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GLOBAL MONITORING OF SPORADIC PLASMA LAYERS IN THE LOWER IONOSPHERE DURING PERIOD 2001-2008 BY USE OF CHAMP AND FORMOSAT-3 GPS OCCULTATION DATA

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Summary: A classification of the ionospheric effect on the amplitude of radio occultation (RO) signal is introduced. Sporadic amplitude scintillation observed in RO experiments contain important information concerning the seasonal, geographical, and temporal distributions of the ionospheric disturbances and depend on solar activity. The general number of RO events with strong amplitude variations can be used as an indicator of the ionospheric activity. We found that during 2001-2008 the daily averaged S_4 index measured during CHAllenging Minisatellite Payload (CHAMP) mission depends essentially on solar activity. The maximum occurred in January 2002, minimum has been observed in summer 2008. Different temporal behavior of S_4 index has been detected for polar (with latitude greater than 60º) and low latitude (moderate and equatorial) regions. For polar regions S_4 index is slowly decreasing with solar activity.

1 INTRODUCTION

The radio occultation (RO) technique is a kind of bistatic radio location when a receiver is located on board of Low Earth Orbit satellite (LEO) at an extended distance relative to transmitter of radio waves[1]. In distinction with the radio tomography methods (see, for example[2], and references therein), RO technique may be applied practically simultaneously to investigation of both the atmosphere and ionosphere. High-stable synchronized with atomic clocks radio signals emitted at two frequencies 1575.42 MHz and 1227.6 MHz by GPS satellite navigation system are broadly used for radio occultation (RO) investigation of the Earth's plasma sheath. Plasma disturbances cause variations in the amplitude and phase of high-stable signals of navigation satellites during propagation of these signals through the Earth's magnetosphere, ionosphere, and mesosphere along the satellite–satellite paths. The amplitude scintillations are very important because in the case of layered structures they are directly connected from one side– with the eikonal acceleration and from another side– with vertical gradients of refractivity in the plasma layers[3]. In this contribution it is shown that (1) the S_4 ndex of amplitude variations can be considered as an index of the ionospheric plasma influence on RO signal in the trans-ionospheric satellite-to-satellite links in a like fashion with the S_4 index introduced formerly for the trans-ionospheric satellite-to-Earth links (2) the S_4 index can be used in the satellite-to-satellite links as a radio-physical index of activity of plasma disturbances in the ionosphere; and (3) the relative number of GPS RO events with high values of the S_4 index in the satellite-to-satellite links can be used to establish a connection between the intensity of plasma disturbances and solar activity.

2 VARIATIONS OF THE S_4 INDEX AND SOLAR ACTIVITY

The amplitude variations of RO signal can be described by the S_4 cintillation index

$$s_4 = \frac{[\langle I - \langle I \rangle \rangle^2]^{1/2}}{\langle I \rangle} \quad (1)$$

where < > is the average relevant to the height of the RO ray perigee above 40 km, and *I(t)* is the intensity of RO signal. When the amplitude and phase variations are caused by layered ionospheric structures, the S_4 scintillation index can be connected with the refractive attenuation X and the eikonal acceleration variations a[3]:

$$s_4 = [\langle X - 1 \rangle^2]^{1/2} = m[\langle a \rangle^2]^{1/2} \quad (2)$$

where m is coefficient depending on the parameters of the GPS and LEO satellites taking part in the RO experiment[5]. The relationships (1) and (2) give new possibility to reveal the origin of the phase and amplitude scintillations in the near-Earth propagation medium and may have a general significance for the trans-ionospheric satellite-to-satellite and satellite-to-Earth links. In the following we will indicate that the S_4 scintillation index obtained from the RO amplitude data is a key parameter connecting the amplitude variations of RO signal with space weather on a global scale. Influence of sporadic solar activity can be considered in the case of solar flare during October 29– 31, 2003. We treat about 2000 CHAMP RO events from October 27 to November 9, 2003. Histograms of integral distribution of the S_4 index are shown in Fig. 1. A ratio R of a number of cases with the magnitude S_4 larger, than value plotted on the abscissa, to the total number of measurements for the corresponding day, is plotted on the ordinates in Fig. 1. Histograms in the right panel correspond to data of S_4 measurements on October 29–31, as well as on October 28, November 1, and November 4 2003, performed during relatively intense and weak disturbances in RO signal, respectively. The initial histogram values for the entire period of observations are coincident and correspond to a magnitude S_4 of ~2.8%, which depends on the level of fluctuations of the receiver noise. Three days, October 29–31, with considerably higher S_4 levels than on the remaining days are distinguished in Fig. 1.

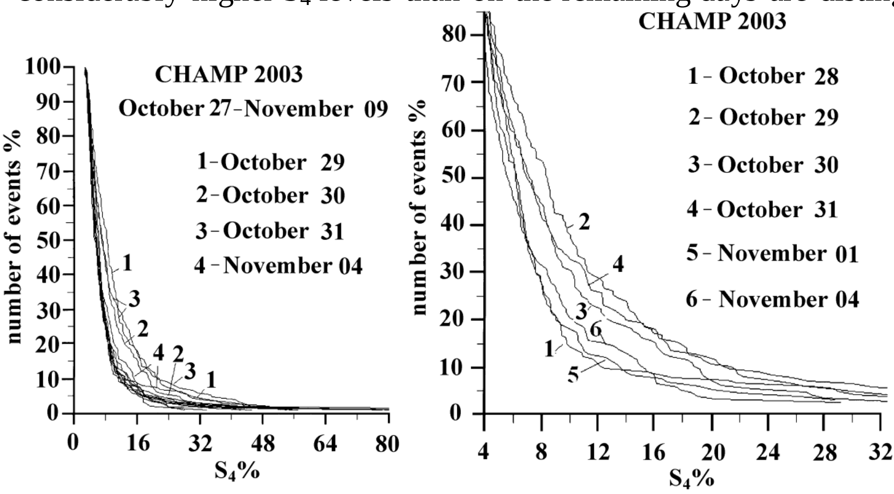

Fig. 1: Histograms of S_4 index corresponding to the altitudes of CHAMP RO signal trajectory perigee higher than 40 km. Curves corresponding to the histograms for October 27 and 28 and for November 1–3 and 5–9, 2003, are almost indiscernible (left-hand panel). The right panel demonstrates the histograms in more details.

The histograms for this time interval are much higher than for the remaining days. The most difference between the histograms is observed in the 5%–19% interval of the S_4 index with maximum about of 12% (Fig. 1, left and right panels). Value 12% of the S_4 index is by a factor 4.3 greater than the level of the receiver’s noise. Therefore, in the CHAMP RO experiments at the first

GPS frequency values of S_4 index in the 5%–19% interval can be considered as the most sensitive for estimation of the ionospheric influence on RO signal. The histograms in Fig. 1 are in good agreement with variations in the hourly index of the solar wind magnetic field.

Analysis of about ~500,000 CHAMP RO session data obtained during the time period 2001-2008 allows revealing long-scale variations of the averaged index S4. For each RO session the index S_4 has been determined according to eq. (1) as an averaged value of the intensity variations when the RO ray perigee height exceed 40 km altitude. At these altitudes the ionospheric influence on the amplitude of Ro signals prevails contribeution caused by the atmosphere. Therefore of about 200 values of the averaged index S4 have been obtained for different areas of the Earth per day. Then these data were averaged in the time lag 27 days and the latitude distribution of the obtained values of index S4 has been analyzed. The time dependence of S_{4a} index measured from RO CHAMP experiments during 2001-2008 is given in Fig. 2. Curve 1 corresponds to the averaged on a global scale value of the S4 index. Curve 2 indicates the averaged in the equatorial and moderate latitude areas (with latitude below 60º) value of the S_4 index. Curve 3 demonstrates the averaged in the polar latitudes (with latitude greater than 60º) values of the S_4 index. It follows from analysis of Fig. 2, that during 2001-2008 the daily globally averaged RO S_4 index depends essentially on solar activity. The maximum occurred in January 2002, minimum has been observed in summer 2008. Different temporal behavior of S_4 index has been detected for polar (with latitude greater than 60º) and low latitude (moderate and equatorial) regions. For polar regions S_4 index is slowly decreasing with solar activity. In the low latitude areas S_4 index is sharply oscillating, depending on the solar ultraviolet emission variations. The different geographical behavior of S_4 index indicates different origin of ionospheric plasma disturbances in polar and low latitude areas. Origin of the plasma disturbances in the polar areas may be connected with influence of solar wind, the ultraviolet emission of the Sun may be the main cause of the ionospheric irregularities in the low latitude zone. In the low latitude areas S_4 index is sharply oscillating, depending on the solar ultraviolet emission variations. The different geographical behavior of S_{4a} index indicates different origin of ionospheric plasma disturbances in polar and low latitude areas. Origin of the plasma disturbances in the polar areas may be connected with influence of solar wind, the ultraviolet emission of the Sun may be the main cause of the ionospheric irregularities in the low latitude zone. Analysis of Fig. 2 reveals global oscillations with the periods of 5-7 months. Analysis of these oscillations may provide additional connection with solar activity. Therefore, the S_4 index of RO signal is important radio physical indicator of solar activity.

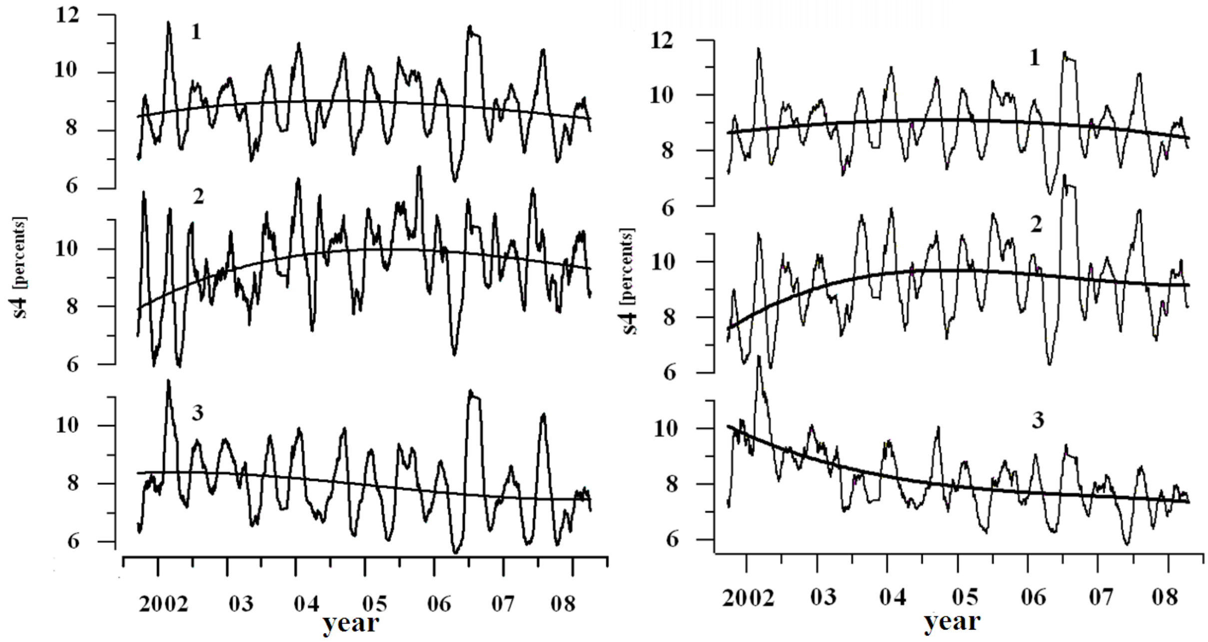

Fig. 2. Annual and latitude distribution of S_4 index measured from RO CHAMP experiments. Curves 1 described the annual distribution of S_4 index with a global coverage. Curves 2 correspond to the areas with latitudes below 30º (left) and 55º (right). Curves 2 correspond to the latitudes greater than 30º (left) and 55º (right). Smooth curves were obtained by a least squares method.

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