Available online at www.sciencedirect.com
ScienceDirect
Advances in Space Research 48 (2011) 500–506
ADVANCES IN SPACE RESEARCH (a COSPAR publication)
www.elsevier.com/locate/asr

Demonstration of the use of the Doppler Orbitography and Radio positioning Integrated by Satellite (DORIS) measurements to validate GPS ionospheric imaging

Ping Yin [a,b,*], Cathryn N. Mitchell [b]

[a] *Tianjin Key Laboratory for Advanced Signal Processing, Civil Aviation University of China, Tianjin, China*
[b] *Department of Electronic and Electrical Engineering, University of Bath, Bath, UK*

Received 25 October 2010; received in revised form 9 April 2011; accepted 11 April 2011
Available online 15 April 2011

Abstract

There is a lack of independent ionospheric data that can be used to validate GPS imaging results at mid latitudes over severe storm times. Doppler Orbitography and Radio positioning Integrated by Satellite (DORIS), a global network of dual-frequency ground to satellite observations, provides this missing data and here is employed as verification to show the accuracy of the ionospheric GPS images in terms of the total electron content (TEC). In this paper, the large-scale ionospheric structures that appeared during the strong geomagnetic storm of 20 November 2003 are reconstructed with a GPS tomographic algorithm, known as MIDAS, and validated with DORIS TEC measurements. The main trough shown in an extreme equatorward position in the ionospheric imaging over mainland Europe is confirmed by DORIS satellite measurements. Throughout the disturbed day, the variations of relative slant TECs between DORIS data and MIDAS results agree quite well, with the average of the mean differences about 2 TECu. We conclude that as a valuable supplement to GPS data, DORIS ionospheric measurements can be used to analyse TEC variations with a relatively high resolution, ~10 s in time and tens of kilometres in space. This will be very helpful for identification of some highly dynamic structures in the ionosphere found at mid-latitudes, such as the main trough, TID (Travelling Ionospheric Disturbances) and SED (Storm Enhanced Density), and could be used as a valuable auxiliary data source in ionospheric imaging.

Keywords: DORIS; GPS; Relative TEC; Main trough; Ionospheric storm

1. Introduction

The main trough density depletion is one of most likely occurring ionospheric signatures at mid latitudes during geomagnetic storms, with sharp gradients in total electron content (TEC) and electron density (Krankowski et al., 2009; Coster and Skone, 2009). Global Positioning System (GPS) observations can offer the possibility of continental-scale ionospheric imaging to reveal features that are a few hundred kilometres in scale, such as the main trough. However, it is difficult to find independent data to verify the imaging results. Although specific regions of the world have incoherent scatter radars, which can be used for verifications, there are regions such as mainland Europe where independent ionospheric data are missing, particularly at severe storm times. Here, an independent data source from Doppler Orbitography and Radio positioning Integrated by Satellite (DORIS) is used as a verification to show the accuracy of the ionospheric GPS images in terms of the total electron content. The main purpose of this paper is to provide evidence that the ionospheric images are reliable during times of ionospheric disturbance, and thus to increase the use of ionospheric imaging for studying extreme events in the ionosphere.

* Corresponding author at: Tianjin Key Laboratory for Advanced Signal Processing, Civil Aviation University of China, Tianjin 30300, China. Tel.: +86 22 24092455; fax: +86 22 24092596.
E-mail addresses: eexpybath@gmail.com (P. Yin), eescnm@bath.ac.uk (C.N. Mitchell).

0273-1177/$36.00 © 2011 COSPAR. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.asr.2011.04.010

In this paper, we focus the study on the storm-time TEC features of the mid-latitude trough over Europe using two data sets. One is from ground based GPS dual-frequency data. With the aid of an advanced tomographic method, GPS reconstructed TEC maps are created for this study to reflect large scale TEC distributions. In addition to GPS measurements, ionospheric products from the French system called DORIS (Willis et al., 2010), have been employed to make comparisons. DORIS data is capable of detecting small- to meso-scale variations of TEC in the ionosphere subject to its 10 s sampling (some tens of km).

The basic principle of the DORIS system is based on the accurate measurement on board the spacecraft of the Doppler shift of radiofrequency signals emitted by ground beacons. Measurements are made on two frequencies: ~2 GHz and 400 MHz. About 56 ground beacon stations transmit dual frequency signals from locations distributed all over the world. The satellites carrying the DORIS receiver include Jason, TOPEX, ENVISAT, SPOT 2, SPOT 4, SPOT 5, at the range of 800–1336 km altitude. The ionospheric products deduced from the Doppler measurements are recorded at each count interval of about 10 s, and are used to derive the ionospheric TEC.

With the aim of validating structures showing in the GPS TEC maps with DORIS data, ionospheric disturbed times during 20 November 2003 are chosen. Extensive ionospheric redistributions occurred over Europe during this storm, for example, Yin et al. (2006) found the uplift of the F2 layer in the ionosphere; large TEC gradients in mid-latitude Europe have been observed by Stankov et al. (2009); and Pokhotelov et al. (2008) investigated the highly dynamic distributions over the northern polar region. Here, we show hourly Dst and Kp variations, to review the occurrence and intensity of this storm. As illustrated in Fig. 1, one can see that around 20:00 UT, Dst has dropped down to −450 nT and Kp up to 9, indicating a severe geomagnetic storm.

2. Observations and methods

Relative slant TEC retrieved from both ground-based GPS data and space-based DORIS satellite measurements are the primary observations for this study. Unlike the simple thin-shell TEC method for ionospheric TEC mapping (Mannucci et al., 1993), here an advanced tomographic algorithm, known as MIDAS (Multi-Instrumentation Data Analysis System), has been used to derive the inverted slant TEC from only ground GPS data (Mitchell and Spencer, 2003). In order to verify the reconstructed TEC estimations and ionospheric structures shown in the GPS TEC maps, an independent TEC data set is calculated from satellite-based DORIS ionospheric correction measurements.

2.1. GPS tomography

GPS data have been widely used with radio tomography to image the ionosphere regionally and globally, over all periods (including ionospheric quiet times and disturbed times). A comprehensive review of ionospheric imaging and data assimilation is given in Bust and Mitchell (2008). In this study, dual frequency ground GPS data from the IGS (International GNSS Service) website in a RINEX format are obtained to conduct the reconstruction. MIDAS has been developed to image the ionosphere in a 3-D spatial geometry (latitude/longitude/altitude) with time evolution. Differential phase observations are firstly used to derive the slant TEC data between the ground receivers and GPS satellites, and then input into the algorithm to estimate the electron density with some *a priori* information of the background ionosphere. Here, an updated version of the MIDAS algorithm has been adopted to reconstruct the disturbed ionosphere of interest. The updates include the regularization and the minimum residual method in linear solutions to stabilize the inversion and to optimise the imaging results.

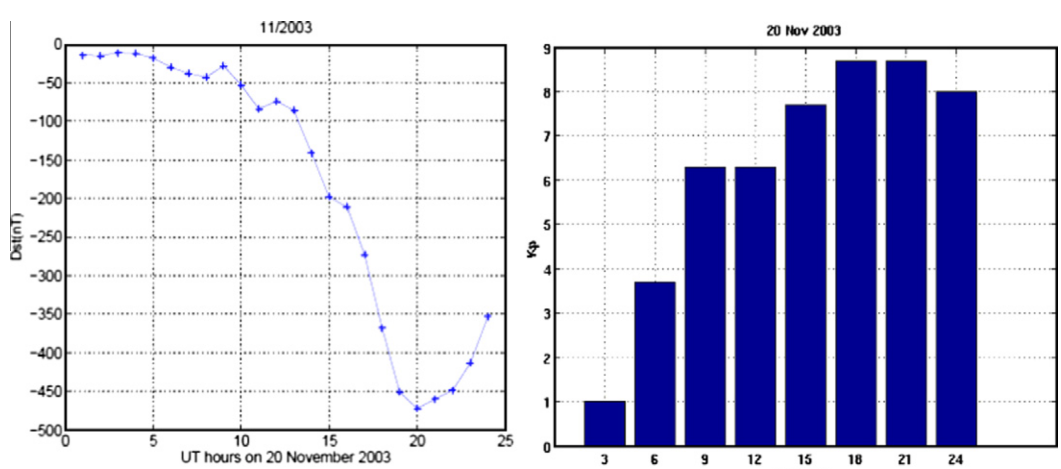

Fig. 1. Geomagnetic indices (Dst and Kp) variations on 20 November 2003.