GPS TEC and ionosonde TEC over Grahamstown, South Africa: First comparisons

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Abstract

The Grahamstown, South Africa (33.3°S, 26.5°E) ionospheric field station operates a UMass Lowell digital pulse ionospheric sounder (Digisonde) and an Ashtech geodetic grade dual frequency GPS receiver. The GPS receiver is owned by Chief Directorate Surveys and Mapping (CDSM) in Cape Town, forms part of the national TrigNet network and was installed in February 2005.

The sampling rates of the GPS receiver and Digisonde were set to 1 s and 15 min, respectively. Data from four continuous months, March–June 2005 inclusive, were considered in this initial investigation. Data available from the Grahamstown GPS receiver was limited, and, therefore, only these 4 months have been considered.

Total Electron Content (TEC) values were determined from GPS measurements obtained from satellites passing near vertical (within an 80° elevation) to the station. TEC values were obtained from ionograms recorded at times within 5 min of the near vertical GPS measurement. The GPS derived TEC values are referred to as GTEC and the ionogram derived TEC values as ITEC. Comparisons of GTEC and ITEC values are presented in this paper. The differential clock biases of the GPS satellites and receivers are taken into account. The plasmaspheric contribution to the TEC can be inferred from the results, and confirm findings obtained by other groups.

This paper describes the groundwork for a procedure that will allow the validation of GPS derived ionospheric information with ionosonde data. This work will be of interest to the International Reference Ionosphere (IRI) community since GPS receivers are becoming recognised as another source for ionospheric information.

1. Introduction

At our Grahamstown, South Africa (33.3°S, 26.5°E) ionospheric field station we have operated a University of Massachusetts Lowell digital pulse ionospheric sounder (Digisonde) since April 1996. Prior to this date a Barry Research Chirp Sounder was operational at the station for a period of about 27 years, and, therefore, the Grahamstown station has a long archive of bottomside ionospheric information.

Recently, in February 2005, an Ashtech geodetic grade dual frequency Global Positioning System (GPS) receiver was installed at the station, collocated with the Digisonde. The GPS receiver is owned by the Chief Directorate Surveys and Mapping (CDSM), who are based in Cape Town. Although, the primary function of the GPS receiver is to fill a gap in the national TrigNet network (http://www.trignet.co.za/), our relationship with CDSM allows us to utilise the GPS data from this station for research. Fig. 1 illustrates the positioning of the ionosondes and GPS receivers within South Africa. Five real-time GPS stations within Southern Africa are owned by the Hartebeesthoek Radio Observatory (HartRAO) and are also shown in Fig. 1 for completeness. A number of additional stations not shown operate within Southern Africa on a non real-time basis.

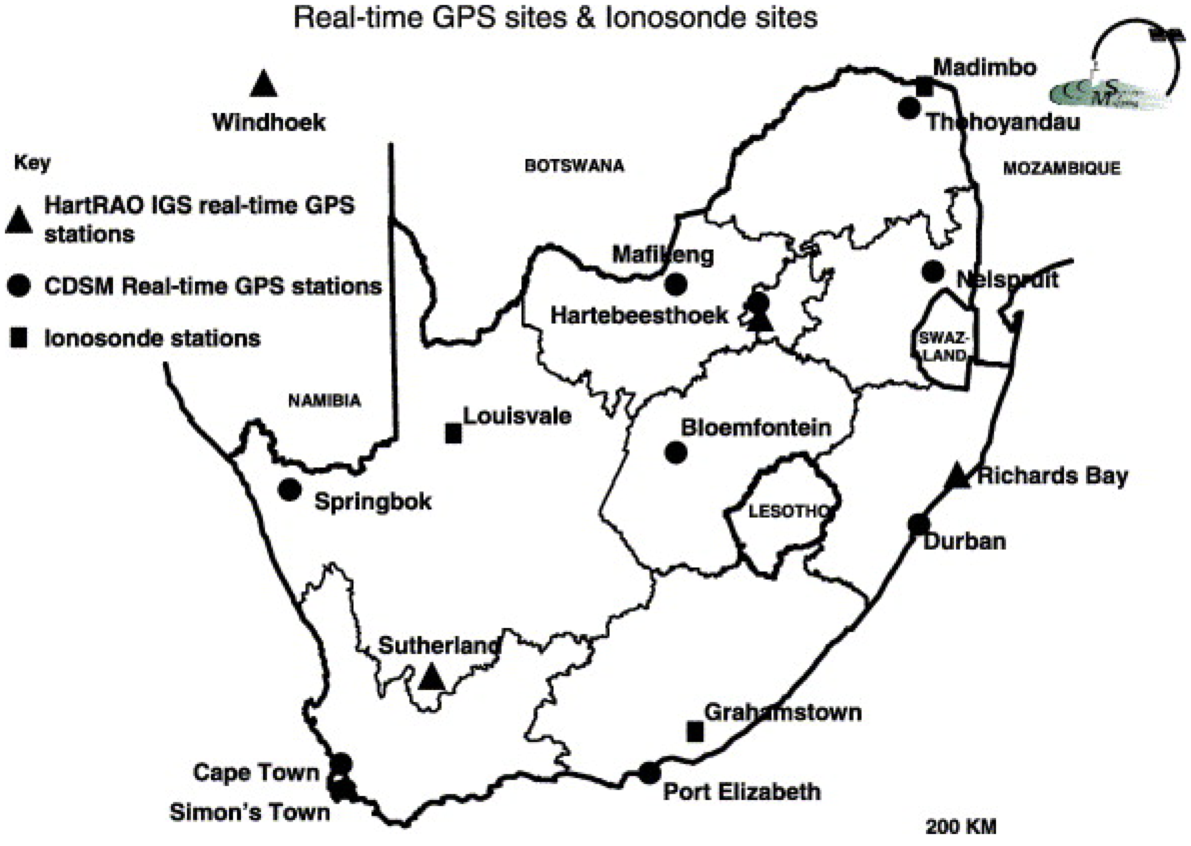

Fig. 1. A map of South Africa depicting the real-time GPS and ionosonde sites. The data used in this study were collected at the Grahamstown site.

Recently, there has been a move within the ionospheric community to use the Total Electron Content (TEC) parameter to characterise the ionosphere. By making use of the ionospheric induced delays on radio signals from GPS satellites orbiting the Earth at 20,200 km, the ionospheric and plasmaspheric TEC can be quantified on a global scale. It has been found that by using the GPS derived TEC values in an inversion method similar to medical tomography, the electron density profiles at any desired location can be derived. Therefore, GPS can provide a cost effective method for characterising the ionosphere, and supplementing ionosonde measurements where needed. Several groups, including but not limited to Breed et al., 1997, Lunt et al., 1999, Hernández-Pajares et al., 1999, Belehaki et al., 2004 and Cilliers et al., 2004, have been researching both the derivation of TEC and the use of ionospheric tomography in this field.

The aim of this paper is to present, for the first time, the results from the comparisons between ionosonde TEC (ITEC), and GPS derived TEC (GTEC) for the Grahamstown station. These results provide the groundwork for a method to validate ionospheric information derived from GPS measurements with ionosonde measurements.

2. TEC data availability

For this study four months of Grahamstown GPS and ionosonde data were used. These four months were March, April, May, and June of 2005, and correspond to a low solar activity period, as well as the autumn and beginning of winter months in the Southern Hemisphere. GTEC is defined as the total electron content derived from GPS measurements, and covers an altitude range up to 20,200 km, the height of orbit of the GPS satellites.

The Grahamstown GPS receiver records measurements at 1-s intervals from all satellites within radio sight of the station, and stores the data in hourly files. To determine the TEC from these measurements, the data was re-sampled at 60-s intervals and spliced into daily files. The TEC value for each 60-s sample was then determined by the use of an Adjusted Spherical Harmonic Analysis method. This procedure will not be described here since the emphasis of this paper is on the results rather than the technique, however, the reader is referred to De Santis et al., 1991 and Schaer, 1999 upon which the procedure was based, and Opperman et al. (2006) for details specific to the determination of TEC from the South African GPS network. The determination of GTEC as used in this study makes allowance for the differential clock biases of the GPS receiver and satellites.

ITEC is the total electron content determined from the electron density profile derived from ionosonde measurements, and covers an altitude range up to 1000 km. The electron density profile up to 1000 km is derived from a combination of the inverted bottomside ionogram (up to the height of the F2 peak) and a modelled topside profile (Reinisch and Huang, 2001). The TEC value is calculated as an integral over the entire profile from 0 to 1000 km. Grahamstown ionosonde measurements are recorded at 15-min intervals, and automatically scaled using the

Lowell scaling software, ARTIST. However, all ionograms used in this study were manually edited to ensure data integrity and to minimise uncertainties due to incorrect interpretation of the ionograms. From these definitions, we can expect that the difference between the GTEC and ITEC value should provide the plasmaspheric contribution to the TEC.

For the comparisons made in this paper, we only used GPS data from one station, Grahamstown, and, therefore, needed to determine the measurements that corresponded to near vertical sightings of the GPS satellites. We chose an 80° elevation angle, which puts a window of 10° around the point directly above the GPS receiver. All measurements that fell into this window were considered for this study. Fig. 2 shows a histogram of the near vertical observation opportunities, at an elevation of 80°, above the Grahamstown station for the period March–June 2005. This histogram indicates that an elevation of 80° allows data at all hours to be considered during the four-month period chosen for this study.

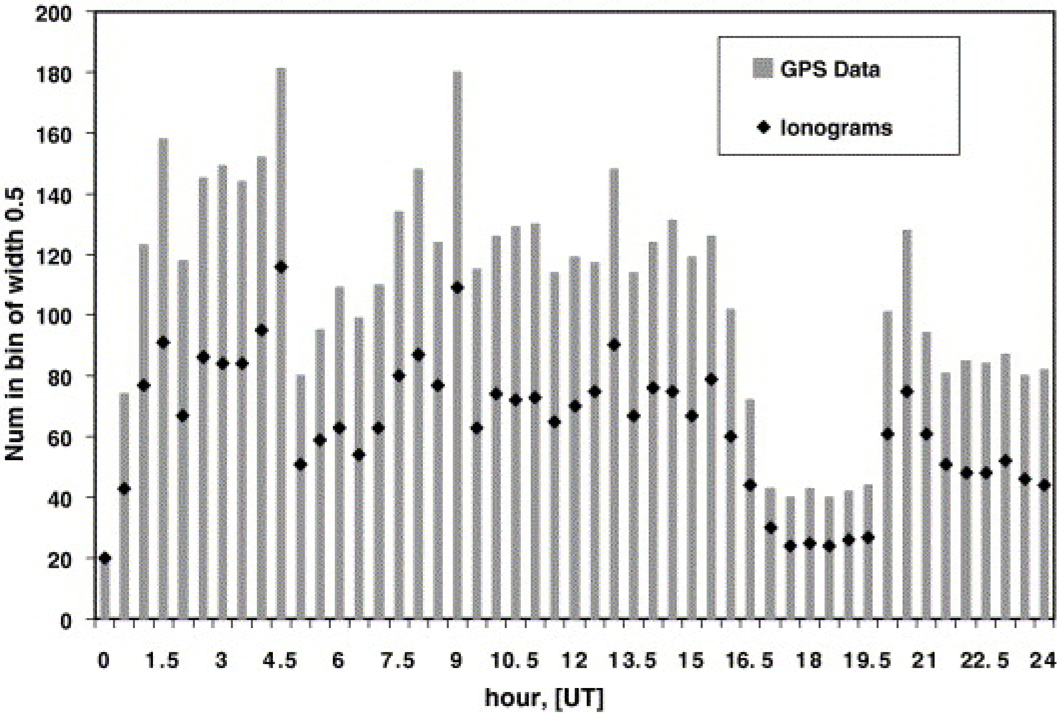

Fig. 2. A histogram depicting the number of GPS measurements recorded near vertical to the station, with the number of possible ionograms recorded within 5 min of a GPS measurement indicated.

Because the time resolution of the ionosonde measurements is much coarser than that of the GPS measurements, we further restricted our dataset to those cases where we had an ionogram recorded within 5 min of a useable GPS measurement. By useable we mean one that satisfied our requirement to be recorded near vertical to the station. Fig. 2 shows, superimposed on the histogram, the number of possible ionograms that could be used in this study. Therefore, the diamond shape points on the histogram in Fig. 2 indicate the number of cases where we had a GPS measurement near vertical to the station and an ionogram recorded within 5 min of that measurement.

3. Results and discussions

The ionospheric parameter foF2 is a measurable quantity from which the maximum electron density, NmF2, in the ionosphere can be determined. The electron density at the peak of the F2 layer, NmF2, makes the largest contribution to the TEC value, and, therefore, a correlation between the NmF2 value and ITEC can be expected. Fig. 3 is included to illustrate this correlation between Grahamstown NmF2 and ITEC. All hours are shown together on this graph, and only the data satisfying the criteria for this study have been used.

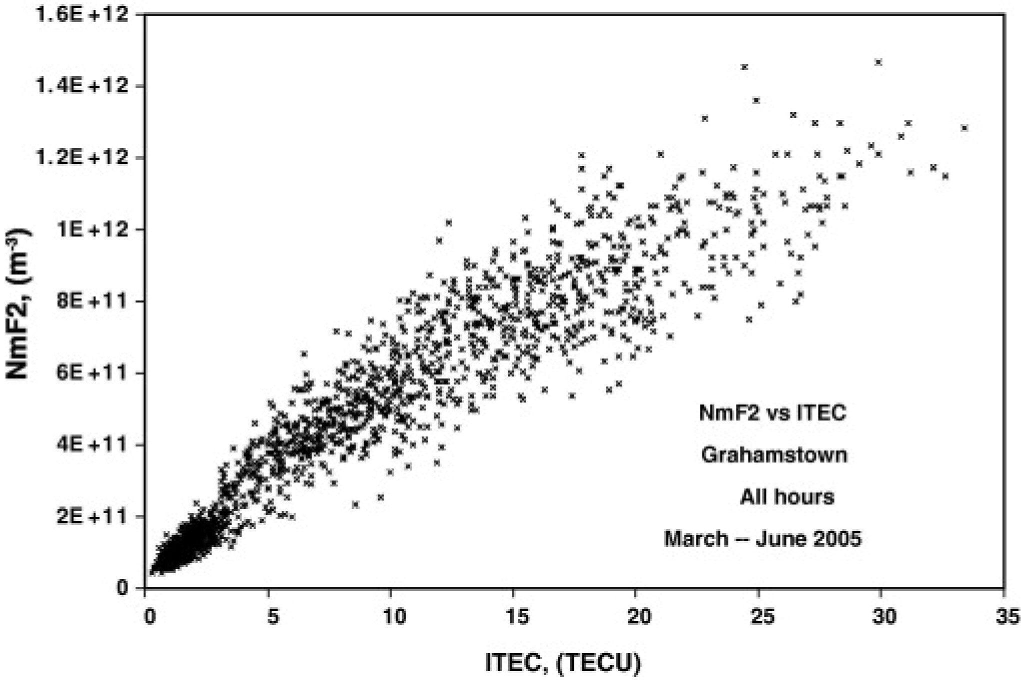

Fig. 3. The correlation between the ionospheric parameter and the peak electron density, NmF2, is shown for all ionograms that were used in this study.

The GTEC and ITEC values for each of the opportunities shown in Fig. 2 were determined. The scatter plot depicted in Fig. 4 shows that there exists a high degree of correlation between the GTEC and ITEC values for the four months used in this study. This is encouraging as these values represent two independent means for determining the TEC, and these results also confirm the findings of Belehaki et al. (2004), who carried out similar studies with one year’s worth of data from Athens (38.0°N, 23.5°E). From Fig. 4 it is clear that on average

GTEC exceeds ITEC by approximately 3.57 TECU at 33.3°S (1 TECU is equal to 10^{16} electrons/m^2), which is lower than what is reported in Belehaki et al. (2004). Since the difference between GTEC and ITEC, from their definitions, gives the plasmaspheric contribution to the TEC, it is of some interest to look at the variations in this quantity. Breed et al. (1997) also reported a higher plasmaspheric TEC value for Adelaide, Australia (34.8°S, 138.6°E). They showed, for 4 days in December 1992, using Faraday rotation measurements to determine the ionospheric TEC values, that the average plasmaspheric TEC was 11 TECU, significantly higher than that of Belehaki et al. (2004), and the value determined in this study. Lunt et al. (1999) showed that the plasmaspheric TEC decreases with increasing latitude, and that between 50.4°N and 53.4°N this value ranged from 1.6 to 0.05 TECU.

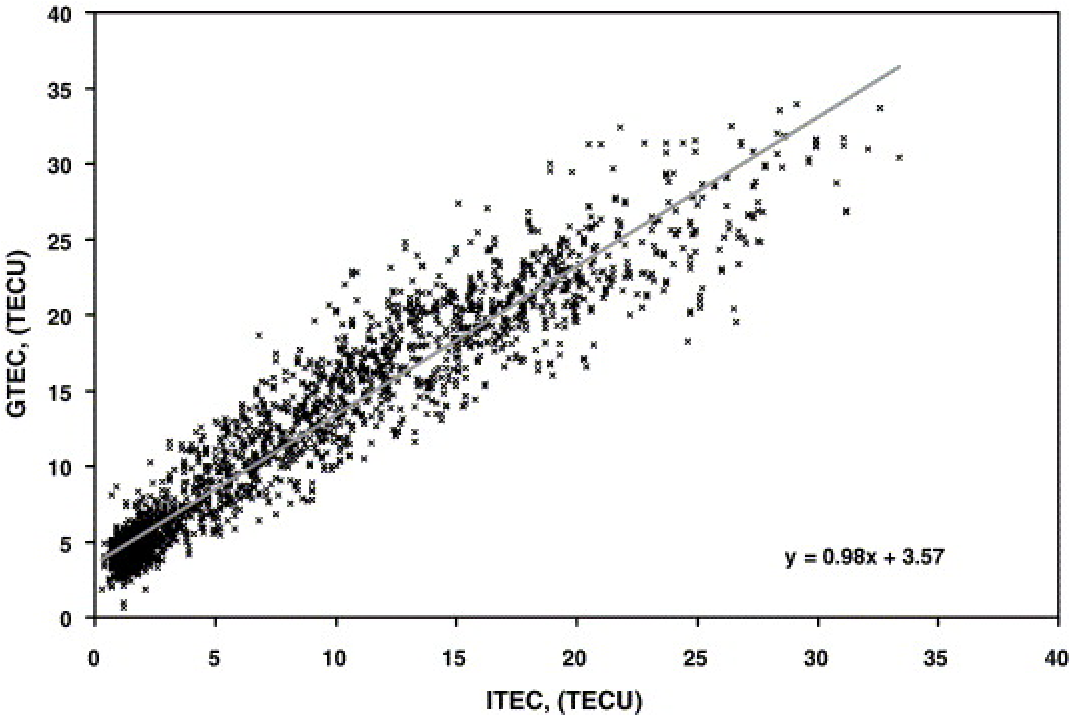

Fig. 4. A scatter plot depicting the comparison between GTEC and ITEC for the period March–June 2005. The best fit line has been included.

The four months contributing to this study cover the autumn and early winter season in the Southern Hemisphere. To confirm that our findings on the plasmaspheric TEC produce the same trend as other groups, we plot the average variation of the deltaTEC (GTEC-ITEC) expressed as a percentage of GTEC in Fig. 5. Included on this graph is the average variation of the deltaTEC in terms of TECU. This plot shows that, for this dataset, the plasmaspheric contribution to the total TEC is approximately 65% during the nighttime and 10% during the daytime, with the higher percentages occurring during the winter months. This is expected since the electron density in the bottomside ionosphere is constantly changing diurnally and is higher during the daytime than at night. This also confirms the findings of Belehaki et al. (2004) and Breed et al. (1997). The deltaTEC value is plotted against hour in UT here, with the local South African Standard Time (SAST) being 2 h ahead of UT.

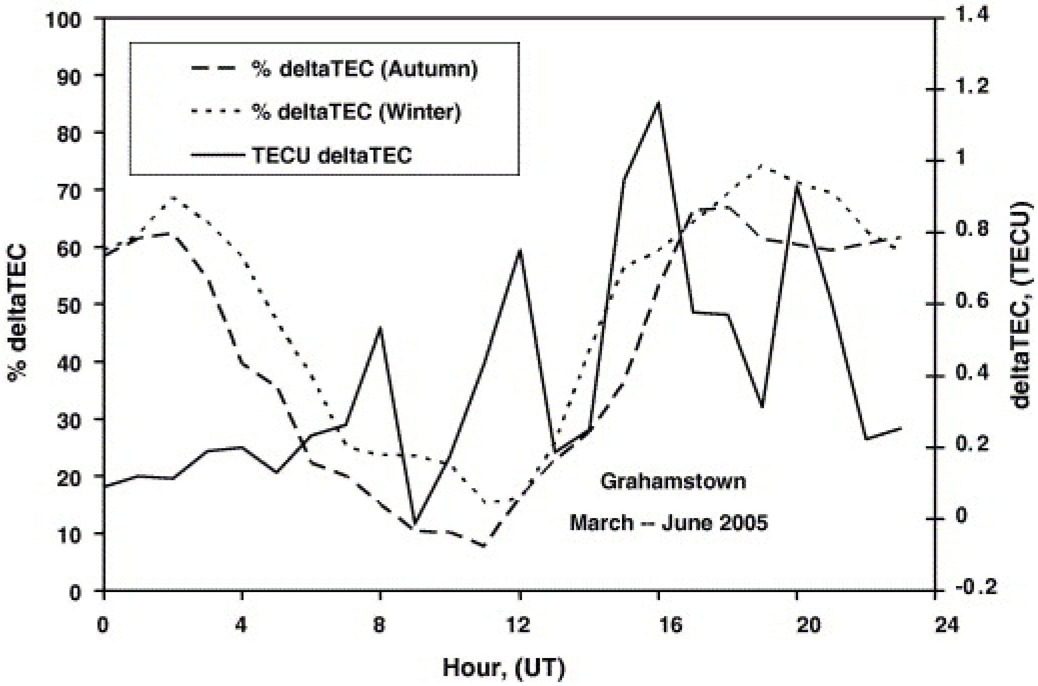

Fig. 5. This graph shows the hourly average variation in deltaTEC, as a percentage of GTEC, for the 4 months, March–June 2005. The autumn and winter months have been separated for the percentage deltaTEC variations in order to show the difference in variation during these two seasons. The hourly average variation of the deltaTEC, in TECU (scale on the right), for all 4 months together is also shown.

In addition, Fig. 5 shows that in terms of TECU, there is a minimum deltaTEC in the morning hours with the greater difference occurring in the late afternoon to evening hours. Some differences between our findings and those of other groups could be attributed to the small quantity of low solar minimum data used in this study compared to that of the other groups.

4. Conclusions

This paper illustrates the first comparisons between our collocated Grahamstown GPS receiver and ionosonde. We have demonstrated our ability to validate GPS derived ionospheric information with ionosonde data, and how, in addition, we can determine the plasmaspheric electron content. Our findings confirm the findings of other groups who have undertaken similar studies, providing confidence in our technique.

It is our intention to increase this study to include at least one year's worth of GPS data, thereby allowing us to investigate the seasonal variation. A more thorough investigation into the plasmaspheric contribution to the TEC is also planned, since we need to understand the plasmaspheric behaviour to be able to use GPS data in ionospheric predictive models.

South Africa has three operational ionosondes, including the Grahamstown one, whose data has been utilised in developing a national model. The South African network of GPS receivers is expanding and it is our long-term plan to utilise the data from these receivers to derive ionospheric information over the areas that are not covered by our ionosondes. This will allow us to use an existing network to supplement our ionospheric network, thereby providing a more comprehensive map of ionospheric behaviour over our country.

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