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Solar Diurnal Variation of Cosmic-Ray Intensity as a Function of Latitude

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The cosmic-ray data collected by A. H. Compton and R. N. Turner on the Pacific Ocean from March 17, 1936 to January 18, 1937 have been analyzed for a possible change with latitude of the solar diurnal intensity variation. A new geomagnetic latitude curve is shown based on these data and designed to remove periodic fluctuations due to unequal distribution of data with time. A method of combining data from a wide latitude range is developed and applied. Solar diurnal variation curves for latitudes ranging from 54.7° N to 40° S (geomagnetic) show no substantial variation in either amplitude or phase. The mean amplitude of the first harmonic of a Fourier analysis is found to be 0.24 percent with time of maximum being 14 hr. 06 min.

THE study of the solar diurnal variations of cosmic-ray intensity at various latitudes, of which a preliminary survey was published previously[1] has now been carried out in more detail. The data used in this study were those obtained by A. H. Compton and R. N. Turner in observations on the Pacific Ocean covering a period of about a year. A Carnegie model C cosmic-ray meter, mounted on the Canadian Australasian Steamship Company's motor ship Aorangi, was carried on 12 voyages between Vancouver, Canada and Sydney, Australia from March 17, 1936 to January 18, 1937. The meter has been described in detail elsewhere[2] and many of the results of the observations previously reported and discussed by Compton and Turner.[3]

The fact that the data at the various latitudes were all recorded by one instrument is a distinct advantage. Experience has demonstrated the difficulty of obtaining results from several meters, even of the same type, which shall be sufficiently consistent for the comparison of variations of small magnitude. Another advantage is that the data for any particular latitude were not obtained continuously, but at intervals distributed throughout the entire period of observation. There are for example on the average 6 days readings in each 2.5° of latitude. Had the meter been operated continuously for this length of time in one zone, and then moved on to the next, several sources of error might easily have influenced the results. Any seasonal change in the variation would have increased or decreased the observed difference due to latitude change, and it would have been difficult to correct equally for any great difference in barometric conditions in the various zones. In addition, slow changes in the constants of the meter itself, if such had occurred, would have been difficult to detect.

There is, however, an unfortunate feature of this method of gathering data for this type of

[1] J. L. Thompson, Phys. Rev. **52**, 140 (1937).
[2] A. H. Compton, E. O. Wollan and R. D. Bennett, Rev. Sci. Inst. **5**, 415 (1934).
[3] A. H. Compton and R. N. Turner, Phys. Rev. **52**, 799 (1937).

study. Since the average cosmic-ray intensity varies by more than 10 percent in going from the latitude of Vancouver or Sydney to the equator, and since this distance is traversed in somewhat less than two weeks, the change in intensity during a twenty-four hour period from this cause is several times as great as the anticipated diurnal variation. Two courses are open to avoid the serious errors introduced by this circumstance: (1) one may, in finding the diurnal effect for a particular latitude, use only data from a latitude zone so narrow that the variation due to change of latitude is inappreciable; or (2) one may endeavor to correct the data for this latitude effect and thus make possible the combining of data from a wide latitude zone. In the present case, the former method is ruled out by the fact that most of the data would be discarded and one would have a hopelessly small amount of data with which to work. This is accentuated by the fact that since the vessel was on a regular schedule, the south-bound trips encountered a given latitude at almost the same time of day every time, and similarly the north-bound trips, giving only portions of the day for which any data would be available at all. Consequently, the method was adopted of correcting the data for latitude effect and then of combining the results from a comparatively wide latitude zone.

Since latitudes are recorded to 0.1°, it is necessary to have average ionization values for each 0.1° if individual readings are to be adjusted.

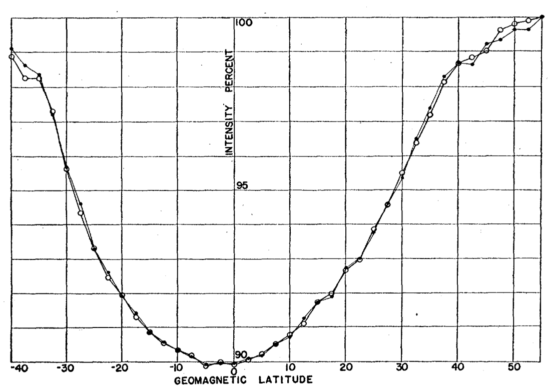

FIG. 1. Mean latitude effect on Pacific Ocean of eleven trips from March 27, 1936 to January 18, 1937. Data of Compton and Turner, showing difference between simple means averaged for each latitude range (black circles) and hourly means over the complete day for each latitude (open circles).

The first necessity in making such a latitude correction is a latitude-effect curve, from which the average ionization value for any latitude may be obtained. The latitudes used in this work are geomagnetic and not geographic, since the latitude effect is in the main a magnetic one. The customary procedure in constructing such a curve is to take the average value of all the data within zones of say 2.5° of latitude and assign that average value to the mean latitude of the zone. This gives a series of points which may be connected by straight-line segments or which may be used to guide in the drawing of a smoothed curve. In this particular case it seemed advisable to treat the data in a somewhat different manner. Since the trips were made on regular schedule, the times of arrival at and departure from principal ports of call were nearly the same on all trips. Thus the total data from all trips were in most 2.5° latitude zones markedly concentrated in certain portions of the day. For example, in the 2.5° zone whose mean latitude is 52.5°, there were 7 and 8 readings each for hours during the night, and only 3 for several of the daytime hours, and this variation was not exceptional. If an average ionization is to be arrived at which will be, as is certainly necessary, independent of any solar diurnal variation, the sampling must be made uniformly from all the hours of the day. To achieve this, the average hourly values were first found, and these in turn averaged over the twenty-four hours in order to fix the true average for the zone. A certain amount of statistical error is introduced by this procedure, since hours with few data are given equal weight with those for which many data are available. It seems clear, however, that where one is restricted to a certain number of data it is more important to eliminate systematic errors as far as possible. The extent to which this has been accomplished may be judged from the comparison of the latitude curve so obtained with that drawn in the more usual manner, as shown in Fig. 1. In general it will be seen that this procedure has been justified, inasmuch as the curve plotted in the usual way shows periodic fluctuations not present in the present curve. Not all of the irregularities are removed, however, and in particular that portion between latitudes 40°N and 54.7°N while improved is still irregular. At 5°S and also at 37.5°S it is definitely more irregular than the original curve.

From the average ionizations obtained in this manner for every 2.5°, values were calculated for every 0.1° by direct linear interpolation. This was done without reference to any curve, although it would correspond to drawing straight-line segments between successive points to form the latitude curve. Despite the fact that the "true" latitude-effect curve must be a smooth curve, the points obtained actually represent the best averages for the various zones, and each point represents about the same number of data. Thus there is no logical way to decide through which points the smooth curve should pass, and linear interpolation offered the best use of the data.

With these values for each 0.1° at hand, each individual hourly value from the original data was adjusted by subtracting the average for the particular latitude at which it was taken. This resulted in transforming the more than 4000 hourly ionization values into hourly deviations from the mean. Insofar as the latitude variation of intensity was concerned, these deviations could be combined from as wide a range of latitudes as desired. The divisions chosen were a 20° zone embracing the geomagnetic equator, two 15° zones to the south and two to the north, and an additional 14.7° zone to the north, extending to but not including Vancouver at the northern extreme, and Auckland, New Zealand at the southern. Data from that portion of the course lying between Auckland and Sydney were not used, since there was but a very small variation in latitude in this portion, and a large variation in longitude.

In each zone except the northernmost, the correction to mean solar time was made by applying the appropriate correction for the mean longitude of the zone, since the variation of mean solar time over the zone was less than one hour. In the case of the zone between 40°N and 54.7°N, since the time variation was 72 minutes, the zone was divided into two parts, and appropriate corrections applied to each part before the data were combined.

It will be noted from the dates given that the period of observation did not cover a full year.

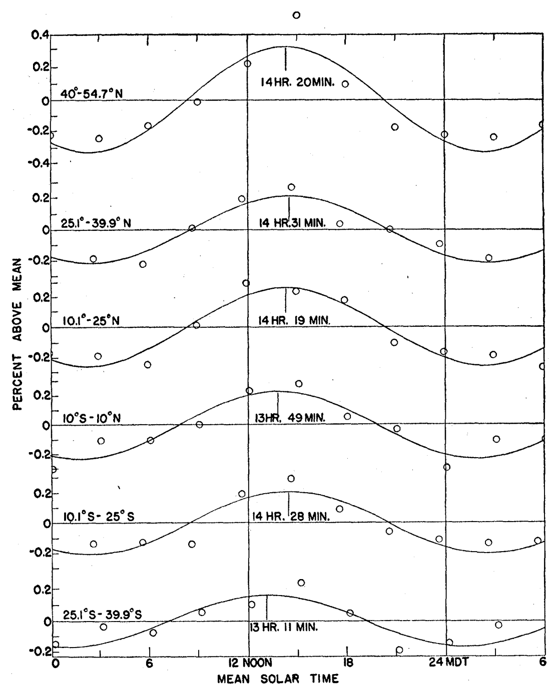

FIG. 2. Three-hourly means and first harmonic curves, showing solar time variations of cosmic rays at different latitudes on Pacific Ocean.

Since it is entirely possible that the diurnal variation may change with the season, the data were further grouped by seasons, and when the mean deviation for each hour had been found for each season, these seasonal averages were in turn averaged to find the yearly mean. In making the seasonal divisions, the solstices and equinoxes were taken as the mid-points of the respective seasons, rather than the dividing points.

From these average hourly deviations, the first harmonic of a Fourier analysis has been calculated, and also the three-hourly averages, both of which have been plotted. These graphs are given in Fig. 2, and a summary of the results in Table I. While it seems by no means necessary to assume an harmonic variation of intensity over the twenty-four hour period, the plotted three-hour means show a reasonably close approach to such a variation. On this assumption it is seen that the amplitude of the solar diurnal variation of intensity is substantially the same for the various latitude zones covered, and of the order of 0.24 percent. If the value of 0.33 percent found for the latitude zone 40°N – 54.7°N be excluded,

TABLE I. *Solar diurnal variation of cosmic-ray intensity at various latitudes.*

	Geomagnetic Latitude	Amplitude of Daily Variation, percent	Time of Maximum
1.	40°–54.7° N	0.33	14 hr. 20 min.
2.	25.1–39.9	0.22	14 31
3.	10.1–25.0	0.26	14 19
4.	10 S–10 N	0.23	13 49
5.	10.1–25.0 S	0.21	14 28
6.	25.1–39.9 S	0.17	13 11

the mean amplitude for all zones is 0.22 percent. Since this zone is the region in which the latitude variation shows the least regularity in these data, considerable doubt is justified as to the significance of this larger amplitude. There also seems to be no significant variation in the time of maximum, whose mean value for all latitudes is 14 hr. 06 min., with a maximum deviation of 55 minutes.

These results are in reasonable agreement with the amplitude of 0.20 percent with maximum at noon, reported by Hess and Graziadei[4] from the records of three years continuous observations at 2300 meters altitude. Other comparable results are the 0.19 percent amplitude, maximum at 9 hr. reported by R. L. Doan[5] at Chicago from the records of five meters operating simultaneously over a period of 10 days of exceptionally small barometric variation, and the 0.17 percent, maximum at 11 hr., reported by Forbush[6] from a critical analysis of data from 273 days record taken at Cheltenham, Maryland (geomagnetic latitude 50.4°).

The irregularity in the present data, noted above, occurs just on the "knee" of the latitude-effect curve, and a continuation of the study to much higher latitudes both north and south under the same conditions is much to be desired.

In conclusion, the author wishes to express his thanks to Professor A. H. Compton for suggesting the problem and making available the reduced data which have been used, and sincere appreciation for his helpful discussions during the course of the work.

[4] V. F. Hess and H. T. Graziadei, Terr. Mag. **41**, 9 (1936).

[5] R. L. Doan, Phys. Rev. **49**, 107 (1936).

[6] S. E. Forbush, Terr. Mag. **42**, 1 (1937).