Range estimation of bowhead whales in shallow Artic waters using a single hydrophone

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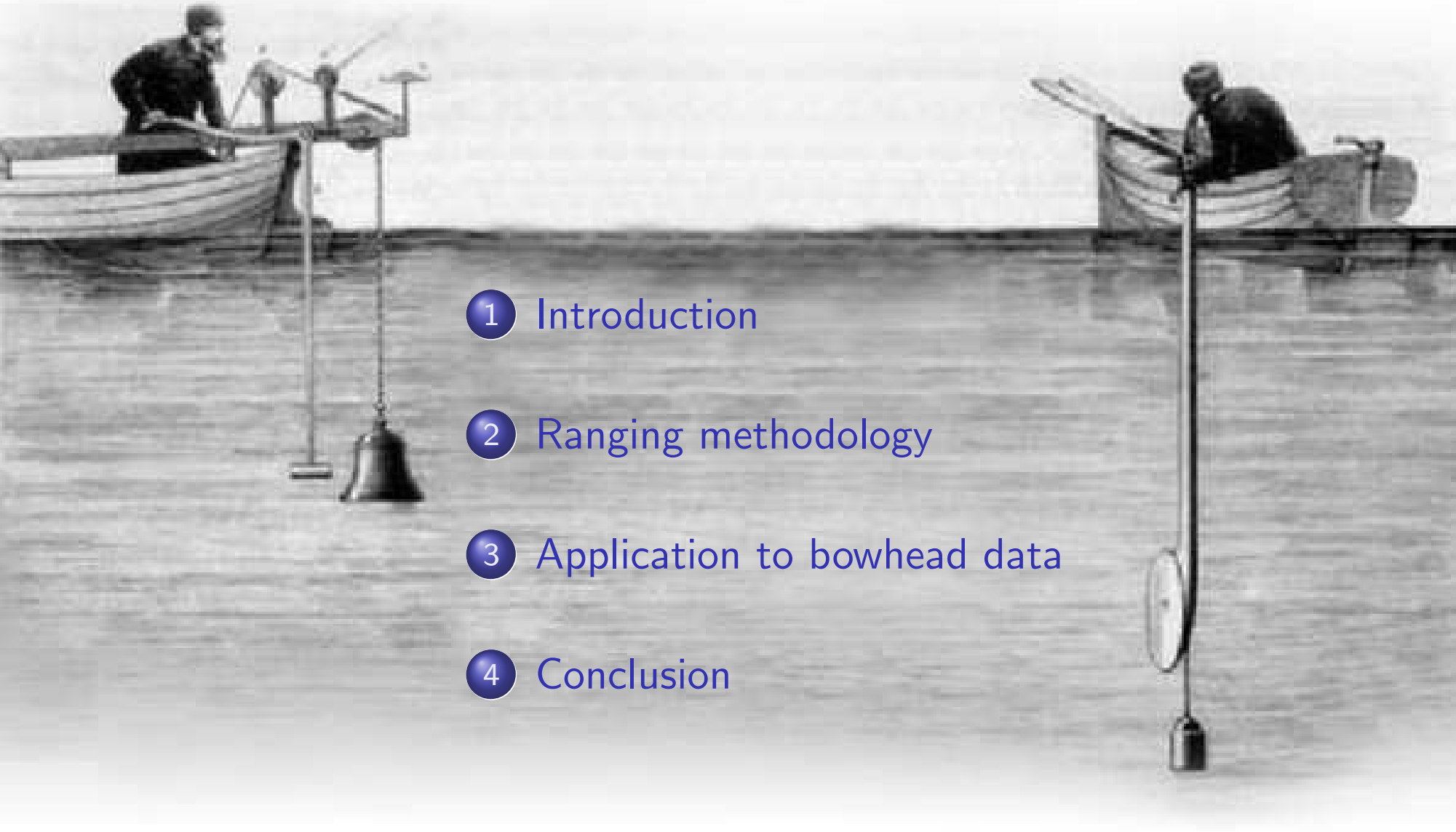
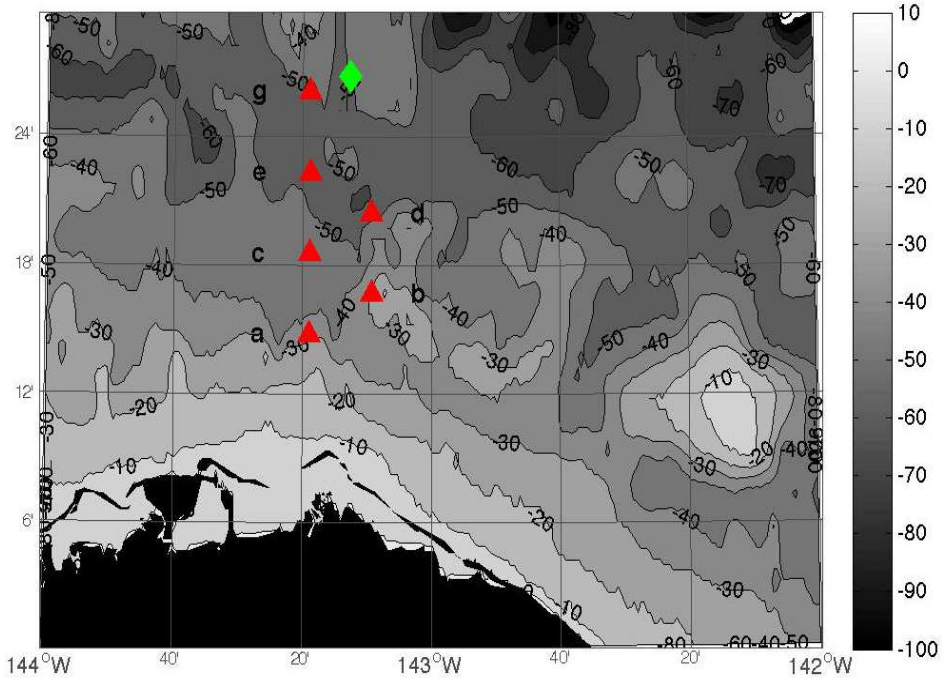
Outline

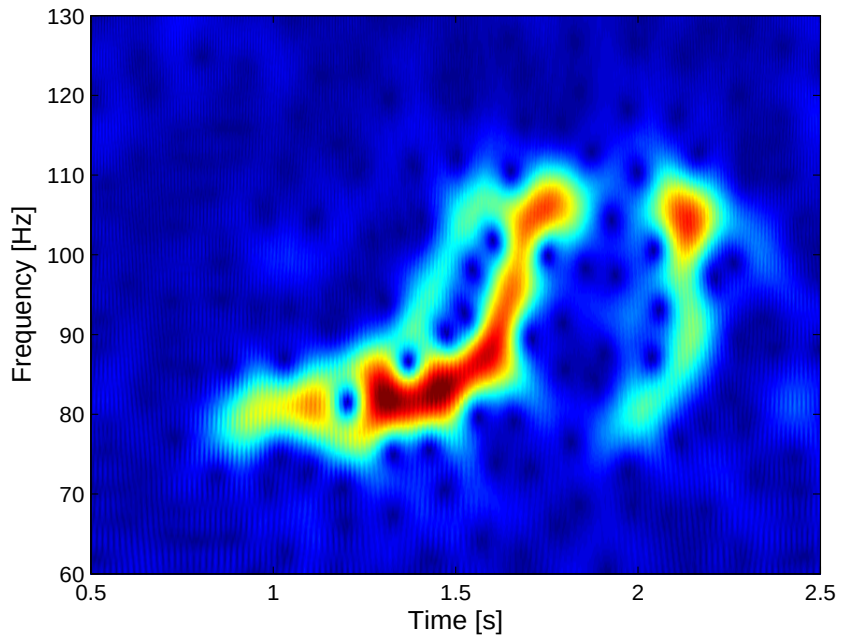


Context

- Bowhead whale vocalization (0-400Hz) in the Beaufort Sea
- Shallow water ($\sim$ 50m) $\Rightarrow$ modal propagation ($N_{modes} \lesssim 5$)
- Modes contain information about propagation : environment, source
- Objective : range (and depth) estimation using a single hydrophone



Environment, VLA (green) and DASARs (red)



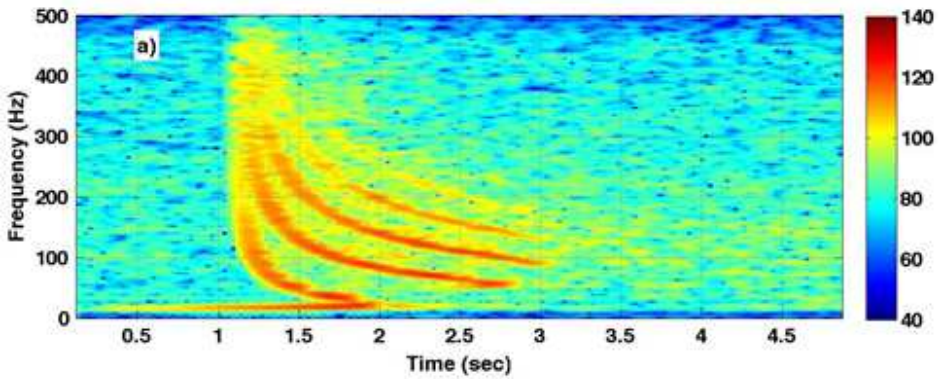
A bowhead whale vocalization

Modal propagation

- Low frequency propagation in shallow water is described by normal mode theory

$$Y(f) = |S(f)|e^{j\phi_s(f)} \sum_{m=1}^{N} \frac{\Psi_m(z_s, f)\Psi_m(z, f)}{\sqrt{rk_{rm}(f)}} e^{jrk_{rm}(f)}$$

- Modal phase $= rk_{rm}(f)$
  - defines travel time
  - position in the spectrogram
  - allows range r estimation
- Modal amplitude $\propto \Psi_m(z_s, f)$
  - energy (color) in the spectrogram
  - allows depth z_s estimation



Example : airgun signal

Passive localization scheme

- Localization scheme
  1. Modal filtering using warping
  2. Range inversion using filtered modes

- Modal filtering using warping
  - idea : transform the signal so that modes become separated
  - aim : warped modes = cw tones (horizontal lines in the spectrogram)
  - how : non-linear resampling

- Range inversion : classical backpropagation methodology (phase only)
  - source IF is obtained as a by-product

- Range/depth inversion : Matched Mode processing

- Geoacoustic inversion is required for each call
  - environment is modeled as a Pekeris waveguide with unknown seabed
  - inversion is performed over range r and seabed soundspeed c_b

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Warping ?

- What warping sounds like
  - Recorded off Australia Play Sound
  - After warping Play Sound
- How it is done

Warping requires a physical model to adjust the non-linear sampling

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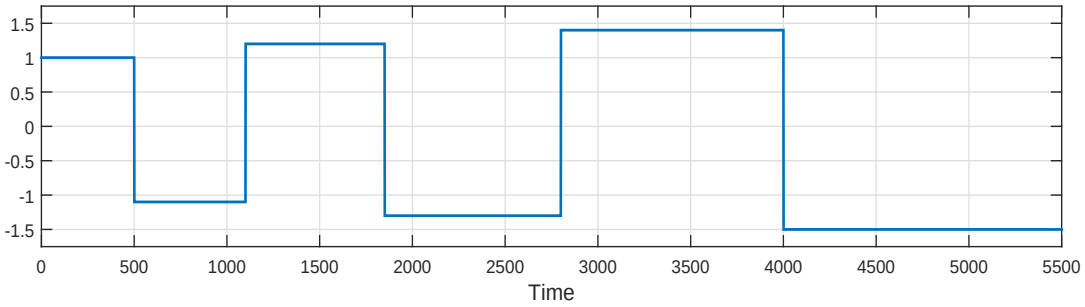

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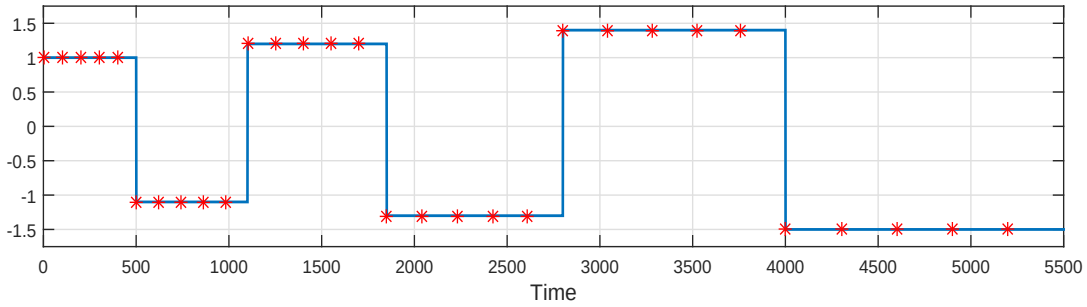

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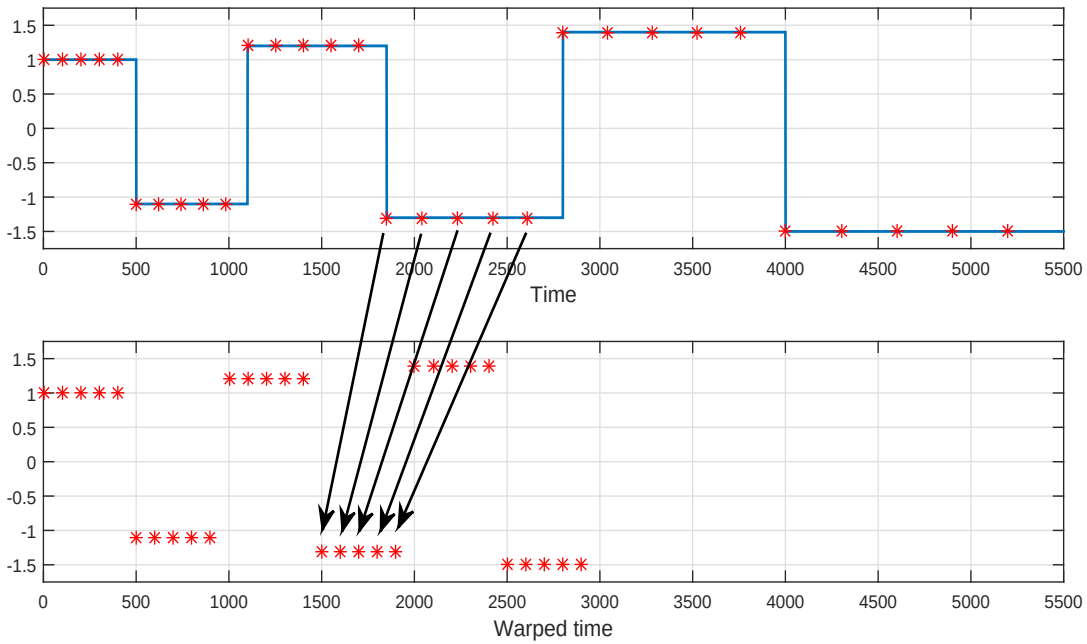

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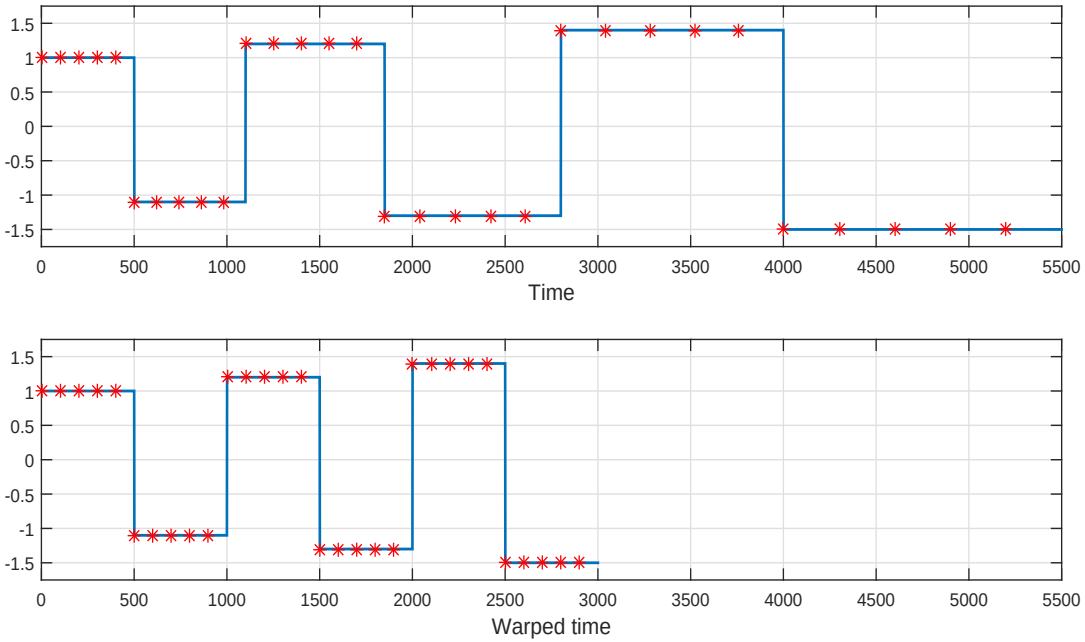

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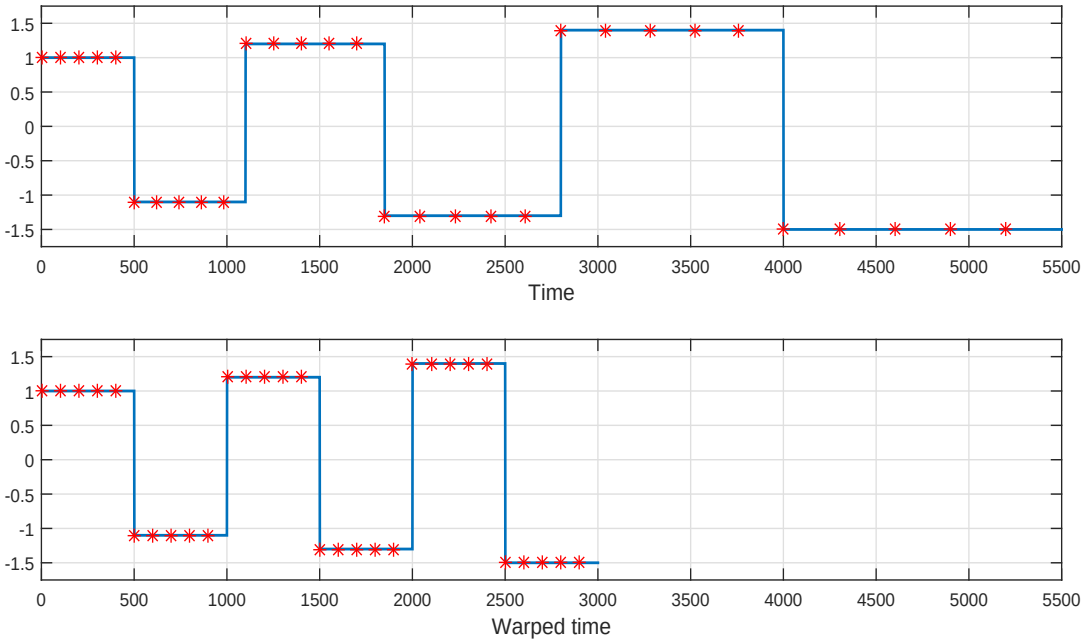

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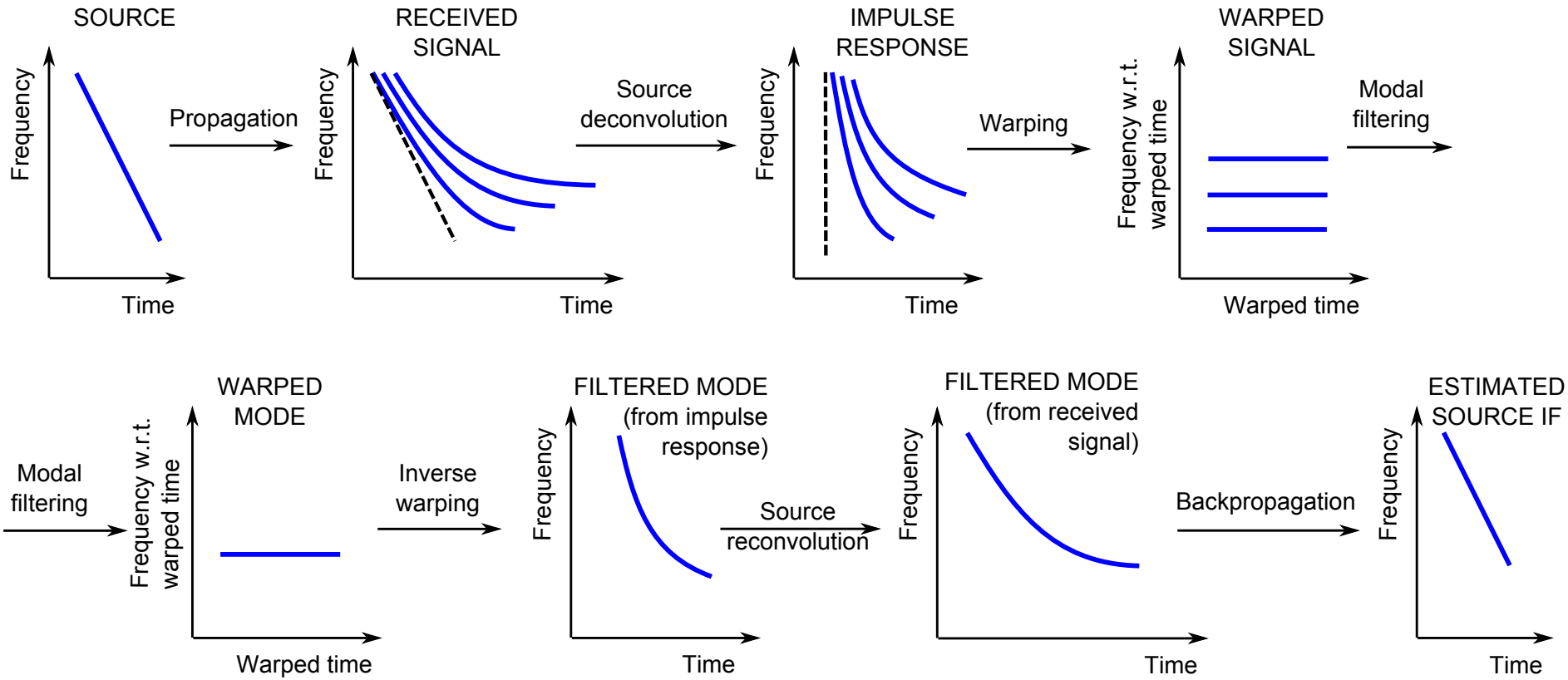
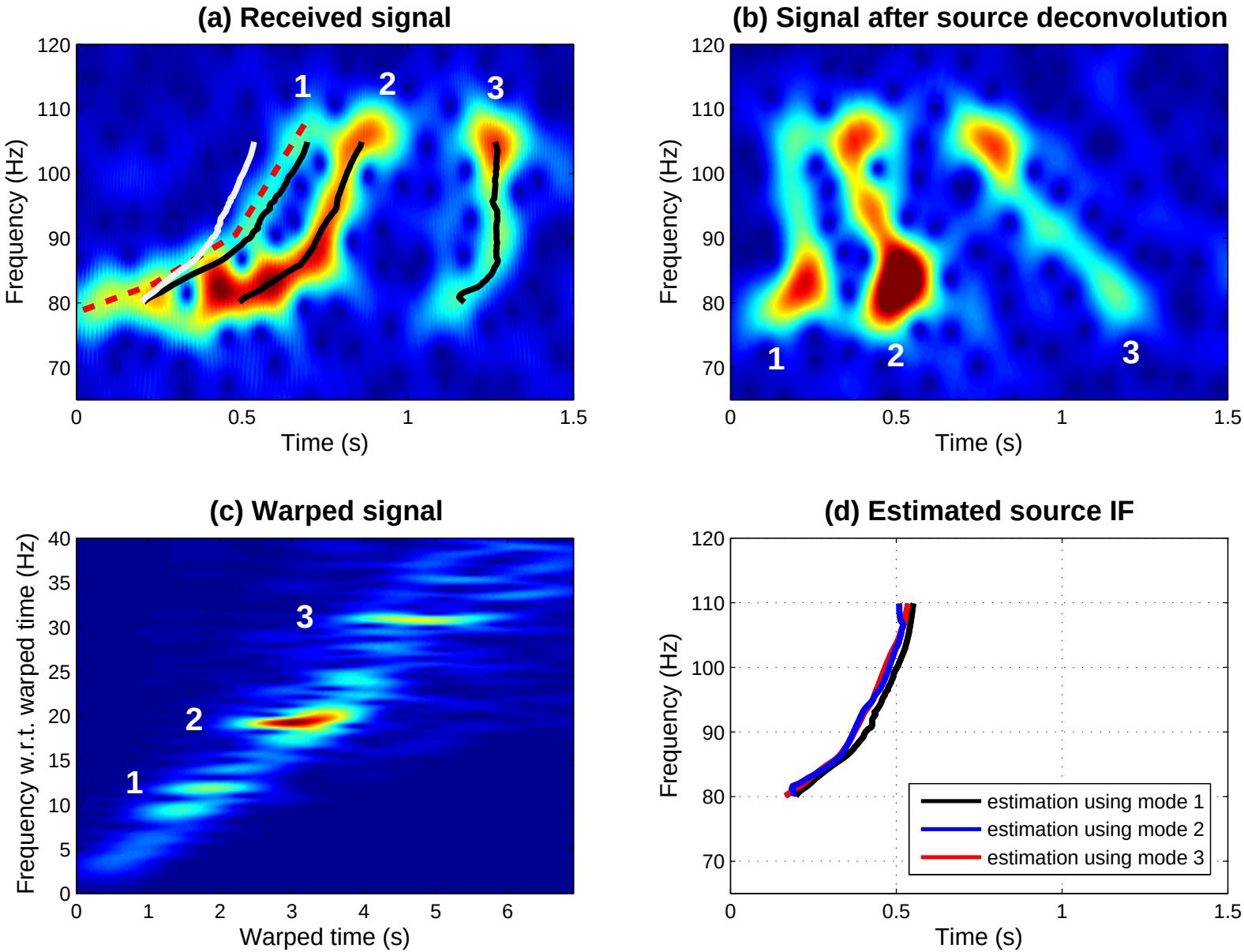
Modal filtering using warping



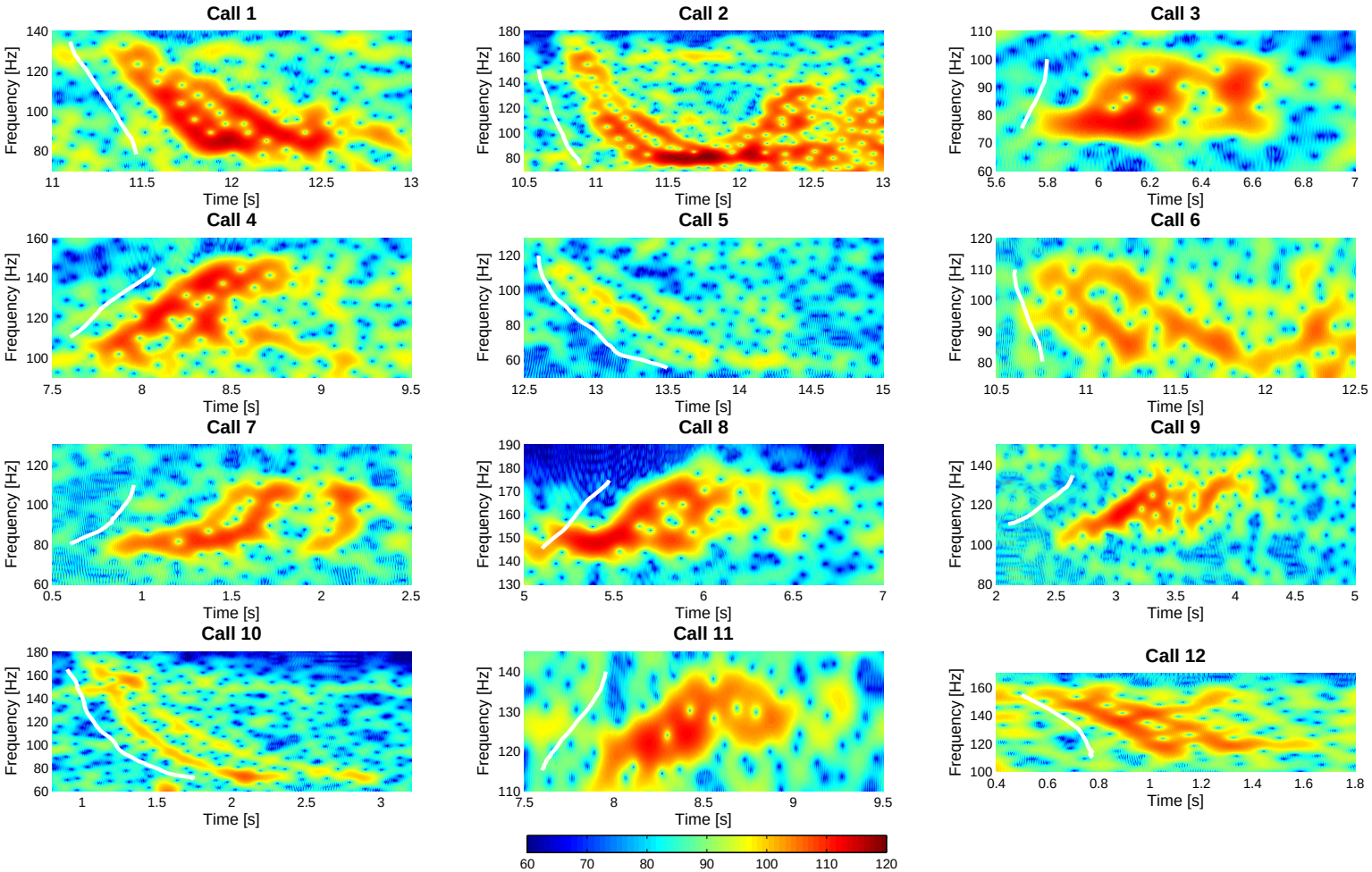
Deconvolution and warping parametrization only need to be accurate enough to allow mode filtering. Inverse steps allow full signal recovery.

Example with real data

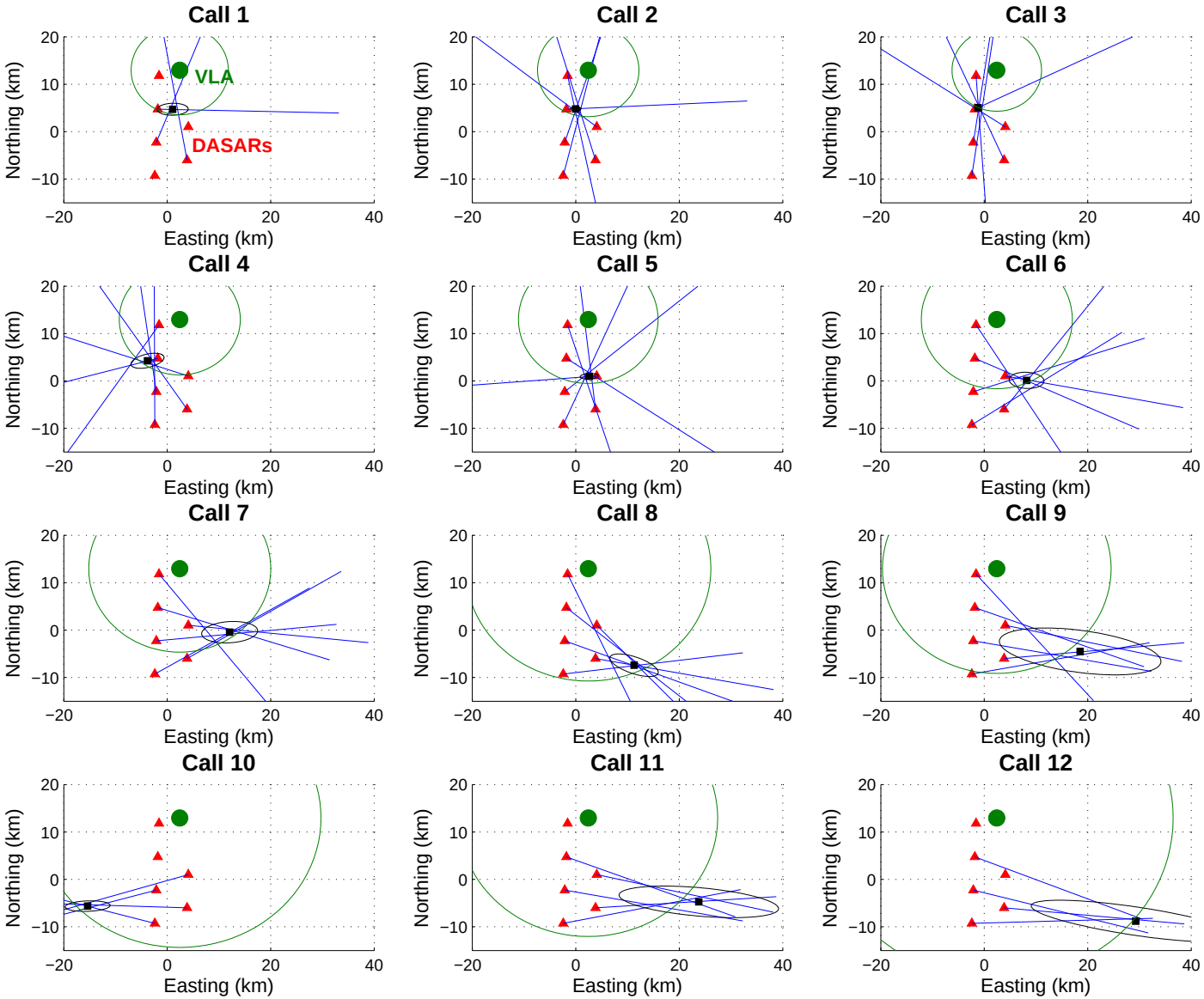


Dataset

Analysis of 12 calls with various bandwidths, durations, structure (fast/slow up/down sweeps), SNR, and modal resolution



Localization results



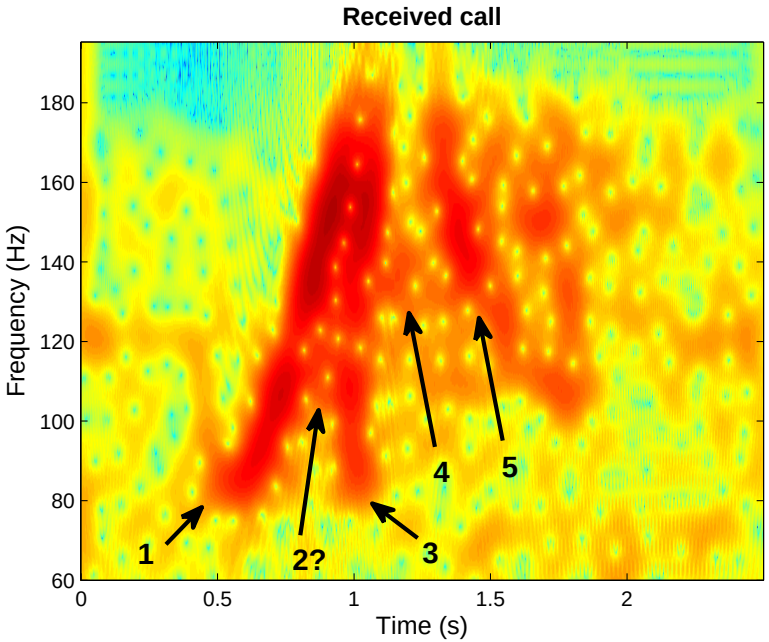
Detailed results

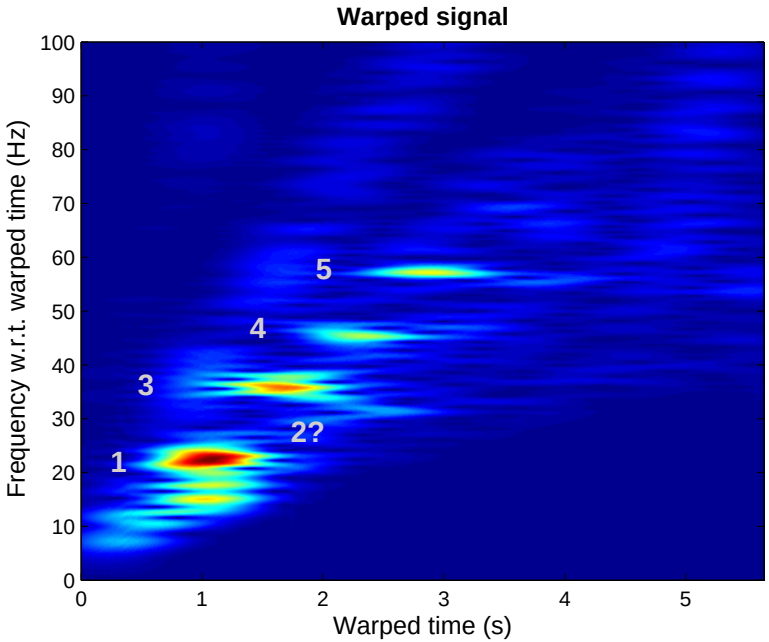
Call parameters			Single receiver inversion				DASAR localization	
n°	time	SNR (dB)	ΔF (Hz)	modes	$\widehat{r}$ (km)	$\widehat{c_b}$ (m/s)	DASARs	$\widehat{r}$ (km)
1	14 :48 :21	15	85-120	1-2-3	9.4 $\pm$ 1.8	1870	b-c-e	8.3 $\pm$ 1.3
2	14 :58 :10	12	85-115	1-2-3	9.8 $\pm$ 1.0	1830	a-b-c-d-e-g	8.5 $\pm$ 0.5
3	02 :08 :16	23	75-90	1-2-3	8.7 $\pm$ 1.3	1950	a-b-c-d-e-g	8.7 $\pm$ 0.2
4	14 :40 :28	18	110-130	1-2-3	11.7 $\pm$1.0	1710	a-b-c-d-e-g	10.7 $\pm$ 0.9
5	01 :46 :22	6	65-115	1-2-3	13.5 $\pm$ 2.0	1580	a-b-c-d-e-g	11.9 $\pm$ 0.6
6	15 :14 :21	9	85-105	1-2-3	14.6 $\pm$ 0.9	1820	a-b-c-d-e-g	14.1 $\pm$ 1.8
7	10 :50 :14	8	85-100	1-2-3	17.6 $\pm$ 1.7	1830	a-b-c-d-e-g	16.5 $\pm$ 3.0
8	15 :14 :15	15	150-175	1-3	23.7 $\pm$ 1.2	1550	a-b-c-d-e-g	22.2 $\pm$ 2.4
9	09 :50 :37	15	110-130	1-2-3	22.1 $\pm$ 1.8	1840	a-b-c-d-e-g	23.8 $\pm$ 6.6
10	02 :27 :31	7	40-140	1-2	27.3 $\pm$ 2.2	1940	a-b-c-d	25.7 $\pm$ 1.5
11	09 :51 :02	13	120-130	1-2-3	25.0 $\pm$ 1.6	1880	a-b-c-d-e	27.8 $\pm$ 5.7
12	10 :57 :48	7	120-145	1-2	34.1 $\pm$ 0.7	1570	a-b-c-e	34.5 $\pm$ 5.0

- single receiver range estimates are consistent with DASAR estimates
- no direct link between range and SNR
- no physical meaning to the seabed sound speed estimates
- estimated source IFs different from received signals

Depth estimation : preliminary results

- Modal filtering $\Rightarrow$ matched mode processing (MMP)
  $\Rightarrow$ range and depth estimation
- Warping $\Rightarrow$ opportunity fo single receiver MMP
- Example on an "easy" call





- Results ($\hat{r} = 7.7$ km, $\widehat{z_s} = 33$ m) consistent with MFP estimation using a VLA (15 hydrophones)

Conclusion

- Bowhead whale ranging using a single receiver
- Modal filtering using warping
  - robust to uncertain knowledge of waveguide environment, experimental geometry and source signal
  - allows modal filtering at "short" range
  - allows source ranging and estimation of the source IF
- Existing dataset can be revisited. However
  - several manual iterations
  - source = monotonic FM sweep
  - at least two propagating modes
- Continuing work
  - automation
  - source depth and source level estimation
  - **depth discrimination $\Rightarrow$ discrimination between Right whales and Humpback whales**

Thanks ! ! ! Any questions ? ? ?