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Variations in cosmic radiation intensity associated with the barometric effect

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RESUMEN

En este trabajo se presenta un estudio del efecto barométrico para el monitor de neutrones de la ciudad de México, basado en los datos de la intensidad de la radiación cósmica durante los años 1990-1997 (más de la mitad del ciclo solar). Hasta la fecha la determinación del coeficiente barométrico se ha basado en pequeñas muestras de datos. El coeficiente barométrico se obtiene mediante la correlación entre la intensidad de neutrones y la presión atmosférica. Para eliminar otros factores de origen geomagnético a solar que influyen en la intensidad de la radiación cósmica, usamos únicamente días geomagnéticamente quietos (k_p<20°). Fue determinada la evolución temporal del coeficiente barométrico del máximo (1990) al mínimo (1997).

PALABRAS CLAVE: Rayos cósmicos, efecto barométrico.

ABSTRACT

The barometric effect for the Mexico City neutron monitor is obtained from cosmic ray intensity data obtained during the years 1990-1997, more than half a solar cycle, by correlation between the neutron intensity and the atmospheric pressure. In order to eliminate other factors of solar or geomagnetic origin we use only geomagnetically quiet days (k_p<20°). The evolution of the barometric coefficient from maximum (1990) to minimum (1997) solar activity is discussed.

KEY WORDS: Cosmic ray, barometer effect.

1. INTRODUCTION

The primary cosmic rays arriving at the top of the atmosphere are fundamentally protons and a small fraction of nuclei, electrons and antinuclei. As these primary cosmic rays propagate downward, nuclear collisions with the components of the atmosphere produce a shower of secondary cosmic rays. The secondary cosmic rays have been classified in a) nucleonic components (protons and neutrons); b) muonic components (muons); and c) electromagnetic components (photons, electrons and positrons).

Their interaction with atmospheric particles depends on parameters that characterize the atmosphere, especially temperature and pressure. Thus the ammount of cosmic rays recorded on a detector out the Earth's surface is a function of atmospheric conditions.

Atmospheric effects on the nucleonic component include the effect of pressure (barometric effect), of temperature, of humidity, of gravity and of electricity. For the nucleonic component, the effects of temperature, humidity, electric field and gravity are negligible as compared to the effect of pressure (Dorman, 1974).

At first it was thought that the barometric effect would only be related to absorption. Dorman (1974) showed that the effects of pressure variations are of three types: (1) absorption: an increase in pressure produces an increase in the mass of air that the cosmic rays travel through and decrease its intensity; (2) decline: an increase in pressure will produce an increase in the altitude where pions and muons are produced site; and (3) generation: additional formation of secondary cosmic rays with increase of pressure.

2. METHODOLOGY

Dorman (1974) found that the intensity ***I*** of secondary neutrons recorded by the detector varies with a small change of pressure ***h*** as

$$I = I_o e^{\beta(h-h_o)} \; , \qquad (1)$$

where β is the barometric coefficient in %/mb, and I_o is the intensity at pressure h_o.

For small variations of pressure, the exponential factor in equation (1) may be substituted by its Taylor series expansion, and we find to first order

$$I = I_o\left(1+\beta(h-h_o)\right) \; . \qquad (2)$$

Equation (2) is often used to obtain the value of β by correlation of the intensity of neutrons with pressure. We may calculate the barometric coefficient using either equation (1) or equation (2).

3. RESULTS AND DISCUSSION

The barometric coefficient for the Mexico City neutron monitor was obtained from cosmic ray intensity data over the years 1990-1997, a period where the Sun goes from a period of maximum activity to one of minimum activity. Earlier cosmic ray barometric coefficient determinations were based on a small sample of data. A value of -0.95%/mmHg was reported (Hurtado and Otaola, 1991). The present determination made over a longer period of time will permit a better accuracy and an estimation of possible dependence on the level of solar activity.

In order to eliminate other factors of solar or geomagnetic origin influencing cosmic radiation, we retain only measurements made on magnetically quiet days, when the index K_p<20°.

Figure 1 shows hourly data of the neutron intensity and the atmospheric pressure corresponding to November of 1990. Note the inverse correlation between intensity and pressure. The negative effects of pressure on cosmic ray nucleonic intensity are dominant over any positive effect.

Table 1 shows the barometric coefficient obtained from a linear approximation of the exponential expression. There are no significant differences between the two determinations. According to the linear approximation the average barometric coefficient for the whole period analyzed is -0.760±0.021% mb, and from equation (1) the value is -0.735±0.021%/mb.

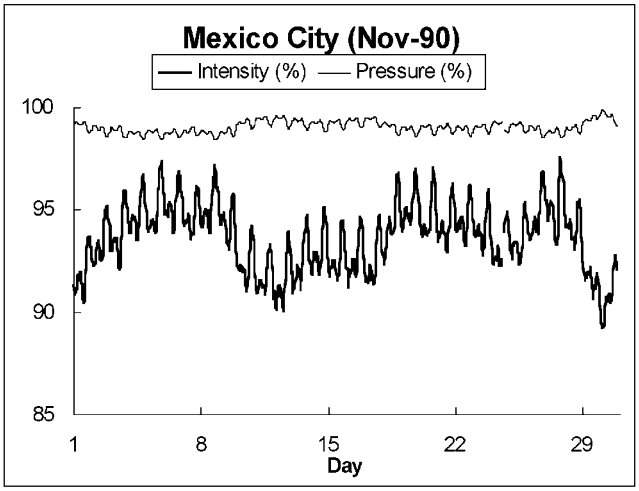

Fig. 1. Intensity of neutrons and atmospheric pressure for November 1990 in Mexico City.

Table 1

Yearly average barometric coefficient for the Mexico City neutron monitor

Year	Linear approximation (%/mb)	Exponential expression (%/mb)
1990	-0.779±0.030	-0.778±0.030
1991	-0.807±0.028	-0.825±0.029
1992	-0.761±0.031	-0.754±0.031
1993	-0.748±0.024	-0.723±0.024
1994	-0.705±0.021	-0.681±0.020
1995	-0.778±0.019	-0.738±0.018
1996	-0.758±0.012	-0.715±0.011
1997	-0.761±0.011	-0.709±0.010
Average	-0.760±0.021	-0.735±0.021

This value of β corresponds to -0.967±0.028%/ mmHg. The earlier value was determined from a small sample of data (-0.95%/mmHg), but it is very close to the new value of β.

The temporal evolution of the barometric coefficient is shown in Figure 2, where we plot the monthly values of β. There is considerable scatter in the monthly values; this is due to the large pressure fluctuations at Mexico City, typical of subtropical latitudes. These large fluctuations mask any general trend due to the solar cycle. We failed to find a significant correlation of β vs. time. In order to remove short period fluctuations in β we filtered the data series using a moving average with a window of 11 months. The trend of the series was not statistically significant. Thus during the half cycle analyzed here there is no significant dependence of β with the solar cycle.

Elsewhere a negative correlation of β with the level of solar activity has been reported (e.g., Kusunose, 1981, Yanchukovsky, 1995). This does not agree with our findings. However, the previous sudies were made at high latitude where the cutoff rigidity is around 2-4GV, and the percentage of low energy particles is larger than at Mexico City, where the cutoff is 9.5GV. Lower energy particles are more strongly influenced by pressure changes; thus a larger β would be expected at high-latitude stations. As the solar cycle advances less lower-energy particles reach the Earth. Therefore high latitude stations tend to be less sensitive to pressure variations. This is reflected in a lower value of β. For low latitude stations such as Mexico City the effect is not noticeable due to the large cutoff.

Dorman (1974) reported that the barometric coefficient at sea level varies between -0.725%/mb for high geomagnetic

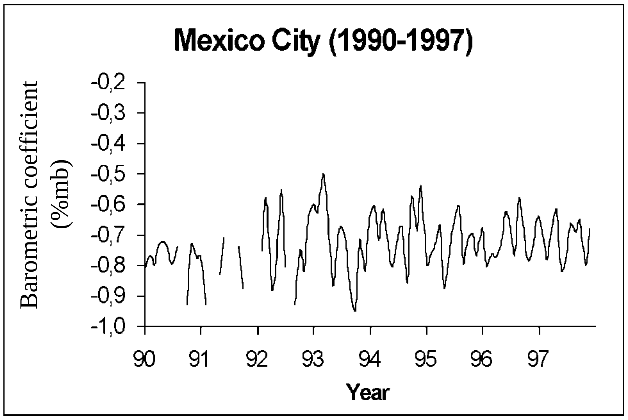

Fig. 2. Temporal evolution of the barometric coefficient for the Mexico City neutron monitor.

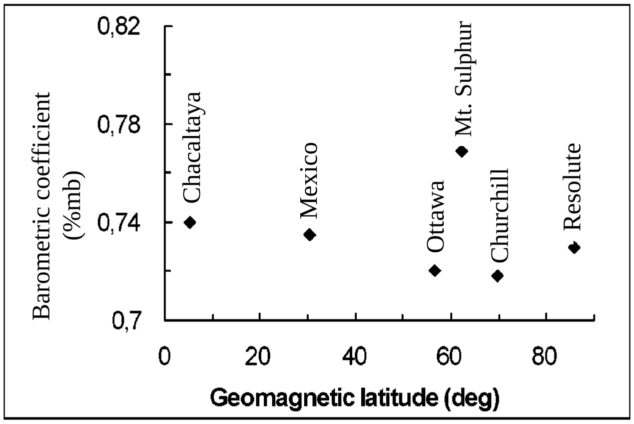

Fig. 3. Average values of barometric coefficients for different neutron monitors.

latitudes and -0.63%/mb for low geomagnetic latitudes. As the neutron monitor in the Mexico City is located at 2240m above sea level we would expect a barometric coefficient larger than -0.63%/mb, because the point of observation is near the level where the atmospheric shower attains its maximum. Hence there is a larger sensitivity to pressure changes. Figure 3 shows the average values of the barometric coefficients from different neutron monitors. Note that for neutron monitors at mountain altitudes (Mt. Sulphur, Mexico, Chacaltaya), the value of the barometric coefficient is lager than at sea level.

4. CONCLUSIONS

A study of the barometric effect for the Mexico City neutron monitor based on cosmic ray intensity data over the 1990-1997 shows that

(1) a linear approximation to the barometric coefficient is a good approximation to the exponential expression,
(2) the barometric coefficient for Mexico City does not vary during the half solar cycle of the recordings,
(3) a value of -0.735%/mb for the barometric coefficient in Mexico City is in agreement with calculations done for other neutron monitors.

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