Challenge #1

Marine acoustic sensing using repurposed fibre optic cables

THALES
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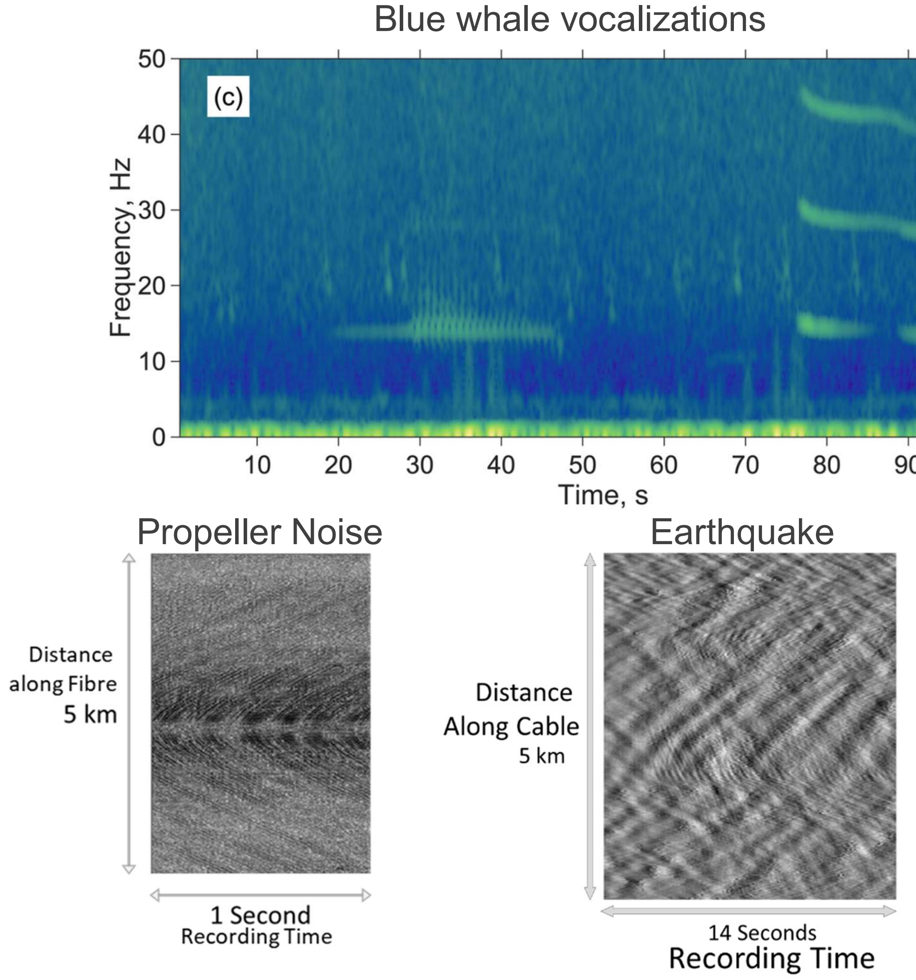
Context

We invite you to work with an exciting new technology; distributed fibre optic sensing. This amazing sensing system uses off the shelf fibre optic cables, like the ones we use for our internet and telecoms, and repurposes them to be vast arrays of microphones (or thermometers) measuring vibrations (and temperatures) every couple of meters over 10's of kilometres.

We have access to the Ocean Observatories Initiative RAPID dataset where two seafloor cables located offshore Oregon recorded data over a 4 day period in 2021 (Wilcock et al., 2023). Over that time period we can observe wave and tidal effects, earthquakes, marine mammals (blue & fin whales), shipping and road traffic. The challenge is to integrate multiple datasets, separate the signals from the noise and improve detection and classification on these data.

In this hackathon, you will be provided with access to these seafloor cable data, and your task will be to develop algorithms that can process and analyze these phenomena.

Example:



Data examples from Wilcock et al., 2023 (top, left) and OptaSense.

Challenge Goals

This is a multi-faceted dataset that includes fibre optic Distributed Temperature Sensing (DTS), fibre optic Distributed Acoustic Sensing (DAS), AIS (vessel tracking data), bathymetry, earthquake catalogues and weather data. For this reason there are many different possibilities, we have suggested a few challenges below. You could tackle these sequentially or you could focus on just one. You are welcome to propose your own challenge as there are so many possibilities!

Challenge 1: Signal Conditioning

Whilst fibre optic data provides new acoustic sensing opportunities it does has challenges including a lower sensitivity. The first challenge is to improve the signal conditioning to improve data quality. In other words,

- What is the optimal processing flow for vessel noise, marine mammals, waves and earthquakes?
- These are vast datasets (26 Terabytes) so automated fast processing automated detection are needed.

How many vessels, whales and earthquakes can your team find !

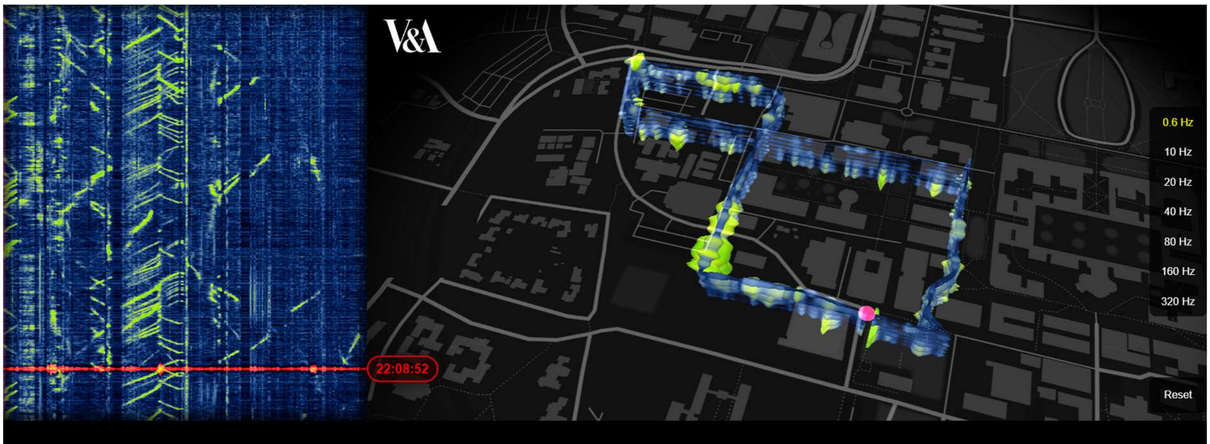
Challenge 2: Information Extraction

Detecting and classifying an event is just the start of an information extraction process. Once we have identified a signal we want to extract more information. So, in the case of propeller noise we would want to know how fast the propeller is turning, how many blades does it have and where is the vessel? For marine mammals we might want to identify the species, it location and its depth. This challenge is to take the identified signals and try to extract as much information from it, such as

- Locating & Tracking vessels/marine mammals
- Characterize ocean hydrodynamics tides/waves etc.

Challenge 3: Visualization of integrated datasets

This is a diverse dataset that would benefit from interactive data visualization tools. If you want to be inspired then take a look at the recent 'Big Glass Mic' exhibit at the Victoria & Albert Museum exhibit [link, Stamen Design]. This shows an interactive acoustic data visualization from 'dark fibre' around Stanford University's campus using waterfall plots and spatial visualizations of the fibre.



Big Glass Microphone is a collaboration between Stamen Design and the Victoria and Albert Museum.

Pre-requisites

We will provide a curated data subset and Jupyter notebooks to jumpstart the process. We will also suggest some libraries that you may wish to preinstall and test.

You will need to bring a laptop with appropriate computing tools e.g. Python / MATLAB etc., as well as any relevant libraries/toolboxes e.g. NumPy, Matplotlib, PyTorch, TensorFlow.

Background Material

1. RAPID: Distributed Acoustic Sensing on the OOI's Regional Cabled Array – Ocean Observatories Initiative. [Link]
2. Victoria & Albert Museum Big Glass Mic Data Visualization [Link]
3. Distributed acoustic sensing recordings of low-frequency whale calls and ship noise offshore Central Oregon: JASA Express Letters: Vol 3, No 2 (scitation.org) [pdf]

Online Resources

awesome-das: A curated list of DAS tools and resources on Github. [Link]

DAS4Whale https://github.com/leabouffaut/DAS4Whales

DASDae DASDAE · GitHub

Ocean Observatories Initiative RAPID dataset

Wikipedia: Distributed Acoustic Sensing [link]

Segment Anything Model [link]

Oriented Filtering [link]

Videos

Using DAS to observe nearshore waves and processes - Hannah Glover & Marcela Ifju [link]

Seafloor Fibre Optic Sensing Joint IRIS & DAS RCN Webinar [link]

References

Wilcock, W. and Ocean Observatories Initiative (2023). Rapid: A Community Test of Distributed Acoustic Sensing on the Ocean Observatories Initiative Regional Cabled Array [Data set]. Ocean Observatories Initiative. https://doi.org/10.58046/5J60-FJ89

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Waagaard, OH, et al, (2021) Real-time low noise distributed acoustic sensing in 171 km low loss fiber. *OSA Continuum,* 4(2), 688–701. doi.org/10.1364/OSAC.408761

Waagard, O. H. 2022. Listening across the oceans: Distributed acoustic sensing.

Ugalde, A. 2022. Noise levels and signals observed on submarine fibers in 1 the Canary Islands using DAS.

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Andreia Pereira, Danielle Harris, Peter Tyack, and Luis Matias. 2016. Lloyd's mirror effect in fin whale calls and its use to infer the depth of vocalizing animals. Proc. Mtgs. Acoust. 27, 070002; doi: 10.1121/2.0000249

Hiroyuki Matsumoto, Eiichiro Araki, Toshinori Kimura, Gou Fujie, Kazuya Shiraishi,

Takashi Tonegawa, Koichiro Obana, Ryuta Arai, Yuka Kaiho, Yasuyuki Nakamura,

Takashi Yokobiki, Shuichi. 2021. Detection of hydroacoustic signals on a fiber-optic submarine cable. Nature Scientific Reports. 11:2797

M. Karrenbach1*, R. Ellwood1, V. Yartsev1, E. Araki2, T. Kimura2, H. Matsumoto2. 2020. Long-range DAS Data Acquisition on a Submarine Fiber-optic Cable. EAGE Workshop on Fiber Optic Sensing for Energy Applications in Asia Pacific.

Data Organization

The data from the North and South cables have been acquired by two separate companies; OptaSense and Silixa. OptaSense recorded data on both cables at different times with different recording parameters and used the HDF5 data format. Silixa recorded data on the South cable with the same recording parameters in the TDMS format.

For your convenience we have converted some of the data into the MatLab™ data format with a format naming convention of

`Company_Cable_YYYYMMDDHHMMSS_GL_SPACING_SAMPLINGFREQUENCY.mat`

where

`Company`	= Company name (Either OPT for OptaSense or SLX for Silixa)
`Cable`	= Cable name (either North or South)
`YYYYMMDDHHMMSS`	= UTC Date and Time stamp
`GL`	= Gauge Length in meters (related to fibre optic DAS)
`SPACING`	= Spacing between adjacent channels in the data
`SAMPLINGFREQUENCY`	= Sampling frequency in Hertz

So for example

Opt_North_20211104020002_51_2_200.mat

is data recorded by OptaSense on the North cable on the 4th November 2021 at 02:02:51 UTC using a gauge length of 51m, with a 2m channel spacing at 200Hz.

The data examples are stored in the data folder with sub folders

- Earthquakes
- MarineMammals
- Oceanography
- Vessels
- README.txt

Data can be converted from the original HDF5 and TDMS data formats using the Python Jupyter notebook

`UKAN2023_ConvertToMatlabFormat_v01.ipynb`

Code

We provide Python Jupyter notebooks (and MatLab™ scripts) to provide a quick start to the challenges;

UKAN2023_Oceanography_v01.ipynb

UKAN2023_Bathymetry_v01.ipynb

UKAN2023_Earthquakes_v01.ipynb

UKAN2023_MarineMammals_v01.ipynb

UKAN2023_Vessels_v01.ipynb

These notebooks will read in data examples, implement minimal processing and display data plots.

UKAN2023_MarineMammals.m

UKAN2023_Vessels.m

We have converted some code from Python to Matlab™.

Marine Mammals

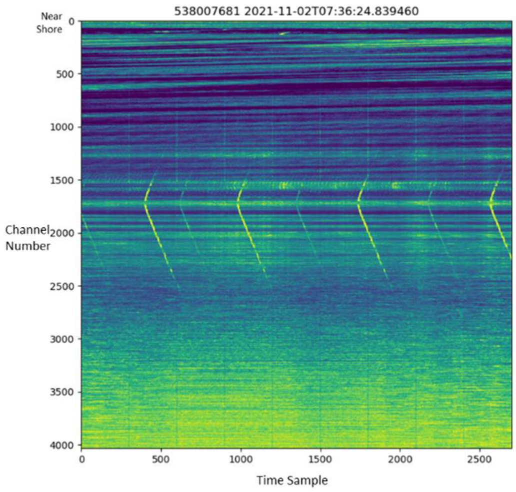
The data were acquired in a region where fin and blue whales are present. A fin whales typical call lasts for about 1 s around 20 Hz. Blue whale calls appear in the 15-40 Hz range.

The plot to the right shows an example of multiple fin whales from the 2nd November 2021 around 07:36.

These calls take on a chevron shape where the apex (around channel 1700) corresponds to the closest channel to the fin whale. The slopes of the chevron can be used to infer the distance from the cable (linear slopes indicate the whale is close to the cable; curved slopes indicate the whale is more distance).

Propeller noise from a shipping vessel (MMSI 538007681) can also be observed around channel 1500.

The data shown is after application of a band pass frequency filter centred around 20 Hz.

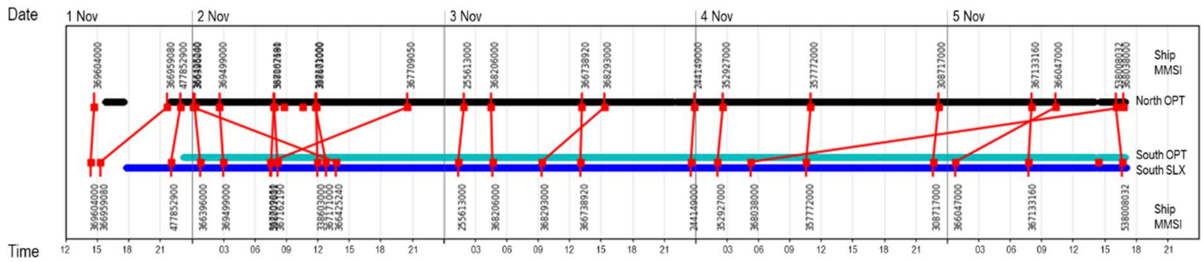


Vessels

Using AIS (Automatic Identification System is a messaging service describing the passage of marine vessels) data we can see that multiple vessels pass above the two cables during the 4 day recording period. The AIS data have been downloaded and stored as a CSV file;

`ClosestVessels.csv`

The AIS information is summarized in the timeline below where the horizontal axis indicates the date and time, the three horizontal lines indicate the data coverage recorded on the North cable by OptaSense (black line) and the cyan and blue cables indicate data recorded on the South cable by OptaSense (cyan) and Silixa (blue). The red lines indicate the approximate times at which vessels pass over the two cables. The vertical text indicates the MMSI number (Marine Mobile Service Identity is a unique number used to identify a marine vessel) for the vessel.



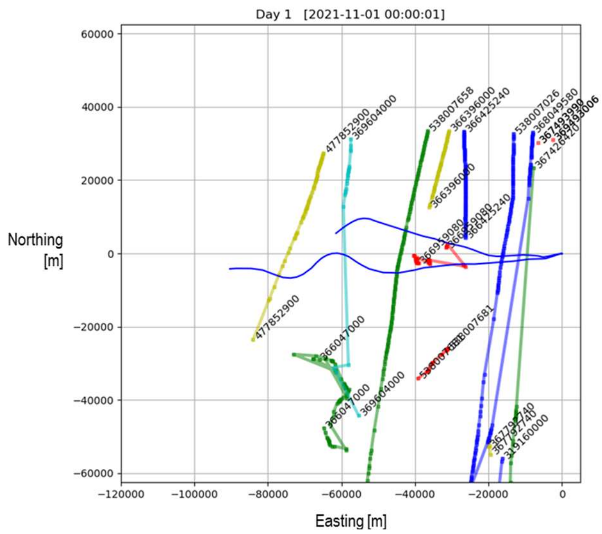
As an example we can see that that the vessel with an MMSI number of 357772000 passes over the South cable at approximately 11 am on the 4th November for which data is available from the OptaSense and Silixa. The same vessel passes over the North cable at a slightly later time for which OptaSense data is available.

Another way to look at the AIS data is to plot the geographic information relative to the cables.

Tracks for individual vessels passing close to the cables on the 1st November 2021 is shown to the right. The location of the North and South cables is shown as blue lines.

Where AIS data is available a solid square is plotted and connected by a line to the next recorded data point.

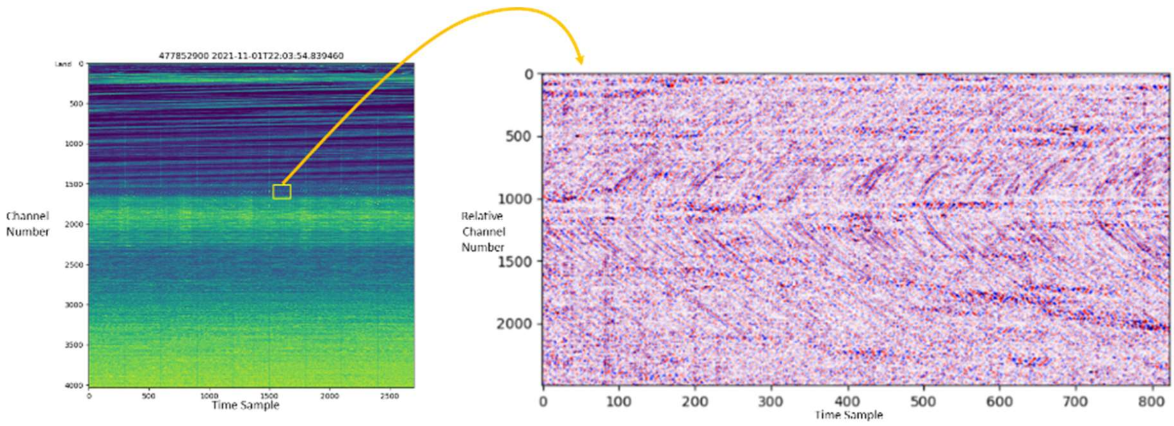
It can be seen that for some vessels there are gaps in the AIS data e.g. vessel with MMSI 369604000 (shown as a cyan line as the second track from the left). AIS data for this vessel is fairly complete towards the north but unfortunately there is a big gap as the vessel passes over the cable.



As an example we show data (after high pass filtering to remove strong low frequency wave noise) from vessel 477852900 (the Western Maple, a bulk carrier) as it passes over the South cable at 22:01 on the 1st November 2021.

The plot to the below shows all the channels over about 13 seconds. The vessel data can be observed around channel 1600, as shown in the zoom shown to the right.

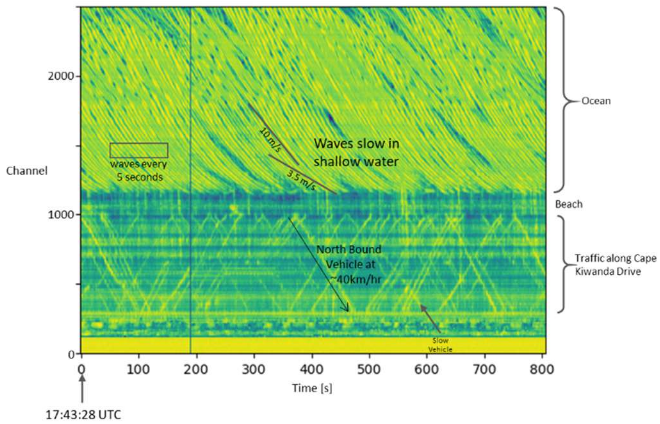
This noise is typical of propellers and can be characterized to estimate the number of blades (e.g. DEMON processing).



Oceanographic

The data provided for the oceanographic challenge has been pre-processed to provide data from the first day of recording to reduce the data volume to a more appropriate sampling relevant to oceanographic scale problems (by block averaging over 1 second intervals and 20 meters).

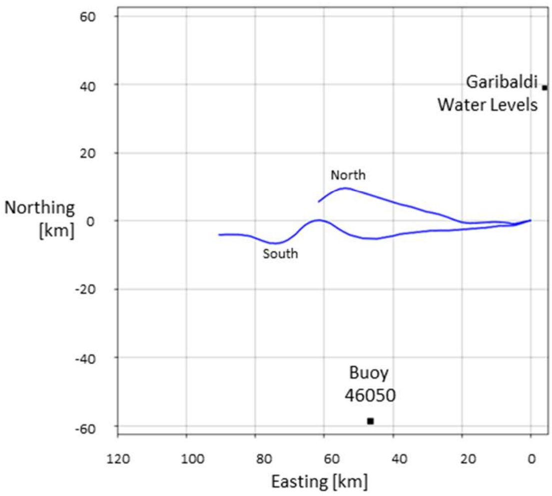
An example of nearshore data is shown below. We can observe that the fibre was deployed parallel to a road for the first kilometre before passing across the beach and into the ocean. Where the fibre was next to the road we can see traffic passing in both directions at approximately 40 km/hour. In the surf zone we can see individual waves breaking onto the beach every 5 seconds and slowing down as they pass into shallower water.

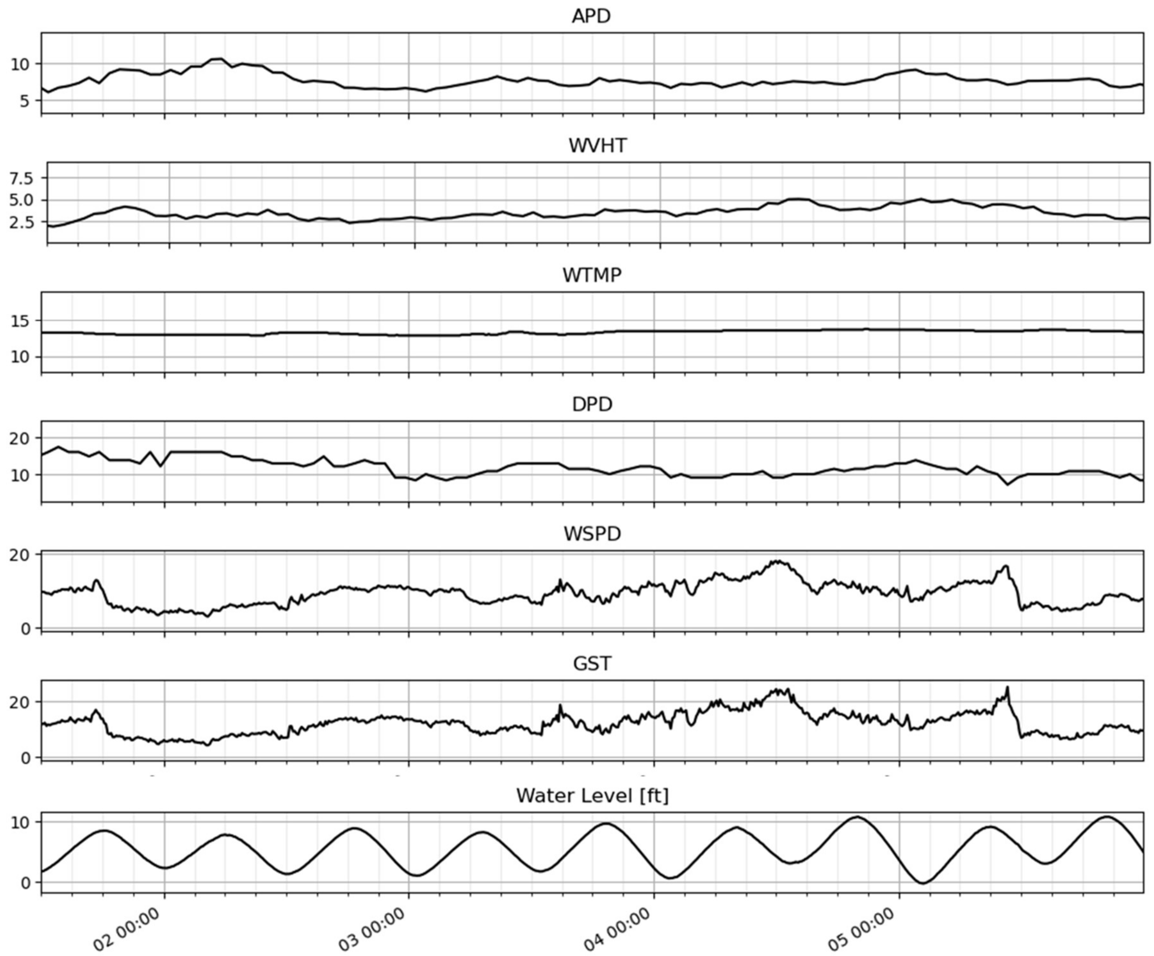


Yellow line is 1.7km, roadside segment is 1.4 km
White box indicates the position reported in the cable geometry file for station 1.

Also provided are NOAA (National Oceanographic and Atmospheric Administration) data recorded on an offshore buoy (4606) and a shore station (Garibaldi).

These data include quantities such as (APD), wave height (WVHT), water temperature (WTMP), Dominant Period(DPD), wave speed (WSPD), gust wind speed (GST) and Water Level (below).

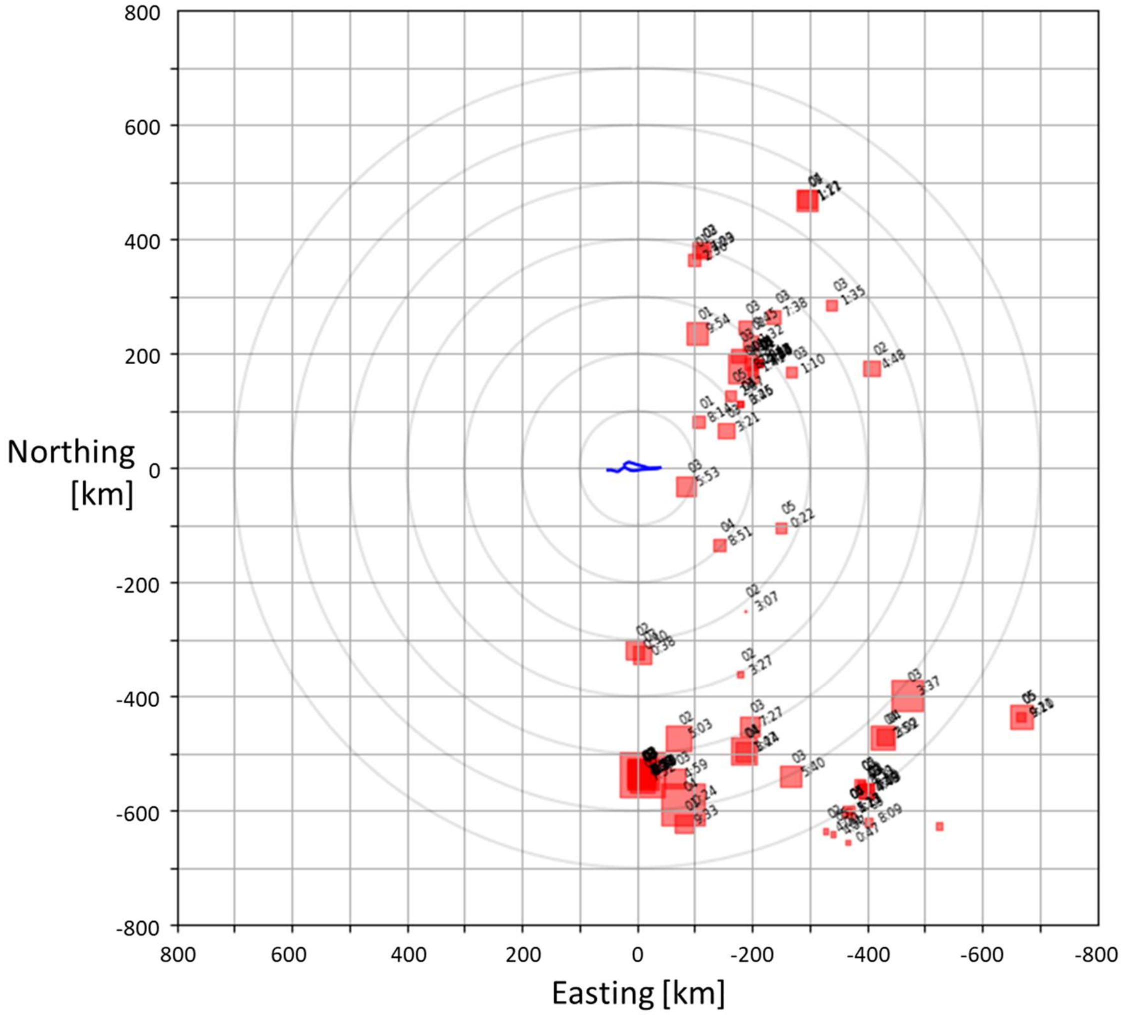



APD
10
5
WVHT
7.5
5.0
2.5
WTMP
15
10
DPD
20
10
WSPD
20
0
GST
20
0
Water Level [ft]
10
0
02 00:00
03 00:00
04 00:00
05 00:00

Earthquakes

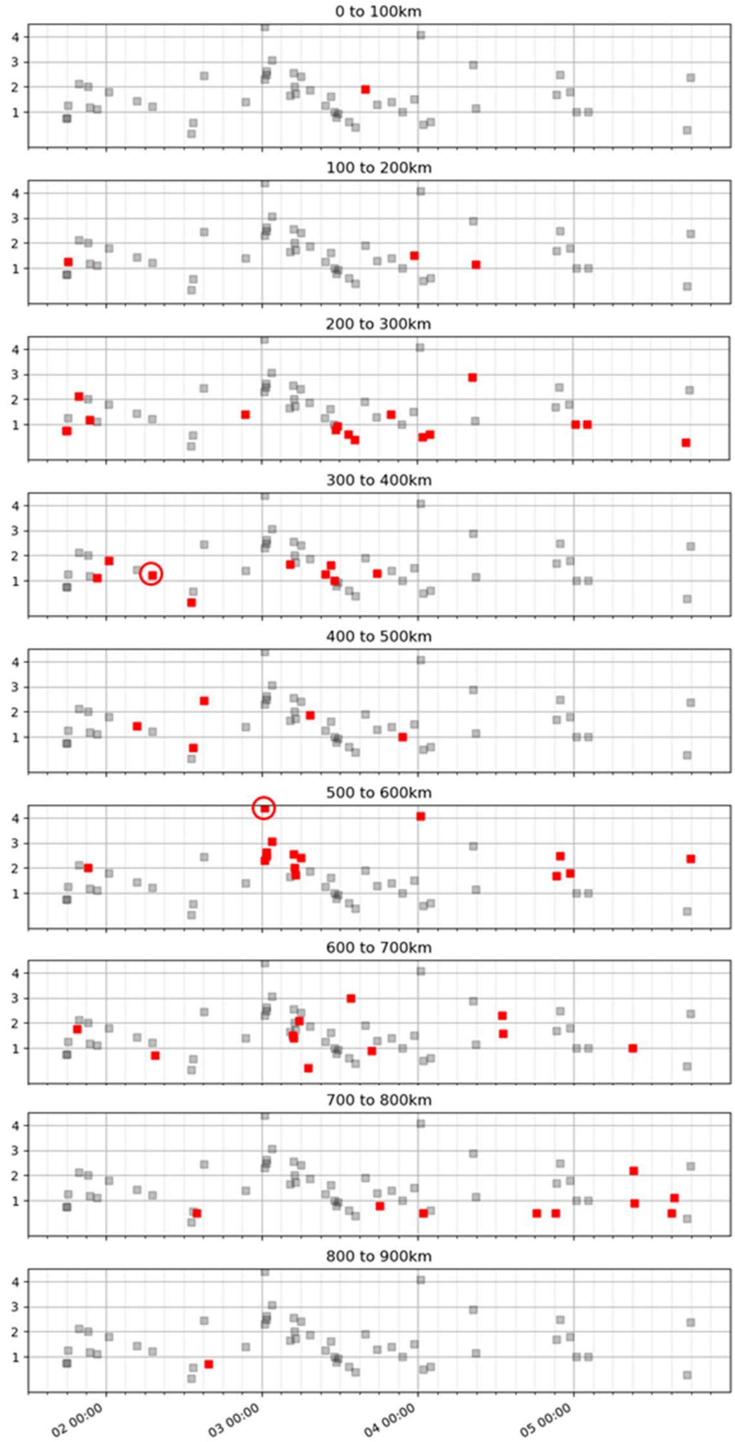
Oregon lies in an active earthquake zone due to its proximity to the Cascadia Subduction Zone. It is estimated that there is potential for a 9+ magnitude earthquake that could result in a 30m high tsunami.

We have extracted data from the USGS (United States Geological Survey) earthquake catalogue over the 4 day period when the fibre optic data were recorded within a range of about 800km. The recorded events (mostly earthquakes but also man made events) are shown below with the events and times of the event shown as black text next to a red square that is scaled according to the magnitude of the event. The largest event in these extracted data is a 4.4 magnitude event that occurred on the 3rd November 2021 at 00:24 approximately 540km to the south of the cables.

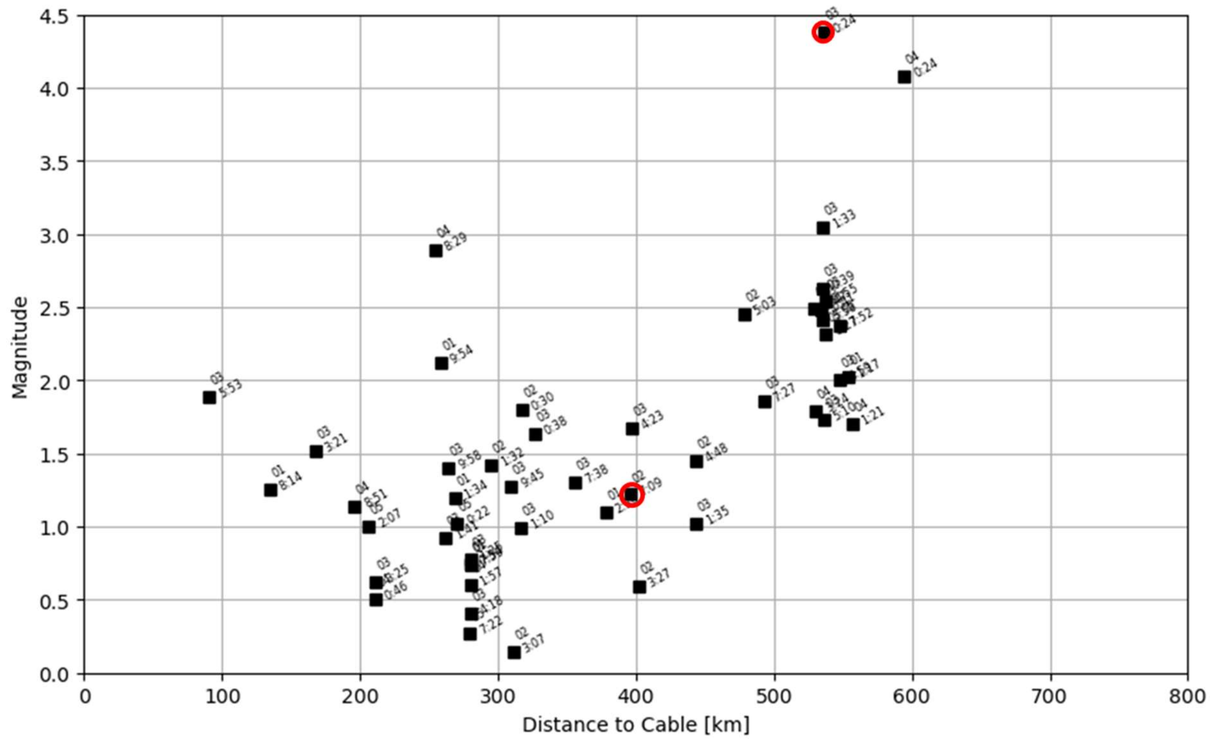


These earthquake data are also plotted as a function of range and time and also as a function of magnitude and distance from the cables. These two plots can be used to identify events that are likely to be observed in the DAS data.

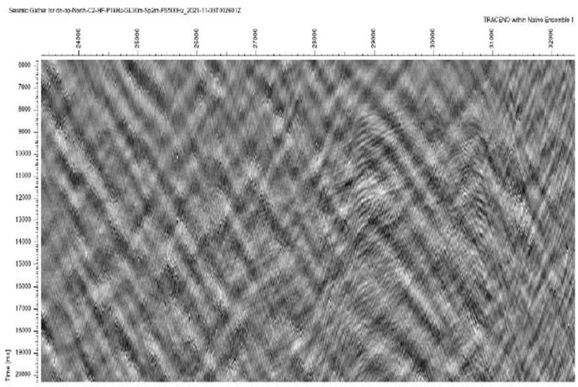
Each of the panels to the right shows events recorded by the USGS in the 4 day time period where fibre optic data are being recorded. Each panel shows data filtered into ranges of 100km with the top panel showing the closest events within 0 to 100 km and the bottom panel showing data in the range 800 to 900 km from the cable. For each panel the horizontal axis indicates the time and date of the event the vertical axis indicates the magnitude of the event. Two data points have been highlighted by red circles and indicate events that have been detected in the DAS data. The red events are all of the earthquake events that occur within the range specified for that graph.



Another way to plot these events is a function of date and magnitude (below). Using this data visualization we can identify events that are more likely to be observed in our data. Events that are more likely to be observed in the DAS data will be large events occurring close to the cable. These events will be plotted to towards the top left. Conversely, small events that occur far from the cables will lie towards the bottom right. The two events that are highlighted with red circles indicate events that are observed in the DAS data.

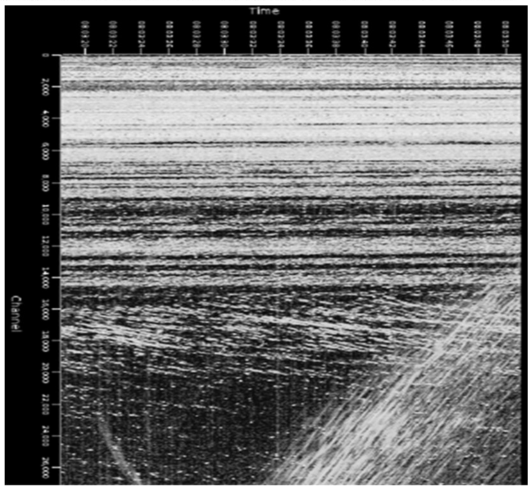


This plot (from the OptaSense acquisition report) shows T-phases from the 4.4 magnitude event on the 3rd November 2021 at 00:24 approximately 540km of the cables. The T-phase ('Tertiary' phase) has a higher frequency content compared to the background noise and corresponds to acoustic energy transmitted through the ocean.

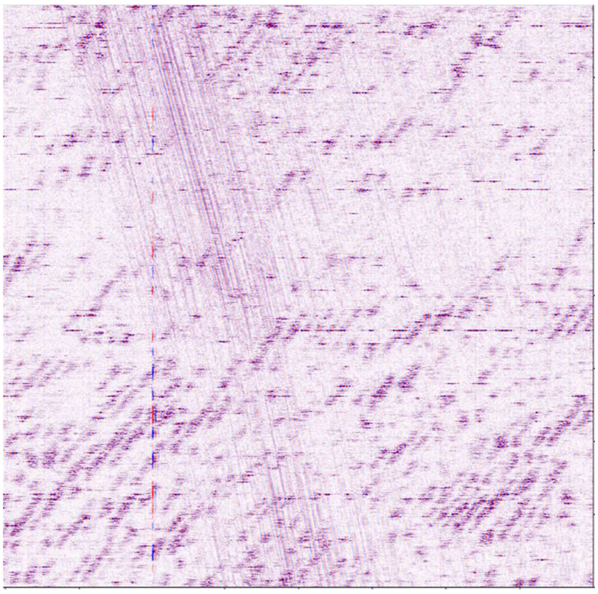


This plot (from the OptaSense acquisition report) shows another T-phase recorded on the North cable in the 12-25 Hz frequency range from the 2nd November 2021 from about 8 in the morning. This is thought to be the 1.2 magnitude event located about 400km from the cables.

Also present is a fin whale call (apex at around channel 20000

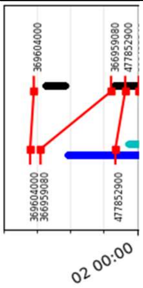


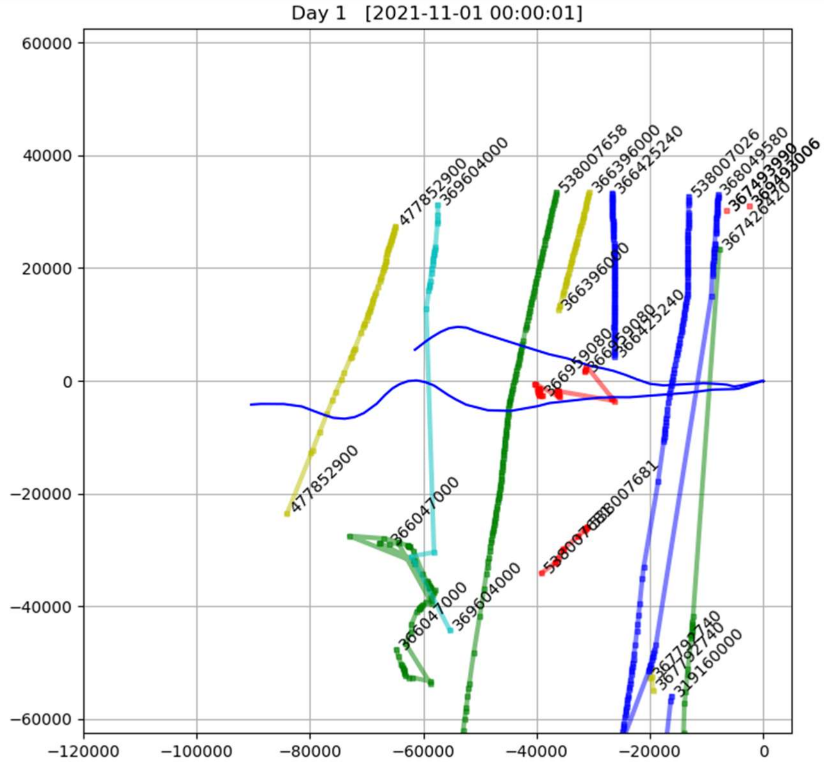
This plot to the right shows a 2.45 magnitude earthquake (nc73647855) located about 500km from the cables. The earthquake occurred on the 2rd November 2021 at 15:03:55 and was detected a minute later on the North cable. The data shown is recorded on the North cable after application of a 2.5Hz high pass filter.



Vessel Challenge

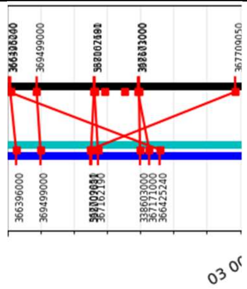
Day 1 [1st November 2021]

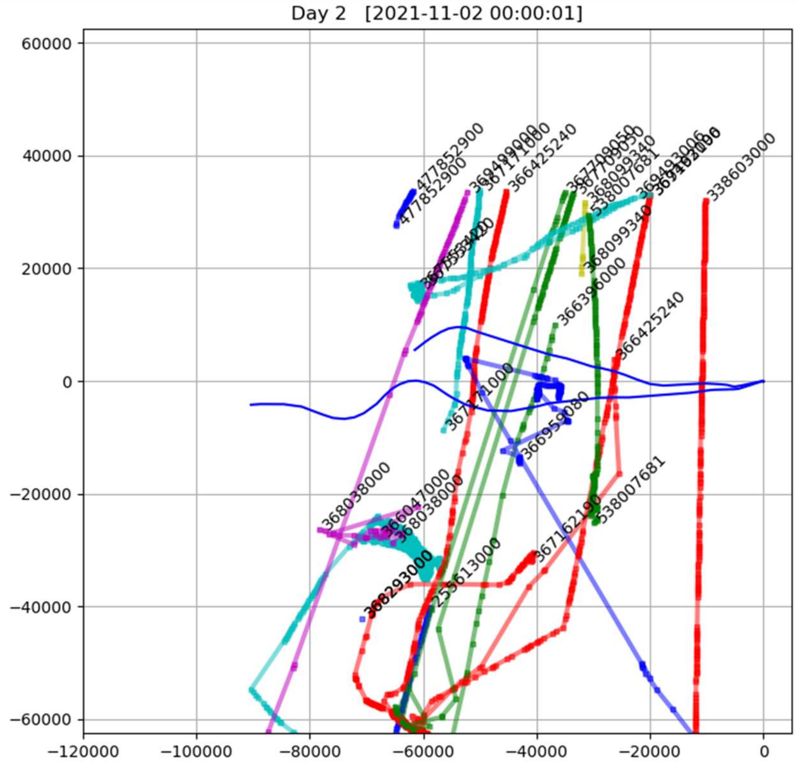




MMSI	FileName
477852900	Slx_South_20211101220154_30_2_200.mat
477852900	Slx_South_20211101220209_30_2_200.mat
477852900	Slx_South_20211101220224_30_2_200.mat
477852900	Slx_South_20211101220239_30_2_200.mat
477852900	Slx_South_20211101220254_30_2_200.mat
477852900	Slx_South_20211101220309_30_2_200.mat
477852900	Slx_South_20211101220324_30_2_200.mat
477852900	Slx_South_20211101220339_30_2_200.mat
477852900	Slx_South_20211101220354_30_2_200.mat

Day 2 [2nd November 2021]





MMSI	FileName
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366396000	Slx_South_20211102004839_30_2_200.mat
366396000	Slx_South_20211102004854_30_2_200.mat
366396000	Slx_South_20211102004909_30_2_200.mat
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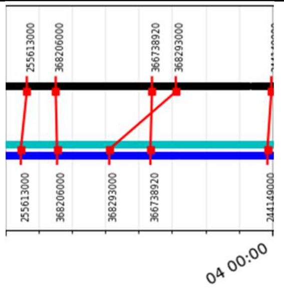
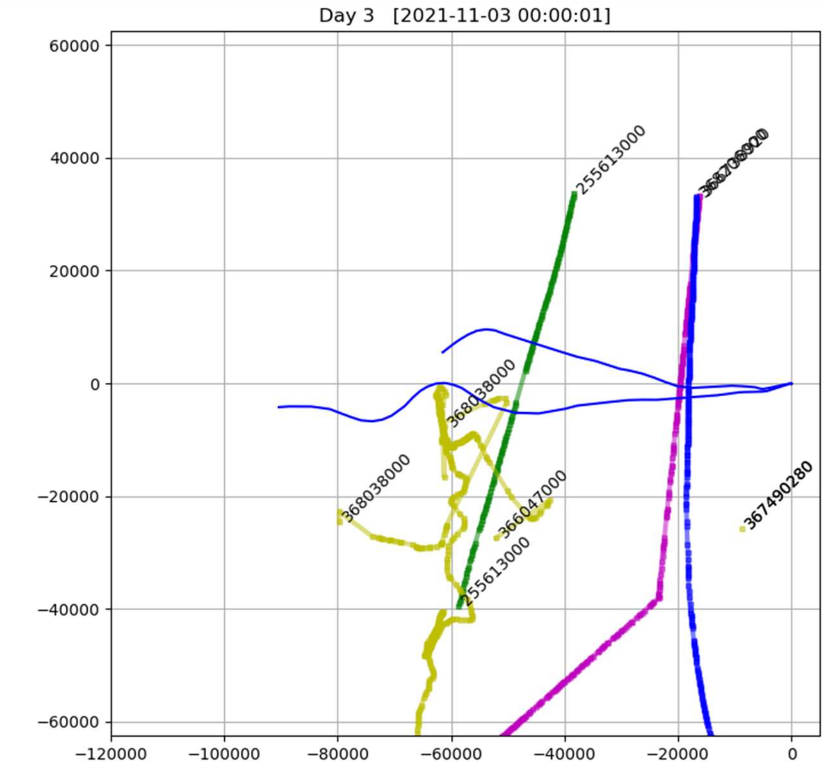
Day 3 [3rd November 2020]





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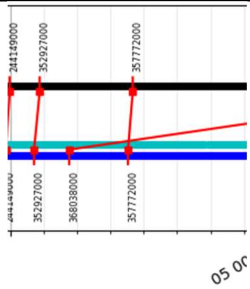
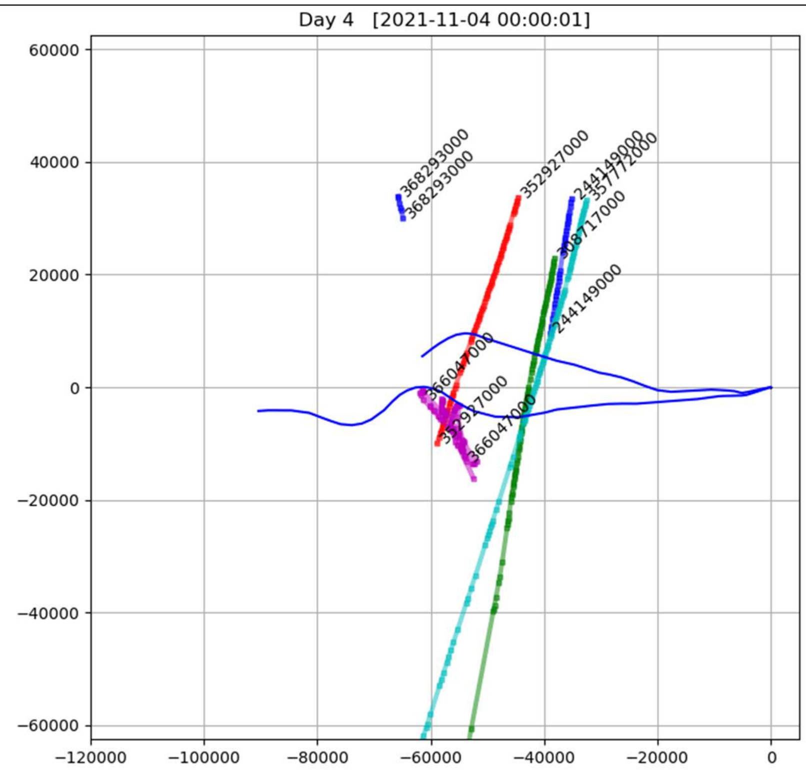
Day 4 [4th November 2021]





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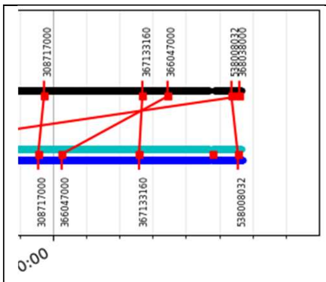
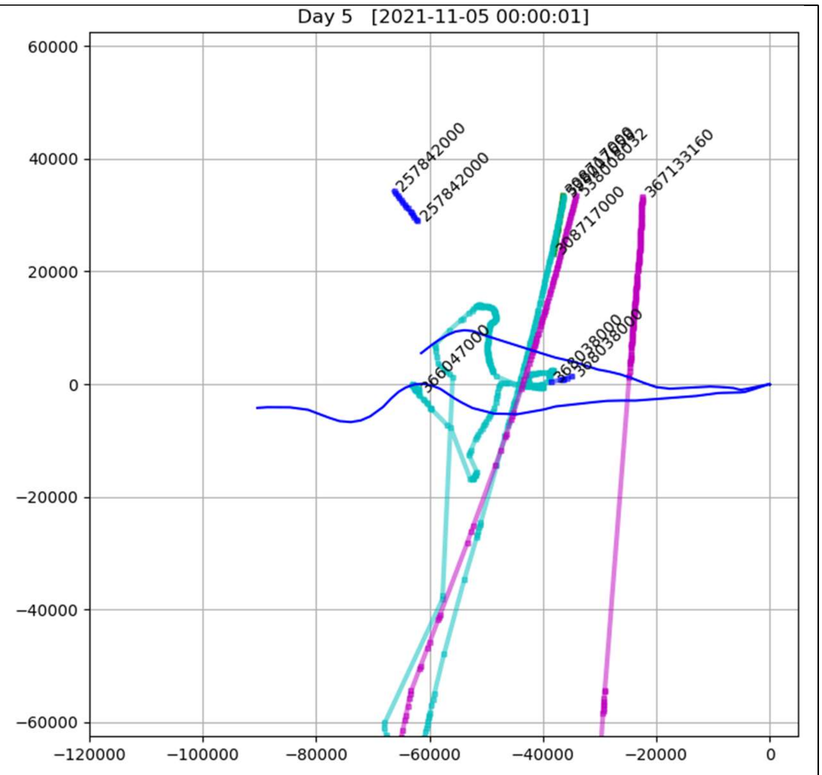
Day 5 [11 November 2021]





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MMSI	Type	Length	Time Closest Approach	Range Closest Approach	Channel Closest Approach	Easting Closest Approach	Northing Closest Approach
366959080	Fishing	20	01/11/2021 15:19	0.466564	14517	394752.7	5002834
477852900	Cargo	179	01/11/2021 22:02	24.83195	39790	346890.1	4999673
366396000	Passenger	45	02/11/2021 00:49	5.24757	20386	382936.4	5001121
369499000	Other	210	02/11/2021 03:01	10.04067	33182	358489.2	5004421
367709050	Fishing	37	02/11/2021 07:29	25.69652	23468	376709.7	5000611
538007681	Cargo	262	02/11/2021 07:35	5.119048	14490	394808.3	5002835
367162190	Fishing	26	02/11/2021 08:11	8.415492	13451	396921.1	5002945
338603000	Fishing	24	02/11/2021 11:59	19.81567	5454	413170.3	5004050
367171000	Fishing	27	02/11/2021 12:48	1.913953	27050	369766.5	5002571
366425240	Fishing	23	02/11/2021 13:44	1.428826	25539	372581.1	5001359
255613000	Cargo	180	03/11/2021 01:25	15.29725	24313	375007.7	5000759
368206000	Fishing	28	03/11/2021 04:40	7.431036	9058	405859.4	5003362
368293000	Fishing	114	03/11/2021 09:21	0.833626	34591	356439.1	5002415
366738920	Fishing	21	03/11/2021 13:04	27.7131	9889	404167.9	5003251
244149000	Cargo	156	03/11/2021 23:35	44.19599	20411	382876	5001161
352927000	Cargo	200	04/11/2021 02:08	17.84723	28241	367697.4	5003836
368038000	Fishing	83	04/11/2021 05:17	0.964288	25717	372229.6	5001446
357772000	Cargo	181	04/11/2021 10:35	10.07669	21443	380817.1	5000727
308717000	Cargo	224	04/11/2021 22:40	30.62101	21646	380415.1	5000632
366047000	Fishing	87	05/11/2021 00:47	5.123894	31789	361006.6	5005697
367133160	Towing	37	05/11/2021 07:46	14.75654	12451	398960.5	5002976
354739000	Cargo	180	05/11/2021 14:24	10.24462	45517	335552.1	5001776
538008032	Cargo	190	05/11/2021 16:41	27.5723	22444	378795.4	5000511
257842000	Cargo	204	06/11/2021 01:41	43.02252	23869	375892.8	5000646
259976000	Cargo	199	06/11/2021 09:11	30.798	20342	383027.9	5001112