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Performance evaluation of the Galileo broadcast ionosphere coefficients over IRNSS Service Area

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Abstract

Ionosphere over service area of Indian Regional Navigation Satellite System (IRNSS) is considered very dynamic due to equatorial ionosphere anomaly. Hence the adequacy of any ionosphere model over IRNSS service area to be assessed before applying it over its service area. In this paper, the analysis is carried out on the performance of the Galileo broadcast ionosphere coefficients (NeQuick-G) over IRNSS service area. The assessment is done using Global Ionosphere Map (GIM) data and IRNSS dual frequency ionosphere measurements (IRMeas). NeQuick-G performance is also compared with the standard NeQuick model with F10.7 as input. It has been found that the NeQuick-G provides better ionosphere error correction than the NeQuick model with F10.7 as input (NeF). The Root Mean Square Difference (RMSD) using NeF reaches up to 2.54 m at IRNSS L5 frequency while RMSD using NeQuick-G (NeG) reaches up to 2.30 m. Similarly, Mean Error (ME) using NeG varies from 0.29 m to 1.3 m which is smaller than the ME of NeF at L5 frequency with respect to GIM data. Observations show that the NeG captures the day to day variations of ionosphere in a better way than NeF. The variations in 2-dimensional ionosphere maps show that the error in NeG is more near to the equator when compared with GIM. Further, results show that NeG and NeF can correct the ionosphere error up to 74.45% and 70.20% respectively, for a given day. It is observed that the Galileo broadcast model performs better than the GPS broadcast model. However, Galileo model shows the dip in the magnitude at the ionosphere peak during local noon time for stations below 15°N when compared with IRMeas. Overall, NeG can correct more than 70% of the ionosphere error with respect to GIM and IRMeas over IRNSS service area.

1. Introduction

In satellite based navigation, the main errors in range measurements are due to the satellite clock, receiver clock, ionosphere delay, troposphere delay and multipath. However, for single frequency users, error due to ionosphere is the highest error source [1]. Therefore, all navigation system broadcast the ionosphere parameters in the broadcast messages along with the ephemeris. Ionosphere coefficients which uses Klobuchar model is broadcast by Global Positioning System (GPS). It is widely used by user community due to its fast and relatively easy user algorithm [2]. However, it can correct the ionosphere error up to 60% globally [1]. Galileo navigation system has adopted different method to correct the ionosphere error for its users. It is the modified version of NeQuick model which uses Galileo broadcast coefficients (NeQuick-G) instead of solar radio flux (F10.7) [3, 4]. Based on literature, it can provide better ionosphere correction than GPS klobuchar model in the nominal ionosphere conditions [4, 5].

However, the performance assessment of NeQuick-G is carried out mostly over mid-latitude region where ionosphere is considered relatively calm. Indian Regional Navigation Satellite System (IRNSS) is regional system which provides service from 30°S to 50°N. Ionosphere over service area of IRNSS is considered very dynamic due to equatorial ionosphere anomaly [4, 5, 6].
A detailed study to assess the performance of NeQuick-G over IRNSS service area has been carried out in this paper. The paper is arranged in four sections: section 2 describes the data and methodology used for performance evaluation. Results are discussed in section 3 which followed by the concluding remark in section 4.

2. Data Used and Methodology

The Galileo broadcast ionosphere coefficients are downloaded from multi-GNSS receiver in Bangalore, India. The user algorithm to derive ionosphere delay is taken from Galileo Signal In Space Interface Control Document [3]. The base model for Galileo broadcast coefficients is the NeQuick model. In general, F10.7 is used in the NeQuick model to compute the ionosphere delay at user's line of sight [7, 8]. To accommodate the local variation, Galileo uses data ingestion method to the NeQuick model and generate the broadcast coefficients which replace F10.7 [9, 10, 11].
Therefore, if Galileo broadcast ionosphere coefficients are used as input to the NeQuick user algorithm then it is referred as NeG and if the F10.7 is used as input to the user algorithm then it is termed as NeF throughout the paper. Here Ne represents NeQuick which is the base model in Galileo user algorithm.

Global Ionosphere Map (GIM) data from Center for Orbit Determination in Europe agency and IRNSS dual frequency reference receiver ionosphere Measurements (IRMeas) are considered as the truth data for comparison. The dates are chosen based on the availability of the IRMeas and Galileo broadcast parameters. Day no. 148 to 150, 2022 are chosen for the analysis based on the availability of IRNSS data and Galileo broadcast parameters.

The assessment of error is carried out in terms of Root Mean Square Difference (RMSD), Mean Error (ME) and the Percentage of Correction (PC).

4. Results and discussion

The spatial variation of the ionosphere delay using GIM and NeG over IRNSS service area at 16 hour Universal Time (UT) for day no. 148, 2022 is shown in Fig. 1. In case of GIM, the maximum ionosphere delay is confined within the 10°S to 10°N. However, NeG and NeF shows a dip around 10°N (Fig. 1).

Fig. 2 indicates the mean error map between GIM- NeG and GIM-NeF for the same data. Typically the difference between GIM and NeQuick ionosphere delay varies from -4 m to 4 m. It has been observed that ME does not follow any specific pattern spatially.

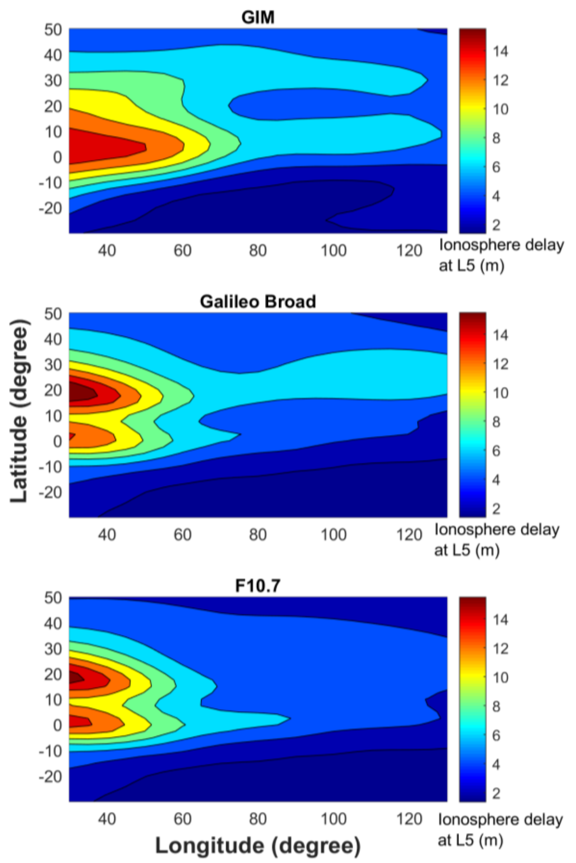

Figure 1. Spatial distribution of ionosphere delay at L5 over IRNSS service area at 16 hour UT for day no. 148, 2022.

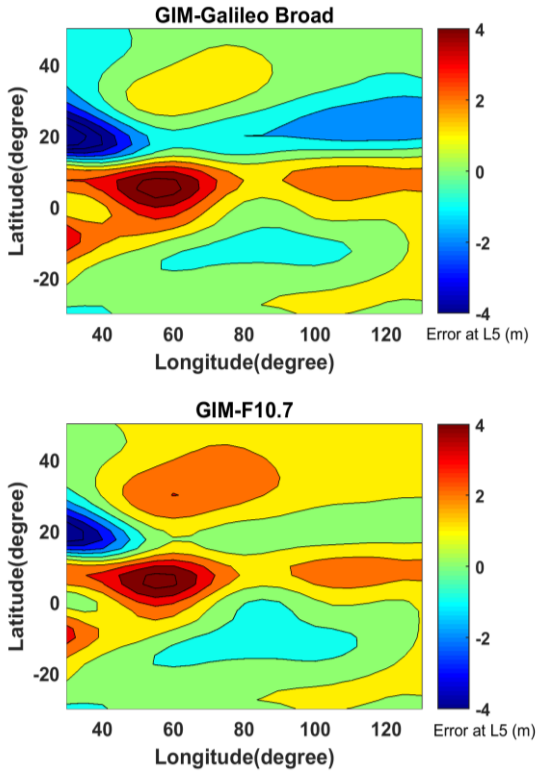

Figure 2. Spatial distribution of ionosphere delay error over IRNSS service area at 16 hour UT for day no. 148, 2022.

To verify the difference in GIM and NeG spatially, we plotted the variation of ionosphere delay over a day using IRMeas, GIM, NeG, and NeF for the location of all IRNSS reference stations within Indian land mass for IRNSS satellite id 03 in Fig. 3. Blue, red, cyan and magenta colours represent IRNSS measurements, GIM, NeF and NeG respectively. For completion of analysis, ionosphere delay computed using GPS broadcast ionosphere coefficients are also shown with green colour in the same figure for all IRNSS stations and satellite id 03. It was observed that the GPS broadcast ionosphere coefficients gives less than 60% error correction with respect to IRMeas. Visual inspection shows that even though NeQuick model is better than GPS model, both NeG and NeF shows dip in the ionosphere delay during noon time for few stations which is not visible in the GIM and IRMeas data. It has been observed that the pattern of the dip in the output of NeG or NeF is observed for all stations which are located below 15°N.

To understand the dip in the ionosphere delay computed using NeG and NeF, we further investigated the variation of ionosphere delay for two stations, one is below 15°N (Bangalore station) and the other above 15°N (Pune station) for all available IRNSS satellites.

Fig. 4 shows the typical variation of line of sight ionosphere delay over a day for Pune station with all available IRNSS satellites for day no. 148, 2022. Blue, red, cyan and magenta colours represent IRNSS measurements, GIM, NeF and NeG respectively.

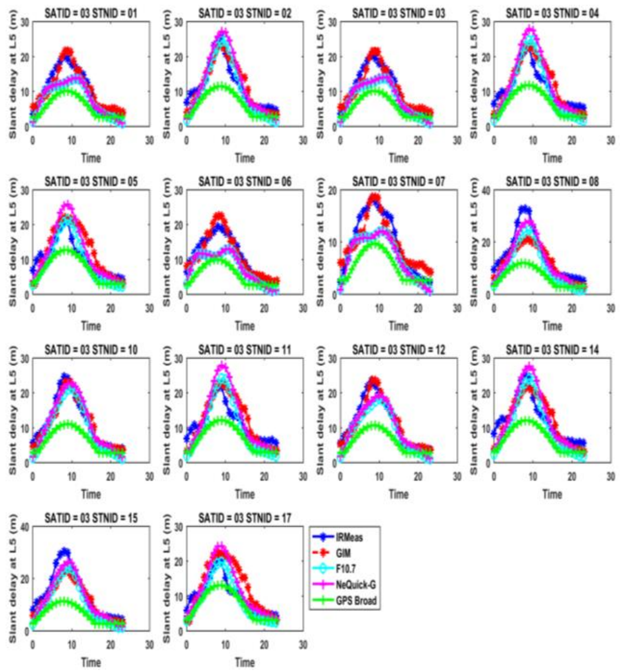

Figure 3. Variation of slant ionosphere delay with time for IRNSS satellite id 03 and all IRNSS stations for day no. 148, 2022.

It has been observed that NeG is matching well with the IRMeas for all line of sights. Further, between NeG and NeF, NeG is more close to the IRMeas. However, it is observed that there is a significant difference between NeG and IRMeas ionosphere delay during noon time. The difference between NeG and IRMeas increases further when we compare the ionosphere delay for the stations which are below 15°N latitude.

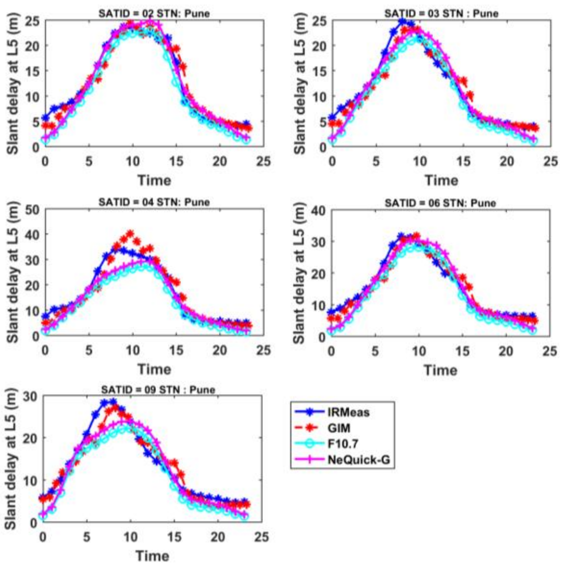

Figure 4. Variation of slant ionosphere delay at L5 with time for IRNSS Pune station for all available IRNSS satellites for day no. 148, 2022.

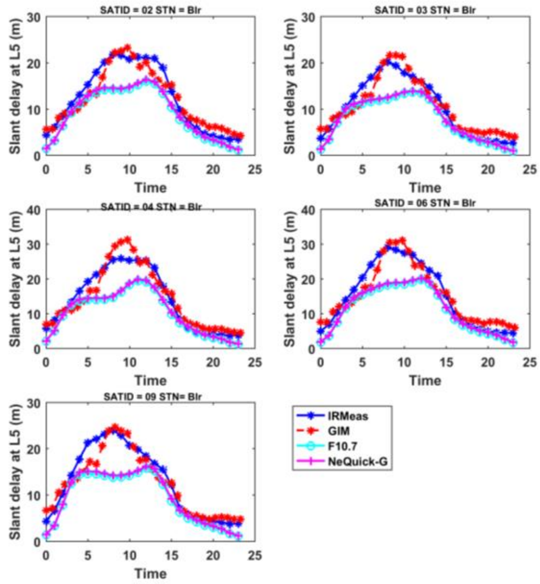

Figure 5. Variation of slant ionosphere delay at L5 with time for IRNSS Bangalore station for all available IRNSS satellites for day no. 148, 2022.

Similar to Fig. 4, the ionosphere delay at Bangalore station over a day is shown in Fig. 5. For Bangalore station, the performance of NeG and NeF is almost same. However, both NeG and NeF show a dip in the ionosphere delay during noon time which is not present in the IRMeas for the same station.

The error statistics of NeG and NeF are shown in table 1to compare the performance of NeG and NeF over IRNSS service area. As observed from table 1, RMSD value reached up to 2.30 m when NeG is used while it reaches to 2.54 m if NeF is used to correct the ionosphere error. The highest mean error due to NeG is 1.29 m while it goes up to 1.86 m for NeF model. NeG can capture the local variation of ionosphere due to data ingestion while NeF can only capture the variation in ionosphere due to Sun. Therefore, NeG model corrects 2-6 % more error than NeF (table 1). Overall, it has been observed that the NeG model performs better than NeF, when compared with GIM data for all the available days.

Table 1. Error statistics of the Galileo based NeQuick model and Solar radio flux based NeQuick model with respect to GIM ionosphere data.

Day no., 2022	**RMSD (m)**		**ME (m)**		**PC**	
	NeG	**F10.7**	**NeG**	**F10.7**	**NeG**	**F10.7**
148	2.30	2.54	1.29	1.86	76.02	70.92
149	1.79	2.12	0.84	1.42	78.19	72.39
150	1.74	1.64	0.29	0.82	78.56	76.27

5. Conclusion

In this work, performance assessment of the Galileo broadcast ionosphere coefficients over IRNSS service area at L5 frequency has been carried out. The global ionosphere map is used for comparison. It has been found that the Galileo ionosphere coefficients correct more than 70% of ionosphere error over IRNSS service area. Observations show that the mean error in the ionosphere delay is more near to the equator than the area away from the equator. Moreover, NeQuick output with Galileo broadcast coefficients provides better results than the NeQuick model with solar radio flux as input. Due to the availability of dual frequency measurements over Indian land mass, the variation of the ionosphere delay from Galileo broadcast coefficients over a day is compared with the IRNSS measurements. It is observed that even though Galileo broadcast model performs better than the GPS broadcast model, Galileo model shows a dip in the ionosphere delay for the stations below 15°N especially during the local noon time where ionosphere peak is observed in the measurements.

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