Analysis of Ionospheric Correction Approach for IRNSS/NavIC System Based on IoT Platform

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Abstract. The supreme success of the future Internet of Things (IoT) depends on the ubiquitous and immaculate connectivity provides by satellite. Ionosphere is one of the major contributing factor in signal propagation for satellite based application, which results in degradation of measurement accuracy. In the India, Indian Regional Navigation Satellite System (IRNSS)/Navigation with Indian Constellation (NavIC) both *L*5 and *S* band signals are more affected by this ionosphere due to its low latitude geographical location. So, the future success of IRNSS system based on IoT platform depends on accuracy of ionospheric mitigation algorithm. This paper concentrate on comparative analysis of coefficient based model and dual frequency model based ionospheric model. The data is collected from IRNSS/NavIC receiver located at communication research laboratory, Electronics Engineering Department, SVNIT surat (21.16° Lat, 72.78° Long) provided by SAC, ISRO Ahmedabad. It is observed that the amount of delay contribution by *L*5 band is more compared to *S* band. The performance of dual frequency and coefficient based model is checked on different geomagnetic *Kp* index. It is also deduced from the comparison that the dual frequency model works better in stormy days, where coefficient based approach gave bad performance.

Keywords: Indian Regional Navigation Satellite System (IRNSS) · Navigation indian constellation (NavIC) · Ionodelay · Grid iono vertical error (GIVE) · Klobuchar · Dual frequency

1 Introduction

The goal of the IoT is that all devices should be connected wherever they are located. Where Wi-Fi, Bluetooth and GSM networks are fail to provides the ubiquitous and seamless coverage services there satellites works better. Hence, The ultimately future of IoT will depend on the satellite based network [1]. The satellites network provides a good Coverage, high reliability, low latency, high speed, versatile and cost effective services [2]. Integrating IoT with satellite system will solved many problem of navigation e.g. transportation problem like, traffic jam, road block etc. The success of satellite based navigation application depends on accuracy of measurement and it is noticed that measurements always affected by different error sources.

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Indian Space Research Organization (ISRO) developed IRNSS/NavIC, which will gives positioning service with a 10 m of accuracy for both civilian and military users of the India [3]. The IRNSS consists three Geostationary Earth Orbit (GEO) and four Geo Synchronous Orbit (GSO) satellites [4]. The arrangement of three GEO is done at 32.5 °*E*, 83 °*E* and 131.5 °*E* longitude and four GSOs are in two planes that cross the equator at 55° and 111.75° East respectively. The IRNSS satellites broadcast the signal in L_5 band (1164.45 1188.45 MHz) and *S* band (2483.5–2500 MHz) with a carrier frequency of 1176.45 MHz and 2492.08 MHz respectively [4, 5]. The military or defense signal is encoded and modulated by Binary Offset Carrier (BOC) (5,2) for secure communication. In contrast with it, the civilian signal is simply used Binary Phase Shift Keying (BPSK) modulation [4, 6]. Currently, the IRNSS fully operational as all seven satellites, 1A, 1B, 1C, 1D, 1E, 1F and 1G are available in an orbit [7]. IRNSS/NavIC satellites consist navigation and ranging payload. The IRNSS/NavIC users compute their position by the navigation signal provides by the receiver.

The IRNSS/NavIC both *L*5 and *S* band signals passes through the atmosphere before reaching the user receiver, thus the signals are always affected by different error sources whether it is intentional or unintentional [8]. Hence the position computed by IRNSS/NavIC users is always deviated. The ionosphere with an altitude between 60 km to 700 km above the earth's surface contribute highest error in position measurement by IRNSS/NavIC. The behavior of ionosphere is irregular when the earth's magnetic field is disturbed, geomagnetic storm and mass ejection of the solar corona is occurred [9]. In India as the large irregularities are available in ionosphere IRNSS/Navic both signals are highly affected by it. To mitigate this error due to ionospheric irregularities, different methods is applied like, dual frequency methods, differential correction approach and various single frequency ionodelay models. In this paper performance investigation of eight coefficients (four α and four β) based model [10, 11], dual frequency model is done for ionospheric correction on IRNSS/Navic receiver. In IRNSS/NavIC users can apply the ionospheric correction by three ways (i) grid based (ii) coefficient (iii) dual frequency. The IRNSS/NavIC is broadcasting, 8 correction coefficient of coefficient based model and 80 Ionospheric Grid Point (IGP)correction for GIVE model in *L*5 band signal [4]. Detail information related to coefficient based and dual frequency model is described in the Sect. 1. Section 2 contains the analysis of all ionospheric model. Finally, conclusion of this paper is included.

2 Ionospheric Correction Models

The amount of delay contributed by the ionosphere depends on density of free electron present on it, called Total Electron Content (TEC). The TEC density is changed during day and night time due to recombination and ionization process. It is also depends on seasonal behavior condition and solar cycle and geographical location of the user [12]. The quiet and stormy days are identified by a variety of geomagnetic indices, such as *K*, K_p, A_p and D_{st}, and it is correlated with the variation of TEC in the ionosphere [13]. There is a large gradient observed in ionosphere near Indian region. Hence, the IRNSS performance only succeeds when these effects will be mitigated effectively using some models or method in real time scenario. In a matured GPS system normally coefficient based (klobuchar model) is applied for the correction [14]. Here coefficient based correction is also applied on both the bands of IRNSS, which is explained below.

Ionodelay Computation Using Coefficient. The master frame of IRNSS contains four sub frames and each sub frame is 600 symbols long, so total 2400 symbols per frames [4, 7]. Sub frames 1 and 2 transmit primary and sub frames 3 and 4 transmit secondary navigation parameters respectively [3]. Secondary navigation parameters include, ionospheric delay correction coefficient and Ionospheric grid delays and confidence values. The Ionodelay computation using coefficient is empirical model and estimated the delays based on 8 coefficient [10, 14], which are broadcasted through navigation data once in a day. The steps for the algorithm is as follows

Algorithms

Step-1: Using Azimuth (A_z) and Elevation (El) angles, compute Earth's central angle (Ψ) in semi-circles [4, 14].

$$\Psi = \frac{0.0137}{El + 0.11} - 0.022 \tag{1}$$

Step-2: Compute geodetic latitude (ϕ_i) and longitude (λ_i) of the earth projection intersection point of ionosphere in semi-circles [10].

$$\phi_i = \phi_u + \psi \sin A_z \qquad |\phi_i| \leq 0.416 \tag{2}$$

if $\phi_i > +0.416$ then $\phi_i = +0.416$
if $\phi_i < -0.416$ then $\phi_i = -0.416$

$$\lambda_i = \lambda_u + \frac{\Psi \sin A_Z}{\cos \phi_i}$$

where, λ_u and ϕ_u are user's geodetic longitude and latitude in semi-circles respectively.

Step-3: By assuming mean ionospheric height h 350 km geomagnetic latitude at point where projection of earth intersect with ionosphere is calculated by [4, 11, 14]

$$\phi_m = \phi_i + 0.064 \cos(\lambda_i - 1,617) \tag{4}$$

Step-4: After correction coefficient (α,β) received from satellites, compute the amplitude and delay of the ionospheric delay denoted as A_I and T_I [4].

$$A_I = \sum_{n=0}^{3} \alpha_n \phi_m^n \quad A_I \geq 0 \tag{5}$$

if $A_I < 0$ then $A_I = 0$

$$T_I = \sum_{n=0}^{3} \beta_n \phi_m^n \quad T_I \geq 72{,}000 \tag{6}$$

if $T_I < 72,\ 000$ then $T_I = 72,\ 000$ (sec) and depending on T_I value parameter x is derived by

$$x = \frac{2\pi(t - 50{,}400)}{T_I}$$

Where, t is calculating as,

$$t = \left(4.32 * 10^4\right) * \lambda_i + TOWC(IRNSS)$$

Step-5: Depending on this x parameter value ionospheric correction is applied as [4, 14].

If, $|x| < 1.57$ then

$$T_{iono} = F * \left[5.0 * 10^{-9} + AMP\left(1 - \frac{x^2}{2!} + \frac{x^2}{4!}\right)\right] \tag{7}$$

otherwise

$$T_{iono} = F * \left(5.0 * 10^{-9}\right) \tag{8}$$

Coefficient model is very simple, As the coefficients are fixed for a day, it can not work efficiently. Compare to that dual frequency model is more efficient which is explained next.

2.1 Dual Frequency Model

Instead of using coefficient based single frequency ionospheric correction model for estimation of ionodelay at user's location, another method can be adopted. This method uses NavIC/IRNSS pseudo-range measurement at both L_5 and S frequencies. The TEC is computed and converted into ionodelay in meter using conversion factor. The two frequencies L_5 and S user shall correct for the group delay due to first order ionospheric effects by applying the relationship [4]:

$$\sigma = \frac{\sigma_{L_5} - \gamma * \sigma_s}{1 - \gamma}, \tag{9}$$

where, denoting the nominal center frequencies of L_5 and S respectively,

$$\gamma = \left(f_s^2/f_{L_5}^2\right), \tag{10}$$

where, σ = pseudorange corrected for first order ionospheric effects. σ_{L5}, σ_S = pseudorange measured on the channel indicated by the subscript. The comparative analysis between dual frequency and single frequency model is included in below section.

3 Simulation and Results Discussion

Ionospheric delay estimation for NavIC/IRNSS is carried out based on MATLAB. The simulation flow diagram is depicts in Fig. 1. The one week data starting, which is start on Sunday and end at Saturday have been used for analysis. The one week raw data of IRNSS/NavIC satellites starting from Time Of Week Count (TOWC) 0 (starting of the Sunday) to 648000 (end of the Saturday) is collected by the IRNSS/NavIC receiver at communication research laboratory, SVNIT, Surat (21.16° Lat, 72.78° Long). Ranges between IRNSS satellites (1A, 1B, 1C, 1D, 1E, 1F, 1G) and user receiver is calculated by extracting primary information from the raw data. First ranges for both L_5 and S band are calculated then dual frequency approach [8] is applied to measure the ionodelay for individual satellite.

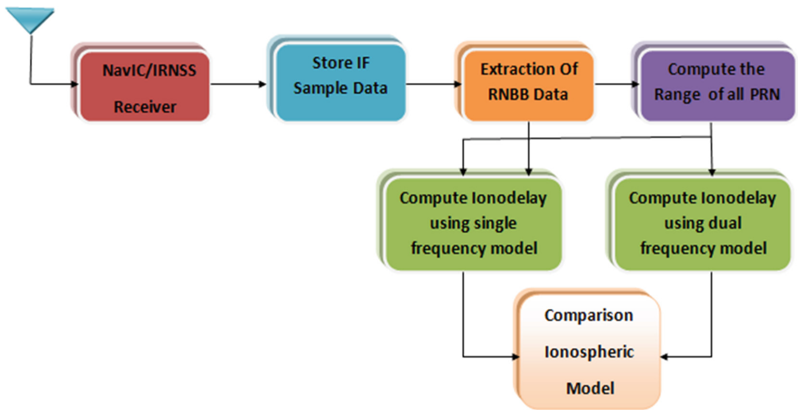

Fig. 1. Block diagram of simulation setup

Figure 2 shows the comparisons of ionodelay calculated by dual frequency approach for IRNSS six satellites namely 1B, 1C, 1D, 1E, 1F and 1G on the stormy day 14/08/16 ($3 < K_P < 5$). The observation was carried out for individual six satellites and it is observed that all individual satellites have a large ionodelay in $L5$ band compared to S band. As per the literature maximum ionodelay will happen when the ionosphere recombination rate is lowest. And for the low latitude Indian region, it will happen in

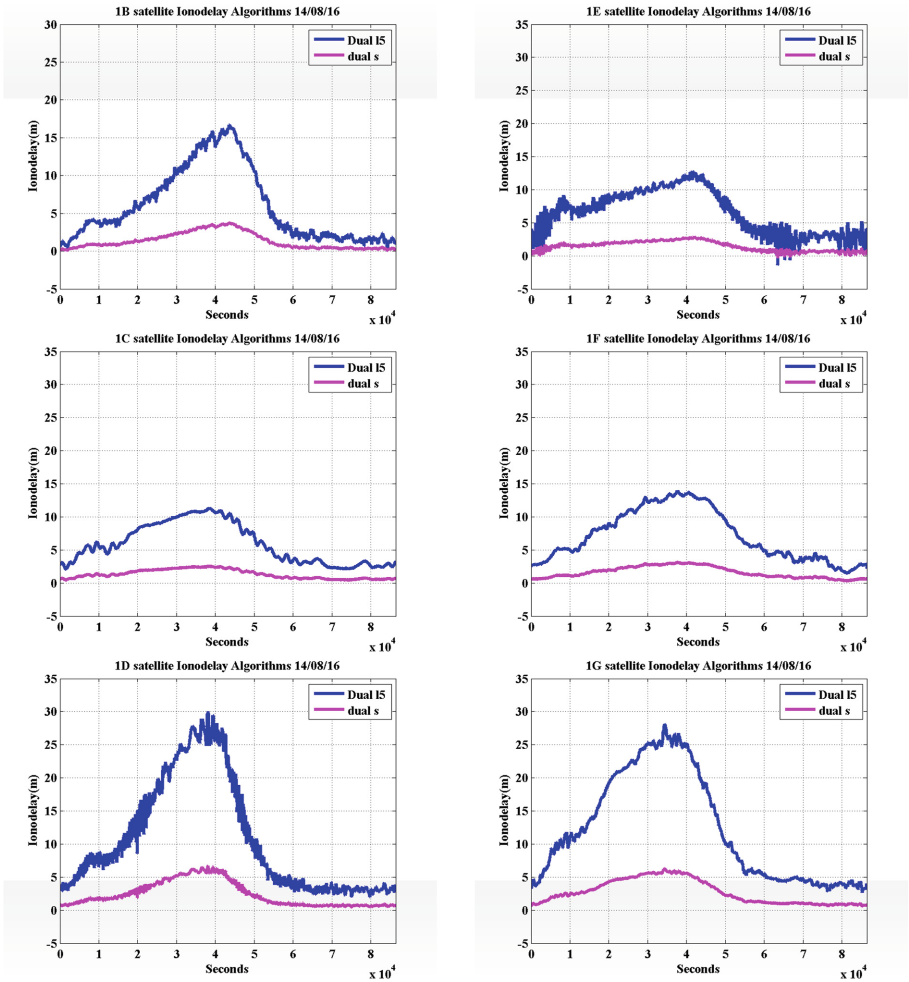

Fig. 2. Ionodelay computed by the dual frequency model on a quiet day 14/08/16 ($3 < K_P < 5$)

the afternoon around period (12.00 to 14.00 h). It is also found from the comparison that maximum ionodelay is estimated at Local Time (LT) around 14.00 (hours).

Ionodelay shown in Fig. 1 is compared in term of maximum, mean and stand deviation values, which are listed in Table 1. The value of maximum ionodelay in meter are 18.0632 m, 11.9698 m, 30.8831 m, 13.4083 m, 14.7313 m, and 29.3238 m for satellites 1B, 1C, 1D, 1E, 1F and 1G respectively. It is noticed that Maximum ionospheric effect felt by satellites 1B and 1D satellites. 1D satellite has a higher delay among all the satellites and its value for L_5 and S bands are **30.8831** m and **06.8828** m respectively. In the case of mean value 1G satellite have a highest value 12.1734 m for L_5 and 02.7130 m for S band. Similarly for the comparison of standard deviation 1G satellites in L_5 (08.1183 m) and 1D satellite in a S(01.8767 m) band have a higher value.

Table 1. Detail ionospheric delay comparisons computed by dual frequency model on 14/08/16 ($3 < K_P < 5$)

Satellites	1B	1C	1D	1E	1F	1G
L5 band dual frequency approach (14/08/16)						
Maximum(m)	18.0632	11.9698	**30.8831**	13.4083	14.7313	**29.3238**
Mean (m)	6.0113	5.9133	**10.6249**	6.4330	7.1613	**12.1734**
Standard deviation (m)	4.8206	3.0610	**8.4209**	3.3964	3.8722	**8.1183**
S Band Dual Frequency Approach (14/08/16)						
Maximum(m)	4.0257	2.6676	**6.8828**	2.9882	03.2832	**06.5352**
Mean (m)	1.3397	1.3179	**2.3679**	1.4337	1.5960	**2.7130**
Standard deviation (m)	1.0743	0.6822	**1.8767**	0.7569	0.8630	**1.8093**

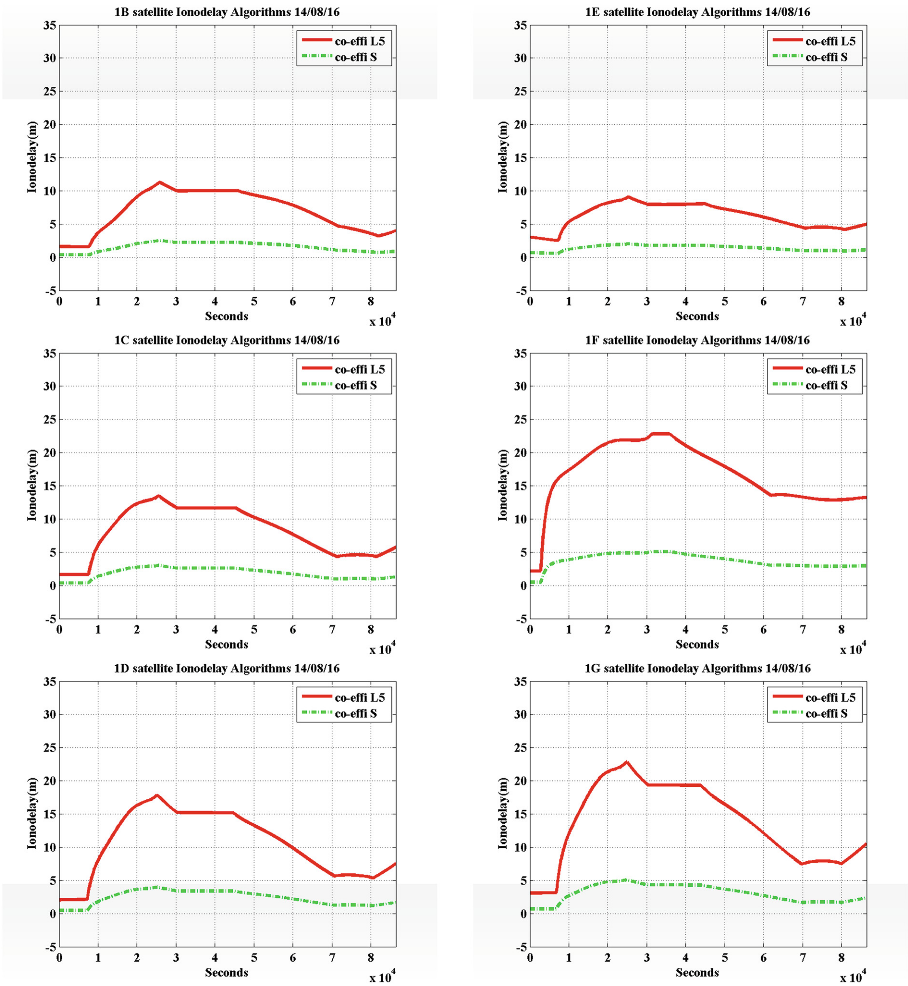

Fig. 3. Ionodelay computed by the 8 coefficient based model on a quiet day 14/08/16 ($3 < K_P < 5$)

As mentioned in literature dual frequency approach gives always better performance, but it has a cost of additional frequency. Hence, the single frequency ionodelay model is applied for comparison. To apply coefficient based model, The broadcasted ionospheric correction coefficients are extracted from raw data. The detail performance comparison of coefficient based model for both band are done for 14/08/16, which is shown in Fig. 3. It has been observed that in coefficient based model cases also L_5 band signal suffers more delay compared to S band signal. The detail comparison is listed in Table 2.

Table 2. Detail ionospheric delay comparisons computed by 8 coefficient model on 14/08/16 ($3 < KP < 5$)

Satellites	1B	1C	1D	1E	1F	1G
L5 band eight coefficient based model (14/08/16)						
Maximum(m)	11.3029	13.4974	17.8568	9.0782	**22.8248**	**22.8896**
Mean (m)	6.9525	8.1487	10.6045	6.2006	**16.7774**	**13.7900**
Standard deviation (m)	3.0082	3.5927	**4.7369**	1.8211	4.6225	**5.8495**
S band eight coefficient based model (14/08/16)						
Maximum(m)	2.5190	3.0081	3.9796	2.0233	**5.0868**	**5.1013**
Mean (m)	1.5495	1.8160	2.3634	1.3819	**3.7391**	**3.0733**
Standard deviation (m)	0.6704	0.8007	**1.0557**	0.4059	1.0302	**1.3037**

It has been observed from the comparison that dual frequency approach has a maximum delay for 1D satellite and its value is around 30.8831, while the coefficient based model have the value 17.8568. So, the coefficient based model perform worst compared to dual frequency model. The performance of the dual and coefficient model also checks for another stormy day ($K_P > 5$) 16/08/2016 where large iono-gradient present. This comparison is shown in Fig. 4.

It has been found that coefficient based model correct only around 50% ionospheric delay correction compared to the dual frequency. The detail comparison is covered in Table 3. Here also noticed that the coefficient based model has failed to compute better

Table 3. Detail ionospheric delay comparisons computed by dual frequency model and 8 coefficient model on 16/08/16 ($5 < KP < 7$)

Satellites	1B	1C	1D	1E	1F	1G
L5 band dual frequency approach (16/08/16)						
Maximum(m)	22.3615	16.8779	**28.0752**	21.5387	21.1992	**29.9452**
Mean (m)	8.0338	8.2158	**11.6218**	9.8453	9.9320	**15.2298**
Standard deviation (m)	6.6234	5.2157	**7.9698**	6.4735	6.3990	**9.3670**
L5 band eight coefficient based model (16/08/16)						
Maximum(m)	10.0792	11.6613	15.2376	8.1150	**22.8218**	**19.3657**
Mean (m)	7.5289	8.6454	11.2386	6.4872	**16.6324**	**14.4466**
Standard deviation (m)	2.3803	2.7243	**3.6256**	1.3776	3.3636	**4.4180**

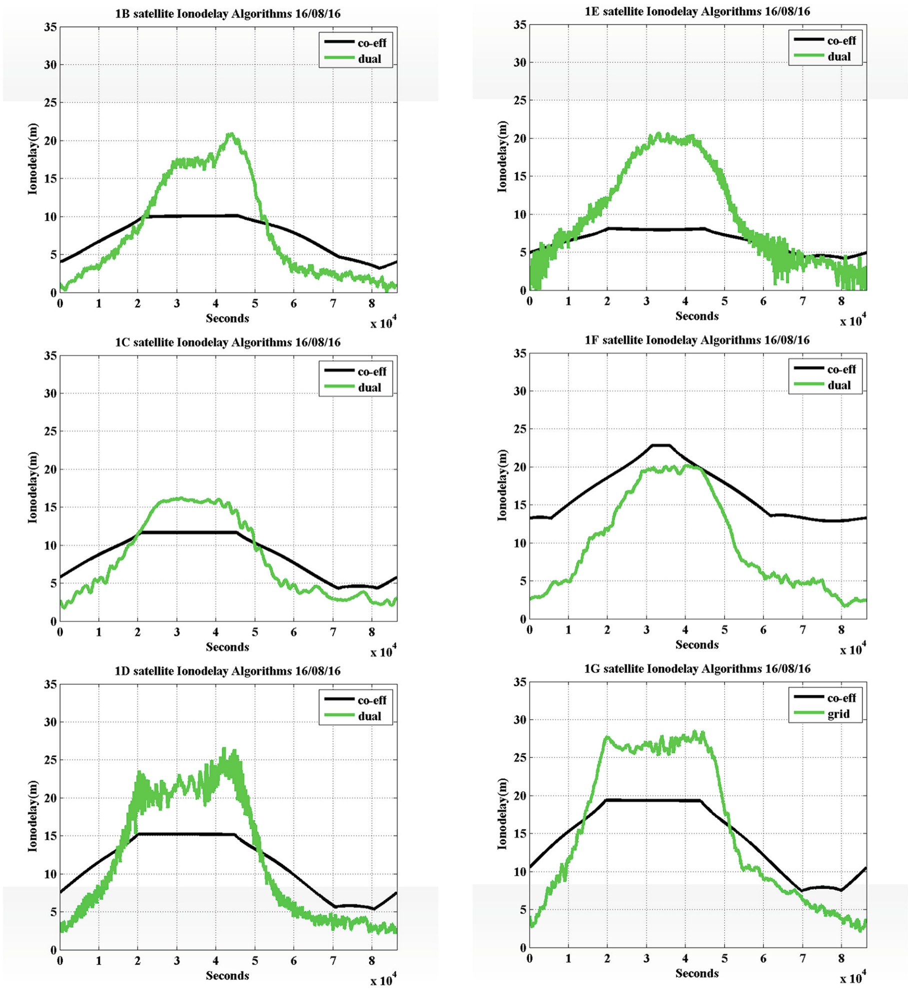

Fig. 4. Ionodelay computed by the dual frequency and 8 coefficient based model on a day 16/08/16 ($K_P > 5$)

ionodelay in both stormy days. Where, the dual frequency model perform good in stormy days also.

4 Conclusion

The paper contains a comparative analysis of different ionospheric models for future NavIC/IRNSS system based IoT platform. The comparison is done between dual frequency method with single frequency eight coefficient model. It has been observed from the dual frequency analysis that $L5$ band signal gets more affected by ionosphere compared to *S* band signal. The maximum error contributed by ionosphere for *L*5 band signal is around 30 m at LT 14.00 h. To reduced the cost of extra frequency conventional eight coefficient single frequency model is applied. However, the coefficient base model provides around only 57% correction for a quiet day 14/08/16 and for a stormy day 16/08/16 it's performance is worst. It has been deduced from the comparison that in the both cases dual frequency models gives good performance but with the cost of extra frequency.

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