Characterizing Blanketing Sporadic E in the Vicinity of Magnetic Dip Equator Using Ground-Based Station and GNSS Radio Occultation Measurements

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ABSTRACT

In the vicinity of the magnetic dip equator, two basic types of sporadic E (*Es*) are observed equatorward of dip latitude (Φ) at approximately ±5 °, namely, the equatorial types E_{sq} and E_{sb} [*Tsunoda* 2008]. E_{sq} type is produced by Bragg scattering of radio signals from small-scale field-aligned irregularities embedded in the equatorial electrojet (EEJ) [*Rastogi* 1972; *Tsunoda* 2008]. The E_{sb} type, as reported by *Devasia* [1976] and *Reddy and Devasia* [1970], is the most common type observed in the equatorial region and is produced by the reflections from a thin layer of enhanced plasma density (N); the layer itself is formed from the convergence in the altitude of long-lived metallic ions, which result from a vertical shear in the zonal neutral wind (U) [e.g., *Axford and Cunnold* 1966]. The term "blanketing" denotes that N in E_{sb} is dense enough to prevent the travel of radio signals up to the F layer, which causes the disappearance of the F trace in an ionogram at such frequencies [*Tsunoda* 2008].

E_{sb} were distinguished by the first ionosonde experiments in the first half of the 20th century, but their origin and formation processes were unclear for a long time particularly near the magnetic dip equator. In recent years, techniques for E_{sb} observations have been advanced remarkably. In this regard, GPS radio occultation (RO) observations (satellite-satellite communication links) provide an ideal geometry for studying E_{sb} layer structure [*Wu et al.* 2005; *Arras et al*, 2008].

E_{sb} occurrence can result in daytime GHz scintillation [*Seif et al*, 2015]. The basis for the association of radio scintillations to E_{sb} is largely observational. Given that this association appears to be real, the understanding of the E_{sb} formation process in mid-latitudes relies on the wind shear theory proposed by *Whitehead* (1961). This theory was proposed for the mid-latitude ionosphere, where the inclination of the geomagnetic field (**B**) is steep enough to produce a thin layer of high plasma density, via horizontal wind-shear. According to this theory, an E_{sb} layer will not form where the inclination angle of **B** becomes too small. Nevertheless, our observations show the presence of daytime GHz scintillation in the vicinity of the magnetic dip equator. These observations suggest the existence of E_{sb} near the magnetic equator, where the equatorial electrojet is strong but the inclination angle of B is too small for wind-shear to be a significant factor. Therefore, the **key objective** of this study is to investigate of the nature of this behavior. This unexpected result will address the pressing need to in-depth understanding of physical processes that lead to the appearance of E_{sb} in association with daytime scintillation at the magnetic dip equator, where the inclination angle is zero. We bring two data sets to bear, from ground and space, which provide a unique opportunity to study characteristics of E_{sb} near the magnetic dip equator in association with daytime GHz scintillation.

In this study, we present the occurrence of daytime GHz scintillation using GPS Ionospheric Scintillation and Total Electron Content Monitor (GISTM) systems from the Langkawi (6.19°N, 99.51°E; Φ = 1.90°S) station in Malaysia situated very close to the magnetic dip equator. To identify the occurrence of E_{sb} at the magnetic dip equator over this station, we use GPS-COSMIC RO data. Ultimately, we evaluate our result with *Oyinloye* [1971] Model, where the model shows the characteristics of E_{sb} near the magnetic dip equator using eight ionosonde stations including Talara, Chiclayo, Chimbote, Huancayo, Juliaca, La Paz, Ibadan, Ilo. According to this model, (see Figure 1) the low occurrence of E_{sb} (~3%) is presented, where $|I| \leq 6°$ and its rapidly increased to considerable values of (15–27%), where $|I| \approx 8°$.

Results:

In this study, a close relationship between daytime GHz scintillations and appearances of E_{sb} in the vicinity of the magnetic dip equator has been studied. This indicates E_{sb} can sometimes occur near the magnetic dip equator under favorable conditions. Such a favorable condition is when the electric field becomes zero; that is, the zonal wind shear produces the convergence of metallic ions to an altitude where the upward and downward forces become zero. There, in the absence of an electric field, the wind will transport the E_{sb} sheet equatorward. Moreover, the extensive analysis result obtained from the 5 years RO dataset revealed the low occurrence of E_{sb} in the

vicinity of the magnetic dip equator. This result is consistent with that obtained by *Oyinloye's* [1971] model.

These scientific efforts play an important role in reliable space weather forecast and the development of space weather applications; it may seamlessly lead to improvement of our understanding of E_{sb} formation and evolution in the vicinity of magnetic dip equator, which also is very important in enhancing the capability of GPS satellite positioning and navigation. Our further research in this area will be presented.

Key words: Blanketing Sporadic E, Ionosphere, GNSS, Scintillation, Radio Occultation

REFERENCES

[1] Tsunoda, R. T., "On blanketing sporadic E and polarization effects near the equatorial electrojet", *Journal of Geophysical Research*, Vol. 113, A09304, doi:10.1029/2008JA013158, 2008, pp. 1-10.

[2] Rastogi, R. G. (1972), Equatorial sporadic E and plasma instabilities, Nature, 237, 73, doi:10.1038/237073a0.

[3] Devasia, T. N., K. Burrows, and J. D. Stolarik (1967), A latitudinal survey of the equatorial electrojet with rocket-borne magnetometers, J. Geophys. Res., 72, 1845, doi:10.1029/JZ072i007p01845.

[4] Reddy, C. A., and C. V. Devasia, "Formation of blanketing sporadic E layers at the magnetic equator due to horizontal wind shears", *Planet. Space Science,* 1973, 21, pp. 811, doi:10.1016/0032-0633(73)90098-6.

[5] Axford, W. I. and Cunnold, D. M. "The wind-shear theory of temperate zone sporadic E". *Radio Science,* 1966, pp. 191–198.

[6] Wu, D. L., Ao, C. O., Hajj, G. A., M. de la Torre Juarez, and Mannucci A. J., "Sporadic E morphology from GPS-CHAMP radio occultation", *Journal Geophysics Research.,* 110, 2005. A01306, doi:10.1029/2004JA010701.

[7] Arras, C., Wickert J., Beyerle G., Heise S., Schmidt T., and Jacobi C., A global climatology of ionospheric irregularities derived from GPS radio occultation, *Geophysical Research Letter.,* 35, 2008, L14809, doi:10.1029/2008GL034158.

[8] Whitehead, J., The formation of the sporadic-E layer in the temperate zones, *Journal of Atmospheric and Terrestrial Physics*, Vol, 20, 1961, pp. 49–58.

[9] Seif, A., Roland T. Tsunoda, Mardina Abdullah, and Alina Marie Hasbi. 2015. "Daytime Gigahertz Scintillations Near Magnetic Equator: Relationship to Blanketing Sporadic E and Gradient-Drift Instability", Earth, Planets and Space Journal, DOI: 10.1186/s40623-015-0348-2.67:177. PP.1-13.

[10] Oyinloye, J . O., A study of sporadic E in the equatorial region, Planet. Space Science. , Vol. 19, 1971, pp. 1131–1139. doi:10.1016/0032-0633(71) 90109-7.

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