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A Study of the Origins of Microwave Fading on Terrestrial Microwave Links.

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A Study of the Origins of Microwave Fading on Terrestrial Communications Systems.

A Final Report under

Department of Supply and Services

Contract # 36001-8-3515

submitted to

Communications Research Centre,

Department of Communications,

Ottawa, Ontario, Canada.

Principle Investigator: A. R. Webster.

Research Associates: H. Wong, S Jantzi.

December, 1988.

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I. Introduction.

The primary objective of the work described in this report was the processing of data accumulated over previous fading seasons, together with that expected to be added in 1988, from the operation of a microwave system developed to measure angles-of-arrival (AOA) on a typical terrestrial microwave link. The system consists of a wide aperture array comprising 16 vertically spaced receiving antennas and a reference antenna situated close to the centre; a description of the system may be found in the final report of a previous contract [1].

A second objective was, if practicable, to relocate the equipment to another link in Eastern Ontario (Kemptville-Avonmore) where other related experiments were scheduled to be operated by other parties. In the end, the system was moved and installed in August 1988. As a result, useful data have now been obtained for three separate links; Uniondale/University of Western Ontario (31 km.), Russelldale/London RR (41 km.) and Kemptville/Avonmore (51 km.).

Developments also were continued on a microprocessor controlled vertical acoustic sounder designed as a replacement for the standard commercial unit (supplied by C.R.C.) which provides valuable ancillary data on the occurrence of atmospheric layers and which are largely responsible in one way or another for multi-path propagation. This unit was completed and installed at Avonmore, though very late in the season and mainly as a check on its operation and in anticipation of further measurements in 1989.

II. Equipment Developments.

The microwave system itself was essentially unchanged from that described in the previous report. However, a major improvement was made in the actual collection of the raw data which consisted of amplitude and phase from each of the 16 elements plus the amplitude of the reference antenna taken in a period of about 50 msec. and repeated once per second. Previous recording of these data was on 9-track tape situated at the receiving site with control being exercised by a microcomputer also at the site. While manageable when operated reasonably locally, the operation of the tape recorder was in many ways very inconvenient. These difficulties certainly would be exacerbated by distant location and for these reasons a system for remote operation via a dedicated telephone line was developed.

In the new scheme, the original microcomputer is used remotely at the receiving site to operate the microwave system, oversee the scanning of the array and capture the raw data; this aspect remained unchanged from previous procedure. Overall control is assumed by a second microcomputer at "headquarters" which operates via the modem/telephone-line as shown in fig.II-1. Codes sent by the control computer initiate appropriate actions at the remote end and oversee such operations as the phase locking of the receiver (this is especially useful since very wide swings in temperature in the building were experienced). Data from the array is manipulated and sent once per second down the line to the control computer for storage on 9-track tape; blocks of one minute of such data (2 kBytes) are stored and each 2400 foot tape holds about 87 hours of data.

Program options have been refined so that the system is fully automated. In the event of a power outage at either end of the system, operation at the other end is suspended until a signal is received indicating the restoration of power whence full operation is restored at the beginning of the next minute. This includes the tape drive itself which normally requires manual restart; hardware modifications were made to facilitate this.

Development of the microprocessor controlled acoustic sounder was completed and the unit successfully tested in the field. The microcomputer oversees all operations including generation of the transmitted pulse, receiver gain variation, analog-to-digital conversion of the return signals and storage on hard disk for eventual transfer to magnetic (cartridge) tape. Real time graphical output is produced using a standard dot matrix printer.

III. Experimental Results.

III.1 The Wide Aperture Array.

This system has now been operated on three separate links; Uniondale-UWO in the fall of 1986 and spring, 1987; Russelldale-London RR fall, 1987 and spring, 1988; Kemptville-Avonmore fall, 1988. The first period in the fall of 1986 was described in the last report [1]; some results from the other four observational periods are presented here. Path profiles of the three links are shown in fig. III-1

The basic treatment of the original data consists of Fourier transformation of the complex amplitude across the array obtained at each 1 second interval. This results in a record such as is shown in fig.III-2 in which the individual rays in a multipath situation are resolved, provided they are separated in angle by more than the basic resolution of the system (approx 0.13^{o}). From this point, routines have been developed to extract the required information such as the statistics presented shortly. Dolph-Chebychev 40 dB weighting is used routinely to reduce side-lobe levels. However, to avoid possible contamination from such lobes, a limit of 20 dB down from the strongest ray is used in recording the presence of rays as indicated by the peaks. Rays are labelled 1, 2, 3,..... in descending amplitude, from the strongest, in a given record.

The distribution in angle-of-arrival of the three strongest rays for the different observing periods are shown in figs.III-3 to 6 inclusive. A feature common to all is the tendency towards elevated AOA for the strongest ray clearly indicating atmospheric origin; it should be noted that only records involving at least two resolved rays are included in these statistics. The distribution of the weaker rays is more wide-spread with some indication of significant features.

Fig.III-7 shows the separation of the two strongest rays during multipath propagation for each of the observational periods. The resolution is such that separations of less than about 0.13° are not accessible. The consistent peak at about $\pm\ 0.2^{\circ}$ appears to be real and is in line with the predictions of ray-tracing (see [2] for example).

All of this suggests that multipath rays occur well distributed within a range of about $\pm\ 0.5^{\circ}$, or perhaps a little more, of the AOA of the normal single path value. An example of severe fading of the reference signal is shown in fig.III-8. The details of the behaviour of the multiple paths as seen by the wide aperture array during this fading are shown in fig.III-9. Here the top trace is the reference channel amplitude while the other two represent the amplitude and AOA of the individual rays as indicated by the Fourier transform output with the restrictions outlined above applied (see fig.III-2); in the AOA plot, the line width is a measure of the amplitude of the individual ray which may be gauged more accurately from the centre plot. The complexity of the situation is apparent, though the predominance of elevated rays is to be noted.

III.2 The Vertical Accoutic Sounder.

Much of the effort here has been devoted to the development of a reliable and versatile instrument. Some data have been accumulated from the operation of the system, though much remains to be done in the way of analysis. Examples from the simultaneous operation of the microwave system and the sounder while operating on the Russelldale-London link are shown in figs.III-10 to 12. While the sounder was located close to one end of the microwave link, rather than near the middle, a good deal of correlation between the presence of layers, as indicated by the sounder, and the occurrence of anomalous propagation has been observed. Broadly speaking, elevated layers produce atmospheric multipath provided that the height of such layers is not too great. On no occasions was multipath observed where a layer occurred at a height greater than about 180 m. above local ground level. Again this is consistent with the predictions of ray-tracing.

IV. Discussion.

A considerable amount of data relating to anomalous microwave propagation has been accumulated over the past few fading seasons and some inroads have been made in the present study into the analysis and interpretation of the information contained within it. Nevertheless, it is clear that much remains to be accomplished and a good deal of extra information awaits extraction.

The distribution of angles-of-arrival seem to be quite consistent with an atmospheric origin as a major source of multiple paths, although low (that is depressed) values of AOA are clearly in evidence. The latter are perhaps best accounted for in terms of ground reflections in which case the spread in AOA seems to favour the idea of diffuse rather than consistent specular reflection from well identified locations. The idea [3] that a substantial fraction of deep fading is caused by a reduced amplitude (defocussed) main ray interacting with small amplitude ground reflected rays is not particularly supported by the evidence so far, although there is room certainly for such a mechanism on occasion and this should not be discounted. This point is of some importance in assessing the main causes of signal degradation and definitive answers should emerge from planned further analysis.

From the limited experience so far, it seems likely that the consistent operation of the microwave system with the acoustic sounder, particularly if the latter is located more favourably, will enhance the available information considerably. The addition of planned direct refractivity measurements over the first few hundred meters in height will add a further dimension to the overall picture.

Acknowledgements.

The help of personnel at Ontario Hydro and, for the more recent experiments, at Bell Canada is gratefully acknowledged; without this help none of this work would be possible. The microwave equipment itself was assembled largely by Tim Merritt for previous measurements and has operated without problems since that time. Assistance from Laura Webster in transcribing the data to graphical form is also noted with thanks.

References.

[1] T.S.Merritt, A.R.Webster and H.Wong, "Experimental Determination of the Structure of Multipath Propagation on Terrestrial Microwave Links", Final Report, DSS Contract# 36001-6-3532, December,1987.

[2] A.R.Webster, "Raypath Parameters in Tropospheric Multipath Propagation", IEEE Trans. Ant. Propagat., AP-30, 796-800, 1982.

[3] R.L.Olsen, L.Martin and T.Tjelta, "A Review of the Role of Surface Reflections in Multipath Propagation over Terrestrial Microwave Links", Proc. NATO/AGARD Symp. on "Characteristics of Modern Systemsof Communications, Surveillance, Guidance and Control", Ottawa, 1986.

Table 1. Equipment Details.

<u>Transmitter.</u>

Frequency...............16.65 Ghz.
Transmitted Power.........80 mW.
Antenna...................0.6 m paraboloid.
  Gain..................37 dB
  Beamwidth.............2.0 deg.
  Polarization.........horizontal.

<u>Receiver.</u>

Reference Channel:
  Antenna..............0.6 m paraboloid as above
  Receiver bandwidth...30 kHz.
  Dynamic range........55 dB
Array Channel:
  Antenna..............Optimum Pyramidal Horns.
    Gain............20 dB.
    Beamwidth.......17 deg.
    Polarization....horizontal.
  Receiver bandwidth...13 kHz.
  Dynamic range........55 dB.

Table 2. Microwave Link Details.

<u>Uniondale - UWO.</u>

Path length...............31 km.
Transmitter height........45 m above local ground.
Receiver height...........25 m above local ground.
Operational Period........April 7 to June 18, 1987.

<u>Russelldale - London.</u>

Path length...............41 km.
Transmitter height........90 m above local ground.
Receiver height...........66 m above local ground.
Operational Periods.......August 6 to November 1, 1987.
......May 6 to July 20, 1988.

<u>Kemptville - Avonmore.</u>

Path length...............51 km.
Transmitter height........51 m above local ground.
Receiver height...........57 m above local ground.
Operational period........August 4 to October 30, 1988.

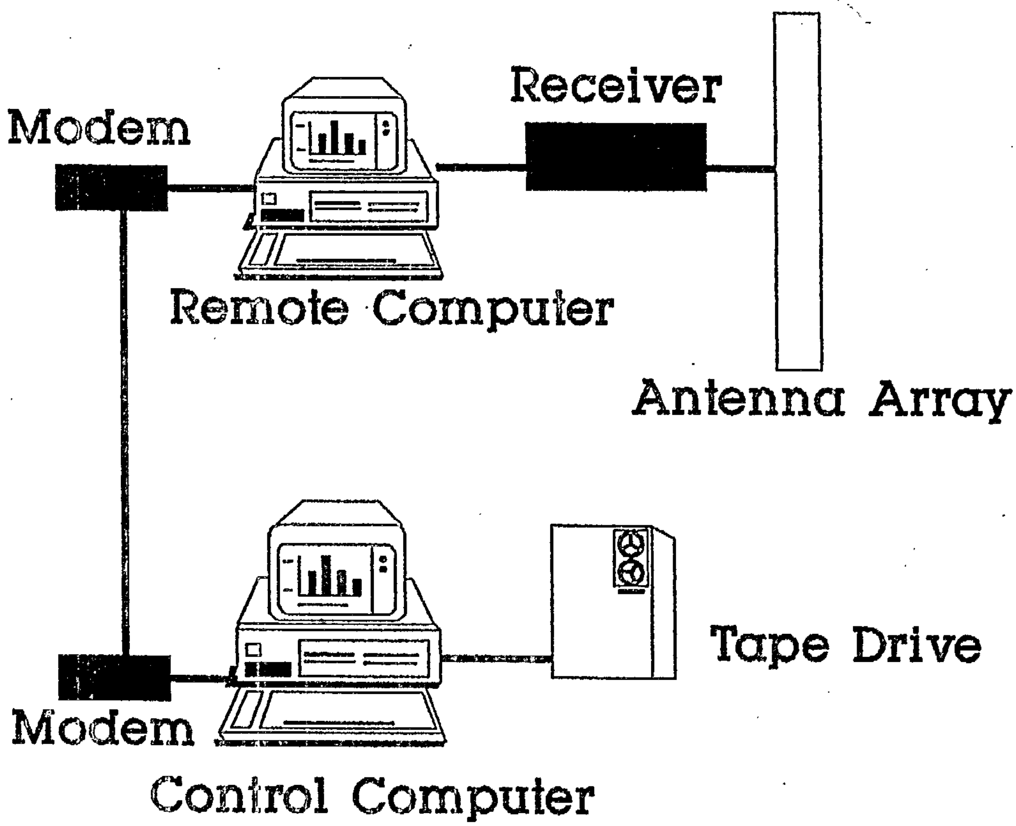

Fig.II-1 The scheme for remote operation of the microwave system.

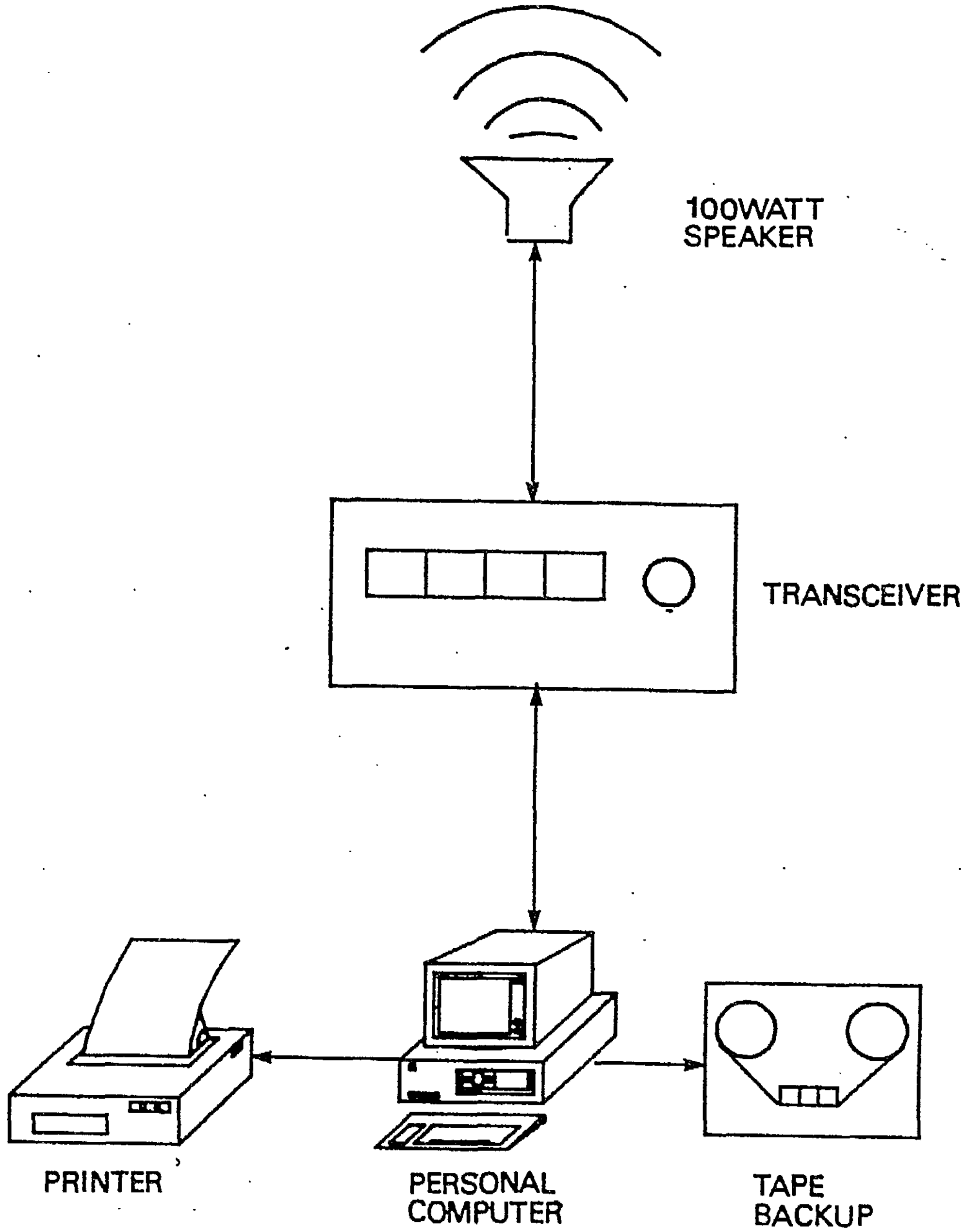

Fig.II-2 The basics of the acoustic sounder.

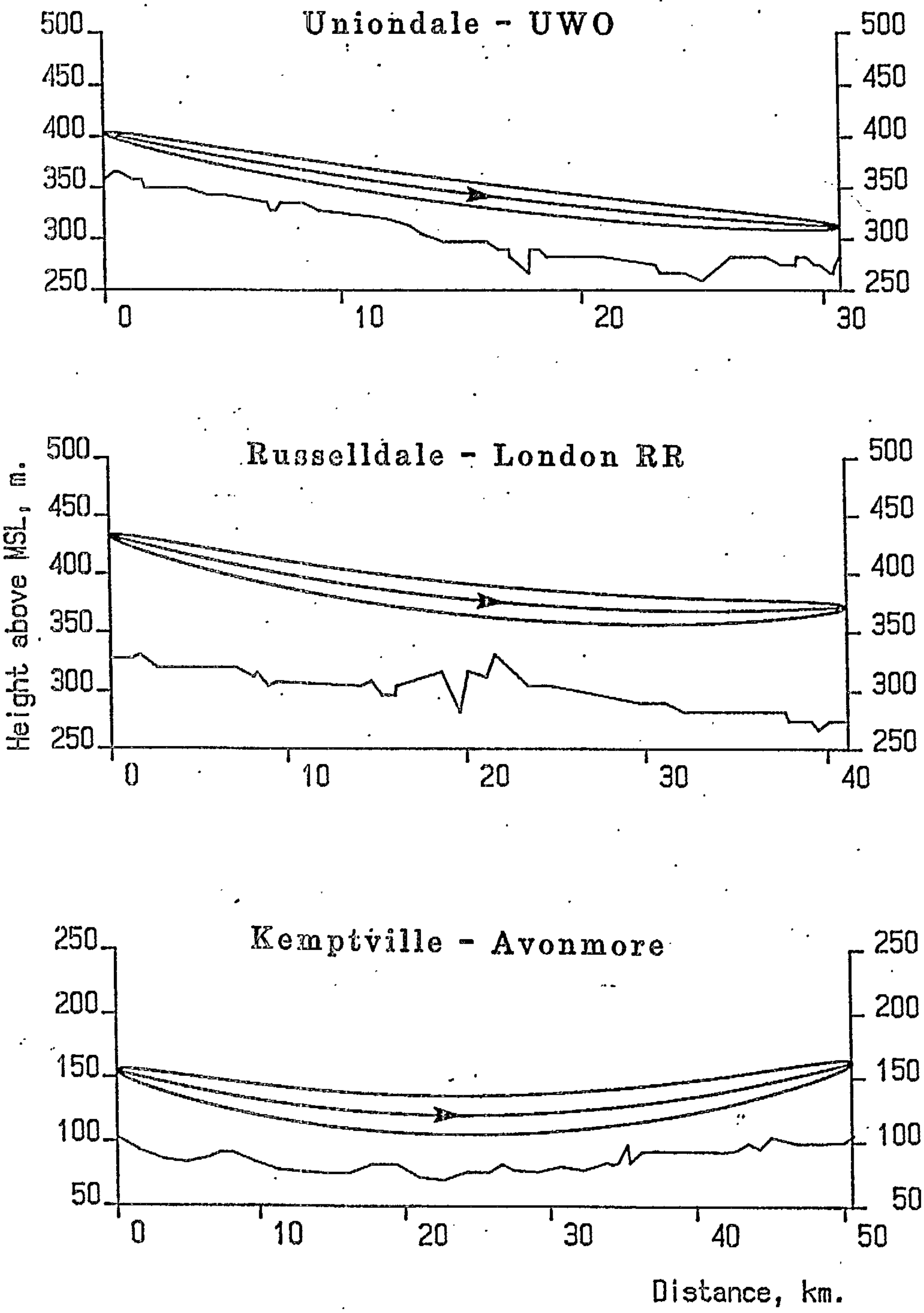

Fig.III-1 The path profiles of the three links used in the colletion of data; K = 4/3 and 1st Fresnel zone shown.

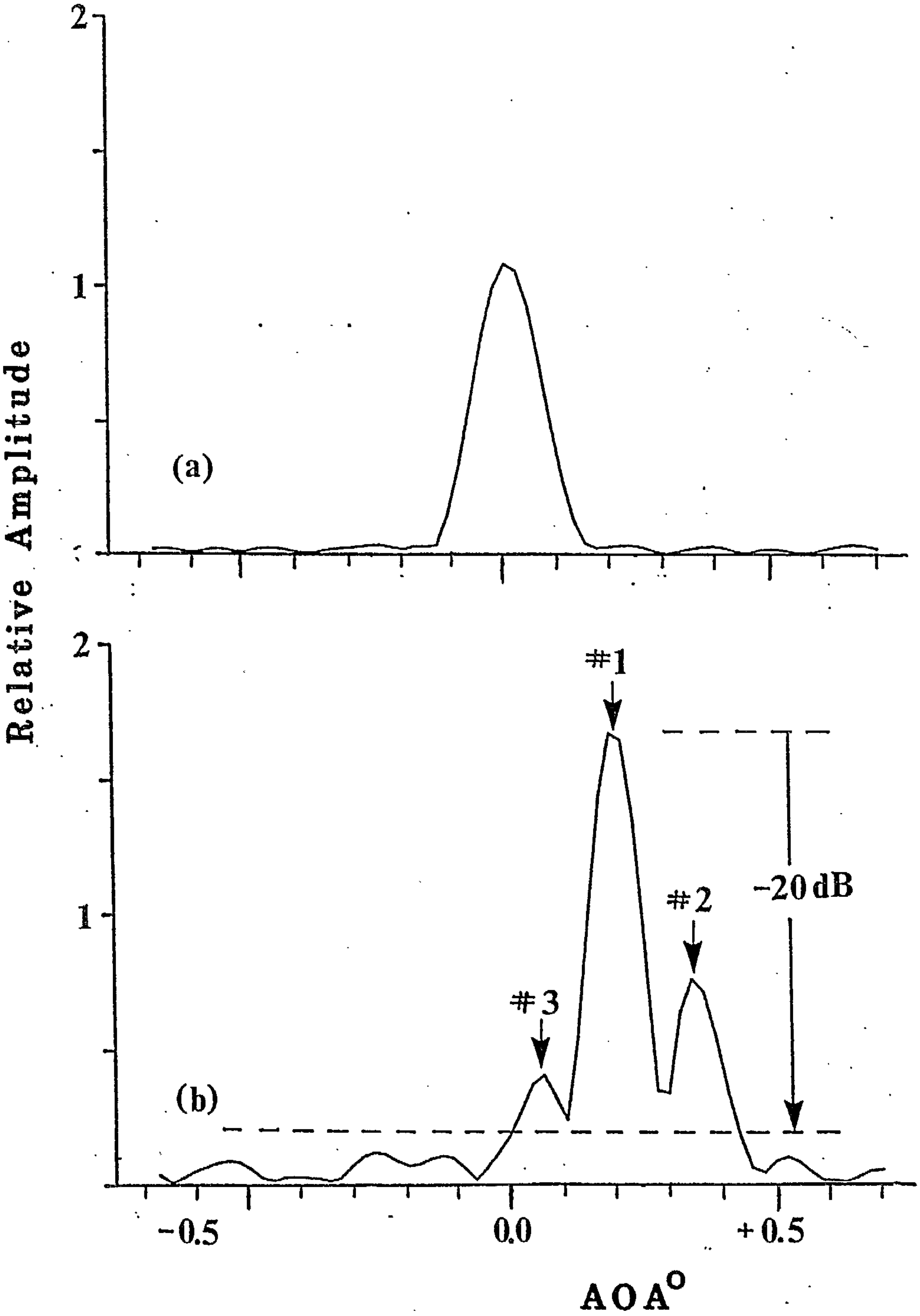

Fig.III-2 Illustrating the output from the Fourier transform routine for (a) normal single-path and (b) multi-path propagation.

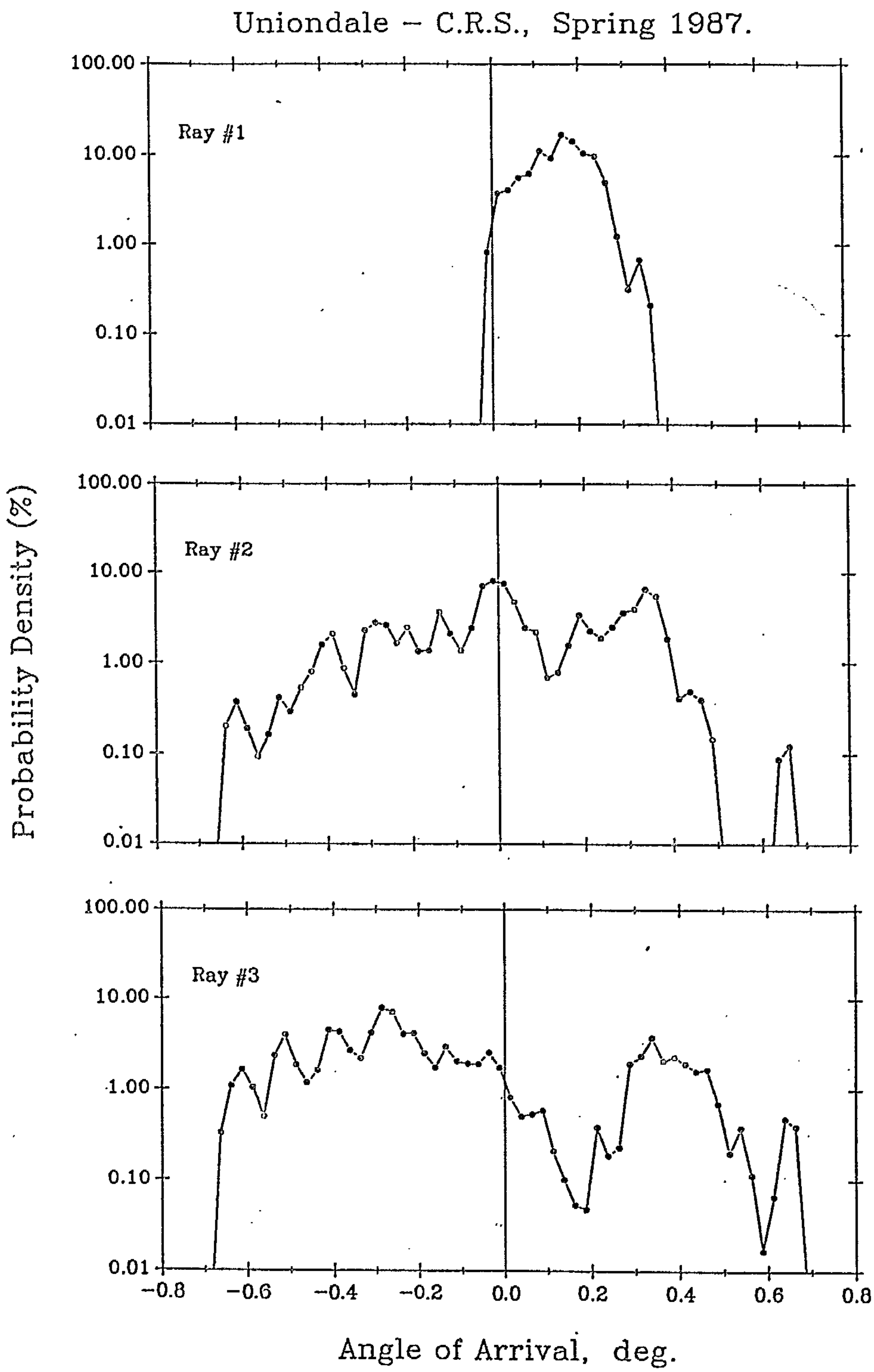

Fig.III-3 The distribution in AOA of the 3 strongest paths. Presented as probability of occurrence within a given 0.025° interval and expressed as a %age of the total. Uniondale/CRS(UWO), Spring 1987.

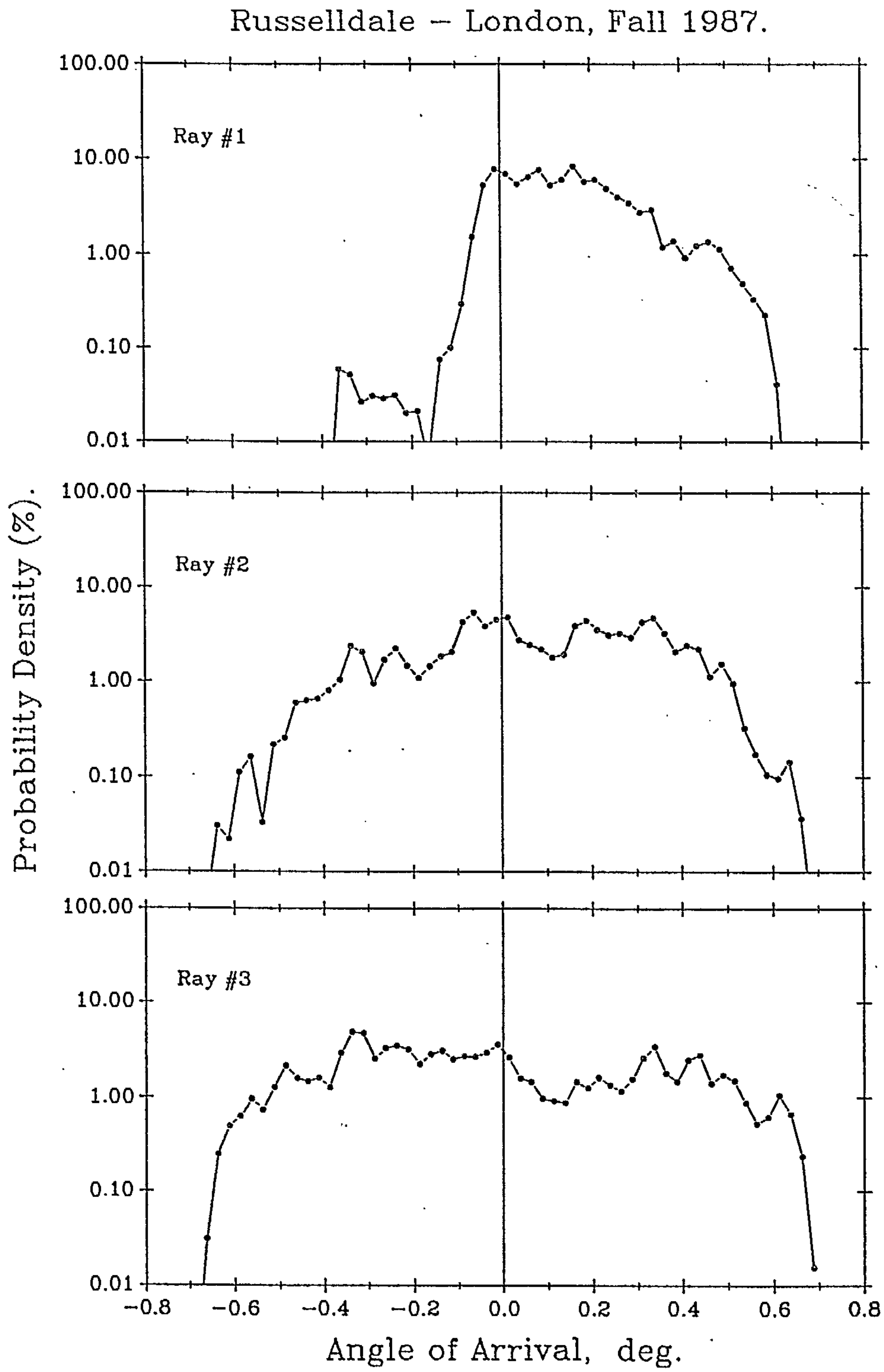

Fig.III-4 As fig.III-3, Russelldale/London, Fall 1987.

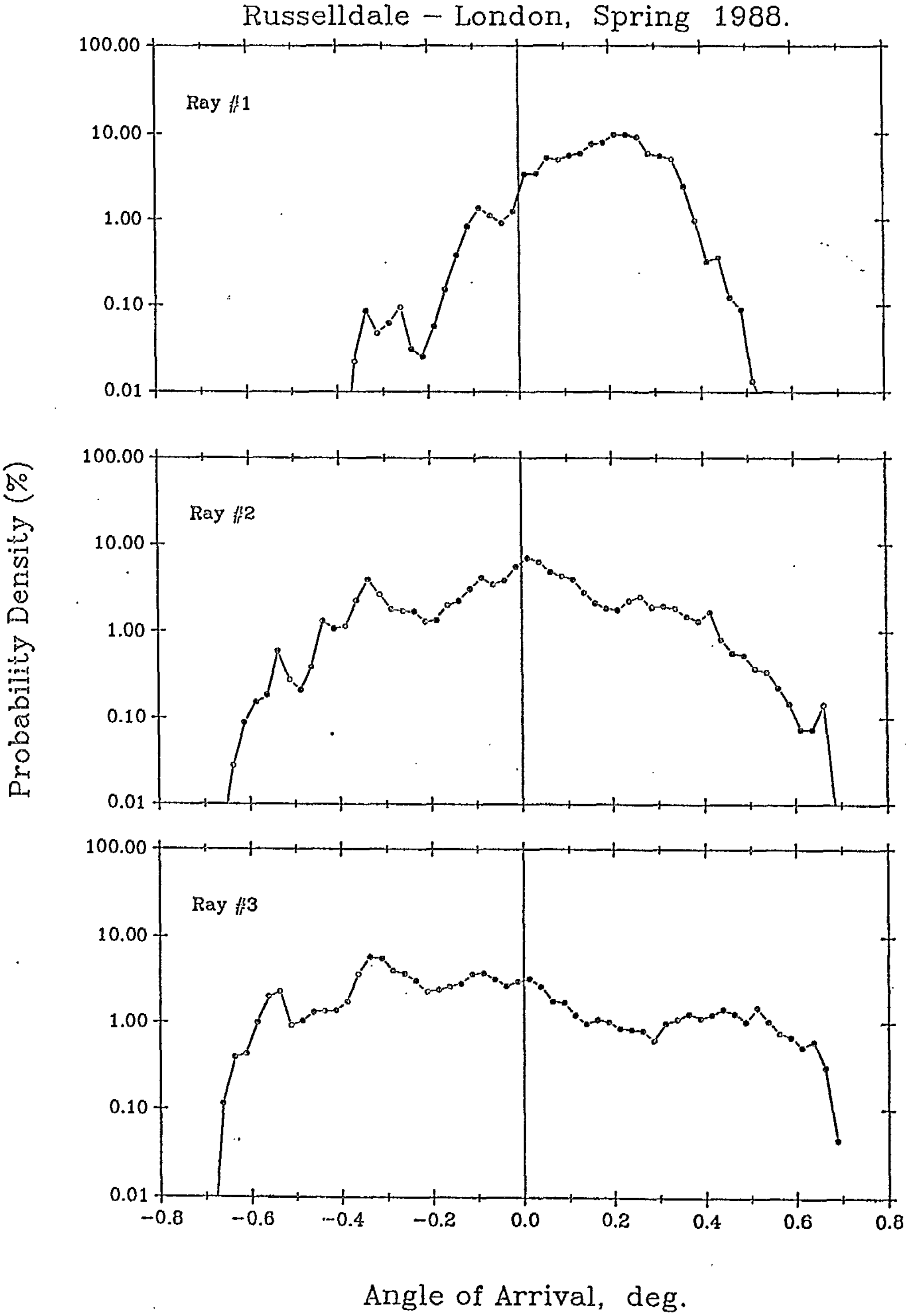

Fig.III-5 As fig.III-3, Russelldale/London, Spring 1988.

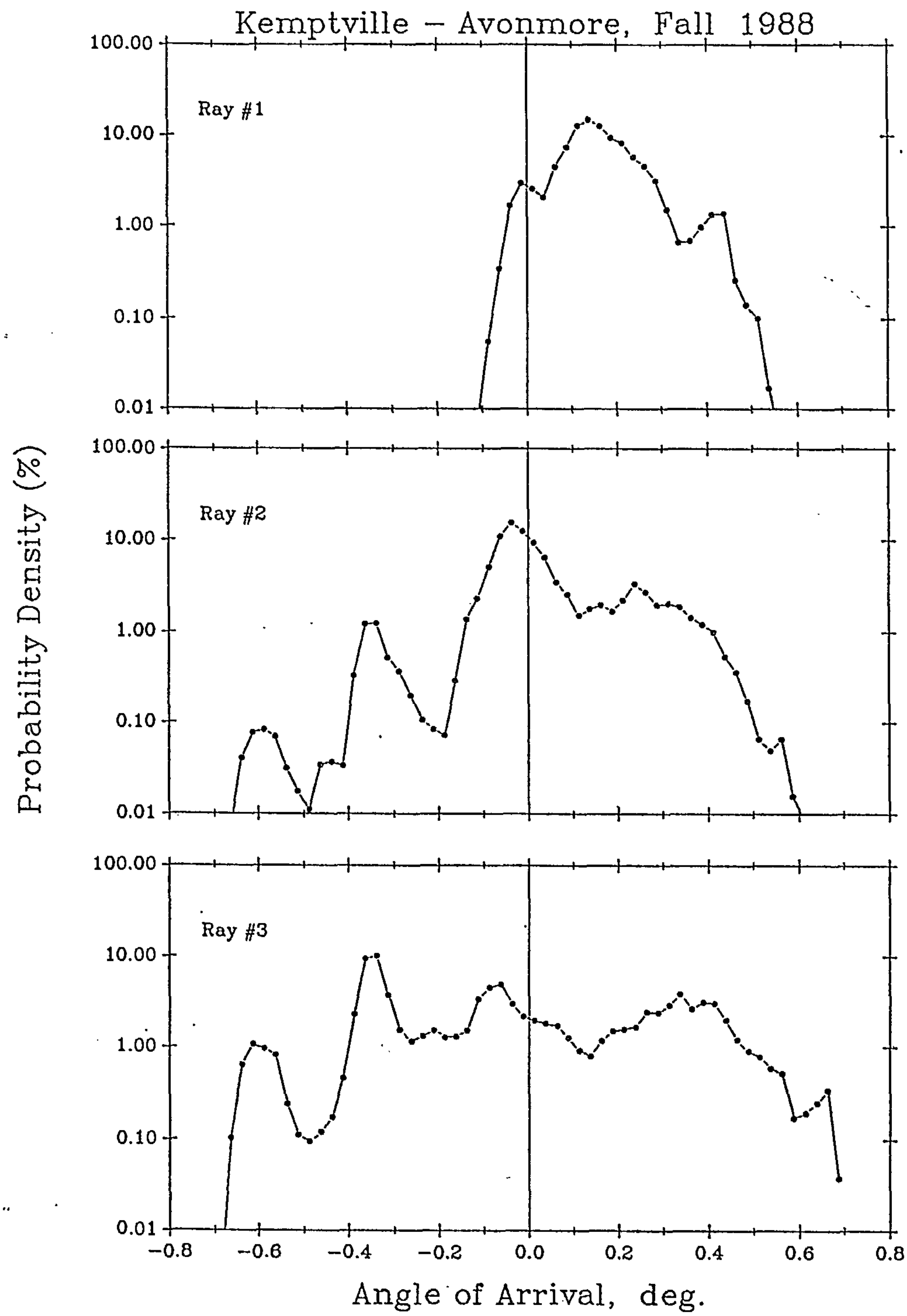

Fig.III-6 As fig.III-3, Kemptville/Avonmore, Fall 1988.

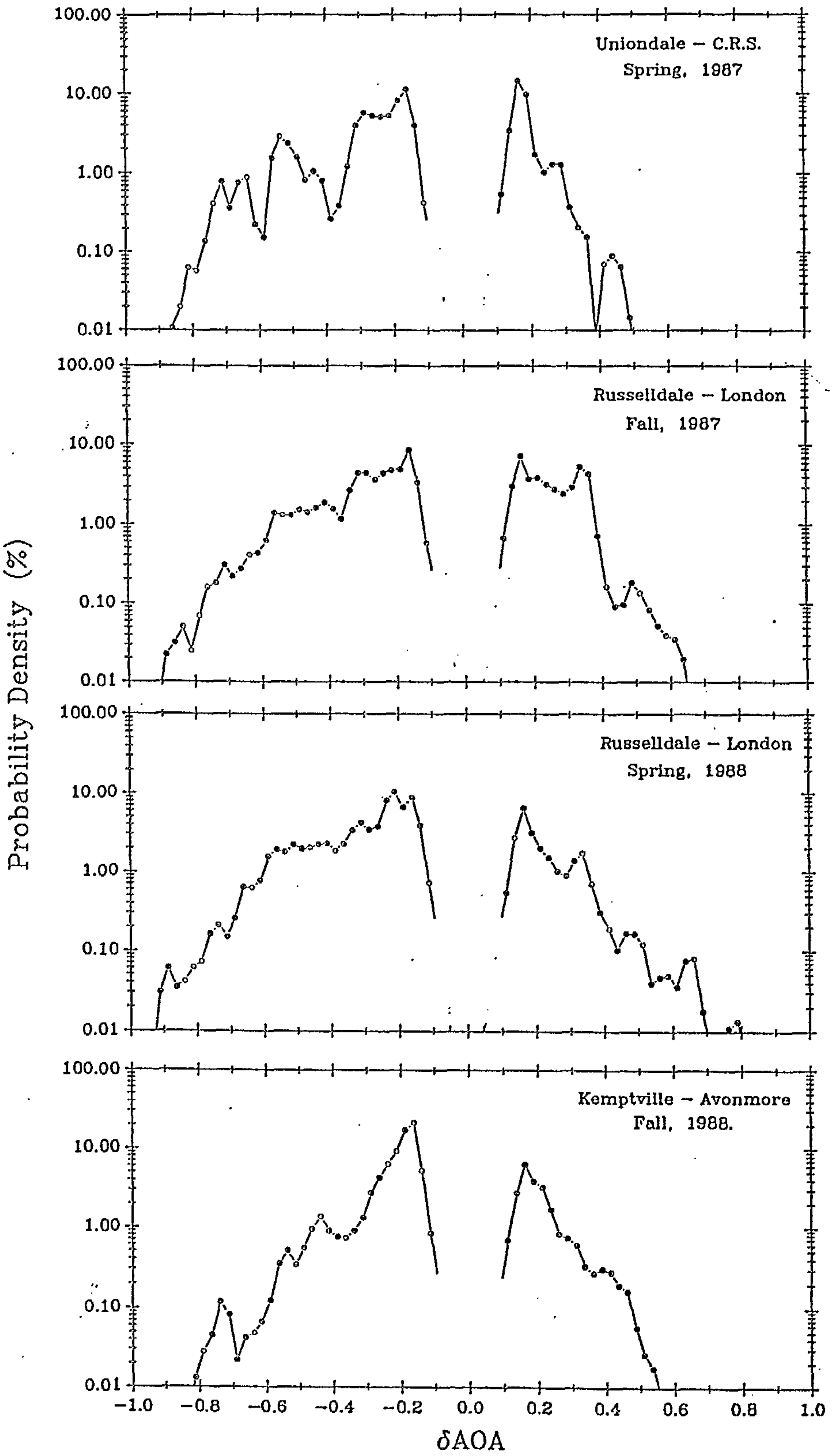

Fig.III-7 Angular separation statistics; AOA of ray#2 relative to AOA of ray#1.

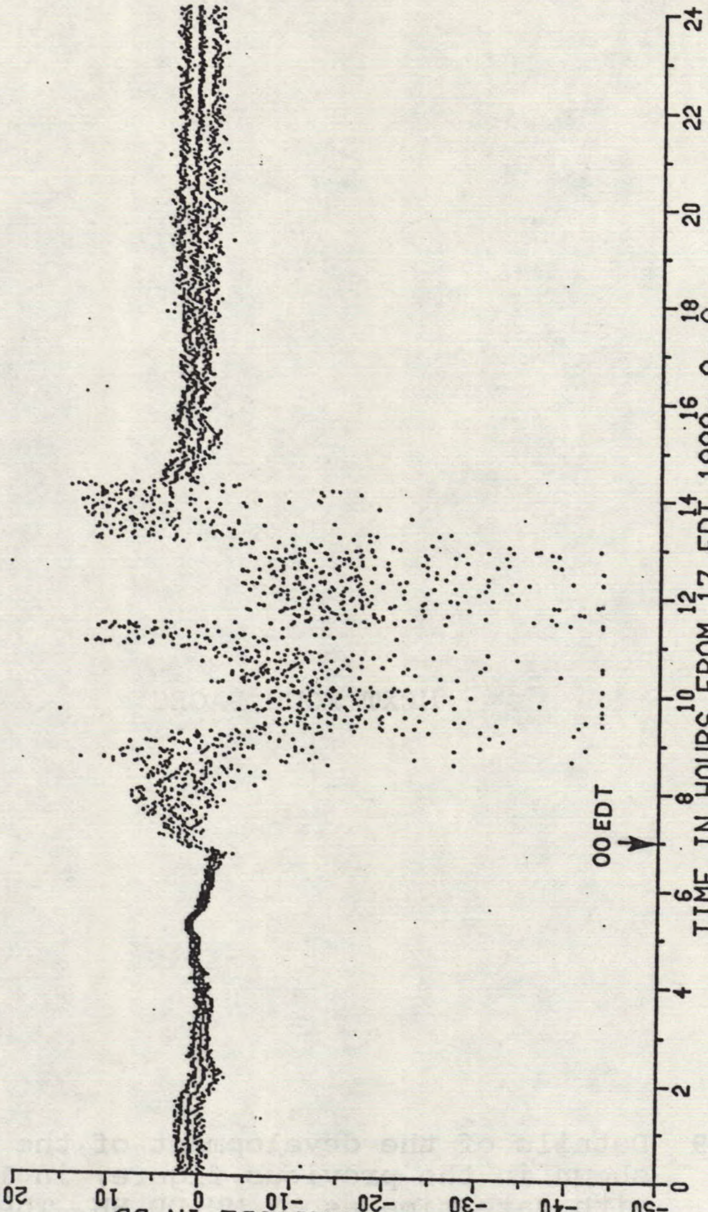

Fig.III-8 An example of fading of the reference channel signal, Kemptville/Avonmore, 1988.

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Fig.III-9 Details of the developmant of the multipath shown in the previous figure; in 1 hour blocks with date/time as YY MM DD HH. The top trace is the received reference amplitude in dBm, normal level -55 dBm. The centre trace is the amplitude of the individual rays as provided by the Fourier transform routine and the bottom trace is tha AOA of these individual rays with line width proportional to the amplitude. The 20 dB limit on weak rays applies (see text).

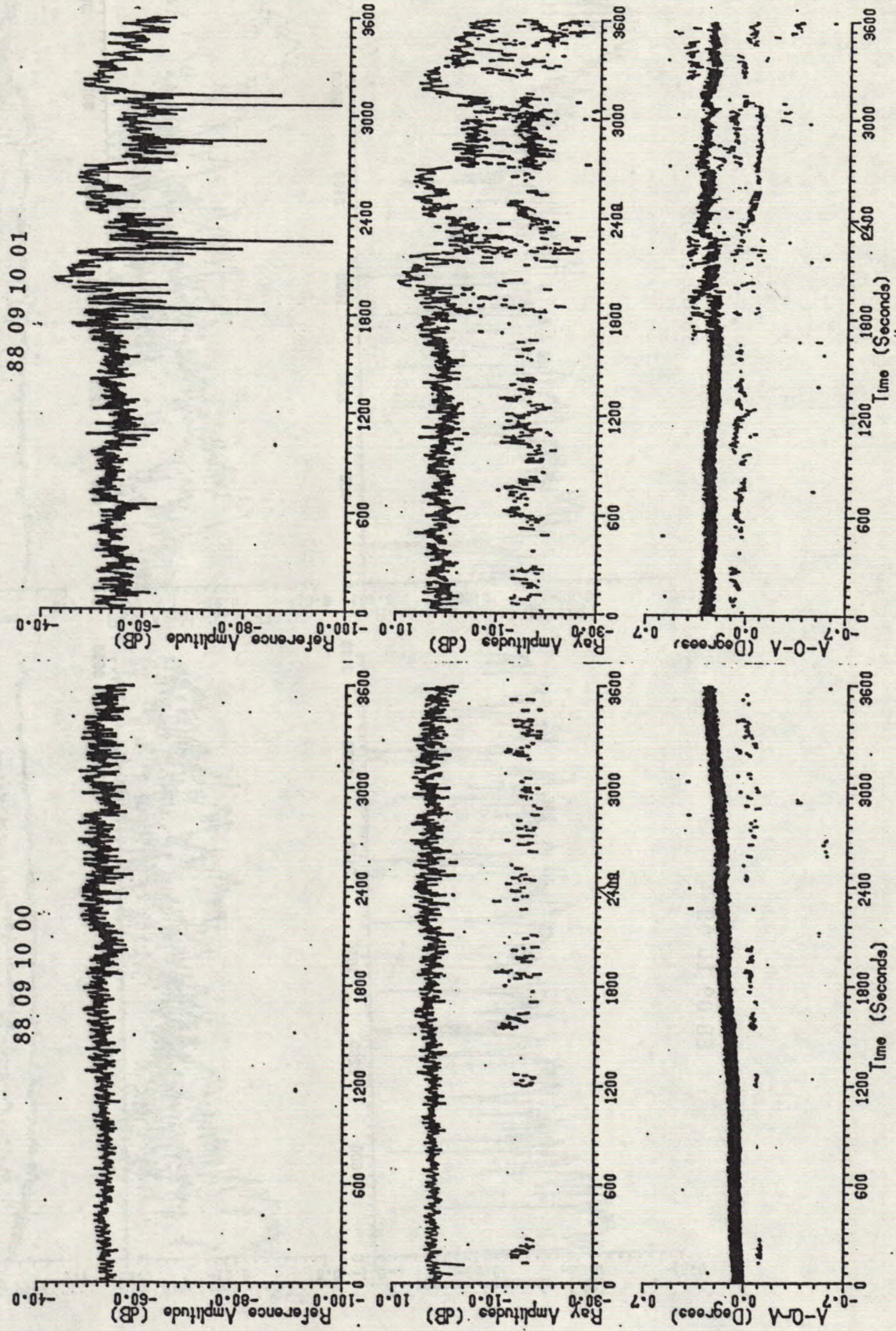


Fig.III-9 continued.

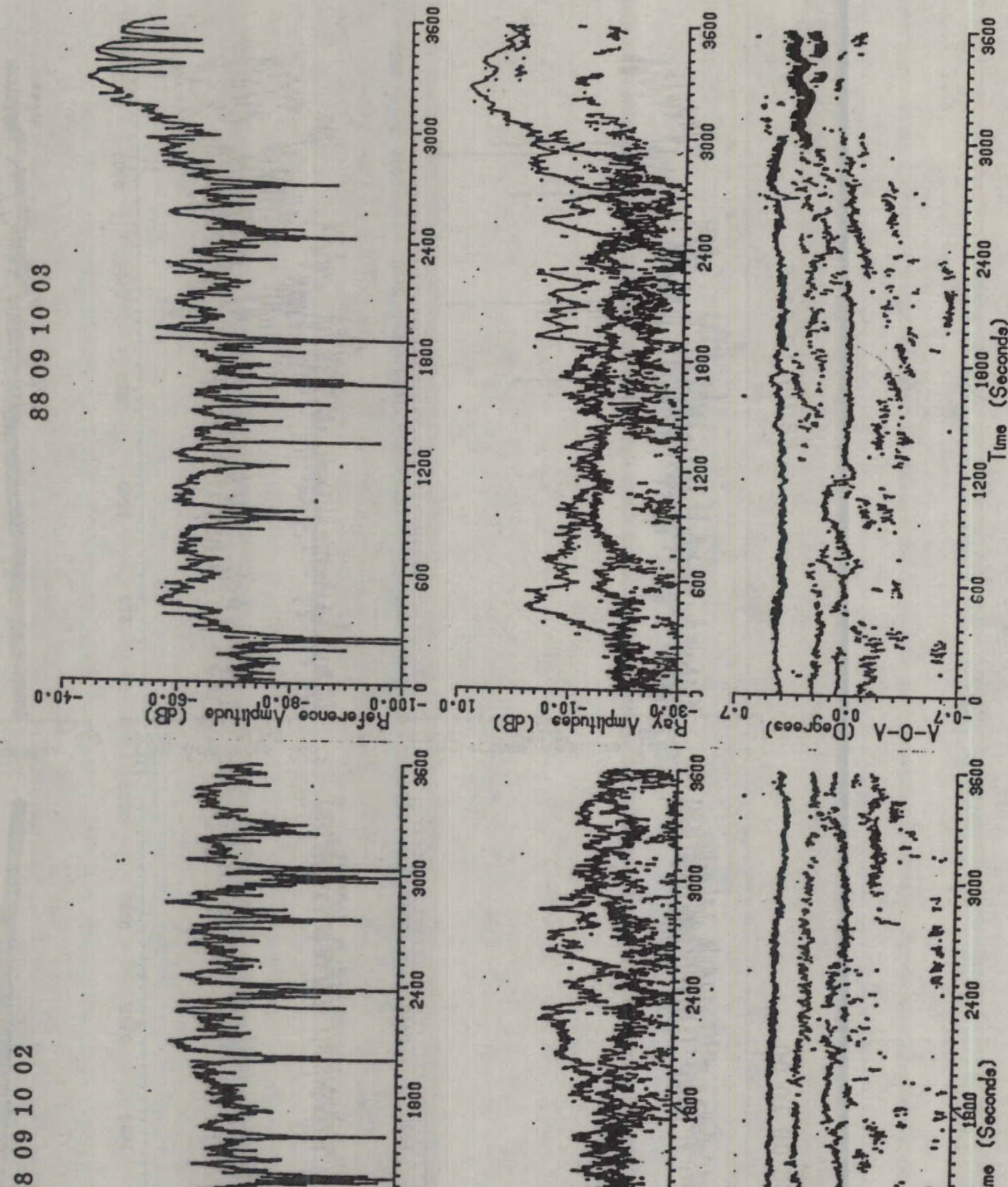


Fig.III-9 continued.

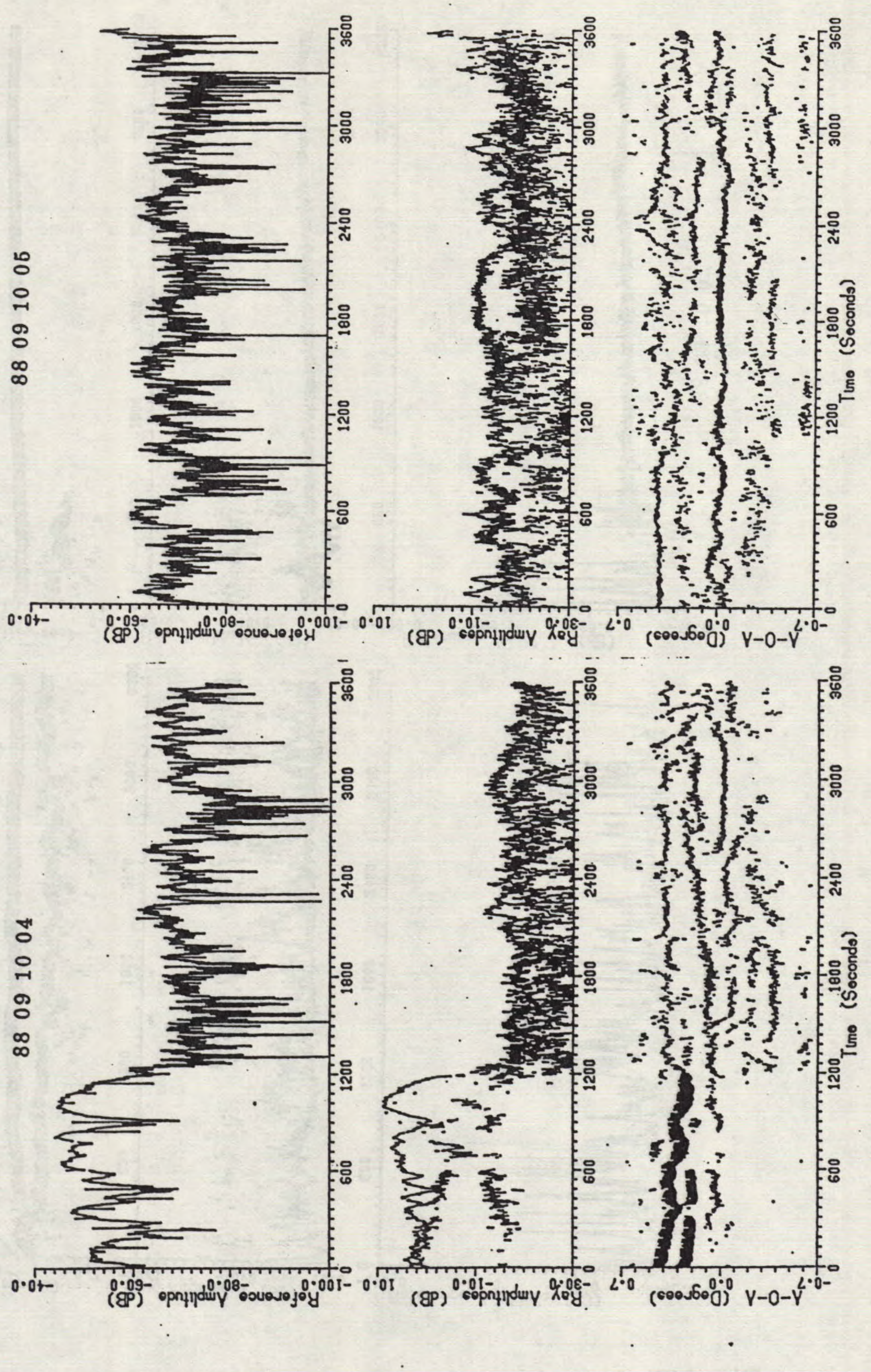


Fig.III-9 continued.

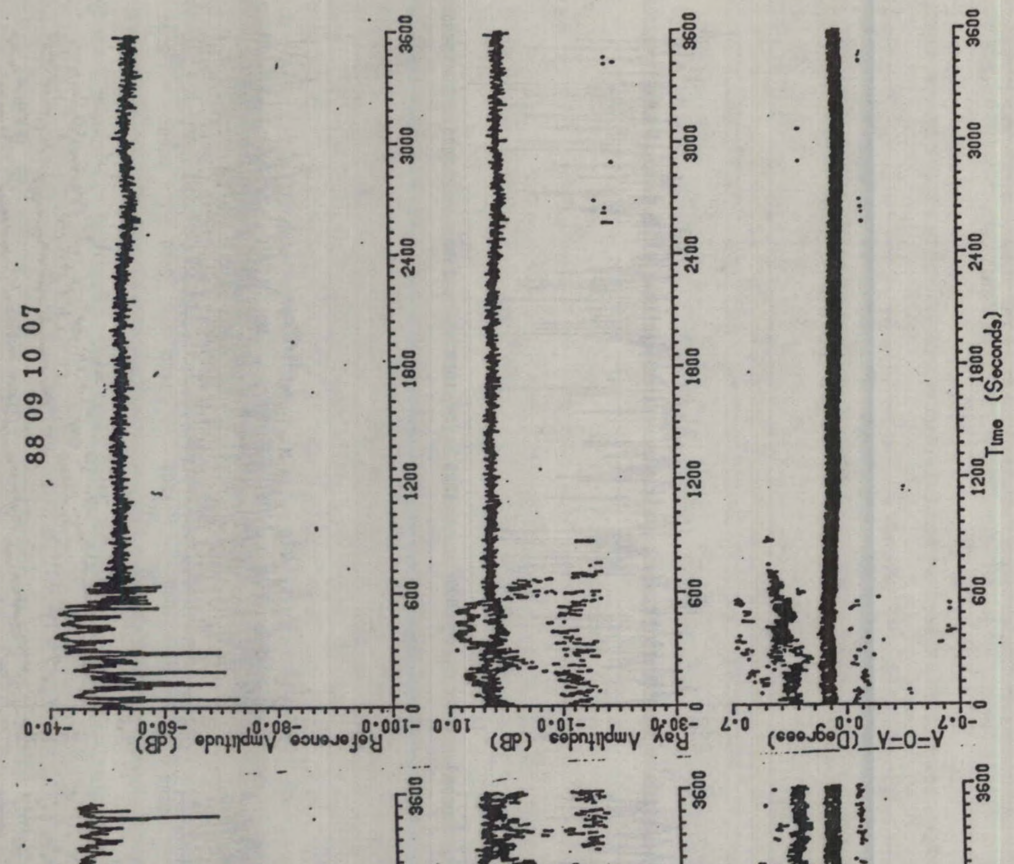


Fig.III-9 continued.

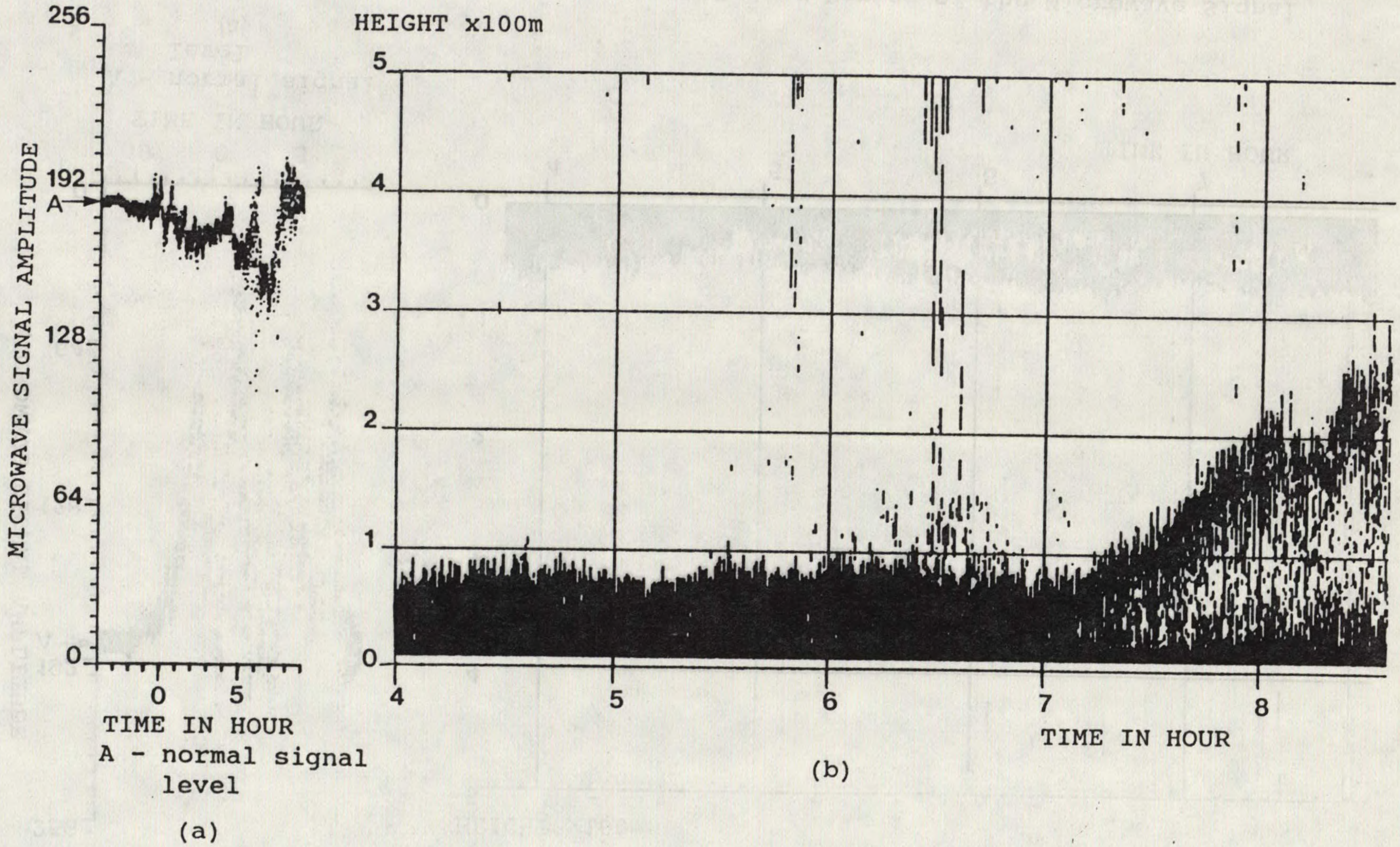


Fig. III-10 (a) A Shallow Fading Period of the Microwave Signal Observed during the night of 30th, June and morning of 1st, July 1988, (b) the Sodar Record

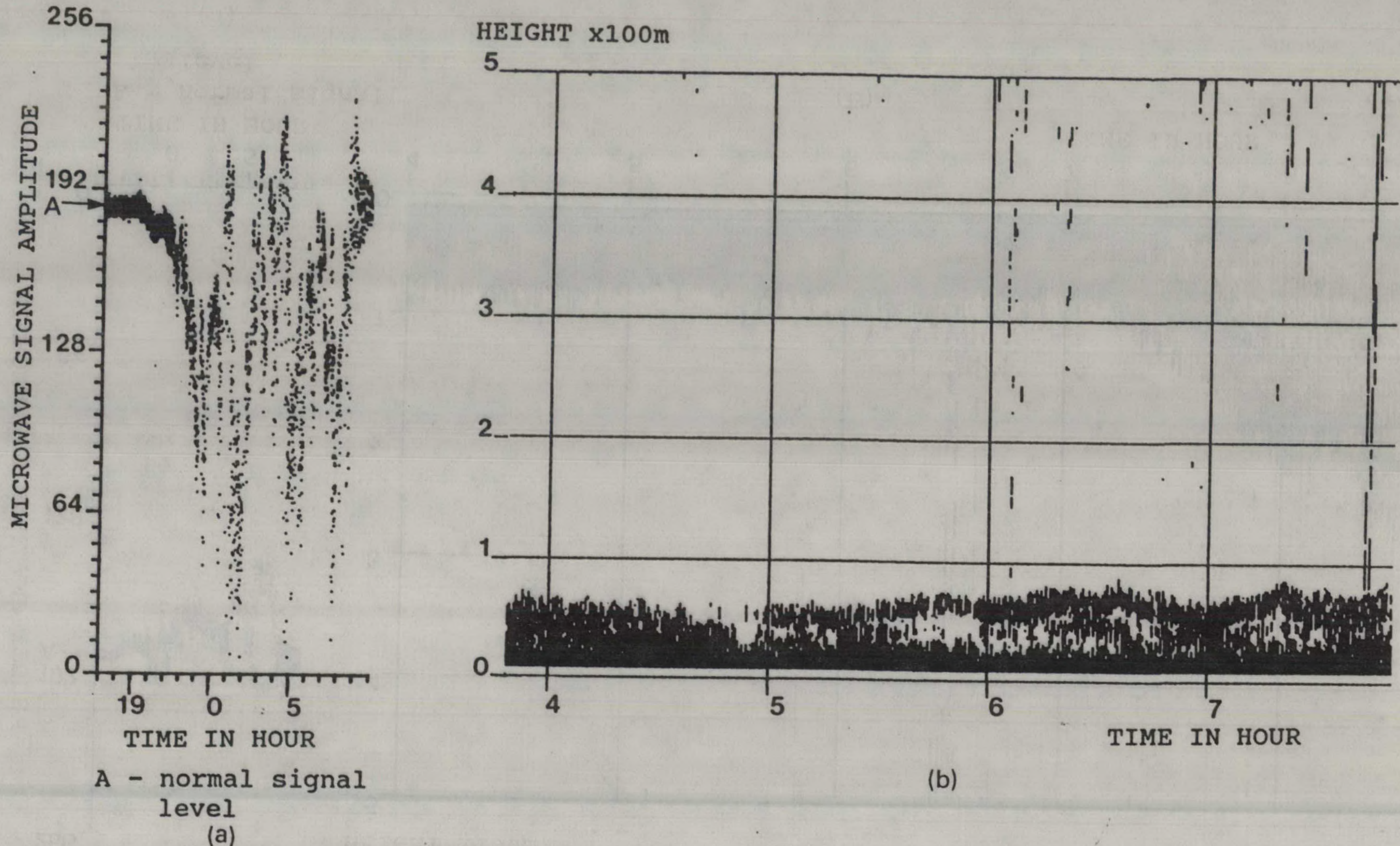
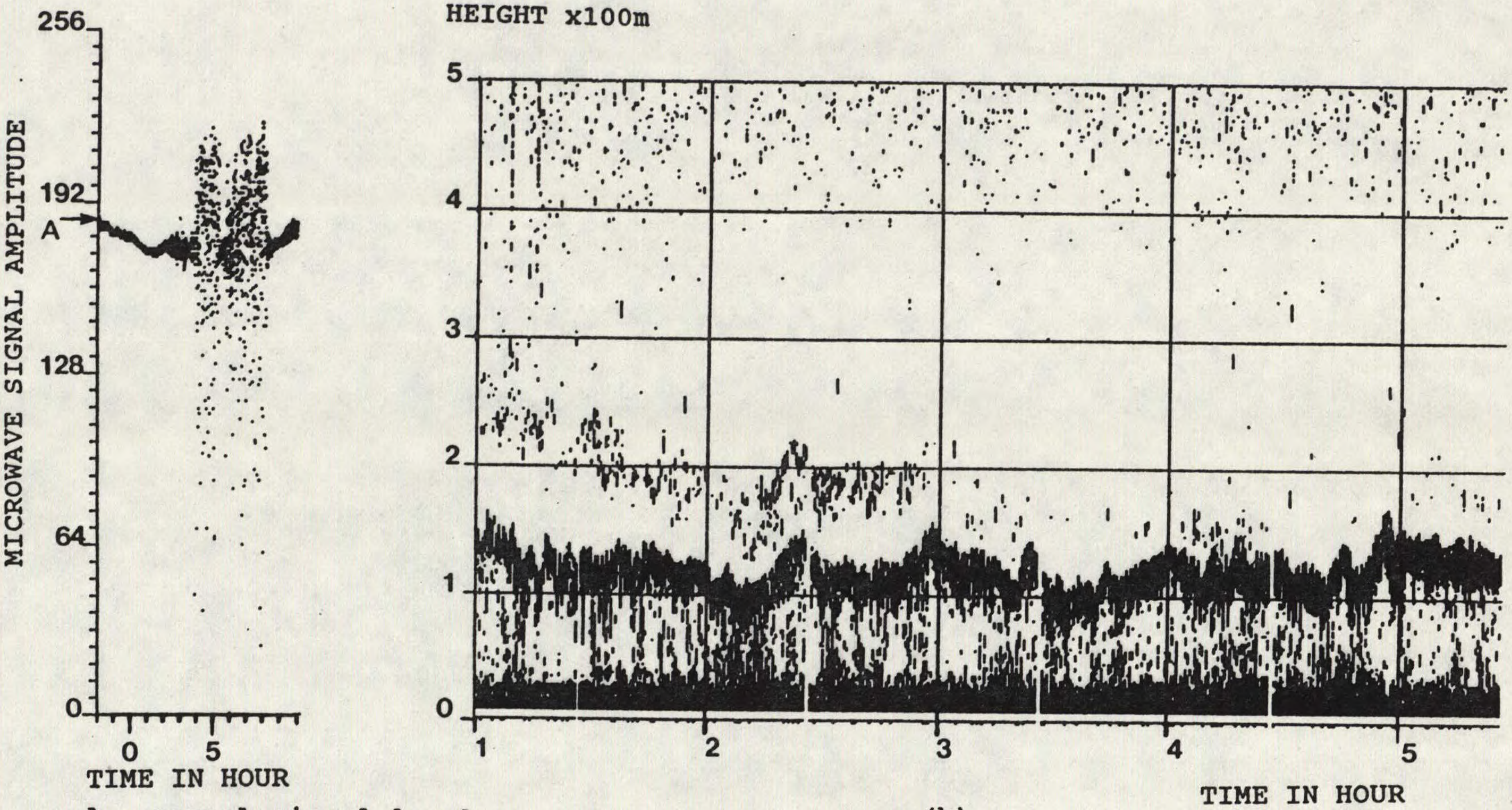


Fig. III-11 (a) A Fast and Deep Fading Period of the Microwave Signal Observed during the night of 5th, July and morning of 6th, July 1988, and (b) the Sodar Record



A - normal signal level
(a)

(b)

Fig. III-12 (a) A Fast Fading Period of the Microwave Signal Observed during the morning of 19th, Sept. 1987 and (b) the Sodar Record