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GPS-TEC Ionospheric Observations at High Latitude Conjugate Stations during 2003

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1. Introduction

A good knowledge over the structure of the ionosphere and the dynamics of the ionization variability are essential to improve the present and in predicting the future of radio communication and navigation services and space weather. Despite significant recent progress in studies of the behaviour of the ionosphere, there are still many questions to be investigated in order to achieve better understanding of the energy coupling processes between the Sun and the Earth [1].

The Polar Regions offer unique vantage points and act as open natural laboratories for remote sensing the vast regions of near-Earth because the Earth's magnetic field focuses many geospace effects to these regions. To date Antarctica has been under-exploited relative to the Arctic despite the fact that it provides huge landmass to base instruments near the magnetic pole while providing undisturbed background conditions in which to run measurement for research in the physics of the ionosphere of the southern higher latitude atmosphere. Higher latitude regions are directly affected by the entry of charged solar particles and energy, thus the ionosphere becomes highly irregular.

Global navigation satellite systems such as GPS offer a unique opportunity to remote sensing the ionosphere and its dynamics. Using a simple differencing technique across the two L-band frequencies transmitted by the GPS satellites, a variety of the ionospheric effects and structures can be observed [2]. By taking advantage of the large number of visible GPS satellites and the advances in the GPS receiver technology, it is now possible to monitor the ionosphere on a global basis at lower cost.

In this paper we investigate the GPS-TEC ionosphere at polar conjugate stations for the year 2003 (during the declining phase of the 23rd Solar Cycle). Our primary objectives are to determine the ionospheric variations and its conjugacy effects in order to understand its physical processes on upper atmosphere.

2. Measurement Systems and Method

The GPS TEC measurement system at SBA was installed on November 2002 under the Antarctic New Zealand K141Z, Malaysian Antarctic Research Programme (MARP). It consists of a Trimble TS5700 24-channel, high precision, dual-frequency GPS receiver, Trimble Zephyr Geodetic antenna, and a Dell notebook computer for data logging. The Trimble Zephyr Geodetic antenna has improved accuracy, resulting from sub-millimetre phase centre repeatability, enhanced multi path resistance, and superior satellite tracking at all elevation angles and in difficult environments.

Table 1: Geographical and geomagnetic coordinates for SBA and RESO stations.

Station	Geographical Coordinates	Geomagnetic Coordinates
SBA	77.85°S 166.76°E	79.94°S 327.63°E
RESO	74.69°N 265.12°E	83.17°N 320.95°E

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The GPS TEC measurement system at RESO uses the Ashtech Z-X113. Data from this system were obtained from the Scripps Orbit and Permanent Array Center (SOPAC) and California Spatial Reference Center (CSRC) database [3]. Table 1 provides the geographical and corrected geomagnetic coordinates for SBA and RESO stations. The local time at SBA station UT+12 and at RESO station is UT-5.

2.1 Data Processing

The GPS receiver at SBA was set to tracks GPS signals at 1 second sampling rate and the cut-off elevation angles was set to 13° to eliminate the multi-path effects on GPS data. The TEQC routine developed by UNAVCO [4] is used to convert the TRIMBLE *.dat binary data into RINEX files. A standard of 30 seconds data sampling was executed in order to reduce processing time. Data processing are implemented in Matlab and missing data are taken as Not a Number (NaN). TEC variance equal to 26.4 TECU for SBA and 26.8 TECU for RESO based on 96 sample data per day (taken on a clear day of 24th March 2003). 1 TECU = 1×10^{16}em^{-2}.
The GPS observable are biased by instrumental delays; therefore it is necessary to remove these biases for accurate estimation of TEC. Instrument biases both from the receiver and the satellite are removed based on absolute TEC determination [5] where, in this method, the time delay measurement is used to remove the ambiguity term, and by combining the phase and code measurements for the same satellite pass to obtain absolute TEC. In our work, the instrument time delay potential errors are corrected using the code biases obtainable from AIUB Data Centre, University of Bern [6]. The GPS data are recorded in UT.

2.2 GPS_TEC calculations

The calculation to determine the absolute TEC uses the method of Warnant et al [7]. The geometry-free combination (GFC) of dual frequency code and phase measurements of the dual frequency GPS receiver is calculated using Eq. 1:

$$P_r^s = P_r^s{}_{L1} - P_r^s{}_{L2}$$
$$\Phi_r^s = \Phi_r^s{}_{L1} - \frac{f_{L1}}{f_{L2}} \Phi_r^s{}_{L2} \qquad (1)$$

where $P_r^s{}_{L1}$ and $P_r^s{}_{L2}$ are the GPS P-code measurement (in meters), s and r are satellites and receiver representation, $\Phi_r^s{}_{L1}$ and $\Phi_r^s{}_{L2}$ are the GPS carrier phase measurements (in cycles), and f_{L1}, f_{L2} are the GPS frequencies: f_{L1}=1575.42 MHz and f_{L2}=1227.60 MHz.
Calculate the geometry-free linear combination of code and phase measurements as a function of TEC from Eq. 2:

$$P_r^s = -0.105TEC_r^s + (Dg_r - Dg^s)$$
$$\Phi_r^s = -0.552TEC_r^s + N_r^s \qquad (2)$$

where Dg^s and Dg_r are the satellite and the receiver differential group delay and N_r^s is the ambiguity term (in cycles). Resolve the ambiguity term by combining the geometry-free code with phase measurements for each satellite path using Eq. 3:

$$P_r^s - \lambda_1\Phi_r^s = (Dg_r - Dg^s) - \lambda_1 N_r^s \qquad (3)$$

where λ_1 is the wavelength of the frequency f_1. Obtain the equivalent vertical TEC for each satellite path using Eq. 4 and Eq. 5:

$$VTEC_r^s = TEC_r^s \cos\chi \qquad (4)$$

$$\chi = \arcsin\left(\frac{R}{R+h_m}\cos\theta\right) \qquad (5)$$

where χ is the zenith angle of the line of sight at the sub ionospheric point, θ is the elevation angle and R is the mean radius of the earth (6378.137 km) and h_m is the approximately ionospheric height layer at 400 km.

3. Results

A total of one year of GPS-TEC data have been processes per station at Scott Base station, Antarctica (SBA) and the Canadian Resolute Cornwallis Island station (RESO), Artic respectively. The observation period for seasonal is breakdown as per Table 2 base on : vernal equinox : from 6th March 2003 – 3rd April 2003; autumnal equinox : from 6th September 2003 – 4th October 2003, Summer : from 4th April 2003 – 5th June 2003 & 5th July 2003 – 5th September 2003; winter from 4th January 2003 – 5th March 2003 & 5th October 2003 – 5th December 2003; summer solstice from 6th June 2003 – 4th July 2003 and winter solstice from 6th December 2003 – 3rd January 2004 with reference to the Northern Hemisphere.

Table 2: Seasonal Summary of Conjugate Stations TEC (TECU) Statistics 2003

		TTEC		Tecmean		TECmax		TECmin	
		SBA	RESO	SBA	RESO	SBA	RESO	SBA	RESO
Summer		55344.4	118264.2	4.8	11.6	44.8	31.7	-7.3	2.6
Winter		143323.8	77698.3	14.1	8.0	115.6	165.9	-1.8	9.2
Equinox	Vernal	31486.5	30933.3	12.8	11.2	39.9	44.0	-2.4	1.0
	Autumn	21120.1	20985.8	8.3	9.5	33.9	34.9	-1.9	0.9
Solstice	Summer	7537.1	29302.0	2.8	12.2	24.9	22.0	-3.4	4.2
	Winter	25772.6	nil	11.7	nil	31.1	nil	0.4	nil
Annual	Total	284584.5	277183.6						
Equinox	Total	52606.6	51919.1						

From the table, super high value for TECmax corresponds to super geomagnetic storm in late October 2003. Both conjugate stations have approximately similar total TECmean during the equinoxes (VE+AE) of about 21 TECU. The minus TECmin at SBA is due to the fixed receiver bias employed at the station.

Figure 1 and 2 exhibits the relationship of daily GPS-TEC during 2003 for SBA and RESO respectively. To show the similarities between the ionospheric variations and solar activity, the TEC is multiply by a factor of 10. Here it can be clearly seen the similarity existence of TEC pattern variations with respect to the solar indicator index of $F_{10.7}$ and SSN.

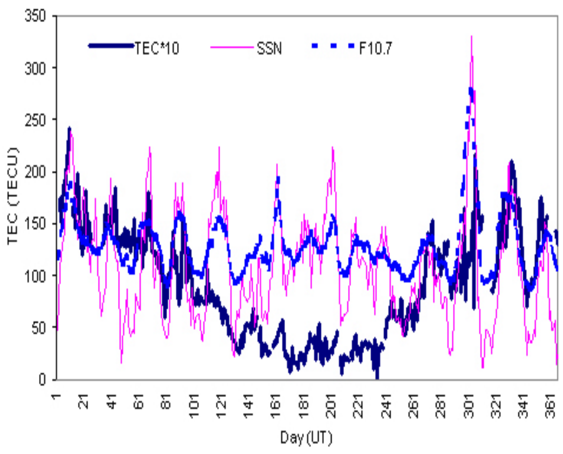

Figure 1 : Daily SBA GPS-TEC Vs SSN, F10.7 for 2003

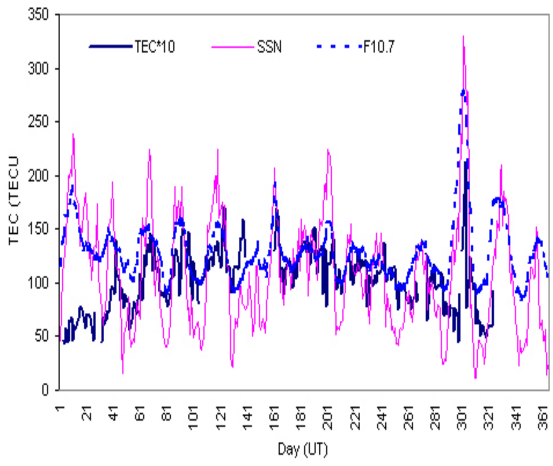

Figure 2 : Daily RESO GPS-TEC Vs SSN, F10.7 for 2003

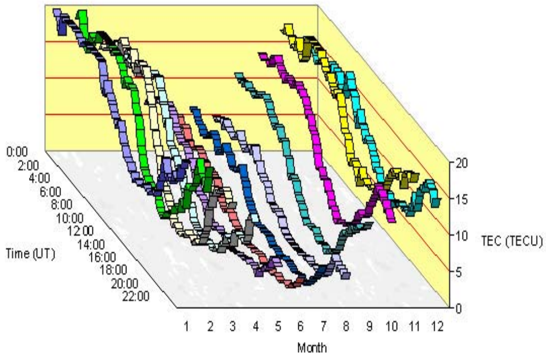

Figure 3 : Monthly SBA GPS-TEC Variations for 2003

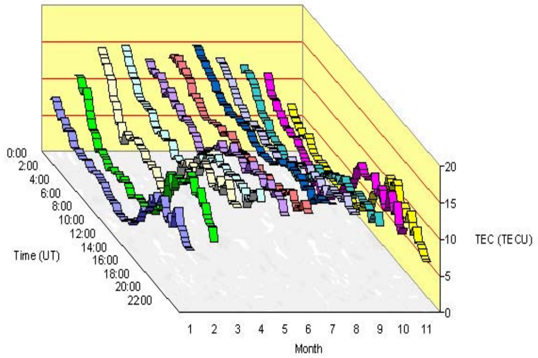

Figure 4 : Monthly RESO GPS-TEC Variations for 2003

Figure 3 and 4 shows the 2003 monthly GPS-TEC for SBA and RESO respectively. For SBA the ionospheric TEC day maximum occurs at post noon to evening between 1400 to 1900 LT while day minimum occurs at post midnight to sunrise between 0100 to 0600 LT. For RESO the ionospheric TEC day maximum occurs at post noon to evening between 1300 to 1800 LT while day minimum occurs at midnight to early sunrise between 0000 to 0500 LT.

4. Summary

The seasonal difference of TECmean between the two stations during VE and AE is due to the changing of season, from spring-to-summer at one station and from autumn-to-winter at the conjugate station, exhibiting"sea-saw" features. These results indicate that both SBA and RESO stations during equinoxes exhibits approximately symmetrical ionospheric statistical properties.
On the relationship between the ionosphere and solar activity there exist similarity of TEC pattern variation with respect to the solar activity index of $F_{10.7}$ and SSN. TEC is shown higher during late October 2003 and mid November 2003 corresponding to extraordinary solar activity and super geomagnetic storm events. This event shows the strong relationship of the TEC-solar activity even during winter months (normally expected lower TEC due to absence of sun light).

Acknowledgments

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