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Abstract

"GNU Radio Beacon Receiver (GRBR) is a new digital receiver based on GNU Radio and USRP (Universal Software Radio Peripheral) [Yamamoto, 2008]. In this paper, the GRBR observations of large-scale wave structure (LSWS) and the subsequent development of equatorial spread F (ESF) using total electron content (TEC) derived from the ground based reception of signals from the radio beacon on board C/NOFS (Communications/Navigation Outage Forecasting System) satellite are presented. The other evidences of LSWS include the 'satellite traces' observed in ionograms. These observations show that LSWS appears to play an important role in the development of ESF.

1. Introduction

Equatorial spread F (ESF) is a generic name, which refers to the presence of a wide spectrum of field-aligned irregularities in the equatorial nighttime F-region that can have spatial scales from 100 km to 10 cm. The linear growth rate of generalized Rayleigh-Taylor (R-T) instability, which directly and indirectly depends on all these factors, is often used as an indicator of when and where ESF can occur, if there are seed perturbations present [*5*]. But, in any season and solar epoch, under seemingly identical ionospheric conditions, ESF might occur on one night and might be absent on another, and this enigmatic day-to-day variability still poses a challenge to the complete understanding of this phenomenon. For instance, though the occurrence of ESF is climatologically related to the post-sunset rise (PSSR) of the F-layer - which is often regarded as the most important pre-requisite for ESF- it can appear to be unrelated to ESF when examined on a day-to-day basis [*2*].

In an alternative approach, *Tsunoda* [8] reported that the presence of a large-scale wave structure (LSWS) in the bottom side F-layer actually dictates the subsequent development of ESF. The LSWS can be identified as a quasi-periodic modulation in the altitude of isoelectron density contours in the bottomside F-region, superimposed on a mean slope that increases in altitude from west to east; the latter is consistent with the PSSR [*10*]. The zonal wavelength of LSWS was determined to be ~400 km, and this corroborated with the earlier observations of *Röttger* [3] that ESF occurs quasi-periodically in the longitudinal direction The observations of LSWS were mostly based on measurements by ALTAIR, located at Kwajalein Atoll, (9.4°N, 167.5°E, 4.3° dip lat) [*7,8,10*], in-situ probes [*4*], and those of satellite to ground total electron content (TEC) measurements [*11*] using a satellite in a low inclination orbit. *Abdu et al* [1] showed that "satellite traces" preceded range type ESF in the ionograms over Fortaleza. Recently, such "satellite" traces in ionograms [*9*], both obtained from Kwajalein Atoll, were identified as signatures of LSWS. In this paper, we present the signatures of LSWS in the TEC data, measured by a new digital beacon receiver.

2. Data and Method of Analysis

"GNU Radio Beacon Receiver (GRBR) is a new digital receiver based on GNU Radio and USRP (Universal Software Radio Peripheral), developed at RISH, Kyoto University, which measures total electron

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content (TEC) of the ionosphere from the phase difference between the dual-band (150 and 400 MHz) beacon signals from low-earth orbiting satellites. The open-source software toolkit for the software defined radio, GNU Radio, is utilized to realize the basic function of the receiver and perform fast signal processing. The open-source hardware called Universal Software Radio Peripheral (USRP) is used as a frontend to acquire the satellite beacon signals of 150 and 400 MHz. The technical details of the receiver can be found in [14]. The design information including software is open to public at the URL http://www.rish.kyoto-u.ac.jp/digitalbeacon/ .

A GRBR system is installed and continuously being operated at Bac-Lieu, Vietnam (9.2°N, 105.6°E, 1.7°N dip latitude) from January 2009. The C/NOFS as well as the other low-earth orbiting satellites like the Cosmos and OSCAR have been continuously tracked and the line of sight relative TECs are obtained from the differential phase information, using the 150 and 400 MHz transmissions. Typical data duration is 12-15 minutes for each satellite pass. The line of sight TECs are then projected into the relative vertical TECs. As the C/NOFS orbits close to the equatorial plane, we obtain the longitudinal variation of relative TEC (whereas the satellites in the high-inclination orbit give the latitudinal variation), and the perturbation component was derived by subtracting a running average corresponds to a zonal distance of ~1000 km. This is done keeping in mind that the zonal wavelength of LSWS is usually in the range 100-700 km [*3,13*].

3. Results

Figure 1 (a-d) shows the TEC observations from four passes of C/NOFS on 22 January 2009. The blue curve in each panel represents the variation in the perturbation component of TEC with the ionospheric penetration point (IPP) longitude. Previous observations of the typical altitude structure of the LSWS show that the density modulations exist in the bottomside of the F-region and the region above this modulation is more or less horizontally stratified [*10*]. Hence, the observed modulations (upwellings and downwellings) in the perturbation TEC are directly interpreted as a signature of similarly varying plasma density (LSWS) in the bottom side of the F-region [*11*]. The beginning of the first pass (Fig.1a) was at 12:19:33 UT (LT=UT+7 hrs at Bac Lieu), and at 95°E IPP longitude, the solar zenith angle was 97.5°, which means the solar shadow height was 55.9 km, and the E region was still sunlit. The presence of LSWS is evident even at this time. The zonal wavelength was found to be ~500-700 km. This is the first direct evidence that the LSWS can form before the E region sunset itself. Four crests can be easily identified at ~96°E, 101°E, 109°E and 116°E. The pass at 2103 LT (Fig.1b) shows that LSWS still persisted and small-scale irregularities started to appear. An interesting feature that can be seen in this figure is that the west wall of the eastern-most crest region first shows small perturbations. The satellite pass at 0031 LT (Fig. 1c) shows well-defined plasma depletions in TEC, with the most severe depletions between 100°E and 105°E. The last pass (Fig. 1d) shows that the irregularities persisted over this region even after midnight.

Figure 1(e-h) shows the TEC observations from four consecutive passes of C/NOFS on 25 January 2009. The beginning of the first pass (Fig. 1e) was at 11:30:39 UT (LT=UT+7 hrs at Bac Lieu), and at 95°E IPP longitude, the solar zenith angle was 86.56°. This means that the solar shadow height was zero, and the E region was still sunlit. Four crests can be easily identified at ~103°E, 109°E, 112°E and 117°E. In this case, the E region sunset over Bac Lieu was at 1844 LT, which means that the E region was sunlit even while the C/NOFS passed over Bac-Lieu, thus giving further confirmation that LSWS can form well before the E region sunset. The next satellite pass (Fig. 1f), at 2014 LT shows that the amplitude of the LSWS has increased, especially between 104°-117°E. This also corroborates with the earlier observations [*10*]. After ~2 hrs, the entire region between 104°-117°E shows irregular structures, which continues further. In these two passes, there is some zonal drift of the LSWS, and there are some weak irregularities in the 95°E-104°E region also, at 2341 LT (Figure 1g-h).

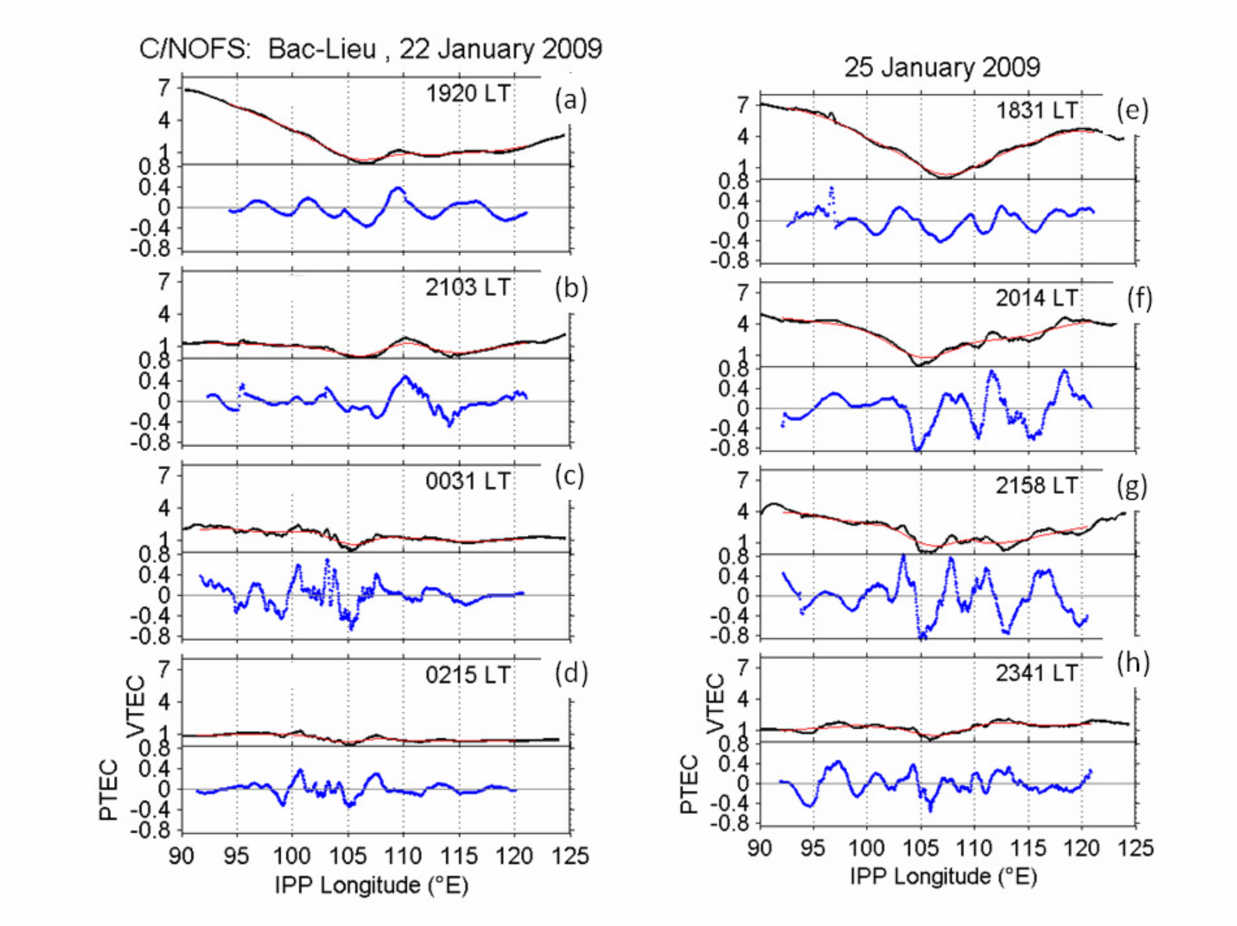

Figure 1 TEC observations from four passes of C/NOFS on 22 January 2009 (a-d), on 25 January 2009 (e-f). The black curve represents observed relative TEC, the red curve is a smooth curve to facilitate the identification of the LSWS, and the blue curve represents the variation of perturbation component of TEC.

As mentioned earlier, these C/NOFS observations provide the zonal picture of the irregularities. It must be mentioned here that there are similar observations of LSWS using beacon receivers from the Pacific sector as well [12]. Using ionograms from two nearby locations, together with measurements of total electron content, they have shown that LSWS and ESF coexist in regions that are bounded geographically. Similarly, a new digital ionosonde (Digisonde, DPS-4D) installed at Trivandrum, India (8.5^{o} E; 77^{o} E; 0.5^{o} N magnetic dip latitude) often shows the presence of 'satellite traces' before the onset of ESF All these observations confirm the undeniable importance of LSWS in the in the day-to-day variability in occurrence of ESF.

4. Conclusion

The observations of LSWS and subsequent ESF development by ground based TEC measurements using radio beacons on board C/NOFS satellite are presented. The observations indicate that the LSWS can form much before the E region sunset, which indicates that the source of the LSWS is not PSSR, but is perhaps located in the E region. The LSWS does not have significant zonal drift in the initial stages, and the zonal wavelength appears to be ~500–700 km, which corroborates with the earlier results. The irregularities form around the crests of the LSWS, mostly initiated as small-scale structures near the west walls of the upwellings. These initial results from BacLieu are published [6]. In the presentation, we briefly review these observations and present more similar observations from this sector, which further confirm that the presence of LSWS is often a necessary pre-requisite for the subsequent ESF development.

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6. References

1. Abdu, M. A., I. S. Batista, and J. A. Bittencourt (1981), Some characteristics of spread F at the magnetic equatorial station Fortaleza, J. Geophys. Res., 86, 6836– 6842, doi:10.1029/JA086iA08p06836.
2. Hysell, D. L., and J. Burcham (2002), Long term studies of equatorial spread F using the JULIA radar at Jicamarca, J. Atmos. Terr. Phys., 64, 1531–1543, doi:10.1016/S1364-6826(02)00091-3.
3. Ro¨ttger, J. (1973), Wave-like structures of large-scale equatorial spread-F irregularities, J. Atmos. Terr. Phys., 35, 1195–1196, doi:10.1016/0021- 9169(73)90016-0.
4. Singh, S., F. S. Johnson, and R. A. Power (1997), Gravity wave seeding of equatorial plasma bubbles, J. Geophys. Res., 102, 7399 – 7410, doi:10.1029/96JA03998.
5. Sultan, P. J. (1996), Linear theory and modeling of the Rayleigh-Taylor instability leading to the occurrence of equatorial spread F, J. Geophys. Res., 101, 26,875– 26,891, doi:10.1029/96JA00682.
6. Thampi, S. V., M. Yamamoto, R. T. Tsunoda, Y. Otsuka, T. Tsugawa, J. Uemoto, and M. Ishii (2009), First observations of large-scale wave structure and equatorial spread F using CERTO radio beacon on the C/NOFS satellite, Geophys. Res. Lett., 36, L18111, doi:10.1029/ 2009GL039887.
7. Tsunoda, R. T. (1981), Time evolution and dynamics of equatorial backscatter plumes: 1. Growth phase, J. Geophys. Res., 86, 139–149, doi:10.1029/JA086iA01p00139.
8. Tsunoda, R. T. (2005), On the enigma of day-to-day variability in equatorial spread F, Geophys. Res. Lett., 32, L08103, doi:10.1029/2005GL022512.
9. Tsunoda, R. T. (2008), Satellite traces: An ionogram signature for large scale wave structure and a precursor for equatorial spread F, Geophys.Res. Lett., 35, L20110, doi:10.1029/2008GL035706.
10. Tsunoda, R. T., and B. R. White (1981), On the generation and growth of equatorial backscatter plumes: 1. Wave structure in the bottomside Flayer, J. Geophys. Res., 86, 3610– 3616, doi:10.1029/JA086iA05p03610.
11. Tsunoda, R. T., and D. M. Towle (1979), On the spatial relationship of1-meter equatorial spread-F irregularities and depletions in total electron content , Geophys . Res . L e t t ., 6, 873 – 876, doi:10 .1029/GL006i011p00873.
12. Tsunoda, R. T., D. M. Bubenik, S. V. Thampi, and M. Yamamoto (2010), On large□scale wave structure and equatorial spread F without a post□sunset rise of the F layer, Geophys. Res. Lett., 37, L07105, doi:10.1029/2009GL042357.
13. Weber, E. J., J. Buchau, and J. G. Moore (1980), Airborne studies of equatorial F layer ionospheric irregularities, J. Geophys. Res., 85, 4631– 4641, doi:10.1029/JA085iA09p04631.
14. Yamamoto,M. (2008), Digital beacon receiver for ionospheric TEC measurement developed with GNU Radio, Earth Planets Space, 60, e21– e24.