On the linkage between ionospheric scintillations and radar plumes under post-sunset and post-midnight sectors

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The present study shows the ionospheric scintillations observed on very high frequency (VHF) and L-band signals transmitted from geostationary satellites and Global Positioning System (GPS) satellites, respectively, while the Indian Mesosphere-Stratosphere-Troposphere (MST) radar at Gadanki (13.5° N, 79.2° E; dip latitude 6.3° N), a low-latitude station, was operated simultaneously in the ionospheric mode. Spaced-receiver VHF scintillation observations were carried out at four locations in India to study the association between scintillations and radar plumes. Also, ionosonde observations of the virtual height of the F-layer (h'F (km)) have been utilised to examine the post-sunset (midnight) height rise of the F region at Tirunelveli, an equatorial station. While radar is sensitive to metre-scale irregularities, scintillations arise mainly from the intermediate- to kilometre-scale-sized irregularities. We studied the evolution of the scintillations under post-midnight and post-sunset sectors and their correlation to the simultaneous radar observations. It is noticed that when the irregularities reach higher altitudes in the radar map during the post-sunset period, scintillations could be extended up to Prayagraj. Conversely, when post-midnight plasma irregularities are noticed, weak scintillations are found, and their latitudinal extent is reduced. The spectral analysis suggests the presence of shallower and steeper slopes under post-sunset and post-midnight sectors, respectively. The latitudinal extent of scintillations in the post-sunset sector could be attributed to the non-linear evolution of irregularities towards higher latitudes under Rayleigh-Taylor instability, observed as plasma plumes by radar. However, the weakness or absence of scintillations during the post-midnight period, when radar detects weak patchy structures, indicates the involvement of additional mechanisms in the generation and evolution of these irregularities. It is suggested that scintillation parameters such as the S4 index, spectral index, zonal drifts, and auto- and cross-correlation analysis, along with radar observations, are useful in characterising the structure and dynamics of the equatorial plasma irregularities and their latitudinal extent, which have potential implications for scintillation predictions.

Keywords: Equatorial plasma bubbles, ionospheric scintillations, low-latitude ionosphere, MST radar, radar plumes

THE equatorial ionosphere is a bed for a variety of electrodynamical and plasma processes, such as the equatorial electrojet (EEJ), equatorial ionisation anomaly (EIA), and equatorial spread F irregularities (ESF) or equatorial plasma bubbles (EPBs) due to its unique geometry. The variability in atmospheric gravity waves, atmospheric tides, and planetary waves significantly translates their momentum and energy into variability in the ionosphere density and electric fields. Additionally, the occurrence of space weather events introduces additional complications. Accordingly, these plasma processes have been extensively studied at equatorial and low-latitude stations[1–3]. Special attention has been paid to understanding the plasma irregularities, plasma bubbles, or plasma plumes for their prediction, as they have significant implications for radio wave communication, GPS navigation, and space weather applications. The importance of these studies underlines the fact that these irregularities affect radio wave communication adversely. Hence, there is a need to understand and predict their generation, evolution, and latitudinal extent. While plasma plumes or plasma bubbles occur mainly in the nighttime, they are influenced by a number of other electrodynamical processes in the daytime that are believed to play a role in the nighttime. So, it is important that we understand them in a comprehensive way. These irregularities follow the Kolmogorov spectrum with '-5/3', where energy cascades from larger scales to smaller scales, and they enter into the viscous domain where these small-scale irregularities are either dissipated or damped. These plasma irregularities have been studied using a number of ground-based radio and optical observations as well as in situ rocket and satellite-based observations[4–6]. Due to faster recombination of the E-region density and electrodynamic upward drift of the F-layer plasma due to E×B

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