Fluctuations in shallow water multipath sound propagation

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1. Introduction

The propagation of sound in littoral waters is affected by scattering characteristics of bottom and surface boundaries and by the structure of the ocean sound velocity field. Fluctuations of sound velocity are strongest at thermocline depth. Since sound waves confined in a shallow water duct potentially cross this depth range several times, the sound velocity fine structure can be expected to have more impact on sound transmissions in shallow seas than in a deep water configuration. Simulations of sonar conditions and underwater communication affected by acoustic variability, require a proper understanding of the fluctuations of the sound velocity field and of the mechanisms, which result in the loss of performance of acoustical methods. In a realistic littoral environment, sound speed fluctuations in the water column are accompanied by inhomogeneities of the ocean boundaries such as changes of the bottom composition or depth. Measurements with moving platforms would amalgamate local changes with time variability. For the separation of effects, acoustic experiments with fixed source and receivers are compulsory.

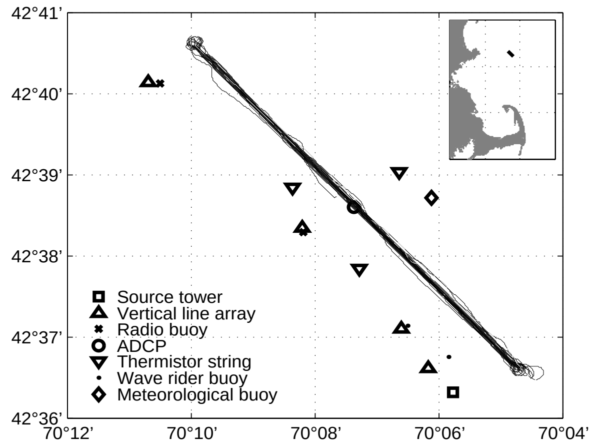

Figure 1: Mooring positions and CTD chain tracks.

In June 2001, imbedded in the oceanographic trial ASCOT 01, experiments on acoustic time variability were carried out in the Gulf of Maine, 20 nautical miles east of Cape Ann (Fig. 1). A test site was selected congruent as much as possible with the 100 m bathymetric contour line. The hard bottom was rough with deviations up to 2 m from the mean depth along the 10 km acoustic range. A tower-like frame with a sound source mounted 4.5 m above its base was lowered to ground at the SE end of the site. The source was powered by a cable connection with the NATO Research Vessel ALLIANCE. A vertical line array with 64 elements was moored 10, 5, 2 and 0.78 km from the source, each location for one day allowing for recovery and re-deployment. Received acoustic signals were sent back via radio link to NRV ALLIANCE.

2. Environmental monitoring

Special emphasis was laid on environmental monitoring. Bathymetry with 20 m horizontal resolution was obtained by swath mapping and additionally acquired by a single beam echo sounder with on-track sampling every 4 m. Sea surface roughness due to wind waves was continuously measured by a wave rider buoy. Three thermistor strings, each equipped with 11 thermistors with 5 m vertical separation, were deployed at the corners of an equilateral triangle with side length 2.35 km. While one standard thermistor string was sampled every 2 minutes, two strings had response times and sample rates of 10 seconds, appropriate to resolve the fastest significant changes of the temperature structure, which are partly caused by internal waves and partly due to advection by ocean currents. An upward looking acoustic Doppler current profiler was located in the centre of the triangle. Ocean currents in the period of the acoustic trials had 25 cm/s maximum strength. They consisted primarily of tidal oscillations, predominantly parallel to depth contours.

Since the advection speed through ocean currents has the same order of magnitude as the phase speed of the shortest internal waves, the records of the moored thermistor strings reflect an inseparable mix of temporal fluctuations and spatial fine structure. For the duration of short acoustic transmissions, the environment can be regarded as frozen, so that the instantaneous spatial sound velocity structure is an input parameter to calculations of the impact of ocean variability on sound propagation. Traditionally (e.g. [1,2]) a model representation of the internal wave field is generated from a standard internal wave spectrum, which may or may not be justified in a shallow water case. An alternative approach, the construction of spatial fluctuation realizations from a measured internal wave frequency spectrum, is impeded by the contamination of the data set from the moored thermistor strings with advected fine structure.

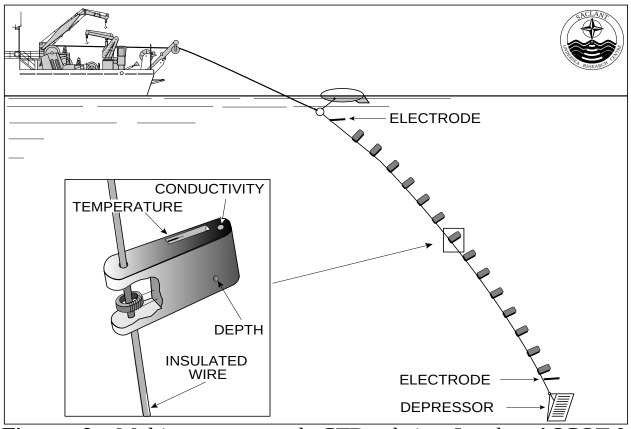

Figure 2: Multi-sensor towed CTD chain. In the ASCOT 01 configuration, horizontal and vertical sampling distances are 4 and 3 m respectively.

Instead, the spatial structure was directly measured with a CTD chain [3] (Fig. 2). The sensitive section had a vertical aperture of 70 m between a depressor and a surface float. It was continuously towed there and back along the acoustic range by the small research vessel Gulf Challenger. With only about 1.5 m/s towing speed she went rather slow, but still sufficiently fast to preserve in the records of the ocean fine structure the dominance of spatial structures over temporal changes. A full cycle of CTD (conductivity, temperature, depth) measurements was acquired every two seconds, so that horizontal resolution is almost the same as vertical. Sensor depth variations and deviations from vertical alignment due to towed chain curvature were adjusted during data postprocessing, and a 2-dimensional sound velocity field on a regular rectangular grid obtained. Below 70 m, the depth of the lowest towed sensor, there was hardly any change in salinity and temperature. A constant sound velocity gradient due to increasing pressure was assumed between 70 m and bottom.

3. Results of acoustic trials

The acoustic experiments of ASCOT 01 were similar to the fixed range experiments in ADVENT 99 [4], but under different environmental conditions. Early summer stratification decreased the importance of surface reflected paths, internal waves were more energetic, and the bottom was different from the previous trial in the

Sicilian Channel. Broadband linear-frequency-modulated (LFM) and multi-tone (MT) acoustic signals were transmitted every minute for 10 to 19 hours over each source-receiver range. Two separate frequency bands reached from 150 to 850 Hz and from 800 to 1600 Hz.

The correlation between normalized received signals at a certain time with signals at a later time drops off below 0.5 within minutes for most frequencies and all ranges. This is very different from the results of ADVENT 99 [4], where high correlations were obtained at all ranges and frequencies for at least one hour, and much longer at 2 km range. It is fascinating, that in ASCOT 01 at the shortest range, 0.78 km, the correlation comes back to high values after 2.5 hours. A plausible explanation is the presence of an internal wave, which passes by and after one cycle restores the old sound velocity structure. Internal wave velocities discussed above are consistent with this view.

Signals at every hydrophone location are superpositions from direct (if it exists) and reflected paths. The fast decorrelation of ping sequences is indirectly caused by the high reflectivity of the bottom and hence the high number of contributing paths. At 2 km range, remarkable energy is transmitted through bottom reflected eigen-rays with up to 35° grazing angles. This gives rise to multiple arrivals, the relative delay times of which vary with time, when the properties of the sound channel are changing.

The simplest model of a time variant sound channel takes into account tidal elevations in an otherwise stationary and range independent environment. At the test site in the Gulf of Maine, tidal elevations of the sea surface had a peak-to-peak height of at most 15 cm with a maximum rise and fall rate of 4 cm/h. This is too small to generate phase shifts on reflected paths, which would be able to significantly distort the composite signal. The model of constant environmental conditions modified only by tidal elevations of the sea surface is too simple for an explanation of observations. Wind generated waves modify the upper boundary of the sound channel on time scales, which are much shorter than ping repetition rates. If the correlation between sequential signals decreases by sea state, it should reach its final value already after one time lag. An observed decorrelation, which takes longer, must be caused by something different, i.e. changes in the water column.

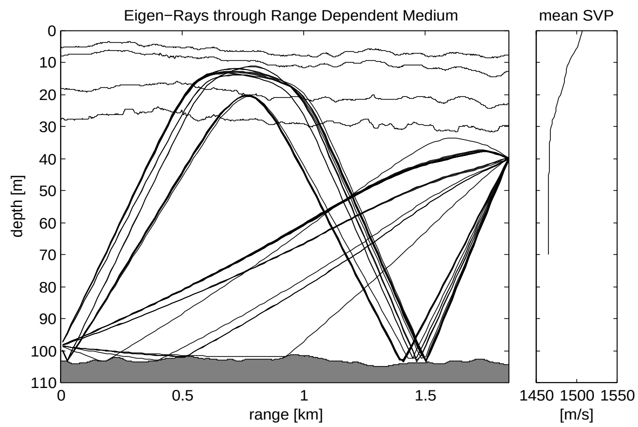

Figure 3: Several ray paths with the same number of turning points and different travel times exist in a range dependent medium, which is indicated by lines of equal sound velocity and a rough bottom.

Time dependence of the sound velocity structure in the ocean can be regarded as a change (within hours) of the average sound velocity profile in a transect plus a re-distribution (within minutes) of spatial inhomogeneities by advection or internal wave motion. The impact of a changing mean sound velocity profile in ASCOT 01 is apparent in the transmissions over 10 km. At this range, the most important eigen-rays do not reach the surface, but are refracted back to depth in the thermocline. Internal tides in the Gulf alter the thermocline depth by several metres. Travel times are changing with the length of the eigen-rays. The arrival pattern is compressed in time, when the thermocline descends. Although the overall signal structure changes with time, it is still a superposition of single eigen-ray transmissions.

In a range dependent environment this clarity is lost (Fig. 3). Instead of a countable number of eigen-rays from the source to a receiver, which are classified by the number of turning points or reflections at the boundaries, several separated eigen-rays with the same classification can exist in a range dependent environment. Travel times may differ and intensities be irregularly distributed, which gives rise to frequency dependent fading and some uncertainty of signal arrival times (Fig. 4). Range dependent slopes of the sound channel boundary, which directly translate into angles of reflection, can impact the received signal more than spatial changes of the sound velocity profile, while fluctuations of the sound velocity field are required to explain temporal fluctuations of the received signals.

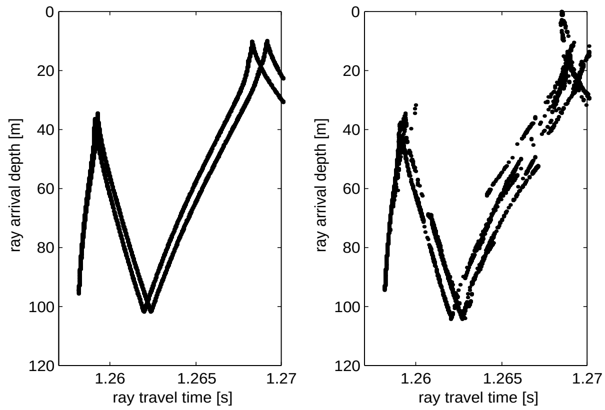

Figure 4: Arrival time and depth of the shallowest rays. Left: Range independent. Right: Range dependent environment (see Fig. 3).

4. Conclusion

Acoustic and environmental data were acquired on the New England shelf. The hard bottom caused multi-path sound spreading, the details of which are controlled by range dependent bathymetry and by the sound velocity structure in the ocean. Emphasis was on the proper description of the environment by measurements, which are used as input into models and for validation. From a first assessment of the combined data set, features of the observed acoustic multi-path arrivals are understood and can be qualitatively reproduced by modeling.

Acknowledgement

The experiments were carried out as part of the scientific programme of work of SACLANT Undersea Research Centre.

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