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ORIGINAL ARTICLE

Solar flare induced D-region ionospheric perturbations evaluated from VLF measurements

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Abstract The results of very low frequency (VLF) wave amplitude measurements carried out at the low latitude station Varanasi (geom. lat. 14°55′N, long. 154°E), India during solar flares are presented for the first time. The VLF waves (19.8 kHz) transmitted from the NWC-transmitter, Australia propagated in the Earth-ionosphere waveguide to long distances and were recorded at Varanasi. Data are analyzed and the reflection height H' and the sharpness factor β are evaluated. It is found that the reflection height decreases whereas sharpness factor increases with the increase of solar flare power. The H' is found to be higher and β smaller at low latitudes than the corresponding values at mid and high latitudes. The sunspot numbers were low during the considered period 2011–2012, being the rising phase of solar cycle 24 and as a result cosmic rays may impact the D-region ionosphere. The increased ionization from the flare lowers the effective reflecting height, H', of the D-region roughly in proportion to the logarithm of the X-ray flare intensity from a typical mid-day unperturbed value of about 71–72 km down to about 65 km for an X class flare. The sharpness (β) of the lower edge of the D-region is also significantly increased by the flare but reaches a clear saturation value of about 0.48 km^{-1} for flares of magnitude greater than about X1 class.

Keywords Sun: flares, X-rays · Waves: VLF · Ionospheric perturbations

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1 Introduction

The neutral atmosphere in the lower D-region (∼50–70 km) is ionized mainly by solar EUV radiation and galactic cosmic rays. Although, the down going solar EUV radiation is increasingly absorbed by the increasing atmospheric density, but the available free electron density become very small due to high electron attachment and recombination rates. The partially ionized lower D-region forms the upper boundary of the Earth-ionosphere waveguide, while the oceans and ground form the lower boundary. Usually these boundaries are stable and allow VLF waves (∼3–30 kHz) propagation with little or no perturbation. Occasionally solar flares (Mitra 1974; Thomson et al. 2004), geomagnetic storms (Peter et al. 2006), solar proton events (Clilverd et al. 2006), γ-ray bursts (Tanaka et al. 2010), solar eclipse (Klobuchar and Whitney 1965; Singh et al. 2012), lightning discharges (Rodger 1999), particle precipitations due to whistler mode wave particle interaction (Inan et al. 2010) and earthquakes (Hayakawa et al. 1996) could produce additional ionization in the lower D-region and perturb the upper boundary of the Earth-ionosphere waveguide. As a result the amplitude and phase of the VLF waves propagating through the Earth-ionosphere waveguide also get perturbed (Pant 1993; Rodger 1999). Observations of these waves are used as one of the best probes available for characterizing the height and sharpness of the lower D-region (Thomson 2010; Thomson et al. 2011). Amongst the other techniques, rockets yields good results but they are expensive and transient and practically it is not possible to use the technique for diurnal, seasonal and latitudinal studies. Other techniques such as incoherent scatter radar, balloons, satellites, etc have limitations due to low altitudes and large air densities (Inan et al. 2010).

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