Measurement of acoustic noise in Lake Baikal

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Abstract:
We have performed a series of hydro-acoustic measurements in Lake Baikal in order to investigate the spectrum of acoustic noise, its dependence on depth and angle of incidence, and its correlation to external factors like wind or processes in the ice cover of the Lake. Data have been taken in Spring and Summer 2003. We observe daily variations which are stronger than the dependence on depth. Occasional effects like rain or the possible release of methane bubbles form the bottom of the Lake do also strongly change the acoustic background — the integral noise as well as the spectral characteristics. The preliminary results obtained so far indicate a rather complicated picture of acoustic noise in Lake Baikal. After this “first look” we plan a second, more systematic series of measurements in 2004.

1. Introduction

Since several years, feasibility studies towards acoustic detection of particle cascades are performed in Lake Baikal. The mechanism of an acoustic signal is supposed to be thermo-elastic. The energy deposited by the cascade heats the medium and causes a sudden expansion. The width of the resulting bipolar acoustic signal increases with the diameter of the cascade, its amplitude is proportional to the cascade energy and inversely proportional to the squared diameter of the cascade [1,2,3].

The present studies at Lake Baikal follow two lines: *a)* the detection of acoustic signals coinciding with an extensive air shower hitting the ice and *b)* the possibility to measure cascades generated in neutrino interactions in deep water. Cascades generated in neutrino interactions have diameters of the order of 10 cm, cascades due to the core particles of extremely energetic air showers hitting the ice and the upper layer of water have diameters of a meter or more. Preliminary results of the search for correlations between air showers and acoustic signal have been presented at various occasions [4,5] but did not yield a positive result until now [6,7].

Here, we present results of a first attempt to study the hydro-acoustic noise in Lake Baikal, its dependence on depth, its frequency spectrum and its correlation to various external factors.

The signal from neutrino induced cascades is expected to peak at frequencies of 20 kHz, with calculated amplitudes for a 10 PeV cascade at 400 m distance ranging from a few μPa [3] to a few tens of μPa [2,8]. The detection is far from being trivial since the signal has to be separated from various sources of noise. Surface waves, ship traffic and seismic background dominate the sub-kHz range, noise from rainfall and wind as well as thermal noise of higher frequencies [9]. Other effects are movements of the ice layer covering northern waters in winter and spring, formation and implosion of bubbles, or biologically generated noise. Most of these sources have transient character. Detection of a single bipolar signal from a high energy particle interaction requests a good understanding and continuous monitoring of the acoustic noise. Apart from that, acoustic detection of underwater signals is used for environmental and biological studies.

Section 2 describes the hydro-acoustic recorder used for the measurements, section 3 the four campaigns of data taking, section 4 the results. Section 5 summarizes the results and gives and outlook to activities planned for 2004.

2. The hydro-acoustic recorder

For the purpose of noise measurement, an autonomous hydro-acoustic recorder with two input channels has been developed. We will refer to this system as ÒrecorderÓ in the following. The principal scheme of the recorder is shown in Figure 1.

Acoustic signals are received by two spherical piezo-ceramic hydrophones with 5 cm diameter and a sensitivity of about 0.2 mV/Pa. Their signal is further processed by preamplifiers with 78 dB amplification and frequency correction. In the range down from 1 kHz, the relative amplification is lowered by 20 dB per octave in order to suppress low frequency noise. High frequency noise is suppressed by discrete low-pass filters[1] following the preamplifiers. The further processing is performed by a micro-controller[2] which includes a 12-bit Flash-ADC with a maximum conversion rate of 0.2 Msamples/sec and a multi-channel analog multiplexer. The cut frequency of the low pass filter was set to 50 kHz, in accordance with the number of channels and the maximum conversion rate of the Flash ADC.

Data are written to a 10 Gbyte hard disk[3]. The interface to the hard disk is provided by a subprogram running on the micro-controller. A clock provides the time stamp. A Ni-Cd accumulator battery (4.5 AÆhours) supplies the power for the hard disk and the digital part of the electronics. The analog part is powered by an alkaline battery[4]. The RS-232C serial interface connects the recording device to a personal computer and allows initial tuning and tests of the system in the laboratory.

The electronics is housed by a cylindrical container made from an Al-Mg alloy[5], with 17.0 cm outer diameter and 60.0 cm length. Three hermetic connectors penetrate the upper cap of the container. Two of them are used to connect the hydrophones. A LED signaling the functionality of the recorder is mounted on the third. Two magnetic contacts (Start/Stop) installed at the inner surface of the cap can be operated by a small magnet from outside. They allow to initialize or to interrupt measurements.

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[1] Linear Technology Corporation LTC1569-6

[2] Texas Instruments MSP430F149

[3] Fujitsu MHM2100AT

[4] PROCELL

[5] AMg-6

The characteristics of the recorder system was determined in two ways. Firstly, the amplitude-frequency response was calibrated by well-defined input signals. Secondly, by replacing hydrophones and cables by 30 pF capacitors (corresponding to the capacity of the hydrophones), the internal noise spectrum was measured. Noise measurements have been performed for two conversion frequencies (156 863 Hz and 235 294 Hz). Fig. 2 shows the resulting spectrum. The integrated noise between 1 and 50 kHz (the bandwidth of the recorder) is about 12.5 mPa.

3. Data Taking

Data have been taken in four series. The first three were part of the 2003 winter/spring campaign of the Baikal Neutrino Collaboration and have been performed from the ice cover, the fourth has been performed in June 2003 from a ship. Table 1 summarizes the basic information for the four series.

Date	**Start Time**	**End Time**	**Number of depth steps**	**Max depth (meters)**	**Weather**
26-03-03	12:45	17:11	19	1300	Sunny, no wind
31-03-03	22:21	02:29	16	1300	Dark night, no wind
05-04-03	15:01	17:56	10	1200	Cloudy, no wind
18-06-03	5:31	6:56	10	1250	Onset of rainfall

The vertical distance between the two hydrophones was 143 cm for the first two series and 96 cm and 237 cm for the last two series. One measurement at a certain depth took 5 to 10 minutes.

During the measurements at greater depth, the noise at shallow depth was monitored with the help of an additional hydrophone read out by an external recorder. These data reflect the global noise situation and can in particular be used to select artifacts related to operations at the ice camp. Since the aim of his channel is the indication of relative changes and not an absolute measurement, the corresponding data in the following figures are shown in arbitrary units.

4. Results

4.1. Depth dependence

The depth dependence of the noise integrated over the bandwidth of the recorder is shown in Figs. 3-6. The upper two curves correspond to the effective fluctuation of the acoustic noise field in each of the two channels, expressed in mPa. The lower curve (ÒControlÓ) gives the variations in the control channel at shallow depth.

It turns out to be difficult to draw general conclusions on the depth dependence of the noise since the depth effects are combined with meteorological effects. Data obtained at the same depth but at different times can differ considerably. An illustrative example are the measurements of the first series at March 26. The data have been taken at windless, sunny weather, starting at 12:45. As time went by, the sun set. The warm ice cooled down and the micro-movements due to the pressure in ice decreased, leading to a four-fold reduction of noise at 500 m depth for measurement #16 at 16:55 when compared to the earlier 500-m measurement #9 from 14:05.

The significant daily variations are illustrated in Fig. 7, showing the integral noise measured over 11 days at a depth of 1080 m. For these measurements a special instrument has been used which measures the acoustic signals integrated over 10-sec intervals. In most cases, 1-2 maxima per day are observed, the one typically shortly after noon, the other at night (when the cooling ice develops cracks).

A different noise behavior is observed for the second series of measurements which started at 22:28 and went over four hours (Fig. 4). The average noise level is by a factor 2-3 lower than that in Fig.3, but still larger than the ~40 mPa lowest value in Fig. 3. The increase in noise observed for the 400-m point (1:36-1:47) corresponds to a possible general increase in noise as indicated by the values of the control hydrophone.

The third series of data (Fig.5) was taken at a cloudy day, so that the influence of the sun was minimal, with nearly no wind. This results in a very low noise level, only 1.5-2 times the internal noise of the recorder. We note a small increase of noise below 600m, at the same time when the surface noise is falling.

Fig. 7 shows the data for the summer measurement performed from a ship (and without the control device at shallow depth). The curve starts bottom right with a value close to the minimum value observed during winter at this depth (see Fig.5). Down to 500 m the noise does not change significantly. During the lowering to the next measurement position, rain set in. This is the likely reason for the increase of noise along the further path of the recorder.

Fig. 7 shows the integral noise measured over 11 days (see above). Fig.8 shows the mean square deviations of the noise amplitudes versus the file number. Data are cut out of four measurements. Curves shown in Figs. 3-6 have been extracted from original data files of this kind.

4.2. Directionality of signals

The combined data taken by two vertically separated hydrophones allow to estimate the vertical angle of incidence of acoustic signals. In Fig. 9, the angle with respect to the horizon is plotted versus the signal amplitude (in units of noise standard deviations, Fig. 9a) and versus depth (fig. 9b). The signals entering these two plots have been requested to have a length smaller than 50 μs and an amplitude larger than four standard deviations. These criteria have been chosen in order to select those noise signals which may mimic signals due to high energy particle cascades.

It is obvious that most noise sources are in the upper hemisphere. Signals from below or close to horizon are supposed to be due to refraction of signals from the upper hemisphere. Refraction is expected due to the depth dependence of the speed of sound, c_{sound}. During the period of ice cover, c_{sound} increases with depth z as shown in Fig.10.

Down to 150-200 m, the slope is $dc_{\text{sound}}/dz \sim 0.13\ \text{s}^{-1}$ and is dominated by the rising temperature, below 200 m, $dc_{\text{sound}}/dz \sim 0.015\ \text{s}^{-1}$, due to the rising pressure. Supposing that the dominant source of noise in winter is the ice, then all acoustic signals with an angle less than 9.5 degrees w.r.t. horizon are objected to total internal reflection, down to the depth of the so-called meso-thermal maximum (the maximum of temperature at ~250 meters depth). After maximally 3600 m path length, these signals return to the ice cover, are reflected with a coefficient of about 0.4, and continue their path. Signals with a larger initial angle penetrate the meso-thermal maximum but are bent towards horizon.

A considerable number of signals in the third series (dots in Fig.9) come from close to horizon. They are supposed to be due to noise from ice cracks at larger distances. These signals have been bent due to refraction. In the first two series (crosses and triangles in Fig. 9) they are masked by the much stronger signals from close sources.

Fig. 11 shows an event recorded at 600 m depth which resembles an acoustic signal from a particle cascade in water. The angle of incidence is 12.5 degrees below horizon and it has a bipolar form. The two upper plots show the zoomed signals in the two deep hydrophones, the two lower plots show the long-term time series. The abscissa is the number of the conversion interval (step width 8.5 μs), the ordinate gives the amplitude in units of standard deviations. The middle time series gives the covariance function for the two upper fragments. The abscissa is in units of 0.425 μs (i.e. 0.05 the conversion interval). We note that events of this kind are observed very rarely.

4.3 Spectral Characteristics

Examples for the power spectral density (PSD) of the recorded noise signals are given in Fig. 12. Shown are spectra taken at March 26 at 1300 m depth (Fig. 12a) and at April 5 at 3 m depth (Fig. 12b) and 1200 m depth (Fig. 12c). Fig. 12d shows data taken at June 18 at 500 m depth.

We first note the significant difference between the spectra taken at nearly the same large depth (Fig. 12a and 12c). The April 5 data exhibit several narrow-band sources at about 20 kHz and above, and also — although less pronounced — in the few-kHz region. Similar structures have been observed in autumn 2002, when acoustic signals have been measured close to a known location of spontaneous release of methane from the LakeÕs bottom. The oscillations of the gas bubbles under the water pressure at the location of release may proceeds with frequencies in the observed range [11]. This hypothesis seems reasonable since in a campaign in September 2002, a group of the Limnology Institute in Listvianka (Lake Baikal) has measured an increased concentration of methane close to the location of the neutrino telescope NT-200. The flattening and rise of the spectrum at 20-30 kHz seems to be related to resonance frequencies of the hydrophones in this range.

We also note the difference between the two channels at low frequencies which was observed at April 5,when the instrument was at shallow depth (Fig.12b). The upper hydrophone was at 3 m depth, the lower at 4 m depth (distance between hydrophones 96 cm). One may interpret this as an indication for a strong vertical inhomogeneity of the noise field close to the ice layer (the effect of an under-ice Òacoustic channelÓ, which appears due to the specific depth dependence of the sound speed in the winter lake (see Fig. 10).

Fig.12d shows the spectral distribution before and after the onset of rain in a measurement at June 18, 2003. The increase of noise above 10 kHz correlated to the rain is very pronounced.

5. Summary and Outlook

The results of our first measurement of acoustic noise in the Lake Baikal shows its complicate structure and strong dependence from different factors.

The main source of acoustic noise in winter are cracks of the ice due to temperature variations of the ice. Its seems that the integral level and the spectral shape of the noise depend more on meteorological conditions than on depth. In a case when the noise from the ice was low, we observed a change in the spectrum which we assign to a source in the deep water. We guess that the noise is produced by gas bubbles released from the bottom of the lake. We note that we also observe bipolar pulses which resemble the form of an acoustic signal from particle interactions in water below 4¡C. At this point we have no idea what the source of these signals could be.

It is obvious that — after having had a Òfirst lookÓfrom these measurement — more systematic studies are mandatory in order to draw clear conclusions.

For the 2004 season, we plan the following improvements:

a) We will use 4 instead of only 2 hydrophones, with higher sensitivity than the 2002 hydrophones. This will result in a lower detection threshold and a better directional information of sources of noise.
b) We will improve electronics and increase the on-board memory. This will result in lower detection threshold, better time resolution and longer time series.
c) We will install a stationary device for long-term monitoring. This device will allow a systematic study of correlations between noise and meteorological conditions such as wind speed, air temperature, solar radiation, rain, etc.
d) We intend to perform periodical measurements during the winter season as well as from a ship during summer. These measurements will be performed at different depths. Accurate monitoring of meteorological conditions and deployment times which are short compared to changes in solar radiation or other conditions will allow us to better disentangle the various effects.

Acknowledgments

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References:

1. G.A.Askaryan, Atomnaya Energiya 3 (1957) 152.

2. G.A.Askaryan et al., NIM 164 (1979) 267.

3. J.G.Learned, Phys. Rev. D19 (1979) 3293.

4. G.V. Domogatsky, Proc. ÒNeutrino 2000Ó

5. A. Rostovtsev, presentation at a Baikal Collaboration Meeting

6. S. Mikheev, presentation at the Baikal Collaboration Meeting, June 2003.

7. V.I. Lyashuk, Presentation at the Baikal Collaboration Meeting, June 2003.

8. L.G. Dedenko et al., Proc 24th ICRC (1995), vol 1, 797.

9. N.G.Lehtinen, Sh.Adam and Giorgio Gratta, Astropart. Phys. 17 (2002) 279.

10. Wenz, Journal of the Acoustic Society of America 34 (1962) 1936 (communication by J.Learned)

11. Cavitation and Bubble Dynamics. by Christopher Earls Brennen. ' Oxford University Press 1995 . http://caltechbook.library.caltech.edu/archive/00000001/00/chap3.htm#L8

Figure Captions:

1. *a)* Principal scheme of the underwater hydro-acoustic recorder system, *b)* mechanical construction of the device.

2. Internal noise spectrum of the recorder system.

3. Dependence of the integral noise on depth and time (March 26, 2003)

4. Dependence of the integral noise on depth and time (March 31, 2003)

5. Dependence of the integral noise on depth and time (April 5, 2003)

6. Dependence of the integral noise on depth and time (June 18, 2003)

7. Time variation of the integral noise

8. Variation of the acoustic noise as a function measurement, for four measurements cycles

9. *a)* Scatter plot of angles of incidence versus acoustic amplitude. The angles are counted from horizon, with positive values for signals from the upper hemisphere and negative values for signals from below. Amplitudes are in units of standard deviations. *b)* Scatter plot of angles of incidence versus depth.

10. Depth profiles of speed of sound and of temperature in Lake Baikal as typically for March.

11. Example for a bipolar impulse being a candidate to fake a signal from a particle cascade.

12. Frequency spectra of acoustic signals.
    a) March 26, depth = 1300 m
    b) April 5, depth = 3 m
    c) April 5, depth = 1200 m
    d) June 18, depth = 500 m
    For *a)- c)* , the two upper curves correspond to the two hydrophones, for *d)* the two upper curves correspond to data taken before and after the onset of rain.

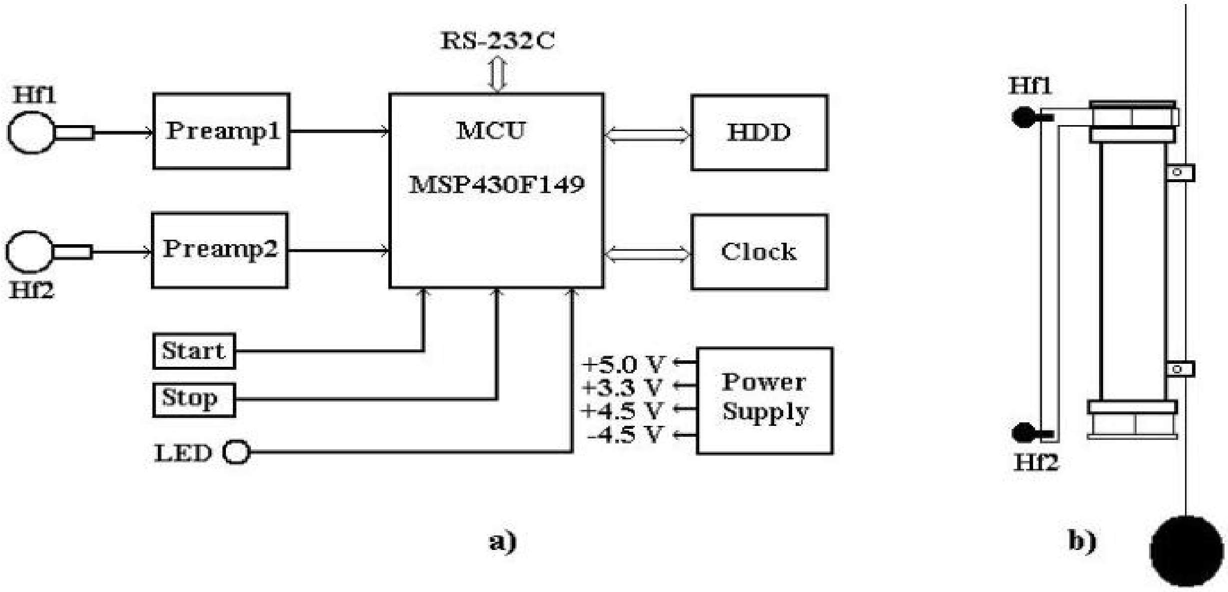

RS-232C
Hf1
Preamp1
MCU
MSP430F149
HDD
Preamp2
Clock
Hf2
Start
Stop
LED
+5.0 V
+3.3 V
+4.5 V
-4.5 V
Power Supply
a)
Hf1
Hf2
b)

Fig. 1

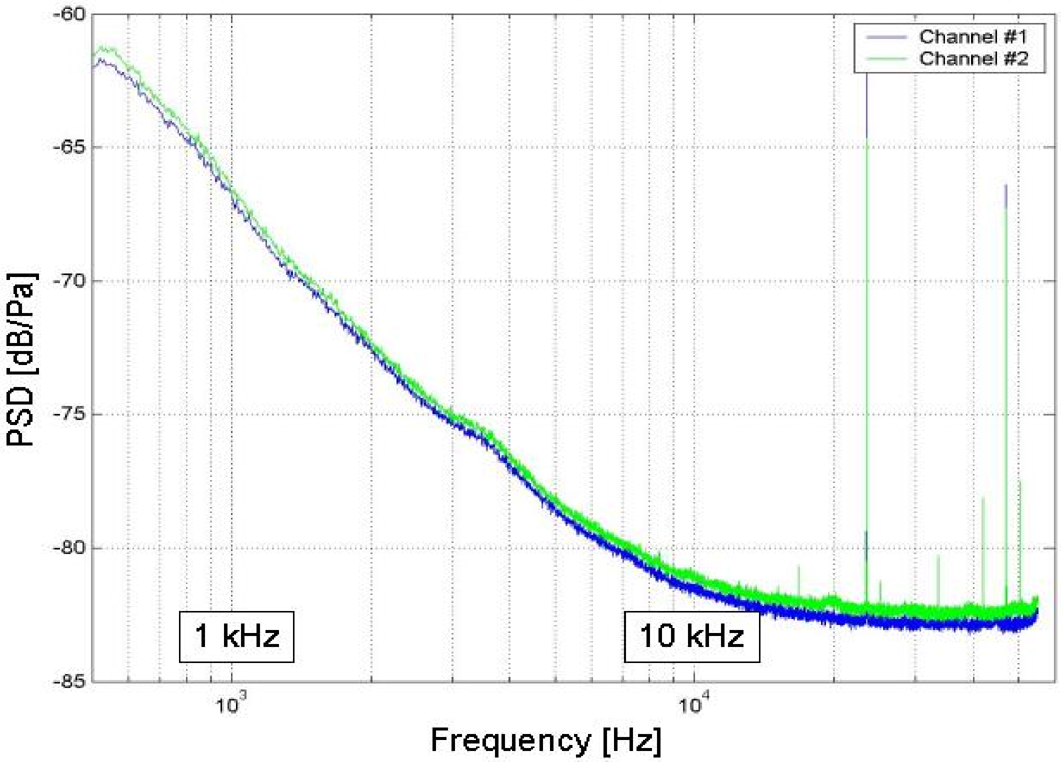
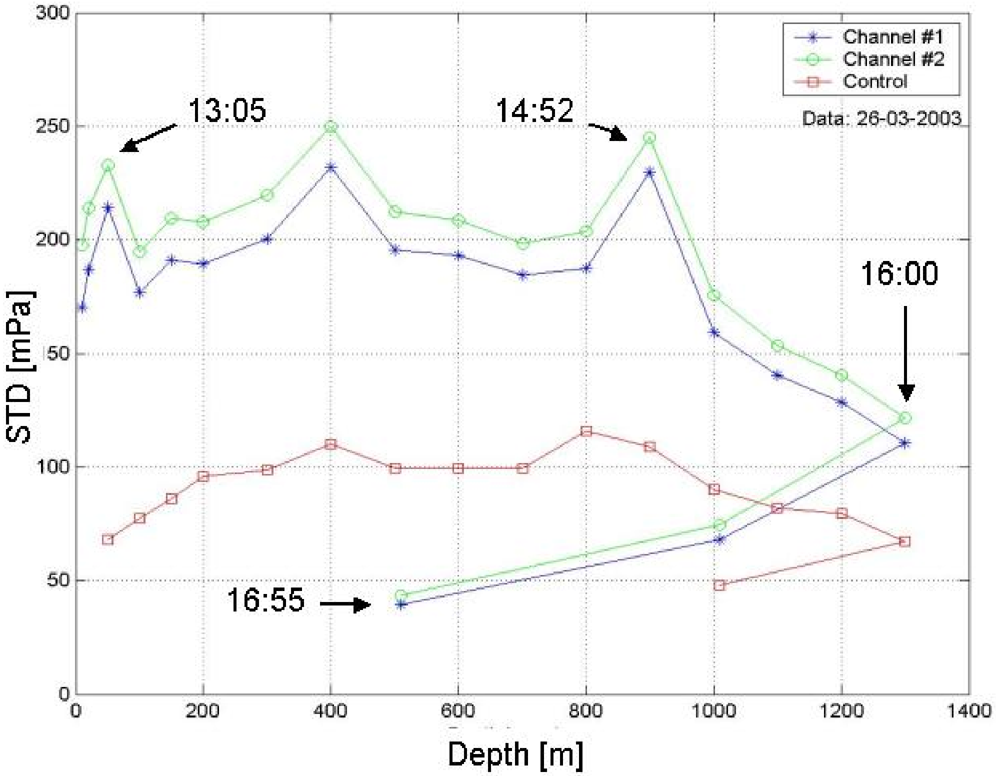

-60
-65
-70
-75
-80
-85
PSD [dB/Pa]
10^3
10^4
Frequency [Hz]
Channel #1
Channel #2
1 kHz
10 kHz

Fig. 2



Channel #1
Channel #2
Control
Data: 26-03-2003
13:05
14:52
16:00
16:55
STD [mPa]
Depth [m]
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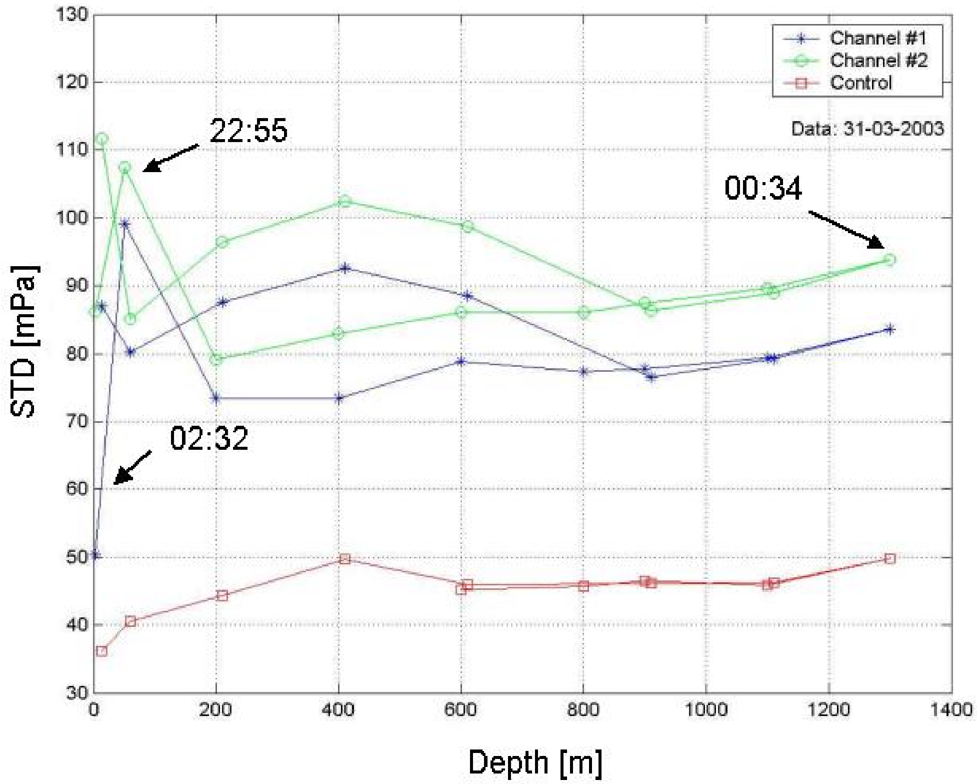
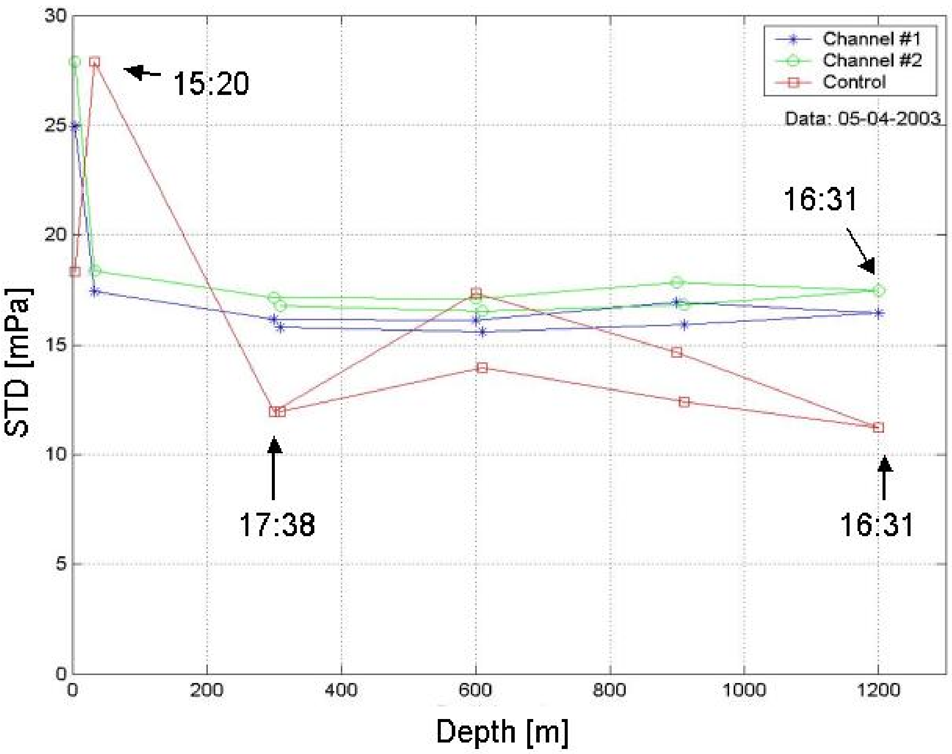
250
200
150
100
50
0
0
200
400
600
800
1000
1200
1400

Fig. 3



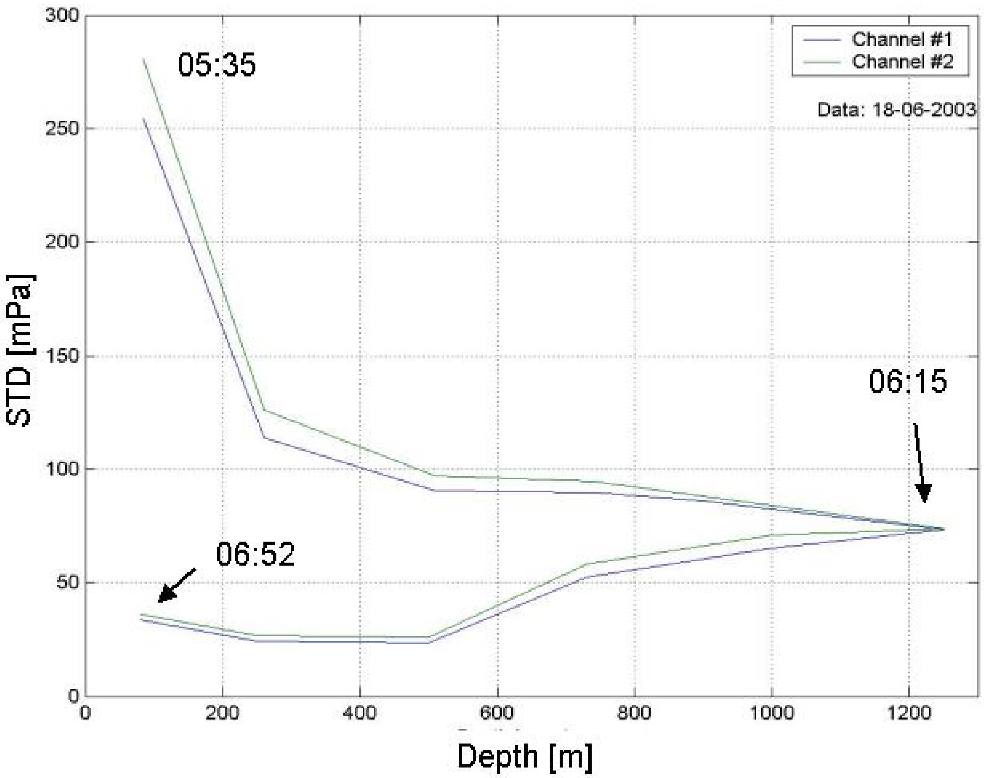
Channel #1
Channel #2
Control
Data: 31-03-2003
22:55
00:34
02:32
STD [mPa]
Depth [m]
130
120
110
100
90
80
70
60
50
40
30
0
200
400
600
800
1000
1200
1400

Fig. 4



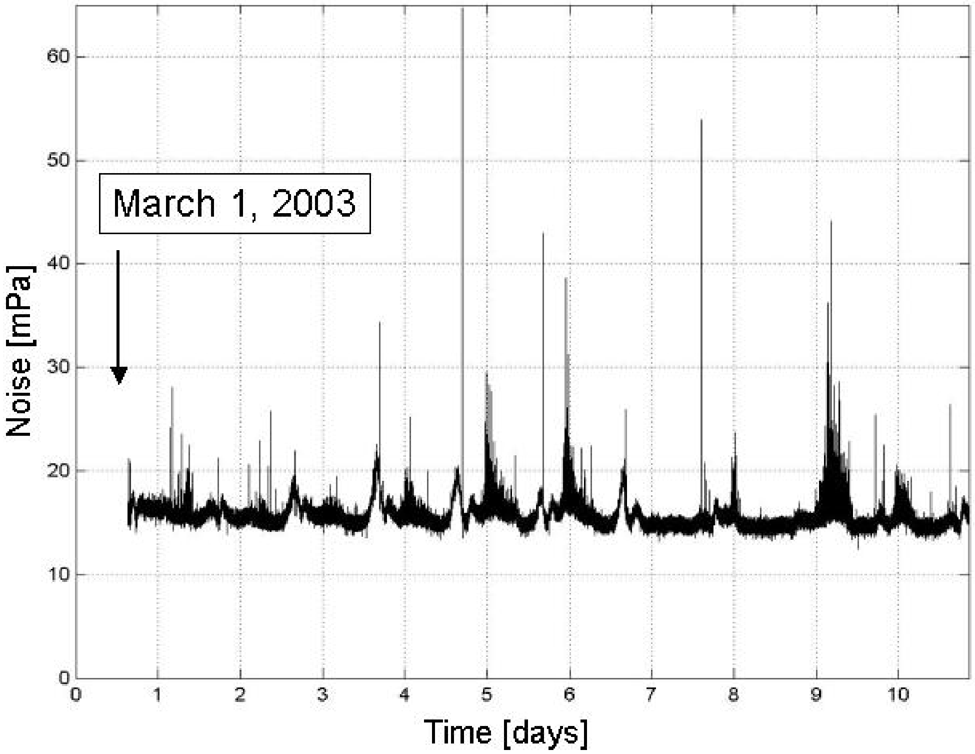
30
25
20
15
10
5
0
0
200
400
600
800
1000
1200
STD [mPa]
Depth [m]
Channel #1
Channel #2
Control
Data: 05-04-2003
15:20
16:31
17:38
16:31

Fig. 5



300
250
200
150
100
50
0
0
200
400
600
800
1000
1200
STD [mPa]
Depth [m]
Channel #1
Channel #2
Data: 18-06-2003
05:35
06:15
06:52

Fig. 6


March 1, 2003
Noise [mPa]
Time [days]
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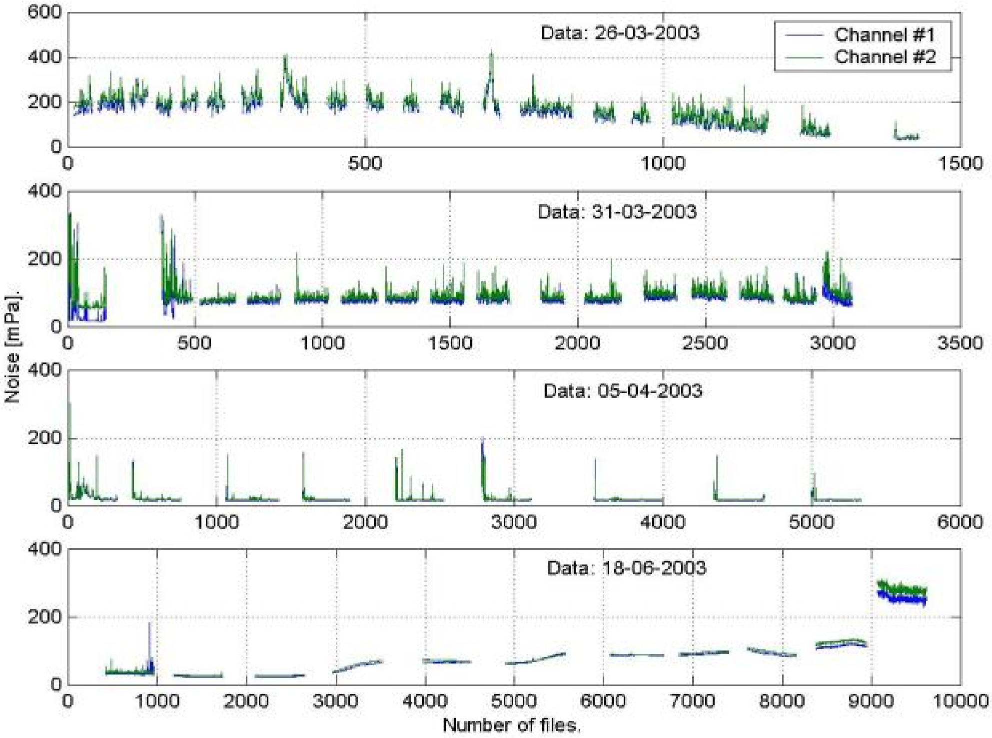
10
20
30
40
50
60
0
1
2
3
4
5
6
7
8
9
10

Fig. 7


Data: 26-03-2003
Channel #1
Channel #2
Data: 31-03-2003
Data: 05-04-2003
Data: 18-06-2003
Noise [mPa].
Number of files.
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200
400
600
500
1000
1500
2000
2500
3000
3500
4000
5000
6000
7000
8000
9000
10000

Fig. 8

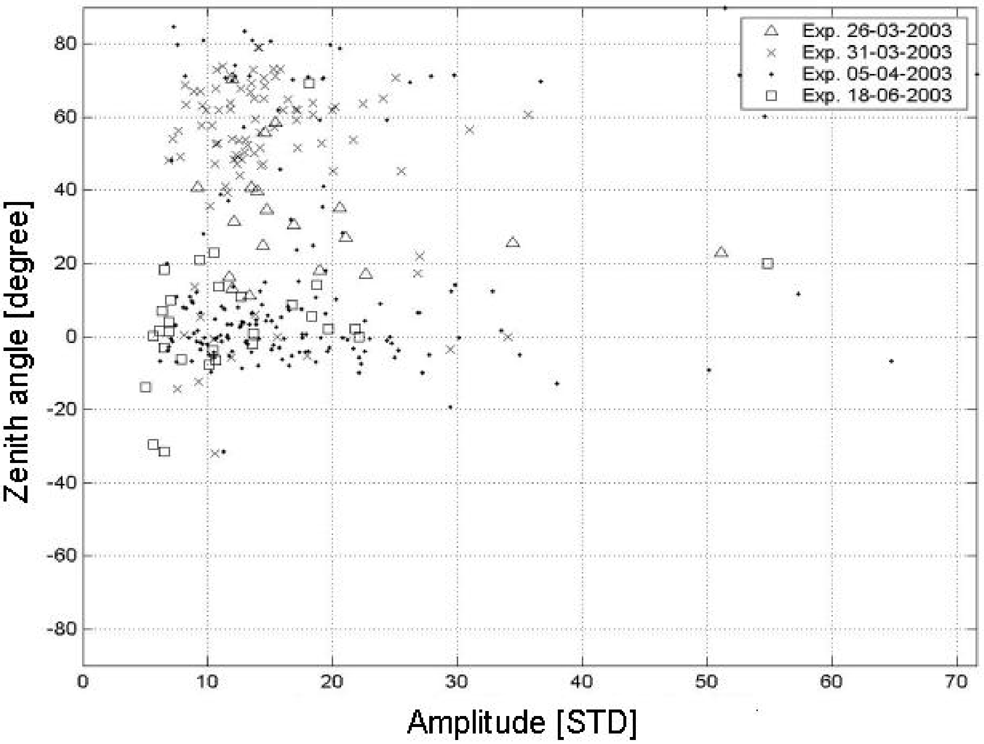
Exp. 26-03-2003
Exp. 31-03-2003
Exp. 05-04-2003
Exp. 18-06-2003
Zenith angle [degree]
80
60
40
20
0
-20
-40
-60
-80
0
10
20
30
40
50
60
70
Amplitude [STD]

Fig. 9a

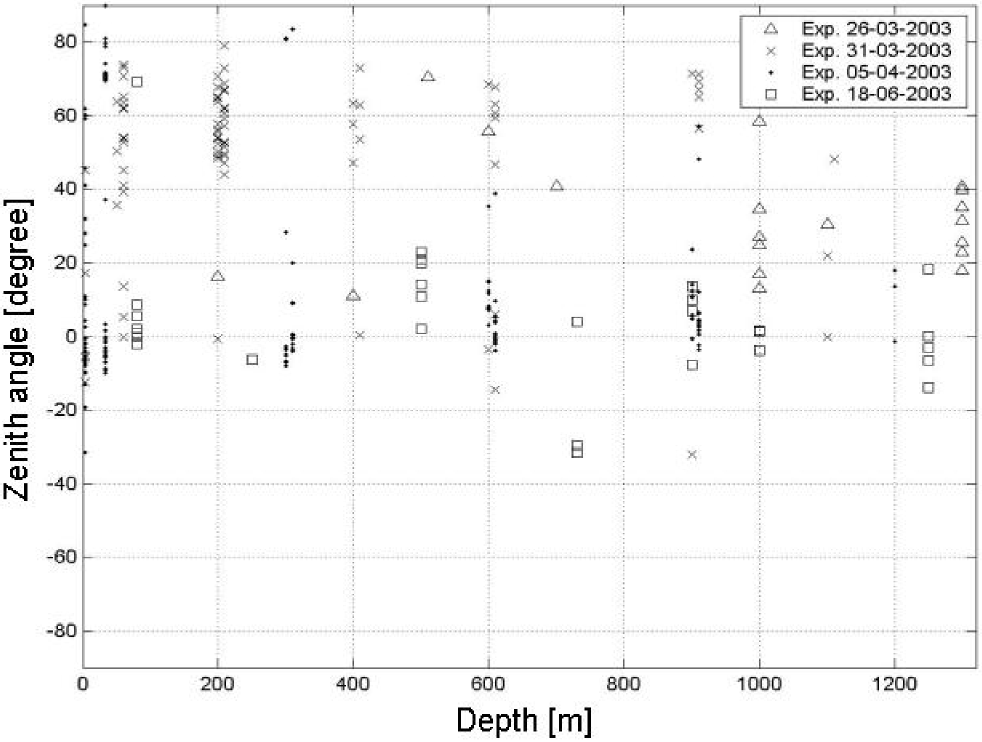
Exp. 26-03-2003
Exp. 31-03-2003
Exp. 05-04-2003
Exp. 18-06-2003
Zenith angle [degree]
80
60
40
20
0
-20
-40
-60
-80
0
200
400
600
800
1000
1200
Depth [m]

Fig. 9b

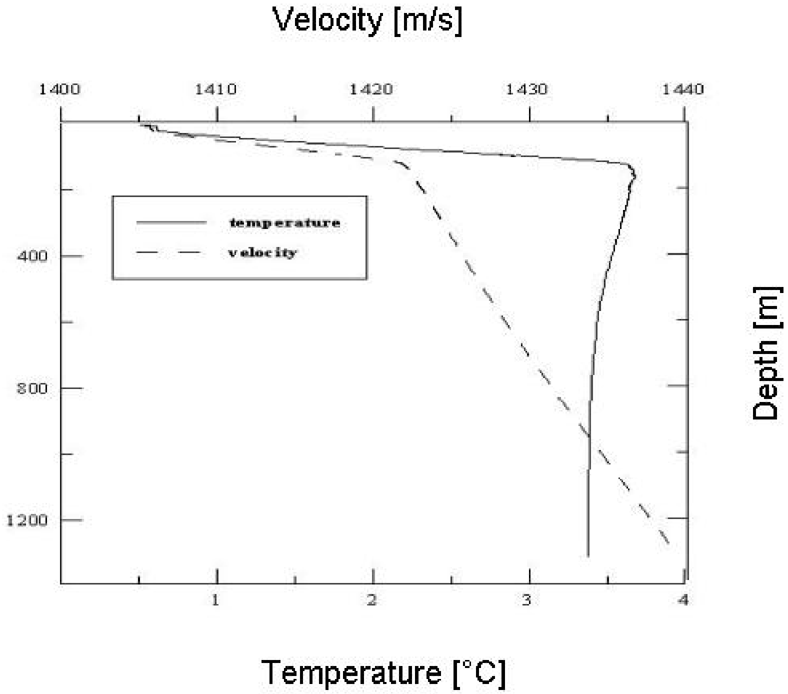
Velocity [m/s]
1400
1410
1420
1430
1440
temperature
velocity
400
800
1200
1
2
3
4
Depth [m]
Temperature [°C]

Fig. 10

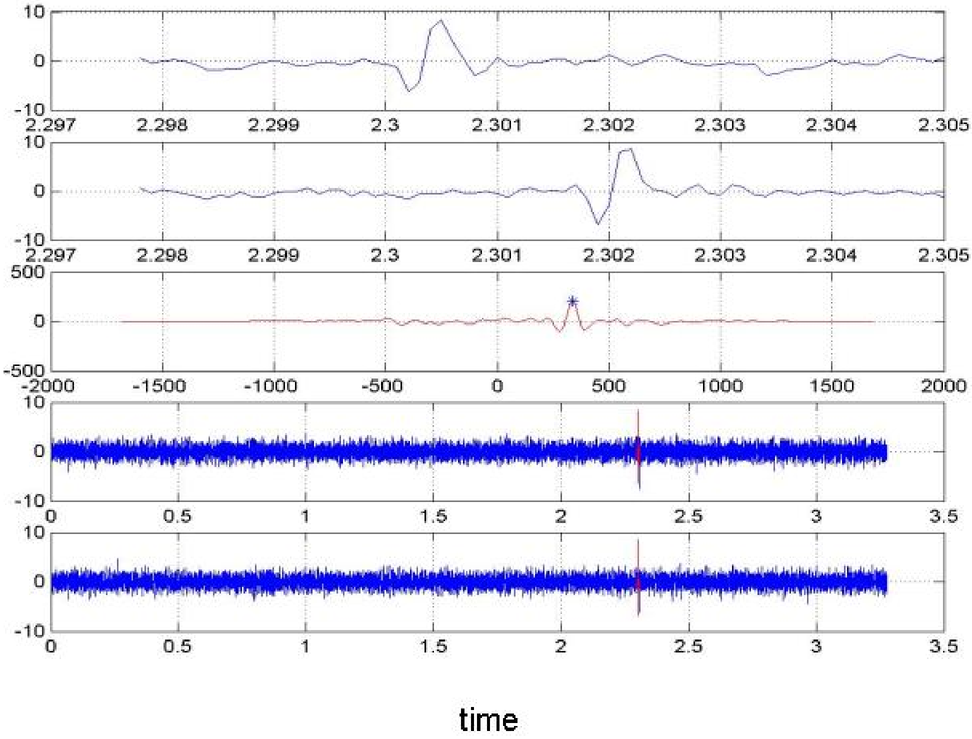
10
0
-10
2.297
2.298
2.299
2.3
2.301
2.302
2.303
2.304
2.305
500
-500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
0.5
1
1.5
2
2.5
3
3.5
time

Fig. 11

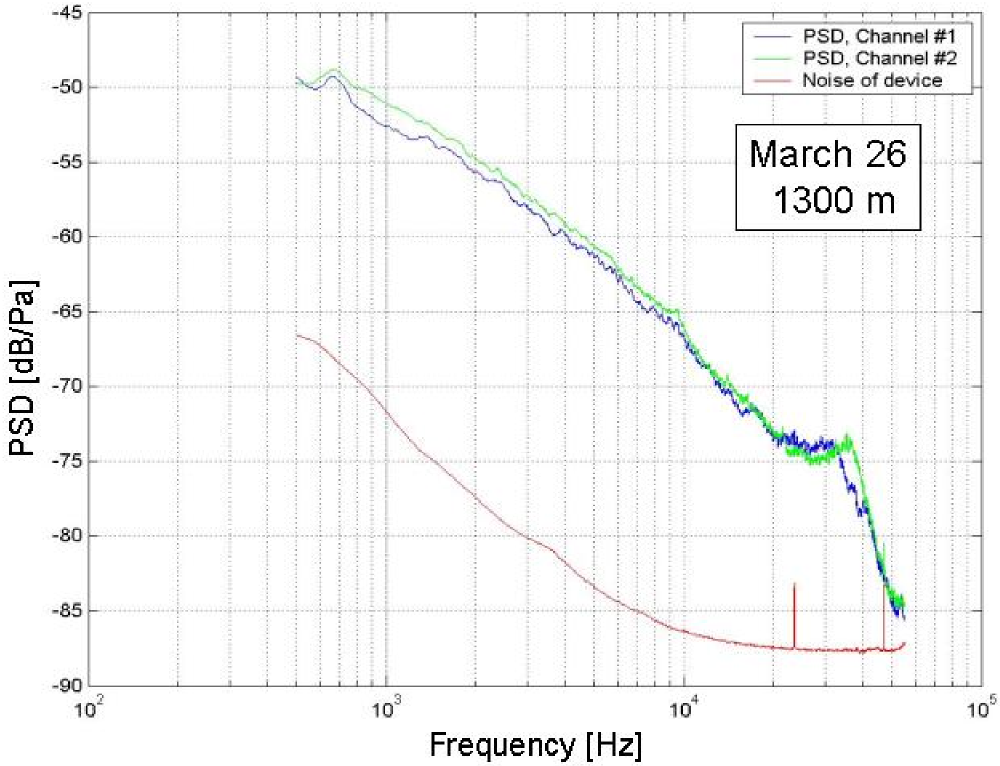

Fig. 12a

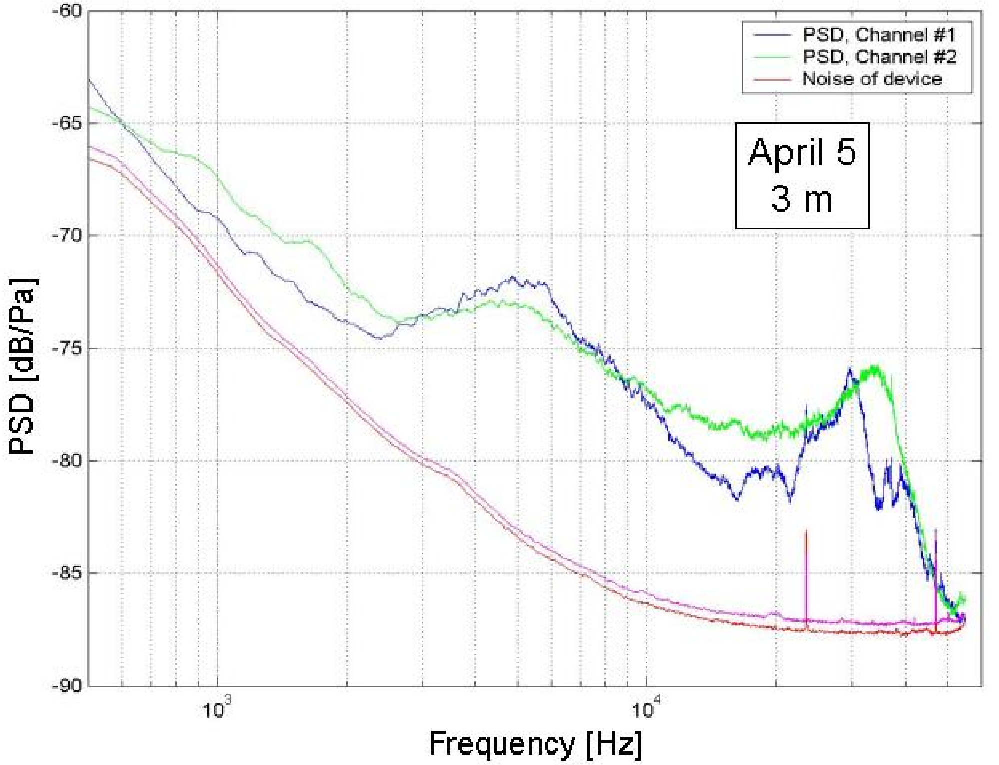

Fig. 12b

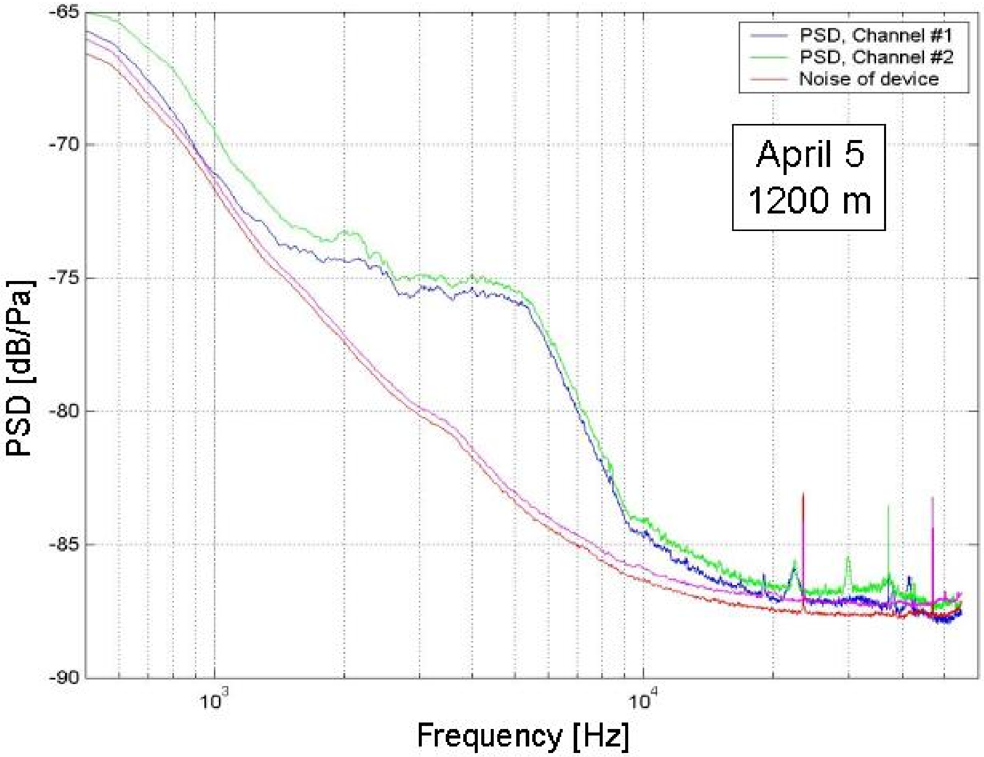

Fig. 12c

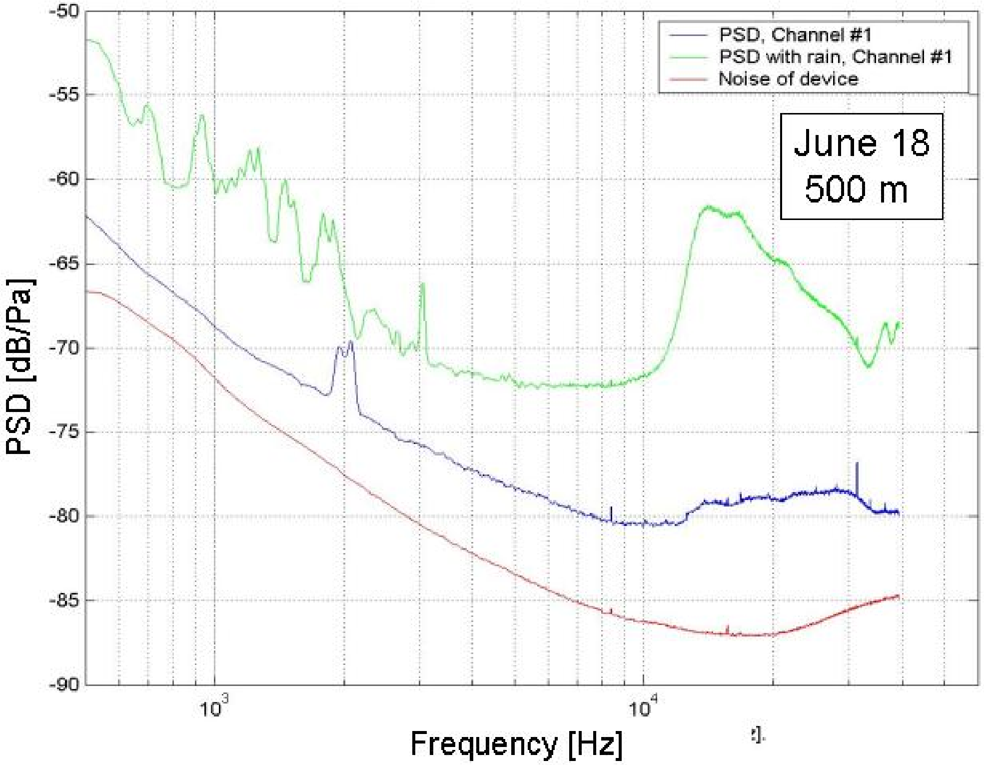

Fig. 12d