Pressure Correction of GLE Measurements in Turbulent Winds

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Abstract

Analysis of the Jungfraujoch neutron monitor (NM) data for the 6 November 1997 ground-level enhancement (GLE) is complicated by the fact that the measurements of the atmospheric pressure were strongly affected by turbulent winds. Consequently, the correction of the NM count rates for the effects of changes in the air mass above the detector using raw barometer data leads to erroneous results. We propose a technique which compensates for this effect and improves the reliability of pressure corrected NM data.

1 Introduction:

The change in the air mass above a neutron monitor (NM) station has a large effect upon the count rate of the cosmic ray detector. It has been found that this change is the only significant meteorological factor producing variations in the nucleonic component of cosmic radiation in the atmosphere (Simpson et al., 1953; Lockwood & Yingst, 1956). In practice the barometric pressure is used as a proxy for the air mass to normalize the NM data to a constant atmospheric depth. The barometric pressure coefficient for a NM depends on the characteristics of the detector, on the altitude and the geomagnetic latitude of its location as well as on the primary cosmic ray spectrum. It has a value of approximately 1 % / mmHg (Carmichael & Bercovitch, 1969). Therefore, the barometric pressure at a NM station must be measured very accurately. At mountain altitudes, however, turbulent and high speed winds affect the pressure measurements with conventional barometers. The amount of distortion of the pressure data depends upon the wind speed, its direction with respect to the topological environment, and the housing of the barometer. In general, the main effects are the following: (1) Strong winds cause the readings of conventional barometers to be diminished (Bernoulli effect), and (2) due to gusty winds, the barometric pressure readings exhibit significant short-time fluctuations. In this paper we discuss a procedure which compensates for these effects in the analysis of the 6 November 1997 GLE NM data obtained at Jungfraujoch.

2 Observations:

The University of Bern operates two NMs at Jungfraujoch (46.55° N, 7.98° S): an 18 IGY NM at 3550 m asl and a 3 NM64 at 3475 m asl. The IGY NM is located at a saddle on the top of the so-called Sphinx rock. The NM64 is situated on the south flank of the Jungfraujoch and is therefore less exposed to winds than the IGY NM. At both locations identical aneroid barometers (GB1, Meteolabor AG, CH-8620 Wetzikon) are used inside the housing of the NMs.

Figure 1 shows the relative pressure corrected hourly count rates of the IGY and NM64 NM for November 5-7, 1997 (top panel). For this figure the pressure corrections were made with the pressure measured at the two locations. The middle panel shows the 5-minute pressure read-outs of the barometers at the IGY and NM64 NM site, p_{IGY} and p_{NM64}. Here, the pressure measurements taken at the NM64 location were adjusted to the altitude of the IGY NM station. The third curve in the second panel labelled $p_{Bernoulli}$ corresponds to the pressure measurements at the IGY NM location corrected for wind speed by assuming a simple Bernoulli effect. The pressure measurements p_{IGY} were hereby corrected by adding $(\rho \cdot v^2/2)$, where v is the measured wind speed in m/s and ρ the average density of the air (ρ = 0.83 kg/m^3) at Jungfraujoch. The bottom panel finally shows the observed wind speed averaged over 10 minutes.

During the selected time period the cosmic ray conditions near Earth were disturbed, as illustrated in figure 1. On November 6 a GLE was observed by the worldwide network of NMs with onset time between 1220 and 1235 UT. Evidence of this GLE was seen by the NMs at Jungfraujoch with a maximum increase of about 2.5 % in the 5-minute data. The onset time was between 1230 and 1235 UT. Unfortunately, analysis of the Jungfraujoch NMs data for this GLE is complicated by atmospheric effects.

Mainly on November 6 the pressure corrected count rates of the two NMs at Jungfraujoch show a different time behavior. The most significant difference in the intensity-time profiles occurs during the few hours after 1400 UT when the IGY NM data exhibit a decrease of 2.5 %, whereas this decrease is much smaller for the NM64. This time interval coincides with a period of extremely strong wind. The highest wind speed measured was almost 180 km/h. The wind direction was SE and S during the entire period November 5-7, 1997. Due to the strong and gusty winds the barometric measurements were strongly affected. These effects can be seen in the second panel of figure 1.

There is almost no difference in the pressure data between the two locations, p_{IGY} and p_{NM64}, in the first half of November 5, when there was only weak wind at Jungfraujoch. But with increasing wind speed the three curves p_{IGY}, p_{NM64} and $p_{Bernoulli}$ show increasing differences. During the time with highest wind speeds, p_{IGY} was reduced by about 3 mmHg compared with p_{NM64}. Due to the different locations of the two NM stations p_{IGY} was reduced more than p_{NM64}. The IGY NM site is more exposed to the winds than the NM64 location. Therefore, $p_{Bernoulli}$ is relatively close to p_{NM64}, with the only exception during the second half of 6 November when the wind speed was extremely high. It therefore seems that the pressure measurements at the NM64 site were influenced by the Bernoulli effect significantly only during times with extremely high wind speeds. Due to the gusty nature of the wind the pressure measurements show rapid fluctuations at both sites. The maximum difference between two consecutive pressure readings of the barometer in the 1-minute values at the IGY location was 1.2 mmHg.

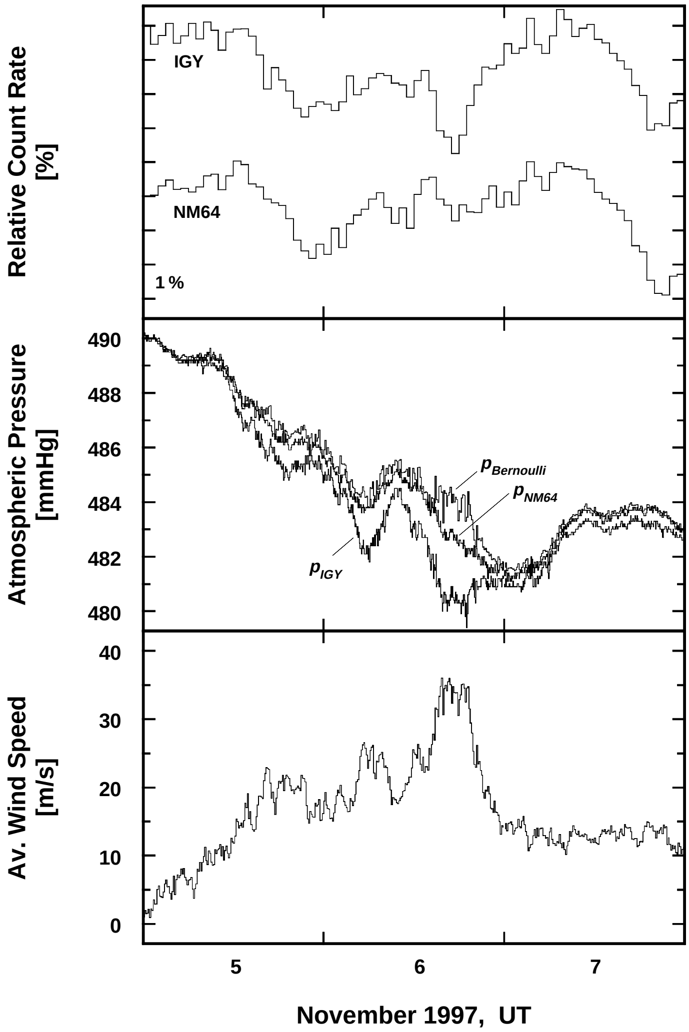

Figure 1: Top panel: Relative count rate of the IGY and NM64 NMs at Jungfraujoch (hourly values). Middle panel: Atmospheric pressure at Jungfraujoch. Measurements at IGY NM and at adapted NM64 location, p_{IGY}, p_{NM64} (5-minute values). Measurements at IGY NM location corrected for Bernoulli effect, $p_{Bernoulli}$ (10-minute values). Bottom panel: Averaged wind speed (10-minute values). For details see the text.

3 Method of pressure correction of NM data:

The reduction of barometric measurements during periods with high wind speeds and the possibility of compensating for this effect has been discussed by different authors (e.g. Falconer, 1947; Lockwood & Calawa, 1957; Lockwood, 1988). To get more reliable information about the air mass above the station these authors proposed the use of Pitot tubes. However, in an alpine environment as e.g. at Jungfraujoch the use of such instruments is limited. Especially during periods with strong winds there is often snowfall, and consequently Pitot tubes would not work reliably.

In an alternative approach we made an attempt to use the readings of the two barometers located at different sites for the pressure corrections of the NM data. Due to the behavior of the two pressure measurements described in the preceding section the pressure correction of the IGY NM data during GLE on 6 November 1997 was based on the pressure measurements at the NM64 site. As discussed above it is very unlikely that the short-time fluctuations in the atmospheric pressure readings correspond to actual changes in the air mass above the station. Therefore in our pressure correction method, the fluctuations in the pressure measurements are smoothed. For the smoothing, the cubic Savitzky-Golay moving-window least-squares averaging (Press et al., 1992) is used. The size of the moving window was determined by minimizing the root mean square of the pressure corrected count rate variations. This root mean square decreases sharply between window sizes 0-6 and reaches a more or less constant value with a moving window size of ≥ 6 data points.

In figure 2 different processed count rates of the IGY NM and the crucial meteorological data are plotted. The top panel shows the relative count rate not pressure corrected, N_{npc} (thin line) and the relative count rate pressure corrected with the raw pressure measurements, N_{rpc} (thick line). The difference between these two curves, $\Delta_n = N_{npc} - N_{rpc}$, is plotted in the second panel (thin line). The thick line in this second panel illustrates the difference $\Delta_s = N_{spc} - N_{rpc}$ where N_{spc} is the relative count rate corrected with smoothed pressure measurements at the NM64 site adjusted to the altitude of the IGY NM station, p_s. In the third panel we plotted the raw pressure measurements at the IGY NM site, p_{IGY}, and the smoothed barometric pressure measured at the NM64 location adjusted to the altitude of the IGY NM station, p_s. The wind speed averaged over 10 minutes is shown in the bottom panel.

The results plotted in figure 2 show that during the time interval between 1000 UT and ~1300 UT the relative IGY NM count rate is practically not affected by pressure changes and wind effects. However, after ~1300 UT the combined effects of decreasing atmospheric pressure and strong winds are clearly visible

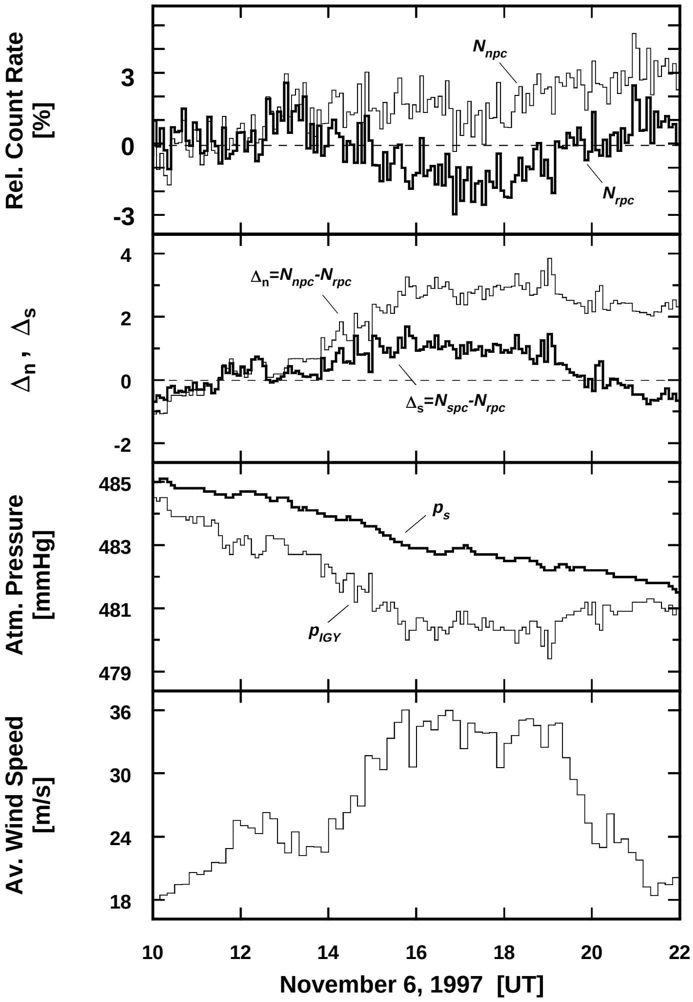

Figure 2: First panel: Relative count rate of the IGY NM (5-minute values). N_{rpc}: corrected with p_{IGY}. N_{npc}: not pressure corrected. Second panel: $\Delta_n = N_{npc} - N_{rpc}$; $\Delta_s = N_{spc} - N_{rpc}$, where N_{spc} is the count rate corrected with p_s. Third panel: Smoothed barometric pressure measurements at NM64 site adjusted to the altitude of the IGY NM station, p_s and measured barometric pressure at the IGY NM site, p_{IGY} (5-minute values). Fourth panel: Average wind speed at the site of the IGY NM (10-minute values). For details see the text.

and must therefore be taken into account in the analysis of the Jungfraujoch IGY NM data for the 6 November 1997 GLE if a period of more than one hour after the onset of the event and not only the onset phase is considered. Based on the arguments presented above it appears that for the pressure correction of the IGY NM count rate during this GLE the use of p_s is both a reasonable and suitable approach. The intensity-time profile of the relative pressure corrected IGY NM count rates obtained using this procedure is shown in figure 3 together with the relative NM64 count rates at Jungfraujoch and Kiel.

4 Conclusions:

The analysis of the Jungfraujoch data for the GLE on 6 November 1997 has shown that pressure corrections are essential for the analysis of short-time cosmic ray variations if the barometric pressure changes are considerable. During times with significant changes in the atmospheric pressure, strong turbulent winds are often predominant at mountain altitudes, strongly affecting the pressure measurements. The described method based on the comparison of the data of two barometers and using smoothed pressure measurements during periods with turbulent winds provides statistically better results for pressure corrected NM count rates.

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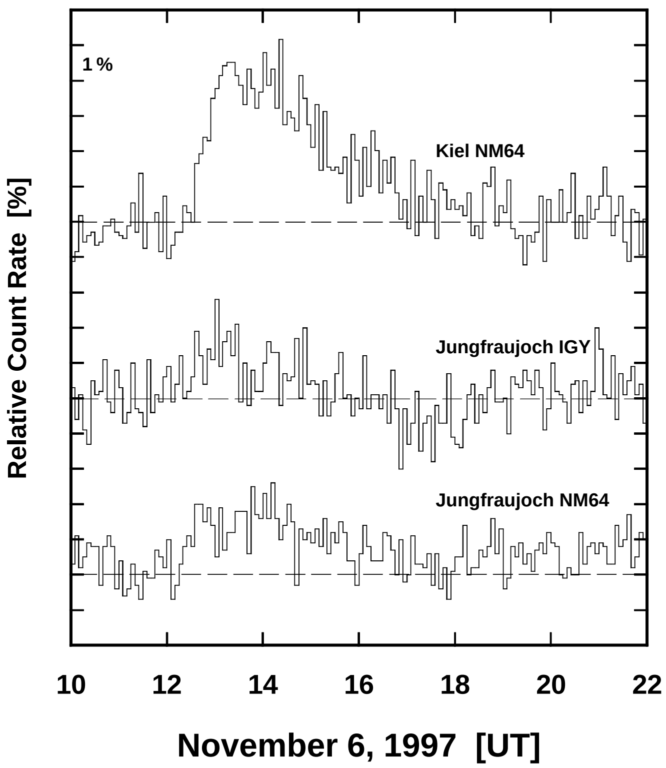

Figure 3: Relative pressure corrected count rate of the Kiel NM64, Jungfraujoch IGY and NM64 (5-minute values).

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