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BAROMETRIC EFFECT OF NEUTRON COMPONENT OF COSMIC RAYS AT ANTARCTIC STATION MIRNY

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The barometric effect of cosmic ray neutron component was estimated on the example of the Antarctic station Mirny. We used hourly data from continuous monitoring of neutron component and data from a local weather station for 2007–2014. Wind speed at the station Mirny reaches 20–40 m/s in winter that corresponds to the dynamic pressure 5–6 mbar and leads to a 5 % error in variations of neutron component because of dynamic effects in the atmosphere. The results can be applied to detectors located in high-latitude and high-mountain regions where the wind speed can be significant.

Keywords: *galactic cosmic ray variations, barometric effect, neutron monitors.*

INTRODUCTION

Cosmic ray variations can be very effectively studied by such precision detectors as neutron monitors. For instance, the hourly-averaged statistical accuracy of a standard neutron super-monitor 18-NM-64 at sea level is ~0.15 %; therefore the level of other possible errors must be not worse than the statistical error. Among such possible errors are those caused by exclusion of barometric effect from observations. A typical accuracy of modern pressure sensors is 0.2 mbar. This guarantees the required accuracy in corrections ≈0.15 %. However, there is another circumstance that is difficult to take into account. The barometric effect primarily caused by neutron absorption in the atmosphere depends on the amount of matter over a sensor, i.e. on static pressure. Commonly used pressure sensors measure total pressure as a sum of static and dynamic pressure. Objectives of this study include experimental determination of dynamic pressure contribution and introduction of necessary corrections to observation data.

Dynamic pressure is conditioned by a wind flow and is equal to kinetic energy of unit volume of matter:

$$P_{\mathrm{D}} = \frac{1}{2}\rho V^2,$$

where ρ is the air density, V is a flow velocity. However, only a part of kinetic energy $C_x P_{\mathrm{D}}$ is converted into potential energy and has an effect on an obstacle and in the end on pressure sensor readings. The proportionality coefficient C_x, or aerodynamic coefficient, depends on obstacle geometry and Reynolds number. Wind effects for some events have been studied before [Lockwood, Calawa, 1957; Dubinsky et al., 1960; Kawasaki, 1972; Buticofer, Flugiker, 1999; Dorman, 2004]. These studies are reviewed in [Dorman, 1972; Dorman et al., 1999]. However, a detailed analysis of dynamic wind effect that would involve Antarctic stations observing very strong gravity winds has not been carried out yet.

DATA

The station Mirny has been regularly monitoring cosmic and weather parameters since 2007. We analyze hourly-resolved data corrected for barometric effect, using a classical method [Kobelev et al., 2011] and the count rate of the neutron monitor 12-NM-64. Flow turbulence is estimated from data on atmospheric pressure and wind speed at 1-minute resolution.

Antarctic stations, in particular the station Mirny, due to their topographic features can observe gravity winds. The winds become strongest in Antarctic winter – from April to November they are blowing almost continuously. Figure 1 depicts the wind speed observed from 2007 to 2014 at 1-minute resolution.

METHOD

The barometric effect is easily excluded through the law of emission absorption in the atmosphere according to deviation of measured atmospheric pressure (it is assumed to be static pressure P_S) from the standard one P_0 for this observing station:

$$N_C=N_U\exp[-\beta(P_0-P_S)], \quad (1)$$

where $\beta=1/\mu$ is the so-called barometric coefficient, μ is a particle path in the atmosphere, N_U is a measured count rate of the detector , N_C is a count rate of the detector reduced to the standard level P_0.

Since the barometric pressure measured by the sensors we use is a sum of static and dynamic pressures P at a given atmospheric point, the static pressure is a difference between measured and dynamic pressures, i.e. $P-C_xP_D$.

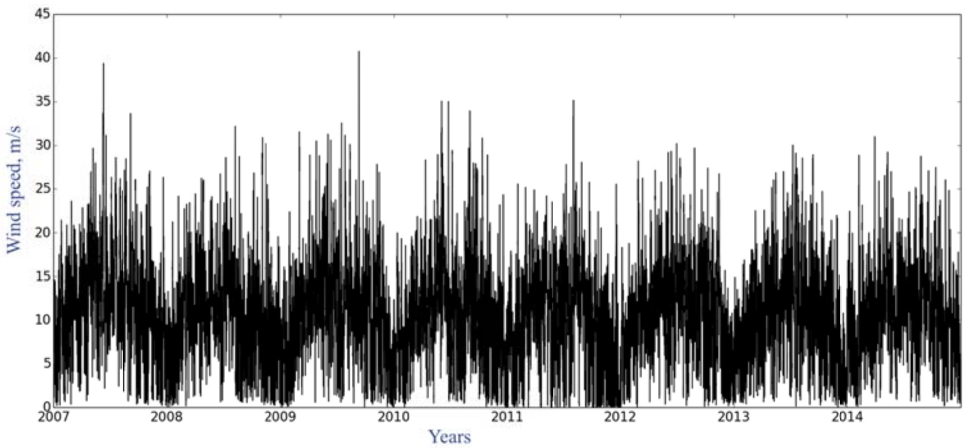

Figure 1. Wind speed at the station Mirny

The count rate of the detector N_C corrected for barometric effect (static pressure) can be represented as

$$N_C = N_U e^{-\beta[P_0-(P-C_x P_D)]} = \underbrace{N_U \exp(-\beta(P_0 - P))}_{N_C^0} \exp(-\beta C_x P_D), \tag{2}$$

where P_0 is an average pressure in the time range. The barometric effect β>0 (for Mirny β=0.73 %/mbar, P_0=980 mbar) is determined during a quiet and windless period. By finding the logarithm of Equation (1) and transposing terms with unknowns to the right side, obtain

$$\ln N_C^0 = \ln N_C + \beta C_x P_D, \text{ or } y = a + cx,$$

where $y = \ln N_C^0$, $a = \ln N_C$, and $x = \beta P_D$, , i.e. a regression equation linear in *a* and *c*.

DATA CORRECTION FOR PRIMARY VARIATIONS

When solving the problem of estimated barometric effect, we should remove primary variations from the measured count rate of the detector N_U [Dorman, 1974; Krymsky et al., 1981; Kobelev et al., 2013]. This can be accomplished if we substitute N_U with

$$N_U / (1 + \nu),$$

where ν denotes primary variations for this station. The last equation is derived from $\nu = (N_U - N_B)/N_B$; then Equation (2) is

$$N_C = \underbrace{N_U / (1+\nu) \exp(-\beta(P_0 - P))}_{N_C^0} \exp(-\beta C_x P_D). \tag{3}$$

In a zero-harmonic approximation, primary variations can be excluded from data acquired at a reference station S as follows. Write variations for two detectors as $\nu = a_{10} C_0$ and $\nu^S = a_{10} C_0^S$, where C_0 and C_0^S are reception coefficients for the station Mirny and reference station respectively.

By eliminating the unknown zero harmonic amplitude a_{10}, derive

$$\nu = \nu^S \frac{C_0}{C_0^S}. \tag{4}$$

Equation (4) accounts for the difference between parameters of the stations (altitude, geomagnetic cutoff rigidity) and allows us to employ any station as a reference one. In this study, the reference station is Oulu Cosmic Ray Station.

It is important to solve the problem of accounting for primary variations correctly because the station whose data are used in the analysis is high-latitude. The amplitude of primary variations for the station is high and can often be comparable with barometric effect, considering that the given time range includes several years (2007–2014).

RESULTS

For the analysis, we have selected about ten events with an observed wind speed of over 30 m/s. Let us consider as an example an event of September 2009 with the maximum wind speed of 42 m/s. Figure 2 shows a correlation between the count rate and the calculated dynamic pressure P_D. The count rate (gray circles) was corrected with the above method (Formula 4) for primary variations (black circles). The correlation analysis for this event yields the aerodynamic coefficient C_x=0.63±0.03; the correlation coefficient is 0.93 (before the data correction for primary variations it was 0.91). For this event, the correlation coefficient proved the best.

Strictly speaking, the aerodynamic coefficient depends on the Reynolds number value proportional to wind speed. However, in the limited range of speeds considered we can ignore this dependence if the estimated Reynolds numbers are outside the critical resistance region [Shakina, 2013].

Details of the analysis are given in Figure 3. The top panel depicts time dependencies of the count rates corrected for barometric effect with and without regard to the wind effect, as well as wind speed values.

Anticorrelation between the count rate of the detector N_C^0 and the wind speed is obvious. It is completely removed after correction for the dynamic effect according to Equation (4). The middle panel illustrates the time dependence of wind speed (at 1-minute resolution) and the result of filtration of the first differences. It is apparent that at wind speeds of over 15 m/s, flow turbulence increases; this fact should be taken into account in the course of further investigations. On the bottom panel are readings of two pressure sensors and their difference (1-minute resolution). These results suggest that readings of spaced (~900 m) pressure sensors are identical during low-wind periods and fluctuate during strong-wind

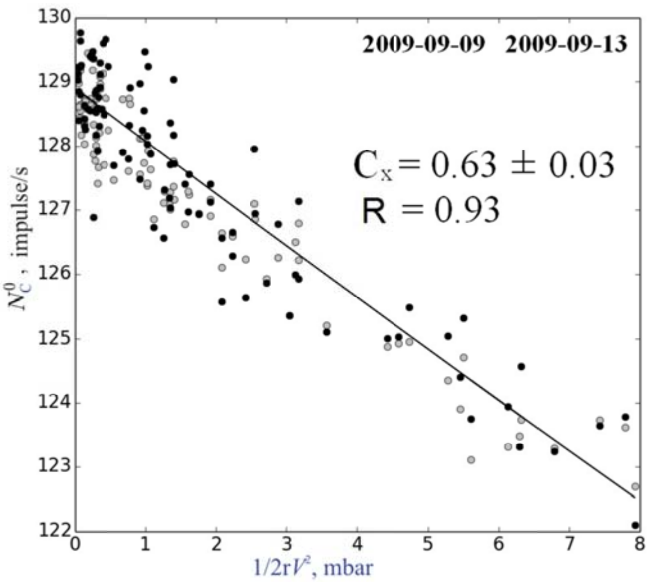

Figure 2. Correlation dependence of the count rate uncorrected and corrected for primary variations (gray and black dots respectively) on dynamic pressure; the curve shows the approximation of corrected data by the least square technique

ones, as evidenced by flow turbulence. The turbulence observed for a free sensor of pressure P_M is lower than that for a sensor of pressure P at a building; this is attributed to the air flow condition.

The aerodynamic coefficients C_x we obtained enable us to take account of the dynamic effect for the entire observation period; this is shown in Figure 4 where v_{corr} indicates cosmic ray variations after corrections for dynamic pressure. Given that the accuracy of observed variations is the tenth of one percent, a possible error caused by the dynamic effect (Figure 4) may be as much as several percent during strong winds.

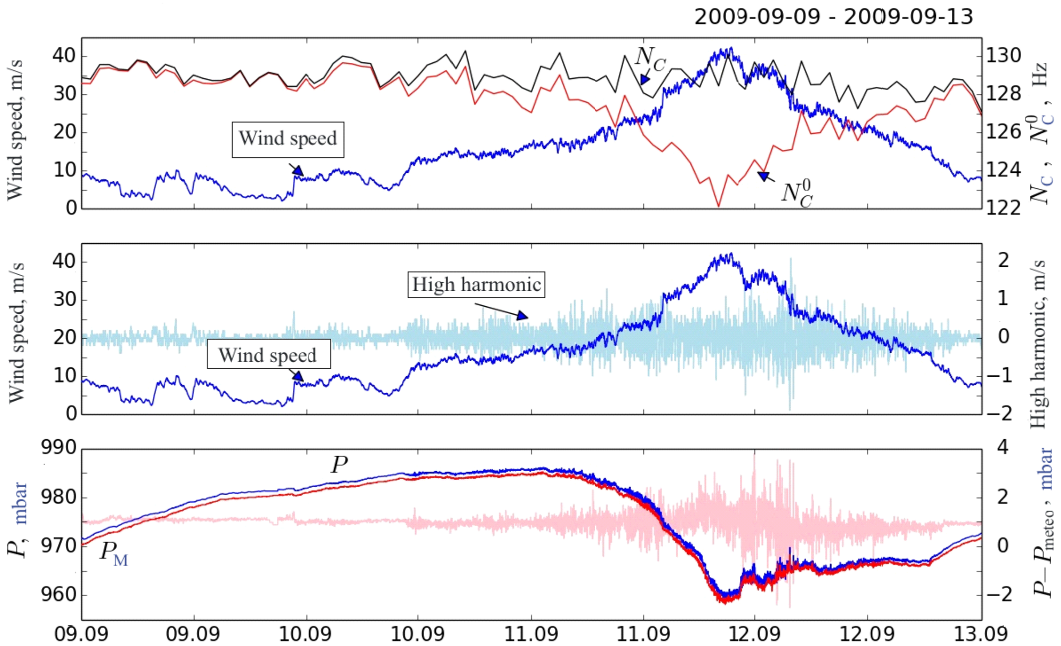

Figure 3. Time dependencies of count rates corrected for barometric effect with and without regard to the wind effect (N_C^0 and N_C), as well as wind speed values (top panel). Time dependence of wind speed with 1-minute resolution and the result of filtration of first differences (middle panel). Readings of two pressure sensors and their difference (bottom panel)

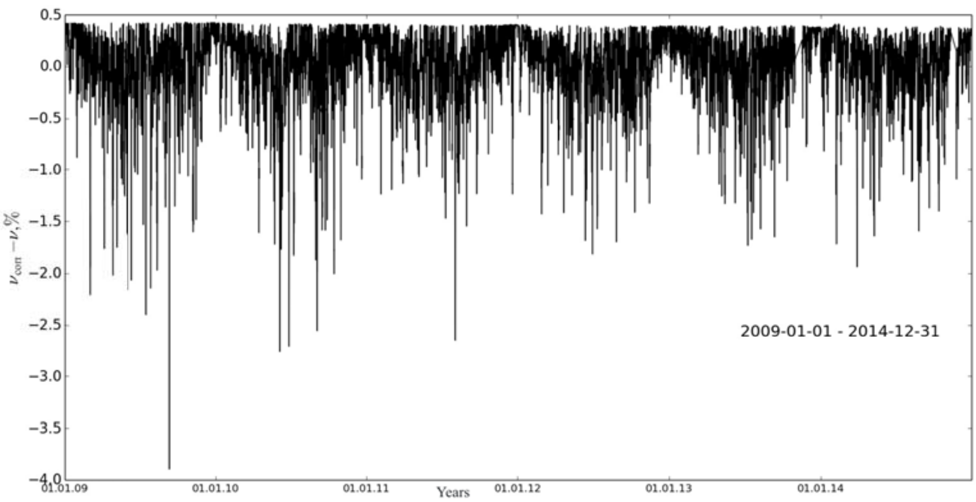

Figure 4. Correction for dynamic effect for observed cosmic ray variations in the time range 2009–2014

CONCLUSION

We have shown that at the station Mirny where wind speeds are often high, the absolute error in determining variations may run to 2–4 %. Thus, to acquire accurate data, we should always recalculate barometric effect with respect to dynamic wind effect. To reveal the Reynolds number dependence of aerodynamic coefficient, the number of events to study must be increased and the range of wind speeds considered must be expanded. Besides, it is of great importance to examine dynamic effects for other polar detectors, first for the neutron monitor Mauson where the highest regular wind flows are observed. It is also vital to use data from mountain detectors that have radically different air flow conditions.

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