THE DIURNAL VARIATION OF THE BAROMETER COEFFICIENT FOR COSMIC RAYS AT HOBART

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Summary

The records from a vertical counter telescope measuring the hard component of cosmic radiation at sea-level have disclosed significant diurnal variations of the barometer coefficient at Hobart, Tas. The amplitude of the variation is about 5 per cent., and there are secular changes of the same order during the mean day.

It is shown that it is meaningless to correct the diurnal variations of intensity to conditions of standard surface pressure using a barometer coefficient averaged over the mean day if the standard pressure chosen is very different from the observed mean value. Moreover, there is evidence from the Hobart results for 1954 that the observed diurnal maximum of the corrected intensities is associated with a low barometer coefficient and the minimum with a high coefficient, suggesting that the form of the corrected intensity variations may be determined largely by variations occurring within the atmosphere. Possible reasons for the variation of the barometer coefficient are discussed and an experiment is suggested which might decide what is the main cause of these variations, a changing primary spectrum or changing properties of the atmosphere.

I. INTRODUCTION

The main purpose of the study of the diurnal variations of cosmic ray intensity at the Earth's surface is to make deductions concerning the variations in solar time of primary cosmic rays at the top of the atmosphere. However, before this can be done it is necessary to take into account the effect of diurnal variations of the atmosphere on the cosmic ray intensity.

The effect produced by the atmosphere may come about in various ways. Consider first a local atmosphere which has uniform properties from hour to hour except that it undergoes a periodic fluctuation of surface pressure and whatever may be related to this, such as the heights and temperatures of pressure levels. For instance, let H be the height of the mean pressure level at which mesons are produced, and T be the temperature in the neighbourhood of that level. Then, according to Duperier (1949) a change of surface pressure ΔB is accompanied by a change of cosmic ray intensity ΔI such that

$$\Delta I=\mu\Delta B+\mu'\Delta H+\alpha\Delta T,$$

where μ,μ', and α are the mass, decay, and positive temperature coefficients respectively. The barometer coefficient β is then

$$\beta=\Delta I/\Delta B=\mu+\mu'\Delta H/\Delta B+\alpha\Delta T/\Delta B.$$

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In a local atmosphere in which $\Delta H/\Delta B$ and $\Delta T/\Delta B$ remain constant throughout the day, the changes $\beta\Delta B$ may be estimated by the use of the standard barometer coefficient β. The corrected cosmic ray intensities refer to a uniform atmosphere of constant surface pressure. Provided this reference pressure is chosen within the range for which the pressure dependence is linear, the difference between the pressure corrections $\beta\Delta B_x$ and $\beta\Delta B_y$ for two different hours will remain the same for any choice.

However, in a real atmosphere the coefficients $\Delta H/\Delta B$ and $\Delta T/\Delta B$ are not constant and the barometer coefficient will vary. Thus the pressure corrections at two different times will become $\beta_x\Delta B_x$ and $\beta_y\Delta B_y$. The difference between these obviously depends upon the choice of reference pressure, and this choice will therefore affect the form of the " corrected " daily intensity variation.

Variations in the relative intensities of the low and high energy primaries would also produce changes in the barometer coefficient, since this is a function of the energy of the particles arriving at sea-level (Fenton 1952).

In what follows it will be shown that there is evidence for a diurnal variation of the barometer coefficient and that one has to be very careful before ascribing diurnal variations remaining in the hourly cosmic ray intensities after correction, to variations in the primary radiation. This applies particularly to cases such as the present one, in which only sea-level meteorological data are available.

II. Results

A vertical counter telescope with a counting rate of approximately 80,000 counts/hr and an opening angle of 60°, measuring cosmic radiation which penetrates 10 cm of lead absorber, has been in operation at Hobart, Tas., since September 1953. Five 3-monthly groups of data have been analysed, from December 1953 to February 1955 inclusive. Within each group the days have been divided into six 4-hourly periods, and for each of these periods the mean intensity, surface pressure, and barometer coefficient have been obtained. Only complete days have been considered, and of these all days during which the passage of meteorological fronts occurred have been discarded.

The results, showing the daily variations of the barometer coefficient for each seasonal group, are displayed in Figure 1, in which the errors shown are the 95 per cent. fiducial limits. The last point on each graph refers to the same local time as the first point, but for the following day, so that it can be seen that not only are there periodic effects, but that quite large secular changes occur between the end points in some cases. As will be shown later, the large secular effect is due to the frequent passage of cold fronts, and the repeating pattern between cold fronts. Because of the errors of the end points, only a rough correction can be made for the secular effect but it appears that there are seasonal changes in the amplitude of the periodic variations and probably changes in phase as well.

Consider what happens when the observations are averaged over the year from December 1953 to November 1954 inclusive. Figures 2 (*a*), 2 (*b*), and 2 (*c*) show the variations of surface pressure, intensity, and barometer coefficient respectively. An obvious feature is that there is practically no secular change of intensity corresponding to the secular decrease in pressure. On the basis of the existence of a standard barometer coefficient one would expect an increase of intensity of 0·7 scaled counts at the end of the day for the fall in pressure of 0·83 mb. The secular decrease of the barometer coefficient is the cause of this apparent anomaly.

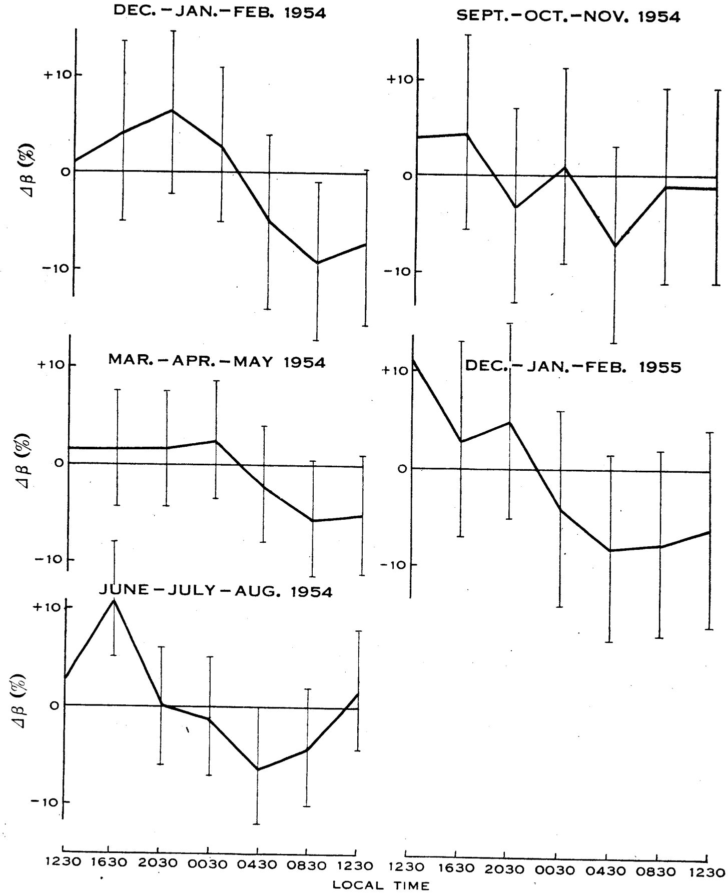

Fig. 1.—The diurnal variation of the barometer coefficient in 3-monthly groups. Errors shown are the 95 per cent. fiducial limits.

In Figure 2 (*d*) the full line shows the variation of intensity about the annual mean, corrected to an arbitrary pressure level using the standard coefficient, and adjusted for secular change. Alternatively correction could have been carried out using the observed coefficient appropriate to each 4-hr period and a reference pressure equal to the annual mean. There is no practical difference in the corrected values whichever method is used. Dashed lines show the effect of using the observed 4-hourly coefficients to correct the data to a pressure 15 mb above, 5 mb above, and 15 mb below the annual mean. The tails drawn are the 95 per cent. fiducial limits. There is a clear trend from a large amplitude at high to a small amplitude at low reference pressures. In fact, comparing the barometer coefficient variations, adjusted for secular change, with those of intensity corrected with the standard coefficient, it is interesting to notice that high barometer coefficients correspond to low intensities and vice versa. It is possible to choose a reference pressure at which the range of variation of the corrected intensity is within the statistical limits. The implication is that, for the year 1954, the cause of the barometer coefficient variations may have been the cause of the diurnal variations in the observed cosmic ray intensity.

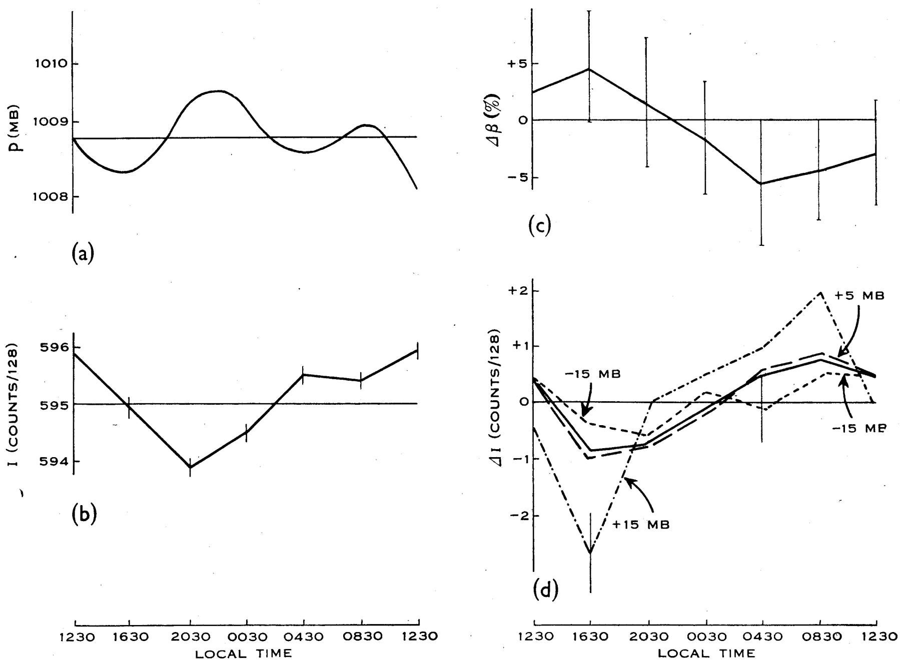

Fig. 2.—Diurnal variations averaged over the year December 1953 to November 1954 inclusive. Error tails show the 95 per cent. fiducial limits. (*a*) Surface pressure variation. (*b*) Variation of uncorrected intensity. (*c*) Variation of the barometer coefficient. (*d*) Variation of the corrected intensity. Full line—intensity variation corrected with a fixed long-term barometer coefficient to an arbitrary pressure level. The variation is practically identical if correction is made to the annual mean pressure using the observed 4-hourly coefficients. Dashed lines—the intensity variations corrected with the observed 4-hourly coefficients to a surface pressure 15 mb above, 5 mb above, and 15 mb below the annual mean pressure.

It should be pointed out that the apparent annual changes in amplitude and phase of the corrected intensity variations could be partly due to correction procedures.

III. Discussion

The periodicity of the coefficients may have a primary origin. Primary cosmic ray intensity variations which are not accompanied by changes in the energy spectrum cannot alone produce such a periodicity. If the energy spectrum does change, then it appears that it is such as to favour the arrival of high energy particles during the morning (from 3 a.m. to 3 p.m.) and lesser energies between 3 p.m. and 2 a.m. when the barometer coefficients are higher. Alternatively, the periodicities may be caused by changing atmospheric properties ; for instance $\Delta H/\Delta B$ might be less between 3 a.m. and 3 p.m. than it is for the rest of the day. To distinguish between these possible influences a comparison should be made between the diurnal variations of intensity within a narrow energy band and the variation of the total hard component intensity. Then, if there is no appreciable diurnal variation of β within the selected narrow energy range by comparison with that for the total intensity it is likely that a change in primary spectrum is responsible for the overall β variations. Or, if the variations of β within the narrow energy band are the same as those for the whole spectrum, changing atmospheric properties must be producing the main effect.

Whatever may be the cause of the truly periodic variations, the secular decrease of the barometer coefficient is of atmospheric origin. It has come about in the following way. The data have been selected to exclude all days during which frontal passages occurred. In Tasmania, these are almost always cold, or occluded cold fronts. In other words, as far as possible all periods of change of air mass accompanied by rapid cooling have been eliminated. If they were not, there would be present in the data a number of brief periods containing abrupt increases of intensity of the order of 1 per cent., together with increases of the barometer coefficient of the order of 100 per cent., and it is quite impracticable to correct for these effects (Jacklyn 1954). Thus there remain the days during which the atmospheric temperature up to the production level for mesons is on the average increasing. Considering in this context only the mass effect and μ-meson decay, the barometer coefficient β is $\beta=\Delta I/\Delta B=\mu+\mu'\Delta H/\Delta B$. It has been shown (Jacklyn 1954) that $\Delta H/\Delta B$ is less in warm air masses than it is in cold air in the neighbourhood of fronts, so that gradual warming associated with a decrease of surface pressure should be accompanied by a decrease in the barometer coefficient. It is significant that all the seasonal groups of data show a secular decrease in pressure as well as a decrease in the barometer coefficient.

Corrections to the observed intensity variations for a purely secular change of β have periodic components due to the periodic variation of surface pressure. These do not vanish when the final linear adjustment is made for the secular change of corrected intensity.

IV. Conclusions

The consequences of the variations of the barometer coefficient for the study of cosmic ray diurnal variations may be summarized as follows :

(*a*) The data should be selected to exclude days during which frontal passages occur, otherwise large irregularities will obscure the relationship between cosmic ray intensity and surface pressure.

(*b*) Significant secular changes in the barometer coefficient should be expected. These are of atmospheric origin.

(c) If two sets of data, between which there is a large difference of the mean station level pressure, are to be compared under conditions of standard atmospheric pressure, then the diurnal variations of the barometer coefficient should be obtained and the data corrected using the observed coefficients. It should be noted that differences in mean station level pressure are involved, not differences in pressure due to altitude.

(d) Correction of data to an arbitrary standard atmospheric pressure does not entirely remove the diurnal variations produced by the atmosphere. The results from Hobart during 1954 suggest that at the time of maximum of the corrected diurnal variations of intensity there was a minimum barometer coefficient and at the time of minimum intensity there was a maximum barometer coefficient. Therefore, for this particular period the atmosphere may be largely responsible for the diurnal variations which have already been " corrected " for the atmospheric effect. These results, obtained during a period of low solar activity and presumably small primary intensity variations, serve to show that care must be exercised when attributing residual diurnal variations after correction to variations in the primary radiation.

(e) A changing primary spectrum and changing atmospheric properties may both contribute to the diurnal variations of intensity produced by the atmosphere. The study of intensity variations using a differential telescope should show which of these has the greater influence.

V. Acknowledgments

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VI. References

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