Ionospheric Response to the Geomagnetic storms of May and October 2024

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Abstract

Pole-to-pole VTEC data from the Madrigal GNSS network on May 10–12 and October 10–12, 2024, were analyzed to diagnose the ionospheric response during the May superstorm and the October severe storm. VTEC, superimposed with S4 and σ scintillation, was used to study the spatiotemporal evolution of small-scale irregularities, while ROTI data from the ISEE GNSS network complemented the analysis by examining large-scale irregularities during both events. ROTI keograms at 90°–60°W and 60°–90°E longitudes revealed an eastward PPEF response, which favored the development of both small- and large-scale irregularities.

1. Introduction

May 10-13, 2024 generated the most powerful coronal mass ejection (CME) that has occurred over the past 20 years which prompted geomagnetic storm complemented with auroras observed worldwide. The storm event showed significant solar-terrestial coupling and that got its scientific name as "Mothers day supertorm". The storm commencemnt to the main phase showed ionospheric turbulent and classified as supertorm (see Table 1). More information about this storm is published in Fagundes et al. (2025). Similarly, October 10, 2024 had a fast-moving CME that impacted earth and prompted another strong geomagnetic storm, currently under scientific investigation. Both storms showed significant ionospheric features and their scientific impact is beneficial to systems that relays on radio signals.

Table 1. Information about May and October geomagnetic storms.

Storm type	Storm commencement	Storm mínima	Dst	Class
G5	17:10 UT (May 10)	1:35 UT (May 11)	-412 nT	Super
G4	15:25 UT (October 10)	2:00 UT (Oct 11)	-335 nT	Severe

Table 1 shows detailed information about storms. CMEs are massive eruptions of solar plasma and embedded magnetic fields from the Sun's corona, as well one of the primary drives of geomagnetic storms.

Table 2. CME days and time of occurrence with velocities of propagation.

Event	CME start Time/Day	Angular width	Velocity (km/s)
1	9:24 UT (May 9)	166	1250
2	7:12 UT (May 10)	92	679
3	8:12 UT (May 10)	112	213
4	2:24 UT (May 11)	360	1008
5	17:36 UT (May 11)	174	520
6	3:36 UT (May 12)	96	452
7	9:24 UT (May 13)	150	919
8	10:12 UT (May 13)	172	618

Event	CME start Time/Day	Angular width	Velocity (km/s)
1	22:12 UT (Oct 7)	166	446
2	23:48 UT (Oct 16)	104	318
3	3:48 UT (Oct 24)	222	844

Table 2 shows occurrence of CMEs, the angular width that indicate CME type and their velocities. During this CME occurences, the ionosphere experinced several turbulents which resulted in excursions of both solar and geomagnetic parameters as seen in Figure 1.

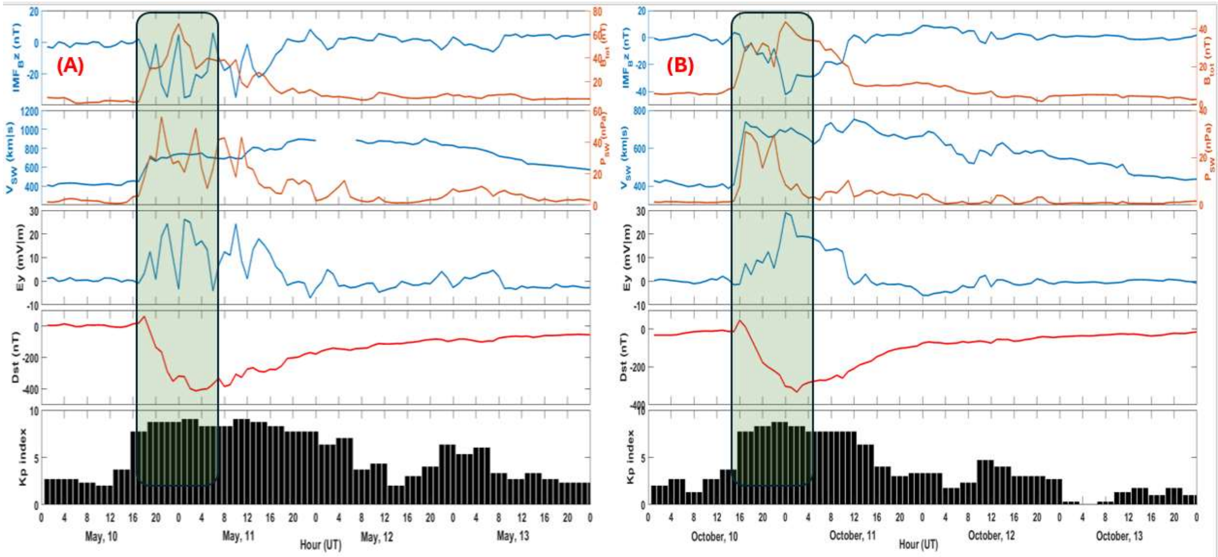

Figure 1. May 2024 solar wind and geomagnetic parameters (A) and Ocober (B).

2. Data and method

To characterize the response of the ionsophere during both storms, pole-to-pole 5-min VTEC data from the Madrigal GNSS network on May 10–12 and October 10–12, 2024, were analyzed to diagnose the ionospheric response during the May superstorm and the October severe storm. VTEC, superimposed with S4 and σ scintillation, was used to study the spatiotemporal evolution of small-scale irregularities, while 5-min ROTI data from the ISEE GNSS network complemented the analysis by examining large-scale irregularities during both events. VTEC meridional average of zonal drift at 90°–60°W and 60°–90°E longitudes were computed followed by prompt penetration electric field (PPEF) data obtained from PPEF model to see space-time VTEC depletions that must have resulted from ambient electric fields over longitudes that gave rise to ExB drift.

3. Results

Th storms information (Fig. 1) from top to bottom has highlighted both interplanetary and geomagnetic conditions observed during both events. To quantify the arrival of CMEs with geomagnetic storm effect, a partial hallo CME occurred at 9:24 UT (May 9) that may have arrived earth ~33 hrs following moderate to fast CME cascades that occurred May 10 and resulted to high solar wind (indicated green) above > 700 km/s. For the October storm, this same event arrived earth ~ 65 hrs (22:12 UT, October 7) with very high solar wind speed > 800 km/s. These geoeffective disturbance created conditions for a geomagnetic storm. Figure 2 shows selected space-time evolutions of VTEC overlayed with S4 and σ scintillations for both north and south hemispheres. Extreme scintillation (S4 and σ ≥ 0.5) corresponded with VTEC depletion were observed at 20:30 UT and 20:50 UT in northern hemisphere in May 10 (signifies storm main phase) and no corresponding occurrence in south hemisphere for May storm. Extreme scintillations were also observed on May 11 at 3:40 UT immediately during storm recovery but no scintillations were observed on May 12.

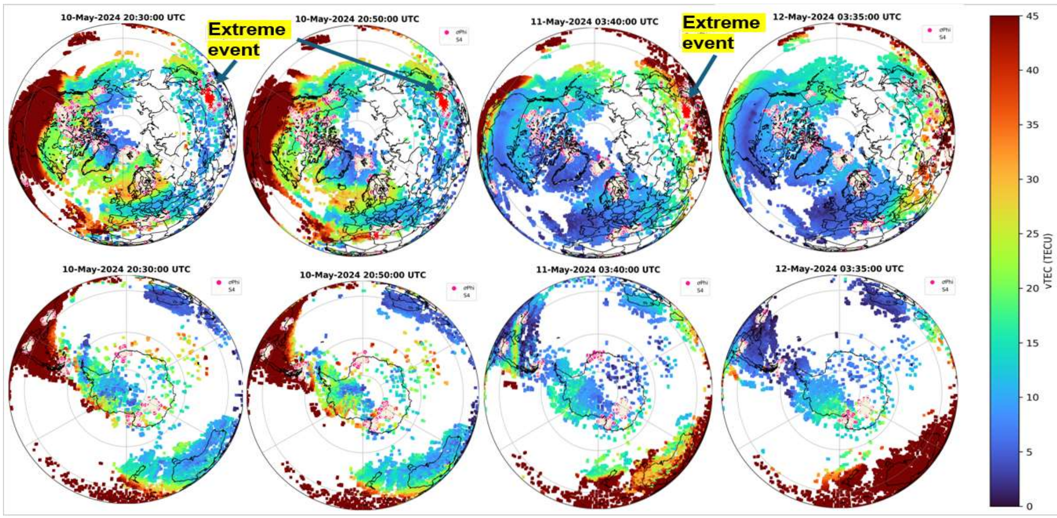

Figure 2. VTEC + S4 and σ scintillation spatial evolution for each 5-min timestamps for May 10-12, 2024

October storm (Figure 3) showed different occurrence where VTEC depletions and corresponding scintillation started to occur from 15:40 UT before the storm commencemnt. October 11 and 12 also recorded extreme scintillations, indicating strong ionospheric disturbance. October 11 at 0:45 UT recorded north and south hemisphere severe scintillation at different sector. This significant ionospheric irregularities that can disrupt GNSS signals. ROTI keogram in Figure 4 clearly show strong plasma bubbles for October storm more than May storm. Again, strong interhemispheric plasma bubbles is observed during storm recovery on October storm (Fig. 4).

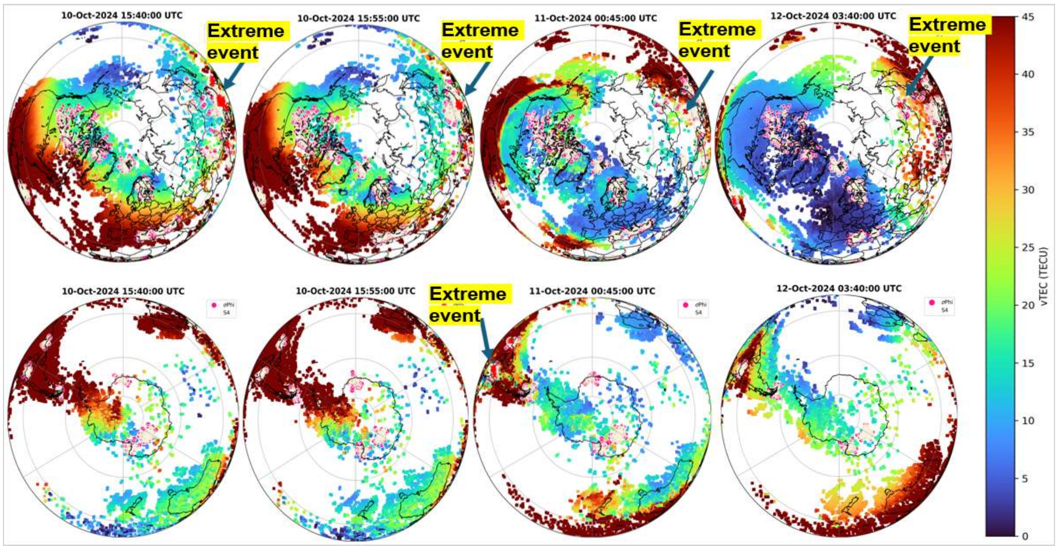

Figure 3. VTEC + S4 and σ scintillation spatial evolution for each 5-min timestamps for October 10-12, 2024

Table 3 showed statistics of S4 and σ scintillation that occurred simultaneously for each sector. The time evolutions of scintillation indicated more occurrence for October storm if compared to May storm.

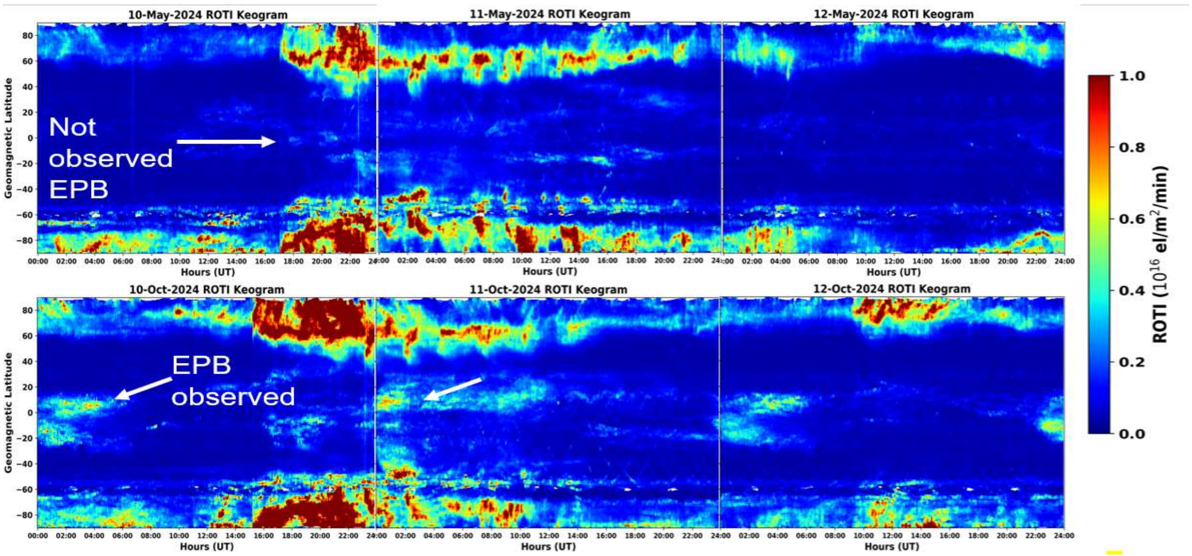

Figure 4. ROTI space and time evolution during both storms.

Table 3. Statistics of time and sector scintillations occurrences for both storms.

Event	S4/σphi North	S4/σphi South	Event	S4/σphi North	S4/σphi South
May 10	12:55 (Asia)	17:55 (Africa)	Oct 10	0:40-1:40 (America)	0:30-2:25 (America)
	13:05 (Asia)	18:00-18:35 (Africa)		11:20-11:45 (Asia)	4:20-4:50 (America)
	13:20 (Asia)	23:15 (Antarctica)		12:10-16:25 (Asia)	16:20 (Africa)
	13:25 (Asia)			16:50-17:30 (Africa)	19:00-20:25 (Africa)
	15:55 (Asia)			17:35 (America)	
	16:40 (Asia)			18:30-18:50 (Europe)	
	17:50 (America)			19:00-19:35 (Africa)	
	19:40 (Africa)			21:35 (America)	
	20:45 (Africa)			21:40 (Africa)	
	20:30-20:50 (Asia)				
	22:20 (Africa)		Oct 11	0:0-0:15 (Africa)	0:0-1:45 (America)
	22:50 (America)				3:55 (America)
May 11	12:30 (Asia)				
	18:55 (Asia)		Oct 12	11:40 (Asia)	2:00 (America)
	22:10 (Asia)			13:00 (Asia)	4:25-5:00 (America)
				13:55-14:00 (Asia)	5:35 (America)
May 12	*	*		17:30 (Asia)	19:10-20:05 (Africa)
				19:20-20:05 (Africa)	

4. Conclusion

The analysis of both storms have revealed significant and interesting ionosphere response. The following conclusions were drawn:

i. Scintillation observed when TEC < 25 TECU during the storm commencemnt and < 10 TECU for storm main (20:30 UT) for May superstorm.

ii. The commencemnt to the recovery stages for October storm showed extreme scintillations & strong interhemispheric widespread large-scale irregularities.

References

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