

EFFECTS OF OCEAN THERMAL STRUCTURE ON FISH FINDING WITH SONAR

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THE ACTIVE SONAR FORMULA

The sonar equipment has become in common use in most modern offshore fisheries in the North Atlantic. The performance of the sonar in fish finding depends on a multitude of factors, such as the technical properties of the sonar itself (e.g. the frequency used), the self noise of the vessel, the skill of the operator and, not least, the environment in which the sound propagates. This paper deals with the effects of the ocean thermal structure on the sound propagation.

The noise limited active sonar equation can be presented in a general form:

$$M_n = (S_o + T - 2H) - (N + \Delta R)$$

where M_n is the signal to noise ratio (or the recognition differential), S_o is the original signal strength, T is the target strength (or its scattering cross section) and $2H$ is the two-way propagation loss in the water. N and ΔR present the self noise and the directivity index (i.e. the gain of the signal due to receiving directivity) respectively. In reverberation limited condition, the last term ($N + \Delta R$) represents the reverberation level.

The noise level N depends on environmental noises, such as those caused by breaking waves, by noise making marine animals, rain, traffic, and first of all, by the ships' own noises carrying the sonar.

EFFECTS OF OCEAN ENVIRONMENT ON THE PROPAGATION OF SOUND

The sound impulse emitted by a sonar or an echo sounder is subject to a number of losses during its travel through the water: the absorption

Contribution given in honour of Gunnar Rollesfsen at his 70th birthday.

loss in water, the geometrical spreading loss, surface scattering (reverberation), volume scattering and bottom reflection or scattering loss.

The absorption loss in water is greatly dependent on the frequency used by the sonar, and also depends on the temperature of the water:

$$a = \frac{0.17}{T + 18} f^2$$

where a is absorption loss, T is temperature of the water and f is the frequency. The surface scattering depends on the roughness of the surface (e.g. the wave height) and sonar frequency. The bottom scattering is a relatively complex function of the type of sediment, bottom roughness and frequency. The volume scattering depends on frequency and on the amount of scatterers (such as air bubbles, plankton and fish).

The geometrical spreading loss depends on the vertical distribution of the sound speed in the water. This aspect of the sound propagation is described in this paper in relatively easily measured and/or predicted ocean thermal structure parameters—sea surface temperature (SST), mixed layer depth (MLD) (the depth of the top of the thermocline), and the gradient of temperature between the surface and the MLD (“in layer gradient”, INGRAD).

EFFECTS OF OCEAN THERMAL STRUCTURE ON THE PROPAGATION OF SOUND

GENERAL SOUND PROPAGATION MODEL IN RELATION TO THERMAL STRUCTURE

The sound waves, as most true wave motions, follow the SNELLIUS law, i.e. they refract towards the lower velocity of propagation. It is most appropriate to present the propagation paths in the form of sound rays which are perpendicular to the wave front.

A typical sound speed structure and a few significant sound rays are given in Fig. 1. The following features of interest are depicted in this figure: (a) the sound propagation in the surface duct, (b) the distance of the “partial shadow zone”, and (c) the width and distance of the bottom bounce beam. The dependence of these features on the thermal structure were investigated, using a precision ray tracing technique (AYRES, WOLFF, CARSTENSEN and AYRES 1966) on the CDC 1604 computer. This ray tracing technique uses a time step of 1/124 second and a space step of 10 metres and includes the effects of the curvature of the earth. A ray bundle of 16° ($+8^\circ$ to -8°) was used corresponding roughly to the average beam width of sonars in use.

The ray traces of various thermal structure profiles (33 in number) with varying SST, MLD and INGRAD were computed. A few examples

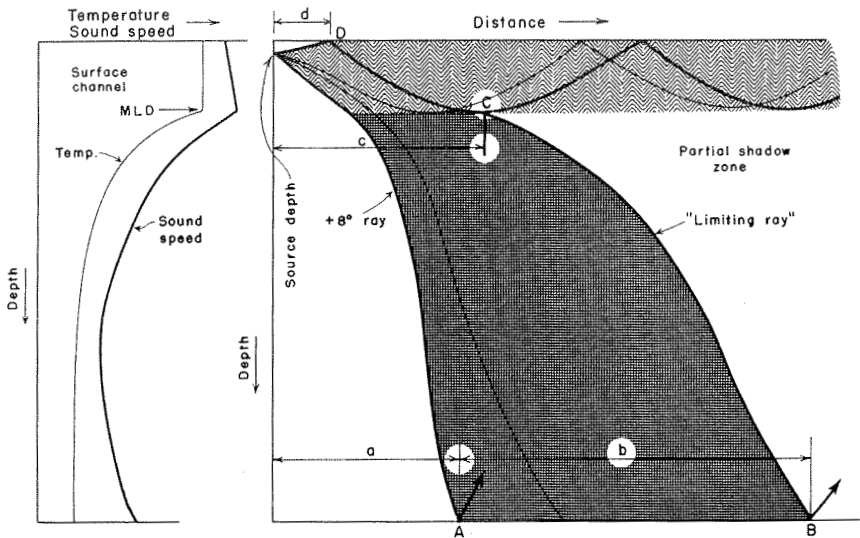


Fig. 1. A typical temperature and sound speed profile and significant sound rays.

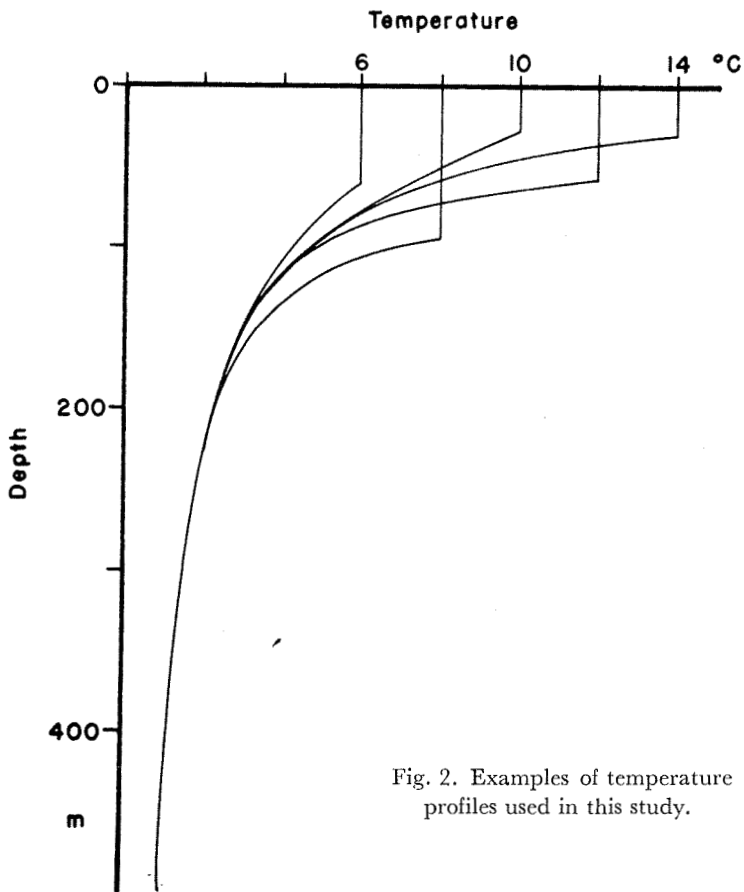


Fig. 2. Examples of temperature profiles used in this study.

of the selected profiles are shown in Fig. 2. The study of the influence of SST and MLD on the sound propagation parameters of interest was made with an isothermal layer from surface to MLD. Thus, the sound speed increases from the surface to the MLD where it reaches a maximum due to pressure effects on sound speed. Some of the nearly horizontal sound rays will become trapped in the surface mixed layer as the sound rays bend slightly towards the surface above the MLD. A separate study was made of the effects of negative temperature gradients between the surface and the MLD.

The ray tracing was computed to a maximum depth of 500 metres and to a maximum distance of 10 kilometres. The salinity was taken constant from the surface to 500 metres. The effect of salinity on sound speed is considerably smaller than that of temperature. Furthermore, it is relatively easy to ascertain the synoptic thermal structure (e.g. with bathythermograph cast) from a fishing vessel, whereas the determination of synoptic salinity structure from fishing vessels is, at present, not possible.

SEA SURFACE TEMPERATURE, MIXED LAYER DEPTH AND "IN LAYER GRADIENT" AS BASIC PARAMETERS FOR ESTIMATION OF SOUND PROPAGATION PATH IN NEAR-SURFACE LAYERS

The portion of sound energy, trapped in the surface layer and measured here in terms of the width of the trapped beam, depends greatly on the MLD (Fig. 4) and partly on source depth. However, Fig. 4 indicates that this beam width is also slightly dependent on SST. This latter dependence is mainly caused by the non-linearity of the sound speed dependence on temperature and depth (see Fig. 3).

The relation of the width of the bottom bounce beam to the SST and MLD is shown on Fig. 5. The "inner limit" (distance a on Fig. 1) is independent of MLD but dependent on SST. The relation to SST, although statistically a very good and reliable one, is, however, an indirect relation, the direct cause being the thermocline gradient and magnitude. It can be noted that if the transducer/receiver beam width is 16° and if it is horizontal, the area with a radius of a (see Fig. 1) is not sonified by such a sonar beam. This area, however, is sonified by vertical beams (such as an echo sounder beam).

The width of the bottom bounce beam (distance b) depends on depth (taken constant, 500 m in Fig. 5), SST and MLD. Again, the relation to SST is an indirect one via thermocline gradient and magnitude.

Fig. 6 presents the relations between SST, MLD and the closest point immediately below the top of the thermocline where the "partial shadow zone" starts (distance c in Fig. 1). The term "partial shadow zone" is



Fig. 3. Sound speed at different temperatures (0 and 500 m depth, salinity = 35‰).

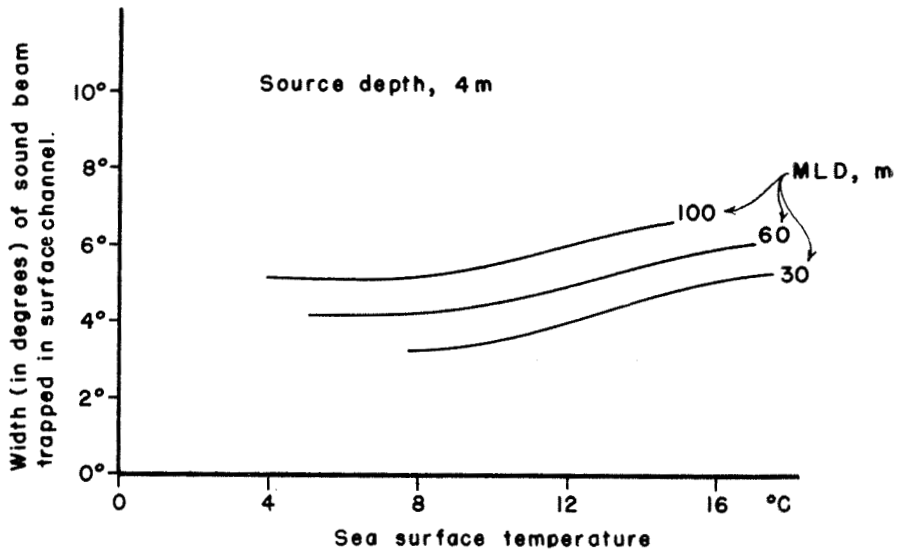


Fig. 4. Beam width of sound trapped in surface channel at different SST and MLD (source depth 4 m).

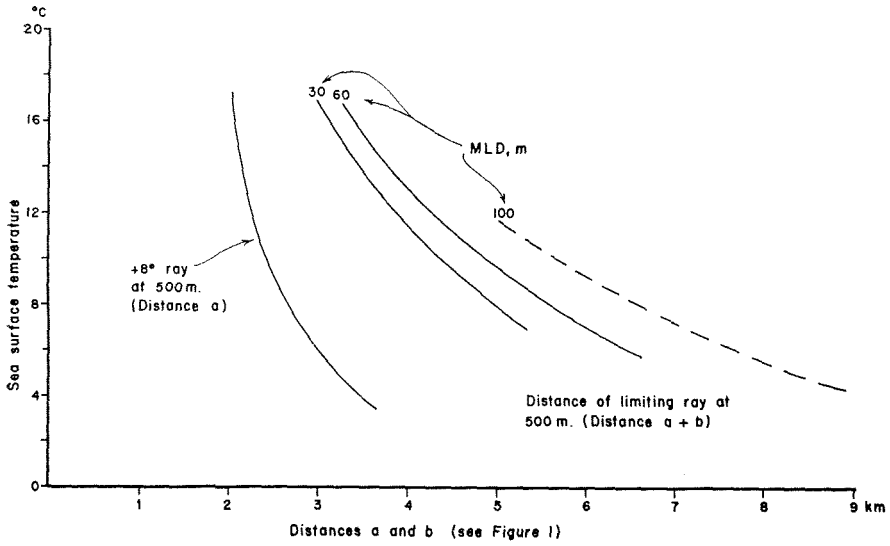


Fig. 5. Horizontal distance and width of the bottom-bounce beam in 500 m depth in relation to different SST and MLD.

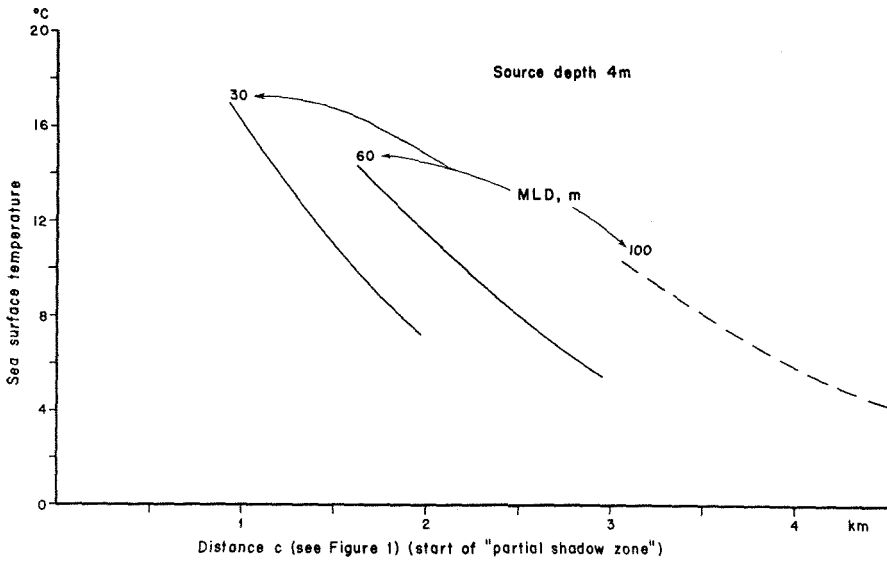


Fig. 6. Closest distance to "partial shadow zone" immediately below MLD in relation to different SST and MLD.

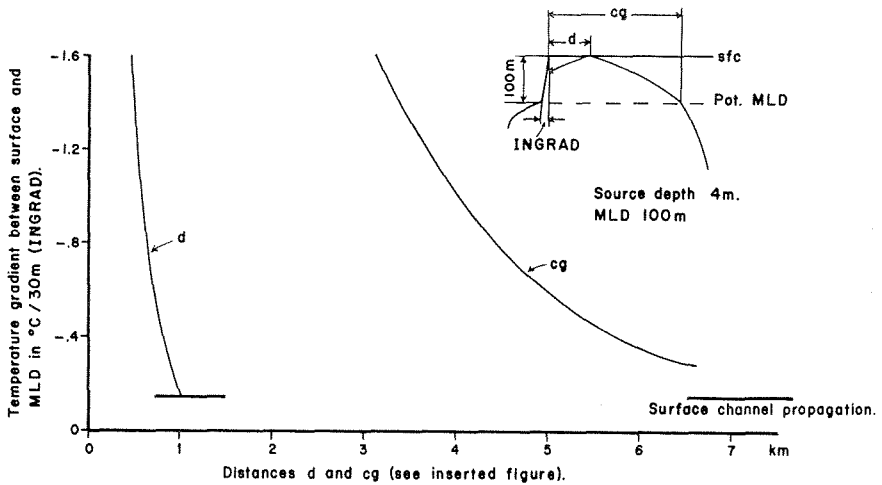


Fig. 7. Maximum grazing distance at the surface and distance at which last surface grazing ray leaves surface channel at different "in layer gradient" (INGRAD) (source depth 4 m, MLD 100 m).

used because this zone is not entirely void of sound (derived from bottom bounce and from bounce on irregular surface and irregularities in the interface (MLD)). The "distance c " is obviously greatly dependent on MLD and source depth, but also depends on SST, as Fig. 6 indicates. This latter dependence is directly caused by the sound speed change with temperature and by the non-linearities in this change (Fig. 3).

The above described relations referred to the isothermal surface mixed layer. However, this layer is not always isothermal and contains small transient thermoclines, especially during the heating season in spring and early summer. Computations with different negative temperature gradient above the top of the thermocline were made, and the results are presented in Fig. 7.

When the temperature gradient (INGRAD) in the surface layer is more negative than -0.15°C per 30 m, there is no surface channel propagation. The distance at which the last ray leaves the surface layer depends on the MLD and the INGRAD (see Fig. 7).

Finally, it is emphasized that the relations described above referred to the delineation of the sonified field. The computation of fishing sonar ranges must include propagation loss computations and other parameters, as briefly outlined in the first two chapters.

SUMMARY

1. The width of the sound beam trapped in the surface channel depends, besides on MLD and INGRAD, also on SST. The latter relation is brought about by nonlinearity in the sound speed dependence on temperature and depth (Fig. 4).
2. The bottom bounce beam width depends primarily on the temperature gradient and magnitude of change in the thermocline. With limited sonar beam width, the area near the ship below the thermocline is not accessible to horizontal beams (Fig. 5).
3. The distance to the "partial shadow zone" depends primarily on MLD, but is also affected by SST (Fig. 6).
4. If the INGRAD is more negative than -0.15°C per 30 m, there is no surface channel propagation. The distance at which the sonified field in the surface channel ends, depends on INGRAD and MLD (Fig. 7).

REFERENCES

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