DIRECTIONAL MEASUREMENTS OF THE DAILY VARIATION OF COSMIC RAY MESON INTENSITY AT $\lambda=73$ °S.

By N. R. Parsons*

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Summary

Measurements are reported of the daily variations of meson intensity at Mawson, Antarctica ($\lambda=73$ °S.), recorded by counter telescopes inclined at 45° to the vertical in each of north, east, south, and west directions. The results, together with those from a vertical telescope, are examined and found to be inconsistent with an assumed common origin of the different directional variations in the interaction of an anisotropic primary radiation with the Earth's dipole field.

I. Introduction

Directional measurements of daily variations in cosmic ray intensity have been made in recent years by several observers using counter telescopes at stations in the northern hemisphere, e.g. Malmfors (1949), Elliot and Dolbear (1951), Elliot and Rothwell (1956). These measurements have shown that the form of the observed daily variation depends on the direction of arrival of the recorded particles. The nature of the experiments precludes an explanation of this in terms of atmospheric influences, and the experiments thus establish the existence of daily variations in the intensity of primary particles entering the atmosphere.

Attempts have been made to relate the daily variations to the entry of an assumed anisotropic primary radiation into the region occupied by the Earth's magnetic field. The form of the variation observed would then depend on the deflections suffered by the particles in traversing the field and thus on the directional properties of the recorder (cf. Brunberg and Dattner 1954). However, it has been found very difficult to explain on this basis recent directional measurements made at London (Elliot and Rothwell 1956). Elliot and Rothwell conclude that the interpretation in terms of a primary anisotropy outside the field region may be wrong, and that some intensity-modulating mechanism inside the field region is probably responsible for the observed effects.

Directional counter telescope measurements have been carried out during the period May 1955 to February 1956 at the Australian National Antarctic Research Expedition's station at Mawson, Antarctica ($\lambda=73$ °S.; geographic coordinates 67° 36′ S., 62° 53′ E.). Records are available for the four directions, geographic north, east, south, and west, with the telescope axis inclined 45° to the vertical. Simultaneous records from a vertical telescope are also available for comparison. We shall examine whether these results are consistent with the interpretation mentioned above.

* Antarctic Division, Department of External Affairs, Melbourne; present address: Physics Department, University of Tasmania, Hobart.

II. The Experimental Arrangement

For the inclined measurements, a single telescope of high counting rate was used. It was supported, with its axis at 45° to the vertical, on a turntable adapted from a naval-type Bofors gun base. Chronometer-controlled drive and switching mechanisms allowed automatic change of telescope azimuth at the end of each hour of the Greenwich day, the actual recording period at each azimuth setting being 59 min. The sequence geographic north, east, south, west, north, . . . , commencing at a north heading during hour 01 G.M.T., was maintained throughout the 10-month period May 1955 to February 1956.

The design of the telescope itself and of the associated electronic circuits is identical with that of the vertical telescope operated concurrently (Parsons 1957*a*). A detailed description has been published elsewhere (Parsons 1957*b*). Briefly the telescope consists of three counter trays of sensitive area 1 by 1 m,

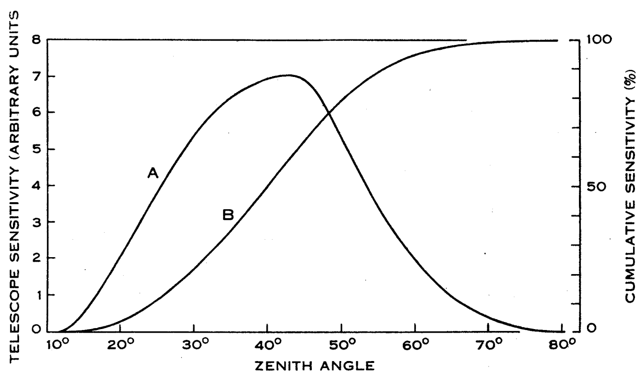


Fig. 1.—Curve *A*, variation with zenith angle of the relative sensitivity of a telescope of dimensions (1 by 1) by 1·5 m inclined 45° to the vertical. Curve *B*, cumulative sensitivity curve for the same telescope.

the separation of extreme trays being 1·5 m. A lead absorber, 10 cm thick, is situated between the lower two trays. Threefold coincidences are recorded with a resolving time of 2·5 μsec. A scale factor of 2^7 is employed and hourly count totals are recorded on electromechanical registers. The average counting rates with the telescope axis vertical and inclined 45° are approximately 85,000 and 45,000 particles per hour respectively.

An accurate determination of the zenith angle sensitivity of the inclined telescope has been carried out assuming that the meson intensity falls off with increasing zenith angle θ as $\cos^{2\cdot 2}\theta$ (Parsons 1957*c*). The sensitivity diagram is reproduced in Figure 1, curve *A*. The direction of maximum sensitivity is at $\theta=42\cdot 5°$. The " cumulative sensitivity " diagram (Fig. 1, curve *B*) indicates that the mean inclination of all radiation recorded is 40·3° and that 50 per cent. of the recorded radiation is incident from zenith angles within approximately 8·5° of this mean value.

III. Analysis of Records

Six equally spaced hourly readings were obtained each day for each azimuth setting of the inclined telescope. In all, records from 274 complete days have been used, and discussion will be restricted to the mean daily variations over the full period.

The mean vertical and inclined directional variations have been corrected for the mean daily barometric pressure variation using a single barometer coefficient of $-2 \cdot 31$ per cent. per cm Hg. This correction procedure has been discussed in a previous paper (Parsons 1957*a*). The mean daily pressure variation at Mawson is predominantly diurnal in character but its amplitude is quite small. The elimination of its effects produces little change in the intensity variation actually observed. Corrections to the intensity variations for small residual secular changes have also been made, assuming these to be linear over the mean day.

Table 1

Amplitudes and times of maximum of fitted 24- and 12-hr components of the mean daily variations, May 1955–February 1956

Direction	24-Hr Component		12-Hr Component	
	Amplitude (%) ±S.E.	Time of Maximum (L.M.T.)	Amplitude (%) ±S.E.	Time of 1st Maximum (L.M.T.)
North	0·081±0·016	1450± 45 min	0·039±0·016	0440
East	0·060±0·016	1320± 60 min	0·057±0·016	0130
South	0·014±0·016	1350±260 min	0·023±0·016	1100
West	0·064±0·016	1610± 55 min	0·027±0·016	0550
Vertical ..	0·079±0·006	1345± 15 min	0·031±0·006	0230

Because of the relatively wide acceptance angle of the inclined telescope (see Fig. 1), and since continuous records from the vertical telescope show a smooth daily variation without sharp peaks, it is reasonable to assume that the mean variation for each azimuth, represented by six equally spaced hourly figures, should also be smooth. Consequently the figures have been subjected to harmonic analysis by standard methods and the variations represented by the sum of fitted 24- and 12-hr components.

The results of the harmonic analysis, giving amplitudes and times of maximum of the two components, are set out in Table 1. Standard errors quoted are calculated on the assumption that departures of individual hourly readings on single days from the mean fitted waves are due only to statistical fluctuations. The fitted waves together with the observational points are shown in Figure 2.

IV. Discussion

The most striking feature of the results is the absence of a significant mean daily variation in the south direction. The north, east, and west variations are not greatly different in form and amplitude from the vertical variation, but phase differences are apparent.

The differences in the directional variations show that, in part at least, they must originate outside the atmosphere. Further, the absence of a significant variation in the south direction suggests that residual atmospheric contributions may be quite small. This conclusion has been drawn previously (Parsons 1957*a*)

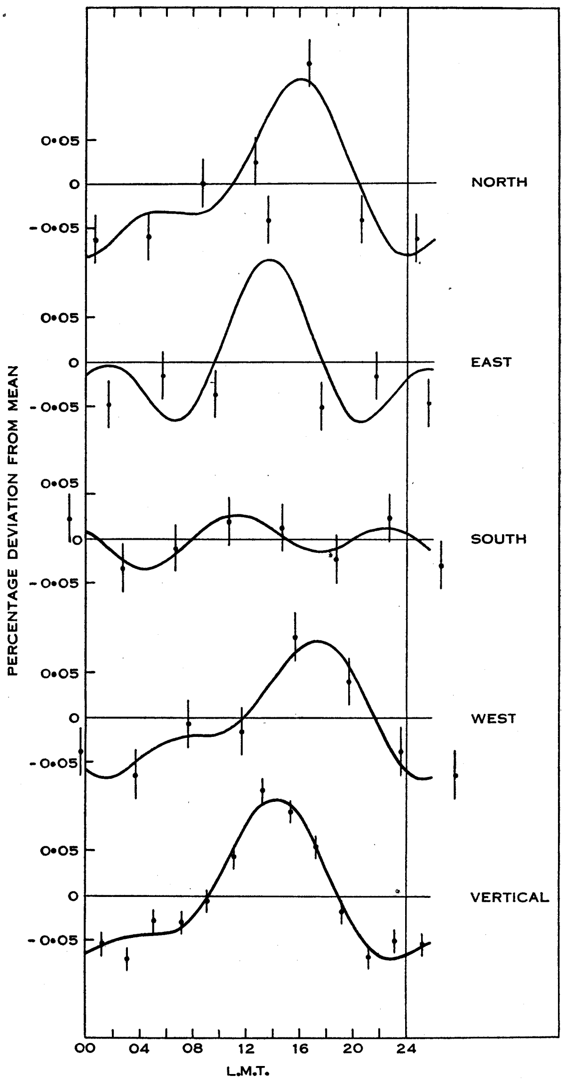


Fig. 2.—The solar daily variations in meson intensity observed with directional telescopes at Mawson, averaged over the period May 1955–February 1956. Standard errors are indicated with the observational points.

from the correlation between long-term phase changes apparent in results from stations in both the northern and the southern hemisphere. The times of maxima in the diurnal directional intensity waves (see Table 1) occur during the early afternoon hours. Any contributions arising from atmospheric temperature effects would almost certainly be in the form of simple 24-hr waves, the two major contributions being associated with the height of the mean level of meson production and with the temperature in the production region. If the results quoted by Dolbear and Elliot (1951) following an examination of upper air measurements over England can be regarded as typical of most localities, the two contributions mentioned would be almost directly opposite in phase, the first producing a daily intensity maximum shortly after midnight and the second a maximum shortly after noon. Each may have an amplitude as large as $0 \cdot 2$ per cent. but they may very nearly cancel. Even if a significant resultant exists, it would be either nearly in phase or 180° out of phase with the observed intensity variations, and therefore unlikely to affect to any appreciable extent the relative phases of the observed directional 24-hr intensity waves. It thus seems reasonable to assume that both the relative amplitudes and phases of the pressure-corrected directional variations are not greatly influenced by residual atmospheric effects.

If as envisaged by Brunberg and Dattner (see Section I) the daily variations arise from an anisotropic distribution of the primary radiation entering the Earth's field, then we should be able to determine approximately an initial direction of approach of the excess radiation and a mean energy for the particles involved, which together will be consistent with the several observed directional daily variations. We shall examine the plausibility of this interpretation, using the trajectory data of Brunberg and Dattner (1953), i.e. assuming that the effective Earth's field is of dipole form described at the Earth's surface by the system of geomagnetic coordinates in current use (McNish 1936).

For a particular arrival direction at Mawson (geomagnetic coordinates 73 °S., 104 °E.) and for a chosen primary particle energy, we may find the initial approach direction. It is specified by two angles ; Φ, the asymptotic latitude (inclination of trajectory to the geomagnetic equatorial plane), and Ψ_E, a geomagnetic longitude angle measured eastwards from the geomagnetic meridian plane containing the Mawson station. We shall assume a mean arrival direction of 40° from the vertical for particles recorded by the inclined telescope (see Fig. 1 and Section II).

The azimuth headings of the telescope were respectively geographic north, east, south, and west, and since geomagnetic north is 30° west of true north at Mawson, estimates of Φ and Ψ_E appropriate to the geographic arrival directions are based on considerable interpolation from the Brunberg and Dattner curves and must be regarded in most cases as rough approximations only. However, the estimates are considered sufficiently accurate for the present purpose.

Estimated values of Φ and Ψ_E for the various arrival directions and for several values of primary particle energy are set out in Table 2. The energy range covered includes that within which Brunberg and Dattner suggest that the mean energy of the anisotropic primaries lies. Elliot and Rothwell (1956) have shown that the assumption of a lower mean energy leads to serious difficulties.

For a particular primary particle energy and arrival direction at Mawson, Φ and Ψ_E may be regarded as specifying a point P on the Earth's surface through which the Earth's radius points in a direction parallel to the initial approach direction of the particles. Various such points P may be found corresponding to different arrival directions and primary particle energies. Their geographic coordinates may be found from the curves of McNish (1936). Now we expect the maximum in the daily intensity variation to be recorded by a particular telescope when the Earth's radius through the appropriate point P makes its minimum angle with the direction of maximum primary intensity outside the

TABLE 2

ESTIMATED VALUES OF Φ_S AND Ψ_E FOR PARTICLES OF VARIOUS ENERGIES ARRIVING AT MAWSON FROM PARTICULAR DIRECTIONS

Direction	$1{\cdot}5\times10^{10}$ eV		$2{\cdot}0\times10^{10}$ eV		$3{\cdot}0\times10^{10}$ eV		$4{\cdot}0\times10^{10}$ eV		$5{\cdot}0\times10^{10}$ eV	
	Φ_S	Ψ_E	Φ_S	Ψ_E	Φ_S	Ψ_E	Φ_S	Ψ_E	Φ_S	Ψ_E
40 °N. (geographic) ..	58°	7°	54°	—9°	43°	—8°	37°	—3°	35°	2°
40 °E. (geographic) ..	47°	16°	37°	24°	33°	42°	34°	55°	37°	64°
40 °S. (geographic) ..	51°	32°	50°	53°	57°	89°	59°	133°	59°	151°
40 °W. (geographic) ..	61°	30°	67°	39°	71°	73°	62°	—101°	60°	—82°
Vertical	54°	26°	56°	29°	62°	32°	65°	31°	68°	28°

field region. Relative times of maximum for the different arrival directions will thus be determined by the geographic longitude differences between the appropriate points P. Similarly, as the Earth rotates, the differently directed telescopes will sweep out celestial latitude belts given by the geographic latitudes of the appropriate points P, and relative amplitudes of the observed variations should thus contain information concerning the form of the anisotropy.

TABLE 3

GEOGRAPHIC COORDINATES OF POINTS P (SEE TEXT) APPROPRIATE TO THE VARIOUS ARRIVAL DIRECTIONS AT MAWSON

P	$1{\cdot}5\times10^{10}$ eV		$2{\cdot}0\times10^{10}$ eV		$4{\cdot}0\times10^{10}$ eV	
	Lat. (S.)	Long. (E.)	Lat. (S.)	Long. (E.)	Lat. (S.)	Long. (E.)
P_N	53°	58°	52°	42°	33°	41°
P_E	40°	60°	29°	64°	23°	92°
P_S	43°	75°	39°	92°	51°	155°
P_W	52°	77°	57°	86°	73°	294°
P_V	45°	71°	47°	74°	57°	79°

Table 3 lists the geographic coordinates of points P appropriate to the various arrival directions at Mawson.

Figure 3 (a) indicates schematically the celestial latitudes scanned by the telescopes at three values of primary particle energy. Figure 3 (b) shows the relative positions of the points P in geographic longitude, again for three values of primary particle energy. Obviously the times of maximum recorded intensity should occur in the order of decreasing east longitude.

From Figure 3 (*a*), we see that middle asymptotic latitudes are involved for the arrival directions and range of primary energies considered. Further, at each of the energies considered the south-pointing telescope scans a celestial latitude belt close to and intermediate between those scanned by the other telescopes. It is therefore very difficult to explain the virtual absence of a daily variation in the south records when for each of the other directions significant and broadly similar variations are observed.

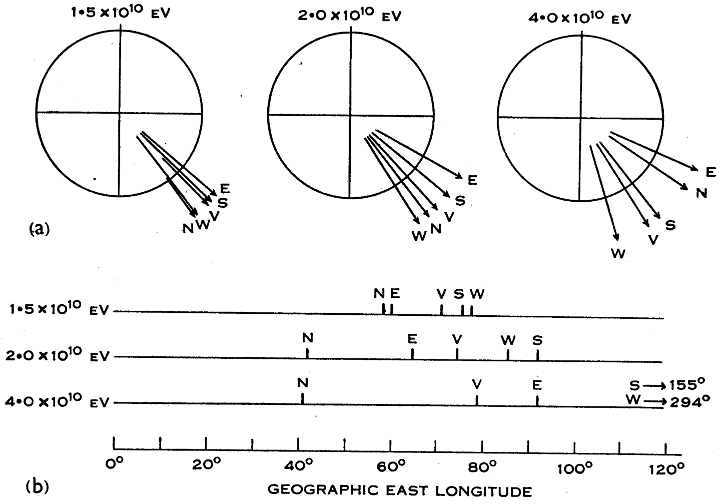
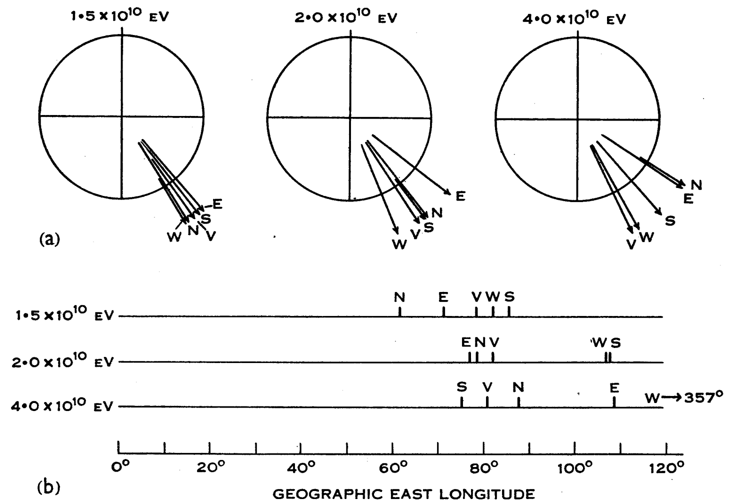


Fig. 3 (*a*).—Schematic representation of the geographic south latitudes of the points *P* (refer text) appropriate to each direction of particle arrival at Mawson, and to three values of primary particle energy. The diagram indicates the celestial latitudes scanned by the directional telescopes.

Fig. 3 (*b*).—Schematic representation of the geographic east longitudes of the points *P*. The expected order of occurrence of maxima in the daily variations is that of decreasing east longitude, with phase differences as indicated.

Again, comparison of Figure 3 (*b*) with the observed times of maximum (Fig. 2) shows that the observed order of occurrence of maxima and time intervals between them are not similar to those predicted at the energies considered.

It is clear then that the observed directional daily variations cannot be satisfactorily explained on the assumption of a fixed external anisotropy interacting with a dipole field described by the geomagnetic coordinate system in current use. The possibility exists that the observations may be more consistent with such an interpretation if, as suggested by Simpson *et al.* (1956), the geomagnetic field is rotated westward through about 45° while remaining substantially of dipole form. Consequently the calculations described above have been repeated using the new system of geomagnetic coordinates. Figure 4 for this case may be compared with Figure 3 and with the observed daily variations of Figure 2. It is clear that the situation is not improved by the suggested change of geomagnetic coordinates.



Figs. 4 (*a*) and 4 (*b*).—As in Figure 3, but calculated by assuming a 45° westward rotation of the Earth's dipole field.

V. Conclusions

No satisfactory explanation of the observed directional daily variations has been found in terms of an anisotropic primary radiation outside the region of the Earth's field and its interaction with this field, if the latter is assumed to be of simple dipole configuration.

The assumption of anisotropies of a variable character offers an attractive explanation of many cosmic ray variational phenomena, but, unless the Earth's field deviates significantly from the dipole form assumed in the calculations of the foregoing section, then the difficulties revealed by the present study and those reported by Elliot and Rothwell remain. If we continue to assume that external anisotropies are responsible for the daily variations, then it seems difficult to avoid the conclusion that the field is sufficiently distorted to render deductions from the published trajectory data open to serious error.

If the observations cannot be reasonably well explained in the above manner, then we must conclude, with Elliot and Rothwell, that the daily variations are probably produced locally by intensity-modulating mechanisms operating within the region occupied by the Earth's field.

VI. Acknowledgments

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