Development of Grid Based Model for GAGAN

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Introduction :

Indian Space Research organization (ISRO) in collaboration with Airport Authority of India (AAI), has taken up the challenging task to demonstrate Wide Area Differential GPS (WADGPS) Technique, over Indian Airspace. This Technique, popularly known as Wide Area Augmentation System (WAAS), aims to provide Category I Positioning Accuracy and Integrity to all the civilian aircrafts, in Indian Airspace, while landing. This project is known as GAGAN (GPS Aided GEO Augmented Navigation). As the name implies, it is an augmentation to the existing Global Positioning System (GPS) satellites. The major error in GPS, is the Ionospheric Propagation delay, at 1575.42 MHz, transmitted by GPS satellites. This is of the order of 25-50 m over Indian Airspace, which lies in the Equatorial Anomaly region. For the last 50 years, ionospheric Scientists have carried out Ionospheric measurements, to study the Ionospheric behaviour and tried to develop models. But none of these models, can be used to correct Ionospheric effects in GPS to an accuracy better than 0.5m, required in GAGAN implementation. It is felt that a near real time Ionospheric Model, based on near real time ionospheric measurements, should be developed for GAGAN. This paper presents, the results of three approaches to a Real Time Grid based Ionospheric Model. The models have been tested with Ionospheric data collected from a network of Dual Frequency GPS Receivers, over the Indian region.

Description of Network for Data Collection :

In a Grid Based Ionospheric Model [1], the Ionospheric Vertical Delay corrections, at specified 5^0 by 5^0 Ionospheric Grid Points, are broadcast via a Geostationary Satellite, to the user aircrafts. This estimation of Grid Ionospheric Vertical Delay (GIVD), is done by a Ground segment, using slant Total Electron Content (TEC) measurements from a network of Dual frequency GPS Receivers. The transmission is done as per a standard format [1], so that a user aircraft using a WAAS Receiver can receive these corrections and use it. A User Aircraft, depending on the grid in which he is located, uses the Vertical delay Estimates at the corners of the grid to estimate the vertical delay at the Ionospheric Pierce Point to a satellite, converts this to slant delay, towards the satellite and applies this correction. In Fig. 1, the location of 18 stations are shown in a map of India, where we have set up GPS receivers for data collection. Each station is located approximately at the center of a 5^0 by 5^0 Grid and collects raw pseudorange and carrier phase measurements round the clock from all the visible GPS satellites above 15^0 Elevation. The raw measurements are converted to TEC at intervals of one minute and stored in a PC. This data is archived in a Server, located at Ahmedabad, for further data analysis.

Data Analysis :

Bakry El-Arini et al [2], were the first to evaluate the performance of different grid based algorithms and other real time ionospheric algorithms that could be implemented at the ground ionospheric reference stations, as well as at the airborne receivers. They suggested that Inverse Distance algorithm, weighted with Klobuchar Model, is suitable over US. But in the currently implemented US WAAS, GIVDs are estimated by Planar Model, by fitting a planar fit to the vertical TEC observations, obtained from slant TEC measurements. Lejeune et al [3], using simulated equatorial ionospheric data, generated by LowLat model, showed that the thin shell model of the Ionosphere that underlies Planer fit model, can severely limit the accuracy in Equatorial region. Attila Komjathi et al [4], based on a limited data over the South American region (Equatorial Ionospheric region), showed that WAAS's Planar Fit algorithm is not suitable over Equatorial Ionospheric region. Either Kriging or Tomography Techniques are suggested by the SBAS Ionospheric Group, as alternate approaches over Equatorial region.

In this paper, using the TEC data collected from March 2004 to December 2004, we have tested the performance of (1) Inverse Distance Algorithm (IDW), weighted with Klobuchar Model (2) Kriging Technique (3) Ionospheric Tomography Technique.

The approach of the Kriging Technique is very similar to that described by Blanch [5]. The Tomography Technique used by us is very similar to the approach described by Hansen [6].

The data analysis was carried out separately for all magnetically quiet days ($\Sigma a_p < 50$) and for magnetically disturbed days ($\Sigma a_p > 150$). For each station, on an average seven to eight satellites were visible and on an average, each minute, 120 to 140 slant TEC measurements were available over Indian airspace. From each station, one TEC measurement at the highest elevation was excluded in generating the GIVD values. Then using the GIVD values at all the 18 grids, the slant TEC at the highest elevation point for each station was computed and compared with the observation at that point.

The monthly mean differences between the observed and estimated value, using the model, was computed separately for the quiet and disturbed days. The algorithms were tested for both 5^0 by 5^0 grid and 1^0 by 1^0 grid. The analysis was carried out for all 24 hours at intervals of 2 hours.

Results :

The accuracy requirement of the Ionospheric Model for GAGAN, is better than 3 TEC units (corresponding to a delay of 0.5m). It has been observed in general that the worst performance of the models are around 0800 UT (corresponding to 1330 IST), when the TEC values are high and also the Equatorial Anomaly gradients are a maximum over Indian Region. In Fig. 2, the results for 5^0 by 5^0, for quiet and disturbed days at 0800 hrs UT, using IDW and Kriging are shown. Both IDW and Kriging do not meet the accuracy requirements. The major problems with both the models are that (1) Both models use a Simple Geometric Mapping Function, to convert slant TEC to vertical TEC and Vice Versa, assuming that the Ionosphere is horizontally stratified (2) The mapping function assumes a constant Ionospheric Pierce Point height of 350 km [1]. In Fig. 2, we have also shown the results obtained using Tomography. The performance of Tomography is better than IDW & Kriging techniques. But still it does not meet the accuracy requirement of GAGAN. We tested the performance of the models with reduced grid size of 1^0 by 1^0 and the results are shown in Fig. 3. Both Kriging & Tomography techniques provide accuracy better than 3 TEC units, with reduced Grid size.

Conclusions :

As part of the ISRO-AAI Satellite Navigation Project, GAGAN, a network of 18 stations, with Dual Frequency GPS Receivers, is in operation for more than last one year. The performance of three approaches to implement real time Grid Based Ionospheric Model (with 5^0 by 5^0 Grid Size) over Indian Airspace has been tested, with TEC data collected over nine months. We observed that the Inverse Distance algorithm, weighted with Klobuchar Model , is not suitable over Indian region, even on magnetically quiet days. This is mainly because India lies in the Equatorial Anomaly region, where large gradients in Total Electron Content (TEC) exists and the TEC maximum in the afternoon hours is observed $\pm 15^0$ on either side of the magnetic equator. We tested the performance of Kriging and Ionospheric Tomography Techniques with 5^0 by 5^0 grid size. Both the techniques do not meet the accuracy requirements of GAGAN. We also tested the performance of Kriging and Tomography techniques, with 1^0 by 1^0 grid size. We observed that Kriging and Tomography Techniques with 1^0 by 1^0 grid size meets GAGAN requirements, even on magnetically disturbed days. Further data analysis will be carried out with more observations collected over Indian region. This will help to recommend a suitable approach and grid size and suitable update interval, to implement grid based Ionospheric model for GAGAN.

References :

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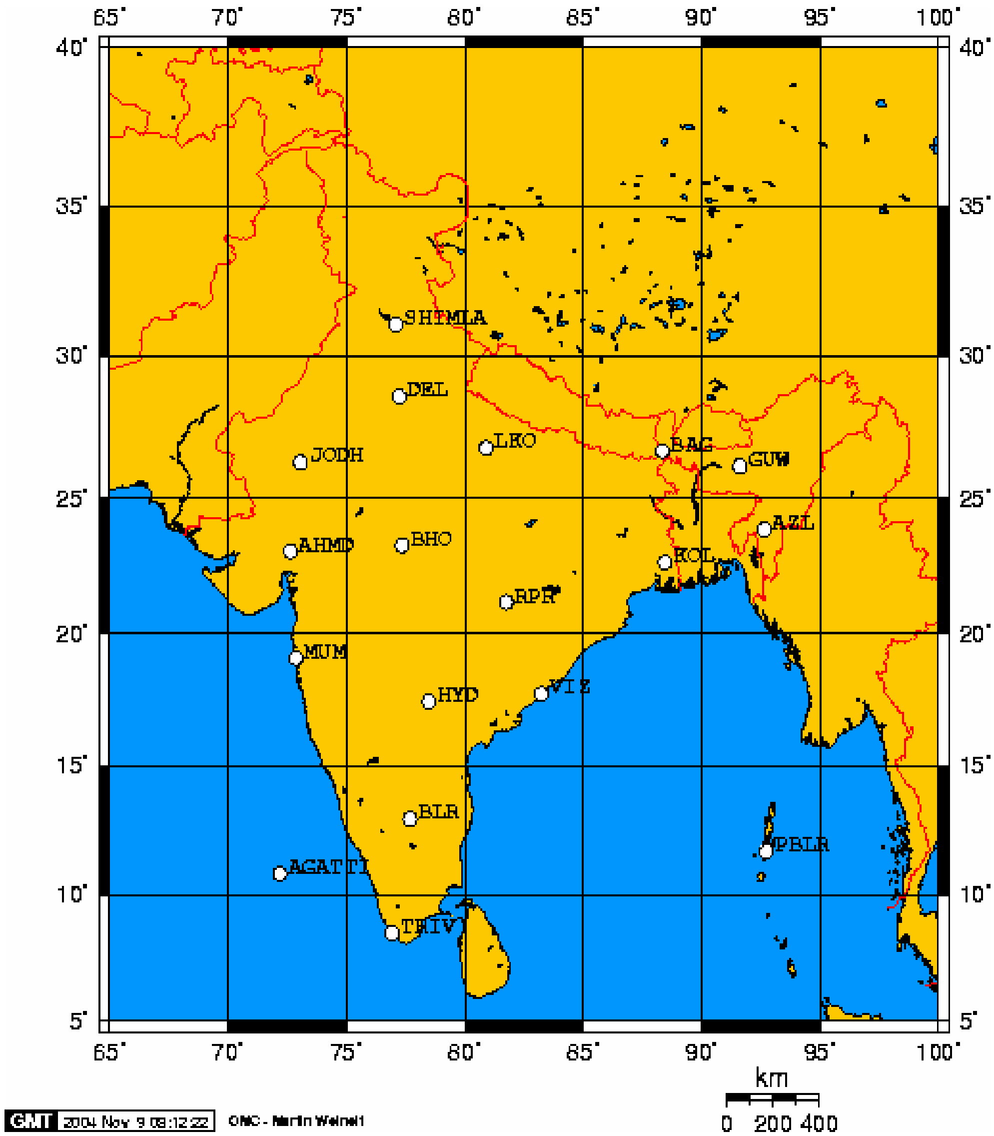

Fig. 1. Map showing 5^0 by 5^0 Grid and the location of GPS Receivers.

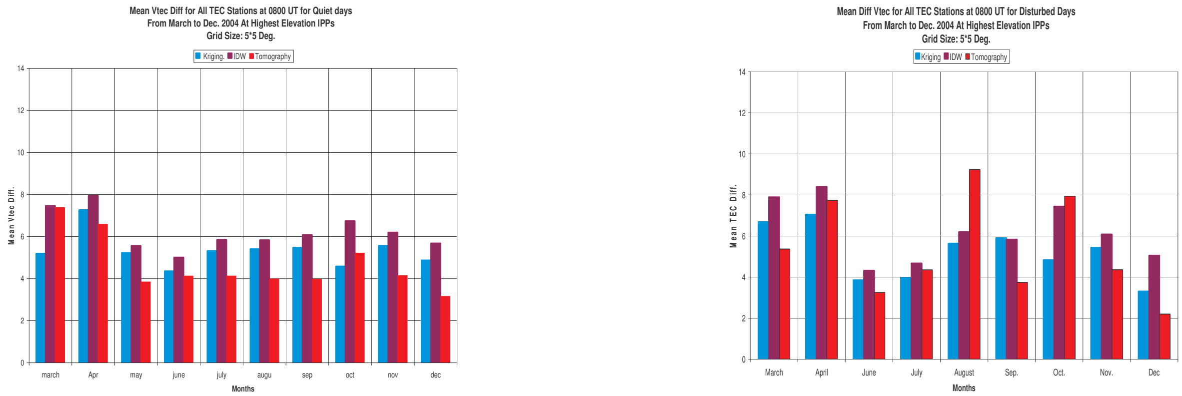

Fig. 2 . Plot showing results for 5^0 by 5^0 for quiet and disturbed days at 0800 UT for kriging , IDW and Tomography.

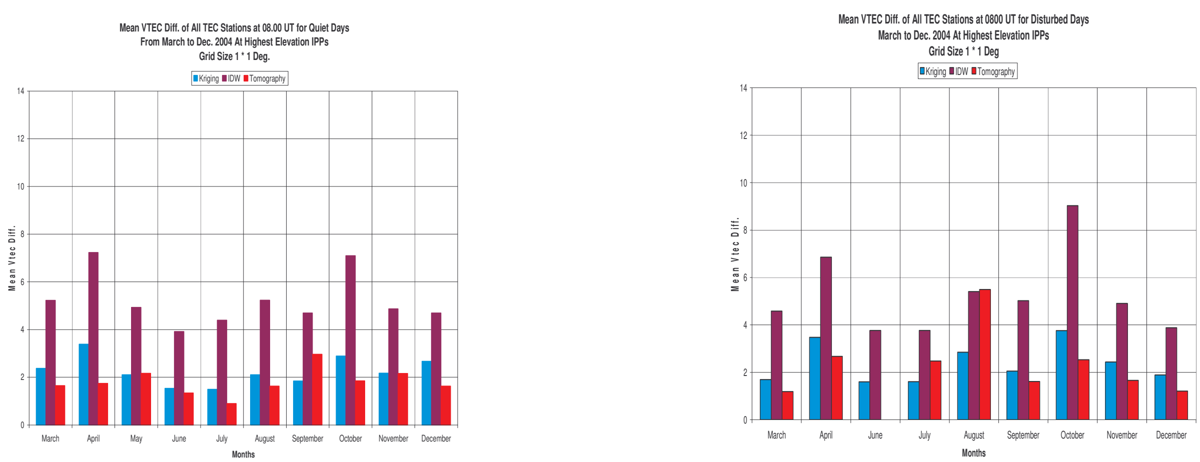

Fig. 3. Plot showing results for 1^0 by 1^0 for quiet and disturbed days at 0800 UT for kriging, IDW and Tomography.