Reply to Anonymous Referee #2's comments at https://doi.org/10.5194/angeo-2024-9-RC2

Dear Anonymous Referee #2,

Thank you very much for your comments. Author's reply and changes in the manuscript are marked in turquoise.

I am pleased to recommend the acceptance of this manuscript for publication. The author has presented a thorough and insightful analysis of the geomagnetic storm that occurred on April 23–24, 2023, a significant two-step event within Solar Cycle 25. Their use of data from near-meridional chains of magnetometer stations across both hemispheres provides a robust foundation for examining the latitudinal variations and underlying mechanisms of this severe geomagnetic disturbance. The clarity of the results and the depth of analysis reflect a high level of expertise and make a meaningful contribution to our understanding of geomagnetic storm dynamics.

The manuscript effectively highlights the detailed observations of geomagnetic field variations and their implications, particularly during the second step of the storm. The authors' approach to exploring the spatial and temporal characteristics of geomagnetic field disturbances is commendable. Their findings, which reveal significant increases in geomagnetic field strength and variations with latitude, add valuable insights into how such storms impact different regions of the Earth. The careful presentation and interpretation of these results enhance the manuscript's scientific value.

To further enrich the manuscript, I suggest incorporating comparisons with recent studies on this extreme space weather event. Kalpesh Ghag et al. (2024) offer a thorough examination of this geomagnetic storm and their analysis attributes the storm's intensity to the transformation of an ICME sheath into quasi-planar magnetic structures, which they demonstrate significantly enhances the southward magnetic field component, thereby intensifying geomagnetic activity [1]. Irina Despirak et al. (2024) further elucidate the sources and behaviors of geomagnetically induced currents (GICs) during this event, highlighting the influence of interplanetary shocks, magnetic clouds, and localized geomagnetic disturbances on GIC intensities [2]. Additionally, Souza et al. (2024) provides a thorough analysis of the effects of storm-time prompt penetration electric fields (PPEF) and traveling atmospheric disturbances (TADs) on TEC, foF2, and hmF2 during this geomagnetic storm, revealing significant shifts in the Equatorial Ionization Anomaly (EIA) and detailed characteristics of TAD propagation. Their findings effectively illustrate how these disturbances impact ionospheric and thermospheric conditions, contributing valuable insights to the understanding of space weather dynamics [3]. Habarulema et al. (2024) report a unique observation of missing high-frequency echoes from ionosondes during the same storm, attributing this anomaly to significant ionospheric depletion and gradients as detected by TIMED/GUVI and simulated by TIEGCM [4]. The references to Kamide Y.'s work, particularly the detailed discussion on the two-step development of geomagnetic storms [5], could provide valuable additional context and further enhance the manuscript's depth and historical grounding.

Overall, this manuscript is a significant contribution to the field of space weather research. The author has provided a detailed and insightful analysis of a complex geomagnetic storm, and their work is of high quality. I strongly support its acceptance for publication, with the aforementioned suggestions for additional context and comparisons to further strengthen its impact.\

Dear Anonymous Referee #2, Thank you very much for your comments. We have added the following paragraph to Introduction section:

The main feature of the storm under study is its two-step nature. The comprehensive statistical investigation of Kamide et al. (1998) was one of the first to arrive at the conclusion that intense two-step main phase geomagnetic storms can result from two successive moderate storms driven by successive interplanetary, southward structures. Regarding the geomagnetic storm of the 23–24 April 2023, it has already been dealt with in a few papers. One of them demonstrated that an interplanetary coronal mass ejection sheath was transformed into quasi-planar structures that enhanced the strength of the southward interplanetary magnetic field (IMF) component and consequently the efficient transfer of plasma and energy into the Earth's magnetosphere and thus causing the observed extreme storm (Ghag et al., 2024). A comprehensive analysis of the effects that the storm-time prompt penetration electric fields and traveling atmospheric disturbances had on the total electron content, critical F_2-layer frequencies, and *F*-layer peak altitudes during this geomagnetic storm has revealed significant shifts in the equatorial ionization anomaly and characteristics of traveling atmospheric disturbance propagation (Souza et al., 2024). The ionospheric storm caused by this geospace storm was also so great that high frequency reflections from the ionospheric F_2 layer were absent in the ionosonde observations over two stations, Grahamstown (33.3°S, 26.5°E), South Africa and Pruhonice (50.0°N, 14.6°E), Czech Republic during 23–25 April 2023 (Habarulema et al., 2024). The 23–24 April 2023 storm also affected technological infrastructure, power and gas lines, with the induced currents attaining 46 A during the second step of the storm (Despirak et al., 2024).

References

[1] Kalpesh Ghag et al. (2024) Quasi-planar ICME sheath: A cause of the first two-step extreme geomagnetic storm of the 25th solar cycle observed on 23 April 2023. Advances in Space Research 73(12), 6288-6297. https://doi.org/10.1016/j.asr.2024.03.011
[2] Irina Despirak et al. (2024) Geomagnetically induced currents (GICs) during strong geomagnetic activity (storms, substorms, and magnetic pulsations) on 23–24 April 2023. Journal of Atmospheric and Solar–Terrestrial Physics 261, 106293. https://doi.org/10.1016/j.jastp.2024.106293
[3] Souza,J.R., et al. (2024). Impacts of storm electric fields and traveling atmospheric disturbances over the Americas during 23-24 April 2023 geomagnetic storm: Experimental analysis. Journal of Geophysical Research: Space Physics, 129, e2024JA032698. https://doi.org/10.1029/2024JA032698
[4] Habarulema,J.B., et al. (2024).Absence of high frequency echoes from ionosondes during the 23–25 April 2023 geomagnetic storm; what happened? Journal of Geophysical Research: Space Physics, 129, e2023JA032277. https://doi.org/10.1029/2023JA032277
[5] Kamide, Y. et al. (1998). Two-step development of geomagnetic storms. Journal of Geophysical Research, 103(A4), 6917-6921. https://doi.org/10.1029/97JA03337

The author is grateful to Anonymous Referee #2 for the valuable comments that have helped Author greatly improve the draft of his paper.

Sincerely,
Leonid Chernogor.