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Estimation of Galileo like ionosphere coefficients using IRNSS data for equatorial region

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Abstract

The objective of this paper is to explore the use of Galileo ionosphere model for Indian Regional Navigation Satellite system (IRNSS) L5 frequency users to provide better ionosphere error correction. In this direction, we have proposed an algorithm to estimate Galileo-type ionosphere coefficients using IRNSS reference receivers' data which can be broadcasted for IRNSS L5 frequency users. The performance evaluation of the proposed method is carried out with the existing minimum root mean square (MRMS) method of computing coefficients for IRNSS measurements. A rigorous statistical analysis shows that the slant delay determined using proposed method provides better ionosphere error correction with root mean square difference varies from 1.2 to 1.7 m than MRMS method with respect to IRNSS measurements. Our results show that the error difference between delay from IRNSS and proposed method is least than MRMS method and method using solar radio flux as an input.

Keywords: IRNSS, NeQuick, Ionosphere, Broadcast coefficients

1. Introduction

Ionosphere produces one of the major error sources while estimating user position using Global Navigation Satellite System (GNSS) signals. Therefore, GNSS service providers broadcast ionosphere parameters for ionosphere error corrections. Indian Regional Navigation Satellite system (IRNSS) is a regional navigation system, provides its services to its service area which comes in ionosphere equatorial anomaly region. Moreover, the signal operates at L5 frequency which experiences more ionosphere delay as compare to L1 frequency. IRNSS signal in space Interface Control Document [1] explains the use of grid based and Klobuchar like ionosphere coefficients for IRNSS L5 signals similar to GPS-aided GEO augmented navigation (GAGAN) and Global positioning system (GPS)[1, 2,3]. However, Galileo signals uses NeQuick model and researchers have been showed that the use of Galileo ionosphere coefficients provides better ionosphere error correction than Klobuchar model [4, 5,6,7] .

In case of IRNSS L5 frequency users, limited literature is available on the use of NeQuick model and its performance for IRNSS L5 signals [8].

The method in the literature is based on the concept of minimum root mean square (MRMS) and computation of effective ionization level (Az) using NeQuick. Also, the paper explains the use of single Az value for entire IRNSS service area. According to Galileo SIS ICD [9], there are three broadcast coefficients which are in quadratic relation of Az. In case of NeQuick, the Az should be a function of modified dip latitude and should change if the user position changes.

In this paper, we explain a methodology which is different from MRMS method to estimate Galileo type ionosphere coefficients using IRNSS reference receivers' measurements. Section 2 and 3 explain about IRNSS and Galileo ionosphere model. Proposed methodology to estimate ionosphere coefficients is explained in section 4 which is followed by the result and discussion in section 5. The results are concluded in section 6.

2. IRNSS Measurements

Presently, IRNSS comprises of 3 Geo stationary (GEO) and 5 Geo synchronous (GSO) satellite constellation. The ground segment of IRNSS consists of 16 dual frequency reference receivers which provide range measurements at L5 and S frequency [1]. These range measurements are further processed to determine slant ionosphere delay (SD) at each receiver - satellite line of sight at L5 frequency. In this paper, these processed reference receivers' ionosphere measurements from day number 204 to 210, 2018 are used for the generation of the Galileo like coefficients and for further validation.

3. Galileo ionosphere Broadcast Model

Galileo is the European Satellite Navigation System which broadcast three ionosphere coefficients; a_0, a_1 and a_2 for single frequency users to correct ionosphere error [9]. By using broadcast coefficients, Az is computed as given in Eq. (1).

$$A_z = a_0 + a_1\mu + a_2\mu^2 \tag{1}$$

where μ is the modified dip latitude at a location of user.

The Az is then used as an input to NeQuick model to compute SD. For computation of SD from NeQuick in offline mode, solar radio flux (SF) is used as input similar to Az. Thus,

$$SD = f(Az) \text{ or } SD = f(SF) \quad (2)$$

4. Methodology

To estimate Galileo type coefficients using IRNSS measurements (IR meas), we use weighted least square method in batch processing mode (BWLQ). In case of least square approach, the residual between state vector (X) and measurements (Y) is defined as

$$\varepsilon = Y - HX \quad (3)$$

if Y_k represents measurements and X_k is the state vector at epoch k then

$$Y_k = H_k X_k \quad (4)$$

where H_k is the transformation matrix. Further, expansion of vectors is represented as,

$$Y_k = [Y_1 \quad Y_2 \quad \cdots \quad \cdots \quad Y_n]^T$$

and

$$X_k = [a_0 \quad a_1 \quad a_2]^T$$

(5)

Here, n is the total number of measurements at a given epoch and Y is the SD at each line of sight of satellite – receiver pair.

For a given satellite and receiver pair, at a given time, the H matrix is computed based on the equations given below

$$H_k = \begin{bmatrix} \frac{\partial f_1}{\partial a_1} & \frac{\partial f_1}{\partial a_2} & \frac{\partial f_1}{\partial a_3} \\ \frac{\partial f_2}{\partial a_1} & \frac{\partial f_2}{\partial a_2} & \frac{\partial f_2}{\partial a_3} \\ \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots \\ \frac{\partial f_n}{\partial a_1} & \frac{\partial f_n}{\partial a_2} & \frac{\partial f_n}{\partial a_3} \end{bmatrix} \quad (6)$$

The derivative of right hand side of Eq. (6) is rewritten as

$$\frac{\partial f_i}{\partial a_j} = \frac{\partial f_i}{\partial Az_i} * \frac{\partial Az_i}{\partial a_j}$$

(7)

where i varies from 1 to n and j varies from 1 to 3. The function f used in Eq (7) is defined in Eq. (1).

In NeQuick model, the derivative of SD with respect to Az is calculated using numerical center difference method.

The cost function (J) is defined in such a way that it minimizes weighted sum of the squares between observed value and state vector which gives

$$\frac{\partial J}{\partial X} = 0$$

which gives the estimated state vector by using formula given in Eq (8)

$$\hat{X} = \left(\sum H^T W^{-1} H\right)^{-1} \left(\sum H^T W^{-1} Y\right) \quad (8)$$

Matrix W is a diagonal matrix which provides weight to the measurements using elevation angle.

5. Results and discussion

In this section, the performance of the BWLQ method is discussed. The assessment is carried out in two ways. The comparison of the model output using BWLQ method is evaluated with respect to the MRMS method. Along with that, the assessment in the performance of BWLQ coefficients is done with respect to the SF value used as an input.

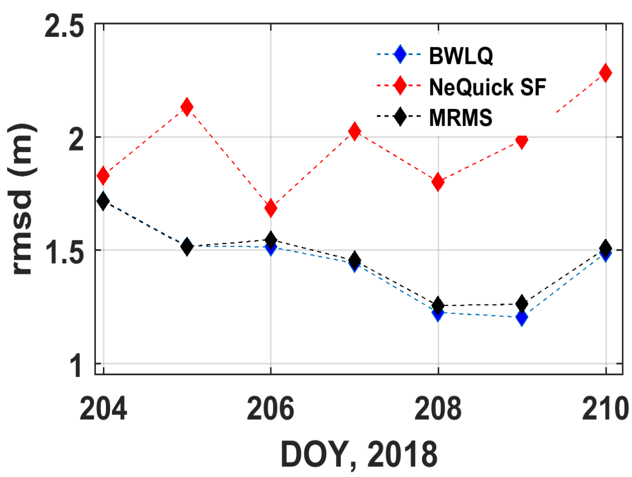

Figure 1. Performance of NeQuick in terms of root mean square difference (rmsd) with respect to IRNSS reference receivers' measurements. Black, blue and red colours represent rmsd using Az from MRMS method, BWLQ method and solar radio flux respectively.

Overall comparison in the performance of the NeQuick model output using different inputs with respect to IR meas from day number 204 to 210, 2018, is shown in Fig 1, 2 and 3. As shown in Fig. 1, the overall delay using ionosphere coefficients estimated from BWLQ algorithm provide least rmsd than using MRMS and SD computed using SF (NeQuick SF) with respect to IR meas.

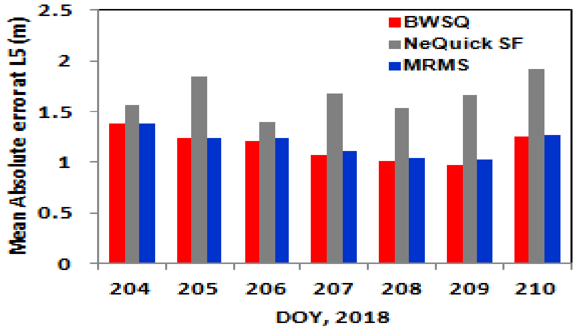

Figure 2. Bar graph represents the mean absolute error of the slant delays computed from different methods with respect to IRNSS measurements for DOY 204 to 210, 2018. Red, grey and blue colors are the mean error bars due to BWLQ, NeQuick SF, and MRMS methods respectively.

Similar trend is observed when the mean absolute error and standard devation of the absolute error is computed as shown in fig. 2 and 3. SD computed using SF gives the highest rmsd, mean absolute error and standard deviation of absolute error with respect to IR meas at L5 frequency among all three methods for all seven days. However, it has been observed that for some days, the MRMS and BWLQ methods show overall similar statistical behavior.

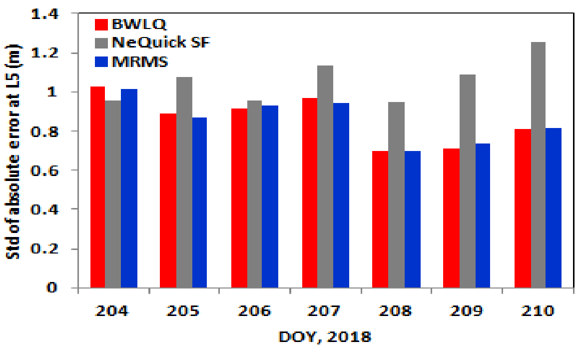

Figure 3. Bar graph represents the standard deviation of the absolute error of the slant delays computed from different methods with respect to IRNSS measurements for DOY 204 to 210, 2018. Red, grey and blue colors are the standard deviation of error bars due to BWLQ, NeQuick SF, and MRMS method.

Further, to study the performance of BWLQ and MRMS methods closely, day number 206, 2018 is chosen. Fig. 4 represents the variation of Az with MODIP. The red and blue colors represent the Az computed using MRMS method and BWLQ methods respectively. As seen in the Fig. 4, the coefficients estimated using BWLQ method provides a second order polynomial fit of Az with respect to MODIP. The Az estimated using MRMS method is similar to the average value of all Azs computed using BWLQ method.

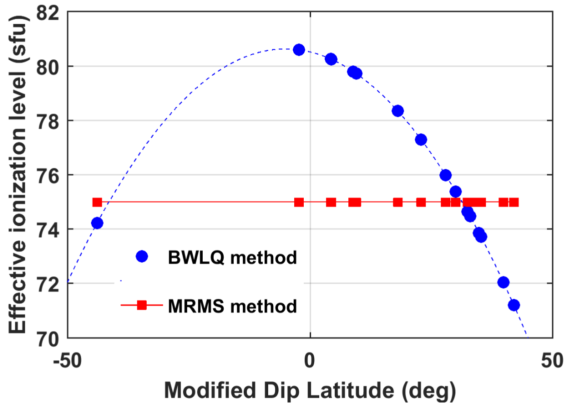

Figure 4. Variation of Effective ionization level (sfu) with modified dip latitude for DOY 206, 2018. The red and blue colors represent the Az computed using MRMS method and BWLQ methods respectively.

Since Az computed from BWLQ and MRMS is not same for all receivers' location, the evaluation is further divided into two test cases to compare BWLQ and MRMS for IRNSS. In case 1, the receiver location is taken in such a way that the Az using BWLQ and MRMS differs with each other. In case 2, the receiver location is chosen in such a way that the Az computed from MRMS lies on the Az computed from BWLQ method. For case 1, station id (STNID) 07 and PRN ID 09 is chosen while for case 2, STNID 04 and PRN ID 04 is taken based on their MODIP value.

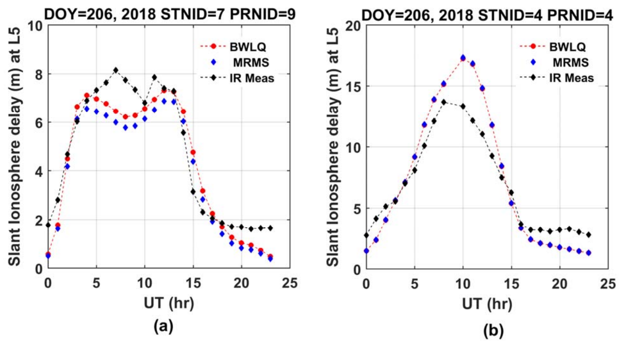

Figure 5. Diurnal variation of the slant delay of IRNSS measuremnets, MRMS and BWLQ methods. (a) Case 1: when the Az computed from MRMS differs from Az computed using BWLQ. (b) Case 2: when Az computed from MRMS is same as Az computed using BWLQ.

Table 1 shows that in case 1, statistically in terms of rmsd, mean absolute error and standard deviation of error, BWLQ performs better than MRMS. The rmsd using BWLQ method is 0.88 m while it is 1.05 m if MRMS method is used. The diurnal variation in Fig 5(a) also verifies that the difference between SD due to MRMS method and IR meas is more than the difference between SD due to BWLQ method and IR meas.

Table 1. Statistical parameters of Case 1: when the Az computed from MRMS differs from Az computed using BWLQ for DOY 206, 2018 (PRNID- 09 and STNID- 07).

DOY 206, 2018					
Case 1 (PRNID 09, STNID 07)					
MODIP = -2.24 (deg)					
Rmsd (m)		Mean Absolute error (m)		Std of absolute error (m)	
BLWQ	MRMS	BLWQ	MRMS	BLWQ	MRMS
0.88	1.05	0.74	0.91	0.49	0.54

In case 2, the statistical parameters are matching since the value of Az is same using both the methods (Table 2). As shown in fig. 5(b), the error due to MRMS and BWLQ is also similar with respect to the IR meas for the given line of sight. Therefore, it has been found that BWLQ gives better ionosphere error correction to IRNSS L5 users than MRMS method.

Table 2. Statistical parameters of Case 2: when Az computed from MRMS is same as Az computed using BWLQ for DOY 206, 2018 (PRNID- 04 and STNID- 04).

DOY 206, 2018					
Case 2 (PRNID 04, STNID 04)					
MODIP = 32.5 (deg)					
Rmsd (m)		Mean Absolute error (m)		Std of absolute error (m)	
BLWQ	MRMS	BLWQ	MRMS	BLWQ	MRMS
1.50	1.50	1.369	1.374	0.629	0.626

6. Conclusion

In this paper, we present a technique to estimate Galileo like ionosphere coefficients for IRNSS single frequency users. The method uses batch weighted least square technique to estimate ionosphere coefficients by using IRNSS reference receivers' data with NeQuick as a base model. It has been found that the performance of the method proposed in the paper is better than the minimum root mean square (MRMS) method. Overall different statistical parameters such as root mean square, mean absolute error and standard deviation of the absolute error are used to assess the performance of the proposed method than the MRMS method. The evaluation shows that the proposed method provides better result to all receivers when the effective ionization level computed using our method and MRMS method differ with each other and also for those have the same value. It has been found that the MRMS method provides an average value of effective ionization level to all IRNSS reference receivers and thus gives large error as compare to the proposed method for some receivers. Also, the slant ionosphere computed using coefficients provides better ionosphere error correction than using solar radio flux as an input in NeQuick model for IRNSS at L5 frequency.

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