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Characteristics of SBAS grid sizes around the northern crest of the equatorial ionization anomaly

A. Paul [a,b,*], A. Das [b], A. DasGupta [b]

[a] Institute of Radio Physics and Electronics, University of Calcutta, Calcutta, India
[b] S.K. Mitra Center for Research in Space Environment, University of Calcutta, Calcutta, India

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ABSTRACT

The region around the crests of the EIA accounts for the highest values of TEC and its steep gradients, which introduces high values of range-errors on GPS signals and degrade the position-fixing accuracy of an SBAS. As the TEC gradient is sharper on the poleward side rather than towards the magnetic equator, grid sizes should be different on either side of the crest of the EIA. The present paper highlights the necessity for a differential grid size around the northern crest of the EIA using data recorded from stations under the Indian SBAS GAGAN during the moderate sunspot number year 2004.

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 2100 LT, sometimes even beyond midnight during high sunspot number years, the ionospheric irregularities mainly occur in the post-sunset to midnight local time sector. The highest TEC values in the world normally occur around the crests of the EIA, and these regions consequently have the largest ionospheric range delay values for any potential space-based augmentation system. The location and magnitude of the very high TEC values are directly related to the strength of the equatorial electrojet on a day-to-day basis (Rastogi and Klobuchar, 1990). Also the largest absolute latitudinal gradients in TEC occur on the poleward side of the equatorial anomaly. This was apparent in early TEC recordings made by Tyagi and Mitra (1970) and have been seen in topside sounder recordings of the density of the topside of the ionosphere (King et al., 1967). The day-to-day variability of the location of the anomaly peak, and its intensity is large (Rastogi and Klobuchar, 1990; Huang et al., 1989). This imposes severe restrictions on the applicability of commonly used ionospheric models to the low latitudes.

One of the major propagation effects affecting satellite based communication and navigation systems is the group delay of a radio signal traversing the ionosphere. This results in degradation of position accuracy of a satellite based navigation system. The group delay suffered by a transionospheric signal is directly proportional to the ionospheric TEC and is practically omnipresent throughout the day in varying degrees. The TEC in the equatorial region is characterized by large temporal and spatial gradients in the Earth's ionosphere under normal as well as disturbed conditions (Klobuchar et al., 2001; Niranjan et al., 2007). Prediction of the range error introduced by the ionosphere in the equatorial zone is thus very difficult. In spite of the long tradition of ionospheric research in India, no TEC model suitable for this region of the globe has been developed. The models normally used for navigation in single-frequency GPS receivers are empirical in nature and are based on TEC data measured at several locations in the mid-latitudes. Validity of these models in the highly dynamic equatorial ionosphere is an outstanding issue. A Differential GPS (DGPS) network provides a remedial measure by measuring the difference between the observed pseudo range and the geometrical range from a reference station whose position is accurately known. The error data are transmitted to users in the neighborhood of the reference station. Because of the steep ionization gradients occurring in the equatorial zone, the range over which the error data are valid from a reference station is limited.

An extension of the DGPS is the Satellite Based Augmentation System (SBAS). A number of such systems are planned/operational in continental USA (WAAS—Wide Area Augmented System), European continent (EGNOS—European Geostationary Navigation Overlay System), Japan (MSAS—Multi-functional Transport Satellite

* Corresponding author at: Institute of Radio Physics and Electronics, University of Calcutta, Calcutta, India. Tel.: +91 33 23509115, 23523028; fax: +91 33 23515828.
E-mail address: ashik_paul@rediffmail.com (A. Paul).

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Fig. 1. Locations of GPS receivers on a map of India under the GAGAN program. Stations enclosed in the box indicates the stations whose data have been used in the present paper.

(MTSAT) Satellite based Augmentation System) and India (GAGAN—GPS and Geo Augmented Navigation), where a number of reference stations distributed over a large area will monitor TEC data. 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 the very few GPS tracking and monitoring stations available in India. In GAGAN, a Master Control Center would be set up at a location near Bangalore. It may be noted that only two International GPS Service (IGS) stations are operational in India, namely at Bangalore (12.95°N lat, 77.68°E long, 11.69°N dip) and Hyderabad (17.44°N lat, 78.47°E long, 21.9°N dip).

The International Civil Aviation Organization (ICAO) has suggested an SBAS grid size of $5^\circ \times 5^\circ$ for navigation by civilian aircrafts. Applicability of the same grid size of $5^\circ \times 5^\circ$, used in the relatively placid ionosphere over the mid-latitudes, to the very dynamic equatorial ionosphere is an issue yet to be addressed. When a user like an aircraft enters a grid, it receives data about the ionospheric error in the vertical direction at the grid point and the nature of distribution of the vertical error over the grid. Ionospheric errors along the slant path to different GPS satellites would have to be calculated. The problem thus essentially translates into conversion of the recorded Slant TEC from reference

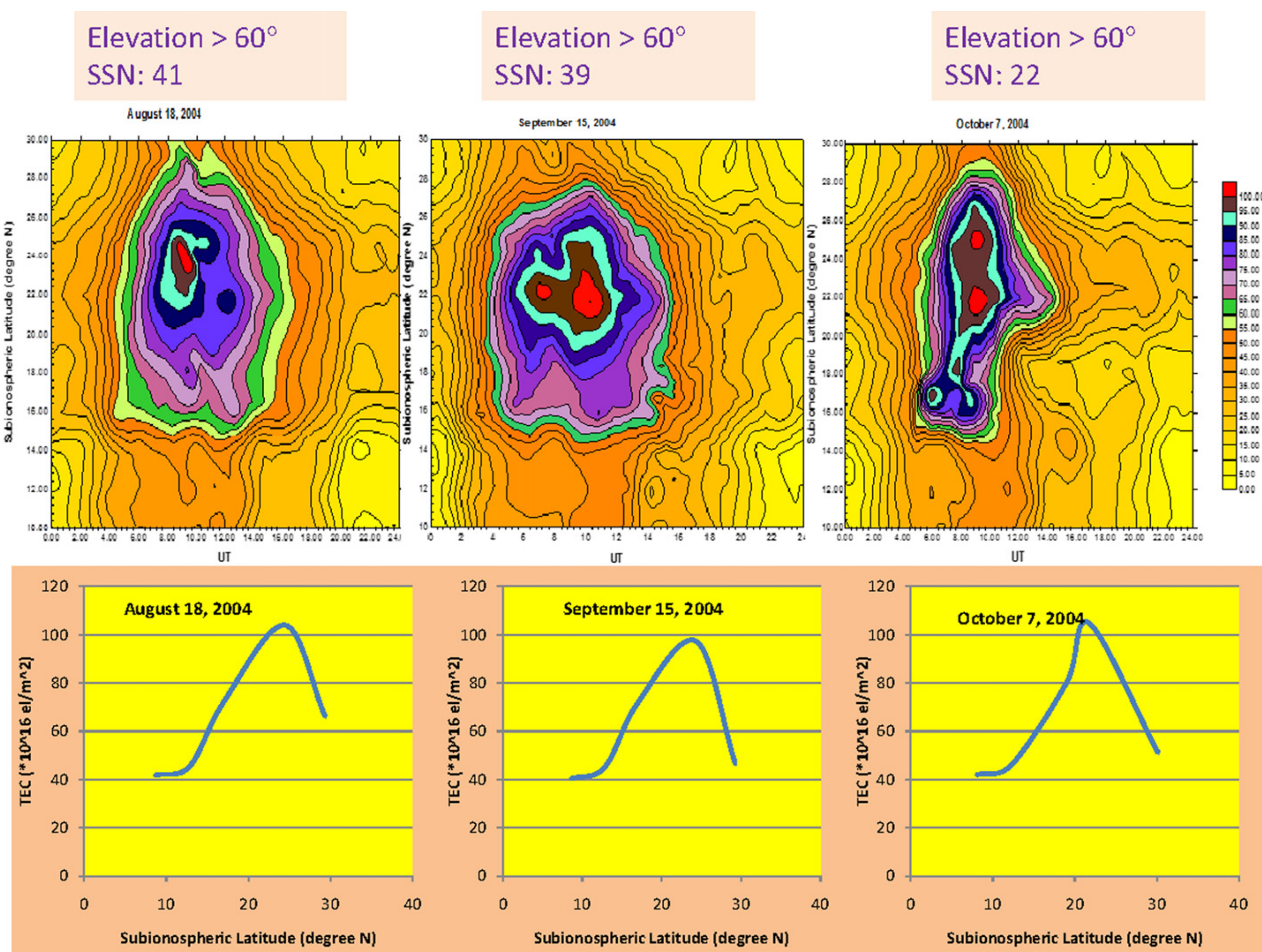

Fig. 2. Spatial and temporal variation of TEC measured at the five stations at elevation angles greater than 60° on three days, namely, August 18, September 15 and October 7, 2004. Top panel shows the contours of measured TEC at different times of the day and at different subionospheric latitudes ranging from 10°N to 30°N on these three days. Bottom panel illustrates the latitudinal gradient of TEC existing from the magnetic equator to the northern crest of the EIA and beyond these dates.