Shapinsay Sound Tidal Test Site: Acoustic Characterisation

Final Report, January 2013
(E.J.Harland)
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Contents

1. Executive Summary

Chickerell BioAcoustics was contracted by the European Marine Energy Centre (EMEC) to carry out work to characterise the ambient noise field at the Shapinsay Sound tidal energy test site in Orkney, UK. The project was funded by the Scottish Government.

The scope of the project was to assess the methodology and equipment specified for measuring acoustic noise at EMEC's main grid-connected tidal test site and advise on its suitability for use at the nursery tidal test site, and to train EMEC staff in the use of the recommended methodology and equipment for collecting acoustic data at the site. The project called for three surveys to be carried out using the selected methodology and equipment. Data collected from the surveys were analysed and used to characterise the ambient acoustic baseline for the site. The results of these analyses will be made available to developers testing tidal energy converter devices at the Shapinsay Sound test site, to assist with the acoustic characterisation of their devices. The characterisation of noise from specific devices operating at the test site was out-with the scope of this project.

The work involved carrying out a number of surveys through autumn and winter 2011-2012 with each survey covering a range of tidal and weather conditions. Initial surveys were carried out using the existing EMEC 'Drifting Ears' hydrophone equipment but later surveys used an upgraded system, the Drifting Acoustic Recorder and Tracker system developed by Chickerell BioAcoustics and EMEC.

The results of analysing the data collected show that ambient noise levels were in line with that which could be expected for this type of shallow water site, with anthropogenic noise (from shipping and a 'seal scarer') being the major contributors to the ambient noise field. Other significant contributions to the noise field include noise from aircraft, chains, rain, wind, and waves. No sources of noise associated with strong tidal flow across bathymetric features were identified, and no geographical variation in noise level was observed.

2. Introduction

This report has been produced for the European Marine Energy Centre (EMEC), Orkney, UK as part of a contract with Chickerell BioAcoustics, Dorset, UK. The work is funded by the Scottish Government and aims to characterise the ambient acoustic noise signature at the EMEC nursery tidal test site at Shapinsay Sound, Orkney. This work will provide an acoustic baseline to aid future developers of Tidal Energy Convertor (TEC) devices deploying at the site to characterise the acoustic output of their devices. The work was carried out by Chickerell BioAcoustics working with EMEC staff.

Measurements were made between September 2011 and May 2012 using drifting acoustic recorders, with data collected over a range of tide, sea and meteorological states. The data were then analysed and reported in a manner suitable to form an acoustic baseline reference for the site.

There is currently no formal methodology which can be used to characterise the ambient noise field at shallow water sites. A number of international committees are attempting to address this issue but it is unlikely that a standardised procedure will be available in the near future. This study presents the noise spectrum to be expected under the quietest conditions and then looks at contributions that add to that baseline noise field.

This report outlines the expected acoustic characteristics of the Shapinsay Sound test site, describes the methods used to collect the data, and presents the results of the data analyses. A discussion on the collected data with recommendations for future work is also included.

3. Review of the Shapinsay Sound Tidal Test Site

3.1 Physical Characteristics

The EMEC nursery tidal test site is located in Shapinsay Sound to the north - east of Kirkwall, between the Orkney Mainland and the island of Shapinsay. The limits of the tidal test site are shown by the red rectangle in Figure 1 below.

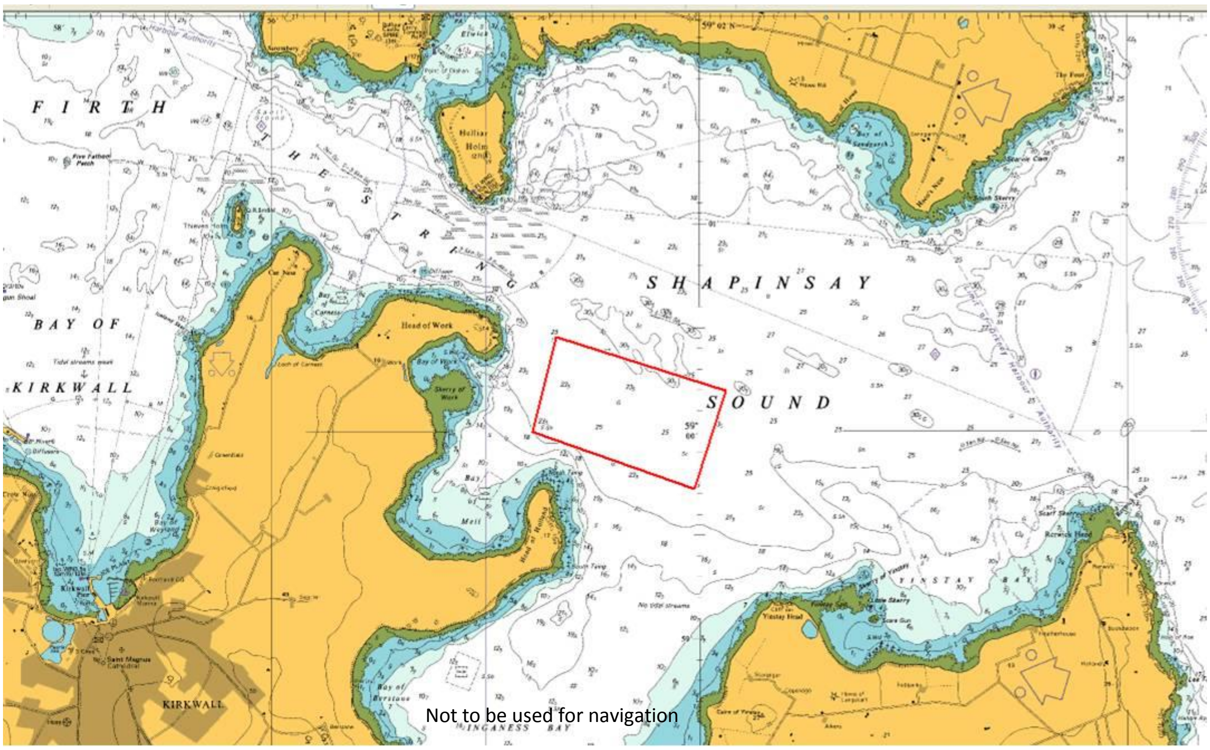

Figure 1. Location of the Shapinsay Sound test area

The water depth is around 25 metres and the seabed a mixture of gravel and stone, with sand and shingle inshore of the site. The main tidal flow is through the String, the area of water between the Head of Work on Orkney Mainland and Helliar Holm on Shapinsay. The northern part of the test site is within this main tidal flow while the south-western part of the site is in a more turbulent region with less predictable currents. The expected tidal flow through the area is zero to 0.6 - 0.75 m/s reaching up to 0.9 m/s at spring tides (1.17 – 1.46 Knots, reaching 1.75 Knots at spring tides).

A full description of the environmental aspects of the site can be found in the document "Shapinsay Sound scale site: Environmental description" (EMEC, 2011).

3.2 Acoustic aspects

The site is close to the eastern approach to Kirkwall Harbour and shipping noise will be a significant contributor to the ambient noise field. Shipping movements include various ferries, both large and small, and a variety of work boats and fishing boats. The site has an open aspect to the east and this may mean that more distant shipping will also be audible.

With the site being exposed to the east, under easterly gale conditions surf noise from the shoreline is likely to be a significant contributor to the noise field. The shoreline is mostly rocky with a few small sandy beaches apart from the more extensive sandy beaches in the southern part of the Bay of Meil and Inganess Bay. There is unlikely to be significant noise from beach material movement.

Fish farms are shown on the charts of the area and are located in the Bay of Carness, the Bay of Meil and Inganess Bay. The use of acoustic seal scarers may make a significant contribution to the noise field across the test site.

The tidal flow through the String, the western entrance to Shapinsay Sound, may be sufficient under some conditions to trigger sediment transport. This could be a major contributor to the noise field, particularly at higher frequencies.

Shapinsay Sound is likely to be used by a variety of marine mammals and their calls can be expected to add to the noise field. On-going wildlife observations carried out by EMEC from vantage points at Head of Holland and Head of Work (commenced in 2010 and currently funded by the Scottish Government) have identified four species of marine mammal as commonly present at the test site. These are grey and harbour seals, harbour porpoise and Risso's dolphins.

The ambient noise field at a site such as the EMEC Shapinsay Sound test site is not well understood. Urick (Urick, 1975) reports measurements made at various shallow water sites and also presents the well-known Wenz curves originally presented in Wenz, 1962. These curves describe the major contributors to the ambient noise field in deep water. Both of these pieces of information provides a measure of the expected sound field, but neither are directly applicable to the Shapinsay Sound test site. Various measurements of shallow water ambient noise have been made since 1975, but no one has attempted to summarise the data to describe what may be expected at a 'typical' shallow water site.

4. Acoustic Surveys

This section describes the equipment used and survey work undertaken to provide data for input to this report.

4.1 Equipment Used

A review of the equipment and methodology used to measure acoustic noise at the EMEC grid-connected test site (the Drifting Ears[1] system developed by the Scottish Association for Marine Science (SAMS) and EMEC) confirmed that this drifting hydrophone system would be suitable for use at the Shapinsay Sound test site. The initial surveys in this project used the existing Drifting Ears equipment, but the February and May 2012 surveys used the upgraded Drifting Acoustic Recorder and Tracker (DART) equipment developed by Chickerell BioAcoustics and EMEC. The general layout of the Drifting Ears system is shown in Figure 2 below. The arrangement for the DART system is very similar except that the electronics within the recording case have been upgraded to improve performance and reliability. The same methodology is used to deploy the Drifting Ears and DART systems, and this is fully described in Wilson & Carter, 2008.

The system consists of a hydrophone deployed at about 5 metres depth, cabled to a flotation buoy and thence to a water-tight recording case. The recording case has a vertical pole with a flag attached to aid tracking, and a counter-weight to keep it upright in the water. The recording case contains a recorder, GPS receiver, data storage, and batteries. The hydrophone is suspended using shock cord to provide a degree of decoupling from surface waves. The hydrophone is suspended within a drogue to ensure that the hydrophone moves with the water mass rather than wind and surface effects.

A free-drifting hydrophone package such as Drifting Ears/DART is used in sites with high tidal flows to overcome the problems of flow-induced noise in boat deployment systems, e.g. wave slap noise and cable strum, and the problems of securing and retrieving sea bed systems. They can also sample across the whole area rather than at a single point. They do have the limitation of travelling at up to 7 knots so the sample time in any one location is rather short. This can be alleviated by repeated deployments using multiple units across the area.

Data collection at the EMEC test site can only take place under the following conditions:

- Sea state must be no greater than 4
- Wind speed must be no greater than force 6
- Visibility must be at least 3 miles and forecast to stay at least 3 miles for the duration of the survey period
- All necessary safety paperwork (Method Statement, Task Risk Assessment, EMEC Permit to Work, and Notice to Mariners) has been produced and distributed appropriately

These conditions are imposed by both safety and scientific requirements.

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[1] See Wilson & Carter, 2008 for more information on the Drifting Ears equipment.

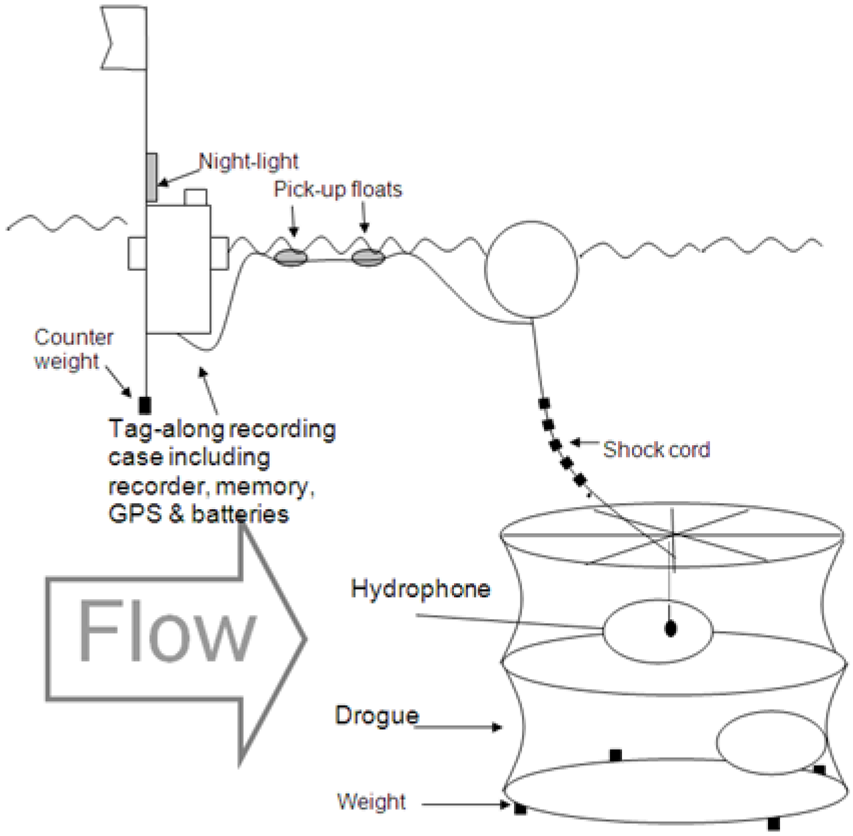


Figure 2. Components of the Drifting Ears/DART system

An initial acoustic assessment of the site was undertaken in July 2011 with the main surveys carried out in September and November 2011 and February and May 2012. Three surveys were initially planned as part of the current project, to be carried out in September 2011, November 2011 and February 2012. However, both the September and November surveys were affected by poor weather and equipment failure. The February 2012 survey was also affected by strong winds so an additional survey was carried out in May 2012.

The equipment problems encountered during the September and November surveys included issues with the various battery packs required to power the individual components of the Drifting Ears system and failure of the commercial recorder units incorporated into the system.

In the DART system, the hydrophone interface, recorder, and battery supplies have been replaced by a Wildlife Acoustics Inc. Song Meter SM2+ recording unit (SM2+) with an improved hydrophone interface. The whole system is powered by a single battery pack. The SM2+ recorder also incorporates an integrated GPS logger so that the location of the unit is recorded along with the acoustic signal rather than in a separate recorder as with Drifting Ears. The hydrophones used, a Cetacean Research C55[2], is the same for both Drifting Ears and DART, and the mounting arrangement in the drogue has also been retained to ensure compatibility between the data collected in this and previous studies. The SM2+ is capable

[2] The C55 hydrophone is a direct replacement for the C54XRS referred to in Drifting Ears documentation

of recording at a number of sample rates. For this work the sample rate was set to 48 kHz giving a bandwidth of 24 kHz.

4.2 September 2011 Survey

This survey was carried out on the 20th September 2011 using three Drifting Ears units and achieved one usable run with one of the three units providing data. The two other units suffered equipment failure.

4.3 November 2011 Survey

This survey was carried out on 14th and 16th November 2011 and achieved five deployments using 1 prototype DART unit and 3 Drifting Ears units. Of the 16 possible recordings, only 8 were successful due to equipment problems.

4.4 February 2012 Survey

Due to adverse weather this survey achieved only one run with one DART unit within the test site area. During this run the wind was measured at 19 knots average gusting to 23 knots. The wind was from the NNW. The sea state was 4 in the north of the area.

The opportunity was taken to test the new DART equipment by deploying in the northern part of Shapinsay Sound, just outside of the test site area. Only the data from run 3 (within the test site area) is used for the purposes of this report. Figure 3 below shows the tracks for the runs achieved during this survey. The labels used to identify the tracks in Figure 3 and all subsequent diagrams describe the DART unit number and the run number, eg 'D1R1' refers to DART 1, run 1.

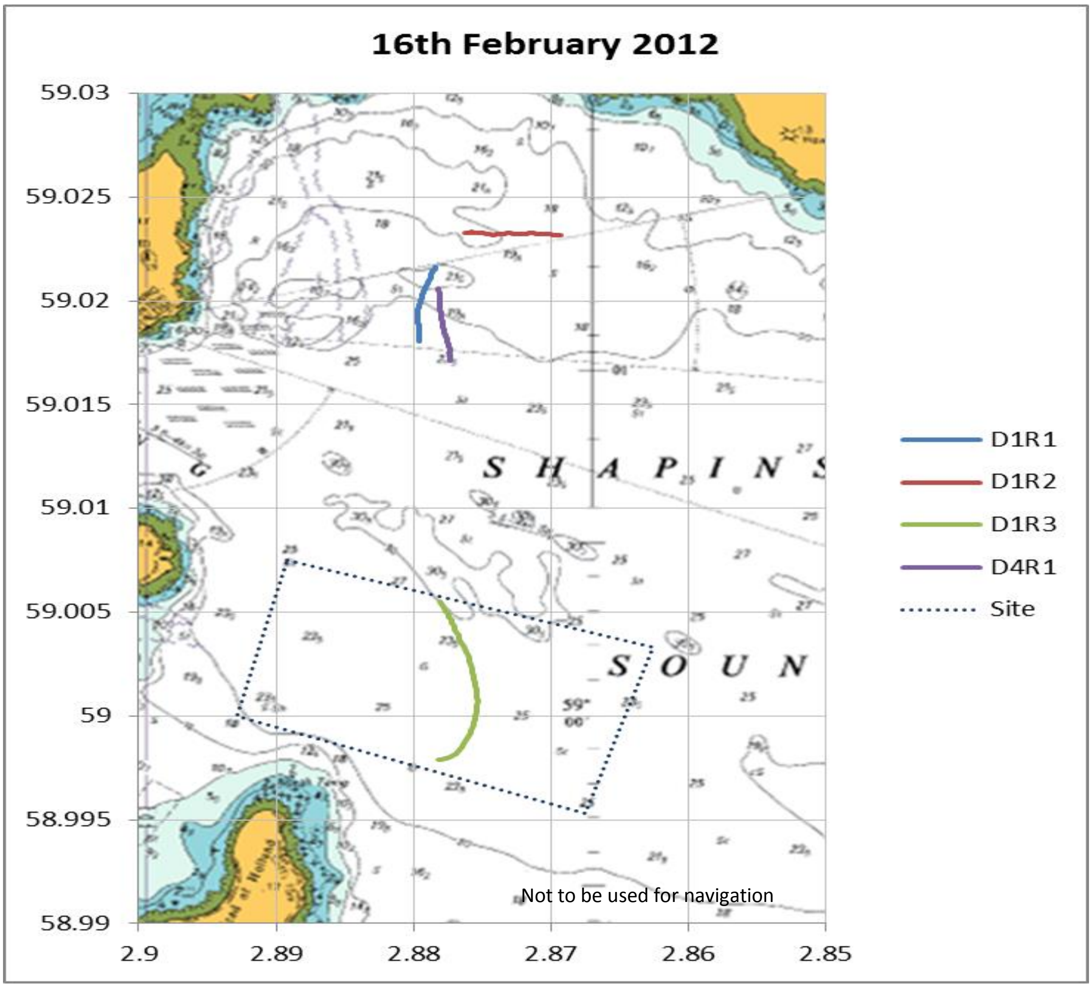


Figure 3. Tracks achieved during the February 2012 survey

4.5 May 2012 Survey

This survey took place on the 17th May 2012 with 9 runs using two DART units. All recordings were successful.

The wind was typically 8 knots gusting 12 knots at the start of the survey period increasing to 17 knots with gusts to 23 knots at the end. The wind was from the NE throughout the survey period. There was heavy rain during runs 8 and 9. The sea state was 2 at the start of the survey period, increasing to 3 by the end. Figures 4 and 5 below show the tracks achieved for the two DART units during this survey.

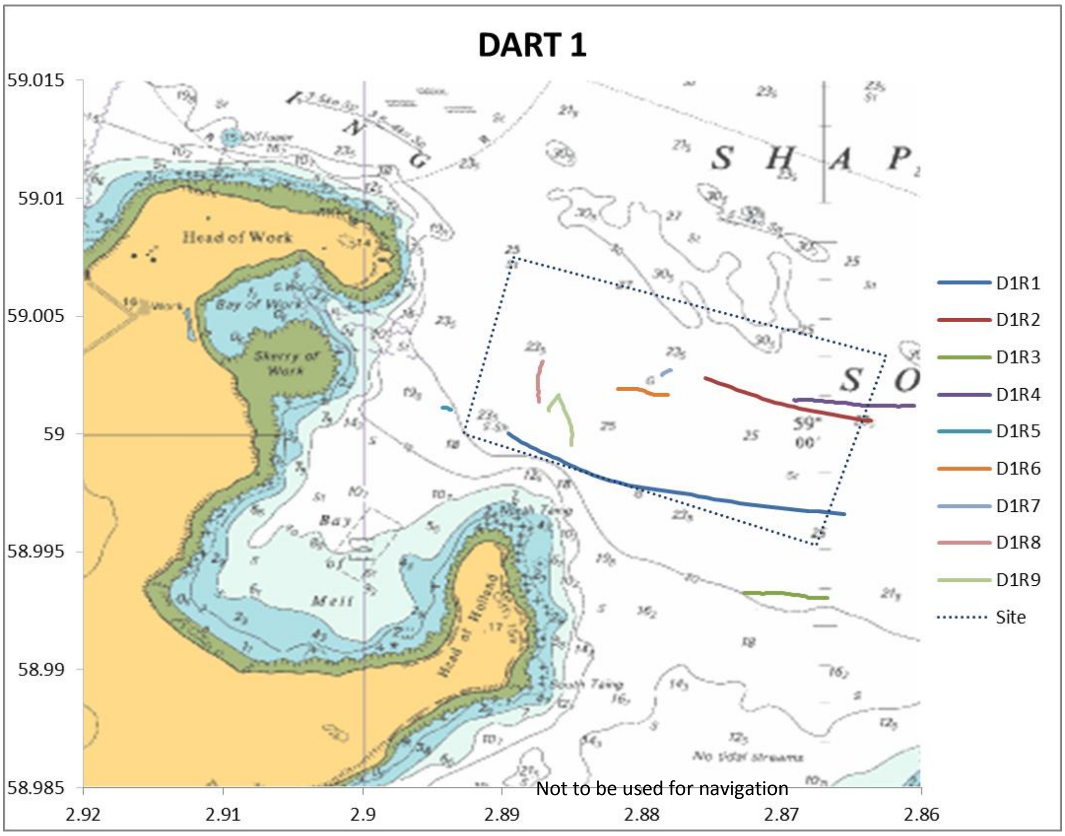


Figure 4. Tracks for DART1 during the May 2012 survey.

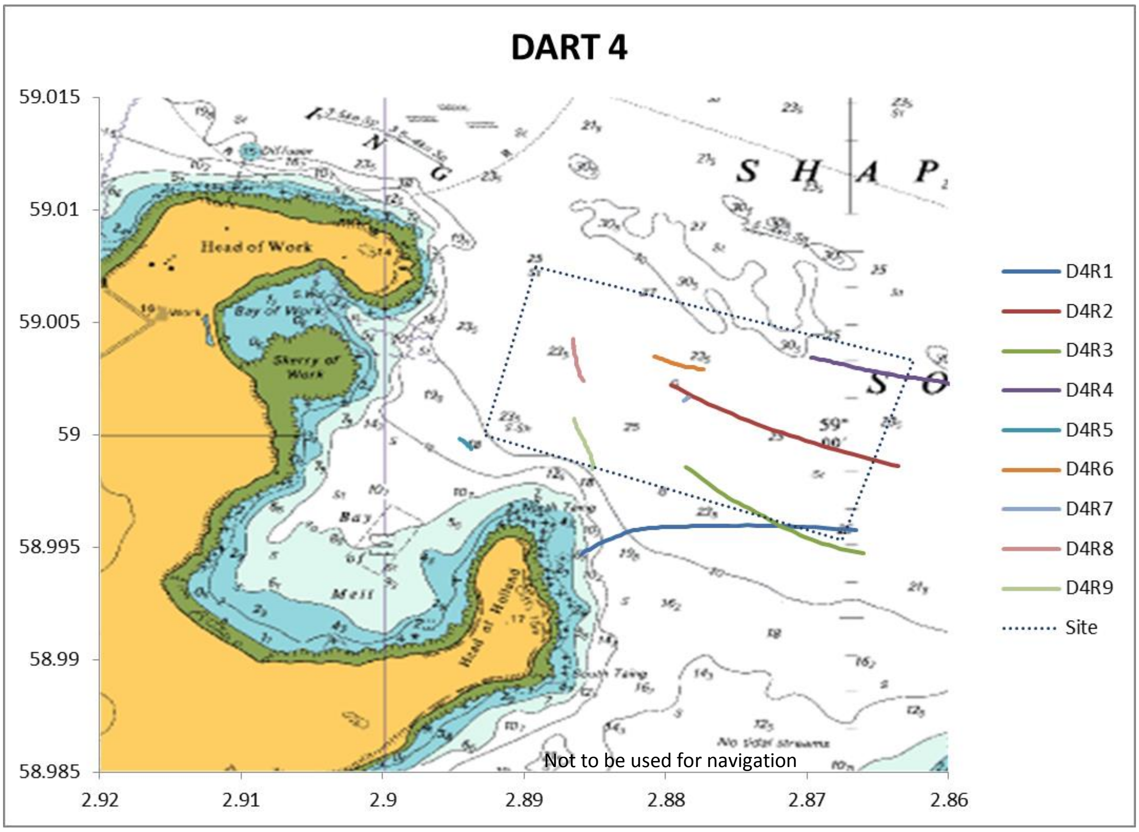


Figure 5**. Tracks for DART 4 during May 2012 survey.**

5. Data Analysis

After each survey the data collected were scanned as an initial quality check and to identify key features to be looked at in more detail in the main analyses. This showed up a number of minor problems, including bubble noise as air escapes from the drogue rings and what appear to be collisions with drifting debris. The analysis procedure used excludes these data sections when calculating mean levels and spectra.

A full analysis of the data collected during each run in the surveys is presented in appendices B and C of this report. This identified a problem with the DART 4 unit which showed higher levels of high frequency noise than expected. The cause of this should be identified and resolved before the unit is used for further work. Data from DART 4 has not been used to calculate mean spectra. However, The data is still useful when receiving high levels of sound such as the seal scarer.

5.1 Spectra and Levels

The May 2012 survey data were scanned to locate the lowest noise level in order to identify the baseline ambient noise levels at the site. The identified levels were at 5 minutes into run 2 from DART 1 (Figure 6 below). The vertical axis has been corrected with the calibration factor (described in Appendix A of this report) to give spectrum level.

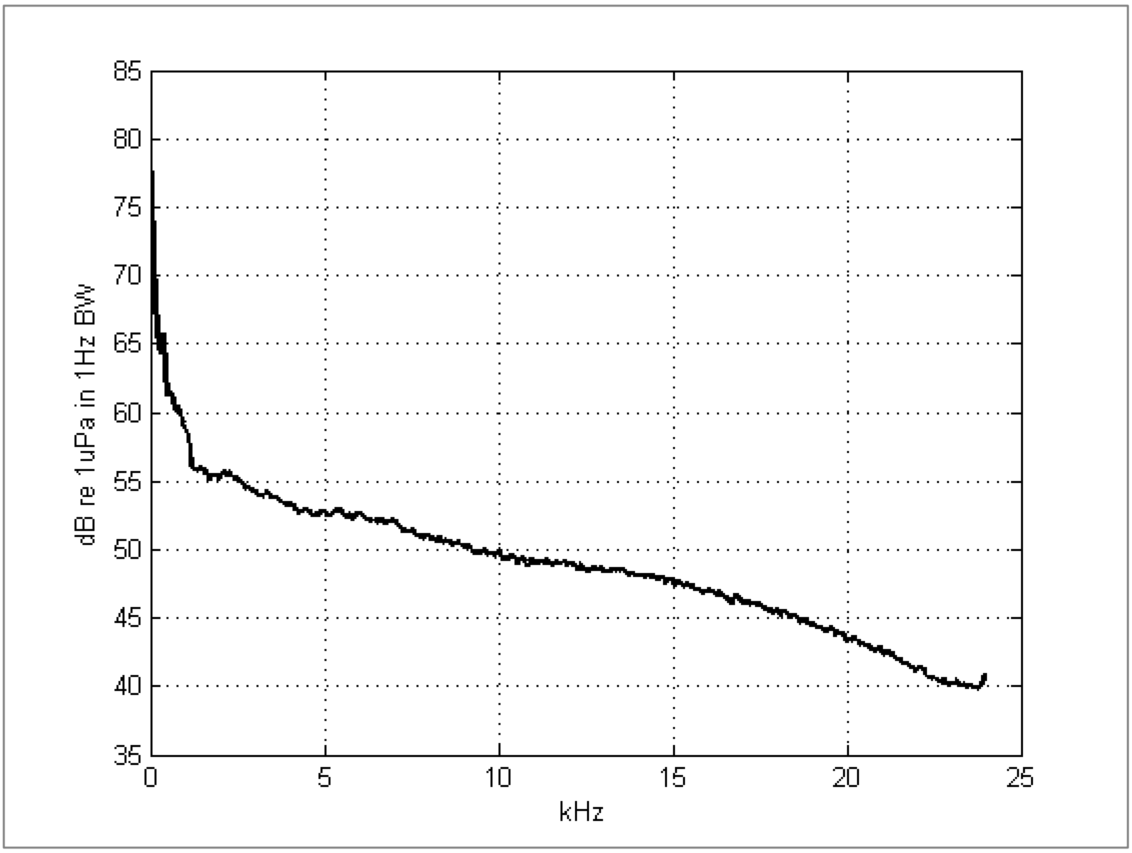


Figure 6. Lowest noise level during surveys

The increase in noise level at low frequencies is from distant boats operating in the area. Some faint wave noise can be heard at this time. Above 5 kHz the levels are similar to those suggested in Urick (Urick, 1975). Below 5 kHz they are lower than the figures reported by Urick and this likely to be due to the enclosed nature of the area.

Rain fell during runs 8 and 9 of the May 2012 survey and levels during run 9 are shown in Figure 7 below. Levels typically increased by 12 dB over the quietest noise levels. The increased levels below 1 kHz are due to a mechanical rubbing sound, most probably from the hydrophone mounting.

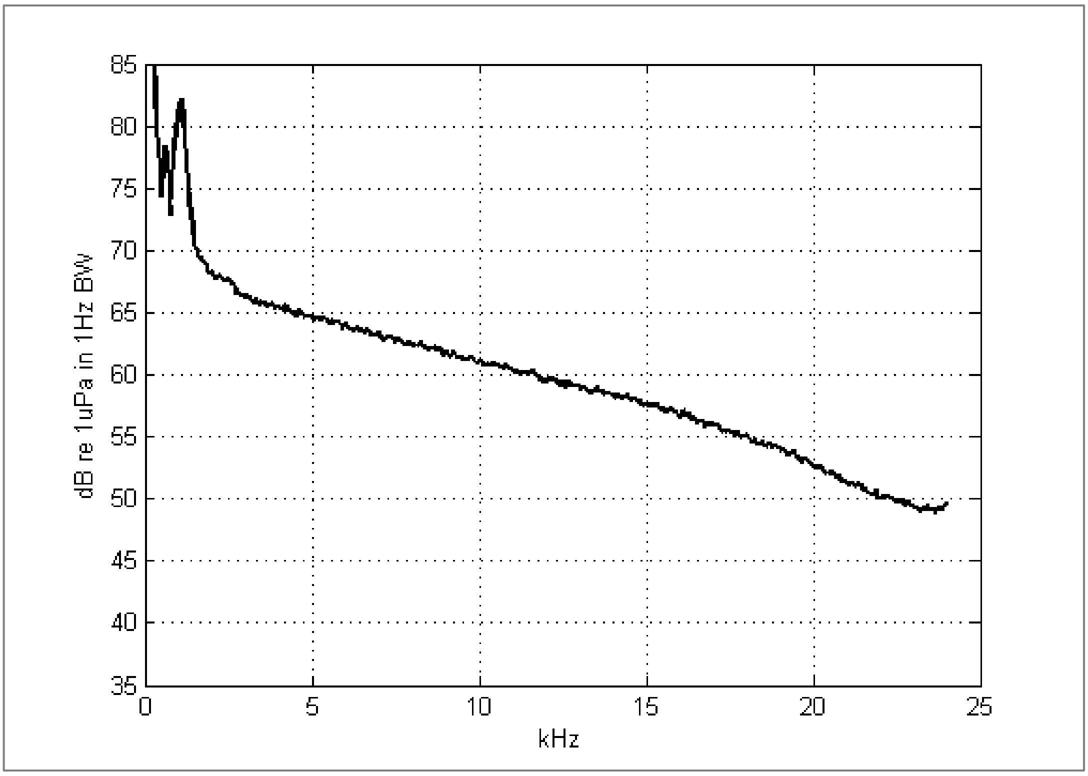


Figure 7. Noise levels during rain, DART 1, run 9.

Passing boats can cause a considerable increase in noise levels. Figure 8 below shows the level from a passing dive boat during run 4.

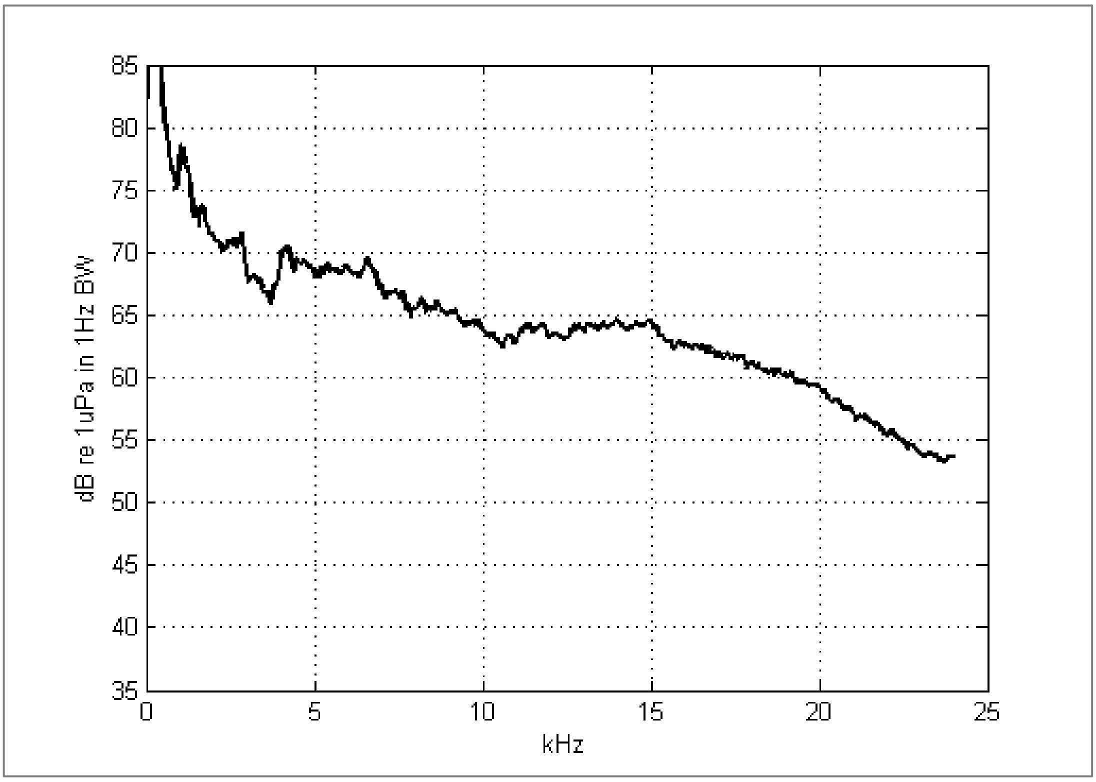


Figure 8. Boat noise from DART 1, run 4.

5.2 Variation in Sound Levels

The data for each run were processed to give sound levels in four 2 kHz bandwidths centred on 2.5, 5, 10 and 15 kHz. This data is then averaged for twenty seconds to produce the plots. The four channel plots were examined and the lowest noise levels chosen to minimise contamination from boat noise or local self-noise. These were plotted in the bar graphs in Figures 9 and 10 for DART 1 and DART4 respectively.

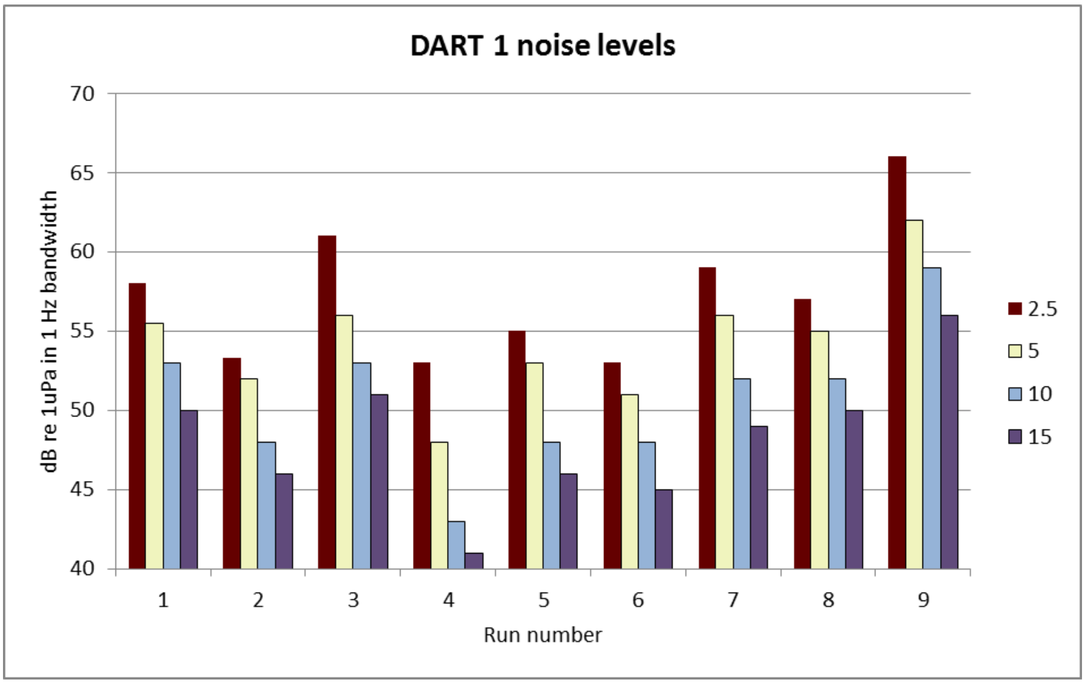


Figure 9. DART 1 lowest noise levels

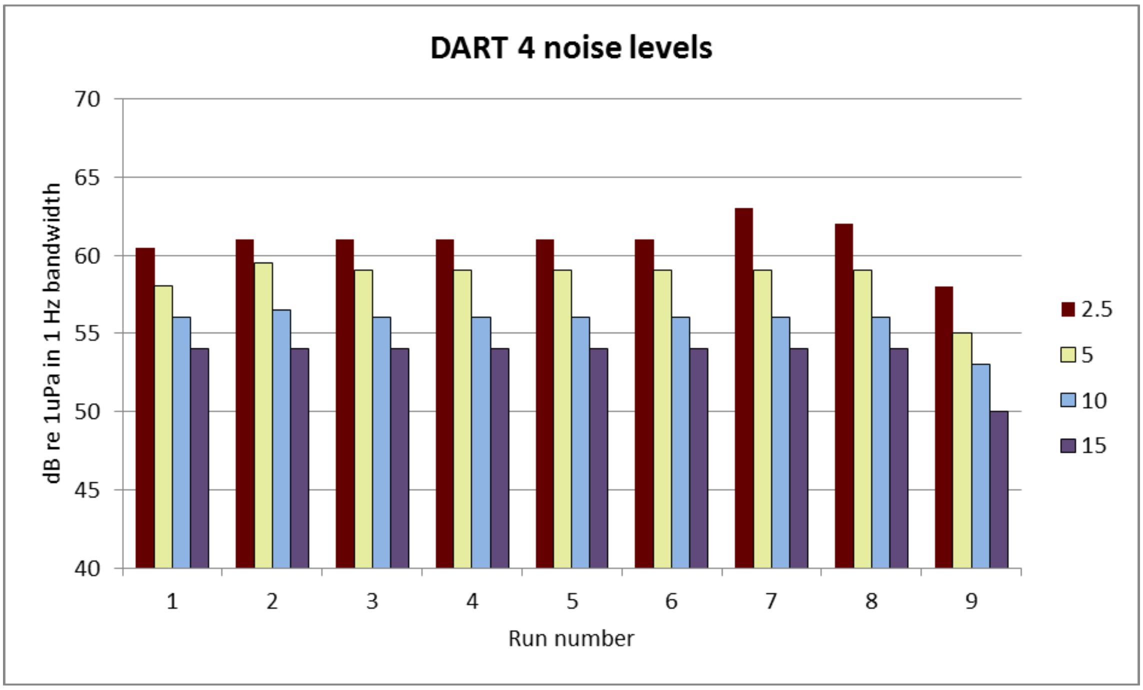


Figure 10. DART 4 lowest noise levels

The internal noise problem in DART 4 is immediately apparent as, except in the lowest frequency band, no variation in minimum noise level is observed. The variation in level in DART 1 is, with the exception of run 3 which suffered from a self-noise problem (see Appendix C), roughly consistent with drift rate and hence tidal flow rate. Runs 8 and 9 had additional noise from the rain through most of the runs but the noise level chosen is that coinciding with minimum rain noise. Further work will be required to establish a clear relationship between tidal flow and noise levels as these may well vary with location within the test area.

5.3 Dominant Components of Ambient Noise

Processing the various data files collected suggested that the following were the dominant sources of ambient noise.

Shipping noise

Shipping noise was heard for 24% of the total run time of 470 minutes during the February and May 2012 surveys. The sounds were mostly from small ships or pleasure craft. This figure is likely to be fairly representative of the area.

Airplane noise

The site lies to the north of Kirkwall Airport and planes heading to and from the northern Orkney Islands pass low over the test site. Although airborne noise does not couple well into the water, under quiet conditions the sound can be clearly heard (e.g. Appendix C run 6, May 2012 survey).

Wind and wave noise

These are likely to be major contributors to the ambient noise field on this site. Wave noise was audible during both the February and March surveys and shows as bursts of wideband noise. The noise comes from breaking waves. During the May survey the waves were small and infrequent. During rough weather the frequency and size of the breaking waves will increase. Figure 11 below shows a typical breaking wave from run 5 of the May survey. The horizontal scale is 4 seconds.

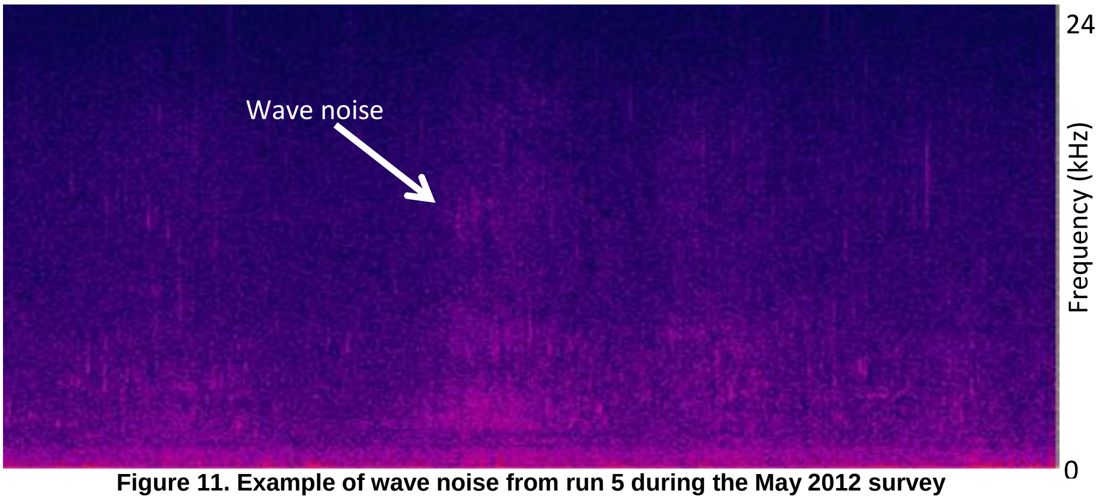


Figure 11. Example of wave noise from run 5 during the May 2012 survey

Precipitation noise

Rain noise was detected during runs 8 and 9 of the May survey. It is particularly heavy 4 minutes into run 8 (see Figure 12 below). The horizontal scale is 3 minutes. The bright signal near the beginning of the spectrogram is the seal scarer noise identified (see below).

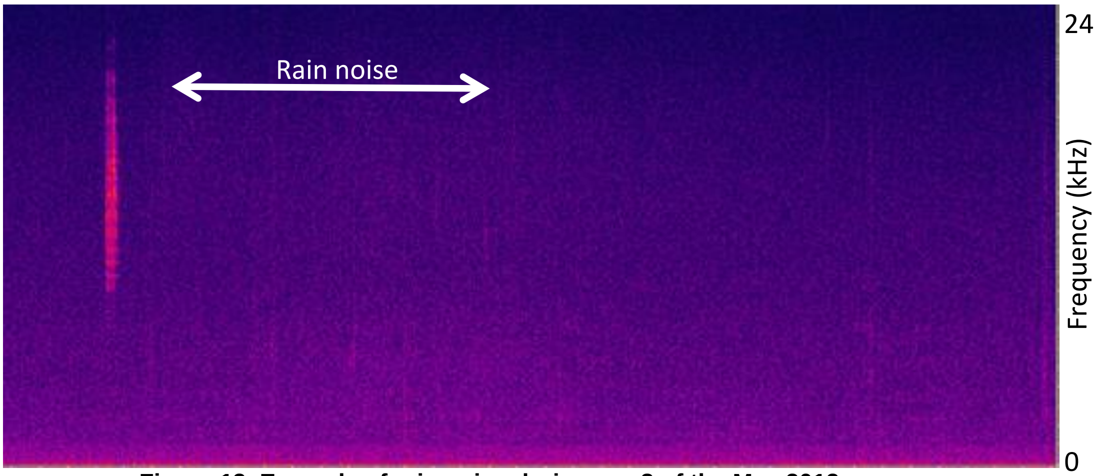


Figure 12. Example of rain noise during run 8 of the May 2012 survey

Flow noise
There were no detectable sources of flow noise in the data collected during the February and May surveys. Flow noise is noise originating from the flow of water around physical features such as the seabed.

Chain noise
Chain noise was heard from two different chains during the surveys. One had a resonant frequency of 3.8 kHz, the other a resonant frequency of 7.2 kHz. Neither were particularly strong signals. Figure 13 below shows an example of the 3.8 kHz chain sound. The horizontal scale is 3.5 seconds.

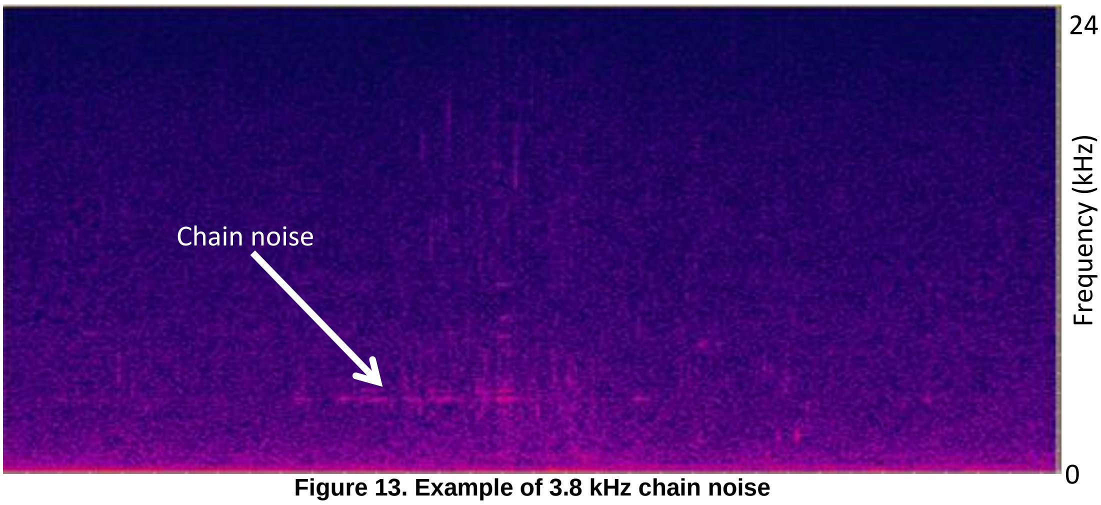


Figure 13. Example of 3.8 kHz chain noise

Seal scarer
During the February and May surveys a loud transmission was heard which is believed to be a seal scarer. The transmission consists of approximately 40 down sweeps from 20 kHz to 9 kHz over a period of 1.9 seconds. This has the typical characteristics of a seal scarer but it was not possible to identify the manufacturer. The geographic distribution of the signal strongly suggests that it originates from a fish farm within the Bay of Meil. A typical transmission is shown in Figure 14 below (this sound can also be seen near the beginning of the spectrogram in Figure 12 above). The horizontal scale is 3.2 seconds.

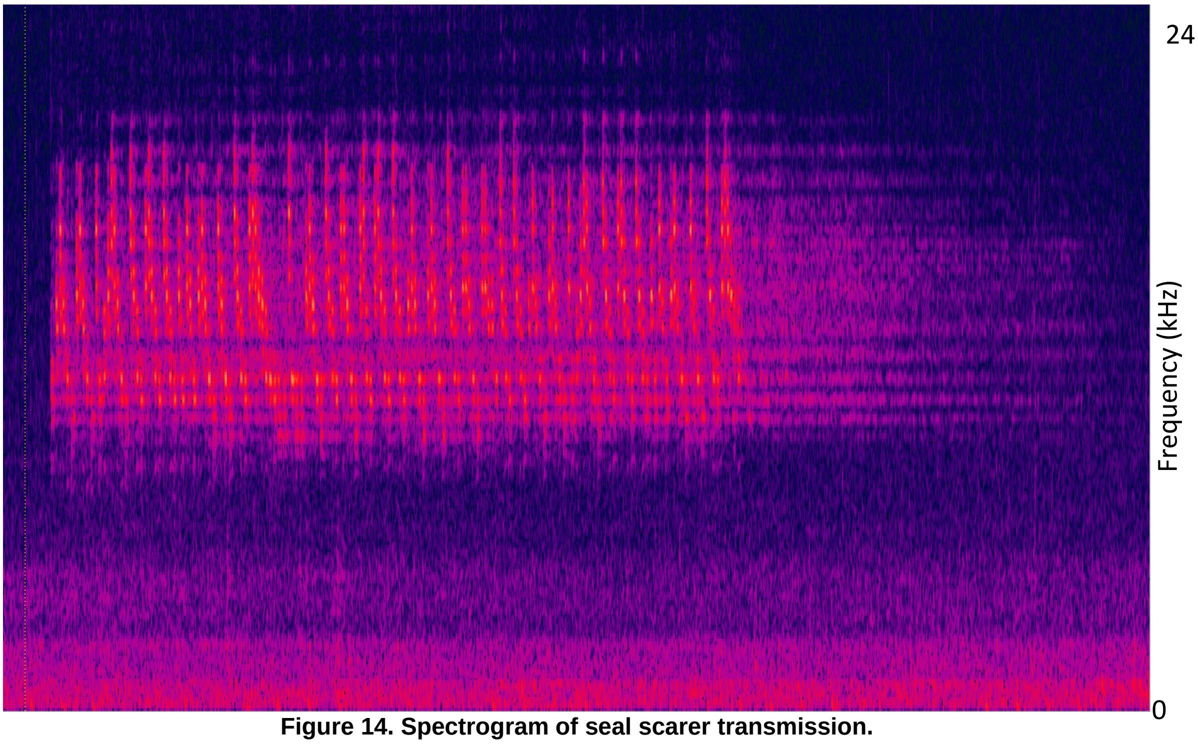


Figure 14. Spectrogram of seal scarer transmission.

During the February survey the transmission was repeated in groups of 1-4 transmissions at a repetition rate of 6 seconds. The groups were transmitted at a random interval between 30 seconds and 4 minutes. During the May survey the transmissions were being made singly at a fixed repetition rate of five minutes.

5.4 Geographic Variations in the Noise

The data were analysed to try to detect any consistent geographic variation of the noise levels. Although the seal scarer levels varied across the area, and shipping noise varied with both time and location, no consistent variation of ambient noise levels could be detected. This suggests that the tidal flow rates were not sufficient during the surveys to trigger noise generation mechanisms associated with fixed features.

5.5 Data Limitations

This study has been carried out using data measured during the two surveys in February and May 2012 so the results presented are partially representative of the full range of possible noise sources and levels. Sounds at frequencies below 1 kHz are most likely attributed to anthropogenic noise (eg shipping).

Poor weather and the equipment problems experienced during the September and November 2011 surveys limited the amount of useful data collected. In particular, no useful runs were achieved along the northern edge of the area where the tidal flow will be greatest. The drift rates achieved varied from 0 to 1.4 knots.

This study only sampled the sound field at 5 metres depth. There may be a depth-dependence within the noise field.

6. Conclusions

Data collected and analysed during this project have enabled ambient noise at the EMEC Shapinsay Sound tidal test site to be partially characterised. Further surveys over a range of tidal and environmental conditions, covering all seasons, are required in order to provide complete characterisation of the site. The following conclusions can be drawn from this study:

- The drifting hydrophone methodology and equipment specified for measuring acoustic noise at EMEC's main grid-connected tidal test site is suitable for use at the Shapinsay Sound test site
- The lowest ambient noise levels measured are consistent with an enclosed shallow water site
- No sources of flow noise from fixed geographic locations have been identified
- Shipping noise is a significant contributor to the ambient noise field with levels up to 100 dB re 1uPa in a 1Hz bandwidth recorded from passing small boats
- A 'seal scarer' contributes levels up to 90 dB re 1uPa in a 1 Hz bandwidth

7. Discussion and Recommendations

This project set out to characterise the ambient noise field at the EMEC nursery tidal test site in Shapinsay Sound. The early work suffered from bad weather and unreliable equipment. Later surveys used improved equipment and the May survey had good weather. While it is useful to characterise ambient noise over a range of weather conditions the noise from the hydrophone mounting arrangement does increase at higher sea states and will need addressing before this high sea state region can be fully explored. Higher sea state information will provide information on how noise levels increase with increasing wind speed and sea state. In open water the increase in underwater noise levels with increasing wind and sea state is well understood (e.g. Urick, 1975). For enclosed shallow water sites the interaction can be more complex and further work would clarify this relationship.

Acoustic measurements made during this study of the Shapinsay Sound test site indicate that ambient noise levels at the site are comparable to those suggested by Urick, 1975 for shallow coastal sites. Below 5 kHz the levels are increasingly lower than for an open water site. This is most likely due to a lower contribution from shipping noise at this site.

During the May 2012 survey DART 4 exhibited higher noise levels at the higher frequencies. The source of this is not clear and will need further investigation, although it appears to be due to a higher noise level originating within the hydrophone. This noise is only evident in conditions where noise levels at higher frequencies are very low, such as those encountered during the May survey. Only high level acoustic signals, such as the seal scarer or passing boats, were reported from this unit.

No significant sources of flow noise originating from fixed geographic locations were detected. This contrasts with a similar survey carried out at the EMEC Fall of Warness test site (Harland, E.J. 2012) which identified a number of such sources. This may be due to the lower tidal rates observed in Shapinsay Sound or may be due to differences in the sea bed types between the two sites.

The data from Shapinsay Sound suggests a dependence on drift rate and thus tidal flow but this survey alone cannot adequately describe this dependence. Further deployments will be needed under good weather conditions to allow more data to be collected. This suggests that while tidal flow was not strong enough to trigger noise from fixed geographic features, it was sufficient to generate turbulent noise and/or wave noise.

The loudest sounds encountered were from a seal scarer and from passing ships. The seal scarer was always present, but did vary its operating characteristics. It is strongest in the west of the tidal test site. Shipping noise is likely to be loudest in the north of the site.

It is recommended that future studies into the acoustic characterisation of the Shapinsay Sound tidal test site should

- Investigate the relationship between tidal flow and noise levels, and how these vary with location within the site
- Explore the ambient noise signature at higher sea states in order to understand how noise levels increase with increasing wind speed and wave height
- Improve the statistics of the noise from passing ships

8. References

EMEC Report “Acoustic monitoring of the European Marine Energy Centre Fall of Warness tidal-stream test site; Phase 2: Development, testing and application.” (Wilson,B. & Carter,C. 2008).

EMEC Report “Shapinsay Sound scale site: Environmental description. (EMEC, 2011).

EMEC Report “Fall of Warness Tidal Test Site: Additional acoustic characterisation” (Harland,E.J. 2012)

Urick,R.J. 1975. Principles of underwater sound. McGraw-Hill Inc. ISBN 0-07-066086-7.

Wenz,G.M. 1962. Acoustical ambient noise in the ocean: Spectra and sources. Journal of the Acoustical Society of America, 34(12), pp1936-1956.

APPENDIX A: System Calibration

The hydrophone used by both the drifting Ears and DART units is the Cetacean Research C55 unit. This includes an internal preamplifier. The manufacturer states that the hydrophone unit has a sensitivity of -165 dB re 1V/µPa. This gives the hydrophone sensitivity relative to a device that would give 1 volt output for a 1 µPa signal arriving at the hydrophone. The specification of the hydrophone, taken from the manufacturer's data sheet, is shown in Table A1 below.

Linear Frequency Range (±3dB) [kHz]	0.020 to 44
Usable Frequency Range (+3/-12dB) [kHz]	0.009 to 100
Transducer Sensitivity* [dB, re 1V/µPa	-185
Preamplifier Gain [dB	20
Effective Sensitivity* [dB, re 1V/µPa]	-165
SPL Equiv. Self Noise at 1kHz [dB, re 1µPa/√Hz]	46 (Sea State Zero)
Power Requirement [Vdc]	5 to 32
RMS Overload Acoustic Pressure [dB, re 1µPa]	169 to 186
Maximum Operating Depth ** [m]	460
Operating Temperature Range [ºC]	-40 to 60
Output Impedance [Ohms]	10
Dimensions [mm]	119 L x (25 to 16) dia
Integral Connector	Subconn MCBH3MSS
Directivity	Omnidirectional below 10kHz

Table A1. C55 hydrophone manufacturer's specification data.

Cylindrical hydrophones have a flat response from a low frequency determined by the capacitance of the ceramic element and the input impedance of the preamplifier. The data sheet states this to be 20 Hz at the 3 dB point. The high frequency limit is usually determined by the resonant frequency of the hydrophone. The manufacturer states that it is omnidirectional to 10 kHz and therefore has a flat response to 10 kHz. The useable frequency range extends to 44 kHz at the 3 dB point. The recorder in DART records up to 24 Khz so it is likely that the response drop off will be significantly less than the 3 dB at 44 kHz. A reduction of around 1 dB is likely and this is considered acceptable for this type of study where the experimental error in the measurement is likely to be rather more than 1 dB.

DART includes an internal amplifier giving a gain of +10dB. The signal is then passed to the SM2+ recorder. This means that a signal arriving at the hydrophone of +155 dB re 1uPa will give a 1 Volt RMS signal at the recorder input.

The recorder input is defined as 1 Volt RMS at the recorder input and with the internal gain set to 0dB will give a full-scale signal at the A/D output. The WAV-format files produced, when read by MATLAB, have a full scale range from -1 to +1 units peak to peak. There is therefore a 3 dB loss from the recorder input to the MATLAB file.

WAV Calibration factor = 165 – 10 + 3 dB re 1 MATLAB unit/µPa
= 158 dB re 1 MATLAB unit/µPa

The data is then processed using the MATLAB spectrogram function. The spectrogram is formed by the repetitive application of the FFT function, each repetition being time shifted by a specified amount. This function is not normalised so the transfer function is dependent on the windowing function used and the number of input points. For a Hanning window and 1024 input points to the FFT the transfer gain was measured at 53 dB. A further correction factor has to be applied to convert the bandwidth of the spectrogram outputs to 1Hz in order to obtain spectrum level. For a 1024 input point FFT and sample rate of 48 kHz, the output bandwidth will be:

FFT bandwidth = 48000/(2*512) Hz
= 46.875 Hz

Converting this to dB using 10 x $\log_{10}$ gives a bandwidth correction factor of 16.7 dB

The overall calibration factor is therefore:

Calibration factor = 158-53-16.7
= 88.3 dB re 1 MATLAB unit/µPa

DART includes a calibration oscillator that injects a 50 mVolt RMS signal at 700 Hz into the input of the +10 dB gain amplifier. The signal is injected at the start of each run and provides confidence that the system gain is as expected and has not changed due to factors such as changes in the gain of the recorder.

A typical calibration signal is shown below.

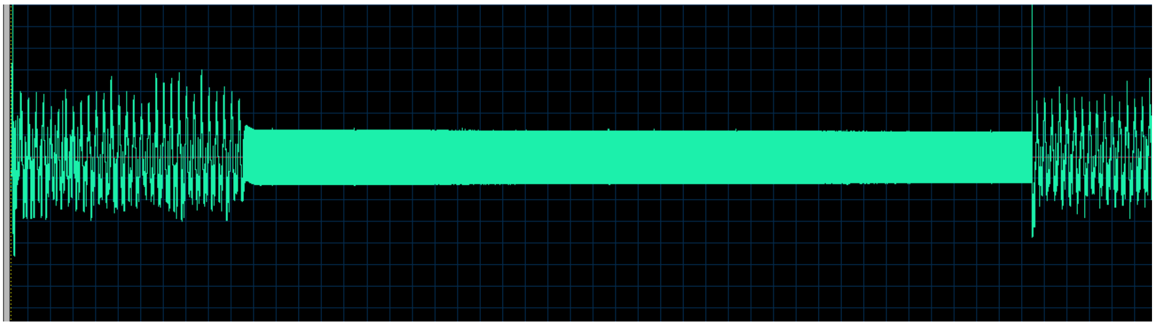


Figure A1. Typical calibration signal

Appendix B: Data Analysis – February 2012 survey

This appendix presents the detailed analysis of the only run from the February 2012 survey of Shapinsay Sound that was processed to produce this report. Only one run was possible within the tidal test site due to the weather. The plots shown are:

- Geographic plot of the run
- Amplitude at four frequencies through the run
- Drift rate through the run
- Spectrogram of run

These are produced using the following methods:

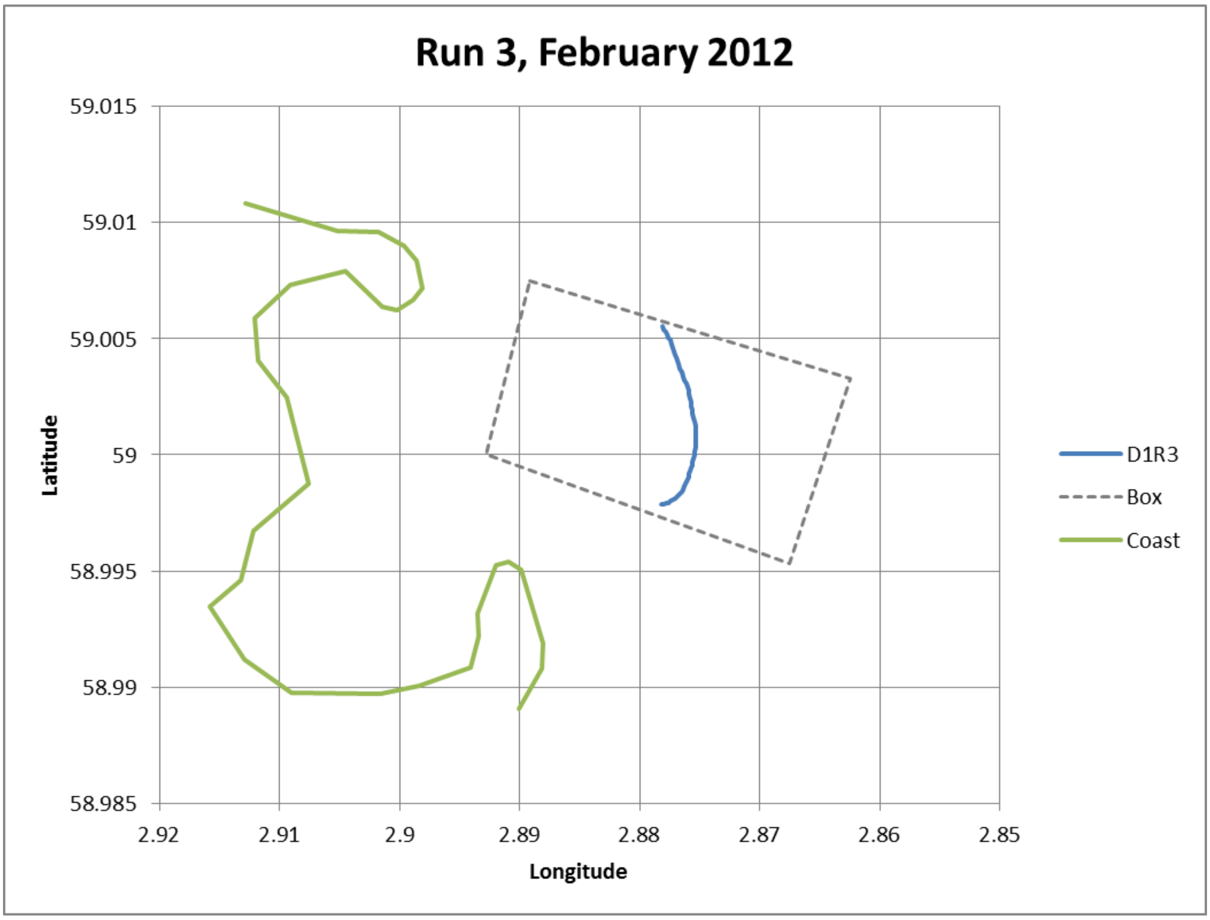
Amplitude plot
The data was processed using a 1024 input sample FFT to produce 512 spectrum samples. There is no block overlap and a Hamming window is used. This data is then averaged for twenty seconds to produce the plots. The data was filtered into four 2 kHz bandwidth regions centred on 2.5 kHz, 5 kHz, 10 kHz and 15 kHz. This is implemented by summing the squares of the FFT output points across the appropriate band of frequencies. The processing is implemented as a MATLAB function.

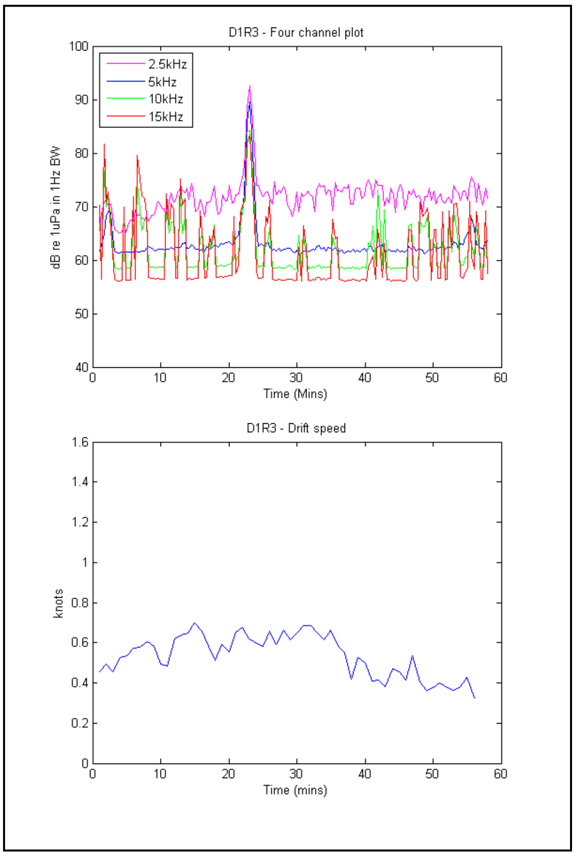
Spectrogram
The whole run spectrograms are produced using the CoolEdit 2000 software. It uses a 512 point FFT with Hamming weighting and no block overlap for compatibility with the other processing functions. The horizontal scale for all the spectrograms is 0-24 kHz. The vertical scale is time (in minutes) and varies from run to run.

Drift rate
The GPS data is sampled at 1 minute intervals and then used to calculate the drift rate. The distance travelled is the sum of the distances travelled during each minute.

A selection of plots for the run processed is presented on the following pages. The first plot is the geographic plot and shows the track of each unit deployed relative to the coastline. The data for each deployed unit is then shown as the four channel plot and the drift rate plot. The spectrogram is shown for the whole run followed by notes about the sounds heard during the run.

Weather
During the only run of this survey period the wind was measured at 19 knots average gusting to 23 knots. The wind was from the NNW. The sea state was 4 in the north of the area.





Data not available from DART 4

Distance travelled: DART 1 924 metres, tide flooding.

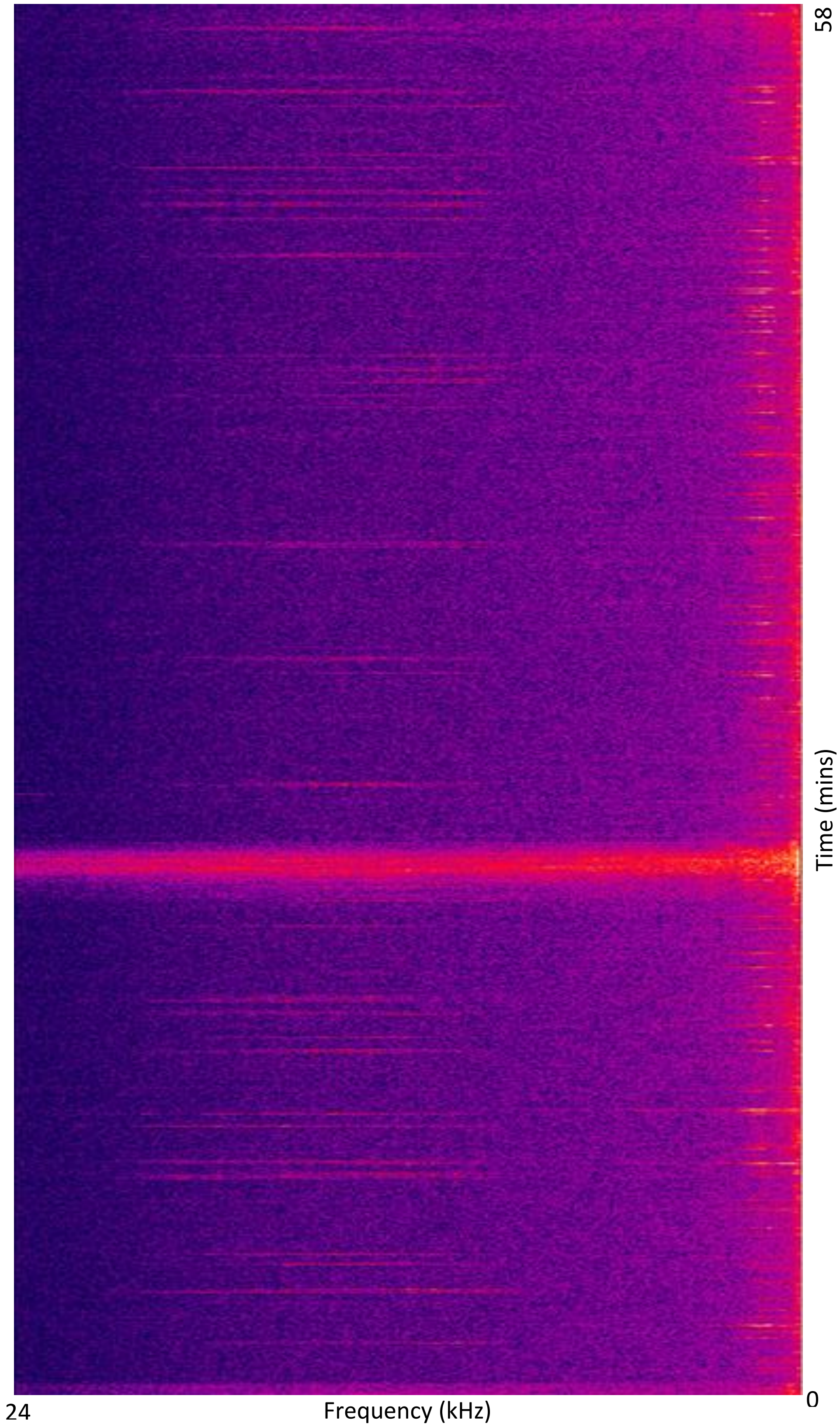


Figure B1. DART 1 spectrogram, run 3

During the afternoon the weather abated and it was possible to move onto the tidal test site for this run. The data from DART 4 was not available for this run because the recorder failed to start.

The seal scarer is active throughout the run. The acoustic path is obstructed by the headland so the signal strength is lower than expected.

Boat noise is audible throughout the run. The loud noise just before the middle of the run is the support boat re-positioning to stay with the drifting units. There are two other boats in the area, a fishing boat operating to the west of the test site and the survey boat C-Odyssey approaching from the east, passing to the north, and then heading west.

There is a loud squeaking sound from the hydrophone because of movement of the drifter in the waves. This sound is the principal cause of the elevated noise levels at 2.5 kHz in the four-frequency plot.

APPENDIX C: Data Analysis – May 2012 survey

This appendix presents the detailed analysis of each run that was processed to produce this report. The plots shown are:

- Geographic plot of the run
- Amplitude at four frequencies through the run
- Drift rate through the run
- Spectrogram of run

These are produced using the following methods:

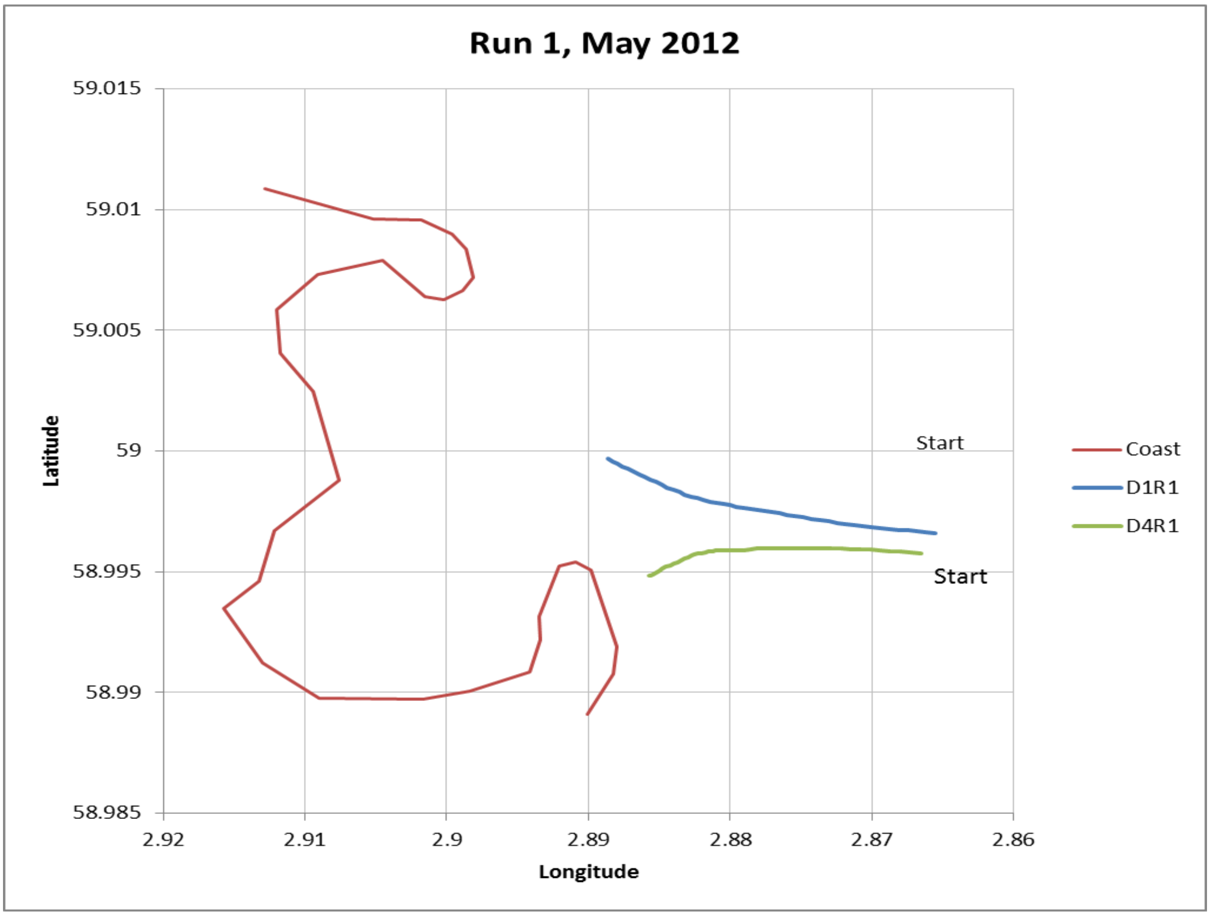
Amplitude plot
The data was processed using a 1024 input sample FFT to produce 512 spectrum samples. There is no block overlap and a Hamming window is used. This data is then averaged for twenty seconds to produce the plots. The data was filtered into four 2 kHz bandwidth regions centred on 2.5 kHz, 5 kHz, 10 kHz and 15 kHz. This is implemented by summing the squares of the FFT output points across the appropriate band of frequencies. The processing is implemented as a MATLAB function.

Spectrogram
The whole run spectrograms are produced using the CoolEdit 2000 software. It uses a 512 point FFT with Hamming weighting and no block overlap for compatibility with the other processing functions. The horizontal scale for all of the spectrograms is 0-24 kHz. The vertical scale is time (in minutes) and varies from run to run. Only one spectrogram is shown for each run as the two are very similar. For consistency the spectrogram used is from DART 1.

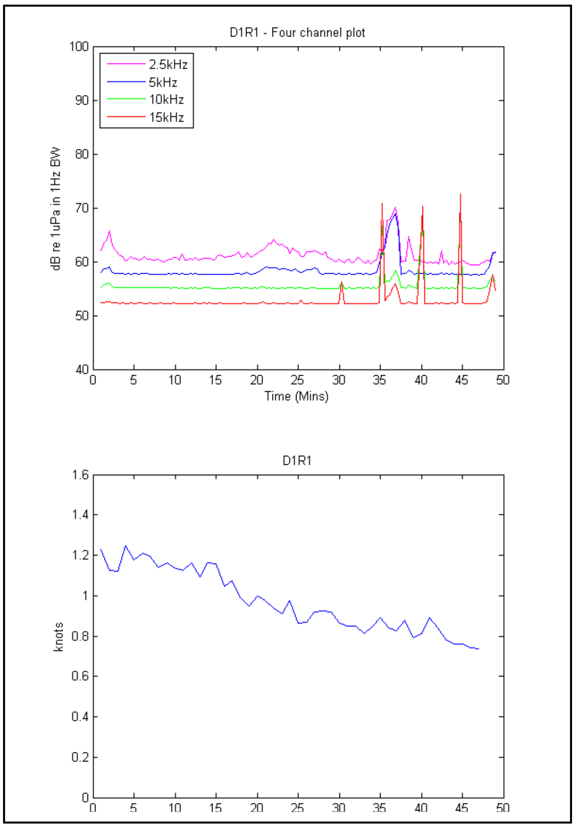
Drift rate
The GPS data is sampled at 1 minute intervals and then used to calculate the drift rate. The distance travelled is the sum of the distances travelled during each minute.

A selection of plots for each run processed is presented on the following pages. They are grouped by day and run. The first plot is the geographic plot and shows the track of each unit deployed relative to the coastline. The data for each deployed unit is then shown as the four channel plot and the drift rate plot. The spectrogram is shown for the whole run followed by notes about the sounds heard during the run.

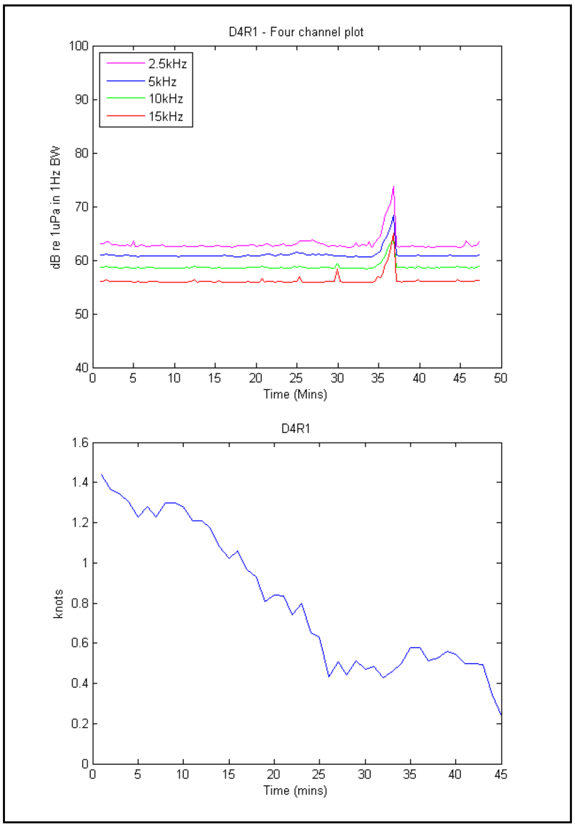
Weather
The wind was typically 8 knots gusting 12 knots at the start of the survey period increasing to 17 knots with gusts to 23 knots at the end. The wind was from the NE throughout the survey period. There was heavy rain during runs 8 and 9. The sea state was 2 at the start of the survey period, increasing to 3 by the end.



Run 1, May 2012
Latitude
Longitude
Start
Start
Coast
D1R1
D4R1



D1R1 - Four channel plot
2.5kHz
5kHz
10kHz
15kHz
dB re 1uPa in 1Hz BW
Time (Mins)
D1R1
knots



D4R1 - Four channel plot
2.5kHz
5kHz
10kHz
15kHz
dB re 1uPa in 1Hz BW
Time (Mins)
D4R1
knots
Time (mins)

Distance travelled: DART 1 1400 metres, DART 4 1130 metres. Tide: ebbing.

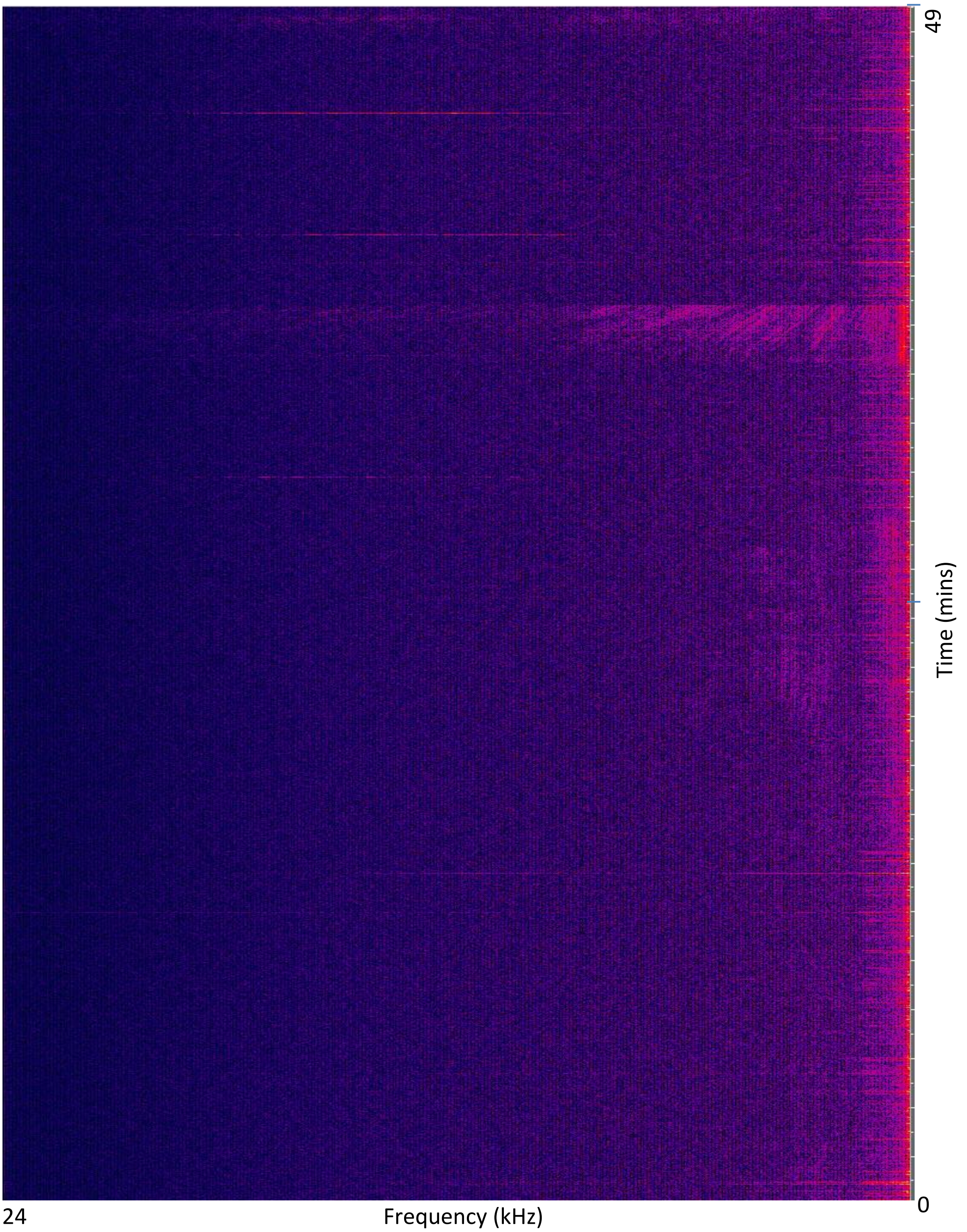
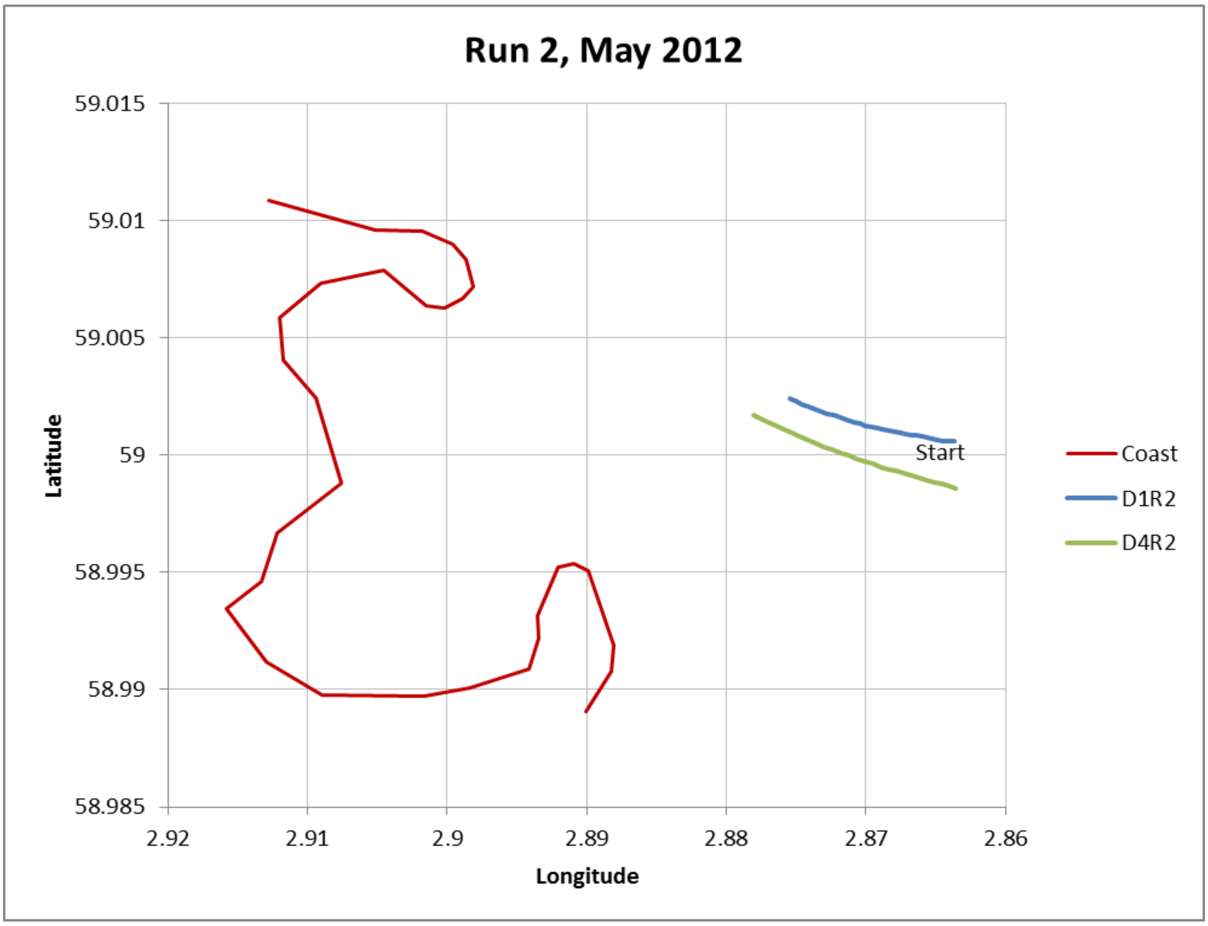
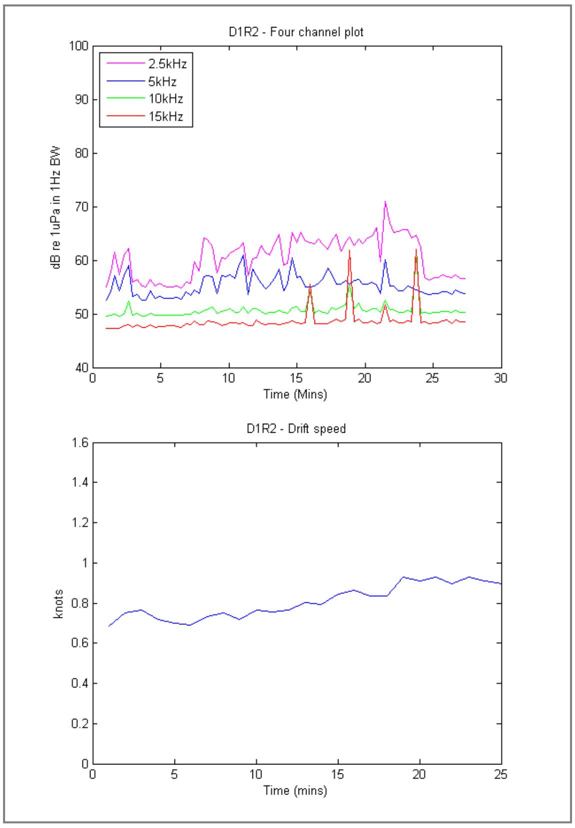


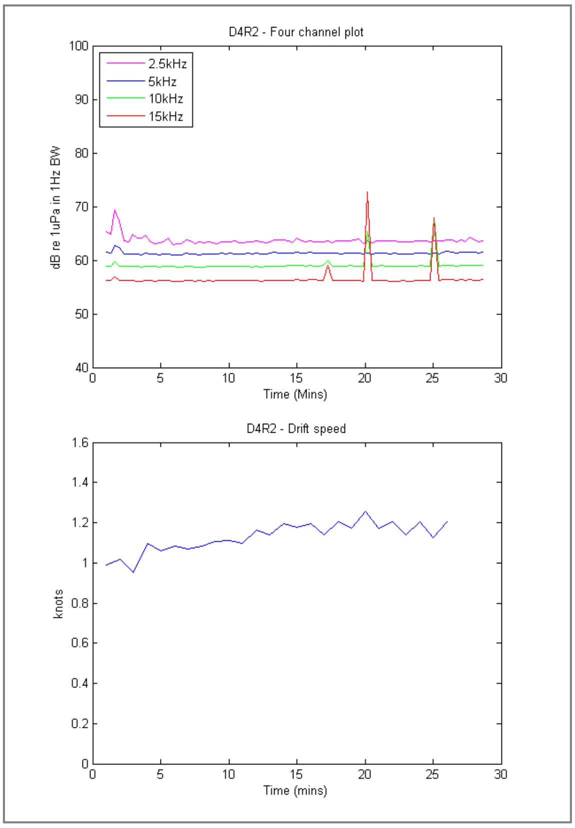
Figure C1. DART 1 spectrogram, run 1.

The noise at 36 minutes is the support boat starting engines and then re-positioning to stay with the drifting units. More boat noise is apparent at 20-25 minutes both on the four-channel plots and the spectrogram and this is caused by another vessel manoeuvring, possibly a small pleasure boat seen approximately 1 mile to the north.

The spikes in the second half of the four-channel plots are caused by the seal scarer transmissions. Comparing the amplitude with the geographic position of the drifters strongly suggests the sound is originating in the Bay of Meil.


Run 2, May 2012
Latitude
Longitude
Start
Coast
D1R2
D4R2


D1R2 - Four channel plot
2.5kHz
5kHz
10kHz
15kHz
dB re 1uPa in 1Hz BW
Time (Mins)
D1R2 - Drift speed
knots
Time (mins)


D4R2 - Four channel plot
2.5kHz
5kHz
10kHz
15kHz
dB re 1uPa in 1Hz BW
Time (Mins)
D4R2 - Drift speed
knots
Time (mins)

Distance travelled: DART 1 620 metres, DART 4 905 metres. Tide: ebbing.

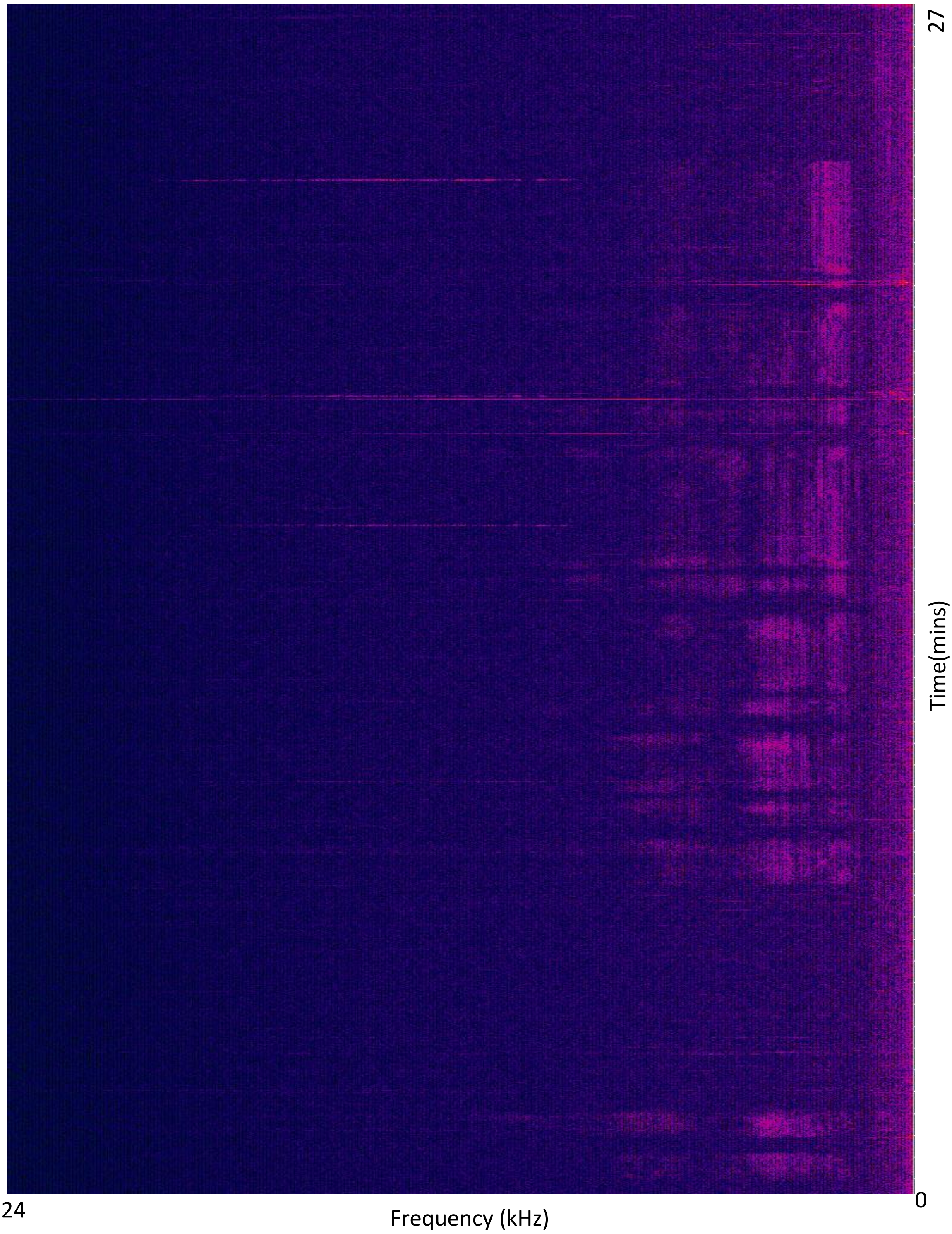
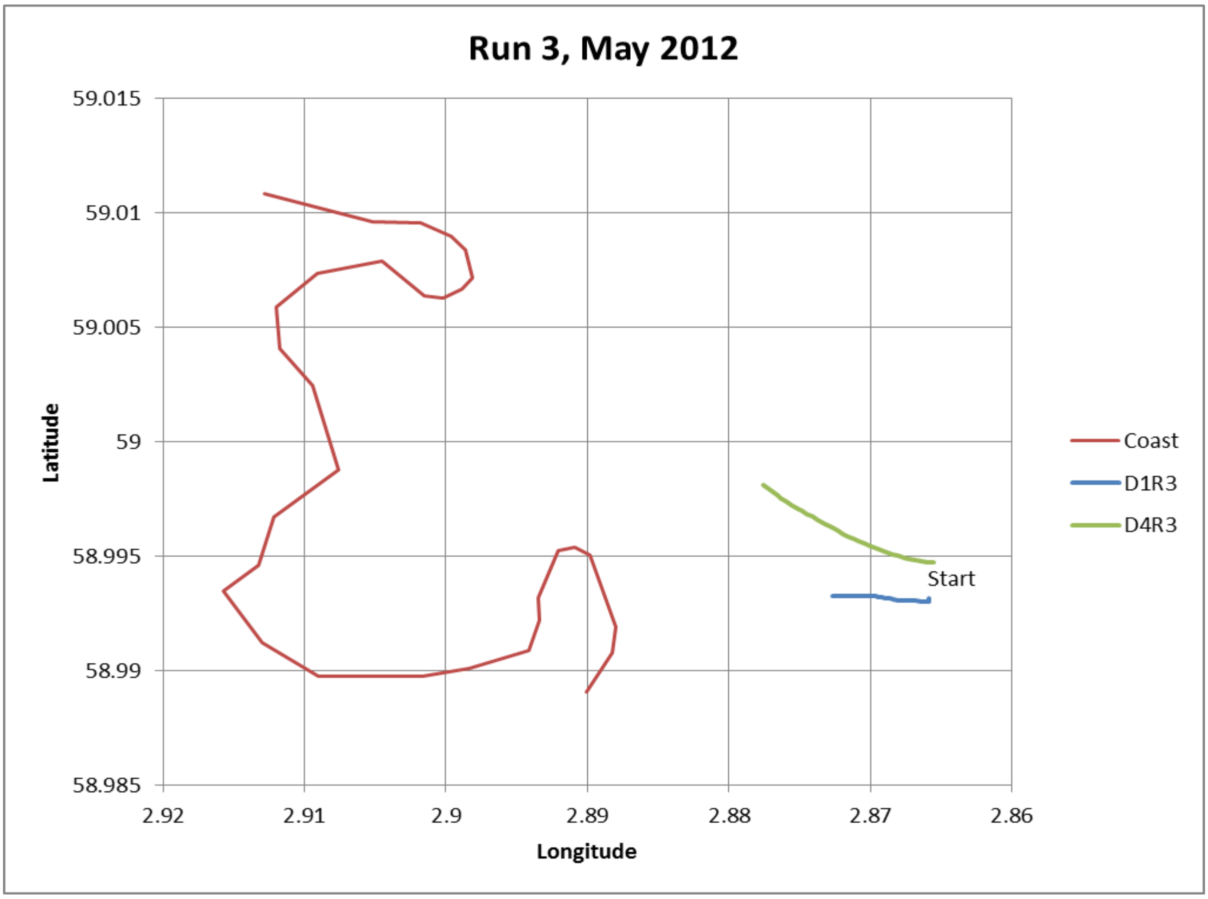
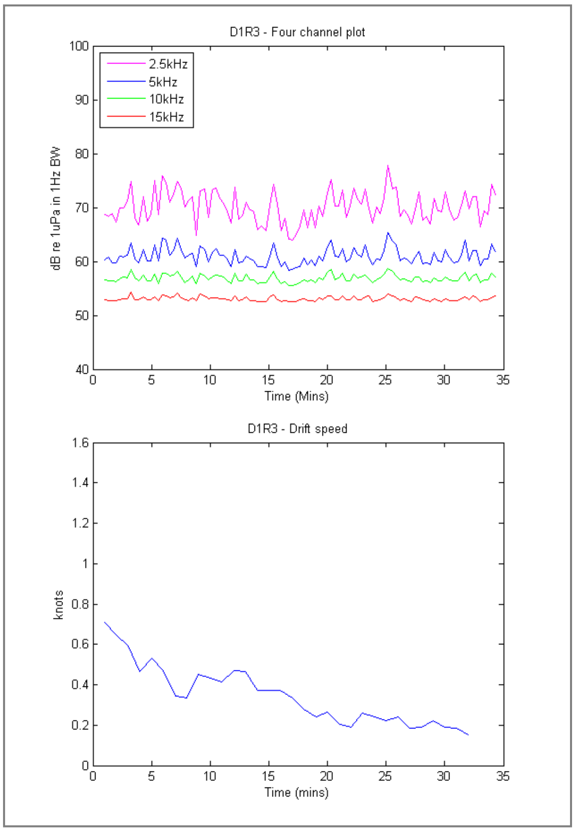


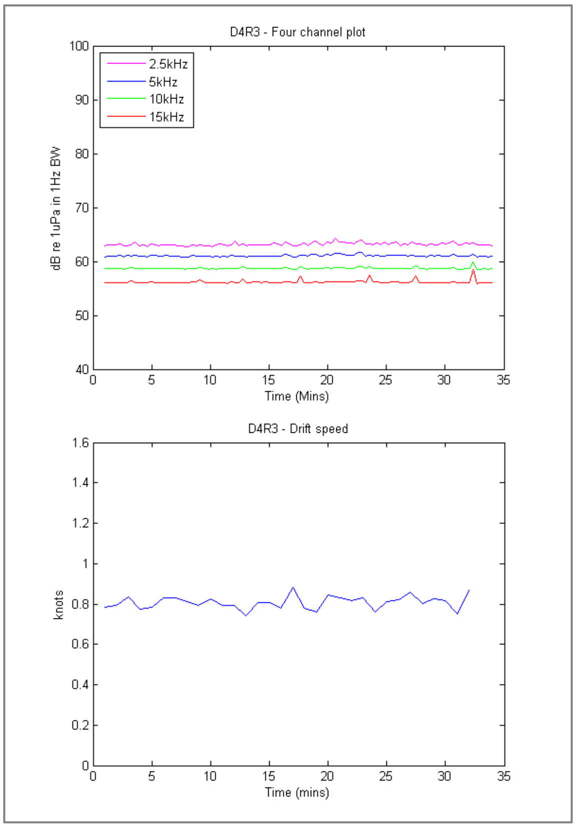
Figure C2. DART 1 spectrogram, run 2

Boat noise is present for most of the run. A creel boat was observed operating about a mile east of the DART units and this may well have been the cause of the noise.

Wave noise can be heard throughout the run. Bubbles can be heard escaping from the drogue rings at 21 minutes into the run.


Run 3, May 2012
Latitude
Longitude
Coast
D1R3
D4R3
Start


D1R3 - Four channel plot
2.5kHz
5kHz
10kHz
15kHz
dB re 1uPa in 1Hz BW
Time (Mins)
D1R3 - Drift speed
knots
Time (mins)


D4R3 - Four channel plot
2.5kHz
5kHz
10kHz
15kHz
dB re 1uPa in 1Hz BW
Time (Mins)
D4R3 - Drift speed
knots
Time (mins)

Distance travelled: DART 1 340 metres, DART 4 798 metres. Tide: Ebbing.

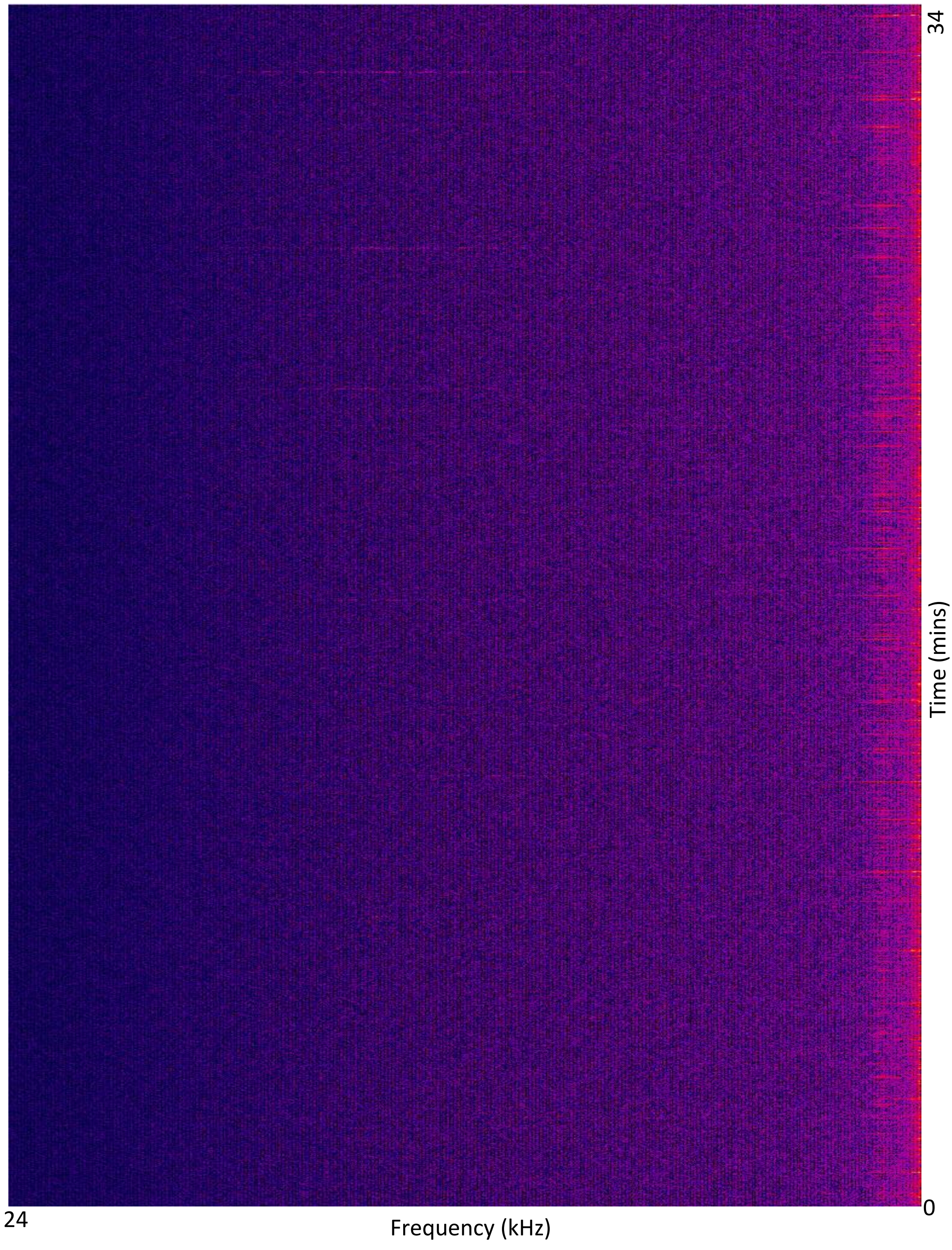
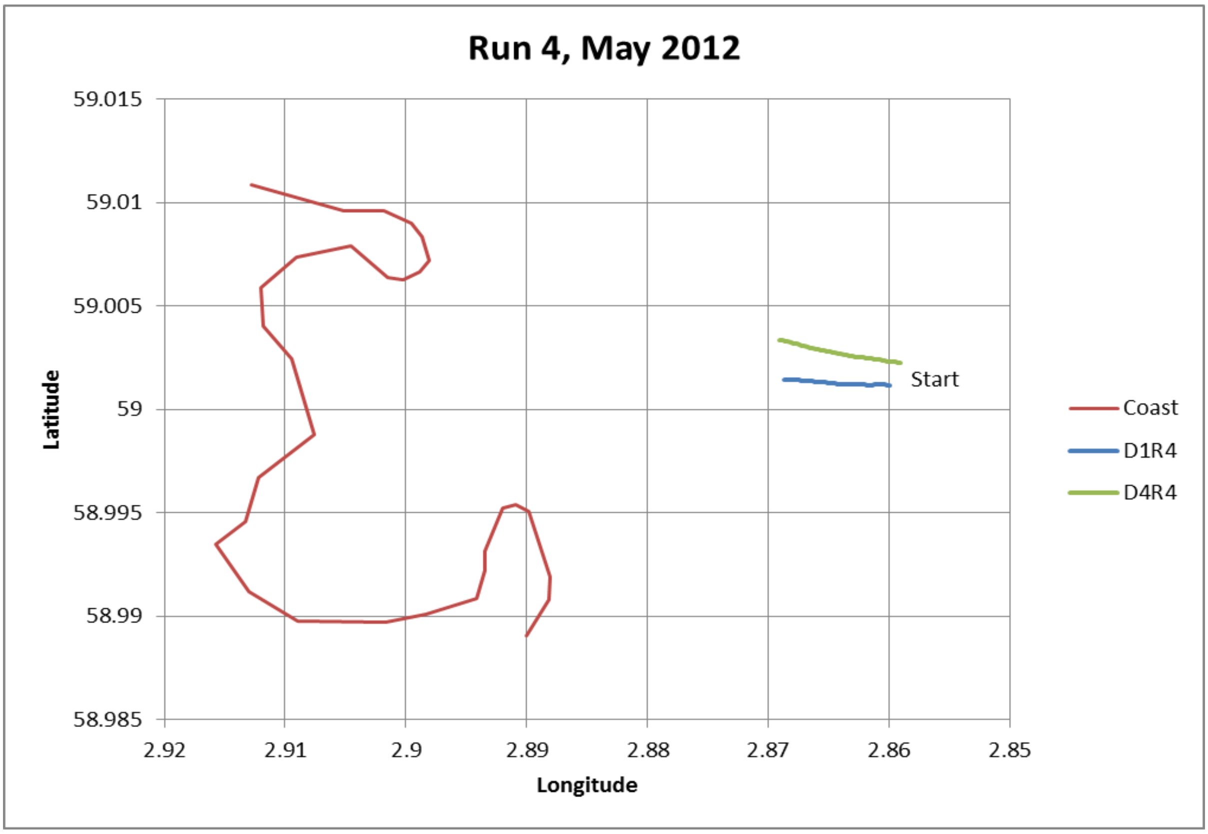
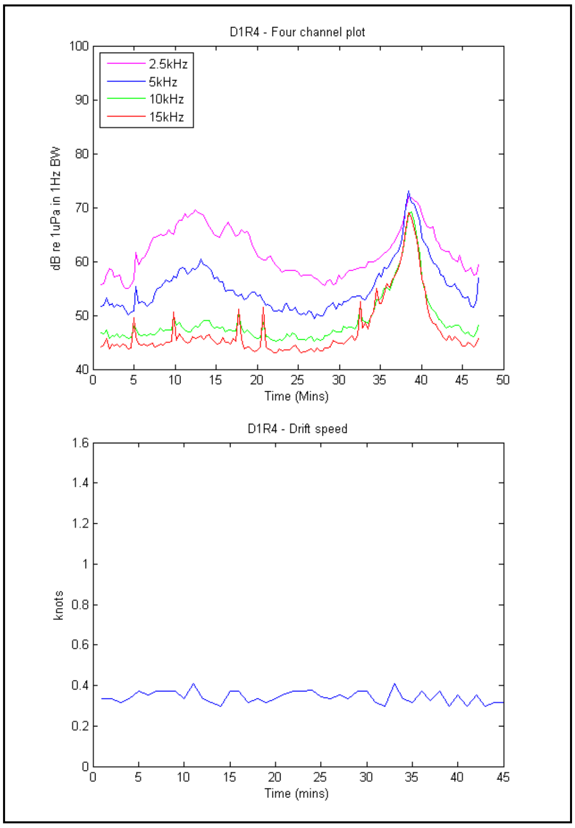
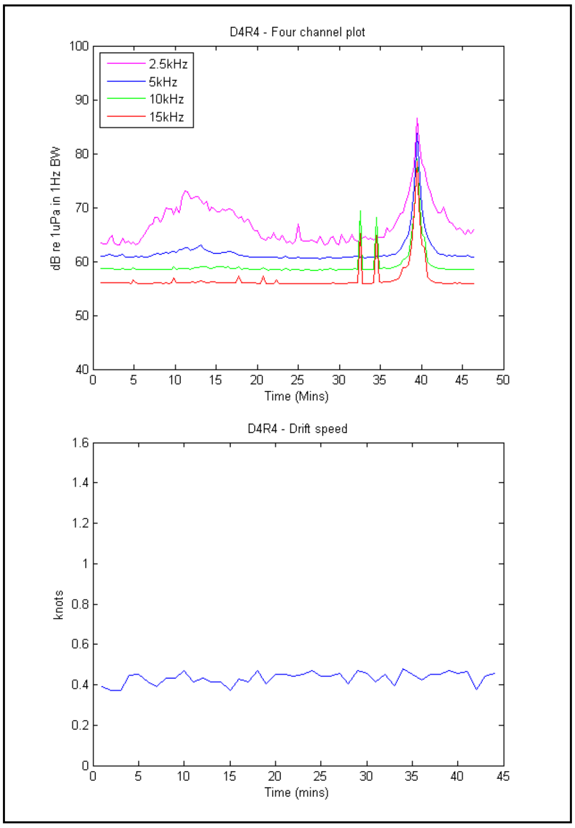


Figure C3. DART 4 spectrogram, run 3.

DART 1 data was affected by a loud rubbing sound from the hydrophone suspension system. It is likely that the hydrophone may have snagged the drogue support during deployment. The sound can be seen by the high noise levels in the four frequency plot.
The spectrogram is from DART 4 for this run and the only acoustic event of note are the pulses from the seal scarer. There is some low level, low frequency noise from the hydrophone suspension system and this can be seen as the bright band at around 1 kHz.


Run 4, May 2012
Latitude
Longitude
Start
Coast
D1R4
D4R4


D1R4 - Four channel plot
2.5kHz
5kHz
10kHz
15kHz
dB re 1uPa in 1Hz BW
Time (Mins)
D1R4 - Drift speed
knots
Time (mins)


D4R4 - Four channel plot
2.5kHz
5kHz
10kHz
15kHz
dB re 1uPa in 1Hz BW
Time (Mins)
D4R4 - Drift speed
knots
Time (mins)

Distance travelled: DART 1 478 metres, DART 4 588 metres. Tide: Ebbing.

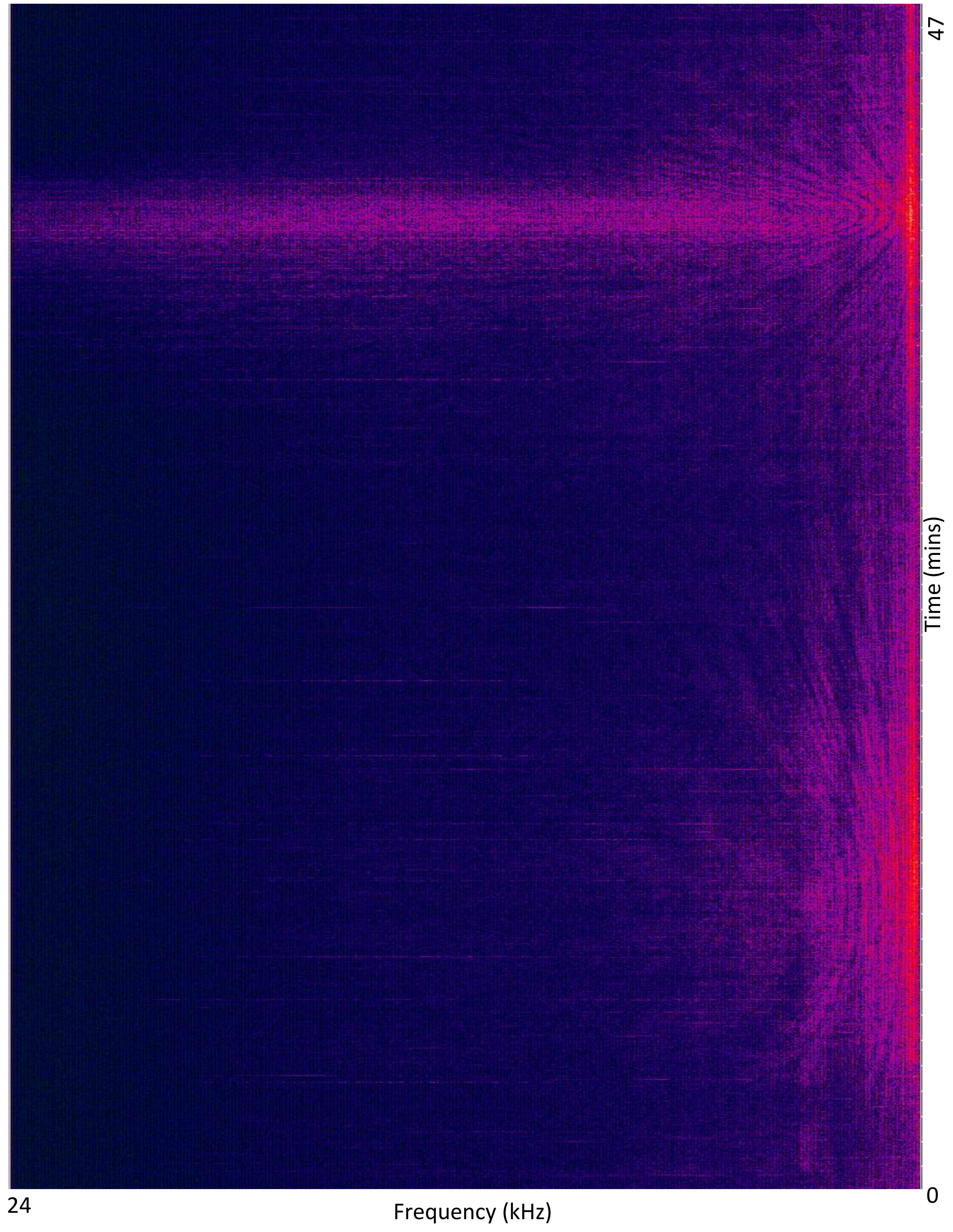
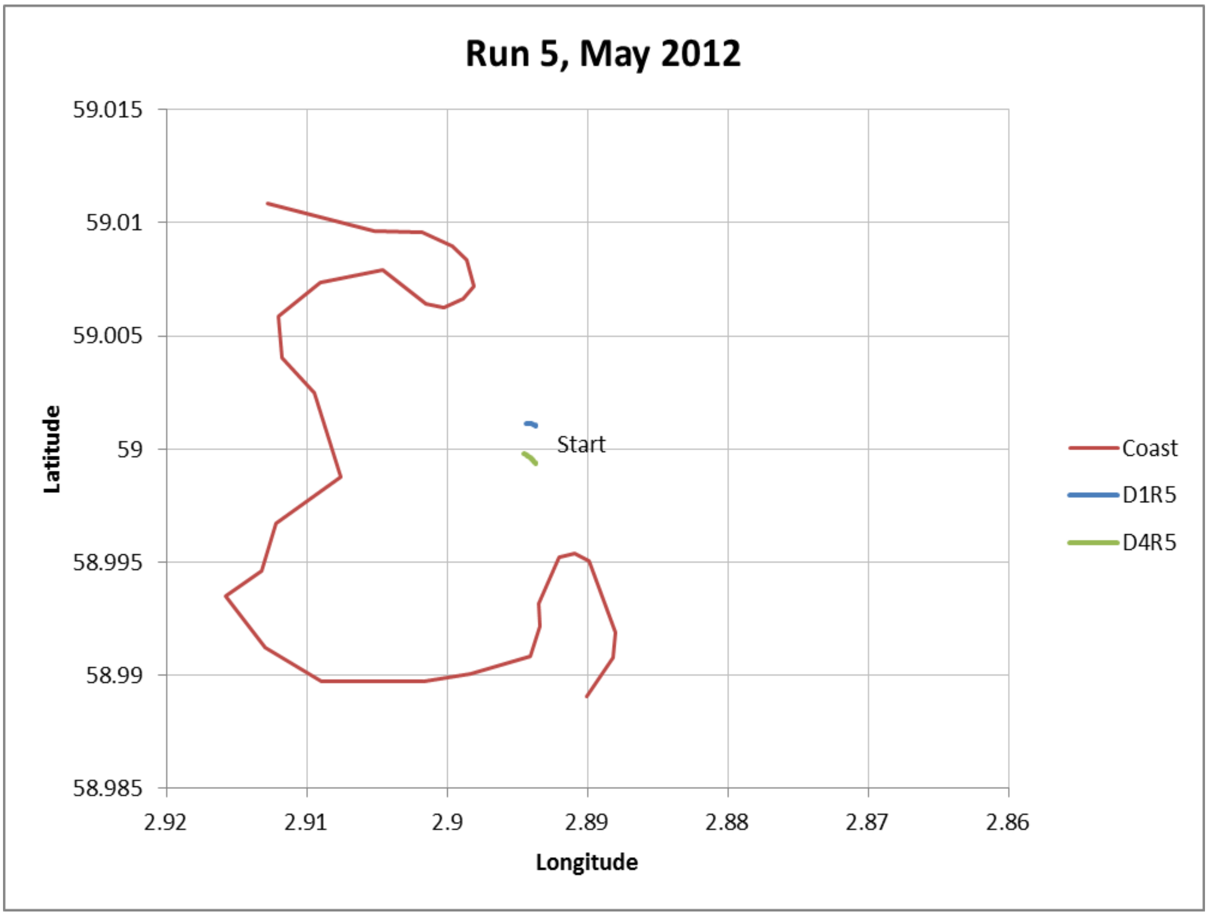
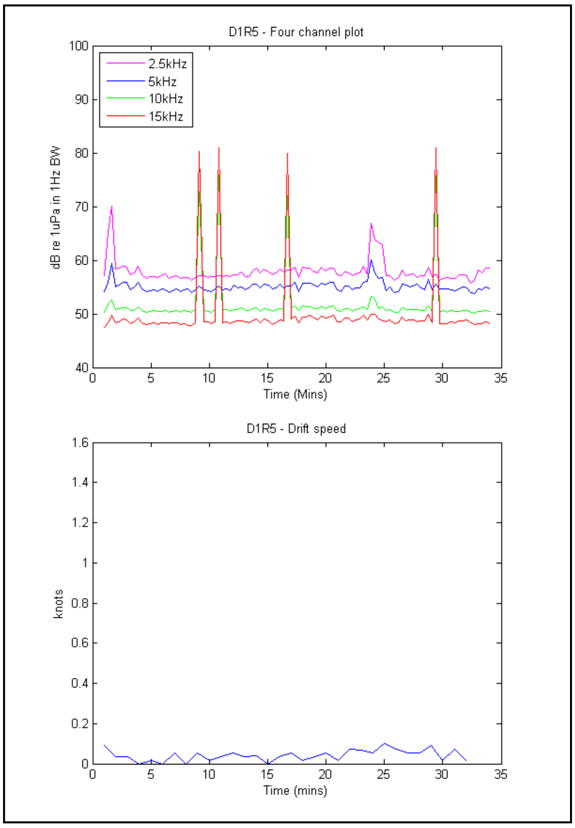
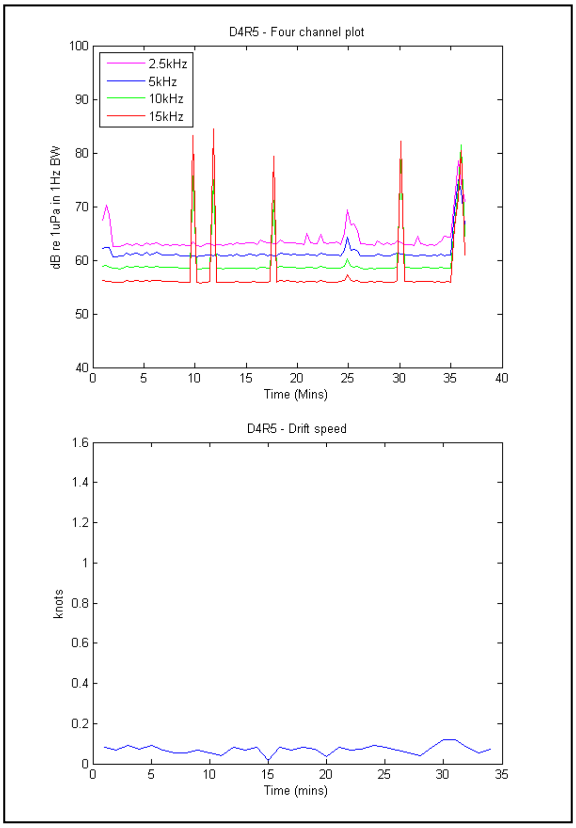


Figure C4. DART 1 spectrogram, run 4.

This run is dominated by shipping noise. A fishing boat passes at about 0.5 miles at closest point of approach in the first half of the run. A dive boat passes very close to the DART units in the second half of the run.


Run 5, May 2012
59.015
59.01
59.005
59
58.995
58.99
58.985
Latitude
Start
2.92
2.91
2.9
2.89
2.88
2.87
2.86
Longitude
Coast
D1R5
D4R5


D1R5 - Four channel plot
2.5kHz
5kHz
10kHz
15kHz
dB re 1uPa in 1Hz BW
Time (Mins)
D1R5 - Drift speed
knots
Time (mins)


D4R5 - Four channel plot
2.5kHz
5kHz
10kHz
15kHz
dB re 1uPa in 1Hz BW
Time (Mins)
D4R5 - Drift speed
knots
Time (mins)

Distance travelled: DART 1 42 metres, DART 4 74 metres. Tide: Ebbing.

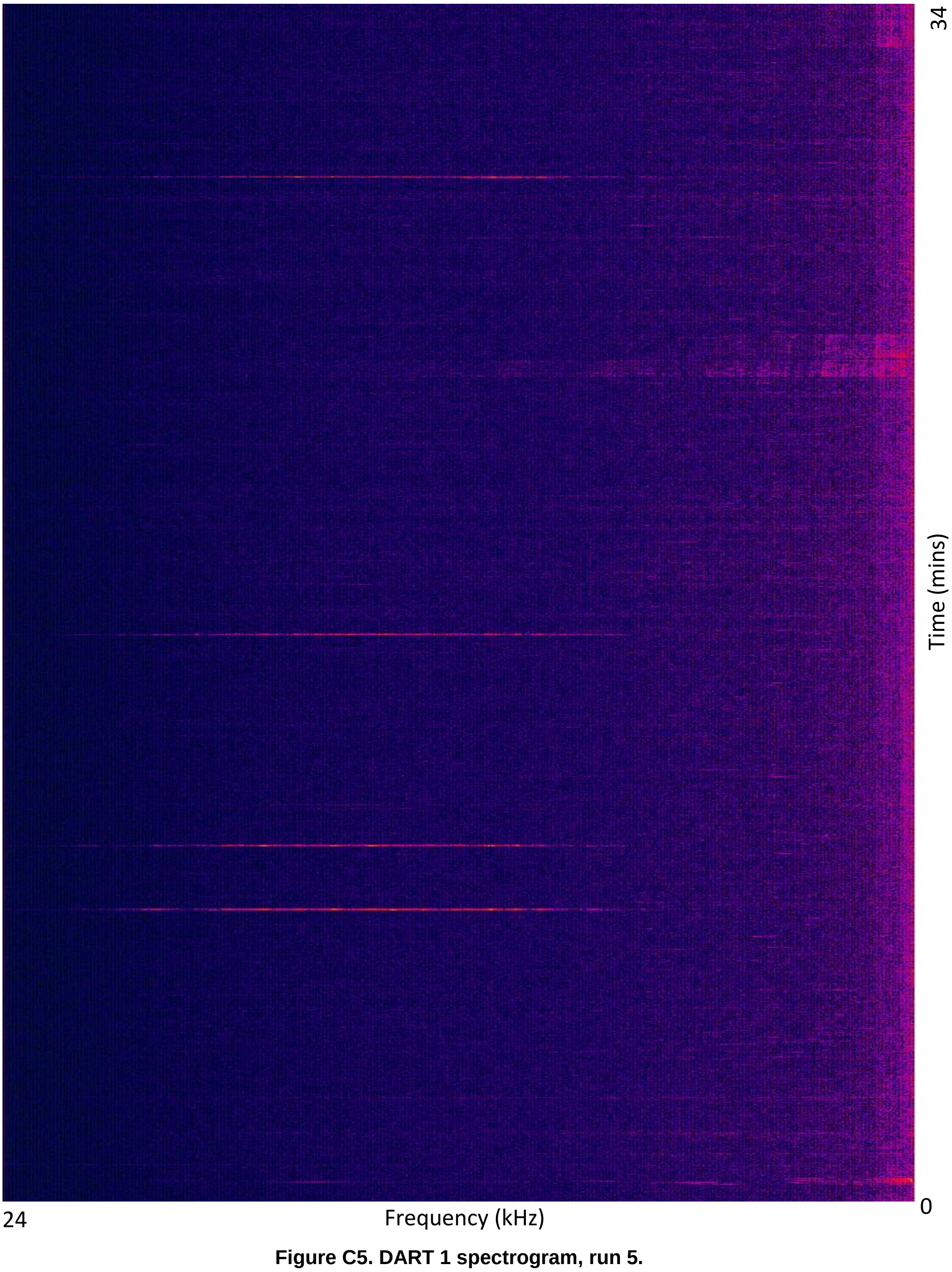


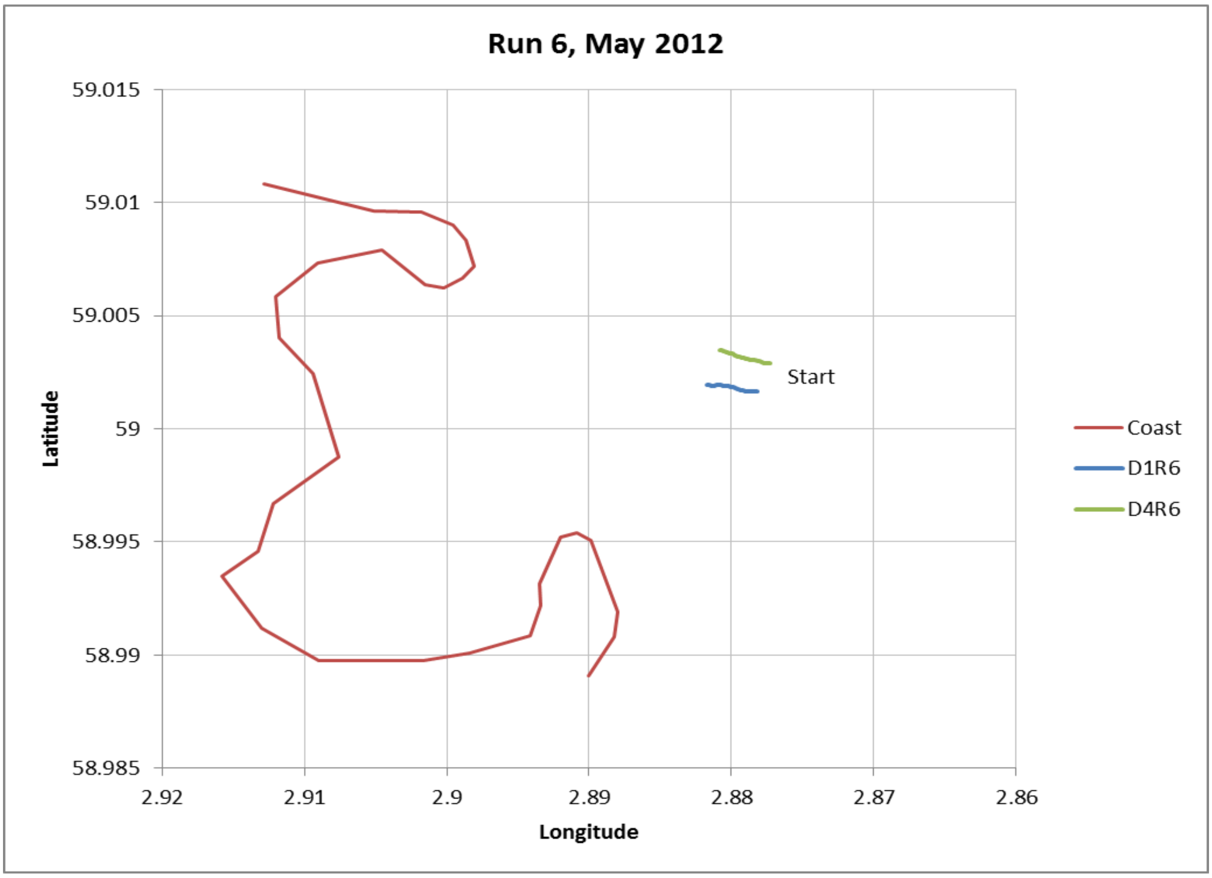
Figure C5. DART 1 spectrogram, run 5.

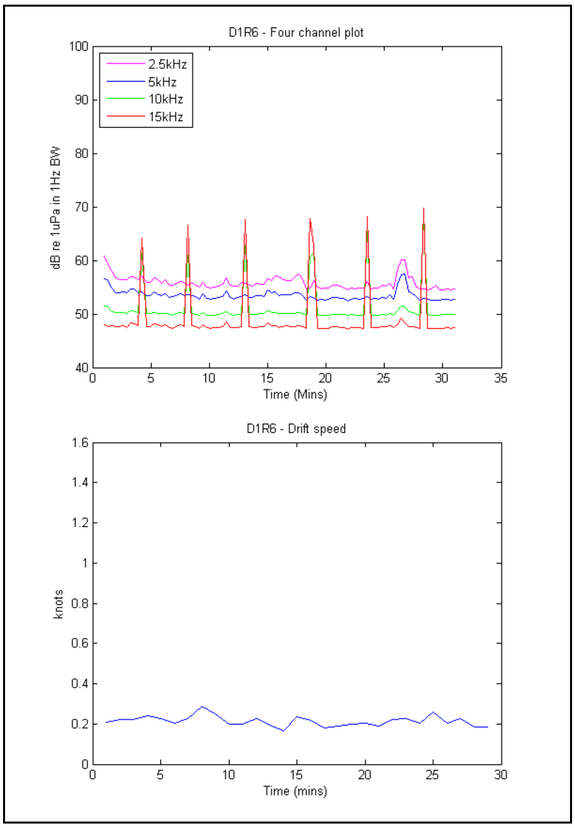
The loud engine noise at 24 minutes into the run is caused by the support boat repositioning. Throughout the run there is weak engine noise which is loudest at around 15 minutes into the run.

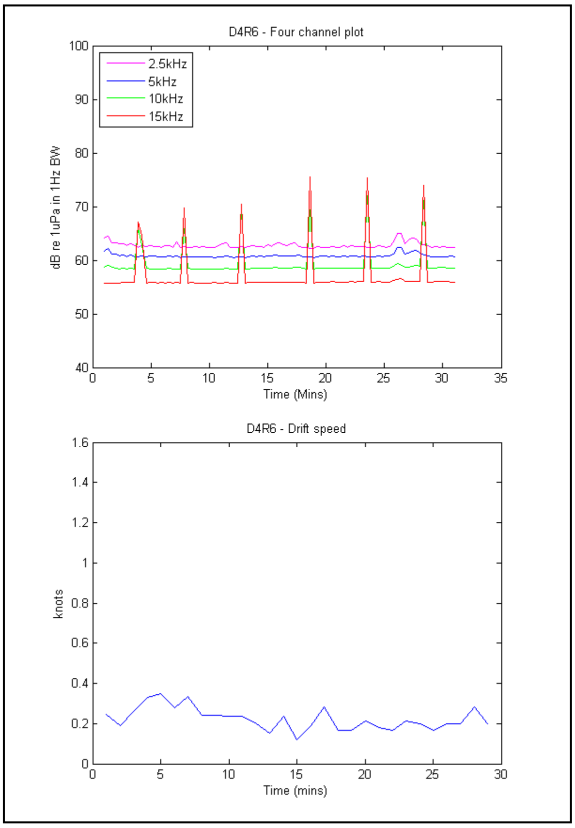
Two boat movements were observed visually during the run, a fishing boat approached about a mile away while a small boat passed, also about a mile away, with closest point of approach about 15 minutes into the run.

Weak chain noise can be heard throughout the run with a peak frequency of 3.8 kHz. There is also wave noise throughout the run.

The signals from the seal scarer were loud throughout the run.


Run 6, May 2012
59.015
59.01
59.005
59
58.995
58.99
58.985
Latitude
2.92
2.91
2.9
2.89
2.88
2.87
2.86
Longitude
Start
Coast
D1R6
D4R6


D1R6 - Four channel plot
2.5kHz
5kHz
10kHz
15kHz
dB re 1uPa in 1Hz BW
Time (Mins)
D1R6 - Drift speed
knots
Time (mins)


D4R6 - Four channel plot
2.5kHz
5kHz
10kHz
15kHz
dB re 1uPa in 1Hz BW
Time (Mins)
D4R6 - Drift speed
knots
Time (mins)

Distance travelled: DART 1 191 metres, DART 4 200 metres. Tide: Ebbing.

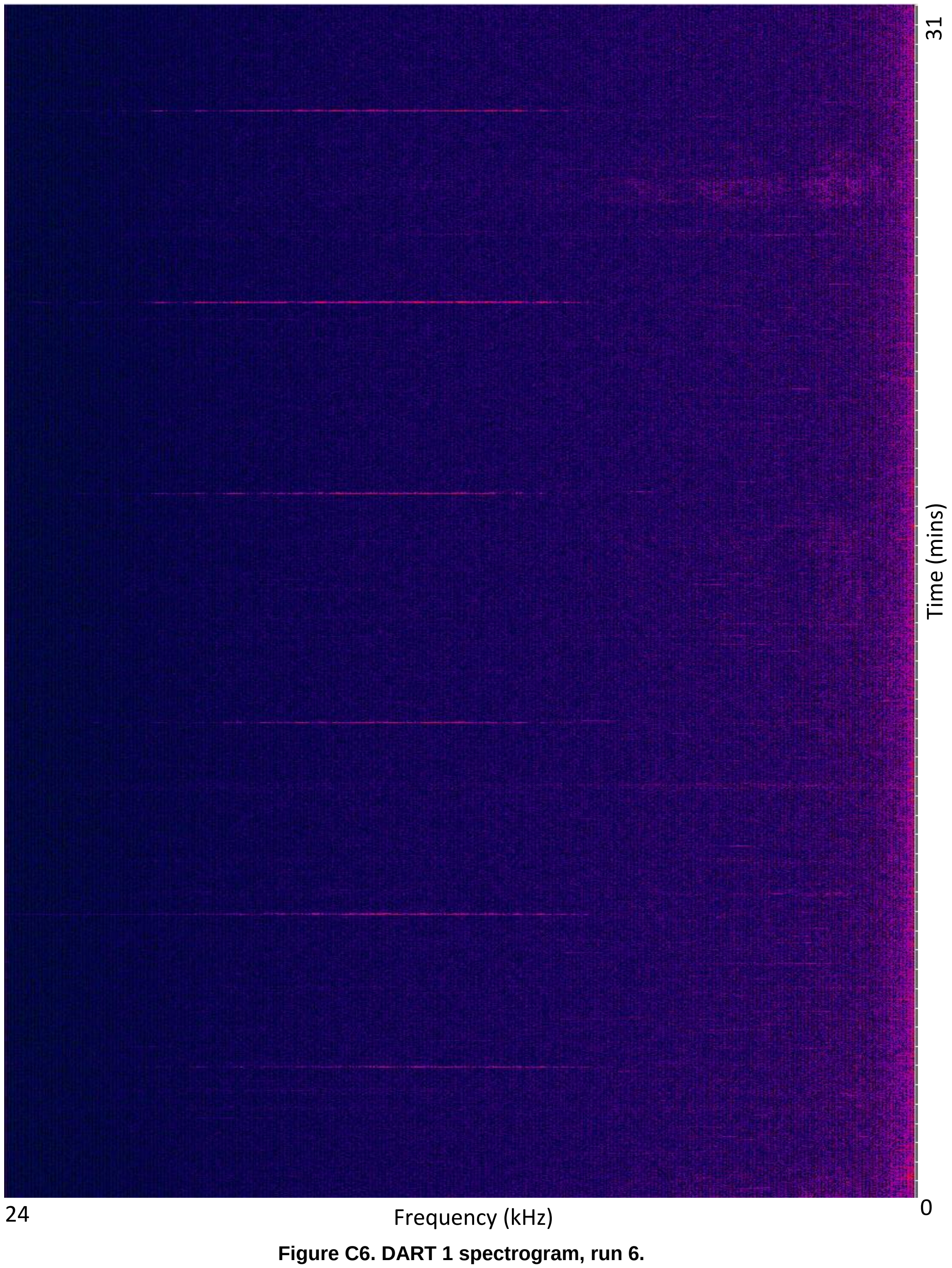


Figure C6. DART 1 spectrogram, run 6.

There are two regions of boat noise. There is very weak noise at 15-17 minutes into the run caused by a dive boat approximately 2 miles to the east and then another burst of noise at 26 minutes caused by a ferry passing approximately 1 mile away. At the start of the run an aircraft passed over and the low frequency sound from the propellers is visible, peaking at 36 seconds into the run. This is shown expanded in Figure C7 below.

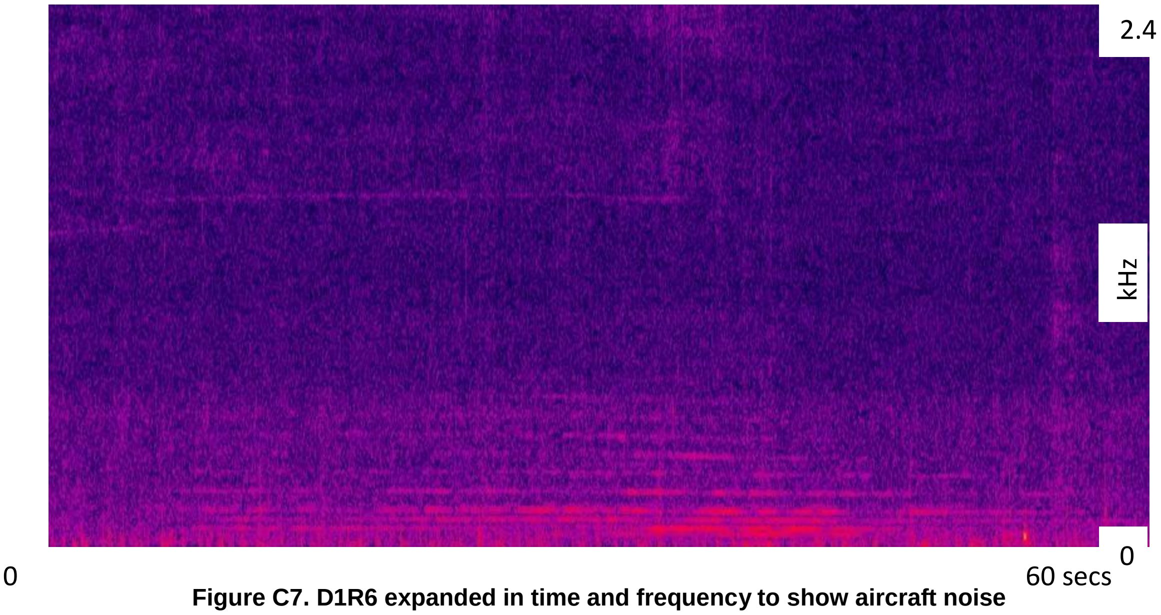
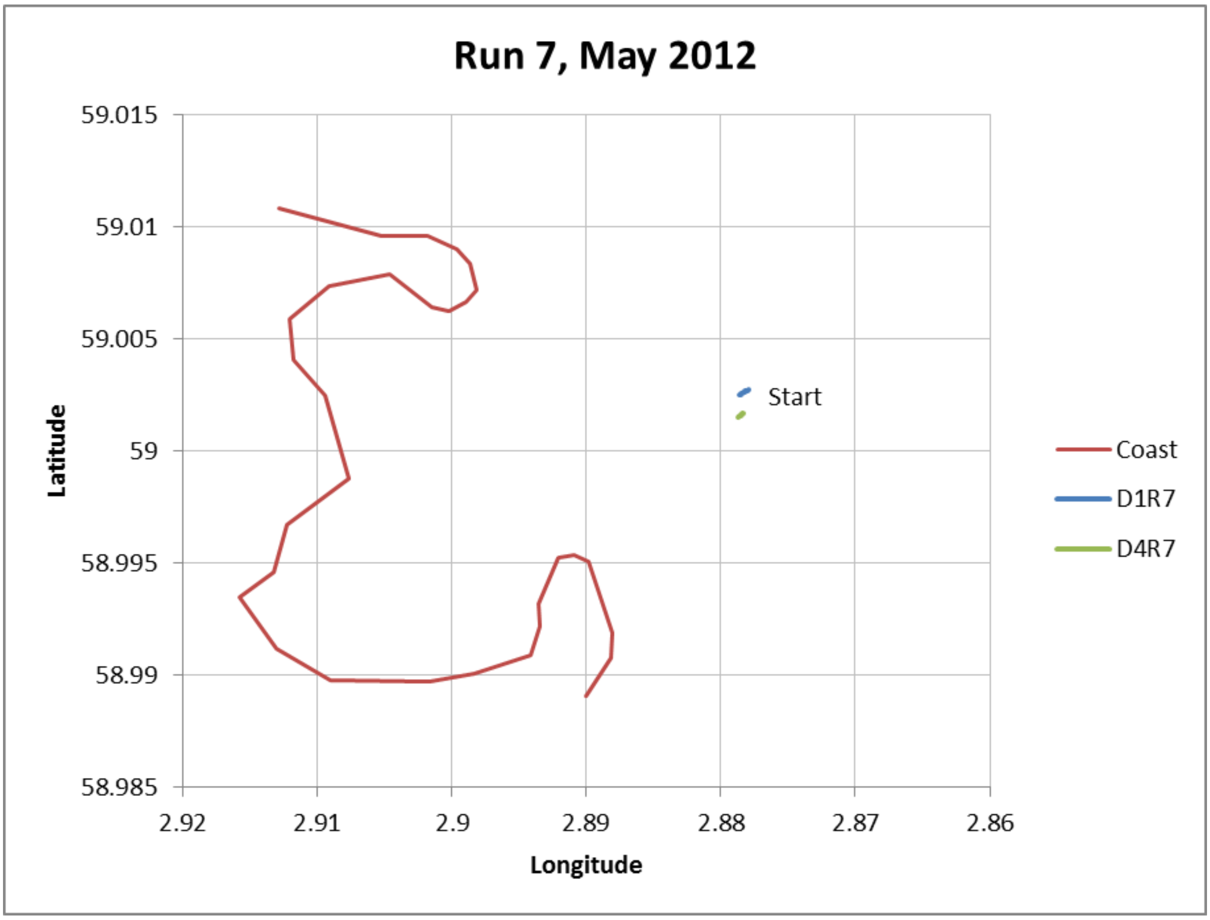
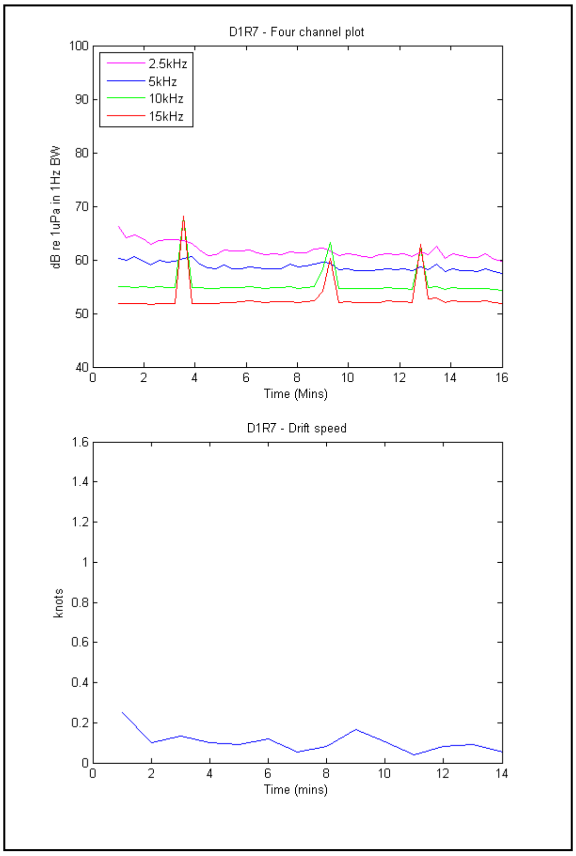
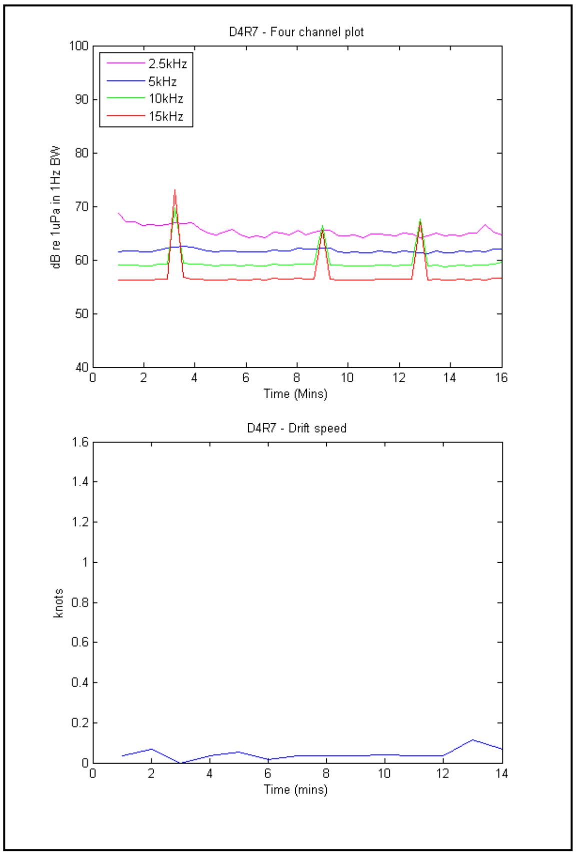


Figure C7. D1R6 expanded in time and frequency to show aircraft noise

Wave noise can be heard throughout the run and at times is fairly loud. There is no chain noise. The seal scarer is not as loud as in run 5, possible cause by shielding by the Head of Holland.


Run 7, May 2012
Latitude
Longitude
Start
Coast
D1R7
D4R7


D1R7 - Four channel plot
2.5kHz
5kHz
10kHz
15kHz
dB re 1uPa in 1Hz BW
Time (Mins)
D1R7 - Drift speed
knots
Time (mins)


D4R7 - Four channel plot
2.5kHz
5kHz
10kHz
15kHz
dB re 1uPa in 1Hz BW
Time (Mins)
D4R7 - Drift speed
knots
Time (mins)

Distance travelled: DART 1 45 metres, DART 4 19 metres. Tide: Slack water.

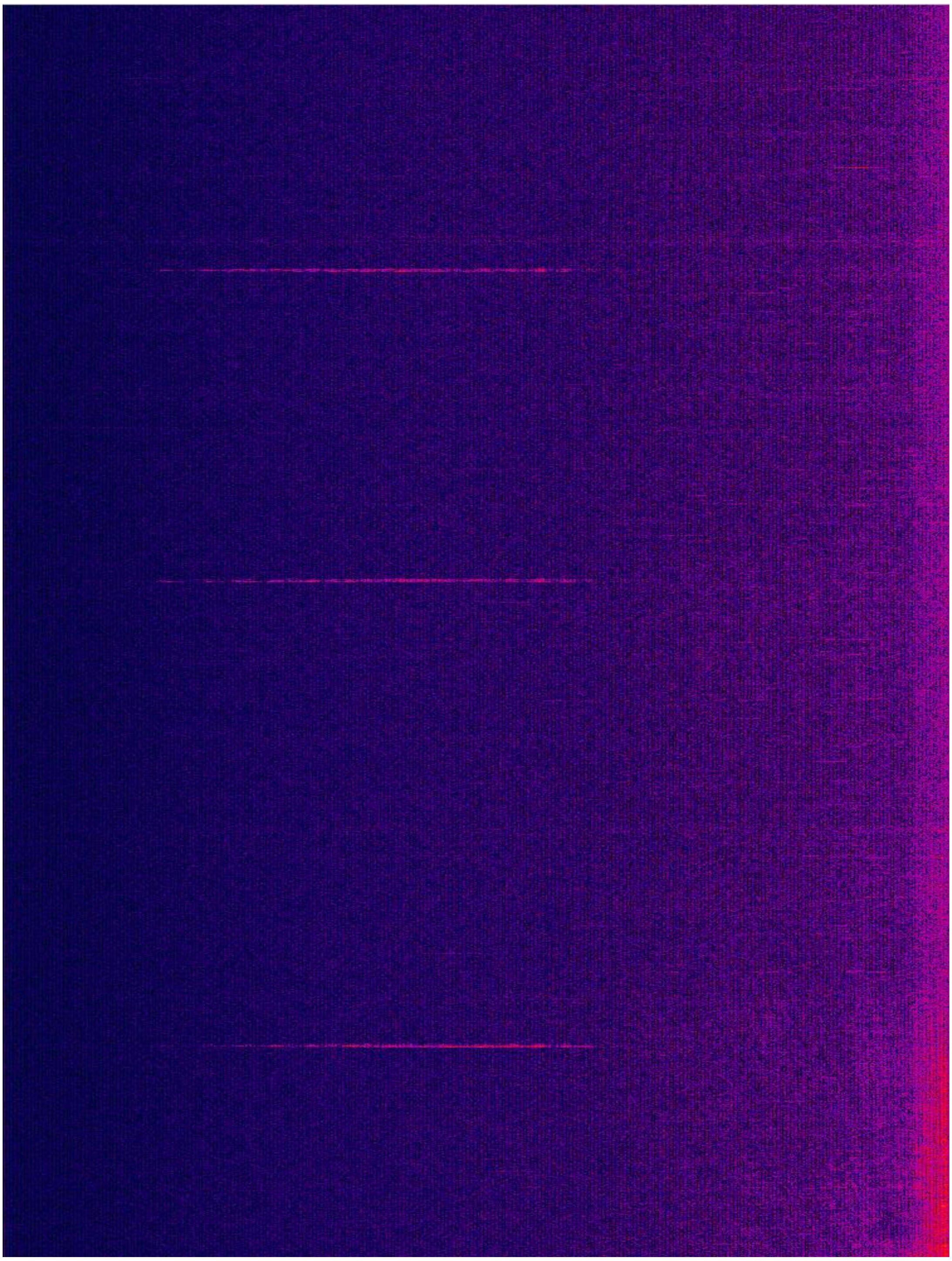
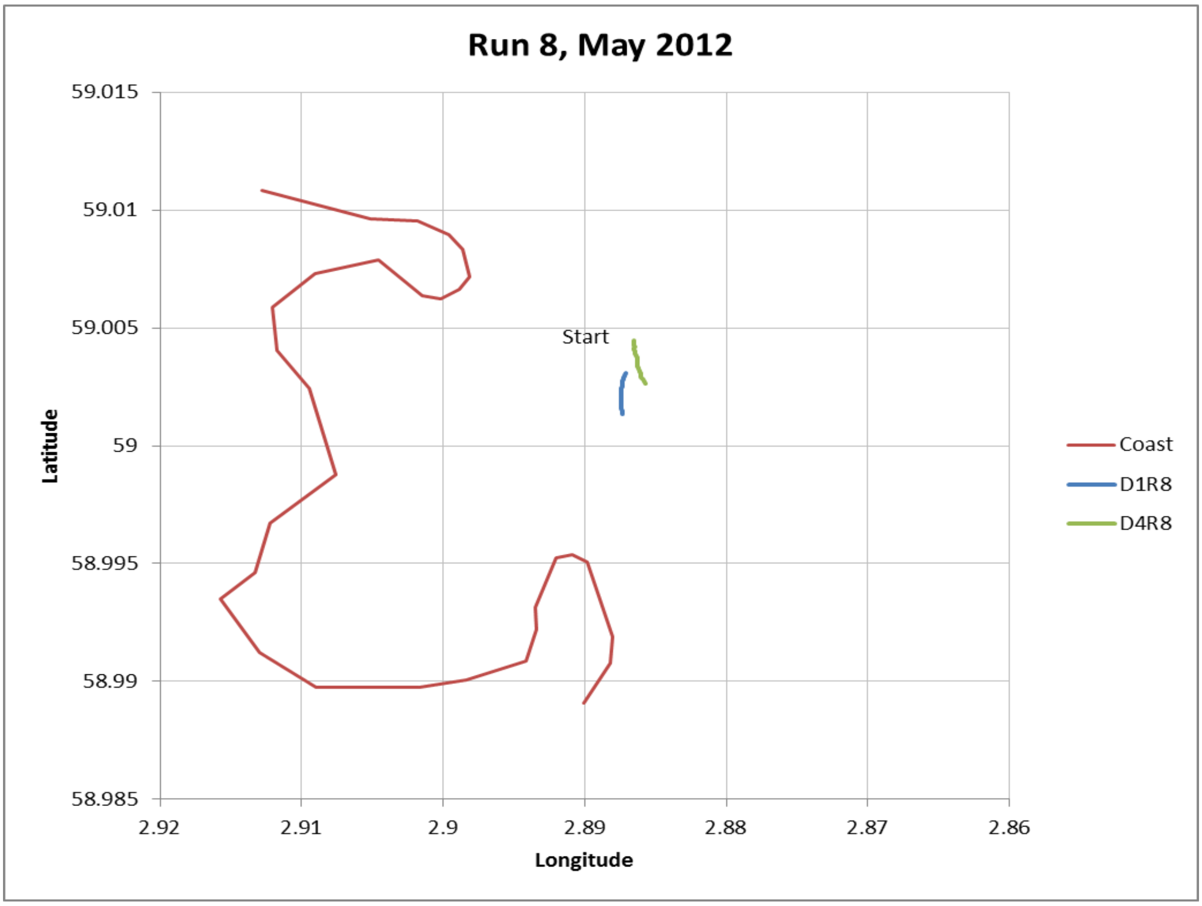
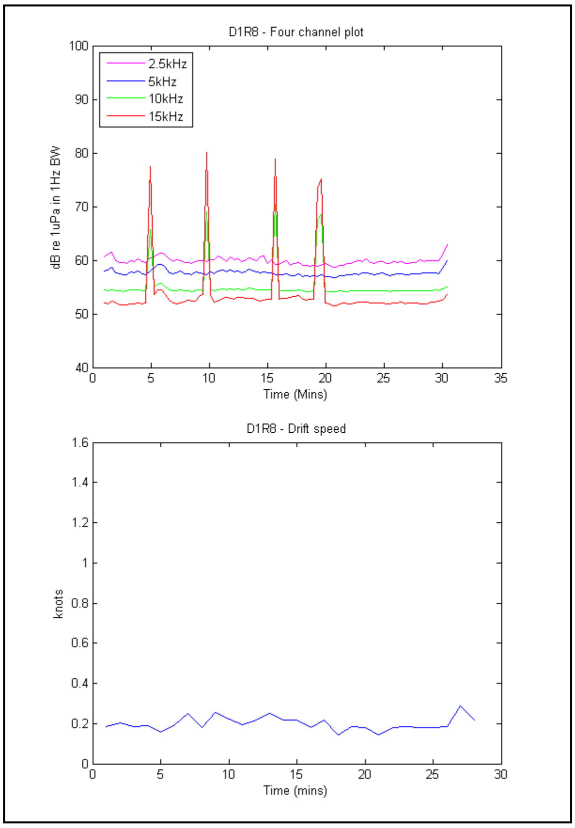


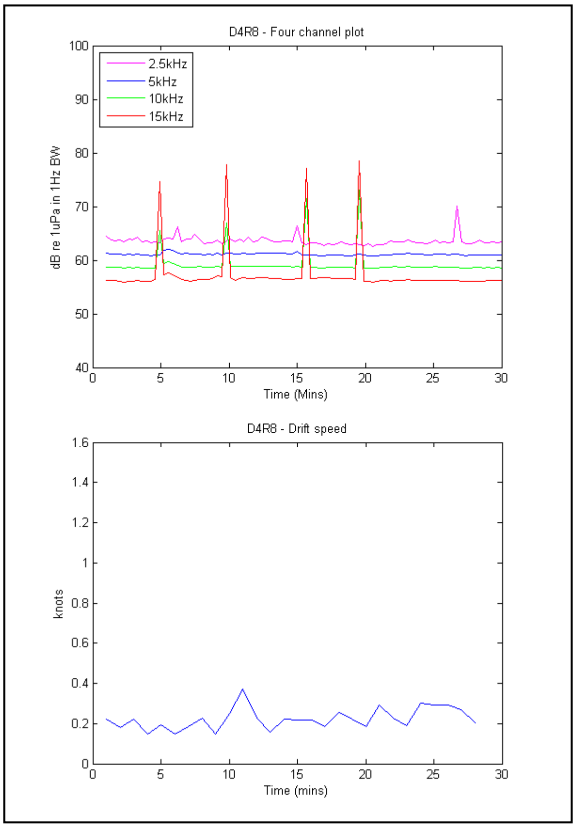
Figure C8. DART 1 spectrogram, run 7.

The first 6 minutes of the run is dominated by noise from a distant boat. Wave noise can be heard throughout with occasional bursts of louder wave noise. There is no chain noise. Three seal scarer signals were heard.

There is a very loud impulsive sound at 12:32 into the run. This is clearly an acoustic signal originating away from the DART unit. Surface and bottom reflections can be seen.


Run 8, May 2012
59.015
59.01
59.005
59
58.995
58.99
58.985
Latitude
2.92
2.91
2.9
2.89
2.88
2.87
2.86
Longitude
Start
Coast
D1R8
D4R8


D1R8 - Four channel plot
2.5kHz
5kHz
10kHz
15kHz
dB re 1uPa in 1Hz BW
Time (Mins)
D1R8 - Drift speed
knots
Time (mins)


D4R8 - Four channel plot
2.5kHz
5kHz
10kHz
15kHz
dB re 1uPa in 1Hz BW
Time (Mins)
D4R8 - Drift speed
knots
Time (mins)

Distance travelled: DART 1 314 metres, DART 4 193 metres. Tide: Flooding.

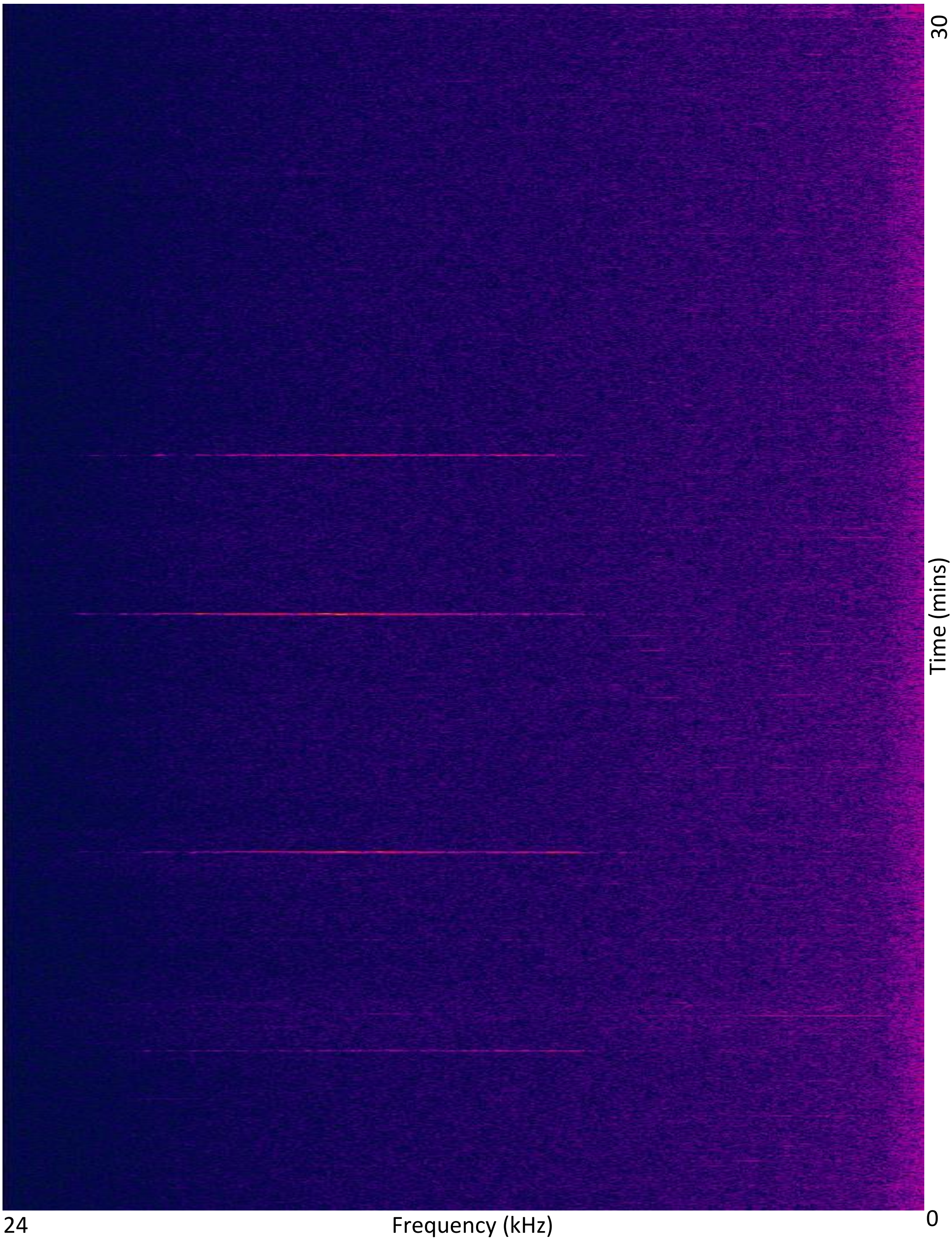


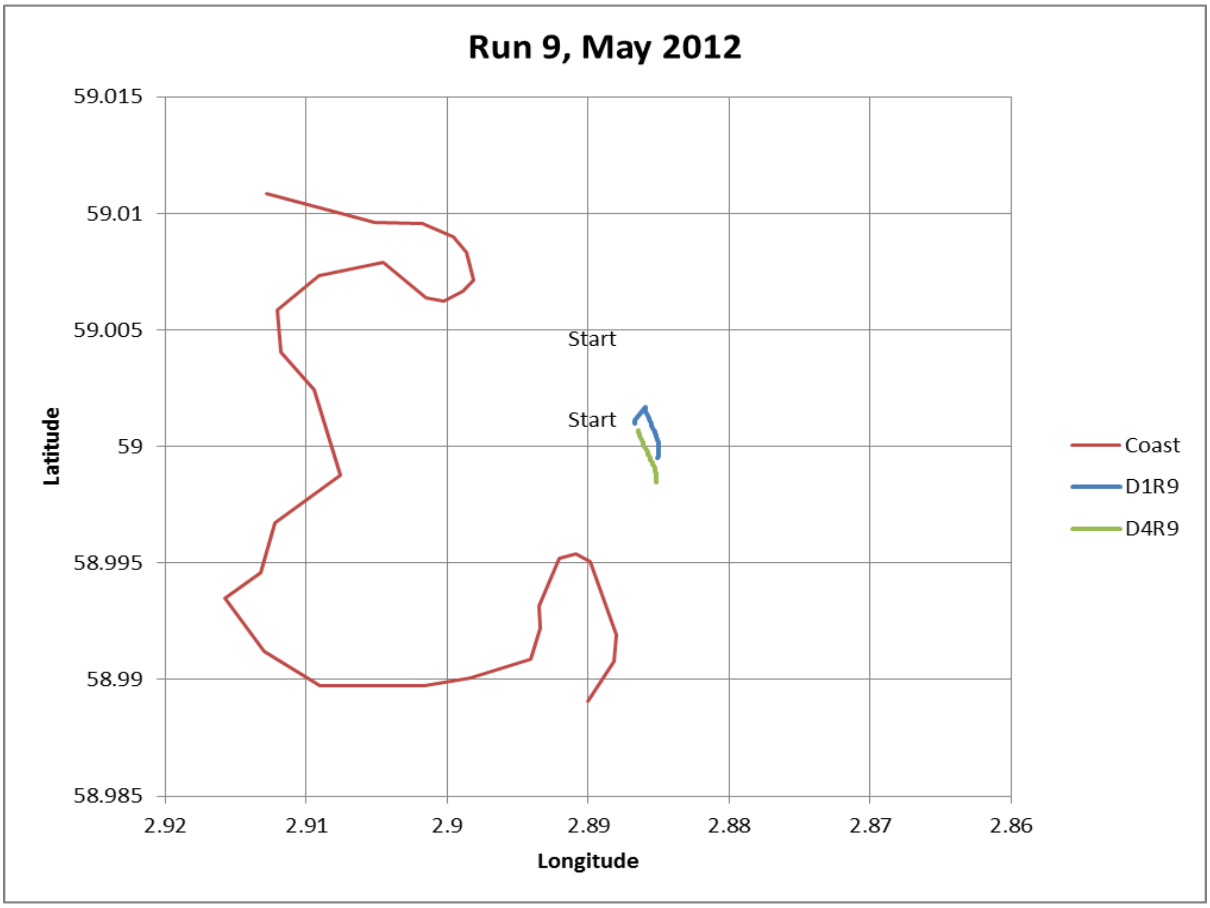
Figure C9. DART 1 spectrogram, run 8.

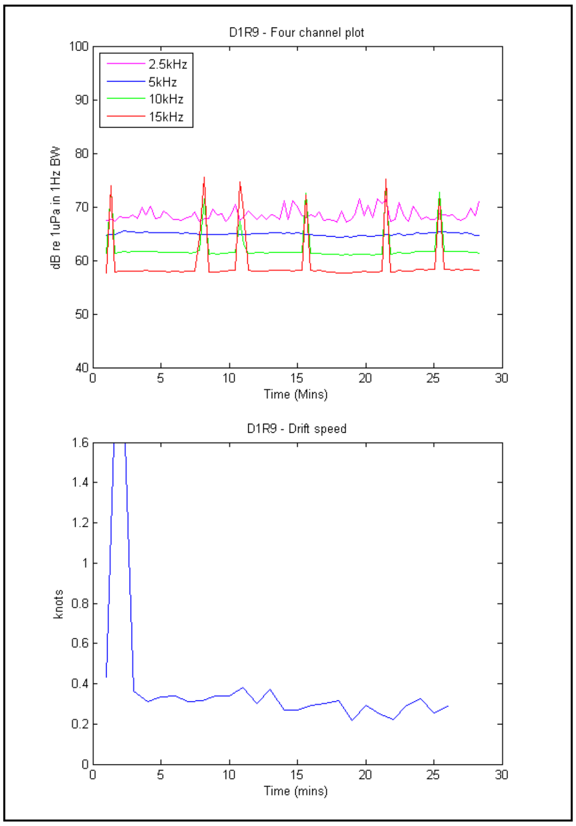
There is no boat noise detectable during this run. A plane passed over at 26 minutes into the run, but the higher noise level compared with run 6 meant it is only just audible.

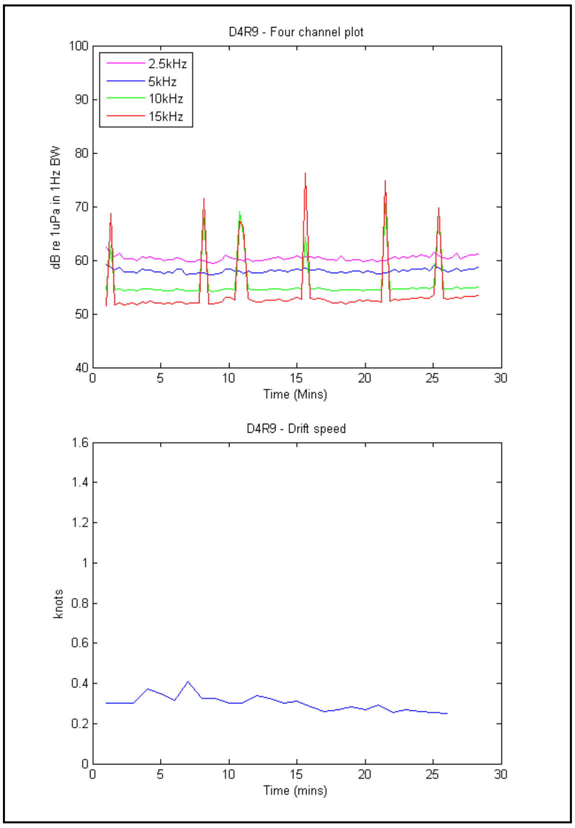
Heavy rain noise can be seen for about a minute at 5 minutes into the run. There appears to be lighter rain noise throughout the run.

There are four seal scarer pulses. At 14.2 minutes into the run there are two loud clicks. They are acoustic signals as surface and bottom reflections can be seen. The cause of these clicks is not known.

Through much of the centre part of the run there is what appears to be weak chain noise with a peak at 7.2 kHz, which suggests a very small link size chain. This noise peaks at 16 minutes into the run.


Run 9, May 2012
Latitude
Longitude
59.015
59.01
59.005
59
58.995
58.99
58.985
2.92
2.91
2.9
2.89
2.88
2.87
2.86
Start
Start
Coast
D1R9
D4R9


D1R9 - Four channel plot
2.5kHz
5kHz
10kHz
15kHz
dB re 1uPa in 1Hz BW
Time (Mins)
D1R9 - Drift speed
knots
Time (mins)


D4R9 - Four channel plot
2.5kHz
5kHz
10kHz
15kHz
dB re 1uPa in 1Hz BW
Time (Mins)
D4R9 - Drift speed
knots
Time (mins)

Distance travelled: DART 1 314 metres, DART 4 242 metres. Tide: Flooding.

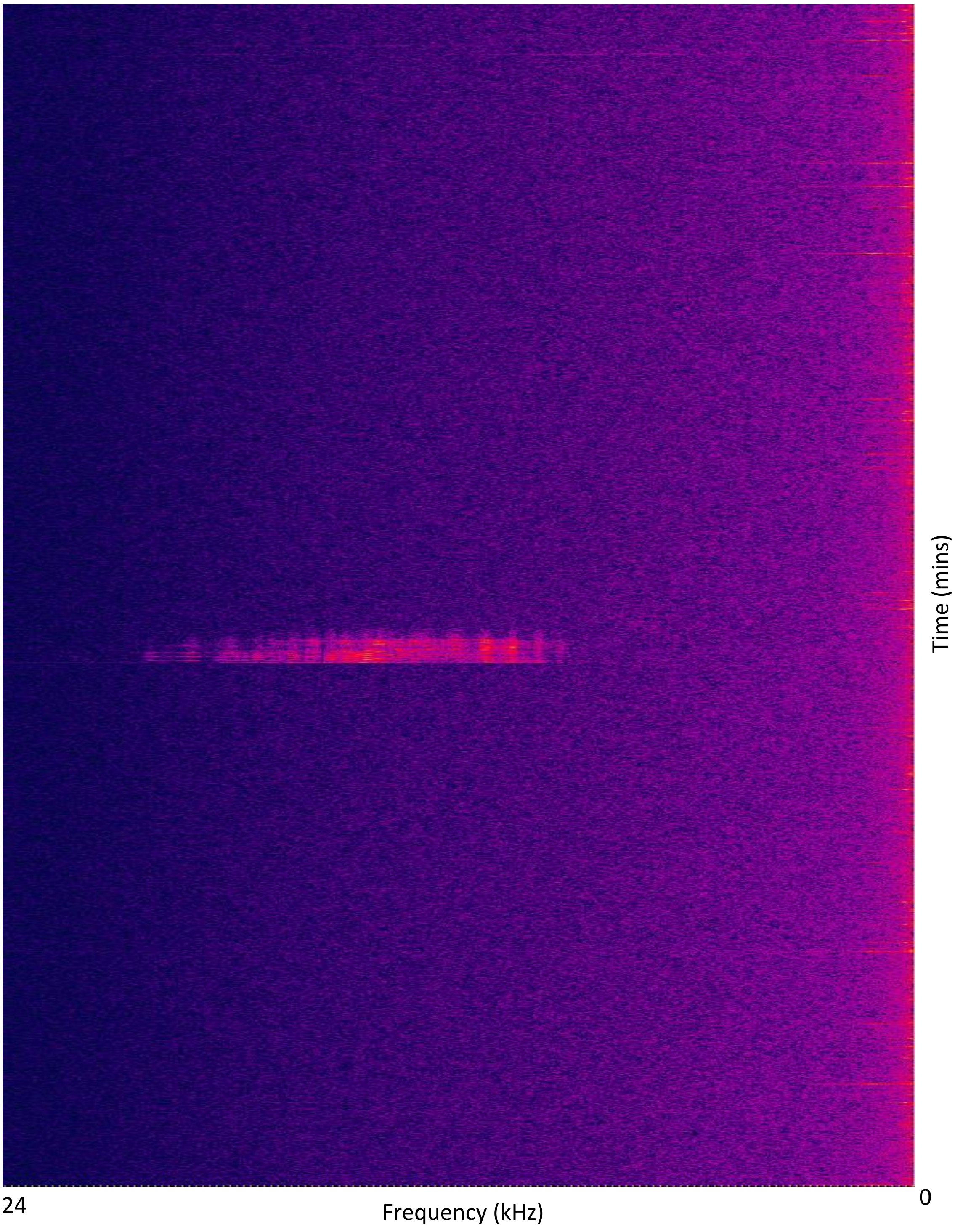
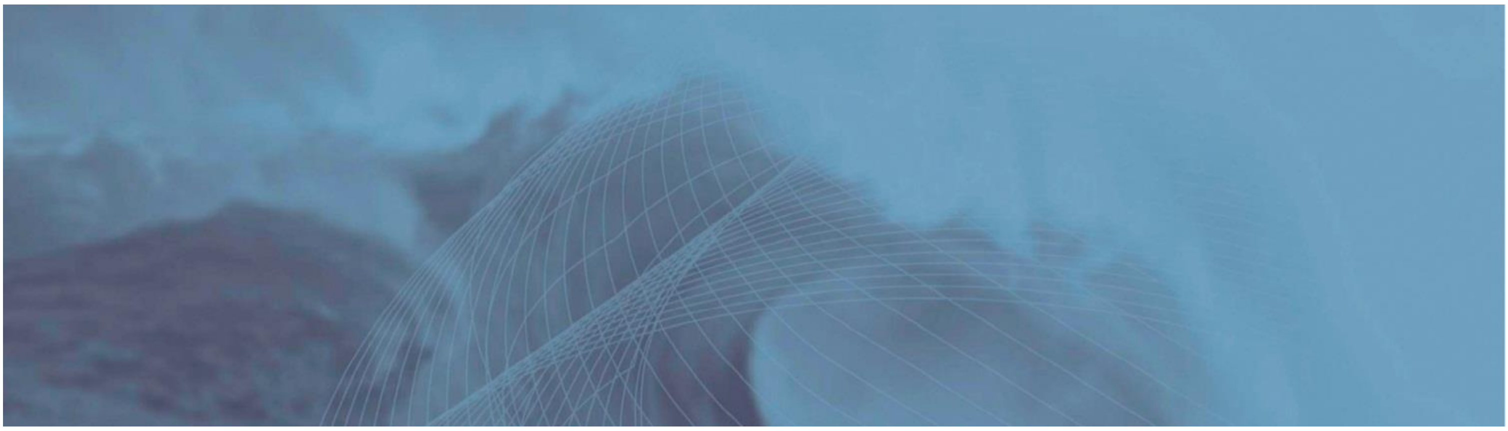
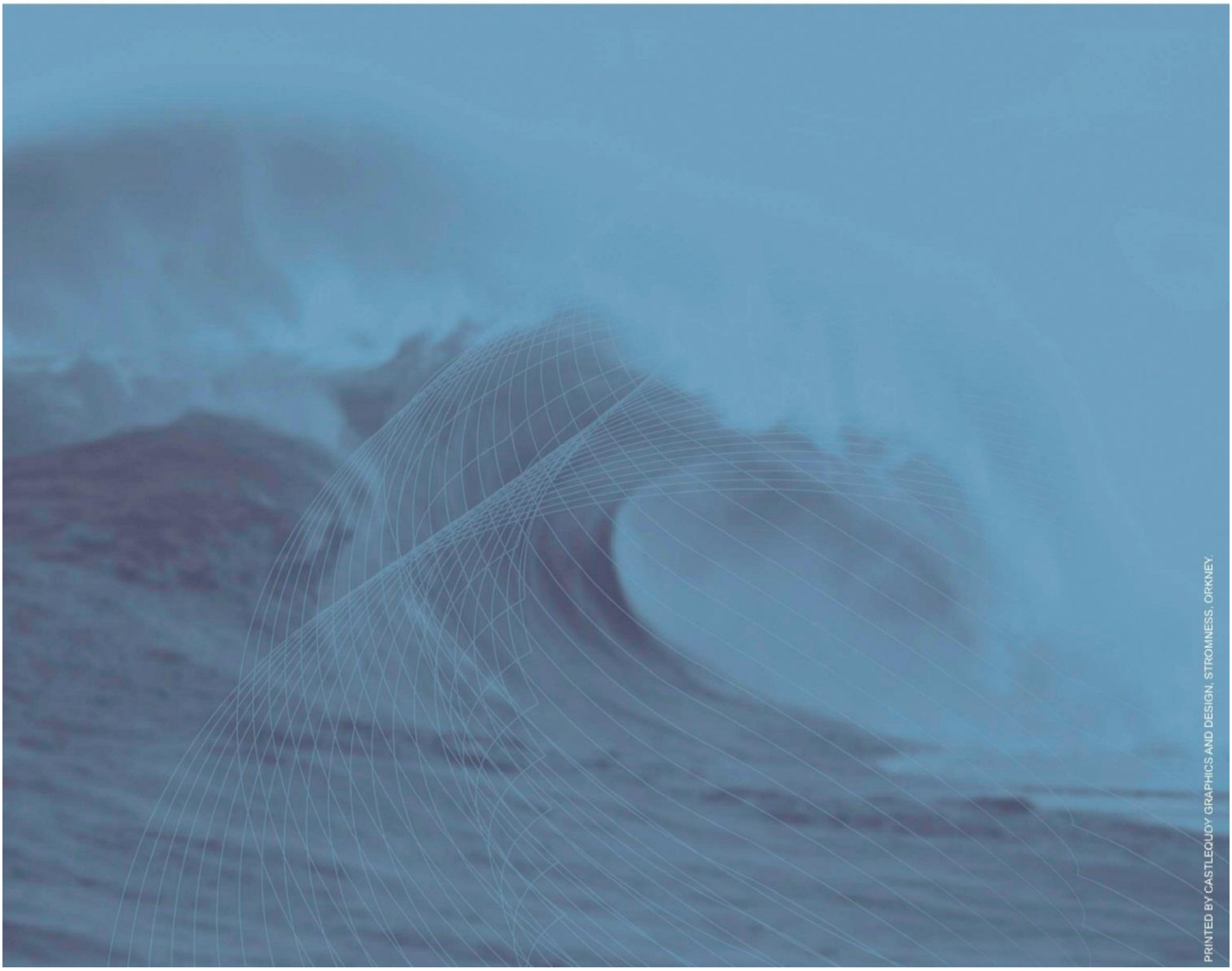


Figure C10. DART 1 spectrogram, run 9.

There is no boat noise during this run. The dominant noise source is rain noise and this is apparent throughout the run.

There is some low level rattling from the hydrophone suspension and this shows in the spectrogram as the pulses at low frequencies. No wave noise or chain noise can be heard, they may well be masked by the rain noise. Five seal scarer pulses were heard during the run.





FOR FURTHER DETAILS PLEASE CONTACT:

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