SOFT SOLAR X-RAYS AND SOLAR ACTIVITY

V: *Relation of the Course of Soft X-Ray Fluctuations to the Course of Solar Activity, 9 March, 1967–18 May, 1968*

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Abstract. Soft solar X-rays in the wavelength interval 8–12 Å were observed from OSO III. The totality of the observations that were made between 9 March, 1967, and 18 May, 1968, is summarized graphically and compared to the course of solar activity as observed at other wavelengths, with particular emphasis upon visible activity.

1. Introduction

Solar soft X-rays in the wavelength band 8–12 Å were observed with an ion chamber photometer on board the third Orbiting Solar Observatory (Teske, 1969; Thomas, 1970). The measurements thus acquired form a nearly complete record of high quality which covers the time period from early 1967 through mid-1968. Because the soft X-rays are very sensitive to the general level of solar activity, our record vividly portrays changing activity on the sun over a fifteen-month period. There was no evidence of a significant drift of the energy scale of the Michigan ion chamber photometer during the months discussed here. An onboard calibration indicated a maximum drift of $\pm 1\%$, while some analyses and comparisons of the data suggest that any possible drift was less than 5%–10%.

In an attempt to survey the course of solar activity as depicted by the Sun's soft X-radiation, we have prepared the data in graphical form on a highly compressed time-scale. The presentation of the material in this way reveals many quantitative and qualitative aspects of the relationship of solar activity and fluctuations in the soft X-ray flux.

We present the material here together with a brief discussion of some salient observations on the relationship of the X-ray fluctuations to the optical and radio sun. In Section 2 the general course of solar activity during 1967 and 1968 is reviewed. In Section 3 we describe the preparation of the X-ray graphs and discuss some of their information content.

2. Review of Solar Activity, 1967–1968

In Figure 1 we have summarized solar activity from mid-1966 through early 1969.

There was a continuing slow increase in monthly mean sunspot number and monthly mean 2800 MHz flux during the interval covered by the X-ray data presented here (9 March, 1967–18 May, 1968). During that time there was a range of fluctuation of

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about 50% in the monthly mean sunspot number and of about 30% in the monthly mean 2800 MHz flux.

The number per month of flares of importance 1 or greater is also shown in Figure 1. This number has been obtained at the McMath-Hulbert Observatory from the *Quarterly Bulletin on Solar Activity* on the basis of criteria which reject seemingly spurious flare reports. The curious and severe drop in the number of flares in early and mid-1968 is apparently not due to poor weather in the northern hemisphere but is almost certainly real.

We have formed a quantity, the 'flare rate', which is the number of flares (imp$\geqslant$1) per month divided by the monthly mean sunspot number. This quantity shows that the number of flares produced per unit spot number was at its highest during 1967 and the first two months of 1968 (Figure 1).

Lastly we have included in the Figure an index of the numbers of active regions that were strong emitters at 9.1 cm wavelength, and the numbers of regions which were accompanied by spot groups of area in excess of 1000 millionths of a hemisphere. To represent the former quantity we have used for each month the sum of the number of days each individual active center was brighter than 25 flux units at 9.1 cm.

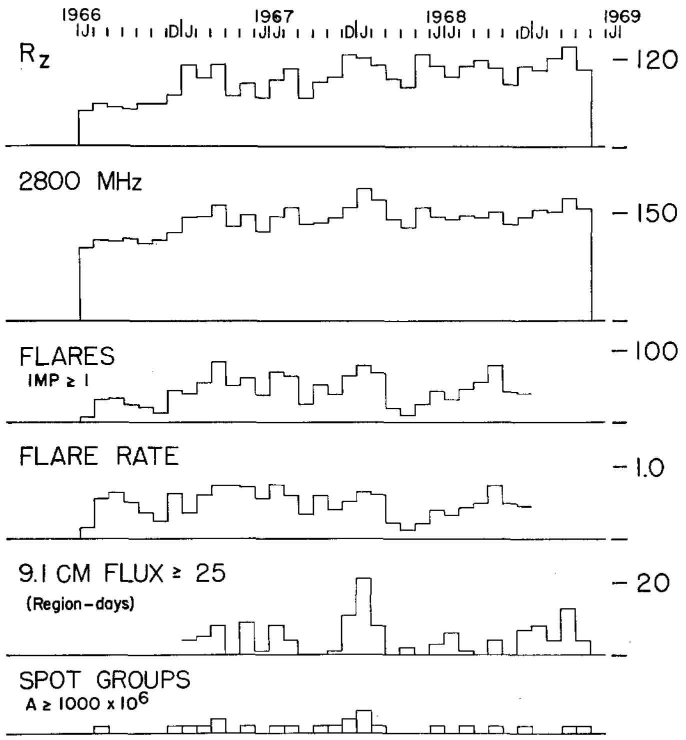

Fig. 1. Graphical summary of the general level of solar activity from mid-1966 through mid-1969, on a monthly basis. The 'flare rate' is the quotient of number of confirmed flares imp$\geqslant$1 by the monthly mean sunspot number.

Additionally, during 1967 and 1968 numerous proton and electron events in space, and terrestrial Polar Cap Absorption events, took place.

These data demonstrate that the interval covered by our X-ray observations included periods of both high and low activity on the Sun, and that it was an advantageous period to have been making such observations.

There would be no advantage to be gained by contrasting these data against similar material from other solar cycles. As a means of comparing X-ray events from other cycles we have, however, considered the SID reports made by the British Broadcasting Corporation from a station it maintains near Slough, England. These reports give the number of days per year on which SID phenomena were seen. It is our belief that the Slough data are self-consistent from 1944 to the present.

The yearly mean sunspot number is compared in Figure 2 with the percentage of days during that year that Slough recorded ionospheric disturbances, for solar cycles 18, 19 and the beginning of 20. At the bottom of the Figure is the quotient of the two quantities. The data for the current solar cycle have a different trend with time as compared with the two previous cycles, the years 1967 and 1968 appearing as intervals when the Sun was relatively unable to produce SID phenomena.

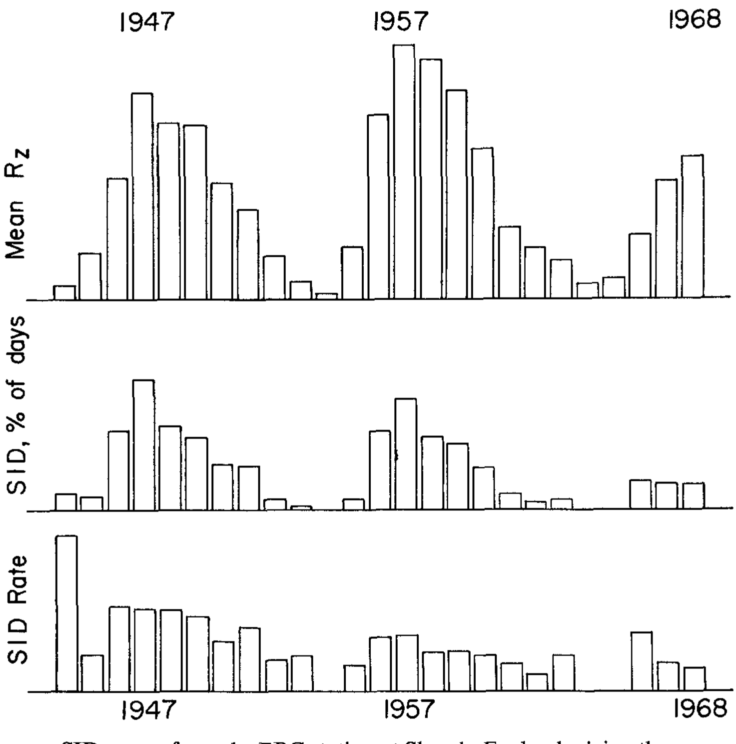

Fig. 2. Data on SID events from the BBC station at Slough, England, giving the percentage of days during each year on which SID phenomena were detected (middle) and that percentage divided by the yearly meansunspot number (bottom).

The Slough data for the current cycle may at least partially be explained if the solar rate of production of X-ray flares is below the rate of production during previous cycles. But, whatever interpretation we may place upon these SID data, Figure 2 cautions us about being too bold in extending conclusions about our X-ray observations to all flares in all solar cycles.

3. Summary Graphs of the Solar Soft X-Ray Flux

Summaries of the OSO III soft X-ray data, Figures 3a through 3i, were prepared by inspecting our original large-scale computer-drawn plots of flux *vs* time. These large-scale plots had been broken up into time-segments by the intervention of satellite night, by interruptions caused by play-back of the satellite tape-recorders and by intervals of particle interference. From each segment of data we read the maximum and minimum fluxes and recorded the times of beginning and end. The totality of this information was punched on IBM cards and then plotted by a computer. The maximum and minimum fluxes for each data interval were graphed on a logarithmic energy scale as short horizontal lines of length proportional to the length of the time-segment. These were then joined by a vertical line to indicate their companionship. Segments of data shorter than eight minutes were not plotted. Thus, Figures 3a–i appear to consist of vertical lines whose tops and bottoms represent the maximum and minimum X-ray flux during the depicted time-interval.

Time on the graphs is given in terms of Bartels' days.

Many flares are not on the graphs because OSO III missed them altogether. Other great flares with high-amplitude X-ray bursts do not look great because the X-ray maximum was missed and some events are partial or absent because our data were of poor quality and not included in the data summaries. A few errors that crept in even after proof-reading are apparent (e.g. 2 January, 1968; 5 January, 1968; 1 March, 1968). Our detector saturated at a flux level near 0.12 erg cm^{-2} s^{-1}. X-ray bursts of peak flux above this value (e.g. 23 May, 1967, 29/30 October, 1967) are not designated on the graphs but can easily be discerned.

The lower envelope of the data portrays fairly well the variations of the Sun's X-ray background, but not necessarily in all instances. Because of a tendency for the soft X-rays to remain enhanced following flares, the apparent background may be spuriously raised to a slight extent during periods of rapid flaring on the Sun. Although this effect is of slight importance when the background is already high, it is of relatively greater importance when the X-ray background is low. However, periods of rapid flaring usually occur during intervals of high solar activity when the background X-ray flux is already high.

Sometimes this effect has caused disappointment. McCabe (1970) has reported excellent optical observations of a disappearing filament and associated chromospheric brightenings on 28/29 April, 1967. At this time our data show an appreciable enhancement of the X-ray background. However, the rate of flaring at the time was such that we cannot unambiguously ascribe the observed X-ray background rise to X-ray

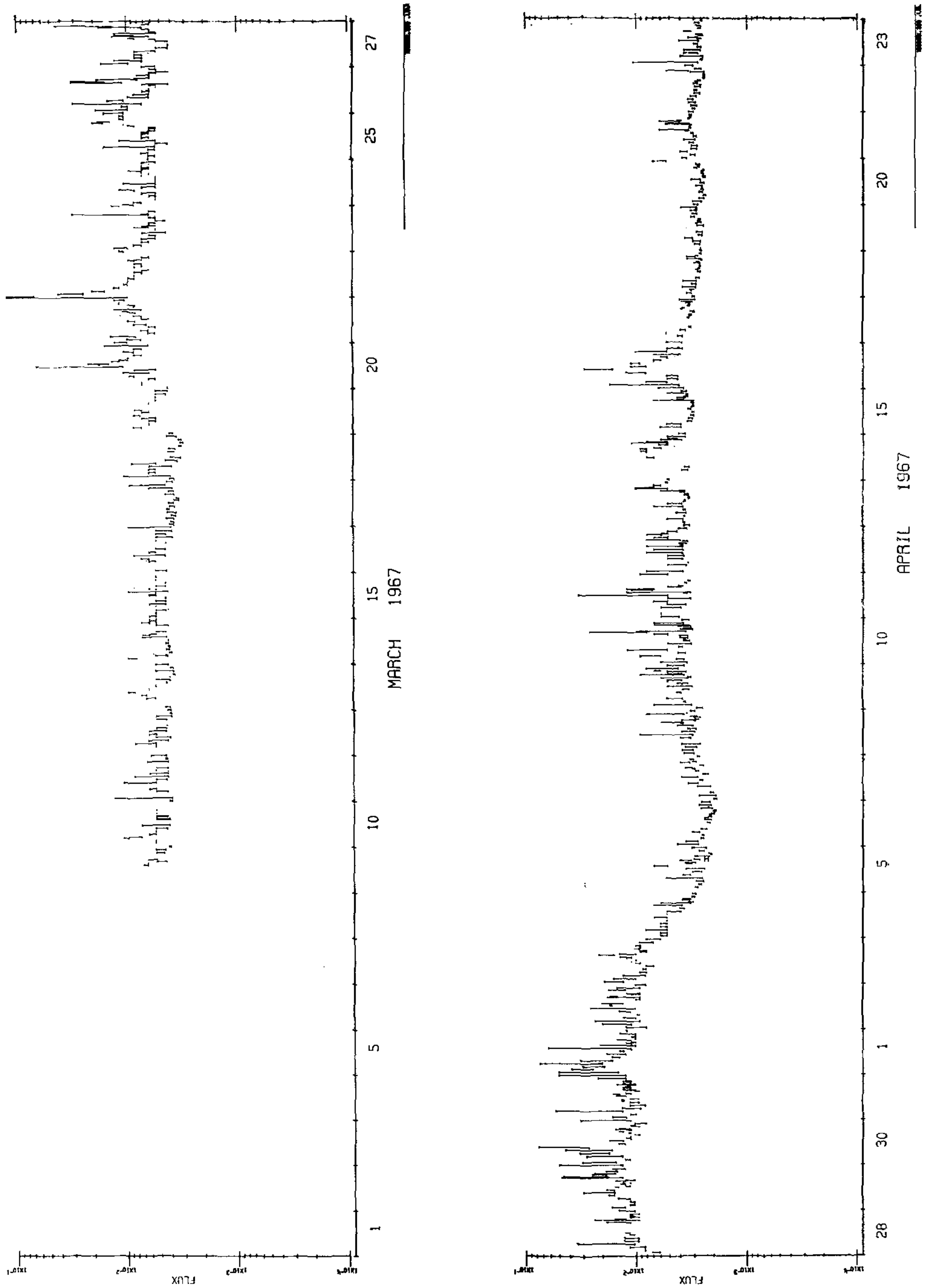
MARCH 1967
APRIL 1967
FLUX
FLUX
1
5
10
15
20
25
27
28
30
1
5
10
15
20
23

Fig. 3a.

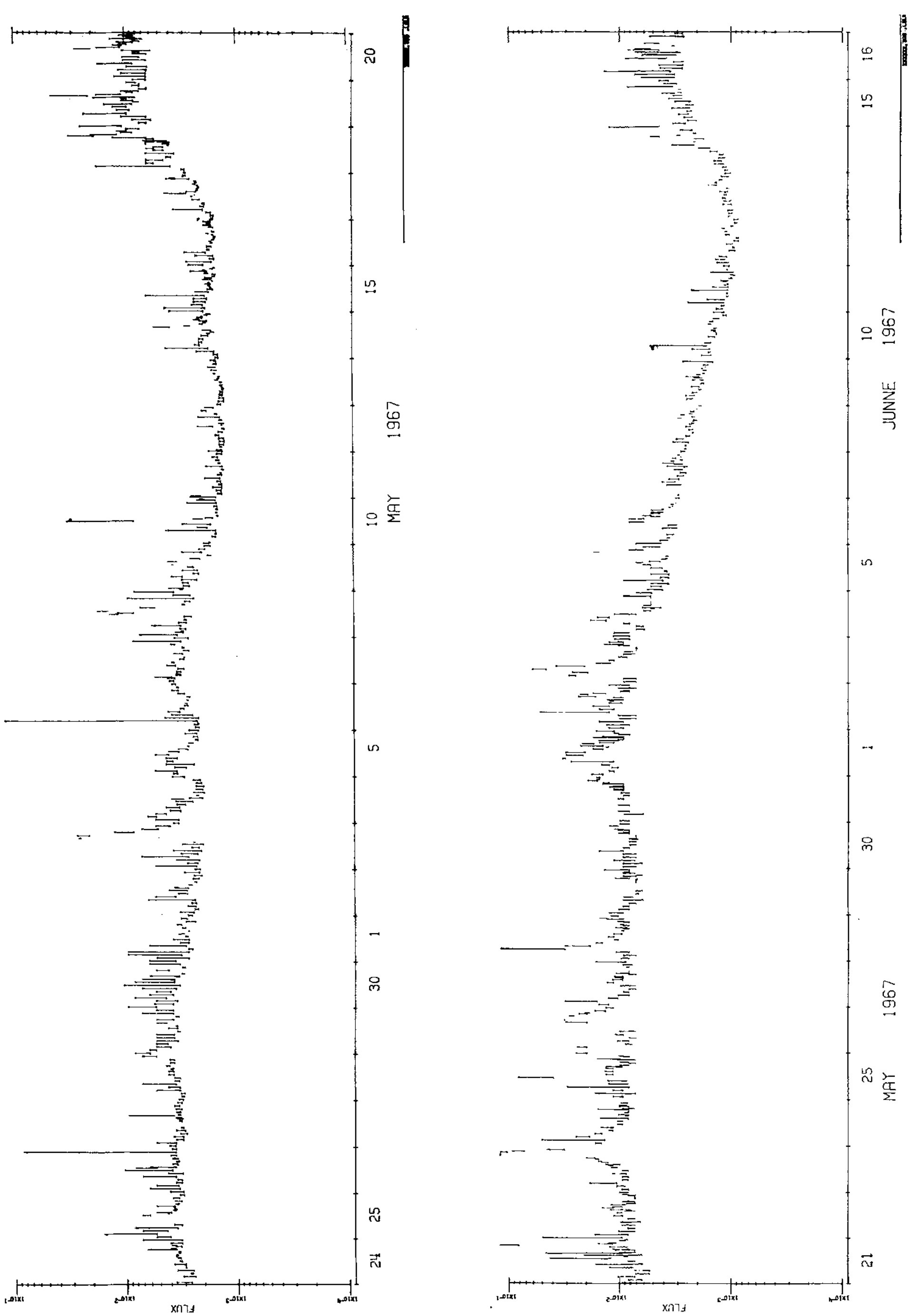
FLUX
MAY 1967
24
25
30
1
5
10
15
20
FLUX
MAY 1967
JUNNE 1967
21
25
30
1
5
10
15
16

Fig. 3b.

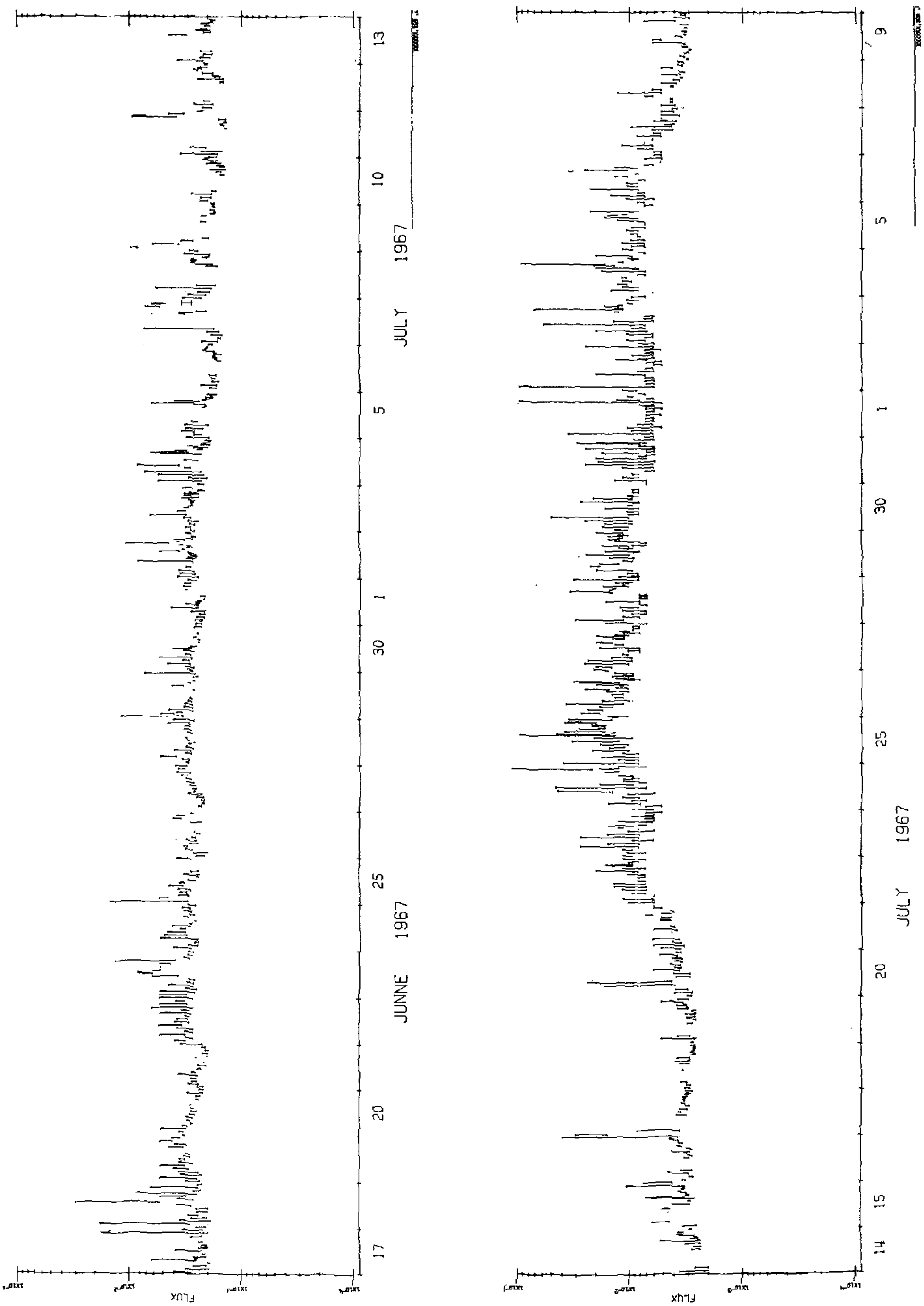

Fig. 3c.

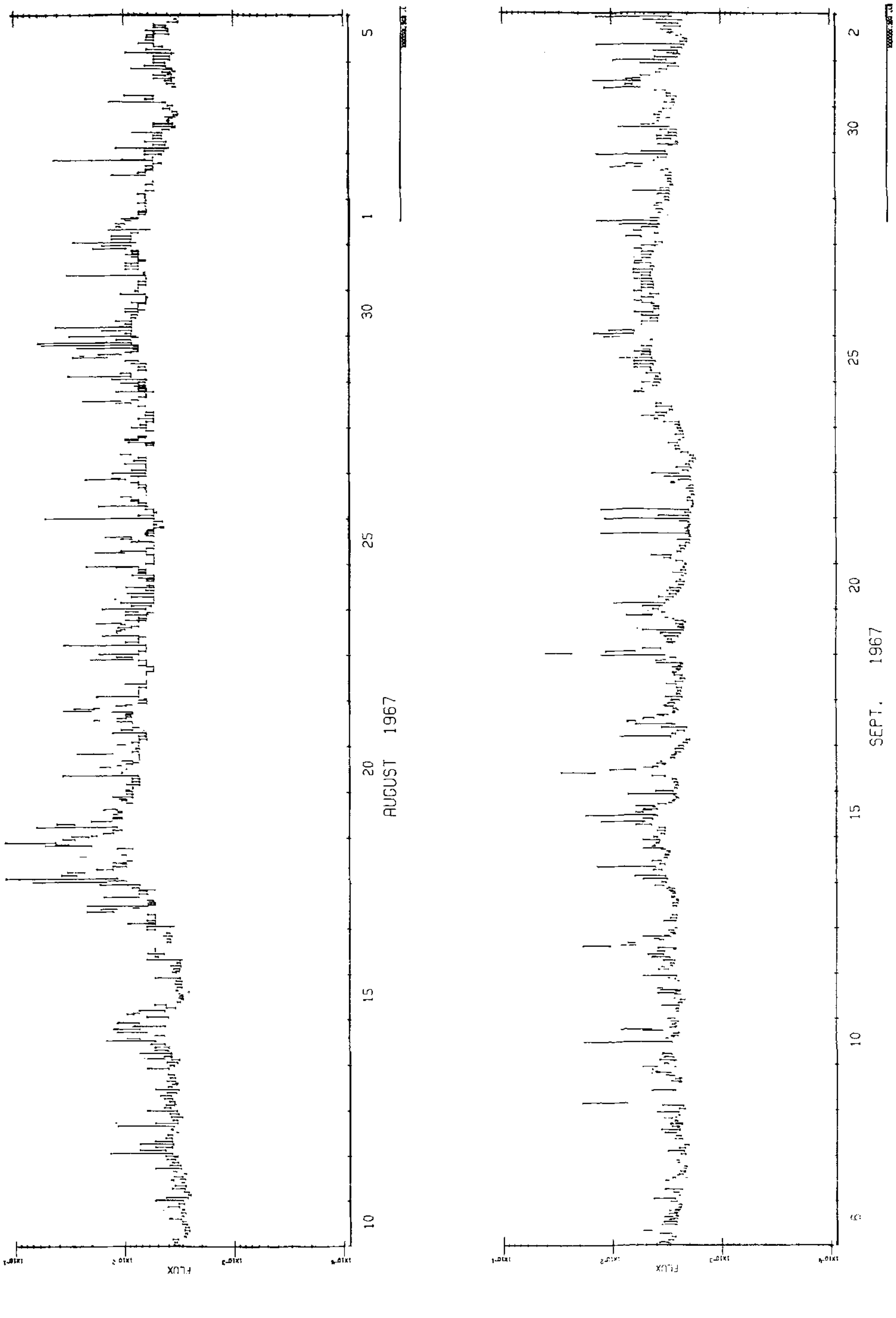

Fig. 3d.

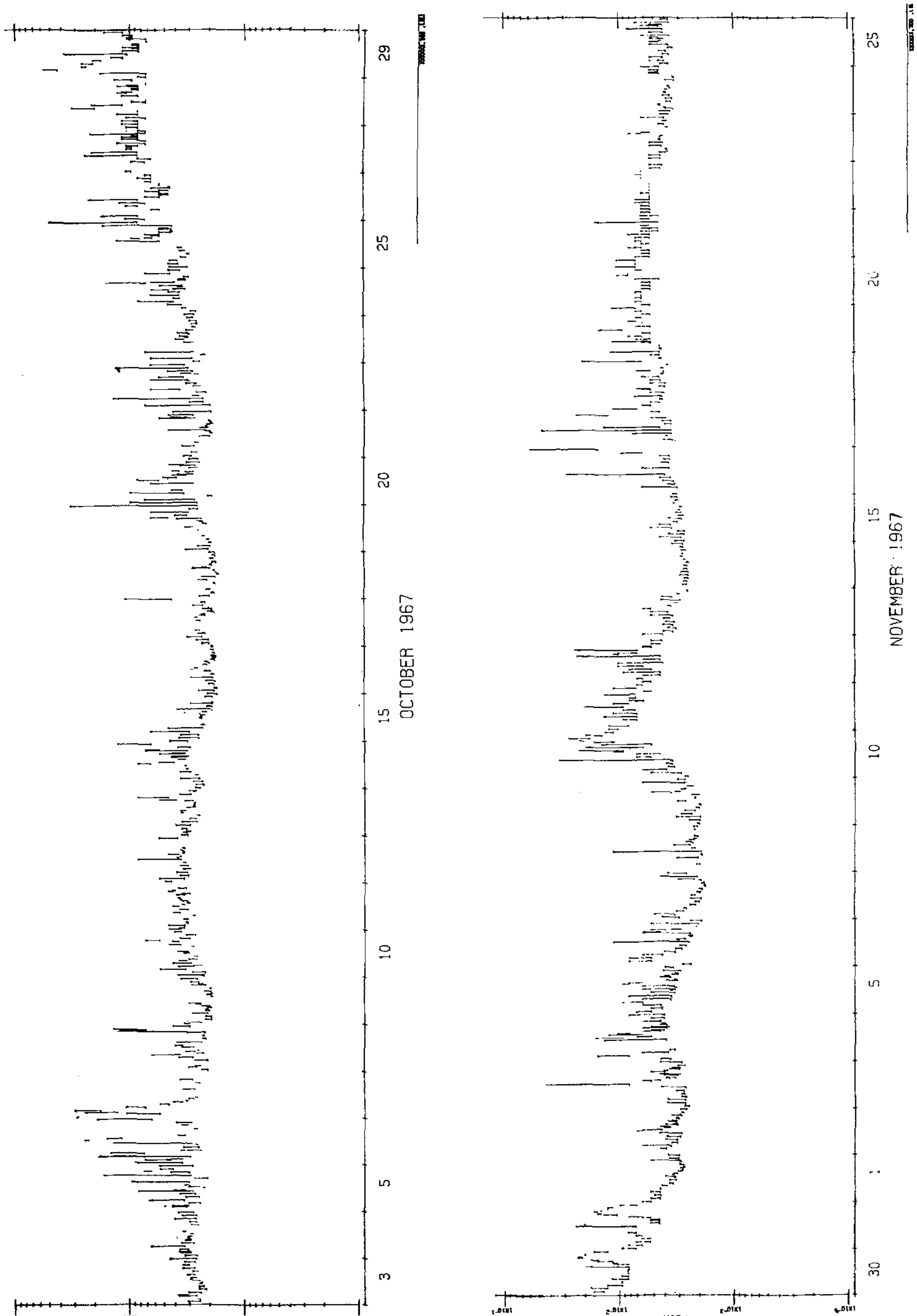

Fig. 3e.

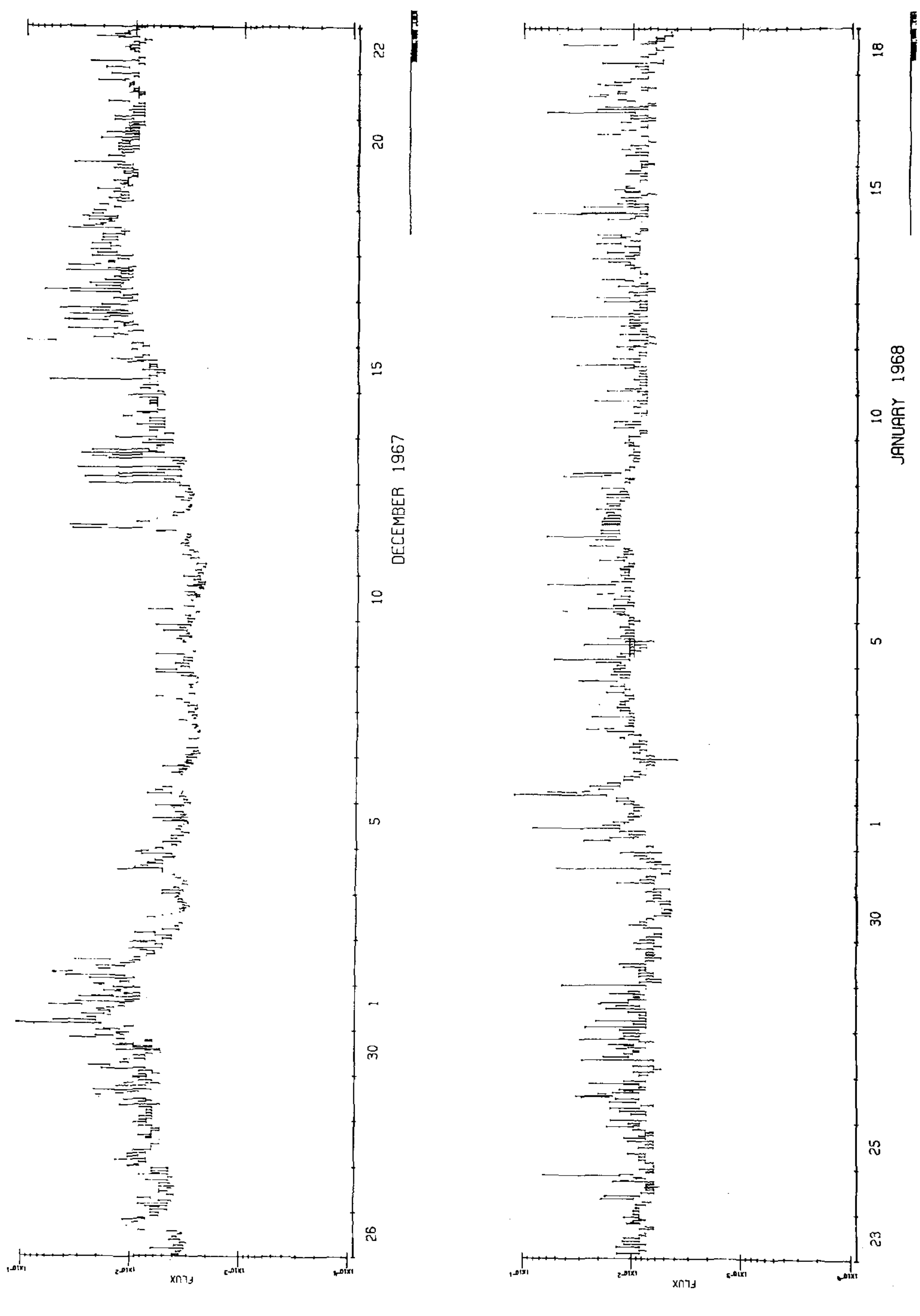

Fig. 3f.

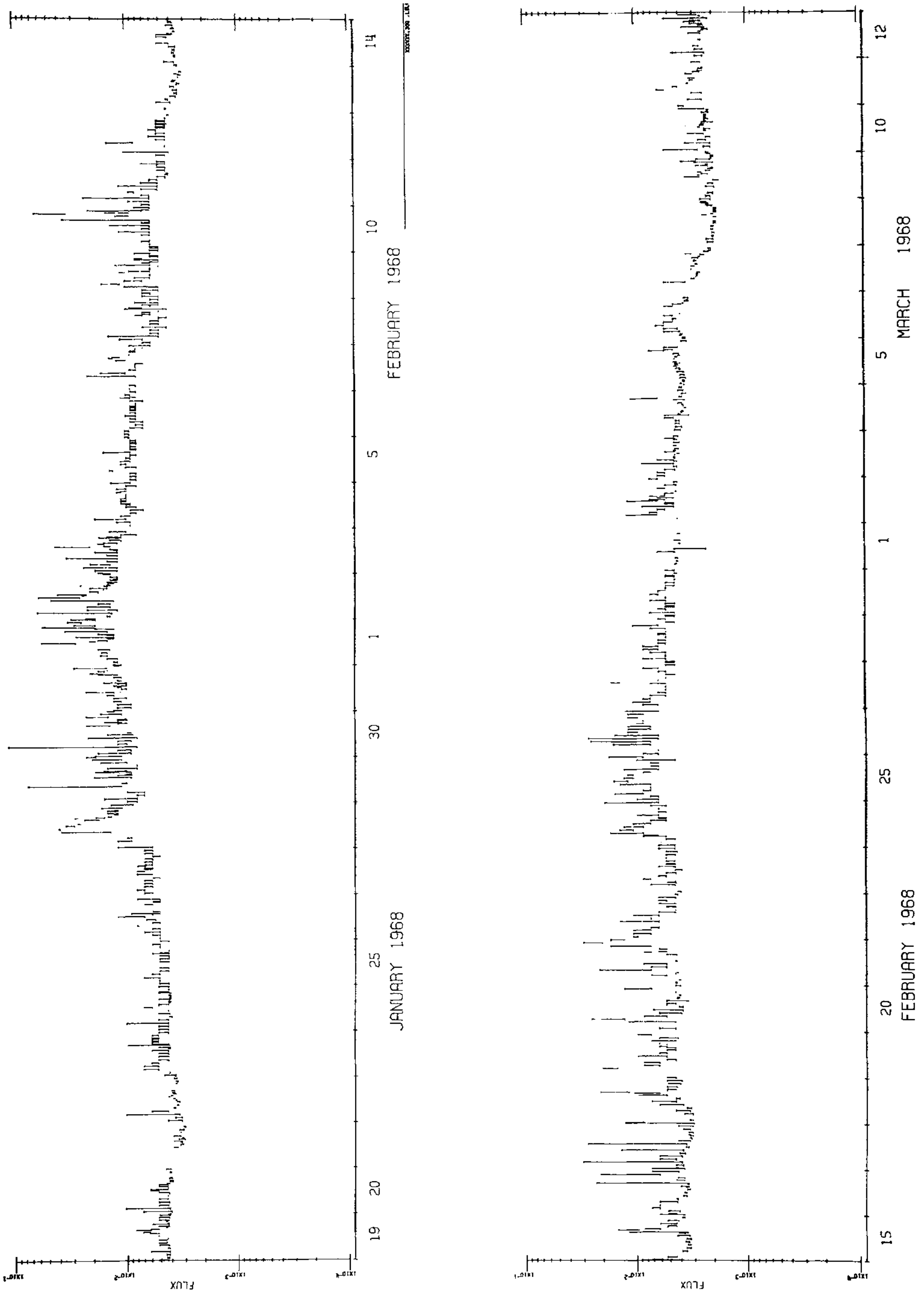
JANUARY 1968
FEBRUARY 1968
MARCH 1968
FLUX
19
20
25
30
1
5
10
14
15
20
25
1
5
10
12

Fig. 3g.

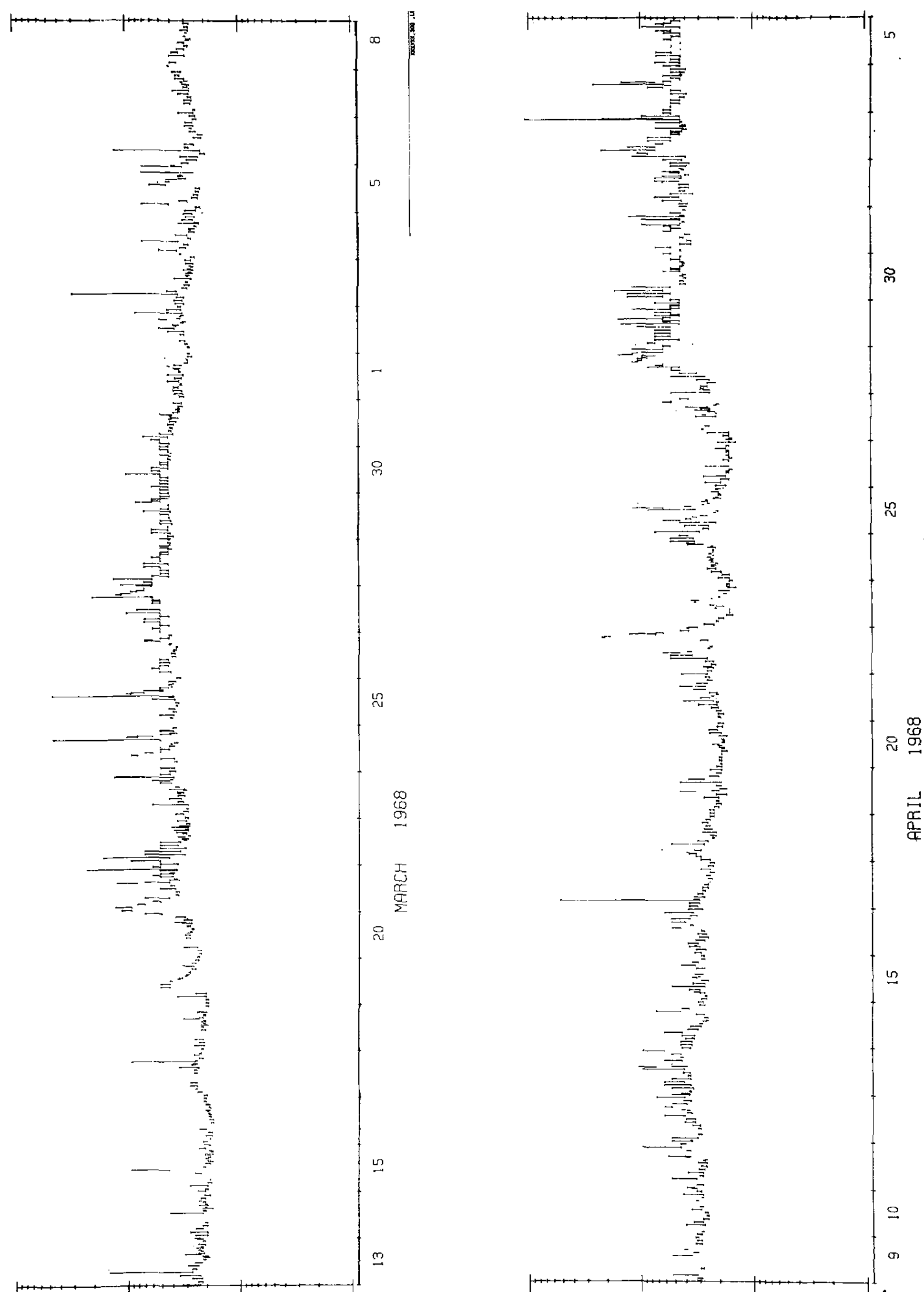
FLUX
13
15
20
25
30
1
5
8
MARCH 1968
FLUX
9
10
15
20
25
30
5
APRIL 1968

Fig. 3h.

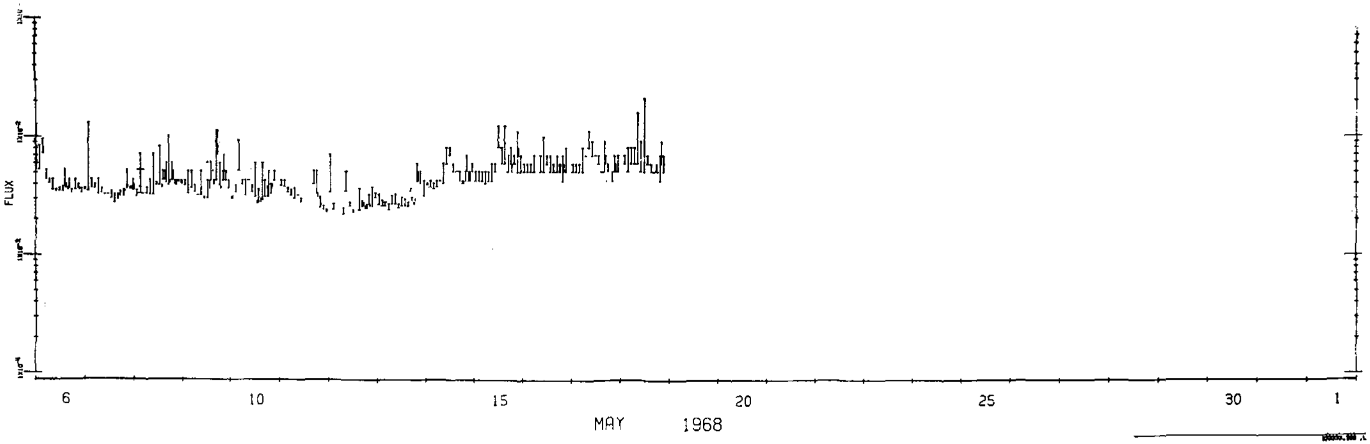

Fig. 3i.

Fig. 3a–i. Each vertical line represents an interval of data-taking. The maximum soft X-ray flux during the interval corresponds to the top of the line, the minimum to the bottom of the line. The flux scale is logarithmic; the time-scale is in terms of 'Bartels Days'.

emission associated with the *disparition*, since our data have no angular resolution on the Sun and we must depend upon time-coincidence for identification.

We have organized the following discussion of the graphical summaries to bring into view first of all the X-ray variations which take place with the development and appearance of active regions, variations that take place on a time-scale of a day or so. Next, events on a time-scale of many hours will be considered. These are associated with flares and with other transient activity. The shorter time-scale events, X-ray bursts which occur at the time of Hα flares, have already been discussed in an earlier paper (Thomas and Teske, 1971). None of the discussion here is intended to be exhaustive – the information content of the material is too great. This material has been deposited at the ESSA World Data Center A on punched cards. It is also available from the author on punched cards.

3.1. Events with a time-scale of a day or more

3.1.1. *Limb Passages of Active Centers*

The east limb appearance of active regions is signalled by a rise in the X-ray background. The rise is not abrupt, but depends upon the fractional area of the plage that is revealed to the earth by the rotation of the Sun. For example, the east limb arrival of McMath Plage 8818, an extensive, flare-rich region, on 17 and 18 May, 1967, was signalled by an increase in the X-rays that covered a two day period. Similarly the prolifically-flaring plages 8905 and 8907 appeared on 20, 21 and 22 July, 1967, with an accompanying rise of soft X-ray background.

At times of relatively low activity when the X-ray flux is weak, the east limb appearance of quiescent regions may be discerned as a small rise in background, such as that on 27 June, 1967, when plage 8875 came into view.

The west limb departure of active regions is visible as a decline in the X-rays. We cite the departure of flare-productive regions 8739 and 8740 on 3 and 4 April, 1967, and of 8942 and 8949 on 1 and 2 September, 1967, and the X-ray declines accompanying limb passage of quiescent plages 9273 on 31 March, 1968 and 9279 on 1 April, 1968.

Usually the marked rise and decline of soft X-ray background coincides in time with limb passage of the visible plage within about half a day. Thus it appears that the bulk of soft X-rays is generated at solar atmospheric altitudes near 10^4 km or below.

Evidence for intense X-ray structures at higher altitudes is afforded by the west limb passage of plage 9034 on 30 October, 1967, and by both limb passages of plage 9184 in late January and early February, 1968. The decline of soft X-rays from plage 9034 continued for at least 24 h after the last vestiges of the calcium plage had set behind the limb, attesting that significant parts of the X-ray source volume extended to at least 2×10^4 km and perhaps to 5×10^4 km, depending upon where it lay over the plage. Similarly, an intense X-ray source may have extended to 1.5×10^4 km or higher above plage 9184.

These observations are not in disaccord with the remarkable X-ray photographs that have been secured on rocket flights (e.g. VanSpeybrock *et al.*, 1970) and which show extensive X-ray emitting structures rising to great coronal altitudes. Our data indicate only that the bulk of the soft X-rays is produced at relatively lower levels. They cannot be used at the present time to describe the height distribution of soft X-ray sources above active centers.

A high correlation between the daily solar 2800 MHz flux and the daily X-ray background has been found by many investigators (e.g. Wende, 1969). Our data yield a correlation coefficient of 0.89. At times when the X-ray background is dominated by one or at most two active centers we have found a discernable difference in the variation of these two fluxes as the region(s) transit the disk. The maximum 2800 MHz flux tends to peak near CMP, while the X-ray background tends to have a flat time-history from limb to limb, suggesting that the background X-rays arise in a medium that is optically thin.

3.1.2. *Conditions Affecting the X-Ray Background Level*

In the soft X-ray summary graphs, intervals of very high background accompany the appearance of active centers with three characteristics: (1) those regions that are highly flare-productive, such as between 20 July and 6 August, 1967; (2) newly-developing regions such as on and after 28 April, 1968 (plage 9358), and resurgence of activity in older regions such as on and after 28 March, 1967 (plage 8739), and on and after 28 November, 1967 (plage 9091); (3) regions in which great sunspots are found, such as plage 9184 in late January and early February, 1968. This latter plage region was not very productive of major flares, although many flares of imp$\leqslant$1 occurred in it.

Neupert (1967) observed that the highest UV fluxes from an active center are emitted during its youth, and constructed a model in which the permanent coronal condensation is hottest and most dense in its early history, as defined by the development of the associated spot group. Our data (point 2 above) indicate that the changes which occur in the corona over a developing region are at times relatively abrupt, taking place on a time scale on the order of a day. Marked rises of the X-ray background are found with those developing regions that quickly become strongly flare-active. It is as though the disposition to great flare activity is closely linked with the (often) relatively rapid establishment of an extensive, dense and hot permanent coronal condensation. The bulk of the X-ray flux is emitted from the lower extremities of the condensation.

Closely allied is the area and magnetic configuration of the sunspots in the region. It is now established (Covington and Harvey, 1960) that a component of the Sun's 2800 MHz radiation is associated with plage area, and another component with sunspot area. The Michigan soft X-ray fluxes correlate better with plage area than with an index of the volumes of coronal condensations (Thomas, 1970), yet the correlation with plage area is low (0.7). Our data, especially the high X-ray background with plage 9184 and its great associated spot, suggest an X-ray component linked to spot area as in the case of the cm-λ background. This should be searched for with angularly-resolving instruments in current and future experiments.

It is not possible to relate the observed X-ray fluxes during the disk passage of plage 9184 to changes in the spot area and magnetic configuration unambiguously. Although this region dominated the X-rays during its apparition, the peak of the background on 2 February, 1968, contains a contribution by the development of plage 9203 and by three other plages at the east limb. The greatest magnetic complexity in 9184 occurred on 31 January and the spots reached maximum area on 1 February. The region's 9.1 cm flux was highest on 30 January.

Although the totality of our information strongly indicates that the magnetic complexity of a spot group is also involved in the level of a region's soft X-ray background, the evidence for the role of δ configurations is negative. Of the dates on which spot groups were observed to develop the δ polarity configuration only one, 15 December, 1967, saw a clearly discernable rise in the X-ray background. On that data a δ spot appeared in plage 9115. We have attributed the rise on that date to the east limb passage of plage 9118, a flare-active region, and to the heightening of flaring in a second plage, 9108. Thus the formation of the δ polarity configuration does not appear to produce any marked change in the soft X-ray emission of the associated active center, and we infer that no marked change occurs in the constitution of the permanent coronal condensation.

In this connection we call attention to the measured decrease of magnetic field gradients in the great May, 1967, region (Malville and Tandberg-Hanssen, 1969). Magnetographic observations by them showed a two-fold decrease in field gradients in plage 8818 during 22 and 23 May, 1967, which was not reflected in the soft X-ray background, as judged from our records.

3.1.3. *X-Rays Accompanying the Growth or Resurgence of Active Centers*

Often the development of plages and the onset or resurgence of flaring in them is clearly marked by the soft X-ray flux. A striking example is the rise in X-ray background that accompanied changes in plages 8739 and 8740 in March, 1967. Between early 27 March and late 28 March the X-ray background more than doubled. Plage 8740 had been flare-rich prior to these times, and had produced a PCA flare while still far in the Sun's eastern hemisphere (Castelli, 1969). The leading spot group of this region became dominant after 27 March, the following spot group declining. SWF productivity and the general amplitude of flare soft X-ray bursts increased after the 27th, and the region continued its high rate of flaring until west limb passage on 4 April. Plage 8739 was quiescent until after its CMP on 26 March. It underwent rapid growth and brightening on 27 March, with the formation of a bipolar spot group on that date. Flaring began on the 28th and the flare rate continued moderately high until west limb passage on 3 April. We attribute the major portion of the soft X-ray rise on 27 and 28 March to the development of plage 8739. The rapid rise of the general level of activity in that region was accompanied by a rapid increase in its soft X-ray flux.

A second example of the resurgence of a region is plage 9034, which transited the Sun's disk in late October, 1967. Having produced some flares of imp$\leqslant$1 prior to 25 October, the spot group on that date began a further development, the plage brightened and the pace of flaring increased, culminating in a flare of imp 2 observed at the west limb late on 29 October. During the interval 25–27 October, the X-ray background increased from $\sim$0.003 erg cm^{-2} s^{-1} to $\sim$0.008 erg cm^{-2} s^{-1}.

Plage 9091 developed on the disk on 24 November, 1967, a spot group appearing in it on the same date; the spot was classified as βp until 1 December, when it was classified as αp. This region remained small and relatively inactive until 27 November when the spot group became more extensive and the plage grew in area and brightness. By 29 November the rate of flaring in the region was heightening and it continued high as long as the plage remained visible. These changes are reflected in the slow rise of the soft X-ray background and in the increasing number of flare spikes visible in the data.

Often the level of X-ray rise is closely related to the level of activity which is to take place. Significant X-ray enhancements accompanying regions which became flare-productive have been pointed out above. Compare the X-ray rise associated with the resurgence of plage 9250 on 5 March, 1968. That region was not at all flare-productive, and the X-ray rise associated with its resurgence was small. Other examples exist in the data to demonstrate the generality of the relationship. However, sometimes the resurgence of flare-productive regions does not produce a marked soft X-ray enhancement.

An active center in which no clear rise in X-ray background accompanied heightened flare activity was plage 9004 in early October, 1967. The soft X-ray summary record shows the increasing amplitude and frequency of flare spikes after a resurgence of this previously quiescent region on 4 October which was accompanied by a growth of the spot group, but the X-ray background was essentially unaffected. On 5 October the spot group had developed the δ configuration. The lack of response of the X-ray background was not because the background contributed by other regions was already too high, as a comparison with the late November, 1967, region shows.

Similarly, the brightening and resurgence of flaring in plage 9128 on 26 December, 1967, following the formation of a very large bipolar spot on Christmas day, was not reflected in the X-rays. Still a third example is the development of flaring in plage 8963 beginning on 9 September, 1967. Both of these regions and the one discussed in the previous paragraph were productive of electron events observed in space (Lin, 1970a). However, counterexamples of enhancement of the X-ray background in developing regions which were also electron-productive are plages 9034 (late October, 1967) and 9091 (late November and early December, 1967).

3.1.4. *Decline of X-Ray Background Associated with the Decline of Active Centers*

Analogous to the rise in X-ray background with the appearance or resurgence of certain regions is the decline in the background following cessation of flaring. An example is plage 8831 (CMP 4.0 June, 1967), which dominated on the disk between

4 June and 9 June. A moderately flare-rich region while it traversed the Sun's eastern hemisphere, after 6 June flaring in plage 8831 had essentially ceased, and the associated spot groups declined after that date. This decline in the region's activity was reflected in a gradual diminution of its soft X-ray flux, and in the decay of its 9.1 cm flux. The roughly exponential decline of the soft X-rays has an *e*-folding time of about 4.4 days. Because this time scale exceeds the time scale for cooling of the associated permanent coronal condensation, it very likely portrays a decreasing energy input into the condensation. Possibly the decline in energy input was connected with the decline of the spot group.

The good correlation between soft X-rays and solar cm-λ flux may be followed both qualitatively and quantitatively with the summary data. Even short-term fluctuations are seen to be associated. For example, between 8 and 10 January, 1968, the X-ray background decreased by some 40%. Over the same period the Stanford 9.1 cm fluxes from plages 9144, 9145, 9146 and 9153 were reported each to have decreased by 20%–40%. These regions dominated on the disk at that time. However our data cannot be used to trace the history of individual regions unless they are alone or dominant on the disk, because the instrument had no angular resolution on the Sun.

3.2. Events with a Time Scale of Hours

Long-enduring solar X-ray events have been seen to accompany not only solar flares but have been reported to accompany other transient events such as eruptive prominences (Kreplin *et al.*, 1962). Our records contain many bursts lasting for an appreciable fraction of a day or longer and which we have identified with a variety of phenomena observed at other wavelengths. A number, though, cannot be identified with any reported phenomena.

3.2.1. *Thermal cm-λ Phenomena Associated with Protracted Soft X-Ray Events*

Chief among the identified soft X-ray outbursts of long duration are those which accompany and outlast flares which are associated with long-duration, thermal cm-λ bursts. In a rough way, protracted X-ray events are seen with those cm-λ events classified as Gradual Rise and Fall (GRF) when the peak radio flux is in excess of 5–10 flux units (one flux unit is 10^{-22} W m^{-2} Hz^{-1}), and are also seen with those cm-λ post-burst increase events of similar or greater amplitude which have a duration in excess of 30 min or an hour. There are, however, many violations and variants which suggest that other controlling factors are also involved which we have not yet fully assessed.

For instance, the duration of an X-ray outburst associated with GRF will vary from one region to another. This is shown in our summary graphs by flares which took place in late April and early May, 1967. Major flares occurring in the same plage (8791) on 26 April (imp 2), 6 May (imp 3) and 10 May (imp 2) were all accompanied by relatively brief X-ray bursts, although GRF was reported at radio frequencies. However, on 3 and 4 May, two imp 2 flares in other regions (8795 and 8798) were also accompanied by GRF but also by protracted X-ray outbursts.

We do not think it is significant that the latter of these two flares, in plage 8795, occurred in a region with no sunspots and that the former signalled cessation of flaring in plage 8798, nor that both flares were apparently associated with the same disappearing filament. A counter-example of a long-duration X-ray outburst associated with an imp 2 flare in a youthful major spot group is afforded by that in plage 9184 on 28 January, 1968. The X-ray maximum of that flare was missed by OSO III. In the first few post-maximum hours, the *e*-folding decay time of the X-ray outburst was $\sim$6 h, changing to about 17 h later on. The radio spectrum at the time of the 28 January flare was, however, curious, with a weak cm-λ component and a very strong m-λ component.

Enomé *et al.* (1969) reported observation of a GRF outburst on 7 October, 1967, having the large size of 2.2 arc min diam, and associated with modest flaring in plage 9004. We have associated a long-duration soft X-ray outburst with that event. A GRF source of 'classical' diameter (Kundu, 1965) on 19 February, 1968, was also reported by Enomé *et al.* Apparently associated with an imp 1 flare, this event seems also to have been accompanied by protracted X-rays, although our data are incomplete for this latter event.

In Figure 3, *e*-folding soft X-ray decay times in the neighborhood of 4 h following flares are reasonably common, and 6 h is not at all rare. We believe these decay times indicate the rate of decline of the energy source rather than indicating the rate of radiative and conductive relaxation of the emitting volume, which would provide a much faster decay rate than those observed.

3.2.2. *X-Ray Outbursts with Electron-Productive Flares*

A comparison of our data with Lin's (1970a) list of electron events during 1967 is also suggestive of the dependence of the duration of soft X-ray outbursts upon the physical structure in active regions. Lin divided his electron events into two classes: the C class events were associated with Type I noise storms; the S class events had no such association. By inspection of our data we qualitatively divided the soft X-ray outbursts associated with the 'electron flares' into three classes: short duration (such as on 29 and 31 December, 1967); moderate duration (as on 17 December, 1967); long duration (as on 1 and 2 December, 1967). Fifty-seven events were compared as to duration class and as to association with Type I noise storms (Lin's C and S classes). The resulting distributions are shown in Table I. There is a strong tendency for short-duration soft X-ray events to be associated with Lin's C class events (the probability of this distribution occurring by chance is 2.7×10^{-5}) and a weaker tendency for long-duration X-ray outbursts to be associated with S class electron events (probability of chance occurrence is 0.050).

Most of the short-duration events were contributed by plage 8905. We eliminated from consideration events that were associated with that region to see how they might have affected the comparison. The remaining distributions are also given in Table I. Again the probabilities of achieving those distributions by chance are low (0.017 for the C class distribution, 0.029 for the S class distribution).

TABLE I
Distributions of soft X-ray outburst duration with Lin's C and S class electron events

	Short-duration X-ray events (number)		Moderate duration X-ray events (number)		Long-duration X-ray events (number)	
	Including plage 8905	Excluding plage 8905	Including plage 8905	Excluding plage 8905	Including plage 8905	Excluding plage 8905
C Class electron events	17	6	2	0	3	2
S Class electron events	7	6	6	5	12	12

There is no other evidence, however, that the duration of a soft X-ray outburst is related to the production of Type I noise storms. We have listed all Type I events listed in the *Quarterly Bulletin on Solar Activity* between 10 March, 1967, and 10 May, 1968, and have examined the duration of X-ray outbursts at the times of those events. There is no apparent preference for long or short duration of the X-ray events associated with Type I in the general (non-'electron flare') case. We mention parenthetically that we could not re-establish a 'C' or 'S' classification for Lin's flares that was identical to his by using the Quarterly Bulletin material on Type I.

3.2.3. *X-Ray Rises Preceding Great Flares*

Rarely, slow X-ray rises precede the beginning of great flares. The two PCA flares of 22 March, 1967 (Castelli, 1969), and of 23 May, 1967, were preceded by monotonic enhancements of the soft X-ray background over several hours' time. On 22 March, the rapid pace of subflaring which preceded the main flare makes it difficult to assess the duration and magnitude of the pre-flare rise. However, on 23 May subflaring before the main flare was quite minimal, giving confidence that the pre-flare rise was real. This rise began more than 6 h before the flare.

The interval preceding the 23 May proton flare, during which the soft X-rays were increasing in intensity, is approximately the interval during which, according to McIntosh (1969), two major umbrae of opposite polarity in the spot group were drifting towards one another, resulting in a heightening of magnetic field gradients between those spots. McIntosh's study is the only information that we know of which shows changes in the active center so far in advance of the flare. Other evidence cited in the previous section indicates that field gradients measured in the photosphere are not closely related to the background X-ray level. It is not clear whether this evidence may be applied to the 23 May event.

That a protracted, monotonic rise in soft X-rays does not always precede a PCA flare – even in the same active center – may be demonstrated with respect to the PCA flare of 28 May, 1967, which occurred in the same plage as did that of 23 May.

3.2.4. *Protracted X-Ray Outbursts with Unusual Events*

Soft X-ray outbursts on a long time scale have been found to accompany systems of loop-type prominences (Teske, 1971). We have identified the slow events of 1 June, late on 30 October and on 31 October, 1967, with great loop systems. Other cases are tabulated in the above reference.

Weak flaring activity is also occasionally accompanied by long-duration X-ray outbursts. We have cited a case of a small flare in plage 9004, with GRF, on 7 October, 1967, above. A second example is the enhancement on 26 November, 1967, which coincided with a subflare in plage 9082. A relatively shorter outburst, on 17 December, 1967, coincided with small brightenings – not reportable as flares – in plage 9115*. In this latter event the X-rays lasted for at least 2 h, and radio bursts of Types II, III and IV were reported at the time. It was followed by weak PCA and by an electron event in space.

There are, however, numerous examples of X-ray enhancements which cannot be directly identified with optical or radio events. One of them took place on 3 June, 1967. Lin (1970a) reported an electron event in space at the time. We speculate that the X-rays may have been associated with activity in plage 8818 behind the Sun's west limb. This region gave rise to the two PCA flares of late May, 1967, and was very active during its disk passage. The last vestiges of the calcium plage rotated around the west limb on 2 June.

3.2.5. *X-Ray Outbursts Possibly Associated with Plage Formation?*

Other examples of unidentified X-ray outbursts coincide well in time with the formation of plages on the disk. In the last section we described the rises in X-ray background accompanying the resurgence of plages. These had a time scale of a day or two. There are two examples in our data of outburst-like events with a time scale of a day or less, both morphologically similar, that accompanied the rapid development of active centers. The first of these occurred on 10 November, 1967, in association with the resurgence of flaring in plage 9047. On 28 April, 1968, plage 9358 and its spot group appeared on the disk, the spots growing rapidly during the day. With regard to the growth of active regions, we also mention the X-ray outburst of early 21 March, 1968, for which we can find no flare candidate. The X-ray event took place at the time of the formation of plage 9281 near the Sun's central meridian; the associated spot group grew rapidly. Although the summary graphs contain additional examples of protracted soft X-ray outbursts which accompanied the birth of plages and their associated spot groups, a number of examples exist for which no X-ray response to the formation of the plage was seen, and the issue remains unclear. It will be of interest to examine data from instruments having an angular resolution on the Sun to see if plage birth is sometimes actually accompanied by a weak, protracted X-ray outburst.

* We thank Dr C. Sawyer for examining flare patrol films in an effort to identify the source.

4. Summary

Although the bulk of soft X-ray emission from active centers appears to arise from solar atmospheric levels at and below 10^4 km, the magnitude of this emission is related to the extent, density and temperature of the associated coronal condensation. Our data indicate that physical conditions in the coronal condensation are often highly responsive to the general level of activity in the underlying active center. Rapid spot growth and the accompanying onset or resurgence of flaring may introduce marked changes in the coronal condensation over intervals of a day or two. In two cases the plage development appears to have produced an X-ray outburst lasting less than a day (10 November, 1967, and 28 April, 1968). However, we have noted examples for which modest spot growth and the onset of flaring did not lead to marked changes in the X-rays. Such regions produced electron events that were observed at the Earth. Lin (1970b) has viewed electron events as indicative of an open magnetic field structure above an active center. Possibly the open field structure does not trap plasma in such a way as to build a coronal condensation that is sufficiently dense and hot to provide a marked enhancement of the soft X-rays.

The background flux level from active centers is related to the complexity of the magnetic field structure revealed by observation of the associated spot group. An examination of the role of δ spots and a comparison of our data with the investigation by Malville and Tandberg-Hanssen indicates that field gradients measured in the photosphere are not a strong controlling factor in setting the background (non-flare) X-ray flux level. By inference, the field gradients shown by photospheric observations have no strong influence upon the temperature and density in associated coronal condensations.

The cessation of flaring and the decay of a spot group are accompanied by decay of soft X-ray flux on a time scale long enough as to suggest that we are viewing a decline in energy input to the volume overlying an active center, rather than viewing its cooling and dissipation after an abrupt energy cutoff.

Long-duration soft X-ray outbursts on a time scale of many hours are seen in association with many flares. These events are generally accompanied by GRF or by a thermal post-burst increase at cm wavelengths. However, not all GRF and post-burst increase events are accompanied by a protracted X-ray outburst. The conditions that determine whether or not the association will be observed with a given flare appear to be dependent upon the properties of individual active centers. For example, long-duration outbursts usually do not follow electron-productive flares if a Type I noise storm is occurring in the region.

A slow monotonic increase of soft X-ray flux was observed to take place several hours prior to two proton-producing flares in 1967. The rise does not take place prior to all such flares, however.

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