On the Appearance of Sporadic-E and the Occurrence of Daytime GHz Scintillation

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Abstract

Scintillations on gigahertz (GHz) radio signal are observed during daytime due to electron density irregularities in the equatorial E-region. The occurrence of these irregularities in presence of sporadic E (E_s) can result in GHz scintillations during daytime. This study focuses on the investigation of E_s in the equatorial region using Global Navigation Satellite System (GNSS) signal transmissions received on the ground and in space. We bring two datasets to bear; (1) GNSS based radio occultation (RO) technique, which provides an ideal limb-viewing geometry from space for studying the feature of E_s, and (2) GPS ground-based station. These two datasets provide a unique opportunity to study the feature and structure of E_s. The occurrence of daytime GHz Scintillation (DGS) present from GPS scintillation/TEC data recorded by the GSV4004 receiver at Universiti Kebangsaan Malaysia (UKM) (2.55°N, 101.46°E; dip latitude (Φ) = 5.78°S) station in Malaysia. The results obtained from these two datasets show that (1) E_s structures existed over the UKM station as denoted by the RO observations, and (2) the appearance of E_s is associated with the occurrence of DGS.

1. Introduction

The Sporadic E (E_s) layers can affect radio signal propagation in the high frequency (HF) band due to the higher electron density compared with the regular E-layer. They can also affect propagation in the very high frequency (VHF), ultra-high frequency (UHF) and gigahertz (GHz) bands. Therefore, an improved understanding of the structure and occurrence of E_s is crucial. On the other hand, a few observations of scintillation in the range of GHz from mid latitudes to low latitudes have reported a correlation between the occurrence of daytime GHz scintillation (DGS) and E_s layer [1, 2, 3, 4, and 5]. Given limited information about the nature of DGS and E_s phenomena in the equatorial region, knowledge about both phenomena could be enhanced through a good understanding of either phenomenon. To do this, we require a wide band method of observations. In this regard, GPS ground-based receivers are an adequate and accepted technique to observe the scintillation of radio waves in Earth's ionosphere [6]. The Global Navigation Satellite System (GNSS) based radio occultation (RO) technique provides an ideal limb-viewing geometry from space for studying ionospheric high vertical structures of E_s layers. Therefore, combining ground-based data with the limb-viewing geometry from space provides a unique opportunity to retrieve complementary information about E_s signature.

The objective of this study is, to advance our understanding of physical processes that lead to the appearance of E_s in association with daytime scintillation in the equatorial region. We first show absence of F-region irregularities during daytime using GNSS RO data. We then present the comparison between the SNR measurements of L1 C/A code at 50-Hz derived from the FORMOSAT-3/COSMIC (F-3/C) RO experiment and the simultaneous observations of the DGS at equatorial region in Malaysia.

2. Data and Methodology

The result presented here are all derived from an equatorial ground-based GPS station dual-frequency receiver called GPS Ionospheric Scintillation and Total Electron Content (TEC) Monitor (GISTM) installed at Universiti Kebangsaan Malaysia (UKM) (2.55°N, 101.461°E; dip latitude 5.78°S) in Malaysia in 2010. In the analysis, scintillations are categorized as strong S4 ≥ 0.4, moderate 0.3 ≤ S4 ≤ 0.4, and weak 0.2 ≤ S4 ≤ 0.3.

The detection of E_s is restricted to specific latitude, longitude, local time, and year to cover the location of UKM in the E region during the daytime 6:00-18:00 local time (LT) in 2010. The L1 C/A code signal-to-noise ratio (SNR) data at 50-Hz sampling rate provide in the level 1b files. Occultation rays from GPS to the L1 C/A code SNR fluctuations recorded during FORMOSAT-3/COSMIC (F-3/C) RO events were used in this study as functions of tangent point height. The position of the tangent point is determined by the assumption of a sphere for the Earth in this study. That is, we estimate the L1 C/A code SNR fluctuations as function of the tangent point height using the assumption that the observed SNR fluctuations are mainly caused by ionospheric irregularities near the tangent point of occultation ray. This assumption has been used in the previous studies [7, 8, and 9] and proven to work well for RO technique. In this study, only SNR

measurements made from F-3/C RO ray with altitude of 90-120 km taken into account. In addition, the analysis is further limited to SNR measurements satisfying three criteria simultaneously, which are as follows (1) The locations of the tangent points of occultation rays are within ~ (±10°) of UKM in latitude and longitude (2) The RO event took place within ±1 h of the observing time for each ionospheric scintillation event recorded at UKM, and (3) The SNR has an obvious U shape as reported by *Zeng and Sokolovskiy* [2010].

3. Results

3.1 Daytime Scintillation and E-region Irregularities

Following suggestions that the possible presence of daytime F-region irregularities could produce GHz scintillation particularly in the late afternoon, we present the reasons why there is no compelling need to consider this possibility.

GNSS RO signals provide information on the altitude distribution of the irregularities that allow us to distinguish the contribution of the respective layers. The objective of this experiment is to investigate relation between DGS and E_s in the equatorial region. For the purpose of this work, we present an evidence against the likely existence of late-afternoon F-region irregularities that can produce GHz scintillation. We show amplitude scintillation measured by the F-3/C satellites as a function of tangent point altitude for each RO event in 2010.

Figure 1a shows global characteristics of the s4max9s in 2010, whereas Figure 1b presents characteristics of the s4max9s restricted over Malaysia covered UKM ground based station. It can be seen in Figure 1a and b that RO events cluster in three groups (1) altitude between 90-120 km with sudden increase of high scintillation activity (0.3 ≤ s4max9s ≤ 1.5), (2) altitude between 200-400 km and s4max9s ≥ 0.3, and (3) low scintillation across all the altitude. This result is consistent with the result that obtained by *Carter et al*, [2013]. The first group compromises RO events, where measured in the E-region, which attributed to the presence of E_s [8], which is the primary focus of this study. The second group corresponds to the ionospheric irregularities in the F-region. Figure 1c and d present the same data as Figure 1a and b, respectively, but with LT as the *x* axis. The histograms (red, black and magenta) indicate percentage occurrence of RO events corresponding to the E-region, F- region, and both E and F- regions, respectively.

It can be seen the most of the points in the second group correspond to 19-02 LT, where clearly show no occurrence of scintillation during daytime. The most significant feature is the rapid rise in the s4max9s after 19 LT. This is an evidence that clearly shows the scintillation occurred between 006 and 1800 LT are due to E-region irregularities only.

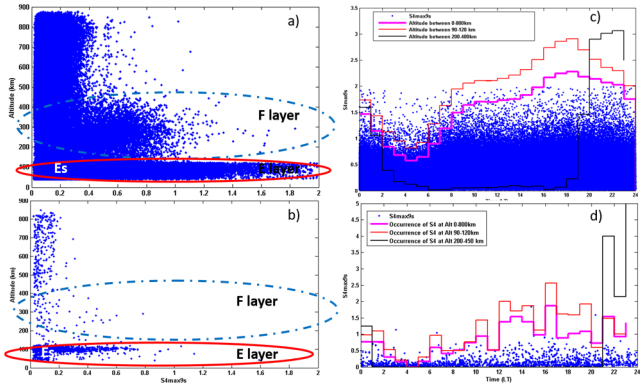

Figure 1. a) Global distributions of S4max9s at different altitude measured in 2010 (b) Distributions of S4max9s at different altitude measured in 2010 over Malaysia. (c) Distributions of S4max9s as a function of local time in 2010 occurred at altitude 0-800 km (represents by blue dots). Magenta histogram presents the hourly percentile for the points (s4max9s >= 0.3) with altitude of 0-800 km. Red histogram displays the hourly percentile for the points (s4max9s >= 0.3) occurred at E-region (90-120 km). Black histogram shows the hourly percentile for the points (s4max9s >= 0.3) at F-region (200-400km). (d) The same data as Figure 1c, but data restricted over Malaysia.

3.2 Evaluation by Coincident Occurrence of E_s and DGS

Further analysis is conducted to determine when and where scintillation occurs at GPS station. We evaluate occurrence of E_s with the appearance of DGS using satellite and ground-based station. The days and times of scintillation occurrences at UKM in 2010 have been subjected to a comparative study to verify (i) whether scintillation was present during daytime and (ii) whether *Es* appeared at the UKM station to produce irregularities that are responsible for DGS. In the following sub-sections, we will show a case study, where DGS coincident with the appearance of E_s layer.

3.2.1 Daytime Scintillations Occurrence at UKM

Figure 1 shows the diurnal variations of the amplitude scintillation (S4 index) activities for all PRNs observed at the UKM station on 26 December 2010. Each plot shows the S4 index for the corresponding month in UT, where LT = UT + 8. To detect the occurrence of amplitude scintillation activity, S4 measurements from the GPS satellites must exceed a value of 0.2 for more than 4 min.

As can be seen in Figure 1, moderate to strong scintillation event (S4 ≥ 0.4) is recorded by PRN 3 at 0300 UT (1100 LT), whereas two moderate scintillation events (0.3 ≤ S4 ≤ 0.4) simultaneously measured by two PRNs 13 and 18 at 0600 UT (1400 LT). The occurrences of these daytime scintillation events are further investigated to understand their relationship with the E_s layer.

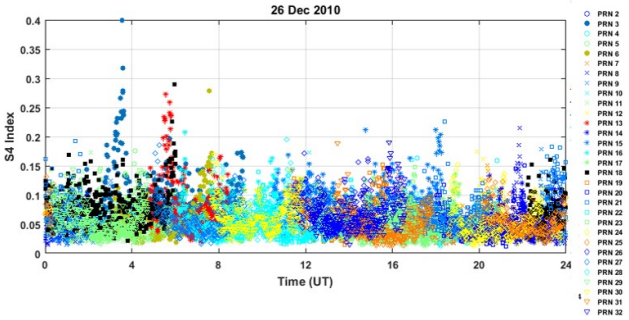

Figure 1. The diurnal variations of amplitude scintillation observed at UKM on 26 December 2010.

3.2.2 Appearance of *Es* denoted by RO

To understand the relationship of E_s with DGS, further analysis was conducted using F-3/COSMIC RO data on 26 December 2010 in the vicinity of UKM station, in which two RO events (number 1 and 2) coincident with the occurrence of DGS that can be discussed in this section.

Figure 2 displays RO event number one, which took place near the UKM station on 26 December 2010. Figure 2a-b illustrate the S4 profile and SNR measurements of L1 C/A code SNR profile as a function of altitude. Figure 2c shows S4 profile as a function of LT. Figure 2d-f illustrate the location of tangent point, S4 as a function of latitude and longitude, respectively. From Figure 2, the F-3/C RO event number one occurred at 1055 local time tangent point of S4 max (lttps4max) at geographic location about 4 °N, 108.04 °E. It can be seen from Figure 2 that abrupt SNR fluctuations associated with the presence of ionospheric irregularities are clearly present at ionospheric E region altitudes (between 100 and 115 km) at 4 °N, 108.04 °E, which indicate the presence of E_s in that height region.

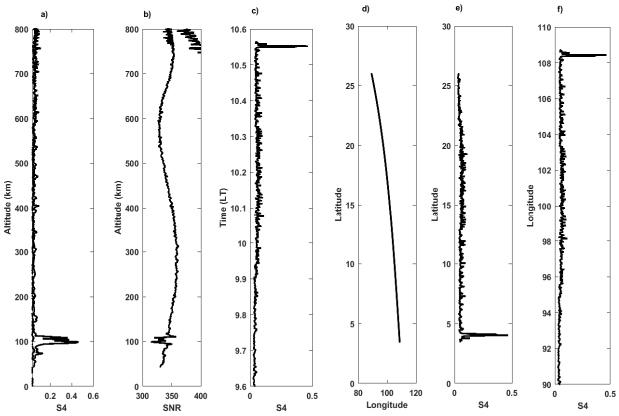

Figure 2. a) S4 profile, (b) L1 SNR, (c) Time of S4 maximum, (d) The location of tangent point, (e) and (f) geographic location of S4 observed from one selected RO data denoted by F3/COSMIC on day 360 (26 December 2010), when there was an E_s layer appear over the occultation region at 1055LT. The tangent point locations for each RO event used in this study is limited to the longitude (92ºE-109ºE) and latitude (2ºS-6ºN) ranges at the time the S4 was measured.

Figure 3 shows RO event number two that took place at 1423 at about 2.5 °N, 93°E. The arrangement of the panels in Figure 3 is same as that in Figure 2. It can be seen from Figure 3 that abrupt SNR fluctuations associated with the presence of ionospheric irregularities take place at the heights between 90 and 100 km at 2.5 °N, 93°E.

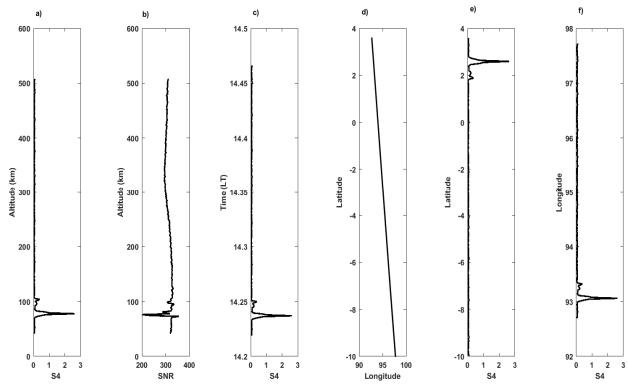

Figure 3. The same as Figure 4, but observation is related to RO event number 2 that occurred at 1423 LT.

3.2.3 Geographic Distributions of E_s and DGS

Th geographic locations of scintillation and RO events observed simultaneously on 26 December 2010 presented in Figure 4. DGS location are marked by stars, where RO events are represented by red circles.

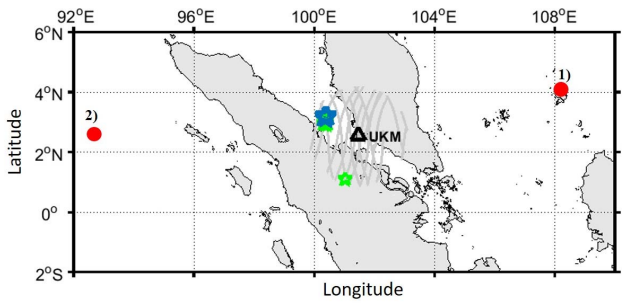

Figure 4. Geographic locations of scintillation and RO events occurred on 26 December 2010. DGS location are marked by stars, where RO events are represented by red circles. The blue star represents the location of moderate to strong scintillation event recorded by PRN 3. The green stars show location two scintillation events observed by two PRN_S 3 and 18 at 14 LT. The grey curves show location of ionospherie pierce point (IPP), where S4 was negligible.

It can be seen from Figures 2 and 3 that E_s inducing abrupt L1 C/A code SNR fluctuations along F-3/C occultation rays existed in the vicinity of UKM (within ±10° in latitude and longitude) during the observing time for the daytime scintillation registered at UKM on 26 December 2010. Thus the scintillation/TEC observations obtained by the

GSV4004 receiver and SNR measurements from F-3/C RO show that the DGS observed at UKM on 26 December 2010 was caused by E_s layer irregularities.

4. Summary

A comparison has been done in the present study between the scintillation from ground based station as well as F-3/C RO. The SNR measurements of L1 C/A code at 50-Hz sampling rate obtained from RO data and the simultaneous observations of the scintillation well approved ground-based. It is found that E_s structures existed over the UKM station as denoted by the RO observations when large SNR fluctuations were observed at ionospheric E-region heights during F-3/C RO, which occurred in the vicinity of the UKM station. More such observations can help to explore the structure and evolution of the E_s layer irregularities, which are not yet understood well. And, such a study is in progress. On the other hand, spatial coverage with even better spatial and temporal resolution can be expected with the upcoming launch of the F-3/C2 satellites to provide new insights to scintillation and ionospheric science study.

5. Acknowledgements

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6. References

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