The Pathway

A program for regulatory certainty for instream tidal energy projects

Presentation

Passive acoustic monitoring in tidal channels and high flow environments

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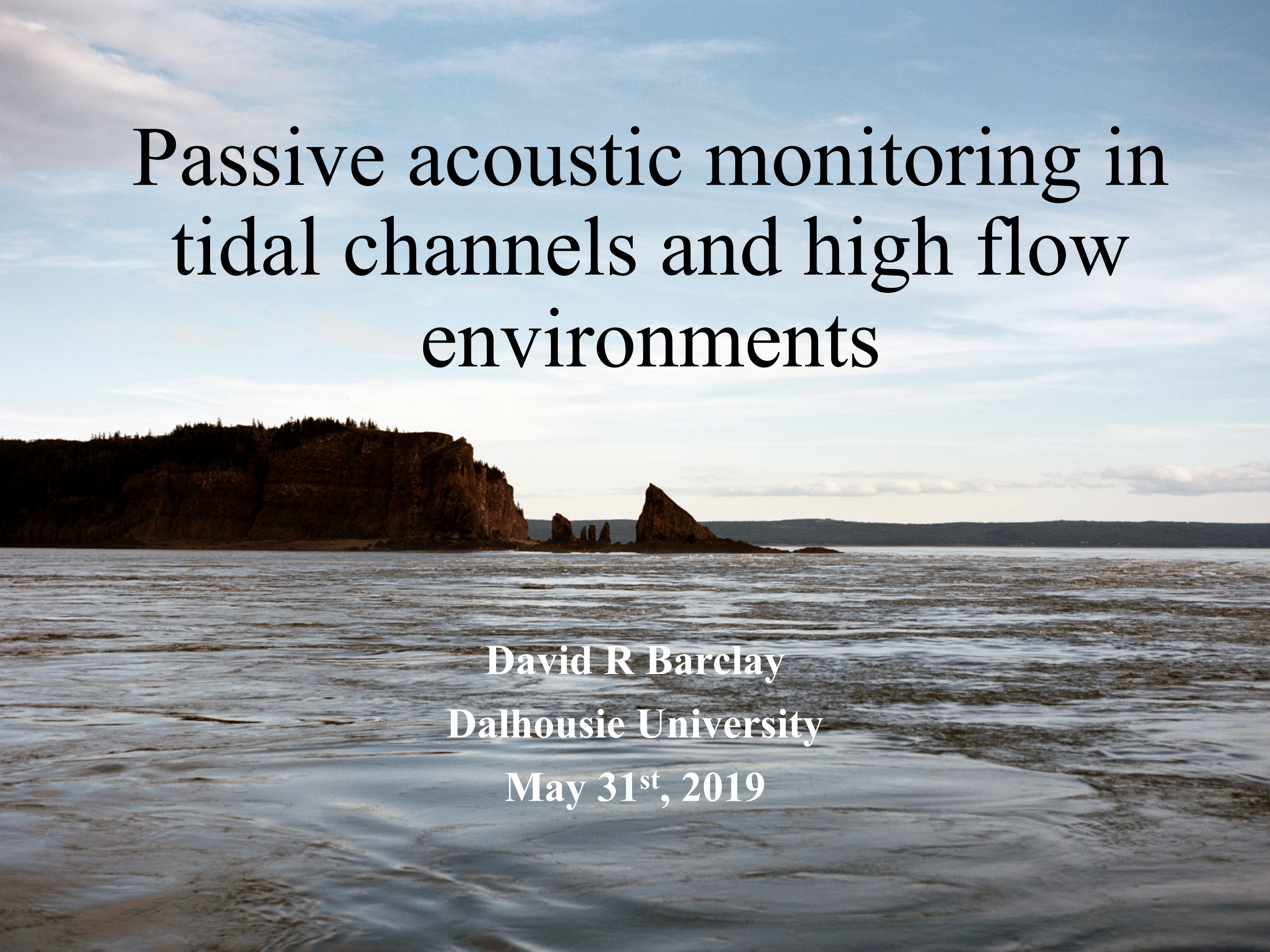
This project provides an overview of methods, data processing techniques, and equipment used to make passive acoustic measurements in tidal channels. The acoustic field is measured in these energetic environments to characterize the natural noise field, quantify contributions by tidal energy and other human deployed devices, and to detect and localize vocalizing marine animals, the latter being the primary objective of interest in this project. No commercially available, purpose built acoustic monitoring systems have been designed for operation in turbulent tidal channels, estuaries, or rivers, despite a growing body of underwater acoustic field work being carried out in the context of environmental impact assessment of tidal energy extraction. However, a number of technologies designed for more benign oceanographic conditions have been experimentally deployed in high flow environments, including conventional cabled or autonomous hydrophone and analogue-to-digital instrument packages, internally recording hydrophones with digital interfaces, autonomous and cabled hydrophone or vector sensor arrays, and integrated hydrophone and data processing systems for marine animal detection. Flow noise, natural ambient noise, sensor size and geometry, and deployment method all have an effect on the detection efficiency of the passive acoustic systems. Experimental results and system performances are compared across all instrument package types, deployment methods, and study areas.

This project is part of "The Pathway Program" – a joint initiative between the Offshore Energy Research Association of Nova Scotia (OERA) and the Fundy Ocean Research Center for Energy (FORCE) to establish a suite of environmental monitoring technologies that provide regulatory certainty for tidal energy development in Nova Scotia.



Passive acoustic monitoring in tidal channels and high flow environments

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Outline

- Ambient noise, turbine noise, and animal detection in tidal channels
- Survey of sites, measurements, and technologies
- Flow noise & self noise identification and mitigation
- Detection, classification and localization of marine animals
  - Technology comparison studies
  - Detection range estimates
- Performance summary
- Conclusions and discussion

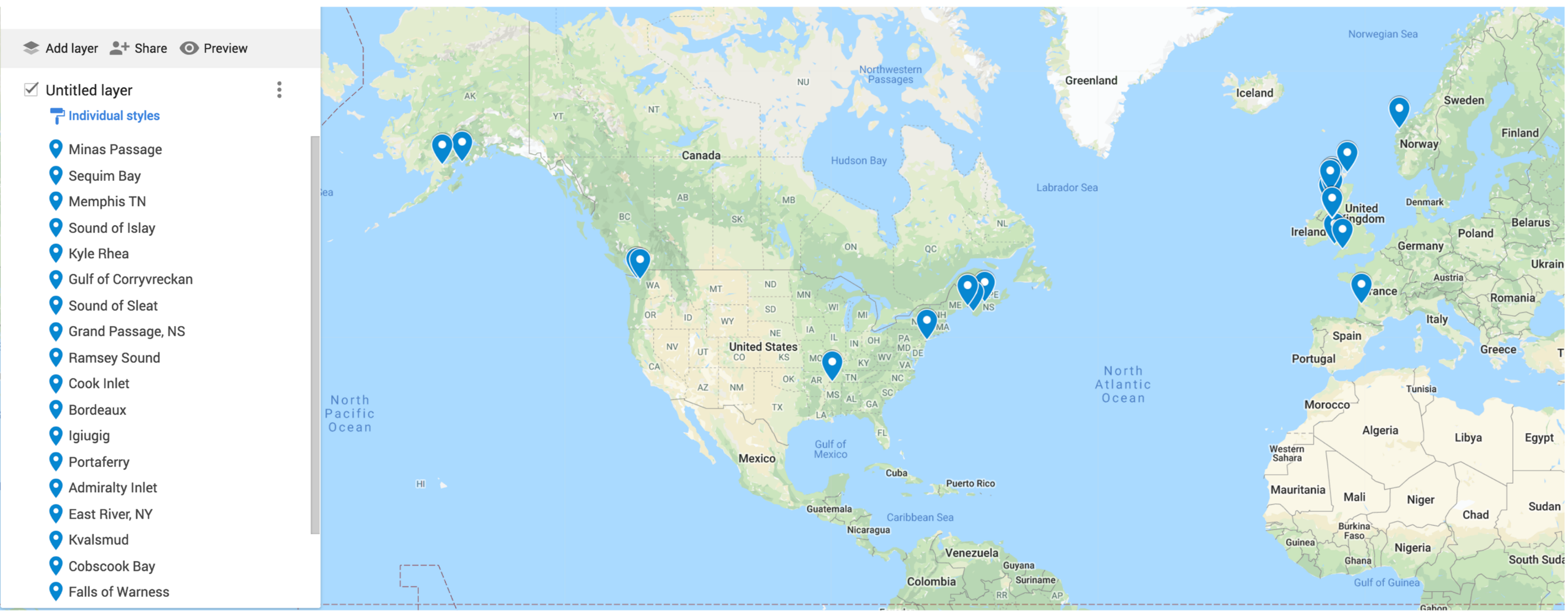
Problem statement

- The collective objective of passive acoustic research in tidal channels is to measure:
    1. Ambient background noise to establish pre-industrial baseline (wideband);
    2. Turbine generated noise and other industrial activity (< 1kHz) ;
    1. Detect the presence of marine animals (wideband)

This type of work is routinely carried out in benign ocean environments, thus a large amount of methods and apparatus exist.

Summary of sites

- 20 study areas, with multiple studies at most sites
- ~ 40 publications on passive acoustics in tidal channels and high flow environments



Deployment methods and instruments

- 6 sites employed moored or bottom mounted systems,
- 14 used drifting buoy or boat measurement
- 5 have been measured using drifting and moored hydrophones, some simultaneously
- 2 used directional sensors (1 vector sensor array)
- 4 have used arrays
- 2 have towed systems
- 3 have mounted sensors directly on turbines

Manufacturers of passive acoustic instruments used in tidal channels

1	Reson TC4014-5	hydrophone	instrument package	Reson
2	Reson TC4032-1	hydrophone	instrument package	Reson
3	CPODs	x		chelonia
4	SoundTrap 300	x		OceanInstrumentsNZ
5	C54XRS	hydrophone		Cetacean Research Technology
6	GeoSpectrum 4 ch array		x	GeoSpectrum
7	Hi-Tech HTI-96-MIN	hydrophone	instrument package	Hi-Tech Industries
8	DSG	hydrophone		Loggerhead Instruments
9	CR55XS	hydrophone	instrument package	Cetacean Research Technology
10	Bruel & Kjær 8104	hydrophone	instrument package	Bruel & Kjaer
11	VR2W	x		VEMCO
12	icListen HF	x		Ocean Sonics
13	GuardBuoy	x		GeoSpectrum
14	AMAR	x		JASCO
15	Drifting AMAR		x	JASCO
16	Quad and VLA, Magrec HPO3 hydrophones		x	Custom
17	Seiche		x	Custom
18	DASAR	x		GreenRidge Scientific
19	Ecological Acoustic Recorder	x		Oceanwide Science Institute
20	Drifting EARS		x	SAMS
21	TR Orca	x		Turbulent Research
22	ORCA	x		Seiche

Evaluate by:

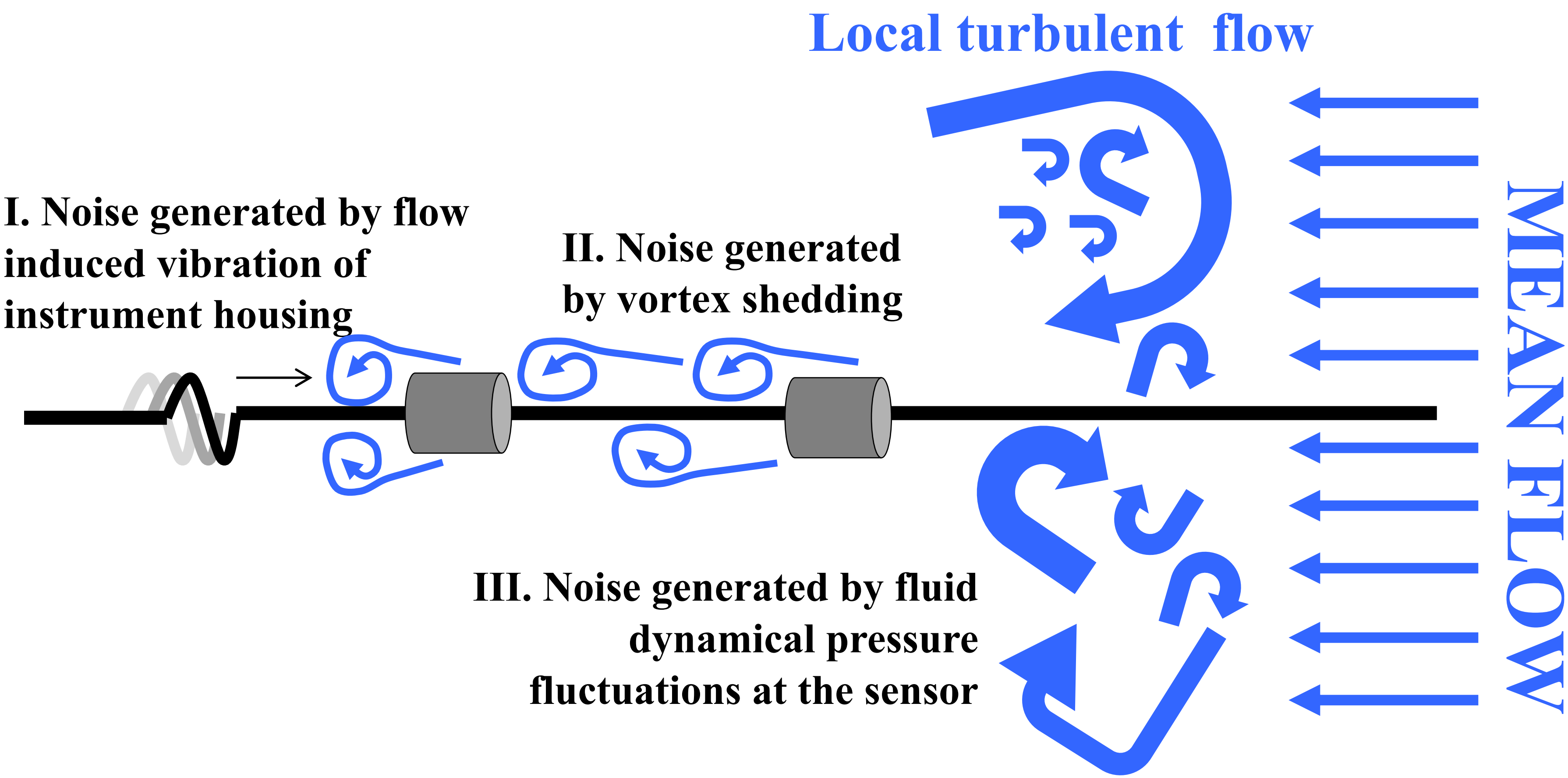
Bandwidth
Commercial availability
Power consumption
Ease of deployment
Performance

Primary challenges

- High flow environments lead to large:
  - pseudo (flow) noise on the hydrophone,
  - mooring noise,
  - background noise, particularly sediment generated noise.

- Some solutions:
  - Deploy Lagrangian drifters
  - Instrument placement in depth and lateral position
  - Flow shields and baffles
  - More sensors, larger sensors

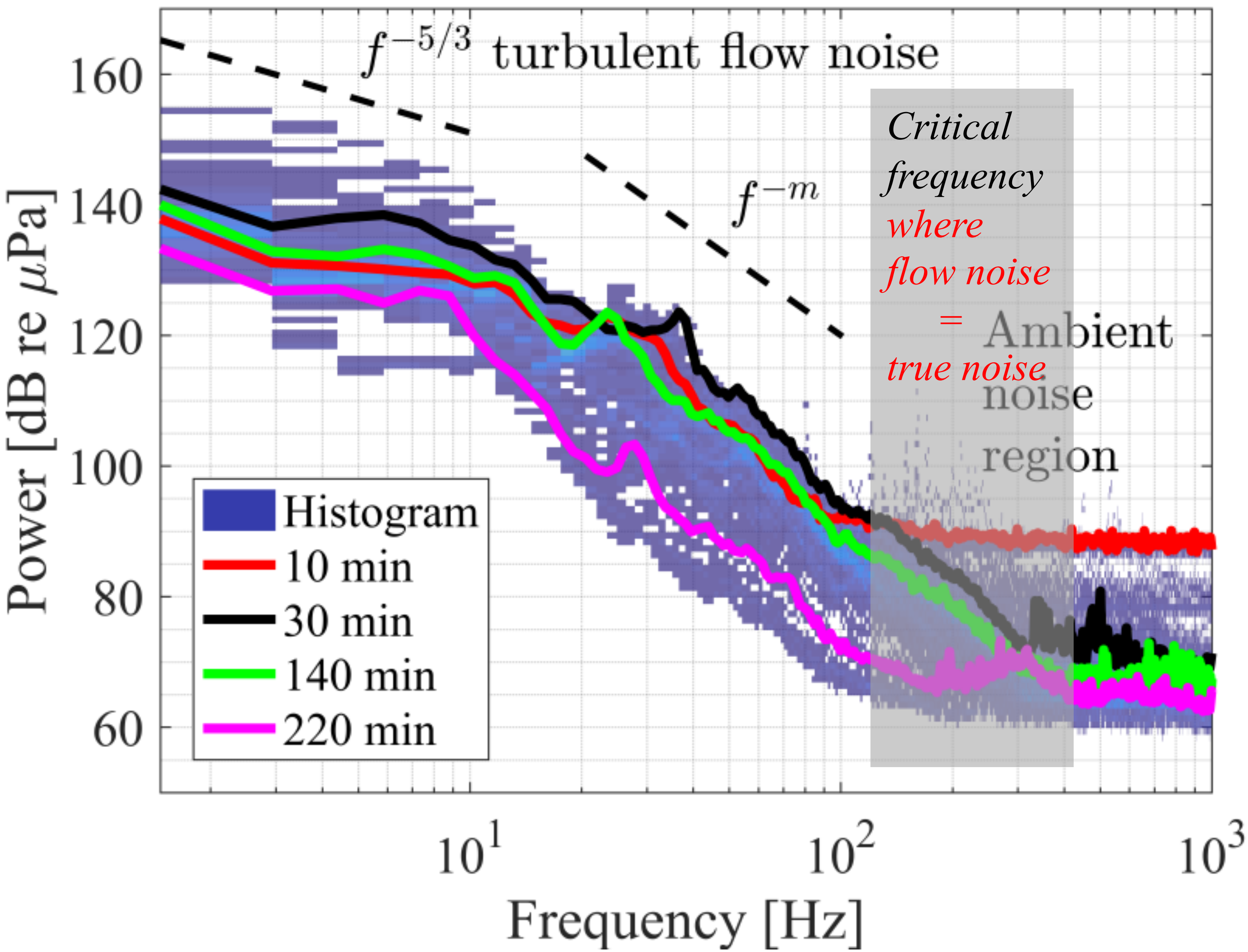
Flow noise in a tidal channel



The sensor provides a spatial average of the noise generated by turbulent flow.

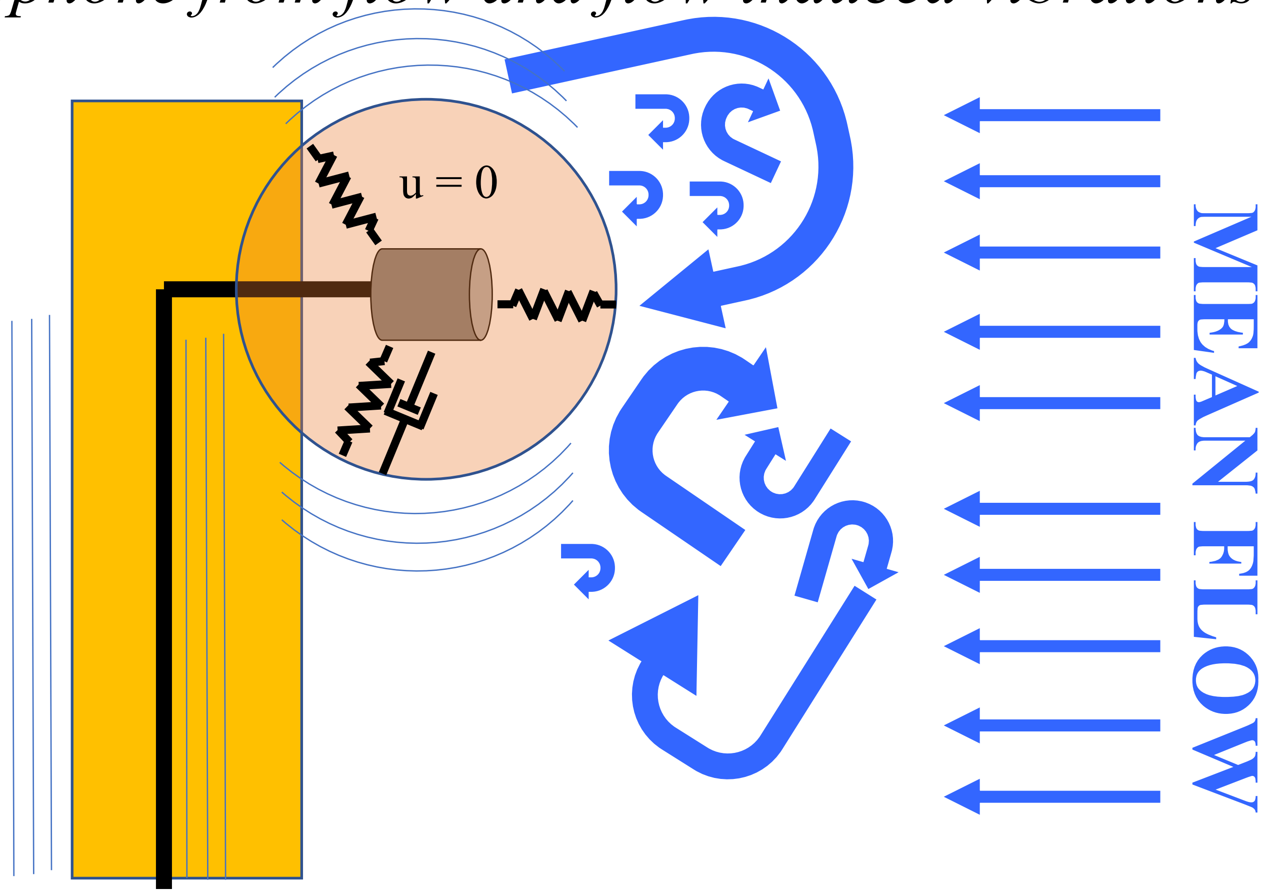
A larger sensor's sensitivity to flow noise decreases more rapidly with increasing frequency than a smaller sensor.

Identifying flow noise using spectra



Flow shields & suspension

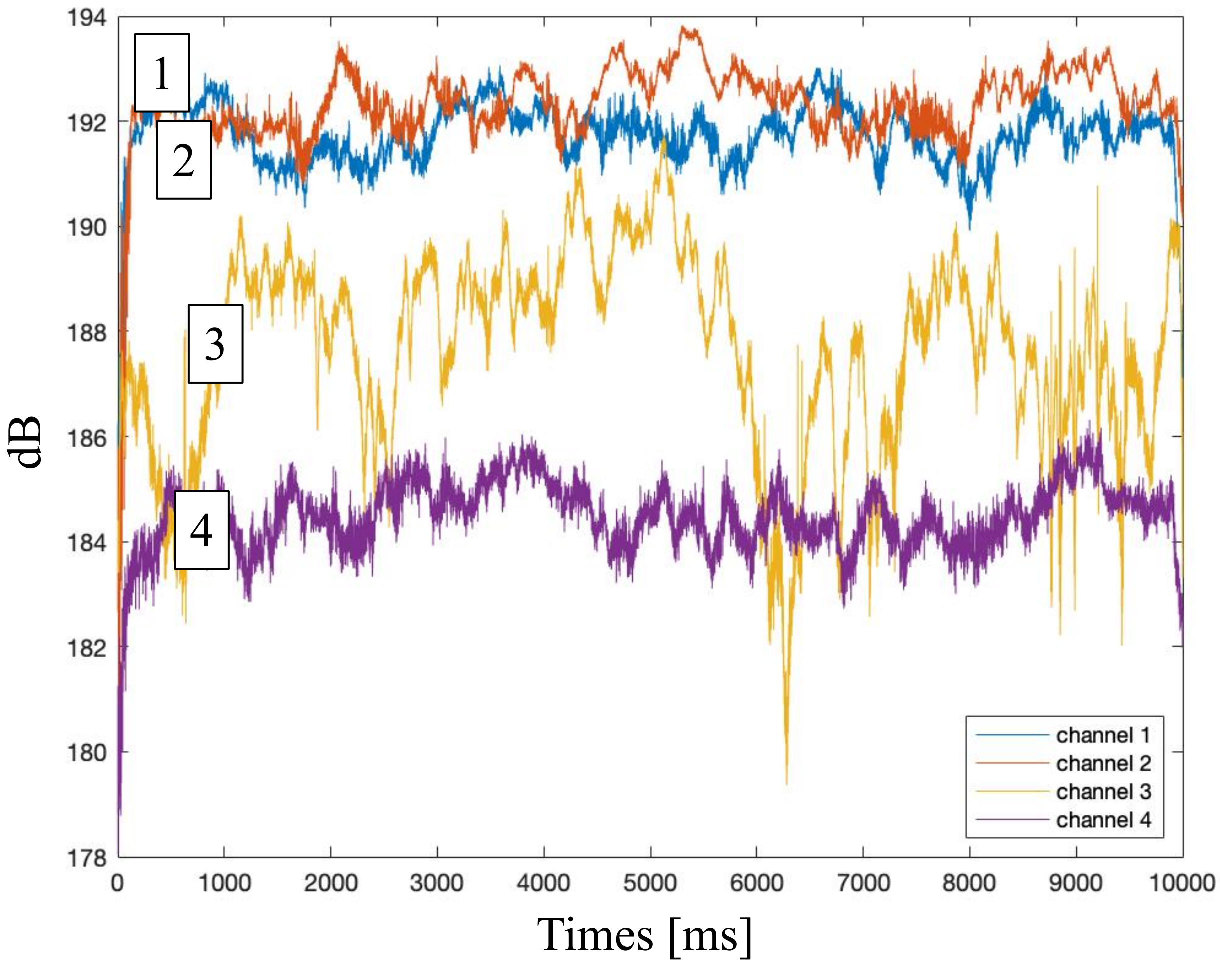
Isolate hydrophone from flow and flow induced vibrations

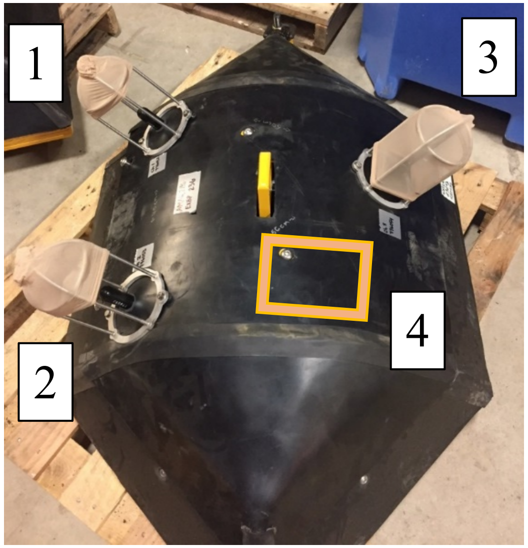


Experimental results are mixed. Flow shields are occasionally totally ineffective [Porskamp, 2015][Malinka, 2015].

Flow shields can reduce sensitivity

Example: Receive level fluctuations of a 8 kHz tone, Grand Passage, NS.





JASCO AMAR

Lessons from towed and flush mounted arrays

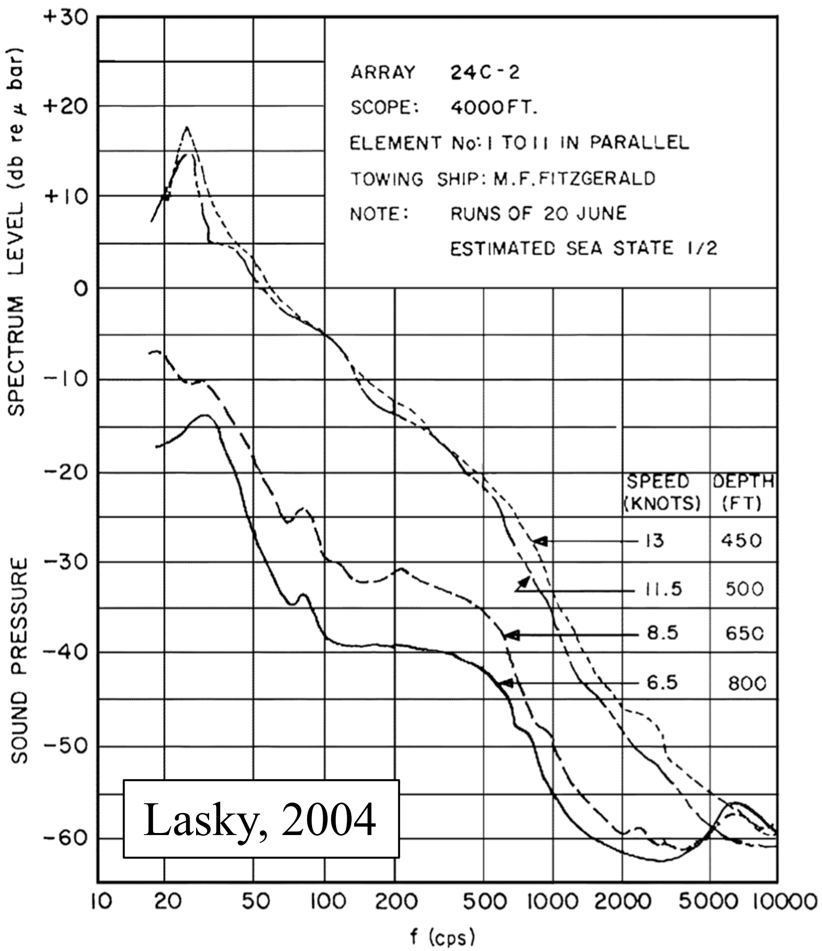


Fig. 11. Effect of speed on background noise for of 11-element array at 4000-foot cablescope.

For flush mounted hydrophones, sensor shape, an elastomer layer and more hydrophones reduces turbulent boundary layer flow noise [Ko, 1992].

Arrangement of array elements, including interelement spacing has little effect on the performance of the flow noise suppression.

Coherent arrays in tidal flows also demonstrate flow noise suppression [Worthington, 2014][Auvinen, 2018].

Flow noise conclusions

- Flow noise can potentially mask sound over a very large bandwidth (0 – 10 kHz).
- The bandwidth of flow noise contamination can be identified by spectral slope coherence between adjacent sensors in an array.
- Increasing the size of a sensor lowers the upper frequency limit at which flow noise masks.
- A coherently averaged array of sensors lowers the upper frequency limit at which flow noise masks.
- Shielded sensors near the bottom boundary have reduced flow noise contamination.

Detection of marine animals

Marine animals detect at tidal energy sites			
Marine animal	Study site(s) present	Characteristics of vocalizations	Instrument used
Dolphins (bottlenose dolphin, Risso's dolphin, short-beaked common dolphin, Atlantic white- sided dolphin and white-beaked dolphin)	Ramsay Sound, Minas Passage	Clicks: with root mean square bandwidths of 23−54 kHz, centred at ~ 90kHz Whistles, varying bandwidth: low 10's of kHz	C-POD Turbine mounted hydrophones
Harbour porpoise	Great Race, Scarba, Sound of Islay, Minas Passage, Admiralty Inlet, Kyle Rhea	Clicks: centred at 130 kHz with 16kHz bandwidth. Highly directional (beam pattern 9.5 to 16 degrees).	C-POD (bottom mounted, SUB moored, drifting) Boat drifting vertical line array Drifting hydrophones
Beluga Whale	Cook Inlet	Non-echolocation calls: 2.0 to 5.9 kHz Clicks between 40 – 120 kHz	EAR C-POD DASAR

Table 2. Survey of acoustically detected marine animals in tidal channels, characteristics of sounds produced, and instrument packages used for detection.

Why are other animals seen but not heard?

- Harbour and grey seals, and humpback, fin, and minke whales have been visually observed in Minas Passage but have never been acoustically detected.

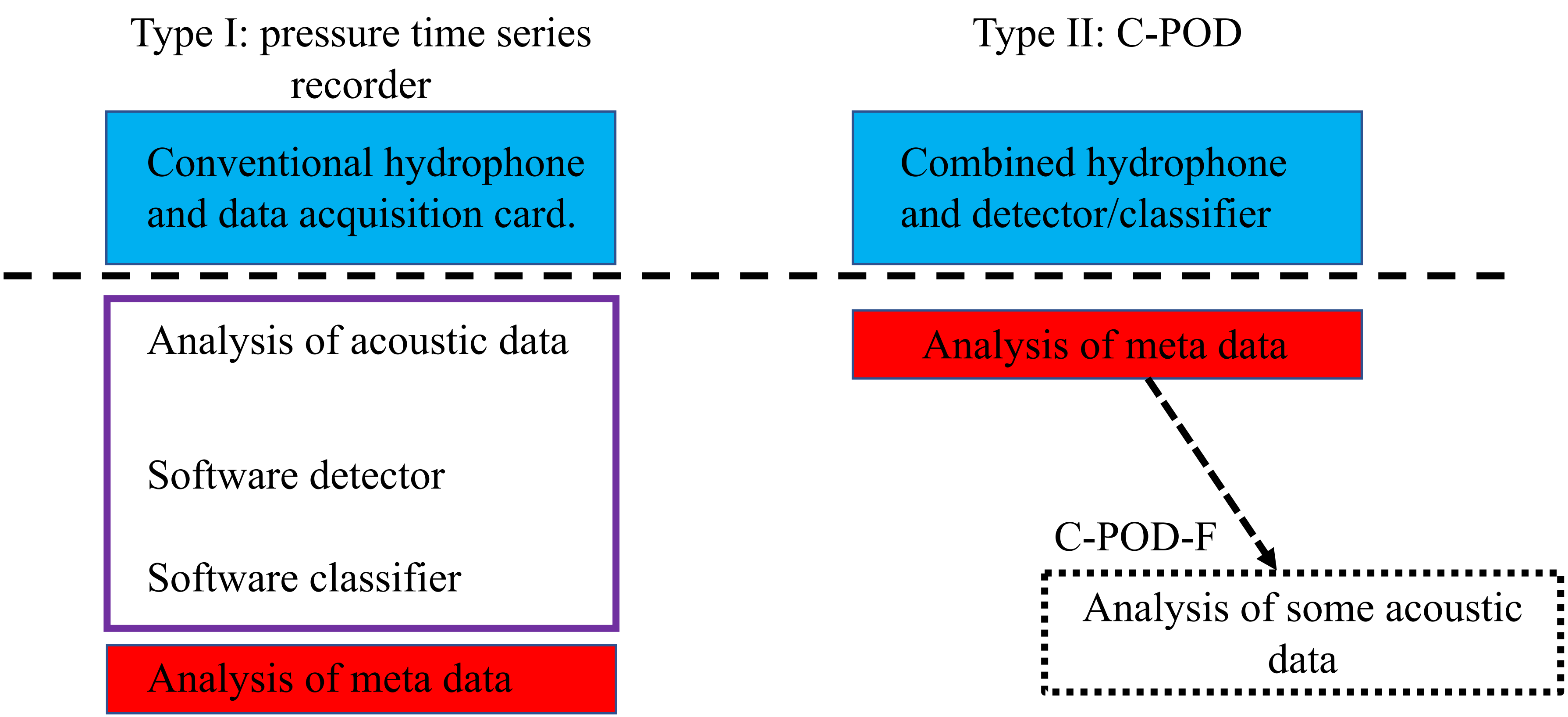
- Presence of these animals can be rare

- They produce sound mostly below 1 kHz, and always below 5 kHz.

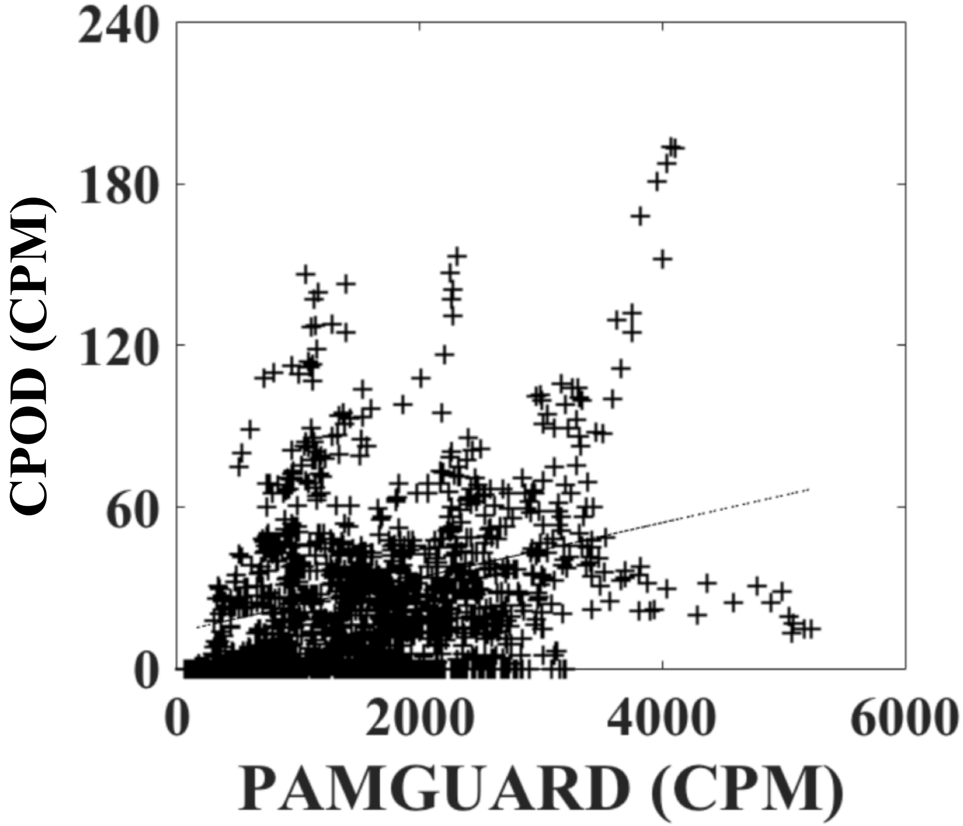
Porpoise, dolphin and click detection

Short duration, wide bands (10 – 50 kHz) with center frequencies (90 – 130 kHz).

Instrument packages used and available:



Relative performance of a C-POD in the Baltic



No linear relationship

Time varying relative performance ratio.

To compare data, hydrophone sensitivity (effective listening volume), detection efficiency must be known on both systems

C-POD detection criteria is stringent.

C-POD detected between 21 – 94% of the click trains detected by SoundTrap & PAMGUARD. [Sarnocinska, 2016].

Relative performance of a C-POD in Monterey Bay, CA [Jacobson, 2017]

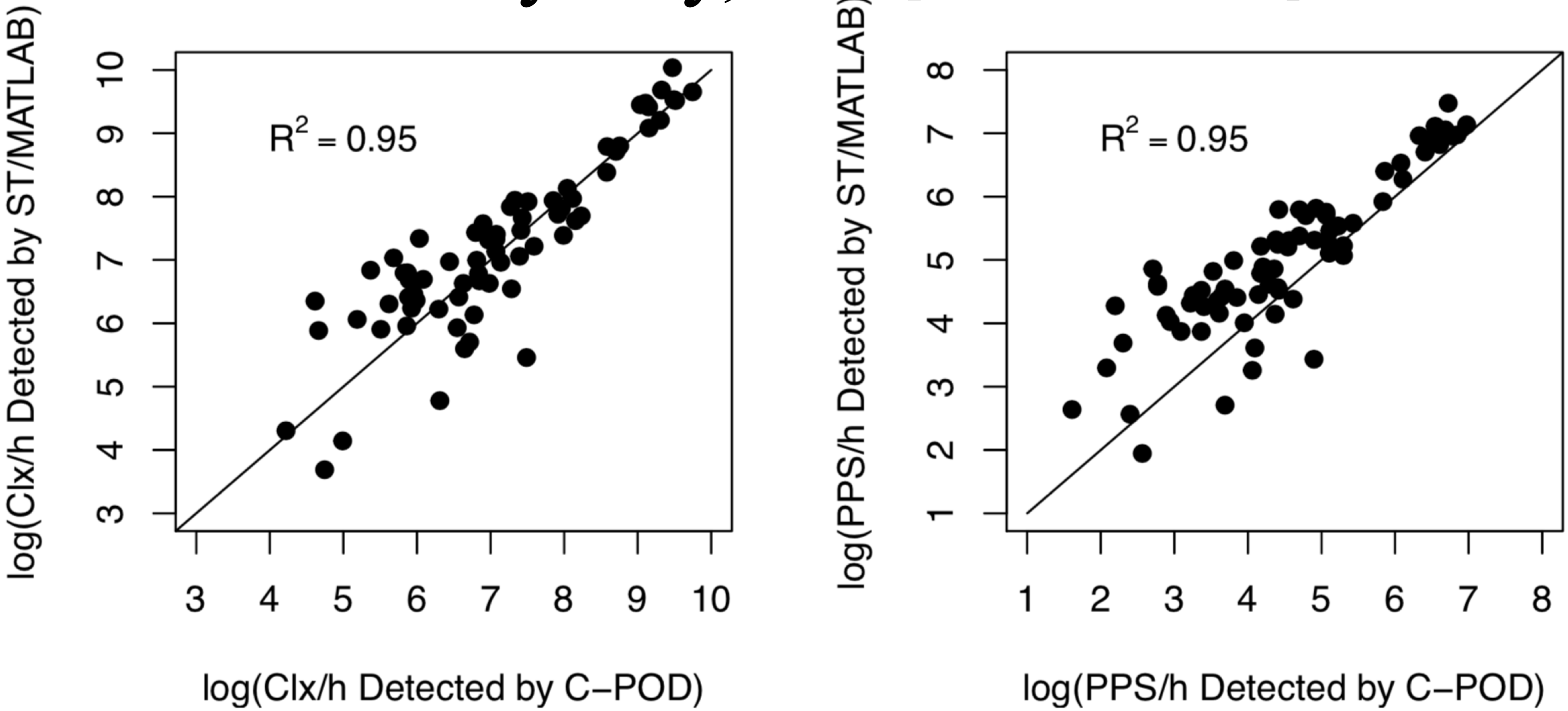


Figure 5: Log-transformed comparison of the number of echolocation clicks detected by each instrument per hour (left panel) and the number of porpoise positive seconds (PPS) detected by each instrument per hour (right panel) with correlations for each comparison and a one-to-one line (black) indicating perfect agreement.

Use of metrics such as positive minutes per hour, or positive hours per day can improve agreement between detectors.

C-POD performance in tidal channels

Minas Passage [Porskamp, 2015]

Co-located deployment of:

- two bottom mounted C-PODs
- icListen HF
- one moored C-POD in a SUB float 3 m off seafloor.

Bottom units had 10 x more detection minutes per day than moored unit.

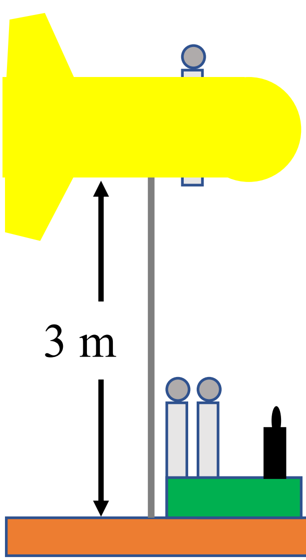
icListen had an additional 5 x more detection minutes per day

Most 'lost time' on SUB float unit

sediment generated noise

mooring noise (blown down against the bottom)

flow noise



Most likely mooring noise (or flow noise (note: *f* >>)?)

C-POD performance in tidal channels

Minas Passage [Porskamp, 2015], [Tollit, 2013]

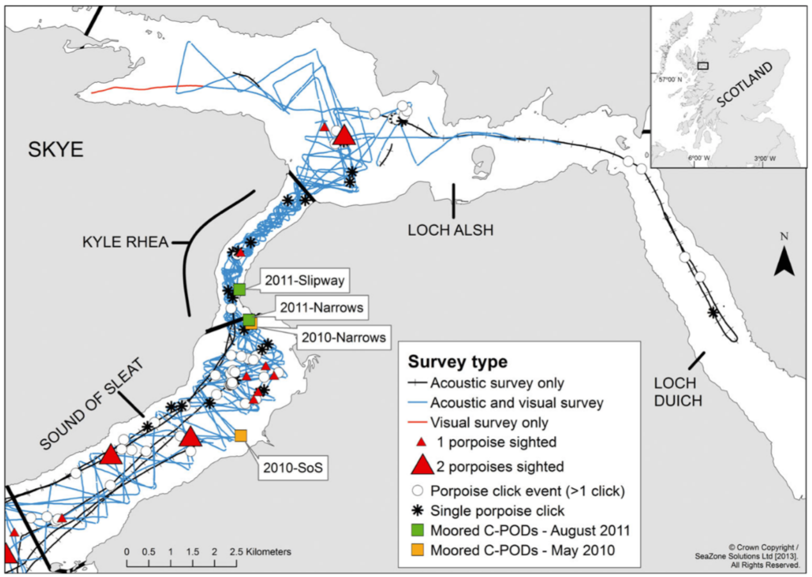
- A 2nd study found 10 x more detection minutes per day than co-located C-PODs.
- May be due to:
  - Less flow noise on device
    - not likely as physical dimensions are similar, *f* >>
  - Less electronic noise/higher sensitivity/greater detection volume

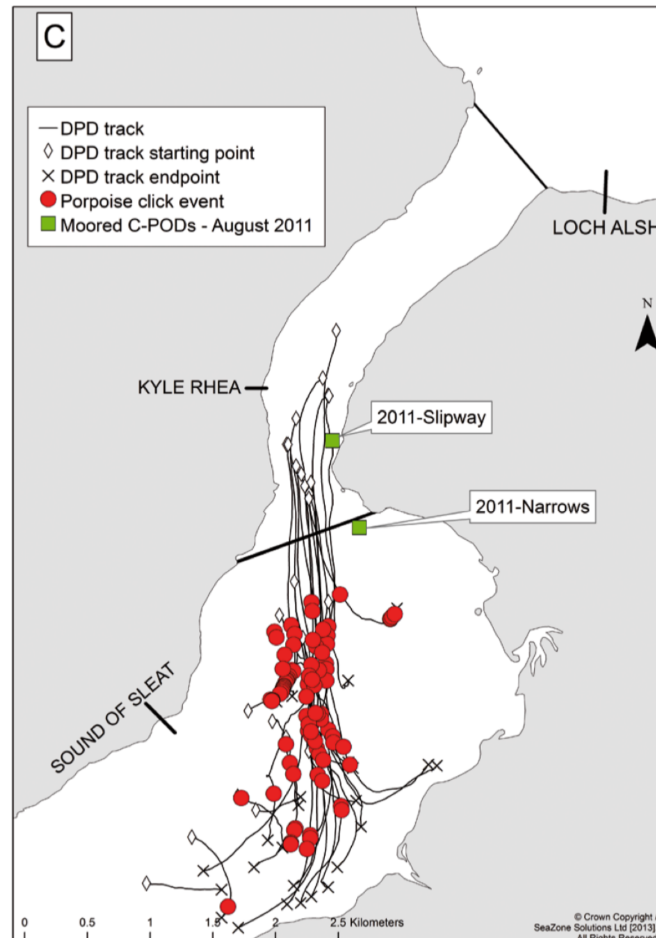
    receiving sensitivity of the C-POD is -211 dB re 1V/μPa and the icListen is -169 dB re 1V/μPa
  - More ‘sensitive’ detection algorithm

C-POD performance in tidal channels

Kyle Rhea [Wilson, 2013]

Drifting C-POD deployed over moored C-PODs





Inter-comparison of data is difficult and click detections are low.

Moored C-PODs have great amount of lost time while drifting ones have very little.

Spatial inhomogeneity in noise field?

C-POD performance in tidal channels

Minas Passage [Adams, 2018]

- Drifting pair of C-PODs and icListen HFs
  - Detection rate on hydrophone 4 – 5 x more than C-POD
  - Difficult to determine if poor detection performance is due to hardware (lower hydrophone sensitivity) or software (more stringent detection algorithm).
- The drifting C-PODs suffered no lost time
  - Sediment generated noise

    Investigate the depth-dependence and spatial variability with icListen
  - Is it possible that flow noise causing lost time?

- The standard C-POD detection limit of 4096 clicks/min can be easily exceeded on moored, bottom mounted, and drifting C-PODs, (Benjamins, 2016, Wilson, 2013).

Detection range estimation in benign ocean

- In shallow water, using 69 kHz signal, the combined sensitivity of the C-POD hydrophone and click-detection algorithm is lower than the icListen [Tollit 2013] [Porskamp 2013].
- Difficult to compute detection efficiency because C-POD is closed system, and detection ratio due to environment
- Results: 500 m for icListen, 375 m for C-POD

- Similar study found reliable C-POD detection range in shallow estuary of 300 m [Roberts, 2015], in agreement with previous T-POD and C-POD studies (Kyhn et al. 2008, 2012)

Detection range estimation in high flow

- Back propagation estimates in the Minas Passage gave a mean of ~275 m and a typical daily maximum of 500 m for the DT of an icListen (Porskamp, 2013).

- Detection ranges of C-PODs at the EMEC site were reported to be < 150 m (Benjamins, 2017).

- Deployment of a C-POD in Admiralty Inlet showed detections of 'landmark' click trains (where the C-POD itself is the target of the echolocation) at a distance of 90 m (Polagye, 2012).

Uncertainty in transmission loss (scattering attenuation) and background noise.

Detection range estimation in high flow

Factors that influence detection efficiency on C-PODs are confounding:

Tollit (2013) reported that the deeper the C-POD, the higher the number of porpoise detections in the Minas Passage (on 7 SUBs deployed units).

This may be due to the larger effective listening volume of the sensor deployed in deeper water, lower background noise level at 10’s and 100’s kHz at deeper depths (Moore, 2016), or by porpoise usage of the passage.

Detection and localization

- Two studies:
- 7 turbine mounted phones [Malinka, 2018]
  - 20 - 200 m for sound sources with source level 178 – 205 dB re 1 $\mu Pa_{p\text{-}p}$, respectively.
  - Probability of detection & localization down to 50% for ranges of greater than 20 m, and 10% at 50 m.
- 8 element drifting VLA with 2 horizontal phones [Macaulay, 2017].
  - Detection range of 200 m

Performance summary

- Pressure time series hydrophone with software detector (PAMGUARD, Coda, homegrown) always outperform C-PODs.
- The inability to distinguish between masking sources confounds the performance comparison between drifting, moored, and bottom mounted C-PODs.
- Drifting C-PODs were found to have the least lost time, followed by bottom mounted C-PODs, with mooring deployed C-PODs performing the worst

Suitable off the shelf systems

- Bandwidth is limiting factor (f_s >250 kHz)

- icListen HF (Ocean Sonics)
- SoundTrap 300 (Ocean Instruments NZ)
- AMAR G4 (JASCO)
- ORCA Acoustic Recorder (Seiche)
- TR-ORCA (Turbulent Research)

Conclusions

- The ideal system has the highest sensitivity, best mitigation of flow noise, and records the entire pressure time series.

- Can be bottom deployed for long term monitoring without flow noise reduction, and they will be able to detect animals at ranges of 150 – 300 m in tidal channels.

- pressure time series recorders outperform C-PODs and provide higher data analysis capability.

- For non-echolocation call detection, flow noise suppression must be improved by sensor design or signal processing methods.