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No. 326

AN ATLAS OF SOLAR FLARE EFFECTS IN THE IONOSPHERE OBSERVED WITH A HIGH-FREQUENCY DOPPLER TECHNIQUE

September 1960 – December 1962

BY
DONALD M. BAKER

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS

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An Atlas of Solar Flare Effets in the Ionosphere Observed with a High – Frequency Doppler Technique September 1960 – December 1962

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AN ATLAS OF SOLAR FLARE EFFECTS IN THE IONOSPHERE OBSERVED WITH A HIGH-FREQUENCY DOPPLER TECHNIQUE

SEPTEMBER 1960 - DECEMBER 1962

Donald M. Baker

Records of selected solar flare effects (sudden frequency deviations) in the ionosphere detected by a high frequency Doppler technique from September 1960 through December 1962 are presented. When available, records of short wave fadeouts (SWF) are also given.

Key Words: solar flare effects in the ionosphere, shortwave fadeouts, sudden frequency deviations, Doppler technique.

1. Introduction

The purpose of this atlas is to present a selection of the records of sudden frequency deviations (SFD) which have been observed from September 1960 through December 1962. Where available, records of the received signal strength have been included to show whether or not a sudden frequency deviation was accompanied by a short wave fadeout (SWF). Sudden frequency deviations are associated with solar flares, and the temporal variations of the SFD are thought to reflect the corresponding fluctuations in the solar ionizing radiation responsible for the enhanced production of electrons in the E and F regions of the ionosphere. Some flares produce both SWF and SFD, some SWF without SFD, and others SFD without SWF. These records (both SWF and SFD) should be of value in helping to distinguish between ionospheric disturbances of natural origin and those resulting from nuclear explosions. The records will also be of value for studies of the ionosphere, for comparison with other sudden ionospheric disturbance data and solar radio emission records, and for detailed comparison with optical observations of the solar flares.

Sudden frequency deviations are detected by means of the high-frequency Doppler technique described by Watts and Davies [1960]. The frequency of an ionospherically propagated radio signal is monitored by comparing the received frequency with the signal from a stable local oscillator and recording the resultant beat signal on magnetic tape. Changes in the propagation medium cause variations in the received frequency which are detected as variations in the recorded beat frequency. The local oscillator is set a few cycles per second below the transmitted frequency to permit the sense of a frequency variation (positive or negative) to be determined. The solar-flare-induced disturbances detected by the technique have been given the name "sudden frequency deviations", abbreviated SFD, by Chan and Villard [1963].

The radio signals used in this technique (2-20 Mc/s) are usually reflected from the F region of the ionosphere, and, therefore, the signals are subject to changes in the D, E, and F regions. Our present knowledge indicates that the changes which cause sudden frequency deviations occur chiefly in the E and F regions (i.e. above the 100 km level). Thus, SFD's provide information on solar-flare-induced disturbances not provided by short wave fadeouts (SWF), sudden phase anomalies (SPA), sudden cosmic noise absorption (SCNA), or sudden enhancements of atmospherics (SEA)--- all of which detect changes in the D region.

The events in this atlas were selected on the basis of size, prospective usefulness, quality of the records, and uniqueness. An index of the events included is given on pages 12 to 13. The paths, frequencies, and path lengths used, and the period of operation of each path-frequency combination are given in Table 1.

2. Characteristics of Sudden Frequency Deviations

A sudden frequency deviation is, by definition, associated with a solar flare. However, all solar flares do not produce sudden frequency deviations. Table 2 gives the percentage of the solar flares reported from October 1960 through December 1962 which were accompanied by SFD's.

Table 1

Paths and Frequencies in Operation from September 1960 thru December 1962

Path Transmitter - Receiver	Path Length (km)	Frequency (Mc/s)	Effective Period of Operation (1960 - 1962)
WWV to Boulder	2430	20	1 September 1960 - 2 June 1961 8 September 1961 - 17 January 1962
		15*	21 December 1960 - 30 January 1961 17 January 1962 - 31 December 1962
		10*	30 January 1961 - 31 December 1962
WWV to Shickley	1780	10*	12 August 1961 - 18 April 1962
Sunset to Boulder	25	5.054	4 August 1961 - 31 December 1962
		4.000	30 July 1961 - 31 December 1962
WWVH to Anchorage	4480	15**	8 June 1962 - 3 December 1962
WWVH to Midway	2200	15**	31 May 1962 - 10 July 1962
		10**	31 May 1962 - 10 July 1962
		5**	31 May 1962 - 10 July 1962
WWVH to Wake	3900	10**	26 May 1962 - 29 July 1962

* Subject to interference from WWVH
** Subject to interference from JJY (Tokyo)

Transmitter locations:

WWV (Beltsville, Md.)	38°59'33" N, 76°50'52" W
Sunset, Colorado	40°02' N, 105°27' W
WWVH (Maui, Hawaii)	20°46' N, 156°28' W
JJY (Tokyo, Japan)	35°42' N, 139°31' E

Receiver locations:

Shickley, Nebraska	40°26' N, 97°39' W
Boulder, Colorado	40°03' N, 105°11' W
Anchorage, Alaska	61°10' N, 150°00' W
Midway Island	28°15' N, 177°25' W
Wake Island	19°18' N, 166°36' E

Table 2

Percentage of flares reported from October 1, 1960 through December 31, 1962 which were accompanied by SFD's.

Flare Hα Importance	Number of Flares	Percentage with SFD
1-	2994	10
1	648	21
2	55	49
3	10	80
1, 2, 3	713	24
1-, 1, 2, 3	3707	13

Sudden frequency deviations show great variation in shape, size, and duration. The most distinctive characteristic of an SFD is a rapid increase in the received frequency. This positive frequency deviation is usually followed by a smaller negative deviation and a gradual recovery to the pre-flare frequency. However, some SFD's show only a positive deviation followed by a return to the pre-flare frequency. Some SFD's have only one peak while others are complex events with multiple peaks of varying sizes. The time variation of the frequency during the positive phase of an SFD is thought to be closely related to the time variation of the ionizing radiation which causes the SFD.

The size of an SFD is dependent on the frequency, path length, and the solar zenith angle as well as the size and rate of change of the flare-produced burst of ionizing radiation. The maximum positive frequency deviations observed on WWV-10 Mc/s received at Boulder have ranged from a few tenths of a cycle per second to over 50 cycles per second. Most SFD's are less than 1 cycle per second; an SFD of over 1 cycle per second is considered to be a large event. Large SFD's are observed during both large and small optical flares, but a large flare (importance 2 or 3) is more likely to be accompanied by a large SFD than is a small flare.

The duration of SFD's has been observed to range from less than one minute up to more than 15 minutes. The most frequent duration is of the order of 4 minutes, and the most frequent time taken to rise to the peak is from 1 to 2 minutes. Sudden frequency deviations almost always occur between the start and maximum phase of the optical flare as seen in $H\alpha$ (6563 Å) with the peak of the SFD usually preceding the $H\alpha$ peak by 1 or 2 minutes.

More complete discussions of the characteristics and interpretation of sudden frequency deviations and the statistics of their occurrence have been given by Kanellakos, Chan, and Villard [1962]; Kanellakos [1963]; Chan and Villard [1963]; Knecht and Davies [1961 a,b]; Davies [1962, 1963]; Davies, Watts, and Zacharisen [1962]; and Agy, Baker, and Jones [1965]. A catalog of SFD's detected at Boulder from October 1960 through December 1962 has been given by Agy, Baker, and Jones [1965].

3. Description of Records

The Doppler records (figure 2) show the variation of the received frequency (in cycles per second) as a function of time; time increases from left to right, frequency increases upward. Universal Time (UT) is used throughout. The timing accuracy of the records included in this atlas is ± 1 minute; more accurate times can be obtained from the original records, but the labor involved prohibits obtaining such accuracy on a routine basis. The WWV transmission is interrupted for approximately 4 minutes each hour beginning at 45 minutes past the hour. All WWV records were originally timed from the beginning of a transmission break, and some records include either a complete transmission break (figure 11) or the start of a break (figure 41 c,d,e). The Sunset, Colorado transmitters were keyed every 10 minutes for purposes of identification, and these keying breaks often show up on the records (figure 28; 1430 and 1440 UT).

Many records have more than one trace. On the Sunset to Boulder records the existence of two traces usually means that both ground wave and sky wave were being received (figure 28 a); the steady, undeviated trace is the ground wave while the deviated trace is the sky wave. During some flares the increase of ionospheric absorption is so great that only the ground wave is received (figure 57 a,b). The existence of multiple traces on the WWV to Boulder and WWV to Shickley records can be due either to the reception of more than one propagation mode or to an interfering signal. When two traces are observed during an SFD (figure 18), the one which undergoes the larger deviation is usually due to a signal reflected from the F region while that with the smaller, or no, deviation is the result of a reflection from the E layer. In most cases the existence of three or more traces is caused by the reception of several transmission modes (one-hop, two-hop, etc., and possibly ordinary and extraordinary rays) which are affected differently by the flare-induced ionization. Traces due to an E-layer (undeviated) and three different F-layer modes can be seen in figure 67 d. Traces due to two E-layer modes and single F-layer mode are present in figure 35 c.

Several countries have standard frequency stations on 10 and/or 15 Mc/s. Consequently, signals from two or more transmitters are occasionally received at these frequencies. The daily and hourly transmission schedules of the possible sources of interference on 10 and 15 Mc/s are shown in figure 1. At Boulder both WWV and WWVH are frequently received simultaneously, and occasionally a signal of unknown origin has appeared on the records at a time when both WWV and WWVH were off the air. An example of the simultaneous reception of WWV and WWVH is shown in figure 23; the presence of WWVH is indicated by the additional transmission breaks at 1515 and 1530. An example of the reception of a strong signal of unknown origin is shown in figure 45 d; a clean transmission break from 1445 to 1449 is seen on 15 Mc/s (figure 44 e) indicating the reception of WWV only; however, no such break is observed on 10 Mc/s, and it is impossible to be sure that the signal after 1449 is WWV. The presence of non-WWV transmission breaks, or the absence of WWV breaks at the expected times, usually provides the only available indication of the presence of an unwanted signal. When signals from two or more transmitters are present, the only way to separate them, when possible, is by a close inspection of the original records for several hours before and after the period of interest. In the cases where more than one transmission was received, the usefulness of the records for detailed study of the ionosphere is severely restricted; however, the records are still useful for time comparisons with other SID data, with solar radio emission records, and with optical flare observations. Lack of space has often prohibited the inclusion of time breaks on the records in this atlas. During the day the signal received on 10 and 15 Mc/s is predominantly WWV, but there will be instances where interference from WWVH (and occasionally from other stations) is present. There are usually no interference problems on 4.000, 5.054, or 20 Mc/s. An exceptional case of severe interference on 4 Mc/s can be seen in figure 37 a.

A third source of multiple traces, on any of the frequencies, is equipment. At times the records show one or more harmonics of the fundamental trace (figure 33 c,d). These multiple traces are easily

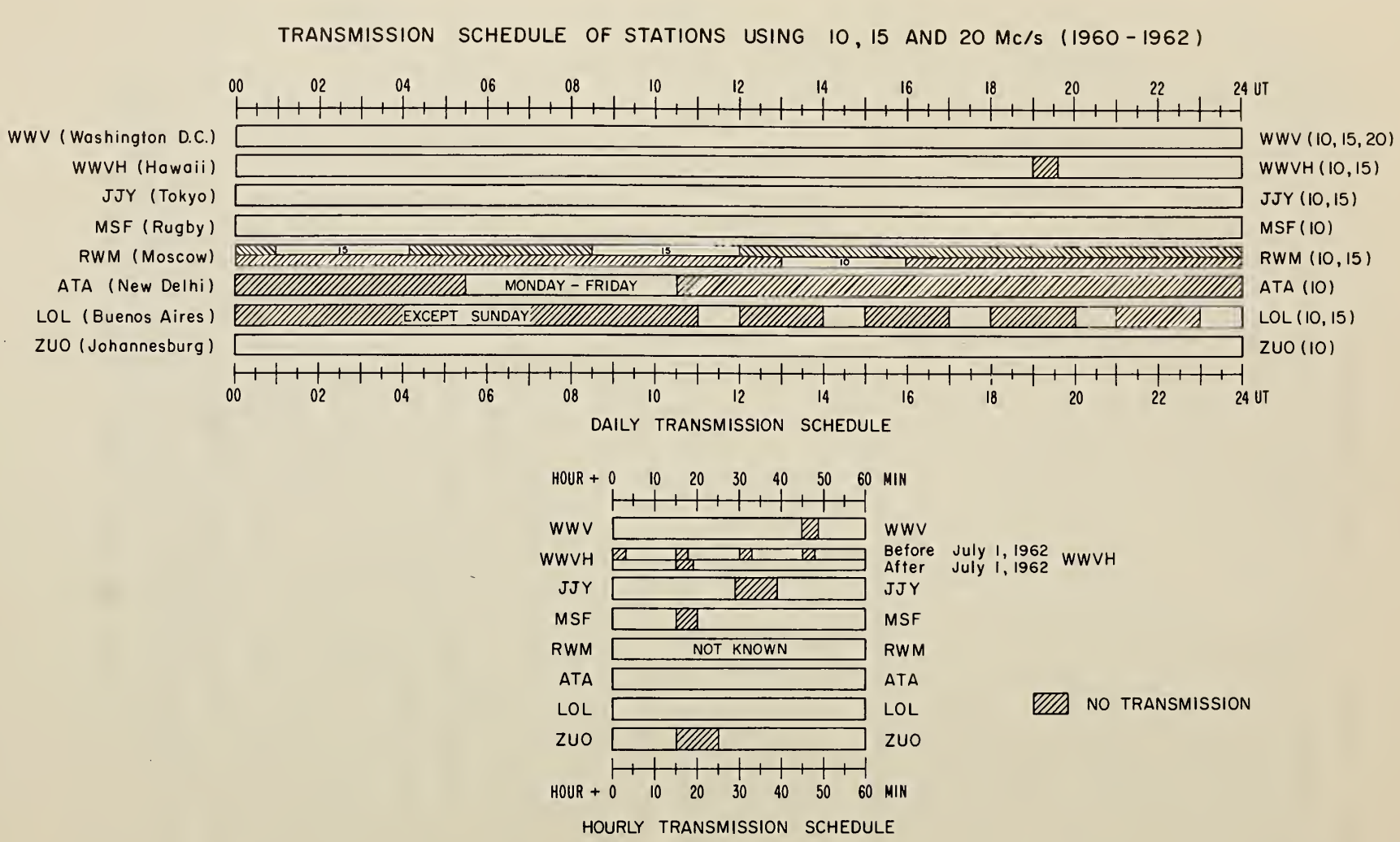
TRANSMISSION SCHEDULE OF STATIONS USING 10, 15 AND 20 Mc/s (1960 - 1962)
00 02 04 06 08 10 12 14 16 18 20 22 24 UT
WWV (Washington D.C.)
WWVH (Hawaii)
JJY (Tokyo)
MSF (Rugby)
RWM (Moscow)
ATA (New Delhi)
LOL (Buenos Aires)
ZUO (Johannesburg)
MONDAY - FRIDAY
EXCEPT SUNDAY
WWV (10, 15, 20)
WWVH (10, 15)
JJY (10, 15)
MSF (10)
RWM (10, 15)
ATA (10)
LOL (10, 15)
ZUO (10)
DAILY TRANSMISSION SCHEDULE
HOUR + 0 10 20 30 40 50 60 MIN
WWV
WWVH
JJY
MSF
RWM
ATA
LOL
ZUO
NOT KNOWN
Before July 1, 1962
After July 1, 1962
WWVH
NO TRANSMISSION
HOURLY TRANSMISSION SCHEDULE

Figure 1

distinguished from those of other sources and usually create no problems; however, during some large SFD effects (figure 67 c) the fundamental and harmonics do get mixed together so that it becomes difficult to determine the magnitude of the frequency deviation.

A second type of instrumental effect occurs when a negative frequency deviation becomes larger than the frequency offset between the transmitted frequency and the reference oscillator. In such a case, the negative deviation is mirrored in the zero frequency axis so that it looks like a positive deviation on the records. An example of this effect is shown in figure 55 c; what appears to be a positive deviation between 1936:00 and 1936:20 is probably a negative phase.

The signal strength records (figure 34 c) were derived from the feedback voltage of the automatic gain controls of the receivers. They show the relative signal strength (in decibels above 1 microvolt) as a function of time; signal strength increases upward and time increases from right to left. Although a time scale is printed on the chart paper, the recorders often deviate from this scale. In using these records, the times indicated at the bottom should be used. On the WWV to Boulder records, the transmission breaks at 45 minutes past the hour serve to establish the time scale. On the Sunset to Boulder records, the keying breaks repeat at approximately 10 minute intervals, but the exact times at which they begin vary from day to day.

The signal strength records show whether an SFD was accompanied by an appreciable increase in absorption (a short wave fadeout or SWF) and give an order of magnitude estimate of the increase in absorption. These records show no measurable increase of absorption during many SFD's (figures 51 and 52 for example), whereas during some flares there is a large increase in absorption but no sudden frequency deviation (figures 33 and 34).

The signal strength of WWV shows regular fluctuations with a period of 5 minutes. These fluctuations are caused by the modulation schedule of WWV. Any features on the signal strength records which are of equipmental origin are marked by the letter C. All signal strength records

included in the atlas are either reproductions of the original records or tracings from the original records. All tracings are identified as such in the figures.

4. Acknowledgement

The preparation and publication of this atlas were supported by the Advanced Research Projects Agency, Nuclear Test Detection Office under Contract No. 183.

5. References

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6. Index of Events

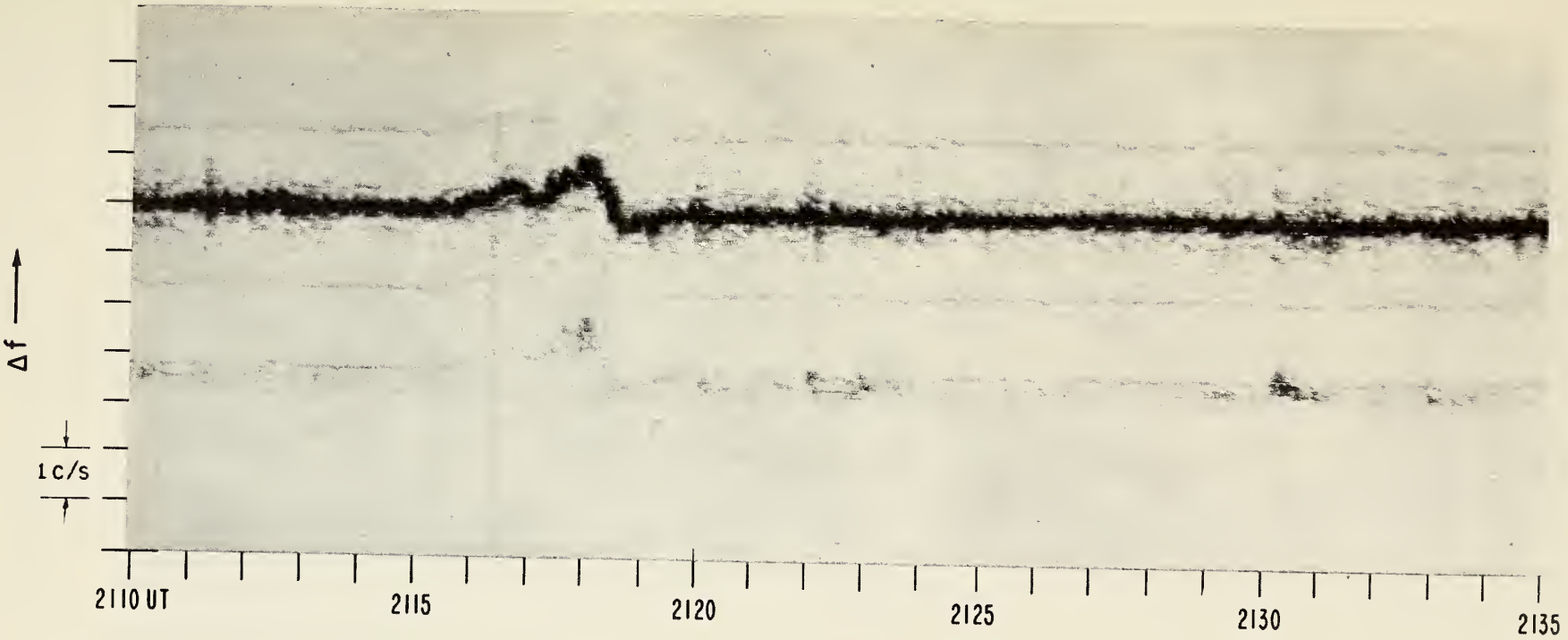
Date	Start Time UT	SFD Records	Signal Strength Records
1960 September 24	2115	15	
September 27	1702	16	
September 27	2058	17	
November 11	1512	18	
November 11	1709	19	
November 12	1324	20	
1961 January 30	1423	21	
January 30	2003	22	
January 31	1512	23	
January 31	2133	24	
April 3	1710	25	
April 5	1621	26	
April 26	1650	27	
May 4	2204	28	
May 10	1858	29	
May 28	1906	30	
June 15	1718	31	
June 29	2108	32	
July 1	2132	33	
July 10	1732	34	
July 13	2212	35	
July 15	1508	36	
July 16	1557	37	
July 17	1913	38	
July 19	2055	39	
July 21	1715	40	
September 4	1431	42,43	44
September 4	1513	46,47	44
September 4	1902	48,49	44

Date	Start Time UT	SFD Records	Signal Strength Records
1961 September 4	1914	50,51	44
September 10	1950	52,53	54,55
September 27	1952	56,57	58,59
September 28	2213	60,61	62,63
November 22	2015	64,65	66,67
1962 February 21	1829	68,69	
February 23	1830, 1842	70,71	
February 28	1936	72,73	
March 1	1635	74,75	
March 13	1449	76,77	78
April 14	1257	80,81	82,83
April 14	1916	84,85	86,87
April 15	2050	88,89	90,91
April 17	2253	92,93	94,95
April 19	1935	96,97	98,99
April 20	1959	100,101	102,103
April 27	1411	104	105
May 1	1914	106	107
July 5	1937	108,109,110	111
August 13	2039	112	113
October 13	1805	114,115	116

7.

ATLAS

OPTICAL FLARE, IMPORTANCE 2, 2116-2118-2139D

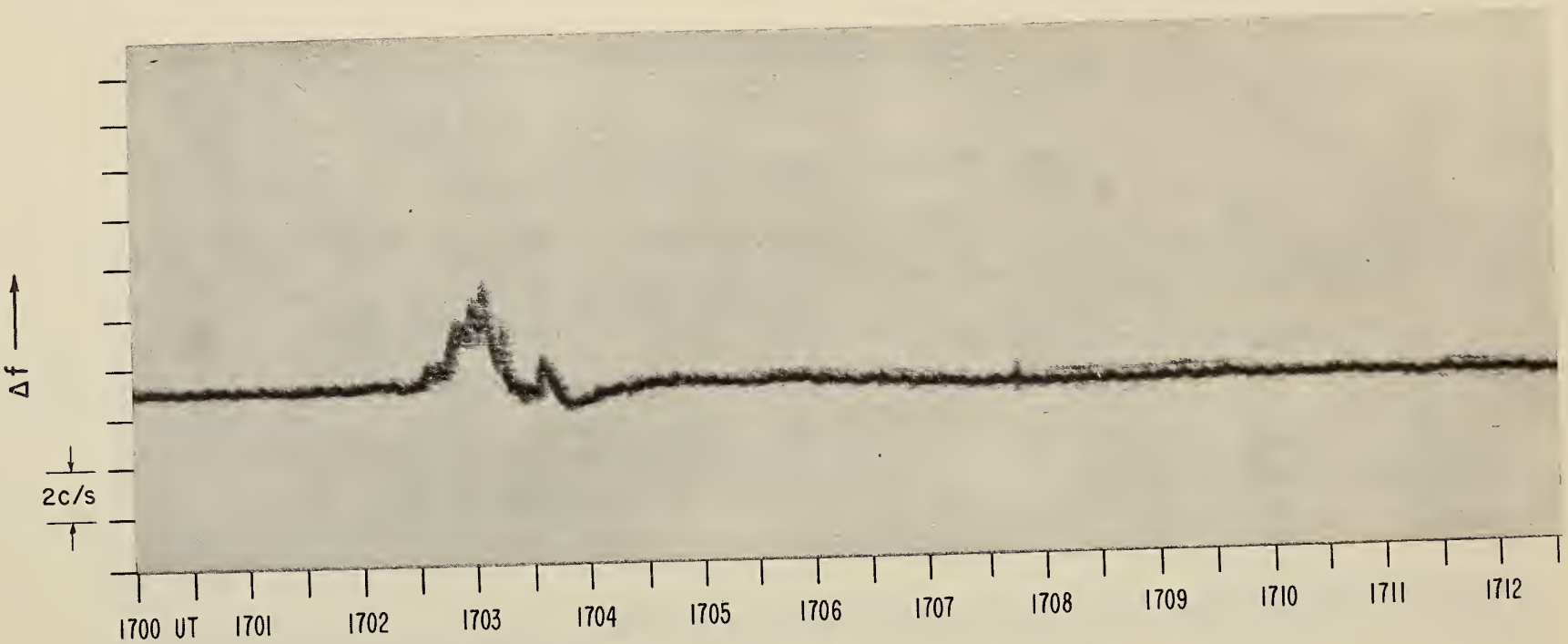


(a) 20 Mc/s, WWV TO BOULDER

24 SEPTEMBER 1960

Figure 2

OPTICAL FLARE, IMPORTANCE 1 , 1702 - 1705 - 1723



(a) 20 Mc/s, WWV TO BOULDER

27 SEPTEMBER 1960

Figure 3

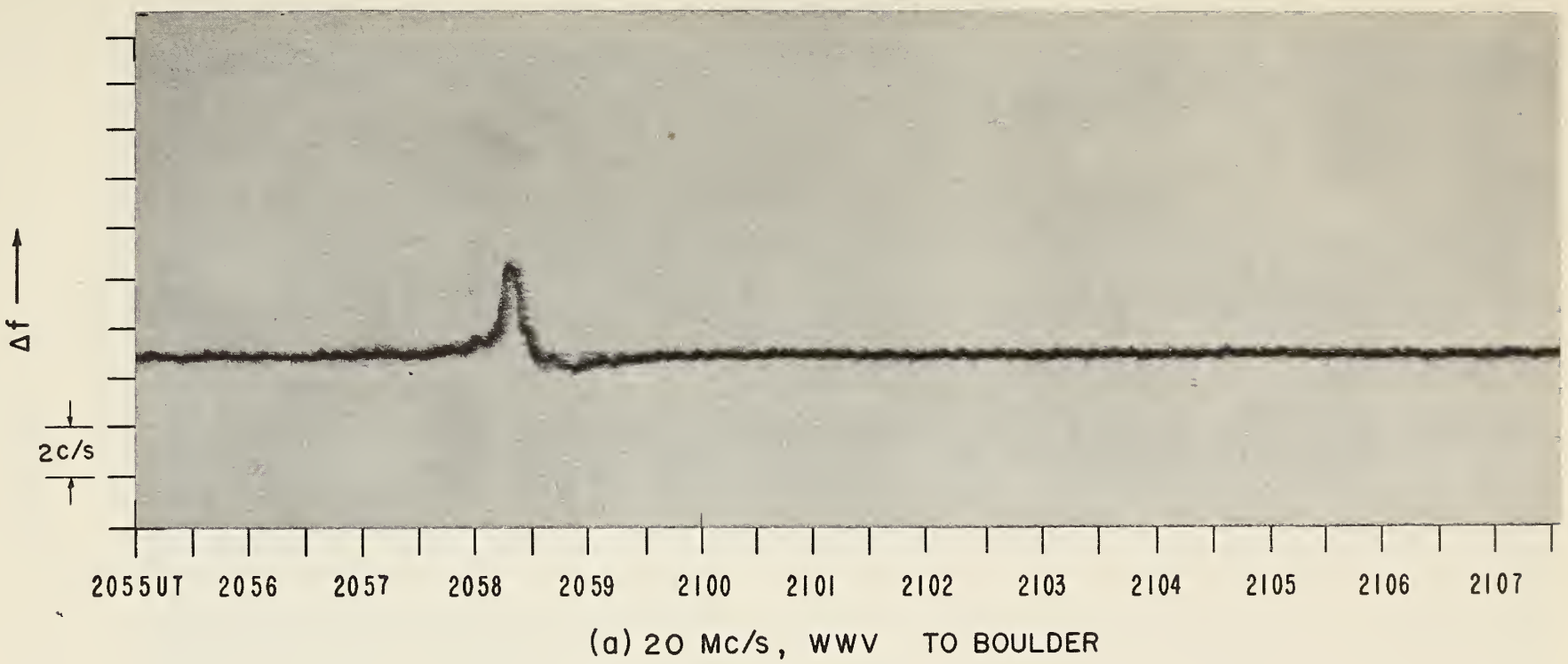
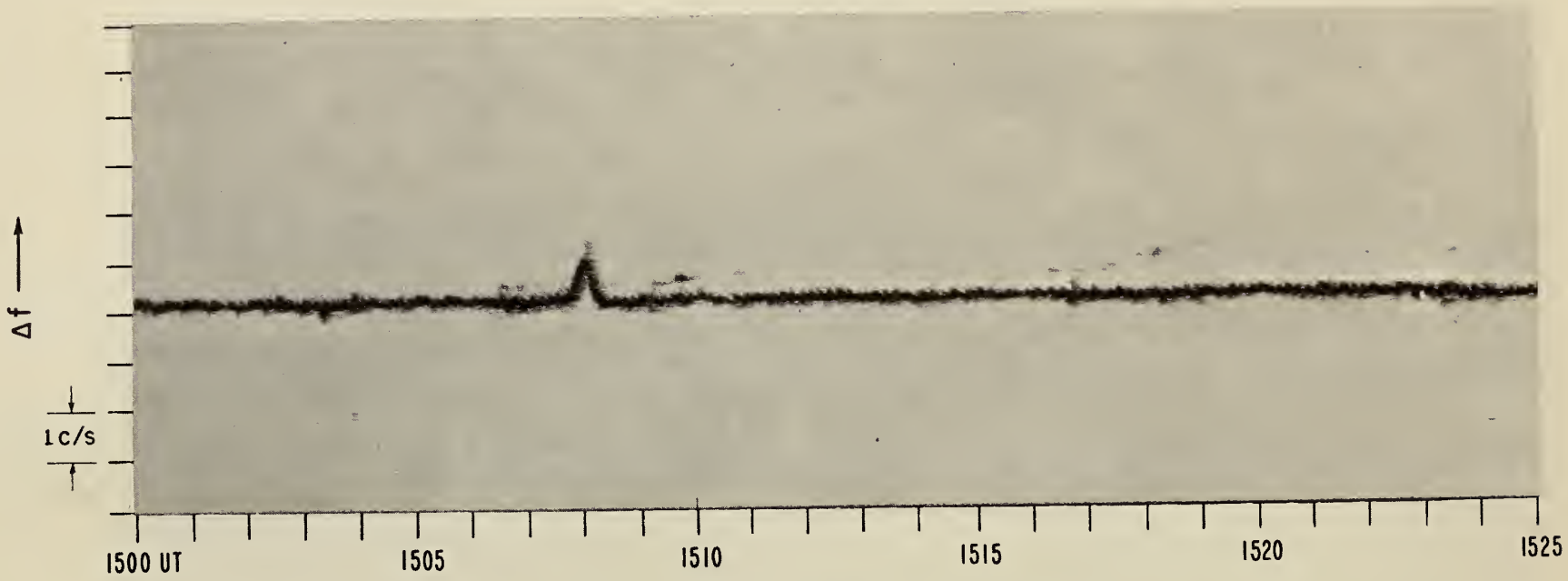

OPTICAL FLARE, IMPORTANCE 1- , 2056
Δf
2c/s
2055UT
2056
2057
2058
2059
2100
2101
2102
2103
2104
2105
2106
2107
(a) 20 Mc/s, WWV TO BOULDER
27 SEPTEMBER 1960

Figure 4

OPTICAL FLARE, IMPORTANCE 1, 1510E - 1510U - 1558U

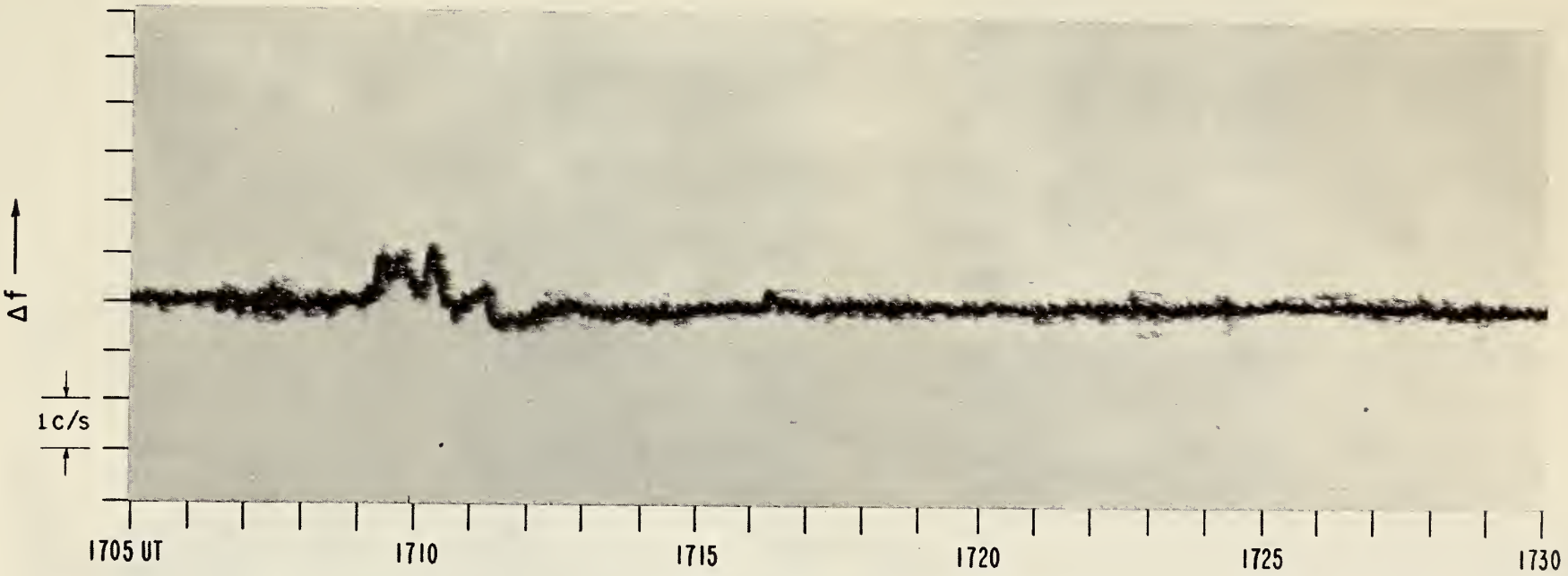


(a) 20 Mc/s, WWV TO BOULDER

11 NOVEMBER 1960

Figure 5

OPTICAL FLARE, IMPORTANCE 1-, 1704



(a) 20 Mc/s, WWV TO BOULDER

11 NOVEMBER 1960

Figure 6

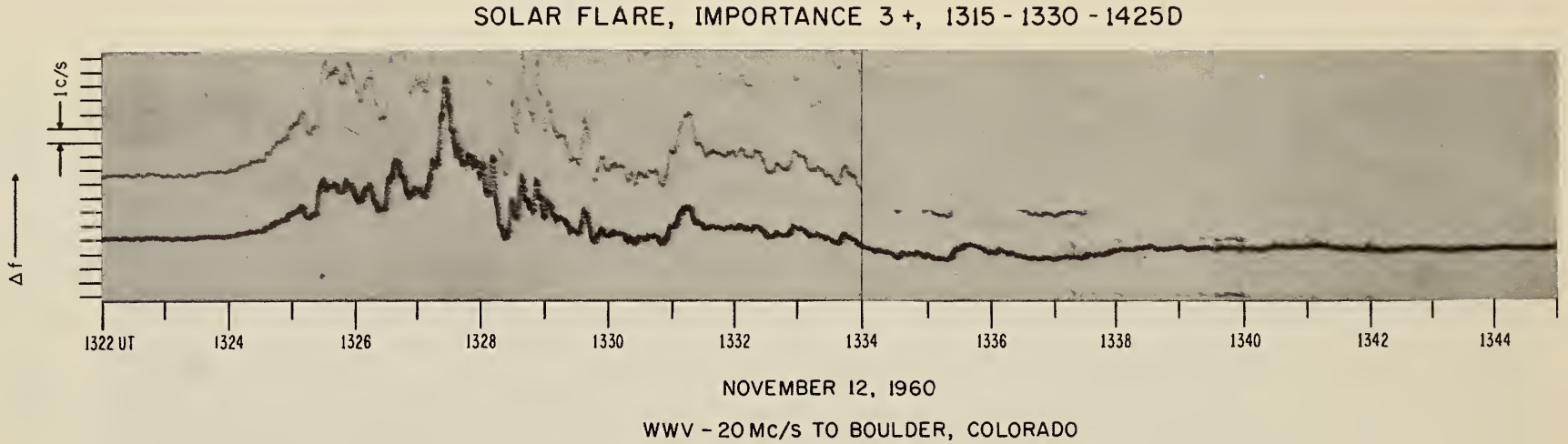
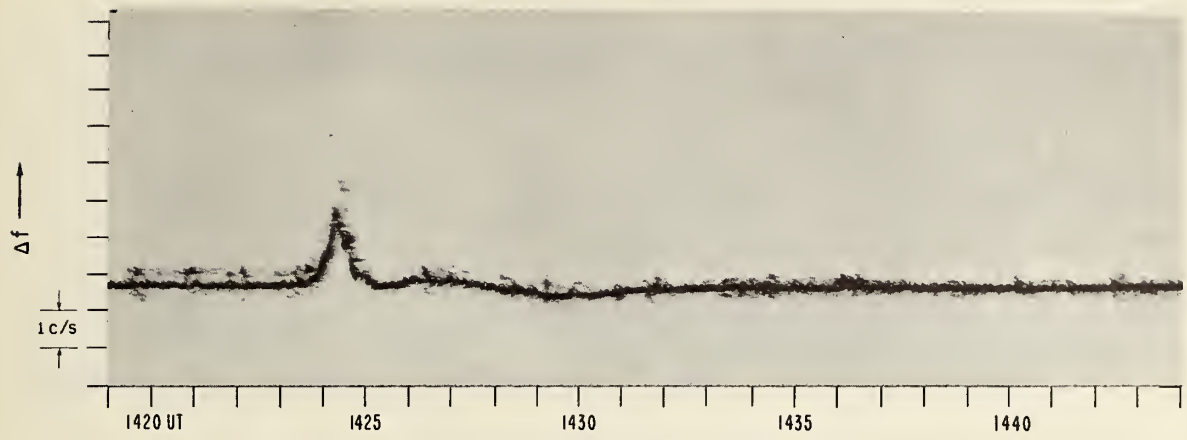
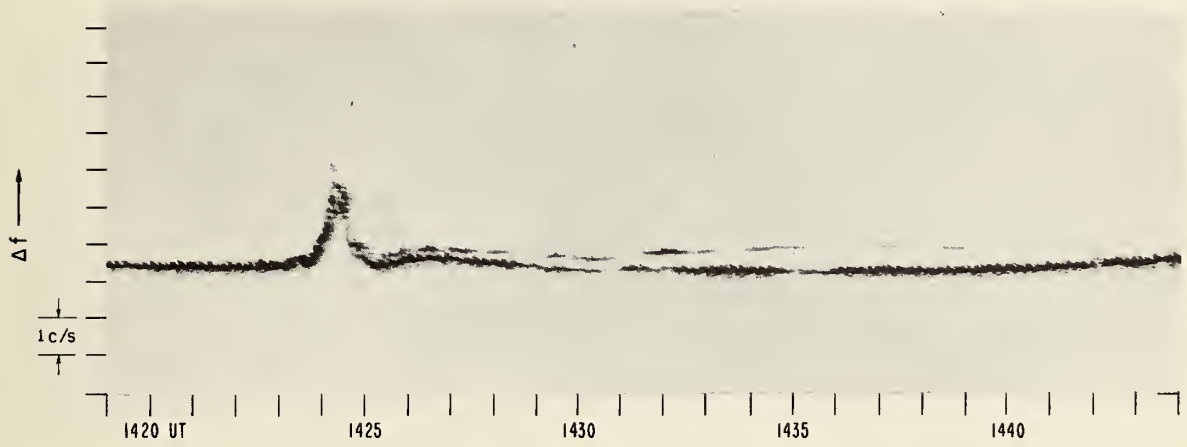

SOLAR FLARE, IMPORTANCE 3+, 1315 - 1330 - 1425D
1c/s
Δf
1322 UT
1324
1326
1328
1330
1332
1334
1336
1338
1340
1342
1344
NOVEMBER 12, 1960
WWV - 20 Mc/s TO BOULDER, COLORADO

Figure 7

OPTICAL FLARE, IMPORTANCE 1 , 1420-1425-1440



(a) 15 Mc/s, WWV TO BOULDER

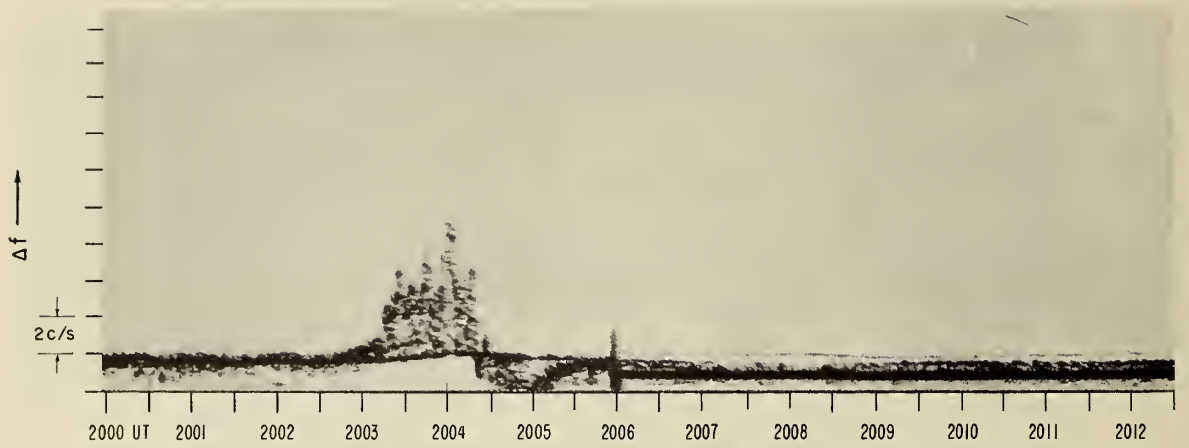


(b) 20 Mc/s, WWV TO BOULDER

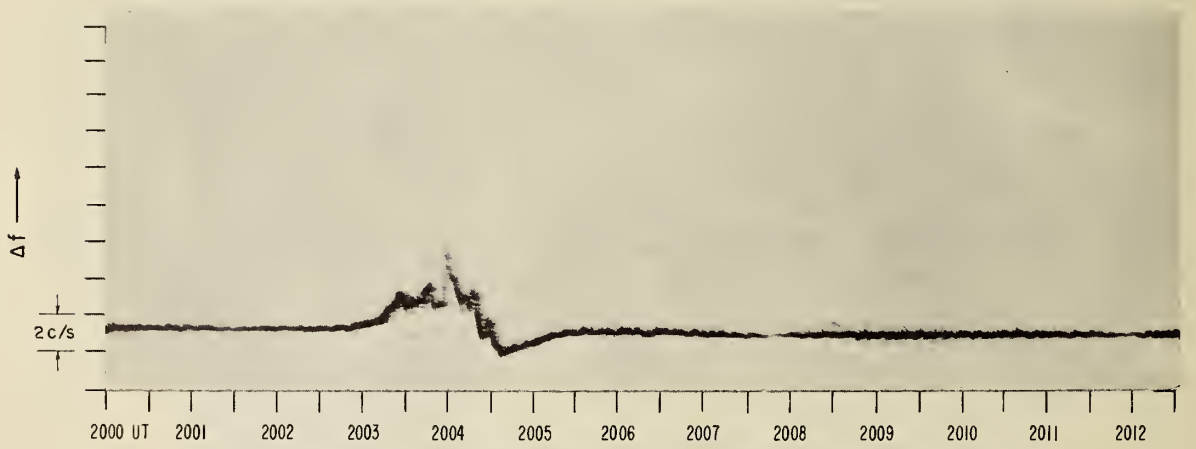
30 JANUARY 1961

Figure 8

OPTICAL FLARE, IMPORTANCE 1 , 2000 - 2004 - 2013



(a) 10 Mc/s, WWV TO BOULDER

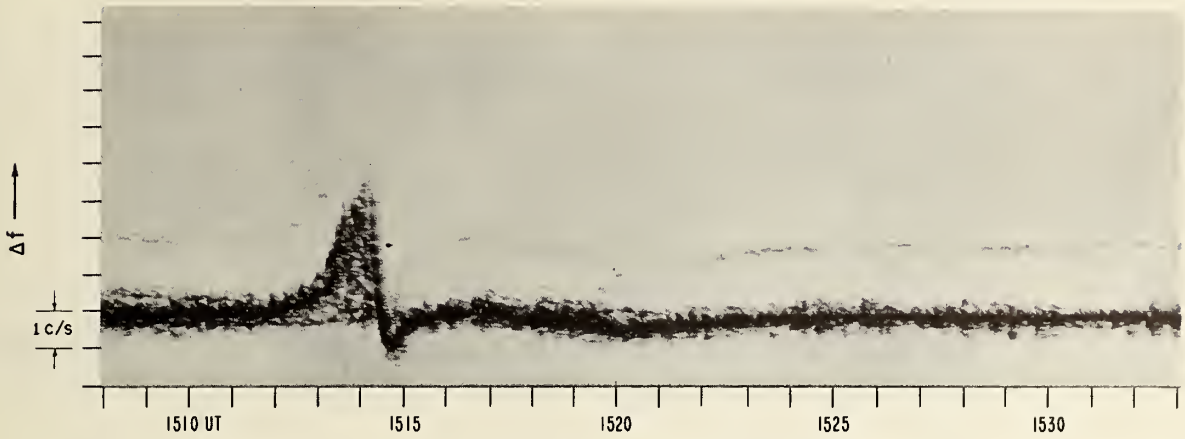


(b) 20 Mc/s, WWV TO BOULDER

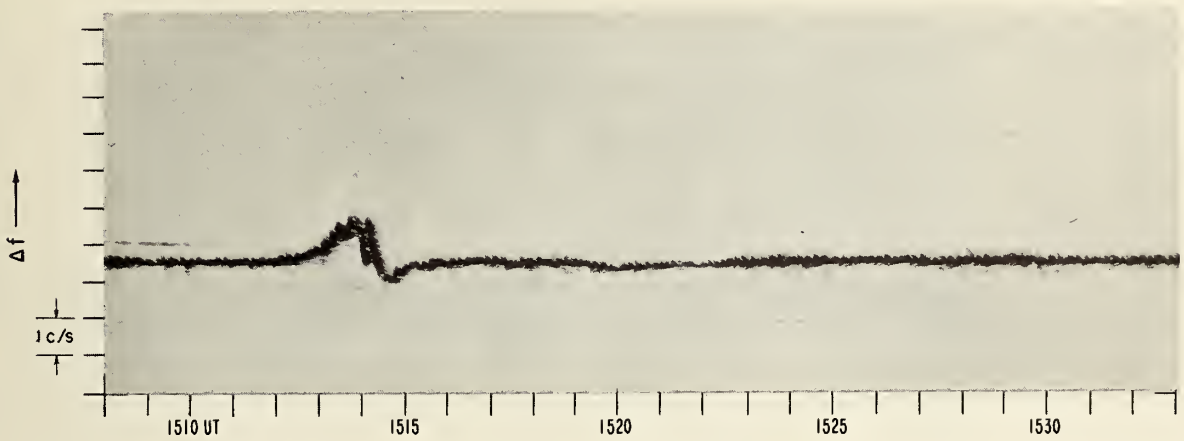
30 JANUARY 1961

Figure 9

OPTICAL FLARE, IMPORTANCE 1-, 1509-1514-1535



(a) 10 Mc/s, WWV TO BOULDER

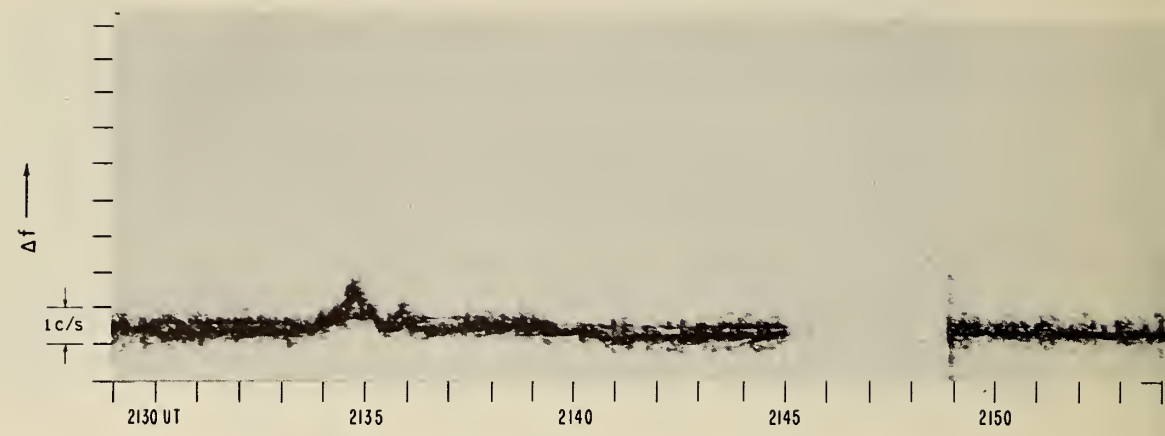


(b) 20 Mc/s, WWV TO BOULDER

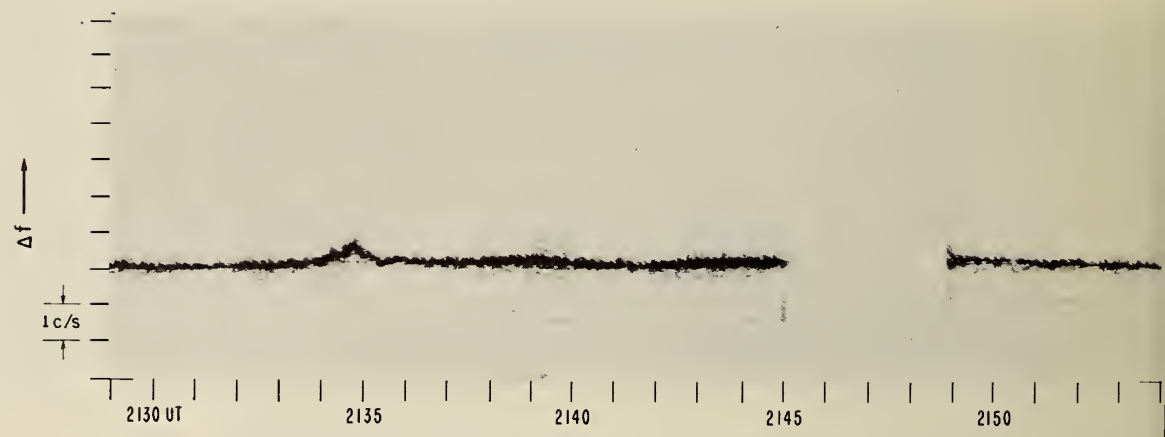
31 JANUARY 1961

Figure 10

OPTICAL FLARE, IMPORTANCE 1, 2131-2137-2155



(a) 10 Mc/s, WWV TO BOULDER

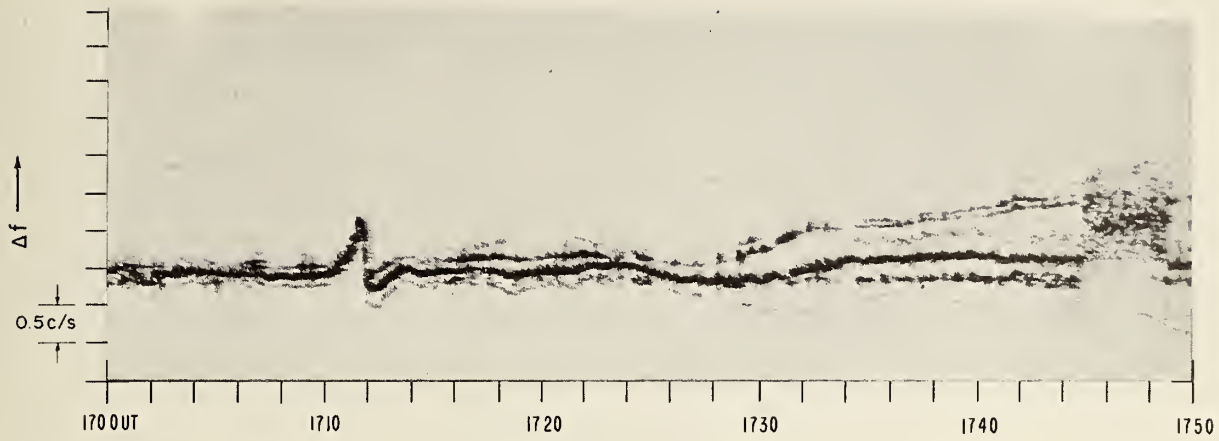


(b) 20 Mc/s, WWV TO BOULDER

31 JANUARY 1961

Figure 11

OPTICAL FLARE, IMPORTANCE 1+, 1711- 1725 D

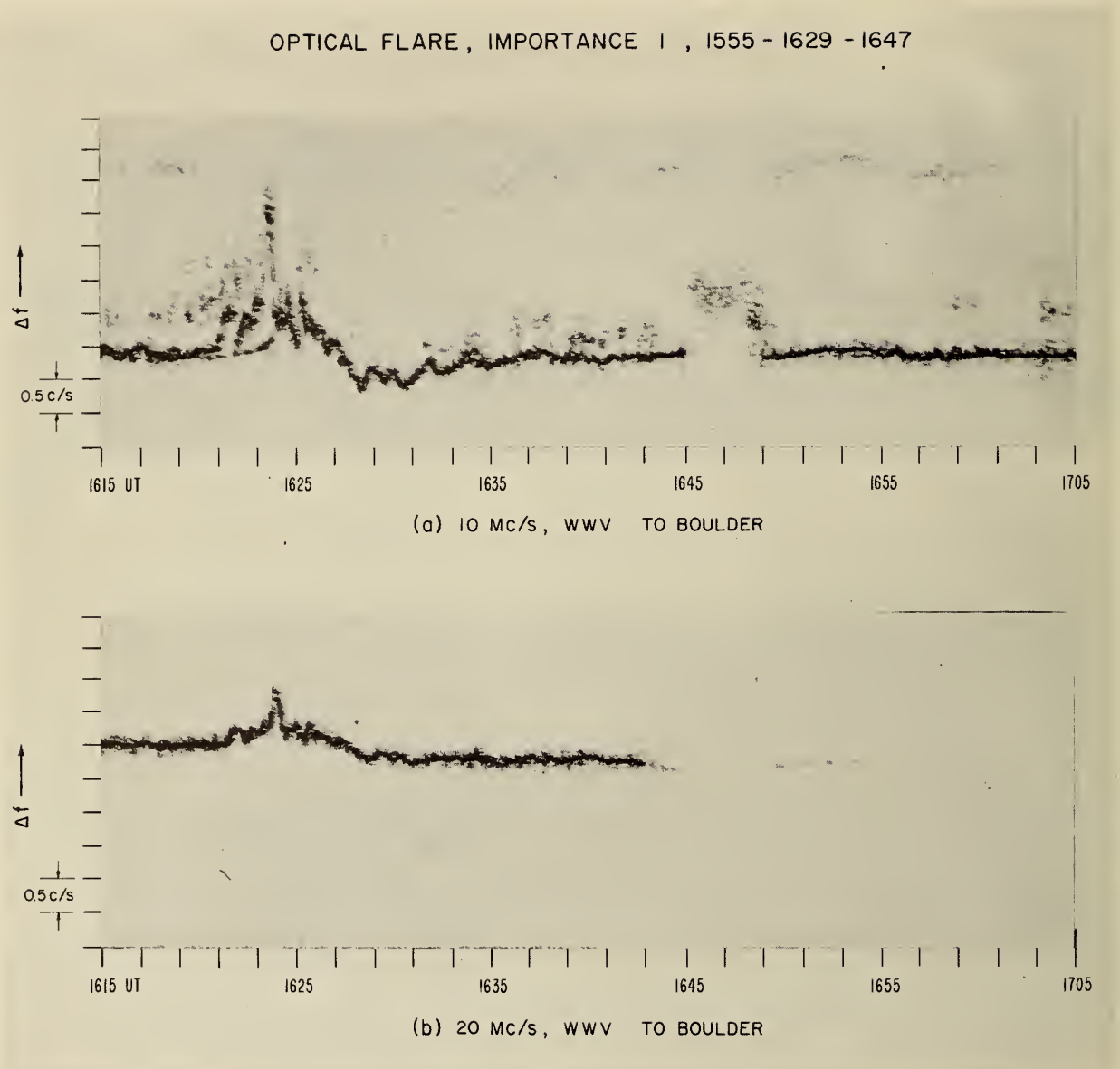


(a) 10 Mc/s, WWV TO BOULDER

(b) 20 Mc/s, WWV TO BOULDER

3 APRIL 1961

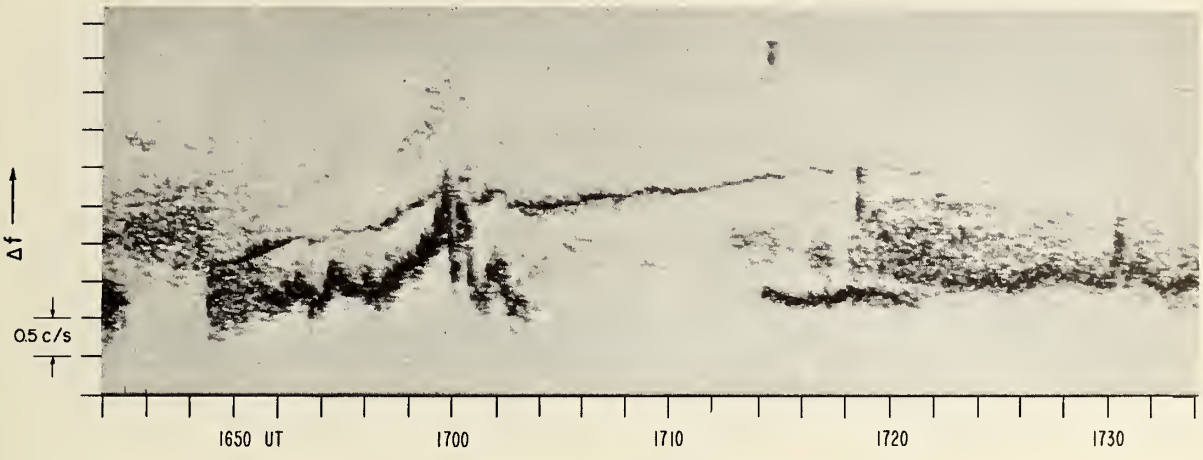
Figure 12



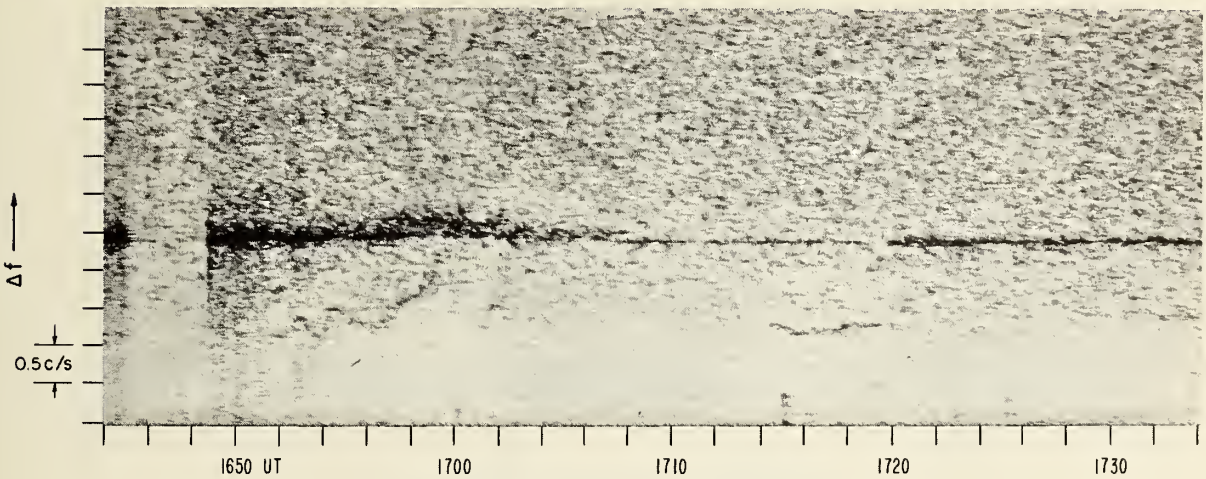
5 APRIL 1961

Figure 13

OPTICAL FLARE, IMPORTANCE 3 , 1648 - 1718 - 1945



(a) 10 Mc/s, WWV TO BOULDER

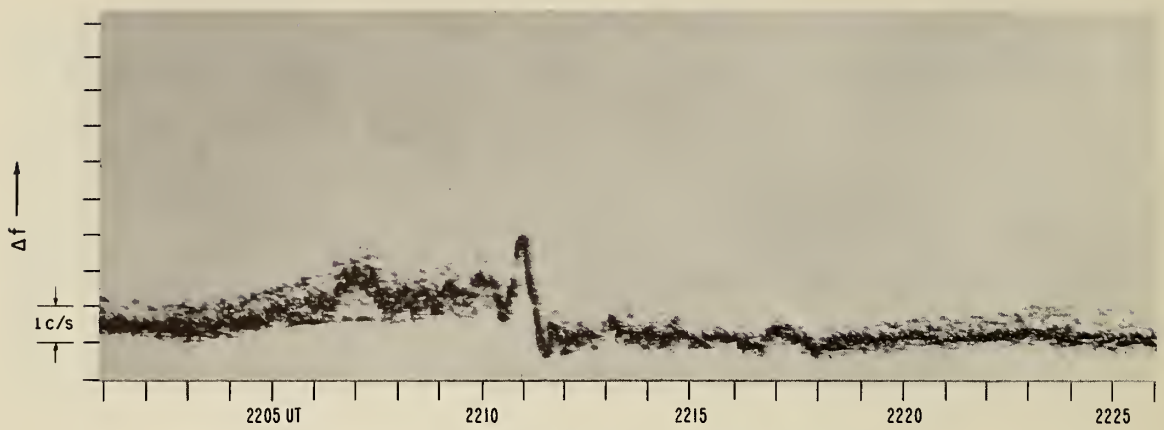


(b) 20 Mc/s, WWV TO BOULDER

26 APRIL 1961

Figure 14

OPTICAL FLARE, IMPORTANCE 3, 2145-2212-2333D



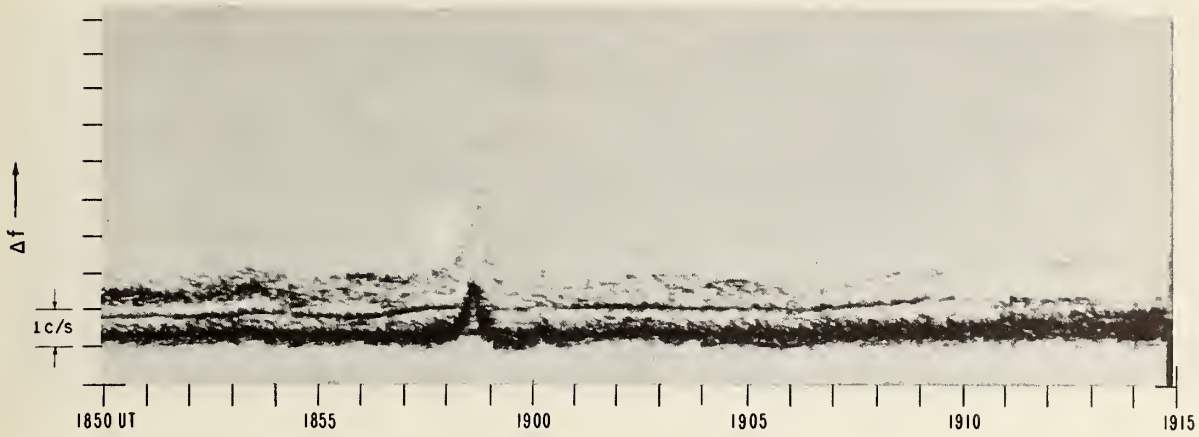
(a) 10 Mc/s, WWV TO BOULDER

(b) 20 Mc/s, WWV TO BOULDER

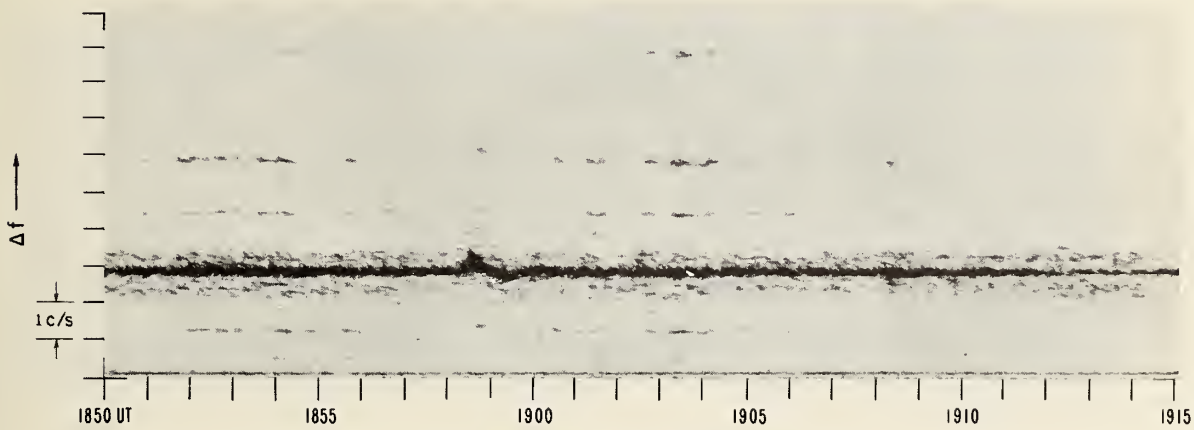
4 MAY 1961

Figure 15

OPTICAL FLARE, IMPORTANCE 1-, 1858



(a) 10 Mc/s, WWV TO BOULDER

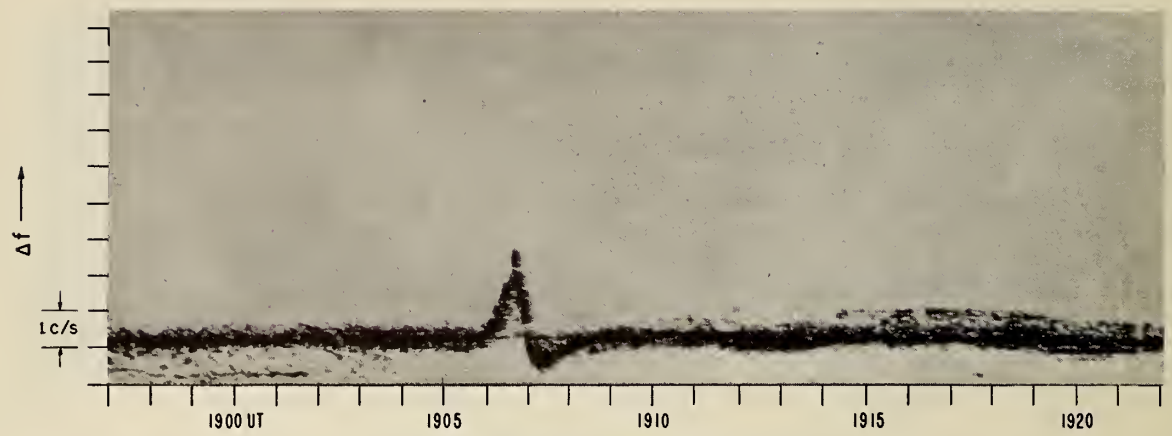


(b) 20 Mc/s, WWV TO BOULDER

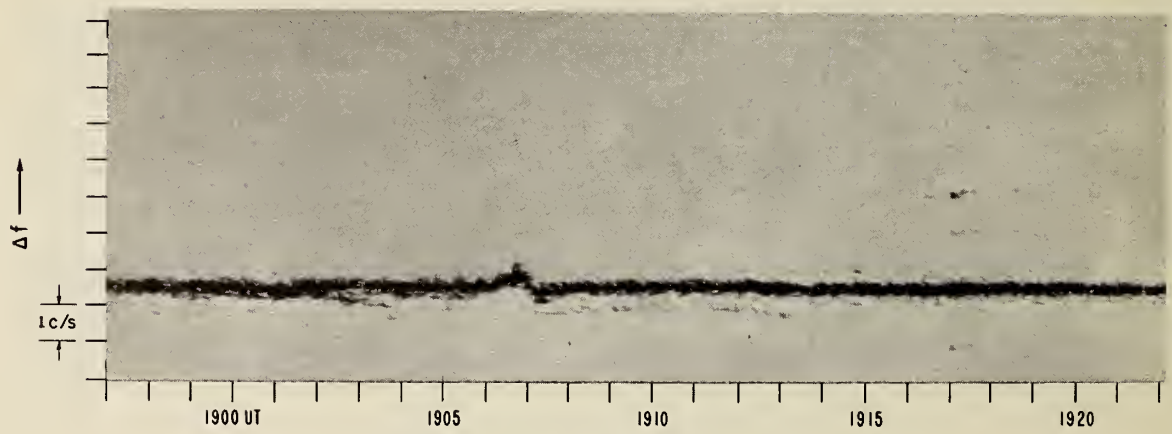
10 MAY 1961

Figure 16

OPTICAL FLARE, IMPORTANCE 1-, 1904



(a) 10 Mc/s, WWV TO BOULDER

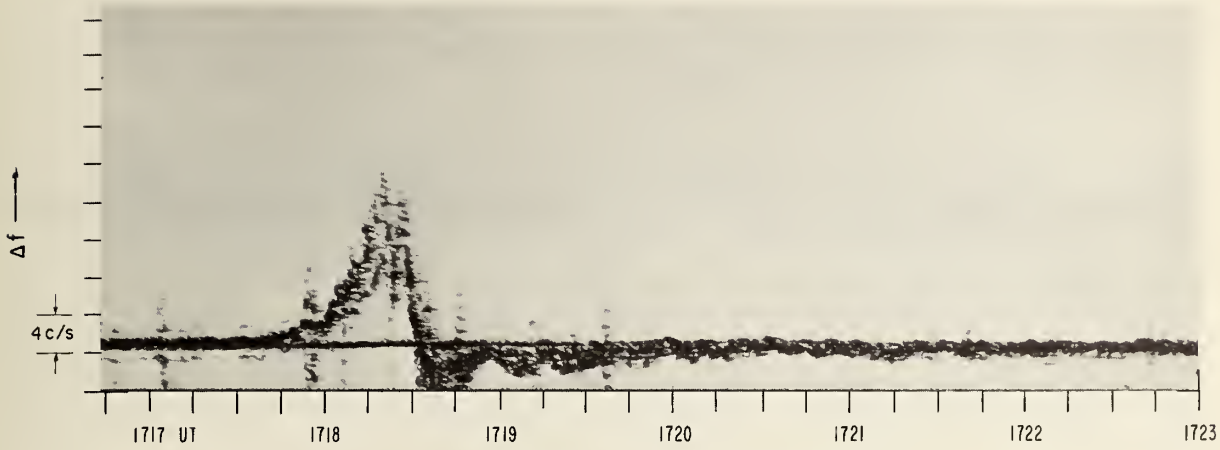


(b) 20 Mc/s, WWV TO BOULDER

28 MAY 1961

Figure 17

OPTICAL FLARE, IMPORTANCE 1 , 1718E - 1720U - 1728U



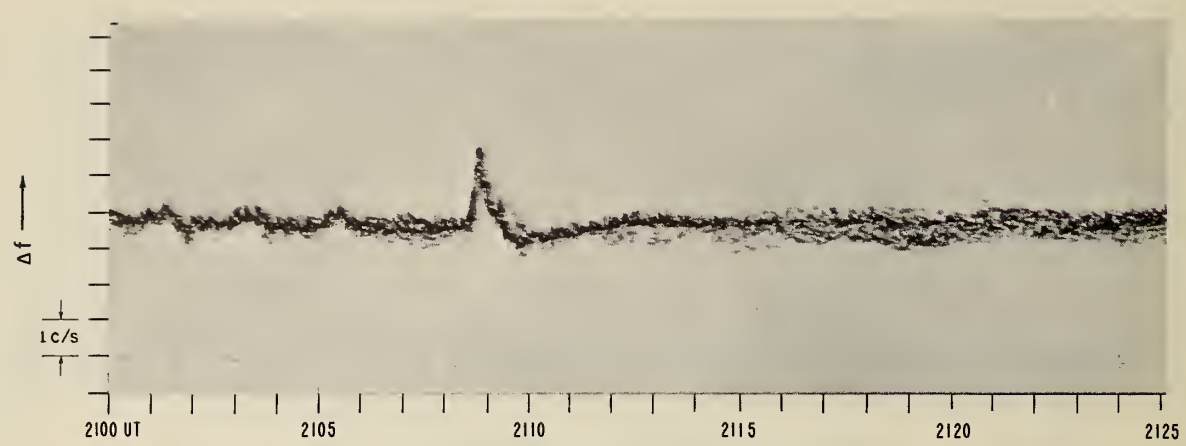
(a) 10 Mc/s, WWV TO BOULDER

(b) 20 Mc/s, WWV TO BOULDER

15 JUNE 1961

Figure 18

OPTICAL FLARE, IMPORTANCE 1-, 2057



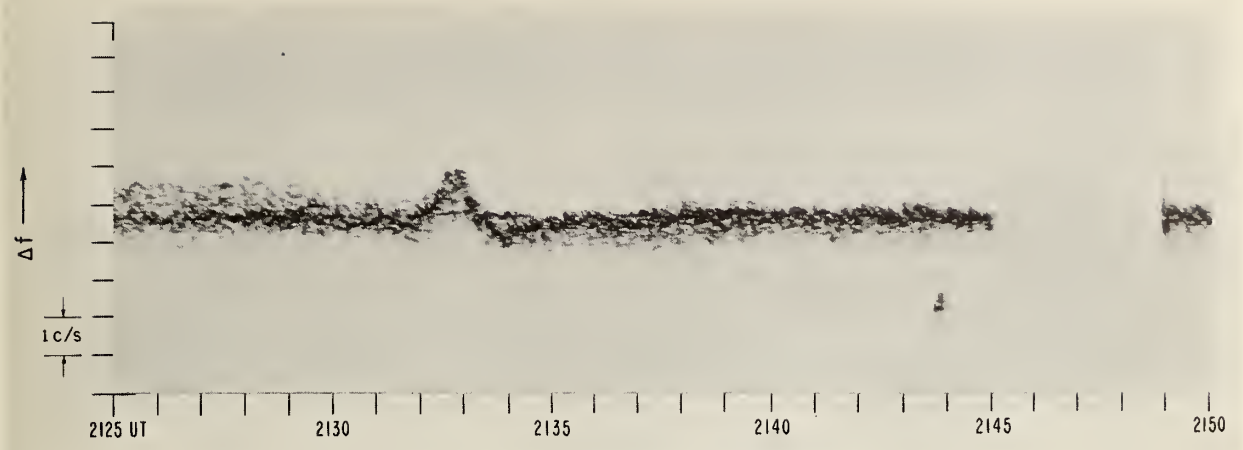
(a) 10 Mc/s, WWV TO BOULDER

(b) 20 Mc/s, WWV TO BOULDER

29 JUNE 1961

Figure 19

OPTICAL FLARE, IMPORTANCE 1-, 2132



(a) 10 Mc/s, WWV TO BOULDER

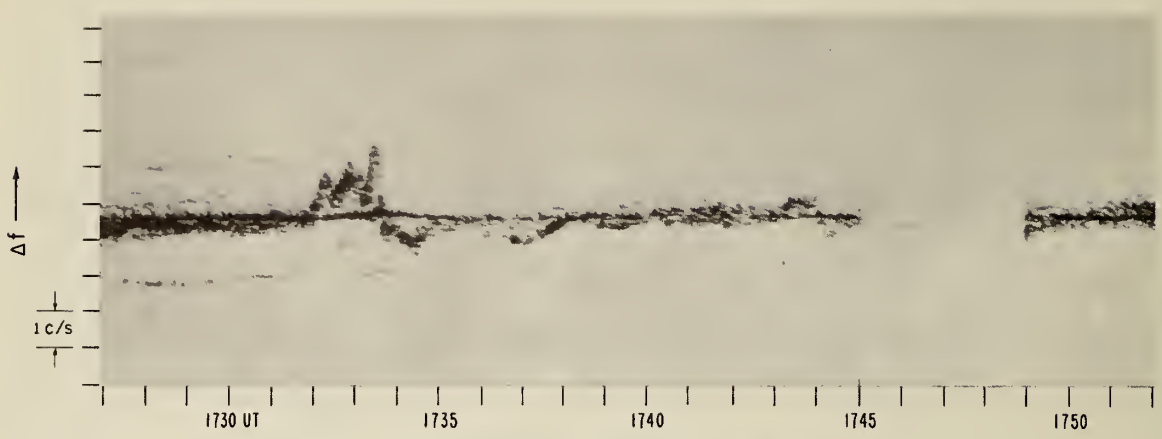
NO RECORDS

(b) 20 Mc/s, WWV TO BOULDER

1 JULY 1961

Figure 20

OPTICAL FLARE, IMPORTANCE 1, 1741-1753-1800



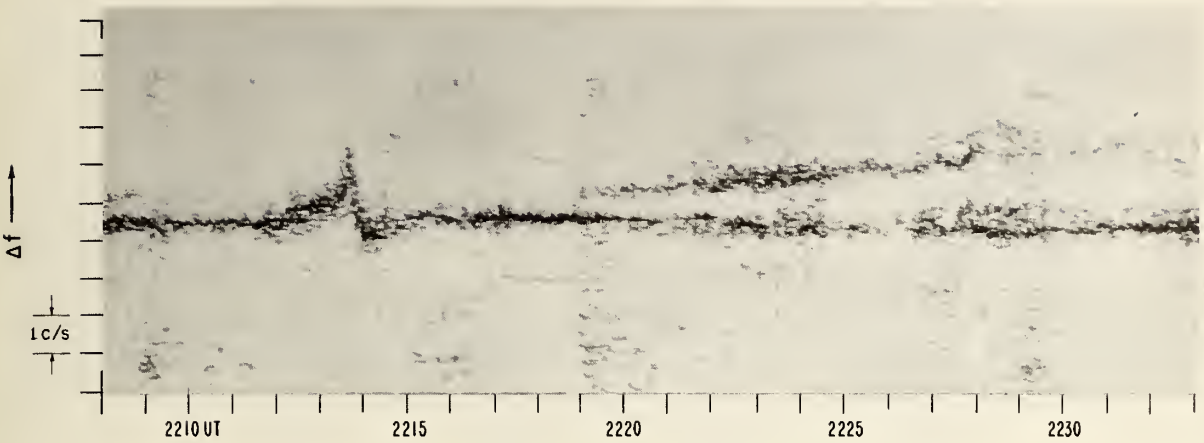
(a) 10 Mc/s, WWV TO BOULDER

(b) 20 Mc/s, WWV TO BOULDER

10 JULY 1961

Figure 21

OPTICAL FLARE, IMPORTANCE 1-, 2211



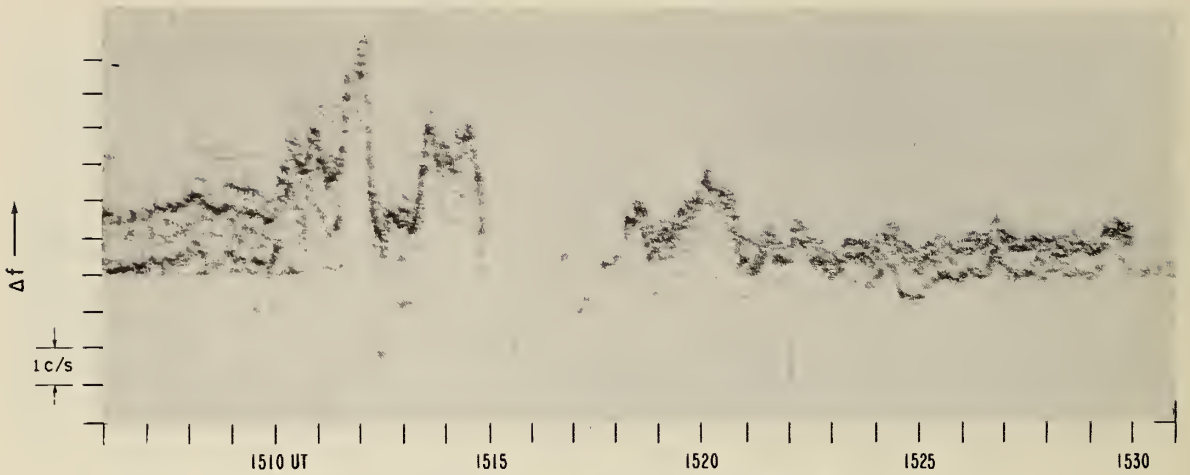
(a) 10 Mc/s, WWV TO BOULDER

(b) 20 Mc/s, WWV TO BOULDER

13 JULY 1961

Figure 22

OPTICAL FLARE, IMPORTANCE 2, 1508-1512-1530



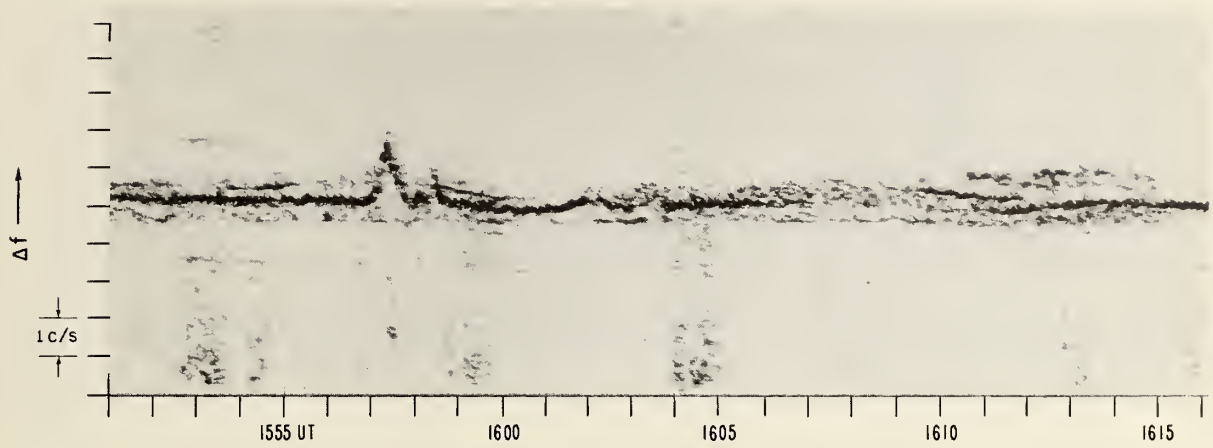
(a) 10 Mc/s, WWV TO BOULDER

(b) 20 Mc/s, WWV TO BOULDER

15 JULY 1961

Figure 23

OPTICAL FLARE, IMPORTANCE 1-, 1556



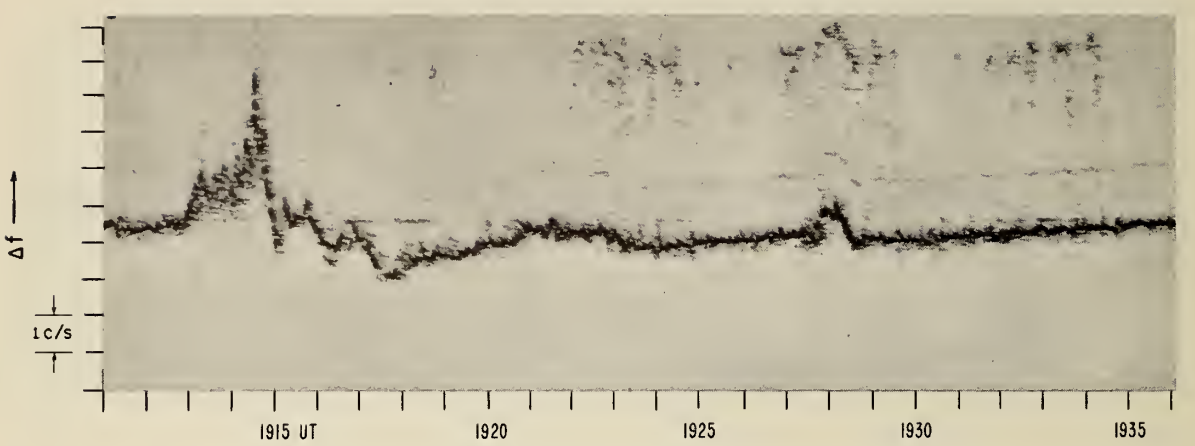
(a) 10 Mc/s, WWV TO BOULDER

(b) 20 Mc/s, WWV TO BOULDER

16 JULY 1961

Figure 24

OPTICAL FLARE, IMPORTANCE 1 , 1907 - 1916 - 1935



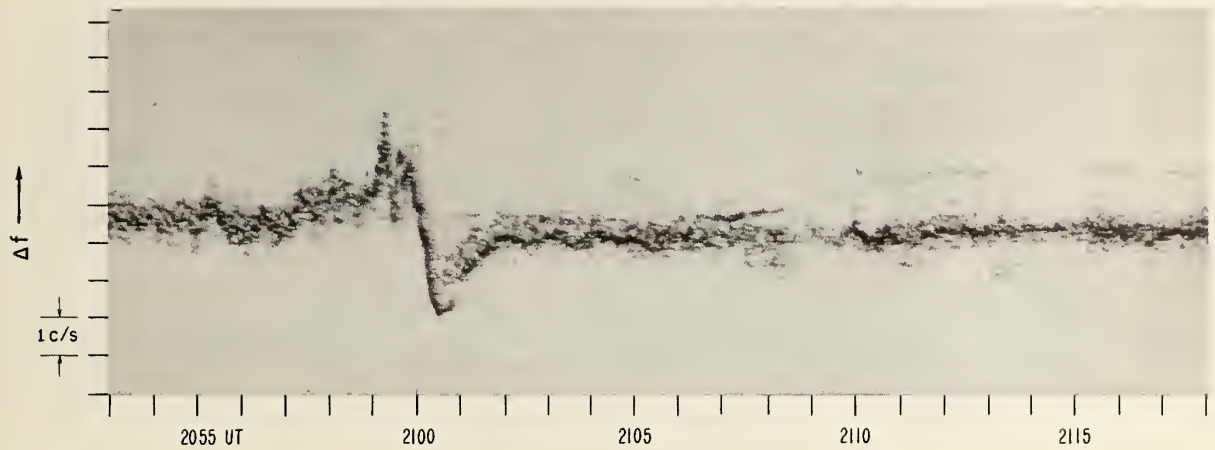
(a) 10 Mc/s, WWV TO BOULDER

(b) 20 Mc/s, WWV TO BOULDER

17 JULY 1961

Figure 25

OPTICAL FLARE, IMPORTANCE 1 , 2051 - 2102 - 2120



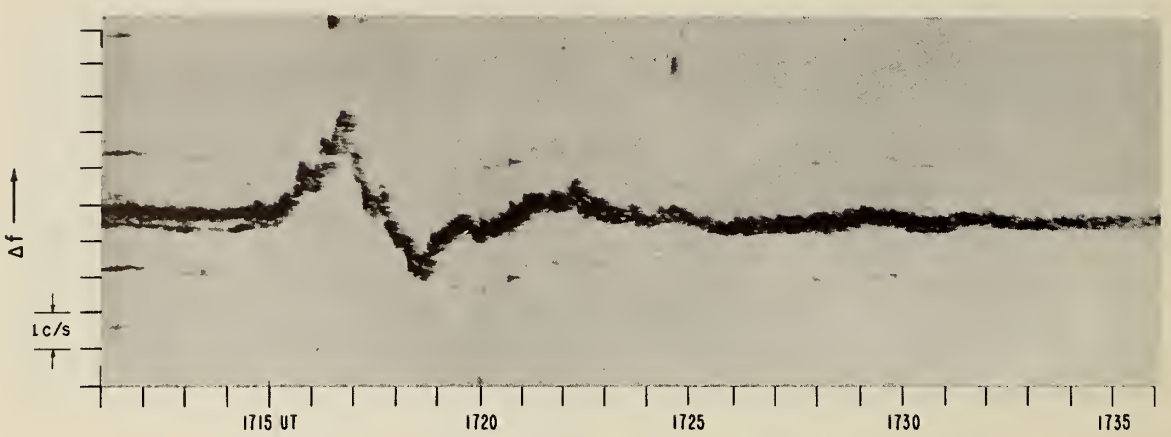
(a) 10 Mc/s, WWV TO BOULDER

(b) 20 Mc/s, WWV TO BOULDER

19 JULY 1961

Figure 26

OPTICAL FLARE, IMPORTANCE 2, 1714-1718-1734



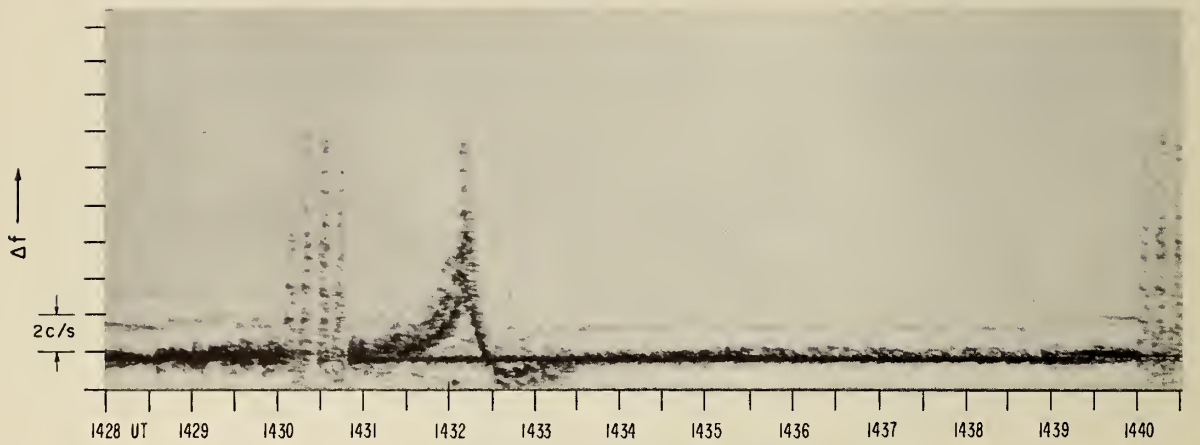
(a) 10 Mc/s, WWV TO BOULDER

(b) 20 Mc/s, WWV TO BOULDER

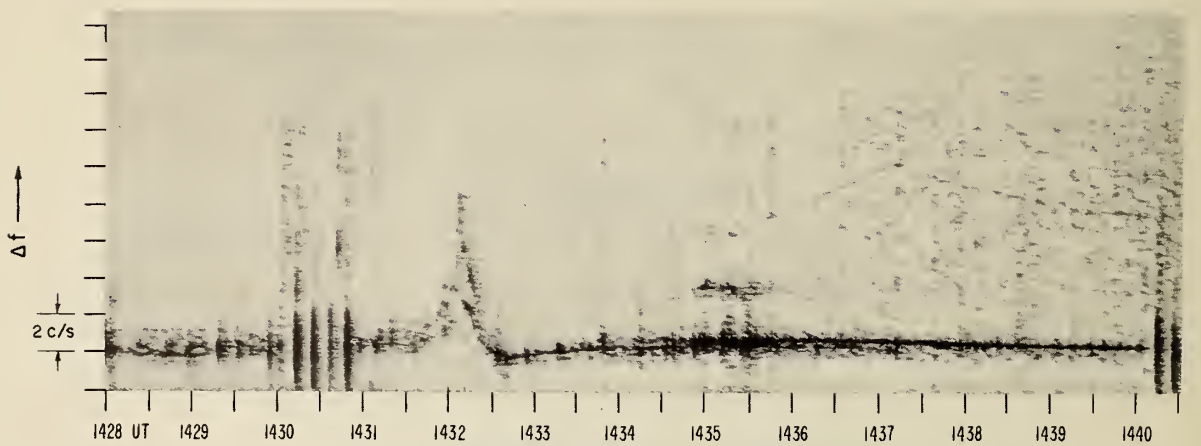
21 JULY 1961

Figure 27

OPTICAL FLARE, IMPORTANCE 1 , 1425 - 1435 - 1512



(a) 4.000 Mc/s, SUNSET TO BOULDER

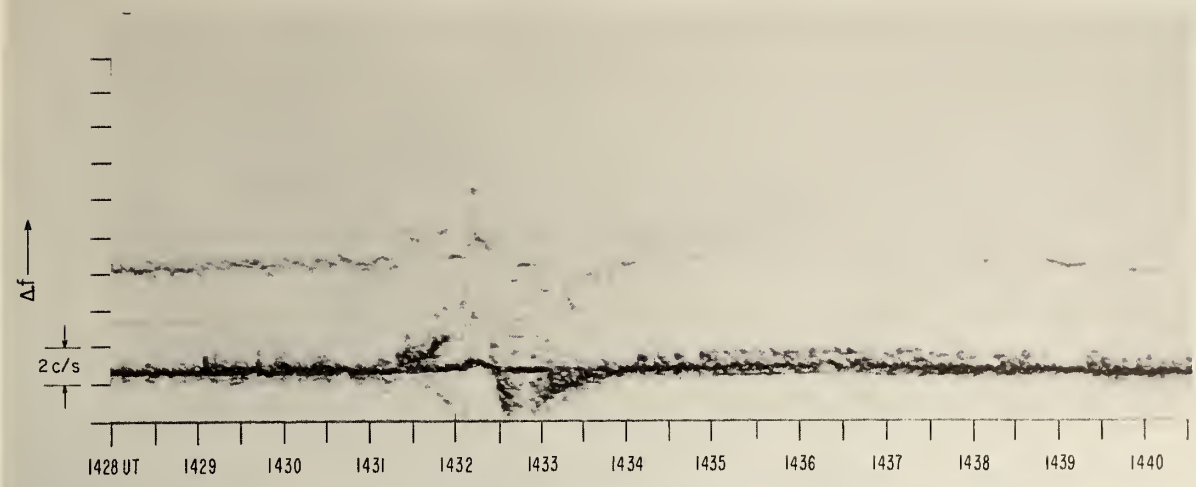


(b) 5.054 Mc/s, SUNSET TO BOULDER

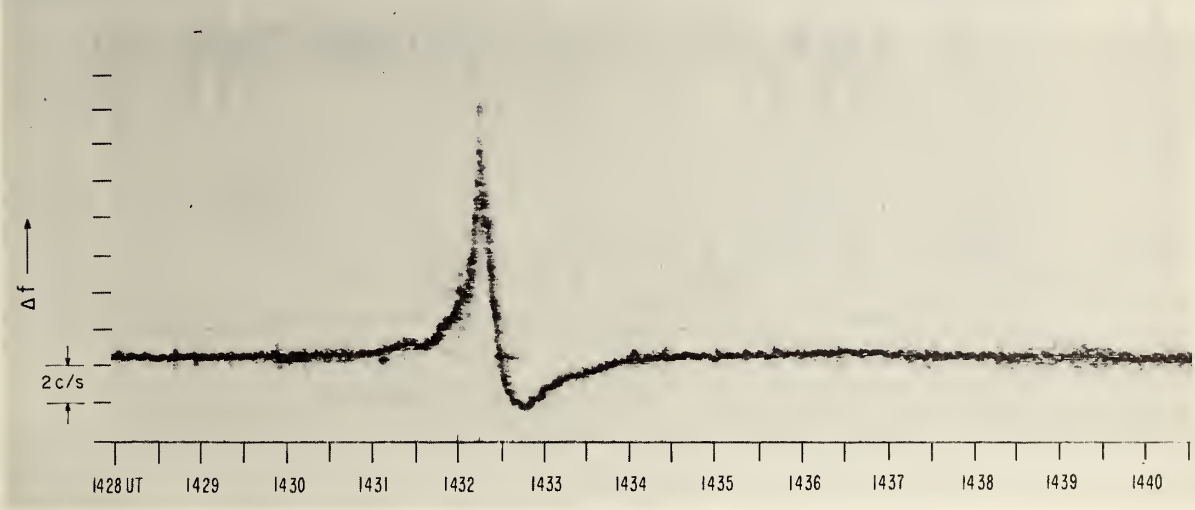
4 SEPTEMBER 1961

Figure 28

OPTICAL FLARE, IMPORTANCE 1 , 1425-1435-1512



(c) 10 Mc/s, WWV TO SHICKLEY

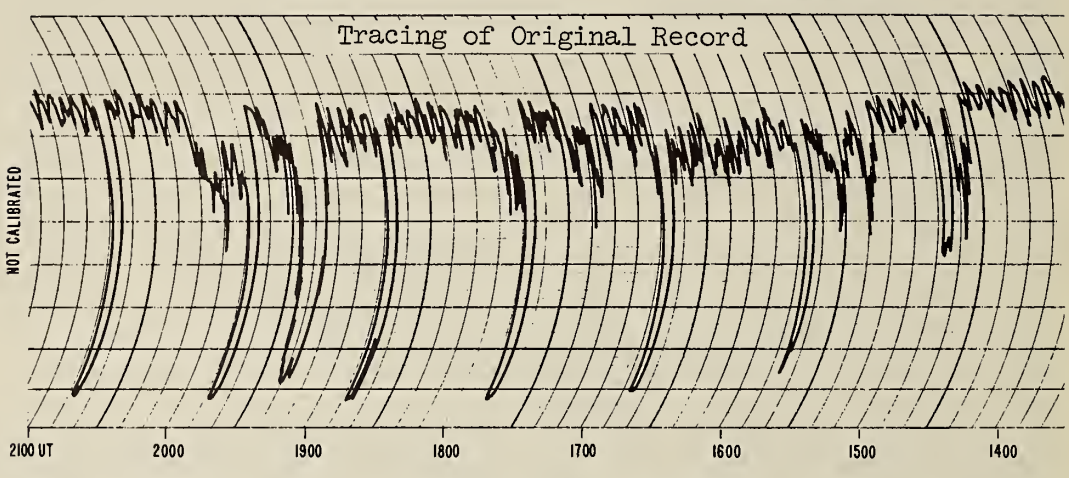


(d) 10 Mc/s, WWV TO BOULDER

(e) 20 Mc/s, WWV TO BOULDER

4 SEPTEMBER 1961
Figure 28

OPTICAL FLARE, IMPORTANCE 1 , 1425-1435-1512
1 , 1512-1520-1540U
1-, 1538E
1-, 1807
1+, 1834-1846-2010
1 , 1902-1905-1919U
2 , 1911-1924U-2018



(a) 10 Mc/s, WWV TO BOULDER

SIGNAL STRENGTH dB ABOVE 1μV

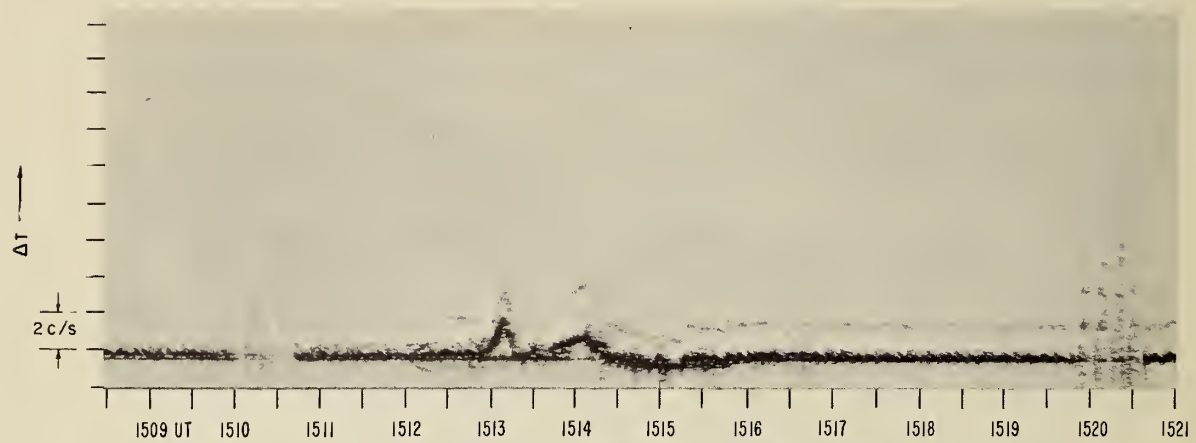
NO RECORDS

(b)20 Mc/s, WWV TO BOULDER

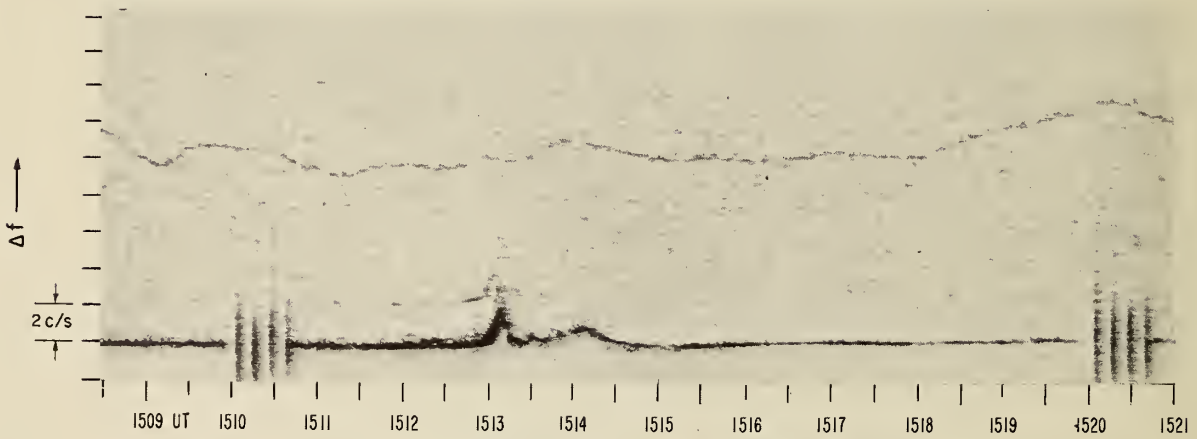
4 SEPTEMBER 1961

Figure 29

OPTICAL FLARE, IMPORTANCE 1 , 1512 - 1520 - 1540U



(a) 4.000 Mc/s, SUNSET TO BOULDER

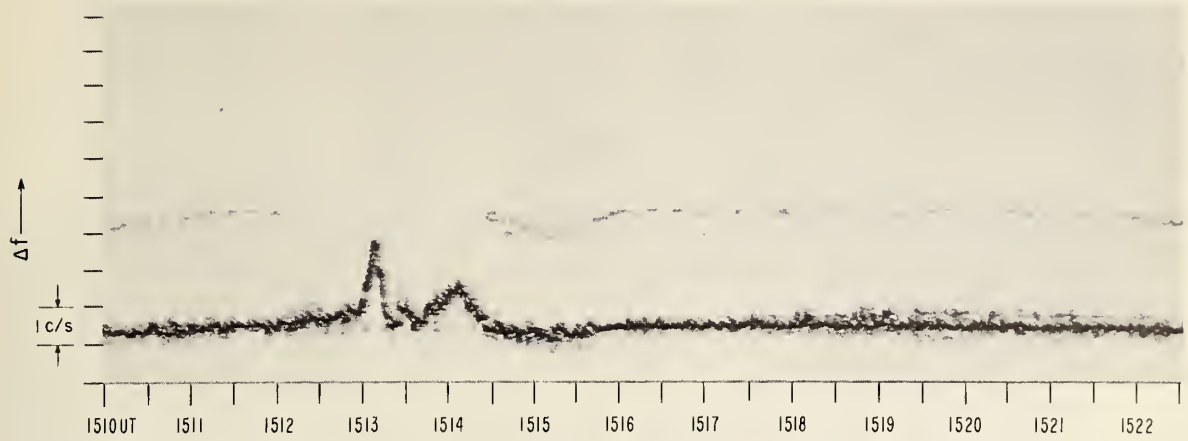


(b) 5.054 Mc/s, SUNSET TO BOULDER

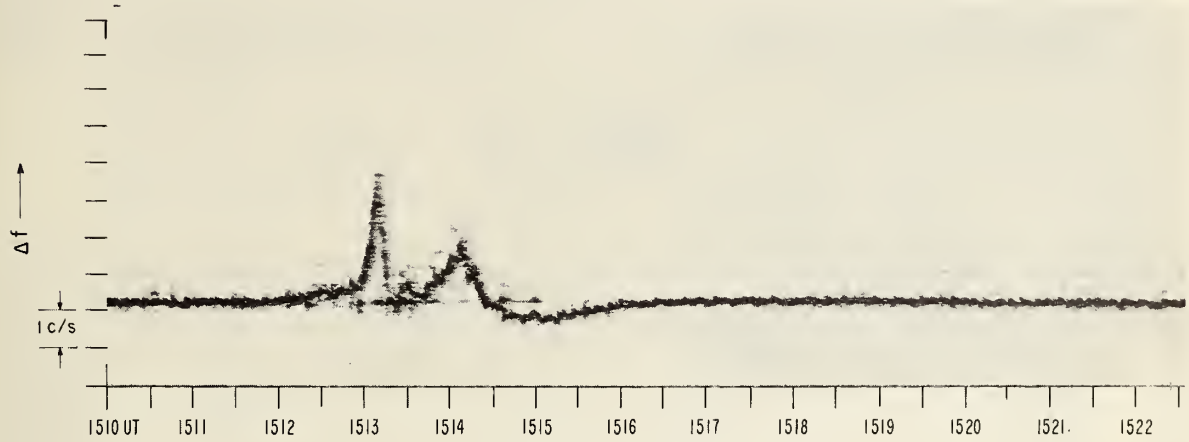
4 SEPTEMBER 1961

Figure 30

OPTICAL FLARE, IMPORTANCE 1 ,1512-1520-1540U



(c) 10 Mc/s, WWV TO SHICKLEY

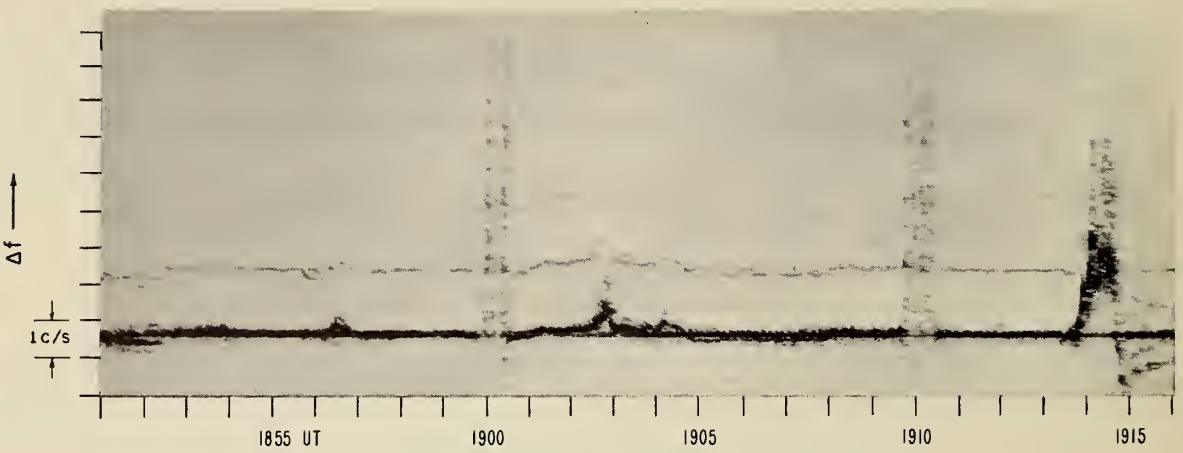


(d) 10 Mc/s, WWV TO BOULDER

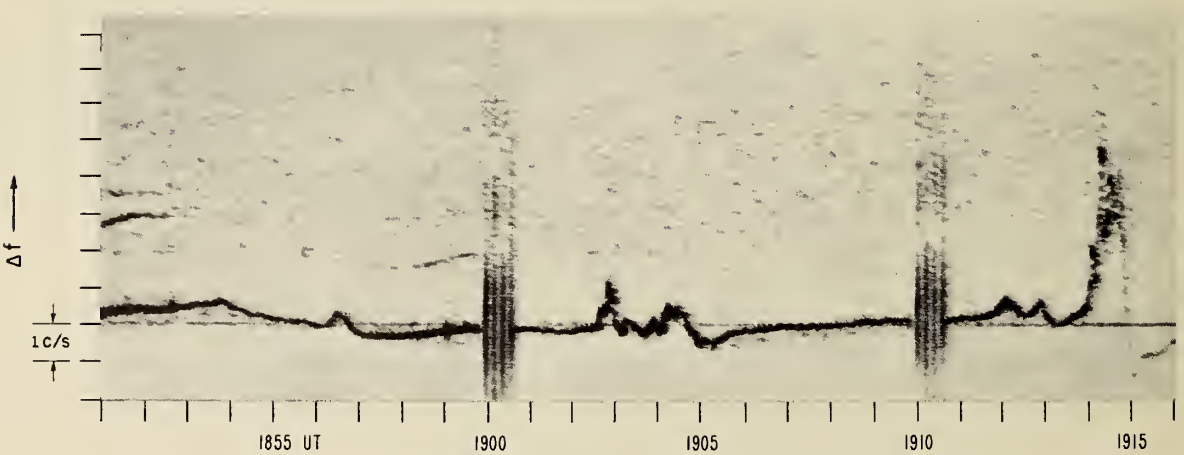
(e) 20 Mc/s, WWV TO BOULDER

4 SEPTEMBER 1961
Figure 30

OPTICAL FLARE, IMPORTANCE 1 , 1902 - 1905 - 1919 U
2 , 1911 - 1924 U - 2018



(a) 4.000 Mc/s, SUNSET TO BOULDER

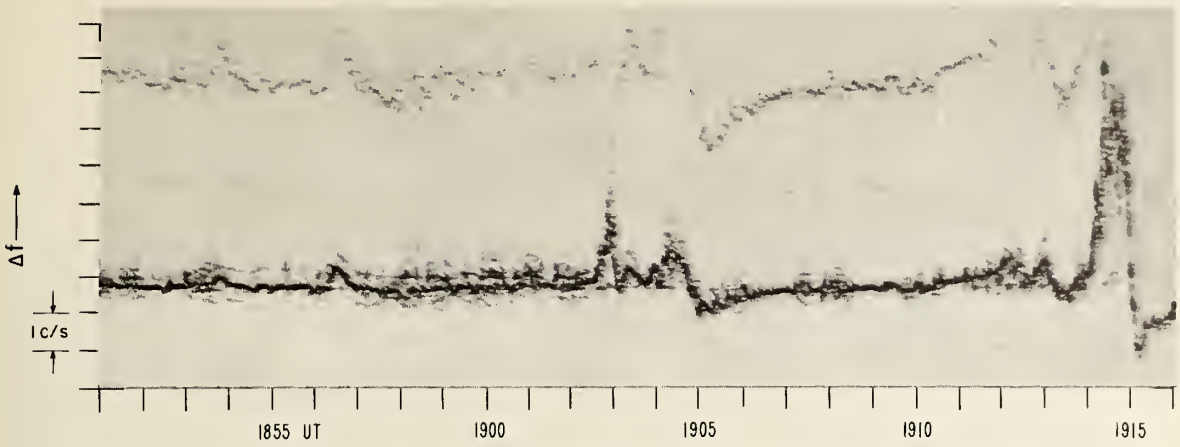


(b) 5.054 Mc/s, SUNSET TO BOULDER

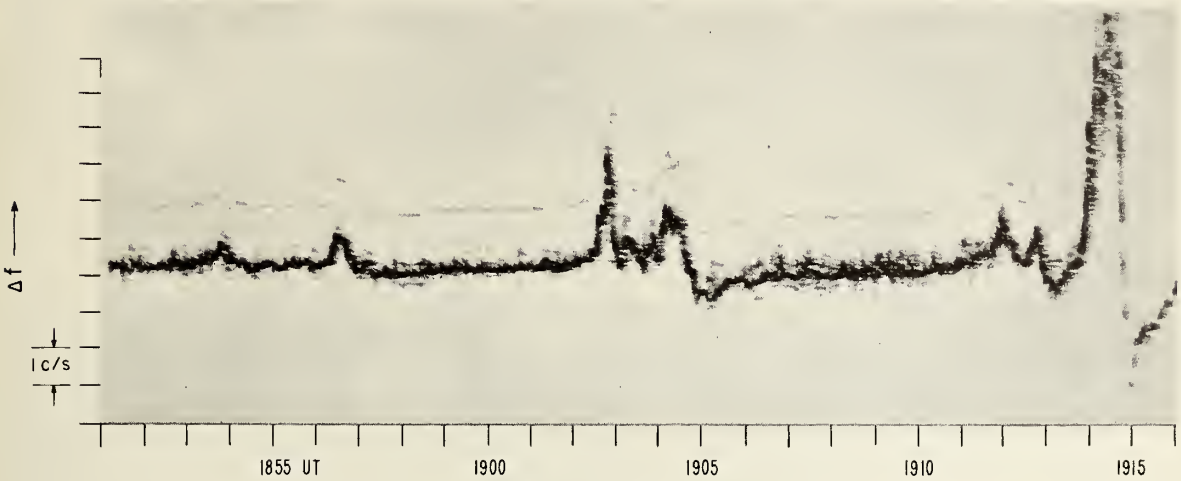
4 SEPTEMBER 1961

Figure 31

OPTICAL FLARE, IMPORTANCE 1 , 1902 - 1905 - 1919U
2 , 1911 - 1924U - 2018



(c) 10 Mc/s, WWV TO SHICKLEY

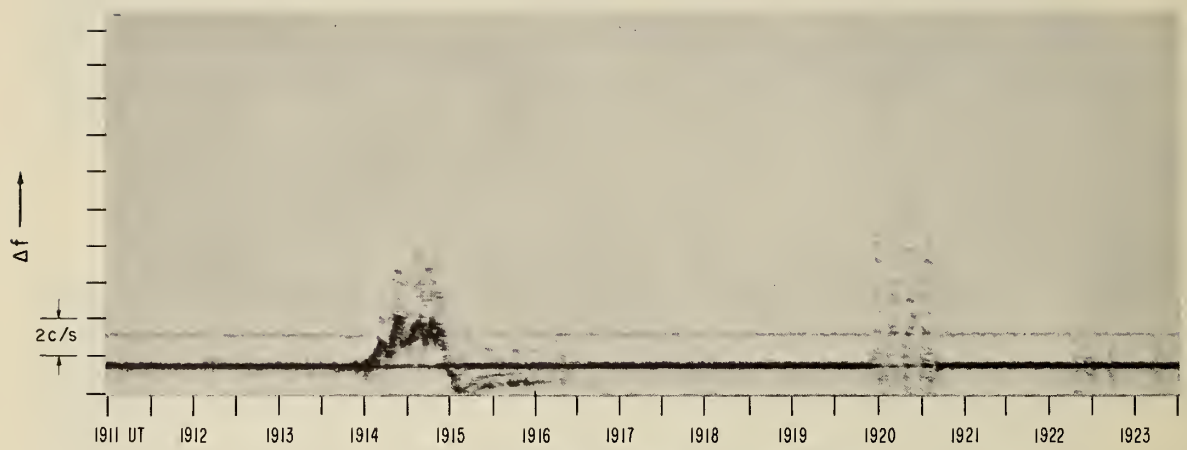


(d) 10 Mc/s, WWV TO BOULDER

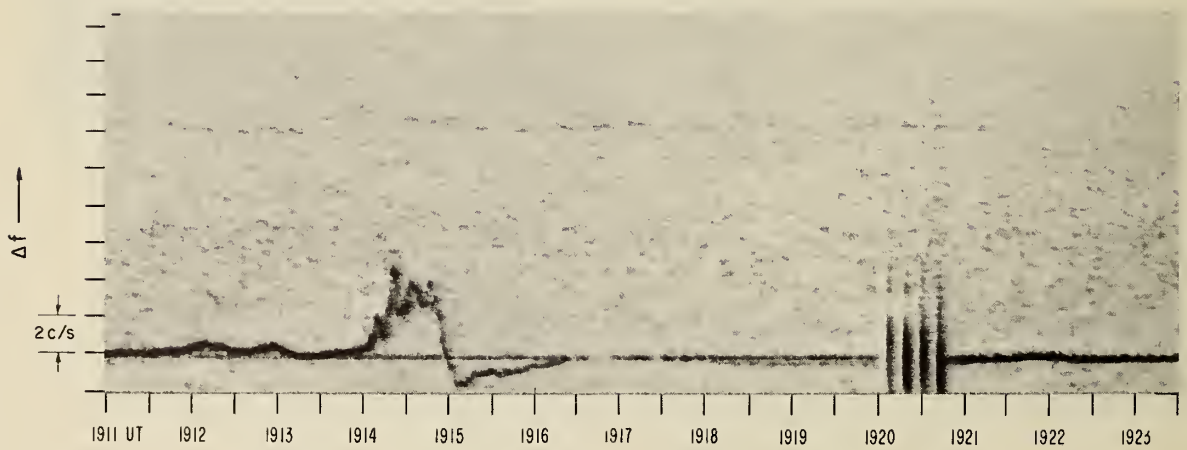
(e) 20 Mc/s, WWV TO BOULDER

4 SEPTEMBER 1961
Figure 31

OPTICAL FLARE, IMPORTANCE 2 , 1911 - 1924U - 2018



(a) 4.000 Mc/s, SUNSET TO BOULDER

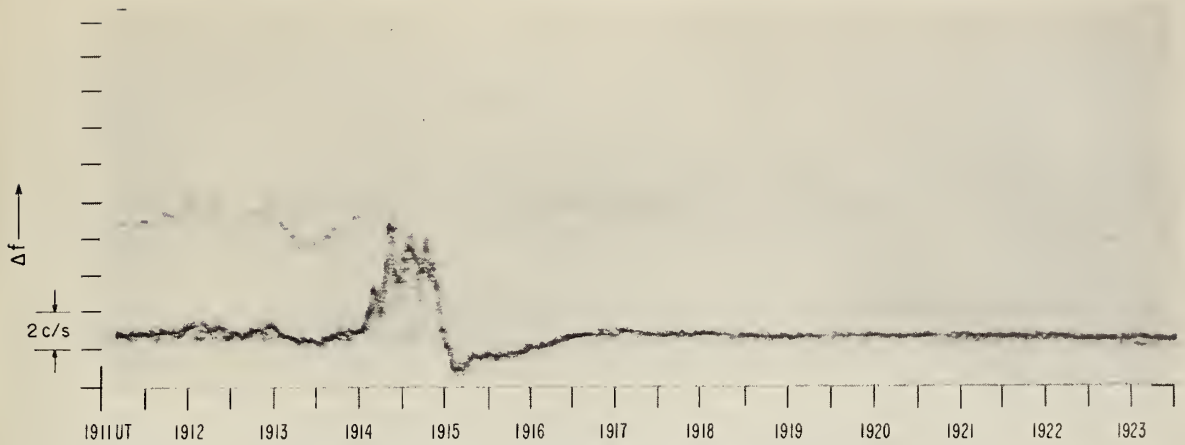


(b) 5.054 Mc/s, SUNSET TO BOULDER

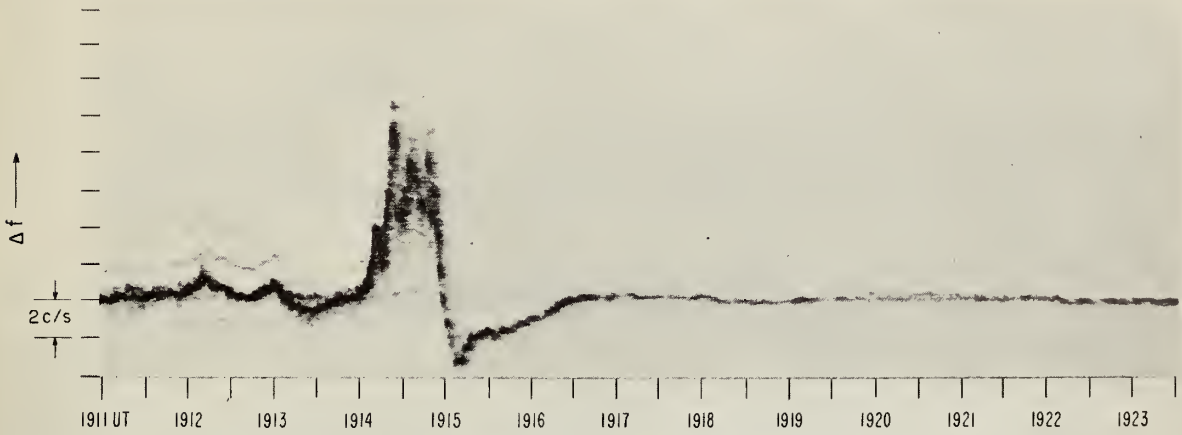
4 SEPTEMBER 1961

Figure 32

OPTICAL FLARE, IMPORTANCE 2 , 1911-1924 U-2018



(c) 10 Mc/s, WWV TO SHICKLEY

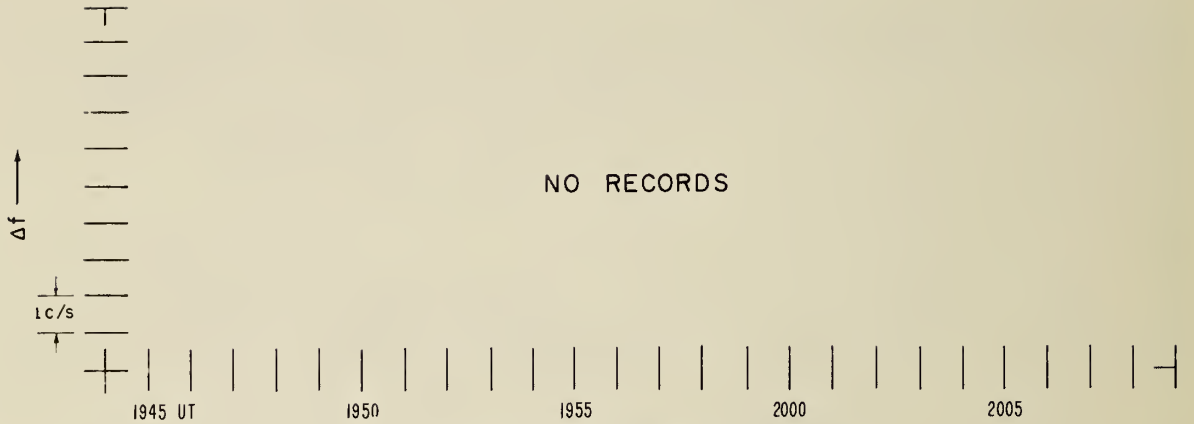


(d) 10 Mc/s, WWV TO BOULDER

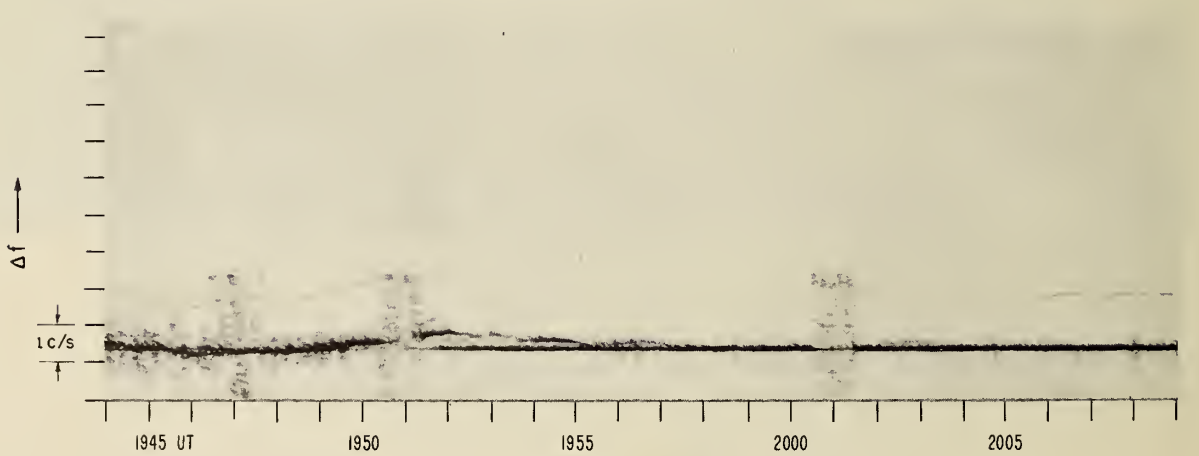
(e) 20 Mc/s, WWV TO BOULDER

4 SEPTEMBER 1961
Figure 32

OPTICAL FLARE, IMPORTANCE 1 , 1950 - 2010 - 2052



(a) 4.000 Mc/s, SUNSET TO BOULDER

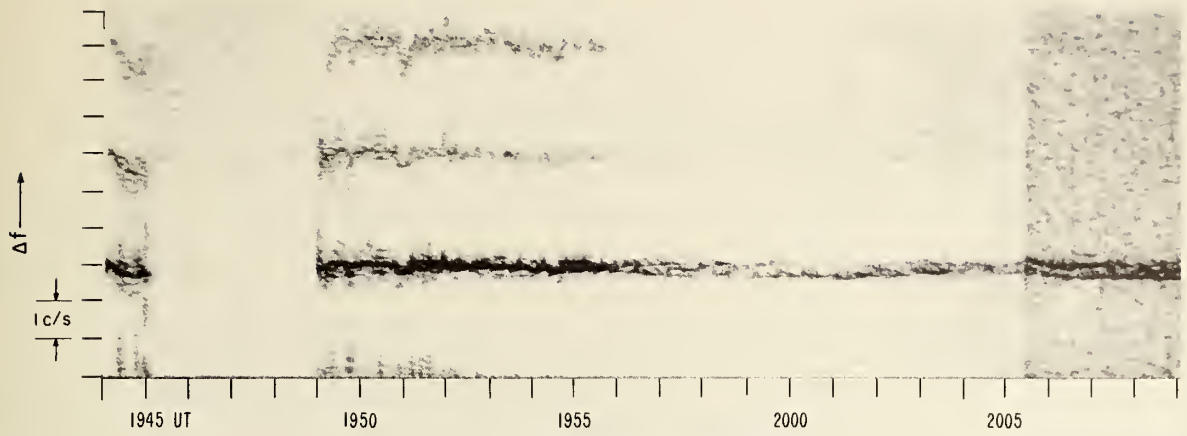


(b) 5.054 Mc/s, SUNSET TO BOULDER

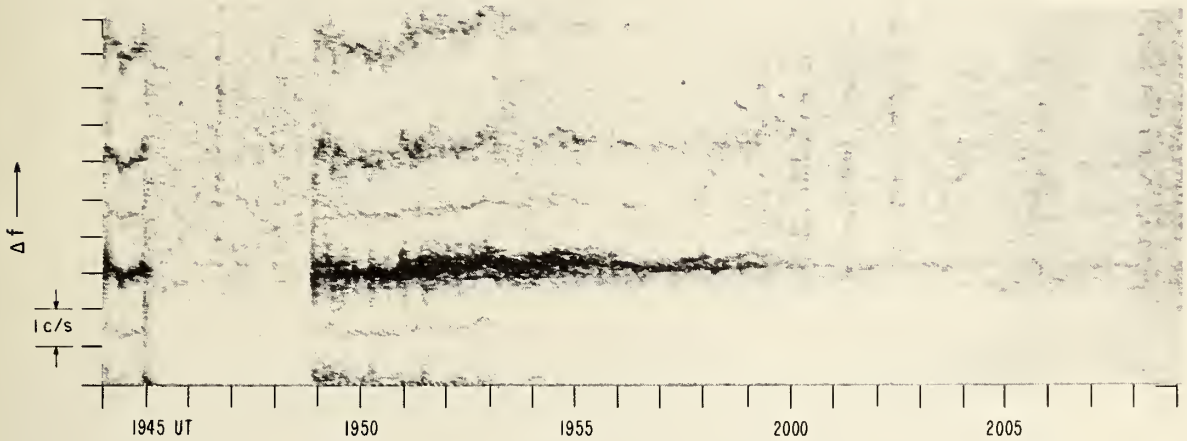
10 SEPTEMBER 1961

Figure 33

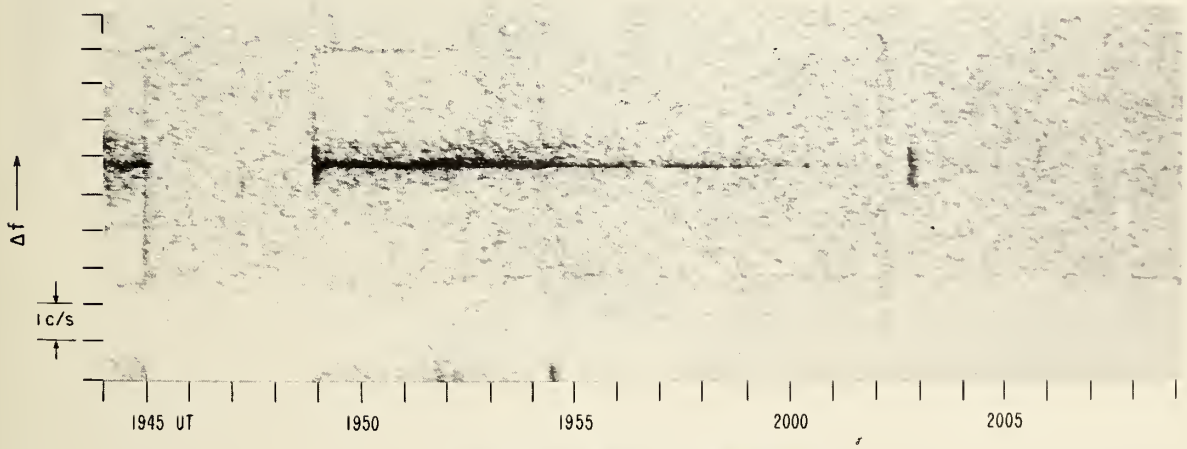
OPTICAL FLARE, IMPORTANCE 1 , 1950 - 2010 - 2052



(c) 10 Mc/s, WWV TO SHICKLEY



(d) 10 Mc/s, WWV TO BOULDER



(e) 20 Mc/s, WWV TO BOULDER

10 SEPTEMBER 1961
Figure 33

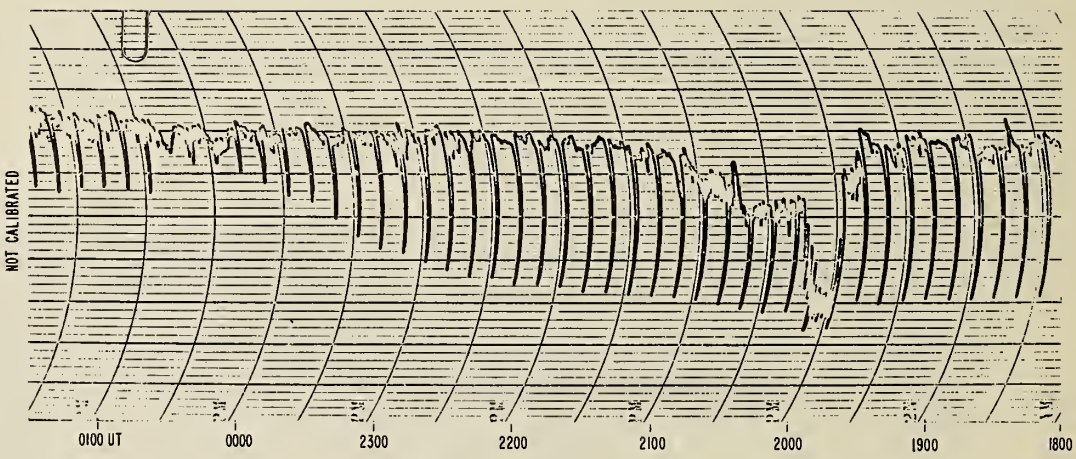
OPTICAL FLARE, IMPORTANCE 1, 1950-2010-2052

SIGNAL STRENGTH dB ABOVE 1μV

NO RECORDS

(a) 4.000 Mc/s, SUNSET TO BOULDER

SIGNAL STRENGTH dB ABOVE 1μV



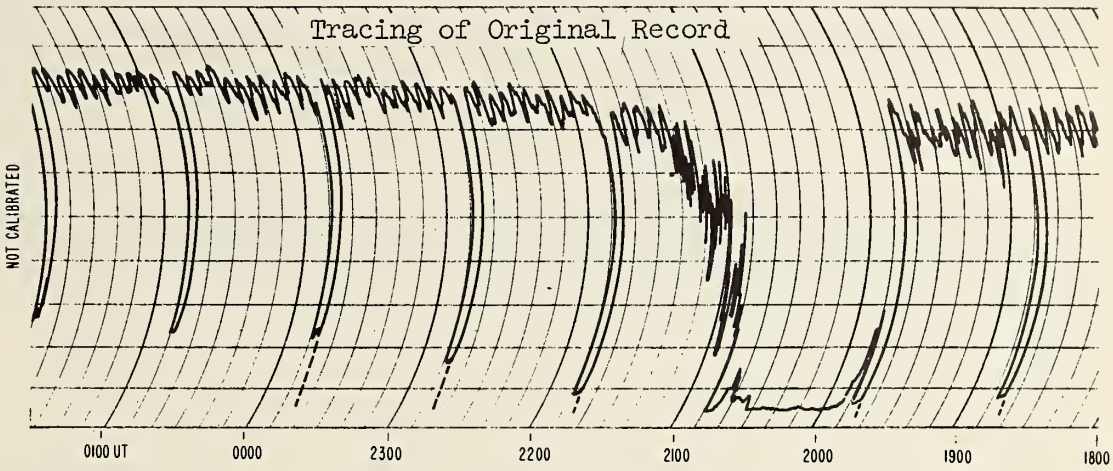
(b) 5.054 Mc/s, SUNSET TO BOULDER

10 SEPTEMBER 1961

Figure 34

OPTICAL FLARE, IMPORTANCE 1, 1950-2010-2052

SIGNAL STRENGTH dB ABOVE 1μV



(c) 10 Mc/s, WWV TO BOULDER

SIGNAL STRENGTH dB ABOVE 1μV

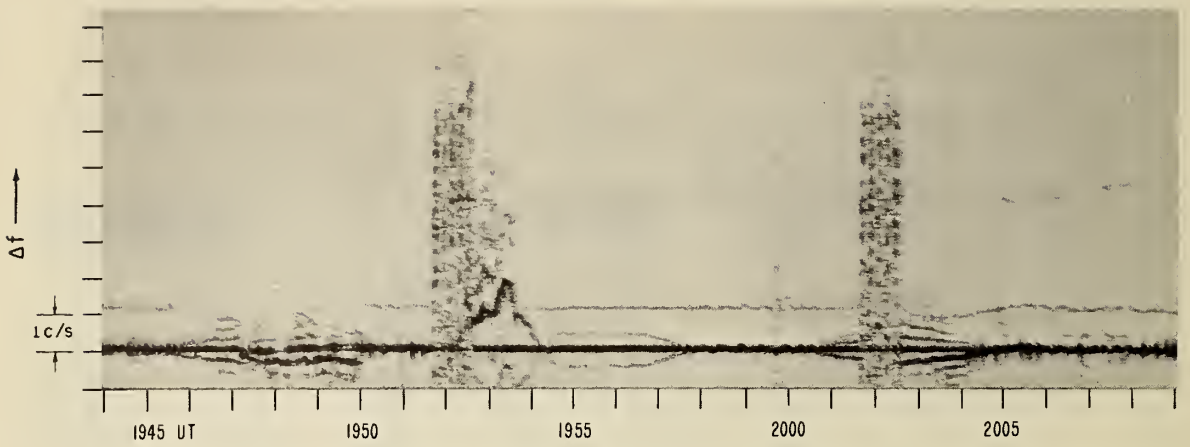
NO RECORDS

(d) 20 Mc/s, WWV TO BOULDER

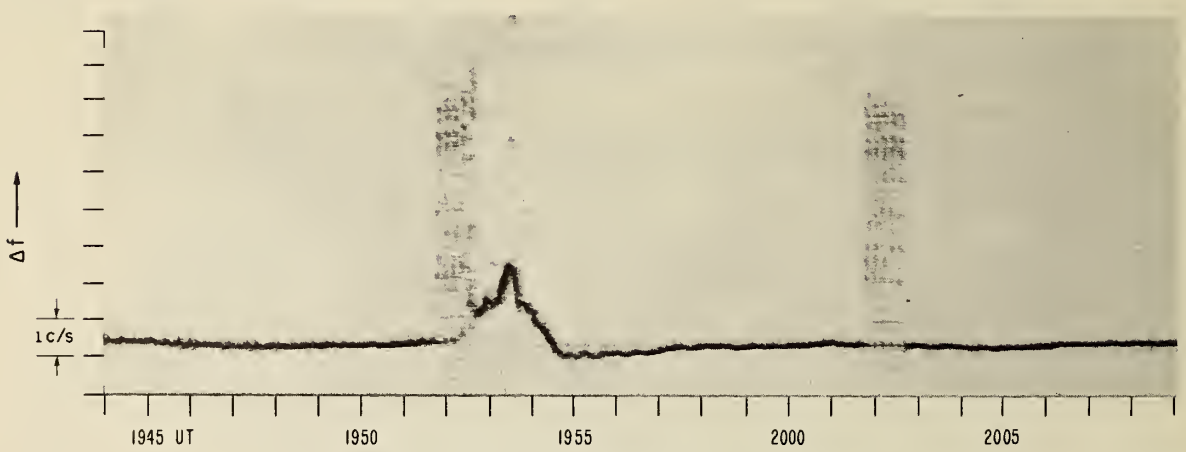
10 SEPTEMBER 1961

Figure 34

OPTICAL FLARE, IMPORTANCE 1 , 1950 - 1958 - 2007



(a) 4.000 Mc/s, SUNSET TO BOULDER

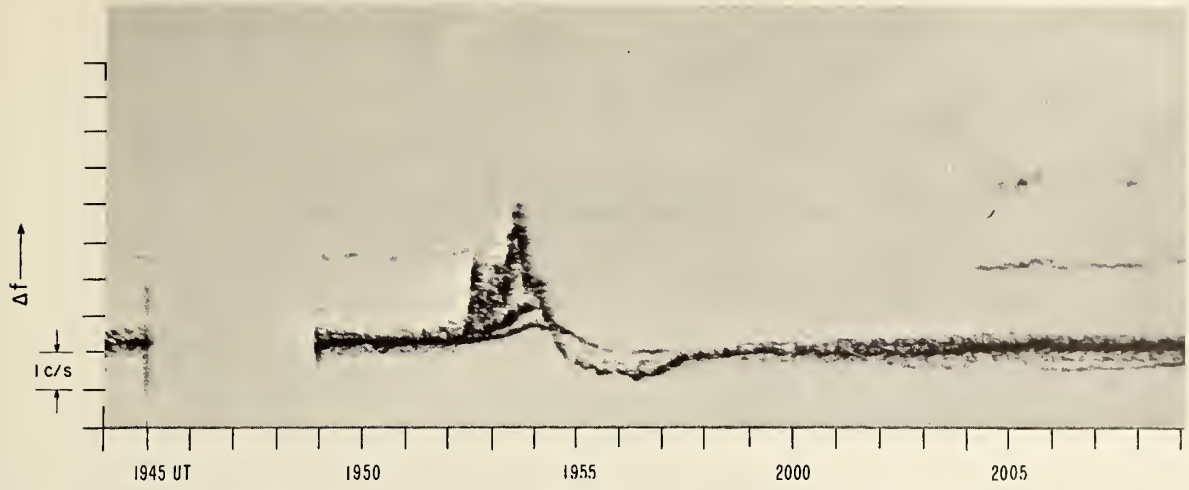


(b) 5.054 Mc/s, SUNSET TO BOULDER

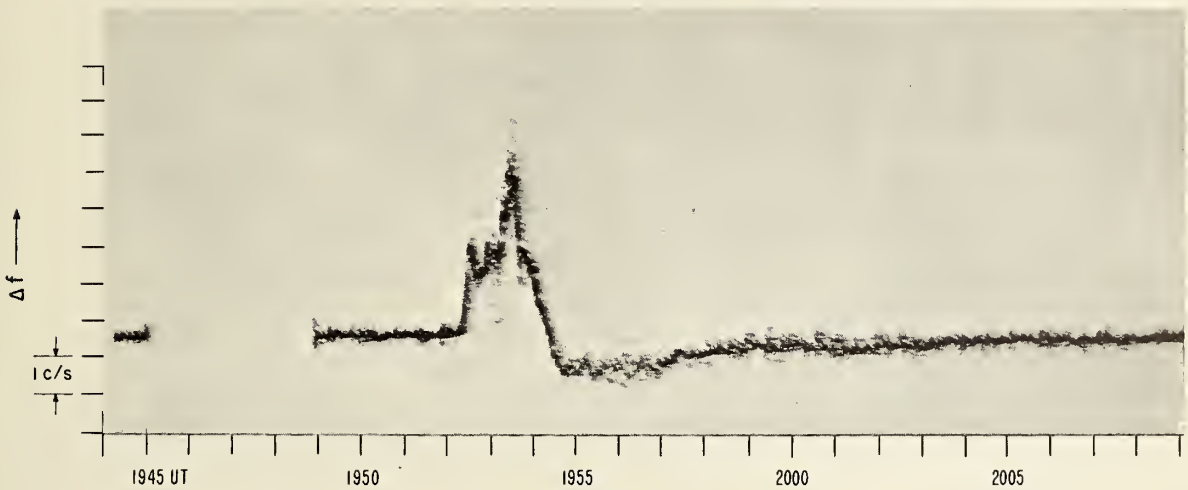
27 SEPTEMBER 1961

Figure 35

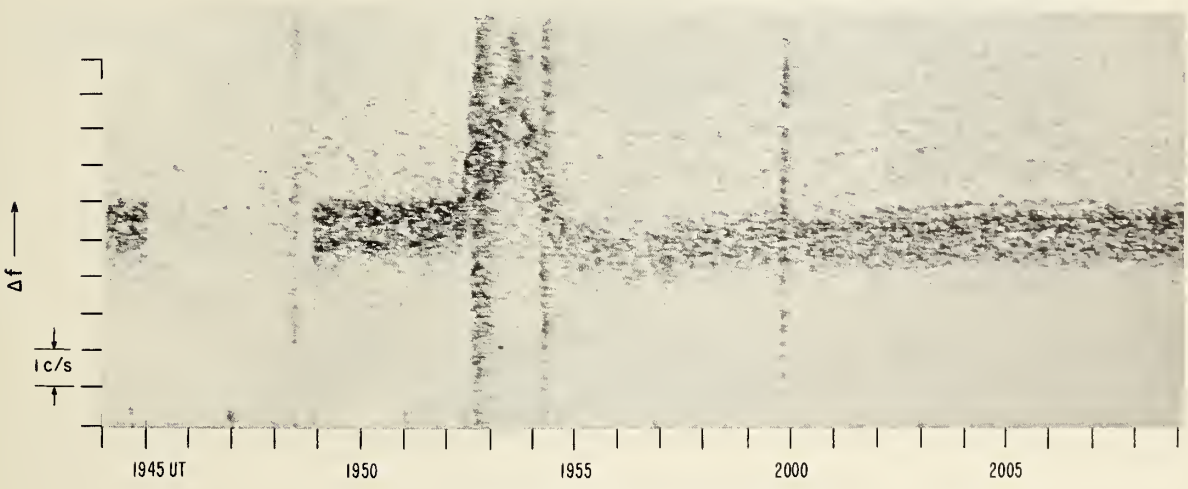
OPTICAL FLARE, IMPORTANCE 1 , 1950-1958-2007



(c) 10 Mc/s, WWV TO SHICKLEY



(d) 10 Mc/s, WWV TO BOULDER



(e) 20 Mc/s, WWV TO BOULDER

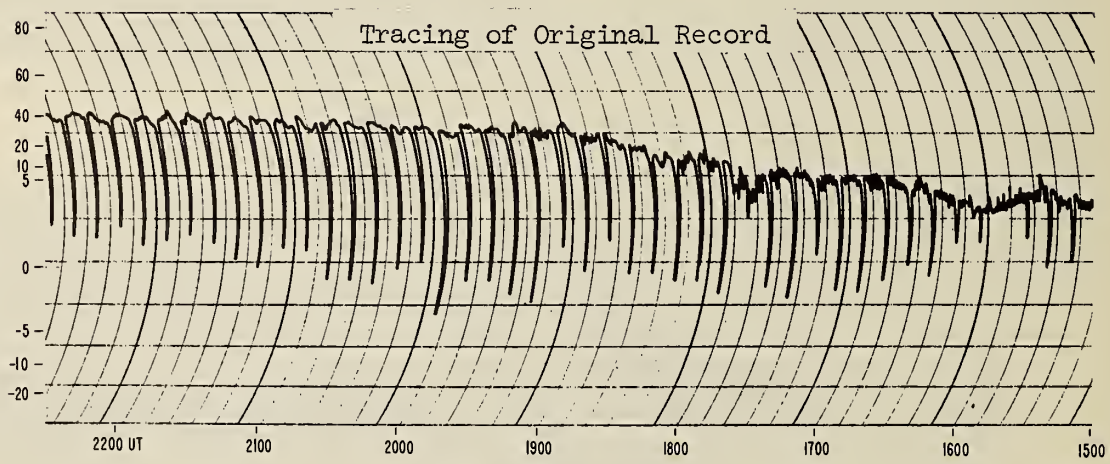
27 SEPTEMBER 1961
Figure 35

OPTICAL FLARE, IMPORTANCE 1, 1950-1958-2007

SIGNAL STRENGTH dB ABOVE 1μV

NO RECORDS

(a) 4.000 Mc/s, SUNSET TO BOULDER



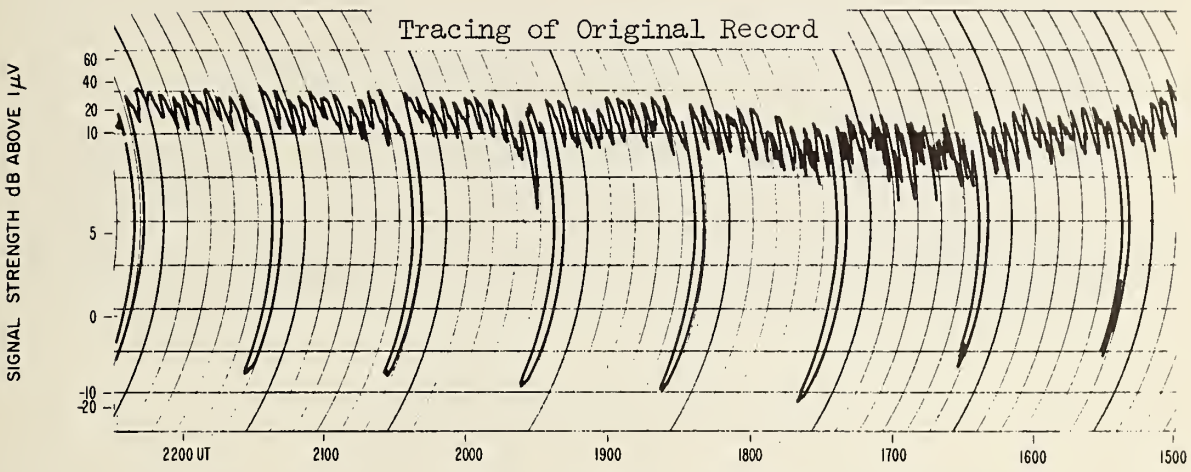
SIGNAL STRENGTH dB ABOVE 1μV

(b) 5.054 Mc/s, SUNSET TO BOULDER

27 SEPTEMBER 1961

Figure 36

OPTICAL FLARE, IMPORTANCE 1, 1950-1958-2007



(c) 10 Mc/s, WWV TO BOULDER

SIGNAL STRENGTH dB ABOVE 1μV

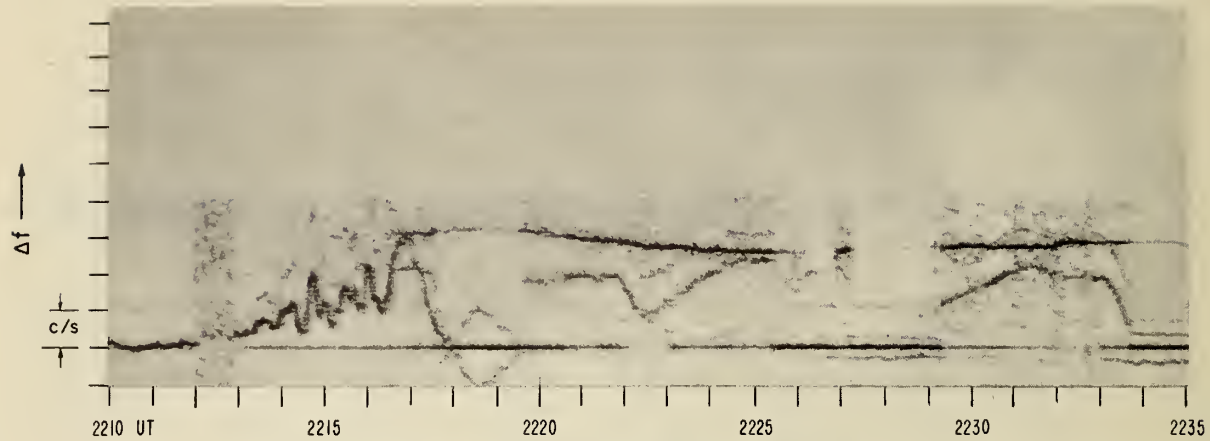
NO RECORDS

(d) 20 Mc/s, WWV TO BOULDER

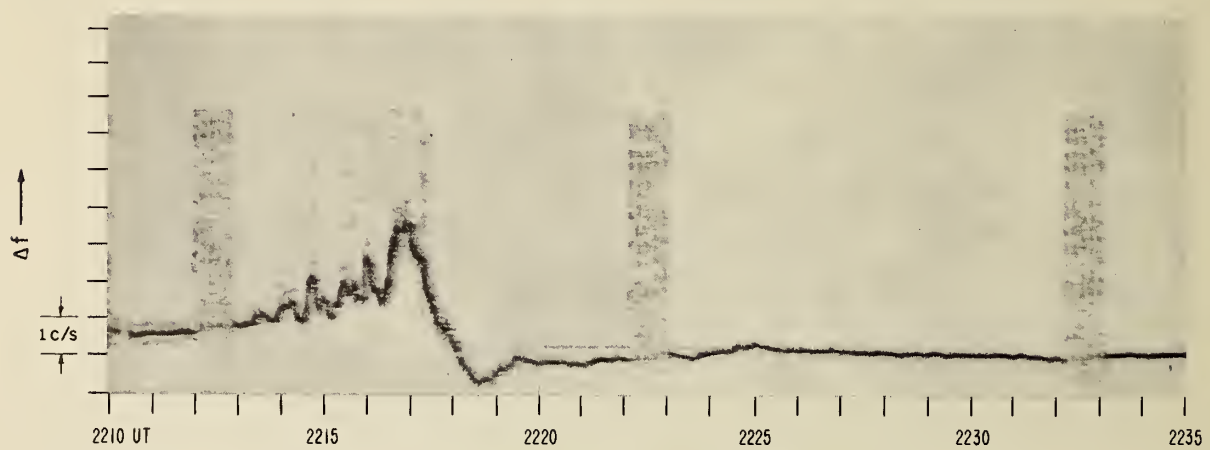
27 SEPTEMBER 1961

Figure 36

OPTICAL FLARE, IMPORTANCE 3 , 2202 - 2224 - 2530



(a) 4.000 Mc/s, SUNSET TO BOULDER

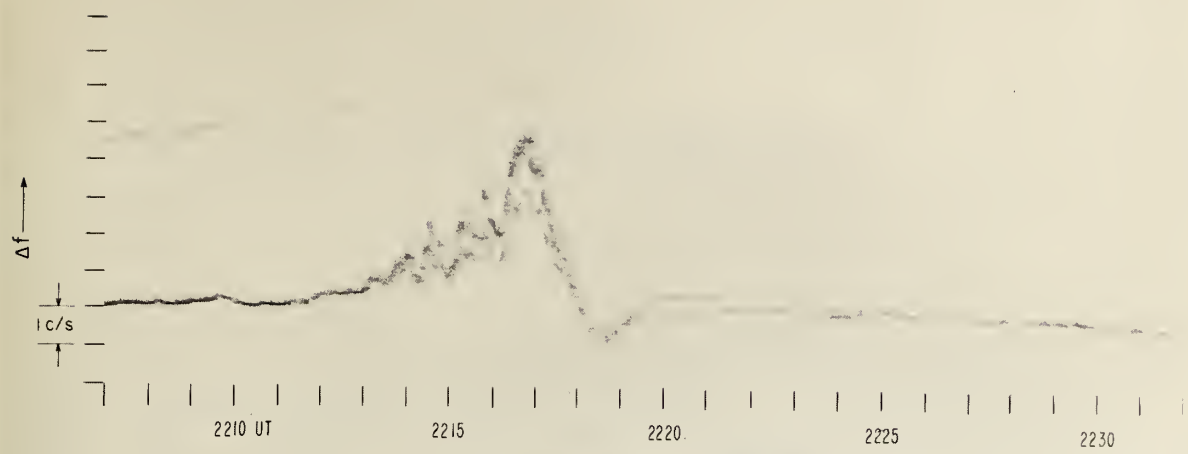


(b) 5.054 Mc/s, SUNSET TO BOULDER

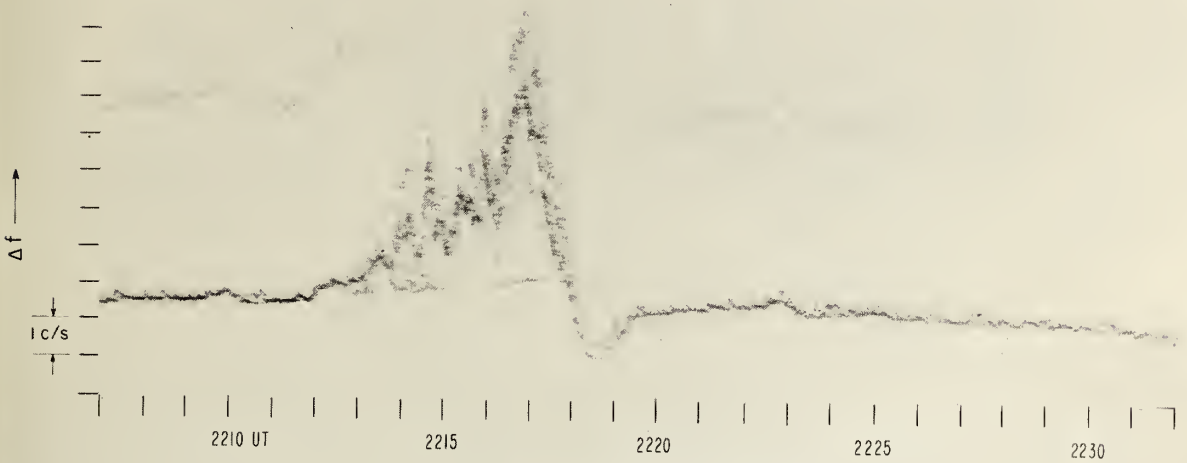
28 SEPTEMBER 1961

Figure 37

OPTICAL FLARE, IMPORTANCE 3 , 2202-2224-2530



(c) 10 Mc/s, WWV TO SHICKLEY



(d) 10 Mc/s, WWV TO BOULDER

(e) 20 Mc/s, WWV TO BOULDER

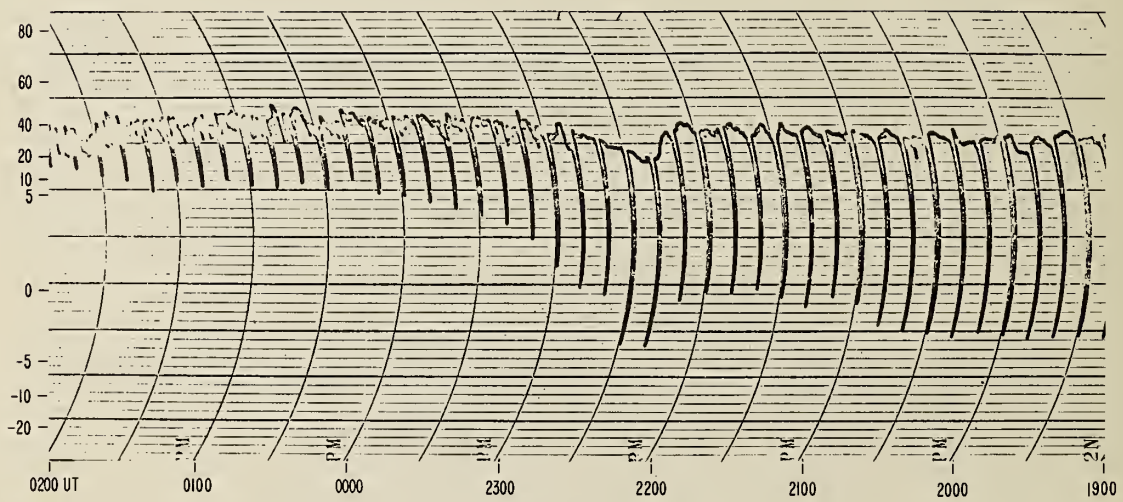
28 SEPTEMBER 1961
Figure 37

OPTICAL FLARE, IMPORTANCE 3, 2202-2224-2530

SIGNAL STRENGTH dB ABOVE 1μV

NO RECORDS

(a) 4.000 Mc/s, SUNSET TO BOULDER

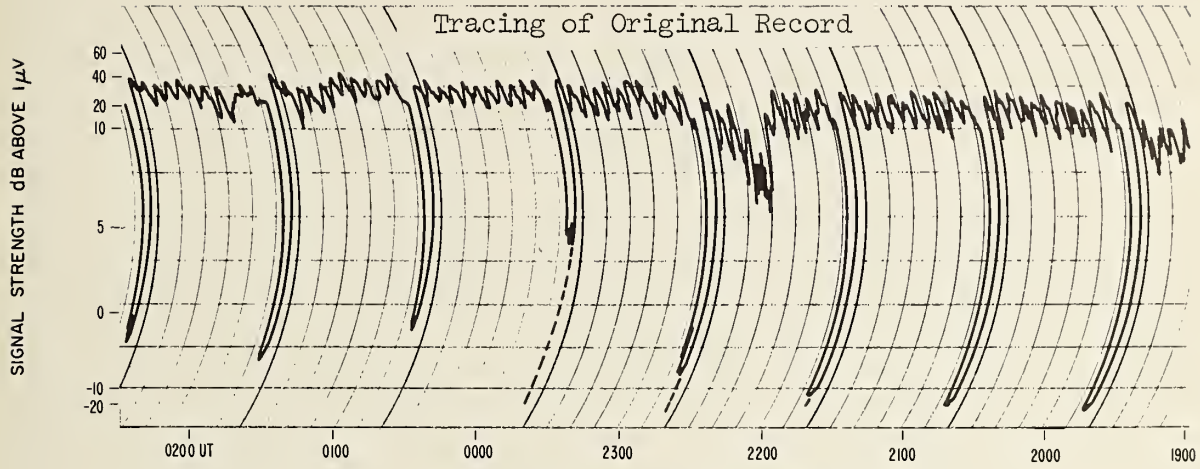


(b) 5.054 Mc/s, SUNSET TO BOULDER

28 SEPTEMBER 1961

Figure 38

OPTICAL FLARE, IMPORTANCE 3, 2202-2224-2530



(c) 10 Mc/s, WWV TO BOULDER

SIGNAL STRENGTH dB ABOVE 1μV

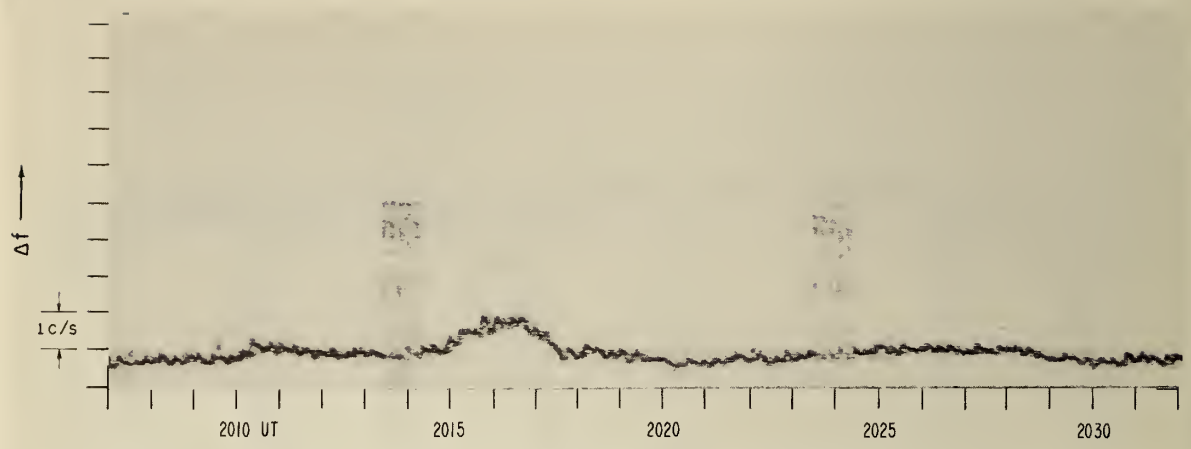
NO RECORDS

(d) 20 Mc/s, WWV TO BOULDER

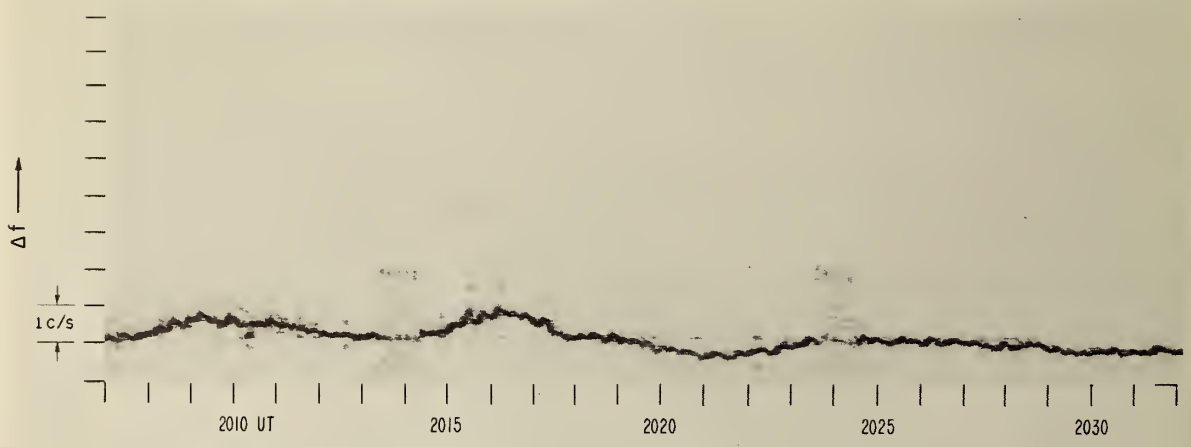
28 SEPTEMBER 1961

Figure 38

OPTICAL FLARE, IMPORTANCE 2 , 2012 - 2016 - 2044



(a) 4.000 Mc/s, SUNSET TO BOULDER

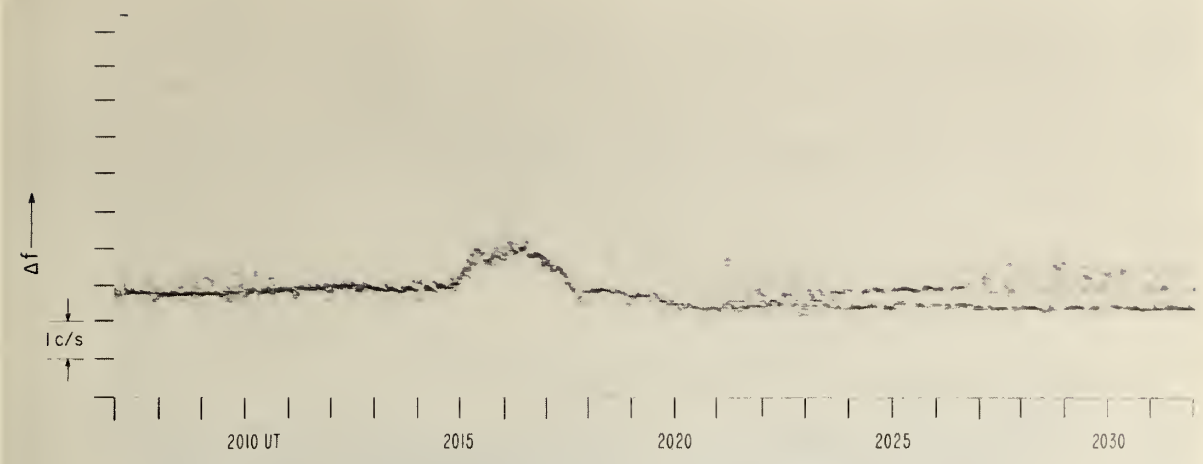


(b) 5.054 Mc/s, SUNSET TO BOULDER

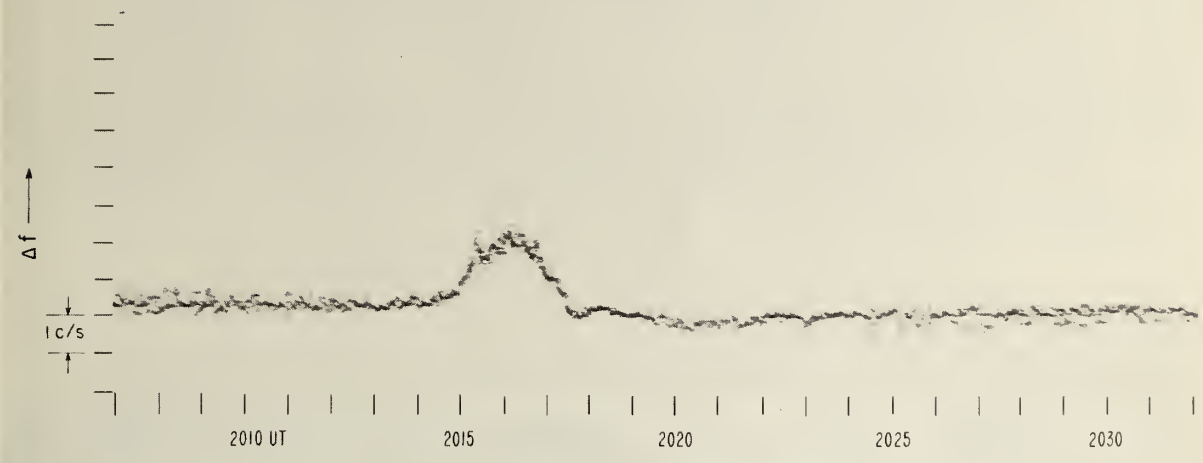
22 NOVEMBER 1961

Figure 39

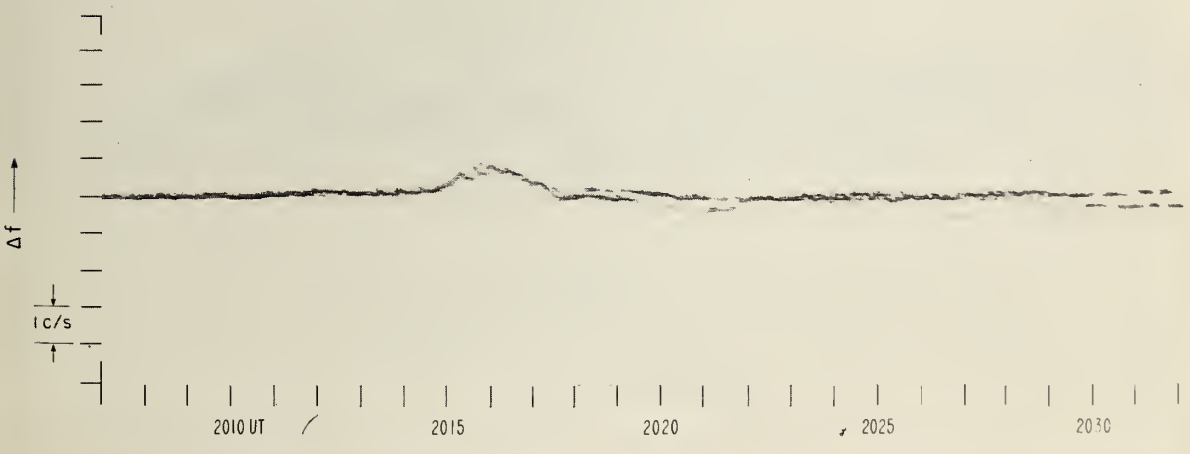
OPTICAL FLARE, IMPORTANCE 2 , 2012 - 2016 - 2044



(c) 10 Mc/s, WWV TO SHICKLEY



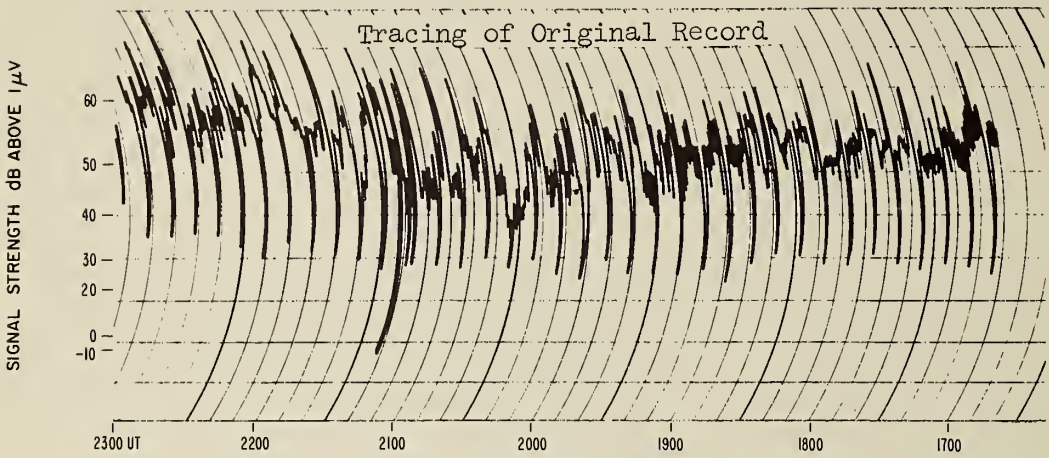
(d) 10 Mc/s, WWV TO BOULDER



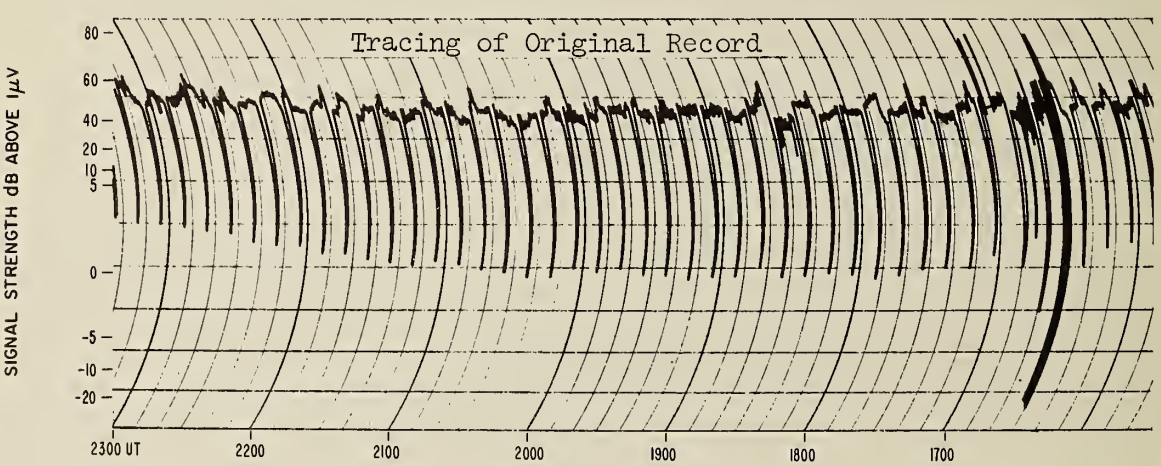
(e) 20 Mc/s, WWV TO BOULDER

22 NOVEMBER 1961
Figure 39

OPTICAL FLARE, IMPORTANCE 2 , 2014-2016-2024



(a) 4.000 Mc/s, SUNSET TO BOULDER

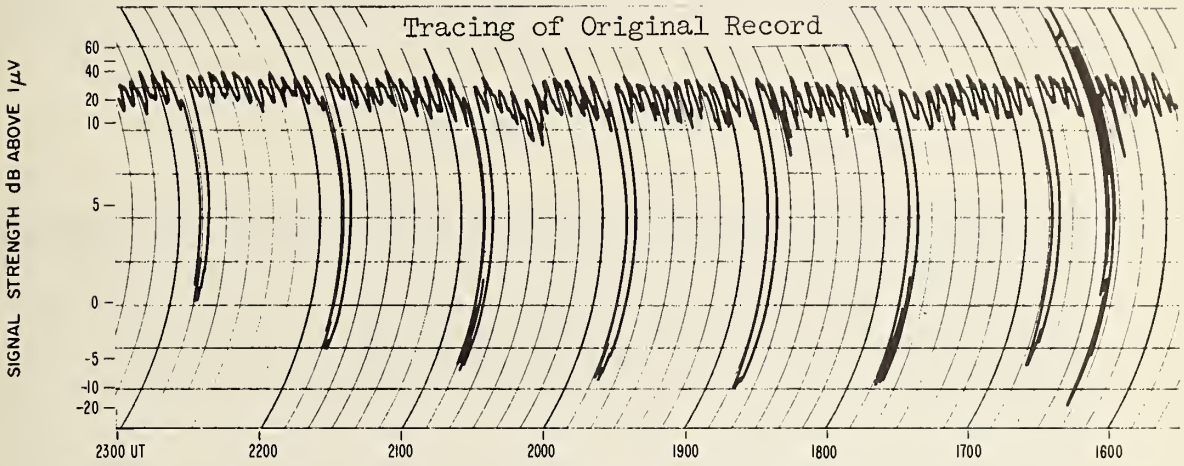


(b) 5.054 Mc/s, SUNSET TO BOULDER

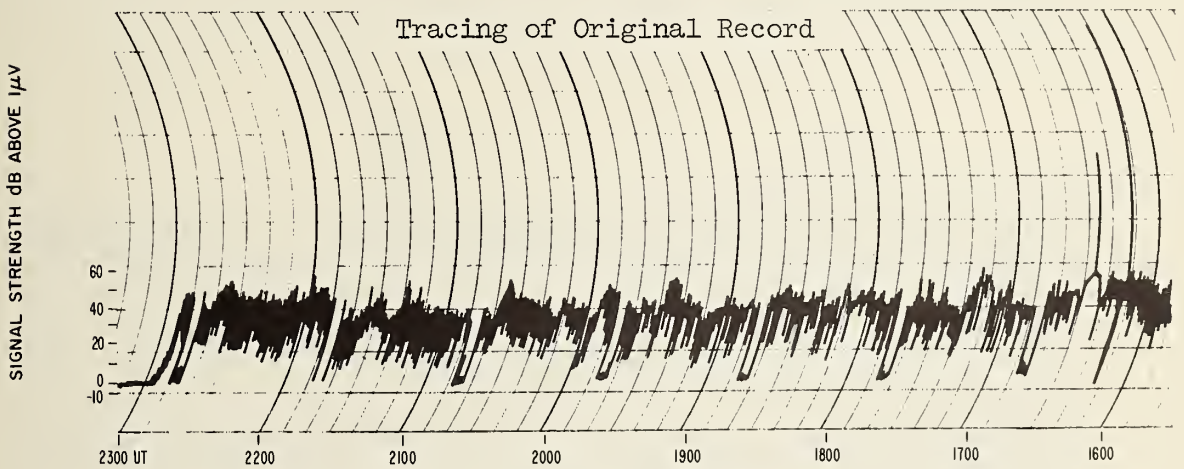
22 NOVEMBER 1961

Figure 40

OPTICAL FLARE, IMPORTANCE 2 , 2014-2016-2024



(c) 10 Mc/s, WWV TO BOULDER

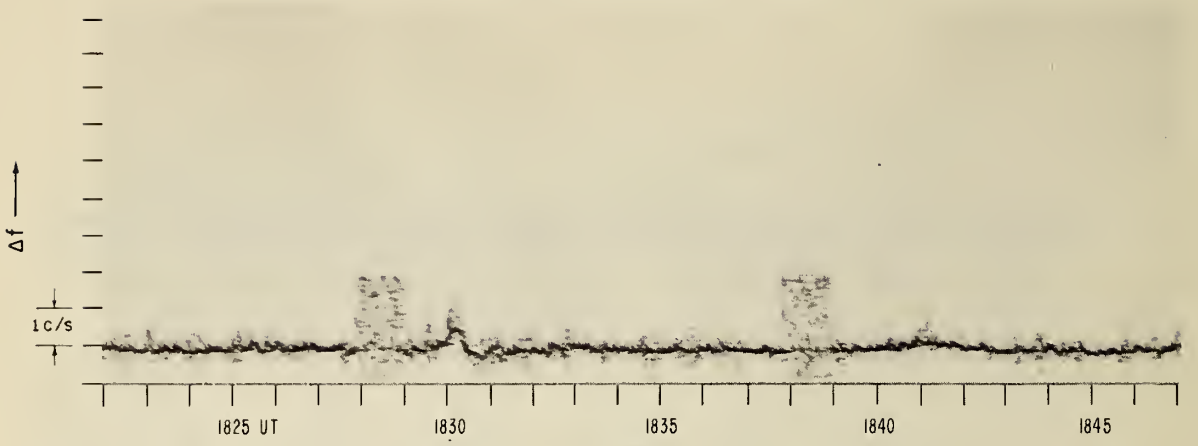


(d) 20 Mc/s, WWV TO BOULDER

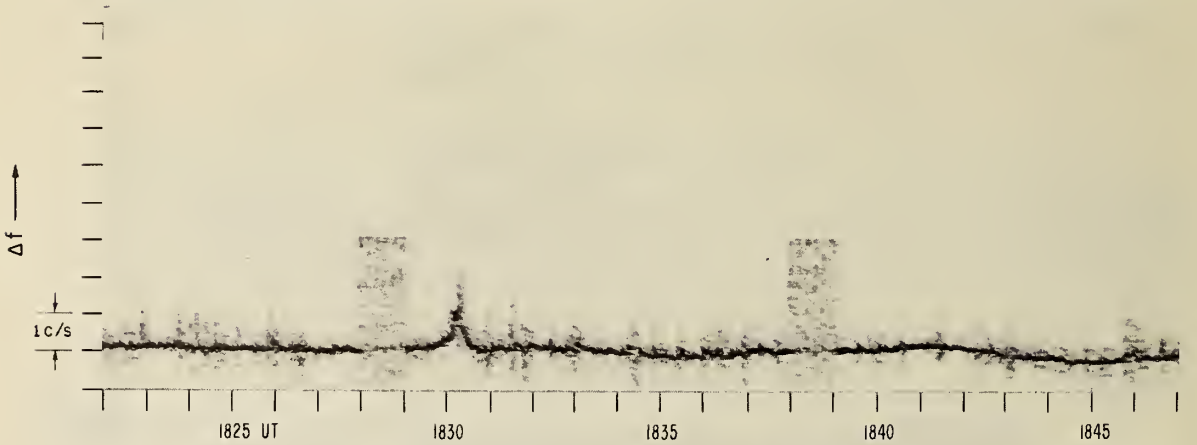
22 NOVEMBER 1961

Figure 40

OPTICAL FLARE, IMPORTANCE 1-, 1835E - 1835U - 1855



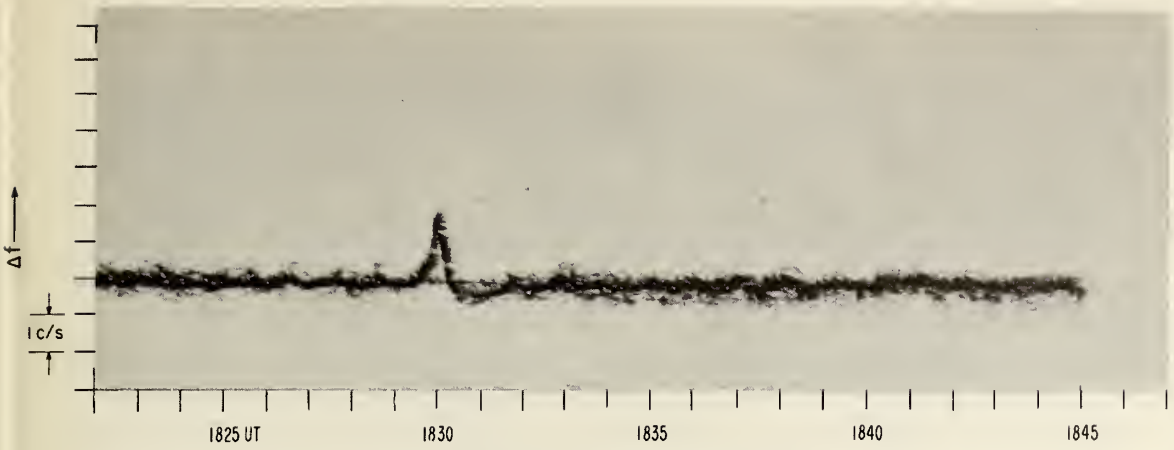
(a) 4.000 Mc/s, SUNSET TO BOULDER



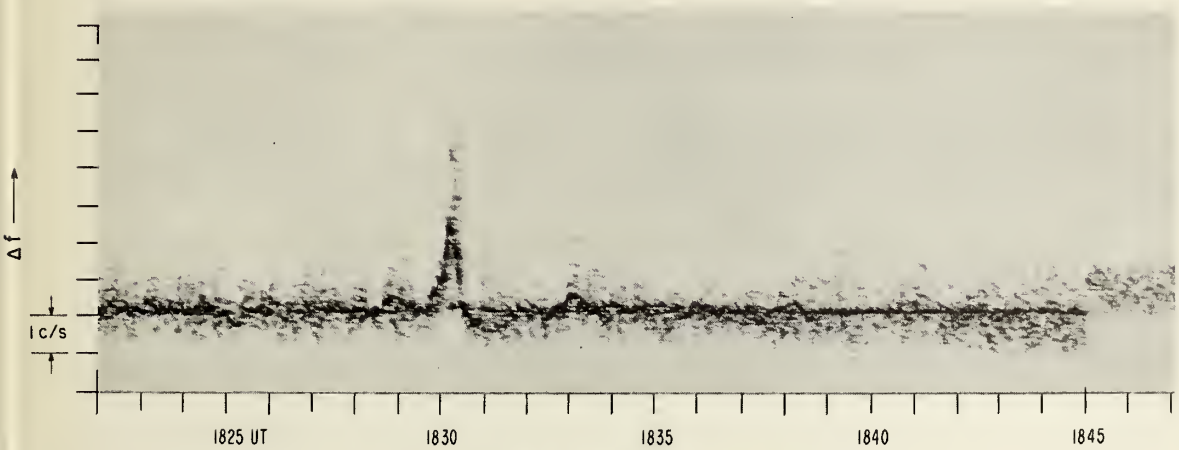
(b) 5.054 Mc/s, SUNSET TO BOULDER

21 FEBRUARY 1962

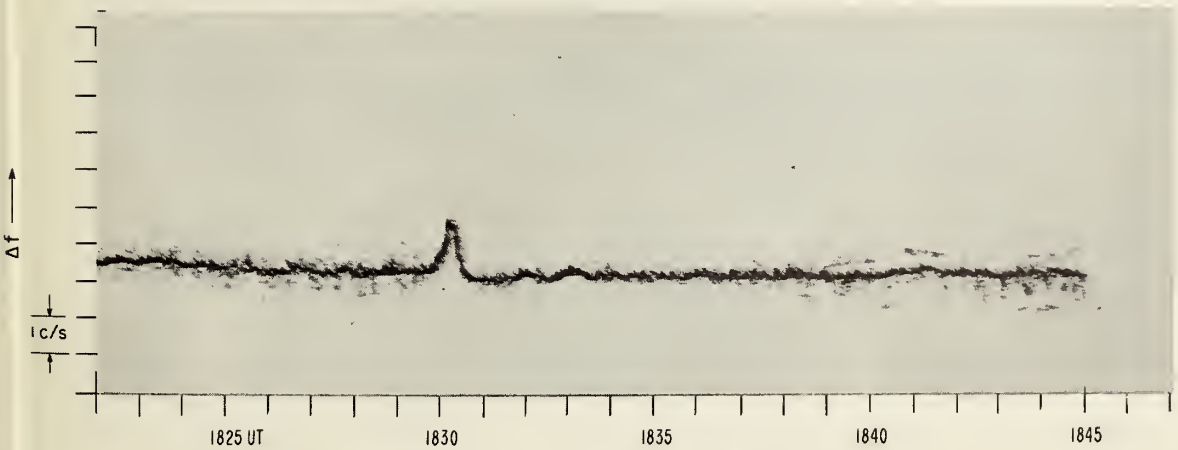
Figure 41



(c) 10 Mc/s, WWV TO SHICKLEY

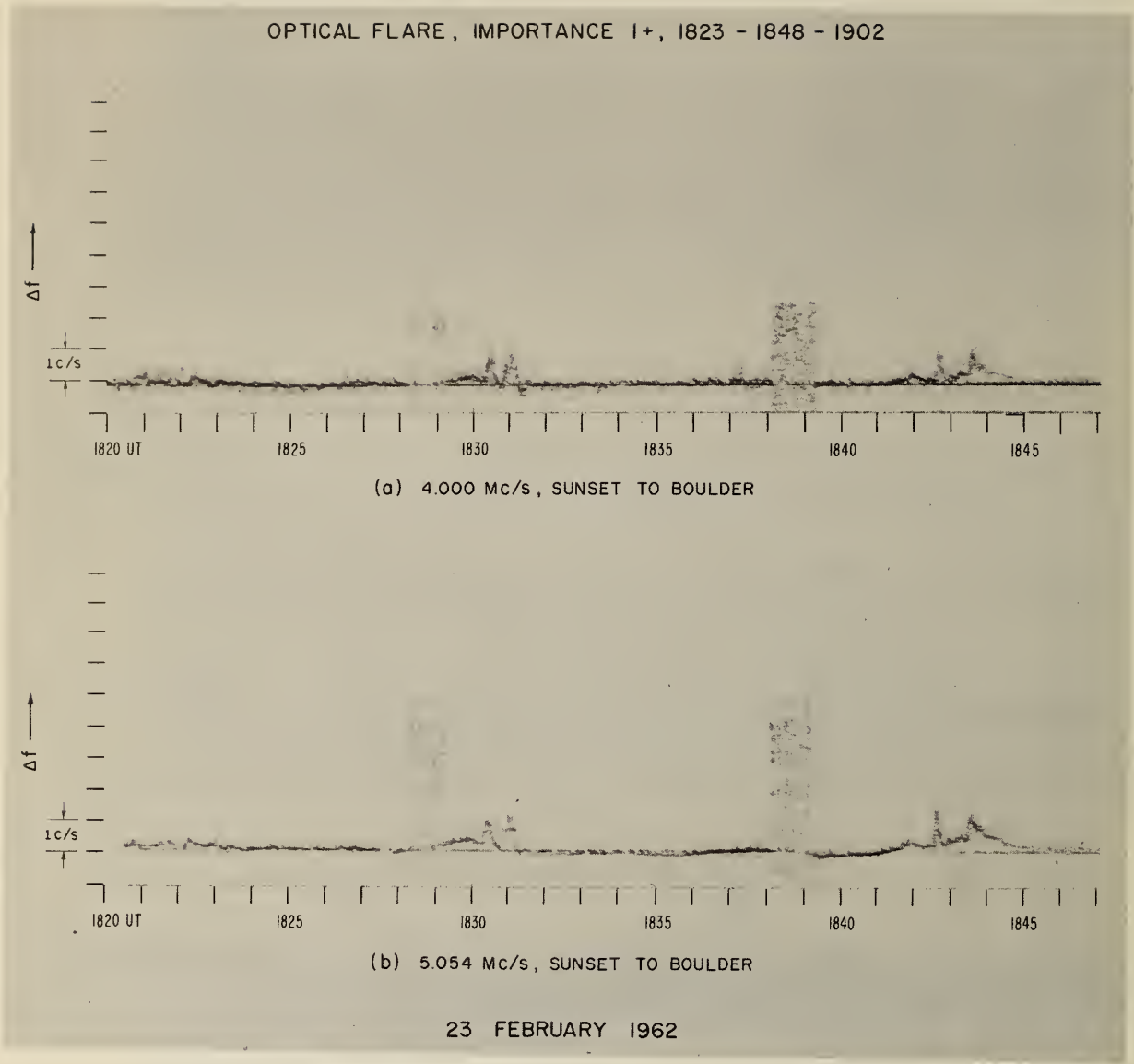


(d) 10 Mc/s, WWV TO BOULDER



(e) 15 Mc/s, WWV TO BOULDER

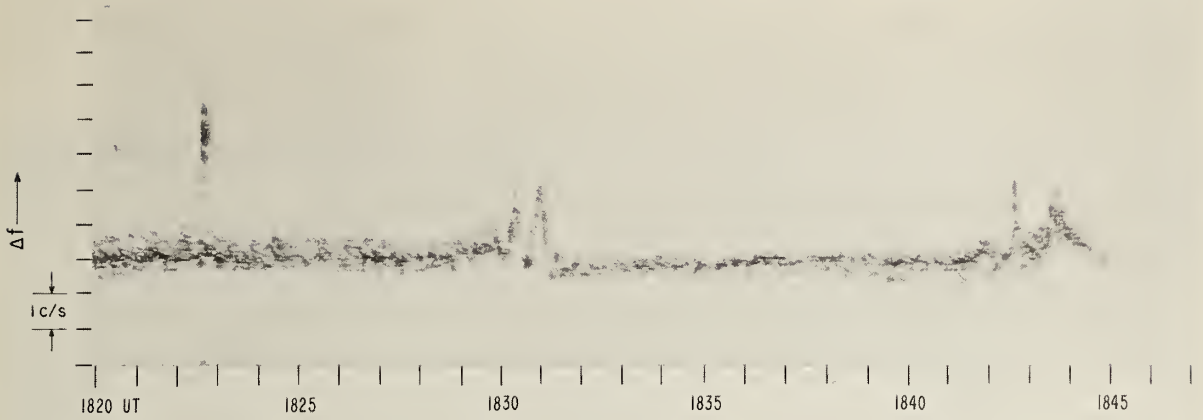
21 FEBRUARY 1962
Figure 41



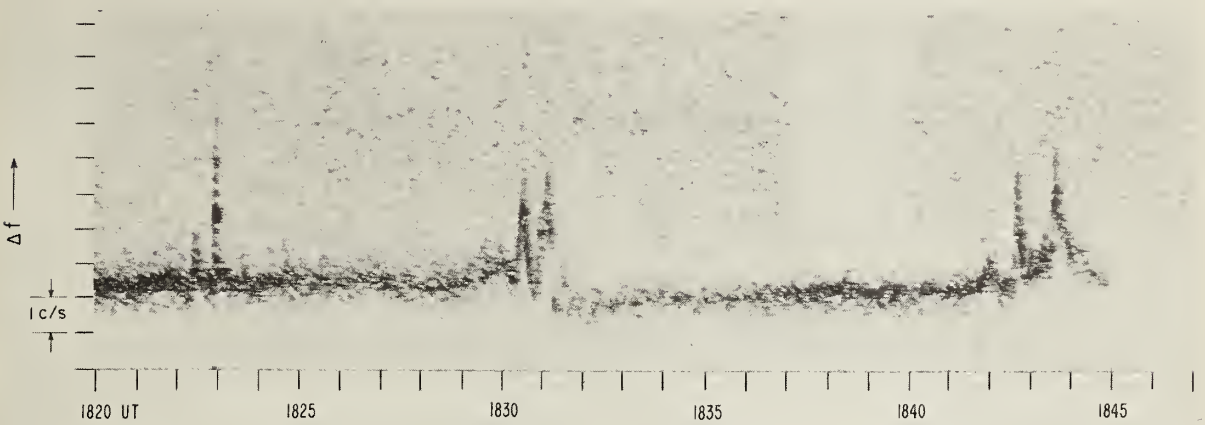
23 FEBRUARY 1962

Figure 42

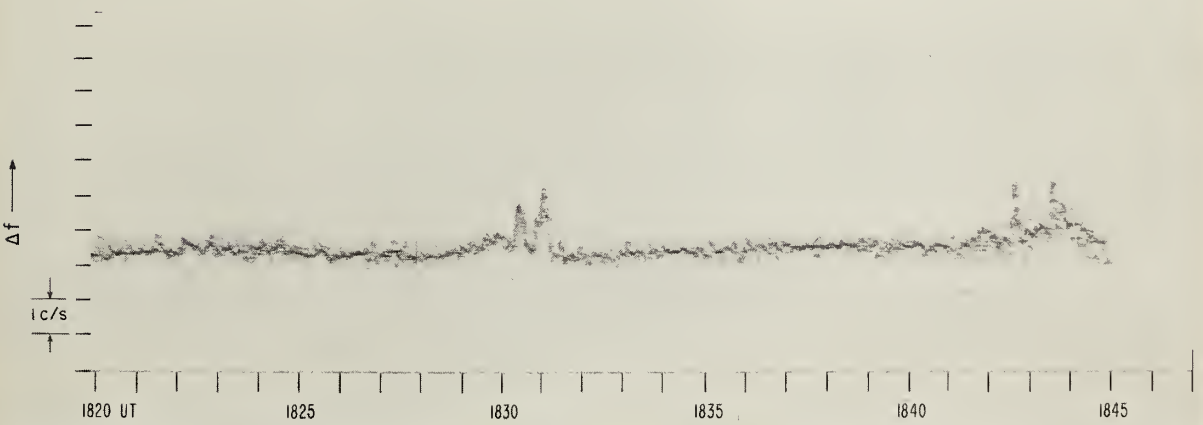
OPTICAL FLARE, IMPORTANCE 1+, 1823 - 1848 - 1902



(c) 10 Mc/s, WWV TO SHICKLEY

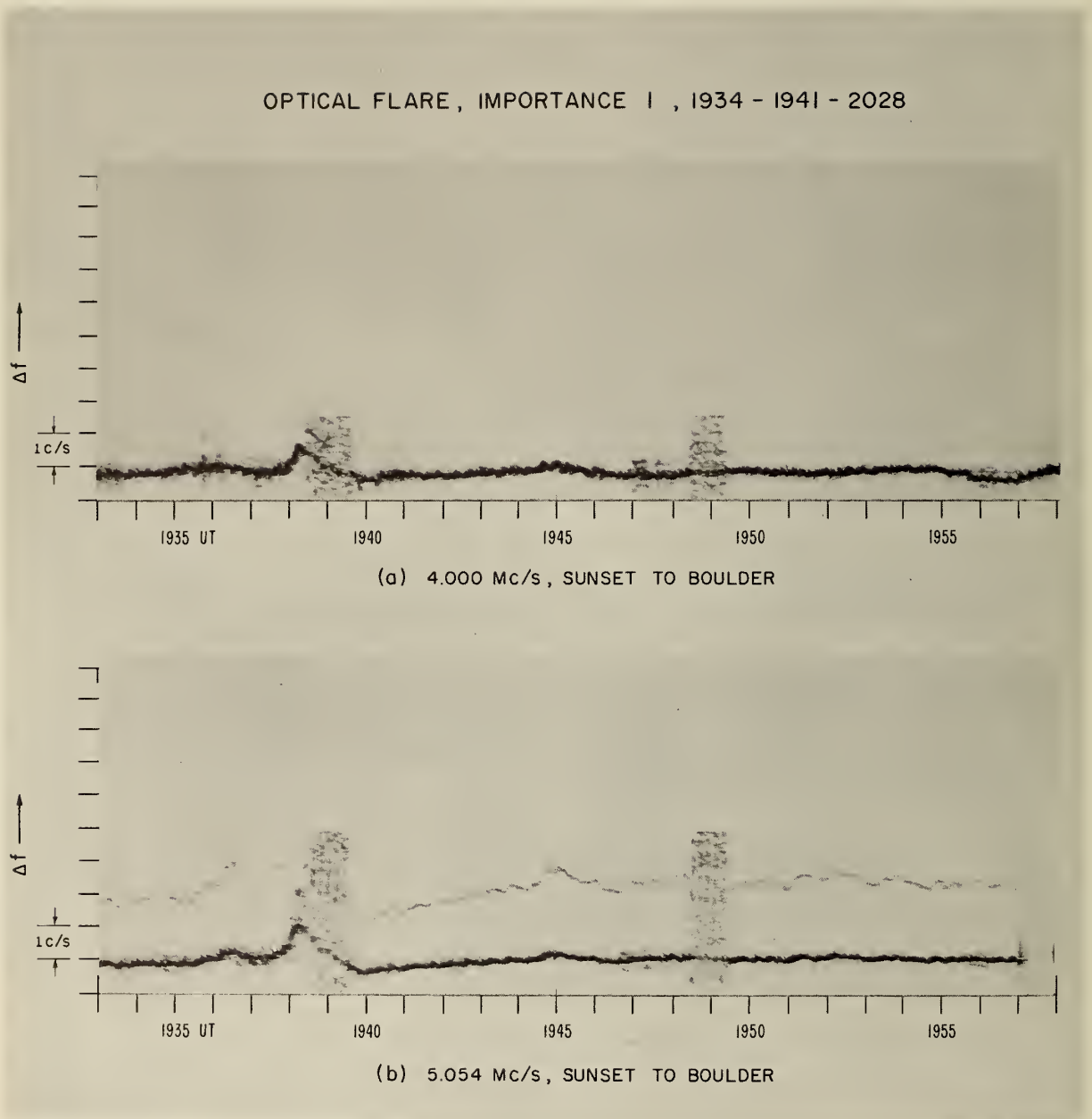


(d) 10 Mc/s, WWV TO BOULDER



(e) 15 Mc/s WWV TO BOULDER

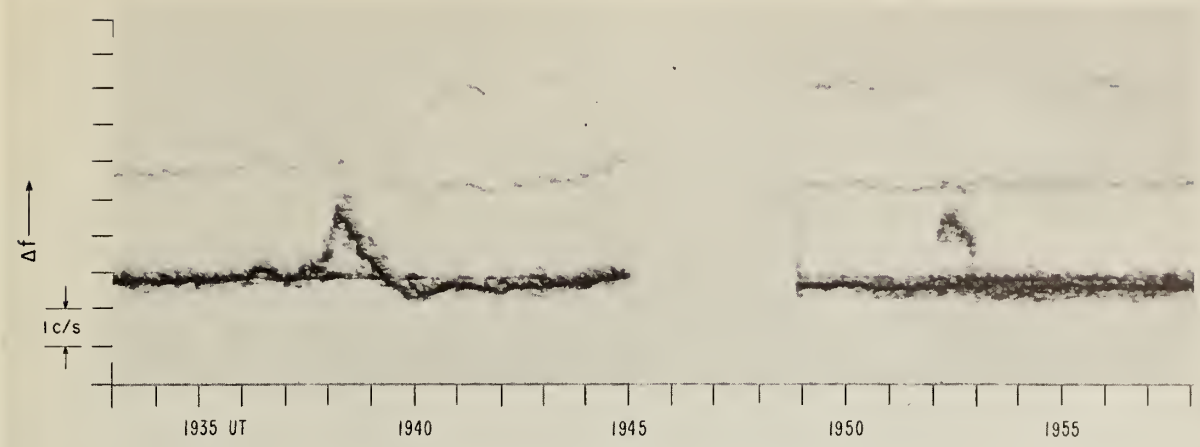
23 FEBRUARY 1962
Figure 42



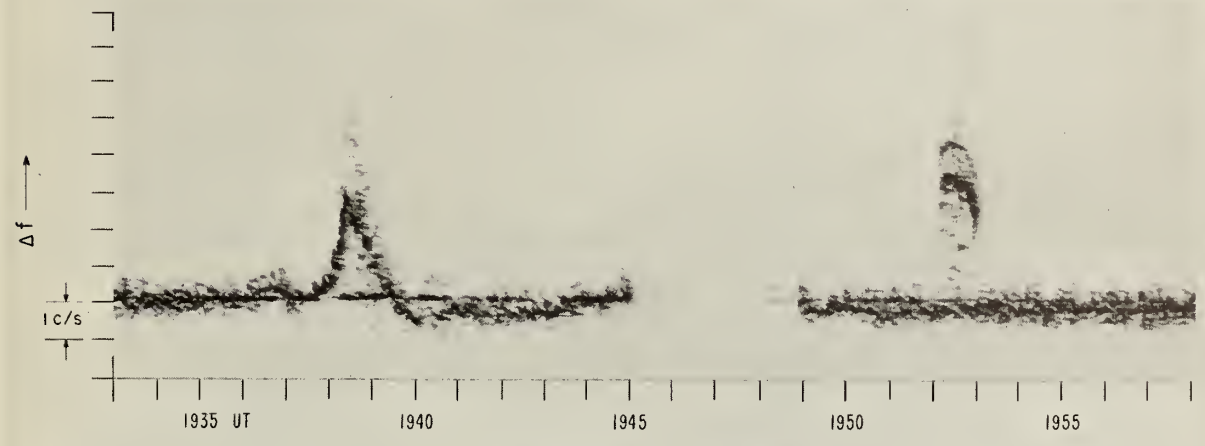
28 FEBRUARY 1962

Figure 43

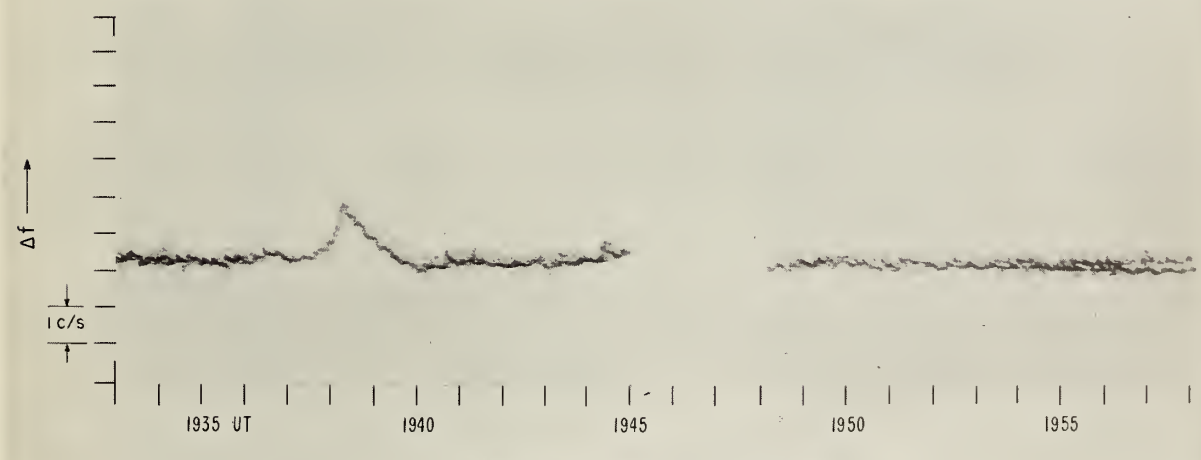
OPTICAL FLARE, IMPORTANCE 1 , 1934 - 1941 - 2028



(c) 10 Mc/s, WWV TO SHICKLEY



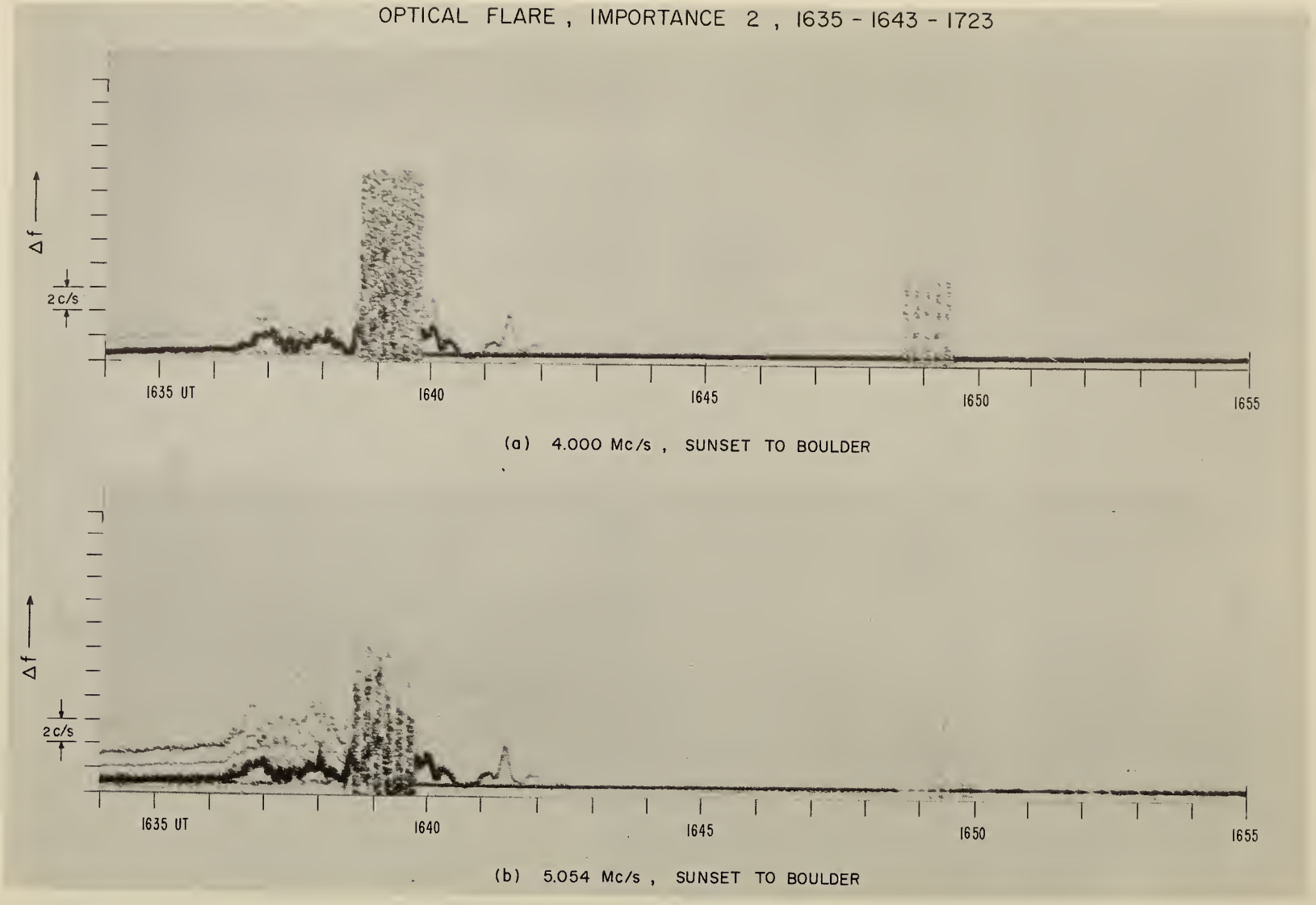
(d) 10 Mc/s, WWV TO BOULDER



(e) 15 Mc/s, WWV TO BOULDER

28 FEBRUARY 1962

Figure 43

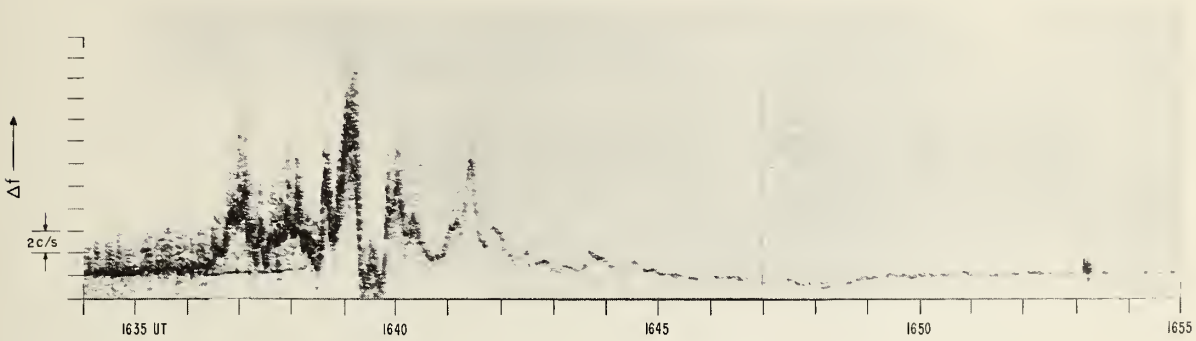


1 MARCH 1962

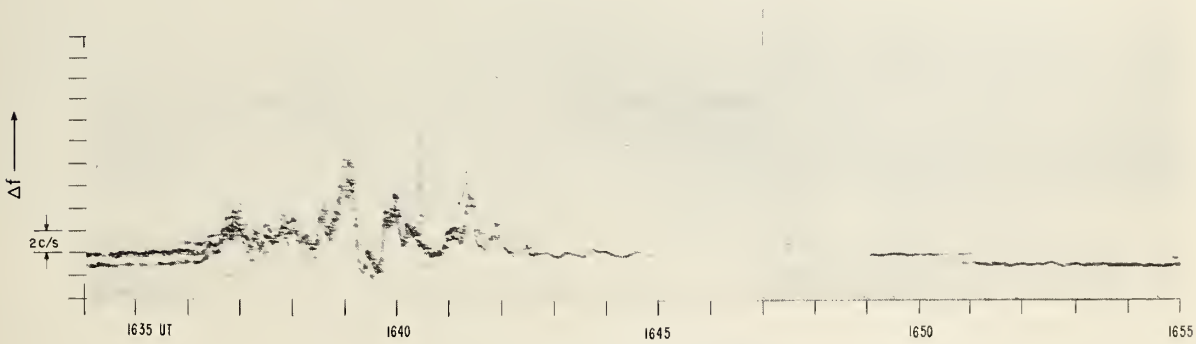
Figure 44

OPTICAL FLARE , IMPORTANCE 2 , 1635 - 1643 - 1723

(c) 10 Mc/s , WWV TO SHICKLEY



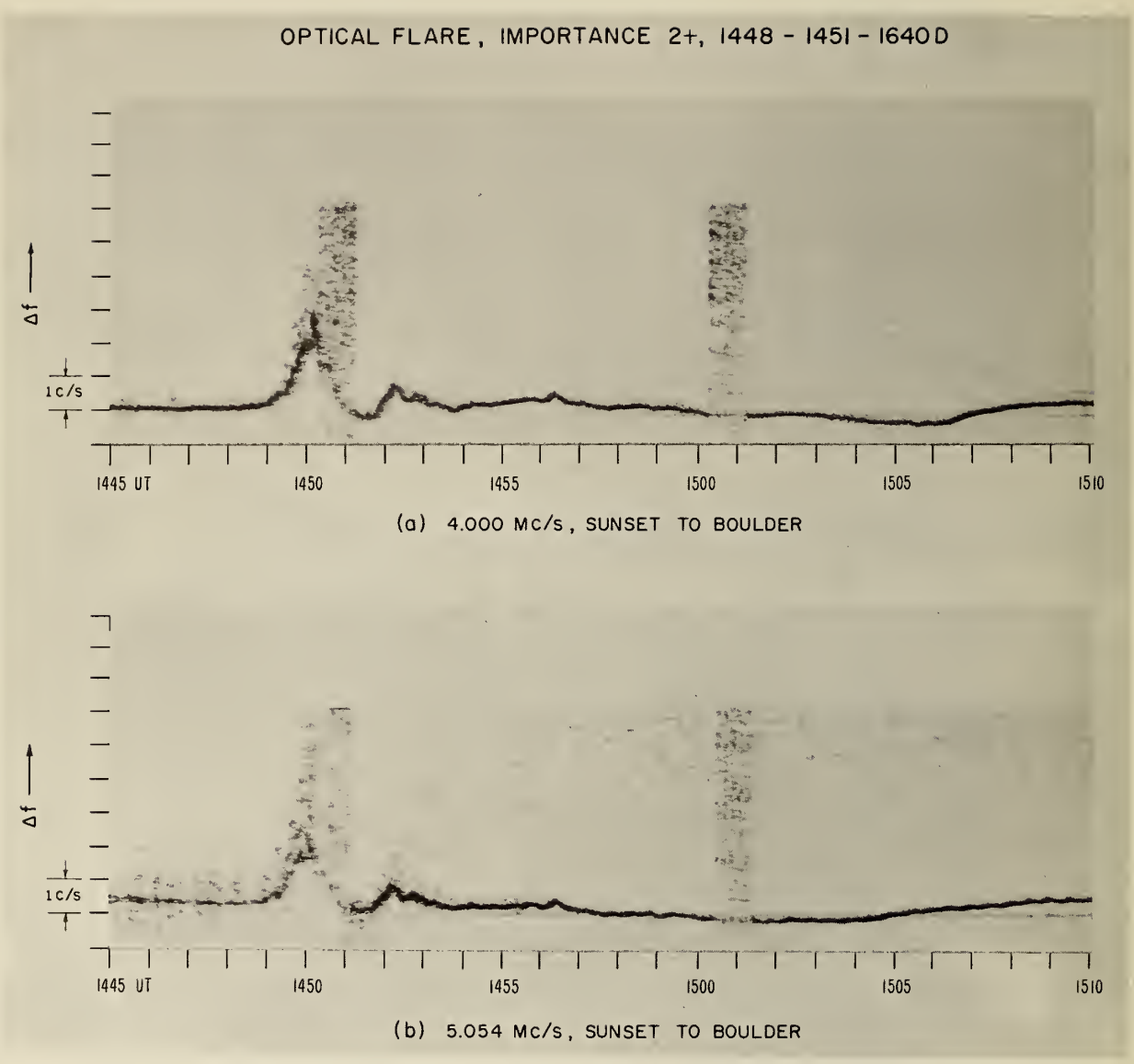
(d) 10 Mc/s , WWV TO BOULDER



(e) 15 Mc/s , WWV TO BOULDER

1 MARCH 1962

Figure 44

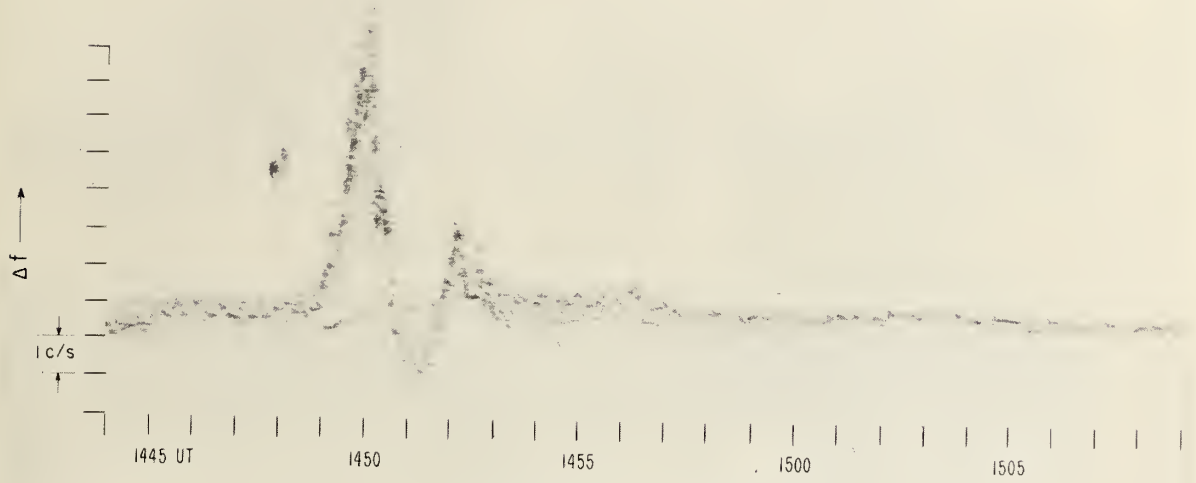


13 MARCH 1962

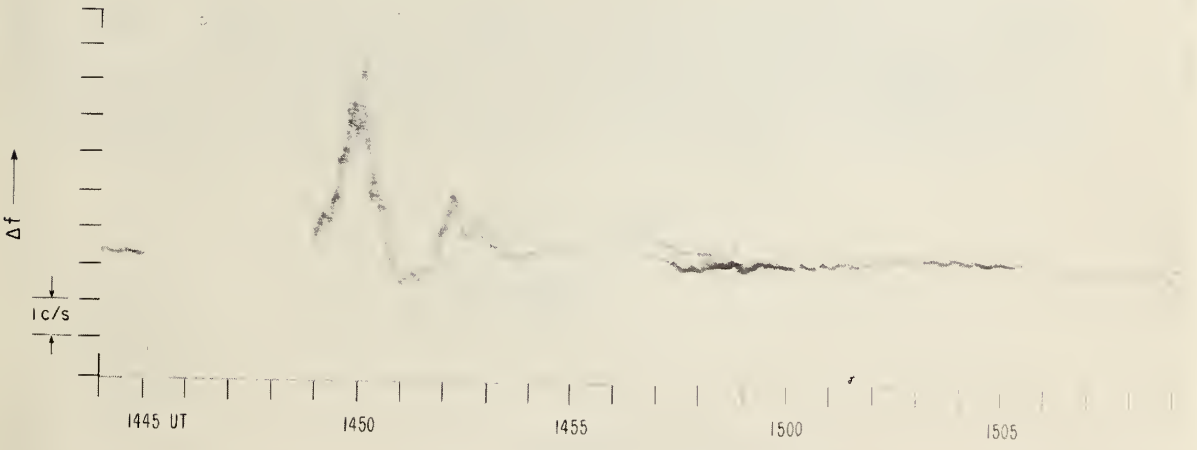
Figure 45

OPTICAL FLARE, IMPORTANCE 2+, 1448 - 1451 - 1640 D

(c) 10 Mc/s, WWV TO SHICKLEY



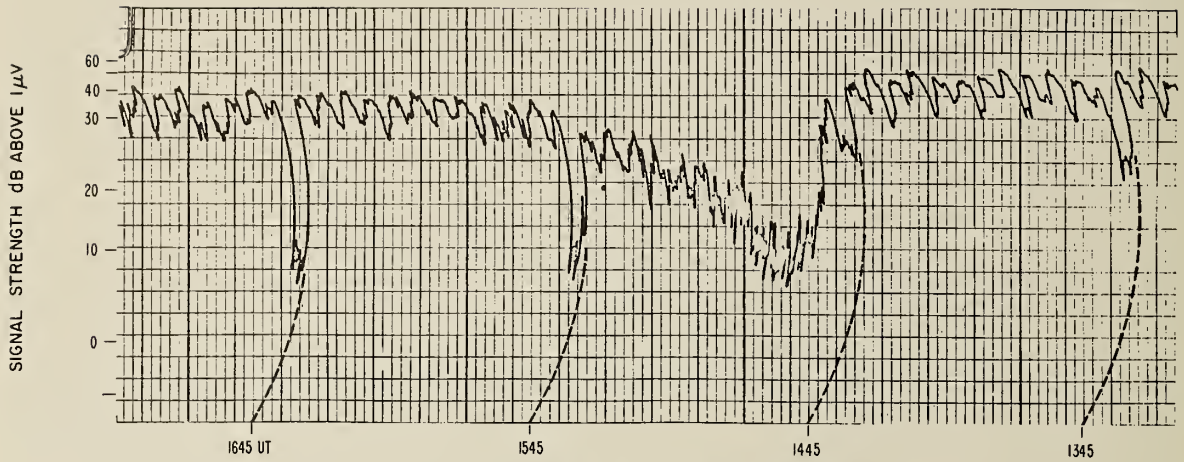
(d) 10 Mc/s, WWV TO BOULDER



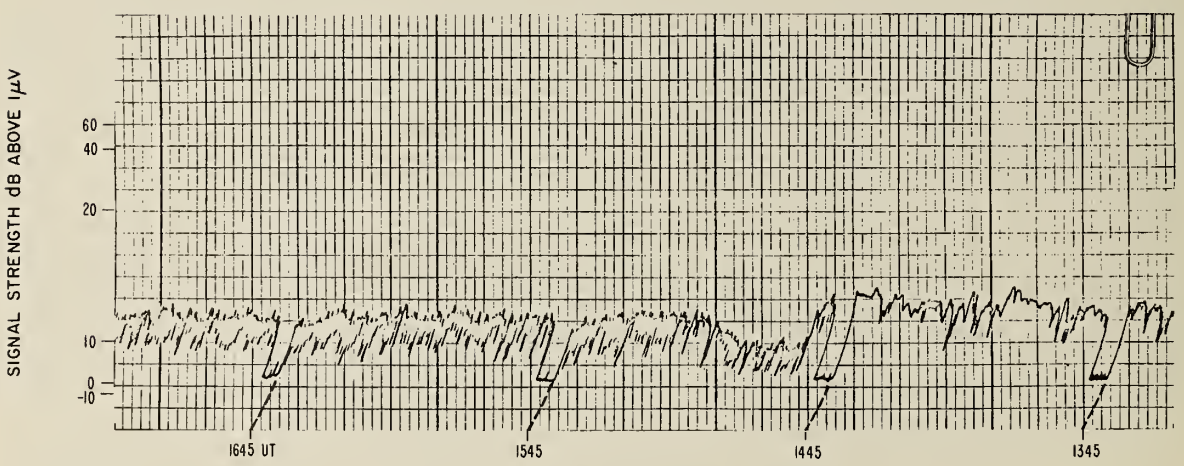
(e) 15 Mc/s, WWV TO BOULDER

13 MARCH 1962
Figure 45

OPTICAL FLARE, IMPORTANCE 2+, 1448-1451-1640D



(a) 10 Mc/s, WWV TO BOULDER

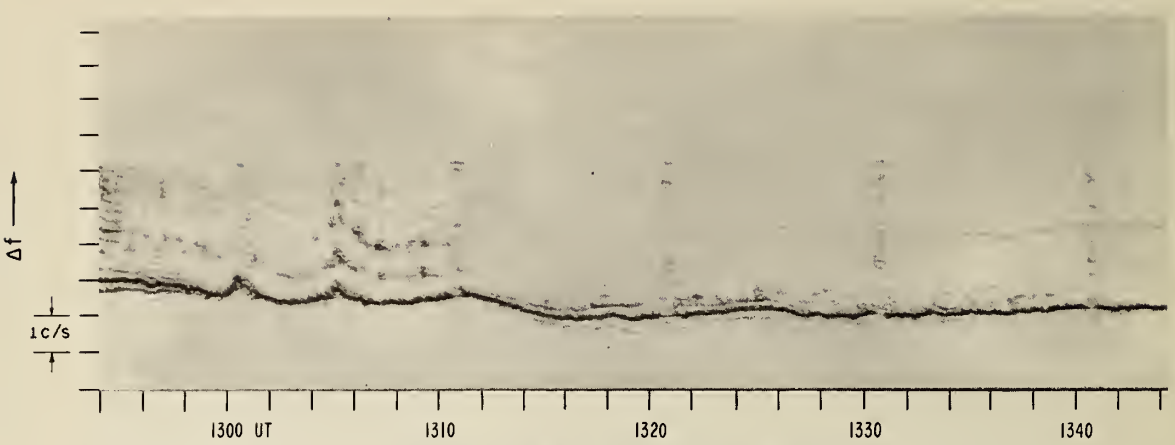


(b) 15 Mc/s, WWV TO BOULDER

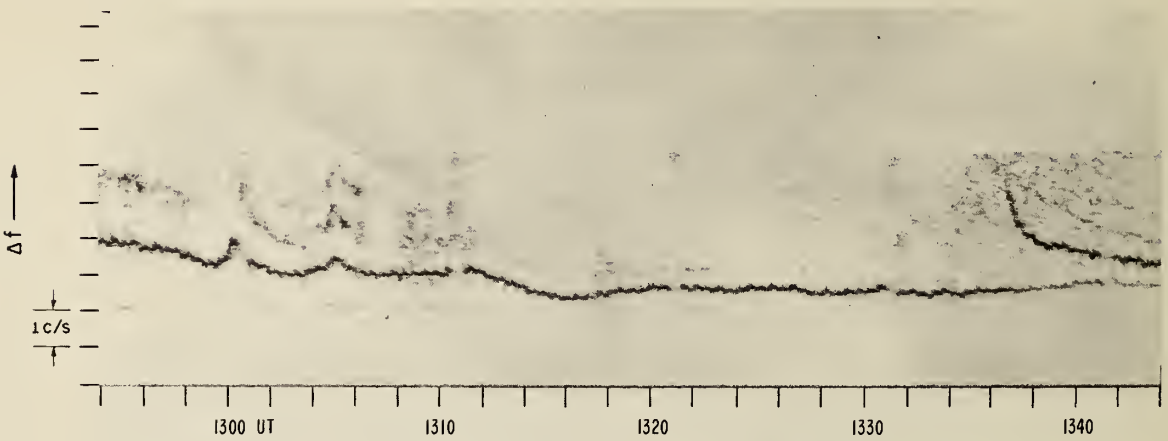
13 MARCH 1962

Figure 46

OPTICAL FLARE, IMPORTANCE 1-, 1300 E - 1307 - 1320



(a) 4.000 Mc/s, SUNSET TO BOULDER

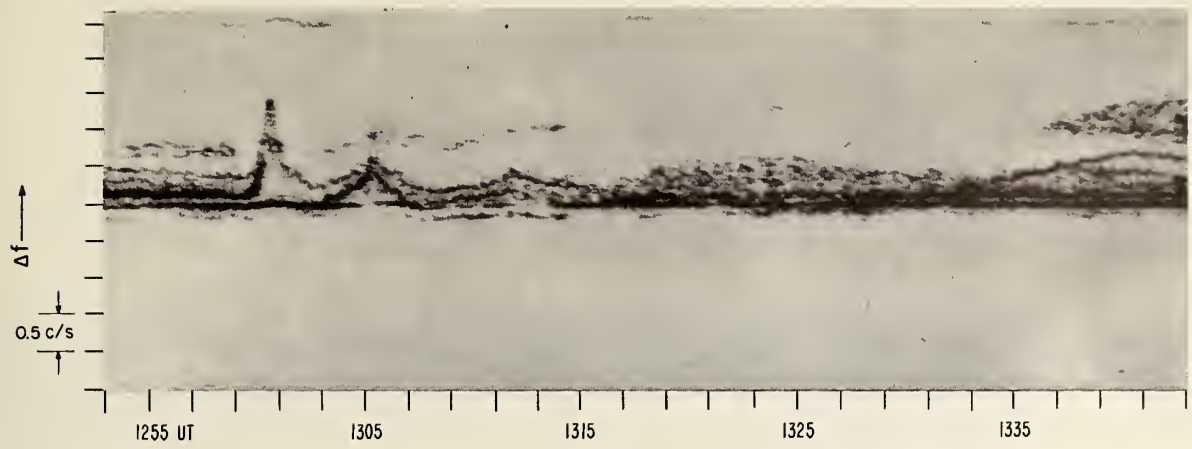


(b) 5.054 Mc/s, SUNSET TO BOULDER

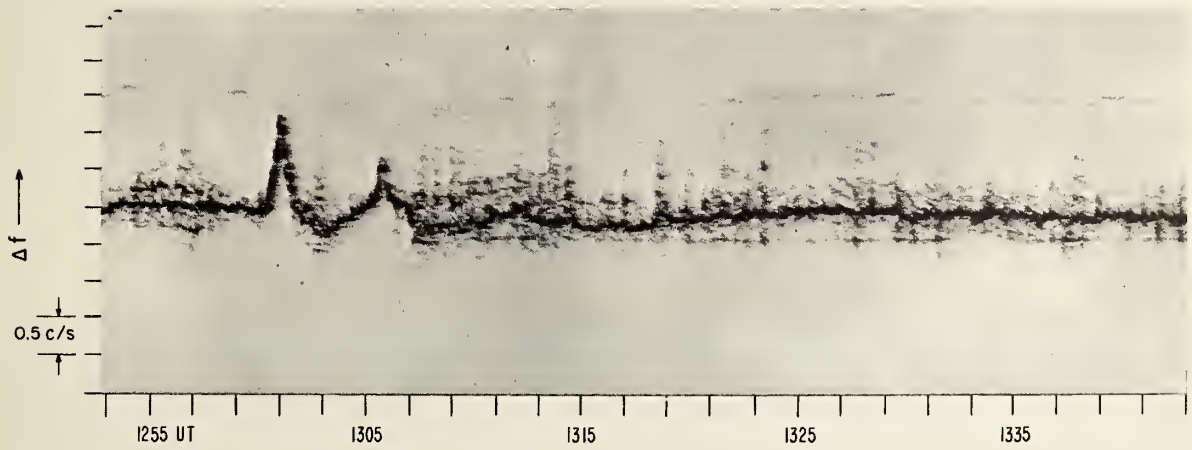
14 APRIL 1962

Figure 47

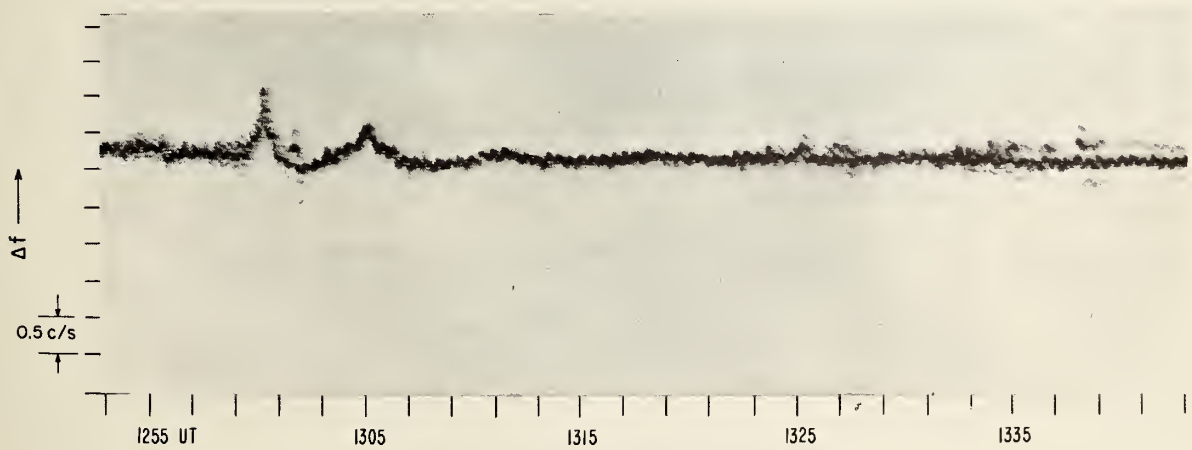
OPTICAL FLARE, IMPORTANCE 1-, 1300 - 1307 - 1320



(c) 10 Mc/s, WWV TO SHICKLEY



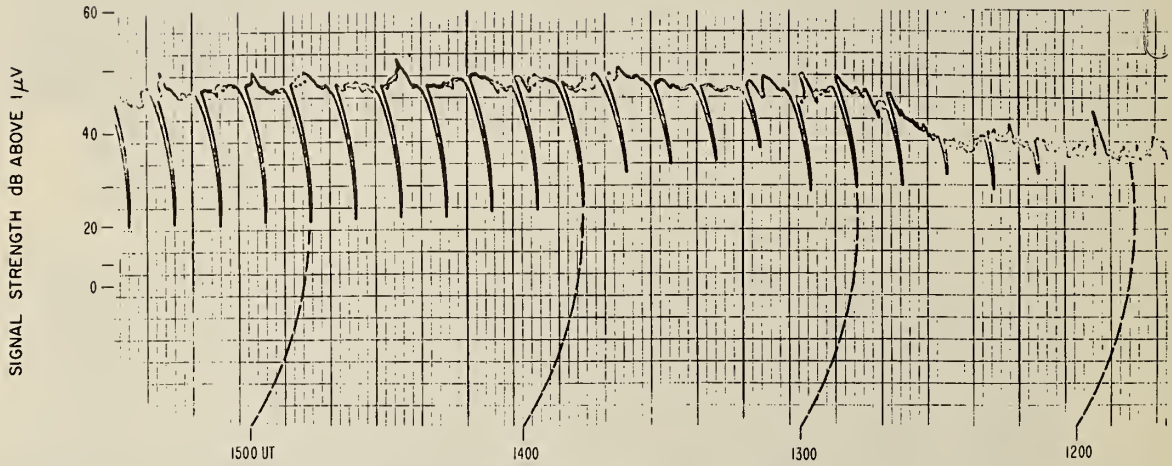
(d) 10 Mc/s, WWV TO BOULDER



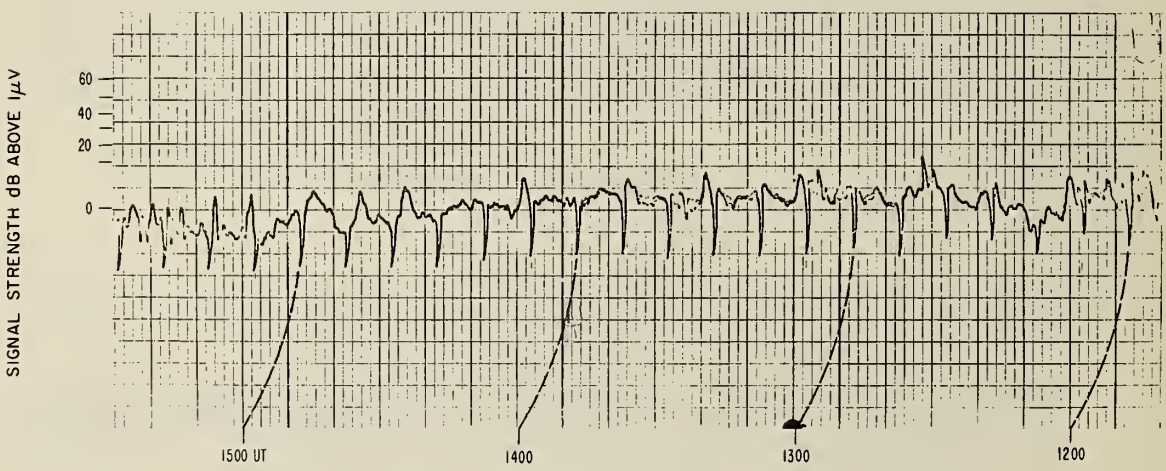
(e) 15 Mc/s WWV TO BOULDER

14 APRIL 1962
Figure 47

OPTICAL FLARE, IMPORTANCE 1- , 1300E-1302-1320
1- , 1300E-1307-1320



(a) 4.000 Mc/s, SUNSET TO BOULDER

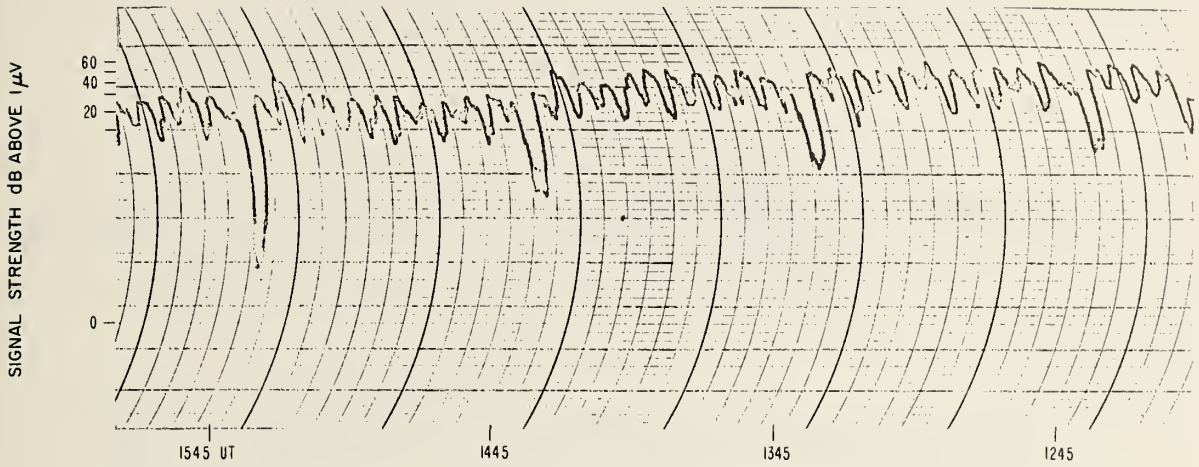


(b) 5.054 Mc/s, SUNSET TO BOULDER

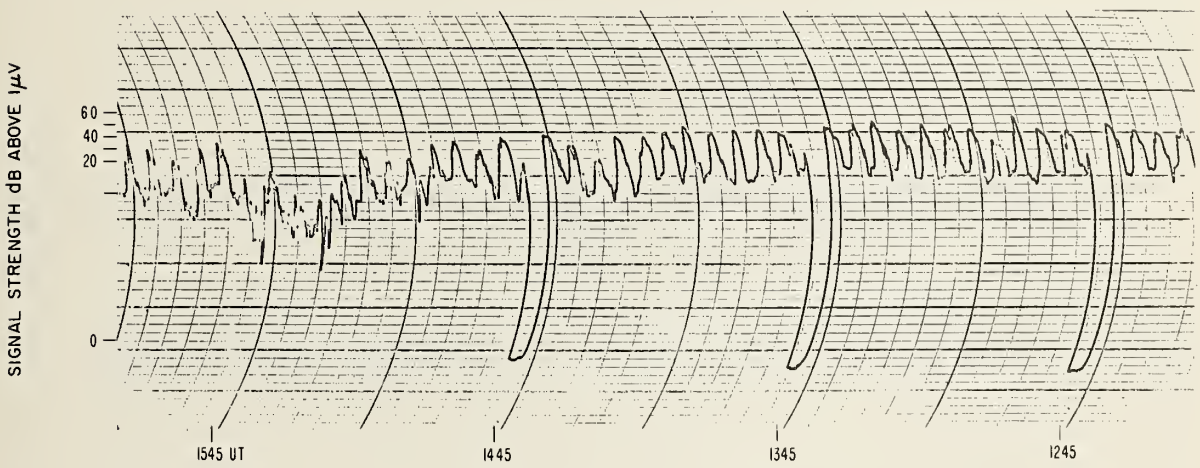
14 APRIL 1962

Figure 48

OPTICAL FLARE, IMPORTANCE 1- , 1300E-1302-1320
1- , 1300E-1307-1320



(c) 10 Mc/s, WWV TO BOULDER

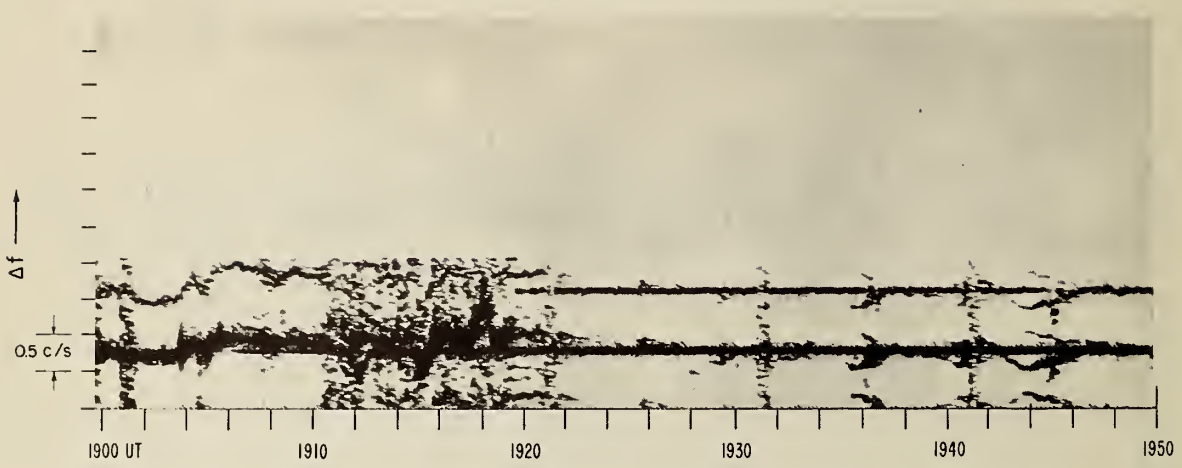


(d) 15 Mc/s, WWV TO BOULDER

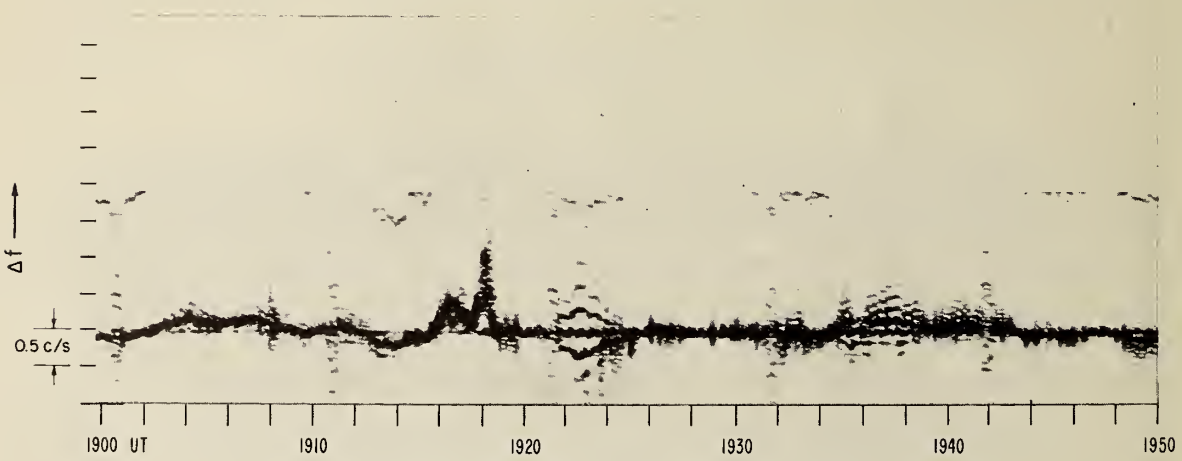
14 APRIL 1962

Figure 48

OPTICAL FLARE, IMPORTANCE 1 , 1910E - 1924 - 2005



(a) 4.000 Mc/s, SUNSET TO BOULDER

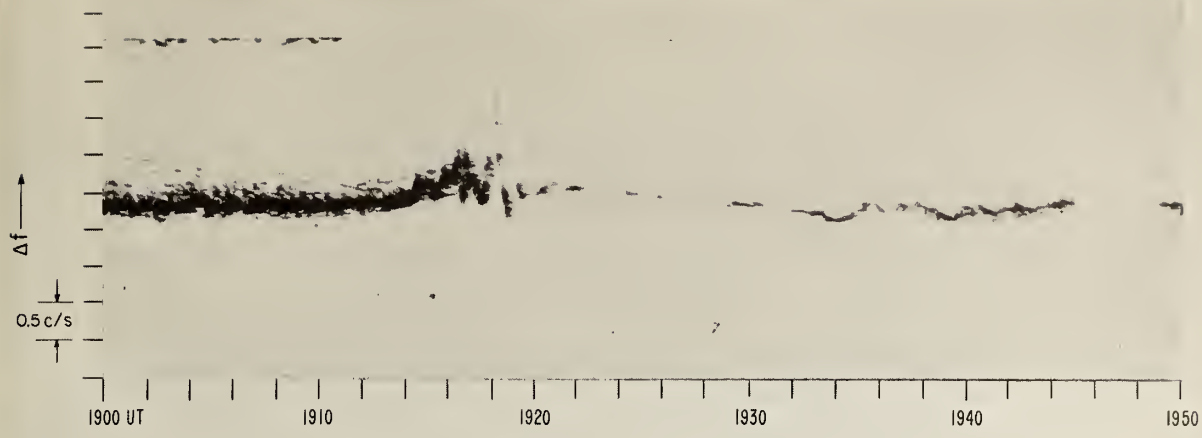


(b) 5.054 Mc/s, SUNSET TO BOULDER

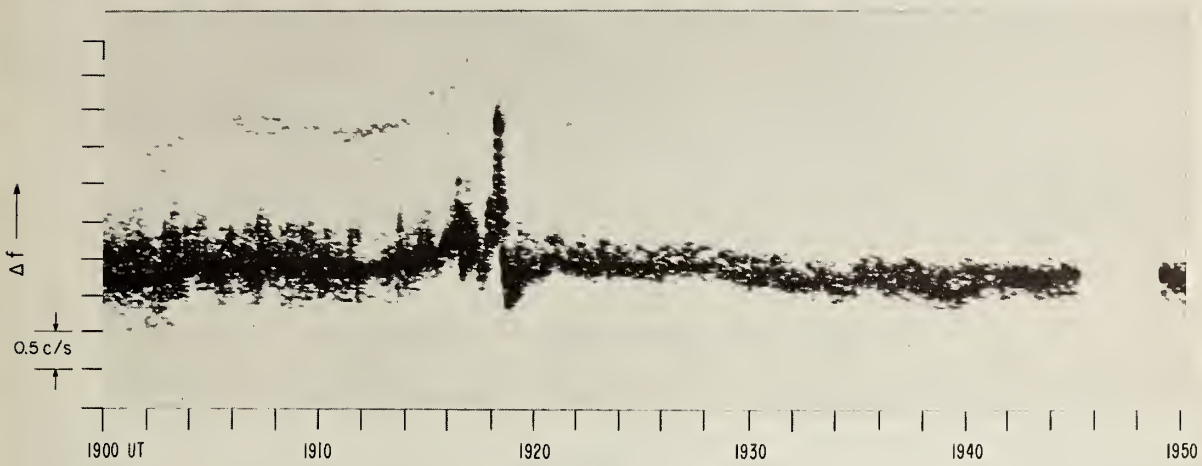
14 APRIL 1962

Figure 49

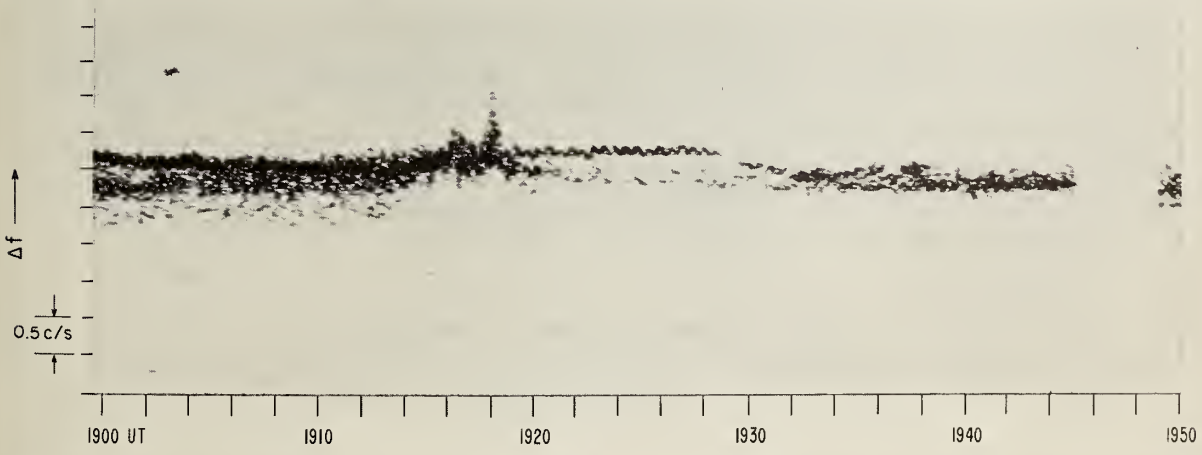
OPTICAL FLARE, IMPORTANCE 1, 1910E - 1924 - 2005



(c) 10 Mc/s, WWV TO SHICKLEY



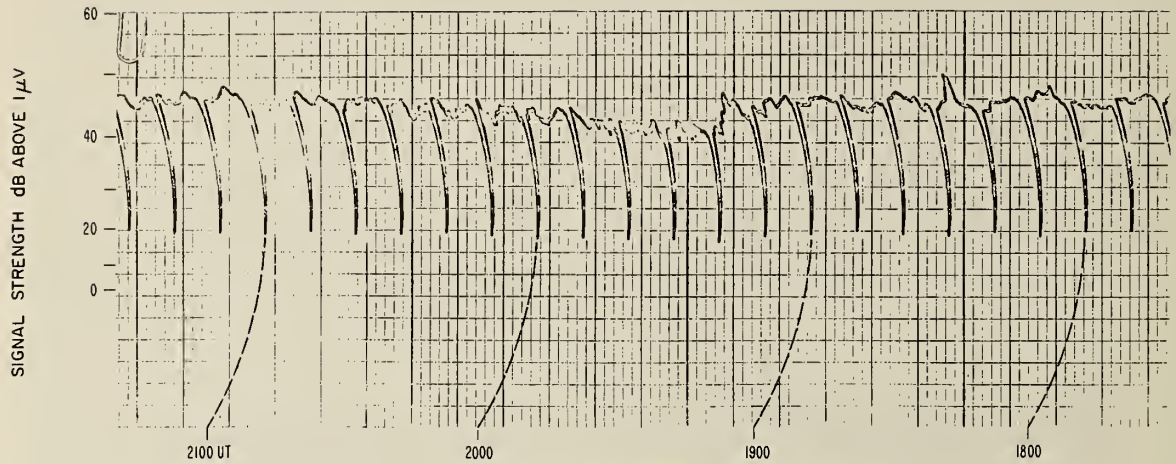
(d) 10 MC/S, WWV TO BOULDER



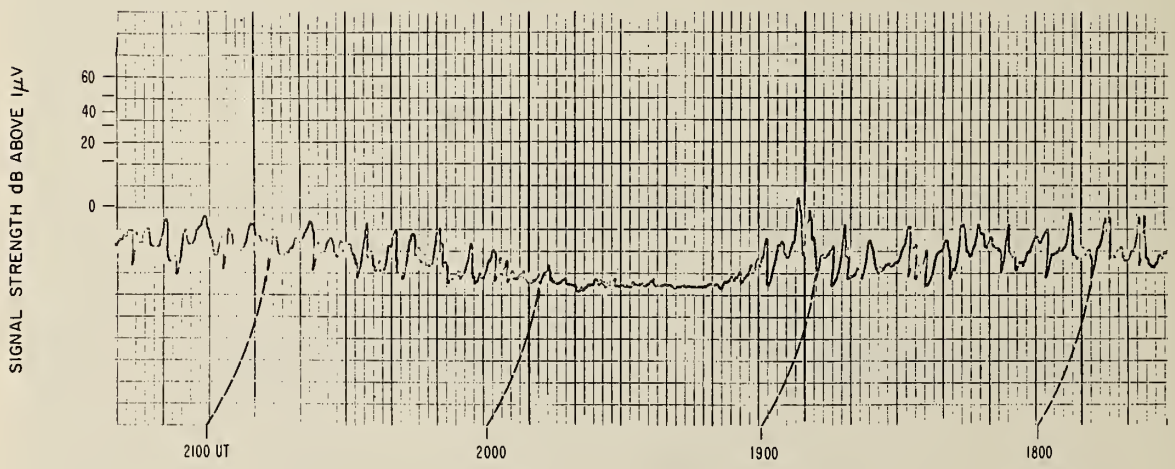
(e) 15 Mc/s WWV TO BOULDER

14 APRIL 1962
Figure 49

OPTICAL FLARE, IMPORTANCE 1 , 1910E-1924-2005



(a) 4.000 Mc/s, SUNSET TO BOULDER

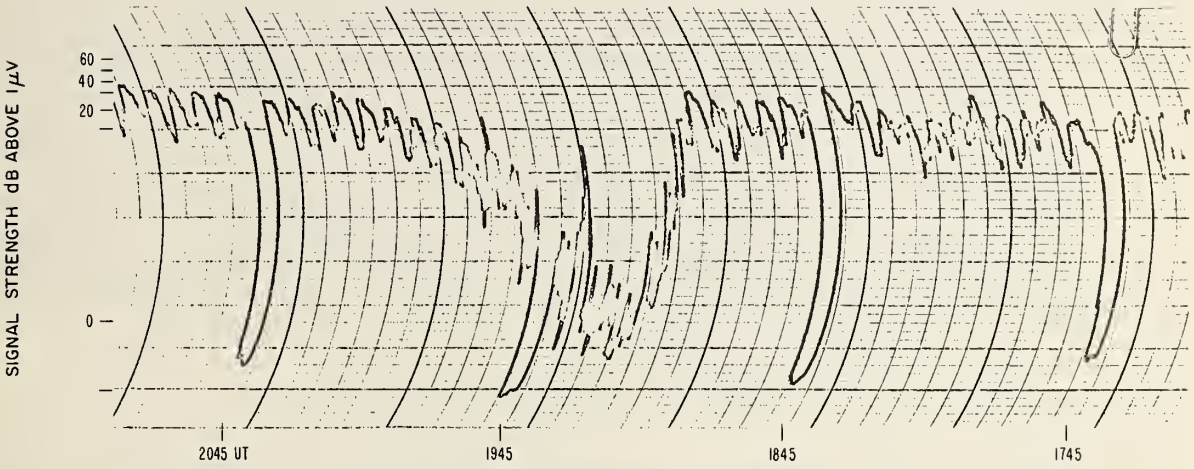


(b) 5.054 Mc/s, SUNSET TO BOULDER

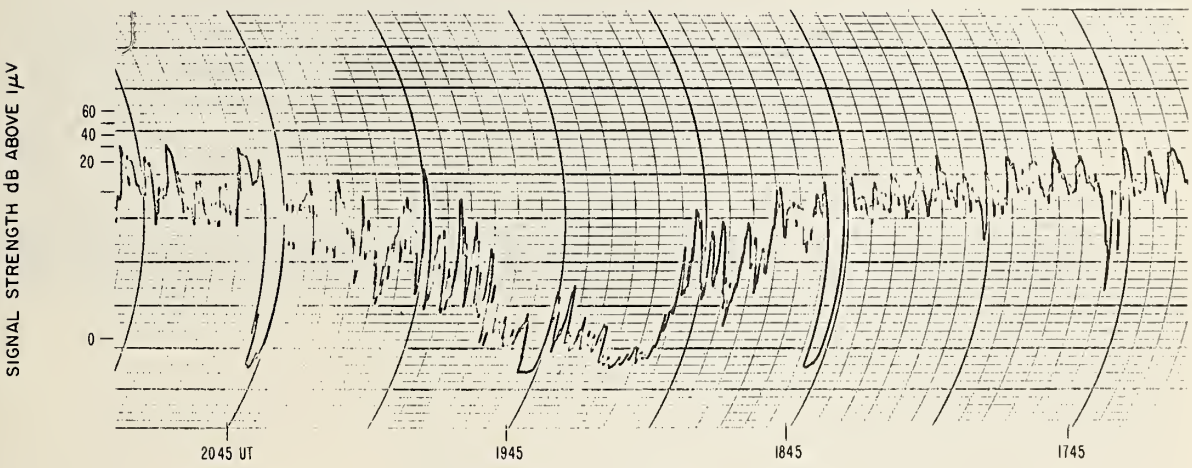
14 APRIL 1962

Figure 50

OPTICAL FLARE, IMPORTANCE 1 , 1910E-1924-2005



(c) 10 Mc/s, WWV TO BOULDER

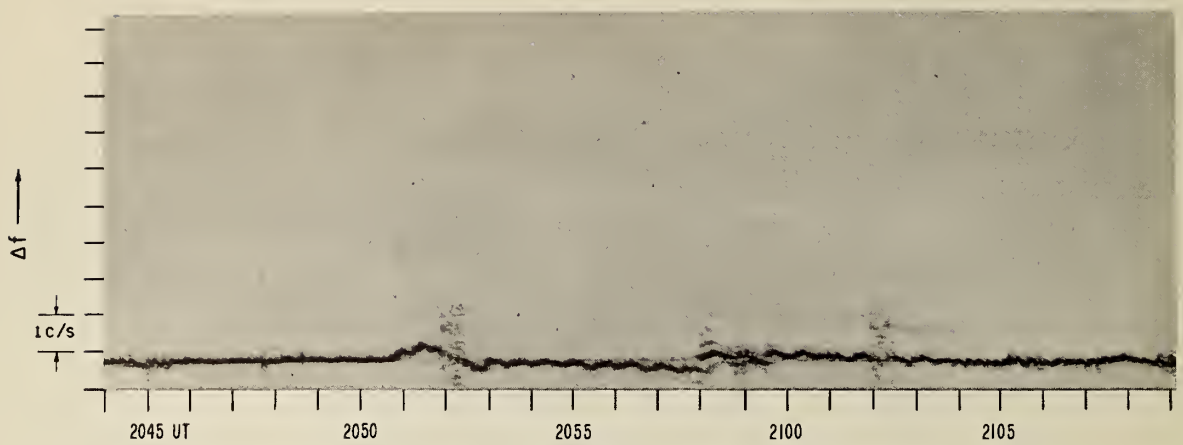


(d) 15 Mc/s, WWV TO BOULDER

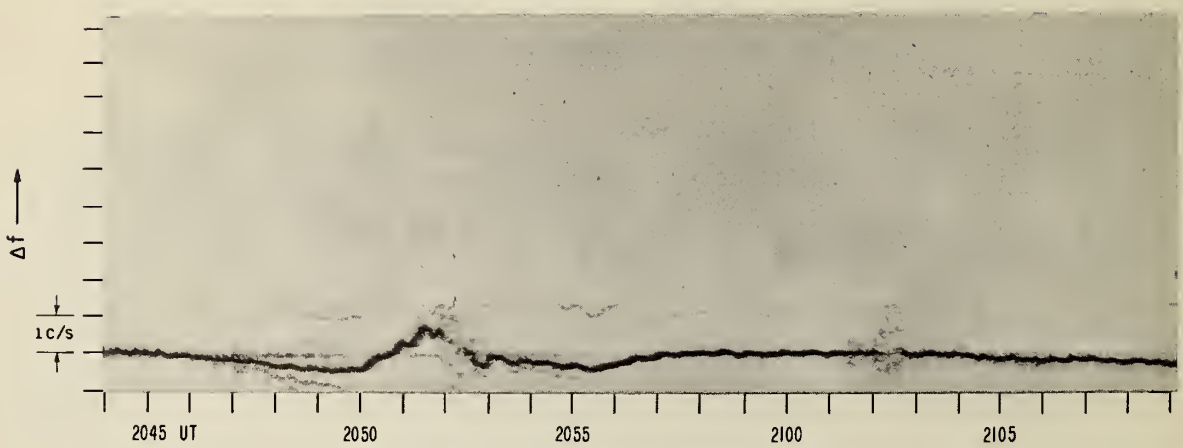
14 APRIL 1962

Figure 50

OPTICAL FLARE, IMPORTANCE 1-, 2051 - 2053 - 2058



(a) 4.000 Mc/s, SUNSET TO BOULDER

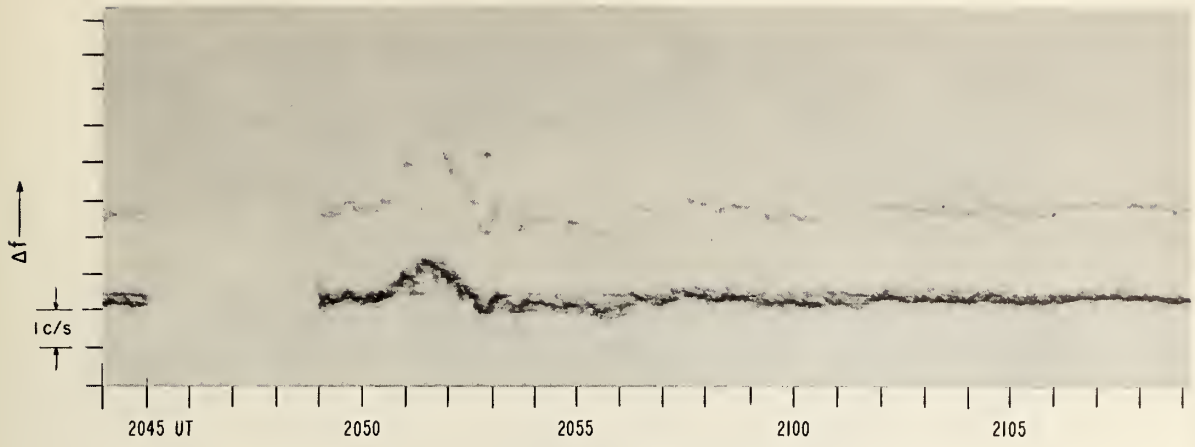


(b) 5.054 Mc/s, SUNSET TO BOULDER

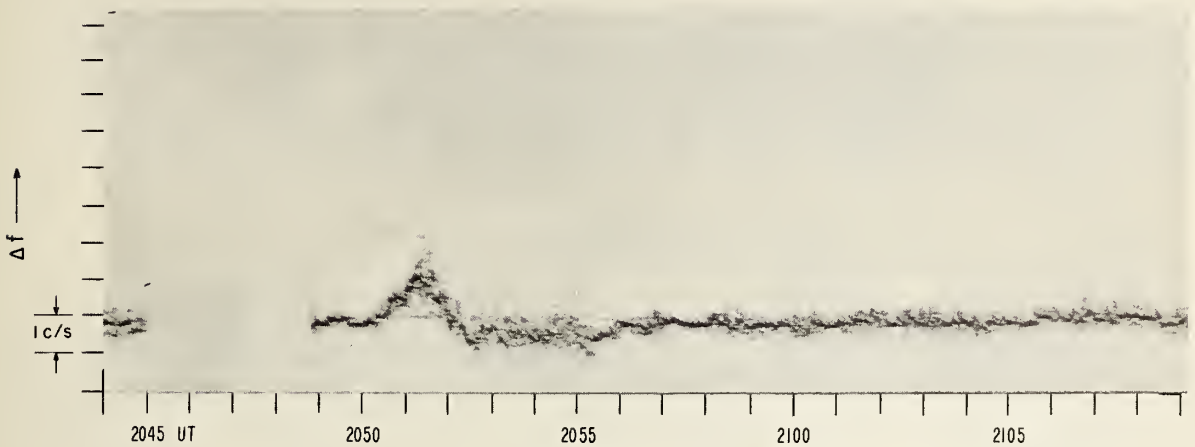
15 APRIL 1962

Figure 51

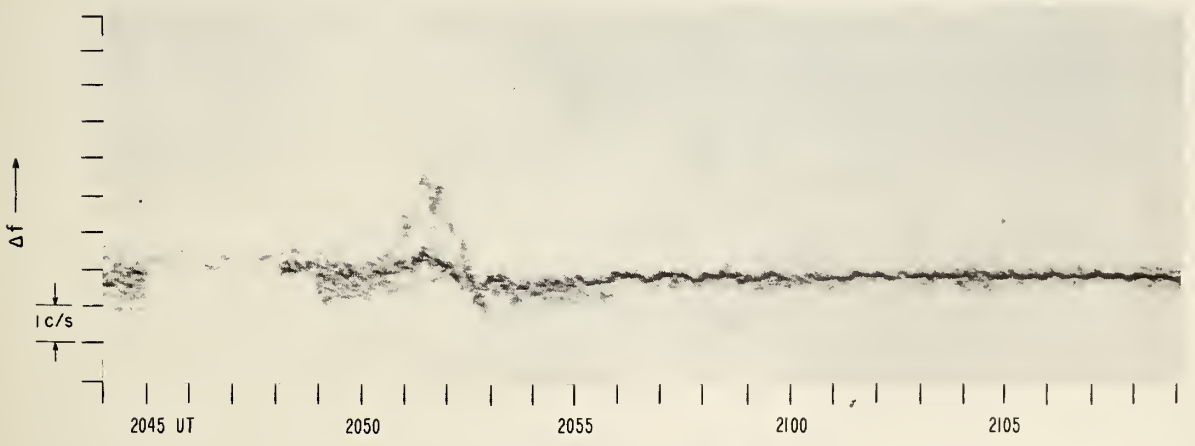
OPTICAL FLARE, IMPORTANCE 1-, 2051 - 2053 - 2058



(c) 10 Mc/s, WWV TO SHICKLEY



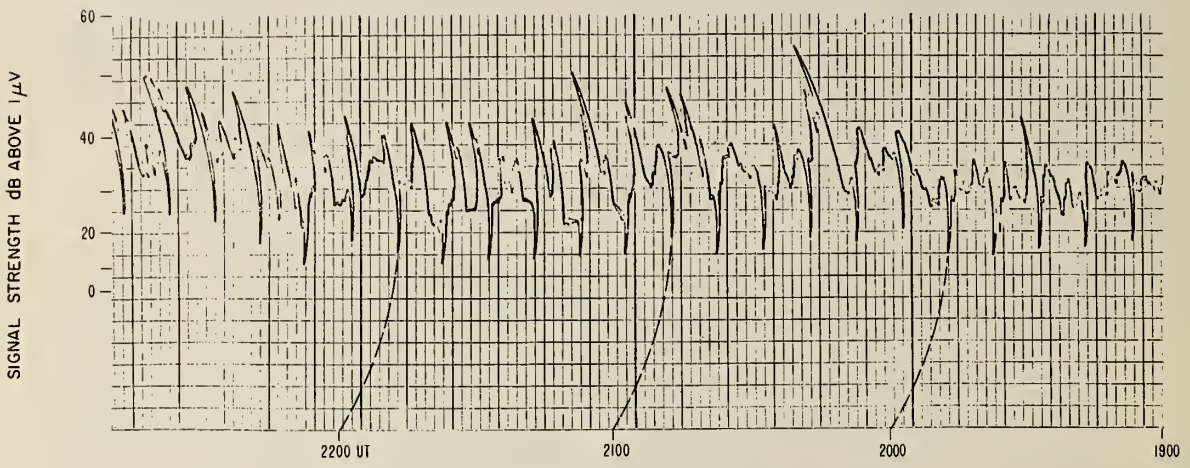
(d) 10 Mc/s, WWV TO BOULDER



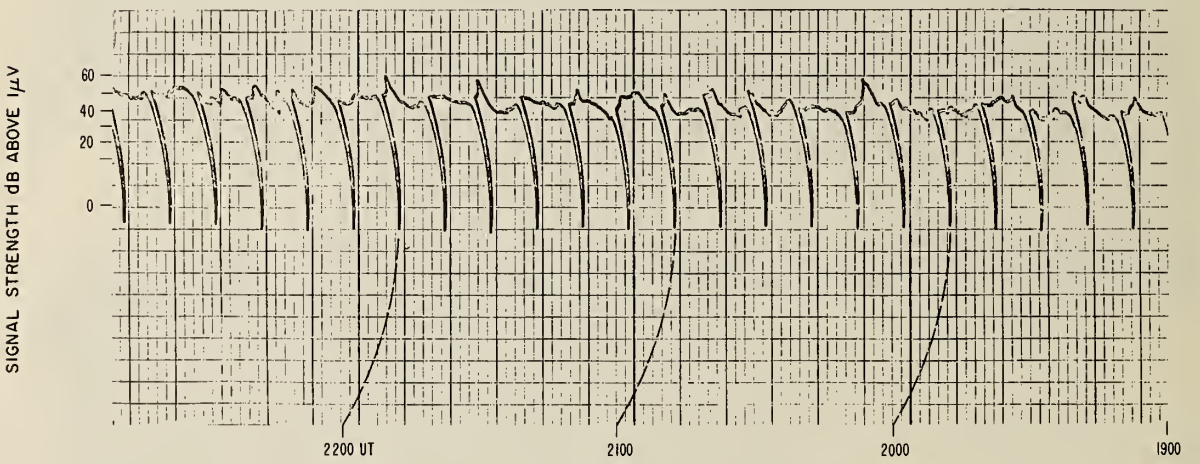
(e) 15 Mc/s WWV TO BOULDER

15 APRIL 1962
Figure 51

OPTICAL FLARE, IMPORTANCE I- , 2051-2053-2058
I- , 2153-2155-2158
I , 2241-2245-2252



(a) 4.000 Mc/s, SUNSET TO BOULDER

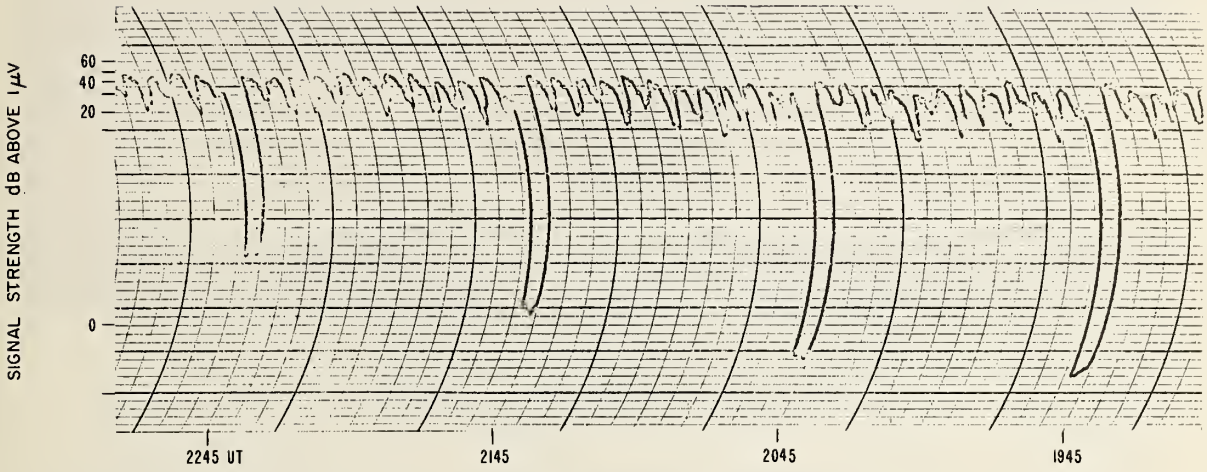


(b) 5.054 Mc/s, SUNSET TO BOULDER

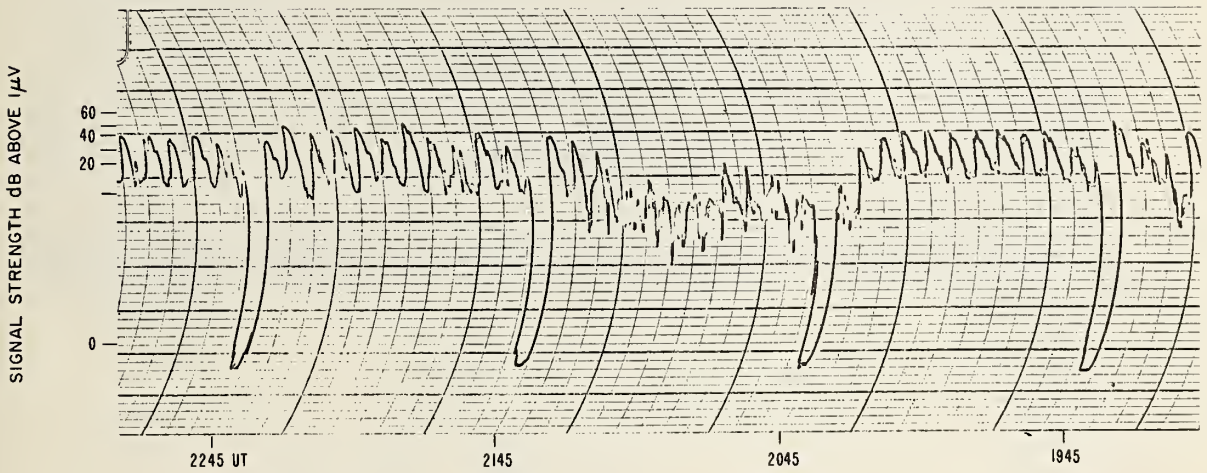
15 APRIL 1962

Figure 52

OPTICAL FLARE, IMPORTANCE 1- , 2051-2053-2058
1- , 2153-2155-2158
1 , 2241-2245-2252



(c) 10 Mc/s, WWV TO BOULDER

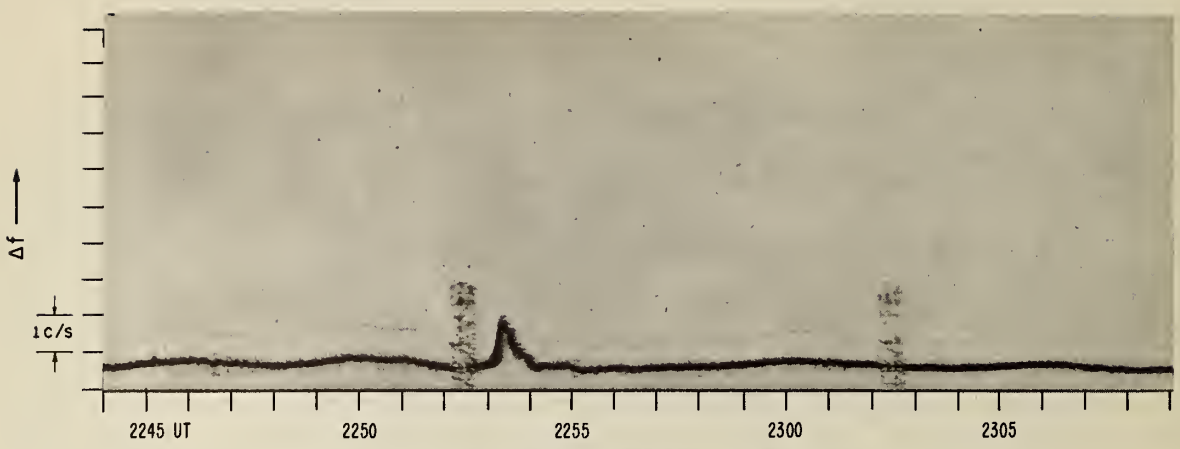


(d) 15 Mc/s, WWV TO BOULDER

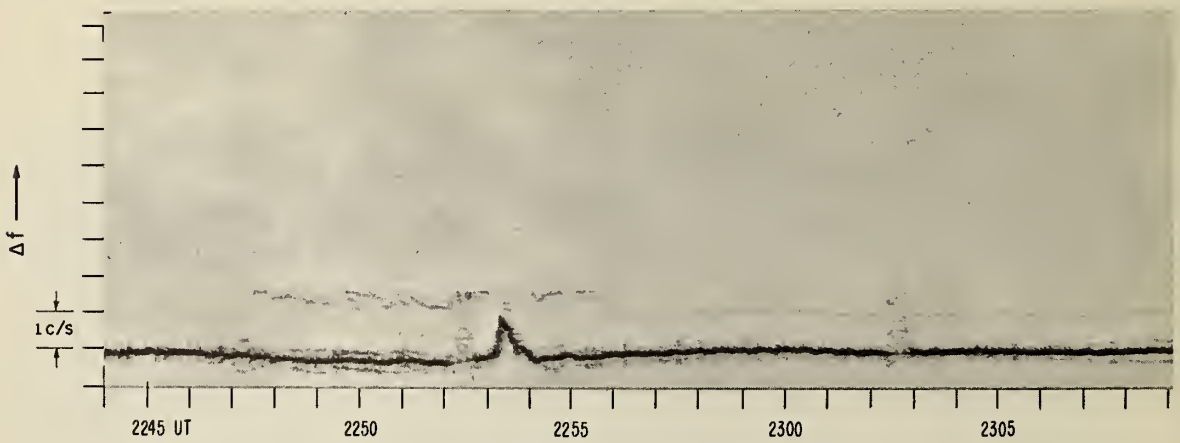
15 APRIL 1962

Figure 52

OPTICAL FLARE, IMPORTANCE 1- , 2252 - 2256 - 2313



(a) 4.000 Mc/s, SUNSET TO BOULDER

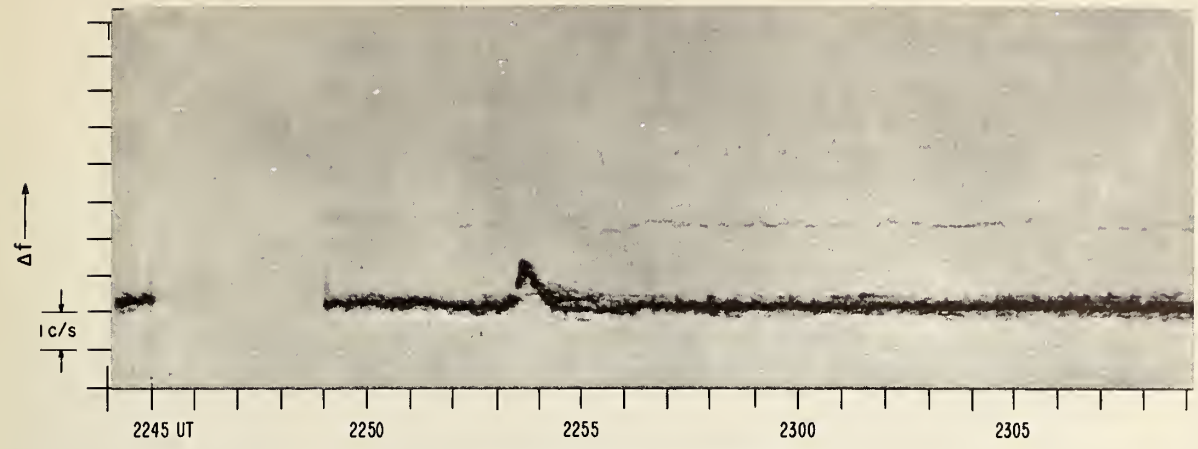


(b) 5.054 Mc/s, SUNSET TO BOULDER

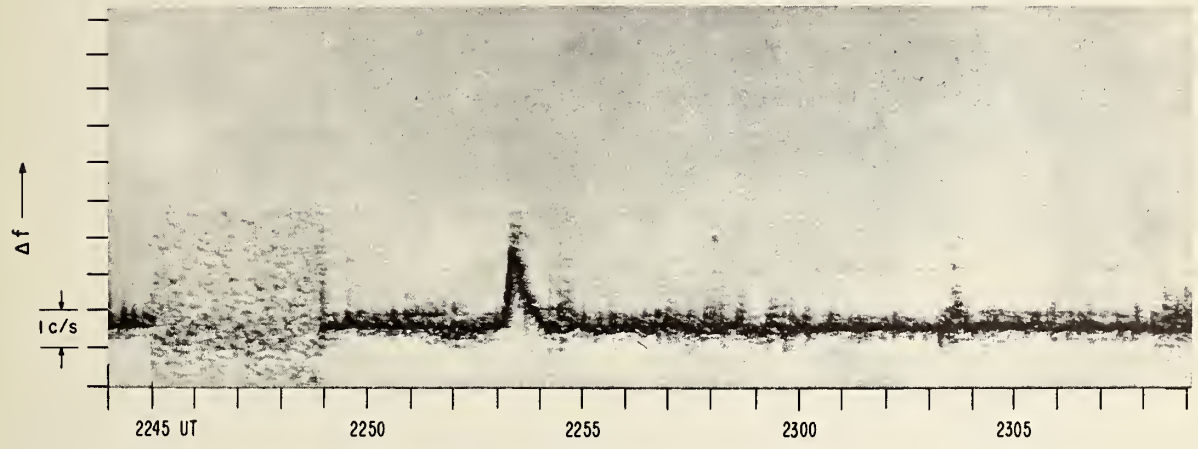
17 APRIL 1962

Figure 53

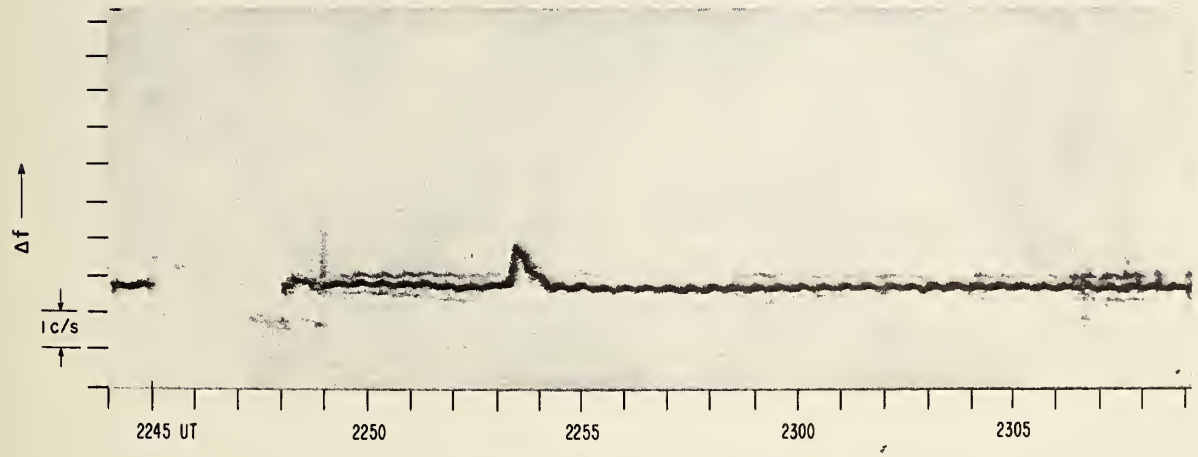
OPTICAL FLARE, IMPORTANCE 1-, 2252 - 2256 - 2313



(c) 10 Mc/s, WWV TO SHICKLEY



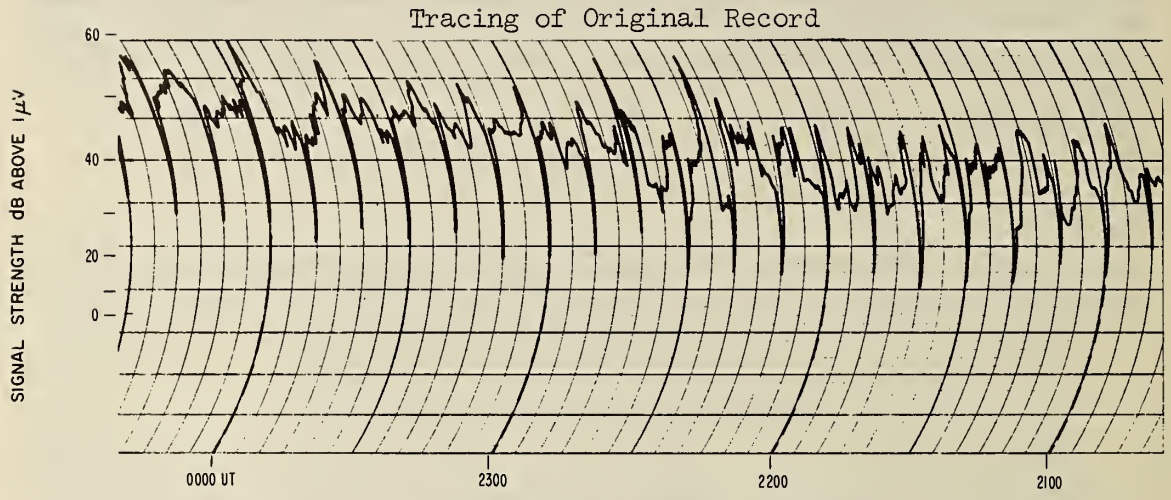
(d) 10 Mc/s, WWV TO BOULDER



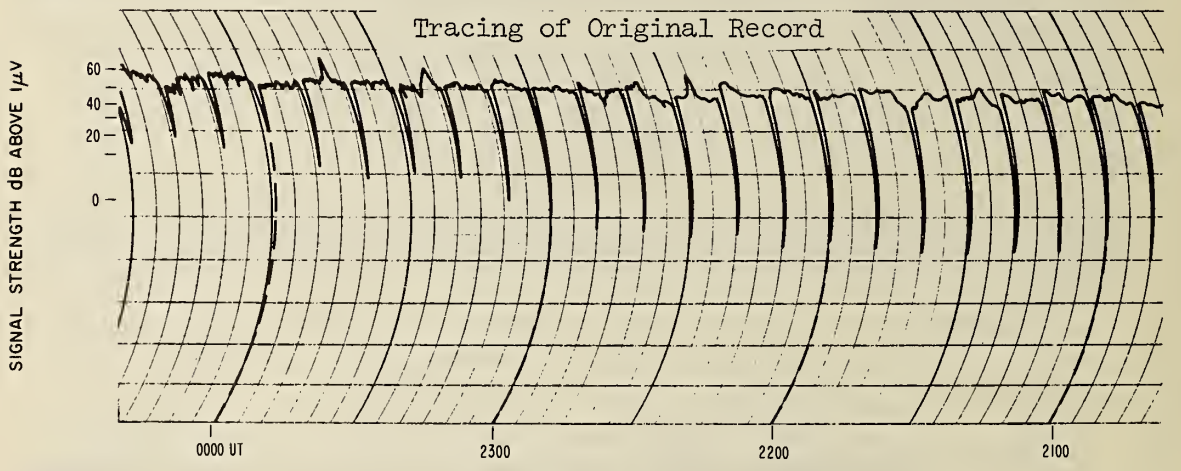
(e) 15 Mc/s WWV TO BOULDER

17 APRIL 1962
Figure 53

OPTICAL FLARE, IMPORTANCE 1-, 2252-2256-2313



(a) 4.000 Mc/s, SUNSET TO BOULDER

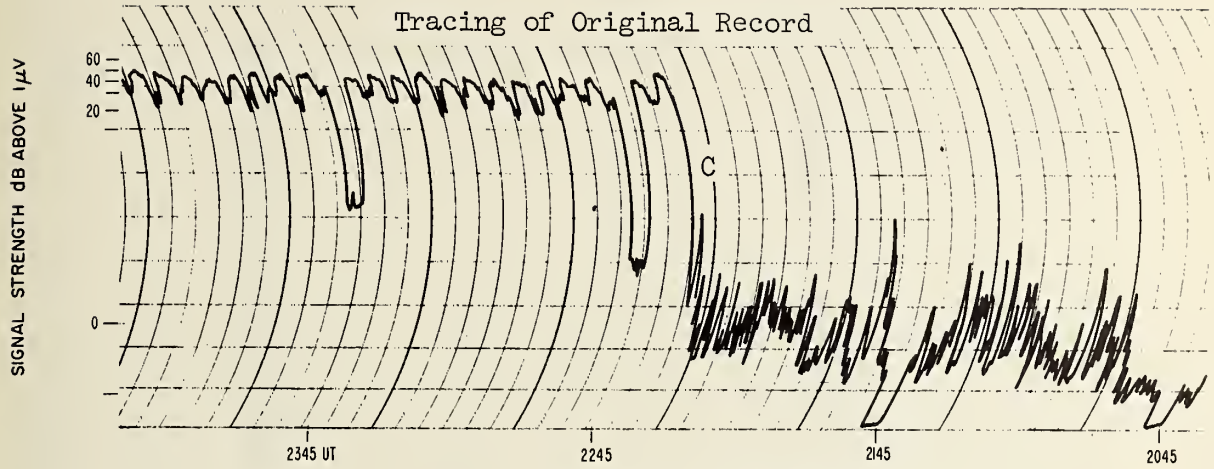


(b) 5.054 Mc/s, SUNSET TO BOULDER

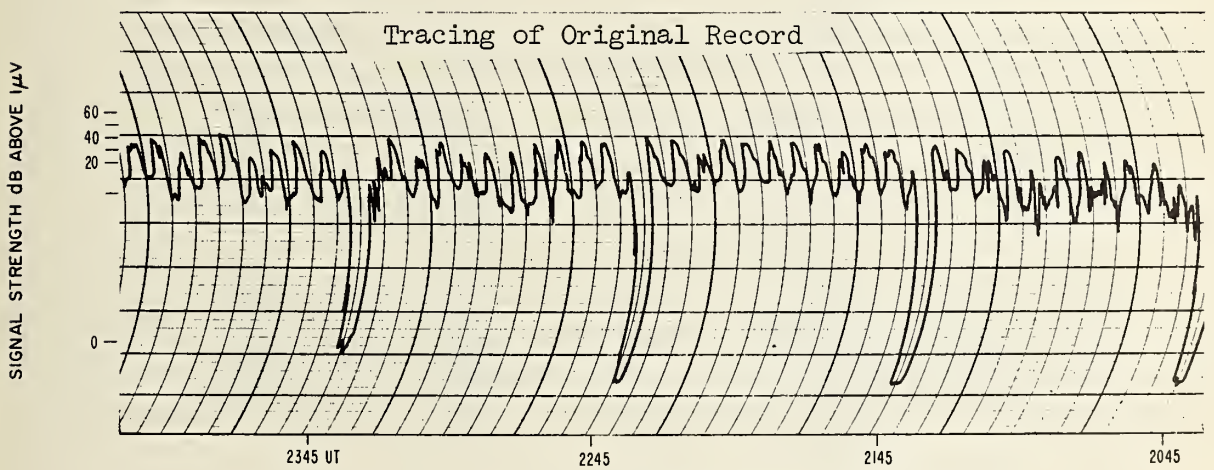
17 APRIL 1962

Figure 54

OPTICAL FLARE, IMPORTANCE 1- , 2252-2256-2313



(c) 10 Mc/s, WWV TO BOULDER

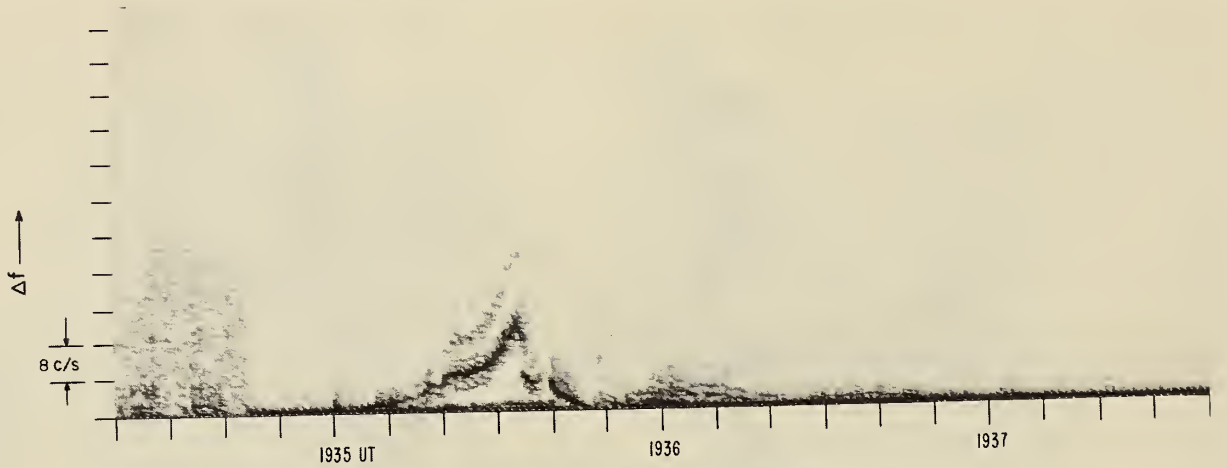


(d) 15 Mc/s, WWV TO BOULDER

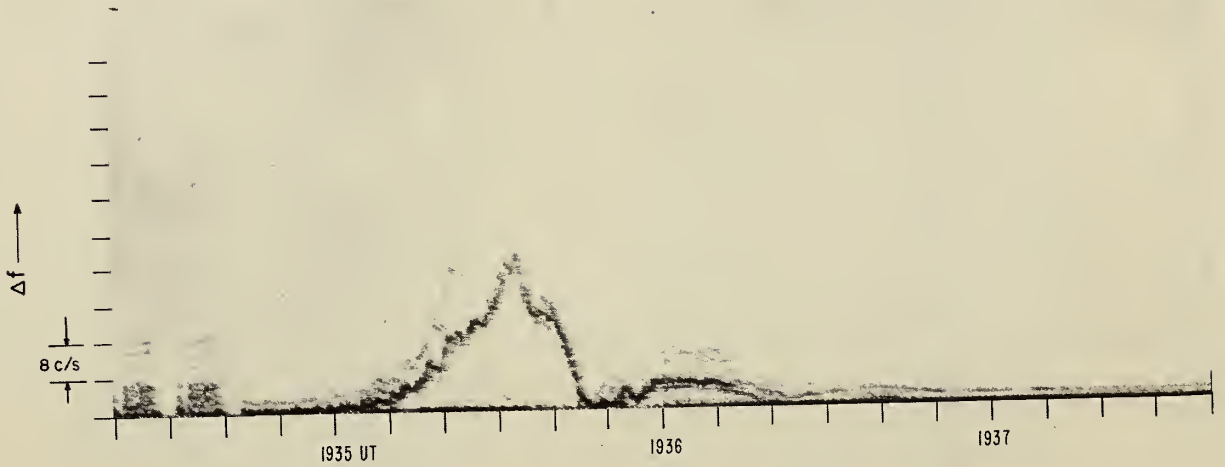
17 APRIL 1962

Figure 54

OPTICAL FLARE , IMPORTANCE 2 , 1935 - 1937 - 2031

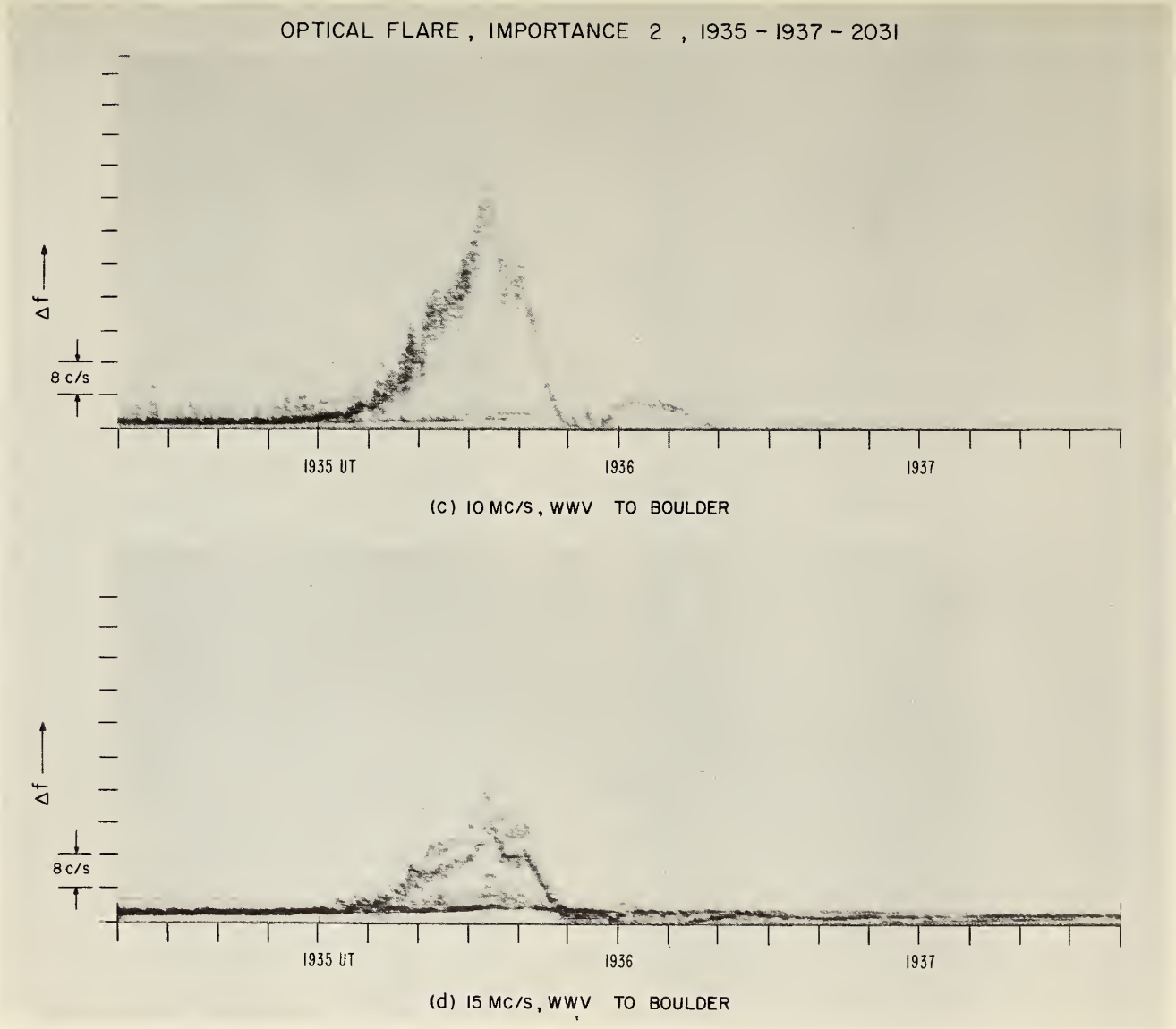


(a) 4.000 Mc/s , SUNSET TO BOULDER



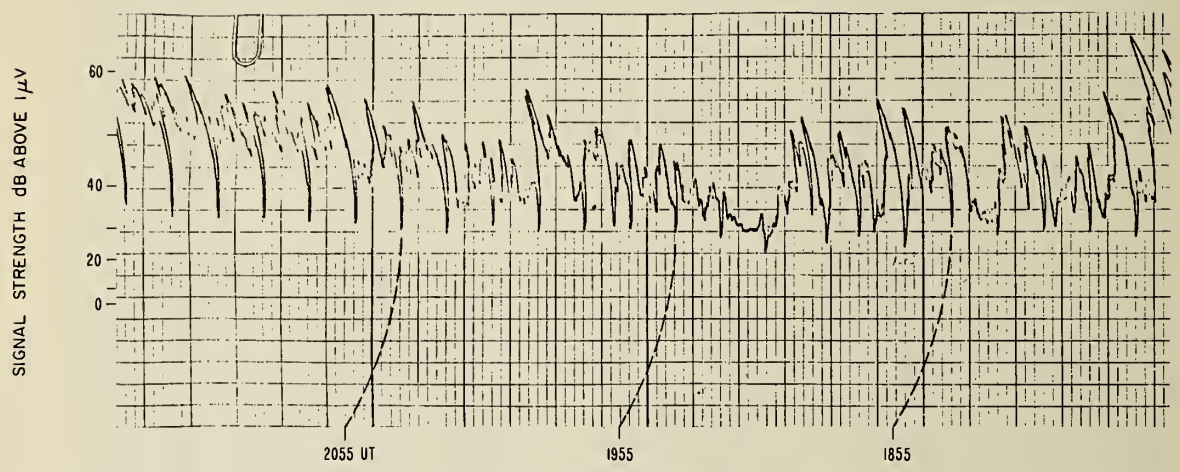
(b) 5.054 Mc/s , SUNSET TO BOULDER

19 APRIL 1962
Figure 55

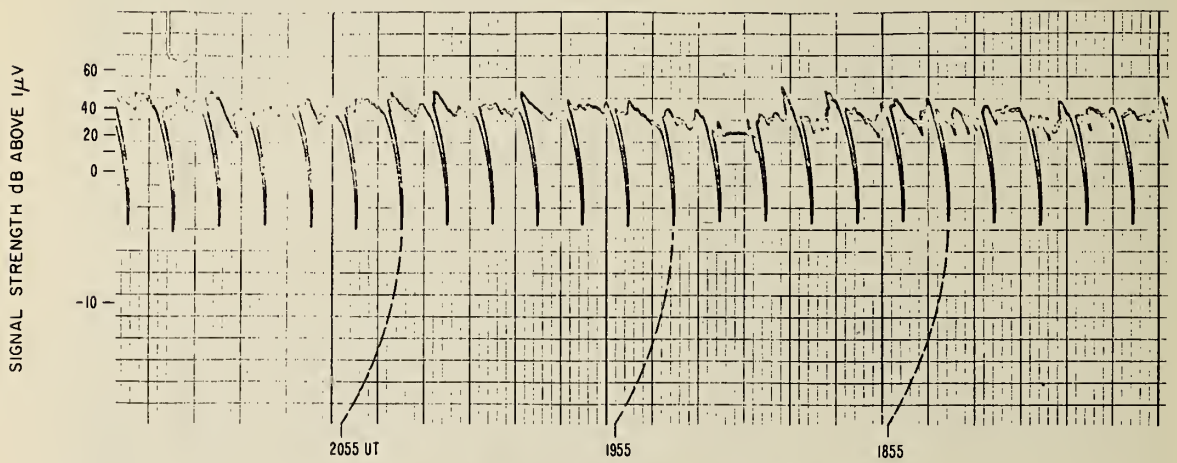


19 APRIL 1962
Figure 55

OPTICAL FLARE, IMPORTANCE 2 , 1935-1937-2031



(a) 4.000 Mc/s, SUNSET TO BOULDER

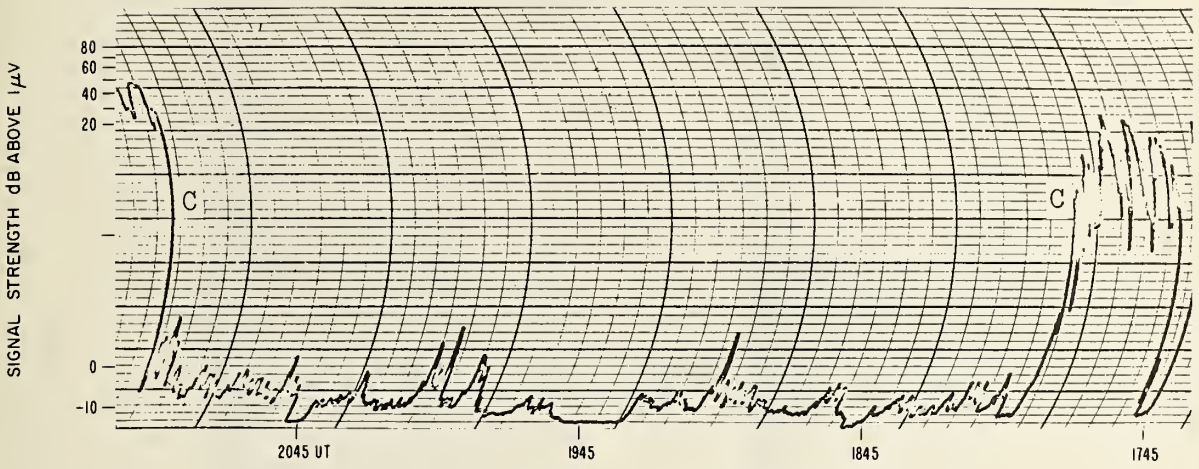


(b) 5.054 Mc/s, SUNSET TO BOULDER

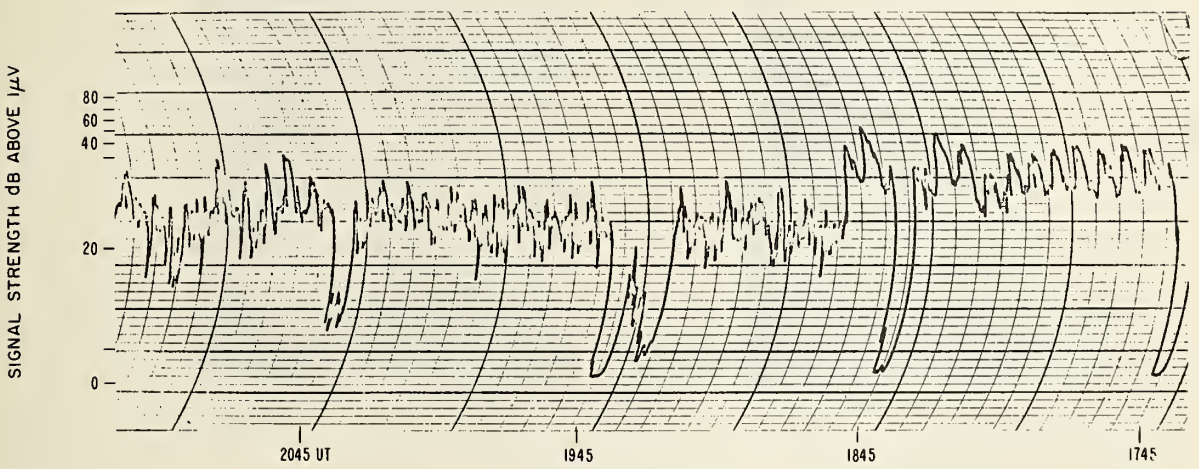
19 APRIL 1962

Figure 56

OPTICAL FLARE, IMPORTANCE 2 , 1935-1937-2031



(c) 10 Mc/s, WWV TO BOULDER

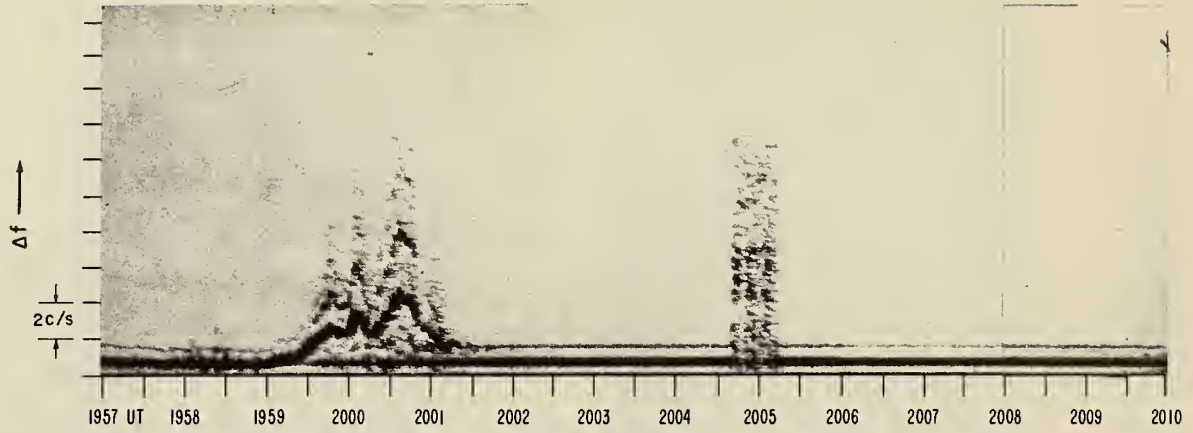


(d) 15 Mc/s, WWV TO BOULDER

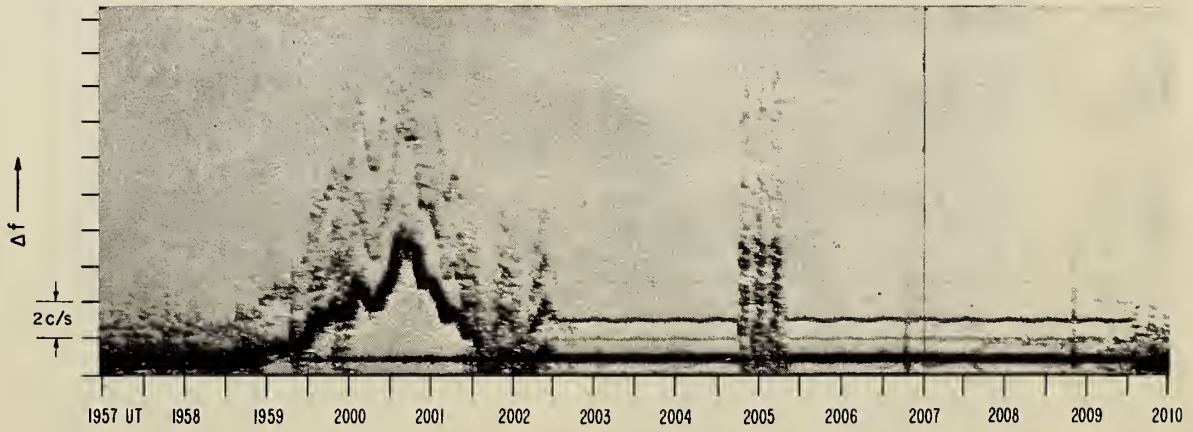
19 APRIL 1962

Figure 56

OPTICAL FLARE, IMPORTANCE 2 , 1958 - 2002 - 2038



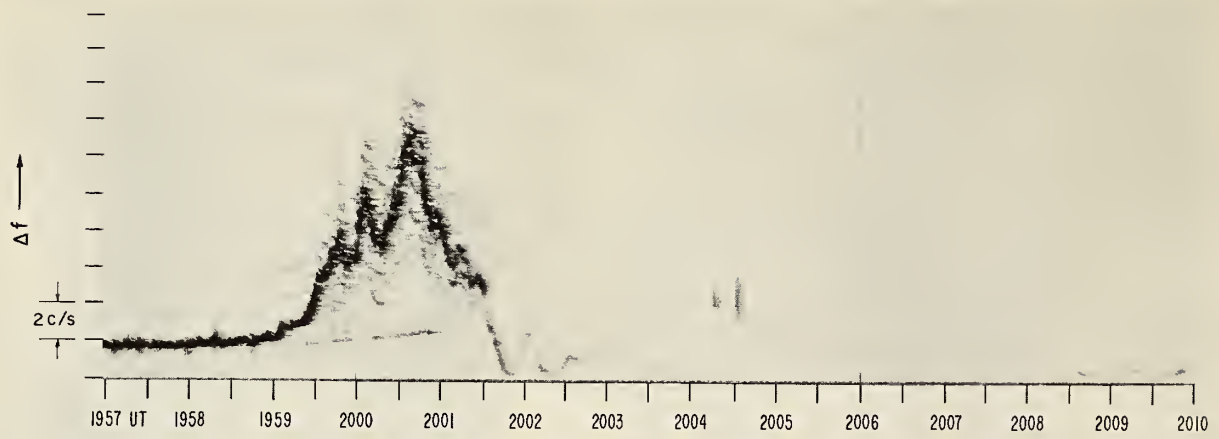
(a) 4.000 Mc/s, SUNSET TO BOULDER



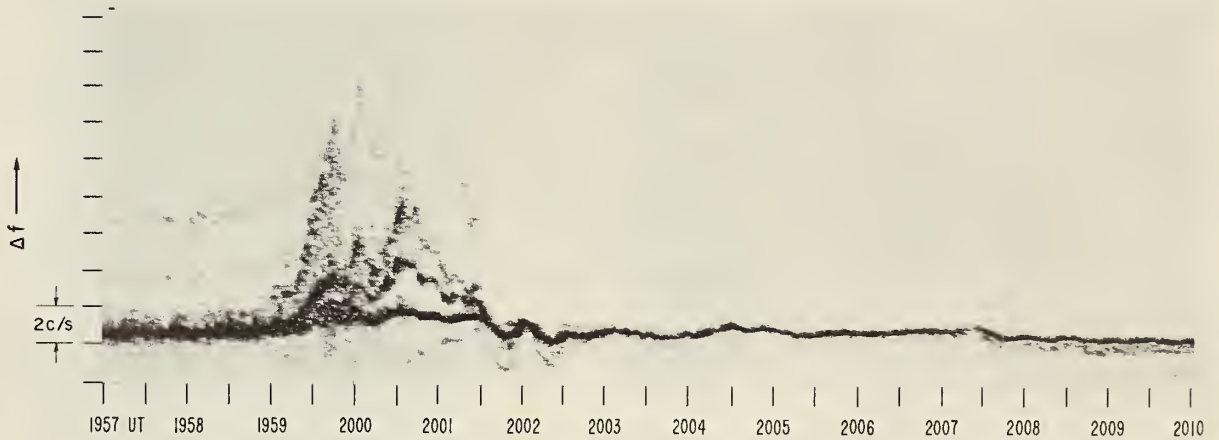
(b) 5.054 Mc/s, SUNSET TO BOULDER

20 APRIL 1962
Figure 57

OPTICAL FLARE, IMPORTANCE 2 , 1958 - 2002 - 2038



(c) 10 Mc/s, WWV TO BOULDER



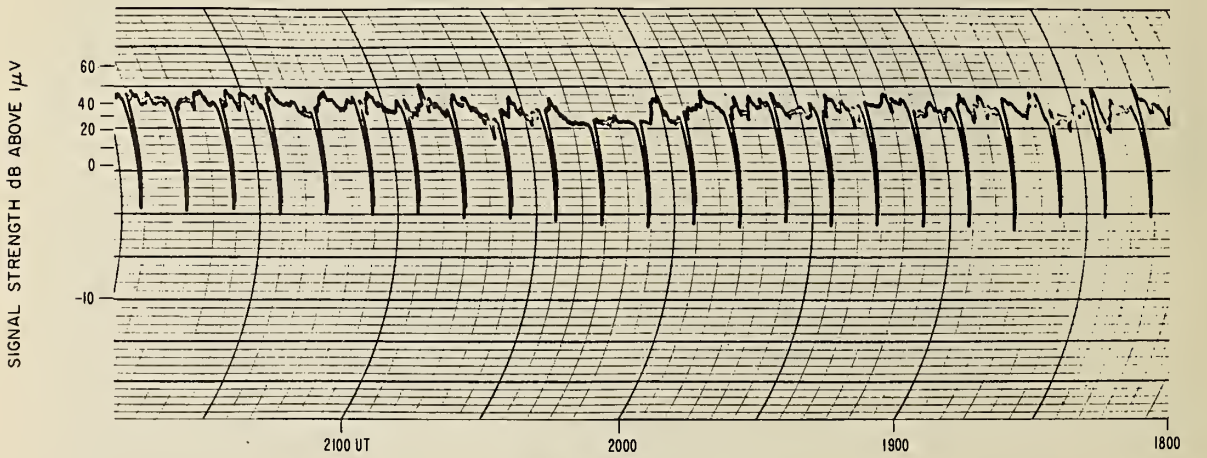
(d) 15 Mc/s, WWV TO BOULDER

20 APRIL 1962

Figure 57

OPTICAL FLARE, IMPORTANCE 2 , 1958-2002-2038

(a) 4.000 Mc/s, SUNSET TO BOULDER

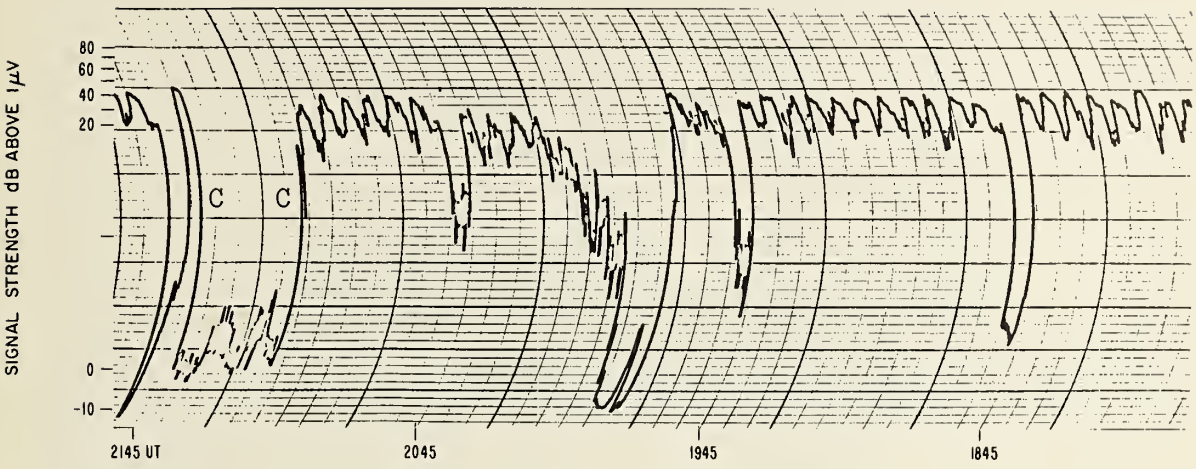


(b) 5.054 Mc/s, SUNSET TO BOULDER

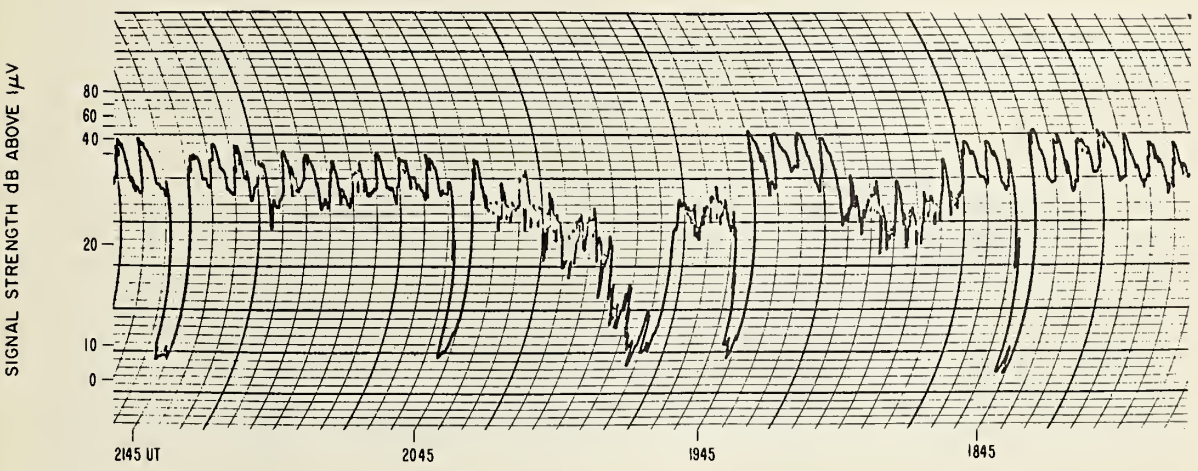
20 APRIL 1962

Figure 58

OPTICAL FLARE, IMPORTANCE 2 , 1958-2002-2038



(c) 10 Mc/s, WWV TO BOULDER



(d) 15 Mc/s, WWV TO BOULDER

20 APRIL 1962

Figure 58

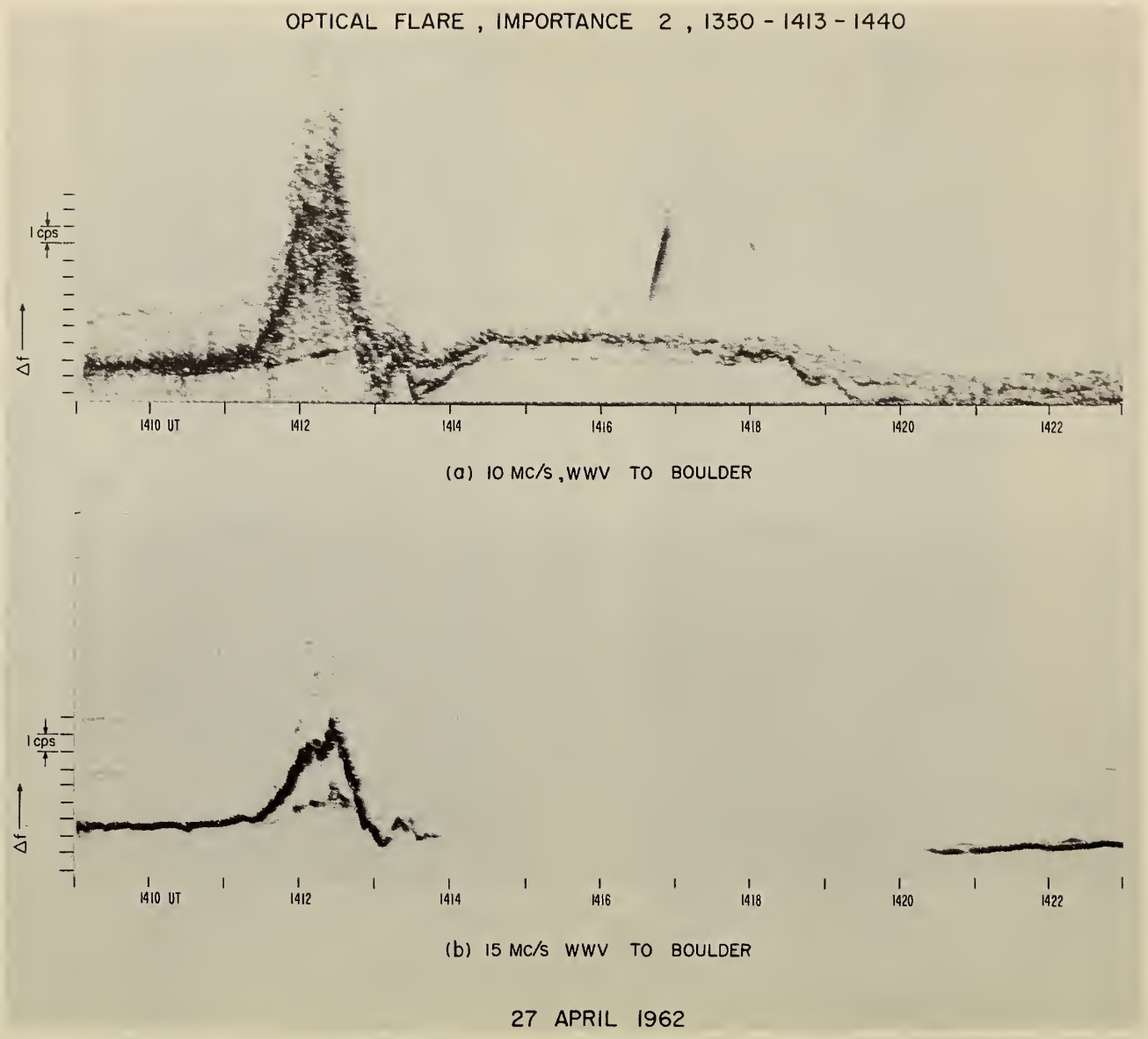
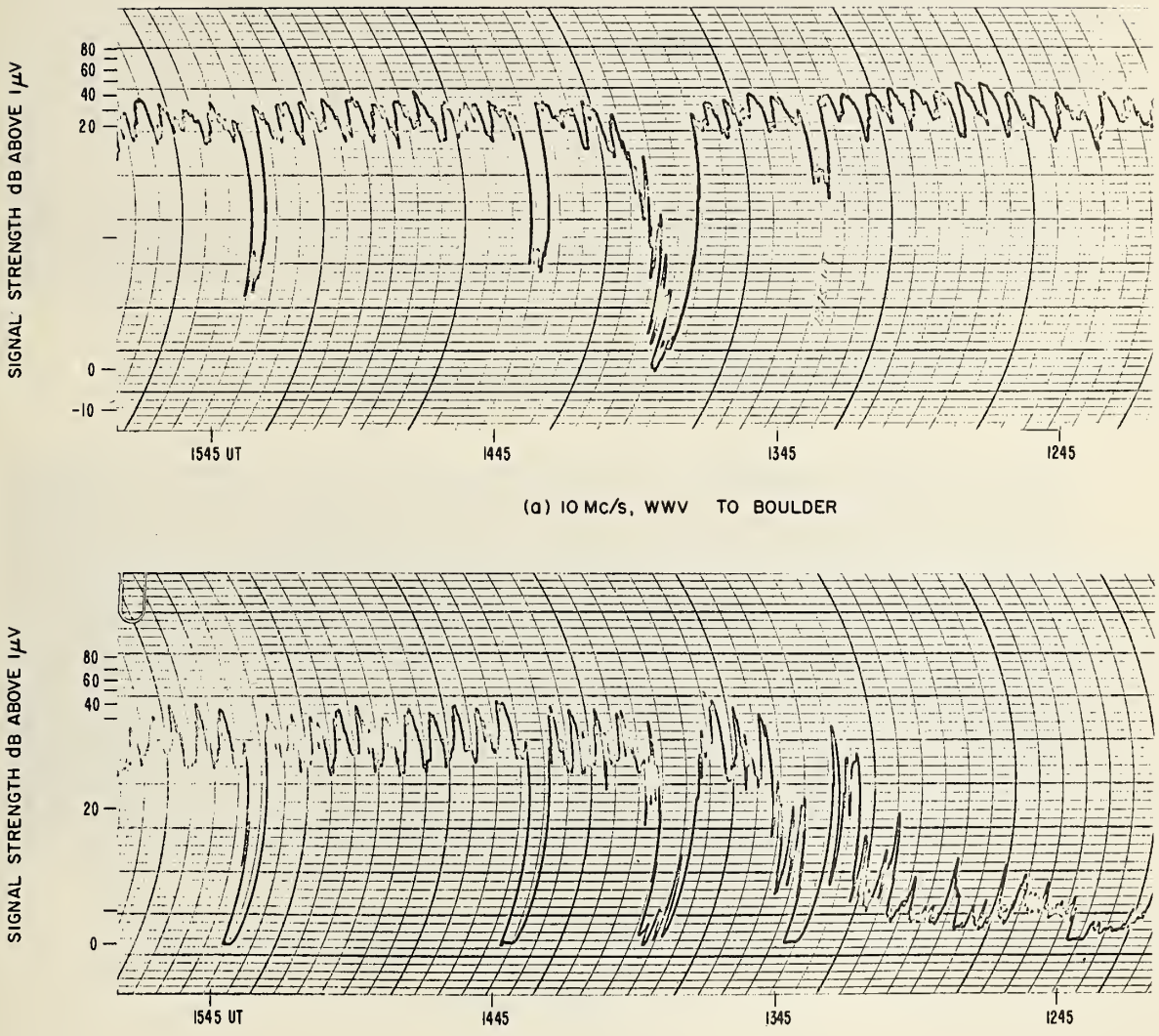

OPTICAL FLARE , IMPORTANCE 2 , 1350 - 1413 - 1440
1 cps
Δf
1410 UT
1412
1414
1416
1418
1420
1422
(a) 10 MC/S , WWV TO BOULDER
1 cps
Δf
1410 UT
1412
1414
1416
1418
1420
1422
(b) 15 MC/S WWV TO BOULDER
27 APRIL 1962

Figure 59

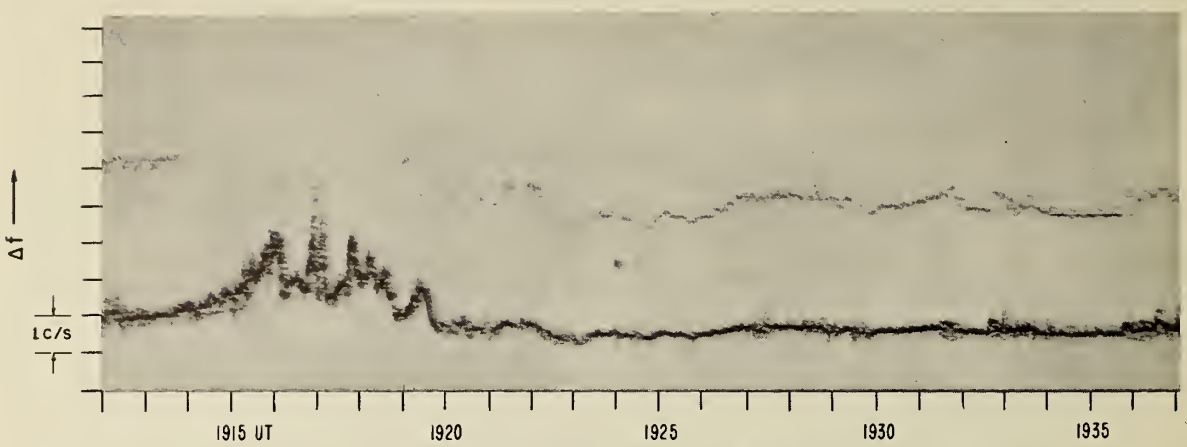
OPTICAL FLARE, IMPORTANCE 2 , 1350-1413-1440



27 APRIL 1962

Figure 60

OPTICAL FLARE, IMPORTANCE 1 , 1915 - 1920 - 1928



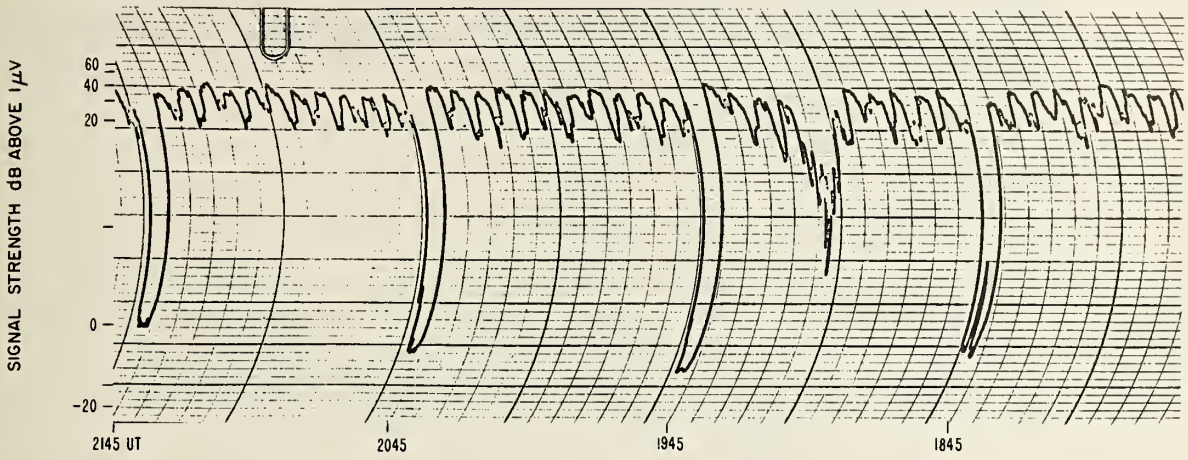
(a) 10 Mc/s, WWV TO BOULDER

(b) 15 Mc/s, WWV TO BOULDER

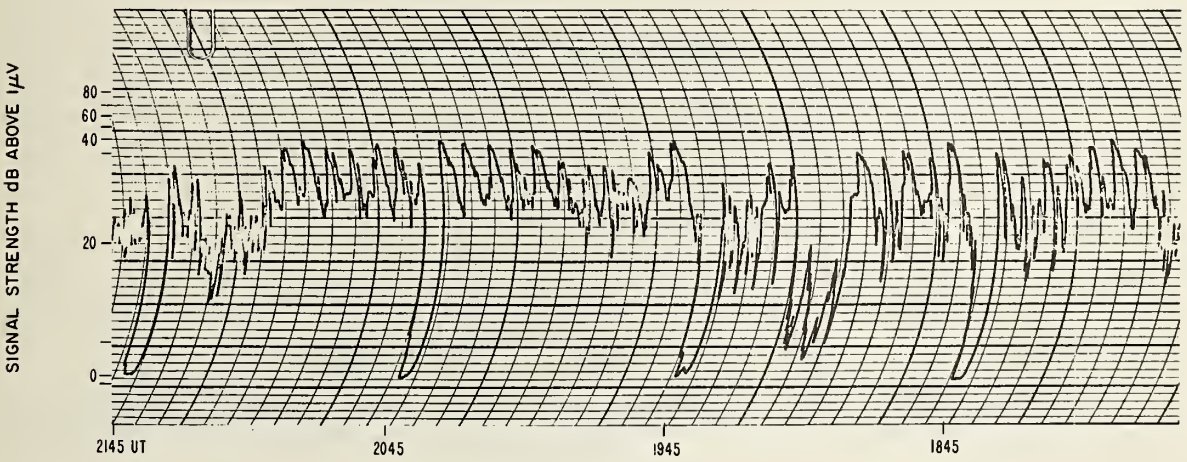
1 MAY 1962

Figure 61

OPTICAL FLARE, IMPORTANCE 1 , 1908-1916-1934



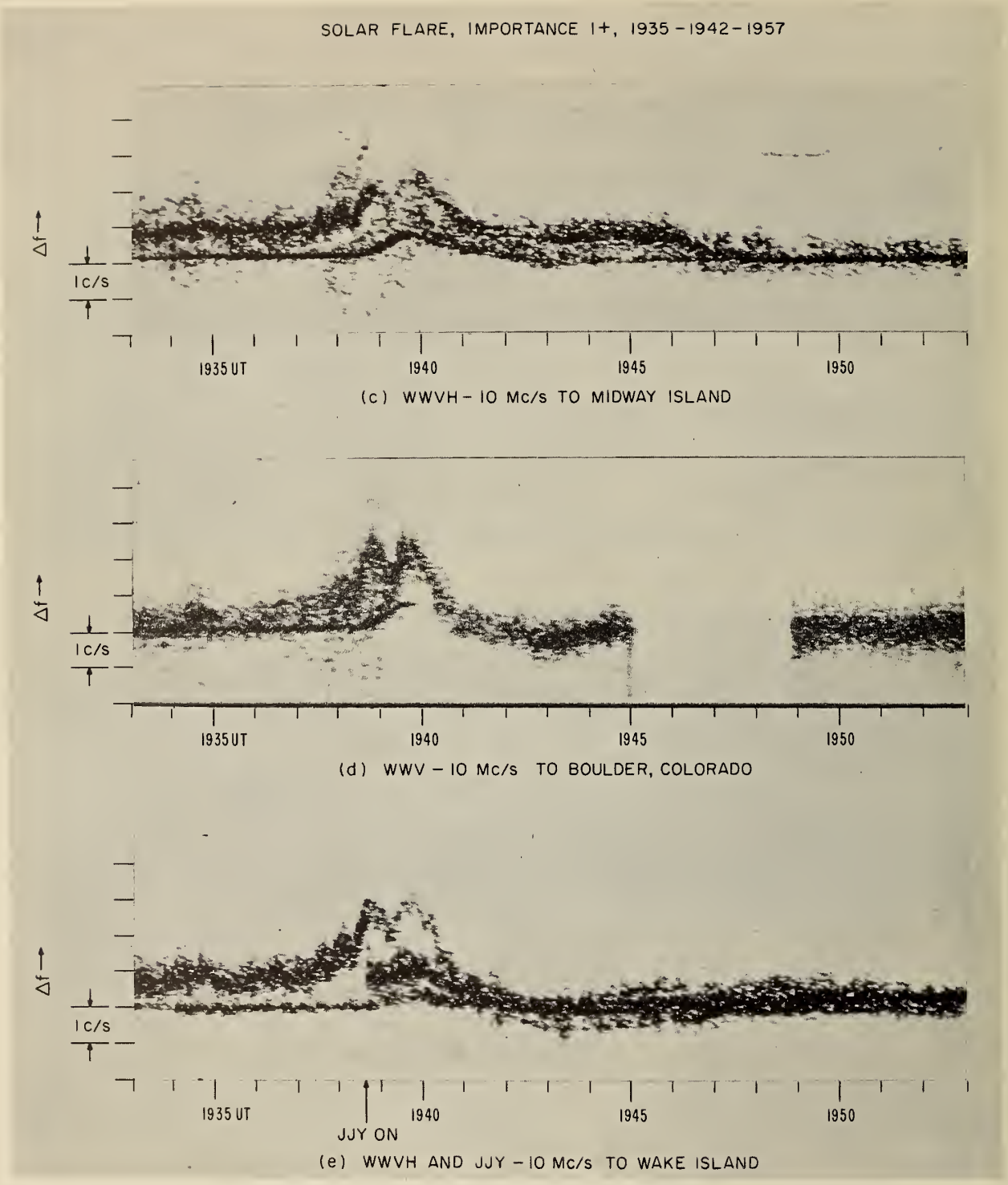
(a) 10 Mc/s, WWV TO BOULDER



(b) 15 Mc/s, WWV TO BOULDER

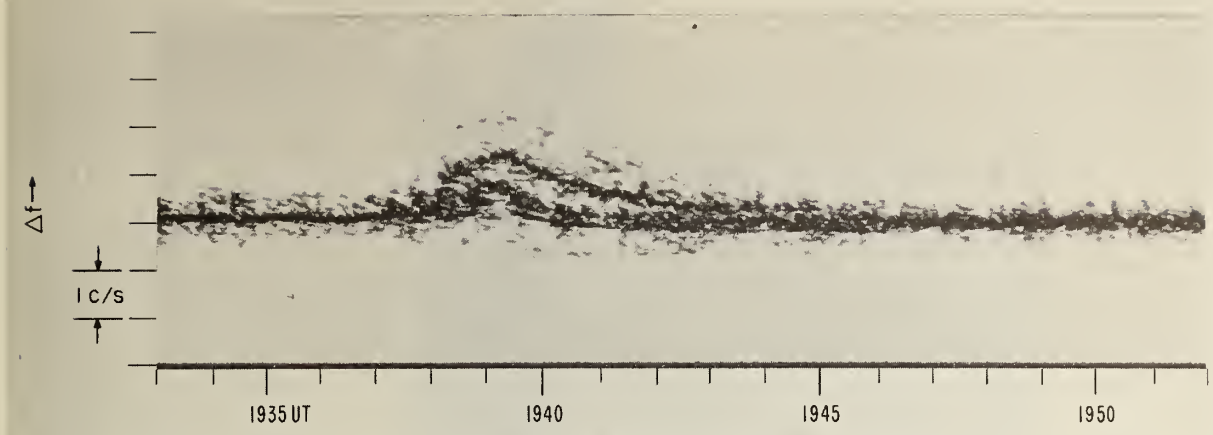
1 MAY 1962

Figure 62

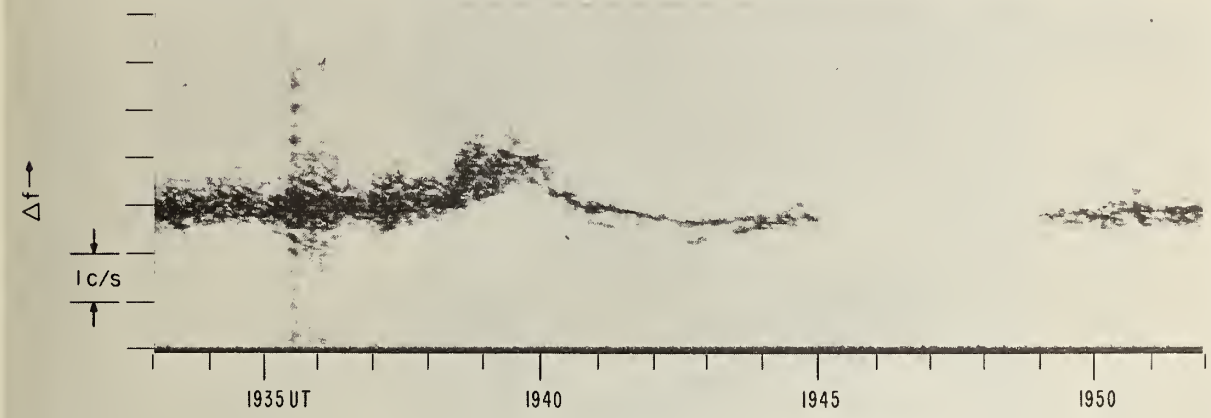


JULY 5, 1962
Figure 63

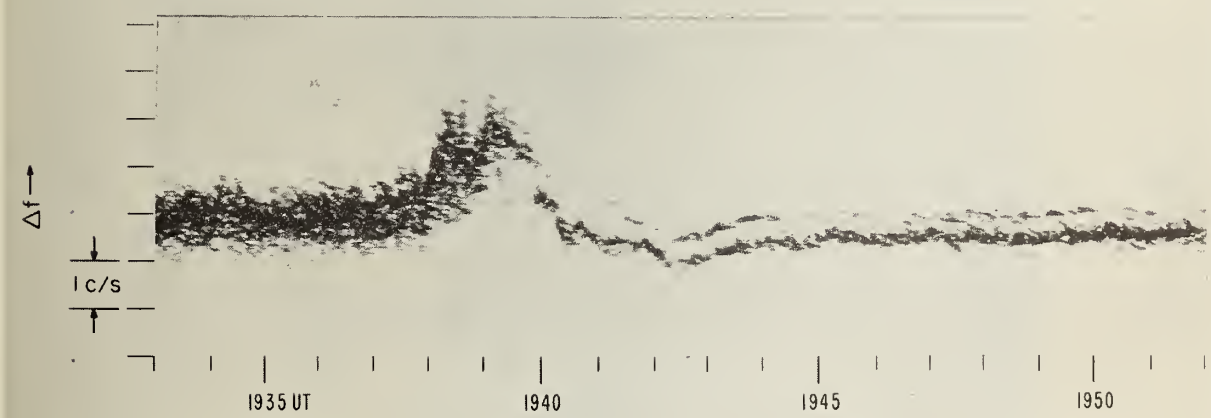
SOLAR FLARE, IMPORTANCE 1+, 1935-1942-1957



(f) WWVH – 15 Mc/s TO MIDWAY ISLAND



(g) WWV – 15 Mc/s TO BOULDER, COLORADO

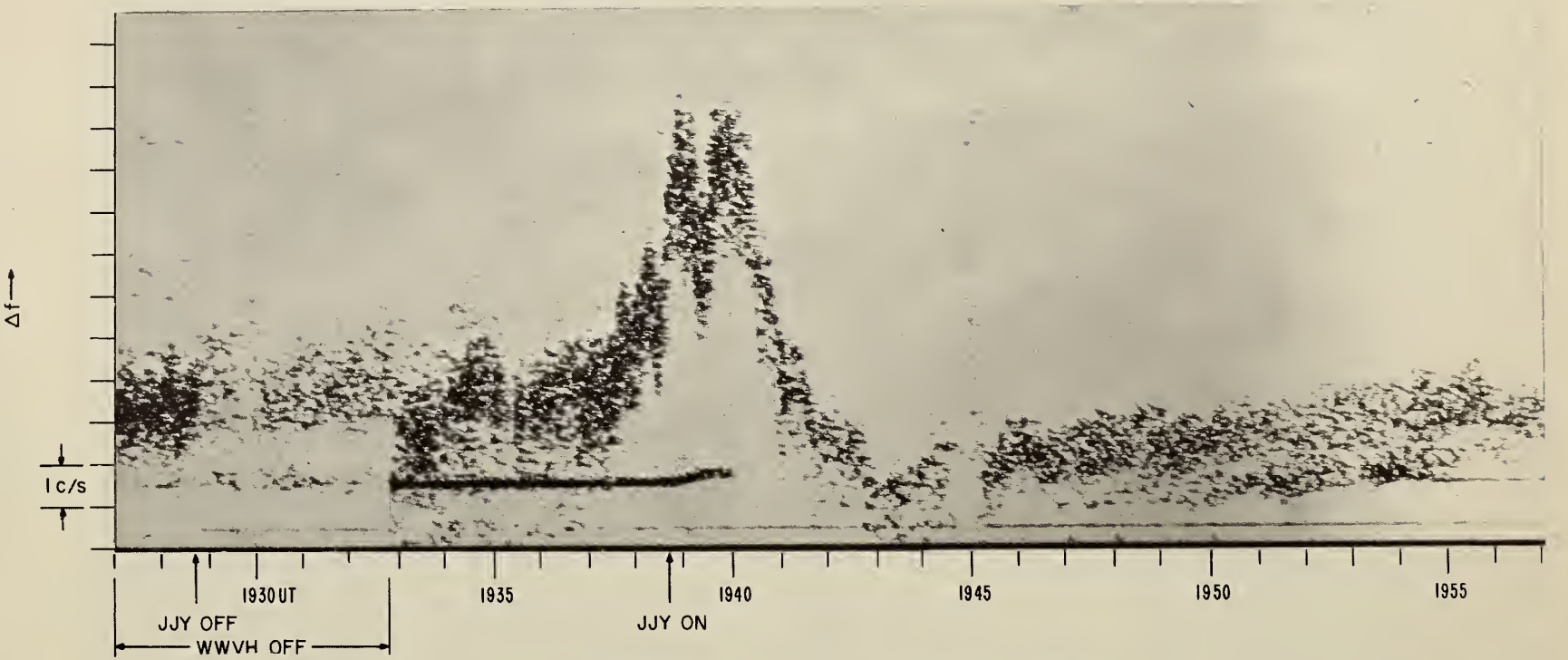


(h) WWVH – 15 Mc/s TO ANCHORAGE, ALASKA

JULY 5, 1962

Figure 63

SOLAR FLARE, IMPORTANCE 1+, 1935-1942-1957

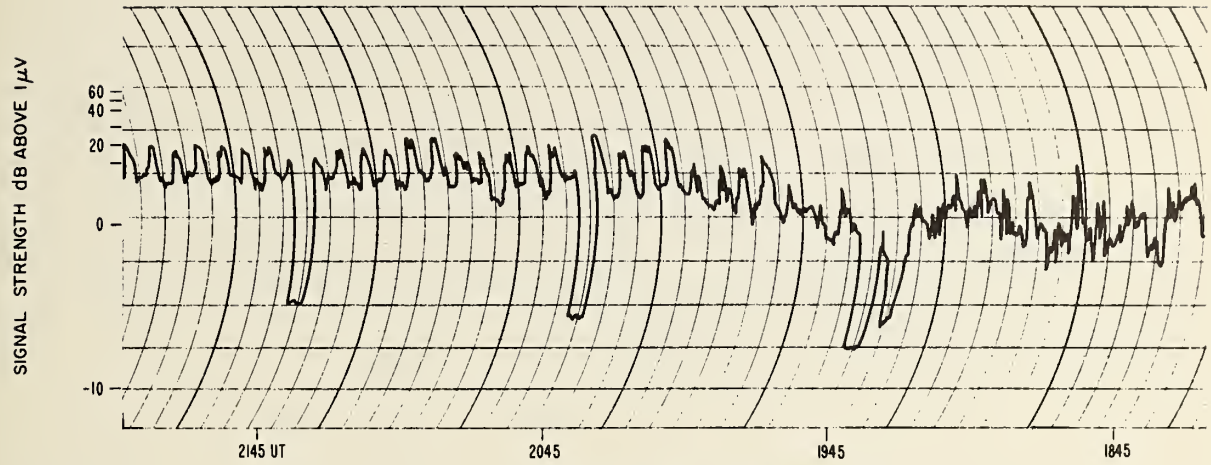


(a) WWVH AND JJY - 5 Mc/s TO MIDWAY ISLAND

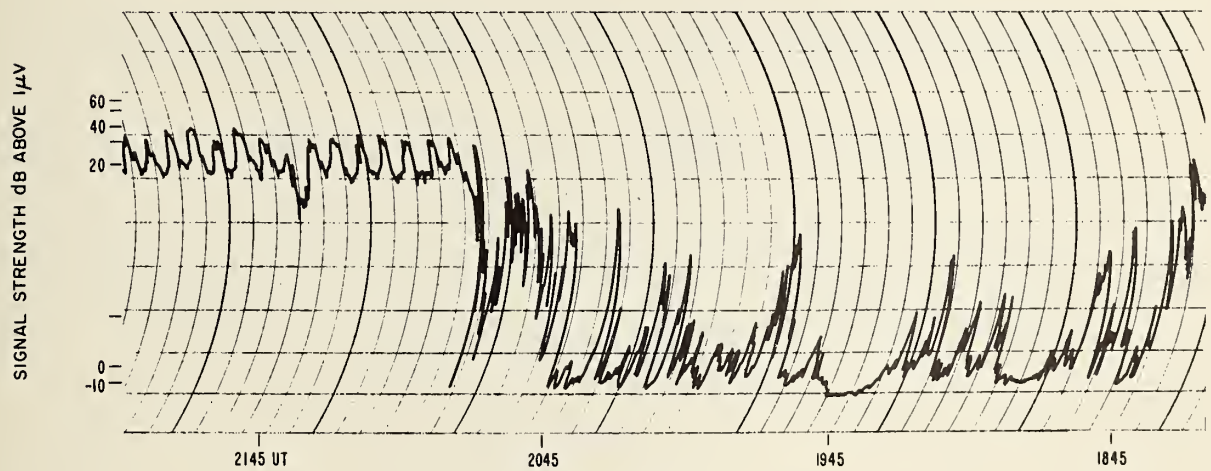
JULY 5, 1962

Figure 63

OPTICAL FLARE, IMPORTANCE 1+ , 1935-1942-1957



(a) 10 Mc/s, WWV TO BOULDER

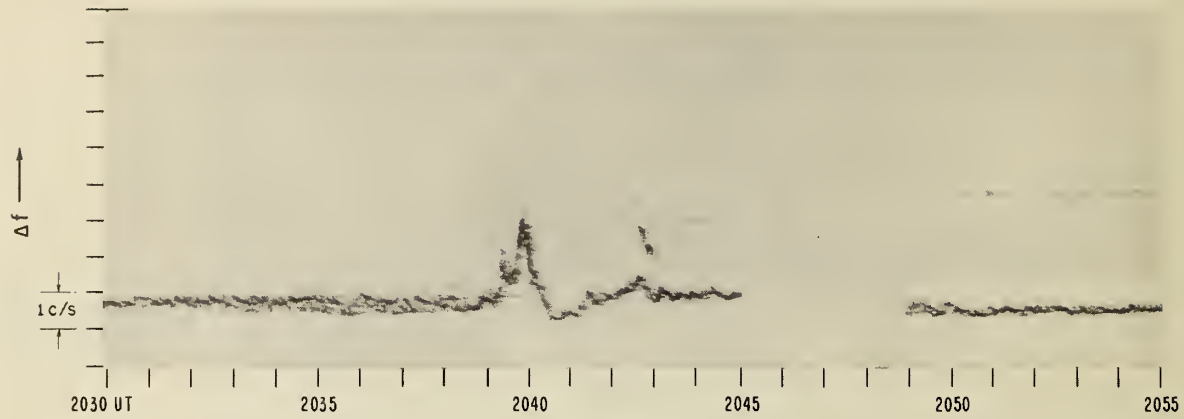


(b) 15 Mc/s, WWV TO BOULDER

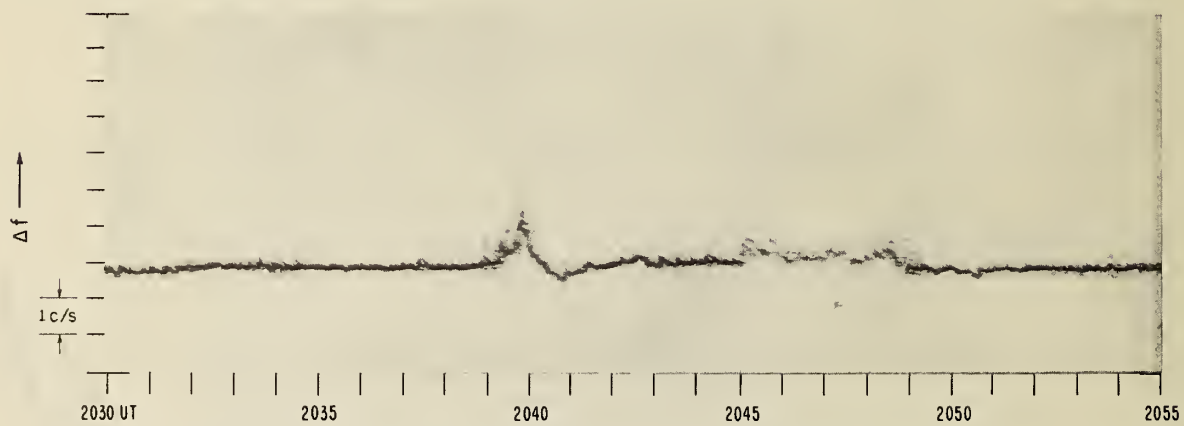
5 JULY 1962

Figure 64

OPTICAL FLARE, IMPORTANCE 1-, 2037–2045–2118



(c) 10 Mc/s, WWV TO BOULDER

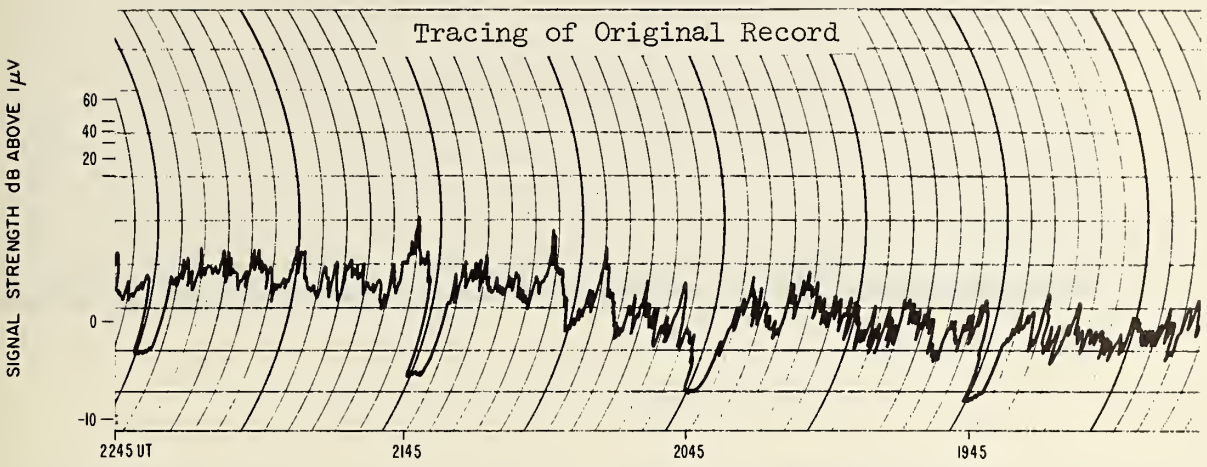


(d) 15 Mc/s, WWV TO BOULDER

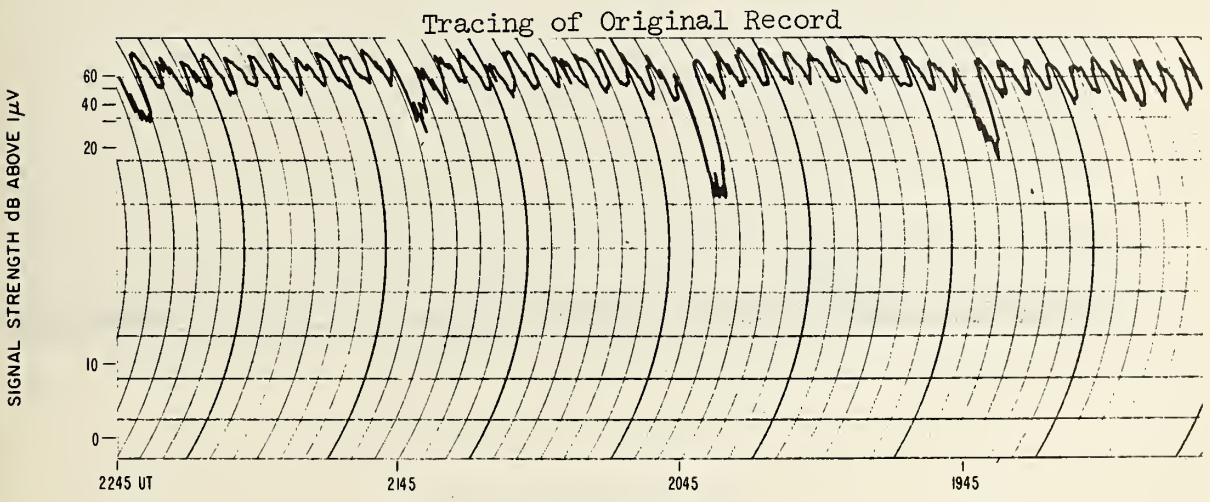
13 AUGUST 1962

Figure 65

OPTICAL FLARE, IMPORTANCE 1- , 2037-2045-2118



(a) 10 Mc/s, WWV TO BOULDER

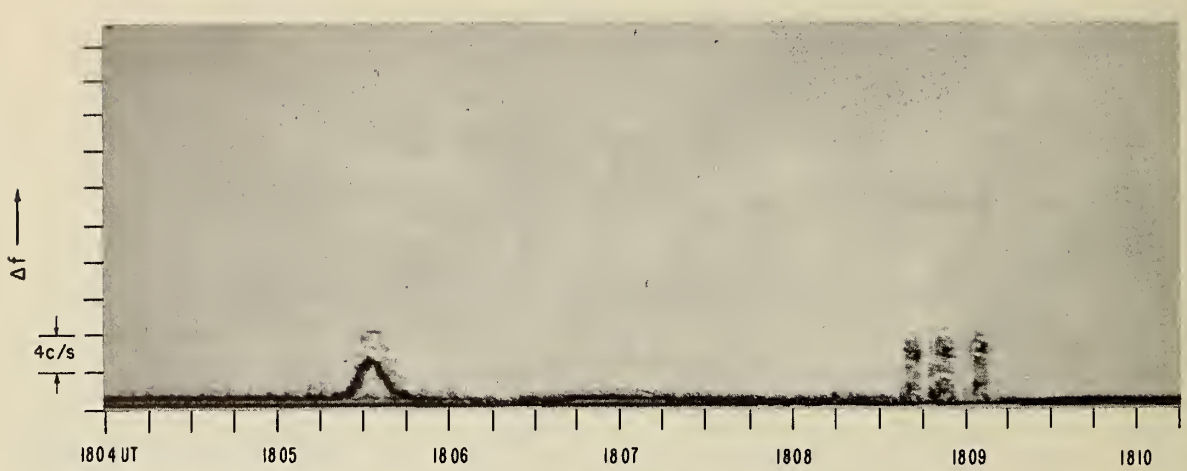


(b) 15 Mc/s, WWV TO BOULDER

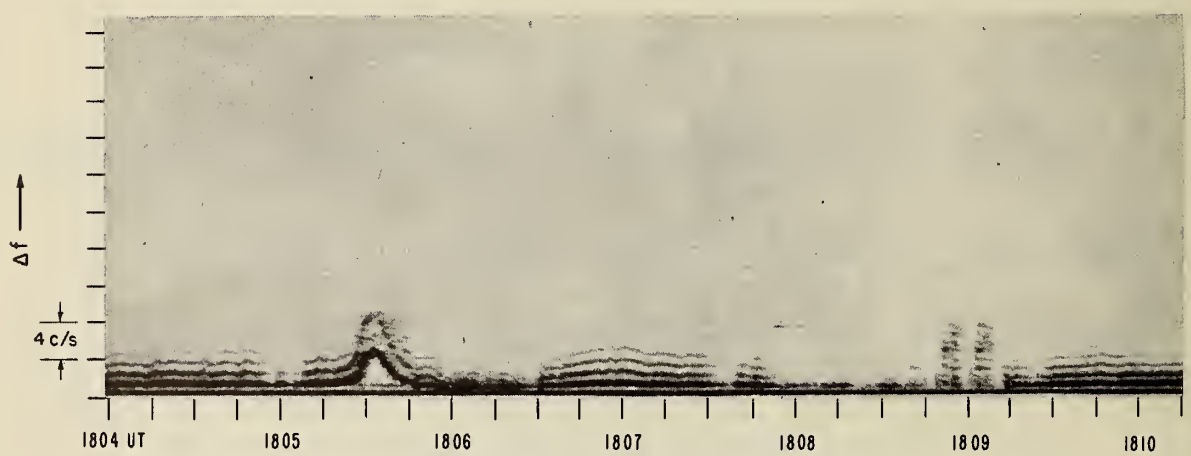
13 AUGUST 1962

Figure 66

OPTICAL FLARE, IMPORTANCE 1- , 1805-1808-1825



(a) 4.000 Mc/s, SUNSET TO BOULDER

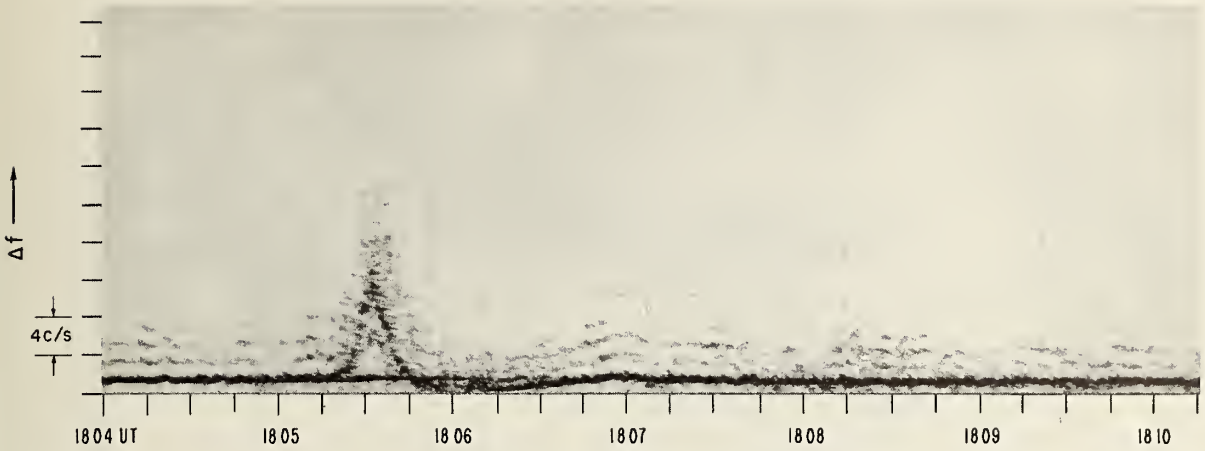


(b) 5.054 Mc/s, SUNSET TO BOULDER

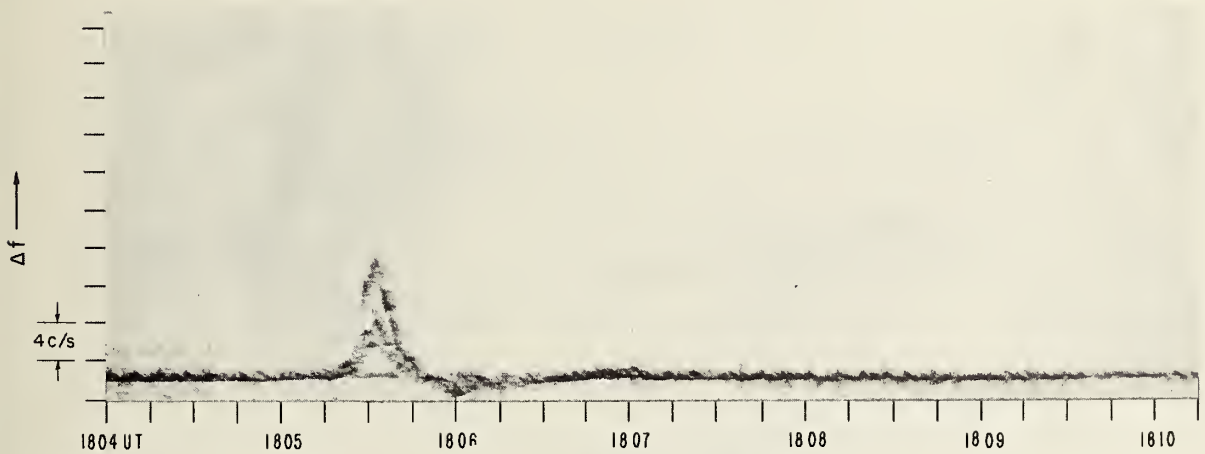
13 OCTOBER 1962

Figure 67

OPTICAL FLARE, IMPORTANCE 1-, 1805-1808-1825



(c) 10 Mc/s, WWV TO BOULDER

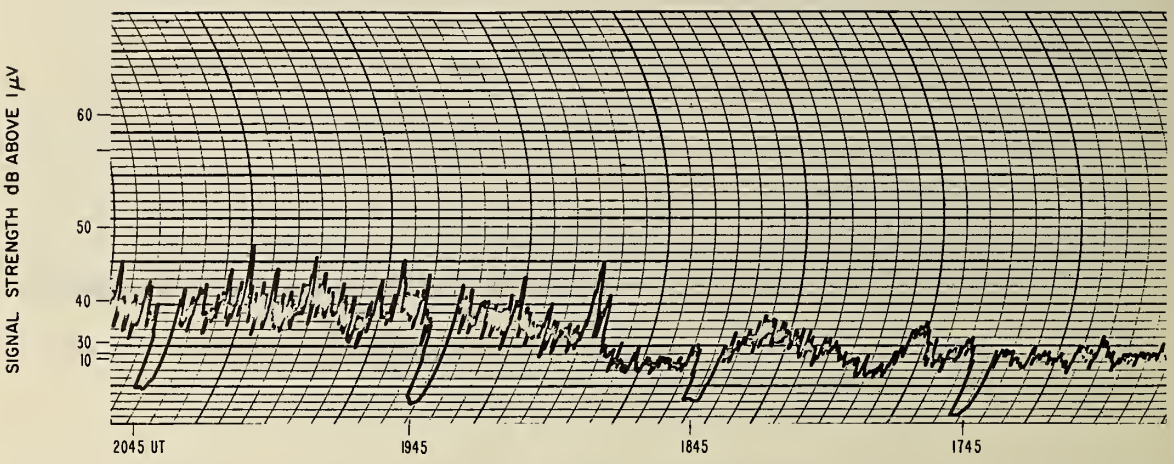


(d) 15 Mc/s, WWV TO BOULDER

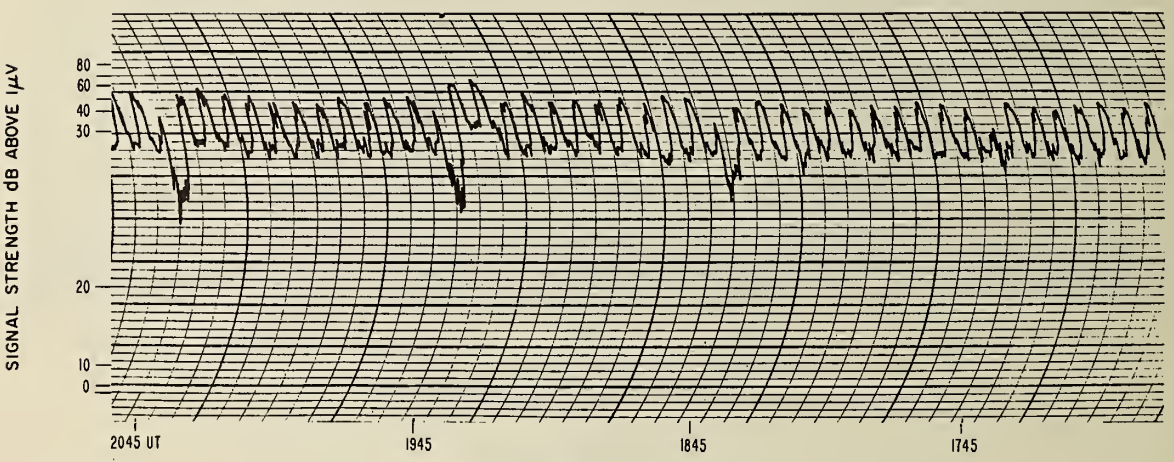
13 OCTOBER 1962

Figure 67

OPTICAL FLARE, IMPORTANCE 1- , 1805-1808-1825



(a) 10 Mc/s, WWV TO BOULDER



(b) 15 Mc/s, WWV TO BOULDER

13 OCTOBER 1962

Figure 68

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