Numerical simulation of European VLF network response to X-class solar flare in September 2017.

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We present the experimental evidence for European VLF network data on the response of the lower ionosphere and frequency-dependent VLF data under the consequent X-class solar flares 06 September and 10 September 2017. The stations under analysis include European AWESOM monitors, which are distributed over all Europe. Data from geophysical observatory "Mikhnevo" (MKH) of the Institute of Geosphere Dynamics (54.57N, 37.46E) covers frequency range from 1Hz to 100 kHz, thus allowing the monitoring of all VLF/LF transmitters as well as Schumann resonance. The monitoring is evaluated both in magnetic field channel by METRONIX MFS07 magnetometer (3 components) and in electric field channel by Rhode&Schwarz ESCI receiver (vertical electric field).

The results of measurements clearly demonstrate the significant difference between X-class flares on 06 and 10 September respectively. These flares have close class, but different integral energy flux as well as temporal dynamics. The aforementioned statement is proved by Schuman resonance shift measurements. In order to explain the evidence the numerical simulation approach is used.

The ionosphere model of the lower ionosphere [1] is used with extended ionization source by solar X-ray flux. The model includes NO^+,O_2^-, positive and negative cluster ions and electrons. Original 1-min data from GOES-15 were converted to the X-ray spectrum with further calculation of spatial and temporal distribution of the ionization rate by means of Monte-Carlo simulation. This simulation includes the sphericity and the upper energy boundary is 100 keV. The neutral atmosphere major constituents are given by NRLMSISE empirical model. The following set of paths was simulated: GBZ-MKH, GQD-MKH, NRK-MKH, TBB-MKH, DHO-MKH, DCF-MKH, ICV-MKH, FTA-MKH. The complement set of AWESOM paths from GQD, GBZ and DHO was simulated too.

The X-flare 06.09.2017 was observed from 11:56:23UT to 13:38:00UT (at the level 10^{-4} W/m^2), energy integral was 0.45 J/m^2 in 0.5-4 nm band and 1.41 J/m^2 in 1-8 nm band. The X-flare 10.09.2017 was observed from 15:54:19UT to 17:26:08UT (at the same level), integral energy was 0.6 J/m^2 in 0.5-4 nm and 1.94 J/m^2 in 1-8 nm band. The respectively close elongation (104 and 92 minutes) of flares is accompanied by different integral energy and sharpness. This results in very different spatio-temporal distribution of ionization source. Figure 1 provides the result of numerical simulation of the excess X-ray ionization on September 6 2017 over MKH station. Figure 2 provides the same results for 0E meridian on September 10 2017.

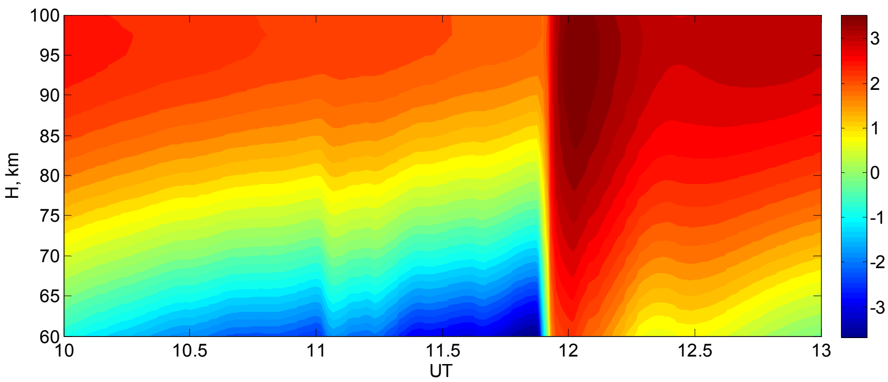

Figure 1. The excess ionization by X-flare 06 September 2017 over "Mikhnevo" (logarithmic color scale, units are el/cm^{3}sec)

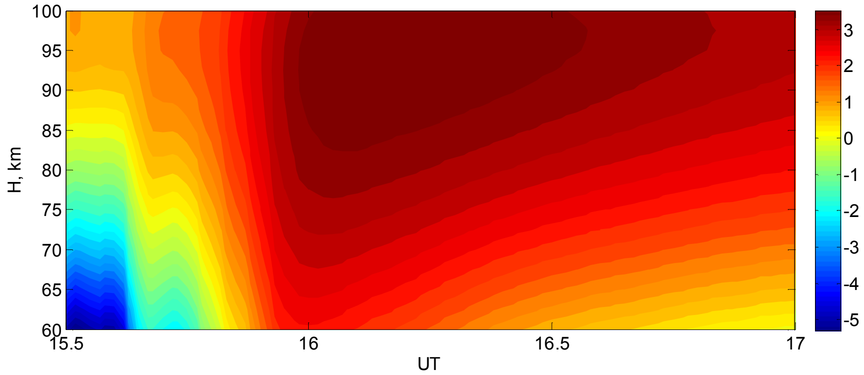

Figure 2. The excess ionization by X-flare 10 September 2017 over the point 52N,0E (logarithmic color scale, units are el/cm^3sec)

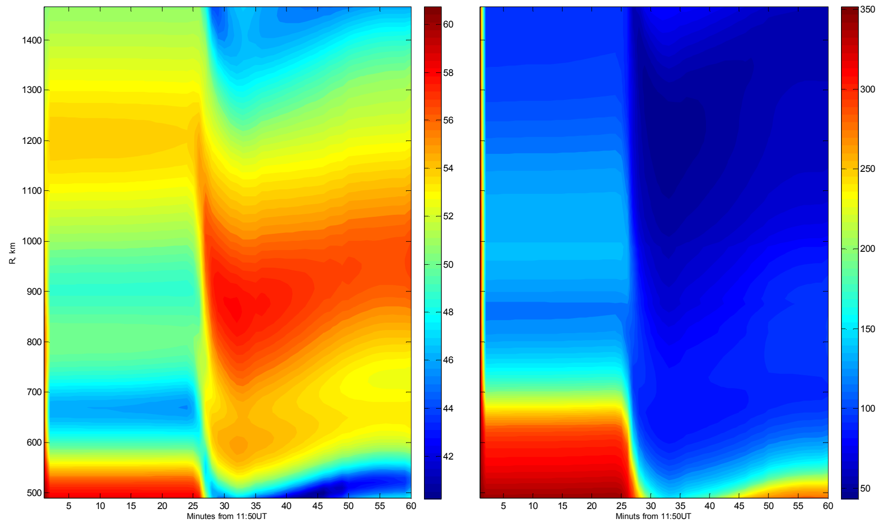

Figure 3. Distribution of electric field amplitude (dBuV/m – left panel) and phase (degrees- right panel) from GBZ transmitter (19.8 kHz) to the A118 SID receiver (44N, 0.5E) under the X-flare 06 September 2017

Figure 3 provides the results of numerical simulation for the European path from GBZ transmitter to A118 SID station monitor (https://sidstation.loudet.org/data-en.xhtml). The simulation of the radio wave propagation was evaluated by LWPC code in the range profile mode [2].

The dependence of positive/negative amplitude response to the solar flare is reproduced. The different response at various stations (paths) is explained by the complex dynamics of the field distribution over the propagation path.

1. A.A. Egoshin, V.M. Ermak, Y.I. Zetzer, S.I. Kozlov et al., "Influence of meteorological and wave processes on the lower ionosphere during solar minimum conditions according to the data on midlatitude VLF-LF propagation," *Izvestiya-Physics Of The Solid Earth*, **48**, 3, pp.275-286, doi: 10.1134/S1069351312030020
2. Ferguson, J. A., 1998, Computer Programs for Assessment of Long-Wavelength Radio Communications, version 2.0, Technical document, 3030, Space and Naval Warfare Systems Center, San Diego, California, USA.