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High-Resolution Echo-Sounding and Estimation of Sediment Properties using Nonlinear Acoustics

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Abstract

There are a lot of advantages using nonlinear echo sounders compared to linear ones in particular in shallow water areas. An important problem in sediment acoustics is to determine the thickness of sediment layers. If the sound velocity is known, the thickness can be calculated from the travel times. Nonlinear acoustics combined with principles of refraction seismic allow to estimate the sound velocity of selected sediment layers. Nonlinear acoustics has also advantages while obtaining frequency dependent sediment properties like attenuation coefficients.

Nonlinear Acoustics

Nonlinear (parametric) echo sounders transmit at least two signals of slightly different high frequencies (primary frequencies f_1,f_2) at high sound pressures simultaneously. Because of non-linearities in the sound propagation at high pressures the transmitted signals interact and new frequencies arise.

The so-called secondary frequency ($F=|f_1-f_2|$) is low enough to penetrate the seafloor. The reflected primary-frequency signals may be used for exact determination of water depth even in difficult situations, e.g. soft sediments.

The directivity for the difference frequency is similar to the primary frequency. Therefore small transducers can transmit narrow beams at low frequencies. For different secondary frequencies the directivity is nearly the same and the sounded bottom area will have nearly the same size. This is important if echo prints from different frequencies are compared. There are no significant side lobes for the difference frequency.

Because of the high system-bandwidth of a parametric system, really short signals can be transmitted. This makes parametric systems particularly useful in shallow water areas.

Due to the small beam-width and the high frequency-bandwidth the bottom echoes from parametric echo sounders have a steeper slope than echoes from linear ones. These steeper signals are better to detect at low signal to noise ratios, for instance in areas with dredging activities. Detection of small changes in the acoustic impedance and a high resolution of layers become possible and a more realistic and more accurate picture from the bottom layer and the sediment structures beneath the bottom will be produced.

For parametric systems, short pulses, narrow beams and the absence of side lobes results in less volume reverberation as well as less reverberation from the bottom surface compared to linear systems. This gives a better signal to noise ratio, especially in areas with siltation.

The Parametric Echo Sounder Systems SES-96 and SES-2000

Based on fundamental research and components developed by the Underwater Acoustics Research Group of Rostock University, a product line of parametric echo sounders, used worldwide for a great variety of applications, is developed by INNOMAR Technologie GmbH (www.innomar.com). The compact design of this family of echo sounders – only the transducer and one water-protected 19-inch unit is required – allows very easy and mobile installations, see figure 1.

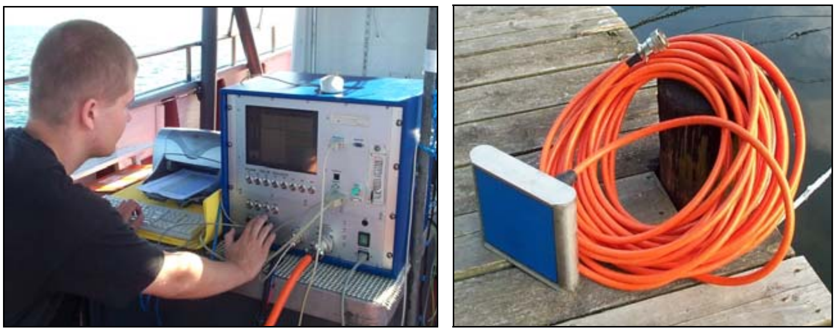

Fig. 1: SES-96 standard (left) and transducer (right)

Water depth range	1 … 1,500 m
Vertical resolution	up to 6 cm
Penetration depth	up to 50 m
Accuracy of the depth measurement	0.02 m + 0.02% of the water depth
Primary transmitter frequency	ca. 100 kHz
Secondary transmitter frequency	4, 5, 6, 8, 10, 12, 15 kHz
Transmitter pulse length	0.07…1 ms
Repetition rate	up to 50 s^{-1}
Beam width	±1.8° @ 4…15 kHz
Beam steering range	±16°
Transducer dimensions	ca. 20 cm × 20 cm

Table 1: SES-96 and SES-2000 Main Parameters

The SES-96 and SES-2000 sub-bottom profilers achieved very good results in shallow water areas as well as in water depths of 1,500 m and above. The transducer was mounted in moon pools as well as over the side, even at larger ships.

There is a side-scan option available and a new parametric fan-subbottom-profiler is under development.

Estimation of Sediment Layers' Sound Velocity

The water depth and sediment layer thickness is calculated from sound pulse travel times. To get exact layer thickness, knowledge of sound velocity inside the sediment is necessary. The sound velocity can be obtained by core measurements, but there is a big amount of work involved with this method.

Using parametric acoustics in-situ estimation of sediment layers' sound velocity becomes possible. For this purpose sound pulses are transmitted vertical as well as oblique simultaneously, see fig. 2. The sound velocity is calculated from the travel times of both sound pulses.

A prototype echo sounder using this method was realized by the Underwater Acoustic Research Group of Rostock University, see fig. 2. Figure 3 gives an echo plot example and table 2 contains the determined values.

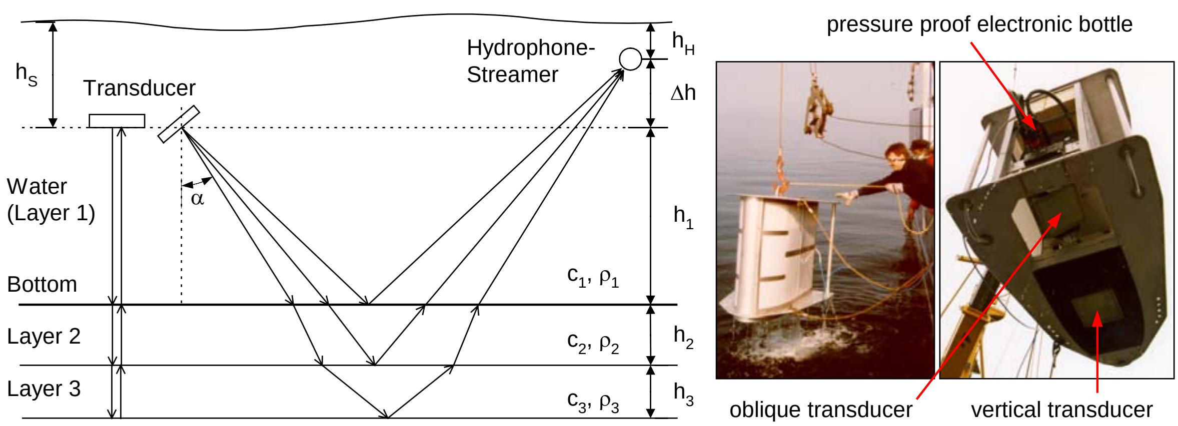

Fig 2: Principle for sediment layers' sound velocity estimation (left) and experimental device (right)

Layer No.	Travel time vertical [ms]	Travel time oblique [ms]	Refraction index	Sound Velocity [m/s]	Thickness [m]
1	60.84	69.97	0.802	1164	1.35
2	63.15	72.11	1.166	1357	1.05
3	64.68	73.49	1.252	1700	1.60
4	66.54	75.07	1.087	1847	3.40
5	70.21	78.15	0.778	1438	1.35
6	72.09	79.87			

Table 2: Values for sound velocity estimation example (see fig. 3)

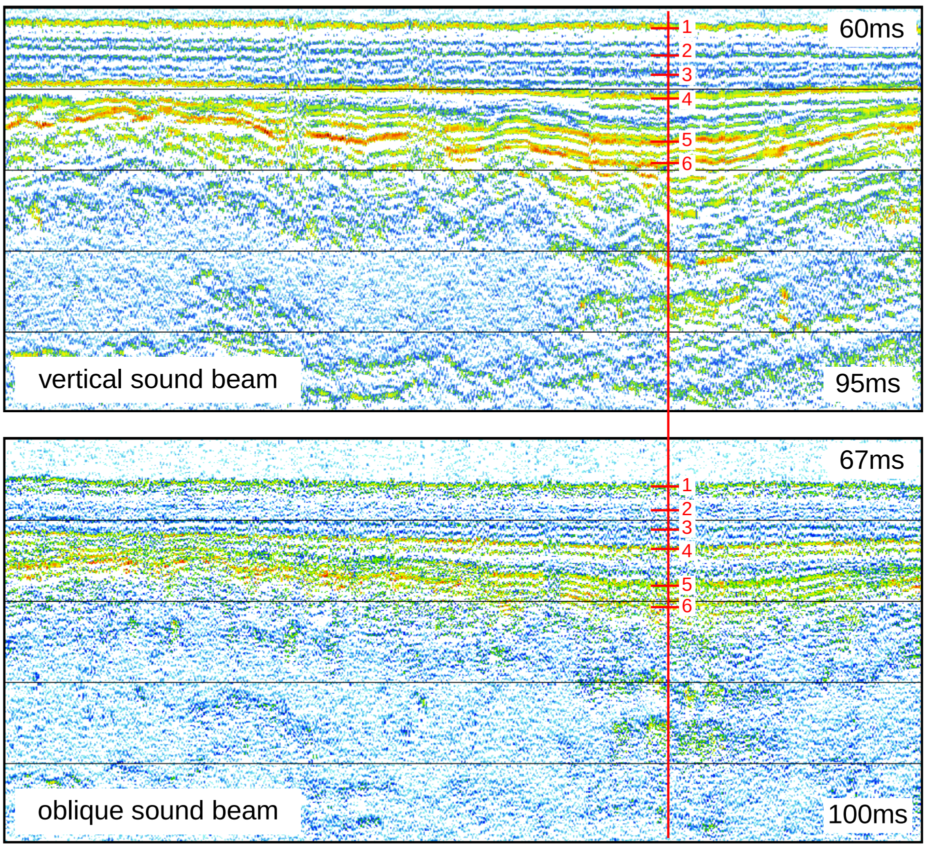

Fig 3: Example echo plot for sediment layers' sound velocity estimation (Baltic Sea, water depth about 45m, values see table 2)

Estimation of Sediment Layers' Attenuation Coefficient

Another important sediment parameter is the attenuation coefficient. If several frequencies are used for sediment sounding, the attenuation coefficient can be estimated. For this purpose often Chirp sub-bottom profilers are used as multi-frequent source.

But in this case the sounded bottom area for different frequencies will not be the same as described above. The changes in the received signal will not only represent the sediment properties but also the directivity pattern.

Nonlinear echo sounders are better suited for this task, because the beam pattern will be nearly the same for all secondary frequencies. Therefore changes in the received signal directly depend on the sediment properties.

Figure 4 shows a profile recorded at 6 kHz and 12 kHz with the same pulse length. The profiling at both frequencies was realized simultaneously with the parametric sediment echo sounder SES-96 standard. Transmission of other combinations of frequencies is also possible.

If there are two frequencies, as for this example, the attenuation coefficient ($a = k f^n$) can be calculated from the layer-bottom amplitude ratios at both frequencies. This is only possible on the assumption $n = 1$. Otherwise it is necessary to use more frequencies. For this analysis also the multiple echoes has to be taken into account.

If the attenuation coefficients are known, the reflection coefficients and the density for these layers can be estimated, too.

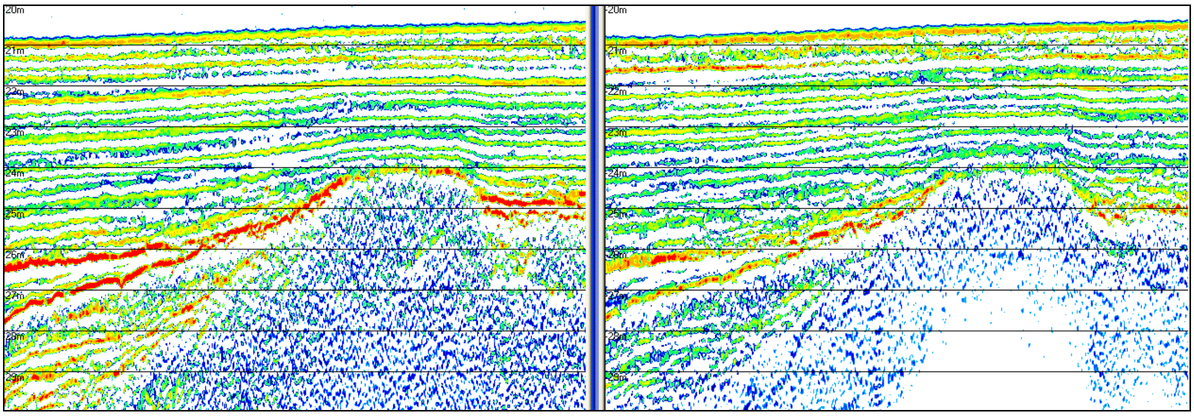

Fig 4: Echo print from at 6 kHz (left) and 12 kHz (right), pulse length 330 µs

Conclusions

The use of parametric sub-bottom profilers offers the possibility to get online survey results with excellent vertical and horizontal resolutions at acceptable penetration. The short transmitting pulses without ringing permit the operation in very shallow water. Despite of small transducer dimensions low frequency signals can be transmitted with a very narrow beam. The sounded area at all generated frequencies differs only hardly. Nonlinear acoustics combined with principles of refraction seismic allow to estimate the sound velocity of selected sediment layers. The use of different low frequencies simultaneously allows the estimation of additional material properties like attenuation coefficients and densities.

Acknowledgements

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