SPORADIC-E AND ITS IMPLICATIONS FOR RADIOCOMMUNICATIONS

Proceedings of a Colloquium held at the Rutherford and Appleton Laboratories, Slough on [illegible]4 February 1981

PREFACE

Sporadic-E (symbol Es) is the generic name given to ionisation irregularities which arise at E region heights in the ionosphere. These have a number of separate physical causes, with associated different geographical and temporal morphologies. Their common features include intense ionisation over a height range of only a few kilometres, irregularity blobs often elongated along the direction of the Earth's magnetic field with lengths of several kilometres contained in drifting patches extending over hundreds of kilometres and, as the name implies, an intermittent occurrence from day to day.

There are a number of experimental techniques available for studying sporadic-E, including vertical-incidence and backscatter sounding as well as various forms of oblique-path measurements, but the greatest wealth of data comes from vertical sounding. Sporadic-E is categorised into types depending on the form of the sounder records. It is recognised that this classification may not be consistent with the different sources of Es, each of which may have characteristic attributes and associated relevance to oblique-path signal scattering.

Sporadic-E is undoubtedly important to radiocommunications at HF and VHF. There are advantageous and deleterious effects. Improved knowledge of its scattering characteristics and occurrence, both statistically and in near-real time, is desirable for system planning and operation.

As a fore-runner to the possible promotion of future research activity, a Colloquium was held at the Rutherford and Appleton Laboratories (RAL), Slough on Tuesday, 24 February 1981, with the objectives of reviewing current information on sporadic-E relevant to communications, identifying limitations in this knowledge and highlighting priority areas where more work is needed and holds promise of being fruitful.

The meeting had an attendance of about fifty, drawn mainly from the universities and government research establishments, but also with some industrial participants present. Additionally, we were pleased to welcome representatives from the Radio Society of Great Britain. Speakers reviewed sporadic-E parameters scaled from vertical-incidence ionograms and their long-term modelling, the morphology of Es at different latitudes and available information on scattering losses. The roles of backscatter sounding and amateur observations in synoptic studies were examined, and user requirements for sporadic-E information were summarised.

This proceedings, which includes written versions of the invited papers, together with an interpretation of remarks made by contributors to the discussion sessions has been prepared with the assistance of Dr. M. Lockwood of RAL and is forwarded as a permanent record of the occasion. My thanks go to all speakers and attendees for making the event a success.

P. A. BRADLEY
(Ionospheric Radio Propagation Section)

11 April 1981

CONTENTS

PART I: CURRENT INFORMATION ON SPORADIC-E

1. Sporadic-E parameters scaled from vertical-incidence ionograms

(Mr. R.W. Smith, Rutherford and Appleton Laboratories)

Consideration is given to the sporadic E (Es) parameters which are regularly scaled from ionograms and which are published in monthly bulletins by ionospheric observatories throughout the world. Much of the information has been taken from the standard Handbook of Ionogram Interpretation and Reduction, UAG23A, by Piggott and Rawer, which is used worldwide and has been translated into French, Russian, Japanese and other languages.

Sporadic E, which Appleton and the early workers referred to as abnormal E, is most appropriately named as shown by the following main features:

(a) Occurs at any time of day or night, at any time of the year. There is no regular diurnal variation, some seasonal variation but no apparent sunspot cycle effect.

(b) The height can be anywhere between 75 km and 200 km, but mostly in the range 100 to 150 km: the thickness is typically 100 m to 1 km.

(c) Usually moves around in clouds with an electron density which varies horizontally.

(d) Can reflect frequencies up to 20 MHz at vertical incidence. There are large hour to hour changes in critical frequency and at times Es completely screens the F layer from the ground.

(e) Can be either a total or partial reflector and the top frequency is often equipment sensitive.

(f) Exists in various types, some latitude dependent, others appear only when the ionosphere is disturbed.

Es parameters - Definitions

Figure 1 shows an idealised ionogram. The following E and Es parameters are scaled from this:

fmin - minimum frequency of ordinary wave reflection.

foE - ordinary wave critical frequency of normal E
h'E - minimum virtual height of normal E
h'Es - minimum virtual height of Es

foEs - ordinary wave top frequency for a mainly continuous Es trace

fxEs - extraordinary wave top frequency for a mainly continuous Es trace

fbEs - Blanketing frequency of an Es layer: lowest ordinary wave frequency at which layer becomes transparent

Es types and number of multiple reflections

(Note fx - fo = fB/2 = 0.6 MHz for Slough).

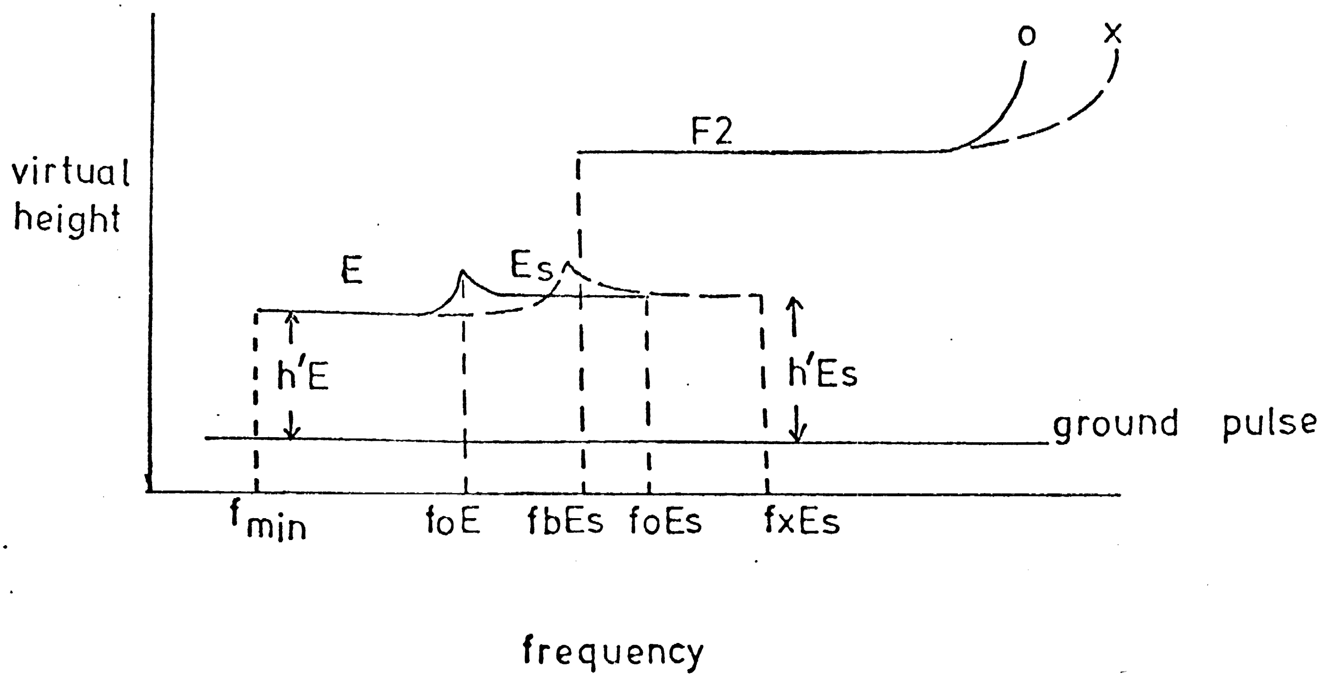


Figure 1: Es parameters scaled from an ionogram

Rules for deciding if top frequency ftEs is foEs or fxEs

It is often not possible to identify the top frequency because there is no discernible height separation of the two components. However the following criteria will cover most cases. For the remainder we use a set of rules too detailed for discussion here:

(a) Night. D and E layers have disappeared.
Hence little absorption. ftEs = fxEs

Two exceptions to this rule:

(i) Periods of high absorption

(ii) ftEs < fB + 0.3 MHz
In these cases ftEs = foEs

(b) Day. At the lower frequencies, the X-component is much more heavily absorbed than the O-component:

ftEs < 3.5 MHz	ftEs = foEs
ftEs = 3.5 - 5.0 MHz	ftEs either foEs or fxEs depending on fmin.
ftEs > 5.0 MHz	ftEs = fxEs

Definition of Es types (See Fig. 2)

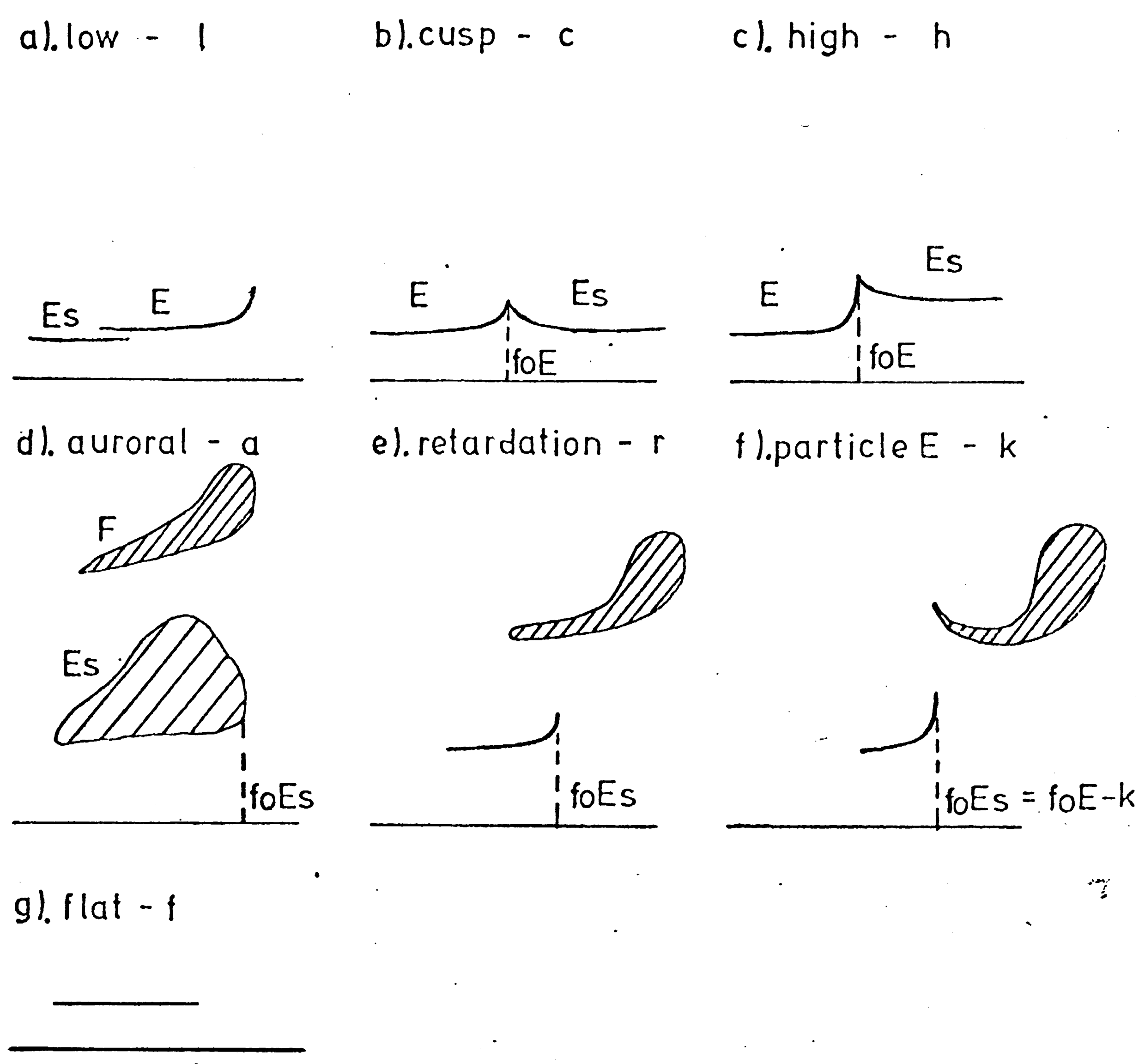


Figure 2 : Es types commonly observed on ionograms

There are 11 specific categories into which Es types are classified:

f - flat. Night; no increase in height with frequency; usually total reflector to foEs; often blankets F layer completely; worldwide distribution.

l - low. h'Es < h'E	)	Day; very common in Summer
c - cusp. h'Es > h'E but ≤ hmE	))	(May-Aug.); often blankets
h - high. h'Es > hmE	)	F layer; worldwide

(hmE - height of maximum electron density of normal E)

q - equatorial	Diffuse trace, often to high frequencies. Does not blanket E or F layer.
a - auroral	Spread trace often over large height range with sloping lower edge. Comprises oblique reflections so does not blanket. Associated with high magnetic activity.
r - retardation	An oblique discrete trace with a definite upturn at critical frequency. Does not produce retardation (downturn) at minimum frequency of F trace.
k - particle E	Resembles a thick normal E; blankets to foEs; is overhead equivalent of r type. Occurs mainly at night and until recently was called night E. Types a, r and k often appear together when magnetic activity is high. Is occasionally observed at Slough.
s - slant	Normally a weak trace; always oblique and height increases uniformly with frequency; appears to originate at foE or foEs.
d - D region	Partial reflection from D region at 75 - 90 km; occurs at times of very high absorption, usually in frequency range 1 - 2.5 MHz; is only trace visible during polar blackouts.
n -	any other type.

Es types are recorded in the following way: the first type relates to the layer giving foEs, fbEs and h'Es; it is followed by the total number of traces. Additional types are listed in order of number of multiples e.g. h1c2l (only five characters are permitted).

Finally, some Es features observed at Slough in recent years which warrant further study:

(a) Whenever low type Es blankets normal E, there appears to be a significant decrease in D region absorption as monitored by fmin.

(b) The number of times the F layer is completely blanketed by Es during the summer months varies irregularly from year to year. In 1976, for example, the occurrence rose sharply to levels more appropriate to those normally observed in the Mediterranean area.

(c) Es often produces many orders of reflection. By studying the amplitude of the higher orders (fourth upwards) over the ionogram frequency range, it should be possible to detect changes in the overall sensitivity of the ionosonde.

(d) During winter months (Nov. Dec. mainly) a very low Es at 95 km occasionally appears in the early afternoon. It gradually falls to 90 km and then returns to around 95 km before disappearing. The layer is seen for 3 - 4 hours and is a good reflector, often producing second and third-order echoes.

Combined Es and F reflections: M and N

M and N reflections occur when the Es is semi-transparent (Fig. 3). They appear on the ionogram between F and 2F. h'M = h'2F - h'Es; h'N = h'F + h'Es. Other combinations are possible such as N + F, M + Es, etc.

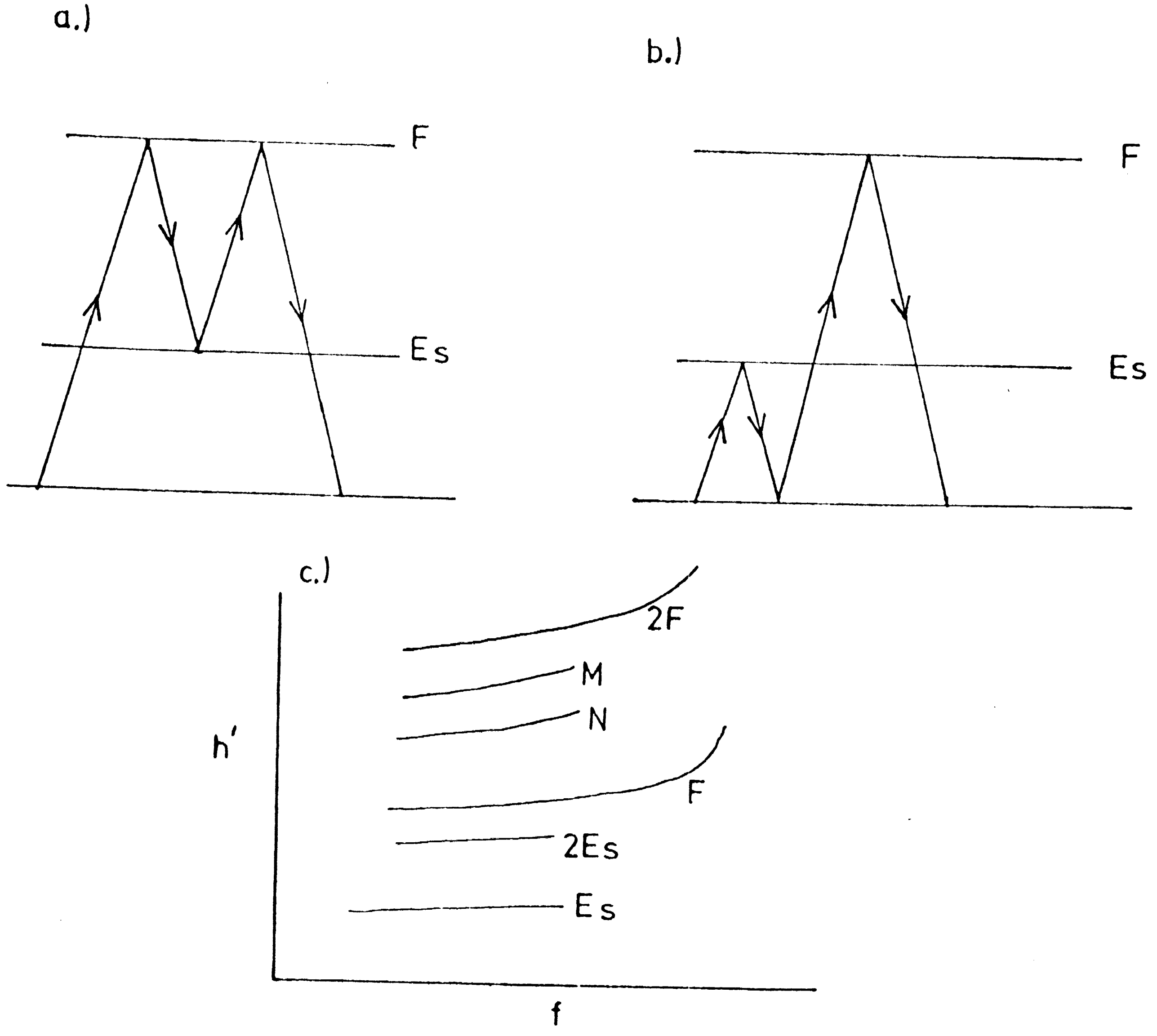


Figure 3: Multiple reflections from Es and F layers:

(a) an M mode;

(b) an N mode

and (c) the corresponding ionogram traces

2. Long-term modelling of Es parameters

(Dr. K. Hughes, Home Office)

The existence of Es is very important to ionospheric radiowave propagation, both in that it provides an extension to the range of usable frequencies and has the potential to increase the number of interfering signals; also it can severely attenuate signals propagated via regular layer modes. Hence knowledge of Es occurrence and behaviour is of great value in aiding more efficient spectrum utilisation. There is a need to be able to predict the incidence of Es at a given location, time-of-day and season. In addition, a reliable model is wanted by which Es propagation, including signal strengths, may be estimated. One such model recommended by the CCIR (1978) relies on a statistical relationship existing between received signal strength and the value of foEs at the mid-point of the propagation path. This model was developed from measurements made at VHF. Its use requires complementary predictions of foEs.

foEs Data

A significant contribution to foEs mapping was made by Leftin et al. (1968). They have provided world maps of lower decile, median and upper decile values of monthly distributions of foEs for all 12 months of both a solar-cycle maximum and solar-cycle minimum year : 1958 and 1954 respectively (Fig. 1). These are based on numerical techniques similar to those employed in the mapping of F2-layer parameters. The maps provide a valuable indication of the world-wide behaviour of Es and are a useful tool in ionospheric radiowave-propagation studies. For example, they permit the estimation of MUF(2000)Es, FOT(2000)Es, and the probability of propagation by Es at a given frequency, which is needed in evaluating the CCIR method. The foEs database upon which the CCIR method primarily depends was compiled by Smith (1978) with a principal contribution from ionosondes located in Europe, the Far East and the USA. For geographical areas not covered by this network the world maps of Leftin et al. (1968) were used. In addition Smith has employed the same data to compile maps indicating the percentages of time for which foEs exceeds certain frequencies (Fig. 2).

In order to determine the value of foEs exceeded for a given percentage of time, an interpolation method known as the Phillip's rule is generally used. This is based on the equation :

$$\log P = a + bf$$

where P is the probability of foEs > f, with f as the frequency. The constants a and b are given by the fit to the curves of Smith. In Fig. 3 lines are shown following the Phillip's rule and joining two values of time percentage at which foEs exceeds 7 and 10 MHz at different hours and seasons.

The Es transmission-loss data

Data on Es attenuation were derived in the main from EBU measurements of VHF television signals between 1962 and 1972. Twenty-three paths were monitored in the study and these covered a frequency range, f, from 41 to 58 MHz. Values of Es attenuation were estimated by comparing the received signal strength with the calculated free-space signal strength for each path. Data were then combined with values of foEs at the mid-point of the path (determined from Smith's maps) and attenuation curves compiled as a function of (f/foEs). The curves and those of foEs versus percentage of time are presented in the description of the CCIR prediction method. The procedure is therefore to find the appropriate value of foEs applicable to the time percentage of interest, divide this into the operating frequency and then use the attenuation curves to determine the attenuation of the Es signal relative to free space.

Shortcomings and other work

The above prediction model has been found of limited application. In particular it appears to underestimate Es losses at VHF above about 70 MHz. This is not too surprising as it is based on measurements around 50 MHz. Another area of possible error is that of the Phillip's rule not representing correctly the time distribution of foEs. Consideration of alternative laws is currently being undertaken; in fact the distribution possibly varies as a function of geomagnetic latitude. Close to the equator a linear variation of probability with frequency has been found best.

There is a need for (i) continued collection of basic sporadic E vertical-incidence data for modelling purposes with particular regard to times of occurrence, locations and solar-cycle dependence, and (ii) further measurements and monitoring of Es propagation, especially at frequencies around 100 MHz

References

CCIR (1978) : 'Method for calculating sporadic-E signal strength', Recommendation 534, Docs. of XIVth Plenary Assembly, Kyoto.

Smith, E. K. (1978) : 'Temperate zone sporadic-E maps (foEs > 7 MHz)', Radio Sci. 13, 3, pp 571-5.

Leftin, M., Ostrow, S. M. and Preston, C. (1968) : 'Numerical maps of foEs for solar cycle minimum and maximum', ESSA Technical Report ERL 73-ITS 63.

Figure 1(a)

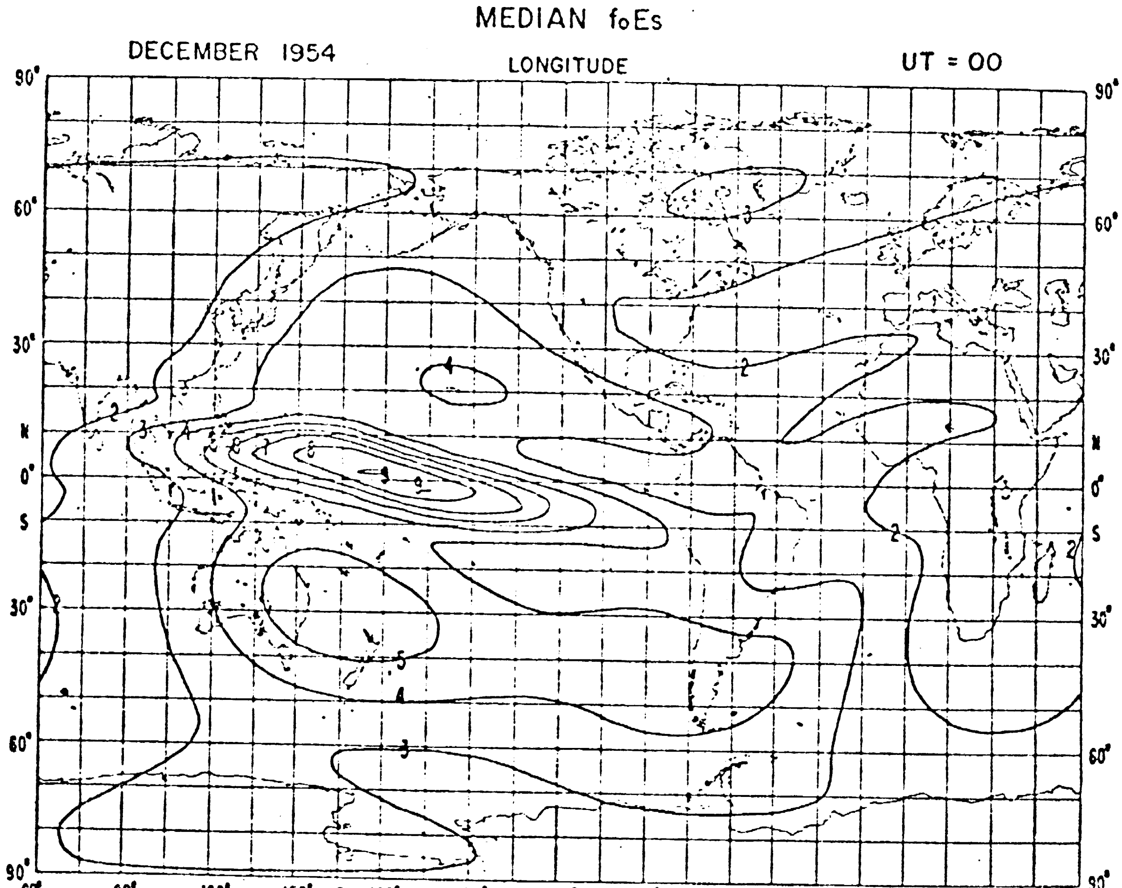


Figure 1. Examples of the foEs maps by Leftin et al. (1968)

(a) Median values for 00 UT, December 1954;

(b) Lower decile values for 06 UT, June 1954

and (c) Upper decile values for 18 UT, March 1954

Figure 1(b)

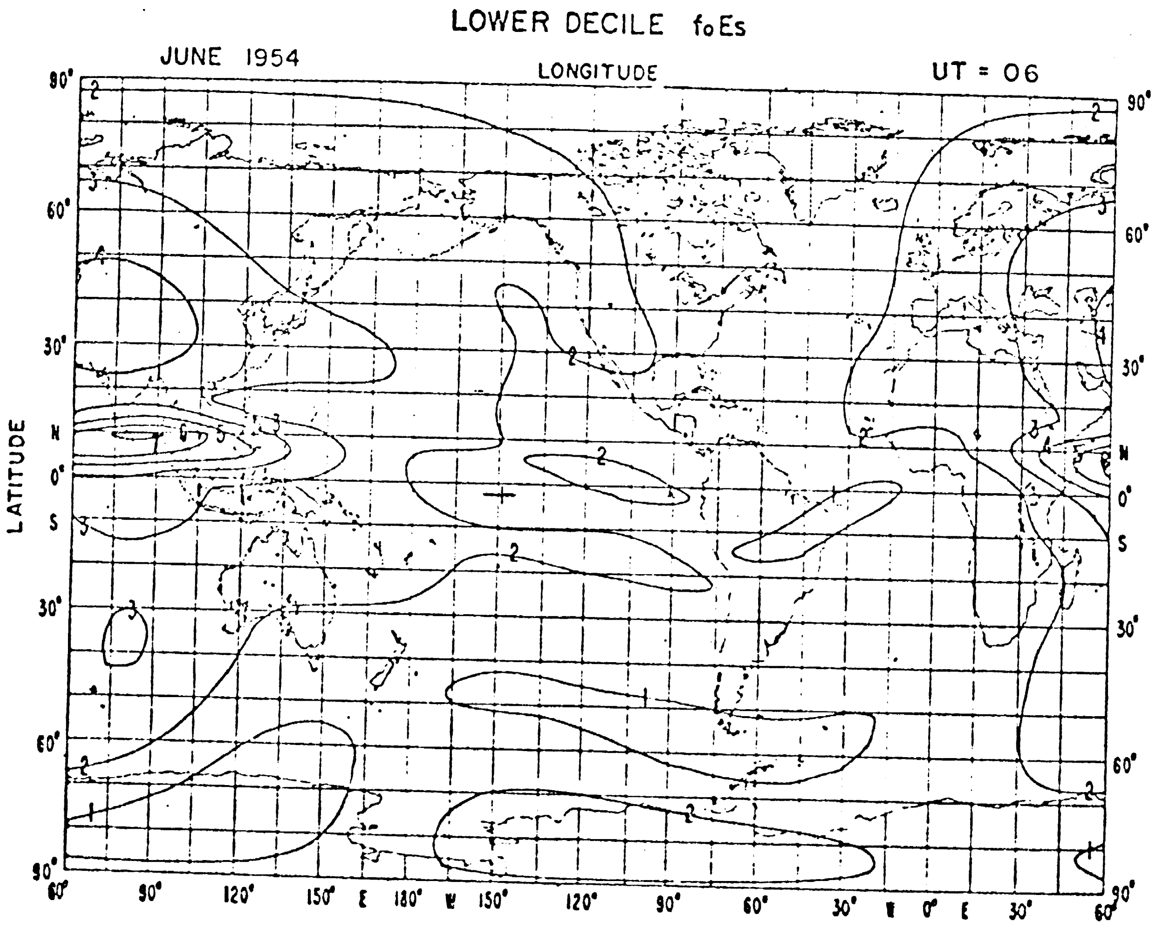
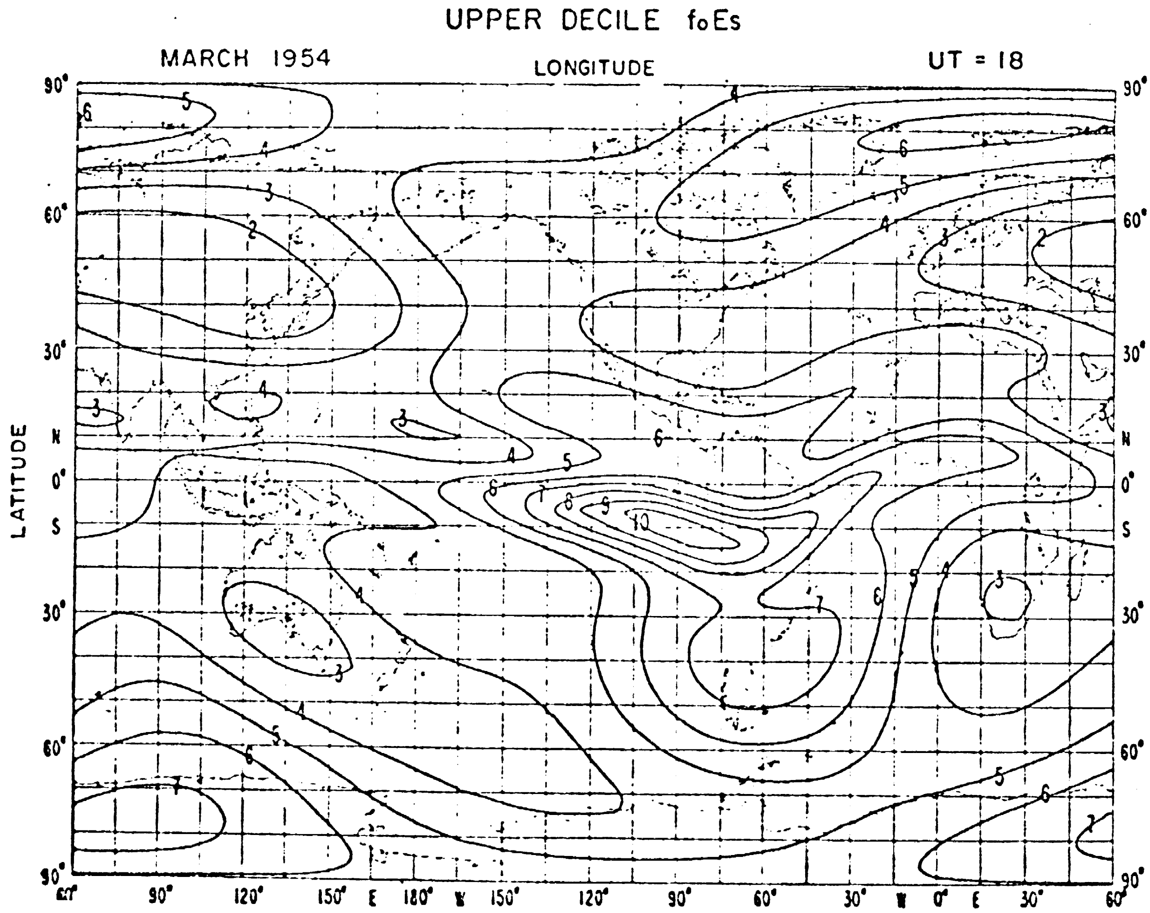

LOWER DECILE foEs
JUNE 1954
LONGITUDE
UT = 06
LATITUDE
90°
60°
30°
N
0°
S
30°
60°
90°
60°
90°
120°
150°
E
180°
W
150°
120°
90°
60°
30°
W
0°
E
30°
60°

Figure 1(c)


UPPER DECILE foEs
MARCH 1954
LONGITUDE
UT = 18
LATITUDE
90°
60°
30°
N
0°
S
30°
60°
90°
60°
90°
120°
150°
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180°
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0°
E
30°
60°

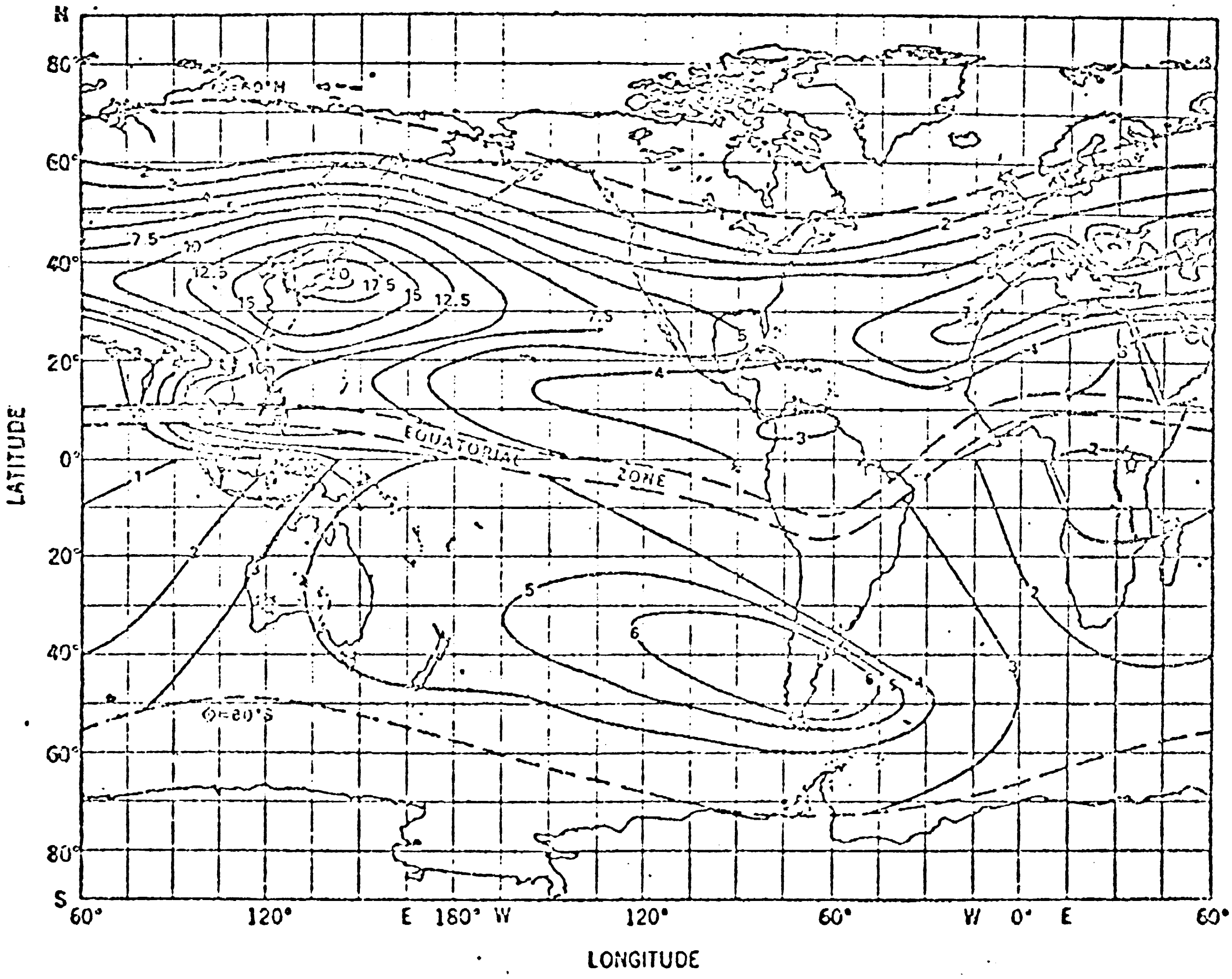

Figure 2. Map of percentages of time for which foEs exceeds 7 MHz for summer conditions by Smith (1978).

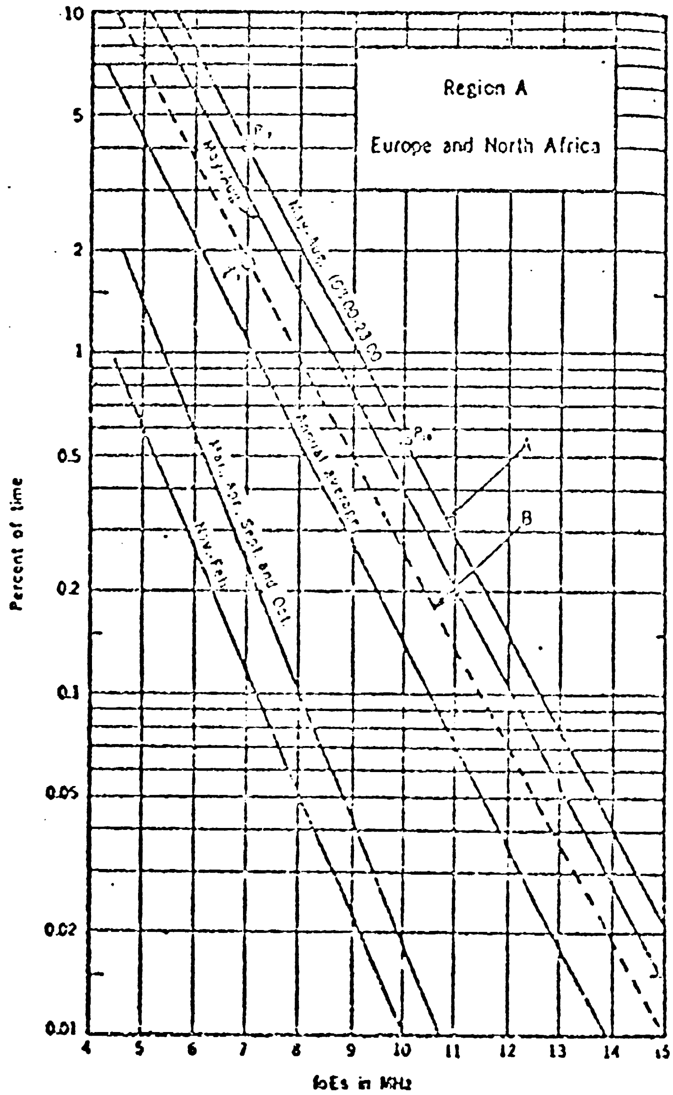

Figure 3. Values of foEs equalled or exceeded for indicated percentages of time for Europe and North Africa. (CCIR, 1978).

3. Use of backscatter sounding in Es studies

(Professor E. D. R. Shearman, University of Birmingham)

The pulsed backscatter radar technique permits studies of the geographical distribution of Es. Signals reflected by a sporadic-E cloud illuminate a limited area of the Earth's surface and are returned to the radar receiver by ground backscatter and subsequent propagation via the reciprocal path. Antenna beam steering gives the cloud bearing and azimuthal extent; the group delay yields its slant range. A film made using a 17 MHz radar at Slough, with a 60° beam rotating antenna, shows Es clouds forming, moving and dissipating. One frame of the film, with a large cloud to the south-west of the sounder, is reproduced in Fig. 1.

A similar type of sounder at Stanford University, developed for the IGY, operated at 12, 18 and 32 MHz and thus gave estimates of cloud densities as well as of their spatial extent, (Clark and Petersen, 1956; Petersen et al., 1959.) Observations of Es clouds were more common for certain bearings, implying that the differing ground-scattering properties of the surrounding terrain were affecting the derived spatial distribution, due to insufficient transmitter power. Furthermore this bias was different at each of the three sounding frequencies because of the dependence of the scattering cross-section on signal frequency. Results from backscatter radars to the Stanford design in both the northern and southern hemispheres have revealed a predominant westwards cloud motion. Velocities were of the order of 200 km/hr and were greater than and were uncorrelated with wind speeds as deduced by drift observations.

In the Slough experiments, carried out with higher power and shorter pulses, no such geographical bias was seen. At Slough there was little seasonal variation of slant range to the ground-scattering region (Fig. 2). Figure 3 shows the relative occurrence of various ground slant ranges for different signal frequencies at 13 UT in August 1952. At this time a signal frequency in excess of 15 MHz is required in order to achieve modal resolution of the Es and F2 modes. The mean dimensions of clouds were of the order of 150 km (Fig. 4); the mean duration was about $1\frac{3}{4}$ hours (Fig. 5). Cloud incidence is less than that of Es traces seen on vertical-incidence ionograms. This difference can be attributed either to the presence of very small patches since the received backscatter power decreases as the illuminated ground area decreases, or to blobby or partially-reflecting clouds which scatter the incident signals or cause these to penetrate. The radar is at a disadvantage for the same transmitter power due to the losses in the ground backscatter process; hence there may be small clouds visible on ionograms that remain undetected by the backscatter radar. Losses due to partial reflections at the cloud are doubled in backscatter and can give rise to similar effects. However clouds observed by backscatter can always be seen by a suitably positioned ionosonde.

The interpretation of the motions of Es clouds observed by backscatter is complicated when the cloud approaches the skip zone of the radar. This alters the apparent cloud shape and moves its centroid, leading to a false drift component. Very small clouds disappear completely as they approach the sounder, medium-sized clouds appear to drift around the sounder to one side, and clouds which are large anough seem to split into two, the two halves moving around opposite sides of the sounder in a near-circular path. This third effect is illustrated in Fig. 6. At Slough it was found that motions were predominantly south-westerly (Fig. 7).

In order to obtain higher angular resolution it is necessary to reduce the beamwidth of the radar antenna. This can be done employing large antenna arrays. Such systems are, however, very costly and a cheaper alternative is to adopt synthetic aperture techniques. (Shearman et al., 1973).

A 32 MHz radar built at Defford has been employed to observe sporadic-E with an interferometric version of synthetic-aperture radar. One antenna is fixed while the other is mounted on a railway carriage and moved up and down a 300 m line. Observations at five-minute intervals and with an azimuthal resolution at broadside of 2^{o} were used to produce a film of Es morphology over the European continent. Examples of results obtained are given in Fig. 8 (a.b and c). Even between frames the cloud positions and densities were greatly changed. There are some problems with SAR techniques when signals are backscattered by a sea surface. The Doppler shift imparted to the signals by surface waves then affects the observed bearing and clouds are split into two images. The Doppler shifts due to wave motion are considerably greater than those imparted by vehicle motion and it should be relatively easy to filter these out.

References

Clark, C and Petersen, A. M. (1956) : 'Motion of sporadic-E patches determined from high-frequency backscatter records', Nature, 178, pp 486-487.

Harwood, J. (1961) : 'Some observations of the occurrence and movement of sporadic-E ionisation', J. Atmos. Terr. Phys., 20, pp. 243-262.

Petersen, A. M., Egan, R. D. and Pratt, D. S. (1959) : 'The IGY three-frequency backscatter sounder', Proc. I.R.E., 47, pp. 300-314.

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Shearman, E. D. R., Fotiades, L. and Bagwell, D. J. (1974) : 'Sequence of maps from ionospheric backscatter aperture synthesis radar', University of Birmingham, June 1974.

Shearman, E. D. R. and Harwood, J. (1960) : 'Sporadic-E as observed by backscatter techniques in United Kingdom', J. Atmos. Terr. Phys., 18, pp. 29-42.

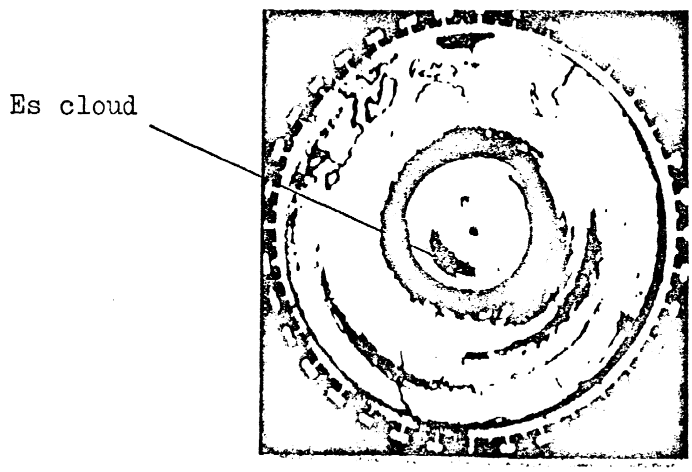
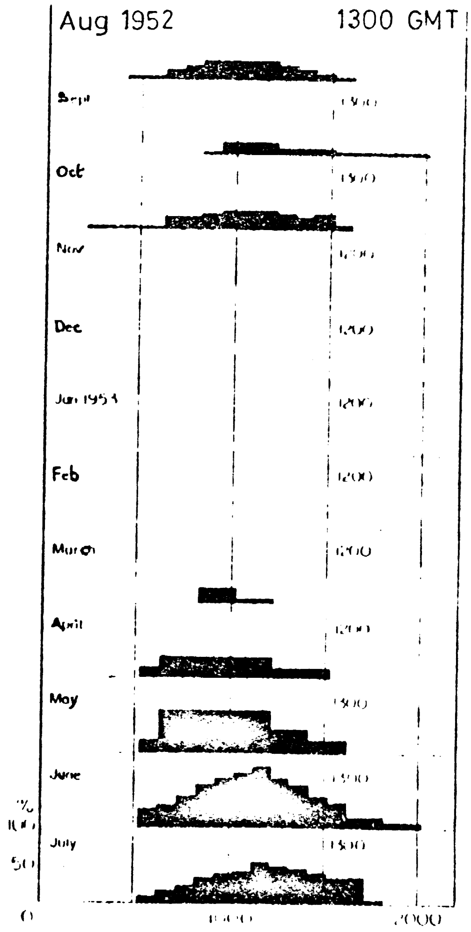


Figure 1. Plan Position Indicator display of areas of ionospheric reflection observed by the Slough backscatter radar (Shearman and Harwood, 1960)



Slant Range, km

Figure 2. Percentage of occasions ground scatter was observed as a function of range for various months at 21 MHz in the direction 80°E of N from Slough (Shearman and Harwood, 1960)

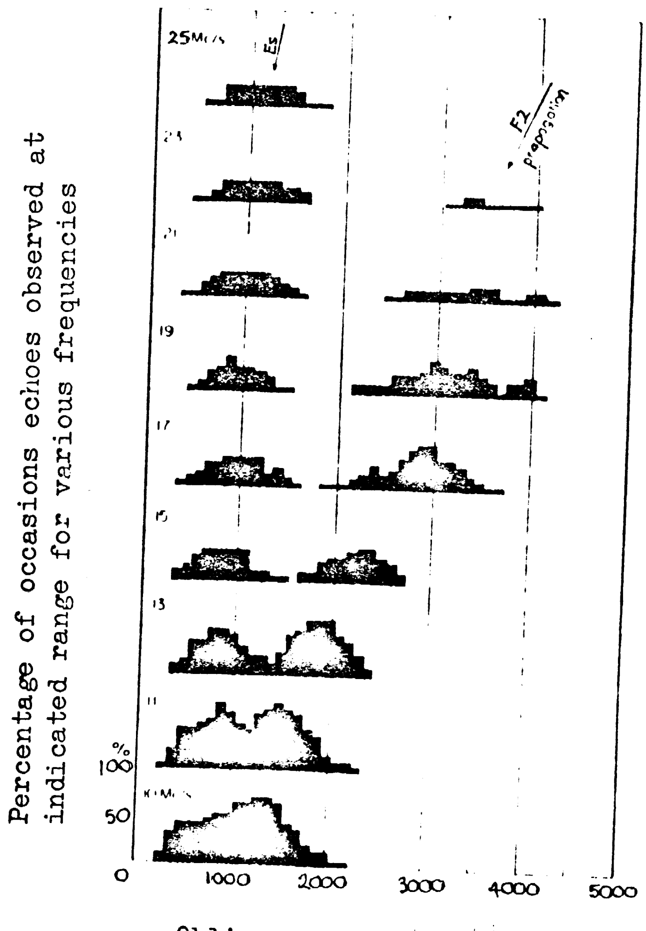


Figure 3. Variation of occurrence of ground scatter with transmitter frequency, 1300 UT, August 1952 (Shearman and Harwood, 1960)

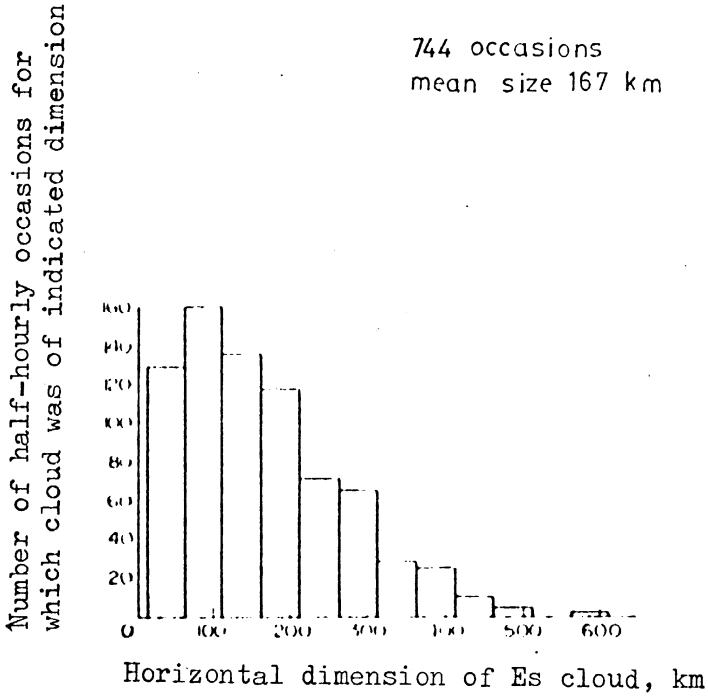


Figure 4. Distribution of Es cloud dimensions observed by Shearman and Harwood (1960)

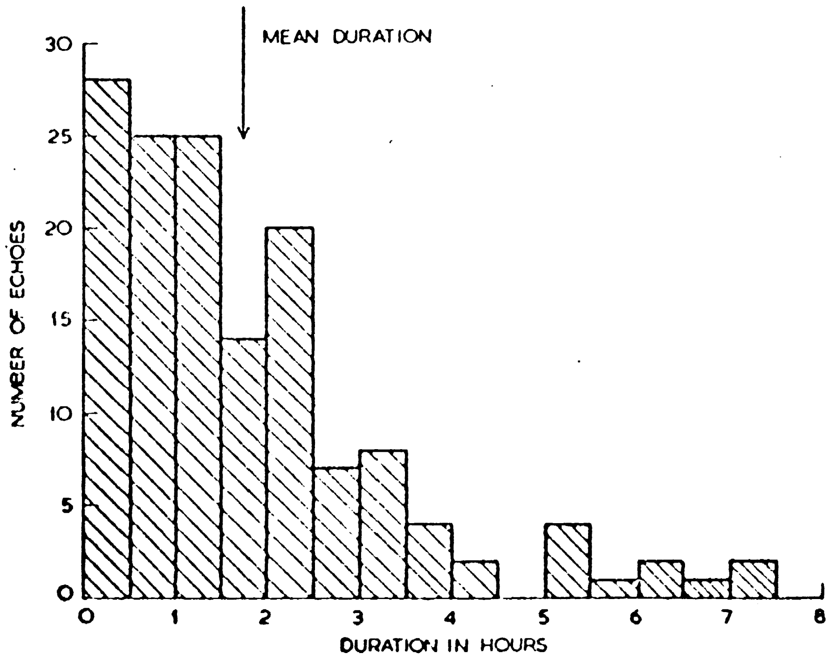
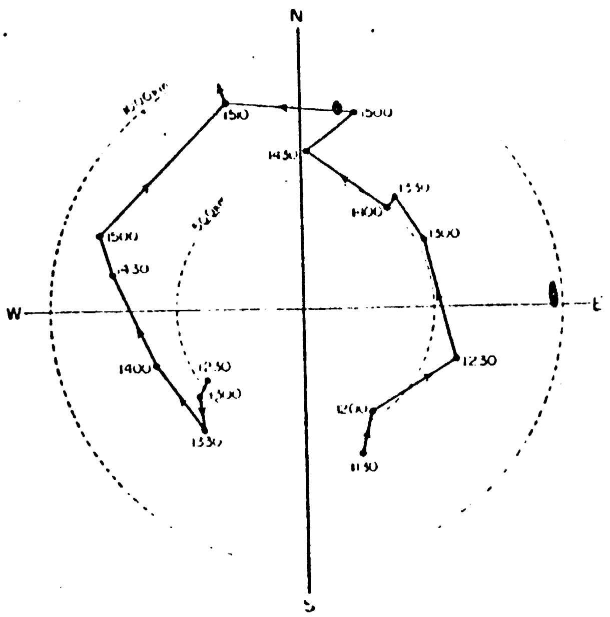


Figure 5. Distribution of Es echo durations observed by Harwood (1961)



(a)

(b)

Figure 6. (a) Apparent motion of Es clouds observed at Slough on 19 May 1958 by Shearman and Harwood (1960)

(b) Shape and motion of Es cloud deduced from (a)

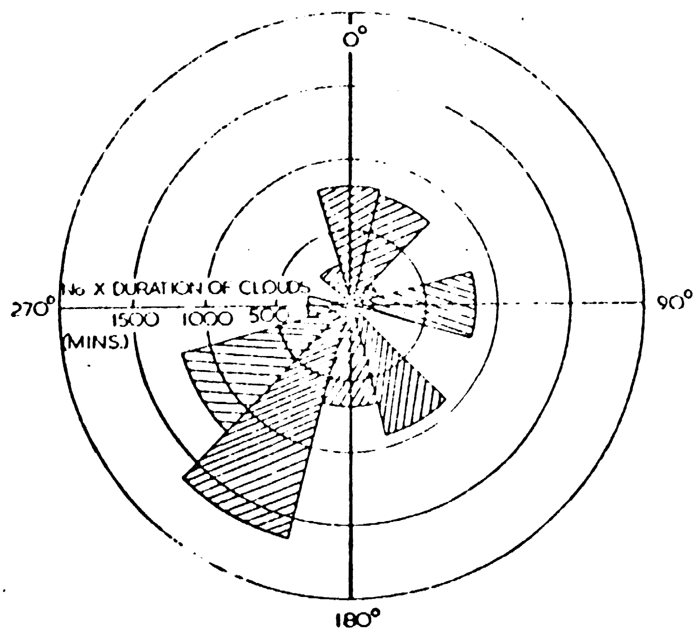


Figure 7. Distribution of cloud movements observed at Slough by Harwood (1961)

Figure 8. Sequence of Es cloud observations by synthetic-aperture backscatter radar on 25 July 1973: (a) 10:02 UT; (b) 10:08 UT and (c) 10:15 UT. Contours show the locations of Es irregularities and are plotted as a function of ground range and azimuth from the radar.

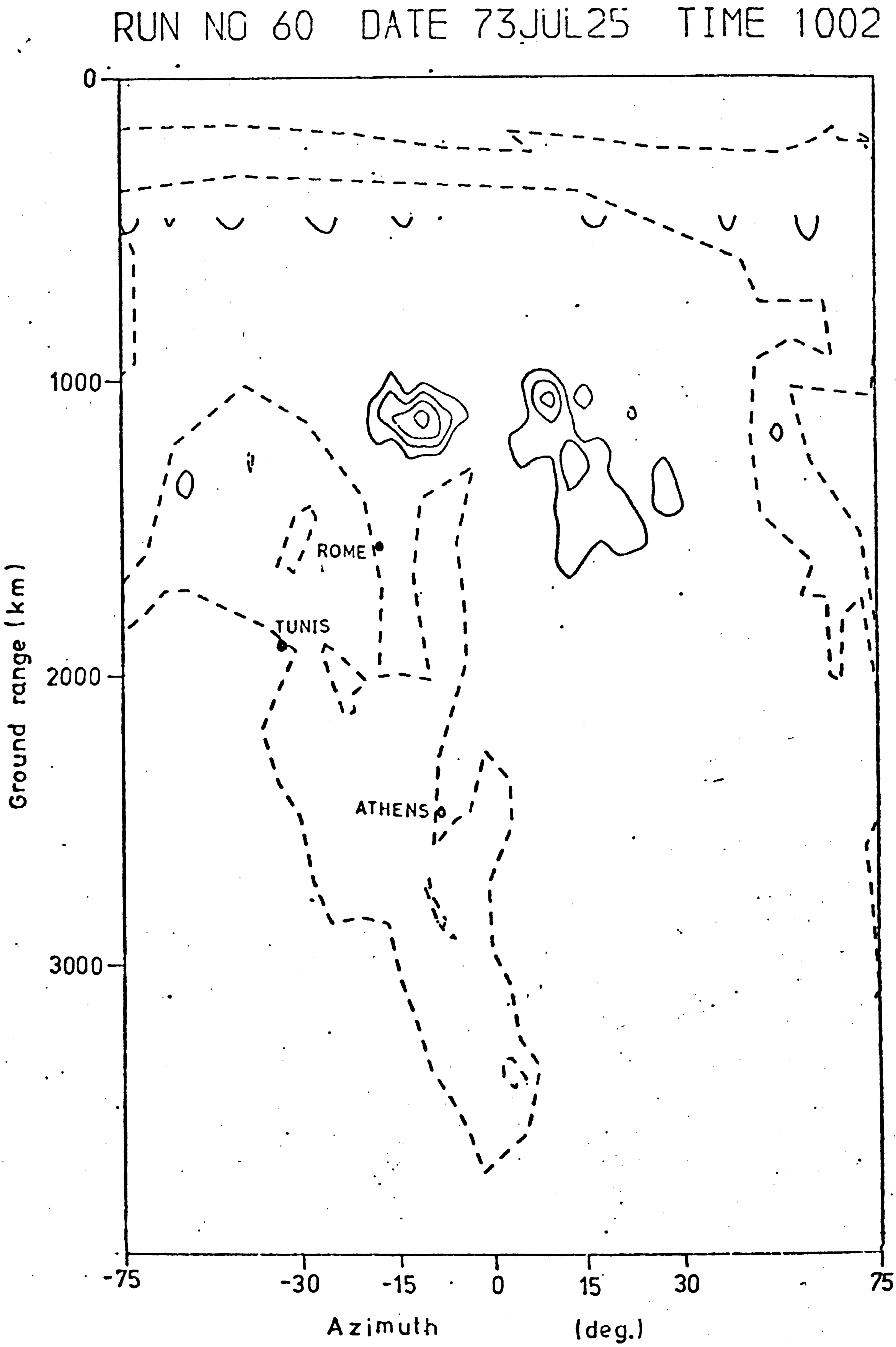


Figure 8(a)

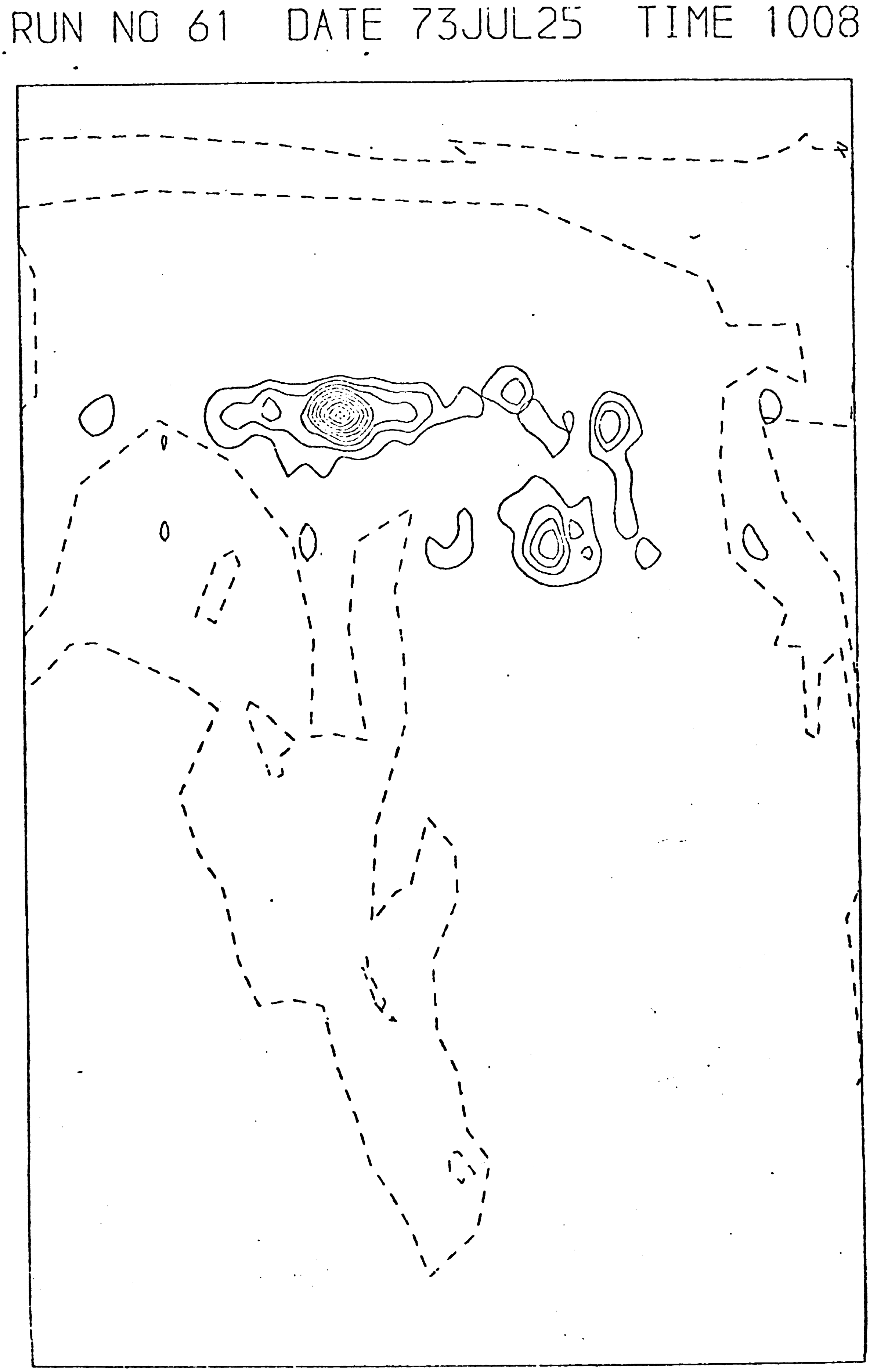


Figure 8b.

RUN NO 62 DATE 73JUL25 TIME 1015

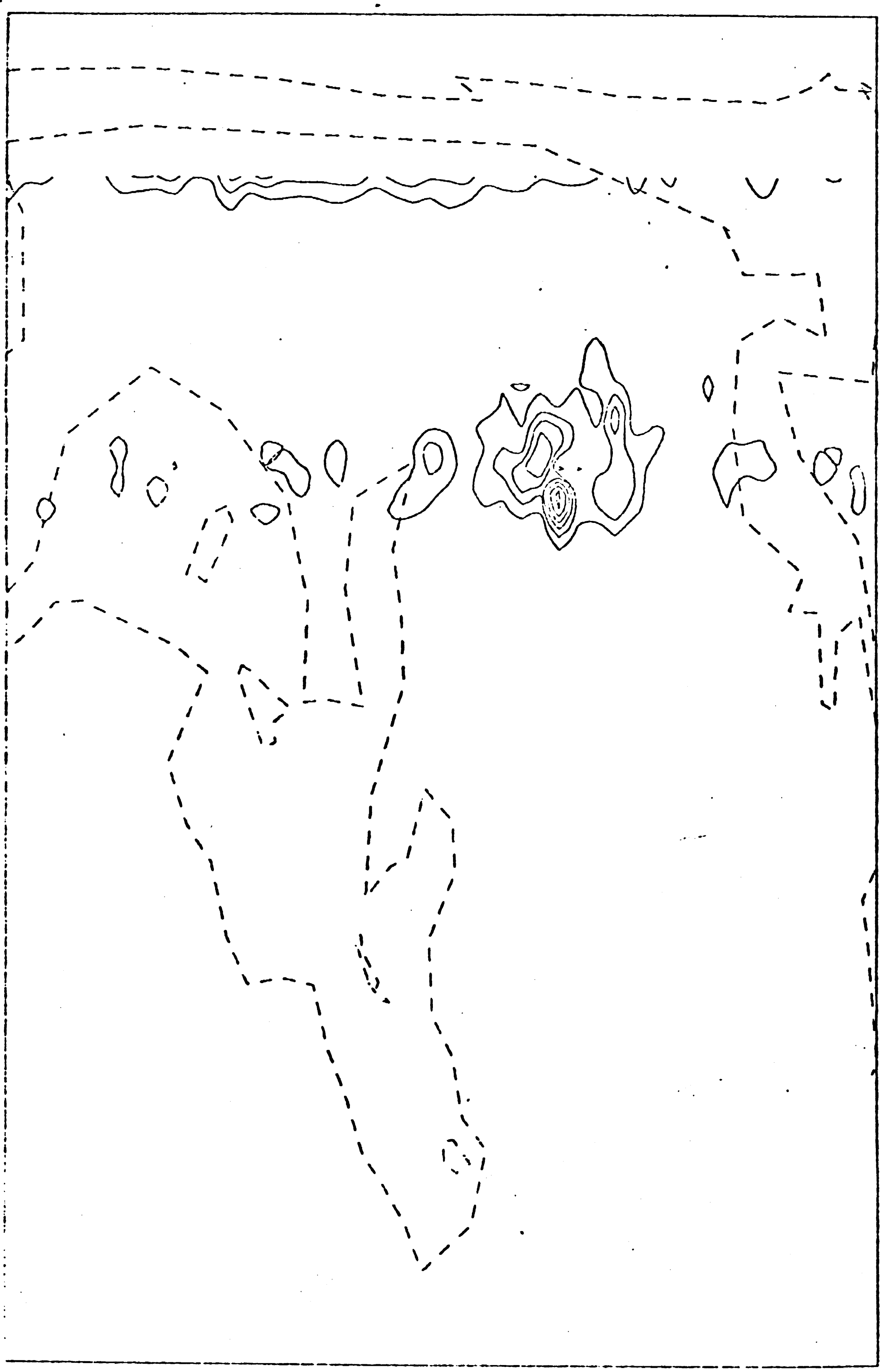


Figure 8c

4. Differences between high, middle and low-latitude sporadic E

(Dr. W.R. Piggott, Chairman, Ionospheric Network Advisory Group)

A major problem with mapping sporadic E is that the results are very dependent on the methods of observation and compilation employed. Mapping requires consistently acquired data to be processed in a uniform manner, with due allowance for the effects of cloud motions and the variety of types of Es observed.

In the past, maps have generally been based on observations made at the limited number of stations where a high-sensitivity ionosonde has been in use. Data from such stations have been given greater credibility and other data used only when these are found to be consistent. In practice not only do values of foEs and fbEs depend on the sensitivity of the sounder, but also different ionosondes tend to detect different types of Es. High sensitivity sounders require high differentiation of the receiver output signal. This prevents saturation of the photographic record when the signal frequency is swept through congested parts of the spectrum but leads to a failure to discriminate between different Es types. The variations of foEs and fbEs for various Es types are shown in Fig. 1 as a function of ionosonde sensitivity. With high differentiation the meteoric and cloud types of Es cannot be distinguished apart; thus there is a tendency to conclude that foEs varies with the ionosonde according to the dashed curve. Hence it is wrongly assumed that some ionosondes observe larger values of foEs and fbEs by virtue of their higher sensitivity whereas in reality a different type of Es is often being recorded. For this reason the Slough ionosonde tends to look at meteoric Es, whereas American sounders are biased towards dense and cloud types. The failure to allow for the effects of ionosonde sensitivity and differentiation is one of the major shortcomings of IGY data on Es, and of attempts to map Es morphology.

For oblique HF propagation, Es effects are best characterised in terms of (foEs - foE) because an Es layer is superimposed onto a normal E-layer background. In general, obscuration and blanketing effects are more important than Es-supported modes, for which elevation angles and antenna gains tend to be low. In converting vertical-incidence observations of radiowave absorption into predictions of field strengths for propagation over oblique paths, allowance should be made for obscuration by Es.

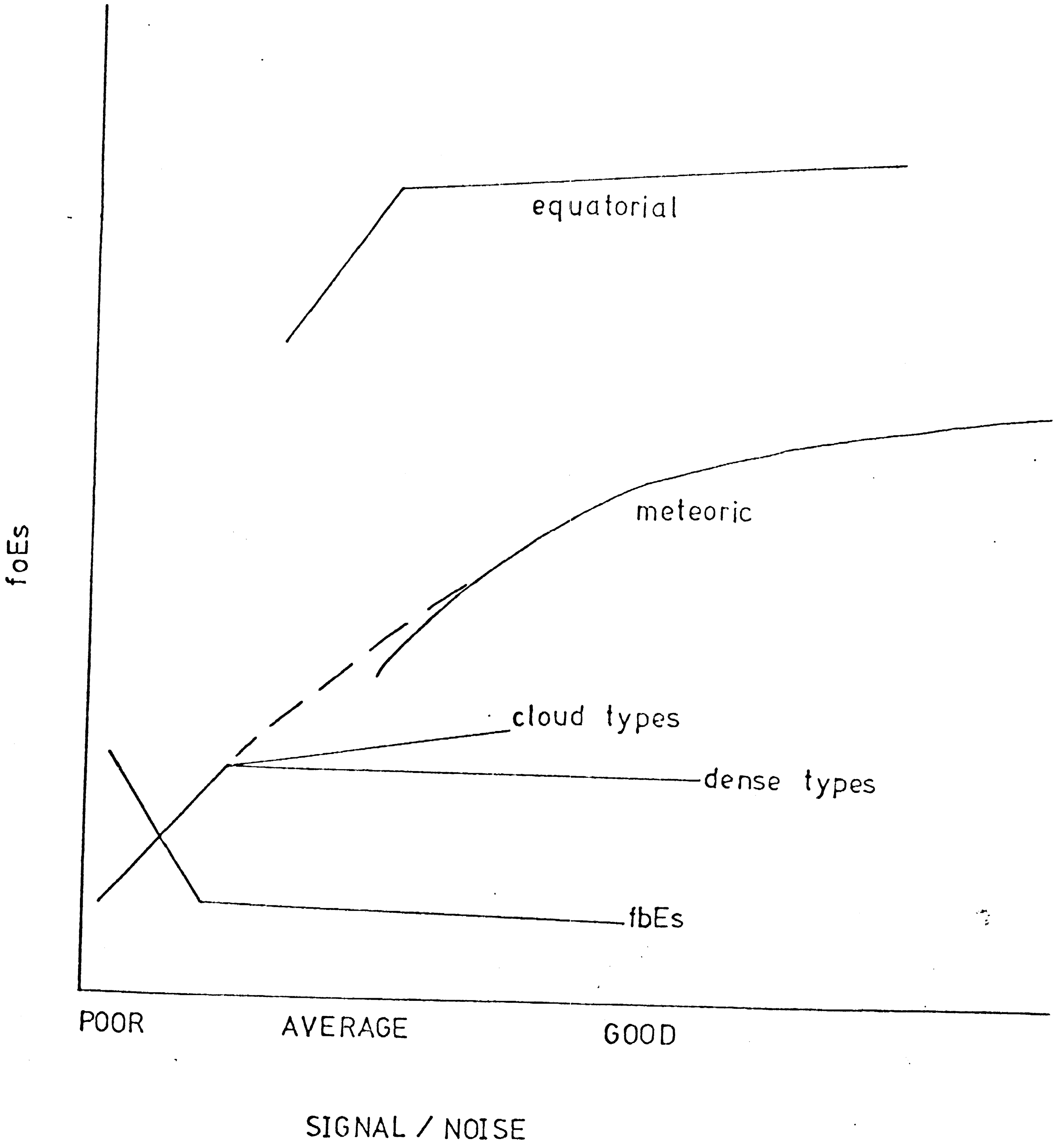


Figure 1. Dependence of foEs on signal to noise ratio for various Es types.

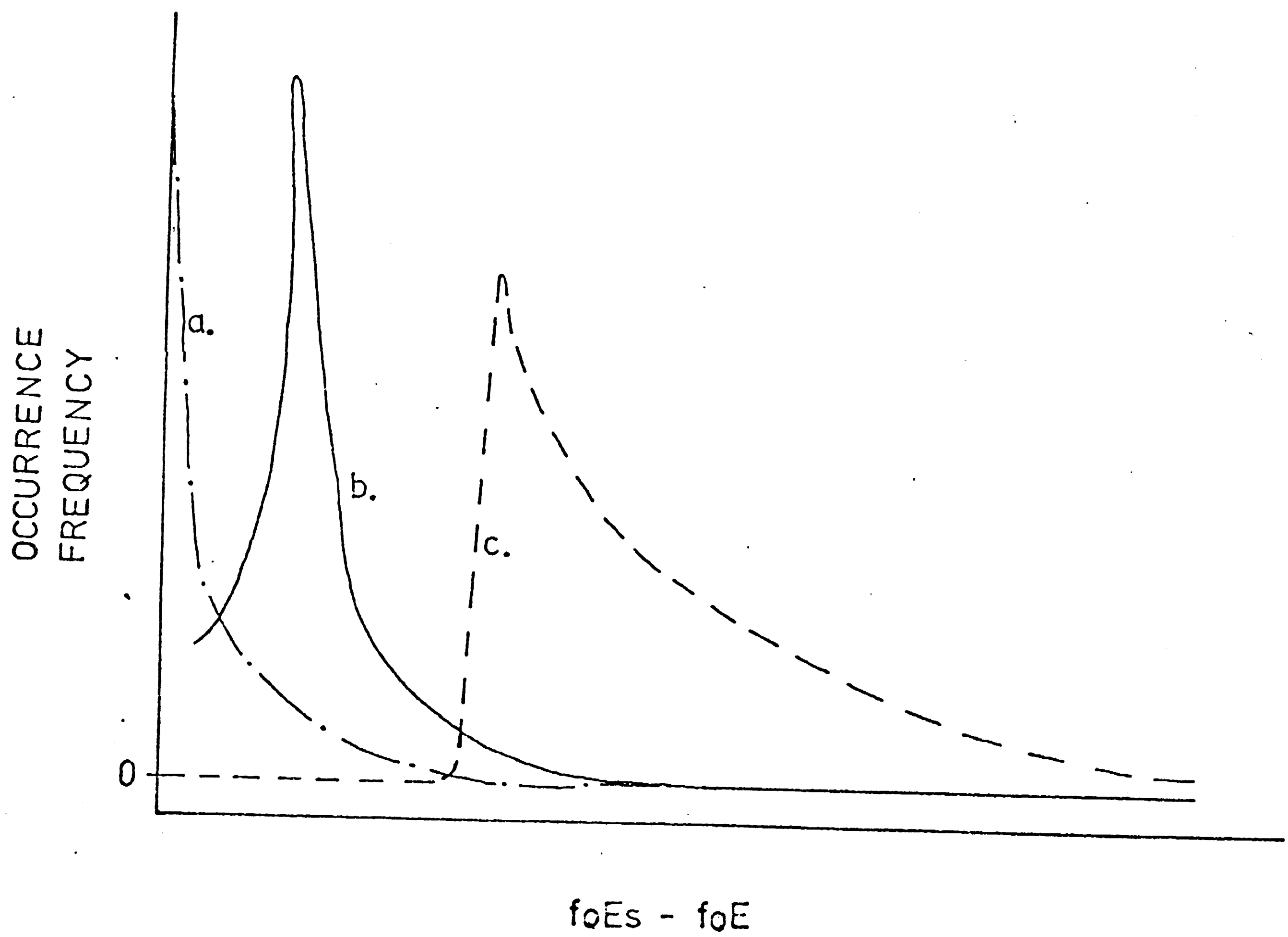


Figure 2. Occurrence frequency as a function of (foEs - foE) for

(a) night;

(b) winter day

and (c) summer day

Figure 2 shows the overall occurrence frequency of Es oblique-path modes as a function of the (foEs - foE) for night-time, daytime winter and daytime in summer. It can be seen that in all three cases the occurrence falls for large (foEs - foE). However, for daytime conditions there is a peak in the distribution, and this arises at a higher (foEs - foE) in summer than in winter. The mean values of (foEs - foE) show a strong seasonal variation, rising very rapidly in mid-May in both hemispheres. The solar-cycle variation at mid-latitudes is complicated by the presence of two major types of Es. The occurrence frequency of temperate-latitute Es decreases with increase of latitude in the region equatorward of the auroral oval, whereas auroral Es becomes more common. The latitude of transition from predominant temperate to predominant auroral Es types moves equatorward at times of increased magnetic activity with the general expansion of the auroral oval. Hence the relative amounts of these two types of Es in mid-latitudes varies during a solar cycle.

Storm Es duration is limited to a few hours. There are longitude effects which are more marked in rate of occurrence than in cloud densities. At high latitudes, storm Es can be of great value to communicators and should be exploited whenever it is available.

5. Current methods of prediction of Es reflection and obscuration losses at HF

(Mr. P.A. Bradley, Rutherford and Appleton Laboratories)

Many standard methods for estimating HF sky-wave field strengths ignore sporadic-E effects. The simplest approach to including an allowance is to define an Es-MUF and to incorporate propagation modes involving unattenuated transmission at higher frequencies and perfect reflection at lower frequencies. The Es-MUF is given in terms of the midpath foEs by an obliquity factor sec i_{110} appropriate to mirror reflection from a height of 110 km (see Fig. 1).

There are a number of more sophisticated treatments (Table 1) leading to finite reflection and obscuration loss estimates. Procedures have been devised either from simple theory together with empirical factors (Lloyd, 1975; Phillips, 1963) or from oblique-path signal strength measurements (Miya et al., 1978; Sinno et al., 1976).

Figure 2 gives reflection loss L_r at oblique-wave frequency f as a function of ground range for single and two-hop paths and for a selection of f/foEs, where foEs is the midpath value. These curves were produced mainly from EBU field-strength data at 40 - 60 MHz collected over path lengths of 1000 - 2500 km, and have been adopted for use by the CCIR at VHF (CCIR, 1978a). To determine the monthly median loss, use is made of the monthly median foEs; other percentile values of the day-to-day loss variability are given from the corresponding foEs percentiles. The curves are interpreted as incorporating mean allowances for absorption, polarisation-coupling loss and raypath focusing. They are also used in the latest CCIR field-strength prediction procedure for HF at frequencies above the MUF of all regular-layer modes which involve refraction alone (CCIR, 1978b).

Phillips (1963) has suggested, as also described by Wheeler (1966), that sporadic-E losses can be related to the probability of mode support given from the spatial variability of foEs. The spatial variability is assumed to have the same standard deviation as that of the day-to-day changes. Further, the so-called Phillips law has been formulated, whereby probability of Es-layer reflection P is taken as being related logarithmically to foEs. Table 2 gives a formula for obscuration loss L_q, where the empirical factor m is to be interpreted as a mean allowance to compensate for using foEs instead of fbEs. Figure 3 (a) shows L_q as a function of $x = \frac{f}{\text{foEs} \cdot \sec i_{110}}$. Note that the loss never exceeds 10 dB, even at the lowest frequencies. This is not borne out in practice.

Lloyd (1975) has followed a similar approach leading to equations for obscuration (L_q) and reflection (L_r) losses used in the latest ITS Boulder prediction procedure, IONCAP (Lloyd et al. 1978) - see Table 3. Here, probability of support is assumed to be given from foEs following two half-Gaussian distributions in terms of mapped median, upper and lower decile values (Leftin et al., 1968). The factor m of Phillips is eliminated and this leads to much greater obscuration losses at the lower frequencies as seen from Fig. 3(b), where curves for F_ℓ = lower decile/median foEs of 0.8 and 0.5 are presented. The equations give L_q = 3 dB for x = 1. Figure 4 (b) compares values of reflection loss from the Lloyd equation for selected values of F_u = upper decile/median foEs with estimates from other methods. The lower limit loss of 8.9 dB is consistent with the excess system-loss concept of Laitinen and Haydon (1950). The factor of 0.7 in the expression was derived empirically and leads to L_r = 13.2 dB at x = 1.

Extensive measurement programmes aimed at studying Es losses have been undertaken in Japan (Sinno et al., 1976). Signals from the standard-time transmitter JJY in Tokyo at 2.5, 5 and 10 MHz were received at Akita (range 450 km) and Wakkanai (1090 km) at the same times as foEs was monitored at the midpath (Fig. 5). By night, good correlation was found between oblique-path signal strength and simultaneous values of foEs (Fig. 6). Analysis of these types of data lead to the equations of Table 4 for L_q and L_r. Note that with R as the amplitude-reflection coefficient, these are consistent with the reflection loss being proportional to R^2 and the incident power being the sum of that transmitted and reflected.

Figure 7 shows that the Sinno equations explain nicely why foEs and fbEs differ on ionograms. At x = 1 they give L_r = 20 dB and for this example fbEs occurs at a frequency corresponding to L_q = 7 dB. We have $L_q = L_r$ = 3 dB for x = 0.67. Ionograms with different fbEs/foEs could be simulated using different values of the parameter n.

Comparison of the Sinno equations with other published Japanese field-strength data at VHF, mainly associated with reception of Okinawa 50 MHz transmissions at 4 sites over ranges of 1000 - 2000 km leads to the values of L_r at x = 1 given in Table 5. No positive conclusions are drawn but Sinno suggests that further work may show his procedure to be capable of development, perhaps by finding some dependence of the parameter n on wave frequency and fbEs/foEs.

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Table 1. Available expressions for Es reflection and obscuration losses

	Reflection	Obscuration
Semi-empirical	Lloyd (1975)	Phillips (1963) Lloyd (1975)
Measurements	Miya et al. (1978) Sinno et al. (1976)	Sinno et al (1976)

Table 2. Obscuration loss relationship of Phillips/Wheeler

$$L_q = -10 \log_{10} (1 - mP) \text{ , dB}$$

with m = 0.9 daytime

0.7 night

$$\log P = bz + K$$

with z = normalised frequency $\dfrac{f - f_m}{\sigma}$

where f_m = median foEs . sec i_{110}

σ = standard deviation

Table 3. Obscuration and reflection-loss relationships of Lloyd

$$L_q = -10 \log_{10} (1 - P) \text{, dB}$$

where P is given in terms of $\dfrac{f}{\text{foEs . sec } i_{110}}$ with foEs varying Gaussian in terms of mapped median, upper and lower decile values

$$L_r = 8.9 - 10 \log_{10} 0.7 P \text{, dB.}$$

Table 4. Obscuration and reflection-loss relationships of Sinno et al.

$$L_q = -10 \log_{10} (1 - R^2) \text{ , dB}$$

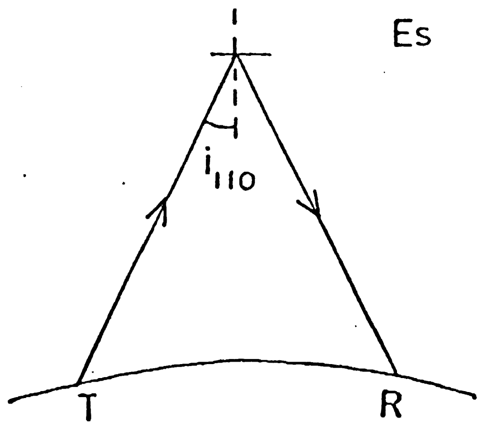
$$L_r = -20 \log_{10} R \text{ , dB}$$

$$R = \frac{1}{1 + 10x^n} \quad \text{with } n = 8$$

$$\text{where } x = \frac{f}{\text{foEs . sec } i_{110}}$$

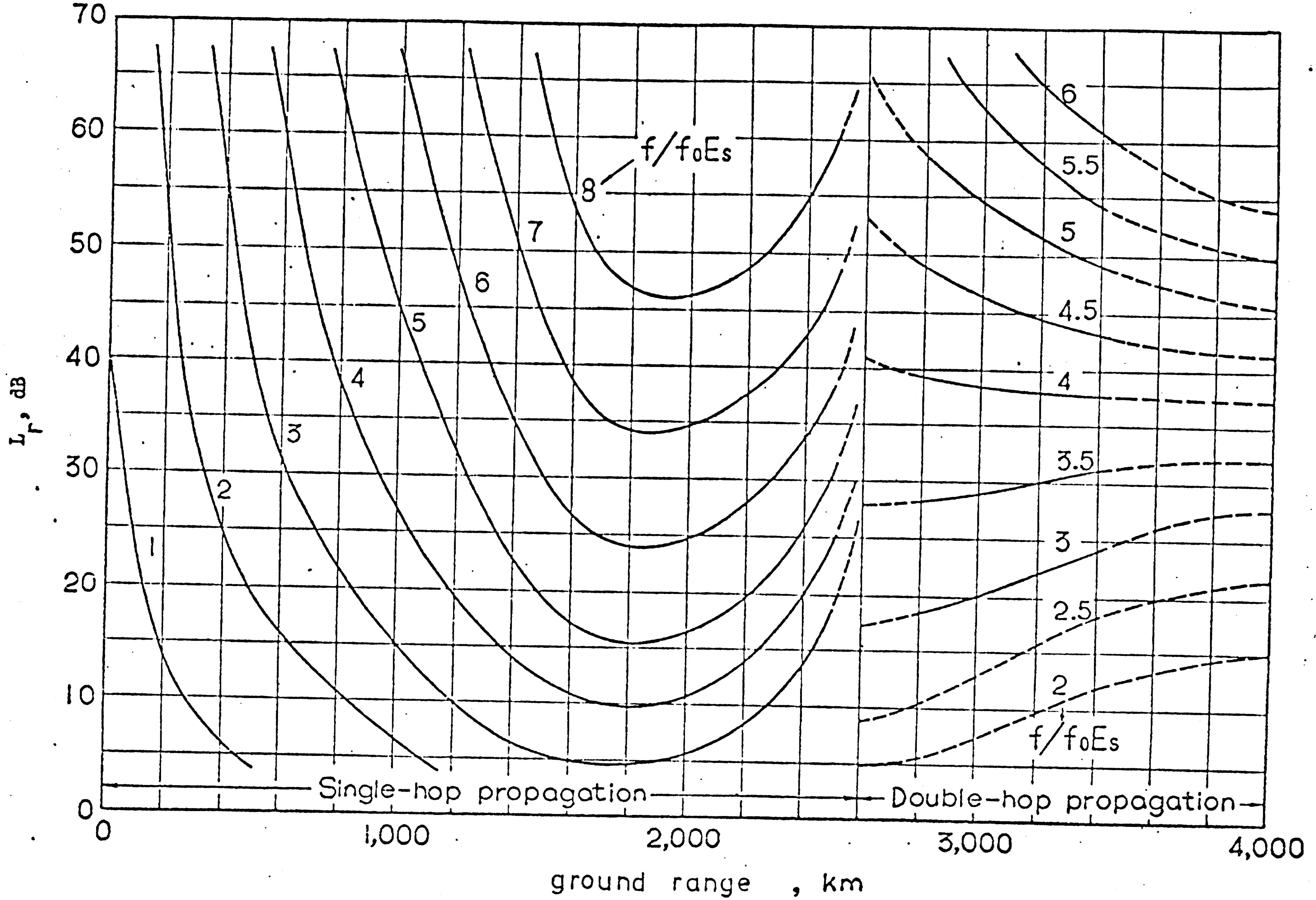
Table 5. Reflection losses given by Japanese measurements

		L_r for x = 1 (dB)
VHF	Kono	10 - 20
	Kobayashi	25
	Miya	20 - 30
	Davis	30 - 40
HF	Sinno (day)	8 - 15
	Sinno (night)	20 - 100



$$\text{Es-MUF} = \text{foEs} \cdot \sec i_{110}$$

<u>Figure 1.</u> Relationship between Es-MUF and midpath foEs



<u>Figure 2.</u> Reflection loss L_r for single and two-hop paths (CCIR, 1978a)

Figure 3. Obscuration loss L_q as a function of x : (a) Phillips (1963)
(b) Lloyd (1975); (c) Sinno et al. (1976)

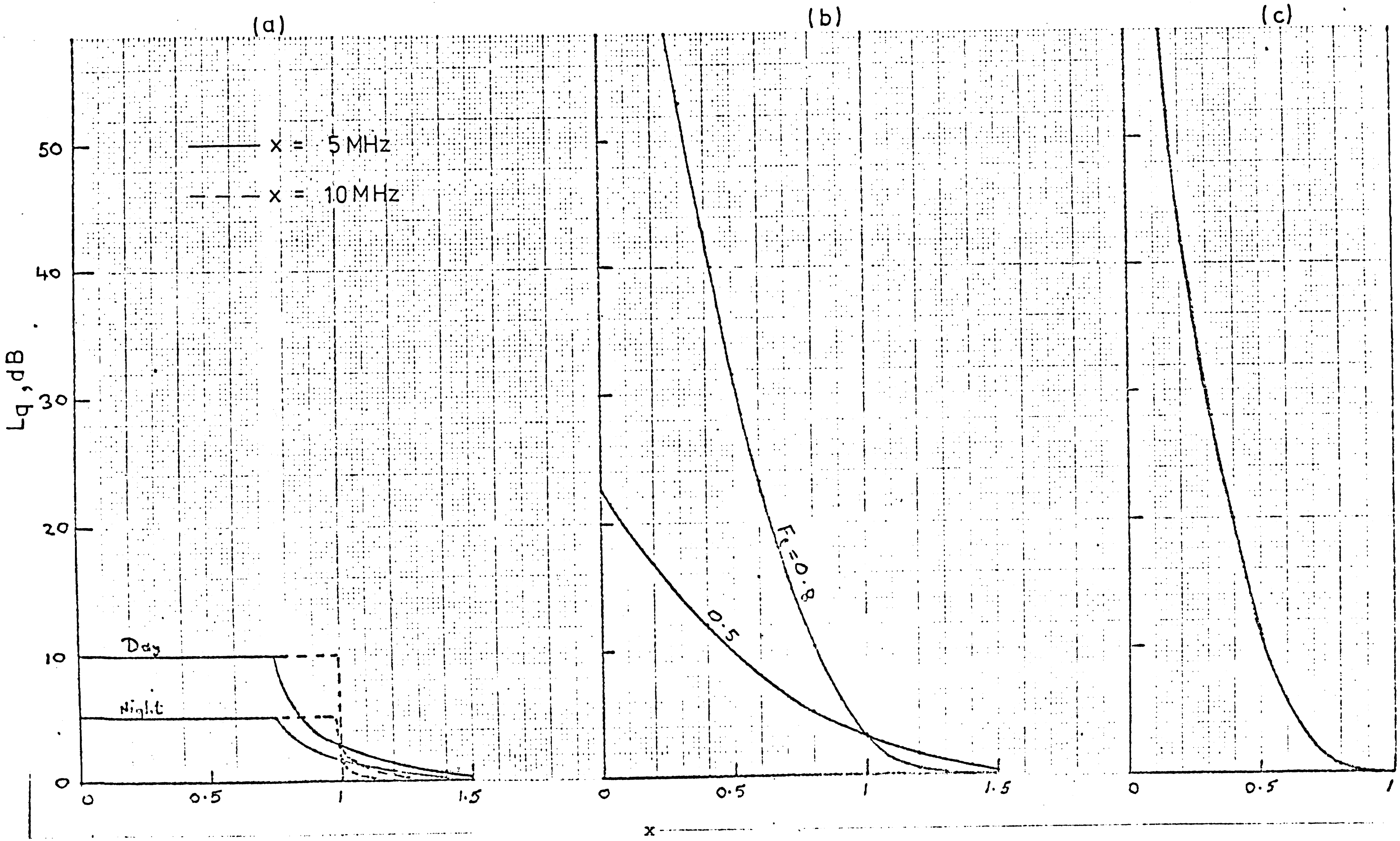
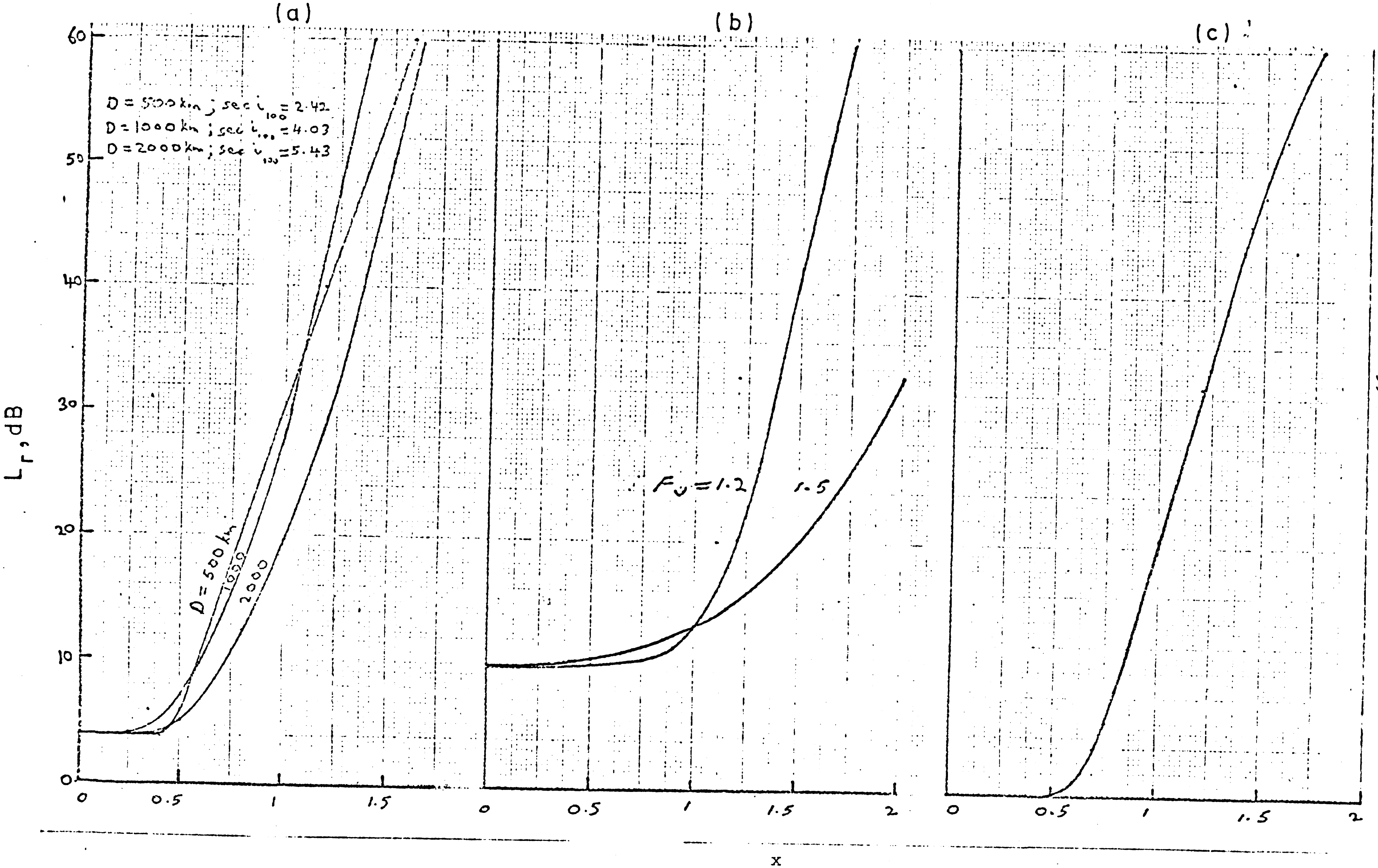


Figure 4. Reflection loss L_r as a function of x: (a) CCIR (1978a); (b) Lloyd (1975); (c) Sinno et al. (1976)



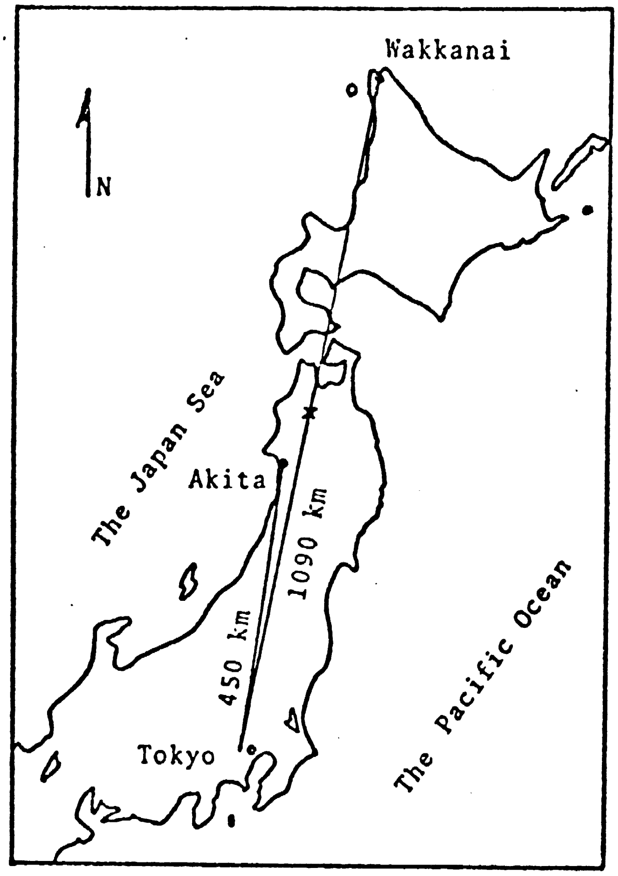


Figure 5. Propagation paths studied by Sinno et al. (1976)

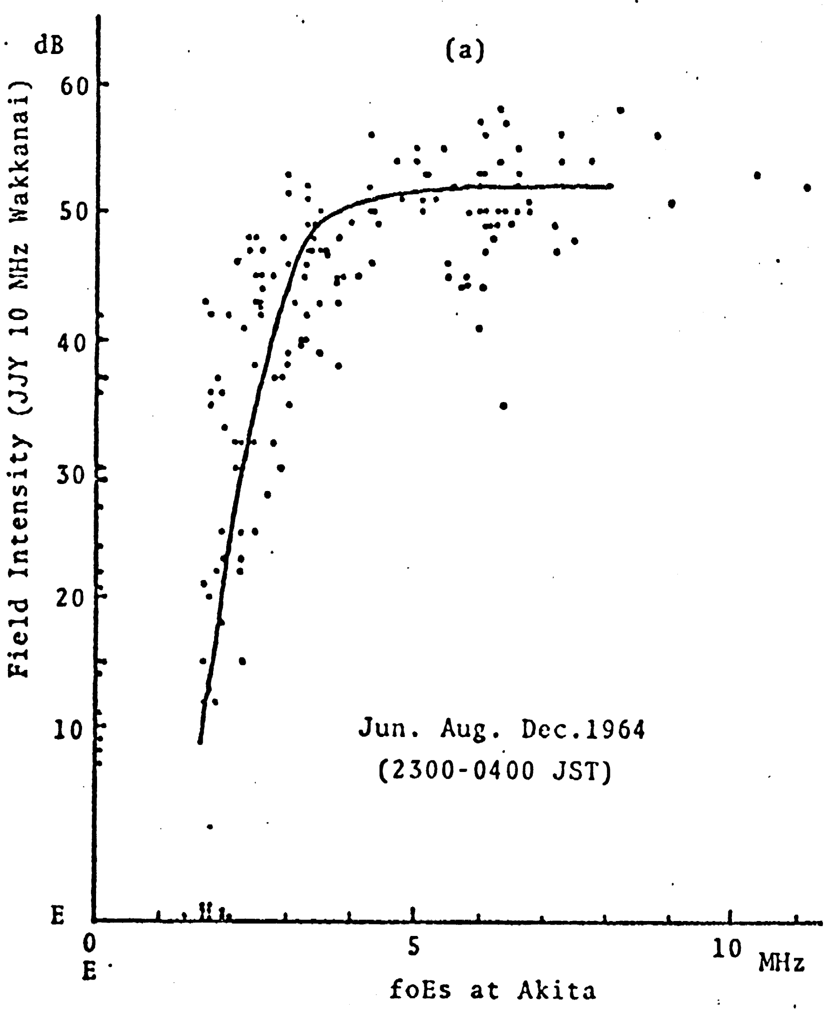


Figure 6. Variation of field intensity with midpath foEs (from Sinno et al., 1976)

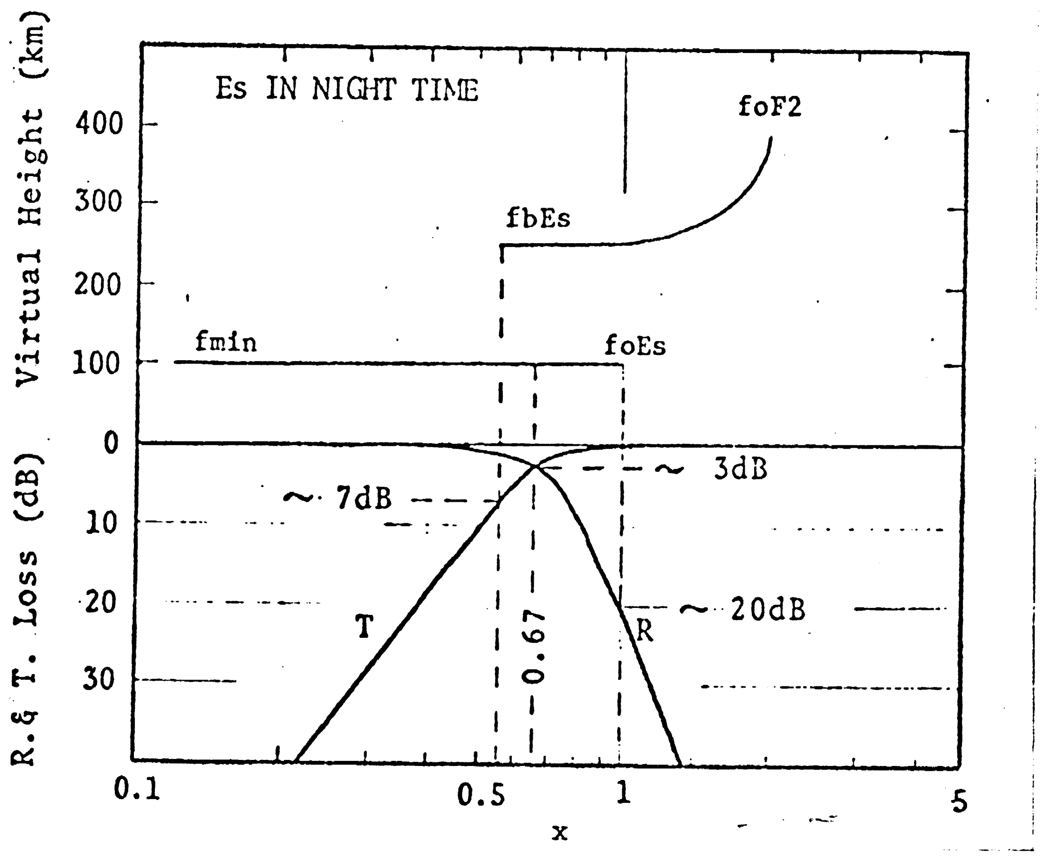


Figure 7. Sample ionogram and corresponding values of reflection (R) and obscuration (T) losses given by equations of Sinno et al. (1976)

6. Calculations of reflection and scattering from Es layers

(Dr. E.N. Bramley, Rutherford and Appleton Laboratories)

Experimental data on the field strength, and hence the effective reflection coefficient (expressed as a loss of N decibels) for VHF oblique-incidence propagation at frequency f via the Es layer are represented by the CCIR (1978) curves which give N as a function of ground range and f/foEs. Somewhat similar values are given by an empirical expression of Sinno et al. (1976). An attempt was made by Bramley (1972) to compare the dependence of N on f and on angle of incidence i, as indicated by the above data, with what would be expected for (a) reflection from smooth layers with various vertical profiles or (b) scattering from irregular layers with given types of spatial irregularity power spectrum.

The calculations show that none of the smooth layers considered gives a good representation of the data. An irregular layer with a Gaussian power spectrum gives $N \propto f^2 \cos^2 i$, to which the data conform over a range of values; but this model fails to reproduce the observed dependence of N on the background plasma density. Thus none of the simple models analysed gives a ready explanation of the practical behaviour of the Es layer.

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RADIO SOCIETY OF GREAT BRITAIN

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7. THE ROLE OF AMATEURS IN SPORADIC-E PROPAGATION MONITORING

R G Flavell, G3LTP
Chairman
Propagation Studies Committee
R.S.G.B.

Introduction

In the limited time available at the Symposium it is not possible to outline all the ways by which amateurs believe they can contribute to Sporadic-E propagation studies. What follows is but a sample, chosen to indicate aspects which seem to suit the spirit of the meeting.

The work of amateurs in this field is in no way intended to compete with the research being carried out by professionals; in many ways the two are complementary. As will be seen, some amateur projects involve a level of activity that no professional organisation could afford to establish for a one-off exercise, yet we are in a position to repeat them as often as required.

Thanks to a level of co-operation which appears to be impossible in any other field, the Amateur Service can now draw on the combined efforts of a large number of national societies, particularly in the European area, thanks to the existence and influence of the International Amateur Radio Union.

Co-ordination of the Sporadic-E Studies for the IARU is in the hands of a Frenchman, Serge Canivenc, who, unfortunately, was unable to attend the Symposium to describe the work himself. The present contribution was prepared and presented on his behalf and Mr Brian Dower, G3COJ, who has had considerable experience in amateur Sporadic-E studies, kindly agreed to attend in order to assist in providing answers at question time.

Listener reports

Although the term "radio amateur" generally means a person equipped with a privately owned transmitter and a licence to operate it as a hobby, there are many who are quite content to confine their efforts to listening and maintaining detailed logs of what they receive.

One such is Mr Ron Ham, of Storrington, Sussex, who completes his activities each year by compiling a Sporadic-E report which is published in the monthly journal of the RSGB, Radio Communication.

Mr Ham regularly monitors the television synchronising pulses transmitted on Ch E2, 48.25 MHz, and Ch R1, 49.75 MHz, for advanced warning of Sporadic-E and, when this appears he tunes up and down between 40 and 80 MHz on both a communications receiver and a multi-standard television set.

From his own results, and others sent to him by like-minded colleagues, he is able to illustrate his surveys with charts showing the days on which Sporadic-E was observed, broken down into times and frequencies, together with a table showing the distribution by countries and dates in respect of long-range television reception.

The report for 1980 (op.cit. 56, 1298-1299, December 1980) shows the "season" for that year lasted 108 days, from 3 May to 18 August.

The DUBUS Organisation

Although much may be learned from listener reports the benefits of two-way communication are considerable. Because the studies are no longer confined to certain terminal locations (at the reporting end of the paths), in a very short time a very dense network of completely random paths may be set up once the presence of Sporadic-E has been recognised. Transferred to a suitable map these paths immediately identify the area within which the activity is taking place and a sequence drawn over a period of time is capable of following the movements of the clouds - or sheets - of ionisation until they finally dissipate or move out over the sea.

For this type of study there is no need for calibrated equipment or elaborate measurements. The mere fact that a certain long-range transmission path has shown itself to be open is sufficient information in itself. It is in the nature of amateur radio interests that each of the participating stations of such a pair will go on to explore the surrounding area for further contacts with other stations for as long as the opportunity exists. If personal circumstances demand a premature halt there are generally other stations nearby to continue the quest. Not all who participate in this way are prompted by the cause of propagation research, many will join in whose only concern is to make new friends or gain points towards an operating award, but the end result is the same - the establishment of a network of random paths determined by the location of the Sporadic-E ionisation.

Prominent among those who make it their business to collect and distribute reports from co-operating amateur stations is a German organisation known as DUBUS, who regularly publish and pass on to subscribers a booklet containing times, call-signs and locations of amateur stations participating in studies of various modes of propagation - all tidily classified under the appropriate headings, Sporadic-E, Auroral-E, tropospheric, meteor-scatter, etc. The DUBUS reports are collected from co-operating stations covering almost the whole of Europe by Claus Neie, DL7QY, D-7181 Rudolfsberg 24, Germany.

In the past one of the main objections to using amateur radio observations for propagation studies was the difficulty in finding the locations of the stations concerned. Nowadays that problem has been solved. All the reports given in the DUBUS publication contain 5-unit alphanumeric groups which are based on latitude and longitude (e.g., ZL56B, which identifies a part of Wokingham, Berkshire). Maps, on various scales, marked with the locator grid references are available (Fig 1). For many purposes the first two letters, which identify an area 1 degree of latitude by 2 degrees of longitude, are sufficient.

The International Amateur Radio Union

All the reports collected by DUBUS, as well as those gathered in by the various national societies, go to the IARU Sporadic-E Co-ordinator, Serge Canivenc, F8SH, 6 Rue de Pont-Hélé, 22700 Perros-Guirec, France.

For amateur radio purposes auroral-E propagation is a separate phenomenon (and it had not been realised that it would be of relevance to the Symposium until question time). Control of that project is with the United Kingdom and the Co-ordinator is Charlie Newton, G2FKZ, 61 Merriman Road, Blackheath, London, SE3 8SB.

The work of Serge Canivenc

As Project Co-ordinator, Serge Canivenc has access to all the Sporadic-E data from amateur sources. Some aspects of his subsequent analyses have been described in a paper "Contribution of the Amateur Service to VHF Sporadic-E propagation studies in the European area", which was prepared for, and submitted to, Interim Working Party 6/8 CCIR, of which M. Canivenc is a member.

In that paper he has pointed out that, until a few years ago, it was generally considered, even among amateurs, that the probability of long-distance propagation via Sporadic-E at 144 MHz was too low to be of practical interest and that any openings must inevitably be of short duration.

The results obtained by amateurs since 1972 have shown that the maximum observed frequency could go well beyond 144 MHz for relatively short periods. On one occasion, 9 July 1974, it reached 203 MHz. On another, 10 July 1978, it reached 201 MHz. These, and two other occasions, 4 July 1965 and 24 May 1971, have been made the subject of in-depth reports, published by the International Amateur Radio Union, Region 1.

Due to the ever-increasing amount of Sporadic-E data received each year (for just the one opening of 10 July 1978, which lasted over 8 hours, there were over 1500 reports) processing has had to become more sophisticated. A computer program is now used to locate the reflection points, evaluate statistics for chosen periods and to draw up maps showing the position and movement of Sporadic-E areas.

The paper referred to above contains diagrams showing, for each of the years 1974 - 1980, those days during the summer periods when Sporadic-E activity was reported in the European area and the maximum observed frequency on each occasion. There is also a diagram showing the number of minutes of reported activity for the four active months of each of the years 1973 - 1980, compared with the average sunspot number of the four months concerned in each case. This is shown in Fig 2. It must be noted however, as was pointed out from the floor, that the number of minutes recorded each year may be influenced by the number of amateurs taking part in the project and this has probably increased steadily over the period covered.

Mindful of the fact that what are good periods for amateurs are bad periods for almost everyone else concerned with radio communication, Serge Canivenc prepared also, for Region 1 IARU, a paper entitled "An evaluation of interference problems during long-distance Sporadic-E propagation in the European area". Also available for inspection at the Symposium was IARU Technical Propagation Report No IARU/SEPN-02, "Analysis of the long-distance Sporadic-E opening of 24 May 1971".

The work of John Branegan

A Scottish amateur, John Branegan, GM4IHJ, of Saline, Fife, has made a detailed study of VHF Sporadic-E from July 1977 onwards, using rotatable antennas and separate receivers for the bands 45-54 MHz, 65-74 MHz, 86-108 MHz and 144-146 MHz. In order to make positive identification of overseas TV he uses a multi-standard VHF TV receiver with tunable preamplifier. Details of frequency offsets for most European TV stations are held, and standard call-sign, caption and time signal photographs are kept for regular TV channels, to assist identification.

He has found a major feature of all Es events to be a concentration of signals from the zone 1000-2000 km but, so far, no attempt has been made to investigate the effect of elevating the antenna (see Fig 3). An interesting feature is that, despite repeated searches for them, TV signals from France, with their distinctive standards, are extremely rare, having appeared only 3 times in 3 years, whereas over 200 events have involved Spanish stations.

Fig 4 shows an interesting analysis of a major event, showing the times at which the various bands were affected and the areas from which signals were received. In most events the lowest frequencies are propagated most strongly and consistently, the intermediate frequencies less so, while the higher frequencies, if they are propagated at all, appear only at irregular intervals.

The more widespread and sustained is the geographical spread of stations heard at the lower VHF the more likely one is to hear fleeting bursts at higher and higher frequency.

It is expected that a full account of this work by John Branegan will appear later this year in Radio Communication.

HF Beacons

Not all amateur interest in Sporadic-E is at VHF. It is recognised that there is still much to be learned at HF and to satisfy this need the Amateur Service operates a co-ordinated series of 28 MHz beacons in various parts of the world.

28175 kHz	VE3TEN, Ottawa	28237 kHz	LA5TEN, Oslo
28205 kHz	DLØIGI, Mt Predigtstuhl	28245 kHz	A9XC, Bahrain
28207 kHz	WD4MSN, Florida	28247 kHz	EA2HB, San Sebastian
28210 kHz	3B8MS, Mauritius	28252.5 kHz	VE7TEN, Vancouver
28215 kHz	Crowborough, Sussex	28257 kHz	DKØTE, Konstanz
28220 kHz	5B4CY, Zygi, Cyprus	28277 kHz	DFØAAB, Schleswig-Holstein
28225 kHz	VE8AA, Lake Contwoyto	28284 kHz	VP8ADE, Adelaide I, Antarctica
28230 kHz	Mt Climie, New Zealand	28280 kHz	YV5AYV, Caracas
28235 kHz	VP9BA, Bermuda	28290 kHz	VR6HK, Hong Kong

A number of other stations are planned, but are not yet in service. The International Beacon Project is co-ordinated by Alan Taylor, G3DME, Altadena, South View Road, Crowborough, Sussex, who is also the "beacon keeper" for GB3SX.

The work of Martin Harrison

Among the amateurs who regularly monitor HF beacons is Martin Harrison, G3USF, of Keele, Staffordshire. He has maintained hourly records between 0745 and 1800 GMT every day of the year since 1973, an extremely valuable contribution to our studies, and one which requires the understanding and occasional assistance of the, by now, well trained members of Prof. Harrison's family.

In the limited time available at the Symposium only samples of this work could be shown. In Fig 5 are monthly averages for two consecutive years, 1978 and 1979, of the percentage time the path Cyprus - Keele was open at 28220 kHz between 0745 and 1800 GMT.

In Fig 6 January and July are compared. The two diagrams on the left compare the amount of activity in successive years between 1973 and 1980 . The two diagrams on the right are for January and July 1980 in terms of time of day. In all these diagrams the ordinate scale is percentage time that the path is open between Cyprus and Keele as compared to the maximum possible for the respective periods under consideration.

In these studies openings by Sporadic-E and propagation by the regular layers are combined, but from the basic records the two may be separated and studied independently. The results are passed regularly to the Sporadic-E Co-ordinator, Serge Canivenc.

Conclusion

Of the many amateurs throughout Europe who are studying Sporadic-E propagation there has been time only to outline briefly the work of three and to indicate the extent of the basic data available as a result of international co-operation.

As to the future, well, clearly, we like doing what we do best. We like to use our very considerable numbers and the fact that we are scattered over most of the inhabited parts of the globe to establish networks - or, sometimes, to let them establish themselves - to locate Sporadic-E and to follow its movement with time.

When the IARU computer program becomes fully operational results should follow very quickly. Part of our task then will be to encourage more and more amateurs to take an active part in organised studies.

We are less-happy about long-term monitoring, which ties up expensive equipment and prevents us from using it for the more sociable aspects of our hobby. For that reason most amateurs tend to avoid that sort of commitment. But there are many among us who would be happy to look after receivers and chart recorders if the necessary equipment was made available to us. Perhaps that points a way forward for some professional organisation with equipment on the shelf but no hands available to work it.

To sum up, radio research in the Amateur Service is alive and well and very much involved with Sporadic-E (including auroral-E). The fact of the matter is that there are now so many people co-operating with the project that we would find it difficult to call a halt!

Figure 1. DUBUS grid classification system for radio amateur station locations.

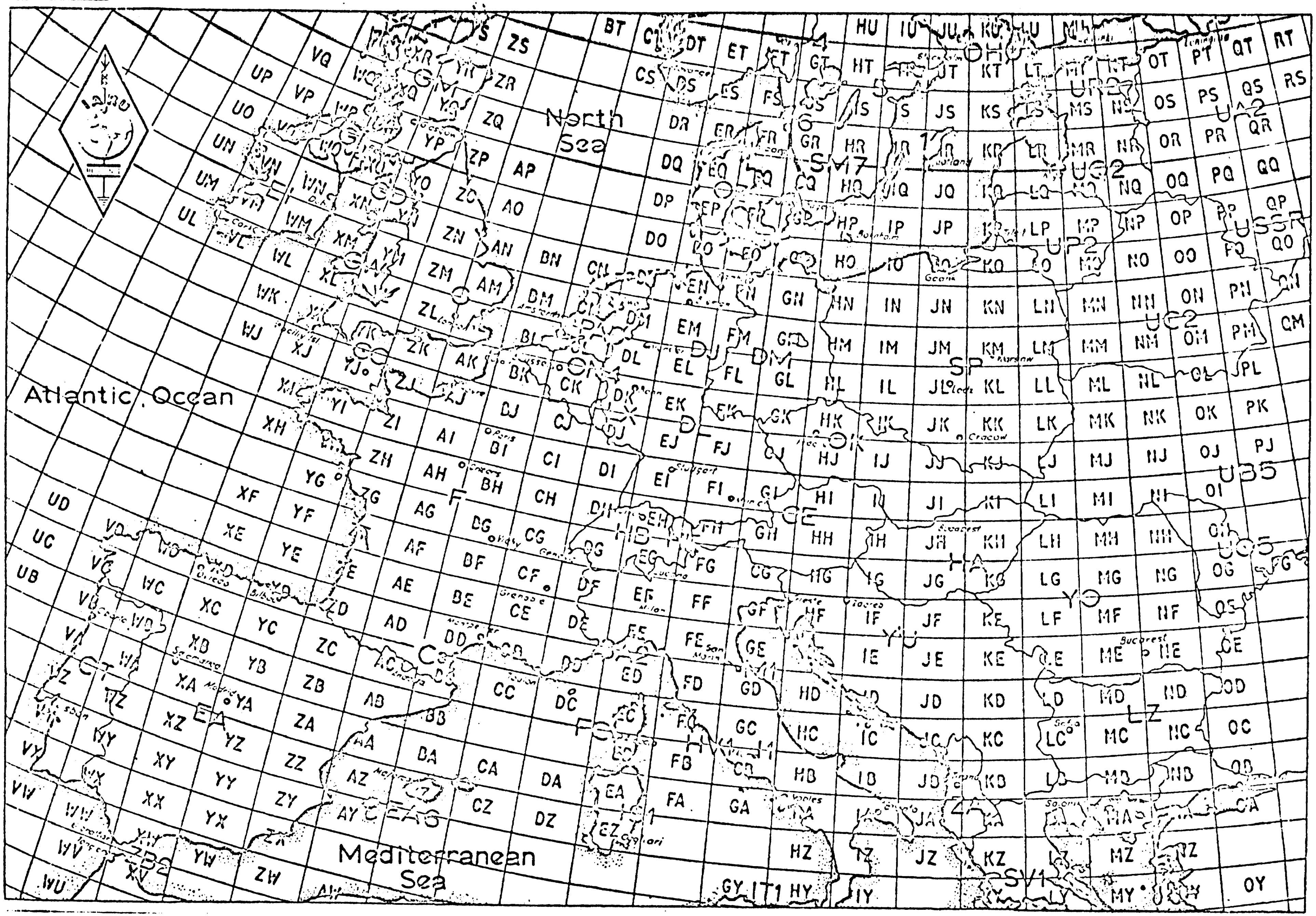
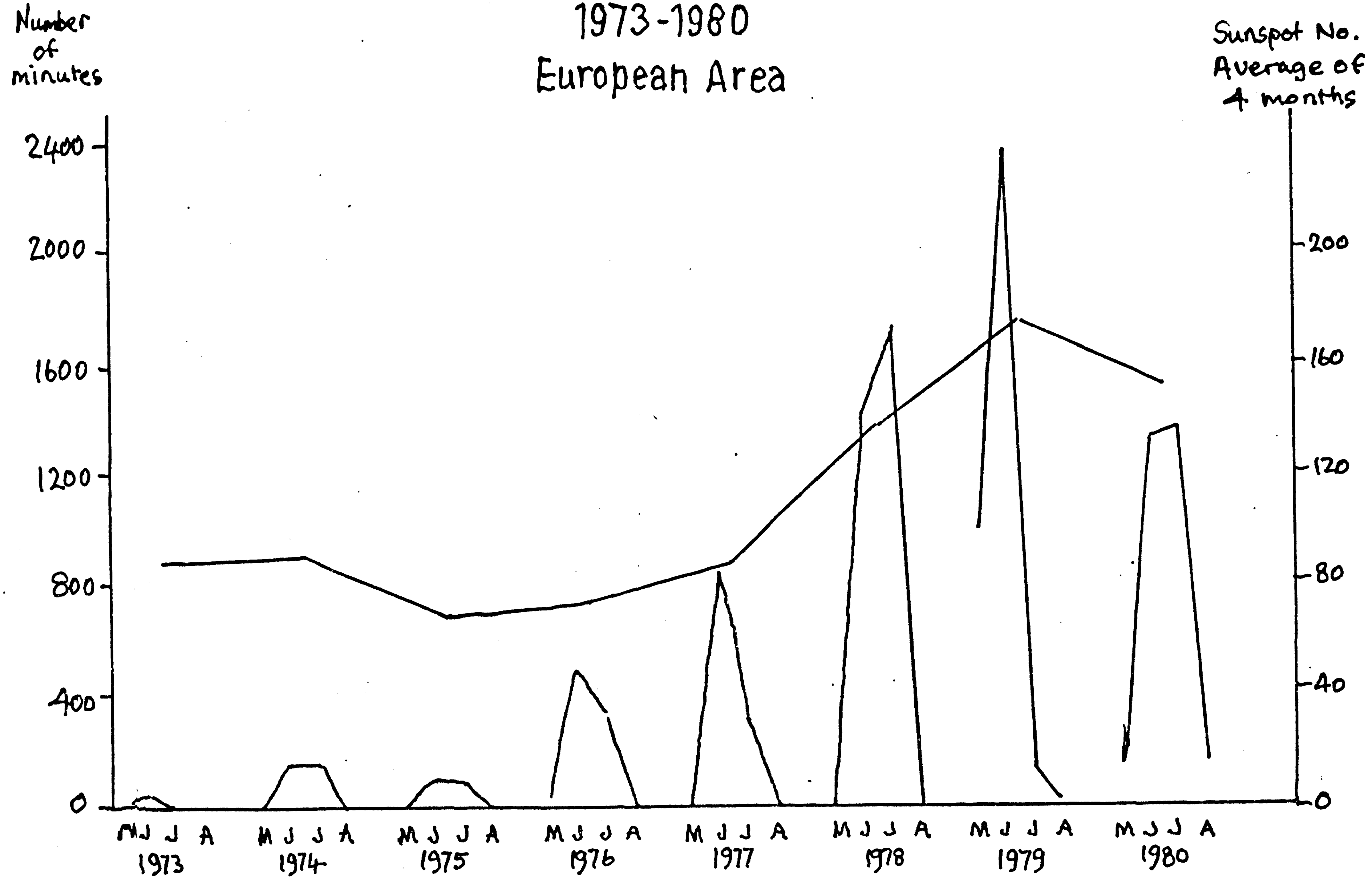


Figure 2 : Evaluation of 144 MHz Sporadic-E Activity Periods 1973-1980 European Area



Serge Canivenc, F8SH. IARU E_s CO-ORDINATOR

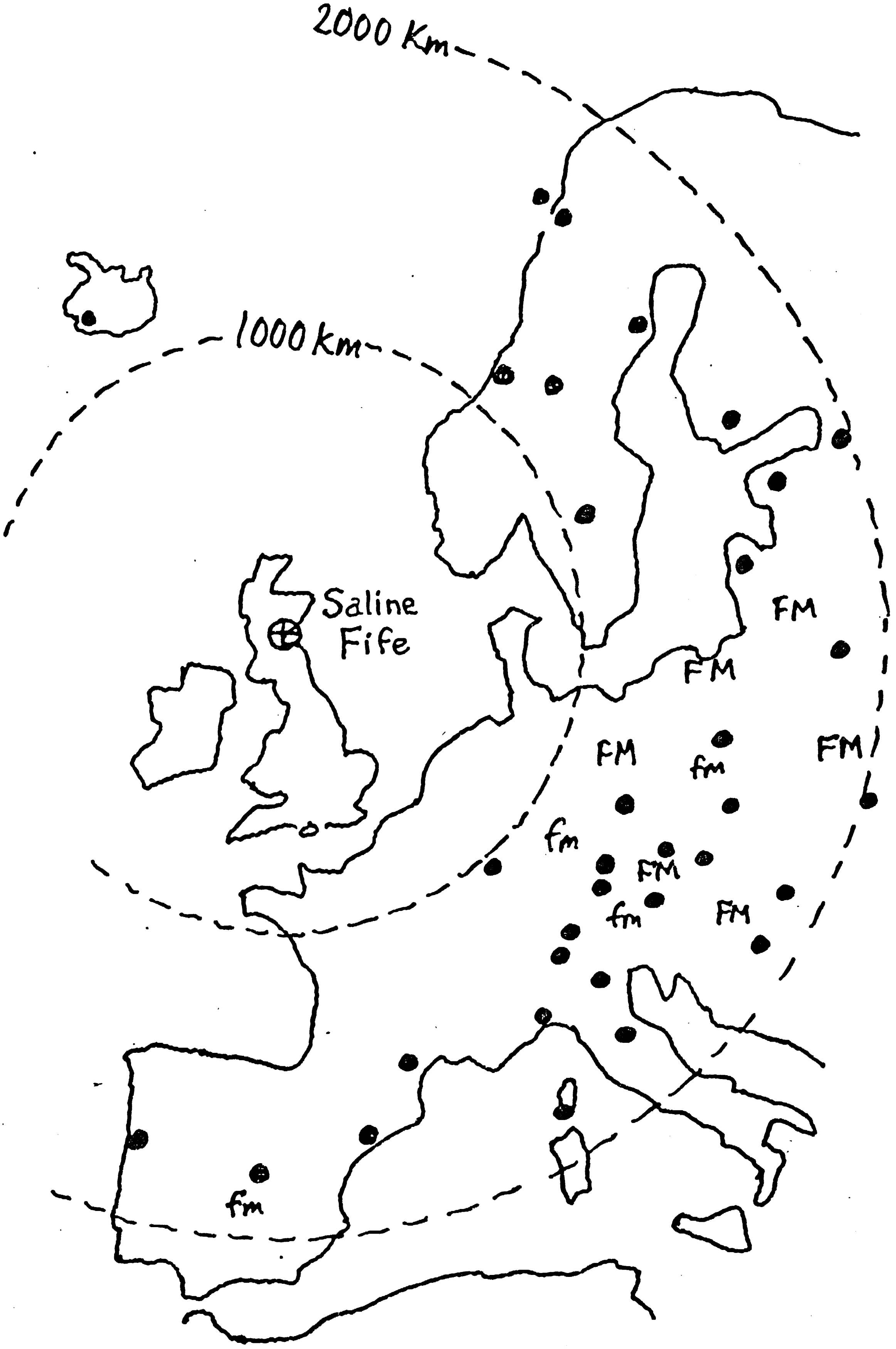
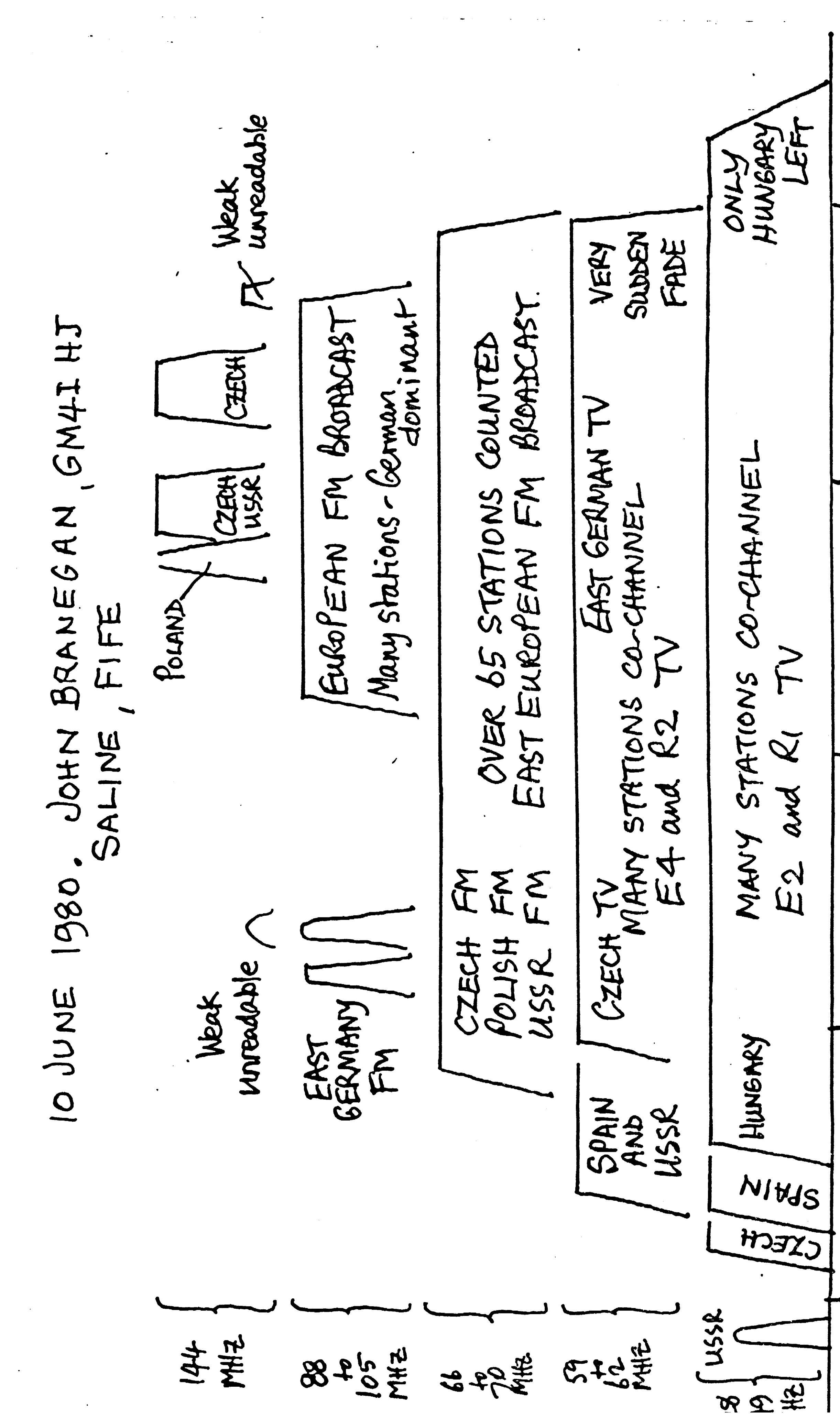
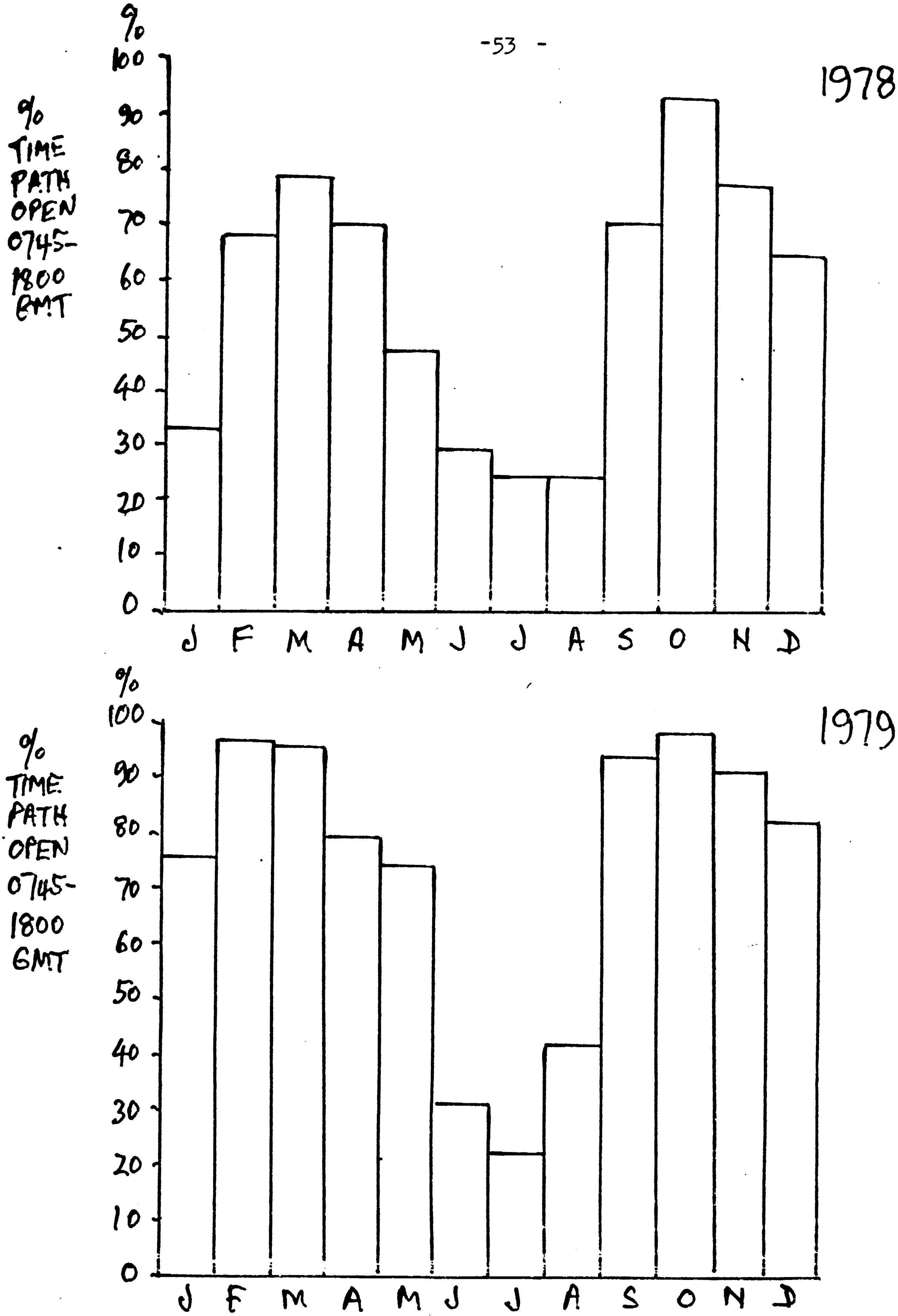


Figure 3 : STATIONS RECEIVED VIA Es AT SALINE, FIFE
JOHN BRANEGAN GM4IHJ

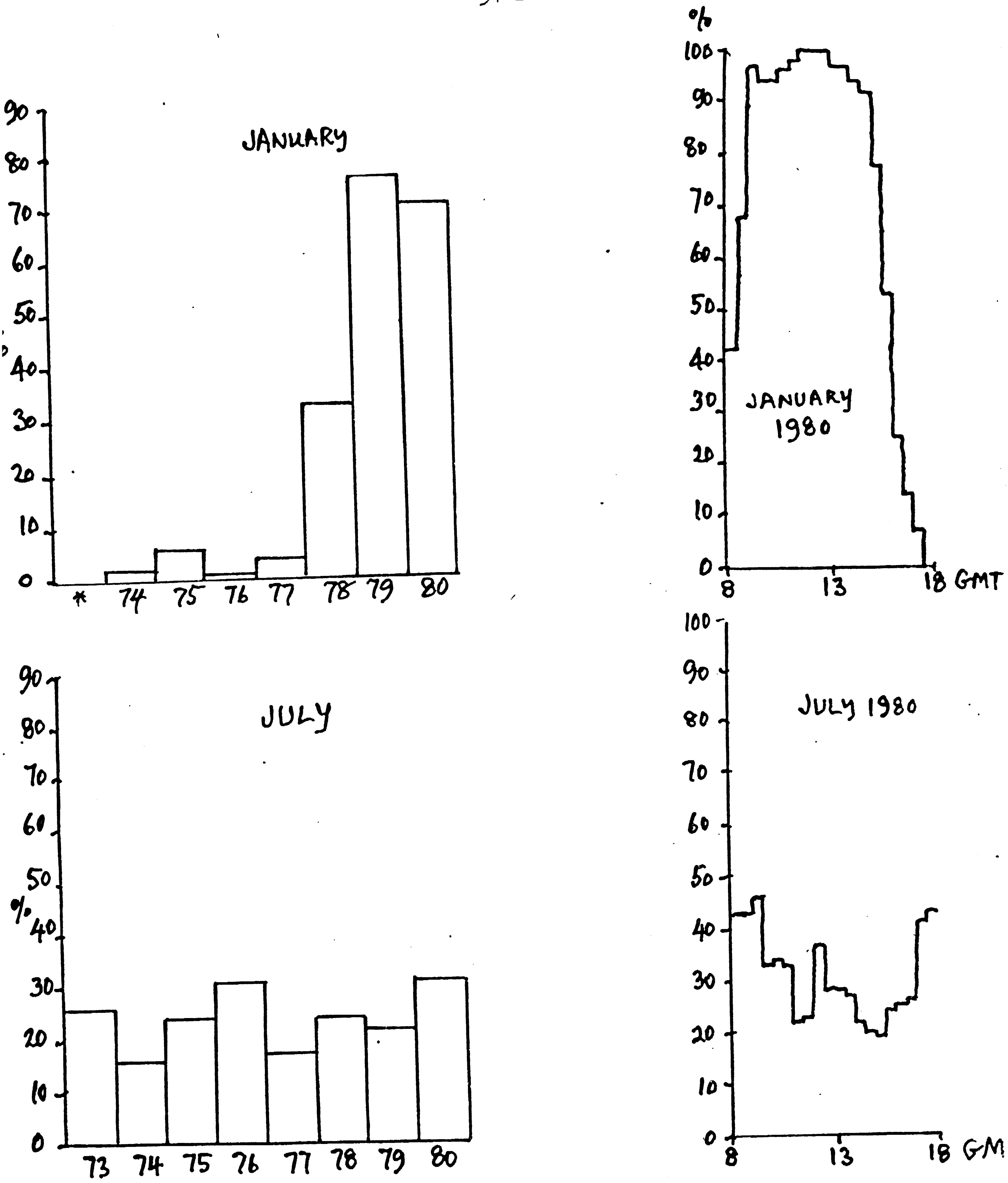
Figure 4 FREQUENCY vs. TIME FOR A MAJOR E_s EVENT





RECEPTION OF 5B4CY (CYPRUS) 28220 kHz AT KEELE (3540 km). MARTIN HARRISON, G3USF

Figure 5



RECEPTION OF 5B4CY (CYPRUS) 28220 KHZ
AT KEELE (3540 KM). MARTIN HARRISON, G3USF

Figure 6

8. Sporadic-E Statistics at Slough

(Mr. L.J. Prechner, BBC External Services)

Sporadic-E layer statistics are presented for Slough over the period 1976-79 i.e. during the rising phase of sunspot cycle 21 and compared with corresponding data for cycle 20. Figure 1 contrasts monthly median values of foE, foEs and fbEs in June and July of each year, the time of maximum seasonal occurrence of the E and Es layers.

As expected, foE values show a marked degree of solar control, peaking around local noon and increasing from about 3.2 MHz during sunspot minimum to about 3.9 MHz during sunspot maximum. foEs values show a more irregular diurnal variation, often with a morning and an evening peak. There did not appear to be any obvious correlation between foEs and sunspot cycle. Peak foEs values were of the order of 4.2 to 4.6 MHz from 1976 to 1979, and the difference between these and the corresponding peak foE values decreased with the increase in solar activity. The most marked difference between foEs and foE usually occurred around 0900 and 1800 UT.

The fbEs values showed a similar variation to that of foEs, but they were slightly lower, usually by about 1 to 2 MHz. This indicated that the Es layer at Slough was generally fairly opaque.

Figure 2 shows the highest recorded single readings on any hour of any day of foEs during each of the summer months from 1976 to 1979. It is seen that:-

(i) foEs has exceeded 10 MHz in June, July and August during each of these years.

(ii) The peak foEs value reached during that period was 15.3 MHz on 25 July 1976 at 1800 UT. This corresponds to an Es-MUF for a 2200 km length path of about 84 MHz (assuming a MUF factor of 5.5).

The incidence of Es at Slough has been analysed statistically to quantify its large and irregular variations with time. Two values were selected in the distribution of the hourly critical frequencies, namely foEs $\geq$ 4 MHz, and foEs $\geq$ 8 MHz. These particular values were chosen because the corresponding Es-MUF's for 2200 km (the approximate limit of a single-hop mode) are about 22 MHz, and 44 MHz; i.e., appropriate to the 21 MHz HF broadcast band and TV Channel 1, Band 1, respectively. Figure 3 shows the variation over 24 hours for all months from 1976 to 1979. Es was most prevalent during the summer day. foEs exceeded 4 MHz on more than 50% of the days during some hours, and it peaked at about 80% during June 1979.

The corresponding incidence of foEs ≥ 8 MHz peaked at 10 - 20% during some hours in July 1976, but, generally, it was considerably lower. Es was least prevalent during the late night and early morning, and also in winter (November to March). It is concluded that Es could have played a significant role during summer in the oblique propagation of HF and VHF transmissions in Europe.

Figures 4 and 5 present the percentages of hours that the monthly median foEs exceeds 4 and 8 MHz, and compare them with results for cycle 20 (1964-1976). Each year there was a similar seasonal variation in the incidence of Es. Firstly there was a large and sudden increase in May, then a sharp summer peak, followed by a decline to very low values after September. This peak incidence usually occurred in June and/or July, reading about 30% to 40% of all observed hours for foEs ≥ 4 MHz and about 2% for foEs ≥ 8 MHz. Highest values were of the order of 46% (June 1968) and 5% (July 1976) respectively.

Figure 6 shows the variation in the daily incidence of Es day-to-day during April, May and June, from 1976 to 1979. The date of onset of the springtime increase varies from year to year, but values of foEs ≥4 MHz start appearing in the second part of April, and their incidence is then greatly increased in May, e.g., after May 10th foEs ≥ 4 MHz was recorded on each day of observations during May and June, from 1976 to 1979. As temperate-zone sporadic-E is thought to be associated with wind shears in the E region, it may be that a major change occurs each May in the large scale ionospheric wind circulation pattern in that region.

Figure 7 summarises the overall annual incidence of foEs. It will be seen that foEs ≥ 4 MHz and foEs ≥ 8 MHz were present on about 10% and about 0.5% respectively of all observed hours in a year. Jagger (1974) has concluded that there is a positive correlation between the incidence of foEs ≥ 4 MHz at Slough and the Zurich smoothed sunspot number. He quotes a product moment correlation coefficient for the years 1958 - 1972 of 0.76.

References

Jagger, G. (1974) Report ITM. 74/1, Research Division, GEC Marconi Electronics Ltd. January 1974

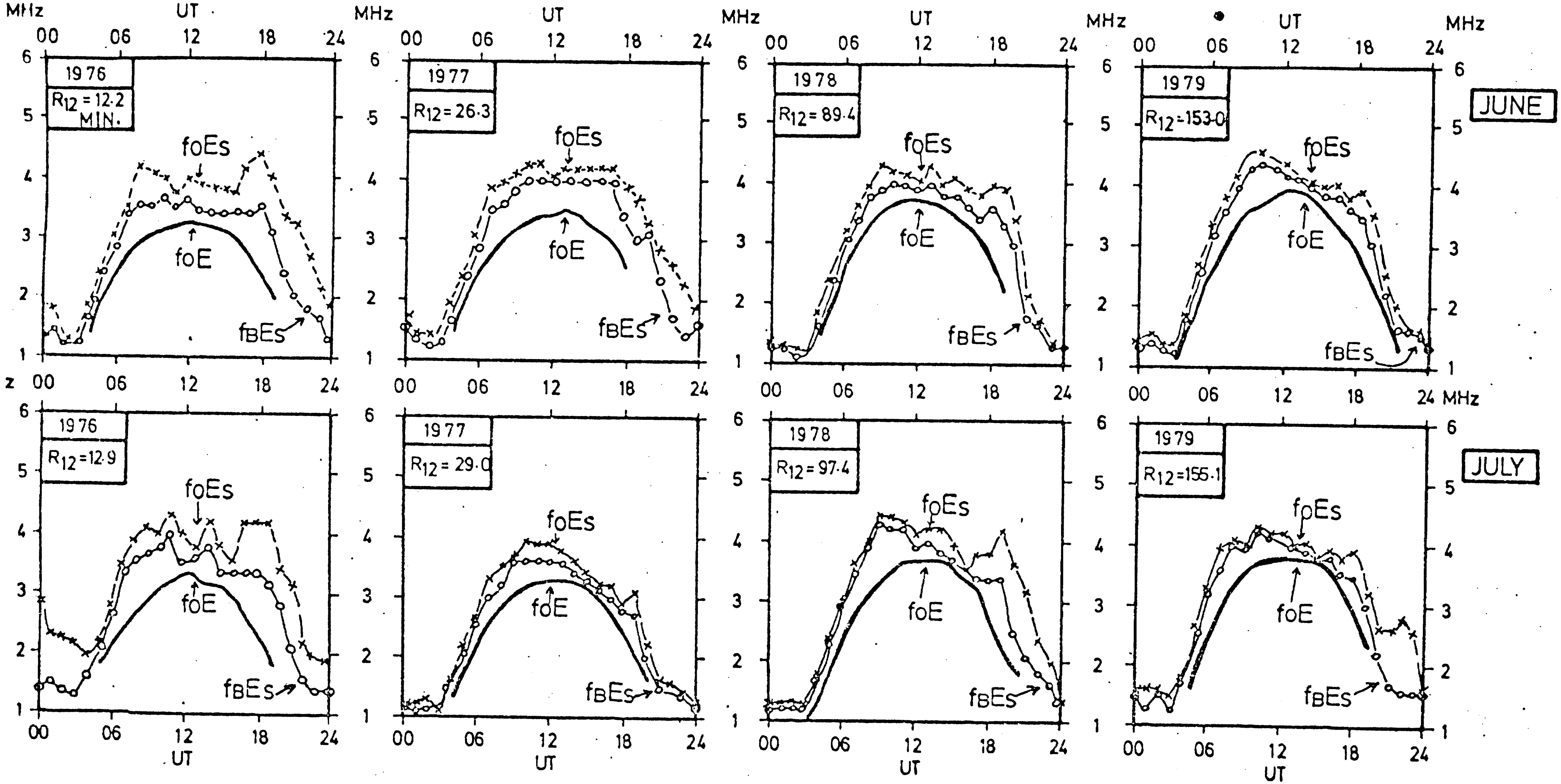


Figure 1. Monthly median values of foE, foEs and fbEs at Slough

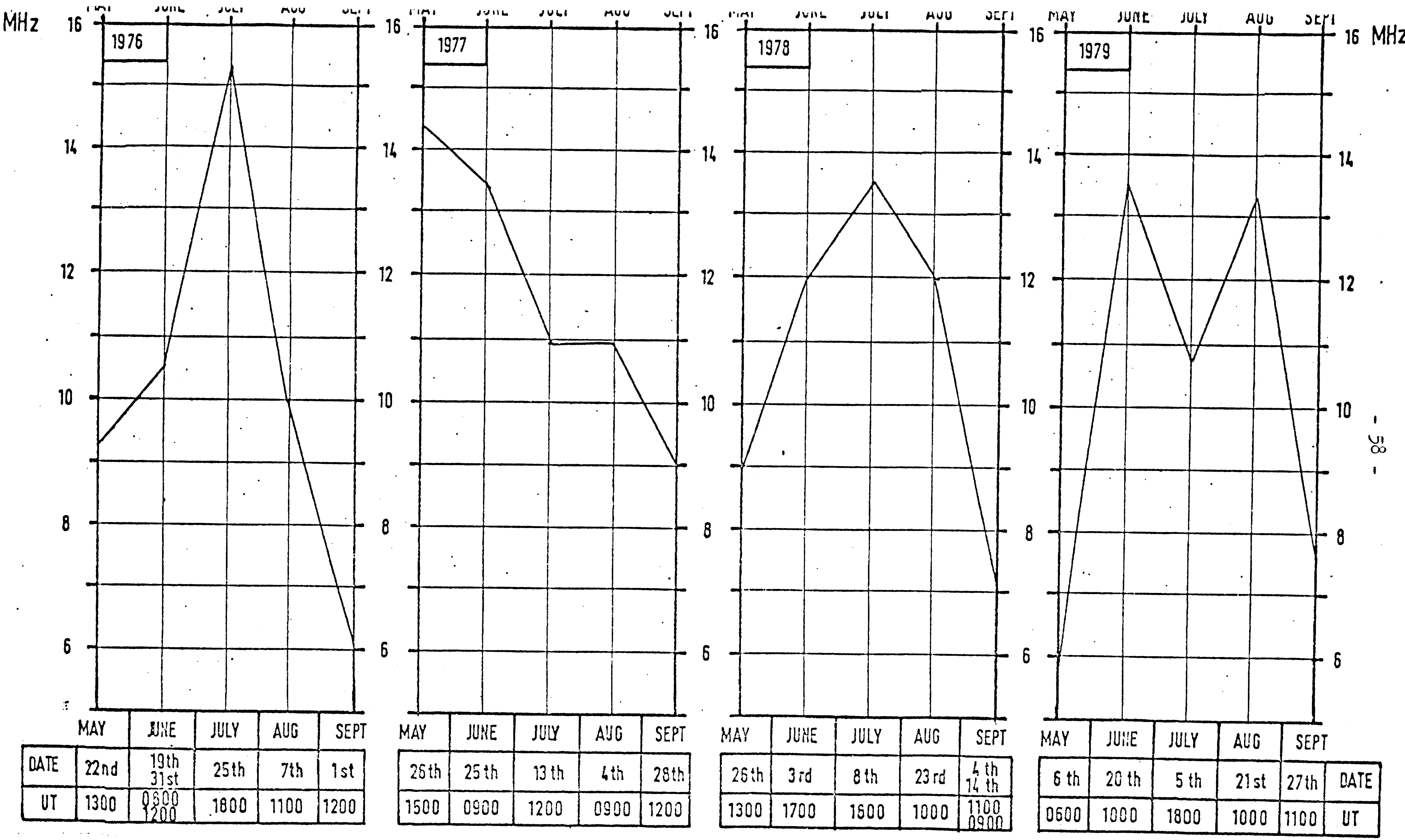


Figure 2. Highest recorded values of foEs at Slough for each month from May to September 1976-1979

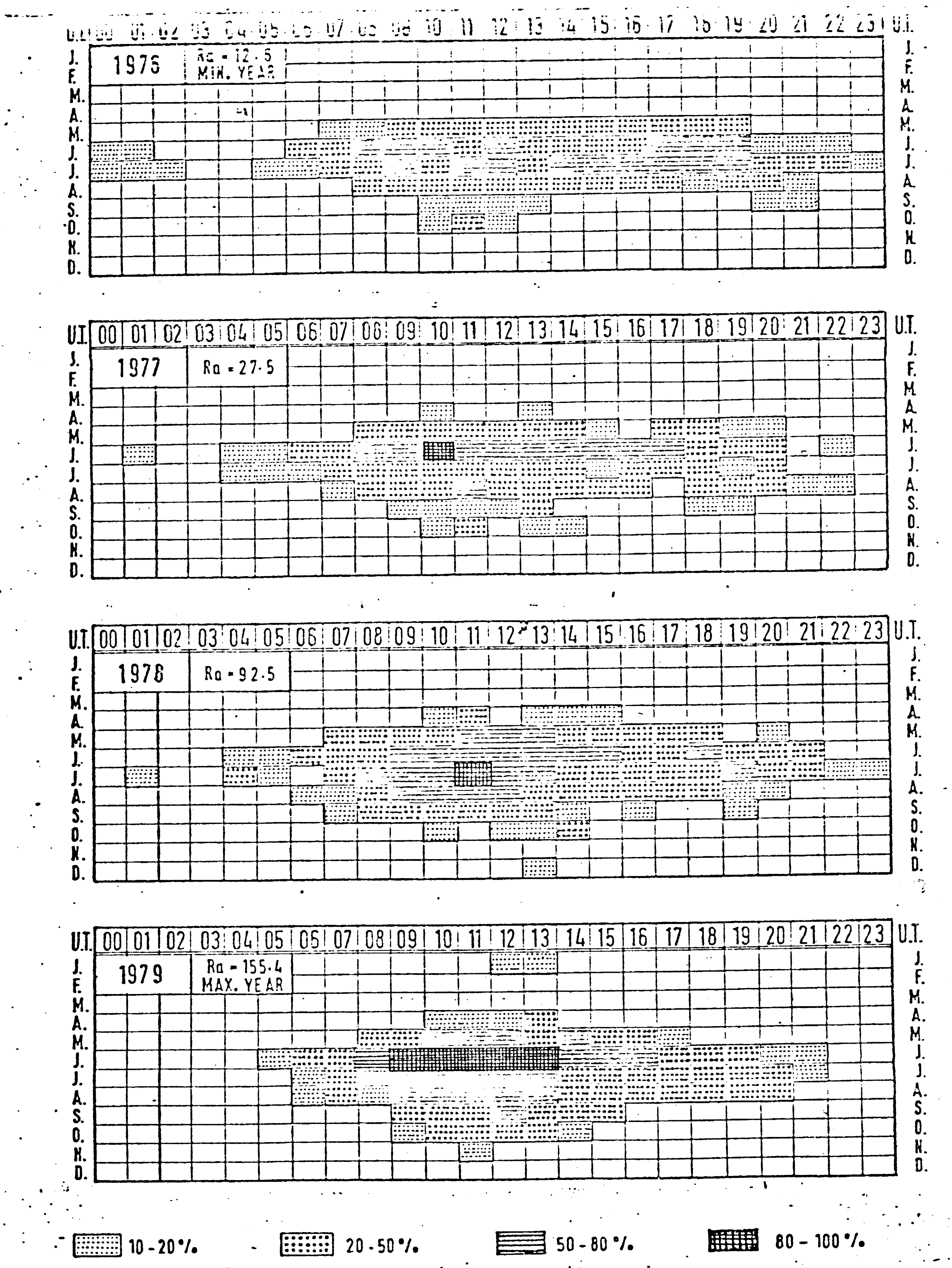


Figure 3a. Percentage of days with foEs at Slough exceeding 4 MHz

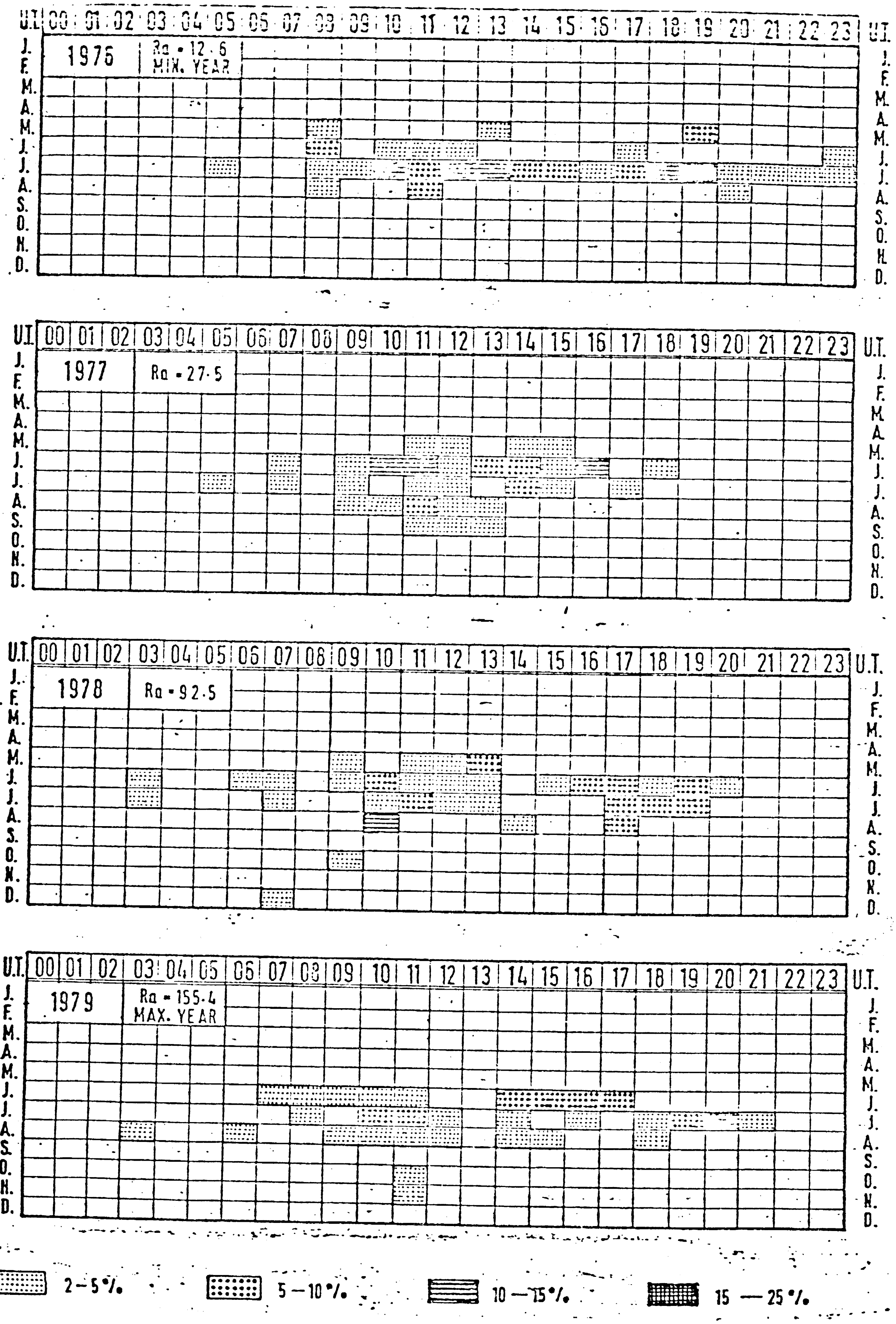


Figure 3b. Percentage of days with foEs at Slough exceeding 8 MHz

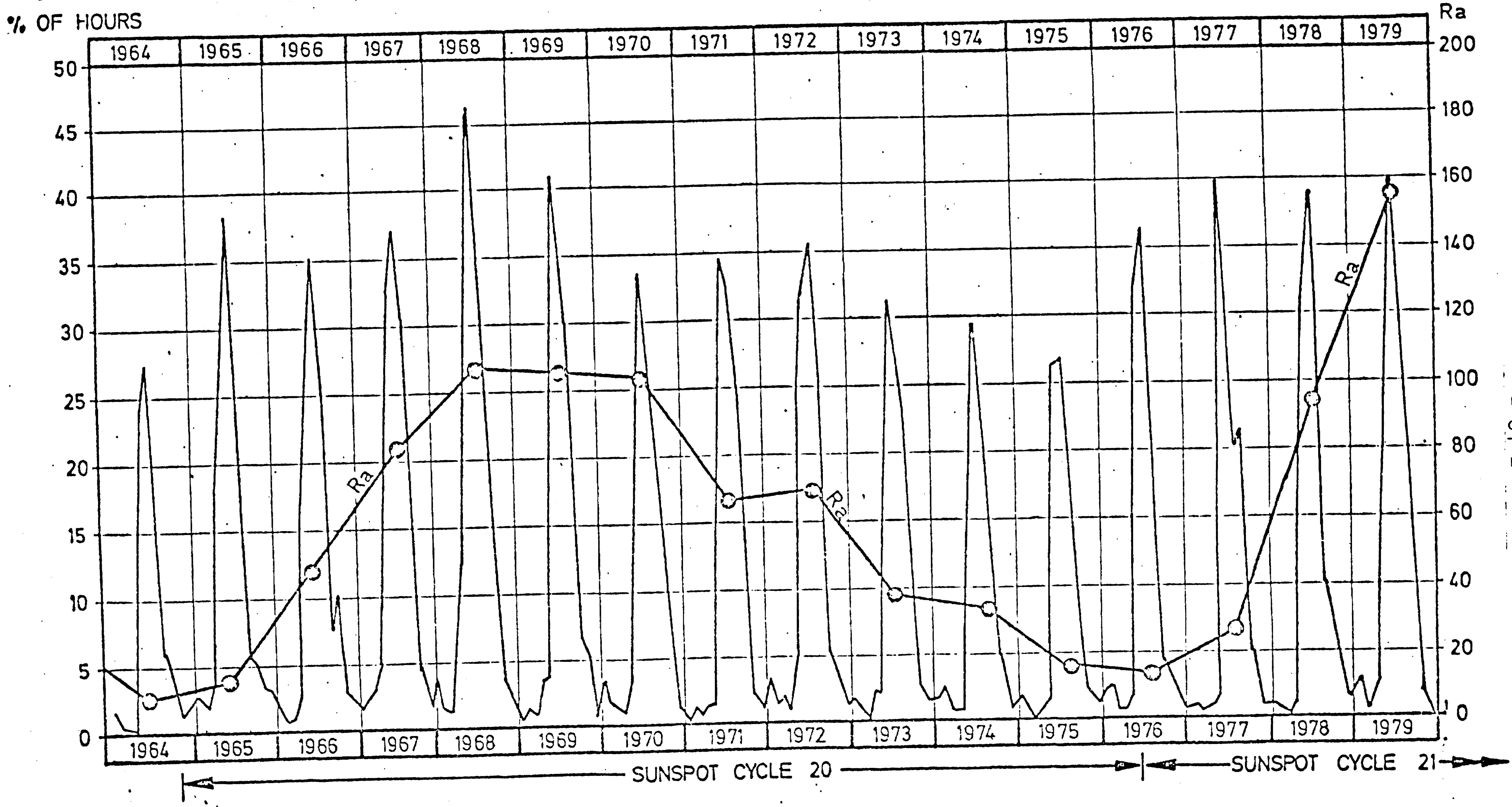


Figure 4a. Percentage of time foEs $\geq$ 4 MHz at Slough

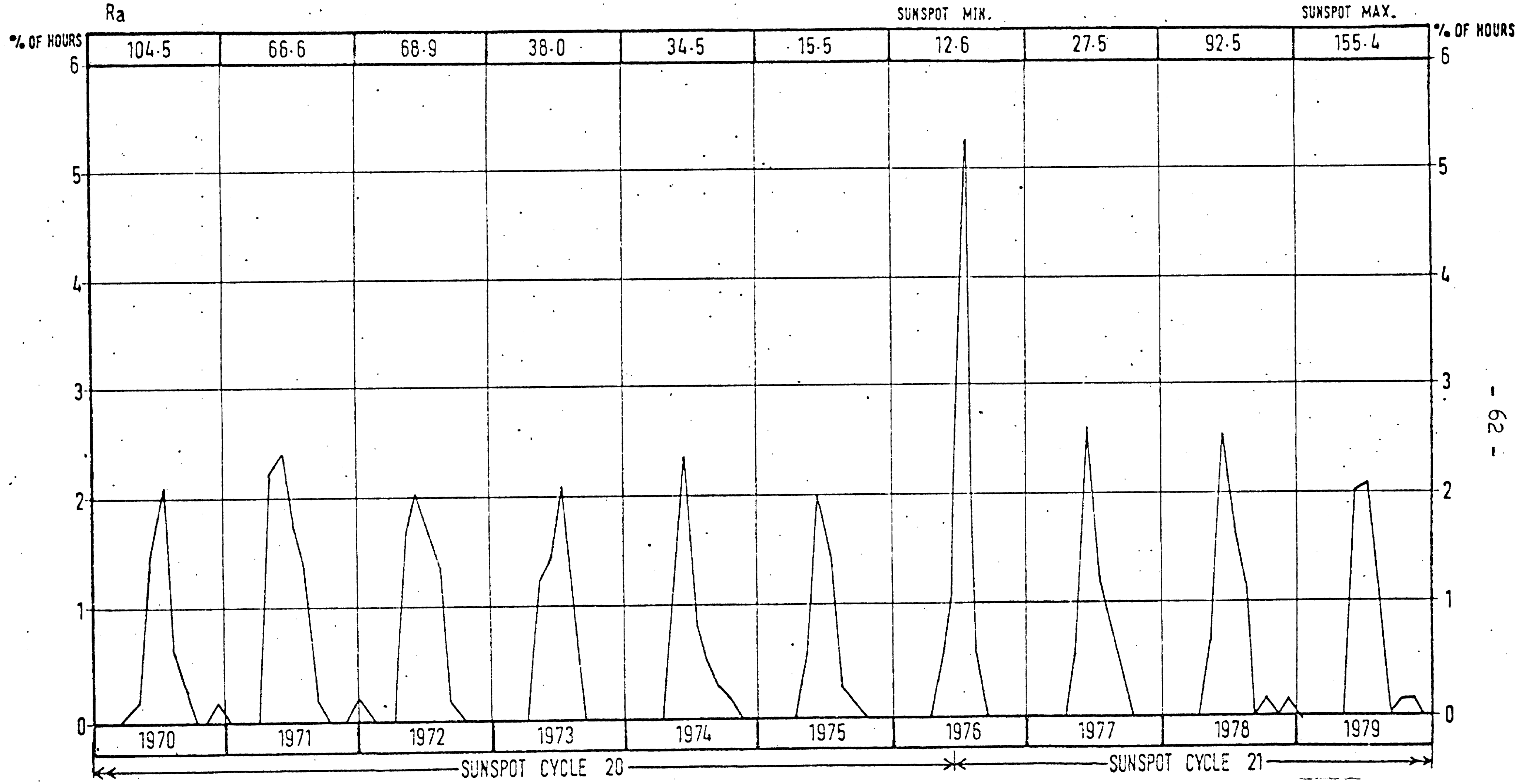
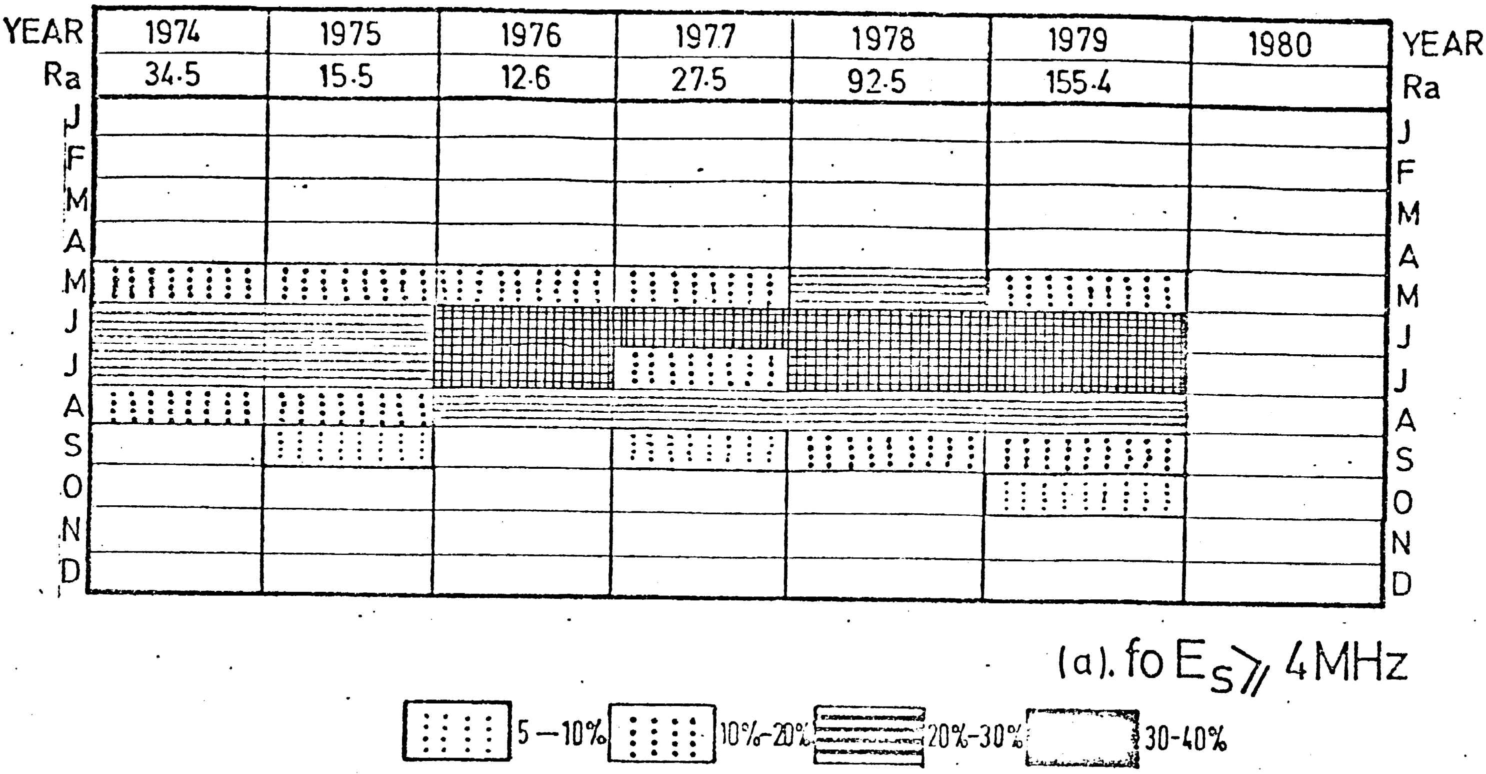


Figure 4b. Percentage of time foEs ⩾ 8 MHz at Slough



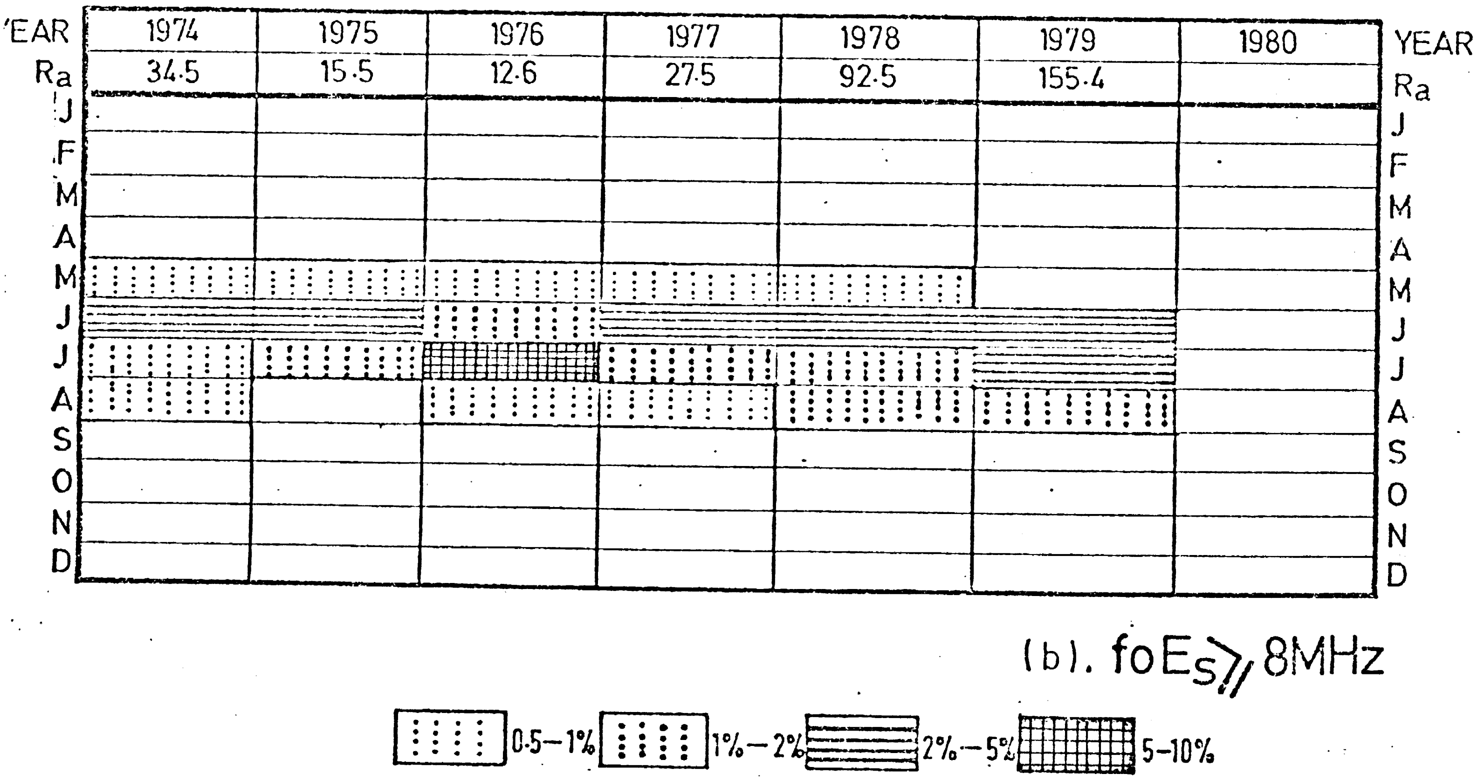


Figure 5. Monthly incidence of sporadic E at Slough. Percentage of all hourly observations with (a) foEs ≥ 4 MHz and (b) foEs ≥ 8 MHz

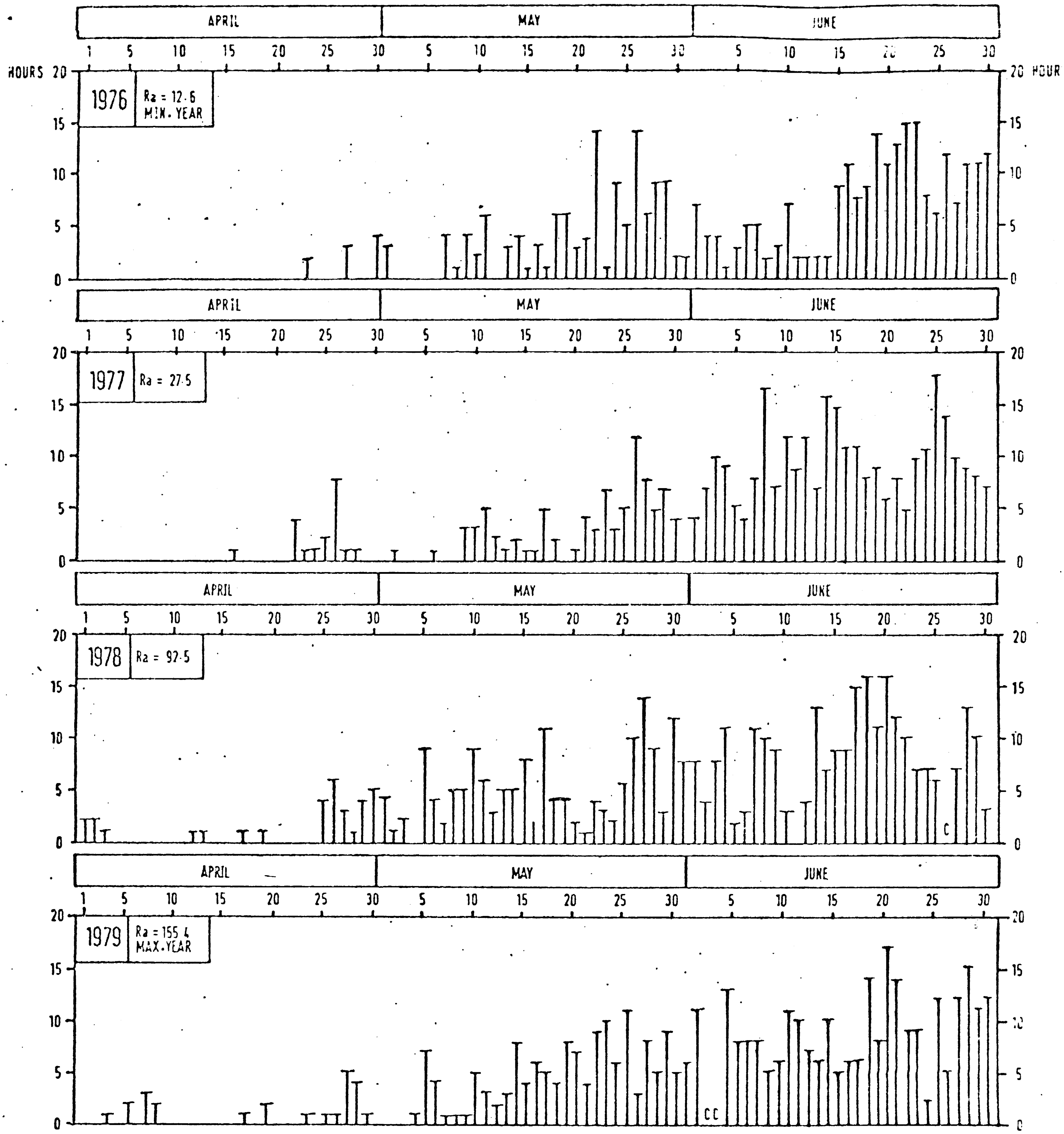


Figure 6. Numbers of hours per day with foEs ≥ 4 MHz at Slough

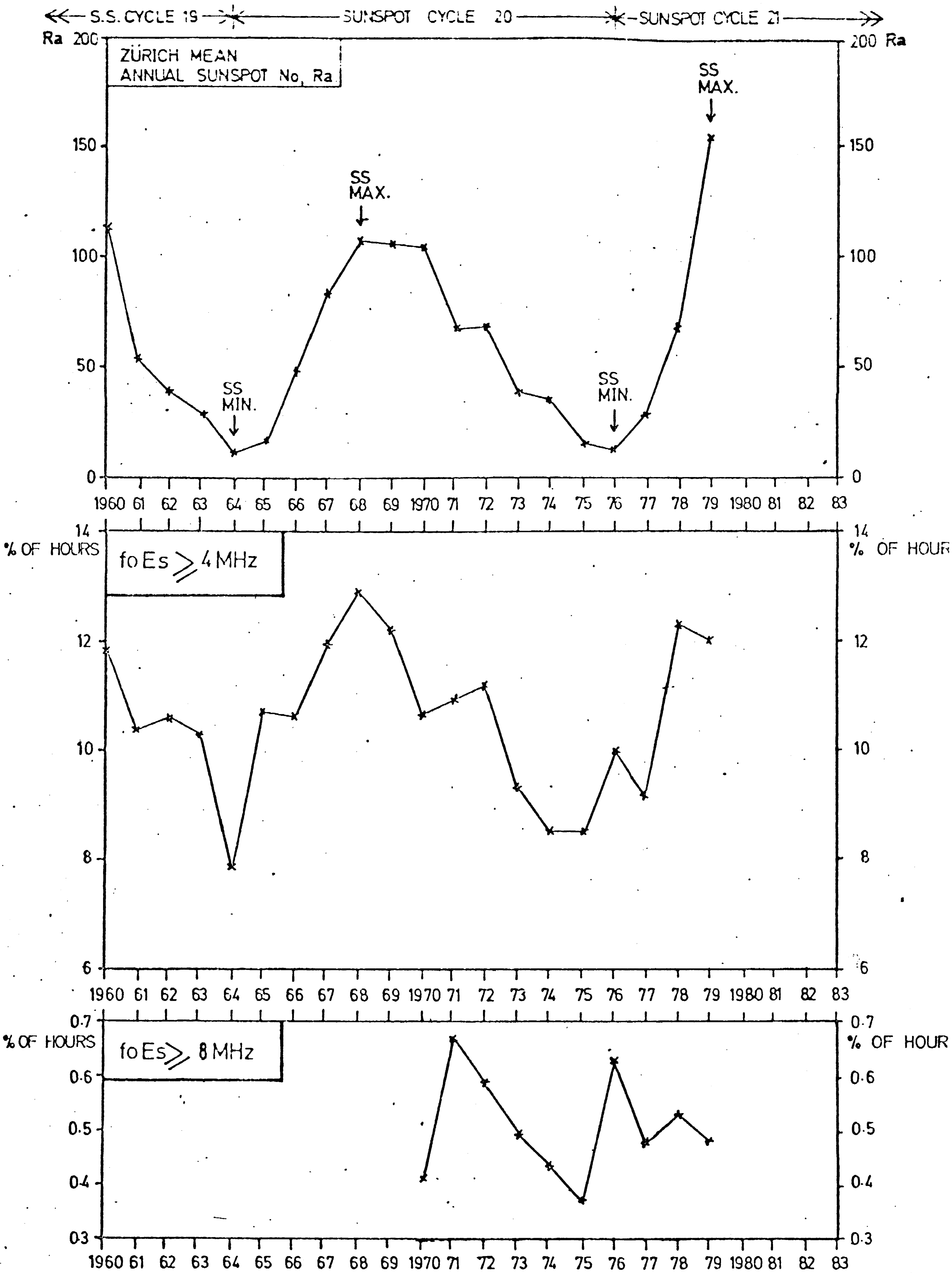


Figure 7. Yearly variation of Es incidence at Slough and solar activity

PART II - POSSIBLE FUTURE STUDIES

9. Discussion

Dr. Piggott noted that the UK is at slightly lower geomagnetic latitudes than when ionospheric sounding first commenced, due to the secular motion of the geomagnetic pole. Although the shift is very small, in sub-auroral regions the effect on Es may be significant. Hence in Scotland, for example, this may be the cause of changes in the relative occurrences of auroral and mid-latitude types.

Mr. Bradley stated that not all Es types classified from ionograms have equal importance to oblique propagation and that there have been discussions within INAG aimed at restricting the number of categories to those kinds which are most relevant to communications.

Dr. Dickinson remarked that during rocket flights he had observed sporadic E clouds descending and wondered if one type seen on an ionogram can later evolve into another. Mr. Smith confirmed that with sufficient frequency of sounding this can indeed be observed to happen.

Concerning the use of the Phillips' rule (as discussed by Dr. Hughes) Mr. Bradley commented that this is most appropriate to VHF propagation involving the tail of the day-to-day distribution of foEs, corresponding to low probabilities of mode support. The Phillips' rule is an empirical expression based on an assumed exponential variation; this is not a good approximation at HF where values between the median and upper decile need to be estimated. At HF it is probably more appropriate to use the Leftin upper decile, median and lower decile foEs maps together with a different form of interpolation. Dr. Hughes agreed but mentioned other limitations in these maps. In particular the lower decile values are influenced by occasions when the foEs value is below the minimum frequency that can be observed by the ionosonde. Dr. Williams noted that both the Leftin and Smith maps suffer from lack of observational data in certain geographical regions and are too detailed for their accuracy. Mr. Bradley commented that Leftin et al. have also published maps of the ionospheric characteristic fbEs.

Mr. Bradley asked about the potential of backscatter as a diagnostic tool to which Professor Shearman replied that the large antenna required is a major limitation, but such a system involving the use of a long linear array is currently operational from a site in Southern England; this is also being used as a sea-state sensing radar in a joint Birmingham University and Appleton Laboratory research project. The advantages of providing synoptic information on the size and motion of Es patches can be retained, whilst costs are reduced, if synthetic-aperture techniques are employed. However, there is a need then for filtering of results to eliminate double images when the backscatter is from the sea surface. These arise from the Doppler shift imparted to the radar signal by the presence of sea waves.

Dr. Piggott pointed out that the area and intensity of Es patches are correlated, and this may be of value in diagnostic applications.

Mr. Bradley commented that insufficient use is made of the large quantities of sporadic E event data available from the amateur radio community. One problem with these data mentioned by Dr. Dickinson is that meaningful statistics require a knowledge of the times of all observational periods, including those with no event reports. Dr. Piggott raised the further difficulties of not knowing the locations of ionisation patches responsible for Es events - indeed, whether these are mid-latitude or auroral. Direction-finding studies on a UK-Cyprus path had shown that often propagation was via Es irregularities in the auroral oval.

Professor Shearman expressed some disappointment that there had not been more discussion of the physical causes of Es formation, but Mr. Bradley explained this had been a deliberate policy in view of the time available. Dr. Piggott confirmed that there is now less scientific interest in Es, but for practical applications there are still many problems to be solved. For long paths, blanketing effects tend to be the most important because few systems have antennae with sufficient gain at low elevation angles to exploit Es reflections. He also offered the opinion that oblique sounders have never fulfilled their potential in this, as in other, fields. Those built by engineers work well but have not been fully exploited, whereas those designed by scientists never function properly!
Dr. Williams pointed to the practical advantages of real-time adaptive systems relying on Es when present in the way that meteor trails are used in meteor-scatter systems.

1. User requirements for Es information

(Mr. L.W. Barclay, Home Office)

The term user is taken in this context to encompass all forms of communication including broadcasting. Effects of sporadic-E ionisation may be beneficial or detrimental. The principal source of Es data is vertical-incidence sounding and the implications to oblique mode support need to be better understood. For example, Es can extend the range of usable frequencies - how is the top frequency related to foEs as observed on a midpath vertical-incidence ionogram? Rules concerning ionogram interpretation have altered throughout the years but in some instances the analysis of old data may be preferable to collecting new results.

Ionisation at HF is an essential part of the communication link whereas at VHF its role is mainly to support interfering signals. Table 1 summarises user requirements for Es information in both these frequency ranges.

The designer of an HF communication system needs to know how often Es is likely to affect propagation modes over the planned link. If Es-produced extensions to the usable frequency range are to be exploited fully then the probability of occurrence of a given foEs value must be known. Suitable antennae should be used with a vertical directivity matched to the raypath directions. Information is wanted on likely field strengths as a function of foEs and signal frequency. Estimates of the signal dispersion, distortion and Doppler shift are required in order to optimise the data transmission modulation. System designers also require an evaluation of the potential detrimental effects of Es, such as blanketing of modes otherwise reflected from higher ionospheric layers and interfering signals reaching the receiver via Es reflection.

It is desirable for an HF system operator to be able to recognise Es propagation when present. Information is wanted on how long such conditions are likely to last and what signal frequency would be best. Knowledge of the probability of Es mode occurrence would aid decisions and any precursor of Es effects could be used to warn operators of a desirable frequency change.

VHF system planners must assess the probability and severity of interference from other transmissions caused by the presence of Es. The geographical regions from which interfering signals are most likely to originate needs to be examined. The duration of bursts of interference is of great importance, long periods of incessant interference usually being less acceptable than disruptions which are brief yet more frequent. Figure 1 shows the distribution of durations of Es-supported signals (events) received during summer on 69.65 MHz at Tunbridge Wells. Few events are long lived, less than 10% exceeding 20 minutes and half less than

2 minutes. Figure 2 summarises other results of a study of numbers and integrated durations of events which exceed one minute. The observations were made at the University College of Wales, Aberystwyth between 1972 and 1976 at three frequencies: 59.25, 62.25 and 77.25 MHz. Occurrence is seen to drop with increase of frequency and to be greater for years of higher solar activity.

For VHF operations there is little scope for adaptation as propagation conditions change, particularly with broadcasting services for which frequencies must be pre-planned; nonetheless precursors of disturbed conditions, if available, would still be of considerable value.

Table 1 - User Requirements for Es Information

HF		VHF
Planning	Operations	Planning
Occurrence	Recognition	Occurrence
Usable Extension to Frequency Range	Duration	Interference Level
Antennae	Selection of New Frequency	Range of Interfering Transmitters
Signal Strength	Probability of Occurrence	Duration
Dispersion	Precursors	
Blanketing		
Interference		

Figure 1. Durations of Es events observed at Tunbridge Wells between 10 June and 4 August 1980

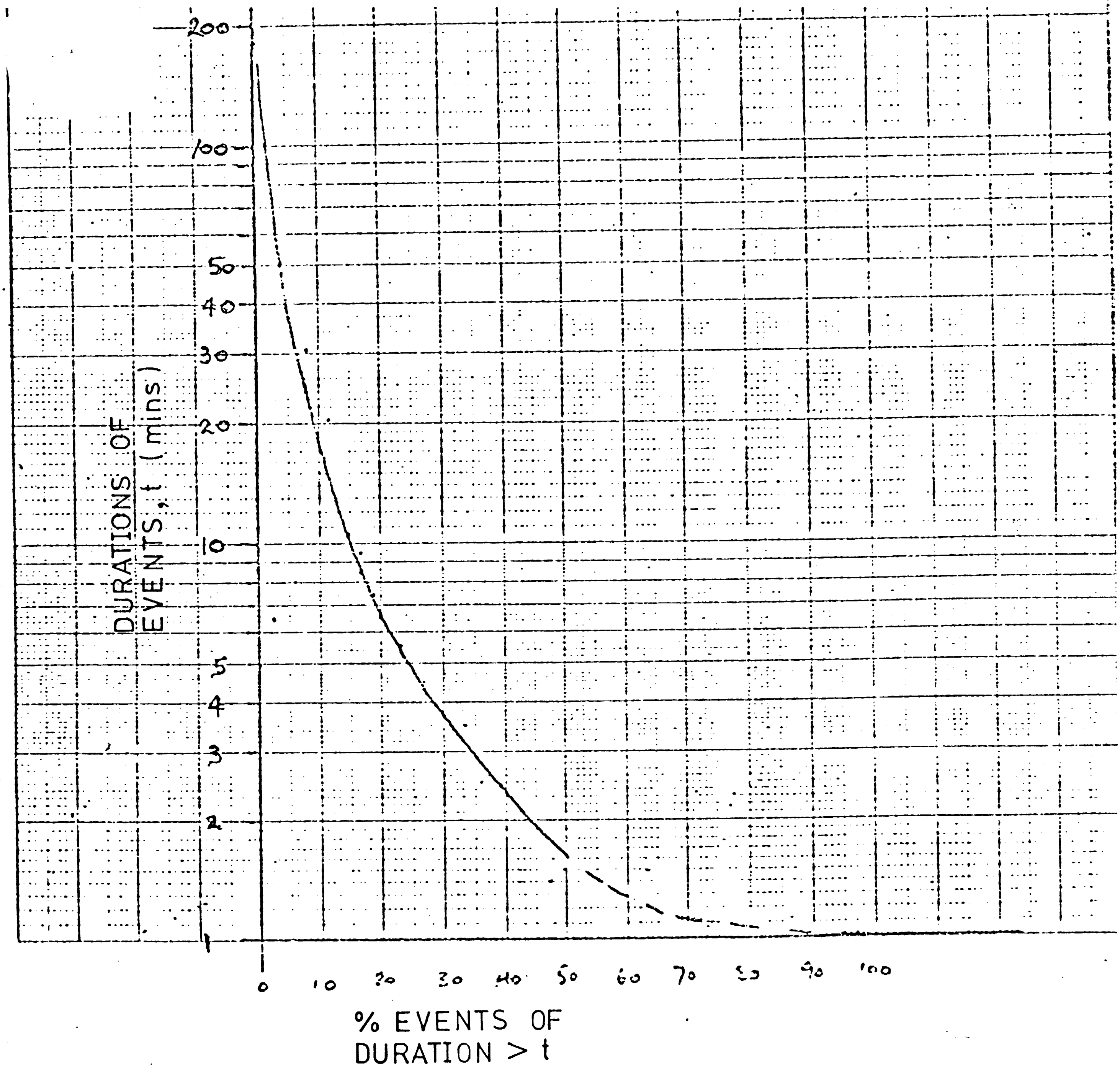
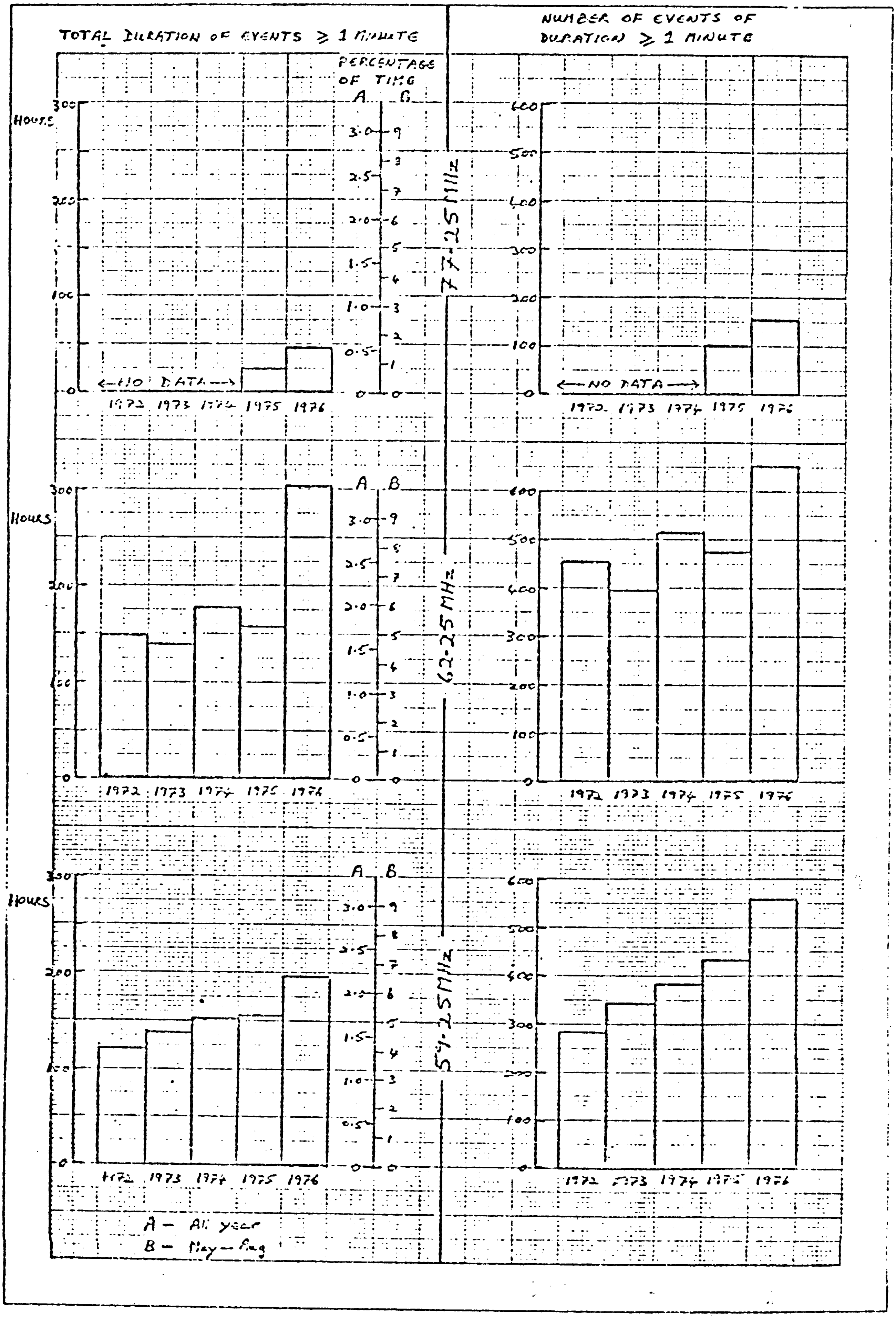


Figure 2. Total durations and numbers of Es events lasting for more than one minute observed at Aberystwyth on 77.25, 62.25 and 59.25 MHz between 1972 and 1976



2. Discussion

Mr. Bradley opening the discussion on future research requirements to yield data to meet user needs, suggested concentration on a few priority topics. Programmes would then be optimised for these specific features. Mr. Barclay confirmed that he views event durations as a subject for which more information is needed urgently. Mr. Bradley listed various available research techniques discussed in the symposium (see table 1) and invited comments on their relative merits and cost-effectiveness. Mr. Barclay stated that in his view the high expense and undesirable large transmitter powers necessary with backscatter radar, coupled with difficulties of data interpretation make this approach rather unattractive. Professor Shearman, however, emphasised again that backscatter offers a way of observing the distributions and motions of Es clouds; it can be of particular value as a real-time adjunct to broadcasting operations in assessing receiving site or service-area coverage.

Dr. Mitchell announced that equipment and expertise exist at Exeter University for studies of Es involving vertical or oblique-path observations. Dr. Bain questioned if a few complex monitoring facilities, for example the NOAA advanced sounder, are likely to be more productive than a network of conventional vertical sounders, which, in view of the lower unit costs, could be more extensive. Mr. Bradley pointed out the relevance of the work of Turunen in Finland using a specially-adapted vertical-incidence ionosonde which also measures the received echo field strength. Dr. Bain advocated work attempting to correlate ionosonde fbEs and foEs data with oblique-path HF signals.

Mr. Bradley stressed again the value of amateur networks in the extensive numbers of propagation paths that can be monitored and expressed the hope that in future it may be possible to use more effectively the types of data that Mr. Flavell had shown are being obtained by radio amateurs.

In closing the meeting it was generally agreed that there are a number of important areas in which further Es data are needed. Steps should be taken to make good the deficiencies, and the most effective ways are likely to involve combinations of available techniques. More information on event durations has high priority and studies involving vertical and oblique-path measurements, together with appropriate theory, offer most obvious potential for meaningful new results.

Table 1 - Available Techniques for Sporadic-E studies

Vertical sounding.

Backscatter sounding.

Oblique-path signal measurements.

Amateur networks.

Theoretical investigations.

ANNEX

List of Attendees

Dr. D.J. Bagwell	Birmingham University
Dr. W.C. Bain	R & AL
Mr. L.W. Barclay	Home Office
Mr. A.H.B. Bower	RSGB
Mr. P.A. Bradley	R & AL
Dr. E.N. Bramley	R & AL
Mr. S.M. Broom	BAS
Mr. C. Coward	Cable & Wireless
Mr. M.I. Dick	R & AL
Dr. P.H.G. Dickinson	R & AL
Mr. R.J. Eaton	BBC Research Department
Mr. K. Feldmesser	R & AL
Mr. R.G. Flavell	RSGB
Mr. R. Fricker	BBC External Services
Mr. D. Green	Marconi Research Laboratories
Mr. M.H. Green	GCHQ
Mr. G. Gorman	Leicester University
Mr. R. Herring	Marconi Research Laboratories
Dr. K.A. Hughes	Home Office
Mr. R.M. Hunt	Exeter University
Mr. J. Hodgson	RSRE
Mr. M.J. Jarvis	BAS
Professor T.B. Jones	Leicester University
Dr. L. Kersley	University College of Wales
Dr. M. Lockwood	R & AL
Dr. R.Y. Liu	R & AL
Mr. G. May	RAE
Mr. J.D. Milsom	Marconi Research Laboratories
Dr. V.B. Mitchell	Exeter University
Dr. J. Pennington	ASWE
Dr. W.R. Piggott	INAG
Mr. L.J. Prechner	BBC External Services

Dr. H. Rishbeth	R & AL
Mr. A.J. Rodger	BAS
Mr. J.C. Samuel	R & AL
Dr. A.K. Sen	Calcutta University
Professor E.D.R. Shearman	Birmingham University
Mr. P.A. Smith	R & AL
Mr. R.W. Smith	R & AL
Dr. S. Theodoridis	Birmingham University
Mr. A.P. Van Eyken	R & AL
Mr. R. Warrington	Leicester University
Mr. R.G. Wilkinson	ASWE
Dr. H.P. Williams	ex-SHAPE Technical Centre
Mr. E. Winstanley	GCHQ
Dr. L. Wyatt	Birmingham University