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Role of gravity wave seed perturbations in ESF day-to-day variability: A quantitative approach

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Abstract

The role of seed perturbations in the day-to-day variability of occurrence of Equatorial Spread F (ESF) is studied using Ionosonde data for years 2005–2007 at magnetic equatorial location Trivandrum (8.5°N, 77°E, and dip 1.3°N). In this paper, we present the novel result that, the amplitude of the seed perturbations, is a very critical parameter which decides, whether or not ESF would occur on a given day and that, this threshold level of seed perturbation amplitude required on a given day decreases as the post sunset height of the F layer increases. Further, the requisite seed perturbation at a particular altitude shows solar activity dependence with progressively lower requisite seeds being observed at lower levels of solar activity. Moreover, the requisite seed is also found to be showing unique altitudinal dependence for each season. These results underline the need to evolve a new ESF prediction parameter, which takes into account the amplitude of the seed perturbation along with the layer height.

Keywords: Equatorial Spread F; Seed perturbation; Gravity wave

1. Introduction

Equatorial Spread F is a spectacular night time manifestation of plasma irregularities occurring in a range of scale sizes, in the ionospheric F region (Farley et al., 1970; Abdu et al., 1981; Fejer et al., 1999). ESF irregularities are primarily generated by the RT instability mechanism under certain favorable conditions (Haerendel, 1973). The occurrence of ESF shows variability with season, solar cycle and geomagnetic activity in addition to a day to day variability (Chandra and Rastogi, 1970; Abdu et al., 1981; Subbarao and Krishna Murthy, 1994; Devasia et al., 2002; Jyoti et al, 2004; Manju et al., 2007). Although the seasonal and solar activity variability is reasonably well understood, the day to day variability aspect still remains an enigmatic scientific problem. A complete understanding of this problem remains a challenge owing to the complexity involved in the various ionospheric, thermospheric and magnetospheric processes that govern their initiation, propagation and dissipation. The post sunset enhancement of the zonal electric field which drives the vertical drift of ionospheric F layer to higher altitudes where the rate of recombination is quite less, has been identified as a major requisite for ESF development. Apart from this, the thermospheric meridional wind patterns have also a significant influence on the generation and propagation of the irregularities. Another major factor is the role of seed perturbations in inducing the perturbation electric fields along the base of the F layer, which eventually facilitates the Raleigh-Taylor instability mechanism of ESF development. The role of gravity waves in the initiation of ESF had been reported by Kelley et al. (1981). Off late, several researchers have reported results which demonstrate the role of seed

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perturbations in controlling the day to day variability of ESF.

On a statistical basis, gravity wave generation sources associated with the ITCZ (Inter Tropical Convergence Zone) have been shown to influence the seasonal and longitudinal patterns of ESF occurrence (McClure et al., 1998; Tsunoda, 2010). Further, case studies have identified large scale wave structures (LSWS) in the background electron density as precursor signatures to ESF/plasma bubble development from incoherent scatter radar measurements over Kwajelein (Tsunoda and White, 1981). Abdu et al (2009) showed that when the PRE vertical drift was larger (smaller), the amplitude of the precursor wave structure required for the ESF growth, was smaller (larger). Off late, various methods have been employed to detect the presence of the seed perturbations such as the VHF radar, rocket campaigns, optical interferometer techniques and TEC measurements (Fritts et al., 2008; Sreeja et al., 2009; Takahashi et al., 2009; Kherani et al., 2009; Abdu et al., 2009; Tsunoda, 2010a,b; Bagiya and Sridharan, 2011; Abdu et al., 2015). Nevertheless, a quantification of the strength of such perturbations required to trigger the irregularities during identical background conditions is still enigmatic. Further, the problem is compounded by the fact that other conditions such as the strength of PRE/vertical drift of the layer, background neutral density variations etc. affect the seed perturbations. In this context, the present study assumes importance in attempting to quantify the role of gravity seed perturbations in the day to day variability of ESF. It has become evident from this study that, the threshold level of seed perturbation for ESF to occur varies with the post sunset F layer height. A combination of the evaluation of seed strengths and their corresponding heights has revealed a unique threshold curve that determines the requisite seed strength at each altitude for ESF initiation and development. The seasonal as well solar activity variations in this parameter are also examined, which provides significant insight towards realizing a complete understanding of the day-to-day variability of ESF. This is a pilot study which will be extended in future to cover a solar cycle.

2. Data and methodology

Ionosonde data from the geomagnetic equatorial location of Trivandrum, for the autumnal equinox of low solar activity years 2005, 2006 and 2007 are used for the study. Further the same for the vernal equinox, summer solstice and winter solstice of 2005 are also used. Only magnetically quiet days with $Ap < 18$ are presented here.

The location of the station with respect to the magnetic equator during 2005 period estimated using the IGRF model is shown in Fig. 1.

For autumnal equinox (AE) all the magnetically quiet days with data availability from August15 to October 31 are used while for vernal equinox (VE) the same between February 15 and April 30 are used. For winter solstice (WS) and summer solstice (SS) the durations considered (with data availability) are from November 15 to January 31 and May 15–July 31 respectively of each year.

A number of studies have been undertaken recently which characterize the temporal variations in h'F as seeding amplitudes of gravity waves (Sreeja et al., 2009; Abdu et al., 2009, 2015). The wave structure, manifesting itself as the height oscillations of the bottom-side F layer during daytime, becomes amplified towards post sunset hours leading to ESF development. The vertical and zonal winds, associated with a gravity wave, propagating zonally, and in slant upward direction, generate polarization electric fields. A vertical perturbation wind (ΔU_Z) produces the zonal polarization electric field (E_y), through the expression $E_y = -\Delta U_Z \times B_0$, that is responsible for the observed height oscillations. B_0 is the magnetic field intensity. The zonal scale sizes of the wave structures can be estimated from their period range (which is ~1 h). Zonal wavelengths of the large scale wave structure, LSWS as reported by Tsunoda and White (1981) and Abdu et al. (2009) is of the order of 400 km. That is, a spatially propagating gravity wave gives rise to temporal fluctuations in the ionosphere.

In the past several workers have shown the presence of gravity waves of periods in the range of 30 min to 1.5 h using temporal fluctuations in different ionospheric parameters both in E and F regions of ionosphere (Manju and Viswanathan, 2005; Manju et al., 2014; Sreeja et al., 2009; Abdu et al., 2009; Abdu et al.,2015). Upward amplitude propagation and down ward phase propagation characteristics of these waves have proven the gravity wave origin of the fluctuations. In the present study, a zonal wave length of 400 km is assumed and for the observed ionospheric temporal fluctuations with periodicities of 30–60 min, the phase speeds are of the order of 100–200 m/s.

The peak frequency of the F layer (foF_2) is scaled from 0600 to 2400 h for each day. 'h' corresponds to Indian Standard Time which is 5 h 30 min ahead of Universal Time. The data cadence is 15 min. For each day, the scaled data for the above mentioned period is subjected to wavelet analysis to delineate the periodicities in the range of 30 min to 1 h considering these to represent the gravity wave seed perturbations. The foF_2 data is subjected to 'Morlet' wavelet analysis ($dt = 0.25$; $S = 0.5$; PAD = 1, DJ = 0.25, $k = 6$) according to the methodology given by Torrence and Compo (1998).

It is well known that the most probable time of post sunset ESF occurrence in the Indian sector is the 1900–1930 h (Jyoti et al., 2004). We have used the average wavelet power of the periodicities in the 30–60 min range for the duration 1800–1845 h which is near the ESF start time, to represent the magnitude of the seed perturbations on a given day. The h'F (virtual height of the base of the F layer at 2.5 MHz) at 1900 h is considered as representative of the magnitude of the post sunset enhancement on each day. The foF_2 and h'F values used for the study