Short range acoustic propagation through non-linear internal waves

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Introduction

On August 18, mid-frequency acoustic transmission data were collected on a vertical array over a continuous 7-hour period at range 550 m.

The combination of acoustic frequency (1 to 10 kHz) and range (550 m) were expected to be useful for studying the effects of both *linear* and *non-linear* internal waves

Motivation

Linear internal waves often are modeled as a background random process introducing random fluctuations in the acoustic field.

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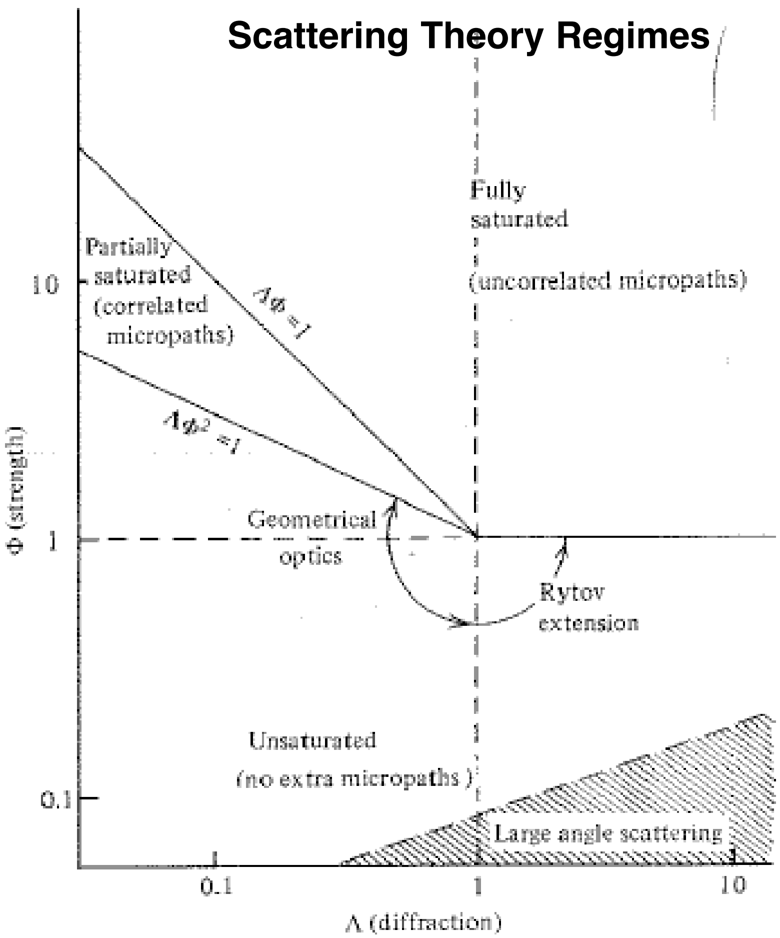
Scattering Theory Regimes

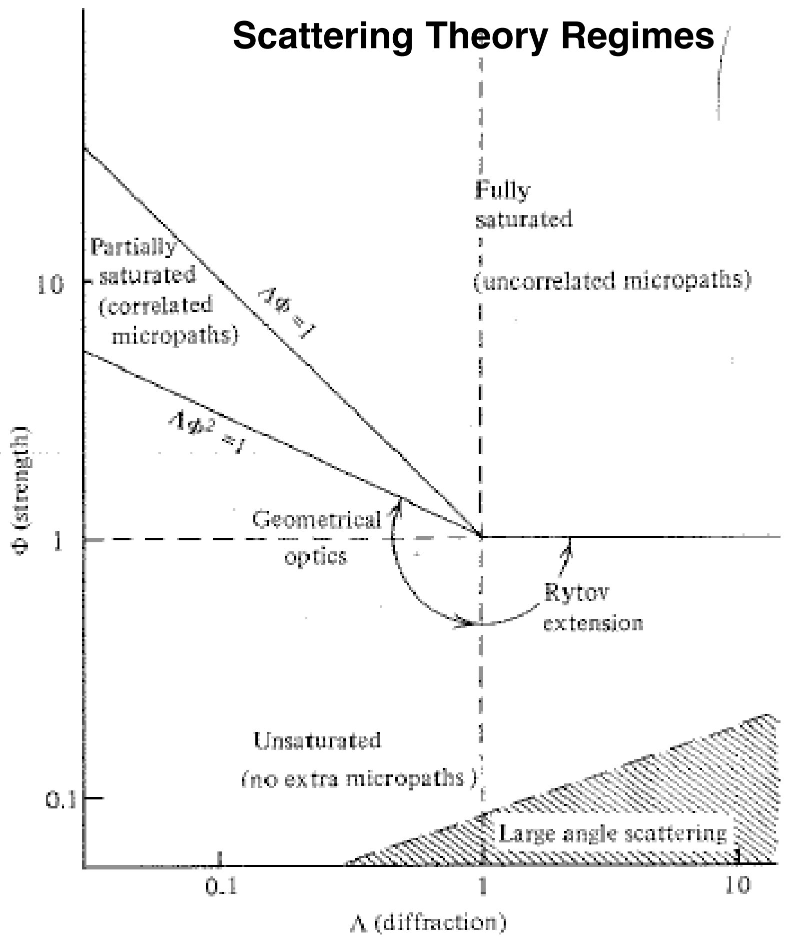


(From Flatté *et al.* [1978].)

Acoustic fluctuations may be examined using WPRM theory:

Motivation

Linear internal waves often are modeled as a background random process introducing random fluctuations in the acoustic field.



(From Flatté *et al.* [1978].)

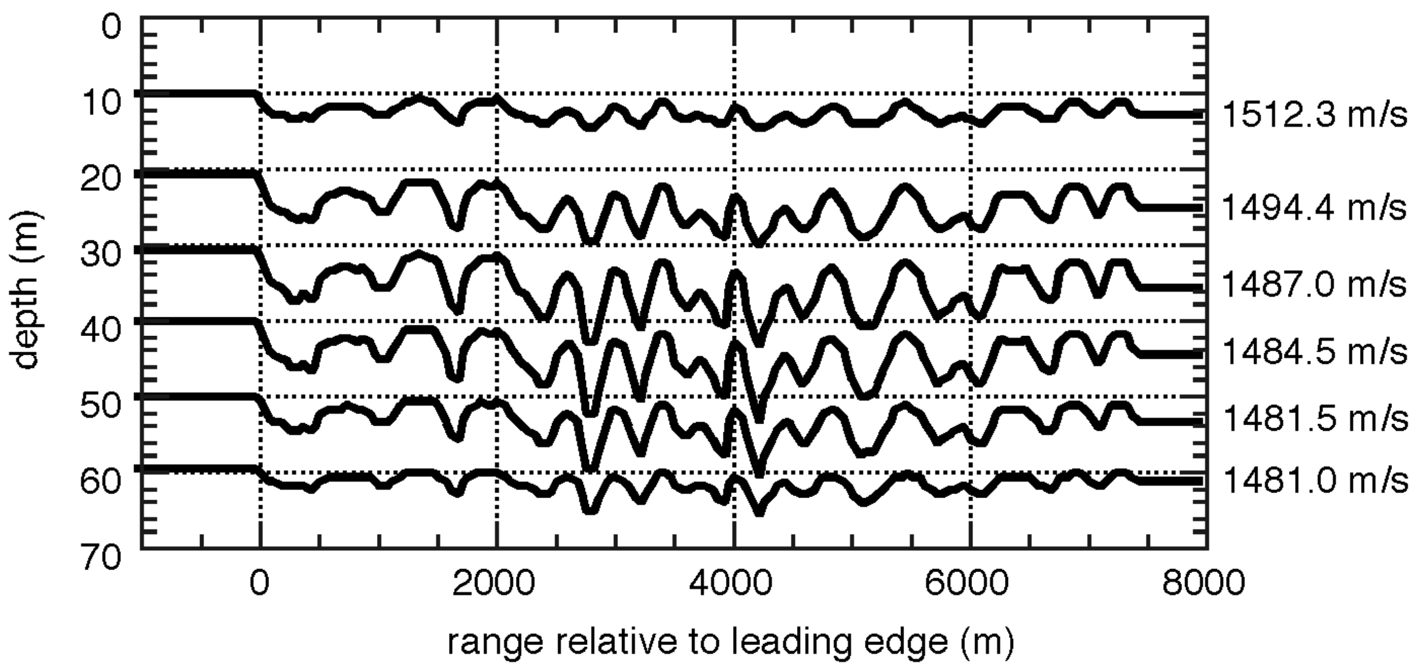
Acoustic fluctuations may be examined using WPRM theory:

- At 1 kHz and range 550 m, should be in weak-scattering Rytov regime.
- At 10 kHz and range 550m, should be in strong-scattering regime.

Motivation

Non-linear internal waves are often modeled as a more event-like process causing strong, localized changes in the acoustic sound speed.

Example: Isotachs observed during 1996 Coastal Mixing and Optics Experiment (from Rouseff, 2001).



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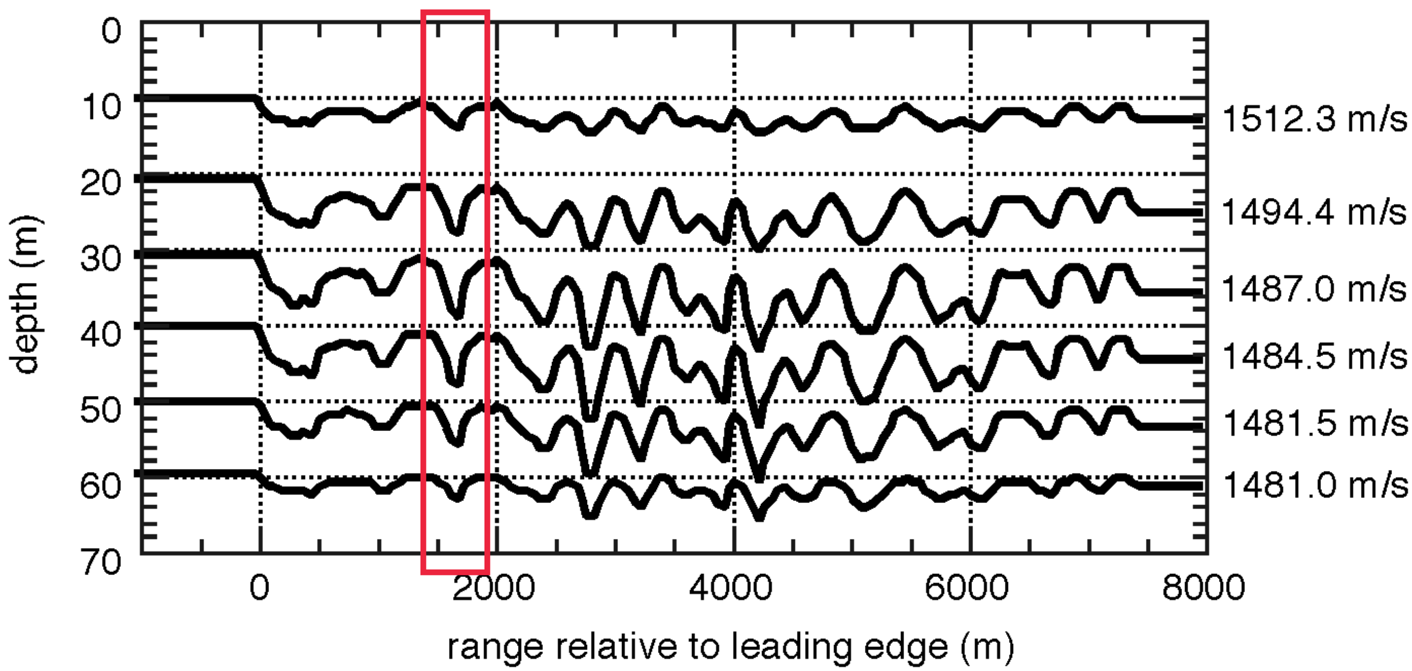


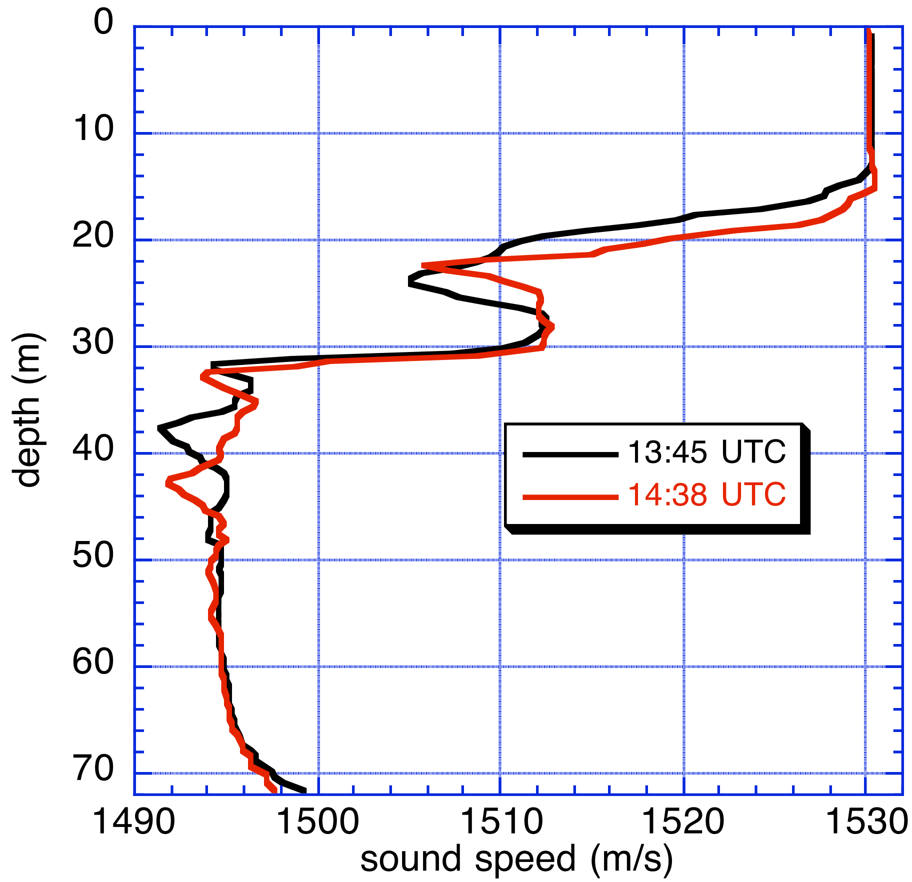
550 m acoustic path might permit individual waves in the packet to be isolated.

Data Modeling and Analysis

Present analysis considers ~0.5 hours of data collected immediately before, during, and after the passage of a non-linear internal wave.

Pre Non-Linear Internal Wave

Measured sound speed profiles showed anomalous bump at ~30 m that hadn't been observed earlier in experiment. Layer of warm, salty, neutrally buoyant water present.



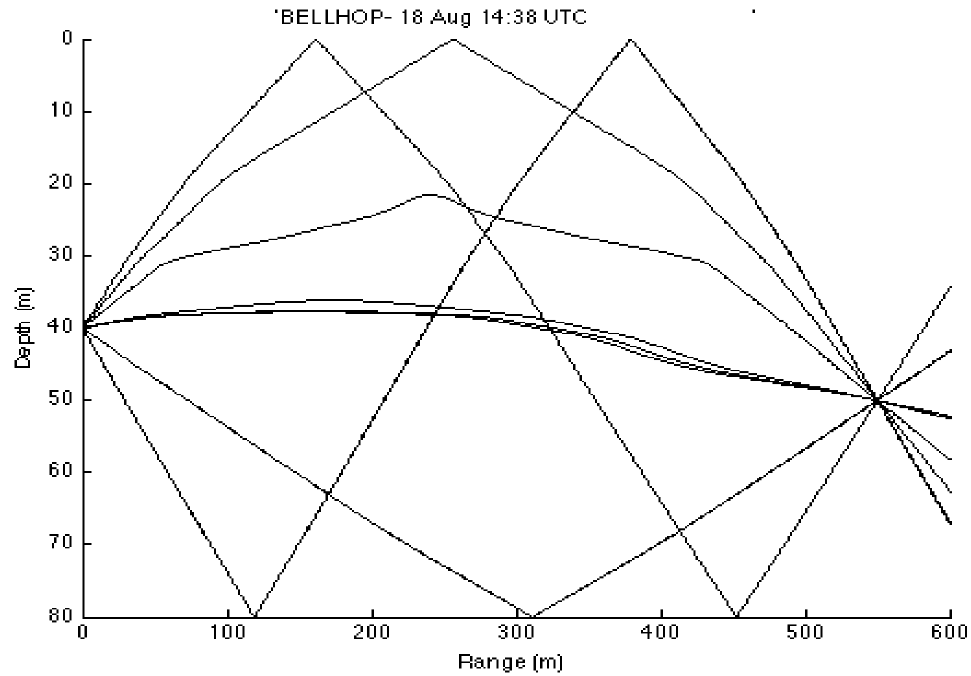
Based on measurements, decision made to put source at depth 40 m.
(Source depth was 30 m on data collected earlier in experiment.)

Pre Non-Linear Internal Wave

Modeling Result: Eigenrays to receiver at depth 50 m for assumed range-independent environment.

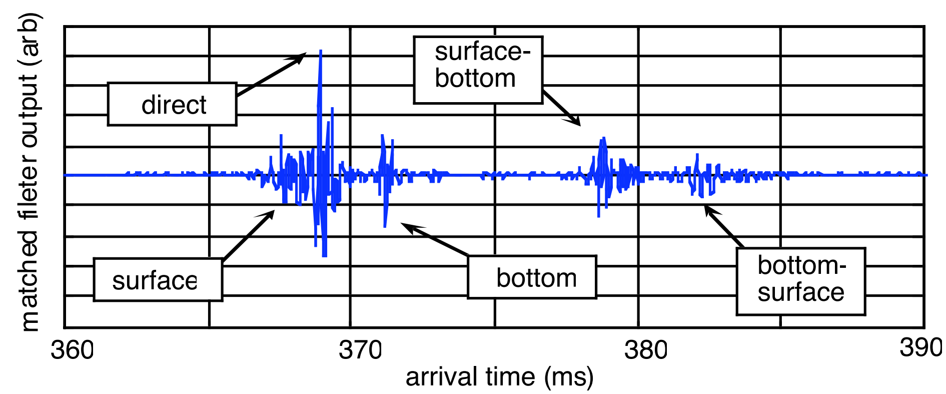
Indistinct direct path sensitive to details of sound speed profile.

Strong, distinct bottom-bounce path.



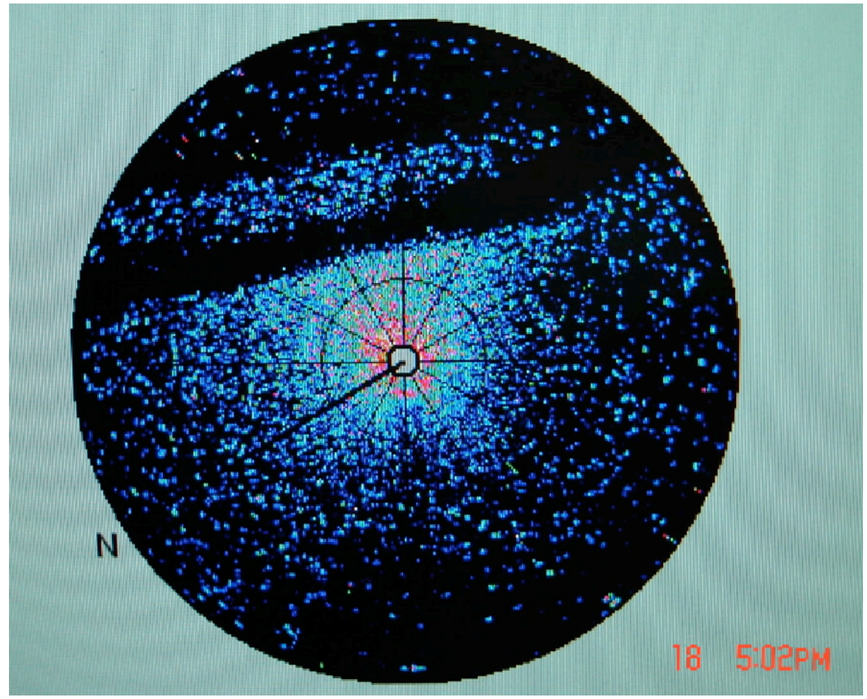
Experimental Result: Matched filter output for LFM chirp signal.

Strong, distinct bottom-bounce path.



Internal Wave “Sonny”

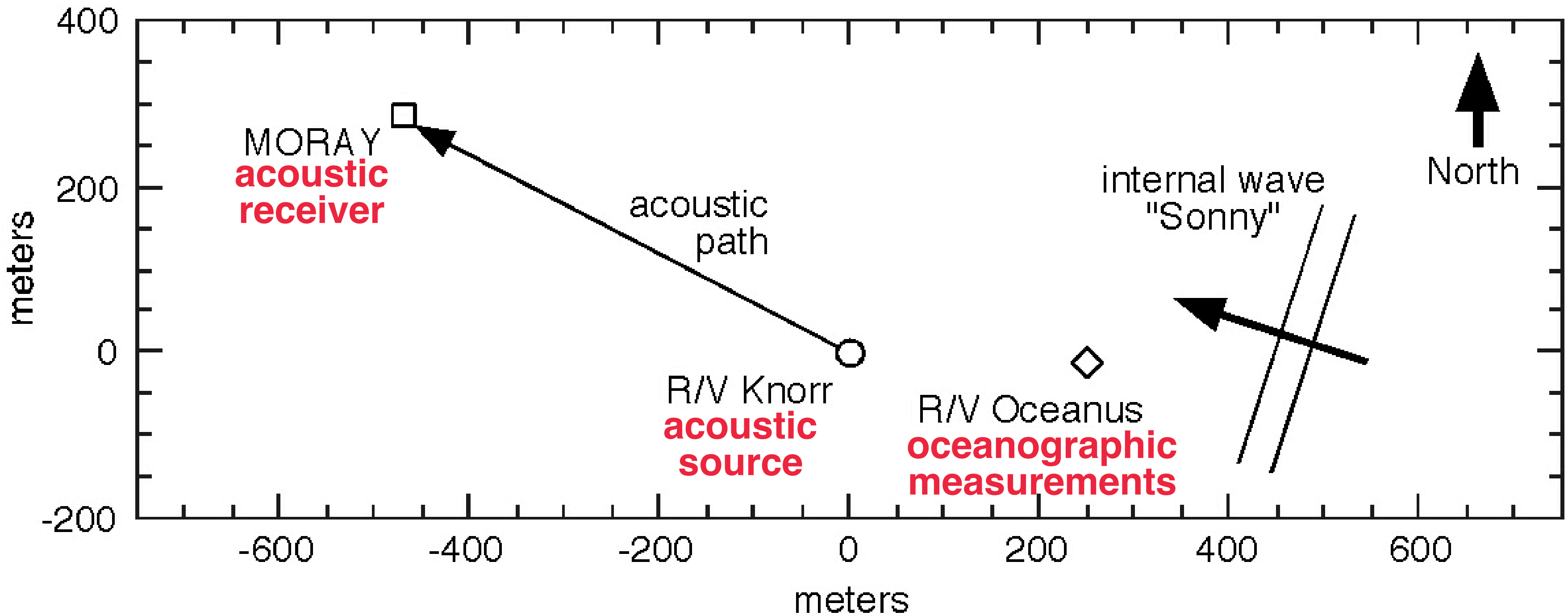
Non-linear internal wave named “Sonny” as observed by radar aboard the R/V Knorr.



R/V Oceanus collected oceanographic data on Sonny in close proximity to acoustic source deployed off stern of R/V Knorr.

Experiment Geometry

Positioning of Assets:



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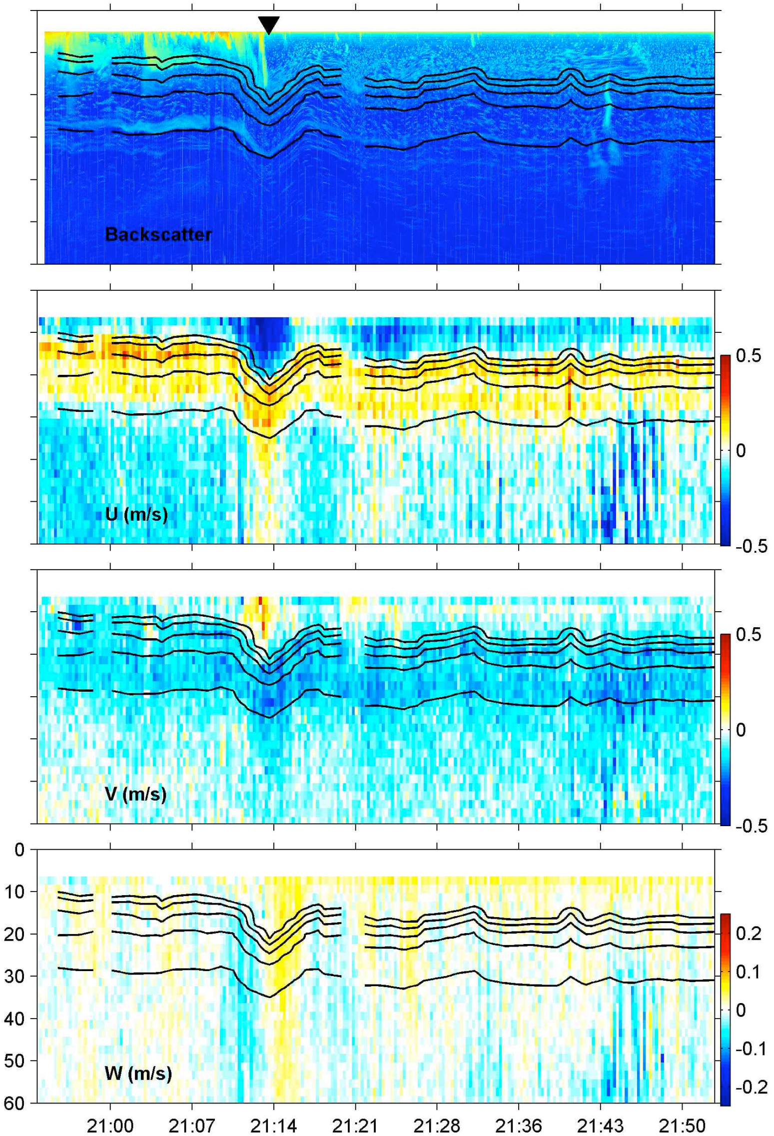
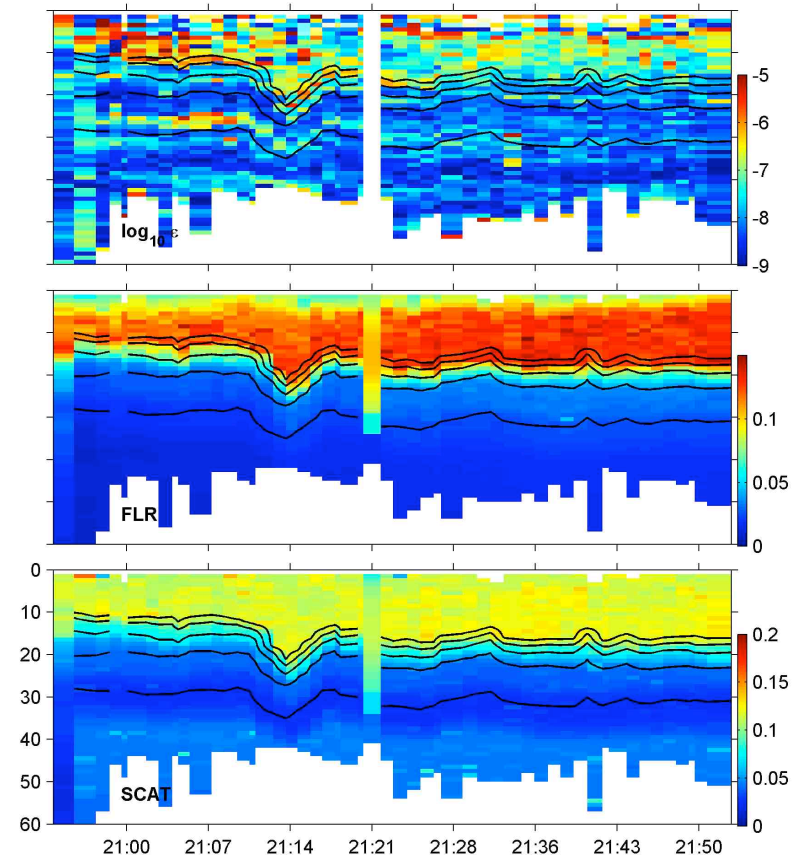
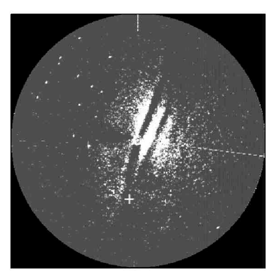




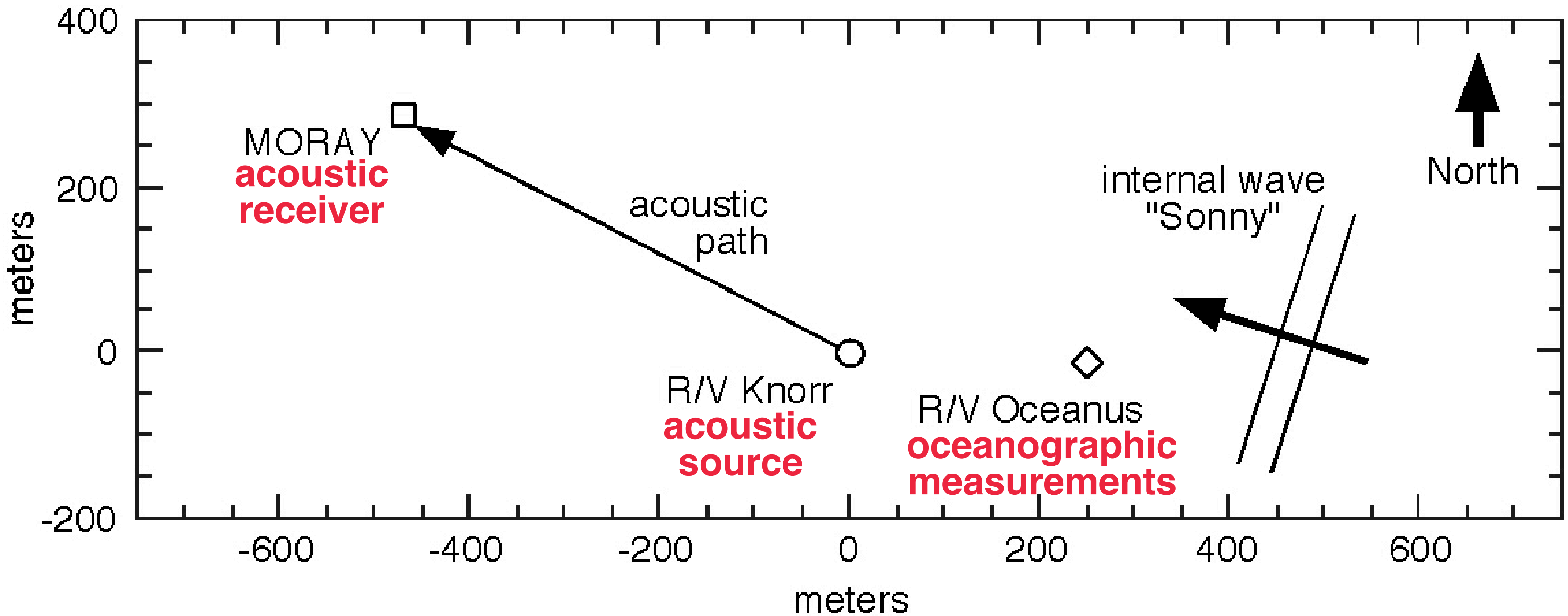


Sonny
18-Aug-2006 20:53:31 → 18-Aug-2006 21:53:15
39.0218 N, -73.0294 W

Measurements made from R/V Oceanus

Experiment Geometry

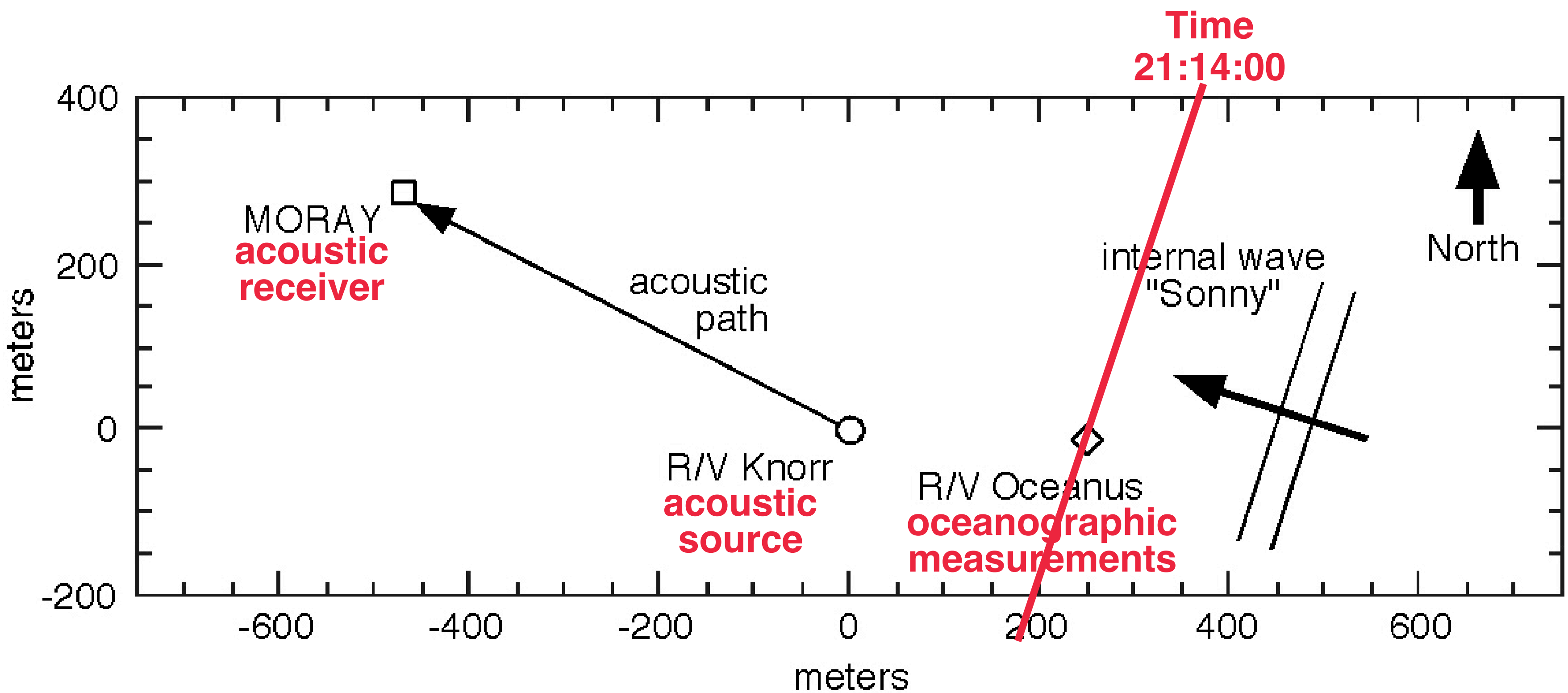
Positioning of Assets:



Using the measured bearing and speed (0.89 m/s) of Sonny observed at R/V Oceanus, we can estimate when wave will pass acoustic assets.

Experiment Geometry

Positioning of Assets:



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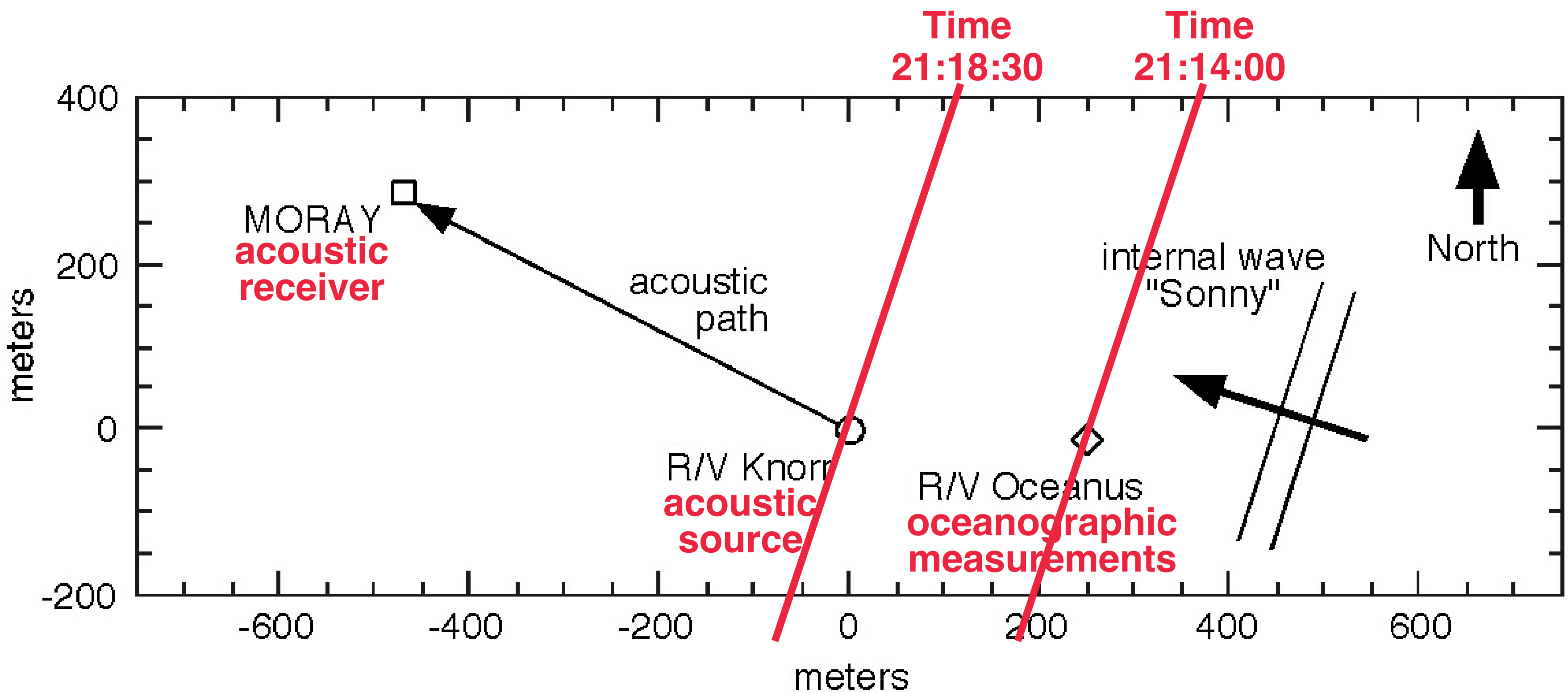

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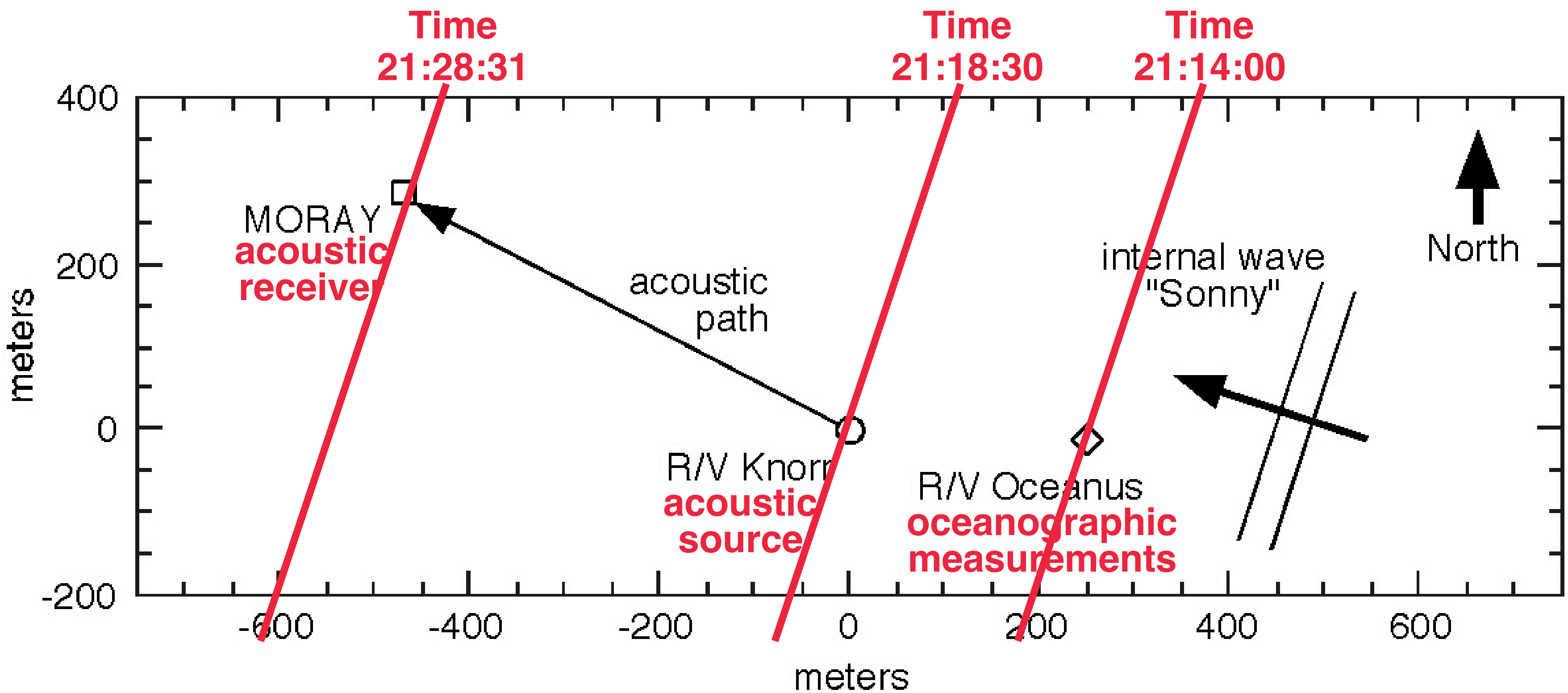

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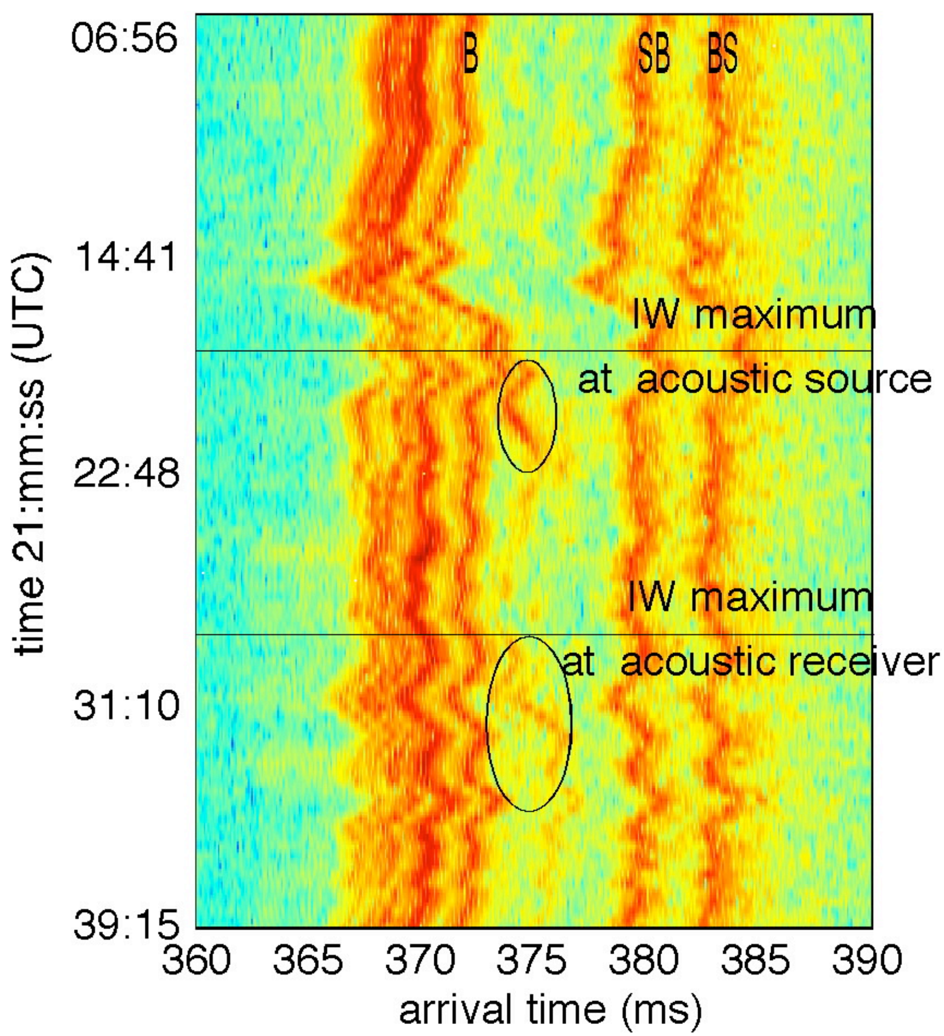
Results

Acoustic arrival pattern evolving over 32 minutes at depth 50 m.

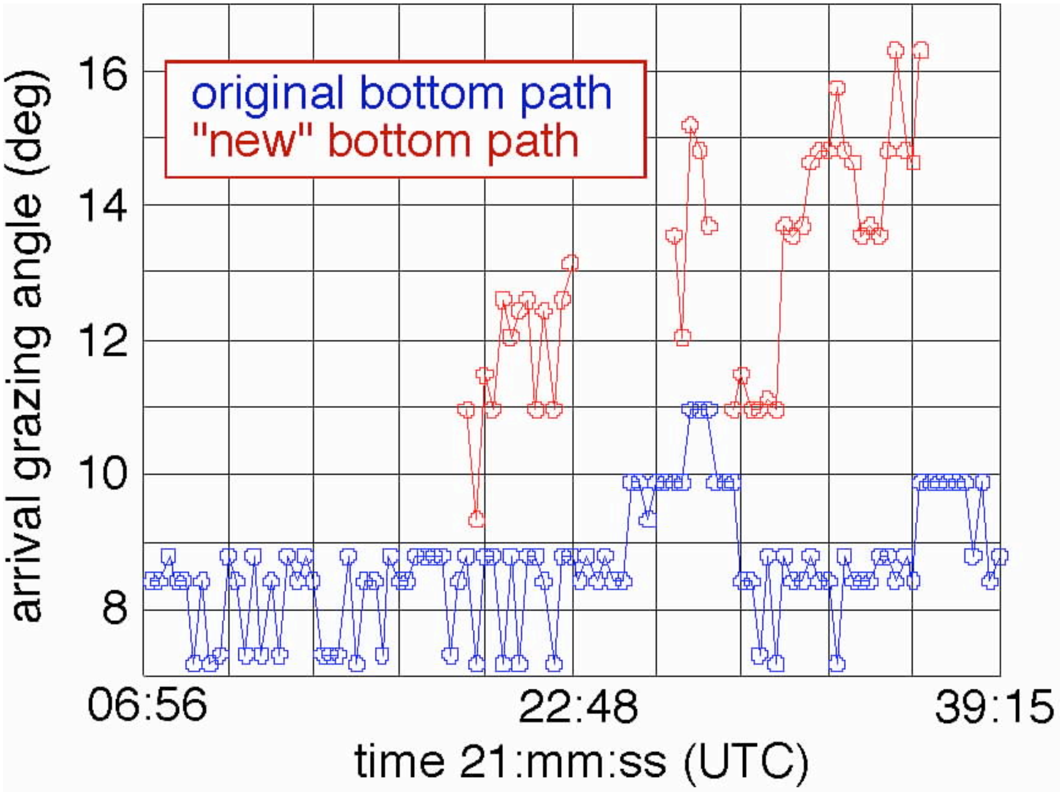
Bulk shift in arrivals due to source and/or receiver motion.

Bottom (B), Surface-Bottom (SB) and Bottom-Surface (BS) paths noted as is position of internal wave.

Main Result: New acoustic path “splits” from bottom bounce as internal wave passes above acoustic source.

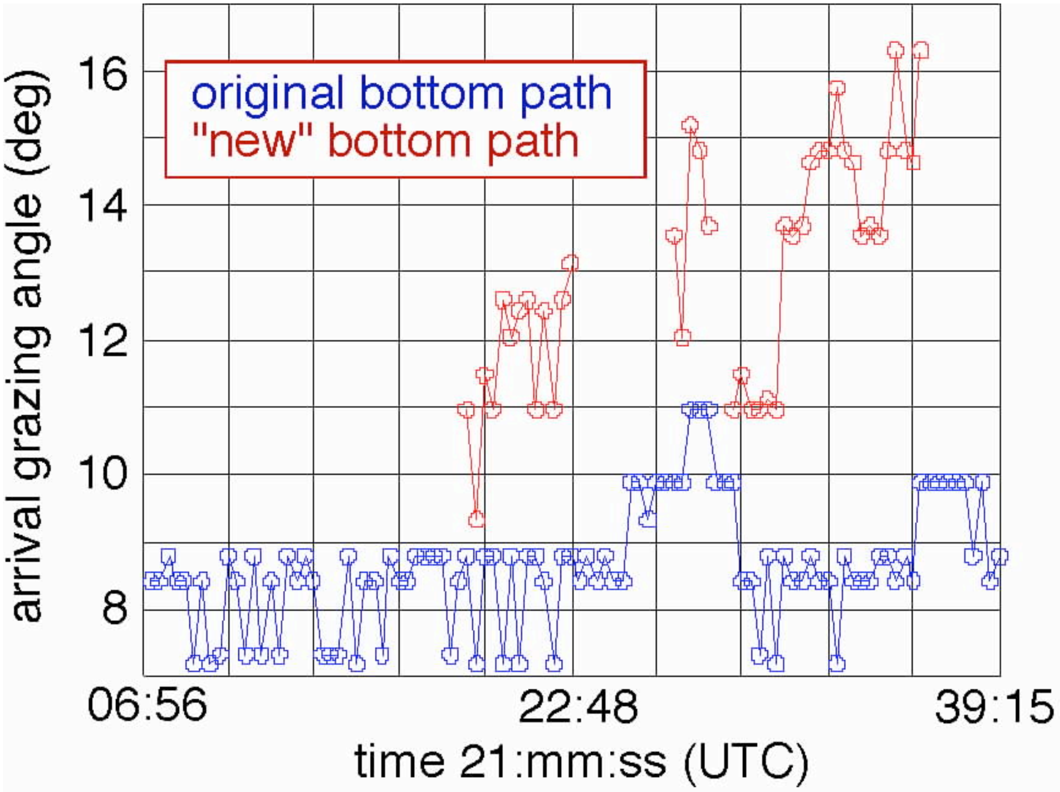


Results



New acoustic arrival induced by passing internal wave arrives at steeper angle than original bottom-bounce path.

Results



Hypothesis: Upward launched ray refracted downward by passing internal wave. Ray strikes bottom further downrange than original bottom-bounce path and so arrives at receiving array at steeper angle.

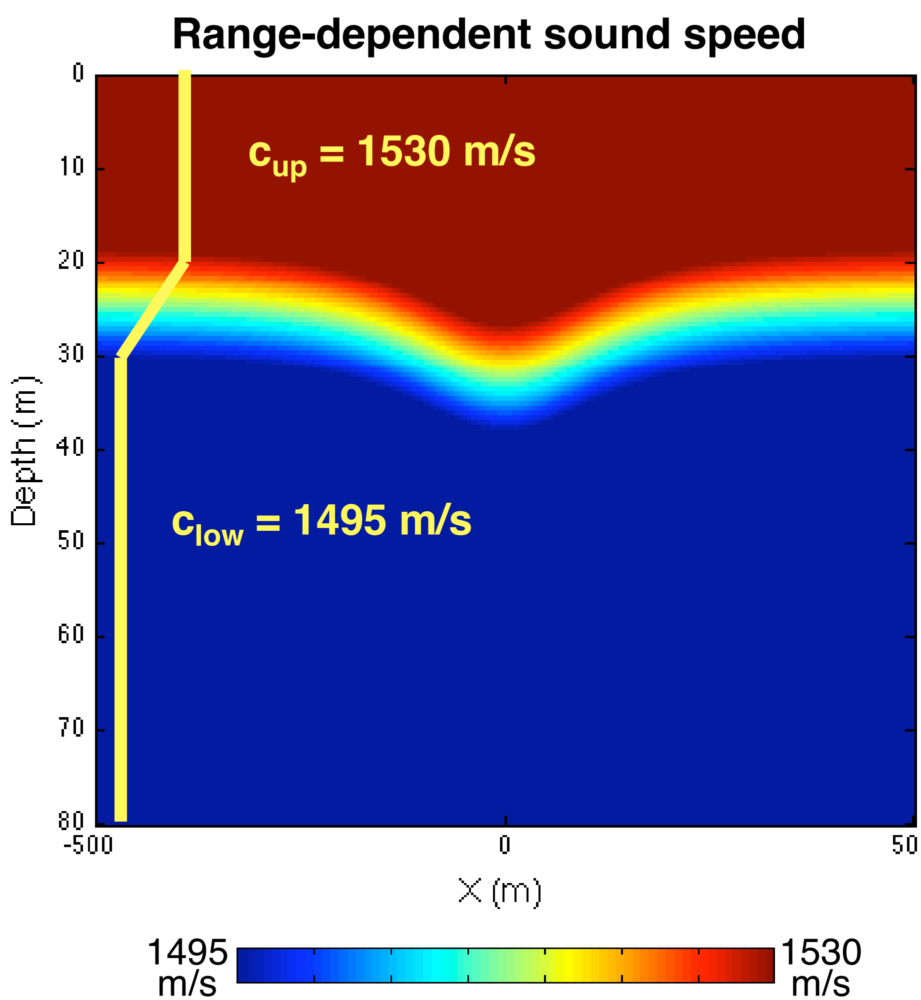
Modeling

Preisig and Duda (1997) developed a 3-layer model for the sound speed:

• Upper layer c_{up}, lower layer c_{low}, middle layer with constant gradient.

• Soliton model for IW displacement:

$$\eta(x,t) = a\,\mathrm{sech}^2((x - c_p t)/L)$$



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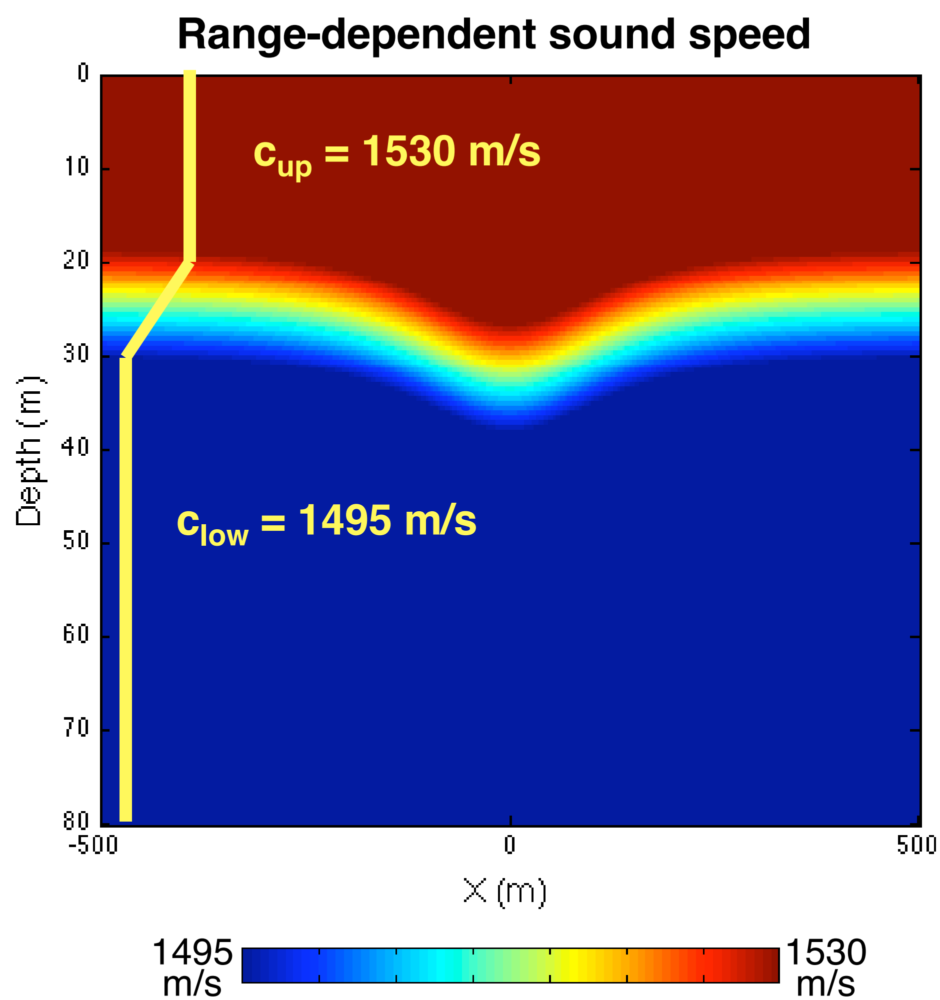
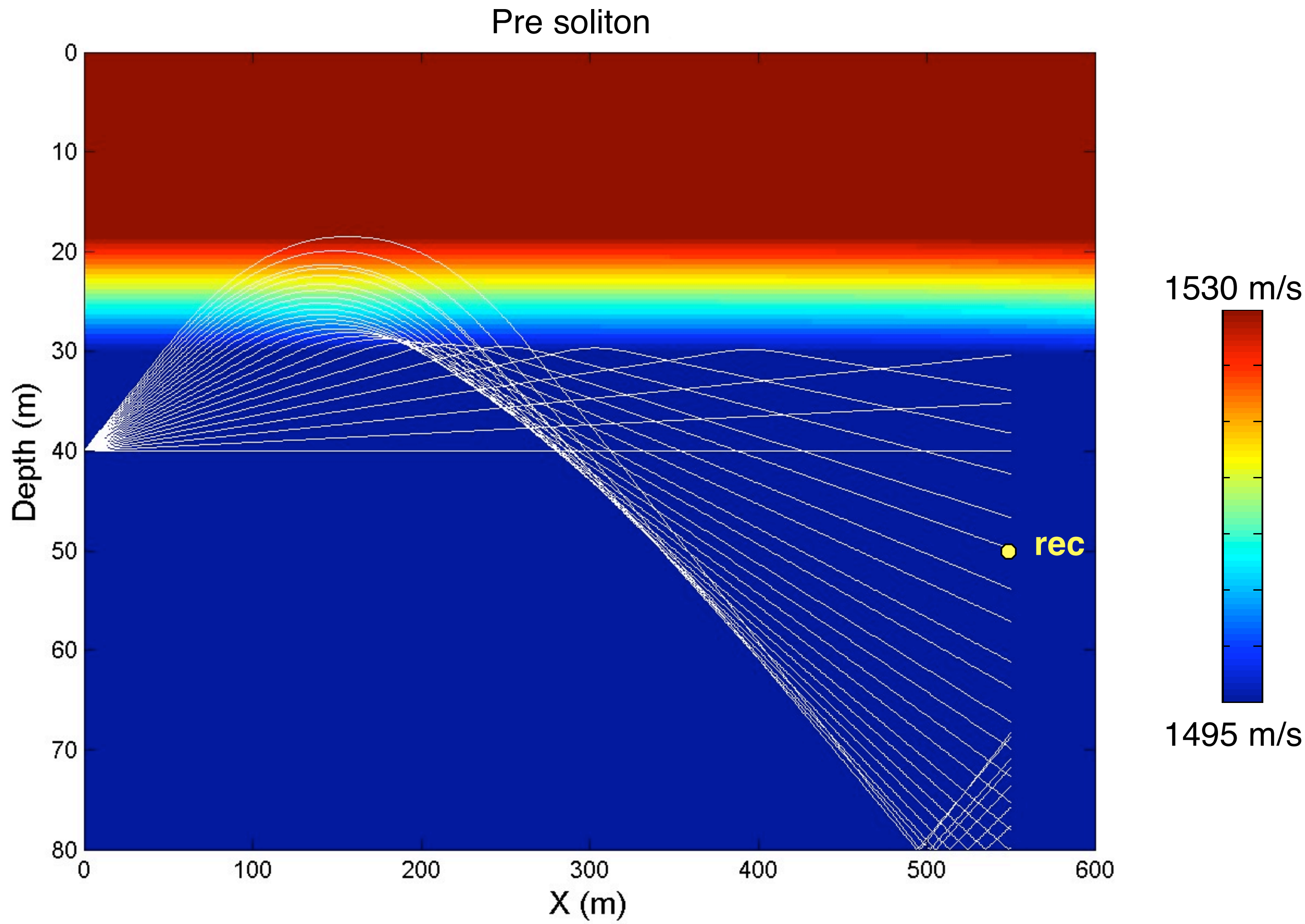
Apply model in ray trace study to test hypothesis using appropriate parameter values:

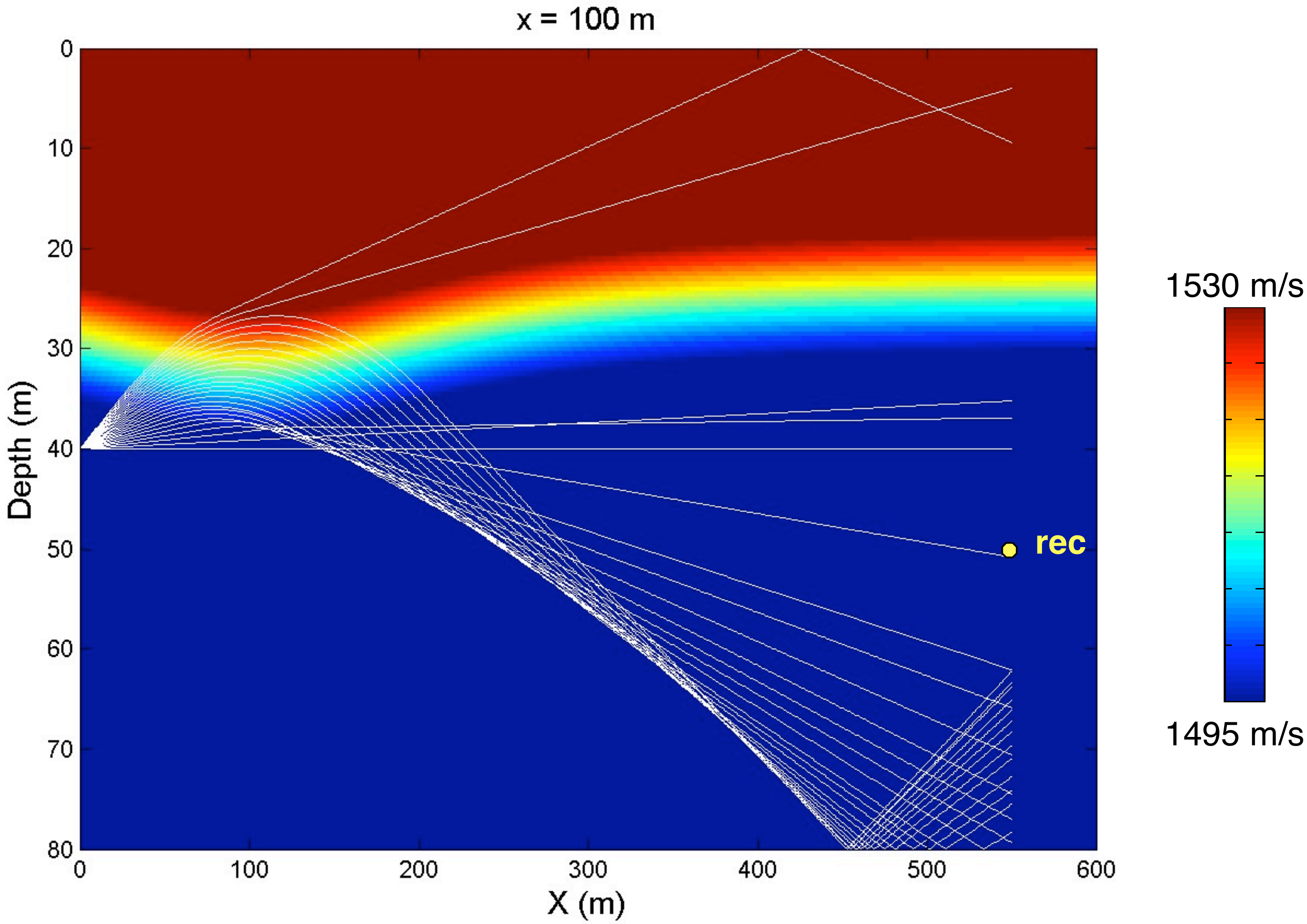
c_{up} = 1530 m/s, c_{low} = 1495 m/s,
z_{up} = 18 m, z_{low} = 30 m,
a = 8 m, L = 100 m, c_p = 0.89 m/s.



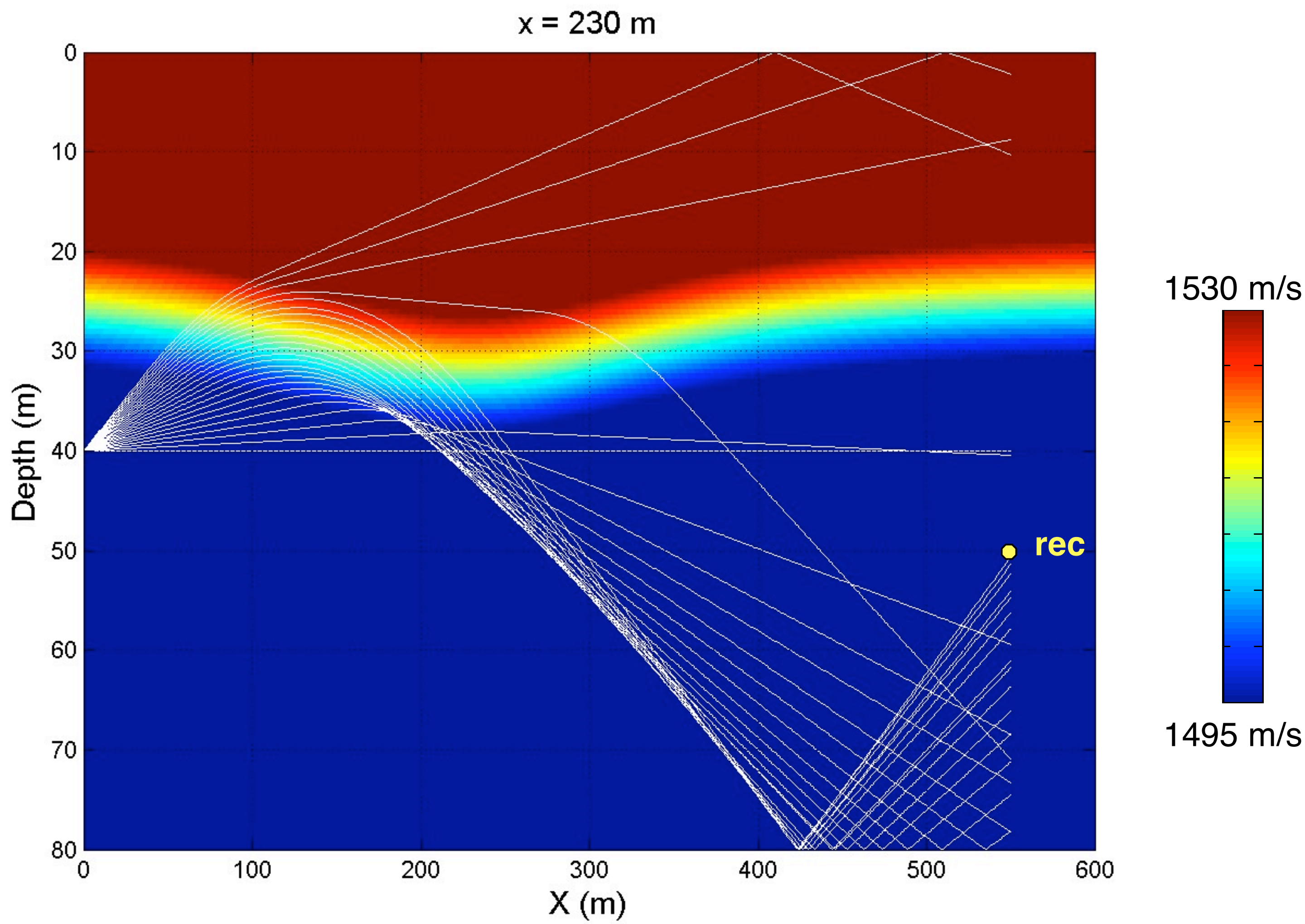
Modeling


Pre soliton
0
10
20
30
40
50
60
70
80
Depth (m)
0
100
200
300
400
500
600
X (m)
rec
1530 m/s
1495 m/s

Modeling

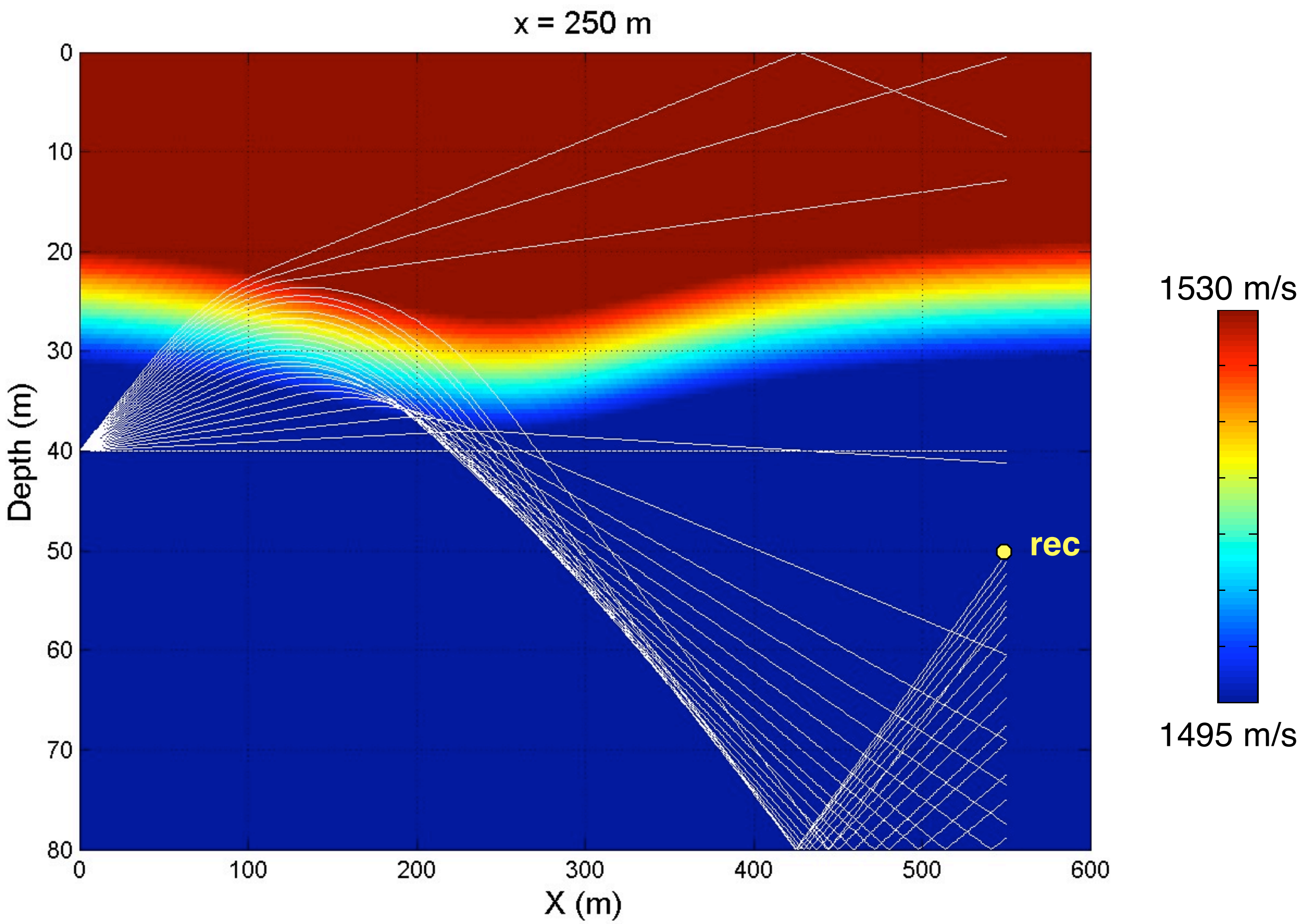

x = 100 m
0
10
20
30
40
50
60
70
80
Depth (m)
0
100
200
300
400
500
600
X (m)
rec
1530 m/s
1495 m/s

Modeling



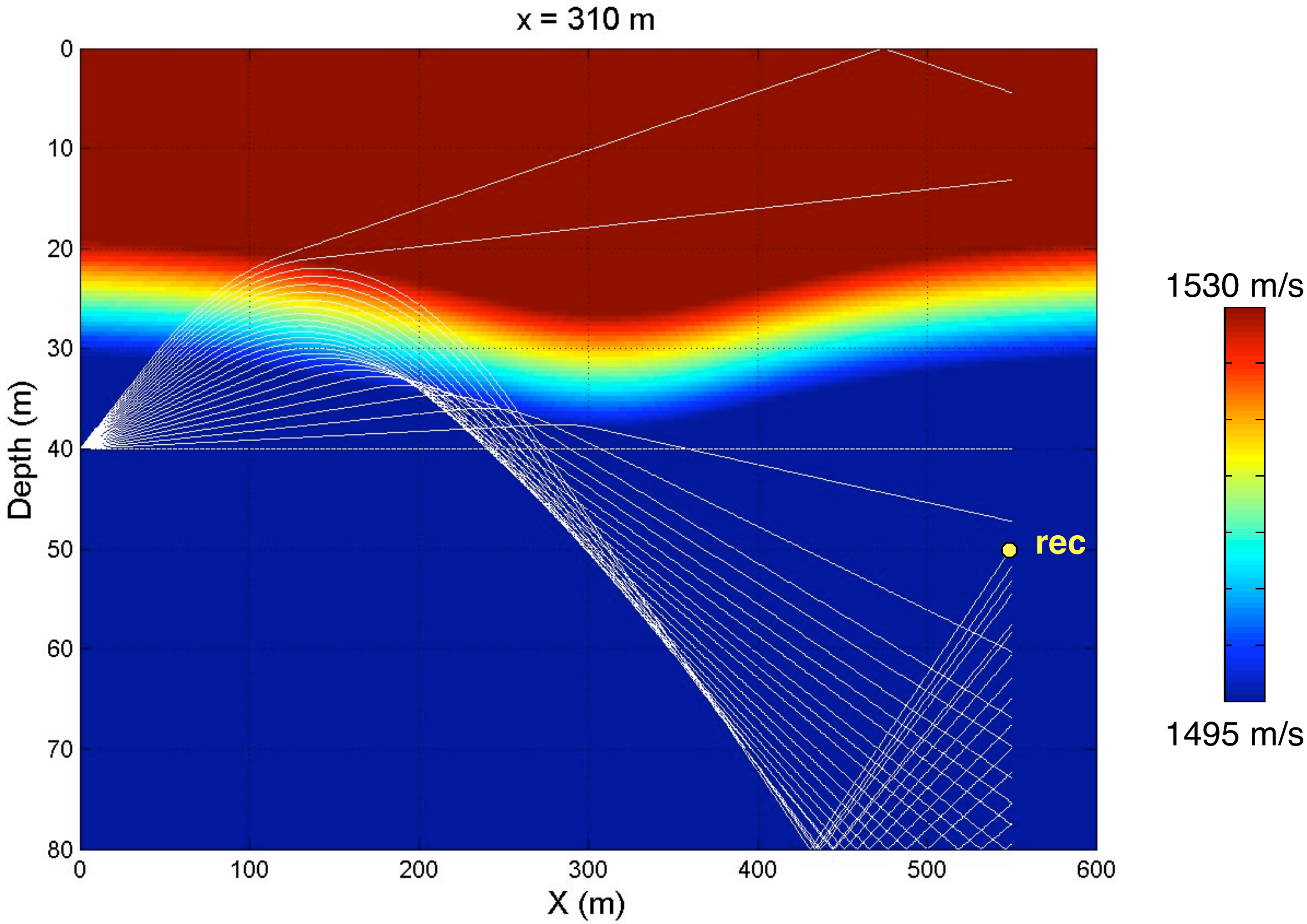
x = 230 m
0
10
20
30
40
50
60
70
80
Depth (m)
0
100
200
300
400
500
600
X (m)
rec
1530 m/s
1495 m/s

Modeling

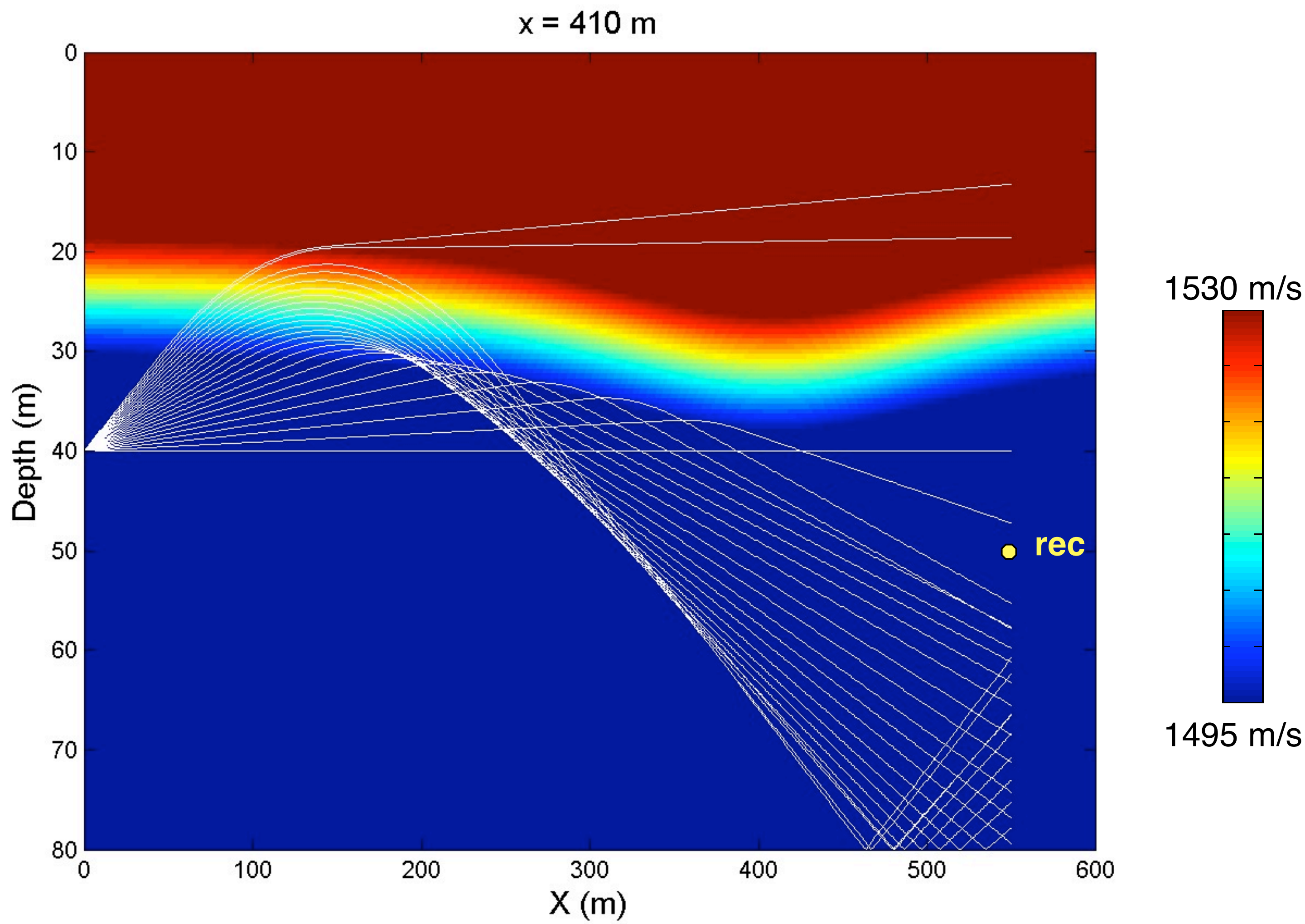


x = 250 m
Depth (m)
X (m)
rec
1530 m/s
1495 m/s
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500
600

Modeling


x = 310 m
Depth (m)
0
10
20
30
40
50
60
70
80
0
100
200
300
400
500
600
X (m)
rec
1530 m/s
1495 m/s

Modeling



x = 410 m
0
10
20
30
40
50
60
70
80
Depth (m)
0
100
200
300
400
500
600
X (m)
rec
1530 m/s
1495 m/s

Summary

Mid-frequency acoustic transmission data were collected on a vertical array over a continuous 7-hour period at range 550 m.

Present analysis considers data collected immediately before, during, and after the passage of a non-linear internal wave.

Results show a new acoustic path being generated as the internal wave passes above the acoustic source.

Simple model produces results consistent with observed new ray path.

Future work includes: acoustic data analysis of complete 7-hour period; range-dependent acoustic modeling that is better integrated with the collected oceanographic data; data/model comparison; data/scattering-theory comparison.