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Revised assessment of an active microwave pressure sounder's performance under conditions of broken precipitating cloud.

by

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1. Introduction

As a result of further investigations of the pressure sounder's ground resolution, some modifications to the conclusions of Met O 19 Branch Memo 48 [1] have been made concerning the ability of the sounder to probe through holes in precipitating cloud. These modifications are described in this note.

2. Ground - resolution

In their report, [2] , Table 11, Flower and Peckham (FP) take the 'effective along-track ground resolution' of the pressure sounder, to be 80 km for an orbital height of 800 km. It was assumed in [1] that, by reducing integration time, a straightforward reduction in this effective resolution could be achieved, albeit at the expense of increasing retrieval error because of the smaller statistical sample of independent return signals. It was concluded that, with possibly acceptable retrieval error, holes of diameter $\leq$ 50 km in precipitating cloud could be succesfully probed. The arguments given in reaching this conclusion were partially in error, and the question of ground resolution must be re-examined.

2.1. Assumption and the basic FP system

In the following it will be assumed that the instantaneous field of view of the pressure sounder is defined by the first zero of the diffraction pattern of an aperture corresponding to the geometric size of the antenna. On this basis and assuming antennadimensions of 20 x 150 cm (the short axis being along track) and an orbital height of 800 km, the fields of view for the six operating frequencies of Flower and Peckham's primary system design (12.1.1 and 12.1.2 of [2]) are given in Table 1. More important is the total field of view, which represents the bounds of such instantaneous fields allowing for along track motion of the antenna during the signal integration period. Assuming an integration time, t, of 12 sec (see Table 10 of [2]) and a satellite orbital speed of 7.45 km s^{-1} (with corresponding ground speed, v, of 6.65 km s^{-1}), the total ground field of view is as listed in the final column of Table 1. These values are in agreement with the 'ground resolution' quoted in Table 11 of [2].

Flower and Peckham defined an "effective along-track ground resolution" which they equated with the distance vt travelled over the ground within the integration period; this is 80 km for the basic design (independent of channel frequency). Let us assume that the apatial distribution of energy received at the detector within the integration period can be computed on the basis of equal response from all points within the instantaneous field of view. Then the spatial distribution corresponds to the fraction of the integration period for which any location is within an instantaneous field of view. These distributions are shown in Fig 1. The percentage of the integrated energy which arises from within $\pm$ 40 Km of the centre of the total field ranges from 75 to 90% between channels 1 and 6 respectively. The along-track distance which contributes 80% of total energy ranges from 90 to 67 km. Thus FP's statement that "more than 80% of the total energy received during the integration period comes from within the sub-satellite path length" (ie vt, 80 km) is true for all except channel 1.

In practice the assumption of equal response within the instantaneous field of view will be in-valid. The antenna gain will vary across the field of view, probably with a marked decrease between the centre and the edge. In the limit, in which motion during the integration period far exceeds the instantaneous field of view, this will have no effect. For channel 6 the effect will be small; for channel 1 the effect will be substantial. It will increase the fraction of total energy originating within the ground-track distance vt and thereby improve the validity of FP's definition of "effective along-track resolution" (or, to be precise, field of view).

In the following section the assumption of uniform response is adopted.

2.2 Impact of reducing the effective ground resolution

Reduction of integration time t, whilst maintaining the FP antenna dimensions, will reduce the "effective" total field of view, but not in the straightforward manner assumed in [1]. The correct situation is illustrated by Fig 2. Fig 2a shows the distribution of received energy along the flight direction for chan 1. As stated in Sec 2.1, the "effective along-track field of view" is 80 km; 75% of total received energy originates within this zone. Figures 2b and 2c show the distribution as t is reduced to 6 and 3 sec respectively. If we now adopt the distance which contributes 75% of total signal as a measure of Effective Resolution, then this falls correspondingly to 64 and 61 km. But these are accompanied by successive factor of 2 decreases in the number of independent signal samples. The impact on that part of retrieval error caused by sea-surface statistics is shown in Fig 3. The minimum Effective Resolution attainable by reducing the integration time alone is 61 km (ie 75% of the instantaneous field of view of 81 km, see 2d).

Another way of reducing the effective field of view is to increase the along-track dimension of the antenna, which reduces the instantaneous field of view in proportion. However, since the coherence length of the back-scatter signal is proportional to this dimension, there will be an increase in the retrieval error. An example, for an antenna dimension of 40 cm, is given in Fig 2e. The Effective Resolution is 63.5 km; the statistical component of the retrieval error is about 1.6 mb. Reduction of integration time in combination with this larger antenna allows one to approach a limiting Effective Resolution of 31 km but with increased retrieval error. An example (40 cm, t = 6s) is shown in Fig 2f.

One might adopt a flexible scheme (eg by ground data processing) with respect to the integration time, such that an instrumental value (eg 3s) was used in areas where the smallest spatial resolution was desirable (eg to avoid precipitation in cellular convective conditions), whilst further ground smoothing to t = 12s would be used to minimise the retrieval error in more favourable atmospheric conditions. A change of antenna dimension would be more fundamental. For the same effective resolution the retrieval error under favourable conditions will always be larger. In the case of a 40 cm antenna the overall retrieval error will be 20% greater, at 1.4 mb. These relationsips between resolution and retrieval error are presented in Fig 3 and Table 2. This discussion has been confined to channel 1, which has the largest field of view. For the other channels the problem should be less serious.

3. Conclusion

It was concluded in [1] that the pressure sounder was unable to probe through precipitating cloud, though in most other cloudy conditions retrieval error should not exceed 2 mb, being as low as 1.2 mb in cloud-free conditions. Hence, for example, the sounder would be unable to probe through active frontal cloud. Other areas of interest discussed in [1] were active regions of (open-cell) mesoscale convection where individual cloud cells would be impenetrable, but where regions of descending air might have sufficient horizontal dimensions to permit intermittent sounding. Such regions of convection are common to the west of the UK, where average open cell diameters are $\simeq 50$ kms.

From the analysis in Section 2 it has been shown that such resolution can be achieved with retrieval error of about 2 mb (over 3 mb for 30 km resolution), but at the expense of incfeasing clear sky retrieval error to 1.4 mb. Such an increase may well off-set the advantage in probing through holes of diameter less than 60 km (the limit for the basic 20 cm antenna).

This modifies the conclusions of [1], and as a result the following amendment to [1] should be noted:

a. p 14 para 3 to p 15 para 1 are replaced by the text of this note;

b. the last two entries of table 4 should be replaced by table 2;

c. figure 18 should be replaced by figure 3 of this note.

References

1. Palmer T.N. An assessment of the effect of atmospheric liquid water on the retrieval accuracy of an active microwave pressure sounder. Met O 19 Branch Memorandum No.48, March 1979.

2. Flower D.A and Peckham G.E. A microwave pressure sounder. JPL document 78-68, August 1978. (Also issued as NASA Contractors Report CR-157567, 1978).

channel number.	frequency, GHz.	instantaneous field of view, km.	total ground field of view, km.
1	29.25	82 x 10.9	162 x 10.9
2	36.55	65 x 8.7	145 x 8.7
3	44.80	53 x 7.1	133 x 7.1
4	52.80	45 x 6.0	125 x 6.0
5	67.51	35 x 4.7	115 x 4.7
6	73.01	32 x 4.4	112 x 4.4

TABLE 1. Fields of view for the Flower and Peckham Primary System Design.

The instantaneous field of view is based on the first minimum of a diffraction limited 20 x 150 cm antenna at an orbital altitude of 800 km. This computation is based on the statement in the last paragraph of sec 12.1.2 and the results given in the last column of Table 11 [2]. The total ground field of view corresponds to an integration time of 12 sec and a ground speed of 6.65 km/sec.

integration time, sec.	along-track antenna dimension, cm.	effective resolution, km.	retrieval error, mbar.	clear sky retrieval error (t=12s), mbar.
12	20	80	1.2	1.2
6	20	64	1.6	1.2
3	20	61	2.2	1.2
12	40	$63\frac{1}{2}$	1.6	1.6
6	40	$40\frac{1}{2}$	2.2	1.6
3	40	$32\frac{1}{2}$	3.1	1.6

TABLE 2. Retrieval error for various combinations of integration time (t) and antenna size.

Retrieval error includes atmospheric variability.
Clear sky retrieval error is that which would be obtained with the same antenna and an integration time of 12 sec.
Note that, for a 40cm antenna, t can be increased to $15\frac{1}{2}$ sec whilst retaining an effective resolution of 80 km. For this combination the error would be 1.4 mbar.

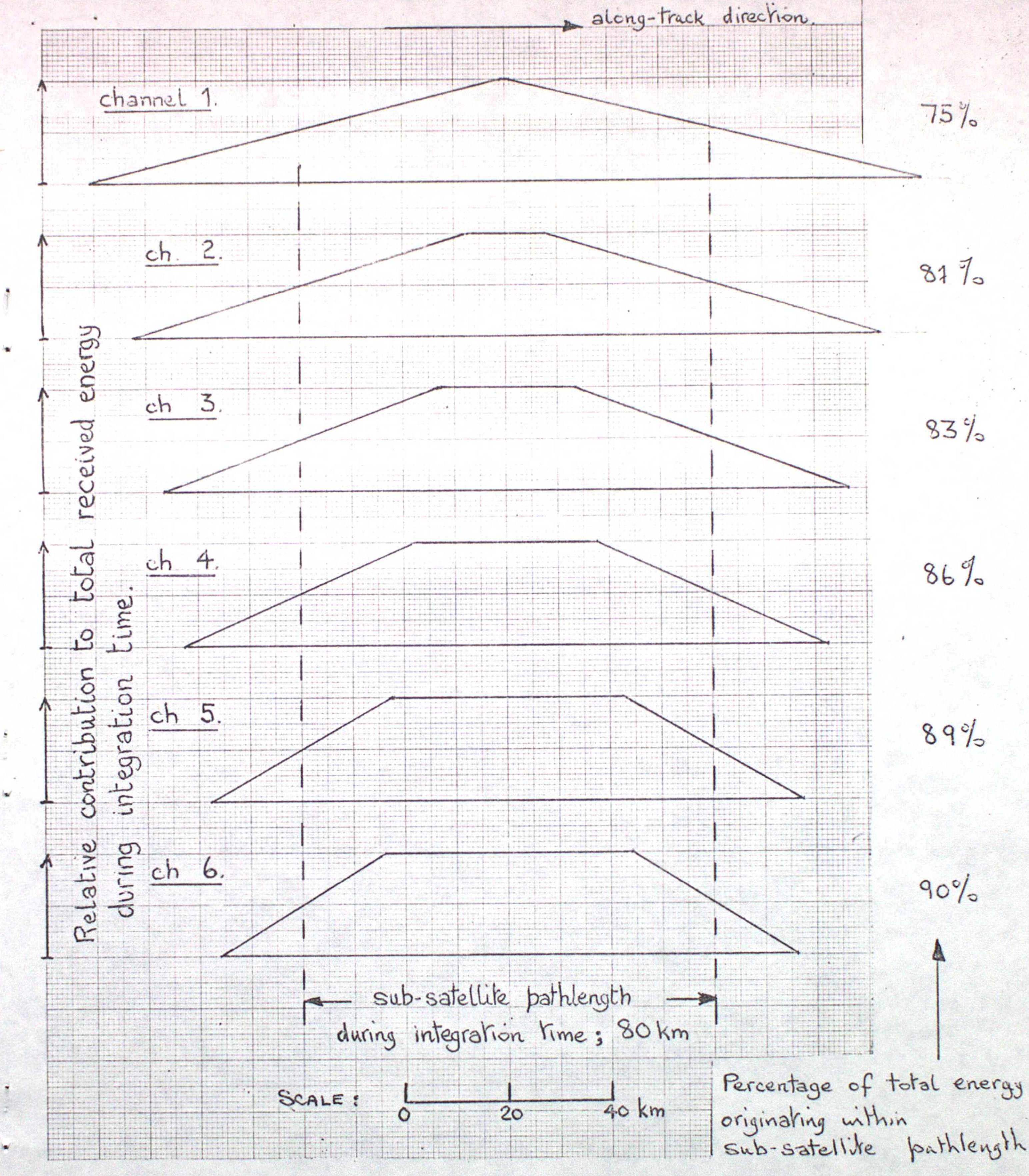

Figure 1. Distribution of energy received at detector during integration period for 6 channels of the Flower and Peckham basic design. Orbital height 800 km.

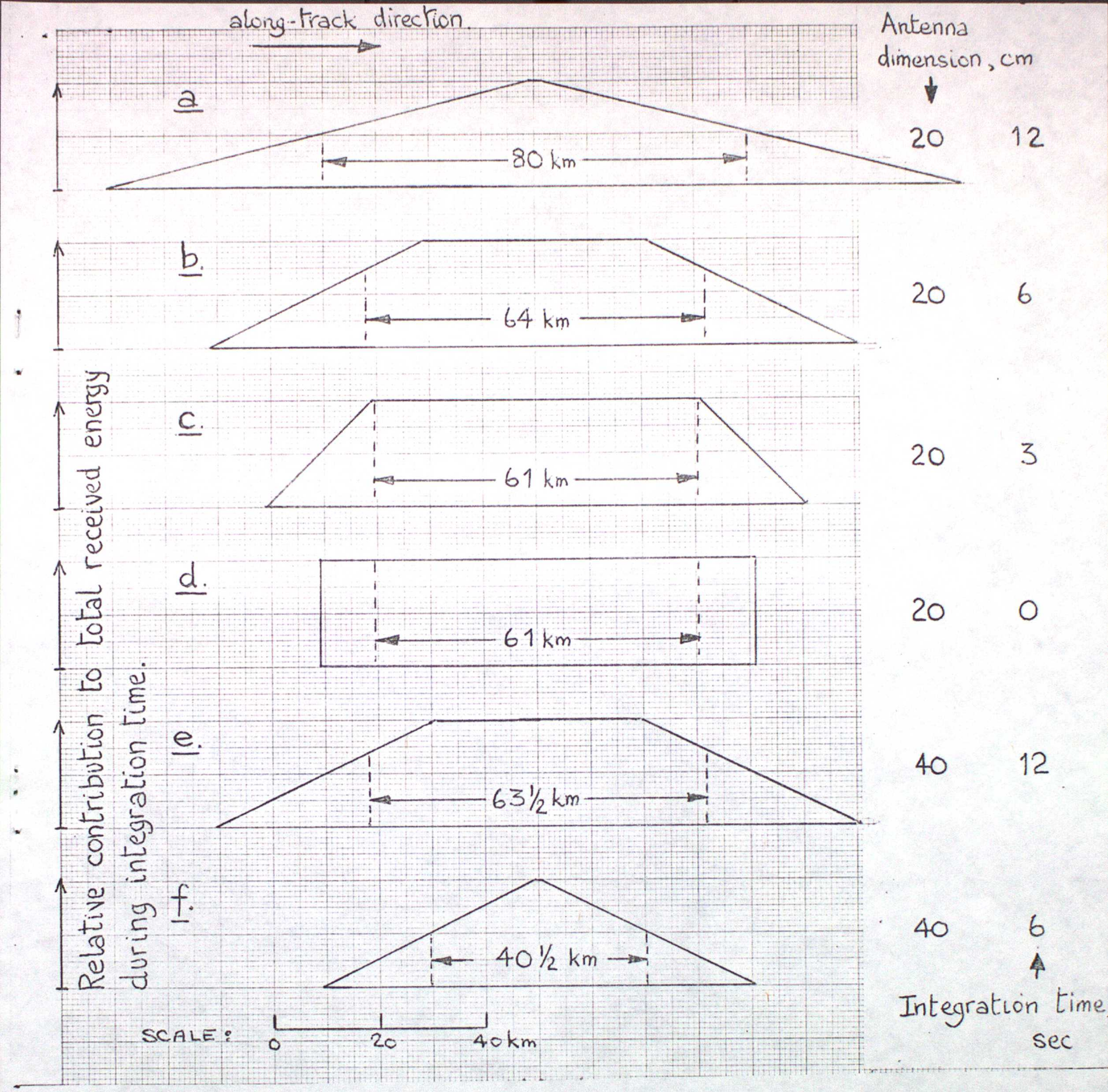

Figure 2. Effective resolution, defined as the distance within which 75% of integrated energy originates:
a), basic design;
b–d), reduced integration time;
e–f), increased antenna size.
All for frequency channel 1.

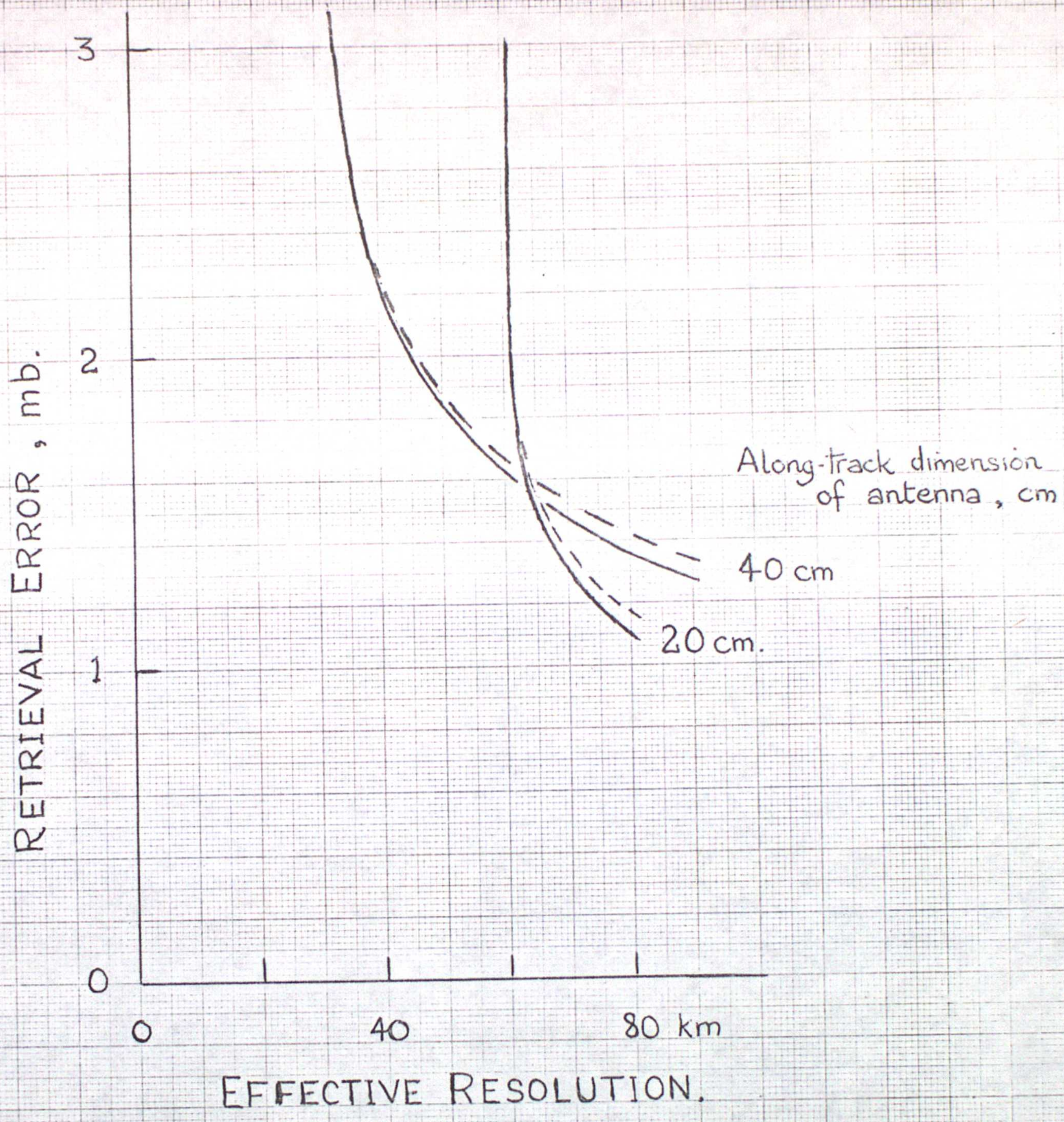

Figure 3. Relationship between Effective Resolution and retrieval error, for two sizes of antenna.

—, sea-statistics component alone.

– –, combined with 0.4 mb rms caused by variability of temperature and water vapour distribution.