

Dear Editor,

Thank you for sending us the report on "Ionospheric Plasma Irregularities During Intense geomagnetic storms of Solar Cycle 25" manuscript No. egosphere-2025-86 submitted to Annales Geophysicae. We are very grateful to the Editor and anonymous referee for the time and efforts invested in reviewing and improving our work.

Sincerely,

Nadia Imtiaz and Co-Authros.

Reply to the Editor Report: Modifications in the manuscript are highlighted in the bold text.

• The focus of your study is mainly on the equatorial ionosphere/EIA region. This fact should be reflected in the title of the manuscript.

Reply: Following respected Editor suggestion, we have changed the title of our manuscript as 'Generation of Equatorial Plasma Bubbles During Intense geomagnetic storms of Solar Cycle 25'.

• I cannot entirely agree with the statement in the Introduction (lines 31-33) "Ionospheric effects on applications are generally minor in mid-latitudes, causing only small perturbations in signal propagation that may be roughly expected, especially during magnetic storms". This depends mainly on the strength of the geomagnetic storm and the time at which the initial phase begins, as well as a number of other factors. During the main phase of strong storms, total absorption may occur alongside F-layer spread, sporadic opaque E-layer and high TID activity moving southwards from the auroral region. All of these factors can significantly affect signal propagation and cause inaccuracy in GNSS applications at mid-latitudes.

Reply: We are thankful to the respected Editor for clarifying this. We agreed that ionospheric effects on GNSS applications depend mainly on the strength of the geomagnetic storm and the time at which the initial phase begins, as well as a number of other factors. We have removed this paragraph.

- What is the point of having information on the solar radio flux at 10.7 cm (F10.7) for analysis?

Reply: The F10.7 index also serves as a key indicator of solar activity. Moderate solar flux values ($100 < F10.7 < 200$) were recorded during the equinox (March–April) and winter solstice (November) storm periods, while enhanced solar activity ($F10.7 > 200$) characterized the May solstice storm (Mother's Day event). Such elevated F10.7 levels correspond to increased solar EUV irradiance, resulting in a denser and more variable ionosphere due to intensified ionization processes particularly during mother's day storm.

- I would like to see a more detailed assessment of how the intensity (and possibly seasonal dependencies and local time) of the analysed storms impacts ionospheric changes over equatorial regions. Of the storms analysed, one is a superstorm (10–13 May 2024), one is an intense storm (April 2023) and the remaining two are strong storms.

Reply: Previous studies have reported that the seasonal variation of equatorial plasma bubbles (EPBs) is primarily governed by the angle between the magnetic meridian and the solar terminator. The occurrence probability of post-sunset EPBs is generally higher during equinoctial months (March and April) and minimal around the summer solstice (as seen during the May storm). In our study, the occurrence of EPBs during equinox storms can therefore be attributed mainly to seasonal effects. In contrast, the suppression of post-sunset EPBs during the main phase of the November storm can be explained by the fact that the prompt penetration electric field (PPEF) arrived after midnight local time, when post-sunset conditions were no longer favourable for bubble development. The unseasonal generation of post-sunset EPBs during the Mother's Day storm appears to result from the combined influence of strong solar flux and a significant eastward PPEF near local sunset.

- The introduction section, which is 3.5 pages out of a total of 16 pages of text (which also contains images and tables), seems too extensive. On the contrary, the

Conclusions are too brief and too general. Here, it would be appropriate to highlight the novelty of the analysis and avoid information that is already widely known.

Reply: We have revised the manuscript according to the respected Editor's requirements. Here is our conclusion:

We presented a comprehensive analysis of four geomagnetic storms (March 23–25, April 23–25, and November 4–6, 2023, and May 10–13, 2024) to investigate storm-time coupling between solar wind forcing, Joule heating (JH), thermospheric dynamics, and low-latitude ionospheric responses. This multi-event, multi-season comparison provides one of the first systematic characterizations of how high-latitude energy input through JH modulates equatorial ionospheric structures and post-sunset irregularities.

- The magnitude and spatial distribution of JH varied significantly with storm intensity, local time, duration, and season. A clear solstice-equinox contrast was observed, with the May 2024 storm exhibiting the most intense post-sunset JH and the November 2023 storm showing the weakest. Nearly symmetric JH patterns were observed during equinoctial storms, whereas solstice events exhibited pronounced hemispheric asymmetries.
- Distinct electrodynamic pathways were identified linking JH-driven equatorward winds to the evolution of the equatorial ionization anomaly (EIA). The combined influence of storm-time electric fields and thermospheric winds determined whether single- or double-crest EIAs developed, with asymmetric winds amplifying or suppressing the anomaly in opposite hemispheres.
- The seasonal variation of post sunset EPBs was consistent with previous findings, being primarily controlled by the angle between the magnetic meridian and the solar terminator. The occurrence probability of post-sunset EPBs was highest during equinoctial storms (March and April) and minimal during the summer solstice (May storm). In our analysis, the EPBs observed during equinox storms reflect seasonal effects, while their suppression during the November 2023 storm is attributed to a delayed PPEF arriving after midnight, when post-sunset conditions were no

longer favourable for instability growth. Conversely, the unseasonal generation of post-sunset EPBs during the Mother's Day storm resulted from the combined influence of elevated solar flux and a strong eastward PPEF near local sunset.

- The results further highlight the dynamic interplay between overshielding and undershielding PPEFs and thermospheric winds in modulating PRE that further affects the post-sunset plasma uplift and EPBs onset. Variations in EIA gradients and vertical plasma drifts control EPBs intensity and occurrence, exhibiting clear seasonal and hemispheric dependencies.