Estimating spatial densities of vocalizing animals using bearings of signals detected with a directional acoustic recorder

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Introduction

Animal population density is defined as

$$D=M/S$$

where M is the number of animals presented in an observation area of size S over a certain observation interval.

The goal of this work is to estimate the number of vocalizing animals, M.

Canonical Density Estimator

The most popular density estimators are based on a fundamental assumption that “in passive acoustic surveys, it is often not possible to count the number of animals directly” (Marques et al., 2013).

The canonical density estimator:

$$D = N_c (1-c)/p\,T\,r\,S$$

where

- N_c is the total number of the detections (or detected cues)
- c is the probability of false positives estimate
- p is the detection probability estimate
- r is the call rate estimate

Marques, T. A., Thomas, L., Martin, S. W., Mellinger, D. K., Ward, J. A., Moretti, D. J., Harris, D., and Tyack, P. (**2013**). “Estimating animal population density using passive acoustics,” *Biol. Rev.* ***88***, 287–309.

Canonical Density Estimator

The canonical density estimator provides acceptable accuracy if the following assumptions hold true:

A1: The call rate, r, is a stationary ergodic random process.

A2: The mean call rates are equal for all sources, $r_m = r$, $m = 1 \ldots M$.

A3: For all sources, all detection probabilities are equal, $p(d_m) = p$, $m = 1 \ldots M$.

A4: The average probability of false positives, c, is constant.

A5: The estimates c, p and r are unbiased and have small mean square error and coefficient of variation (CV).

A6: Over the observation interval, the number of animals presented in the observation area is constant.

Canonical Density Estimator

The assumptions *A1-A6*, are rarely met in practice because of

- Animals travel across the habitat, such that the number of animals in an area and source-to-sensor distances change with time;
- For many animals, changes in their calling rates may be significant, such that no call rate estimates with low CVs available;
- The proportion of false positives may change significantly over a long observation interval due to changes in ambient noise conditions;
- The CV for the probability of false positives, c, may be high.

The parameters p, r, and c requires manual counts of the automatic detections. Manual analysis is a very time consuming and expensive task.

Bearing-based Density Estimator

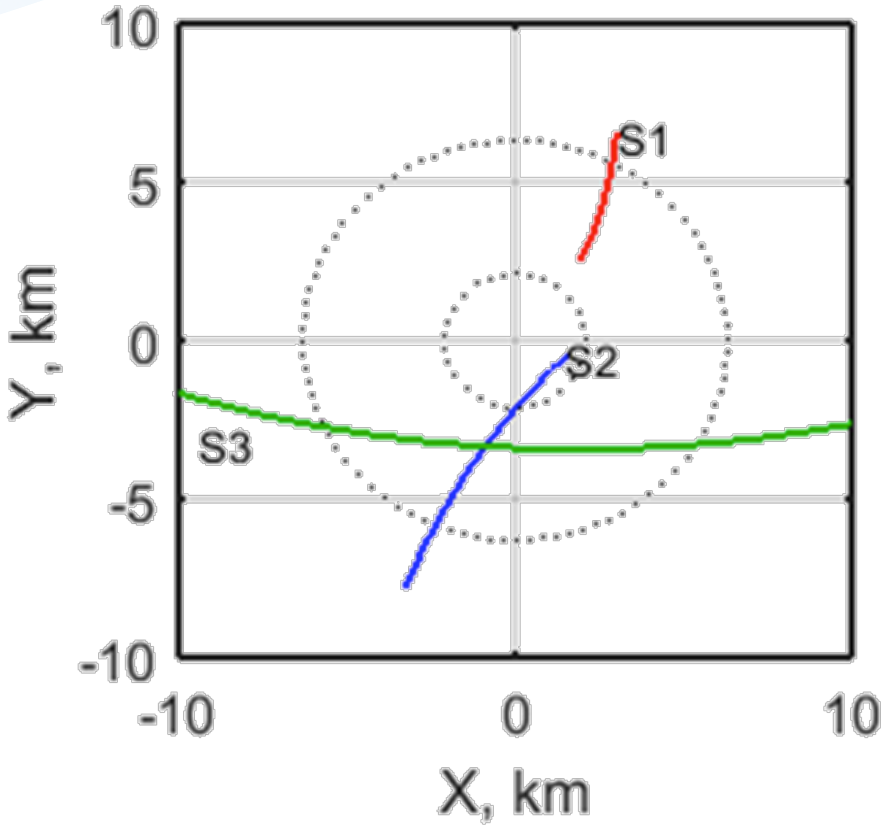


Fig. 1. Trajectories of three moving sources.

Simulations:

Sources S1 and S2 simulated the behavior of Blainville's beaked whale.

The speeds of sources $S1$ and $S2$ were 1.2 and 2.5 m/s. Call rates were r1=3.3 and r2=2.5 calls per second, respectively.

The source S3 simulated a ship travelling with a speed of 8 m/s.

Bearing-based Density Estimator

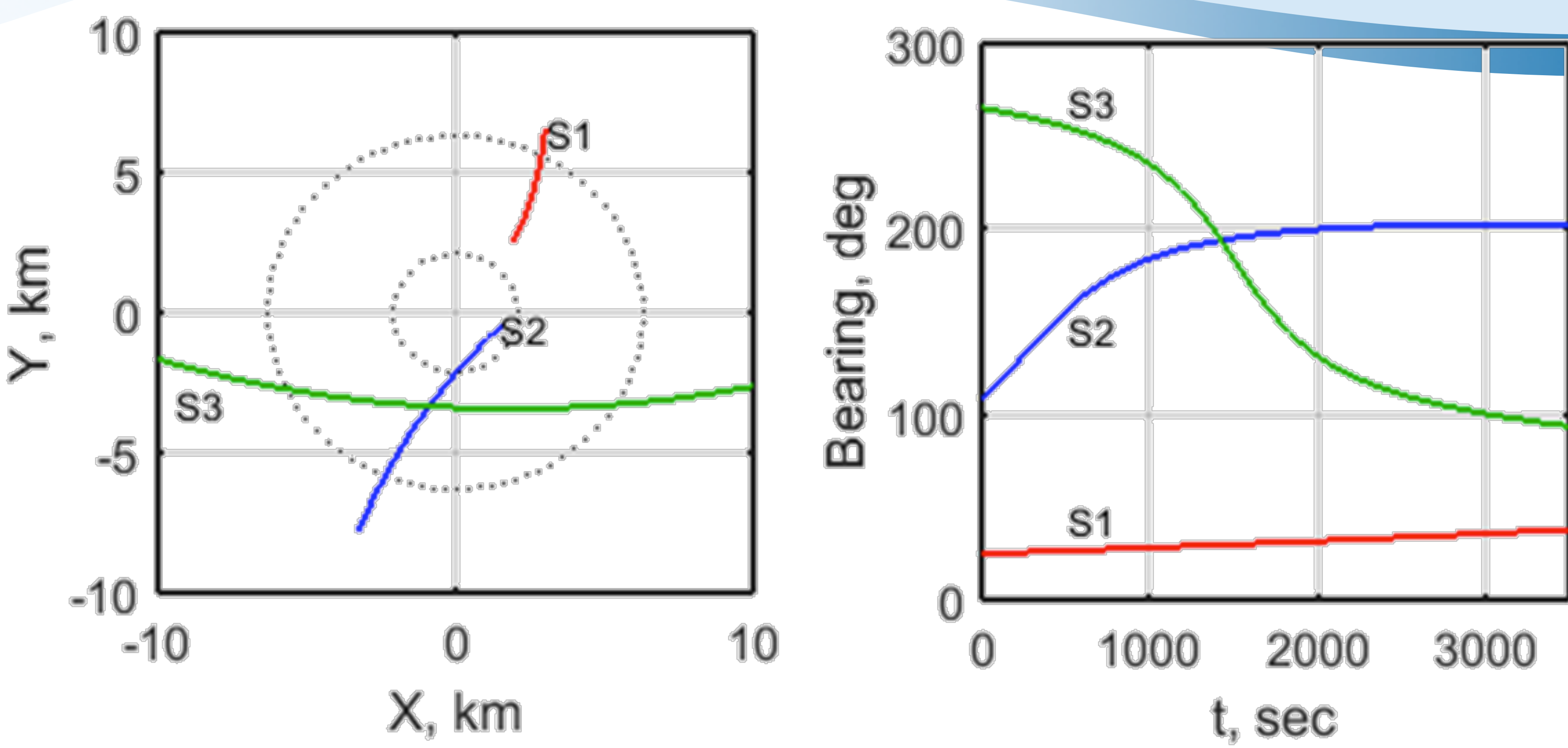
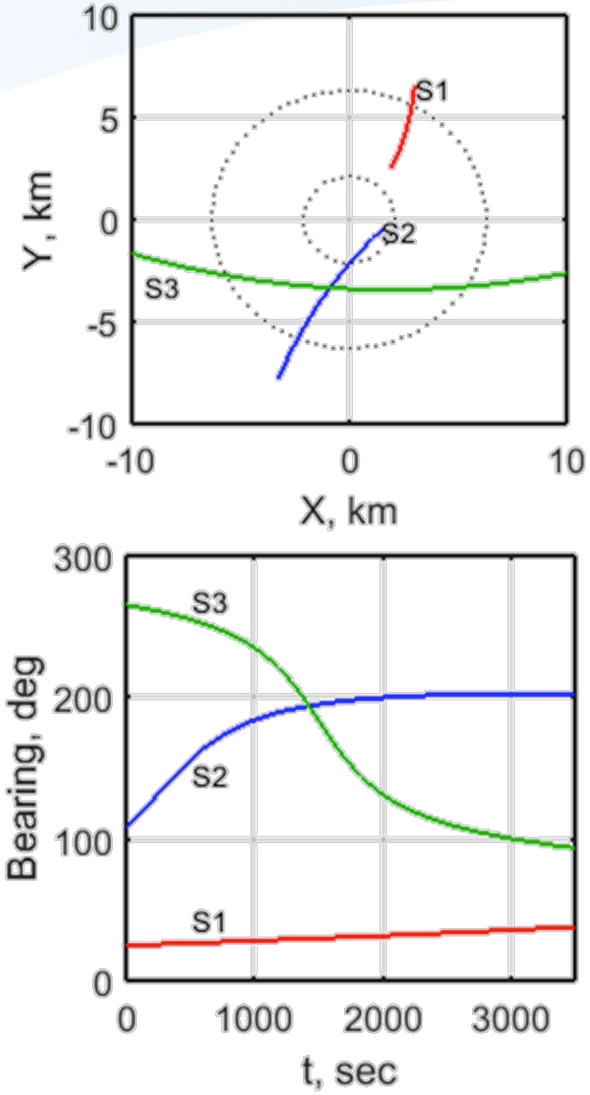


Fig. 2. (Left) Trajectories of three moving sources, (right) source bearings

Bearing-based Density Estimator



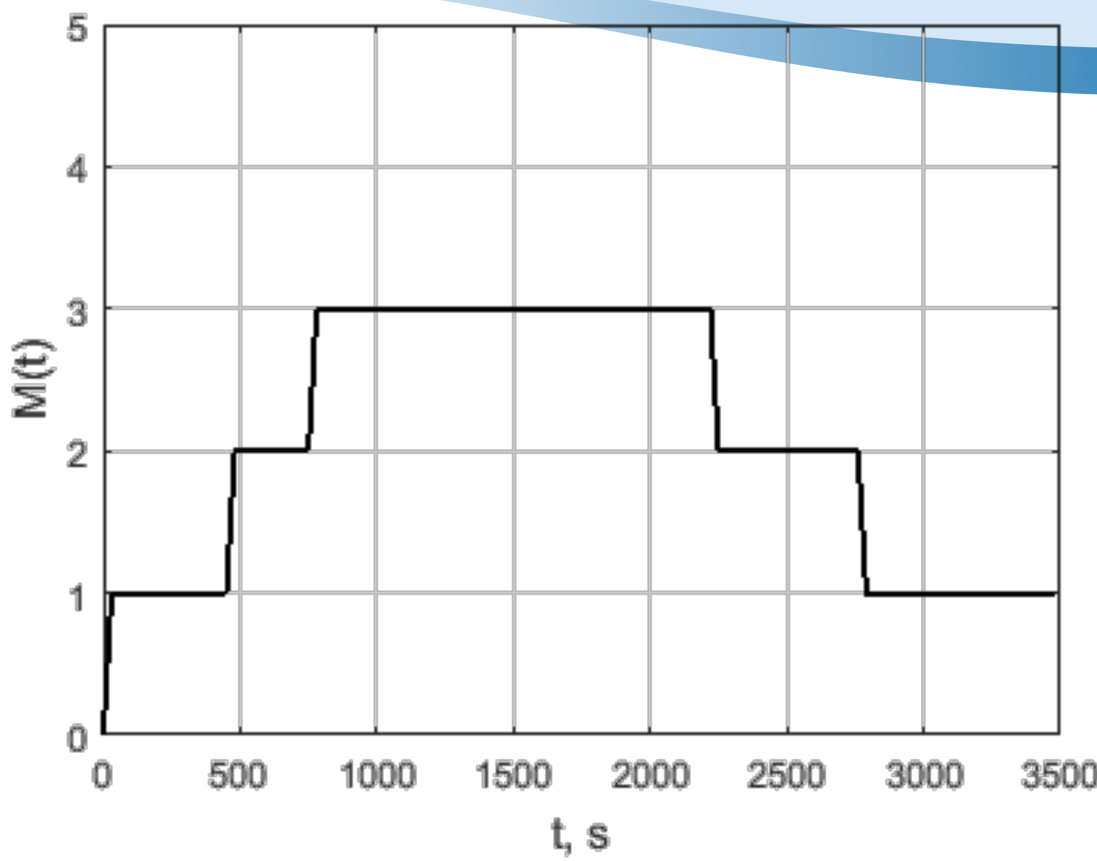
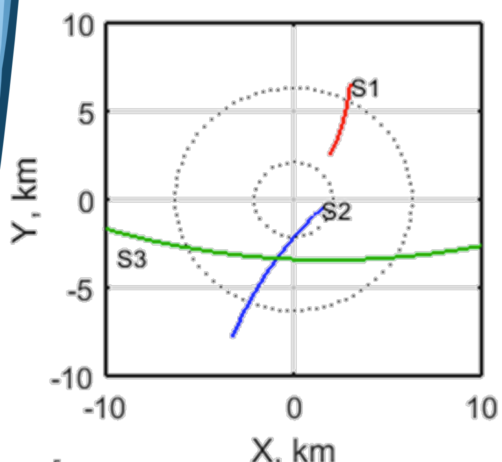
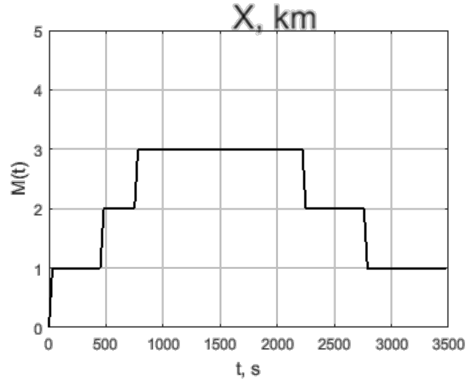


Fig. 3. The number of detectable sources

Bearing-based Density Estimator

To estimate the number of sources, M(t), the short-time bearing distribution (STBD), W(α,t), is proposed.





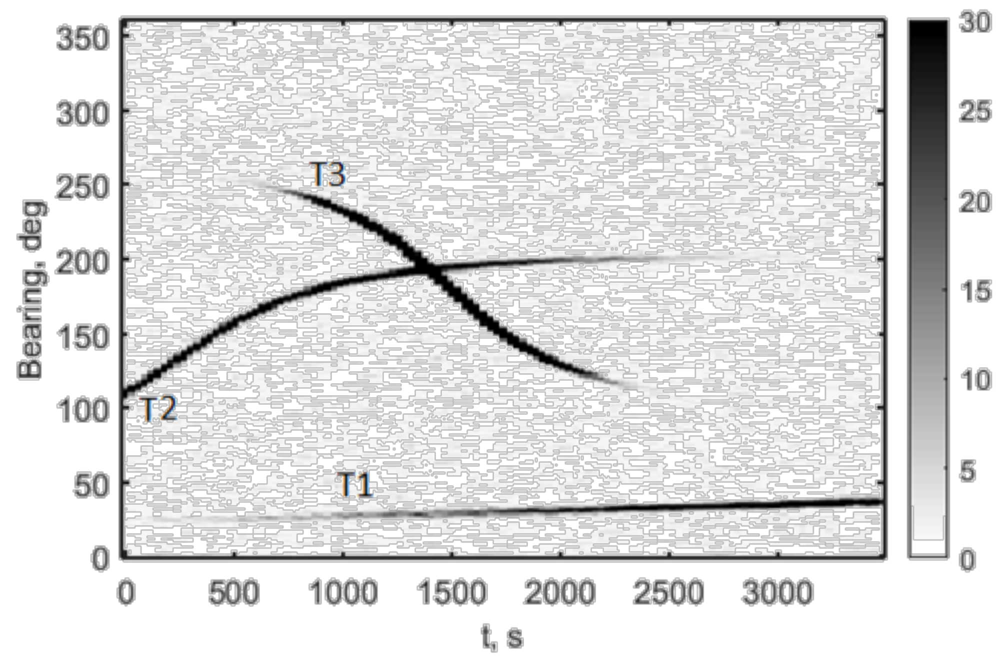


Fig. 4. The short-time bearing distribution

Bearing-based Density Estimator

In practice, the short-time bearing distribution (STBD) can be computed using bearings estimates provided by the directional sensor.

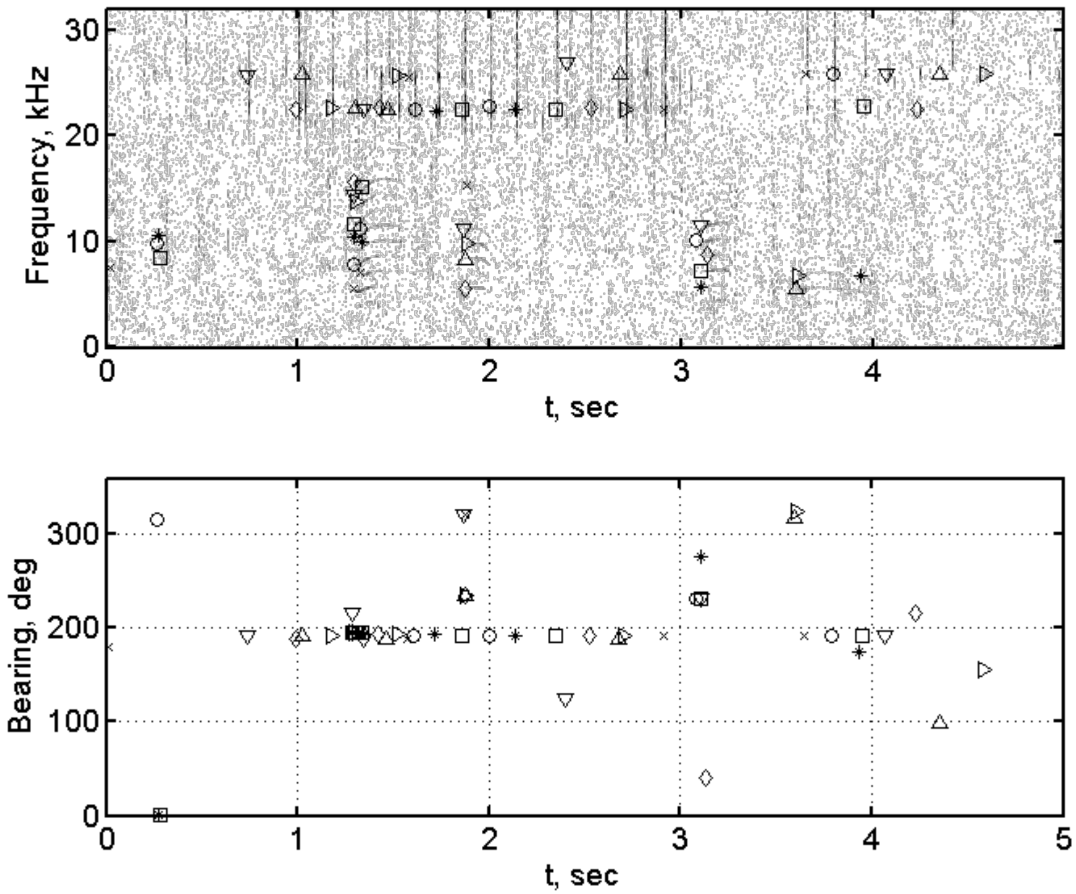
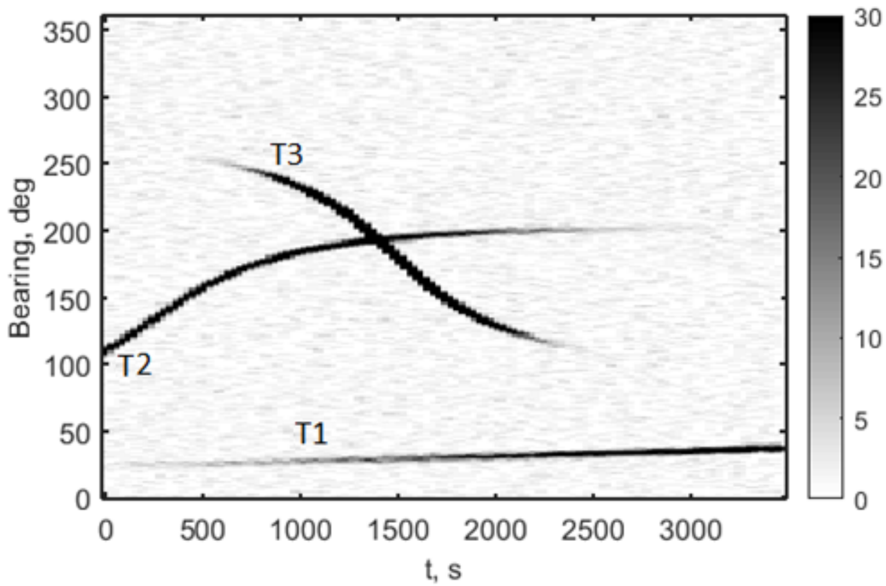


Fig. 5. Output of the directional sensor. Top: data spectrogram. Bottom: bearing estimates of the detected signals.

Bearing-based Density Estimator

Using the empirical STBD, the following estimators of the number of sources are proposed:



Instantaneous estimator:
$M_I(t)$ is the number of peaks of the empirical STBD that exceed some threshold, $W(\alpha,t)>c_0$

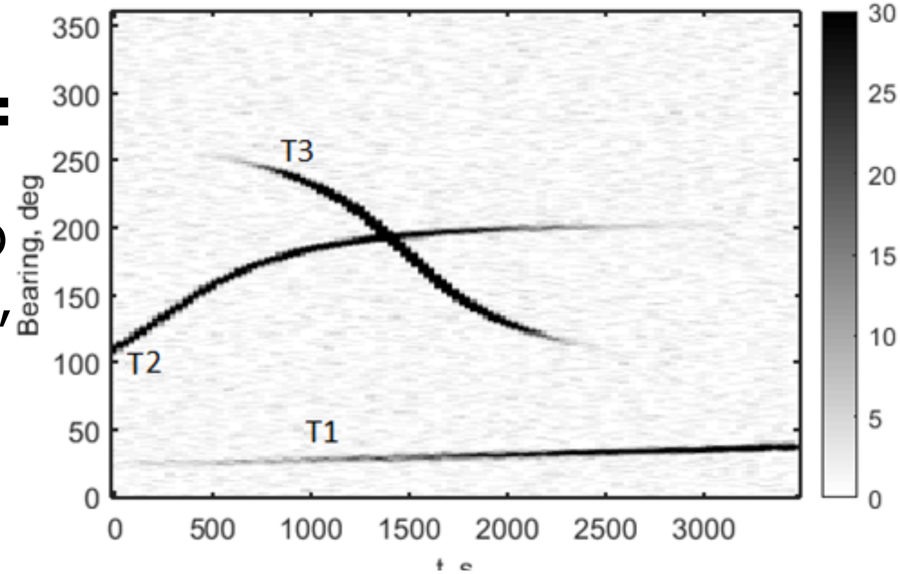
Smoothed estimator:
$M_S(t) = smooth\{M_I(t_j),L\}$ is the smoothed estimate of $M_I(t)$

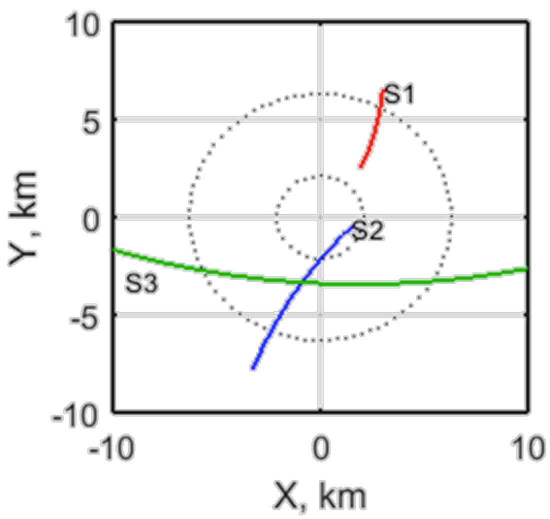
Track-based estimator:
$M_T(t)$ is the number of bearing tracks created automatically or manually by visually analyzing the empirical STBD

Simulations

Instantaneous estimator:

$M_I(t)$ is the number of peaks of the empirical STBD that exceed some threshold, $W(\alpha,t) > c_0$





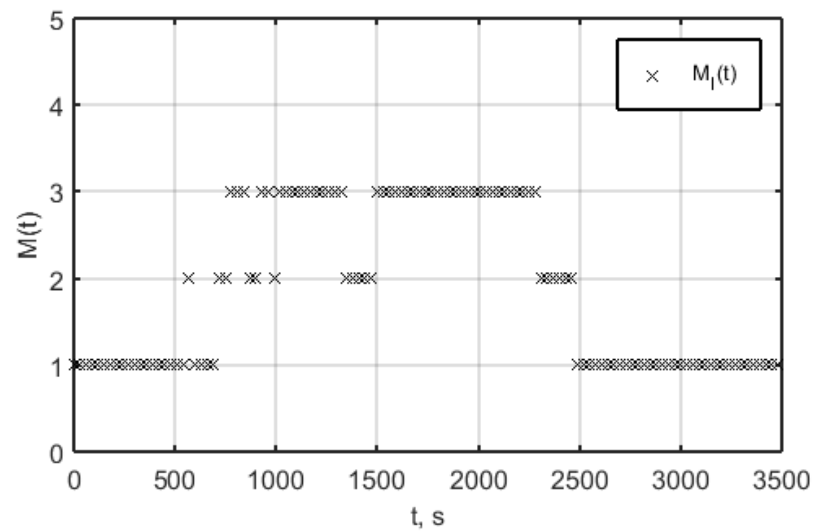
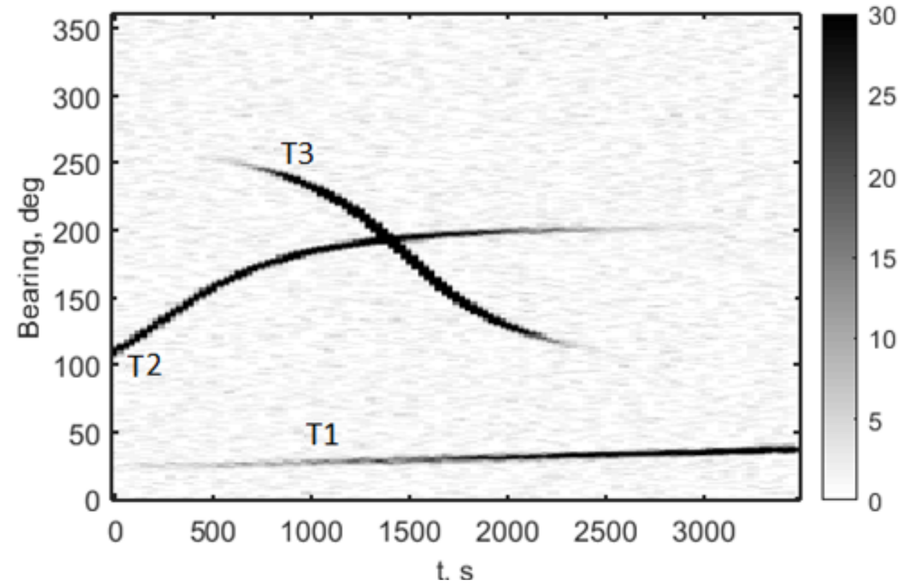
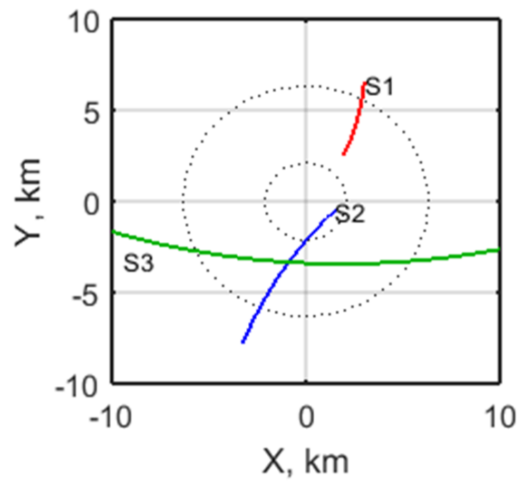


Fig. 6. Top: empirical STBD of the detected signals.
*Bottom: **instantaneous** estimates of the number of sources.*

Simulations

Smoothed estimator:
$M_S(t) = smooth\{M_I(t_j),L\}$
is the smoothed estimate
of $M_I(t)$





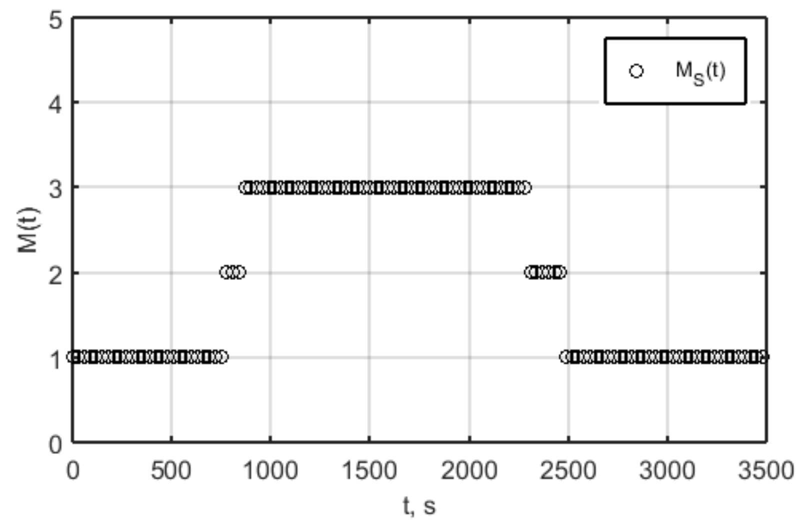
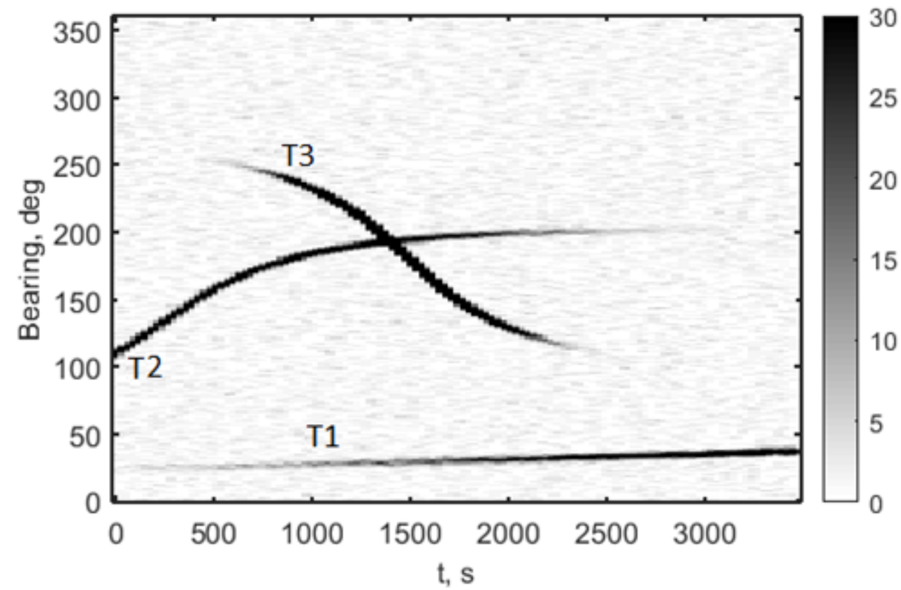
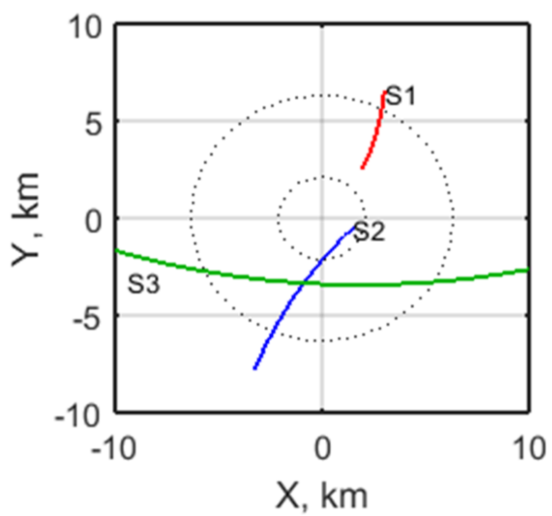


Fig. 7. Top: empirical STBD of the detected signals.
Bottom: ***smoothed*** *estimates of the number of sources.*

Simulations

Track-based estimator:
$M_T(t)$ is the number of bearing tracks created manually by visually analyzing the empirical STBD





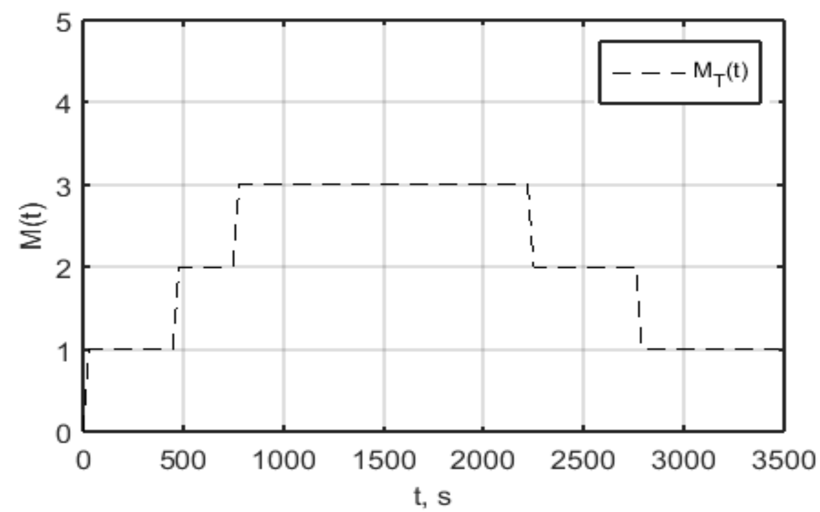


Fig. 8. Top: empirical STBD of the detected signals.
Bottom: Track-based estimates of the number of sources.

Simulations

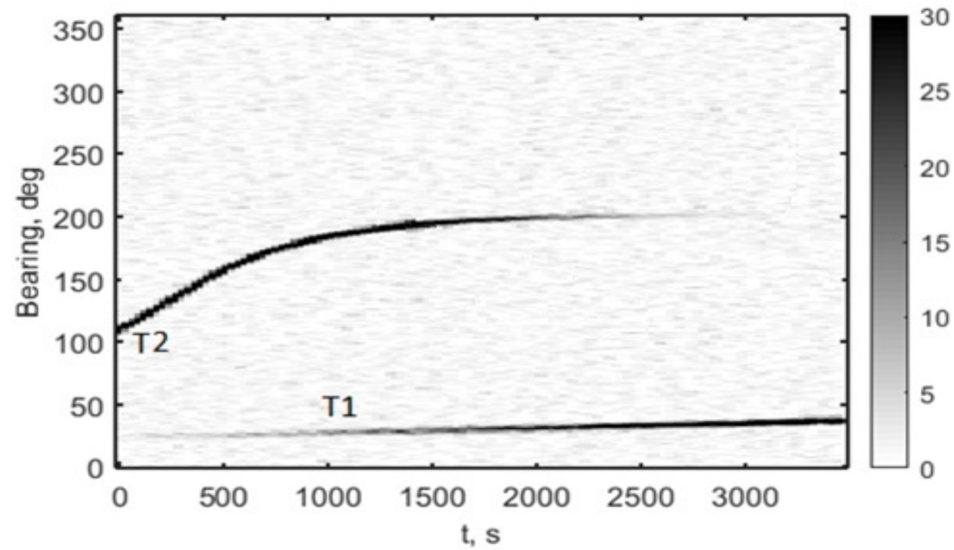
Canonical estimator:

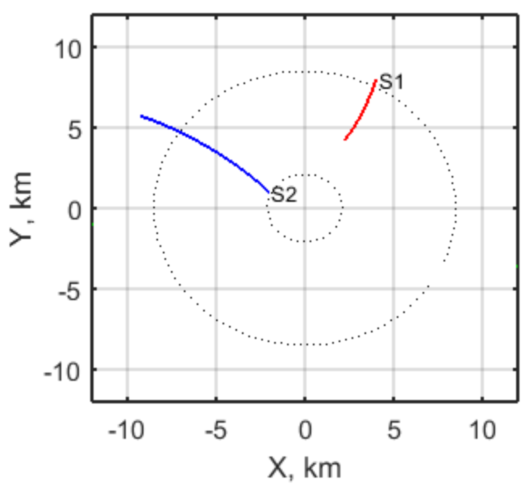
$M = N_c(1-c)/pTr$

$r = 2.9$ ($r_1 = 3.3$; $r_2 = 2.5$)

$N_d = N_c(1-c) = 8871$

$p = \{0.2, 0.45, 0.72\}$ ($p_1 = 0.4$; $p_2 = 0.47$)





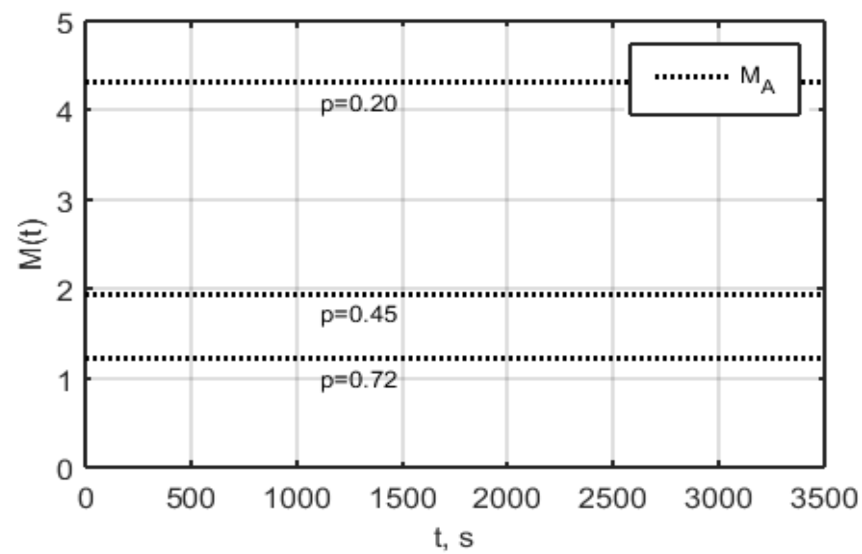
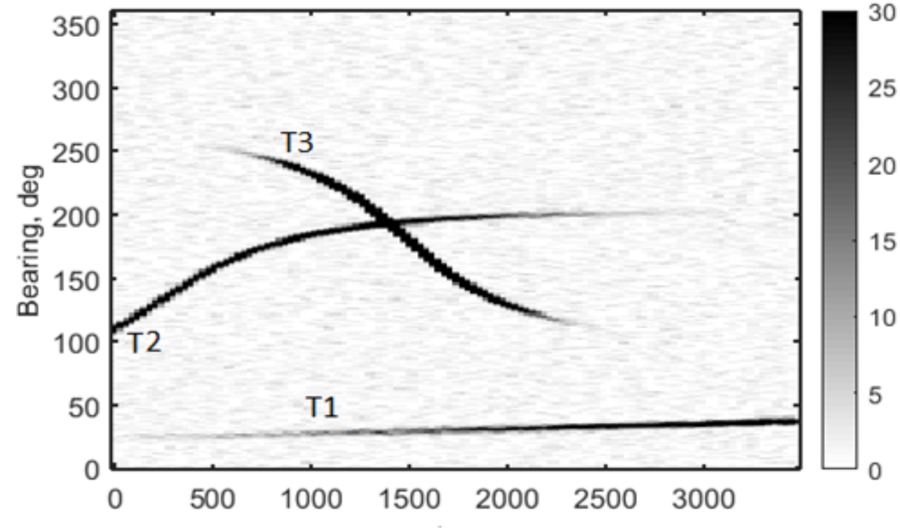
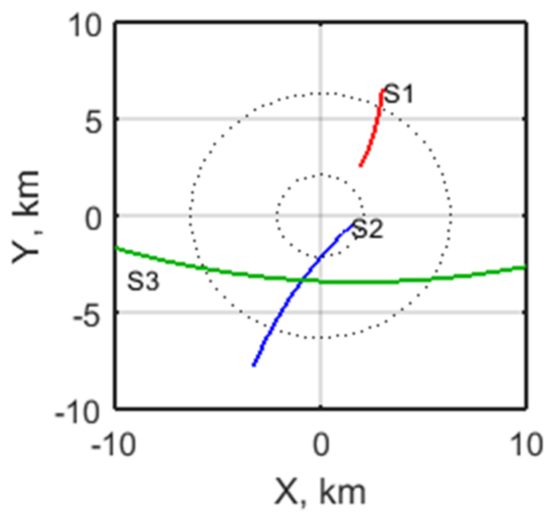


Fig. 9. Top: empirical STBD of the detected signals.
*Bottom: **Canonical** estimates of the average number of sources.*

Simulations

Comparison of the canonical and bearing-based estimators.





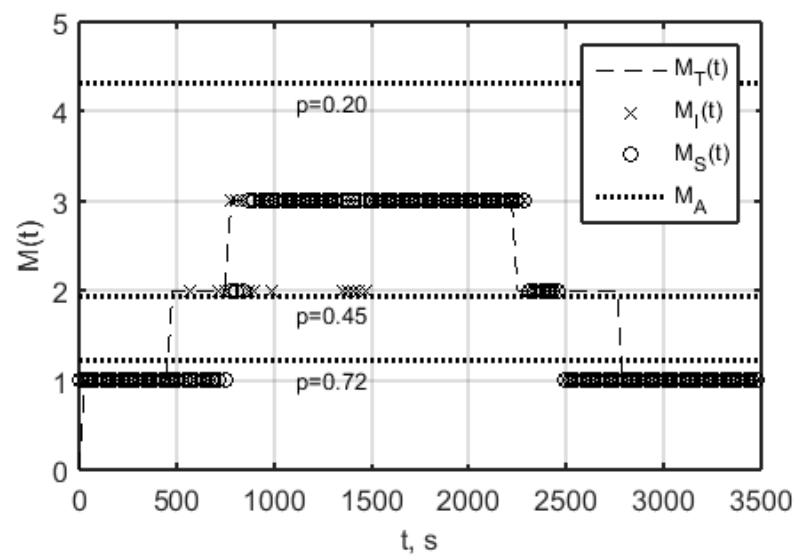
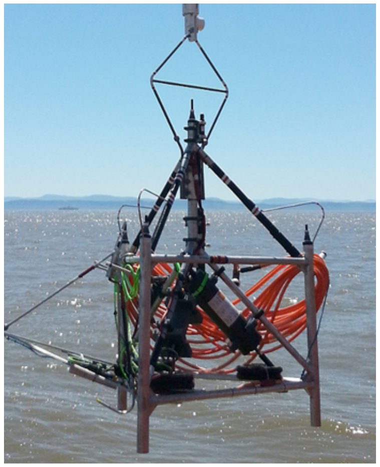


*Fig. 10. Top: empirical STBD of the detected signals. Bottom: **Bearing-based** and **canonical** estimates of the number of sources.*

In Situ Tests Using the Directional Sensor

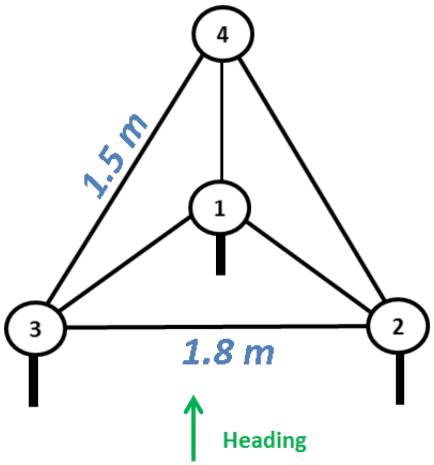
Directional sensor:

- Tetrahedral frame
- 4 hydrophones
- 64 kHz sampling rate:
- 1° bearing estimation accuracy



Deployment:

- VENUS ocean observatories operated by Ocean Network Canada:
  - East node (172 m)
  - DDL node (144 m)
- Near BC ferry routes, Vancouver vessel traffic lanes and active area for Marine Mammals



AMARs on Venus

In Situ Tests Using the Directional Sensor

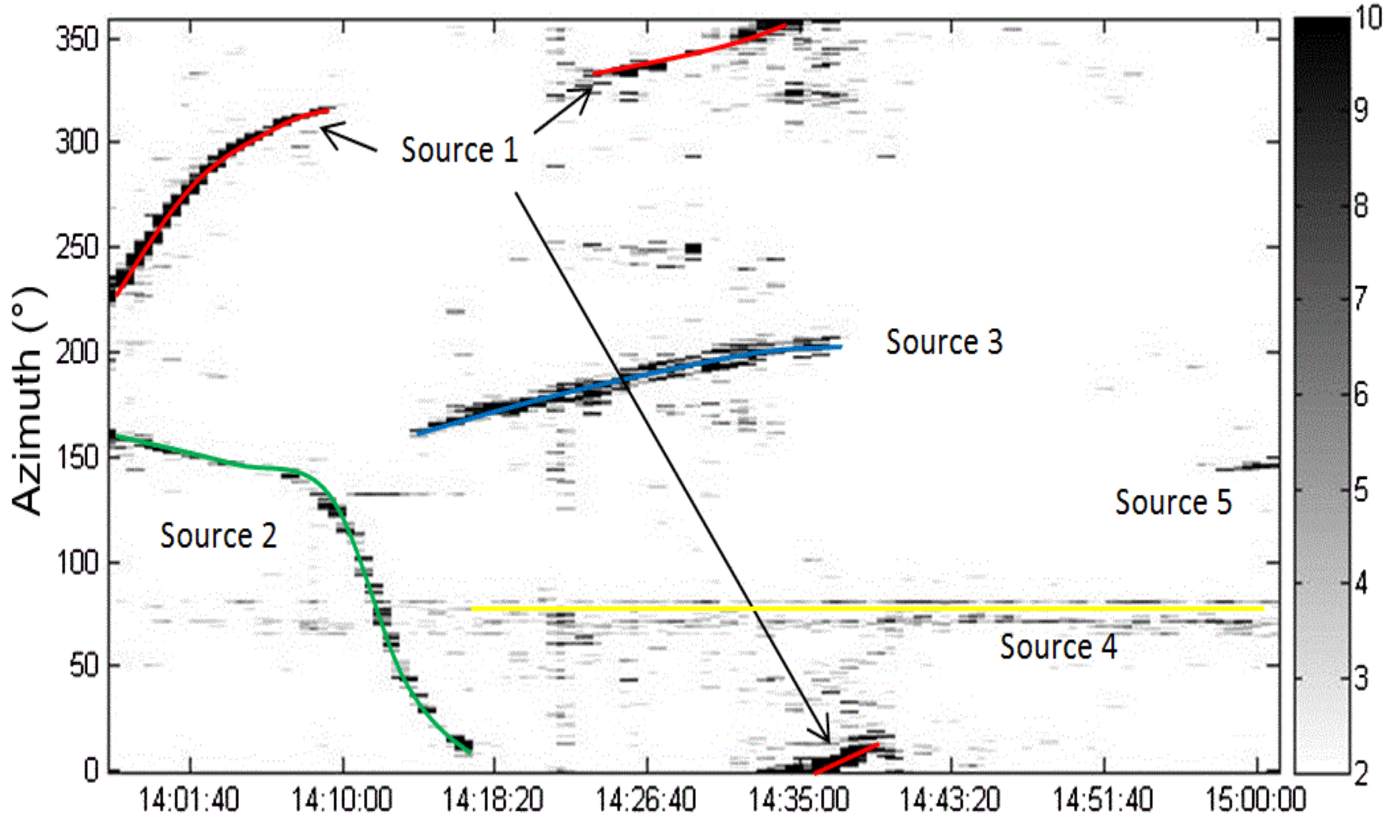


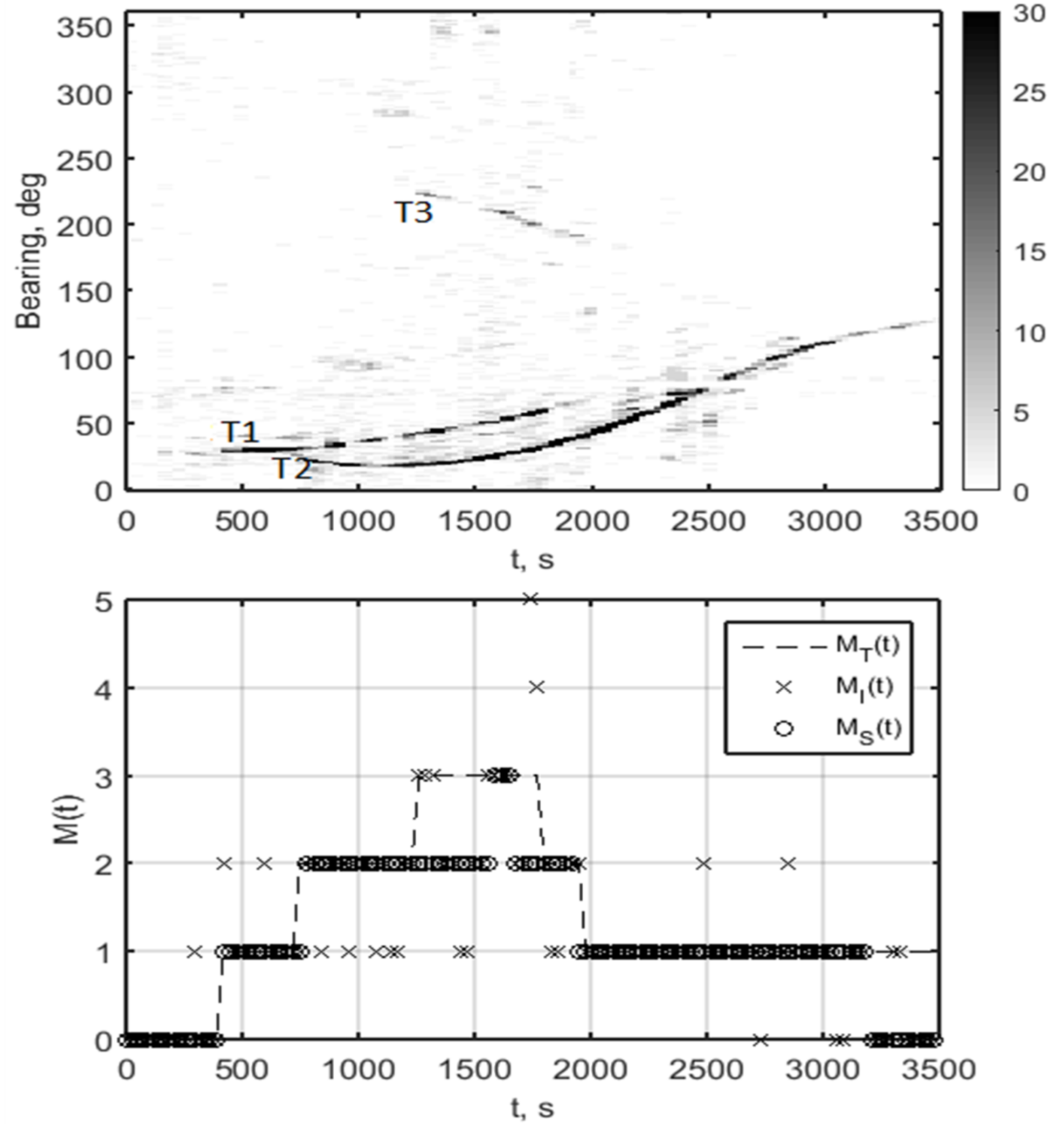
Fig. 11. Empirical STBD computed using TDOA-based maximum likelihood localization algorithm (Urazghildiiev and Clark, 2013).

I. Urazghildiiev and C. W. Clark, "Comparative analysis of localization algorithms with application to passive acoustic monitoring," *J. Acoust. Soc. Am.*, Vol. 134, pp. 4418–4426, 2013.

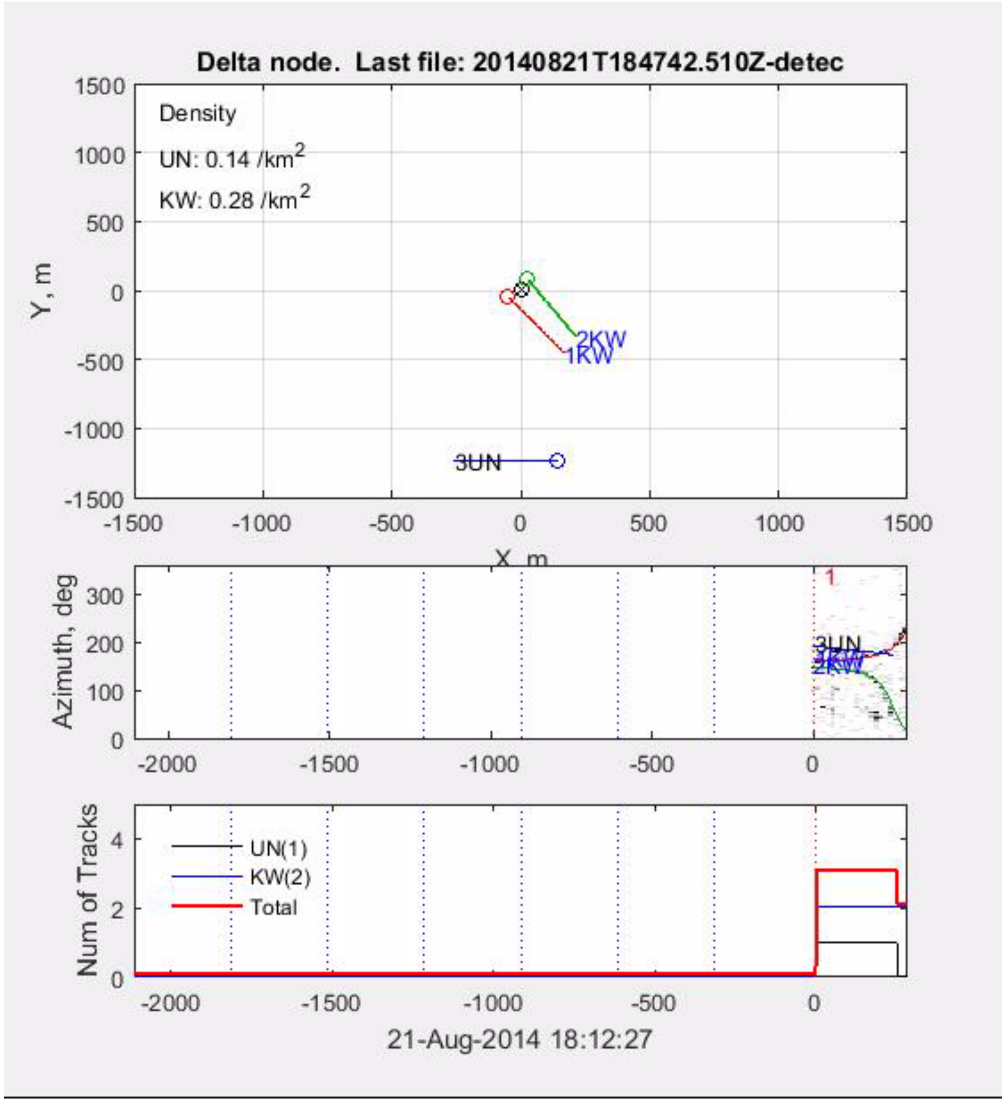
In Situ Tests Using the Directional Sensor

Fig. 12.
(Top) Empirical STBD computed for the data collected on June 17, 2014;

(Bottom) Bearing-based estimates of the number of sources (Killer whales).



In Situ Tests Using the Directional Sensor



Near-real time automatic DCLT and DE of marine mammals:

- *VENUS ocean observatory;*
- *DDL node;*
- *August 21, 2014.*

Conclusions

- Bearing measurements of detected signals can be used as an important feature to solve the problem of DE for a variety of vocalizing animals and anthropogenic noise sources.
- The number of sources can be directly counted as a number of different bearings or as a number of bearing tracks extracted from empirical short-time bearing distributions.
- The bearing-based estimators provide accurate estimation of the number of sources if the directional acoustic sensor produces bearing estimates with accuracy of about 1 degree.
- No prior information about the detection probability as a function of source to sensor range, false alarm probability, or calling rate is required

Questions?

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