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Single hydrophone multipath ranging: Dealing with missing and spurious arrivals

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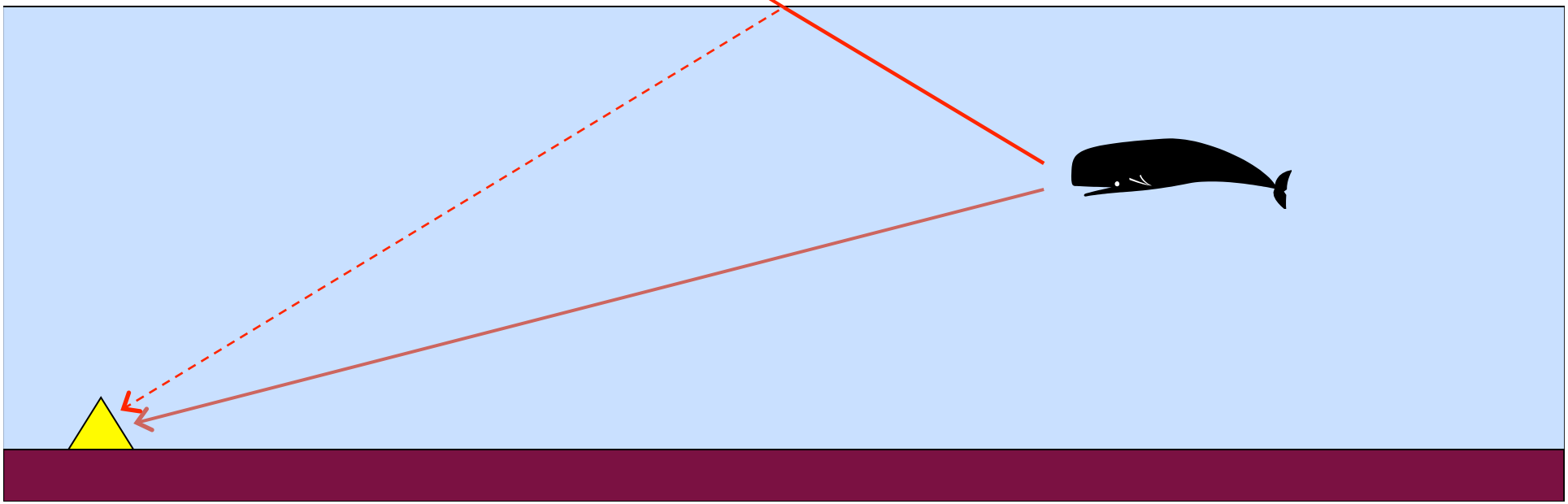
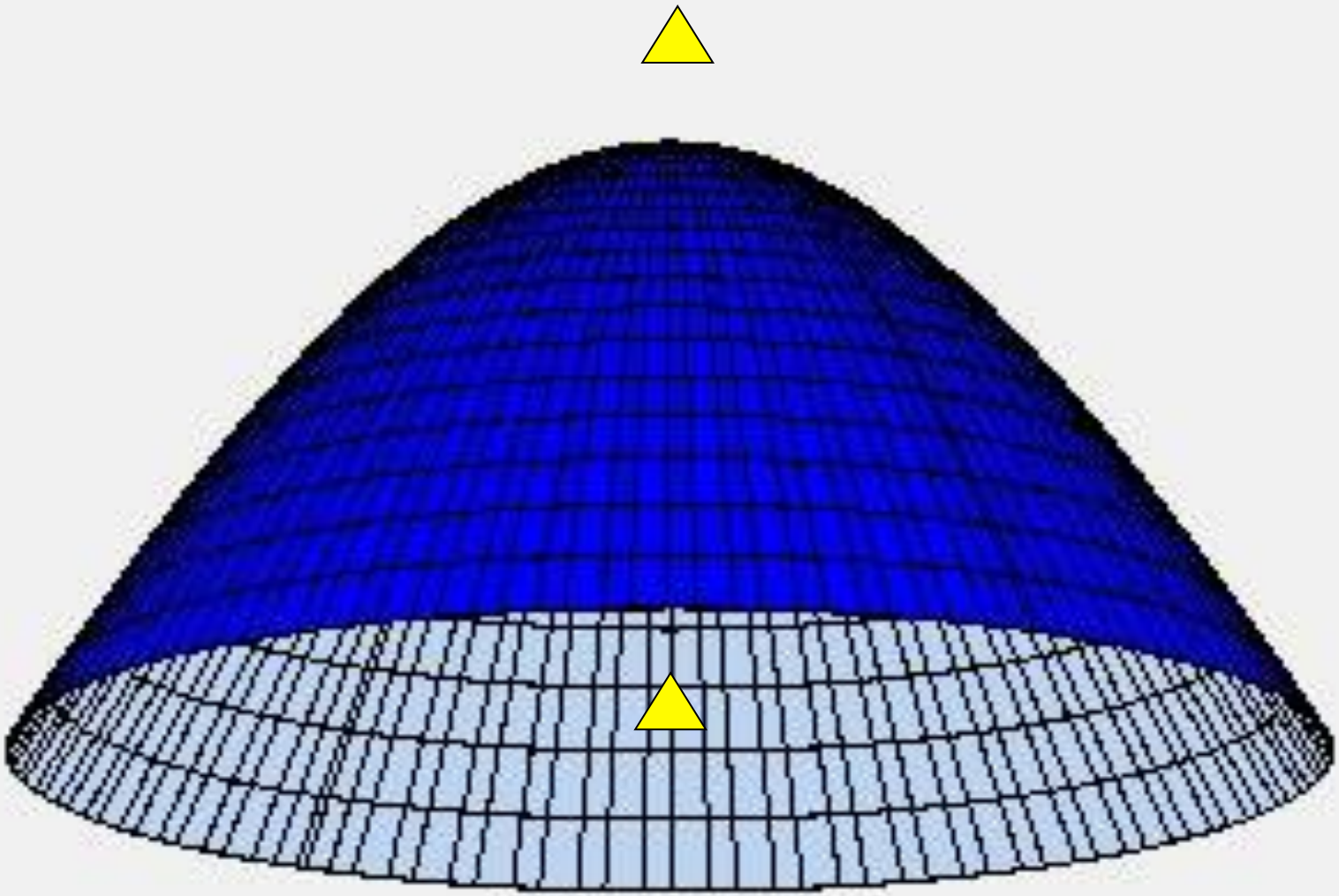
Single hydrophone localization

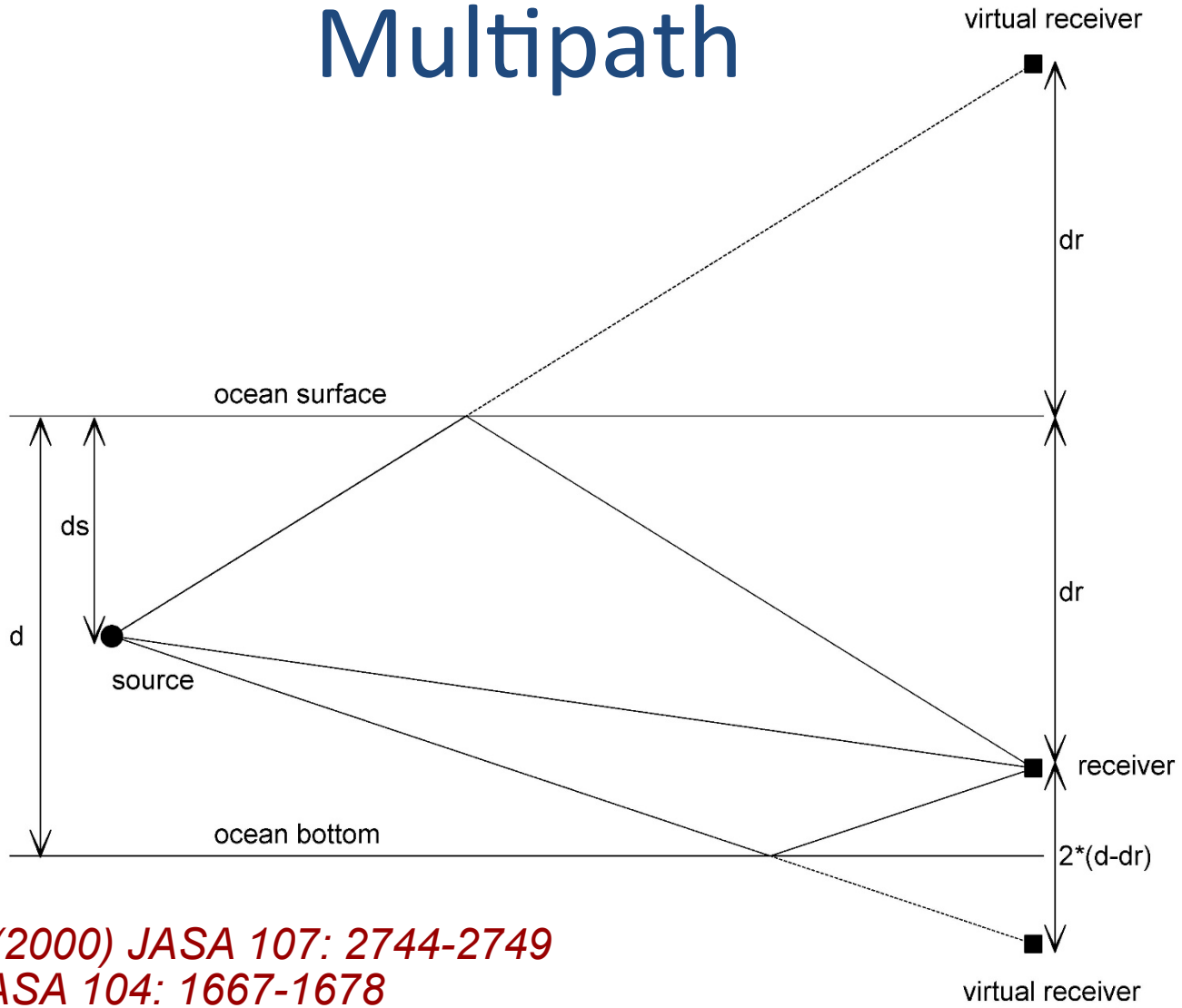
- Data recorded on a single hydrophone can (sometimes) be used to estimate animal location
  - Range + depth for a flat bottom
  - 3D location for azimuth dependent bathymetry
- Impulsive (or highly stereotyped), high-frequency vocalizations
- Treat reflection at arriving at a “virtual receiver”



“Virtual” receiver



Multipath



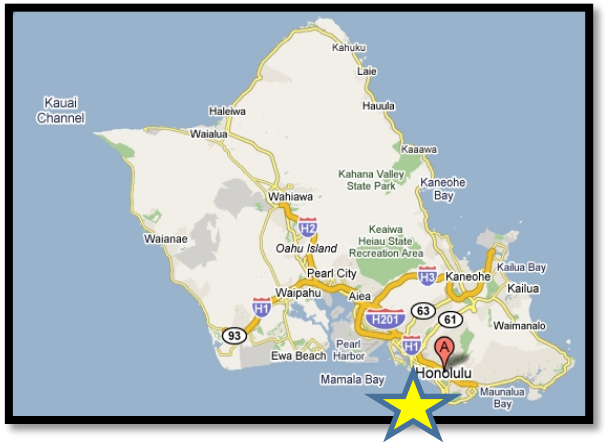
Aubauer et al (2000) JASA 107: 2744-2749
Cato (1998) JASA 104: 1667-1678
Thode et al (2002) JASA 112: 308-321
Nosal & Frazer (2006) Appl. Acoust. 87: 1187-1201
Tiemann et al. (2007) JASA 120: 2355-2365

Motivation

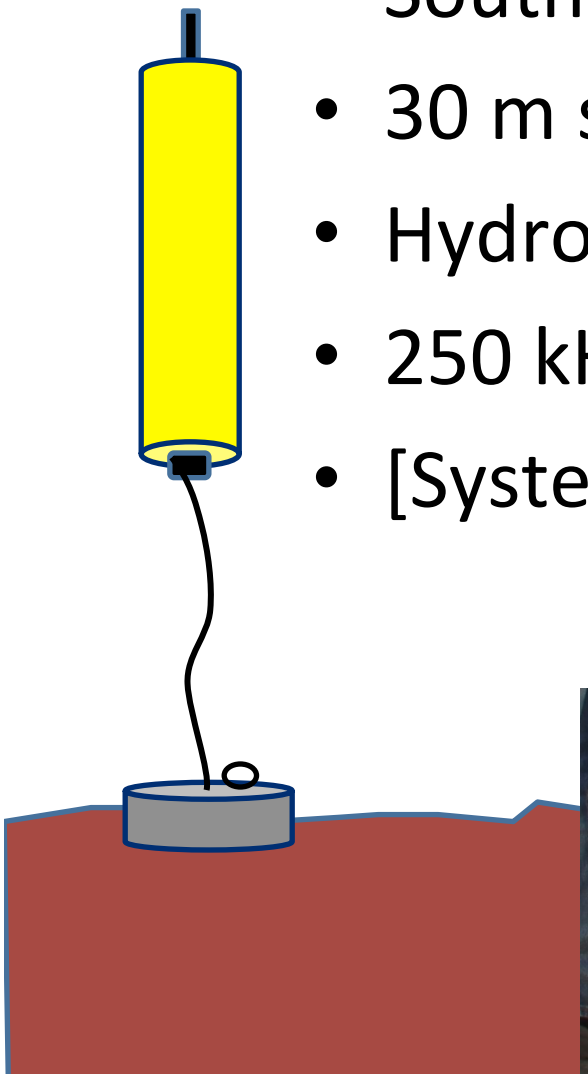
- Most existing methods require that multipath arrivals are detected and identified/classified (as direct, bottom-reflected, surface-reflected etc).
- This can be difficult & highly time/user-intensive
  - Incorrectly labeled arrivals
  - False arrivals (e.g. with multiple animals)
  - Missed arrivals (e.g. due to directionality)
- My goal:

Automation & robustification!

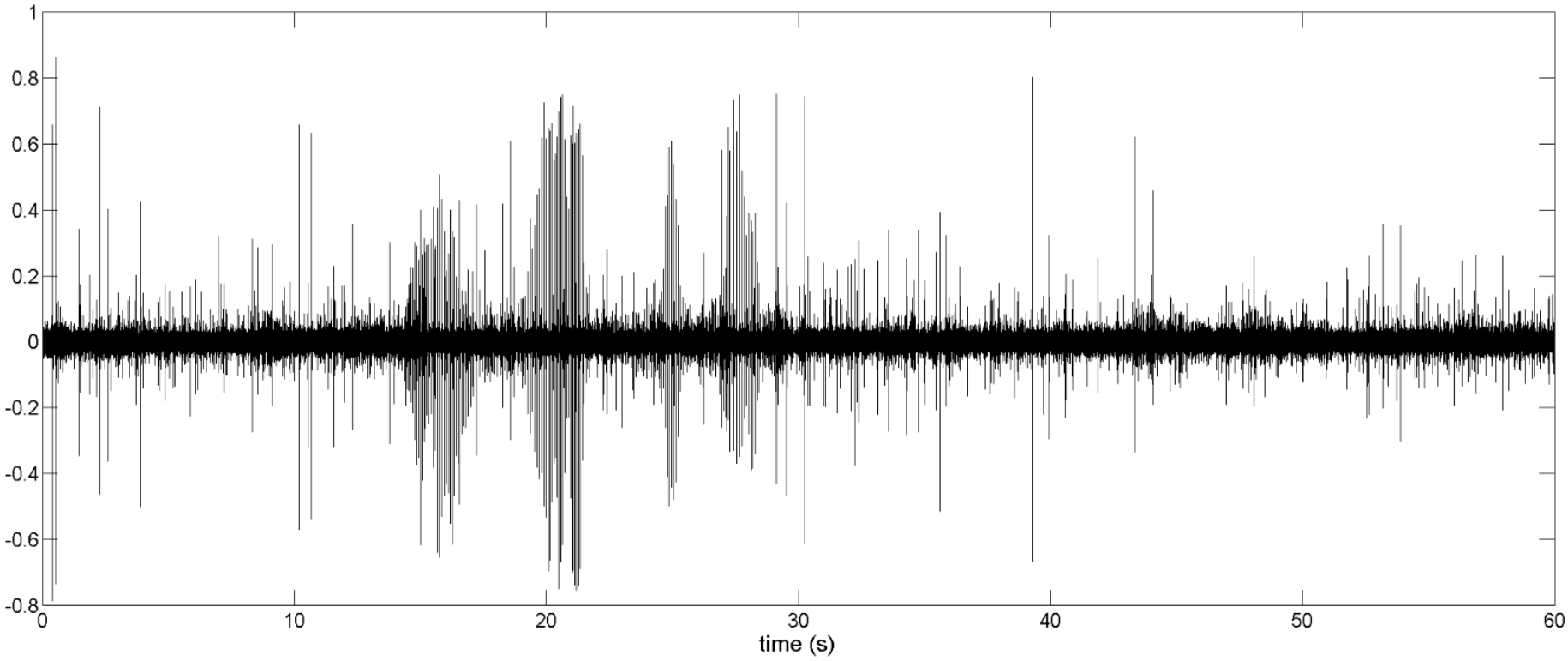
Data



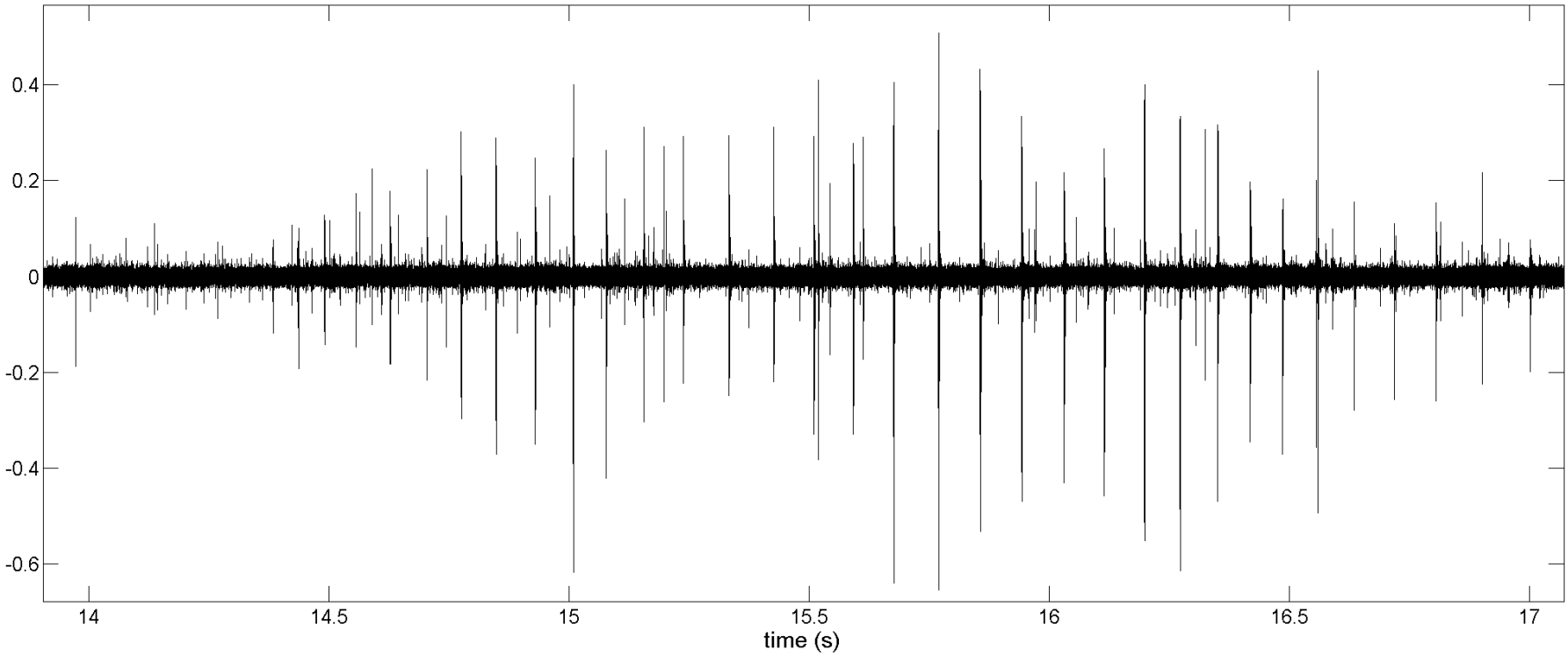
- South of Honolulu, Oahu
- 30 m seafloor depth
- Hydrophone tethered 5m off seafloor
- 250 kHz sampling rate
- [System details in Tom Fedenczuk's talk]



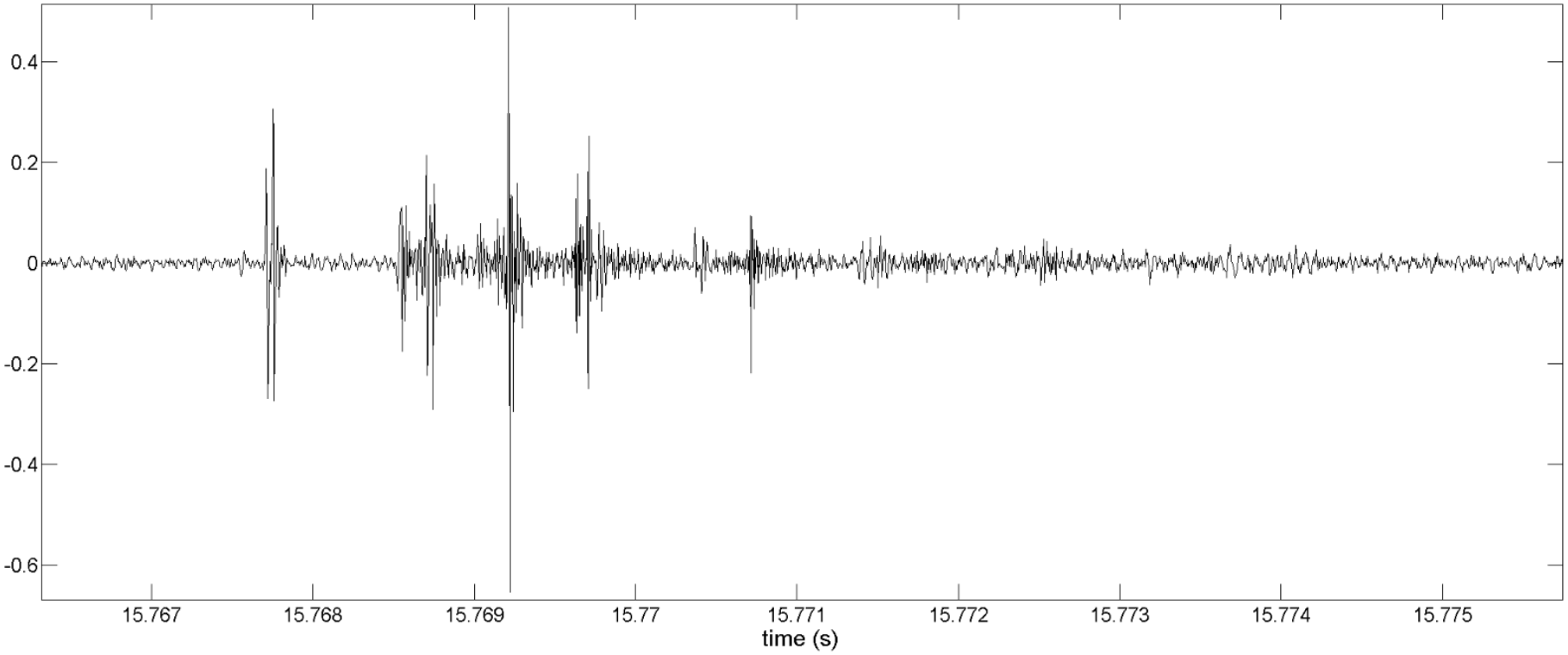
Data



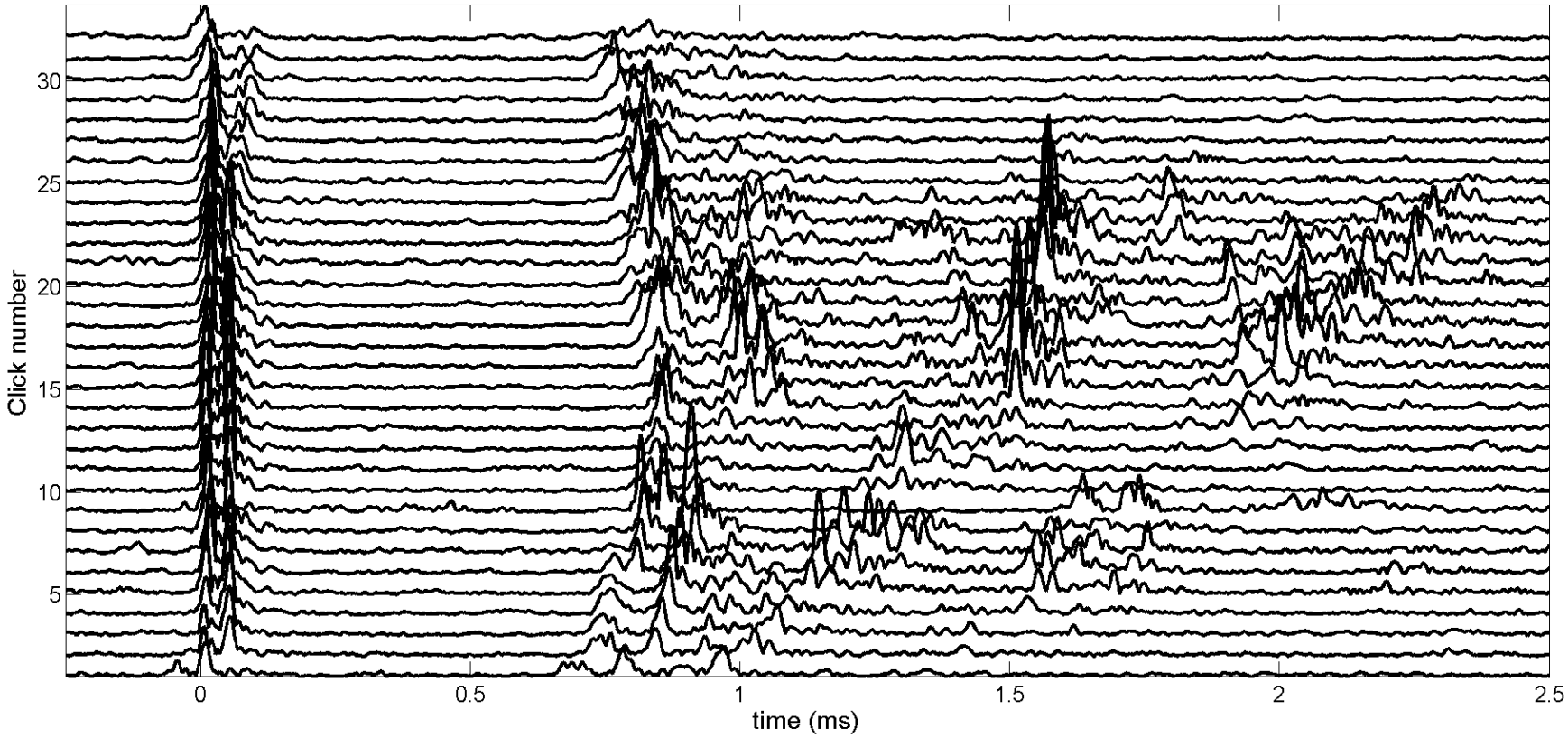
Data

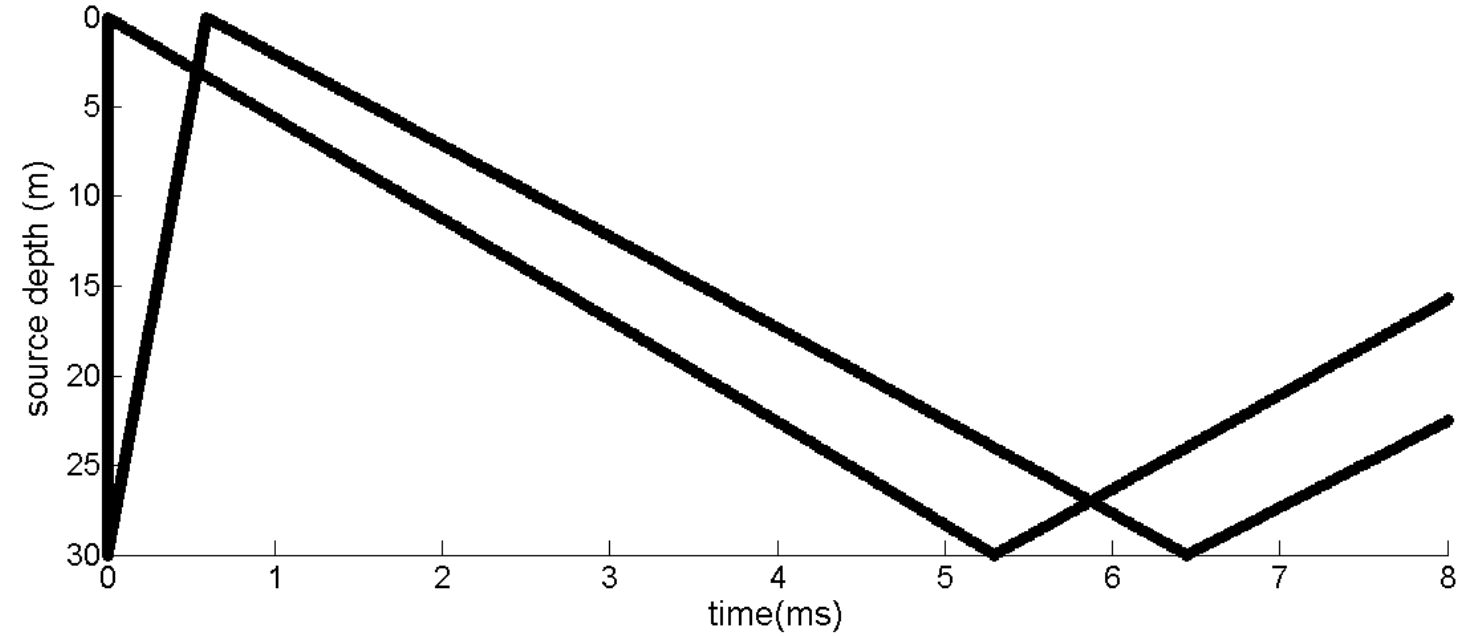


Data

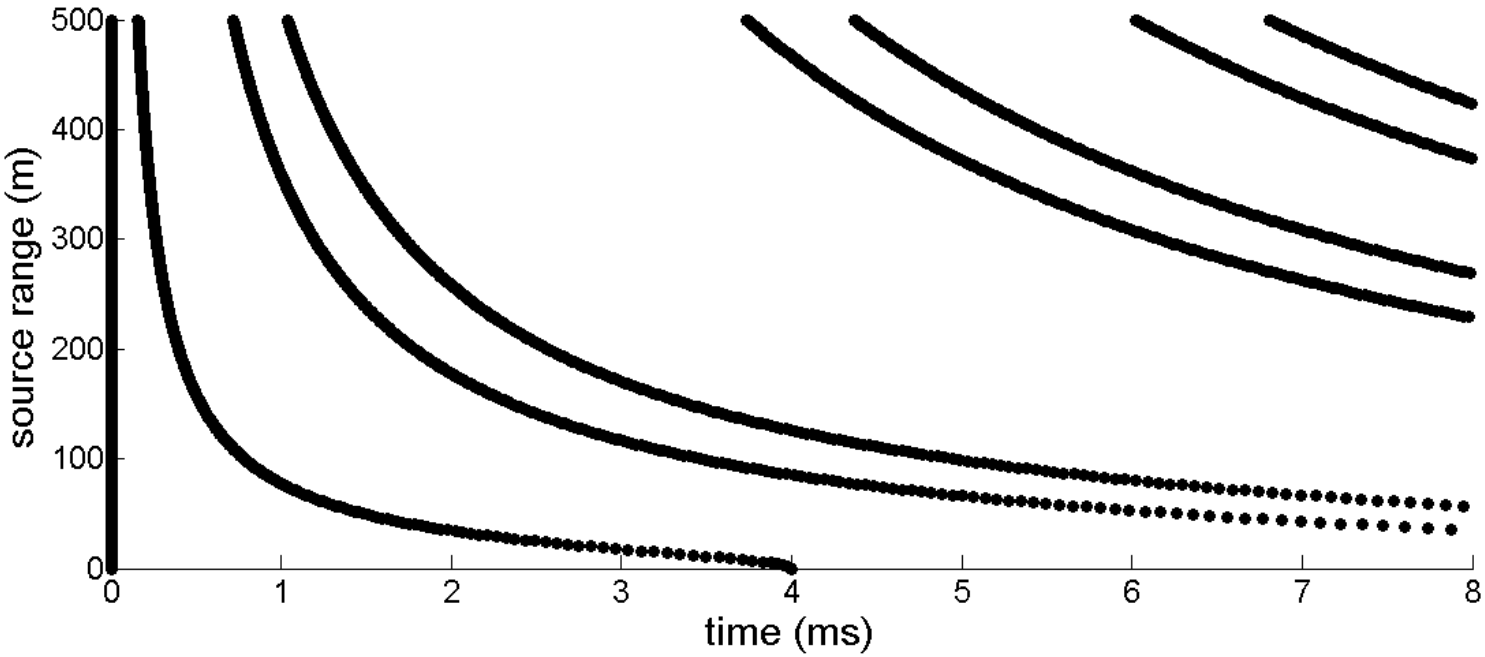

0.4
0.2
0
-0.2
-0.4
-0.6
15.767
15.768
15.769
15.77
15.771
15.772
15.773
15.774
15.775
time (s)

Click train





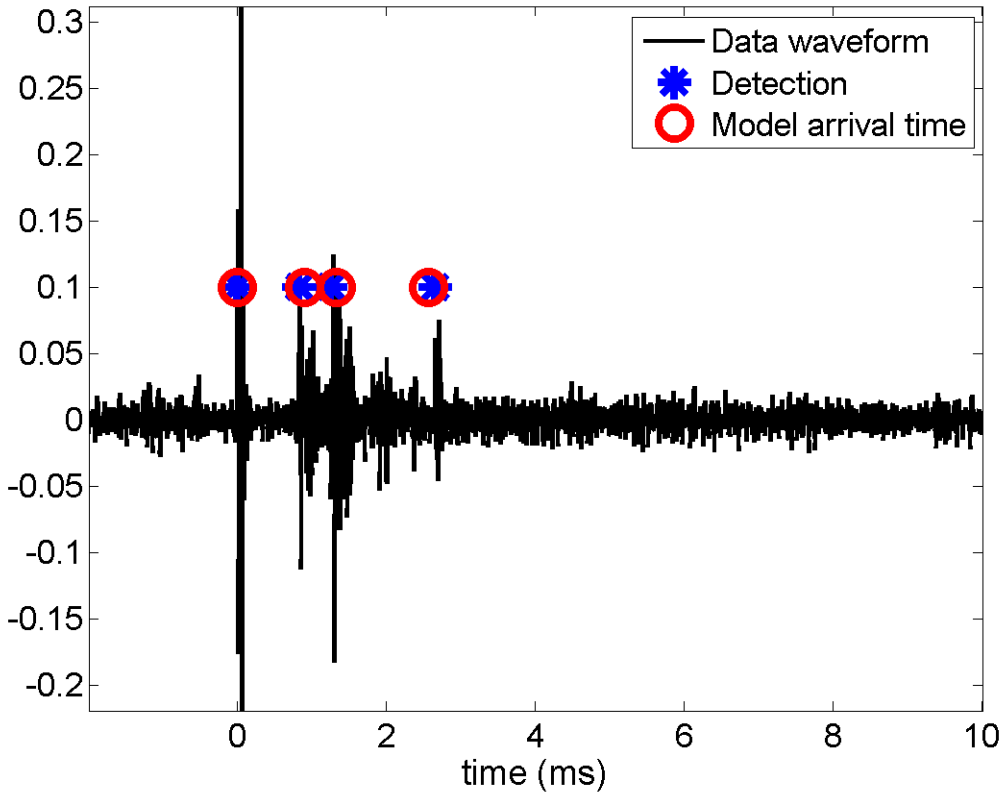
200 m range

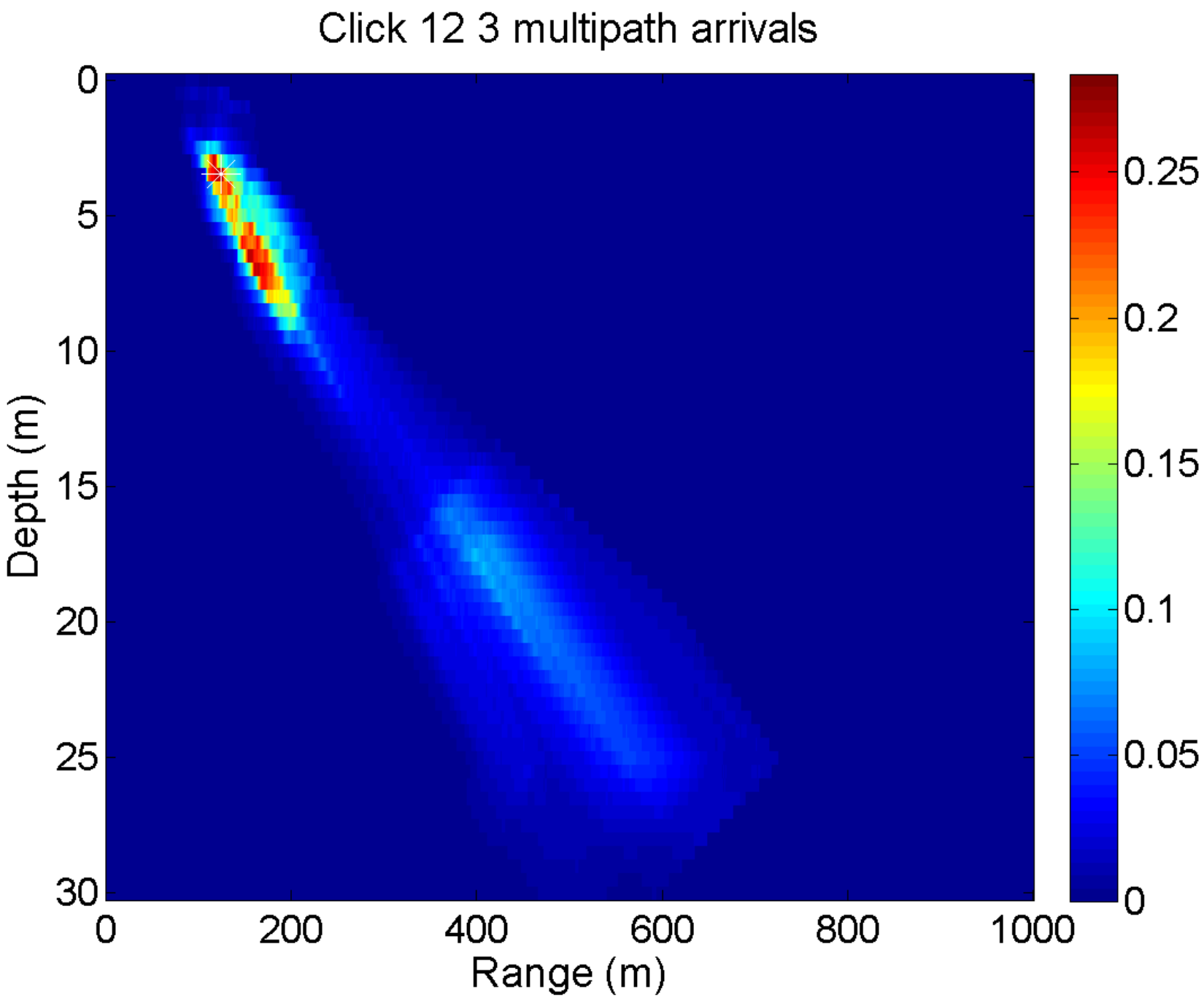


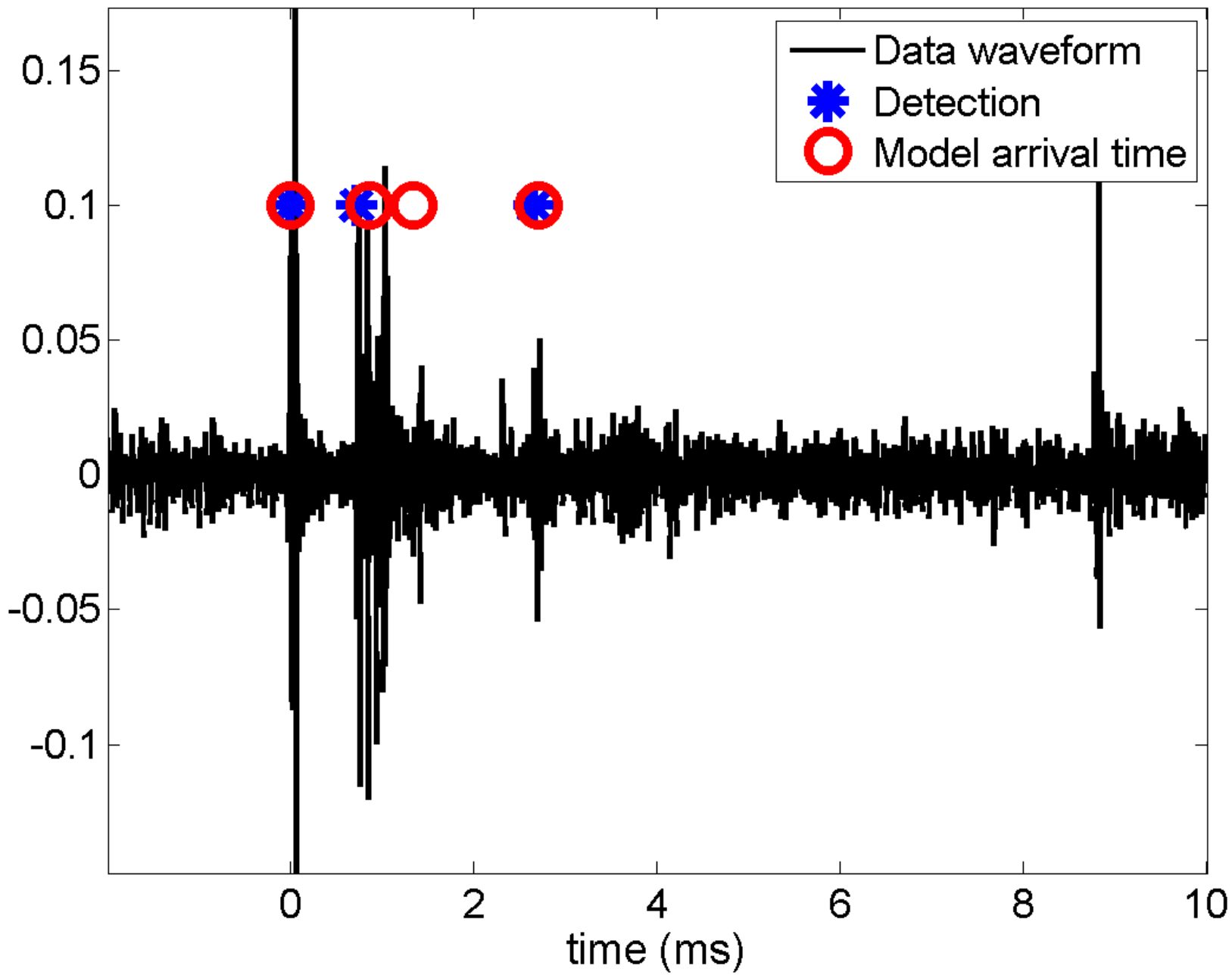
10 m depth

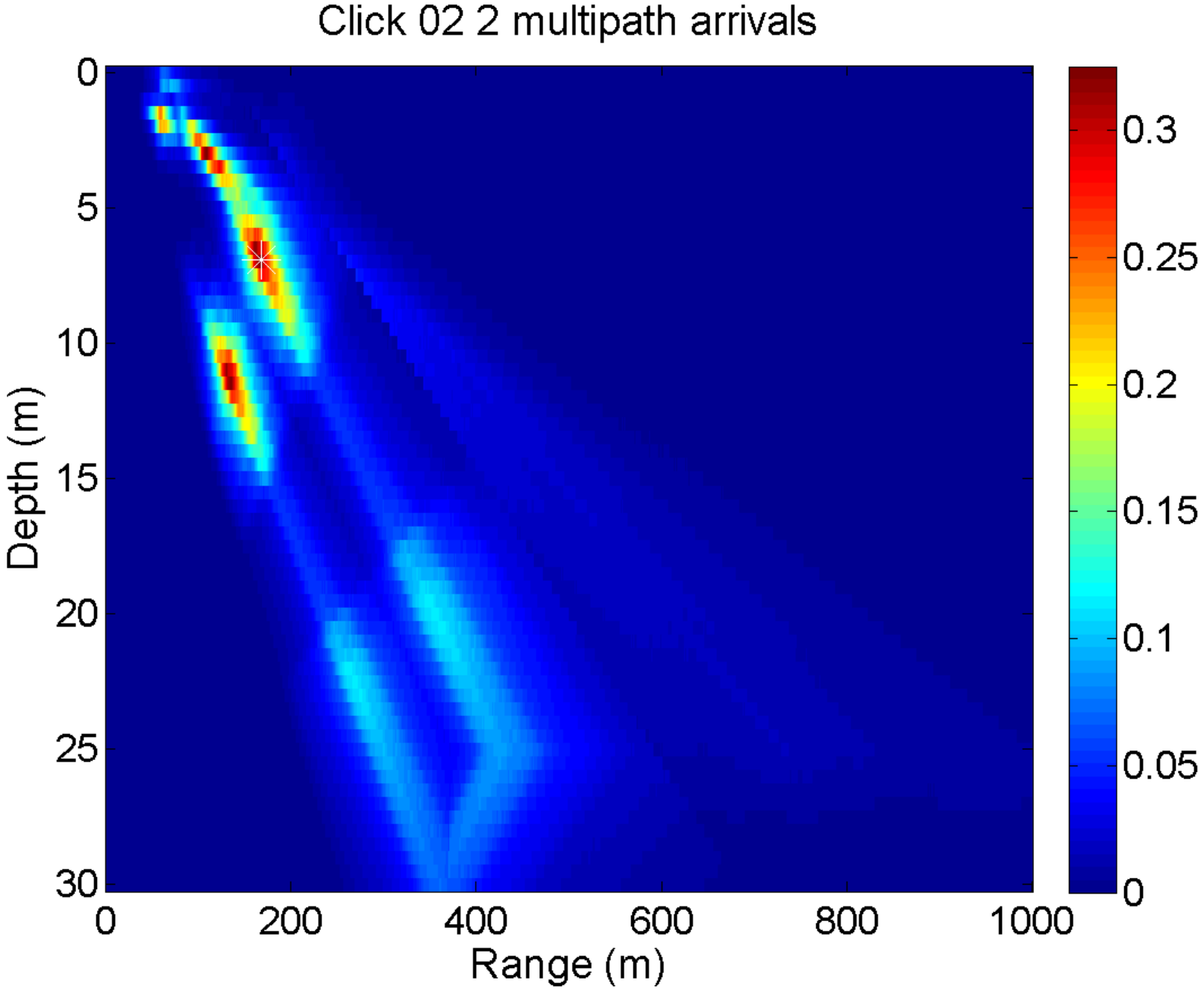
Theory

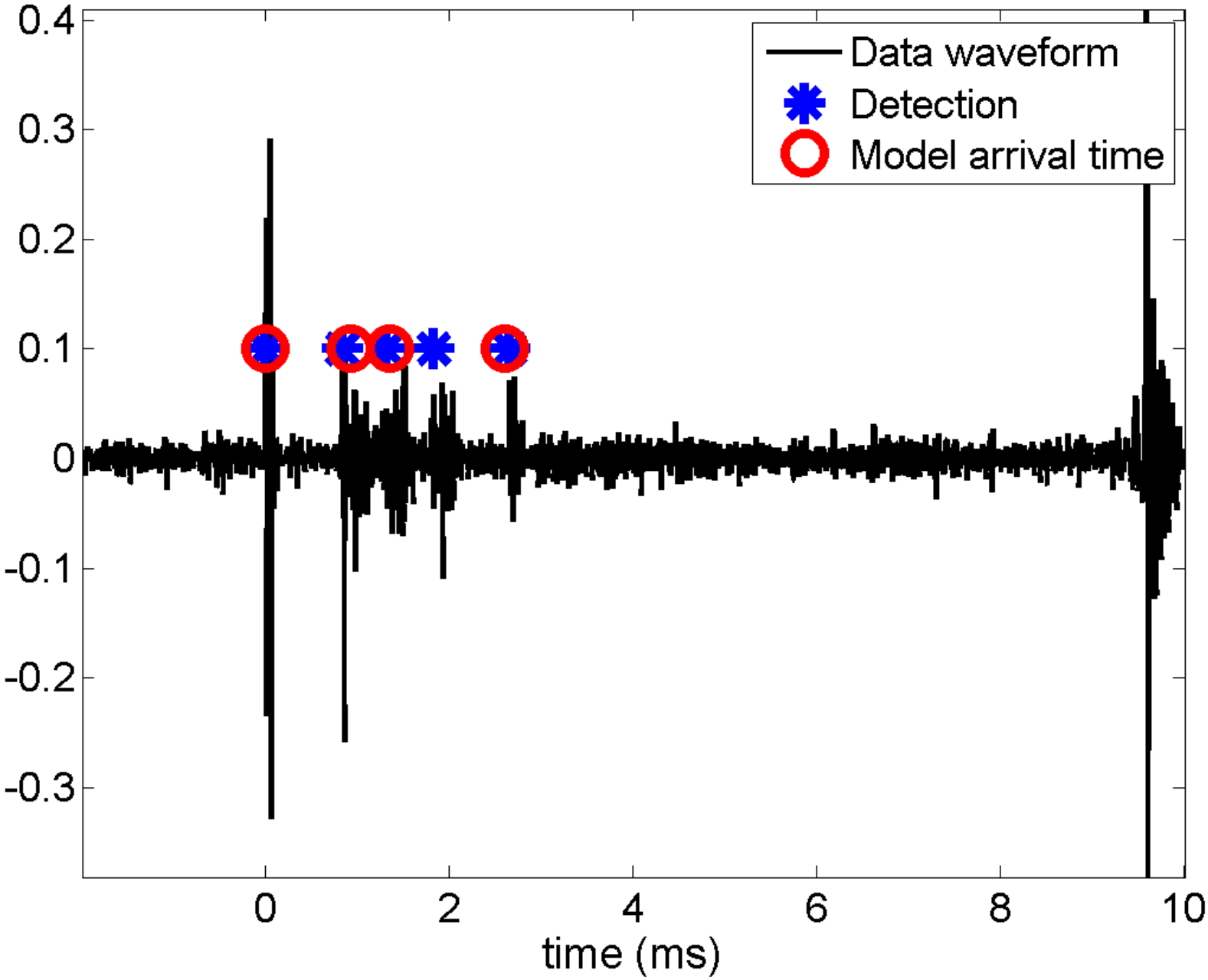
$$AS(r,d) = \prod_{\max 4 \, i} \left\{ \max_j \left[H(\Delta \hat{t}_j(r,d)) \, e^{-\frac{1}{2\sigma}(\Delta t_i - \Delta \hat{t}_j(r,d))^2} \right] \right\}$$

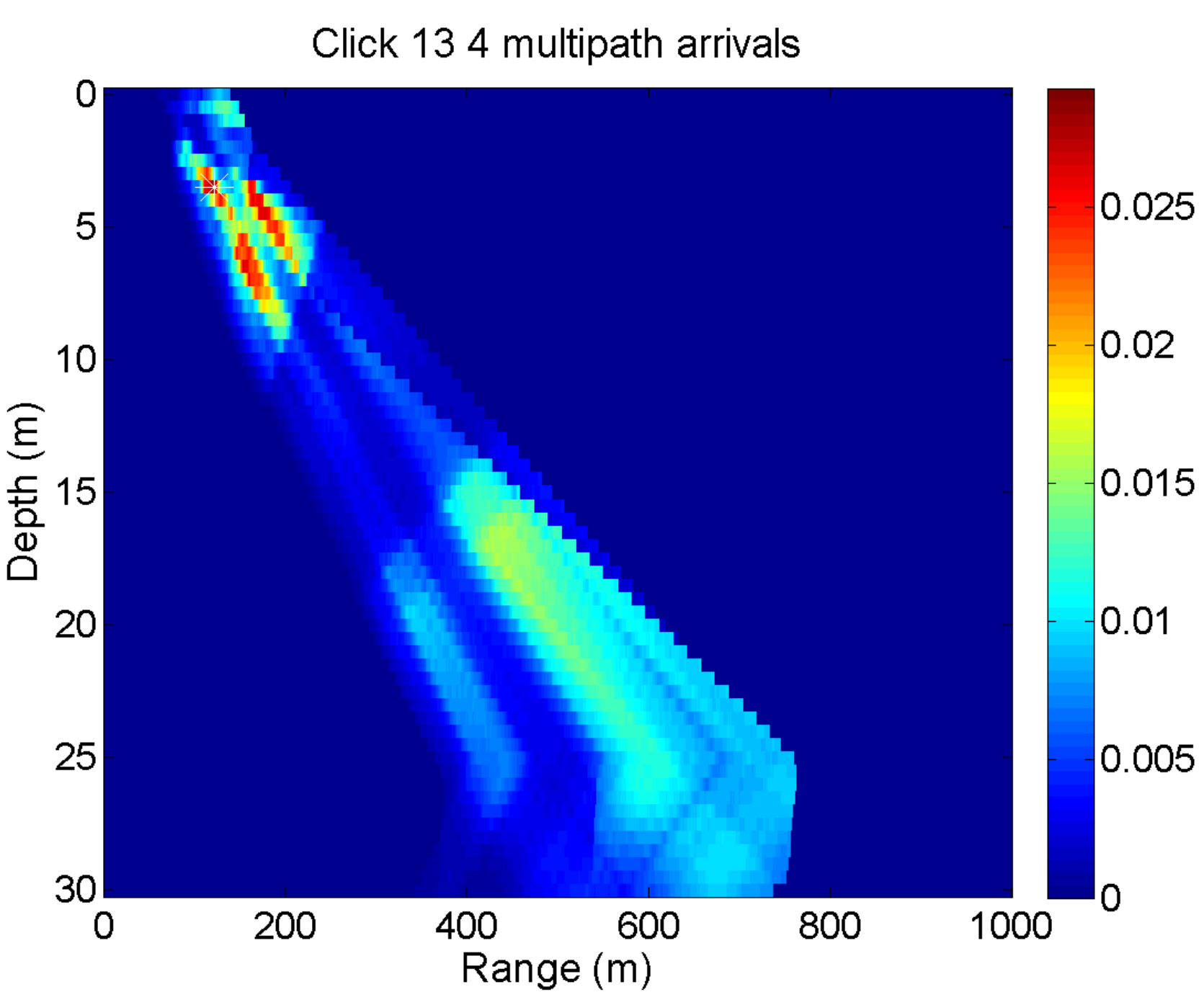


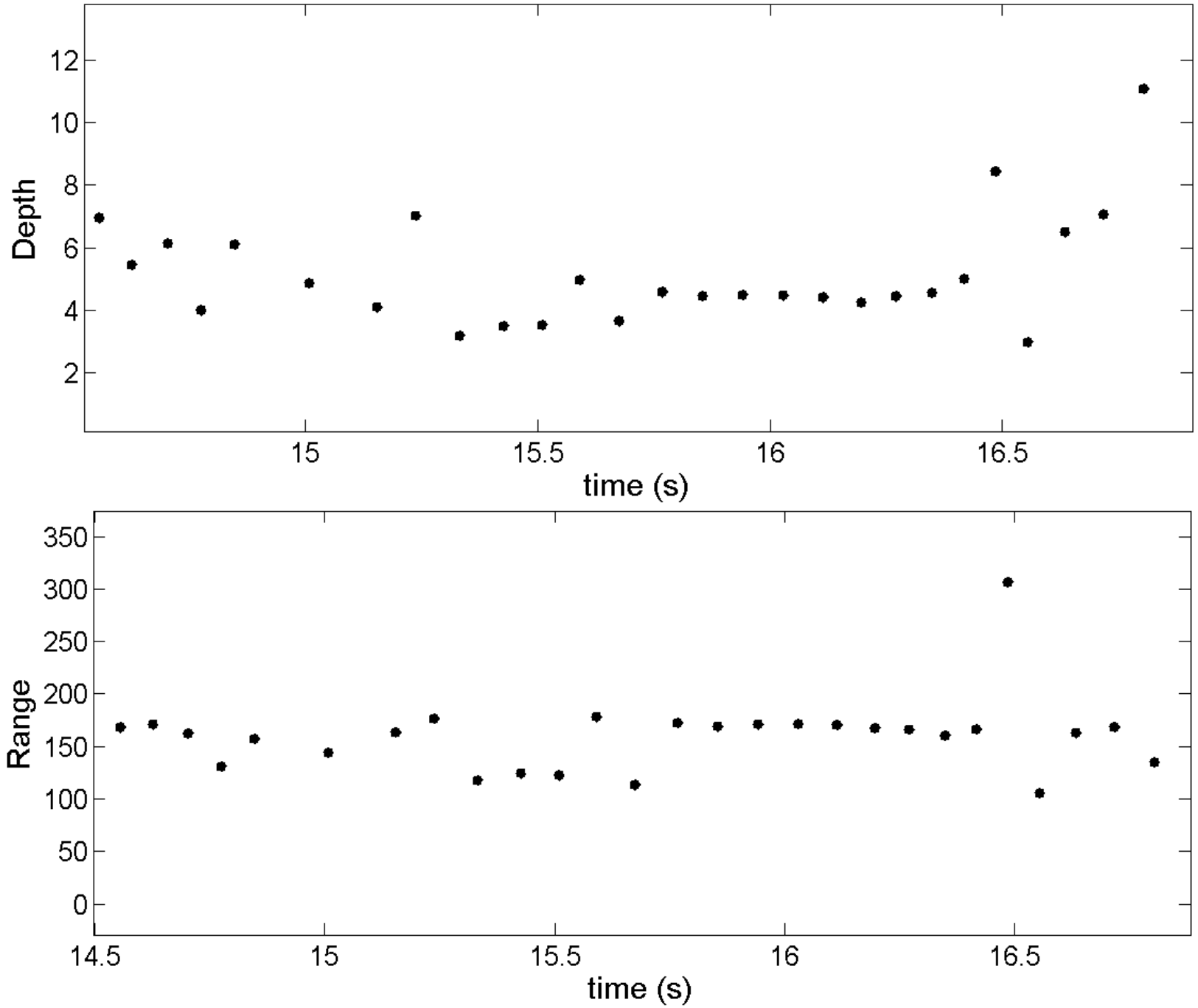

Click 12 3 multipath arrivals
Depth (m)
0
5
10
15
20
25
30
0
200
400
600
800
1000
Range (m)
0.25
0.2
0.15
0.1
0.05
0


Data waveform
Detection
Model arrival time
0.15
0.1
0.05
0
-0.05
-0.1
0
2
4
6
8
10
time (ms)


Click 02 2 multipath arrivals
Depth (m)
0
5
10
15
20
25
30
0
200
400
600
800
1000
Range (m)
0.3
0.25
0.2
0.15
0.1
0.05
0


Data waveform
Detection
Model arrival time
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
2
4
6
8
10
time (ms)


Click 13 4 multipath arrivals
Depth (m)
0
5
10
15
20
25
30
0
200
400
600
800
1000
Range (m)
0.025
0.02
0.015
0.01
0.005
0

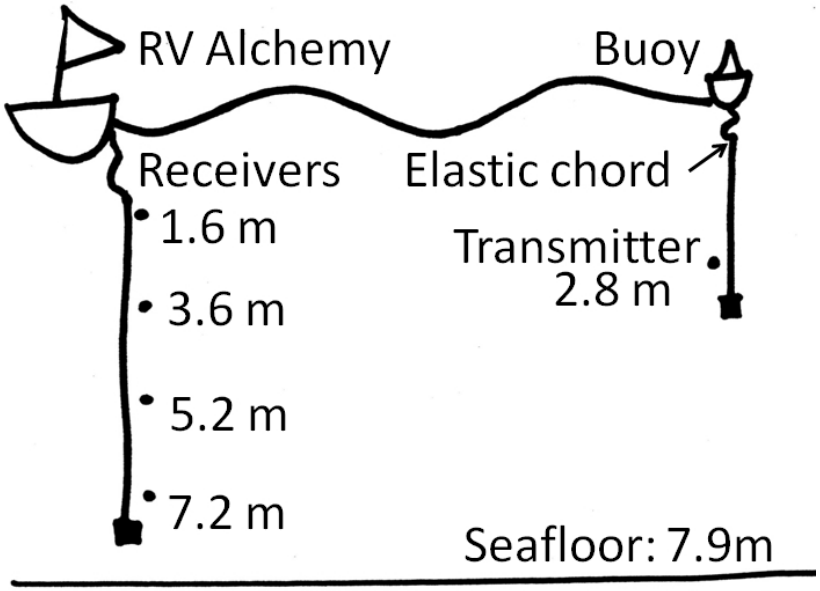

Depth
12
10
8
6
4
2
15
15.5
16
16.5
time (s)
Range
350
300
250
200
150
100
50
0
14.5
15
15.5
16
16.5
time (s)

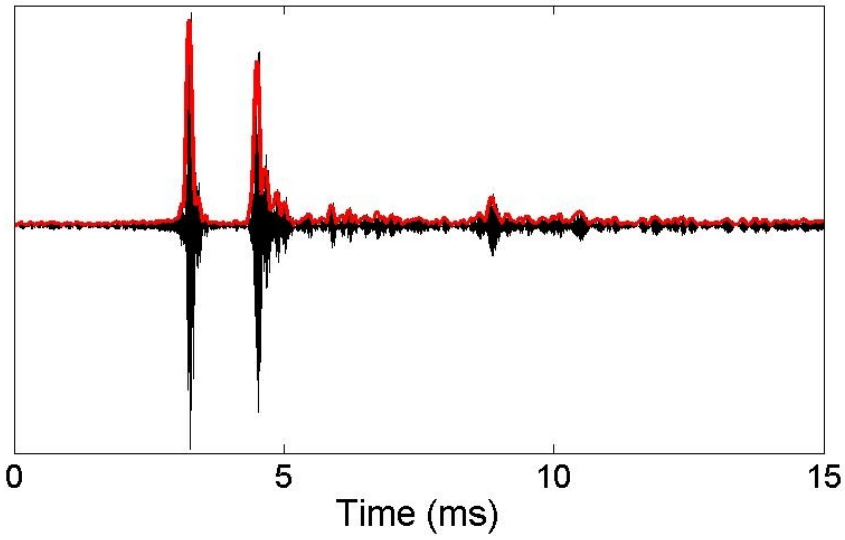
Thank you

- Funding
  - Office of Naval Research (ONR), Mike Weise & Dana Belden
- Engineering/hardware
  - Teknologic Engineering LLC

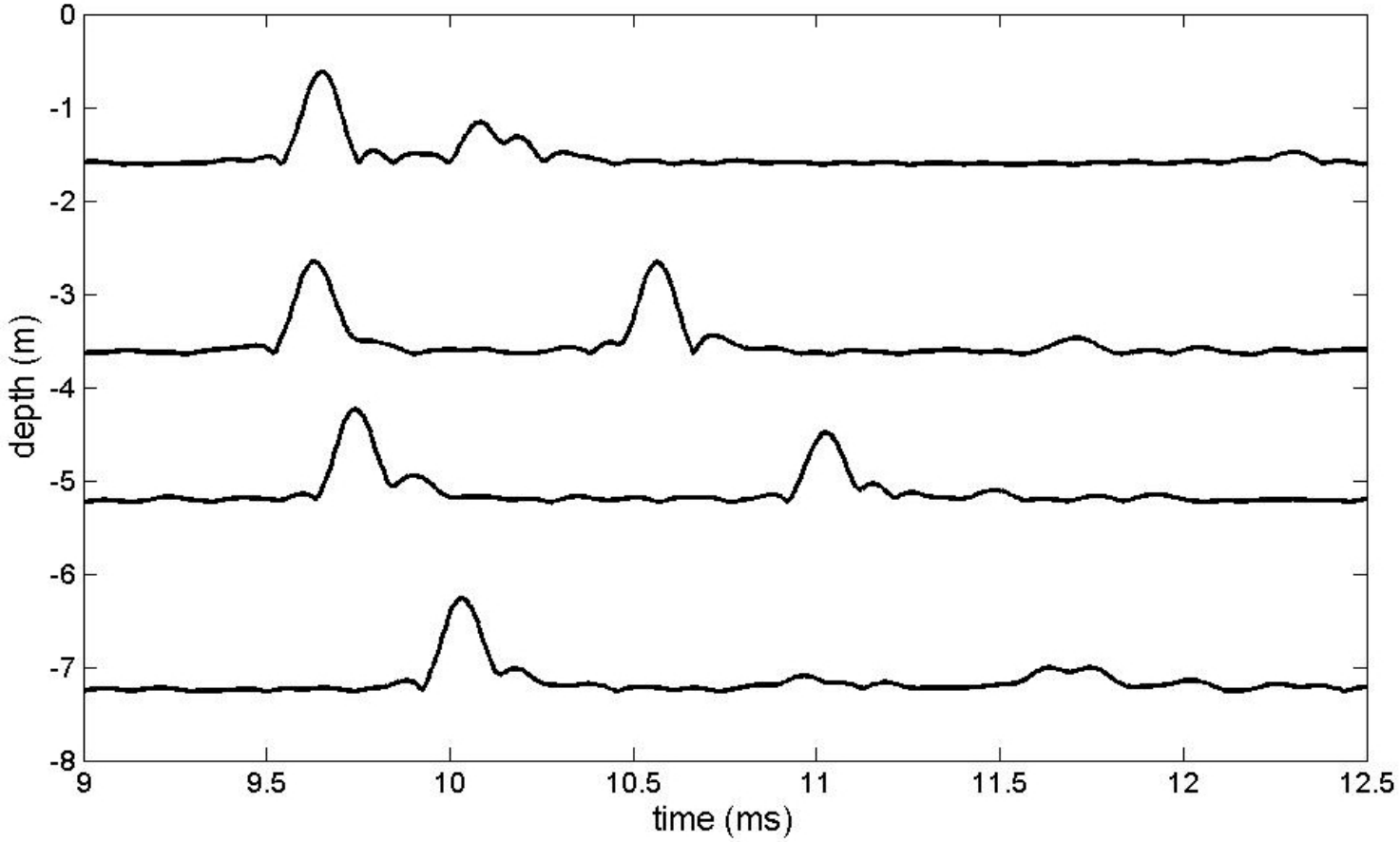
“Controlled” experiment

- Sea state:
  - 9.7s dominant period swell
  - 0.75m significant wave height
  - 5 knot winds
- Sound speed almost constant at 1536 m/s
- Transmit signals:
  - FW sweeps, m-sequences
  - 10-40 kHz
  - ~90dB re. 1µPa
- Cross correlate transmit signals with (filtered) received signals ➔ Impulse

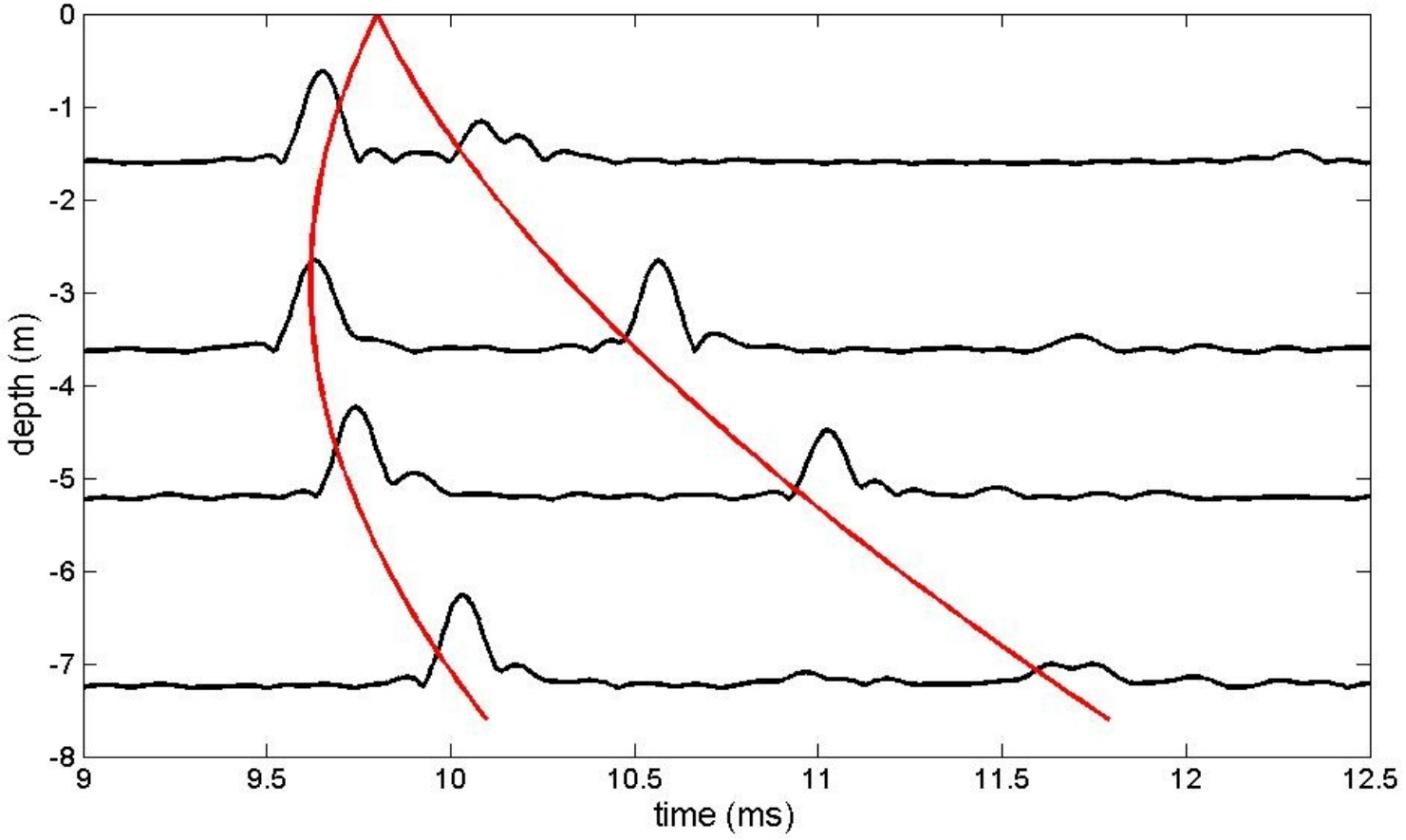




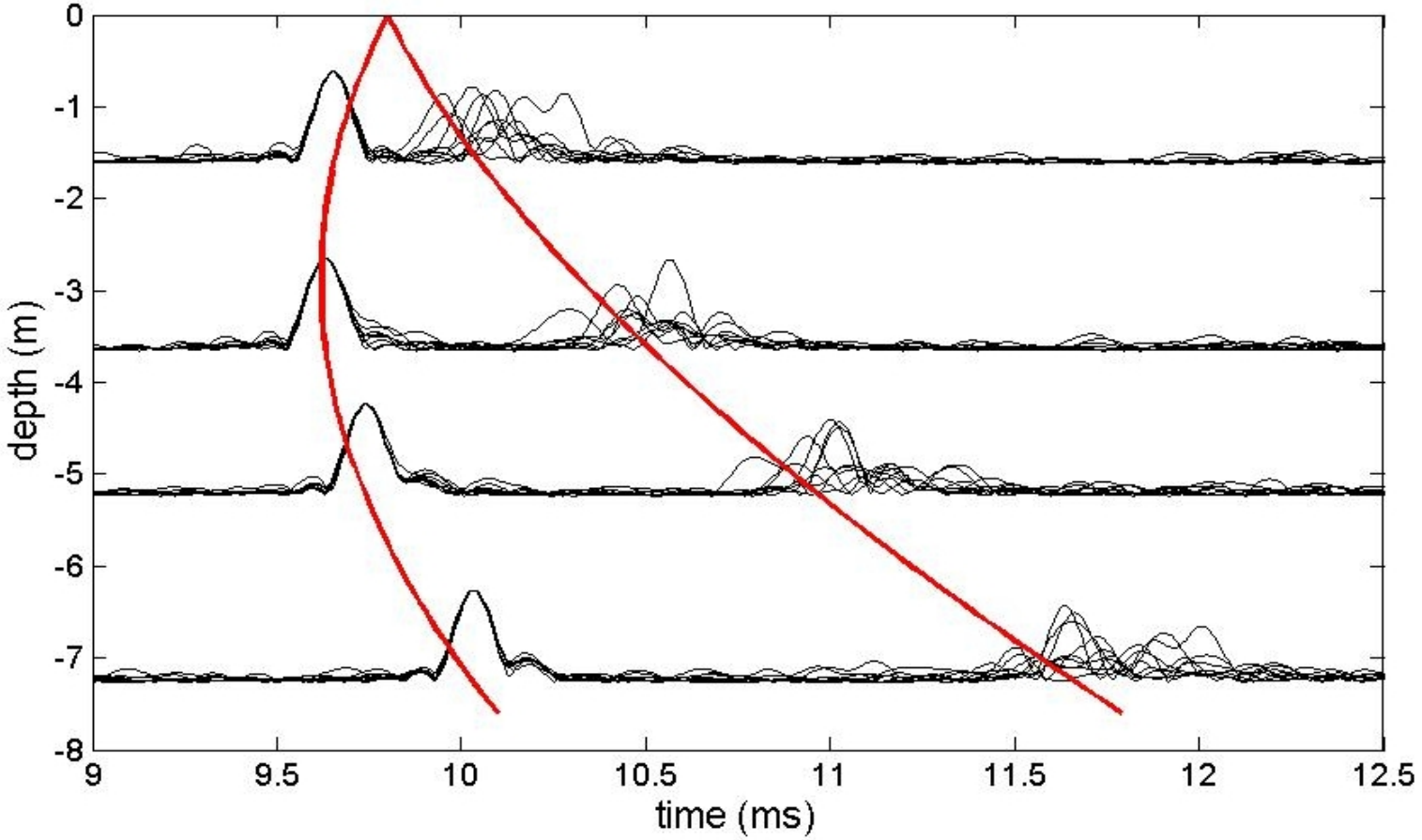
“Controlled” experiment



“Controlled” experiment



“Controlled” experiment



- Surface reflections can vary rapidly and significantly in arrival time, shape, and magnitude due to dynamic surface wave-field and wave focusing