Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research 53 (2014) 763–775

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

Response of the Earth's lower ionosphere to the Ground Level Enhancement event of December 13, 2006

Vida Žigman[a], Karel Kudela[b,*], Davorka Grubor[c]

[a] University of Nova Gorica, Vipavska 13,5000 Nova Gorica, Slovenia
[b] Institute of Experimental Physics, SAS, Košice, Slovakia
[c] University of Belgrade, Faculty of Mining and Geology, Physics Cathedra, Djusina 7, 11000 Belgrade, Serbia

Received 29 July 2013; received in revised form 17 December 2013; accepted 20 December 2013
Available online 3 January 2014

Abstract

In this study we analyze the Ground Level Enhancement Event No 70 observed on December 13, 2006, by correlating the observations from two research topics: Cosmic rays and Very Low Frequency (VLF < 30 kHz) wave propagation, as two ground based techniques for the detection of solar proton events, and their impact on the lower ionosphere. The observations have been endorsed from recordings of worldwide network ground based Neutron Monitors as well as by satellite data from the satellites GOES 12 (www.swpc.noaa.gov) and Pamela (www.pamela.roma2infn.it).

We have evaluated the ionization rate for protons in the altitude range relevant to VLF propagation, and for galactic cosmic ray (GCR) background, finding that at energies up to ~2 GeV the ionization rate of solar protons exceeded the GCR ionization by 1.5 orders of magnitude.

We have applied the Long Wave Propagation Capability (LWPC) code to evaluate the enhancement of the electron density from VLF signal perturbation and have inferred corresponding electron densities from the evaluated ionization rates and effective recombination coefficients from literature, to find the two independent sets in good agreement.
© 2013 COSPAR. Published by Elsevier Ltd. All rights reserved.

Keywords: VLF; Ground Level Enhancement Event; Cosmic rays; Solar proton event

1. Introduction

The Earth's mesosphere and lower ionosphere, the D-region in particular which extends from some 50 to 90 km in height, are the ultimate depository of solar energy in the Earth's ionized environment, and thus one of the final links in the Sun–Earth connection.

On the Earth's surface this connection is dramatically manifested through Ground Level Enhancement events (GLE) – sporadic high energy processes at and near the Sun yielding increases in cosmic ray intensity, mainly protons, with energies high enough to produce secondary particles observable by *ground based detectors*, above the flux of those particles produced by galactic cosmic rays. GLEs, as the name suggests are readily recorded by ground-based neutron monitor (NM) networks.

At higher altitudes above the D-region (i.e. the E and F regions), the standard sounding of the ionosphere, using ionosonde networks or Incoherent Radar Scattering (IRS) campaigns, (HF and VHF/UFH-band radio waves, respectively) is applicable. However these frequencies are too high for the exploration of the D-region, characterized by low electron and high neutral densities. D-region electron densities are successfully observed by the differential absorption technique by using MF and HF radars (Holdsworth et al., 2002; Singer et al., 2011) and by wave reflection of VLF signals (VLF < 30 kHz) from man-made transmitters (McRae and Thomson, 2000). VLF waves

* Corresponding author. Tel.: +421 556224554.
E-mail addresses: vida.zigman@ung.si (V. Žigman), kkudela@kosice.upjs.sk (K. Kudela).

0273-1177/$36.00 © 2013 COSPAR. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.asr.2013.12.026

travel along the Earth–ionosphere waveguide, probing the lowest ionosphere by reflections and thus bear signatures of solar eruptive activity through wave amplitude and phase deviations from regular quiet day behavior. The induced deviations are caused by ionization enhancements triggered by space weather phenomena e.g. X-ray flares, solar energetic particles, coronal mass ejections.

Solar X-ray flares have been widely studied by VLF propagation, since the pioneering works of e.g. Mitra (1974), till present (Thomson et al., 2005; Clilverd et al., 2009). Radiation in the range 0.1–0.8 nm penetrates to altitudes below 85 km and dominates over all other radiation (including Lyman alpha) during flares, significantly changing the electron density on the dayside atmosphere. However, the night side of D-region is not as extensively discussed in the literature (Pappert and Hitney, 1988; Thomson et al., 2007).

It is the aim of this study to investigate, by using VLF wave propagation, ionization changes of the nighttime D-region, caused by solar energetic particles, in particular.

Indeed, one of the possible contributors in changing the ionization production at the altitudes important for transmission of VLF waves on the night side of Earth, is the variability of cosmic ray flux. To check this effect in particular cases, it is suitable to select the events on rather short time scale with strong changes of high energy particle fluxes, i.e. either decreases (Forbush decrease, Forbush, 1937) or GLE increases. The numbering of GLEs started from 1 in late February 1942 (described in paper by Forbush (1946)) and as accepted by the cosmic ray community, 71 events have been detected until now (the list can be found e.g. at http://neutronm.bartol.udel.edu/~pyle/GLE_List.txt). The GLEs characteristics, like energy spectra and anisotropy have been studied using ground level cosmic ray equipments (e.g. Cramp et al., 1977; Vashenyuk et al., 2000; Vashenyuk, 2011; Bütikofer et al., 2013 among others). For strongly anisotropic events one has to include "magnetospheric optics" too.

With increasing amount of data of high energy particle measurements on satellites, the energy spectra of solar proton events (SPE) in which GLEs are involved as the highest energy events, have received increased attention and their time evolution along with the anisotropy have become a topic of intensive study. During the 23rd solar activity cycle, 16 GLEs have been observed (discussion in connection with various space weather consequences e.g. by Shea and Smart (2012) and Gopalswamy et al. (2012)).

For detection of the highest energies to which the protons during the solar flare and/or at plasma discontinuities in interplanetary space have been accelerated, the data from a network of neutron monitors are used. Such data have been recently collected and are regularly updated at (http://nmdb.eu). Specific role play the high altitude neutron monitors with high statistical accuracy allowing to observe small increases during the GLEs. Using the list of GLEs observed at Lomnický Štít (Kudela and Langer, 2008) we have selected an unusually high GLE of 13 December 2006, accompanied the X3.4 X-ray flare with the onset at 0240 UT. Namely, this is the only event (named GLE70), during local night time in Europe with >10% increase at Lomnický Štít out of all GLEs in 23rd solar cycle, on one hand (Fig. 1, upper panel). The GLE70 had also a paramount signature on the amplitude and phase of the VLF signal from the transmitter NAA/24.0 kHz at Main Cuttler (USA) (44.63N, 67.28W), as received by the AbsPAL VLF receiver at Belgrade VLF Observatory (44.85N; 20.38E), on the other.

Fig. 2(a) and (b) clearly illustrate the extent of the signal changes with respect to quiet conditions The registered dramatic decrease of 18 dB in amplitude and the accompanying 190 deg increase in phase correspond to the onset of the hard proton event (Fig. 2(b)).

Therefore it is the aim of this study to analyze the GLE70, i.e. the impact of the associated solar proton event on the lower ionosphere from two, above outlined distinct points of view: cosmic ray ionization and VLF propagation, in order to check the unique picture of the ionization enhancement in the altitude range 50–90 km. The high-energy proton observations and the VLF registrations are endorsed by satellite measurements from GOES 12 and Pamela.

In the following sections we (i) compute the ionization rate due to solar protons for the second phase of the GLE70; (ii) discuss the corresponding amplitude and phase deviations observed in the VLF transmission; (iii) by utilizing the LWPC code we determine the electron density height profile in the D-region and compare it with electron density estimates that follow from the evaluated proton ionization rates and effective electron recombination coefficients taken from literature.

2. The GLE70: observations and characteristics – ionization by protons at >30 km

On 13 December 2006, during the solar activity phase not distant from the solar minimum of the 23rd solar cycle, an exceptionally strong GLE70 triggered by a powerful X3.4 X-ray solar flare with the maximum emission at 0240 UT has been observed. During the GLE70, on 13 December 2006, the geomagnetic activity decreased to mostly quiet levels, the quiet conditions persisting through the first half of 14 December 2006 (NOAA Weekly Reports, www.swpc.noaa.gov).

The GLE70 has been found to have the remarkable feature of a two-phase (or two-component) event, with the first more intensive and anisotropic pulse (prompt phase/component) and the second less intensive and less anisotropic pulse (delayed phase/component), (Miroshnichenko et al., 2009; Moraal and McCracken, 2012).

For the GLE70 there exist measurements accumulated from many neutron monitors on nmdb.eu data base (e.g. see Fig. 1, upper panel). The satellite measurements (GOES, PAMELA) provide the data during that event at lower energies and thus the energy spectra in wide range

Download English Version:

https://daneshyari.com/en/article/1763893

Download Persian Version:

https://daneshyari.com/article/1763893

Daneshyari.com