Available online at www.sciencedirect.com
ScienceDirect
Advances in Space Research 38 (2006) 2318–2323
ADVANCES IN SPACE RESEARCH
(a COSPAR publication)
www.elsevier.com/locate/asr

A study of the spatial density distribution in the topside ionosphere and plasmasphere using the FedSat GPS receiver

E. Yizengaw *, P.L. Dyson, E.A. Essex †

Cooperative Research Centre for Satellite Systems, Physics Department, La Trobe University, Vic. 3086, Australia

Received 29 October 2004; received in revised form 27 September 2006; accepted 28 September 2006

Abstract

The spatial electron density distribution observations using the Global Positioning System (GPS) receiver onboard, the Australian research micro satellite FedSat, are being used to investigate more detailed information about the topside ionospheric and plasmaspheric density distribution than can be obtained using ground based receivers. This is because with ground based receivers, the topside ionosphere and the plasmasphere contribute only a small fraction to the total electron content and so the measurements are dominated by the higher ionospheric structure at the F2 peak. Being in a polar Low-Earth Orbit (LEO), and with a GPS Total Electron Content (TEC) sampling rate of 10 s, FedSat is capable of covering a large area of interest within short period of data sampling period which is very important to obtain realistic electron density profiles of the topside ionosphere and plasmasphere. The GPS data from FedSat can be divided into two types: GPS below-the-horizon data that is recorded when FedSat detects GPS signals that have traversed the ionosphere below FedSat's orbiting height, GPS above-the-horizon data that is recorded when FedSat receives signals that have crossed the ionosphere above its orbiting height. FedSat's GPS below-the-horizon data can be used to supplement ground based GPS data to provide tomographic reconstruction with better resolution. FedSat's GPS above-the-horizon data can be used by itself to obtain the electron density distribution of the topside ionosphere and plasmasphere using tomographic reconstruction technique. For this paper we have used only above-the-horizon data to obtain the topside ionospheric electron density distribution during both geomagnetically quiet and severe storm-time conditions.

Keywords: FedSat; Topside ionosphere; Plasmasphere; Tomography

1. Introduction

The ionosphere and plasmasphere cause distorting effects or errors in satellite communications, navigation and altimetry, and numerous experimental techniques are used to advance our understanding of these effects by improving our knowledge of the ionosphere and plasmasphere. Instruments such as incoherent scatter radars provide profiles of both the topside and bottomside ionosphere, but not on a continuous basis. Furthermore they are distributed irregularly around the globe and so provide non-homogeneous coverage of the bottomside ionosphere that is basically limited to observations over land. The coverage is particularly sparse in the Southern Hemisphere which is mostly covered by sea.

The upper topside ionosphere and the plasmasphere have not been well studied even though they contribute significantly to errors in satellite navigation systems and degradation of satellite communications. The problem is that these regions cannot readily be monitored systematically on a long-term basis. The few instruments available, such as incoherent scatter radars, topside sounders and in situ satellite-based diagnostics provide some information on the topside ionosphere but generally not on the plasmasphere. The advent of the Global Positioning System

* Corresponding author. Present address: Institute of Geophysics and Planetary Physics, University of California, Los Angeles, USA. Fax: +1 310 206 3051.
E-mail addresses: ekassie@igpp.ucla.edu (E. Yizengaw), p.dyson@latrobe.edu.au (P.L. Dyson).
† Deceased in March 2004.

0273-1177/$30 © 2006 COSPAR. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.asr.2006.09.029

(GPS) with 29 satellites in 12 h orbits at 20,200 km does provide an opportunity to monitor the variation of the ionisation content of the ionosphere and plasmasphere on a global basis (Yizengaw et al., 2004a; Heise et al., 2002; Tsai et al., 2002), however the general reliance on ground based GPS receiver networks means that the observations generally provide detailed information on the behaviour of ionosphere near the F2 peak rather than of the upper topside ionosphere and plasmasphere. In contrast, the existence of GPS receivers on satellites in Low Earth Orbit (LEO) above the F2 peak provides an excellent opportunity to study the upper topside ionosphere and the plasmasphere in detail by monitoring satellite to satellite GPS signals. This paper reports the first results obtained using the GPS receiver on board the LEO, Australian scientific microsatellite, FedSat.

FedSat, the first Australian satellite in over 30 years, was developed by the Cooperative Research Centre for Satellite System (CRCSS) of which La Trobe University is a partner. Its name commemorates the centenary of Australian Federation. FedSat, which weighs 50 kg, was launched by an H-2 rocket from the Japanese Space Flight Centre, Tanegashima, at 0131 UT on Saturday 14 December 2002, and successfully deployed into orbit at an initial altitude of ~840 km. The payload includes a dual-frequency GPS receiver built by Spectum Astro of Arizona, USA and supplied by NASA. It is used for determining the satellite's position, for studying the Earth's ionosphere and plasmasphere, and for providing the timing reference for other instruments. FedSat's initial orbital parameters were: a period of 100.9 min, apogee 806 km, perigee 793 km, and inclination 98.7°.

The two coherently related GPS frequencies at $f_1 = 1.57542$ GHz and $f_2 = 1.22760$ GHz, are used to provide high precision measurements of the total electron content (TEC) (Horvath and Essex, 2003; Yizengaw et al., 2004a,b). The retrieval algorithm requires two main inputs: low rate (1 Hz) navigation measurements from FedSat and the orbital data of both FedSat and the GPS satellites being used. These provide precise information on the positions of the satellites. For FedSat, a LEO satellite at ~800 km altitude, the ray path descends (ascends) for a setting (rising) GPS satellite at speed of ~3.87 km/s. This very fast speed of FedSat implies that it takes ~10 min to sample the ionosphere tomographically for a single FedSat pass in the region of interest. To begin the analysis, the FedSat GPS data is pre-processed to remove outlier values and cycle slips which are either removed or corrected. The algorithms used have been described by Horvath and Essex (2003) and Yizengaw et al. (2004b). The TEC values are then obtained after correction for the receiver and satellite differential group delay biases. Details of the method of bias estimation are given in Breed et al. (1997).

FedSat GPS data can be classified into two categories. The first type consists of an overhead, or above-the-horizon mode where the ray paths from the GPS satellites are contained in a vertical cone above FedSat that passes through the upper topside ionosphere and the plasmasphere. The second type is the occultation mode (Hajj et al., 1994), when the ray paths from the GPS satellites pass almost horizontally through the ionosphere and hence provide scans through the ionosphere as FedSat rises and sets with respect to a GPS satellite [Hajj and Romans, 1998].

As FedSat orbits at ~800 km, most of the ionisation measured by this technique is located in the plasmasphere and upper topside ionosphere. Therefore, FedSat's GPS above-the-horizon data can be used by itself to obtain the electron density distribution of the topside ionosphere and plasmasphere using tomographic reconstruction. Details of the tomographic algorithm can be found in (Yizengaw et al., 2004a), and the Global Plasmasphere Ionosphere Density (GPID) model (Webb and Essex, 2004) has been used to provide the initial estimate of the plasma structure required to start the Algebraic Reconstruction Tomography (ART) tomographic algorithm.

In this paper we present three observations of structure in the upper topside ionosphere and plasmasphere derived by tomographic reconstruction of FedSat GPS receiver above-the-horizon data. The first two observations are for moderate magnetic conditions and examine the structure in the plasmasphere at low latitudes and across the magnetic equator, and at mid-latitudes. The third observation shows the effect of the large magnetic storm of 30 October 2003 on the plasmasphere at mid and high latitudes. Comparison of the results with the GPID model (Webb and Essex, 2004) show that the structure of the plasmasphere is more complicated than expected on the basis of models derived from our current knowledge of average conditions in the plasmasphere. The results demonstrate the great potential of LEO–GPS tomography in advancing our knowledge of the detailed behaviour of the plasmasphere.

2. Results

This paper presents space-based GPS TEC data from the FedSat GPS receiver on FedSat obtained on 18 & 19 June and 30 October 2003. As an example of the coverage obtained during a FedSat pass, Fig. 1 shows FedSat-GPS a sample of the ray paths obtained during a north-to-south crossing of the Australian region at ~2150 UT on 30 October 2003. The pass extended from 9.519°S, 175.0°E to 68.567°S, 150.0°E geographic (23.812°S to 80.017°S geomagnetic) with FedSat taking just 15 min to cover the region. During the pass FedSat obtained 13,653 measurements of TEC using signals from GPS satellites above its orbital horizon of elevation angle greater than 30°, and sections of just 10% of the total ray paths are plotted in Fig. 1. While the FedSat-GPS ray paths are not all contained in the one vertical plane, the variation in longitude is less significant than in latitude and so the ray paths are plotted in the vertical-latitude plane. In the analysis the derived plasma density structures are assumed to lie in this plane. It is obvious from Fig. 1 that the data consists of a dense array