



Multiple-longitude conjugate hemispheric ionospheric response to the 23-24 March 2023 geomagnetic storm

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The effects of the March 23-24, 2023 geomagnetic storm in the magnetically conjugate low-latitude regions along the $77^\circ\text{E} \pm 5^\circ$, $95^\circ\text{E} \pm 5^\circ$ and $130^\circ\text{E} \pm 5^\circ$ sector are presented. The TEC/NmF2 data from a chain of GNSS/ionosondes, and the global satellites data are utilized. In addition to the absolute difference, the perturbation in the latitudinal gradients of TEC is discussed. As the storm commenced in the night sector of 23 March for the India-East Asia region, the most prominent TEC variations, manifested only on 24th March. Along the 77°E sector, the northern VTEC (Ahmedabad) on 24th March was considerably depleted ($\sim 37\%$) with respect to 21st March, whereas the depletion over southern crest region of Diego Garcia ($\sim 8.93\%$) was marginal. However, along the 95°E sector, the VTEC over the northern station, Dibrugarh, was depleted ($\sim 79\%$) to much larger extent. In contrast, over the southern conjugate station Cocos, the negative effect in VTEC ($\sim 36.3\%$) was relatively less severe. A similar trend of sharp depletion was observed over the north stations of Dimapur ($\sim 68.6\%$ depletion) and Shillong (73.3% depletion) respectively. We observe the most pronounced reduction over Dibrugarh, which is the northern most station. However, over the equatorial station Port Blair, the ionospheric response of VTEC differed, and exhibited a positive effect on 24th March (26%) with respect to 21st March. The NmF2 changes along Okinawa and Darwin ($130^\circ\text{E} \pm 5^\circ$ sector) and Bac Lieu (equator) were similar to VTEC changes in the 95°E sector with stronger perturbation in north ($33\sim\%$) as compared to southern station ($7\sim\%$). The equatorial station Bac Lieu displayed a positive effect in NmF2 in accordance with the equatorial TEC trend over PB. On 24th March, the NmF2 exhibited a wave-like pattern over Okinawa which followed similar pattern over Yamagawa to the north by about 15 minutes. The periods of 2-4 hours suggested propagation of MSTID from higher latitude. On 23rd most changes are significant only in day time and asymmetric on 24th March as changes are significant only in the north (Okinawa). The GNSS TEC over each low latitude station for different satellite path were filtered using azimuthal angle to separate the TEC variations in the north and south of the station. These provided an estimate of the latitudinal gradient over the low latitude region which is normally higher in the equatorial side. Therefore, along the $95^\circ\text{E} \pm 5^\circ$ sector over Dibrugarh, the south-north(equatorward) gradient exhibited notable differences between 24th March and the pre-storm values on 21st March. The most striking difference is the suppressed gradient observed throughout the day on 24th March, following the storm recovery phase. This suppression of the daytime latitudinal gradient aligns with the observed weakening of the absolute TEC over Dibrugarh on 24th March. Similar to the quiet day, the gradient gradually weakens around midnight, but with an overall suppressed magnitude. When it experienced a noticeable upsurge. Following this surge, the gradients fluctuated in strength before falling down sharply. Over Cocos on 21st March, the TEC gradient steadily decreased throughout the daytime hours until around 12 UT at 14 UT. After recovering its strength at 15 UT, the gradients exhibited a steady decrease after 17 UT (local midnight). In contrast, 24th March showed a steady increase in the gradients from 6-9 UT, followed by a gradual decrease throughout the day. A minor upsurge occurred around 17 UT but was subsequently followed by a further decrease. The latitudinal gradient strength on 24th March was reduced in comparison to the quiet day values on 21st March, which was manifested in the TEC depletion as well. Although the weakening of the gradient strength was observed on 24th March over both the conjugate stations, the gradient suppression over Dibrugarh was much more severe than at Cocos. The longitudinal and hemispheric asymmetry of the storm response in VTEC might be attributed to electrodynamic as well as thermospheric changes.