Correlation of Cosmic-Ray Ionization Measurements at High Altitudes, at Sea Level, and Neutron Intensities at Mountain Tops

H. V. NEHER*
California Institute of Technology, Pasadena, California

AND

S. E. FORBUSH
Carnegie Institution of Washington, Washington, D. C.
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Although fluctuations in cosmic rays have been measured at sea level and high altitudes for a number of years, no serious attempt seems to have been made to correlate the two. As a result of a rather long series of balloon flights in the summer of 1951 it now becomes possible to correlate ionization measurements at high and low altitudes. Recent neutron intensity measurements during the same period by Simpson *et al.* permit a further comparison with this component. There seems to be a good correlation, during this period of observation, between the fluctuations as measured in (1) the ionization at 70,000 ft over North Dakota, (2) the meson component at Cheltenham, Maryland, (3) the meson component at the geomagnetic equator, and (4) the neutron component at mountain tops in Colorado and New Mexico.

IN a recent issue of this journal, Simpson *et al.*[1] reported a correlation of the fluctuations of neutron intensity, measured at three widely separated land stations. It is the purpose of this note to point out that correlations also exist between cosmic-ray intensity measurements at both high and low altitudes and the above neutron measurements.

In the summer of 1951 while these neutron measurements were being made, a group from the California Institute of Technology was making a series of balloon flights at Bismarck, North Dakota using ionization chambers. Also during this period, continuous measurements of cosmic-ray intensities were being made at Huancayo, Peru and at Cheltenham, Maryland by the Carnegie Institution of Washington. Plotted in Fig. 1 are the four sets of data. The neutron data were scaled from the curve given by Simpson *et al.*[1] for Climax, Colorado and are for the first 12-hour period of the respective days on which balloon flights were made. In three cases two flights were made on the same day at Bismarck, on July 27, August 6, and August 14. In such cases the trend of the neutron data at the particular times was taken, and what appeared to be a reasonable value was assigned. For the corresponding data at Cheltenham, the hourly values, corrected for bursts and barometric changes, for the 6 hours just before the balloon flights reached their maximum height and the 6 hours just afterward, are averaged. For the case of the data from Huancayo the daily mean values are plotted. Thus, the first point on July 18, is the mean for that day on 75° west meridian mean time. The points, for the respective times under consideration, are arbitrarily connected by straight lines in the figure. The balloon data at Bismarck are taken from the individual curves and are at 50 g cm^{-2} pressure or about 70,000 ft.

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[1] Simpson, Fonger, and Wilcox, Phys. Rev. 85, 366 (1952).

In Fig. 2 are shown the data for Cheltenham and Huancayo compared with the neutron measurements of Simpson *et al.*, for the three months of July, August, and September of 1951. The ionization data are daily averages, while the neutron measurements are for 12-hour periods.

These data show that, during this period of observation, there was a very good correlation in time of the fluctuations measured (1) in the total ionization due to cosmic rays at 70,000 ft elevation over North Dakota; (2) in the neutron intensity at 11,000 ft elevation at Climax, Colorado; (3) in the sea level ionization, of particles that can penetrate 12 cm of lead, at Cheltenham, Maryland; and (4) in the ionization at 11,000 ft elevation at Huancayo, Peru as measured by an instrument similar to the one at Cheltenham.

The approximate ratios of the relative fluctuations

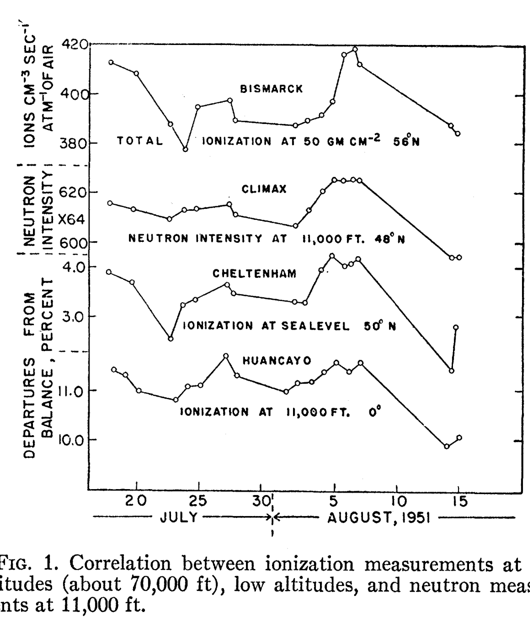

FIG. 1. Correlation between ionization measurements at high altitudes (about 70,000 ft), low altitudes, and neutron measurements at 11,000 ft.

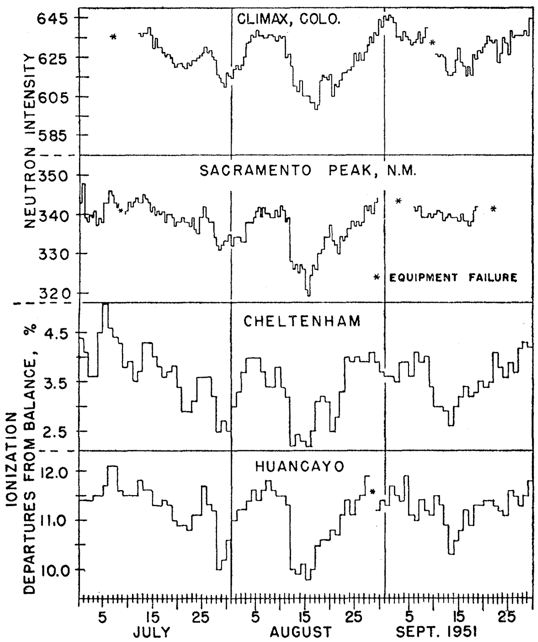

FIG. 2. Correlation between neutron measurements and ionization measurements at or near sea level.

as given in Fig. 1 are as follows: ionization at 70,000 ft to that at Cheltenham, 7:1; neutrons at 11,000 ft to ionization at Cheltenham, 3:1; ionization at Cheltenham to that at Huancayo, 1:1. A more detailed analysis[2] has shown that in the last case, the ratio between the fluctuations at Cheltenham and Huancayo is more nearly 1.1:1.

In addition to the above, two other pieces of experimental evidence are pertinent to the present discussion:

(1) A study of the differences in the balloon curves obtained at Bismarck during July and August, 1951 shows that there is a fairly wide distribution in the energy of the particles that fluctuate from day to day.

(2) In the summer of 1946 (data unpublished) an ionization chamber was sent up at Ft. Worth, Texas during the magnetic storm that followed the large flare of July 25 of that year. The percentage decrease in ionization compared with the normal value shown at 70,000 ft during this flight was approximately four times the decrease found in an unshielded ionization chamber at Mt. Wilson, California during the same period.

The manner in which the radiation responsible for these fluctuations is absorbed in the atmosphere is consistent with the fact that the fluctuations are also present at Huancayo, Peru. Since these fluctuations are also present at Thule, Greenland,[3] it is evident that they are world-wide and hence represent real changes in the total energy being brought into the earth by cosmic rays. The average energy of the particles must, however, be somewhat less than that for the total cosmic-ray particles since the fluctuations in ionization increase with altitude, and are less pronounced at the equator.

These changes do not appear to be of the same type that have been measured during sudden increases in cosmic-rays, such as occurred on November 19, 1949 and on July 25, 1946. This conclusion is borne out by (a) the small changes in neutron intensity, relative to those measured with ionization chambers shown in Fig. 1, as compared with the much larger relative change measured[4] during the increase of November 19, 1949; (b) the fact that on no occasion has as appreciable increase in cosmic rays been measured at Huancayo when these increases occurred at intermediate and higher latitudes, while the changes shown in Fig. 1 do occur also at the equator. On the contrary, we believe that these fluctuations are similar to those that have been correlated with magnetic disturbances[3,5] both of the long period type and the short period type such as that which occurred one day following the solar flare of July 25, 1946.

In conclusion we wish to thank the U. S. Weather Bureau and particularly Mr. F. J. Bavendick for their cooperation at Bismarck. We also wish to thank Dr. Vincent Peterson, Mr. Edward Stern, and Mr. Alan Johnston for their help in preparing the instruments, in carrying out the flights, and in reducing the data.

[2] S. E. Forbush, Phys. Rev. **54**, 975 (1938).

[3] Neher, Peterson, and Stern, Phys. Rev. **85**, 772 (1952).

[4] On this occasion the ratio of neutron increase to the increase in ionizing particles at Manchester, England was 60:1. See N. Adams, Phil. Mag. **41**, 503 (1950).

[5] S. E. Forbush, Internatl. Assoc. of Terrest. Mag. and Elec., Washington Assembly (September, 1939); also, S. E. Forbush and I. Lange, Phys. Rev. **76**, 1641 (1949).