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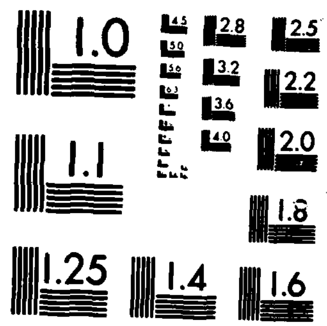

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RANRL TECHNICAL MEMORANDUM
(EXTERNAL) No 6/85

BUOY-TRACKING TRIALS USING DECCA 916 RADAR AND THREE TYPES OF REFLECTOR

M.R. BATTAGLIA
and
J.W. HILL

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BUOY-TRACKING TRIALS USING DECCA 916 RADAR AND THREE TYPES OF REFLECTOR

by

M.R. BATTAGLIA

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ABSTRACT

Trials are described involving the detection and tracking of buoy-mounted radar reflectors using a Decca 916 radar on HMAS ATTACK. Observed blip/scan ratios for various reflector type/reflector height combinations are compared with the RANRL radar model. The agreement with the model enabled the prediction of the tracking performance of HMAS COOK navigation radar, as required for future oceanographic trials, over a range of environmental conditions.

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CONTENTS

1. Introduction

Towards the end of 1984 a requirement arose for trackable ocean-going buoys. These were to be equipped with parachute-type drogues set at various depths so as to reveal the relative motion between different levels in the oceanic mixed layer. This motion was to be correlated with the relative temperature rise between the levels. Both are aspects of the 'afternoon effect', a loss of sonar performance which occurs characteristically at that time of day (refs 1,2). It was proposed to equip each buoy with a light mast and radar reflector, and track these by means of HMAS COOK's Decca 916 (I-band) radar set. Three types of radar reflector were found to be available for RANRL use, and it was proposed to make the best selection among these by means of comparative sea trials. Unfortunately HMAS COOK was unavailable for this purpose. Accordingly, with the cooperation of COMAUSMINPAB, it was arranged for the trials to be made from the patrol boat HMAS ATTACK which was equipped with the same radar set, but with the antenna mounted much lower (10 m instead of 25 m above sea level). To take account of this difference between installations, it was proposed to make use of the RANRL radar model (ref 3). This would enable the comparison between trials and model predictions at 10 m to be projected confidently to 25 m, and would also indicate the degradation in tracking performance to be expected with rising sea states and precipitation rates.

The principal features of the reflectors used in the trials are set out in Table 1. Reflectors 1 and 3 are commonly used by the RAN for marking of boats, channels, bridges, etc. Reflector 2 is used by weather authorities for balloon tracking, which calls for extremely lightweight construction. There is no objection to large physical size in this application since the balloon tends to move with the wind, keeping the velocity of air relative to reflector low.

2. HMAS ATTACK Trials

2.1 RANRL Participation

M.R.Battaglia , J.Mentjox (Operations Research Group).

J.W.Hill, W.Kongas (Ocean Sciences Group).

2.2 Procedure

On 10th and 11th December 1984, a series of buoy-tracking trials was conducted using the Decca 916 navigation radar on HMAS ATTACK. Three reflectors (two corner reflector clusters and one lens reflector) were used and these were mounted on buoys at heights of 4 m or 5 m above sea level by means of tubular aluminium masts.

The radar set was checked by Weapons Electronic Production Group (GIP) before and after the trials, and all radar parameters were found to be within normal tolerances. A section of defective waveguide was replaced before the first trial.

---- Table 1 ----

REFLECTOR	1	2	3
Type	corner reflector (cluster of 8)		Luneberg lens
Construction	welded Al sheet	metallized fabric stretched over tubular Al framework (two clusters of four used)	plastic-coated sphere
RAN pattern No	5840-99-918-6502	N/A	5840-66-098-109
Principal overall dimension (mm)	640 (reflector side)	1370	307 (diameter)
Weight (kg)	7	2	7
Windage area (m^2)	0.40	1.88	0.074
Mean I-band radar cross-section (m^2)	2.75 (est.)	20.0 (est.)	10.0 (manufacturer's specifications)
Directional performance	subject to nulls in specific directions		omnidirectional in azimuth

Detailed manual records of blip/scan ratios were kept for all trials. In addition, a 16 mm camera was used to record time-lapse photographs of the 916's PPI and the camera's associated time code generator at the rate of between one and two frames per antenna scan. Environmental data (sea, swell, dry and wet bulb air temperature, sea surface temperature, wind speed) were recorded before and after each run.

Each run involved launching the buoy approximately 10 n.miles from the coast near Sydney and proceeding due north at 12-16 knots. After radar contact with the buoy was lost, the course was maintained for an extra 3-4 n.miles to ensure that data was recorded up to the radar horizon. The course was then reversed, and initial contact and blip/scan data were recorded for the return leg.

It was originally intended to trial all reflectors at heights of 4 m and 5 m. However the metal corner reflector was found to be somewhat top-heavy for the buoy and mast arrangement used. The fabric reflector was found to present a rather large surface for stability, even in the moderate winds encountered. Accordingly the 5 m runs with these reflectors were aborted. The spherical reflector gave no trouble in either of these respects, and was used at both heights.

2.3 Summary of results

The principal results are set out in Table 2. Detailed analysis of blip/scan ratios and comparison with the radar model are set out in figures 1-4 inclusive.

----- Table 2 ------

Reflector number	Height above sea level (m)	Notional Detection Range (n.mile) (50% blip/scan ratio)
1	4.0	5.9
2	4.0	7.0
3	4.0	6.7
3	5.0	7.0

2.4 Choice of reflector

The summary in Table 2 indicates that the fabric reflector has a slight advantage in range over the other two. Meanwhile, the trials provided an opportunity for studying the seakeeping qualities of the buoy/mast/reflector arrangements. As already indicated, stability - i.e. a ready return of the mast to vertical - was found to be critical. While size was found to be of minor importance under the trial conditions, it was felt that it would become important in heavier winds. On all counts, then, the metal reflector is inferior to the others. The choice between the fabric and spherical reflector is more difficult, and might well depend upon the circumstances for further use. For the prospective HMAS COOK cruise, however, it was felt that the very much reduced windage (by a factor of 25) far outweighed the slight loss in range (approximately 10%). A more detailed analysis of the trials results, and calculations of the performance at the higher antenna height (25 m) under variable environmental conditions is given in the following sections.

3. The Radar Model

The radar model used in this work is described in references 3-5. Signal, clutter and noise levels are calculated for non-ducting conditions. The resulting signal to noise-plus-clutter ratio is used to calculate blip/scan ratios, utilising the Marcum/Swerling approach and the algorithms described in the references.

The peak power (P_r) received at the antenna is given by the radar equation

$$P_r = \frac{P_t G^2 \lambda^2 \sigma F^4}{(4\pi)^3 \; R^4 L} \qquad 1.$$

where P_t is the peak transmitted power, G is the gain of the antenna at wavelength λ, R is the range of the target of radar cross-section σ, L is the atmospheric loss factor due to precipitation and uncondensed gases, and F is the pattern propagation factor which accounts for multipath effects.

The sea clutter return (P_c) is obtained using equation 1 with the sea clutter radar cross-section (RCS) given by

$$\sigma = \sigma^{o}.R.\theta^{H}.c\tau/2 \qquad 2.$$

where c is the speed of light, R is the target range, θ^H is the horizontal beamwidth, τ is the pulse width, and the clutter return per unit area (σ^0) is obtained from a fit of Nathanson's data (ref 6). Volume clutter is calculated in an analogous manner. The volume cell is corrected for earth curvature, with an upper ceiling applied to the rain cell.

The effective receiver noise power, referred to the antenna, is determined by the receiver noise figure (NF), receiving line losses (L_r), receiving line and antenna noise temperatures (T_r, T_a) and pulse width:

$$P_n = k[\ T_a + T_r(L_r-1) + L_rT_o(NF-1)\ ]/\tau \qquad 3.$$

in which P_n is the noise power, k is Boltzmann's constant, and T_o=290 K.

For the purposes of blip/scan calculations it is assumed that clutter and receiver noise are both Rayleigh-distributed. The dominant noise source is clutter at short range and receiver/antenna noise at long range so that, under the Rayleigh assumption, it is adequate to define signal-to-noise as

$$S/N = P_r/(\ P_n + P_c\ ) \qquad 4.$$

3.1 Corner versus Lens Reflectors

A single corner reflector provides a large RCS in relation to its physical dimensions over a narrow range of aspects. The peak return in the specular region (l>>λ) is the same as for a flat plate of the same area (A)

$$\sigma^{peak} = 4\pi.A^2/\lambda^2$$

$$= \pi.l^4/\lambda^2 \qquad 5.$$

A more isotropic return is generally required for low sea states and wind speeds to ensure that the target is not in a null for extended periods. To achieve this, clusters of eight back-to-back corner reflectors were used in the trials. With this geometry the return, averaged over all aspects, will be of the same order of magnitude as a spherical reflector

$$\sigma^{av} = \pi.l^2 \qquad 6.$$

Trials data for the cluster of eight corner reflectors fits the formula

$$\sigma^{av} = K\ l^2 \qquad 7.$$

where l is the side of a single reflector, and K is an empirical value which was found to be in the range 6.7 - 10.6 . (The variation arises because K was derived from mean detection range. Since the reflectors are not truly omnidirectional, the frequency of aspect-dependent nulls and maxima for a given geometry depends on reflector weight,windage, etc.)

The dielectric lens reflectors used are omnidirectional and have a nominal RCS of 10 m^2 at 10 GHz. This data was used without further calibration.

4. Detailed results

The only data for a 5 m reflector height is for the 10 m^2 lens reflector, this is shown in figure 1. The two lines are for target heights 0.5 m above and below the nominal height, and provide an estimate of the variation in blip/scan ratio arising from relative motion of antenna and target due to sea and swell. Variation in the effective radar horizon is in the order of 0.5 n.mile, while the effect on the multipath nulls for 10 m antenna height is to wash out the structure and increase the scintillation rate at shorter ranges (ref 5). The quality of the recorded data in the region 6-7 n.miles was not adequate for plotting, but sensible interpolation would result in a blip/scan ratio of 50% at around 7 n.miles.

The same reflector was used in a second trial at 4 m height (fig 2). As expected from multipath and radar horizon considerations, the notional detection range (50% blip/scan) is reduced by 0.5 n.mile. The falloff in blip/scan ratio with range is sharper than calculated, however the notional detection range is in good agreement. A better fit could be obtained using a faster scintillation rate - say Swerling case II rather than case I - but this has little effect on the notional detection range. The latter arises because the 'fluctuation loss' is oppositely-signed for high and low S/N with a cross-over at a blip/scan ratio of around 33% (ref 5).

Figure 3 shows the results of the trial and calculation for the larger of the corner-reflector clusters mounted at 4 m. Because of the additional aspect-dependence contribution to the scintillation, Swerling case II was used in the calculations. The small increase in notional detection range is in the order expected for a 3 dB increase in mean RCS.

Results for the smaller of the two corner-reflector clusters is shown in figure 4. In this run there was a significant difference in the observed blip/scan ratios for the two legs. This difference could not be explained on the basis of wind aspect, due to the light winds and moderate sea state. This run was made immediately after a period of light rain, and the environmental conditions may not have been homogeneous over the path from radar to target, nor sufficiently constant with time. The mean data were, however, in agreement with the prediction that this was the least effective of the reflectors tested.

The conclusion to be drawn from the trials and predictions is that considering problems associated with windage and weight, and the inverse fourth power range equation, the optimum selection of reflector/height is the lens reflector mounted at 4 to 5 m. With this arrangement a radar of similar characteristics to the Decca 916, with antenna mounted at around 10 m, should be able to track a buoy from ranges of up to 7 n.miles. With the free space range of this radar considerably in excess of the radar horizon, a greater antenna height should result in even longer ranges for targets in the 'intermediate zone' (ref 4). Conversely, the ranges for I-band radars are considerably reduced in the presence of rain. These factors are treated in the following section on the predictions of the performance of the HMAS COOK radar under various environmental conditions.

5. HMAS COOK - Predictions

The navigational radar on HMAS COOK has similar electrical characteristics to that used in the HMAS ATTACK trials, so that the main difference in performance is due to increased range to the radar horizon. Under standard propagation conditions, the increase in detection range for low altitude targets is approximately in the ratio of the square root of antenna heights - viz an extra 4 n.miles.

Blip/scan ratio predictions for HMAS COOK and 5 m target height are shown in figure 5. Environmental conditions are mean values for the north of Australia in February, and target height is constant at 5 m.

Results are plotted up to sea state 4, although low wind speeds and wave heights are expected in this area in February. At all sea states, the maximum notional range is more than 10 n.miles. Neglecting ship/target relative motion, the principal effect of sea state is to broaden the multipath nulls. This is shown more clearly in figure 6, where raw signal levels for a 1 m² target are compared with surface clutter and receiver noise levels. Beyond 6 n.miles the clutter return is negligible at all sea states due to vanishing grazing angle, and the signal-to-noise ratio is positive for target strengths greater than 1 m². In the region of the first interference null (3 to 5 n.miles) clutter exceeds noise level above sea state 2, and increasing sea state broadens the null. A second effect of sea and swell is to vary the relative antenna height, and thus introduce a fluctuation in the relative phases of the direct and reflected paths. This is illustrated in figure 9 for a 0.4 m variation in relative height. For greater variations, and moderate sea states, the blip/scan ratio will take at least the averaged value of 0.5 between 3 and 5 n.mile depending on the time-scale of the variation.

The effect of rain on signal-to-noise ratio is to attenuate the signal return (0.1 - 0.01 dB/n.mile) but more important at I-band is its contribution to the volume clutter. For the purposes of calculating the clutter cell volume, the ceiling for rain is set at 10,000 ft although this will generally increase with rain rate. In figure 7, blip/scan ratios are plotted for sea state 1 and rainfall rates of 0.15 to 12.0 mm/hour. In the case of light drizzle (0.25 mm/hr), the effect is similar to an increase of sea state to 2 - 3. Above 1 mm/hr rain rate, the blip/scan ratio is severely degraded between 3 and 5 n.miles, although detection is possible again around 6-7 n.miles. For moderate to heavy rain (greater than 4 mm/hr) detection is unlikely ($p<50\%$) beyond 2 n.miles.

Raw signal and clutter levels are plotted in figure 8 for the four rainfall rates. At intermediate ranges the 1 m² signal level is of the same order as the volume clutter for moderate rain rates. With only about 6 pulses integrated per scan, target RCS needs to be of order of 100 m² (20 dB) to ensure adequate signal-to-noise over the range of interest. Near the horizon, the marginal increase in clutter with rain rate is negligible for moderate rain due to self-attenuation, and the variation in signal-to-noise ratio is dominated by signal attenuation.

The above discussion does not include the effects of ducting. For I-band surface-based radars, the surface evaporative duct can greatly enhance or reduce detection ranges for low altitude targets. However, evaporative duct calculations for 90% relative humidity and near-neutral stability (ref 7) indicate that typically only 1-2 modes would be trapped for target and radar sited in the duct. More dramatic effects require moderately strong wind, low humidity and/or unstable thermal conditions (air cooler than the sea) (refs 7,8).

6. Conclusions

A 10 m^2 lens reflector mounted on a buoy at 5 m above sea level should be trackable up to 10 n.miles using a Decca 916, or similar I-band navigation radar, at a height of 25 m and with optimum environmental conditions. At rainfall rates greater than 4 mm/hr, performance is degraded to less than 2 n.miles.

ACKNOWLEDGEMENTS

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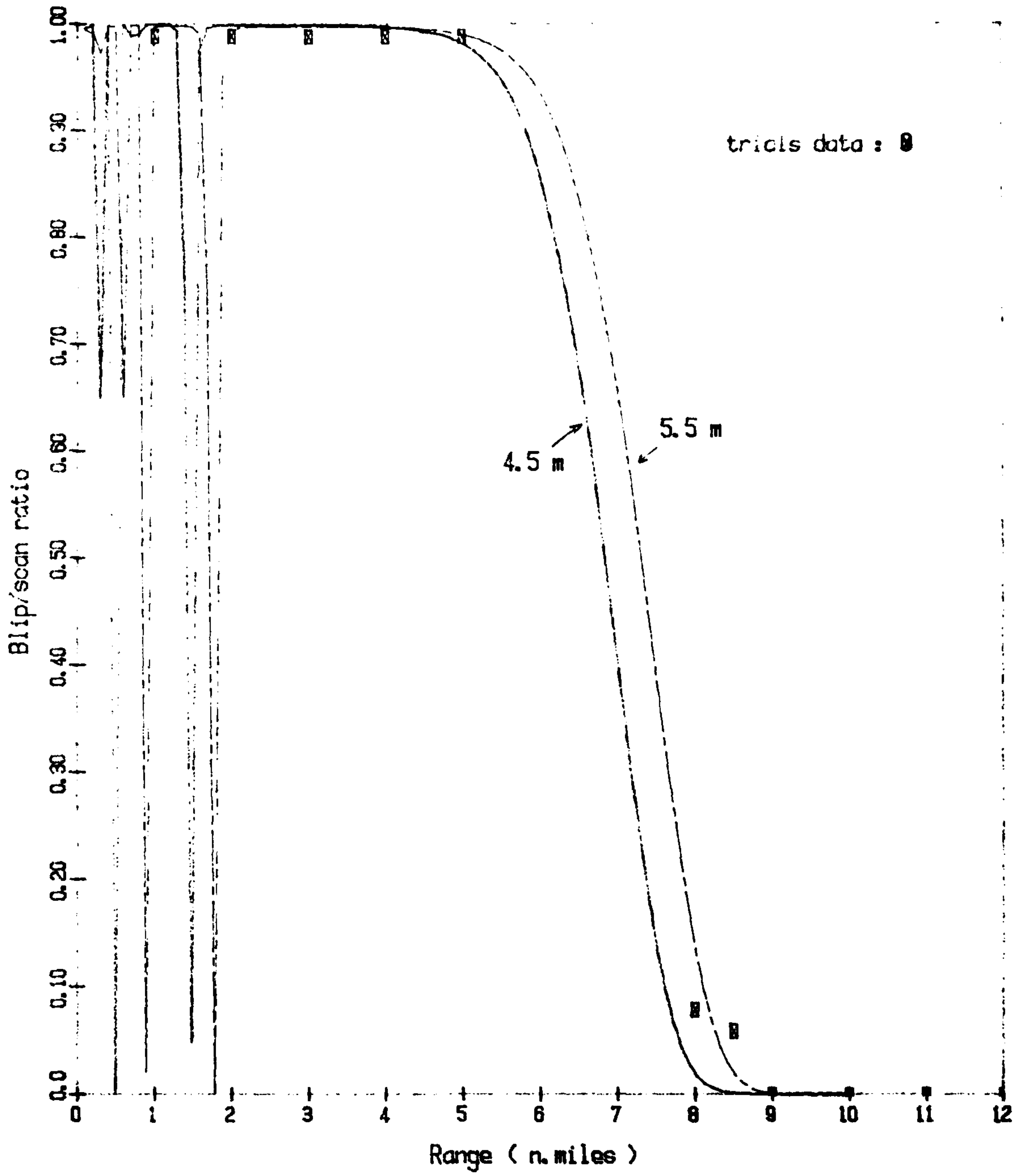

Figure 1. Calculated and observed blip/scan ratios.
Radar : Decca 916 mounted at 9.75 m.
Target: 10 m^2 lens reflector mounted at 5 m.
Assumed fluctuation: scan-to-scan.
Environmental: Air temp : 21.8 C.
Humidity : 80%
Sea temp : 20.0 C
Sea : 0.3 m.
Swell : 0.5m.
Wind speed : 7 knots

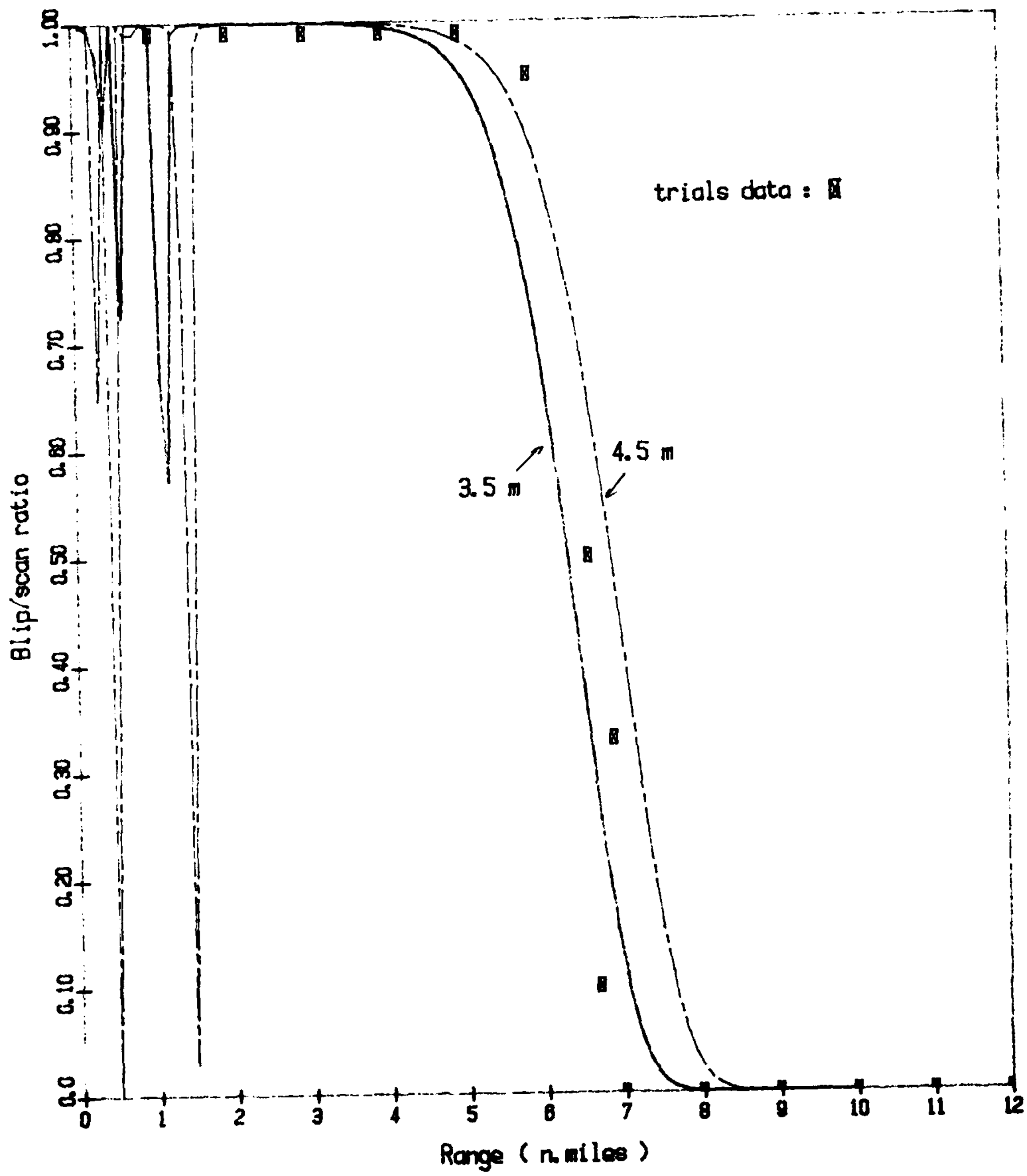

Figure 2. Calculated and observed blip/scan ratios.
Radar : Decca 916 mounted at 9.75 m.
Target: 10 m^2 lens reflector mounted at 4 m.
Assumed fluctuation: scan-to-scan
Environmental: Air temp : 24.5 C.
Humidity : 86%
Sea temp : 20.0 C.
Sea : 0.3 m.
Swell : 0.5m.
Wind speed : 11 knots

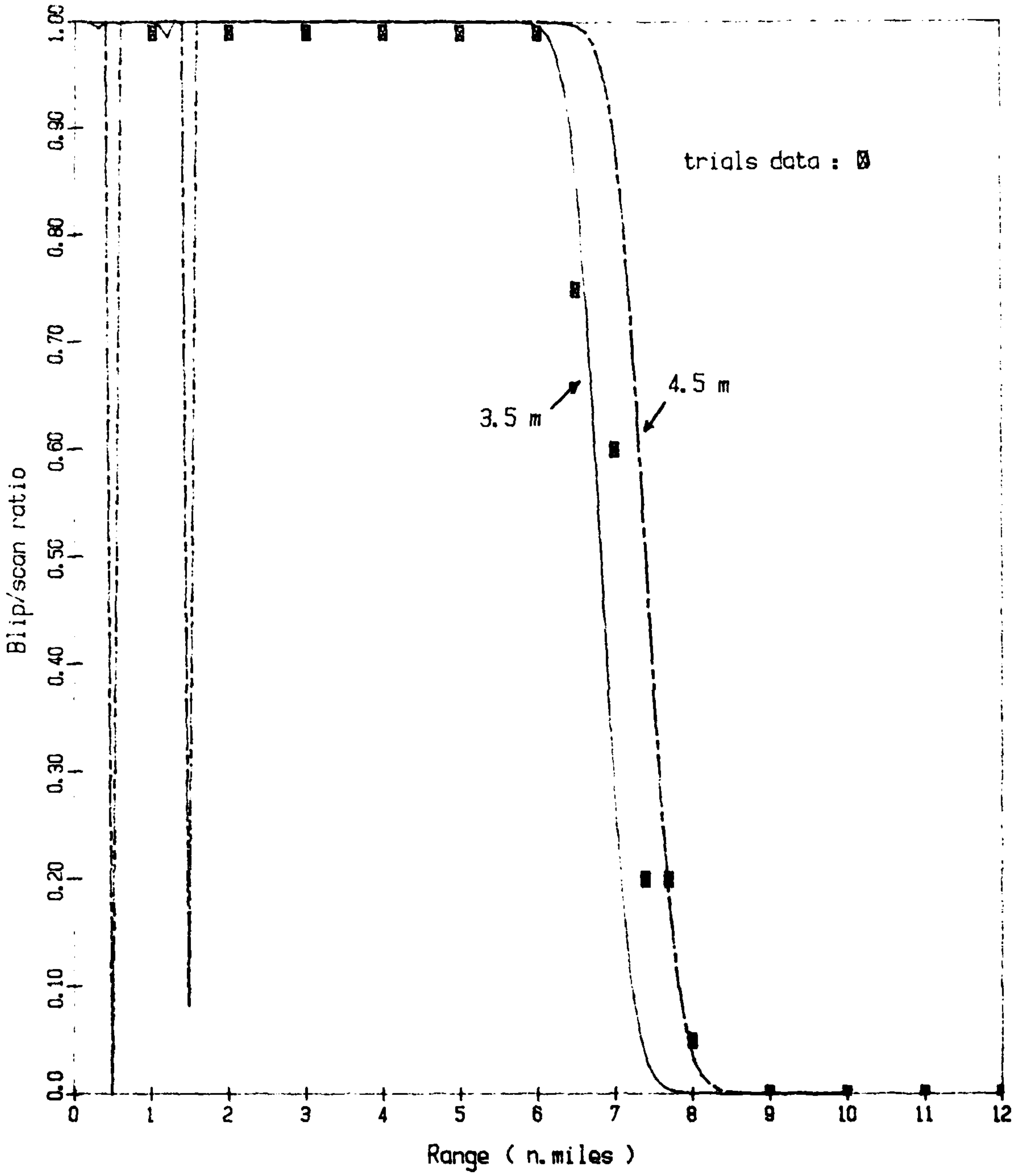

Figure 3. Calculated and observed blip/scan ratios.
Radar : Decca 916 mounted at 9.75 m.
Target: 20 m^2 corner reflector mounted at 4 m.
Assumed fluctuation: pulse-to-pulse
Environmental: Air temp : 22.5 C.
Humidity : 89%
Sea temp : 20.0 C.
Sea : 0.3 m.
Swell : 0.5m.
Wind speed : 5 knots

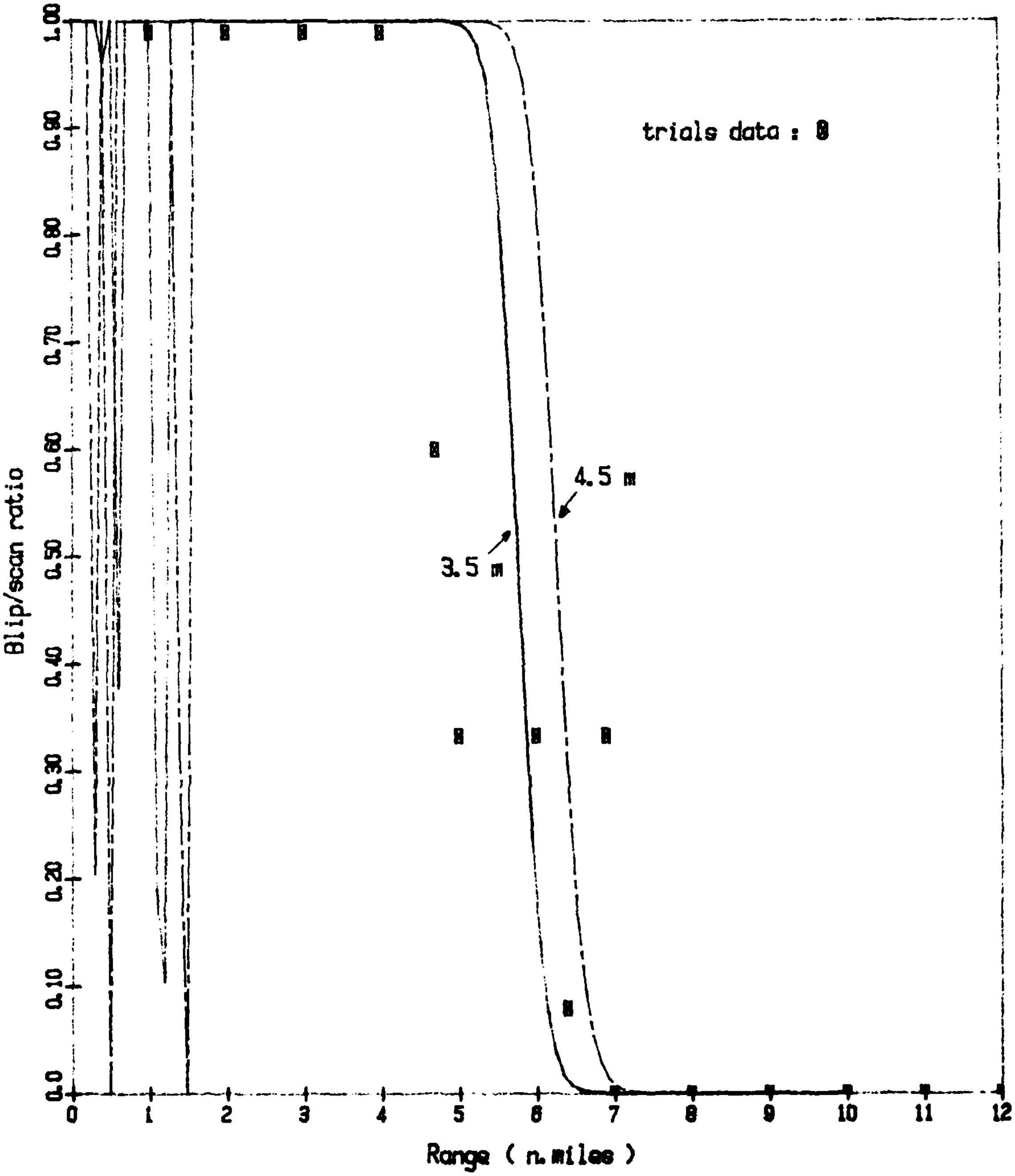

Figure 4. Calculated and observed blip/scan ratios.

Radar : Decca 916 mounted at 9.75 m.

Target: 2.75 m^2 corner reflector mounted at 4 m.

Assumed fluctuation: pulse-to-pulse

Environmental: Air temp : 18.0 C.

Humidity : 90%

Sea temp : 20.0 C.

Sea : 0.3 m.

Swell : 0.5m.

Wind speed : 5 knots

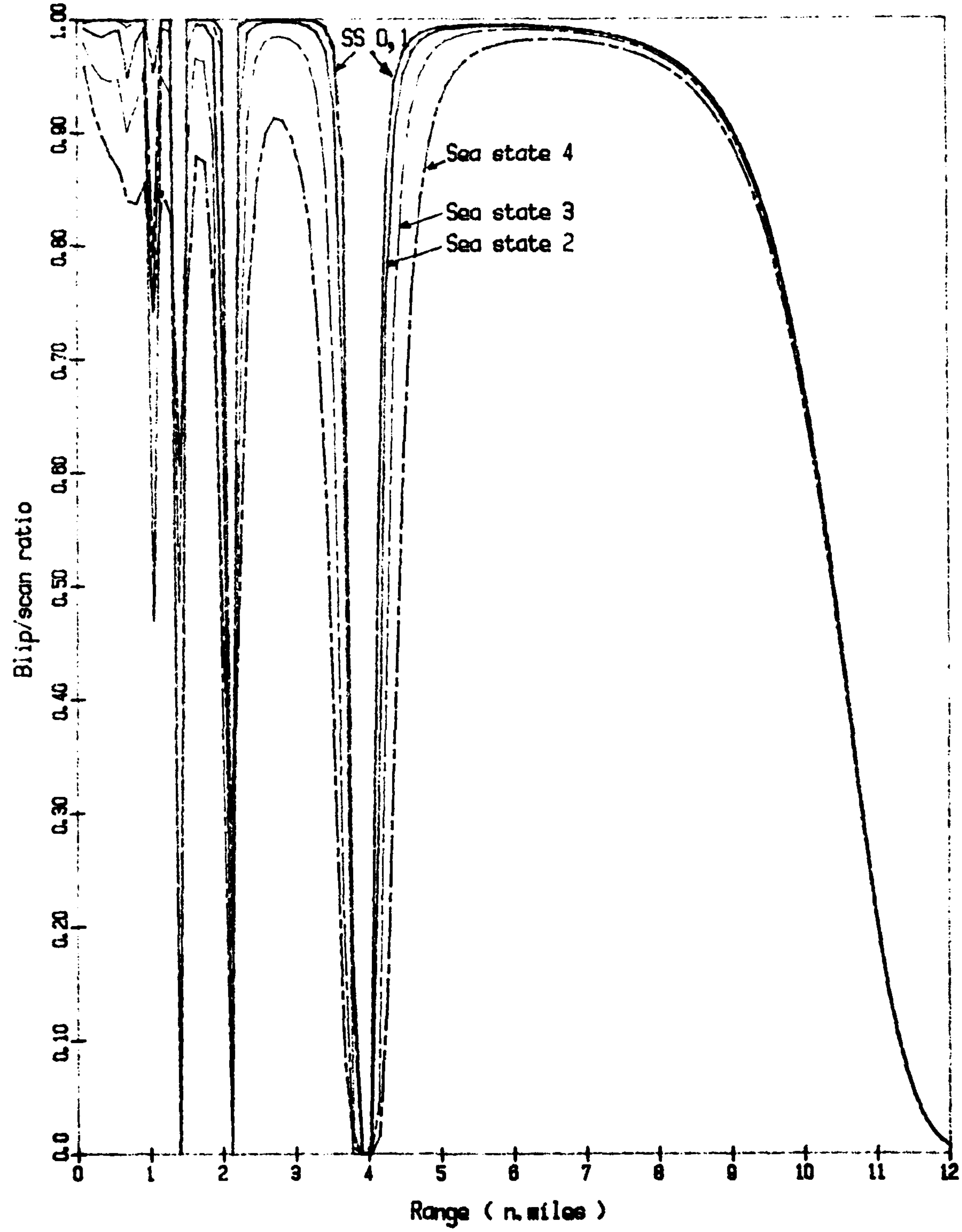

Figure 5. Calculated blip/scan ratios for HMAS Cook radar.
Target: 10 m^2 lens reflector mounted at 5 m.
Assumed fluctuation: scan-to-scan.
Environmental: Air temp : 28.0 C.
Humidity : 85%
Sea State: 0 to 4 (Douglas scale)

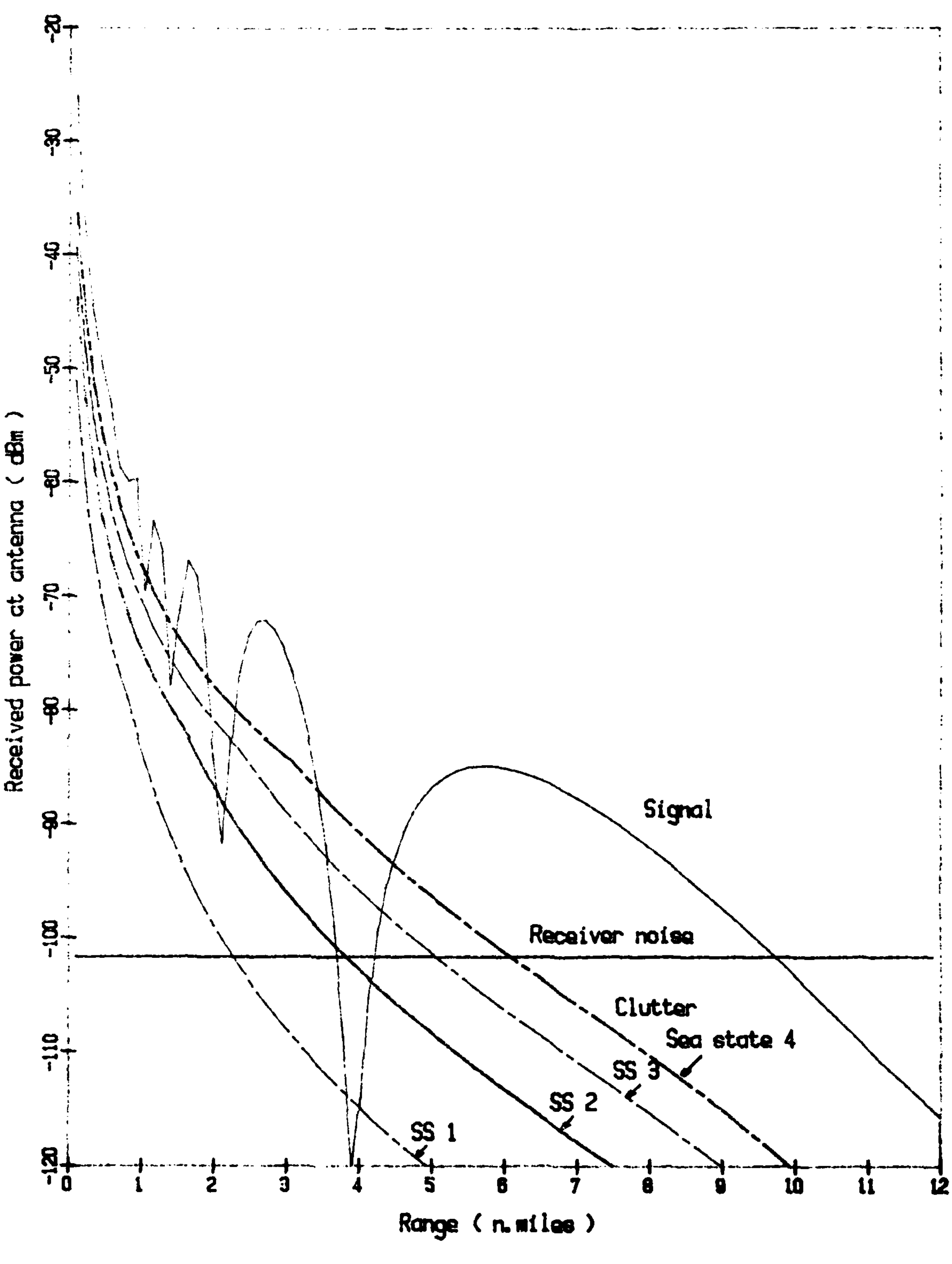

Figure 6. Calculated Clutter and 1 m^2 signal levels for HMAS Cook.
Target: 1 m^2 mounted at 5 m.
Assumed fluctuation: scan-to-scan.
Environmental: Air temp : 28.0 C.
Humidity : 85%
Sea State: 1 to 4 (Douglas scale)

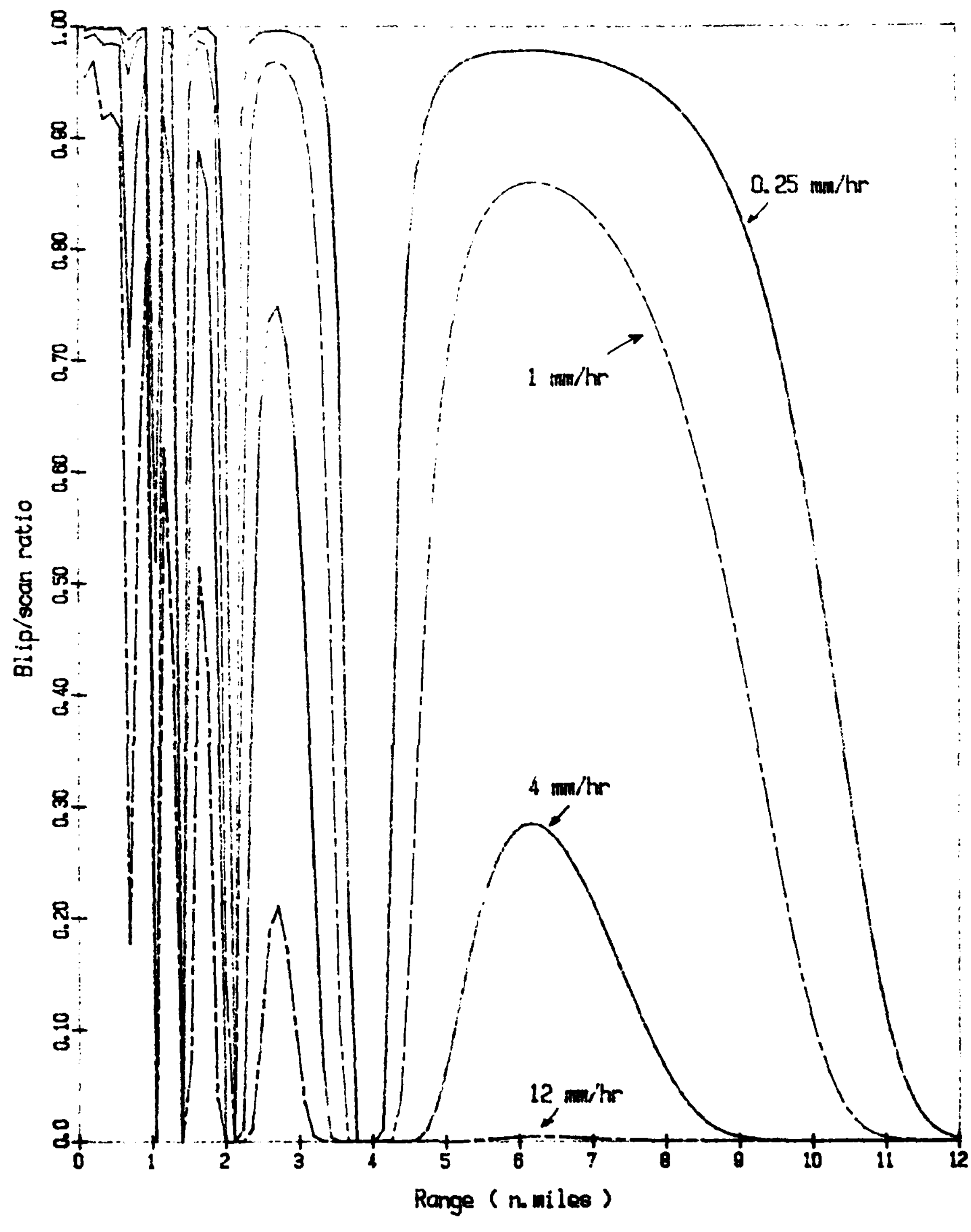

Figure 7. Calculated blip/scan ratios for HMAS Cook radar in presence of rain.
Target: 10 m^2 lens reflector mounted at 5 m.
Assumed fluctuation: scan-to-scan.
Environmental: Air temp : 28.0 C.
Humidity : 85%
Sea State: 1 (Douglas scale)
Rainfall : 0.25 to 12 mm/hr

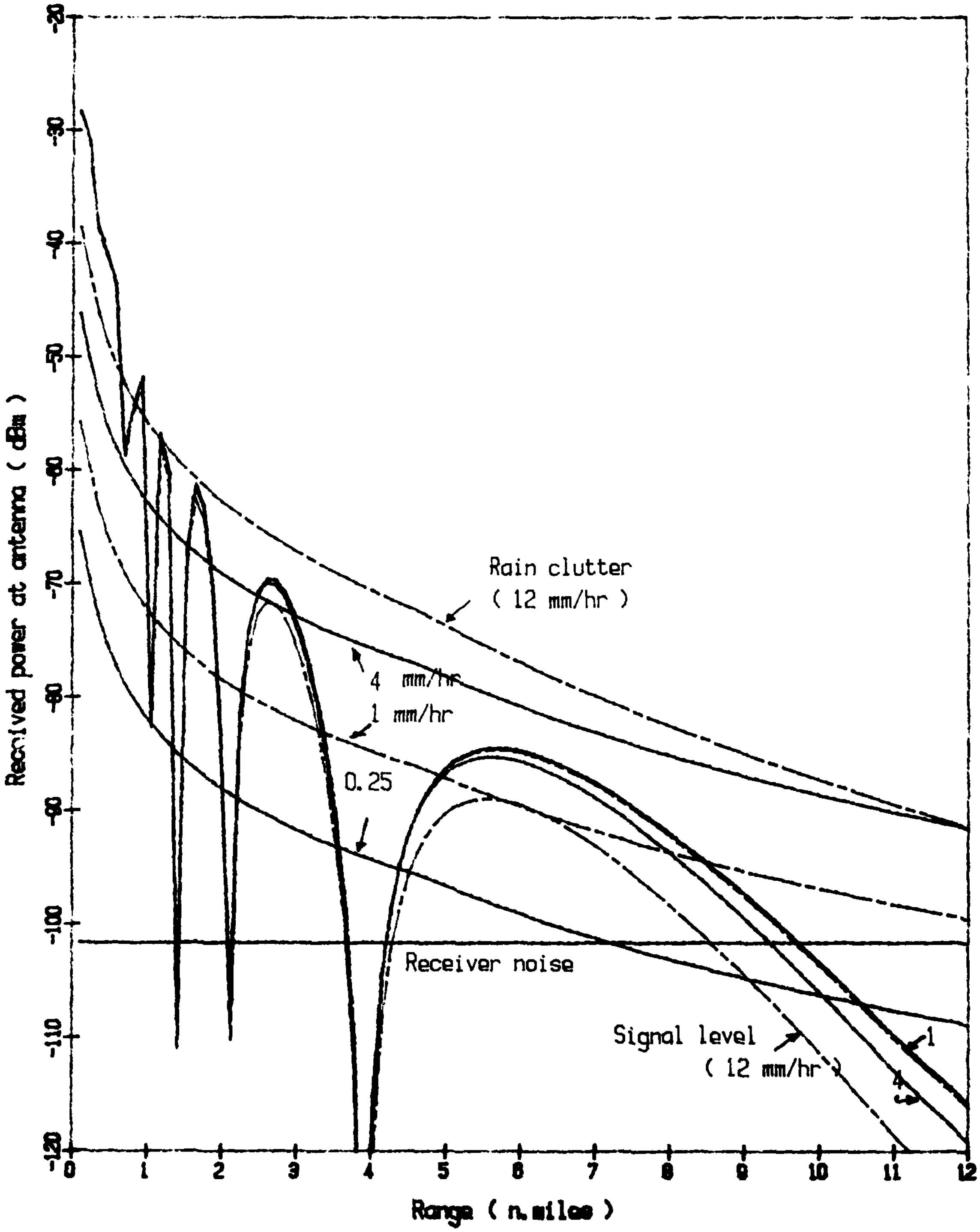

Figure 8. Calculated Rain Clutter and 1 m^2 signal levels for HMAS Cook.
Target: 1 m^2 mounted at 5 m.
Assumed fluctuation: scan-to-scan.
Environmental: Air temp : 28.0 C.
Humidity : 85%
Sea State: 1 (Douglas scale)
Rainrate : 0.25 to 12 mm/hr

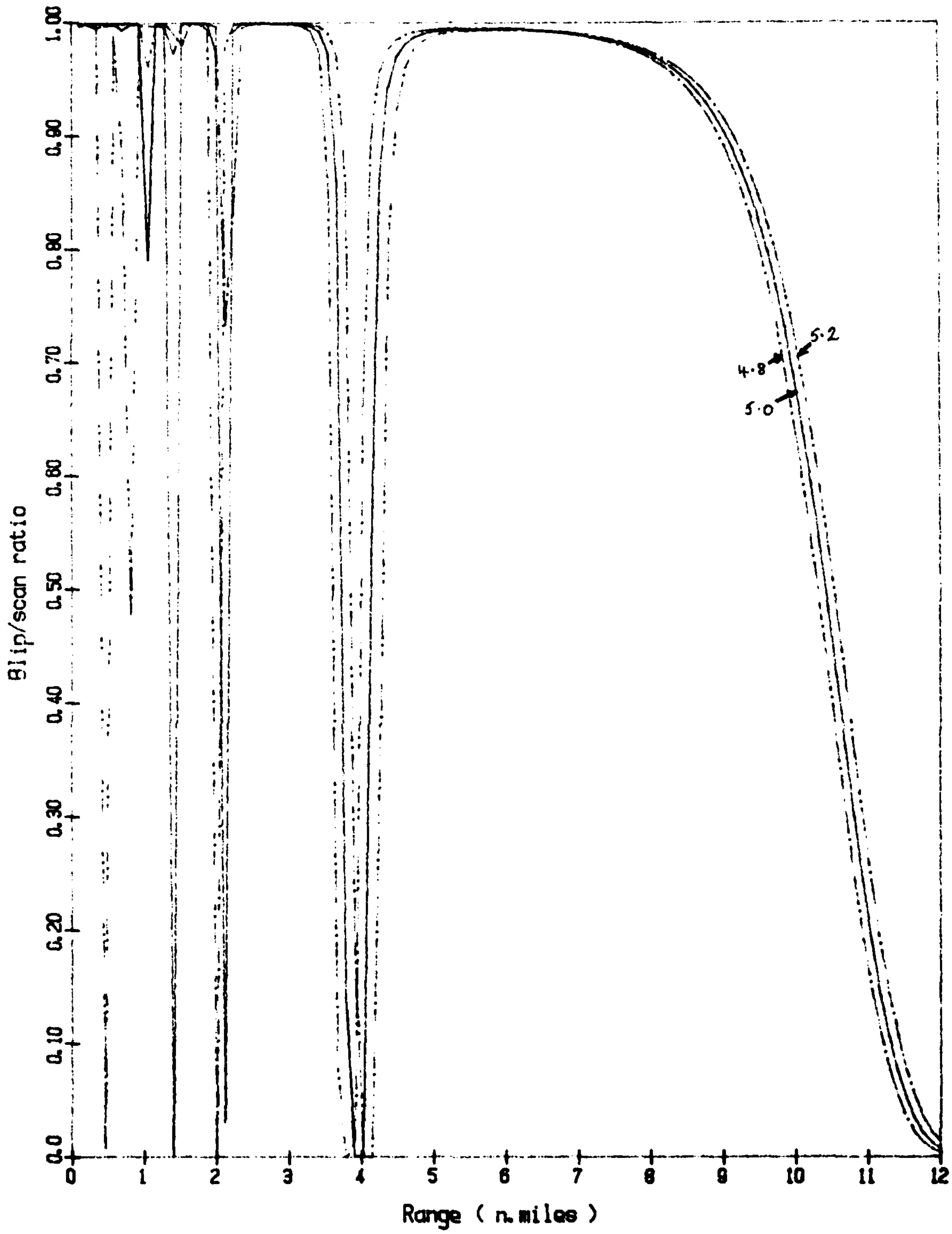

Figure 9. Effect of varying target height on detection by HMAS Cook radar.
Target: 10 m^2 lens reflector mounted at 4.8, 5.0 and 5.2 m.
Assumed fluctuation: scan-to-scan.
Environmental: Air temp : 28.0 C.
Humidity : 85%
Sea State: 1 (Douglas scale)

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16. Abstract

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