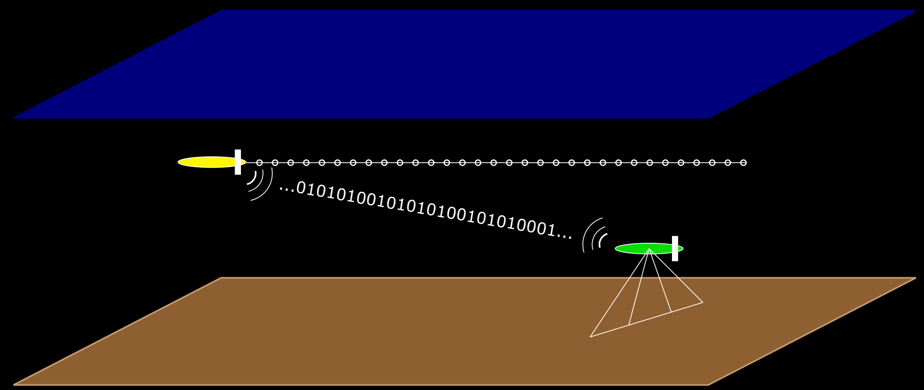
Improving underwater vehicle communication in the littoral zone through adaptive vehicle motion



Acoustical Society of America 157th Meeting

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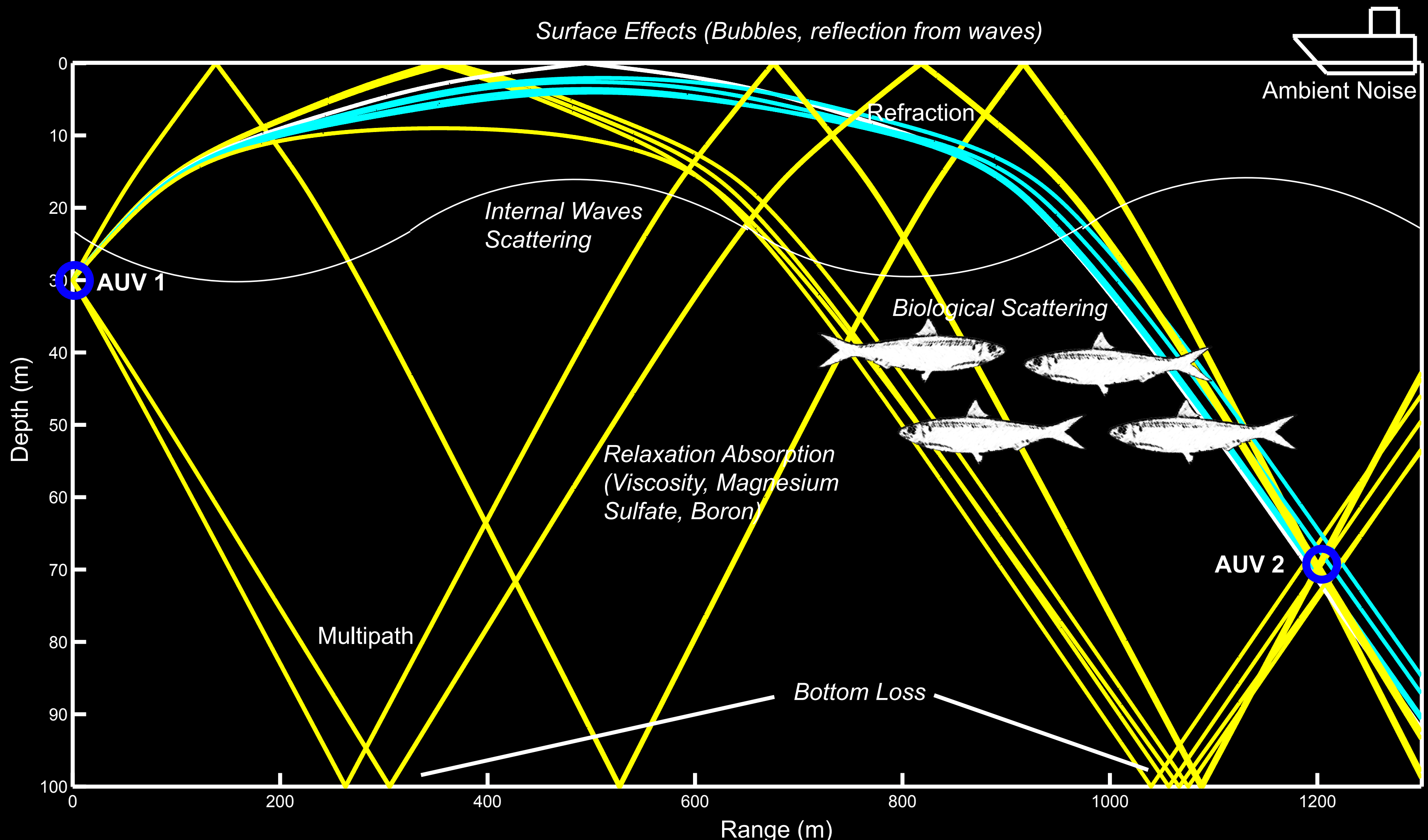
Problem

Using environmental information, is it possible to adaptively control an AUV to improve acoustic modem performance in a shallow water environment?



GLINT08 Experiment

Acoustic Equipment: WHOI MicroModem (Band C) mounted on Bluefin 21 AUV (mobile) and buoy (fixed):

- frequency: $f = 23\text{-}27$ kHz
- wavelength: $\lambda = 6.5\text{-}5.6$ cm

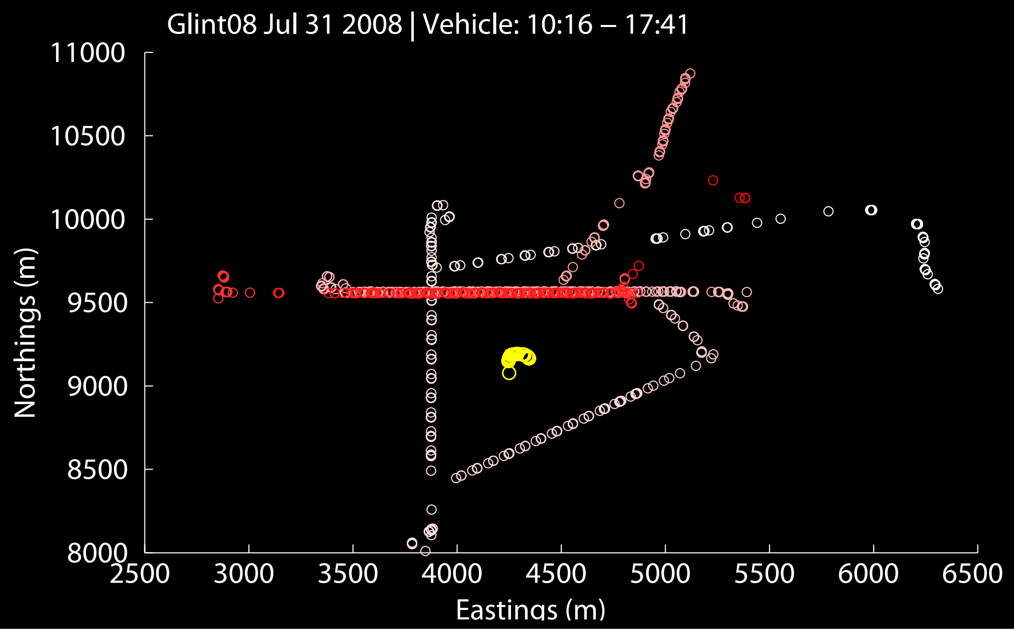
Environment overview:

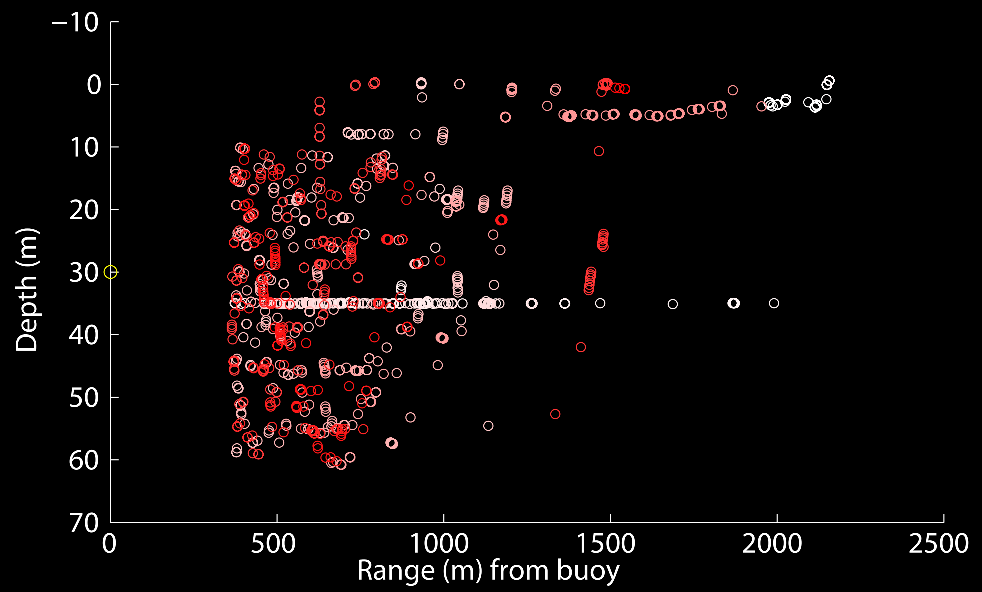
Mediterranean Sea, near Elba, Italy. Shallow water (nearly constant 100 m depth). Visibly calm seas.

Initial Model Assumptions:

- Flat, smooth bottom (roughness less than wavelength over fresnel radius of 2-4 meters)
- Flat, smooth surface (in general, not a good assumption even in calm seas)
- Sound speed homogenous in range and over course of one day

AUV & Buoy Positions at Transmission





- Vehicle (red to white) ran at 0-60 m at a range of 380 - 2100 m from buoy
- Buoy (yellow) essentially fixed at 30 m depth
- We will ignore transmissions at < 10m depth

AUV (start of experiment):
AUV (end of experiment):

Buoy:

Ray Tracing | Ray Paths

Ray equations (derived from the Helmholtz equation):

$$\frac{dr}{ds} = c\xi(s), \quad \frac{d\xi}{ds} = -\frac{1}{c^2}\frac{dc}{dr}$$

$$\frac{dz}{ds} = c\zeta(s), \quad \frac{d\zeta}{ds} = -\frac{1}{c^2}\frac{dc}{dr}$$

$(r(s), z(s))$ - trajectory of ray along arclength s

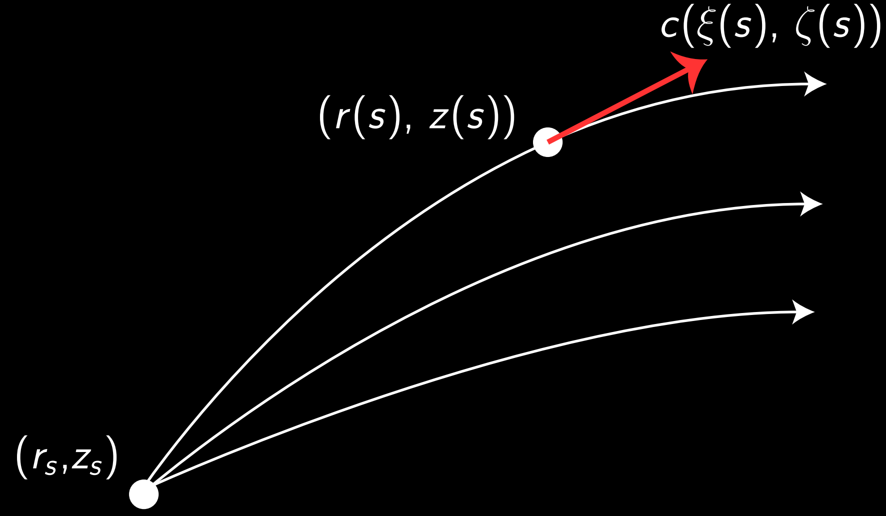
$c(\xi(s), \zeta(s))$ - tangent vector to ray

with these initial conditions for a fan of rays each with angle θ to the source:

$$r = r_s, \quad \xi = \frac{\cos\theta}{c(0)}$$

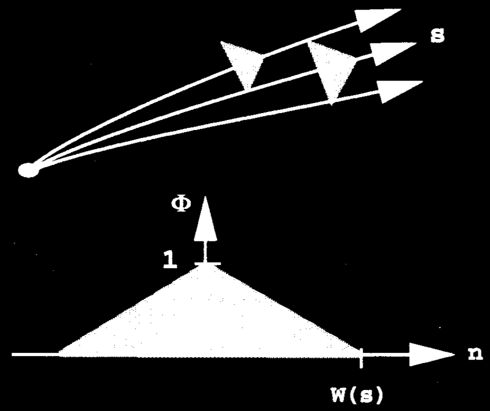
$$z = z_s, \quad \zeta = \frac{\sin\theta}{c(0)}$$

(r_s, z_s) - source position



Ray Tracing | Transmission Loss

BELLHOP uses finite element rays:



Amplitude of the ray ($A_0(s)$) is computed by the dynamic ray equations:

$$\frac{dq}{ds} = cp(s), \quad \frac{dp}{ds} = \frac{1}{c^2(s)} \frac{d^2c}{dn^2} q(s) \qquad q(0) = 0, \quad p(0) = \frac{1}{c(0)}$$

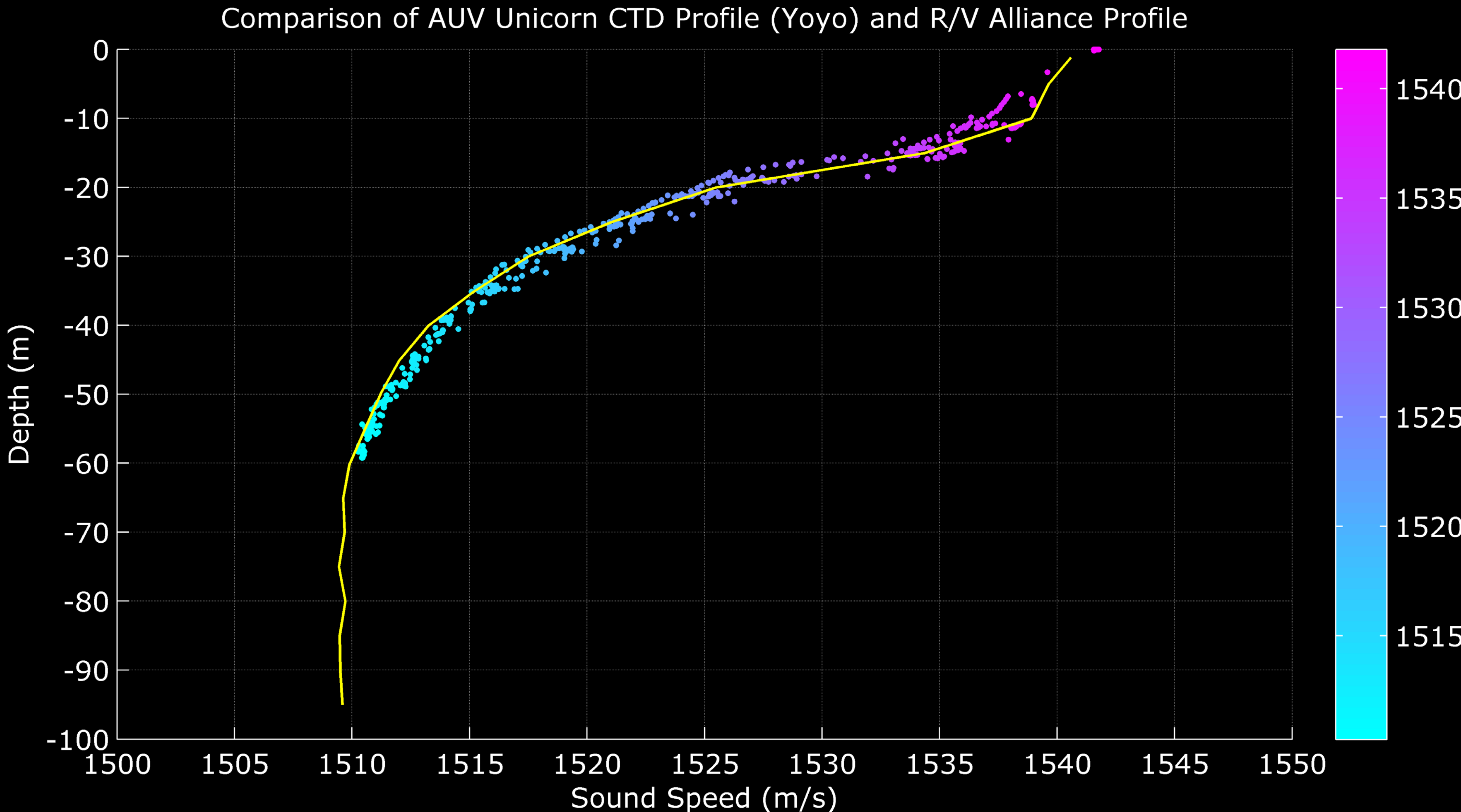
n - direction normal to ray path

$$A_0(s) = \frac{1}{4\pi} \left| \frac{c(s)\cos(\theta)}{rc(0)q(s)} \right|^{1/2}$$

For high frequency problems, ray tracing is fast compared to normal modes and sufficiently accurate.

References: M.B. Porter, Y-C Liu. *Finite Element Ray Tracing,* Theoretical and Computational Acoustics
F.B. Jensen, W.A. Kuperman, M.B. Porter, H. Schmidt. *Computational Ocean Acoustics.*

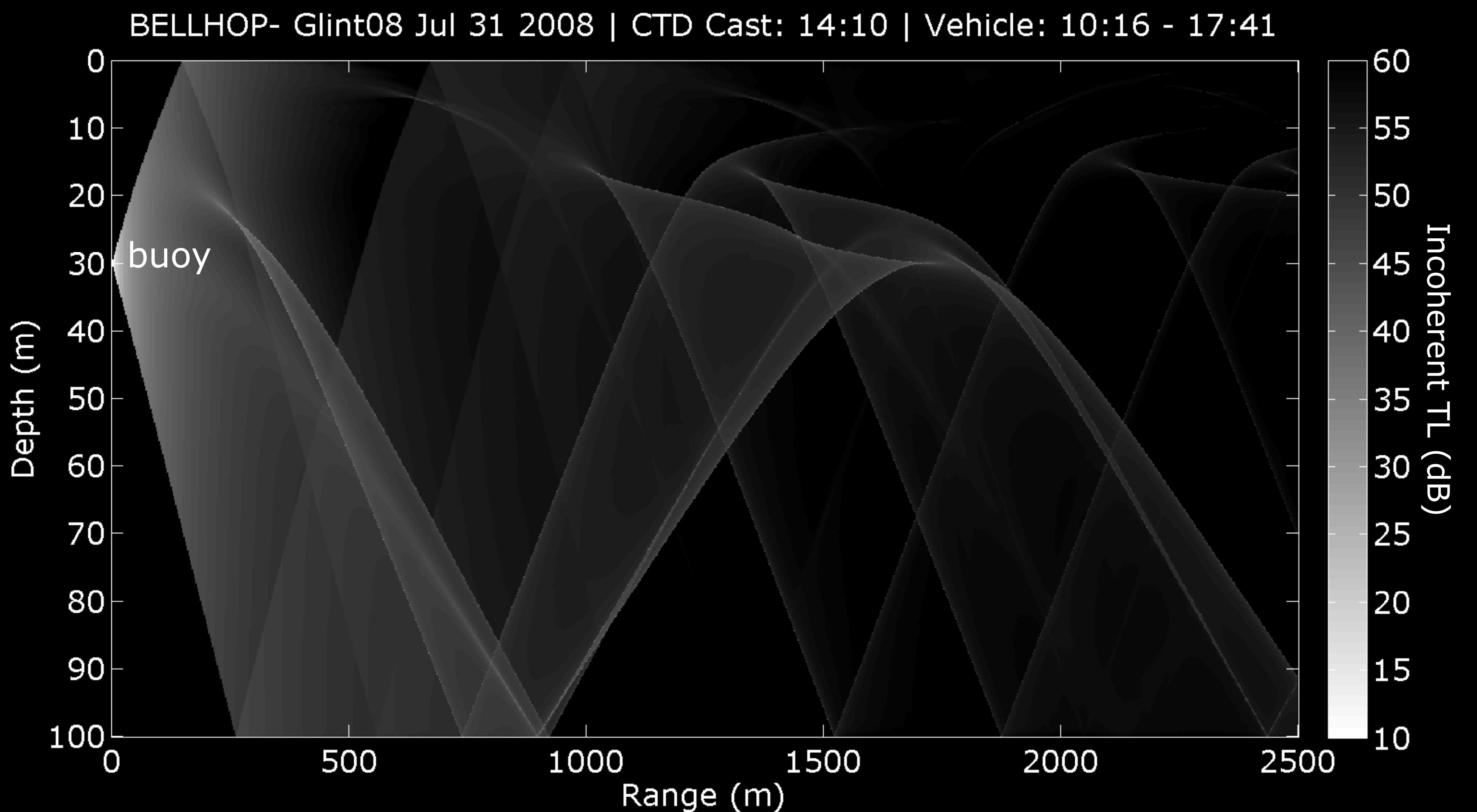
Sound Speed Profile



- dots: AUV sampled profile (Jul 31 2008 12:16-19:41 UTC)
- yellow line: ship cast profile (Jul 31 2008 16:10 UTC)

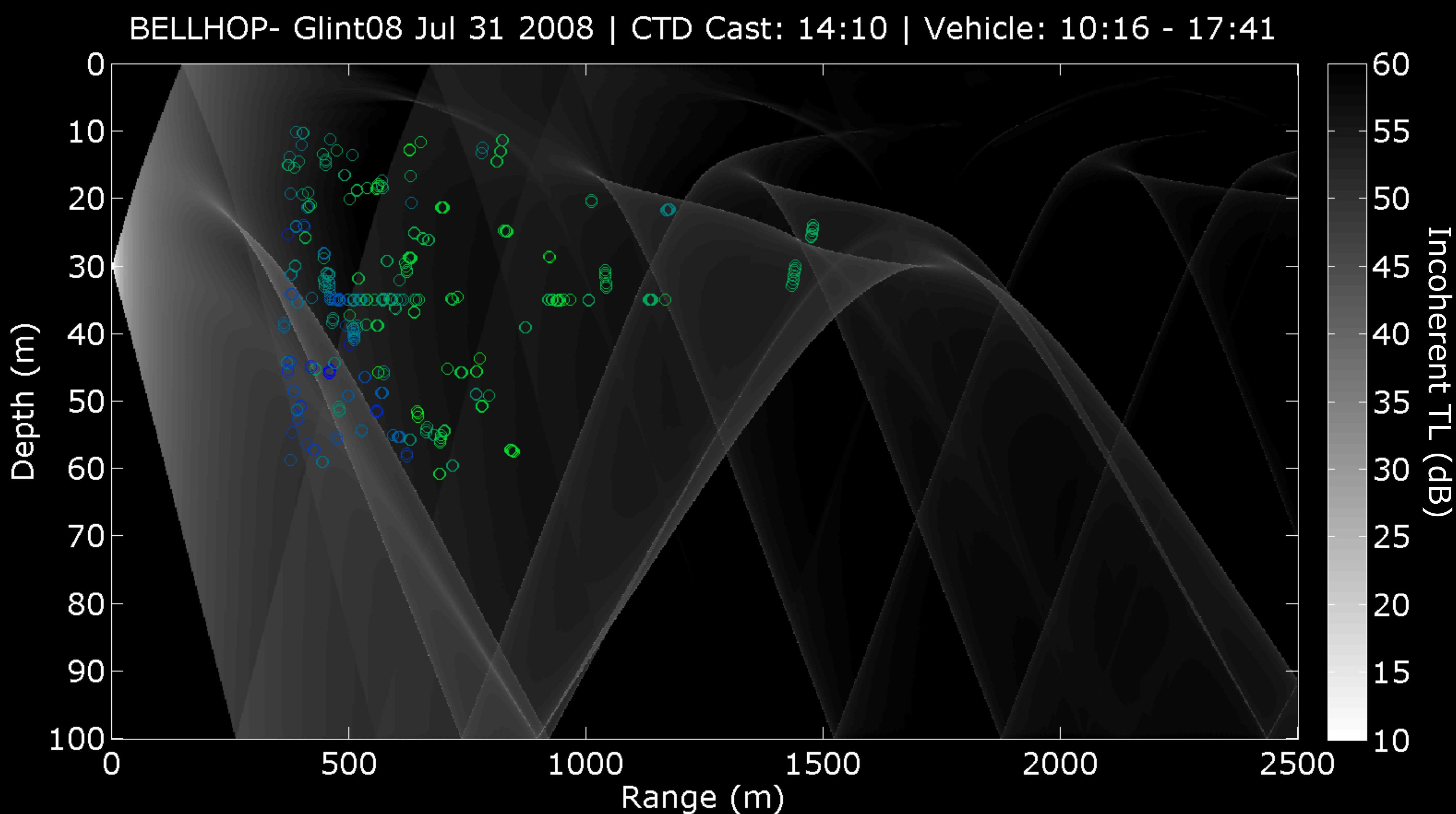
Single ship cast acceptable approximation

Ray Tracing | Modeled TL



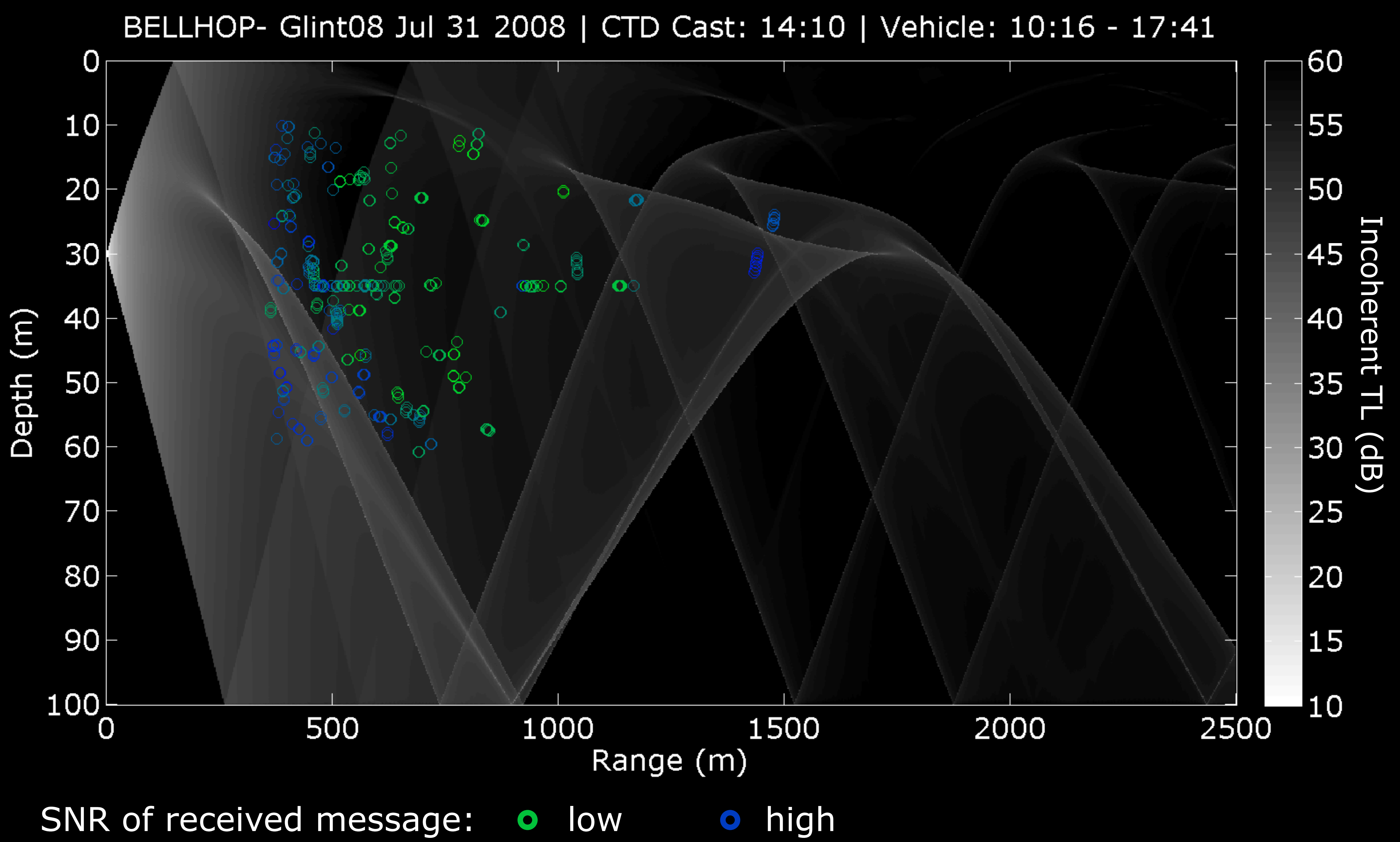
Incoherent transmission loss for R/V Alliance CTD profile (Jul 31 2008 16:10 UTC) from a 30 m source (buoy) in a 100 m homogenous (in range) waveguide.

SNR (before equalizing)



SNR of received message: low high

SNR (after equalizing)



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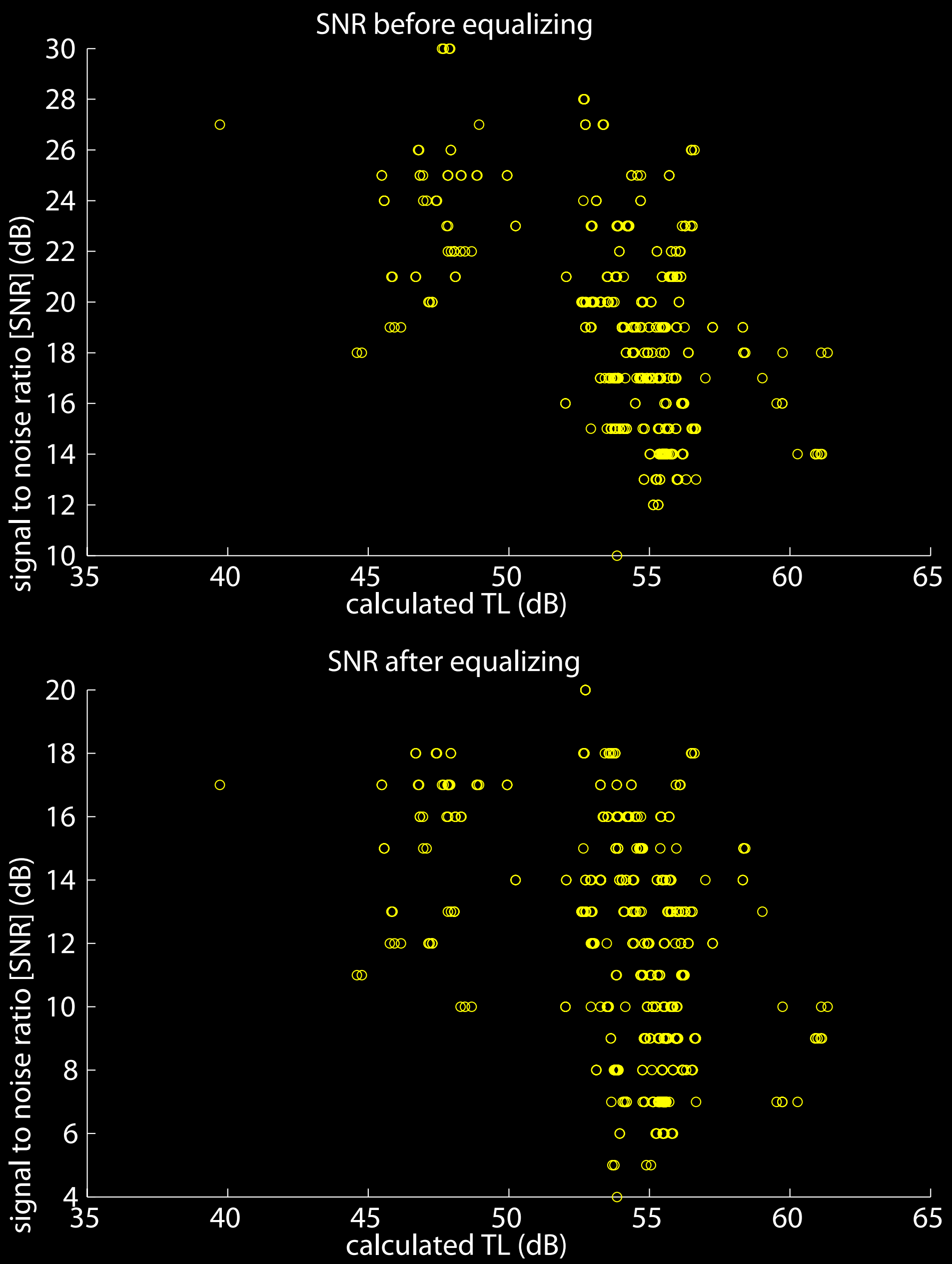
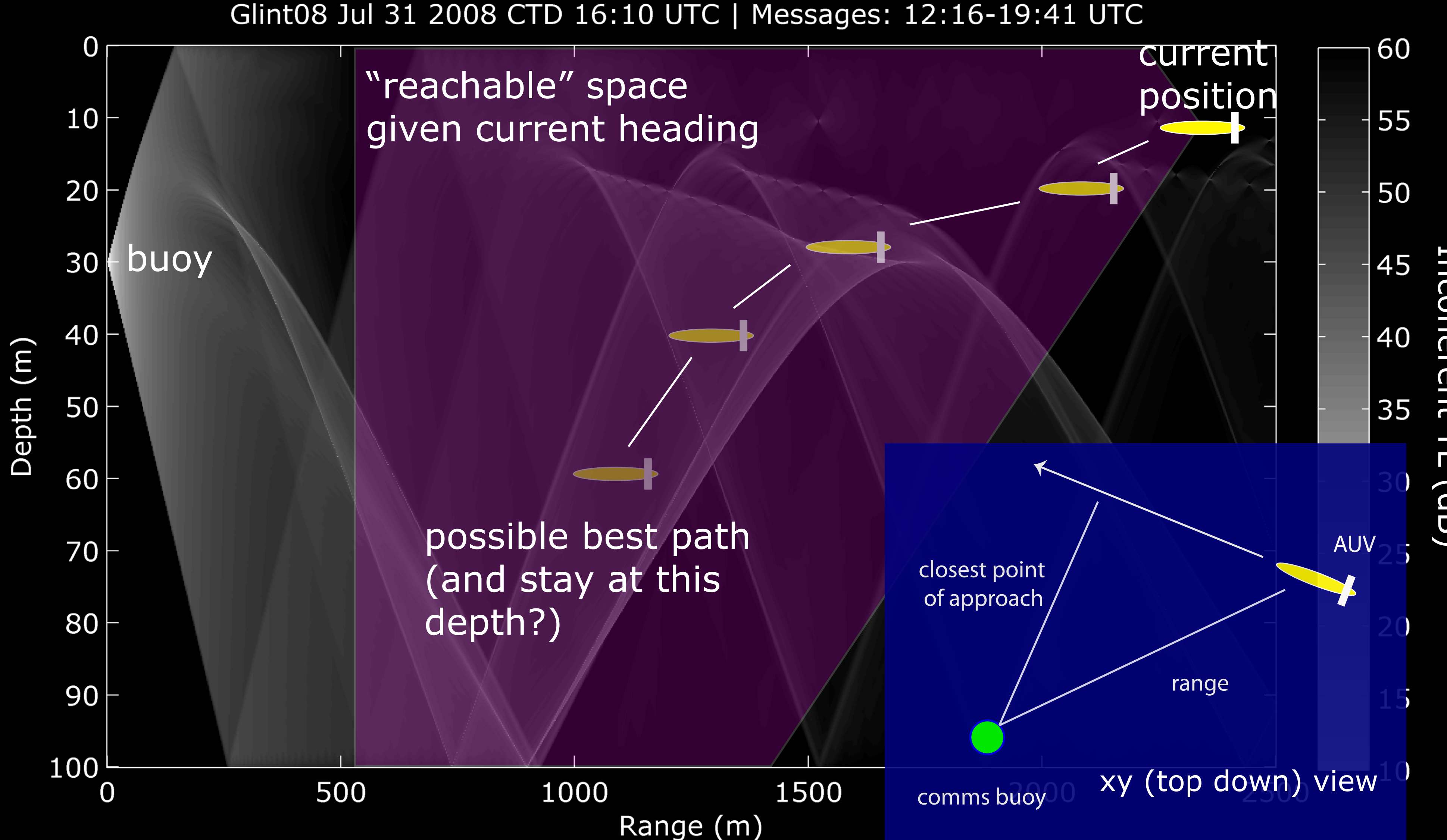
SNR versus Modeled TL



- Expect trend of lower SNR with increased TL
- Some trend: can hope to improve with better surface/ bottom modelling and fewer assumptions of homogeneity.

Acomms Improvement Behavior

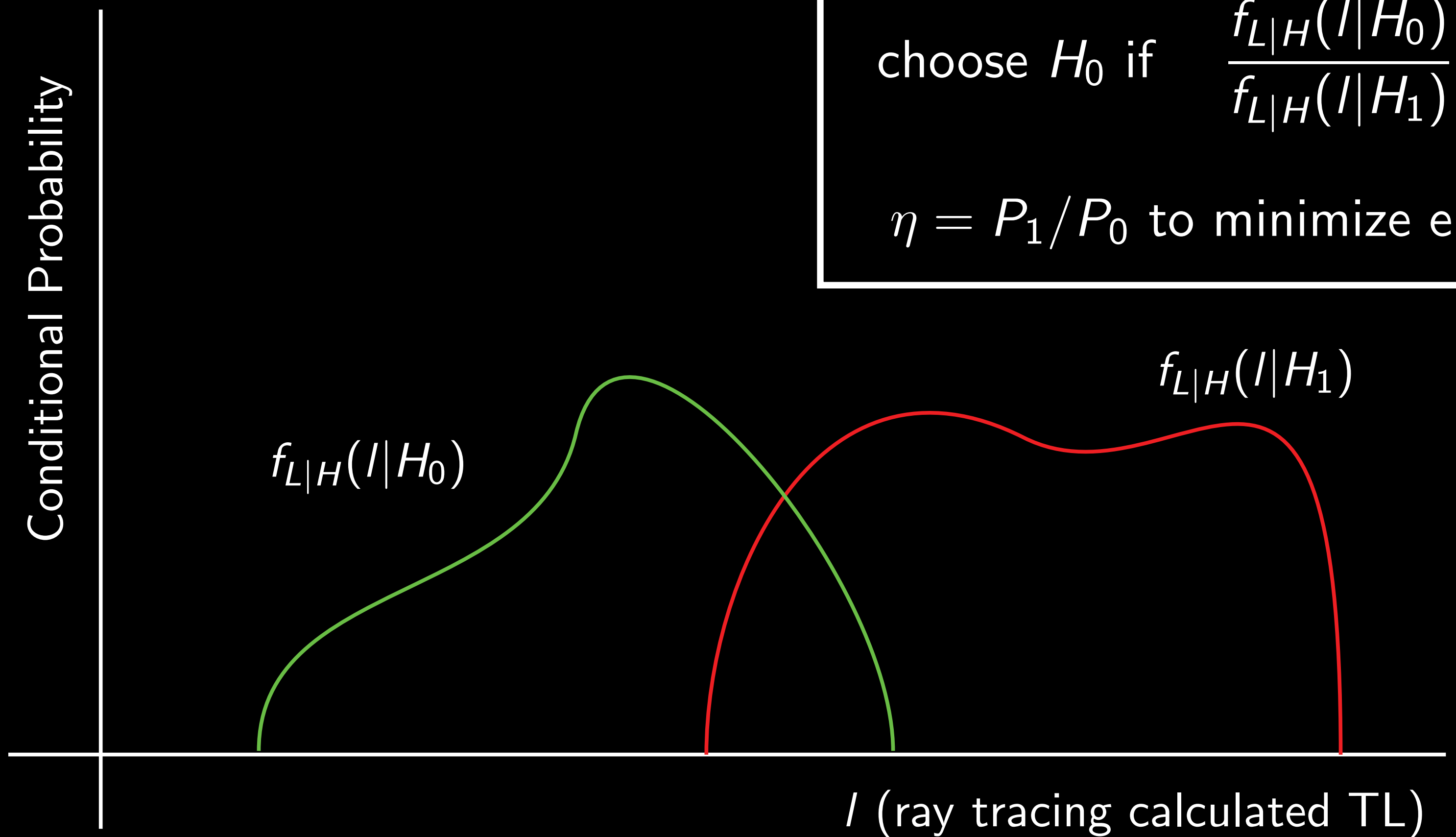


Given sound velocity profile and position of receiving vehicle (or buoy), change depth to optimize placement in sound field.
currently being implemented, then test in simulation.

Hypothesis Testing

choose H_0 if $\dfrac{f_{L|H}(l|H_0)}{f_{L|H}(l|H_1)} > \eta$

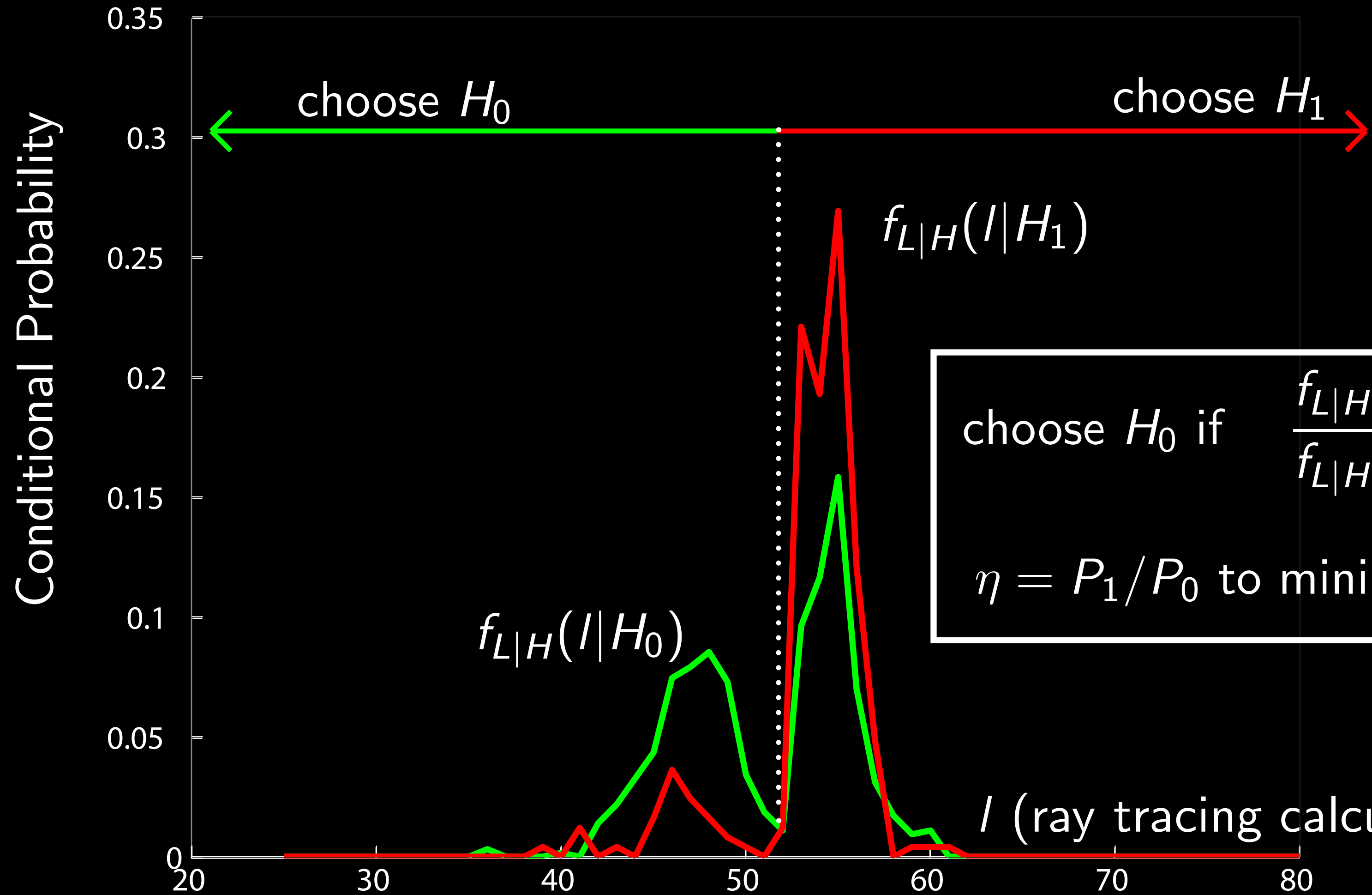
$\eta = P_1/P_0$ to minimize error.



Want to "decide" before sending a message whether it will be received

- hypothesis 0: message will be received
- hypothesis 1: message will be dropped

Hypothesis Testing | Glint08 Jul 31



choose H_0 if $\quad \dfrac{f_{L|H}(l|H_0)}{f_{L|H}(l|H_1)} > \eta$

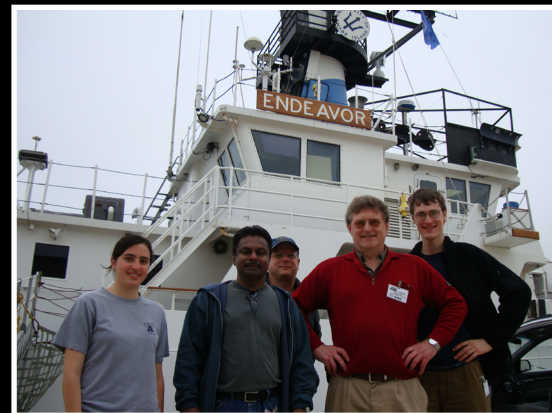
$\eta = P_1/P_0$ to minimize error.

Given choice of hypothesis:

- transit to depth within 'H_0' regime or
- choose different rate (with different probabilities)

Acknowledgments

- LAMSS: H. Schmidt, A. Balasuriya, K. Cockrell, R. Lum, S. Petillo



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