Solar Disturbances and the Cosmic Ray Equator

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Abstract

The location of the cosmic ray equator off the west coast of Africa has been established from measurements obtained with a shipboard neutron monitor which made ten crossings between November, 1956, and October, 1958. From the individual determinations of the point of minimum cosmic ray intensity, the mean geographical position was $6.7 \pm 0.8°$ N at 14° W. Direct measurements of zero magnetic inclination were made at the same time in the immediate vicinity of this point.

Although solar and geophysical activity varied considerably during this period, the location of the cosmic ray equator appears to have remained fixed within approximately 1°. However, the possibility of a small progressive change of about the magnitude of the uncertainty cannot be precluded.

Comparison of the results with plots of measurements of the magnetic elements along the ship's route reveals a significant difference between the location of the points of maximum horizontal intensity and minimum cosmic ray intensity.

1. Introduction

Ambiguities generally inherent in the mapping of isocosms on the basis of data previously obtained by various investigators do not apply to determinations of the location of the cosmic ray equator. In particular, temporal variations in the cosmic ray intensity introduce a considerable uncertainty in the comparison of measurements obtained at different times, and the problem of correctly normalizing data obtained in a survey encompassing large distances is quite complex. Furthermore, it is well established that changes in the primary spectrum are produced by an externally-acting modulation mechanism. Thus, for example, it would be incorrect to assume that the locus of the so-called "knee" represents an isocosm at high latitudes (POMERANTZ, POTNIS and AGARWAL, 1959).

It appeared reasonable to expect that these factors do not seriously influence determinations of cosmic ray intensity minima. The errors in the location of the cosmic ray equator introduced by the normalization procedure are probably smaller than statistical and systematic uncertainties. Therefore, in order to obtain additional evidence relating to the possibility that the trajectories of cosmic ray particles are significantly affected by distortions of the earth's magnetic field by ionized interplanetary gas, repeated determinations were made of the location of the cosmic ray equator during a period characterized both by a high level and extreme variability of solar activity.

The greatest discrepancy between the position of the cosmic ray minimum and the location of the equator based on the dipole representation occurs off the west coast of Africa. It was previously reported on the basis of preliminary results (POMERANTZ, SANDSTRÖM and ROSE, 1958) that at longitude 14° W the cosmic ray minimum occurs at approximately 15° N

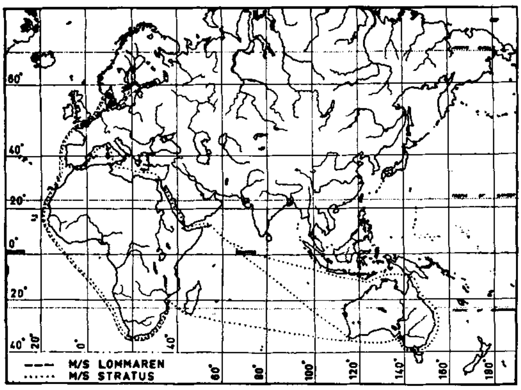

Fig. 1. Routes of M/S Lommaren and M/S Stratus. Nov. 1956—Jan. 1960

of the conventional geomagnetic equator, and is inconsistent with other equators based upon the dipole approximation, but lies very close to the isoclinic equator representing a surface measurement of the dip angle of the earth's magnetic field equal to 0°. Hence, this region appeared to afford optimum conditions for monitoring the cosmic ray intensity minimum over a protracted period of time in the hope of distinguishing between the two alternative explanations of the discrepancy: (1) local magnetic field anomalies and (2) effects of conducting interplanetary gas.

2. Experimental Procedure

The construction of the pile and counters in the shipboard neutron monitor designed for the present program was identical in every respect with that utilized earlier during cruises of HMCS Labrador and USS Atka (Rose and Katzman, 1956). The pile and all associated equipment were installed in a thermostatically-controlled air-conditioned hut which was carried aboard M/S Lommaren from 15 Oct., 1956, until 20 Jan., 1958, and was subsequently transferred to M/S Stratus, where it remained between 9 March, 1958, and 11 Feb., 1959. Fig. 1 shows the routes of the two ships. The station operated continuously during four cruises of Lommaren from Sweden to South Africa and return, and during two cruises of Stratus from Sweden to Australia and return. The southbound voyages of Stratus followed the same route as Lommaren. Thus, during the period November, 1956, to October, 1958, the neutron monitor traversed the equator off West Africa ten times, eight aboard Lommaren and two aboard Stratus.

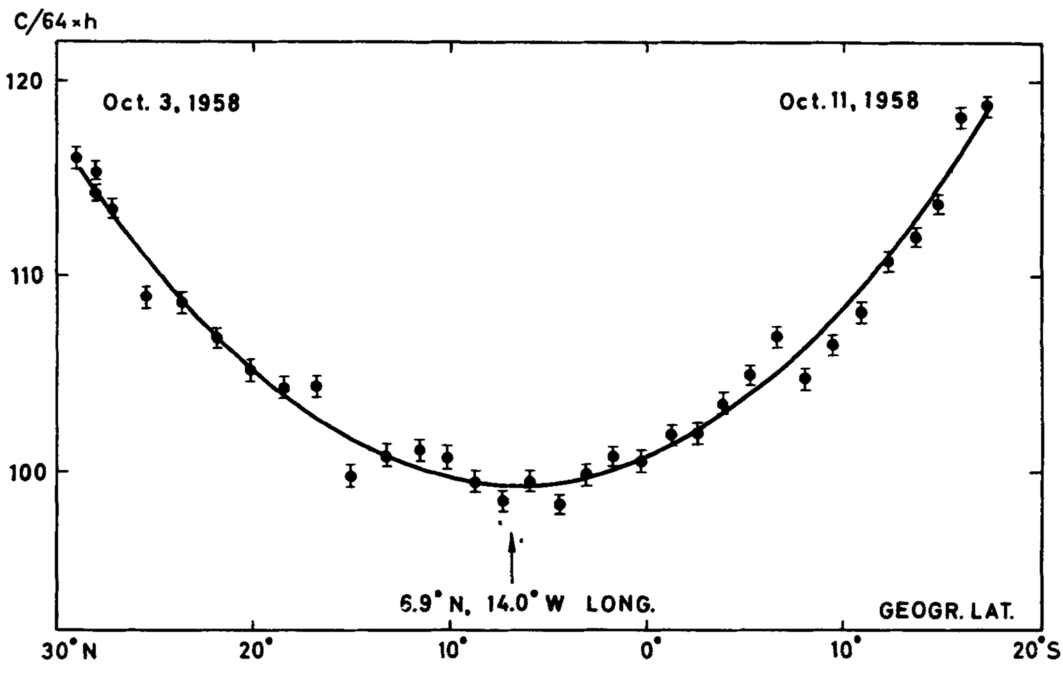

Fig. 2. Ship board monitor, M/S Stratus, equator crossing, 6 hour averages.

3. Results

A. *Determinations of Cosmic Ray Equator*

Fig. 2 is a plot of a typical set of data. Each of the points comprises a six-hour interval. The raw bi-hourly counting rates were corrected for variations in barometric pressure with the usual exponential factor and single absorption coefficient (— 0.96%/mm Hg) (POMERANTZ, POTNIS and AGARWAL, 1959). The data were entered on punched-cards, and data reduction including continuous internal consistency checks was performed by machine. All of the data were normalized for world-wide variations on the basis of the Uppsala neutron monitor records.

For each of the crossings, a machine determination of the function $y = \sum_{0}^{n} a_n x^n$ best representing the points between 30° N and 20° S was performed by the method of least squares. In every case the analysis was carried out for $n = 2$ and 3. In a few cases computations were extended up to $n = 5$. The effect of the choice of n upon the position of the minimum was not appreciable.

Similar treatment of data for crossing normalized on the basis of the Huancayo neutron monitor records revealed that, within the resolution of the experiment, the position of the minimum was not dependent upon the selection of the reference station, even when the most adverse conditions (greatest variability) prevailed.

Table 1. Summary of Cosmic Ray Equator Determinations at Longitude 14° W.

Date	Location of Cosmic Ray Equator, Geographic Latitude	Location of Dip Equator, 1955 Chart Geographic Latitude
November 1956..	7.5° N	8.3° N
January, 1957...	8.4° N	
March, 1957	6.4° N	
May, 1957......	6.3° N	
July, 1957	7.1° N	
August, 1957....	6.8° N	
November, 1957 .	6.1° N	
December, 1957 .	5.5° N	
April, 1958......	6.2° N	
October, 1958 ...	6.9° N	8.6° N
Mean Value	6.7° ± 0.8° N	8.4° N

U.S. Navy Hydrographic Office Observations of Zero Dip.

Date	Longitude	Latitude	Latitude at 14° W
March 9, 1956....	12° 31′W	7° 28′ N	7.0° N
February 8, 1957..	12° 35′W	7° 32′ N	7.0° N

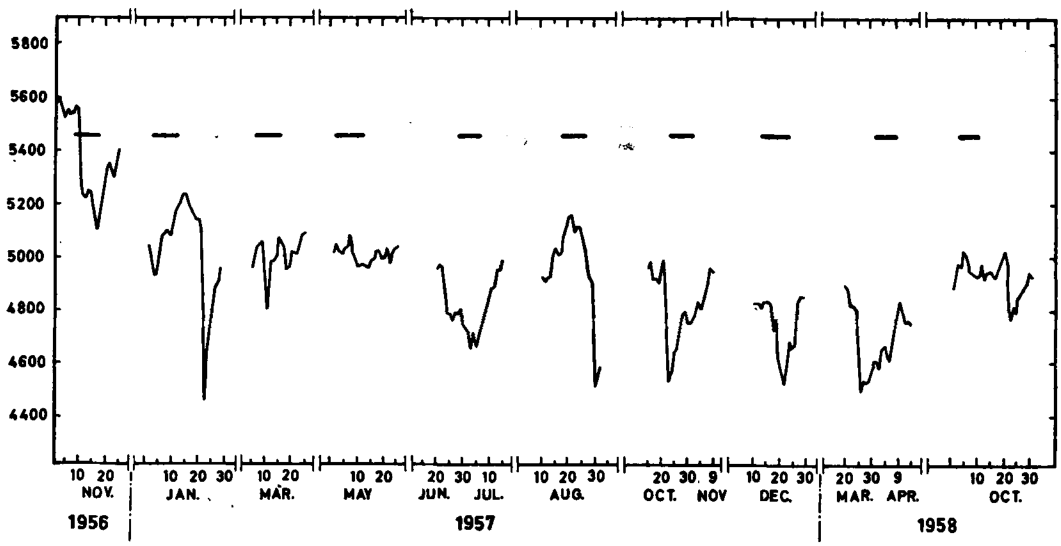

Fig. 3. The curves represent daily averages of the nucleonic intensity at Uppsala. The short horizontal lines indicate the periods of ship passages through Equatorial Region.

In six cases, the position of the minimum was the same for $n = 2$ and $n = 3$, and shifted less than 1° in the remainder. Table 1 gives a summary of the location of the cosmic ray equator thus determined for each of the crossings, with $n = 2$. The individual uncertainties are approximately 1°. The indicated standard error in the mean is computed from the observed scatter of the points under the assumption that the position of the cosmic ray equator is constant. The location of the magnetic dip equator according to the 1955 U.S. Navy Hydrographic Office isoclinic chart, taking into account the predicted secular variation, is also listed.

The differences between the positions of the cosmic ray equator and the dip equator indicated on the chart appear to exceed the uncertainty in the former. The Hydrographer of the U. S. Navy has kindly provided data concerning two actual measurements of zero dip in the immediate vicinity of the cosmic ray intensity minimum. These observations are also summarized in Table 1. The small differences in longitude were taken into account by a slight extrapolation. The mean value of the cosmic ray intensity minimum coincides with the observed position of the directly-measured dip equator.

B. *Effects of Solar Activity*

It has been pointed out that the purpose of this program was to determine whether the position of the cosmic ray equator is dependent upon the level of solar activity. The observations summarized in Table 1 extend over a period characterized by a profusion of spectacular geophysical effects of solar origin, and great variability in the level of solar activity. Of particular relevance to the present discussion is the fact that the cosmic ray intensity fluctuated appreciably. Fig. 3 shows the daily average intensity of the nucleonic component during the periods of the ship's passage through the equatorial region (i.e. geographical latitude 30° N—20° S). It is evident that the present determinations of the position of the cosmic ray minimum represent widely different conditions in the interplanetary medium.

Indeed, the nucleonic intensity displayed large short-term fluctuations, as well as considerable changes in base "level". If interplanetary gas clouds were responsible for both cosmic ray intensity fluctuations and distortions of the earth's magnetic field at large distances, a variation in the position of the cosmic ray equator, correlated with the primary flux, might occur.

As seen in Fig. 4, the results are not inconsistent with this possibility. The solid line represents the mean value based upon the assumption that the equator did not move, whereas, the dash-dot curve is the best-fit straight line determined by the method of least squares without this restriction. The latter has a slope of 1.5° per 12 % decrease in the nucleonic intensity at sea level at a high latitude.

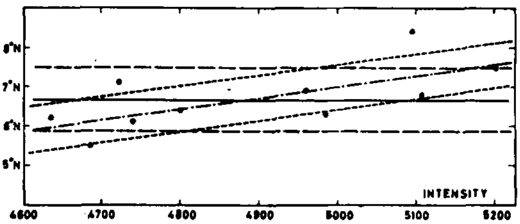

Fig. 4. Cosmic ray equator at 14° West ard nucleonic intensity, Nov. 1956—Oct. 1958.

Consideration of all factors involved, however, leads to the conclusion that the position of the equator remained constant within approximately 1°, despite significant changes in the primary flux. In any event, it is clear that comparisons between single determinations of the position of the cosmic ray minimum by shipboard monitors are subject to considerable uncertainty.

C. *Comparison with Magnetic Observations*

It is of interest to compare the location of the cosmic ray equator with magnetic observations in the equatorial region along the route followed by the shipboard neutron monitor. Fig. 5 is a plot of the magnetic elements *vs* geographic latitude. The data from which these curves were prepared were kindly provided by the Hydrographer, U. S. Navy.

There is a significant difference between the location of the points of maximum horizontal intensity and minimum cosmic ray intensity. Although the tracks of the magnetic survey did not cross the ship's route at the dip equator,

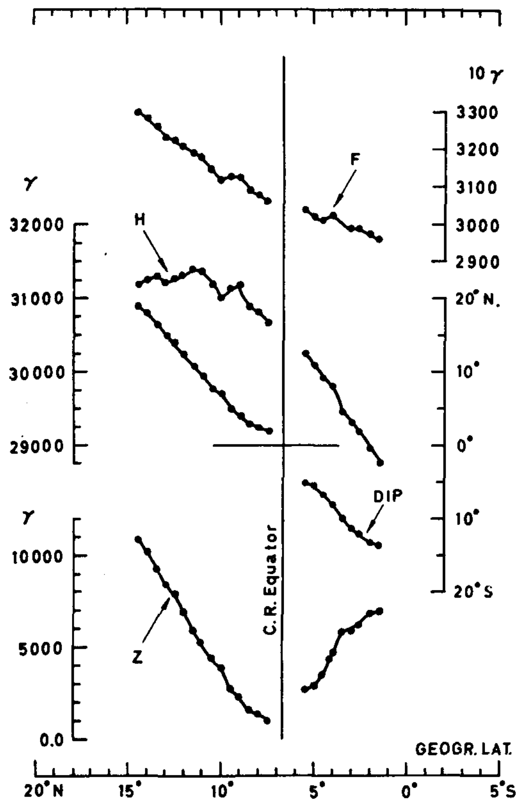

Fig. 5. Magnetic elements along the ships route.

the previously-discussed close correspondence of the zero vertical intensity and zero dip point with the cosmic ray equator is suggested.

4. Acknowledgements

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