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Variations of HF radio propagation conditions during geomagnetic storms

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Introduction

A variable state of the near-Earth space weather is known to affect significantly human activity on the Earth [1],[3],[4],[5],[6]. Essentially perturbed space weather conditions, caused by some irregular solar processes, harmfully affect not only spacecrafts (satellites and vehicles) but also various ground-based services and systems (communications, radars, navigations). The powerful geomagnetic disturbances occur usually rarely but their long-term influence on the sensitive technological and fine biological systems can lead to catastrophic consequences. That is why one of the important objectives of current interest is if not to learn how to control the disturbed space weather state then at least to understand the physical mechanisms of these disturbances or to make an attempt to forecast them and to reduce their effects in a certain degree.

The present paper deals with a problem of impact of the world-famous geomagnetic storms from a list of CEDAR, GEM and ISTP storms within 1997-99 on a technological system involving in three high-latitude HF radio paths of north-west Russia in particular. This impact is estimated through variations of the operational frequency range MOF-LOF (the maximum and lowest observed frequencies) on each path before, during and after a magnetospheric storm. The aim of the paper is to reveal certain peculiarities and regularities of the frequency range behavior on each path under the essentially disturbed conditions. Finding such regularities is obviously important for organization and planning of the HF communication links activity in polar and subpolar regions, e.g. with planes, helicopters, ships, geophysical stations, saving search groups, and so on during the critical states of space weather.

Operational techniques

The first St. Petersburg-Lovozero path of 1000 km length has the reflection point located on geomagnetic latitude $\Phi' = 61^{o}$. It is a subauroral path as its receiving center St. Petersburg is located at mid-latitudes but the transmitting center Lovozero is situated inside the auroral oval. The reflection point of the path lies inside the main ionospheric trough (MIT) closer to its polar edge under the quiet geomagnetic conditions. During a magnetospheric storm the polar edge of the trough (PET) is moved equatorward and the reflection point of the path most likely gets into the boundary of diffuse precipitation (BDP) region.

The second St. Petersburg- Heiss Island path of 2450 km length has a reflection point located on geomagnetic latitude $\Phi' = 66^{o}$ in the auroral oval. The path refers to a transauroral class, its receiving center St.Petersburg is situated at middle latitudes and the transmitting one Heiss Island is situated inside the polar cap area. According to [7], there is a great possibility for appearance of the sporadic E_{sr} layers. However the one hop reflections of HF signals from the E-layer on this path have a very low probability because the one hop propagation via E-layer is possible up to 2000 km whereas the length of the considered path is 2450 km.

The third Lovozero-Heiss Island path of 1450 km length has a reflection point at latitude $\Phi' = 69{,}5^{o}$ near the border between auroral oval and polar cap area. The reflection point is moved inside the polar cap during appreciable disturbances. The path appears to be a polar-auroral one as its receiving center Lovozero is located in the auroral zone and transmitting center Heiss Island lies inside the polar cap. Here the E_s-reflected signals can be often expected apart from the F2-reflections.

An oblique ionospheric sounding on the paths was held 24 hours a day on a sweeping frequency from the range $\Delta f = 2{,}5 – 27{,}5$ MHz. The sounding session was carried out on the 50th, 51st and 53rd minute respectively on the first, second and third paths hourly. Two radio propagation

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parameters in the receiving point, the MOF and the LOF were determined. The MOF value characterizes either ionospheric F- or E-layer state depending on region that reflects a signal at the moment. The MOF magnitude is specified by the critical frequency of a reflection layer and its altitude. The LOF value depends on the technical equipment of radio path, absorption level in the lower ionosphere or its ionization density.

St.Petersburg- Heiss Island radio path is the most informative. Fig.1. illustrates variations of parameters for this path.

Parameters of geomagnetic storms

Experimental study was carried out in north-west of European part of Russia. It is necessary to mention that geomagnetic storm manifestations in the ionosphere of this region can significantly differ from similar manifestations in other regions [2].

AE-index was chosen to estimate the storm intensity not accidentally. Other characteristics such as K_p and D_{st} are known to be used along with it. However, although AE-index is not ideal for the world storm description [6], nevertheless it is preferable here as more dynamic.

A value A,dB estimates the intensity of absorption through the riometer data at frequency f = 30 MHz by Sodankyla station, Finland. This station is situated closely to the system of used paths. Nevertheless the estimation of absorption here is approximate and more likely has qualitative characteristics than quantitative ones.

The results

1. Investigated storms differ essentially from each other by their parameters. There are also differences between their effects on the ionosphere and radio propagation on HF radio paths. Nevertheless, during storms there was revealed the common character of following manifestations: frequency range variations on the paths, correlation of the LOF values and riometer absorption A, signal loss due to great absorption during intense disturbances, similarity of behavior of parameters both ionosphere and propagation for the day-time storms and separately for the night-time storms, and so on.
2. The frequency range Δ = MOF – LOF is getting wider during several hours before the storm, then it narrows during a storm-time and further it expands again several hours after the storm has ended. These regularities may be useful for the HF radio communication organization at the high latitudes.
3. Variations of F2MOF (when signal is reflected from F2-layer) represent the interference of main effects of separate substorms, from which the storm consists. The main effect represents the positive ΔfoF2 values within several hours before To moment (the moment of storm expansive phase onset), further negative ΔfoF2 within the interval To – Te_and positive ΔfoF2 over again within several hours after Te moment (the moment of the end of storm expansive phase). The total, rather complex, picture of a storm depends on a temporal interval between AE splashes and their intensities.
4. Variations of riometer absorption A and AE-index are basically similar during not much intensive storms, though sometimes splashes of absorption A are observed delayed as compared with splashes of AE-indexes. The same splashes of absorption A and splashes of LOF values often coincide. Hence, LOF values are defined mainly by absorption in the lower ionosphere. Intensive splashes of A and/or AE cause the significant growth of absorption and signal loss on radio paths in general.
5. Two main phenomena (i) ionization increase in the F2 layer (positive ΔfoF2) several hours before To moment and (ii) drastic increase of riometer absorption in the beginning of development of the storm expansion phase may be considered as forecasting forerunners of the storm expansion phase development. There is a certain relation between the time of storm onset To and τ_o (storm period τ_o = To – Te) value. It is explained physically by the fact that particles, precipitating inside the diurnal cusp and auroral zone before the storm, ionize the ionospheric F2-layer longer at day-time, that is within τ_o = 4 h, than at night-time within τ_o = 2 h when precipitation occurs from the night side of plasma ring (auroral peak).

6. St.Petersburg- Heiss Island radio path has a time-interval of destroyed path t_{des} (interval of signal failure) depending on the local time LT. The median value of t_{des} is 6 h, and median value of τ is 20 h for the day-time storms. While for the night-time storms, the median value t_{des} is 2 h, and the median value of τ is 10 h. The average percent of path destruction during the disturbance within an interval τ = Te – To makes 30% for all day-time storms and accordingly 20% for all night-time storms. Thus, first, duration of storms is longer during the day than during the night. And, second, during disturbances the path is destroyed more often at the day-time than at the night.
7. In despite of the established general regularities of behavior of such parameters as the MOF, LOF, A and AE during a magnetospheric storm, there are always storm events which as exception do not comply with the general tendencies.
8. Space weather during the intensive magnetospheric storms crucially changes the processes in the magnetosphere and ionosphere. According to the present experiment at high latitudes there exist not only the traditional mechanism of solar energy transfer into the upper atmosphere through the magnetosphere tail, plasma sheet and auroral ionosphere but the quite another, little-known, mechanism - through the diurnal cusp and the enter sheet of magnetosphere.

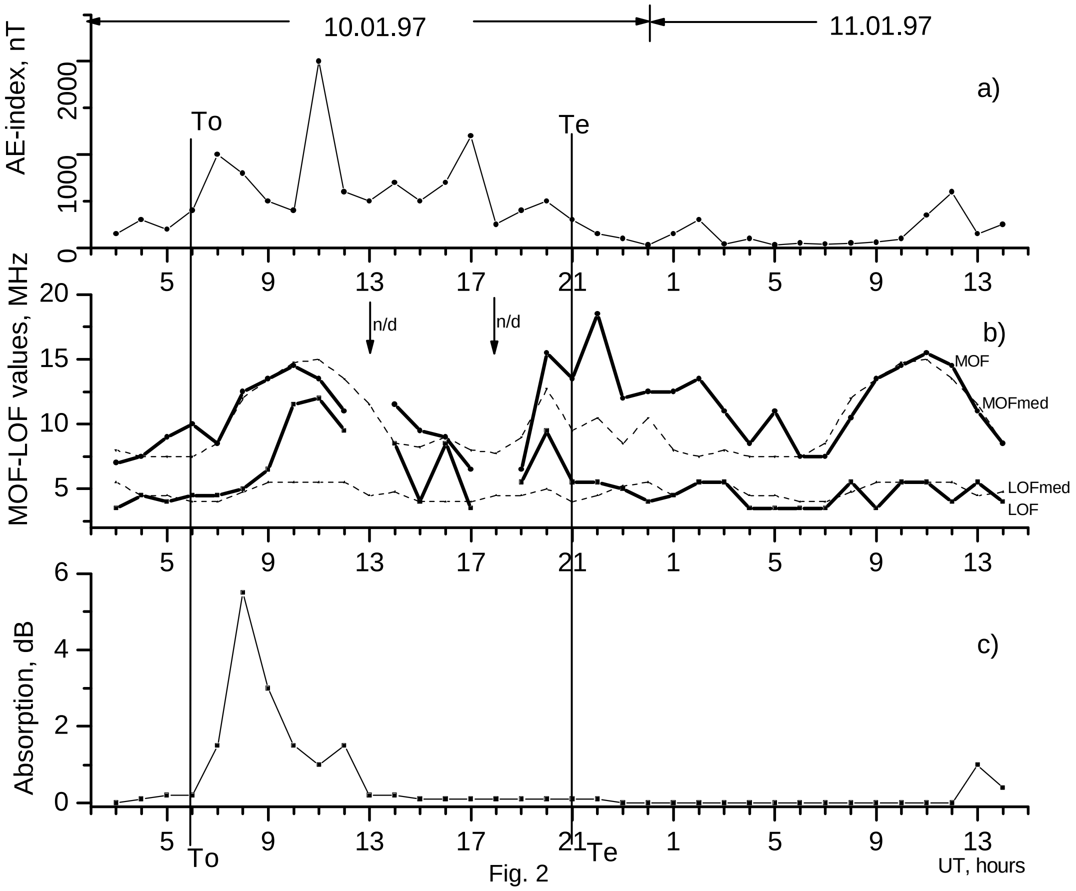

Fig. 2

Figure 1. Variations of the AE-index (panel "a"), MOF and LOF values on the St. Petersburg – Heiss Island path (panel "b") and absorption level A by Sodankyla riometer (panel "c") during a famous storm of 10-11 January 1997. Absent of propagation is shown by arrows.

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