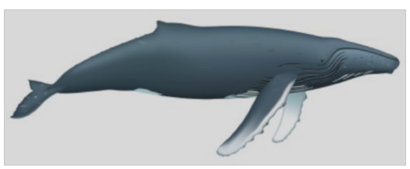
3-D Localization and Swim Track Kinematics of Humpback Whales on the Navy's Pacific Missile Range Facility

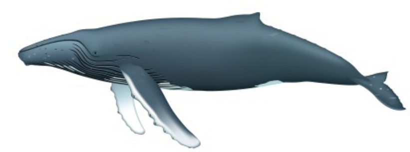
DCLDE San Diego, 2015



Tyler Helble | tyler.helble@navy.mil

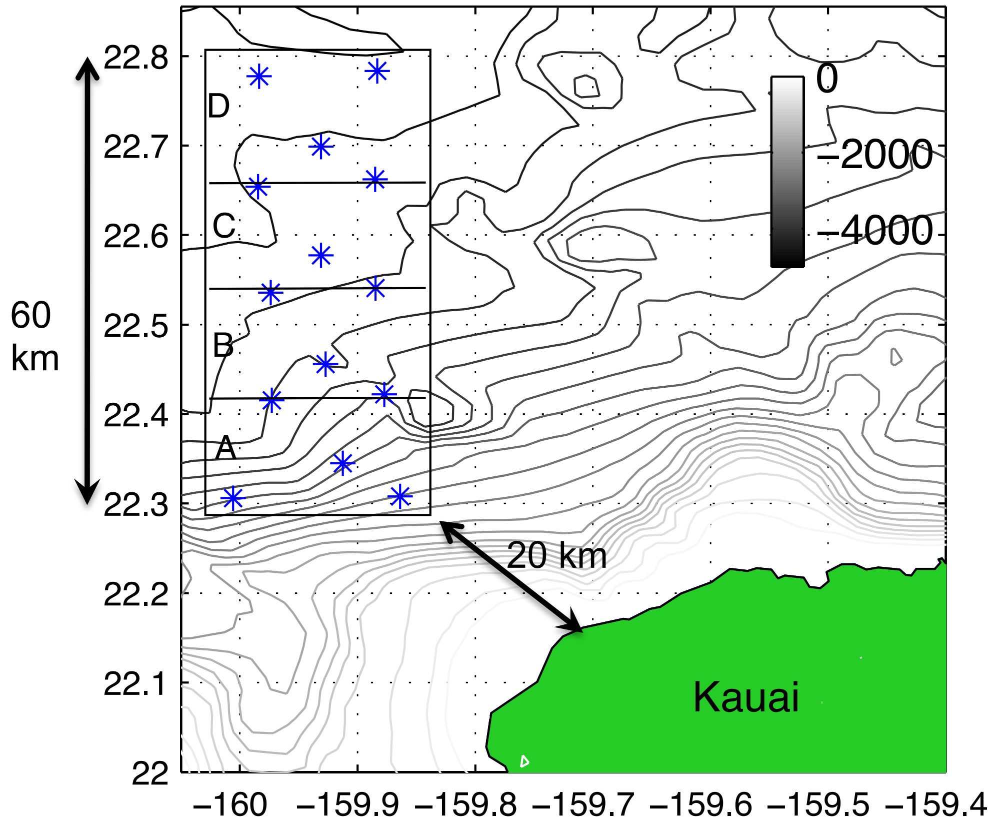
SSC-PAC 56470 Environmental Readiness

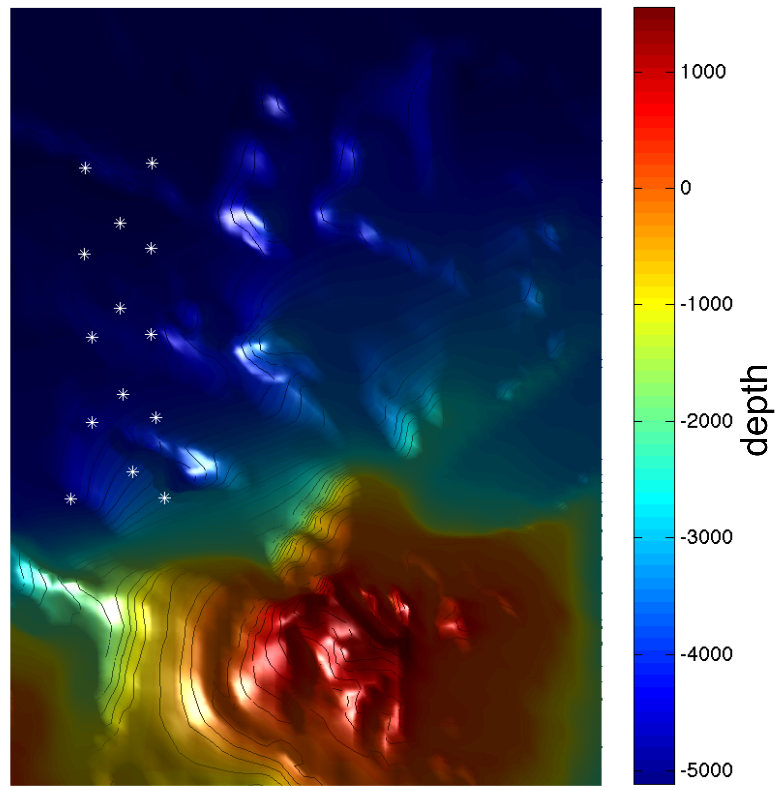
26 Oct 2014



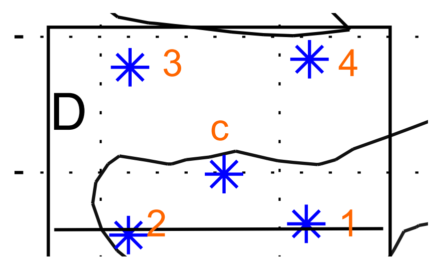
Glenn Ierley (SIO), Steve Martin (SSC-PAC), Gerald D' Spain (SIO), Roanne Manzano (SSC-PAC), Elizabeth Henderson (SSC-PAC)

Objective: Acoustically localize and track vocalizing humpback whales in real-time as they transit through the PMRF range.





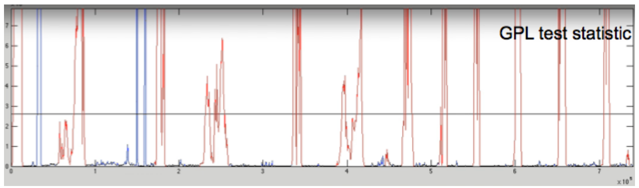
Traditional localization methods fail because of the high number of calls.



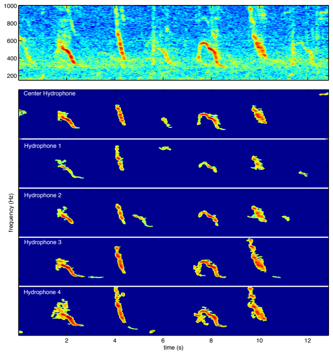
Methods for localization

1
Detection and Feature Extraction

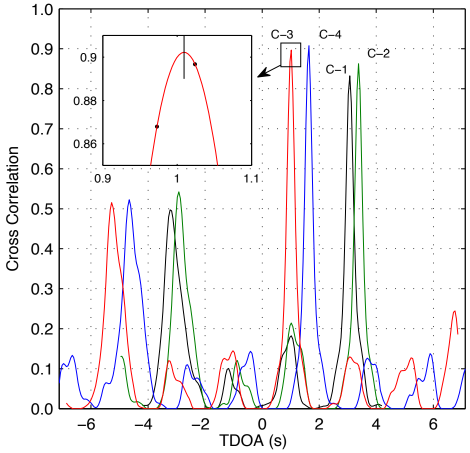
GPL Detector



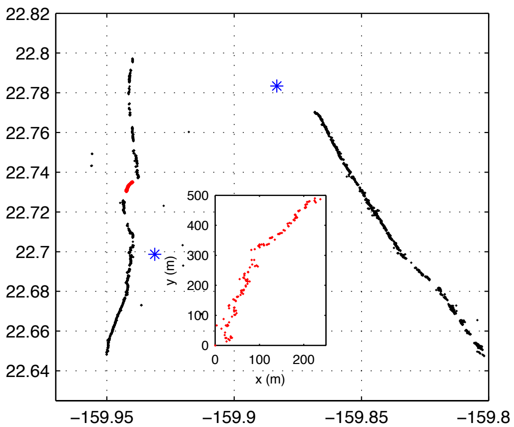
Feature Extraction



2
Cross Correlation

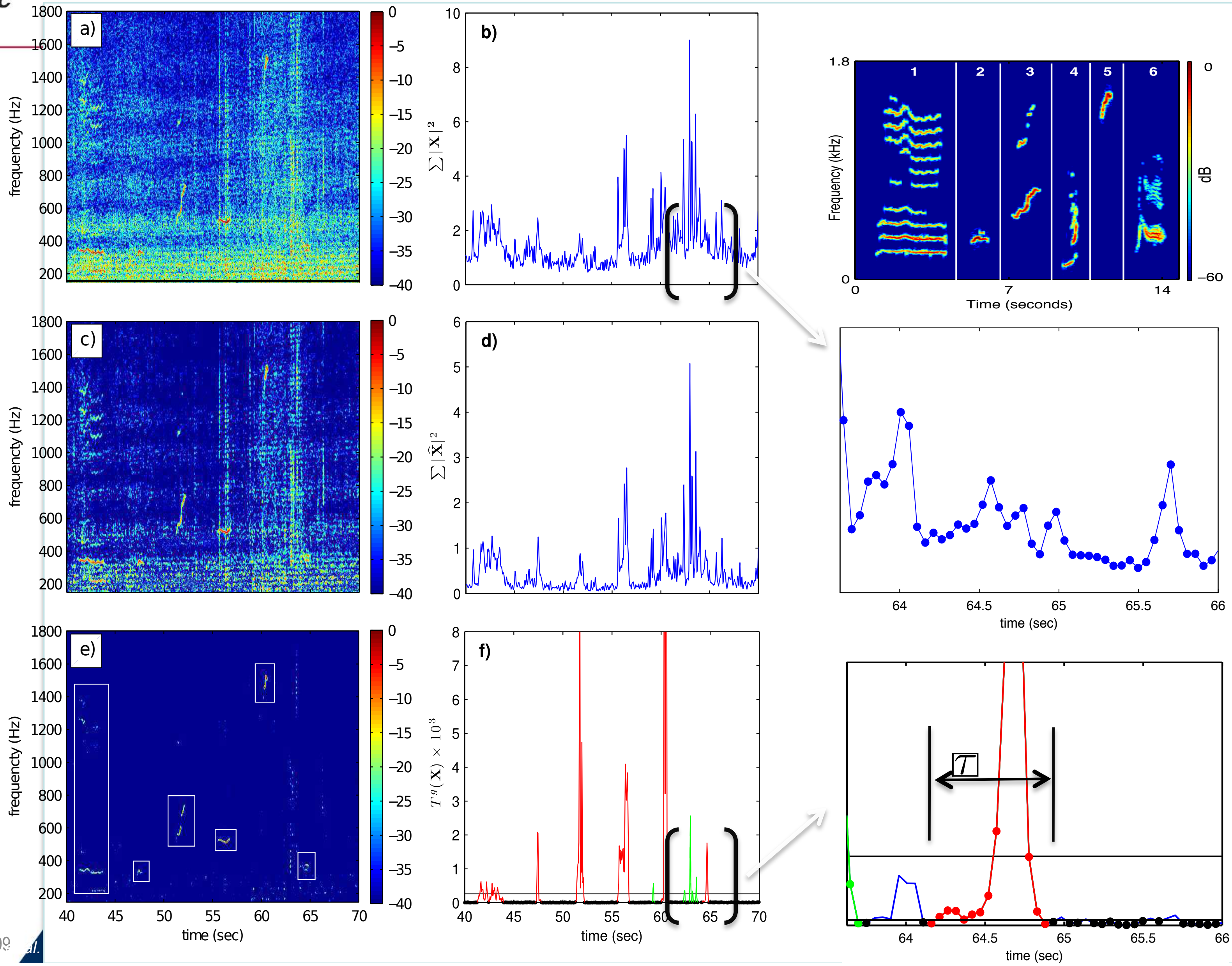


3
TDOA Based Localization

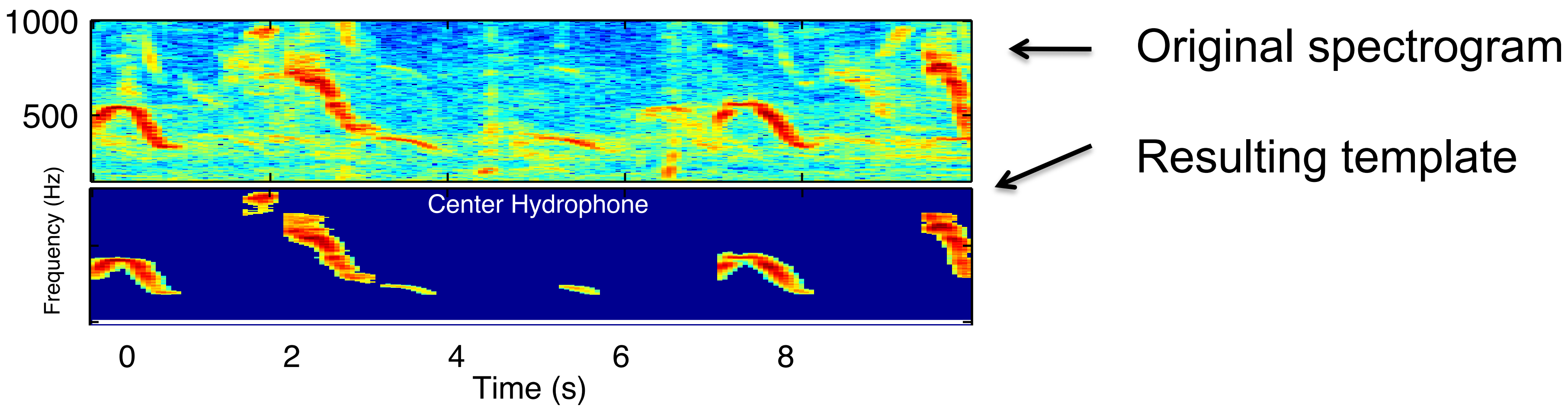


1

Generalized Power-Law Detector



Templating Procedure



Mean noise level for detected unit is determined by reshaping segment into a single column vector, mean noise level subtracted.

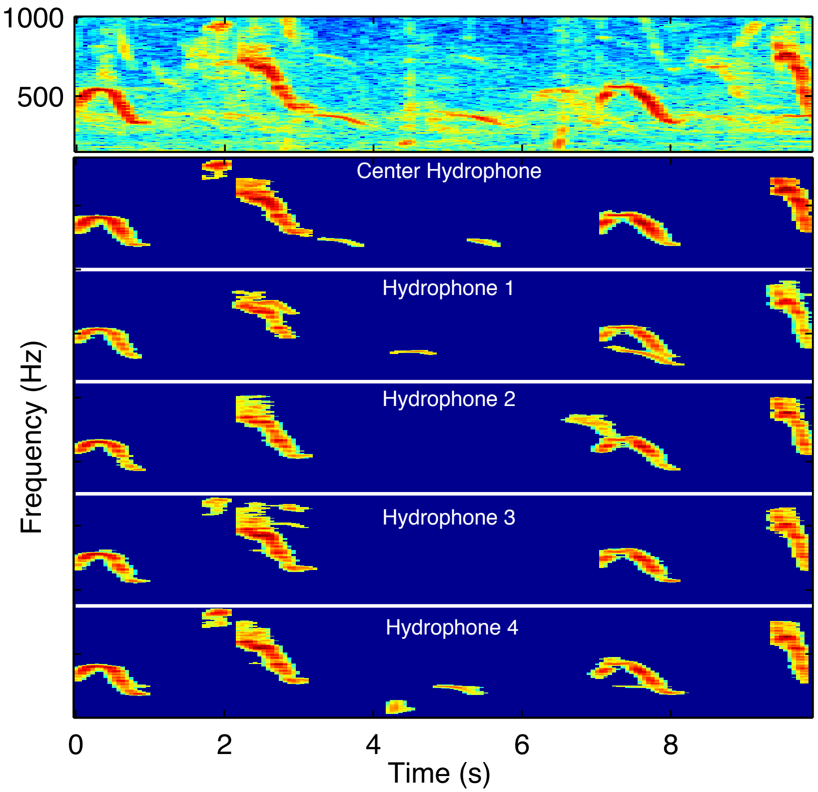
All elements exceeding 4X mean noise level are set to 1, all others to 0.

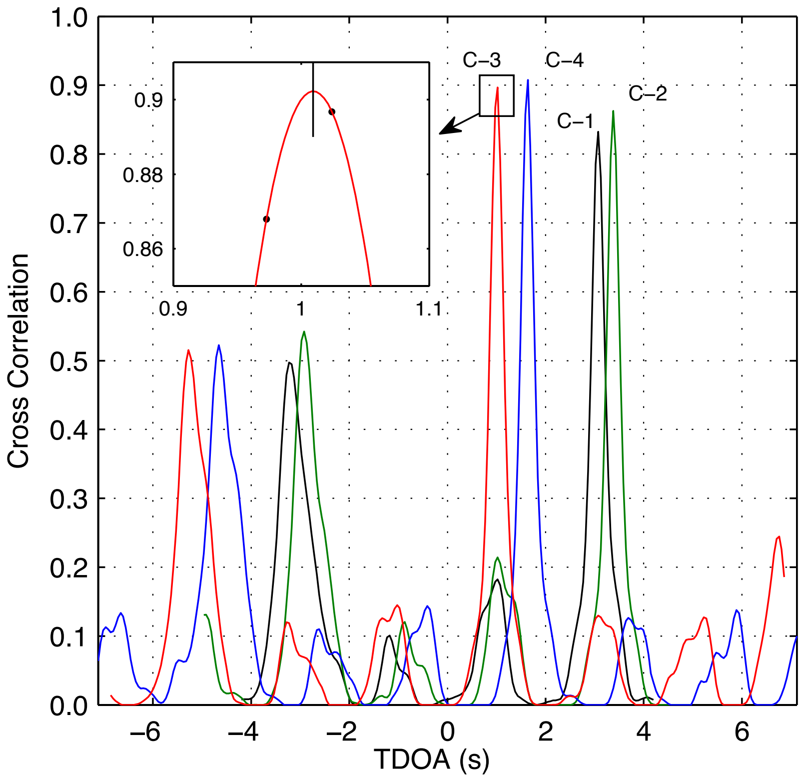
Largest “island” is selected (usually corresponding to fundamental).

“Island” used as a mask over whitened spectrogram (in amplitude not energy).

2

Obtaining Time Difference of Arrival (TDOA)



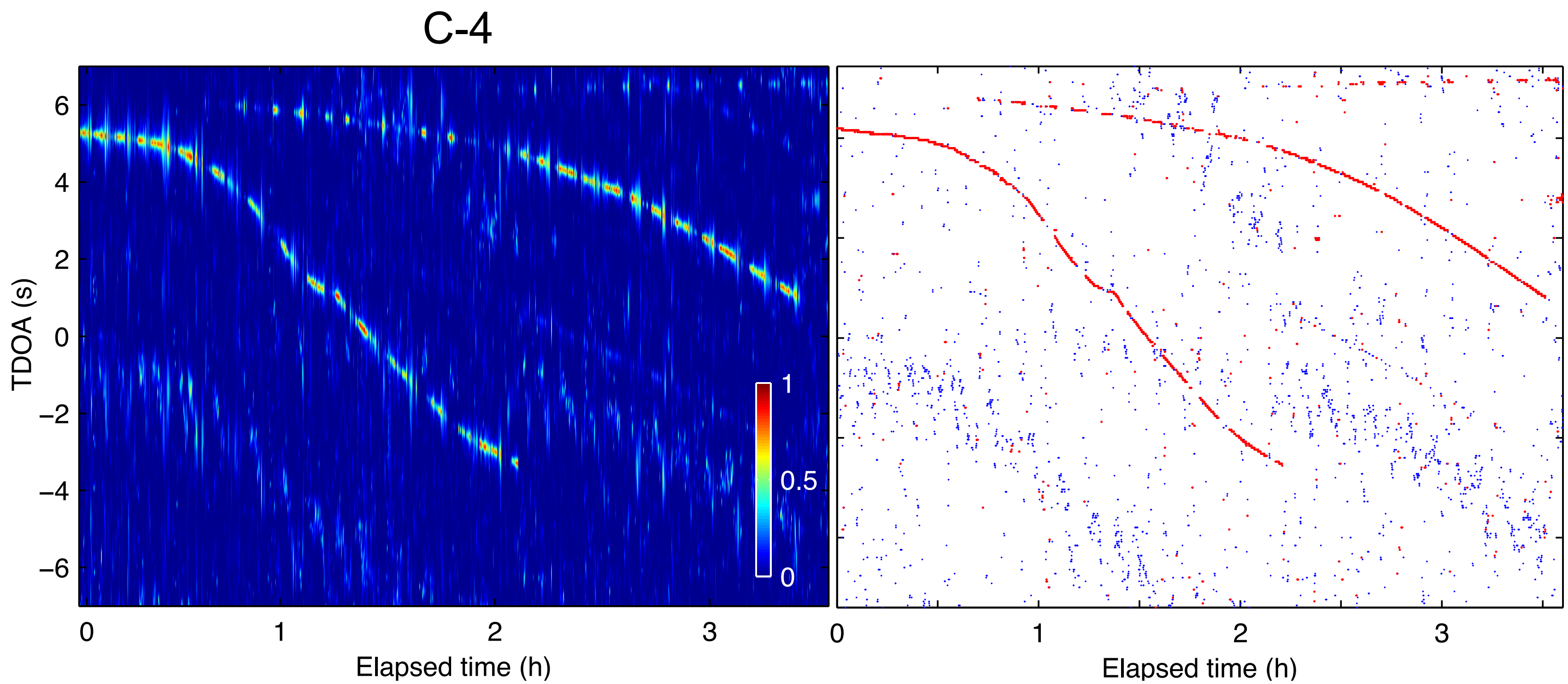


Original spectrogram and time-aligned *sequences* created from templates.

7 units are used (as determined by center hydrophone).

Cross Correlations used to extract time difference of arrival (TDOA) on hydrophone pairs.

Obtaining Time Difference of Arrival (TDOA)



TDOA over a 3 hour period when two humpback whales transit through the monitored area.

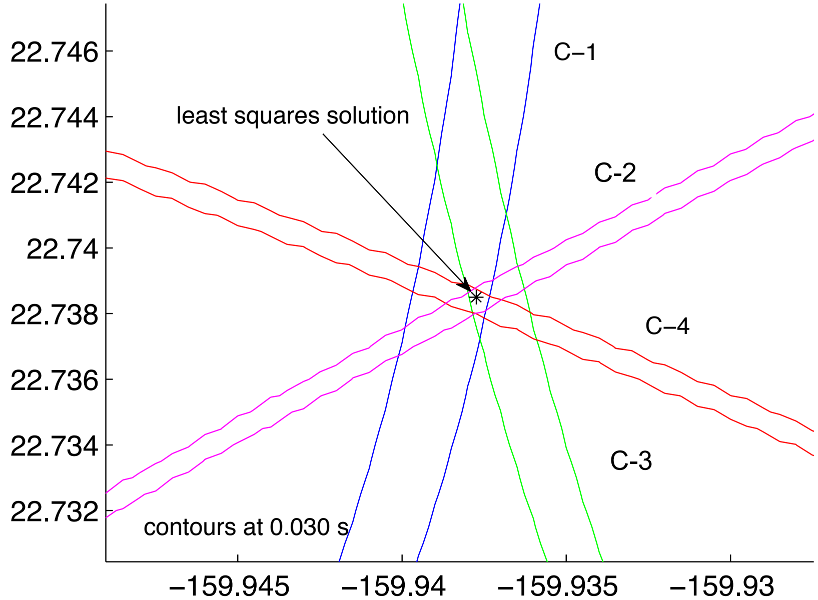
Highest peak (red) and 2nd and 3rd highest peaks (blue).

3
Model-based LSQ for localization

Maximal likelihood estimator (if timing errors are Gaussian)

$$\mathrm{LS}(\mathbf{w}) \propto \prod_{ij} \left\{ \max_k \left(\exp\left[\frac{-1}{2\sigma_{ij}^2} (\Delta t_{ij}(k) - \Delta\hat{t}_{ij}(\mathbf{w}))^2 \right] \right) \right\} \qquad (1)$$

Perfect fix = 1

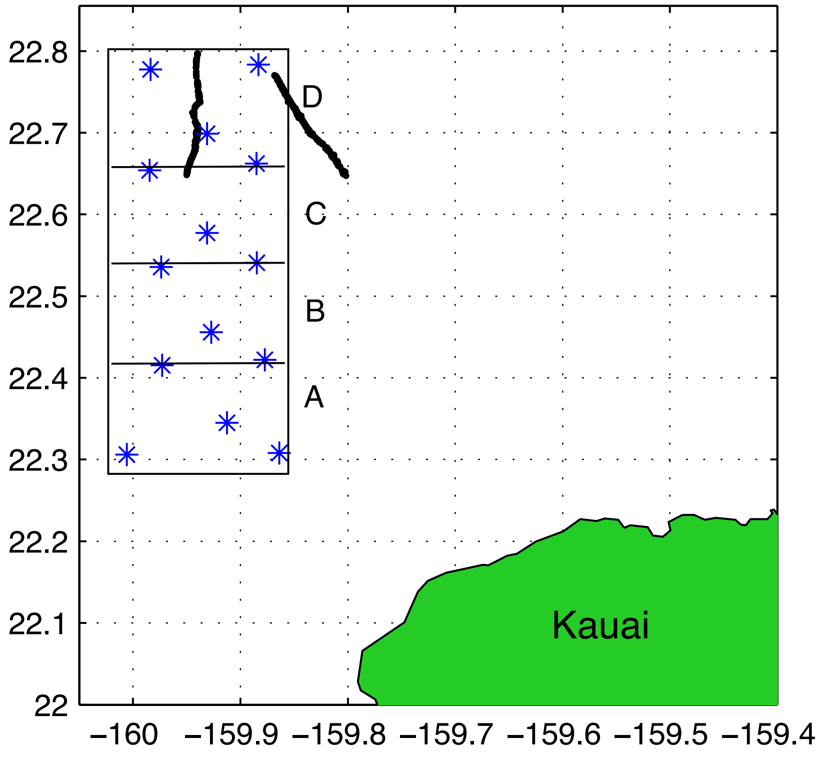


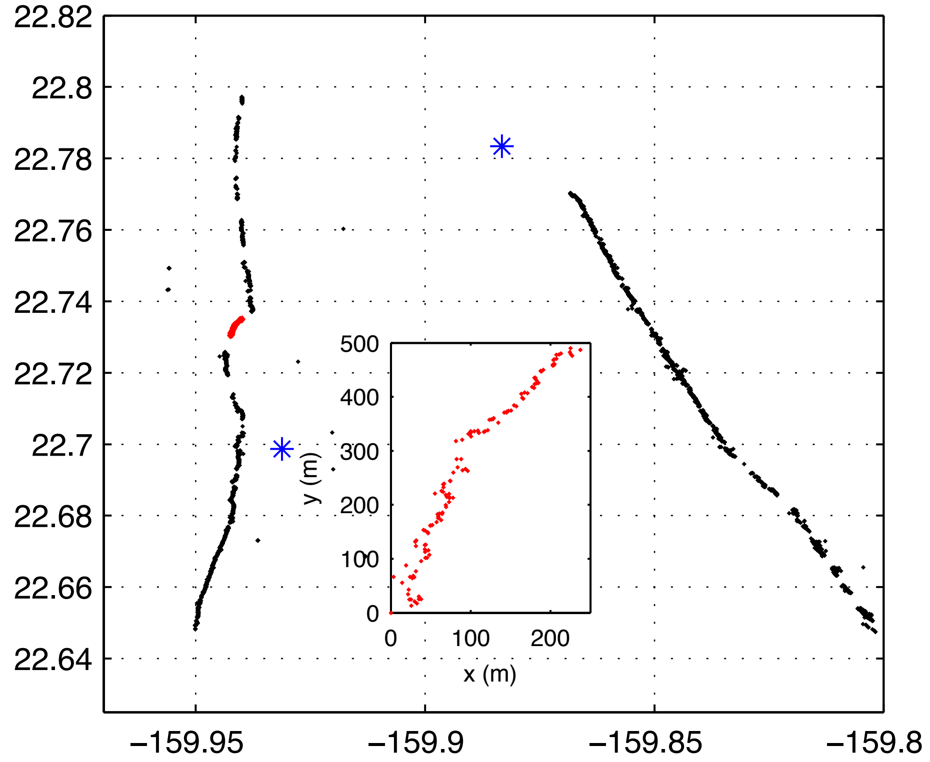
E.-M. Nosal, “Methods for tracking multiple marine mammals with wide-baseline passive acoustic arrays”, J. Acoust. Soc. Am. 134, 2383–2392 (2012).

Vass, A.E. "Refraction of the direct monotonic sound ray", TM No. 322, p.3 (1964).

Model-based LSQ for localization

Two humpback whales transiting through the range over 3.5 hour period

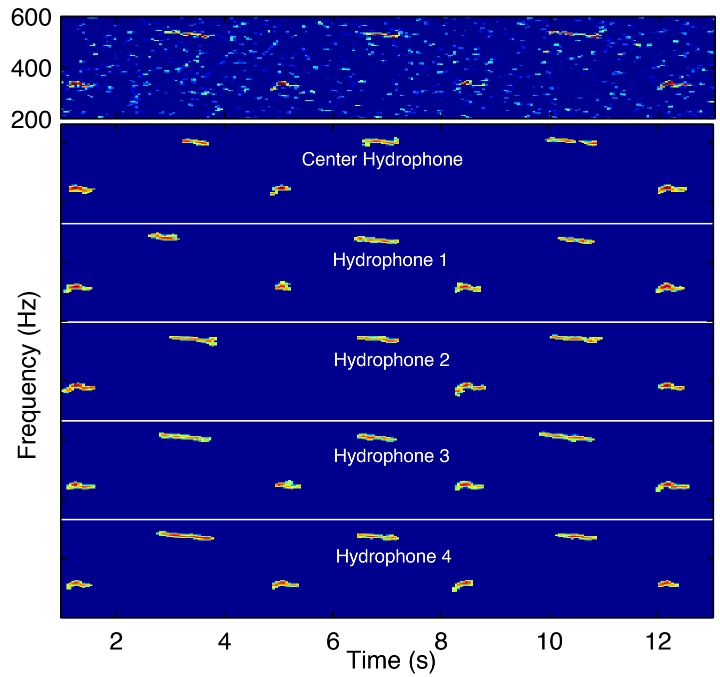


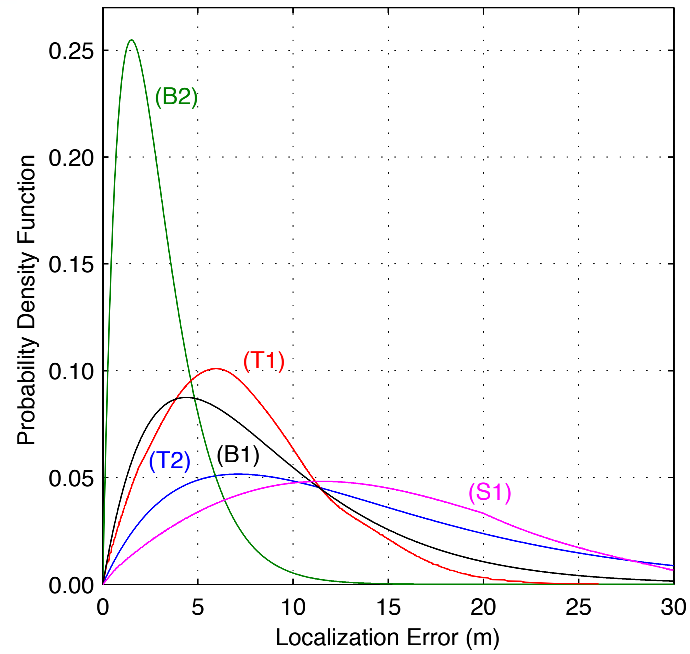


Standard deviation from trackline = 17 m
3,500 localizations during 3.5 hour period

Localization Accuracies

Monte Carlo simulations





Example spectrogram and related templates used to quantify timing and localization errors

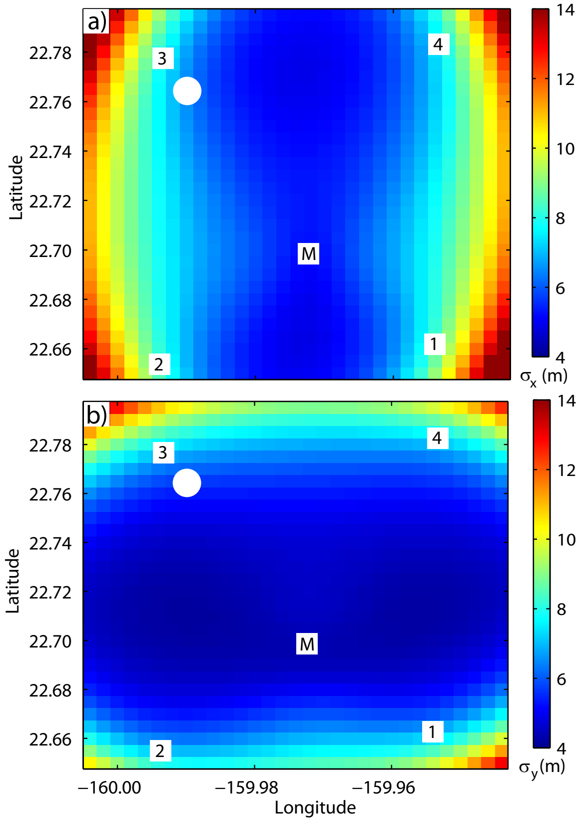
Case	Description	Noise level	σ_t	σ_x	σ_u
B1	Benchmark	Medium	4.85 ms	6.43 m	5.58 m
B2	Benchmark	Low	1.69 ms	2.25 m	1.96 m
B3	Benchmark	None	0.61 ms	0.98 m	0.64 m
T1	Energy	Medium	4.84 ms	6.52 m	5.68 m
T2	Shape	Medium	9.53 ms	12.95 m	11.16 m
S1	Two unit	Medium	11.40 ms	15.84 m	13.12 m
S2	Single grunt	Medium	9.06 ms	11.48 m	10.76 m
S3	Single tonal	Medium	42.61 ms	58.44 m	48.75 m

Localization Accuracies

Parameter estimation problem

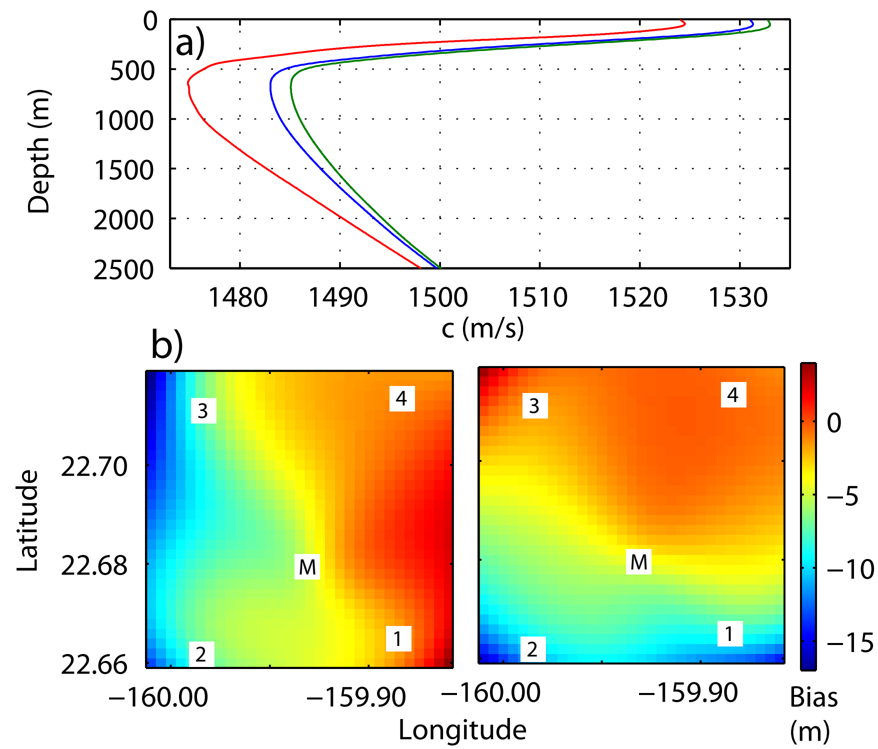
<u>Variance (or std deviation)</u>

arise primarily from timing delay errors



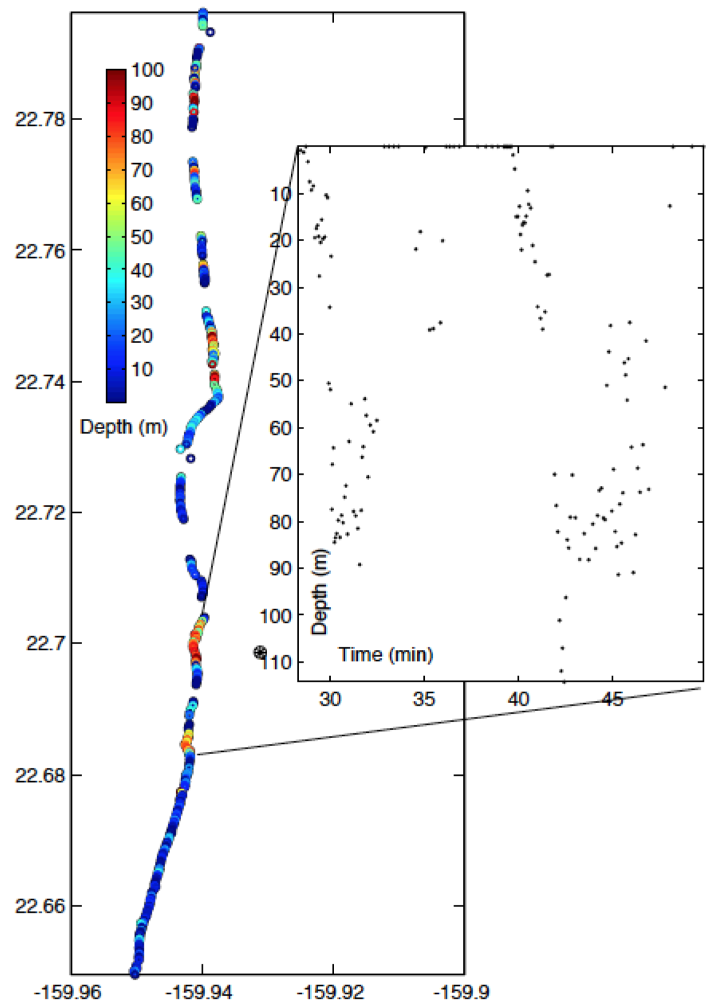
<u>Bias</u>

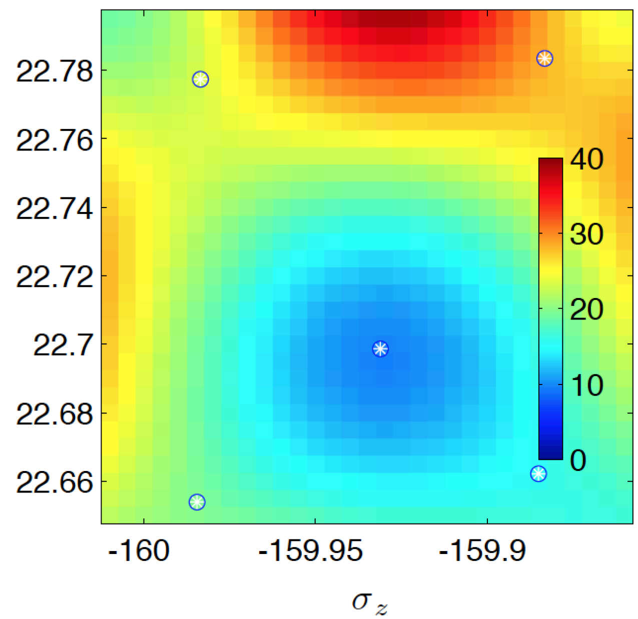
arise primarily from SSP mismatch



Automated acoustic localization and call association for vocalizing humpback whales on the Navy's Pacific Missile Range Tyler A. Helble[1,a)], Glenn R. Ierley[2], Gerald L. D'Spain[2] and Stephen W. Martin[3], JASA, 2015

Humpback transiting trends – 3D localization

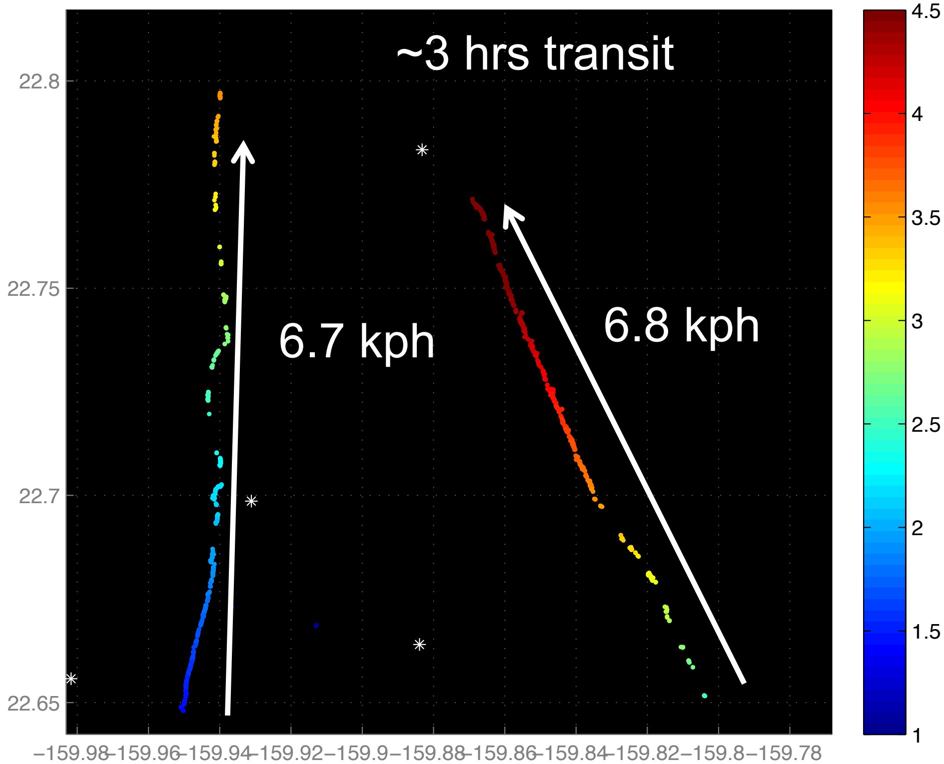




Timing delay errors extended to depth

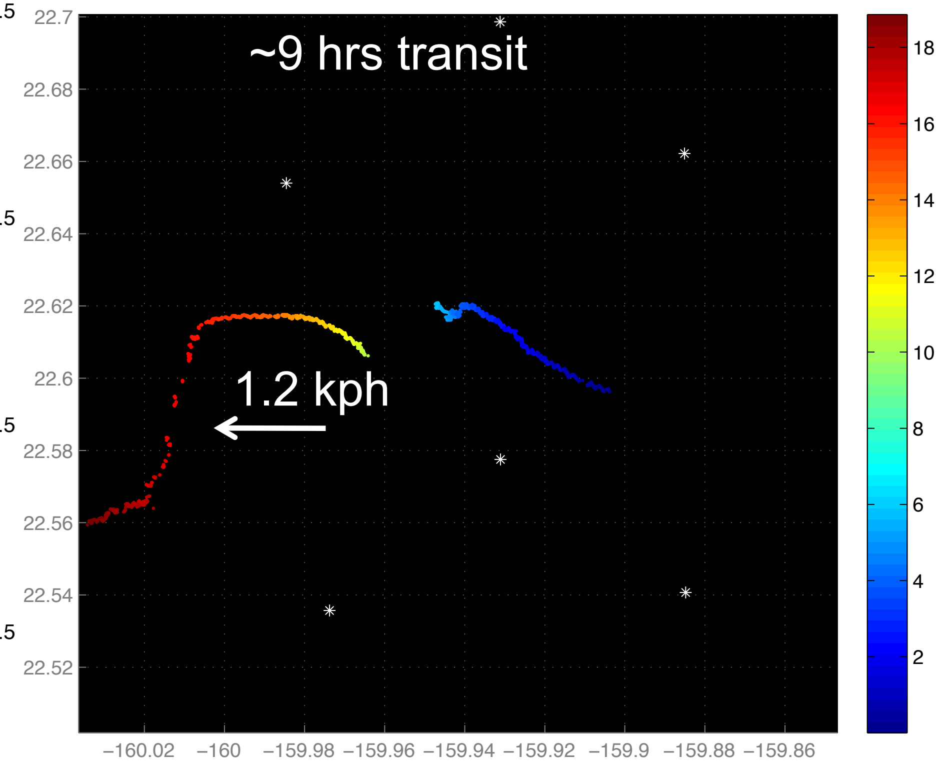
Humpback transiting trends

11 March 2013



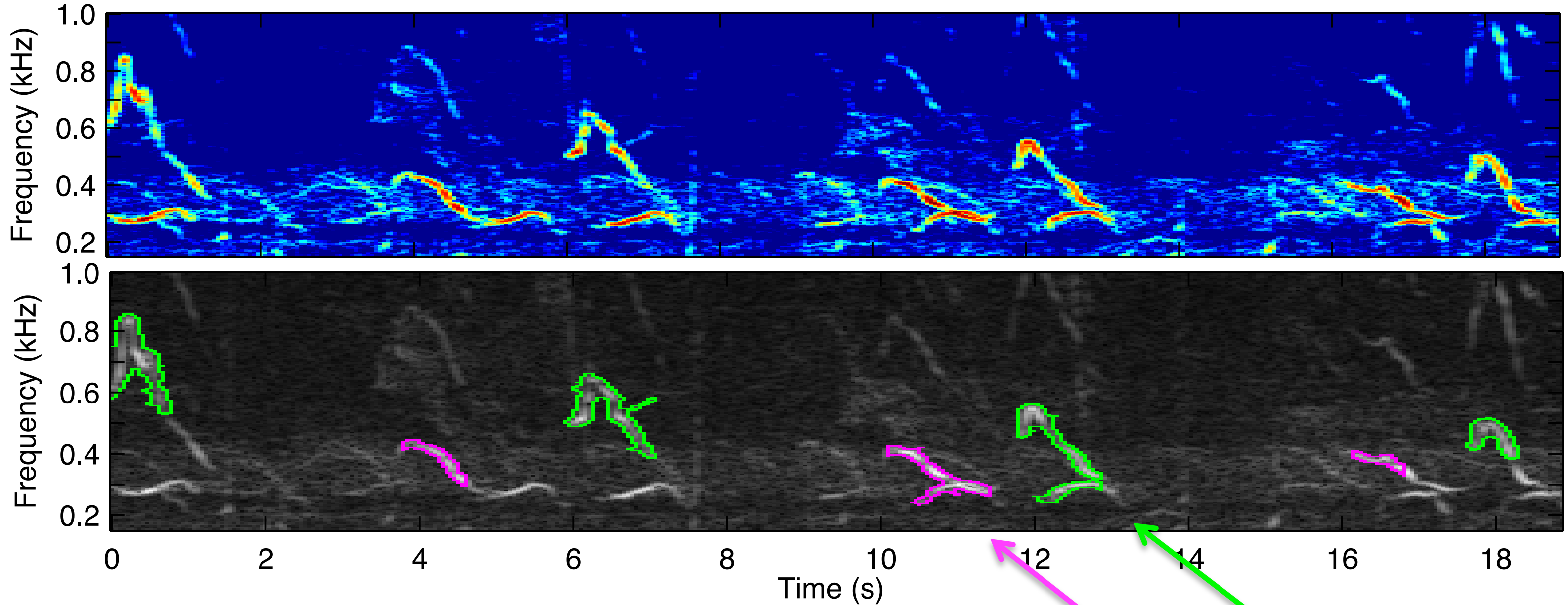
20 km

10 January 2013

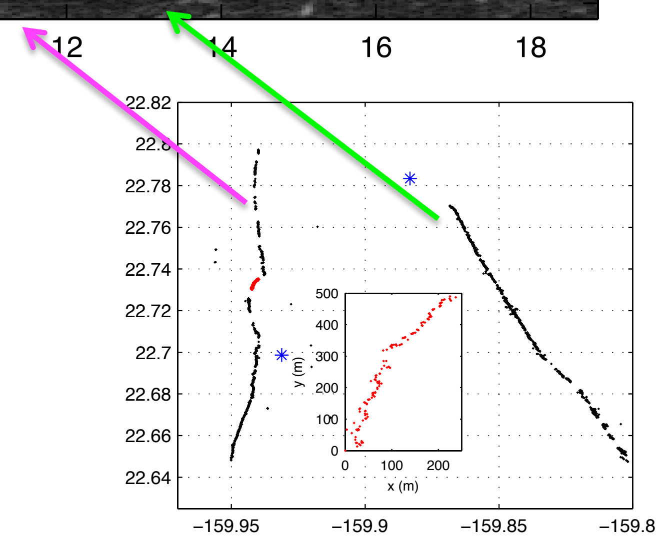


20 km

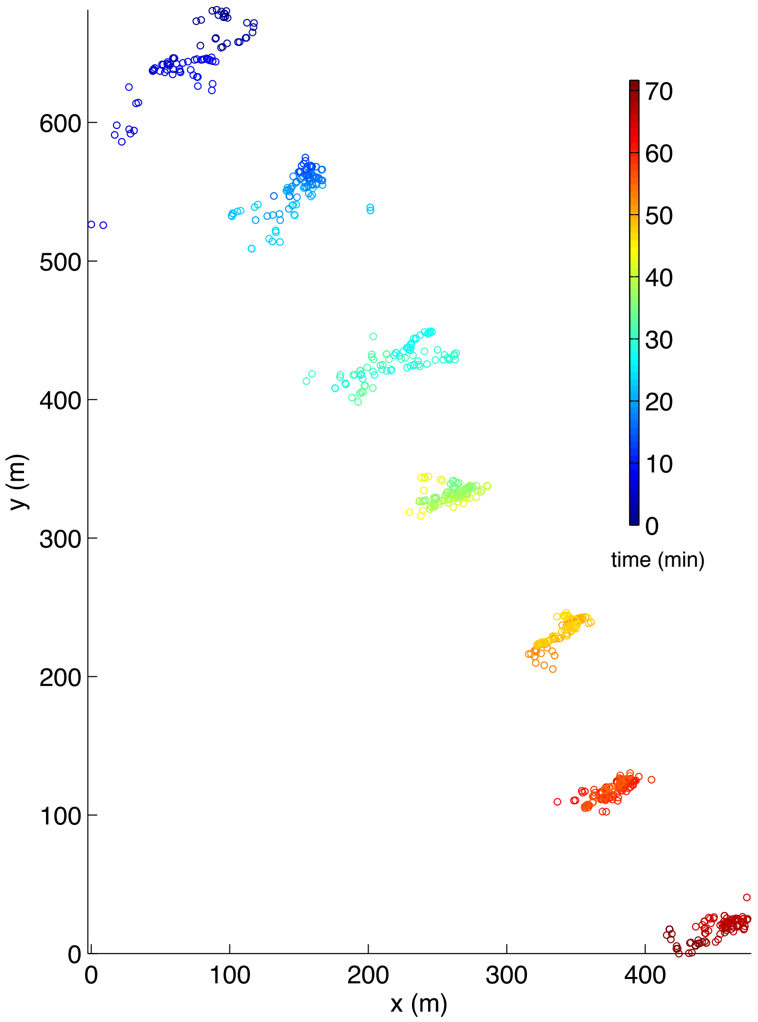
Call Association



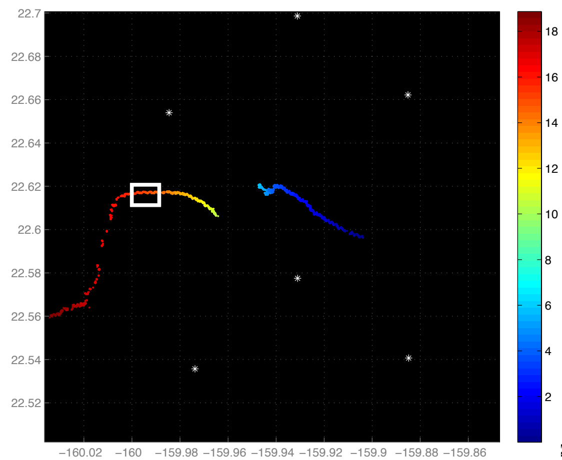
Localization coordinates can be used to isolate individual singers in spectrograms.



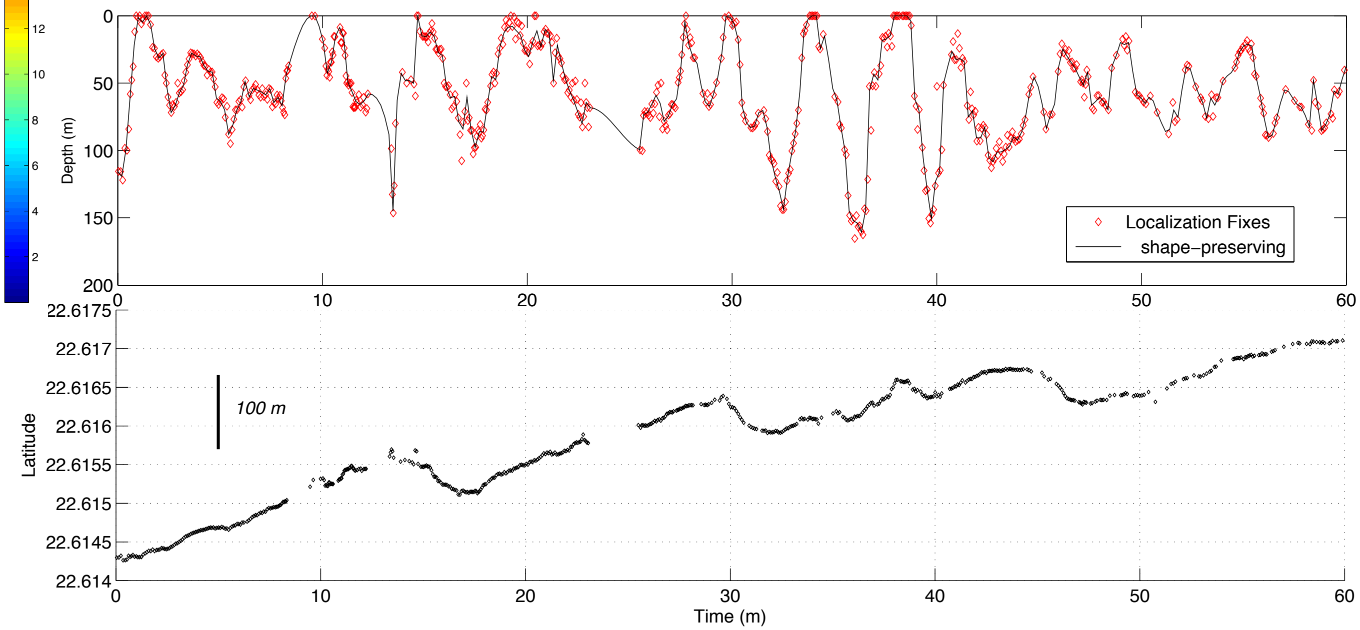
Humpback transiting trends



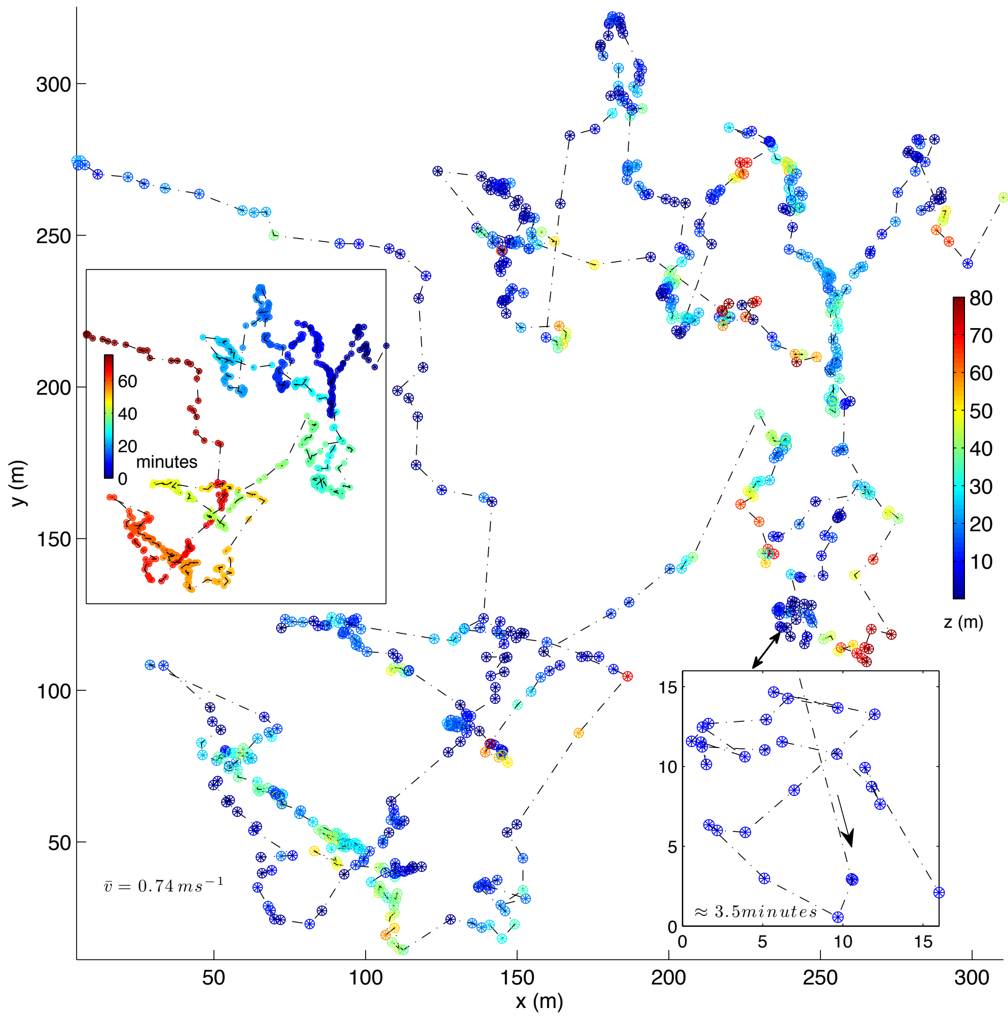
Humpback transiting trends – 3D localization



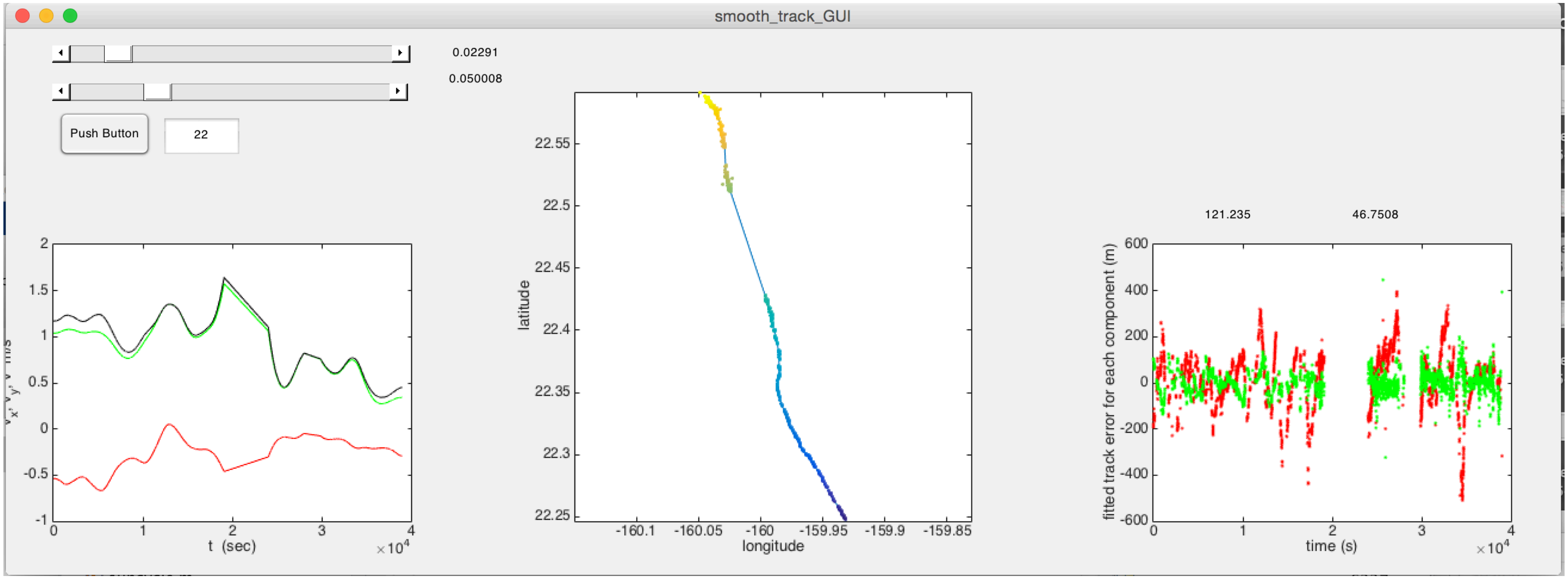
Whales often deep dive while singing



Humpback transiting trends – 3D localization



Humpback track kinematics



Humpback track kinematics

Harvest statistics to test for variations against environmental, sonar, and ocean noise conditions.

Context Context Context…

More information overall, and when both species are present can usually still differentiate.

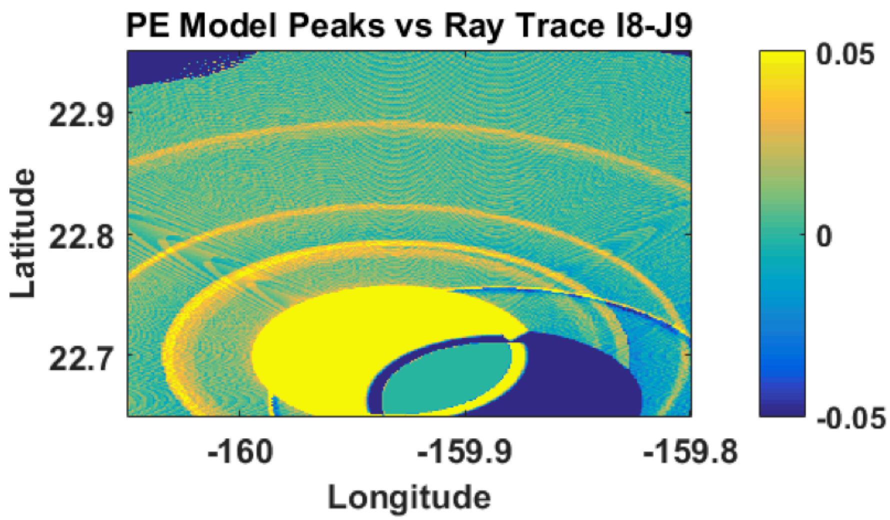
```
track_struct =

          track: [4x5252 double]
          fname: 'PMRF_localizations_09Mar11_012500__all1...
            ldt: 39.6586
            tdt: 39.9106
     direct_ind: 0.9937
          etime: 10.8350
        ldt_vel: 3.6602
        min_vel: 3.3230
        max_vel: 4.5942
       mean_vel: 3.8565
       DevIndex: 0.0148
        bearing: 344.8646
     start_date: [2011 3 9 19 30 55.3345]
       end_date: [2011 3 10 6 21 1.3523]
        daytime: 1
      day_night: 0
      nighttime: 0
   depthMetrics: [9.0996 34.3300 111.5276]
      BehStateT: 'Travel'
```

Predicting TDOAs of baleen whale signals in shallow water

-Localization capability is dependent on the ability to accurately predict the expected travel time of a signal.

-Roanne R. at SSC-PAC is currently investigating methods for using the Peregrine PE based code to predict travel times (SEE POSTER).



Closing remarks

Stay tuned…Liz Henderson, SMM

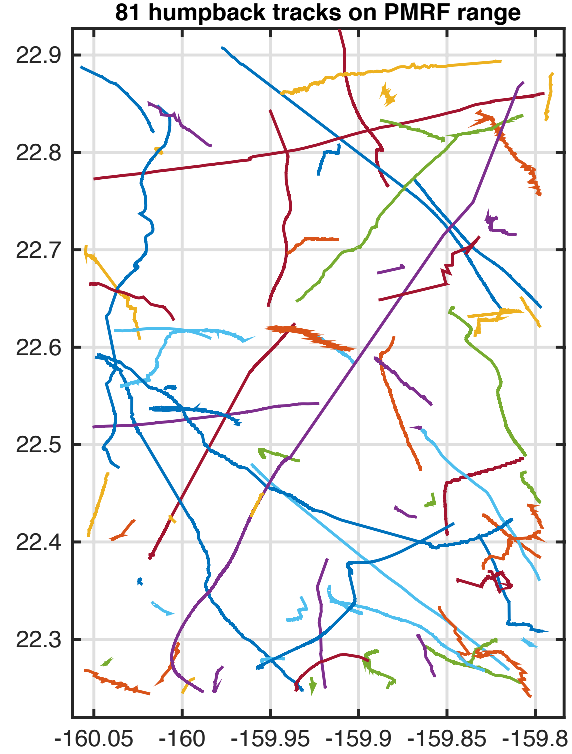
Localization allows for:

-Automatic minimum density estimates.

- Classification
(**additional context** of cue rate, track kinematics, aggregated call type information allows for classification of species type when otherwise difficult for single sensors).

- Fully automated, faster than real-time.

-Study relationship of track kinematics with environment/noise/sonar



Closing remarks

Software available!

1) Matlab structure arrays define hydrophone location and setup.

2) GPL parameter file defines detection, template, and ensemble size.

3) TDOA structure file holds predicted travel time tables.

With a few simple adjustments can change between minke, fin, humpback, and Bryde's calls on PMRF range.

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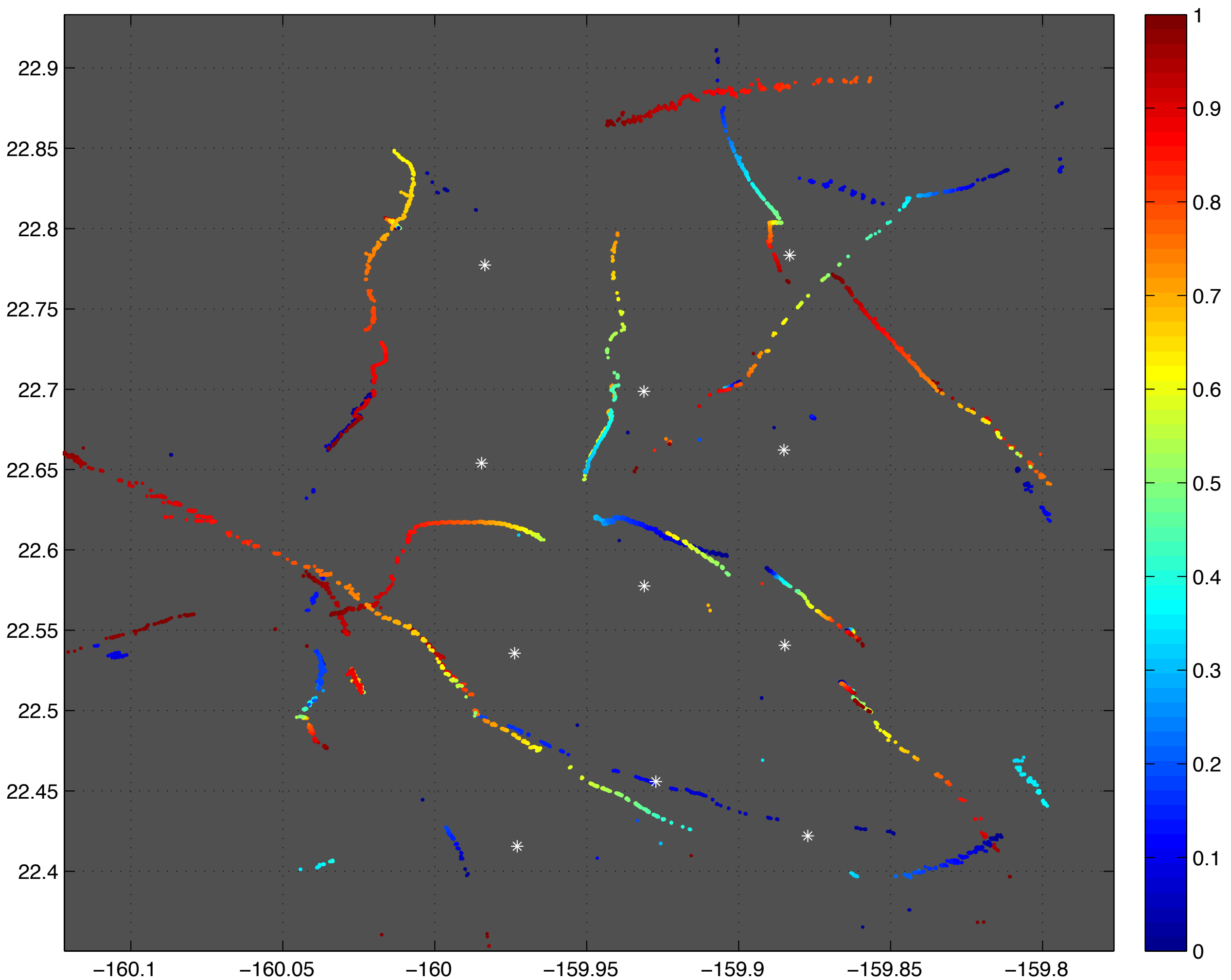

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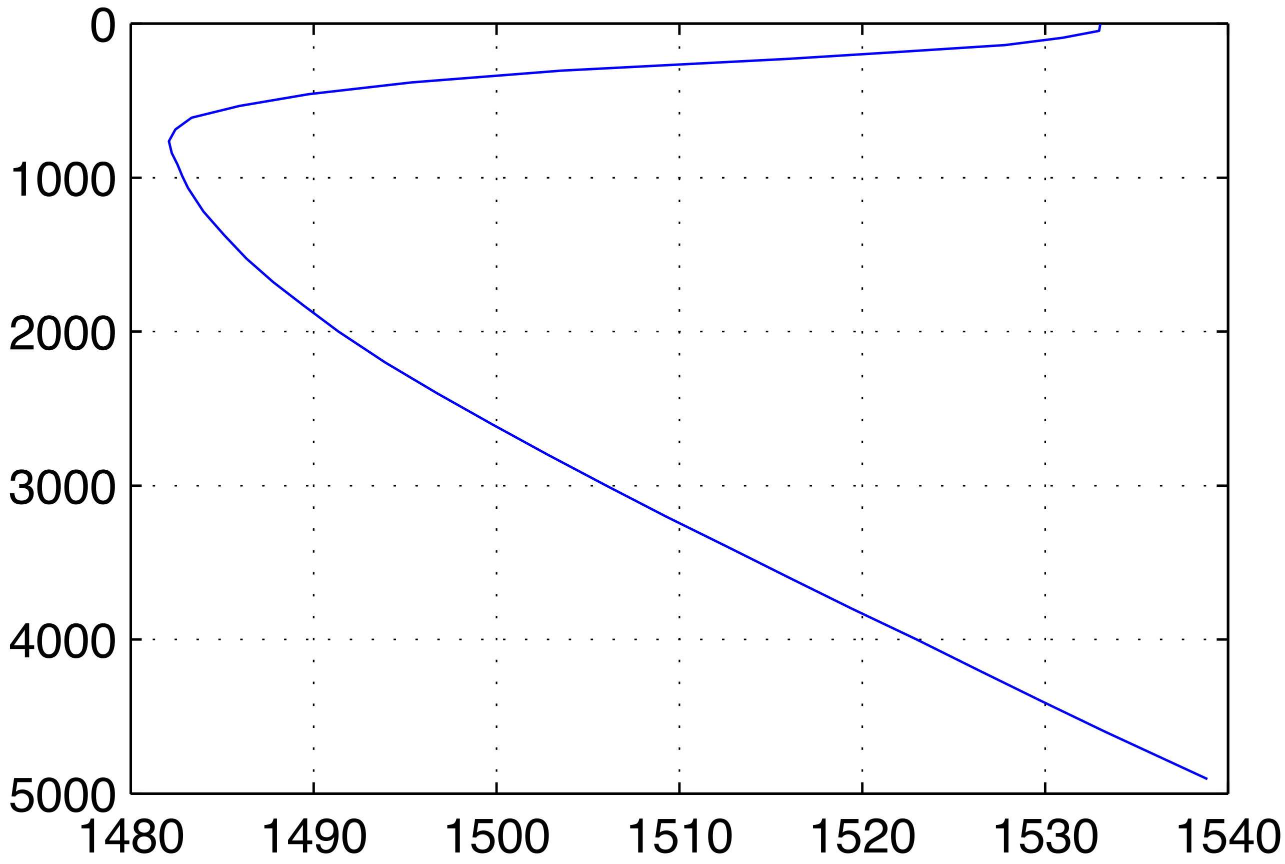

Model-based LSQ for localization

Maximal likelihood estimator (if timing errors are Gaussian)

$$\mathrm{LS}(\mathbf{w}) \propto \prod_{ij} \left\{ \max_{k} \left(\exp\left[\frac{-1}{2\sigma_{ij}^2} (\Delta t_{ij}(k) - \Delta\hat{t}_{ij}(\mathbf{w}))^2 \right] \right) \right\} \qquad (1)$$

Perfect fix = 1

"i" limited to center hydrophone
"j" limited to 4 corner hydrophones

Model-based TDOA estimate at position **W**

- Based on direct arrival travel time, accounting for SSP
- Using ensembles of 7-12 units

kth Measured TDOA (limited to top 3)

E.-M. Nosal, "Methods for tracking multiple marine mammals with wide-baseline passive acoustic arrays", J. Acoust. Soc. Am. 134, 2383–2392 (2012).

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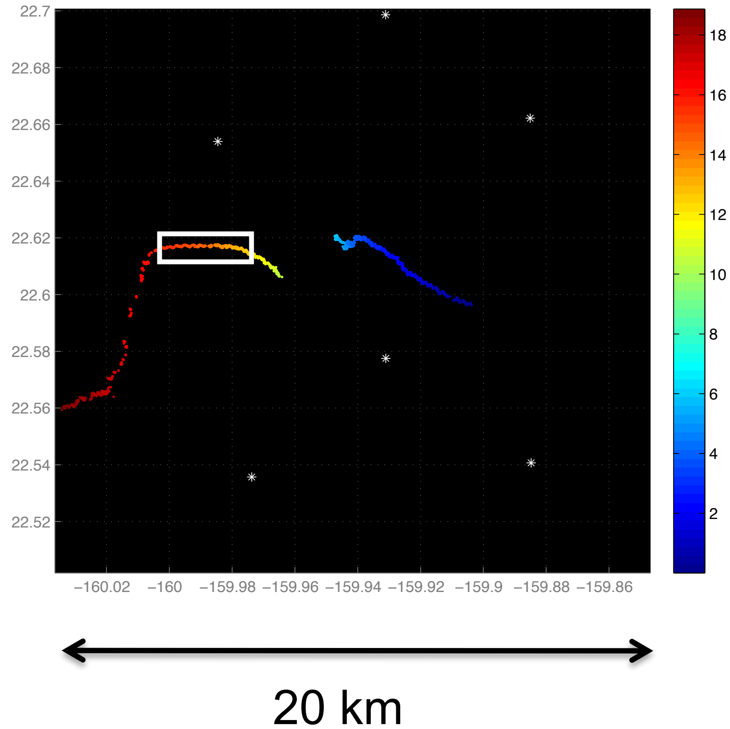
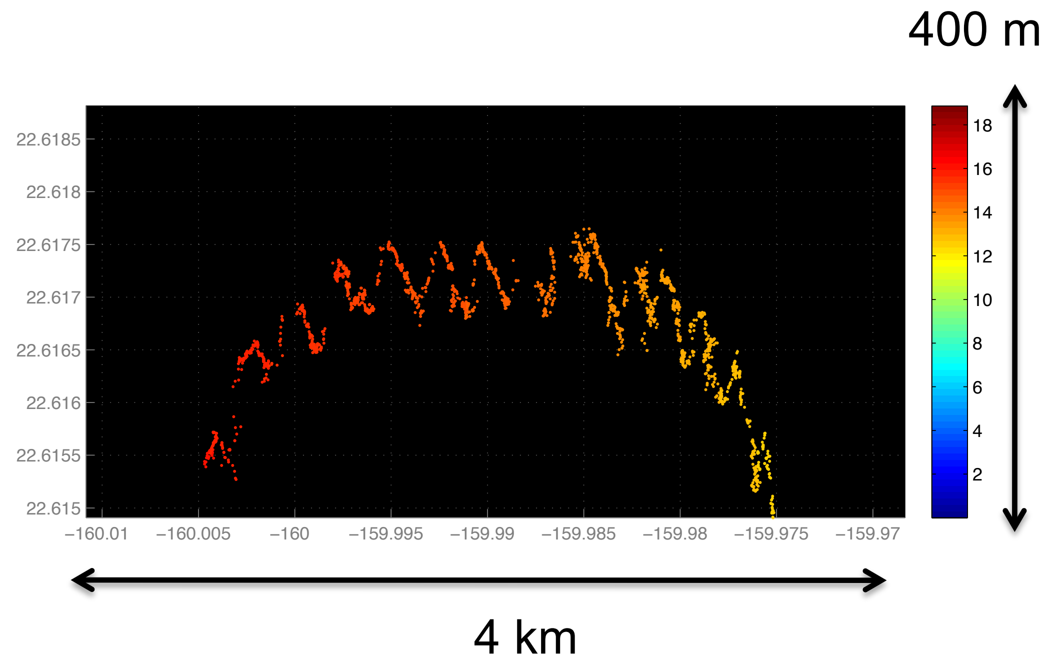
Humpback transiting trends

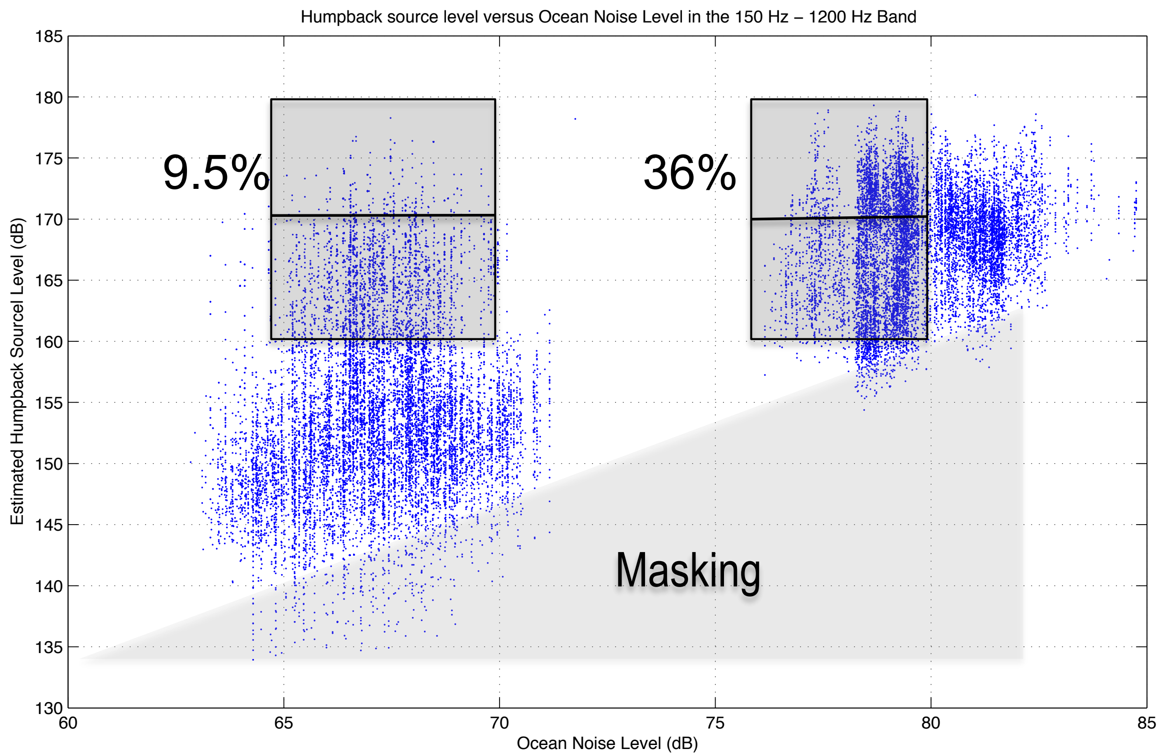
10 January 2013





- Whale appears to "drift" with current for 100 m
- Could correspond to breathing? ~15-20 min intervals

Potential Lombard?

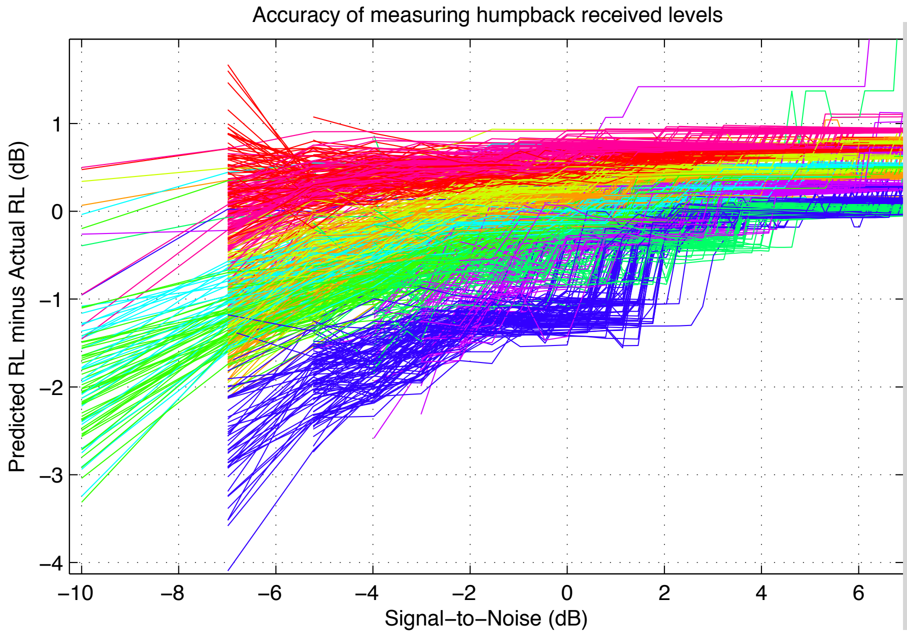


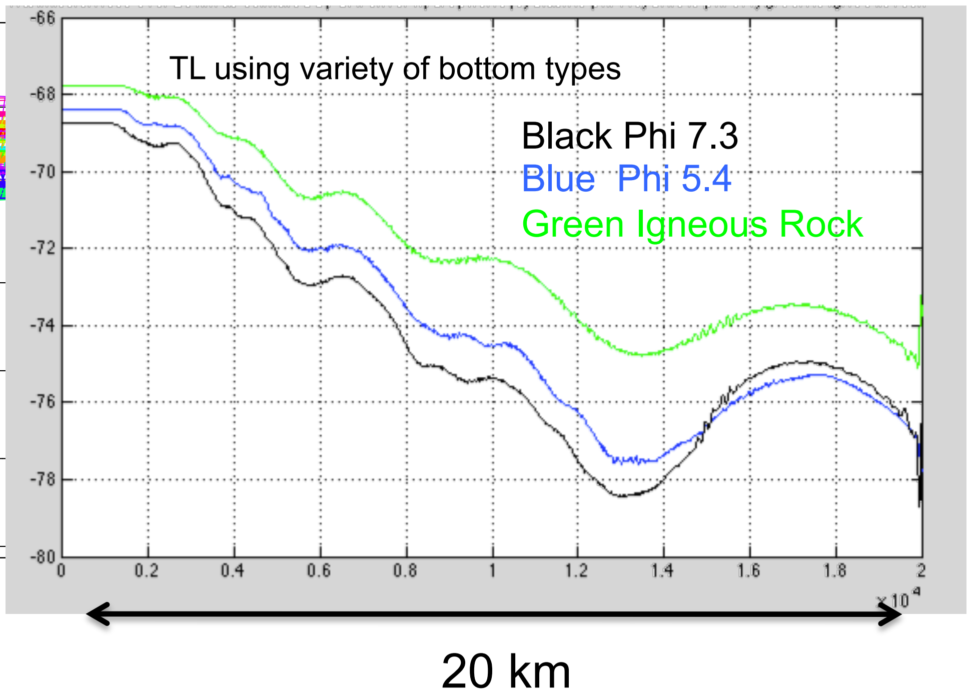
Welch's T-test
(unequal sample size, unequal sample variance)

Reject null hypothesis

Number of samples = 49,151, limited to 10 km to center hydrophone

Estimating Source Levels





$$SL = RL + TL$$