On the pressure dependence of the cosmic ray intensity recorded by the standard neutron monitor

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ABSTRACT

Pressure coefficients have been determined for some standard neutron monitors at high latitudes for the years 1957–1959 with due regard to variations of primary origin. The following coefficients were obtained: (1) for Murchison Bay and Uppsala $\alpha = -0.710 \pm 0.006$ per cent/mb; (2) for Resolute, Churchill and Ottawa $\alpha = -0.725 \pm 0.005$ per cent/mb; (3) for Mawson and Mt. Wellington $\alpha = -0.736 \pm 0.004$ per cent/mb. The differences in α between the three groups of stations are certainly not due to a purely statistical scattering. They probably reflect dissimilarities in the neutron monitors and the pressure recording devices. As a by-product it has proved that for two stations above the latitude knee, the quotient between the pressure corrected daily neutron intensities is remarkably constant in time. It can thus be used as a sensitive indicator of changes in counting rate.

Introduction

The standard neutron monitor recommended for the IGY is a local neutron production detector. The atmospheric effects on the secondary cosmic radiation to which it is sensitive are rather well known. The mass absorption effect is satisfactorily described by the relation

$$N(P_0 + \delta P) = N(P_0) \exp(\alpha \delta P). \qquad (1)$$

Here δP denotes the difference between the barometric pressure at the time of recording and the mean station pressure P_0. $N(P)$ is the intensity recorded at the pressure P and α is a negative constant (the pressure coefficient). Relation (1) is often written in the form

$$N(x_0 + \delta x) = N(x_0) \exp(-\delta x / L). \qquad (2)$$

The atmospheric depth x is here chosen as independent variable instead of the barometric pressure. L, which is inversely proportional to α, is the attenuation length or the absorption mean free path.

The value of α is about -0.7 per cent/mb. The results of some determinations of α, published in the years 1949–1959, are graphically represented in Fig. 1. The large neutron monitors now in continual operation furnish data on which rather accurate calculations of the pressure coefficient can be founded. This is reflected by the relatively small errors in the right part of Fig. 1.

The third publication of neutron monitor data from The National Committee for the IGY in Tokyo presents data from 48 recording stations. A frequency diagram of the pressure coefficients used at these stations is shown in Fig. 2. More than 50 per cent of the stations use $\alpha = -0.72$ per cent/mb. According to SIMPSON and FONGER (1953) and MCCRACKEN and JOHNS (1959) one would expect to find high mountain stations and low latitude stations in the left part of the diagram.

Due to the presence of meson links between the primary radiation and the locally produced neutrons the recorded intensity should be dependent on the atmospheric temperature conditions. The temperature effect has been estimated theoretically by SIMPSON, FONGER and TREIMAN (1952) and by DORMAN (1957). The experimentally determined temperature coefficients are not significantly different from zero.

The present paper contains some new investigations on the mass absorption effect. It is claimed that the magnitude of the pressure coefficient to some extent must be considered a property of the recording apparatus.

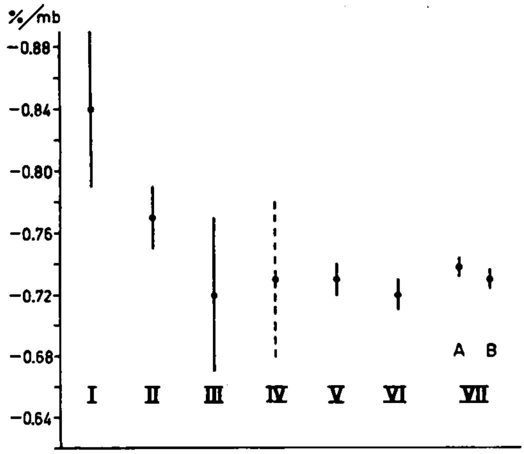

Fig. 1. Pressure coefficients determined for graphite-lead and paraffin-lead piles by I Cocconi Tongiorgi, 1949. II Adams and Braddick, 1951. III Simpson, Fonger and Treiman, 1952. IV Simpson and Fagot, 1953. V Lockwood and Yingst, 1956. VI Mathews (Ottawa), 1958. VII McCracken and Johns (A: Mawson, B: Mt. Wellington), 1959.

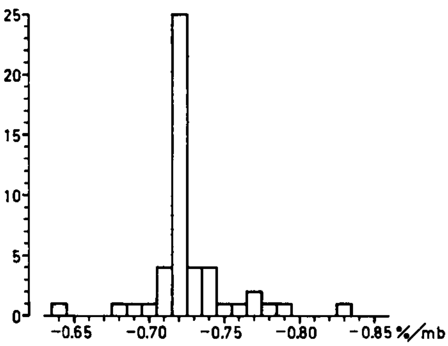

Fig. 2. Frequency diagram of the pressure coefficient used at 48 neutron monitor stations according to CR intensity during the IGY, No. 3 (April 1960) published by The National Committee for the IGY, Tokyo.

Some new determinations of the pressure coefficient

We put $N(P_0 + \delta P) = N$ and $N(P_0) = N^*$ in eq. (1) and apply it to two different stations (subscripts 1 and 2). We get

$$\ln(N_1/N_2) = \ln(N_1^*/N_2^*) + \alpha_1 \delta P_1 - \alpha_2 \delta P_2 \quad (3)$$

If the differences in altitude and geomagnetic latitude are not very large, it seems reasonable to assume that $\ln(N_1^*/N_2^*)$ is a constant, C.

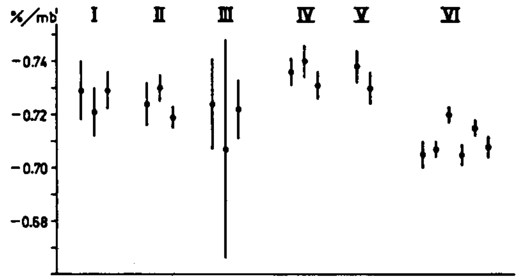

Fig. 3. Pressure coefficients determined for: I, Resolute and Churchill, according to eq. (4). II, Churchill and Ottawa, according to eq. (4). III, Ottawa (Mathèws, 1958). IV, Mawson and Mt. Wellington, according to eq. (4). V, Mawson and Mt. Wellington (McCracken and Johns, 1959). VI, Murchison Bay and Uppsala, according to eq. (4).

By means of eq. (3) we can now determine α_1 if α_2 is known and vice versa. If neither of them is accurately known, we put $\alpha_1 = \alpha_2 = \alpha$:

$$\ln(N_1/N_2) = C + \alpha(\delta P_1 - \delta P_2) \quad (4)$$

This equation is suitable for determinations of α without disturbing effects from variations in the primary intensity. Stations above the latitude knee should be preferred as $\ln(N_1^*/N_2^*)$ is assumed to be a constant, and periods with large variations in $\delta P_1 - \delta P_2$ should be aimed at.

In the present paper the following pairs of stations have been treated:

(1) Murchison Bay ($\lambda = 75.13°$) and Uppsala ($\lambda = 58.03°$) (Sweden)
(2) Resolute ($\lambda = 85.18°$) and Churchill ($\lambda = 72.77°$) (Canada)
(3) Churchill ($\lambda = 72.77°$) and Ottawa ($\lambda = 59.72°$) (Canada)
(4) Mawson ($\lambda = -63.67°$) and Mt. Wellington ($\lambda = -54.34°$) (Australia)

It should be mentioned that daily means of N and P have been used in all the calculations.

It is clear from the geomagnetic latitudes listed above (Quenby and Webber, 1959; Cogger, 1960) that all the stations are located north of $\lambda = 50°$ or south of $\lambda = -50°$. Furthermore, they are all sea level stations except Mt. Wellington which is situated 725 m above sea level.

Details about the periods analysed and the results are found in Table 1. It is evident from Fig. 3 that the pressure coefficients obtained

TABLE 1. *Pressure coefficients calculated according to eq. (4).*

Middle of period	Number of days	$\sigma_{\delta P_1 - \delta P_2}$ mb	α per cent/mb
Murchison Bay–Uppsala			
September 21, 1957	30	17.2	-0.705 ± 0.005
November 22, 1957	49	19.4	-0.707 ± 0.003
January 22, 1958	38	20.0	-0.720 ± 0.003
December 11, 1958	40	16.9	-0.705 ± 0.004
January 21, 1959	31	26.0	-0.715 ± 0.003
February 26, 1959	23	22.3	-0.708 ± 0.004
		20.3	-0.710 ± 0.006
Resolute–Churchill			
October 3, 1957	28	9.0	-0.729 ± 0.011
February 20, 1958	51	9.0	-0.721 ± 0.009
November 11, 1958	65	9.7	-0.729 ± 0.007
		9.2	-0.726 ± 0.004
Churchill–Ottawa			
November 7, 1957	32	11.6	-0.724 ± 0.008
February 2, 1958	48	15.5	-0.730 ± 0.005
January 10, 1959	45	16.9	-0.719 ± 0.004
		14.7	-0.724 ± 0.005
Mawson–Mt. Wellington			
November 11, 1957	96	12.3	-0.736 ± 0.005
July 6, 1958	67	12.4	-0.740 ± 0.006
May 12, 1959	39	14.7	-0.731 ± 0.005
		13.1	-0.736 ± 0.004

for the Canadian stations (I and II; $\alpha = -0.725 \pm 0.005$ per cent/mb) are in good agreement with the coefficients found by Mathews for Ottawa (III). The coefficients calculated for the Australian stations (IV; $\alpha = -0.736 \pm 0.004$ per cent/mb) agree very well with those determined by McCracken and Johns (V).

The Swedish stations yield values of α that are considerably smaller (VI; $\alpha = -0.710 \pm 0.006$ per cent/mb). However, they must be considered rather reliable as they are calculated for periods with remarkably large variations in the pressure variable, $\delta P_1 - \delta P_2$. The mean value of the standard deviation of $\delta P_1 - \delta P_2$ is > 20 mb for the six periods treated (Table 1).

To test the assumption $\alpha_1 = \alpha_2 = \alpha$ for the Swedish stations, pressure coefficients have been calculated for each of them by means of eq. (3). The periods listed in Table 1 were used even in this case, although they were chosen to give maximum variations in the difference $\delta P_1 - \delta P_2$. In the determination of α for Murchison Bay, $\alpha = -0.71$ per cent/mb was assumed for Uppsala and vice versa.

The pressure coefficients obtained in this way are presented graphically in Fig. 4. The mean values for Murchison Bay ($\alpha = -0.713 \pm 0.007$ per cent/mb) and Uppsala ($\alpha = -0.707 \pm 0.008$ per cent/mb) differ by 0.006 per cent/mb. About the same difference (0.008 per cent/mb) was found between Mawson and Mt. Wellington by McCracken and Johns. These differences, existing *within* the Swedish and Australian groups of stations, are only about one third of the difference existing *between* the groups.

Discussion

It seems improbable that the difference in α between, e.g., the Swedish and Australian sta-

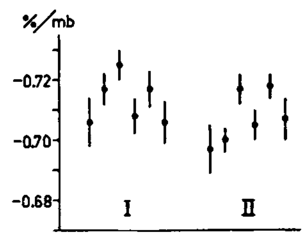

Fig. 4. Pressure coefficients determined according to eq. (3) for: I, Murchison Bay; II, Uppsala.

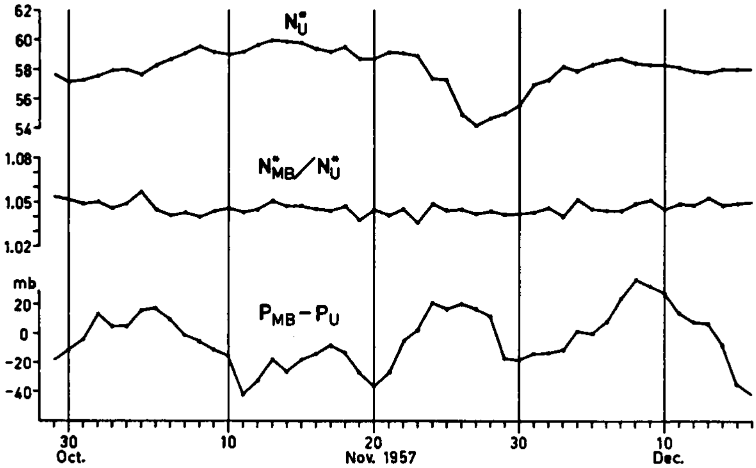

Fig. 5. N_U^* = pressure corrected intensity for the Uppsala neutron monitor; N_{MB}^*/N_U^* = quotient between pressure corrected intensities for the neutron monitors at Murchison Bay and Uppsala; $P_{MB}-P_U$ = pressure difference between Murchison Bay and Uppsala. The figure illustrates the large and rapid variations in $P_{MB}-P_U$ which occur frequently. No effect of the CR decrease at the end of November is apparent in the quotient N_{MB}^*/N_U^*.

tions should be due to a purely statistical scattering as the highest value obtained for the former group is 0.01 per cent/mb lower than the lowest value obtained for the latter (Table 1). The difference cannot be a latitude effect as such an effect would manifest itself in larger pressure coefficients for the Swedish pair of stations.

The differences in α within the Swedish and Australian groups are not significantly different from zero. However, it should be pointed out that the larger values have been obtained for the stations closer to the poles which might be interpreted as a latitude effect.

Lockwood and Calawa (1957) have shown how large errors may be introduced in determinations of α for windy stations if the dynamical part of the total pressure is neglected. The wind speed is usually higher when the pressure is low which leads to an underestimation of α. The only mountain station treated here is Mt. Wellington and the pressure coefficient obtained for that station is one of the largest.

If the differences in α found in the present material were due to instrumental dissimilarities, they would be expected to be larger *between* the groups than *within* the groups as the two stations constituting a pair are built and supervised by the same staff in all the four cases. As what would thus be expected agrees with the actual situation it is plausible to suspect some details of the recording apparatus.

If a pressure recording instrument gives the deviations from the normal station pressure one per cent too small, it will give rise to a pressure coefficient that is 0.007 per cent/mb too large and vice versa. It is not improbable that dissimilarities with that effect exist among the pressure recording devices.

Another detail which might be responsible for the unexpected discrepancies in α, is the counter background. An increase of the background with one per cent causes a decrease of α amounting to 0.007 per cent/mb.

There are no indications outside the limits of error that α should have varied during the two years covered by the present analysis.

At an early stage of the calculations it proved advantageous to plot

$$\ln(N_1/N_2) - \alpha(\delta P_1 - \delta P_2)$$

as a function of time in order to check the performance of the neutron monitors. In the preceding section it was assumed that for the groups of stations treated here this function should be independent of time: $\ln(N_1^*/N_2^*) = C$. This assumption was not contradicted by the curves drawn for the present investigation.

Fig. 5 shows such a curve for Murchison Bay–Uppsala. In some cases it has been possible to detect changes in counting rate due to short power failures just by careful inspection of such curves. On the other hand it has not been possible to use the curves for a study of long term variations in the quotient N_1^*/N_2^* because of the difficulties to eliminate changes in counting rate e.g. due to power failures.

Up to now $\alpha = -0.737$ per cent/mb has been used for the pressure correction of the Swedish neutron monitor data. The correct value seems to be about four per cent smaller, at least for Uppsala. As deviations from the normal station pressure amounting to 20 mb are common at Uppsala and Murchison Bay and negative deviations of 40 mb occur in connection with strong depressions it is evident that considerable errors have been introduced.

However, the amplitudes of the first and second harmonics of the daily pressure variation are only of the order of 0.1 mb at the Swedish cosmic ray stations. For this reason no appreciable errors are inherent in the extensive studies of the diurnal and semidiurnal variations made on the basis of the Swedish neutron monitor data.

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