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Assessment of the F2-layer electron density peak inferred from Formosat-3/COSMIC radio occultations over half a Solar Cycle

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ABSTRACT

GNSS radio occultation (RO) measurements have become crucial to provide valuable information on the vertical electron density structure of the Ionosphere. Ionospheric key parameters such as the maximum electron density (NmF2) and the corresponding peak height of the F2 layer (hmF2) can be easily derived. In the current work, in order to assess the accuracy of NmF2 and hmF2 inferred from Formosat-3/COSMIC (F-3/C) RO measurements, an efficient electron density retrieval method, previously developed at the UPC (Barcelona, Spain), has been applied for a period of more than half a solar cycle between 2006 and 2014. Ionosonde measurements from the Space Physics Interactive Data Resource (SPIDR) network have been used as reference. Results show that relative variations of NmF2 differences are in the range of 22%–30% and 10%–15% for hmF2. Equatorial and mid-latitude sectors at daytime and dawn present the highest consistency whereas degradations have beendetected in the polar regions during night. Moreover, it has been found that the solar activity can be traced by means of the global averages of NmF2 and hmF2 derived from F-3/C RO, hence becoming alternative indicators of solar activity trends.

Key words: Radio occultations, Inversion methods, Electron density retrieval, Formosat-3/COSMIC

Introduction

Radio occultation (RO) is a remote sensing technique that has proven to be of utmost importance to measure the physical properties of a planetary atmosphere. In the particular case of the Earth, the deployment of the GPS constellation allowed envisaging such system as a planetary scanner of the Earth's atmosphere with the assistance of Low Earth Orbit (LEO) satellites equipped with a GPS receiver on board [1]. In the particular case of the Ionosphere, the electron density profiles (EDPs) derived from RO measurements are widely accepted in the modelling of ionospheric electron density (Ne), helping to gain a global data coverage and increased sensitivity for the vertical structure of the Ne distribution.

Retrieval of the electron content from RO

Since the Ionosphere is a dispersive medium, GPS dual-frequency measurements from onboard LEO satellite can be exploited to extract information about the current Ne distribution due to the fact that changes in the carrier phase data are proportional to the Slant Total Electron Content (STEC). Ne profiles below the LEO orbit can be derived from STEC using retrieval techniques such as the Abel transform inversion, which assumes spherical symmetry in the Ne distribution. From each dual-frequency occultation measurement, STEC can be obtained as:

$$STEC = \int_{GPS}^{LEO} Ne(s)ds = 2\int_{TP}^{LEO} Ne(s)ds + STEC^{TOP} \qquad (1)$$

where TP stands for the so-called tangent point (TP), which is defined as the closest point to Earth along the line-of-sight (LOS) between GPS and LEO satellite at a specific occultation epoch. $STEC^{TOP}$accounts for the ionospheric contribution above the LEO orbit. The use of the Abel transform inversion implies that no horizontal gradients are considered in Ne. To account for this drawback, the separability hypothesis [2], [3], is introduced, which consists of describing the Ne distribution as a function of VTEC scaled by a shape function parameter SF(h):

$$Ne(\varphi, \lambda, h, t) = VTEC(\varphi, \lambda, t)SF(h) \qquad (2)$$

The new unknown parameter to be estimated is the SF at the TP positions. VTEC is assumed to be given and can, for instance, be extracted from IGS GIMs.

Experiment Data

This study has been performed between June 10, 2006 and April 29, 2014, covering almost 8 years of measurements. More details can be found in [4]. The starting date corresponds about two months after the launch of F-3/C due to missing data and orbits in the initial period of the constellation. A homogeneous sampling of 30 days has been chosen resulting into a total of 97 days under investigation. The source for the external ionospheric information to perform the improved Abel inversion envisaged by UPC is the IGS Analysis Center CODE, which provides 2 h sampled GIMs.

The assessment of the accuracy of the F2 layer peak retrieved from RO measurements has been carried out by means of ionosonde data from the SPIDR network. These data areavailable via the National Geophysical Data Center (NGDC) website as a public service by the US Department of Commerce, National Oceanic and Atmospheric Administration(NOAA) and National Environmental Satellite, Data and InformationService (NESDIS).

Evolution of the F2 layer peak

The evolution of NmF2 and hmF2 along the eight years under study has been evaluated in a first

step. All retrieved electron density profiles that have passed a screening process are taken into account for the derivation of F2 layer electron density peaks and the computation of global, daily averages.. As expected, an increase of the daily averages from lower towards higher solar activity has become evident in the time series for both parameters NmF2 and hmF2 [3]. Corresponding daily standard deviations have been calculated to characterize the variability of the parameters in the global domain. It has been noted that σ[NmF2] increases with the solar activity while the magnitude of σ[hmF2] remains rather constant, quasi-independent of the solar conditions. This effect may be interpreted as an increase of the global variations for NmF2 in correlation with the solar activity whereas hmF2 likewise increases but with a consistent fluctuation magnitude.
Comparisons have been also performed with the daily sunspot number R and the solar radio flux parameter F10.7 as solar physical indicators of the solar activity [3].

Peak evaluation versus magnetic latitude and local time

The evaluation has been carried out after discriminating the data into latitude sectors and local time intervals. Results show that for NmF2, the corresponding relative variations are determined in the range 22%–35% depending on the latitude sector and time interval. In particular, the highest correlations (> 0.9) are found at the Equator and mid-latitudes during day and dawn. Weaker agreement is observed for measurements at the Poles, generally during night. Regarding hmF2, standard variations lay in the range 10%-16%. Correlations of 0.7 have been obtained during day and dawn for the equatorial and mid-latitude regions. However, the correlations at the Poles and during night are significantly reduced.
The results obtained in this work are in line with the ones from other publications that concentrated on the assessment by using only few selected ionosonde stations. Unfortunately, it was necessary to perform an extensive pre-processing and data screening for both the RO and ionosonde data to eliminate inconsistencies in the data, hence improving the data reliability.

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