Latitude Effect of Cosmic Rays Above 50°N Latitude

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The latitude effect for cosmic rays above 50° N magnetic latitude has been measured by a continuously operating, ionization type meter mounted on shipboard. From these data the monthly mean temperature coefficient is found to be -0.09 ± 0.03 percent per degree centigrade. When this correction is applied to the data the latitude *vs.* intensity curve is found to be flat within the limits of the probable error over the range of magnetic latitudes from 53° 30′ N (Seattle) to 61° 36′ N (Juneau).

INTRODUCTION

THE latitude effect between about 55° N and 55° S magnetic latitude has been reported by Compton and Turner[1] and by Gill.[2] These observations were carried out by a continuously operating meter mounted on shipboard. North of the region mentioned, observations have been carried out only at isolated stations. Therefore the present investigation was undertaken in order to obtain, at higher latitudes, data of accuracy comparable to those of Compton and Turner and of Gill. It was also hoped that the present investigation would give additional information on the seasonal change in cosmic-ray intensity and on the so-called "atmospheric" latitude effect.

DATA AND RESULTS

The apparatus used has been described in a previous paper.[3] Its location on shipboard enabled the continuous determination of hourly values of the cosmic-ray intensity as the ship traveled over a range of geomagnetic latitude extending from 53° 30′ N geomagnetic latitude (Seattle) to 61° 36′ N (Juneau). A complete round trip was made, on the average, every two weeks. Data were taken over the period from February 1939 to May 1940. A record was kept by the first officer aboard the *Northland*, giving each day the ship's position, reading of ship's aneroid, against which the barometer on the apparatus was checked, maximum and minimum temperature in the meter house since last reading, and shade temperature on deck as well as the time of all observations. Additional checks on the position of the ship were given by the times of arrival and departure at all ports. The hourly values of the cosmic-ray intensity were averaged over six hourly periods and the results reduced to a standard barometer of 30 inches of mercury by using the correction given by Gill[2] for identical apparatus. The mean magnetic latitude of the ship for the six-hour interval was obtained from the data given in the first officer's record.

The data for each 30 minutes of latitude were then averaged by seasons. The results, given in Fig. 1, agree with those of previous investigators[1,2] in showing the greatest intensity in winter and the least intensity during the summer. The results for spring and those for fall (indicated by the crosses) lie intermediate between the two. A yearly mean curve was obtained from the data, and this is shown in the upper, broken line of Fig. 2. One of the outstanding features of all these curves is the decrease in intensity at Juneau amounting to about 2 percent and also the drops at 59° 15′ and 57° 45′. Measurements with a sextant indicate that these drops occur at places where the mountains rise steeply from the water and thus reduce appreciably the solid angle within which the rays can reach the meter.[4] Apart from these sharp drops there is an over-all rise of 0.5 percent from 53° 30′ to 61°, before the

[1] A. H. Compton and R. N. Turner, Phys. Rev. **52**, 799 (1937).

[2] Piara S. Gill, Phys. Rev. **55**, 1151 (1939).

[3] A. H. Compton, E. O. Wollan and R. D. Bennett, Rev. Sci. Inst. **5**, 415 (1934).

[4] An attempt was made to obtain a quantitative check between the actual decreases and those that would be expected, using a $\cos^2 z$ distribution for the cosmic rays, where z is the zenith angle. However, this failed apparently because of the incompleteness of the measurements on the angular elevation of the mountains. There was a definite qualitative check in that increased angles were accompanied by decreased intensities.

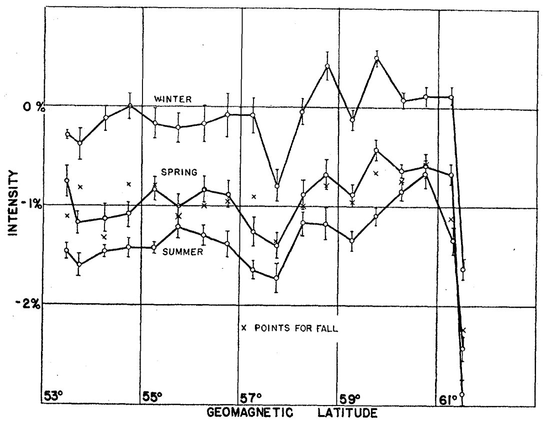

FIG. 1. Seasonal mean cosmic-ray intensities as a function of latitude.

Seattle mean temperature correction has been applied.

I. The temperature effect

Previous investigators[1,2] have ascribed the seasonal variation, as well as the gradual increase of intensity with latitude to the effect of atmospheric temperature on the intensity of the cosmic rays as measured at the earth's surface. In order to determine the effect of temperature on intensity, the daily mean values of intensity were plotted against daily mean temperatures for all the measurements made in Seattle. From this plot a value of -0.11 percent per degree centigrade is obtained for the temperature coefficient. Recently, however, Vallarta and Godart[5] have suggested that a part at least of the seasonal effect may be due to the sun's magnetic field. In order to reduce any contribution which this might make to the true temperature effect the temperature coefficients were computed for each month by computing the mean intensity on the one-way trip having the highest mean temperature for any given month and also the mean intensity on the trip with the lowest mean temperature. The results obtained from these data are listed in Table I. The results for May, 1939, and April, 1940, are undoubtedly affected by the world-wide changes which occurred during these months, as indicated on the apparatus at Huancayo.[6]

It might seem justifiable to eliminate these months from the final result, however; world-wide changes of equal magnitude occurred in April, 1939, and evidently were instrumental in producing the rather large negative value for that month, and also changes of smaller magnitude occurred in other months. Thus it appears that there is no valid reason for excluding some of the above months while preferring others, and the value -0.09 ± 0.03 has been used in making all temperature corrections. This value is identical with that recently given by Hess[7] from data collected during a period of five years on the Hafelekar, but it is somewhat smaller than the value (-0.13) given by Gill for Vancouver and is considerably smaller than the value (-0.22) of Compton and Turner at the same place. It is to be noted that the number of separate readings entering into the computation is considerably greater in the case of the present work than in the results of Compton and Turner and of Gill, but that it is, in turn, considerably less than that of Hess. The fact that the coefficient is slightly higher when computed on the intensity *versus* temperature basis may be an indication of a seasonal effect other than that caused by temperature; however, the difference is not greater than the statistical error and no definite conclusions can be drawn. The mean obtained by omitting the two positive values is also given for comparison.

II. The latitude effect

The upper curve in Fig. 2, which gives the yearly mean intensity as a function of latitude has an over-all upward slope which is about half of that reported by Compton and Turner[1] in the region above the knee but which agrees well with the more recent results of Gill.[2] When a temperature correction based on the coefficient given above is applied the lower curve in Fig. 2 results. The intensity in the region from 55° to 57° seems to fall below that at Seattle, whereas the intensity 59° to 61° is, apart from the fluctuations mentioned before, the same as that at Seattle within the limits of the probable error. No conclusions for the regions from 57° to 59° and above 61° can be drawn because of the

[5] M. S. Vallarta and O. Godart, Rev. Mod. Phys. **11**, 180 (1939).
[6] Private communication from A. H. Compton.

[7] Victor Francis Hess, Phys. Rev. **57**, 781 (1940).

"horizon effect." The probable errors in intensity as computed from the statistical fluctuations vary from 0.05 percent to 0.08 percent for the uncorrected curve, and from 0.05 percent to 0.28 percent for the corrected curve. The greater part of the error in the corrected curve is due to the probable error in the temperature coefficient which also explains the progressive increase in error with latitude which is apparent on the lower curve. It is improbable that the slight decrease between 55° and 57° is a real one and may possibly be caused by a "horizon effect" of smaller magnitude than that producing the decreases at 57° and above 61°. Our conclusions, then, agree with those of Gill that there is no evidence of a geomagnetic latitude effect beyond the knee.

Nature of the Plateau

According to the theory of Lemaître and Vallarta,[8] the cosmic-ray intensity ought to increase monotonically with latitude, the exact character of the increase depending on the energy distribution of the primary rays. The fact that no increase occurs beyond a certain latitude has been attributed by various authors to one or more of the following conditions: (1) The energy spectrum of the primary rays is such that there are very few or no rays with energy less than a certain critical value represented by the threshold energy for the latitude at which the knee occurs. (2) The knee occurs for that minimum energy of the secondary mesotrons which enables them to penetrate the barrier of the earth's atmosphere.[2] (3) Particles below a certain minimum energy are prevented from reaching the earth at all by the action of the sun's magnetic field.[9]

TABLE I. *Temperature coefficients for cosmic-ray intensity.*

Month	Coef. in %	Month	Coef. in %
March, 1939	−0.27	November, 1939	−0.34
April	−0.23	December	−0.07
May	+0.25	January, 1940	−0.18
June	−0.11	February	−0.11
July	−0.04	March	−0.14
September	−0.04	April	+0.23
October	−0.15		
Mean			−0.09±0.03
Mean without May, 1939 and April, 1940,			−0.15±0.02

The improbable nature of the energy distribution required to satisfy the first viewpoint is a considerable objection. Against the second viewpoint, Vallarta and Godart[5] have pointed out that the variation in the position of the knee with increasing altitude is not in complete agreement with this hypothesis. In confirmation of this view the fact that the magnetic storm of March 24, 1940, produced a decrease in intensity in the region north of the knee[10] can be taken as an argument in favor of the third view, since the effect of a change in the earth's magnetic field in this region would be merely to shift the latitude of the knee. Thus the "cut-off" appears to be caused, at least in part, by a magnetic effect, external to the earth, which experiences changes at the time of magnetic storms.

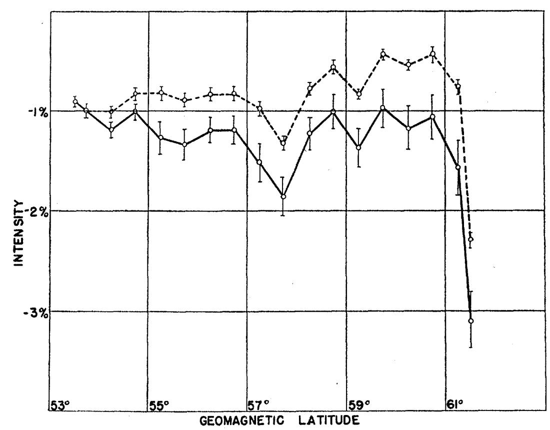

FIG. 2. Upper curve gives yearly mean cosmic-ray intensity as function of latitude, no temperature correction. Lower curve gives same results reduced to Seattle mean temperature as standard.

In conclusion, we wish to express our sincere appreciation to Dr. Arthur H. Compton for making available the apparatus and for helpful discussion of the results. Also, we are indebted to the Northland Transportation Company for the use of the space aboard their ship and to Mr. B. W. Joyce, First Officer of the *M.S. Northland* for careful attention to the apparatus.

[8] G. Lemaître and M. S. Vallarta, Phys. Rev. **43**, 87 (1933).

[9] M. S. Vallarta, Nature **139**, 839 (1937).

[10] D. H. Loughridge and Paul F. Gast, Phys. Rev. **57**, 938 (1940).