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SOUND PROPAGATION THROUGH AN OCEANIC FRONT

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Résumé - L'effet des fronts océaniques sur la propagation du son à longue distance a été étudié théoriquement. Un modèle numérique du type équation parabolique (PE) a été utilisé pour simuler la propagation à travers un front réel, observé sur l'arête Féroé-Islande en Octobre 1985. Le front séparant les eaux chaudes de l'Atlantique des eaux froides de l'Arctique présentait une variation horizontale du profil de célérité de 30 m/s, sur une distance de 50 km. Les effets acoustiques du front sur un trajet de transmission de 150 km se sont révélés significatifs (> 10 dB), mais dépendants fortement des paramètres de l'environnement ainsi que des profondeurs source/récepteur et de la fréquence.

Abstract - The effect of ocean fronts on long-range sound propagation in the ocean has been investigated theoretically. A numerical model of the parabolic equation (PE) type was used for simulating propagation across a real front observed on the Faroe-Iceland Ridge in October 1985. The front separating warm Atlantic water from cold Arctic water had horizontal sound speed changes of 30 m/s over a range of 50 km. The acoustic effects of the front for a 150 km transmission path were found to be significant (> 10 dB), but with strong dependence on environmental parameters as well as on source/receiver depths and frequency.

1 - INTRODUCTION

Fronts and eddies are mesoscale oceanographic features which separate or enclose water masses of different origin, and therefore of different temperature and salinity. They are the oceanic equivalent of weather systems in the earth's atmosphere, and are observed in most ocean areas /1/. They are, however, much more persistent than their atmospheric counterparts, with time scales of the order of months or even years. Some of the stronger fronts are easily identified on infrared satellite images of the sea surface, with temperature changes of as much as 5-10 °C over horizontal distances of 5-50 km. However, even the strongest fronts have horizontal sound-speed gradients that are one order of magnitude smaller than the sound-speed gradient in depth due to pressure effects alone (~16 m/s per km).

While front and eddy structures have been studied extensively in the oceanographic community, their effect on long-range sound propagation in the ocean is much less explored. However, some interesting modelling results were reported by Lawrence /2/ in 1983 concerning propagation across the edge of a warm-core eddy in the Tasman Sea. He observed a drastic change in propagation conditions as ducted sound near the surface in the eddy was converted into convergence zone (CZ) propagation outside the eddy. The same effect was observed by Akulichev /3/ in experimental data collected recently in the Northwest Pacific across the Kuroshio current. The simulation studies by Heathershaw et al. /4,5/ addressed propagation through simplified frontal structures (no topographical effects), again noting the possibility of propagation changing from surface ducting to CZ-type propagation across a front.

The present study is an attempt to include the full environmental complexity (including topography) in the modelling of propagation through a real front in the North Atlantic. With the front being located in 1000 m of water, we expect propagation to be heavily influenced by the sea floor and, hence, we should observe propagation characteristics quite different from those seen in previous simulation studies on deep-water fronts.

2 - THE OCEAN ENVIRONMENT

We selected a particular frontal structure observed on the Faroe-Iceland Ridge in October 1985. A series of six sound-speed profiles were measured along the 150 km track, where bottom depths varied between 500 and 2500 m (Fig. 1a). The front separating warm Atlantic water from cold Arctic water is located at a range of approximately 70 km, its position being determined by a maximum in the horizontal sound-speed gradient at the surface. The composite plot of

sound-speed profiles in Fig. 1b shows that we have sound speed changes of nearly 30 m/s between profiles 1 and 2 at a depth of 500 m. Shown here is also the historical (monthly mean) profile H, which is seen to be similar to profile 1 measured within the warm Atlantic water.

3 - MODELLING RESULTS

The acoustic simulations were performed with a well-tested numerical propagation model of the parabolic equation type /6,7/. Environmental inputs (sound-speed profiles, bathymetry) were interpolated linearly in range. The seabed was assumed to be homogeneous with the following geoacoustic parameters: $c=1600$ m/s, $\rho=1.7$ g/cm³ and $\beta=0.5$ dB/wavelength. Both sea surface and sea floor were assumed to be smooth. Propagation loss was calculated for several source/receiver combinations and for source frequencies between 25 and 400 Hz.

A qualitative depiction of the propagation conditions is given by the ray diagrams in Fig. 2. The upper graph is generated using the historical profile over the entire track, while the lower graph is based on the full frontal information. It is evident that the presence of the front affects both surface-duct and deep sound-channel propagation. In particular, the front causes sound to be channeled at a much shallower depth than is the case for the historic profile. Also, we note that there are no convergence-zone paths in this bottom-limited environment.

Examples of computed propagation loss at 400 Hz are given in Fig. 3. It is clear that the full frontal information is required for accurate loss predictions at both receiver depths. Note that propagation conditions are quite stable on the first half of the propagation track, independent of the profile chosen. Beyond 75 km we have large level differences, particularly for the shallow receiver (15 m). We note that the dependence of the results on profile and receiver depth is quite complicated, with the historical profile giving too low loss for the shallow receiver and too high loss for the deep receiver.

In summary, if we ignore the presence of the front and just use a single profile (historical or measured) in a propagation prediction, this can lead to level errors of 10-20 dB at 400 Hz. The effect of the front at lower frequencies is less important, but it is still significant at 100 Hz (Fig. 4).

4 - CONCLUSIONS

It is clear from this study that the acoustic effect of a front can indeed be significant (> 10 dB), but with the effect being strongly dependent upon 1) the shape of the average sound-speed profile, 2) the lateral sound speed variation across the front, 3) the bottom topography in the frontal region, 4) the depth of source and receiver, and 5) the source frequency.

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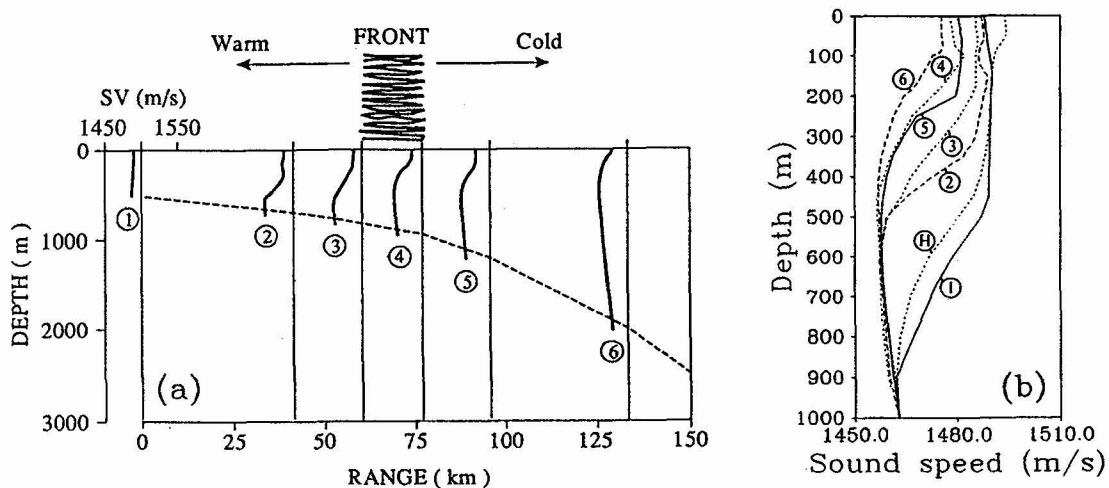


Fig. 1 - Measured sound-speed profiles and bathymetry in frontal region.

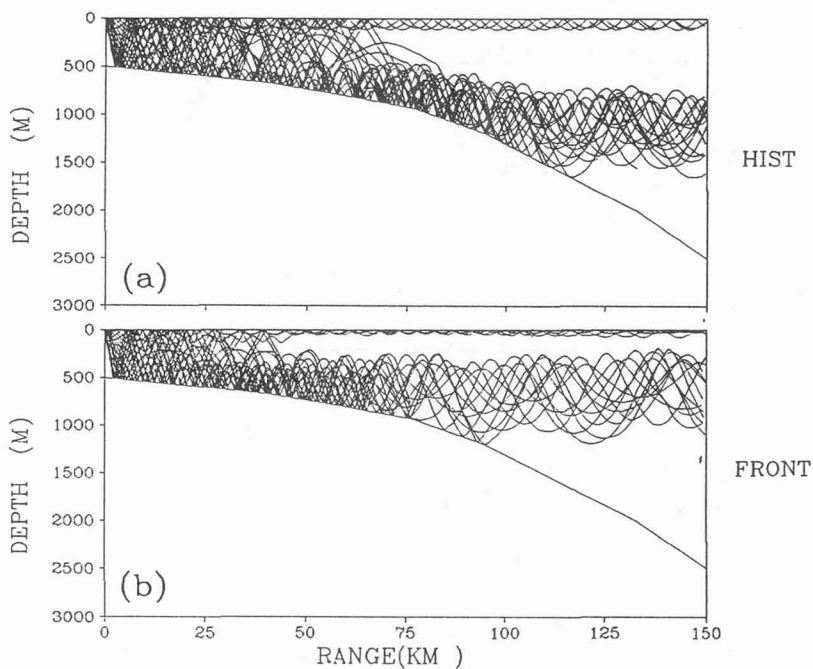


Fig. 2 - Ray diagrams showing qualitative differences in propagation conditions between a single-profile situation (climatology) and the use of the full frontal information (6 profiles).

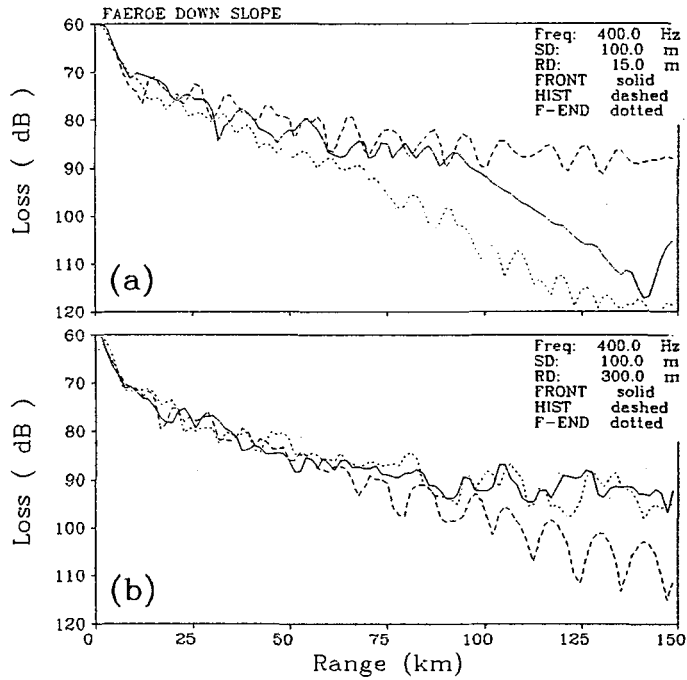


Fig. 3 - Predicted propagation losses at 400 Hz for a source at 100 m depth and receivers at (a) 15 m and (b) 300 m. The three curves in each figure refer to: full frontal information (solid line), historical profile (dashed line), deep-end profile (dotted line).

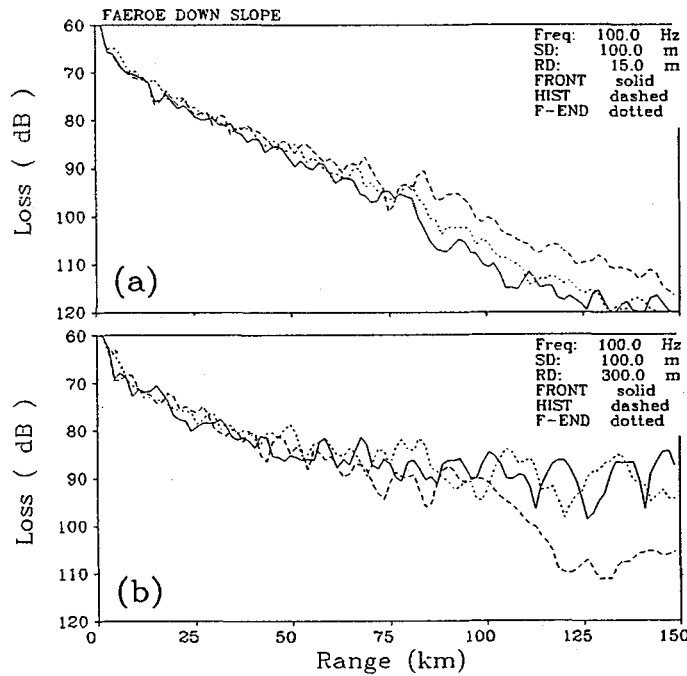


Fig. 4 - Predicted propagation losses at 100 Hz for similar situations as shown in Fig. 3.