GROUND LEVEL EVENT on DECEMBER 13 2006: IMPLICATIONS FOR VLF TRANSMISSION

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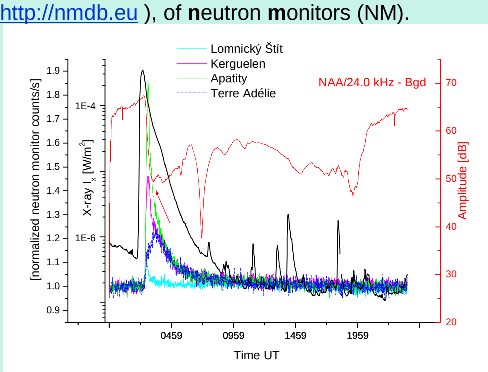
MOTIVATION

To analyze the **G**round **L**evel **E**nhancement **E**vent **GLE70** at altitudes 50-90 km, by two independent techniques: cosmic ray monitoring and **V**ery **L**ow **F**requency (VLF< 30 kHz) wave propagation, with the aim to investigate the extent to which the two approaches, supported by appropriate modelling, can provide an unified and and consistent picture of the impact of solar proton events on the lower ionosphere.

OBSERVATIONS

On 13 December 2006, an exceptionally strong GLE numbered 70 (GLE70), triggered by a powerful X3.4 X-ray solar flare with the maximum emission at 0240 UT has been detected by the ground-based network (http://nmdb.eu), of **n**eutron **m**onitors (NM).

Fig. 1: GLE70 signatures on: **NM networks** **GOES X-ray flux** **VLF Amplitude**



Correspondingly large amplitude attenuation in coincidence with phase increase of the VLF wave propagating between the transmitter NAA/24.0 kHz (Main,USA) and the AbsPAL receiver at the Belgrade VLF Observatory have been recorded, Fig.1.The VLF signal travels through the Earth-ionosphere waveguide, along the completely unlit 6548 km long path. The event has been recognized by the time corrrelation between the NM and VLF recordings and the satellite measurements of the high energy proton spectra e.g. GOES12 (Fig.1), PAMELA (Fig. 3).

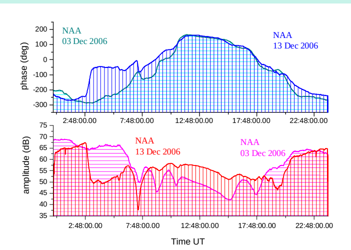


Fig. 2: VLF signatures of GLE70

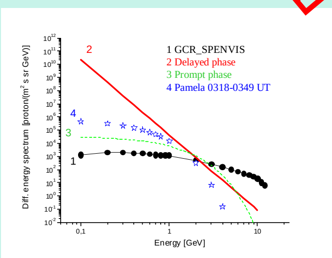


Fig. 3:Diff. Energy spectra, SP and GCR

Amplitude and phase of the VLF signal from NAA (44.63N, 67.28W), as measured at Belgrade (44.85N; 20.38E), on 13 December 2006 during the GLE70, are presented in Fig.2, superimposed on the respective values for the closest quiet day - 3 December 2006. The intensity of the event is evident: the signal amplitude remains above the quiet level of 3 December by remarkable 8 dB, throughout the main part of the day.
GLE70 has been a double-pulsed event with two distinct pulses/*phases:* the prompt and the delayed one (e.g. Moraal and Mc Cracken, 2012). The reconstructed proton differential energy spectra for the prompt and delayed phase of GLE70, according to Miroshnichenko et al. (2009), along with the background **G**alactic **C**osmic **R**ay (GCR) spectrum according to SPENVIS are presented in Fig. 3.
Here we refer to the second, delayed, less anisotropic phase of GLE70.

Modelling & Computation

The ionization rate *q(h)*, of **s**olar **p**rotons (SP) has been evaluated *ab initio* on the ground of the reconstructed proton energy spectrum (line 2 on Fig. 3) and the proton stopping power as given by PSTAR program (http://physics.nist.gov).The energy span of the primary proton kinetic energies (0.1-10^4 GeV) has been chosen in view of the cut-off rigidity values along the wave path, and the height span settled so as to comprise the domain of VLF wave propagation (50-90 km), the D – region. Ionization effects on VLF wave propagation have been modelled by the traditional Long Wavelength Propagation Capability (LWPC). The code determines, on the basis of amplitude and phase deviations from quiet night values, the disturbed electron density height profile $N(h)$ on the VLF signal path, in terms of the ionospheric reference height and sharpness. To provide comparison with the proton ionization, the induced electron density $N(h)$ is considered as a result of equilibrium between ionization and recombination processes:

$$q = \alpha N^2.$$

Here q is the ionization rate, presently evaluated and averaged over the cut-off rigidity along the VLF signal path and α is the effective electron recombination coefficient taken from literature.

RESULTS

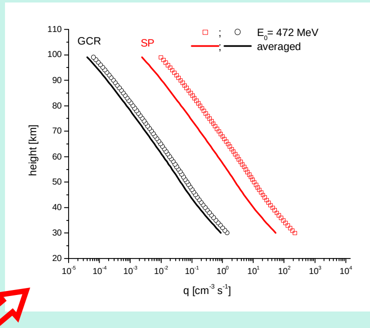
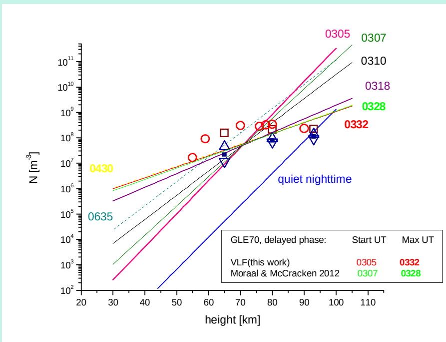


Fig. 4: Ionization rate profiles for SP and GCR

The averaging of q along the Earth-ionosphere waveguide, probed by VLF waves, results in q values which for solar protons are about 1.5 order of magnitude higher than that for CGR. The respective values for the lowest cut-off rigidity on the wave path (threshold energy 472 MeV) are 2 orders of magnitude higher.

Fig.5: Lines: electron density height profiles for 13 Dec. 2006, according to LWPC at different UT stages of the GLE70. Points: electron density from evaluated solar proton ionization rate and effective recombination coefficient as taken from: Osepian et al., 2009 (red circles), and Friedrich et al., 2004 (red squares – day values, blue squares –night values, blue triangles expected night deviations from temperature variation).



Electron density enhancements of two to three orders of magnitude above regular night values have been deduced from two independent monitoring techniques and pertaining modelling.The time structure of the GLE70 as recognized by the VLF amplitude and phase perturbations is in remarkable agreement with NM data prediction (inset in Fig.5). The two approaches support and guide one another, improving our knowledge on the impacts of GLE70.

References: Friedrich et al. 2004, Adv. Space Res. 34, 1937-1942
Miroshnichenko et al. 2009 *Bull. Russian Acad of Sci: Phys, 73, no. 3. 297–300*
Moraal and McCracken, 2012 Space Sci. Rev 171:85-95
Osepian et al. 2009, Ann. Geophys., 27, 3713–3724

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