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

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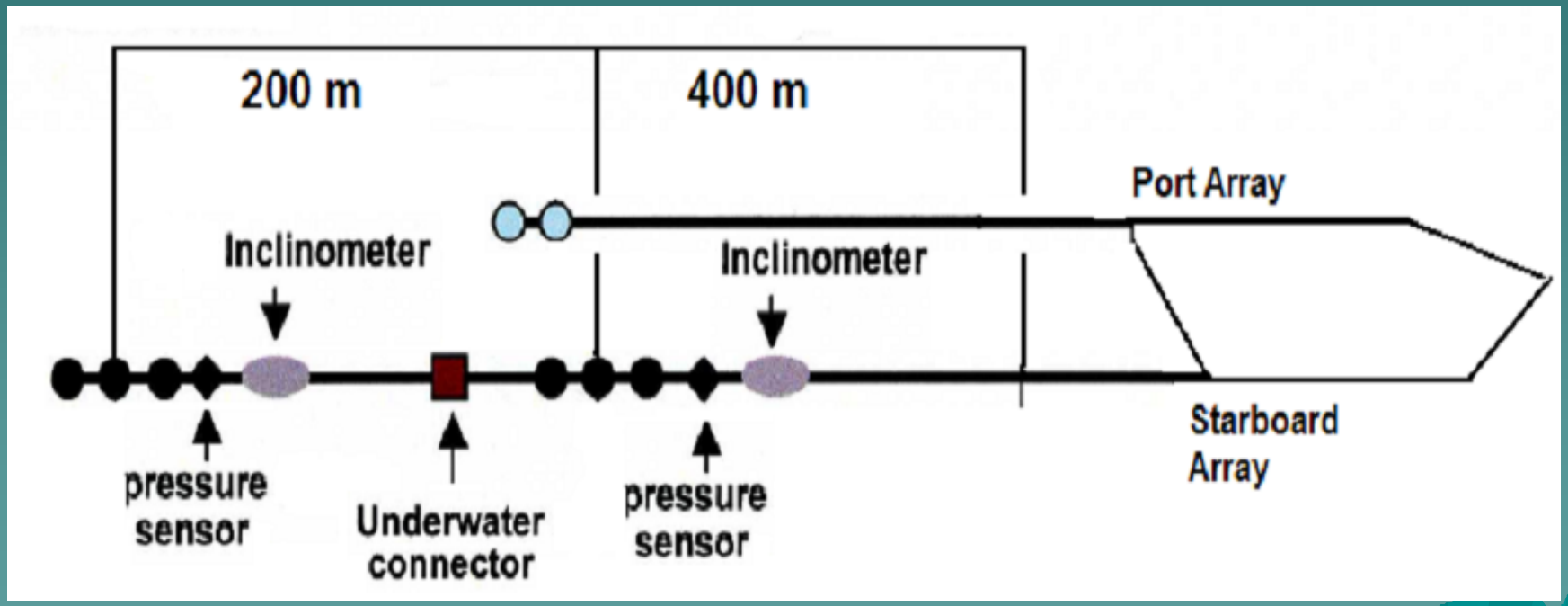
Project Goal: 3-D Positions of Deep-Diving Animals in Vicinity of Tow Vessel

- 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

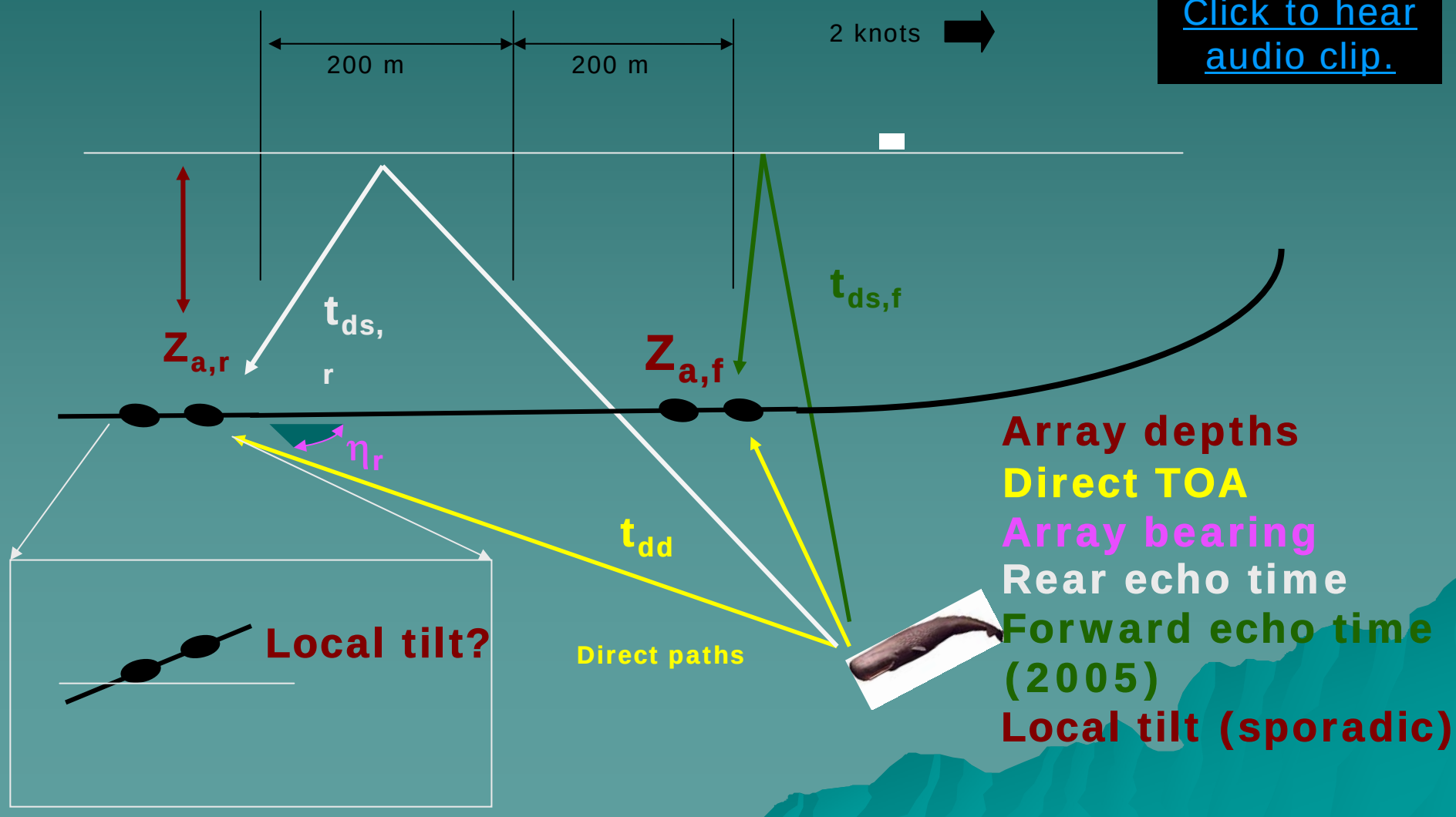
SWSS Tracking Deployment in 2004–2005

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

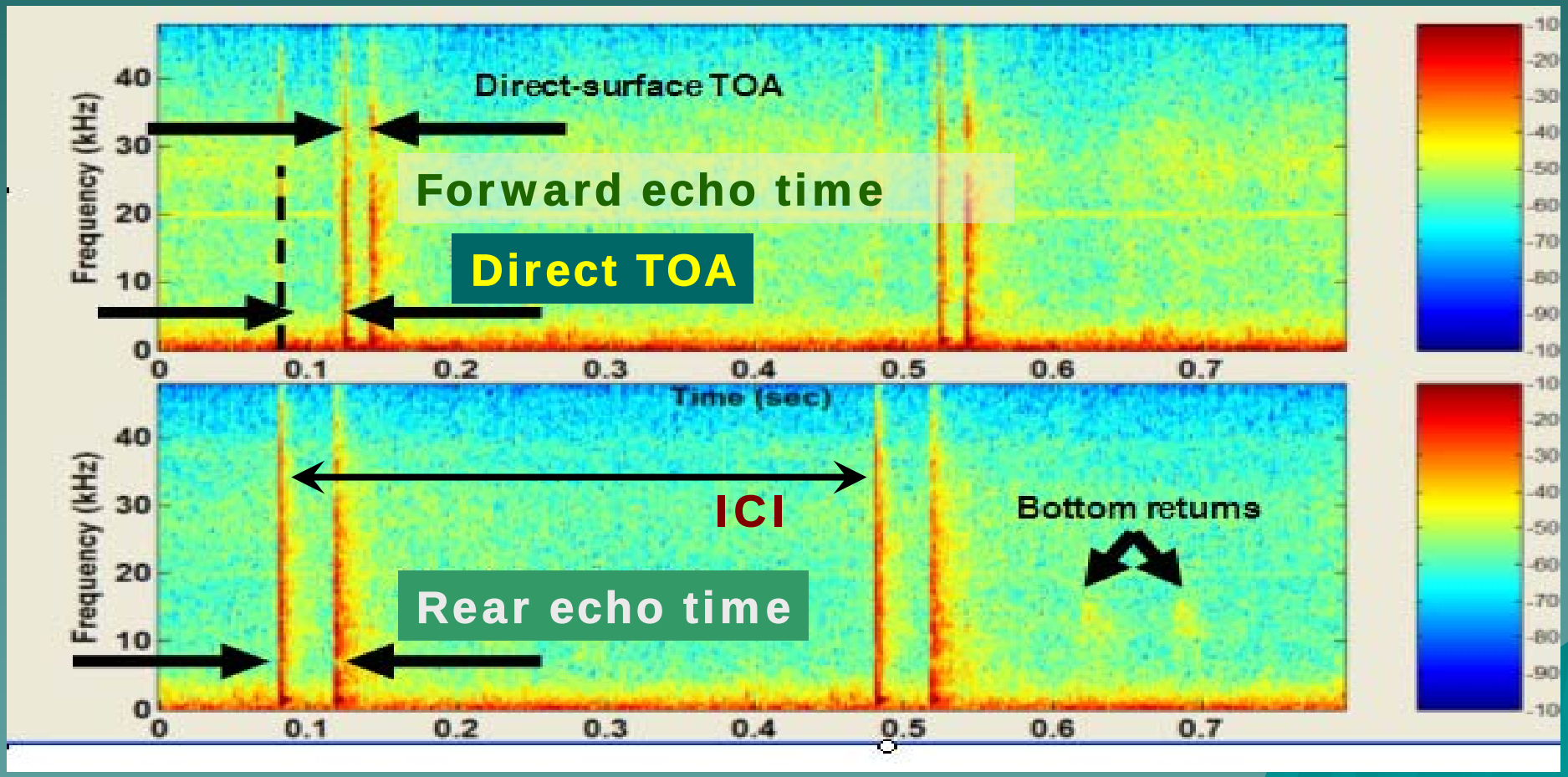


Thode, A. 2005. Three-dimensional passive acoustic tracking of sperm whales (*Physeter macrocephalus*) in ray-refracting environments. J. Acous. Soc. Am. 18(6):3575–3584.

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



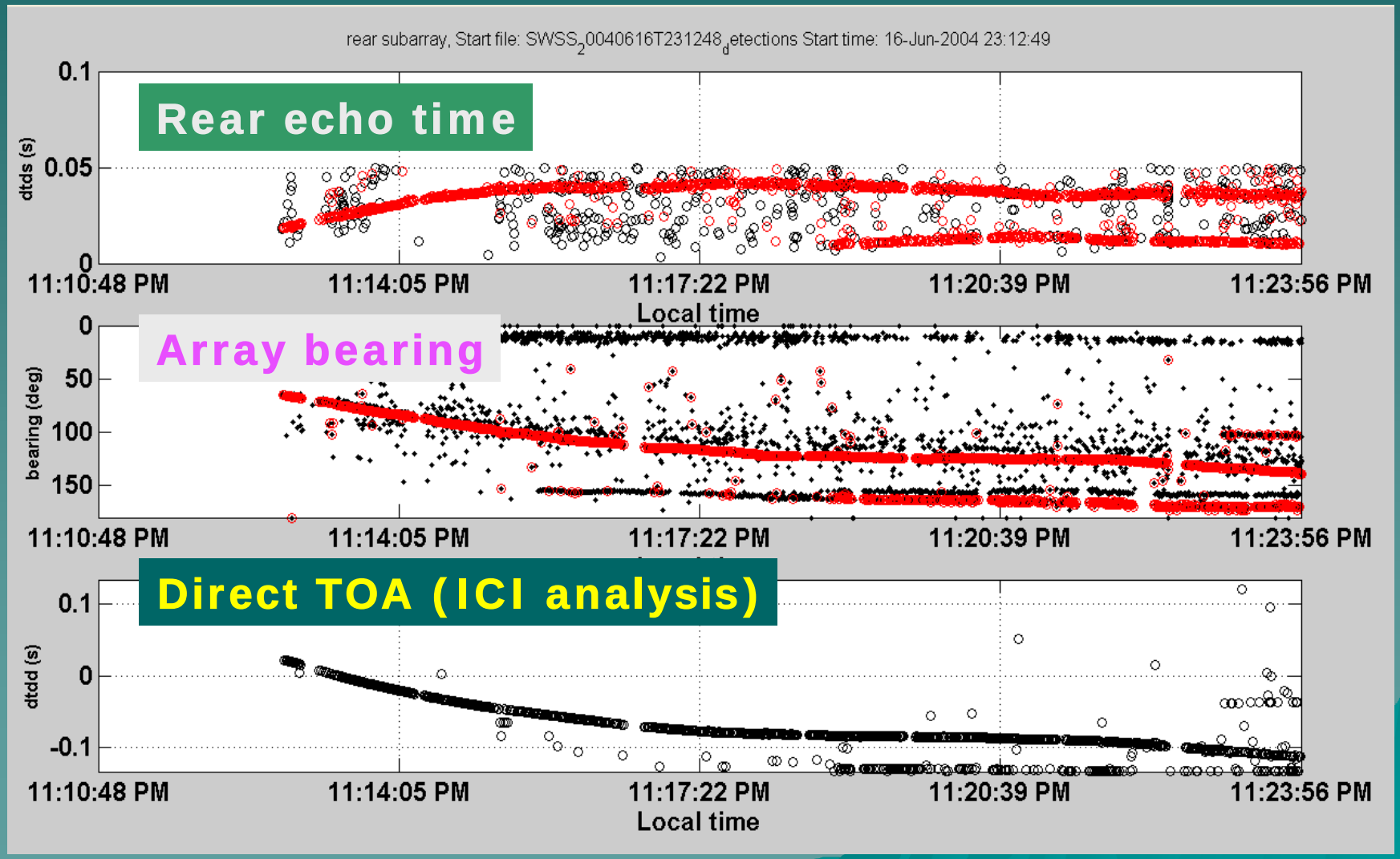
Visual Representation of Localization Parameters



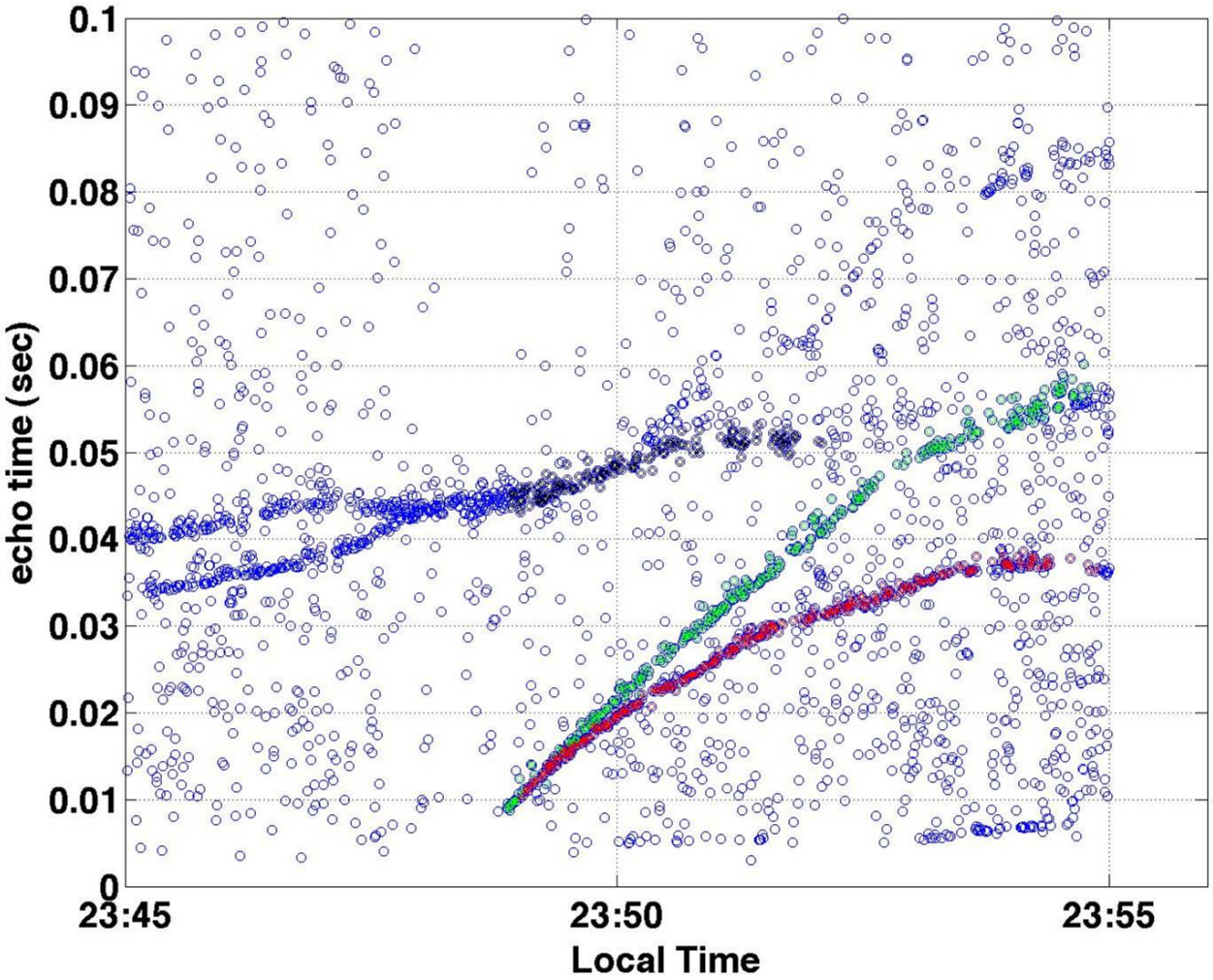
Array Data Collected During Nights and Rough Sea Conditions During S-Tag Cruise

- 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

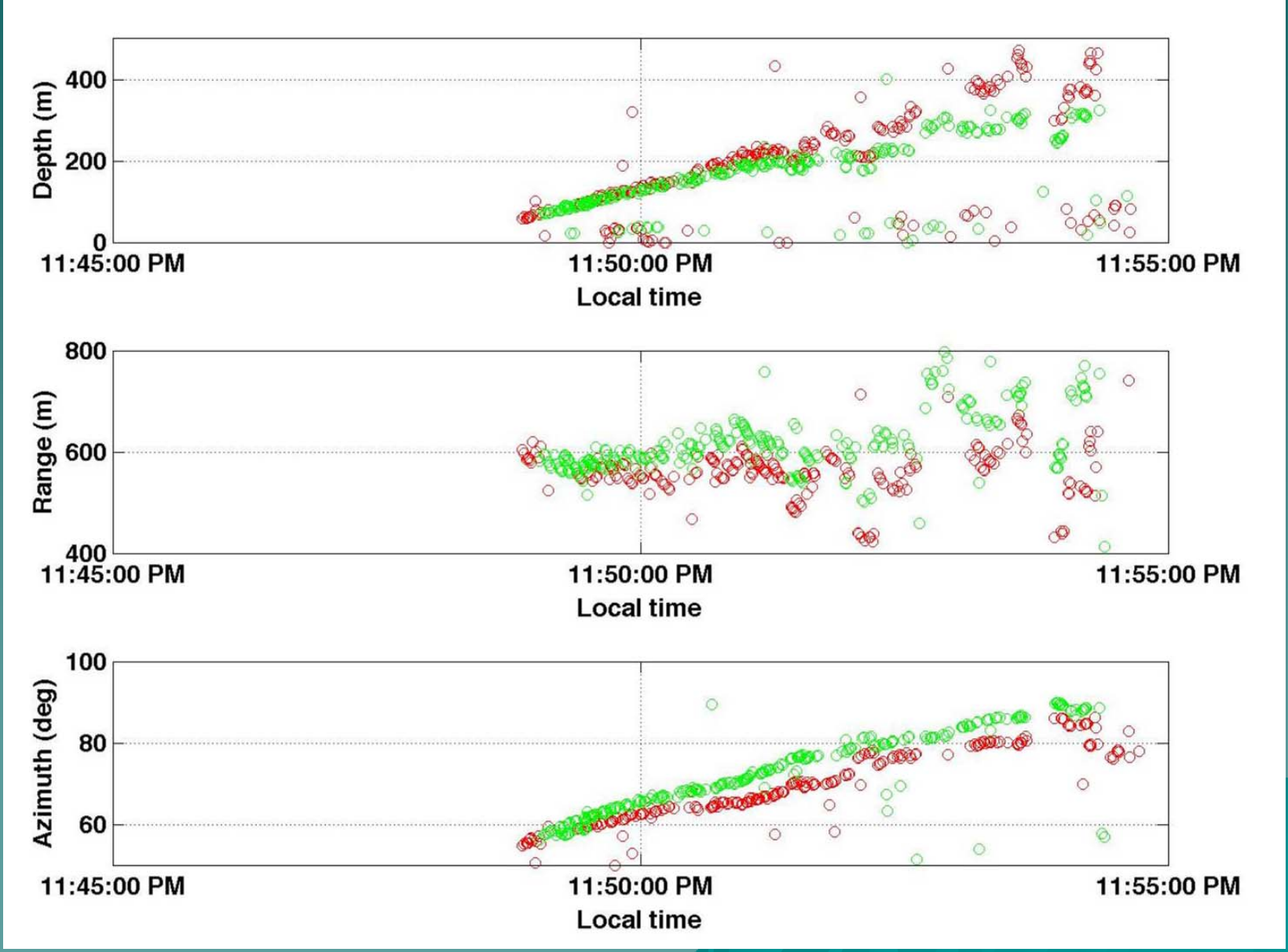
Localization Parameters Automatically Extracted in Post-Processing (2004)



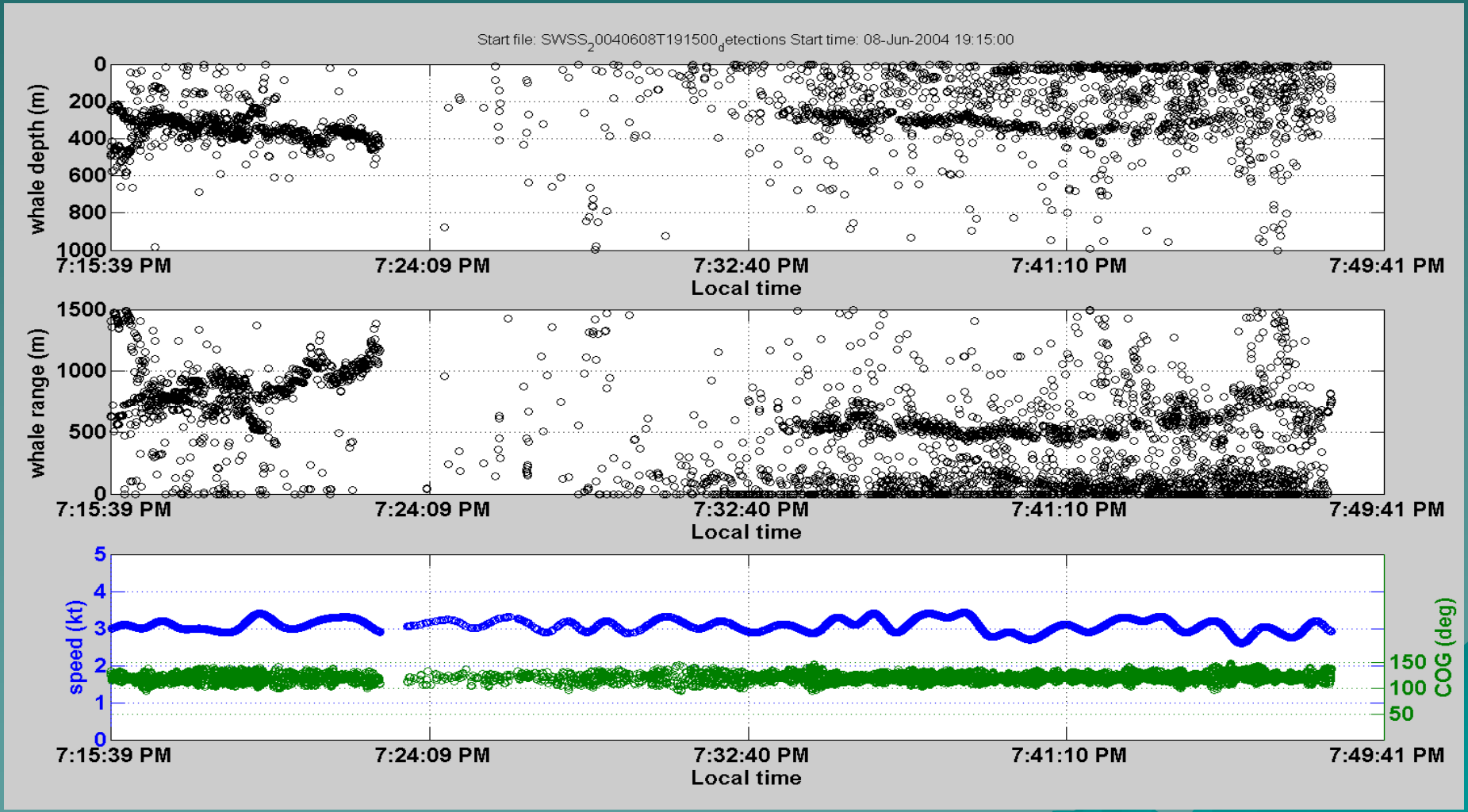
Plotting “Echo Time” Convenient for Selecting Tracks (2005)



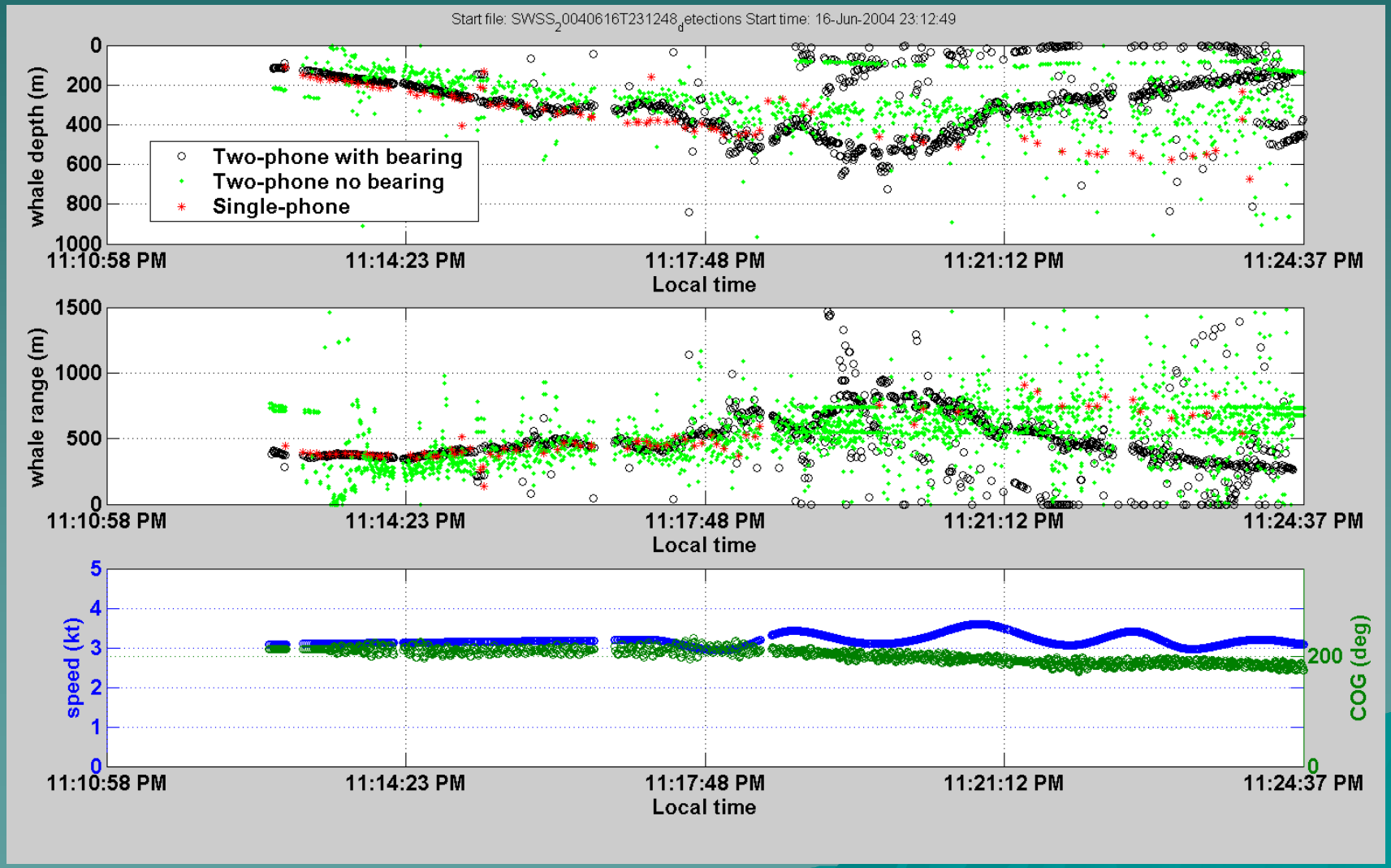
Example of Initial Dive Profiles



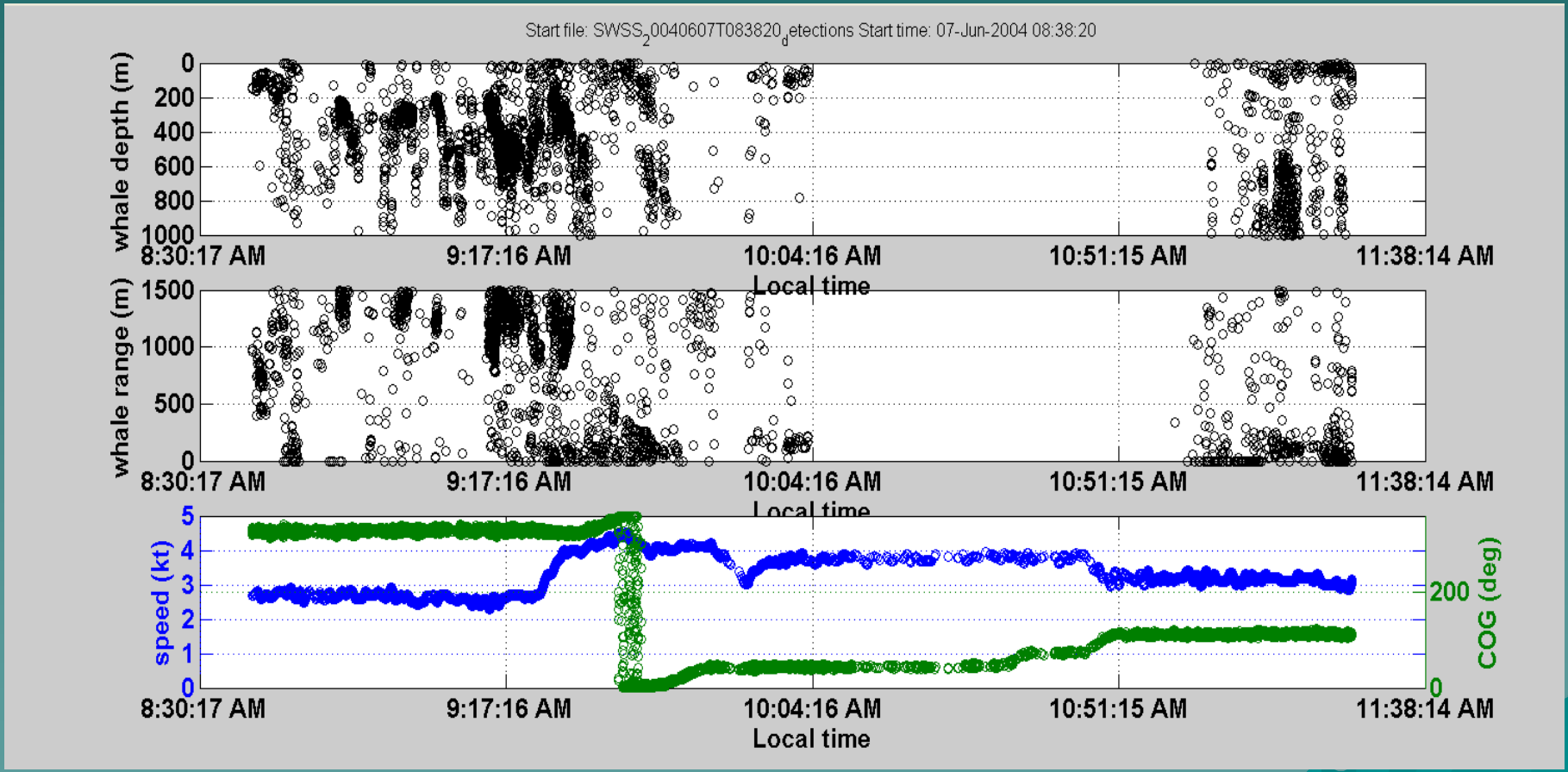
Tracking Results for a Ship on a Steady Course



Great Weakness of Method Is Turning Ship

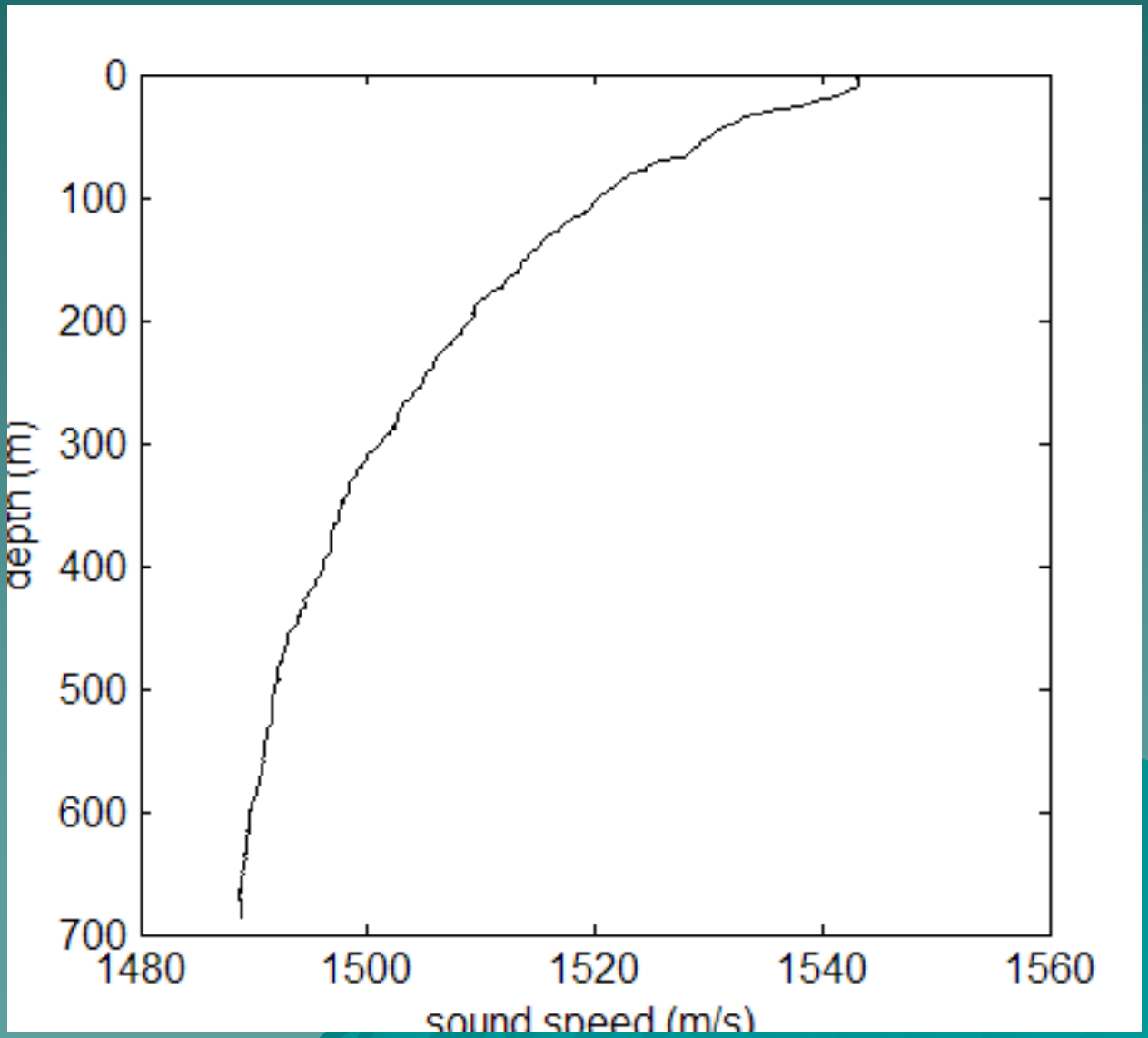


Why I Should Not Be Driving (or Why Magnetic Heading Needed)



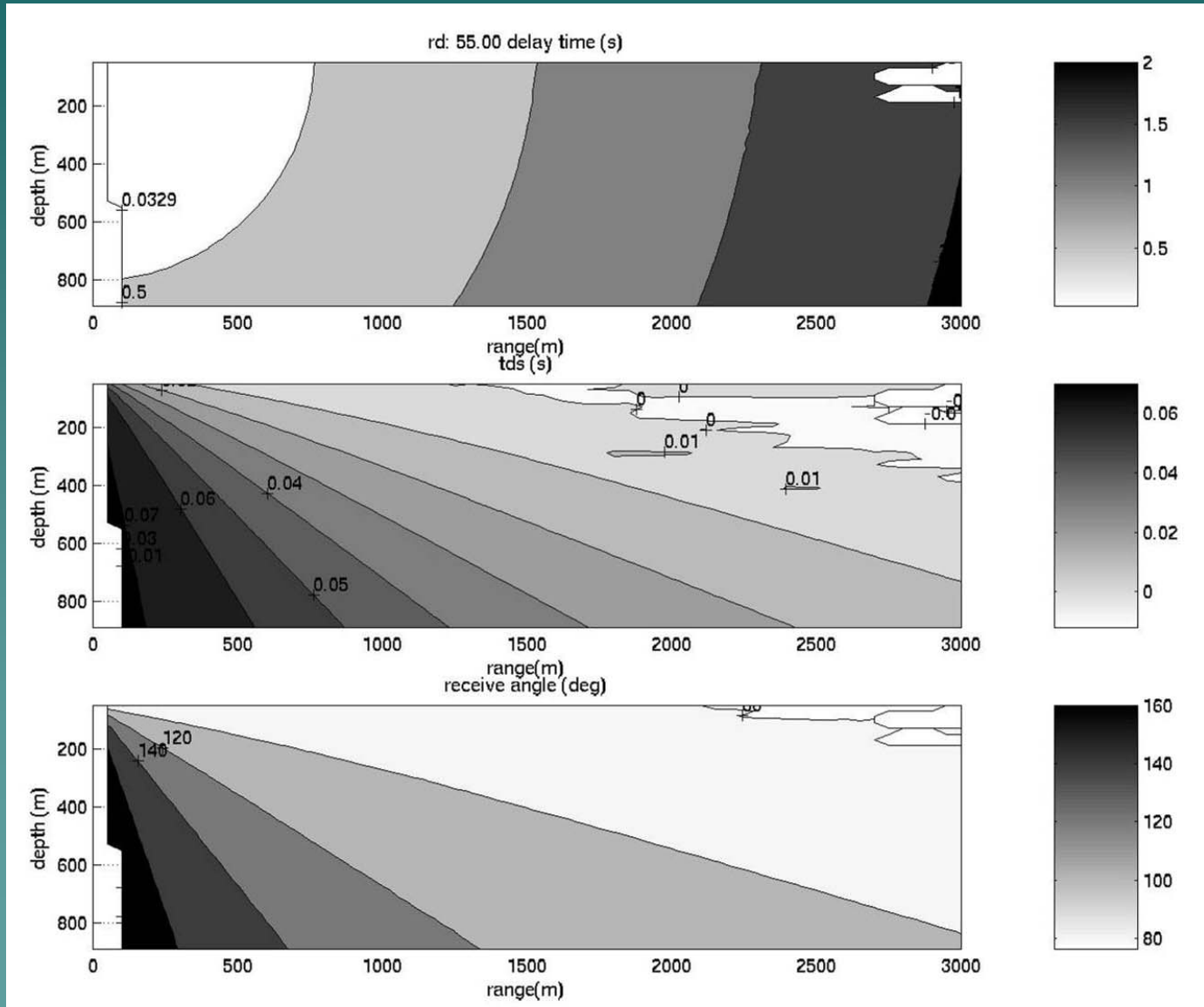
Ray-Refraction Effects Incorporated with Ray-Tracing Propagation Code

2-D grids can be used to solve the 3-D problem

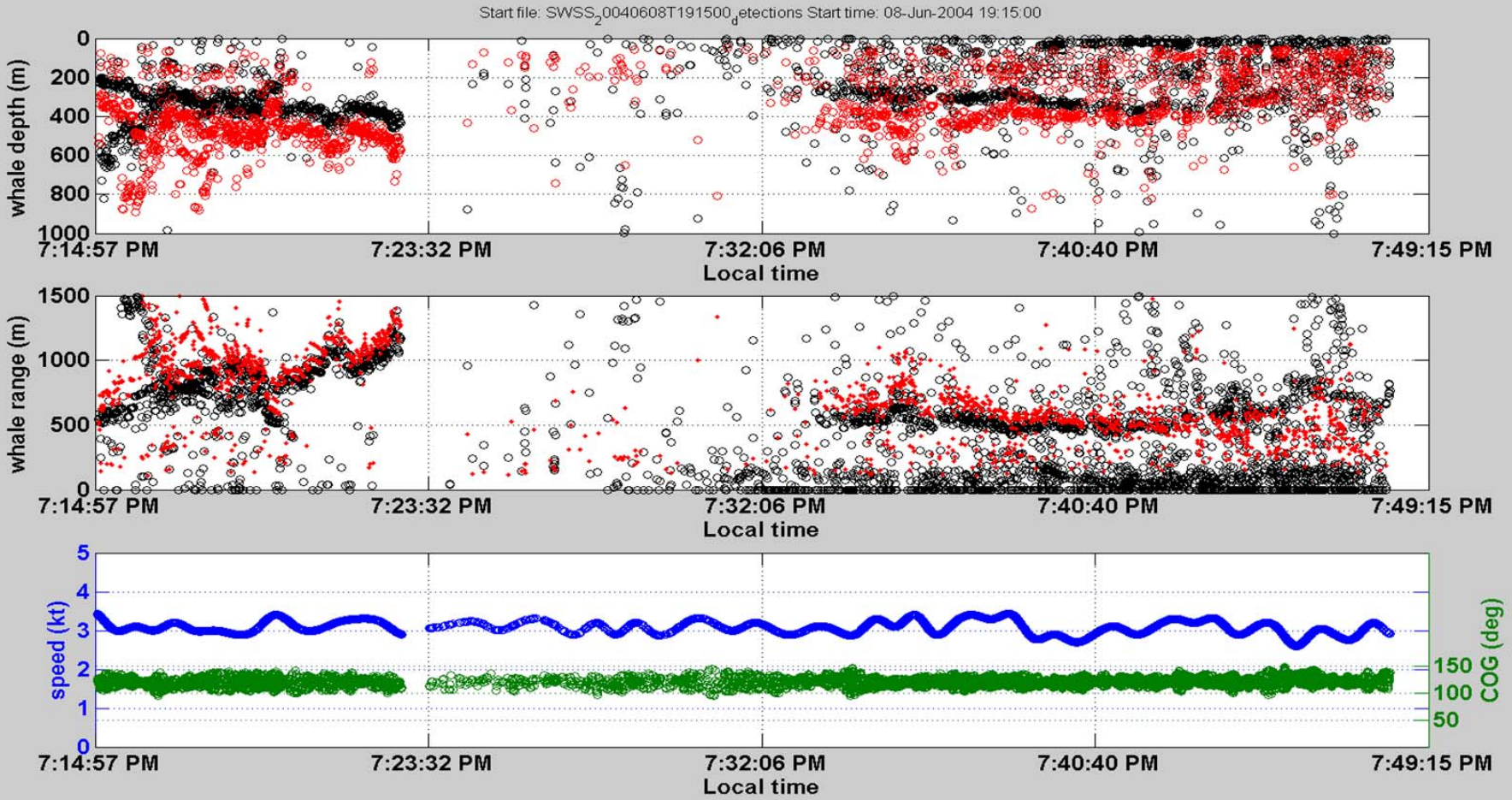


Ray-Refraction Effects Incorporated with Ray-Tracing Propagation Code

Shadow zone begins at 3 km for 50 m deep hydrophone

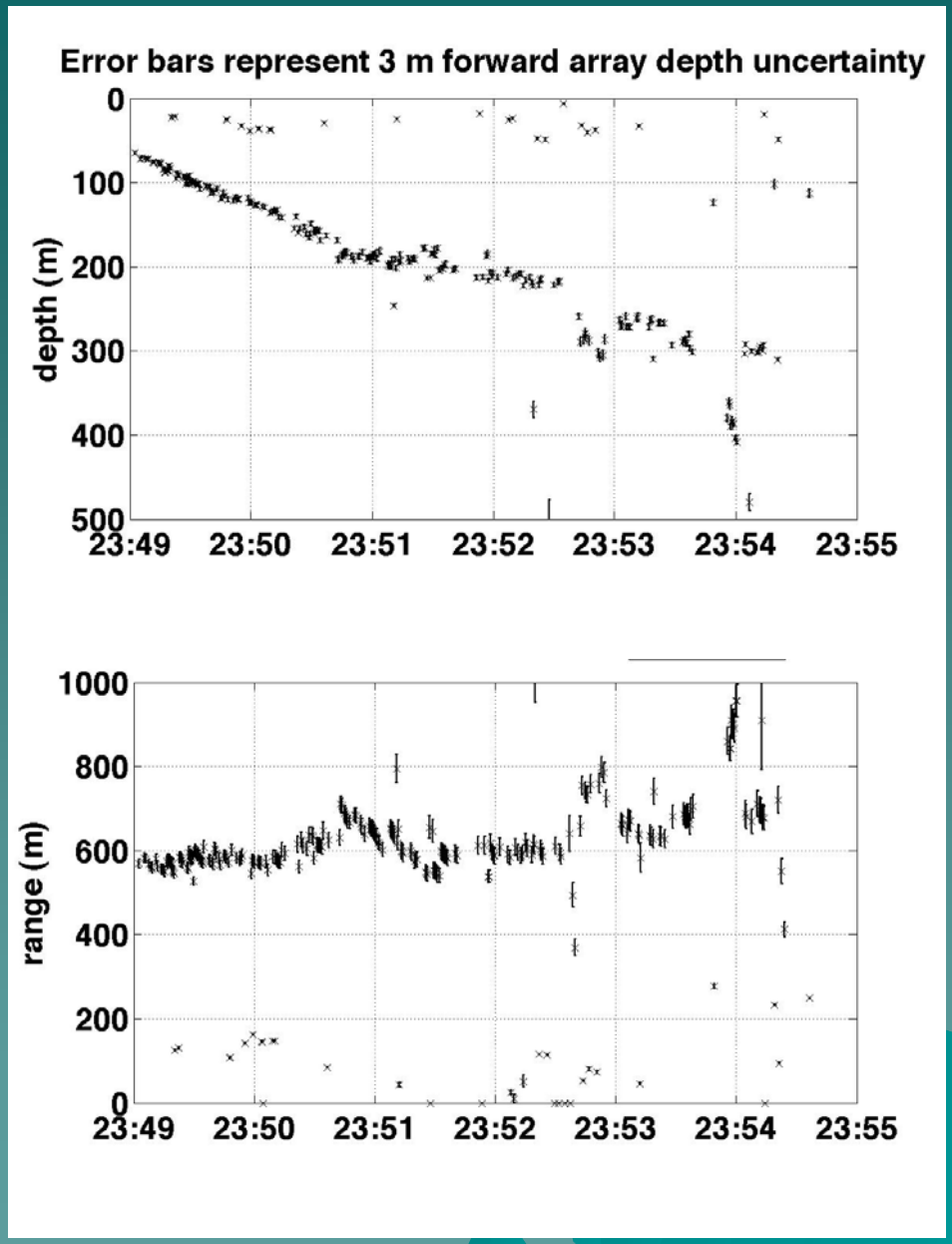


Effect of Realistic Sound Speed Profile

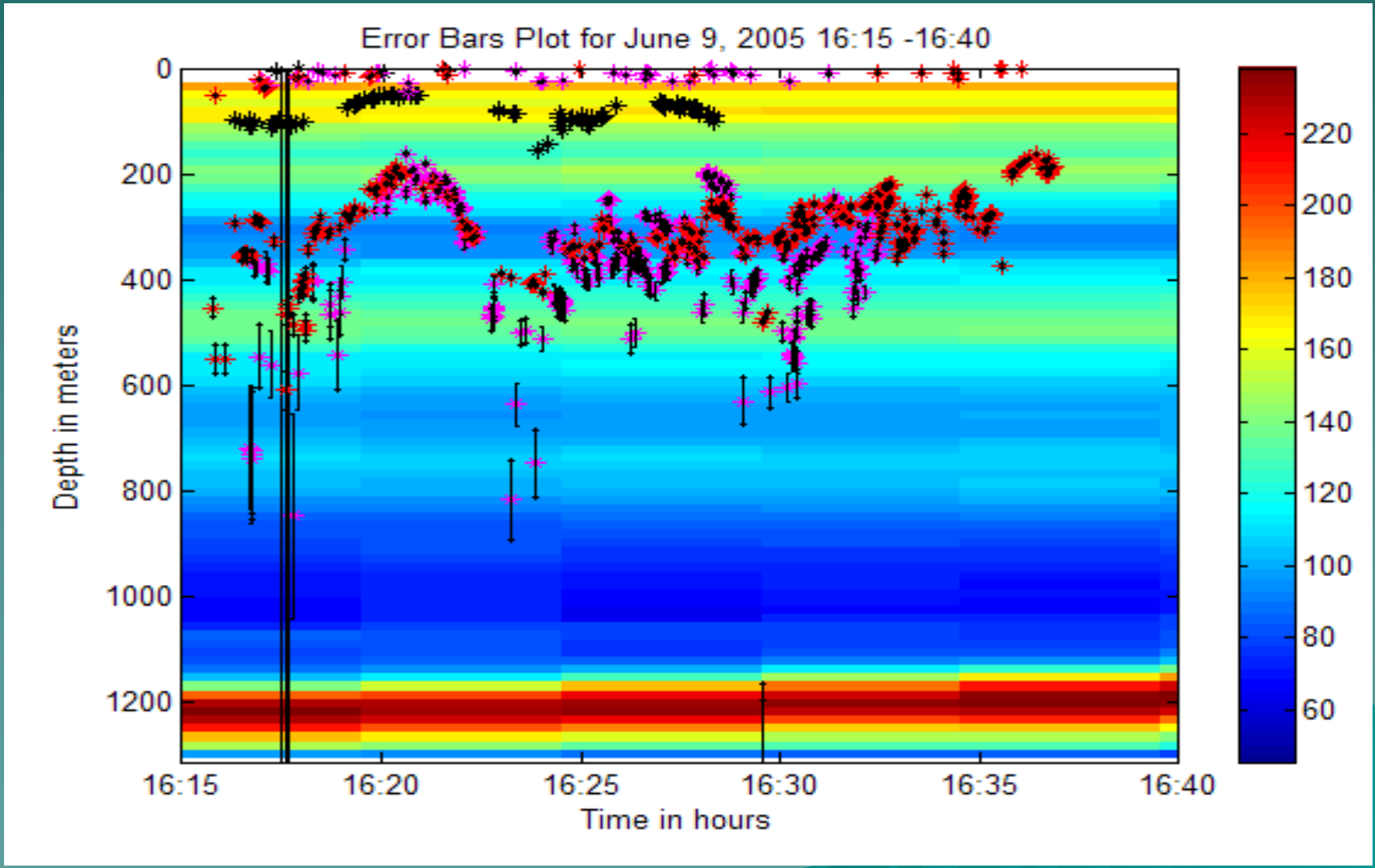


Array Depth and Tilt Uncertainty Greatest Source of Systematic Error

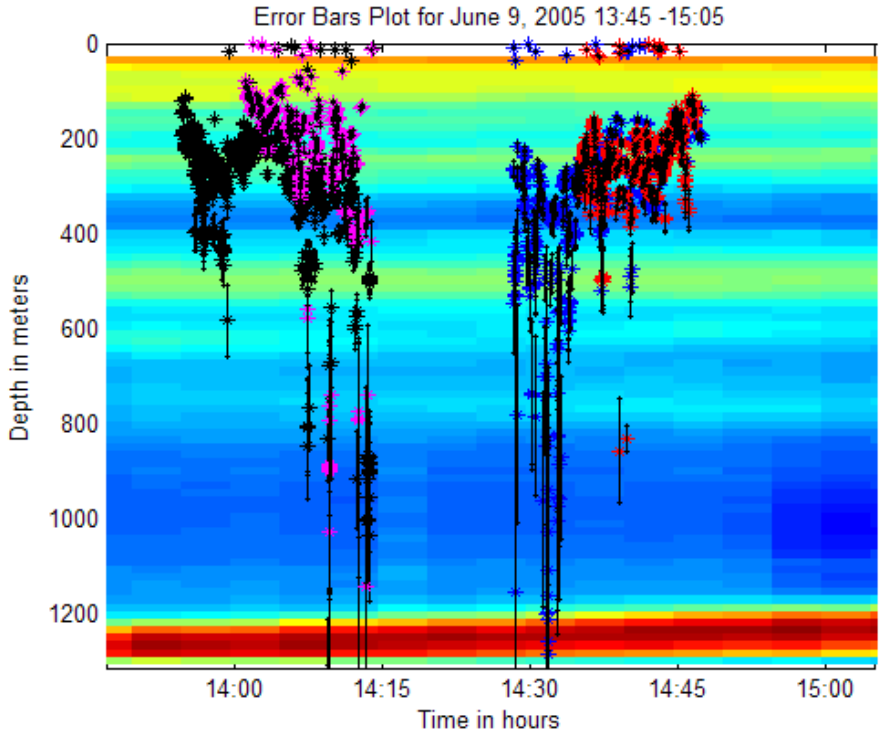
200 m aperture causes significant uncertainties in slant ranges greater than a kilometer.

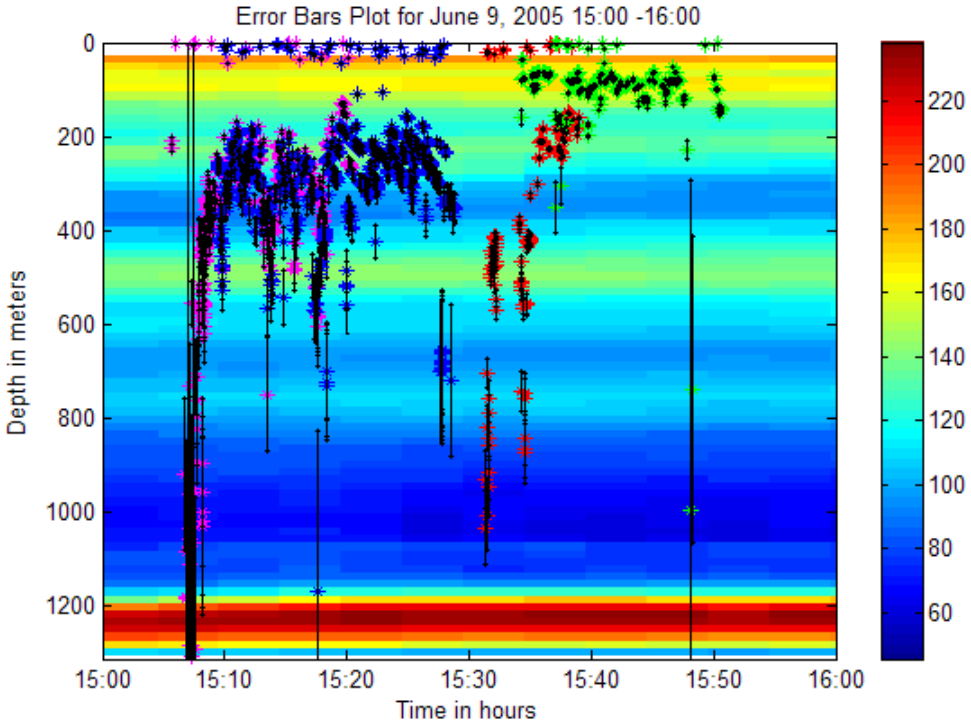


Current Work: Merging Tracks with Backscatter Data



Example of Simultaneous Tracks



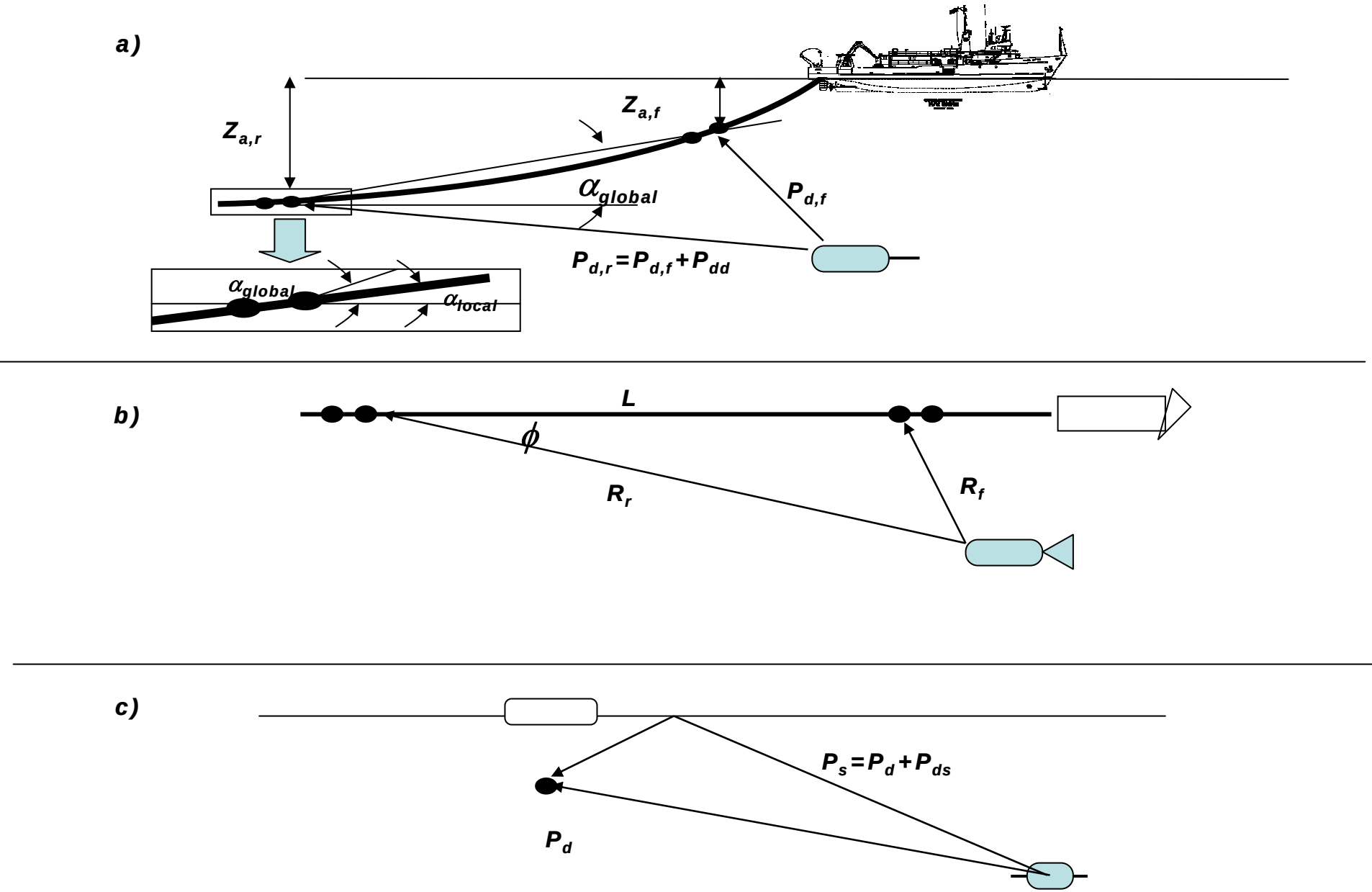


Five Years Reviewed in Fifteen Seconds ...

- 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

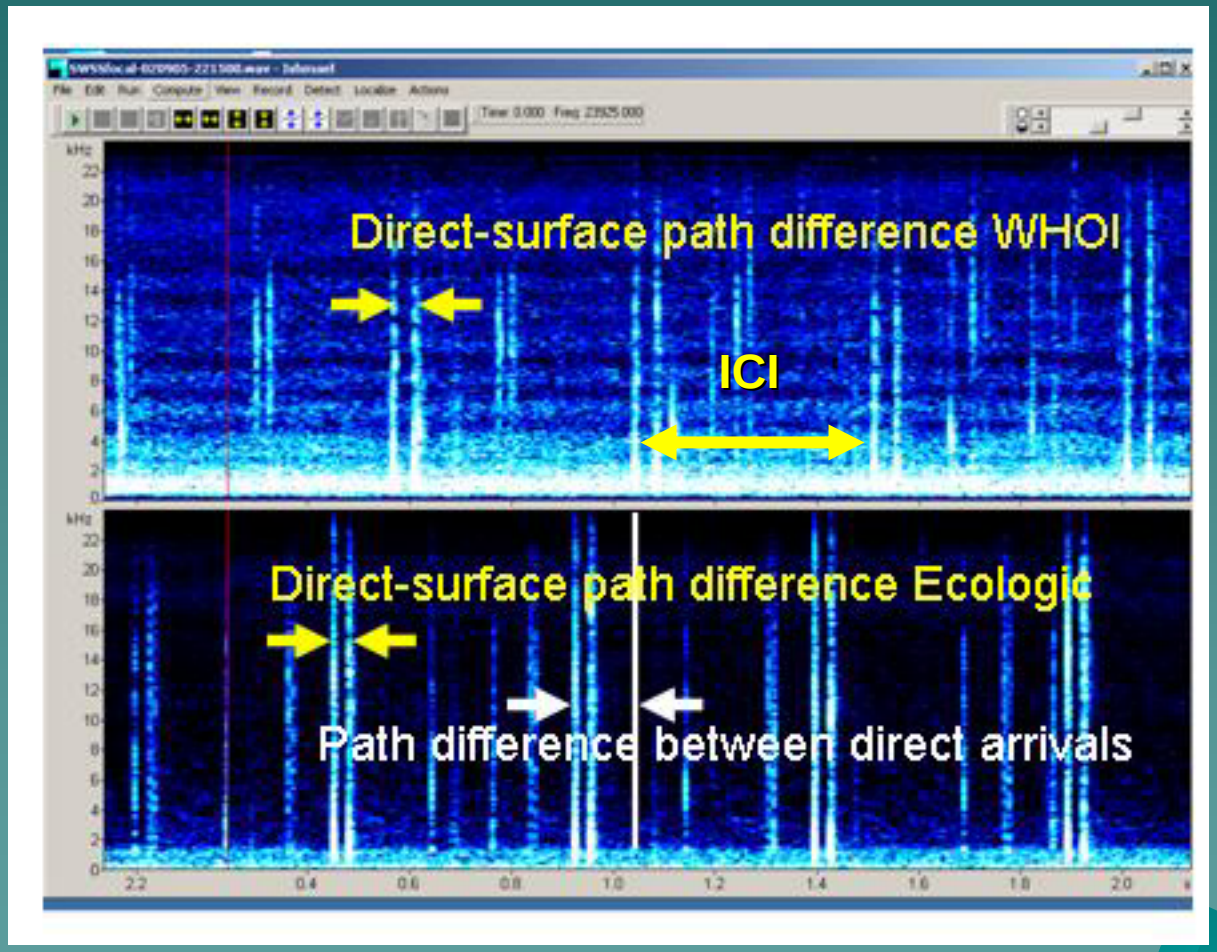
- Merging of data sets with backscatter results
- New array being built
  - 400 m aperture (2 km range)
  - Inclination and heading provides wider circumstances of use
- Real-time software development supported under PAMGUARD project
- Directional sensor to remove left/right ambiguity
- Field-test off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


a)
$Z_{a,r}$
$Z_{a,f}$
α_{global}
$P_{d,f}$
$P_{d,r}=P_{d,f}+P_{dd}$
α_{global}
α_{local}
b)
L
ϕ
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



Frequency

Time

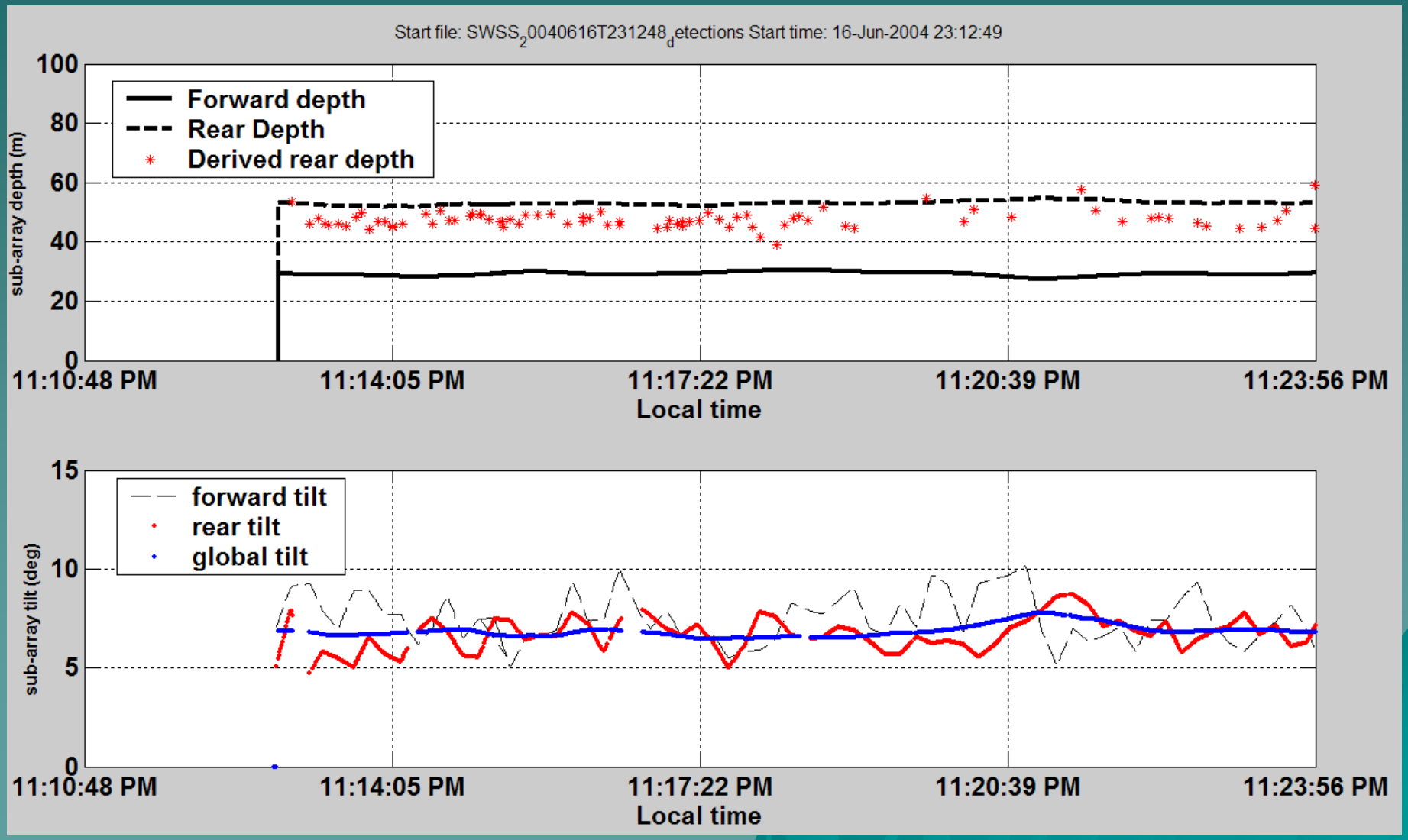
5 September 2002

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

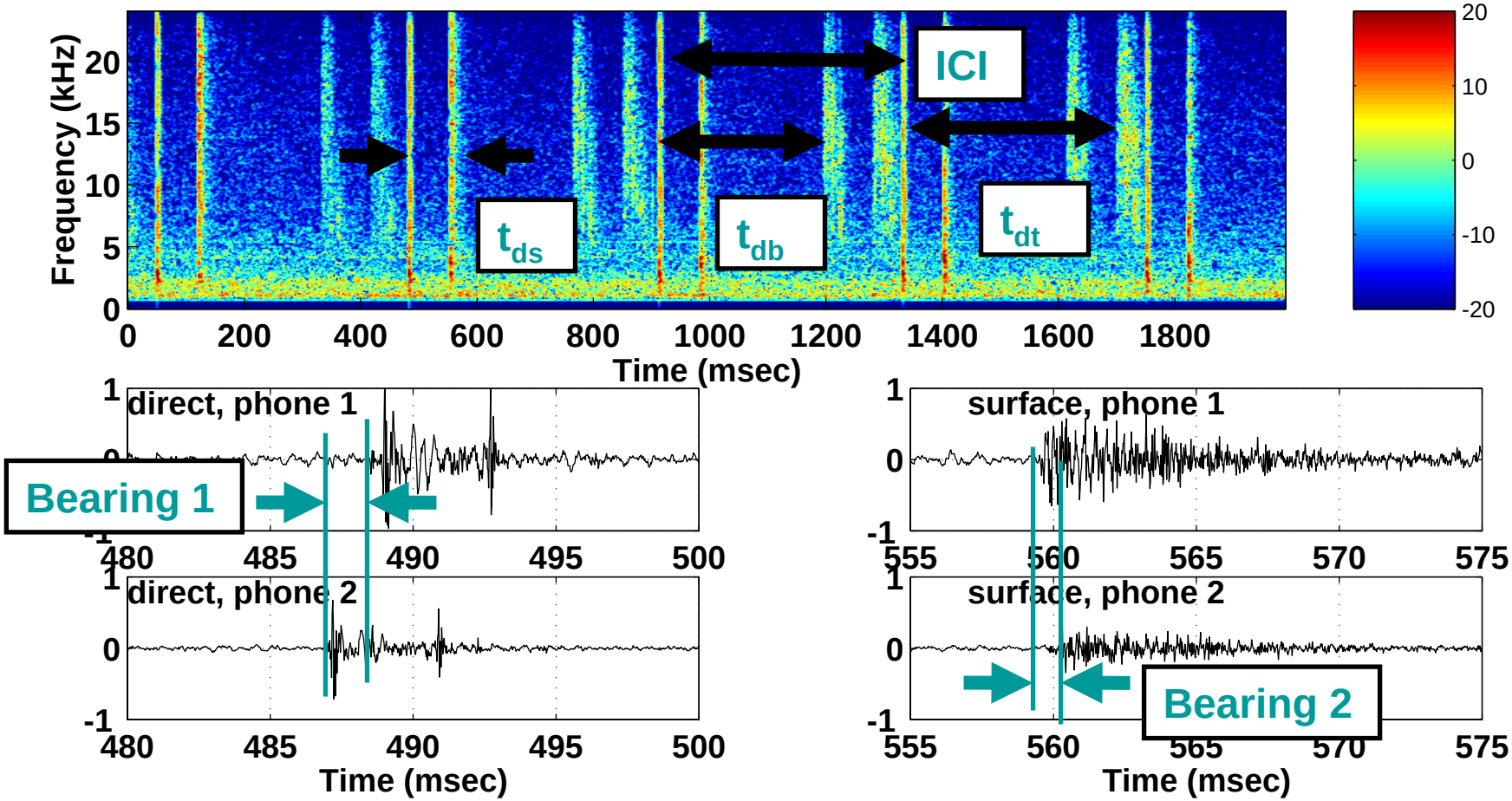


Array Successfully Deployed and Tested During S-Tag 2004 and 2005

- 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

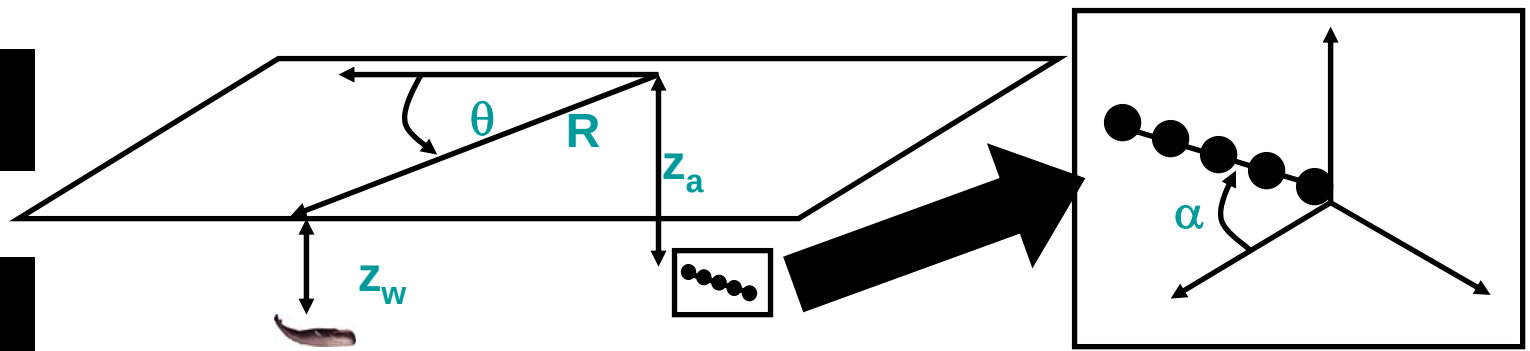
The Eddie Webb slide of honor

A single click yields up to five pieces of information

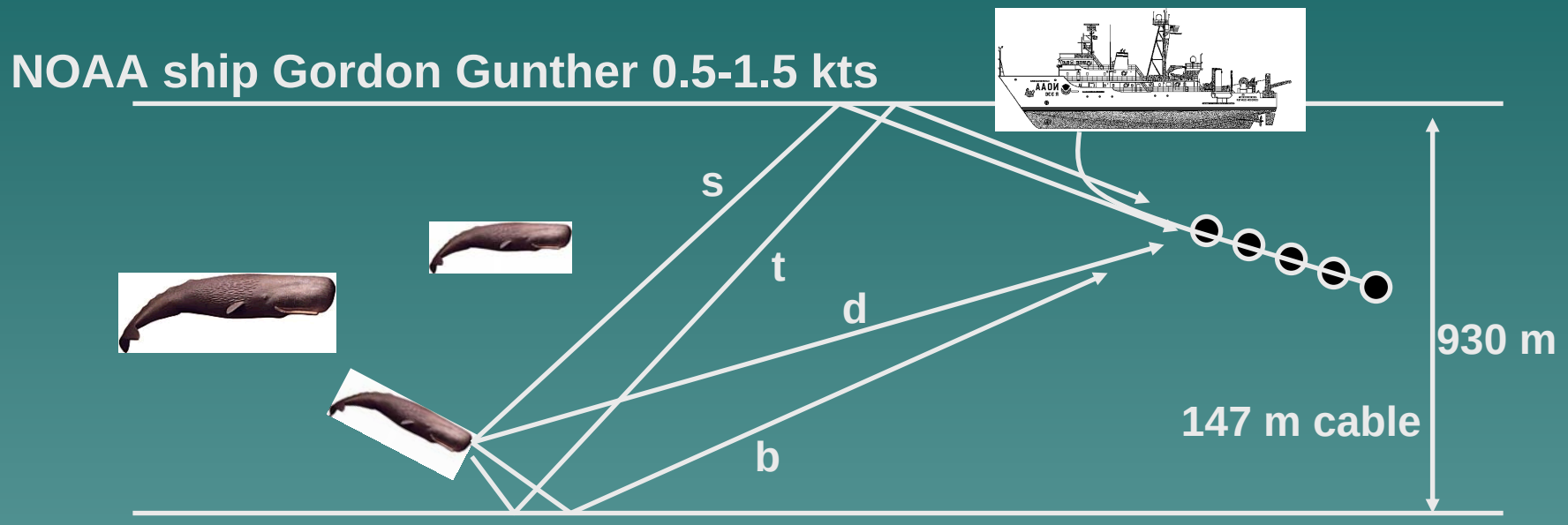


Click to hear audio clip 1.

Click to hear audio clip 2.

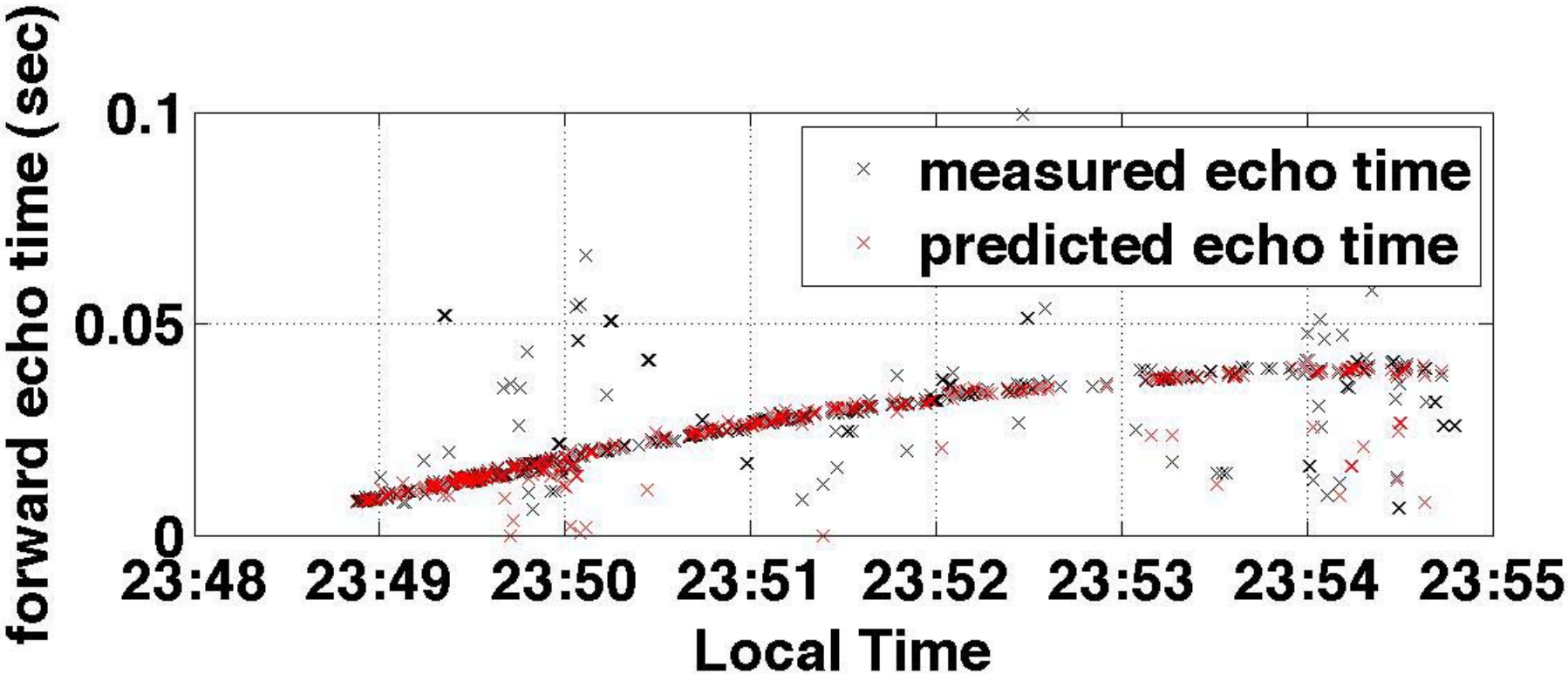
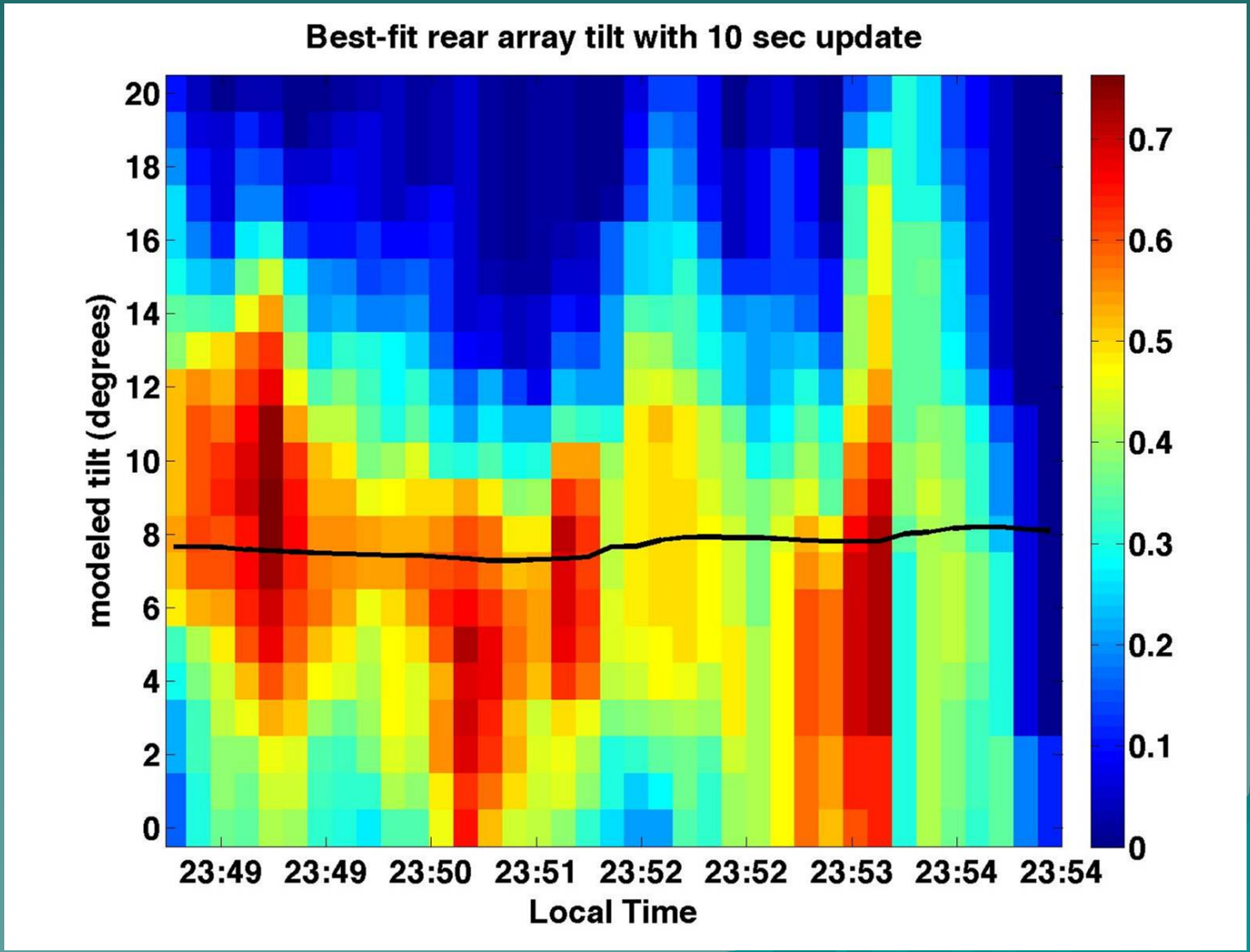


Sperm Whales Tracked with Single Hydrophone During MMS Cruise in 2000



- Multipath from ocean bottom required
- Ocean depth needed
- Hydrophone depth optional
- Published in Thode, A.M., D.K. Mellinger, S. Stienessen, A. Martinez, and K. Mullin. 2002. Depth-dependent acoustic features of diving sperm whales (Physeter macrocephalus) in the Gulf of Mexico. J. Acoust. Soc. Am. 112(1):308–321.

In 2005 Results, Depth Measurements Checked Using Forward Echo Time



Measured Inclination vs. Derived Inclination Encouraging