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Using Solar X Rays as Indicators of Solar-Flare Activity

D. M. Horan, R. W. Kreplin,
A. T. McClinton, Jr., and L. C. Schneider

E. O. Hulburt Center for Space Research
Space Science Division

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NAVAL RESEARCH LABORATORY
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CONTENTS

ABSTRACT

X-ray and particle emission during solar flares can sufficiently increase the electron density in the lower regions of the ionosphere to cause disruption of high-frequency radio communications. For several years NRL has been measuring solar x-ray flux levels in the 0.5 to 3 Å, 1 to 8 Å, 8 to 20 Å, 1 to 20 Å, and 44 to 60 Å bands. Based on these measurements criteria have been established to predict periods of high solar activity during which solar flares capable of disrupting communications might occur. A study of solar-flare occurrence and solar x-ray flux levels over 14 months has shown that solar flares are three times more likely to occur when the criteria are met than when they are not met.

PROBLEM STATUS

This is a report of the work accomplished to date on the problem; work on other phases of the problem continues.

AUTHORIZATION

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IONOSPHERIC EFFECTS OF SOLAR X RAYS

High-frequency (hf) radio waves, i.e., those with frequencies in the range of 3 to 30 MHz, can be bounced off the higher (E and F) regions of the ionosphere to achieve communication beyond the line of sight. Naval ship-to-shore and ship-to-ship communications depend on this principle. The lower (D) region of the ionosphere must be traversed twice by hf signals bounced off the higher E and F regions. Because of this double traversal, the condition of the D region is an important factor in hf communications.

Passage of hf radio wave through the D region causes the electrons present to oscillate at the frequency of the radio wave. In this way energy is transferred from the wave to the electrons. If the oscillating electrons do not collide with neutral particles, the energy absorbed from the wave is reradiated at the original frequency, and the net result is no loss of energy by the wave. However, if the oscillating electron loses its newly acquired energy by collision, the energy has been effectively removed from the radio wave. The wave has been partially absorbed.

Normally the D region has a large number of neutral particles and relatively few electrons. Therefore, some absorption of a hf signal normally occurs in the D region, but because of the small number of electrons present the absorption of energy is slight. If the electron density is increased, the energy absorption from the hf signal is increased until complete absorption of the signal can occur during passage through the D region. When this occurs, hf radio communication is impossible.

Undoubtedly solar flares cause changes in the D region which completely eliminate effective hf communications. There are two important ways in which this is done. Solar x rays having wavelengths less than 8 Å are able to penetrate to the D region. These x rays dissipate their energy by ionizing atoms and molecules. The increased emission of these relatively short wavelength x rays during solar flares results in increased ionization of the D region and a higher electron density than normal. The absorption of hf radio signals resulting from this increased x-ray emission is called short-wave fadeout (SWF).* The ionospheric changes which cause SWF's are largest at the subsolar point, i.e., the point on earth where the radius from the earth's center points directly at the sun, and decrease with distance from the subsolar point. Therefore, SWF's, per se, do not occur at high latitudes or on the night side of the earth. The time lag between the detection of a solar flare by optical or x-ray sensors and changes in the D region is a matter of seconds. Most SWF's last less than 1 hour, but occasionally a SWF will last 2 or 3 hours.

Changes in the D region are also caused by the increased emission of charged particles during solar flares. As the charged particles approach the earth, they are guided toward the polar regions by the earth's magnetic field. This results in an increased electron density in the lower altitudes of the polar regions and absorption of hf radio signals passing through the polar regions. This phenomenon is called a polar blackout or a polar cap absorption (PCA). Although PCA's are generally confined to the northern and southern auroral zones, unusually intense solar particle bombardment can cause them to spread to lower latitudes. In 1956 a PCA spread to within 30 degrees of the equator,

*H.J. Smith and E. Smith, "Solar Flares," New York: MacMillan, p. 249, 1963.

although its effects were still most pronounced and long lasting at higher latitudes.* PCA's are not confined to the daylight hemisphere of the earth. The time lag between the detection of a solar flare and the onset of a PCA varies from several hours to a day or two, if the PCA occurs at all. Although PCA's are due to solar flares, only a few flares, and not necessarily the largest, produce them. However, when a PCA does occur, it lasts for several days.

EARLY NRL SOLAR X-RAY EXPERIMENTS

In 1956, NRL began studying solar x-ray emission by means of rocket-borne detectors. The rockets were prepared for launching and then held ready until a solar flare was detected. The rocket was then immediately launched to gather x-ray data during the course of the flare. These rocket flights over several years established that the shorter wavelength solar x rays were able to penetrate to the lower ionospheric regions in sufficient quantity during solar flares to produce SWF's.

Because of the impossibility of observing the initial phases of a solar flare by rocket-borne instruments and because of the short duration of the individual rocket flights, earth satellites were used to carry the x-ray detectors beginning with Solrad 1 in June 1960. The data from Solrad 1 demonstrated that, if the solar x-ray flux in the band of wavelengths less than 8 Å is less than approximately 2×10^{-3} ergs/cm^2-sec, no SWF's would occur. Data from Solrad 7b, which was launched in March 1965, showed gradual rises in the flux levels of several wavelength bands prior to the sudden large increase which characterizes the flare itself. This was one of the first indications of the possibility of using gradual x-ray flux changes as a precursor to a solar flare.

NRL SOLAR-FLARE-ACTIVITY PREDICTIONS

There are several components which are essential to a prediction operation. There must be a data source, a means of making the data available within minutes of acquisition, someone to study the data and make decisions, and a set of criteria on which to base decisions. All of these components were assembled and a small-scale, limited, and informal flare-activity prediction operation was begun in August 1966. The data source was Solrad 8, which was launched in November 1965 with x-ray detectors covering the 0.5 to 3, 1 to 8, 8 to 20, 1 to 20, and 44 to 60 Å x-ray bands, plus ultraviolet detectors. Although Solrad 8 was equipped with a memory, the memory had ceased to operate before August 1966 and so only continuously transmitted, real-time data were available. A temporary ground station was setup in nearby Hybla Valley, Virginia, to record the real-time data from Solrad 8 whenever the satellite was simultaneously within range of that ground station and observing the sun. This limited daily data acquisition to a minimum of three and a maximum of eight passes of approximately a 10-minute duration each. Personnel at the ground station were able to reduce the raw data to x-ray flux values and telephone these flux values to NRL within minutes of the completion of a pass. Based on data received from Solrad 8 between November 1965 and August 1966, a set of criteria had been established which became the basis for making flare-activity-prediction decisions. Only one person was generally available to make the decisions, and since he was available only 40 hours a week, the nature of the operation was limited.

It is important to understand that no attempt was made to predict the occurrence of specific, individual solar flares or to predict specific communications disruptions. Based on the established criteria, the prediction stated a high probability that a period of several days of increased solar activity was imminent during which flares capable of producing SWF and PCA events might occur. This alert was telephoned to representatives

*H.J. Smith and E. Smith, "Solar Flares," New York:MacMillan, p. 242, 1963.

of the Naval Communications Command. During the several days after an alert was called, follow up phone calls were made whenever a significant x-ray flare was detected.

In September 1966, the spin stabilization system on Solrad 8 ran out of fuel. As the spin rate decreased, the satellite began a slow wobble which prevented its sensors from scanning the sun during several periods ranging from 3 to 5 weeks in duration. During these periods no solar data could be obtained from the satellite; therefore, no predictions of solar-flare activity based on x-ray fluxes could be made. In July 1967 the Orbiting Geophysical Observatory 4 (OGO-4) was launched by NASA, and in October 1967 the Orbiting Solar Observatory 4 (OSO-4) was launched. Both of these satellites carried NRL x-ray experiments with sensors similar to those on Solrad 8. NASA was able to provide NRL with quick-look data from these experiments beginning in August 1967. Both OGO-4 and OSO-4 were equipped with a data memory, and the quick-look data provided by NASA made available a continuous record over approximately 90 minutes of each day. However, the data were anywhere from 24 to 72 hours old on arrival at NRL and therefore suitable primarily as a back up and filler for Solrad 8 data. Nevertheless, whenever Solrad 8 was not scanning the sun and after Solrad 8 ceased to operate in November 1967, the OGO-4 and OSO-4 data had to be used as the basis for solar-flare-activity predictions.

After the demise of Solrad 8, the temporary ground station at Hybla Valley was moved to its permanent location at Blossom Point, Maryland. Hardline communication was established between Blossom Point and NRL so that the telemetry received from a satellite passing within range of the ground station could be instantly retransmitted to a data center at NRL for reduction and evaluation.

Solrad 9 was launched in March 1968 with x-ray detectors covering the 0.5 to 3, 1 to 8, 8 to 20, 1 to 20, and 44 to 60 Å bands and ultraviolet detectors. Although Solrad 9 was equipped with a memory, only the real-time data were immediately available for use in the solar-flare-activity prediction operation. Although, as in the case of Solrad 8, the data were limited to between three and eight 10-minute passes each day, the spin stabilization system was operating, and the data were available every day. In early August 1968 the personnel at the NRL data center became able to consistently provide flux values from the Solrad 9 memory within 24 hours after the memory was read without degrading their real-time data handling capability.

CRITERIA FOR SOLAR-FLARE-ACTIVITY PREDICTIONS

The problem of establishing criteria to be used as bases for solar-flare-activity predictions and then comparing the daily data with these criteria is similar to the problem of guessing the information contained in a paragraph when only four or five nonsequential words are known. The pattern of data available was such that 10 minutes of continuous data would be followed by 90 minutes of no data. This pattern would be repeated from three to eight times each day; then there would be a data gap of approximately 12 to 20 hours until the daily cycle started repeating again. Frequently, there is no way to tell with certainty whether a 10-minute data sample represented the x-ray output of the active nonflaring sun or the x-ray output during the slow decay of a solar flare. In both cases the data show relatively constant flux values of moderate magnitude for the 10-minute pass. If the flux values change greatly over 10 minutes or if they are relatively constant but very large in magnitude for several minutes, it is safe to consider them as the output from a solar flare. If they are constant and of very small magnitude, it is safe to consider them as the background output from the nonflaring sun.

The interpretation of a sample of data as originating from a flaring or nonflaring sun is extremely important, because the prediction criteria are tied to slow variations in the background x-ray flux values. Study of solar x-ray data acquired over several months showed that there generally is a slow rise in the background x-ray flux values prior to the onset of a period in which numerous solar flares will occur. Therefore, interpreting high background data as of flare origin would fail to generate an appropriate alert, and interpreting isolated flare data as of background origin would generate an unnecessary alert.

Although classification of data as of flare or background origin did hamper the establishment of solar-activity-prediction criteria, the problem was somewhat alleviated by the ability to obtain some gap-filling data from various NASA and COSPAR ground stations around the world. (It takes several weeks, at best, to obtain this gap-filling data; therefore, this aid is not available to the real-time prediction operation.) Nevertheless, the intermittent nature of the data, which hampered the conversion of observed qualitative changes to quantitative criteria, encourages constant efforts to improve the criteria.

The first set of criteria, which was used from August 1966 until early 1967, is as follows:

1. Generally rising but variable flux levels in the 8 to 20 and 1 to 8 Å bands.

2. 1 to 8 Å flux levels exceeding 1×10^{-3} ergs/cm^2-sec.

3. Observation of 0.5 to 3 Å flux above the 2.0×10^{-6} ergs/cm^2-sec lower limit of the detector.

When all of these criteria were met, it was possible to state with some certainty that a period of solar activity was to be expected during which solar flares capable of producing SWF and PCA events might occur. Unfortunately, the fact that these criteria were not met did not preclude the occurrence of a few isolated flares, but, in general, they were good indicators of expected solar-flare activity. Evidently, the gradual rise in the background flux levels was due to the buildup of an active region or regions on the sun which were becoming capable of spawning flares. This cannot be shown from our data, because the detectors used lack spatial resolution, but x-ray photographs of the sun do show enhanced x-ray emission from active regions.

The first revision of the criteria was not a real change but merely a further quantization of the original criteria. These criteria were first used in early 1967 and are as follows:

1. An increase in the background level of the 1 to 8 Å flux by a factor of 10 to 20.

2. An increase in the background level of the 8 to 20 Å flux by a factor of 5 to 10.

3. Consistent observation of the 0.5 to 3 Å flux above the 2.0×10^{-6} ergs/cm^2-sec level.

As the more active phases of the solar cycle were entered, the minimum background levels encountered began creeping upward. This is due to the sun being rarely devoid of active regions in the phases of the solar cycle approaching solar maximum. Since the difference between low and high background flux levels was smaller, the large increases in background level required to meet the criteria were no longer encountered, and a new set of criteria was needed. The criteria established in early 1968 are as follows:

1. The background level of the 44 to 60 Å flux rises to 2.3×10^{-1} ergs/cm^2-sec or greater.

2. The background level of the 8 to 20 Å flux rises to 1.3×10^{-2} ergs/cm^2-sec or greater.

3. The average background level of the 1 to 8 Å flux rises to 1.0×10^{-3} ergs/cm^2-sec, and the flux levels fluctuate greatly from pass to pass.

4. Flux levels for the 0.5 to 3 Å band fluctuate greatly from pass to pass and are generally greater than 1.0×10^{-5} ergs/cm^2-sec.

In several instances criteria 1 and 2 were met a day or two ahead of criteria 3 and 4, but it is too early to tell if this is a general rule. More weight is usually given to criteria 3 and 4. These criteria are still in use, but the newly acquired capability of processing the data from the Solrad 9 memory in time for some use in predicting solar-flare activity will certainly force a revision of the criteria. However, this revision is not imminent, because more experience in using the memory data must first be obtained.

ACCURACY OF NRL SOLAR-ACTIVITY PREDICTIONS

Anyone interested in making serious predictions of any kind must face the question of how accurate the predictions are. The obvious way to do this is to compare the number of selected events occurring when alerts are and are not in effect. However, this approach cannot yet be used to measure the accuracy of solar-flare-activity predictions based on x-ray flux changes. Because of the discontinuous nature of the x-ray data available and the limited nature of the operation, there are undoubtedly many instances where alerts should have been called but were not. For instance, it is quite possible that x-ray flux levels sometimes rose to fulfill the flare-activity-alert criteria when the Solrad 8 sensors were unable to scan the sun for several days. At other times observed high flux levels may have been erroneously attributed to isolated flare activity instead of high background levels, and no alert would be called. Also, if the flux levels rose to meet the criteria over a weekend, the alert would be called late, and many events could have already occurred. If continuous, real-time x-ray flux data were immediately available and if an around-the-clock operation were in effect, these deficiencies should not be present. However, they must be recognized in this case.

As an alternative, it seems reasonable to compare the number of selected events occurring on days when the flare-activity-alert criteria are met with the number occurring on days when the criteria are not met. This approach assumes that if a round-the-clock operation were in effect with continuous, real-time data immediately available, an alert could be called as soon as the background flux levels fulfilled the criteria. This is reasonable, because with the continuous data the background levels would be readily identifiable, and there would be no need for a day or two delay to be certain that observed high flux levels were really background and not isolated flare activity. This alternative approach would examine the validity of the premises on which the prediction operation is based without being tied to the actual predictions which have been made and without becoming hopelessly involved in the handicaps under which the present rudimentary system is operating.

The next step is to determine what event is to be selected as a measure of the accuracy of the criteria. There are three choices: ionospheric disturbances, x-ray events, and solar flares of Class 2 or greater. Although it would be of great operational significance to the Navy if the fulfillment of the solar x-ray flux criteria were found to be an accurate predictor of SWF and PCA activity, it must be noted that as of now, at least, NRL is not trying to make ionospheric disturbance predictions. This fact, together with the scarcity of reliable, complete ionospheric disturbance data, makes the choice of ionospheric disturbances a poor one. Although solar x-ray events are really what NRL is trying to predict and although they have a direct connection to SWF's, the choice of x-ray events for the present period of quite incomplete monitoring is also a poor one. The main source of data on x-ray events is the very same x-ray flux data which are used as the bases of NRL's flare activity predictions. Not only are these data extremely discontinuous, but the confusion between isolated x-ray flare events and high background levels could easily bias the study.

This leaves us with the choice of Class 2 or greater solar flares, and for the present, at least, this is the best choice. Good data on solar flares are obtainable. Although there is no necessary connection between solar flare class and the x-ray emission from the flare, it is generally, but by no means always, true that higher flare classifications yield higher x-ray fluxes. Therefore, there is a connection between flare class and ionospheric disturbances, although it is accidental and more remote than in the case of x-ray events.

In summary, the accuracy of the criteria will be measured by comparing the number of flares of Class 2 or greater which occur on days when the solar-flare-activity criteria are met with the number of flares of Class 2 or greater which occur on days when the solar-flare-activity criteria are not met.

The Environmental Science Service Administration's series of bulletins IER-FB, titled "Solar-Geophysical Data," was used as a source of information on the date of occurrence and classification of solar flares. The date of occurrence of all Class 2 or greater solar flares occurring between January 1, 1967, and February 29, 1968, was listed. The data for January through December 1967 were obtained from the Revised Solar Flare lists appearing in the volumes IER-FB-275 through 286. In examining these data it was noted that certain stations frequently observed Class 2, 3, and even Class 4 flares at times and places where no other station observed even a subflare. In such cases the flare was counted but was labeled "Questionable." A flare was counted without question if some disturbance was detected by two or more stations, and the general consensus of the several observing stations was that it was a Class 2 or greater flare. This consensus was determined by the group classification given in the tables. The data for January and February 1968 were taken from the Confirmed Solar Flare lists appearing in the volumes IER-FB-287 and 288. The confirmed list differs from the revised list in that questionable flares have been removed from the confirmed list. Therefore, all flares of Class 2 or greater listed in the confirmed list were counted without question. Table 1 gives a summary of the dates of occurrence of Class 2 or greater solar flares as obtained from the ESSA publication. The portion labeled "All Listed" includes questionable flares and those accepted without question. The numbers appearing in parentheses after a date denote the number of flares when more than one occurred on the same day.

Figures 1a-1n show the x-ray data plots for the months January 1967 through February 1968 which were used to determine the days on which the solar-flare-activity prediction criteria were met. The criteria used are the most recent and are as follows:

1. The background level of the 44 to 60 Å flux rises to 2.3×10^{-1} ergs/cm^2-sec or greater.

2. The background level of the 8 to 20 Å flux rises to 1.3×10^{-2} ergs/cm^2-sec or greater.

3. The 1 to 8 Å flux rises to 1.0×10^{-3} ergs/cm^2-sec, and the flux levels fluctuate greatly from pass to pass.

Table 1
Dates of Occurrence of Class 2 or Greater Solar Flares

Month	Day All Listed	Month Total
January 1967	10,11,14,29,31	5
February	3,4,6,7(2),13,18,22(6),23(2),24(2),27(2)	19
March	6,20,22,26,30,31(2)	7
April	1(4),3,9(2),11(2),20,28,30	12
May	2,3(4),4,5,6(2),8(2),10,18,19(2),21,23(5),25,26,27,28(3)	27
June	4,5	2
July	2,11(2),22,24,25(2),26,28(2),29(4),30,31(2)	17
August	1,4,6,9,12(2),19(3),20,21,23,24,25,29(2)	16
September	1,17(2),18,19,20,28	7
October	8,13,19,20(2),30(2),31(2)	9
November	11(3),13,16(3),20(2)	9
December	1,2(2),11,13(2),15(2),16(2),27(2)	12
January 1968	4,5,9,14,15,20,31	7
February	1,2(2),10,15(2)	6
		155
Questionable		
January 1967	10,11,31	3
February	7,22(2)	3
April	3,9,30	3
May	3(2),5,6,19(2),23	7
July	2,11(2),22,25(2),28(2),29,30,31	11
August	12,20,25	3
September	20	1
October	13,19,20(2),30(2),31(2)	8
November	11(3),13,20	5
December	1,2(2),13,15(2),16	7
		51

4. Flux levels for the 0.5 to 3 Å band fluctuate greatly from pass to pass and are generally greater than 1.0×10^{-5} ergs/cm^2-sec.

These criteria were applied to the whole period covered in the accuracy analysis, because the high background levels specified in these criteria are essentially the same as the high background levels encountered when applying the set of criteria used during most of 1967.

Table 2 identifies the dates on which the criteria clearly are and are not met, the dates on which it is questionable whether the criteria are met, and the dates for which there are no data. Questions as to whether the criteria are met arise not only in cases where the flux levels are extremely close to the levels noted in the criteria but also in cases where the aspect angle of Solrad 8 was great enough to make the flux values unreliable. Dates for which there are no data include some dates on which there were data but the data were too sparse to render a decision.

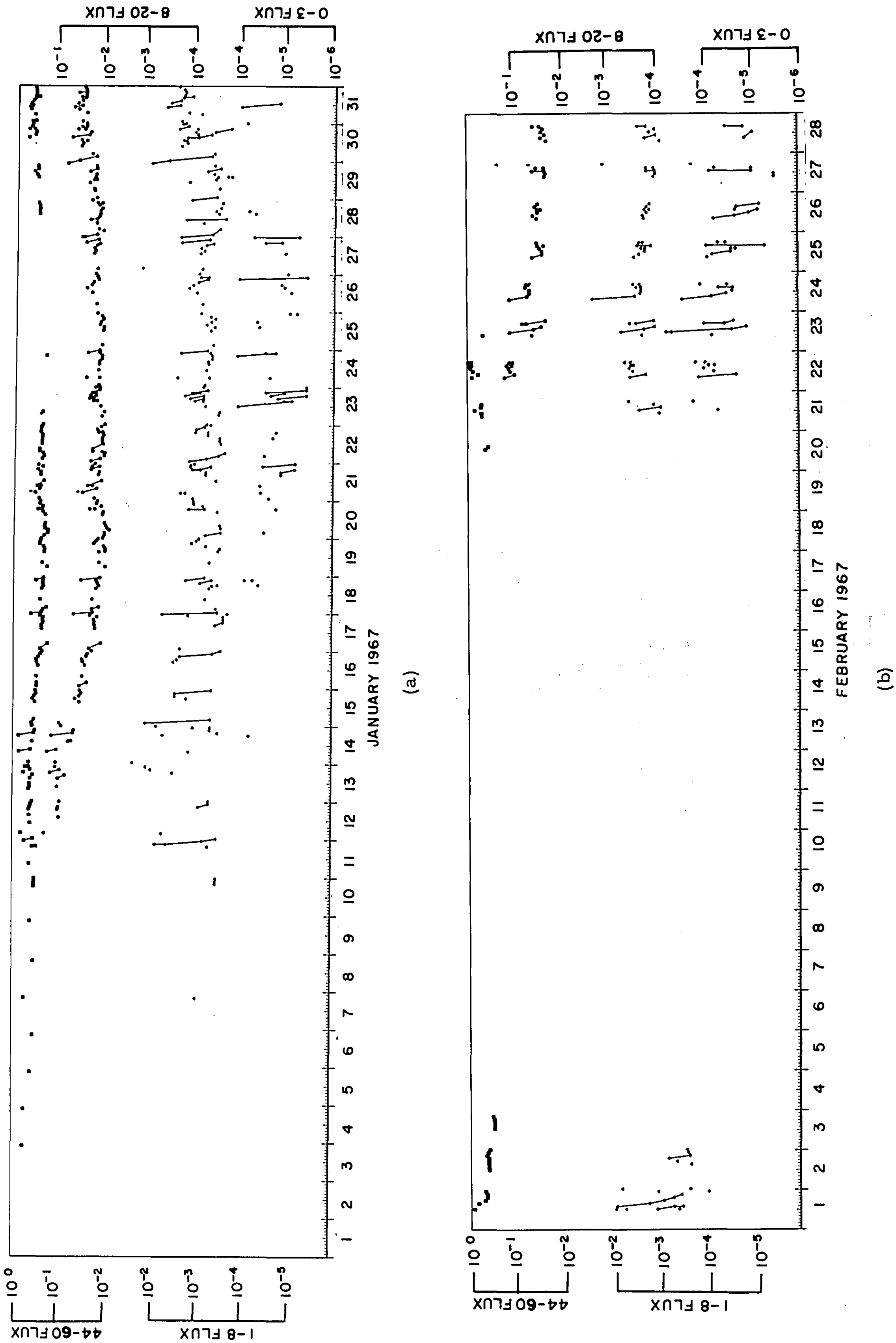
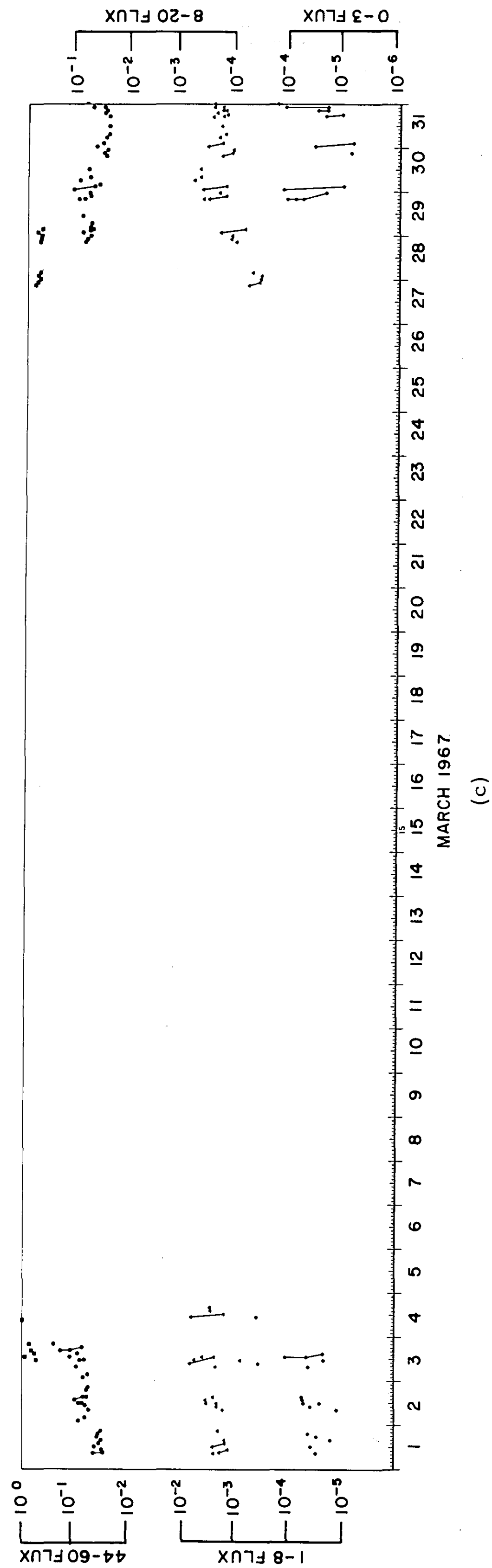
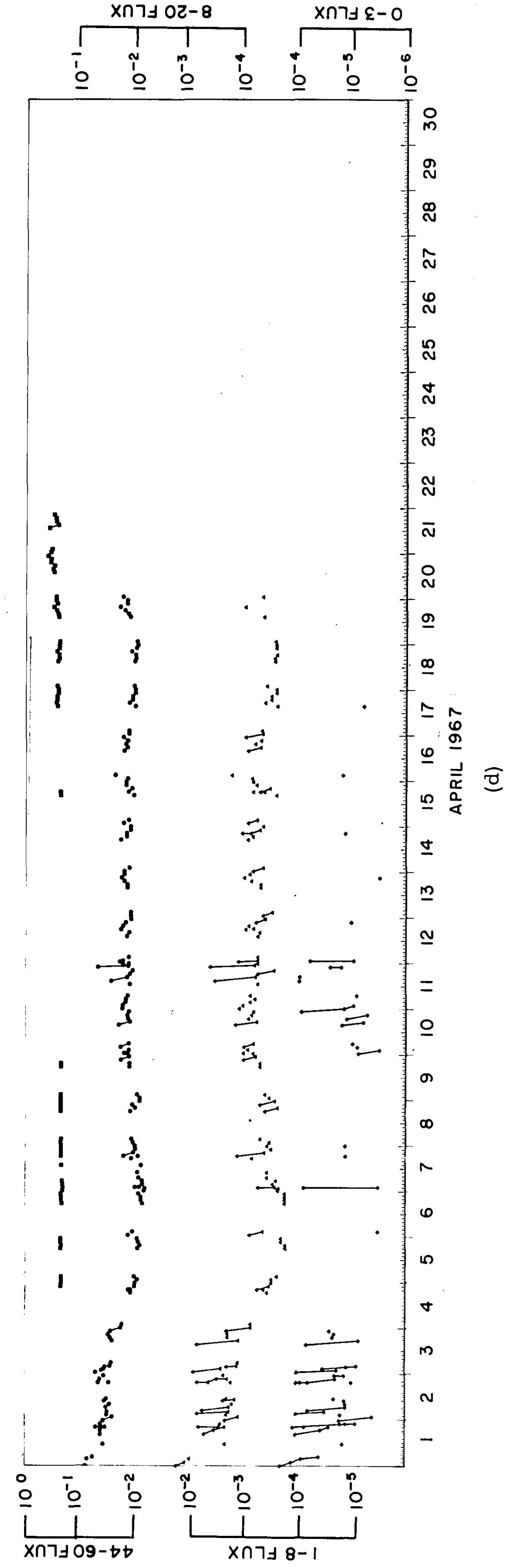


Fig. 1 - Solar x-ray flux levels



(c)



(d)

Fig. 1 (Continued) - Solar x-ray flux levels

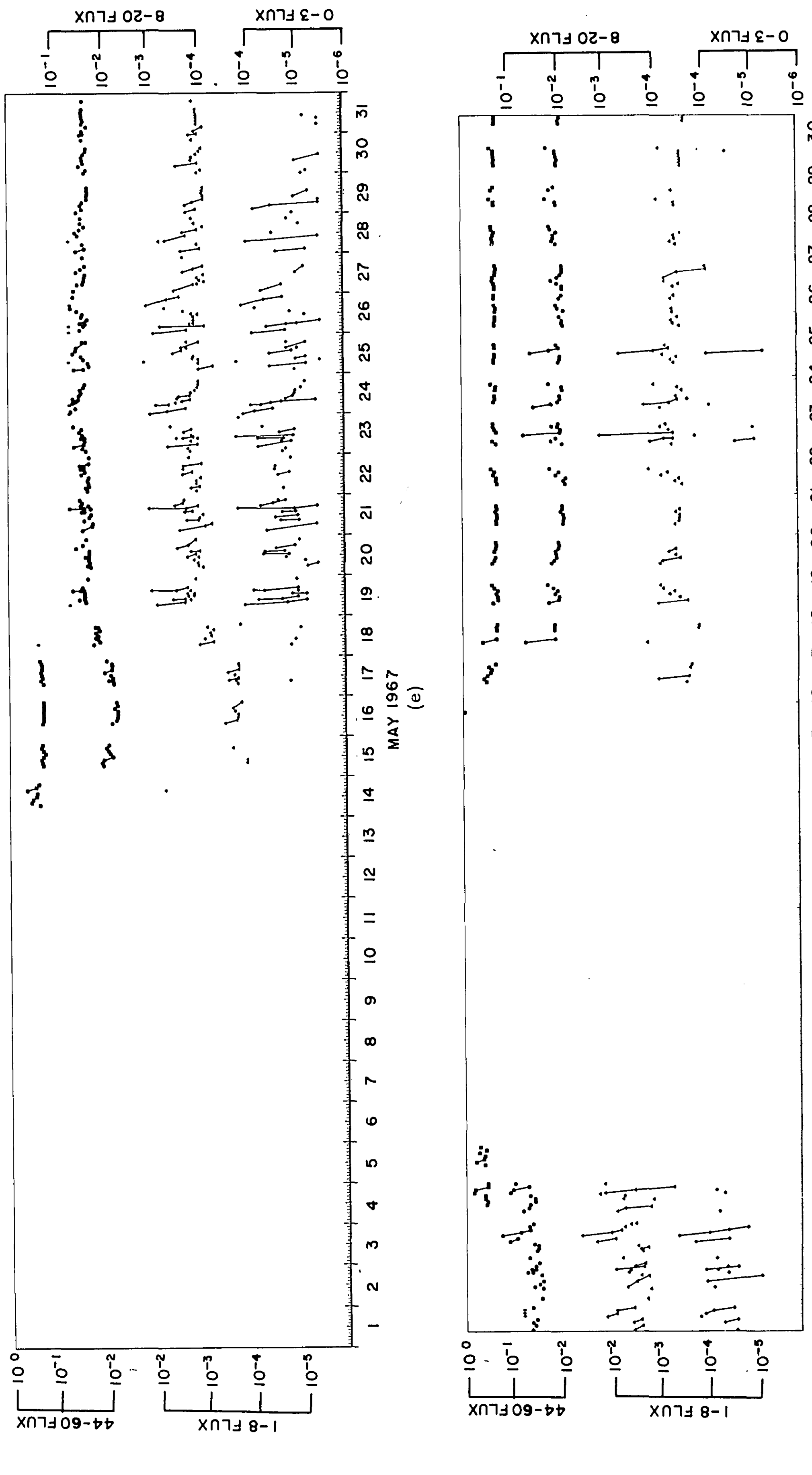


Fig. 1 (Continued) - Solar x-ray flux levels

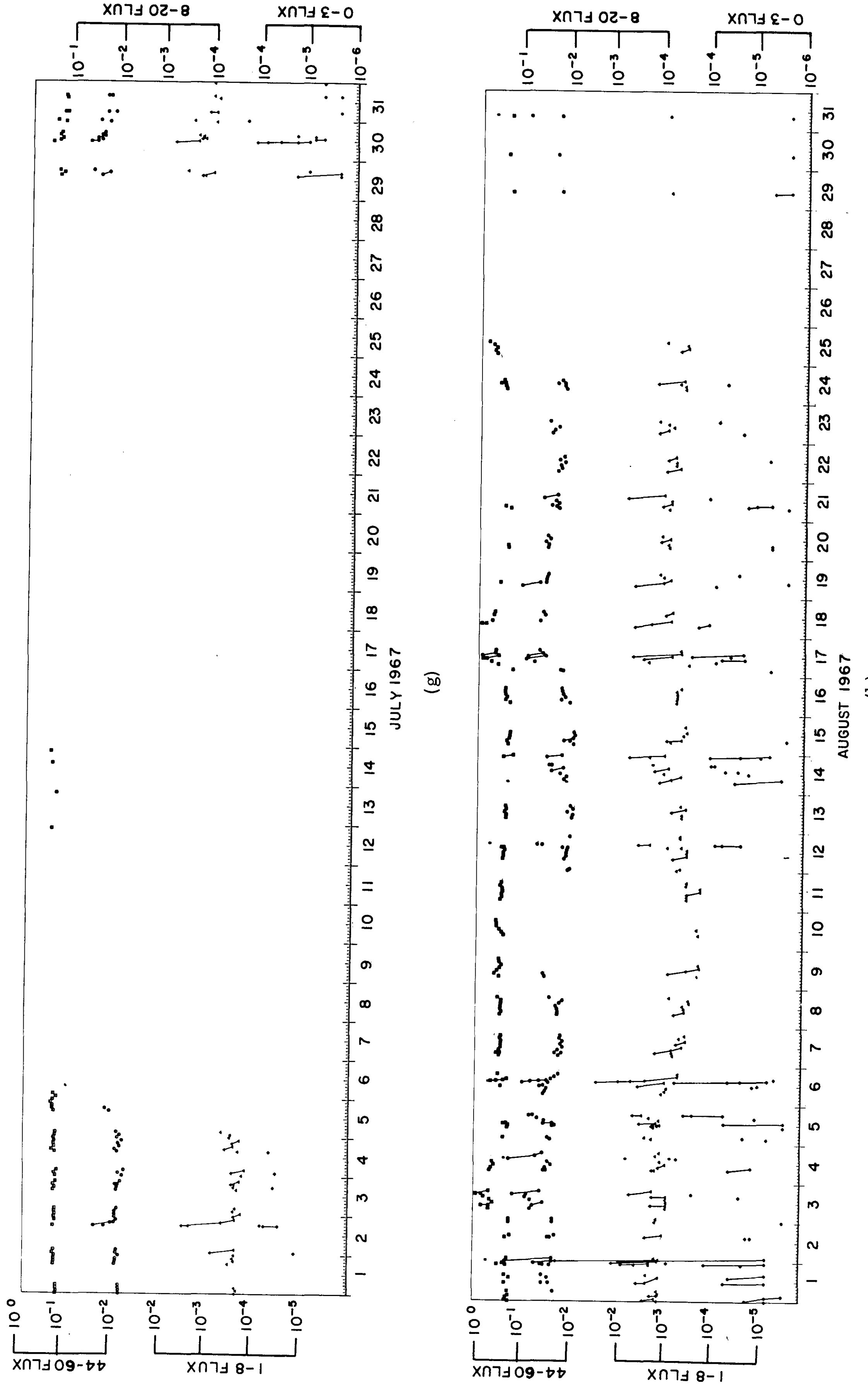
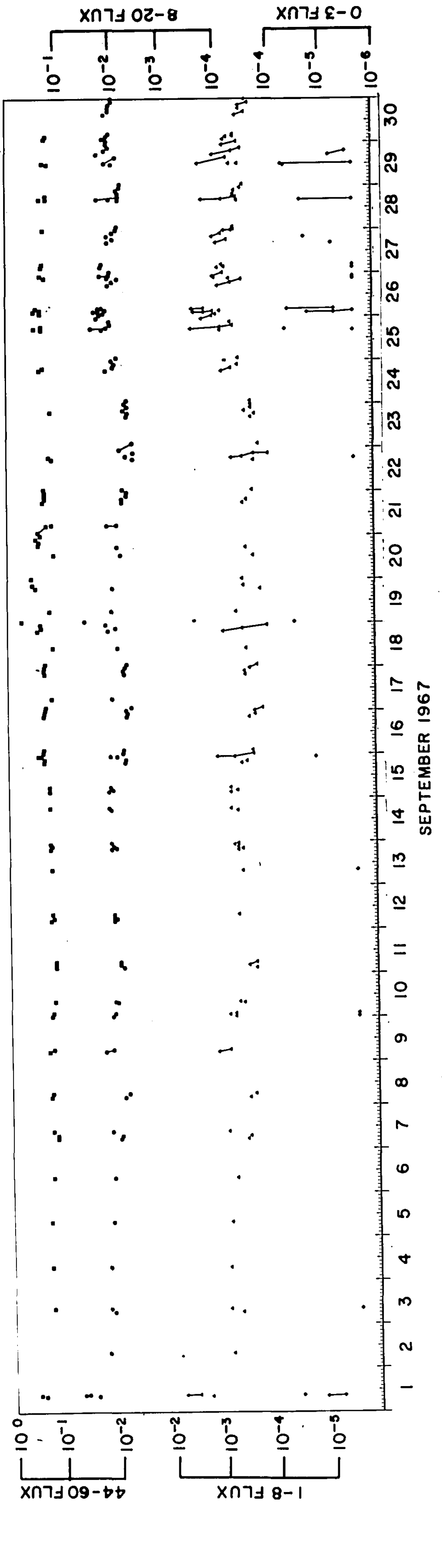
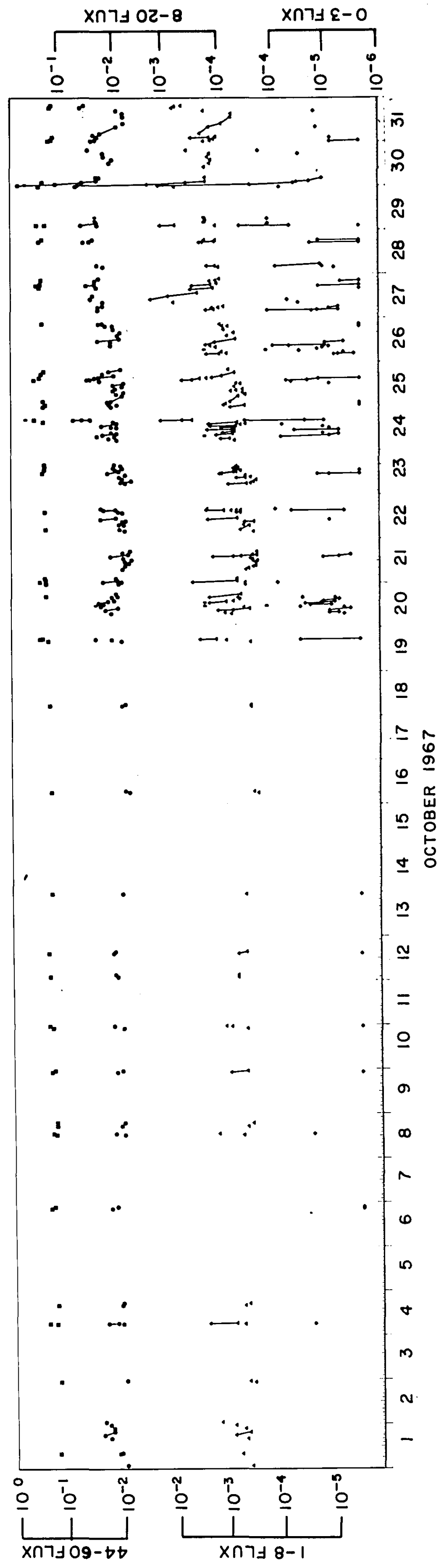


Fig. 1 (Continued) - Solar x-ray flux levels

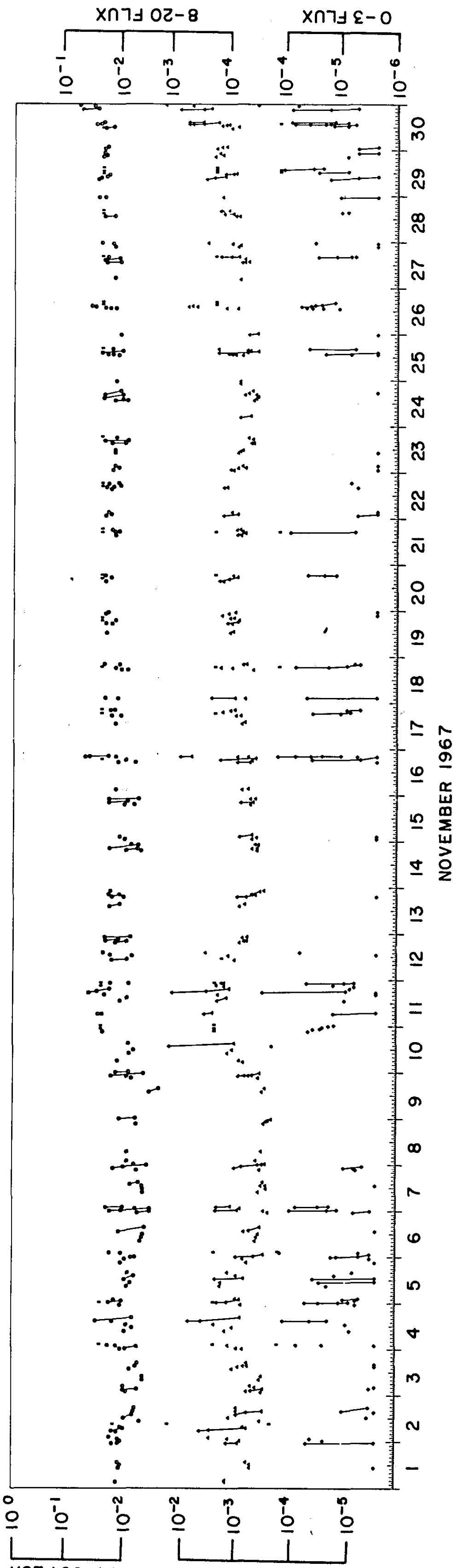


(i)

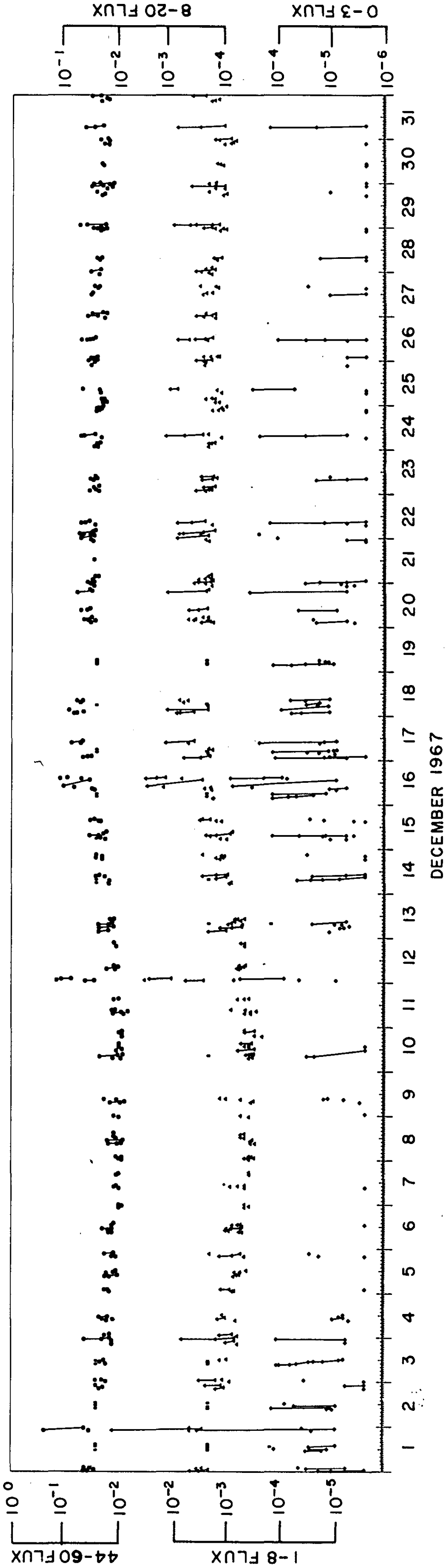


(j)

Fig. 1 (Continued) - Solar x-ray flux levels



(k)



(l)

Fig. 1 (Continued) - Solar x-ray flux levels

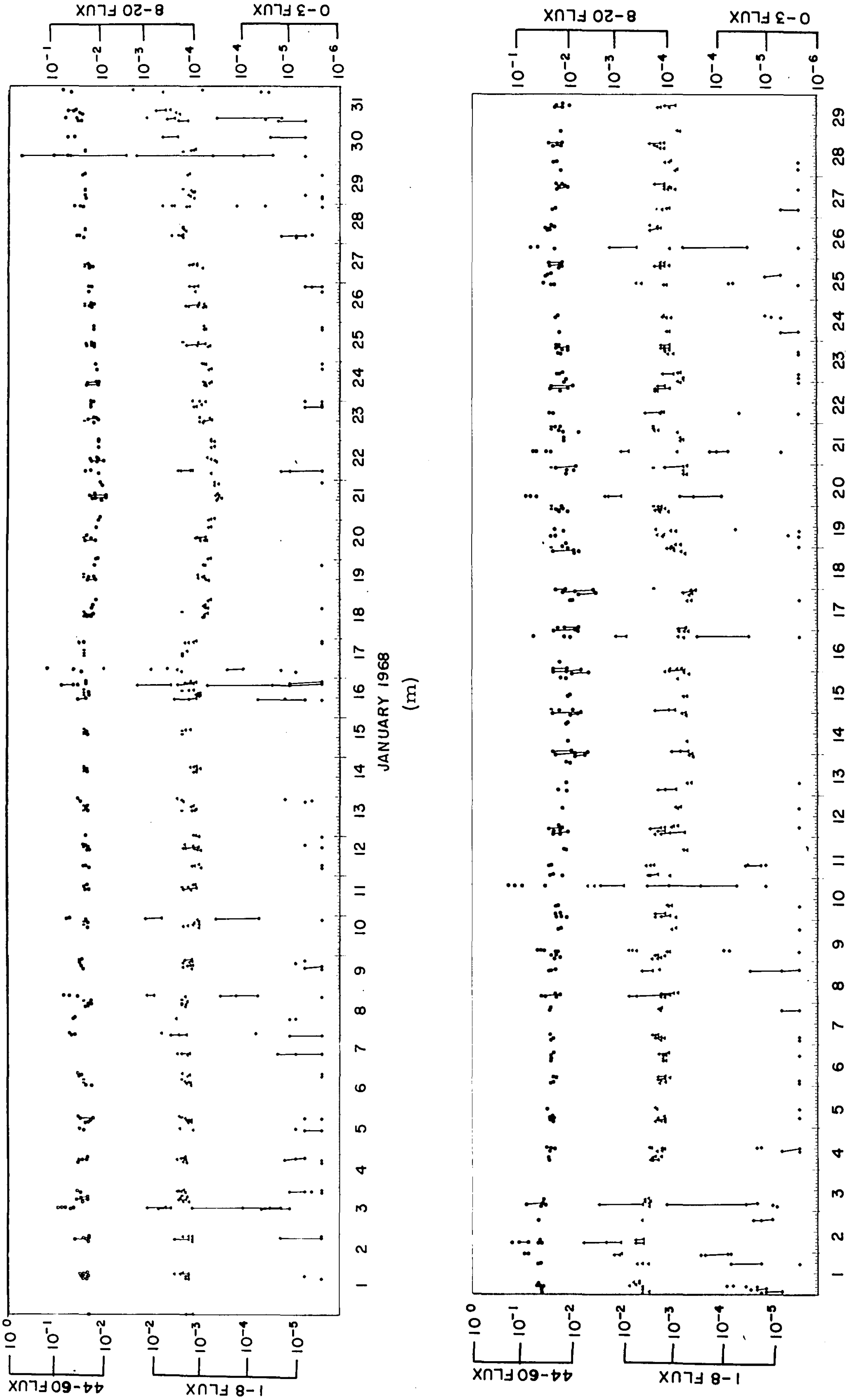


Fig. 1 (Continued) - Solar x-ray flux levels

Table 2
Solar-Flare-Activity Criteria

Month	Dates on Which Criteria Are Clearly Met	Dates on Which Criteria Are Possibly Met	Dates on Which Criteria Are Clearly Not Met	Dates on Which No Data Are Obtained
January 1967	30-31	-	15-29	1-14
February	23-28	22	-	1-21
March	1,30-31	2,29	-	3-28
April	1-3	-	4-19	20-30
May	19-29	-	15-18,30-31	1-14
June.	1-4	-	18-30	5-17
July	29-31	-	1-5	6-28
August	1-2,5,14,17-21	3-4,6	7-13,15-16,22-24	25-31
September	25-26	-	15-24,27-30	1-14
October	27-30	26,31	20-25	1-19
November	10,26,29-30	4-5,11-12,20 27-28	1-3,6-9,13-19 21-25	-
December	1-2,15-30	3,14,31	4-13	-
January 1968	1-17,28-31	26-27	18-25	-
February	1-4,8-11,19-22, 25-26	5-7,23-24,27-29	12-18	-
Total Days	104	28	131	162

Tables 3 and 4 follow directly from the data shown in Tables 1 and 2. They show the number of Class 2 or greater flares occurring, by month, on days when the solar-flare-activity criteria clearly are, possibly are, and clearly are not met, and the number of flares occurring on days when there are no x-ray flux data. Table 3 covers all Class 2 or greater flares listed, and Table 4 covers only those Class 2 or greater flares accepted without question.

The premises on which the prediction operation is based were also examined by comparing the frequency of occurrence of Class 2 or greater flares with the average value for a day of the 1 to 8 Å x-ray flux. The daily average of the 1 to 8 Å flux is a daily average in only the crudest sense, because it is obtained from the intermittent and discontinuous x-ray flux data, which cover, at most, only about 8% of a day. The average is calculated after obvious flares have been removed from the data and is really intended to be an estimate of the background x-ray flux level. In spite of the fact that the absolute values of the daily averages are open to question, the comparison was made because there is significance in the relative values of the daily averages. Table 5 shows the number of days having a daily average between stated limits, the number of Class 2 or greater flares, and the number of flares per average day. All listed Class 2 or greater flares were included in Table 5. Figures 2 and 3 are graphical displays of the information contained in Table 5.

In both Tables 3 and 4 the data indicate that a Class 2 or greater flare is approximately three times more likely to occur on a day when the solar-flare-activity criteria are met than on a day when the criteria are not met. The data of Table 5 also indicate that it is three times more likely that such a flare will occur on a day when the daily

Table 3
Comparison of Flare Occurrence and Days on Which Criteria Met
All Listed Flares

Month	Days on Which Criteria Are Met	Days on Which Criteria are Possibly Met	Days on Which Criteria Are Not Met	Days on Which No Data Are Obtained
January 1967	1	0	1	3
February	6	6	0	7
March	3	0	0	4
April	5	0	4	3
May	14	0	1	12
June	1	0	0	1
July	7	0	1	9
August	6	2	5	3
September	0	0	6	1
October	2	2	2	3
November	0	6	3	0
December	9	0	3	0
January 1968	6	0	1	0
February	4	0	2	0
Total Flares	64	16	29	46
Total Days	104	28	131	162
Flares/Day	0.62	0.57	0.22	0.28

average of the 1 to 8Å flux is above 1.0×10^{-3} ergs/cm^2 -sec. This demonstrates the importance of the criterion for the 1 to 8 Å flux level. Table 5 is not independent of Tables 3 and 4.

CONCLUSIONS

The information contained in Tables 3, 4, and 5 indicates that the use of the present solar-flare-activity criteria identifies periods of increased solar-flare activity with sufficient accuracy to warrant continued study of solar x-ray flux levels as indicators of flare activity. X-ray flux data from the NRL x-ray experiment on OGO-4 are now being processed, and these data will provide a much more continuous set of x-ray data from July 29, 1967, to the present. The x-ray flux data from the memory of the NRL Solrad 9 satellite will provide an even more continuous record than OGO-4 for the period commencing March 5, 1968. Figure 4 is an example of the Solrad 9 memory data covering a 9-hour period. The x-ray data from these two satellites will be used to refine the criteria for solar-activity predictions and to make a much more thorough analysis of the accuracy of solar-flare-activity predictions based on x-ray flux levels. The results of this future analysis will inspire much greater confidence than the results of the present analysis, but until such a study is possible, the results of the present study will have to be used. The continuous x-ray flux records will also be closely examined for precursors to individual flares. If such precursors can be identified, predictions of individual,

Table 4
Comparison of Flare Occurrence and Days on Which Criteria Met
Unquestioned Flares Only

Month	Days on Which Criteria Are Met	Days on Which Criteria Are Possibly Met	Days on Which Criteria Are Not Met	Days on Which No Data Are Obtained
January 1967	0	0	1	1
February	6	4	0	6
March	3	0	0	4
April	4	0	3	2
May	11	0	1	8
June	1	0	0	1
July	4	0	0	2
August	5	2	4	2
September	0	0	5	1
October	0	0	0	1
November	0	1	3	0
December	3	0	2	0
January 1968	6	0	1	0
February	4	0	2	0
Total Flares	47	7	22	28
Total Days	104	28	131	162
Flares/Day	0.45	0.25	0.17	0.17

Table 5
Flare Occurrence Compared to Daily Average
of the 1 to 8 Å Flux

Limits of Av. Flux (10^{-4} ergs/cm^2-sec)	No. of Days	No. of Flares	Flares/Day
0 - 5.00	77	11	0.14
5.00 - 10.00	92	26	0.28
10.00 - 15.00	62	27	0.44
15.00 - 20.00	37	25	0.68
Above 20.00	33	28	0.85
0 - 10.00	169	37	0.22
Above 10.00	132	80	0.61

specific solar flares could be made instead of predictions of periods of increased solar-flare activity.

A solar-flare-activity prediction system based on x-ray flux levels has a tremendous potential for improvement. In addition to usefulness in refining criteria and identifying precursors to individual solar flares, continuous x-ray flux data will be an invaluable tool in a prediction operation. Figure 4 shows how easily background flux levels can be distinguished from flare activity when continuous data are available. However, the availability of continuous memory data within 24 hours after a memory dump is not good enough for a full-scale prediction effort. To achieve the full potential of an x-ray-based solar-flare-activity prediction system, complete and continuous x-ray flux data should be less than 4 hours old when made available, and if precursors to individual solar flares have been identified, even 4-hour-old data may be too old.

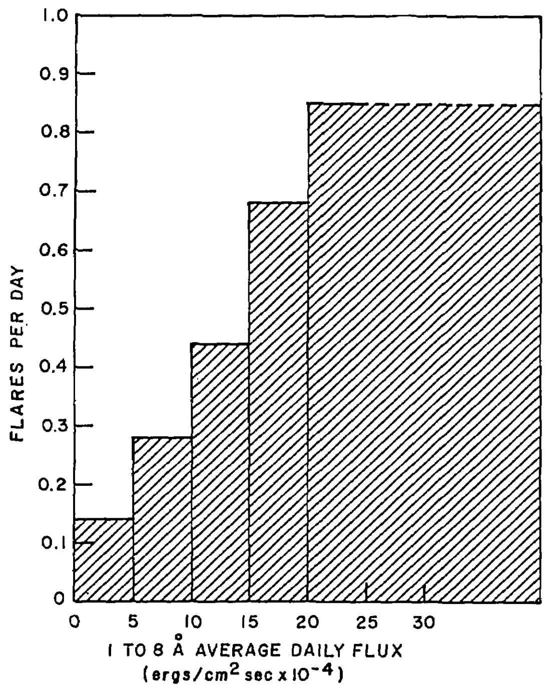


Fig. 2 - Flare occurrence compared to daily average of 1 to 8 Å flux

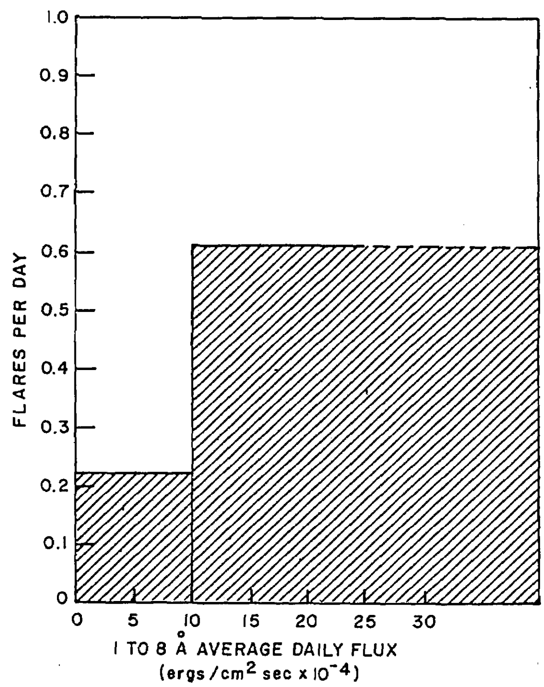


Fig. 3 - Flare occurrence compared to criterion for daily average of 1 to 8 Å flux

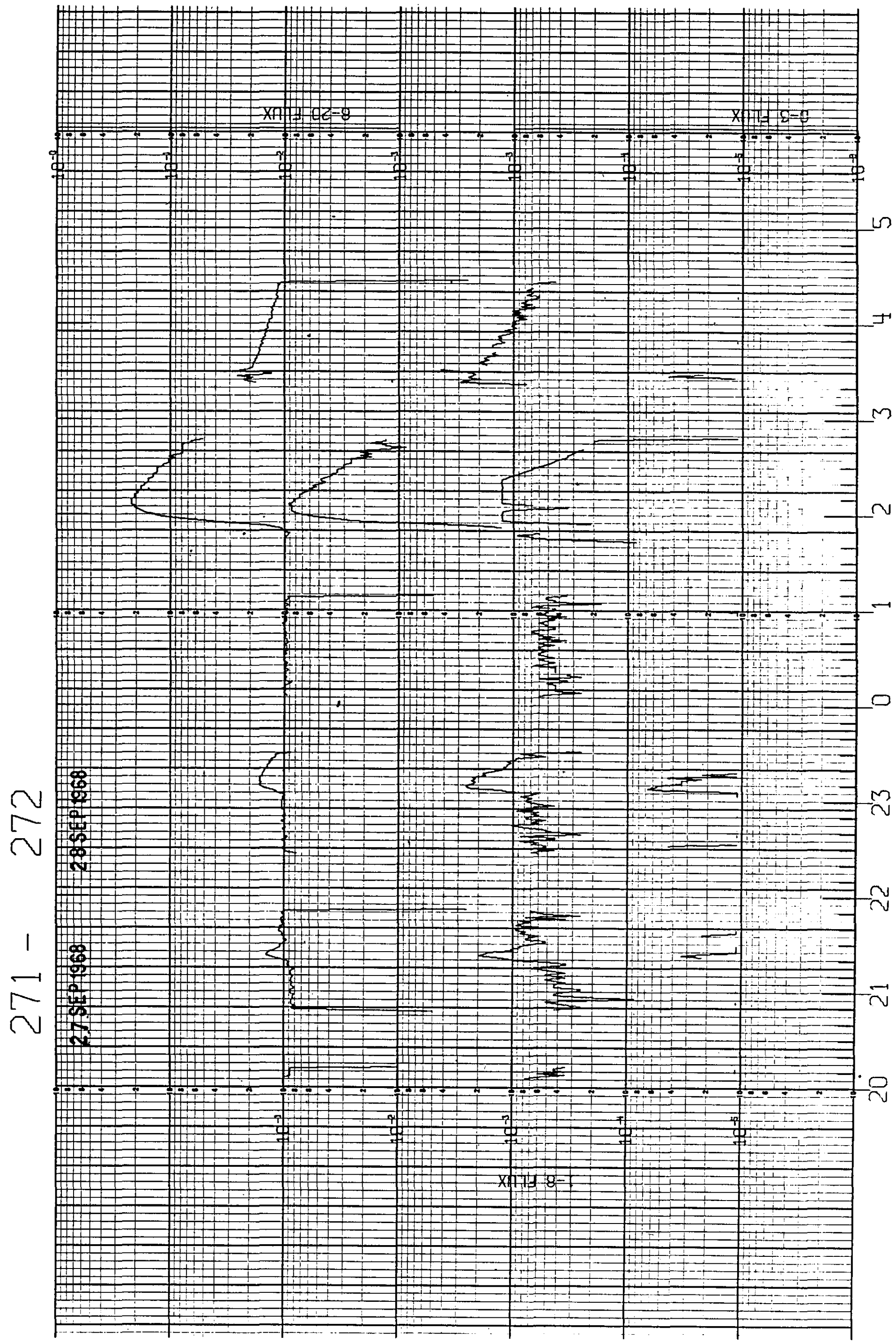


Fig. 4 - Solrad 9 stored x-ray flux data

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13. ABSTRACT

X-ray and particle emission during solar flares can sufficiently increase the electron density in the lower regions of the ionosphere to cause disruption of high-frequency radio communications. For several years NRL has been measuring solar X-ray flux levels in the 0.5 to 3 Å, 1 to 8 Å, 8 to 20 Å, 1 to 20 Å, and 44 to 60 Å bands. Based on these measurements criteria have been established to predict periods of high solar activity during which solar flares capable of disrupting communications might occur. A study of solar-flare occurrence and solar x-ray flux levels over 14 months has shown that solar flares are three times more likely to occur when the criteria are met than when they are not met.

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