REPORT CRPL-1-3 ISSUED DECEMBER 29, 1947



U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
CENTRAL RADIO PROPAGATION LABORATORY
WASHINGTON, D. C.

# SOME METHODS FOR GENERAL PREDICTION OF SUDDEN IONOSPHERIC DISTURBANCES

BY A. H. SHAPLEY AND J. V. LINCOLN

Report No.
CRPL-1-3

NATIONAL BUREAU OF STANDARDS
CENTRAL RADIO PROPAGATION LABORATORY
WASHINGTON 25, D. C.

# SOME METHODS FOR GENERAL PREDICTION OF SUDDEN IONOSPHERIC DISTURBANCES

By A. H. Shapley and J. V. Lincoln

- Foreword -

This report describes the methods of predicting sudden ionospheric disturbances (SID) which are applied in the recently inaugurated SID prediction service of CRPL. A rigorous statistical treatment of the phenomena has not been attempted. Such a study is deferred until the present period of numerous SID has been passed. The new prediction service was undertaken at the request of the Army and Navy communication services because of the large number of service interruptions being experienced.

## INTRODUCTION

Sudden ionospheric disturbances are characterized by approximately simultaneous fadeouts on a large range of useful high frequencies. They cannot be predicted in the strict sense in the light of our present knowledge; that is, the minute or hour of onset of the disturbance cannot be anticipated. In 1935 Dellinger indicated the close association between fadeouts and bright chromospheric eruptions on the sun. The time difference between the two phenomena, when appreciable, is too small for the solar flare to serve as a practical prognostic of SID. More general predictions, however, are feasible: the likelihood that an SID will occur on a given day, or the number to be expected in a given longer interval may be estimated. If it is assumed that the association of SID with short-lived bursts of solar activity has been demonstrated satisfactorily, a prediction may be made on the bases that (1) the associated solar region remains at least intermittently active and on the visible face of the sun for up to 14 days or (2) that the region is again on the face of the sun and potentially active after one or more solar rotation periods or (3) that a larger number of active regions are present on the sun during the maximum stage of the sunspot cycle than at other stages. These general characteristics of active solar regions have been amply confirmed by observation. One may expect, therefore, more than random probability that an SID one day will be followed, for instance, by one the next day or the 27th day following. Also, the annual frequency of occurrence of SID should also be high in the years near the sunspot maximum. The observations of SID on paths terminating at Washington over a sunspot cycle are in accord with this reasoning. Numerical estimates of the various probabilities derived from analysis of Washington data may be considered predictions for these same paths.

The physical processes that take place in the ionosphere during an SID can be summarized as follows: Intense radiation, presumably ultraviolet light from the sun, traverses the F-region of the ionosphere with no appreciable effect on the distribution of electron-density.

The radiation is absorbed at the lower part of or somewhat below the normal E, or $E_1$-layer, and creates a region of unusually high density of electrons. High-frequency radio waves incident on a highly ionized layer at heights less than 100 km are strongly absorbed rather than reflected. The observational evidence indicates that the increased intensity of the ionizing radiation is abrupt; adjacent bands of high frequencies are affected with a time lag of only a few minutes. The lower frequencies are absorbed first; they also recover last from the effects of the SID. If the SID is of low intensity (a partial fadeout), transmission will continue to be possible on the higher frequencies. Only the daylight hemisphere is affected; the absorption during an SID varies roughly as the cosine of the zenith distance of the sun, i.e., the great circle distance to the subsolar point. If we define the control points of a path affected by an SID as those where the path normally traverses the lower E region, it is clear that a path may be in darkness for the greater part of its length, but still will be affected by an SID if one of its control points is in daylight.

SID are distinct from ionospheric storms, although both phenomena are associated with solar activity. SID often occur before, during or after a storm; indeed the occurrence of SID, together with the presence of an associated important solar region not yet near the center of the solar disk, comprises one of the more dependable situations forewarning of an ionospheric storm. Their effects on radio wave propagation are opposite; the higher usable frequencies are affected first by a storm, last by an SID. The SID is usually associated with a specific burst of solar activity while the relation of ionospheric storms and solar activity needs to be expressed in more general terms.

## 2. OBSERVATIONS 1936-1947

The list of SID observed at Washington, started by Dellinger[1], has been extended monthly first in the Proceedings of the Institute of Radio Engineers (to October, 1941) and then in the reports of ionospheric observations issued by the IRPL and the CRPL. Usually these reports are based on inspection of the continuous recordings of the field intensities of high frequency broadcasting stations; an example of one of these records is given in Fig. 1. The stations recorded for long intervals during 1936 to 1947 are W8XAL, Mason Ohio and CFRX, Toronto, Canada. Some of the early reports include SID observed at vertical incidence with multifrequency ionospheric equipment. Since 1944, the field intensity of Station WWI, Beltsville, Maryland, which is only 34 miles from the receiving station at Sterling, Virginia, has provided information on SID nominally overhead at Washington.

Since the primary concern is with the identification of occurrences of the phenomenon, the precise frequencies at which SID are observed over the various paths are unimportant, as long as they are in the high-frequency range. The geographical position of the paths, however, affects the statistics of the frequency of occurrence of SID. The records obtained for any one station constitute a monitor of SID between the times of sunrise at the eastern control point of the paths and sunset at the western control point. For example, the effective coverage of SID at the Washington receiving station was increased while recordings were being made of a station in England.

Similarly, because the effects of an SID increase the nearer a control point is to the subsolar point, a larger number of SID can be detected on the Washington-Mexico City path, which was recorded for part of the period. These non-uniformities were ignored in this analysis; they are assumed negligible in a rough determination of the statistics of the occurrence of SID.

The total number of days on which SID were observed in each year during the period 1936 to 1947 is given in Table 1 and Figure 2. It is apparent that the number of days of SID is closely related to the sunspot number, and, indeed, the number of days per year having SID is roughly given by 0.8R where R is the relative sunspot number. In 1944, at sunspot minimum, a day having at least one SID occurred every two months on the average; in 1946 one out of every four days had an SID, and in 1947, near sunspot maximum, they were even more frequent. Disruptions to communications because of this phenomenon reach practical proportions probably only near the maximum of solar activity. Significantly fewer days of SID took place during the winter season than in summer (Fig. 3). Since all of the paths were in medium northern latitudes, their control points were, on the average, nearer the sub-solar point in summer than in winter. In the period under consideration SID were detected on a somewhat larger number of days in the equinoctial season, comprising March, April, September and October, when ionospheric storms were most prevalent.

The seasonal trend is shown by months in Fig. 4. April and September were the most populous equinoctial months as regards days of SID in 1936-46, while July headed the summer months. The winter minimum in November and December is well marked. The year-to-year monthly record, Figure 5, indicates that the mean monthly distribution is not consistent enough to justify detailed extrapolation to future years. The tendency towards the bunching of SID-days within a month is evident.

Also in Table 1 are listed the number of times in each year that days of SID occurred at intervals of 1, 2, 27 and 54-days. In years of great solar activity (Group A in Section 3 below), nearly half of the SID-days were followed the next day by another SID-day, about 2/5 were followed by one two days later, and almost 1/4 were followed by an SID-day 27 days later and 54 days later. At other stages of the cycle, a smaller number of repetitions at these intervals took place.

A rough classification of individual fadeouts made from the published tables is analyzed in Table 2 where the numbers of days in each year are listed on which were observed intense, extended or multiple SID. The number in parenthesis after each entry is the number of instances an SID of any character was observed on the succeeding day, a direct measure of the persistence of the phenomenon. An SID was classified "intense" when the field intensity of W8XAL during the maximum of the SID was one tenth or less of its normal value. An SID lasting more than one hour was called "extended"; the occurrence of two or more SID on the same day was classified as "multiple" SID.

## 3. PREDICTION METHODS

Predictions of SID-days will be made simply by the application to future years of the statistics of the phenomenon in past years contained in Tables 1 and 2. As has been pointed out, the number of SID-days per year at Washington varied in phase with the sunspot cycle. A superficial examination of Table 1 shows a similar variation in the strength of the tendency for SID-days to recur at intervals of 1, 2, 27, and 54 days. For this reason the solar cycle was divided into 3 groups of years for the purpose of obtaining estimates of the quality of empirical predictions based on the data of Table 1 and 2. Group A contains the years of high sunspot activity, including the year of sunspot maximum and the first year before and after; 1936, 1937, 1938, 1946 and 1947 fall into this class. Group B includes 1939, 1940, 1941 and 1942, the descending years of the sunspot cycle. The years 1943, 1944 and 1945, are in Group C, and comprise the year of minimum epoch ± one year. Because of the rapid increase in sunspot activity after 1944, the ascending portion of the last cycle could not be separately recognized.

The following prediction methods were proposed a priori (except Nos. 6 and 7), all based on repetition and recurrence tendencies of the phenomenon: an SID-day is expected

(1) 1 day after an SID-day
(2) 1 day after an intense SID
(3) 1 day after an extended SID
(4) 1 day after a multiple SID
(5) 1 day after an extended or multiple SID
(6) 2 days after an SID-day
(7) 1 and 2 days after an SID-day
(8) 27 days after an SID-day
(9) 54 days after an SID-day
(10) 1 and 27 days after an SID-day
(11) 1 and 54 days after an SID-day
(12) 1, 27 and 54 days after an SID-day
(13) 27 and 54 days after an SID-day

The results of trials of the various prediction methods are given in Table 3, for the whole span of observations, and separately for Groups A, B, and C respectively. In every instance the prediction of an SID-day is considered a success if one or more SID of any intensity or duration whatever occur at any time during the designated day. The worth of a prediction method may be judged by "hits" (predictions substantiated), "superfluous" (predictions not substantiated) and "misses" (failure to predict). It is not much use, for instance, to predict that every day in the year will be an SID-day even though there will be no "misses" to the discredit of the method. On the other hand a single prediction though successful and thus rating 100% on "hits" would not be adequate either. The performance of the various methods on past observations is indicated in Table 3, in which are shown the average or expected number of SID-days per year, the number of predictions by the method, the success of these predictions, the percentage of predictions which were superfluous and the percentage of SID-days not anticipated by the method. An accurate method will have a large hit-to-prediction ratio, while a comprehensive method will have a small miss-to-SID day ratio. A relatively efficient method will be jointly accurate and comprehensive for a given number of predictions attempted.

Of the 13 methods evaluated, Nos. 1 to 4, 6, 8 and 9 are taken directly from Tables 1 and 2. In compiling the statistics for the remainder, the combined methods, the number of predictions and the number of successes have been reduced so that no day is counted twice. Methods 1 to 7 cannot anticipate the first SID-day in a succession of such days and from a practical standpoint may therefore have a limited value. The methods which can predict the first of a sequence err in predicting too many occurrences. A number of such erroneous predictions might be eliminated by application of some simple criterion of minimum chromospheric activity just preceding the predicted day. Unfortunately, consistent solar records were not available for all the period considered.

The most significant results are those given in Table 3, for Group A, the years of high sunspot activity when SID are common. Prediction method No. 4 is the most accurate of all the methods and No. 12 the most comprehensive, in the senses defined above. Neither one is efficient since the former was applicable in only a few instances and the latter resulted in a large number of erroneous predictions. No. 2 and, especially, No. 5 are the efficient methods among those which strive for accuracy. No. 7 seems to be the best of the comprehensive methods (Nos. 1 and 6-13). Of the prediction methods Nos. 8, 9 and 13, applicable more than two days in advance, No. 13 works out the best. The relative advantages of the various methods remain about the same in the other stages of the sunspot cycle; however, it hardly seems worthwhile to attempt predictions in years of low sunspot activity.

A few other methods have been tried with inconclusive or unsatisfactory results. Method No. 1 was tried separately for each of the three seasonal groups of months; the predictions were not significantly more successful in any one season. In classifying the SID of the published lists, those which lasted 0-30 minute (36% of total number of SID) and 31-60 minute (35%), as well as the extended SID (29%) were noted. It was found that the predictions made for the day following brief or middle-length SID failed more often than those based on extended SID.

The best of the methods of predicting SID-days, then, appear to be Nos. 5, 7, and 13, based on the tendency for a sequence of SID-days to continue, especially if the SID are multiple or extended, and on the weak 27 and 54-day recurrence tendency. The choise of the method of prediction needs to be determined by the ultimate use which is to be made of the predictions, considering the relative advantages and disadvantages either of predicting too many occurrences or failing to predict enough. SID occur more often and the quality of predictions is higher in the years of great sunspot activity. It is to be noted that these are empirical predictions and depend for their validity on an assumption that the past 12 years give a fair sample of the tendencies of the phenomenon. In any event, they apply specifically only to the group of paths terminating at Washington on which the listed SID were observed.

## Reference

(1) J.H. Dellinger, "Sudden disturbances of the ionosphere", J. Research National Bureau of Standards, 19, 111, 1937.

Table 1.--Days of SID observed at Washington and number of cases in which SID again occurred 1, 2, 27 and 54 days later, 1936-47.

| Year | Total SID-days | Repetition Intervals | | | |
|---|---|---|---|---|---|
| | | 1 day | 2 days | 27 days | 54 days |
| 1936 | 47 | 12 | 11 | 6 | 3 |
| 1937 | 84 | 40 | 38 | 19 | 23 |
| 1938 | 73 | 28 | 29 | 6 | 12 |
| 1939 | 53 | 24 | 16 | 8 | 6 |
| 1940 | 44 | 10 | 10 | 7 | 4 |
| 1941 | 25 | 7 | 5 | 4 | 1 |
| 1942 | 28 | 3 | 5 | 4 | 2 |
| 1943 | 9 | 1 | 2 | 0 | 1 |
| 1944 | 5 | 1 | 0 | 0 | 0 |
| 1945 | 17 | 5 | 3 | 1 | 0 |
| 1946 | 92 | 36 | 27 | 26 | 20 |
| 1947* | 140 | 85 | 77 | 55 | 55 |
| 1936-47* | 617 | 252 | 223 | 136 | 127 |
| Group A* (max.) | 436 | 201 | 182 | 112 | 113 |
| Group B (desc.) | 150 | 44 | 36 | 23 | 13 |
| Group C (min.) | 31 | 7 | 5 | 1 | 1 |

*Estimate for 1947 is 1.4 times total for Jan.-Aug. 1947

Table 2.--Days of intense, extended and multiple SID observed at Washington and number of cases in which SID occurred one day later (in parenthesis), 1936-1947.

| Year | Intense SID | Extended SID | Multiple SID |
|---|---|---|---|
| 1936 | - | 12 (5) | 7 (4) |
| 1937 | 66 (30) | 33 (16) | 39 (21) |
| 1938 | 62 (25) | 19 (7) | 21 (13) |
| 1939 | 44 (18) | 11 (5) | 15 (9) |
| 1940 | 35 (6) | 4 (1) | 6 (2) |
| 1941 | 21 (5) | 8 (4) | 1 (0) |
| 1942 | 11 (3) | 8 (2) | 0 (0) |
| 1943 | 7 (1) | 2 (0) | 1 (0) |
| 1944 | 3 (1) | 2 (0) | 0 (0) |
| 1945 | 10 (4) | 4 (1) | 6 (5) |
| 1946 | 62 (18) | 31 (15) | 31 (13) |
| 1947* | 83 (59) | 43 (35) | 70 (53) |
| 1936-47* | 404 (170) | 177 (91) | 197 (120) |
| Group A* (max.) | 273 (132) | 138 (78) | 168 (104) |
| Group B (desc.) | 111 (32) | 31 (12) | 22 (11) |
| Group C (min.) | 20 (6) | 8 (1) | 7 (5) |

*Estimate for 1947 is 1.4 times total for Jan.-Aug. 1947.

Table 3--Evaluation of prediction methods

| | (1) All Years | | | | | (2) Group A years | | | | | (3) Group B years | | | | | (4) Group C years | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Method* | SID days per year | Predictions per year | Hits/predictions | Superfluous/predictions | Misses/SID days | SID days per year | Predictions per year | Hits/predictions | Superfluous/predictions | Misses/SID days | SID days per year | Predictions per year | Hits/predictions | Superfluous/predictions | Misses/SID days | SID days per year | Predictions per year | Hits/predictions | Superfluous/predictions | Misses/SID days |
| 1 | 51 | 51 | 0.41 | 0.59 | 0.59 | 87 | 87 | 0.46 | 0.54 | 0.54 | 38 | 38 | 0.29 | 0.71 | 0.71 | 10 | 10 | 0.23 | 0.77 | 0.77 |
| 2 | 51 | 36 | 0.42 | 0.58 | 0.70 | 87 | 68 | 0.48 | 0.52 | 0.66 | 38 | 28 | 0.29 | 0.71 | 0.79 | 10 | 7 | 0.30 | 0.70 | 0.81 |
| 3 | 51 | 15 | 0.51 | 0.49 | 0.85 | 87 | 28 | 0.57 | 0.43 | 0.82 | 38 | 8 | 0.38 | 0.62 | 0.92 | 10 | 3 | 0.12 | 0.88 | 0.97 |
| 4 | 51 | 16 | 0.61 | 0.39 | 0.81 | 87 | 34 | 0.62 | 0.38 | 0.75 | 38 | 6 | 0.50 | 0.50 | 0.93 | 10 | 2 | 0.71 | 0.29 | 0.84 |
| 5 | 51 | 25 | 0.52 | 0.48 | 0.75 | 87 | 46 | 0.56 | 0.44 | 0.70 | 38 | 13 | 0.39 | 0.61 | 0.87 | 10 | 5 | 0.36 | 0.64 | 0.84 |
| 6 | 51 | 51 | 0.36 | 0.64 | 0.64 | 87 | 87 | 0.42 | 0.58 | 0.58 | 38 | 38 | 0.24 | 0.76 | 0.76 | 10 | 10 | 0.16 | 0.84 | 0.84 |
| 7 | 51 | 82 | 0.35 | 0.65 | 0.44 | 87 | 134 | 0.40 | 0.60 | 0.38 | 38 | 64 | 0.26 | 0.74 | 0.56 | 10 | 19 | 0.16 | 0.84 | 0.71 |
| 8 | 51 | 51 | 0.22 | 0.78 | 0.78 | 87 | 87 | 0.26 | 0.74 | 0.74 | 38 | 38 | 0.15 | 0.85 | 0.85 | 10 | 10 | 0.03 | 0.97 | 0.97 |
| 9 | 51 | 51 | 0.21 | 0.79 | 0.79 | 87 | 87 | 0.26 | 0.74 | 0.74 | 38 | 38 | 0.09 | 0.91 | 0.91 | 10 | 10 | 0.03 | 0.97 | 0.97 |
| 10 | 51 | 91 | 0.31 | 0.69 | 0.44 | 87 | 152 | 0.36 | 0.64 | 0.36 | 38 | 69 | 0.21 | 0.79 | 0.61 | 10 | 20 | 0.13 | 0.87 | 0.74 |
| 11 | 51 | 92 | 0.30 | 0.70 | 0.46 | 87 | 153 | 0.35 | 0.65 | 0.38 | 38 | 70 | 0.20 | 0.80 | 0.63 | 10 | 20 | 0.13 | 0.87 | 0.74 |
| 12 | 51 | 132 | 0.24 | 0.76 | 0.39 | 87 | 217 | 0.28 | 0.72 | 0.30 | 38 | 102 | 0.15 | 0.85 | 0.59 | 10 | 30 | 0.10 | 0.90 | 0.71 |
| 13 | 51 | 92 | 0.21 | 0.79 | 0.63 | 87 | 152 | 0.25 | 0.75 | 0.56 | 38 | 69 | 0.12 | 0.88 | 0.77 | 10 | 20 | 0.03 | 0.97 | 0.94 |

* Method 1, one day after SID-day; Method 2, one day after intense SID; Method 3, one day after extended SID; Method 4, one day after multiple SID; Method 5, (3) and (4) corrected for duplicates; Method 6, two days after SID-day; Method 7, (1) and (6) corrected for duplicates; Method 8, twenty-seven days after SID-day; Method 9, fifty-four days after SID-day; Method 10, (1) and (8) corrected corrected for duplicates; Method 11, (1) and (9) corrected for duplicates; Method 12, (1), (8) and (9) corrected for duplicates; Method 13, (8) and (9) corrected for duplicates.

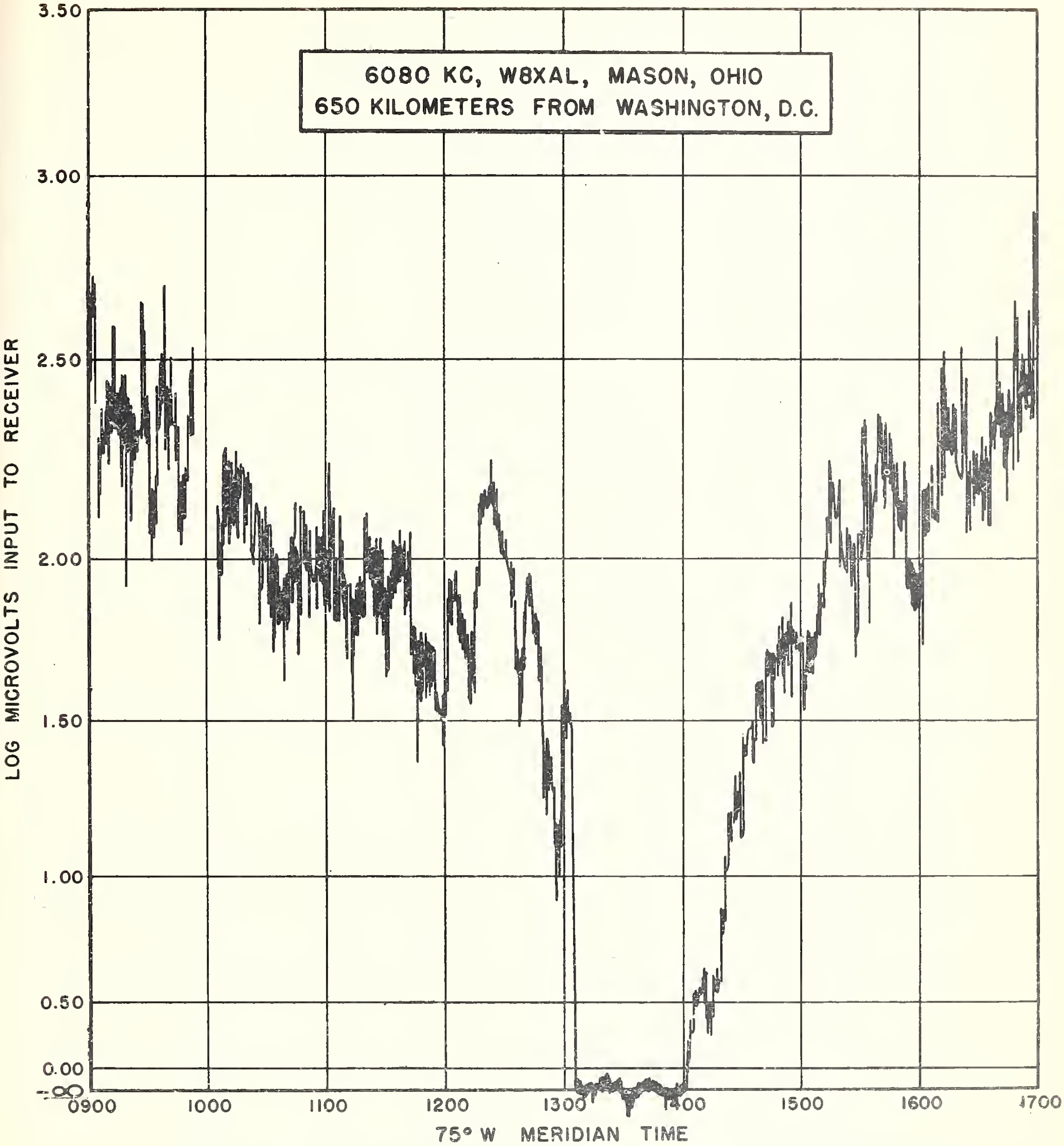


Fig. 1. SUDDEN IONOSPHERIC DISTURBANCE OBSERVED FEBRUARY 28, 1946.

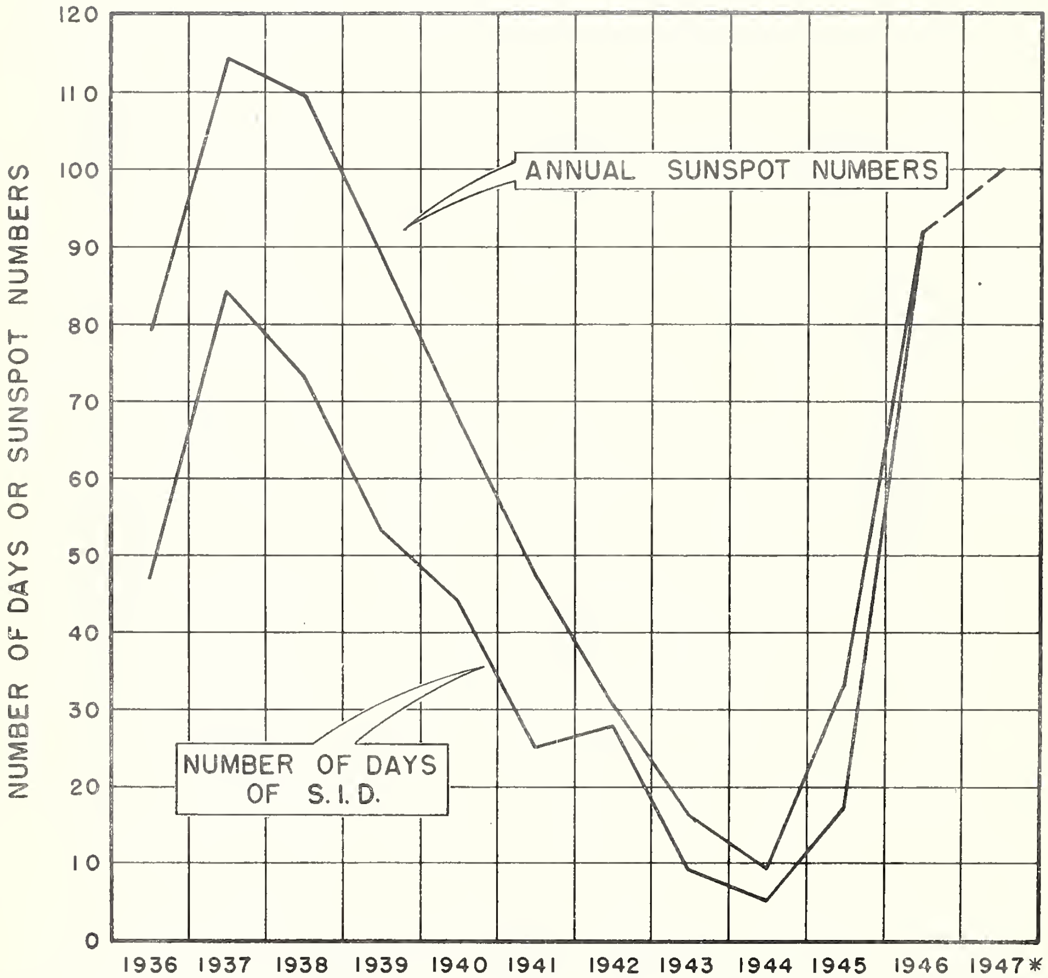


Fig. 2. NUMBER OF DAYS OF S.I.D. PER YEAR OBSERVED AT WASHINGTON, D.C. AND ZÜRICH ANNUAL SUNSPOT NUMBERS.

* DATA THROUGH AUGUST

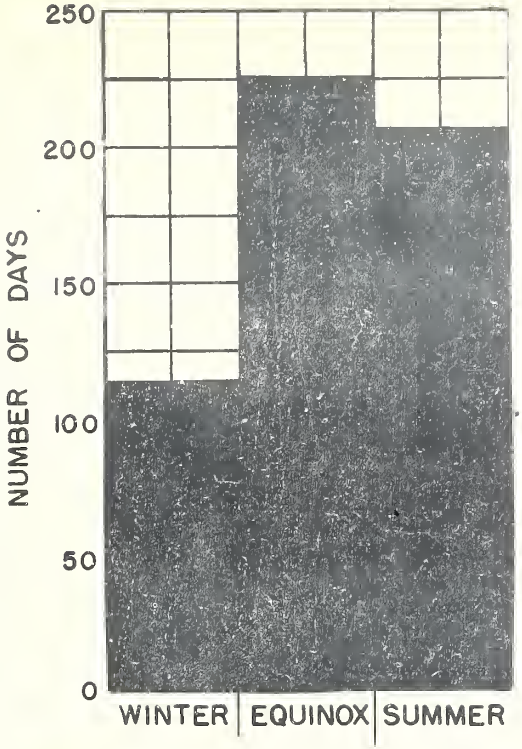


Fig. 3. NUMBER OF DAYS OF S.I.D. BY SEASON, JAN. 1936 - JUNE 1947, OBSERVED AT WASHINGTON, D.C.

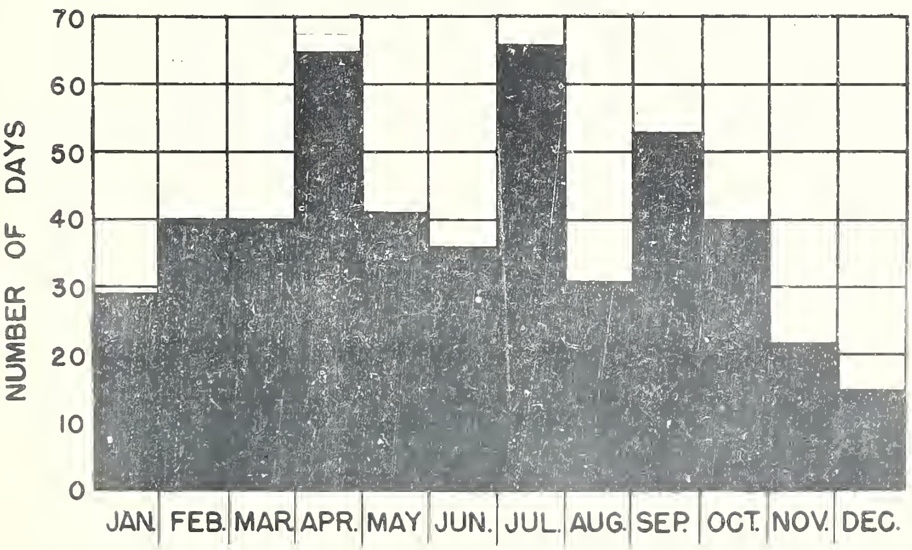


Fig. 4. TOTAL MONTHLY DISTRIBUTION OF THE NUMBER OF DAYS OF S.I.D. FOR THE YEARS 1936-1946, OBSERVED AT WASHINGTON, D.C.

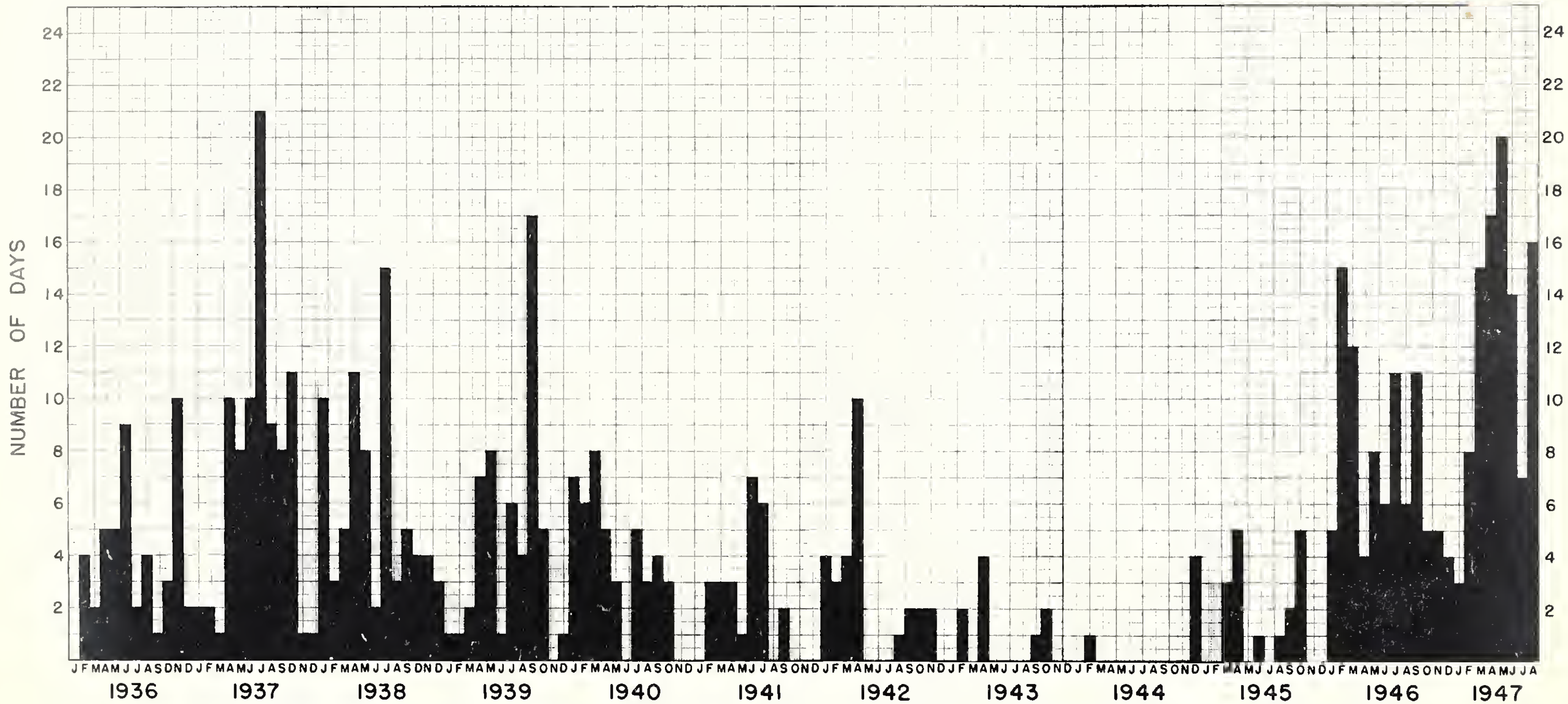


Fig. 5 NUMBER OF DAYS OF S.I.D. PER MONTH, JANUARY 1936–AUGUST 1947, OBSERVED AT WASHINGTON, D.C.