THE BAROMETER COEFFICIENT AND AIR MASS EFFECTS ON COSMIC RAYS AT MACQUARIE ISLAND

By R. M. Jacklyn*

[*Manuscript received November* 16, 1953]

Summary

The changes in cosmic ray intensity associated with the passage of weather fronts over the observing station have been investigated, using data from Macquarie Island. The effects can be explained in terms of the different way in which the height of the production layer for mesons varies with surface pressure for warm moist and cold dry air masses. The barometer coefficients found for these air masses are respectively $-0 \cdot 120 \pm 0 \cdot 058$ per cent. per mb and $-0 \cdot 220 \pm 0 \cdot 041$ per cent. per mb for the penetrating component. These results indicate that the frequently observed fluctuations in short-term barometer coefficients may be traceable to changes in air mass types.

I. Introduction

During the past 10–15 years several workers (Loughridge and Gast 1940; Nishina *et al.* 1940*a*, 1940*b*; Trumpy 1949; Lindholm 1950) have commented on the marked changes which cosmic ray intensities undergo with the passage of fronts over the recording station. This effect was studied at the Australian National Antarctic Research Expedition (A.N.A.R.E.) station at Macquarie Island (lat. 54 °S., long. 159 °E.) during 1951.

The weather at the station was typically overcast, with a yearly average humidity of 88 per cent. Daily and seasonal surface temperature fluctuations were comparatively small, but large variations of surface pressure occurred, often accompanied by a change of air mass. (The phrase " air mass ", for the purpose of this study, refers to a characteristic combination of surface and upper air temperatures, humidity, and surface wind direction, which usually persists over the station for several days at a time, and with the passage of a surface of discontinuity, the front, changes to another typical set of the quantities.)

A change of air mass was generally associated with a cold or an occluded cold front. The origin and orientation of fronts and the tracks of major depressions in the Southern Ocean are still matters of conjecture, partly because there are very few observing stations in the area. Gibbs, Gotley, and Martin (1952) have assumed that the major source region of fronts is in the close neighbourhood of the Antarctic Continent. Briefly, they appear to develop as follows. Outbursts of cold dry air move northwards behind Antarctic fronts until they become the polar fronts of middle latitudes. Wave developments in these fronts result in the growth of major depressions. One of the two main tracks followed by

* Member of the Australian National Antarctic Research Expedition at Macquarie Island, 1951–52; present address: Physics Department, University of Tasmania, Hobart.

these depressions, and their associated fronts, is in a south-east direction from the south-west coast of Australia to the vicinity of Macquarie Island, reaching maximum development at 60 °S. As they approach the Antarctic coastline and gradually dissolve, the depressions cause fresh outbreaks of Antarctic air to occur, with new Antarctic fronts as their forward boundaries. So it seems likely that cold fronts at Macquarie Island are either well-developed polar fronts associated with depressions tracking from the north-west, or else Antarctic fronts associated with fresh air masses from the Continent.

II. Equipment and Method of Analysis

The cosmic ray records used for this work were obtained from two independent units, identical in geometry with those used by Caro, Law, and Rathgeber (1948). But the recording circuits differed, and gave a resolving time for coincidence of 2 μsec.

A wide angle vertical telescope comprised two closely spaced trays of Geiger counters, each having an effective sensitive area of 400 cm^2. Double coincidences from this unit measured the wide angle total intensity (referred to as count 3) at a rate of about 20,000 counts/hr. The other unit, a narrow angle vertical array comprised four trays of the same type as above, with a spacing of 15 cm between adjacent trays. Ten cm thickness of lead was placed over the bottom tray so that triple coincidences from the lower trays measured the narrow angle penetrating component (referred to as count 2) at a rate of about 3400 counts/hr. The top three trays were used in triple coincidence to measure the narrow angle total intensity (referred to as count 1) at a rate of approximately 4800 counts/hr. Since counts 1 and 2 were derived from arrays with identical geometry, an approximate measure of the non-penetrating radiation could be obtained by taking the difference between them, but the derived counting rate was found to be too low to give results of sufficient statistical accuracy for this work.

Count 3 (wide angle total intensity), count 1 (narrow angle total intensity), and count 2 (penetrating component) were each analysed for the average effects produced by the passage of fronts, following a procedure used by Loughridge and Gast (1940). For an individual front, the counting rates were collected into 6-hr groups, referred to the time of passage over the station. Thus the 6-hr group immediately preceding the change of air mass was centred about the time 3 hr before the passage of the front. The counting rates were corrected to a standard pressure of 940 mb using the appropriate bi-monthly barometer coefficient, derived from the daily mean rates and surface pressures. To minimize the effects of fluctuations in the general level of intensity between one front and another, the corrected rates were normalized to the second 6-hr group preceding the front. Thus only the mean differences were plotted between this and other groups.

Counts 1 and 2 were analysed for six well-defined cold fronts and five double cold fronts (for each of which the frontal changes occurred in two distinct stages several hours apart) recorded between June and November 1951. These have been treated as a single group of 11 cold type fronts, to obtain a better estimate of the post-front changes. Over the same period, results from count 3 were available for 14 cold type fronts.

Since the same apparatus was in operation at Macquarie Island during 1950, the records for that year were also analysed for the effect of fronts, and in this case it was decided to consider only the occasions for which both independent units were operating, so that the records for all counts were simultaneous. This restricted the results to 12 marked cold fronts. No double fronts were included in this group.

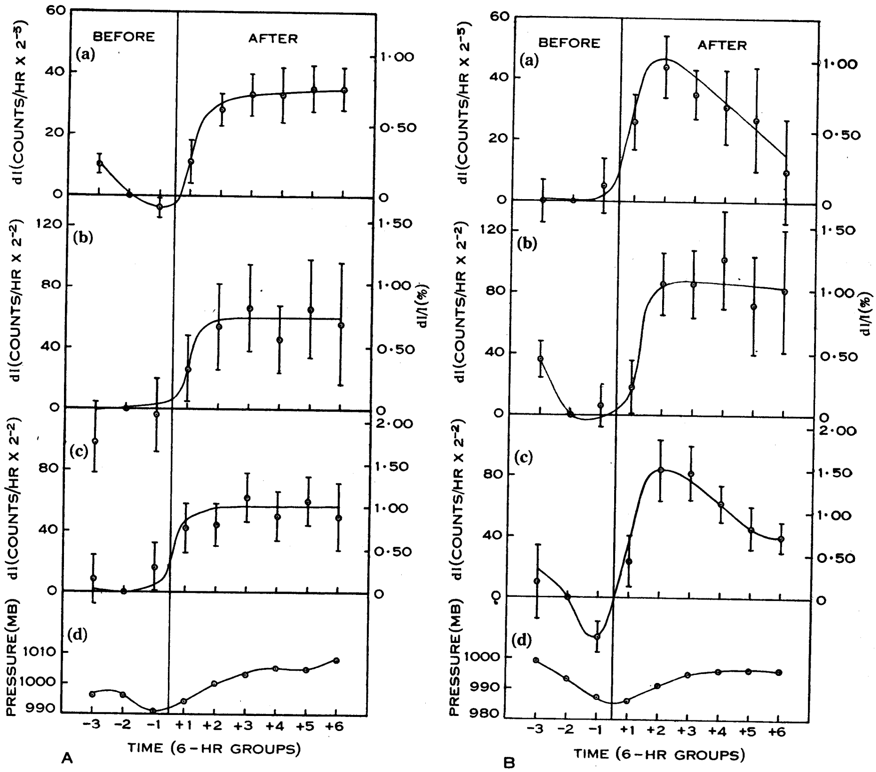

Fig. 1*A*.—The average effect of the passage of cold fronts during 1950 on (*a*) the wide angle total intensity (count 3), (*b*) the narrow angle total intensity (count 1), (*c*) the narrow angle penetrating component (count 2), together with (*d*) the mean surface pressure variations. The error tails shown are the 95 per cent. fiducial limits.

Fig. 1*B*.—The average effect of the passage of cold type fronts during 1951. (*a*)–(*d*) as for Figure 1*A*.

III. The Front Effects

The average effects on the corrected counting rates for each of the years 1950 and 1951 are shown graphically in Figures 1*A* and 1*B*, together with the mean surface pressure variations. The post-front increases in the level of corrected scaled counts for each type of telescope as well as the percentage increases are set out in Table 1. It can be seen that the increases are consistent for both years, and they are in qualitative agreement with the ionization chamber measurements made by Loughridge and Gast. The increases in corrected scaled counts for the penetrating radiation and total radiation are the same for the two telescopes with the same geometry. The smaller percentage increase in total radiation is practically the same for both the narrow angle and the wide angle telescopes. Thus it appears that the post-front effects are almost entirely due to variations in the penetrating radiation.

TABLE 1

POST-FRONT INCREASES IN COSMIC RAY INTENSITIES CORRECTED FOR PRESSURE USING A TOTAL BAROMETER COEFFICIENT

	Year	Count 2	Count 1	Count 3
Number of fronts	1950	12	12	12
	1951	11	11	14
Total increase (scaled counts)..	1950	50–60	50–60	
	1951	80–90	80–90	
Percentage increase	1950	0·93	0·75	0·75
	1951	1·5	1·0	1·0

IV. THE MECHANISM OF THE FRONTAL EFFECTS AND THE VARIABILITY OF THE BAROMETER COEFFICIENT

As Duperier (1949) has pointed out, cosmic ray intensity may be regarded as a function of several meteorological variables. He proposed that the following three were predominant: the surface pressure B, the height H of the pressure level where the majority of mesons are produced, and the mean temperature T in the neighbourhood of this level. Thus a variation of the intensity I is given by

$$\delta I = \mu\delta B + \mu'\delta H + \alpha\delta T.$$

On the other hand, if cosmic ray intensity is regarded as a function of surface pressure only, and

$$\delta I = \beta\delta B,$$

where β is the total barometric regression coefficient, then

$$\beta = \mu + \mu'\frac{\delta H}{\delta B} + \alpha\frac{\delta T}{\delta B}. \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Evidently then, the pressure coefficient varies with the upper air meteorological conditions, and may undergo marked and consistent changes when one type of air mass replaces another.

With this in mind, the total pressure coefficients for the pre-front moist warm air and the post-front polar air for the months June to November were obtained from the 1951 records. (Unfortunately it was not possible to extract this kind of data for the 1950 results.) The coefficients for counts 1 and 2 are set out in Table 2 (the errors given being the 95 per cent. fiducial limits) together with the bi-monthly coefficients used for the analysis described above. In the passage from a temperate to a polar air mass there is a significant increase in the pressure coefficient for the penetrating radiation, and that for the total intensity shows a similar trend. Notably, all the bi-monthly coefficients have values lying between the two air mass values.

TABLE 2
BAROMETER COEFFICIENTS 1951

	Penetrating Component (counts/mb)	Narrow Angle Total Intensity (counts/mb)
Temperate air mass ..	—1·018±0·49 (—0·120±0·058%/mb)	—1·093±0·41 (—0·184±0·069%/mb)
Polar air mass	—1·877±0·35 (—0·220±0·041%/mb)	—1·563±0·23 (—0·260±0·037%/mb)
Bi-monthly means		
May–June	—1·591	—1·44
July–August	—1·426	—1·44
September–October ..	—1·231	—1·44

If the counting rates are corrected using the appropriate coefficients for the air masses (Fig. 2), it is obvious that the change in corrected rates on passing through a front is arbitrary, depending on the choice of a standard pressure. If, as in the case of count 2, the standard pressure is chosen corresponding to the point of intersection of the regression lines (1005 mb) there should be no change in corrected rates on passing from the temperate to the polar air mass. But it is clear that if a single average pressure coefficient is used, as in the data summarized in Figure 1, its value lying somewhere between the values for the polar and temperate air mass coefficients, the rates corrected to a standard pressure must increase after the passage of a cold front. This accounts for the fact that the pattern of variation of penetrating and total radiation, corrected using the same barometer coefficient before and after cold type fronts, is consistent for both years on Macquarie Island and is in qualitative agreement with the observations made by Loughridge and Gast (1940). This being so, referring to equation (1), the ratios $\delta H/\delta B$ and $\delta T/\delta B$ must vary consistently both in different years and in different places on passing from warm moist to cold dry air.

Now, Trumpy (1949) has accounted for variation in meson counting rate due to the passage of fronts by assuming that the surface pressure B and the height of the 100-mb level H are the predominantly effective variables, so that

$$\delta I = \mu \delta B + \mu' \delta H.$$

The corresponding expression for the barometer coefficient β is

$$\beta=\mu+\mu'\frac{\delta H}{\delta B}.$$

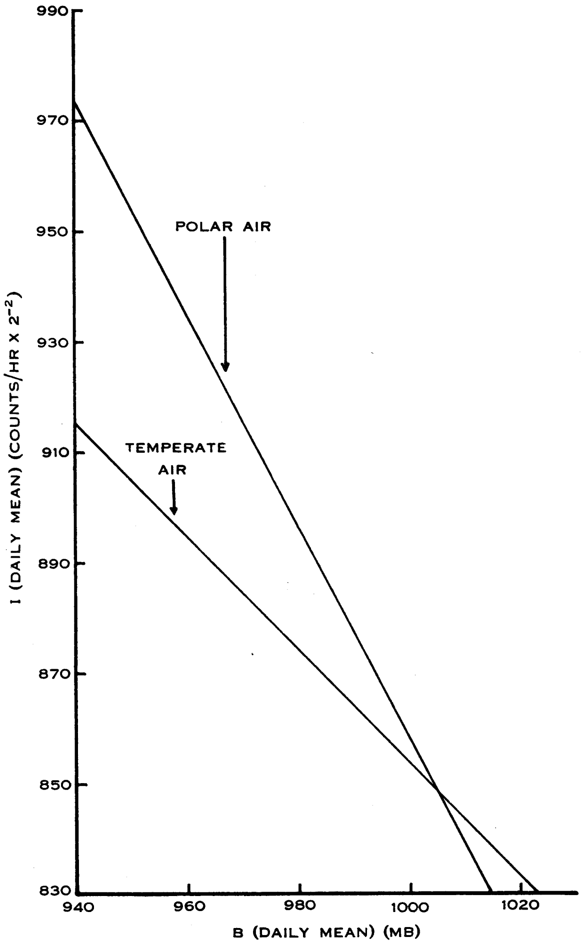

Fig. 2.—The line of regression of penetrating radiation (count 2) on surface pressure under different air mass conditions.

Using the suffixes P and T to denote polar air mass and temperate air mass conditions respectively, we have

$$\beta_P=\mu+\mu'\left(\frac{\delta H}{\delta B}\right)_P, \qquad \text{(2)}$$

$$\beta_T=\mu+\mu'\left(\frac{\delta H}{\delta B}\right)_T. \qquad \text{(3)}$$

With the data obtained from the daily radiosonde flights conducted at the station, values of $(\delta H/\delta B)_P$ and $(\delta H/\delta B)_T$ were found using the least squares method of regression analysis. Over the same period for which β_P and β_T had been calculated, they are as follows :

$$\left(\frac{\delta H}{\delta B}\right)_T = -3\cdot 048 \times 10^{-5} \text{ km/mb } (-0\cdot 194 \times 10^{-3} \text{ per cent./mb}),$$

$$\left(\frac{\delta H}{\delta B}\right)_P = +1\cdot 612 \times 10^{-2} \text{ km/mb } (+0\cdot 1028 \text{ per cent./mb}).$$

The mass absorption coefficient μ, the decay coefficient μ', and the mean range for mesons before decay, L (the reciprocal of μ', where μ' is expressed as the fractional change of intensity per km, $(1/I)(\delta I/\delta H)$, obtained by substitution in equations (2) and (3), compare favourably with the values found by Trumpy in Norway, as shown in Table 3.

TABLE 3

Place	μ (%/mb)	μ' (%/km)	L (km)
Macquarie Island ..	—0·120	—5·52	18·1
Norway	—0·151	—5·8	17·3

V. CONCLUSIONS

Summing up, it appears that marked changes in cosmic ray intensities occur following the passage of cold fronts, and they become more apparent after correction with the total bi-monthly barometer coefficients. The apparent increases are due to changes in the value of $\delta H/\delta B$, upon which the barometer coefficient depends, $\delta H/\delta B$ having a greater value (in the positive sense) for cold dry air masses than for warm moist air. The frequently observed fluctuations of short-term barometer coefficients may be largely traceable to this cause.

VI. ACKNOWLEDGMENTS

Acknowledgment is due to Drs. A. G. and K. B. Fenton, who suggested and encouraged this work ; to Professor A. L. McAulay for his valuable criticisms of the draft paper ; to Messrs. Martin and Gibbs of the Melbourne Weather Bureau for extracting the 1950 frontal data ; to the A.N.A.R.E. for providing the cosmic ray data ; and to the C.S.I.R.O. for the funds which enabled this study to be continued at Hobart.

VII. REFERENCES

CARO, D. E., LAW, P. G., and RATHGEBER, H. D. (1948).—*Aust. J. Sci. Res.* A **1** : 261-74.

DUPERIER, A. (1949).—*Proc. Phys. Soc. Lond.* A **62** : 684-96.

GIBBS, W. J., GOTLEY, A. V., and MARTIN, A. R. (1952).—Aust. Nat. Antarctic Res. Expedition Reports, Series D, Meteorology. Vol. 1, Part 1 (*c*).

LINDHOLM, F. (1950).—*Tellus* **2** : 63-7.

LOUGHRIDGE, D. H., and GAST, P. F. (1940).—*Phys. Rev.* **58** : 583-5.

NISHINA, Y., SEKIDO, Y., SIMAMURA, H., and ARAKAWA, H. (1940*a*).—*Phys. Rev.* **57** : 663.

NISHINA, Y., SEKIDO, Y., SIMAMURA, H., and ARAKAWA, H. (1940*b*).—*Phys. Rev.* **57** : 1050.

TRUMPY, B. (1949).—Univ. Bergen Årb. 1949, No. 3.