

# Online application for the barometric coefficient calculation of NMDB stations

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## Abstract

The primary data processing of neutron monitors includes a variety of actions and procedures that each cosmic ray station follows in order to provide the worldwide neutron monitor network with good quality of data. One of the most important corrections of primary data is the pressure correction due to the barometric effect. This correction requires the definition of the barometric coefficient which is calculated experimentally. This paper presents the implementation of an online tool which can effectively calculate the barometric coefficient of a cosmic ray station, using the data of NMDB database.

## 1. Introduction

It is known that the barometric effect of cosmic ray intensity is the affection of atmospheric pressure to the observation of the secondary cosmic rays at the Earth. The barometric effect induces an important variation to the counting rate of a cosmic ray detector. This variation is not related to the real variation of the cosmic rays flux but only to the local atmospheric pressure of the station. For this reason, the correction of the counting rate, regarding the barometric pressure, is a main task of the primary data processing.

The dependency of the counting rate on the atmospheric pressure has been studied in both a theoretical and an experimental point of view in the past. Presently all cosmic ray stations correct their data by using a parameter, named barometric coefficient, which is calculated experimentally. This work presents the implementation of an online application that calculates the barometric coefficient of a neutron monitor station included in the worldwide neutron monitor network. This implementation is possible due to the NMDB database which provides real time data of the neutron monitor stations in a common format (<http://www.nmdb.eu>).

## 2. Barometric coefficient calculation

The method of defining the barometric coefficient of the different components of secondary cosmic rays, has been studied by many authors in the past (Carmichael et.al., 1968; Dorman, 1972; 1974). Specifically, the affection of the barometric pressure to the counting rate of neutron monitors can be represented by:

$$dN = -\beta \cdot dP \quad (1),$$

where  $dN$  is the change of detector counting rate (due to pressure change),  $dP$  is the change of pressure and  $\beta$  is the barometric coefficient. By integrating this expression and supposing that for pressure  $P_0$  the counting rate is  $N_0$ , the counting rate  $N$  of the detector is:

$$N = N_0 \cdot e^{-\beta \cdot (P - P_0)} \Rightarrow$$

$$\boxed{\ln N - \ln N_0 = -\beta(P - P_0)} \quad (2),$$

where  $P$  is the current atmospheric pressure.

The equation (2) is valid when the incoming cosmic ray flux is stable, so any variation of the detector counting rate is only due to the change of barometric pressure. In the case that there are variations in the cosmic ray flux, the equation (2) has the form:

$$N = N_0 \cdot (1 + v) \cdot e^{-\beta \cdot (P - P_0)} \Rightarrow$$

$$\ln N - \ln N_0 - \ln(1 + v) = -\beta \cdot (P - P_0) \quad (3),$$

where  $v$  is the variation of the cosmic ray flux. In order to calculate the variation  $v$ , the corrected for pressure data of a reference station ( $S$ ) are used (Chiba, 1976). The station ( $S$ ) should have similar cut-off thresholds to the main station in order to assume that they both have similar cosmic ray spectra. The primary variation of cosmic rays for the reference station is:

$$v_S = \frac{N_{pcorr}^S - \overline{N_{pcorr}^S}}{\overline{N_{pcorr}^S}} \quad (4)$$

Since equation (4) includes the corrected for pressure data of the reference station, the change to  $v$  is only related to the change of cosmic ray flux. In order to transform the primary variation of the reference station to the variation of the main station, coupling coefficients are used (Belov et al., 1993). If the coupling coefficients of the zero harmonic are  $C_0$  and  $C_0^S$  for the main and reference station respectively, equation (3) becomes:

$$\boxed{\ln N - \ln N_0 - \ln\left(1 + \frac{C_0}{C_0^S} v_S\right) = -\beta(P - P_0)} \quad (5)$$

Equations (2) and (5) can be used to experimentally calculate the barometric coefficient  $\beta$  by applying a linear regression on the measured values of  $N$  and  $P$  for a specific time period. The parameters  $N_0$  and  $P_0$  are the average values of counting rate and atmospheric pressure respectively, over the defined time period. More details of this method are given in Kobelev et al. (2011).

### 3. Implementation

Based on the previous analysis, the online application uses the two basic equations of the previous section, namely equations (2) and (5) in order to calculate the barometric coefficient. Each station input data are provided from the NMDB mirror server, located in Athens cosmic ray station. The application is separated in three main parts:

1. The input form where the online user determines the necessary parameters for the application. The form has been implemented in HTML with the support of javascript.

2. The main program that, according to the parameters set on the form, calculates the values that correspond to the left and right part of the equation (2) or (5). The procedure is performed in PHP and the calculations are performed by sending SQL queries to the NMDB mirror server.
3. The graph where the calculated values from the previous step are plotted. The graphs are drawn by using the Jpgraph library which is written in PHP (<http://jpgraph.net>). Apart from the points that are plotted, the graph also shows the regression line, the slope of which corresponds to the barometric coefficient of the station.

In the following paragraphs, each one part of this application is analyzed thoroughly.

### 3.1. Input form

The input form of the online application, running in the Athens NM website, is shown in Figure 1 ([http://cosray.phys.uoa.gr/Local\\_Data/barometricForm.html](http://cosray.phys.uoa.gr/Local_Data/barometricForm.html)).

**Athens Cosmic Ray Station**  
**Barometric Coefficient Form**

	Year	Month	Day	Hour	Minute
From	2012	Jan	1	0	0
To	2012	Jan	31	23	59

Resolution  
☒ 1 Hour   ☐ 1 Day  
 Plot Type  
☒ Beta Calculation   ☐ Monthly Variation

☐ Allow usage of 1 minute data table  
☐ Define the average pressure  mb

Main Station	Reference Station
ATHN	No Correction

previous version can be found [here](#)

**Brief Description**

- The Barometric Coefficient of Neutron Monitors is calculated using the NMDB Data
- Due to performance reasons, the "1 Hour" resolution is limited to 3000 points. For more points the resolution is forced to "1 Day"
- The resolution of the "Monthly Variation" plot is forced to "1 Day" for time periods more than 5 years.
- checkbox "Allow usage of 1 minute data table": use of the 1 minute data of the stations in case of 1 hour data absence
- checkbox "Define the average pressure": allows the user to enter the desired average pressure of the station

[REF] Variations of Barometric Coefficients of the Neutron Component in the 22-23 Cycles of Solar Activity  
 P.Kobelev, A.Belov, E.Mavromichalaki, M.Gerontidou, V.Yanke, 32nd International Cosmic Ray Conference, Beijing 2011

**Figure 1: Application Form**

At first, the user has to set the time period for which the calculation of the barometric coefficient will be performed. This is achieved by using the drop-down menu for 'Year', 'Month', 'Day', 'Hour' and 'Minute' located in 'From' and 'To' sections. The user is free to select any combination of beginning and ending dates. The only limitation is that the beginning date should be before the ending one. Despite the user being free to select the time period, the calculation is better to be performed for a time period up to a few months for an accurate result.

After that, the user has to set the resolution of the data that will be used in the calculation. This tool gives the choice of selecting between hourly and daily data, using two radio buttons. The decision between these two available selections is made for several reasons. The hourly data provide a good resolution of data while they minimize the statistical fluctuations of the measurements. Also, daily

values provide a good resolution and reduce the influence of the anisotropy of the cosmic rays. It is obvious that in order to effectively calculate the barometric coefficient, the values used should be as many as possible. For this reason the '1 hour' resolution is recommended when the defined time period is short while the '1 day resolution' is more appropriate for long periods of time. Since the application is online and in order to protect the NMDB mirror server from big loads, the '1 hour' resolution has a limit of retrieving up to 3000 rows from the database. When the rows that will be retrieved are more than 3000, the resolution is automatically changed to '1 day'. The 3000 rows limit was selected because it allows a good statistical calculation of the barometric coefficient and gives a reasonable execution time for both the NMDB mirror server and the Athens local host.

In the final step, the user selects the station for which the barometric coefficient will be calculated. The selection is performed by using the 'Station' dropdown menu. The second dropdown menu, labeled 'Support', is used in the case the barometric coefficient will be calculated with the support of a reference station. In the case the 'No Correction' choice is selected, the calculation will be performed using the equation (2). In the case a support station is selected, the calculation will be performed using the equation (5). Although the user is free to select any station as a reference, the correct evaluation of the barometric coefficient, according to the theoretical analysis, requires the support station to have similar cut-off threshold.

Moreover, the form contains a checkbox labeled 'Allow usage of 1 minute data table'. The application normally uses the hourly data of the stations for two reasons. The hourly data of the stations are characterized as of better quality compared to the minutely data. Also since the available resolutions are '1 hour' and '1 day', the usage of the hourly data optimize the performance of the application. However, in some cases the hourly data of the stations are not available in the NMDB database. By checking the discussed checkbox, the application is allowed to use the 1 minute data of the station in case of the 1 hour data absence.

Finally, the form allows the possibility of a graph that plots the monthly values of the barometric coefficient for a specified period of time. The selection of this graph is performed via the 'Monthly Variation' radio button under 'Plot type' section. In that case, only the year and the month of the starting and ending dates are used. The selection criteria described above are valid for this plot type as well. Due to performance reasons, the '1 hour' resolution for the 'Monthly Variation' plot is limited to 5 years periods of time. For longer periods the resolutions is forced to '1 day'.

### 3.2. The main program

The main program, which is implemented in PHP, retrieves the data from the NMDB mirror server, according to the parameters set in the form. The PHP program gets the parameters from the form via the POST method. It also connects to the NMDB server using a read-only user which was created for this application.

The program performs two main tasks. The first task is the calculation of the mean values ( $N_o$ ,  $P_o$ ,  $\overline{N_{pcorr}^S}$ ) used by the equations (2), (4) and (5). During this task the program sends one to three SQL queries to the NMDB database. These queries have dual purposes. Apart from the calculation of the mean values, the queries check if there are valid data for the selected stations and for the specified time period, since the absence of data will result to a null reply from the database. The possible cases that are checked, are presented in Table 1.

In case the 'Allow usage of 1 minute table' checkbox of the form is not checked, only the first case is checked. If data are found in the '1 hour' data table the program proceeds, otherwise an error message is displayed. In case the check box is checked then if the first case is not fulfilled, the program proceeds to the check of the following cases. If in one of them there are valid data the program proceeds to the next step, otherwise an error message is displayed.

Case	Without Support Station	With Support Station
1	station_1h table	station_1h table JOIN support_1h table
2	station_ori table	station_1h table JOIN support_ori table
3	-	station_ori table JOIN support_ori table

**Table 1: Cases checked for data availability**

If valid data have been found in the first step, the program retrieves the data by sending a query that returns the data according to the equation (2) or (5). Actually the last and basic query retrieves the data as a set of rows with two columns. The first column corresponds to  $(P-P_o)$ , while the second one corresponds to the left part of the equation (2) or (5).

Depending on which plot type is selected, the described procedure is performed one or more times. In the case of the 'beta calculation' plot, the procedure takes place once. In the case of the 'monthly variation' plot, the procedure is performed for each month that is included in the time window determined from the starting and the ending date.

In general, the most important task in the main PHP program is the correct built of SQL queries. The problem is that the desired resolution of the retrieved data is '1 hour' or '1 day' while the data in the NMDB database can be found with 1 hour or 1 minute resolution. Either only one main station is to be used or a join between main and reference stations is to be used, the data in the corresponding NMDB tables should firstly be constructed to the desired '1 hour' or '1 day' resolution. This is achieved by a method that creates time slices in the database. The time slices are constructed by using the `TIMESTAMPADD`, `TIMESTAMPDIFF` and `FLOOR` function of SQL.

The following example shows how the method works. If the starting date of the calculation is the 1<sup>st</sup> of September 2011 and the desired resolution is '1 day data', the `TIMESTAMPDIFF` function is used in order to find the difference in days between the starting time of calculation and the table record's timestamp. The SQL expression is the following:

`TIMESTAMPDIFF(DAY,'2011-09-01 00:00:00',start_date_time)`

The output for a record that has a timestamp that differs less than a day will be in the form 0.xxxx. The use of `FLOOR` function on this expression rejects the decimal part of the output number. So the number 0.xxxx becomes zero. Finally, the application of the `TIMESTAMPADD` function creates a new date that is called time slice:

`TIMESTAMPADD(DAY, FLOOR( TIMESTAMPDIFF(DAY,'2011-09-01 00:00:00',start_date_time)), '2011-09-01 00:00:00')`

The expression above outputs the same date for all the timestamps that are within the same day, starting counting from the 1<sup>st</sup> of September 2011.

The method of time slices is used in all the queries of the PHP main program except the ones for which the desired resolution is '1 hour' and the hourly data of NMDB database are to be used.

Finally, equation (5) makes use of the coupling coefficients. The coupling coefficients of the zero harmonic for most stations have been calculated in the past and are used directly from the application. For each station two coupling coefficients are available. The one corresponds to the minimum of the solar cycle and the other one to the maximum. For the time periods after the 1<sup>st</sup> January 2007, the minimum value is used while for periods before that date, the maximum value of

the coupling coefficient is used. For time periods that contain the 2007-01-01, the mean value of the minimum and maximum values is considered.

### 3.3. Graphical Presentation

The data that are retrieved from the last and basic query are plotted using the Jpgraph library (<http://jpgraph.net>). The library gives a variety of plot types and formatting choices through its classes. For this application a scatter plot is used. The linear regression of data is performed using the Linear Regression class of the library. The output graph has a .png image format. Since the graph is the output of the application, all the necessary information about the execution is displayed on it. The displayed information is given in the Table 2.

Station and Reference Station (in case it exists)
Resolution of data (1 hour or 1 day)
NMDB tables that were used (1 hour or 1 minute)
<b>Barometric Coefficient</b> (the slope of the regression line)
Standard Error of the linear regression
<b>Correlation Coefficient</b> of the linear regression
Number of points plotted

**Table 2: Information displayed on the output graph**

The calculated value of the barometric coefficient and the correlation coefficient are the main values that the user should take into account. A correlation coefficient of about 0.99xxxx corresponds to a faithful calculation of the barometric coefficient.

Apart from the graph, the output webpage of the application contains links to additional plots. These plots correspond to the NMDB data that was used in the calculations. So, there are links for the uncorrected data and pressure plots of the main station and also a link for the corrected for pressure data plot of the reference station. These additional plots are very useful because the user can immediately check if the calculation of the barometric coefficient was done in a quiet or in a disturbed cosmic ray period.

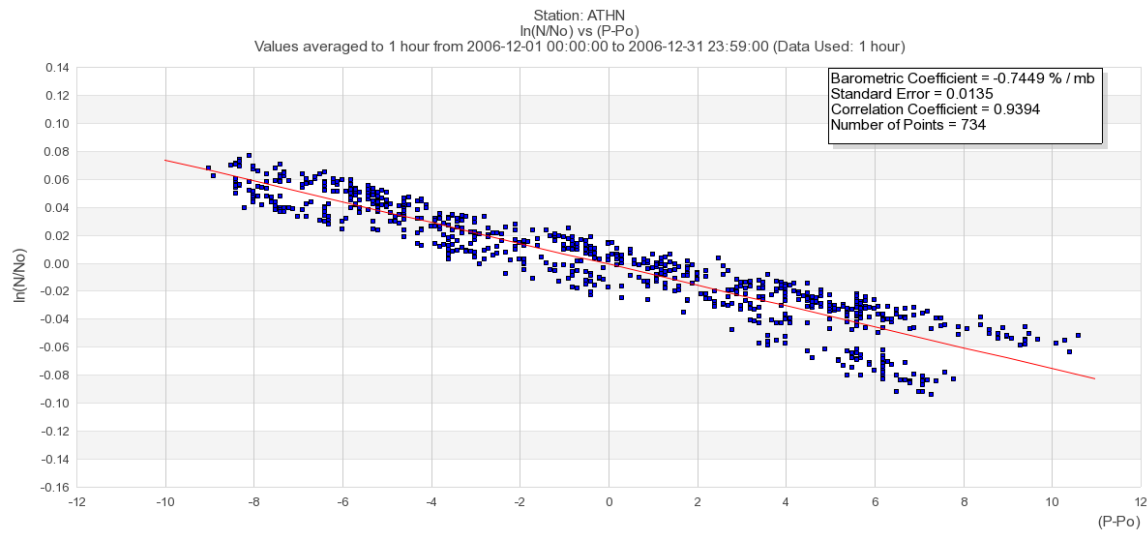
In the case of the 'monthly variation' plot, the barometric coefficient and the correlation coefficient for each month are not calculated from the Jpgraph's Linear Regression class, but they are directly calculated using a nested SQL query. The barometric coefficient and the correlation coefficient are calculated by using the equations:

$$\beta = \frac{\overline{X \cdot Y} - \overline{X} \cdot \overline{Y}}{\overline{X^2} - \overline{X}^2}, \quad r = \frac{n \cdot \sum X_i \cdot Y_i - \sum X_i \cdot \sum Y_i}{\sqrt{n \cdot \sum X_i^2 - (\sum X_i)^2} \cdot \sqrt{n \cdot \sum Y_i^2 - (\sum Y_i)^2}} \quad (6)$$

In that case, the Jpgraph library is only used to plot the calculated barometric and correlation coefficient of each month.

#### 4. Results

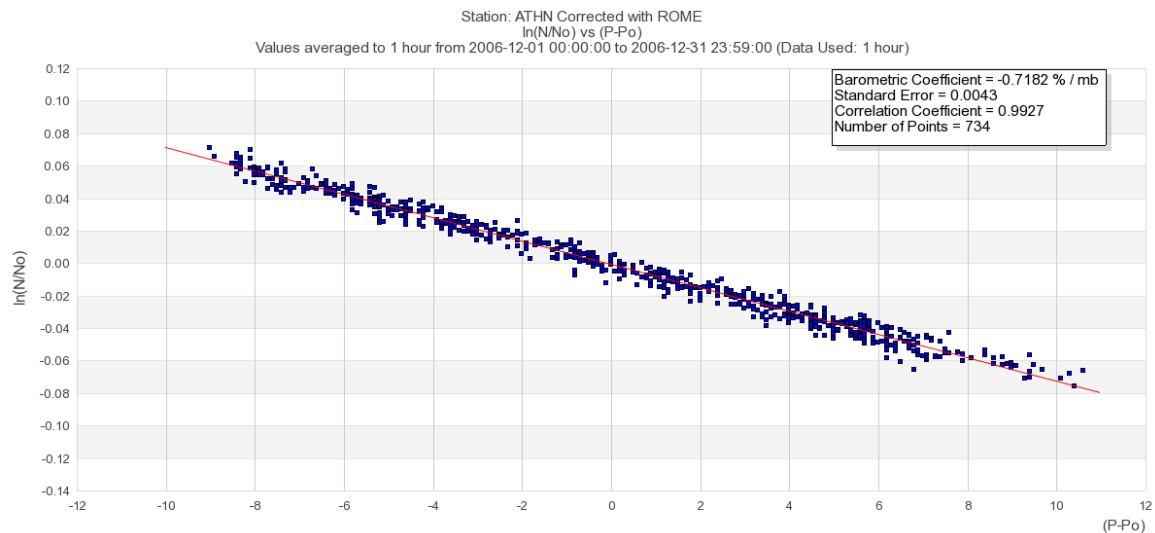
The calculation of barometric coefficient for Athens NM station for December 2006, which was an active period, is shown in Figure 2.



**Figure 2: The barometric coefficient calculation during December 2006 for Athens NM station without using a reference station is presented.**

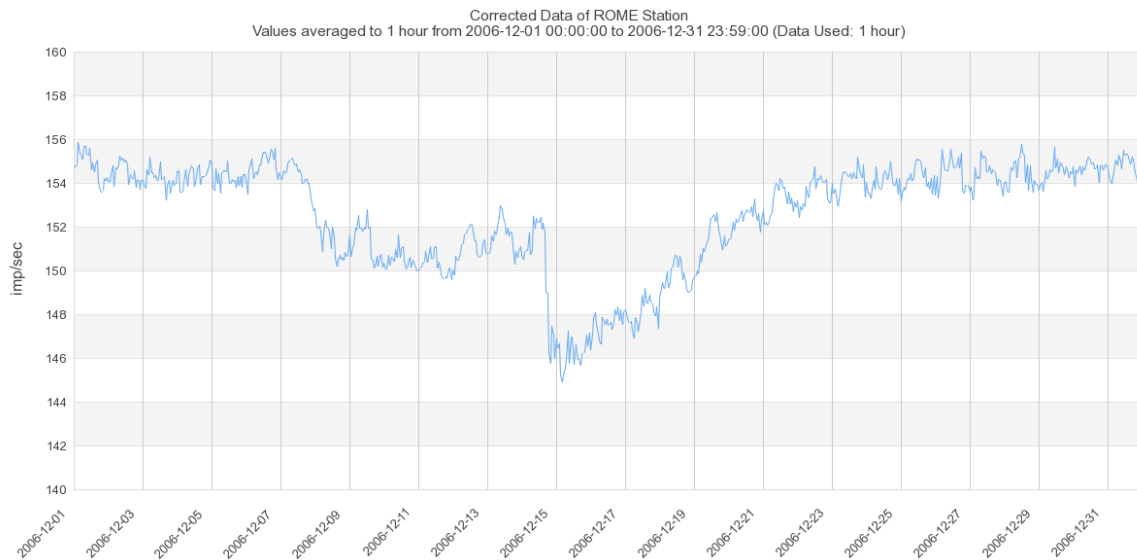
It is obvious that the calculation in this case is not very accurate. The plotted points are far from the regression line and this is reflected on the correlation coefficient which is 0.9394.

The same calculation taking the Rome station as a reference station is given in Figure 3.



**Figure 3: The barometric coefficient calculation during December 2006 for Athens NM station using Rome station as a reference one is given.**

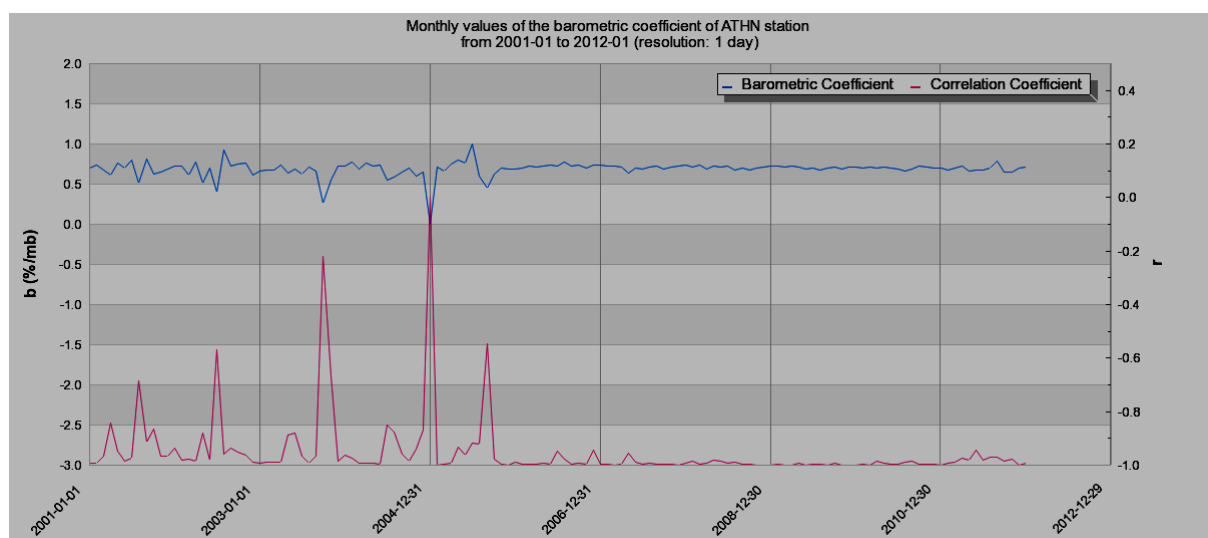
The correlation coefficient becomes 0.9927 and all the points are close to the regression line that means that the method is working well. The corrected for pressure data of Rome for the same time period is given in Figure 4.



**Figure 4: Pressure corrected data of Rome station during December 2006 where Forbush decreases were occurred.**

As it can be seen, there is a series of Forbush decreases in that period. So, the calculation of barometric coefficient without using a reference station is not recommended since the variation of the counting rate of Athens neutron monitor (uncorrected data) is not only due to the pressure changes but also to the Forbush decrease.

During a quiet period, the calculation of the barometric coefficient does not show important differences when a reference station is used. Finally, an example of a 'monthly variation' plot for the Athens NM station from 2001 until now is shown in Figure 5.



**Figure 5: Monthly variation of the barometric coefficient of Athens station, from January 2001 to January 2012**



This figure shows the monthly values of the barometric and the correlation coefficient of Athens station from January 2001 to January 2012. As it can be seen, the barometric coefficient is almost stable from 2006 and on. From year 2001 to year 2005 there are some fluctuations. However it is important to notice that when there are important fluctuations of the barometric coefficient, the corresponding value of the correlation coefficient is far from value 1, which means that the measured data of that period do not lead to a successful calculation of the barometric coefficient.

## 5. Conclusions

The above described online application has the following advantages:

- It can effectively determine the barometric coefficient of a cosmic ray station for a specific time period.
- The use of a reference station leads to satisfactory results even in active cosmic ray periods.
- Each station is able to easily check if the barometric coefficient used for primary data processing is correct.
- It can check the stability of the barometric coefficient over time. It is important to highlight that the correct calculation of the barometric coefficient highly depends on the correct setting of the application's parameters.
- Finally, we can say that the new online tool will be very useful for testing the data quality of the stations.

**Acknowledgements:** This work depends mainly on the NMDB project which provides online high-resolution data of neutron monitors. The authors thank all the providers of the NMDB stations.

## Reference

- Belov A. V., Gushchina R. T., Sirotina I., Proc 23th ICRC, Calgary, 605, 1993.  
Carmichael H., Bercovitch M., Shea M.A., Magidin M., Peterson R.,: Canad. J. Phys., 46, 1006, 1968.  
Chiba, T.: Ann. Rep. Fac. Educ., Iwate Univ., 36, 1976.  
Dorman L.I.: Nauka, 211, 1972.  
Dorman L. I.: Moscow, 492, 1974.  
Kobelev P., Belov A., Mavromichalaki E., Gerontidou M., Yanke V.: Proc. 32nd ICRC, icrc00654, 2011