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Multi-instrument study of the response of intense solar flares during the descending period of the 24th solar cycle

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Solar flares (SFs) are rapid, intense bursts of radiation that emerge from the sun in the order of tenths of nanometers. Based on peak emission in X-rays (0.1 - 0.8 nm), SFs are classified into four classes: X (≥ 10−4 Wm−2), M (≥ 10−5 Wm−2), C (≥ 10−6 Wm−2), and B (≥ 10−7 Wm−2). During the day, X-ray flares contain excess Lyman α (121.6 nm) radiation, penetrating up to 70 - 75 km in the ionosphere and directly ionizing to NO, forming the D region. However, a dramatic rise in X-ray flux (~ 0.1 - 0.2 nm) reduces the effective height and enhances the electron density of the N2 and O2 particles in the D region. [1] Numerous studies have investigated the effects of the D-region during SF using VLF waves transmitted by navigational transmitters [2,3]. Various studies of TEC measurement over different locations for intense SF have been done using the global network known as the International GNSS Service (IGS) network. [4,5] Low Earth Orbit (LEO) satellites, such as COSMIC and SWARM, have been launched to measure ionospheric characteristics. In the present study, the influence of SFs on the D-layer using VLF amplitude perturbation and F layers using GPS satellite-derived TEC, COSMIC satellite, and SWARM satellite will be discussed over India, situated in the Equatorial Ionization Anomaly (EIA) crest region.

This study delves into the ionosphere's response in low and equatorial regions of the two most powerful solar flares in the descending phase of the 24th solar cycle, which was attained on July 23, 2016, and April 02, 2017, using multi-instrument measurements using very low frequency (VLF) waves, global positioning system (GPS) based total electron contents (TEC) over four different IGS stations, electron density profiles derived from COSMIC and SWARM satellite (Figure 1). Due to the sudden increase in ionization of the D layer, VLF signals exhibited an elevation in amplitude during a solar flare at a low-latitude station, Varanasi. A strong correlation exceeding 70% was identified between X-ray flux and VLF amplitude variation. Additionally, a sudden rise in ionospheric TEC from 4 different IGS stations indicated an augmentation up to ~4.40 TECU. Notably, the M7.16 flare, which occurred at 02:12 UT, induced a greater enhancement in electron density and TEC compared to the X1.09 flare, largely due to its timing. Ground-based measurements further corroborated electron density profiles derived from COSMIC and SWARM satellite data, showcasing significant variations near the F-region, where electron density peaked dramatically. The study highlights how solar flares impact different ionospheric layers based on region, with increased extreme ultraviolet (EUV) flux driving photo-ionization and TEC enhancements in the upper ionosphere (F region), while elevated flux triggers ionization and disturbances in the lower ionosphere (D region).Apart from E- and F- regions the D-region of ionosphere also changes due to solar eclipse.[2,3] In the present study, the effect of various solar eclipses on low latitude ionosphere will be presented using measurements by GNSS receivers and Very Low Frequency (VLF) receivers at various low latitude Indian stations. The VLF signals transmitted from different VLF transmitters are recorded at different low latitude Indian stations to find any significant variations in the amplitude and phase of the VLF signal. The GPS measured of DTEC is used to find oscillation observed in the ionosphere induced by atmospheric gravity waves (AGWs) generated during the period of the solar eclipse.

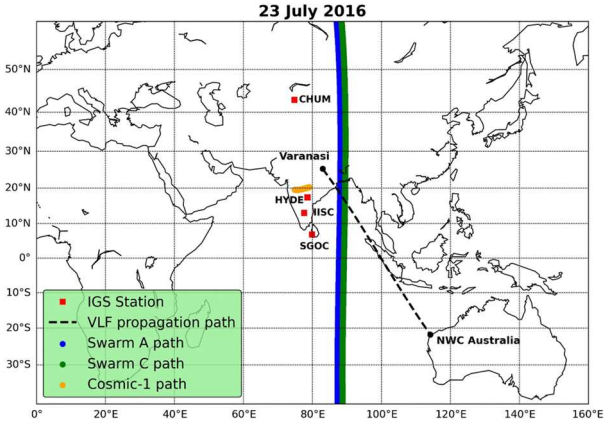

Figure 1: Geographic map showing IGS stations, VLF propagation path, SWARM satellite path on 23 July 2016, and COSMIC-1 satellite path over the Indian subcontinent.

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