The Propagation of the Electromagnetic Waves at Frequencies of the Russian Radio Navigation System RSDN-20 (Alpha) during a substorm at high latitude ionosphere

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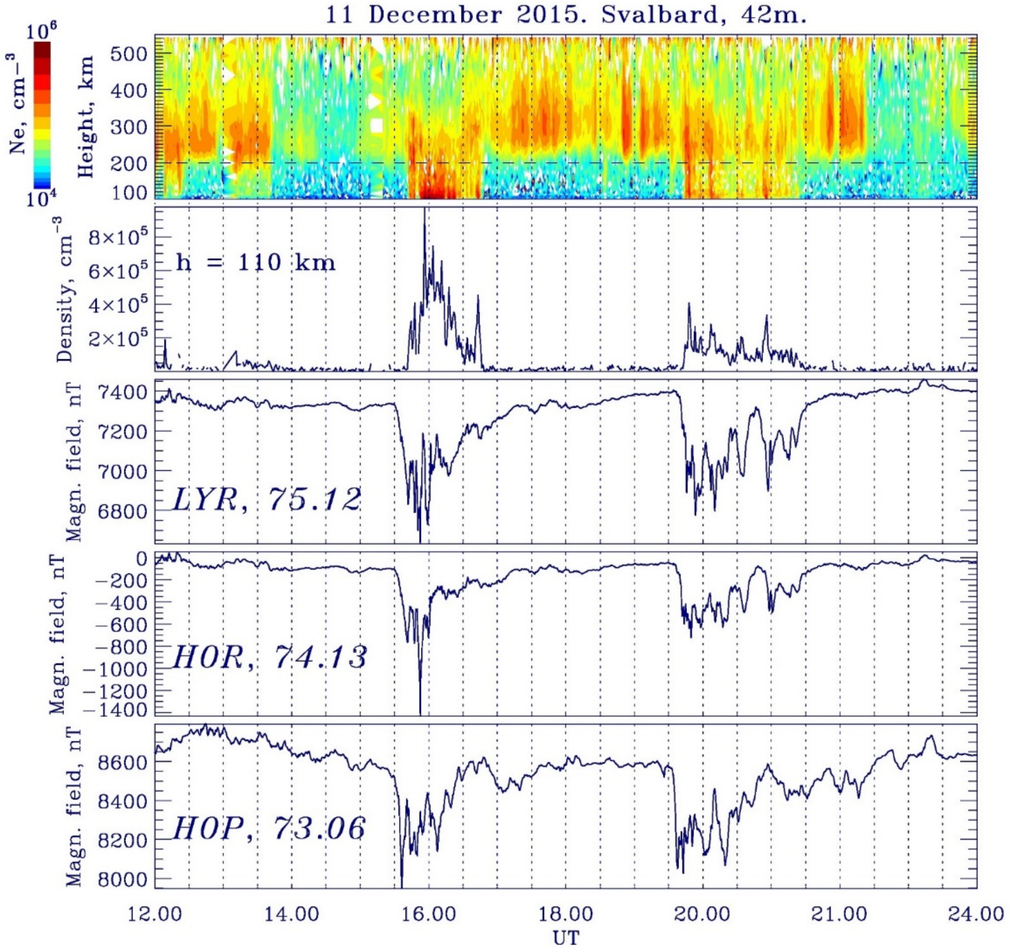
The report presents the results of the simulation of electromagnetic wave propagation with frequency corresponding to carrier in the network of transmitters of radio-technical system of long-distance navigation (RSDN-20) operating on the territory of Russia in the range of ultra-long waves. The numerical experiment was performed with ionospheric parameters corresponding to the magnetic substorm on 11.12.2015. These simulation results were obtained with using EISCAT incoherent scatter radar data on Svalbard and the Wait's two-parameter exponential profile for the D-region of the ionosphere. The Russian radio navigation system RSDN-20 (Alpha) system consists of four transmitters which are located in Novosibirsk (55°45′, 84°26′), Krasnodar (45°24′, 38°09′), Komsomolsk-on-Amur (50°04', 136°36′) and the Revda (68°02′, 34°40′) in Murmansk region. These transmitters broadcast signal at 11905 Hz, 12649 Hz, and 14881 Hz frequencies.



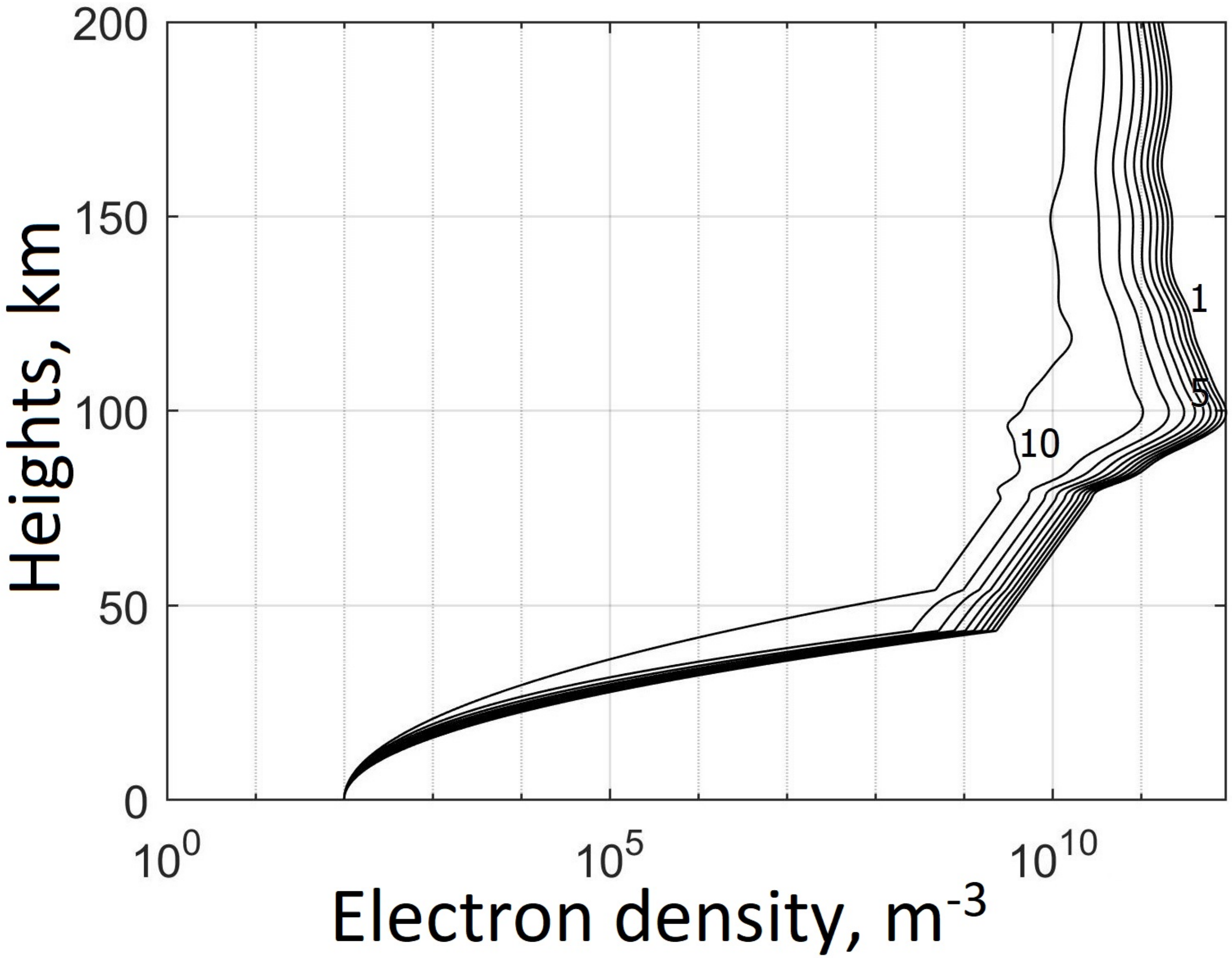
The variations of the ionosphere plasma density Ne with the altitude according to the EISCAT 42m radar data on Svalbard, variations of the Ne at altitude 110 km; variations of X-component of the geomagnetic field on LYR, HOR, HOP, after the station code the geomagnetic latitude is shown.

The polar substorm on 11 December 2015 (Figure 1) year was studied in detail in time interval 15.30-17.00 UT (evening sector, MLT=UT+3). The substorm was observed during the absence of the magnetic storm. The substorm amplitude reaches the value 1000 nT on HOR (Hornsund) station of the IMAGE magnetometer network. The substorm leads to the abrupt increase of the ionosphere plasma density (more than order) at altitudes 100-110 km according to the EISCAT 42m radar data on Svalbard. It was quite strong ionosphere disturbance for this latitude because substorm for example leads to the strong growth of the GPS phase scintillations (more than 2 radians) and gap in total electron content (TEC) variations according to the GPS receiver data on NYA (Ny Ålesund) station.

Working space and source

As a working area for the numerical experiment, the authors used the uniform horizon section of the Earth-ionosphere waveguide. The horizontal size of the section was 128x400 km. Altitude in the atmosphere and ionosphere - 200 km, in depth in the lithosphere - 25 km. The grid step above the Earth's surface is 500 m in all direction, vertically in the lithosphere is 250 m. The center of the signal source was located at a distance of 64 km from the three side faces of the obtained parallelepiped. For all external faces except the lower one, the condition of free wave departure together with the adapted absorbing layers PML and Berenger's loss profile was used.

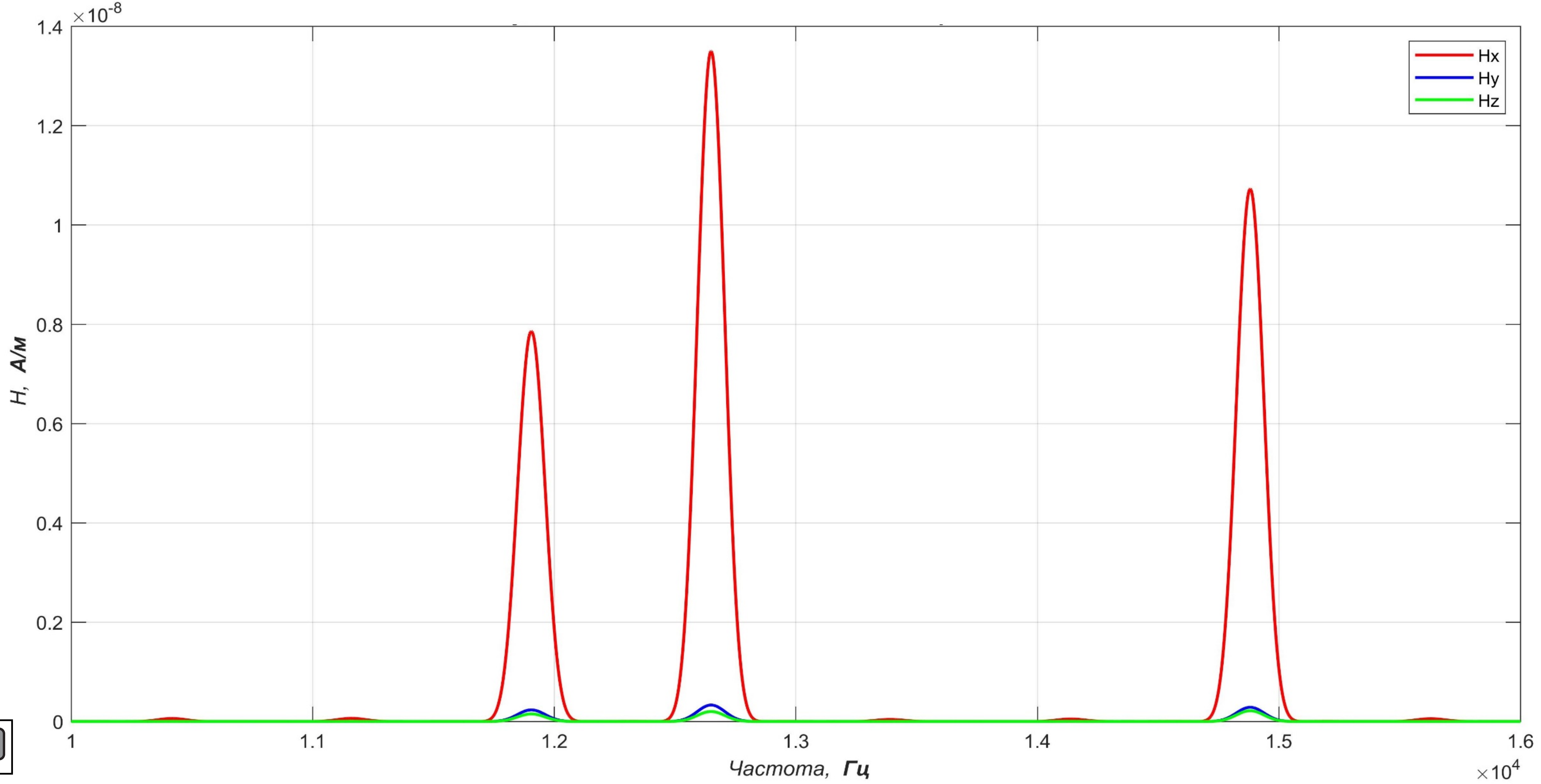
A flat array of 60 km high and 60 km wide electric dipoles was used as the source. Source signal was the sum of harmonic oscillations at frequencies of radio technical system of long-distance navigation (RSDN-20) 11905 Hz, 12679 Hz and 14881 Hz.



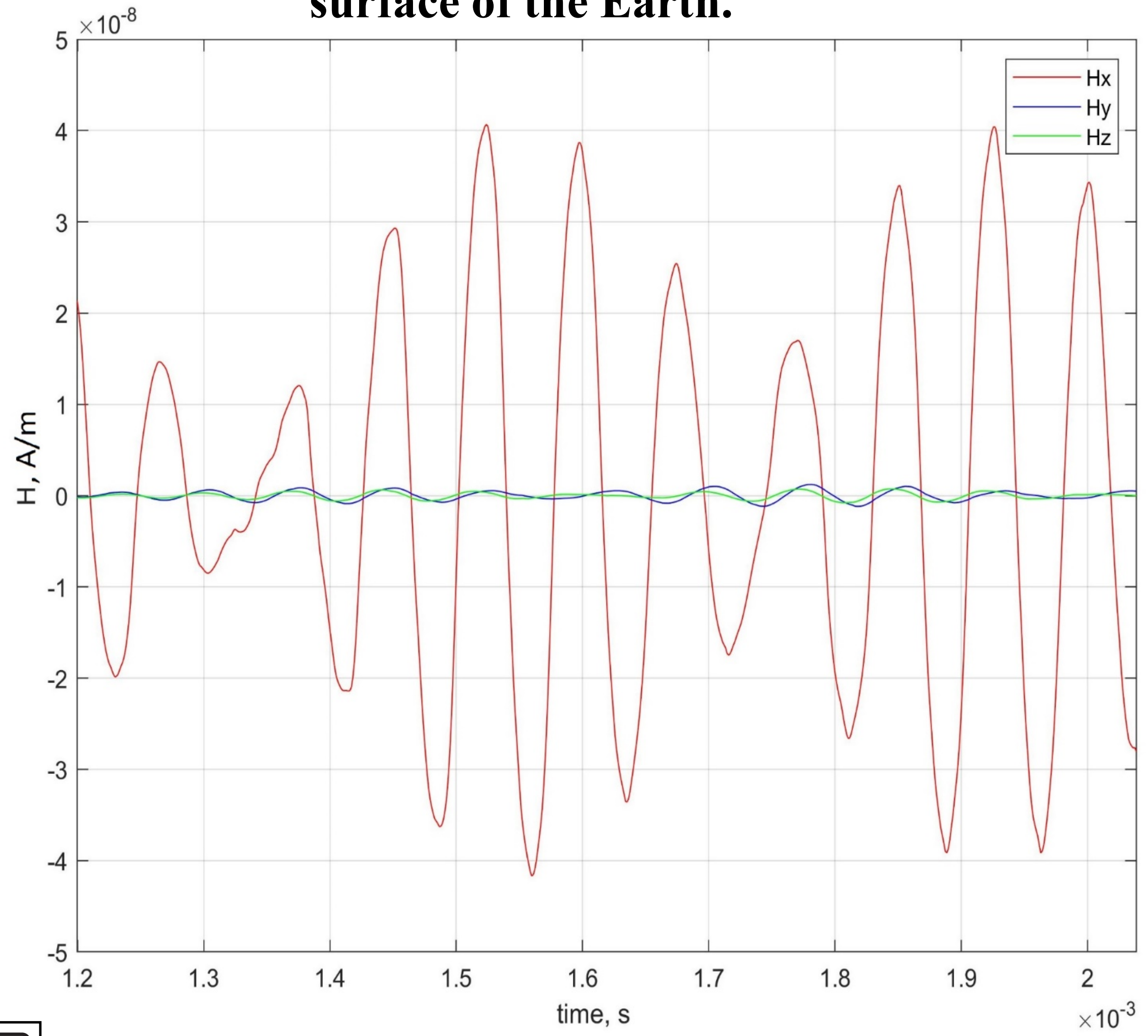
Electronic density profile series. From perturbed ionosphere conditions with marked digit 1 and corresponding substorm 11.12.2015 to calm conditions with marked digit 10.

The conductivity profile of the lithosphere was approximated on the basis of the results of the conductivity studies on the Kola Peninsula of several scientific groups published in the paper [Korja T., Engels M., Zhamaletdinov A.A., Kovtun A.A., etc. Crustal conductivity in fennoscandia—a compilation of a database on crustal conductance in the fennoscandian shield. EarthPlanetsSpace, 54, 2002, 535–558]

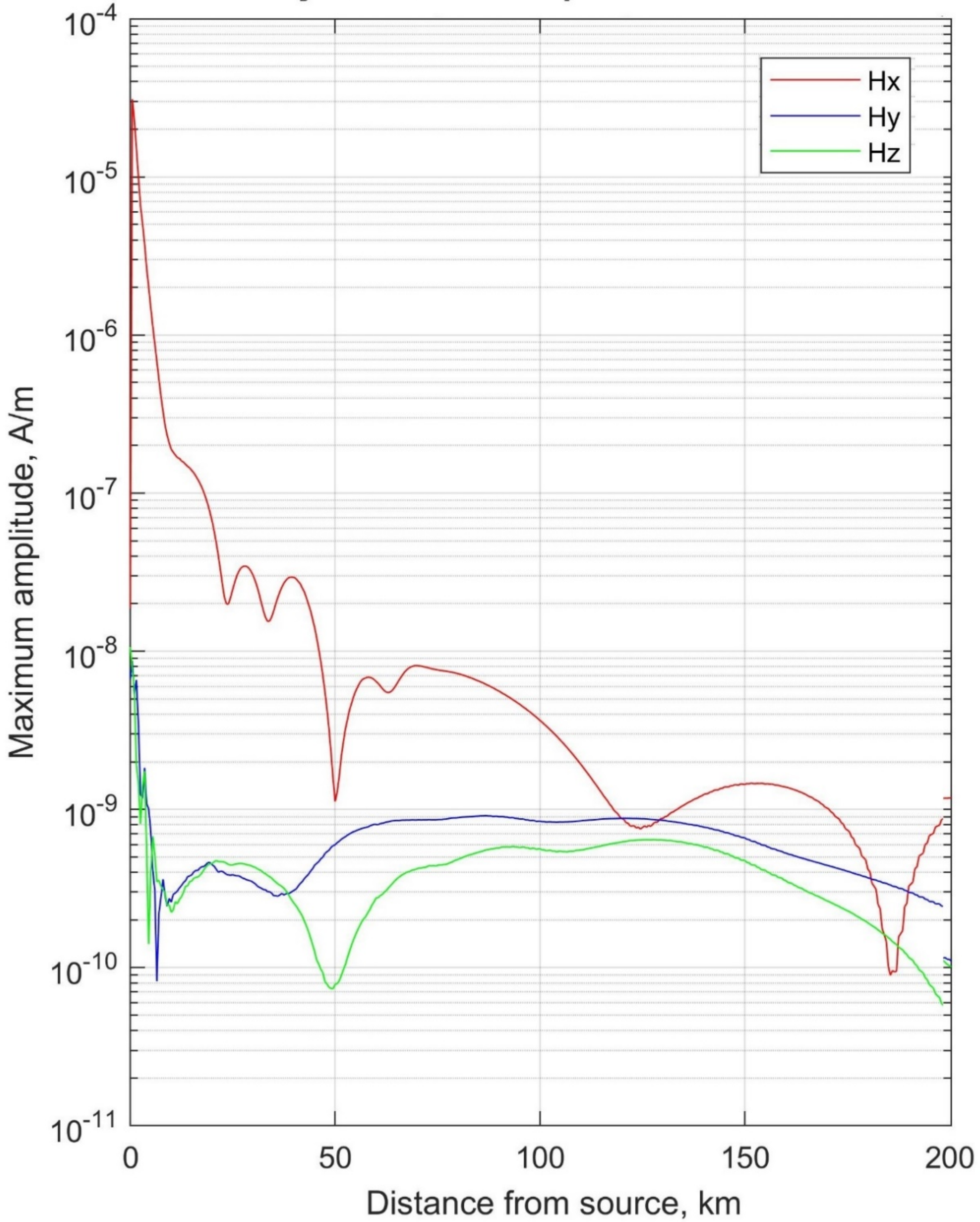
The amplitude-frequency dependence of the magnetic field at a distance of 49.5 km from the source

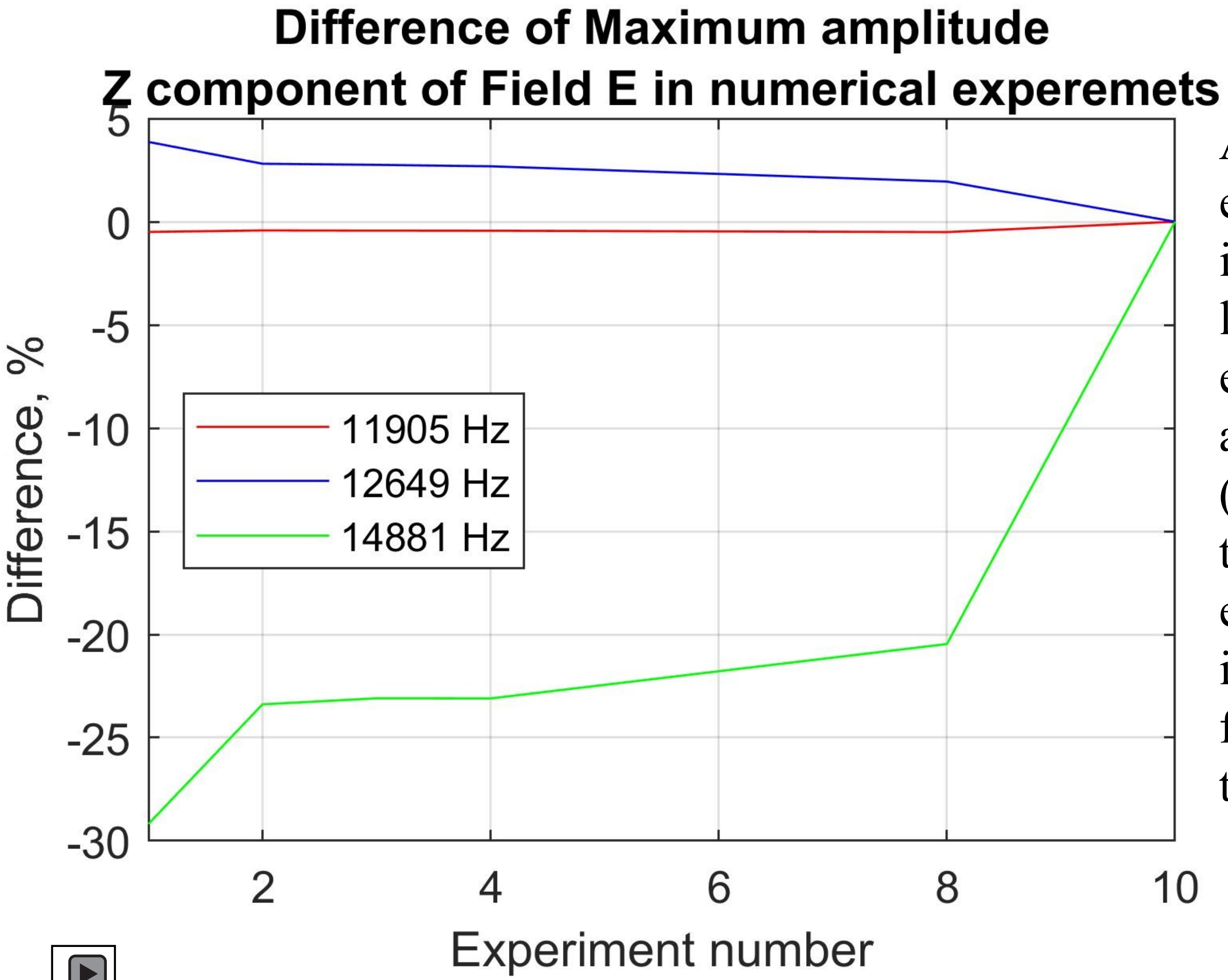


Variations of the components of the magnetic field in time at a distance of 49.5 km from the source at the surface of the Earth.

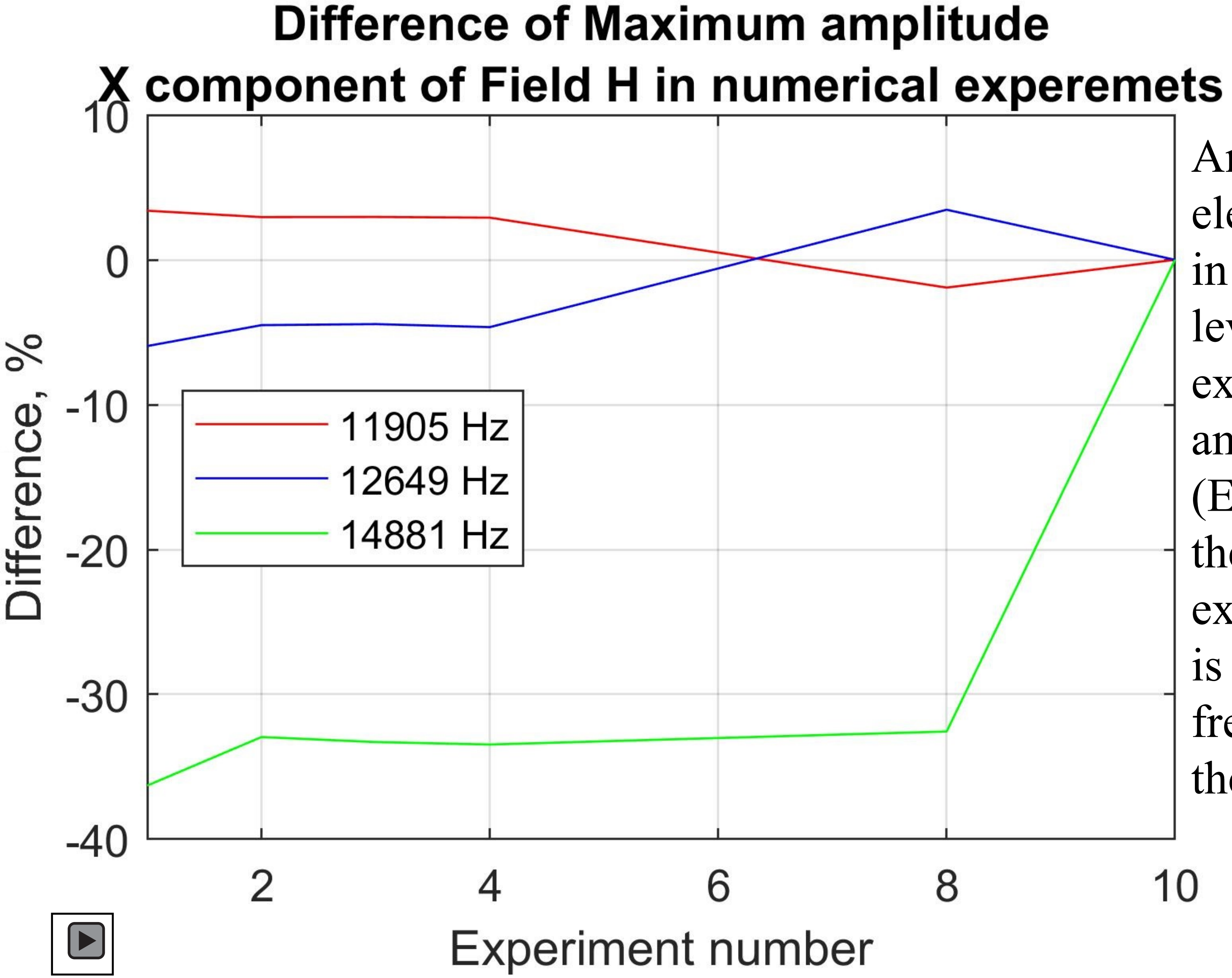


Maximum amplitude components of Field H by distance at freqence 11905 Hz

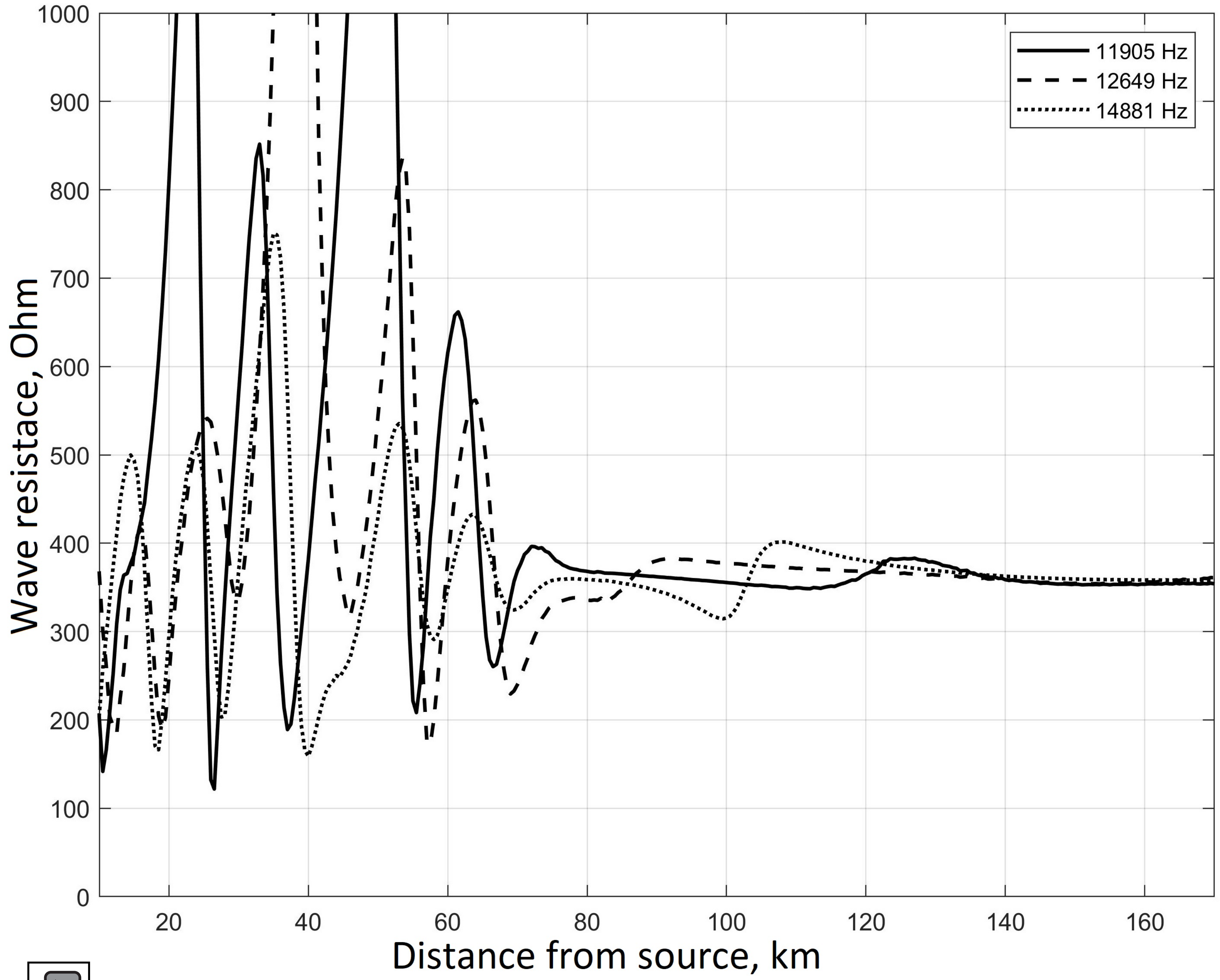




Amplitude changes of the E_z electromagnetic field component in percent at the Earth's surface level for different numerical experiments compared to the amplitude under calm conditions (Experiment 10). On the x axis, the graphs indicate the experiment number, and the color is the graphs for different frequencies from the set used by the RSDN-20 system.



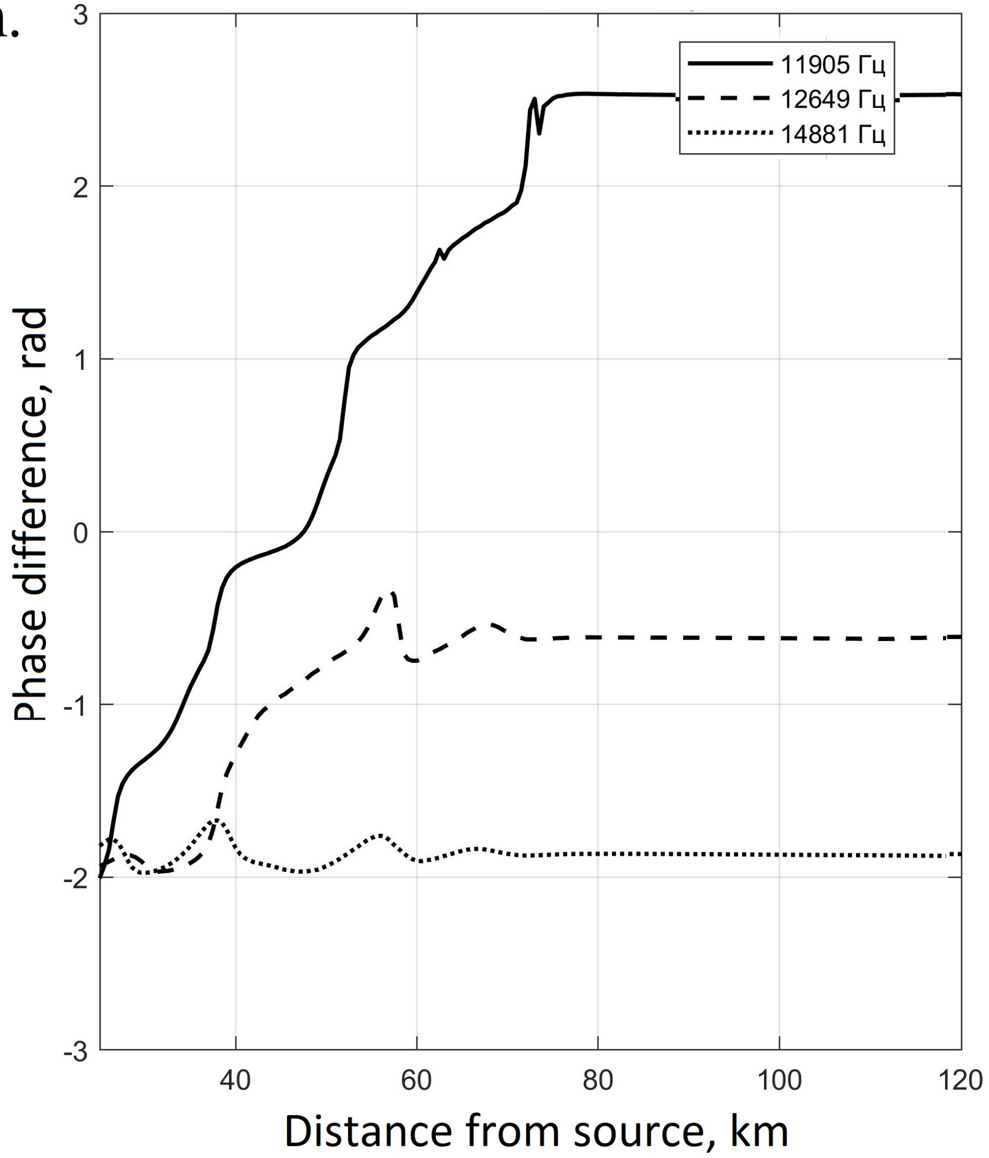
Amplitude changes of the H_x electromagnetic field component in percent at the Earth's surface level for different numerical experiments compared to the amplitude under calm conditions (Experiment 10). On the x axis, the graphs indicate the experiment number, and the color is the graphs for different frequencies from the set used by the RSDN-20 system.



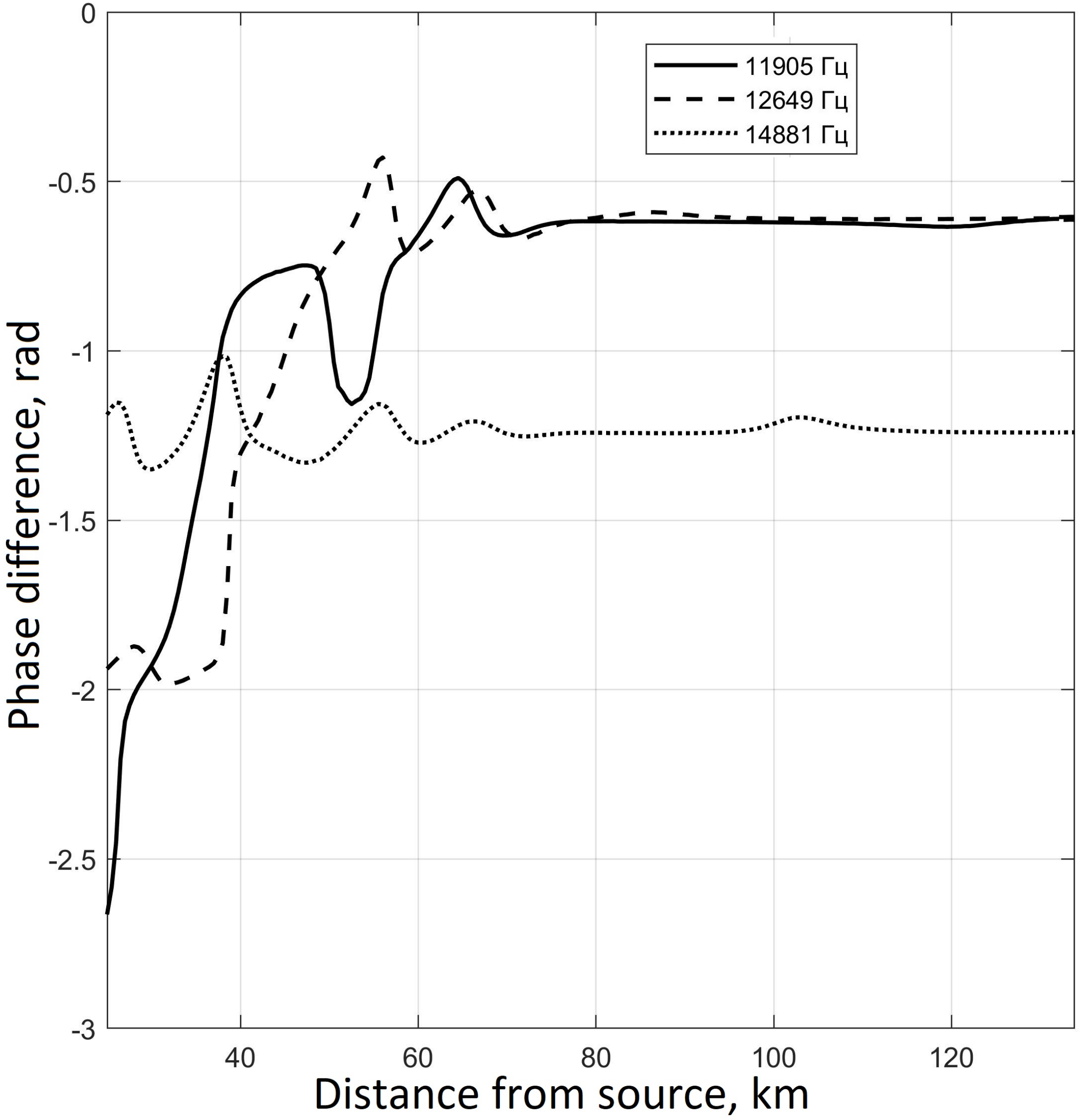
Wave resistance as a function of the distance to the source for the case of a no disturbed ionosphere. The line type indicates the frequency of the signal.

At distances from the source less than 80 km, the wave impedance varies widely, and at a distance from the source of more than 140 km, the wave impedance practically does not change. The resistance value after 140 km is ~ 360 Ohm.

The phase difference between the field components E_z and H_x in the case of a sub storm.



The phase difference between the components of the field E_z and H_x in calm conditions.



Conclusions

Under the conditions of magnetic substorm on 11.12.2015, according to the obtained data of numerical experiments, there are significant, more than tens of percent, deviation of signal amplitudes at the level of the Earth's surface. At the same time the phase characteristics proved to be much more stable, their changes for different profiles of ionosphere parameters did not exceed 2.5%. Significant frequency dependence was observed in the disturbed ionosphere conditions. With increasing frequency, the amplitude distortion of the signals of the radio navigation system also increases in the case of disturbed ionosphere. At the maximum frequency of the system RSDN-20 14881 Hz there is a decrease in amplitude of the main components of the electromagnetic field up to 30% under magnetic substorm conditions.

The obtained results make it possible to conclude on possibility of using RSDN-20 signal at frequency 14881 Hz for geophysical research of ionosphere.