PERGAMON

Available online at www.sciencedirect.com

ScienceDirect

Acta Astronautica 63 (2008) 1350–1359

ACTA ASTRONAUTICA

www.elsevier.com/locate/actaastro

Sporadic structures in equatorial ionosphere as revealed from GPS occultation data

O.I. Yakovlev[a], J. Wickert[b], A.G. Pavelyev[a,*], S.S. Matyugov[a], V.A. Anufriev[a]

[a]*Institute of Radio Engineering and Electronics, Russian Academy of Sciences, Russian Federation*
[b]*GeoForschungsZentrum Potsdam (GFZ — Potsdam), Germany*

Received 28 March 2008; accepted 30 May 2008
Available online 9 July 2008

Abstract

A method for monitoring of sporadic formations in the lower ionosphere by use of the amplitude and phase variations of decimeter radio waves in the occultation trans-ionospheric link GPS satellite — LEO CHAMP satellite is described. Typical variations of the amplitude and phase of the occultation signal, caused by layered formations in the lower ionosphere, are considered. Parameters of sporadic structures measured during period of especially strong solar flashes from October 25 till November 9, 2003, are described. Results of statistical analysis of the occurrence frequency of sporadic layers, their altitude distribution, and thickness are presented. The electron density distribution in the lower ionosphere in the equatorial zone is estimated.

Keywords: Satellite; Monitoring; Ionosphere; Radio occultation

1. Introduction

Sporadic formations E_S are thin layered structures in the E-layer of the ionosphere with heightened values of the electron density relative to an average background. Sporadic formations E_S usually have sharp changes in the vertical gradient of the electron density. Knowledge of characteristics of sporadic E_S formations is important for studying the solar-terrestrial interconnections and atmospheric dynamics. The Earth-based methods were used previously for studying the structure of the lower ionosphere: vertical and oblique radio-sounding, investigation of UHF radio waves propagation effects, and occasional measurements by use of geophysical rockets [1,2]. As a result a great volume of data about E_S structures has been obtained in the Northern Hemisphere's moderate latitudes, and minor volume of data is relevant to the equatorial areas. Radio occultation in the satellite–satellite [3,4] communication links is a perspective method for global monitoring of E_S layers. The first experiments, which have been carried out in the decimeter wave band in the communication links the MIR station — geostationary satellites and navigating satellites GPS — satellite Microlab-1 (mission GPS/MET), have shown that the radio occultation method allows one to determine the altitude profiles of electron density in the lower ionosphere with resolution sufficiently adequate for studying thin layered structures [5,6]. The further researches were provided by use of communication links GPS–CHAMP. During missions GPS/MET and CHAMP a great volume of radio occultation data has been obtained. These data now are used

* Corresponding author. Fax: +7 495 702 95 72.
E-mail address: pvlv@ms.ire.rssi.ru (A.G. Pavelyev).

0094-5765/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.actaastro.2008.05.023

for investigation of characteristics of the lower ionosphere. Application of various techniques for analysis of radio occultation data allowed investigating sporadic layers morphology, studying the wave phenomena and turbulence in the lower ionosphere [7–14].

Determination of the ionospheric parameters is difficult below 120 km altitudes because of low electron density and smallness of the phase and amplitude changes of decimeter waves. It is essential that during radio occultation the line of sight passes through the upper part of the ionosphere where the electron density is high and, therefore, this part can contribute appreciable variations in the RO signal. Instability of the upper ionosphere imposes restrictions on the possibility of monitoring of the lower ionosphere. For this reason it is necessary to find out what characteristics of the lower ionosphere and under what conditions can be defined by radio occultation measurements. For this purpose we analyze the features of changes in the amplitude and phase of radio waves caused by E_S structures in the equatorial ionosphere and we substantiate a simple method of determination of the height, thickness, and other characteristics of sporadic layers. To achieve this aim we used results of 684 radio occultation events in the equatorial ionosphere, relevant to period from October 25 till November 9, 2003. This period is characterized by the record-breaking series of intensive solar flashes alternating with quiet solar conditions. The radio occultation events in which measurements began at the altitude of the line of sight about 120 km have been selected for analysis. The local time in the investigated areas was close to noon or midnight. From October 25 till November 9, 2003 381 event of measurements from $\sim$ 12 o'clock till $\sim$ 14.5 o'clock and 303 events from $\sim$ 0 o'clock till 2.5 o'clock of local time satisfy these conditions. The purpose of this paper consists in studying the changes in the amplitude and phase of RO signal during sounding of E_S structures, development of a new technique for revealing of such structures, and determination of the characteristic parameters of sporadic formations in the equatorial area within $\pm 30°$ latitude.

2. Features in changes in the amplitude and phase of radio waves

Results of measurements of the amplitude and phase of coherent signals emitted by navigating satellites GPS at frequencies $f_1 = 1.575$ GHz and $f_2 = 1.228$ GHz and received on board satellite CHAMP were used for the determination of the ionospheric E_S structures parameters. The scheme of radio occultation experiment is shown in Fig. 1. GPS satellite is located at point G at the altitude $H_g = 20\,200$ km, the satellite CHAMP is moving along the circular orbit C_1C_2 with height $H_c = 470$ km, the shaded circle corresponds to terrestrial surface, point O is the center of the Earth. It is possible to consider the radio ray path GC as a straight line because at GPS frequencies f_1 and f_2 the refraction effect in the ionosphere is small. The minimum height H of the line of sight GC over the terrestrial surface is reached at point D, where $H = DK$ (Fig. 1). When the satellite CHAMP moves to the Earth limb the height of the line of sight decreases and at $H = D_1K \approx 120$–130 km the registration of the amplitude and phase of RO signals begins with sampling frequency 50 Hz. The speed of change of the minimum height of the line of sight $\mathrm{d}H/\mathrm{d}t$ is in average approximately equal to 2.2 km s^{-1}; therefore, during the time interval 40–50 s the altitude of point D changes from $H_1 = D_1K = 130$ km to $H_2 = D_2K = 40$ km and the satellite occupies position C_2 (Fig. 1). Usually during one RO event approximately 2×10^3 measurements of the amplitude E at frequency f_1 and the phase excesses Φ_1 and Φ_2 at frequencies f_1, f_2 caused by the influence of the plasma environment on the line GC have been provided. For brevity, we will name the phase path excess as the phase. The refraction effects in the lower ionosphere are small and, as a consequence, the average level of the RO signal amplitude changes slightly. The amplitude variations relative to the average level have different intensities, frequencies, and origin. High-frequency fluctuations of the amplitude are caused by the receiver noise and small-scale irregularities of the electron density. The influences of large-scale irregularities and layered structures of the ionosphere lead to low-frequency amplitude variations. The phases Φ_1 and Φ_2 change because of the different conditions in the ionosphere by 10 times. These variations are caused owing to the regular contribution of the total electron content (TEC) along the line of sight

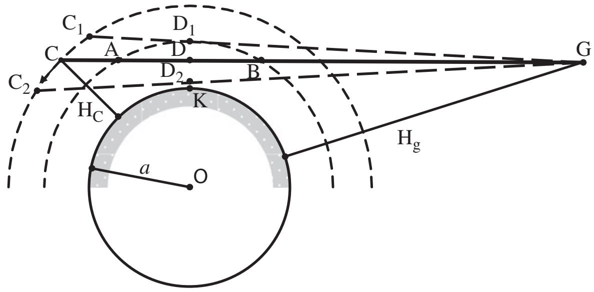

Fig. 1. Geometry of RO measurements.