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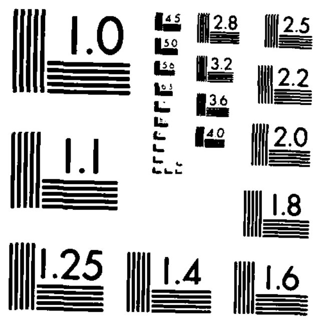

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RANRL TECHNICAL MEMORANDUM (EXTERNAL) No. 9/83

SIMPLE PREDICTION OF CONVERGENCE ZONE PROPAGATION IN WATERS AROUND AUSTRALIA

MARTIN W. LAWRENCE

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SIMPLE PREDICTION OF CONVERGENCE ZONE PROPAGATION IN WATERS AROUND AUSTRALIA

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ABSTRACT

The horizontal ranges to convergence zones are determined for waters around Australia, using historical sound speed profile data and a computer model. A good correlation is found between sound speed at the surface and the convergence zone range, but with a different relationship between these parameters than observed in various Northern Hemisphere waters. The relationship between critical depth and surface sound speed for Australian waters is found to be similar to, although not identical with, that for the North Pacific Ocean.

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P.O. Box 706, Darlinghurst, N.S.W. 2010

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1. INTRODUCTION

1.1 Convergence Zones

In the deep ocean acoustic energy generated near the sea surface is frequently found to return to the sea surface, after being refracted at depth, to form what is known as a convergence zone, at a horizontal range of order tens of nautical miles.

The acoustic energy is often focussed at the convergence zone. If the acoustic transmission loss is examined against horizontal range, the convergence zone will appear as a peak of energy frequently 20 dB above surrounding energy levels.

A convergence zone may be characterized by such parameters as: horizontal range from source, horizontal width, and acoustic strength above background. These characteristics depend on the sound speed profile with depth. Horizontal homogeneity is assumed throughout this discussion.

A typical sound speed profile is shown in Figure 1. Acoustic energy from a source near the sea surface may be trapped by the positive (increasing sound speed with increasing depth) sound speed gradient near the sea surface. This trapping occurs for rays which are nearly horizontal, provided the acoustic frequency is high enough to permit trapping. Rays which escape this "surface mixed layer" are refracted downward by the underlying thermocline (negative sound speed gradient region) and are subsequently refracted upward by the deep region with positive sound speed gradient (due to pressure). Figure 2 illustrates this process.

Provided that the water is deep enough, the pressure dominated positive gradient will refract rays coming from near the surface, so that

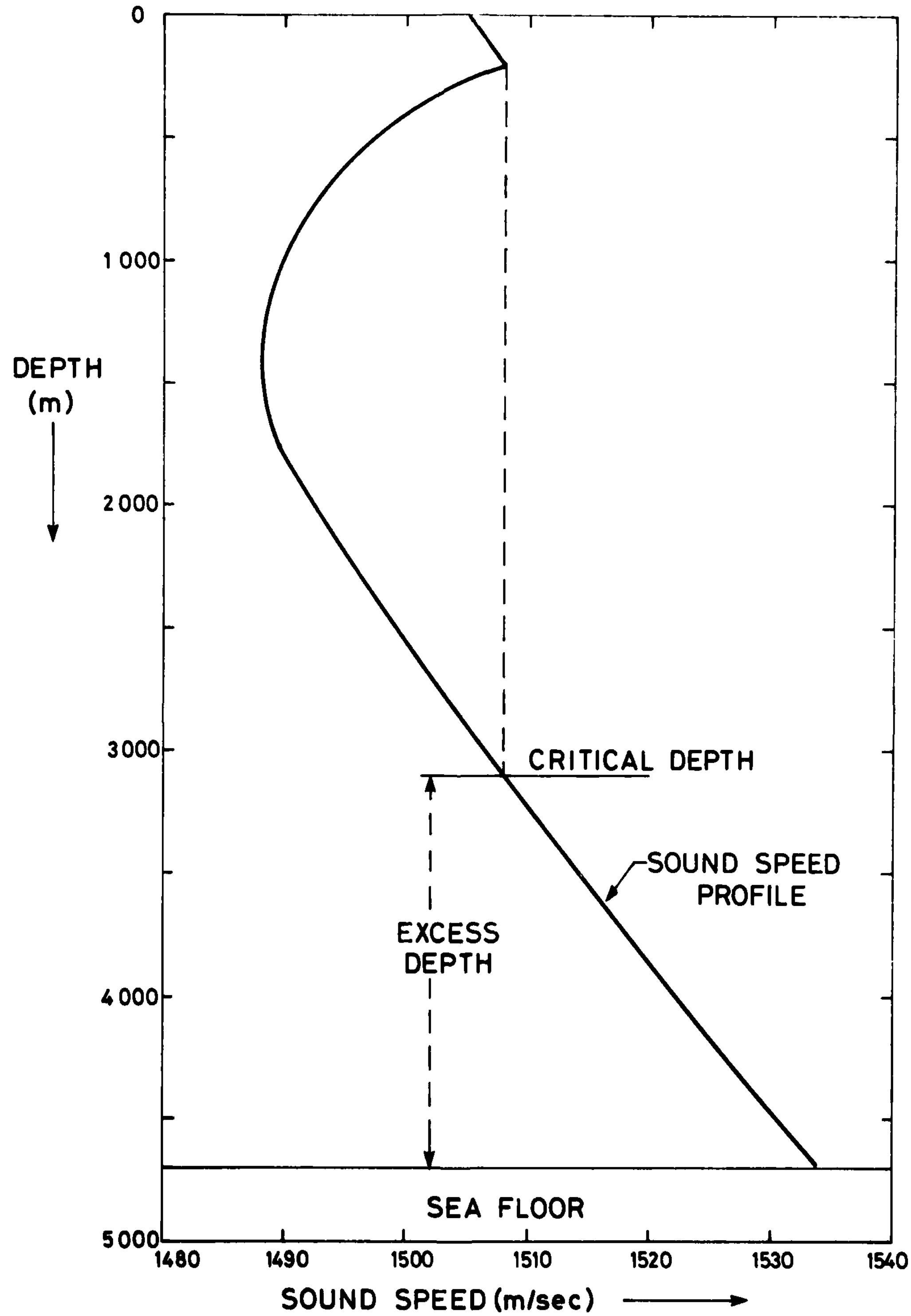

Fig.1. Typical sound speed profile.

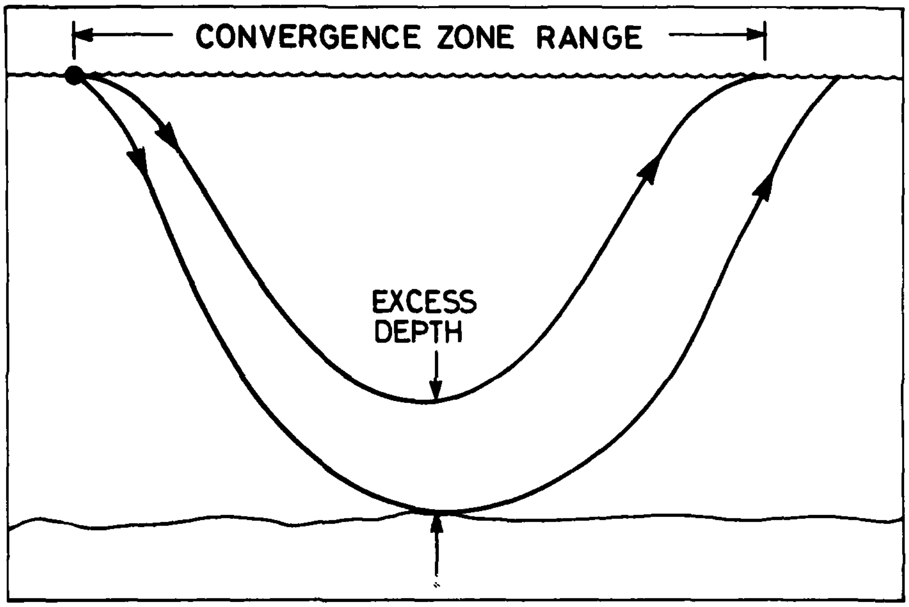

Fig. 2. Convergence zone illustration.

they become horizontal at some depth and then are refracted back towards the sea surface to form a convergence zone. The minimum depth at which these rays become horizontal is known as the "critical depth". A large "excess depth", below the critical depth, will allow a large return of energy to the convergence zone.

1.2 Prediction of Convergence Zones

A "Convergence Zone Range Slide Rule" (Tacaid 6-10) has been produced (ref 1) by the Naval Underwater Systems Center for use by the United States Navy. This slide rule allows determination of horizontal range separating source and convergence zone, by using the value of sound speed (or temperature) at the sea surface. In addition the excess depth may also be determined, provided that the water depth is also known. The slide rule uses different relationships for the following ocean areas: North Atlantic Ocean, North Pacific Ocean, Mediterranean Sea and Norwegian Sea.

This document examines the relationships which exist in the waters around Australia, and compares these to those used on the existing slide rule.

Propagation loss against range curves have been determined from measured profiles. This allows the potential accuracy and validity of this type of slide rule to be discussed.

A study by Nysen (ref 2) has examined the variation in convergence zone range, as a function of specific changes in an idealized sound speed profile. Nysen's study shows that surface sound speed and mixed layer depth are the most critical determinants for convergence zone range variability in the North East Indian Ocean. It also provides an insight into how specific changes in profile affect convergence zone range.

2. CONVERGENCE ZONE RANGE

2.1 Method

The technique used in this investigation was to select experimentally observed sound speed profiles (whether directly measured or calculated from temperature, salinity and depth). Profiles were only chosen if they went to near the sea floor and were taken in water deep enough to provide convergence zone propagation. The measured profiles were extrapolated to the sea floor.

All profiles were selected from waters around Australia. The profiles were from the data bank of the National Oceanographic Data Centre, and the Cruise Reports of the U.S.N.S. Eltanin (ref 3). Data which satisfy all the above criteria are scarce; in most Marsden Squares examined, all available profiles were used. The locations used are shown in Figure 3, by hatching of relevant Marsden Squares.

The calculational technique used was the ray theory computer program FACT, developed by Spofford (ref 4). This program assumes no horizontal range dependence and it approximates the sound speed profile by a piecewise-linear function of depth. The program also calculates caustics using asymptotic expansions, suppresses false caustics, and includes bottom loss varying with bottom grazing angle. Propagation entirely within the mixed layer is handled by empirical formulae, rather than ray theory. For details see ref 3.

As used in the calculations of this study, FACT added the contributions of each path (to the same point) incoherently. Also, a high value of bottom loss was chosen (parameter 8 in FACT). The source and

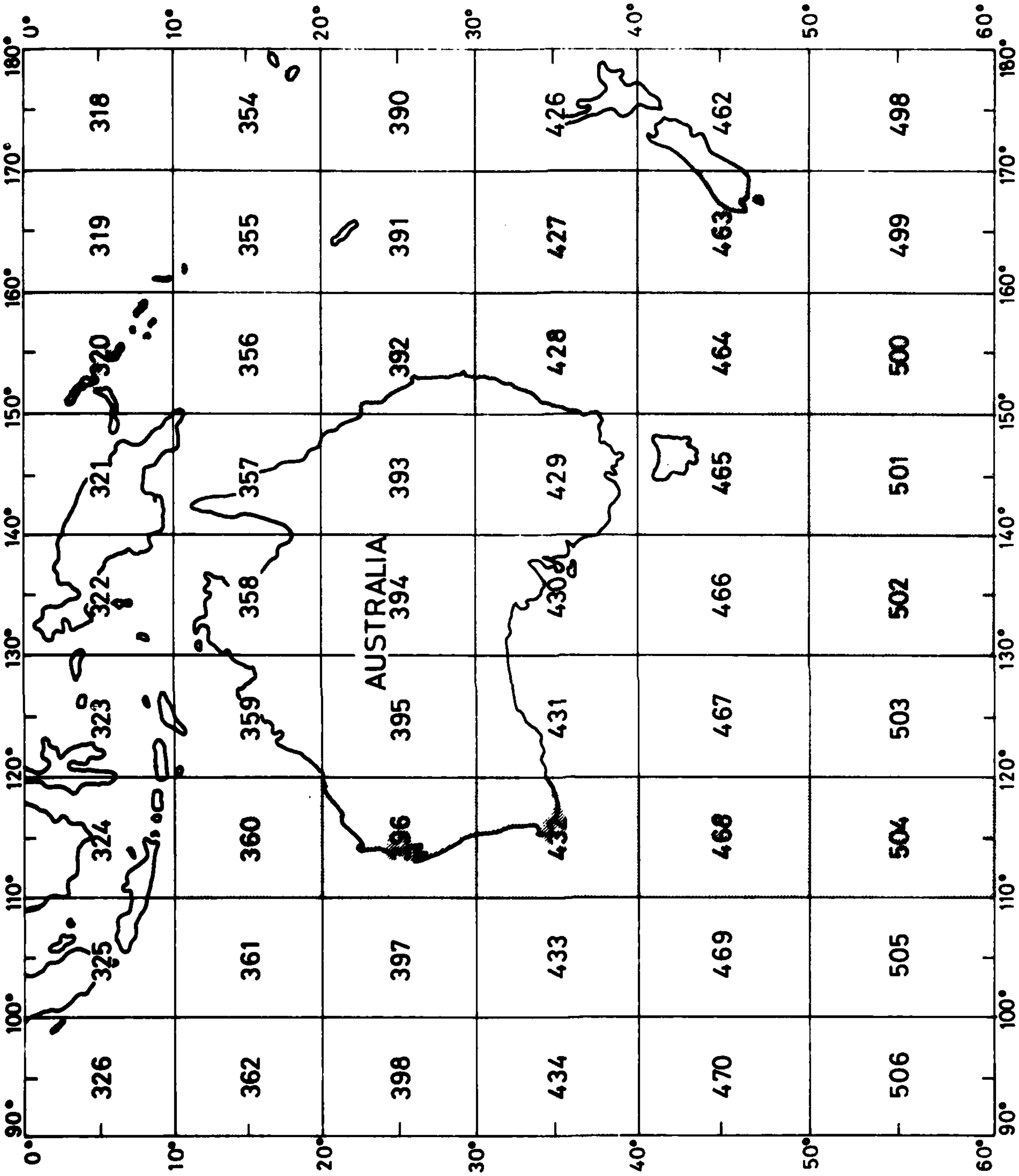

Fig. 3. Location of sound speed profiles.

receiver depths chosen were close to the surface (10 m).

For most profiles, the frequency at which the calculation was performed was 100 Hz. At the higher latitude locations, the surface mixed layer was sometimes so thick that the mixed layer propagation masked the convergence zone. For these locations the calculations were repeated at a frequency of 20 Hz. The poorer trapping in the mixed layer at this lower frequency prevented this masking in all cases.

2.2 Results

Figure 4 shows a typical propagation loss against range curve produced by FACT for one sound speed profile. The main contributing path at each range is also indicated.

From each of these curves (one for each profile), a value of the horizontal range to the first convergence zone was determined, by measuring from the source to the point at which the convergence zone propagation loss is 3 dB below its peak (measured on the side nearer to the source). Thus the range that we are determining here is the range to the near side of a convergence zone. The width of the convergence zone will be affected both by the excess depth and the shape of the profile.

Figure 5 shows curves from the NUSC slide rule for the ocean areas which it covers. These curves (of convergence zone range against surface sound speed) extend as far as the coverage by the slide rule. The Mediterranean Sea is very different to the other areas because it has relatively hot water ($\simeq 13^{o}C$) at the sea floor. All differences between

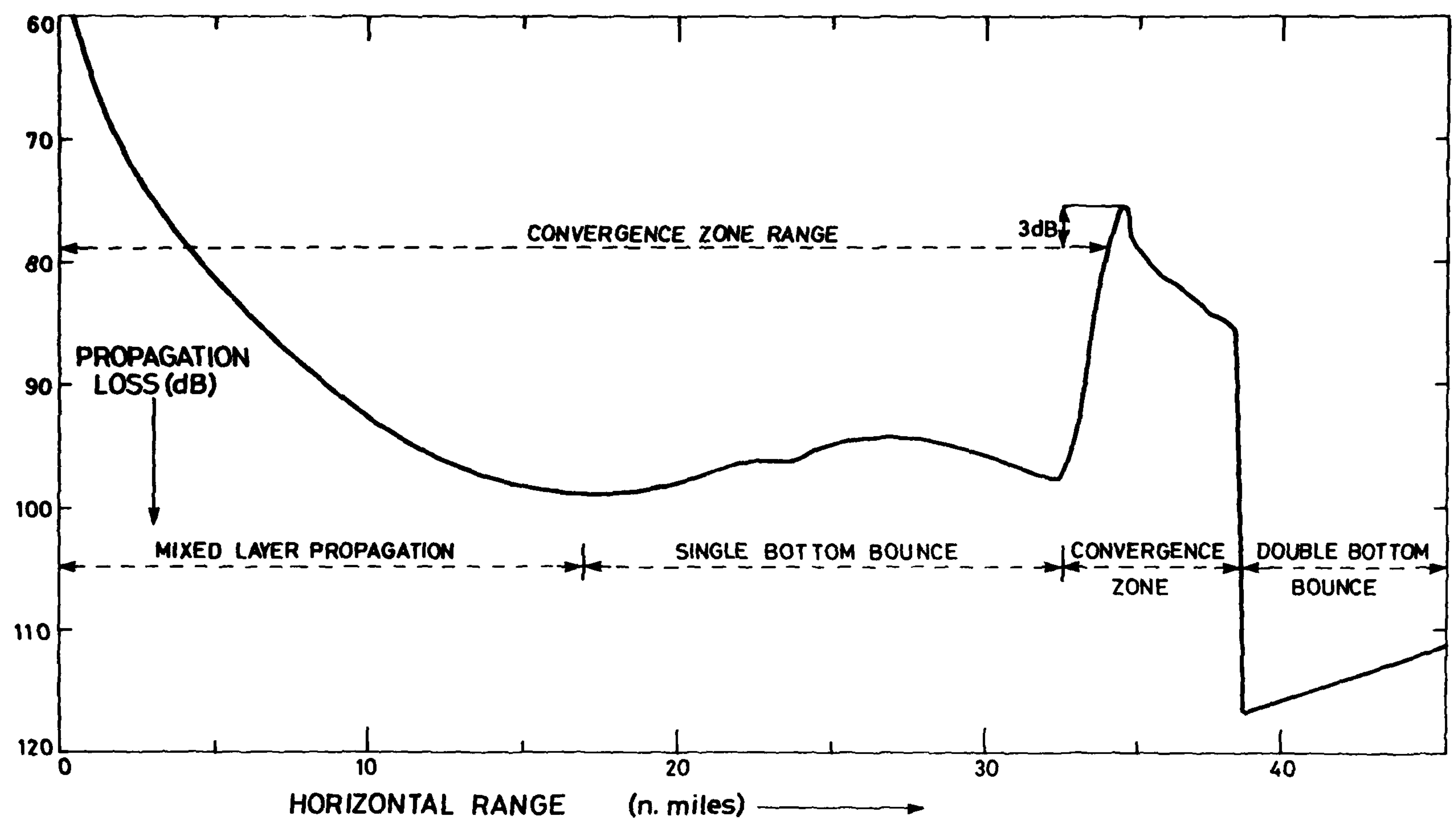

Fig. 4. Typical propagation los curv

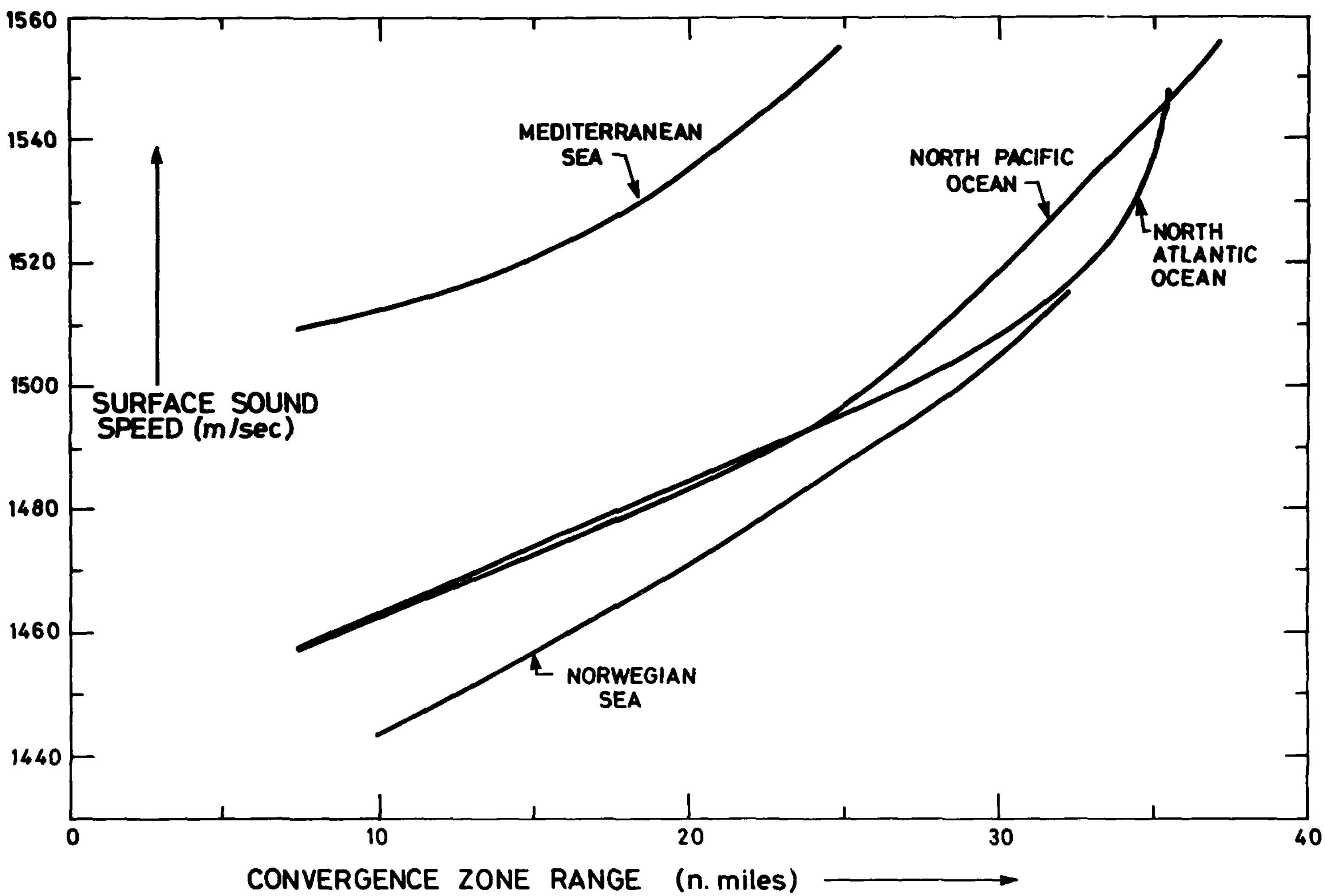

Fig. 5. Convergence zone ranges from NUSC slide rule.

the curves must result from characteristic (i.e. average) differences in the sound speed profiles, given the same surface sound speed.

Figure 6 shows the results for Australian waters superimposed on the curves of Figure 5. It is evident that there is good agreement between the results from East and from West of Australia, but that the results are noticeably different to any of the curves from the Northern Hemisphere. Most of the points for the Australian Region can be reasonably approximated by a smooth curve (as drawn on Figure 6).

In order to test the technique used here, four sound speed profiles from the North Atlantic Ocean (ref 5) were used in the same way to give convergence zone ranges. The results are plotted in Figure 7, where it is evident that these points are more consistent with the North Atlantic Ocean curve than with the Australian Water results.

2.3 Discussion

The above calculations have been performed in such a way as to clearly show the convergence zone propagation by minimizing the other modes of propagation. The usefulness of a relationship between sea surface sound speed and convergence zone range can be affected by a number of factors, which are discussed below.

A surface mixed layer can lead to strong propagation via this layer, which masks the convergence zone. The effect of a mixed layer is frequency dependent, with the lower frequencies propagating less well by this path. In particular, frequencies below $1.76 \times 10^5 \times H^{3/2}$ Hz, are

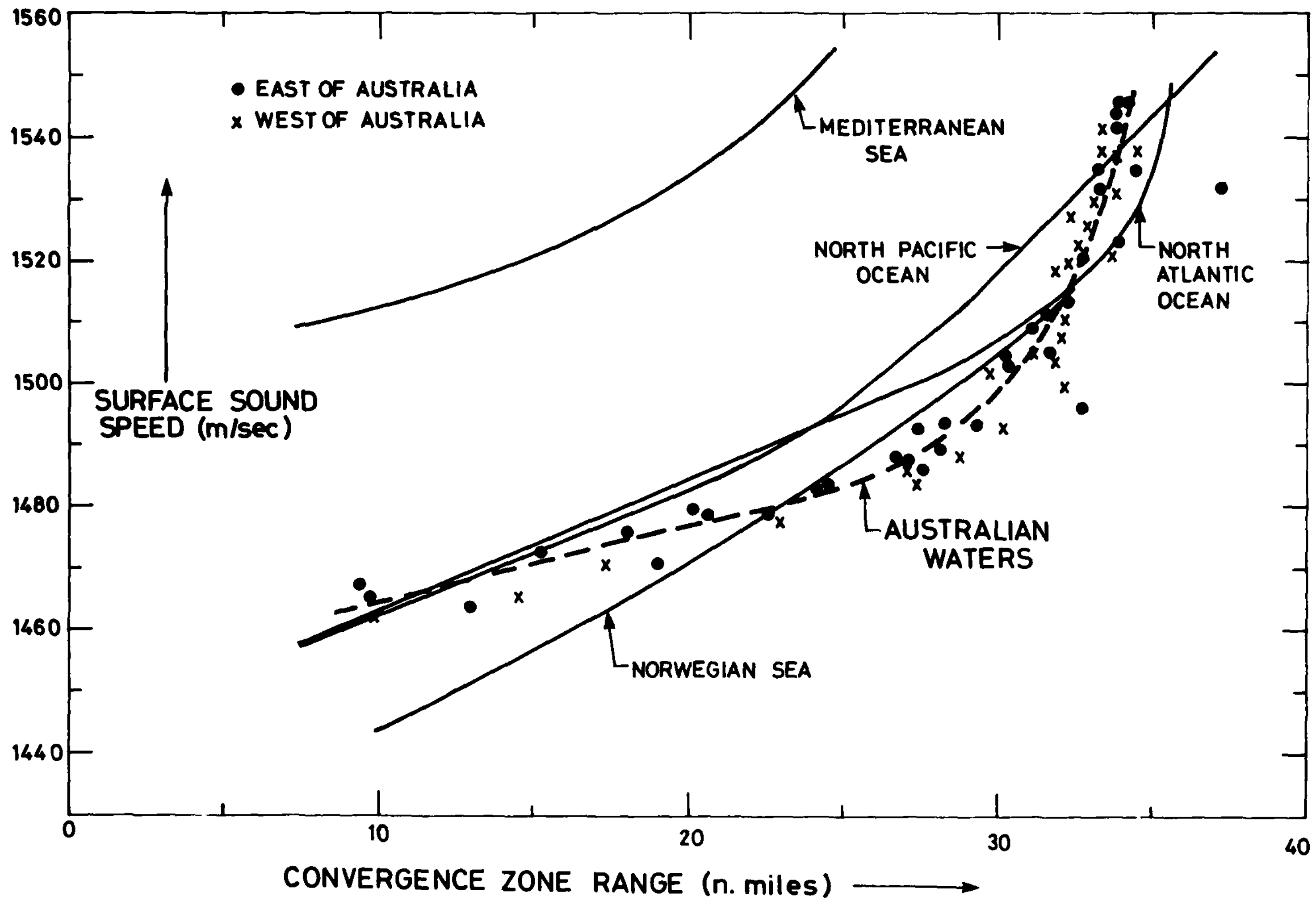

Fig. 6. Convergence zone range for Australian waters.

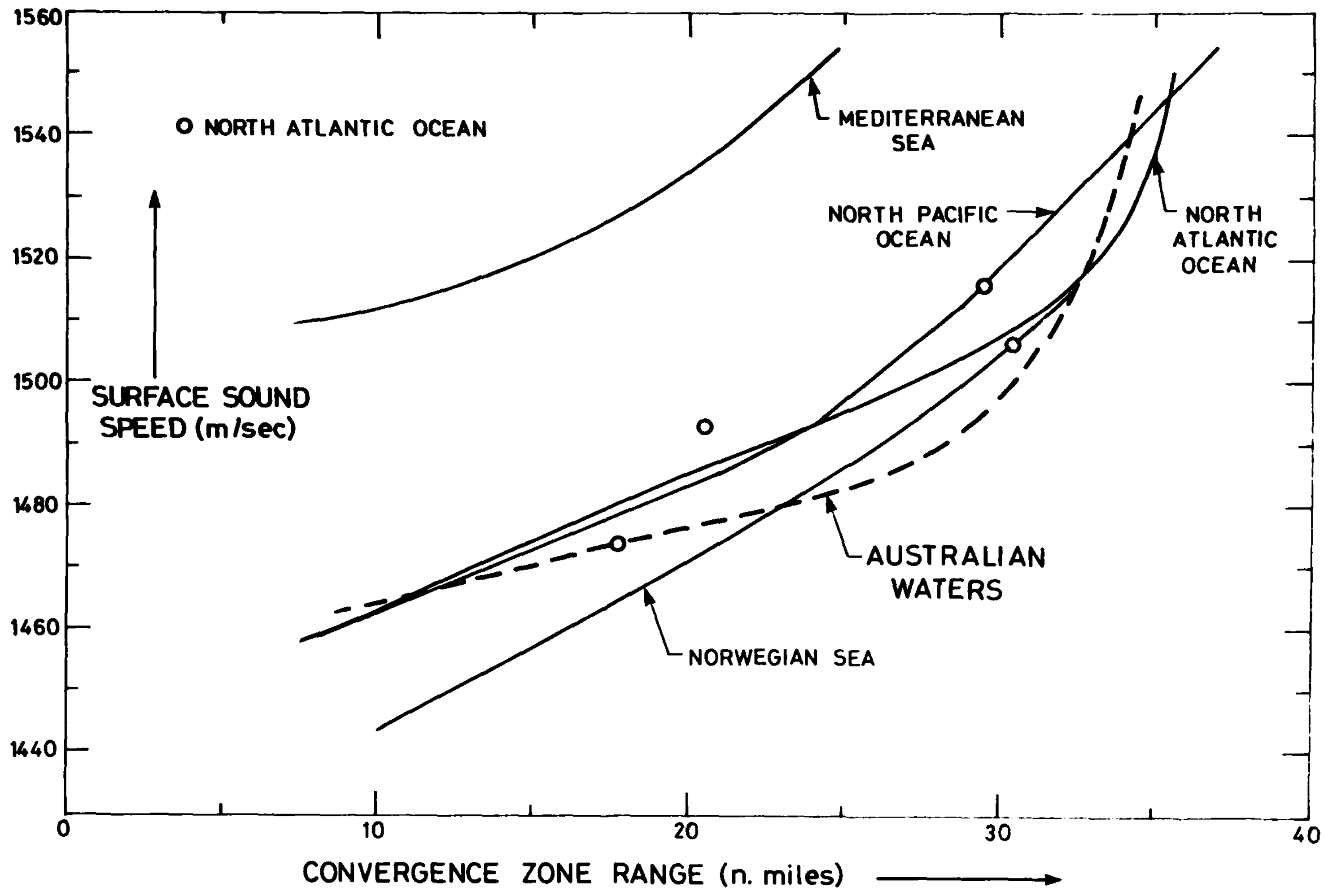

Fig. 7. Convergence zone range for locations in North Atlantic Ocean.

essentially cut off from propagating in the mixed layer (where H is the mixed layer thickness in metres (ref 6).

Horizontal variability is such as to reduce the effect of mixed layer propagation, since the thinnest region of the mixed layer on the propagation path will set the cutoff frequency. Mixed layer thickness is one of the oceanographic parameters with highest horizontal variability.

Surface Interference

Another effect which can significantly affect the observed convergence zone propagation is the "Lloyd's Mirror" effect. That is interference between the direct path and the surface reflected path. This surface reflection can be significant for reflection both near the source and near the receiver. The calculations reported here were performed with incoherent addition of intensities. This was done because the surface interference effect is strongly dependent on source depth, receiver depth, and frequency. Thus, general curves must avoid this effect.

The result of surface interference is to significantly enhance the received signal (at some ranges) due to constructive interference and to significantly reduce the received signal (at other ranges) due to destructive interference. These effects can be in excess of 10 dB of transmission loss, which can result in a significantly altered curve of transmission loss against range.

Multiple Convergence Zone Peaks

Convergence zones repeat at multiples of the range between the source and the first convergence zone. However, for some sound speed profiles, the first convergence zone can be split into two distinct peaks. This effect is a direct result of the shape of the sound speed profiles. A lesser effect of this same phenomenon is the variation in shape of the convergence zone peak for the various sound speed profiles. The multiple convergence zone peaks occur most frequently when the surface sound speed is between 1480 and 1490 m/sec. Splitting of the convergence zone appears to be associated with the presence of more than one sub-surface minimum in the sound speed profile.

The implications of split convergence zone peaks should be considered in any application of convergence zone propagation.

Range Dependence of Sound Speed Profile

Variation of sound speed profile along the propagation path should have negligible effect on parameters determined from the curves of this document. Any single profile from along the propagation path should fit these curves; a combination of these profiles will not fit any worse.

Further Results

Calculations using more sound speed profiles would minimize the possibility that some profiles that give unusual results have been missed. Further calculations would also be useful in investigating any difference between the curves obtained for winter and for summer.

Finally, the areal extent over which the "Australian Waters" curves apply could be delineated by calculations in more Marsden Squares.

However it is plausible that these curves will apply to all of the Southern Ocean (which has similar properties at all longitudes) and all oceans which are strongly influenced by the Southern Ocean.

3. CRITICAL DEPTH

The critical depth was determined (directly from the sound speed profiles) as the shallowest depth for a horizontal ray in the pressure driven positive gradient region. This depth is that with sound speed equal to the maximum sound speed in the profile above this depth. The results are plotted in Figure 8.

It is evident that there is a fairly tight relationship between surface sound speed and critical depth, except at low values of surface sound speed. Most of the observed deviation from a smooth curve is due to surface mixed layer effects, especially at low surface sound speeds.

Figure 9 contains critical depth curves from the NUSC slide rule, together with a smooth fit to the data from Australian waters. It is evident that the Australian curve is close to, although not identical with, the curve for the North Pacific Ocean. None of these curves contains any component for low values of surface sound speed because of (i) large variability due to mixed layer problems, and (ii) the critical depth is so shallow that there is normally an adequate excess depth for convergence zone propagation.

The excess depth, as given by the NUSC slide rule, may be determined directly from the difference between the actual water depth and the critical depth.

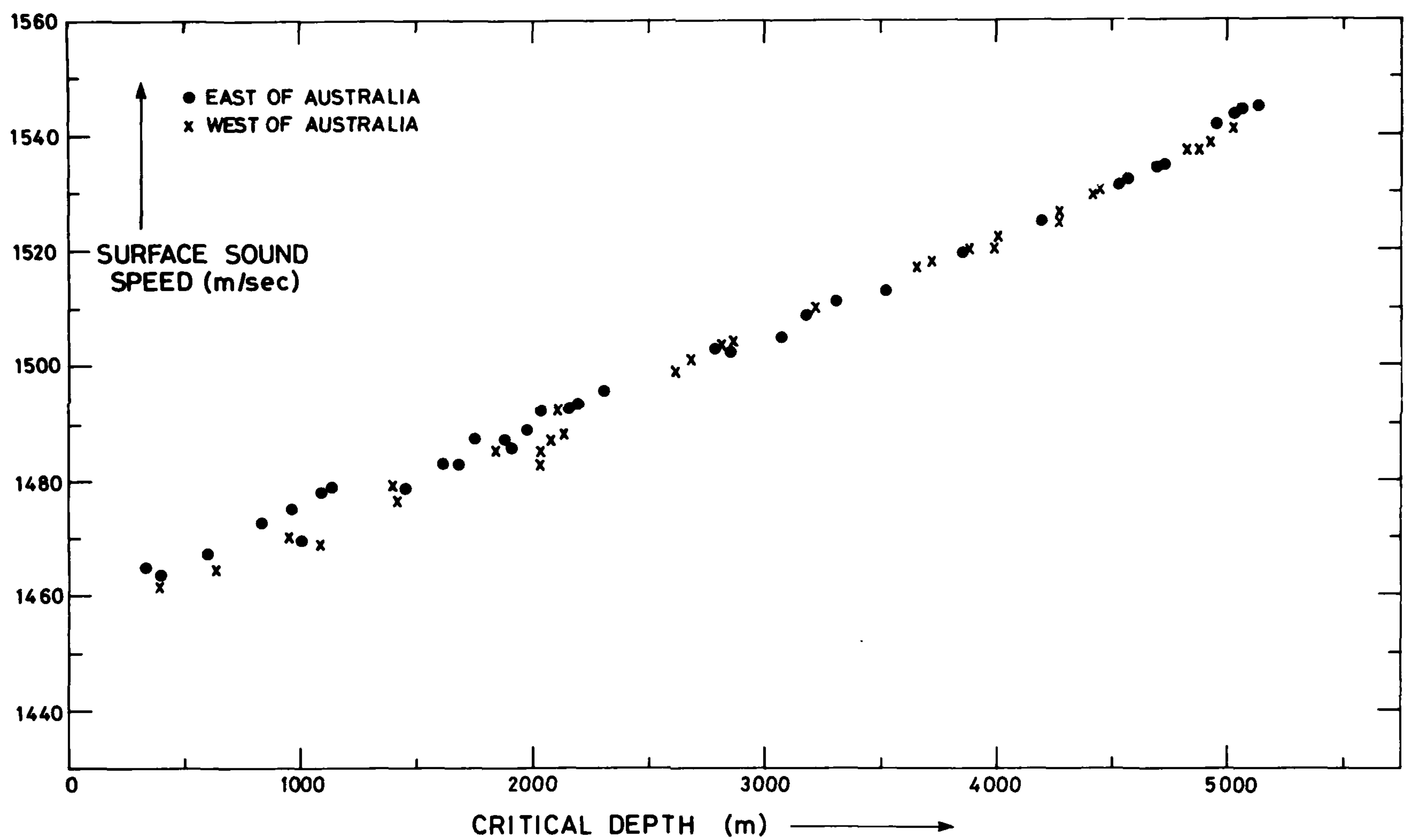

Fig. 8. Critical depth for Australian waters.

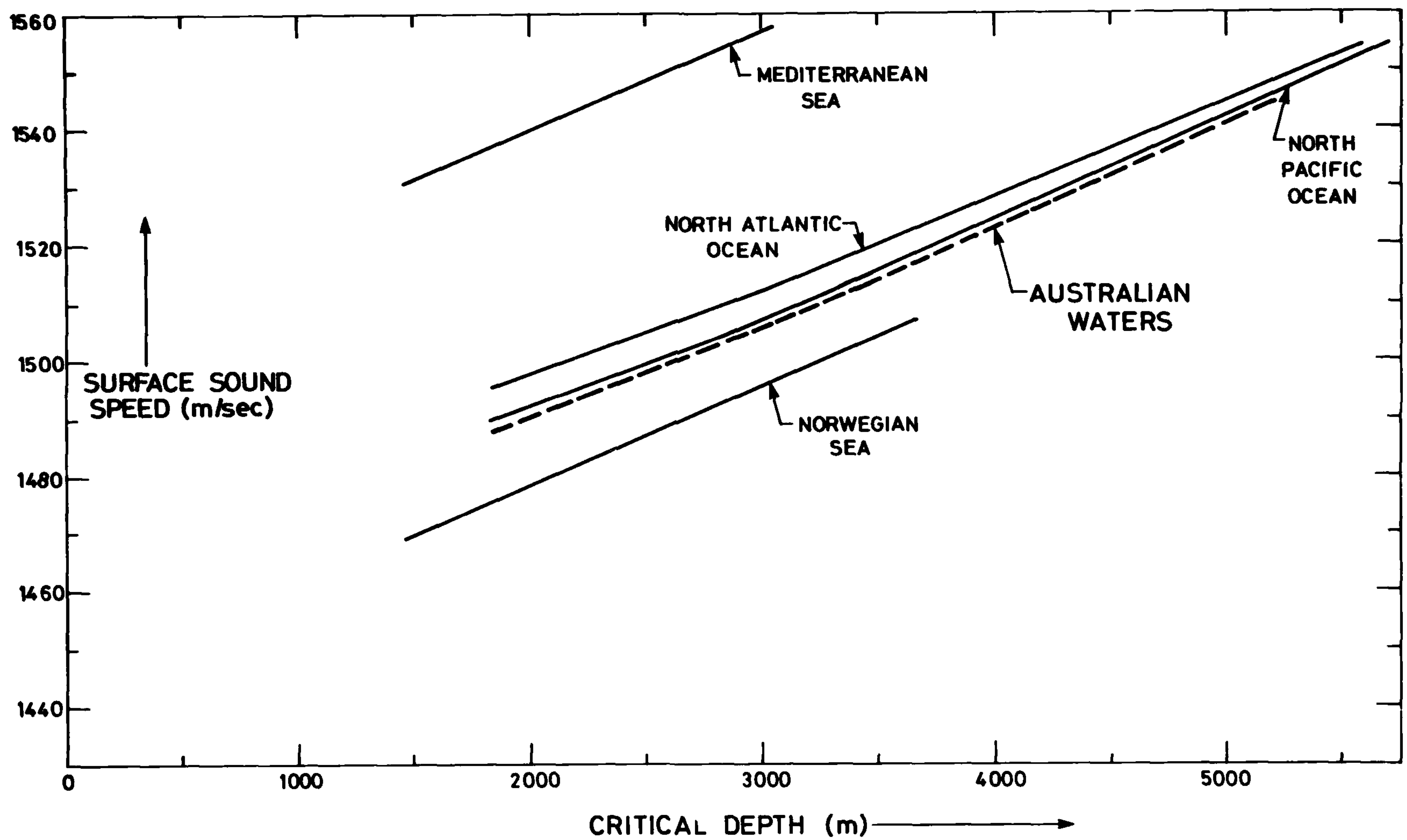

Fig. 9. Critical depth from NUSC slide rule, together with Australian waters.

4. CONCLUSIONS

The sound speed (and hence the temperature) at the sea surface is found to be a reasonably good predictor of the horizontal range to the first convergence zone. The same relationship between these parameters may be used for all waters around Australia. The relationship is significantly different to those used in various Northern Hemisphere waters.

The relationship between critical depth and surface sound speed in Australian Waters is found to be close to, but not identical with, that for the North Pacific Ocean.

ACKNOWLEDGEMENTS

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