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Impact of strong solar flares on the lower ionosphere: radio waves, satellite observations and modeling

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Solar flare X-ray energy can significantly increase electron density in the Earth's atmosphere (Srećković et al. 2021). Such intense solar radiation due to increased solar activity can cause abrupt ionospheric disturbances, potentially leading to natural disasters (e.g. Kolarski et al. 2022 and references therein).

The primary goal of this research is to examine the changes caused by strong solar X-ray flares using very low frequency (VLF) and low frequency (LF) radio signals and satellite observations.

Numerical modeling is used to compute the ionosphere parameters caused by intense solar radiation.

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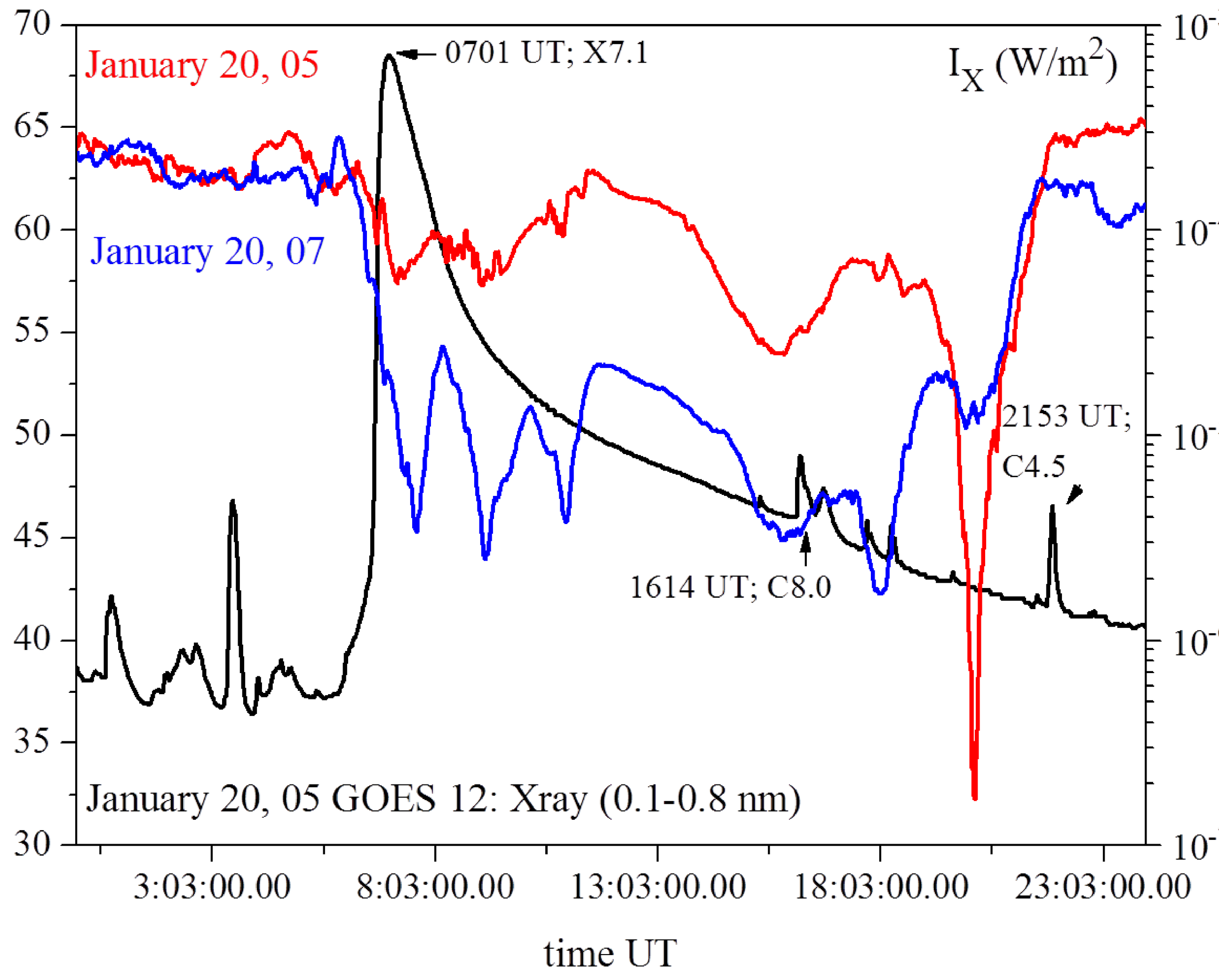
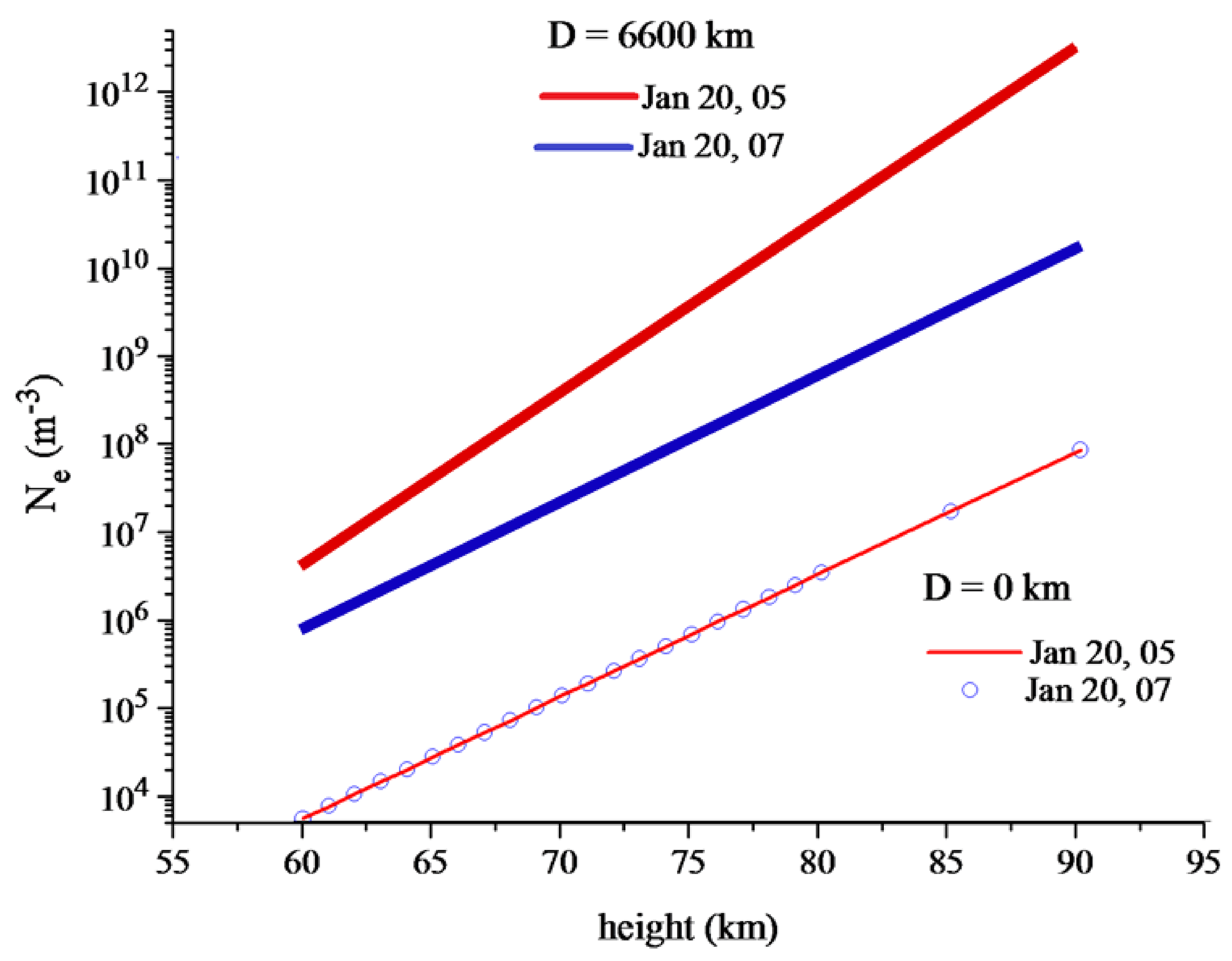
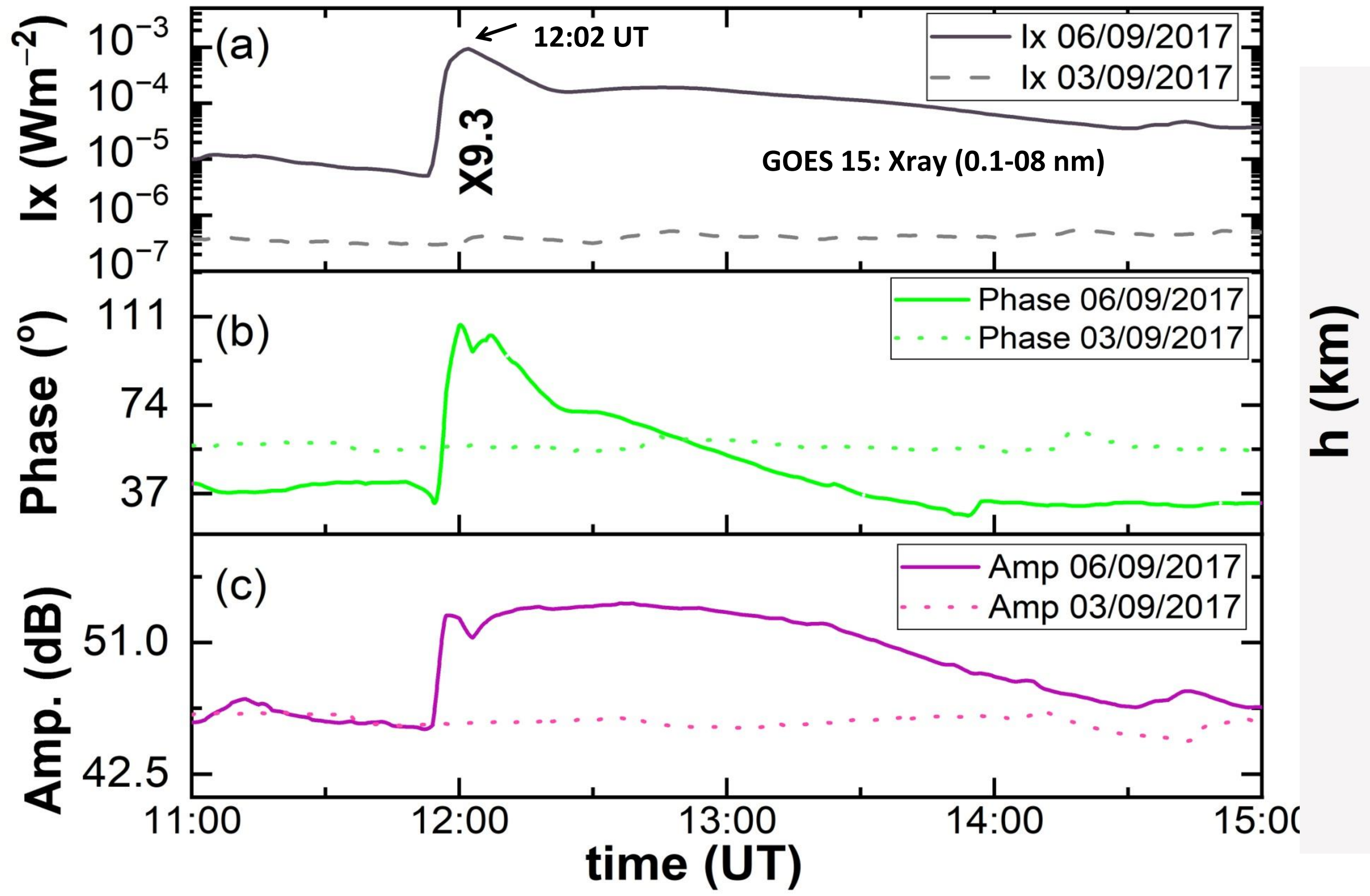
Impacts of strong X-ray SFs to VLF propagation parameters



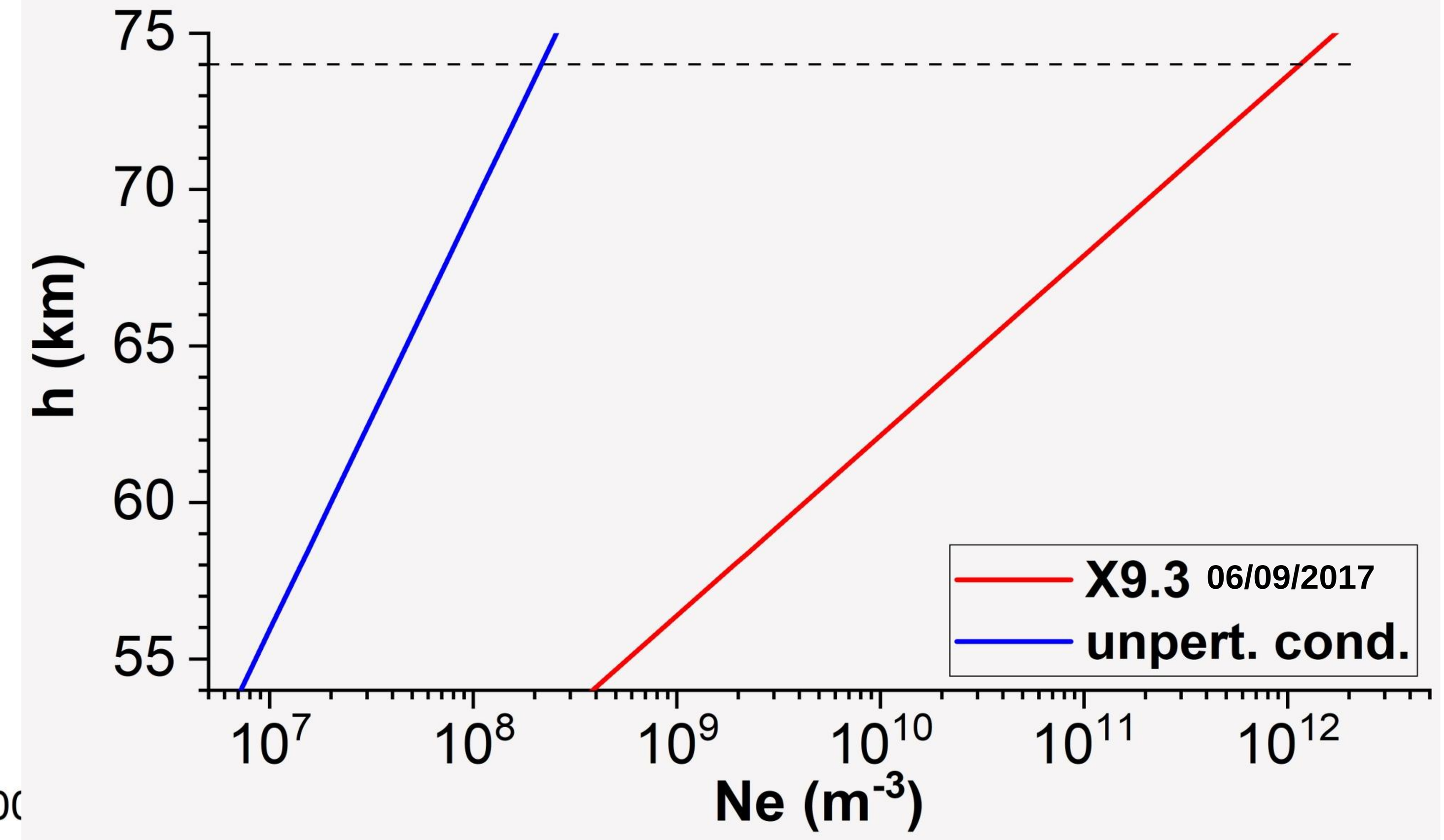
X-ray irradiance diurnal variation on perturbed day - January 20th, 2005 (black); NAA signal amplitude variations on perturbed day - January 20th, 2005 (red) and on quiet day – January 20th, 2007 (blue)



Electron density height profiles $N_e(z)$ in 60 - 90 km altitude range for NAA Tx-Rx GCP distance D, at midday max time 11:28 UT; perturbed day – January 20th, 2005 (red), quiet day – January 20th, 2007 (blue)



Variation of X-ray flux on perturbed day – September 6th, 2017 (black); GQD signal on perturbed day – amplitude (solid pink) and phase (solid green) Quiet GQD signal (dotted lines) on September 3th, 2017



Electron density height profiles $N_e(z)$ for GQD signal at peak intensity of X9.3 SF (red) on perturbed day September 6th, 2017 and in unperturbed ionospheric conditions (blue); reference height 74 km is indicated by dotted line

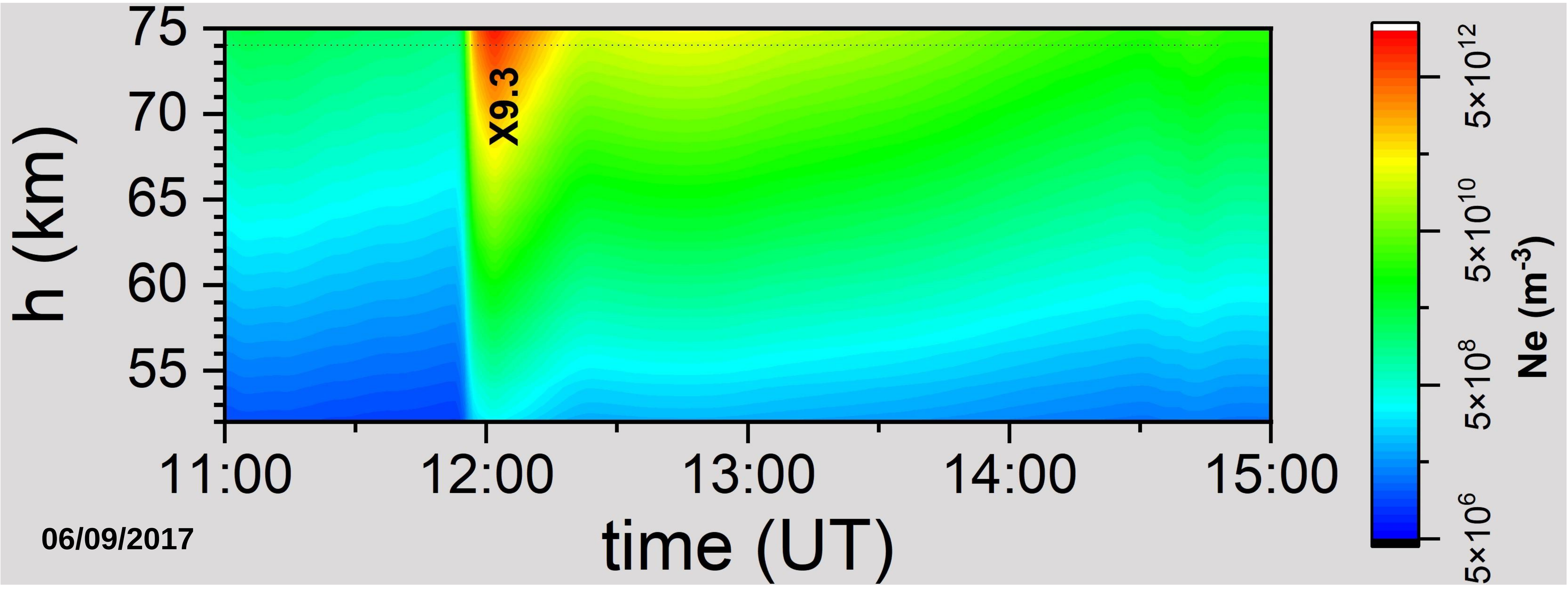
Analyzed VLF signals recorded by BEL station

Numerical modeling of lower ionospheric response to strong solar flares based on VLF propagation was conducted by means of Long Wave Propagation Capability (LWPC) program routine (Ferguson, 1998). $Ne(z)$ (m^{-3}) was calculated using expression designed for sunlit daytime ionospheric conditions (Wait and Spies, 1964), for given parameters sharpness β (km^{-1}) and reflection height H' (km):

$$Ne(z, H',\beta) = 1.43 \cdot 10^{13} e^{-0.15 H'} e^{(\beta-0.15)(z-H')}$$

FlarED' Method and Approximate Analytic Expression application, designed for obtaining VLF signal propagation parameters β and H' from incident solar X-ray irradiance, gave electron density profiles calculated by using polynomial equation (Srećković et al. 2021):

$$\log Ne(h, Ix) = a_1(h) + a_2(h)\cdot \log Ix + a_3(h)\cdot(\log Ix)^2$$



Electron density height profiles for GQD signal during four hours including peak intensity of X9.3 SF obtained through application of approximative equation; reference height 74 km is indicated by dotted black line