Curtin University

Centre for Marine Science and Technology

A Matlab toolbox for Characterisation of Recorded Underwater Sound (**CHORUS**)

USER'S GUIDE

Version 8.**0**

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Contents

1. Introduction

This is an updated version of the User's Guide of CHORUS V.5, describing the latest version of CHORUS, V.8. The major changes are as follows:

1. Processing and analysis of MSEED (.msd) sound files recorded by GA Ocean Bottom Seismographs are added in the toolbox. Also processing and analysis of data recorded by the LS1(2) underwater noise recorders is added.
2. Instead of specifying the format of sound files, .DAT, .WAV or .MSD, in the new version the user needs to specify the recorder model: CMST-DSTO LF, CMST HF (with SM2 board and calibration input), SM2M (no calibration), SoundTraps 300 and 500, GA OBS or LS1(2). This has been modified partially because the .WAV files recorded by CMST-HF/SM2M and SoundTraps and LS1(2) have to be processed in a slightly different way to get proper values of sound pressure.
3. The UTC time correction menu has been changed from a wrong range from 0 to 23.5h to a correct one of -11.5 – 12h.
4. Some cosmetic corrections have been made to make a better appearance of graphics in the later version of Matlab (font size and weight, menu text alignment, *etc.*).

Additional information about CHORUS and its applications can be found in Gavrilov and Parsons (2014).

Sea noise data processing and analysis with CHORUS consist of two parts:

1. Data pre-processing. This involves: (1) extraction of necessary timing data from the recording files; (2) calculation of Power Spectrum Density (PSD) using a time window of chosen length in each recording; and (3) correction of PSD for recorder's sensitivity, gain and, when possible, frequency response to get the output data in sound pressure units (µPa). The resulting data are saved in MAT-files in a format suitable for further data analysis in CHORUS Graphic User's Interface (GUI). Data pre-processing of a single set of recordings is done in a batch mode, so no operator attendance is required.
2. Data analysis in CHORUS GUI. CHORUS GUI can be run either in the Matlab environment or as a stand-alone executable program, CHORUS_GUI.exe. See Sections 3 and 4 for details of data analysis.

The pre-processing Matlab routines available in the toolbox for six recorder models can be straightforwardly modified to pre-process data from other sea noise recorder models in a way suitable for CHORUS GUI.

2. Short instructions for data pre-processing

Before starting data pre-processing, make sure that all raw data files with sea noise recordings from a single dataset are stored in or copied into one folder. Also make sure that this folder does not contain other files with the same extension as the raw data files (.WAV, .DAT or .MSD).

Add the folder with CHORUS routines in Matlab path (Set Path – Add Folder – Save).

2.1 Data from CMST-DSTO low-frequency sea noise recorders (http://cmst.curtin.edu.au/products/underwater-sound-recorder/)

Run CMST_LF_data_preprocessing.m, then follow instructions in the Matlab Command Window:

1. Input a dataset ID, a digital ID of arbitrary length (use four-digit IDs for CMST datasets).
2. Find and open the calibration file (with the white noise calibration signal) in a dialog box (in Windows/File Explorer. The calibration file MUST be stored in a different folder than the raw data folder.

3. Input the level of the calibration white noise signal in dB re 1 V^2/Hz.
4. A figure with the recorder frequency response (system through gain vs frequency) will be displayed. Make sure that the curve is acceptable. If it is not acceptable (e.g. with spikes), stop the routine and rerun it with a different calibration file (if such exists);
5. Input the hydrophone sensitivity in dB re 1 V/μPa.
6. Specify the length of the time window in seconds to calculate PSD of sea noise. The default length is the length of each recording. If a shorter window, e.g. 10s, 20s or 50s, is specified, PSD for each time window in each recording will be calculated and saved. This will not affect analysis in CHORUS GUI in any way. This option is added only for additional spectrum analysis in Matlab outside CHORUS GUI.
7. Input the time period in the number of days for which the calculated PSDs will be saved in a single file. Five days is a default option, which is acceptable for a recording frequency bandwidth of up to 95 kHz, depending on computer's RAM. Use shorter time periods (1 to 3 days) for broader frequency bands of recording with higher sampling rates.

2.2 Data from CMST high-frequency sea noise recorders with SM2 digital recorder boards

Run CMST_HF_data_preprocessing.m, then follow the same instructions in the Matlab Command Window, as those for CMST-DSTO noise recorder data. Please NOTICE, the hydrophone sensitivity specified in CHORUS must be: hydrophone's sensitivity value (in dB) specified by its manufacturer MINUS hydrophone preamplifier's gain, which should be known or measured in advance.

2.3 Data from SM2M noise sea noise recorders from Wildlife Acoustics (no calibration circuit, https://www.wildlifeacoustics.com/uploads/user-guides/SM2M-User-Manual.pdf)

Run SM2plus_data_preprocessing.m then follow instructions in the Matlab Command Window:

1. Input a dataset ID, a digital ID of arbitrary length (use four-digit IDs for CMST datasets).
2. Input the channel number, 1 or 2, used for recording (SM2M recorders have 2 channels).
3. Input SM2M board gain (governed by DIP switches on recorder's board) set for the recording channel.
4. Input the hydrophone sensitivity in dB re 1 V/μPa.
5. Point 6 in Section 2.1.
6. Point 7 in Section 2.1.

2.4 Data from Sound Trap sea noise recorders from Ocean Instruments (https://www.oceaninstruments.co.nz/product/soundtrap-st500-std/)

If noise recordings were made by a SoundTrap recorder in a continuous recording mode, split large (GBs) recording files into sections of chosen length using ST_split_long_files_into_sections.m

Run ST_data_preprocessing.m then follow instructions in the Matlab Command Window:

1. Input a dataset ID, a digital ID of arbitrary length (use four-digit IDs for CMST datasets).
2. Input sensor's sensitivity in dB re 1 μPa. For ST300, the sensitivity values are specified for each recorder ID (S/N to be entered at http://oceaninstruments.azurewebsites.net/App/#/%23) for either low or high gain setting programmed in the recorder. For ST300, the sensitivity value to be entered is comprised of the sensitivity of the hydrophone used with ST500 and the system gain: for example, if the hydrophone sensitivity is -177 dB re 1 V/uPa and recorder gain is -1.8 dB (typical for ST500), then the total sensitivity is 175.2 dB.
3. Point 6 in Section 2.1.

4. Point 7 in Section 2.1.

2.5 Data from GA Ocean Bottom Seismographs (OBS)

Run GA_OBS_data_preprocessing.m then follow instructions in the Matlab Command Window:

1. Input a dataset ID, a digital ID of arbitrary length (use four-digit IDs for CMST datasets).
2. Input hydrophone's sensitivity in dB re 1 μPa (default value -165 dB, as in the GA OBS deployed on the NW shelf in 2014-2015).
3. Point 6 in Section 2.1.
4. Point 7 in Section 2.1.

2.6 Data from LS1(2) recorders from Loggerhead Instruments (https://www.loggerhead.com/ls1-multicard-recorder)

Run LS_data_preprocessing.m then follow instructions in the Matlab Command Window. There are two options depending on LS model modification: (1) LS with no calibration available for the recording system and (2) LS models (new) with HTI hydrophones with a calibration input connected to an audio plug built in the LS electronic board to calibrate the frequency response of the entire recording system, including the hydrophone's preamplifier.

1.1 Input a dataset ID, a digital ID of arbitrary length (use four-digit IDs for CMST datasets).

1.2 Input gain setting (dB) programmed in SL.

1.3 Input hydrophone's sensitivity in dB re 1 μPa (according to the specs of its manufacturer.

1.4 Point 6 in Section 2.1.

1.5 Point 7 in Section 2.1.

2.1 Input a dataset ID, a digital ID of arbitrary length (use four-digit IDs for CMST datasets).

2.2-2.7 Points 2 to 7 in Section 2.1, taking into account the notice (in red) in Section 2.2.

3 Data review and analysis in CHORUS GUI

Start CHORUS GUI either in the Matlab environment (CHORUS_GUI.m) or as a stand-alone program (CHORUS_GUI.exe).

Select the folder with data (recording files and pre-processed MAT-files. The window shown in Figure 1 will be displayed.

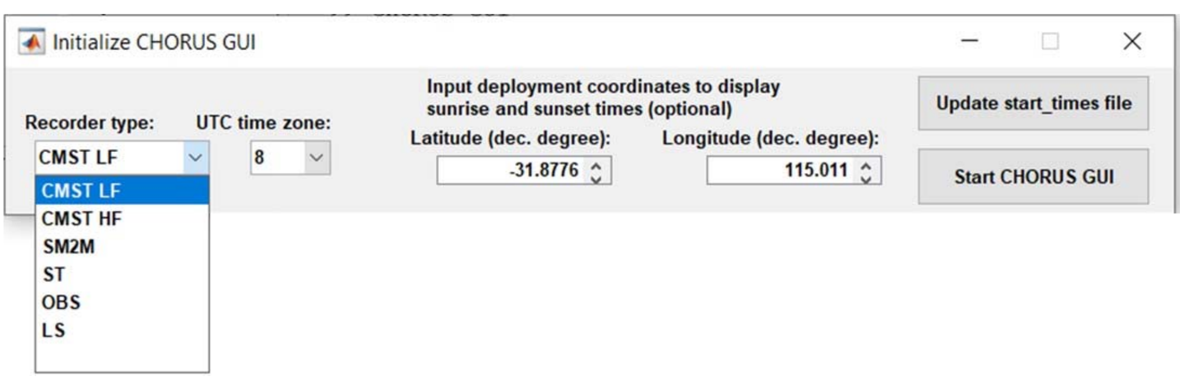

Figure 1: Initial menu of CHORUS GUI.

A proper sea noise recorder model will automatically appear, if the dataset to be analysed has been pre-processed with the latest version of CHORUS (V.8). For datasets pre-processed in the older versions, select the proper model from the pop-up menu. It will be saved for further sessions of CHORUS with the analysed dataset, if you press the "Update start times file" button.

Select the time zone from the pop-up menu, if needed. It will also be saved for further sessions of CHORUS with the analysed dataset.

Input coordinates of the deployment. The coordinates are needed only to display the sunrise and sunset times in CHORUS GUI, otherwise these fields can be left empty. Coordinates will be saved for further sessions of CHORUS with the analysed dataset, so the user will not need to input them again, if you press the "Update start times file" button.

The Main GUI menu is shown in the top menu panel in Figure 2. In this menu you can specify the time period (first and last days) for which a long-time average spectrogram of sea noise, compiled from the pre-calculated PSDs, will be displayed after pressing the "Spectrogram" button. The minimum averaging time is the duration of individual recording. At the minimum averaging time, the maximum number of days that can be displayed in the spectrogram is 15 to 60 depending on computer's capacity. The averaging time can be increased by a factor of 2, 3 or 4, if the user wishes to display a longer time period. In this case, the corresponding number of pre-calculated PSDs will be averaged.

If the deployment coordinates were specified, press the "Sunrise/set" button after displaying the spectrogram to add the sunrise and sunset times indicated by red triangles pointed up and down respectively. The dynamic range of PSD levels displayed by different colours can be changed using the minimum and maximum level pop-up menus.

Once the long-time average spectrogram is displayed (Figure 2), the Recording menu will automatically appear below the spectrogram (bottom menu panel in Figure 2). The first action to be done in the Recording menu is to press the "Select time" button and then click the mouse (controlling a cursor) on the top panel spectrogram at the time you choose to analyse sea noise in detail, based on the spectral features in the long-time average spectrogram, e.g. intense noise at whale call frequencies. The corresponding raw data file will be found and loaded. Select settings in the Recording menu according to your preferences and press "Display" to display the waveform and spectrogram of sea noise recorded at the chosen time (bottom panels in Figure 3).

Using the zoom function of the standard Matlab figure menu, you can select a section of the waveform to zoom in. After zooming in or out, press "Display" to update the spectrogram in the right panel (Figure 4).

The settings available in the Recording menu are as follows:

<u>FFT length</u>: The length of FFT window can be chosen in the pop-up menu from 0.05s to 2s depending on the duration and frequency contents of signals to be properly displayed in the spectrogram;

<u>FFT overlap</u>: Overlap of FFT windows can be varied from 10% to 90% with a 10% increment;

<u>Frequency scale:</u> The frequency scale in the spectrogram can be either logarithmic (default) or linear;

<u>High-pass cut-off frequency:</u> High-pass filtering of noise signal. The cut-off frequency is specified as a fraction of Nyquist frequency (default 0 for no filtering);

<u>Low-pass cut-off frequency</u>: Low-pass filtering of noise signal. The cut-off frequency is specified as a fraction of Nyquist frequency (default 1 for no filtering);

<u>Speed up:</u> Factor 1, 2, 5 or 10 to speed up signal's playback (see Playback button description). Default is 1 to play back with normal speed.

The actions available from the Recording menu are as follows:

<u>De-spiking</u>: If it is selected "on" from the pop-up menu, an additional de-spiking menu will pop up with several settings. Use the default ones as optimum for depressing snapping shrimp noise. Once the settings are saved, press the "Display" button to see results of de-spiking in the waveform and spectrogram panels. The de-noised waveform is shown by the blue line in Figure 5 for illustration of

the effect. An auto-regression (AR) method (Vaseghi and Rayner, 1990) is used to locate impulses of snapping shrimp noise, remove them and interpolate the signal waveform within the resulting gaps.

Signal stats (applicable primarily to transient signals): By pressing this button, some characteristics of the signal displayed in the waveform panel will be calculated. These characteristics are: maximum peak-to-peak pressure in Pa, maximum received level in dB re 1 μPa, sound exposure level in dB re 1 $\mu Pa^2 \times s$, and signal duration in seconds containing 90% of its energy. After pressing "Signal stats" a modal dialog box will appear asking to select the option for correcting the calculated values for background noise (correction panel in Figure 6). If automatic correction is selected, the program finds a 5% section of the waveform with minimum RMS pressure, which is assumed to correspond to the intensity of background noise used for correction. If manual correction is chosen, the user will be asked to indicate the start and end times of the waveform fragment, containing only background noise, by clicking the mouse in the waveform panel. Once the correction option is chosen, the program calculates the required characteristics and the results are displayed in a separate window and at the bottom of the waveform panel (Figure 6).

Display: Press this button to update the waveform and spectrogram panels every time the settings are changed.

Play, Pause and Stop: Use these buttons to play back, pause or stop sound. The waveform shown in the waveform panel will be played back (rather than the whole recording). Playback is sped up according to the speed-up factor chosen. A sliding vertical bar in the waveform panel indicates the playback progress.

Save to WAV: Press this button to save the waveform shown in the waveform panel in a Windows sound (*.wav) file. The sampling frequency in the saved file is the original sampling frequency times the speed-up factor. The amplitude is normalized so that it does not exceed unity. An additional file with the same name but different extension, .CLB, will also be saved. This is a text file containing just one number – a factor by which the signal amplitude must be multiplied to convert it into μPa.

4 Detection

Press this button in the Main menu to start detection of specific sounds. Detection of calls from pygmy blue whales of the Eastern Indian Ocean population, fin whales and "spot call" whales is currently implemented in the Toolbox. Other sounds of both biological and man-made origin will be added in CHORUS as soon as detection algorithms for those sounds are developed and tested. Detection is carried out over the time period specified by the first and last days selected in the Main menu. It is NOT NECESSARY to display the spectrogram for the specified period, so the time period specified for detection can be as long as needed.

Pygmy blue whales

When pygmy blue whales are selected in the main Detection menu (left menu panel in Figure 7), pygmy blue whale detection menu appears (middle menu panel in Figure 7). It contains several settings and options to be selected from:

Detect: Press this button to start detection. Progress in searching through the recordings during the selected time period is indicated by a sliding bar in the Detection progress panel (right panel in Figure 7). The detection process can be interrupted by pressing button "Stop" in the Detection progress panel.

Sensitivity (low, normal, high): Select "Low" to get less false detections at the cost of some increase in the missed detection rate. Select "High" to get less missed detections at the cost of some increase in the false detection rate. Use "Normal" as a trade-off.

Display detection progress: If this option is chosen, a spectrogram of every next recording containing detected whale calls will be displayed to review the correctness of detection (Figure 8). Press Enter to proceed to the next recording with detected calls.

Estimate number of animals: If this option is selected, the number of different whales vocalising in the same time interval (length of individual recording) will be estimated.

Save signals: When searching through the chosen time period is finished, the detection times and some signal parameters, such as RMS pressure or received level, will be saved in a MAT-file. If "Save signals" is selected, the waveform of all detected signals will also be saved in the output MAT-file. BE CAREFUL with this option, as the waveforms to be saved can require too much memory, when whale calls are frequent and the time period chosen for detection is long.

Fin whales

When fin whales are selected in the main Detection menu (left menu panel in Figure 9), fin whale detection menu appears (middle menu panel in Figure 9). It contains several settings and options to be selected from:

Detect: Press this button to start detection. Progress in searching through the recordings during the selected time period is indicated by a sliding bar in the Detection progress panel (right panel in Figure 9). The detection process can be interrupted by pressing button "Stop" in the Detection progress panel.

Sensitivity (low, normal, high): Select "Low" to get less false detections at the cost of some increase in the missed detection rate. Select "High" to get less missed detections at the cost of some increase in the false detection rate. Use "Normal" as a trade-off.

Display detection progress: If this option is chosen, a spectrogram of every next recording containing detected whale calls will be displayed to review the correctness of detection (Figure 10). Press Enter to proceed to the next recording with detected calls.

Save signals: When searching through the chosen time period is finished, the detection times and some signal parameters (such as RMS pressure or received level) will be saved in a MAT-file. If "Save signals" is selected, the waveform of all detected signals will also be saved in the output MAT-file. BE CAREFUL with this option, as the waveforms to be saved can require too much memory, when whale calls are frequent and the time period chosen for detection is long.

"Spot call" whales

The species of whale producing the so called "spot calls" is still unidentified with certainty, but is believed to be the southern right whale (Ward, *et.al*, 2017). When "spot call" whales are selected in the main Detection menu (left menu panel in Figure 11), "spot call" whale detection menu appears (middle menu panel in Figure 11). It contains several settings and options to be selected from:

Detect: Press this button to start detection. Progress in searching through the recordings during the selected time period is indicated by a sliding bar in the Detection progress panel (right panel in Figure 11). The detection process can be interrupted by pressing button "Stop" in the Detection progress panel.

Sensitivity (low, normal, high): Select "Low" to get less false detections at the cost of some increase in the missed detection rate. Select "High" to get less missed detections at the cost of some increase in the false detection rate. Use "Normal" as a trade-off.

Expected frequency: The fundamental frequency of spot calls is steadily decreasing over years but may rapidly recover back to around 28 Hz in the near future, as this took place in 2006 (Ward, *et.al*, 2017). So, select the frequency expected for the season/year and location of data collection.

Display detection progress: If this option is chosen, a spectrogram of every next recording containing detected whale calls will be displayed to review the correctness of detection (Figure 12). Press Enter to proceed to the next recording with detected calls.

Save signals: When searching through the chosen time period is finished, the detection times and some signal parameters (such as RMS pressure or received level) will be saved in a MAT-file. If "Save signals" is selected, the waveform of all detected signals will also be saved in the output MAT-file. BE CAREFUL with this option, as the waveforms to be saved can require too much memory, when whale calls are frequent and the time period chosen for detection is long.

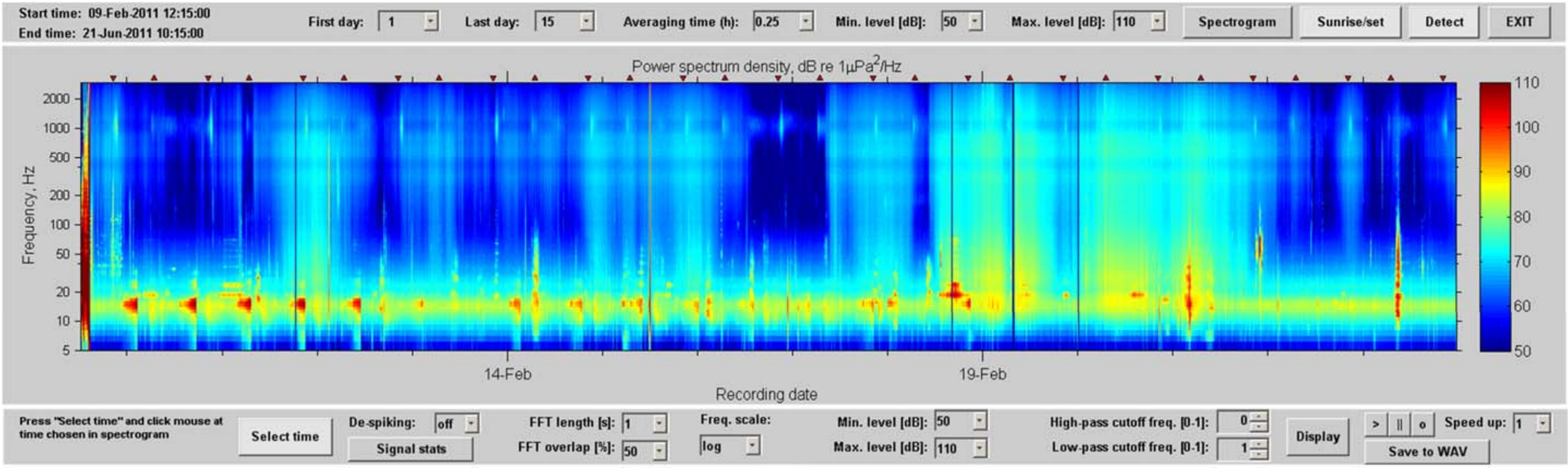

Figure 2: Main GUI menu (top panel), long-time average spectrogram panel (middle), and Recording menu (bottom).

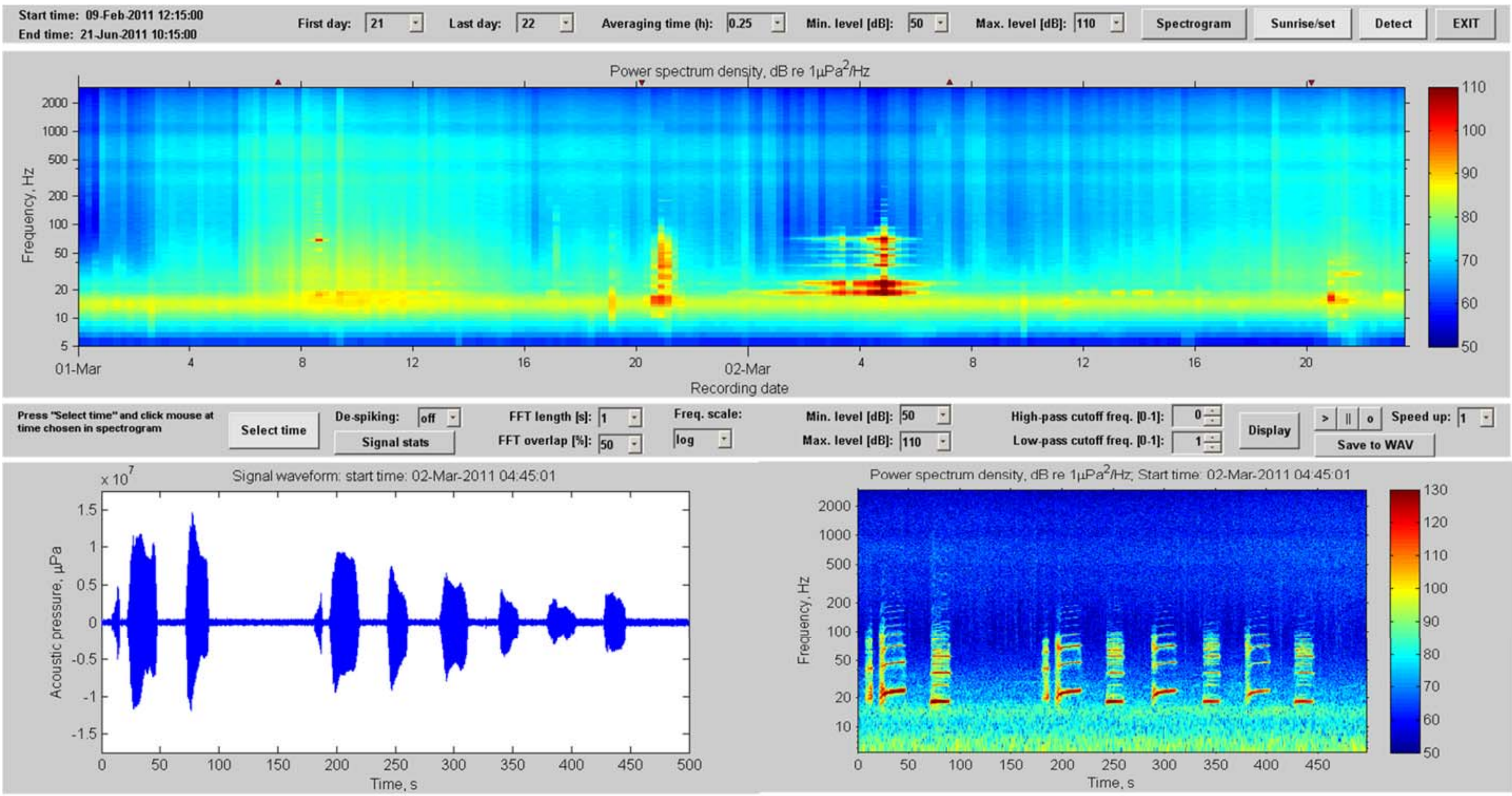

Figure 3: Waveform (bottom left) and spectrogram (bottom right) panels of an individual recording which corresponds to the time selected in the top panel spectrogram.

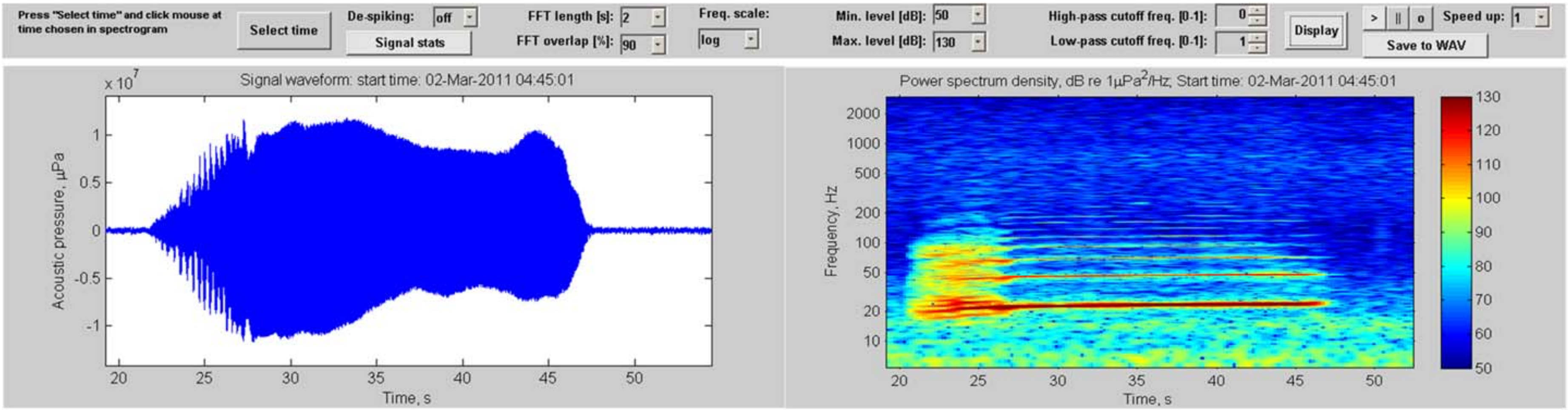

Figure 4: Waveform (bottom left) and spectrogram (bottom right) panels of the individual recording in Figure 3 after zooming in.

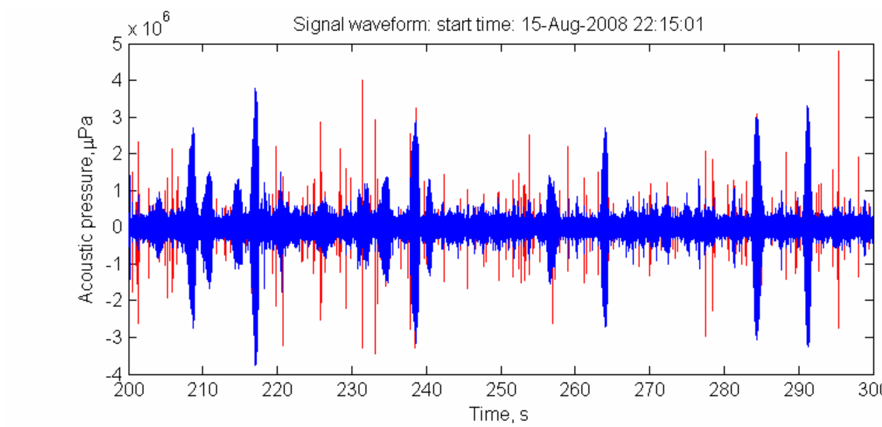

Figure 5: Waveform of a series of humpback calls after signal de-noising using an AR-algorithm for detection and interpolation of spiky noise from snapping shrimp (blue) and spikes of snapping shrimp noise removed (red).

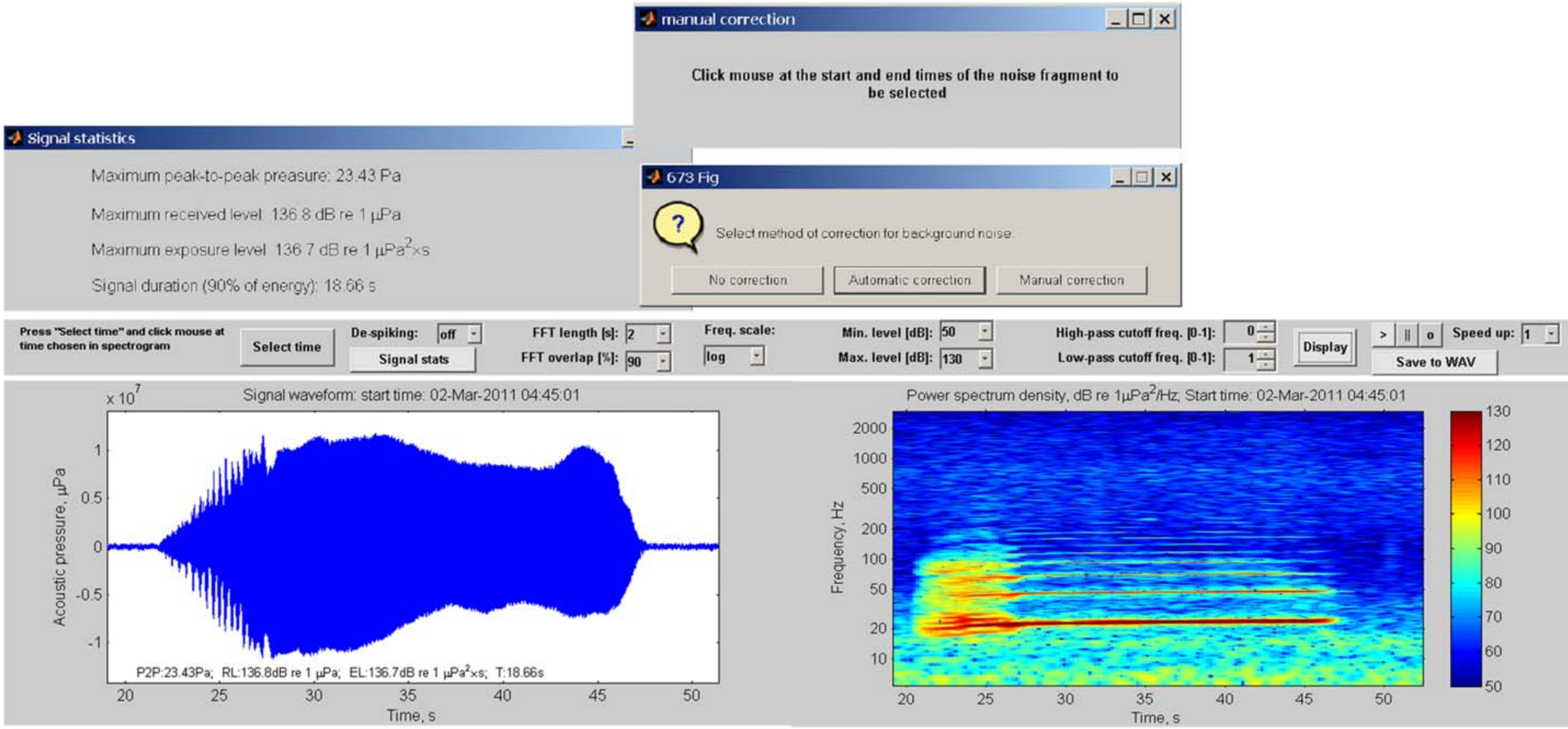

Figure 6: Menu (top right panels) and results (top left) of measuring signal characteristics.

Figure 7: Main detection menu (left panel), Pygmy blue whale detection menu (middle panel) and Detection progress panel (right).

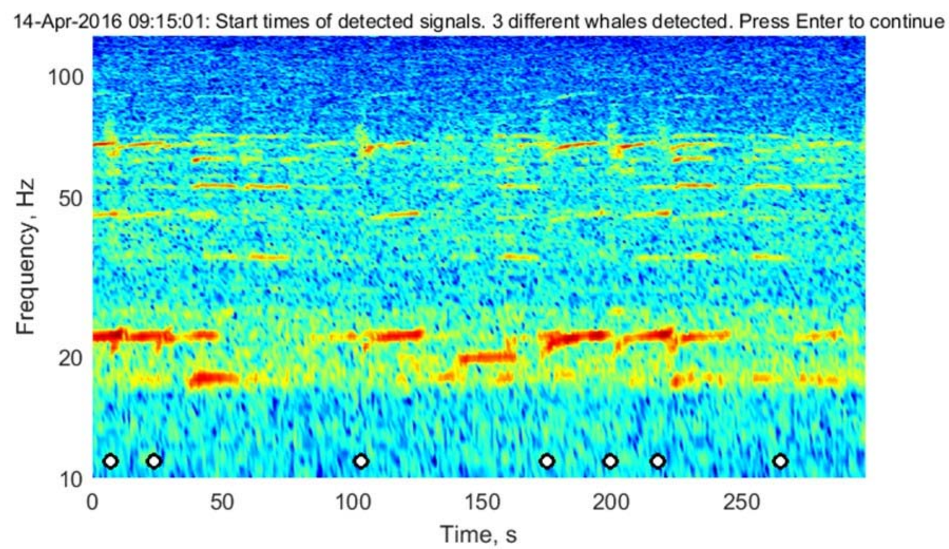

Figure 8: Spectrogram of an individual recording with the detection times of pygmy blue whale calls indicated by dots.

Figure 9: Main detection menu (left panel), fin whale detection menu (middle panel) and Detection progress panel (right).

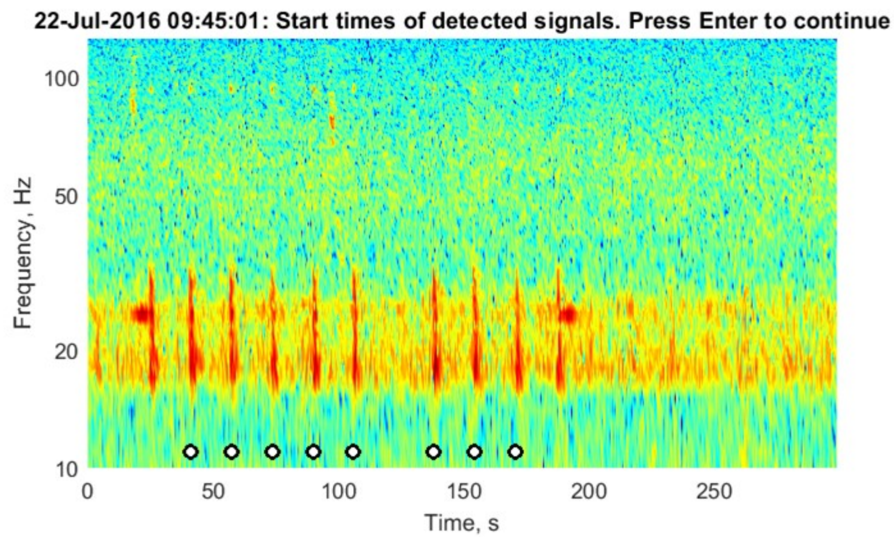

Figure 10: Spectrogram of an individual recording with the detection times of fin whale calls indicated by dots.

Figure 11: Main detection menu (left panel), “spot” whale detection menu (middle panel) and Detection progress panel (right).

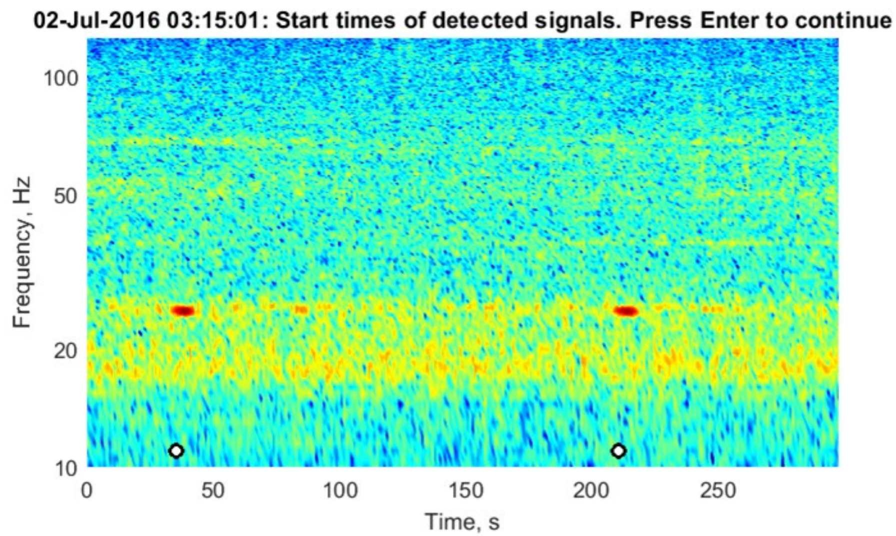

Figure 12: Spectrogram of an individual recording with the detection times of “spot” whale calls indicated by dots.

References

Gavrilov A.N. and Parsons M.J.G. (2014), “A Matlab tool for the Characterisation Of Recorded Underwater Sound (CHORUS)”, *Acoustics Australia* v.42, No.3, pp. 190-196.

Vaseghi S.V. and Rayner P.J.W. (1990), “Detection and suppression of impulsive noise in speech communication systems”, *IEE Proceedings*, v.137, Pt.1, No.1, pp. 38-46.

Ward, R., Gavrilov, A. N. and McCauley, R. D. (2017), “Spot” call: A common sound from an unidentified great whale in Australian temperate waters”, *J. Acoust. Soc. Am* **142**(2), pp. EL231-236.