V.I. Il`icev Pacific Oceanological Institute
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Vladivostok, Russian Federation

Acoustic & Hydrographic Studies on the North East Sakhalin Shelf

1st July to 3rd October, 2009

Sakhalin Island, Russian Federation

S.V. Borisov
D.G. Kovzel
R.A Korotchenko
A.N. Rutenko
V.A. Sosnin
V.G. Ushipovsky

Prepared for

Exxon Neftegas Limited
&
Sakhalin Energy Investment Company,

Yuzhno-Sakhalinsk, Sakhalin,
Russian Federation

March 2010

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Executive Summary

In 2009 the Pacific Oceanological Institute (POI) deployed 22 Autonomous Underwater Acoustic Recorders (AUARs), two of which were also equipped with a digital radio-telemetry channel (DT-AUARs), enabling them to transmit acoustic data with a bandwidth of 2-500 Hz, and a potential dynamic range of 96 dB, to an onshore receiving station. Field tests were also conducted on a DT-AUAR with a digital radio-telemetry channel that can transmit acoustic data with a bandwidth of 2-2000 Hz; this unit was developed for real-time monitoring of seismic signals from the SEIC 4D seismic survey planned for 2010. The Mollusk-07 vertical autonomous acoustic and hydrologic recording array and an autonomous frequency-modulated (290-330 Hz) transducer were used for propagation studies. The goal of the program was to measure key acoustic and hydrologic data, and to estimate sound propagation to the feeding areas of the Korean-Okhotsk gray whale (*Eschrichtius robustus*)[1].

Hydrologic studies were conducted in parallel with acoustic measurements, and during the expedition 265 vertical hydrologic profiles were acquired at 220 stations [121 in July, 82 in August, and 17 in September]. At some stations, vertical profiles were acquired more than once, bringing the total number of hydrologic profiles to 265 (12 at station 177, 12 at station 178, 20 at station 179, 4 at station 193, and 2 at station 213). The hydrologic surveys and individual transects were acquired to obtain hydrological data for different meteorological conditions during the summer and fall seasons.

The Mollusk-07 vertical autonomous acoustic and hydrologic recording array and an autonomous transducer generating a FM_290-330 Hz frequency-modulated signal were used to acquire data on the characteristics of the internal waves and their effect on low frequency transmission loss. Nine thousand two hundred and sixty (11,432) km of bathymetry data were acquired in 2009; these data were used to study the spatial and temporal variation of hydro-physical parameters under the influence of winds, tides and storms. The relationship between benthos development and the hydrology of the area was also analyzed.

[1] The Korean Okhotsk (western) gray whale population is listed as endangered in the Russian Red Book and critically

1 INTRODUCTION

The shallow water (6 - 15 m) part of the NE Sakhalin shelf, starting south of the mouth of Piltun Bay and extending northwards up the Sakhalin coast, is the most important known summer and fall feeding area for Korean-Okhotsk (western) gray whales. Mother-calf pairs are usually seen in water depths of less than 10 m in the Piltun feeding area. Acoustic studies have been conducted in the area since 1999 since some of the planned oil and gas developments are near the Piltun feeding area. In 2001 a second gray whale feeding area (the offshore feeding area) was discovered in deeper water (30-60 m), approximately 20 km South East of the mouth of Chayvo Bay.

The acoustic program conducted on the NE shelf of Sakhalin Island in 2009 had the following objective:

- An extension to the long-term acoustic monitoring program initiated in 2003. This acoustic program was designed to study temporal and spatial variations in the amplitude and frequency characteristics of ambient and anthropogenic sound at the edges of the Piltun and offshore gray whale feeding areas.
- In addition to the program monitoring the background acoustic environment, ENL and SEIC acquire a comprehensive grid of bathymetric and hydrologic data were acquired by ENL and Sakhalin Energy across the study area. These data were also used to investigate the spatial and temporal variations in the hydrology due to weather events (e.g. typhoons).
- Two joint studies were initiated in 2005 in conjunction with the behavioral and benthic teams; these studies were continued in 2009. The first study analyzed the data recorded near the behavioral monitoring stations; the spectral density of the data in the frequency range from 20 Hz to 15 kHz was analyzed in 1-minute windows and converted to one octave bands. The second, conducted jointly with the benthic team, investigated the relationship between the distribution of benthos and the bathymetry and hydrology of the study area [Fadeev, 2009].

This report describes the objectives of the 2009 program, the operational strategy and methodology; the equipment used during the 2009 field season (both new and upgraded [Borisov et. al. 2006, 2007, 2008]), its testing and calibration as well as the data processing and analysis methodology. This report also includes a listing of the data acquired during the 2009 field season and a DVD containing the sonograms in 24-hour segments for all the acoustic data recorded in 2009 as well as the bathymetric and hydrologic data acquired during the 2004 to 2009 field seasons.

This report is mainly dedicated to analysis of the data, and includes conclusions and recommendations for future work. This data analysis includes the following components:

Western gray whale research program – Acoustic studies

1. Quantitative spectral analysis of the variation in the ambient acoustic noise level with weather conditions (including cyclones).
2. A temporal, spectral and spectral-temporal analysis of the acoustic data recorded at different locations on the Sakhalin shelf[2].
3. A temporal analysis of the variation of the spectral density (one-third octave bands) of acoustic data recorded at monitoring stations inside and at the edge of the Piltun and offshore feeding areas.
4. Analysis of the hydrologic data (sound velocity, temperature, and salinity) recorded between 2004 and 2009.
5. An experimental study of the relationship between the distribution of benthos and the hydrology and bathymetry of the study area, conducted jointly with the benthic team, [Fadeev 2009].

The acoustic measurements were conducted using 16 digital Autonomous Underwater Acoustic Recorders (AUARs) developed at POI FEB RAS[3] (POI) (Figure 1.1), two of which were equipped with a digital radio-telemetry channel (T-AUAR). Six smaller mini-AUARs with reduced (90 hours) endurance were used for short term TL and source level measurements (Figure 1.2). The AUARs were designed to accurately record frequencies between 1-15,000 Hz and enable accurate, synchronous acoustic measurements over a broad range of frequencies (including infrasounds[4]).

In addition, the Mollusk-07 autonomous vertical acoustic and hydrologic recorder was used for field studies in 2009. This system was specially developed at POI for stationary measurements in a 31.5 m water layer of the vertical structure (eight depths) of the acoustic field in the frequency range from 10 Hz to 5 kHz, and of the temperature field (resolution 0.005°C). The data from the Mollusk-07 can be used to evaluate the accuracy of experimental TL estimates which can vary due to refraction and scattering on three-dimensional inhomogeneities in the sound velocity field at the thermocline generated by internal waves. Figure 1.3 shows the major components of the Mollusk-07.

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[2] The use of Autonomous Underwater Acoustic recorders (AUARs) for the 2009 program allowed an unprecedented characterization of the ambient sound levels at the Sakhalin monitoring stations. However, since the vessels used to house the scientists (*Academik Oparin*) was often a significant distance from the AUAR the identification and specific location of any transient anthropogenic sound source is generally unknown.

[3] POI FEB RAS – V.I Il`ichev Pacific Oceanological Institute, Far East Branch of the Russian Academy of Sciences.

[4] Infrasounds are sounds with a frequency of less than 20 Hz.

Figure 1.1 – Autonomous Underwater acoustic recorder (AUAR).

Figure 1.2 – Mini-AUAR used for short-term source or TL measurements.

Figure 1.3 – Mollusk-07 autonomous vertical acoustic and hydrologic recording array.

The first 2009 field season deployment of two AUARs at acoustic monitoring stations Odoptu-S-20 and A9, and of two T-AUARs at stations Odoptu-N-10 and Odoptu-N-20 took place on 14th June using an ENL supply vessel. These AUARs were retrieved in July by the research vessel Akademik Oparin, and all of the subsequent deployments of AUARs and T-AUARs were performed by the Akademik Oparin (Figure 1.4). Synchronous acoustic measurements were made at stations ranging from north of the Odoptu license area to the southern edge of the offshore feeding area (Figure 1.5), an area whose western edge extends 180 km along the NE Sakhalin shelf.

Figure 1.4 - Research vessel *Akademik Oparin*.

Previous work has shown that the results from acoustic modeling are very sensitive to the hydrologic, bathymetric and elastic properties of the sea bottom along the profile of interest. A comprehensive suite of bathymetric and hydrologic measurements were therefore acquired using the sonar on the *Akademik Oparin* and a hydrologic sonde. During the expedition 265 vertical hydrologic profiles (comprising sound velocity, temperature and salinity), and approximately 11,432 km of bathymetry data were

acquired by the *Akademik Oparin*[5]. Figure 1.6 includes two maps showing the extent of the bathymetric grid and the points at which vertical hydrologic profiles were acquired. This plot shows the combined 2004 (323 vertical hydrologic profiles and 8,400 km of bathymetry data), 2005 (354 profiles and 7,788 km), 2006 (372 profiles and 12,147 km), 2007 (634 profiles and 7,200 km), 2008 (198 profiles and 9,260 km) and 2009 data.

1.1 Objectives of the Acoustic Program

The acoustic program conducted on the NE shelf of Sakhalin Island in 2009 had four main objectives:

1. To study both temporal and spatial variations in the amplitude and frequency characteristics of ambient and anthropogenic sound at a series of monitoring stations located throughout the development area. These monitoring stations were positioned to be at the nearest outside edge of a gray whale feeding area to a proposed facility. The goal of this annual acoustic monitoring program is to estimate any change in the acoustic levels in the gray whale feeding areas due to the oil development and production activities.
2. To acquire a comprehensive grid of bathymetric and hydrologic data across the study area, and to investigate the spatial and temporal variations in the hydrology due to weather events (e.g. typhoons). These data will be integrated with the 1,881 vertical hydrologic profiles and 44,795 km of bathymetry data acquired between 2004 & 2008.
3. To estimate the one-third octave spectral density over the frequency range from 20 Hz to 15 kHz in 1 minute windows for all the monitoring AUARs in the Piltun feeding area.
4. To study the relationship between the distribution and development of benthos and the hydrology and bathymetry of the study area [Fadeev, 2009].

1.2 Operational Strategy and Methodology

The shallow water (5 - 15 m) part of the NE Sakhalin shelf starting south of the mouth of Piltun Bay and extending northwards up the Sakhalin coast is one of the most important summer feeding areas for western gray whales. For this reason acoustic studies have been conducted in the area since 1999.

[5] Of the 265 vertical hydrologic profiles acquired in 2009, 121 were acquired in July, 126 in August, and 18 in September.

Figure 1.5 - Map of the NE Sakhalin Shelf showing the locations of the LUN-A, Molikpaq, Orlan and PA-B platforms as well as the AUAR deployment locations.

Figure 1.6 - Map of the NE Sakhalin Shelf showing (a) the 2004 to 2009 bathymetric grids and (b) the locations where vertical hydrologic profiles were acquired in 2004 to 2009.

In 2008, the main acoustic program was operated from a vessel and was led by Dr. Alexander Rutenko; the vessel used in 2009 was the *Akademik Oparin*. The plan was that both the acoustics and biology (distribution, benthic and Photo-ID studies) programs would be operated from the *Akademik Oparin* with Dr. Yuri Yakovlev as the expedition leader.

In 2009 16 AUARs designed and developed by POI were used to capitalize on the enhanced flexibility of a vessel-based program and to allow synchronous acoustic measurements to be conducted over a greatly enlarged spatial area. Fourteen (14) of these AUARs could be deployed at depths up to 50 m (two to 100 m), could record continuously for greater than 24 days and could measure the absolute acoustic amplitude of a signal over a frequency band from 1-15000 Hz. The expedition also had 6 mini-AUARs with similar recording characteristics, but only four days recording duration. A detailed description of this equipment was given in [Borisov et. al. 2006]. As in 2007 and 2008, The Mollusk-07 vertical autonomous acoustic and hydrologic recording array was used in 2009. This equipment was developed by POI for experimental studies of the modal composition of internal waves and low-frequency sound propagating in offshore areas. The Mollusk-07 can make stationary synchronous measurements in a 31.5 m water layer of the vertical structure (eight depths) of the acoustic field in the frequency range from 10 Hz to 5 kHz, and of the temperature field (resolution 0.005 °C). Two pressure sensors are used to confirm the depth of the upper and middle hydrophones and a micro-rotor measures current velocity at one depth. The Mollusk-07 is designed to be deployed in water depths up to 100 m, using an anchor with an acoustic release. An onboard computer allows program control of the data acquisition and storage schedules. The system can operate autonomously for at least 7 days.

One of the operational advantages of the *Akademik Oparin* is that it can operate in water depths as shallow as 10 m. The AUARs were deployed from the stern of the *Akademik Oparin* as the vessel sailed slowly along its course. AUARs were retrieved manually using a zodiac deployed from the *Akademik Oparin* (

Figure **1.7**). After each AUAR was pulled to the surface it was towed to the vessel by a zodiac and transferred to the *Akademik Oparin* using its crane (Figure 1.8).

Figure 1.7 – Raising a T-AUAR from the Zodiac.

1.3 Ambient Noise Studies and Western Gray Whale Core Areas[6]

One of the key goals of the acoustic studies in the western gray whale research program is to measure and characterize the ambient noise field on the NE Sakhalin shelf. This long-term program commenced in 2003, and is currently ongoing. These data, in conjunction with the measurement of the acoustic signature of present and future facilities will allow the cumulative effect of oil development and production operations on the acoustic background in the area, as well as on the gray whale population, to be more effectively estimated.

[6] This section is based on work performed by LGL Limited (Robin Tamasi, Peter Wainwright, Judy Muir, Sergei Yazvenko, Sonya Meier, and Steve Johnson).

Figure 1.8 – Towing the AUAR using a Zodiac, and lifting it onboard the *Akademik Oparin* using the stern crane.

In order to strategically plan the location of the monitoring stations for the 2003 to 2009 and future programs it was critical to estimate the core areas for the gray whales on the NE Sakhalin shelf. In 2003 the core areas were estimated and the acoustic monitoring locations selected using the sightings from all of the 2001 and 2002 aerial surveys [Borisov et. al. 2004], however in 2001 many more aerial surveys were acquired and they were concentrated in a reduced seasonal range. Furthermore, no correction was made for survey effort. For 2004, on the other hand the core areas were determined using whale densities estimated from the 2003 and 2004 aerial survey data taking the survey effort into account[7].

In these analyses, probability contours are used to visualize areas with the greatest likelihood of encountering gray whales, and to examine shifts in the 'centers of activity' of gray whales over time8. Cumulative probability contours of 50% and 95% were generated to visualize the distribution of gray whales. The 50% contour represents the area within which 50% of the whales sighted are expected to be found. In 2003 the probability contours were estimated using a conventional kernel density method9. This kernel density method employed a square-gridding process, which is robust for small sample sizes unless the variances of the north-south and east-west components of the distribution are very different.

For the Piltun feeding area, however, the distribution of whale sightings is oriented parallel to the coast with significantly greater variance in the along-shore direction than in the perpendicular-to-shore direction. For this reason, in 2004, a spatial grid was constructed for the Piltun feeding area that was oriented along-shore and with an along-shore grid cell dimension greater than the perpendicular-to-shore dimension, (i.e. each cell was 4 km by 0.5 km). Density was then computed for each cell as the number of observed whales divided by the cumulative area surveyed within the cell. The same methodology was employed for the offshore feeding area except that, in this case, the conventional assumptions about distribution were satisfied and a spatial grid of 1 km by 1 km cells was employed.

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[7] Density is the number of whales per unit area; multiple surveys over a grid cell result in larger densities within that cell if densities are not compensated for survey effort and average densities computed.
[8] Cumulative probability contours were computed independently for the Piltun and offshore feeding areas.
[9] The kernel density contours were mapped using the ArcView© 3.1 extension Animal Movement 2.04 [Hooge et. al., 1997]. Kernel density contours are an estimator that assesses an animal's probability of occurrence at each point in space based on a utilization distribution.

There was significant variation among the 2003, 2004, 2005, and 2006 estimates of the western gray whale core areas. Consequently, this analysis was updated in 2007 using all available systematic survey data. These included data from the 2001 to 2005 aerial surveys, 2002 to 2006 vessel-based surveys, 2001 to 2006 shore-based behavior scan surveys, and the 2004 to 2006 shore-based vehicle scan surveys. Appendix C gives details of this analysis.

1.3.1 Monitor, Control and Acoustic Station Locations

A systematic acoustic monitoring framework was developed in 2003 and extended from 2004 to 2006. The goal is to monitor changes in the acoustic field on the NE Sakhalin shelf and most importantly those changes in the anthropogenic sound level that could cause a significant increase in the Received Level (RL) in either the Piltun or offshore feeding areas.

Three types of stations for recording acoustic data were designated:

- **Monitor stations** - These are locations that will be systematically monitored to gain an understanding of the changes in the acoustic field over time. They will be reoccupied multiple times in a season and over multiple seasons. The monitor stations will generally be located at the edge of a gray whale feeding area nearest to a proposed facility or in a location where the greatest cumulative impact from multiple facilities could be expected.
- **Control station(s)** - Dr. John Richardson (LGL Limited) recommended that a control station or stations be set up far enough away from the proposed development operations that the anthropogenic acoustic field would not be expected to increase. This station would reflect any changes to the ambient noise field unrelated to the oil development activities.
- **Acoustic stations** - These locations will be infrequently monitored; their purpose is to gain an understanding of the anthropogenic sound field from a known location at a specific time related to development activities or to conduct TL experiments.

Eleven stations were designated prior to the start of the 2003 field season; seven were monitor stations, three were acoustic stations and one was a control station. For the 2004 season a further six monitor stations and seven acoustic stations were designated. In 2005 one additional acoustic station was designated. In 2006 one additional monitor station and four acoustic stations were designated. No new stations were designated between 2007 and 2009. Table 1.1 gives the names, numbers and locations of these stations[10].

[10] Where possible in order to facilitate long term monitoring the numbers and names of the monitor stations will be

Table 1.1 - Numbers, names, locations and depths of the acoustic, monitoring and control stations.

#	Station		Latitude	Longitude	Depth
Monitor Stations:					
1	Lunskoye	Лунское	51° 51' 45" N	143° 37' 27.3" E	48 m
2	OFA (Offshore Feeding area)	ГЗК (Глубоководная зона кормления)	52° 10' 18" N	143° 36' 1.8" E	40 m
3	Orlan	Орлан	52° 21.6' N	143° 35.0' E	32 m
4	Arkutun-Dagi	Аркутун-Даги	52° 19' 9.6" N	143° 44' 4.6" E	40 m
5	Piltun-S	Пильтун-Ю	52° 40' 51" N	143° 22' 34" E	10 m
6	Piltun	Пильтун	52° 49.3' N	143° 24.9' E	20 m
7	PA-B-10	ПА-Б-10	52° 53' 2.1" N	143° 20' 10.6" E	10 m
8	PA-B-20	ПА-Б-20	52° 54' 00" N	143° 23' 20.5" E	20 m
9	Odoptu-PA-B	Одопту-ПА-Б	53° 00' 00" N	143° 21' 18" E	20 m
10	Odoptu-S-10	Одопту-Ю-10	53° 03.7’ N	143° 18.3' E	10 m
11	Odoptu-S-20	Одопту-Ю-20	53° 03' 42" N	143° 19' 58" E	20 m
12	Odoptu-N-10	Одопту-С-10	53° 09.1' N	143° 17.4' E	10 m
13	Odoptu-N-20	Одопту-С-20	53° 09' 6" N	143° 18' 42' E	20 m
14	**Control**	**Контрольная**	**53° 25' 57' N**	**143° 11' 06' E**	**20 m**
15	Molikpaq	Моликпак	52° 45' 52" N	143° 26' 38" E	24 m
Acoustic Stations:					
A1	#1 (Chayvo-1)	#1 (Чайво-1)	52° 27.8' N	143° 19.0' E	11 m
A2	#2 (Chayvo-2)	#2 (Чайво-2)	52° 25.9' N	143° 20.6' E	11 m
A3	#3 (Chayvo-3)	#3 (Чайво-3)	52° 26.8' N	143° 24.6' E	17 m
A4	#4 (Piltun-1)	#4 (Пильтун-1)	52° 43' 14.4" N	143° 22' 26.7" E	10 m
A5	#5 (Piltun-2)	#5 (Пильтун-2)	52° 43' 48" N	143° 25' 49" E	20 m
A6	#6 (Piltun-3)	#6 (Пильтун-3)	52° 49.3' N	143° 24.9' E	20 m
A7	#7 (PA-B-1)	#7 (ПА-Б-1)	52° 55' 54" N	143° 19' 39" E	10 m
A8	#8 (PA-B-2)	#8 (ПА-Б-2)	52° 55' 54" N	143° 21' 42.4" E	20 m
A9	#9 (BEH-	#9 (Одопту (Пов))	53° 12' 33.1" N	143° 15' 51" E	10 m
A10	#10 (BEH-north)	#10 (Пов-север)	53° 17' 52.4" N	143° 13' 25.4" E	10 m
A11	#11 (Chayvo-4)	#11 (Чайво-4)	52° 34' 00" N	143° 23' 00" E	~18 m
A12	#12 (Lunskoye-	#12 (Лунское-1)	51° 24' 12" N	143° 38' 30" E	47 m
A13	#13 (Lunskoye-	#13 (Лунское-2)	51° 22' 42" N	143° 36' 00" E	37 m
A14	#14 (Lunskoye-	#14 (Лунское-3)	51° 22' 00" N	143° 34' 42" E	31 m
A15	#15 (Lunskoye-	#15 (Лунское-4)	51° 21' 12" N	143° 33' 24" E	24 m

The locations of the monitor stations were determined with reference to the major gray whale concentrations in the area (Figure 1.9)[11]. For the offshore feeding area, the locations of the stations (except the OFA station) were chosen to be on the 95% probability contour at the point closest to a current or proposed facility. The location of the monitor stations remained constant between 2004 and 2009[12]. The western gray whale distribution in the Piltun feeding area varies with bathymetry, with most whales feeding in water depths between ~8-12 m. Mother-calf pairs have been seen in the Piltun feeding area, often in water depths of 5-10 m, and fewer whales have been seen outside the 20 m contour. Thus, the two key acoustic monitoring points are the 20 m and the 10 m bathymetry contour (regarded as the edge and center of the whale distribution).

The control station location has remained the same since 2003[13]. This location has a similar hydrology and bathymetric character to the Piltun feeding area, is far enough away to serve as an acoustic control point, but close enough for effective operational support. Stations A1 to A8 and A11 to A15 were not occupied in 2009. All the unused acoustic stations were previously used for TL experiments.

1.4 Data Recorded on the NE Sakhalin Shelf During the 2009 Field Season

During the 2009 expedition, as previously, AUARs were used to make synchronous acoustic measurements over a shelf area extending about 180 km from the northern boundary of the Odoptu license area to the southern edge of the offshore feeding area (Figure 1.9). To prevent the possible loss of an AUAR monitoring of acoustic noise in the Offshore Feeding Area had to be abandoned in September 2009 because at that time, more than six fishing vessels were bottom trawling for pollack in the area and it was feared a unit would be caught in trawl gear and lost.

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[11] Various vessel-based (MMO, Photo-ID, Benthic) and land based (vehicle surveys, behavioral) biology programs were being conducted over the same seasonal range, so an evaluation of the effect of any changes in the acoustic field on the behavior or distribution of gray whales could be evaluated.

[12] 2004: The Orlan station is on the 95% cumulative probability contour (from 2003) closest to the proposed location of the Orlan platform, the Lunskoye station is at the southern edge of the offshore feeding area, the OFA (Offshore Feeding Area) station is approximately in the center of the offshore feeding area and the Arkutun-Dagi station is at the North Eastern edge of the offshore feeding area. 2005: The Odoptu-S-10, Odoptu-N-10, Odoptu-N-10 and Odoptu-S-10 stations were at the 10 m and 20 m bathymetry contours off the coast from the two proposed Odoptu well pads. The Piltun station is at the 20 m bathymetry contour between the Molikpaq platform and the major gray whale concentration off Piltun lighthouse. The PA-B stations were at the 10 m (PA-B-10) and 20 m (PA-B-20) bathymetry contours closest to the proposed PA-B location. The Piltun-S station is on the 95% cumulative probability contour at the southern bathymetry contour of the Piltun feeding area and the Odoptu-PA-B station at the 20 m bathymetry contour between the proposed locations of the Odoptu-S well pad and the PA-B platform. 2006: The Molikpaq station is at the 20 m bathymetry contour between the Molikpaq platform and the major gray whale concentration off Piltun lighthouse.

[13] The control station was located on the 20 m bathymetry contour approximately 40 km north of the Odoptu North pad site.

Figure 1.9 - Map showing the AUAR locations and cumulative probability contours showing the density distributions of western gray whales from the 2001 to 2005 aerial surveys, 2002 to 2006 vessel based surveys, 2001 to 2006 shore-based behavior scan surveys and the 2004 to 2006 shore-based vehicle scan surveys.

This section discusses the data recorded on the NE Sakhalin shelf during the 2009 field season. It describes the deployment dates, recording times, hydrophone depths and locations of the AUARs as well as their operational characteristics. Tables 1.2 and 1.3 give these details for the 16 AUARs used in the study.

All the acoustic data from the 2008 field program will be presented as sonograms[14], where the spectral density values *G(f,t)* are represented by different colors[15], one sonogram representing the acoustic data for one AUAR for one day. These daily sonograms also include plots of the variation in sound pressure level $D(\Delta f,t)$ with time over the annotated bandwidth. The sonograms *G(f,t)* cover a broad frequency band (2 Hz to 15 kHz) and are plotted with a logarithmic frequency axis to aid in the visual analysis of the data (e.g. Figure 1.10). The logarithmic scale on the frequency axis clearly shows the pseudo-noise signals below 15 Hz. This is flow noise caused by a tidal current with a velocity exceeding 1 m/s and is recorded twice a day. The acoustic data for the infrasonic band should therefore be analyzed during slack tide periods when flow noise is absent (approximately 4 hours). These sonograms *G(f,t)* show the variation in the spectral levels of ambient and anthropogenic sound with frequency and time due to changing meteorological conditions, vessel movements and industrial activity. All sonograms *G(f,t)* will be in absolute amplitude (dB re 1 μPa^2/Hz), all instrument and sensor corrections having been applied to the data. Appendix A shows the days on which data were acquired at each station, sonograms for all the data are available on a DVD at the back of this report.

It was expected that seismic surveys would be acquired in the area using air guns. Therefore, when the AUARs were deployed at the annual monitoring stations the gain in the analog channel of each AUAR was set to reduce likelihood of overload (clipping) of the recorded acoustic signal, even during seismic exploration. Analysis of the acoustic data recorded by the AUAR at the Control monitor station (Figure 1.11) characterizes the level of background noise caused by the passage of a cyclone (8th to 12th September) and strong acoustic signals from a nearby seismic vessel between the 14th and 23rd of September.

[14] A sonogram is a plot showing the variation in acoustic power spectral density level with frequency and time *G(f,t)*.
[15] The scale of the sonograms varies from 37 to 120 dB re 1 μPa^2/Hz in 3 dB increments.

Table 1.2 (a) - Operational times, parameters and locations of AUARs at monitor stations 1 to 10.

Station		Date		Time		Time	AUAR	Location		Depth	Gain	Sens.
Name	#	Start	End	Start	End	(hr)	#	Latitude	Longitude	(m)		(mV/Pa)
Lunskoye	1	5-Jul	3-Aug	09:00	15:17	702	№ 16	51°51.743	143°37.452	48	8	52.1
Lunskoye	1	13-Aug	6-Sep	13:30	17:00	580	№21	51°51.787	143°37.415	46	8	49.7
OFA	2	6-Jul	3-Aug	00:00	17:00	689	№ 2	52°10.308	143°35.992	40	8	49.0
Orlan	3	5-Jul	3-Aug	17:00	23:00	702	№ 13	52°21.605	143°35.130	33	8	49.5
Arkutun-Dagi	4	5-Jul	3-Aug	12:45	18:00	701	№ 21	52°19.210	143°44.157	45	8	49.7
Piltun-S	5	10-Jul	6-Aug	19:20	07:00	636	№ 5	52°40.868	143°22.598	17	2	49.0
Piltun-S	5	10-Aug	3-Sep	12:50	11:45	575	№ 27	52°40.877	143°22.705	18	2	50.2
Piltun-S	5	11-Sep	24-Sep	16:45	09:00	304	№ 11	52°40.822	143°22.678	18	8	49.5
Piltun	6	12-Jul	31-Jul	15:45	20:00	460	№ 26	52°49.212	143°24.595	22	8	50.0
Piltun	6	9-Aug	4-Sep	22:00	19:00	621	№ 16	52°49.212	143°24.610	22	8	52.1
Piltun	6	11-Sep	25-Sep	14:30	11:50	334	№ 27	52°49.128	143°24.588	24	8	50.2
PA-B-10	7	12-Jul	9-Aug	18:45	15:00	668	№ 27	52°53.037	143°20.523	10	2	50.2
PA-B-10	7	10-Aug	4-Sep	19:00	06:40	598	№ 8	52°52.552	143°20.765	11	2	44.5
PA-B-10	7	4-Sep	25-Sep	18:00	15:30	502	№ 17	52°52.978	143°20.765	11	8	49.6
PA-B-20	8	10-Jul	8-Aug	19:00	00:00	701	№ 4	52°53.968	143°23.348	19	8	49.4
PA-B-20	8	11-Aug	4-Sep	11:40	16:05	580	№ 4	52°53.968	143°23.400	20	8	49.4
PA-B-20	8	4-Sep	24-Sep	20:30	14:00	474	№ 26	52°53.985	143°23.327	19	8	50
Odoptu-PA-B	9	12-Jul	7-Aug	14:10	00:00	634	№ 8	53°00.055	143°21.325	22	8	44.5
Odoptu-S-10	10	7-Jul	25-Jul	09:00	09:45	421	№ 19	53°03.397	143°18.270	10	2	48.5
Odoptu-S-10	10	1-Aug	30-Aug	12:45	18:00	701	№ 19	53°03.412	143°18.303	10	2	48.5
Odoptu-S-10	10	2-Sep	28-Sep	20:00	10:30	614	№ 19	53°03.397	143°18.313	10	2	48.5

Table 1.2 (b) - Operational times, parameters and locations of AUARs at monitor stations 11 to 15, the control station.

Station		Date		Time		Time	AUAR	Location		Depth	Gain	Sens.
Name	#	Start	End	Start	End	(hr)	#	Latitude	Longitude	(m)		(mV/Pa)
Odoptu-S-20	11	14-Jun	7-Jul	16:15	08:15	544	№ 5	53°03.698	143°20.070	20	38	49.0
Odoptu-S-20	11	7-Jul	25-Jul	10:30	15:00	437	№ 6	53°03.405	143°20.062	20	8	49.9
Odoptu-S-20	11	26-Jul	19-Aug	15:15	09:00	570	№ 6	53°03.457	143°20.125	20	8	49.9
Odoptu-S-20	11	18-Aug	14-Sep	10:45	11:00	648	№ 27	53°03.332	143°19.825	19	8	49.5
Odoptu-S-20	11	18-Sep	28-Sep	09:15	09:50	241	№ 7	53°03.453	143°20.097	21	8	49.2
Odoptu-N-10	12	14-Jun	7-Jul	20:45	12:15	543	№ 11	53°09.012	143°17.863	12	2	49.5
Odoptu-N-10	12	7-Jul	30-Jul	20:30	13:40	593	№ 8	53°08.892	143°17.352	10	2	49.5
Odoptu-N-10	12	9-Aug	27-Aug	07:00	19:50	445	№ 11	53°09.063	143°17.290	10	2	49.5
Odoptu-N-10	12	11-Sep	27-Sep	07:00	16:00	393	№ 4	53°09.068	143°17.375	11	2	49.4
Odoptu-N-20	13	14-Jun	8-Jul	17:05	09:00	568	№ 9	53°09.102	143°18.700	20	2	49.5
Odoptu-N-20	13	8-Jul	1-Aug	18:00	12:55	571	№ 9	53°09.032	143°18.877	21	2	49.5
Odoptu-N-20	13	2-Aug	17-Aug	07:10	04:40	245	№ 9	53°09.085	143°18.895	20	2	49.5
Odoptu-N-20	13	20-Aug	14-Sep	19:00	09:00	590	№ 6	53°09.132	143°19.177	22	8	49.9
Odoptu-N-20	13	27-Aug	11-Sep	11:00	09:00	358	№ 9	53°09.065	143°18.887	21	2	49.5
Odoptu-N-20	13	14-Sep	27-Sep	20:00	16:00	307	№ 6	53°09.092	143°18.892	22	8	49.9
Molikpaq	15	10-Jul	29-Jul	17:00	12:15	451	№ 7	52°45.510	143°26.385	22	8	49.2
Molikpaq	15	11-Aug	3-Sep	15:20	09:45	547	№ 7	52°45.928	143°26.625	23	8	50.0
Molikpaq	15	11-Sep	25-Sep	15:15	08:30	329	№ 16	52°45.852	143°26.617	24	8	52.1
Control	14	14-Jul	8-Aug	00:00	10:00	610	№ 17	53°25.917	143°11.115	20	1	49.6
Control	14	7-Sep	23-Sep	09:00	09:30	385	№ 8	53°26.033	143°11.023	20	2	44.5
Odoptu-N-8km		18-Aug	14-Sep	18:10	02:30	633	№ 2	53°08.960	143°22.610	28	8	49.0

Table 1.2(c) - Operational times, parameters and locations of AUARs at acoustic stations A9 & A10.

Station		Date		Time		Time	AUAR	Location		Depth	Gain	Sens.
Name	#	Start	End	Start	End	(hr)	#	Latitude	Longitude	(m)		(mV/Pa)
BEH-Odoptu	A.9	14-Jun	7-Jul	19:10	15:00	548	№ 4	53°12.785	143°15.847	12	38	49.4
BEH-Odoptu	A.9	7-Jul	25-Jul	16:15	16:45	433	№ 3	53°12.505	143°16.072	10	2	46.4
BEH-Odoptu	A.9	8-Aug	6-Sep	13:50	19:00	701	№ 3	53°12.527	143°16.042	11	2	46.4
BEH-Odoptu	A.9	13-Sep	23-Sep	15:30	03:00	238	№ 9	53°12.522	143°16.082	11	2	46.4
BEH-north	A.10	9-Aug	3-Sep	08:45	18:15	597	№ 17	53°17.867	143°13.940	10	2	49.6
BEH-north	A.10	11-Sep	23-Sep	10:45	11:00	288	№ 21	53°17.845	143°13.967	11	2	49.7

Table 1.3 – Plot showing the days when AUARs were active at each monitoring station (by station).

Figure 1.10 - Sonogram *G(f,t)* with plots of sound pressure level *D(Δf,t)* of acoustic energy recorded at the Piltun acoustic station on 16 September 2009.

Figure 1.11 - Sonogram *G(f,t)* with plots of sound pressure level *D(Δf,t)* of acoustic energy recorded at the Control station in July and September of 2009

The summer and fall of 2009 were characterized by the passage of frequent powerful atmospheric cyclones. As discussed earlier, the retrograde motion of water particles in propagating surface waves with wave heights greater than 1 m causes intense, low-frequency, flow noise (pseudo-noise), which could also overdrive the analog channel of the AUAR. This effect is dependent on water depth and is at a maximum for AUARs deployed at the 10 m bathymetry contour. Turbulent bottom currents (due to the orbital motion of water particles in propagating surface waves) trap and transport sand, altering the sea floor topography. In the 2009 season, massive fouling by polychaetes and their shells (Figure 1.12(a)) was found to occur on the pyramidal frames and rubber straps used to deploy the measuring hydrophones on the bottom at the annual acoustic monitoring stations mollusks were also seen attaching directly to a hydrophone (Figure 1.12(b)). This was the first time

this had occurred and possibly added low-frequency pseudo-noise to the acoustic signal.

1.5 Terminology and Algorithms Used in the Report

Ambient and anthropogenic acoustic data recorded by an AUAR were written to the AUAR disc in a raw format and converted to microPascals (μPa)[16] after downloading to the computer on the *Akademik Oparin* (or during analysis). Acoustic spectra in decibels were used to describe the variation in acoustic power as a function of frequency. In this report sound pressure power density spectra $G(f)$ ($\mu Pa^2/Hz$)[17] will be used when spectral data are plotted. The sonograms $G(f,t)$ are plots of power spectral density vs. frequency and time and also include the variation in sound pressure level $D(\Delta f,t)$ (dB re 1 μPa^2) with time over the annotated bandwidth[18]. Figure 1.11 shows a sonogram; the color scales generally run from 37 to 120 dB re 1 $\mu Pa^2/Hz$ and the frequency range from 2 Hz to 15 kHz. The ***spectral level*** of an acoustic signal relates to the level of acoustic power in a 1 Hz band. This term is only applied to sounds with continuous frequency spectra[19]. These spectra are often averaged over a number of one-second windows[20] to improve the statistical stability of the ambient noise data[21]; throughout this report the number of one-second windows used in the averaging is given at the top of each spectrogram plot if the data are averaged over multiple windows.

1.6 Units

A number of different unit notations have been used in this report. This is due to differences in standard notation between different disciplines and nationalities[22]. For spectral density plots - although the units for power spectral density are $\mu Pa^2/(s\ Hz)$, $\mu Pa^2/s/Hz$ or μPa^2, the units for power spectral density are sometimes defined as $\mu Pa^2/Hz$ or $\mu Pa/\sqrt{Hz}$.

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[16] The data was scaled (after incorporating hydrophone sensitivity, system instrument response and system gain (at 1 kHz), to convert the data to standard units of pressure (measured through an omni-directional hydrophone).
[17] Energy and power spectra are scaled to 1 Hz whatever the analysis length.
[18] Sound pressure level is the integral of the acoustic energy over the specified frequency band.
[19] A continuous frequency spectrum is a spectrum with signal present at all sampled frequencies.
[20] Average of X 1-second spectral estimates.
[21] Spectral averaging is used to obtain a lower variance spectral estimate.
[22] The following are equivalent units using the different standard nomenclatures: 1 mkPa = 1 μPa and 1 mkV = 1 μV.

Figure 1.12 – (a) Fouling with polychaetes, and (b) attachment of mollusks to hydrophones on stations deployed at 10 m depth.

Table 1.4 (a) - Operational times, parameters and locations of AUARs at monitor stations 1 to 10.

Station		Date		Time		Time	AUAR	Location		Depth	Gain	Sens.
Name	#	Start	End	Start	End	(hr)	#	Latitude	Longitude	(m)		(mV/Pa)
Lunskoye	1	5-Jul	3-Aug	09:00	15:17	702	№ 16	51°51.743	143°37.452	48	8	52.1
Lunskoye	1	13-Aug	6-Sep	13:30	17:00	580	№21	51°51.787	143°37.415	46	8	49.7
OFA	2	6-Jul	3-Aug	00:00	17:00	689	№ 2	52°10.308	143°35.992	40	8	49.0
Orlan	3	5-Jul	3-Aug	17:00	23:00	702	№ 13	52°21.605	143°35.130	33	8	49.5
Arkutun-Dagi	4	5-Jul	3-Aug	12:45	18:00	701	№ 21	52°19.210	143°44.157	45	8	49.7
Piltun-S	5	10-Jul	6-Aug	19:20	07:00	636	№ 5	52°40.868	143°22.598	17	2	49.0
Piltun-S	5	10-Aug	3-Sep	12:50	11:45	575	№ 27	52°40.877	143°22.705	18	2	50.2
Piltun-S	5	11-Sep	24-Sep	16:45	09:00	304	№ 11	52°40.822	143°22.678	18	8	49.5
Piltun	6	12-Jul	31-Jul	15:45	20:00	460	№ 26	52°49.212	143°24.595	22	8	50.0
Piltun	6	9-Aug	4-Sep	22:00	19:00	621	№ 16	52°49.212	143°24.610	22	8	52.1
Piltun	6	11-Sep	25-Sep	14:30	11:50	334	№ 27	52°49.128	143°24.588	24	8	50.2
PA-B-10	7	12-Jul	9-Aug	18:45	15:00	668	№ 27	52°53.037	143°20.523	10	2	50.2
PA-B-10	7	10-Aug	4-Sep	19:00	06:40	598	№ 8	52°52.552	143°20.765	11	2	44.5
PA-B-10	7	4-Sep	25-Sep	18:00	15:30	502	№ 17	52°52.978	143°20.765	11	8	49.6
PA-B-20	8	10-Jul	8-Aug	19:00	00:00	701	№ 4	52°53.968	143°23.348	19	8	49.4
PA-B-20	8	11-Aug	4-Sep	11:40	16:05	580	№ 4	52°53.968	143°23.400	20	8	49.4
PA-B-20	8	4-Sep	24-Sep	20:30	14:00	474	№ 26	52°53.985	143°23.327	19	8	50
Odoptu-PA-B	9	12-Jul	7-Aug	14:10	00:00	634	№ 8	53°00.055	143°21.325	22	8	44.5
Odoptu-S-10	10	7-Jul	25-Jul	09:00	09:45	421	№ 19	53°03.397	143°18.270	10	2	48.5
Odoptu-S-10	10	1-Aug	30-Aug	12:45	18:00	701	№ 19	53°03.412	143°18.303	10	2	48.5
Odoptu-S-10	10	2-Sep	28-Sep	20:00	10:30	614	№ 19	53°03.397	143°18.313	10	2	48.5

Table 1.2 (b) - Operational times, parameters and locations of AUARs at monitor stations 11 to 15, the control station.

Station		Date		Time		Time	AUAR	Location		Depth	Gain	Sens.
Name	#	Start	End	Start	End	(hr)	#	Latitude	Longitude	(m)		(mV/Pa)
Odoptu-S-20	11	14-Jun	7-Jul	16:15	08:15	544	№ 5	53°03.698	143°20.070	20	38	49.0
Odoptu-S-20	11	7-Jul	25-Jul	10:30	15:00	437	№ 6	53°03.405	143°20.062	20	8	49.9
Odoptu-S-20	11	26-Jul	19-Aug	15:15	09:00	570	№ 6	53°03.457	143°20.125	20	8	49.9
Odoptu-S-20	11	18-Aug	14-Sep	10:45	11:00	648	№ 27	53°03.332	143°19.825	19	8	49.5
Odoptu-S-20	11	18-Sep	28-Sep	09:15	09:50	241	№ 7	53°03.453	143°20.097	21	8	49.2
Odoptu-N-10	12	14-Jun	7-Jul	20:45	12:15	543	№ 11	53°09.012	143°17.863	12	2	49.5
Odoptu-N-10	12	7-Jul	30-Jul	20:30	13:40	593	№ 8	53°08.892	143°17.352	10	2	49.5
Odoptu-N-10	12	9-Aug	27-Aug	07:00	19:50	445	№ 11	53°09.063	143°17.290	10	2	49.5
Odoptu-N-10	12	11-Sep	27-Sep	07:00	16:00	393	№ 4	53°09.068	143°17.375	11	2	49.4
Odoptu-N-20	13	14-Jun	8-Jul	17:05	09:00	568	№ 9	53°09.102	143°18.700	20	2	49.5
Odoptu-N-20	13	8-Jul	1-Aug	18:00	12:55	571	№ 9	53°09.032	143°18.877	21	2	49.5
Odoptu-N-20	13	2-Aug	17-Aug	07:10	04:40	245	№ 9	53°09.085	143°18.895	20	2	49.5
Odoptu-N-20	13	20-Aug	14-Sep	19:00	09:00	590	№ 6	53°09.132	143°19.177	22	8	49.9
Odoptu-N-20	13	27-Aug	11-Sep	11:00	09:00	358	№ 9	53°09.065	143°18.887	21	2	49.5
Odoptu-N-20	13	14-Sep	27-Sep	20:00	16:00	307	№ 6	53°09.092	143°18.892	22	8	49.9
Molikpaq	15	10-Jul	29-Jul	17:00	12:15	451	№ 7	52°45.510	143°26.385	22	8	49.2
Molikpaq	15	11-Aug	3-Sep	15:20	09:45	547	№ 7	52°45.928	143°26.625	23	8	50.0
Molikpaq	15	11-Sep	25-Sep	15:15	08:30	329	№ 16	52°45.852	143°26.617	24	8	52.1
Control	14	14-Jul	8-Aug	00:00	10:00	610	№ 17	53°25.917	143°11.115	20	1	49.6
Control	14	7-Sep	23-Sep	09:00	09:30	385	№ 8	53°26.033	143°11.023	20	2	44.5
Odoptu-N-8km		18-Aug	14-Sep	18:10	02:30	633	№ 2	53°08.960	143°22.610	28	8	49.0

Table 1.2(c) - Operational times, parameters and locations of AUARs at acoustic stations A9 & A10.

Station		Date		Time		Time	AUAR	Location		Depth	Gain	Sens.
Name	#	Start	End	Start	End	(hr)	#	Latitude	Longitude	(m)		(mV/Pa)
BEH-Odoptu	A.9	14-Jun	7-Jul	19:10	15:00	548	№ 4	53°12.785	143°15.847	12	38	49.4
BEH-Odoptu	A.9	7-Jul	25-Jul	16:15	16:45	433	№ 3	53°12.505	143°16.072	10	2	46.4
BEH-Odoptu	A.9	8-Aug	6-Sep	13:50	19:00	701	№ 3	53°12.527	143°16.042	11	2	46.4
BEH-Odoptu	A.9	13-Sep	23-Sep	15:30	03:00	238	№ 9	53°12.522	143°16.082	11	2	46.4
BEH-north	A.10	9-Aug	3-Sep	08:45	18:15	597	№ 17	53°17.867	143°13.940	10	2	49.6
BEH-north	A.10	11-Sep	23-Sep	10:45	11:00	288	№ 21	53°17.845	143°13.967	11	2	49.7

Table 1.5 – Plot showing the days when AUARs were active at each monitoring station (by station).

2 ACOUSTIC RECORDING AND PROCESSING EQUIPMENT

The acoustic measurements were conducted using 16 digital AUARs (Figure 1.1) developed at POI. Between 2005 and 2007 an additional six mini-AUARs (Figure 1.2) were constructed; these were smaller with a reduced (72 hours) record time and were used for TL and source level measurements. The AUARs (all variants), were designed to enable accurate, autonomous, synchronous acoustic measurements over a broad range of frequencies (1 Hz to 15 kHz, including infrasounds[23]) to be recorded. In 2009 three AUARs were also equipped with digital radio-telemetry channels for real-time acoustic monitoring (DT-AUARs). Two of the DT-AUARs were able to transmit acoustic data with a frequency range of 2–500 Hz, and the other 2–2,000 Hz. The Mollusk-07 vertical autonomous acoustic and hydrologic recording array can make stationary synchronous measurements of the vertical structure of the acoustic and temperature field at eight depths, and the current velocity at the bottom. The hydrological studies were conducted on vertical profiles using a Valeport SVXtra autonomous combined sonde, which measures hydrostatic pressure (depth), sound velocity, temperature and conductivity (salinity). A detailed description of this equipment has been provided by Borisov [Borisov et. al. 2006].

2.1 Autonomous Underwater Acoustic Recorder (AUAR)

The AUARs[24] are made of welded titanium alloy and are rated to depths of up to 50 m (two are rated to 100 m). Two external sensors (hydrophones, accelerometers or hydrologic measuring equipment) can be input to the AUAR electronics. Inside the AUAR there are batteries secured in a titanium frame and the AUAR electronics and power handling circuitry is attached to the lid. The AUARs have three sealed 115 ampere-hour batteries, enabling continuous operation for over 25 days. During the 2009 expedition most of the AUARs and all six mini-AUARs were modified to enable continuous recording of acoustic signals (after laboratory and field tests); thus the units did not have the 22-minute gaps (Figure 1.10) required to write data from the flash drive to the hard disk. This was accomplished by removing the 1 GB flash drive in the on-board computer and recording the data directly on the hard drive in 10 MB blocks. The hard drive was mounted on a rubber cushion which isolates it mechanically from the AUAR housing. Figure 2.1 gives plots of the internal noise

[23] Infrasounds are sounds with a frequency of less than 20 Hz.

of AUARs with a flash drive and with direct recording to the hard drive for analog channel gains of 2 and 38. Those AUARs that were not converted in 2009 operated with periodic gaps in the data as described in Borisov et.al. (2009).

All of the AUARs and mini-AUARs use cylindrical hydrophones (model # GI-50 (ГИ-50)) (Figure 2.1(b)) with integrated pre-amplifiers designed specifically for use with the AUARs. Figure 2.1(a) shows the parallel charging of three AUAR batteries on the *Akademik Oparin.*

Figure 2.1 – Internal noise spectra of an AUAR recorded using a flash drive (black) and a hard drive without pauses (red)with an analog channel gain of (a) 2; (b) 38.

[24] 2003/2005/2006/2007/2008/2009 AUAR dimensions are length 0.8 m, diameter 0.38 m, weight in air ~155 kg.

(a.)

(b.)

Figure 2.2 - (a) Charging AUAR batteries; (b) Hydrophone used in AUAR & mini- AUAR.

The AUARs digital recorder is based on the Prometheus single board computer, which has an integrated 16 bit analog to digital converter (ADC). In order to optimize the dynamic range of the 16 bit ADC the signal amplitudes should be approximately equal across the entire frequency range. However, ambient noise generally has an amplitude maximum at low frequencies and drops off with higher frequencies. The ADC does not always have the instantaneous dynamic range required to record ambient and anthropogenic noise at frequencies from 1 Hz to 15 kHz. Therefore, for all hydrophones, low-frequency amplitude correction is effected in the hydrophone preamplifier. These amplitude corrections ensure a consistent signal level across the entire frequency band for the analog channel of the AUARs with these hydrophones. An inverse correction is applied during spectral estimation.

In 2006, the resolution of the system timer in the QNX operating system was increased and periodic software corrections of the hardware clock were made to reduce the clock drift to less than one minute in a 19 day AUAR deployment. A tone was used to confirm that the AUAR computer was operating correctly prior to deployment. Prior to deployment of an AUAR a standard test signal was recorded; this signal is used to verify the AUAR gain and any other scaling factors.

Figure 2.3 shows the deployment of the two types of AUAR and how the AUAR and its hydrophone are anchored when deployed. Practical experience has shown that at shallow deployment depths (10-30 m), movement of any surface buoy due to wave action can be mechanically conducted down the rope or cable to the hydrophone, where this mechanical movement can be recorded as acoustic noise. Therefore the mini-AUAR surface buoys (Figure 2.3(b)) are deployed so as to reduce this noise by isolating the hydrophone from the surface buoy with an anchor, thus reducing the mechanical coupling between the surface buoy and the hydrophone. The hydrophone is also deployed 15 m from the AUAR to prevent distortion of the acoustic field by scattering or masking by the AUAR container at high frequencies. The hydrophone is deployed inside a pyramid shaped metal frame to which it is attached by rubber straps, isolating it to the best extent possible from the sea floor. In 2009, acoustic releases were used in all AUARs deployments (Figure 2.4). Using acoustic releases (Figure 2.3(a)) virtually eliminates the possibility of unauthorized retrieval of the AUAR and ‘isolates’ the hydrophone as much as possible from surface waves.

Figure 2.3 – Deployment schematics for (a) AUAR; (b) Mini-AUAR.

The AUARs and mini-AUARs employed during the 2009 field season utilized GI-50 hydrophones. The frequency response of these hydrophones is shown in Figure 2.5 (a, b, c). All of these hydrophones have a low-frequency amplitude correction accomplished by the hydrophone preamplifier. This eliminates the need for any additional low-frequency gain correction in the AUAR amplifier [Borisov et. al. 2006]. Calibration certificates for all the hydrophones used in the 2008 expedition are listed in Appendix B and available in a file on the DVD available with the report.

To compute TL from acoustic measurements made by different AUARs, and to compare acoustic data over time, the data have to be calibrated to an absolute pressure standard. The hydrophones were manufactured with nominal sensitivities and the gains were set in the field (copies of the calibration certificates are given on the DVD). Field cross-

calibrations confirmed the absolute calibration of the data. Further details of the AUARs used in 2009, their location, deployment depth and recording settings can be found in Table 1.2. A detailed description of the testing of the recording equipment is given in [Borisov et al., 2007].

Figure 2.4 – Acoustic release and buoy.

2.1.1 AUAR Instrument Test Analysis

In order to ensure that all of the AUARs adhered to the design specifications, and that the AUARs recorded accurate absolute acoustic measurements, a set of instrument tests was created. These tests were designed to ensure that all the AUARs were operating within specifications and to generate an instrument response filter for the analog component of each AUAR.

Figure 2.5 - Spectral characteristics of the hydrophones used during the 2009 field season: (a & b) Cylindrical (GI-50) hydrophones (50mV/Pa sensitivity) used by AUARs; (c) GI-50 hydrophones (10mV/Pa and 5mV/Pa sensitivity) used by mini-AUARs and as a transducer reference.

This estimate of the AUAR analog instrument response, measured in the laboratory prior to the field season *K(f)* and the hydrophone sensitivity *M(f)* was used to generate an inverse filter; this filter was subsequently applied to the analog voltage measurements to back out the system instrument response and generate absolute acoustic measurements. These frequency dependent responses correct the acoustic data over the range from 1 Hz - 15 kHz.

In 2009, measurements of the internal noise, dynamic range and analog channel system filter response of each AUAR were made using the procedure described by Borisov [Borisov et.al. 2007]. The following results quantitatively characterize the performance of the AUARs used during the 2009 field season.

2.1.2 AUAR Internal Noise

The AUAR internal noise was measured using a dummy GI-50 equivalent hydrophone constructed in 2005. The preamplifier electronics in the shielded housing of the equivalent hydrophone is identical to that of the corresponding hydrophone except that a piezoceramic capacitor with the same capacitance as the hydrophone piezoceramics is connected to its input. The internal noise measurements were performed using the procedure approved in 2006 and described in Borisov [Borisov et.al. 2007]. Figure 2.6 displays a spectral analysis of the results, showing the internal noise of the AUAR analog channels with a GI-50 hydrophone over the frequency ranges 0-15 kHz (top) and 0-350 Hz (bottom)25.

2.1.3 AUAR Dynamic Range

Figure 2.7 displays spectra of the tonal signals recorded by the AUARs during the dynamic range measurements, with the gain factor set to its maximum value of 38. When the sound pressure level is close to the maximum input acoustic pressure level, the dynamic range is limited by non-linear distortion and is 60 dB (Figure 2.7 – Blue curve). If the input signal level is decreased by 10 dB re 1 μPa2/Hz (Figure 2.7 – Green curve), the dynamic range of the AUAR increases to 75 dB and is limited by the second and fourth harmonics. The red curve on Figure 2.7 shows that the internal instrument noise level of the AUAR recording

[25] The results were not corrected by the amplitude-frequency response of the analog channel.

channel with an equivalent GI-50 is approximately 27 dB re 1 μPa2/Hz in the frequency band from 50 Hz to 15 kHz, increasing to a maximum of 35 dB re 1 μPa2/Hz at a frequency between 12-30 Hz. Since the instrument noise is below the harmonic distortion for most of the recorded frequency range, harmonic distortion limits the dynamic range of the AUAR.

Figure 2.6 - Spectra showing the internal noise of the AUAR recording system: (a) 0-15 kHz and (b) 0-350 Hz.

2.1.4 Analog Channel System Filter Response of the AUAR

The filter response of each AUAR analog channel was measured under laboratory conditions using a broadband white noise signal (K(f)), the results are used to estimate an analog instrument filter response for each AUAR, normalized to the gain at 1 kHz (Figure 2.8). The measurements were made for three scaling factors: 2, 8 and 38. Figure 2.8

shows that K(f) decreases with an increase in the gain factor at frequencies below 15 Hz, due to the presence of a 1μF separating capacitor at the output of the hydrophone preamplifier causing a corresponding decrease in the input resistance of the scale amplifier with an increase in gain.

Figure 2.7 - Spectrum showing the internal noise and dynamic range of the AUAR recording system.

This filter response, together with the frequency response of the hydrophone (M(f)) used in a given AUAR (Figure 2.5), is used to construct a system filter response. This is used to correct the data as they are processed, reducing the analog voltage measurements to absolute acoustic pressure for the frequency band from 1 Hz to 15 kHz.

2.1.5 Results of the Instrument Tests

The unit to unit performance of all the AUARs was confirmed by regular testing. All the AUARs were subject to the tests listed in Borisov [Borisov et.al. 2007];

Table 2.1 gives the individual test results for all sixteen AUARs and six mini-AUARs performed in the laboratory. All AUARs performed within specifications.

Figure 2.8 - Amplitude-frequency characteristics of an AUAR analog channel normalized to the gain at 1 kHz, measured using a broadband white noise signal and gain factors of 2, 8 and 38.

Table 2.1 – Performance of AUARs on the instrument tests.

AUAR serial number										
02	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**11**	**13**	**14**
Internal noise (dB re 1 μPa²/Hz) *(1-200 Hz)*										
39.0	40.0	40.0	38.0	39.0	37.0	35.0	36.0	38.0	39.0	42.0
Internal noise (dB re 1 μPa²/Hz) *(200 Hz - 15 kHz)*										
27.0	29.8	27.0	28.2	26.2	27.0	27.5	27.5	27.0	26.0	28.0
Dynamic range , dB										
76.0	76.0	77.0	76.0	75.0	75.0	76.0	75.0	77.0	76.0	77.0
AUAR serial number										
15	**16**	**17**	**18**	**19**	**21**	**23**	**24**	**25**	**26**	**27**
Internal noise (dB re 1 μPa²/Hz) *(1-200 Hz)*										
40.0	38.3	36.0	39.0	36.0	41.0	40.5	41.0	39.0	35.0	36.0
Internal noise (dB re 1 μPa²/Hz) *(200 Hz - 15 kHz)*										
28.0	28.0	27.0	30.0	26.5	27.0	27.5	28.0	29.1	26.0	27.0
Dynamic range , dB										
78.0	75.0	75.0	77.0	78.0	76.0	76.0	76.0	77.0	76.0	75.0

2.2 Autonomous Underwater Acoustic Recorder with Digital Radio-telemetry Channel

In 2009 POI used AUARs equipped with a digital radio-telemetry channel (DT-AUAR) for the first time (Shelf-2009 radio-acoustic station). POI's experience with operating T-AUARs with an analog VHF radio-telemetry channel on the Sakhalin shelf helped in the development. The Shelf-09 was developed to increase the dynamic range of the radio-telemetry channel such that it can transmit with full fidelity the powerful low-frequency pulsed signals generated by seismic exploration.

During 2008 POI developed and successfully tested a digital radio-telemetry system: DRT-POI to replace the analog radio-telemetry used in the old T-AUAR. This system is capable of continuous transmission of 2 to 2,000 Hz acoustic signals over a distance of up to 25 km, with a dynamic range (signal-to-radio noise) of at least 96 dB.

Figure 2.9 shows a diagram of the deployment of the DT-AUAR at sea. The figure shows that the DT-AUAR has two titanium alloy bottom containers, which can be deployed at

depths of up to 70 m, and a radio-telemetry surface buoy. In the first container there is an AUAR, a detailed description of which is given in section 2.1, It also holds the encoder of the digital radio-telemetry system (Figure 2.10) and three 115 Ah sealed lead-helium batteries connected in parallel (Figure 2.2 (a)), which power the AUAR and the encoder.

Figure 2.9 – Deployment schematic for the DT-AUAR (Shelf-09).

Figure 2.10 – AUAR electronics digital radio channel encoder mounted on the lid of a DT-AUAR container.

The second container houses the batteries that power the radio transmitter located in the surface buoy (Figure 2.9). The system is powered by battery modules which contain 42 Duracell Procell D batteries connected in series (Figure 2.11). The modules are connected in parallel through protection diodes, these modules supply an initial voltage of 67 V and have a capacity of approximately15 Ah. The protection diodes prevent the modules from discharging to each other in the event that any of them is damaged. Up to 19 modules can be installed in the container, providing a power source with average output voltage of 63 V and capacity of approximately 285 Ah.

The second container is connected to the surface radio buoy by a 100 m cable. The radio buoy consists of a hardware canister with a flotation collar, a buffer power supply compartment, and a Shakespeare 5241-R VHF antenna.

Figure 2.11 – Power supply modules for the DT-AUAR radio buoy, containing *Duracell Procell D* batteries connected in series, and underwater container No. 2 containing 19 power supply modules connected in parallel, providing average output voltage of 63 V and a total capacity of approximately 285 Ah.

The buffer power supply compartment contains one power supply module similar to those described above, or five 4.5 Ah helium batteries connected in series, with a built-in protection diode. This compartment serves as a keel and provides vertical stability to the buoy, it has a design similar to the power supply compartments of the mini-AUARs and radio buoys that have been used by POI since 2005. The buoy's hardware canister contains a radio transmitter, a module to receive the digital signal from the cable line, and power supply circuits for them; these are based on a DC/DC transformer, which converts 36-72 V voltage into a stabilized 6.7 V voltage for 3-5 W radio transmitters, or 10 V for 10 W radio transmitters.

Figure 2.12 is a schematic of the Shelf-09 station. A cylindrical GI-50 hydrophone with a preamplifier is used as the receiver26. Figure 2.9 shows the hydrophone is deployed 15 m from the AUAR inside a pyramid shaped metal frame to which it is attached by rubber straps. From the output of the hydrophone's preamplifier, the signal goes to the analog channel of the AUAR and in parallel to the input of the radio channel encoder.

A multipurpose encoding module (the encoder) is used to convert the analog signal to a form suitable for transmission through the cable line and over a VHF radio channel. It is capable of converting an analog signal to digital code in a programmed frequency band from 1 Hz to 15 kHz (sampling rate 32 kHz), with 24-bit resolution. A sampling rate of 4,168 Hz was selected for the digital radio system, and the length of a data word was limited to 16 bits. The ADC's remaining 8 bits allow programmed selection of the digital radio system's transmission gain coefficient in the range of 0.5-128.

From the encoder input (Figure 2.12), the analog input signal passes through a stage that simultaneously acts as a low-noise buffer amplifier and a third-order low-pass filter for anti-alias filtering. The cutoff frequency of this filter is 17 kHz and is not reset when the encoder sampling rate is changed. Then the analog signal is then sent to a 24-bit delta-sigma analog-to-digital converter (ADC) (AD7767-2). This microchip contains an ADC that operates in the DT-AUAR at a primary sampling rate of 133.3 kHz,and has three digital low-pass filters connected in series. This results in a sequence of 24-bit words in NRZ serial, two's complement code, which appears at the ADC's output with frequency of 4.168 kHz.

[26] The hydrophone was fabricated and calibrated at the All-Russian Scientific Research Institute of Physico-technical and

The circuit connecting the ADC and the buffer amplifier follows the manufacturer's recommendation. The power-supply and reference circuits have two-stage stabilization, which results in high stability and reliability over a wide range of permissible supply voltages (9.5-30 V). As a result the digital radio system's encoder has a dynamic range close to the maximum possible for this ADC (110 dB), with a signal-to-noise ratio better than 145 dB. The high signal-to-noise ratio made it possible to use a constant gain buffer amplifier in the encoder for the entire range of output voltages from the GI-50 hydrophone preamplifier.

Figure 2.12 - Block diagram of the DT-AUAR recording system (Shelf-09).

Electronic Measurements (FGUP VNIIFTRI).

From the ADC output, this sequence of 24-bit data words goes to a microcontroller where it is processed. First the microcontroller removes any signal bias, the mean is computed by a recursive averaging procedure on 65,536 values of the input data words (i.e. in this case the mean value is computed for the last 15.7 seconds). The use of this software procedure allows the bias control circuit to be eliminated from the encoder's buffer amplifier circuitry and enabled automatic compensation of bias due to temperature and other destabilizing factors. The ADC's 24-bit data words are then converted to 16-bit data words for the digital radio system. At the same time, the required digital radio channel transmission gain coefficient is selected in the range from 1 to 256 (corresponding to an overall gain of 0.5-128 for the channel from the encoder input to the decoder output). Then synchronization bits are added to the digital radio system's 16-bit data words, and they are recoded in OQPSK code, which is used for transmitting the data through the cable and over the radio channel. This code is completely analogous to the one used in the digital radio buoys.

The RS-485 line driver's microchip then feeds the code into the cable line (Figure 2.9) that connects underwater container 1 with container 2 and from there to the surface radio buoy (the total length of the cable is 150 m). In the buoy, the signal goes to the input of an RS-485 receiver and through matching stages to an FM radio transmitter. The bandwidth needed to transmit the digital radio channel's signal is 40 kHz for transmission of an acoustic signal up to 2 kHz and 10 kHz for transmission of an acoustic signal up to 500 Hz. A signal with a bandwidth of ±100 kHz in relation to the carrier frequency is formed at the output of the transmitter. Depending on the type of transmitter used, either a portable ICOM F11 or a mobile Motorola CM 140, its radiating power can be selected from 1 to 5 or from 1 to 10 W.

The radio-telemetry signal is received on a modified ICOM IC-R20 receiver. The signal goes from the output of the radio receiver frequency discriminator to the digital radio system's decoder, which restores the clock signal and the original digital sequence from the OQPSK code, detects errors, and minimizes any distortions that have been introduced. Figure 2.12 diagrams the operation of the decoder, the received signal goes to a comparator. The decoder's clock and information signals are both formed on the basis of the comparator's output signal. In order for OQPSK code to be properly received and decoded, the decoder has to generate clock sequences that are phased in a certain way in

relation to the input OQPSK code. To increase the noise immunity of data reception these sequences must depend slightly on the phase fluctuations of the input signal that are caused by noise in the radio channel. At the same time, phase locking of the input signal and fine-tuning of the clock sequences to it must be performed quickly, in order to reduce data losses caused by synchronization faults in conditions of strong and prolonged radio interference. All of this is performed by a built-in phase-lock system. The crystal master oscillators of all the digital radio system's encoders and decoders are frequency-matched, which significantly improves the reliability, quality, and stability of their operation and enables any decoder to work with the signal from any encoder. The phase-lock system contains parallel channels for tracking the frequency and phase of the input signal, and ensures precise phasing of the clock signals in relation to the signal received over the radio channel.

The data word synchronization system serves to divide the continuous sequence of bits into 16-bit data words, and ensures reliable synchronization even if there are errors in the received signal, including errors in the synchronization words. It uses the signal from the comparator output and clock sequences generated by the phase-lock system for its operation. Up to two timing marks are permitted to pass without loss of synchronization due to errors, and it locks quickly as soon as a signal suitable for decoding appears.

The error detector finds impermissible bit combinations in the OQPSK code. A signal containing information on the quality of a word that has been received goes to the microcontroller, which subsequently processes the signal. Using signals from the data word synchronization system, the phase-lock system, and the comparator, the OQPSK decoder restores the original data sequence. Information restored by the OQPSK decoder is fed into the microcontroller, where it is converted to the input data format for the digital-to-analog converter (DAC), and is sent to the DAC input. The analog signal from the DAC output goes through a low-pass filter to an output terminal on the decoder's housing.

The DT-AUAR (Shelf-09) was developed for offshore acoustic monitoring in real time and the radio receiving station can simultaneously receive radio-telemetry signals from five or more DT-AUARs. The simplest and most reliable way to synchronously enter and store acoustic data in a computer is to use standard analog data input equipment such as that produced by National Instruments. Figure 2.12 shows that the analog signal goes from the

decoder output through a SCXI-1141 elliptical, eighth-order, low-pass filter installed in an external crate to a DAQCard-6036E 16-bit ADC installed on a PCMCI bus in a laptop computer. Double analog-to-digital conversion reduces the dynamic range of the DRT-POI due to an increase in harmonic distortions and noise. However, it makes it simple to synchronously input up to 16 analog signals into a computer. The sampling rate for input of analog signals from decoder outputs into a computer is equal to the sampling rate used in the digital radio system (4,168 Hz).

2.2.1 Testing the Reliability of the Modules of the Radio-telemetry System

Since custom factory-manufactured printed circuit boards were used for the first time in the digital radio system, and the electronic components on them are assembled by hand (some in miniature SMD (surface mounted device) packages) (Figure 2.13).

Figure 2.13 – Basic electronic units of the DT-AUAR digital radio-telemetry system.

After the first encoder was manufactured it was subjected to temperature testing and shock testing (dropping on a hard floor from a height of one meter). This revealed that when the temperature fell below 0°C the encoder's operation was disrupted, checks using a spray freezer were able to localize the problem as: the ADC microchip in an SMD package. To improve the soldering quality, a soldering station with a heat gun was acquired for soldering SMD, and the soldering operation was carefully planned. After soldering the boards were rinsed in purified gasoline and alcohol to remove residues of solder and flux, dried, and the soldering was then carefully visually checked. Afterwards all of the encoders were temperature-tested (Figure 2.14); they were put in the freezer compartment of a refrigerator overnight at a temperature of −16ºC, and then connected one by one to a test bench and operated until their temperature approached room temperature. As this was done their casings sweated, as can be seen in Figure 2.14, but their operation was not disrupted. Then the encoder was heated to +50ºC with a heat gun, while it was still operational. All of the encoders passed the tests on the first try. Two encoders were also thermal-shock tested by using a spray freezer directly onto the printed circuit board. The encoders continued to operate with a millimeter thick layer of frost.

Figure 2.14 – Reduced temperature testing of the DT-AUAR digital radio-telemetry system's encoders.

2.2.2 Measurement of the DT-AUAR Digital Radio System Characteristics

Measurements of the frequency response, dynamic range, and internal noise of the AUARs that compose part of the DT-AUARs were conducted as for other AUARs, according to the procedure described by Borisov [Borisov et.al. 2007]. The results of the analysis are given in Table 2.1. The characteristics of the digital radio system were measured in the laboratory using a test plan, a schematic of which is shown in Figure 2.15. The characteristics of all the modules manufactured for operation in 2009-2010 were evaluated. Measurements of the internal noise, dynamic range and analog channel system filter response of each DT-AUAR used were made using the procedures described below to quantitatively characterize the performance of the DT-AUARs used during the 2009 field season.

Figure 2.15 – Schematic of test sequence for measuring the characteristics of the digital radio system: (a) for stations with an acoustic signal bandwidth of up to 2 kHz and a hydrophone without a coupling capacitor; (b) frequency response of stations with an acoustic signal bandwidth of up to 500 Hz and a hydrophone with a coupling capacitor; (b) internal noise of stations with an acoustic signal bandwidth of up to 500 Hz and a hydrophone with a coupling capacitor.

The test signals were input to a computer using a National Instruments crate with an SCXI-1141 eighth-order elliptical filter and an 8-channel, 16-bit *DAQCard-6036E* ADC installed on a PCMCI card in a laptop computer.

2.2.3 DT-AUAR Internal Noise

Figure 2.16 displays a spectral analysis of the results of internal noise measurements with the minimum digital channel transmission gain factor (0.5) and a hydrophone sensitivity of 5,000 μV/Pa. Since there is no dummy GI-50 equivalent hydrophone with sensitivity of 5,000 μV/Pa, the inputs of the encoder and the reference recording channel were connected

by a common wire. This procedure is reasonable, since with this transmission gain factor and sensitivity the internal noise of the hydrophone (approximately 30 dB) is significantly less than the internal noise of the radio channel. Figure 2.16 shows that the internal noise of the digital radio channel does not exceed 74 dB anywhere in the frequency range with any combination of encoder-decoder modules.

Figure 2.16 - Spectra showing the internal noise of the radio channels containing: (a) Encoder number 2 and decoders number 1-16; and (b) Encoders number 1-11 and decoders number 2.

2.2.4 DT-AUAR Dynamic Range

Figure 2.17 displays spectra that illustrate the dynamic range of the digital radio system relative to the internal noise. The green curve shows the spectrum of a tonal signal with an amplitude close to the maximum, that is passed through a digital radio channel with the minimum digital channel transmission gain factor (0.5) and a hydrophone sensitivity of 5,000 μV/Pa (peak value 1,440 Pa - 183 dB re 1 μPa; in this case, the signal strength reaches 177 dB re 1 μPa^2). The dynamic range of the digital radio channel, which is limited by harmonic distortion, is 70 dB. If the input signal level is decreased (e.g. 164 dB (blue plot)), the dynamic range is at least 75 dB.

Figure 2.17 - Spectrum showing the internal noise (red) and dynamic range of the DT-AUAR recording system with a digital radio channel.

2.2.5 Analog Channel System Filter Response of the AUAR

The filter response of each DT-AUAR digital radio channel was measured under laboratory conditions using a broadband white noise signal. The signal was fed directly to one of the recording channels (the reference channel), and to another after passing through the digital radio system encoder and decoder. Since the analog components of the digital radio system circuitry were minimized, they could be made using precision electronic components. This allowed modules of the same type to be interchanged without changing the frequency response of the radio-telemetry channels in which they are used. The frequency response of channels containing encoder number 2 and all of the decoders (numbers 1-16) are shown in Figure 2.18, and of encoders numbers 1-11 and decoder number 2 in Figure 2.19. These results show that the frequency response of the encoders

does not vary by more than 0.2 dB, and is no more than 0.15 dB for the decoders.

Figure 2.18 – Frequency response of digital radio channels containing encoder number 2 and decoders (numbers 1-16).

Figure 2.19 – Frequency response of digital radio channels containing encoders number 1-11 and decoder number 2.

2.2.6 Results of the DT-AUAR Instrument Tests

Measurement of the respective characteristics of the digital radio channel for T-AUAR No. 29, which was deployed for SEIC is described in the previous section. Two DT-AUARs were deployed for ENL at monitoring stations Odoptu-N-10 (No. 11) and Odoptu-N-20 (No. 9). Additional measurements of the level of internal noise and frequency response were made for these stations. These additional measurements were needed because the sampling rate of the digital radio channel for these stations was lowered by a factor of 4 to 1,042 Hz. Also, these stations used GI-50 hydrophones with sensitivity of 50 mV/Pa, with a 1 μF coupling capacitor at the output. The presence of this capacitor, on top of the input resistances of the AUAR and encoder connected in parallel, causes an additional drop in the frequency response at low frequencies. Therefore, when measuring the frequency response of these two stations, the test signal was fed to parallel-connected inputs of the encoder and AUAR through a 1 μF capacitor (Figure 2.15(b)). The results of the measurements are given in Figure 2.20.

Figure 2.20 – Frequency response of digital radio channels of DT-AUARs No. 9 and 11.

When measuring internal noise at the inputs of the encoder and AUAR, a signal was fed from the output of a dummy GI-50 hydrophone with a sensitivity of 50 mV/Pa and a grounded input (Figure 2.15(c))). The results are shown in Figure 2.21, which clearly shows the noise 'hump' characteristic of the ADC of the DAQCard-6036E. During operation, this hump migrates over the spectrum, increasing as it approaches the right side. Thus, the channel's noise characteristics when receiving weak acoustic signals can be improved either by increasing the gain scaling factor in the crate, at the cost of lowering the upper limit of the dynamic range, or by increasing the DAQCard-6036E's sampling rate, at the cost of increasing the data volume.

Figure 2.21 – Spectrum showing the internal noise of the digital radio channels of DT-AUARs No. 9 and 11.

2.3 Mollusk-07 Vertical Autonomous Acoustic and Hydrologic Recording Array

The Mollusk-07 vertical autonomous acoustic and hydrologic recording array was developed by POI for experimental studies of the spatial and temporal heterogeneities in the sound velocity field generated by subsurface waves propagating along the seasonal thermocline and by other hydrodynamic sources. A vertical array of eight hydrophones and eight temperature sensors 4.5 m apart, allows the modal composition of subsurface waves and low-frequency sound propagating in offshore areas to be studied. The Mollusk-07 allows autonomous, extended duration (more than 7 days), broadband (up to 5 kHz) measurements of sound pressure at 8 depths with coincident, synchronous measurements of water temperature at each hydrophone. This allows the position and characteristics of the seasonal thermocline to be monitored, as well as any internal waves propagating along it. The operational control of the system can be programmed in accordance with the experimental requirements developed for each experiment using the integrated on-board computer. The basic components of the Mollusk-07 are described below along with their technical characteristics, which have been confirmed by instrument tests and field measurements. Figure 1.3 shows photographs of the basic components of the Mollusk-07, and Figure 2.22 is a schematic of the deployment of the Mollusk-07 at sea.

The design of the Mollusk-07 used for the expedition includes eight hydrophones, eight temperature sensors, two depth sensors (hydrostatic pressure transducers), one current velocity transducer and one service channel for checking the power supply voltage. The mechanical structure of the Mollusk-07 is based on a standard surface buoy container and a shortened (2004) AUAR container (Figure 1.3). Two gel batteries each with a capacity of 65 ampere-hours are used to power the unit. The vertical ‘streamer’ with the sensors is constructed from geophysical cable with steel strength members and copper conductors in PVC insulation. Power is supplied from the bottom container to the top hardware container with an identical cable to a T-AUAR; this provides the strength necessary for the entire vertical acoustic and hydrologic array. The Mollusk-07 is deployed using a 75-kg disposable anchor, which separates from the Mollusk-07 using an acoustic release when the system is recovered.

Legend:
Г.1–Г.8 – hydrophones
Т.1–Т.8 – temperature sensors
Д.1, Д.2 – pressure sensors
V – current velocity transducer modules

Figure 2.22 – Diagram showing deployment of the Mollusk-07 at sea.

A built-in Prometheus computer controls multiplexing and digitization of the acoustic signals, as well as buffered recording to the hard drive. The system can record frequencies up to 5 kHz. A single hydrophone and preamplifier from the Mollusk-07 was calibrated (to 5 kHz) at the All-Russian Scientific Research Institute of Physico-technical and Radio-technical Measurements (VNIIFTRI) in 2007. The endurance of the Mollusk-07 when powered by a battery compartment with two 65 ampere-hour batteries is at least seven days. A detailed description of the basic components of the unit and the results of laboratory tests of the Mollusk-07 system are given in [Borisov et al., 2008].

Figure 2.23 – Rapid response current velocity and orientation sensor.

The Mollusk-07 is additionally equipped with a current velocity sensor (Figure 2.23). The sensor operates on the change in resistance of the seawater in a gap in the sensor when the blade of a rotor passes through it. The sensor operates on alternating current, which is generated by a peripheral controller. After initial analog processing, the signal is sent in the form of voltage pulses, with frequency proportional to the current velocity, to an external interrupt input on the controller. The data are then converted to a format convenient for input, through one of the multiplexer inputs, to the 9-channel ADC Prometheus board; the data update time is 0.8 s.

2.4 Hydrologic and Bathymetric Measurements

Calibration with empirical TL data is used to enhance numerical modeling along the TL profiles. To calibrate the model along an acoustic profile, the bathymetry and hydrological characteristics (velocity, temperature and salinity) of the water layer along the profile must be known, however, the hydrological characteristics are constantly changing. Thus, to complement the TL measurements, the bathymetric profile was obtained using the ship's echo sounder and hydrological data were acquired using a hydrological sonde (Figure 2.24).

The sonde is also used to measure the hydrology in the two gray whale feeding areas on the NE Sakhalin shelf; annual hydrological observations are conducted on planned transects using this profiler. These measurements are used to assess the temporal variation in the hydrological characteristics of the feeding areas, and the effects of meteorological conditions, tidal currents, coastal upwelling, and the water inflow from the Amur estuary and Piltun Bay.

Figure 2.24 - SVXtra Hydrologic sonde being deployed from the *Akademik Oparin.*

2.4.1 Recording and Archival of Navigational and Bathymetric Information

NMEA standard format signals from the depth profiler[27] and GPS receiver[28] on the *Academik Oparin* were input into a computer. Signals from the GPS were relayed to the computer through a COM port, and a COM to USB converter and COM port emulator software was used to input signals from the depth sounder. The computer was running the ECS dKart Navigator[29] that can process and store data in NMEA format, and computes and plots the vessel's course (Figure 2.25). Navigation information (time, coordinates, depth, speed, and course (from compass)) was recorded every 10 seconds. The depth estimates were corrected for the vessel draft (approximately 4.5 m). These data were periodically copied to another computer, where they were archived and corrections were applied. Inaccurate or invalid values from the depth sounder and GPS were deleted and data corresponding to times when the vessel was at anchor were also deleted. Depth sounder values were tidally adjusted using POI's Bathymet program. The tidal height was estimated from comprehensive observations in the area of Piltun Bay. This theoretical estimate was subtracted from the measured depth (plus the vessel draft) to give a tide-corrected depth.

In standard practice (for marine navigation), tides are calculated relative to the lowest low water low tide (chart datum), and chart depth is displayed relative to this datum. Common practice is to tide correct the depths by adding the tidal values (from tide tables) to the chart depths. Since the tidal corrections are identical to those from tide tables the correction procedure can be considered as the adjustment of the bathymetry data to the chart datum using generally accepted navigational practice. It is therefore possible to tide-correct the bathymetric measurements by subtracting the theoretical tidal values from real measurements. This correction was applied to all bathymetry data acquired on expeditions between 2004 and 2009. The archive contains both the original and corrected data. In addition, the bathymetric data acquired using a portable depth sounder operated from a Zodiac operating at depths less than 10 m were also added to the archive.

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[27] Wesmar, operating frequency 20 kHz, beam width 7°.
[28] Furuno SPR-1400.
[29] dKart Navigator (version 6.32) is a professional navigation solution for communication with navigation equipment such as GPS, sonar, AIS, radar, compass, log etc.

Figure 2.25 – Computer display showing the navigation data for the vessel.

Bathymetry data also have errors due to surface waves and other stochastic effects. The magnitude of surface waves can be comparable to those of tides, but surface waves fluctuate much more rapidly. This effect can therefore be compensated for by averaging inside a spatial grid (i.e. all the data are divided into spatial groups and averaged). This excludes the effects of surface waves from the data as every cell of the grid contains data from different times and also compensates the bathymetry data for wind driven currents. This procedure will be applied to bathymetric data acquired in the field. Further data processing and visualization will be performed using Surfer. If uncorrected bathymetry is required for a specified time a back correction can be applied (i.e. theoretical tidal value can be added to the corrected data).

3 AMBIENT AND ANTHROPOGENIC ACOUSTIC NOISE ON THE NE SAKHALIN SHELF

This section analyzes the ambient noise measurements recorded in 2009 and discusses the temporal and spectral variation in ambient noise with meteorological conditions and Sea State. The ambient sound levels are also compared with those generated by anthropogenic activities. In 2009, as in the previous years, acoustic data were recorded using AUARs, and ambient noise data were acquired at monitoring stations across the area (Table 1.1 and Figure 1.5).

3.1 Acoustic Noise Recorded in the North and the South of the Study Area

Previous reports have discussed the variation in ambient noise due to wind, surface waves and rain. For example, the broadband noise level near Chayvo rose by 12 dB when the sea state increased from 1 (calm) to 4 (moderate) [Borisov et. al. 2003]. A rainstorm with strong wind squalls pushed the ambient noise level an additional 16-18 dB higher. For frequencies above 2.5 kHz the spectral level of ambient noise recorded during a storm had a peak value of ~64 dB re 1 μPa^2/Hz (56 dB re 1 μPa^2/Hz for a storm without rain). Spectral analysis of the data acquired in 2003 showed that the sound field in the frequency band from 200-800 Hz generated by an approaching storm had the clear interference structure resulting from waveguide propagation on the shelf [Borisov et. al. 2004]. The data showed that noise produced by wind and surface waves is much lower for shallow water (10 m) than for areas outside the 20 m contour. The highest ambient sound level was recorded in the frequency band from 200-1000 Hz. The ambient noise in this frequency band had a peak value of 71 dB re 1 μPa^2/Hz during a storm and 46 dB re 1 μPa^2/Hz in calm weather (no rain).

Meteorological conditions in the summer and fall of 2009 were unstable. Figure 3.1 shows a sonogram of acoustic data recorded at the A9 monitoring station (10 m depth - located in the North of the Piltun feeding area) from 14th June to 23rd September 2009. A passing cyclone brought winds and generated surface waves that produced broadband noise and orbital motion of the water particles; this caused flow noise at, and physical movement of the hydrophone. During this period and other occasional weather events, as can be seen on the sonogram of Figure 3.1 the power spectral density level for frequencies below 10 Hz exceeded 120 dB re 1 μPa^2/Hz. Additionally, narrow band components are present in the spectra due to resonant vibrations of, for example, the hydrophone suspension.

Figure 3.1- Sonogram *G(f,t)* of acoustic data recorded at the A9 monitor station from 14th June to 23 September 2009.

Flow noise marks periods of high tidal currents, cyclones (24th-25th June, 21st-24th August, 21st-23rd September) and heavy swell from the Sea of Okhotsk (7th July, 9th-10th August). Despite a deliberate low frequency reduction in the AUAR analog channel frequency response, sudden physical motion of the hydrophone can occasionally caused clipping of the analog circuits, thus distorting the measurements at higher frequencies.

Figure 3.1 shows that over the period from 14th to 21st September strong anthropogenic noise generated by a seismic survey operation was recorded at the A9 location in September. The origin of this noise can be inferred from the periodic pattern of the levels, which rise and fall as the survey pattern takes the source closer and farther away from the receiver. The spectral density levels within the 80-250 Hz frequency band were ~30 dB higher during the close approaches than the ambient levels in the intervening quiet periods, even in the 20 min averages shown in the sonogram which do not reflect the full amplitude of the seismic pulses.

Figure 3.2 shows a sonogram of acoustic data recorded at the Lunskoye monitoring station located at the southern border of the offshore feeding area, well removed from fixed sources of anthropogenic noise. The water depth at this location is 47 m, therefore even storms and strong swell could not overdrive the analog channel of the AUAR; Figure 3.2 therefore presents power spectral density levels unaffected by signal saturation and clipping. The figure shows well pronounced low frequency flow noise generated by tidal currents. From the 5th July to the 3rd August only ambient noise was recorded, although in the period from 17th to 20th July some signals from a distant seismic survey (as determined from analysis of the original signal time series) were recorded. In the period from 13th August to 6th September sound produced by fishing boats trawling for Pollock was visible above the ambient sound level.

Figure 3.2 - Sonogram *G(f,t)* and plots of sound pressure level of acoustic data recorded at the Lunskoye monitor station.

3.2 Ambient and Anthropogenic Acoustic Measurements Near the PA-B Platform

The map in Figure 3.3 shows the locations of the acoustic stations where the measurements were made and the profiles along which anthropogenic sound generated by the platform and its supply vessels propagated. Stations PA-B-20 and PA-B-10, located at the eastern border and inside the Piltun feeding area respectively, are positioned to measure along a common propagation radial the anthropogenic noise originating at or near the PA-B platform (Figure 3.4). The side by side sonograms in Figure 3.5 provide a quantitative estimate of

temporal variations in ambient and anthropogenic acoustic levels, and their attenuation along a profile whose depth changes from 20 to 10 m over the 4 km interval from PA-B-20 to PA-B-10. The presence of significant flow-induced measurement artifacts below 20 Hz in the spectrograms shown Figure 3.5 indicates that the most accurate estimate of received broadband SPL (line plots to the right of each spectrogram) is obtained from the 20-15000 Hz frequency band (red line).

Figure 3.3 – Map showing the Pa-B and Molikpaq (PA-A) platforms and acoustic monitoring stations and acoustic monitoring stations PA-B-10, PA-B-20 and Molikpaq.

Figure 3.5 shows that acoustic levels at PA-B-20 are on average 6 dB higher than at PA-B-10. The transmission loss for sound propagating shoreward in a steadily decreasing water column depth exceeded 10 dB in the frequency range from 20-100 Hz, which caused the anthropogenic noise to drop below ambient at PA-B-10. The anthropogenic noise level at station PA-B-10 in the frequency band from 150-250 Hz, on the other hand, is above ambient in ordinary weather conditions, and only during the passage of a cyclone on 8th to 10th September ambient levels were found to exceed industrial noise in this frequency range. Figure 3.5 shows that the broadband SPL measured in the frequency range from 20-15000 Hz and averaged over 20 minutes exceeds 110 dB re 1 $\mu Pa^2/Hz$ only during brief

episodes when a passing vessel approaches closely the receiving station or during the period of sea state caused by the atmospheric cyclone.

Figure 3.4 – Platform PA-B.

Figure 3.5 - Sonogram *G(f,t)* and plots of sound pressure level of acoustic data recorded at the PA-B-10 and PA-B-20 monitor stations.

3.3 Ambient and Anthropogenic Acoustic Measurements Near the Molikpaq Platform

The acoustic monitoring station Molikpaq, located 10 km from the homonymous platform on the eastern border of the Piltun feeding area, is an important monitoring location for anthropogenic sound generated by industrial activities at the platform (Figure 3.6). Figure 3.7 gives sonograms of acoustic data recorded at this station from 11th July to 29th September 2009. Comparing these plots to those for station PA-B-20 situated 8 km from the PA-B platform the sound pressure levels in the frequency range from 20-15000 Hz at the Molikpaq station (red line on Figure 3.7) are approximately 10 dB higher and average ~110 dB re 1 $\mu Pa^2/Hz$. Figure 3.8 illustrates the presence of well pronounced narrow band components in the frequency band from 30-400 Hz that appear to be generated by the platform supply vessels and equipment on the platform itself (Figure 3.6).

Figure 3.6 – Platform Molikpaq (PA-A).

Figure 3.8 presents acoustic spectra of data recorded by the Molikpaq monitoring station in typical acoustic conditions for 2009. The plots for 14.08.2009 at 01:10 (black curve) and 22.08.2009 at 05:00 (green curve) provide a quantitative acoustic estimate for sound

generated on the Molikpaq platform at night in good weather and during a storm respectively. By comparing these curves with ambient measurements taken in 2008 at the Lunskoye monitoring station during the passage of a storm (curve 3 on Figure 3.9) it can be seen that above 300 Hz the spectral shapes are comparable, with the calm weather curve being a constant offset below the others in power spectral density. This indicates that the night time anthropogenic noise from the platform does not exceed ambient levels for frequencies above 300 Hz although it is dominates ambient noise below that frequency. The plots for 14.08.2009 at 08:00 (blue curve) and 11:35 (red curve) correspond to the most active phases of daily activities on the platform. The red plot is the most significant as narrowband levels at approximately 50 Hz reached 115 dB re 1 $\mu Pa^2/Hz$. The acoustic source cannot be identified by the spectral shape, but does not fit the pattern of a vessel passing nearby.

Figure 3.7 - Sonogram *G(f,t)* and plots of sound pressure level of acoustic data recorded at the Molikpaq monitor station.

Figure 3.8 - Spectra *G(f)* of acoustic data recorded at the Molikpaq monitor station in 2009.

Figure 3.9 - Spectra *G(f)* of ambient noise recorded at the Lunskoye monitor station both before (curve 1) and during a strong protracted typhoon in the Sea of Okhotsk (Sakhalin Island 2008).

4 ACOUSTIC MEASUREMENTS & THEORETICAL STUDIES CONDUCTED AT THE ODOPTU-N WELL SITE

Construction activities were carried out at the Odoptu North Well Site (Odoptu-NWS) and Odoptu-First Stage Production (Odoptu-FSP) areas in 2009 as part of the development of the Odoptu field. One of these activities was the installation of piles to support the camp facilities. Acoustic monitoring station Odoptu-N-20 is located at the 20 m isobath seawards from the Odoptu-NWS. Figure 4.1 shows pictures of the camp taken in 2008 and 2009.

Odoptu-N-2008

Odoptu-N-2009

Figure 4.1 - Pictures of the Odoptu-NWS located on the Piltun spit shorewards from the Odoptu-N-10 & 20 acoustic monitoring stations.

During the planning stage for the Odoptu-development it was considered that the pile installation activities could excite low frequency elastic waves in the earth; and that these could propagate as compressional or shear waves. These waves could couple into ocean due to scattering on spatial inhomogeneities and water bottom relief converting the elastic wave energy into water borne pressure waves. To estimate the level of this propagation a series experiments were designed and executed in 2006 and 2007, the results of these experiments were supported by numerical modeling. The goal of the experiments was to study and quantify the propagation of low frequency tonal signals generated on land and received at sea and vice versa [Borisov et al. 2007, 2008]. These experiments accurately predicted the propagation and attenuation of water borne tonal signals at frequencies from 18 to 33 Hz generated on land.

4.1 Analysis of the Pulses Produced at the Odoptu-NWS and Measured at Sea

Figure 4.2 gives a map of the study area showing the standard acoustic monitoring locations for the WGW program. AUARs were deployed for acoustic recording at the regular stations; A10, A9, Odoptu-N-10, Odoptu-N-20, Odoptu-S-10, Odoptu-S-20 and Odoptu-PA-B and at an additional station (Odoptu-N 8km) 8km seaward of the Odoptu-NWS. In parallel DT-AUARs were deployed at the Odoptu-N-10 and Odoptu-N-20 stations for real time measurements. Digital radio-telemetry signals from these units were received and analyzed at the Odoptu camp.

The following section describes the spectral and temporal characteristics of the low frequency pulses generated by pile installation activities at the Odoptu-NWS and measured synchronously at the stations indicated in Figure 4.2.

Figure 4.2 - Map of the study area with the locations where pulses generated by pile installation activities at Odoptu were measured. The picture on the left shows the pile hammer conducting final stage of pile installation.

Figure 4.3 to Figure 4.6 show that energy transferred through the pile couples into the ground and propagates in a form of a low frequency pulse, which couples into the water; thus ensonifying the area adjacent to the Odoptu camp. Analysis of the data allows the following conclusions to be stated:

- The low frequency pulses generated by pile installation at the Odoptu-NWS were recorded at the A9, Odoptu-N-10, Odoptu-N-20, Odoptu-S-10, and Odoptu-S-20 stations; in favorable weather and ambient noise conditions they could also be seen at the Odoptu-PA-B station. The pulses were not found in the acoustic recordings for the A10 station.
- Most of the acoustic energy generated during pile installation and propagating to the ocean propagates through the sea floor and ensonifies the area offshore of the Odoptu camp. The extent of this ensonification depends on the depth and spatial orientation of the propagation profile. For example, the distance from the Odoptu site to station A10 was 17 km and to Odoptu-PA-B was 18 km. However, the pulses were recorded at Odoptu-PA-B and not recorded at A10 despite comparable ambient noise conditions.

- The power spectral density level of the pulses at 27 Hz was more than 10 dB higher at Odoptu-N-20 than Odoptu-N-10 (Figure 4.4 and 4.5); this result concurs with the results of previous experimental studies. At frequencies above 45 Hz the spectral level *G(f)* at Odoptu-N-20 is lower than that at Odoptu-N-10 and the difference increases rapidly with frequency: for example it can reach 20 dB at frequencies between 80-170 Hz (Figure 4.4).
- Propagation in a shallow waveguide results in high cut filtering and frequencies above 35 Hz attenuate rapidly. Figure 4.5 shows that the transmission loss at 50 Hz relative to Odoptu-N-10 is -5 dB at Odoptu-N-20, -20 dB at A9, -45 dB at Odoptu-S-20 and -48 dB at Odoptu-S-10. The signal level at frequencies between 7 and 24 Hz were below 82 dB re 1 μPa^2/Hz at the Odoptu-PA-B station.

Analysis of the Odoptu data is ongoing.

Figure 4.3 - Acoustic pressure *p(t)* recorded at the water bottom by T-AUAR and AUARs deployed at the Odoptu-N-10, Odoptu-N-20 and A9 acoustic monitoring stations during pile installation operations at Odoptu.

Figure 4.4 - Spectral estimates of the signals measured at the named locations during pile installation at Odoptu-N. The dotted line shows the ambient noise recorded at Odoptu-S-20 without pile installation.

The estimates are averages of 1 s spectra smoothed in 8 Hz windows.

Figure 4.5 - Spectral estimates of the signals measured at the named locations during pile installation at Odoptu-N. The dotted line presents the ambient noise recorded at Odoptu-PA-B without pile installation.

The estimates are averages of 1 s spectra smoothed in 8 Hz windows.

Figure 4.6 - Sonogram *G(f,t)* and spectra *G(f)* of acoustic signals measured during pile installation at Odoptu. The green spectrum is the ambient noise level at Odoptu-PA-B (300 one second spectra were averaged to produce a 5 minute spectral estimate).

5 ANALYSIS OF BATHYMETRIC AND HYDROLOGIC STUDIES ON THE NE SAKHALIN SHELF

The 2009 season saw a continuation of hydrological observations in the shallow-water Piltun and deep-water offshore NE Sakhalin gray whale feeding areas. The observations were conducted both over extended areal surveys as well as along individual transects semi-perpendicular to the shoreline. Observations along standard transects through the Piltun and offshore feeding areas were planned and conducted at approximately the same times each year in order to evaluate the intra-annual variability of hydrological characteristics and to compare the year to year differences. In order to evaluate the inter-annual variability of hydrological characteristics during the summer season, hydrological data at four representative locations were acquired repeatedly throughout the season (as in previous years).

This section presents the analysis of bathymetric and hydrological measurements performed during the 2009 field season. The hydrological work on the NE Sakhalin shelf was performed with the Valeport SVXtra sonde[30] (Section 2.4 and Figure 2.24) which is equipped with temperature, conductivity, pressure and sound velocity sensors (this sonde has been used for these measurements since 2003). The expedition acquired vertical hydrologic profiles at 220 stations in 2009. These included 121 in July, 82 in August and 17 in September. At some stations, measurements were taken several times, bringing the total number of measurements to 265 (12 measurements at station 177, 12 at station 178, 20 at station 179, 4 at station 193, and 2 at station 213). The location of these hydrological stations is shown in Figure 5.1.

The oceanographic observations were conducted in the Piltun and Offshore gray whale feeding areas. Hydrological surveys and individual transects were acquired for differing summer and fall weather conditions. Repeat observations along the same profile in Piltun Bay in July and August 2009 allowed the short-term variability of hydrological parameters to be evaluated. Unfortunately, the probe was lost on 9th September 2009, and hydrological surveys could not be conducted during the autumn season.

[30] A detailed description of the sonde and its specifications is given in [Borisov et. al., 2006]; the calibration certificates are on the DVD in the back of this report.

5.1 Meteorological Conditions Observed in the Study Area in 2009

Before proceeding to a direct analysis of the hydrological data, it is valuable to discuss the peculiarities of the weather observed over the Sea of Okhotsk in 2009. Firstly, 2009 was characterized by relatively unstable weather over Eastern Siberia and the Far East. For all of June and July southerly and southeasterly winds were predominant in the Sea of Okhotsk. This atmospheric circulation pattern resulted in many foggy days near the NE tip of Sakhalin Island, with dense fog and drizzling rain prevalent in near-shore waters. In this respect, the weather in 2009 was in sharp contrast with the previous year which was characterized by clear calm weather and virtually no fog.

Table 5.1 summarizes the weather in the survey area as recorded in the log of the *Akademik Oparin.*

Figure 5.1 - Map of the NE Sakhalin Shelf showing the bathymetry of the study area and the locations where vertical hydrologic profiles were acquired.

Table 5.1 shows that in July of 2009 the predominant weather along the NE shore of Sakhalin Island was overcast days alternating with frequent foggy days. Clouds cleared in

only three cases and only one day was sunny. In August, the number of sunny days increased to five and clearing clouds were recorded on four occasions. In September there were five sunny days and nine days with intermittent clouds. Overcast weather was not conducive to local warming of the sea surface by solar radiation. The area was hit by cyclones on several occasions during the summer and the research vessel had to seek shelter twice in the Northern and Sakhalin Bays. The autumn storm of 23rd-26th September was caused by a severe cyclone hitting the Kamchatka Peninsula from the Pacific. At that time the survey area near the shore of Sakhalin Island was hit by a strong northerly wind accompanied by heavy swell.

Table 5.1: Weather Conditions in the Survey Area
Abbreviations: O – overcast; F – fog; C – clear

Day of month	July	August	September
1	-	F	C
2	-	F	C
3	-	-	C-O
4	-	-	O-F
5	-	-	O-F
6	F	-	F
7	C	-	F
8	O	C	O
9	F-O	O-C	O
10	F	C-O	O
11	O	O	O-C
12	O-F	C-O	C
13	O-C	O-F	C-O
14	F	F-O	O-C
15	F-O	O	C
16	O	O	F
17	O	O-F	F-O
18	F	F	F-C
19	O	F-O	O
20	O	F	C
21	O	O	C-O
22	F-C	O	O-C
23	O	O	C
24	F-C	C	F-O
25	O	C	O
26	F	C-O	O
27	F	O	O-C
28	F	O	O
29	O-F	O	-
30	F	C	-
31	O-F	C	

Figure 5.2 – Average daily wind speeds for the summer months of 2009. The red line is the average for each month (Orlan platform).

Figure 5.2 presents data on the speed and direction of winds during the summer period of 2009. The figure shows average daily wind speeds for the summer of 2009 (the data are averages for the period of observations – daylight hours). The red lines show the average wind speed for each month (the average wind speed for July was 6.7 m/s). For the same month of 2008, it was almost 1 m/s higher (Figure 5.3).

Figure 5.3 – Average daily wind speeds for the summer months of 2009. The red line is the average for each month (Orlan platform).

In July of 2008 southerly and westerly winds were predominant (Figure 5.4); in July 2009 northeasterly winds were often recorded in addition to steady southerlies (Figure 5.2). A westerly wind lasting only two days was also recorded. The steadiness of the southerly winds was, in turn, conducive to steady upwelling in near-shore waters.

Figure 5.4 - The wind rose (%) and maximum wind speeds (m/s) in the area of the Orlan platform in 2008. Wind directions are shown in blue and maximum wind speeds are shown in red.

In August southerly winds were still predominant, although the number of days with westerly winds increased perceptibly. In the same month, wind speeds increased significantly, too, averaging 9.6 m/s, 2.5 m/s above the average for August 2008.

In September, when the atmospheric circulation started following the winter monsoon pattern, southerly and northwesterly winds became increasingly more pronounced against the background of southeasterly winds (Figure 5.2). The average September 2009 wind speed of 9.3 m/s was 1 m/s higher than in September of 2008. The gales during the first decade of the month, topping 18 m/s, were associated with the passage of a deep cyclone along the Kuril Islands toward Kamchatka, which fueled northerly winds along the shore of Sakhalin Island.

Thus, the meteorological setting during the summer season of 2009 was characterized by overcast weather and fog governing the hydrological regime of the near-shore waters of NE Sakhalin. The wind activity in 2009 was much higher than in 2008, as demonstrated by the higher average wind speeds throughout the summer period.

5.2 Hydrological Conditions Observed Over the Study Area in July 2008

Vertical hydrologic profiles were acquired at 121 stations in July in 2009; these profiles allow in the offshore feeding area. The results of these measurements were used to plot maps of the distribution of water temperature and salinity on the surface (Figure 5.5).

Figure 5.5 - Spatial distribution of water temperature and salinity near the sea surface in July 2009 (constructed from vertical hydrologic profiles acquired between 20th and 23rd July, 2009).

The observations show that in the offshore feeding area the maximum water temperature near the surface of the sea in July did not exceed 11°C and was a minimum of 7°C. The maximum salinity near the surface was 30.5 psu (practical salinity units) and was 28.75 psu at a minimum. . High temperatures and low salinity levels were recorded in the central part

of the area farther offshore, whereas near the shore the seawater temperature was about 8°C with a higher salinity. On the whole, salinity variations at the sea surface did not exceed 1.5 psu. This trend is borne out by the distribution of both parameters over the section along latitude 52°08' N (Figure 5.6).

Figure 5.6 - Distribution of Temperature *T(r,z)* and salinity *S(r,z)* and the location of the sampling stations for a hydrologic transect near Chayvo Bay acquired in July 2009 (52º 08' N).

Figure 5.6 shows that the thermocline and halocline coincided with the 8-12 m depth interval overlying seawater with higher salinity and lower temperature. Water temperatures below 0°C were recorded in the eastern part of the section at a depth in excess of 40 m. The temperature and salinity distribution near the seafloor in the offshore feeding area, shown in Figure 5.7, indicates that low seawater temperatures were typical of the entire

area.

If the results of the July 2009 survey are compared with those of 2008 (

Figure 5.8), it is clear that 2009 was markedly colder than previous years [Borisov et.al. 2005, 2006, 2007, 2008, 2009]. This is corroborated by lower temperature highs in the section of the offshore feeding area closest to the shore and broader seafloor tracts with seawater temperature below -1°C, non-existent a year ago.

Figure 5.7 – Spatial distribution of water temperature and salinity near the sea floor in July 2009 (constructed from vertical hydrologic profiles acquired between 20th and 23rd July, 2009).

It was not possible to carry out the full scope of the hydrological observations near Piltun Bay in July 2009. During July 2009 several transects close to 53° N were acquired and these give an idea of the seawater characteristics at that time.

Figure 5.9 shows the distribution of seawater temperature and salinity along latitude 53°03' N on 29th July, 2009. Low seawater temperatures (6-7°C) were recorded near the surface, against a background of relatively high salinity (at least 30.5 psu).

Figure 5.8 – Spatial distribution of water temperature and salinity near the sea floor in July 2008 (constructed from vertical hydrologic profiles acquired between 11th and 18th July, 2008).

Low seawater temperatures near the surface stand out against temperatures below 0°C at depths below 10 m. Water temperatures below -1°C were found at a depth of about 15 m, near the shore water temperatures below 0°C were found close to the 20 m isobath.

Two thin lenses of warmer and less saline water can be discerned at the surface. They seem to be a result of small amounts of Amur River water finding their way into the survey area from Sakhalin Bay. This hypothesis is supported by a marked temporal variability of the hydrology recorded in the area. Specifically, a hydrological survey was performed in the area three days previously (Figure 5.10), this revealed a thin layer of warmer and less saline water at the surface, spread over the entire transect. In all likelihood, this lens of warm and fresher water must have dispersed without a trace three days later.

Figure 5.9 - Distribution of Temperature *T(r,z)* and salinity *S(r,z)* and the location of the sampling stations for a hydrologic transect near Piltun Bay acquired on 29th July 2009 (53º 03' N).

Observations have shown than lenses of warm water appeared near Piltun Bay on a regular basis and, depending on atmospheric circulation above the Sea of Okhotsk, they could be either in direct proximity to the shore (Figure 5.10) or farther offshore (Figure 5.11).

The presence of warm fresh water far from the shore is normal when southerly and southeasterly winds cause upwelling, where low-salinity waters near the surface find themselves at the maximum distance from the shore and cold waters with very low temperatures rise from the seafloor to near the surface close to the shore. The vertical seawater temperature distribution shows that at these times seawater with temperatures below 0°C does not form a clear cold front in the deeper part of the section anymore (unlike Figure 5.10). Under conditions of near-shore upwelling, water with temperatures below 0°C was found at depths of about 8 m (Figure 5.11), this indicates the onset of the upwelling process.

Figure 5.10 - Distribution of Temperature *T(r,z)* and salinity *S(r,z)* and the sampling station locations for a hydrologic transect near Piltun Bay acquired in July 2009.

Comparing the 2009 findings with the results of the 2008 survey, when the seawater temperature along the entire NE shore topped 13°C and the salinity was 24.0 psu, shows that the temperatures this year were much lower, whereas salinity was higher. The most likely explanation is insufficient warming of the seawater due to the shortage of sunny days in July as well as a meager discharge of the Amur River and, accordingly, an unusually (for this time of year) low influx of Amur River water into the area.

Figure 5.11 - Distribution of Temperature *T(r,z)* and salinity *S(r,z)* and the location of the sampling stations for a hydrologic transect near Piltun Bay acquired on 29th July 2009 (53° 03' N).

5.3 Hydrological conditions during August 2009

In August, the Piltun and Offshore feeding areas were both surveyed; Figure 5.12 shows the results of the survey performed between 7th and 18th August.

The seawater temperature and salinity distribution near the surface in August 2009 is quite patchy; however, Figure 5.12 is a reasonable representation of the hydrological situation in 2009. The maps show a low surface water temperature background by mid August, the limited size warm water spots represent small lenses of fresher and are caused by the influx of small amounts of discharge from the Amur River. The presence of warm water near the shore indicates that no upwelling took place during this period, the temperature and salinity distribution along the latitudinal transect through the northern part of the Offshore feeding area on 26th August 26, 2009 (Figure 5.13) also supports this analysis. Slightly above zero sea floor temperatures could be found not only near the coast, but also much farther offshore.

Figure 5.12 – Spatial distribution of water temperature and salinity near the surface in August 2009 (constructed from vertical hydrologic profiles acquired between 7th and 18th August, 2009).

Figure 5.13 - Distribution of Temperature *T(r,z)* and salinity *S(r,z)* and the location of the sampling stations for a hydrologic transect through the northern part of the offshore feeding area on 26th August 2009 (52º 30' N).

Figure 5.14 shows the distribution of near-bottom water temperature and salinity in August and also reveals the presence low absolute temperatures along the entire shoreline as well as in the offshore feeding area. In 2009 the minimum sea water temperature in the offshore feeding area was as low as -1°C.

Figure 5.15 displays 3 maps showing near-bottom water temperatures between 2004 and 2006 for comparison with 2009. These maps show that for the period between 2004 and 2009 the lowest temperatures were in 2009.

Figure 5.14 – Spatial distribution of water temperature and salinity near the sea floor in August 2009 (constructed from vertical hydrologic profiles acquired between 7th and 18th August, 2009).

In early September, a hydrological survey was acquired in the offshore feeding area (Figure 5.16). The survey shows that warm fresh waters continued to flow into the area in greater volumes than in the preceding months.

By September, sea water in the offshore feeding area already exhibits the higher temperatures (up to 11.5°C) and lower salinity (less than 27 psu) typical of discharge from the Amur River. This water occupies a rather thick surface layer, the thickness of this lens is greatest at the northern end of the transect, diminishing southward and tapering off completely at the southern end of the transect. These data indicate that the discharge from the Amur River reached its maximum effect on the hydrology of the gray whale feeding areas off NE Sakhalin only in early September.

Figure 5.15 – Spatial distribution of water temperature and salinity near the sea floor in August 2004, 2005, 2006.

It should be noted that the size of the lower salinity lens was not as large as initially suggested by the analysis of Figure 5.16. A latitudinal transect surveyed at the same time in the southernmost part of the offshore feeding area (Figure 5.17) shows that a lens of Amur River water was observed in the near-shore waters as well, however, its thickness was considerably smaller.

Unfortunately, hydrological observations in the offshore feeding area could not be continued and the results of the 6th September, the 2009 survey was compared with the data for late September of 2008; however, the time difference between the surveys should be taken into consideration. Figure 5.18 presents the 2008 data, and shows that the hydrological setting in 2009 is markedly different from that in 2008, this is especially true for the surface layer. This comparison seems to indicate that the influx of Amur River water

entering the sea of Okhotsk early in the summer season of 2009 was much smaller than in 2008. It is probable that the high water period of the Amur River occurred somewhat later in 2009.

Figure 5.16 - Distribution of Temperature *T(r,z)* and salinity *S(r,z)* and the location of the sampling stations for a hydrologic transect in the offshore feeding area on 6th September 2009.

It is likely that poor weather conditions (overcast days with frequent fog throughout the period) led to the insufficient local warming of the surface waters

5.4 Features of Near-shore Upwelling in the Summer of 2009

Upwelling near the NE shore of Sakhalin Island continued to be studied in 2009. Frequent southeasterly winds caused regular upwelling events near the shore in 2009. Several upwelling events observed in July 2009 have been discussed in the previous sections. The event of 16th July, 2009, is illustrated in Figure 5.11. This transect shows only the earliest signs of upwelling driven by southerly winds, the surface water temperature measured at a shallow-water station in this area was 2.8°C. To gain a better insight into the dynamics of upwelling, observations in these shallow waters were continued on 17th July, 2009. Several measurements were taken when the research vessel was at anchor in the area (Figure 5.19).

Figure 5.17 - Distribution of Temperature *T(r,z)* and salinity *S(r,z)* and the location of the sampling stations for a hydrologic transect through the northern part of the offshore feeding area on 6th September 2009.

Figure 5.19 shows clearly that upwelling continued to pick up momentum as shown by the decreasing absolute water temperature near the surface. Over a period of ten hours it fell from 2.5 to 0.3°C reaching sub-zero levels at a depth of 2 m. At the same time the salinity rose, giving additional evidence that cold, near-bottom waters, were rising to the surface.

Yet another upwelling event was recorded between the 22nd and 24th August, 2009, when the research vessel was sheltering from easterly winds in Sakhalin Bay. During the period between 3:45 pm on 22nd August and 4:53 am on 24th August, hydrological observations were conducted while at anchor, to determine the variability of temperature and salinity during a easterly and northerly blowing gale.

Figure 5.18 - Distribution of Temperature *T(r,z)* and salinity *S(r,z)* and the location of the sampling stations for a hydrologic transect in the southern part of the survey area on 21st September 2008.

The observations began at 3:45 on 22nd August. At that time the water in the bay had a typical muddy reddish color, the water temperature in the upper 5.5 m of the water column was 15.2°C with a salinity of 17.42 psu (Figure 5.20).

A few hours later, the wind changed direction from easterly to northerly, giving an additional boost to the upwelling. At 7:17 am the following morning (23rd August, 2009) the thickness of the warm water layer was only 2 m, whereas cold water (temperature below 0°C) was at a depth of only 6 m. The next measurement, taken one hour and twenty minutes later showed that the water temperature at the surface was only 1.33°C with a salinity of 32.02 psu. Subsequent observations indicated that the water salinity near the surface continued to increase, reaching 32.27 psu after 25 hours of observations. Cold water with a temperature of 1.8°C and a salinity of 32.14 psu persisted until the very end of the observation period.

Figure 5.19 – Water temperature and salinity observations made while at anchor in the Odoptu area (53º 15' N, 143º 17' E) on 17th July 2009.

Figure 5.20 – Water temperature and salinity observations made while at anchor in the Sakhalin Bay between 22nd and 24th August 2009.

5.5 Monitoring the Inter-annual Variation of Hydrology in the Feeding Areas

Hydrological observations to monitor the inter-annual variability of hydrological parameters in the Piltun and offshore feeding areas were continued in 2009. Hydrological data were acquired at the same locations where sampling took place in previous years. The following section discusses the results of observations in both areas for July and August 2009.

Figure 5.21 and Figure 5.22 are plots showing the vertical distribution of sea water temperature and salinity in the Piltun Bay area in July and August of 2009. Analysis of these data indicates that 2009 was a 'cold' July which is typical of the previous two years, where the hydrology is characterized by low sea water temperatures and relatively high salinity near the surface. These values lie within the typical ranges for temperature and salinity and do not stand out from the general trend for this time of year.

The range of temperature and salinity variations in the deeper layers has been rather narrow in July for the last 5 years; this indicates an inter-annual stability in the hydrological setting in this area at the onset of the summer season. Observations from 2009 are consistent with this analysis. The vertical distribution of hydrology in August 2009 shows values typical of a 'cold' August. The relatively high salinity in the surface layer stems from the low discharge of the Amur River during this time of the year. The sea floor water temperatures were at their lowest for the entire observation period, only +1.99°C, with a salinity of 32.04 psu, giving weight to the observation that August 2009 was the coldest month for sea floor water temperatures in the Piltun feeding area throughout the observation period.

Figure 5.23 and Figure 5.24 are plots showing the vertical distribution of sea water temperature and salinity in the offshore feeding area in July and August of 2009. In the month of July, none of the hydrology measured within the offshore feeding area stood out from the previous model. The relatively high salinity near the surface at this time of the year indicates that the impact of Amur River waters on the hydrological setting of the area is insignificant during the month in question.

August of 2009 turned out to be the coldest month in the offshore feeding for the entire 5 year observation period. The water temperature at the sea surface was as low as 7.69°C, which is the absolute minimum for the entire observation period, with a salinity of 31.86 psu, which is the absolute maximum for this month. High salinity near the sea surface in August was an indication that the discharge from the Amur River had an insignificant influence on the hydrology of the area in August. The sea water temperature at the sea floor of the offshore feeding area was also at its lowest throughout the observation period (0.86°C below zero with a salinity of 32.78 psu).

Figure 5.21 – Inter-annual water temperature and salinity variations in the Piltun feeding area for July.

Figure 5.22 – Inter-annual water temperature and salinity variations in the Piltun feeding area for August.

Figure 5.23 – Inter-annual water temperature and salinity variations in the offshore feeding area for July.

Figure 5.24 – Inter-annual water temperature and salinity variations in the offshore feeding area for August.

6 MAIN RESULTS

1. The POI developed digital radio-telemetry system (DRT-POI) (Section 2.2) was successfully tested in 2009. The system was used to monitor seismo-acoustic signals on the shelf in real time. The digital radio-telemetry system adapted to transmit a frequency range from 2-500 Hz, was successfully used on two autonomous underwater acoustic radio recorders (DT-AUAR) for the entire expedition. A radio receiving station was set up directly at the Odoptu camp to monitor in real time the sound generated by construction activity at Odoptu and received at DT-AUARs deployed at the Odoptu-N-10 and Odoptu-N-20 stations. .
2. During the 2009 expedition the team switched the mini-AUARs and most of the AUARs to continuous acoustic recording with no 20-minute gaps to write to disk.
3. The hydrological sonde and a digital radio buoy were lost in 2009; however, POI found the AUAR that had been installed in 2008 at the Arkutun-Dagi station and accidently caught in a bottom trawl. In 2008 after recovering the acoustic release, POI found the release (along with an anchor) 1.5 km from the deployment location. The rope connecting the anchor to the bottom container of the AUAR had been severed by the trawl.
4. The Mollusk-07 vertical autonomous acoustic and hydrologic recording array was operated effectively during the 2009 expedition. This system allows stationary synchronous measurements at eight depths, of variations in sound pressure (frequency range 10 Hz to 5 kHz) and water temperature (resolution 0.006°C) as well as current velocity and direction at one depth. POI used this system to acquire specialized acoustic measurements, obtained new current data and further evaluated the character of internal waves typical of the Northeast Sakhalin shelf.
5. The analog gain factors for many of the AUARs deployed in 2009 were increased for AUARs deployed near areas where seismic exploration was expected. Thus, POI were able to record accurately the impulsive signals generated by seismic exploration operations conducted near the study area by other companies; these signals may be analzed to assess their acoustic imprint.
6. The AUARs designed and developed at POI recorded 25,026 hours (1,043 days) of acoustic data. Acoustic monitoring was conducted from 14th June to the 28th September 2009 (Table 1.3). All the data acquired in 2009 are displayed as daily

sonograms (2 Hz to 15 kHz, 48 1-second spectral averages) and plots of sound pressure level for five frequency bands (2 Hz - 15 kHz, 20 Hz - 15 kHz, 10 - 100 Hz, 100 - 2000 Hz, 2 - 15 kHz) are on a DVD in the back of this report.

7. Eleven thousand, four hundred and thirty two (11,432) km of bathymetry data and 265 vertical hydrologic profiles were acquired in 2009. All the bathymetric data acquired from 2004 to 2009 were tide-corrected and together with hydrology data are available on the DVD at the back of this report.
8. The hydrological surveys and individual transects allowed researchers to obtain data for different meteorological conditions within the summer season.

7 CONCLUSIONS

1. The summer and fall of 2009 were marked by powerful atmospheric cyclones passing over the study area, generating high-amplitude surface waves. Therefore, the acoustic data obtained at shallow depths could be contaminated by pseudo-noise generated by water flow around the hydrophones and possibly by physical movement of the sensor, which could overload the analog recording channel of the AUAR.
2. This was the first year when acoustic monitoring stations located on the 10 m contour encountered large numbers of polychaetes and their shells tangled on the pyramids and rubber straps used to deploy the hydrophones on the bottom (Figure 1.12(a)). There was also an example when mollusks landed directly on a hydrophone (Figure 1.12(b)). This biota apparently added pseudo-noise to the acoustic measurements and must be taken into account when analyzing the acoustic data.
3. Fishermen were actively trawling for Alaskan pollack along the sea floor in the offshore gray whale feeding area during August-September 2009. Therefore the anthropogenic sound levels recorded in the 20-126 Hz frequency interval at the Lunskoye monitoring station in August were roughly 10 dB higher than they had been in July (see 75% curve). Meanwhile, the percentage distribution curves for the low frequencies showed slight upticks and peaks caused by sound generated by fishing vessels.
4. In September 2009 strong anthropogenic sound levels were regularly observed at annual acoustic monitoring station A9 (Figure 3.1). The sound was generated by a seismic exploration vessel acquiring a seismic survey. The sound level in the 80-250 Hz frequency range exceeded background levels by 30 dB, even when averaged over 20 minutes (14th-21st September).
5. At station PA-B-10 the narrow-band anthropogenic sound level at frequencies of 150-250 Hz exceeded background levels, but during a cyclone (8th-10th September) it was lower than the background level. Figure 3.7 shows that the integral levels $D(\Delta f)$ measured over the 20-15,000 Hz frequency band and averaged over 20 minutes exceeded 110 dB re 1 μPa^2 only when vessels or atmospheric cyclones were passing near the monitoring station.

6. Statistical analysis of the acoustic measurements from the Molikpaq station showed a stable 50 Hz peak in the acoustic spectrum reaching a level of approximately 113 dB per μPa^2 (Figure 3.8).
7. It should be noted that the anthropogenic noise levels in the 50-200 Hz frequency range measured at the Molikpaq station were the same in 2009 as they were in 2006 when the offshore pipeline was being constructed, in 2008 the sound levels in this frequency range were approximately 10 dB lower.
8. Monitoring of the levels of low-frequency sound generated by pile installation activities at the Odoptu camp at various distances from the coast, including measurements made with Mollusk-07 system, correlated well with the results of propagation surveys conducted along the same profile in 2006 and 2007.
9. Peak acoustic levels as high as 5.5 Pa (135 dB re 1 μPa^2) were observed at the Odoptu-N-10 site during pile installation at the Odoptu-NWS; the corresponding level was 4 Pa (132 dB re 1 μPa^2)at Odoptu-N-20 and 1 Pa (120 dB re 1 μPa^2) at station A9
10. Researchers have observed the high-frequency filtering effect when low-frequency energy is scattered and absorbed in a heterogeneous coastal waveguide: wave energy with frequencies above 35 Hz attenuates rapidly. Figure 4.4 shows that, relative to the Odoptu-N-10 monitoring station, other stations showed the following transmission losses at 50 Hz: -5 dB at Odoptu-N-20; -20 dB at A9; -45 dB at Odoptu-S-20; and -48 dB at Odoptu-S-10. Wave energy with frequencies of 7 to 24 Hz reached Odoptu-PA-B (see Figure 4.5 and 4.6) at levels under 82 dB per µPa2/Hz.
11. In 2009, researchers measured hydrological data at 220 hydrological stations (at which 265 vertical hydrologic profiles were acquired). These were used to analyze the spatial distribution and temporal variability of the hydrology. The following conclusions can be drawn from the analysis of the hydrological data:
    - The summer of 2009 was characterized by unstable atmospheric conditions with frequent fog and overcast weather that was not conducive to warming of the offshore waters.
    - Frequent southeasterly winds in 2009 caused regular upwelling events along the coast; this was not conducive to warming the water.
    - Unfavorable weather conditions and a low flow volume from the Amur River

caused the surface water temperature in the Piltun Bay area to measure only 6.02 ºC, with a salinity of 30.68 psu at the end of August. These levels are typical of a 'cold' August.

- In the Offshore area the water temperature of the surface layers in August measured 7.69 ºC with a salinity of 31.86 psu; this is also typical of a 'cold' August in the area.
- In August, the water temperature in the deepest layers of the deeper section of the offshore area reached -0.86 ºC, the lowest level measured throughout the entire observation period (2004-2009)
- The high salinity values in the surface layers of the Piltun and offshore areas during July and August indicate that waters from the Amur River had minimal influence on the hydrological conditions of the study areas. Large volumes of fresh water did not flow into the study area until early September
- When evaluating hydrological characteristics 2009 represents a typical example of a 'cold year'; this was a consequence of adverse weather conditions and low flow from the Amur River in the early summer season.

8 FUTURE PLANS

1. The 2009 field showed clearly that a weak spot of the AUAR design is the three A115 sealed gel batteries that serve as its power source. The experience gained from using these batteries in 2009 was that for unexplained reasons they lose their rated capacity, which causes a significant reduction in the operational time. JASCO associates use Duracell Type D - Procell battery modules to power their autonomous acoustic stations. Since 1999 POI has also used these batteries to power our autonomous sonobuoy systems and readio buoys as well as the mini-AUARs. However, unlike JASCO POI has been soldering the battery modules (Figure 2.11), which significantly increases their manufacturing cost. Figure 8.1 shows a schematic of a battery module for supplying power to the AUAR and DT-AUAR; this module is similar to the one used by JASCO (see Figure 8.1(b)). In 2010, Dalpribor will manufacture the first batch of these modules and POI will test them on the Sakhalin shelf during the 2010 field season.

Figure 8.1 – (a) Diagram of mechanical module for supplying power to the AUAR using Procell batteries; and (b) prototype of the module. ***The module (a) will contain 7 columns holding 5 Duracell batteries each. All batteries are connected in series. Each column has a contact at each end in the form of a stainless steel nickel-coated conical spring.***

Conical spring (14 ea)

2. The AUAR currently uses a Prometheus computer that can operate with two hard drives, but with a maximum capacity of 137 GB each. This volume (274 GB) is enough to record acoustic data for 52 days with no gaps. Three batteries with 115 A/hr capacity can provide autonomous operation for no more than 30 days. Calculations indicate that, if Duracell batteries are used to power an AUAR with two hard drives for 52 days, this will require 400 batteries. These will be loaded in modules that can easily fit in the bottom container of the AUAR's.
3. In 2010, the Prometheus' internal 16-bit analog to digital converter (ADC) will be replaced with an external 24-bit converter, which has performed well in the digital radio channel tested in 2009 (Section 2.2). With this ADC no analog gain and frequency correction will be needed, however, 24-bit data recording will fill up the 274 GB onboard memory in 36 days and require 240 batteries.
4. In 2009 the hydrological sonde (Valeport Model SVXtra Combined CTD & Sound Velocity Profiler), which had been in use since 2003 was lost. If transmission loss studies and multi-year hydrological measurements are to be continued a new sonde will need to be acquired.
5. As in 2008 detailed hydrologic profiling using the sonde and vessel sonar will be conducted in the study area. T
6. During the multiyear western gray whale program, POI has gathered a large quantity of acoustic, hydrologic and bathymetric data. POI will continue establishing a database of field data and analysis results allowing easy access and reliable storage and backup.
7. The integration between the acoustic and hydrologic studies and other components of the western gray whale research program will continue in 2010. Two integrated programs will be conducted in 2010, these are:
    - Recording of ambient and anthropogenic acoustic levels at the 10 m bathymetric contour offshore from the behavioral monitoring stations. Computation of the energy level in one minute windows over the frequency range from 20 Hz to 15 kHz for the monitoring period will be provided to the biologists for the behavioral MVA.
    - Investigation of the correlation between the spatial distribution and development of benthos and variations in the bathymetry and hydrology of the study area. The study, conducted with the benthic team will:

- Determine the size and dynamics of the discharge lens from the Amur River, where the temperature is higher and the salinity lower than the NE coast of Sakhalin Island in the Sea of Okhotsk.
- Determine the impact of the water discharge from Piltun lagoon on the salinity of the water in the near coastal Piltun area.
- Study the intensity of the tide driven (especially summer) and wind driven vertical mixing on the shallow part of the shelf.
- Determine the location and dynamics of the high density, near-bottom, and biogen rich layer formed by convection during the winter.

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11 BIBLIOGRAPHY

1. Blokhin, S.A., S.B. Yazvenko, V.L. Vladimirov and S.I. Lagerev. (2002). Population Size, Distribution and Behavior of Gray Whale (Eschrichtius robustus) Based on Aerial Observations on the Northeast Shelf of Sakhalin Island in the Summer and Fall of 2001 // Report to the conference on Marine Mammals in Remote Regions of the Arctic, September 11–13, 2002, Lake Baikal, Russia.

   Блохин С.А., Язвенко С.Б., Владимиров В.Л., Лагерев С.И. (2002). Численность, распределение и характер поведения серого кита (Eschrichtius robustus) на основании авиационных наблюдений на северо-восточном шельфе острова Сахалин летом и осенью 2001 г. // Доклад на конференции Морские млекопитающие в удаленных районах Арктики, 11-13 сентября 2002 г., озеро Байкал, Россия.

2. Borisov S.V., Kabanov N.F., Rutenko A.N. (1996). Experimental study of acoustic field fluctuations on stationary acoustic profiles. Acoustics Journal, 1996, v. 42 #3, p. 347-458.

   Борисов С.В., Кабанов Н.Ф., Рутенко А.Н. (1996). Экспериментальные исследования флуктуаций акустического поля на стационарных трассах // Акуст. журн. 1996. Т. 42. № 3. С. 347-458.

3. Borisov, S.V., A.V. Gritsenko, M.R. Jenkerson, A.N. Rutenko and A,V. Hodzevich. (2002). Evaluating and Monitoring Acoustic Transmission from the Odoptu 3D seismic Survey 5 August - 9 September, 2001; Sakhalin, Russian Federation // Pacific Oceanological Institute (FEB RAS) report for Exxon Neftegas Ltd.

   Борисов С.В., Гриценко А.В., Дженкерсон М.Р., Рутенко А.Н., Ходзевич А.В. (2002). Оценка и наблюдение распространения акустических сигналов, при проведении трехмерной сейсморазведки в районе Одопту с 5 августа по 9 сентября 2001 г. на о.Сахалин, Россия // Отчет Тихоокеанского океанологического института ДВО РАН для компании Эксон Нефтегаз Лимитед.

4. Borisov, S.V., A.V. Gritsenko, A.N. Rutenko, and A.V. Hodzevich. (2003). Results of Acoustic Studies Within and Adjacent to the Piltun-Astokh License Area 1-6 August, 2001 and 17-24 September, 2001; Sakhalin, Russian Federation // Pacific Oceanological Institute (FEB RAS) report for Exxon Neftegas Ltd. and Sakhalin

Energy Investment Co.

Борисов С.В., Гриценко А.В., Рутенко А.Н., Ходзевич А.В. (2003). Результаты акустических исследований, проведенных с 1 по 16 августа 2001 г. и с 17 по 24 сентября 2001 г. в акватории Пильтунско-астохской лицензионной зоны, а также прилегающей к ней акватории на о.Сахалин, Россия / Отчет Тихоокеанского океанологического института ДВО РАН для компаний Эксон Нефтегаз Лимитед и Сахалин Энерджи Инвестмент Компани.

5. Borisov, S.V., A.V. Gritsenko, M.V. Kruglov, R.A. Korotchenko, and A.N. Rutenko. (2003). Results of Acoustic Studies between Molikpaq and Piltun and Near Chayvo Bay, 12 September to 23 September, 2002; Sakhalin, Russian Federation // Pacific Oceanological Institute (FEB RAS) report for Exxon Neftegas Ltd. and Sakhalin Energy Investment Co.

   Борисов С.В., Гриценко А.В., Круглов М.В., Коротченко Р.А., Рутенко А.Н. (2003). Результаты акустических исследований, проведенных с 12 по 23 сентября 2002 г. на акваториях между платформой Моликпак и заливом Пильтун, и прилегающей к заливу Чайво, на о.Сахалин, Россия / Отчет Тихоокеанского океанологического института ДВО РАН, г. Владивосток, для компаний Эксон Нефтегаз Лимитед и Сахалин Энерджи Инвестмент Компании .

6. Borisov, S.V., A.V. Gritsenko, and A.N. Rutenko. (2004). Acoustic Studies on the North East Sakhalin Shelf, Volume 1: Equipment, Methodology and Data; 15 August to 20 September, 2003; Sakhalin, Russian Federation // Pacific Oceanological Institute (FEB RAS) report for Exxon Neftegas Ltd. and Sakhalin Energy Investment Co.

   Борисов С.В., Гриценко А.В., Рутенко А.Н. (2004). Результаты акустических исследований, проведенных с 15 августа по 20 сентября 2003 г. на северо-восточном шельфе о. Сахалин, Россия. Том 1: «Оборудование, методика и данные» / Отчет Тихоокеанского океанологического института ДВО РАН, г. Владивосток, для компаний Эксон Нефтегаз Лимитед и Сахалин Энерджи Инвестмент Компании.

7. Borisov, S.V., A.V. Gritsenko, A.V. Dmitrieva, A.A. Karnauhov, M.V. Kruglov and A.N. Rutenko. (2005). Acoustic Studies on the North East Sakhalin Shelf, Volume 1: Equipment, Methodology and Data; 30 July to 7 October, 2004; Sakhalin, Russian Federation // Pacific Oceanological Institute (FEB RAS) report for Exxon Neftegas

Ltd. and Sakhalin Energy Investment Co.

Борисов С.В., Гриценко А.В., Дмитриева А.В., Карнаухов А.А., Круглов М.В., Рутенко А.Н. (2005). Результаты гидро-акустических исследований, проведенных с 30 июля по 07 октября 2004 г. на северо-восточном шельфе о. Сахалин, Россия. Том 1: «Оборудование, методика и данные» / Отчет Тихоокеанского океанологического института ДВО РАН, г. Владивосток, для компаний Эксон Нефтегаз Лимитед и Сахалин Энерджи Инвестмент Компании.

8. Borisov, S.V., A.V. Gritsenko, R.A. Korotchenko, D.G. Kovzel, M.V. Kruglov, A.N. Rutenko and A.A. Solovyev. (2006). Acoustic Studies on the North East Sakhalin Shelf, Volume 2: Equipment, Calibration and Methodology; 7 July to 7 October, 2005; Sakhalin, Russian Federation // Pacific Oceanological Institute (FEB RAS) report for Exxon Neftegas Ltd. and Sakhalin Energy Investment Co.

   Борисов С.В., Гриценко А.В., Коротченко Р.А., Ковзель Д.Г., Круглов М.В., Рутенко А.Н., Соловьев А.А. (2006). Гидроакустические есследования, проведенные с 07 июля по 07 октября 2005 г. на северо-восточно шельфе о,Сахалин, Россия. Том 2: «Обороудование, калибровка и методика» / Отчет Тихоокеанского океанологического института ДВО РАН для компаний Эксон Нефтегаз Лимитед и Сахалин Энерджи Инвестмент Компани.

9. Borisov, S.V., A.V. Gritsenko, D.G. Kovzel, M.V. Kruglov, A.N. Rutenko, A.A. Solovyev, V.G. Ushipovsky and F.F. Khrapchenkov. (2007). Acoustic and Hydrographic Studies on the North East Sakhalin Shelf, 15 June to 5 October, 2006; Sakhalin, Russian Federation // Pacific Oceanological Institute (FEB RAS) report for Exxon Neftegas Ltd. and Sakhalin Energy Investment Co.

   Борисов С.В., Гриценко А.В., Ковзель Д.Г., Круглов М.В., Рутенко А.Н., Соловьев А.А, Ущиповский В.Г., Храпченков Ф.Ф. (2007). Акустико-гидрофизические исследования на северо-восточном шельфе о. Сахалин с 15 июня по 05 октября 2006 г.; о. Сахалин, Российская Федерация. / Отчет Тихоокеанского океанологического института ДВО РАН для компаний Эксон Нефтегаз Лимитед и Сахалин Энерджи Инвестмент Компани.

10. Borisov, S.V., A.V. Gritsenko, D.G. Kovzel, R.A. Korotchenko, M.V. Kruglov, A.N. Rutenko, A.A. Solovyev, V.A. Sosnin, V.G. Ushipovsky and F.F. Khrapchenkov. (2008). Acoustic and Hydrographic Studies on the North East Sakhalin Shelf, 22nd June to 15th September, 2007; Sakhalin, Russian Federation // Pacific

Oceanological Institute (FEB RAS) report for Exxon Neftegas Ltd. and Sakhalin Energy Investment Co.

Борисов С.В., Гриценко А.В., Ковзель Д.Г., Коротченко Р.А., Круглов М.В., Рутенко А.Н., Соловьев А.А, Соснин В.А., Ущиповский В.Г., Храпченков Ф.Ф. (2008). Акустико-гидрофизические исследования на северо-восточном шельфе о. Сахалин с 22 июня по 15 сентября 2007 г.; о. Сахалин, Российская Федерация. / Отчет Тихоокеанского океанологического института ДВО РАН для компаний Эксон Нефтегаз Лимитед и Сахалин Энерджи Инвестмент Компани.

11. Borisov S.V., D.G. Kovzel, A.N. Rutenko, V.G. Ushchipovsky. (2008). A self-contained hydro-acoustic station with radio channel for acoustic measurements on the shelf // Instrumental and Experimental Techniques. 2008. Vol. 51. №5. pp. 762-767.

    Борисов С.В., Ковзель Д.Г., Рутенко А.Н., Ущиповский В.Г. (2008). Автономная гидроакустическая станция с радиоканалом для акустических измерений на шельфе // Приборы и техника эксперимента. 2008. №5. С. 132-137.

12. Borisov, S.V., D.G. Kovzel, R.A. Korotchenko, A.N. Rutenko, T.V. Saltanova, V.A. Sosnin, and V.G. Ushipovsky. (2009). Acoustic and Hydrographic Studies on the North East Sakhalin Shelf, 25th June to 10th October, 2008; Sakhalin, Russian Federation // Pacific Oceanological Institute (FEB RAS) report for Exxon Neftegas Ltd. and Sakhalin Energy Investment Co.

    Борисов С.В., Ковзель Д.Г., Коротченко Р.А., Рутенко А.Н.,Салтанова В.А., Соснин В.А., Ущиповский В.Г., (2009). Акустико-гидрофизические исследования на северо-восточном шельфе о. Сахалин с 25 июня по 10 октября 2008 г.; о. Сахалин, Российская Федерация. / Отчет Тихоокеанского океанологического института ДВО РАН для компаний Эксон Нефтегаз Лимитед и Сахалин Энерджи Инвестмент Компани.

13. Brekhovskikh, L.M. and Yu.P. Lysanov. (2003). Fundamentals of Ocean Acoustics, 3rd ed. (Modern Acoustics and Signal Processing). AIP Press, Springer-Verlag.

14. Brovko, P.F. and Y.A. Mikishin. (1999). Modern tendencies in the development of the North East Sakhalin coasts // FERHRI Special Issue # 2, Vladivostok, Dalnauka, pp. 193-203.

    Бровко П.Ф., Микишин Ю.А. (1999) Современные тенденции развития берегов северо-восточного Сахалина // Гидрометеорологические и экологические

условия дальневосточных морей: оценка воздействия на морскую среду. Владивосток, с. 193-203. (Тематический выпуск № 2).

15. Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers and L. Thomas. (2001). Introduction to Distance Sampling. Oxford University Press. New York.

16. Fadeev, V.I. (2006). Benthos and food supply studies in feeding areas of the Okhotsk-Korean gray whale population. // Institute of Marine Biology (FEB RAS), Vladivostok, Russia. Final report for Exxon Neftegas Ltd. and Sakhalin Energy Investment Co. 150 p.

    Фадеев В.И. (2006) Исследования бентоса и кормовой базы в районах питания охотско-корейской популяции серого кита. // Заключительный отчет Института биологии моря ДВО РАН для компаний Сахалин Энерджи и Эксон Нефтегаз. Владивосток. 150 с.

17. Fadeev, V.I. (2007). Status of benthos and food supplies studies in feeding areas of the Okhotsk-Korean gray whale population in 2006. // Institute of Marine Biology (FEB RAS), Vladivostok, Russia. Final report for Exxon Neftegas Ltd. and Sakhalin Energy Investment Co. 122 p.

    Фадеев В.И. (2006) Состояние бентоса и кормовой базы в районах питания охотско-корейской популяции серого кита в 2006 году. // Заключительный отчет Института биологии моря ДВО РАН для компаний Сахалин Энерджи и Эксон Нефтегаз. Владивосток. 150 с.

18. Fadeev, V.I. (2008). Status of benthos and food supplies studies in feeding areas of the Okhotsk-Korean gray whale population in 2007. // Institute of Marine Biology (FEB RAS), Vladivostok, Russia. Final report for Exxon Neftegas Ltd. and Sakhalin Energy Investment Co.

    Фадеев В.И. (2008) Состояние бентоса и кормовой базы в районах питания охотско-корейской популяции серого кита в 2007 году. // Заключительный отчет Института биологии моря ДВО РАН для компаний Сахалин Энерджи и Эксон Нефтегаз. Владивосток.

19. Fadeev, V.I. (2009). Benthos studies in the feeding grounds of the Okhotsk-Korean gray whale population. // Institute of Marine Biology (FEB RAS), Vladivostok, Russia. Report for Exxon Neftegas Ltd., Yuzhno-Sakhalinsk, Russia and Sakhalin Energy Investment Co., Yuzhno-Sakhalinsk, Russia.

Фадеев В.И. (2009). Состояние бентоса и кормовой базы в районах питания охотско-корейской популяции серого кита. // Заключительный отчет Института биологии моря ДВО РАН для компаний Сахалин Энерджи. Южно-Сахалинск, Россия и Эксон Нефтегаз. Южно-Сахалинск, Россия.

20. Gailey, G., O. Sychenko, and B. Würsig. (2006). Western gray whale behavior, movement, and occurrence patterns off Sakhalin Island, 2005, Prepared for LGL ecological research associates Ltd, for Exxon-Neftegas Ltd. and Sakhalin Energy Investment Company, Yuzhno-Sakhalinsk, Russian Federation.

21. Gailey, G., T. MacDonald, R. Racca, O. Sychenko, A. Rutenko and B. Würsig. (2007). Influences of Underwater Sound and Nearshore Vessel Activity on Western Gray Whale Behavior during the Installation of a Concrete Gravity Based Structure off Sakhalin Island, Summer 2005. Prepared for LGL ecological research associates Ltd, for Exxon-Neftegas Ltd. and Sakhalin Energy Investment Company, Yuzhno-Sakhalinsk, Russian Federation. 150 pp.

22. Garrett C., Mank W. (1972). Space-time scals of internal waves // Geophys. Fluid Dyn. 1972. Vol. 3. P. 225-264.

    Гаррет С., Манк В. (1972). Временно-простраственный масштаб внутренних волн. Геофизика. Жидкостная динамика. 1972, т. 3, с. 225-264

23. Garrett C., Mank W. (1975). Space-time scals of internal waves: A progress report // J. Geophys. Res. 1975. Vol. 80. P. 291-297.

    Гаррет С., Манк В. (1975). Временно-пространственный масштаб внутренних волн: Отчет о проведенных исследованиях. Геофизика, 1975, т. 80, с. 291-297.

24. Gershanovich, D.E. and A.M. Muromtsev. (1982). Oceanological principles of the biological productivity of the world's oceans // Gidrometeoizdat, 320 pp.

    Гершанович Д.Е., Муромцев А.М. (1982). Океанологические основы биологической продуктивности Мирового океана. // Гидрометеоиздат. 320 с.

25. Hooge, P.N. and B. Eichenlaub. (1997). Animal movement extension to arcview. Ver. 1.1. Alaska Science Center - Biological Science Office // U.S. Geological Survey, Anchorage, AK, USA.

26. Karnauhov, A.A., M.V. Kruglov and A.N. Rutenko. (2005). Acoustic Studies on the North East Sakhalin Shelf, Volume 2: Analysis, Conclusions and Recommendations; 30 July to 7 October, 2004; Sakhalin, Russian Federation // Pacific Oceanological Institute (FEB RAS) report for Exxon Neftegas Ltd. and Sakhalin Energy Investment

Co.

Карнаухов А.А., Круглов М.В., Рутенко А.Н. (2005). Результаты гидроакустических исследований, проведенных с 30 по 07 октября 2004 г. на северо-восточном шельфе о. Сахалин,Россия. Том 2: «Оборудование методика и данные» / Отчет Тихоокеанского океанологического института ДВО РАН, г. Владивосток, для компаний Эксон Нефтегаз Лимитед и Сахалин Энерджи Инвестмент Компании.

27. Knudsen, V.O., R.S. Alford and J.W. Emling. (1948). Underwater ambient noise // J. Mar. Res. Vol. 7. № 3, pp. 410-429.

28. Korotchenko R.A., Saltanova T.V. (2009). Development of database of acoustical, hyrdrological, and biological data collected in course of monitoring of Western Grey Whale feeding grounds on the Sakhalin shelf. Proceedings of XII Brekhovsky seminar. Acoustics of ocean: M. :GEOS, 2009, pp. 276-279

Коротченко Р.А., Салтанова Т.В. (2009). К разработке базы акустико-гидрофизических и биологических данных мониторинга района нагула серых китов на шельфе о. Сахалин / Доклады XII научной школы-семинара им. Акад. Л.М. Бреховских «Акустика океана»: М.:ГЕОС, 2009, С. 276-279.

29. Kovzel D.G., A.N. Rutenko, and V.G. Ushchipovsky. (2008). The Mollusk-07 self-contained vertical acoustic-hydrophysical measuring system // Instrumental and Experimental Techniques. 2008. Vol. 51. №5. pp. 768-772.

Ковзель Д.Г., Рутенко А.Н., Ущиповский В.Г. (2008). Автономная вертикальная акустико-гидрофизическая измерительная система «Моллюск-07» // Приборы и техника эксперимента. 2008. №5. С. 138-142.

30. Kovzel D.G., and A.N. Rutenko. (2009). A self-contained acoustic station with f digital radiotelemetry channel for monitoring seismic acoustic signals on the shelf // Instrumental and Experimental Techniques. 2009. Vol. 52. №6.

Ковзель Д.Г., Рутенко А.Н. (2009). Автономная акустическая станция с цифровым радиотелеметрическим каналом для мониторинга сейсмоакустических сигналов на шельфе // Приборы и техника эксперимента. 2009. №6 (в печати).

31. Kovzel D.G., and A.N. Rutenko. (2009). Digital radio-telemetry system for real-time monitoring of seismic signals on oceanic shelf. Proceedings of XII Brekhovsky seminar. Acoustics of ocean: M. :GEOS, 2009, pp. 276-279

Ковзель Д.Г., Рутенко А.Н. (2009). Цифровая радиотелеметрическая система для организации в реальном времени мониторинга сейсмоакустических сигналов на шельфе / Доклады XII научной школы-семинара им. Акад. Л.М. Бреховских «Акустика океана»: М.:ГЕОС, 2009, С. 373-376

32. Krasavtsev, V.B., K.L. Puzankov and G.V. Shevchenko. (2000). Wind driven upwelling formation on the northeast shelf of Sakhalin Island. // DVNIGMI special issue No. 3, Vladivostok, Dalnauka, pp. 106–120.

Красавцев В. Б., Пузанков К. Л., Шевченко Г. В. (2000). Формирование апвеллинга на северо-восточном шельфе острова Сахалин под воздействием ветра. // Тематический вып. ДВНИИГМИ № 3. Владивосток: Дальнаука, С. 106-120.

33. Kruglov, M.V., and A.N. Rutenko. (2003). Transmission Loss Studies on the North East Sakhalin Shelf 2001 and 2002; Sakhalin, Russian Federation // Pacific Oceanological Institute (FEB RAS) report for Exxon Neftegas Ltd. and Sakhalin Energy Investment Co.

Круглов М.В., Рутенко А.Н. (2003). Исследования потерь акустических шумов, проведенные в 2001, 2002 гг. На северо-восточном шельфе о.Сахалин, Россия / Отчет Тихоокеанского океанологического института ДВО РАН для компаний Эксон Нефтегаз Лимитед и Сахалин Энерджи Инвестмент Компани.

34. Kruglov, M.V., and A.N. Rutenko. (2004). Acoustic Studies on the North East Sakhalin Shelf, Volume 2: Analysis, Conclusions and Recommendations; 15 August to 20 September, 2003; Sakhalin, Russian Federation // Pacific Oceanological Institute (FEB RAS) report for Exxon Neftegas Ltd. and Sakhalin Energy Investment Co.

Круглов М.В., Рутенко А.Н. (2004) Результаты акустических исследований, проведенных с 15 по 20 сентября 2003 г. на северо-восточном шельфе о.Сахалин, Россия. Том 2: «Анализ, выводы и рекомендации» / Отчет Тихоокеанского океанологического института ДВО РАН для компаний Эксон Нефтегаз Лимитед и Сахалин Энерджи Инвестмент Компани.

35. Kruglov, M.V., A.N. Rutenko and F.F. Khrapchenkov. (2006). Acoustic Studies on the North East Sakhalin Shelf, Volume 3: Analysis, Conclusions and Recommendations; 7 July to 7 October, 2005; Sakhalin, Russian Federation // Pacific Oceanological Institute (FEB RAS) report for Exxon Neftegas Ltd. and

Sakhalin Energy Investment Co.

Круглов М.В., Рутенко А.Н., Храпченков Ф.Ф. (2006). Гидроакустические исследования, проведенные с 07 июля по 07 октября 2005 г. на северо-восточном шельфе о.Сахалин. Том 3: «Анализ, выводы, рекомендации». / Отчет Тихоокеанского океанологического института ДВО РАН для компаний Эксон Нефтегаз Лимитед и Сахалин Энерджи Инвестмент Компани.

36. Kruglov, M.V., A.N. Rutenko and R. Racca. (2006). Estimating anthropogenic sound levels at the boundaries of gray whale feeding areas during construction and production activities on the northeastern shelf of Sakhalin Island // Ocean Acoustics / Proceedings of the 11th L. M. Brekhovskikh Conference. M.: GEOS. pp. 340-343.

Круглов М.В., Рутенко А.Н., Расчет уровней акустических шумов на границах районов кормления серых китов во время проведения строительных работ на северо-восточном шельфе о. Сахалин (2006).// Акустика океана/ Доклады на 11-ой школе-семинаре Л.М. Бреховских/ М.. ГЕОС. С. 340-343.

37. Malme, C.I., P.W. Smith Jr. and P.R. Miles. (1986). Study of the effects of offshore geophysical acoustic survey operations on important commercial fisheries in California. BBN Rep. 6125; OCS Study MMS 86-0032. Rep. from BBN Labs Inc., Cambridge, MA, for Battelle Labs, Ventura, CA, and U.S. Minerals Manage. Serv., Los Angeles, CA. 106 p.

38. Miller, J.F. and S.N. Wolf. (1980). Modal acoustic transmission loss (MOATL): A transmission loss computer program using a normal mode model of acoustic field in the ocean // Naval research laboratory, Washington.

39. Perlov, A.S. and M.K. Maminov. (2002). Population size, distribution and behavior of gray whales (Eschrichtius robustus) in the coastal waters of northeast Sakhalin in 2002 (Vessel Observations) // Pacific Oceanological Institute (FEB RAS), Vladivostok, report for Exxon Neftegas Ltd. and Sakhalin Energy Investment Co.

Перлов А.С., Маминов М.К. (2002) Численность, распределение и характер поведения серого кита (Eschrichtius robustus) в прибрежных водах северо-восточного Сахалина в 2002 г. (судовые наблюдения) // Отчет Тихоокеанского научно-исследовательского рыбохозяйственного центра, г. Владивосток, для компаний Эксон Нефтегаз Лимитед и Сахалин Энерджи Инвестмент Компании ЛТД.

40. Pishchalnik, V.M. and V.S. Arkhipkin. (1999). Seasonal variations in the circulation

of waters on the Sakhalin shelf of the Sea of Okhotsk // Hydrometeorological and Ecological Conditions of Far Eastern Seas: Assessment of Impact on Marine Environment, DVNIGMI special issue No. 2, Vladivostok, Dalnauka, pp. 193-95.

Пищальник В.М., Архипкин В.С. (1999). Сезонные вариации циркуляции вод на охотоморском шельфе острова Сахалин. // Гидрометеорологические и экологические условия Дальневосточных морей: Оценка воздействия на морскую среду. Тематический выпуск № 2. – Владивосток. Дальнаука, С. 84-95.

41. Racca. R. (2008). Acoustic Monitoring of Piltun. (2007). Offshore Construction – Summary Report Ракка и др., (2008).

42. Акустический мониторинг морских строительных операций в Пильтунском районе в 2007 году - заключительный отчет.

43. Rexstad, E. and D. Borchers. (2006). Memorandum: Western gray whale detection function and gradient // University of St. Andrews. Scotland.

44. Richardson, W.J., C.R. Greene, C.I. Malme and D.H. Thomson. (1995). Marine mammals and noise. Academic Press Limited. 576 p.

45. Rutenko A.N. (1989). Experimental study of generation of near bottom turbulence by internal waves. Journal of Marine Geophysics, 1989, v. 3, p. 58-61.

Рутенко А.Н. (1989). Экспериментальное исследование генерации придонной турбулентности внутренними волнами // Морской гидрофизический журнал. 1989. № 3. С. 58-61.

46. Rutenko A.N. (1992). Experimental data about influence of internal waves on surface waves. Methodology and equipment of hydrophysical studies of ocean. Far Eastern University, 1992, p. 12-15.

Рутенко А.Н. (1992). К экспериментальным данным о влиянии внутренних волн на поверхностные волны / В сб. «Методы и средства гидрофизических исследований океана» Изд. ДВГУ. Владивосток. 1992. С.12-15.

47. Rutenko, A.N. (2006). Acoustic Studies on the North East Sakhalin Shelf, Volume 1: Objectives and Data; 7 July to 7 October, 2005; Sakhalin, Russian Federation // Pacific Oceanological Institute (FEB RAS) report for Exxon Neftegas Ltd. and Sakhalin Energy Investment Co.

Рутенко А.Н. (2006) Гидроакустические исследования, проведенные с 07 июля по 07 октября 2005 г. на северо-восточном шельфе о.Сахалин, Россия. Том 1: «Цели и полученные данные». / Отчет Тихоокеанского океанологического

института ДВО РАН для компаний Эксон Нефтегаз Лимитед и Сахалин Энерджи Инвестмент Компани.

48. Rutenko, A.N. (2006). Effect produced on sound propagation by an internal temperature front moving over the shelf // Acoustical Physics, Vol. 52, No. 5, pp, 613-617.

Рутенко А.Н. (2006) Влияние движущегося по шельфу внутреннего температурного фронта на распространение звука // Акустический журнал Том. 52, № 5, С. 710-715.

49. Rutenko A.N., F.F. Khrapchenkov, and V.A. Sosnin. (2009). Near-shore upwelling on the Sakhalin shelf // Russian Meteorology and Hydrology. 2009. Vol. 34. №2. pp. 93-99.

Рутенко А.Н., Храпченков Ф.Ф., Соснин В.А. (2009). Прибрежный апвеллинг на шельфе о. Сахалин // Метеорология и гидрология. 2009. №2. С.44-53.

50. Thomas, L., J.L. Laake, S. Strindberg, F.F.C. Marques, S.T. Buckland, D.L. Borchers, D.R. Anderson, K.P. Burnham, S.L. Hedley, J.H. Pollard and J.R. B. Bishop. (2004). Distance 4.2. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. http://www.ruwpa.st-and.ac.uk/distance/

51. Thomas, L., Laake, J.L., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Hedley, S.L., Pollard, J.H., Bishop, J.R.B. and Marques, T.A. 2006. Distance 5.0. Release 1. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. http://www.ruwpa.st-and.ac.uk/distance/.

52. Yakovlev, Yu.M. (2003). Photo-identification of the Okhotsk-Korean gray whale population (Eschrichtius Robustus) в 2002. // Report for Exxon Neftegas Ltd. and Sakhalin Energy Investment Co.

Яковлев Ю.М. (2003). Фотоидентификация корейско-охотской популяции серого кита (Eschrichtius Robustus) в 2002 г. // Отчет для Эксон Нефтегаз и Сахалин Энерджи Инвестмент Компании.

53. Zhabin, I.A., L.N. Propp, T.I. Volkova and P.Ya. Tishchenko. (2005). Variability of hydrochemical and hydrologic parameters near the mouth of the Amur River // Okeanologiya, Vol. 45, No. 5, pp. 703-709.

Жабин И.А., Пропп Л.Н., Волкова Т.И., Тищенко П.Я. (2005). Изменчивость гидрохимических и гидрологических параметров вблизи устья реки Амур.//

Океанология, том 45, № 5, с. 703-709.

54. Marine Hydrometeorology and Hydrochemistry. Volume 9. Sea of Okhotsk. Edition 1. Hydrometeorological Conditions. St. Petersburg, Gidrometeoizdat, 1998, 342 p. Гидрометеорология и гидрохимия морей. Том 9. Охотское море. Выпуск 1. Гидрометеорологические условия. – С-Пб., Гидрометеоиздат, 1998, 342 с.

July	Lunskoye	OFA	Orlan	Arkutun-Dagi	Piltun-S	Piltun	PA-B-10	PA-B-20	Odoptu-PA-B	Odoptu-S-10	Odoptu-S-20	Odoptu-N-10	Odoptu-N-20	Control	Molikpaq	BEH-Odoptu	BEH-North
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August	Lunskoye	OFA	Orlan	Arkutun-Dagi	Piltun-S	Piltun	PA-B-10	PA-B-20	Odoptu-PA-B	Odoptu-S-10	Odoptu-S-20	Odoptu-N-10	Odoptu-N-20	Control	Molikpaq	BEH-Odoptu	BEH-North
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September	Lunskoye	OFA	Orlan	Arkutun-Dagi	Piltun-S	Piltun	PA-B-10	PA-B-20	Odoptu-PA-B	Odoptu-S-10	Odoptu-S-20	Odoptu-N-10	Odoptu-N-20	Control	Molikpaq	BEH-Odoptu	BEH-North
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Hydrophones:

1.	Certificate # 5/32-008-07	Hydrophone # GI-50	№ 25	Type GI-50 (GI-50)
		Hydrophone # GI-50	№ 28	Type GI-50 (GI-50)
		Hydrophone # GI-50	№ 26	Type GI-50 (GI-50)
		Hydrophone # GI-50	№ 29	Type GI-50 (GI-50)
2.	Certificate # 5/32-009-07	Hydrophone # GI-50	№ 41	Type GI-50 (GI-50)
		Hydrophone # GI-50	№ 43	Type GI-50 (GI-50)
		Hydrophone # GI-50	№ 44	Type GI-50 (GI-50)
		Hydrophone # GI-50	№ 45	Type GI-50 (GI-50)
3.	Certificate # 5/32-010-07	Hydrophone # GI-50	№ 32	Type GI-50 (GI-50)
		Hydrophone # GI-50	№ 34	Type GI-50 (GI-50)
		Hydrophone # GI-50	№ 37	Type GI-50 (GI-50)
		Hydrophone # GI-50	№ 38	Type GI-50 (GI-50)
4.	Certificate # 5/24-006-06	Hydrophone # GI-50	№009	Type GI-50 (GI-50)
		Hydrophone # GI-50	№011	Type GI-50 (GI-50)
		Hydrophone # GI-50	№014	Type GI-50 (GI-50)
		Hydrophone # GI-50	№016	Type GI-50 (GI-50)
		Hydrophone # GI-50	№003	Type GI-50 (GI-50)
5.	Certificate # 5/24-004-05	Hydrophone # GI-50	№004	Type GI-50 (GI-50)
		Hydrophone # GI-50	№006	Type GI-50 (GI-50)
		Hydrophone # GI-50	№018	Type GI-50 (GI-50)
		Hydrophone # GI-50	№010	Type GI-50 (GI-50)
		Hydrophone # GI-50	№008	Type GI-50 (GI-50)
6.	Certificate # 5/24-005-05	Hydrophone # GI-50	№017	Type GI-50 (GI-50)
		Hydrophone # GI-50	№023	Type GI-50 (GI-50)
7.	Certificate # 5/24-002-05	Hydrophone # Г-33	№112	Type G-33 (G-33)

Geophone type A0515 No. 12:

1. Data sheet MGFK.402152.003FO.
2. Basic specifications and acceptance certificate

SVXtra hydrologic sonde:

1.	Valeport SVXtra Calibration Certificate	SN #20797	
2.	SVXtra Instrument Test Certificate		
3.	Instrument Build and Modification Record dated May 4 2006		
4.	Conductivity Sensor Calibration record	SN #14083	Type 62R
5.	Sound Velocity Sensor Calibration record	SN # 24218	Type 100 mm
6.	Pressure Sensor Calibration record	SN # 2467935	Type PDCR4000
7.	Temperature Sensor Calibration record	SN # 1197	Type PRT 100R

Copies of these calibration certificates are in the file 'Calibration certificates (Appendix B)' on the DVD at the back of this report.

In these analyses, cumulative probability contours are used to visualize areas with the greatest likelihood of encountering gray whales, and examine shifts in the 'centers of activity' of gray whales over time[32]. Probability contours of 50% and 95% are generated to visualize the distribution of gray whales. The 50% contour represents the area within which 50% of the whales sighted are expected to be found. In 2003, the probability contours were estimated from 2003 and 2004 aerial survey data that took the survey effort into account[33] using a conventional kernel density method[34]. This kernel density method employed a square-gridding process, which is robust for small sample sizes unless the variances of the north-south and east-west components of the distribution are very different, which is the case for the Piltun feeding area.

For the Piltun feeding area the distribution of whale sightings is oriented parallel to the coast with significantly greater variance in the along-shore direction than in the perpendicular-to-shore direction. For this reason, in 2004, a grid was constructed for the Piltun feeding area that was oriented along-shore and with an along-shore grid cell dimension greater than the perpendicular-to-shore dimension, (i.e. each cell was 4 km by 0.5 km). Density was then computed for each cell as the number of whales divided by the cumulative area surveyed within the cell. The same methodology was employed for the offshore feeding area except that, in this case, the conventional assumptions about distribution were satisfied and a grid of 1 km by 1 km cells was employed.

There was substantial variation among the 2003, 2004, 2005 and 2006 estimates of the western gray whale core areas. Consequently, this analysis was updated in 2007 using all available systematic survey data. These included data from the 2001 to 2005 aerial surveys, 2002 to 2006 vessel-based surveys, 2001 to 2006 shore-based behavior scan surveys, and the 2004 to 2006 shore-based vehicle scan surveys.

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[31] This section is based on work performed by LGL Limited (Robin Tamasi, Peter Wainwright, Judy Muir, Sergei Yazvenko, Sonya Meier, and Steve Johnson).
[32] Probability contours were computed independently for the Piltun and offshore feeding areas.
[33] Density is the number of whales per unit area, multiple surveys over a grid cell can result in larger densities within that cell if the survey effort is not taken into account.
[34] The kernel density contours were mapped using the ArcView© 3.1 extension Animal Movement v2.04 [Hooge et. al., 1997]. Kernel density contours are an estimator that assesses an animal's probability of occurrence at each point in space based on a utilization distribution. It is a non-parametric estimator that has no underlying assumptions of how animals use space.

Because there are significant differences in these survey methods, it is necessary to calibrate the observations or bring them to a common standard, before performing density calculations. This was achieved by using Distance analysis [Buckland et. al. 2001] to correct for differences in the ability to detect whales, and by applying an additional correction for the probability that some whales were underwater during the survey. Details of the density calculations are as follows:

- Distance 4.2 software [Thomas et. al. 2004] was used to compute sightability functions and Effective Strip Width (ESW) for the aerial survey data set. Distance 5.0 software [Thomas et. al. 2006] was used to compute a sightability function and Effective Strip Width (ESW) for the vessel survey data. There are issues with using standard Distance analysis methodology to develop sightability functions for the shore-based surveys. In particular, the assumption that the observation stations are located randomly with respect to the whale distribution is violated because whale density is correlated with water depth. This confounds sightability functions because the variability in detections with distance may be due to effects of both changing density and sightability. The shore-based detection function was determined instead based on an analysis conducted by the University of St. Andrews that used simultaneous shore-based and ship-based sightings to estimate parameters of a shore-based detection function (Rexstad and Borchers 2006). This analysis showed that the shore-based detection function is flat (i.e. the detection probability does not decrease with increasing distance from the observation station) for up to 0.1 reticle radial distance (range 4.5 to 10.8 km) from each shore station, to a maximum of 8 km distance.
- Two grids were produced: one for the Piltun feeding area and one for the offshore feeding area.
- The Piltun feeding area grid consisted of a grid of cells oriented north/south with cell dimensions of 4-km alongshore by ½-km perpendicular to shore with an average area of 2.03 km² (standard deviation = 0.02 km²).
- The Offshore feeding area grid consisted of a grid of cells oriented north/south with cell dimensions of 1-km alongshore by 1-km perpendicular to shore with a cell area of 1.0 km² (standard deviation = 0.02 km²).
- ArcGIS v9.0 (ESRI 2005) geographic information system (GIS) software was used to construct buffers around each aerial survey transect(s) flown (1 km wide for surveys at 300m altitude and 1½ km wide for surveys at 500 m altitude) and each vessel survey transect (4.5 km wide) to represent the surveyed swathes. For shore-based stations, buffers with radius equal to 0.1 reticle radial distance (range 4.5 to 10.8 km) from each shore station, to a maximum of 8 km distance were constructed to represent the area surveyed by each station.
- These resulting buffers were then overlaid on the grid and the area of the cell within the buffer ($Area_i$) was computed. Where less than 10% of the cell area fell within the buffer it was considered inappropriate to estimate density for that cell because survey coverage was not sufficient to provide a reliable estimate of density.
- The number of whales within the buffer within each grid cell was then computed. First, the number of whales for each sighting was inflated for aerial and vessel surveys using

the appropriate sightability function to compensate for the lower probability of sighting whales at greater distances from the observer.

- Next, the inflated whale sightings were overlaid on the result of the grid/buffer overlay. This resulted in an estimate of the number of whales within the surveyed area of each grid cell ($Count_i$). Finally, density was estimated for each grid cell as the number of whales per unit area adjusted by the probability that whales were underwater during the period of the survey (*g(0)*):

$$Density = \frac{\left[\frac{Count_i}{Area_i}\right]}{g(0)} \tag{C.1}$$

  g(0) was estimated separately for each survey type and year based on 2001-2006 western gray whale surface-respiration-dive cycle behavior data, the field of view, and the aircraft or vessel speed or the rate of scanning at shore-based observation stations.

- A weighted average of the density estimates from individual surveys was then computed to obtain an overall average estimated density for each grid cell. The weightings were based on the area of the grid cell that was sampled by the individual survey.

Kernel probability densities were then computed for the Piltun and offshore feeding areas separately as follows:

- The total of the densities of all cells in the feeding area grid was computed.
- The cell data were then sorted by density in ascending order.
- *Cumulative densities* were computed for each cell by summing the densities of all preceding cells in the sorted cell density list, i.e., summing all cells with lower estimated gray whale densities.
- Kernel probability densities were then calculated for each cell by dividing the *cumulative density* of the cell by the total of the feeding area grid densities, expressed as a percentage.
- Finally, the ArcGIS Spatial Analyst extension inverse distance weighting (IDW) method with a distance threshold of 3-km was used to compute 25%, 50%, 75% and 95% probability contours for the feeding area grid. These contours were then used in combination with the kernel probability density grid cells to manually delineate smoothed 50% and 95% probability contours for the feeding area.

Appendix D - Cross-calibration Results

At the start of the 2009 expedition a cross-calibration of the sixteen AUARs and six mini-AUARs used during the 2009 field program was conducted on the *Akademik Oparin*. The purpose of these calibrations was to confirm the absolute calibration[35] of all the recording systems by comparing the acoustic spectra of synchronously measured signals. All AUARs were calibrated by comparing the synchronous spectra of broadband and tonal signals generated by the *Akademik Oparin* and the HF broadband sound transducer. All spectra were corrected for amplitude and frequency (using the instrument response of each system determined by instrument tests in the laboratory), so the absolute acoustic level of the signal was calculated for the specified frequencies.

The field cross-calibration was conducted by tying a number of hydrophones together in a bundle, and deploying them from the *Akademik Oparin* at a depth of 10-15 m while it was drifting in greater than 100 m of water. The hydrophones were divided into groups (Figure D.1) due to the large number of hydrophones being calibrated. One mini-AUAR (No. 23) was used as a control for all the groups. The AUARs on the *Akademik Oparin* synchronously recorded the signals from these hydrophones. The purpose was to simultaneously record the same signal on all the units, allowing the relative calibrations of the AUARs to be confirmed. Data was recorded using the operational configurations for the equipment. The methodology described by Borisov [Borisov et. al., 2006, 2007] was used to calculate the relative error for each AUAR. The results from these measurements are given in Figures D.2 to D.7 and Tables D.1 to D.5.

[35] These cross-calibrations allowed the amplitude response (with frequency) of the analog circuits of the AUARs and sonobuoys to be compared with the laboratory measurements. They also allowed the manufacturer's hydrophone calibrations to be confirmed.

Figure D.1 – Cross-calibration of the AUARs and sonobuoys on the *Akademik Oparin.*

Figure D.2 - Spectra of acoustic signals synchronously measured by AUARs No. 3, 4, 5, 6, and the reference mini-AUAR No. 23 (after instrument response [amplitude-frequency] correction). (a) 10 Hz-15 kHz; (b) 10 Hz-1 kHz; (c) 1-15 kHz.

Figure D.3 - Spectra of acoustic signals synchronously measured by AUAR No. 7, 8, 9, 11, and the reference mini-AUAR No. 23 (after instrument response [amplitude-frequency] correction).
(a) 10 Hz-15 kHz; (b) 10 Hz-1 kHz; (c) 1-15 kHz.

Figure D.4 - Spectra of acoustic signals synchronously measured by AUARs No. 13, 16, 17 and 19, and the reference mini-AUAR No. 23 (after instrument response [amplitude-frequency] correction). (a) 10 Hz-15 kHz; (b) 10 Hz-1 kHz; (c) 1-15 kHz.

Figure D.5 - Spectra of acoustic signals synchronously measured by AUARs No. 2, 21, 26 and 27, and the reference mini-AUAR No. 23 (after instrument response [amplitude-frequency] correction). (a) 10 Hz-15 kHz; (b) 10 Hz-1 kHz; (c) 1-15 kHz.

Figure D.6 - Spectra of acoustic signals synchronously measured by mini-AUARs No. 14 and 24, and the reference mini-AUAR No. 23 (after instrument response [amplitude-frequency] correction). (a) 10 Hz-15 kHz; (b) 10 Hz-1 kHz; (c) 1-15 kHz.

Figure D.7 - Spectra of acoustic signals synchronously measured by mini-AUARs No. 14, 15, 18 and 25, and the reference mini-AUAR No. 23 (after instrument response [amplitude-frequency] correction).
(a) 10 Hz-15 kHz; (b) 10 Hz-1 kHz; (c) 1-15 kHz.

Table D.1 - Cross-calibration - statistical relative error analysis in the frequency bands 10-1000 Hz, 10 Hz to 15 kHz for AUARs No. 3, 4, 5, 6 and the reference (mini-AUAR No. 23)

AUAR #	$D(\Delta f_1)$ [dB] f_1 = 10-1000	$\sigma(\Delta f_1)$ [dB] f_1 = 10-1000	$D(\Delta f_2)$ [dB] f_2 =10Hz-15 kHz	$\sigma(\Delta f_2)$ [dB] f_2 =10Hz-15 kHz
Reference	139.5	0.3	139.7	0.2
3	139.3	0.1	139.5	0.0
4	139.1	0.1	139.3	0.2
5	139.5	0.3	139.7	0.2
6	138.8	0.4	139.2	0.3
Mean	***139.2***		***139.5***	

Table D.2 - Cross-calibration - statistical relative error analysis in the frequency bands 10-1000 Hz, 10-15 kHz for AUARs No. 7, 8, 9, 11, and the reference (mini-AUAR No. 23).

AUAR #	$D(\Delta f_1)$ [dB] f_1 =10-1000 Hz	$\sigma(\Delta f_1)$ [dB] f_1 =10-1000 Hz	$D(\Delta f_2)$ [dB] f_2 =10Hz-15 kHz	$\sigma(\Delta f_2)$ [dB] f_2 =10Hz-15 kHz
Reference	137.2	0.3	137.9	0.1
7	137.1	0.4	137.9	0.1
8	137.0	0.5	137.5	0.5
9	138.2	0.7	138.6	0.6
11	137.8	0.3	138.1	0.1
Mean	***137.5***		***138.0***	

Table D.3 - Cross-calibration - statistical relative error analysis in the frequency bands 10-1000 Hz, 10-15 kHz for AUARs No. 13, 16, 17, 19, and the reference (mini-AUAR No. 23)

AUAR #	$D(\Delta f_1)$ [dB] f_1 = 10-1000	$\sigma(\Delta f_1)$ [dB] f_1 = 10-1000	$D(\Delta f_2)$ [dB] f_2 =10Hz-15 kHz	$\sigma(\Delta f_2)$ [dB] f_2 =10Hz-15 kHz
Reference	138.4	0.3	139.0	0.5
13	137.4	0.7	137.9	0.6
16	138.2	0.1	138.3	0.2
17	137.9	0.2	138.5	0.0
19	138.5	0.4	138.7	0.2
Mean	***138.1***		***138.5***	

Table D.4 - Cross-calibration - statistical relative error analysis in the frequency bands 10-1000 Hz, 10-15 kHz for AUARs No. 2, 21, 26, 27 and the reference (mini-AUAR No. 23).

AUAR #	$D(\Delta f_1)$ [dB] f_1 = 10-1000	$\sigma(\Delta f_1)$ [dB] f_1 = 10-1000	$D(\Delta f_2)$ [dB] f_2 =10Hz-15 kHz	$\sigma(\Delta f_2)$ [dB] f_2 =10Hz-15 kHz
Reference	135.7	0.0	136.5	0.3
2	136.2	0.5	137.3	0.5
21	134.9	0.8	136.0	0.8
26	136.1	0.4	137.1	0.3
27	135.7	0.0	136.9	0.1
Mean	***135.7***		***136.8***	

Table D.5 - Cross-calibration - statistical relative error analysis in the frequency bands 10-1000 Hz, 10-15 kHz for mini-AUARs No. 14, 24, and the reference (mini-AUAR No. 23)

AUAR #	$D(\Delta f_1)$ [dB] f_1 = 10-1000	$\sigma(\Delta f_1)$ [dB] f_1 = 10-1000	$D(\Delta f_2)$ [dB] f_2 =10Hz-15 kHz	$\sigma(\Delta f_2)$ [dB] f_2 =10Hz-15 kHz
Reference	134.8	0.8	140.9	0.0
14 (mini)	136.0	0.4	141.5	0.6
24 (mini)	136.0	0.4	140.3	0.6
Mean	***135.6***		***140.9***	

Table D.6 - Cross-calibration - statistical relative error analysis in the frequency bands 10-1000 Hz, 10-15 kHz for mini-AUARs No. 14, 15, 18, 25 and the reference (mini-AUAR No. 23).

AUAR #	$D(\Delta f_1)$ [dB] f_1 = 10-1000	$\sigma(\Delta f_1)$ [dB] f_1 = 10-1000	$D(\Delta f_2)$ [dB] f_2 =10Hz-15 kHz	$\sigma(\Delta f_2)$ [dB] f_2 =10Hz-15 kHz
Reference	131.3	0.3	137.5	0.5
14 (mini)	131.0	0.0	135.8	1.2
15 (mini)	130.8	0.2	137.7	0.7
18 (mini)	130.7	0.3	136.3	0.7
25 (mini)	131.0	0.0	137.7	0.7
Mean	***131.0***		***137.0***	

Tables D.1 to D.6 give an analysis of power spectral density levels for the two frequency bands (10 Hz to 1 kHz and 10 Hz to 15 kHz) and the calibration error from the mean for the two frequency bands. As can be seen the maximum absolute error for any AUAR from the mean is 0.8 dB in the frequency band from 10 to 1000 Hz and less than 1.2 dB between 10 Hz and 15 kHz[36]. This is within the expected relative error limits for the equipment and the absolute calibration of the data was therefore confirmed.

[36] The highest errors were due to the low level of the calibration signal at low frequencies. These signals are measured approximately synchronously by the AUAR. Also certain field inaccuracies are present in the cross-calibration measurements; the acoustic measurements are not synchronous (the hydrophones are in different position in the bundle and may mask each other), these errors are not large enough to invalidate the results).