TIME-FREQUENCY ANALYSIS OF IONOSPHERIC SCINTILLATION COSMIC GPS-RO DATA USING SYNCHROSQUEEZING TRANSFORM

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ABSTRACT

COSMIC GPS Radio occultation systems are developed for investigating global ionospheric and tropospheric features of atmosphere ionospheric effects are a major critical concern in radio communications and navigation systems. The predominant ionospheric effect is scintillation, which causes small scale fading in GNSS received signals. Hence, there is a necessity to understand the ionospheric morphology, especially in low latitude region. In this paper, GPS RO ionospheric scintillation measurements over the Indian region have been considered for the analysis. A Novel spectral analysis tool based on synchrosqueezing transform (SST) method is proposed for identifying low latitude equatorial Ionospheric anomalies. It is found that SST provides better time-frequency resolution under conditions of severe scintillation.

Keywords: global positioning system, radio occultation, scintillation, synchrosqueezing transform, electrondensity, wavelet transforms.

1. INTRODUCTION

GPS Radio occultation techniques are effective tools to study ionospheric layered structures. Radio occultation missions such as Constellation Observing System for Meterology, Ionosphere and Climate (COSMIC) and Challenging Mini Satellite Payload (CHAMP) are used to sound the earth's neutral atmosphere and ionosphere via a radio link between a GPS navigation satellite and GPS receivers equipped on low Earth orbit satellites. COSMIC electron density measurements can be achieved to capture and identify small-scale ionospheric structures associated with scintillation. The ionospheric conditions in low latitudes are random and least predictable. The morphology of low latitude ionosphere can be characterized with GPS RO data. Global ionospheric scintillations were studied in which the equatorial ionization anomaly crests were located [1]. The maximum amplitude scintillations tend to occur at low latitude regions.

Activity of scintillation varies with 11 years solar cycle and local time, seasons, geographical location and magnetic activity [2, 3]. In these recent years a lot of research studies on the ionosphere using scintillation and electron density data, retrieved by F3/C, have been carried out revealing many significant results [4-7]. But the use of COSMIC-GPS amplitude scintillation index was done in very few research efforts [8-11]. Dymond [12] put an effort to make comparisons between the coincident electron density climatologies and scintillations, which were measured by COSMIC satellites during March and April 2007. The comparisons led to a confirmation that there was a one-one correspondence between scintillations and electron density which was regional but not global. In this paper, scintillations are analyzed with time frequency spectrum analysis, based on Synchrosqueezing transform. The time-frequency analysis of the Fourier transform of a signal is inadequate. To overcome this drawback, Denis Gabor introduced the Short Time Frequency transform which is a windowed-transform known as Gabor transform. The SST was originally introduced in the context of audio signal analysis. Synchrosqueezing had shown superior precision in both frequency and time. Synchrosqueezing can clearly delineate components and could extract the signal with time varying spectrum.

2. SYNCHROSQUEEZING TRANSFORM

The Synchrosqueezing transform (SST), had become the newly developed adaptive data analysis method which is being applied extensively in structural stability analysis, accoustics, medical system and meterology. Synchrosqueezing is the main tool in analyzing auditory signals [13] with so many reallocation methods [14-18]. It has become the special case in aiming to sharpen a time-frequency representation R(t, ω) by "allocating" its value to a different point (t0, ω0) in the time-frequency plane, determined by the local behavior of R(t, ω) around (t, ω). Firstly the time-frequency map through a Continuous wavelet transform was constructed. For this, a mother wavelet is needed that satisfies by definition, the wavelet coefficients are the correlation coefficients between the target signals and dilated and translated versions of a given basic pattern.

$$W_f(a,b)=\int_{\alpha}^{\infty} f(t)a^{-\frac{1}{2}}\varphi^*(t-b/a)dt \qquad (1)$$

ψ^* is the complex conjugate of the mother wavelet, a is the scale factor which determines the frequency and b is the time shift applied to the mother wavelet,. The CWT is the cross correlation of the signal f(t) with several wavelets that are scaled and translated versions of the original mother wavelet. The symbols W_f(a, b) are the coefficients representing a concentrated time.

$$T_f(\omega_l,b)=\frac{1}{\Delta\omega}\sum_{a_k:|\omega(a_k,b)-\omega_l|\le\Delta\omega/2} W_f(a_k,b)a^{-3/2}\Delta a_k \tag{2}$$

The equation (2) shows that the new time-frequency representation of the signal T_f (w, b) is synchrosqueezed along the frequency (or scale) axis only. The primary requirement in demodulation of a signal is to get amplitude, phase and instantaneous frequency information. Synchrosqueezing takes advantage of its reassignment principle to overcome the noise interference of signal. In the reassignment mode, Synchrosqueezing uses superposition of a class of functions that slowly varies with respect to the instantaneous frequencies.

3. RESULTS AND DISCUSSIONS

The occultation path over low latitude region is shown in Figure-1. The COSMIC Satellite travels from (30°N, 85°E) to (44°N, 55°E). COSMIC GPS RO data is accessed from COSMIC data center website (http://cdaac-www.cosmic.ucar.edu/). It can be seen from Figure-2 that strong amplitude scintillations with S_4>0.5 were observed for PRN 20 satellite from 07:50UT. In order to analyze ionospheric scintillations, GPS RO data of 23rd September 2013 electron density and scintillation profiles are derived for carrying out spectral analysis using SST transform.

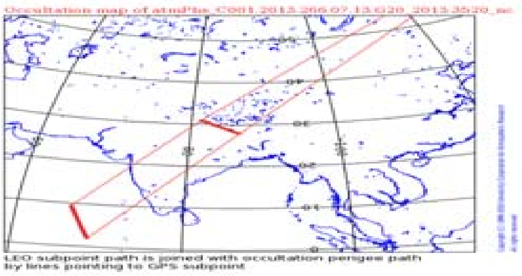

Figure-1. GPS RO occultation path over Indian region. C001 September 23rd 2013 PRN 20 UT 07:13AM.

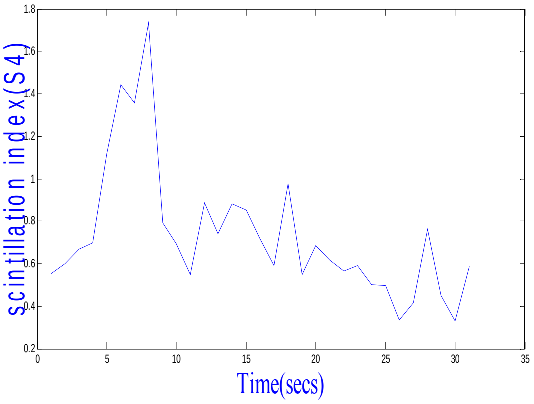

Figure-2. Scintillation index from COSMIC COO1 PRN 20 on 23rd September 2013.

Figure-2 shows severe ionospheric scintillations event occurred on 23rd September 2013 07:15 time. It is observed that the maximum S_4 values are around 1.8. at 07:37 AM

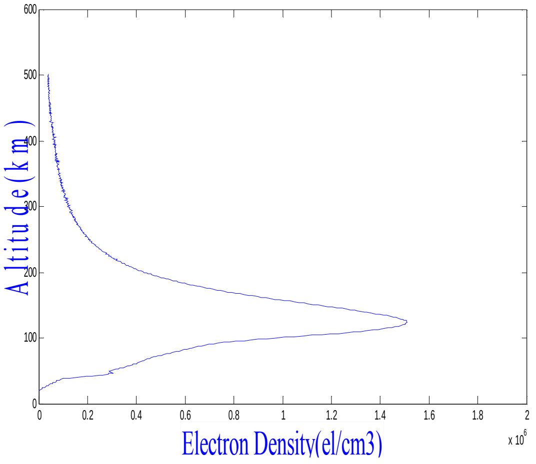

Figure-3. Electron density profile from COSMIC C001 PRN 20 on 23rd September 2013.

Figure-3 shows electron density variations. The maximum value is 1.5×10^6 el/cm^3 at 150 km. The ionospheric scintillations S_4 values are given as input to SST transform.

The wavelet choice is a key issue in synchrosqueezing-based methods. [19-20]. In SST, we first construct the time-frequency map through a CWT, thus, we need a mother wavelet that satisfies the admissibility condition. At the same time, the wavelet must be a good match for the target signal in our implementation; we use a Morlet wavelet with central frequency and bandwidth estimated from the scintillatin index. By using a classical Morlet wavelet and 32 levels for the SST method a good balance between speed and resolution in the frequency representation can be obtained.

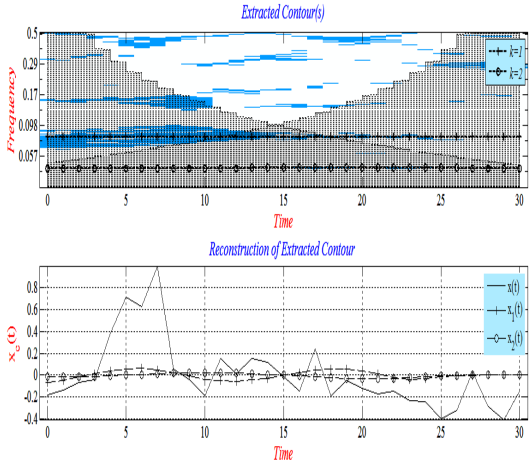

Figure-4. Synchrosqueezing Transform results of PRN 20 on 23rd September 2013.

Figure-4 shows that the disturbance occurred between 5 to 10 seconds in time-frequency plot of ionospheric scintillations signals and the extracted ionospheric scintillations. The SST reallocates coefficients of CWT to get a concentrated image over the time-frequency plane, which provides more accurate and precise time-frequency decomposition. This delineates the location and extent of spectral anomalies more clearly, thus facilitating further interpretation

4. CONCLUSION AND FUTURE SCOPE

GPS RO ionospheric measurements provide an opportunity to investigate global ionospheric morphology. SST is suitable for ionospheric scintillation signal characterization of its non stationary and non linear properties. It is found that ionospheric scintillation fading frequency components upto 0.2Hz.SST method able to mitigate the ionospheric scintillation affected frequency components well. In Future GPS RO electron density and scintillation measurements will be compared with ground based GNSS stations in low latitude regions. GPS RO TEC and Scintillations measurements will be compared with IRI2012, GAIM and SUPIM model.

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