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Online application for the barometric coefficient calculation of the NMDB stations

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HIGHLIGHTS

- The main correction of the primary cosmic ray data is the pressure one due to the barometric effect.
- An online tool that calculates the barometric coefficient for the neutron monitors is described.
- This tool uses the High resolution real-time Neutron Monitor database-NMDB.
- Each station can check if the barometric coefficient used for the data processing is correct.
- The use of a reference station leads to satisfactory results even in the active cosmic ray periods.

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ABSTRACT

The primary processing of the neutron monitor data includes all the necessary actions and procedures that each cosmic ray station follows in order to provide the worldwide neutron monitor network with good quality data. One of the main corrections of the primary data is the pressure correction due to the barometric effect. The barometric effect induces variations to the measured data of the neutron monitors which are related to the variations of the local atmospheric pressure of the stations. This correction requires the definition of the barometric coefficient which is calculated experimentally. The accurate calculation of the coefficient is a prerequisite for the quality of the data. This paper presents the implementation of an online tool which calculates the barometric coefficient of a cosmic ray station, by taking advantage of the fact that most stations publish their data on the Neutron Monitor Data Base.

1. Introduction

Neutron monitors are ground based detectors used to measure cosmic rays that reach the Earth's surface. The cosmic rays consist of the galactic part referring to particles which originate from stellar sources and have been accelerated to extremely high energies. The galactic cosmic rays reach the Earth as highly isotropic flux. However, the solar activity via the solar wind affects the terrestrial magnetic field and modulates the galactic cosmic rays. Moreover, during periods of high solar activity, solar cosmic rays which consist of high energetic solar particles reach the Earth. When the cosmic rays enter the terrestrial atmosphere, they interact with nuclei of atmospheric gasses and produce showers of particles.

The neutron monitors that consist of a number of identical proportional counters, measure the variations of the cosmic ray intensity with time by measuring the neutrons produced by the interaction of the cosmic rays with the atmosphere. The worldwide network of neutron monitors measures the cosmic ray intensity in many locations on Earth, which allows the scientific community to gather important information about the solar activity. During the last years, most of the neutron monitor stations have begun to send their measurements to the global High Resolution Neutron Monitor database in real time, which makes the observation of the cosmic ray variations easier (http://www.nmdb.eu/).

In order for the neutron monitor measurements to be reliable and useful, they must go through procedures that insure their quality. The primary processing of the data includes all the necessary procedures that are used for the quality control of the neutron monitors data. The first control that is applied relates to the filtering of the possible instrument variations that may occur during the operation of the neutron monitors. These detectors include a number of electronic modules that are necessary for the data acquisition such as the power supplies, the pre-amplifiers and amplifiers modules, the ADCs and the discriminating modules. The problematic behavior that some of these modules may show, distorts the quality of the data. Algorithms such as Median Editor, Median Editor plus and Super Editor are responsible for the correction of them when the instrument variations occur by using the efficiency of the neutron monitor counters (Yanke et al., 2011).

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Another parameter that affects the measurements of the neutron monitors is the local atmospheric pressure of the station due to the barometric effect. The barometric effect reflects the change of the atmospheric thickness above the NM location and thus the flux of the secondary cosmic rays at the Earth. Therefore, it induces an important variation to the counting rate of a cosmic ray detector which is not related to the real variations of the cosmic ray intensity. For this reason, the correction of the counting rate, regarding the barometric pressure, is a main task for the primary data processing. More specifically, the measured data should be transformed to a common pressure in order for the time series of the measurements to only reflect the variations of the cosmic ray intensity.

The correction of the primary data for pressure has been studied both theoretically and experimentally in the past. This correction requires the use of the barometric coefficient, which is calculated by each station using the past measurements. In most cases, the study of the barometric effect is performed in a quiet cosmic rays period when the variations of the neutron monitor measurements are related mainly to the variations of the atmospheric pressure. However, since a quiet cosmic rays period is not always the case, another method may be used, which excludes the cosmic ray variations by using the measurements of a reference station.

The accurate calculation of the barometric coefficient is a prerequisite for the good quality of the neutron monitor data. In this work, an online tool for the calculation of the barometric coefficient of the various neutron monitor stations is presented. This tool takes advantage of the fact that most stations publish their measurements on the NMDB in real time and calculates the barometric coefficient either by using a reference station for the exclusion of the primary cosmic ray variations or by only using the main station measurements.

2. Barometric coefficient calculation

The affection of the atmospheric pressure to the measured cosmic ray intensity on the Earth's surface is a well known phenomenon (Carmichael et al., 1968; Dorman, 1972, 1974). In the case the cosmic ray incoming flux is constant, the measured intensity N depends only on the local atmospheric pressure and this dependence can be described via the expression:

$$dN = -\beta \cdot dP \tag{1}$$

where dN is the change of the measured intensity due to the dP change of the pressure and β is the barometric coefficient. By integrating this expression and supposing that for pressure P_o the measured intensity is N_o, the counting rate N of the detector when the atmospheric pressure is P, is:

$$N = N_o \cdot e^{-\beta \cdot (P - P_o)} \tag{2}$$

By applying the natural logarithm on both sides of the equation it becomes that:

$$\ln N - \ln N_0 = -\beta(P - P_0) \tag{3}$$

As it has already been mentioned, Eq. (3) is valid only when the incoming cosmic ray flux is stable, so any variation of the measured counting rate is related to the change of the pressure. In the case that there are variations in the cosmic ray flux, the measured intensity is:

$$N' = N \cdot (1 + v) \tag{4}$$

where N' is the measured intensity and the factor $(1 + v)$ contains the variations of the cosmic rays flux. By using Eq. (4), the Eqs. (2) and (3) become:

$$N' = N_o \cdot (1 + v) \cdot e^{-\beta \cdot (P - P_o)} \tag{5}$$

$$\ln N' - \ln N_0 - \ln(1 + v) = -\beta \cdot (P - P_0) \tag{6}$$

The variations v can be calculated by using the corrected for pressure data of a reference station (S) (Chiba, 1976). The station (S) should have similar rigidity to the main station in order to assume that they both have similar cosmic ray spectra. The primary variation of the cosmic rays for the reference station is:

$$v_S = \frac{N^S_{pcorr} - \overline{N^S_{pcorr}}}{\overline{N^S_{pcorr}}} \tag{7}$$

In order to transform the primary variations of the reference station to the variations of the main station, the coupling coefficients are used (Belov et al., 1993; Yasue et al., 1982). If the coupling coefficients of the zero harmonic are C_0 and C^S_0 for the main and the reference station respectively, Eq. (6) becomes:

$$\ln N' - \ln N_0 - \ln\left(1 + \frac{C_0}{C^S_0} v_S\right) = -\beta(P - P_0) \tag{8}$$

The Eq. (3) and (8) can be used to experimentally calculate the barometric coefficient β by applying a linear regression on the measured values of the variables that are presented in the equations, for a specific time period. The parameters N_o and P_o can be considered as the average values of the N' and P respectively, over the defined time period. More details of this method are given in (Kobelev, 2011).

3. Limitations of the barometric coefficient calculation online tool

The Neutron Monitor Database (NMDB) is a mySQL database with the master server located in the Kiel station and a number of mirror servers located in different places such as the Athens station. The main task of the NMDB is to gather the high resolution data of the worldwide network of neutron monitors in a real time basis. This is a very important task since it makes possible for the scientific community to access these data instantly and in a common format. It also makes possible the implementation of online applications such as the one described in this work. Currently, more than forty stations send their 1-min resolution data to the NMDB every minute. The database consists of five tables for each station and of a common table for all stations. A description of the NMDB tables is given in Table 1.

The online tool described in this work, uses the NMDB data and calculates the barometric coefficient through a linear regression and according to the Eq. (3), (8). More specifically, the tool uses the data from the STATION_1 h or the STATION_ori tables which contain the 1 h and the 1 min measurements respectively. The primary key of these tables is the 'start_date_time' field which has a datetime format and represents the date and the time of the beginning of the measurement. The processing of the data is performed

Table 1
Tables of the Neutron Monitor database.

Table name	Description
STATION_ori	Stores the original 1 min data of the station. The data can be written only once. Any possible revision is stored in the STATION_rev table
STATION_rev	Stores any revision of the original 1 min data
STATION_1 h	Stores the data averaged to 1 h
STATION_env	Stores the environmental data of the station (optional use)
STATION_meta	Stores general information about the station
Station_information	Information about all the stations

Where STATION = the abbreviation of the station's name.