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Study of equatorial spread F using L-band and VHF radar

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Abstract. An important component of ionospheric plasma irregularity studies at low latitudes involves the study of the plasma bubbles which produce intense scintillations of trans-ionospheric satellite signals. In order to investigate the dynamics of plasma density irregularities of different scale sizes, a campaign of multi-technique observations was conducted during 11 to 15 Sep.05 at Gadanki (geog.13.45°N, 79.17°E, dip latitude 6.4°N), an Indian station. A low latitude spread F event occurred during the campaign on the night of 15 Sep.05. The observations were made using dual frequency GPS receiver and VHF coherent backscatter radar from Gadanki and two ionosondes with some latitudinal separation, from Trivandrum and SHAR. Range type spread F on ionograms and radar plume signatures on range-time-intensity maps of the VHF radar were observed. Using the GPS receiver, the amplitude scintillation index (S_4) enhancements by 0.36 and 0.39 with two depletions in total electron content (5 and 12 TECU) are seen. The vertical plasma drift velocity is observed by ionosonde to be high ($\sim$35 m/s) which maximized around 1915 LT, which coincided with onset of range type spread F over the magnetic equator, Trivandrum. The irregularities are observed first at Trivandrum at 1915 hrs, thereafter by GPS receiver and later by VHF radar (off-equatorial station) indicating that the observed bubble is drifting eastward.

Keywords : equatorial spread F – scintillation – GPS – VHF radar – ionosonde

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1. Introduction

The nighttime equatorial ionospheric F-region often shows the presence of a large spatial spectrum of plasma density irregularities which manifest themselves as spread-F on the ionograms, plume-like structures in the Range-Time-Intensity (RTI) images of HF radars, intensity bite-outs in airglow intensity measurements and scintillations on amplitude, as well as phase of VHF and UHF signals from satellites. The different techniques being sensitive to the different parts of the spectrum of the irregularities. This phenomenon is commonly referred to as Equatorial Spread-F irregularities (ESF). In this paper, for the first time coordinated multi-technique measurements of ESF from India are presented. A campaign of observations was carried out with co-located GPS receiver and VHF radar at Gadanki (geog.13.45°N, 79.17°E, dip angle 12.5°N), and two ionosondes, one on the geomagnetic equator at Trivandrum (geog.77°E, 8.5°N, dip angle 0.5°N) and other at an off- equatorial station SHAR (14°N, 80°E, dip angle 14°N), located about 100 km east of Gadanki during the nights of 11-15 September, 2005.

Experimental details

In the present work the data from GPS satellites that are constantly moving along different azimuth-elevation paths has been utilized. Data from all satellites during nighttime 1230–1900 UT, IST=UT+5.30 i.e.1800-0030 IST and with elevation angle higher than 20° have been recorded in the present work. The S_4 index is calculated every 1 min for all satellites being tracked. The Mesosphere-Stratosphere-Troposphere (MST) radar at Gadanki operated at 53 MHz in coherent scatter mode is used to capture the features of ESF irregularities, if any. The geometry of the radar beam is such that the region under our investigation is about 150 km north of Gadanki as indicated in Fig. 1. In addition to the GPS and VHF radar measurements, height of the bottom-side of F-layer, h′F and vertical plasma drift are obtained from digital ionosondes, (KEL make, Model IPS 42) operated from Trivandrum (magnetic equator) and SHAR , a station 100 km east of Gadanki. The temporal resolution of the ionograms obtained for the present campaign is 15 minutes.

2. Observation and results

Fig. 1 shows the location of Trivandrum and SHAR digisondes, field of view (FOV) of VHF radar and GPS receiver for elevation greater than 40° collocated at Gadanki. Fig. 2 shows the pass of the PRN 4 and 9 as observed from Gadanki. The orbital track of PRN 4 is from S to N-E and PRN 9 from N-W of Gadanki. PRN 4 passes over near Gadanki, at 1925 IST (elevation is 88°). So, PRN 4 is considered for further studies. Here in the present study, PRN 9 is also considered, as this satellite only has observed the TEC depletions and high S_4 index during one of the campaign days. The dotted box shows elevation greater than 20°.

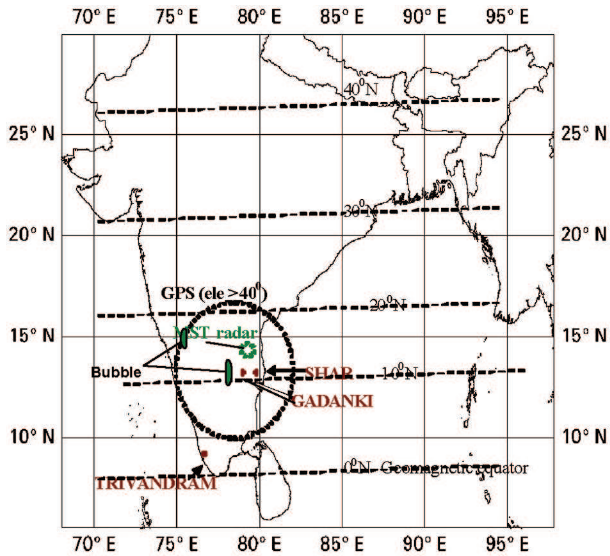

Figure 1. FOV of GPS receiver and MST radar at Gadanki and the location of the stations where equatorial spread F data has been used.

Fig. 3 presents the VTEC and the corresponding S_4 index measured using the signal received from the PRN 4 and 9, on five consecutive nights, 11-15 Sep.05. We observe that on all days (11-14 Sep.05), the TEC gradually decays due to the competing processes of absence of photo-ionization and the loss process due to recombination as observed by both PRN 4 and 9. On 15 Sep.05, depletion in the TEC is observed in the path of PRN 9 around 2030 IST, between 15.6° N, 75°E and 14.6°N, 75°E of 5 TECU (15–10 TECU) and around 2100 IST, between 13.8°N, 78.4°E and 12.9°N, 78.4°E of 12 TECU (15–3 TECU), and the associated enhancements in the S_4 index is also observed (0.39 and 0.36).

Fig. 4 shows the variation of height of the base of the F layer (h′F) over Trivandrum and SHAR from 11-15 Sep.05 during post-sunset period obtained from digisonde data with 15 minute resolution. During the evening of all days, except 15 Sep.05 the virtual height of the base of the F-layer (h′F) was about ∼260 km around 1800 IST, but on 15 Sep.05 h′F starts rising around 1915 IST and goes high up to ∼320 km around 2015 IST, indicating that the plasma was drifting upwards and the ambient horizontal electric field was eastward. Thereafter the base started drifting downwards (indicating a reversal of the ambient electric field) and by 2130 IST the h′F was about 260 km. As observed by the ionosonde, the spread F appeared at about 1915 IST at Trivandrum and was strong by 2015 IST. The digisonde data of SHAR on 15 Sep.05 shows the same height of the base of the F layer (∼260 km) around 1800 IST, and start rising after 1945 IST. But at SHAR, the rise is gradual and peaks around 2300 IST (∼350 km), after which it

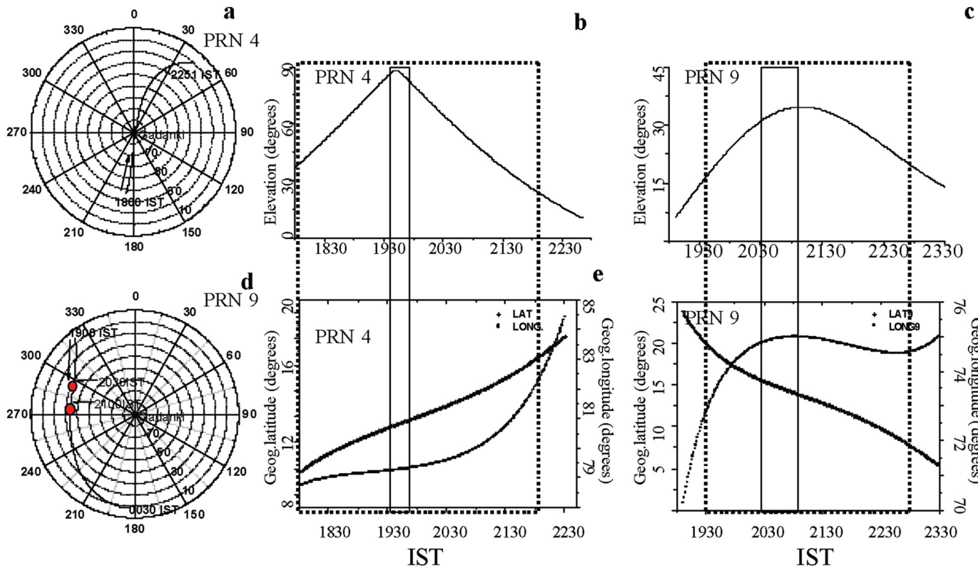

Figure 2. Pass of the PRN 4 and 9 as observed from Gadanki, (i) Azimuth-elevation coordinates for GPS satellite PRN 4 (a) and PRN 9 (d). (ii) elevation of the satellite with IST, PRN 4 (b) and PRN 9 (c). (iii) geographic longitude and latitude of the ionospheric pierce point (IPP), PRN 4 (e) and PRN 9 (f) (Fig. (e) & (f) - Left Y-axis: Geog. Latitude, Right Y-axis : Geog. Longitude).

decreases. The vertical plasma drift, Vz is measured at the two stations using digisondes data. The EXB drift in m/s is computed by using dh′F/dt for 15 minutes period. The drift is upward and is high, ∼35 m/s around 1930 IST at Trivandrum and then becomes downward around 2100 IST indicating a strong eastward electric field around 1930 IST and then electric field becomes westward and the downward drift is also high (∼40 m/s) on 15 Sep.05. On the same day, SHARs data shows a rise in drift around 2130 IST and then a small downward drift of plasma is observed around 2200 IST. The larger upward EXB drift velocity, late reversal time, and smaller early night downward drift velocity can provide favorable conditions for the generation of spread F (Fejer et al. 1999).

Fig. 5 presents an RTI map obtained by the VHF radar for 15 Sep.05. The RTI map shows a low- altitude thin layer of 3-m irregularities developing from about 220 km at 2145 IST. Suddenly around 2215 IST the layer explodes into a high-altitude plume. Radar plumes are interpreted as ionospheric “bubbles” that originate at the base of the F region and may extend over several hundred kilometers in altitude. A steady, vertical, fully grown, strong irregularity region is observed between 250–420 km around 2200 - 2240 IST for 40 minutes duration and later confining into a thin layer of about 130 km thickness. It is thus apparent that the high value of $Vz \sim 35$ m/s has triggered the plasma instability mechanism which resulted in ionospheric irregularities which manifest

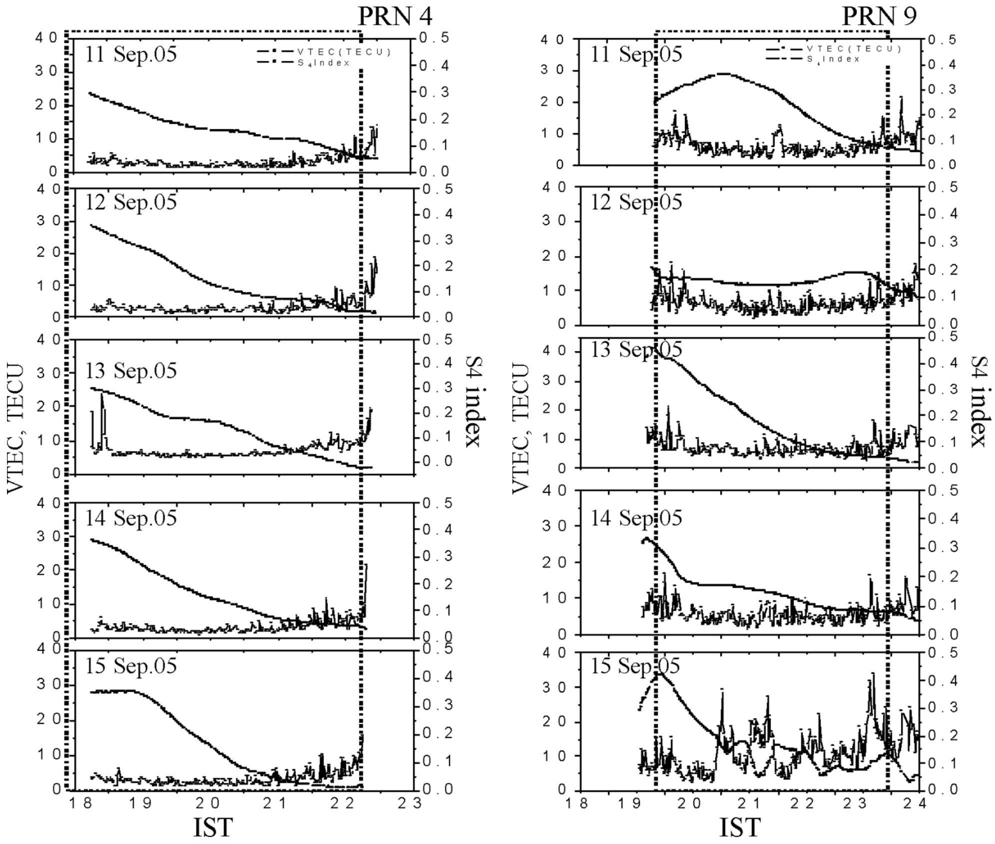

Figure 3. Variation of TEC and S_4 index as observed by PRN 4 and PRN 9 on the consecutive days of the campaign.

as spread F on ionograms. The sudden explosion to a high altitude plume around 2215 IST and appearance of strong TEC depletions between 2030 and 2200 LT and associated scintillations as observed by GPS receiver shows that favorable conditions for instability growth existed on the evening of 15 Sep.05.

3. Discussion and conclusions

As pointed out by Tsunoda et al. (1982), a unique feature that played a major role in the ESF phenomena is the plasma "bubble", a localized depletion in F-region electron density. Plasma bubbles are magnetic flux tubes aligned and cover north-south distances across the magnetic equator of several thousand kilometers, with east-west dimensions of up to a few hundred kilometers. It is now well recognized that plasma irregularities are formed due to the Rayleigh-Taylor gravitational instability process which is operational on the

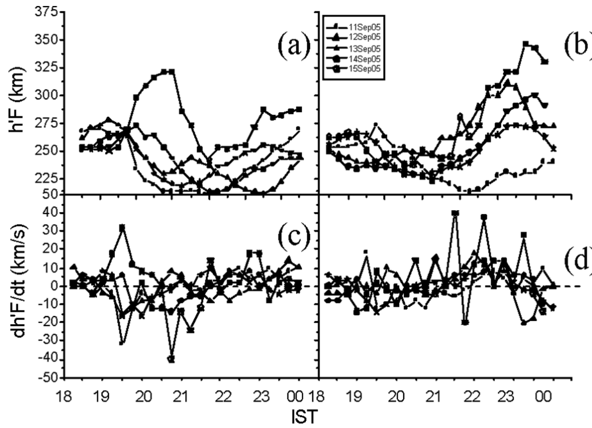

Figure 4. Temporal variation of h′F at 15 minute interval at (a) Trivandrum (b) SHAR (c) dh′F/dt over Trivandrum and (d) dh′F/dt over SHAR.

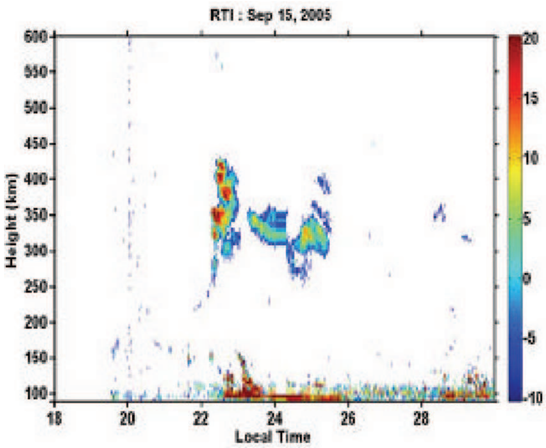

Figure 5. Range-time-intensity plot as seen by MST radar on 15 Sep.05. A steady vertical and fully grown plume which resembles a bubble shows strong irregularity region between 250 – 420 km around 2220 - 2300 IST for nearly about 40 minutes duration.

steep upward gradient of the nighttime base of the F-region at the magnetic equator. The steepening of the base of the F layer results from the fast recombination after sunset and the uplift of the F layer is due to the pre-reversal enhancement of the electric field. The steep electron density gradients thus generated are conducive to the growth of electron density and electric field perturbations. The non-linear development of the instability process leads to the generation of plasma bubbles (Zaleask et al. 1982). As plasma bubbles buoyantly rise upwards, they become highly elongated in the vertical direction

(Tsunoda & Towle 1979), sometimes attaining very high altitudes (>1500 km) at the magnetic equator (Mendillo & Tyler 1983), and the depleted regions extend poleward in the flux tubes (Sales et al. 1996), reaching dip latitudes of over $\pm 15°$ (Rohrbaugh et al. 1989).

The presence of two distinct patches as observed by the GPS receiver may be an indication of the ionospheric plumes breaking into striations at higher off-equatorial latitudes. The L-band scintillations during spread F over Gadanki were not observed at the same time as that of VHF radar as PRN 4 passed over Gadanki a little earlier. It is also possible that, for a given height, different patches belonged to the same bubble since sometimes bubbles bifurcate. Scintillation S_4 index starts to increase only at the rising of the layer and development of the topside plume, when regions of stronger echoes are observed. It is to be emphasized here that even using S_4 data from high-elevation satellites, the same ionospheric region probed by the radar has not been probed by GPS, but still the results similar to those pointed out by GPS satellites have been obtained. Once again, the range type spread F on ionograms at SHAR starts almost simultaneously with the echoes shown in the radar RTI map. The irregularities are observed first at Trivandrum (equatorial station) around 1915 IST, then is observed by GPS receiver and then by VHF radar (off-equatorial station) indicating that the observed bubble is drifting eastward.

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References

Fejer, B. G., Scherliess, L., & de Paula, E. R., 1999, JGR, 104, 19859
Mendillo, M., & Tyler, A, 1983, JGR, 88, 5778
Rohrbaugh, R. P. et al., 1989, JGR, 94, 6763
Sales, G.S. et al., 1996, JGR, 101, 26819
Tsunoda, R. T., & Towle, D. M, 1979, GeoRL, 6, 873
Tsunoda, R.T. et al., 1982 W.B, JGR, 87, 9171
Zalesak, S. T., Ossakow, S. L., & Chaturvedi, P. K, 1982, JGR, 87, 151