Scapa Flow Wave Test Site: Acoustic Characterisation

Final Report, February 2013
(E.J.Harland)
Version 1.1



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Contents

1. Executive Summary

Chickerell BioAcoustics was contracted by the European Marine Energy Centre (EMEC) to carry out an acoustic characterisation of the underwater ambient noise field at their Scapa Flow nursery wave energy test site. 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 wave test site and advise on its suitability for use at the nursery wave 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 wave energy converter devices at the Scapa Flow test site. This will provide a better understanding of ambient noise at the site, to assist with the acoustic characterisation of installed 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. Acoustic data were gathered using a self-contained hydrophone and recorder package deployed on the seabed. One unit was available for use in the surveys. Three surveys were carried out in September and December 2011, and March 2012.

The collected data were analysed to establish the acoustic levels under quiet conditions and this shows that the background noise levels were in line with that which could be expected for this type of shallow water site. Contributions over and above these conditions were then identified, with the major contribution being the natural sounds from wind/waves and precipitation. The major anthropogenic source was shipping noise from distant static and mobile sources. Local shipping traffic also contributed to the sound field, although this was only present for around 7% of the time. Other sounds identified included a thunderstorm, aircraft and various biological sources. The identification of marine mammal vocalisations was out-with the scope of this work; however it can be noted that although seals and harbour porpoise were present in the area at the times of the surveys, no calls from either species were identified on any recordings.

The characterisation was limited by the three survey periods not covering a full year and a full characterisation will need at least two more survey periods. Also, the close proximity of the hydrophone to the recorder canister seems to affect the spatial response of the hydrophone, introducing errors of up to 2.5 dB at some frequencies. It is therefore recommended that the mounting arrangement for the hydrophone be improved prior to undertaking any further surveys. The use of additional mobile hydrophone systems together with concentrated study periods using land-based visual observations would assist the analysis of data obtained from future surveys.

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 field at the EMEC nursery wave test site in Scapa Flow, Orkney. This work will provide an acoustic baseline to aid future developers of Wave Energy Convertor (WEC) 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 March 2012 using a fixed hydrophone and recorder package from Wildlife Acoustics Inc. Data were recorded continuously using a bandwidth of 16 kHz. The data were collected over a range of tide, wave and meteorological states and then analysed and reported in a manner suitable to form an acoustic baseline reference for the site.

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

3. Review of the Scapa Flow Wave Test Site

3.1 Physical Characteristics

The EMEC nursery wave test site is located in the eastern part of Scapa Flow off Howequoy Head as shown in Figure 1 below. The water depth is typically 25 metres but it shelves in the north-east corner to just 10 metres in depth. The seabed is mostly sand with rocky outcrops.

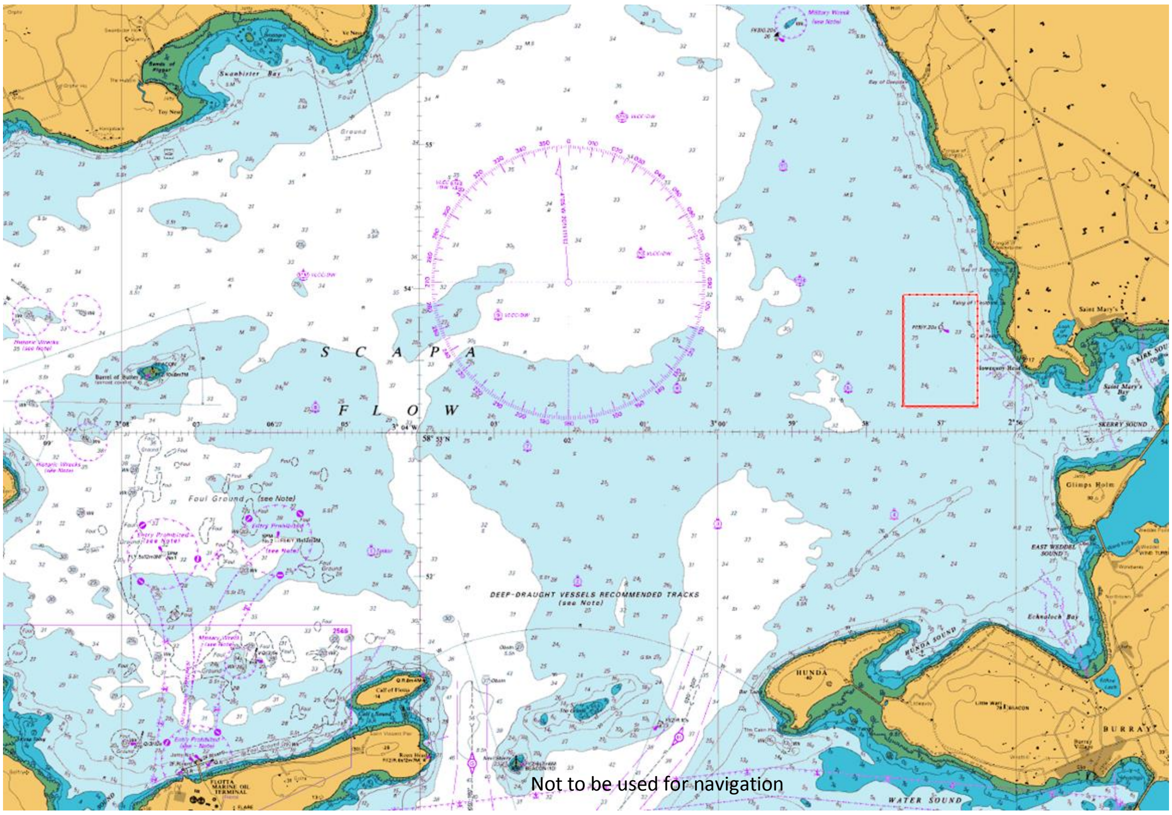

Figure 1: Location of the Scapa Flow test site area (red rectangle)

Although the site is located near the southern tip of Orkney Mainland, the passages between the islands have been blocked by the Churchill Barriers resulting in very little tidal flow through the test site area. The site is exposed to winds from the west.

3.2 Acoustic Aspects

The site is remote from all major shipping routes in Scapa Flow. There is some tug traffic in and out of Scapa harbour and there is some fishing traffic out of St Marys. It is very unlikely that there will be flow noise resulting from tidal flow, but it is likely that waves breaking on the nearby shoreline will be heard in the area. The wildlife observations from the nearby cliff top suggest that both harbour and grey seals are commonly seen in the area, with a few harbour porpoise also seen.

4. Acoustic Surveys

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

4.1 Survey Equipment

An assessment of available methodologies and equipment was carried out. This included an initial survey of the site in July 2011 which used drifting hydrophones together with a hydrophone suspended from a support boat to carry out an initial assessment of the site and the candidate survey methodologies. The conclusion of this work was that the site lends itself to the use of seabed recorders to achieve long time-line recordings. This would allow an extensive acoustic characterisation of the site. If possible, the seabed recorder data should be backed up with acoustic data from hydrophones deployed from drifting boats.

A survey of seabed recorders available at the time suggested that the best option was the Songmeter SM2M Marine Recorder from Wildlife Acoustics Inc. (SM2M). This is a low cost system which uses the same recorder unit used in the EMEC Drifting Acoustic Recorder and Tracker (DART) system. Other units available at that time were either very expensive (up to 8 times the cost) or were known to suffer from internal noise problems. An external view of the unit is shown in Figure 2 below while Figure 3 shows the internal recorder.

A potential problem identified was the close proximity of the hydrophone to the end cap of the canister housing the recorder. The supplier was requested to provide a plug and socket so that the hydrophone could be located away from the unit but such a configuration could not be provided at the time. Current SM2M units are now available with the option of a remote hydrophone, and the manufacture also now offers the option of a low-noise hydrophone for use in quiet sites such as Scapa Flow.

The hydrophone used by the SM2M does not come with a full calibration certificate. See Appendix A: System Calibration for a discussion on the calibration of the recording and analysis system.

The problem with having the hydrophone so close to the canister is that complex interactions can occur between the acoustic field and the mechanical arrangement which will modulate the spatial response of the hydrophone. Moving the hydrophone away from the canister would eliminate this problem.

Figure 2: Wildlife Acoustics Inc. Songmeter SM2M Marine Recorder system

Figure 3: SM2M recorder unit

The orientation of the SM2M when deployed is shown in Figure 4 below (image courtesy of Wildlife Acoustics Inc.).

The SM2M unit is buoyant and for these surveys was attached to a 25Kg clump weight for deployment on the seabed. A length of rope connected the 25Kg clump to a 200Kg clump weight, which in turn was attached to a surface marker buoy. The unit was deployed by lowering the 25Kg clump weight to the seabed with the SM2M attached. The deployment boat then moves away while paying out approximately 100m of rope and then deploying the 200Kg clump weight and marker buoy.

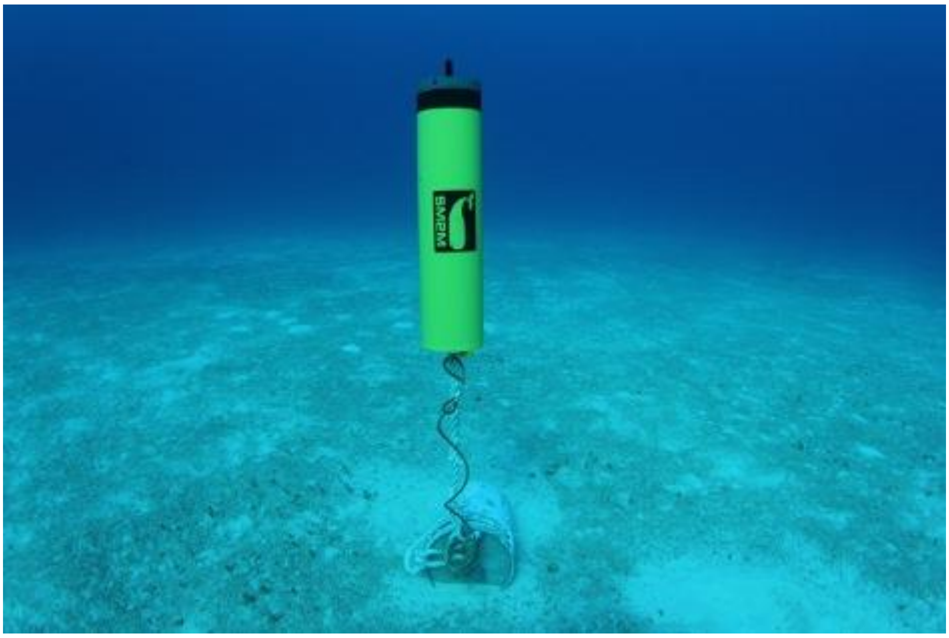

Figure 4: Orientation of the SM2M on the seabed

Three surveys were carried out:

- Survey 1 - 19th to 24th September 2011 at 58° 53.70'N, 2° 57.30'W
- Survey 2 - 2nd to 7th December 2011 at 58° 53.30'N, 2° 56.90'W
- Survey 3 - 14th to 21st March 2012 at 58° 53.91'N, 2° 56.78'W

The SM2M deployment locations are shown by the yellow crosses in Figure 5 below.

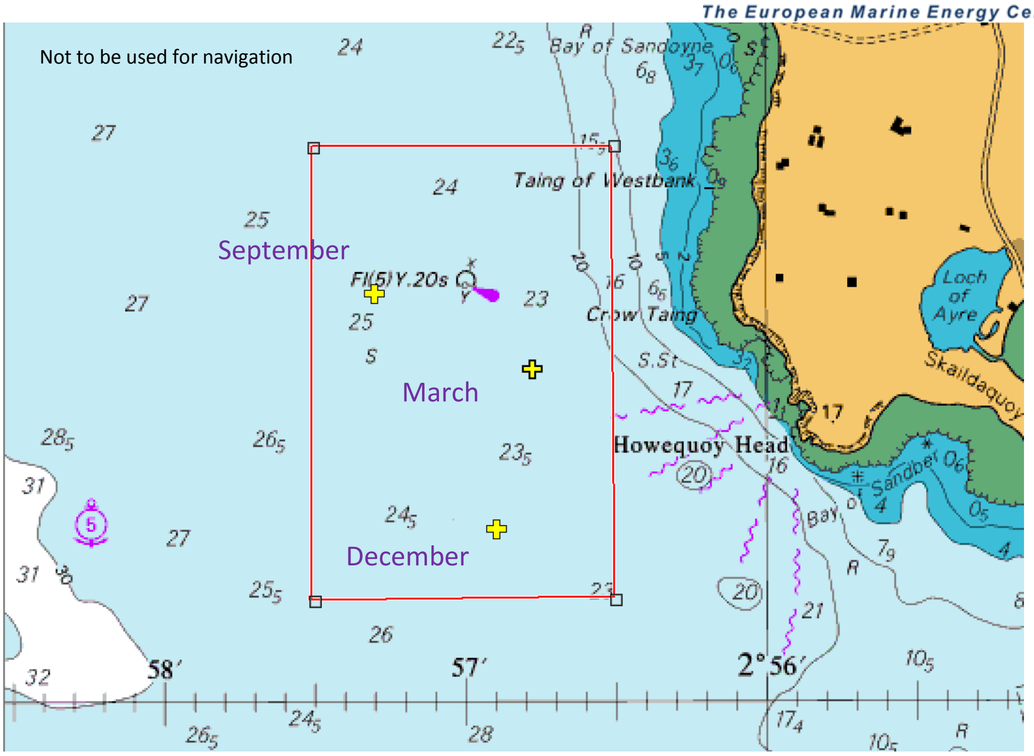

Figure 5: Deployment locations for the three acoustic surveys (shown in yellow)

For all three deployments the sample rate was 32 kHz, giving a bandwidth of 16 kHz, and the internal gain was set to 0 dB.

4.2 Supporting Data

Meteorological data were available from the two EMEC weather stations located at the Bilia Croo wave test site (25 km to WNW), and on the island of Eday near the Fall of Warness tidal test site (31 km to NNE). Neither of these sites is close to the Scapa Flow test site, so while the general trend in wind speed/direction and precipitation is likely to be reflected at the Scapa Flow test site, the detail may be very different.

The nearest tidal station is St Marys, which is very close to the Scapa test site.

Automatic Identification System (AIS) data showing the movements of ships over 300 gt is available for all three survey periods.

Wildlife observations are made from the cliff-top overlooking the test site. A summary of the observations covering the survey periods is provided in Appendix B: EMEC Wildlife Observations.

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 analysis. This showed up a number of minor problems, including abrasion noise and internal noise. The abrasion noise appears to be floating debris rubbing against the hydrophone. The internal noise is very low in level and only apparent under the very quietest conditions.

The collected files were then edited using the Syntrillium Software package *CoolEdit* to create 12-hour long files in WAV format covering midnight to midday and midday to midnight for each day of each survey deployment. Full analyses of each of the data files were then carried out and the results are presented in Appendix C: September 2011 Survey, Appendix D: December 2011 Survey, and Appendix E: March 2012 Survey for each of the September 2011, December 2011 and March 2012 survey periods respectively.

5.1 Spectra and Levels

Figure 6, Figure 7, and Figure 8 below show a selection of mean spectra for each of the three surveys. The spectra are the mean for a four minute period chosen to illustrate a particular aspect of the ambient noise field. For each survey the quietest period, the windiest period without rain, a rainy period and a period with strong vessel noise has been chosen. This gives the degree of variation that may be expected in the ambient noise field. The vessel noise has been chosen to reflect the noise from passing vessels. The levels from vessels working within the test site can be expected to be significantly higher than that shown.

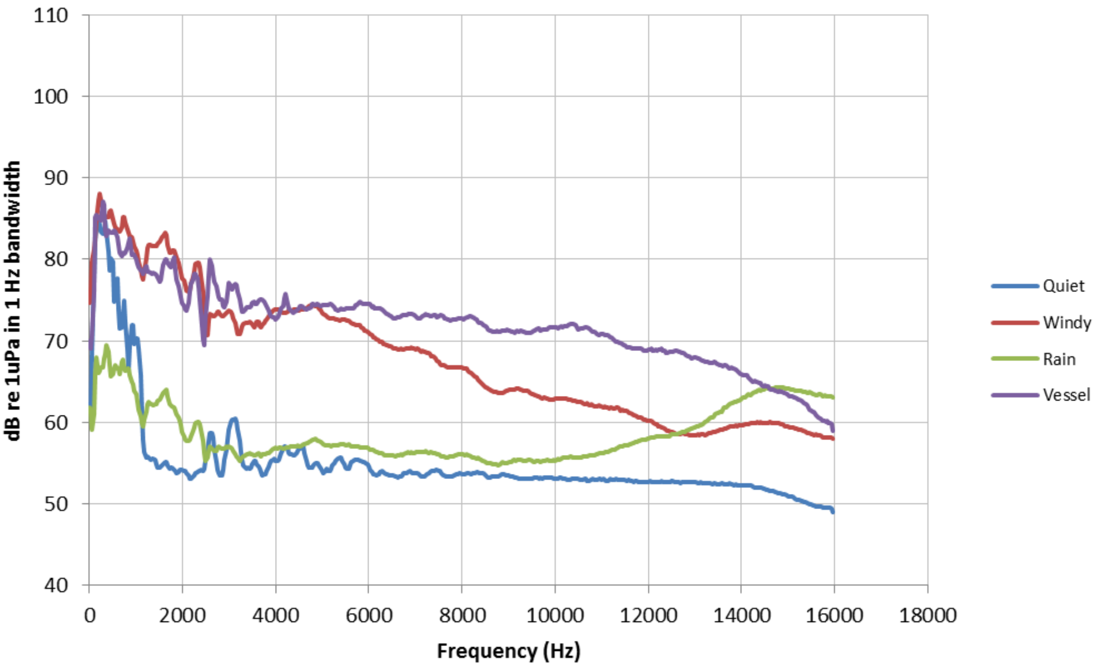

Figure 6: Mean spectra for the September 2011 survey

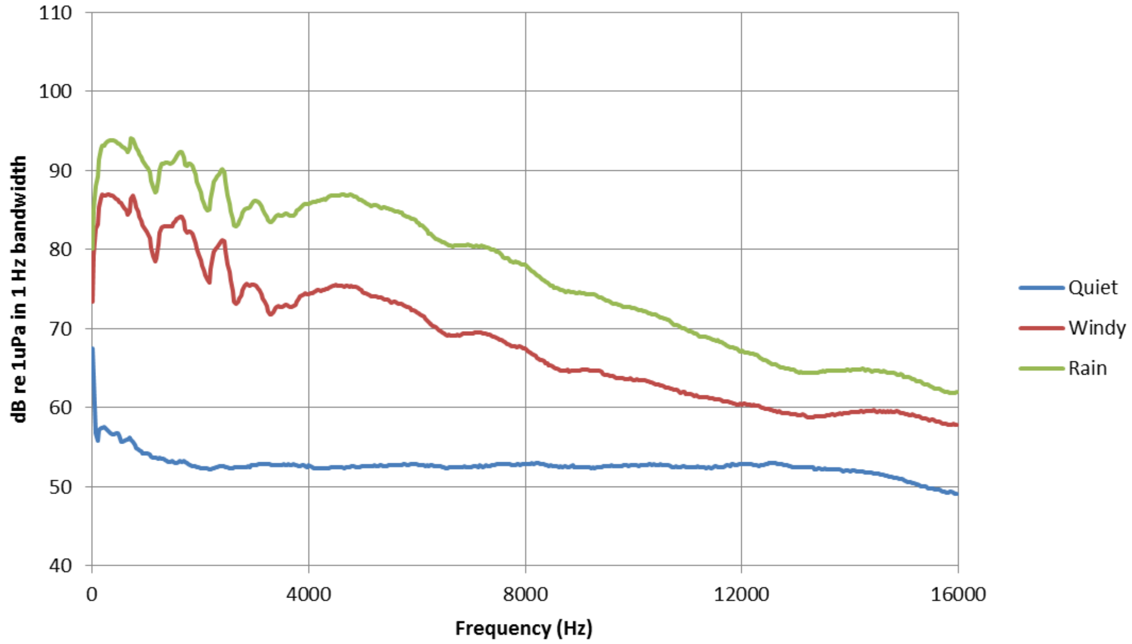

Figure 7: Mean spectra for the December 2011 survey

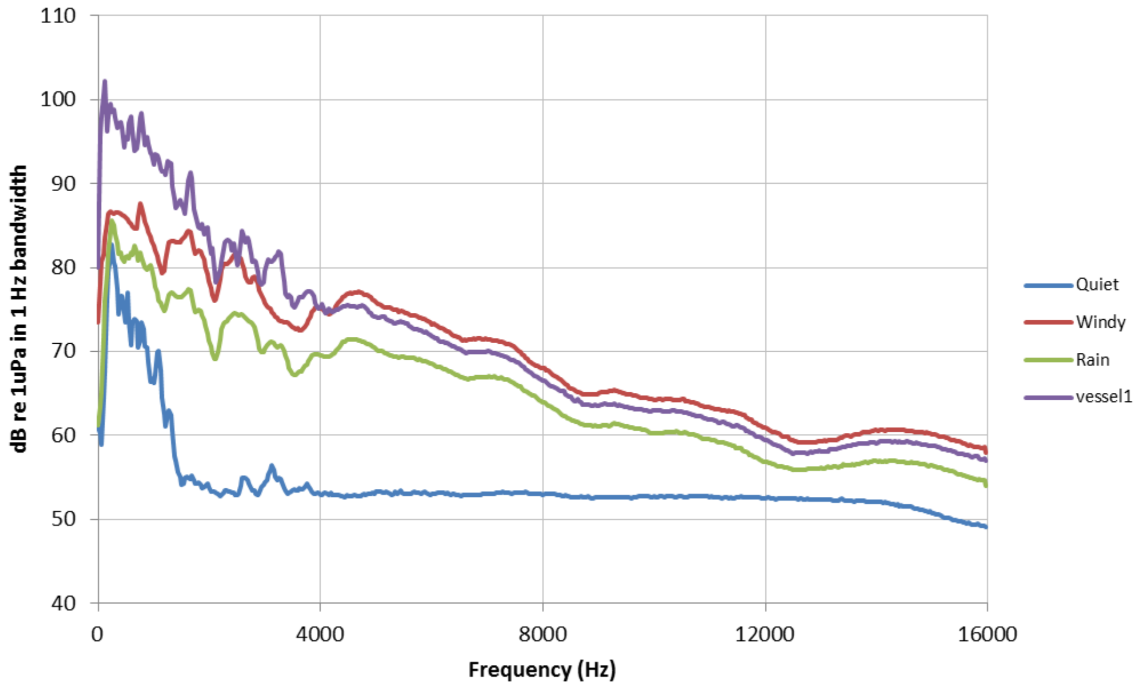

Figure 8: Mean spectra for the March 2012 survey

The spectra for quiet conditions are very similar between the three surveys. The September data show a strong component below 1 kHz and this is due to machinery noise, possibly from a moored vessel within Scapa Flow. This low frequency component is absent in December but can be seen again in the March survey. The quiet levels at low frequencies are typical of levels expected for a quiet shallow water site (Urick, 1975) and compare with similar measurements at the Shapinsay

Sound tidal test site (Harland, 2012). The higher frequency levels are louder than expected and do not have the expected spectral shape. It is likely that the levels shown above 2 kHz are the internal noise level of the recorder and hydrophone rather than levels in the water.

Strong winds raise the ambient noise levels by up to 20 dB around 5 kHz. Rain noise can increase this by another 10 dB, as shown in the December survey. At times the rain noise has a strong band of noise around 15 kHz as shown in the September survey. The actual spectrum resulting from rain seems to depend on various factors and this noise band is not always observed during rain.

The vessel noise spectra show noise from passing vessels. The test site location has no regular vessel tracks close to it and most vessel noise is weak. In December no vessels came close to the hydrophone site so no plot is shown. In the March survey the noise from the closest pass is shown but as only components below 4 kHz contribute to the noise it is likely that this pass was at least 500 metres away. In the September survey the vessel came much closer and here components up to 16 kHz can be seen.

5.2 Variability

It is possible to take many mean spectra as shown in section 5.1 and superimpose them in one plot (see Figure 9 below). The colour scale is proportional to the number of times a particular frequency/amplitude point occurs. This has been carried out for each of the survey periods. The mean spectrum for every ten second interval is calculated and the resulting spectra for the whole period are then summed in a matrix with a resolution of 1 dB vertically and 250 Hz horizontally. Each point on the matrix is the count of the number of times a mean spectrum had a point at the particular frequency/amplitude. Because the dynamic range of such a plot is greater than most printers can reproduce, the logarithm of the count is plotted to compress the range.

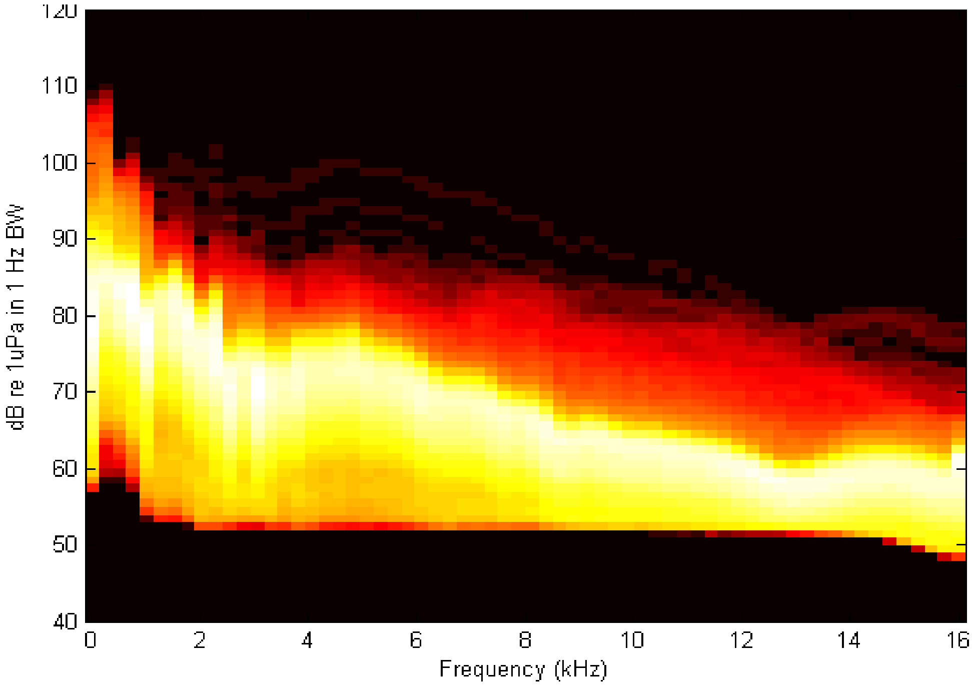

Figure 9: Variability plot for the September 2011 survey

Figure 9 above shows the resulting plot for the September survey. Plots for the December and March surveys can be found in Appendix D: December 2011 Survey, and Appendix E: March 2012 Survey respectively. The broad white band running across the plot represents points that are found most often, and can be considered to represent a 'typical' spectrum of noise for the site. Excursions above this typical spectrum occur when the noise level is raised by bad weather or passing boats. The highest levels are generally from close passes by boats.

Excursions below the typical level occur during periods of quiet weather and no vessel traffic. The lower limit should represent the lowest possible level that can be heard at the site. However, in this case the flat base of the plot suggests that the lower limit is determined by internal noise in the recording equipment rather than external ambient noise. This is likely to be due to the performance limitation of the hydrophone used by the SM2M system (the supplier of the SM2M system now offers a low noise option which reduces the noise floor by 10 dB).

5.3 Spectrograms

The spectrograms for the full bandwidth of each of the 12-hour files were produced and a typical example is shown in Figure 10 below. The spectrograms are prepared by taking 1024 samples, performing the FFT with Hanning weighting, and then averaging the data for 30 seconds. This is then plotted for each 12 hour period.

The spectrogram shown below is for the period from midday to midnight on the 6th December 2011. It illustrates a number of aspects of the acoustic data.

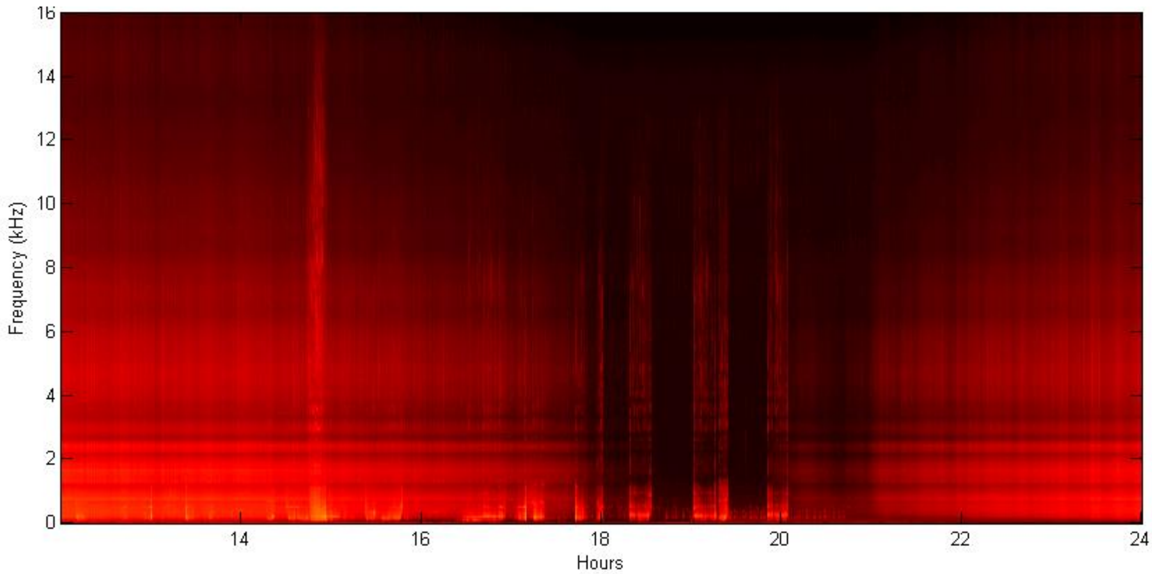

Figure 10: Spectrogram for 6th December 2011, midday to midnight

The spectrogram starts with a high noise level due to strong winds. This progressively reduces as the wind eases to reach a low level around 18:00. There is then a period of low noise before the wind picks up again from around 20:15. The horizontal banding below 4 kHz is caused by structure within the noise, possibly due to multi-path interference effects. The spectral structure does not vary during the survey so appears to be an internal effect of the recorder. It is most likely due to an interaction between the hydrophone and the air-filled instrumentation canister on which it is mounted (see Figure 2). This could be alleviated by moving the hydrophone away from the canister.
The bright band of noise just before 15:00 is due to a passing vessel. Similarly the bright bands that occur from 18:00 to 20:00 are also due to vessel movements. Figure 11 below is produced by expanding the spectrogram at around 15:00.

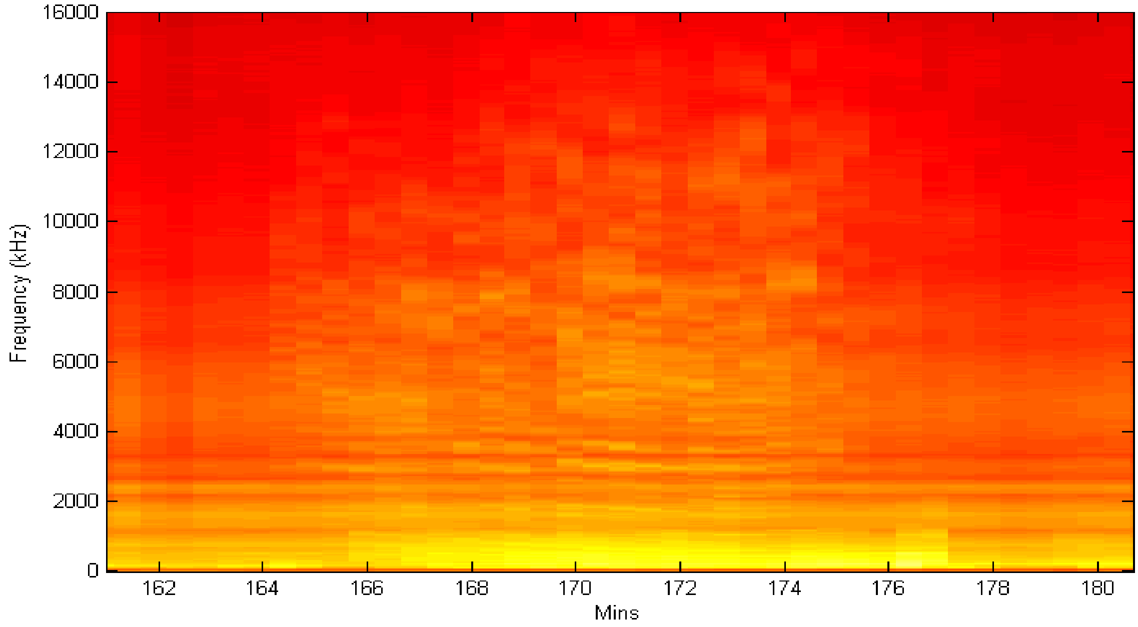

Figure 11: Vessel noise at 170 minutes

Expanding the frequency scale to show the low frequency content produces Figure 12 below.

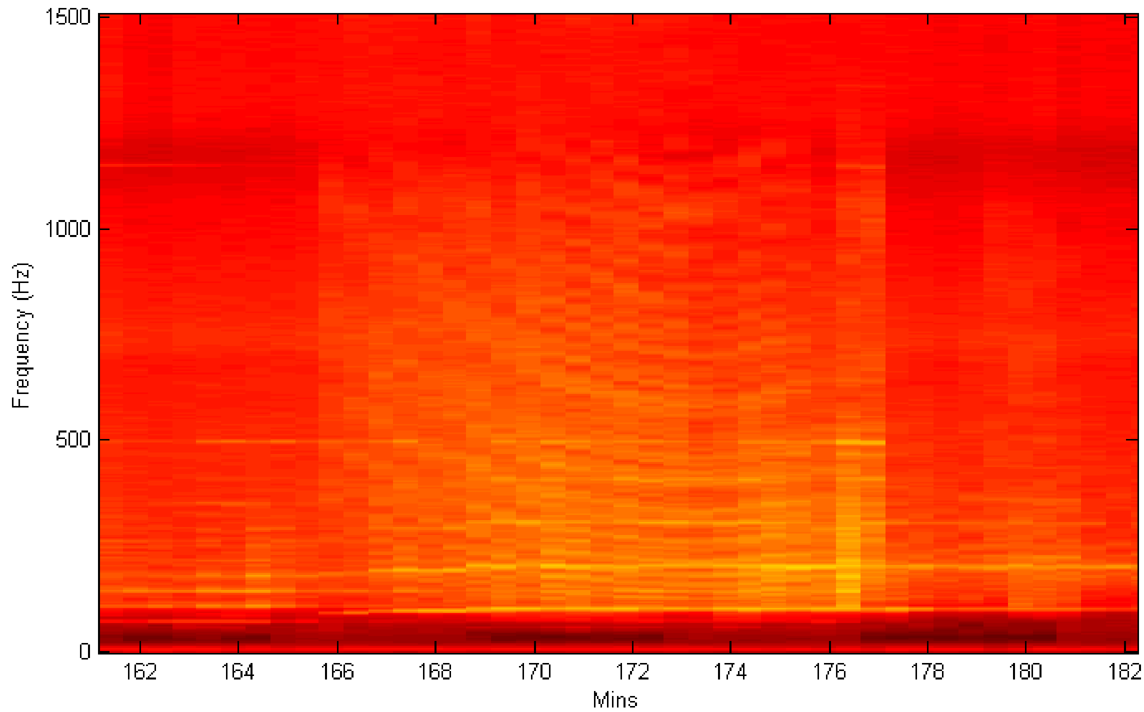

Figure 12: Vessel noise at 170 minutes, expanded frequency scale

This shape is typical of vessels passing reasonably close to the hydrophone. In this case the pass takes 13 minutes and is not very loud, and therefore is likely to be some distance away. The 'bathtub' shape of the spectral components with time is caused by Lloyds mirror effects. Lloyds mirror effect refers to interference between signals travelling directly to the receiver and those reflected off the surface of the water. As the source moves, the frequencies of the peaks and troughs of the interference pattern change. As the source approaches, the pattern moves towards lower frequencies and then increases as the source moves away.

Figure 13 below shows the spectrogram of another vessel passing.

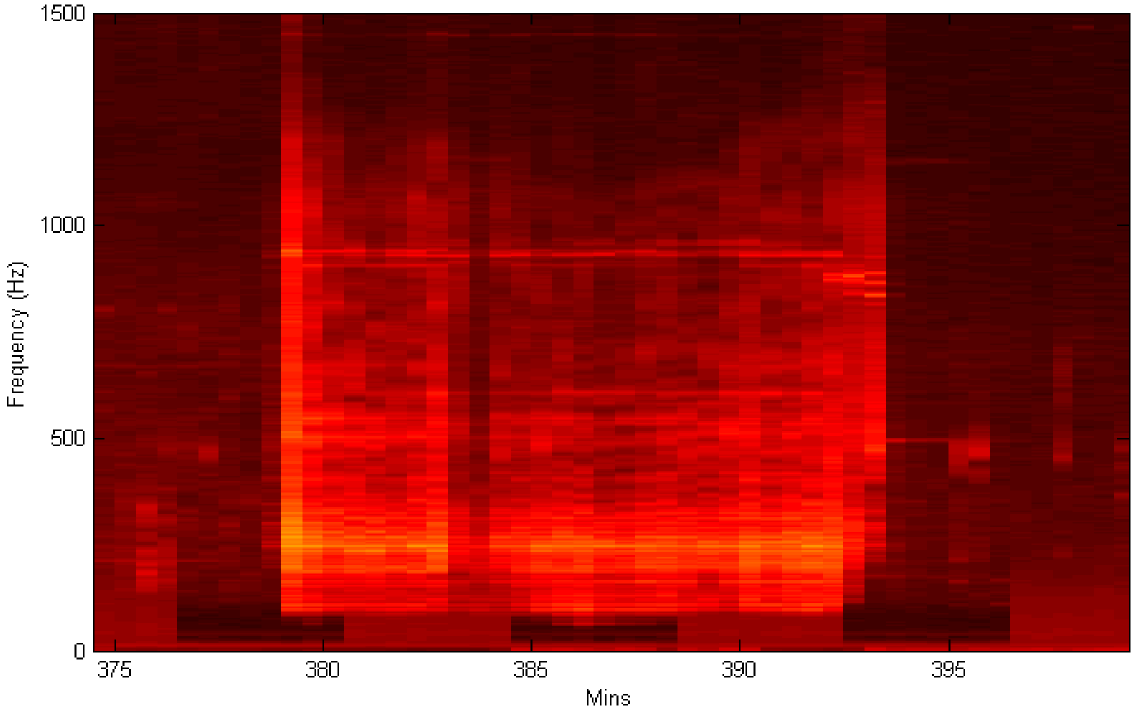

Figure 13: Spectrogram of vessel noise

This spectrogram has characteristic tonals at 386, 935 and 1450 Hz, seen many times throughout the surveys. These tonals are likely to originate from one of the inter-island ferries. A second set of tonals at 493 and 1150 Hz, probably originating from one of the other ferry boats, also appears regularly.

Figure 14 below shows the full 12 hour spectrogram of this vessel noise with the frequency scale expanded. The expanded frequency scale is achieved by decimating the analogue data by a factor of 8 and then low-pass filtering at 2 kHz. The spectrogram is then calculated in the same way as the full frequency range spectrogram.

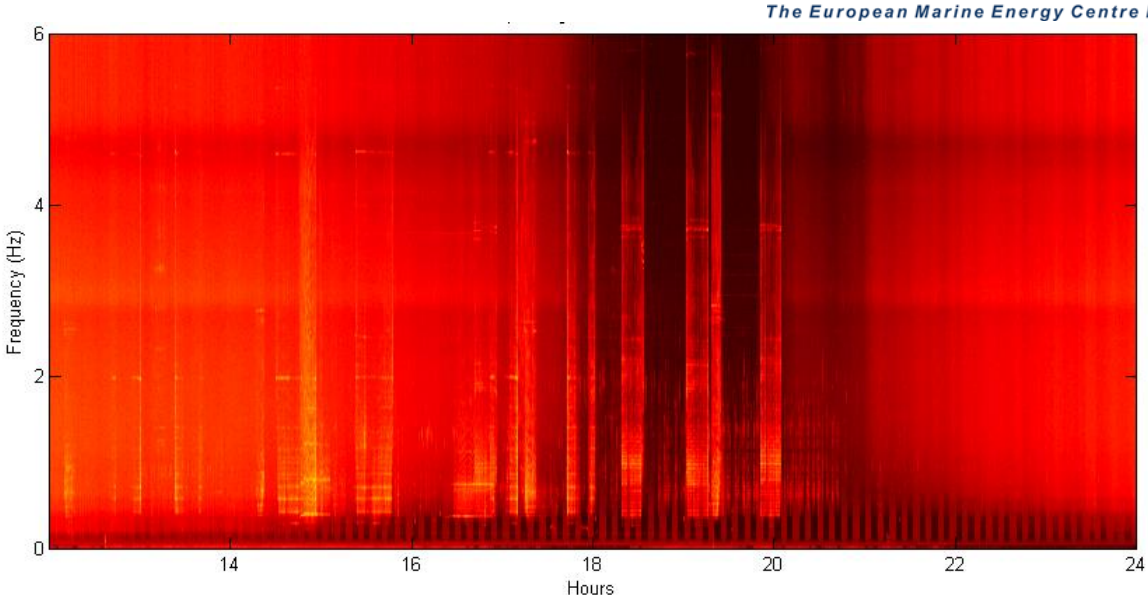

Figure 14: Low frequency spectrogram for 6th December 2011

Note the regular banding at low frequencies in Figure 14 above. This is a particularly good example of the internal digital noise originating within the recorder control system.

5.4 Multi-channel Plots

The data processing also produced five-channel high frequency and four-channel low frequency plots. The aim of these plots is to display the sound level in different frequency bands. This type of display is often more sensitive to changes in spectral shape and content than a spectrogram. The high frequency plot is similar to that used in other EMEC acoustic work (Harland, 2012a, 2012b) with four filters 2 kHz in bandwidth and centred on 2.5, 5, 10, and 15 kHz, with an additional fifth channel centred on 750 Hz with a bandwidth of 200 Hz. This processing is implemented as a MATLAB function by summing the squares of the FFT output points across the appropriate band of frequencies. A bandwidth correction is applied to give the spectrum level. The display for the same twelve hour period as used in section 5.3 is shown in Figure 15 below.

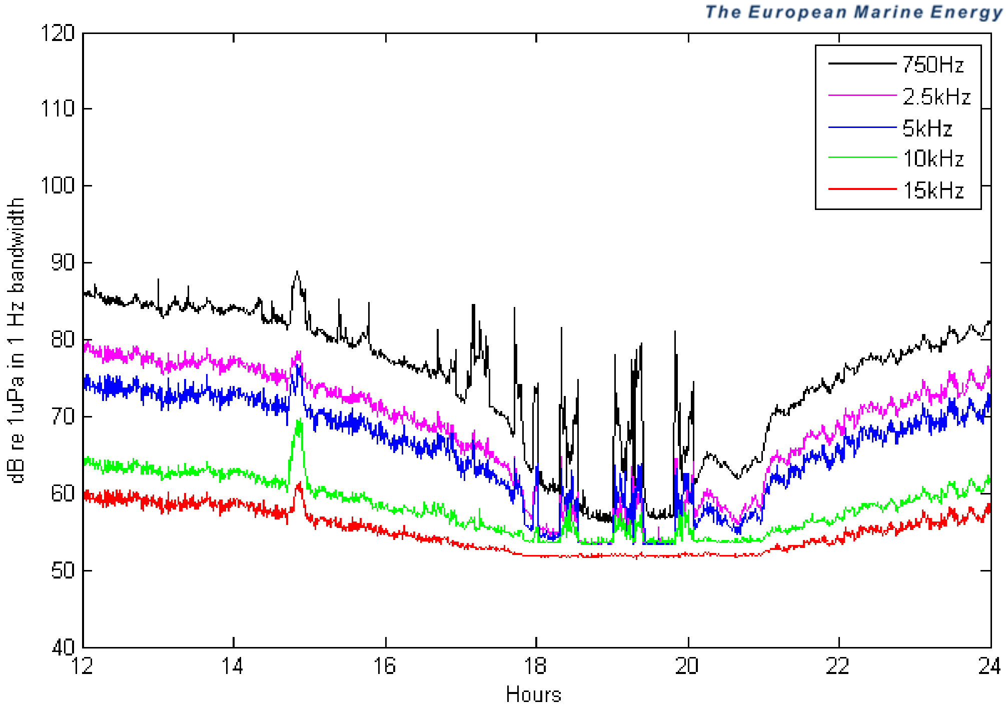

Figure 15: Five-channel high frequency plot for 6th December 2011, midday to midnight

The vessel traffic can be clearly seen as amplitude peaks at lower frequencies. The reduction in natural noise level through the middle of the period can also be clearly seen. The peak at 14:45 is caused by rain, and has higher frequency content than vessel noise.

The low frequency fourchannel display was produced using four filters centred on 63, 125, 250 and 500 Hz corresponding with standard third-octave bandwidth filters. Again a bandwidth correction is applied to give a spectrum level. The two lower frequencies correspond with the two frequencies chosen in the EU MSFD GES Indicator 11[1]. The low frequency plot for the same twelve hour period used for Figure 15 is shown in Figure 16 below.

Note that the shallow water will attenuate the lowest frequencies. In deep water, ambient noise continues to rise as the frequency decreases. In shallow water this is not true because the shallow water will attenuate frequencies below a cut-off frequency determined by the water depth.

[1] At the time of writing the EU Marine Strategy Framework Directive (MSFD) Good Environmental Status (GES) Indicator 11 had yet to be finalised. The draft version calls for long term monitoring of underwater sound levels at 63 and 125 Hz using third-octave bandwidth filters. The DEFRA website gives more information at http://www.defra.gov.uk/environment/marine/msfd/

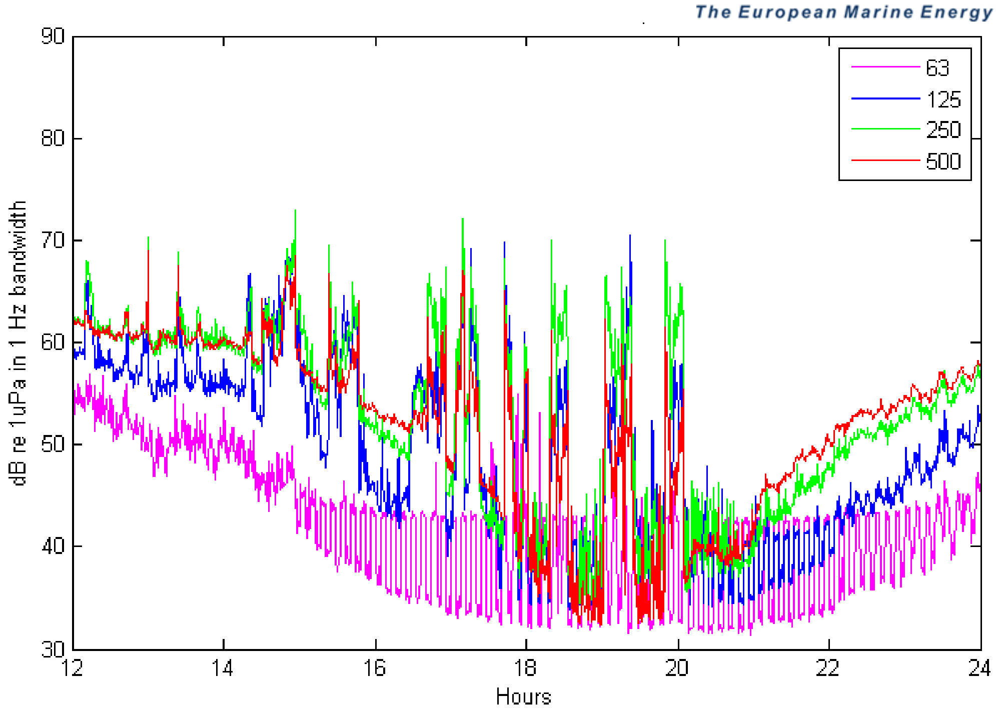

Figure 16: Four-channel low frequency plot for 6th December 2011, midday to midnight

Note the strong banding at 63 Hz due to internal digital noise. This noise is present when the internal processor is active, but disappears when the processor is inactive. The lower level of the oscillation therefore corresponds to the waterborne noise level while the upper level corresponds to the internal noise level. This noise is only apparent when ambient noise is at its lowest levels.

5.5 Contributors to the Noise Field

Processing the various data files collected suggested that the following were the main contributors to the noise field.

Wind and rain

Wind contributes to the noise field in three different ways. There is the direct effect of wind interacting with the surface of the water, an indirect mechanism whereby the wind generates breaking waves within the test site, and lastly the noise generated by breaking waves on the nearby shoreline. The local breaking waves can be heard and make the major contribution at higher frequencies. The shoreline noise tends to be lower in frequency due to the higher frequencies being attenuated by the increased range.

The noise from heavy rain makes a significant contribution. The resulting spectrum can be highly variable with at times a major contribution between 10 and 20 KHz while at other times the major contribution is at lower frequencies. It is not clear what causes this variability.

Shipping

Shipping noise heard during the surveys falls into two categories. For much of the time there is a weak background noise of machinery. This appears to come either from vessels moored in Scapa Flow or possibly from activities at the Flotta Oil Terminal. It is never more than a few dB above the normal ambient noise level. All of this sound is below 1 kHz.

The noise from moving vessels is more significant. The majority of these noises are also weak and merge with the static noise sources. They are most probably from the inter-island ferries and other vessel movements in western Scapa Flow.

On a few occasions vessels passed closer to the survey site and this raised noise levels significantly. This traffic is either tug traffic in and out of Scapa harbour or small boat movement in and out of St Marys. On two occasions work boats operated on the test site and these made a major contribution to noise levels, including the loudest sound heard which sounded like a large chain being deployed very quickly. One such event is shown in Figure 17 below.

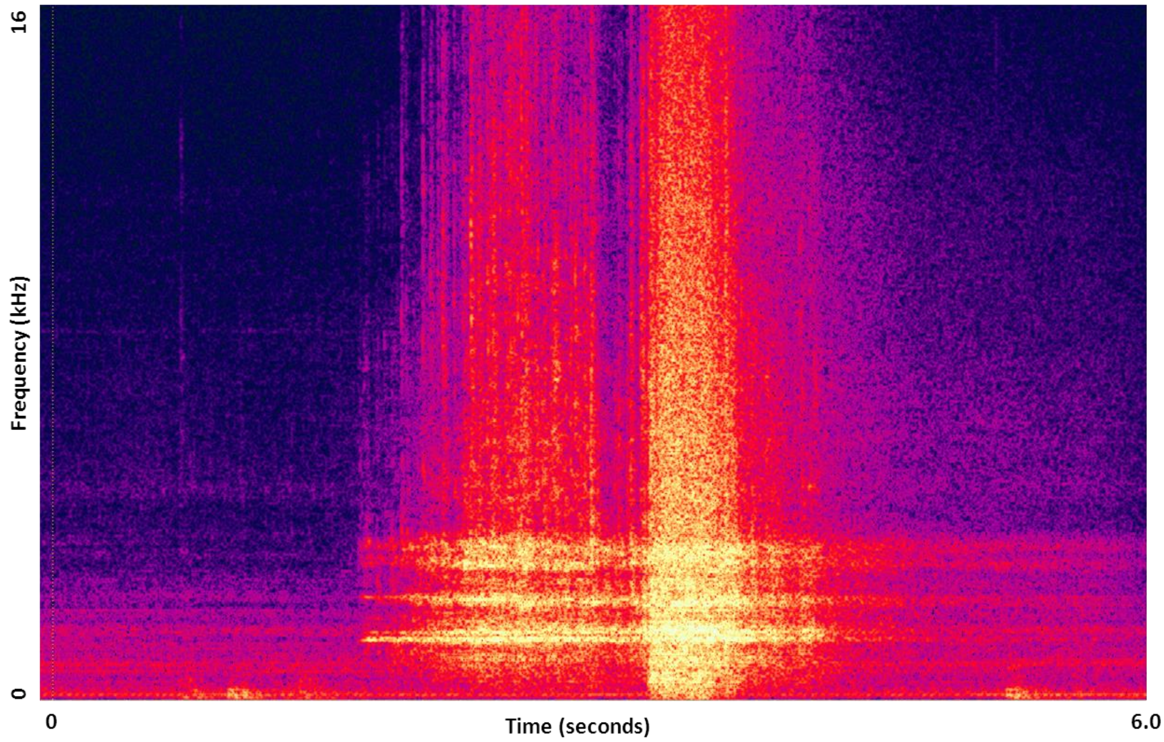

Figure 17: Possible chain noise

This sound was so loud that the recorder clipped the waveform. This implies a sound level greater than 168 dB re 1uPa. This recording was made on the 21st March 2012 at 11am.

Aircraft

The test site is close to Kirkwall Airport and under quiet conditions approaching aircraft noise can be heard. An example is shown in Figure 18 below. The low frequency spectrogram has been zoomed-in to show the aircraft noise at 82, 162 and 243 Hz. Each horizontal bar is one element of the vertical stripe which is the 30 second mean spectrum. The noise is audible for 90 seconds and the Doppler shift as the aircraft approaches and recedes is clearly visible.

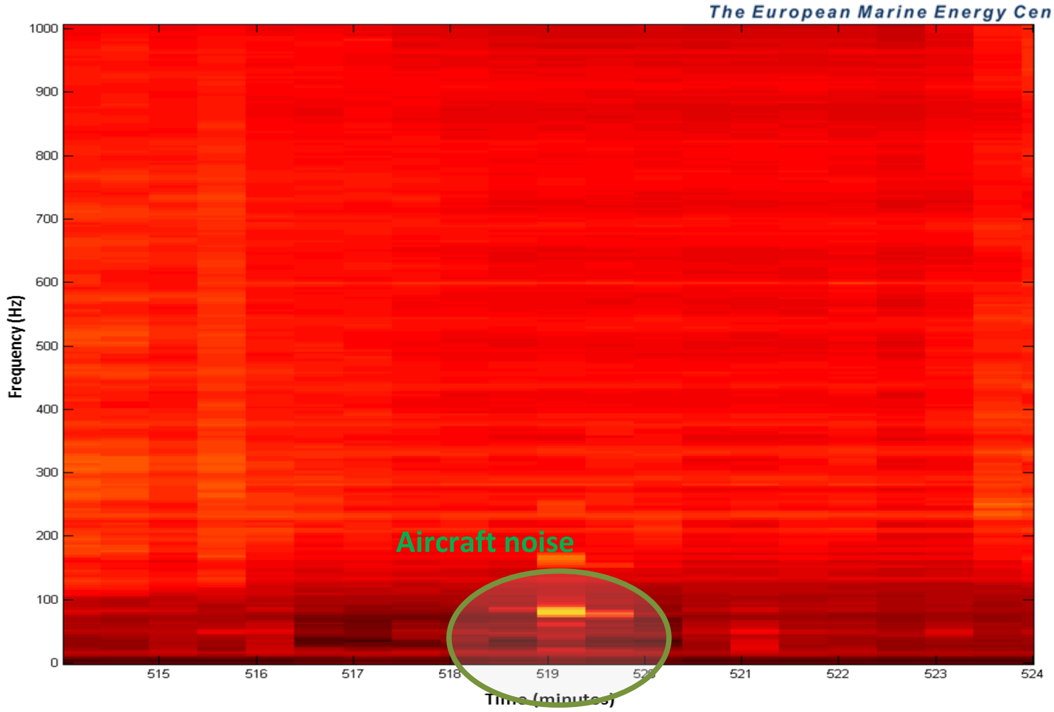

Figure 18: Aircraft noise

Marine mammals
Although seals and harbour porpoise were present in the area no calls from either species were identified on the recordings. Harbour porpoise only produce echolocation clicks centred on 140 kHz, well above the frequency range of the recorder. Grey seals rarely vocalise underwater. It should be noted that identification of marine mammal vocalisations was not within the scope of this work. Rather, the purpose of the work was to provide an ambient acoustic characterisation of the site.

Clicks
Whilst acoustic detection of marine mammals was not a primary aim of the project, it is interesting to note that a number of isolated wideband clicks were heard throughout all three surveys. They were more often heard during the September and December surveys compared with the March survey. They typically occur at intervals of several minutes. An example is shown in Figure 19 below. There is also some evidence of lower level clicks of a similar nature that may be originating further away. These occur 2-3 times a minute.

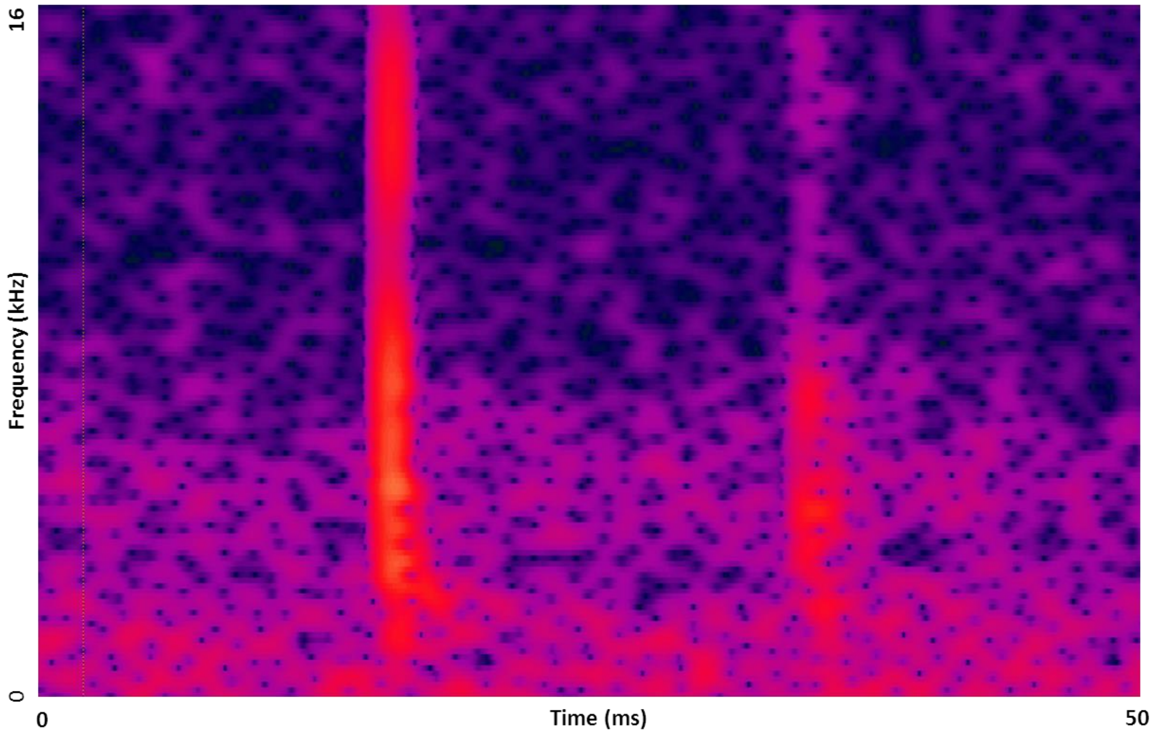

Figure 19: Example of click sound

The click is the first vertical bar; the second vertical bar is the reflection of the click from the surface. There is no evidence of a bottom reflection. The water depth would suggest that the maximum possible transition time is around 32 ms. For this click the separation time is 28 ms, suggesting that the source is located on the seabed about 4 metres away. For most of the clicks the delay is between 20 and 28 ms, corresponding to ranges up to 15 metres. The randomness of the events suggests a biological source. It is unlikely to be snapping shrimp as there is no detectable low-frequency precursor which characterises their snaps.

Three thumps

A sound consisting of three rapidly repeating ‘thump’ sounds was heard during the September and December 2011 surveys. A spectrogram of two examples of this sound is shown in Figure 20 below. A number of sources of this sound were present with slightly different characteristics as can be seen in the spectrogram. The sound was always repeated three times but the gap before the group was repeated varied. The sound was heard mostly during the December survey but was also heard during the September survey. The characteristics of the sound suggest this may be of biological origin, possibly a fish species.

There is a particularly long sequence of groups around 6pm on the 6th December when conditions are very quiet. At least four different sources of the sound are present.

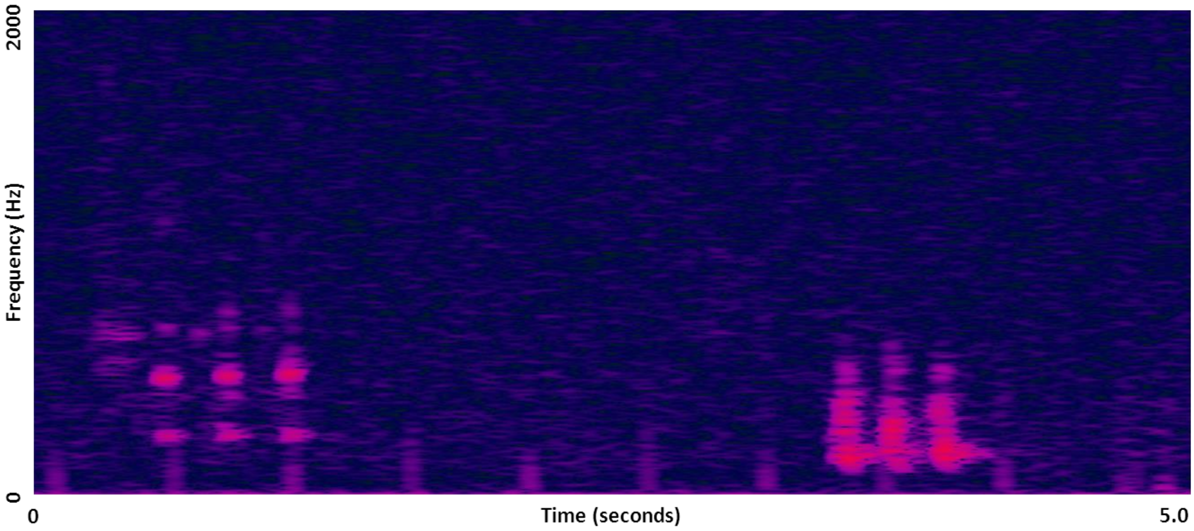

Figure 20: Spectrogram of "Three thump" sound

Thunder

On the 20th September 2011 there is a sequence of low frequency rumbles that last for about 50 minutes starting at 2 am. The spacing is random but typically about 1 minute. The sounds get louder and then die away. It is believed these sounds are due to a passing thunderstorm.

Abrasion noise

A number of episodes of abrasion noise occurred throughout the three surveys. These are mostly caused by floating debris rubbing against the hydrophone and can be very loud. An episode can last for several minutes and typically occurs every 2-3 days.

A second form of abrasion noise occurs less often and appears to be biological in origin. It may be crustaceans crawling on the hydrophone support arrangement or it may be fish feeding on growth on the instrument pod. It is generally much quieter than the noise due to floating debris.

Echo-sounder

On a number of occasions a regular series of clicks repeated at 1 second intervals could be heard centred on 9.5 kHz. These sounds are probably caused by the echo-sounder on nearby boats, although it is not clear whether they are signals generated by the echo-sounder itself or aliased components generated within the recorder. Figure 21 below shows two such clicks.

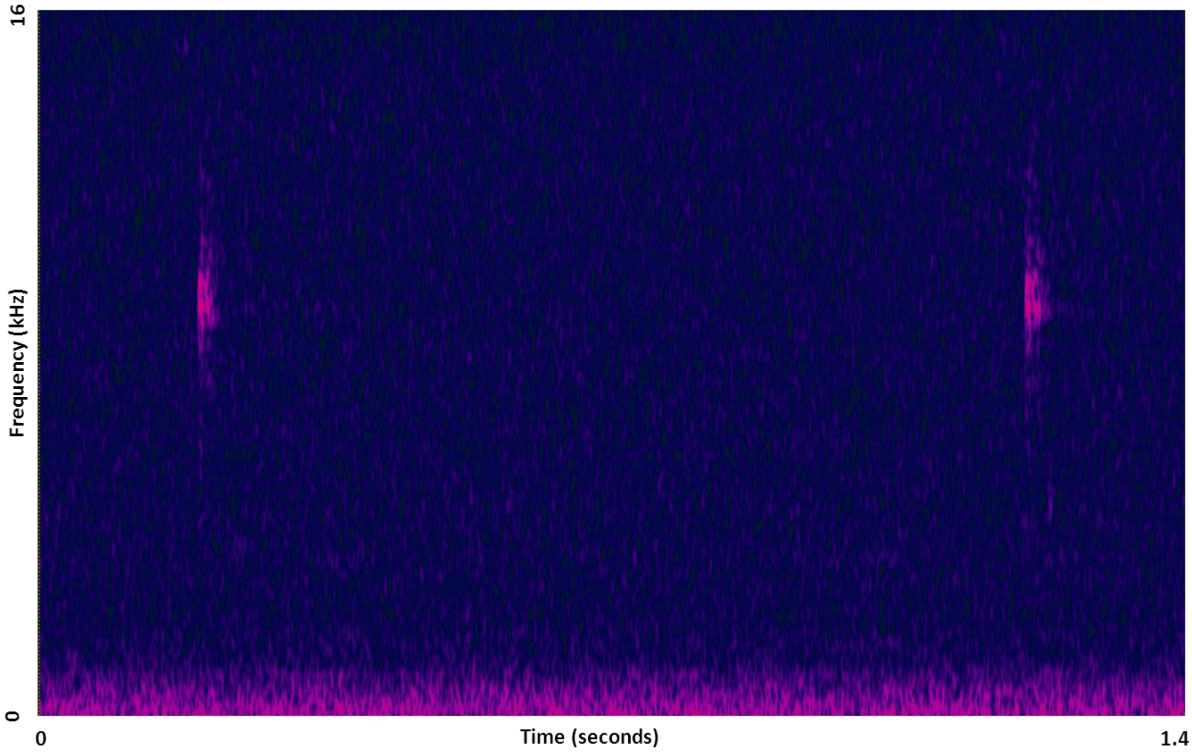

Figure 21: Echo-sounder clicks

5.6 Other Sounds

A number of unexplained sounds were heard. These occurred just once in the surveys and include a single loud wideband click, a possible distant explosion and various weak tonal sounds. All of these were low in amplitude and did not make a significant contribution to the sound field so have not been analysed in detail.

5.7 Site Characteristics

Table 1 below shows the percentage of the time that a particular sound can be heard within the Scapa Flow test site. These have been estimated from the multi-channel plots described above. It is particularly difficult to estimate the percentages for the distant shipping because at times this noise is masked by wave/rain noise and more local shipping. The percentages shown are almost certainly a significant under-estimate.

Sound	September	December	March
Static/Mobile distant shipping	40%	50%	60%
Mobile local shipping	7.9%	6.9%	7.5%
Wind/wave/rain	96.7%	97.8%	95.6%

Table 1: Sounds within the test area

The dominant source of noise is the natural noise due to the wind and resulting waves which can increase noise levels across a broad range of frequencies by up to 20 dB. Heavy rain can increase noise levels by a further 10 dB. The next most significant source of noise is due to vessel traffic. Distant vessel noise, either from machinery on stationary vessels or from moving vessels, is audible for over 50% of the time, but only raises the noise level by greater than 10 dB for approximately 10% of the time during the surveys. Other sources of noise make a very small contribution to the noise field.

Weather noise in December results in a significantly higher noise level than found during the other two survey periods. The only other significant variations between the surveys is the vessel traffic, which is low in December compared with September and March, and a slight decrease in the number of wideband clicks seen in March compared with September and December. There is no other observable change in acoustic activity between the surveys.

5.8 Data Limitations

Data used from these surveys represent data from three weeks spread across September, December and March. A more complete characterisation would require data from late spring e.g. May, and summer e.g. early August.

The data recorded had a bandwidth of 16 kHz. This covers most anthropogenic sound sources but will not normally detect echo sounder pulses or marine mammal echolocation clicks. There appears to be a low-frequency roll-off below 100 Hz but it is not clear if this is due to the recorder or the hydrophone.

The static structuring of the noise with frequency suggests that the close proximity of the hydrophone to the recorder canister is affecting the spatial response of the hydrophone. This will introduce errors of up to 2.5 dB at some frequencies.

Additional support data would assist the analysis of this type of dataset. Concentrated study periods of perhaps half a day using visual watches either on a support boat or ashore combined with additional data such as radar information and AIS data would help validate some of the results. The use of additional mobile acoustic listening systems would help identify some of the sounds recorded.

6. Conclusions

Data collected and analysed during this project have enabled the ambient noise at the EMEC Scapa Flow wave test site to be characterised within the limits of the available temporal coverage. The following conclusions can be drawn from this study:

- The ambient noise levels are consistent with an open, shallow water site
- The dominant source of noise in the test site is the natural noise from wind, waves and rain
- Shipping noise can be heard for over 50 % of the time but is only significant for 10% of the time
- Other occasional sources of noise include aircraft noise, biological noise and thunderstorms. All of these make a very small contribution to the noise field

7. Discussion and Recommendations

Deploying a fixed hydrophone produces a very large amount of acoustic data (the three surveys carried out for this project resulted in 92 Gb of acoustic data being recorded). The analysis of such large volumes of data is a time consuming process and it is recommended that a semi-automated analysis procedure is adopted for future surveys. This can be achieved by developing appropriate MATLAB functions, incorporating the processing developed for this project, which can automatically read the files produced by the SM2M. This process would work better if the recorder was set to change files at 12 hour boundaries.

The SM2M recorder has internal amplifiers which can be used to alter the dynamic range to suit the area being surveyed. For the noisier locations a low gain should be chosen, for the quieter locations a higher gain can be used. These settings can only be determined by experience. The lowest gain setting was used for all surveys during this project. This meant that the loudest sound encountered stayed within the dynamic range of the system, but at the expense of digital noise creeping in at low frequencies during the quietest periods. A series of test deployments could be carried out under very quiet conditions, using a selection of gain settings, in order to optimise system performance. This should include a deployment in a very quiet location in order to measure the internal noise floor. The use of a lower noise hydrophone should be considered.

There is a fixed structure to the spectral data which suggest that there is an interaction between the hydrophone and the canister on which it is mounted. This might be resolved by modifying the unit so that the hydrophone can be mounted remotely from the canister.

The Scapa Flow test site is a very quiet site acoustically, with little vessel noise and no discernible noise due to tidal flow. The quietness of the site does mean that the sound originating from any WEC installed at the site can be more easily characterised than may be possible at a noisier site. It also means that any WEC noise may have a greater potential effect on the marine environment than it would at a noisier site where it may be masked by other anthropogenic and/or natural sounds.

There were a number of unexplained sounds heard and in view of the variety of activities that take place around Scapa Flow this will always be the case. These sounds were weak and will have little impact on the local acoustic environment.

It is recommended that future studies into the acoustic characterisation of the Scapa Flow wave test site should

- include surveys covering spring (e.g. May) and summer (e.g. early August) in order to provide a more complete acoustic characterisation of the site
- investigate modification of the SM2M system in order to mount the hydrophone remotely from the canister
- carry out a series of test deployments under very quiet conditions with a selection of gain settings in order to optimise performance of the SM2M system
- include land-based visual observation periods together with additional mobile acoustic listening systems (i.e. deployed from a stationary boat) to help identify some of the sounds recorded
- develop and adopt a more automated data analysis procedure (e.g. using MATLAB routines)

9. References

EMEC Report “Shapinsay Sound Tidal Test Site: Acoustic Characterisation” (Harland,E.J., 2012a)

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

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

Appendix A: System Calibration

The hydrophone used by the SM2M is made by High Tech Inc. (HTI) and has the following specification:

Sensitivity: -165dB re: 1 V/uPa

Frequency Response: 2Hz to 40kHz (flat to +/- 1dB)

Equivalent Input Self Noise:

- RMS from 1 Hz to 1000 Hz; 78 dB re: 1 uPa; 0.08 uBar
- Spectral
  - 54 dB re: 1 uPa/sq.root Hz @ 10 Hz
  - 42 dB re: 1 uPa/sq.root Hz @ 100 Hz
  - 42 dB re: 1 uPa/sq.root Hz @ 1000 Hz

Maximum Operating Depth: 10,000 feet (3048 meters)

Size: Length is 2.50 inches (6.35 cm) and diameter is 0.75 inches (1.9 cm)

Although the frequency response is shown as being flat to within +/-1dB, it does not show the tolerance on the absolute sensitivity.

The SM2M recorder input sensitivity is such that 1 Volt RMS at the input with the internal gain set to 0 dB will give a full scale signal on the A/D output. The WAV format files produced, when read by MATLAB have a range from -1 to +1 units peak to peak. MATLAB units are therefore 3 dB down on the voltage at the SM2M recorder input. 1 Volt RMS at recorder input = -3 dB on 1 unit in MATLAB

The hydrophone sensitivity is given as -165 dB re 1V/µPa. This means that a signal of 165 dB re 1µPa will give a full scale signal at the A/D output and a -3 dB signal in MATLAB. The calibration factor for this data is therefore:

Calibration Factor =165+3 = 168 dB re 1µPa

The data are then processed using the MATLAB spectrogram function. The spectrogram function 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 the transfer gain was measured at 53 dB. A further correction factor has to be applied to convert the bandwidth of the spectrogram output points to an equivalent 1 Hz bandwidth in order to obtain spectrum level. For a 1024 input point FFT and 32 kHz sample rate, the output bandwidth will be:

FFT bandwidth = 32000/(2*512) Hz
= 31.5 Hz

The bandwidth correction factor is 10*log10 (bandwidth) which is 15 dB. The overall calibration factor is therefore:

Calibration factor = 168-53-15
= 100 dB re 1 MATLAB unit/µPa

Note that for the low frequency plots where the data have been decimated by 8, the bandwidth is 3.91Hz and the bandwidth correction factor is 5.9 dB.

Appendix B: EMEC Wildlife Observations

EMEC carry out wildlife observations from a high level vantage point adjacent to the Scapa Flow test site. Observations are carried out for 4 hours per week, split over two 2-hour watch periods. This appendix summarises the data from the observations made during the periods of the acoustic surveys.

Survey 1: 19th – 24th September 2011

A watch was kept on the 20th September from 11:00 to13:00 and on the 23rd September from 15:00 to 17:00. The sea state was reported as SS3 on the 20th and SS2 on the 23rd. No boat movements were reported during either watch period. A grey sea was observed on the 20th , and a group of six harbour porpoise were seen at 16:45 on the 23rd.

Survey 2: 2nd – 7th December 2011

A watch was kept on the 5th December from 09:00 to 11:00 and on the 7th from 08:45 to 10:45. The sea state was reported as SS1 on the 5th and SS1 on the 7th. On the 5th the creel boat 'Jade Elin' was seen heading south at 10:30. On the 5th one common seal was seen at 09:05 followed by two common seals at 09:35. A single common seal was seen on the 7th at 0905 and at 09:25.

Survey 3: 14th – 21st March 2012

A watch was kept on the 14th March from 15:00-17:00 and on the 15th March from 08:00 to 10:00. The sea state was reported as SS2-3 on the 14th and SS3 on the 15th. On the 14th a fast RIB was seen at 15:00. On the 15th the C-Odyssey was seen at 09:45. A single common seal was observed on the 15th at 08:05.

Appendix C: September 2011 Survey – Data Analysis

Introduction

This survey was carried out from the 19th to the 24th September 2011. The SM2M was deployed at 58° 53.70’N, 2° 57.30’W. The unit was set for 0 dB internal gain and a sampling rate of 32 kHz.

Weather

The wind speed and direction are shown in Figures C.1 and C.2 below. The rain sensor at Billia Croo was not functional during this survey period, therefore the precipitation information shown in Figure C.3 below is from the Eday weather station only.

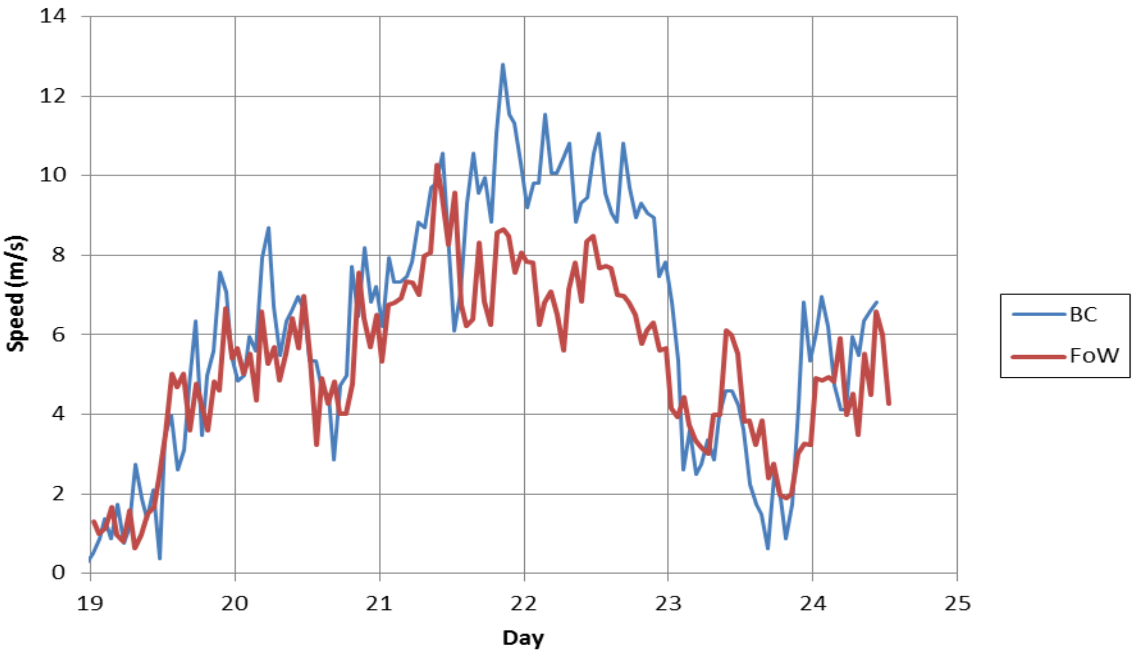

Figure C. 1: Wind speed recorded at Billia Croo and Eday

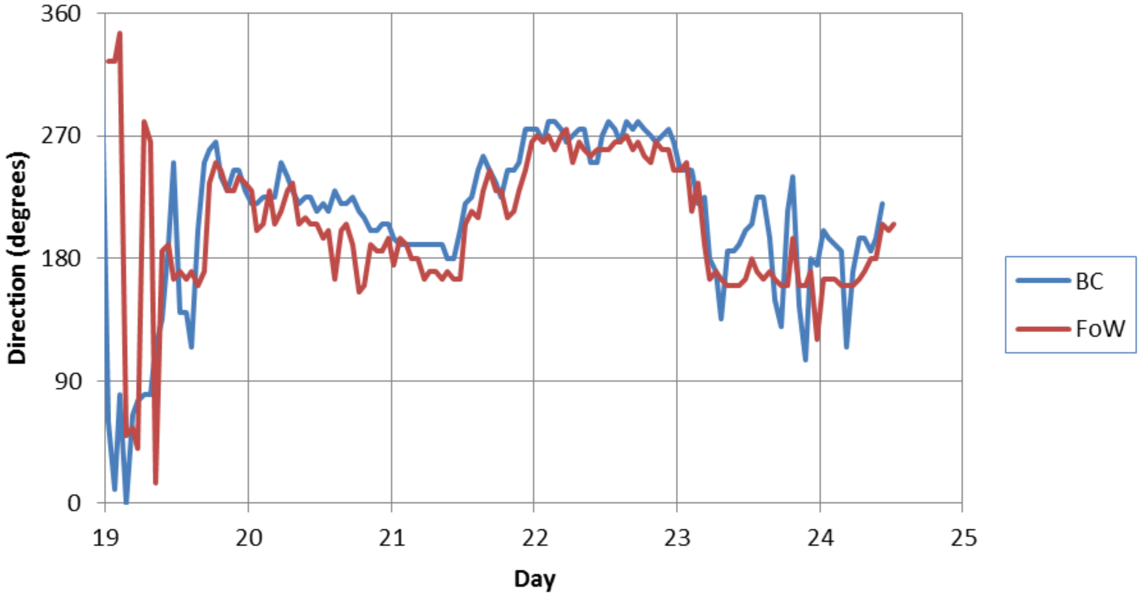

Figure C. 2: Wind direction recorded at Billia Croo and Eday

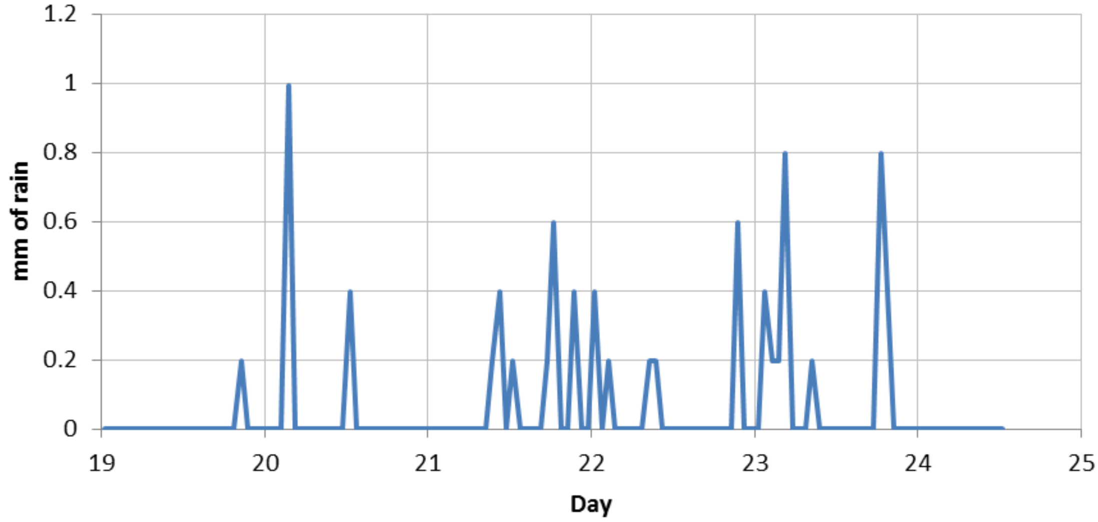

Figure C. 3: Precipitation recorded at Eday weather station

Other non-acoustic data

Automated Identification System (AIS) data on ship movements were available for the survey period. Wildlife observations carried out on the 20th and 23rd September recorded 1 grey seal and a group of 6 harbour porpoise.

Acoustic data

The acoustic data were recorded using the SM2M recorder with SD type memory cards in four internal slots, recording continuously at a sample rate of 32 kHz. The SM2M unit was programmed to start recording at a preset time, and to change files at set times each day. There is a short gap in the recorded data where the recording files change. This gap can vary from a few seconds up to 1 minute.

On recovery of the unit the SD cards were removed and the data downloaded to a PC. The Syntrillium Software audio editing software package 'CoolEdit' was used to re-assemble the files into 12 hour blocks covering midnight to midday, and midday to midnight for each complete day of the survey. The gaps due to the file changes remain in the data.

Each twelve hour block of data were processed to produce the displays shown in this appendix. The data were read in 30 second blocks and a 1024 input point FFT performed repeatedly. The resulting spectra were then averaged to obtain the mean spectrum for these 30 seconds. This operation was performed repeatedly and the resulting mean spectra assembled into the spectrograms shown. In addition, the raw data were decimated by 8 to give a sample rate of 4 kHz. The 30 second mean spectrum was again calculated and the sequence of 30 second mean spectra assembled to give the low frequency spectrograms shown.

The four-channel plots take the FFT output and combine the output power across four channels, each 2 kHz in bandwidth centred on 2.5, 5, 10 and 15 kHz. This was done for both the full bandwidth and the decimated low frequency data. For the full bandwidth plots a fifth channel centred on 750Hz was also calculated. This has a bandwidth of 200 Hz. All channels were normalised to give mean spectrum level. The low frequency plots are only included where they show events of interest.

The wideband mean level plot was obtained by summing the power across a 1-10 kHz bandwidth. This plot provides a broad overview of ambient noise levels and acoustic events through the survey period. Figure C.4 below shows the plot for the September 2011 survey period. The general level is related to weather conditions, particularly wind speed and rainfall as can be seen by comparing this plot with the wind speed shown in Figure C.1. The sharp peaks in noise are generally due to passing vessels. It can be seen that the noise levels for this survey period are generally dominated by weather conditions, with only occasional close vessel passes.

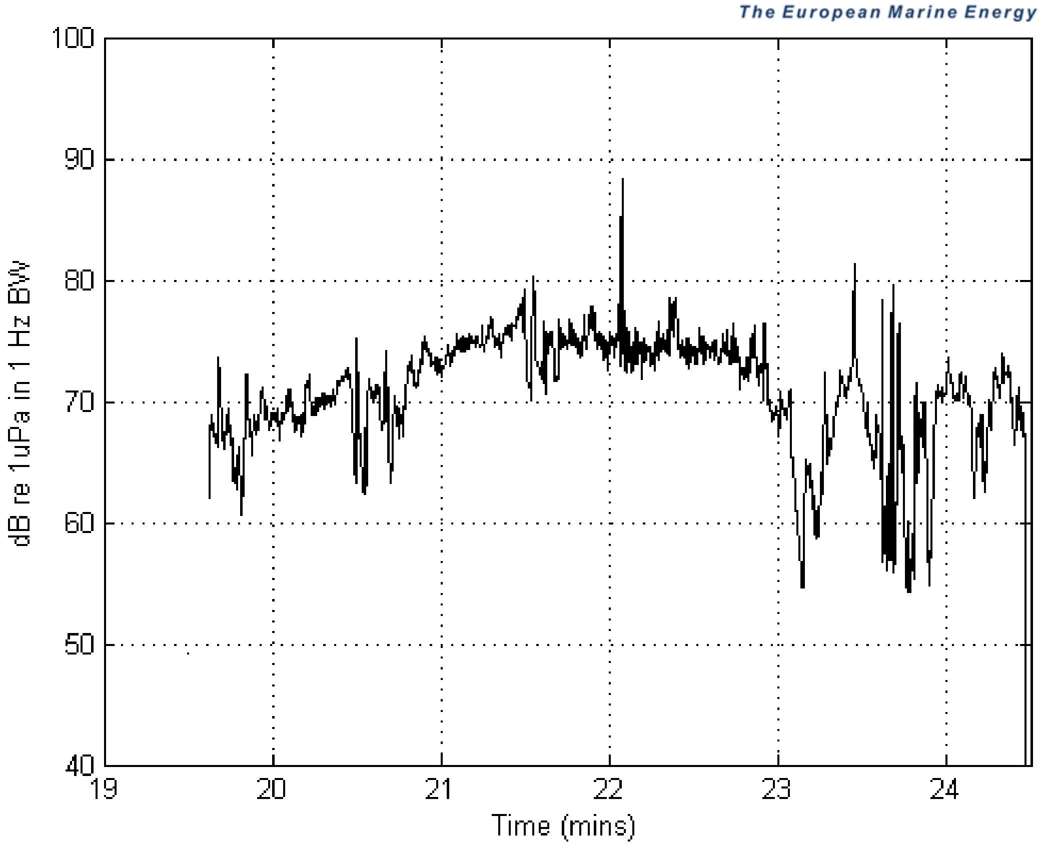

Figure C. 4: Wideband noise level for September 2011 survey

The variability plot was obtained by averaging the FFT data for 10 second intervals and then combining all of the resulting spectra for the whole deployment. The spectrum was reduced in resolution to 1 dB vertically and 250 Hz horizontally. The plot was formed by counting the number of times each of these 10 second spectra have a particular frequency/amplitude component. This can result in a wider dynamic range than most printers can display so the data were compressed by taking the logarithm of the count. The variability plot in Figure C.5 below shows how the measured levels varied during this survey period.

The brighter the colour on the variability plot, the more often that particular frequency/amplitude combination occurs. A broad band of white running through the middle of the plot shows the points that occur most often, and can be used as a 'typical' spectrum for the site. The region above this is due to bad weather, passing vessels, and other sound sources. Passing vessels generally raise the level at the lower frequencies below ~2 kHz while weather-related noise generally raises the levels above 2 kHz.

The region below this 'typical' level occurs when the weather is very quiet. The flat bottom to the plot is symptomatic of an internal noise problem within the recorder and should not be interpreted as the lowest sound level to be found at the site.

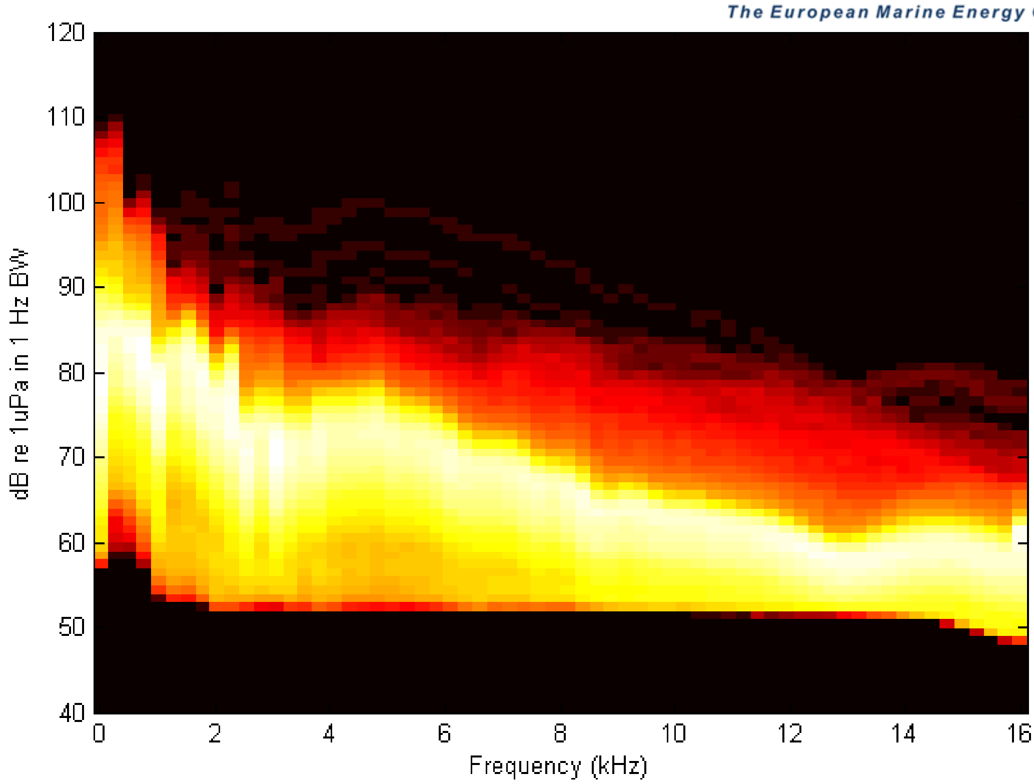

Figure C. 5: Variability plot for the September 2011 survey

Passing vessels
A number of vessels passed through or close to the survey site during the survey period. Where possible these can be identified from the wildlife observer's notes and/or from the AIS data. For this survey the identified vessels were:

21/9/11	12:56	Harald
21/9/11	13:16	Harald
22/9/11	22:28	Clipper Burgundy
23/9/11	10:59	Einar
23/9/11	20:19	Einar
23/9/11	20:56	Clipper Burgundy

The Harald and Einar are tugs based at Scapa harbour. The Clipper Burgundy is a small tanker. Note that AIS data are only available for ships over 300 gt. There will be a number of smaller vessel passes which will not be tracked by AIS, particularly creel boats operating out of nearby St Marys.

Survey data
The plots that follow show the data for each 12 hour period of the survey. The spectrogram and five-channel plot is shown for each period. In addition, the low frequency plots are shown where interesting events occur.

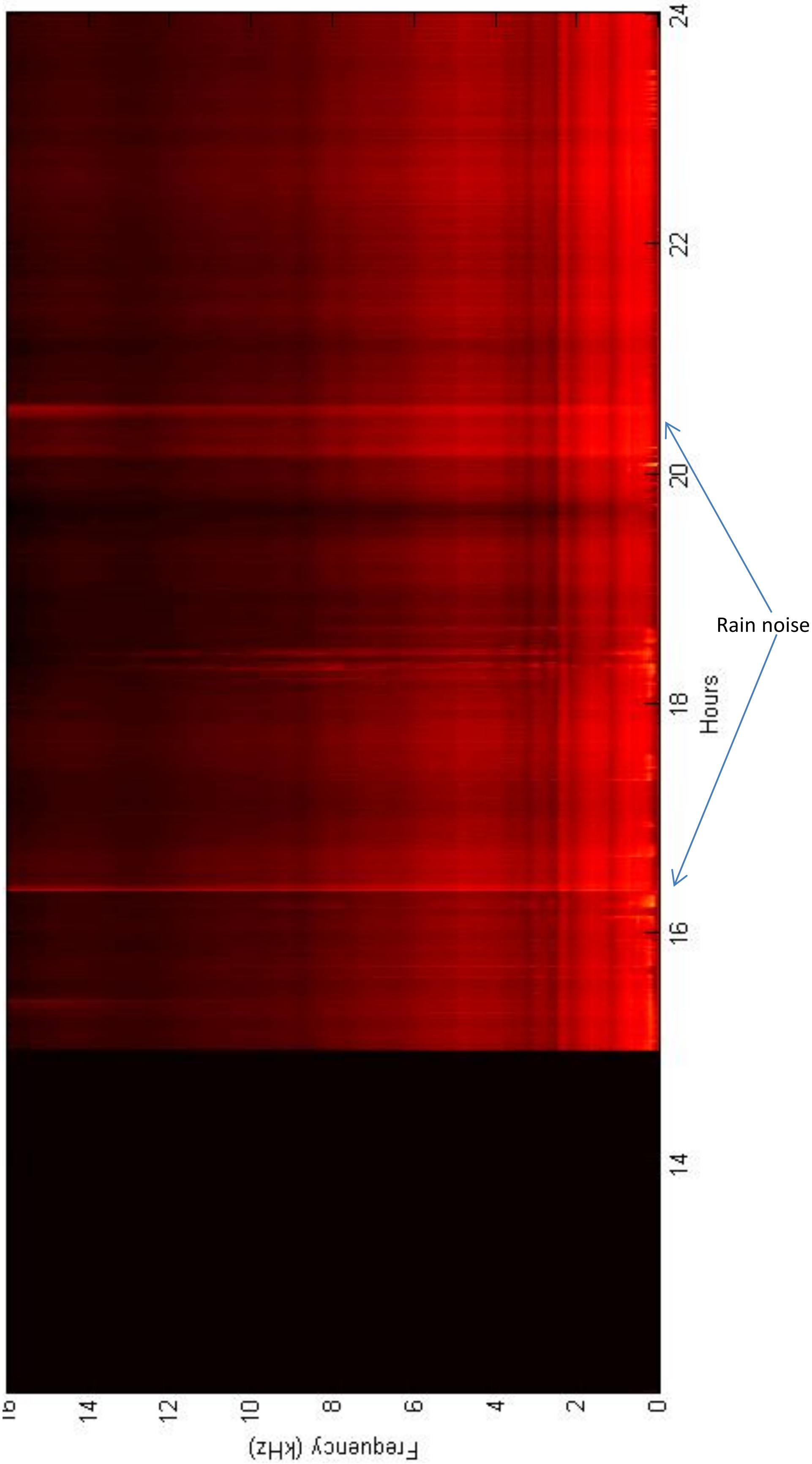

Figure C. 6: Spectrogram for 19th September 2011 afternoon

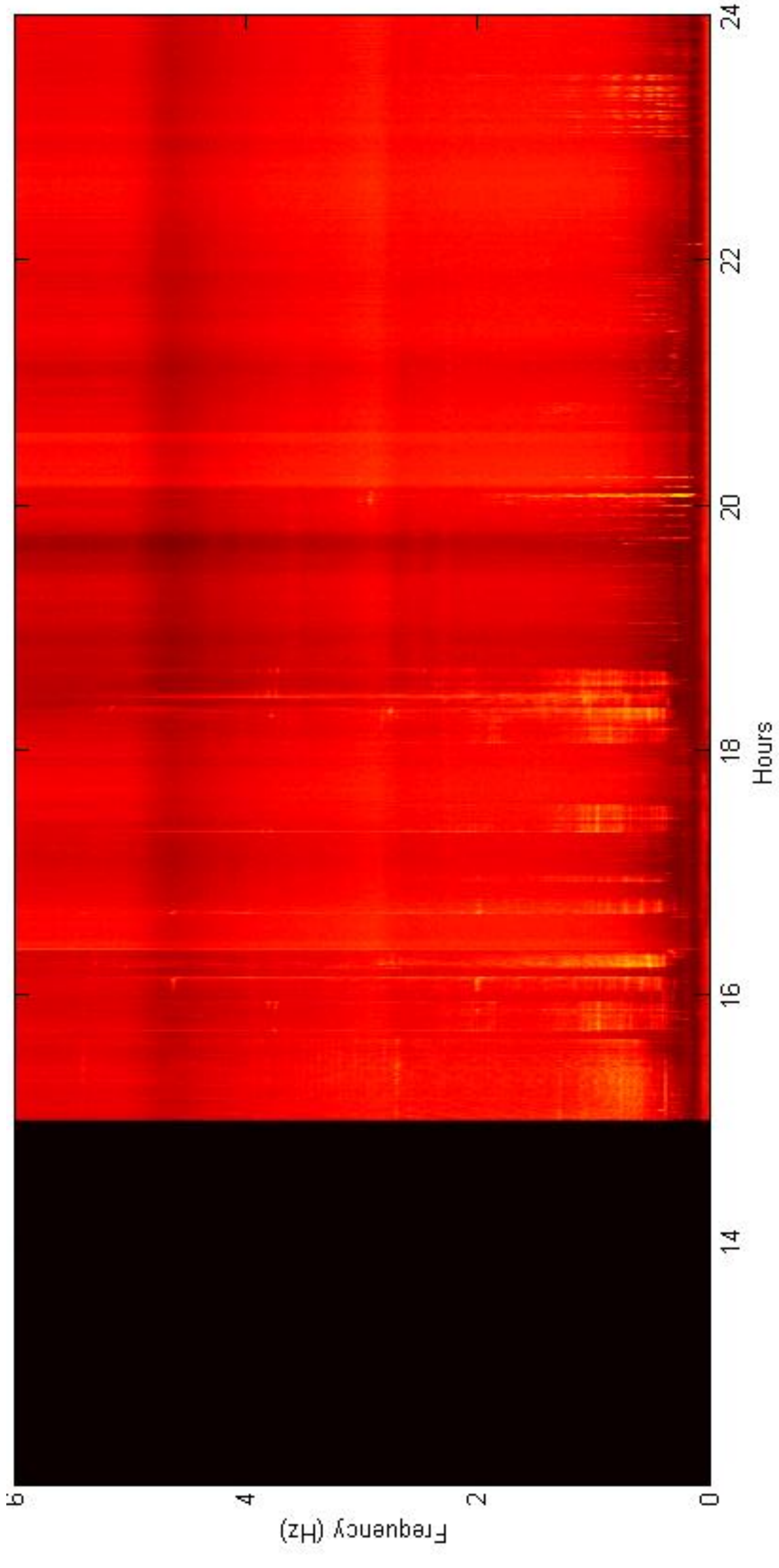

Figure C. 7: Low frequency spectrogram for 19th September 2011 afternoon

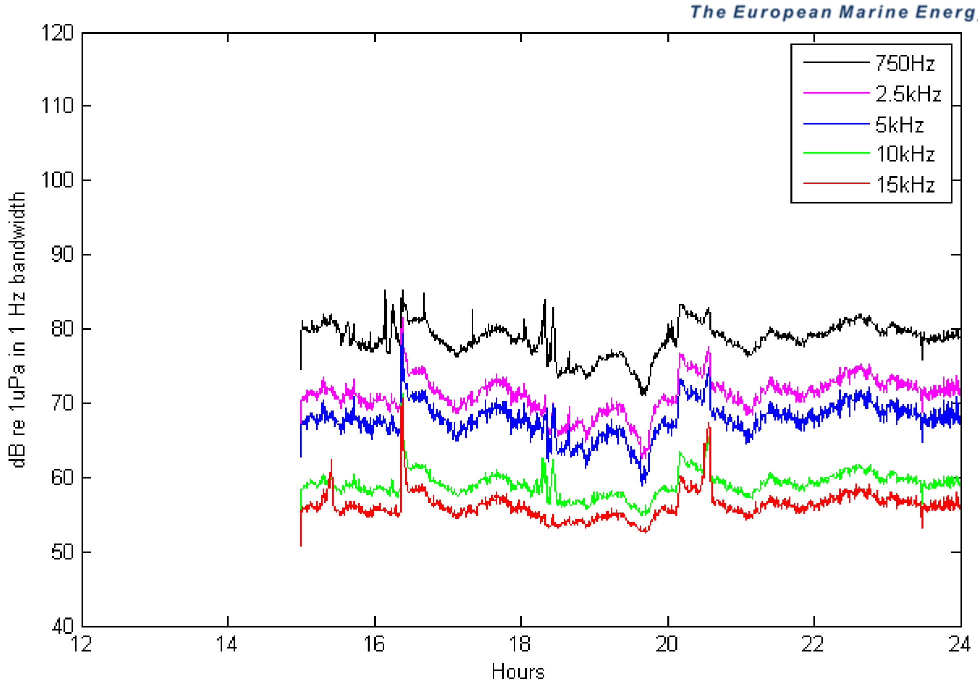

Figure C. 8: Five-channel high frequency plot for 19th September 2011 afternoon

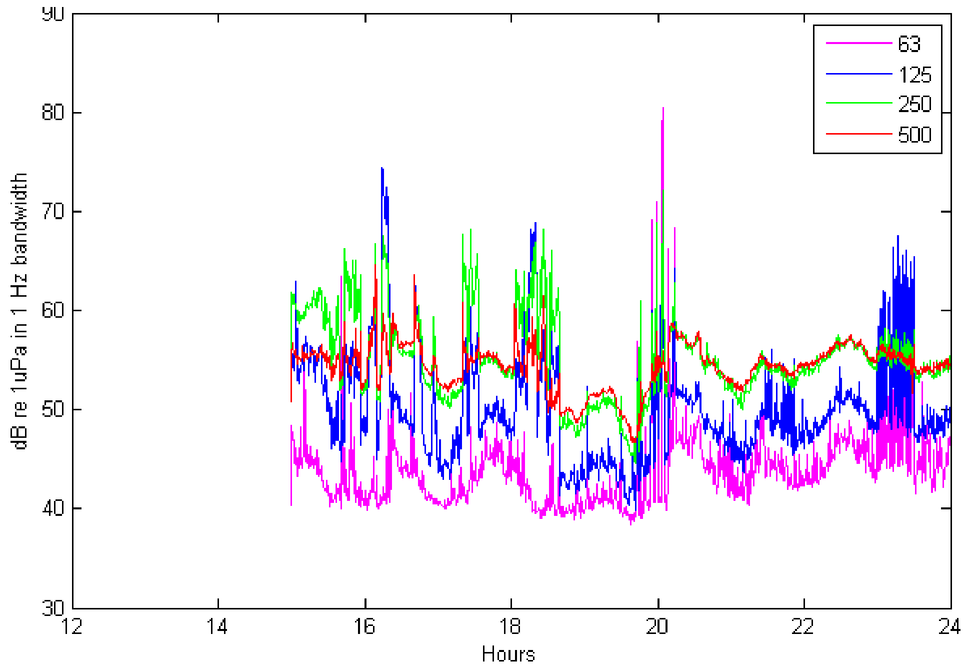

Figure C. 9: Four-channel low frequency plot for 19th September 2011 afternoon

The low frequency spectrogram (Figure C.7) shows continuous low-level shipping activity until 20:00. This is believed to be ship movements in western and southern Scapa Flow, particularly the inter-island ferries. A 'dragging' sound can be heard through the late evening and can be seen in Figures C.7 and C.9, particularly around 23:00. The wind picks up around this time and this sound may be caused by the recorder dragging its mooring.

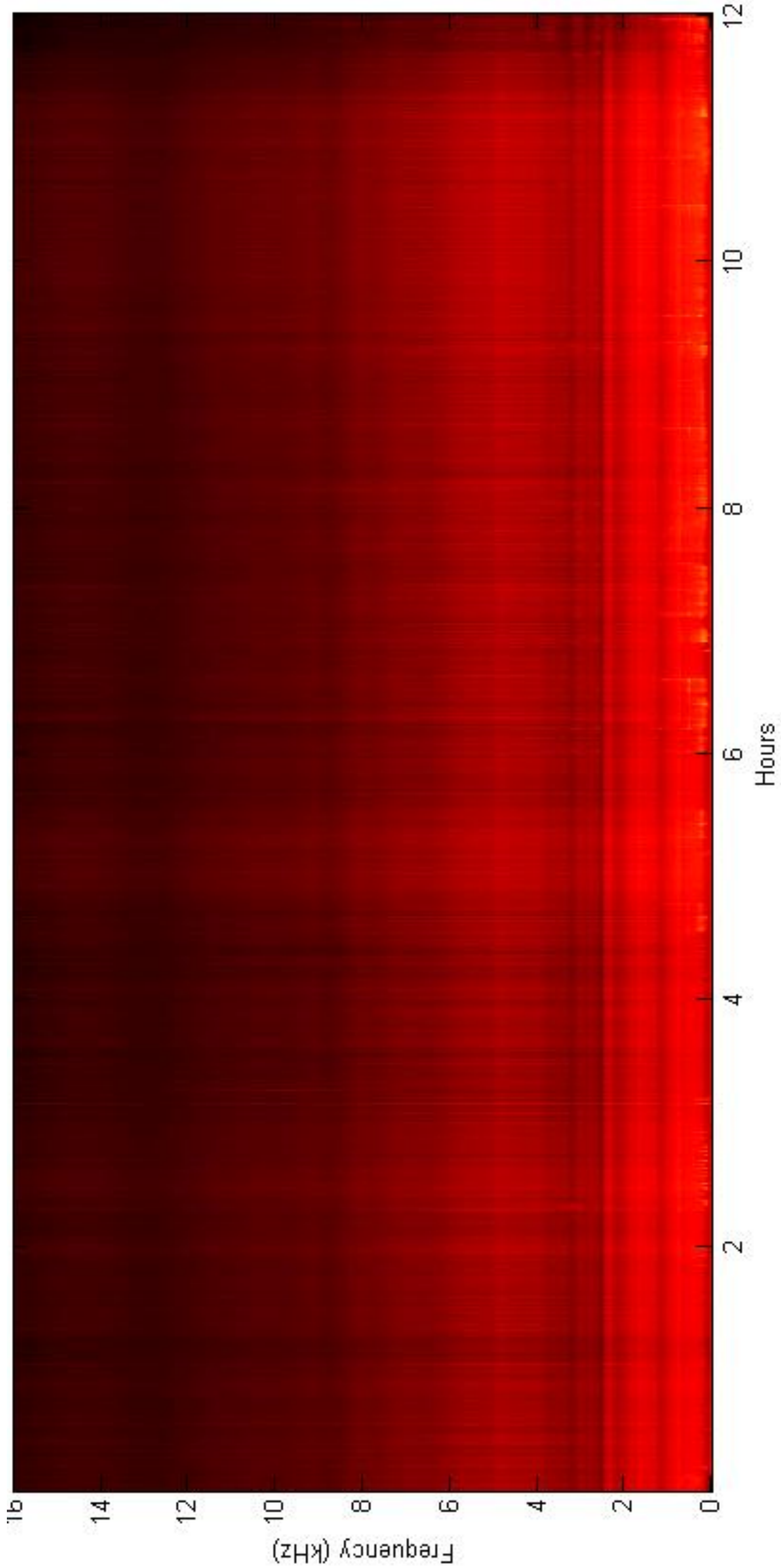

Figure C. 10: Spectrogram for 20th September 2011 morning

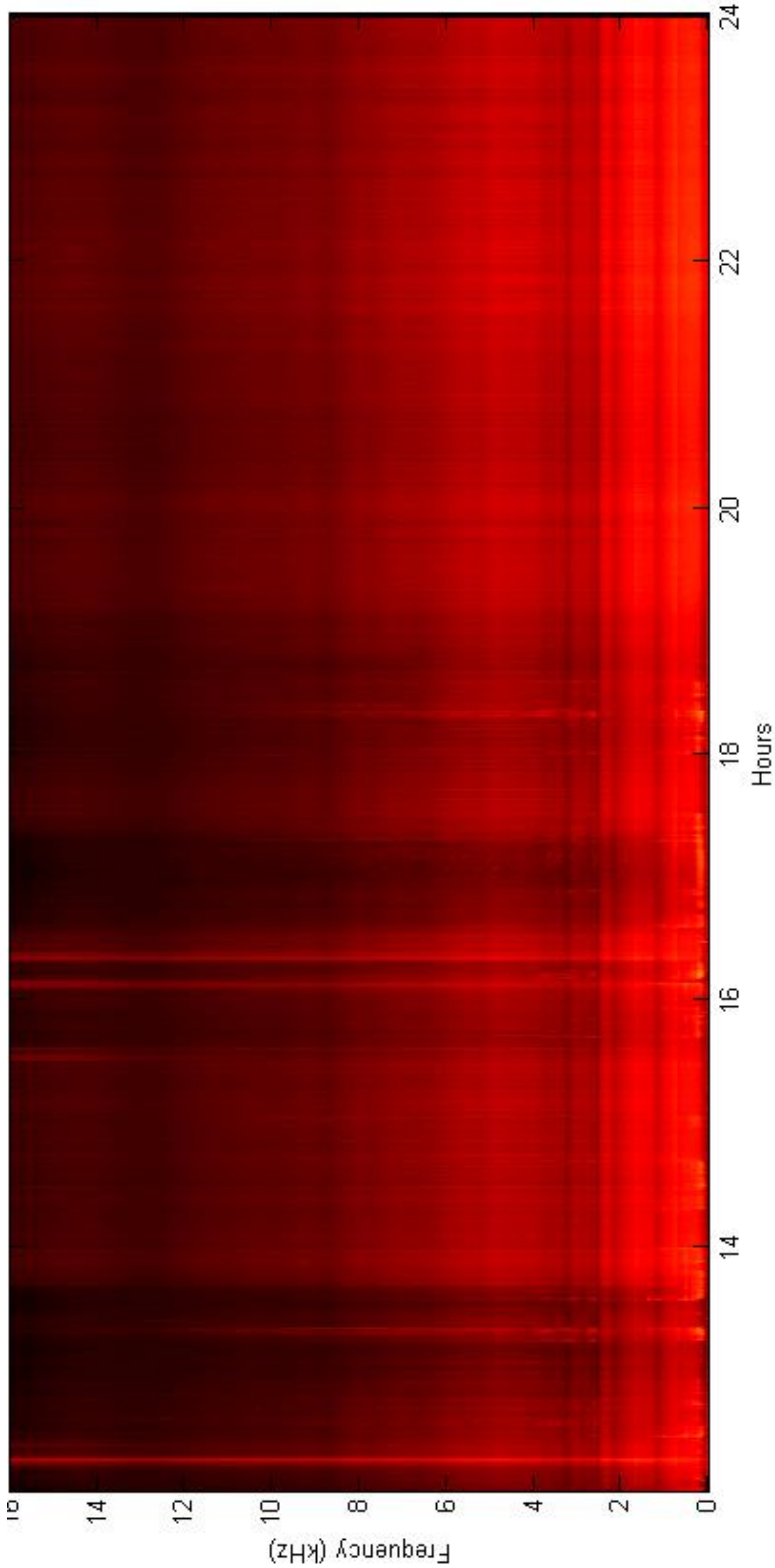

Figure C. 11: Spectrogram for 20th September 2011 afternoon

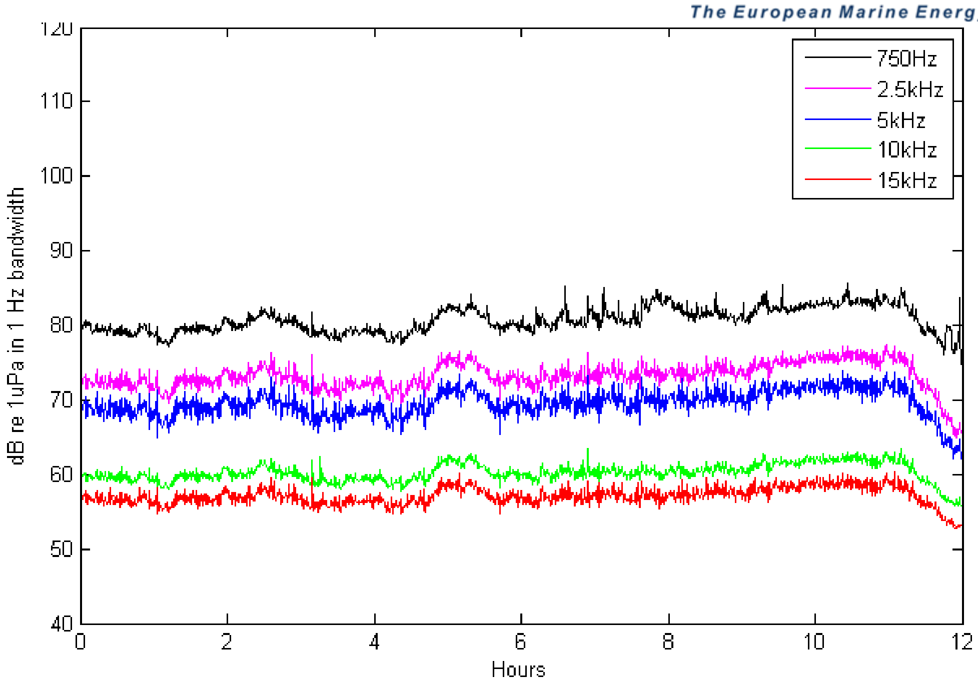

Figure C. 12: Five-channel high frequency plot for 20th September 2011 morning

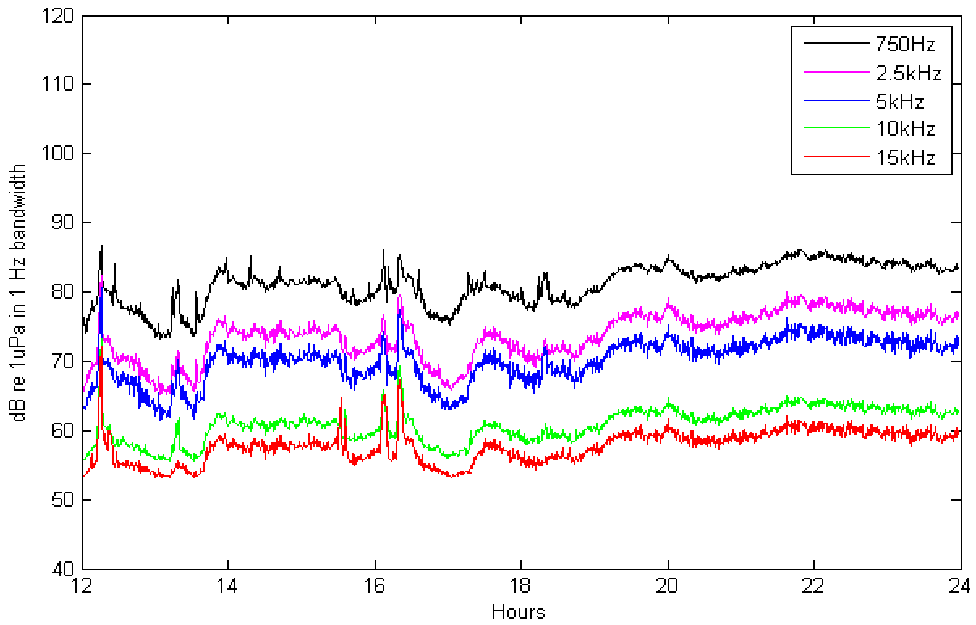

Figure C. 13: Five-channel high frequency plot for 20th September 2011 afternoon

There are no identified vessel movements shown on the AIS data for this day, but looking at the low frequency spectrogram shown in figure C.14 below there is activity starting at around 05:00 and continuing through the day. This activity ceases around 19:00. This noise is believed to be a mixture of inter-island ferry traffic and small boat activity well to the west and south of the survey area.

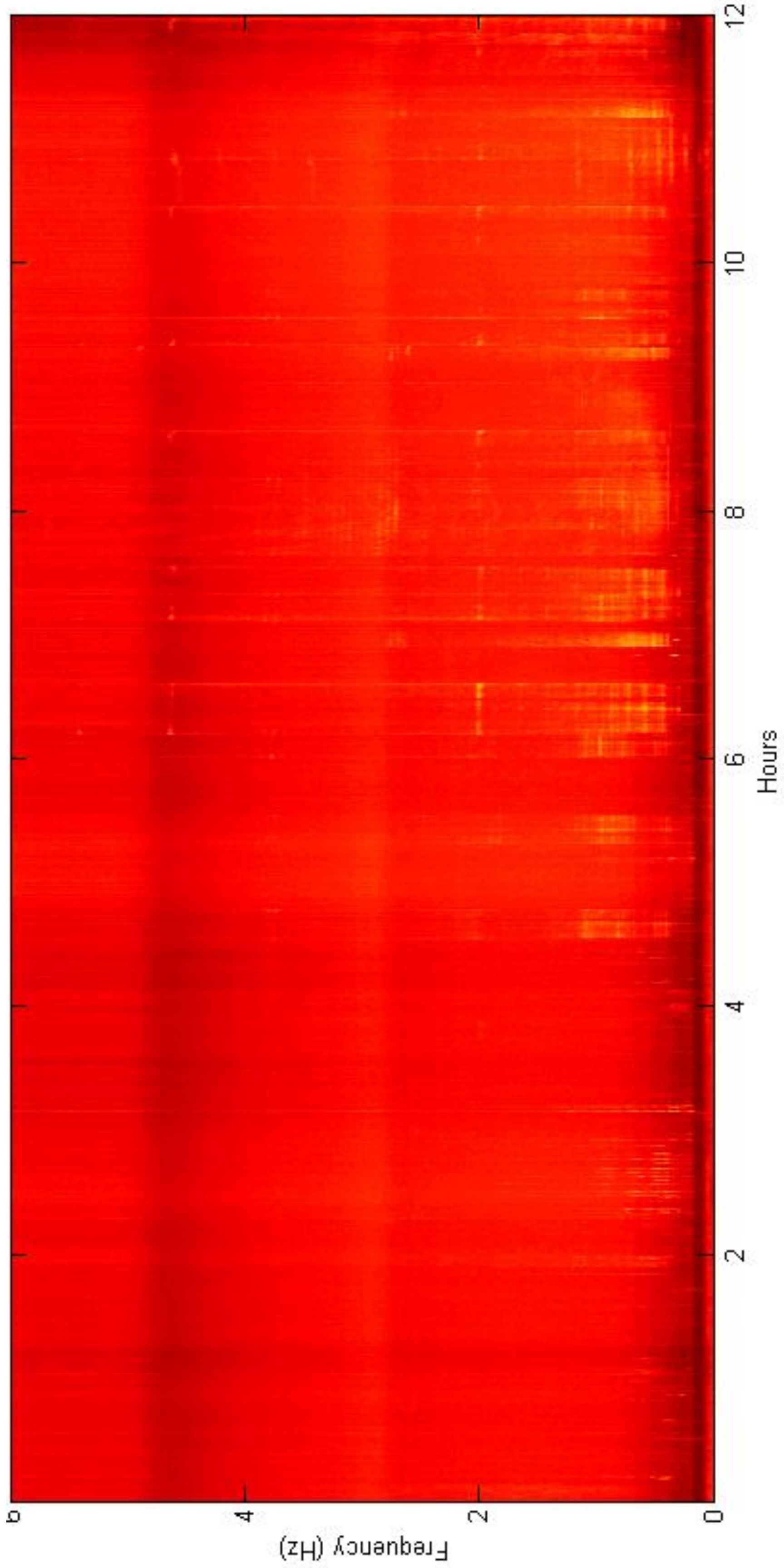

Figure C. 14: Low frequency spectrogram for 20th September 2011 morning

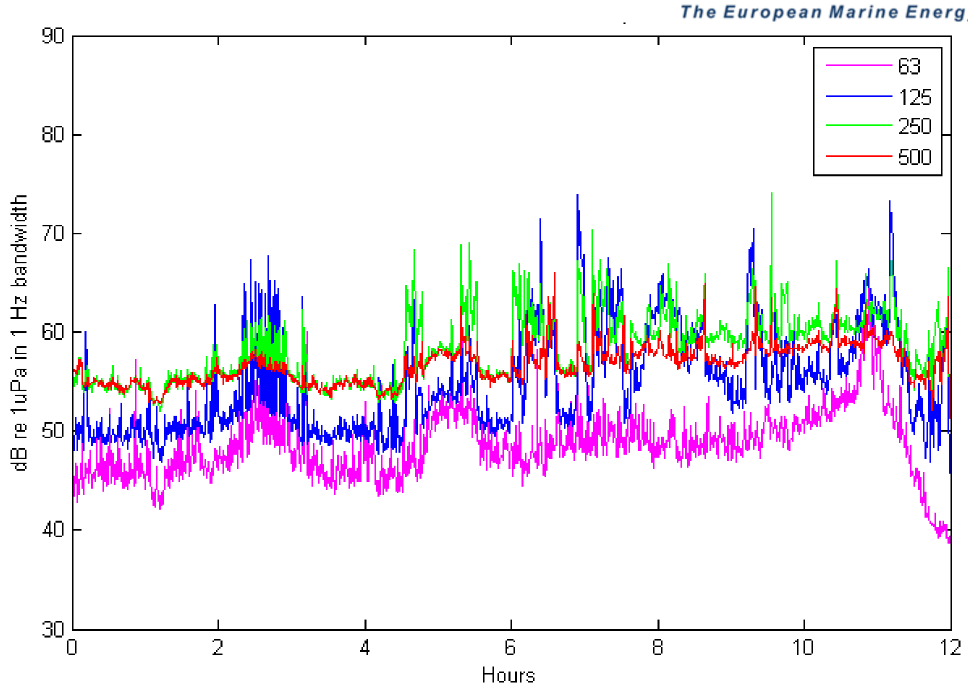

Figure C. 15: Four-channel low frequency plot for 20th September 2011 morning

One particular vessel has a distinctive acoustic signature with strong lines on 500 and 1200 Hz. This vessel was heard every day during this survey. The 125 Hz band in the four-channel low frequency plot (Figure C.15 above) is particularly sensitive to this shipping noise.

Both the full bandwidth and low frequency spectrograms show nulls running through the spectrum. It Is not clear what the cause of these nulls are. If it was from a local noise source the frequency of the nulls would be modulated by the tidal cycle, but this does not happen. There also appears to be no fine structure to the sound, therefore it is unlikely to be machinery noise. These nulls are present for the whole of the survey period. See Section 5.3 in the main report for a discussion on possible causes of this structure.

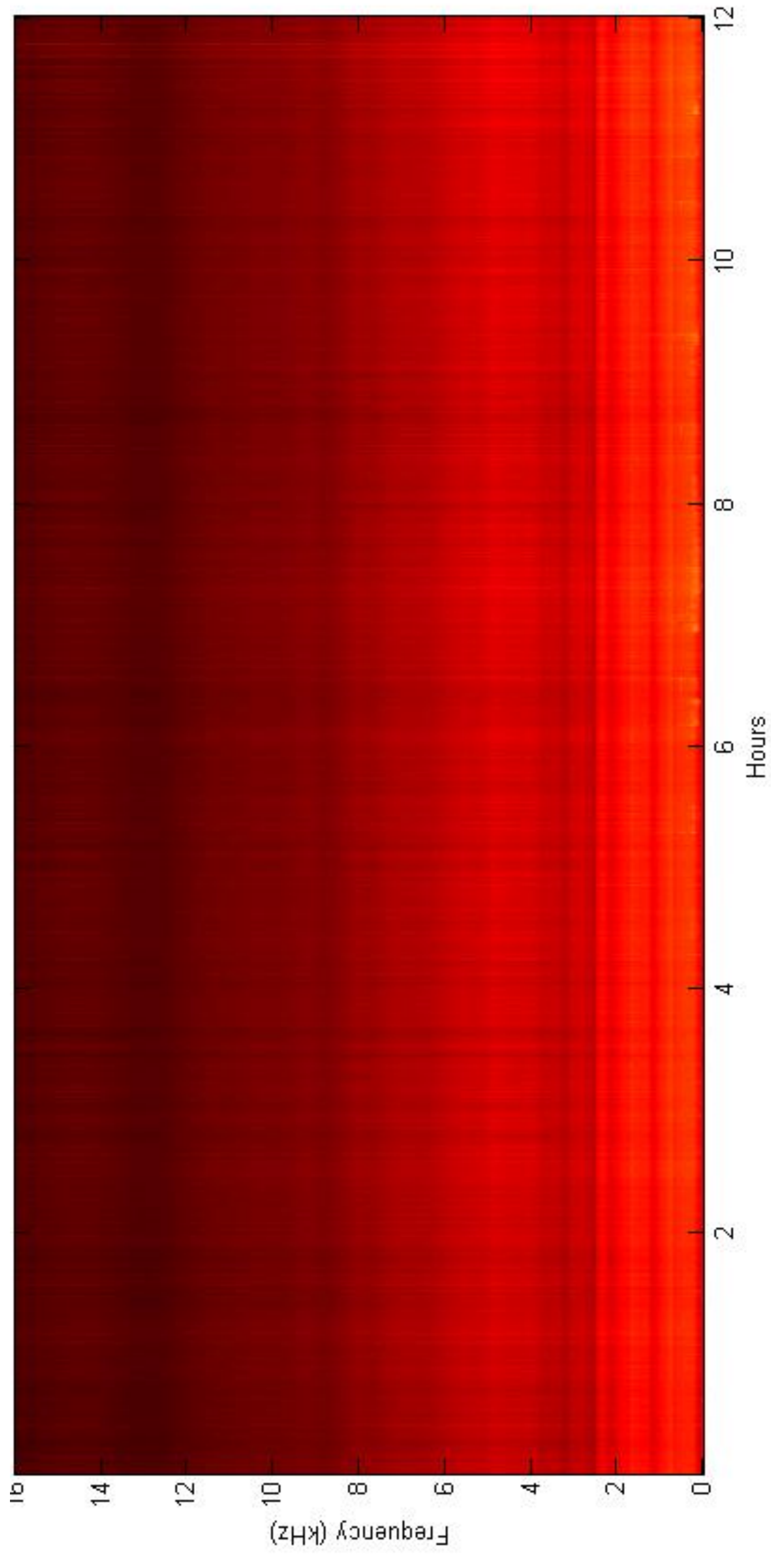

Figure C. 16: Spectrogram for 21st September 2011 morning

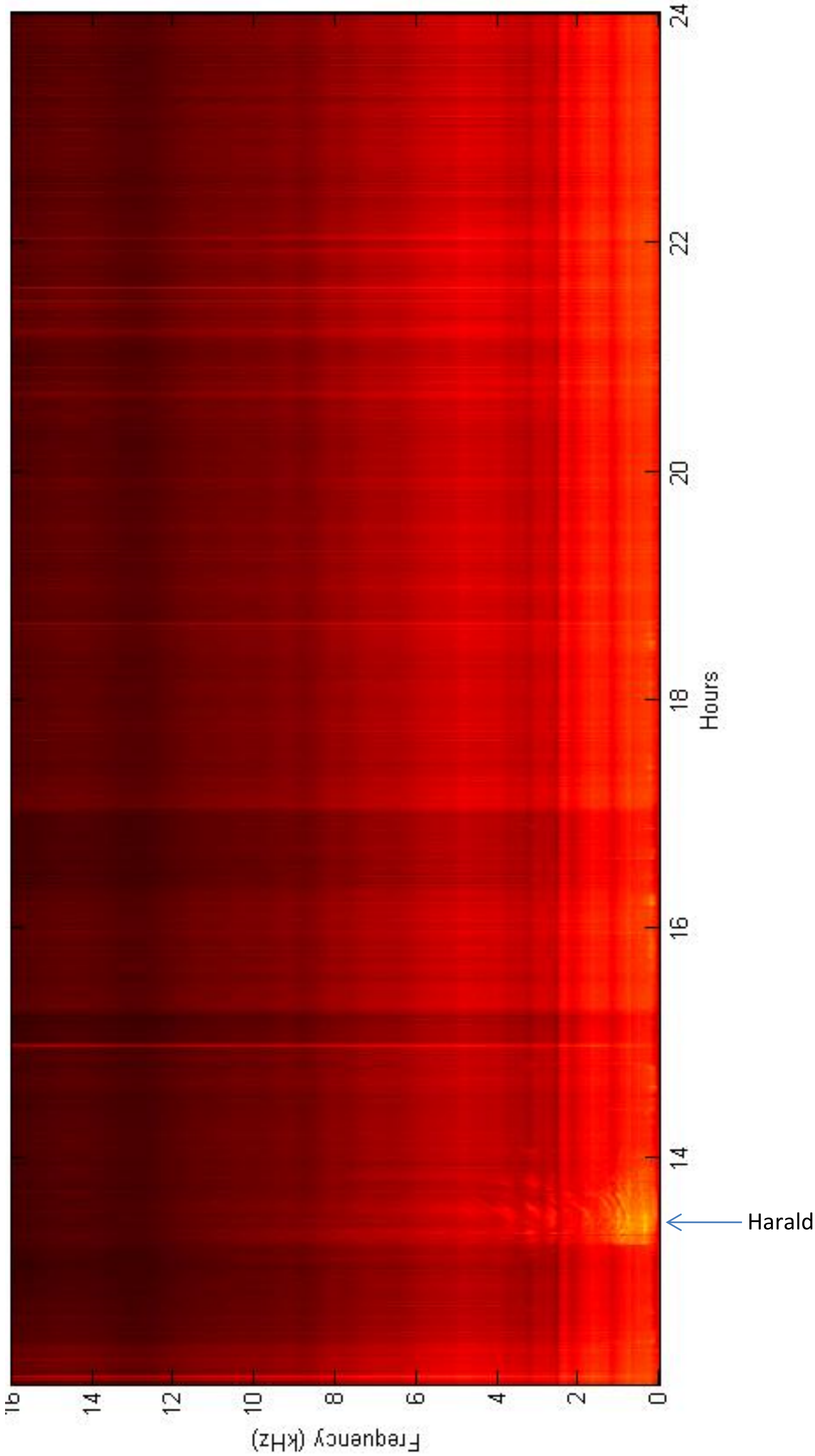

Figure C. 17: Spectrogram for 21st September 2011 afternoon

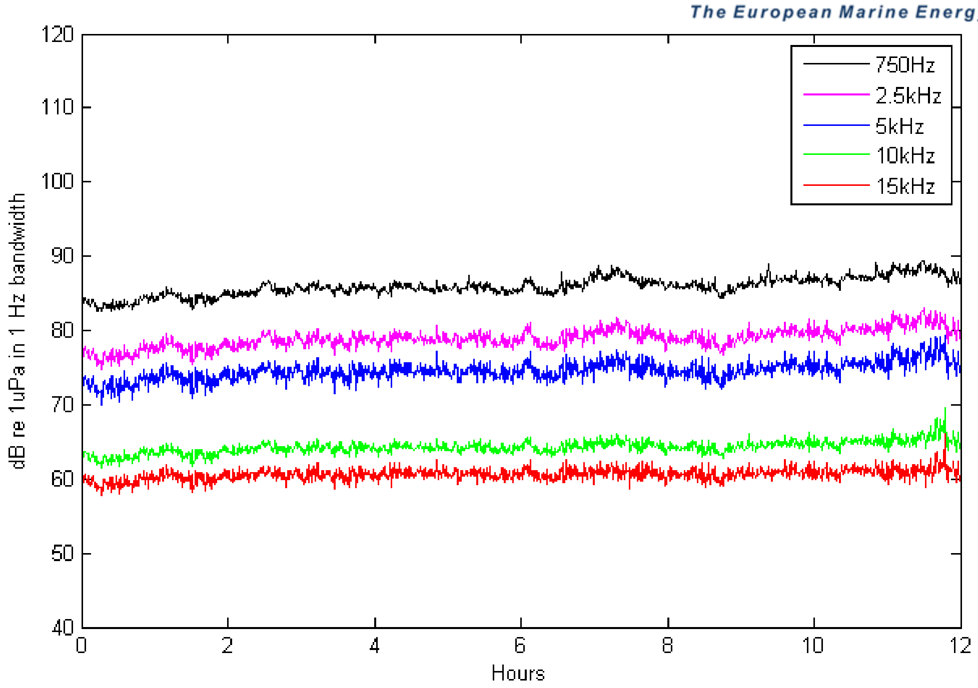

Figure C. 18: Five-channel high frequency plot for 21st September 2011 morning

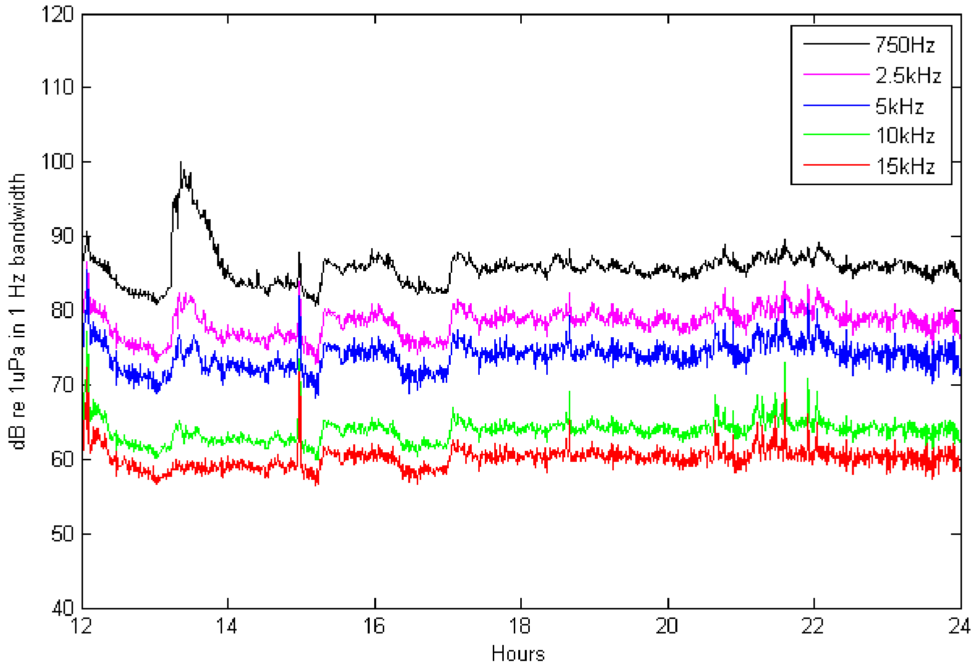

Figure C. 19: Five-channel high frequency plot for 21st September 2011 afternoon

The tug Harald passed to the west at around 13:10. The wind speed picked up through the morning and this causes the steadily increasing noise level. The wind then became variable in speed and direction. The precipitation data suggest that the afternoon and evening period saw some rain, and the combination of this with the variable wind may well be the cause of the step changes in noise level. The sharp peak at 15:10 is a very heavy burst of rain. Breaking waves can be clearly heard late in the evening.

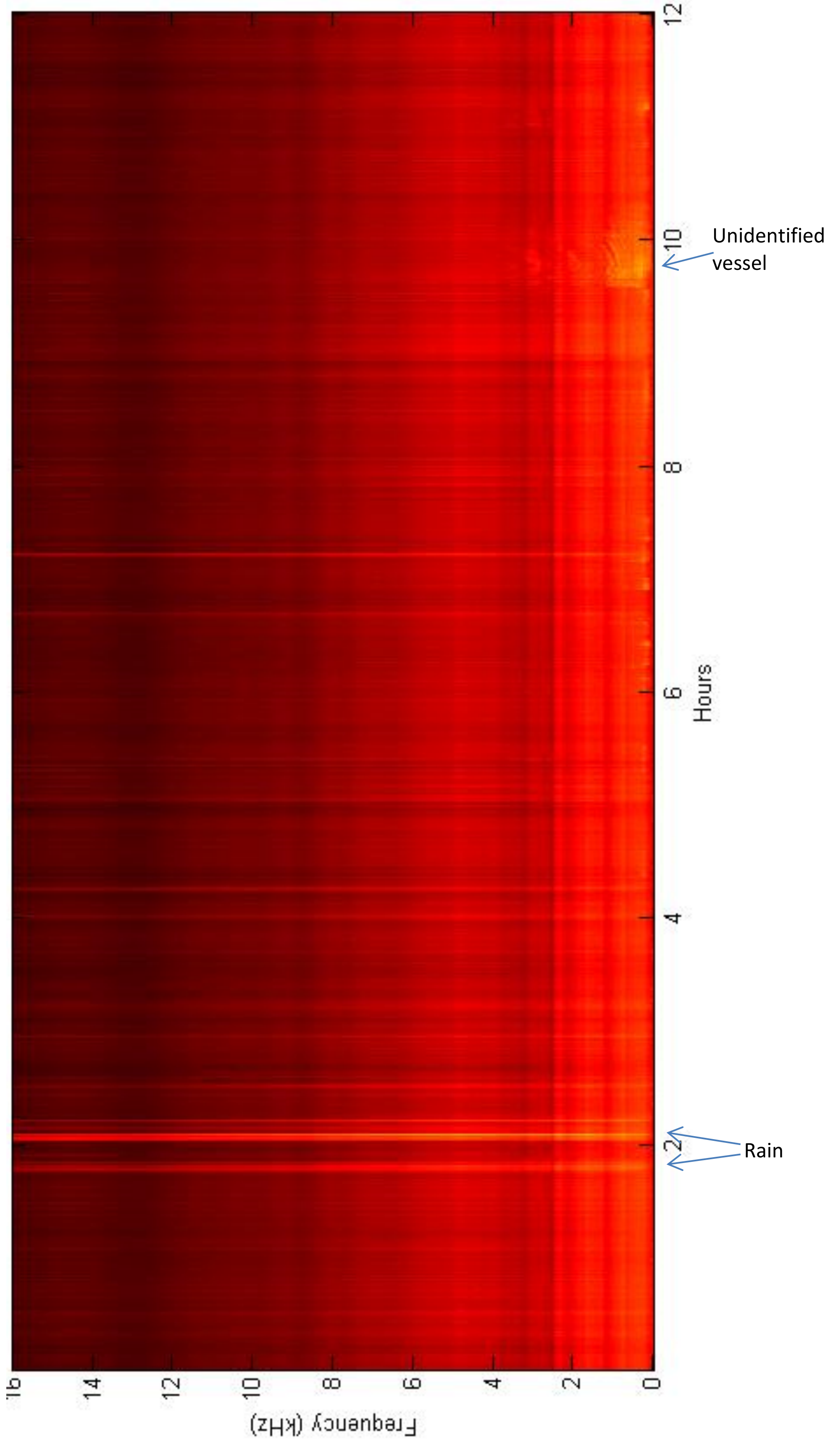

Figure C. 20: Spectrogram for 22nd September 2011 morning

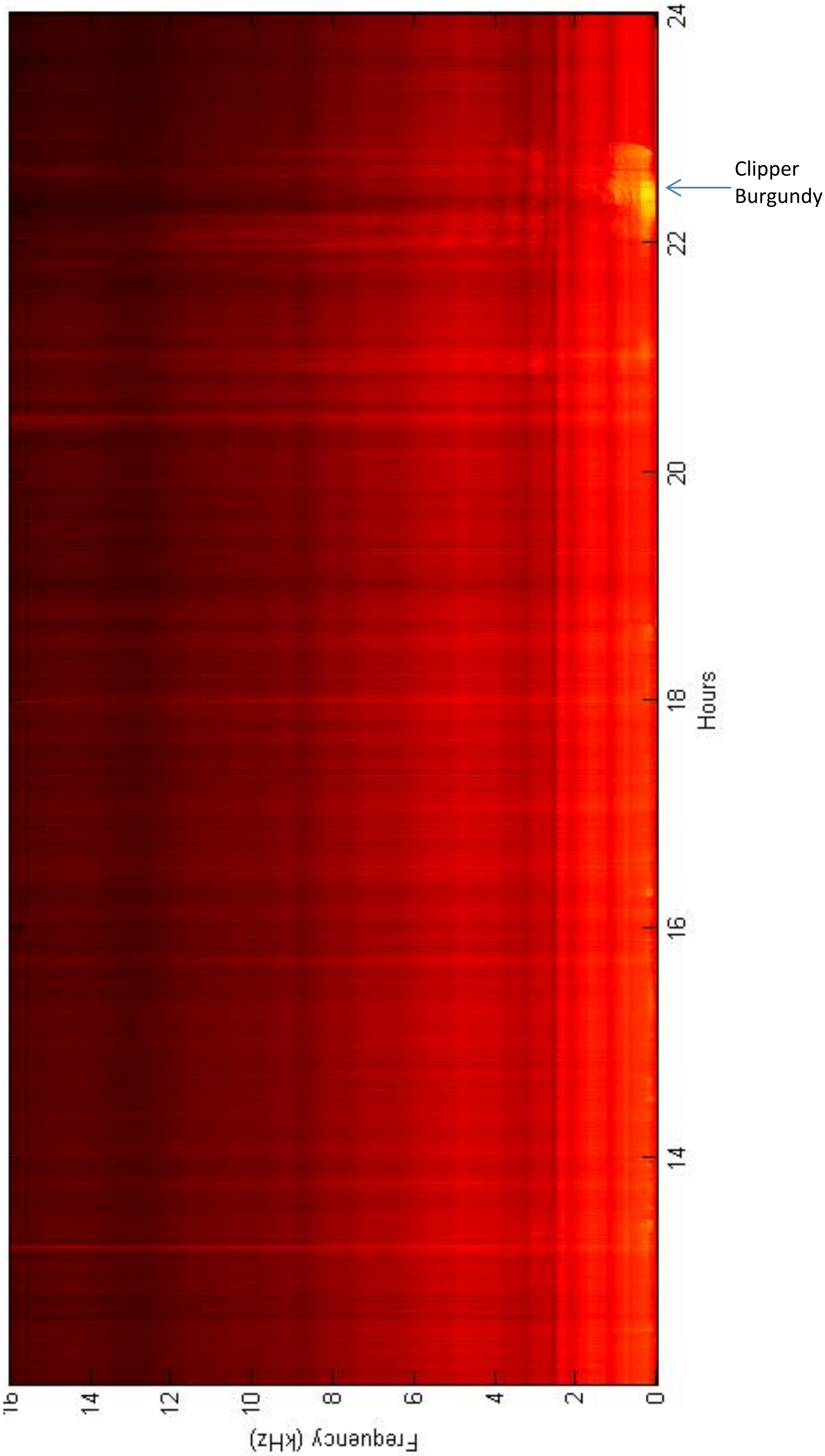

Figure C. 21: Spectrogram for 22nd September 2011 afternoon

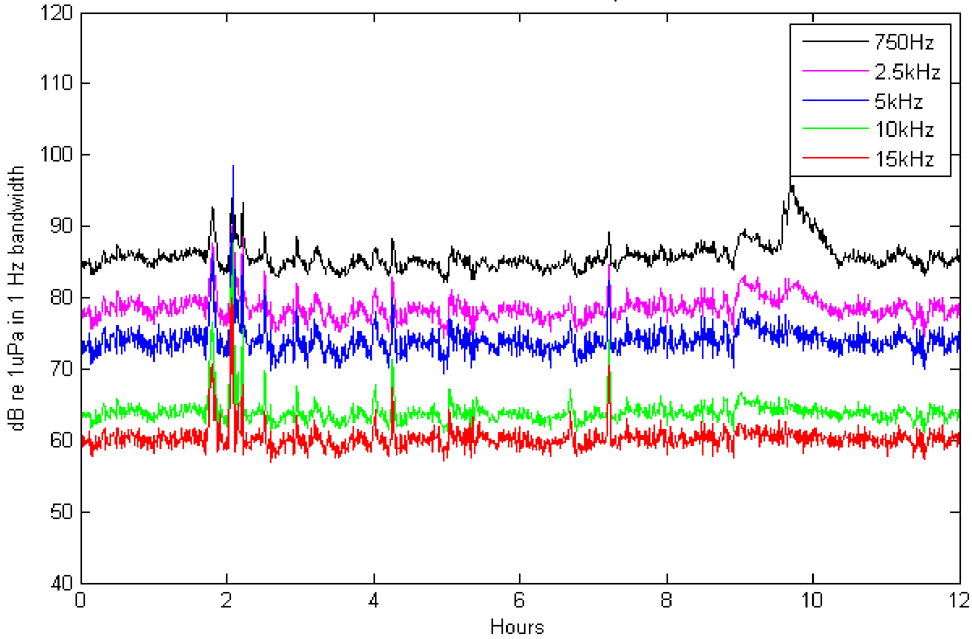

Figure C. 22: Five-channel high frequency plot for 22nd September 2011 morning

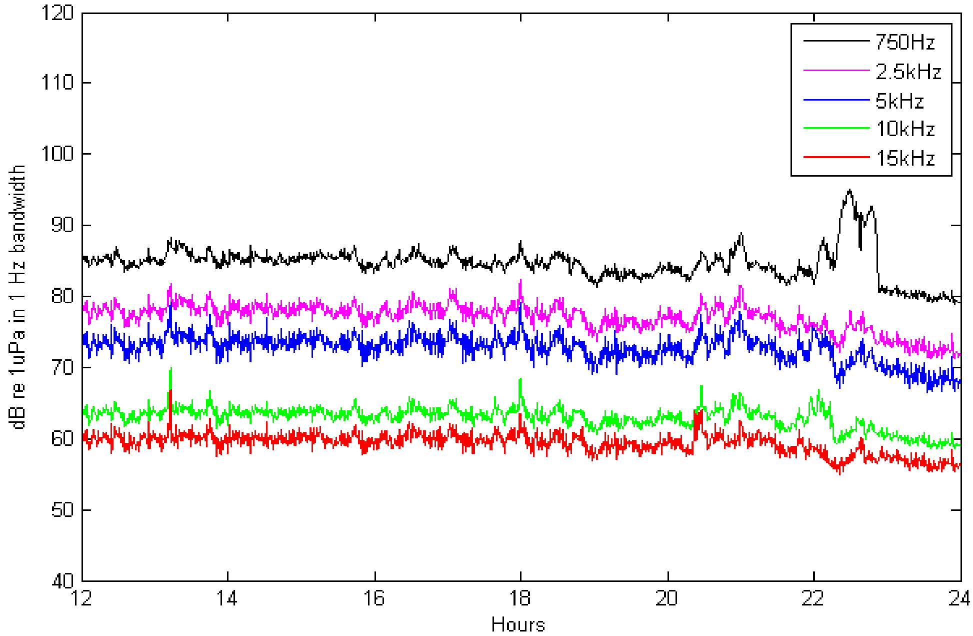

Figure C. 23: Five-channel high frequency plot for 22nd September 2011 afternoon

Through the 22nd the wind was constant in speed and direction until the last few hours, when it started to ease and change direction. This shows as the drop in levels in the last two hours of the day. The tanker Burgundy Clipper passed to the west around 23:00. Immediately before it appears, a weaker vessel sound can be heard. This may be a tug escorting the tanker. An unidentified vessel passed around 10:00. This was probably too far to the west to appear in the AIS data.

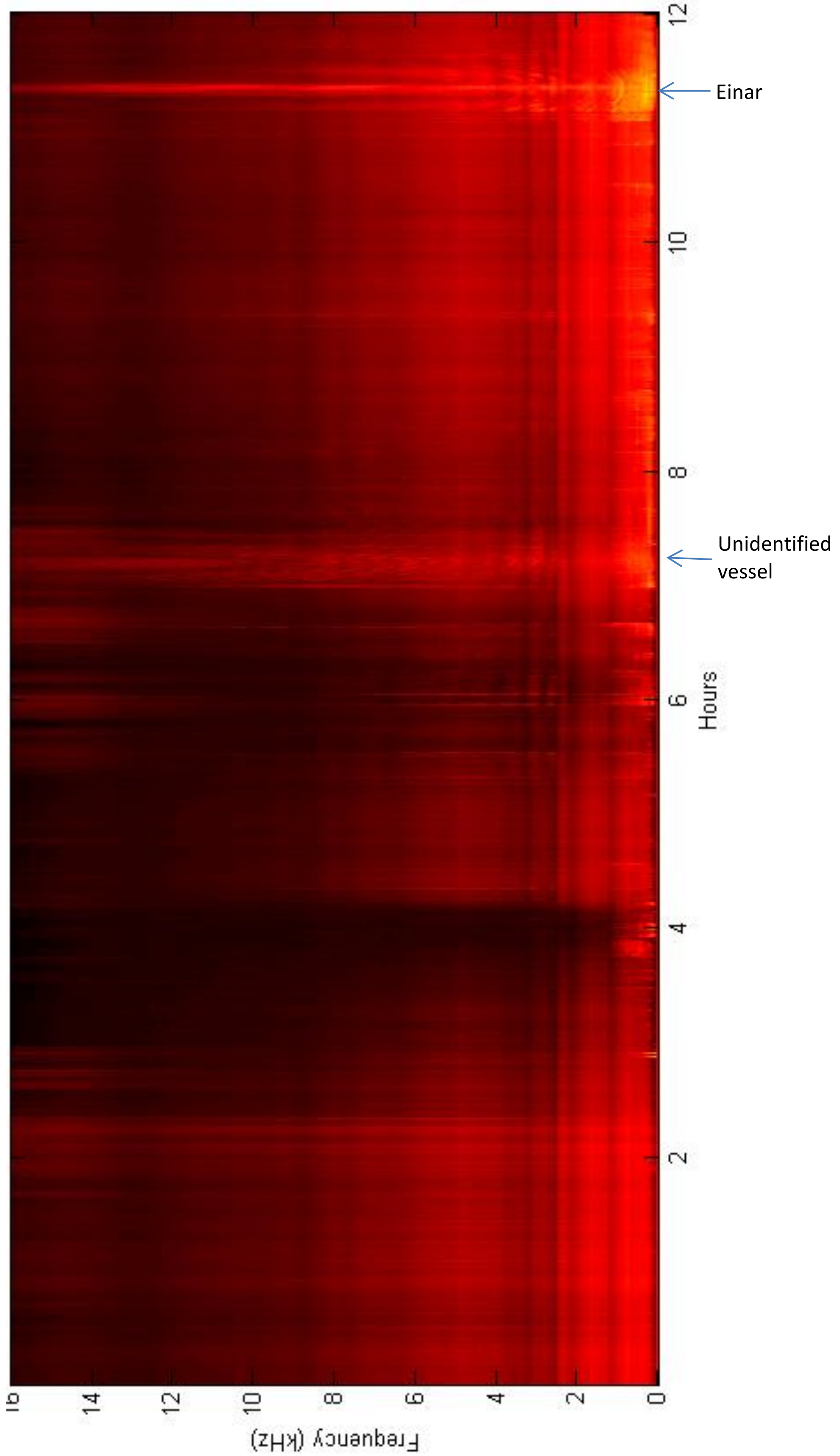

Figure C. 24: Spectrogram for 23rd September 2011 morning

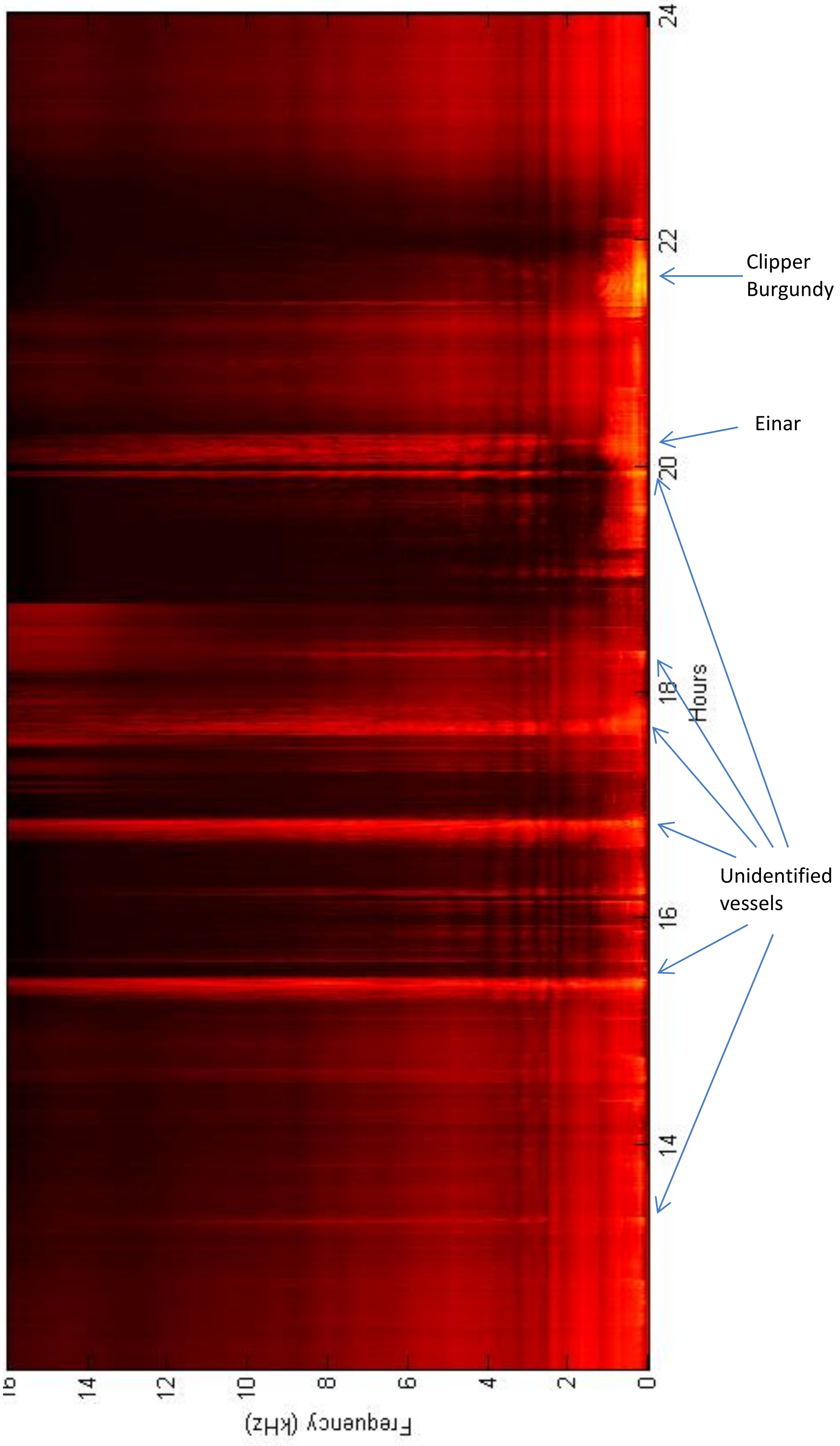

Figure C. 25: Spectrogram for 23rd September 2011 afternoon

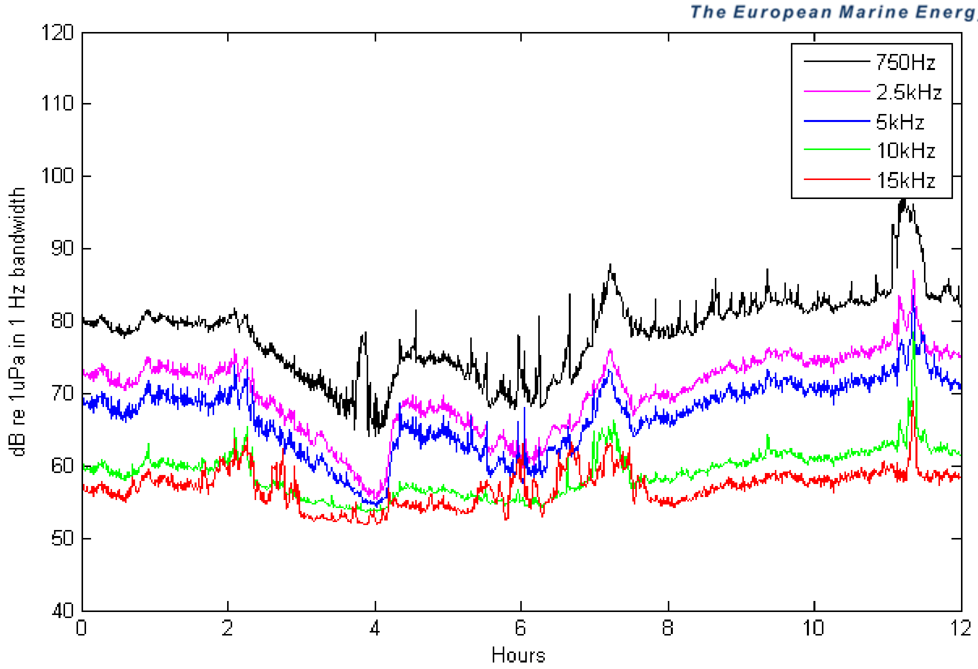

Figure C. 26: Five-channel high frequency plot for 23rd September 2011 morning

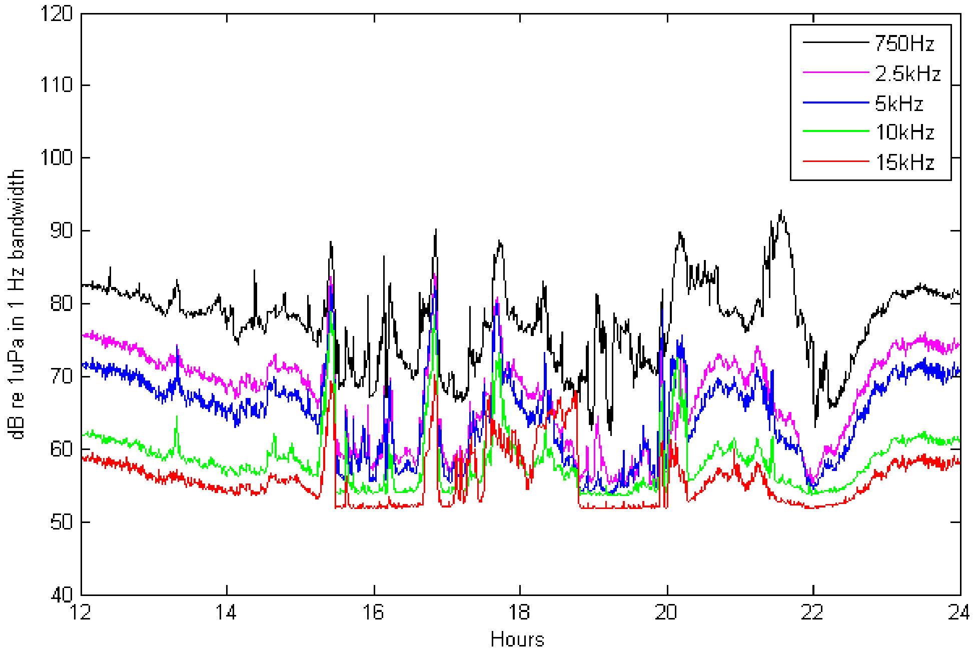

Figure C. 27: Five-channel high frequency plot for 23rd September 2011 afternoon

Just after midnight the wind dropped from near gale force westerly to settle as a breeze from the south. There was also some heavy rain in the early morning and mid-evening. The noise levels were generally low with the usual daily shipping traffic super-imposed. The breeze did pick up through the middle of the day and this is reflected as an increase in noise from 08:00 to 16:00. The changes in noise level through the evening appear to be due to fluctuations in the wind direction. During late evening the wind picks up and increases the noise level. The tug Einar passed by at 11:00 and again at 20:00, and the Clipper Burgundy passed by at 21:45. There is machinery noise present from 19:30 to 21:30, presumably from a stationary vessel.

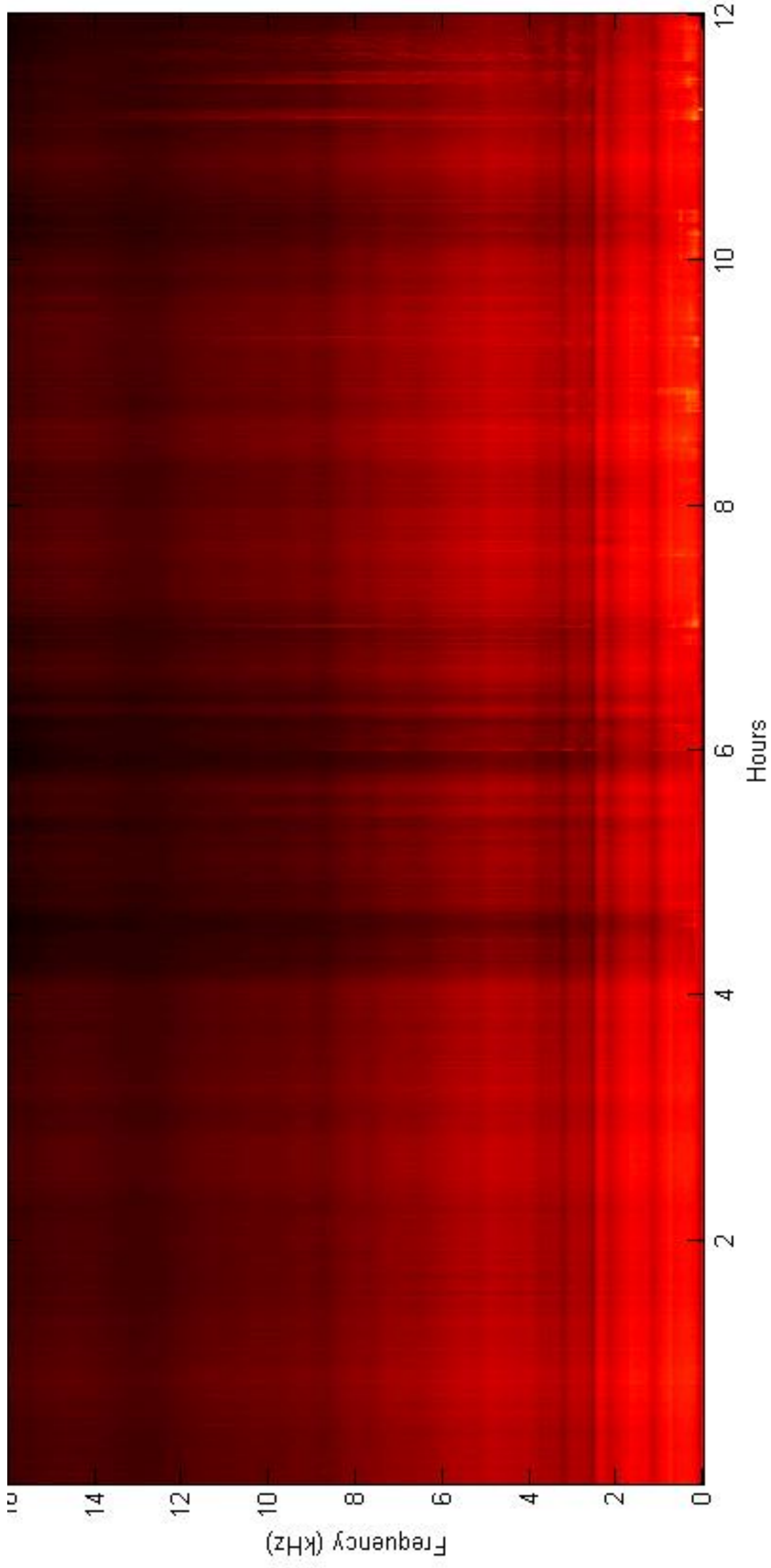

Figure C. 28: Spectrogram for 24th September 2011 morning

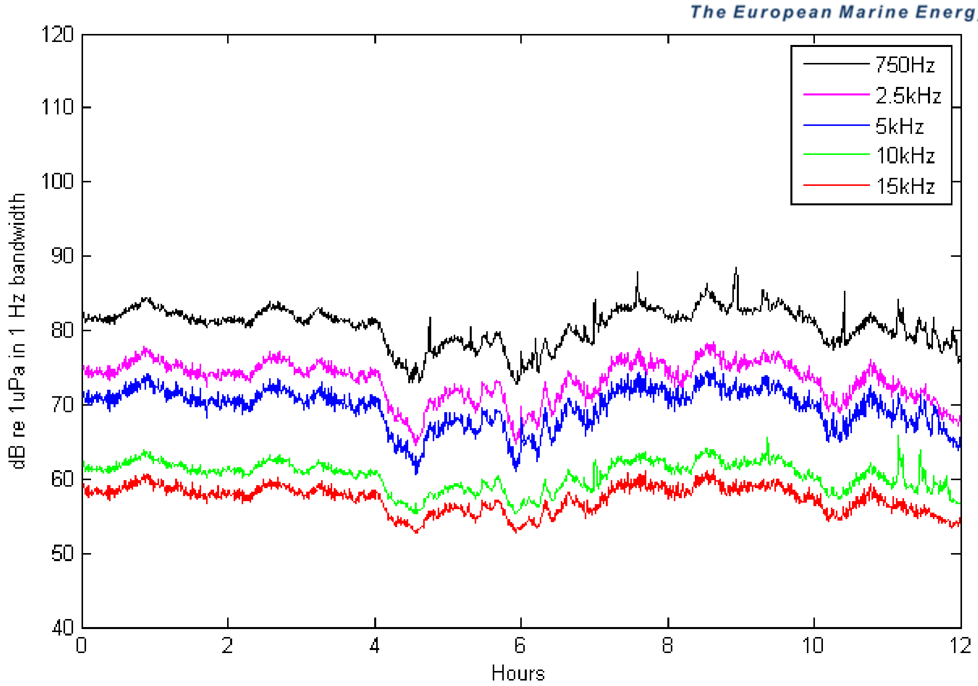

Figure C. 29: Five-channel high frequency plot for 24th September 2011 morning

The survey finished shortly after midday so there are no data for the afternoon. The wind was a strong breeze variable in both speed and direction, and is the most likely cause of the variations in mean noise level.

There are no vessel movements shown by the AIS data, and only distant traffic is detectable.

Appendix D: December 2011 Survey – Data Analysis

Introduction

This survey was carried out from the 2nd to the 7th December 2011. The SM2M was deployed at 58° 53.3'N, 2° 56.9'W. The unit was set for 0 dB internal gain and a sampling rate of 32 kHz.

Weather

The wind speed and direction are shown in Figures D.1 and D.2 below. The rain sensor at Billia Croo was not functional during this survey period, therefore the data shown in figure D.3 are taken from measurements recorded at the Eday weather station only.

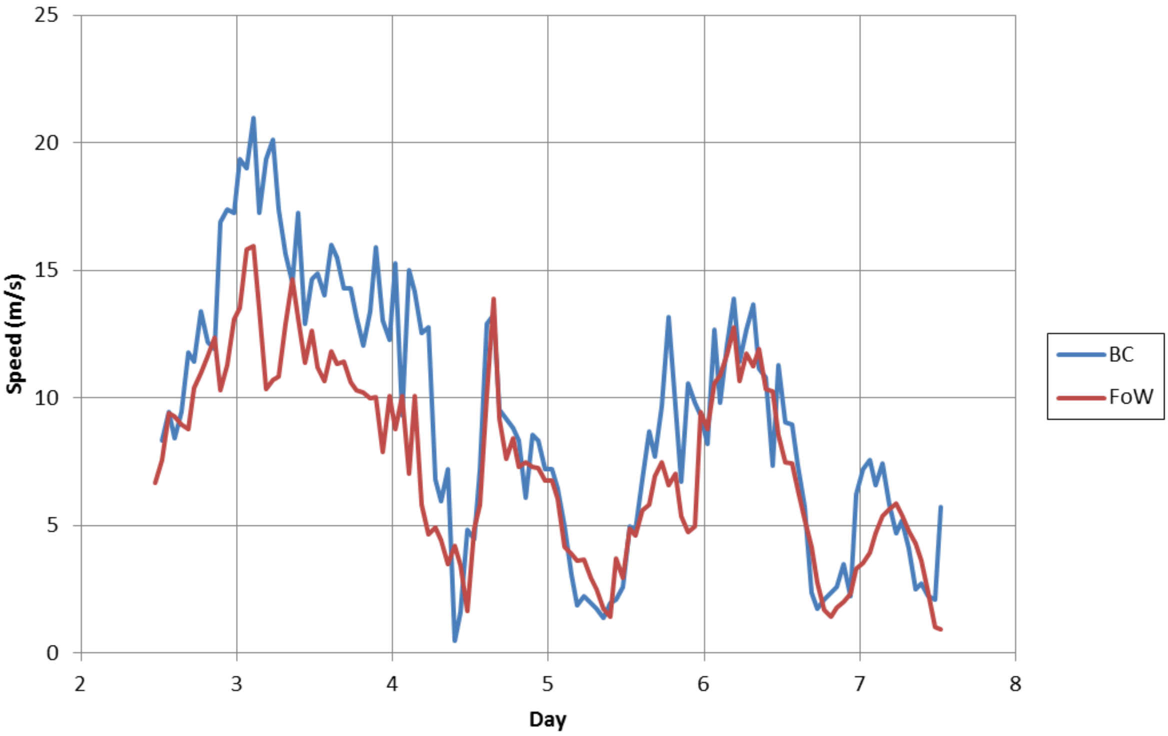

Figure D. 1: Wind speed recorded at Eday and Bilia Croo

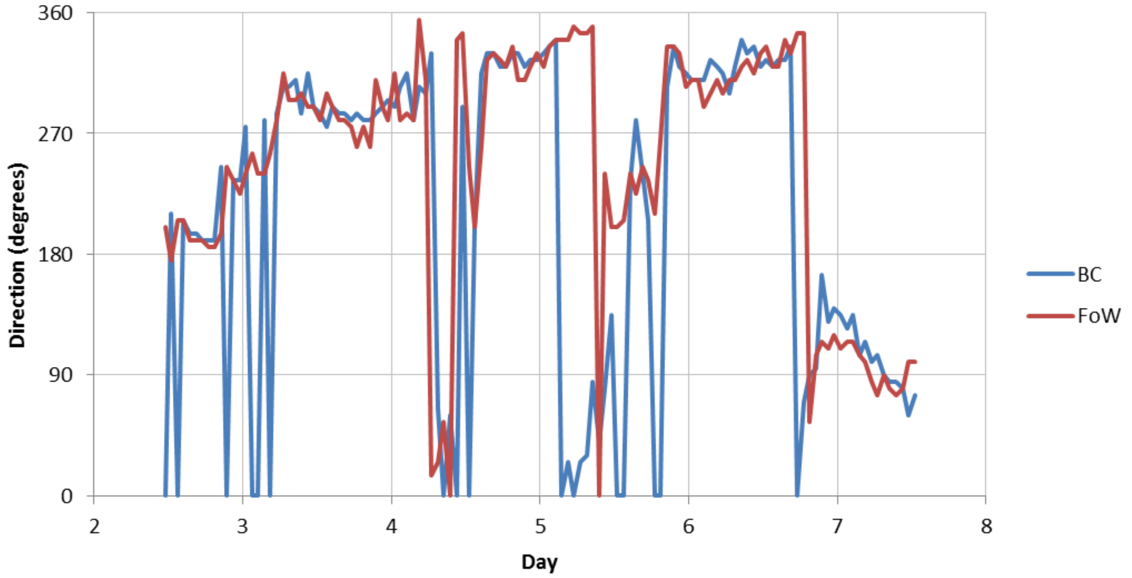

Figure D. 2: Wind direction recorded at Eday and Bilia Croo

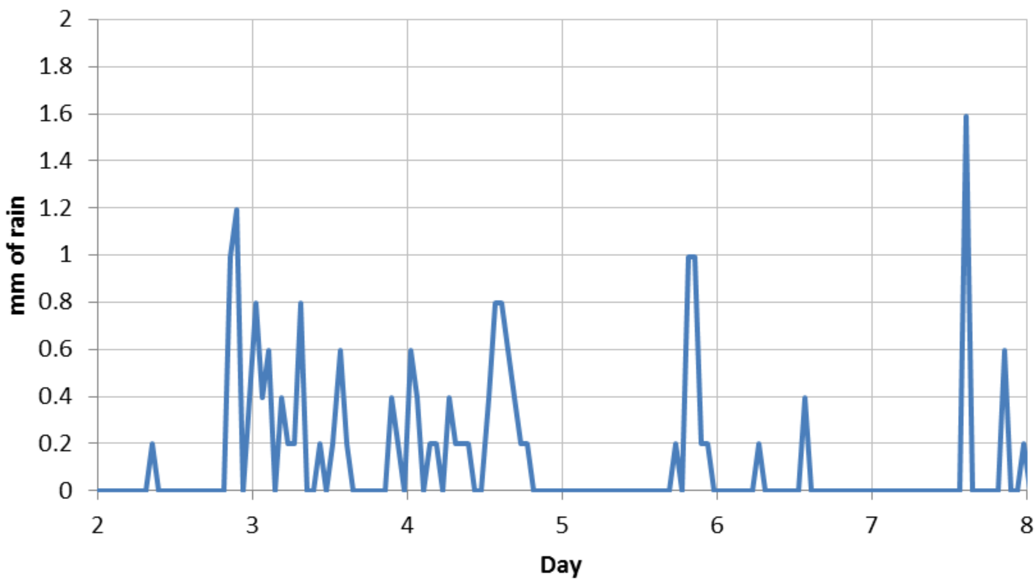

Figure D. 3: Precipitation recorded at Eday weather station

Other non-acoustic data

Automated Identification System (AIS) data on vessel movements were available for the survey period. Wildlife observations recorded two common seals on the 5th and one common seal on the 7th December.

Acoustic data

The acoustic data were recorded using the SM2M recorder with SD type memory cards in four internal slots, recording continuously at a sample rate of 32 kHz. The SM2M unit was programmed to start recording at a preset time, and to change files at set times each day. There is a short gap in the recorded data where the recording files change. This gap can vary from a few seconds up to 1 minute.

On recovery of the unit the SD cards were removed and the data downloaded to a PC. The Syntrillium Software audio editing software package 'CoolEdit' was then used to re-assemble the files into 12 hour blocks covering midnight to midday, and midday to midnight for each complete day of the survey. The gaps due to the file changes remain in the data.

Each twelve hour block of data was processed to produce the displays shown in this appendix. The data were read in 30 second blocks and a 1024 input point FFT performed repeatedly. The resulting spectra were then averaged to obtain the mean spectrum for this 30 seconds. This operation was performed repeatedly and the resulting mean spectra assembled into the spectrograms shown. In addition, the raw data were decimated by 8 to give a sample rate of 4 kHz. The 30 second mean spectrum was again calculated and the sequence of 30 second mean spectra assembled to give the low-frequency spectrograms shown.

The five-channel plots take the FFT output and combine the output power across four channels, each 2 kHz in bandwidth centred on 2.5, 5, 10 and 15 kHz, and a fifth channel centred on 750 Hz with a 200 Hz bandwidth. All channels were normalised to give mean spectrum level. The low frequency plots are only included where they show events of interest.

The variability plot was obtained by averaging the FFT data for 10 seconds and then combining all of the resulting spectra for the whole deployment. The spectrum was reduced in resolution to 1 dB vertically and 250 Hz horizontally. The plot was formed by counting the number of times each of these 10 second spectra have a particular frequency/amplitude component. This can result in a wider dynamic range than most printers can display so the data were compressed by taking the logarithm of the count.

The wideband mean level plot was obtained by summing the power across a 1-10 kHz bandwidth for periods of four minutes. This plot provides a broad overview of ambient noise levels and acoustic events throughout the survey period. Figure D.4 below shows the plot for the December 2011 survey period. The general noise level is related to weather conditions, particularly wind speed and rainfall as can be seen by comparing this plot with the wind speed shown in figure D.1. The sharp peaks in noise level are generally due to passing vessels. It can be seen that the noise level during this survey period is generally determined by weather conditions, with only occasional increases due to close vessel passes.

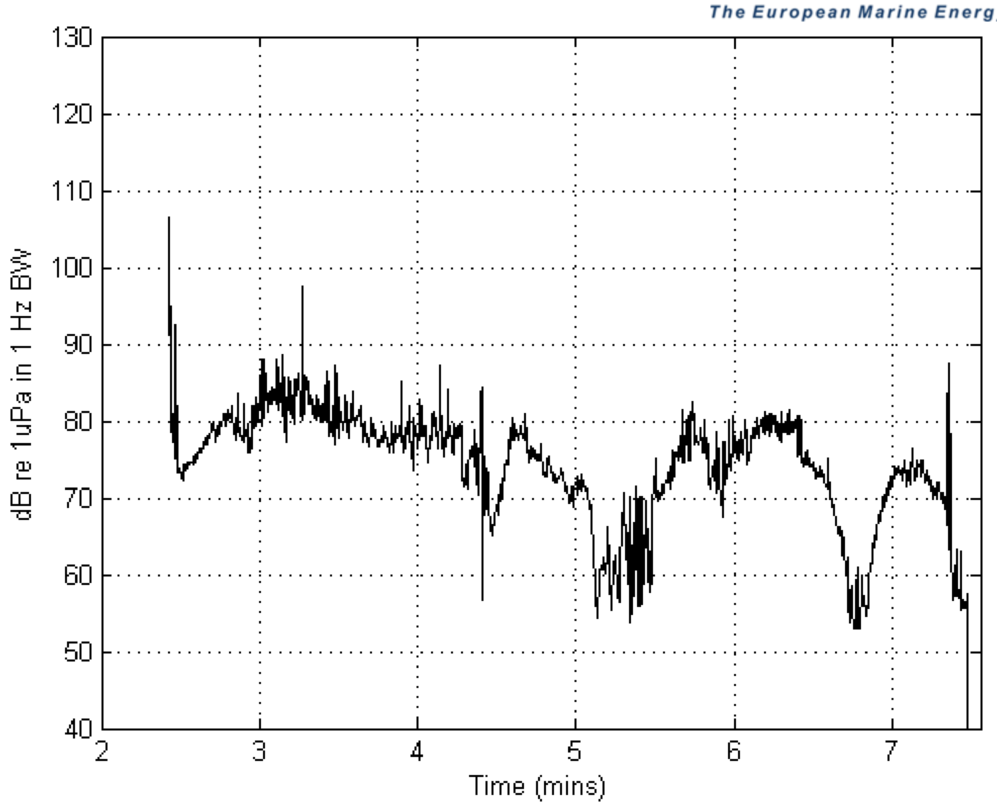

Figure D. 4: Wideband level for the December 2011 survey

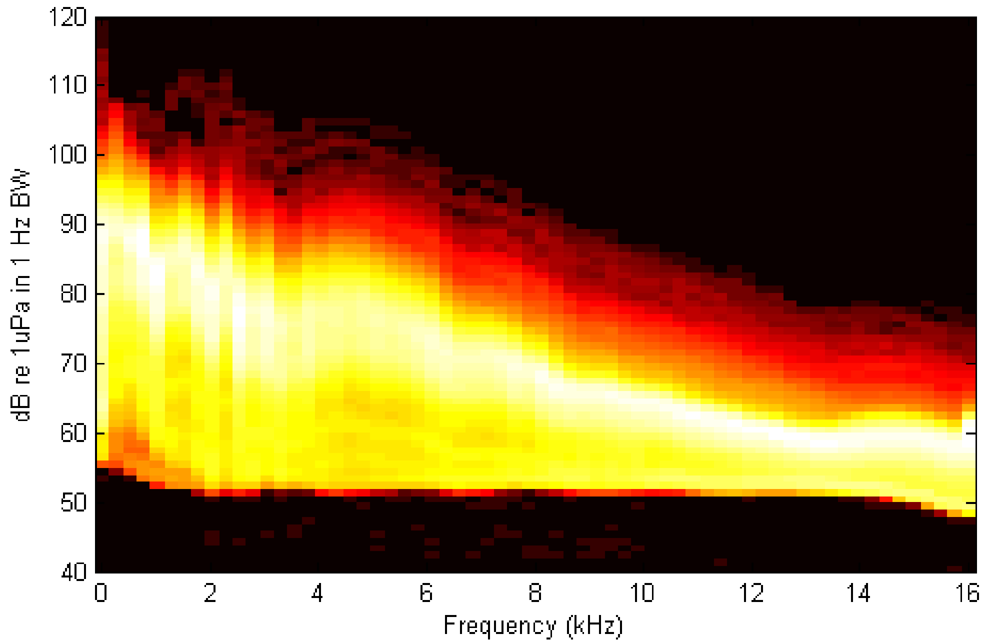

Figure D. 5: Variability plot for the December 2011 survey

The variability plot in Figure D.5 above shows how the acoustic levels varied during the survey period. The brighter the colour on the plot, the more often that particular frequency/amplitude combination occurs. The broad band of white shows the points that occur most often and can be considered as the 'typical' spectrum for the site. The region above this typical spectrum is due to increasing noise, such as that from bad weather. The highest levels are usually due to passing vessels.

The region below this typical spectrum is due to the noise levels dropping when the ambient noise is very quiet. The straight bottom edge to the variability region is due to internal noise within the recording system. It is likely that acoustic noise levels can go lower than this when the ambient noise is very quiet. Below this defined edge there are a few scattered points and these are due to the gaps in the data where the recording file changes, reducing the apparent noise level during the 10 second average.

Passing vessels

A number of vessels passed through the area. Where possible these have been identified from the wildlife observer's notes and/or from AIS data. For this survey the following vessels were identified:

3/12/11	11:20	John Rae
5/12/11	10:30	Creel boat Jade Elin

Other ship activity is apparent during the morning of the 4th and the evening of the 5th.

Survey data

The following plots show the acoustic data for each 12 hour period of the survey. The full spectrogram and five-channel plots are shown for each period. In addition, the low frequency plots are shown where interesting events occur.

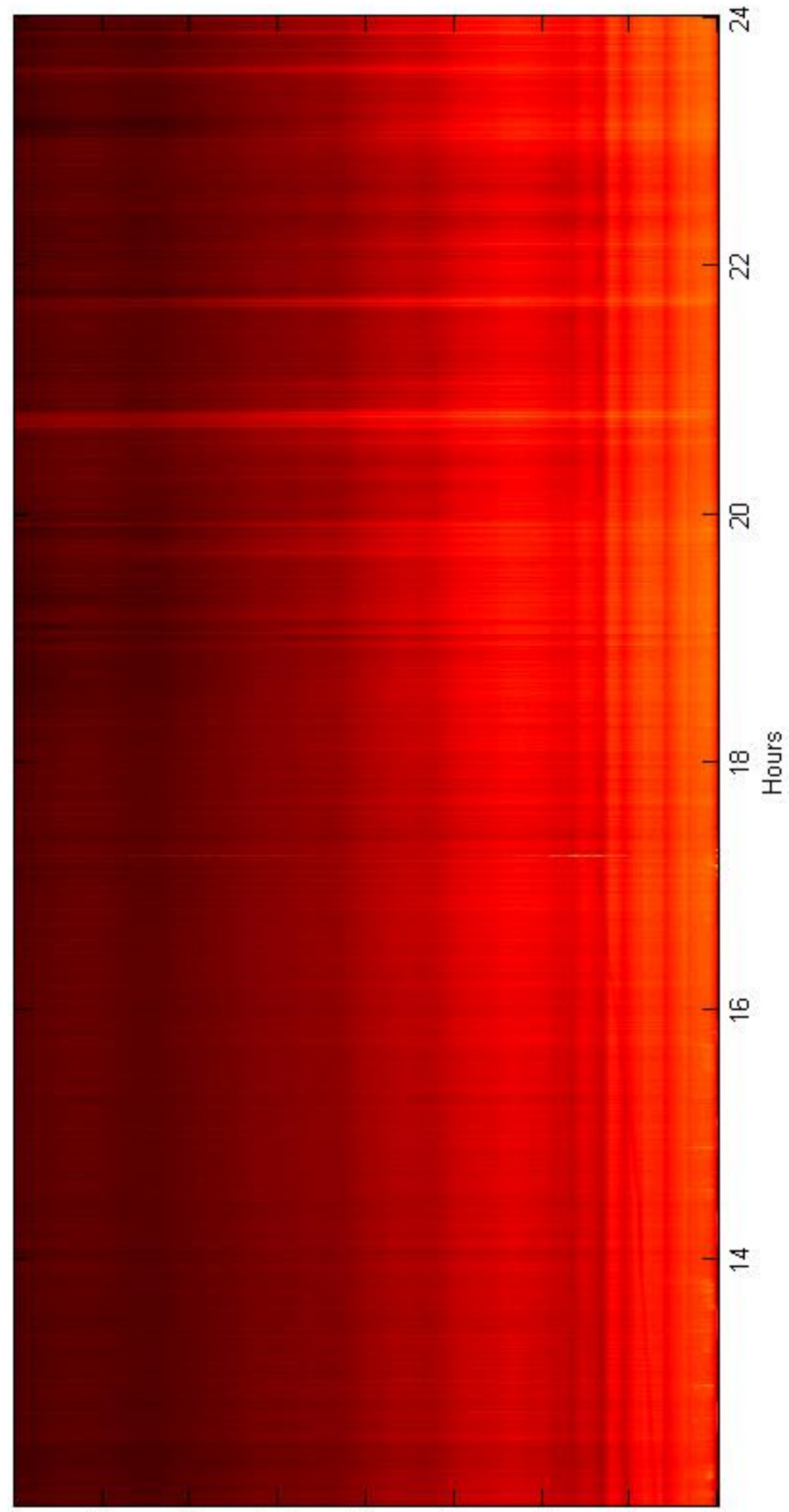

Figure D. 6: Spectrogram for 2nd December 2011 afternoon

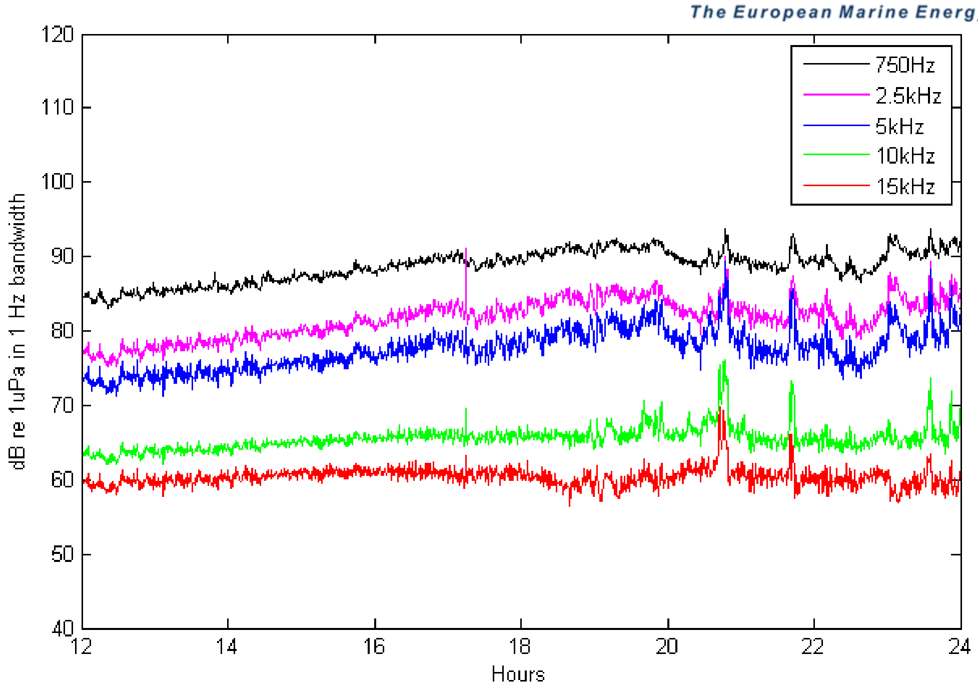

Figure D. 7: Five-channel high frequency plot for 2nd December 2011 afternoon

This period had steadily increasing winds and this is reflected in the increasing noise levels. The peaks from 20:00 onwards are due to bursts of heavy rain.

There is some very weak vessel noise during the first two hours of the recording. This noise then becomes masked by the increasing noise levels due to weather.

The sharp peak just after 17:00 is due to abrasion noise. There are a number of occurrences of this abrasion noise throughout the deployment. It may be due to seaweed or other floating debris hitting the hydrophone, but it is more likely to be crustaceans crawling on the hydrophone and instrument canister.

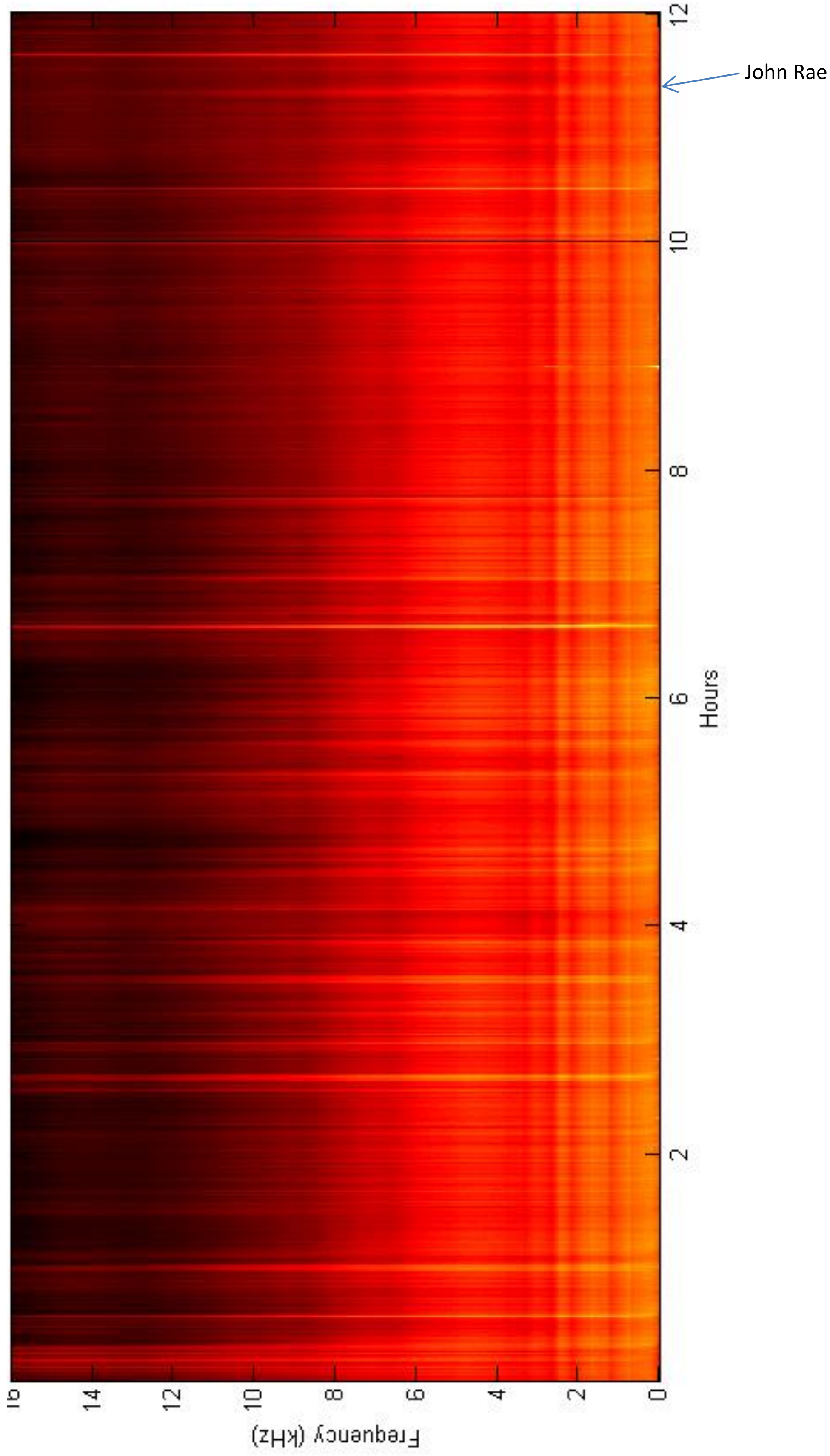

Figure D. 8: Spectrogram for 3rd December 2011 morning

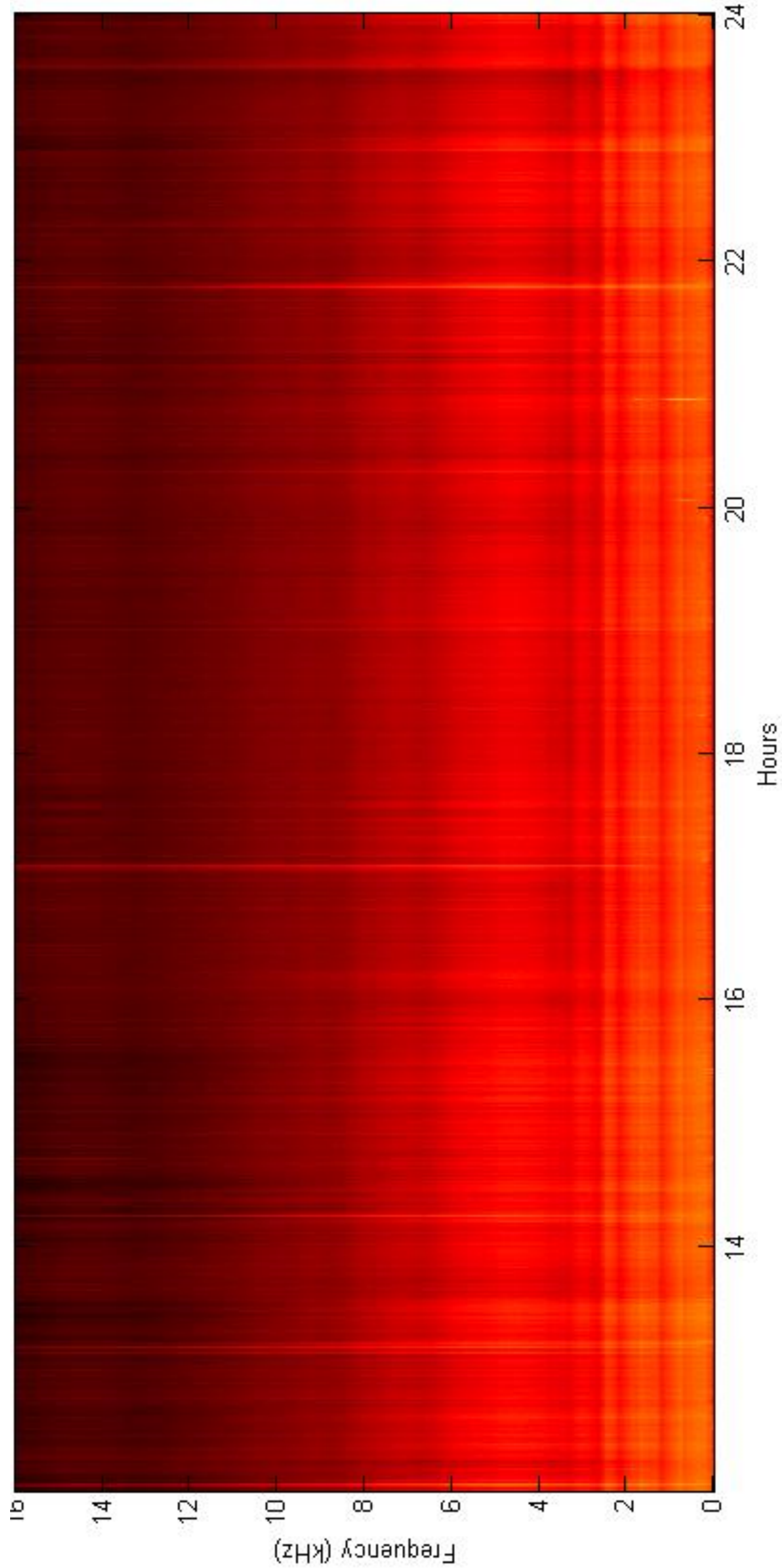

Figure D. 9: Spectrogram for 3rd December 2011 afternoon

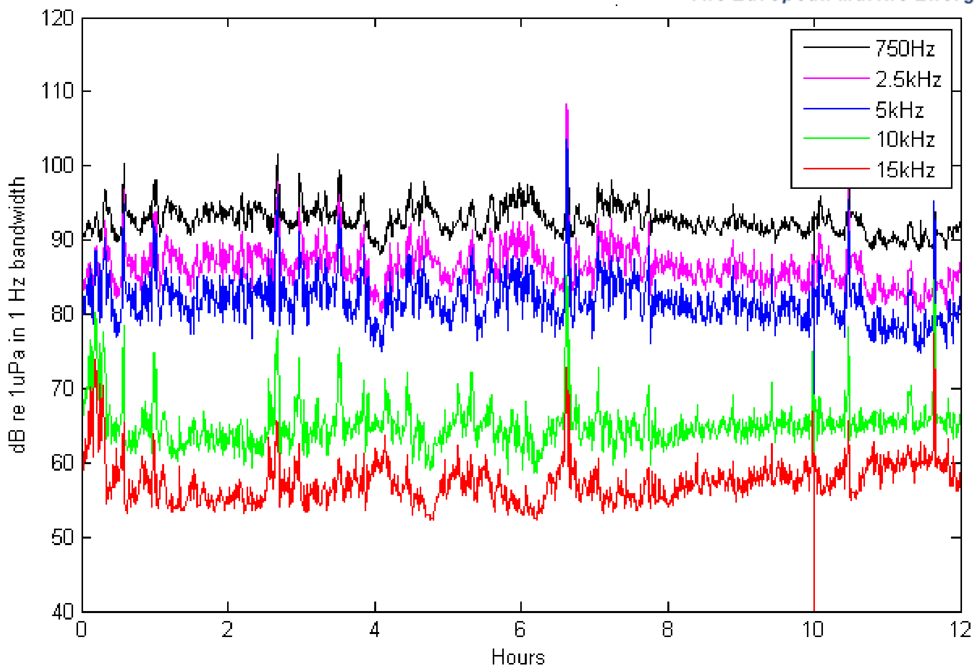

Figure D. 10: Five-channel high frequency plot for 3rd December 2011 morning

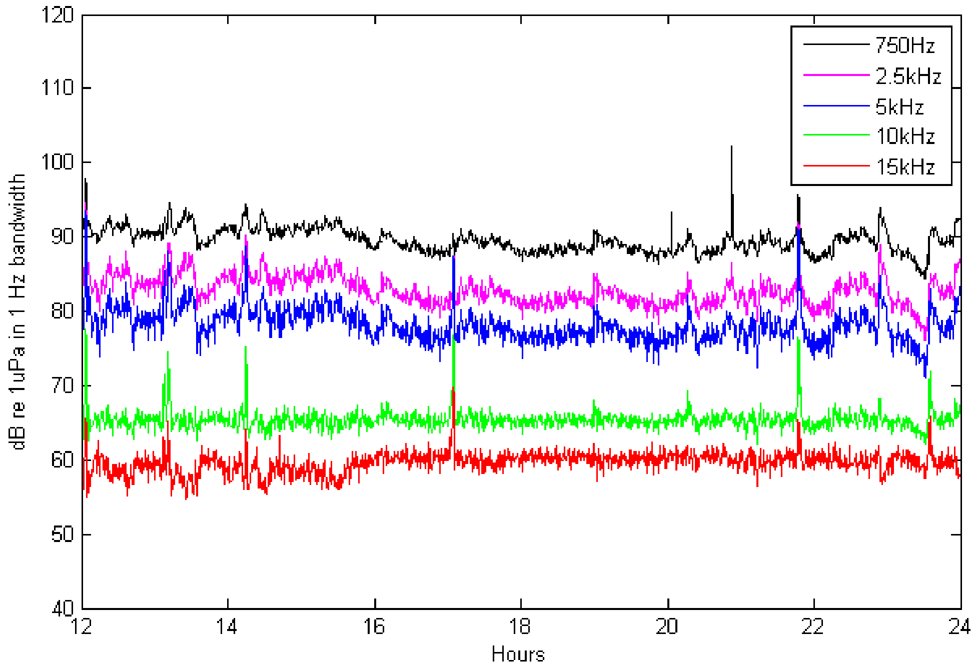

Figure D. 11: Five-channel high frequency plot for 3rd December 2011 afternoon

The abrasion noise re-occurs at approximately 09:00. The peaks at 06:30 and later through the day are periods of very heavy rain. Waves can be heard throughout the day but are particularly loud around 17:00. These may be waves on the nearby shoreline. The peak at low frequencies around 20:45 appears to be a small explosion.

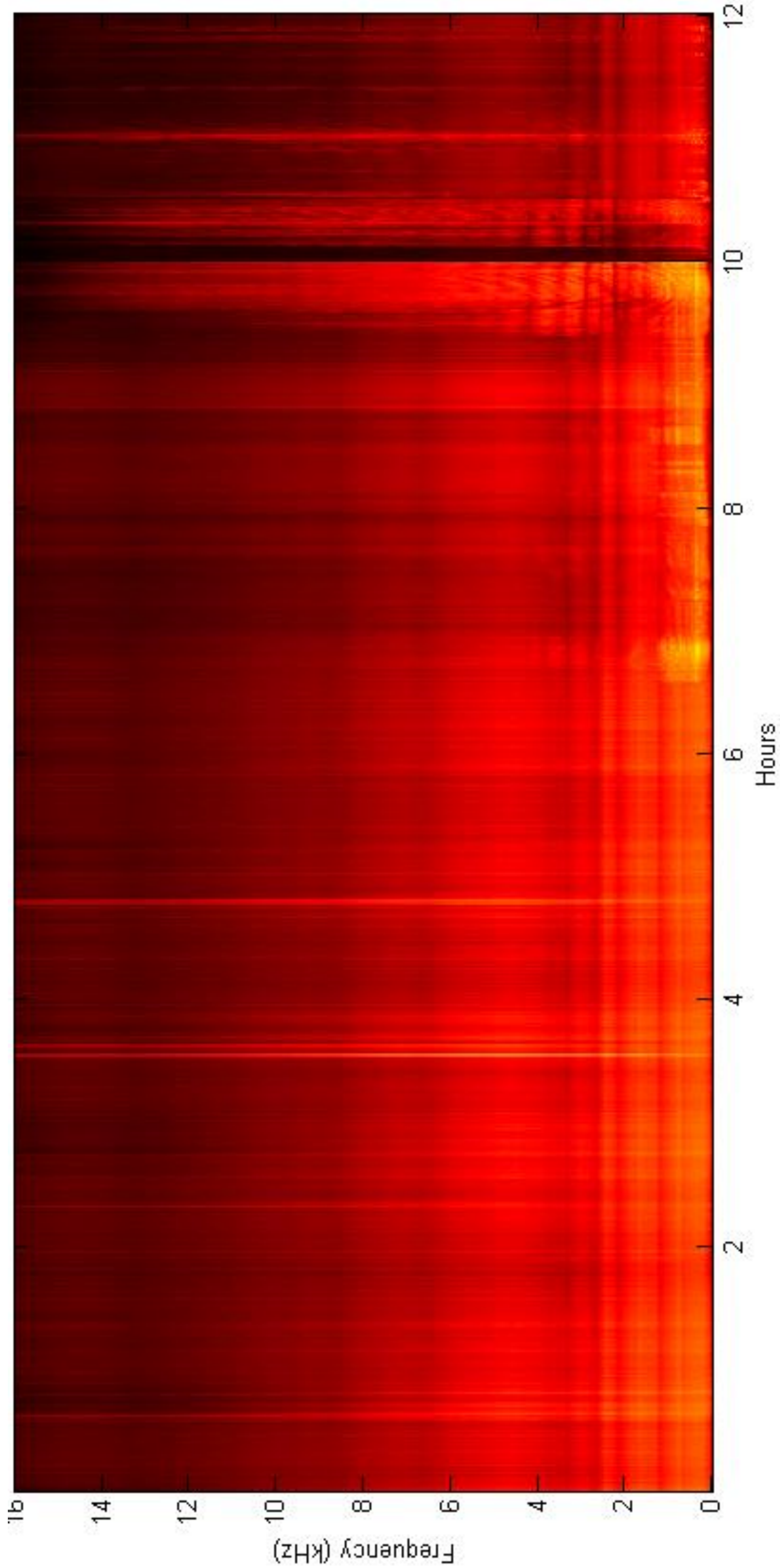

Figure D. 12: Spectrogram for 4th December 2011 morning

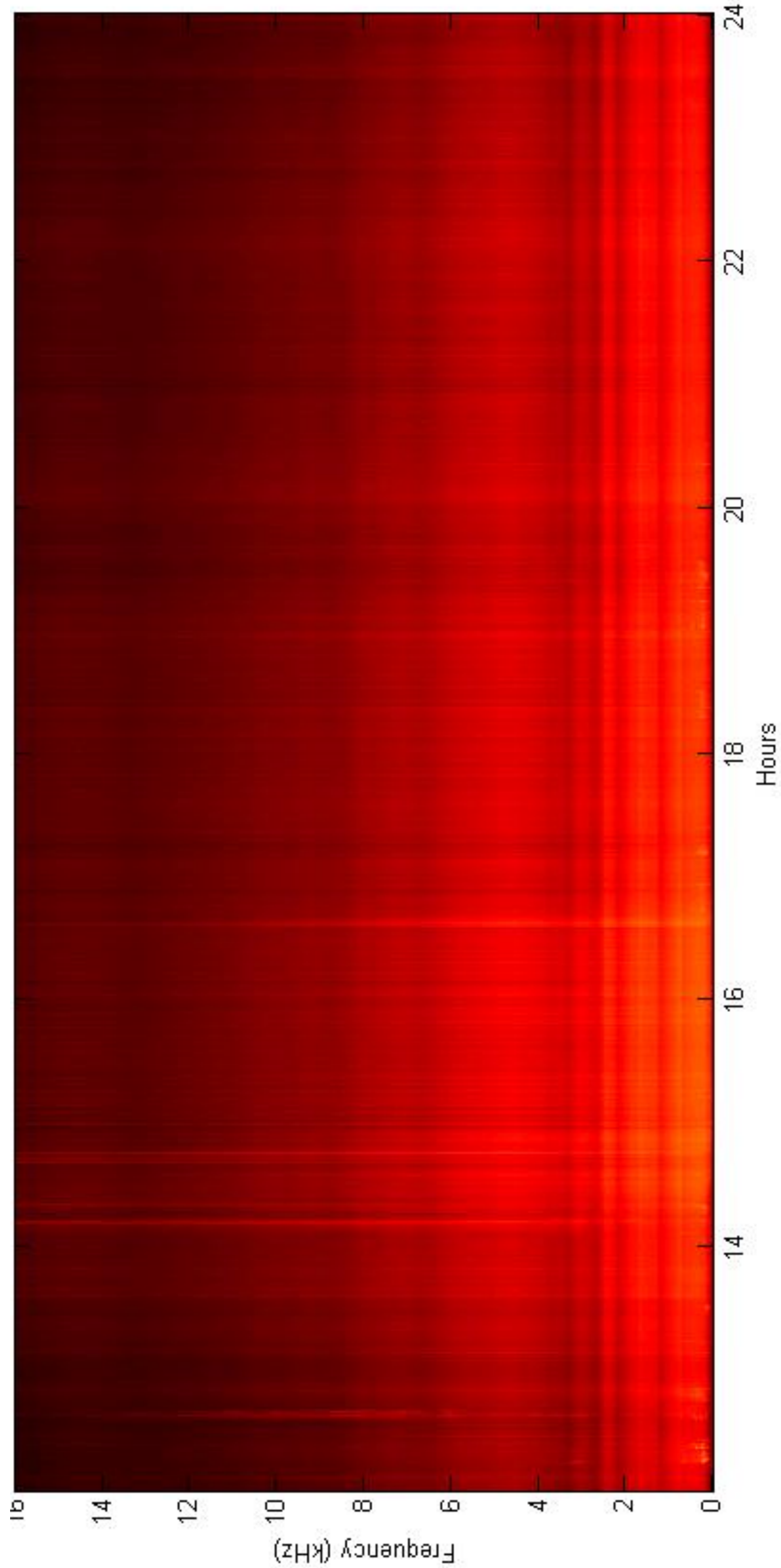

Figure D. 13: Spectrogram for 4th December 2011 afternoon

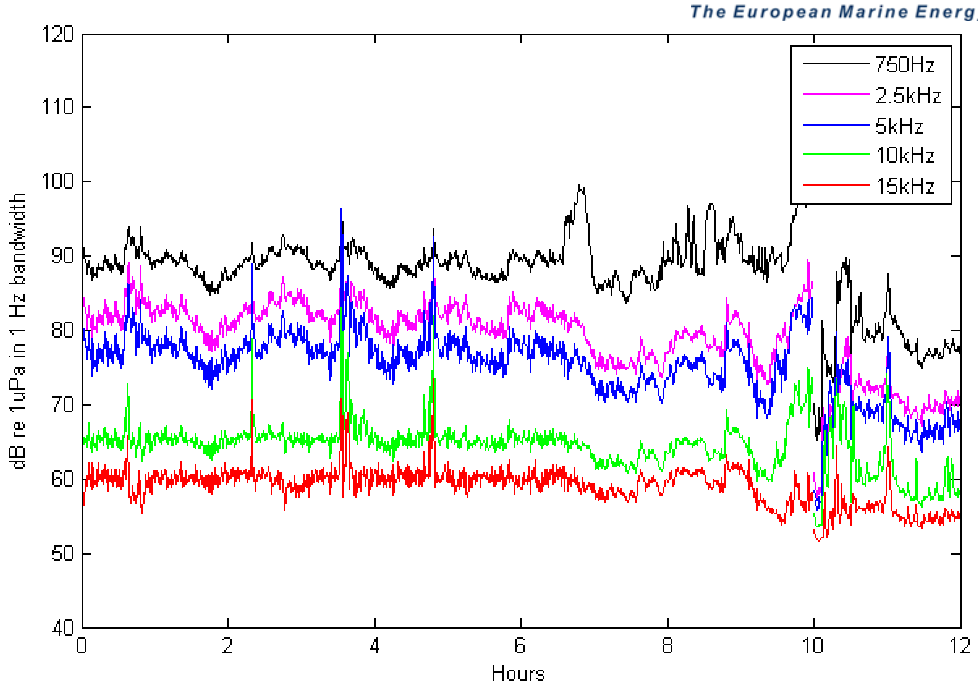

Figure D. 14: Five-channel high frequency plot for 4th December 2011 morning

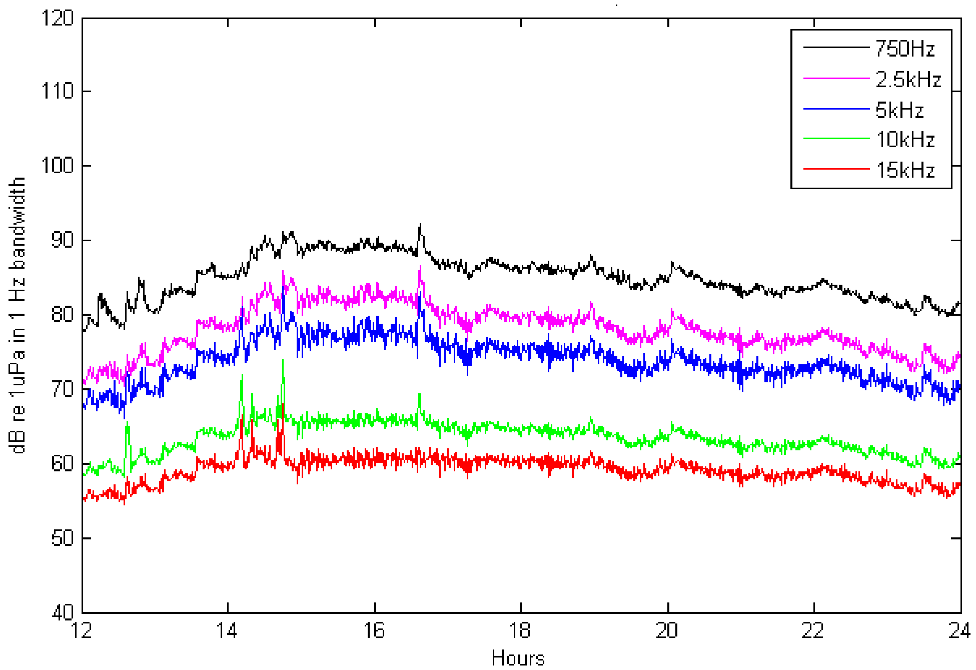

Figure D. 15: Five-channel high frequency plot for 4th December 2011 afternoon

The four peaks at higher frequencies between 00:00 and 06:00 are due to heavy rain. A vessel passes at around 06:45. For most of the morning and into the early afternoon there is a lot of vessel noise. At least four different vessels can be identified, at least one of which is a small vessel with a high revving engine.

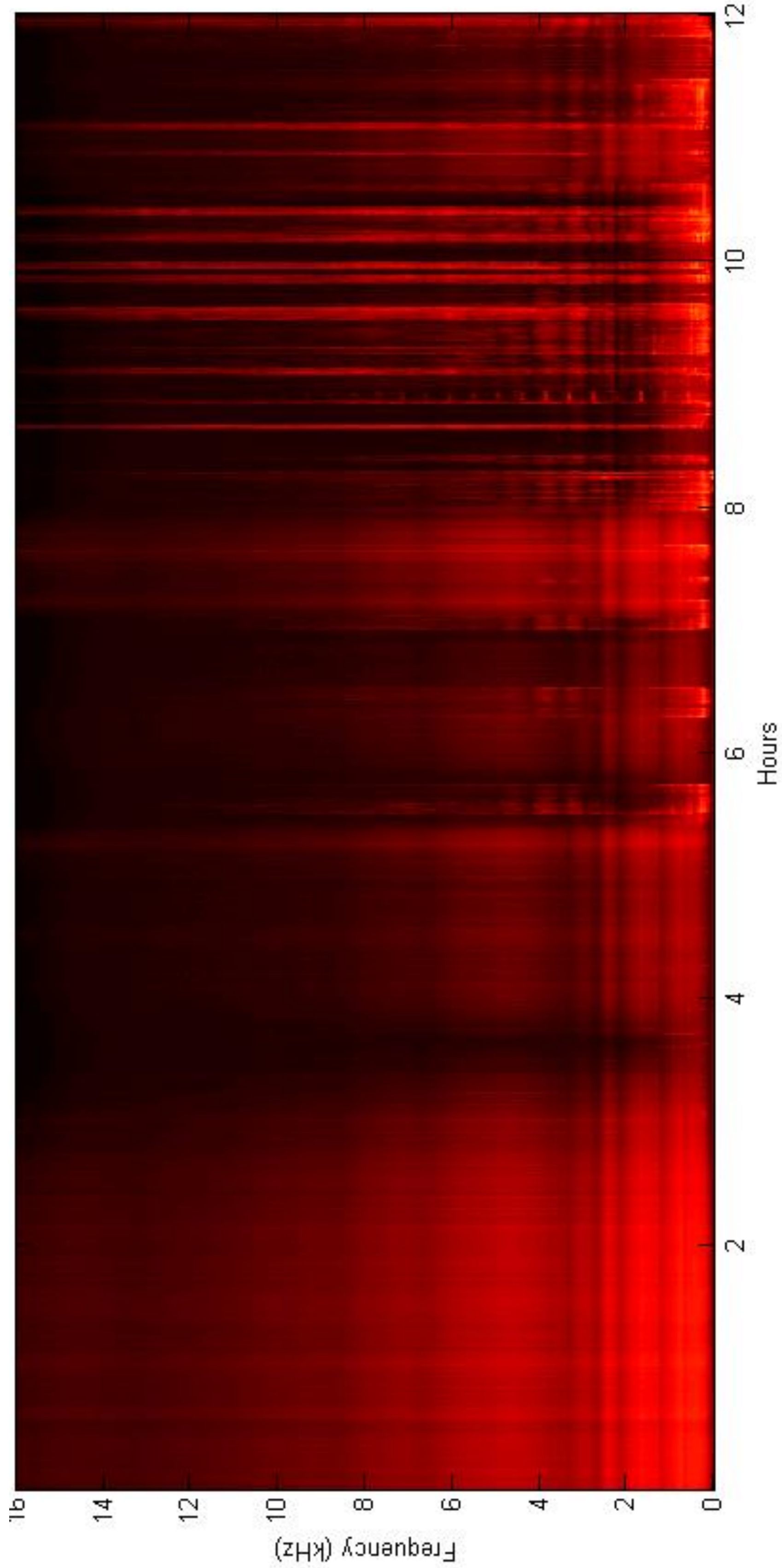

Figure D. 16: Spectrogram for 5th December 2011 morning

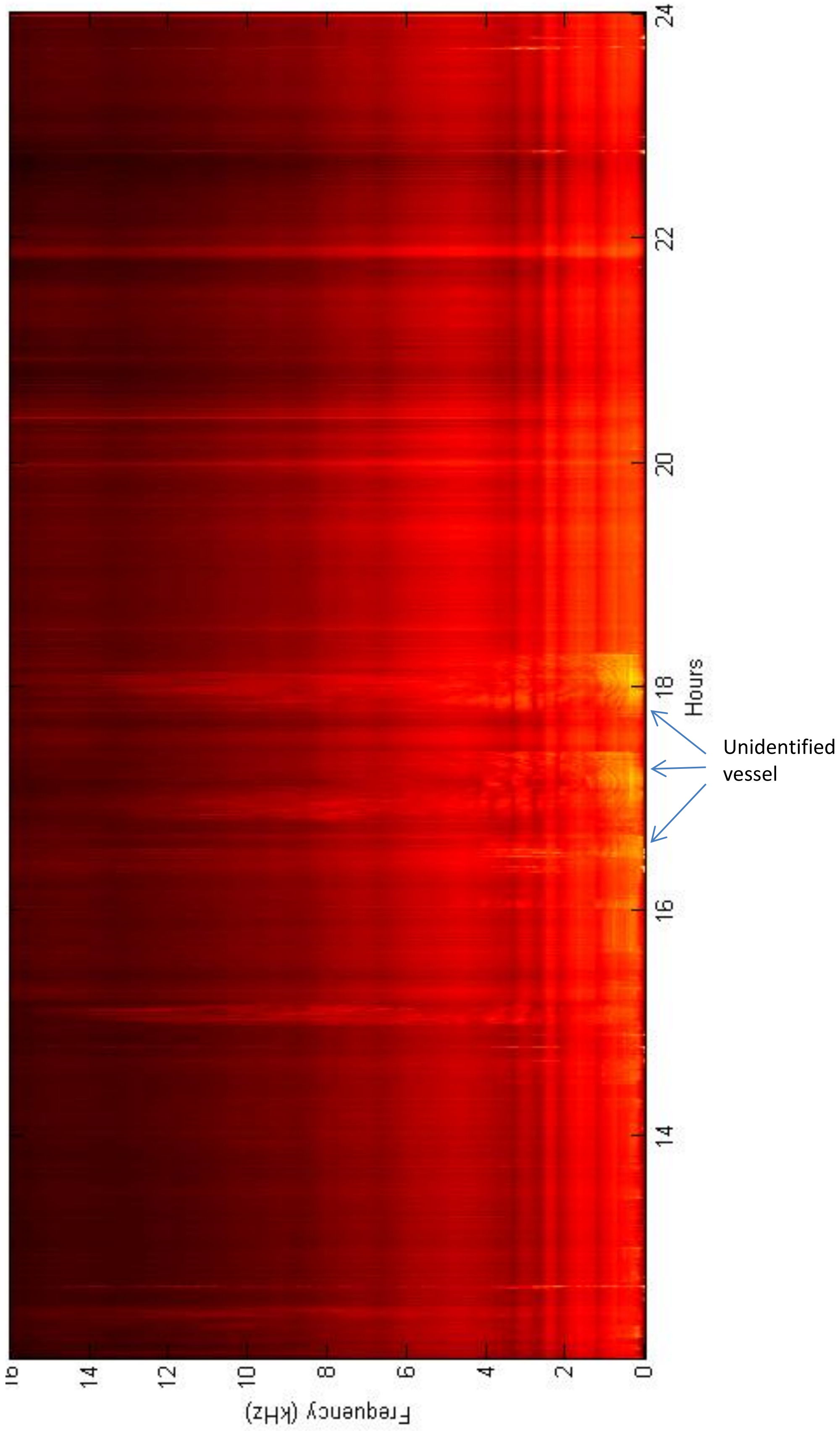

Figure D. 17: Spectrogram for 5th Decemebr 2011 afternoon

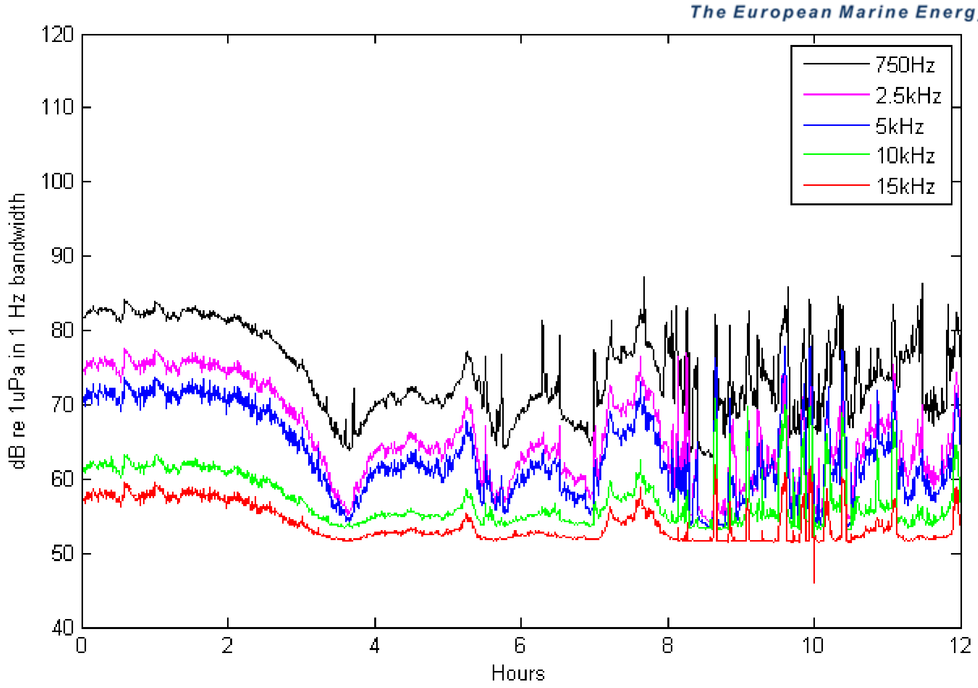

Figure D. 18: Five-channel high frequency plot for 5th December 2011 morning

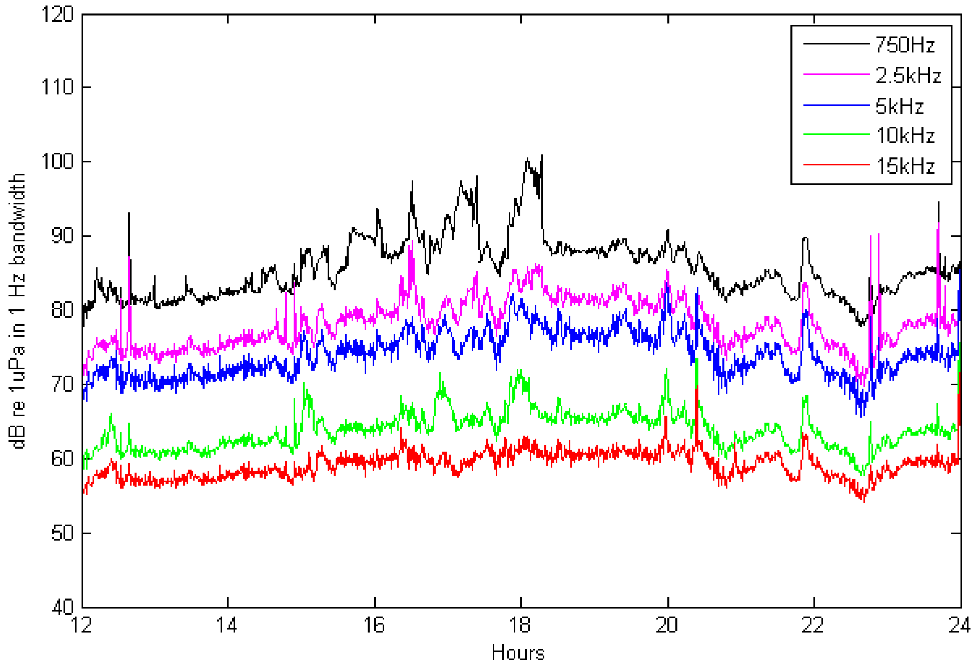

Figure D. 19: Five-channel high frequency plot for 5th December 2011 afternoon

There was a period of calm in the morning and the wind picked up after mid-day. There was a lot of vessel activity throughout the morning, starting around 05:30, involving a number of different vessels. A larger vessel moved around the area from 15:00 to 18:30. There was heavy rain at 21:45 and 23:45, and the abrasion noise appeared at 02:50.

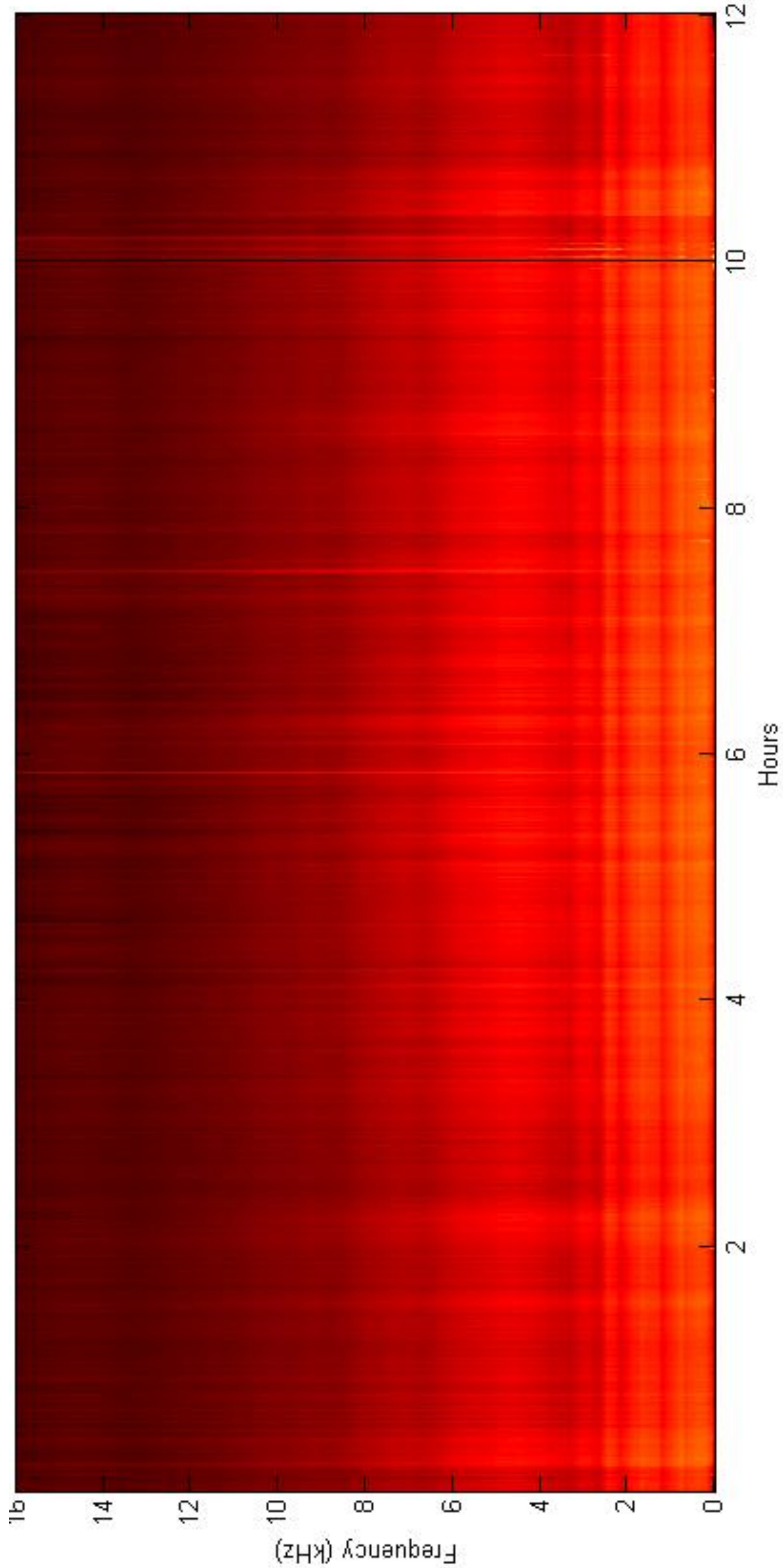

Figure D. 20: Spectrogram for 6th December 2011 morning

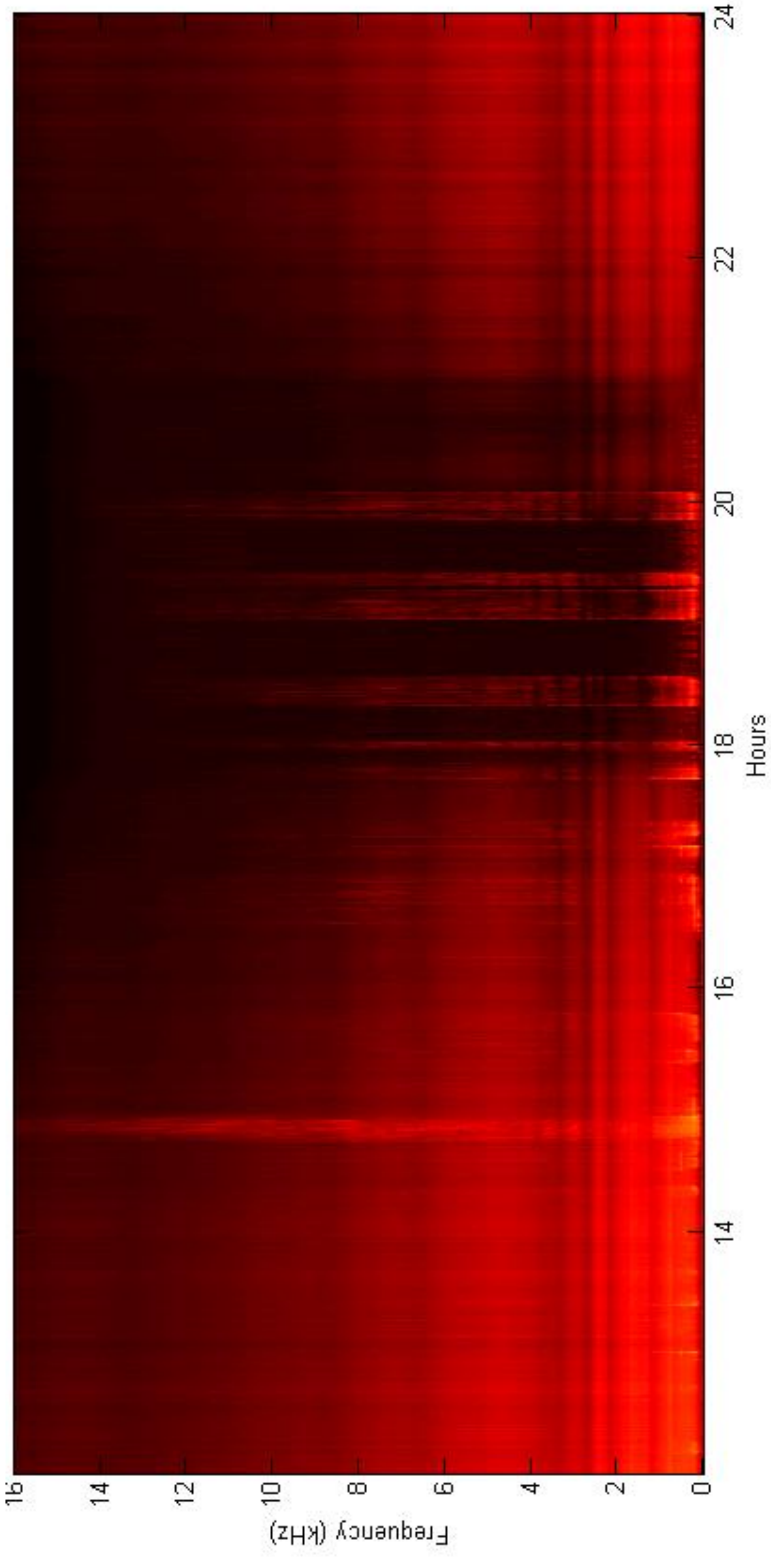

Figure D. 21: Spectrogram for 6th December 2011 afternoon

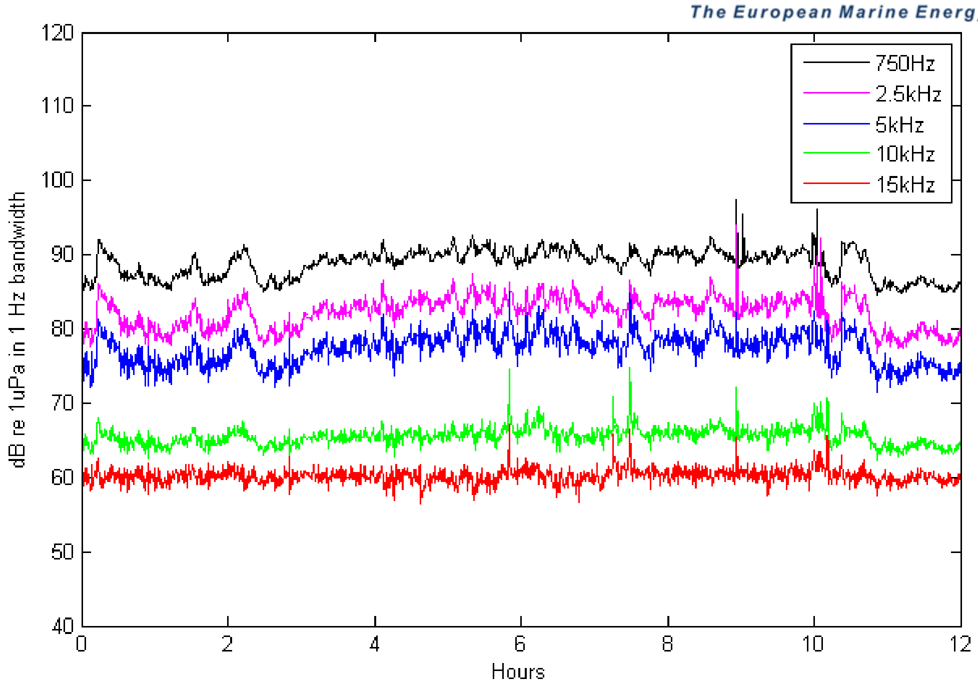

Figure D. 22: Five-channel high frequency plot for 6th December 2011 morning

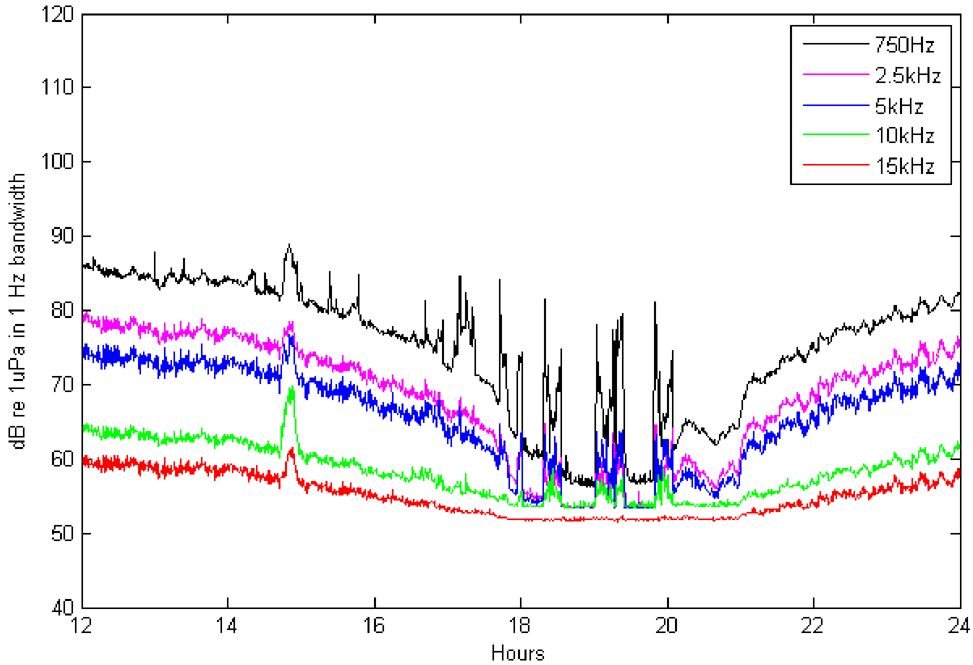

Figure D. 23: Five-channel high frequency plot for 6th December 2011 afternoon

The wind was strong through the morning but eased for several hours late afternoon. There were several bursts of heavy rain throughout the morning. The only vessel noise during the morning was weak and can be seen for a few minutes at 09:00. During the lull in the weather the regular ferry traffic can be heard. Close inspection of the spectrum suggests that at least two vessels were regularly heard. The vessel heard at around 15:00 was detected on a number of occasions and has a characteristic droning sound. The 'triple thump' sound described in the main text of this report and attributed to fish, can be heard throughout the day.

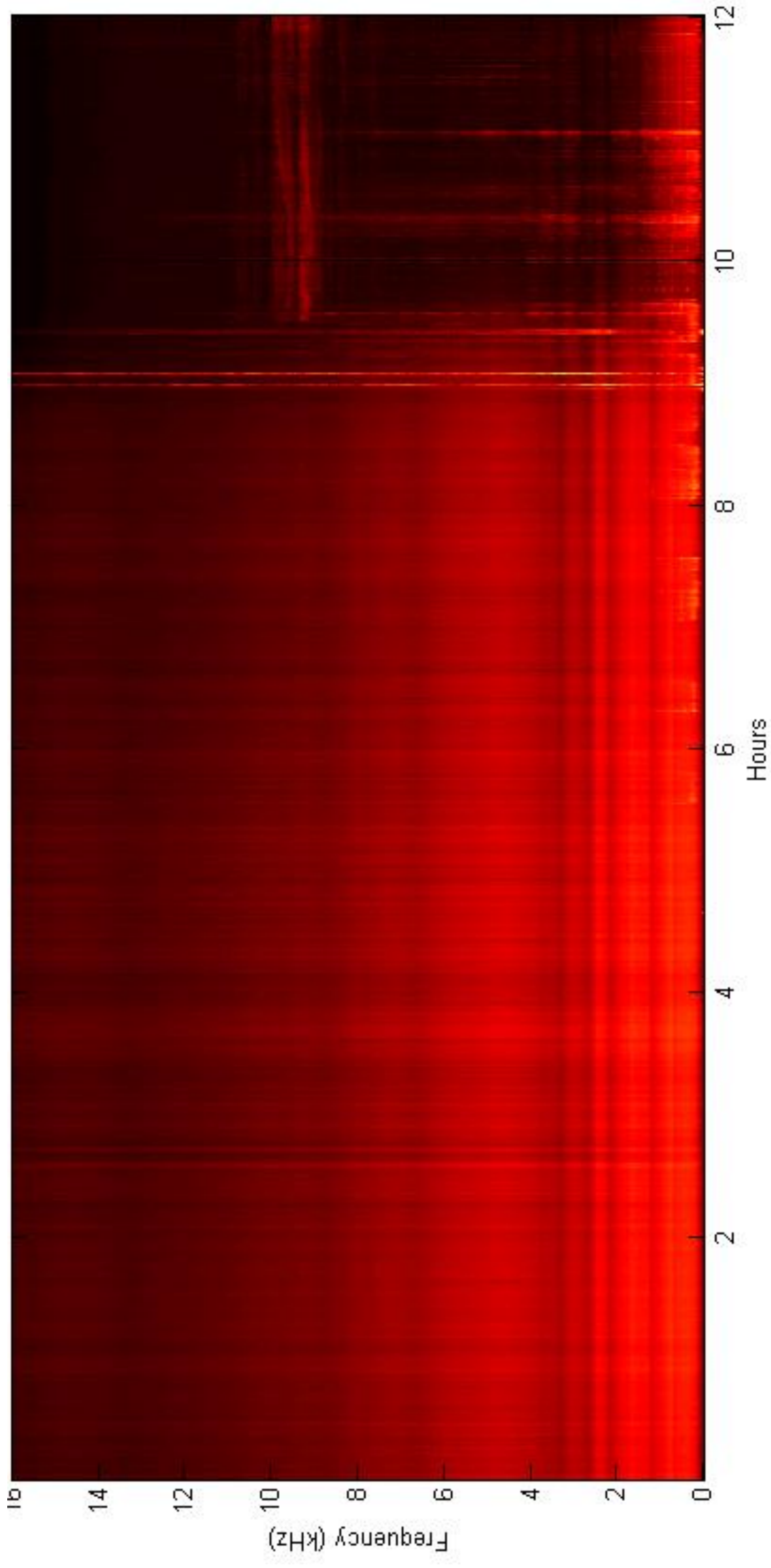

Figure D. 24: Spectrogram for 7th December 2011 morning

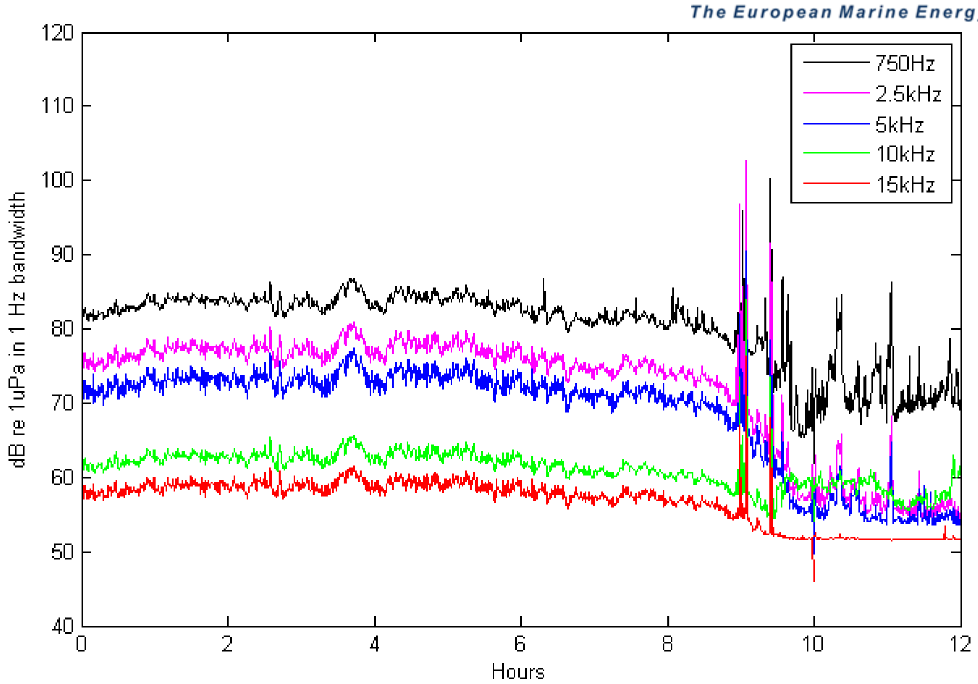

Figure D. 25: Five-channel high frequency plot for 7th December morning

The day started windy but this eased at around 10:00. The 'triple thump' sound attributed to fish can be heard throughout the morning. The vessel activity starting at around 09:00 is unusual. There are various winch and other mechanical handling sounds, and from 09:45 pulsed sonar can be heard on 9.5 kHz. This sound is probably an artefact from an echo-sounder operating at a much higher frequency. This noise suggests that a vessel was working very close to the recorder, yet there are no loud engine sounds as would be expected as such a vessel approaches. In addition, a number of other vessel movements, probably ferries, can be heard during this time.

Appendix E: March 2012 Survey – Data Analysis

Introduction

This survey was carried out from the 14th to the 21st March 2012. The SM2M was deployed at 58 53.91N, 2 56.78W. The unit was set for 0 dB internal gain and a sampling rate of 32 kHz.

Weather

The wind speed and direction during the survey period are shown in Figures E.1 and E.2 below. Data were only available from the Billia Croo weather station during this survey.

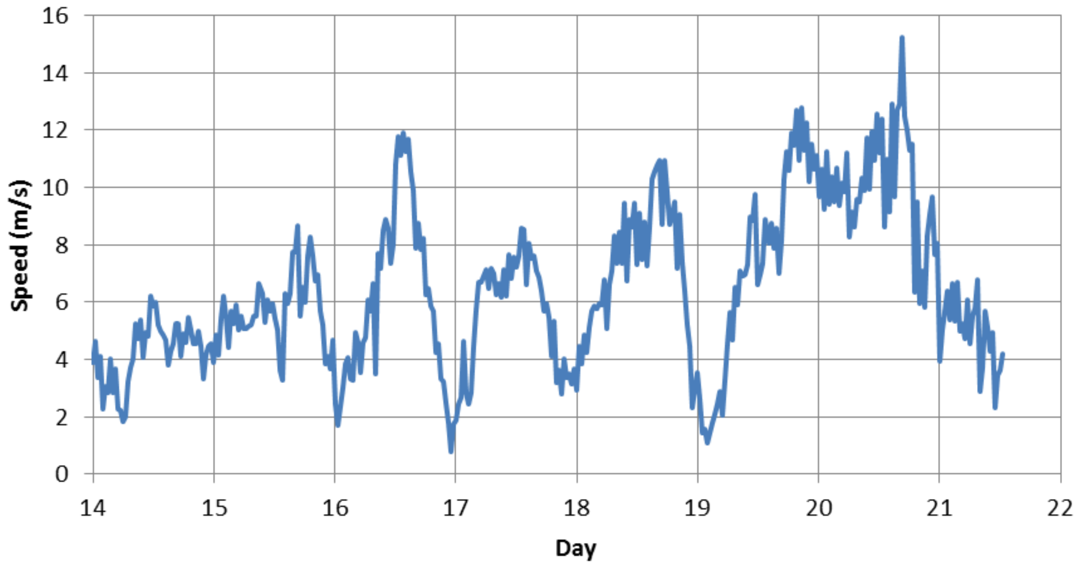

Figure E. 1: Wind speed recorded at Billia Croo weather station

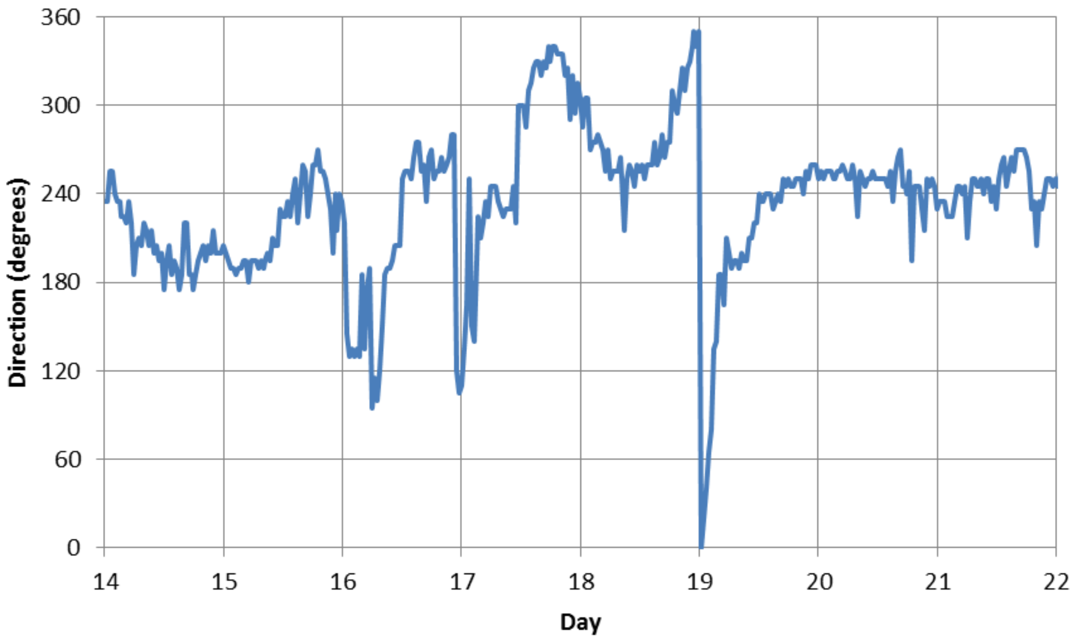

Figure E. 2: Wind direction recorded at Billia Croo weather station

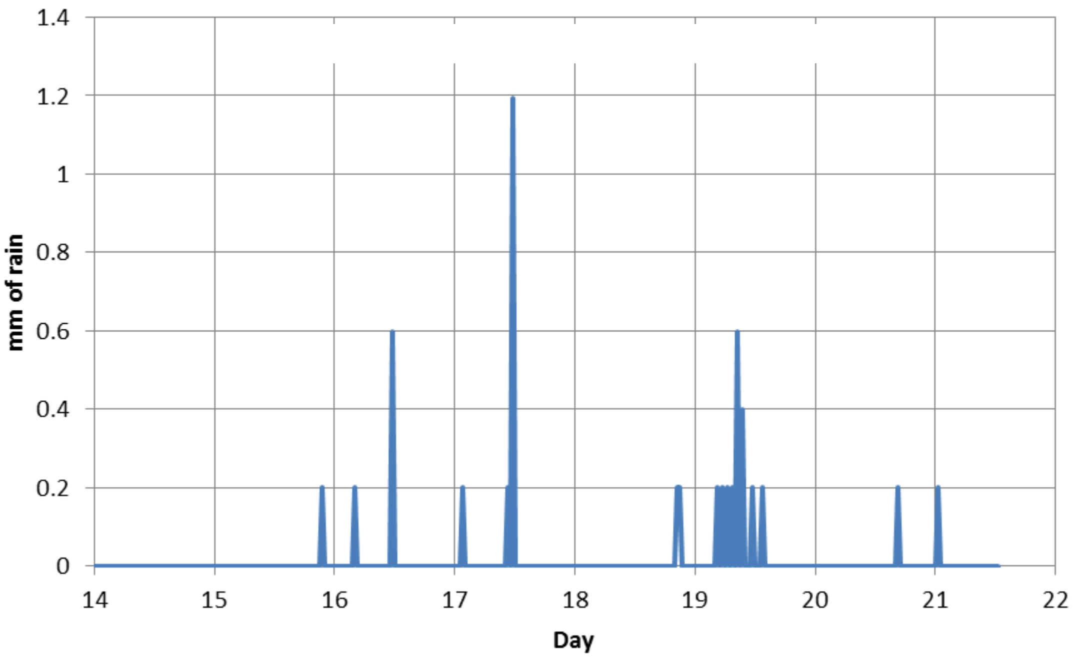

Figure E. 3: Precipitation recorded at Billia Croo weather station

Other non-acoustic data
Vessel traffic data from Automated Identification System (AIS) was available for the survey period. This provided information on the larger vessels moving around the area.

Wildlife observations carried out on the 14th and 15th March recorded a single common seal on 15th March. Notes were also available on vessels seen in the area.

Acoustic data
The acoustic data were recorded using the SM2M recorder with SD type memory cards in four internal slots, recording continuously at a sample rate of 32 kHz. The SM2M unit was programmed to start recording at a pre-set time, and to change files at set times each day. There is a short gap in the recorded data where the recording files change. This gap can vary from a few seconds up to 1 minute.

On recovery of the unit the SD cards were removed and the data downloaded to a PC. The Syntrillium Software audio editing software package 'CoolEdit' was used to re-assemble the files into 12 hour blocks covering midnight to midday, and midday to midnight for each complete day of the survey. The gaps during the file changes remain in the data.

Each twelve hour block of data was processed to produce the displays shown in this appendix. The data were read in 30 second blocks and a 1024 input point FFT performed repeatedly. The resulting spectra were averaged to obtain the mean spectrum for this 30 seconds. This operation was performed repeatedly and the resulting mean spectra assembled into the spectrograms shown. In addition, the raw data were decimated by 8 to give a sample rate of 4 kHz. The 30 second mean spectrum was again calculated and the sequence of 30 second mean spectra assembled to give the low-frequency spectrograms shown.

The four-channel plots take the FFT output and combine the output power across four channels, each 2 kHz in bandwidth centred on 2.5, 5, 10 and 15 kHz. This is done for both the full bandwidth and the decimated low frequency data. For the full bandwidth plots a fifth channel centred on 750 Hz is also calculated. This has a bandwidth of 200 Hz. All channels are normalised to give mean spectrum level. The low frequency plots are only shown where they show events of interest.

The variability plot was obtained by averaging the FFT data for 10 seconds and then combining all of the resulting spectra for the whole deployment. The spectrum is reduced in resolution to 1 dB vertically and 250 Hz horizontally. The plot was formed by counting the number of times each of these 10 second spectra have a particular frequency/amplitude component. This can result in a wider dynamic range than most printers can display so the data is compressed by taking the logarithm of the count.

The wideband mean level plot was obtained by summing the power across a 1-10 kHz bandwidth for periods of four minutes. This plot provides a broad overview of the ambient noise levels and acoustic events throughout the survey period. Figure E.4 below shows the plot for the March 2012 survey period. The general noise level is related to weather conditions, particularly wind speed and rainfall as can be seen by comparing this plot with the wind speed shown in figure E.1. The sharp peaks in noise level are generally due to passing vessels. It can be seen that the noise level during this survey period are generally determined by weather conditions, with only occasional close vessel passes. The increase in noise level at the end of the survey is caused by the arrival of the workboat C-Odyssey at the survey site.

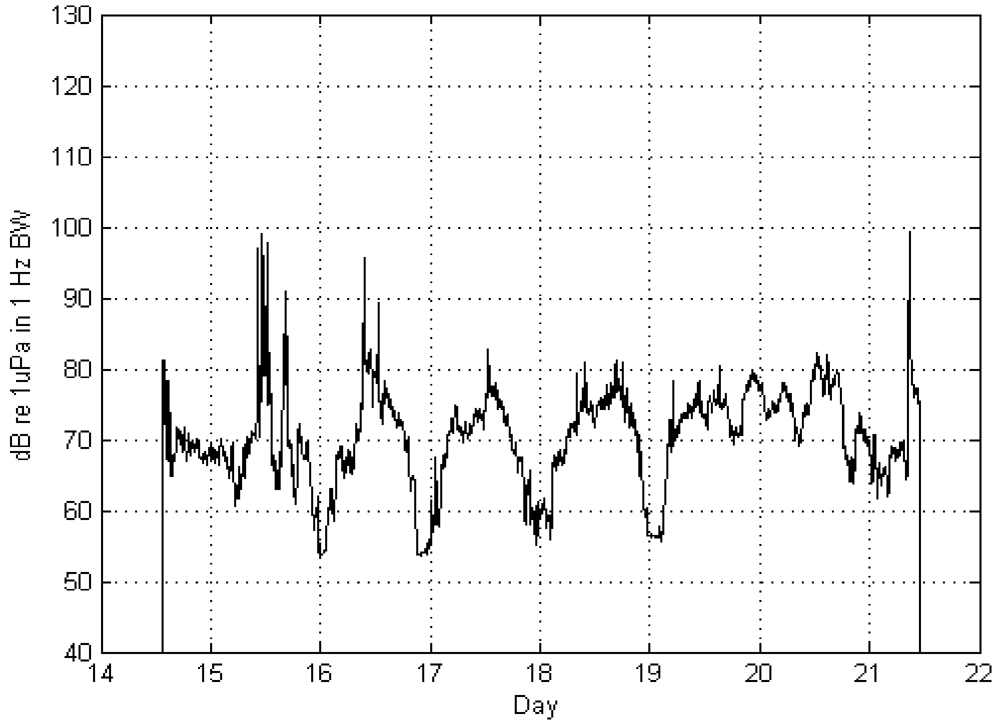

Figure E. 4: Wideband noise level for the March 2012 survey

The variability plot in figure E.5 below shows how the measured levels vary during the survey period. The brighter the colour, the more often that particular frequency/amplitude combination occurs. The broad band of white running through the middle of the plot shows the region where the 'typical' noise spectrum for the site lies. The region above this typical spectrum is caused by increasing noise such as that from bad weather, with the highest levels usually due to passing vessels.

The region below the typical spectrum is due to the noise levels dropping when the weather is very quiet. The straight bottom edge to the variability region is due to internal noise within the recording system. It is likely that acoustic noise can go lower than this when the weather is very quiet. Below this defined edge there are a few scattered points and these are due to the gaps in the data where the recording file changes, reducing the apparent level during the 10 second average.

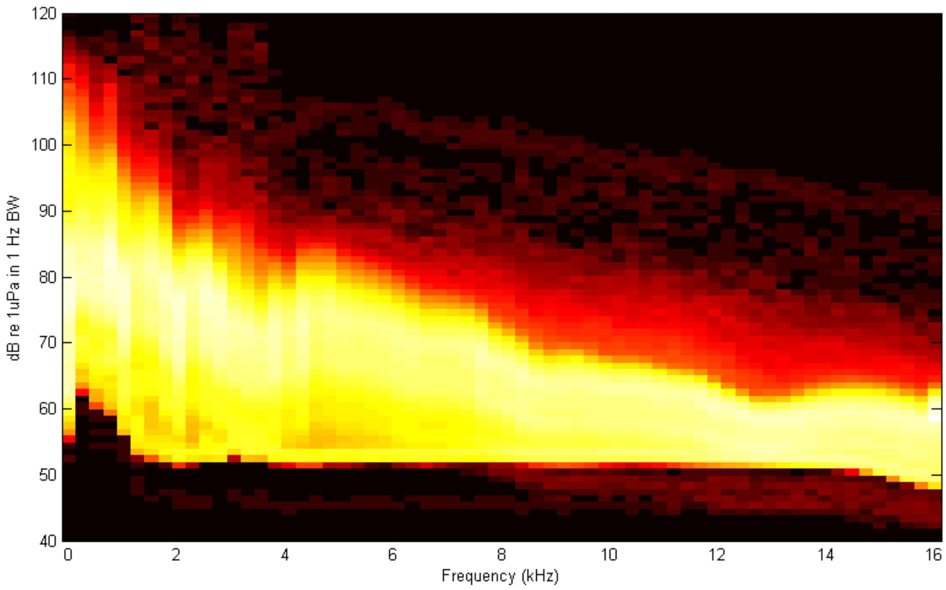

Figure E. 5: Variability plot for the March 2012 survey

Passing vessels

A number of vessels passed through the area during the survey period. The following vessels were identified from the wildlife observer's notes and/or AIS data:

14/3/12	15:00	Fast RIB
15/3/12	10:00-13:15	C-Odyssey
15/3/12	11:00	John Rae
15/3/12	15:45-17:00	C-Odyssey
16/3/12	08:00	Einar
16/3/12	09:45-13:00	C-Odyssey
18/3/12	10:00	Erlend
18/3/12	17:00	Clipper Burgundy
19/3/12	05:00	Clipper Burgundy
19/3/12	05:45	John Rae
19/3/12	15:30	Erlend
20/3/12	15:30	Einar and C-Odyssey
21/3/12	09:15-12:00	C-Odyssey

Other ship movements were recorded, but these were either too far away to be identified or may be small vessels that do not have AIS fitted. The John Rae is the pilot boat and the Einar and Erlend are tugs based in Scapa harbour. The C-Odyssey is a workboat and was working within the EMEC test area. The Clipper Burgundy is a small tanker. Most of these movements were well to the north and west except for the C-Odyssey which came into the EMEC test area on two occasions. The closest approach was on the 21st.

Survey data

The following plots show the acoustic data for each 12 hour period of the survey. The full spectrogram and four-channel plots are shown for each period. In addition, the low frequency plots are shown where interesting events occur.

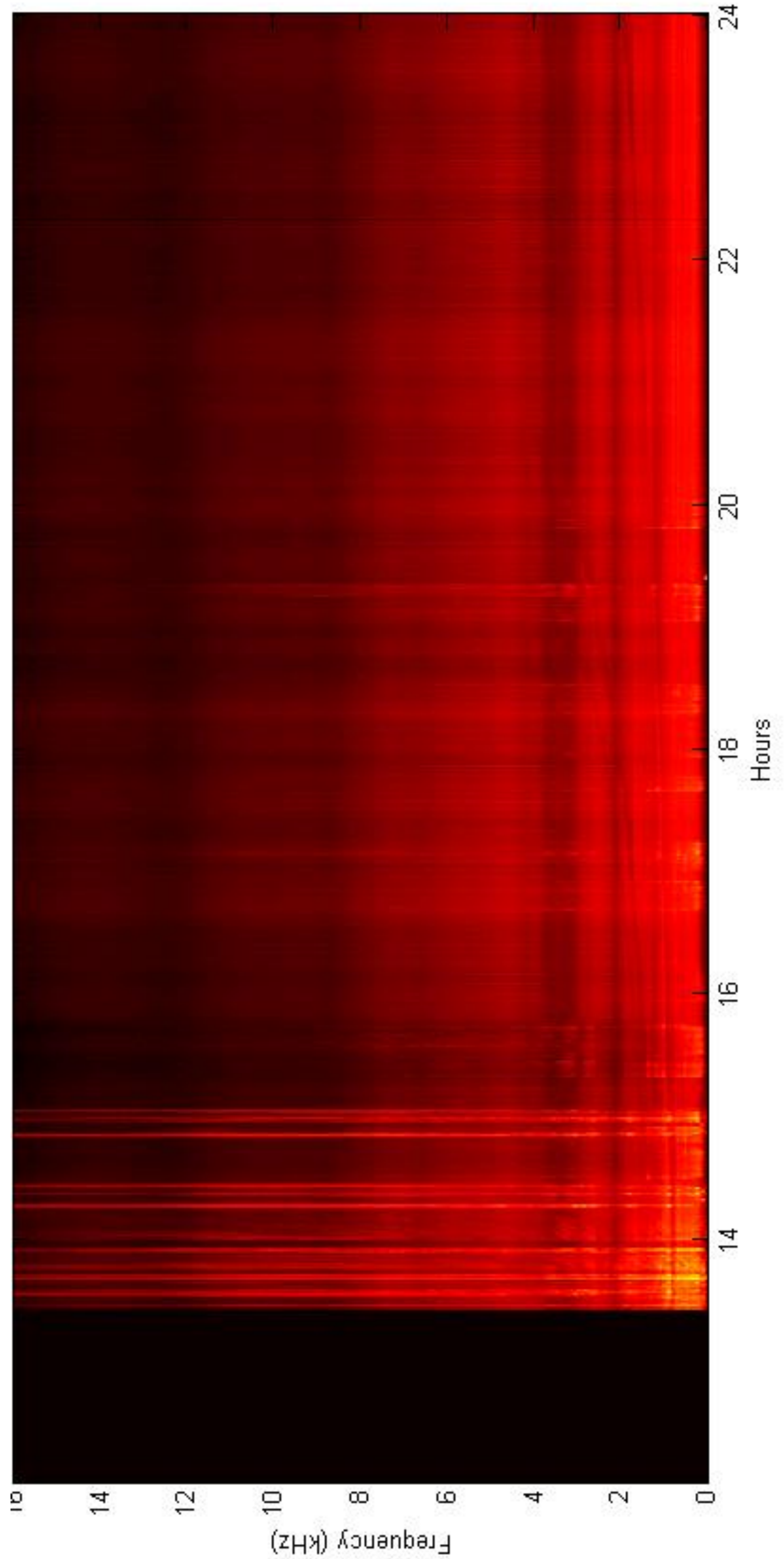

Figure E. 6: Spectrogram for 14th March 2012 afternoon

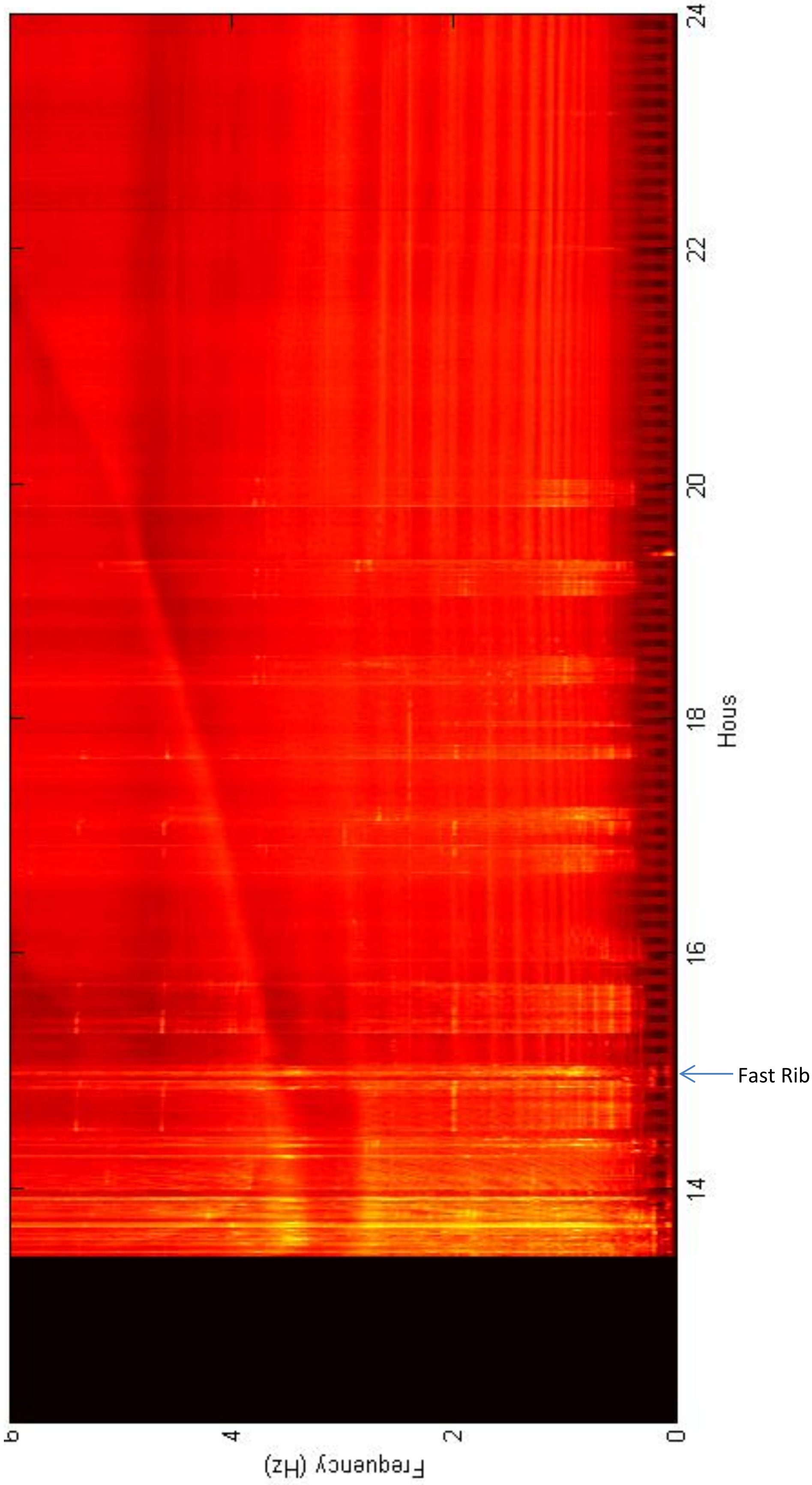

Figure E. 7: Low frequency spectrogram for 14th March 2012 afternoon

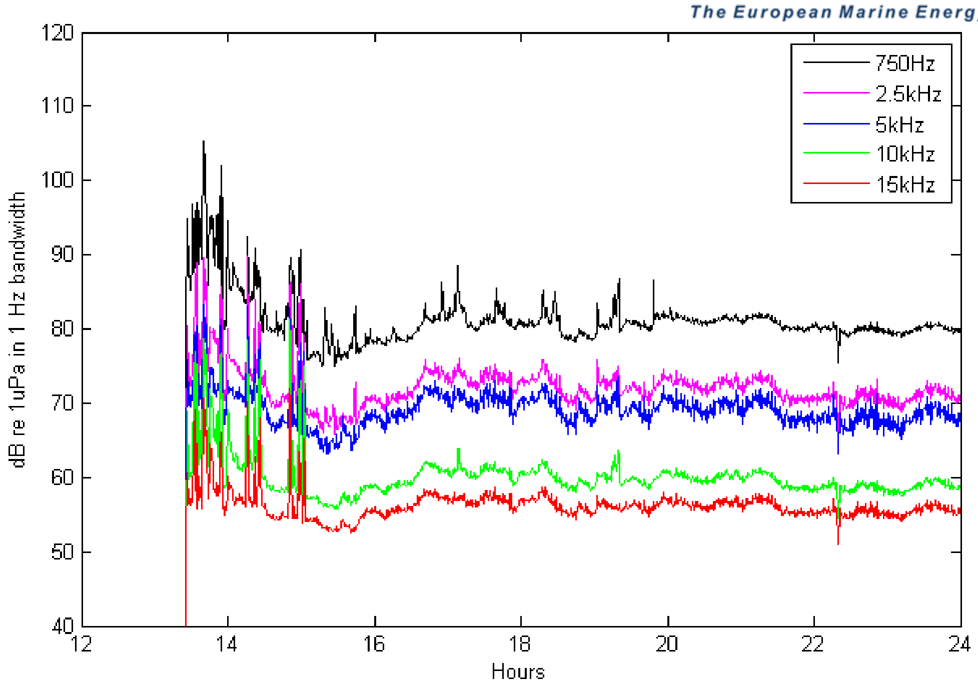

Figure E. 8: Five-channel high frequency plot for 14th March 2012 afternoon

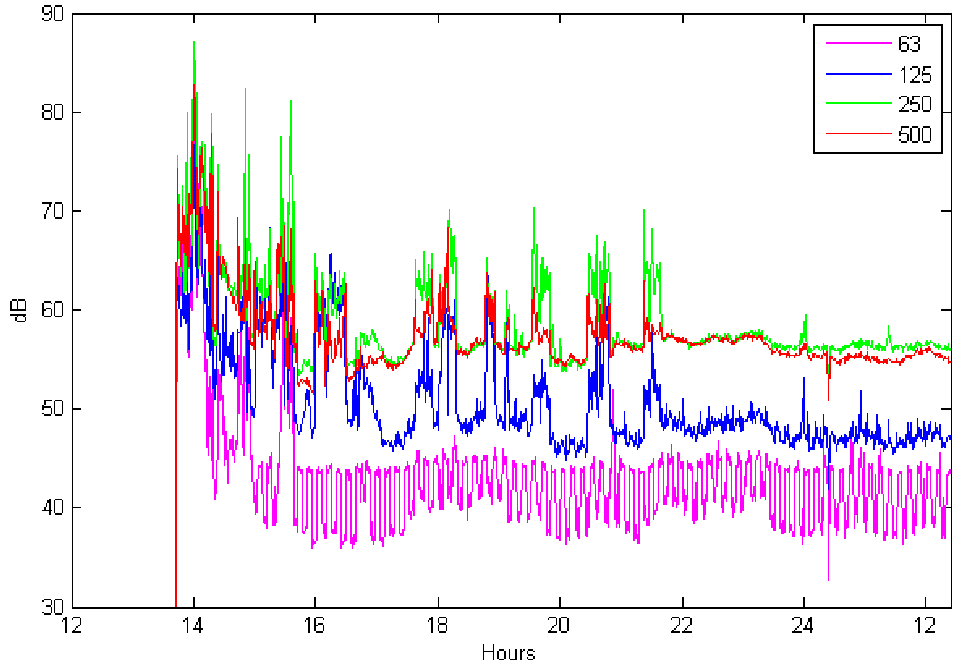

Figure E. 9: Four-channel low frequency plot for 14th March 2012 afternoon

The recording started at 13:25 on the 14th March. The spectrogram in Figure E.6 above shows vessel noise up until 15:00. The low frequency part of the spectrum is expanded in Figure E.7. Here it can be seen that as well as the loud vessel noise at the start of the recording there is also weaker noise continuing up until 20:00. This weaker noise is believed to be the inter-island ferries operating across western and southern Scapa Flow. This weak noise shows up clearly in Figure E.9 above, particularly at 125 Hz. At 500 Hz and above the noise is barely detectable

The oscillating level at 63 Hz is internal noise from the SM2M recorder as discussed in section 5.4 of this report. This also shows as the banding at low frequencies in Figure E.7 above. This noise is apparent when the ambient noise level drops to its lowest level. The dip in the noise levels at 22:17 is caused by the gap in the recording as the recorder changes files. These dips occur at 07:45, 13:00 and 22:17 every day throughout the recordings.

There are a series of peaks and dips in the low frequency spectrum (Figure E.7) which vary through the tidal cycle. This suggests that there is a noise source some distance away and the peaks and dips are the result of the Lloyds mirror interference pattern. The hydrophone used on the SM2M is omnidirectional in response so it is not possible to determine the direction or distance of this noise source. There is also a series of peaks and dips at higher frequencies in the spectrum which are most obvious in the full spectrogram (Figure E.6). These peaks and dips do not change frequency with time, suggesting that they are caused by effects very local to the hydrophone and are not real structure in the ambient noise field.

There is a peak in the spectrum that starts at 3.5 kHz at the beginning of the recording and drifts higher in frequency to around 6 kHz before fading away at around 22:00. The cause of this is not clear and it does not occur anywhere else in the recordings made during this or previous surveys.

The data for the 15th March (Figures E.10-E.13 below) illustrate an effect, which is seen throughout the recordings, of a very fast change in noise level. Typical of this is the step at 19:00 when levels increase by over 10 dB in the space of a few minutes. This appears to coincide with a change in the wind speed and direction, but does not fully correlate with the wind data available. The wind data measurements were obtained from sites some distance from the survey site, so it is possible that a local effect is causing this change.

The weak distant ship movements, believed to be inter-island ferry traffic, run from 05:30 to 20:00 on the 15th, a pattern that is repeated throughout the survey period.

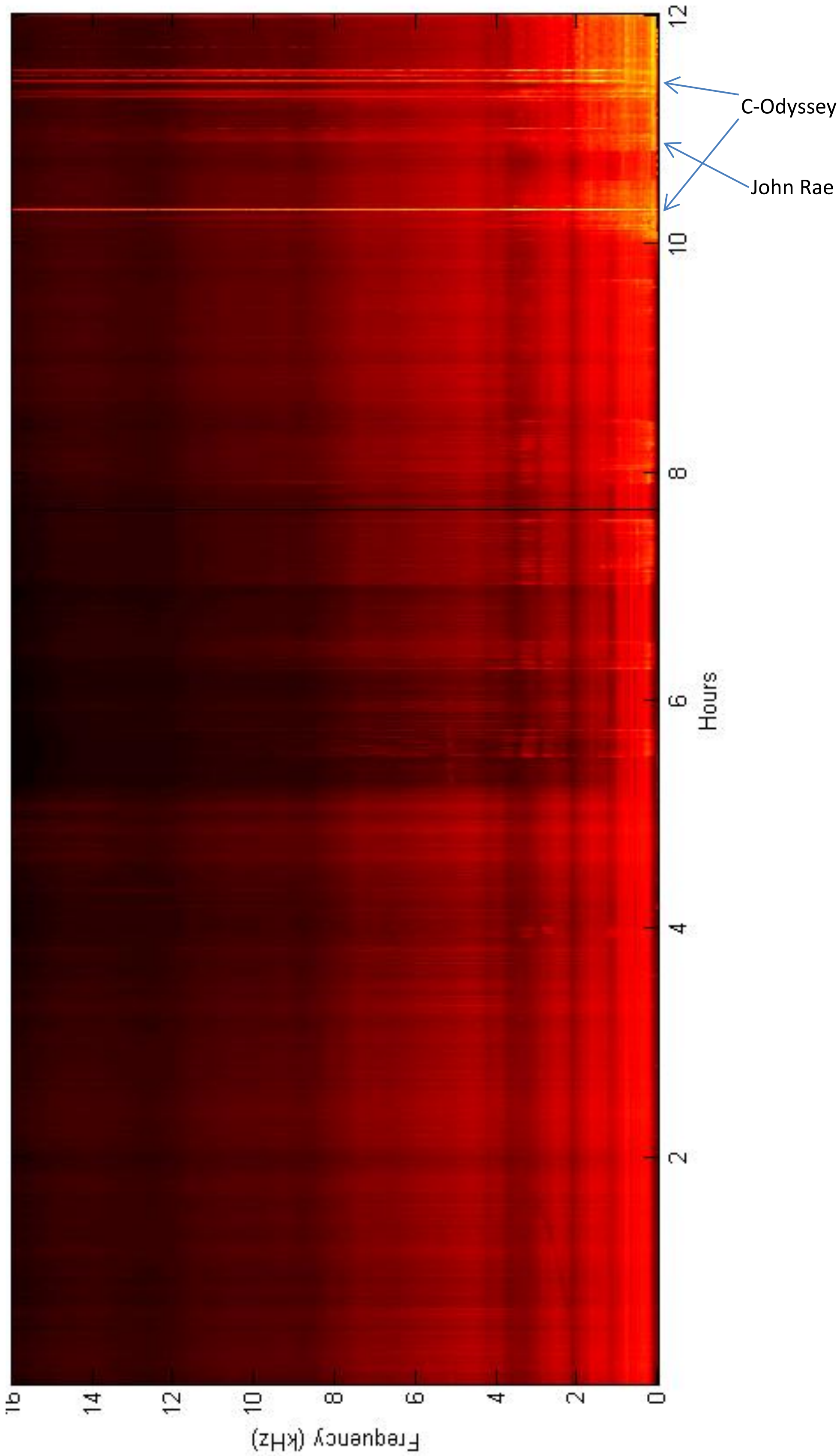

Figure E. 10: Spectrogram for 15th March 2012 morning

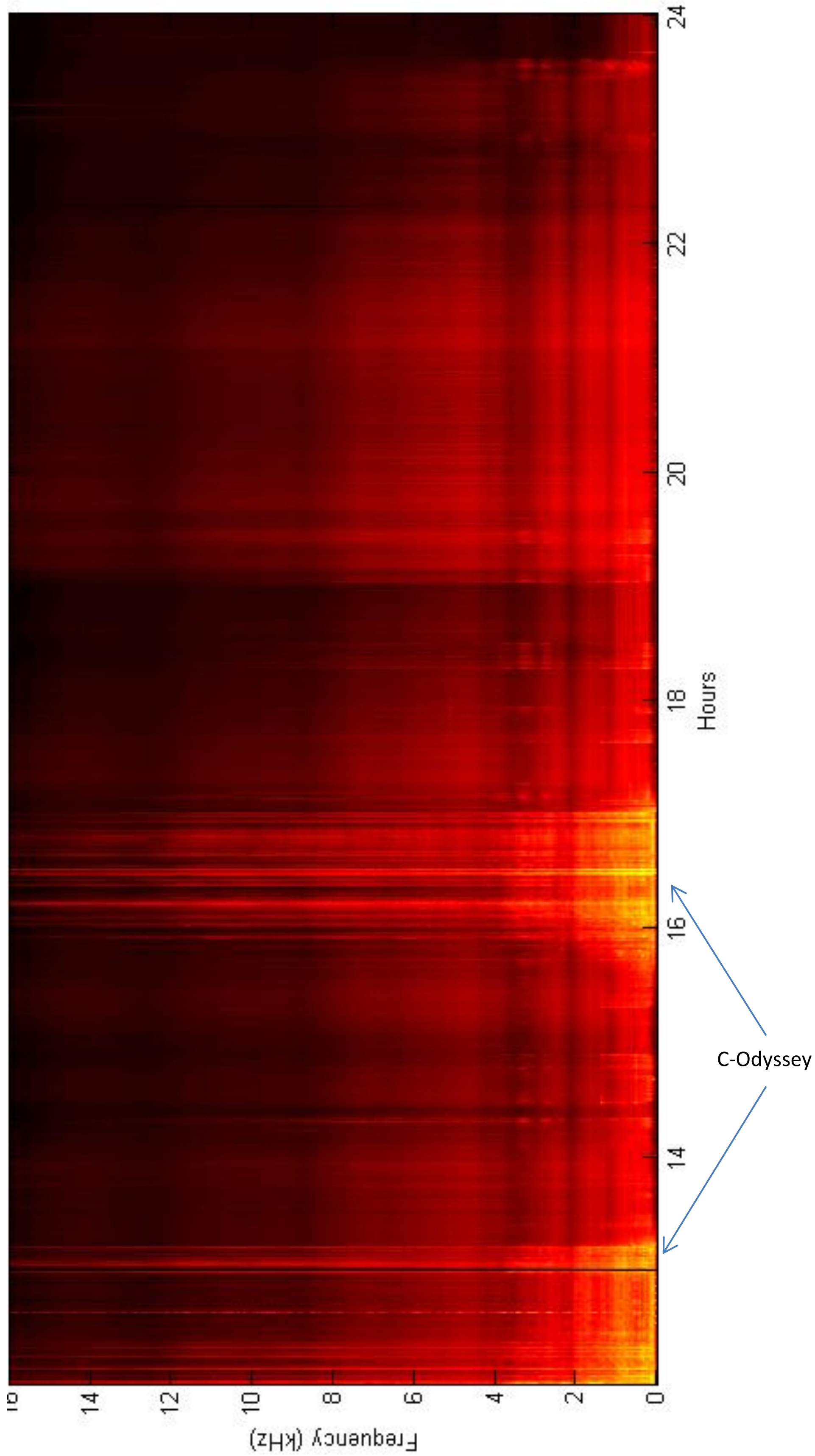

Figure E. 11: Spectrogram for 15th March 2012 afternoon

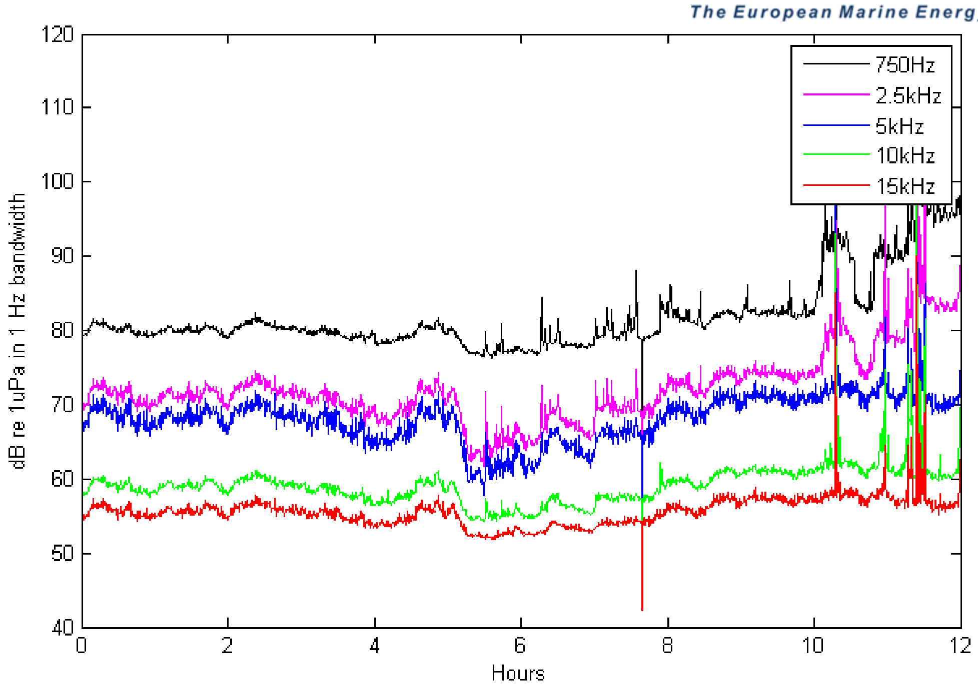

Figure E. 12: Five-channel high frequency plot for 15th March 2012 morning

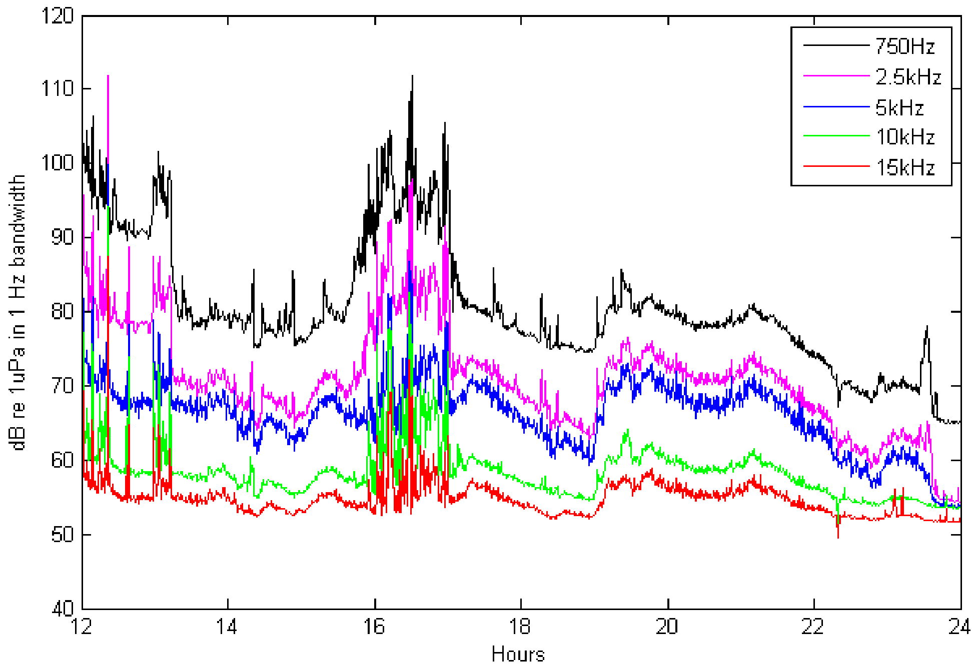

Figure E. 13: Five-channel high frequency plot for 15th March 2012 afternoon

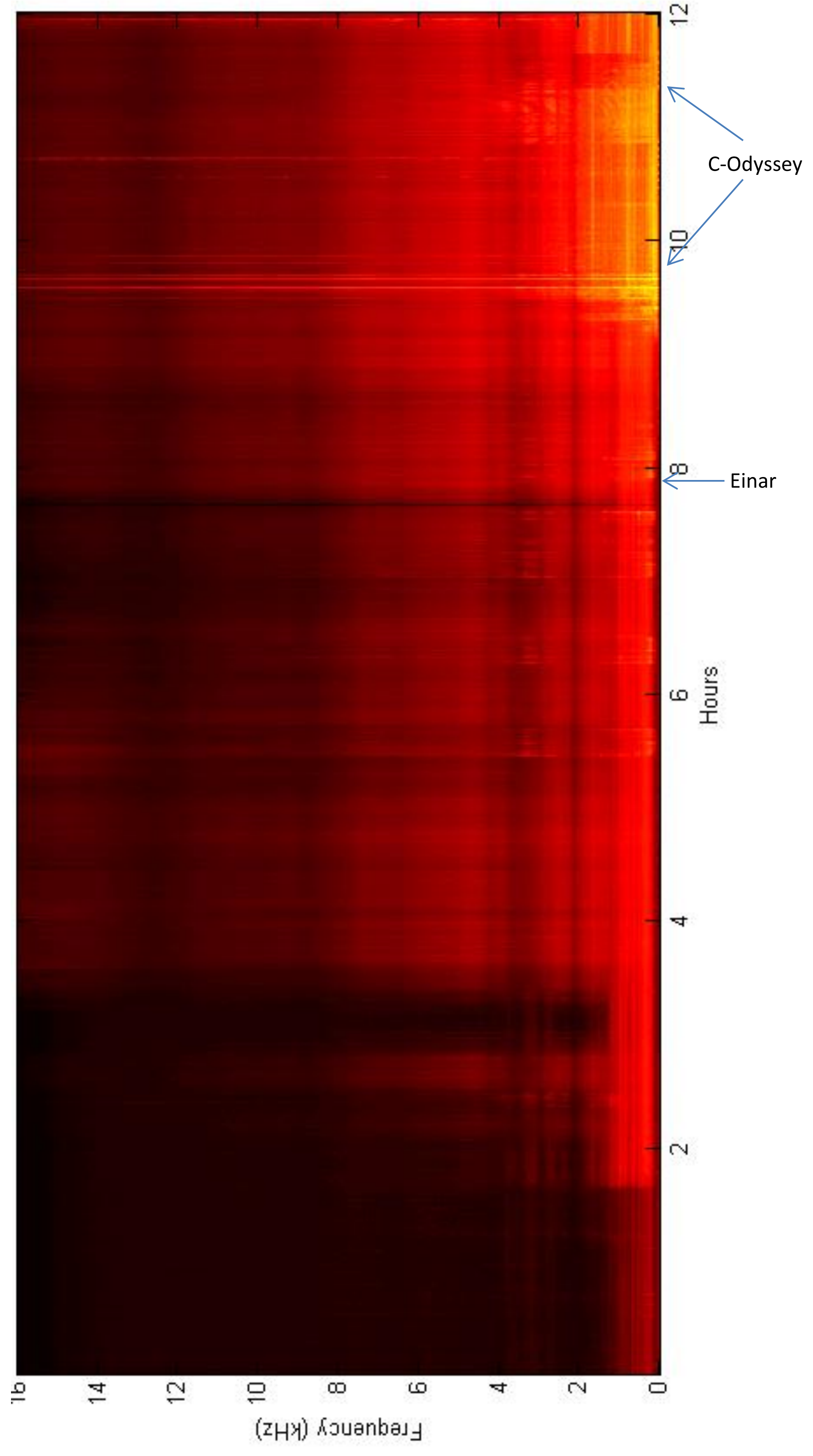

Figure E. 14: Spectrogram for 16th March 2012 morning

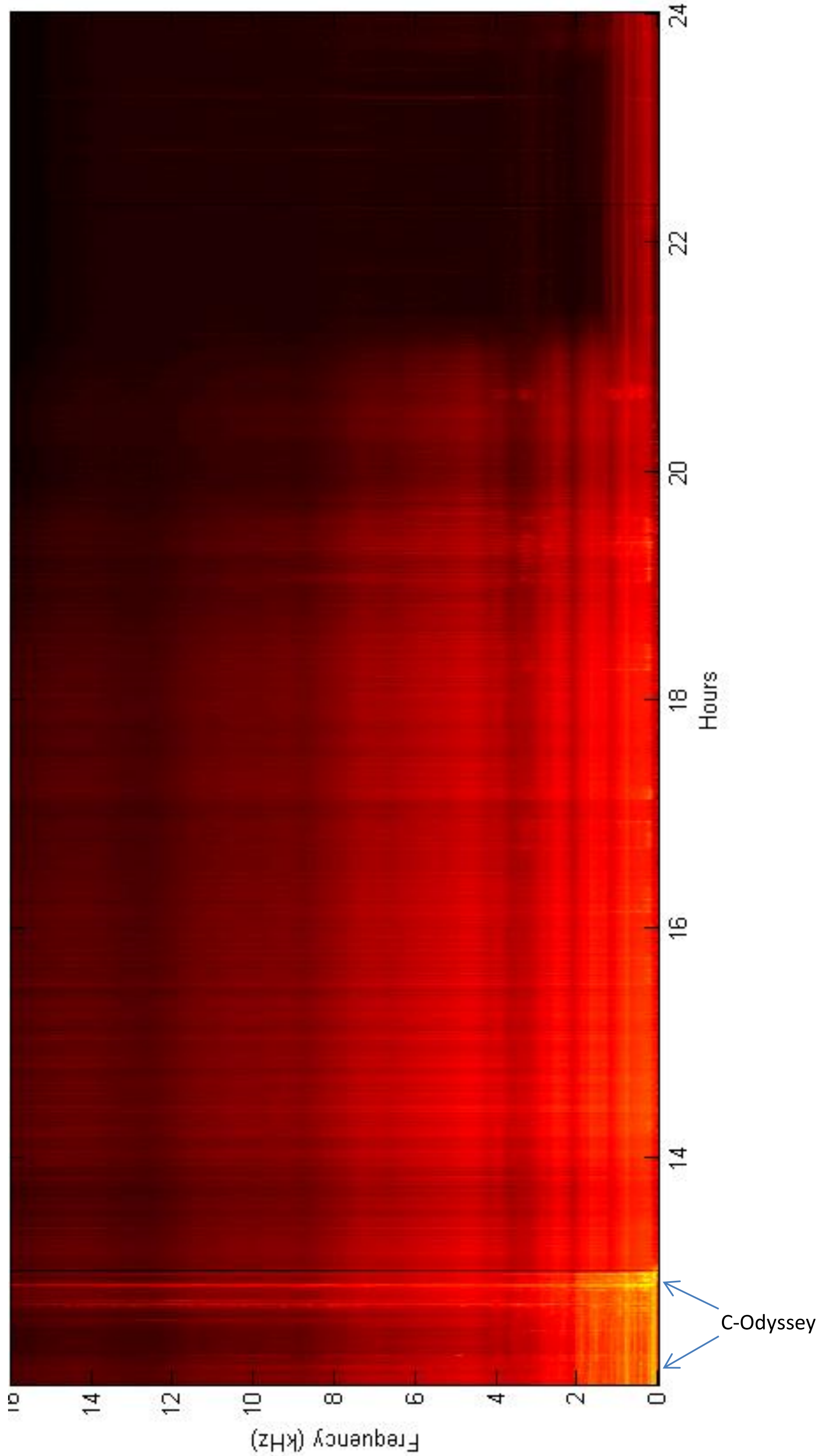

Figure E. 15: Spectrogram for 16th March 2012 afternoon

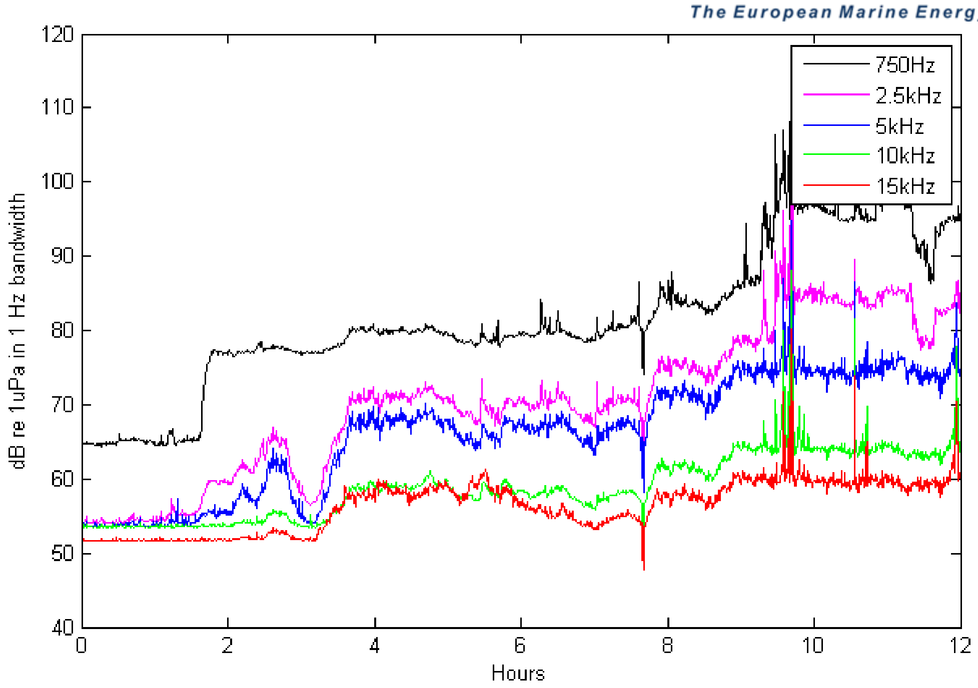

Figure E. 16: Five-channel high frequency plot for 16th March 2012 morning

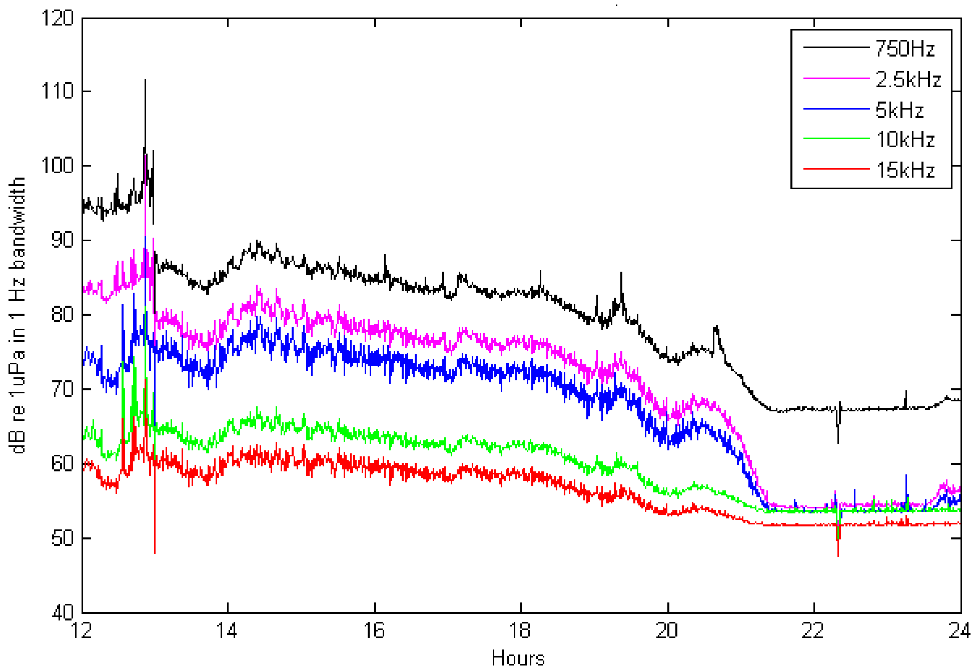

Figure E. 17: Five-channel high frequency plot for 16th March 2012 afternoon

The peak in noise level through the middle of the 16th directly correlates with a peak in wind speed (see Figure E.1). The increase in noise levels starting at 01:00 corresponds with the wind starting to pick up after a short period of calm. The step increase at low frequencies from 10 Hz to around 2 kHz at 01:40 is an increase over 4 minutes of machinery noise. The most likely explanation is that it is from a vessel at anchor which swings in the tide to an aspect that has greater radiated noise. This effect is seen several times during the survey.

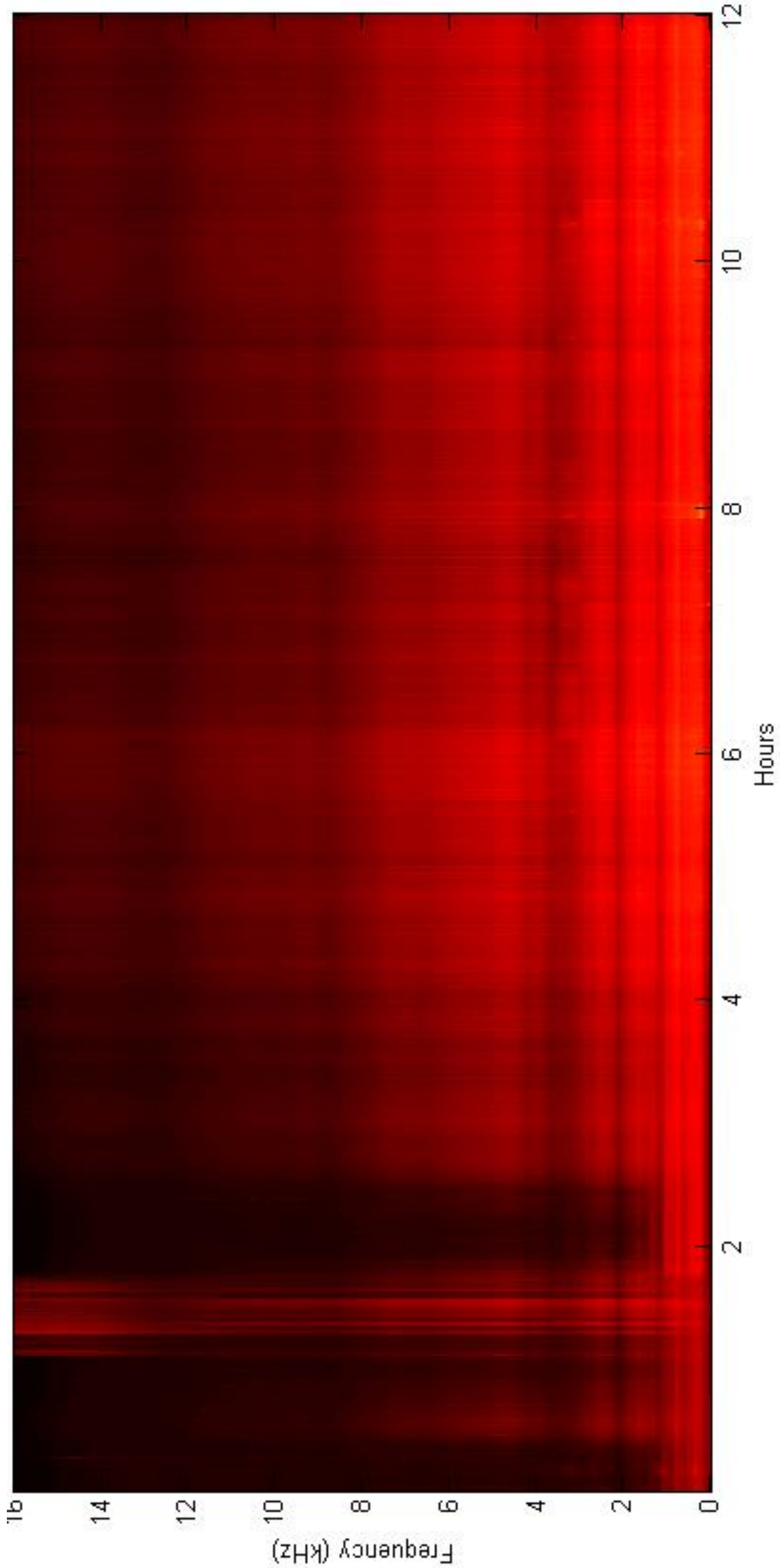

Figure E. 18: Spectrogram for 17th March 2012 morning

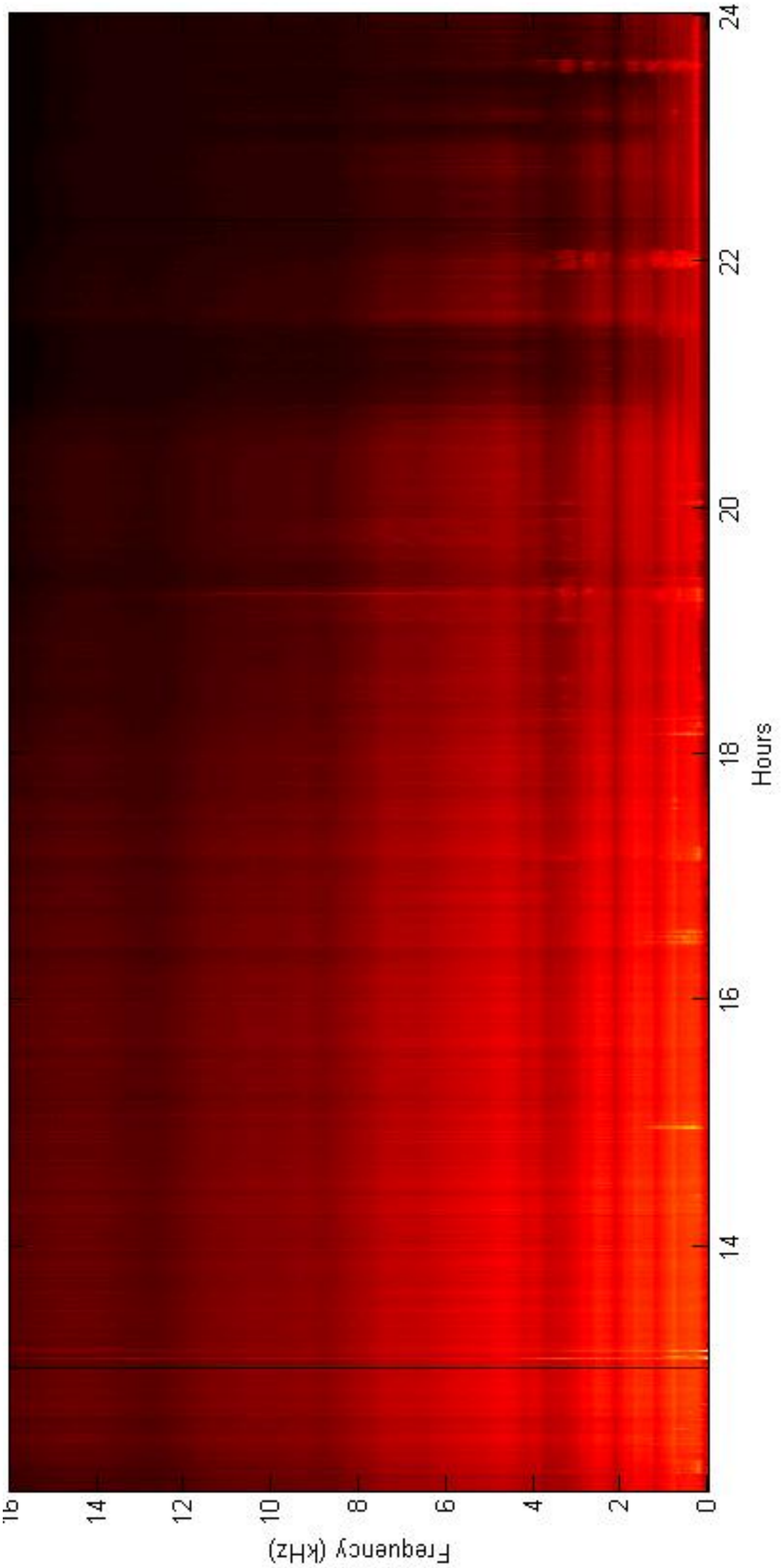

Figure E. 19: Spectrogram for 17th March 2012 afternoon

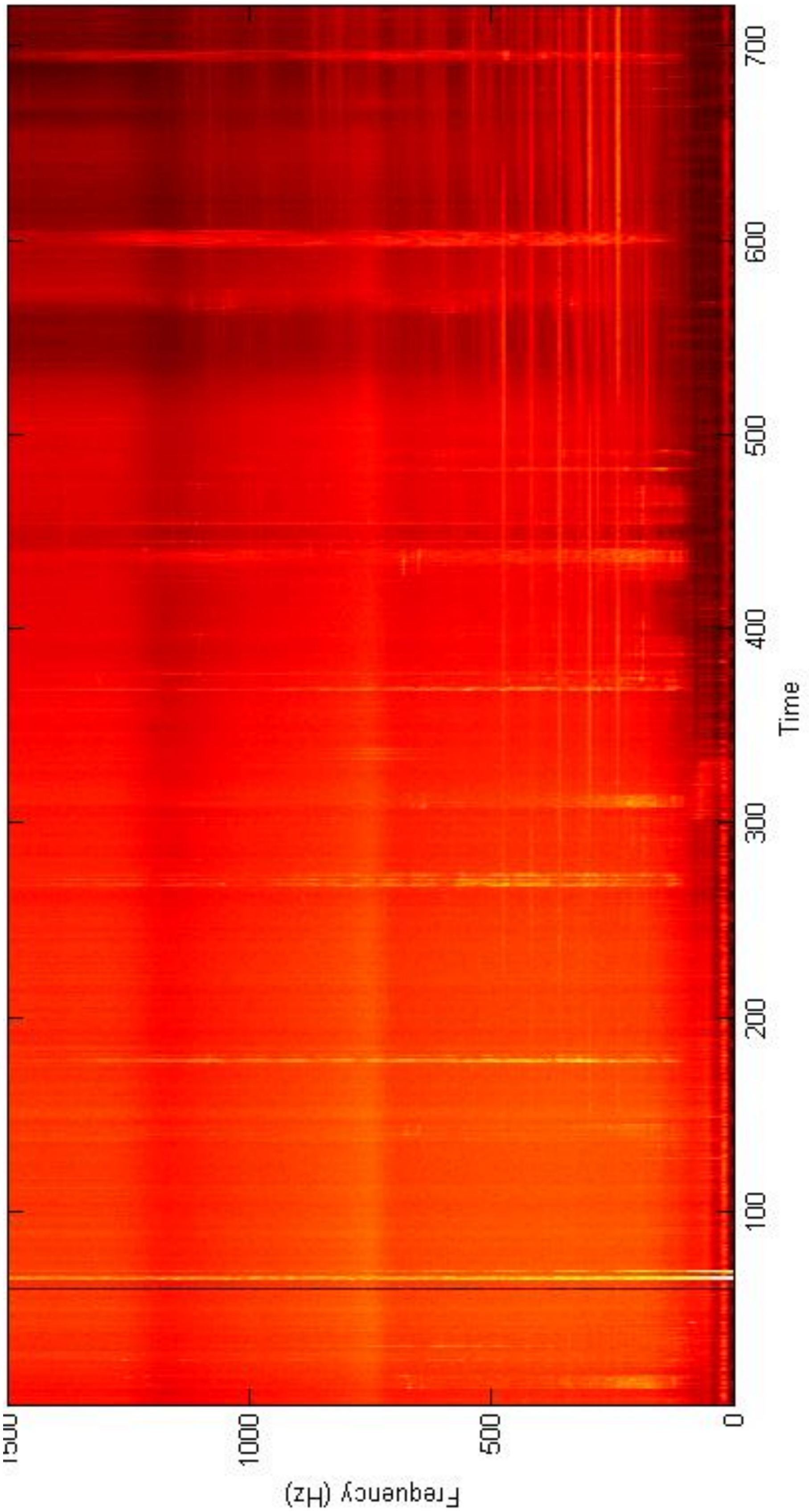

Figure E. 20: Low frequency spectrogram for 17th March 2012 afternoon

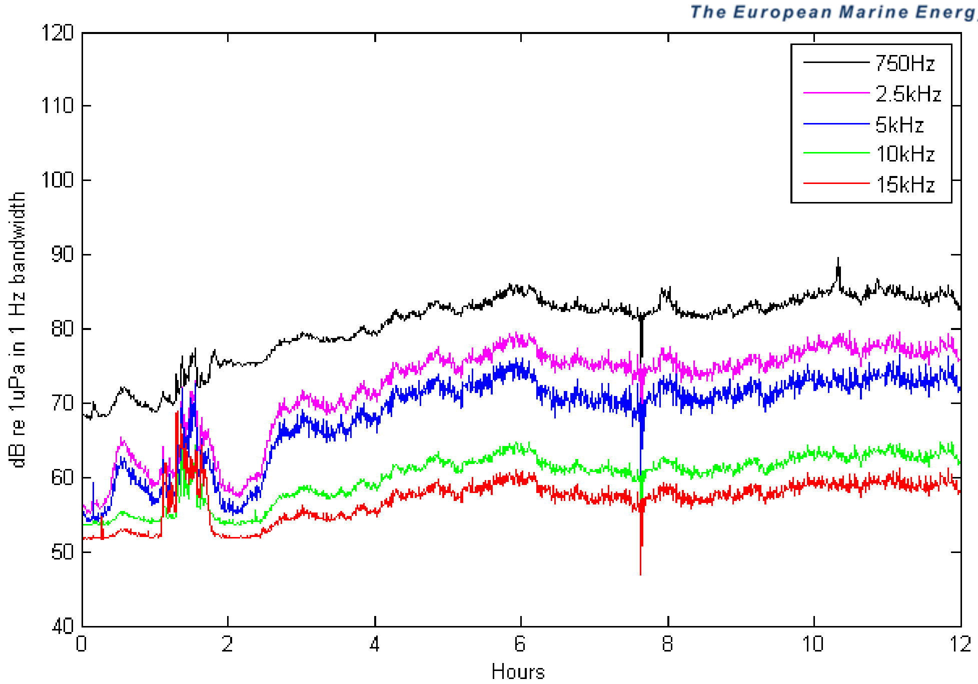

Figure E. 21: Five-channel high frequency plot for 17th March 2012 morning

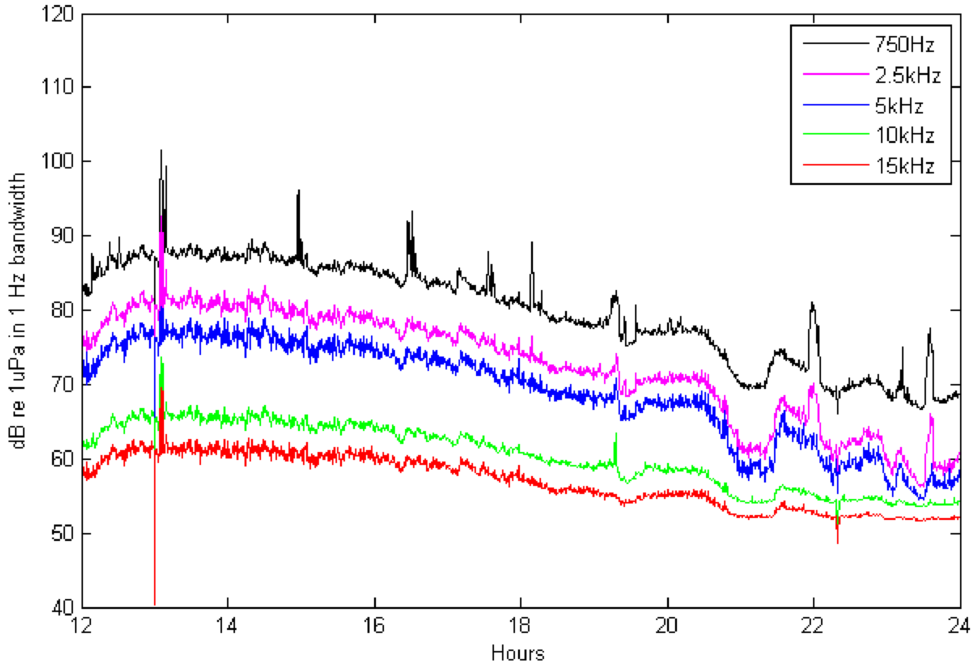

Figure E. 22: Five-channel high frequency plot for 17th March 2012 afternoon

The low frequency spectrogram for the afternoon of the 17th March (Figure E.20) shows a series of high intensity bursts of noise. The first is abrasion noise, probably due to floating debris impacting the hydrophone. The following noise bursts are bursts of machinery noise. The increase in high frequency noise between 01:00 and 02:00 is due to heavy rain.

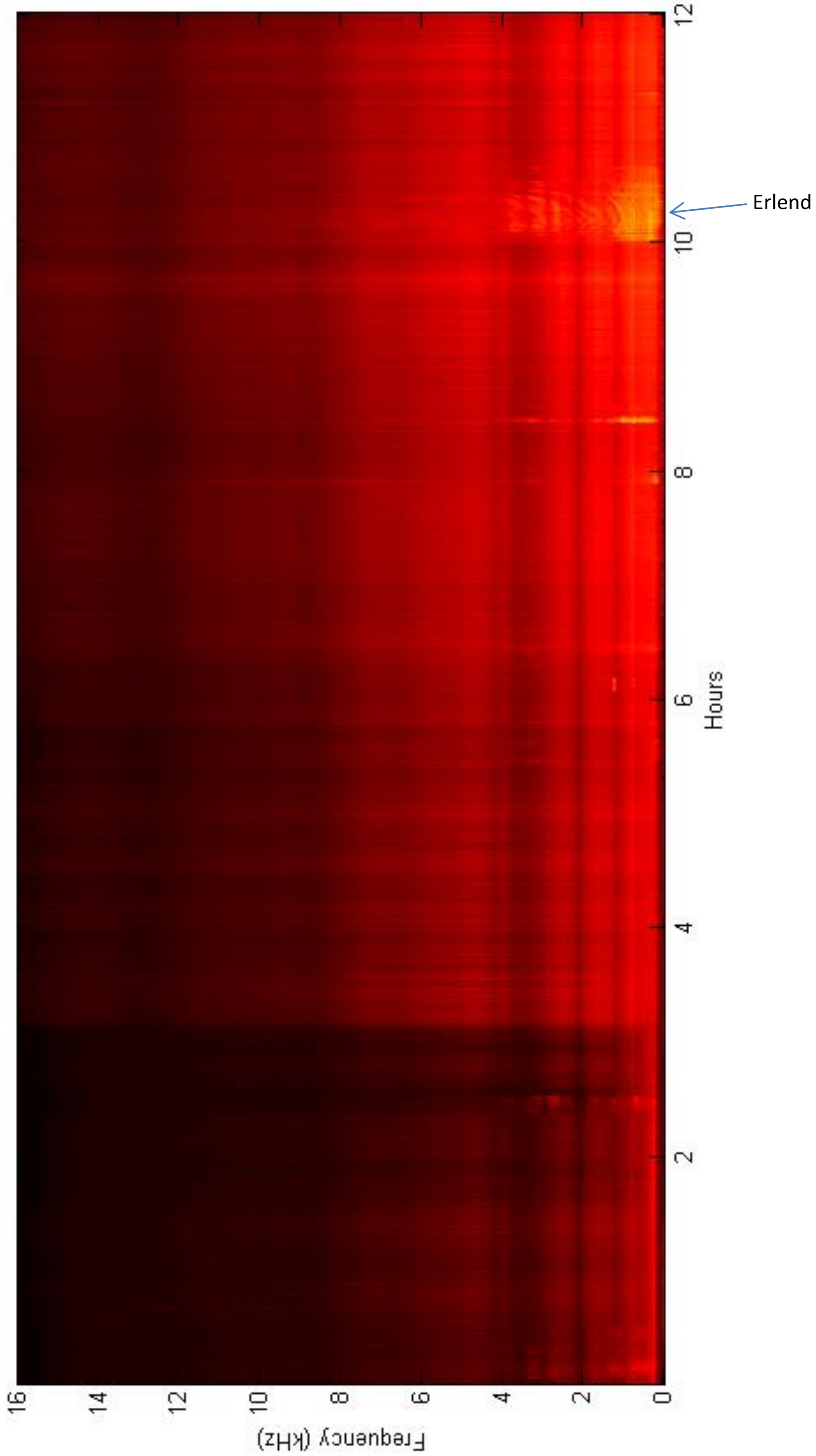

Figure E. 23: Spectrogram for 18th March 2012 morning

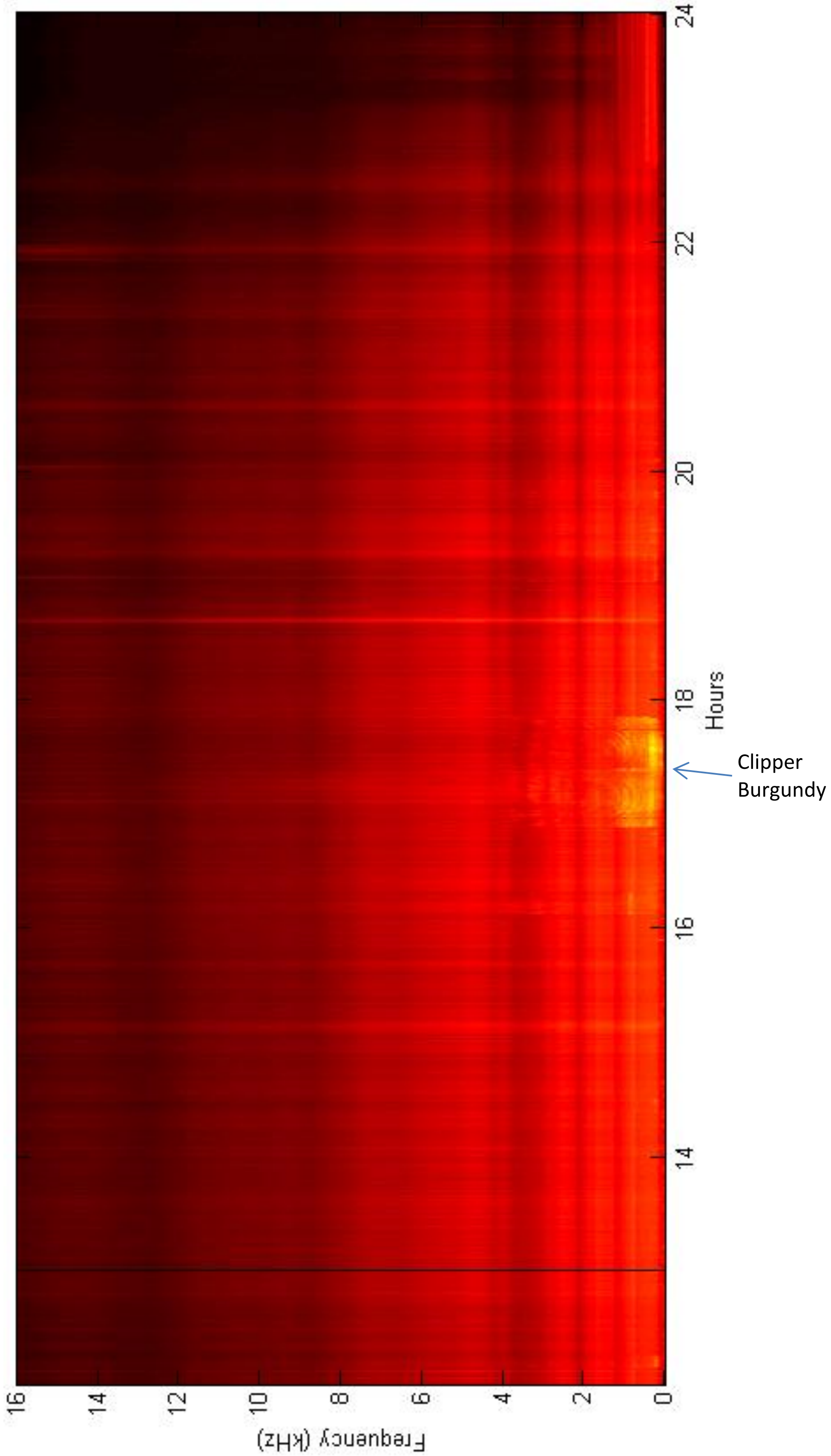

Figure E. 24: Spectrogram for 18th March 2012 afternoon

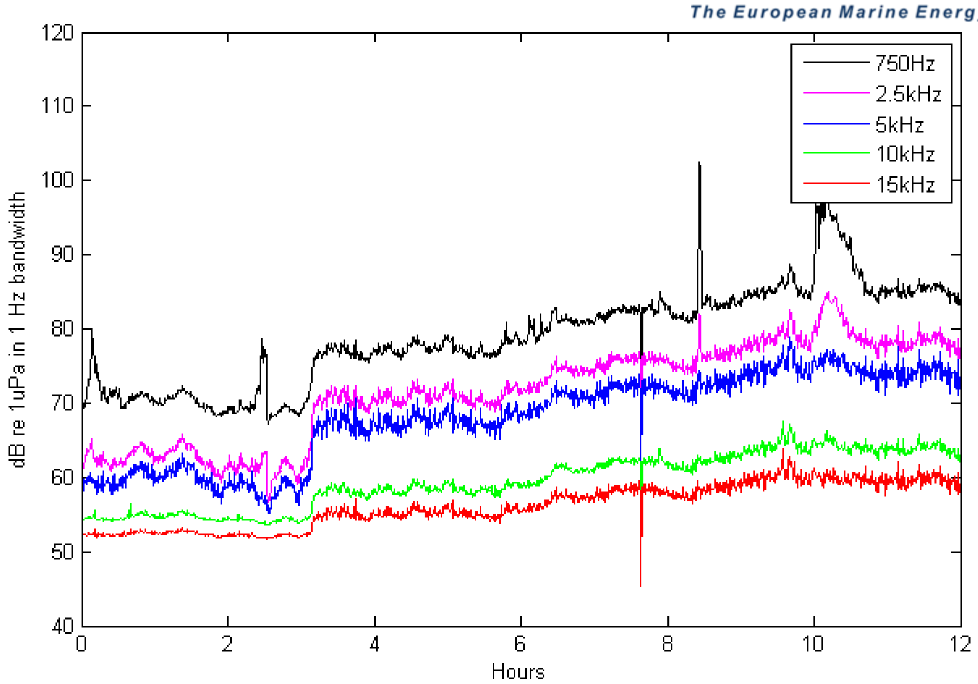

Figure E. 25: Five-channel high frequency plot for 18th March 2012 morning

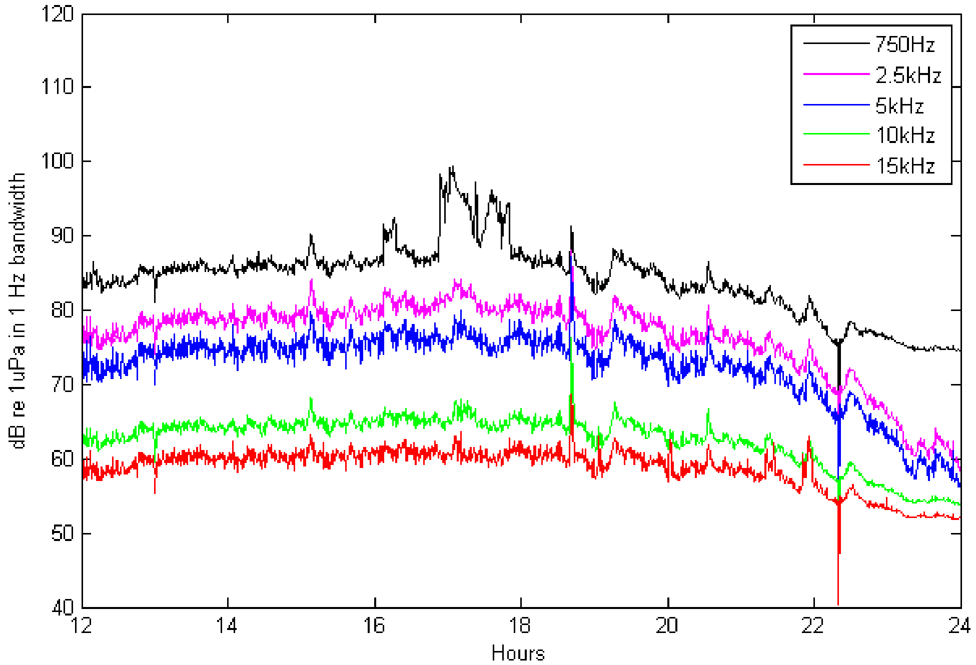

Figure E. 26: Five-channel high frequency plot for 18th March 2012 afternoon

The brief increase in noise level at 02:30 is a distant vessel, while the increase in noise levels at approximately 03:00 is weather related. The strong peak in low frequency levels at 08:30 is caused by machinery noise starting, which then fades away after a few minutes. The peak at about 18:30 covers a much wider frequency range and is caused by a heavy rain shower.

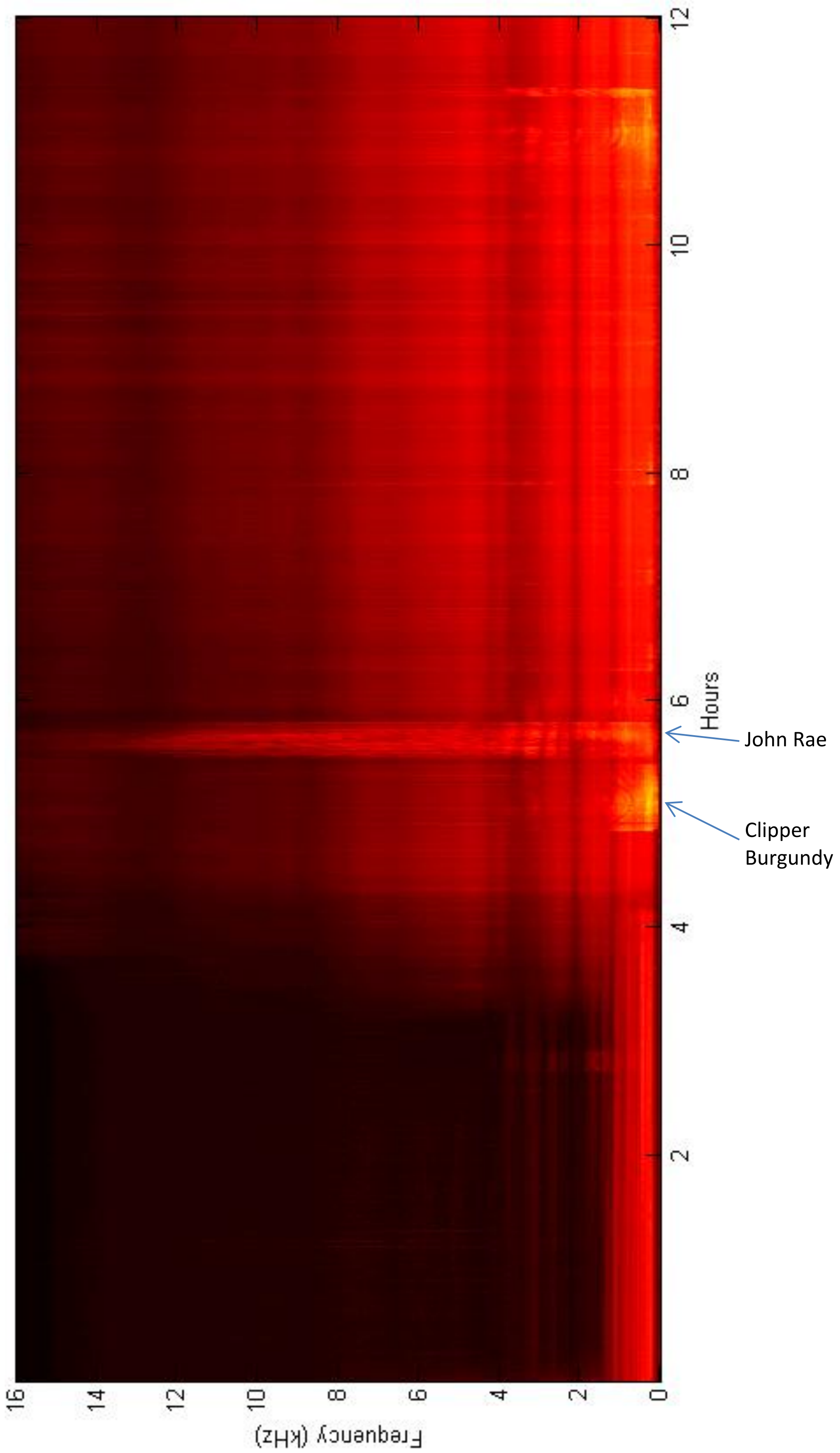

Figure E. 27: Spectrogram for 19th March 2012 morning

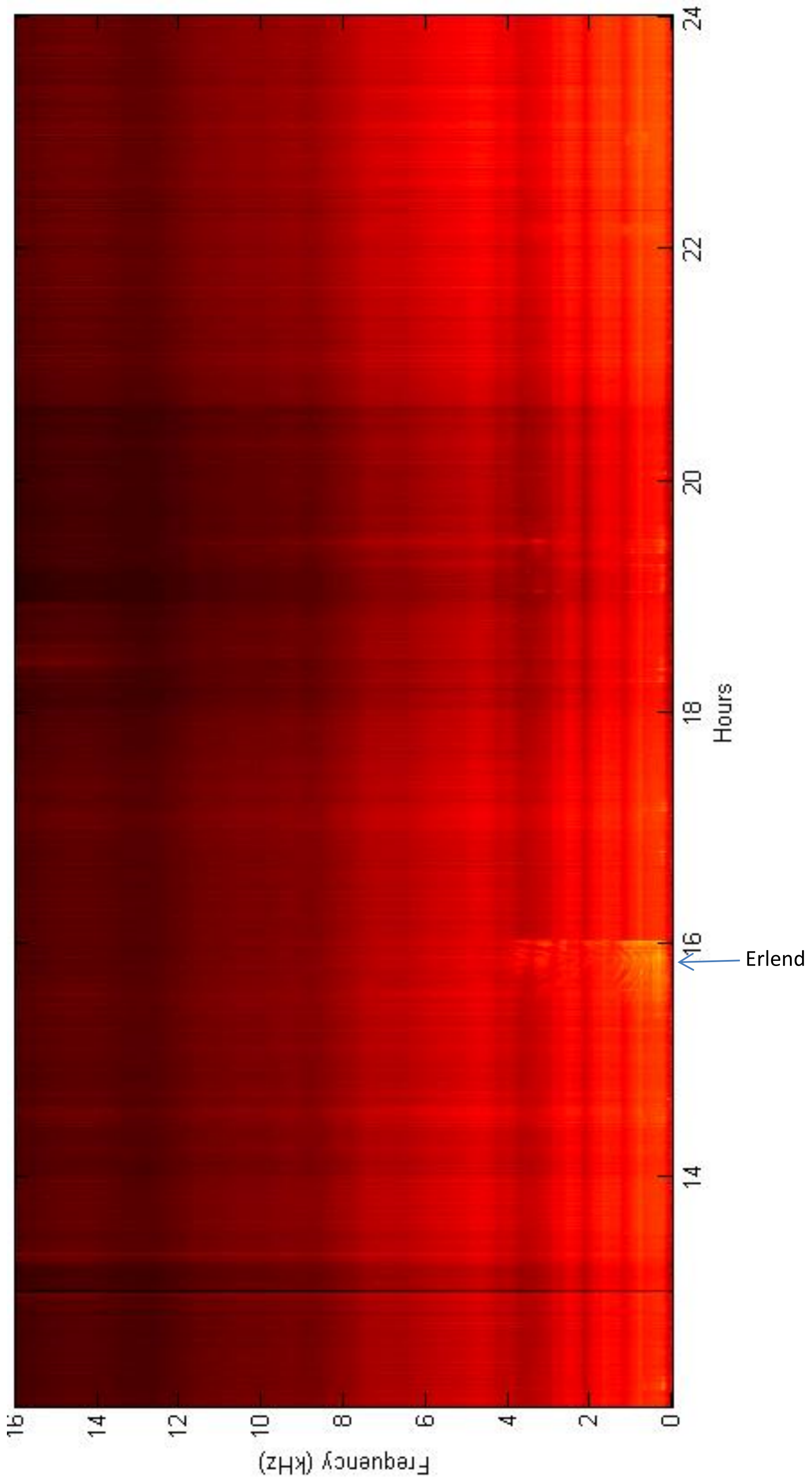

Figure E. 28: Spectrogram for 19th March 2012 afternoon

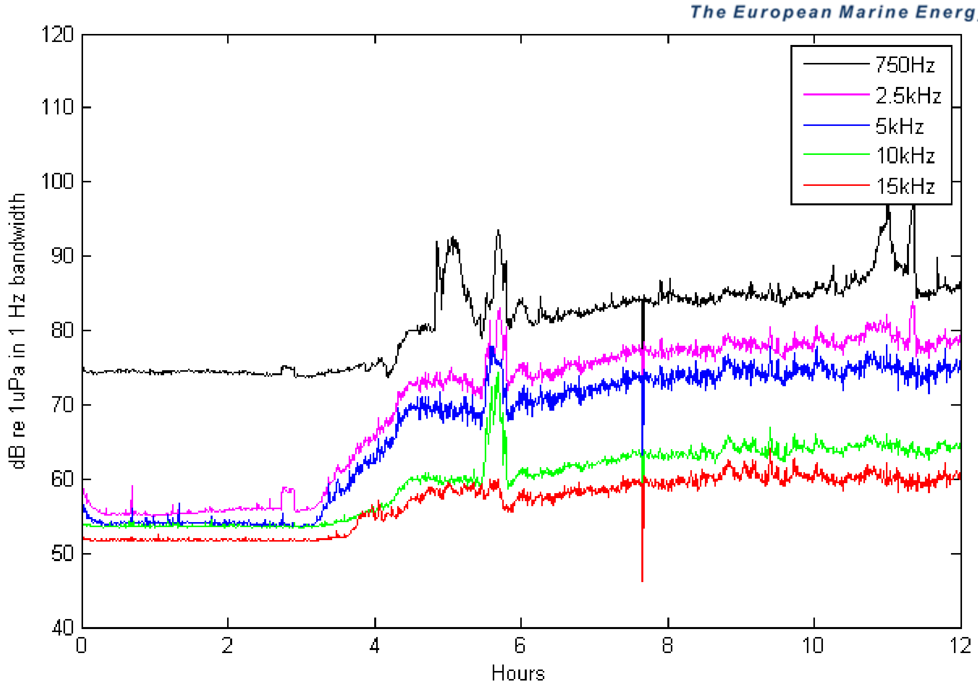

Figure E. 29: Five-channel high frequency plot for 19th March 2012 morning

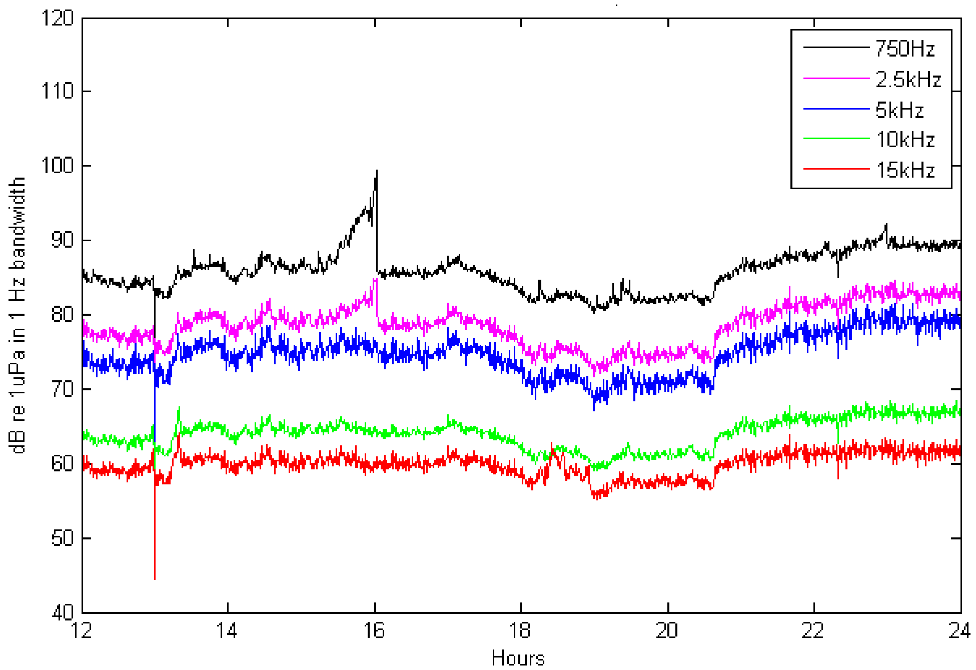

Figure E. 30: Five-channel high frequency plot for 19th March 2012

The general increase in noise level through the day is caused by the wind increasing in strength. The sudden change in noise level at low frequencies at about 16:10 is caused by noise from the tug Erlend suddenly being cut-off, probably as it enters Scapa harbour.

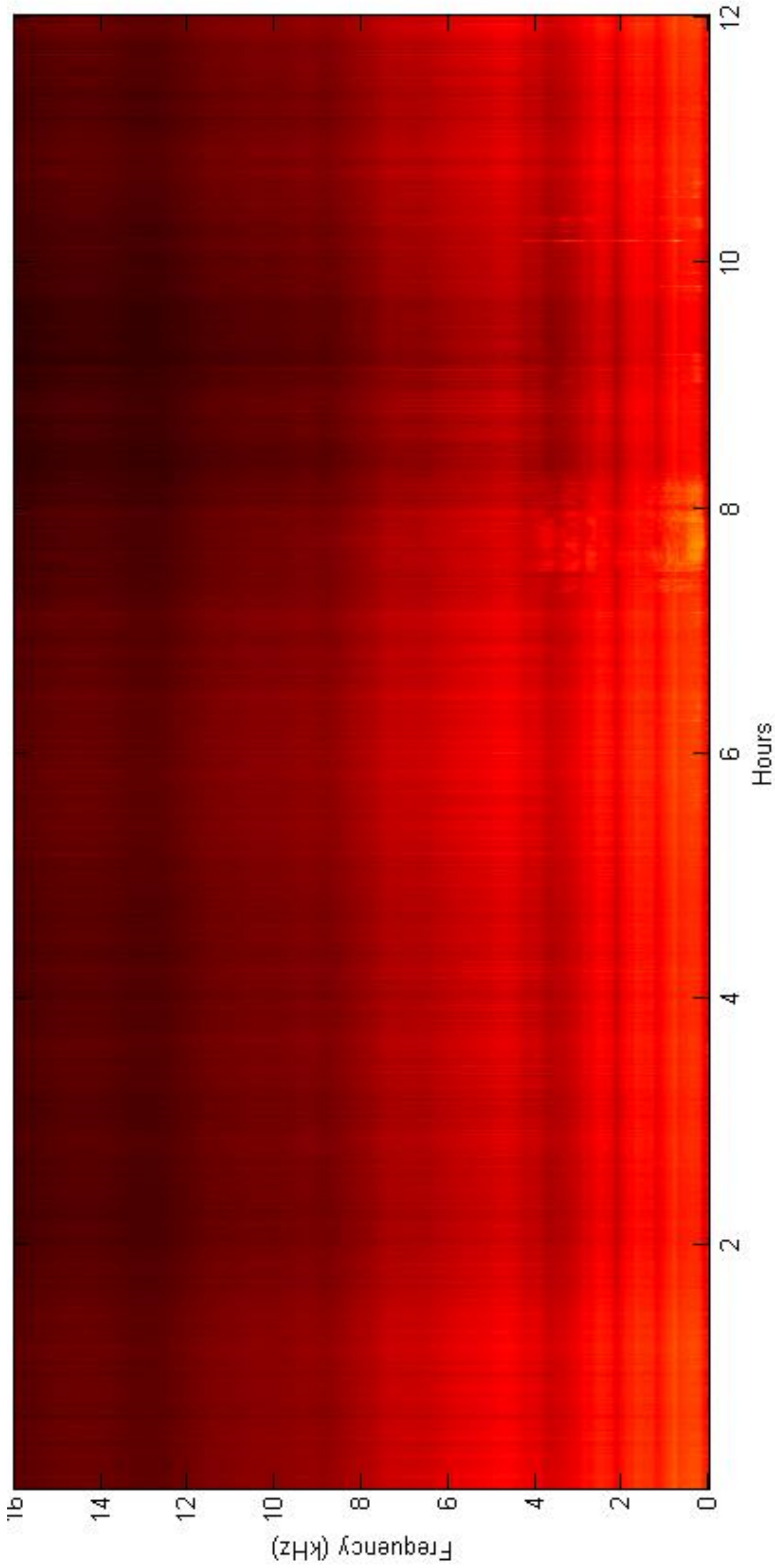

Figure E. 31: Spectrogram for 20th March 2012 morning

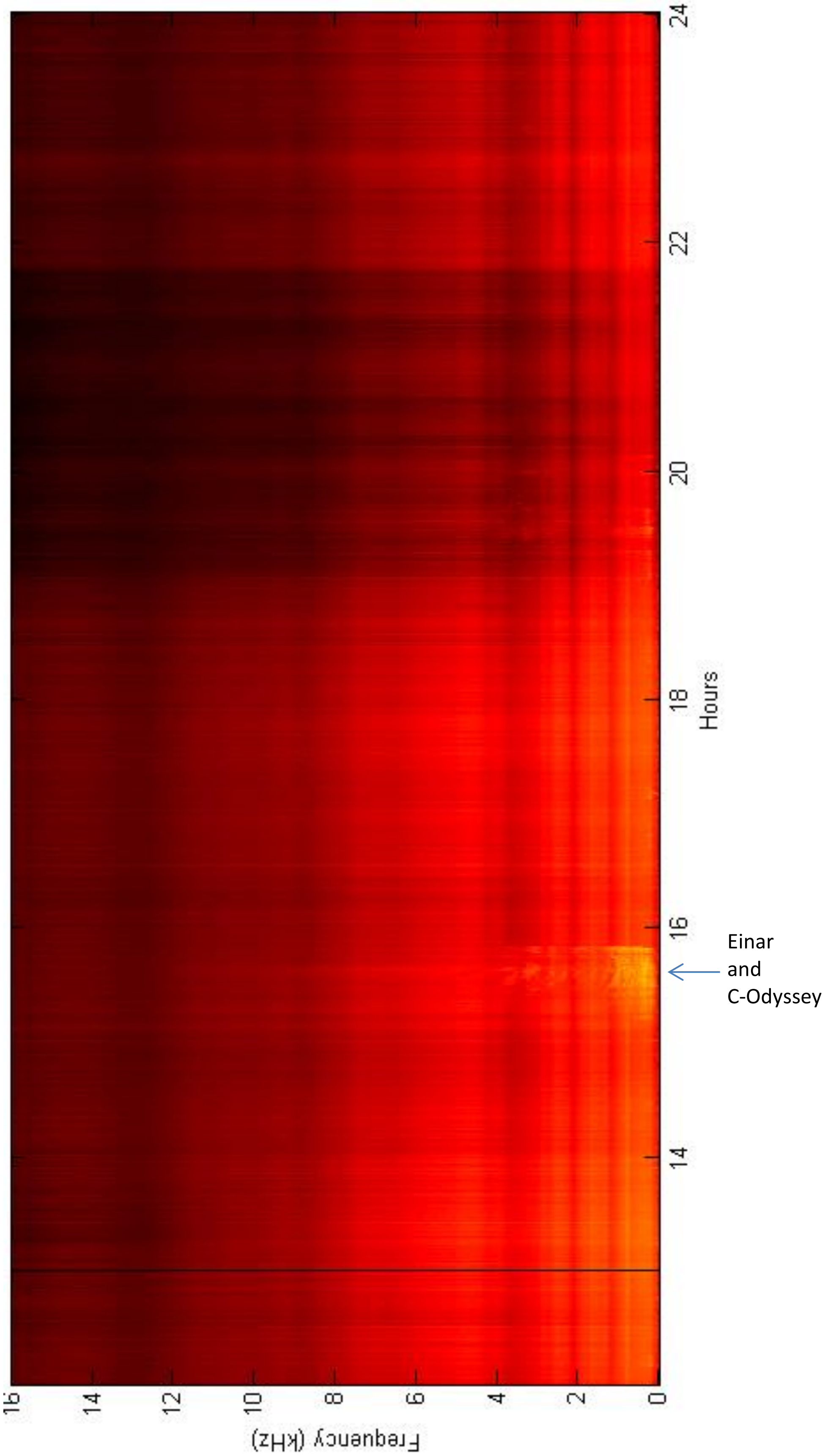

Figure E. 32: Spectrogram for 20th March 2012 afternoon

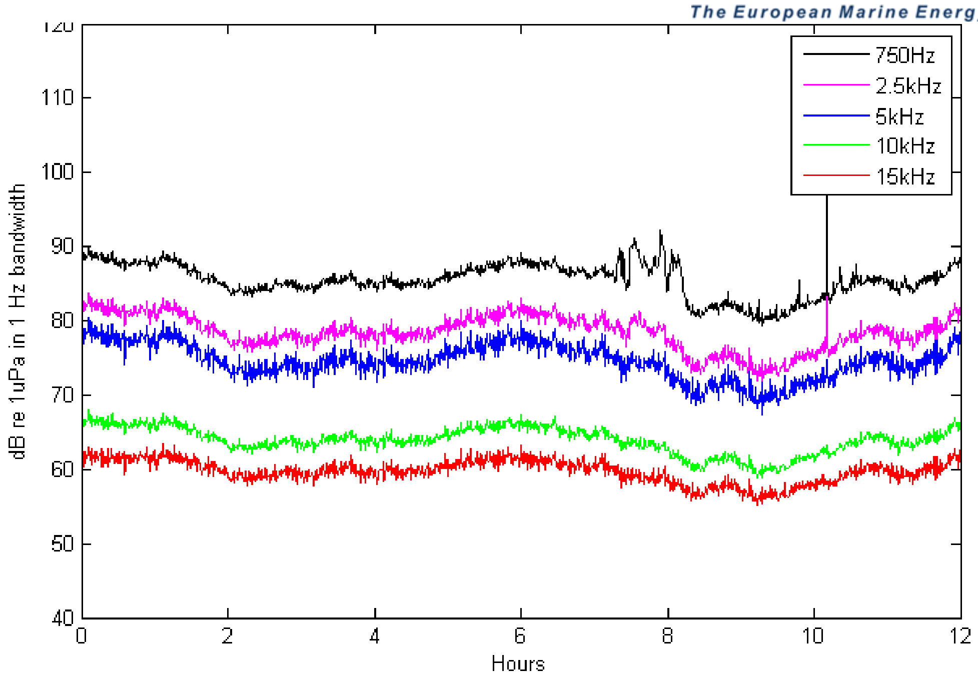

Figure E. 33: Five-channel high frequency plot for 20th March 2012 morning

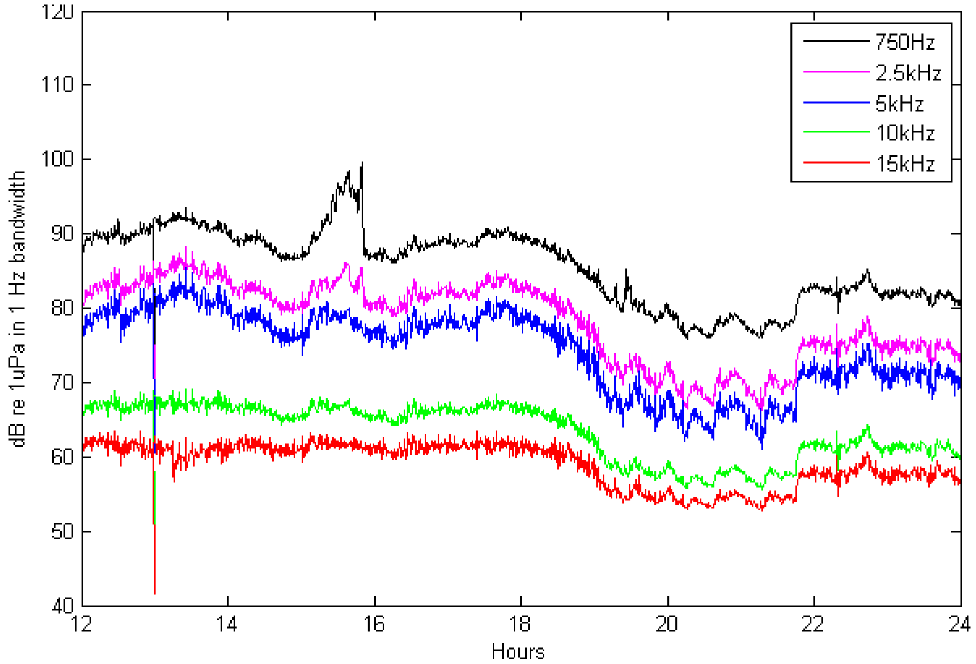

Figure E. 34: Five-channel high frequency plot for 20th March 2012 afternoon

The noise levels throughout the day follow the general trend in wind speed. There is a step increase in noise level across the whole spectrum at 21:45 - this is also weather-related.

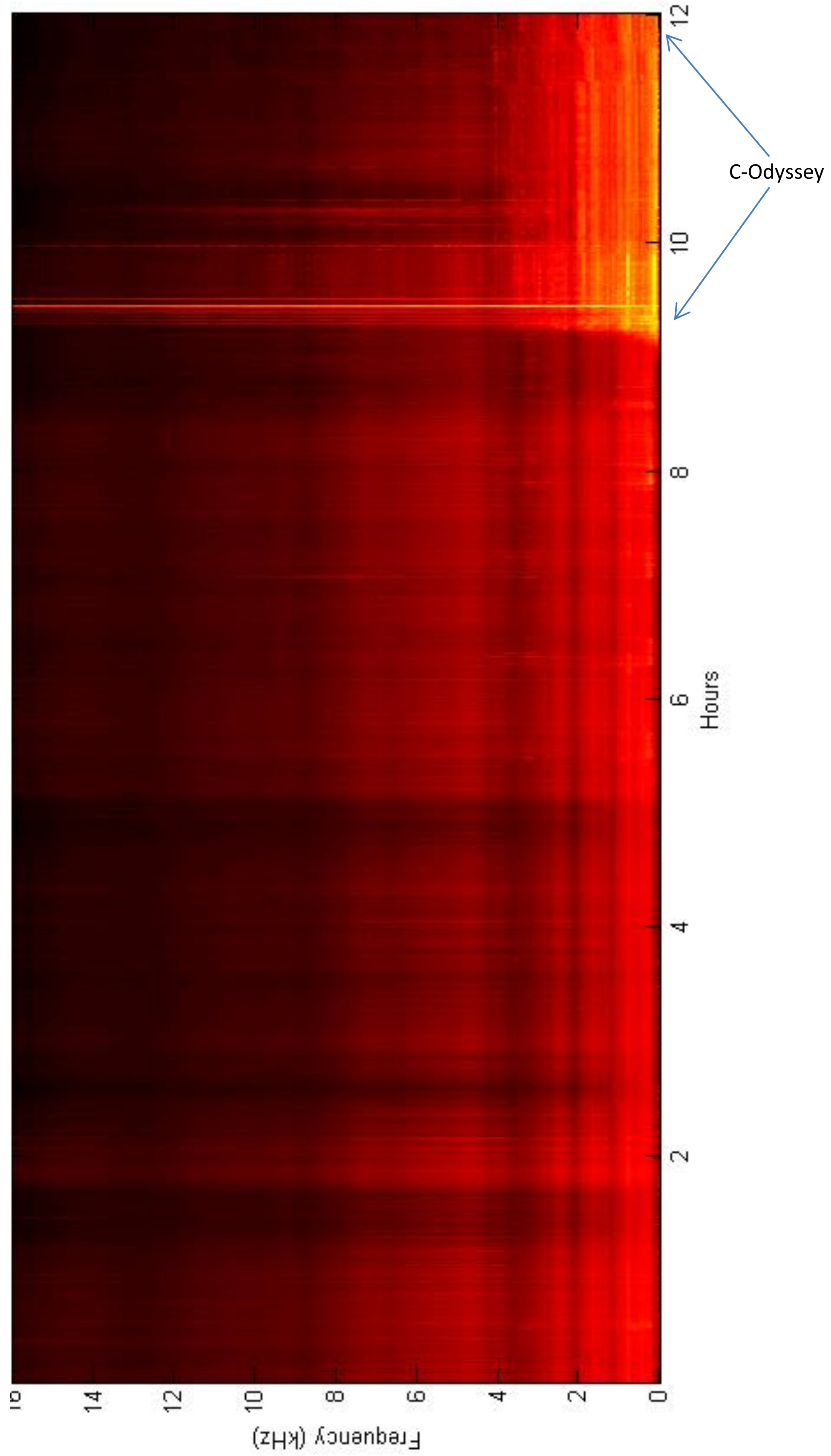

Figure E. 35: Spectrogram for 21st March 2012 morning

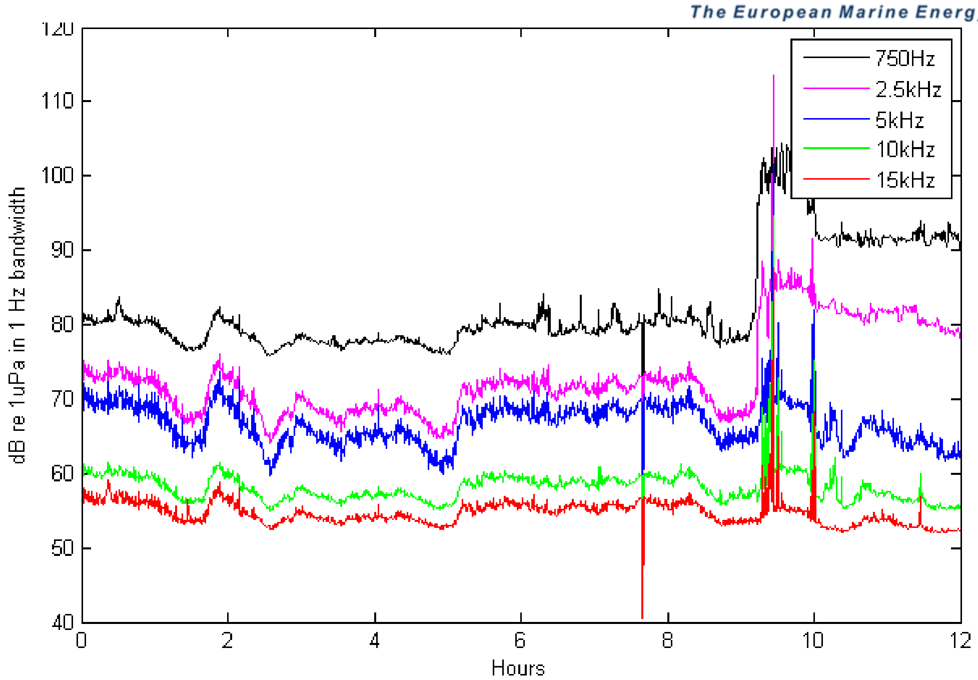

Figure E. 36: Five-channel high frequency plot for 21st March 2012 morning

The major increase in low frequency noise at the end of this recording is caused by the workboat C-Odyssey approaching and starting work near the recorder. Variations in noise level prior to this can be attributed to wind effects.

FOR FURTHER DETAILS PLEASE CONTACT:

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