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The SEVAN Worldwide network of particle detectors: 10 years of operation

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Abstract

The Space Environment Viewing and Analysis Network (SEVAN) aims to improve the fundamental research on particle acceleration in the vicinity of the sun, on space weather effects and on high-energy physics in the atmosphere and lightning initiation. This new type of a particle detector setup simultaneously measures fluxes of most species of secondary cosmic rays, thus being a powerful integrated device for exploration of solar modulation effects and electron acceleration in the thunderstorm atmosphere. The SEVAN modules are operating at the Aragats Space Environmental Center (ASEC) in Armenia, in Croatia, Bulgaria, Slovakia, the Czech Republic (from 2017) and in India. In this paper, we present the most interesting results of the SEVAN network operation during the last decade. We present this review on the occasion of the 10th anniversary of the International Heliophysical Year in 2007.

Keywords: Cosmic rays; Networks of particle detectors

1. Introduction

The sun influences earth in different ways by emission of electromagnetic radiation, solar plasmas, and high-energy particles. Although the total energy of the emitted particles comprises a very small fraction of the energy of the visible light, the study of these particles provides valuable information on the huge solar explosions which affect the near-earth space, space-borne and surface technologies, i.e. on the so-called space weather. In 1957, in an unprecedented international cooperation, more than 66.000 scientists and engineers from 67 nations perform measurements of the major geophysical parameters in the framework of the International Geophysical Year (IGY1957, Chapman, 1959).

Fifty years on, the International Heliophysical Year (IHY 2007, Thompson et al., 2009) again drew scientists and engineers from around the globe in a coordinated observation campaign of the heliosphere and its effects on planet earth. The United Nations Office for Outer Space Affairs, through the United Nations Basic Space Science Initiative (UNBSSI), assisted scientists and engineers from all over the world in participating in the IHY. The most successful IHY 2007 program was to deploy arrays of small, inexpensive instruments around the world to get global measurements of ionospheric and heliospheric phenomena. The small instrument program was (and still is) a partnership between instrument developers and instrument hosts in developing countries. The lead scientist prepared and installed the instruments and helped to run it; the host

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countries provided manpower for instrument operation and maintenance. The lead scientist's institution developed joint databases, prepared tools for user-friendly access to the data, assisted in staff training and paper writing to promote space science activities in developing countries.

The sun is a tremendously variable object, capable of changing the fluxes of the Solar Cosmic Rays (SCR) by 3–4 orders of magnitude in a span of a few minutes. These transient events are called "Solar Proton Events (SPEs)" and "Solar Energetic Particle (SEP) events". Because of the sun's closeness, the effects of the changing fluxes can have a major influence on the earth, including climate, safety, and other areas. The sun "modulates" the low energy Galactic Cosmic Rays (GCR) in several ways. Along with broadband electromagnetic radiation, the explosive flaring processes on the sun usually result in Coronal Mass Ejections (CME) and in acceleration of copious electrons and ions. Particles can be generated either directly in the coronal flare site with a subsequent escape into interplanetary space, or they can be accelerated in CME-associated shocks that propagate through the corona and interplanetary space. These particles are effectively registered by spectrometers located at the Lagrangian point L1 (SOHO, ACE) and on satellites (GOES, SDO). In recent years, the increasing precision and extended energy range of direct cosmic ray measurements supplied by AMS-02 and PAMELA allow shedding light on the details of the solar modulation during solar cycles 23 and 24 (Corti et al., 2016). However, the small size of satellite-based detectors and the small number of satellites does not provide sufficient statistics in the high-energy region for real-time monitoring of the space weather. Therefore, space and ground observations should be conducted simultaneously in a way to provide complementary information.

Networks of particle detectors on earth, located at different latitudes and altitudes are monitoring the solar activity for many decades without interruptions. The highest energy SCRs generate particle showers in interactions with atmospheric nuclei that can reach the earth surface and generate signals in surface particle detectors (similar to ones initiated by GCRs). Such events are called Ground Level Enhancement (GLE). The latitude dependence of the geomagnetic field provides the possibility to use worldwide networks of Neutron Monitors (NM; Hatton (1971a, b), Simpson, 2000) as a spectrometer, registering GCR in the energy range from 0.5 to 10 GeV.

The spectra of GCR can be approximated by a power law $dJ/dE \sim E^{-\gamma}$ with $\gamma \sim 2.7$. The intensity of the SEP events at energies above hundreds of MeV usually decay very fast (with exponential cut-off of the power-law spectrum; Miroshnichenko and Nymmik, 2014). Only for some events, such as the one on 20 January 2005, the spectra of SCR are considerably "harder", reaching energies up to 1 GeV (see Fig. 1 from Labrador et al., 2005 and Table 1 in Asvestari et al., 2017). Thus, for the GeV energies the intensity of the GCR becomes increasingly higher than the intensity of the largest observed SEP events and we are confronted with the very complicated problem of detecting a small signal from the sun against the huge "background" of the GCR. Most existing networks of particle detectors are unable to reliably detect very low particle fluxes of SEP events in the GeV region. Therefore, the maximal energy of solar accelerators is still not determined (Miroshnichenko and Nymmik, 2014). However, measurements at the Aragats Space-Environmental Center (ASEC, Chilingarian et al., 2005) of the huge SEP of January 2005 with a large underground muon detector allowed an estimate of the maximal energy of solar proton accelerators to be up to 20 GeV and more (Bostanjyan et al., 2007, Chilingarian and Bostanjyan, 2009). Through measurements of enhanced secondary fluxes of the various charged and neutral particles at the surface of the earth, it is possible to estimate the power law index of the SEP energy spectra. Considerably large values of the recovered spectral index ($\gamma = 4$–5) at GeV energies is a very good indicator for the upcoming severe radiation storm (abundant SCR protons and ions with energies 50–100 MeV, see Chilingarian and Reymers, 2008), dangerous for astronauts, high polar airplane flights and satellite electronics. Each of the measured secondary particle fluxes has a different, most-probable energy of the primary "parent" (i.e. proton or nucleus). As we demonstrated in (Zazyan and Chilingarian, 2009), for the Aragats facilities these energies vary from 7 GeV (most probable energy of primary protons creating neutrons) to 20–40 GeV (most probable energy of primary protons generating muons with energies above 5 GeV). Thus, for predicting upcoming radiation storms it is necessary to monitor changing fluxes of the different species of secondary cosmic rays with various energy thresholds. To cover a wide range of secondary cosmic rays energies we need networks of particle detectors at different latitudes longitudes and altitudes.

Other solar modulation effects also influence the intensity of the cosmic rays in the vicinity of the earth. Huge magnetized plasma structures usually headed by shock waves travel into the interplanetary space with velocities up to 3000 km/s (so-called interplanetary coronal mass ejection – ICME) and disturb the interplanetary magnetic field (IMF) and magnetosphere. These disturbances can lead to major geomagnetic storms harming multibillion assets in the space and at ground. At the same time, these disturbances introduce anisotropy in the GCR flux. Thus, time series of intensities of high-energy particles can provide highly cost-effective information also for the forecasting of the geomagnetic storm (Leerungnavarat et al., 2003). With data from networks of particle detectors, we can estimate the GCR energy range affected by ICME and reveal the energy-dependent pattern of the ICME modulation effects. For instance, surface particle detectors can precisely measure the attenuation of the GCR flux in the course of a few hours with following recovering during several days (Forbush decreases, FD, see Bostanjyan, Chilingarian, 2009). Measurements of the FD magnitude in the fluxes of different secondary CR species reveal important correla-