A Mini Neutron Monitor in Central Antarctica (Dome Concordia)

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Abstract
A new detector of cosmic rays is installed at station Concordia in Central Antarctica (75°06’S, 123°20’E, 3233 meters a.s.l.). It is built by the North-West University (Potchefstroom, South Africa) for the University of Oulu in the framework of the Finnish Antarctic Research Program (FINARP). The setup consists of two modules: a standard design mini neutron monitor and a lead-free, so-called “bare”, neutron monitor. They got the names DOMC and DOMB, respectively. Station Concordia is an optimal site to detect solar cosmic rays and low-energy cosmic rays because of low geomagnetic cut-off and high altitude. The site has the asymptotic acceptance cone, which is almost perpendicular to the equatorial plane pointing to geographical southern latitudes > 80° for particles with energies above a few GeV. Thus, it is the only station which accepts cosmic rays from the south polar direction.

The instrument has started its operation in January 2015 and works properly since then. The average count rates of DOMC and DOMB are about 16.5 and 4.3 cts/s, respectively. The barometric correction coefficients are -0.75±0.07 %/mb and -0.71±0.04 %/mb with the reference atmospheric pressure set to 650 mb. The data are received on a daily basis and are publicly available in the databases cosmicrays.oulu.fi and nmdb.eu.

Introduction
A neutron monitor is a standard ground-based instrument for cosmic ray (CR) measurements via detection of the hadronic component of the cosmic ray induced cascade in the atmosphere. Several tens of such instruments form the world-wide neutron monitor network widely used for cosmic ray and heliospheric studies. The location of a detector is very important in many senses. Because of the atmospheric attenuation of the cosmic ray cascade, highly elevated detectors are notably more sensitive to cosmic ray particles than sea-level ones. The geomagnetic field plays also a crucial role because it modifies trajectories of charged particles, and low-latitude ones cannot reach the top of the atmosphere. This cut-off is distributed nonuniformly over the globe: it is maximal at the geomagnetic equator and nonexistent at the poles. These facts make highly elevated polar locations very sensitive to charged particles coming from the space, which is important for studies of solar energetic particle events with often insufficient energies to be detected with, e.g., sea-level subpolar neutron monitors.

The geomagnetic field defines not only sensitivity of a site to cosmic radiation, but also its acceptance cones, e.g., a set of directions from where the location accepts cosmic rays. The variety of properties of cosmic ray stations distributed over the world makes sense to use them as a network, a unique joint instrument able to measure spectral and spatial characteristics of cosmic rays. However, the network in the present state is not ideal and has high potential for improvement with new instruments that would be placed in some particular locations, especially in the polar regions.

Site and its sensitivity to cosmic rays
The new cosmic ray station presented here is located at Dome C at the Antarctic Plateau (75°06’S, 123°20’E, 3233 m above sea level, Figure 1). It started operation in January 2015 in the physics shelter of the French-Italian research station Concordia. Dome C is one of the best sites in the world for measurements of cosmic rays because of zero geomagnetic cutoff and relatively low atmospheric attenuation, which make it the low-energy part of the CR spectrum detectable there.

The second key feature of the site is its set of asymptotic acceptance cones. Dome C is unique in this sense because only that station has the field of view in the south poleward direction in the rigidity range of 1-20 GeV (Figure 2). Other existing stations including Antarctic ones receive most of particles from the equatorial plane.

Instruments
The setup consists of two neutron monitors (Figure 3): one has the standard design with a lead layer, and another one is “bare” (lead-free). The instruments have different response functions, and this makes it possible to roughly estimate the cosmic ray spectrum with only single station. The neutron monitors are designed and made by the Centre of Space Research (North-West University, Potchefstroom, South Africa) [2]. The instruments are relatively compact, each of them is about 1/3 in size and weight of 1NM64. The reduced count rate is compensated by BF3-filled counters LND2043. Those tubes have the gas pressure of 933 hPa, which is approximately 3 times higher than in typical BF3-filled counters of NM64.

Each neutron monitor is designed as an independent unit. The instruments have a GPS receiver for precise data and a barometer for atmospheric pressure measurements. The electronics make data records with 1 second resolution, but every count from a detector has own time stamp with the millisecond precision. The units send data via ethernet connection to a local FTP server, which, in turn, sends files to the server of the Oulu cosmic ray station for permanent storage.

Data
According to the traditional four-letter labeling of cosmic ray stations, the standard-design and lead-free neutron monitors were named as DOMC and DOMB, respectively. The barometric coefficients were computed for further data correction according to the equation:

$$C_{CR} = C_{ref} \exp(K(P_s - P)),$$

where $C_{CR}$ and $C_{ref}$ are the count rates, corrected and not corrected, respectively; $K$ is the barometric coefficient, $P_s$ is the reference atmospheric pressure set at 650 mb, $P$ is the measured pressure.

The values of the barometric coefficients are $K_{DOMC} = -0.754±0.068 \%/mb$ and $K_{DOMB} = -0.707±0.042 \%/mb$.

The instruments DOMC and DOMB have average pressure-corrected count rates of 16.5 and 4.3 cts/s. Their time series are shown in Figure 4. During 2015-2016 there were several notable events registered including Forbush decreases and an interesting increase of the count rate on 7 June 2015 (Figure 5). The data show a strong response of the instruments on the variability of the cosmic ray flux, as was expected.

The data are publicly available at the website of Oulu cosmic ray station (cosmicrays.oulu.fi) and in NMDB (nmdb.eu).

Summary
New cosmic ray station with two mini neutron monitors (of the standard design and lead-free) at research station Concordia (Dome C, Antarctica) is presented. The instruments have confirmed high sensitivity of the site to low-energy cosmic rays and show a strong response on cosmic ray variability. The data are publicly available at the websites of Oulu cosmic ray station (cosmicrays.oulu.fi) and in NMDB (nmdb.eu).

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References