Acoustic Source Tracking in the Arctic with Acoustic Vector Sensors

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Introduction

What are Acoustic Vector Sensors (AVS)?

- AVS are a type of sensor platform which measure acoustic pressure and particle velocity simultaneously. This provides a method to determine the instantaneous magnitude and direction of an acoustic sound source.

Why use AVS?

- Detect and localize acoustic sources remotely
  - Natural or anthropogenic
- Small package (sans large sensor arrays)
- Easy implementation and deployment
- Wide range of applications
- Low cost

AVS Sensing Modality

AVS rely on measurement of sound intensity,

$$I = pu\,,$$

which is the product of acoustic pressure (p) and particle velocity (u).

In practice, intensity is estimated as one of the following depending on AVS transducer types:

- $I_x(\omega) = Re\{G_{u_x p}(\omega)\}$ (pressure – particle velocity)
- $I_x(\omega) = Re\{G_{a_x p}(\omega)/j\omega\}$ (pressure – particle velocity)
- $I_x(\omega) = \frac{1}{\rho_0 \omega d} Im\{G_{p_2 p_1}(\omega)\}$ (pressure – pressure)

The azimuth (θ) and elevation (Φ) directions of arrival (DOA) to an acoustic source are estimated as,

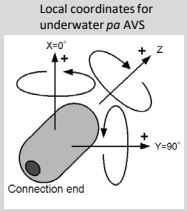
$$\theta_{VS} = \tan^{-1}\left[\frac{I_{West}}{I_{North}}\right]$$

$$\Phi_{VS} = \tan^{-1}\left[\frac{I_{up}}{(I_{North}^2 + I_{West}^2)^{\frac{1}{2}}}\right]$$

where,

$$\begin{bmatrix} I_{North} \\ I_{West} \\ I_{Up} \end{bmatrix} = Q \begin{bmatrix} I_x \\ I_y \\ I_z \end{bmatrix}.$$

The transformation matrix (Q) translates local coordinates to global coordinates



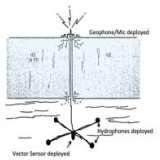
Multiple AVS Sensor Types

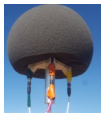
Sensing Mechanisms:

- pressure-particle velocity (*pu*)
- pressure-particle acceleration (*pa*)
- pressure-pressure (*pp*)
- particle velocity-particle velocity (*uu*)

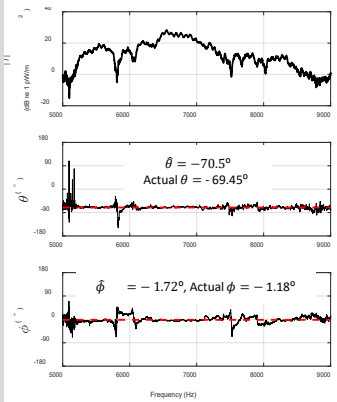
Sensing Mediums:

- Underwater
- In-air
- Surface mount





Acoustic Intensity and Direction of Arrival

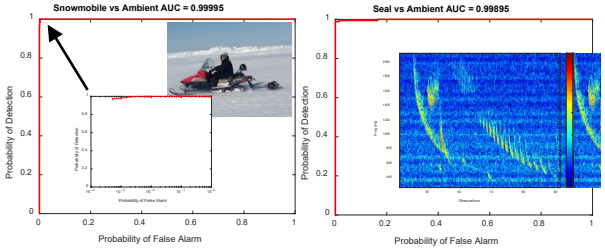


underwater sound source below the ice

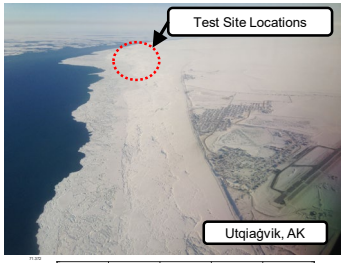
Underwater AVS data for stationary underwater sound source high-frequency pings. Mean azimuth and elevation angles are shown with dashed lines.

Detection Statistics with AVS

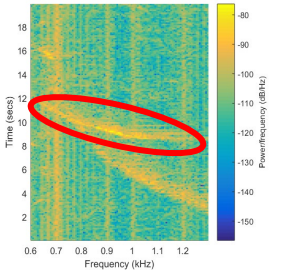
ROC curves for detection of sources vs. ambient background indicate high confidence of detection when using AVS.

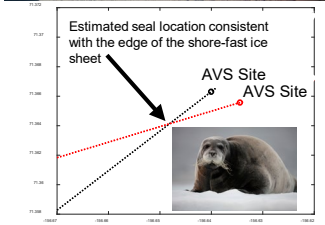


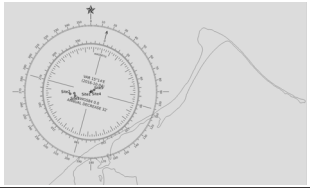
Localizing Natural Sounds with AVS



Bearded Seal

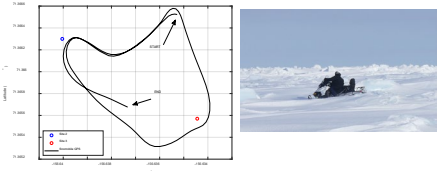


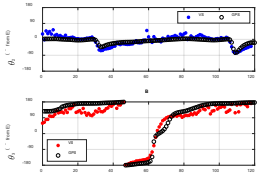




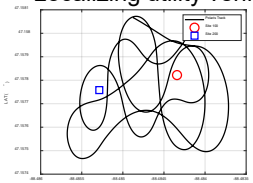
Localizing Anthropogenic Sources with AVS

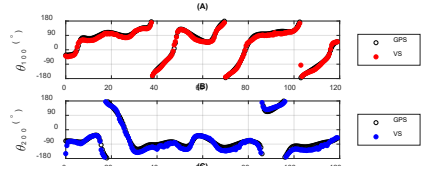
Localizing snowmobile on ice with underwater AVS





Localizing utility vehicle with in-air AVS





Vehicle ground truth position measured by GPS onboard during 120-second data collect. Underwater AVS measurements made at sites for tracking snowmobile. In-air AVS measurements made at sites for tracking utility vehicle. Mean DOA estimates from AVS compared to ground truth azimuth. Underwater AVS shown to be feasible to detect, localize, and track on-ice anthropogenic sources. In-air AVS shown to be feasible to detect, localize, and track ground vehicles.

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