THE MORPHOLOGY OF TOTAL ELECTRON CONTENT PULSATIONS IN THE IONOSPHERE

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ABSTRACT

This report discusses the experimental research results on the morphology and physical origin of total electron content (TEC) pulsations as measured using the data from the global GPS network for 99 days with a different level of geomagnetic and meteorological activity and the number of GPS stations from 100 to 300. A total number of the "receiver - GPS satellites" radio paths used in the analysis is about 700,000. A study is made of the correlation of TEC pulsations and geomagnetic pulsations as well as meteorological phenomena such as hurricanes and typhoons.

INTRODUCTION

Periodic electron density oscillations of the type of wave packets were investigated previously in terms of the hypothesis of their association with geomagnetic field (GP) pulsations. Geomagnetic pulsations represent natural electromagnetic oscillations which are recorded as variations of the electric field (telluric currents). GP are characterized by a quasi-periodic structure and occupy the range from a few thousandths to several Hz. It is believed that geomagnetic pulsations are inherently magnetohydrodynamic (MHD) waves excited in the magnetosphere.

The greater part of evidence of the association between GP ad periodic electron density oscillations in the ionosphere was obtained by recording the frequency Doppler shift if the ionosphere-reflected radio signal [1, 2, 3, 4] and TEC variations measured using signals from geostationary satellites [5, 6]. However, many years of investigations have not yet provided thorough insight into the mechanisms accounting for the linkage between GP and ionospheric variations. One reason for that is the difficulty associated with obtaining statistically significant sets of experimental data.

This report presents a global morphology of TEC pulsations for 99 days with a different level of geomagnetic activity and the number of stations of the global GPS network from 100 to 300. A total number of the "receiver - GPS satellites" radio paths used in the analysis is about 700,000. Quasi-periodic TEC variations in the range of periods from 10 to 20 min are investigated, which is dictated by the fact that the data from the global GPS network are placed on the Internet with a standard temporal resolution of 30 s.

METHOD

The use of the international ground-based network of two-frequency receivers of the navigation GPS system which comprised no less than 900 site as of August 2001 and is currently placing the data on the Internet, opens up a new era of a global, continuous and fully computerized monitoring of ionospheric disturbances of a different class.

We suggests a new technology GLOBDET [7] for global detection of TEC pulsations, on the basis of phase measurements of the TEC in the ionosphere using an international GPS network. Temporal dependencies of TEC $I(t)$ are obtained for a set of spaced receivers of the GPS network simultaneously for the entire set of "visible" (over a given time interval) GPS satellites (up to 5-10 satellites). These series are subjected to filtering in the selected range of oscillation periods. We used the TEC $dI(t)$-variations, thus obtained, in a subsequent

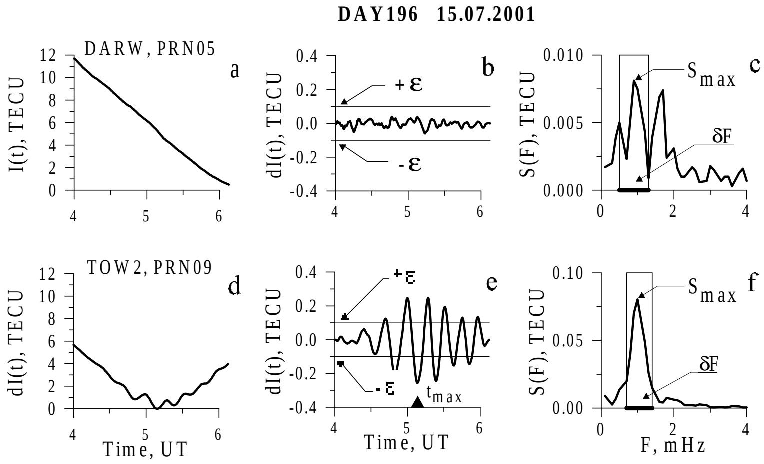

Fig. 1. Illustration of the selection of TEC pulsations

processing.

The selection of TEC series which could be ascribed to a class of pulsations was carried out by two criteria. First of all, TEC variations were selected, for which the value of the standard deviation exceeded a given threshold ϵ (in the present case ϵ=0.1 TECU). In addition, for each filtered series, we verified the fulfillment of the "quasi-monochromaticity" condition of TEC oscillations, for which the ratio R of a total spectral signal power in the selected frequency band δF in the neighborhood of a maximum value of the power S_{max}, to a total spectral signal power outside the frequency band δF under consideration exceeded a given threshold (in the present case R=2).

Fig. 1 illustrates the selection of TEC pulsation: a - an example of variations of the "vertical" TEC $I(t)$ without TEC pulsations; b and c - $dI(t)$ variations filtered from the same $I(t)$ series and its spectrum. Fig. 1d, 1e and 1f plot the same dependencies as in Fig. 1a, 1b and 1c, but for $I(t)$-series which contain TEC pulsations. Thin horizontal lines in Fig. 1b and 1e show the specified threshold ϵ. Thin vertical lines in Fig. 1c and 1f show the boundaries of the frequency range δF.

RESULTS

This report presents the results derived from analyzing the dependence of TEC pulsation parameters on the latitude, local time, and on the level of geomagnetic activity. For identifying the TEC pulsations of a possible meteorological origin, we processed an extensive data set from regional GPS networks in the area of California, the Caribbean basin, and South-East Asia, corresponding to the 17 strongest hurricanes and typhoons for the period 1998-2001 [8]. Most often, the observed TEC pulsations represent wave packets with a duration on the order of 1 hour. It was found that such TEC pulsations are a relatively rare event and are observed on no more than $0.1 - 0.3\%$ of the total number of radio paths.

Fig. 2a, 2b and 2c present dependences of the number of TEC pulsations versus a Dst-index. There is a general tendency of the number of pulsations to increase with the decreasing level of geomagnetic activity. Most pulsations of meteorogical origin occur at values of the Dst-index less than 60 nT. The occurrence probability of pulsations of non-meteorological origin shows one peak at 10 nT and the other at 60 nT.

Figure 2d, 2e and 2f present a diurnal distributions $P(t_{max})$ of moments t_{max} corresponding to the maximum amplitude of pulsations into a certain packet for the same cases as in Fig. 2a, 2b, 2c. It was found that a maximum probability distribution of the TEC occurrence for non-meteorogical data corresponds to local noon, for meteorogical data – to morning time and the distribution for all data has both maximums.

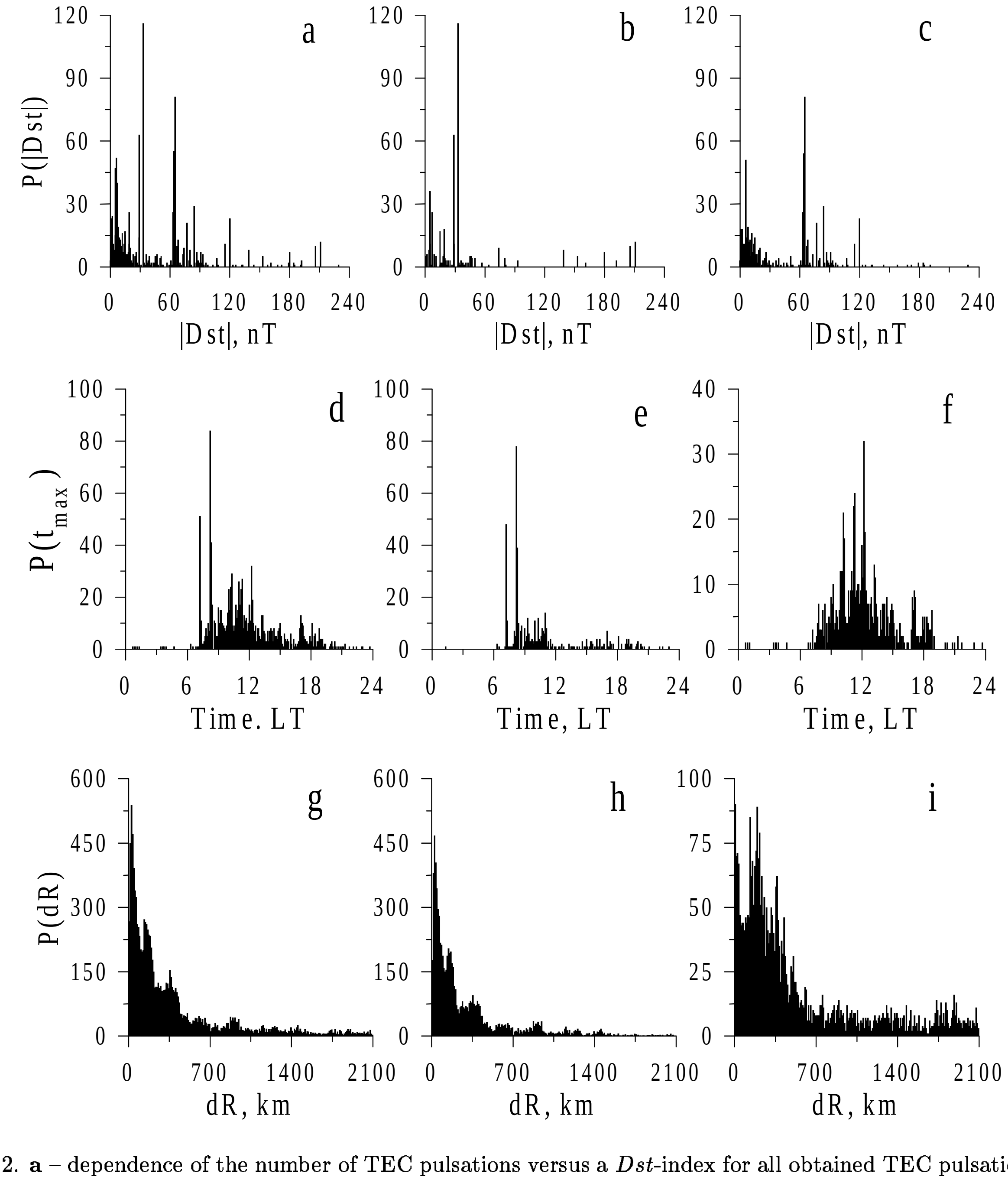

Fig. 2. **a** – dependence of the number of TEC pulsations versus a Dst-index for all obtained TEC pulsations, **b** – for the TEC pulsations of possible meteorological origin and **c** – for all TEC pulsations of non-meteorogical origin. Panels **d**, **e** and **f** present a diurnal distributions $P(t_{max})$ of moments t_{max} corresponding to the maximum amplitude of pulsations into a certain packet for the same cases as in **a**, **b**, **c**. Panels **g**, **h** and **i** show numbers of events $P(dR)$ versus a distance dR for three cases mentioned above.

The availability of a large number of GPS stations in some regions of the globe, in California and West Europe, for example, makes it possibly to determine not only the temporal but also spatial characteristics of TEC pulsations constituting traveling wave packets. In order to estimate a radius of spatial correlation, there were computed various distances dR between points available where pulsations were presented in the certain temporal interval. Fig. 2g, 2h and 2i show numbers of events $P(dR)$ versus a distance dR for three cases mentioned above. The radius of spatial correlation does not exceed a few hundred kilometers for all cases. Most of events for all data and for meteorogical data are restricted by the distance of 500 km. There is another picture for nonmeteorogical data - most of events are restricted only by the distance of 700 km.

CONCLUSIONS

The main results of this study may be summarized as follows:
1. The TEC pulsations are a relatively rare event and are observed on no more than $0.1 - 0.3\%$ of the total number of radio paths.
2. There is a general tendency of the number of pulsations to increase with the decreasing level of geomagnetic activity.
3. Such pulsations are a closely daytime phenomenon.
4. The radius of spatial correlation does not exceed a few hundred kilometers.

However, more reliable conclusions require expanding consideration of TEC pulsation statistics. Hopefully, our investigation would provide additional useful insights into the physical origin of TEC pulsations.

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REFERENCES

[1] H. Rishbeth, O.K. Garriot, "Relationship between simultaneous geomagnetic and ionospheric oscillations," *Radio Sci.*, vol. 68D, pp. 339–343, 1964.

[2] J. Klostermeyer, J. Rottger, "Simultaneous geomagnetic and ionospheric oscillations caused by hydromagnetic waves," *Planet. Space Sci.*, vol. 24, pp. 1065–1071, 1976.

[3] H.J. Duffus, G.M. Boyd, "The association between ULF geomagnetic fluctuations and Doppler ionospheric observations," *J. Atm. Terr. Phys.*, vol. 30, pp. 481–495, 1968.

[4] L.S. Al'perovich, E.N. Fedorov, A.V. Volgin, "Doppler sounding a tool for the study of the MHD wave structure in the magnetosphere," *J. Atm. Terr. Phys.*, vol. 53, pp. 581–586, 1991.

[5] K. Davies, G.K. Hartmann, "Short-period fluctuations in total columnar electron content," *J. Geophys. Res.*, vol. 81, pp. 3431–3434, 1976.

[6] T. Okuzawa, K. Davies, "Pulsations in total electron content," *J. Geophys. Res.*, vol. 86, pp. 1355–1363, 1981.

[7] E.L. Afraimovich, "The GPS global detection of the ionospheric response to solar flares," *Radio Sci.*, vol. 35, pp. 1417–1424, 2000.

[8] Hurricanes, Typhoons and Tropical Cyclones, http://www.solar.ifa.hawaii.edu/Tropical/, 1996.