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**TNO report**

**| Final report**

# Northern Right Whale Sonobuoy Localisation Dataset for the DCDLE workshop

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# Contents

# 1 Introduction

In the DCLDE 2024[1] workshop we revisit North Atlantic Right Whales (NARW) for the third time. The main reasons for selecting this dataset are:

- NARW is a highly endangered species and acoustics can play an important role in managing the impact of human activities on this species.
- NARW localisation with large networks has not been looked at in previous DCLDE workshops.
- A dataset from a large set of synchronized recorders makes it possible to explore how processing techniques that are developed for fixed networks (e.g. Navy ranges, Helble et al., 2015) can be applied to mobile/temporary networks, which are becoming more readily accessible.
- We can build on previous experience in the workshop and the improvements in detection, classifying, and localizing NARW (e.g. Desharnai & Hau, 2004; Gillespie, 2013; Golit & Hildebrand, 2018). This provides the opportunity to (partially) re-use previous datasets.

The DCLDE workshop dataset consists of passive acoustic data from two 3.5-h deployments of fields of 32 sonobuoys deployed in 2018 in the Gulf of St. Lawrence, Canada, one of the core habitats of North Atlantic Right Whales (NARW) in Canadian Waters (Figure 1). Coincident shipboard and aerial NARW visual surveys as well as oceanographic surveys by Slocum ocean gliders were conducted within each sonobuoy array. The objective of this work was to collect a multimodal dataset to advance NARW monitoring, particularly by refining NARW detection, classification, and localisation. Typical sonobuoy spacing was approximately 8 km (4.2 NM), and recorded by the Royal Canadian Air Force (CP-140). This dataset is kindly made available to the DCLDE community by the research consortium consisting of Dalhousie University, Fisheries and Oceans Canada (DFO), Defence Research and Development Canada (DRDC), the Acoustic Data Analysis Centre (ADAC), the National Oceanic and Atmospheric Administration (NOAA) Northeast Fisheries Science Center (NEFSC), the New England Aquarium (NEAq) Anderson Cabot Center for Ocean Life (ACCOL), and the Canadian Whale Institute (CWI). The acoustic data was collected by the Royal Canadian Airforce (RCAF).

Although the current dataset has been mainly set up for testing localisation algorithms we encourage people to explore using this dataset for other purposes, such as detection, classification and density estimation. We look forward to seeing and comparing what great work you all can come up with, and hope to see you at the DCLDE 2024 which is anticipated to take place in the Netherlands.

[1] Note that due to the CoviD-19 situation, the exact timing is unclear. It is currently anticipated that the DCLDE workshop will occur approximately 2 years after the upcoming DCLDE workshop in Hawaii, which is currently planned in March 2022.

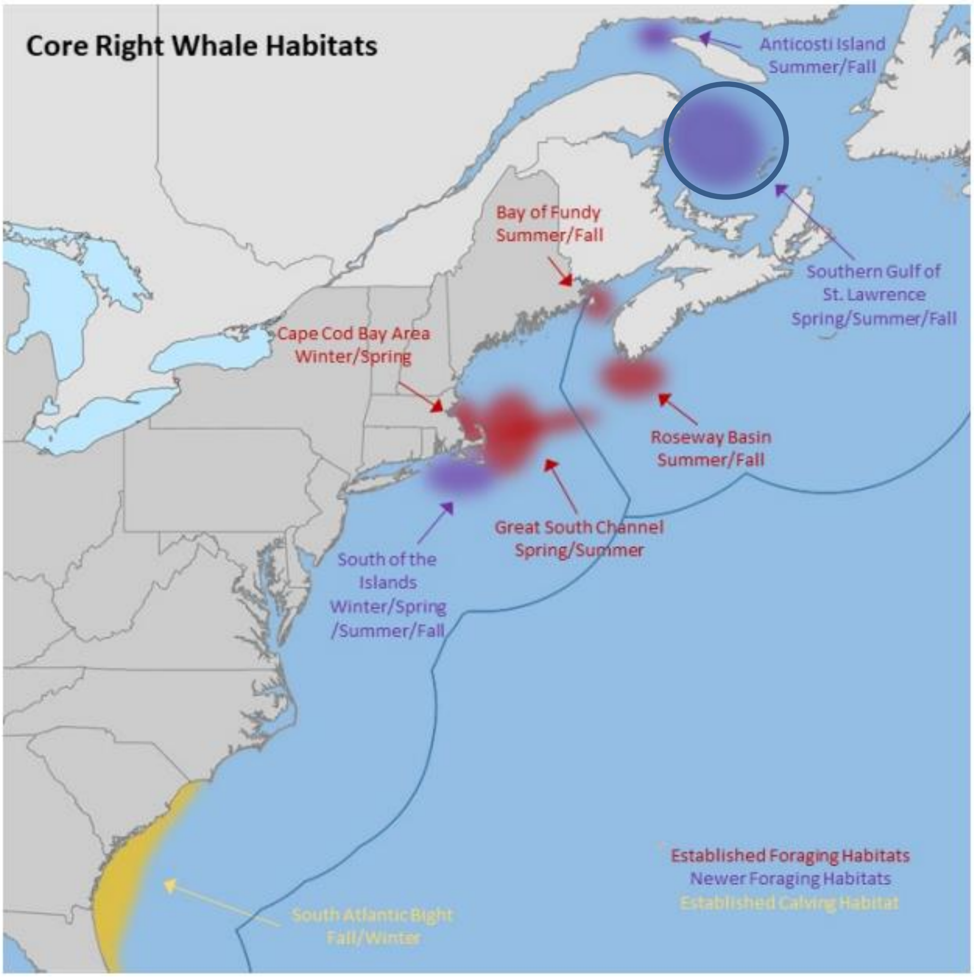


Figure 1 Overview of North Atlantic right whale habitats (NOAA, 2020). The DCLDE workshop dataset was collected in the Southern Gulf of St. Lawrence, Canada (indicated by the blue circle).

# 2 DCLDE workshop dataset description

The dataset consists of two deployments of 32 passive sonobuoys (Figure 2), each with about 3.5 h of recording. At the same time visual sightings were conducted from an aerial survey and a ship-based survey, which can be compared to localisation results. Sonobuoys were positioned in an 8x4 buoy grid with approximately 8 km separation.

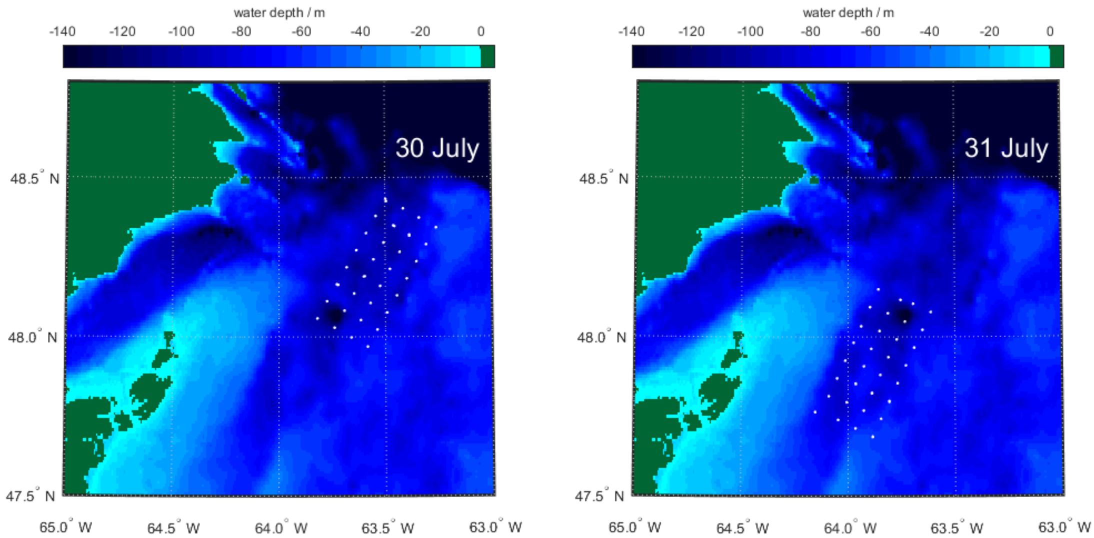


Figure 2 Deployed grid of sonobuoys near right whales in the southern GSL on 30 and 31 July, 2018.

The following sections briefly describe the acoustic data, manual detection, classification, and annotation of NARW calls, visual data collected, and collected environmental data and additional meta-data useful for analysing the dataset.

## 2.1 Passive sonobuoy data

### *2.1.1 Non-Acoustic Data*

Two separate sonobuoy types were used on Day 1 (2018-07-30) and Day 2 (2018-07-31):

- Sonobuoy type AN/SSQ-53F (DAY 1)
- Sonobuoy type AN/SSQ-53D3 (DAY 2) (Figure 3)

The type 53F has regular updates on buoy location. For the second day the type 53D3 had effectively only the splash point at the start of the deployment (with some very irregular updates) (Figure 4). Drift of the buoy locations during the recording period is observable (Figure 5). Due to malfunctioning of a few sonobuoys, these were re-seeded with new buoys to achieve a full coverage of the array. The re-seeding process is shown in Figure 6 and Figure 7. The regular updating of the 53F sonobuoys deployed in Day1 is clearly visible. For the Day 2 only the first drop point of the 53D3 buoys is available, and the buoy location is therefore more uncertain.


Figure 3 Image of the AN/SSQ-53D3 Sonobuoy deployed in this study (source: www.ultra.group) .

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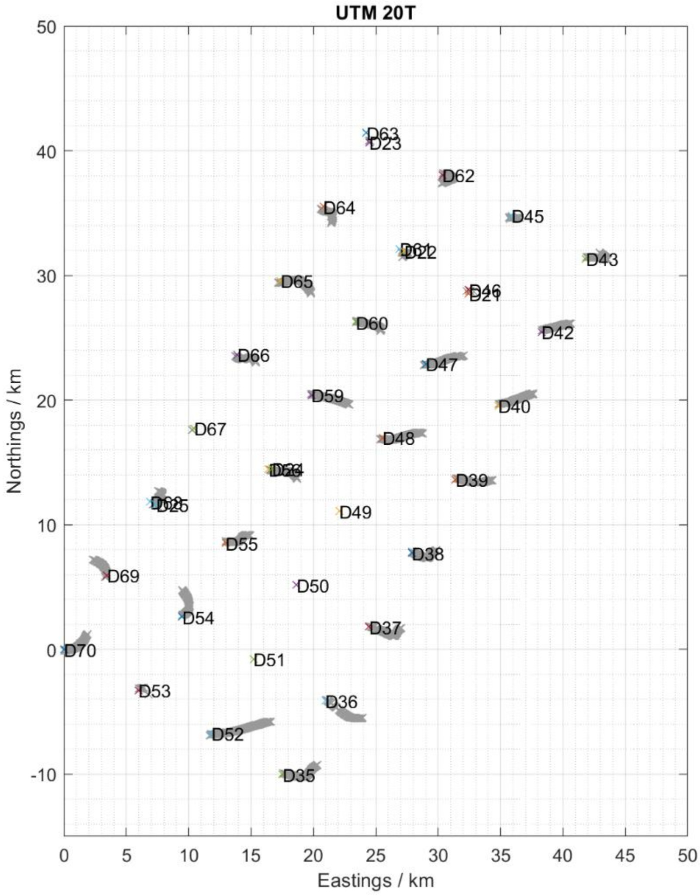


Figure 4 Buoy locations and ID in UTM coordinate systems relative to lower left buoy, showing that the buoys are spaced by approximately 8 km (~4.3 NM) for DAY1. Buoys that had to be redeployed are overplotted. Updated buoy locations are indicated in gray, showing the drift buoys experienced during the duration of the experiment.

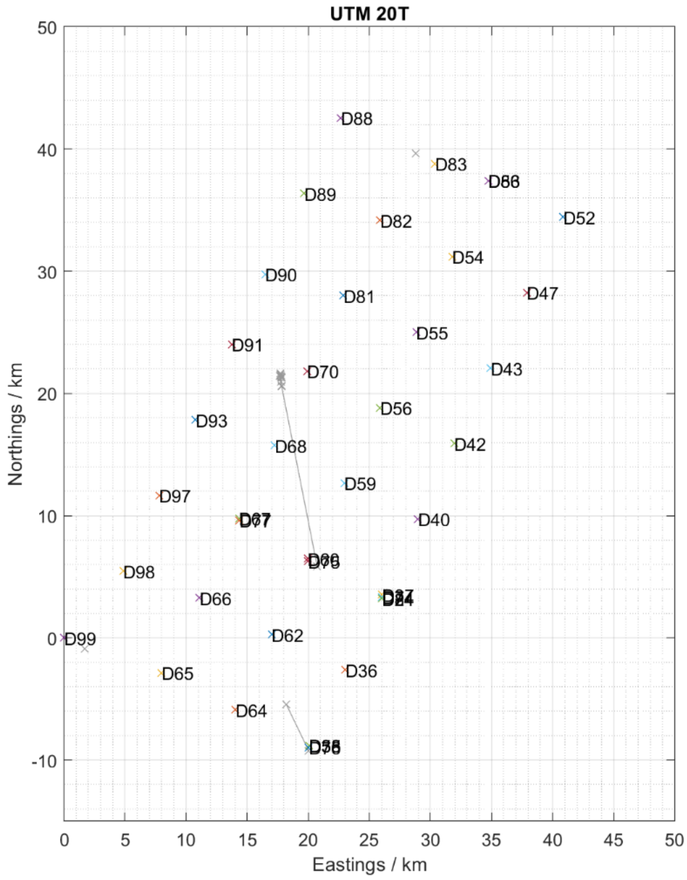


Figure 5 Buoy locations and ID in UTM coordinate systems relative to lower left buoy, showing that the buoys are spaced by approximately 8 km (~4.3 NM) for DAY2. Buoys that had to be redeployed are overplotted. Updated buoy locations are indicated in gray.

The orientation of the DIFAR sensors are relative to Magnetic North. To obtain true geo-referenced angles, a correction should be applied using a magnetic declination of -17.174667 degrees (where the negative indicates west of north).

The hydrophone depths for all buoys were set at 90 feet (27.4 m).

Buoys acoustic channels were time-synchronized with an accuracy of 23 µs.

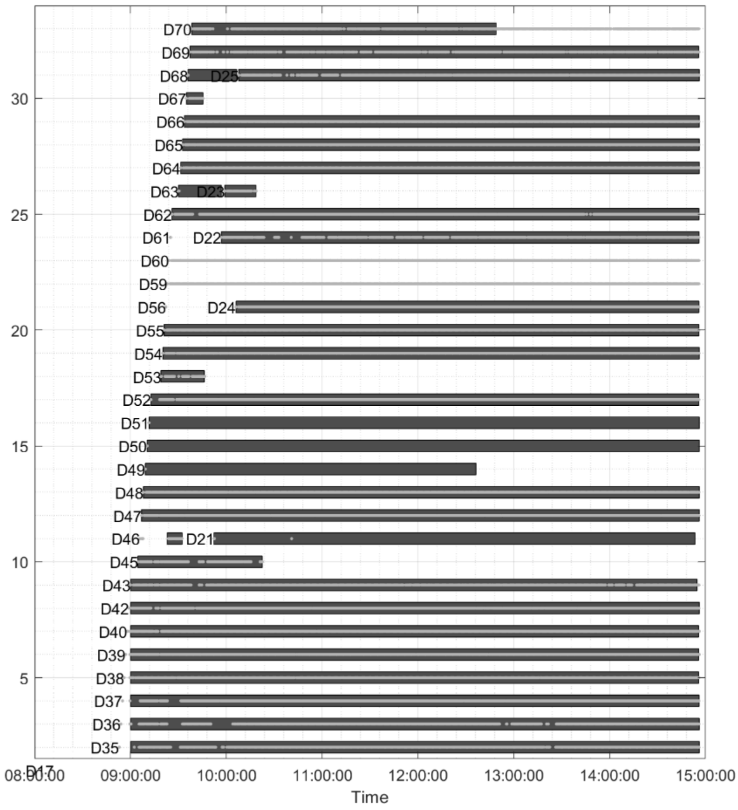


Figure 6 Re-seeding of buoy locations with new buoys on Day 1. Buoy location updates are indicated in light gray. The recording period of each channel is indicated by the dark gray bar. Time plotted is in EST time (UTC-4 h).

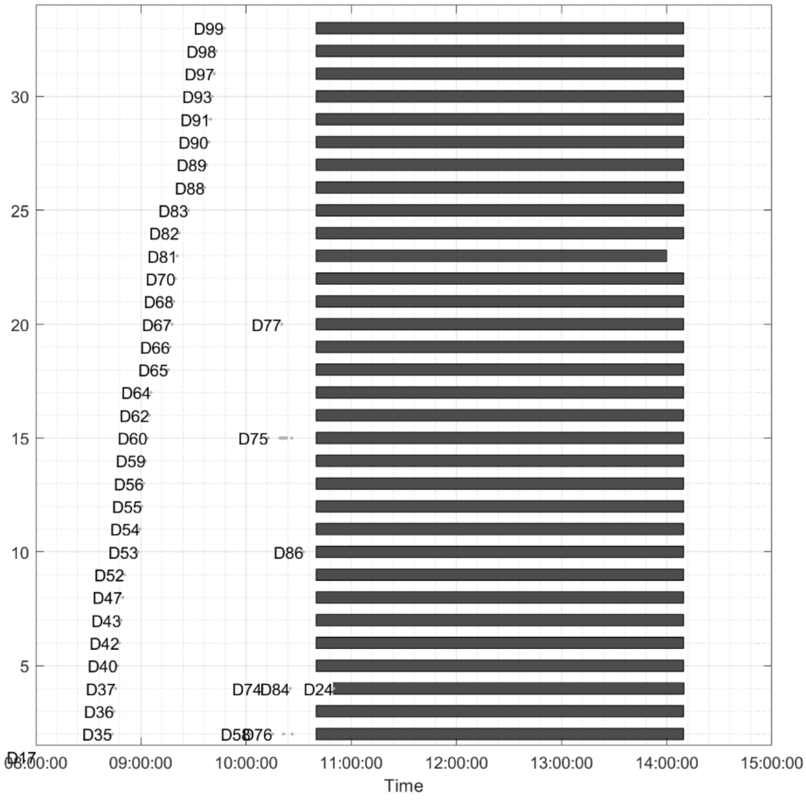


Figure 7 Re-seeding of buoy locations with new buoys on Day 2. Buoy location updates are indicated in light gray. The recording period of each channel is indicated by the dark gray bar. Only very limited updates are available for this deployment. Time plotted is in EST time (UTC-4 h).

### *2.1.2 Acoustic data*

Data was recorded with DIFAR buoys. The acoustic data DIFAR was recorded in multiplexed format by 32 buoys. This was de-multiplexed by DRDC and stored in .wav format, and ordered as omni, sine (East-West), and cosine (North-South) channels. The de-multiplexed data was stored at a sampling rate of 8000 Hz. Channel numbers and corresponding locations are stored in the filename `<channel name>_1345-1445_demux.wav`.

The sonobuoy data is currently uncalibrated, so you'll notice a sharp low-frequency roll-off. Information on a rough calibration of the data can be obtained on https://cradpdf.drdc-rddc.gc.ca/PDFS/unc82/p518209.pdf. This report indicates that the sensitivity of the omni-channel is –125.5 dB re 1V/ µPa at 100 Hz, with the DIFAR channels have a lower sensitivity (4.1 dB) lower sensitivity of -121.4 dB re 1 V/ µPa.

Note that due to RF-interference occasionally the noise can fluctuate on some of the buoys (Illustrated in Figure 8). Further background information on DIFAR buoy processing can be found at (Rudnicki, 2017; Thode et al., 2019).

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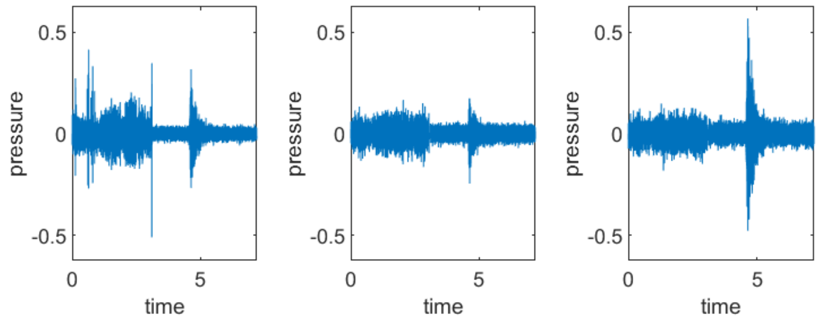


Figure 8 Illustration of changes in system noise (from left to right: Omni, Sine (East-West), and Cosine (North-South) channels, with pressure units uncalibrated in V.

## 2.2 Manual audit of acoustic data

In order to provide convenient access to NARW calls for localization purposes, manual annotations carried out at Dalhousie University are available (kindly provided by Hansen Johnson). Each sonobuoy channel was reviewed independently and individual calls were detected and classified by call type. Annotations include the following information for each call (see also Figure 10):

`file` - name of audio file
`id` - numeric identifier of sonobuoy
`start_time` - start time of the call in seconds elapsed since the start of the file
`end_time` - end time of the call in seconds elapsed since the start of the file
`min_freq` - minimum frequency of the call in Hertz
`max_freq` - maximum frequency of the call in Hertz (capped at about 1 kHz)
`call_type` - code representing the type of call. Codes are as follows:
- `up` - right whale upcall
- `gs` - right whale gunshot
- `mf` - right whale moan
- `sc` - right whale scream
- `mn` - minke whale pulse train
- `lf` - low-frequency pulse (likely blue or fin whale)
- `ds` - low-frequency downsweep (likely blue or sei whale)
- `bl` - blow (unknown species)
- `unk` - unknown (no need to localize)
- `score` - confidence in call type, where `1` is confident and `2` is possible.

Calls with a score of `2` are of low priority to localize. The number of total detections in each call category on the two days are provided in Figure 9 (including both score 1 and 2). As calls are often detected on multiple buoys, the true number of calling animals will be smaller.

NOTE: due to different pre-processing of the acoustic data, there is a small (~1.2 s) time offset between the manual data and the acoustic data timestamps. This time offset should be applied to the ‘start_time’ and ‘end_time’.

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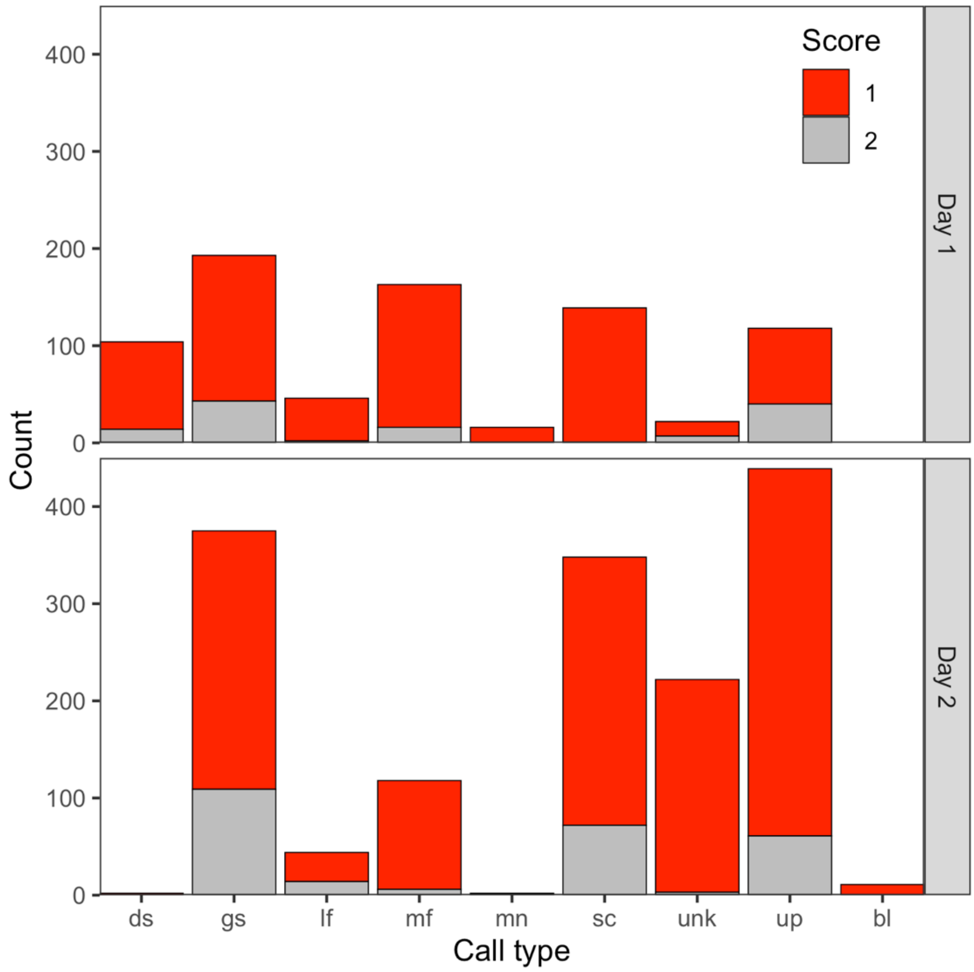


Figure 9 Calls manually annotated by call type on Day 1 and Day 2 over all buoys, including score 1 and 2.

The objective of this process was to obtain a good set of calls for testing localisation algorithms, and detection of calls have been carried out with that objective in mind. The set should not be considered as an ideal ground-truth set for testing/evaluation of classification algorithms, although we certainly recommend people explore this as well.

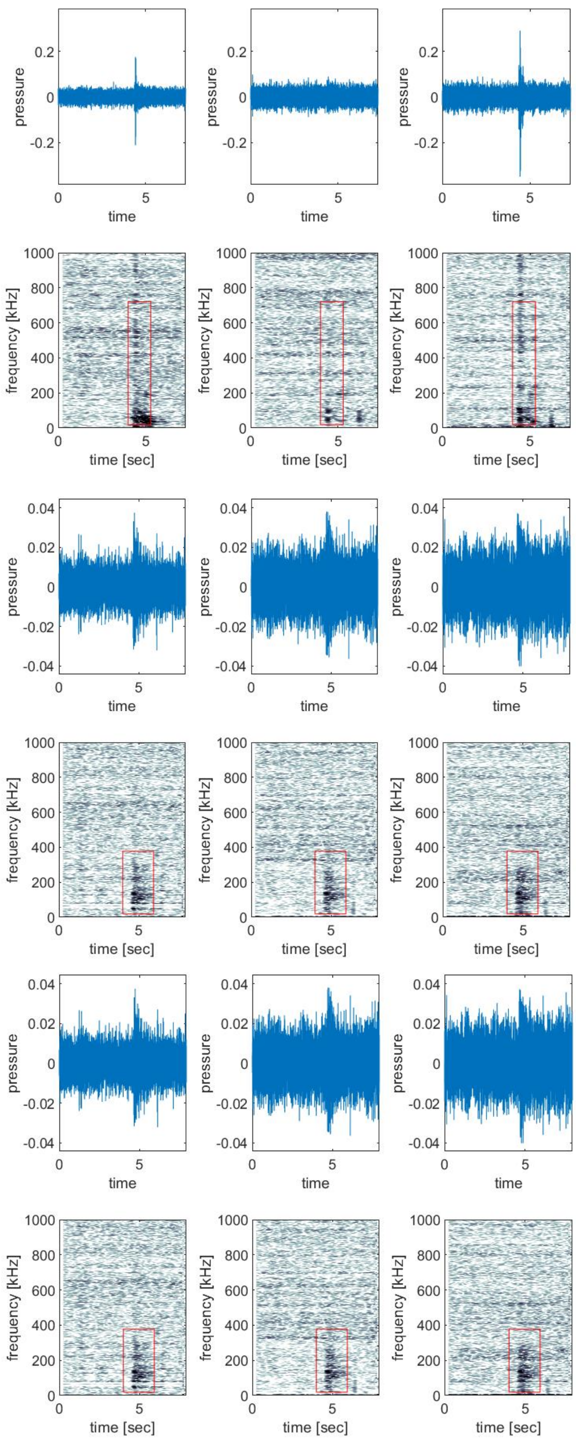


Figure 10 Examples of waveforms and spectrograms of detected NARW calls. From left to right: Omni, Sine (East-West), and Cosine (North-South) channels, with pressure units uncalibrated in V. The red box indicates start, end time, and min and max frequency from the manual annotation. Waveforms were band-pass filtered using a 4th order Butterworth band-pass filter around [$f_{min}$, $f_{max}$]. Spectrograms were made using Hann filter, 4048 length, and 4000 samples overlap), and are colour scaled in dB after normalization. Spectra were normalized by using a 9 sample moving average over the first 10 ms of the signal for each frequency.

## 2.3 Visual observations of North Atlantic Right Whales and weather conditions

Visual observations were carried out during the two deployment days. The ship-based NEAq/CWI/Dal survey team aboard the F/V (fishing vessel) Jean-Denis Martin partially surveyed the array on both days (Figure 11 and Figure 12; kindly provided by CWI). On the second day the NOAA Twin Otter carried out an aerial survey of the area.

Weather conditions were reported during the aerial and ship-based survey. On the first day weather conditions were bad with Sea State (Beaufort scale) ranging between 3 and 6, with poor visibility conditions. This limited the number of sightings overlapping with the array deployment. During the second day weather conditions were better, with sea states between 1 and 4.

For both surveys time, location and group size were noted.

- Time (provided in UTC)
- Location
- (re-sighting)
- Other species (Minke whales, or Unknown)
- Weather conditions

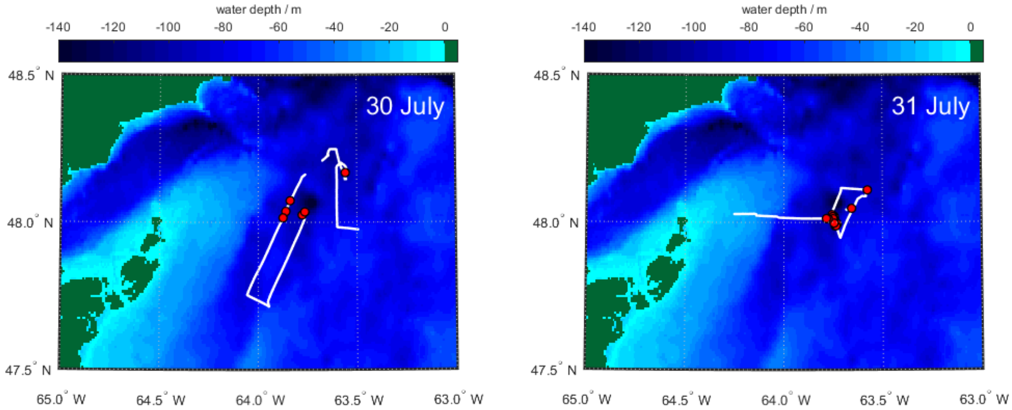


Figure 11 Water depth with NEA2018 sightings superimposed for two the deployment days. The white line indicates the trackline of the vessel used during the ship-based survey, which may serve as a source of opportunity for testing localisation methods.

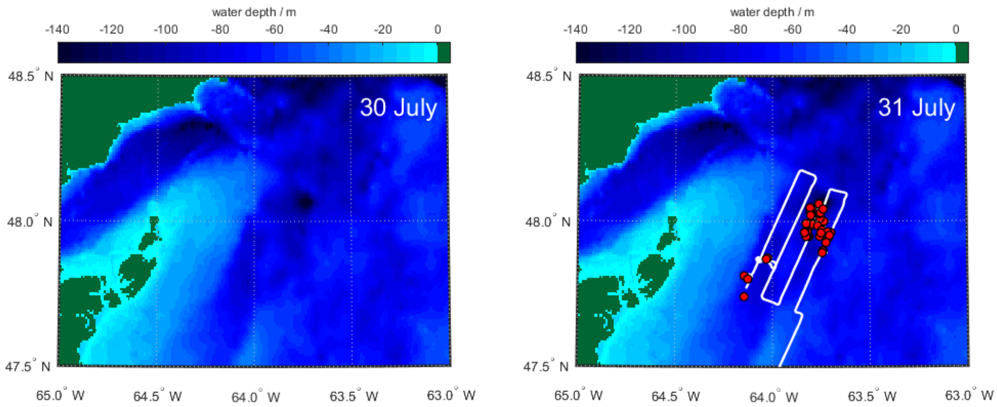


Figure 12 NARW (red circles) sightings for two deployments made from the NOAA2018 aerial survey. The white trackline indicates the flight track of the NOAA Twin Otter plane. Colour scale indicates the water depth in the area which ranged between 50 m and 140 m.

## 2.4 Using visual sightings to ground-truth acoustic localisation methods

Superimposing the buoy locations and visual sightings indicated that there were differences in number of NARW detected during the two deployments (Figure 13 - Figure 16). This can be due to the worse weather conditions on Day 1, but also due to differences in underlying whale distribution for the two deployment locations. On Day 1 there were little sightings that can be used to compare the estimates to. Later in the day shows several events where calls appear to have been detected on multiple buoys. On day 2 multiple sightings are available where there is spatial and temporal overlap between calls recorded on buoys and visual sightings (Figure 16).

In terms of quantity of both calls and sightings Day 2 is optimal, but note that the buoys deployed on Day 1 had a more reliable buoy location data, and even though there is much less ground-truth available, this is still a nice set for testing the localisation performance (see section 3.4: Sources of opportunity).

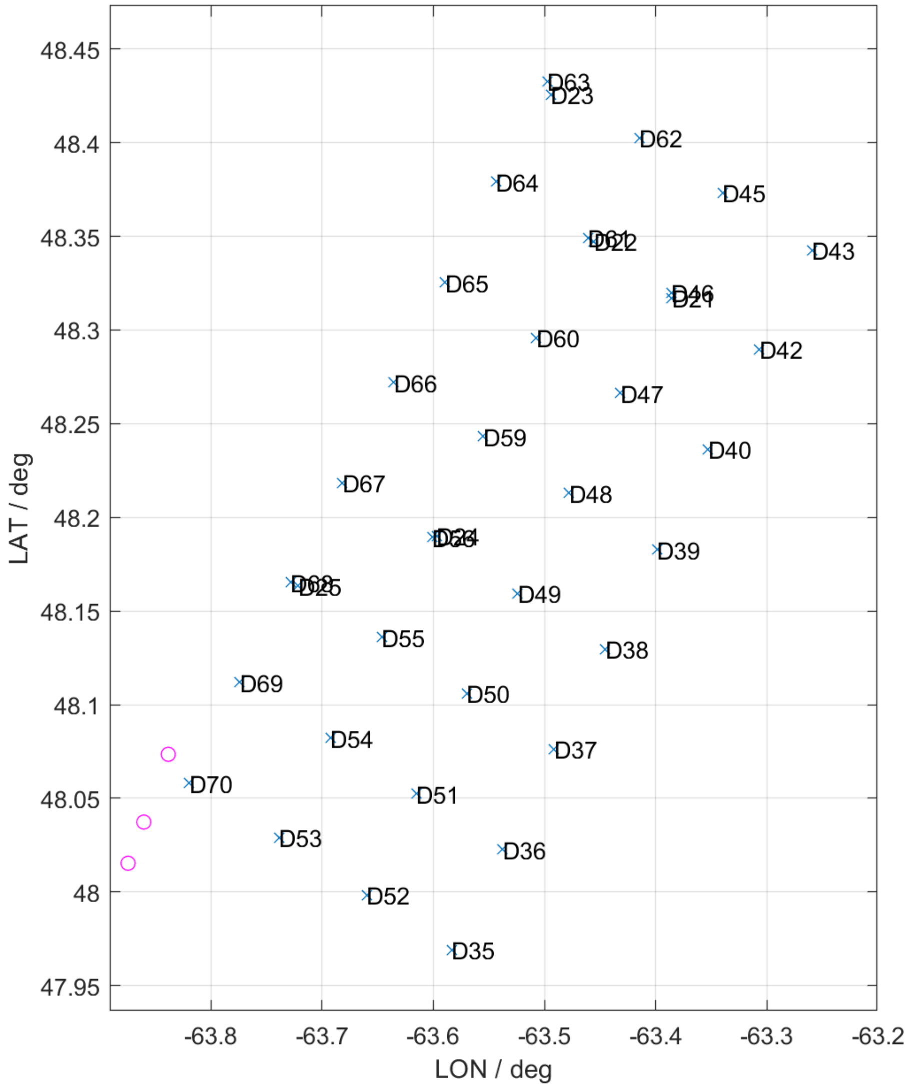


Figure 13 Visual sightings of NARW relative to the buoy locations for 2018-07-30 (DAY1 ) between 09:00 and 18:00.

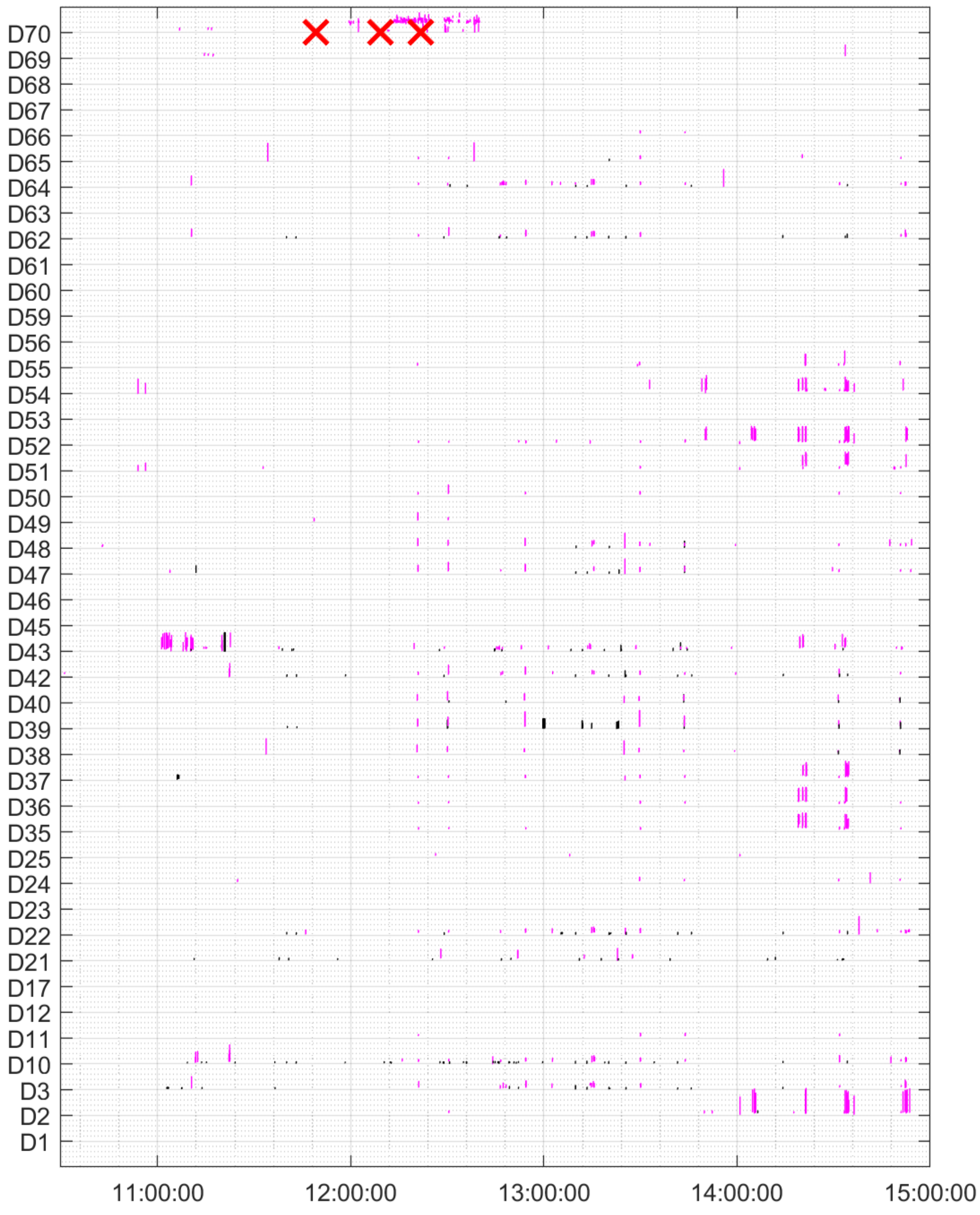


Figure 14 Annotated detections of marine mammal vocalisations for all channels during the 2018-07-30 deployment (DAY 1). Calls are indicated using [$t_{start}$, $t_{end}$] and [$f_{min}$, $f_{max}$] (each channel is normalized between 0 and 1000 Hz), with magenta indicating NARW and black other species. Visual sightings are superimposed using red 'x' on channel corresponding to the buoy closest to the sighting location. Several sightings are clearly co-occurring with NAWR detection, indicating that these can be used as ground-truth for acoustic localisation. Due to poor weather little visual ground-truth was available, although later in the data several occasions with call sequences on multiple sensors were available. Time plotted is in EST time (UTC-4 h).

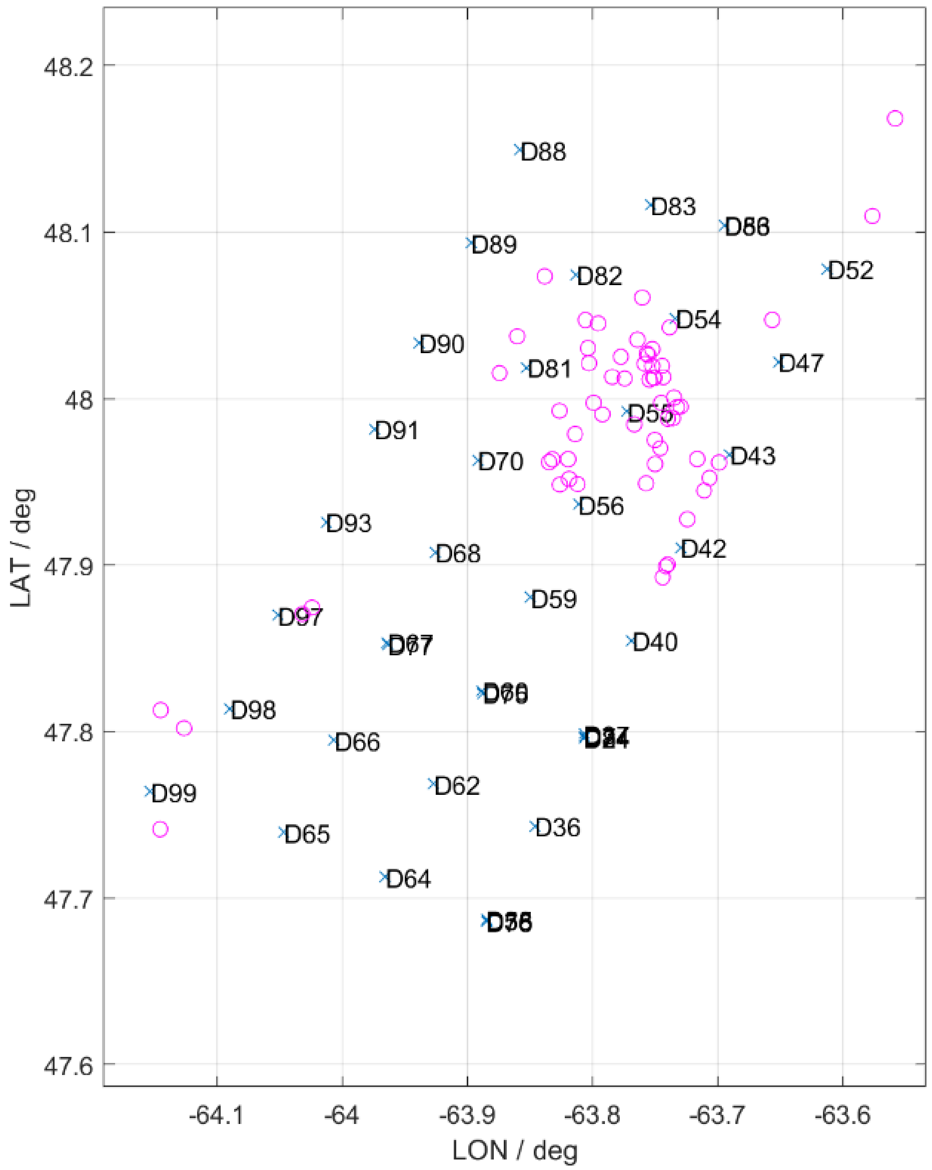


Figure 15 Visual sightings of NARW relative to the buoy locations for 2018-07-31 (DAY2) between 09:00 and 18:00.

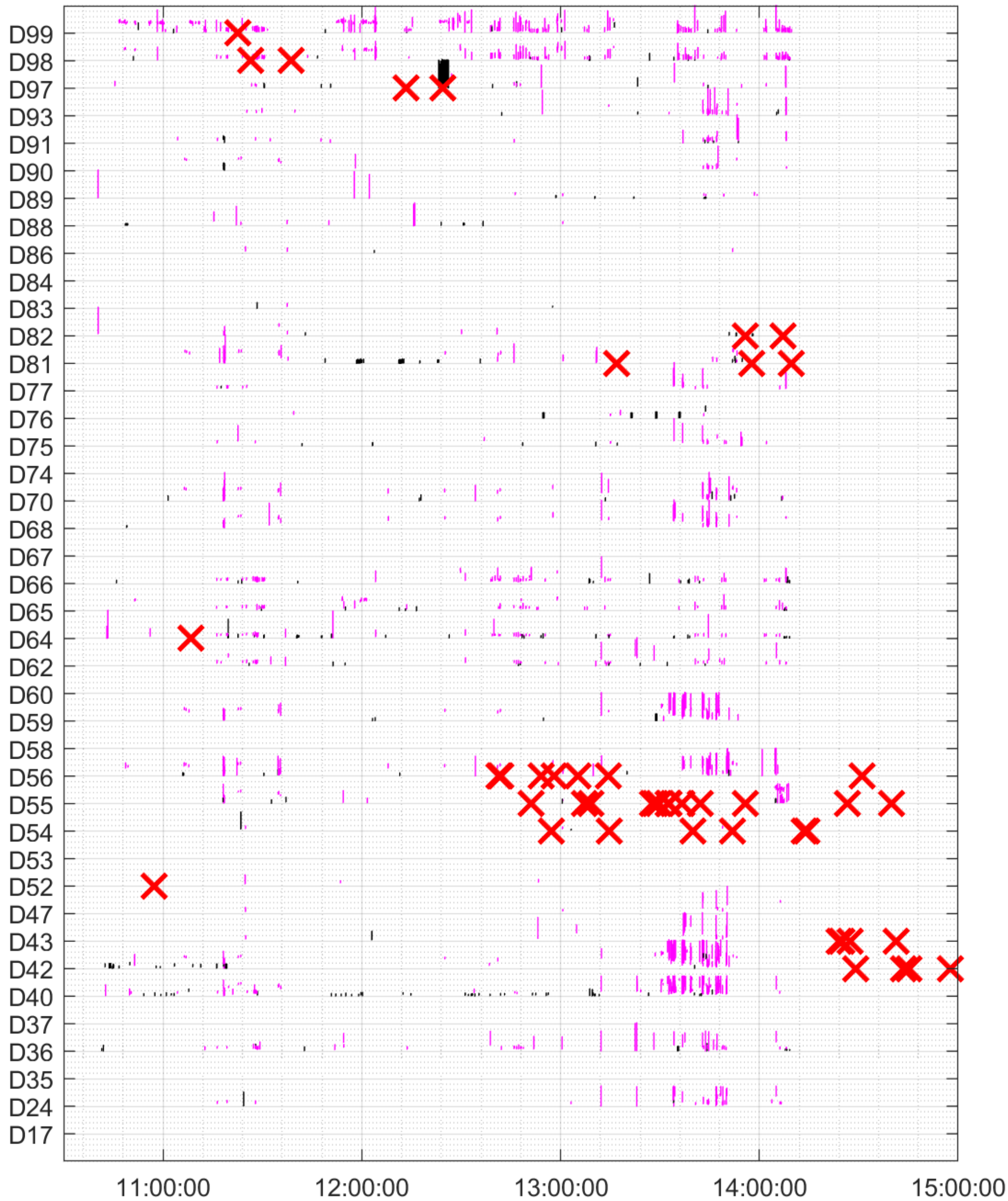


Figure 16 Annotated detections of marine mammal vocalisations for all channels during the 2018-07-31 deployment (DAY 2). Calls are indicated using [$t_{start}$, $t_{end}$] and [$f_{min}$, $f_{max}$] (each channel is normalized between 0 and 1000 Hz), with magenta indicating NARW and black other species. Visual sightings are superimposed using red 'x' on channel corresponding to the buoy closest to the sighting location. Several sightings are clearly co-occurring with NAWR detection, indicating that these can be used as ground-truth for acoustic localisation. Due to poor weather little visual ground-truth was available, although later in the data several occasions with call sequences on multiple sensors were available. Time plotted is in EST time (UTC-4 h).

# 3 Supplemental information

## 3.1 Sound speed profiles

For localisation applications it is useful to known the sound speed in the water. Sound speed information was based on glider data deployed by The Coastal Environmental Observation Technology and Research (CEOTR) at Dalhousie University, made available through CEOTR website (http://ceotr.ocean.dal.ca/gliders/ mission 85 and 87, last accessed 2020-08-13). Gliders recorded time, depth, temperature, salinity, conductivity and pressure. Sound speed was estimated using Mackenzie (1981). Both locations showed a downward refracting profile. No substantial differences in sound speed were observed between the two days, but sound speed at greater depth differed between the two locations (Figure 17 and Figure 18).

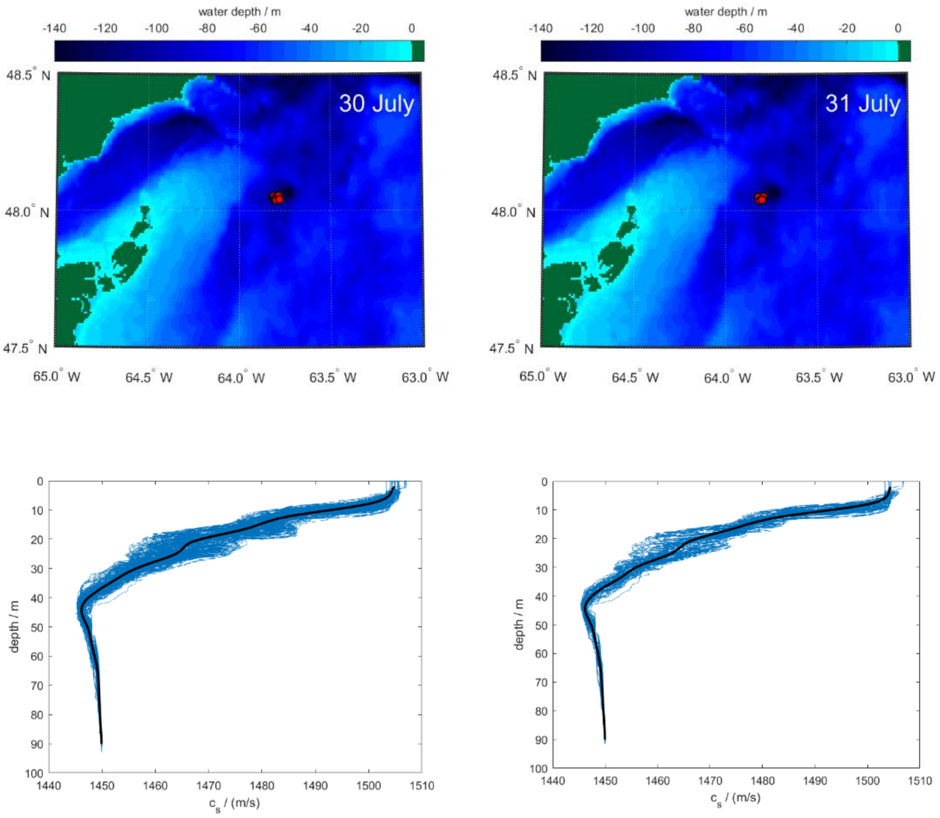


Figure 17 Location and measured sound speed (blue, and mean over 2 m depth intervals in black superimposed) at the two deployment days of glider (Mission M85).

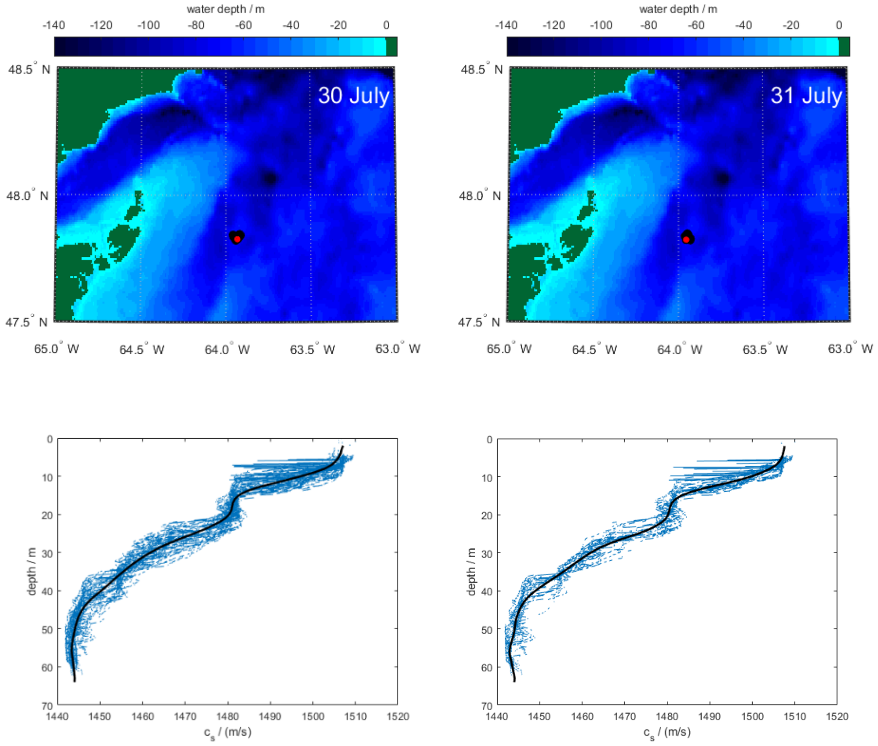


Figure 18 Location and measured sound speed (blue, and mean over 2 m depth intervals in black superimposed) at the two deployment days of glider (Mission M87).

## 3.2 Seabottom geocoustic parameters

Geo-acoustic information in the area can be of interest for some localisation applications. Aulanier et al. (2016) estimated a representative sound speed in the sea floor from model-based inversion of ship sound (Figure 19).

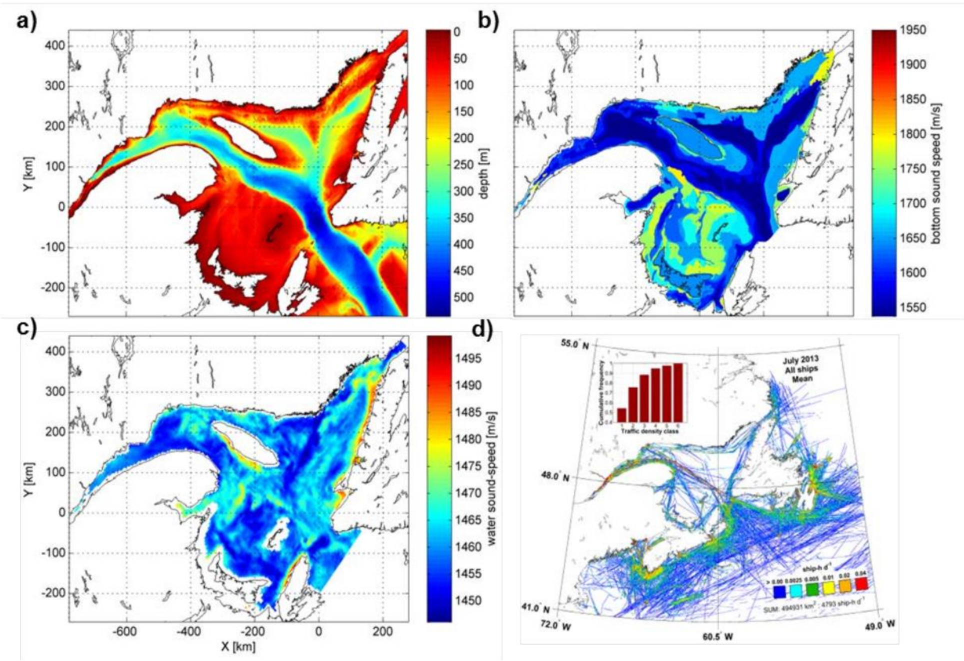


Figure 19 Geo-acoustic parameters of the seabed in Gulf of St. Lawrence (from Aulanier et al. 2016).

## 3.3 Ocean circulation model data

Because source position is not continuously updated on Day 2, it may be useful to consider ocean circulation data to predict the drift patterns of the buoys. This data can be accessed on:

https://weather.gc.ca/grib/grib2_Gulf-St-Lawrence_e.html

UOGRD Zonal component of the surface ocean current [m/s] Oceanic
VOGRD Meridional component of the surface ocean current [m/s] Oceanic

## 3.4 Sources of opportunity

The presence of the CWI survey vessel provides an opportunity to test localisation algorithms using the vessel position as ground-truth. Information of the vessel GPS location is provided (Figure 20).

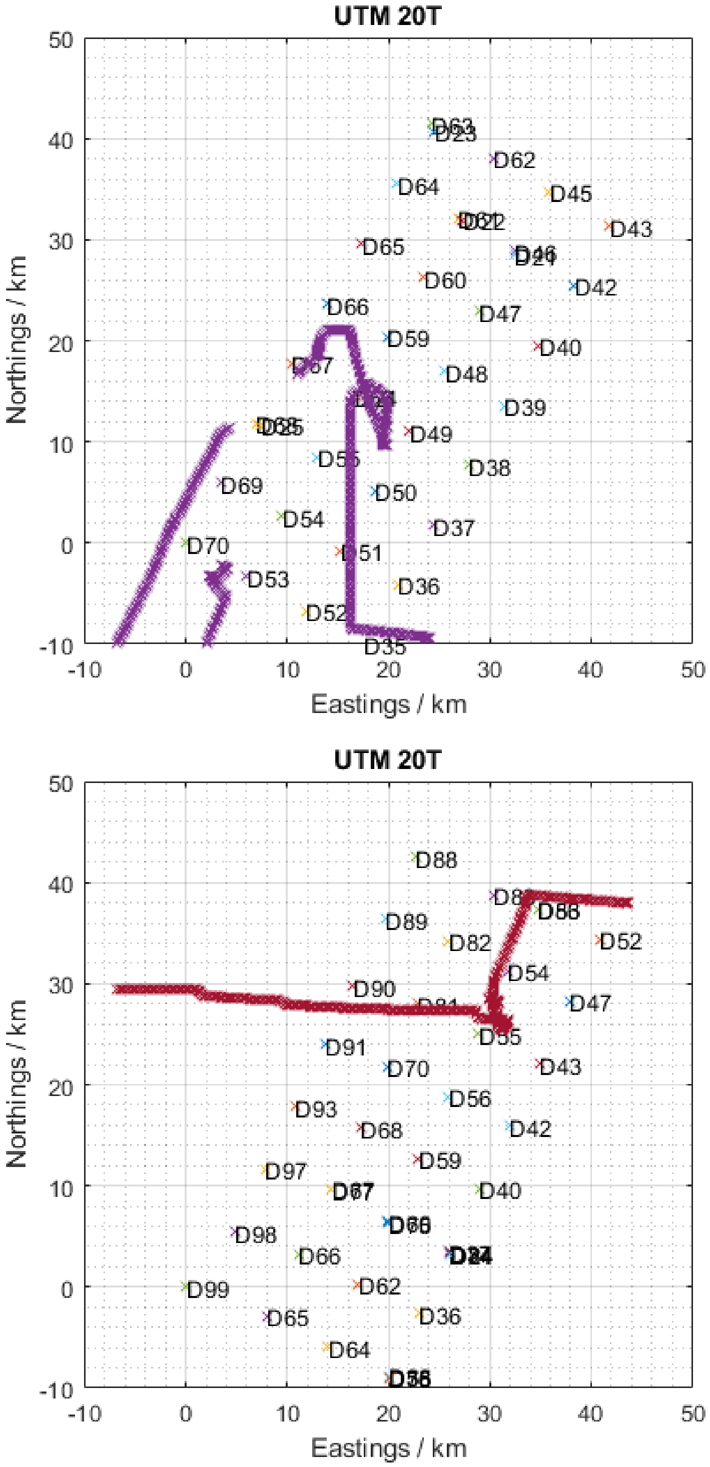


Figure 20 Ship-based survey vessel track (top: Day 1; bottom: Day 2) which may be used as target of opportunity with ground-truth.

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# 4 Workshop comparison process

Step 1: Data release

All data, including ground-truth and meta-data will be released at the DCLD2022 in Hawaii.

Access to acoustic data and meta data is available through the following link per 2022-09-20:

https://sites.drdc-rddc.gc.ca/proj/OS_NARW/
username: DCLDE24C@gmail.com
password: Conference24

Note that this ground-truth dataset is meant to provide a means of evaluating localisation accuracy. As such, these data should not be used to tune localisation algorithms.

Step 2: DCLDE2024 Workshop

We ask people to provide estimated location for calls one week before the workshop so we can collect and compare the estimates.

Provide location estimates in .csv file
Date (UTC), x (UTM20T), y, z, sigma x, sigma y, sigma z, x, $x_{5\%}$, $x_{95\%}$, $y_{5\%}$, $y_{95\%}$, $z_{5\%}$, $z_{95\%}$, Lat, lon (fields optional, leave empty if not available from your method)

At the workshop we intend to organize a dedicated session to compare/discuss localisation methods

- Accuracy
- Robustness
    - SNR
    - Call types
    - Buoy location
    - Environmental uncertainties
- Depth estimates
- Is the method real-time?

Further potential discussion points:

- Ideas for further optimization of mobile networks
- Discuss derived output (if available):
    - Bioacoustics: Animal source level, call rates, etc.
    - Behaviour: Dive behaviour
    - DE: Detection functions, density estimates

# 5 List of data files and units

Table 1 lists all data files with the acoustic, and meta-data for the DCLDE workshop dataset. The total data size is approximately 40 GB, and accessible through https://sites.drdc-rddc.gc.ca/proj/OS_NARW/.

Table 1 Overview of data files containing acoustic recordings and meta-data of the DCLDE workshop dataset

| Filename | Data description |
|---|---|
| <channel name>_1345-1445_demux.wav | Buoy acoustic channels, 8 kHz sampling rate<br>3 channels<br>1) Omni<br>2) Sine (East-West)<br>3) Cosine (North-South) |
| annotations.xlsx | Annotations of whale calls detected on the sonobuoy dataset |
| buoydata.xslx | Buoy locations day + recording times |
| sightings.xlsx | Visual sighting aerial survey using the NOAA Twin Otter and Visual sightings from the ship-based NEA/CWI survey. |
| SSP.xlsx | Sound speed profiles measured using gliders M85 and M87 |
| CWI_vessel_track.xlsx | Ground-truth for NEA/CWI vessel |

**Annotations.xlsx:**

‘time_utc_start’: start time of annotated call in UTC
‘time_utc_end’: end time of annotated call in UTC
‘starttime_since_startrec_sec’: start time since start recording in seconds
‘endtime_since_startrec_sec’: start time since start recording in seconds
‘file’: name of in which annotation was performed
‘buoy_id’: id of buoy in which call was detected
‘min_freq’: minimum frequency of call in Hertz
‘max_freq’: maximum frequency of call in Hertz
‘call_type’: annotation of call type (see Section 2.2).
‘score’: score of confidence of call type (see Section 2.2).

NOTE: due to different pre-processing of the acoustic data, there is a small (~1.2 s) time offset between the manual data and the acoustic data timestamps. This time offset should be applied to ‘time_utc_start’ and ‘time_utc_end’.

**Buoydata.xlsx:**

*Location-tabs:*
'buoy_id': buoy id
'buoy_time_utc': time at which location estimate is provided in UTC
'buoy_lon': buoy longitude in degrees rel. E at given time
'buoy_lat': buoy latitude in degrees rel. N at given time

*Record time tabs*:
'buoy_id': buoy_id
'time_start_rec_utc': start of recording time of buoy in UTC
'time_stop_rec_utc': end of recording time of buoy in UTC

**Sightings.xls**

*NOAA aerial:*
'time_utc': time of sighting in UTC
'altitude': plane altitude in feet
'longitude': plane longitude in degrees rel. E at given time
'latitude': plane latitude in degrees rel. N at given time
'heading': plane heading
'species_code': detected species (only North Atlantic Right Whales, RIWH) shown
'number_whales': group size (number of whales sighted)
'confidence': reliability of species identification (3=definite, 2=probable)
'angle_whale': declination angle from plane in degrees (0º=horizontal, 90º = down)
'observer_pos': Position of the observer who made the sighting (L=left, R=right, C=center)

*NEA2018 sightings:*
'time_utc': time of sighting in UTC
'lat_ship': plane latitude in degrees rel. N at given time
'lon_ship': plane longitude in degrees rel. E at given time
'heading_ship': heading ship in degrees rel. N at given time
'number_whales': number of whales sighted

**SSP.xlsx**

'depth': measurement depth at which mean sound speed is measured
'sound_speed': mean sound speed in depth interval in meter per second
'sigma_sound_speed': standard deviation of sound speed in depth interval in meter per second

**CWI vessel track.xlsx**

'ship_loc_time_utc': ship time in UTC
'ship_loc_lon': ship longitude in degrees rel. E at given time
'ship_loc_lat': ship latitude in degrees rel. N at given time
'ship_loc_x_utm20T': ship x position in UTM20T coordinate system

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‘ship_loc_y_utm20T’: ship y position in UTM20T coordinate system

# 6 Acknowledgements

This dataset is kindly made available to the DCLDE community by the research consortium consisting of Dalhousie University, Fisheries and Oceans Canada (DFO), Defence Research and Development Canada (DRDC), the Acoustic Data Analysis Centre (ADAC), the National Oceanic and Atmospheric Administration (NOAA) Northeast Fisheries Science Center (NEFSC), the New England Aquarium (NEAq) Anderson Cabot Center for Ocean Life (ACCOL), and the Canadian Whale Institute (CWI). The acoustic data was collected by the Royal Canadian Airforce (RCAF). We kindly ask the users of dataset to credit the dataset providers.

Funding to support the preparation of this dataset has kindly been provided by DFO, The Netherlands DMO, and The Netherlands Rijkswaterstaat. A special thanks to Angelia Vanderlaan, René Dekeling and Ingeborg van Splunderen for supporting the preparation of the DCLDE workshop dataset.

# 7 References

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# 8 Signature

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