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Results of Simultaneous ELF Measurements At Brannenburg [Germany] and Kingston, R. I.

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RESULTS OF SIMULTANEOUS ELF MEASUREMENTS
AT BRANNENBURG [GERMANY] AND KINGSTON, R. I.

By

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Abstract

Early ELF measurements and equipment development between 1960 and 1963 have been described in reports AFCRL-990 and 62-734. Based upon this work a series of measurements of the horizontal magnetic field in the 5 to 15 cps frequency range were performed in Kingston, R. I., U.S.A., and Brannenburg, Germany between May, 1963 and June, 1964. These two locations are separated in distance along the earth's surface by approximately 4000 miles; their respective coordinates are lat. 41°30' North, long 71°32' West (Kingston) and lat. 47°26' North, long. 12°03' East (Brannenburg).

Simultaneous readings on paper tape running at 25 mm/sec obtained on 30 different dates for a total of approximately 321 minutes indicate that some ELF bursts were received simultaneously and must have originated from a common source; most of the time, however, the records at the two stations were not similar in appearance.

The rectified output of a narrow band filter about the frequency range of the first Schumann resonance (7.5 - 10 cps) was recorded continuously at both stations over periods of several months. Recordings at the two locations exhibit very similar diurnal variation if the data are referred to <u>local</u> time.

RESULTS OF SIMULTANEOUS ELF

MEASUREMENTS AT BRANNENBURG(GERMANY)

AND KINGSTON, RHODE ISLAND.

1. Introduction

The usual theories of the Schumann resonance phenomenon (2,5,7,9,10) assume homogeneous and isotropic boundaries of the earth-ionosphere cavity. If this assumption is a good approximation in the frequency range concerned, not only for the calculation of resonant frequency, but also for the prediction of local field distribution, it should be possible to receive simultaneously very similar signals at widely separated receiving stations, at least when large bursts - above the usual background level - are present. Furthermore, diurnal variations of intensity level should depend upon the diurnal variation of world-wide thunderstorm activity, corrected for the angular separation between source (presumably a lightning center) and receiving station; data of relative amplitude from two stations at different longitude should thus be similar when plotted against universal time and no similarity is expected when data are plotted against local time.

To verify these effects, and thereby to test to what extent homogeneous, isotropic cavity boundaries may be assumed, when calculating the field intensity at any point in the cavity (at a resonant frequency), a series of simultaneous measurements were performed in Kingston, R.I., near the University of Rhode Island and in Brannenburg, Bavaria, by Dr. H. L. König.

2. Instrumentation

The equipment which was used has been described in detail elsewhere (8 and 11). Very similar, although not identical, instruments and arrangements like that shown in fig. 1 were employed at the two locations. Coils with horizontal coil axis, an axially oriented iron core, and 249000 turns of number 38 wire were used as pick-up devices. They were followed by an amplifying system which compensated for the rising amplitude-frequency characteristic of the coil so as to give recordings proportional to H and not to the time derivative of H. Orientation of the axes of the receiving coils were as follows: During the summer of 1963 until October 1, 1963 the Brannenburg coil was oriented N-S (magnetic) and the Kingston coil E-W; from October 1, 1963 to early February 1964 both coils were oriented E-W; thereafter the Brannenburg coil remained in the E-W direction and the Kingston coil was oriented N-S.

For the synchronized measurements the output of the filter circuits was recorded - without rectification - on paper tape running at 25 mm/sec. The frequencies passed by the system were 5 to 10 cps (flat response) in Brannenburg and 5 to 17 cps or 7.5 to 10 cps, depending upon the filters used, in Kingston. Timing pulses were locally generated, but synchronized in Kingston to within + 20, -10 milliseconds with the Canadian Observatory Station CHU at 7.3350 MC; timing pulses in Brannenburg were set to the time transmissions of the AFN station in Munich at 1.1MC, the maximum error in the position of these pulses was ± 3 milliseconds at the beginning of each three minute recording interval and ± 57 milliseconds at the end of each such interval. Time delays in all amplifying systems were also measured. If differences in time delays and possible timing inaccuracies are added it appears that signals which arrive simultaneously at both locations could be displaced by not more than 0.1 second on the respective records.

Data on diurnal amplitude variation in the first Schumann resonance region were obtained by recording the rectified output of the filters (7.5 to 10 cps in Kingston) on slowly moving paper tape; the Kingston recorder running at 0.2 inches/minute was operated for one minute in each 10 minute interval while the Brannenburg recorder was running continuously at 20 mm/hour.

3. Results of Synchronized Measurements

A total of 107 three-minute recordings (321 minutes) were obtained on 30 different measurement days. Until February 28, 1964 the paper tape recordings made in Kingston reproduced the entire 5 to 15 cps band. Starting on that date the narrow band filter (7.5 - 10 cps) was added to reduce background noise level and to exclude energy in the second resonance (14 cps) region. Measurements were taken on the following dates: June 15, 1963, July 12, 19, 20, 26, August 9, 23, October 11, 18, 25, November 22 and December 13, 1963; February 28, 1964, March 26, May 1, 2, 7, 8, 9, 15, 16, 18, 22, 23, 27 and June 1, 5, 6, 12 and 13, 1964. Simultaneous bursts were noted on the dates indicated in table 1.

Table 1.

Dates on which coincident noise bursts were observed.

$P(x \geq c)$ is the probability of the number of coincident bursts x being equal to or greater than the number of coincident bursts c which were observed; $P(x \geq c)$ is calculated on the assumption that the occurrences of bursts in Kingston and Brannenburg are completely unrelated random events.

June 14, 1963	$P(x \geq 1) = 0.072$
July 12, 1963	$P(x \geq 1) = 0.131$
July 26, 1963	$P(x \geq 1) = 0.027$
Feb. 28, 1964	$P(x \geq 3) = 0.005$
June 1, 1964	$P(x \geq 3) = 0.021$
June 13, 1964	$P(x \geq 1) = 0.017$
June 13, 1964	$P(x \geq 1) = 0.24$

Since the occurrence of simultaneous bursts like those shown on figs. 2 and 3 was a relatively rare event, the hypothesis was tested that the occurrence of simultaneity was simply that random coincidence which must occur occasionally if a large number of bursts are observed at both stations.

If a is the number of observed bursts above background level in Kingston, b the corresponding number for Brannenburg, and n the total number of 0.1 seconds intervals (= 1800 for a three minute recording period), then

$P[A] = \frac{a}{n}$ probability of a noise burst starting in any 0.1 second interval in Kingston

$P[B] = \frac{b}{n}$ probability of a noise burst starting in any 0.1 second interval in Brannenburg

If the records are statistically independent, the probability of a burst starting on both records in the same 0.1 second interval is (4,pp 114-117):

$$P[AB] = \frac{ab}{n^2} \tag{1}$$

If we consider the occurrence of simultaneous events as an independent trial process, each 0.1 second interval is a trial with a probability of success P[AB]. The probability of x successes in n trials is given by the binomial distribution (4, p. 137) which can be approximated by the Poisson distribution if n is large and p small (4, p. 143); thus the probability of obtaining exactly x successes in n trials is

$$f(x) \approx \frac{e^{-nP} (np)^x}{x!} \tag{2}$$

and the probability of the number of "successes" (bursts on the assumption of purely random coincidence) being greater than or equal to the number of observed coincidences, c, is given by

$$P(\ x \geq c\ ) = \sum_{x_i = c}^{n} f(x_i) = 1 - \sum_{x_i = 0}^{x_i = c-1} f(x_i) \tag{3}$$

This probability is also shown in table 1. It is apparent that on five of the seven three-minute records where coincidences occurred, the probability that these coincidences were due to chance alone is less than 0.1.

4. Relation of Simultaneity of Bursts to Geomagnetic and Solar Activity

Since the occurrence of coincident bursts was a relatively rare event the possibility was investigated that the periods when such bursts occurred might be characterized by particular geomagnetic or solar activity. No correlation was found with the magnetic index, K_p, for the appropriate intervals. The evidence for direct connection with solar activity is not conclusive and additional observations over a longer period of time is necessary.

For comparison with solar activity the "Solar Flare Activity Index" F (ref.3) published by the High Altitude Observatory in Boulder, Colorado was used; it is an indication of the integrated Hydrogen-α (6563A°) flare energy from the sun. The data are given in table 2. These averages suggest an association between F and the occurrence of coincident bursts, but no definite conclusion can be reached, because F varied over a rather wide range during the days of observation ($0 \leq F \leq 100$).

Table 2.

Coincident bursts and solar flare activity index.

	F
Average for six days with coincident bursts	30
24 days without coincident bursts	6
Average for all 30 days	11
Average for entire year 6/1/63 - 6/1/64 (Excluding values of F > 100)	16.3

If one distinguishes only between zero and non-zero values of the flare index F, the following table can be constructed which gives the number of days for each event:

Event A $F > 0$ Event C: Coincident bursts occurring

Event $\bar{A}$ $F = 0$ Event $\bar{C}$: No coincident bursts

	C	$\bar{C}$
A	$a = 3$	$b = 5$
$\bar{A}$	$c = 3$	$d = 17$

The probability of events A and C occurring simultaneously on the basis of purely random coincidence is

$$P(AC) = P(A)\,P(C) \tag{4}$$

The total number of events is $n = a + b + c + d$, the probability of C occurring is $P(C) = (a+c)/n$, the probability of C not occurring is $P(\bar{C}) = (b+d)/n$, etc. the expected value (1, p. 78) - on the basis of random coincidence - of simultaneous bursts occurring on a day with flare activity index $F > 0$ is

$$E(a) = n\,P(AC) \tag{5}$$

The expected values for the various combination of events on the basis of pure random coincidence and the actually observed values are shown on table 3.

Table 3.

Expected and observed values for the occurrence of coincident bursts on days with $F > 0$ or $F = 0$.

	Expected	Observed
Simultaneous bursts and $F > 0$	$E(a) = 1.72$	3
No simultaneous bursts and $F > 0$	$E(b) = 6.3$	5
Simultaneous bursts and $F = 0$	$E(c) = 4.3$	3
No simultaneous bursts and $F = 0$	$E(d) = 15.7$	17

Examination of table 3 suggests again that the occurrence of simultaneous bursts on a day with $F > 0$ may not be a chance event, since the number of observed cases, 3, is equal to 1.75 times the expected value (1.72). To obtain a more reliable interpretation of these results, however, the probability that the association of coincident bursts with $F > 0$ was a chance event, was computed by use of the "chi-square statistic" (1, pp. 174, 264). It can be shown that the abscissa of the discrete chi-square distribution is given by

$$\chi^2 = \frac{[ad - bc]^2\, n}{[a+b]\,[c+d]\,[b+d]\,[a+c]} \tag{6}$$

If a correction is made for the fact that the chi-square statistic is discrete, whereas the generally available tabulated chi-square distribution is continuous, it can be shown (1, p. 188) for a two by two table that the adjusted χ^2 is given by

$$\text{adj }\chi^2 = \frac{[\,|ad-bc| - \frac{n}{2}]^2\, n}{[a+b]\,[c+d]\,[b+d]\,[a+c]} \tag{7}$$

Substitution of the appropriate numerical values into (6) and (7) and reference to chi-square tables (1,) leads to the following results:

Probability that flare index $F > 0$ and occurrence of simultaneous bursts are independent: $P[\,\chi^2 > 1.72\,] = 0.19$

This value is not corrected for discreteness or small sample size.

Probability that flare index $F > 0$ and occurrence of simultaneous bursts are independent, computed with correction for discreteness or small sample size: $P[\,\chi^2 > 0.64\,] = 0.43$

The last value indicates that there is still a 43 per cent chance that the occurrence of simultaneous bursts on days with $F > 0$ is a purely chance event. Thus additional observations are needed to establish a connection between $F > 0$ and occurrence of simultaneous bursts despite the appearance of tables 2 and 3.

5. Diurnal Variation of Amplitude

Amplitude data for each hour, averaged over observation periods selected so that continuous data were available for both stations, were normalized to indicate a maximum of one. Fig. 4 is such a plot for 40 days during Oct. - Nov. 1963. The time scale is Universal Time, with noon for Brannenburg (CET) and Kingston (EST) also shown. Times of local sunrise (on Oct. 1, Nov. 1, and Nov. 30) on the earth's surface are shown by upward pointing arrows and times of sunset by downward arrows. On the lower part of fig. 4 the diurnal variation of average thunderstorm activity as published in 1960 (Handbook of Geophysics, ref. 6) is shown for the major thunderstorm centers of the world; the curves from left to right correspond to activity in South-East Asia, Central Africa and Central America. It would seem that if the recorded magnetic field variations in the first Schumann resonance region (7.5 - 10 cps) are primarily due to thunderstorm activity, the Brannenburg station is affected primarily by lightning activity in Asia and Africa, and the Kingston station by corresponding activity in Africa and America. This is not entirely what one would expect on the basis of simple resonance theory which predicts (for example 10) that the horizontal magnetic field in the first mode should vary as the sine of the angle between the source and the observing point. Based upon the "Handbook of Geophysics" the areas of maximum thunderstorm activity in November are shown on table 4; also shown there are the angular separations between these areas and the Brannenburg and Kingston stations. The data for thunderstorm activity represent averages for a period of several years before 1956 and may, of course, not represent the exact situation in 1963 or 1964.

Table 4.

Areas of maximum thunderstorm activity in November and angular separation between these areas and the observation stations.

Area of thunderstorm activity			Angular separation along great circle path between source and Brannenburg	Kingston
Central America	15°S,	60°W	90°	57°
Central Africa	5°N,	5°E	45°	76°
	3°N,	15°E	45°	85°
	3°S,	30°E	54°	100°
South East Asia	2°S,	105°E	94°	138°
	10°S,	125°E	113°	144°

Except for the suggestion that the Kingston station should be least affected by the South East Asia thunderstorm area [$\sin 144^\circ \approx 0.58$], the angular separations shown in table 4 cannot satisfactorily explain the diurnal variations of ELF intensity displayed on fig. 4; for example the Brannenburg data should be affected about equally by activity in Central America (90° separation) and South East Asia (94° to 113°), but activity in Central Africa seems to have a much greater effect than activity in Central America.

The most pronounced effect which is apparent on Fig. 4 is the rapid increase of ELF activity at sunrise for both stations, and the more gradual decay beginning before sunset. The period between 900 and 1500 local time corresponds to maximum activity. These effects are also illustrated by fig. 5 where the ELF amplitude variation is plotted against local time.

Curves for a 30 day period in May 1964 are shown on figs. 6 and 7; the corresponding thunderstorm data are summarized in table 5:

Table 5.

Areas of maximum thunderstorm activity in May and angular separation between these areas and the observation stations.

Area of thunderstorm activity			Angular separation along great circle path between source and Brannenburg	Kingston
Central America	12^oN	85^oW	85^o	32^o
	10^oS	75^oW	90^o	52^o
	2^oS	50^oW	80^o	47^o
Central Africa	5^oN	10^oE	43^o	80^o
	0^o	30^oE	50^o	97^o
South East Asia	10^oN	100^oE	80^o	127^o

The Kingston data seem to be very heavily affected by the Central American activity; a separation of 32^o corresponds, however, only to a distance of approximately 2200 miles (3540 kilometers). Since the free space wavelength at 8 cps is 37500 km, the distance to the Central American thunderstorm center is less than $\lambda/10$ and the Kingston station is still in the induction field of this exciting source; thus corrections to the simple mode theory would be required. Apart from the shift of the Kingston peak from 1400-1600 UT to 1700-2100 UT the relation of ELF amplitude to lightning activity in the areas of South East Asia, Central Africa and Central America is similar to that shown in fig. 4 for October-November. Clearly apparent for both stations, and shown by fig. 7, is again the increase of ELF activity after sunrise and the decrease at sunset. The rate of increase of ELF activity at sunrise is, however, lower in May than in October-November.

6. Conclusions

Synchronized simultaneous measurements of magnetic ELF activity in the first Schumann resonance region indicate that only a small percentage of the total observed bursts above background level seem to originate from the same source. There is some possibility that occurrence of such bursts at both stations may be enhanced by increased solar activity.

Records of diurnal variation of magnetic ELF activity in Central Europe and the East Coast of North America clearly show a dependence upon local sunrise and sunset suggesting that the reception of magnetic fields in this frequency range is affected by the local condition of the ionosphere or at least, by variations of ionospheric properties with longitude.

7. References

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Figures

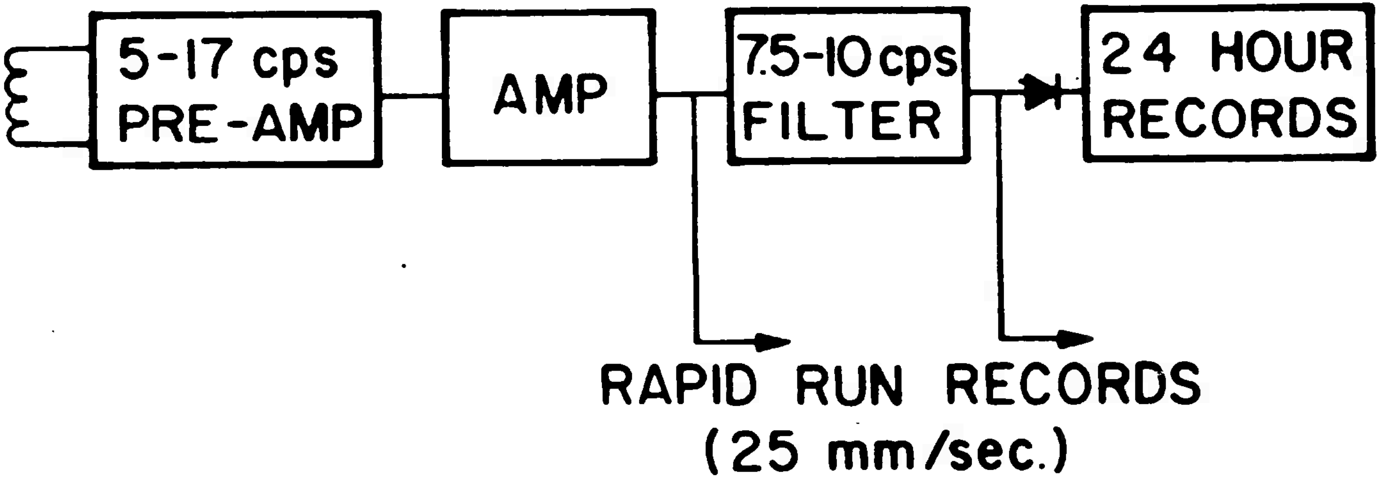

Fig. 1 Block diagram of receiving system.

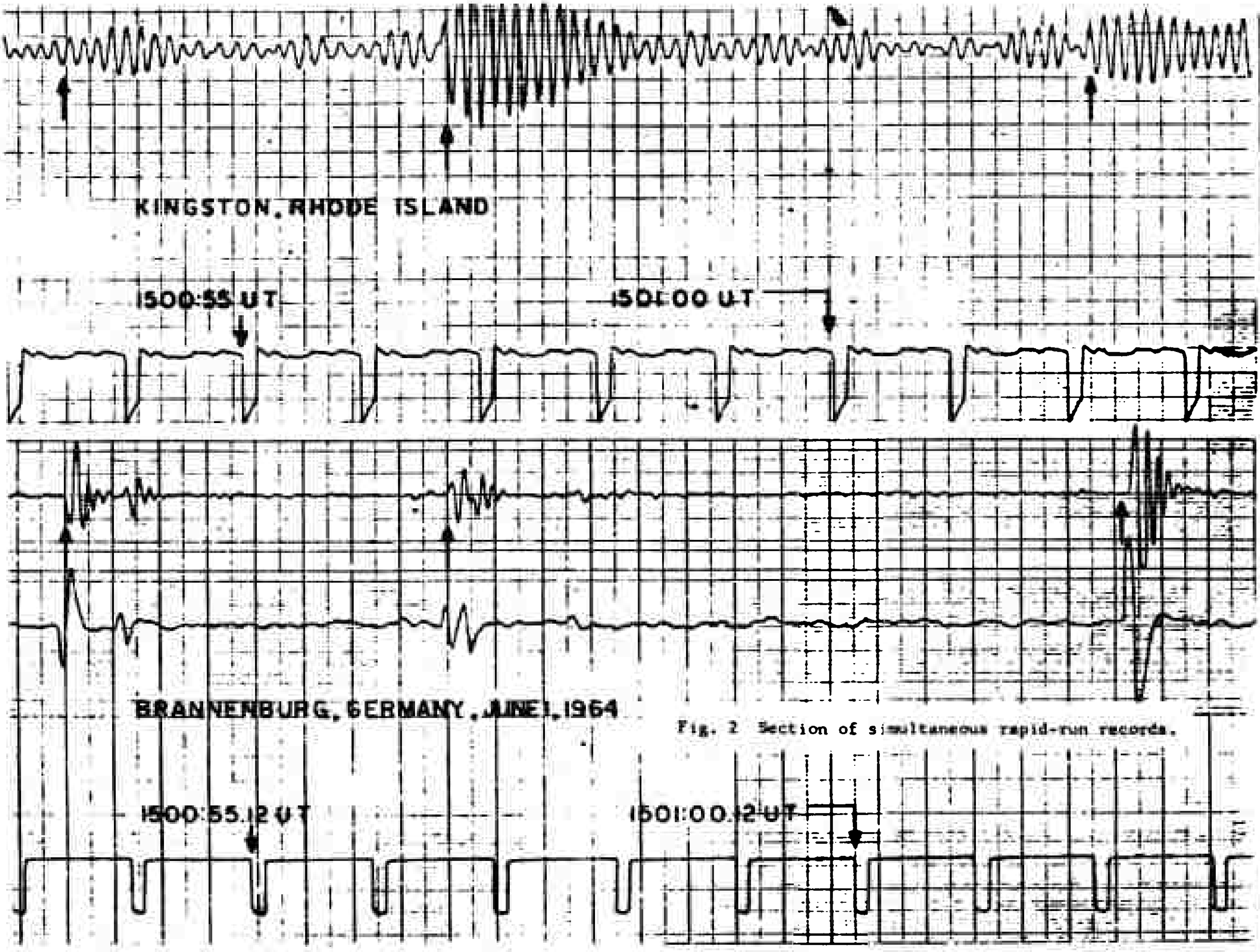

Fig. 2 Section of simultaneous rapid-run records.

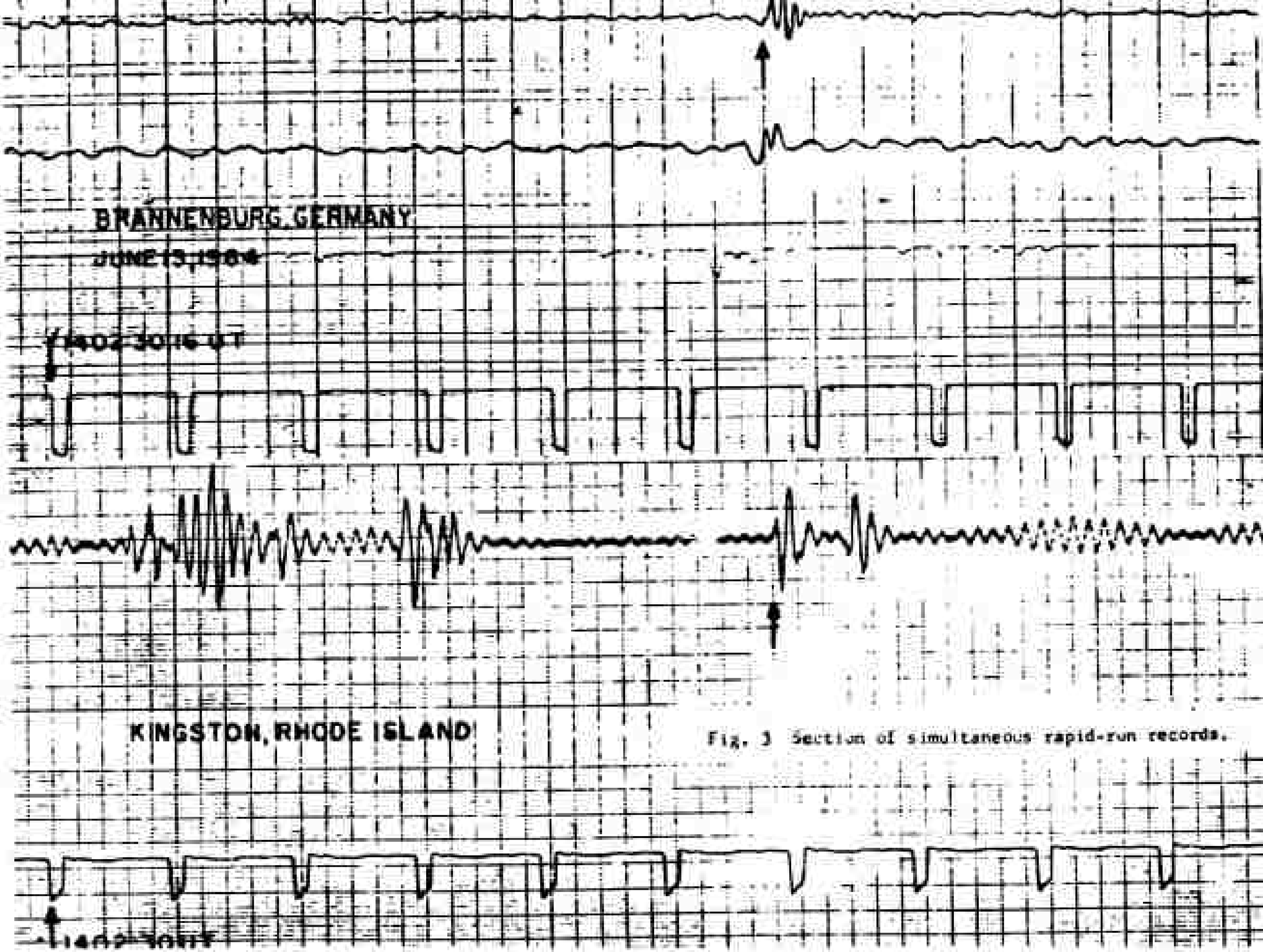

Fig. 3 Section of simultaneous rapid-run records.

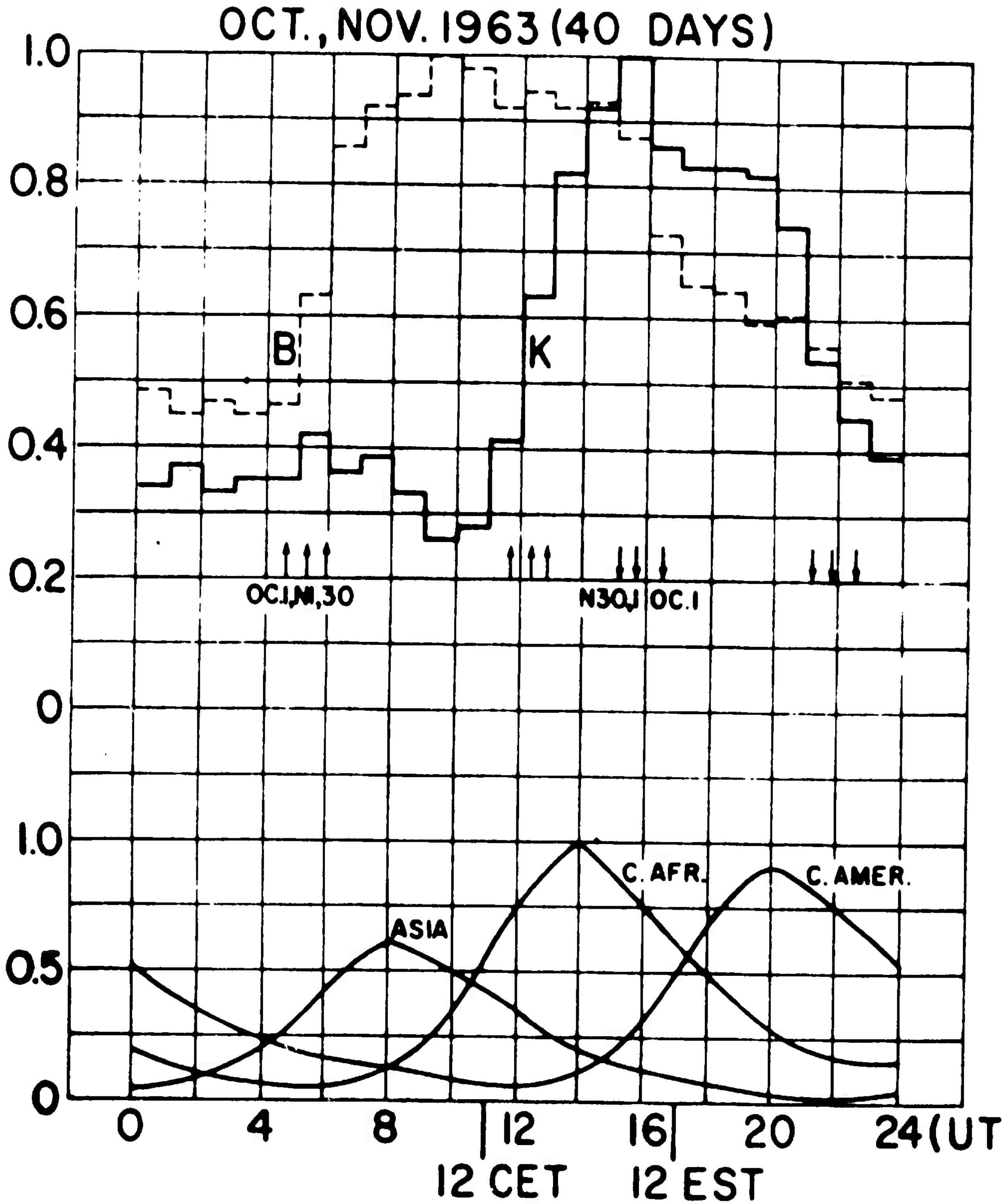

Fig. 4 24-hour records for Brannenburg (B) and Kingston (K), averaged over 40 days in Oct., Nov. 1963 and diurnal variation of thunderstorm activity.

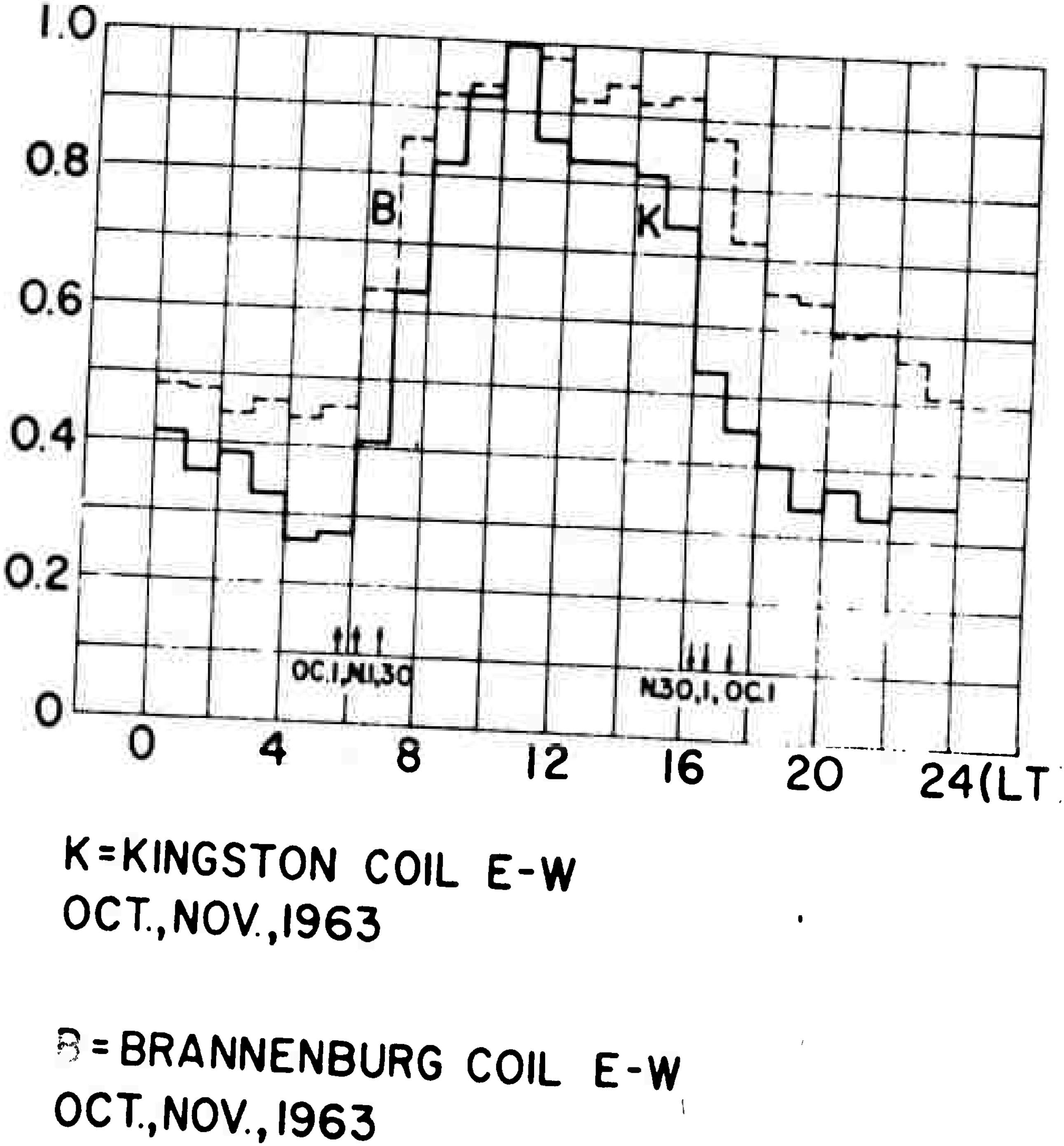

Fig. 5 Oct., Nov. 1963 24-hour records for Brannenburg (B) and Kingston (K) plotted against local time.

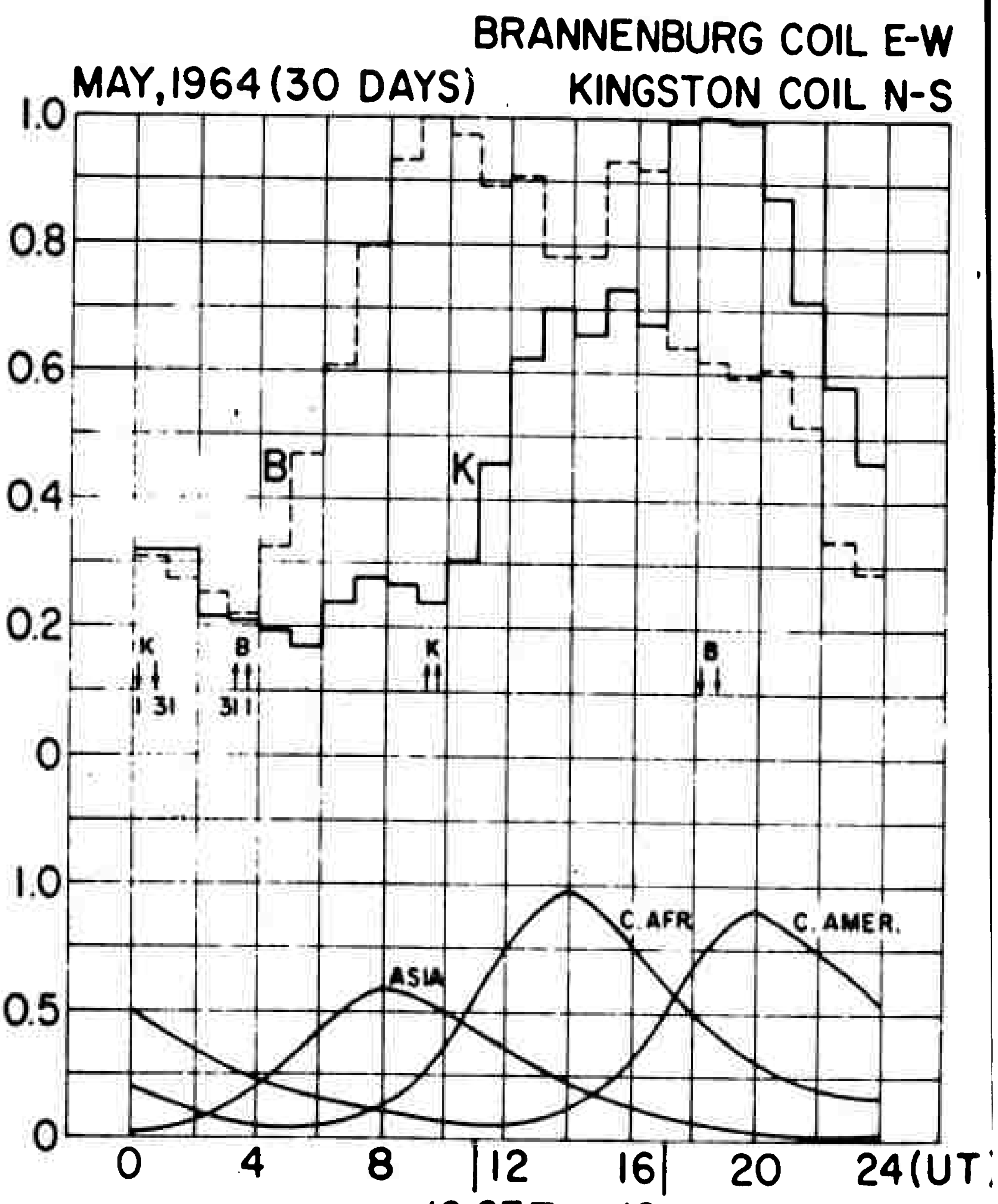

Fig. 6 24-hour records for Brannenburg (B) and Kingston (K) averaged over 30 days in May 1963 and diurnal variation of thunderstorm activity.

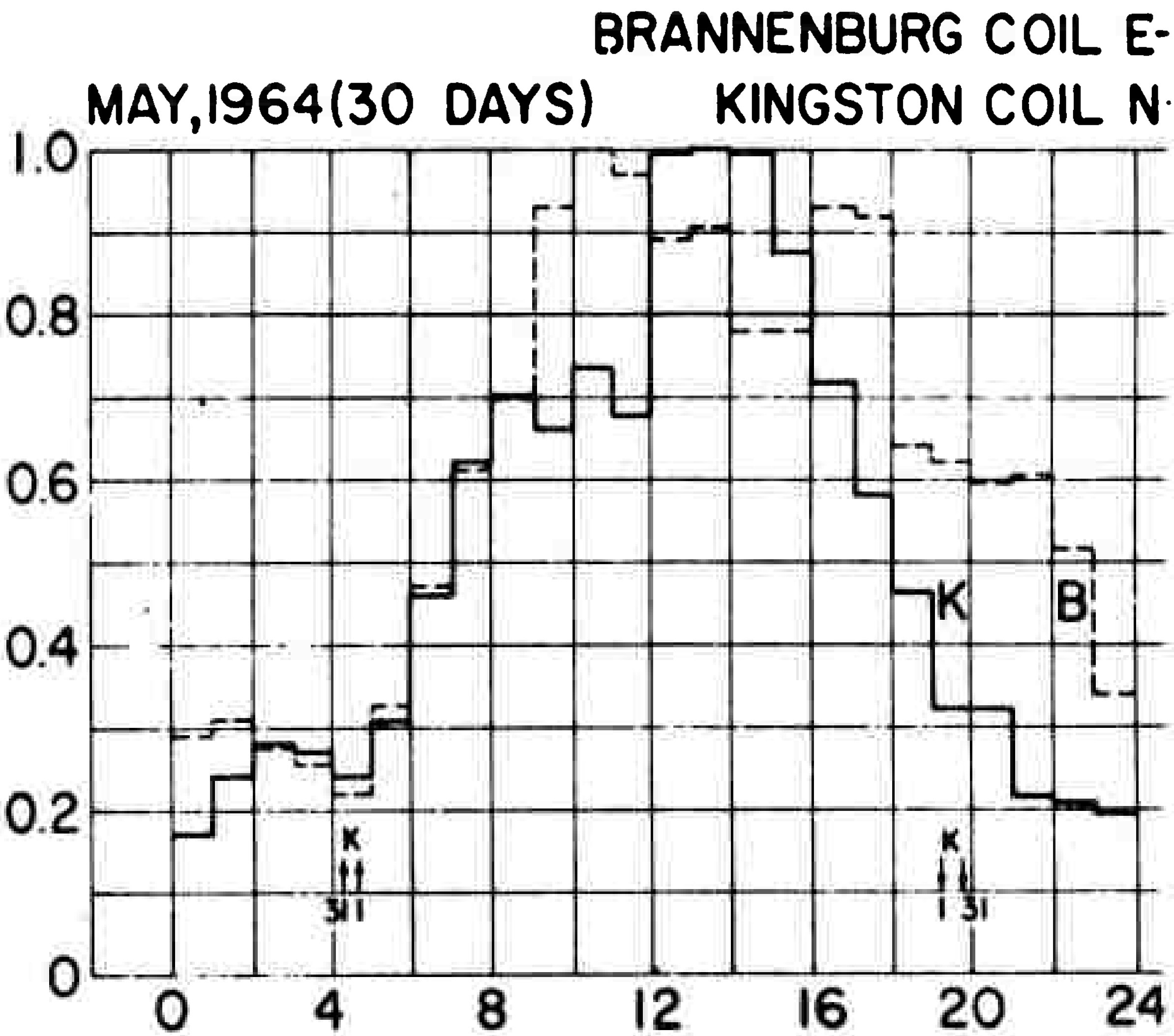

Fig. 7 May 1963 24-hour records for Brannenburg (B) and Kingston (K) plotted against local time.