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CHARACTERISTICS OF SBAS GRID SIZES AROUND THE NORTHERN CREST OF THE EQUATORIAL IONIZATION ANOMALY

Ashik Paul*, Aditi Das† and Ashish Dasgupta†

* Institute of Radio Physics and Electronics, University of Calcutta
92 Acharya Prafulla Chandra Road, Calcutta 700009, India
e-mail: ashik_paul@rediffmail.com
† S.K. Mitra Center for Research in Space Environment, University of Calcutta
92 Acharya Prafulla Chandra Road, Calcutta 700009, India
e-mail: adg1bkpr@gmail.com, aditidas16@rediffmail.com

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1 INTRODUCTION

The equatorial ionosphere is characterized by two very prominent features: i) the **Equatorial Ionization Anomaly (EIA)** and ii) intense irregularities in electron density distributions. While the EIA covers a major part of the day extending up to about 2100LT, the ionospheric irregularities mainly occurs in the post-sunset to midnight local time sector. Gradient of the daytime EIA results in large spatial and temporal variation of the ionospheric.

Total Electron Content (TEC) under normal as well as disturbed conditions[1]. Such large gradients of ionization introduce errors and degrade the position accuracy of a Satellite Based Augmentation System (SBAS). A number of SBAS are planned/operational like WAAS in continental USA, EGNOS in the European continent, MTSAT in Japan and GAGAN (GPS and Geo Augmented Navigation) in India. In India, GAGAN is being set up by the Indian Space Research Organization (ISRO) in collaboration with the Airports Authority of India (AAI). GAGAN is expected to fill up the geographical void existing in the geophysically sensitive Indian longitude sector located between EGNOS on the west and MTSAT in the east. Under GAGAN, 20 dual-frequency GPS receivers are operational at different airports distributed all over India and when fully functional will significantly improve on the very few GPS tracking and monitoring stations available in India. It may be noted that only two IGS stations are operational in India, namely at Bangalore

(12.95ºN lat, 77.68ºE long, 11.69ºN dip) and Hyderabad (17.44ºN lat, 78.47ºE long, 21.9ºN dip).

One of the major problems involved in planning the Indian SBAS is to find an optimum separation between the reference stations. The International Civil Aviation Organization (ICAO) has specified a 5º×5º grid size which is applied to the WAAS in the CONUS or in EGNOS. However the same grid size may not be suitable for the Indian SBAS GAGAN because of large spatial gradients in electron density distribution present in the equatorial region. An effort was earlier made to derive an optimum grid size for the Indian subcontinent with calculations based on TEC measured at Calcutta (22.58ºN lat, 88.38ºE long, 33.82ºN

2 DATA

Total Electron Content (TEC) measured at five different stations operational under GAGAN, during the period August through October 2004, a period of moderate sunspot numbers, have been utilized to study and characterize the different latitudinal gradients of ionization prevalent poleward of the northern crest of the EIA in comparison to that occurring towards the magnetic equator. Slant TEC (STEC) recorded at 1 minute sampling interval from Trivandrum (8.47ºN lat, 76.91ºE long, 0.91ºN dip) situated near the magnetic equator, Bangalore (12.95ºN lat, 77.68ºE long, 11.69ºN dip) and Hyderabad (17.44ºN lat, 78.47ºE long, 21.9ºN dip) lying in between the magnetic equator and the northern crest of the EIA, Bhopal (23.28ºN lat, 77.34ºE long, 33.95ºN dip) lying near the northern crest of the EIA and Delhi (28.58ºN lat, 77.21ºE long, 43.5ºN dip) located beyond the northern crest have been analyzed at different times of the day. The measured STEC have been converted to equivalent Vertical TEC (VTEC) using a Slanting Factor which involves the zenith angle at the station.

3 RESULTS

Figure 1 shows the locations of the five stations used in the present analysis on a map of India along with the other GAGAN stations. It should be noted that these stations lie more or less along the same meridian. Thus measurement of the latitudinal gradient of TEC involving these stations will not be contaminated by any longitudinal variation.

Figure 2 shows the diurnal variation of measured slant TEC at elevation angles in excess of 70º from these five stations on September 11, 2004 over a subionospheric latitude range varying from the magnetic equator to locations beyond the northern crest of the EIA. The high values of TEC occuring in the equatorial región and the sharper gradient of ionization beyond the northern crest could be well understood from the closely spaced contours between a subionospheric latitude range of 22º-28ºN particularly around the time of diurnal máximum in the Indian longitude sector at 10UT.

A quantitative estímate of the gradients occurring equatorward and poleward of the northern crest may be obtained from Figure 3 which shows the latitudinal variation of TEC at 9, 10 and 11UT on September 11, 2004 by combining the data from the five stations. The measured Slant TEC values at elevation angles in excess of 70º have been used so as to reduce the effects of large spatial gradients of ionization as far as possible. It has been observed that the VTEC values at high elevation angle of 70º shows a gradual increase towards the north from Trivandrum to Bhopal and then decreases at Delhi which is situated beyond the northern crest of the EIA. The slope looking north from Trivandrum towards Bhopal was found to be 3.09 TEC units/deg while that from Bhopal northward beyond the northern crest was 4.89 TEC units/deg at 10UT. At 11UT the corresponding figures were 3.25 and 6.94 TEC units/deg respectively.

Figure 4 compares the Slant and Vertical TEC from Trivandrum, Hyderabad and Bhopal looking north at gradually increasing elevation angles of 50º, 60º, 70º and 80º during 9-10UT when the EIA is most developed in the Indian longitude sector. It has been found that at elevation angles less than 70º, the difference between the actually measured STEC and the calculated VTEC are unacceptably high and it depends on the look angle (north or south of a station) of the satellites. From the measured STEC on September 11, 2004, looking north from Trivandrum, the difference between VTEC and STEC is found to be about 2.7 TEC units even at 70º elevation which translates to a range error of nearly 43cm at GPS L1 frequency. On that same day from Hyderabad and Bangalore, this difference is about 3.7 and 4 TEC units looking towards the northern crest. This difference is much higher ~5 TEC units looking north from Bhopal which is situated virtually underneath the northern crest even at elevation angles in excess of 70º. The difference between VTEC and STEC at elevation angles of 70º and 80º has a latitudinal gradient of 3.7 TEC units/deg at Trivandrum near the magnetic equator, about 5.2 TEC units/deg at Hyderabad and nearly 7.1 TEC units/deg at Bhopal near the northern crest. It should be noted that the results presented in Figures 2 through 4 are representative and similar results have been obtained on other days during the period of study covering August through October 2004.

4 CONCLUSIONS

The results presented in this paper highlight the problems likely to be faced in SBAS when estimating an optimum grid size around the northern crest of the EIA. The issue of concern to SBAS system designers is the steeper gradient of the EIA poleward of the northern crest rather than the equatorward side as the optimum grid size and group delays will be different on either side of the crest. A simple ratio of the gradients south and north of the EIA northern crest may be used to scale the grid sizes.

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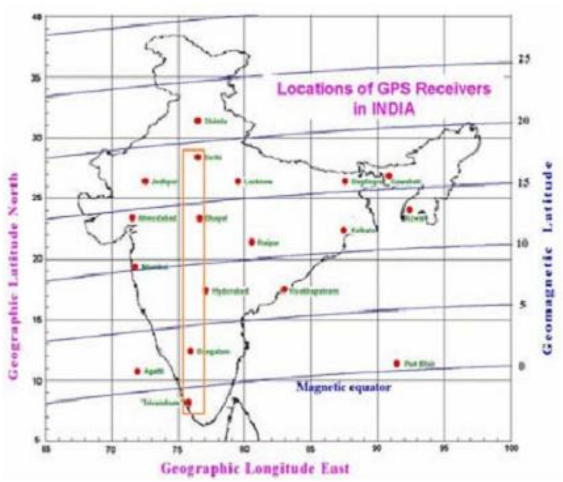

Figure 1: Map of India showing the GAGAN stations with the orange block highlighting the five stations used.

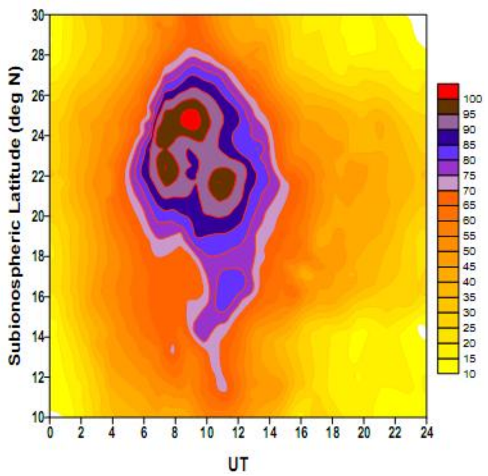

Figure 2: Slant TEC recorded on September 11, 2004 at the five stations.

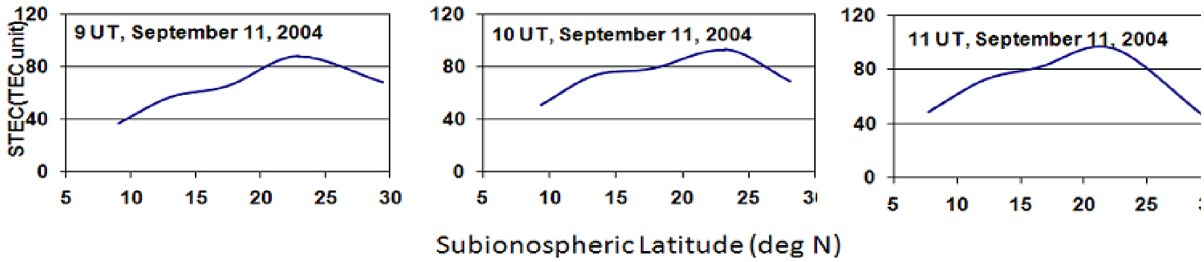

Figure 3: Latitudinal variation of Slant TEC measured from the five stations on September 11, 2004 at 9, 10 and 11UT.

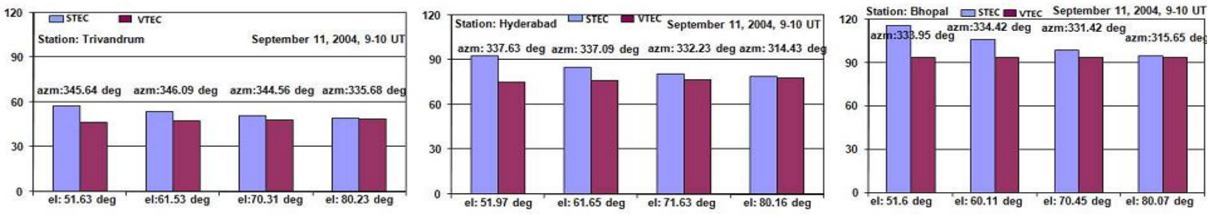

Figure 4: Variation of Slant and Vertical TEC at elevation angles of 50º, 60º, 70º and 80º observed from Trivandrum, Hyderabad and Bhopal on September 11, 2004 during 9-10UT.