URSI - RCRS 2022, IIT (Indore), India, 1 - 4 December, 2022

Study of Sporadic E layer effect on the F layer during 23rd June 2015 geomagnetic storm event

T. Venkateswara Rao[1,2], M. Sridhar[1], D. Venkata Ratnam[1] , and B Suneel Kumar[2]

[1]Department of Electronics and Communication Engineering, Koneru Lakshmaiah Education Foundation (KLEF), Deemed to be University, Guntur, India-522502.
[2]Balloon Facility, Tata Institute of Fundamental Research (TIFR), ECIL Post 5, Hyderabad - 500 062, India.

Abstract

Investigating the sporadic E (Es) layer effect on the F layer during a geomagnetic storm event is essential to understanding the impact of ionospheric irregularities on trans-ionospheric radio communication and navigation systems. In equatorial and low latitude regions, the enhancement in the F layer leads to the development of equatorial spread F (ESF), and the F layer suppression leads to the inhibition of ESF. The Es layer and ESF events recorded by the Canadian Advanced Digital Ionosonde (CADI) system located at low latitude Hyderabad, India (Lat: 17.47°N, Long: 78.57°E) region and co-located global positioning system (GPS) amplitude scintillations index (S4) parameters during 23rd June 2015 geomagnetic storm event are considered in the present analysis. The suppression of spread F due to the presence of Es and subsequent inhibition of amplitude scintillations were examined during adverse space weather conditions from 22nd to 24th June 2015. It is observed from the analysis results that the amplitude scintillations at the low latitude region were inhibited due to the suppression of spread F in response to the development of the Es layer during the considered geomagnetic storm event. The Es and ESF parameters are supporting input parameters to ionospheric prediction or forecasting models and can be used to initiate the scintillation alerts in GPS and High Frequency (HF) communication applications.

1. Introduction

The diurnal, seasonal, and solar cyclic variation in the ionosphere characteristics are due to the influence of equatorial ionization anomaly (EIA), equatorial spread F (ESF) in response to the pre reversal enhancement (PRE), solar and geomagnetic activity, and traveling ionospheric disturbances (TID). Equatorial spread F (ESF) is a general phenomenon observed in the F layer in response to the irregularities in the ionosphere during post-sunset hours (pre and post-midnight) and sometimes after sunrise [1], and solar and geomagnetic storm events. ESF in low latitude regions plays a significant role in the performance of high-frequency communications and satellite-based navigation systems. In equatorial and low latitude regions, the neutral winds from the bottom side of the ionosphere influence the variations in the ionization levels of the E layer, which are coupled to the F layer causing the enhancements or suppression of the F layer spread. The F layer enhancement leads to the development of equatorial spread F (ESF), and the suppression leads to the inhibition of ESF. Booker and Wells (1938) first reported the observations of spread F events in the ionograms [2], and later extensive studies were conducted to investigate the characteristics of spread F [3-9]. Rayleigh Taylor (RT) instability in the F region leads to the spread F irregularities [10-15]. In the ionosphere E layer region, sporadic E layers with very thin ionization levels ranging from 2 km to 10 km are generally noticed between the heights of 90 km to 130 km [16]. The mid and low latitudes E layer ionization developments are due to the vertical shear [17] initiated by the opposite horizontal neutral winds motivated by tidal motions [18] or the gravity waves [19-21].

The manifestation and development of ESF during the onset time of geomagnetic storm events depend on different seasons and the sporadic E (Es) layer in equatorial and low latitude regions. Shi et al. (2011) demonstrated the correlation of GPS amplitude scintillations during strong spread F events [22]. Rao et al. (2021) examined the correlation of strong spread F events with amplitude scintillations (S4) at low latitude station (Hyderabad) during one of the significant geomagnetic storm that occurred on 17th March 2015 [23]. Alfonsi et al. (2013) examined the occurrences of various types of spread F events in correspondence with the amplitude scintillations (S4) during various seasons and geomagnetic storm events. Also, they indicated the role of Es in the occurrence of S4 with future scope of further analysis [24]. Ram Singh et al. (2020) and Wei et al. (2021) examined the geomagnetic storm recovery phase effect on the enhancement and suppression of ESF and Es [25,1]. The onset time of the geomagnetic storm significantly influences the occurrence of ESF irregularities. The reformed electric fields or winds during the storm time may substantially modify the Es layers at low latitudes, which may influence the generation of ESF irregularities [26,27]. Ram Singh et al. (2020) examined the possibilities of generation and suppression of ESF during the onset time of geomagnetic storms in three categories based on Aaron's criteria under different seasons [25]. It is suggested to consider the low latitude sporadic E (Es) layer for better investigation of the ESF. Here in this work, investigated the suppression of ESF and amplitude scintillations due to the development of Es during the geomagnetic storm event occurred on 23rd June 2015.

2. Data samples and data processing

The investigation of suppression of SF and inhibition of S4 due to the presence of the Es layer is evaluated using the data samples collected from the co-located CADI system and dual-frequency global positioning system (GPS) located at low latitude Hyderabad, India (latitude: 17.47^0 N, longitude: 78.57^0 E) region during the adverse geomagnetic storm event occurred on 23rd June 2015. The Space weather parameters such as disturbance storm time (Dst) and inter-planetary magnetic field on z-direction (IMF-Bz) are considered to show the geomagnetic storm event activity during the considered storm period and the data samples are downloaded from https://omniweb.gsfc.nasa.gov/form/dx1.html. The definitions and the interpretation and scaling procedures of various types of Es such as Esq (sporadic E layer at equatorial region) and SF such as frequency SF (FSF), range SF (RSF), mixed SF (MSF) and strong range SF (SSF) are given in the URSI handbook of ionogram interpretation [28]. The Es, FSF, MSF, RSF, and SSF events are automatically detected from the ionograms using the auto-detection tool suggested by Rao et al. (2022) [29] in June 2015 month and manually verified the various events during the considered geomagnetic storm event using the Univap Digital Ionosonde Data Analysis (UDIDA) software and the auto-scaling software tool developed by Rao et al. (2022) [30].

3. Results and discussion

The suppression of SF and inhibition of S4 during onset time of the geomagnetic storm due to the presence of Es layer is investigated and the results are shown in Figure 1. The variations of IMF-Bz and Dst are shown in Figure 1 (a) and (b) respectively, indicating the occurrence of the geomagnetic storm event in June, 2015. Figure 1 (c) depicts the amplitude scintillations index (S4) and Figure 1 (d) represents the occurrence of Es and various SF events during June, 2015. The respective comprehensive analysis on pre, post, and storm days (22nd to 24th June 2015) are shown in Figures 1 (e), (f), (g), and (h). The IMF-Bz oscillates between North-Southward, and Dst variations are close to zero value on pre and post-storm day. On the pre-storm day (22nd June 2015), noticed a sudden storm commencement (SSC) at 19:00 hrs UT, IMF-Bz reaching deep-south with -20nT and Dst with ~-50nT at 20:00 hrs UT. The enhancement of the storm is observed from 02:00 hrs UT on storm day (23rd June 2015) when IMF-Bz turned southward and Dst attained ~ -140nT. The storm recovery phase started at 05:00 hrs UT after Dst reaching the deep negative value of ~215nT and IMF-Bz continuing in the southward direction till 05:00 hrs UT. Consequently, the ionosphere irregularities are similar to the undisturbed pre and post-midnight hours, and significant Es events are observed during 00:00 hrs UT to 08:00 hrs UT on storm day (23rd June 2015). The enhancement of the ESF is suppressed during this storm event due to which no significant SF events were observed, and no amplitude scintillations were noticed in any of the PRN as shown in Figure 1 (g).

The neutral wind influence on the E layer from the bottom side of the ionosphere, the patchy nature and extremely polarized Es layer might have affected the F layer causing uplift of F layer and in turn reducing the Pedersen conductivity in the F layer [31]. This might have suppressed the SF during the onset geomagnetic storm event considered, and due to the suppression of SF, the trans-ionospheric navigation signals could not get affected by the storm time and showed no amplitude scintillations in any of the satellites during this 23rd June 2015 storm event.

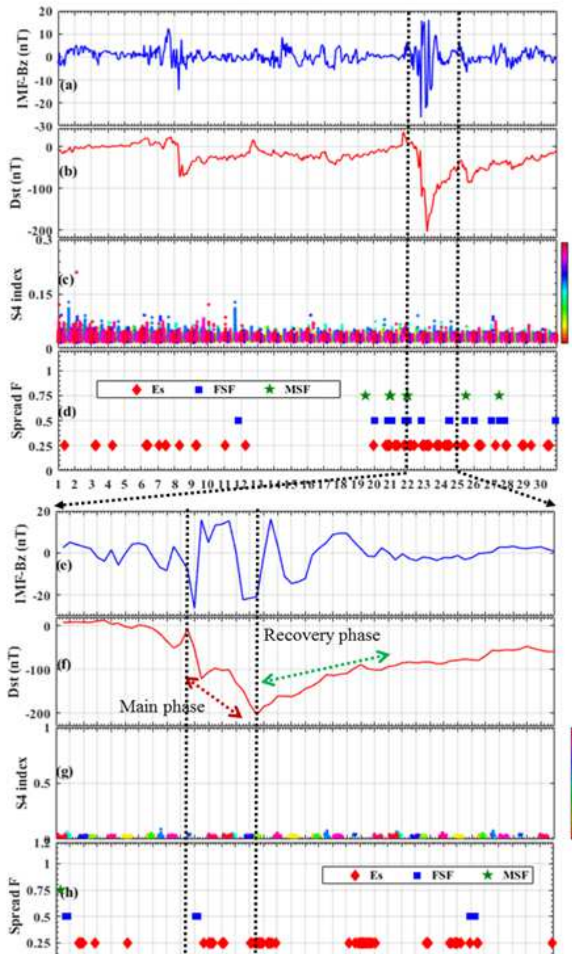

Figure 1. Analysis of suppression of SF and inhibition of S4 due to sporadic E layer activity during the 23rd June 2015 geomagnetic storm event.

4. Conclusions

We have analyzed the amplitude scintillation index (S4) parameters of GPS receiver, and sporadic E (Es) and various types of SF signatures of CADI system ionograms recorded at low latitude station, Hyderabad, India. And examined the Es layer development effect on F layer spread enhancement or suppression and subsequent response on amplitude scintillations during one of the intense geomagnetic storm event occurred on 23rd June 2015. The analysis results show that at low latitude regions, the spread in F layer due to the intense geomagnetic storm conditions is suppressed due to the enhancement of Es layer in response to the neutral winds. Subsequently, the trans-ionospheric navigation signals were unaffected with any ionospheric scintillations because of the effect of ESF on amplitude scintillations was inhibited. An extensive further analysis is required to support the present analysis results, which is beyond the scope of this work but we hope this initiation of work motivates further research work on coupling of Es layer effect onto the F layer.

5. Acknowledgements

The present work has been carried out under the research project sponsored by Science and Engineering Research Board (SERB), New Delhi, India, vide File No: CRG/2021/004529. The authors are thankful to Prof D.K Ojha and Mr. B Suneel Kumar, Scientist-in-charge, Balloon Facility of Tata Institute of Fundamental Research (TIFR), Hyderabad for providing the access to CADI instrument and sharing the data. We thank Mr. Santosh Koli, Balloon facility of TIFR for maintaining the instrument and helping us during the data analysis.

6. References

1. Wei, L., Jiang, C., Hu, Y., Aa, E., Huang, W., Liu, J., Yang, G. and Zhao, Z., 2021. Ionosonde observations of spread F and spread Es at Low and middle latitudes during the recovery phase of the 7–9 September 2017 geomagnetic storm. *Remote Sensing*, *13*(5), p.1010. https://doi.org/10.3390/rs13051010

2. Booker, H.G. and Wells, H.W., 1938. Scattering of radio waves by the F-region of the ionosphere. *Terrestrial Magnetism and Atmospheric Electricity*, *43*(3), pp.249-256. https://doi.org/10.1029/TE043i003p00249

3. Farley, D.T., Balsey, B.B., Woodman, R.F. and McClure, J.P., 1970. Equatorial spread F: Implications of VHF radar observations. Journal of Geophysical Research, 75(34), pp.7199-7216. https://doi.org/10.1029/JA075i034p07199

4 McClure, J.P., Hanson, W.B. and Hoffman, J.H., 1977. Plasma bubbles and irregularities in the equatorial ionosphere. Journal of Geophysical Research, 82(19), pp.2650-2656. https://doi.org/10.1029/JA082i019p02650

5. Dyson, P.L. and Benson, R.F., 1978. Topside sounder observations of equatorial bubbles. Geophysical Research Letters, 5(9), pp.795-798. https://doi.org/10.1029/GL005i009p00795

6. Fejer, B.G., Scherliess, L. and De Paula, E.R., 1999. Effects of the vertical plasma drift velocity on the generation and evolution of equatorial spread F. Journal of Geophysical Research: Space Physics, 104(A9), pp.19859-19869. https://doi.org/10.1029/1999JA900271

7. Argo, P.E. and Kelley, M.C., 1986. Digital ionosonde observations during equatorial spread F. Journal of Geophysical Research: Space Physics, 91(A5), pp.5539-5555. https://doi.org/10.1029/JA091iA05p05539

8. Tsunoda, R.T., 2013. On seeding equatorial spread F: Parallel or transverse transport?. Journal of Atmospheric and Solar-Terrestrial Physics, 103, pp.24-29. https://doi.org/10.1016/j.jastp.2012.10.016

9. Rodrigues, F.S., Nicolls, M.J., Milla, M.A., Smith, J.M., Varney, R.H., Strømme, A., Martinis, C. and Arratia, J.F., 2015. AMISR - 14: Observations of equatorial spread F. Geophysical Research Letters, 42(13), pp.5100-5108. https://doi.org/10.1002/2015GL064574

10. Kelly, M.C. and Heelis, R.A., 1989. The equatorial anomaly. The Earth's ionosphere, pp.192-193.

11. Huang, C.S., Kelley, M.C. and Hysell, D.L., 1993. Nonlinear Rayleigh - Taylor instabilities, atmospheric gravity waves and equatorial spread F. Journal of Geophysical Research: Space Physics, 98(A9), pp.15631 15642. https://doi.org/10.1029/93JA00762

12. Sultan, P.J., 1996. Linear theory and modeling of the Rayleigh - Taylor instability leading to the occurrence of equatorial spread F. Journal of Geophysical Research: Space Physics, 101(A12), pp.26875-26891. https://doi.org/10.1029/96JA00682

13. Abdu, M.A., 2001. Outstanding problems in the equatorial ionosphere–thermosphere electrodynamics relevant to spread F. Journal of Atmospheric and Solar-Terrestrial Physics, 63(9), pp.869-884. https://doi.org/10.1016/S1364-6826(00)00201-7

14. Basu, B., 2002. On the linear theory of equatorial plasma instability: Comparison of different descriptions. Journal of Geophysical Research: Space Physics, 107(A8), pp.SIA-18. https://doi.org/10.1029/2001JA000317

15. Lee, C.C., 2006. Examine the local linear growth rate of collisional Rayleigh - Taylor instability during solar maximum. Journal of Geophysical Research: Space Physics, 111(A11). https://doi.org/10.1029/2006JA011925

16. Denardini, C.M., Resende, L.C.A., Moro, J. and Chen, S.S., 2016. Occurrence of the blanketing sporadic E layer during the recovery phase of the October 2003 superstorm. Earth, Planets and Space, 68(1), pp.1-9.
https://doi.org/10.1186/s40623-016-0456-7

17. Whitehead, J.D., 1989. Recent work on mid-latitude and equatorial sporadic-E. Journal of atmospheric and terrestrial physics, 51(5), pp.401-424.
https://doi.org/10.1016/0021-9169(89)90122-0

18. Chimonas, G., 1971. Enhancement of sporadic E by horizontal transport within the layer. Journal of Geophysical Research, 76(19), pp.4578-4586.
https://doi.org/10.1029/JA076i019p04578

19. Hooke, W.H., 1970. Ionospheric response to internal gravity waves: 2. Lower F region response. Journal of Geophysical Research, 75(34), pp.7229-7238.
https://doi.org/10.1029/JA075i034p07229

20. Lanchester, B.S., Nygren, T., Huuskonen, A., Turunen, T. and Jarvis, M.J., 1991. Sporadic-E as a tracer for atmospheric waves. Planetary and space science, 39(10), pp.1421-1434.
https://doi.org/10.1016/0032-0633(91)90021-2

21. Jayachandran, P.T., Sri Ram, P., Rama Rao, P.V.S. and Somayajulu, V.V., 1999, April. Sequential sporadic-E layers at low latitudes in the Indian sector. In Annales Geophysicae (Vol. 17, No. 4, pp. 519-525). Copernicus GmbH.
https://doi.org/10.1007/s00585-999-0519-1

22. Shi, J.K., Wang, G.J., Reinisch, B.W., Shang, S.P., Wang, X., Zherebotsov, G. and Potekhin, A., 2011. Relationship between strong range spread F and ionospheric scintillations observed in Hainan from 2003 to 2007. Journal of Geophysical Research: Space Physics, 116(A8).
https://doi.org/10.1029/2011JA016806

23. Rao, T.V., Sridhar, M., Ratnam, D.V. and Harsha, P.B., 2021. Comparative analysis of ionosonde spread F and GPS ionospheric scintillations over Hyderabad. Journal of Astrophysics and Astronomy, 42(1), pp.1-13.
https://doi.org/10.1007/s12036-021-09697-4

24. Alfonsi, L., Spogli, L., Pezzopane, M., Romano, V., Zuccheretti, E., De Franceschi, G., Cabrera, M.A. and Ezquer, R.G., 2013. Comparative analysis of spread - F signature and GPS scintillation occurrences at Tucumán, Argentina. Journal of Geophysical Research: Space Physics, 118(7), pp.4483-4502.
https://doi.org/10.1002/jgra.50378

25. Singh, R. and Sripathi, S., 2020. A statistical study on the local time dependence of equatorial spread F (ESF) irregularities and their relation to low - latitude Es layers under geomagnetic storms. Journal of Geophysical Research: Space Physics, 125(1).
https://doi.org/10.1029/2019JA027212

26. Li, G., Ning, B., Wan, W. and Zhao, B., 2006, July. Observations of GPS ionospheric scintillations over Wuhan during geomagnetic storms. In Annales Geophysicae (Vol. 24, No. 6, pp. 1581-1590). Copernicus GmbH.
https://doi.org/10.5194/angeo-24-1581-2006

27. Sripathi, S., Abdu, M.A., Patra, A.K. and Ghodpage, R.N., 2018. Unusual generation of localized EPB in the dawn sector triggered by a moderate geomagnetic storm. Journal of Geophysical Research: Space Physics, 123(11), pp.9697-9710.
https://doi.org/10.1029/2018JA025642

28. Piggott, W.R. and Rawer, K., 1978. URSI Handbook of ionogram interpretation and reduction, Rep UAG-23A, World Data Cent. A, Natl. Oceanic and Atmos. Admin., Boulder, Colo.

29. Rao, T.V., Sridhar, M. and Ratnam, D.V., 2022. Auto-detection of Sporadic E and Spread F events from the digital ionograms. Advances in Space Research.
https://doi.org/10.1016/j.asr.2022.05.046

30 Rao, T.V., Sridhar, M. and Ratnam, D.V., 2022. An Automatic CADI's Ionogram Scaling Software Tool for Large Ionograms Data Analytics. IEEE Access, 10, pp.22161-22168.
https://doi.org/10.1109/ACCESS.2022.3153470

31. Kelley, M.C., Haldoupis, C., Nicolls, M.J., Makela, J.J., Belehaki, A., Shalimov, S. and Wong, V.K., 2003. Case studies of coupling between the E and F regions during unstable sporadic - E conditions. Journal of Geophysical Research: Space Physics, 108(A12).
https://doi.org/10.1029/2003JA009955