Observations of the geomagnetic storm 27-28.05.2017 with LOFAR PL610

Mariusz Pożoga[1], Barbara Matyjasiak[1], Marcin Grzesiak[1], Hanna Rothkaehl[1], Dorota Przepiórka[1] and Roman Wronowski[1]

1. Space Research Centre Polish Academy of Sciences, Bartycka 18A, 00–716 Warszawa, Poland

We present here the measurements and the data analysis obtained by the polish LOFAR station PL610 during the geomagnetic storm which occurred at 27-28.05.2017. The observed G3 type storm that was a result of the Earth's magnetic field disruption is a good laboratory for studying the behavior of the ionosphere. The monitoring of the radio signal scintillations can be used for determining the local properties of the Earth's ionosphere.

1 Introduction

An electromagnetic (EM) wave which propagates through a medium with spatially variable refraction index is scattered on irregularities and superposition of contributions from each structure forms a complex diffraction pattern. Such fluctuations of EM wave, called scintillations, affect performance of many technologies that use EM signals: radio communication, satellite positioning, low frequency radioastronomy etc. Scintillating signals bear many characteristics of scattering medium and can provide information on the medium itself. On 23 May 2017, a coronal mass ejection (CME) took place on the Sun, and it headed toward the Earth and encountered the Earth's magnetic field on 27 May causing strong geomagnetic storm of type G3 (Kp index reached the value of 7). Geomagnetic index Dst, during the main phase of the storm, reached the value of -125 nT on 28 May at morning hours (about 8 UTC). The recovery phase of the geomagnetic storm lasted until 31 of May. During the time period from 26 May to morning hours of 29 May the LOFAR station PL610 worked in a local mode which allowed for monitoring of signal scintillation caused by turbulent ionosphere. The LOw Frequency ARray (LOFAR) designed for study distant astrophysical radio sources operates in the frequency range 10-270 MHz, very suitable for studying weak scintillation regimes that prevail in mid-latitude ionosphere. We present several examples of LOFAR signal analysis that contain signatures related to scattering of the radiosource signal on ionospheric structures during strong geomagnetic storm.

2 Observations

During the time period 26-29 May 2017 overlapping with occurrence of strong G3 type geomagnetic storm, the station PL610 conducted observations mainly focused on the monitoring of the signal scintillation from strong radio sources. Scintillation monitoring was performed on LBA (low band antennas) of LOFAR working in the frequency range from 5 MHz to 52 MHz with the rate of 4 bits per sample.

Measured amplitudes of signal from different frequency bands were used to calculate ionospheric scintillation level. Signal with 1 s time resolution is divided by

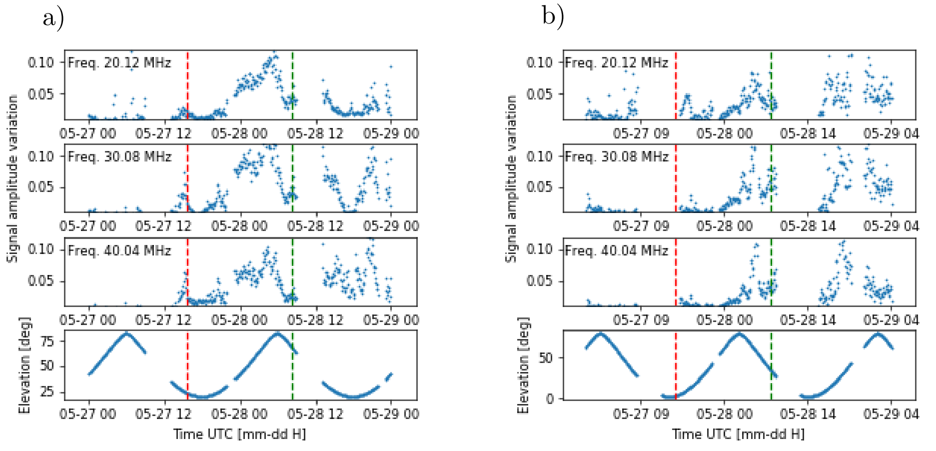

Fig. 1: The signal amplitude variation calculated for 3 different frequencies (3 top panels) of the radio sources: Cas A (a) and Cyg A (b), for a time period of 26-29.05.2017. Bottom panels present the elevation of the observed radio sources.

median and then the standard deviation is computed. Resulted signal amplitude variations for two sources: Cas A and Cyg A are presented in Fig. 1. Enhancements in the scintillation level obviously correlated with the occurring geomagnetic storm can be clearly seen. Sudden commencement occurred on 27 May at 15:36 and it is marked in Fig. 1 a) and b) by a vertical red line. From Cas A observations we can identify an amplitude variations increase correlated with this particular event. Cyg A was not observed due to too low elevation (below 30°). Another clearly visible signature of the storm manifestation is the scintillation peak associated with the minimum Dst value marked by a vertical green line. It can also be seen from Cyg A observations (Fig. 1 b).

3 Analysis

In case of a plane wave, the size of irregularities on which the signal amplitude scintillation occurs is limited by the Fresnel zone equation

$$d_{\mathrm{F}} = \sqrt{2\lambda z_i \sec\theta}, \tag{1}$$

where λ is the wavelength, z_i – the distance to the receiver, and θ – zenith angle of the intersection point of beam and phase screen.

For the frequency bands available for the LOFAR instrument the values are in a range from 1 km to 9 km (240-8 MHz) and they enable calculations of Fresnel frequency which determines point where scintillation spectrum loses its power-law form. For comparison, the size of irregularities affecting GPS measurements is about 300 m. Scintillation intensity is proportional to the $\lambda^{1.5}$ (Fremouw et al., 1978) thus with LOFAR instrument we are able to measure weaker amplitude scintillation than it is possible with GPS receivers. Spectrum of ionospheric plasma irregularities has

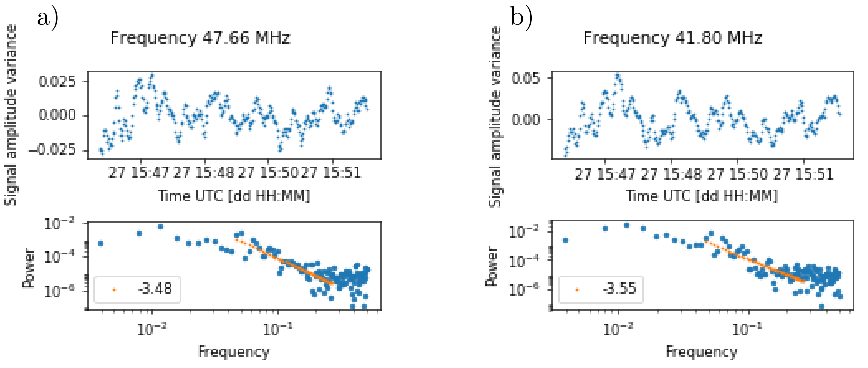

Fig. 2: Signal amplitude variance calculated for 2 different frequencies (top panels) and power spectrum (bottom) with the fitted power-law function (orange dots). Signal was measured from radio source Cas A during 6 min time period.

been shown to have power-law form of

$$W(f) = Tf^{-p}, \tag{2}$$

where f is frequency, p – spectral index and T – parameter related to the strength of turbulence.

The power spectra and amplitude variances for two frequencies from LOFAR measurements, together with fitted power-law functions are presented in Fig.2. Power spectra are calculated using a Welch method with 256 samples per window. Values of calculated p index are -3.48 and -3.55 for frequency 47 MHz and 41 MHz, respectively.

4 Summary

The analysis of signal scintillations from LOFAR single station observations can be a complementary tool for monitoring the ionosphere local properties. From the presented measurements we can summarize that for time periods when significant disturbances in the Earth's ionosphere occured, scintillations of signal amplitude can be measured and are consistent with theoretical predictions. Low-frequency range of the instrument allows for extending ionospheric scintillation studies for frequency bands and for sizes of ionospheric irregularities which are not covered with other methods (e.g GPS).

Acknowledgements. Work was partially supported by grant No. 6158/E-73/SPUB/2016/1 from the Polish Ministry of Science and Higher Education.

References

Fremouw, E. J., et al., *Radio Science* **13**, 167 (1978)