7*(3), 199-202.

Ptitsyna, N. G., & Tyasto, M. I. (2017). Long-term trends and seasonal variations in geomagnetic storms from data of St. Petersburg Observatories (1878–1954). *Geomagnetism and Aeronomy*, *57*, 1056–1062. https://doi.org/10.1134/S0016793217080205

Rashmi, P., Singh, S.B., & Kalyan, B. (2013). A study of seasonal variation of geomagnetic activity. *Research Journal of Physical and Applied Sciences*, *2*(1), 1–011.

Rathore, B. S., Gupta, D. C., & Parashar, K. K. (2014). Relation between solar wind parameter and geomagnetic storm condition during cycle-23. *International Journal of Geoscience*, *5*(13), 1602-1608. http://dx.doi.org/10.4236/ijg.2014.513131

Rathore, B.S., Kaushik, S. C., Bhadoria, R. S., Parashar, K. K., & Gupta, D. C. (2012). Sunspots and geomagnetic storms during solar cycle-23, *Indian Journal of Physics*, https://doi.org/10.1007/s12648-012-0106-2

Reyes, P. I., Pinto, V. A., & Moya, P. S. (2021). Geomagnetic Storm Occurrence and Their Relation with Solar Cycle Phases. *Space Weather*, *19*(9), e2021SW002766. https://doi.org/10.1029/2021SW002766

Reyes, P., Pinto, V. A., & Moya, P. S. (2019). Statistical analysis of geomagnetic storms and their relation with the solar cycle. *Proceedings of the International Astronomical Union, 15*(S354), 224–227. https://doi.org/10.1017/S1743921320000903

Sawadogo, Y., Koala, S., & Zerbo, J. L. (2022). Factors of geomagnetic storms during the solar cycles 23 and 24: A comparative statistical study. *Scientific Research and Essays*, *17*(3), 46-56. https://doi.org/10.5897/SRE2022.6751

Shadrina, L. P. (2017). Two types of geomagnetic storms and relationship between Dst and AE indexes. Solar-Terrestrial Relations and Physics of Earthquake Precursors. In *E3S Web of Conferences* (Vol. 20, p. 01010). EDP Sciences. https://doi.org/10.1051/e3sconf/20172001010

Svalgaard, L., Cliver, E. W., & Ling, A. G. (2002). The semiannual variation of great geomagnetic storms. *Geophysical Research Letters*, *29*(16), 12-1-12-4. https://doi.org/10.1029/2001GL014145

Watari, S. (2017). Geomagnetic storms of cycle 24 and their solar sources. *Earth, Planets and Space*, *67*, 70. https://doi.org/10.1186/s40623-017-0653-z

World Data Center for Geomagnetism, Kyoto. Nose, M., Iyemori, T., Sugiura, M., & Kamei, T. (2015). *Geomagnetic Dst index*. https://doi.org/10.17593/14515-74000

Wu, C., Liou, K., Lepping, R.P., Hutting, L., Plunkett, S., Howard, R. A., & Socker, D. (2016). The first super geomagnetic storm of solar cycle 24: "The St. Patrick's day event (17 March 2015)". *Earth, Planets and Space*, *68*, 151. https://doi.org/10.1186/s40623-016-0525-y