Solar Flares and Their Impact on Potential Gradient and Air-Earth Current Characteristics at High Mountain Stations[1])

By REINHOLD REITER[2])

Summary – Recordings of potential gradient and air-earth current in fair-weather conditions were made at high-elevation mountain stations; the latter were generally above the vertical-mixing layer and not disturbed by local sources. Both electrical quantities increased significantly from the day of appearance of a solar flare (or a maximum incidence of flares) till the fourth day after the event. Peak potential gradient and air-earth current exceed the 'normal levels' measured during quiet-sun conditions by 50–60% in terms of averages. This result was compared with sferics incidence data and daily geomagnetic coefficients grouped around the selected (flare) dates. Both of the latter quantities show time histories (for the days preceding and following the selected dates) closely correlated with the atmospheric-electrical histories of the same intervals. We may conclude from these results that the total potential between the ground and the upper atmosphere increases for several days after solar flares. The results obtained by previous studies on Mauna Loa confirm this inference. The cause of the phenomenon is presumed to be enhanced thunderstorm activity attendant on solar disturbances.

I. Results of previous studies

It has been noted in previous publications (R. REITER [1, 2][3]), that the daily means of the potential gradient E and the air-earth current i show marked, unbroken increases from the day of first appearance of a solar flare (or of a group of flares), until these quantities attain maxima on the fourth day of the existence of such chromospheric outbreaks. This relation, of course, can only be verified on days with 'fair-weather' atmospheric electricity. This latter term implies absence of precipitation and/or cloud at the station, no significant cloud cover, and no charge sources near the observation point that are strong enough to contribute to space charges. High-altitude mountain sites are, in marked contrast to stations on land in general, good observational platforms for recordings of fair-weather electricity (cf. REITER [2]). In order to render comparison of previous and recent results possible, the former are presented in Fig. 1. The data are derived from our measurements of atmospheric electricity and from the

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[3]) Numbers in brackets refer to References, page 267.

flare observations of solar observatories[4]), from January 1956 to December 1959. There was a solar-activity maximum in the said period (IGY); this made the selection of days on which the solar-flare situation was to be considered significant, and hence to be studied in relation to the atmospheric-electrical measurements, rather difficult. We have decided on using only days on which there have been at least three flares (as

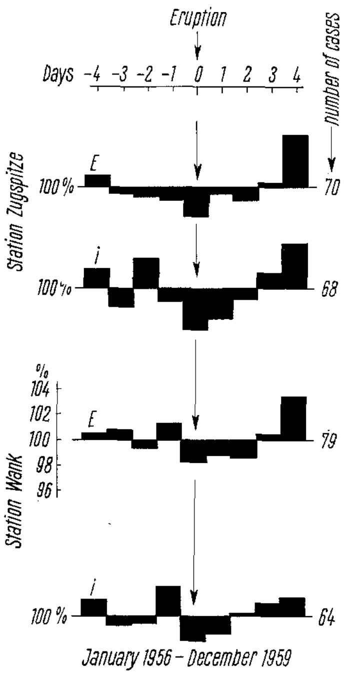

Figure 1
Earlier results. Hourly fair-weather means of potential gradient E and air-earth current i (both in %), grouped around days of flares, in four years of generally high solar activity (1956–1959)
From: R. Reiter [2]

gathered from observatory reports). In cases of enhanced flare activity on several consecutive days, the day was selected on which this activity reached its peak. The heliographic coordinates of the flares and their respective intensity were not taken into account.

It is seen from Fig. 1, that E and i on the Zugspitze, and also E on the Wank summit, attain their peak levels on the fourth day following the flare-activity peak; the averages for these quantities are exceeded by 3 to 4 %. This excess is rather modest and can only be conclusive because of the good statistical correlation between the two sequences of peaks.

This result is not quite satisfactory, because the conclusions drawn are not com-

[4]) Published in: 'Dekadenberichte der Arbeitsgemeinschaft Ionosphäre'.

pletely reliable, and also because selecting days in a period of considerable flare activity makes for unavoidable arbitrariness and a subsequent 'blurring' of possible real effects. In the above-mentioned observation period, there were hardly ever pronouncedly 'quiet' intervals on the sun's surface. Hence, it was felt that the observations and studies should be repeated in a period including the 'quiet sun' interval (IQSY). The results obtained in this second period will be summarized below.

The literature on the subject that appeared since the IGY will be reviewed first, beginning with two papers by L. KŘIVSKÝ [3, 4]. The author found, for 1947–49, a mean increase in rainfall from the flare inception day to the fourth day after, which had maximum mean rainfall. The same author also found that the incidence of sferics rises significantly after flares appear; this agrees with our own findings (R. REITER [5]). As is well known, the atmospheric electrical field is maintained by the sum total of thunderstorm activity in the entire terrestrial atmosphere by means of the 'global current'; therefore, we must, in pursuing this study, also consider the interrelations between solar flares and sferics or thunderstorm incidence levels.

We may mention the experience gathered on the effects of auroras on atmospheric electricity (D. W. SWIFT [6], H. DOLEZALEK [7] and D. E. OLSEN [8]). These seem to be mainly regionally important, as may be seen from OLSEN's paper: OLSEN discovered parallelism between the frequency of auroral pulsations and of oscillatory variations of potential gradient at the ground. These results indicate that relations between terrestrial and solar phenomena definitely exist.

Remarkably, measurements made in Hawaii on Mount Mauna Loa (cf. W. E. COBB [9]) in 3400 m a.s.l. fully corroborate our findings regarding the increase of potential gradient and air-earth current after appearance of solar flares: this is equally true of the amplitudes recorded and the time history encountered (maxima 2–4 days after flare inception). In view of the geographical and climatic conditions of the Alps and of Hawaii, there must be a real solar effect on terrestrial phenomena of a global scale, i.e., encompassing the surface of the entire Earth body.

II. Results of new comparative studies of solar flares and of the atmospheric-electrical parameters E *and* i

In Table 1, the days of the calendar selected as special dates for the studies – on grounds derived from the 'Dekadenberichte der Arbeitsgemeinschaft Ionosphäre' – are listed. By limiting the scope of the study to 'fair-weather situations, without disturbances in atmospheric electricity', the number of representative flare days have been reduced to a considerable extent. In Table 2, the numbers of flares on selected dates and on days before and after these dates are listed. The mean number of flares on the selected dates was 4–5, the corresponding number on the days leading up to or following these dates was approximately unity. In cases where flares persisted for several consecutive days, especially in 1966/67 as solar activity increased, we selected the date with the greatest number of flares.

Table 1

Selected Dates used in this study

1964	1965	1966	1967
Aug. 5. 25.	Mar. 3.	Jan. 14.	Jan. 15.
	Jun. 15. 18.	Apr. 4.	Feb. 7. 12.
	Sept. 5. 23.	May 19.	Mar. 1.
	Nov. 7.	Jul. 8. 22.	
		Aug. 11. 28. 31.	
		Sept. 20.	
		Nov. 7.	

Table 2

Mean number of flares on Selected Dates (S.D.) and on days before and after S.D.

Number of Days before S.D.					Selected Date	Number of Days after S.D.				
−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5
1.4	1.1	0.8	1.2	1.0	4.3	1.3	1.3	1.4	0.9	1.0

Fig. 2 shows the mean potential gradient, Fig. 3 the mean air-earth current on the days preceding and following flares, for the period May 1964 to March 1967, as observed on the Zugspitze peak station. (The mean daily levels of E and i during quiet-sun intervals before and after the selected date are defined as 100%). The mean quiet-sun daily level of E or i *before* the selected date is termed the 'Flankenwert' (i.e., 'side level') I, the corresponding level *after* the selected date the 'Flankenwert' II; these numbers are expressed in terms of the above-defined percentage scale. The areas surrounded by dotted lines in these figures represent the standard deviation σ_M ($\sigma_M = \sigma/\sqrt{n-1}$) of the arithmetic means. As shown by Figs. 2 and 3, E and i increase on the Zugspitze site during the active period, starting with minimum levels before the selected date and reaching a peak on the third day after the selected date; this peak is followed by an immediate decline to near-average levels. The scatter presented for side levels and maxima indicates statistical significance of the latter, as can be verified

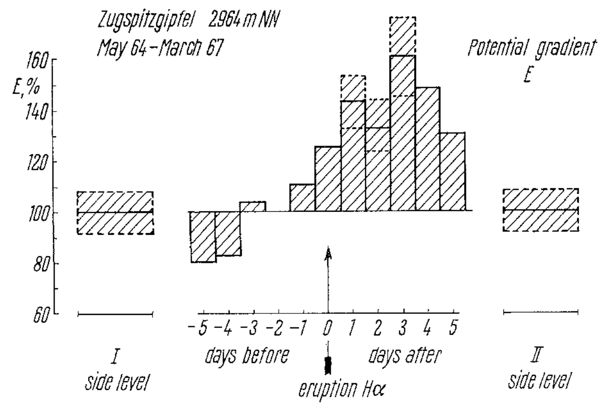

Figure 2
New data. Grouping of hourly means of E (in %) around flare days during three years of generally low solar activity levels (1964–1967), as measured at the Zugspitze station

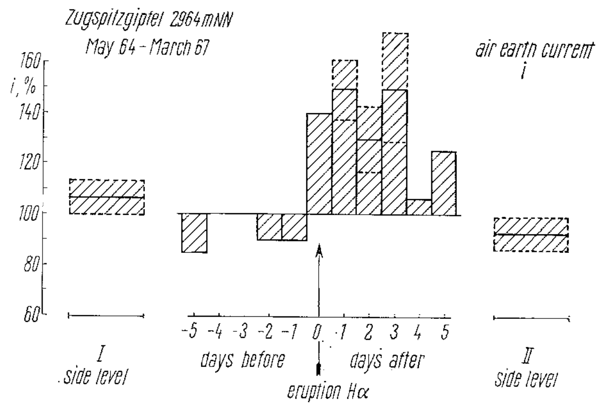

Figure 3
Air-earth current i, arranged as in Fig. 2

by inspection of the diagrams (Figs. 2 and 3). The excess of the maxima over the side levels (quiet-sun levels) is 60 % in E and 50 % in i. The parallelism of E and i on the Zugspitze (and also on the Wank, cf. below) indicates that solar flares produce, by a mechanism not clarified as yet, an increase of the total voltage between the atmosphere and the surface of the earth (of 'ionospheric potential', cf. H. W. KASEMIR [10]).

In Figs. 4 and 5, the corresponding data for the Wank station are presented. E and i are higher after than before the selected dates, and significantly higher than in intervals of solar quietness (side levels). The E maxima are usually found on the fourth day after the last selected date, with a mean excess of 25 % over the overall average; the i maxima usually occur on the third day after the last selected date, and their mean excess is 33 %. It is readily seen that there is qualitative agreement between the results furnished by the two mountain stations. It is not surprising that the solar flares produce lesser effects at the lower station than at the higher level (Zugspitze). The said effects on E and i are found to be the more marked, the less disturbances due to local aerosol and space-charge sources etc. affect the atmospheric-electrical recordings; this is equally true of 'disturb-

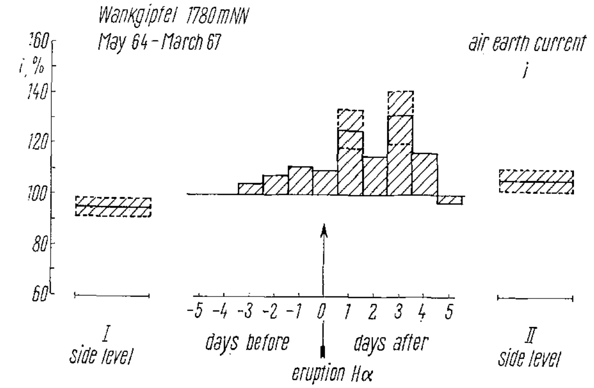

Figure 4
Potential gradient E at the Wank summit station; arranged as in Fig. 2

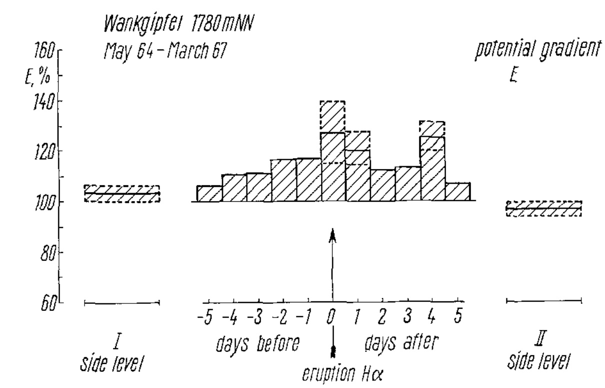

Figure 5
Air-earth current i at Wank; arranged as in Fig. 2

ances' effected by vertical mixing, so that the 'solar' E and i variations will show up best if the mountain station where they are recorded is not, apart from brief and inconsequential exceptions, affected by eddy diffusion. – The solar rise of E and i becomes steadily smaller with decreasing height and is concealed by local effects on the ground or at sea level.

As the said solar effects on E and i can only be interpreted in terms of planetary-scale atmospheric-electrical processes – which conclusion is strongly confirmed by the strikingly similar results from Mauna Loa – it may be inferred that mountain stations of at least 2000m of elevation a.s.l. are particularly useful for research on the global aspects of atmospheric electricity.

We may mention the result of a comparison of previous findings (Fig. 1) with the new data (Fig. 2–5). We are not surprised at differences showing up in the fine detail, in spite of an agreement with respect to basic features (i.e., the increase of E and i from the flare inception day up to a maximum on the fourth day after). The reason for the new study furnishing better results and, above all, much more marked solar variations in E and i, is that the period of solar quietness made selection of dates with considerably greater flare activity than that of the preceding or following days possible. There was also the added advantage of quiet-sun periods that served usefully as 'bases' absent in the earlier studies. Solar events were thus followed much more closely in the presence – or, more precisely, the temporal vicinity – of a quiet background: this background was not available during the years of near-uninterrupted and erratically variable solar activity.

III. Comparative study of daily geomagnetic coefficients

The geomagnetic coefficients (*C9*) for the days preceding and following the selected dates, as quoted in Table 1, have been used to investigate the effects of flares on terrestrial magnetism.[5] The result is seen in Fig. 6: a situation quite similar to the one found in E and i is easily recognized from this diagram. The peak of geomagnetic activity occurs, on the average, four days after the appearance of a flare. However, the *C9* numbers vary considerably from day to day, which is reflected in a scatter obviating confirmation of statistical significance of the mean variation in the flare period (taken to include the before and after phases), at least for the data thus far

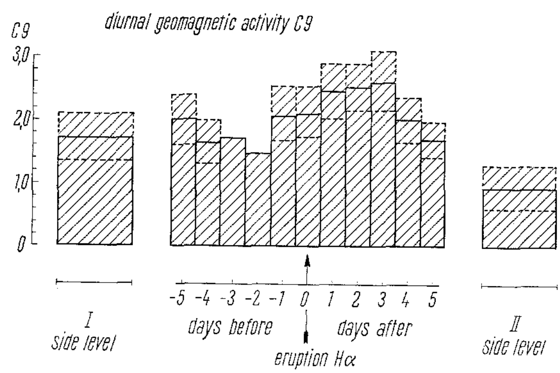

Figure 6
Daily geomagnetic coefficients *C9*, grouped around the selected days as in Fig. 2–5

[5]) We wish to express our thanks to the Geophysical Institute of the Göttingen University for giving us the data.

available. The result of this independent study does, however, suggest that the increase in E and i – like that in *C9* – is caused by slow particles originating from solar disturbances.

IV. Selected correlation coefficients

Table 3 is a list of selected correlation coefficients, based on the time history of the above-mentioned parameters around the selected dates. The highest correlation coefficients are those derived from the atmospheric-electrical data of the Zugspitze

Table 3

Correlations

Parameters	Correlation coefficient, r
E Zugspitze / i Zugspitze	*0.75*
E Wankgipfel/ i Wankgipfel	0.53
E Zugspitze / E Wankgipfel	0.38
i Wankgipfel/ i Zugspitze	0.58
C9/ E Zugspitze	*0.62*
C9/ i Zugspitze	*0.66*
C9/ E Wankgipfel	0.40
C9/ i Wankgipfel	*0.76*

station; however, there is also a surprisingly tight correlation of *C9* and i measured at the Wank summit site. We may conclude from this added statistical evidence of conformity of E- and i-histories at higher elevations, that an increase of potential between atmosphere and earth is indeed effected by solar flares.

V. Time history of sferics incidence before, on and after selected days

At the Garmisch (valley) station of our Institute, sferics are also recorded and counted. Recordings are made by means of a wideband receiver (10–50 kc) at a relatively low sensitivity level; the receiving range for the sferics is thus set at 300–500 km. Table 4 results from arranging the daily means of sferics incidence (in pulses

Table 4

Variation of sferics incidence (in terms of daily means of hourly counts) *before, on and after flare days* (Selected Dates, Table 1)

	−5	−4	−3	−2	−1	0 Sel. Date	+1	+2	+3	+4	+5
Pulses/hr (mean for day)	40.0	30.3	40.0	52.5	34.0	39.9	27.7	35.6	46.6	62.7	58.0
σ_M	14.7	10.2	7.4	10.2	6.3	15.4	7.8	8.5	11.7	17.7	13.4

per hour) around the selected flare dates. It may be noted that, on the average, the highest incidence occurs on the fourth day after appearance of the flare (more exactly: after the selected date). This agrees well with previous findings (R. REITER [5]). The sferics count on and near the selected date is subject to the same type of temporal variation as the atmospheric-electricity parameters E and i. The scattering of the data does not permit verification of statistical significance, as the body of observations is relatively small. However, our results enable us to assume, by way of hypothesis, that there is a stimulation of thunderstorm activity to account for the increase of the air-earth potential which, as we have found from the evidence described above, follows appearance of solar flares.

Only further studies, carefully planned and executed with the objective of testing the above hypothesis, will lead to a final clarification of this issue.

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