GPS GLOBAL DETECTOR OF IONOSPHERIC DISTURBANCES OF NATURAL AND TECHNOGENIC ORIGIN

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ABSTRACT

In the report the results of development by ISTP SD RAS the methods of global detecting of ionospheric disturbances of natural and technogenic origin based on use of satellite positioning systems of the second generation GPS-GLONASS are generalized. The references of application of new ionospheric experiment technology for research in ionospheric storms, solar flares, eclipses, earthquakes, ionospheric response to rockets launch and industrial explosions are available. The application of new technology has enabled new results to be acquired, in comparatively short terms, in the research of ionospheric disturbances of various nature. The list of publications is placed on website: http://rp.iszf.irk.ru/homepage/afra/.

INTRODUCTION

Making use of the international ground-based network of two-frequency receivers of the GPS, the data from which are made available via the Internet, has opened a new era in the field of a global, continuous and fully computerized monitoring of ionospheric disturbances of both natural and technogenic origins as an ingredient of the SPACE WEATHER complex in the geospace. In the very near future this system will be complemented through the use of signals from a similar Russian system, GLONASS.

The global GPS network, numbering over 2500 GPS stations by 2004, whose data are available via the Internet, densely enough covers North America, Europe, with a much poorer coverage for Asia. Even fewer GPS stations are to be found in the Pacific and Atlantic oceans. Thus, the corresponding number of stations operating in the Western hemisphere can reach no less than 1000 as of this date, while the number of simultaneously operating "receiver-satellite" radio paths no less than 5000-8000. Moreover, there are powerful regional networks, for instance, the GEONET network in Japan, numbering about 1000 GPS receivers [60].

An ideology has been worked out and a software complex developed at the ISTP SB RAS for the global detection and monitoring of ionospheric disturbances of natural and technogenic origin (GLOBDET) based on data for total electron content (TEC) variations measured using the GPS signals. Compared to classical radio probing tools for the ionosphere, this technology is the first to ensure real continuous and global coverage provided by a monitoring of ionospheric disturbances. Recently, some authors embarked actively on the development of detection tools for the ionospheric response to powerful earthquakes, rocket launches, and industrial surface explosions. Subsequently, the GPS data began to be used in the context of the spaced-receiver method using three GPS stations to determine the parameters of the full wave vector of traveling ionospheric disturbances [2]. The limitations of the spaced-receiver method with a minimum necessary number of receivers (three) include their low sensitivity and inadequate spatial selectivity, and this gives no way of exploiting the potential of a global GPS system consisting of hundreds of GPS stations. Next in turn is the setting of a more general problem, namely, that of developing processing techniques for the data from the GPS-GLONASS systems, based on the latest achievements in the field of a comprehensive spatio-temporal processing of signals, with due regard for the special features of ionospheric disturbances, however [2, 4, 9, 18].

The application of this new technology has enabled new results to be acquired, in comparatively short terms, in the research of ionospheric disturbances of various nature.

LARGE-SCALE TRAVELING IONOSPHERIC DISTURBANCES (LSTIDS) OF AURORAL ORIGIN

The data of the global network of GPS receivers formed a basis for the first ever determination, with high spatio-temporal resolution, of parameters of large-scale traveling ionospheric disturbances (LSTIDs) of auroral origin [3, 5, 18], including intense soliton-type disturbances, arising during the geomagnetic field's maximal variations in the periods of powerful magnetic storms. These disturbances propagate large distances equatorward without changing their form, at a speed comparable to or exceeding the sound speed. Existing geophysical models allow for these disturbances to be placed into the solitary wave class. Analysis of the distribution of LSTID movement directions at mid-latitudes has demonstrated that the south-eastward direction prevails under night-time conditions (169±20°), with the south-westward direction dominating the day-time conditions (198±25°). LSTID movement velocities in the Earth's nightside (970±300 m/s.) were found to be higher than those in the dayside (660±200 m/s).

MAGNETIC FIELD AND TEC VARIATIONS

A number of papers were devoted to examining the relationship between TEC variations and the Earth's magnetic field variations [3, 5, 18, 20]. For the first time ever it was shown, based on analyses of GPS receiver network data for the 29-31.10.2003 magnetic storm, that local intense variations of the Earth's magnetic field within the period range of acoustic gravity waves were accompanied by increased local variations of the total electron content, with a delay consistent with the sound speed of disturbances moving from the higher latitudes to the lower. This tallies with earlier results found when exploring the interrelationship between the amplitude increase in mid-latitude total electron content variations within the range of AGW periods and the increase of the time-derivative of the geomagnetic disturbance storm time index Dst [5].

IONOSPHERIC EFFECTS OF THE SOLAR ECLIPSES

Data were presented in [1] concerning the first ever TEC measurements and horizontal projections of its gradient during the 9 March 1997 solar eclipse based on GPS radio interferometer data in Irkutsk. Electron concentration altitude distribution found by radio-sounding during the 11 August 1999 solar eclipse was presented in [11]. The obtained TEC variation data testify to profound simultaneous changes in the ion-formation process in the ionosphere during the solar eclipse, within a large portion of space with a radius of no less than 600 km at an altitude of 300 km. The TEC minimum value delay relative to the maximum phase is 10 to 34 min, with a depression depth of 2-3 TECU. The amplitude, duration and delay of the ionospheric response derived from data from 70 stations of the European GPS network (the total eclipse on 11 August 1999) were found to be close enough to those from data of 3 African GPS stations (the total eclipse of 21 June 2001), and were 0.2-0.9 TECU, 30-60 min, 4-9 min, respectively. Response delay of the total electron content relative to the maximum phase of the 11 August 1999 total eclipse depends on local time and increases monotonously from 4 min (10:20 LT) to 8 min (11:02 LT) [11].

IONOSPHERIC RESPONSE TO SOLAR FLARES

The ISTP was the first to develop a new method for global GPS detection of the total electron content response to solar flares under quiet geomagnetic conditions. The technique being proposed differs from known radiophysical methods in higher sensitivity and spatio-temporal resolution [4, 6, 21]. The method allows for detecting the ionospheric response to weak solar flares (X-ray class S). The new method was utilized for the first ever investigation into the dependence of the amplitude of the total electron content response to solar flares on the flare location on the Solar disc (its distance from the central solar meridian) for various X-ray flare classes (S, M, X). For the first time ever, an empirical dependency of the ionosphere's total electron content response amplitude upon the peak power of solar flares in the soft X-ray range (1-8 **A**) was revealed. This dependency is expressed with a power function: $\Delta I = 649\ F^{0.7}$, where ΔI is the mean integral increment of the TEC, F is the peak power of X-ray intensity during the flare. Computations were carried out for flares with a peak power of $2.2\ 10^{-6}$ to $5.7\ 10^{-4}$ W m^{-2}. A new method has been worked out for determining the ionosphere regions that were responsible for the principal contribution into the total electron content response to solar flares, and estimates were obtained of this contribution on the example of a powerful solar flare of 14 July 2000 [21].

WAVE PACKETS AND ISOLATED IONOSPHERIC IRREGULARITIES

Analyses of global GPS receiver network data for 280 days in 1997-2003 were used to establish for the first time that about 1-2% of the total number of registered variations in the total electron content are due to aperiodic S-type fluctuations with a characteristic period of about 10 min, consistent with well-defined isolated ionospheric irregularities, whose horizontal cross-section forms an ellipsis with a bigger-to-smaller axis ratio of about 10 [15]. It was established that about 0.1-0.2% of the overall number of registered variations in the total electron content are due to traveling wave packets with a time period of 10-20 min and about 40 min in duration. Their characteristic radius of spatial correlation does not exceed 500-800 km, with a mean travel speed of about 180 m/s. They are observed chiefly during the day-time in winter and autumn [13].

IONOSPHERIC RESPONSE TO ROCKET LAUNCHES, EARTHQUAKES AND INDUSTRIAL EXPLOSIONS

A special place within the confines of the GLOBDET technology worked out at the ISTP SB RAS is allotted to developing algorithms and programmes aimed at detecting, locating and identifying the major characteristics of, the sources of natural and technogenic cataclysms based on data from the GPS-monitoring of the near-Earth space [7, 8, 19]. The development of this direction is related to the necessity of enhanced sensitivity, accuracy, global character and continuity in the operation of systems for detecting and locating the sources of technogenic impacts (rocket launches, explosions, underground nuclear tests), including those devoted to refining the systems for controlling the non-proliferation of nuclear weapons. This problem has become especially acute latterly due to the growing terrorist threat to the world community. A series of papers [9, 19] have described new techniques for detecting such impacts based on the global GPS network's role as a one-piece phased-array antenna [4], as well as presenting results enabling the justification of principles underpinning the functioning of a radiophysical system for monitoring, detecting and locating the sources of pulsed excitations. A method was developed for determining the "start" time of, as well as locating, the secondary source of an ionospheric disturbance generated during earthquakes. The application of this method to analyzing the ionospheric response to the 25 September 2003 8.3-magnitude earthquake in Japan helped to obtain the first ever corroboration of an ionospheric disturbance model in whose frame the disturbance source is not located in the epicenter but at an altitude of the main maximum of electron concentration above the epicenter [19].

SEARCHING FOR EARTHQUAKE PRECURSORS IN TOTAL ELECTRON CONTENT VARIATIONS IN THE IONOSPHERE

Another important problem consists in monitoring the ionosphere over potential seismic-hazard areas, since, during the pre-earthquake stage, the ionosphere above the epicenter was confirmed to undergo various sorts of specific disturbances. The GPS-monitoring potentials for detecting would-be earthquake precursors on the example of the 16 October 1999 Hector Mine earthquake in California, USA were analyzed in [17]. The choice of the event was based on the fact that a dense network of ground-based GPS stations were operative during this powerful enough (magnitude M=7.1) earthquake, allowing for a high enough spatial resolution. A detailed analysis of TEC variations was presented in [17] for a sufficiently long time interval including the earthquake date (13 to 18 October 1999). The authors also examined a possible reflection by TEC data of known seismo-ionospheric effects: quasi-regular variations in ionospheric parameters and the generation of internal gravity waves. The analysis has shown, however, that observed TEC variations are most likely to be controlled by local time and even by quite moderate geomagnetic activity and to be unrelated to any of the processes expected to accompany the pre-earthquake process.

TESTING OF THE TRANSIONOSPHERIC RADIOCHANNEL IN L FREQUENCY RANGE.

A global GPS detector can be used to carry out research related to estimating the operational error in radiotechnical systems for satellite navigation and radio location under various geophysical conditions based on monitoring the ionospheric radio channel using GPS signals. It was shown in [14] that the error in measurements of the range, doppler frequency shift and arrival angles depends on geomagnetic activity - disturbed conditions result in the error increasing 2- to 10-fold as compared to the quiet conditions.

THE INFLUENCE OF GEOMAGNETIC DISTURBANCES ON THE OPERATION QUALITY OF THE GPS RECEIVERS

It was demonstrated for the first time that ionospheric irregularities formed during the main phase of a magnetic storm within the auroral oval, as well as in areas of enhanced electron concentration gradient, cause strong GPS signal amplitude and phase distortions and result in a sharply increased range measurement failure density and positioning error. Experimental proof is presented for the first time to the effect that propagating large-scale atmospheric high-amplitude gravity waves generate intense medium-scale ionospheric irregularities leading to signal degradation and an increased GPS positioning error [10, 12, 16].

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