COMPARISON OF RAY TRACING PREDICTIONS WITH WIDEBAND PROPAGATION MEASUREMENTS

(ABSTRACT)

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The paper gives an illustration of the latest methods which have been developed at SACLANTCEN for the experimental study of sound propagation in deep water. They are based on a high sampling of the sound field produced by an explosive sound source, digital recording of the received signal, processing of the data by computer programs and finally comparison of the experimental results with a theoretical model of propagation. Trials were conducted during the warming season, in a deep water area where stable oceanographic conditions were expected. Direct measurement of the sound velocity profile was made with a sound velocimeter down to 500 m, and a Nansen cast was taken to investigate the medium deeper.

To check the progressive insonification of the medium with increasing source depths, five different depths were selected from near surface down to critical depth. The receiving hydrophones were distributed on a vertical array at 20 m, 60 m, 100 m, and 600 m depth (Fig. 1 shows the experimental set-up and the sound-velocity profile). The useful frequency band of the sources extends over 10 kHz and their pulse width, 300 μs, allows a good description of the structure of the multipath to be made.

A simple one-dimensional ray-tracing program using linear segments to approximate the sound velocity profile was used to compute the various sound fields. Curves giving the time separation between

the first and successive arrivals versus range were produced for each pair of source-hydrophone depths, together with curves of the propagation loss anomaly obtained by adding incoherently all the rays arriving at the hydrophone.

From the acoustic measurements were derived general time displays of the signals as received on the hydrophones and propagation loss anomalies versus range in a series of third octave filters.

A comparison was made between predictions and experimental observations for different selected cases, with the following results. The general time evolution of the multipath structure, which is well described by the predictions at short range, correspond in the convergence zone only after the theoretical curves have been shifted by 1.5 to 2 km toward the source. (Figs. 2 and 3 show the general time series display of the arrivals as received on the 100 m hydrophone. The sources were at 27 m (Fig.2) and at 105 m depth (Fig.3) respectively. Levels have been corrected for gain settings and spherical spreading, but not for absorption.) This earlier manifestation of the convergence zone cannot be explained by the effect of the earth's curvature, which was proved to account for only a third of the discrepancy. The 90° phase shift which is characteristic of arrivals refracted at the thermocline and passing a caustic is also observed in a few cases for deep refracted arrivals (Fig. 4 is the time-series display of the arrivals received on the hydrophone at 600 m with the sources at 460 m). This confirms the presence at depth of limited caustics which have not been evidenced by the rough ray-tracing based on a smoothed velocity profile.

To be noticed is the incoherent feature of the arrivals when they have been refracted at the bottom of the thermocline, a feature which is amplified when source and receivers are lying in this region (see Fig. 3). The signal refracted, diffracted, scattered by the microstructure inhomogeneities of the medium which are likely to be found in this region has all the characteristics of forward reverberation. Receivers which should have been in the shadow zone are insonified by the scattered sound.

The near-surface shadow zone is also penetrated by the low frequency components of the signal when the source is deep (Fig. 5 shows the time-series display with the hydrophone at 20 m and the sources at 1068 m.). Ray theory breaks down on the thermocline, which acts like a filter - the spectra of the received signal showing more and more attenuation in the high frequency domain as the range from the theoretical shadow zone limit increases.

In Fig. 6 the propagation loss anomaly (which is the propagation loss, less spherical spreading loss, less absorption) is shown as predicted (top left) and as measured in third-octave filters for a 27 m source depth and the hydrophone at 100 m. Fig. 7 is the same as the previous figure, except that the source depth is now 105 m. The measured propagation loss anomalies are in good agreement with the mean theoretical predictions except when the receivers, lying in the shadow zone, are insonified by scattered or diffracted sound. If the convergence gains predicted for the convergence zone have been observed the agreement is limited to the mean value, the high intensification on the caustics being missed.

In conclusion, one-dimensional ray-tracing programs using linearly segmented sound-velocity profiles allow a good interpretation of the experimental results and their accuracy is high enough for general operational predictions. However, they cannot take into consideration all the aspects of propagation such as diffraction and reverberation, and their domain of application should be limited to geographical areas recognized as oceanographically stable.

DISCUSSION

The author said that he had evaluated the curved earth modification while trying to explain the error in the position of the convergence zone, but that it was able to account for only about one third of the discrepancy.

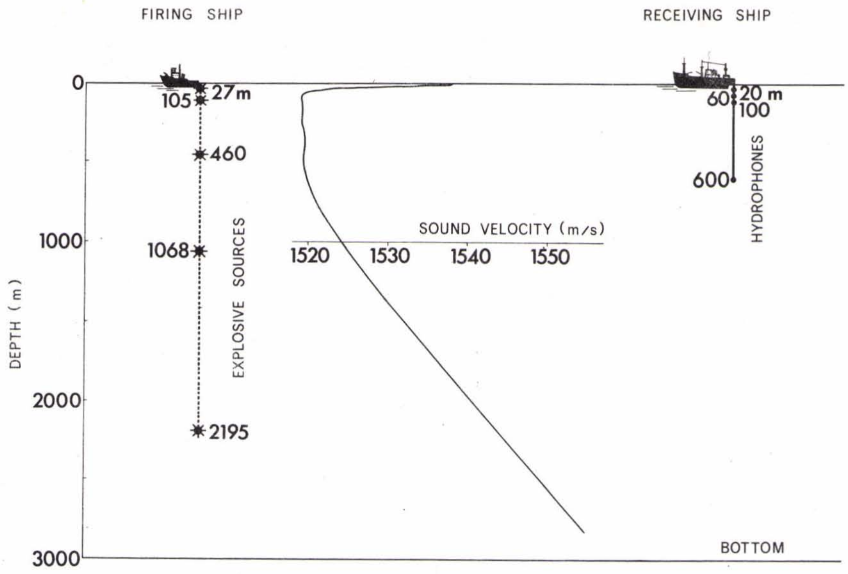
FIRING SHIP
RECEIVING SHIP
0
1000
2000
3000
DEPTH (m)
27m
105
460
1068
2195
EXPLOSIVE SOURCES
SOUND VELOCITY (m/s)
1520
1530
1540
1550
20 m
60
100
600
HYDROPHONES
BOTTOM

FIG. 1

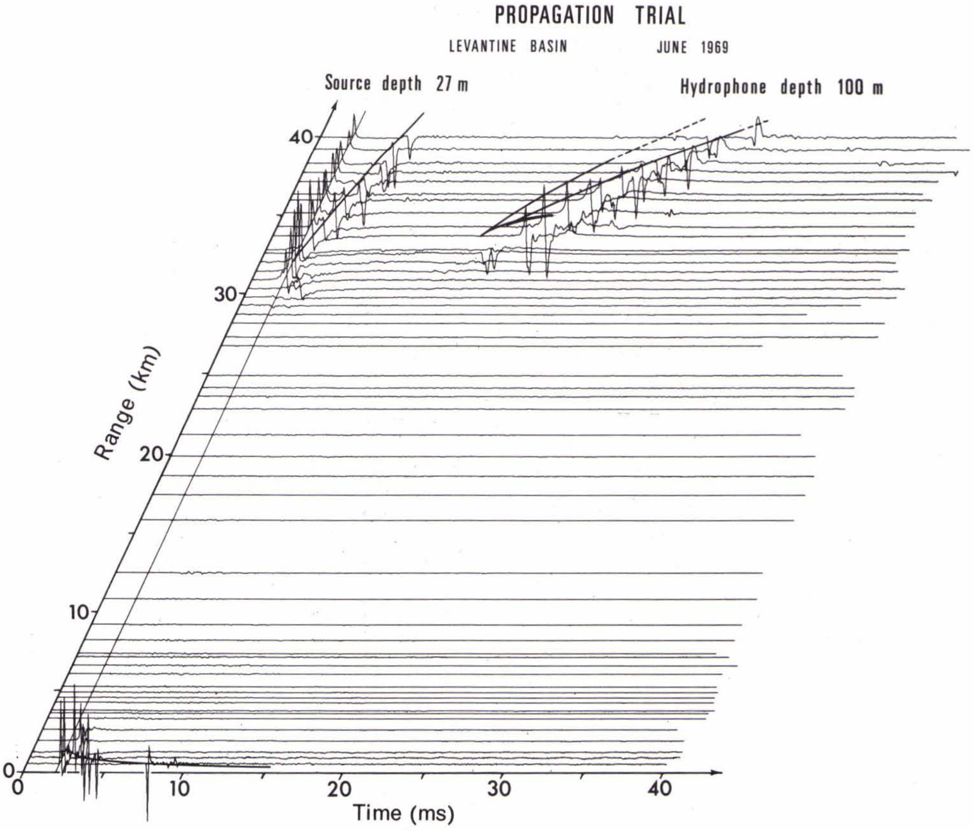
PROPAGATION TRIAL
LEVANTINE BASIN
JUNE 1969
Source depth 27 m
Hydrophone depth 100 m
Range (km)
0
10
20
30
40
0
10
20
30
40
Time (ms)

FIG. 2

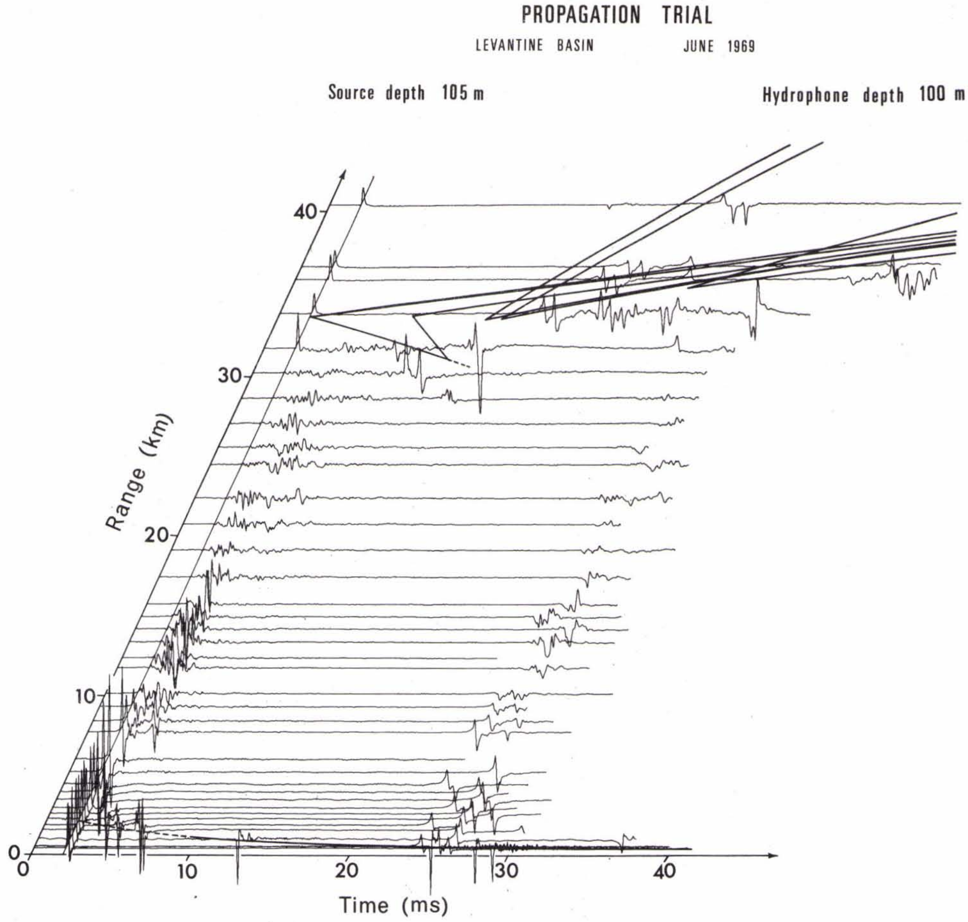
PROPAGATION TRIAL
LEVANTINE BASIN
JUNE 1969
Source depth 105 m
Hydrophone depth 100 m
Range (km)
0
10
20
30
40
Time (ms)
0
10
20
30
40

FIG. 3

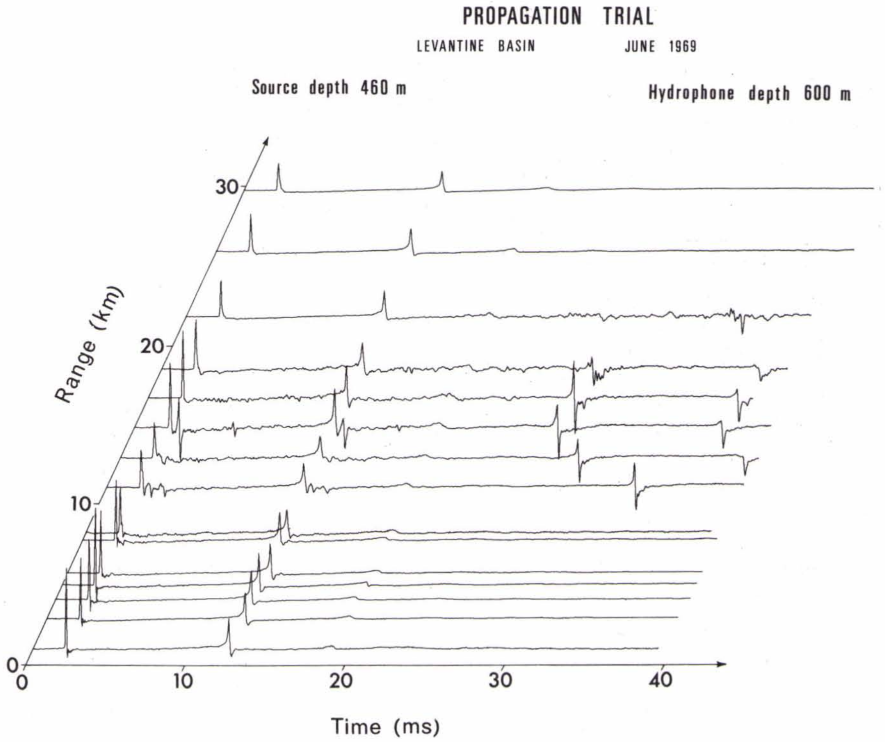
PROPAGATION TRIAL
LEVANTINE BASIN
JUNE 1969
Source depth 460 m
Hydrophone depth 600 m
Range (km)
0
10
20
30
Time (ms)
0
10
20
30
40

FIG. 4

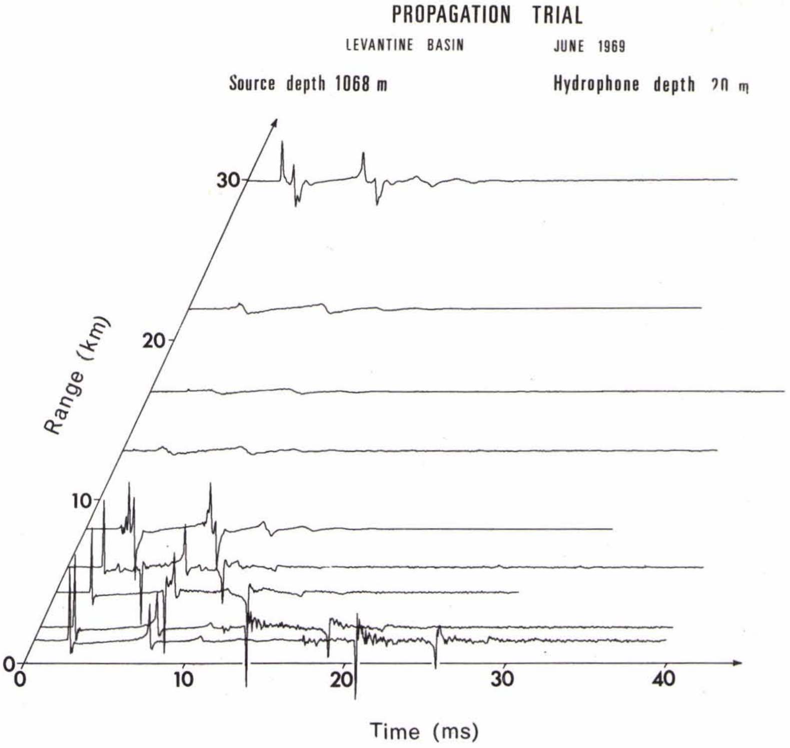
PROPAGATION TRIAL
LEVANTINE BASIN
JUNE 1969
Source depth 1068 m
Hydrophone depth 20 m
Range (km)
0
10
20
30
0
10
20
30
40
Time (ms)

FIG. 5

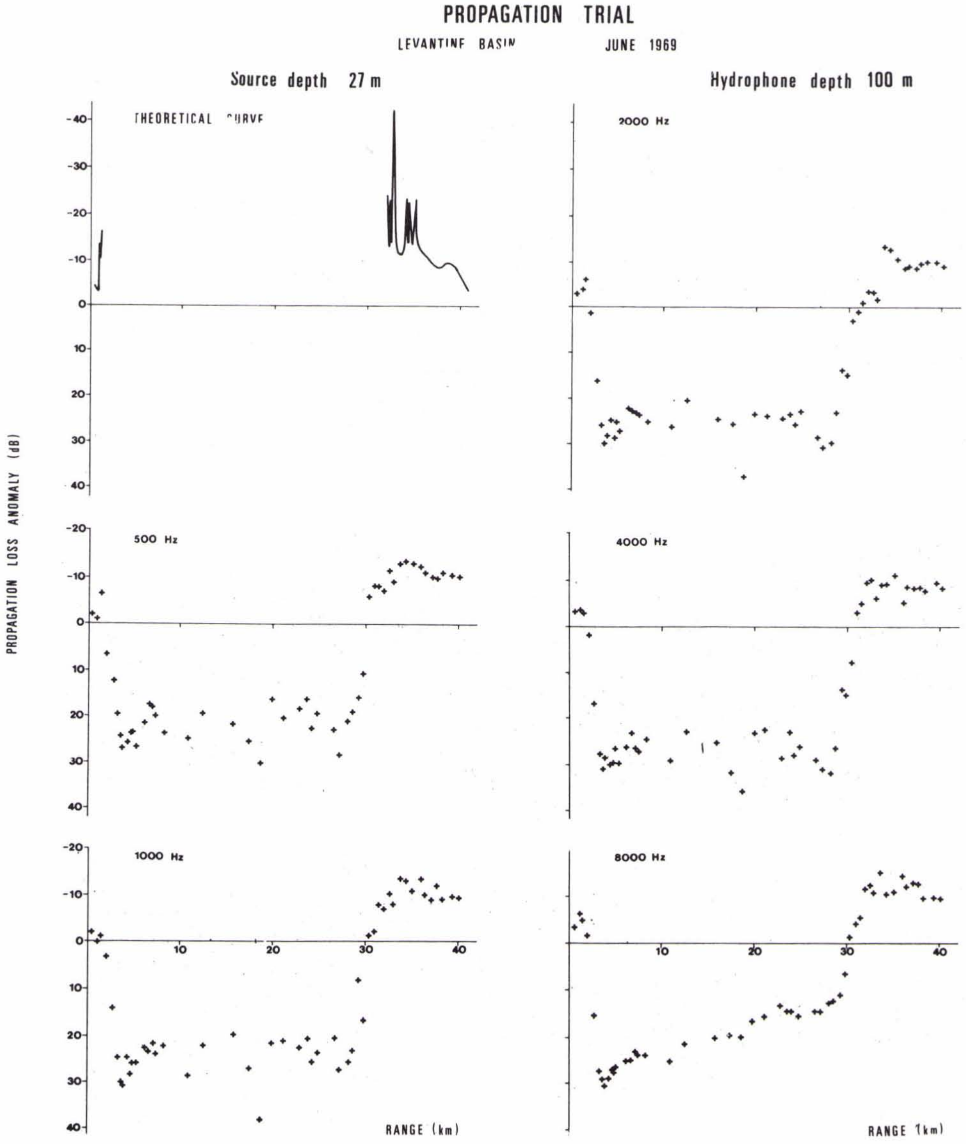
PROPAGATION TRIAL
LEVANTINE BASIN
JUNE 1969
Source depth 27 m
Hydrophone depth 100 m
THEORETICAL CURVE
2000 Hz
500 Hz
4000 Hz
1000 Hz
8000 Hz
PROPAGATION LOSS ANOMALY (dB)
-40
-30
-20
-10
0
10
20
30
40
10
20
30
40
RANGE (km)
RANGE (km)

FIG. 6

PROPAGATION TRIAL

LEVANTINE BASIN JUNE 1969

Source depth 105 m Hydrophone depth 100 m

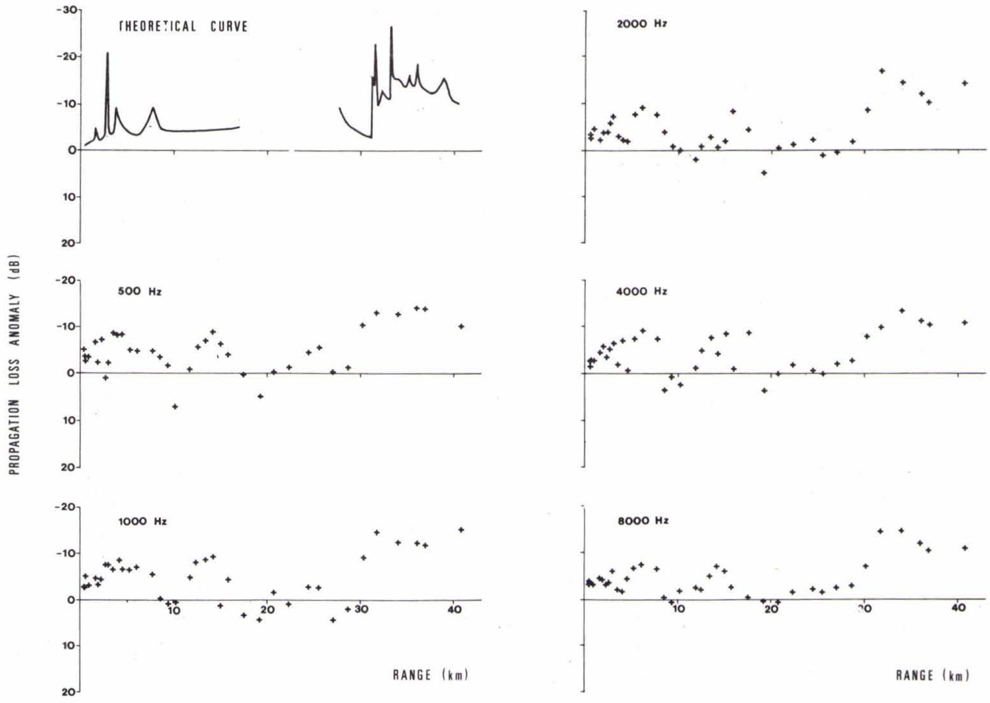

FIG. 7