# Comparison of remote ranging techniques for bowhead whale calls in a dispersive underwater sound channel


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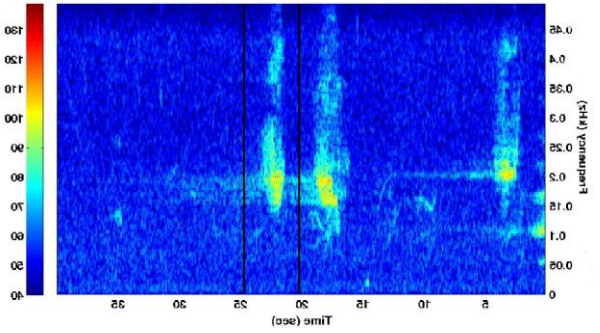


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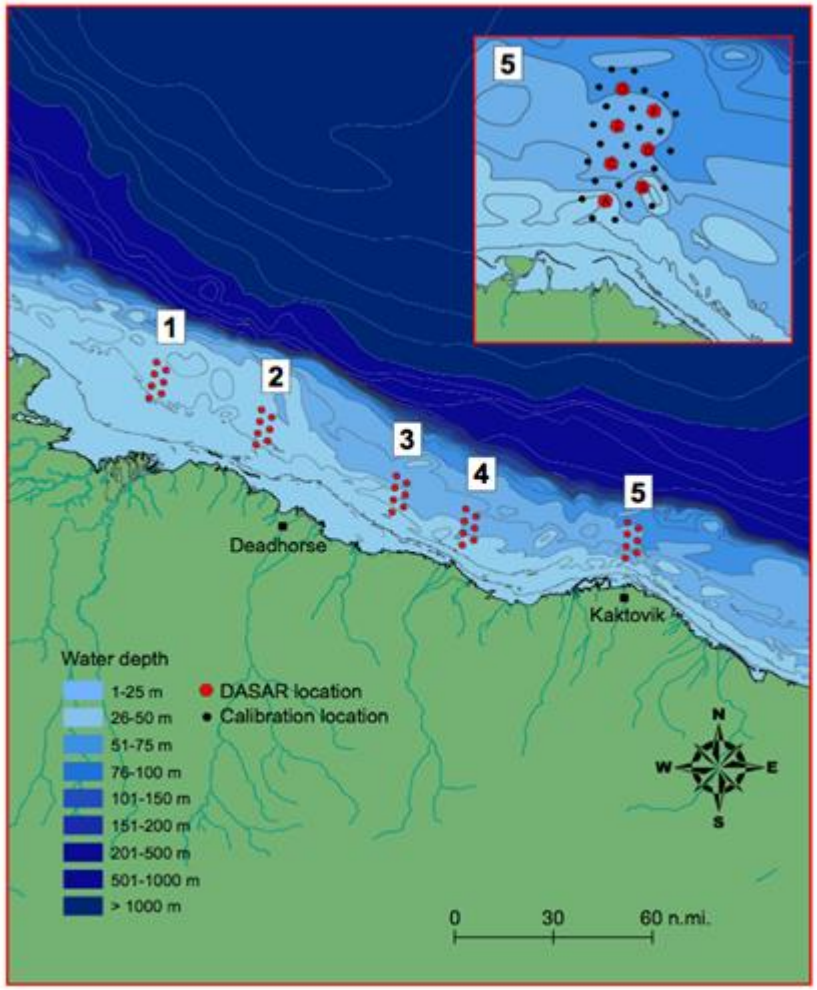
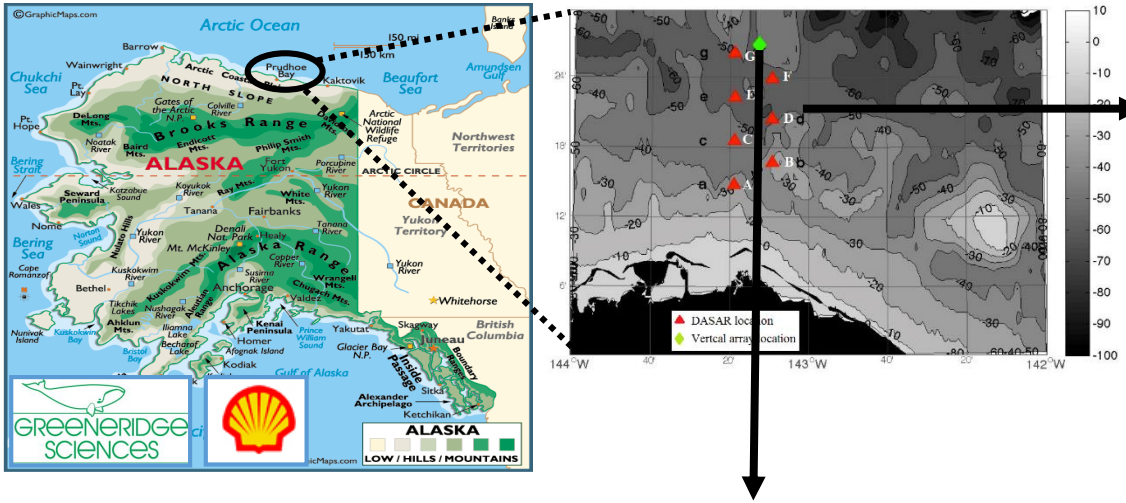
# Motivation: DASAR deployments to monitor bowhead westward fall migration, 2007-2011

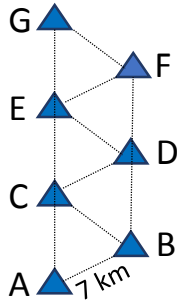



- Whales swim westward along continental shelf.
- 35 recorders (2008) are deployed over a 280 km swath between depths of 20 and 50 m.
- Sponsored by Shell in order to monitor acoustic behavior of whales during industrial activities (seismic airgun and drilling).
- Current methods track whale calls inside each site.
- Can whale calls be localized (or ranged) *outside* each site?
- We will focus on 2010, Site 5.

# Arctic Ocean Experiment 2010




DASARs:
(**D**irectional
**A**utonomous
**S**eafloor **A**coustics
**R**ecorders)

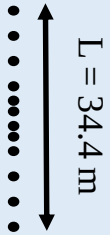



Bowhead whale calls
(50-500 Hz calls)

Vertical Array:
12 elements,
Spanning the
middle 60% of
the water column

$$\rho = 1.00\ \frac{kg}{m^3}$$

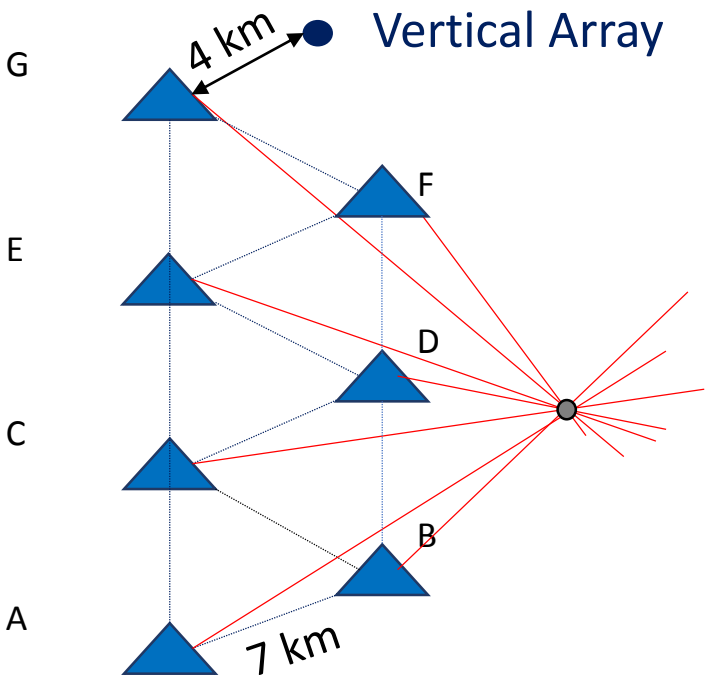
$$c = 1442\ \frac{m}{s}$$




$$\rho_{bottom} = 1.489\ \frac{kg}{m^3},\ c_{bottom} = 1638\frac{m}{s},\ \alpha = 0.94\ \frac{dB}{\lambda}$$

# Three Ranging Techniques-1

1. Conventional Mode Filtering (CMF):
   - Vertical array data
2. Mode-based Synthetic Time Reversal (STR):
   - Vertical array data
3. DASARs Ranging:
   - DASAR data
   - Three channels:
     - Pressure (hydrophone)
     - Acoustic particle velocity in orthogonal directions
   - Reference Ranging Technique



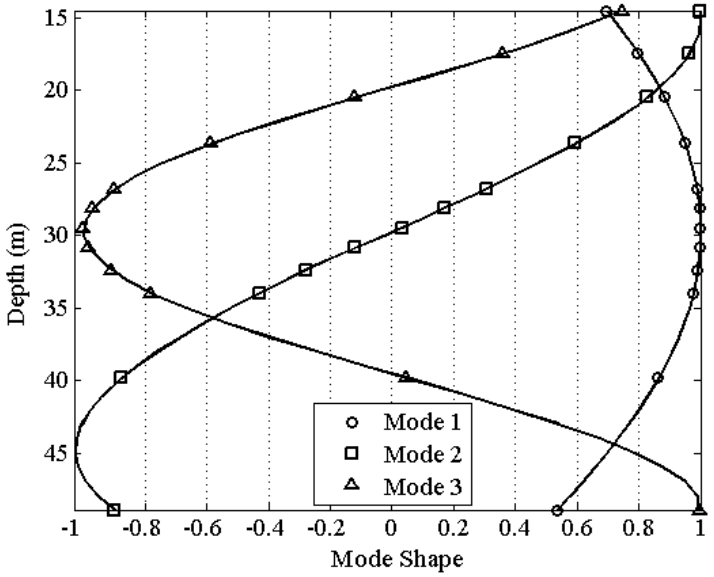

* Greene, McLennan, Norman, Mcdonald, Jakubczak & Richardson (2004), "Directional frequency and recording (DIFAR) sensors in seafloor recorders to locate calling bow-head whales during their fall migration", J. Acoust. Soc. Am., 116, 799-813.
* Thode, Kim, Blackwell, Greene, McDonald & Macrander (2012), "Automated detection and localization of bowhead whale sounds in the presence of seismic airgun surveys", *J. Acoust. Soc. Am., 131*, 3726-3747.

# Three Ranging Techniques-2

## Conventional Mode Filtering (CMF)

$$\hat{S}_m(\omega) = \sum_{j=1}^{N} W_{j,m} P_j(\omega)$$

$$W_{j,m} = \Psi_m(z_j)$$

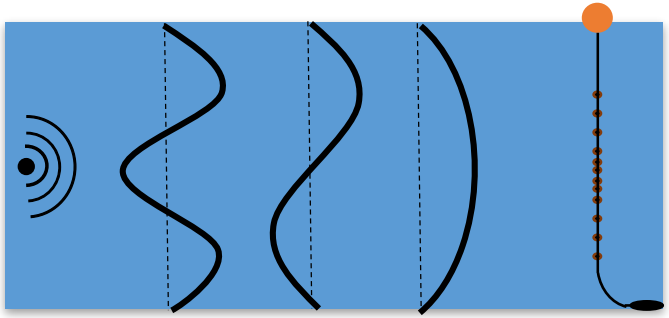



- Requires signal amplitude **and** phase in the signal bandwidth

## Mode-based Synthetic Time Reversal (STR)

$$\hat{S}_m(\omega) = \sum_{j=1}^{N} \left\{ \tilde{P}_j(\omega) e^{-i\alpha_m(\omega)} \right\}^* P_j(\omega)$$

$$\alpha_m(\omega) = \arg\left\{ \sum_{j=1}^{N} \Psi_m(z_j) P_j(\omega) \right\}$$



- Requires only signal phase in the signal bandwidth

# MF and STR Ranging Idea

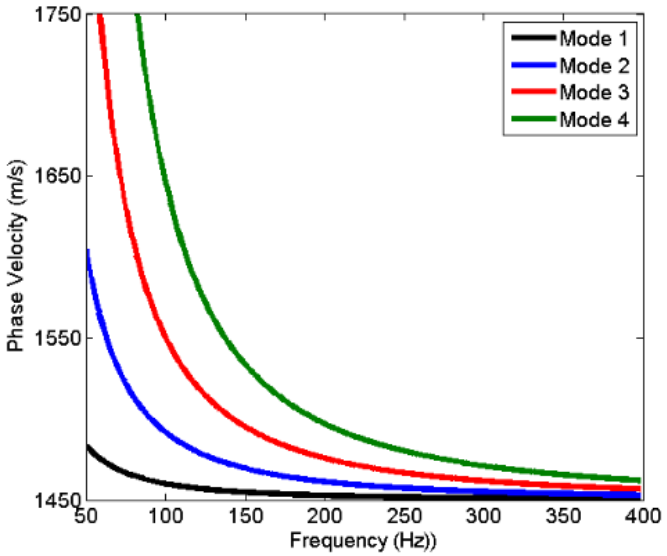
$$\hat{S}_1(\omega) \leftrightarrow \exp(\hat{\varphi}_s(\omega) + ik_1R)$$

$$\hat{S}_2(\omega) \leftrightarrow \exp(\hat{\varphi}_s(\omega) + ik_2R)$$

$$\hat{S}_1^*(\omega)\hat{S}_2(\omega) \leftrightarrow \exp(\hat{\varphi}_s(\omega) - \hat{\varphi}_s(\omega) + i(k_2 - k_1)R) \quad \underline{\mathbf{1}}$$

Grachev, 1993

$$\approx \frac{2\pi.\Delta}{\omega}$$



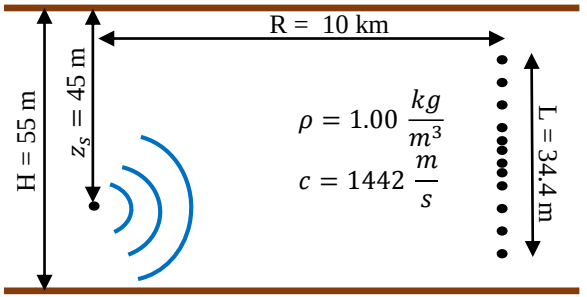

$$Error(R_e) = \sum_{\omega=\omega_1}^{\omega_2} [\{k_2(\omega) - k_1(\omega)\}R_e - \frac{2\pi.\Delta}{\omega}]^2 \quad \underline{\mathbf{2}}$$

Propagation Model

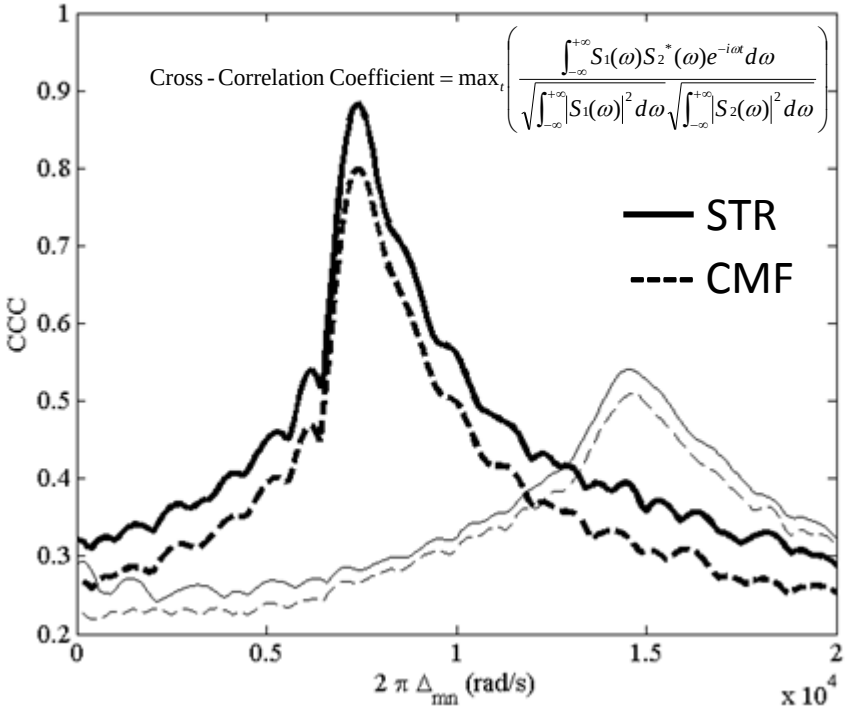
* Grachev (1993), "Theory of acoustic field invariants in layered waveguides", Acoust. Phys., 39, 67-71.

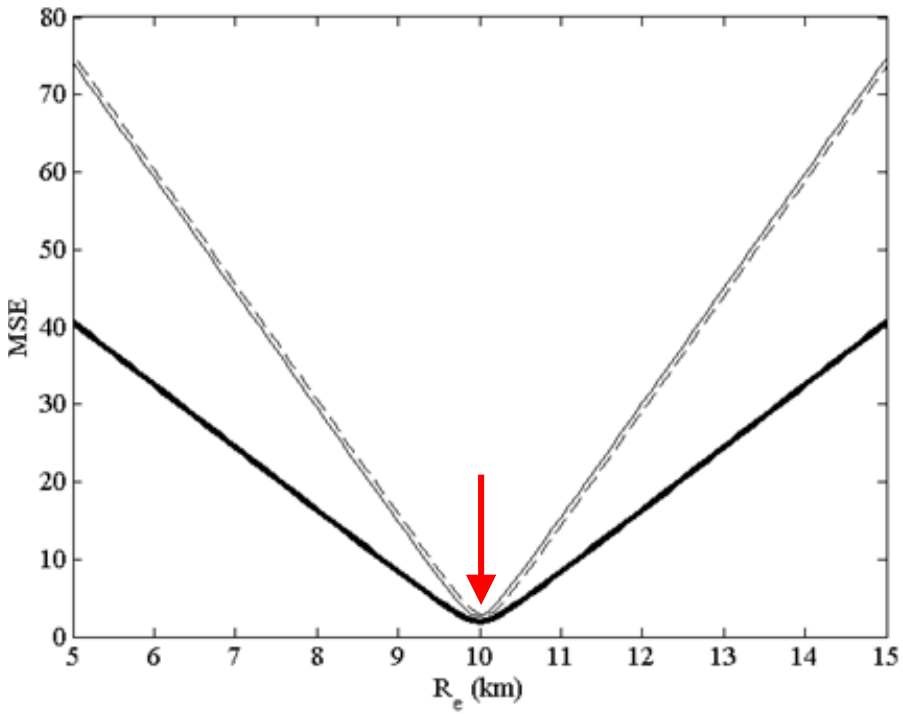
# Simulation Results

- Mode-based STR has slightly higher CCC than CMF.
- Different pairs of modes can be used if:
  - the mode pair is orthogonal across the array aperture.
  - both modes are excited by the sound source.



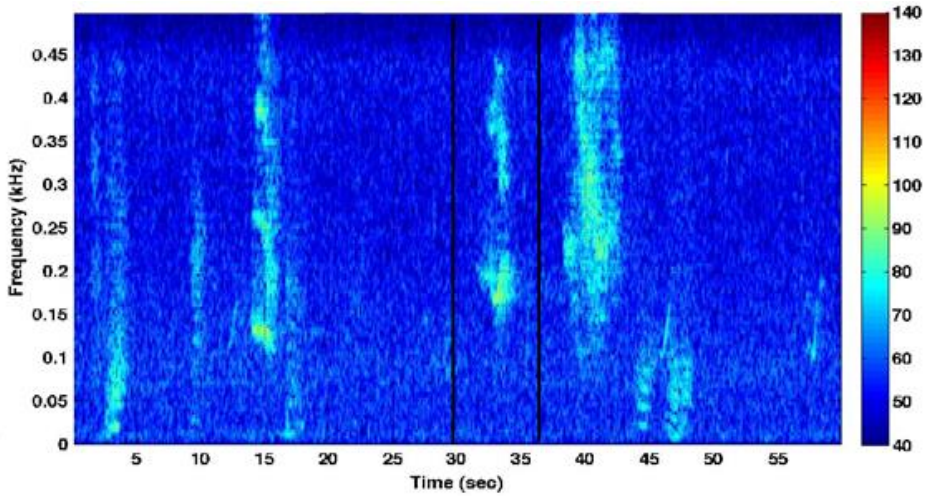

$\rho_{bottom} = 1.489\ \frac{kg}{m^3},\ c_{bottom} = 1638\frac{m}{s},\ \alpha = 0.943\frac{dB}{\lambda}$



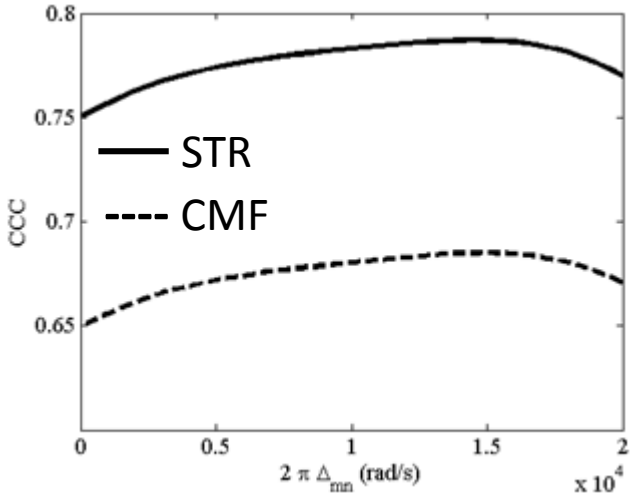



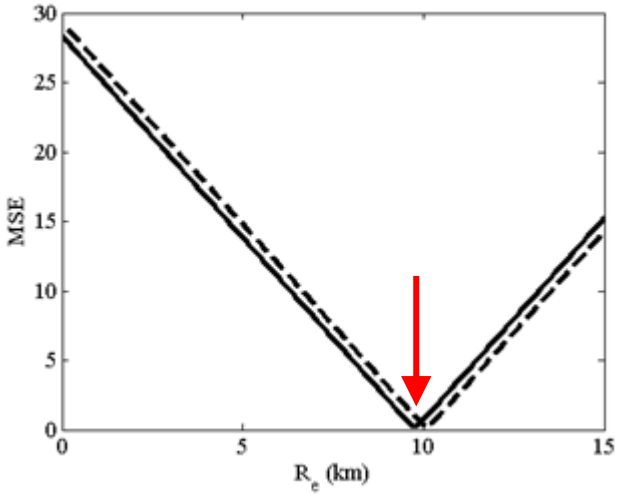
# Natural Whale Call Result

- Recorded Time: 01:01:12 a.m. 31-Aug-2010
- Band Width: 140-450 Hz
- Signal to Noise Ratio: 12.4 dB

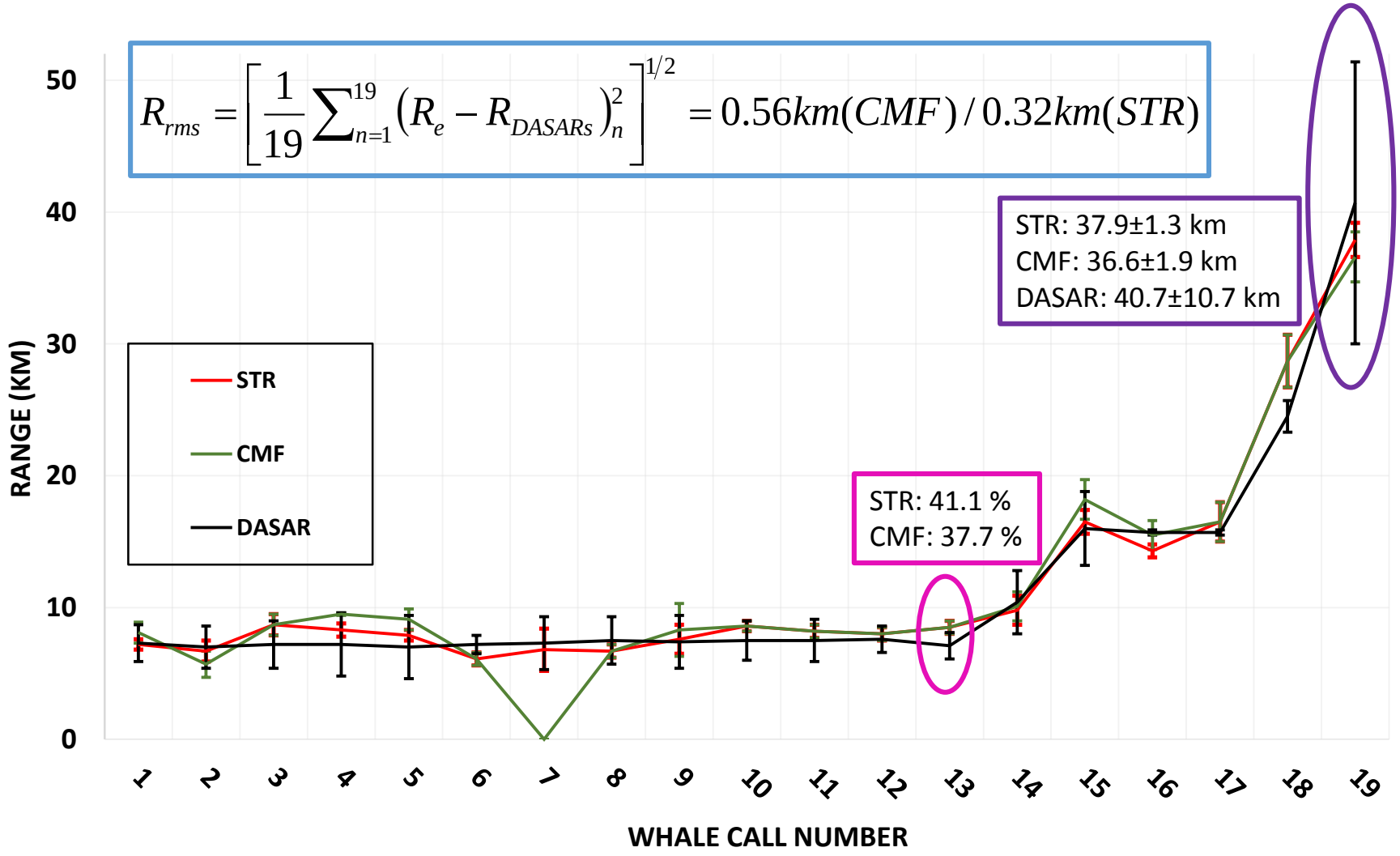



- STR Ranging Result: 9.8 km
- CMF Ranging Result: 10.1 km
- DASAR Ranging Result: 10.4 km



# Arctic Ranging Results




Shima H. Abadi, Aaron M. Thode, Susanna B. Blackwell, David R. Dowling; "Comparison of three methods of ranging bowhead whale calls in a shallow-water dispersive waveguide"; submitted to JASA

# Conclusions

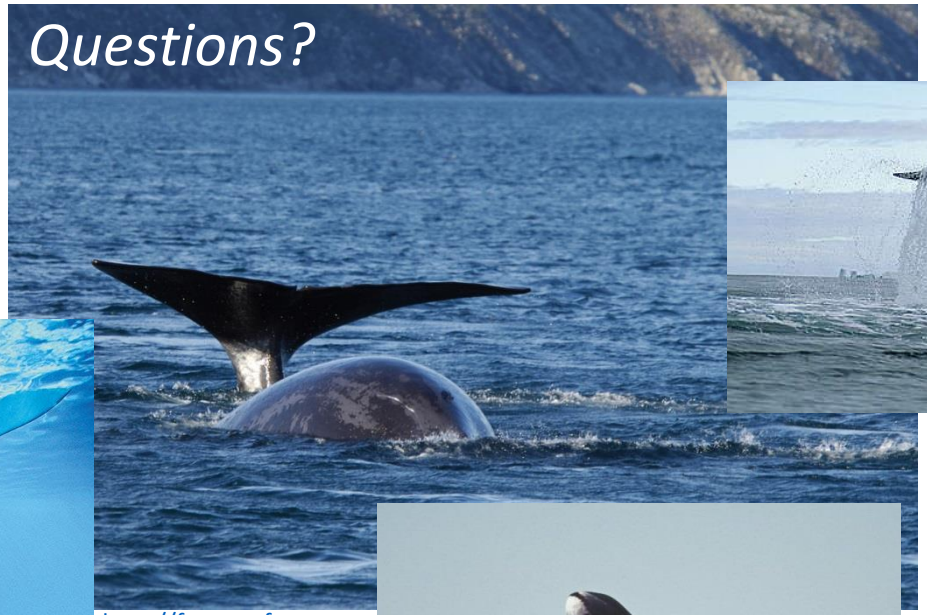
- Mode-based STR can be used for whale-call ranging when modal propagation is dispersive over signal bandwidth.

- STR and CMF results are consistent with those provided by standard DASAR ranging, and may be more precise for calls located outside the DASAR array perimeter.

- Ranging results are robust even when CCC is low between modes.

- For whale call ranging, mode-based STR provides a slight improvement over mode-filtering.

# *Thank you*

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