function. For $l=1$, it is usually assumed that

$$\begin{aligned} f_1(k) &= k/k_0^{\frac{3}{2}}, \quad k<K \\ &= 0 \qquad\;\; , \quad k>K, \end{aligned} \tag{23}$$

with K an appropriately chosen cutoff. In order that η_1 be very small for moderate energy, the cutoff must be large compared to p. In that case

$$\tan\eta_1 \approx -\pi(p/p_0)^3(p_0/K). \tag{24}$$

Equation (16) certainly implies that $\tan\eta_1<0.2$ for $p\approx 2$, but then we must have

$$K \gtrsim 9\pi, \tag{25}$$

which would seem to be an unreasonably large value for K.

The difficulty may result from our use of the Tomonaga approximation. It has been suggested[9] that there is an important correlation between the pions in the bound P-states of the nucleon, in which case the use of a single radial function is inadequate, and the form of Eq. (22) must be revised.[5] No adequate calculation of η_1 has been carried out for the case of correlation, largely because an appropriate substitute for Eq. (23) has not been suggested. It is not clear that such a calculation would lead to small η_1, but the possibility remains until the contrary is demonstrated.

[9] W. G. Holladay and R. G. Sachs, Phys. Rev. **98**, 1155 (1955) and W. G. Holladay, Phys. Rev. **101**, 1198, 1202 (1956).

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Cosmic-Ray Observations at Very High Altitudes During Periods of Intense Solar Activity*

MARTIN A. POMERANTZ
Bartol Research Foundation of The Franklin Institute, Swarthmore, Pennsylvania

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The records of a number of balloon flights which coincided with outstanding solar disturbances during the period 1947–1952 have been subjected to detailed statistical analysis in a search for associated fluctuations in the primary cosmic-ray flux. The intensity at very high altitudes was enhanced in four cases, and normal on five occasions when rf radio disturbances and/or visually-observed solar flares occurred. In some instances, outstanding chromospheric eruptions are not accompanied by any detectable increase in the flux of primary cosmic-ray particles even down to the very low energy required for just penetrating 10 g/cm^2 of matter. On the other hand, additional low-energy particles apparently associated with solar disturbances sometimes are detected at very high altitudes, even when the flares are small and the observing station is outside the morning impact zone.

I. INTRODUCTION

ONLY four unusual increases in the cosmic-ray intensity coincident with the occurrence of outstanding solar flares have been observed with instruments operating at low altitudes in almost two decades.[1] Thus, it is self-evident that certain special conditions must prevail for events of this type to be detected by the existing stations.

One important factor relating to this matter concerns the accessibility of the various allowed regions on the earth for charged particles originating at the sun. A detailed examination of the form of the individual trajectories is required in this case. This problem was first attacked by Schlüter[2] whose results regarding the intensity distribution at the earth, based upon the integration of twenty Störmer orbits, indicated that a maximum should occur at a particular local time, which for positive particles of momentum several Bev$\times Z/c$ originating at the sun in the equatorial plane is 0900 hr. Firor[3] has derived the distribution of impact zones on the earth for particles of magnetic rigidities 1–10 Bv which originally approach from the sun, and has shown that at intermediate latitudes the relative intensities at 0900 hr, 0400 hr, and at all other times are in the ratio 7:3:1. Except at very high latitudes where perturbations may be introduced by nondipole terms in the terrestrial magnetic field, the observed world-wide increases agree with theoretical predictions relating the expected magnitude of the increase to location of the station at the time of the disturbance. Furthermore, data obtained with the Climax neutron monitor[4] appeared to support the supposition that additional particles approach the earth from the direction of the sun at the time of perhaps even all flares, at least when the detector is in a morning impact zone.

* Assisted by the Office of Naval Research and by the U. S. Atomic Energy Commission.

[1] Forbush, Stinchcomb, and Schein, Phys. Rev. **79**, 501 (1950). *Note added in proof.*—The fifth unusual increase, world-wide in character and of much greater magnitude than any observed previously, commenced at 350 UT, February 23, 1956. This event has been reported by numerous stations.

[2] A. Schlüter, Z. Naturforsch. **6a**, 613 (1951).

[3] J. Firor, Phys. Rev. **94**, 1017 (1954).

[4] Simpson, Fonger, and Trieman, Phys. Rev. **90**, 934 (1953).

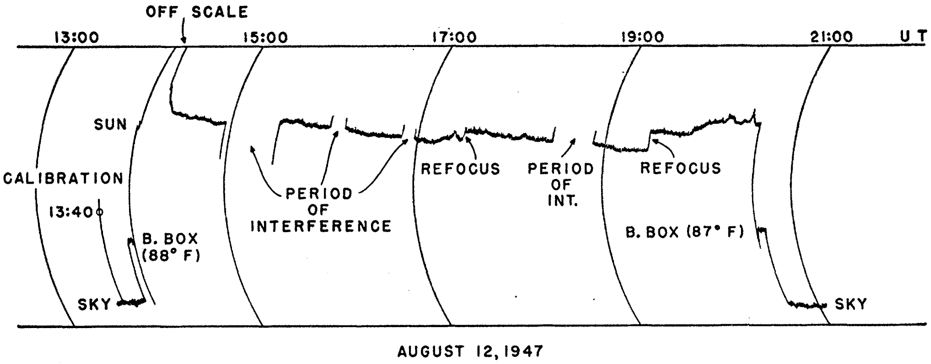

FIG. 1. Trace of 2800-Mc/sec record of August 12, 1947.

Forbush, Stinchcomb, and Schein[1] observed that during the most recent and largest of the four classic events, the percentage increase registered with a shielded ionization chamber at 3500 m was 4.8 times that at sea level. Since only about 10% of the total ionization at this altitude under 12 cm of Pb is normally due to local radiation originating from the nucleonic component to which the flare effect is attributed, the flux of primary particles producing the observed 207% increase probably rose to at least twenty times the normal value, if the additional radiation is in the same band of energy as that ordinarily contributing to this fraction of the ionization.

In view of the foregoing considerations, it seemed reasonable to expect that during disturbed periods G-M counter trains near the "top of the atmosphere" might detect smaller increases which could occur much more frequently and which are not observable at low altitudes, particularly if the energy of the new particles is near the minimum permitted by the earth's magnetic field. One case in which an increase of the primary intensity was detected only at very high altitudes 19 hours after the commencement of the outstanding chromospheric eruption of May 10, 1949, has in fact been reported previously.[5] Neher[6] has also observed fluctuations in the primary radiation attributable to the presence of additional low-energy particles possibly arising from solar flares.

Owing to inherent technical limitations, it has been impossible thus far to perform controlled experiments

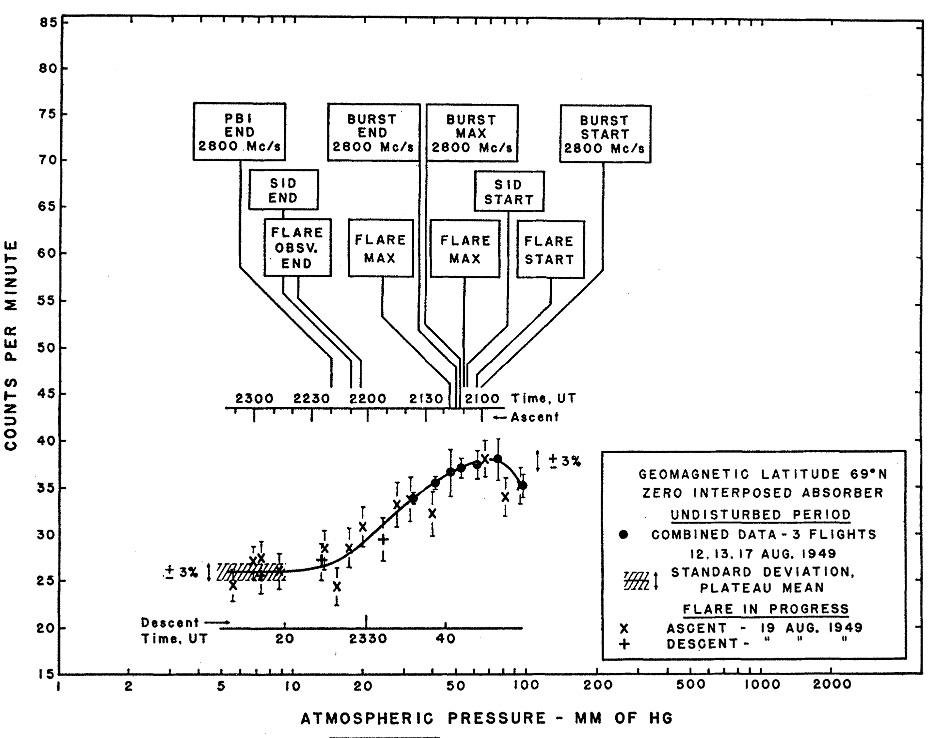

FIG. 2. Cosmic-ray data obtained during balloon flight of August 19, 1949.

[5] M. A. Pomerantz, Phys. Rev. **81**, 731 (1951).
[6] Neher, Peterson, and Stern, Phys. Rev. **90**, 655 (1952).

TABLE I. Summary of balloon flights conducted during

		Hα flare				2800-Mc/sec radio event					
No.	Date	Imp.	Time observed,[a] UT	Time of maximum, UT	Position (degrees)	Time observed,[a] UT	Type[b]	Time of maximum UT	Post-burst increase end, UT	Energy excess[c] Burst	Post-burst
1	August 12, 1947	3	*1401–1501*	1409	13N 24E	*1402–1420*	Single; post	?	1550	>850 (1060)[e]	350
2	May 11, 1949	None reported; 19 hours before flight, 5/10/49; 3+	2000–2220			Null; receiving conditions unfavorable					
3	August 19, 1949	3	*2104*–2205	2111, 2118	13N 10W	*2103–2115*	Single; post	2112	2220	387	565
		1	*2337*–2341	2338	15N 7W						
4	September 27, 1949	None reported				*1535–1539*	Single	1537		5	
5	October 4, 1949	2	1610–*1637*	1623	14N 30E	1609–2209	Period irregular fluctuations	1626		3300	
6	October 11, 1949	2	*1514–1654*	1523, 1551	19N 22E						
		2	1544–*1709*	1651	13S 29E	1528–*1600*	Burst[f]; post	?	1705	>3896	730
7	January 27, 1951	1	1515–*1535*	1517	12S 17E	Not observing					
		1	*1530*–1600	1534	8N 6E						
8	May 17, 1951	1	*1637*–1730	1652?	18N 24W	*1633*–1730	Single; post	1635	1643	12	12
		1−	*1710–1819*	1719	23N 24W	*1709–1715*	Single; post	1713	1749	64	108
		2	*1754*–1912	1758	11N 10W	*1755–1915*	Gradual rise and fall	1802		400	
		1	1910–*1930*	1910	14N 13W						
9	January 17, 1952	Not observing				Null; receiving conditions unfavorable					

[a] Where time is italicized, it refers to the beginning or ending of the event; otherwise it refers to the period during which the event was observed to be in progress.
[b] As described in reference 15.
[c] Units for energy excess are 10^{-20} joules $meter^{-2}$ $(cycle/sec)^{-1}$.

for measuring the primary cosmic-ray intensity with balloon-borne apparatus during large solar flares. However, during the period 1950–1952, several flights were released to coincide with the central meridian passage of extremely active region on the sun at times when other types of solar observations portended possible eruptions. Thus, warnings of impending unusual activity were transmitted by the Central Radio Propogation Laboratory or by the Cornell University Radio Astronomy Observatory.[7] Furthermore, it appeared conceivable that during the course of an extensive balloon-flight program conducted between 1947 and 1952, some flights may have been aloft by chance when a flare occurred. Hence, a search for such coincidences was conducted, and the records re-examined in detail for evidence of any possible statistically-significant fluctuations of the cosmic-ray intensity. The results will be presented herewith together with a summary

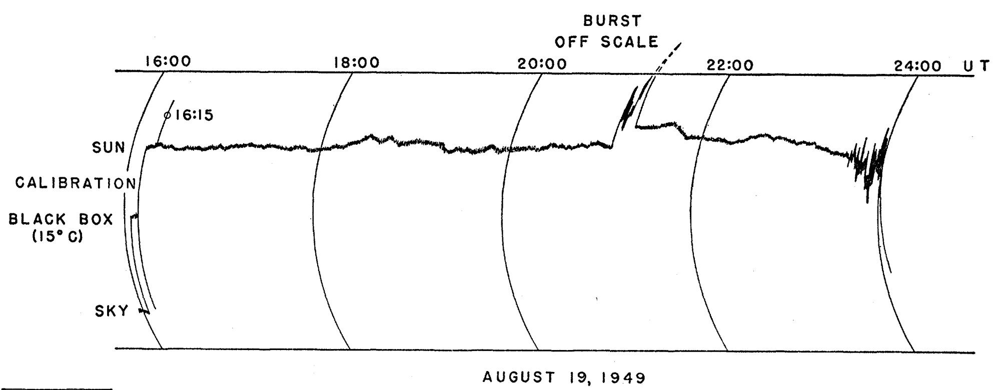

FIG. 3. Trace of 2800-Mc/sec record of August 19, 1949.

[7] The author wishes to express his appreciation to A. H. Shapley of the National Bureau of Standards and S. M. Colbert of Cornell University for their cooperation in transmitting prompt warnings of unusual solar activity.

periods of outstanding solar activity, and related solar data.

200-Mc/sec radio event				Primary cosmic radiation			
Time observed,[a] UT	Type[d]	General activity	Geomagnetic latitude	Interposed absorber, g cm^{-2}	Residual atmosphere at ceiling, g cm^{-2}	Time of arrival at ceiling, local solar time	Particle flux
Not observing			52°N	40	6	1000	Normal
Not observing		Very high base level and burst activity immediately following flight	52°N	16	7	1114	Enhanced
Not observing			69°N	4	7	1655	Normal
Not observing			52°N	86	6	1043	Normal
1628–1629	C4-A	High base level and burst activity	52°N	4	2	1112	Normal
1605–*1645*	RBL		52°N	4	6	1049	Normal
1514–1515 *1638–1639*	C4-A C4-A	High burst activity	52°N	50	32	1006	Enhanced
1627–1628 1300–2100	S_v-D W-A	High base level and burst activity	52°N	50	15	1321	Enhanced
1835–1856 *1917–1922* *1953–1955*	T2-A K2-A C2-A	High base level and burst activity	52°N	86	15	1515	Enhanced

[d] According to Cornell classification, Radio Astronomy Report No. 17, December 1, 1951, School of Electrical Engineering (Cornell University, Ithaca 1951), p. 6.
[e] ( ) Indicates estimated value.
[f] Radio record is incomplete, and detailed classification is not possible.

of all available data obtained by various solar observatories while the flights were in progress.

The apparatus comprised standard quadruple-coincidence counter trains which have previously been described in detail.[8]

II. PRESENTATION OF DATA

The dates upon which flights were aloft at sufficiently high altitudes during periods of significant solar activity are listed in Table I together with the basic observational data. Where time is *italicized*, it refers to the beginning or ending of the event, otherwise to the period during which the event was observed to be in progress. H_α flare data[9] were derived from the Quarterly Bulletin of Solar Activity of the International Astronomical Union and reports of the Central Radio Propogation Laboratory of the National Bureau of Standards. Radio data at 2800 Mc/sec were recorded by the National Research Council of Canada in Ottawa,[10] and at 200 Mc/sec by the Radio Astronomy Observatory of Cornell University at Ithaca, New York.[11] The cosmic-ray data will be presented in detail only for the more interesting examples, although brief comments will be made in each case.

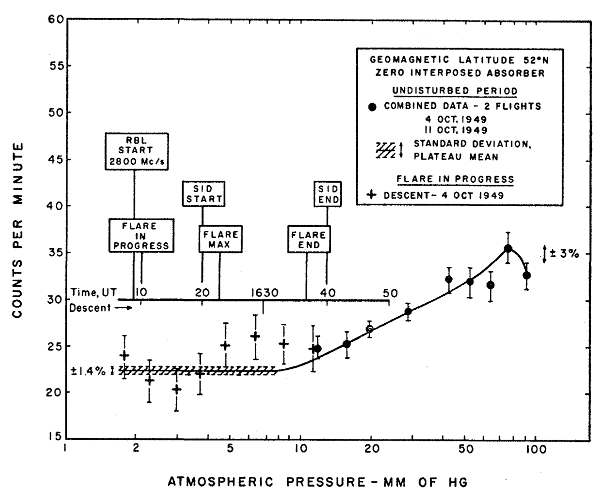

FIG. 4. Cosmic-ray data obtained during balloon flight of October 4, 1949.

[8] M. A. Pomerantz, Phys. Rev. **95**, 531 (1954) and other references contained therein; see also Electronics **24**, 88 (1951).

[9] The author is grateful to Dr. Helen W. Dodson for evaluating some of the solar flare data contained in Table I.

[10] We wish to thank Dr. A. E. Covington for providing the 2800-Mc/sec solar radiation data as well as the tracings of the original records.

[11] We wish to thank Dr. C. R. Burrows for providing the 200-Mc/sec data as well as the reproductions of the original records.

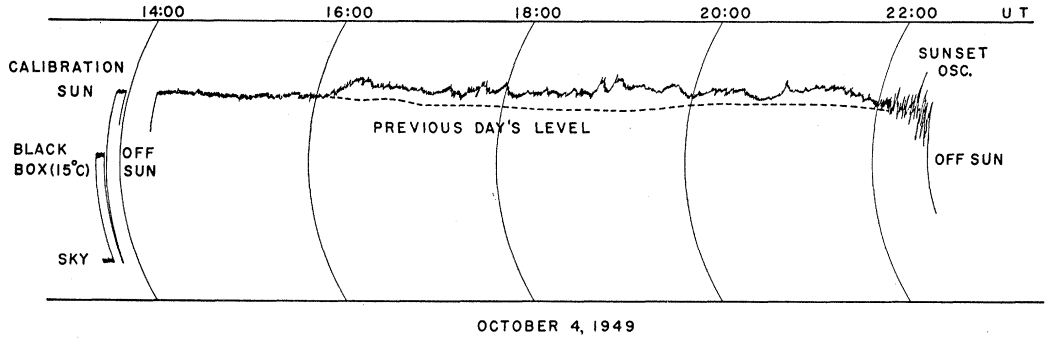

FIG. 5. Trace of 2800-Mc/sec record of October 4, 1949.

1. August 12, 1947.—An H_α flare of importance 3 commenced while the instrument was above 85 000 feet. Detailed statistical analysis of the data recorded at higher altitudes for one hour thereafter, including the chi-square test, revealed no abnormalities. The primary flux determined from the plateau counting rate was in good agreement with the normal value established with the present techniques. The 2800-Mc/sec event, shown in Fig. 1, ranked 17th among the 233 outstanding disturbances listed for a three-year period.

2. May 11, 1949.—Details concerning this flight have been published previously.[5]

3. August 19, 1949.—Figure 2 is a plot of the counting rate as a function of atmospheric pressure for this flight. Combined data obtained in flights during undisturbed periods are represented by solid dots. At altitudes below the lowest for which points are plotted in this and some of the subsequent figures, the data from the indicated flight agree with the composite curve within statistical expectation. Although a flare of importance 3 and a 2800 Mc/sec event (Fig. 3) with moderately large energy excess occurred during the ascent, there is no indication of any significant fluctuation in the cosmic-ray intensity. This case is of particular interest because it is the only example of a coincidence at geomagnetic latitude 69°N, where the cutoff energy imposed by the geomagnetic field is 100 Mev for protons, and the minimum energy required to penetrate the counter train and the residual atmosphere down to the *lowest* point on the counting rate plateau (<17 g cm^{-2} total) is 150 Mev. The record was interrupted during the descent immediately prior to the onset of a second smaller flare. The uncertainties indicated are statistical standard deviations, and the plateau counting rate was determined by averaging all available data obtained with this arrangement at altitudes exceeding that corresponding to 10 mm of Hg.

4. September 27, 1949.—Although no flare was reported, this flight is listed because a small burst was observed at 2800 Mc/sec just before the apparatus reached peak altitude. There is no indication of any abnormal fluctuation in the cosmic-ray intensity either in the plateau region, where the average counting rate agreed with the established value for this arrangement, or during the descent.

5. October 4, 1949.—As is indicated in Fig. 4, a flare was observed to be in progress just after the instrument had attained the record-breaking altitude of 136 000

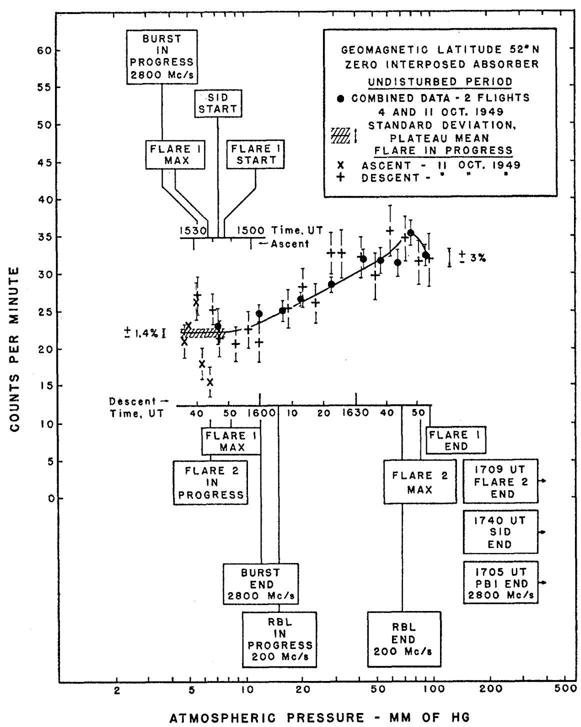

Fig. 6. Cosmic-ray data obtained during balloon flight of October 11, 1949.

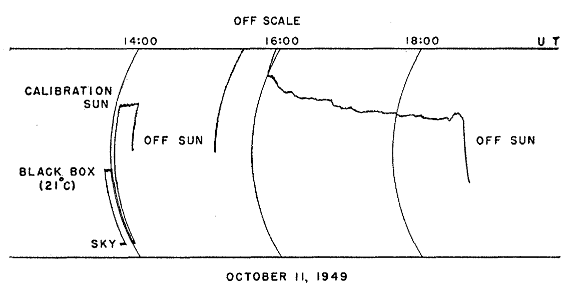

FIG. 7. Trace of 2800-Mc/sec record of October 11, 1949.

feet. No significant fluctuations occurred at any time during the flight, as confirmed by the chi-square test. Although descent data following termination of the flare are not plotted in the accompanying figure, the points are in excellent agreement with the normal curve throughout the atmosphere. It should be pointed out that the time of arrival at the 100-mm level during the descent followed flare maximum by 1 hour, yet no delayed effect was detected at that depth. The 2800-Mc/sec event (Fig. 5) that is designated "period of irregular activity" is relatively rare, only six having been observed out of 233 outstanding disturbances in the three year period, 1947–1950.

6. *October 11, 1949.*—Although two flares of importance 2 occurred simultaneously while this flight was in progress, there are no fluctuations to which statistical significance can be ascribed in the cosmic-ray data plotted in Fig. 6. The chi-square test yielded a satisfactory result. The burst energy excess at 2800 Mc/sec (Fig. 7) is the fourth largest among 233 outstanding disturbances observed in a three-year period, and greatly exceeds the average for all bursts.

7. *January 27, 1951.*—As is evident in Fig. 8, although the data obtained at low altitudes during this flight were in reasonable agreement with those for normal days, a marked departure occurs in the upper regions of the atmosphere ($p<80$ mm). Considerable burst activity was observed at 200 Mc/sec, as is seen in Fig. 9, where the relative counting rates are represented in the form of a histogram. The yellow coronal line, which is quite rare, was visible on the west limb passage of region 51*A* which on this date was one day

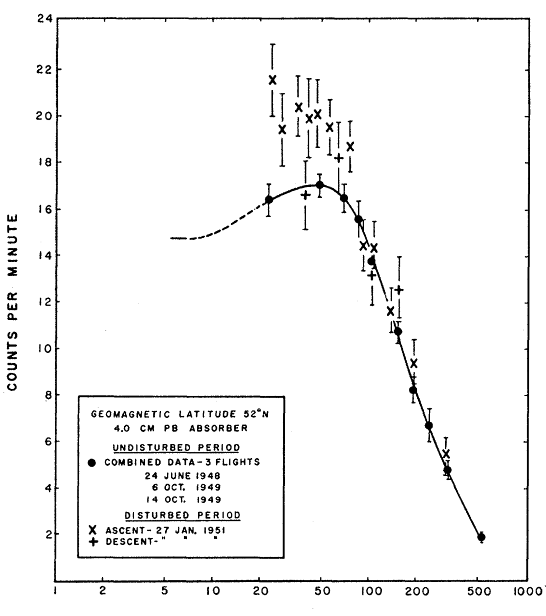

FIG. 8. Cosmic-ray obtained data during balloon flight of January 27, 1951.

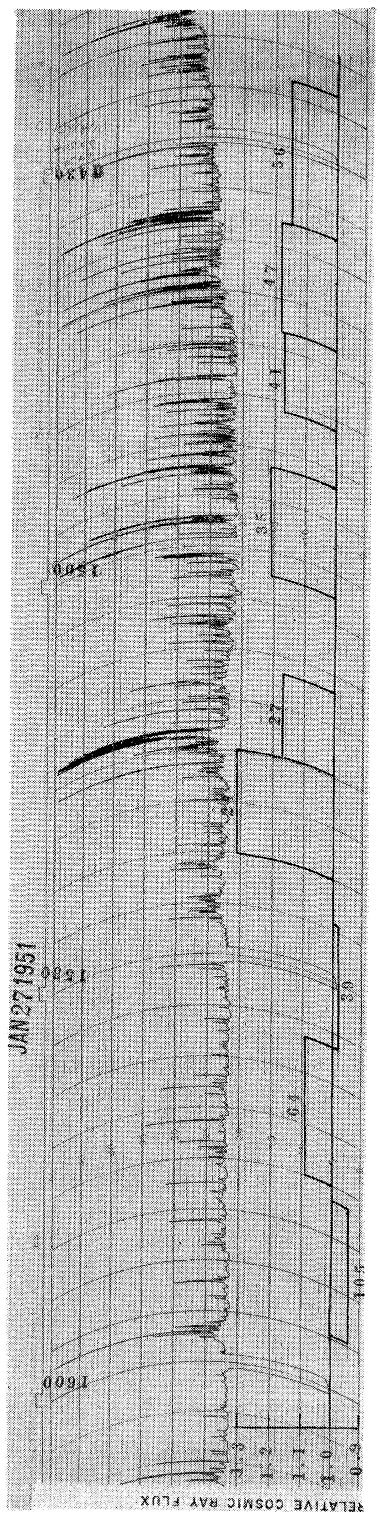

FIG. 9. Reproduction of 200-Mc/sec record of January 27, 1951. The numbers on the histogram refer to the average atmospheric pressure, in mm of Hg, during the indicated intervals.

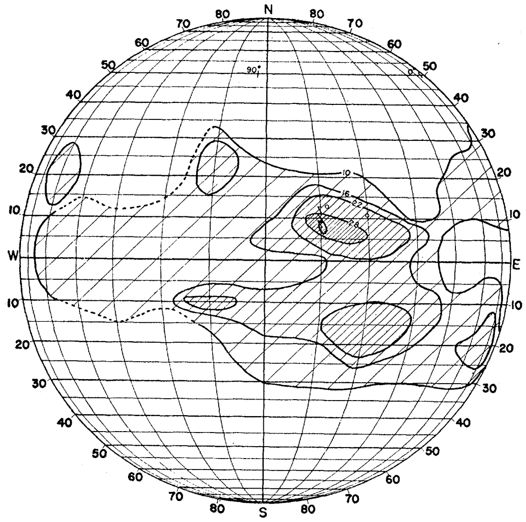

FIG. 10. Isophotal contour map of solar corona on January 27, 1951. Station: Sacramento Peak. Line: 5303 A. Meridians indicate day distance from central meridian. Contours at 10, 16, 22, 28, 34. The open circles denote flares. The zig-zag symbol indicates a yellow line.

east of central meridian as shown on the isophotal contour map[12] in Fig. 10.

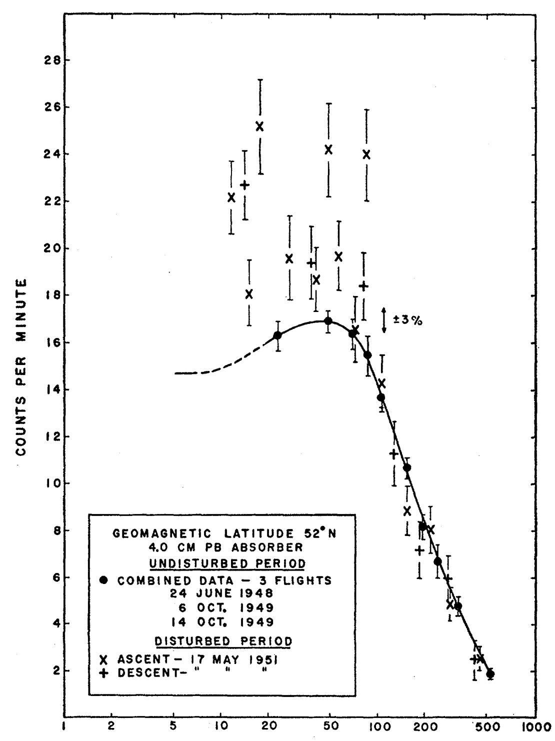

FIG. 11. Cosmic-ray data obtained during balloon flight of May 17, 1951.

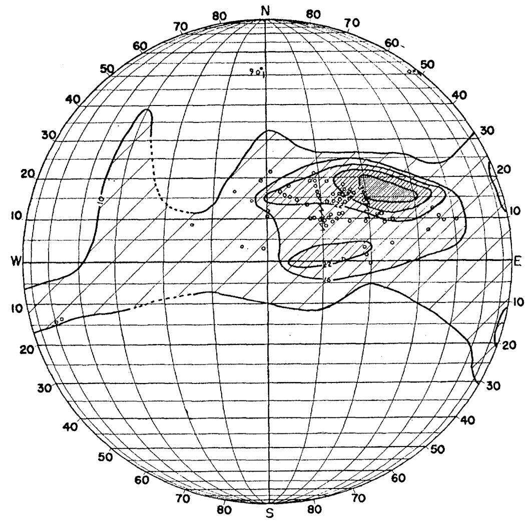

FIG. 12. Isophotal contour map of solar corona on May 15, 1951. Station: Sacramento Peak. Line: 5303 A. Meridians indicate day distance from central meridian. Contours at 10, 16, 22, 28, 34. The open circles denote flares. The zig-zag symbol indicates a yellow line.

8. May 17, 1951.—Figure 11 reveals that although this flight was quite normal in the lower atmosphere, counting rates throughout the upper tenth of the atmosphere were higher than normal. Region 51*A* at central

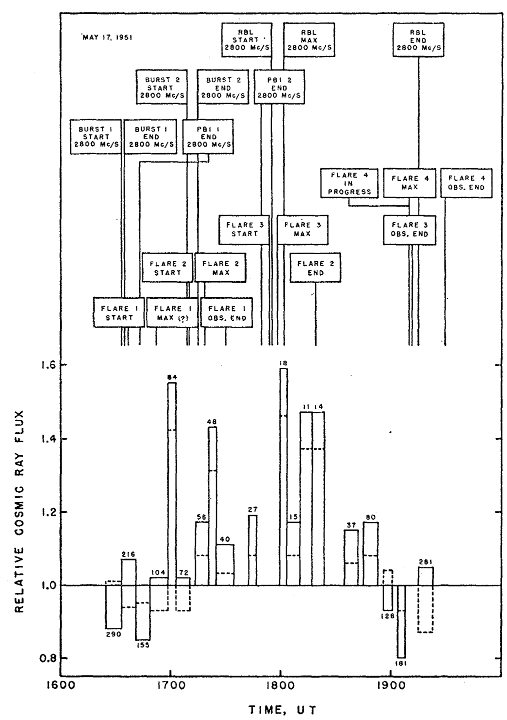

FIG. 13. Relative cosmic-ray flux as a function of time during flight of May 17, 1951. The numbers on the histogram refer to the average atmospheric pressure, in mm of Hg, during the indicated intervals.

[12] The isophotal charts are from Reports of the High Altitude Observatory, Boulder, Colorado, kindly prepared by D. E. Trotter and W. O. Roberts.

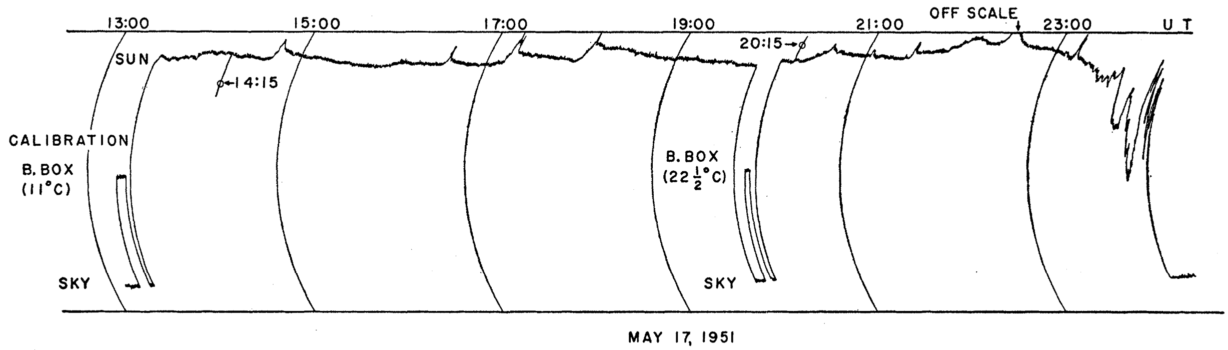

FIG. 14. Trace of 2800-Mc/sec record of May 17, 1951.

meridian on this date (Fig. 12) displayed maximum activity this passage. The associated sun-spot group was one of the largest ever reported, and 61 flares were observed during this transit. The flare-activity index of 2000 was the sixth largest in more than a one-year compilation of this rating.[12] The yellow coronal line was visible at each limb. Figure 13 shows a histogram of the relative cosmic-ray flux as a function of time together with notations about the various phases of the concurrent solar activity, and Fig. 14 is the corresponding 2800-Mc/sec record. Although the bursts are of average magnitude, it is highly unusual for so many to occur during a single day.

9. January 17, 1952.—As may be seen in Fig. 15, the cosmic-ray intensity was high only during certain portions of this flight. There is a suggestion in Fig. 16 of some correlation with the 200-Mc/sec burst activity. Region 51*A* which was the most important of any observed during the preceding year was still active when it crossed central meridian on this date (Fig. 17), although the activity was declining. The other active region, 51*S*, almost indistinguishable from 51*A*, was one day west of central meridian. Very great burst activity and high median flux had been recorded at 200 Mc/sec during the preceding days, January 15–17, with the bursts becoming more distinct and intermittent on the day of this flight.

III. DISCUSSION

Although the number of available observations is necessarily limited in view of the necessity of depending solely upon chance coincidences between successful balloon flights and outstanding solar disturbances, certain general conclusions can nevertheless be drawn. Perhaps the most significant is that some outstanding chromospheric eruptions are not accompanied by any detectable increase in the flux of primary cosmic-ray particles even down to the very low energies required for just penetrating 10 g/cm^2 of matter. On the other hand, additional low-energy particles apparently associated with solar disturbances sometimes are detected at very high altitudes even when the visually-observed flares are small, and the observing station is outside the morning impact zone.

Simpson's observations at aircraft altitudes had indicated that fluctuations and large changes of intensity of the neutron component may occur during solar and terrestrial disturbed days.[13] Experiments with neutron monitors at low altitudes revealed increases of the primary flux apparently coinciding with central meridian passage of active regions on the sun.[14] Event No. 2 above had also demonstrated that a disturbed condition such as is characterized by unusual rf radiation activity may result in additional cosmic-ray particles even though no visual flares are in progress. The possibility is suggested that a sudden chromospheric eruption is an effect, and not a cause; i.e., that both the cosmic-ray increase and the flare may have a

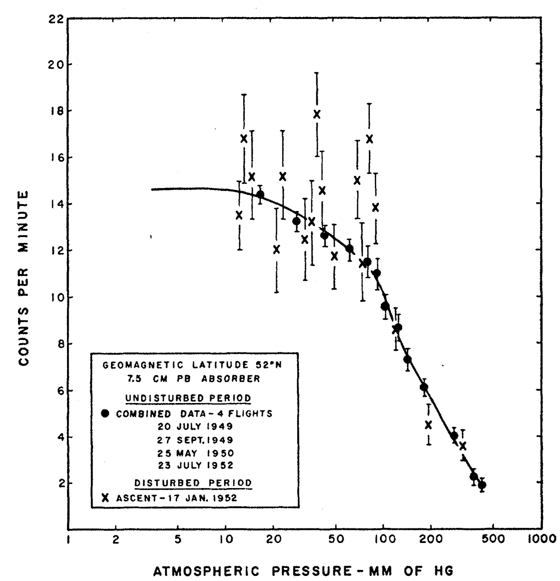

FIG. 15. Cosmic-ray data obtained during balloon flight of January 17, 1952.

[13] J. A. Simpson, Phys. Rev. **83**, 1175 (1951).
[14] Simpson, Fonger, and Wilcox, Phys. Rev. **85**, 366 (1952).

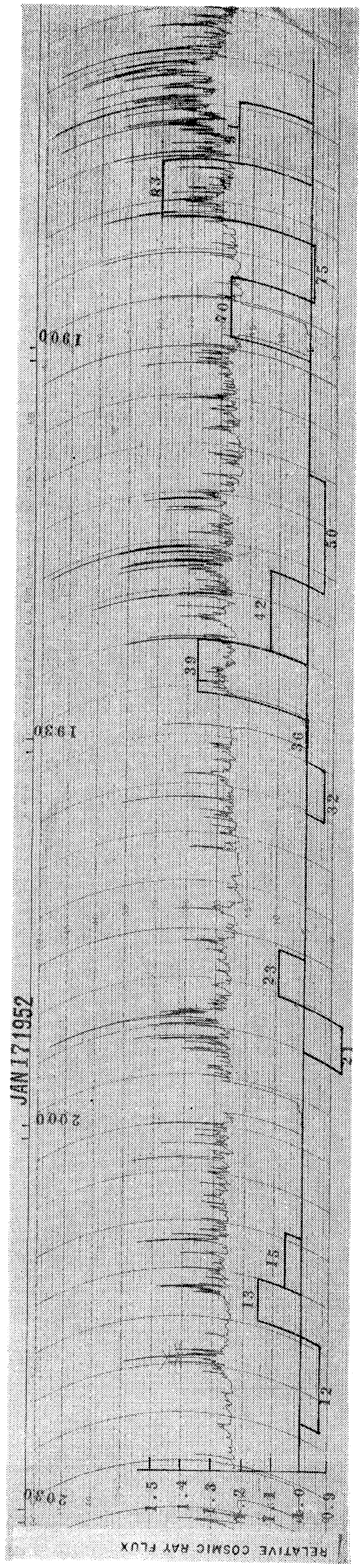

FIG. 16. Reproduction of 200-Mc/sec record of January 17, 1952. The numbers on the histogram refer to the average atmospheric pressure, in mm of Hg, during the indicated intervals.

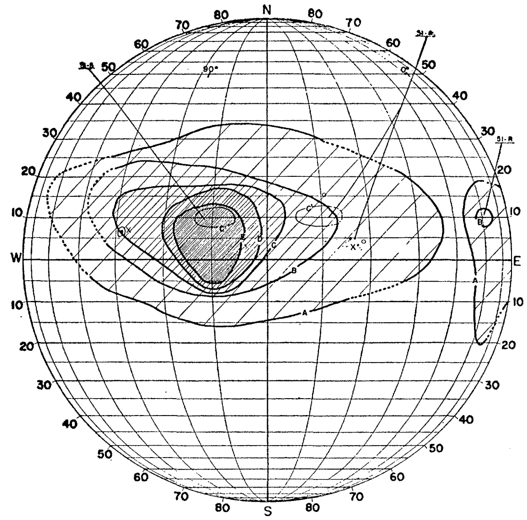

FIG. 17. Isophotal contour map of solar corona on January 17, 1952. Station: Sacramento Peak. Line: 5303 A. Meridians indicate distance from central meridian. Countours at *A*, *B*, *C*, *D*, *E*, and *C′*. Plages, ×. Sunspots: umbrae and penumbral ⊙, flares ○.

common origin. It is of interest to recall that among the world-wide increases observed by Forbush,[1] enhanced intensity persisted in one instance (July 25, 1946) for a period extending 26 hours following termination of the visual flare.[15]

Consideration of all outstanding 2800-Mc/sec disturbances recorded at Ottawa between March 27, 1947 and June 30, 1952 has provided strong evidence that there is an outstanding event or sudden disturbance at this frequency only when a flare or subflare is in progress.[16] However, flares of importance 2 or 3 are not always accompanied by a disturbance at 2800 Mc/sec. Furthermore, although 78% of the flares included in a study of the 200-Mc/sec radiation records of Cornell University were found to have accompanying events at this frequency, 43 flares, including 11 major H_α phenomena, did not.[17] The flares for which no distinctive event occurred represented a random sample of the entire set of 194 examined. Whether the cosmic-ray effects are similar to those of the rf radiation with respect to their association with flares cannot, of course, be decided on the basis of the meager data now available. A systematic approach to this problem during the next active portion of the solar cycle in conjunction with the International Geophysical Year program may help to provide an answer to this question.

[15] *Note added in proof.*—The recent enhancement of February 23, 1956 also excluded for a long period after the plane had subsided. D. C. Rose (private communication) and A. E. Sandström (private communication).

[16] Dodson, Hedeman, and Covington, Astrophys. J. **119**, 541 (1954).

[17] Dodson, Hedeman, and Owren, Astrophys. J. **118**, 169 (1953).

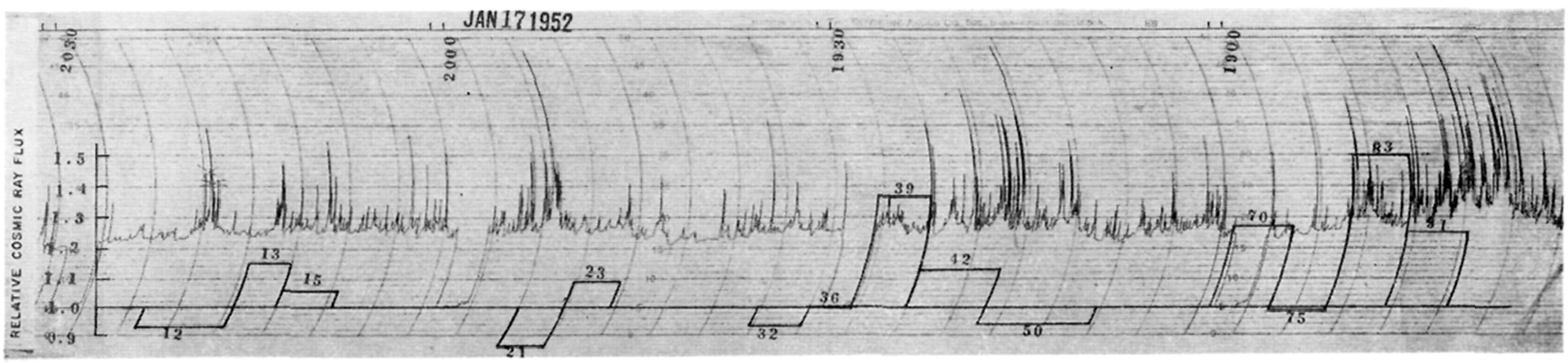

FIG. 16. Reproduction of 200-Mc/sec record of January 17, 1952. The numbers on the histogram refer to the average atmospheric pressure, in mm of Hg, during the indicated intervals.

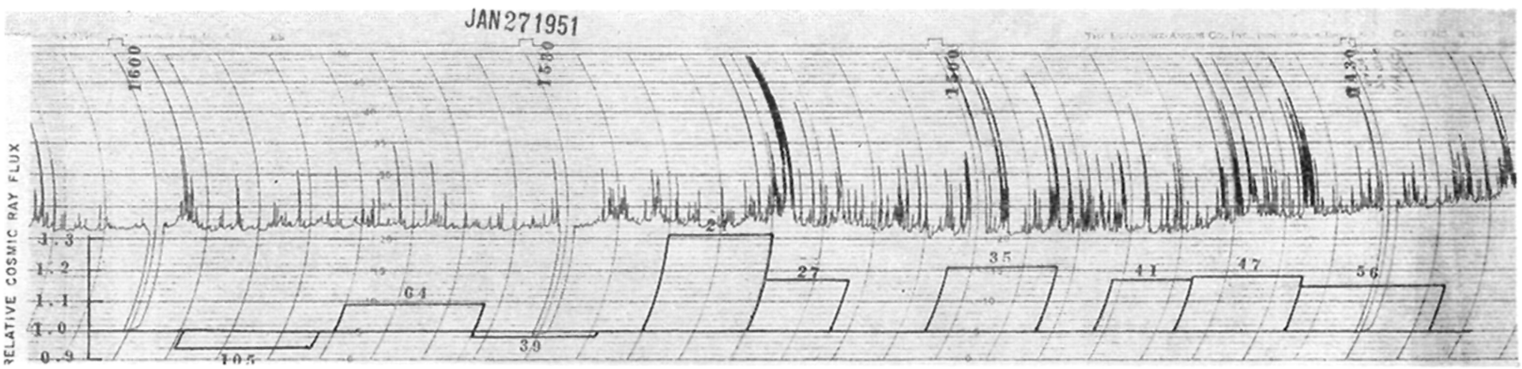

FIG. 9. Reproduction of 200-Mc/sec record of January 27, 1951. The numbers on the histogram refer to the average atmospheric pressure, in mm of Hg, during the indicated intervals.