МОРСЬКИЙ
ЕКОЛОГІЧНИЙ
ЖУРНАЛ

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SOFTWARE SUPPORT FOR INVESTIGATION OF NATURAL METHANE SEEPS BY HYDROACOUSTIC METHOD

The natural gas seepages from the sea floor are commonly recognized acoustically by the flare shaped acoustic images, spreading vertically through the water column. These acoustic images, which are made up of echoes from numerous gas bubbles, convey a lot of information about features of individual bubbles and bubbling vents in whole. To study the ecological role of methane gas bubble streams it is important to obtain such data, especially: the area of a venting site; total number of bubbles, released per a time period; size spectrum and rise velocity of bubbles at different depths through the water column. An approach based on the use of calibrated echo-sounder, digital data recording and processing techniques can provide adequate quantitative analysis of the backscattering signal. This paper describes the concepts for processing of acoustic information and particular realization of these concepts, adapted to the investigation of gas bubble streams with the use of scientific echo sounder SIMRAD EK-500 as a hydroacoustic instrument. The developed software includes a number of specialized procedures expanding performance capabilities of an acoustic method for the study of natural methane seepages. The work of these procedures is demonstrated by examples, obtained during a number of scientific cruises on board the RV "Professor Vodyanitsky".

Keywords: gas bubble streams, acoustic method, echo sounder SIMRAD EK-500, specialized software

Acoustic observations of gas bubble streams (gas seeps) in the Black Sea are performed routinely since 1989, from the time when this natural phenomenon was discovered by scientists of IBSS NASU under the direction of academician NASU G.G. Polikarpov and Dr. Sci. V.N. Egorov [8]. At present, a wide spectrum of research activities in the Black Sea are associated with methane seeps, including accurate localization of seepage areas; analysis of methane bubble behavior in the water column; rating of gaseous methane flux from the sea floor and making an appraisal of its influence upon biotic and abiotic responses of marine environment as well as examining the contribution of natural methane seepages to the global carbon budget; the mechanism of bacterial oxidation of methane and formation of carbonate structures in conditions of hydrogen sulfide contamination of waters; analysis of the newest history of the Black Sea basin with the use of the age and genesis of methane from seepages; geologic and geophysical investigations to quantify reserves of gas hydrate and thermal hydrocarbon deposits in the Black Sea [5]. Results of hydroacoustic surveys are used by most of these works, expressly or by implication.

According to the theoretical justification (e.g., [7]), easy testable experimentally [9], gas bubble streams are strong sound scatterers which can be clearly detected in the water column by acoustic method. When gas seep is subjected to the repeated insonification by conventional echo-sounder (this action is also called pinging), an assemblage of echo returns often resembles in echogram a flare or a plume, so these figurative terms are typically used to indicate the acoustic evidence of a gas seepage occurrence.

Numerous seep echogram images were obtained in the Black Sea with the scientific echo sounder SIMRAD EK-500 on board the RV “Professor Vodyanitsky” [5].

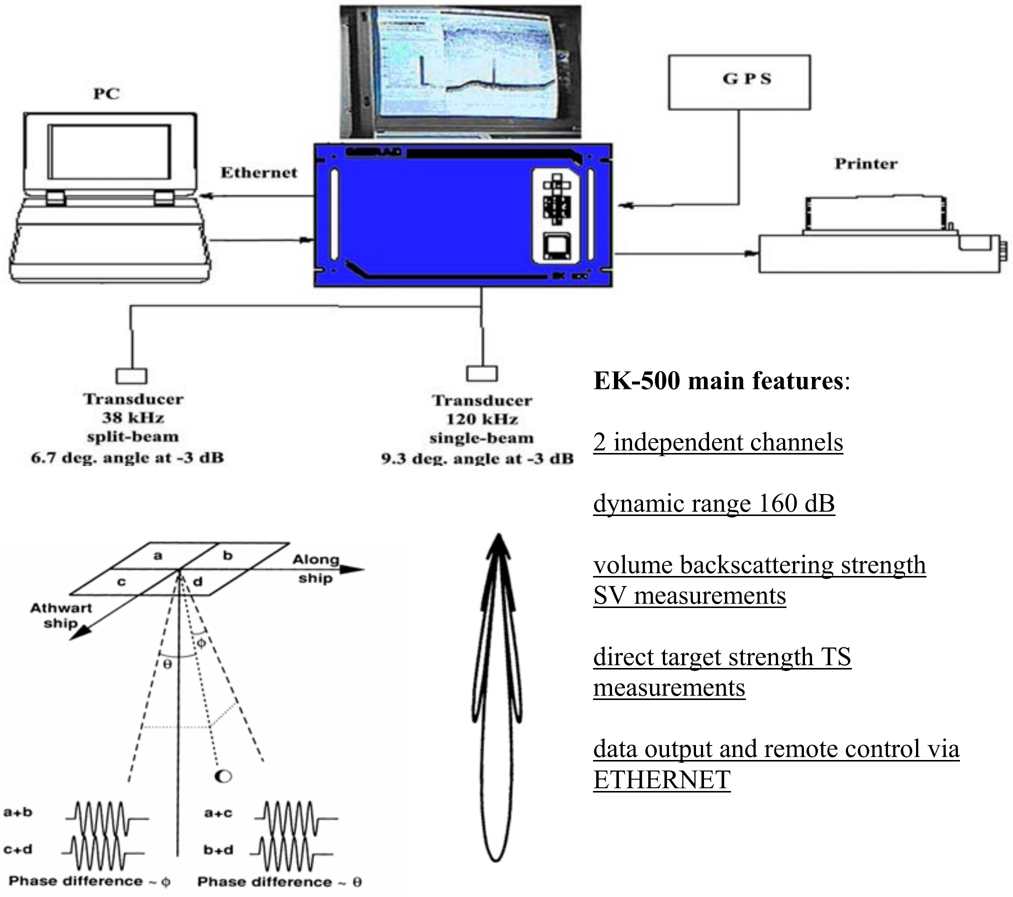
In the early stage of our investigations, echogram records on paper rolls generally documented acoustic observations. Echogram printouts allow performing both the detection of seeps and the phenomenological analysis of acoustic flares for rating of seepage scale, rising speed and rising height of gas streams [9]. Nevertheless, the potential for analysis of acoustic data represented by hard copy echograms is rather scant. In fact, the appearance of a flare, made up of echo responses from numerous gas bubbles, depends not only on bubble attributes, but also on environmental conditions, ship’s speed and a large number of parameters and settings of the acoustic system: frequency, ping rate and duration of the transmitted signal, transducer efficiency, receiver sensitivity, the gain of amplifier, etc. All these factors, affecting the echo-signal, should be expressed quantitatively and considered when gas bubble streams are studied acoustically; however this is hardly practicable with echogram imprints used as a data retrieving medium.

Meantime, modern echo-sounders provide more performance capabilities for acoustic observations than ordinary echo-signal imaging. Thus, the echo sounder EK-500 by the Norwegian company KONGSBERG SIMRAD AS pertains to the series of scientific acoustic instrumentation and can derive automatically the acoustic signatures of insonified objects from accurately measured parameters of the echo-signal [1]. Simplistically, the EK-500 consists of the hardware, responsible for the production of digitized raw measurement data, and the software, which handles processing of these data. Actually, data processing algorithms for quantitative assessment of fish stocks by the echo-integration method [10] are incorporated into the standard EK-500 software. We have found that this software has serious limitations with respect to the study of gas seeps. This mainly concerns the impossibility of processing the acoustic signal on the ping-by-ping basis through the standard EK-500 software. However, due to advanced digital data transferring facilities, the EK-500 allows an access to both processed and unprocessed data, so an additional dedicated analysis of raw data can be enabled if pertinent software exists.

In this paper the concepts and program realization of such software are proposed.

Materials and methods. The echo sounder SIMRAD EK-500 was installed on board the R/V “Professor Vodyanitsky” in 1991. It is supplied with 2 hull-mounted transducers (split-beam 38 kHz and conventional 120 kHz), 2 separate transceivers, internal microcomputer, display and printing units to represent echograms in real-time mode, and various digital data transfer channels (slow RS-32 and fast ETHERNET) for data storage and post-processing at remote computers.

Besides the control functions, the built-in microcomputer operates with raw acoustic data samples to calculate the target strength TS (dB) of single backscatterers and the area integrated echo intensity S_A (m^2/nm^2) [1]. The internal software is programmed by the echo sounder manufacturer and delivered with ROM chips. We have software ROMs version 3.01. TS and S_A data are accessible through the serial RS-32 channel, but we prefer to avoid application of these data for purposes of our investigations. Instead, we treat the echo sounder EK-500 as a source of raw acoustic data that are registered at the output of the high-speed ETHERNET communication line and processed by specially developed software. It should be noted that the format of data transferred via the ETHERNET line is distinctly documented in the operation manual [1], but nominal operating mode of the echo sounder rather does not assume utilization of these data. There are known commercial software (e.g., BI500 by SIMRAD [2] or EchoView by SONARDATA), which can support the EK-500 ETHERNET datagram. However, the use of special-purpose software with “open source code” (i.e. in-house programmed) seems to be a reasonable alternative to these



EK-500 main features:

2 independent channels

dynamic range 160 dB

volume backscattering strength SV measurements

direct target strength TS measurements

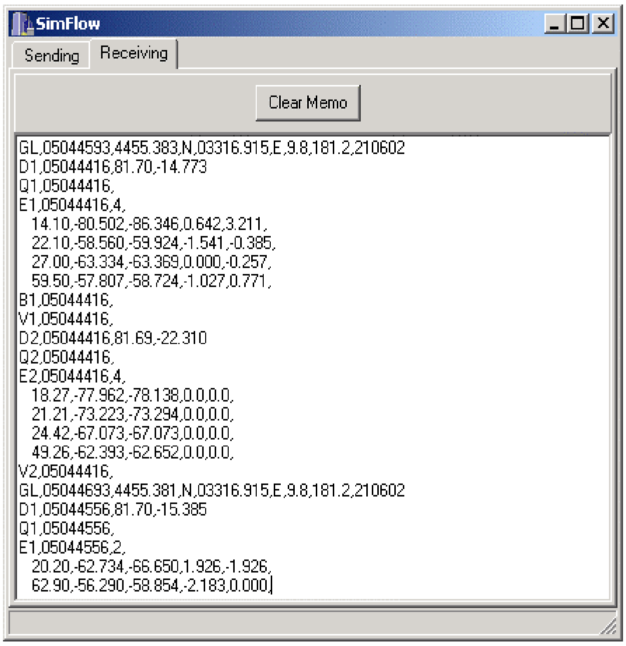
data output and remote control via ETHERNET

Рис. 1. Structure chart of the acoustic system, installed on board the R/V “Professor Vodyanitsky”
Рис. 1. Блок-схема акустического комплекса, установленного на НИС «Профессор Водяницкий»

commercial program products as it can provide greater adequacy of data processing technique to meet demands of our study.

Results and discussion. The software is developed in the Borland C++ to run on Windows systems. It consists of 2 separate component parts – data acquisition program SimFlow and data processing program WaveLens. SimFlow has simplified user interface (Fig. 2) and handles logging of data incoming from echo sounder over ETHERNET bus in accordance with the TCP/UDP Protocol.

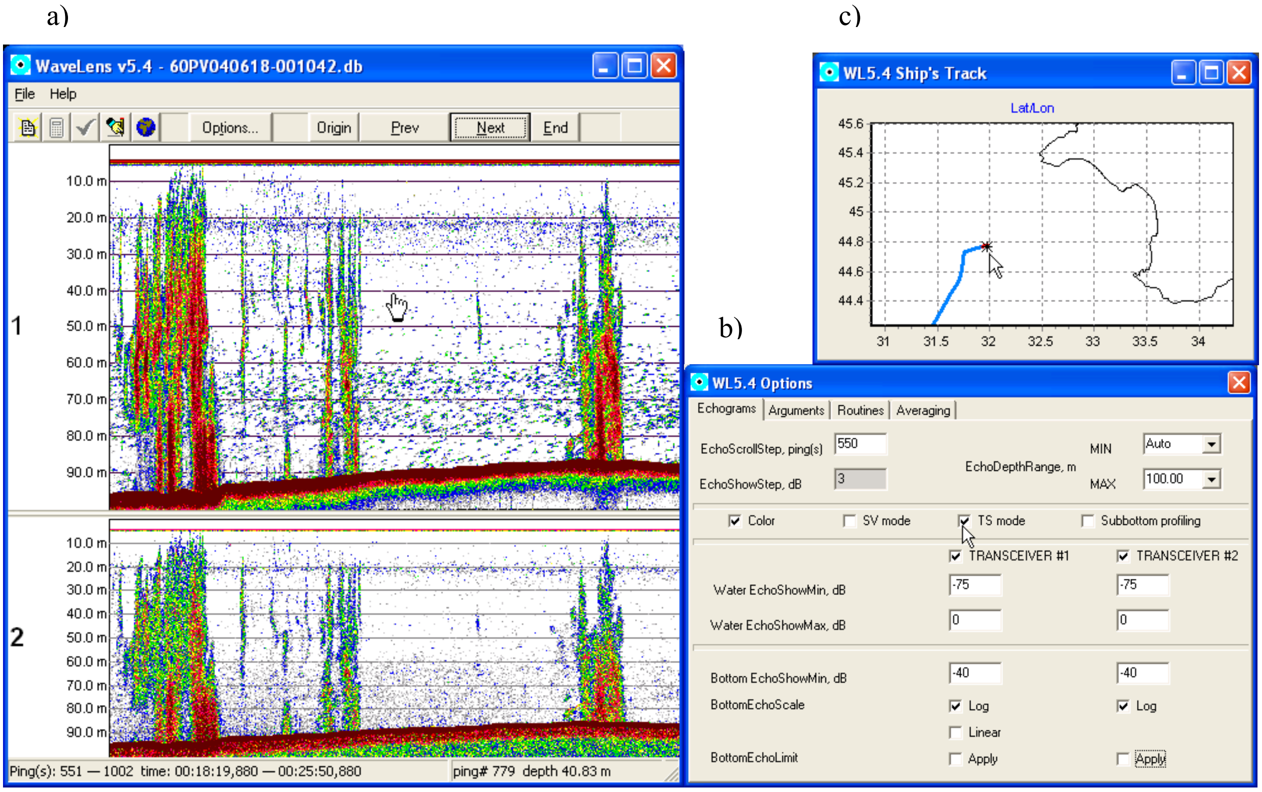
The echo sounder transfers data flow in the asynchronous mode by solid portions (telegrams) supplied with a telegram type identifier. The program verifies the integrity of received telegrams and places them into corresponding files on the hard disk depending on the telegram type. During the working session SimFlow usually generates a set of files composed from: low depth resolution vertical profiles of the volume backscattering strength (maximum 700 samples) *.fq#, high depth resolution vertical profiles of the volume backscattering strength (maximum 5000 samples) *.fv#, phase angles of the electrical output signal from quadrants of the split-beam transducer (maximum 5000 samples) *.fb1 and the received telegram log file *.str, where * is the file set name, and # denotes transkuder number which takes on a value of 1 or 2 (1 – 38 kHz channel, 2 – 120 kHz channel).



```
GL,05044593,4455.383,N,03316.915,E,9.8,181.2,210602
D1,05044416,81.70,-14.773
Q1,05044416,
E1,05044416,4,
  14.10,-80.502,-86.346,0.642,3.211,
  22.10,-58.560,-59.924,-1.541,-0.385,
  27.00,-63.334,-63.369,0.000,-0.257,
  59.50,-57.807,-58.724,-1.027,0.771,
B1,05044416,
V1,05044416,
D2,05044416,81.69,-22.310
Q2,05044416,
E2,05044416,4,
  18.27,-77.962,-78.138,0.0,0.0,
  21.21,-73.223,-73.294,0.0,0.0,
  24.42,-67.073,-67.073,0.0,0.0,
  49.26,-62.393,-62.652,0.0,0.0,
V2,05044416,
GL,05044693,4455.381,N,03316.915,E,9.8,181.2,210602
D1,05044556,81.70,-15.385
Q1,05044556,
E1,05044556,2,
  20.20,-62.734,-66.650,1.926,-1.926,
  62.90,-56.290,-58.854,-2.183,0.000
```

Fig. 2. Main window of data acquisition program SimFlow. The program allows controlling reception of EK-500 telegrams incoming over ETHERNET bus
Рис. 2. Главное окно программы регистрации данных SimFlow. Программа позволяет контролировать порядок приема телеграмм эхолота ЕК-500, поступающих по каналу ETHERNET

The ASCII *.str file tags together references to EK-500 telegrams, successfully received and stored to *.fq#, *.fv# and *.fb1 files. In addition, it contains acoustically determined depth readings and also navigation data from GPS. The design philosophy of the post-processing program WaveLens (Fig. 3) is based on the “smart echogram” technique, which serves for making the user interface to data tuples and mathematical procedures as much comfortable as possible.


a)
c)
b)

Ping(s): 551 — 1002 time: 00:18:19,880 — 00:25:50,880 ping# 779 depth 40.83 m

EchoScrollStep, ping(s) 550
EchoShowStep, dB 3
EchoDepthRange, m MIN Auto
EchoDepthRange, m MAX 100.00
☑ Color ☐ SV mode ☑ TS mode ☐ Subbottom profiling

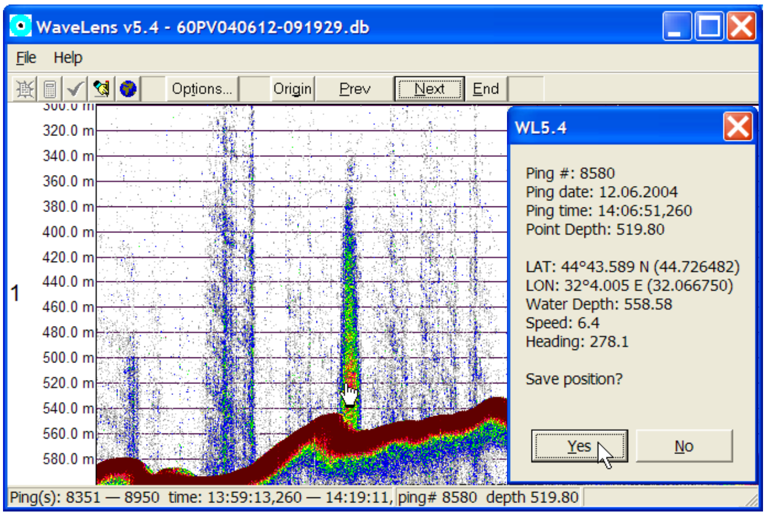
	☑ TRANSCEIVER #1	☑ TRANSCEIVER #2
Water EchoShowMin, dB	-75	-75
Water EchoShowMax, dB	0	0
Bottom EchoShowMin, dB	-40	-40
BottomEchoScale	☑ Log ☐ Linear	☑ Log
BottomEchoLimit	☐ Apply	☐ Apply

Fig. 3. The main (a) and complementary windows of WaveLens: b – the control window, opened on the page for echogram tuning; c – the map with the ship’s track indicated
Рис. 3. Главное (а) и вспомогательные окна программы WaveLens: b – контрольное окно, раскрытое на группе команд настройки эхограмм; с –карта с изображенным маршрутом судна

The main particularities of this technique are considered to be as follows:

1. All data from the file set are linked up into the transient data base, which exists over the time of current session.
2. Acoustic measurements are represented in the echogram windows (Fig. 3).
3. The data retrieval engine starts, which interrelates points (pixels) of the echogram and data base field elements.
4. The graphic interface is launched to provide easy accesses to the data base by simple computer operations with the mouse and key shortcuts (Fig. 3).

Horizontal resolution of the echogram is always 1 ping, while the vertical (depth) resolution allows scaling. To visualize a certain portion of data in the echogram, there is no need to play-back the data base from the beginning, but this can be done at once. The echogram color palette is coded depending on the echo-signal level and can be adjusted for better representation of gas flare details. Having the seep recognized, it is possible to query a database about the seep localization parameters (data, time, geographic coordinates and water depth) simply by the mouse button click when the cursor points at the flare. Then these data can be stored to the separate file and used for the report generation (Fig. 4).



Ping #: 8580
Ping date: 12.06.2004
Ping time: 14:06:51,260
Point Depth: 519.80

LAT: 44°43.589 N (44.726482)
LON: 32°4.005 E (32.066750)
Water Depth: 558.58
Speed: 6.4
Heading: 278.1

Save position?

Ping(s): 8351 — 8950 time: 13:59:13,260 — 14:19:11, ping# 8580 depth 519.80

Fig. 4. Query for the seep localization data after examination of the echogram. There is only gas flare in the current echogram window. Other apparent acoustic patterns are produced by noises

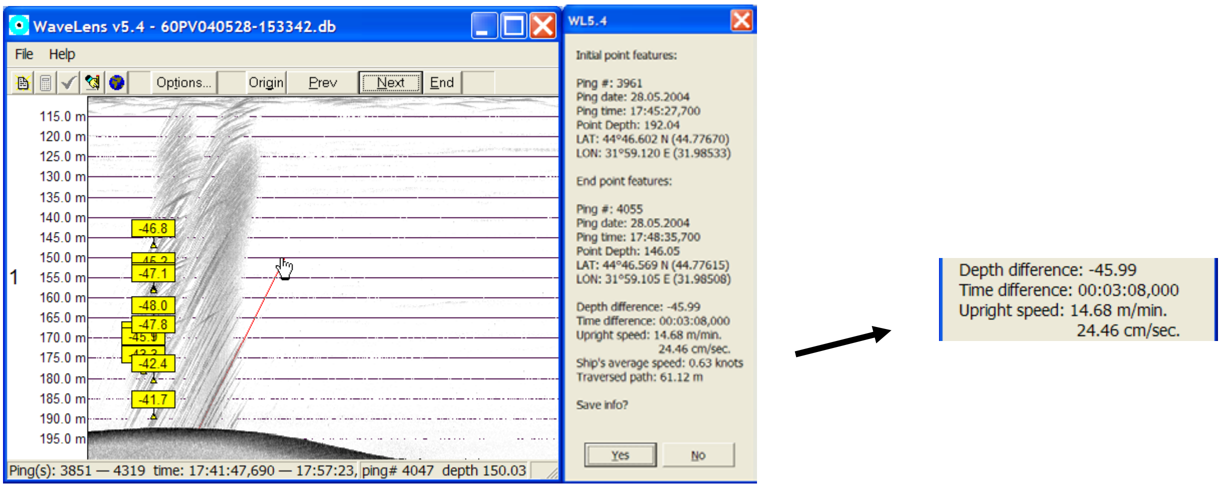
Рис. 4. Получение данных о местонахождении сипа после изучения эхограммы. В текущем окне эхограммы имеется лишь один газовый факел. Другие видимые акустические образы образованы шумами

As an echogram is the two coordinates system with time x-axe and depth y-axe, rising bubbles are represented by declined lines if bubbles exist in the insonified volume for a sufficient time period. To determine roughly their rising speed the “measuring line” tool can be applied by dragging the mouse pointer along the bubble’s path (Fig. 5).

The spatial extension of gas flare can be determined in a similar manner (Fig. 6).

It is important to note that the parameters of seep spatial extension, obtained by such a way, should be treated only as a fast and rough approximation.

Actually, for a non-flat beam pattern this operation is very sensitive to echogram settings, especially the threshold value, i.e. minimal visible echo level, (e.g. see fig. 11b). Moreover, accuracy of the approximation strongly depends on the flare position within the acoustic beam (e.g. see fig. 14).



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Ping(s): 3851 — 4319  time: 17:41:47,690 — 17:57:23, ping# 4047  depth 150.03
```

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Initial point features:

Ping #: 3961
Ping date: 28.05.2004
Ping time: 17:45:27,700
Point Depth: 192.04
LAT: 44°46.602 N (44.77670)
LON: 31°59.120 E (31.98533)

End point features:

Ping #: 4055
Ping date: 28.05.2004
Ping time: 17:48:35,700
Point Depth: 146.05
LAT: 44°46.569 N (44.77615)
LON: 31°59.105 E (31.98508)

Depth difference: -45.99
Time difference: 00:03:08,000
Upright speed: 14.68 m/min.
                      24.46 cm/sec.
Ship's average speed: 0.63 knots
Traversed path: 61.12 m

Save info?
```
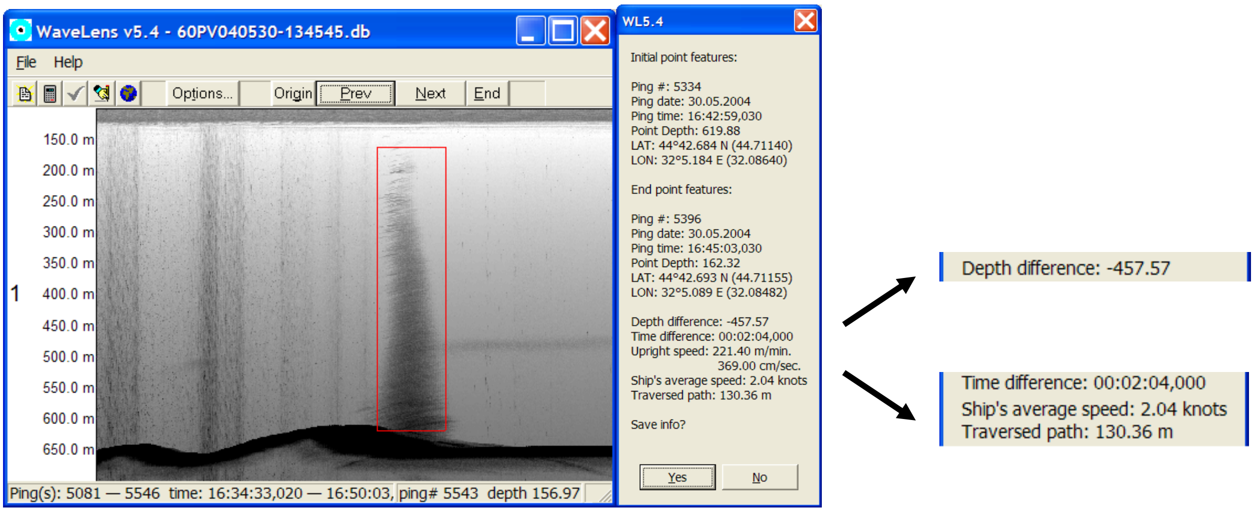

Depth difference: -45.99
Time difference: 00:03:08,000
Upright speed: 14.68 m/min.
24.46 cm/sec.

Fig. 5. The measurement of the rising speed of bubbles. Values in yellow rectangles – target strength TS (dB) of detected single bubbles
Рис. 5. Измерение скорости подъема пузырьков. Желтыми маркерами отмечены значения силы цели TS (dB) детектированных одиночных пузырей



```
Ping(s): 5081 — 5546  time: 16:34:33,020 — 16:50:03, ping# 5543  depth 156.97
```

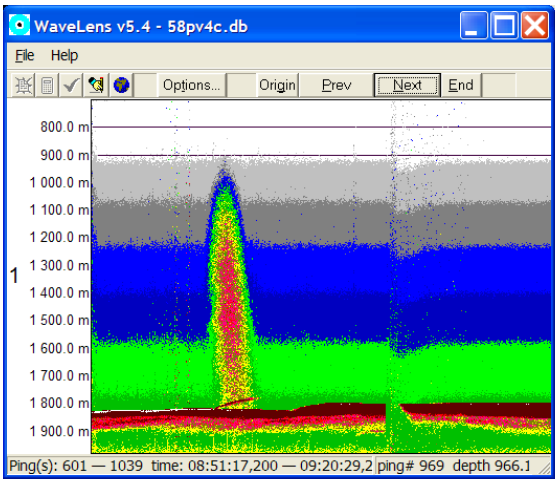
```
Initial point features:

Ping #: 5334
Ping date: 30.05.2004
Ping time: 16:42:59,030
Point Depth: 619.88
LAT: 44°42.684 N (44.71140)
LON: 32°5.184 E (32.08640)

End point features:

Ping #: 5396
Ping date: 30.05.2004
Ping time: 16:45:03,030
Point Depth: 162.32
LAT: 44°42.693 N (44.71155)
LON: 32°5.089 E (32.08482)

Depth difference: -457.57
Time difference: 00:02:04,000
Upright speed: 221.40 m/min.
                      369.00 cm/sec.
Ship's average speed: 2.04 knots
Traversed path: 130.36 m

Save info?
```

Depth difference: -457.57

Time difference: 00:02:04,000
Ship's average speed: 2.04 knots
Traversed path: 130.36 m

Fig. 6. Determination of the spatial extension of a flare. The height of rectangle equals to the flare height (457.6 м). Diameter of a seep can be calculated by subtracting of the transducer footprint from the ship's traversed path (130.4 м). For the 38 kHz transducer the nominal footprint comprises, approximately, 0.1128*H, where H (m) – water depth of the seepage site. As H = 620 м, diameter of the seep is ≈ 60.4 м
Fig. 6. Определение пространственной протяженности сипа. Высота прямоугольника равна высоте сипа (457.6 м). Для получения характерного горизонтального размера сипа следует из длины пройденного судном пути (130.4 м) вычесть поправку на ширину диаграммы направленности антенны эхолота. Для 38 кГц антенны значение поправки составляет, приближенно, 0.1128*H, где H – глубина участка газовыделения. Поскольку H = 620 м, горизонтальная протяженность участка газовыделения составляет ≈ 60.4 м

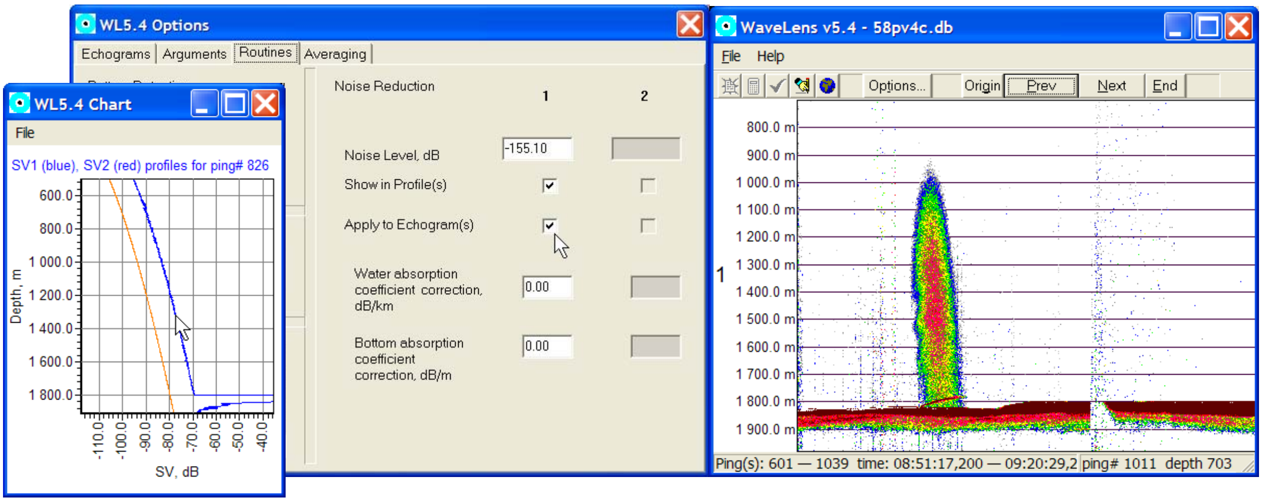
When deep sea flares are observed, the background noise problem usually arises. As a result of sound propagation loss due to the attenuation and spherical spreading, the echo-signal level at long distances becomes comparable with the background noises. For compensating the sound propagation loss the time varied gain (TVG) is usually applied in calibrated echo-sounders. However the background noises are also gained according to the TVG function, merged with the signal and displayed on echograms as the specific horizontal stripes (Fig. 7).



Ping(s): 601 — 1039 time: 08:51:17,200 — 09:20:29,2 ping# 969 depth 966.1

Fig. 7. Untreated echogram of deep-water seep. Noises are displayed by horizontal colored stripes
Рис. 7. Необработанная эхограмма глубоководного сипа. Шумы отображаются цветными горизонтальными полосами

Taking into consideration that in the absence of backscattering targets the background noises strictly tail along the TVG function line, the noise level can be evaluated visually and eliminated from the echo-signal by means of the noise reduction procedure, implemented into WaveLens (Fig. 8).



Noise Reduction

	1	2
Noise Level, dB	-155.10	
Show in Profile(s)	☑	☐
Apply to Echogram(s)	☑	☐
Water absorption coefficient correction, dB/km	0.00	
Bottom absorption coefficient correction, dB/m	0.00	

Ping(s): 601 — 1039 time: 08:51:17,200 — 09:20:29,2 ping# 1011 depth 703

Рис. 8. Removal of noises from the echogram. Evaluation of the background noise level is made using the chart of volume backscattering strength SV (dB) (blue line in leftmost window). In the same chart the assumed noise level is indicated in red. The real noise level is calculated automatically on stacking of both lines at an area of background backscattering. When activated (the middle window), the noise reduction procedure processes the echo-signal prior to it is visualized (right window).
Рис. 8. Очистка эхограммы от шумов. Для оценки уровня шумов используется график профиля силы объемного обратного рассеяния SV (dB) (синяя линия в левом окне). Там же красной линией нанесен предполагаемый уровень шумов. Реальный уровень шумов вычисляется автоматически при совмещении синей и красной линий на участках фонового звукорассеяния. После активизации процедуры шумоподавления (среднее окно), эхо-сигнал обрабатывается перед прорисовкой эхограммы (правое окно).

During acoustic surveys we usually do not confine sampling of the echo signal within the water column, but record also echo returns from the upper sediments. It is feasible in WaveLens to adjust the echogram parts for the water column and the upper sediment layer independently. This screen mode is used in our investigations to detect manifestations of gas-saturated bottom sediments in close proximity to seep sites. By applying different settings for the display threshold and sound attenuation within the water column and sediment sections of the echo-signal, the best possible images of flares and sub-bottom structures can be achieved in the same echogram window (Fig. 9).

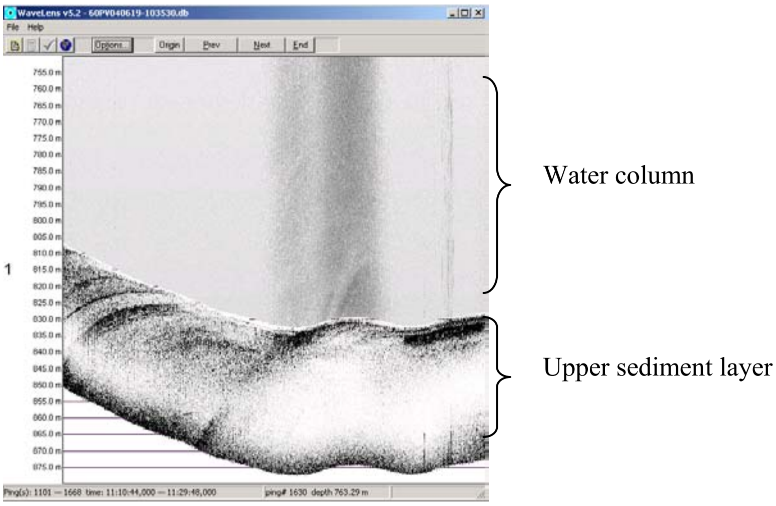
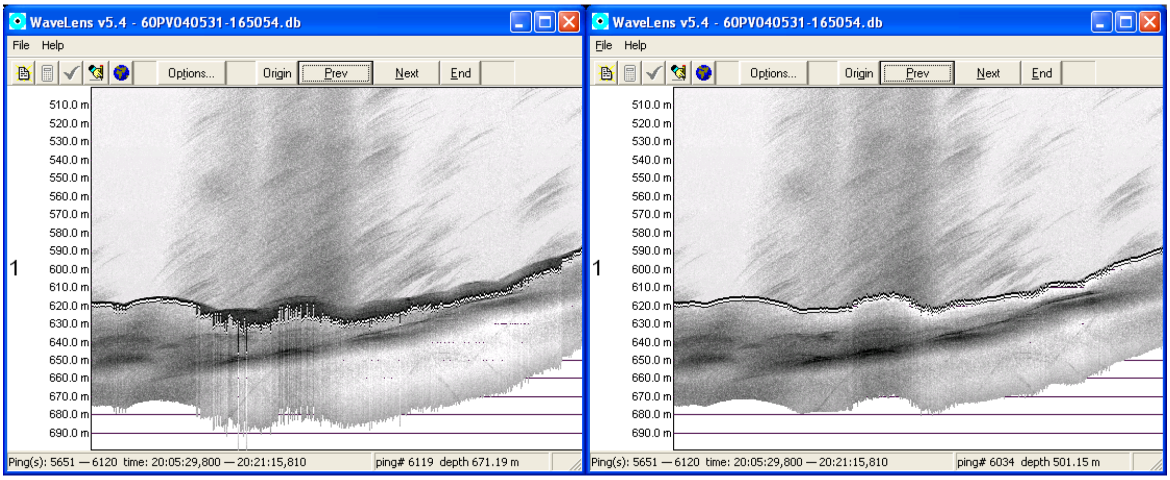


Рис. 9. Echogram with different settings for the display threshold and sound attenuation within the water column and upper sediment layer

Рис. 9. Эхограмма с различными значениями коэффициента затухания звука в водной толще и верхнем слое донных осадков

The composite pelagic/sub-bottom echograms are sensitive to the reliability of bottom detection. The automatic bottom detection algorithm is implemented in the EK-500, which provides correct depth readings in most cases. However, on certain conditions (e.g., on weak return from soft sediments, at high-intensive venting sites, on masking of sound by air bubbles at the ship's trail when maneuvering, at steep slopes), the probability of erroneous depth data-out from EK-500 increases, though the bottom contour can be easily recognized by visual examination of the echogram. Therefore, the depth correction procedure, included into WaveLens, employs the graphic interface. When an area with erroneous depth readings is seen in the echogram (Fig. 10, left window), WaveLens provides the possibility to traced out this area in the special delineation mode. Then WaveLens can perform the forced identification of bottom returns within the bounds of the marked area. The effect of this operation is depicted and checked in the echogram window iteratively. Upon reaching the successful result, erroneous depth readings are replaced by correct values (Fig. 10, right window).

Special attention was paid to the measuring of such important acoustic parameters as the mean volume backscattering strength (MVBS) and the target strength (TS) of single backscatterers. With respect to our investigations, these parameters are essential for the quantitative assessment of methane venting sites, including size spectrum and concentration of bubbles, volume of gas containing in them, gas flux to the water column from single seeps and seep areas. Actually, the lateral scales of most seeps, observed by us, were comparable or less than the transducer footprint, so strong influence of directivity pattern of acoustic beam on the MVBS measurement can be expected. Neglecting this effect may result in the undervaluation of energetic descriptors of the echo signal similarly to what was shown by the example of small fish schools [3]. This problem can be resolved by detailed analysis of the echo signal on the ping by ping basis, however, the standard EK-500 software is not sufficient for this study as MVBS readings from the EK-500 refer to sailed distance intervals (0.1 nm minimum) with the vessel's speed detected by the log or simulated internally over the range 0.1 – 25.0 nm.


WaveLens v5.4 - 60PV040531-165054.db

Ping(s): 5651 — 6120 time: 20:05:29,800 — 20:21:15,810 ping# 6119 depth 671.19 m

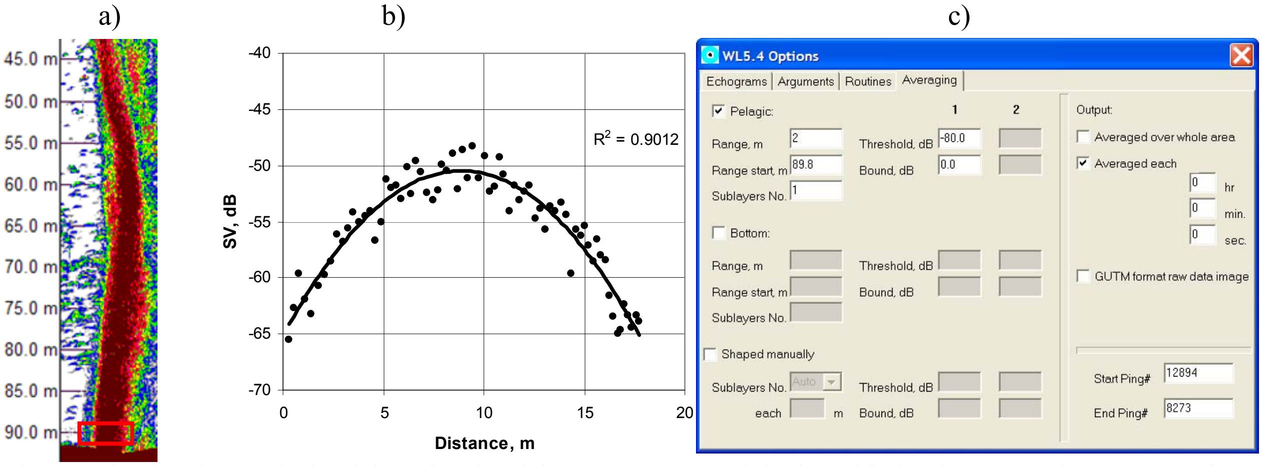
WaveLens v5.4 - 60PV040531-165054.db

Ping(s): 5651 — 6120 time: 20:05:29,800 — 20:21:15,810 ping# 6034 depth 501.15 m

Рис. 10. Example of the echogram before (left window) an after (right window) application of the depth correction procedure. The bottom contour is drawn by the line of special format.

Рис. 10. Пример эхограммы до (левое окно) и после применения процедуры коррекции глубины (правое окно). Контур дна отмечен линией специального формата.

To overcome this limitation, WaveLens was supplied with the echo-integration procedure, which takes advantages of the graphic interface and provides a great flexibility in choosing integration bounds and intervals for MVBS calculation. Fig. 11 illustrates data, which can be obtained by means of the ping-by-ping analysis.


WL5.4 Options

☑ Pelagic:

Range, m 2

Range start, m 89.8

Sublayers No. 1

Threshold, dB -80.0

Bound, dB 0.0

☐ Bottom:

☐ Shaped manually

Sublayers No. Auto

Output:

☐ Averaged over whole area

☑ Averaged each 0 hr 0 min. 0 sec.

☐ GUTM format raw data image

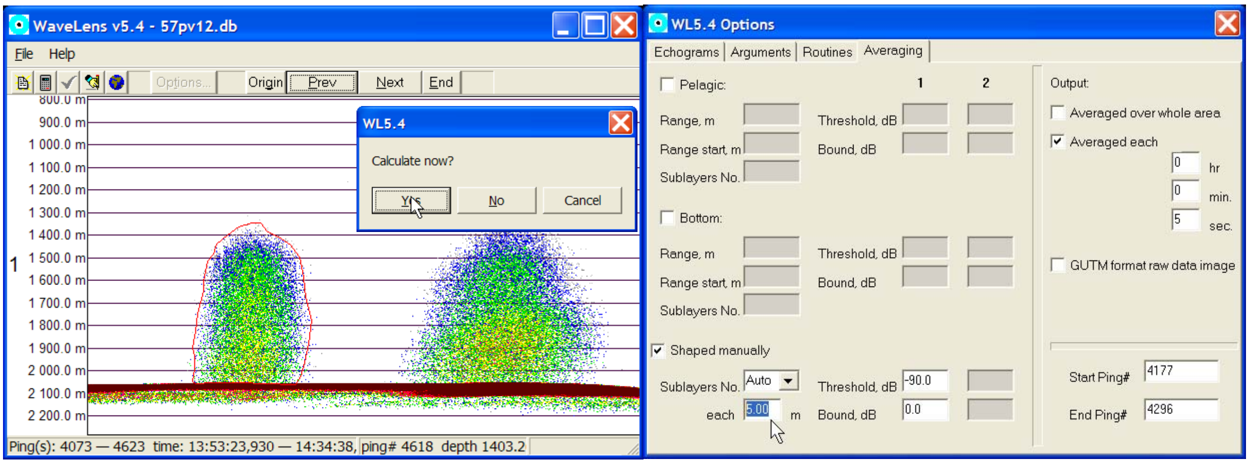
Start Ping# 12894

End Ping# 8273

Fig. 11. Ping by ping analysis of the echo-signal from a seep crossed the insonified volume. a) echogram at 38 kHz. Integration region is marked by the red rectangle; b) MVBS data (close circles) and quadratic regression parabola (solid line) are shown. High regression coefficient ($R^2 \approx 0.9$) indicates that data closely follow the parabolic beam pattern function inherent to split-beam transducers manufactured by SIMRAD. Hence, the acoustic flare is produced by a point seepage, which area is less than the beam footprint; c) control window for the integration settings. MVBS values are calculated by integration of the echo-signal within the depth limits 89.8 – 91.8 m without averaging between pings (averaging interval 0 hr. – 0 min. – 0 sec. means ping by ping data output)

Рис. 11. Подробный анализа эхо-сигнала от сипа при пересечении им озвученного объема. а) эхограмма на частоте 38 кГц. Область интегрирования отмечена красным прямоугольником; b) точками изображены усредненные значения силы объемного обратного рассеяния MVBS, линия - график квадратичной регрессии. Высокое значение коэффициента регрессии (R2 ≈ 0.9) свидетельствует о том, что данные хорошо описываются параболической функцией диаграммы направленности, свойственной антеннам с расщепленным лучом производства фирмы SIMRAD. Следовательно, газовый факел образован точечным сипом, площадь которого меньше, чем сечение луча антенны; c) контрольное окно для установки параметров интегрирования. Значения MVBS получены интегрированием эхо-сигнала в пределах глубин 89.8 – 91.8 м без усреднения по горизонтали (в соответствии с установленным интервалом осреднения 0 ч - 0 мин - 0 сек)

The special usage of the integration procedure, implemented into WaveLens, concerns getting data for 3-D flare imaging. This operation can be done by application of the shaper tool to a flare in the echogram followed by data retrieval from over the shaped area (Fig. 12).


WaveLens v5.4 - 57pv12.db

WL5.4

Calculate now?

Ping(s): 4073 — 4623 time: 13:53:23,930 — 14:34:38, ping# 4618 depth 1403.2

WL5.4 Options

Averaging

☐ Pelagic:

☐ Bottom:

☑ Shaped manually

Sublayers No. Auto

each 5.00 m

Threshold, dB -90.0

Bound, dB 0.0

Output:

☐ Averaged over whole area

☑ Averaged each

0 hr

0 min.

5 sec.

☐ GUTM format raw data image

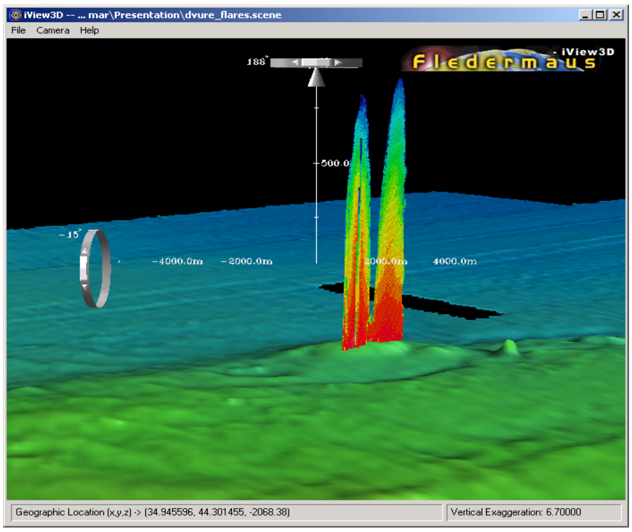
Start Ping# 4177

End Ping# 4296

Рис. 12. Shaping of a gas flare for 3-D imaging. Within the limits of shaped area (left window) the echo level samples are spatially averaged according to the settings (right window). The settings are: time interval - 5 sec; depth interval – 5 m.

Рис. 12. «Оконтуривание» газового факела для построения 3-х мерного изображения. Значения уровня эхо-сигнала пространственно усредняются в пределах контура (левое окно) в соответствии с установленными параметрами (правое окно). В данном примере используются следующие параметры: 5-секундный временной интервал и 5-метровый интервал глубин.

Obtained data can be utilized for creation of a 3-D flare image itself by the use of any suitable software package, for instance, Fledermaus by IVS /www.ivs.unb.ca/ (Fig. 13).


iView3D -- ... mar\Presentation\dvure_flares.scene

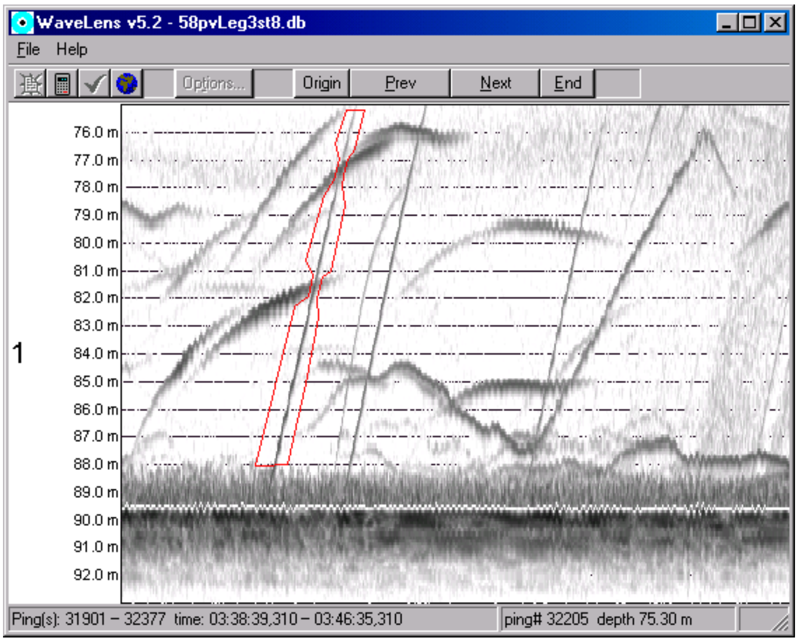
Geographic Location (x,y,z) -> (34.945596, 44.301455, -2068.38)

Vertical Exaggeration: 6.70000

Fig. 13. 3-D image for gas outbursts from the mud volcano Dvurechenskiy (Black Sea). Acoustic observations were made in the 57th Cruise of the R/V “Professor Vodyanitskiy”. Bathymetry data were obtained with the swath bathymetry system HYDROSWEEP in the R/V “Meteor” M52/1 (MARGASCH) Cruise. The image is created by Dr. Jens Greinert with the use of program Fledermaus.

Fig. 13. 3-х мерное изображения струйных газовыделений из грязевого вулкана Двуреченский (Черное море). Акустические данные получены в 57-м рейсе НИС «Профессор Водяницкий». Использованы данные батиметрической съемки морского дна многолучевым эхолотом HYDROSWEEP в рейсе НИС «Метеор» M52/1 (MARGASCH). Изображение получено др. Енсом Грейнертом с использованием программы Fledermaus.

When measuring target strength of a backscatterer, the shape of its impulse response is analyzed on the stipulation that the only bakcscatterer exists in the insonified volume, otherwise measurements are biased due to the formation of composite signal by a number of overlapped echoes [7]. The EK-500 in-built TS measurement algorithm utilizes the split-beam technology [4] to recognize *in situ* a single target, determine its position in the acoustic beam and calculate acoustic cross-section from the amplitude of echo return. Reliability of this algorithm, i.e. stable rejection of multiple targets and acceptance of single targets, strongly depends on the selectivity control settings chosen during the data acquisition session. It was found that optimal work of this algorithm can be hardly achieved on-line, therefore the post-processing design of the TS measurement procedure was accepted in WaveLens. At that, two modes of our algorithm for single target selection are distinguished – "strong" and "weak". The "strong" mode provides improved selectivity of single targets and can be used for estimation of TS distribution in the bunch of bubbles, as well as for study of gas bubble behavior in the water column. For the latter the individual bubble tracking technique can be applied with the use of the WaveLens graphic interface (Fig. 14).



Ping(s): 31901 – 32377 time: 03:38:39,310 – 03:46:35,310

ping# 32205 depth 75.30 m

Fig. 14. Application of the bubble tracking technique. Tracks of single bubbles (straight lines) and moving fishes (tortuous lines) are seen in the echogram. For retrieving that portion of information from the data base, which corresponds to the observed bubble, the trace shaping procedure is used (red line).

Рис. 14. Использование процедуры контроля траектории пузырька. На эхограмме просматриваются следы от одиночных газовых пузырьков (прямые линии) и движущихся рыб. Для выборки из общего массива данных порции информации, относящейся к исследуемому пузырьку, применяется оконтуривание следа пузырька (красная линия на эхограмме).

Data derived from application of this procedure make it possible to assess such gas bubble signatures as the evolution of their size and rising speed depending on the residence time in the water column (Fig. 15).

On the contrary, impulse responses from both single and multiple targets pass through the "weak" algorithm due to the weakened selection criteria. Then the amplitude component of the echo-signal is discarded, but only positions of detected targets (single or multiple) in the sound beam are registered. When seepage crosses the insonified volume the series of positions of detected targets specify the direction towards the seepage relative to the beam axes, hence, geographical coordinates and spatial extension of the seepage can be determined more accurately (Fig. 16).

It is important to note that certain correctional routines are incorporated into the signal processing algorithms developed by SIMRAD for EK-500 firmware to compensate the echo-signal amplitude distortion through the finite bandwidth of transceiver circuits and transducer terminal [1] (Fig. 17), however author was failed in tracing any public domain information about these algorithms.

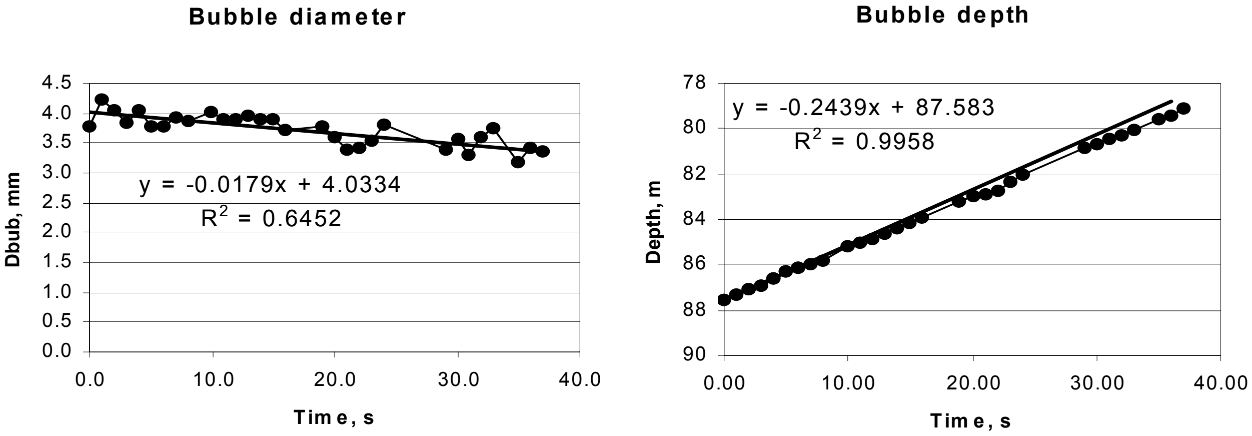


Fig. 15. Example of data, obtained with the use of the procedure for individual bubble tracking. The bubble diameter values are calculated from measured TS according to [7]. Linear regression lines are also shown. The regression fit to the initial 10 s interval is calculated for the depth vs time dependence

Рис. 15. Пример данных, получаемых в результате оконтуривания следа одиночного газового пузыря. Диаметр пузырька рассчитан согласно [7]. Показаны также линии линейной регрессии. Регрессионная зависимость глубины пузырька от времени рассчитывалась для стартового 10 с интервала

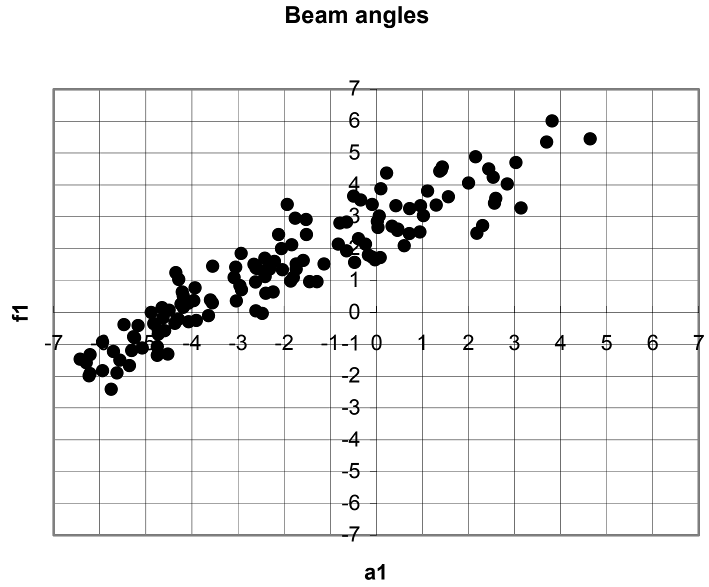


Fig. 16. Example of data, obtained with the use of the “weak” procedure when seepage crosses the insonified volume.

Рис. 16. Пример данных, полученных в результате работы «нестрогого» алгоритма детектирования целей при пересечении сипа лучом антенны.

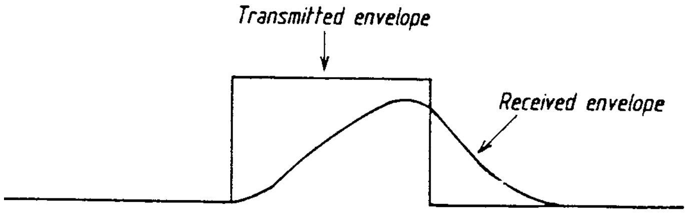


Fig. 17. Transformation of the form of echo-signal in comparison with the transmitted sound signal. Reproduced from [1]

Рис. 17. Изменение формы эхо-сигнала по сравнению с излучаемым зондирующим импульсом. Воспроизведено из [1]

Therefore, the special investigation was undertaken to study the response function of the EK-500 system. As a result, the necessary corrections were reckoned up, programmed and embedded into WaveLens for both point and volume backscattering strength measurements.

Absolute acoustic measurements require accurate calibrations of an echo sounding system. In our investigations we use the recommended for the scientific echo sounder EK-500 calibration method, which is based on the measurement of echoes from a reference target [1]. Normally, the reference target is a solid sphere made of metal, supplied with the certificate of nominal TS and diagrams showing the deviation of TS value depending on the environmental parameters, that is to say water temperature and salinity. We prefer to determine numerically the actual reference TS under calibration conditions. Therefore, the procedure was developed for the TS calculation according to the theory of acoustic scattering on elastic spheres [6]. As provided by this theory, target strength of the metal sphere in the aquatic environment depends on the number of parameters: radius of the sphere, density of a material of sphere, sound frequency, density of water, sound velocity in water, and also longitudinal and transverse sound velocities within the sphere. At that, variation of acoustic cross-section of sphere relatively the geometric cross-section is described by the so-called form-function. An example of form-function for copper sphere manufactured by SIMRAD is shown in Fig. 18.

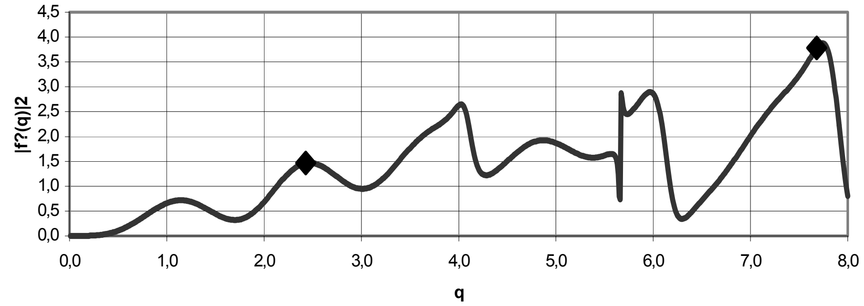


Fig. 18. Dependence of squared form-function modulus on q = k·a, where k – wave number, a – radius of copper sphere (15 mm in our case). Values are marked on the curve, corresponding to 38 (q = 2.4) and 120 (q = 7.6) kHz.
Рис. 18. Зависимость квадрата модуля форм-функции от величины q = k·a, где k – волновое число, a – радиус медной сферы (15 мм в нашем случае). Значками отмечены точки на кривой, соответствующие частотам 38 (q = 2.4) и 120 (q = 7.6) кГц

Conclusions. A software for acquisition and processing of acoustic data, accessible through the ETHERNET interface of the scientific echosounder SIMRAD EK-500, is developed. This software was regularly employed during a number of scientific cruises on board the RV “Professor Vodyanitskiy” for accurate seep detection in the Black Sea and collection of data, which could bring a better understanding of the methane seepage phenomenon, in particular: 1) how much gas escapes from the sea floor, 2) how much gas transfers from ascending bubbles to the water column, 3) how much gas bubbles deliver to the atmosphere.

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Програмне забезпечення досліджень струминних метанових газовиділень акустичним методом. Ю. Г. Артемов. Природні струминні метанові газовиділення з морського дна, звичайно, ідентифікуються акустичним методом по наявності в товщі води ділянок підвищеного рівня ехо-сигналу, форма яких нагадує факели полум'я. У цих акустичних образах, складених з ехо-відгуків від численних пухирців газу, утримується різноманітна інформація про індивідуальні властивості пухирців і всій ділянки морського дна, що виділяє газ, в цілому. При вивченні екологічної ролі струминних метанових виходів газу представляється важливим завданням одержання такої інформації, особливо: даних про розміри ділянки, що виділяє газ; загальну кількість пухирців, що виділяються за певний період часу; розмірному складі й швидкості підйому пухирців на різних глибинах. Використання каліброваного ехолота й цифрових технологій реєстрації й обробки даних представляється адекватним підходом до кількісного аналізу акустичного сигналу. У статті приводиться загальний опис підходу до обробки акустичної інформації й приватна реалізація цього підходу, адаптованого до дослідження струминних виходів газу при використанні наукового ехолота SIMRAD EK-500 як акустичний інструмент. Розроблене програмне забезпечення містить у собі ряд спеціалізованих процедур, що розширюють можливості застосування акустичного методу для дослідження струминних виходів газу. Робота цих процедур розглядається на конкретних прикладах, отриманих у ряді наукових експедицій на НИС «Професор Водяницкий».

Ключові слова: струминні метанові газовиділення, акустичний метод, ехолот SIMRAD EK-500, програмне забезпечення

Программное обеспечение исследований струйных метановых газовыделений акустическим методом. Ю. Г. Артемов. Природные газовыделения из морского дна, обычно, идентифицируются акустически методом по наличию в толще воды участков повышенного уровня эхо-сигнала, формой напоминающих факелы пламени. В этих акустических образах, составленных из эхо-откликов от многочисленных пузырьков газа, содержится разнообразная информация об индивидуальных свойствах пузырьков и всего газовыделяющего участка морского дна в целом. При изучении экологической роли струйных метановых газовыдений представляется важной задачей получение такой информации, в особенности: данных о размерах газовыделяющего участка; общем количество пузырьков, выделяющихся за определенный период времени; размерном составе и скорости подъема пузырьков на различных глубинах. Использование калиброванного эхолота и цифровых технологий регистрации и обработки данных представляется адекватным подход к количественному анализу акустического сигнала. В статье приводится общее описание подхода к обработке акустической информации и частная реализация этого подхода, адаптированного к исследованию струйных газовыделений при использовании научного эхолота SIMRAD EK-500 в качестве акустического инструмента. Разработанное программное обеспечение включает в себя ряд специализированных процедур, расширяющих возможности применения акустического метода для исследования струйных газовыделений. Работа этих процедур рассматривается на конкретных примерах, полученных в ряде научных экспедиций на НИС «Профессор Водяницкий».

Ключевые слова: струйные метановые газовыделения, акустический метод, эхолот SIMRAD EK-500, программное обеспечение.