New Evidence for a Change with Time of the Total Energy Brought into the Earth by Cosmic Rays

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In attempting to find a seasonal or winter-summer difference between the integrated value of the cosmic-ray ionization from sea level up to the top of the atmosphere at Omaha we obtain much too large a difference to be interpreted as an "atmospheric-temperature," or seasonal effect, at all. By comparison with Forbush's world-wide cosmic-ray changes we find in our results new evidence for a change with time in the total energy brought into the earth by cosmic rays.

PRACTICALLY all the work which we have thus far undertaken for the sake of determining the total or integrated ionization within a self-recording electroscope as it is carried from sea level up to a height 98 percent of the way to the top of the atmosphere has been done in mid-summer, i.e., between July and October. So far as we know, no one had ever attempted to determine such depth-ionization curves in mid-winter. This seemed to us an important point to investigate.

Accordingly, in the week before Christmas, 1938, we went to Omaha (Nebraska) where we already had made successful flights in warm summer weather and succeeded in that week in making four successful flights in cold winter weather. There is contained in Table I, columns *A* and *B*, the mean ionization currents as a function of altitude, *h* (measured in meters of water from the top, 10 meters therefore corresponding to sea level), both for the mean of the five flights made in Omaha in September, 1937 and for the mean of the four flights made there in December, 1938. The measuring electroscopes were in large part the same ones in both sets of flights, or when different electroscopes were used they were made essentially identical by identity in structure and careful calibration, so that the readings should be strictly comparable.

A comparison of the readings in the two

TABLE I. *Comparison of Incoming Cosmic-Ray Energies at Different Times.*

h	*A* Omaha Sept. 1937	*B* Omaha Dec. 1938	Percent Increase	*C* Saskatoon Aug. 1937	*D* Bismarck July 1938	Percent Difference
0.2	328	344	5	355	370	3.8
0.3	337	356	5.5	359	375	3.8
0.4	333	361	8.3	361	375	3.8
0.6	326	358	9.7	347	364	4.7
0.8	310	336	8.1	329	346	
1.0	290	314	8.3	308	323	4.4
1.2	267	288	7.8	280	296	5.3
1.4	242	259	7.1	252	268	5.2
1.6	217	235	7.3	225	239	5.8
1.8	195	210	7.5	202	214	5.7
2.0	173	192	11	180	190	5.3
2.25	150	167	11.3	156	159	2.0
2.5	128	146	13.8	134	133	0
2.75	110	127	15.4	115	111	−4
3.0	94	110	17.0	97	93	−4
3.5	69	80	16	68	66	−3
4.0	49	57	16.5	51	48	−6
4.5	35	41	17	36	39	+7
5.0	26	29	12	25	26	+2
5.5	20	23	15	18	17	−5
6.0	16	18	12	13	13	0
7.0	11	12	9	10	7	

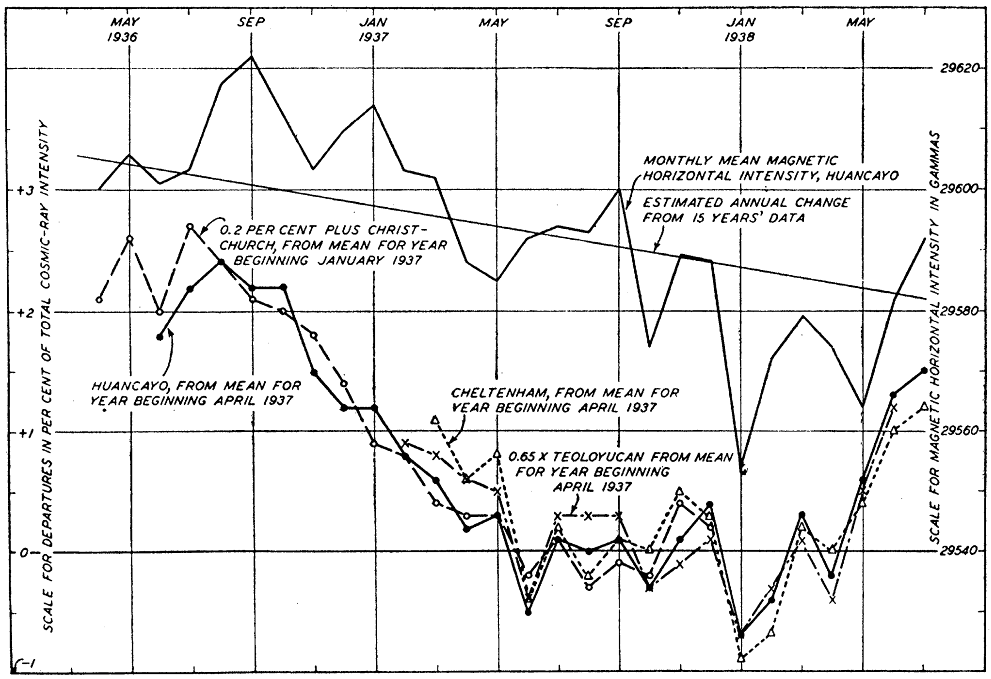

FIG. 1. Reproduction of the curve by Forbush (reference 5) for the world-wide changes in cosmic-ray intensities between April, 1936, and July, 1938.

columns *A* and *B* shows that our winter readings are indeed everywhere very markedly higher than our summer readings. Not only is that true, but it is also true that the total area underneath the depth ionization curve corresponding to our winter readings at Omaha is some 9.7 percent greater than the area underneath the corresponding summer curve in September, 1937.

This result is particularly significant, for it means that since the total incoming energy must ultimately manifest itself in the ionization of the atmosphere, the actual *entering* cosmic-ray energy was greater in December, 1938, than in September, 1937. *This result cannot, then, be interpreted as an "atmospheric-temperature effect" at all.* For any such pure atmospheric-temperature effect, when integrated over the full depth of the atmosphere, must come out independent of temperature, or of season. It can only affect the *distribution* of ionization with altitude, not its total amount.[1]

Although, then, the atmospheric-temperature effect which we studied in the foregoing paper may be involved in, and modify the relation of, the percentage differences shown in the fourth column of the accompanying table, it is wholly inadequate to explain what we have here observed in our attempt to study *seasonal* effects at all altitudes up to the top of the atmosphere. Blackett[2] on the basis of a theory developed by Euler and Heisenberg[3] has suggested an explanation of the pure atmospheric-temperature effect which is intriguing[4] and which we hope that further study will ultimately justify, but we must seek entirely different explanations of the

[1] This conclusion could only be doubted if the extreme assumption were made that an appreciable portion of the incoming energy, instead of appearing ultimately in the form of ionization, did not appear at all but became lost or carried away somehow in unobservable form, by neutrinos, for example. This hypothesis would destroy the most stable basis upon which all theoretical physics rests. We therefore prefer not to make it.

[2] P. M. S. Blackett, Phys. Rev. **54**, 973 (1938).

[3] H. Euler and W. Heisenberg, Ergeb. d. Exak. Nat. (1938).

[4] This theory is essentially that the mesotrons formed in the upper atmosphere by incoming cosmic-ray electrons (or photons) have a radioactive lifetime comparable with the time they require to traverse the atmosphere. This traversal time is less in winter, when the atmosphere is contracted (less deep), than in summer, when it is expanded. More mesotrons, therefore, get down to sea level in winter than in summer and produce there more ionization.

results brought to light in the accompanying table. *They constitute direct evidence that the incoming cosmic rays are variable in intensity, not necessarily seasonally but at least as some sort of a function of time.*

However, this is not the first time that such evidence has been brought to light. For Forbush[5] in his paper entitled "On World-Wide Changes in Cosmic-Ray Intensity" has deducted the seasonal effect, or the "12-month wave," as he calls it, from the data obtained by continuous recording instruments which the Carnegie Institution of Washington is keeping running at Cheltenham (U. S.), mag. lat. 50.1° N., Teoloyucan (Mexico), mag. lat. 29.7° N., Christchurch (New Zealand), mag. lat. 48.0° S., and Huancayo (Peru), mag. lat. 0.6° S., and obtained finally in his Fig. 15,* a figure which we reproduce here for convenience of reference, a curve which gives "the world-wide changes" in cosmic-ray intensities between April, 1936, and July, 1938. This curve shows that between September, 1937, and July, 1938, the intensity of cosmic rays increased the world over as measured in these instruments on the earth's surface by about 1.5 percent. Forbush's curve is not carried up to the time of our observations in December, 1938, but the curve had been moving up rapidly from January, 1938, to July, 1938, and Dr. Forbush informs us that it continued to rise for some months thereafter, so that our result, indicating a considerable increase in the incoming rays between September, 1937, and December, 1938, is at least qualitatively in accord with the Forbush curve.

But the data found in columns *C* and *D* of the accompanying table give still better opportunity for comparison with this curve. For as columns *C* and *D* show clearly, the total cosmic-ray energy coming in at Saskatoon (mag. lat. 60° N.) in August, 1937, is smaller than that coming in at Bismarck (mag. lat. 56° N.) at the end of June and beginning of July, 1938. Since, however, Saskatoon is four degrees farther north than Bismarck, and on the plateau or polar cap of constant cosmic-ray intensities which begins at very high altitudes at about mag. lat. 56°, it should in no case show a *lower* value of the incoming cosmic rays than is found at Bismarck, unless between the observation dates there had been an increase in the total energy of the cosmic rays entering the atmosphere. But *the Forbush curve shows that there was what he calls a "world-wide" increase of about 1.5 percent in the cosmic-ray intensity between these two dates as measured on the earth's surface*, so that at least qualitatively the data both of columns *A* and *B* and those of columns *C* and *D* of the accompanying table are in accord with the predictions of the Forbush curve.

The net result, then, of this preliminary attempt to find a seasonal or atmospheric temperature effect at very high altitudes is *to bring forward new evidence for a change with time of the total energy brought into the earth by cosmic rays which is large enough to mask completely any possible seasonal effect.*

[5] S. E. Forbush, Phys. Rev. **54**, 975 (1938).
* Reference 5, page 986.