3-D Tracking of Simultaneous Sperm Whale Dive Profiles Using a Passive Acoustic Towed Array

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Project Goal: 3-D Positions of Deep-Diving Animals in Vicinity of Tow Vessel

- **Concept**
  - Surface reflections permit a 3-D fix with a towed array, using minimum hydrophones

- **SWSS 2004**
  - Towed array design

- **Challenges**
  - Steady ship course
  - Ray refraction effects and shadow zones
  - Hydrophone position uncertainty

- **SWSS 2005–2006**
  - Combining tracks with acoustic backscatter

- **2007 work**
SWSS Tracking Deployment in 2004–2005

- IRFC funded array
- Pressure sensors to give element depths
- Tracking slant range 1 km

The “Ray Charles” Tracking Technique Uses a Tandem Towed Array

- 200 m
- 2 knots
- Direct TOA
- Array bearing
- Rear echo time
- Forward echo time (2005)
- Local tilt (sporadic)
Visual Representation of Localization Parameters

- Direct TOA
- Rear echo time
- Forward echo time
- ICI
- Bottom returns
Array Data Collected During Nights and Rough Sea Conditions During S-Tag Cruise

- Translation: when everyone else sad, me happy
- Array cable must be 30 m depth
- Array must be straight
- Driving the vessel an art: approaching whales, keep ship straight, not waking others
Localization Parameters Automatically Extracted in Post-Processing (2004)

- Rear echo time
- Array bearing
- Direct TOA (ICI analysis)
Plotting “Echo Time” Convenient for Selecting Tracks (2005)
Example of Initial Dive Profiles

Depth (m)

Range (m)

Azimuth (deg)
Tracking Results for a Ship on a Steady Course
Great Weakness of Method
Is Turning Ship
Why I Should Not Be Driving (or Why Magnetic Heading Needed)
Ray-Refraction Effects Incorporated with Ray-Tracing Propagation Code

2-D grids can be used to solve the 3-D problem
Ray-Refraction Effects Incorporated with Ray-Tracing Propagation Code

Shadow zone begins at 3 km for 50 m deep hydrophone.
Effect of Realistic Sound Speed Profile
Array Depth and Tilt Uncertainty
Greatest Source of Systematic Error

200 m aperture causes significant uncertainties in slant ranges greater than a kilometer.
Current Work: Merging Tracks with Backscatter Data
Example of Simultaneous Tracks
Five Years Reviewed in Fifteen Seconds ...

- Large-aperture towed array permits 3-D tracking under general circumstances
  - 200 m separation -> 1 km slant range
  - Array depths easily exceed 30 m
  - Parameter extraction automated

- Challenges
  - Ship handling to preserve a straight, deep tow
  - Ray refraction effects require pre-computation
  - Array tilt and array depth uncertainty
    - In 2005 using forward echo time to invert for tilt
SWSS Provided Foundation for Future 3-D Tracking Efforts

- Merging of data sets with backscatter results
- New array being built
  - 400 m aperture (2 km range)
  - Inclination and heading provides wider circumstances of use
- Real-time software development supported under PAMGUARD project
- Directional sensor to remove left/right ambiguity
- Field-test off Alaska in July 2007
a) $Z_{a,r}$

$Z_{a,f}$

$\alpha_{global}$

$P_{d,f}$

$P_{d,r} = P_{d,r} + P_{dd}$

b) $L$

$R_r$

$R_f$

c) $P_s = P_d + P_{ds}$

$P_d$
Original Tracking Method Assumed
Array Tilt and Depth Known

- Three-phone method (bearing)
  - Measures bearing on rear sub-array
  - Advantages:
    - Insensitive to array depth, array tilt
    - Less reliance on forward subarray-noise less an issue
  - Disadvantages
    - Insensitive at endfire (directly ahead and behind)
    - Poor results when ship turning (bent cable)
    - Some assumptions about array tilt/inclination
Three Pieces of Information Allow Animal Position If Hydrophone Depths Known

Direct-surface path difference WHOI

ICI

Direct-surface path difference Ecologic

Path difference between direct arrivals

5 September 2002

Ishmael display: David Mellinger
Range-Depth Tracking of Interest in Seismic Surveys

- Ranging important for establishing mitigation zones for directional sources in complex propagation environments
  - Depth measurements needed for deep-diving animals
  - Impact of vessels on diving behavior in near vicinity
  - CEE? (practical issues)

- Current ranging estimates with short-aperture arrays have problems under certain circumstances
  - Time-motion analysis: requires continuous vocalizing, fast ship motion relative to animal, inadequate if animal changing depth
  - Received level measurement: source levels vary between calls, directivity, logarithmic insensitivity
2004 Check: Towed Array Dynamics
Measured, Results Self-Consistent
Array Successfully Deployed and Tested During S-Tag 2004 and 2005

- Integrated into S-tag cruise, night work
- Calibrated 24-bit acoustic recording from all arrays, 50 Hz to 28 kHz flat array response, 12 dB/octave rolloff
- Array depths automatically logged using LabView application
- Deck connector required 48 solder joints in eight hours
- Some crude real-time ranging, mostly post-processing
A single click yields up to five pieces of information:

- **ICI**
- **tds**
- **tdb**
- **tdt**

**Click to hear audio clip 1.**

**Click to hear audio clip 2.**
Sperm Whales Tracked with Single Hydrophone During MMS Cruise in 2000

NOAA ship Gordon Gunther 0.5-1.5 kts

- Multipath from ocean bottom required
- Ocean depth needed
- Hydrophone depth optional
In 2005 Results, Depth Measurements Checked Using Forward Echo Time
Measured Inclination vs. Derived Inclination Encouraging