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Coordinated in situ measurements of plasma irregularities and ground based scintillation observations at the crest of equatorial anomaly

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Abstract

First comparison of in situ density fluctuations measured by the DEMETER satellite with ground based GPS receiver measurements at the equatorial anomaly station Bhopal (geographic coordinates (23.2°N, 77.6°E); geomagnetic coordinates (14.29°N, 151.12°E)) for the low solar activity year 2005, are presented in this paper. Calculation of the diurnal maximum of the strength of the equatorial electrojet, which can serve as precursor to ionospheric scintillations in the anomaly region is also done. The Langmuir Probe experiment and Plasma Analyzer onboard DEMETER measure the electron and ion densities respectively. Irregularities in electron density distribution cause scintillations on transionospheric links and there exists a close relationship between an irregularity and scintillation. In 40% of the cases, DEMETER detects the irregularity structures (dNe/Ne $\geqslant$ 5% and dNi/Ni (O^+) $\geqslant$ 5%) and GPS L band scintillations (S4 $\geqslant$ 0.2) are also observed around the same time, for the low solar activity period. It is found that maximum irregularity intensity is obtained in the geomagnetic latitude range of 10–20° for both electron density and ion density. As the GPS signals pass through this irregularity structure, scintillations are recorded by the GPS receiver installed at the equatorial anomaly station, Bhopal it is interesting to note that in situ density fluctuations observed on magnetic flux tubes that pass over Bhopal can be used as indicator of ionospheric scintillations at that site. Many cases of density fluctuations and associated scintillations have been observed during the descending low solar activity period. The percentage occurrence of density irregularities and scintillations shows good correspondence with diurnal maximum of the strength of electrojet, however this varies with different seasons with maximum correspondence in summer (up to 66%) followed by equinox (up to 50%) and winter (up to 46%). Also, there is a threshold value of EEJ strength to produce density irregularities ($(dNe/Ne)_{max}$ $\geqslant$ 5%) and for moderate to strong scintillations (S4 $\geqslant$ 0.3) to occur. For winter this value is found to be ~40 nT whereas for equinox and summer it is around 50 nT.

Keywords: Ionosphere; GPS; DEMETER; Equatorial anomaly; Scintillation

1. Introduction

Disturbances in the ionosphere cause significant impact on satellite signals for communication and navigation, which are dependent on the signal frequency and the ionospheric electron content. Equatorial ionosphere is highly dynamical, unpredictable and is characterized by the existence of intense equatorial plasma bubble associated irregularities. These irregularities affect almost all radio communication systems utilizing the earth space propagation path. Also, much of the current attention is directed towards understanding the cause and effect of equatorial ionospheric irregularities and their effects on satellite navigation systems. These propagation effects are most severe around the magnetic equator and crests of the equatorial anomaly (Ray et al., 2006). Ionospheric scintillations, the most significant manifestation of such disturbances, often

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takes place in the equatorial region. Equatorial ionospheric irregularities have been studied since more than six decades. Plasma depletions were first observed by the polar orbiting satellite OGO-6 (Hanson and Sanatani, 1973). Experimental observations through ionosonde, radar, and in situ measurements showed a maximum occurrence of irregularities in the postmidnight/premidnight hours. Patra and Phanikumar (2009) made an excellent attempt in studying the F region irregularities using Gadanki MST radar observations in the equatorial region. They found different morphology of the F region irregularities in summer and equinox. In a paper by Joshi et al. (2012) using the same radar data the occurrence probability of F region field-aligned irregularities was found to be 65% in high solar activity and 30–40% in low solar activity. Ning et al. (2012) studied the low-latitude ionospheric E and F region irregularities using radar data. They correlated the spread F events with GPS observations and found that in the pre-midnight hours of solar minimum, GPS L band scintillations coincided with the appearance of F region plasma plume structures. These F region irregularities, associated with various plasma instability processes in the post sunset equatorial region give rise to variety of phenomena such as equatorial spread F and ionospheric scintillations (Vyas and Dayanandan, 2011).

Irregularities in the electron density distribution cause scintillations on transionospheric links and there exists a close relationship between an irregularity and scintillation (Wernik et al., 2007). Interactions in the thermosphere ionosphere magnetosphere system control the formation and evolution of these electron density irregularities that cause scintillation. It is well known that the existence of random electron density fluctuations within the ionosphere is responsible for scintillation of satellite radio signals. These small scale electron density fluctuations range from a few meters to a few kilometers. Scintillation effects are most severe around the magnetic equator and crests of the equatorial anomaly. Two most important effects of equatorial electrodynamics are the equatorial electrojet (EEJ) and the equatorial ionization anomaly (EIA). The EIA refers to double humped structure in the latitudinal distribution of ionization at low latitudes, with a trough at the magnetic equator and two crests of enhanced ionization at $\pm 15°$–$20°$ dip latitudes. Relatively large daytime perturbation in the horizontal component (H) of the geomagnetic field at the ground level is obtained in the equatorial region.

Steep gradient of the F region ionization between the crest and trough may be taken as a precursor to scintillations on transionospheric links (Ray et al., 2006). The probability of occurrence of scintillations is random and development of a nowcasting and forecasting methodology for scintillation occurrence is needed in view of the increased reliance on space based communication and navigation systems which are affected by ionospheric scintillations. Many questions related to following phenomena with associated scintillation occurrences are being investigated, such as latitudinal variation of TEC, post sunset F-region height rise over the magnetic equator, $E \times B$ drift velocity greater than a threshold level and development of electrojet during the daytime. Ray et al. (2006) have studied the latitudinal gradient of TEC and EEJ strength as precursor to ionospheric scintillations in the low latitude region. Tulasi Ram et al., 2006) in their study determined a quantitative relationship between the pre-reversal enhancement in the vertical $E \times B$ drift at the equator and its role in the occurrence of VHF scintillations. They found that the percentage of VHF scintillation occurrences shows a good correspondence with the monthly mean post-sunset vertical drift velocities at the equator, and both the parameters show a clear seasonal behavior. The investigation of all these parameters is of prime importance as they can serve as precursors to ionospheric scintillations in the low latitude region. As such, the day to day variability in occurrence of ionospheric scintillations is a serious concern to users of trans-ionospheric communication.

Bhopal (geographic coordinates: 23.2°N, 77.6°E; geomagnetic coordinates 14.29°N, 151.12°E) located under the northern crest of equatorial ionization anomaly region, provides a good opportunity to investigate the behavior of low latitude ionospheric phenomena. Kumar et al. (1993) studied the ionospheric scintillation at Bhopal from January 1990 to December 1990 using observations of VHF radio signals from FLEETSAT satellite. They found that scintillation occurrence is essentially a night-time phenomenon and day time scintillations are very rare. Annual average nocturnal variation of percentage occurrence of scintillations shows maximum at around 2100–2200 h LT. Seasonally, scintillations are most prominent during equinoxes and least during summer.

In this paper we study two parameters associated with scintillations on GPS signals for a station near the northern crest of the equatorial anomaly region. First parameter is the in situ electron density and ion density fluctuations in the region between trough and crest of the equatorial anomaly region using DEMETER satellite measurements. Second parameter is the calculation of the diurnal maximum of the strength of the equatorial electrojet, which can serve as precursor to ionospheric scintillations in the anomaly region. Both these parameters are correlated with the GPS L band scintillations observed at a station near the northern crest of equatorial anomaly, Bhopal. Period of study has been chosen from January 2005 to December 2005 when both DEMETER and GPS data were available for the equatorial anomaly region. In this study for the first time, the F region irregularities in the midnight sector have been obtained with in situ satellite measurements. These have also been correlated with GPS scintillation measurements.

2. Instrumentation

DEMETER (Detection of Electromagnetic Emissions Transmitted from Earthquake Regions) was placed in a polar, circular and quasi sun-synchronous orbit (10.30