# On the Suitability of Ionospheric Gradient Estimation Techniques for IRNSS based GBAS Applications

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***Abstract*—Time-Step method and Station-Pair method are prominent techniques for estimation of spatial gradients. Since GBAS is meant to serve a limited area of about 50km of an airport for aircraft Precision Approach and landing, these two methods were considered for gradient estimation within the GBAS service area. Much of the work on these techniques has been reported for GPS-based GBAS applications. In this paper, the suitability of these methods to IRNSS-based GBAS applications is investigated. It is observed that since IRNSS satellites are either GEO or GSO, the time interval (Δt), of Time-Step method should be significantly high (30min for GSO), to obtain gradient data for GBAS' service area. With the Station-Pair method, a dense network of stations, each separated by not more than 1-2 kms is required.**

***Keywords*— IRNSS, GBAS, Ionospheric spatial gradients, Time-step method**

## I. Introduction

Indian Regional Navigation Satellite System (IRNSS) is a regional satellite-based navigation system designed, developed and implemented by Indian Space Research Organisation (ISRO), to provide navigation services over Indian region. It consists of a combination of three satellite in GEO orbit (IRNSS 1C at 83°E, 1F at 32.5°E, 1G at 131.5°E with an inclination of ~5°) and four satellites in GSO orbit (IRNSS 1A and 1B at 55°E, 1D and 1E at 111.75°E with an inclination of 29°±2°). All the satellites transmit on two frequencies namely L5 (1176.45 MHz) and S1 (2492.028 MHz). Both the signals experience a delay as they pass through the ionosphere, but S-band signals experience significantly less delay. Also, as India is located in equatorial/low latitude region, severe spatial as well as temporal variability of ionospheric delay is a common phenomenon in this region. The spatial variation of delay (named as spatial gradient) is an important parameter affecting the performance of Local Area DGPS systems like Ground Based Augmentation System (GBAS). Therefore, quantifying and characterizing the gradients is considered as a challenge in the design of robust GBAS systems. Time-step method Station-Pair method and Mixed-Pair method are prominent techniques for estimation of gradients [1],[2]. The suitability of Time-Step method and Station-Pair method was investigated for estimation of spatial gradients on GPS L1 signals within a limited area of 50 kms for Indian GBAS applications and found to be appropriate [3],[4]. In this paper, suitability of these techniques for estimating spatial gradients on IRNSS L5 signals is investigated for IRNSS-based GBAS applications.

## II. Methodology

Data acquired from the IRNSS-GPS-SBAS receivers located at CBIT (17.39$^0$N, 78.32$^0$E) and Osmania University (17.24$^0$N, 78.31$^0$E) stations, Hyderabad, India, is used in this paper. Dual frequency measurements provide precise estimates of ionospheric delay [5]. Raw code and carrier measurements on L5 and S1 frequencies are extracted from the RINEX data. The ionospheric delay on L5 is estimated using code measurements and carrier-phase measurements following the standard equations [6]. The noisy code-based estimates of delay are smoothed using carrier phase-based estimates. The resulting smoothed estimates of delays are slant delays and converted to vertical delays by multiplying with standard Obliquity Factor [7]. The gradients of vertical ionospheric delays are computed using Time-Step method and Station-Pair method.

### *A. Time-Step method*

In this method, the difference of the vertical ionospheric delays experienced by given satellite-receiver pair '*k*' at two distinct epochs of time ($Id^k_{t1} - Id^k_{t2}$) is divided by the corresponding Ionospheric Pierce Point (IPP) separation distance (*d*) to obtain the gradient of vertical ionospheric delay ($VIG^k_{t1,t2}$).

$$VIG^k_{t1,t2} = \frac{\left| Id^k_{t1} - Id^k_{t2} \right|}{d} \tag{1}$$

IPP latitude and longitude are computed using standard equations [8]. The time-interval ($\Delta t = t_1 - t_2$), can be chosen and varied in order to vary the IPP distance and thereby obtain gradients over the area of interest.

### *B.Station-Pair method*

In this method, difference of vertical ionospheric delays ($Id^k_{Rx1} - Id^k_{Rx2}$) experienced by a pair of stations ($R_{x1}$, $R_{x2}$) is divided by the IPP distance ($d$) between the stations to estimate the Vertical Ionosphere Gradients ($VIG^K_{Rx1,Rx2}$).

$$VIG^K_{Rx1,Rx2} = \frac{\left| Id^k_{Rx1} - Id^k_{Rx2} \right|}{d} \tag{2}$$

The gradients are computed for all the IRNSS satellites for several days using these two techniques (Eqns. 1 and 2). However, results due to IRNSS 1B on a typical day (15 May 2017) (1<Kp<5) are presented here.

## III. Results and Discussion

Fig.1 shows the differential delay of IRNSS 1B at CBIT station due to Time-Step method. In order to obtain the gradient data over the GBAS area of interest (45 kms), Δt is increased from 5 min to 30 min, in steps of 1 min. For each data point in the plot, the differential delay value (on Y-axis) divided by the corresponding IPP separation (on X-axis) gives the gradient value (in mm/km). The maximum differential delay is 0.28 m and the maximum gradient is 43.19 mm/km. It is observed that the results due to other two GSO (IRNSS 1D and 1E) are following a similar trend. For the GEO satellites (figure not shown here), IPP distances of only 2.96 km (1C), 6.84 km (1F), 8.20 km (1G), are obtained when Δt is increased to 30 mins.

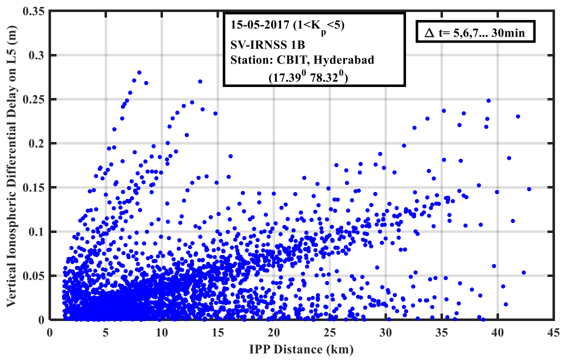


Fig.1. Variation of differential delay with IPP separation Time-Step method (Δt = 5,6,… 30 min)

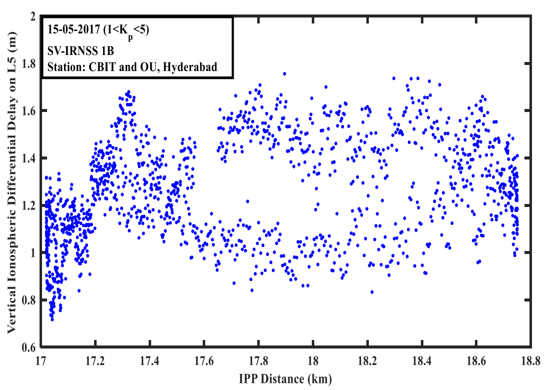


Fig.2. Variation of differential delay with IPP separation Station-Pair method (CBIT,OU stations)

Fig.2 shows the results due to Station-Pair method. The IPP distance in this method, depends on the physical separation between the stations. The differential delays experienced by IRNSS 1B at CBIT and Osmania University (OU) stations, separated by about 22 kms are shown in the figure. Over a period of a day, IPP distance varied from 17 to 18.75 km. The results due to other GSOs also showed a similar trend. For the GEO satellites, it is observed that the IPP variation over a day is 17.35 to 17.37 km (for IRNSS 1C) and in the similar range for other GEOs.

## IV. Conclusions

Time-Step and Station-Pair methods are considered to compute spatial gradients of ionospheric delay on IRNSS L5 signals over GBAS applicable distances. With the time-step method, IPP distances of 45-50 km could be achieved by increasing the Δt to 30mins (for GSO satellites), whereas with the GEO satellites, Δt has to be further increased. Because of such large time interval, the spatial gradient obtained would contain a high component of temporal gradient. The results due to Station-Pair method, showed that over a period of one day, the IPP distance variation is very small (less than 2 km for GSO and less than 1 km for GEO satellites). To obtain gradient data over GBAS applicable distances with this method, a dense network of stations, each separated by not more than 1-2 kms is required. Therefore, Mixed-Pair method, which considers all possible configurations such as, a station-pair observing two different satellites, one station observing a satellite- pair, a station-pair viewing the same satellite has to be implemented to achieve gradient data over IPP distances of 45-50 km.

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