5 Estimation of Exposure Level (EL) at the behavioral observation stations

In order to evaluate whether the oil and gas developments on the NE Sakhalin shelf will have any effect on gray whale behavior, it is important to estimate the total acoustic exposure of the area near the behavioral observation station during and prior to the period of observation. During the 2004 field season six behavioral stations on the coast were occupied by biologists. Where possible, AUARs were deployed at the 10 m bathymetric contour directly offshore from these land-based behavioral monitoring stations to monitor the acoustic levels. The relationship between the locations of the behavioral and acoustic monitoring stations is given in Table 5.1.

Table 5.1 - Relationship between the behavioral and acoustic monitoring stations.

Behavioral station		Acoustic station	
North Station	4	Acoustic station #10	A10
Odoptu Station	2	Acoustic station #9	A9
Station 07	6		
2nd Station	3	Odoptu-S-10	10
1st Station	5		
South Station	1	PA-B-10	7

For the 2004 field season the behavioral and acoustic monitoring stations were synchronously occupied on three days. On 16 August, the South behavioral station and PA-B-10 monitor station (7) were both occupied. On 11 and 19 September, the 2nd behavioral station and Odoptu-S-10 (10) monitor station were synchronously occupied.

5.1 Estimating energy levels at the acoustic monitor stations

To effectively sample the variation in the energy level received at the 10 m contour near to the behavioral monitoring station over time, acoustic energy estimates are made in 10-minute windows. These 10-minute estimates can then be combined into longer time periods (3 hours, 1 day) if required.

One issue that must be contended with in computing energy estimates is the inclusion of non-real acoustic data into the 10-minute energy estimates. In general there are three different scenarios where non-real acoustic levels are present and would be added to the energy estimate unless otherwise identified and corrected:

- Clipped data where the acoustic level exceeds the maximum input voltage of the recorder. This data can be distorted and will not record the acoustic field with good fidelity. Although this could be due to the presence of an acoustic field greater than expected, the most likely cause is mechanical (e.g. the mechanical movement of the hydrophone assembly in a storm).
- Zero data when no data is recorded. The AUAR records to a 1 GB flash disk until it is full, it then stops recording and writes the data to a hard drive. No acoustic data is recorded during this time and the acoustic level is set to zero.
- Non-real acoustic data. Data may be present that while recorded with fidelity does not correctly represent the acoustic field present at the time of recording. An example of this is the high amplitude, low frequency flow noise generated during high tidal current flows.

In order to compensate for these errors, a procedure was established where the 10-minute energy estimate is first computed in 60 10-second windows. The energy in these 10-second windows is then compared with the average energy in the 10 surrounding windows[29]. If the energy in the target window is a pre-defined factor larger or smaller than the average in the surrounding windows, the energy estimate for the target window is replaced by the average of the energy in the previous and following windows[30].

Continuous energy estimates were made over 10-minute windows for the entire day that observations were taken at a behavioral station. Practically this will give at least six hours of energy estimates prior to and following the period of observation. The windows are time synchronized to the start of the day. For every 10-minute window, the total energy (μPa^2) is computed as described above. These energy estimates can be added to make a larger window (e.g. the energy in six 10-minute windows make a one-hour estimate). Figures 5.1 to 5.3 are plots (for three different frequency bands) showing the variation in energy estimated for these 10-minute windows for each of the three observation locations over the day when synchronous behavioral and acoustic measurements were being made.

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[29] Five windows behind and five ahead of the target window.
[30] The number of replacements is tracked as a QC measure.

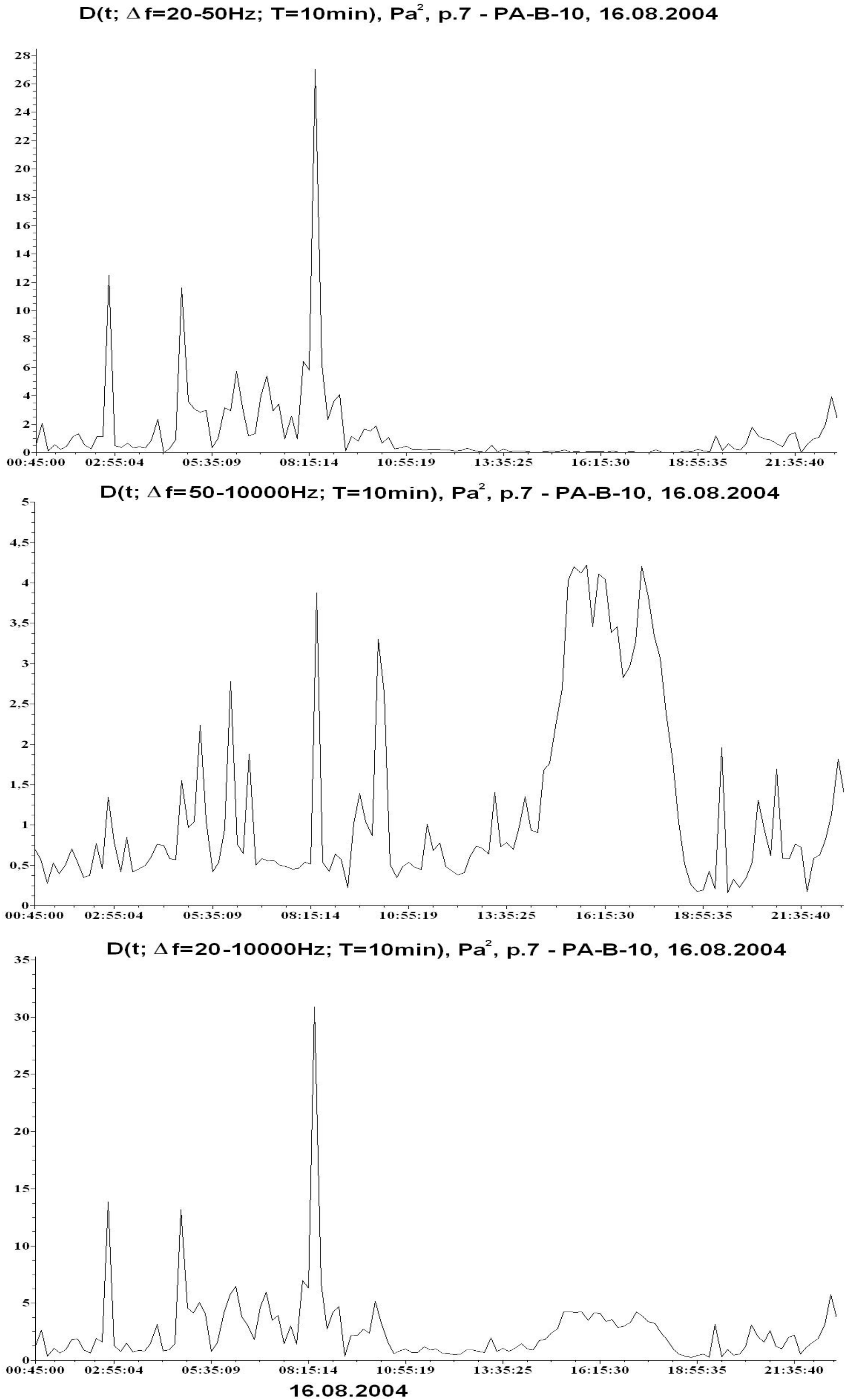

Figure 5.1 - Ten-minute acoustic energy estimates for three frequency bands. The plot is for the PA-B-10 (7) Monitor station on 16 August 2004, when synchronous observations were being made at the South behavioral station.

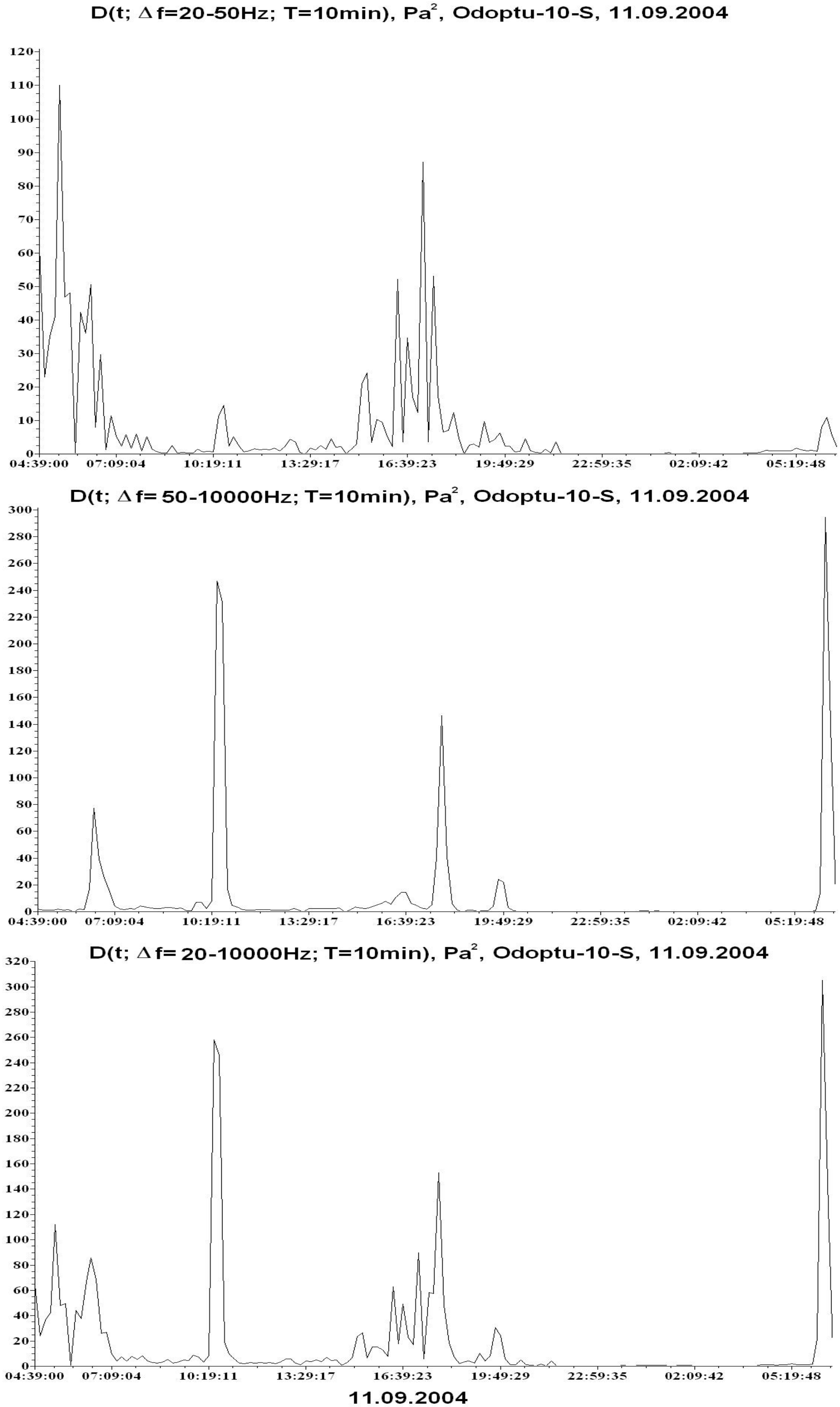

Figure 5.2 - Ten-minute acoustic energy estimates for three frequency bands. The plot is for the Odoptu-S-10 (10) Monitor station on 11 September 2004, when synchronous observations were being made at the 2nd behavioral station.

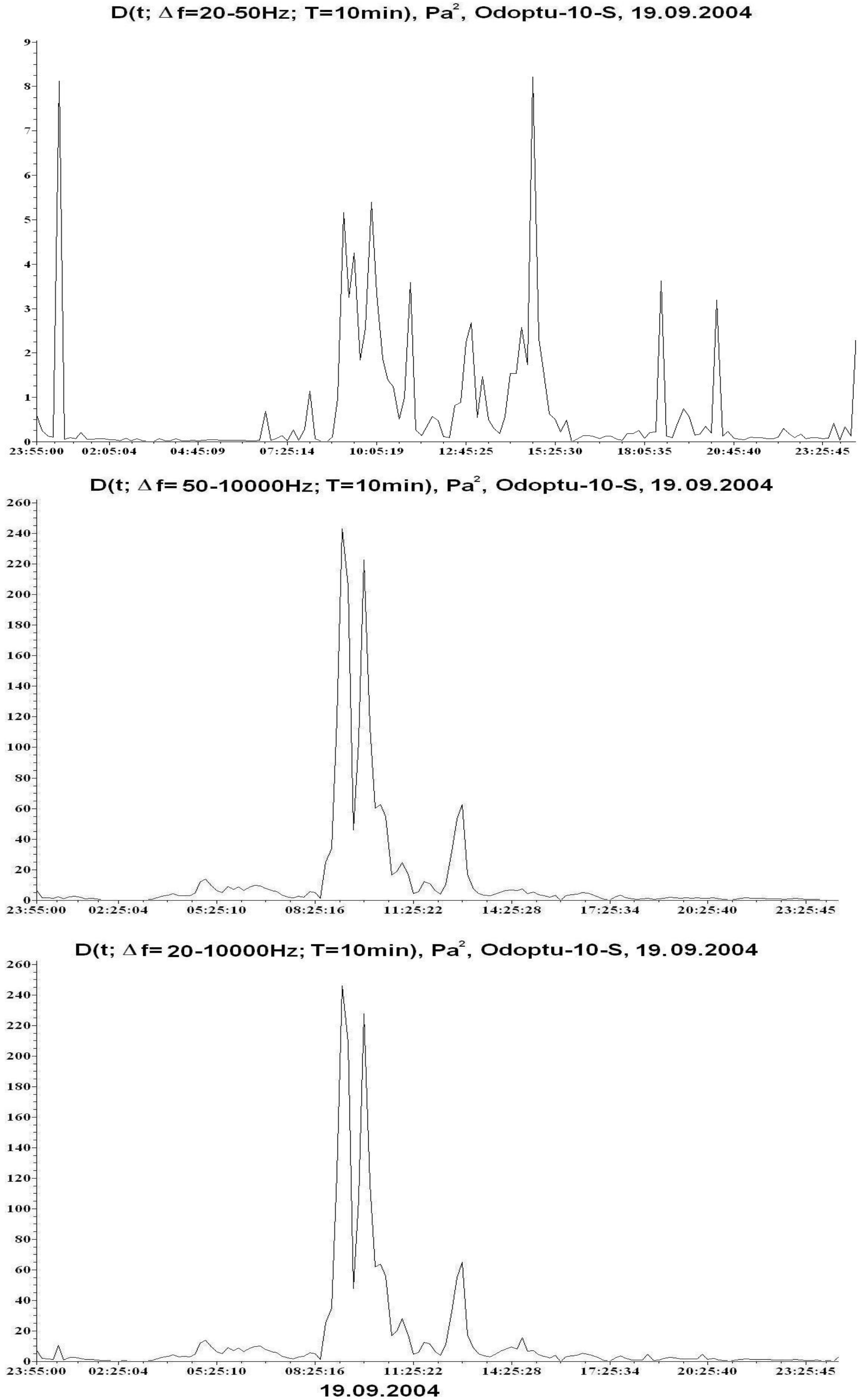

Figure 5.3 - Ten-minute acoustic energy estimates for three frequency bands. The plot is for the Odoptu-S-10 (10) Monitor station on 19 September 2004, when synchronous observations were being made at the 2nd behavioral station.

6 Acoustic Signatures of the *Academik Oparin* and Photo-ID zodiacs

During the 2004 field season the acoustic studies were conducted from the research vessel *Academik Oparin* (Figure 6.1), which was also used to accommodate the biology teams (Benthic, MMO and Photo-ID). The acoustic signatures of the vessels involved in the expedition (*Academik Oparin*[31] and zodiacs) were measured during the 2004 expedition while employed in operations related to biological and acoustical studies in the Piltun and Offshore feeding areas.

6.1 Acoustic measurements of the research vessel *Academik Oparin*

This section discusses the near field (50-100 m) acoustic signature of the *Academik Oparin* measured using a hydrophone deployed from the scientific vessel *Igor Maksimov*. The acoustic signature of the *Academik Oparin* was also recorded on AUARs used for acoustic monitoring while the vessel drifting or maneuvering in the Piltun and Offshore feeding areas.

6.1.1 Acoustic measurements from the Igor Maksimov

Source level measurements were conducted on the *Academik Oparin* near Lunskoye Bay on 25 August 2004. The *Academik Oparin* sailed at 12 knots along straight course 50 m from the stern of the *Igor Maksimov*; the weather conditions were Sea State 4. The hydrophone was deployed on the bottom in a pyramidal frame at 24 m water depth and linked to the recorder on the *Igor Maksimov* by a cable. The distance between the stern of the two vessels was measured using a laser rangefinder. Figure 6.2 gives a schematic of the experiment and spectra *G(f)* showing the acoustic characteristics the *Academik Oparin* estimated in equal 7 second intervals. The spectra correspond to times when the *Academik Oparin* was approaching, at the closest point of approach (CPA), and departing the *Igor Maksimov*. Figure 6.2(b) gives the acoustic spectrum of the *Academik Oparin* at the CPA (50 m). The spectrum *G(f)* contains a spectral peak between 500-600 Hz and shows that low frequency (30-120 Hz) narrow band acoustic energy reached a level of 130 dB re 1 $\mu Pa^2/Hz$. The broad band power spectral density level decreases proportionally to f^{-1} at frequencies between 0.1-10 kHz.

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[31] It has been proposed that the *Academik Oparin* be used for the western gray whale programs on the Sakhalin shelf for the next 5 years. It is therefore very important to better understand the source level of the *Academik Oparin* while engaged in different operations.

Figure 6.1 - The research vessel *Academik Oparin* from Top: ahead and Middle: astern Bottom: *Igor Maksimov.*

Figure 6.2(c) compares the acoustic characteristics of the *Academik Oparin* at a range of 100 m ahead (Figure 6.2(c) - 14:18:15) and astern of the vessel (Figure 6.2(c) - 14:18:55)[32]. The broad band acoustic signature of the *Academik Oparin* is 10 dB greater astern of the vessel than ahead of the vessel.

6.1.2 Acoustic measurements on the Academik Oparin in the Offshore feeding area

In 2004 AUARs deployed at the Orlan and Arkutun-Dagi monitor stations were used for acoustic monitoring. These locations are located approximately on the northern edge of the Offshore feeding area (Figure 6.3(b)[33]). Figure 6.3(a) is a schematic showing the positions, speed and course of the vessel for the time interval for which the spectra *G(f)* (Figure 6.3(c)) were computed is a sonogram *G(f,t)* of acoustic data recorded at the Arkutun-Dagi monitor station when the *Academik Oparin* was operating in the area.

Figure 6.3(b) reveals that the *Academik Oparin* sailing at a range of 5 km from the Arkutun-Dagi monitor station produced numerous tonal and narrow band components. The tonal component at ~540 Hz reached 100 dB re 1 μPa^2/Hz. The spectra changed for longer ranges (7.6 km - 10:58; 10 km - 9:32) due to the propagation characteristics of the area, but retained the main tonal (10:58) and narrow band components (09:32). Figure 6.3(c) illustrates that almost all the acoustic energy generated by the *Academik Oparin* is concentrated in the frequency band from 15-3300 Hz. When the *Academik Oparin* is sailing at a speed of 12.3 knots at a range of 5 km, tonal components at frequencies of approximately 540, 790 and 900 Hz reached spectral levels of 100, 85 and 79 dB re 1 μPa^2/Hz, respectively. Narrow band spectral components at frequencies of 33, 50 and 70 Hz were 85, 95 and 94 dB re 1 μPa^2/Hz, respectively. The high frequency noise level decreased from 84 to 50 dB re 1 μPa^2/Hz between 600 Hz and 3500 Hz. Figure 2.4 demonstrates that during a storm the ambient noise level in the frequency range from 30-3000 Hz was 83-65 dB re 1 μPa^2/Hz. The tonal and narrow band components of the acoustic signature of the *Academik Oparin* exceeded the ambient acoustic levels at frequencies between 50 Hz and 600 Hz by ~20dB.

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[32] Figure 6.2(a) gives the maneuvering schematic for the experiment.
[33] *Academik Oparin* operations*:* drifting (09:25), sailing at 5 knots (9:32), sailing at 12 knots 5 km from the Arkutun-Dagi station (9:58), stopped (10:21), accelerating (10:30), sailing at 7.6 knots (10:58), drifting (11:20).

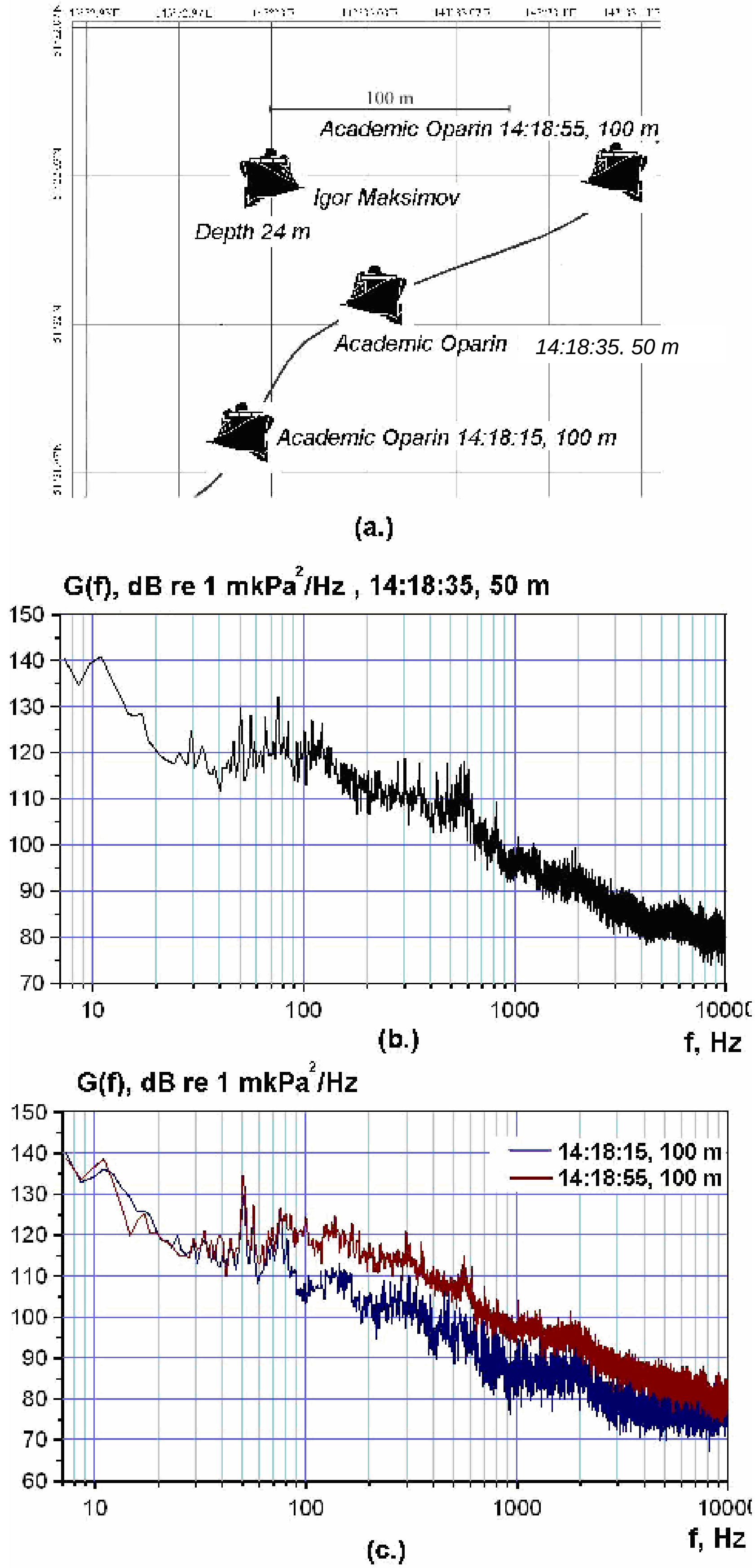
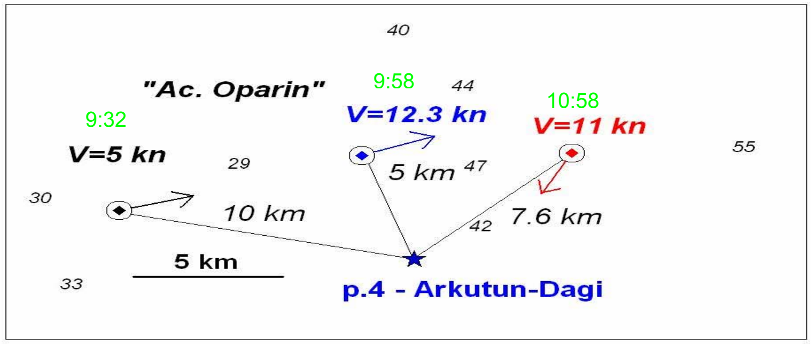
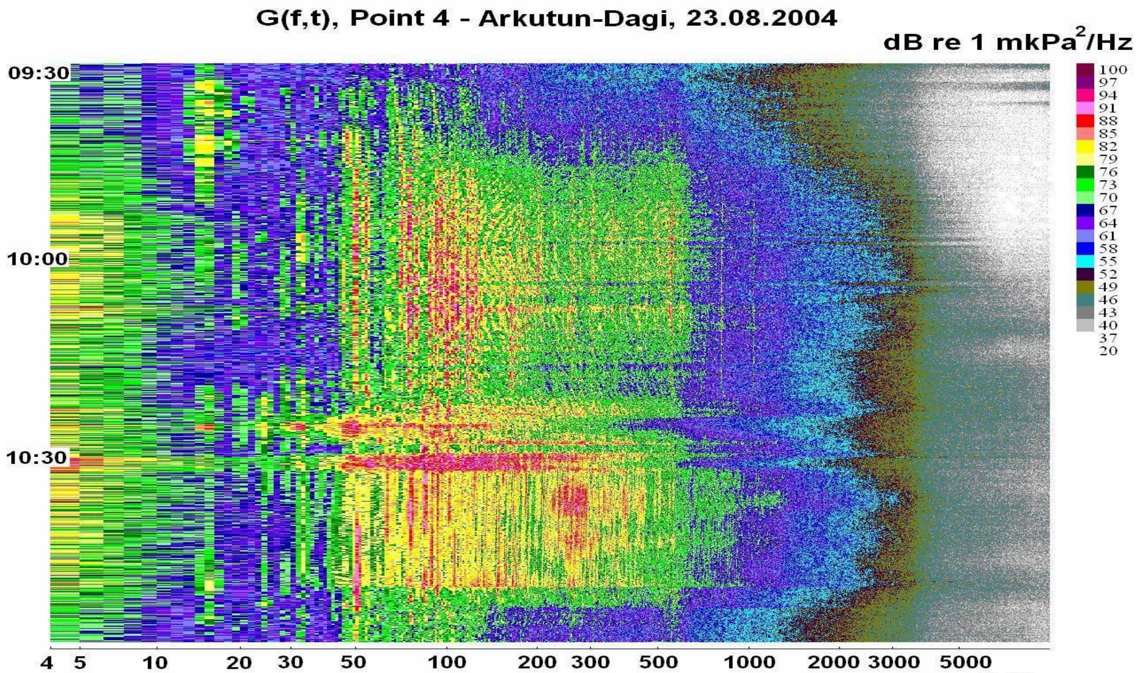


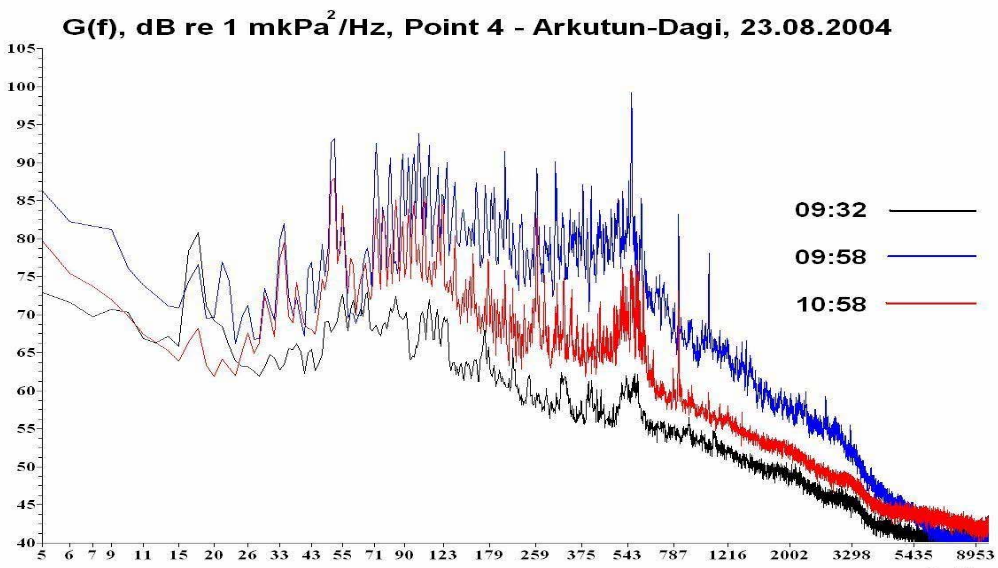
Figure 6.2 - Acoustic characterization of the *Academik Oparin* using a hydrophone deployed from the stern of the *Igor Maksimov*. (a) Schematic of the experiment Spectrum *G(f) showing the acoustic signature generated by the Academik Oparin* as it sailed at (b) 12 knots 50 m from the hydrophone (c) 100 m from the hydrophone.



(a.)



(b.)



(c.)

Figure 6.3 - Acoustic signature of the *Academik Oparin* recorded by an AUAR at the Arkutun-Dagi monitor station. (a) Schematic showing the maneuvers of the *Academik Oparin* (b) Sonogram *G(f,t)* of data from the monitor station (c) Spectra *G(f)* showing the acoustic levels corresponding to the points on the schematic (a).

6.1.3 Acoustic measurements on the Academik Oparin in the Piltun feeding area

Figure 6.4(a) is a schematic showing the position, course and speed of the *Academik Oparin* while supporting acoustic and Photo-ID operations near the 20 m contour. Figure 6.4(b) is a sonogram *G(f,t)* and Figure 6.4(c) spectra *G(f)* of acoustic data recorded on the Odoptu-S-10 monitor station when the *Academik Oparin* was operating in the area. The *Academik Oparin* sailed along the 20 m contour at a speed of 11.4 knots. At approximately 19:40 it began to slow down and drifted with its engine operational. The sonogram *G(f,t)* (Figure 6.4(b)) and spectra *G(f)* (Figure 6.4(c) - 20:00) characterize the acoustic signature of the *Academik Oparin* as it drifted with its engine operational 1.6 km from the Odoptu-S-10 monitor station. At 20:11 the *Academik Oparin* started moving and at 20:16 was sailing at 4 knots along its course. By 20:38 the *Academik Oparin* was 6.6 km away from the Odoptu-S-10 monitor station sailing along the 20 m contour at a speed of 11.1 knots[34].

Spectral comparisons between Figure 6.3(c) at 10:58 and Figure 6.4(c) at 9:58, both corresponding to maneuvering by the *Academik Oparin* at a speed of 12 knots 5 km from the recorder, illustrate that the acoustic signature of the *Academik Oparin* is similar in both feeding areas.

Figure 6.4(c) shows that at the Odoptu-S-10 monitor station when the *Academik Oparin* was drifting with an operational engine *G(f)* (Figure 6.4(c) - 20:00), the narrow band acoustic level exceeded the broad band acoustic level *G(f)* (Figure 6.4(c) - 20:16) by 5-10 dB in the frequency band from 150 to 2000 Hz. Figure 2.7 illustrates that the ambient noise levels recorded at the Odoptu-S-10 monitor station during different phases of a storm (17 September) were more than 20 dB lower (in the frequency range from 35-7000 Hz) than the acoustic signature of the *Academik Oparin* when maneuvering 1.6 km from the station. The *Academik Oparin* operates different equipment while drifting and this alters the noise signature[35].

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[34] As with Figure 6.3(a) the color of the spectrum on Figure 6.4(c) corresponds to the related point on Figure 6.4(a).

[35] For example drifting with two operational generators, with an operational main engine (main shaft not engaged), with the main shaft rotating (with different pitches on the propeller blades) etc.

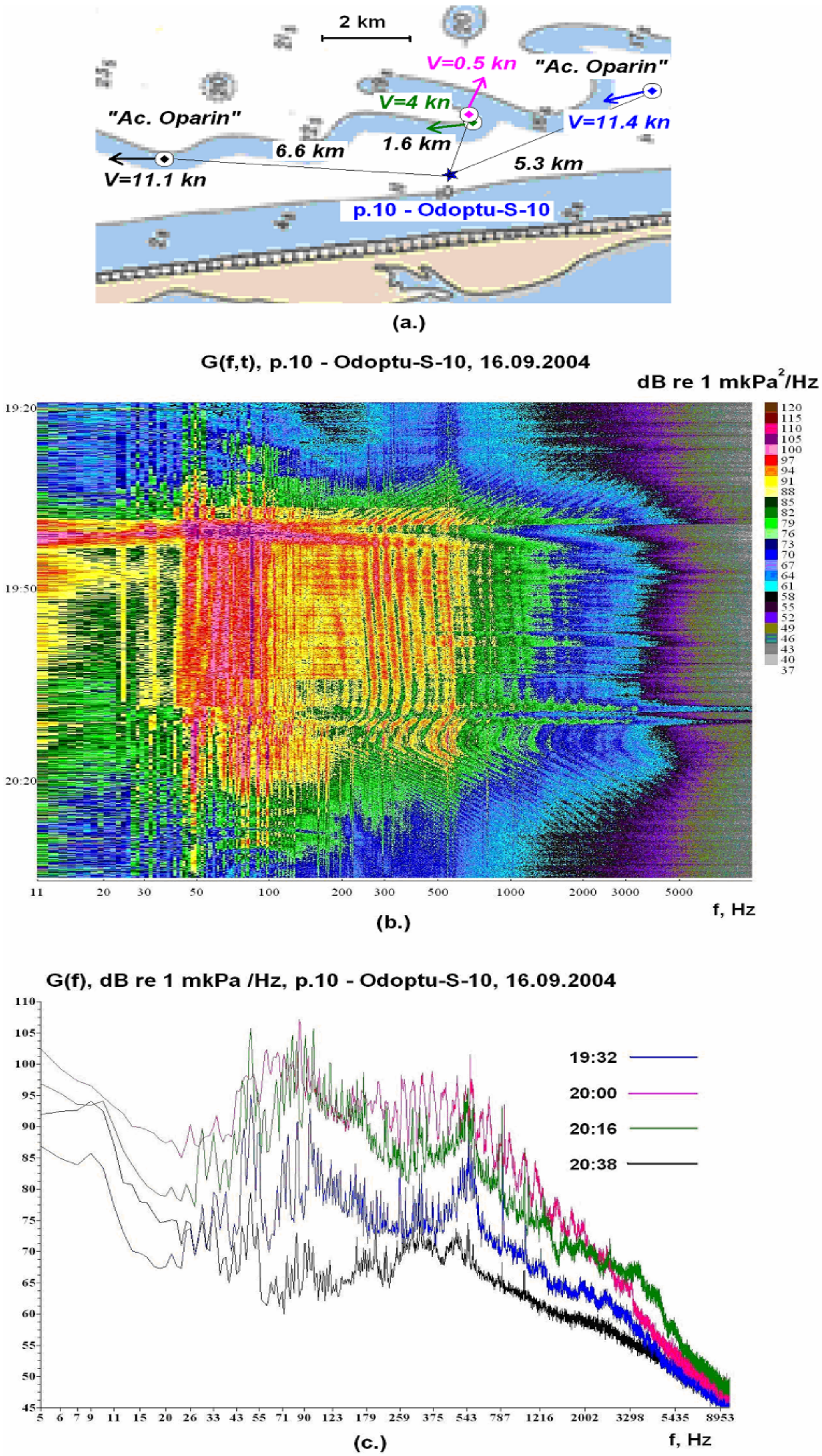
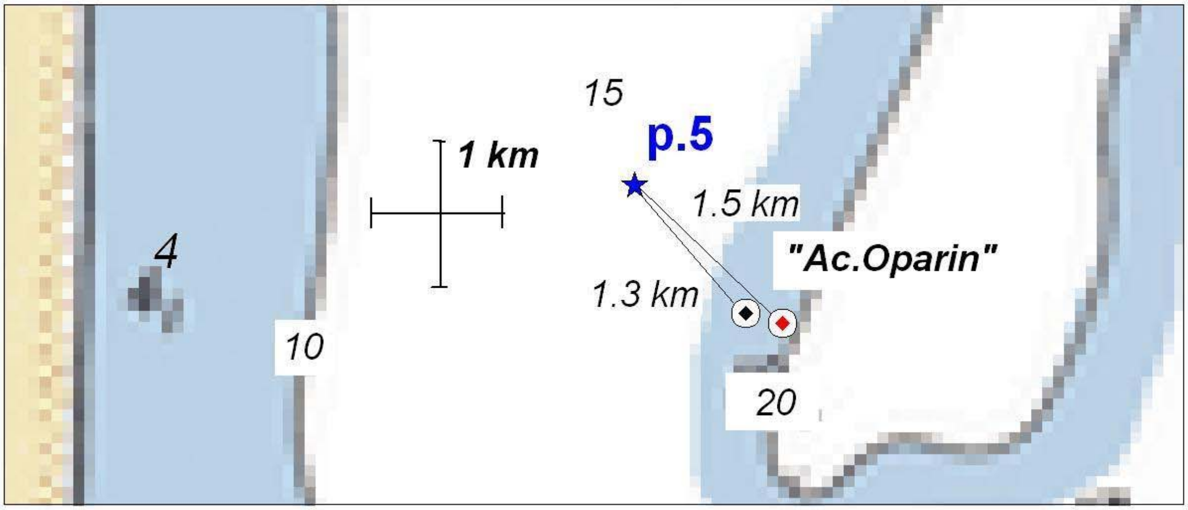
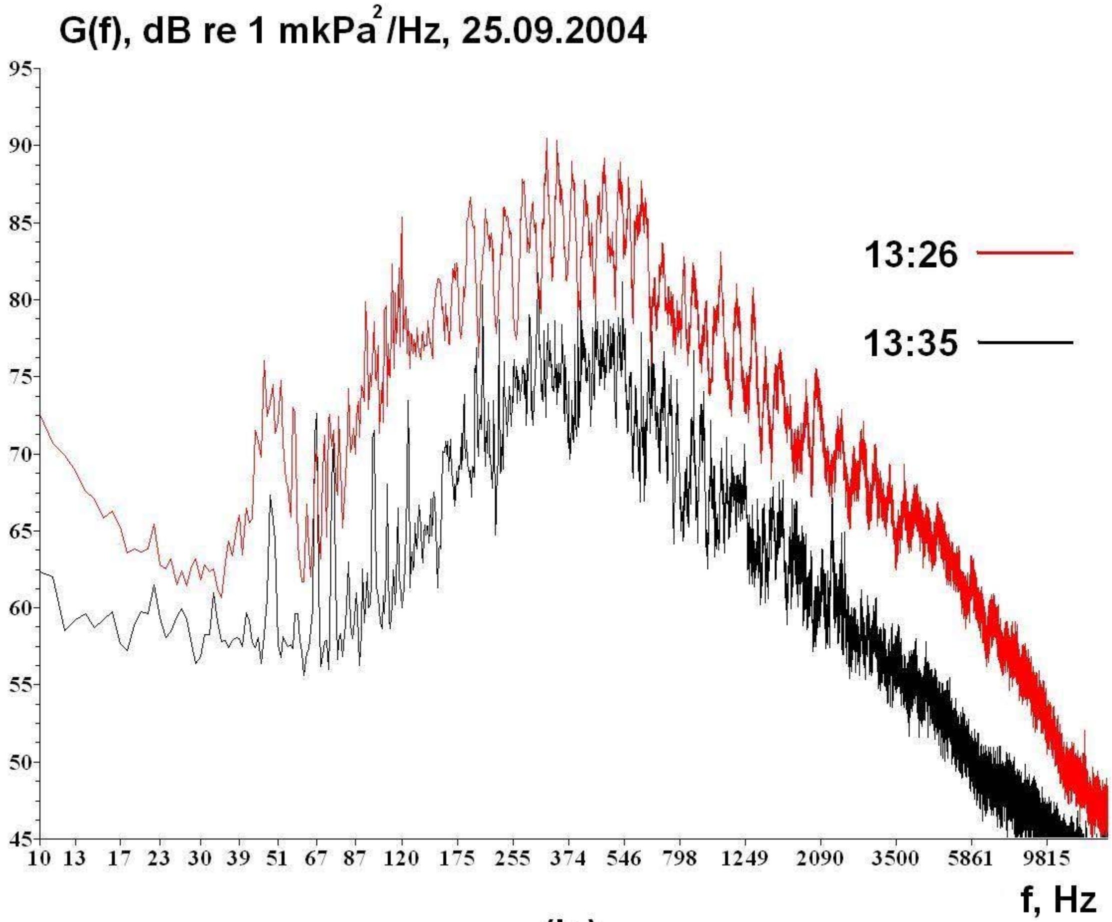


Figure 6.4 - Acoustic signature of the *Academik Oparin* recorded by an AUAR at the Odoptu-S-10 monitor station. (a) Schematic showing the maneuvers of the *Academik Oparin* (b) Sonogram *G(f,t)* of data from the monitor station (c) Spectra *G(f)* showing the acoustic levels corresponding to the points on the schematic (a).

Figure 6.5 displays spectra recorded at the Piltun-S monitor station by an AUAR while the *Academik Oparin* was drifting ~1.4 km away. Figure 6.5(a) is a schematic showing the experiment. The spectra (Figure 6.5(b) - 13:26) correspond to measurements made as the *Academik Oparin* drifted with its engine operational. Figure 6.5(b) - 13:35 illustrates the acoustic signature generated by the *Academik Oparin* as it drifted with its engine stopped or was anchored 1.3 km away. The spectrum has five tonal components below 150 Hz with levels of 68, 73, 71 and 74 dB re 1 $\mu Pa^2/Hz$. The maximum acoustic level is between 200 Hz and 600 Hz and is approximately 76 dB re 1 $\mu Pa^2/Hz$. In the frequency range from 700 Hz to 15000 Hz the broad band power spectral density level decreases proportionally to f^{-1}.



(a.)



(b.)

Figure 6.5 - Acoustic signature of the *Academik Oparin* recorded by an AUAR at the Piltun-S monitor station. (a) Schematic showing the maneuvers of the *Academik Oparin* (b) Spectra *G(f)* showing the acoustic levels corresponding to the *Academik Oparin* drifting with its engine operational (13:26) and with its engine shut down (13:35).

6.2 Acoustic measurements of the Photo-ID zodiacs

Gray whale Photo-ID surveys have been conducted by a specially trained team from IBM led by Dr. Y.M. Yakovlev since 2002 [Яковлев; 2003]. A 4.8 m zodiac with a 2-stroke 40 hp outboard motor was used for the Photo-ID expeditions in 2002 and 2003. Scientific protocols have indicated that a 4-stroke outboard motor is quieter than a 2-stroke outboard motor. For the 2004 field season a 3.8 m zodiac with a 4-stroke 40 hp engine was used to reduce the acoustic signature of the Photo-ID zodiac and minimize any impact on western gray whales due to Photo-ID studies. In order to confirm the efficacy of these protocols the acoustic signatures of the 2-stroke and 4-stroke outboard motors were studied for zodiacs sailing at 7 km/h and 25 km/h. The experiment was conducted in an area with a typical bathymetry for the Piltun feeding area.

Figure 6.6(a) is a schematic showing the experimental design. An AUAR deployed at location 5 recorded the acoustic pressure in the frequency band from 1 Hz to 15 kHz. The zodiacs sailed from point 1 to point 2 at a preset speed using GPS. At the start of the experiment the zodiac with the 4-stroke engine was deployed from the *Akademik Oparin*, which started drifting at the point marked 13:21 (Figure 6.6(a)). At 13:28 the engine of the *Akademik Oparin* was completely stopped; only the diesel generator remained operational. Figure 6.7(a) clearly illustrates this moment. At approximately the same time the 4-stroke zodiac started moving from point 1 to point 2 at an average speed of 25 km/h. At 13:38 it reached the closest point of approach (CPA) to location 5. At 13:38 it started sailing from point 2 to point 1 at an average speed of 7 km/h and at 13:50 reached the CPA to location 5. Figure 6.6(b) and 6.6(c) shows sonograms *G(f,t)* showing the acoustic signatures of both zodiacs during these maneuvers.

Figures 6.7(b), 6.7(c), 6.8(a) and 6.8(b) display spectra *G(f)* showing the acoustic signal recorded by the AUAR at location 5 while the zodiac with the 4-stroke 40 hp engine conducted the maneuvers discussed earlier[36]. The spectrum at 13:12 on Figure 6.7(b) shows the acoustic characteristics of the *Akademik Oparin* as it drifted approximately 2 km away from location 5 with the main engine still operational. After the main engine was shut down, the spectral level of the acoustic signature of the *Akademik Oparin* dropped by 20 dB

[36] The spectral plots *G(f)* on Figures 6.7(c) and 6.8(b) give greater detail in the low frequencies.

(Figure 6.7(b)-13:58), despite it approaching within 1 km of the AUAR (Figure 6.6(a)-13:55). At 14:00 the *Academik Oparin* retrieved the zodiac with the 4-stroke outboard motor and the zodiac equipped with the 2-stroke 40 hp outboard motor used in 2002 and 2003 was deployed. At that time the *Academik Oparin* had drifted too close to location 5; at 14:15 it started its main engine and prepared to move. Despite this the acoustic signature of the zodiac with the 2-stroke outboard motor as it sailed at 25 km/h from point 1 to point 2 is clear on the sonogram *G(f,t)* and spectrum *G(f)* (Figure 6.8(a) and 6.8(b)-14:16). At 14:25 *Academik Oparin* began drifting again. Its main engine and two generators were operational, but the main shaft was not engaged. At 14:30 the zodiac commenced its run from point 1 to point 2 at 7 km/h, however the outboard motor died approximately at the CPA to location 5 (Figure 6.6(a) - 14:45). At 14:49 the zodiac restarted its outboard motor and resumed its course to point 1. Acoustic spectra *G(f)* of recorded at location 5 of the zodiac equipped with the 2-stroke 40 hp outboard motor while sailing at 7 km/h are shown on Figure 6.8(b) (*G(f)* - 14:44). Figure 6.8(b) (*G(f)* - 14: 47) gives ambient acoustic spectra recorded at location 5. The spectra from Figures 6.8(b) and 6.8(c) illustrate that the acoustic level was also higher when the zodiac sailed at 7 km/h than at 25 km/h for the 2-stroke outboard motor.

The spectra *G(f)* on Figures 6.7(b) and 6.7(c) at 13:31 and on Figure 6.9 (V=25 km/h) correspond to the CPA of the zodiac to location 5 (~100 Km) while it was sailing at 25 km/h. The spectra *G(f)* at 13:50 (Figure 6.7) and V=7 km/h (Figure 6.9) are at the CPA to location 5 (~100 Km) while sailing at 7 km/h. These figures illustrate that the highest level of narrow band acoustic energy generated by the zodiac's outboard motor at 25 km/h is 105 dB re 1 $\mu Pa^2/Hz$ at ~170 Hz. At 7 km/h the zodiac's outboard motor produced narrow band acoustic energy that reached ~109 dB re 1 $\mu Pa^2/Hz$ in the frequency range from 40-115 Hz and a 104 dB re 1 $\mu Pa^2/Hz$ tonal component at ~980 Hz. These figures illustrate that the average acoustic energy generated by the zodiac's engine at 25 km/h is much lower than at 7 km/h. Figure 6.10 gives comparison spectra *G(f)* recorded at the CPA to location 5 for zodiacs sailing at 7 km/h and 25 km/h with 2-stroke and 4-stroke outboard motors. This illustrates that the broad band and narrow band acoustic levels generated by the 2-stroke outboard motor are more than 15 dB higher than those generated by the 4-stroke outboard motor.

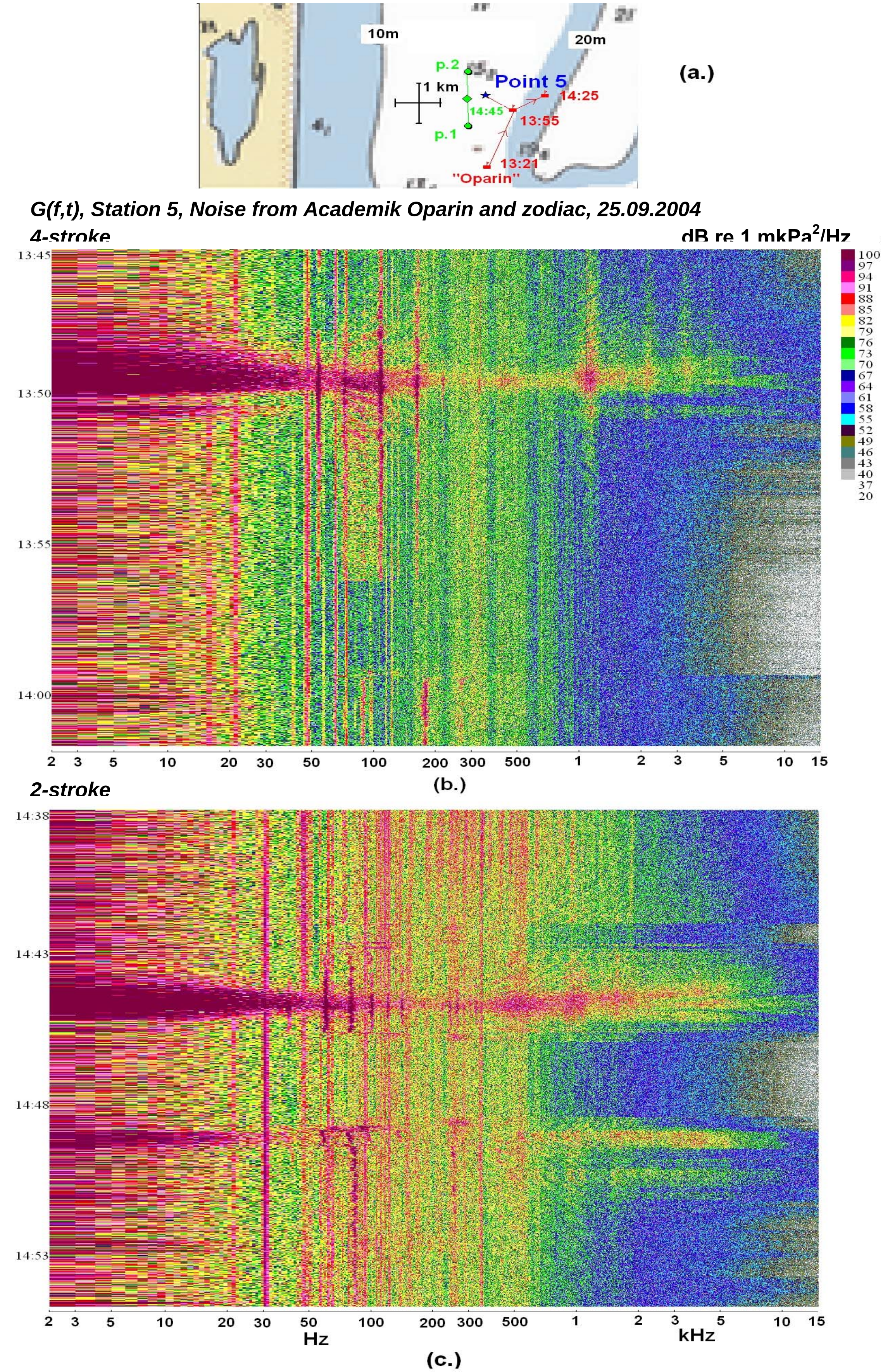


Figure 6.6 - (a) Schematic showing the experimental design. Results of acoustic measurements of the zodiac 40 hp outboard motors recorded at location 5 while the zodiac was sailing at 7 km/h from point 2 to point 1: (b) 4-stroke engine (c) 2-stroke engine.

G(f,t), G(f), Noies *Ac. Oparin* and *Zodiac* *(4 tacts)*, 25.09.2004

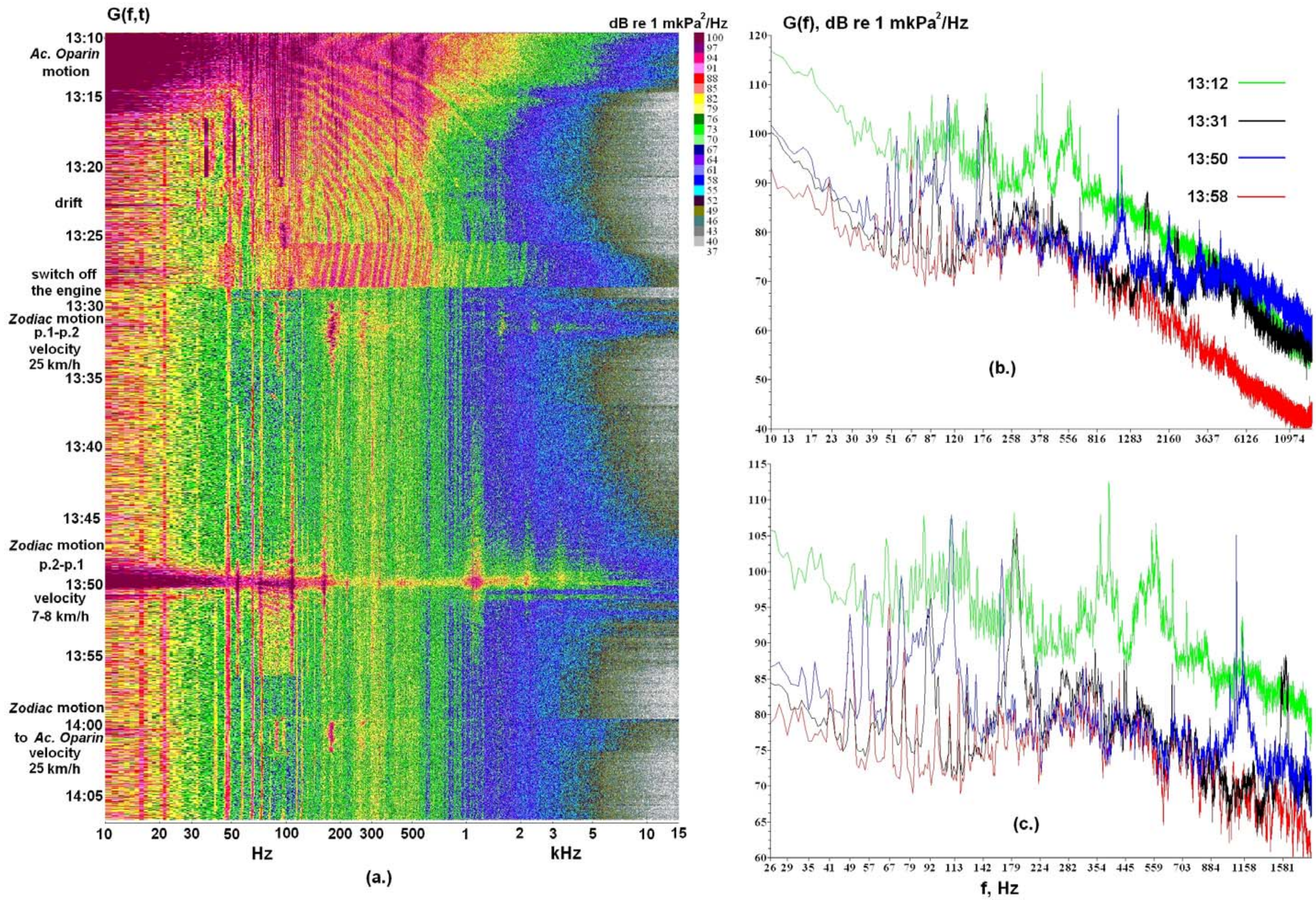


Figure 6.7 - Results of acoustic measurements of the zodiac 4-stroke 40 hp outboard motor recorded at location 5
(a) Sonogram *G(f,t)* (b) spectrum *G(f)* (c) Low frequency spectrum *G(f)*.

G(f,t), G(f), Noise from *Academik Oparin* and Zodiac (2-stroke), 25.09.2004

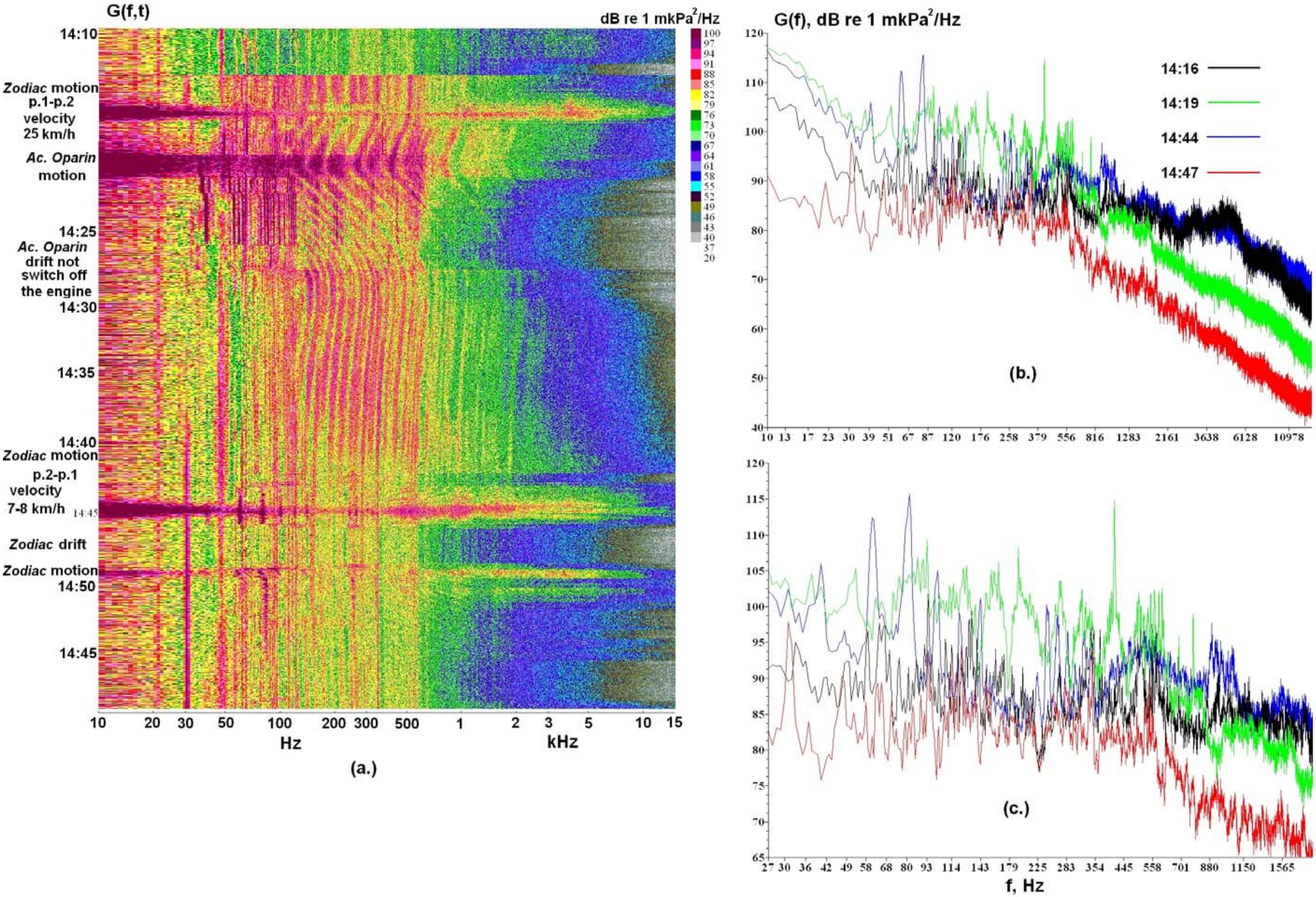


Figure 6.8 - Results of acoustic measurements of the zodiac 2-stroke 40 hp outboard motor recorded at location 5
(a) Sonogram *G(f,t)* (b) spectrum *G(f)* (c) Low frequency spectrum *G(f)*.

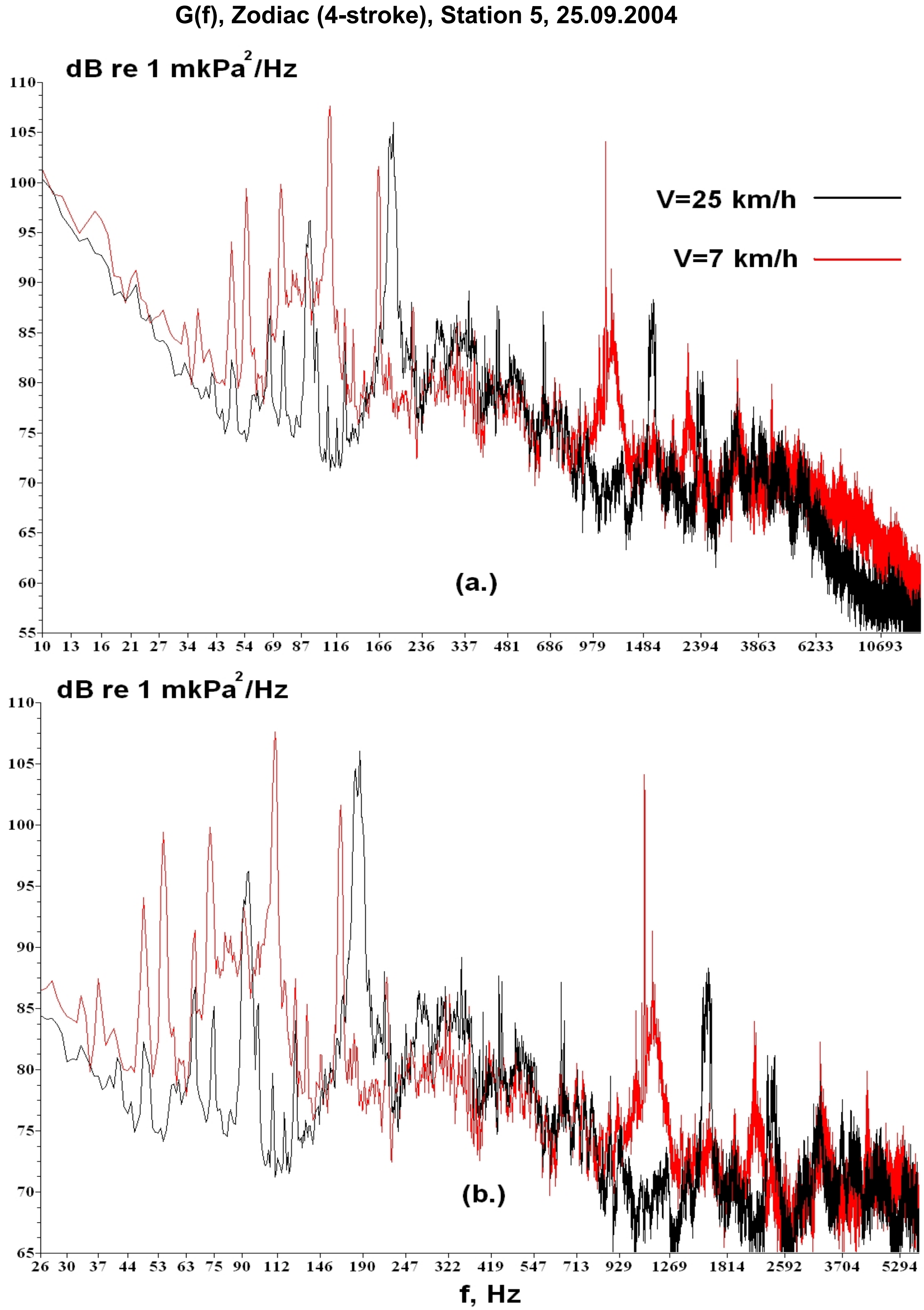


Figure 6.9 - (a) Spectra *G(f)* of acoustic measurements of the zodiac 4-stroke 40 hp outboard motor sailing at 7 km/h and 25 km/h recorded at the closest point of approach to location 5 by the (b) Low frequency part of spectrum.

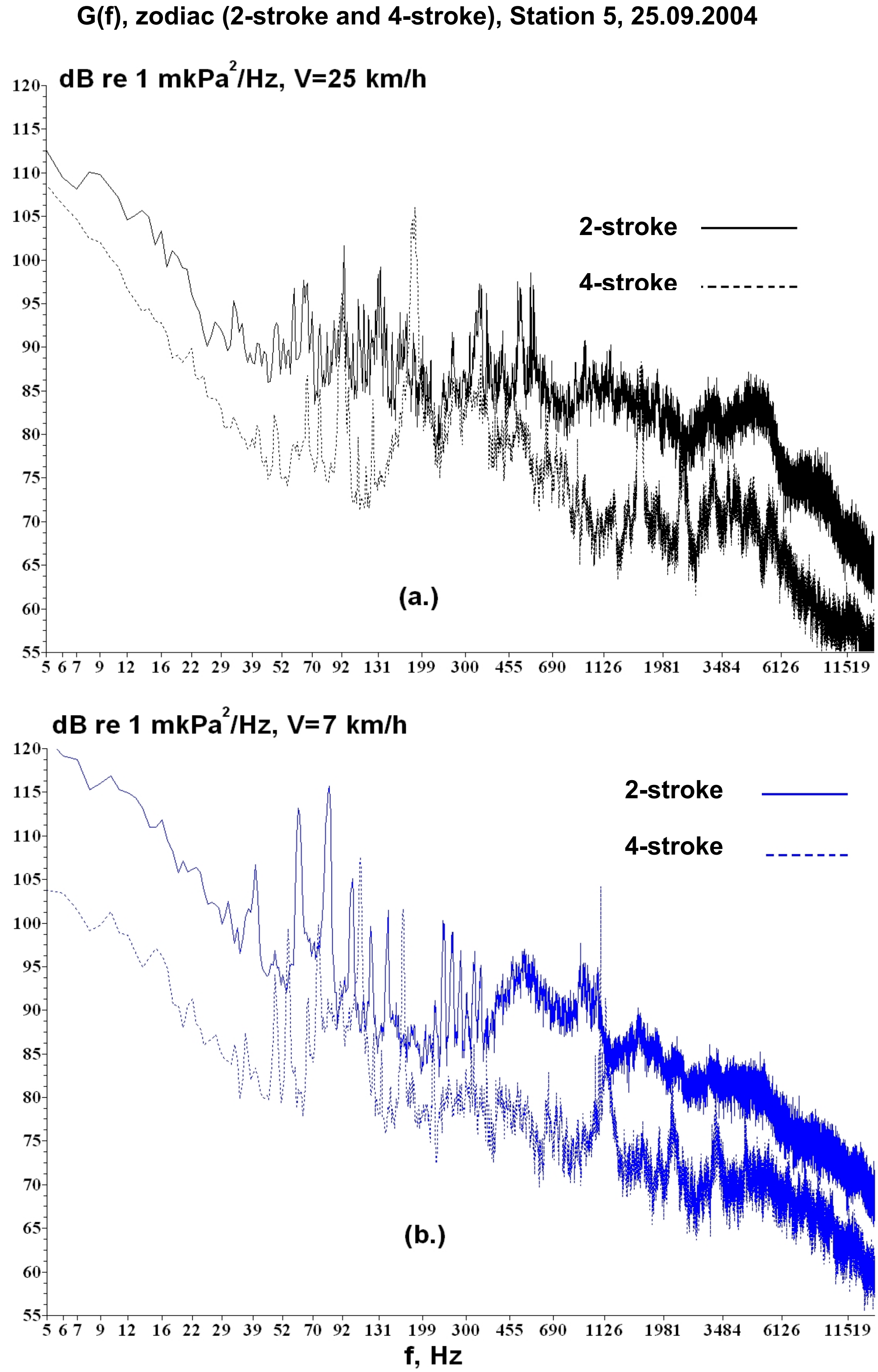


Figure 6.10 - (a) Spectra *G(f)* of the 2-stroke and 4-stroke 40 hp outboard motors for Zodiacs sailing at 25 km/h recorded at the closest point of approach to location 5 (b) identical plot for Zodiacs sailing at 7 km/h.