Latitude effect and atmospheric attenuation of the cosmic ray nucleon component

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(Manuscript received May 18, 1962)

ABSTRACT

The latitude effect has been studied by means of a shipboard neutron monitor during 12 passages of the so-called knee. The latter remained in a fixed position (46.0° ± 1.0° N, 7° W) between Oct. 1956 and Feb. 1959. Above the knee there exists a plateau due to the atmospheric attenuation of the nucleon component. The horizontal part of this plateau extends to a threshold rigidity of 3.2 ± 0.5 GeV/c.

Introduction

The so-called knee of the latitude effect has been the subject of considerable discussion. Observations of the latitude effect at sea level have been interpreted as indicating an atmospheric cut off for primaries below a certain rigidity. The present study is concerned specifically with this subject.

Extensive series of measurements have been collected with a ship-board monitor. At first it was mounted on M/S *Lommaren* during four voyages back and forth between Scandinavian ports and South Africa. Subsequently it was transferred to M/S *Stratus* for two voyages from Scandinavia to Australia via South Africa and returning both times through the Suez Canal. The results from the equator crossings have been published in three papers (Pomerantz, Sandström & Rose, 1958; Pomerantz, Sandström, Potnis & Rose, 1960; Pomerantz, Potnis & Sandström, 1960). The treatment of data has now been carried on to the region around the latitude knee. Several times the ships went well above the knee thus furnishing data for determination of the horizontal part of the intensity–latitude curve. The spread in longitude is shown in Fig. 1.

Experimental procedure

The ship-board neutron monitor has been described previously (Pomerantz, 1957). The pile and all associated equipment were installed in a thermostatically controlled air-conditioned hut which was carried aboard M/S *Lommaren* from October 15, 1956 until January 30, 1958 and then aboard M/S *Stratus* between March 9, 1958 and February 11, 1959. Table 1 and Fig. 4 contain information concerning the periods of measurement covered by the present paper.

The data reductions were done for intervals of one hour. However, for the present purposes the mean counting rates for six hours were employed. The positions were obtained from the ship's log. As concerns the periods passed in port a mean has been calculated for the whole stretch of such a period. Thus some of the points determining the horizontal part of the latitude curve are characterized by very small standard errors.

Analysis of data

To take care of long time variations the data have been normalized by comparison with fixed monitors. Two methods of normalization have been employed. First all the data from the twelve passages of the latitude knee were normalized only with respect to the neutron monitor at Uppsala. In addition the data from the four last passages of the knee were normalized to the monitors at Huancayo *and* Uppsala by means of a linear equation. In the latter case 7 days immediately after the start of the first Stratus voyage were employed as

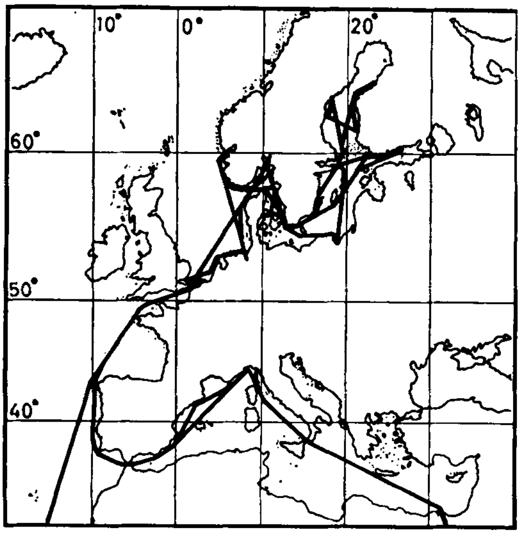

FIG. 1. The routes of M/S *Lommaren* and M/S *Stratus*.

"normal". The normalizations were applied to the bihourly data.

Fig. 2 is a plot of a set of data from one of the passages. The two straight lines have been drawn according to a least square law fit. The data from all the twelve passages are plotted in Fig. 3. The enlarged diagram inserted in this figure illustrates the distribution of the points of measurement determining the horizontal line. Statistically the fit has been found to be good, which is also an indication as to the constancy of the monitors. Concerning the points below the knee, their distribution does not justify an assumption that the position of the inclined straight line has shifted from one voyage to another. Nevertheless the inclined line as well as the intersection point between the two straight lines were determined separately for every one of the twelve passages. The latitude of the intersection point does not display any systematic variations. The confidence region is $\pm 1°$. Inside these limits the position of the intersection point remained constant from Nov. 1956 until Feb. 1959.

The values referring to Oct.-Nov. 1956 and Jan.–Feb. 1957 are higher than the rest. Possibly, this is due to the ship then keeping more easterly courses than during the subsequent passages. It ought to be noted, also, that the ship was well above the knee when the very prominent Forbush decrease took place in Jan. 1957 (Fig. 4).

Concerning Fig. 3 it ought to be observed that the values from the mediterranean crossings (Fig. 1) of M/S *Stratus* have been excluded. As this area is below the knee, the wide spread in longitude might introduce errors when the intensity is plotted as a function of geographical latitude.

Normalization to a neutron monitor situated above the knee facilitates the determination of the horizontal line as the complete set of points of measurement from northern waters can be employed for the purpose. Above the knee, normalization by means of the Uppsala monitor takes care of all kinds of intensity variations. Below the knee there will be an

TABLE 1. *Position of the latitude knee referred to geographical coordinates.*

	Data normalized to Uppsala		Data normalized to Uppsala and Huancayo	
Dated	Longitude, W	Latitude, N	Longitude, W	Latitude, N
Oct.–Nov. 1956	6.3°	46.8°		
Jan.–Feb. 1957	5.8°	47.8°		
Feb.–Mar. 1957	7.6°	45.6°		
May 1957	7.5°	45.7°		
June 1957	6.8°	46.1°		
Aug.–Oct. 1957	7.4°	45.8°		
Sept.–Oct. 1957	7.4°	46.0°		
Dec. 1957–Jan. 1958	7.3°	45.8°		
March 1958	8.3°	45.2°	8.0°	45.7°
July–Sept. 1958	7.7°	45.5°	8.4°	44.6°
Aug.–Sept. 1958	7.0°	46 3°	7.0°	46.3°
Jan.–Feb. 1949	7.5°	45.7°	7.3°	45.8°
Mean value	7.2°	46.0° ± 1.0	7.7°	45.6°

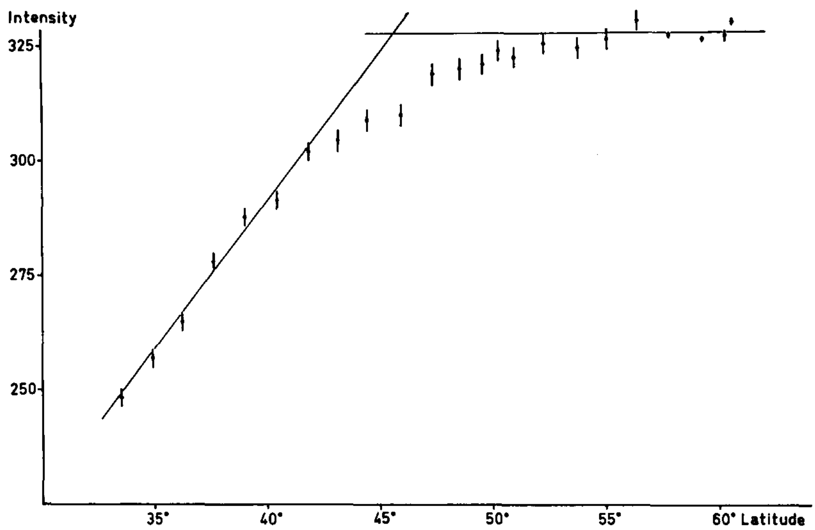

Fig. 2. Cosmic ray intensity versus geographical latitude during the 6th passage of the knee. The intensity scale refers to counts/6 hr with a scaling factor of 192. The values have been normalized to the Uppsala neutron monitor.

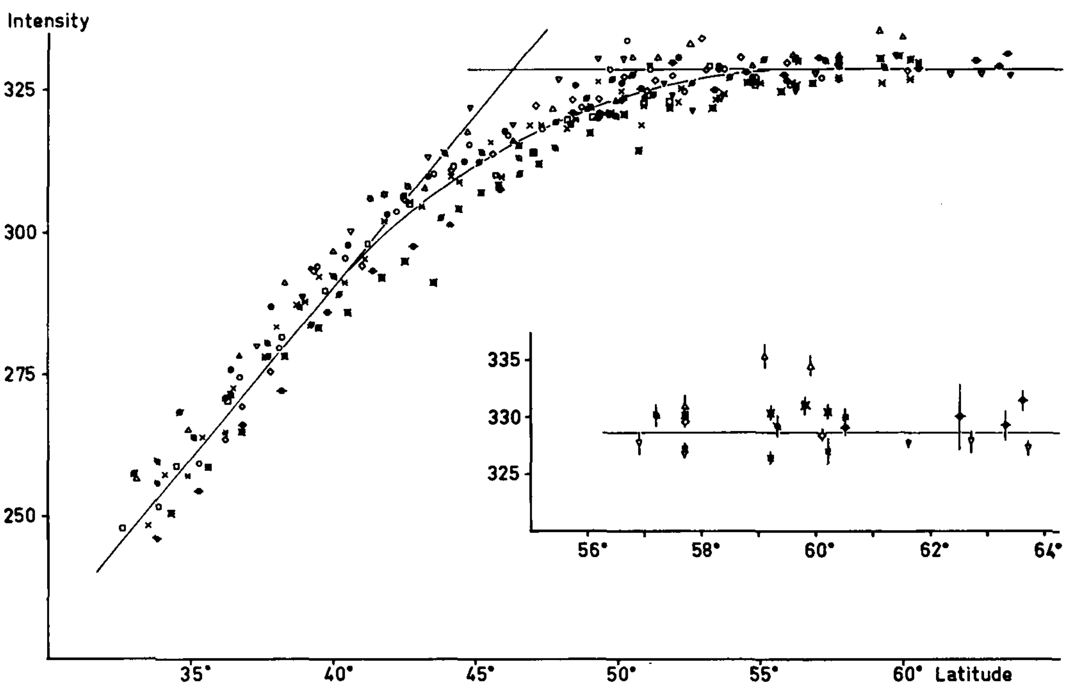

Fig. 3. Cosmic ray intensity versus geographical latitude, all 12 passages. The intensity scale refers to counts/6 hr with a scaling factor of 192. *The individual passages can be identified by means of Fig. 4 and* the symbols employed for the points of measurement (see caption to Fig. 4). The standard errors outside the plateau region are the same as those in Fig. 3. The inserted diagram illustrates the distribution of points determining the horizontal line through the plateau.

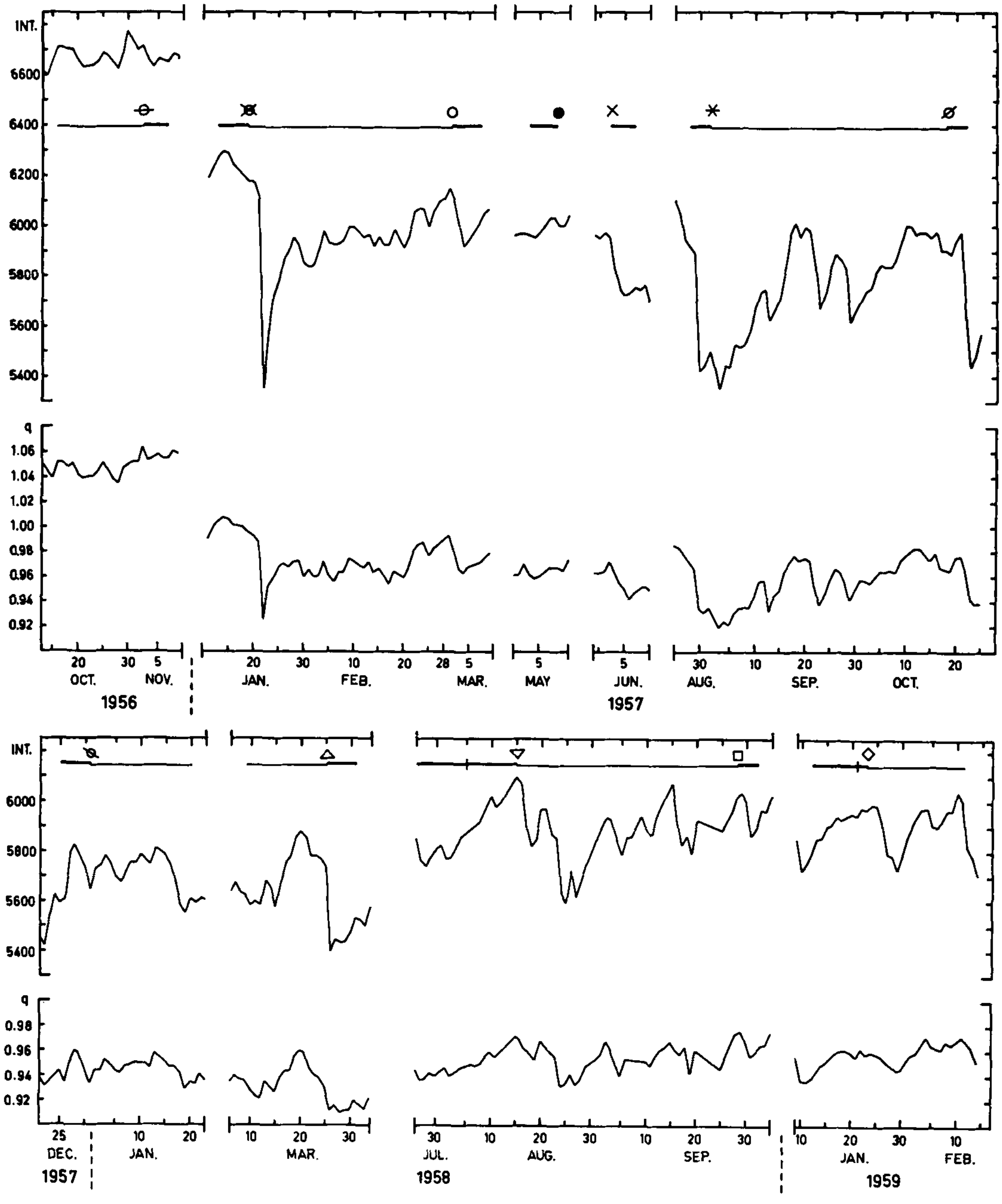

FIG. 4. The ships' passages in relation to the variations of the nucleon component. The passages are marked by the symbols employed for the corresponding points of measurement in Fig. 3. The thin horizontal lines demonstrate the periods spent by the ships above the latitude knee. The heavy lines indicate the passages between 34° N and 46° N. Concerning the 10th and 12th voyages a vertical stroke indicates the ends of the passages of M/S *Stratus* through the Mediterranean. The intensity curve demonstrates the variations of the nucleon component at Uppsala. The scale refers to counts/2 hrs with a scaling factor of 10. The q-curve gives the ratio between the counting rates of the Uppsala and Huancayo monitors as a function of time.

over-correction during at least the first part of the cosmic ray storm following upon a prominent Forbush decrease. As such an over-correction will increase with decreasing latitude the slope of the inclined line will be affected. Selection of an equatorial station for the normalization would result in an undercorrection affecting the whole set of values, those above the knee most seriously.

As mentioned, the four *Stratus* passages were normalized to Uppsala and Huancayo as well as to Uppsala alone. There are no significant differences between the latitudes of the knee as derived in one way or the other (Table 1). Close to the plateau any differences between the Huancayo and Uppsala monitors will be of small importance owing to the linear character of the normalization process. However, the slope of the intensity-latitude curve can be influenced in the region from 34° N upwards.

Fig. 4 illustrates the intensity variations of the nucleon component in Uppsala during the passages between 34° N and 64° N. The distribution of the Forbush decreases can be compared with the transits of the ships. The figure includes, also, a curve illustrating as a function of time the ratio between the intensities in Huancayo and Uppsala. The latitude of the intersection point is independent of the position of the reference station, if this ratio remains approximately constant during the passage below the latitude knee. The ratio also serves as a means of testing the possible influence of decreases taking place during the voyage below the knee. A scrutiny of the q-curves in Fig. 4 reveals that in general the ratio did not vary very much during the *Stratus* passages.

A further study was undertaken including all the 12 passages. In this instance the 6-hr values, already compiled, were employed. The intensity, normalized to Uppsala alone, was transferred into a normalization to Uppsala and Huancayo using the ratio values from Fig. 4 and referring to a period before the start of the first voyage in Oct. 1956. The values derived in this way did not differ significantly from those listed in the second column of Table 1.

The ratio curves in Fig. 4 reveal that a normalization to Huancayo alone would result in a considerable spread of the points above the knee. Thus a completely false picture would be obtained for this region, the spread of the points of measurement being increased by ± 4 per cent.

It is difficult to find a real physical meaning of the intersection point, although it has been widely used by others as defining the position of the knee. However, when the normalization includes a station on the plateau, the intersection point apparently remains in a fixed

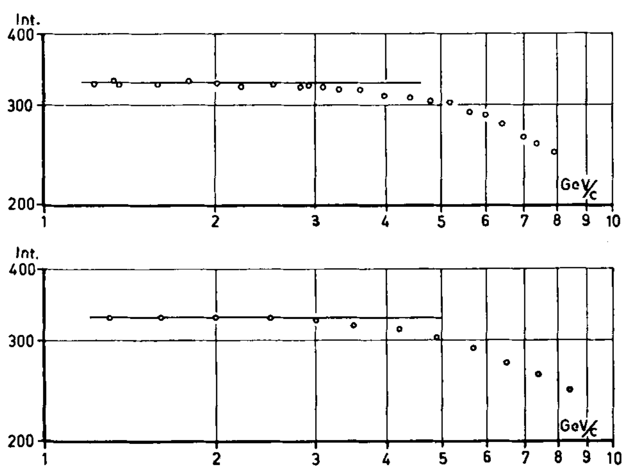

FIG. 5. The cosmic ray intensity as a function of the cut off rigidities deduced by QUENBY & WENK (1962). The upper diagram displays the distribution of the points of measurement from the 6th passage. The lower diagram shows the mean values obtained by averaging over all the 12 passages for equal latitude intervals. The intensity scale refers to counts/6 hr with a scaling factor of 192. The standard errors of the intensity values are covered by the circles. Horizontal lines have been drawn to facilitate an estimation of the end of the plateau.

position inside the limits of error. The reproducibility cannot be due only to the fact that the data from all the twelve passages were normalized to one and the same period, as the four last voyages, normalized to Uppsala and Huancayo and a separate period, yield the same values inside the limits of error (Table 1). The mean intensities of the reference periods are radically different.

The atmospheric attenuation

In the upper diagram of Fig. 5 the data from one of the passages have been plotted as a function of rigidity, the values of the latter being taken from QUENBY & WENK (1962). The threshold rigidities of the points between 7 and 9 GeV/c might be in error (POMERANTZ & AGARWAL, 1962). The lower diagram of Fig. 5 represents the mean values from all the voyages. In this case the mediterranean crossings of M/S *Stratus* have been included.

In this case, too, distribution of points above the latitude knee indicates the existence of a plateau. Nevertheless, at latitudes above that of the knee, primaries with rigidities well into the plateau region are observed at high altitudes.

TABLE 2. *Estimated rigidity corresponding to the end of the atmospheric attenuation plateau.*

Date	Rigidity, GeV/c
Oct.–Nov. 1956	3.1
Jan.–Feb. 1957	2.7
Feb.–Mar. 1957	3.8
May 1957	3.2
June 1957	2.7
Aug.–Oct. 1957	3.0
Sept.–Oct. 1957	3.2
Dec.–Jan. 1958	3.2
March 1958	3.2
July–Sept. 1958	4.1
Aug.–Sept. 1958	2.9
Jan.–Feb. 1959	3.4
Mean	3.2

Thus the attenuation must be of atmospheric origin.

The end of the plateau depends not only upon the attenuation but also on the shape of the spectrum as well as on the relative response of the recording instrument. In Fig. 5 the position of the plateau is indicated by straight horizontal lines. The diagrams reveal that the counting rate decreases slowly between the plateau and the rectilinear slope determined only by the rigidity cut off. Accordingly, the end of the plateau can only be estimated. The resulting rigidity values are listed in Table 2. The error is estimated to ± 0.5 GeV/c in the single cases. These limits cover all the values except one. Therefore, the mean value, 3.2 GeV/c, has to be regarded as representative for typical conditions during the whole period. It is considerably higher than values from calculations based on neutron monitor records during solar flare events (FREON & MCCRACKEN, 1962). Probably most of the difference is due to the steepness of the spectrum of solar flare produced particles. However, part of the difference is undoubtedly attributable to errors in threshold rigidity assignments.

Acknowledgements

We are very grateful to Rederiaktiebolaget Transatlantic, Gothenburg, Sweden for their exceedingly generous cooperation in accommodating the neutron monitor station aboard their ships. Particular appreciation is expressed to Captain A. Lagerwall for his kind cooperation in making all the necessary arrangements. We wish to thank the captains and officers of the ships as well as the students who were in charge of the equipment. Our appreciation is expressed to the National Geographic Society for sponsoring the field operations. Support was also provided by the U.S. National Committee for the I.G.Y., the U.S. Office of Naval Research, and the Natural Science Research Council of Sweden.

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