Orientation azimuth calibration of borehole geophones

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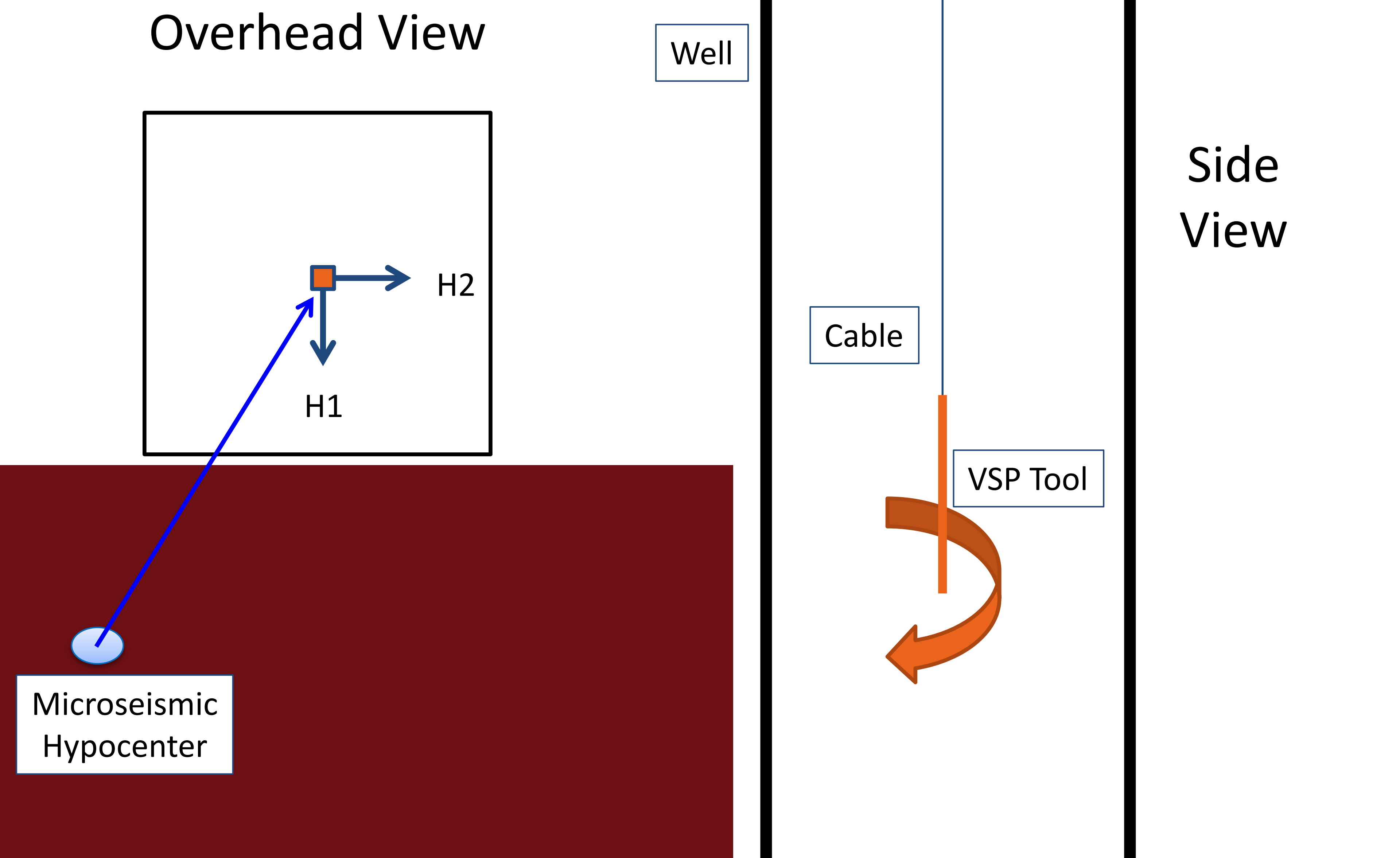
24th Annual CREWES Sponsor's Meeting
November 29, 2012

Geophone orientation calibration



Outline

- Objectives
- Methods and Survey Geometry
- Results and Modelling
- Conclusions
- Acknowledgements

Objectives

- Determine the optimal **survey design** for orientation calibration

- Characterise and quantify the effects of **lateral raybending** and **seismic anisotropy** on geophone orientation azimuth calibration

Geophone Orientation – Analytic Method

- The equation used to analytically calculate rotation azimuths was (DiSiena et al., 1984)

$$\tan 2\theta = \frac{2H_1 \otimes H_2}{H_1 \otimes H_1 - H_2 \otimes H_2}.$$

Vertical Well:

$$\phi_r = \phi_s + \theta$$

- $\otimes$ is a zero lag cross-correlation
- H_1 and H_2 are the windowed data (100 ms)
- θ is the source-receiver (H1 or X) orientation angle

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Deviated Well:

???

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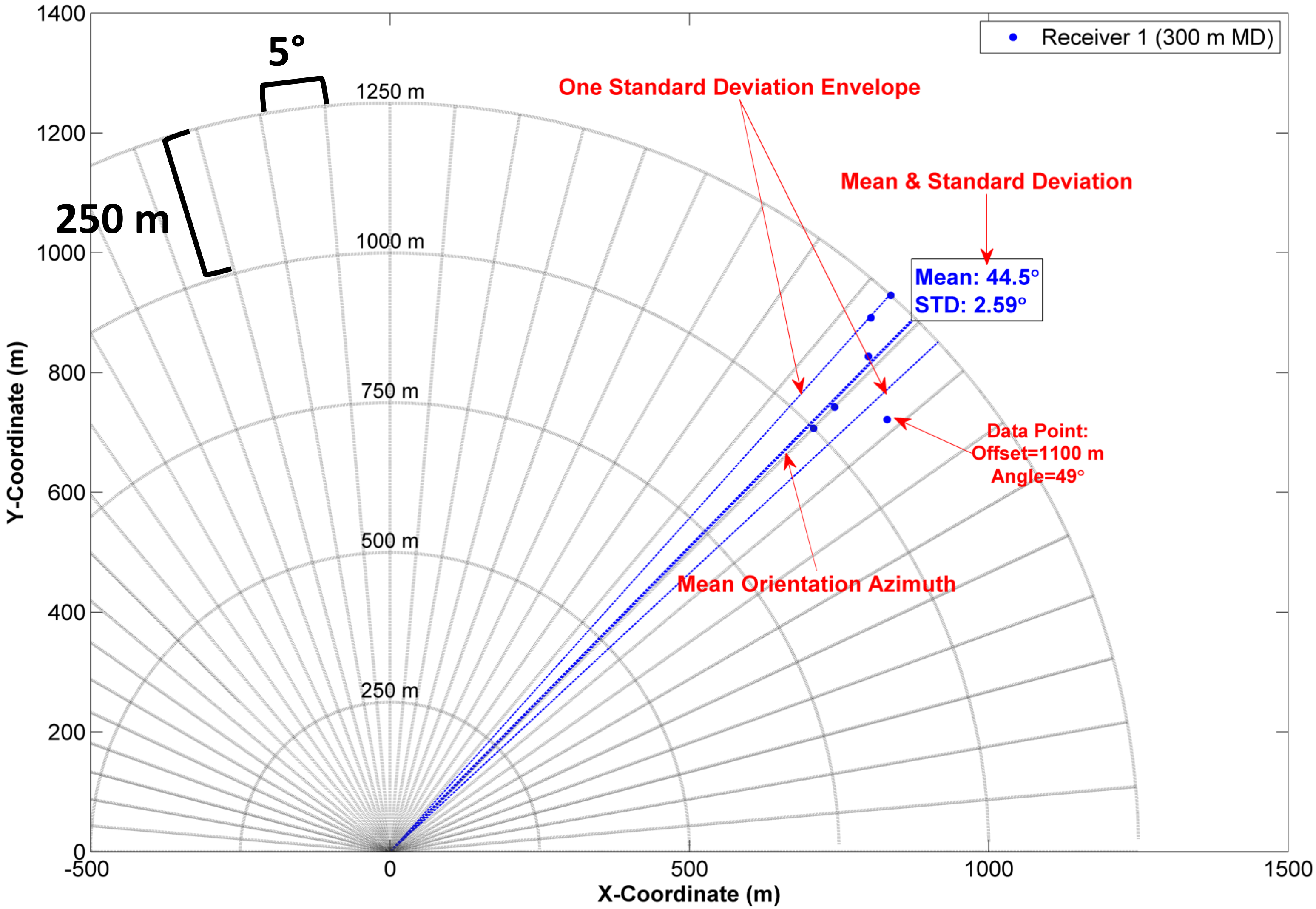
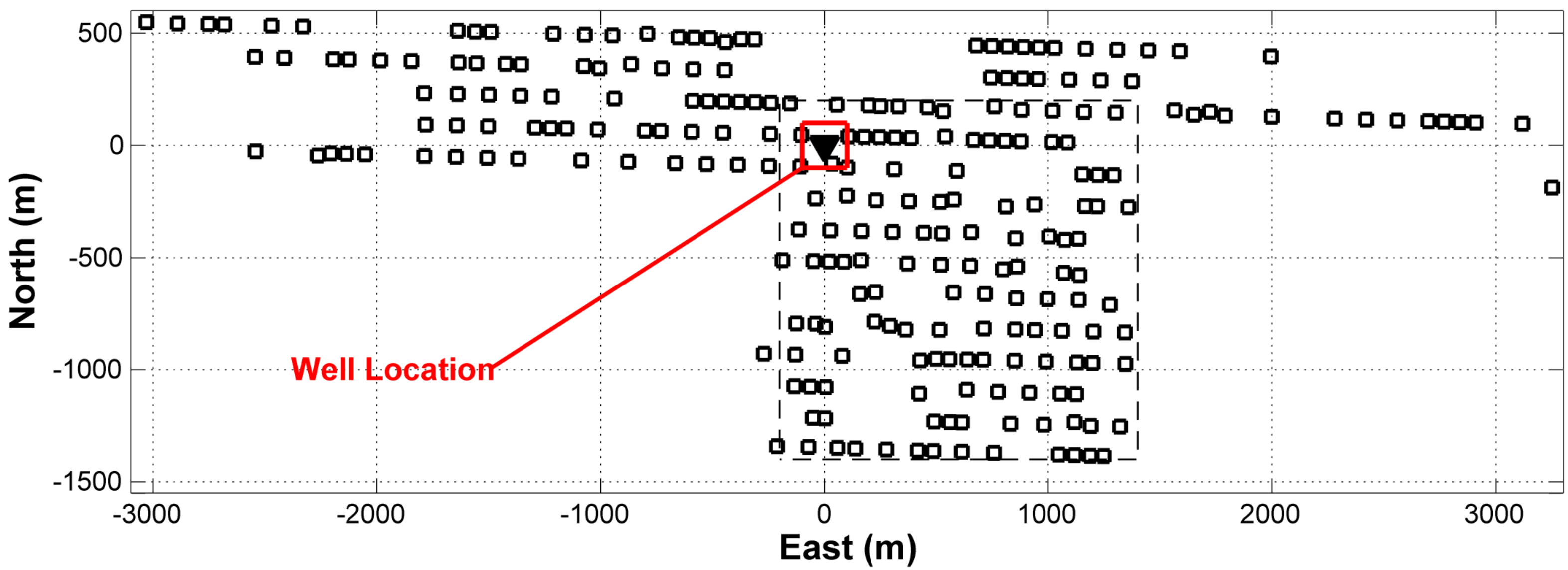
- H_1 and H_2 are the windowed data (100 ms)
- θ is the source-receiver (H1 or X) orientation angle

Example of a Simple Radial Plot

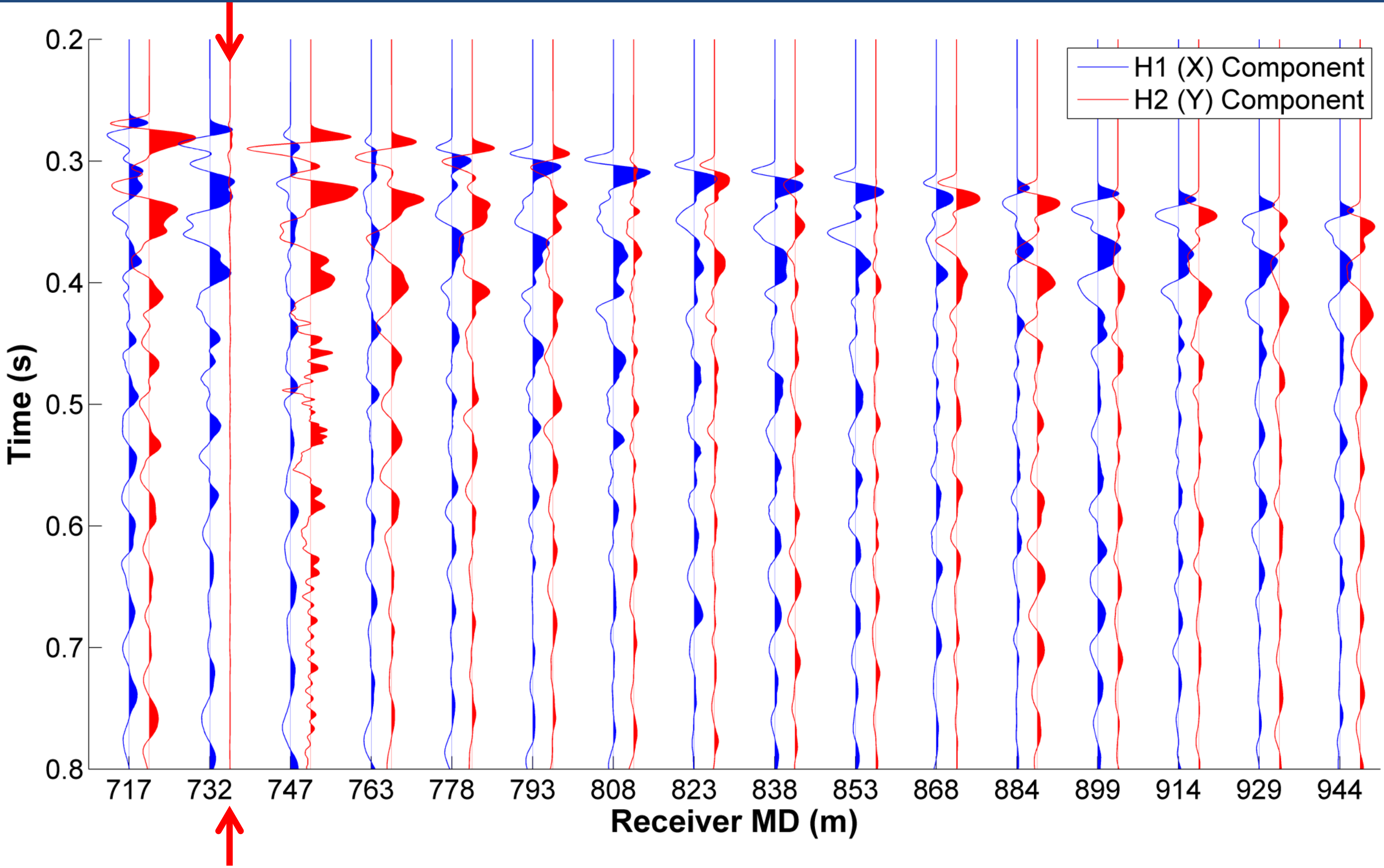


Lousana VSP

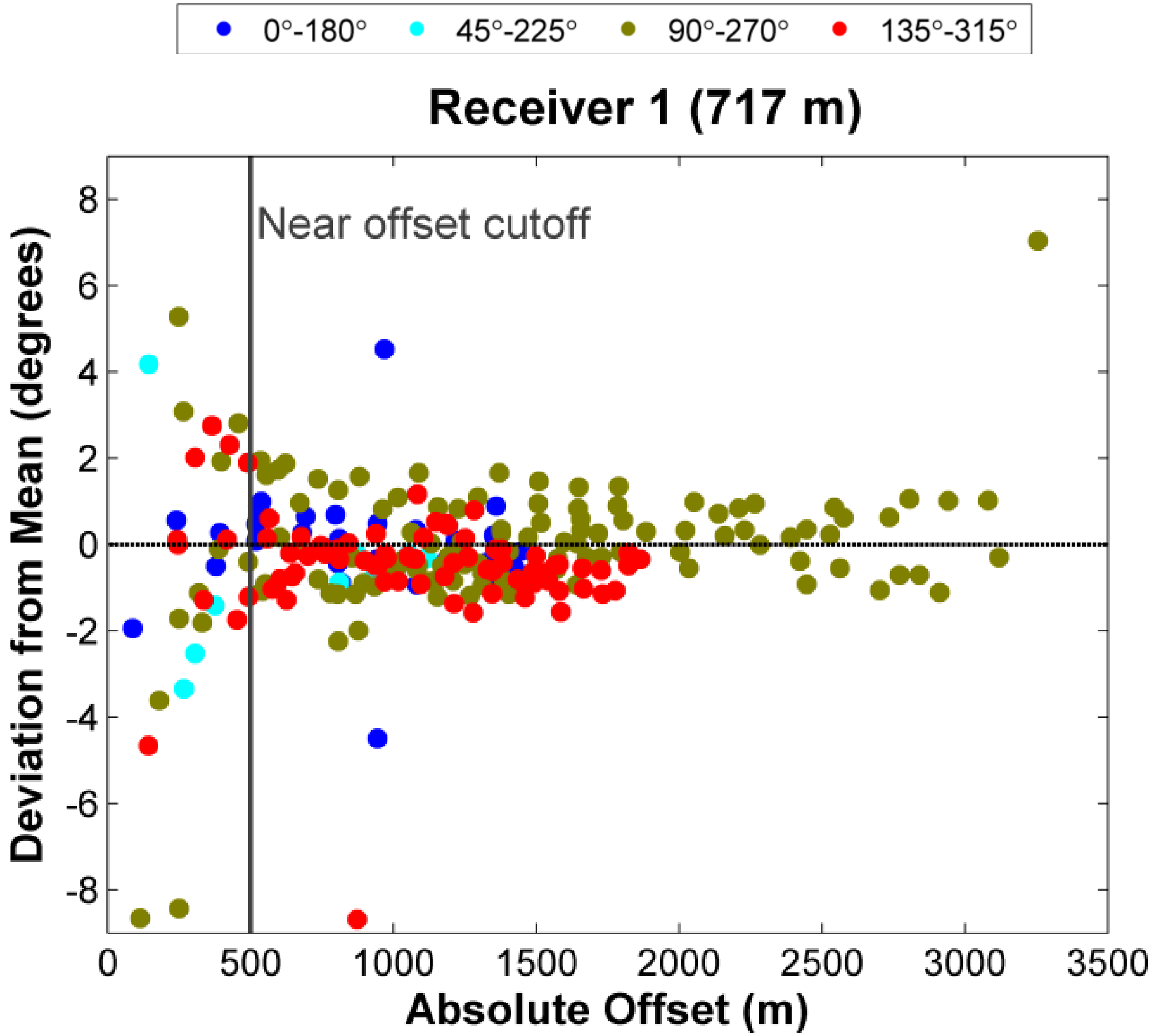
- 16 3-C receivers: spacing of ~15 m
- 2D Survey with four tool positions (64 total levels)
- 3D Survey (249 source locations)
- Vertical Well

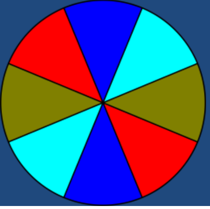


Shot Gather (3D, X = 33 m, Y = -81 m)

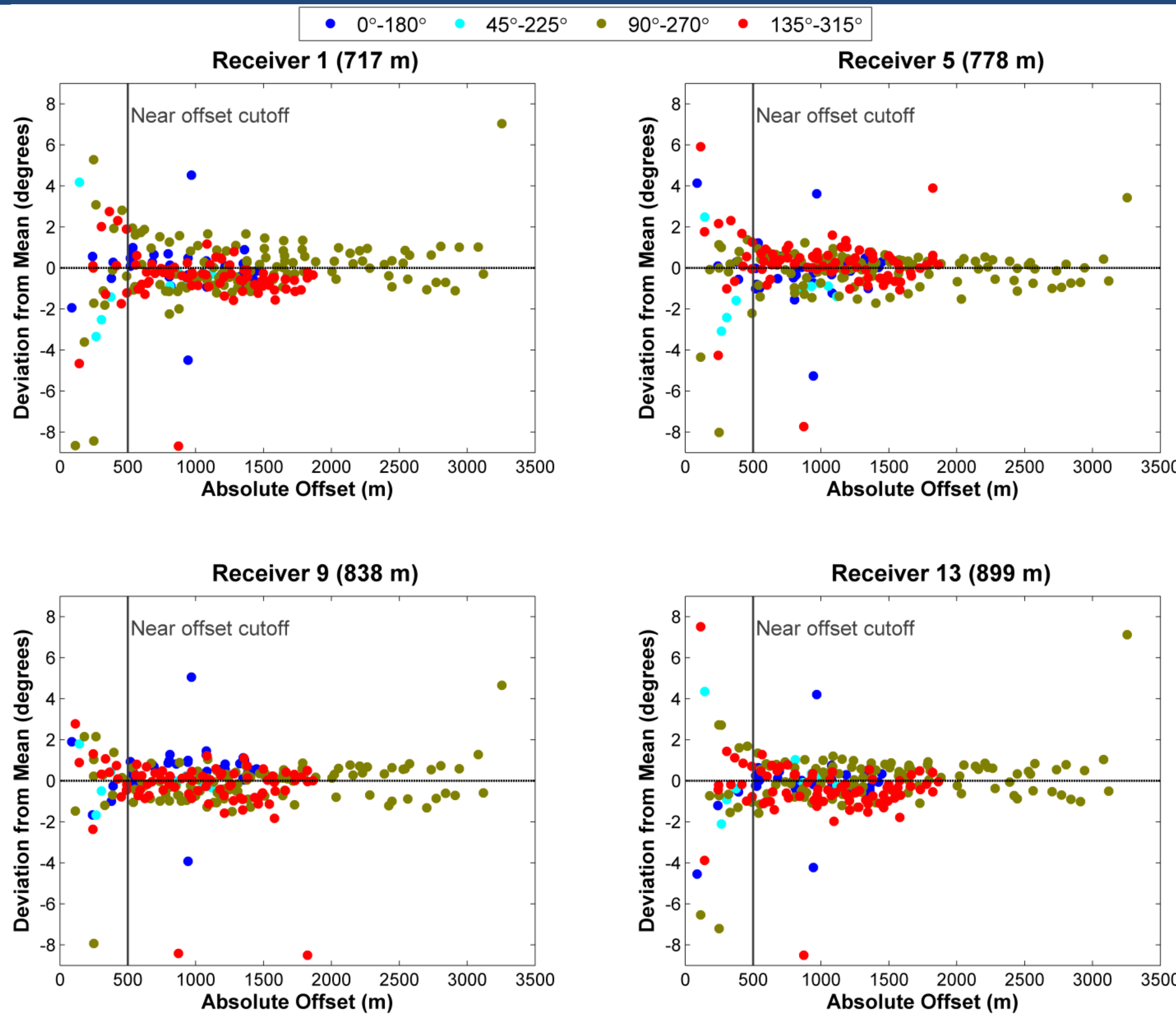


Orientation vs. Offset

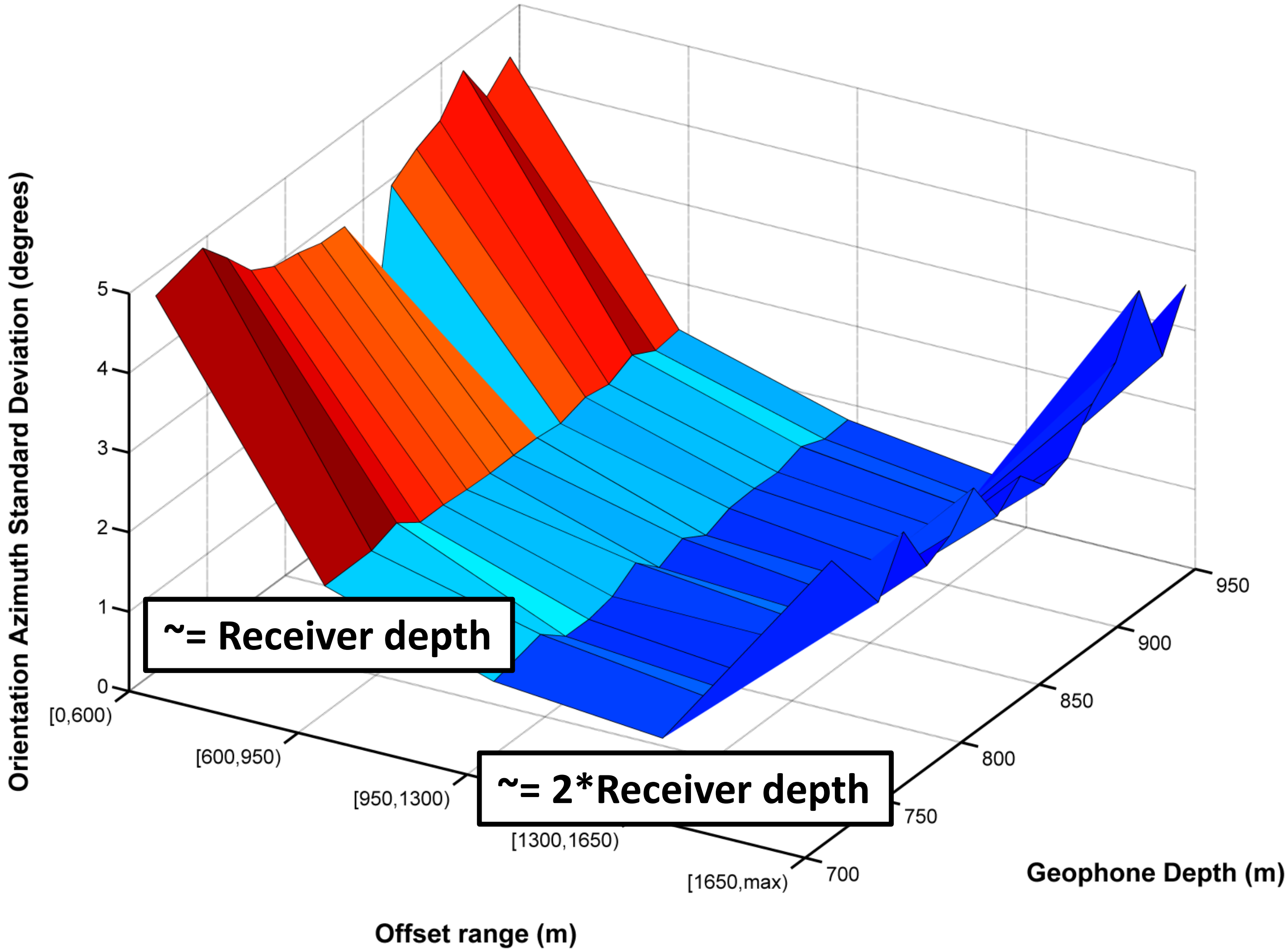




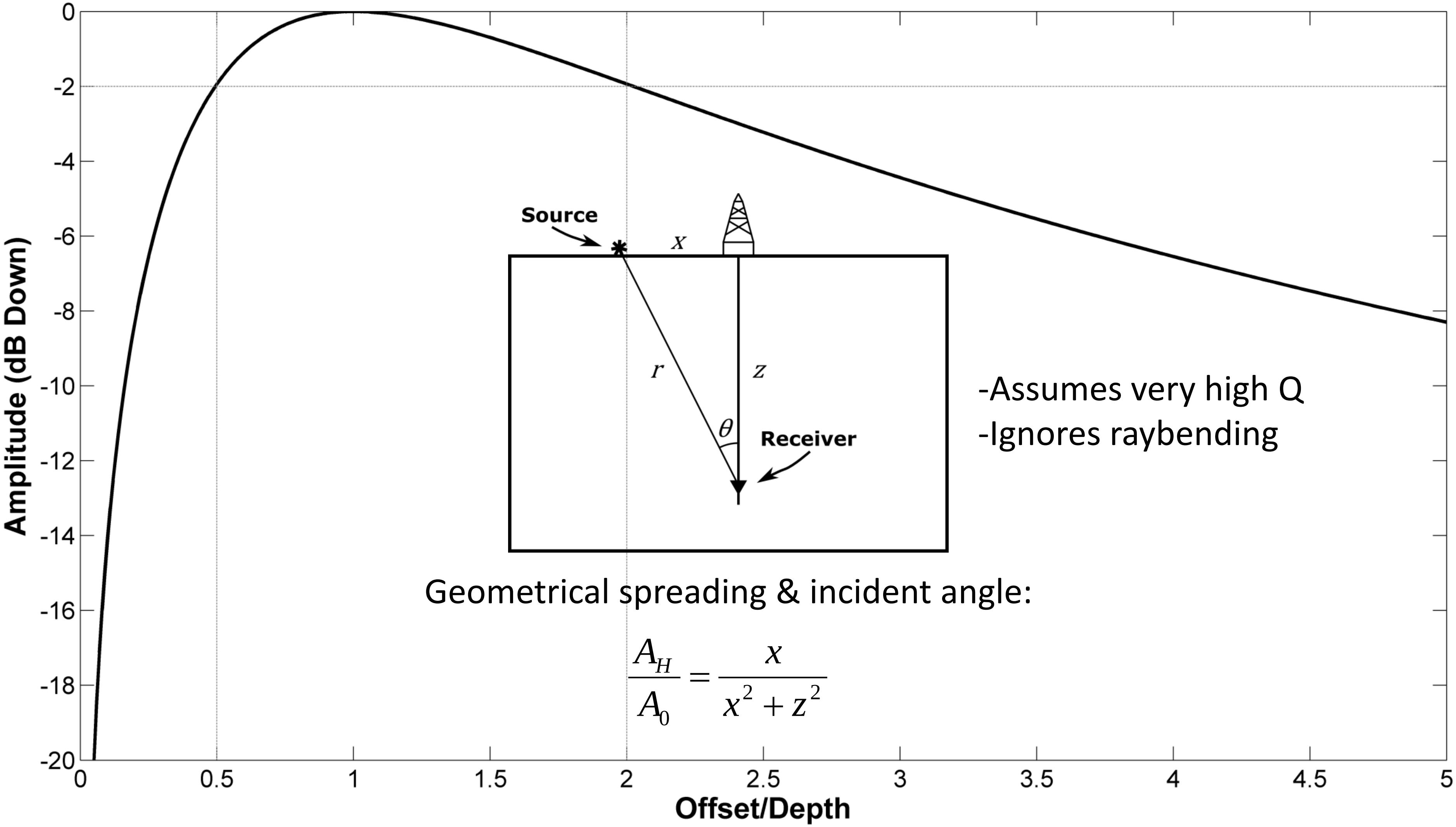
Orientation vs. Offset



Offset Sectoring



Theoretical Signal Based on Offset

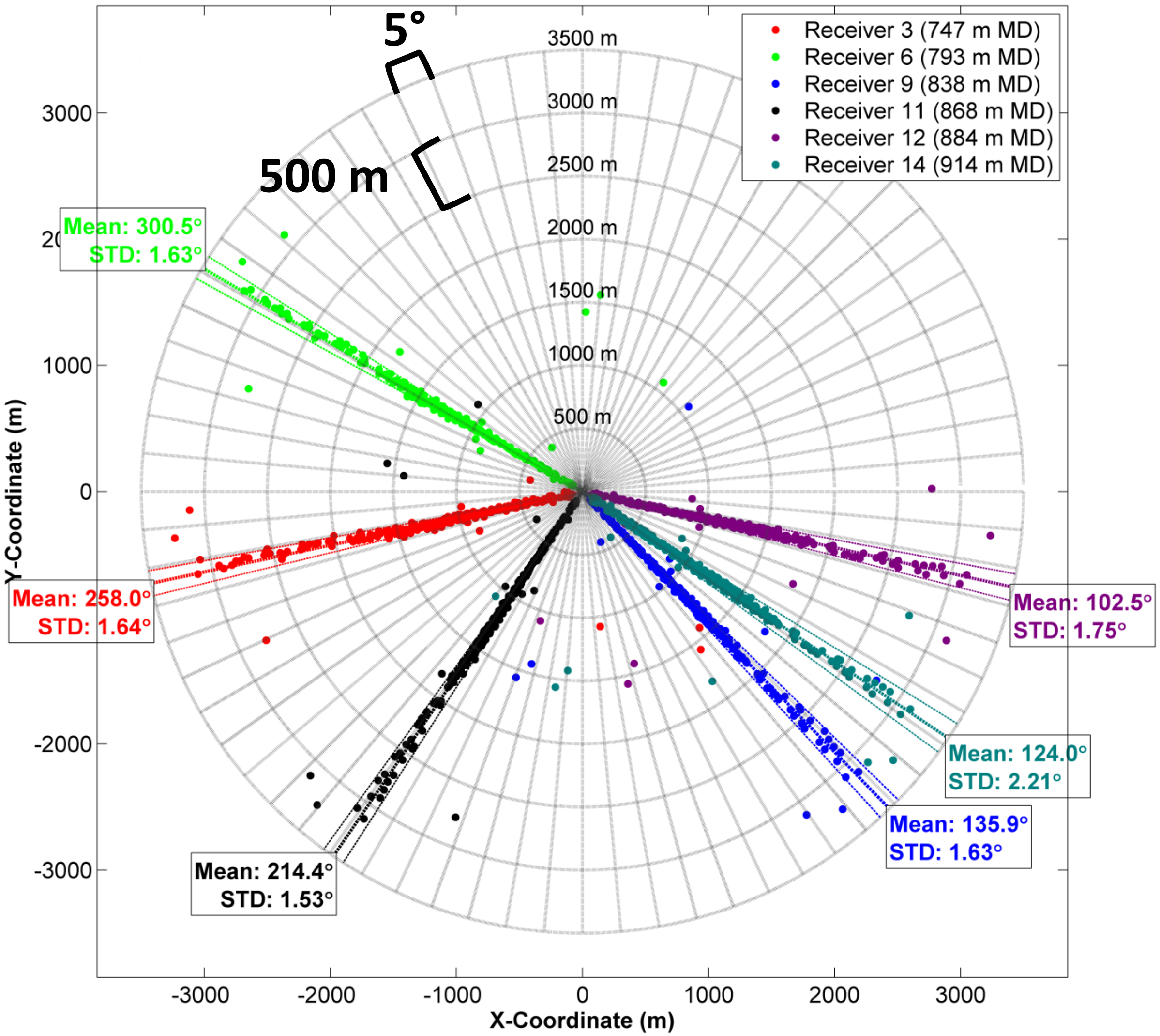


-Assumes very high Q
-Ignores raybending

Geometrical spreading & incident angle:

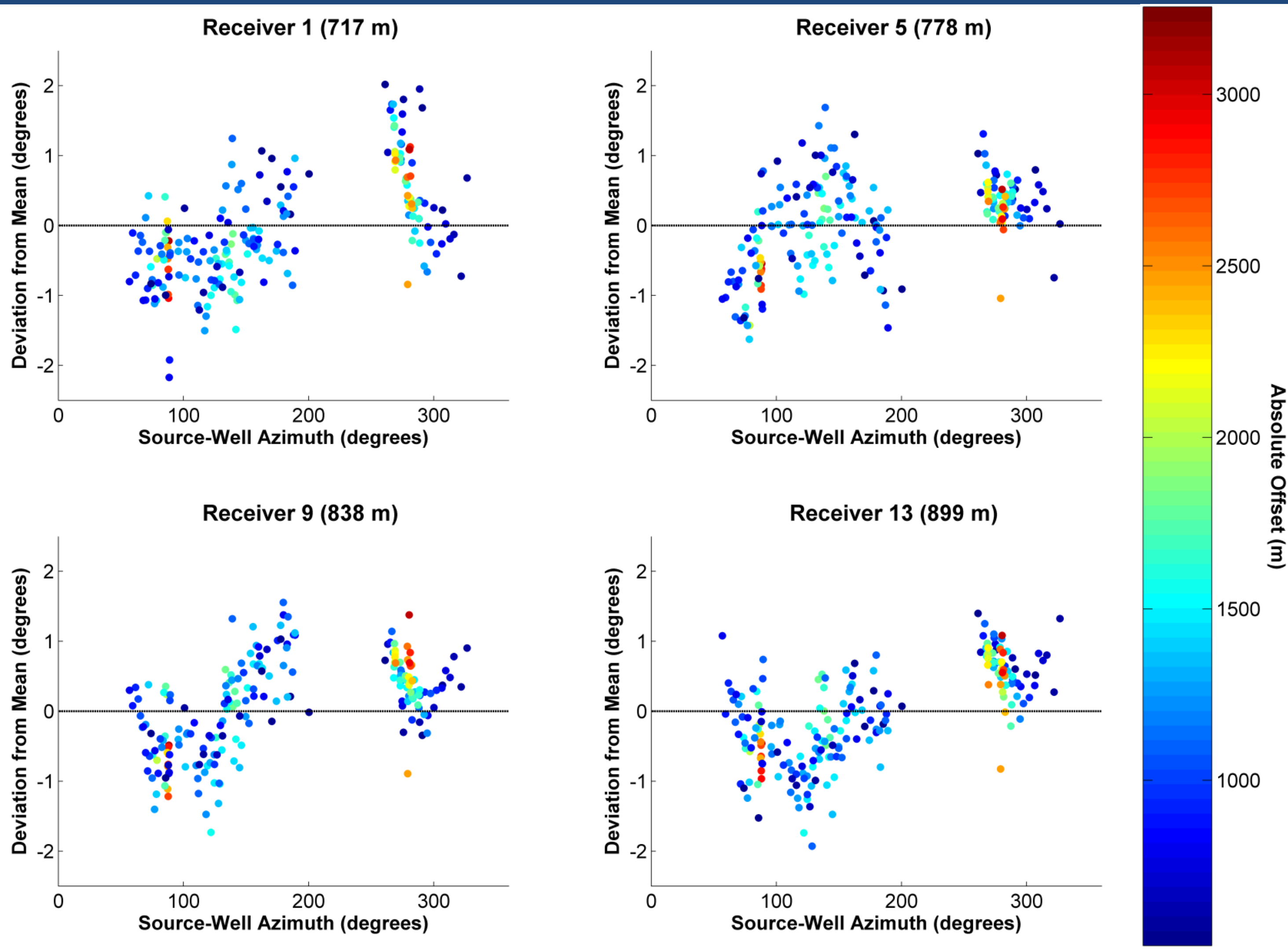
$$\frac{A_H}{A_0} = \frac{x}{x^2 + z^2}$$

Radial Plot

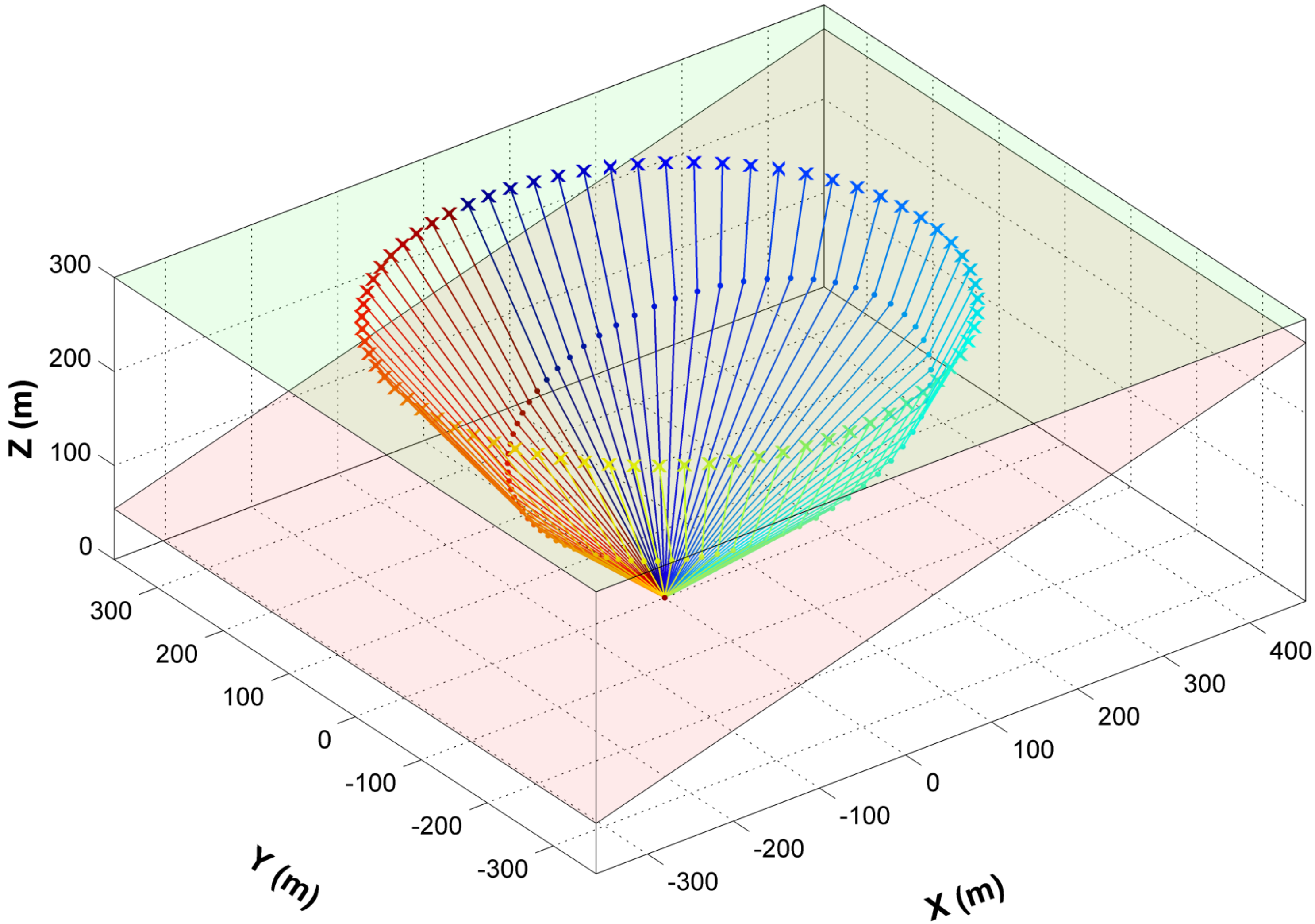


5°
500 m
3500 m
3000 m
2500 m
2000 m
1500 m
1000 m
500 m
Receiver 3 (747 m MD)
Receiver 6 (793 m MD)
Receiver 9 (838 m MD)
Receiver 11 (868 m MD)
Receiver 12 (884 m MD)
Receiver 14 (914 m MD)
Mean: 300.5°
STD: 1.63°
Mean: 258.0°
STD: 1.64°
Mean: 102.5°
STD: 1.75°
Mean: 124.0°
STD: 2.21°
Mean: 135.9°
STD: 1.63°
Mean: 214.4°
STD: 1.53°
Y-Coordinate (m)
X-Coordinate (m)
3000
1000
0
-2000
-3000
-3000
-2000
-1000
0
1000
2000
3000

Orientation vs. Azimuth (Offset > 500 m)



Dipping Beds (Lateral Raybending)



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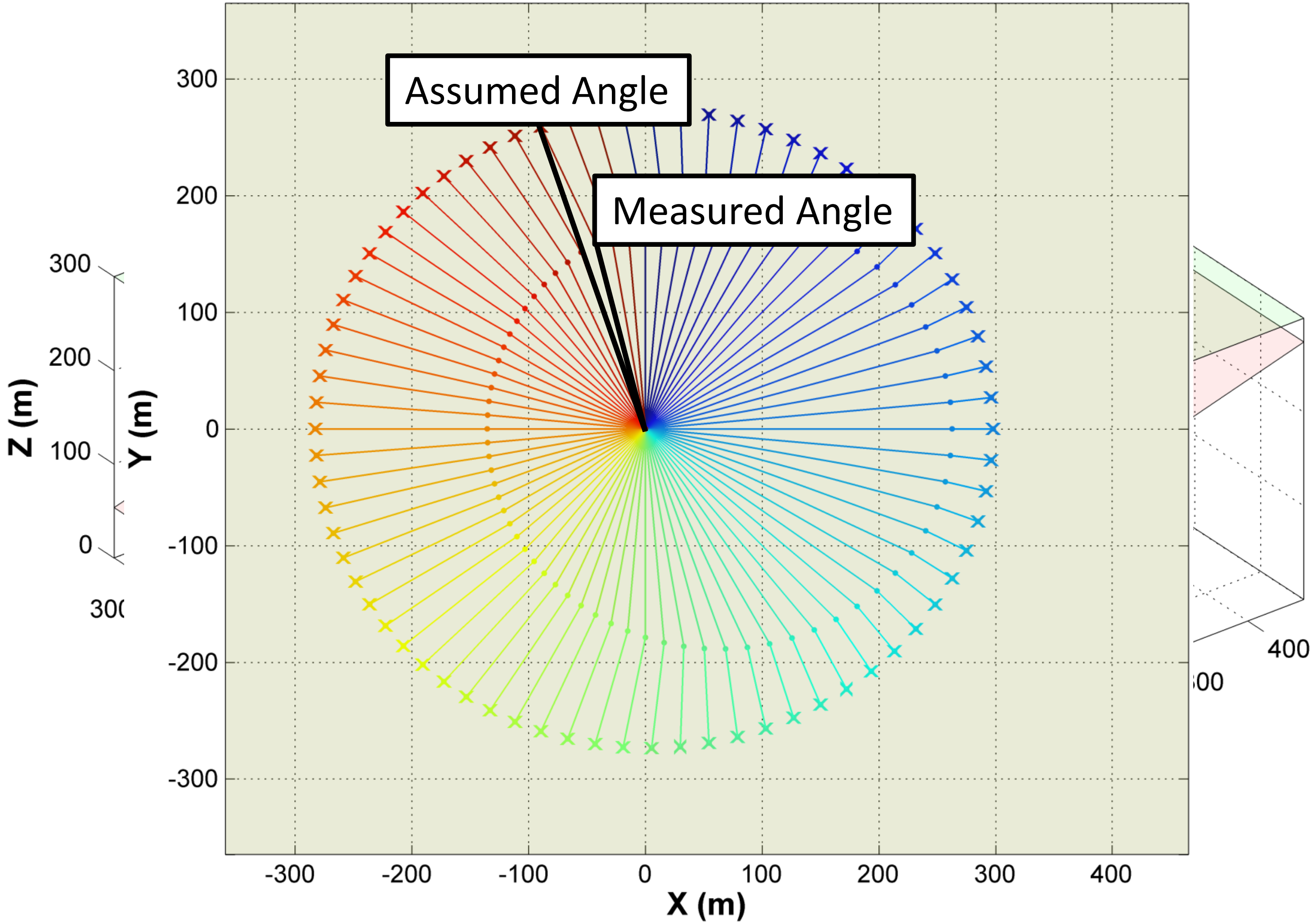
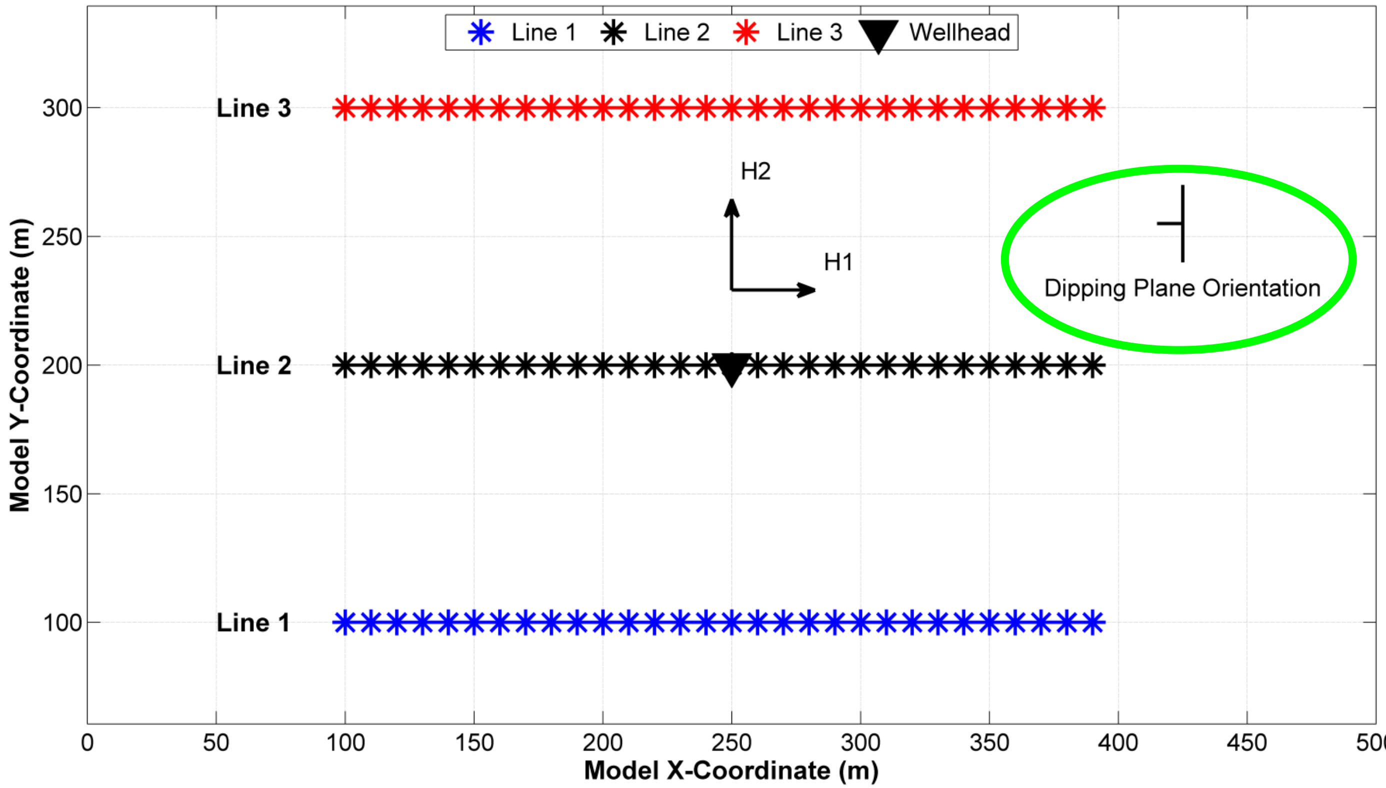


Finite Difference Model (Using TIGER)



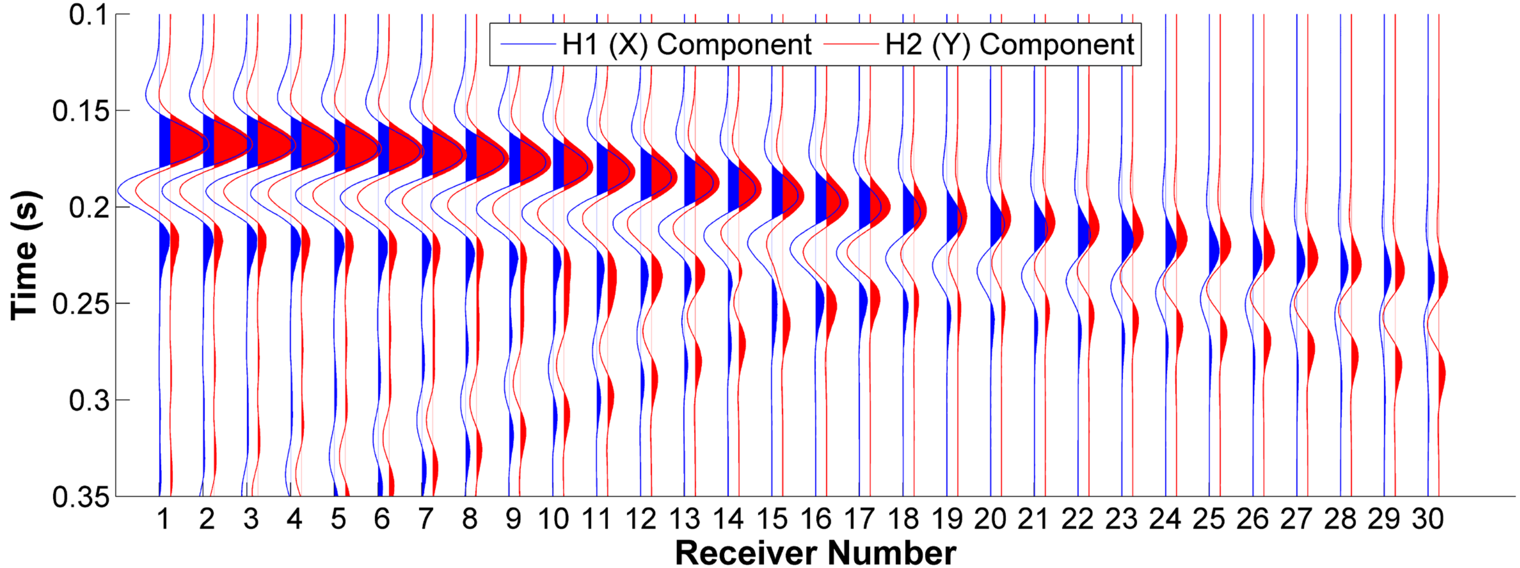
30 receivers
10-300 m
(10 m spacing)

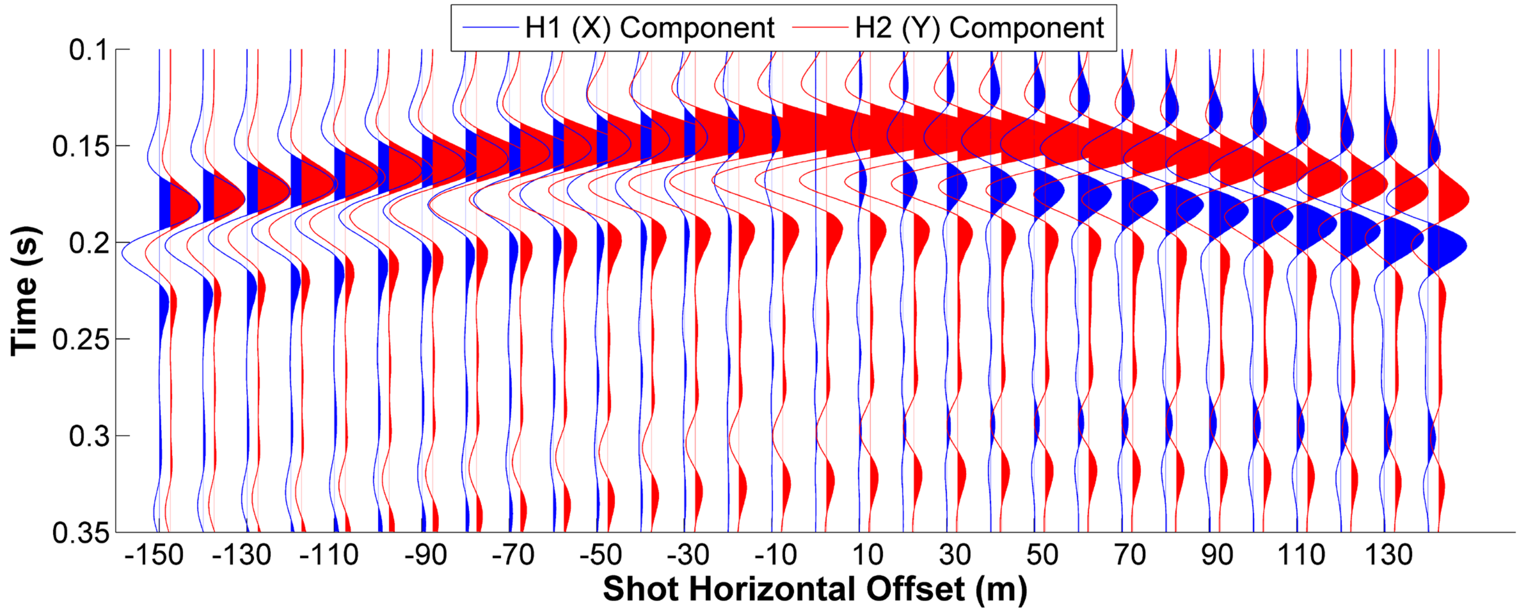
Layer 1 V_P=2000 m/s
Layer 1 V_S=1000 m/s
Layer 2 V_P=2900 m/s
Layer 2 V_S=1740 m/s

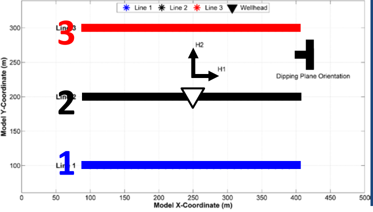
30° Dip
Depth at well=175 m

90 shots (30 per line)
10 m spacing

Shot and Receiver Gathers

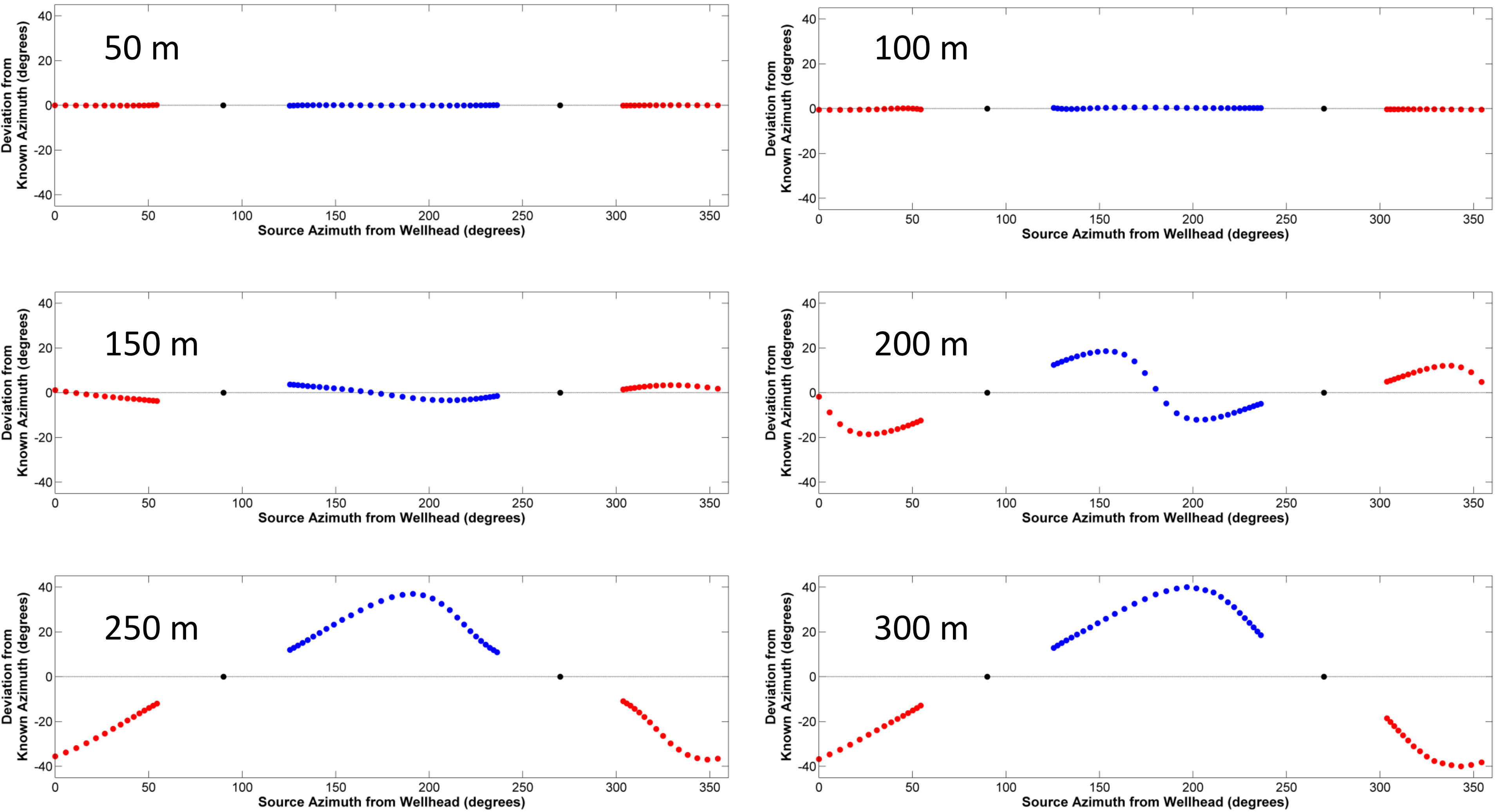






Orientation vs. Azimuth

Range: +/- 40°



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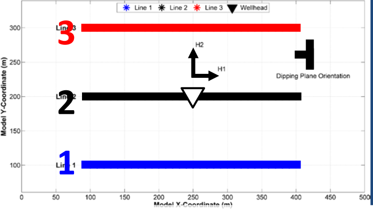
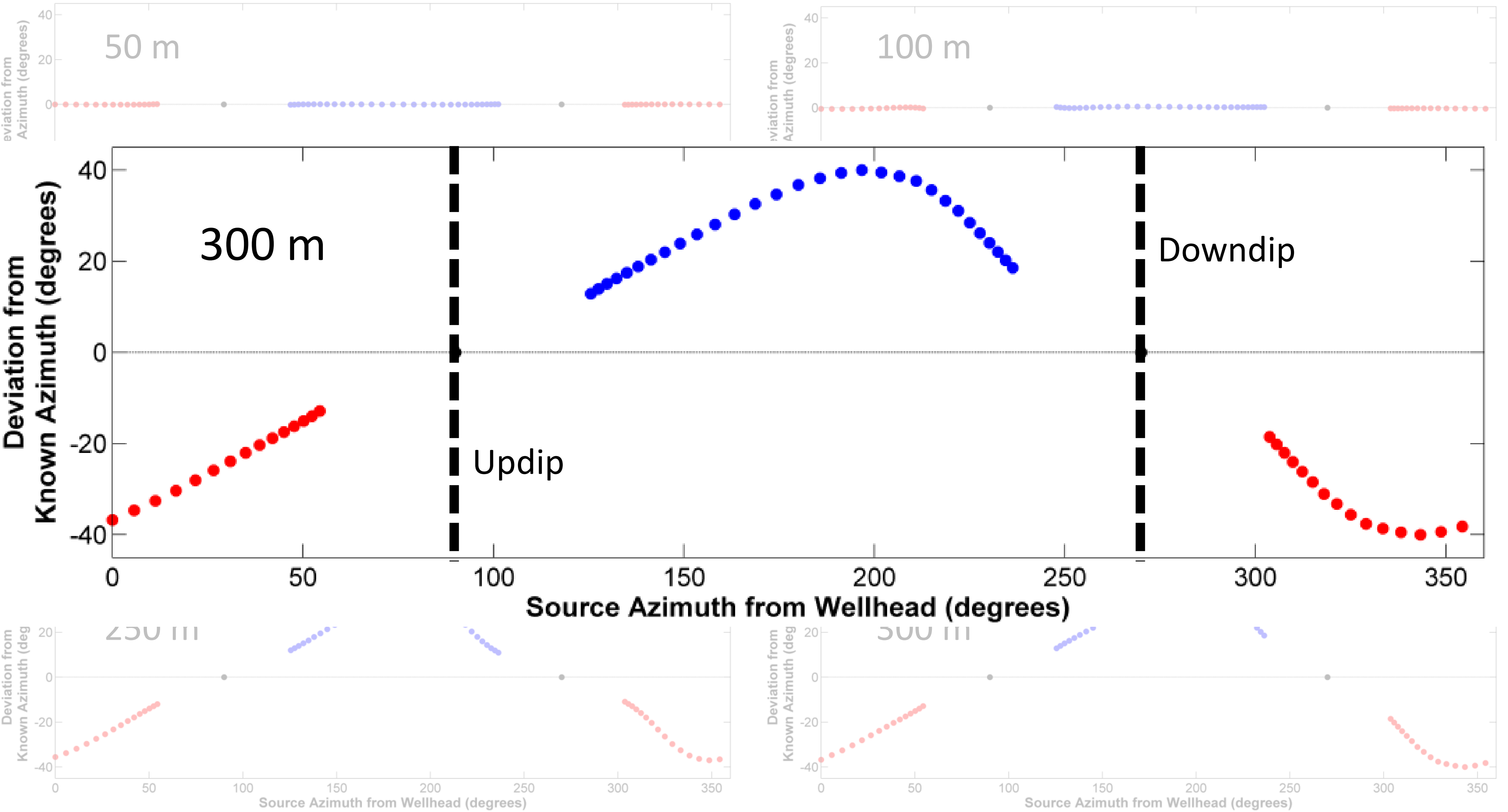
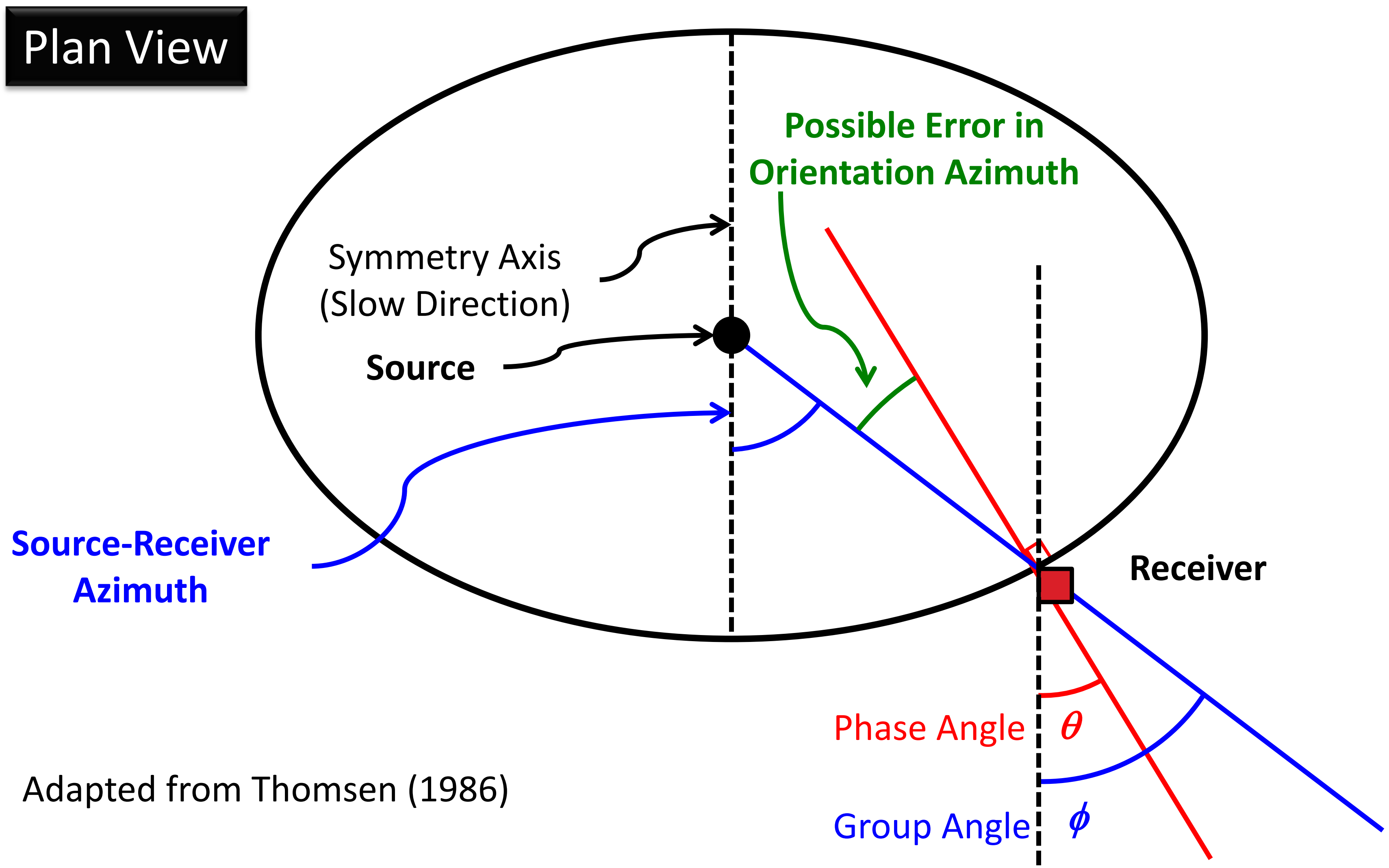


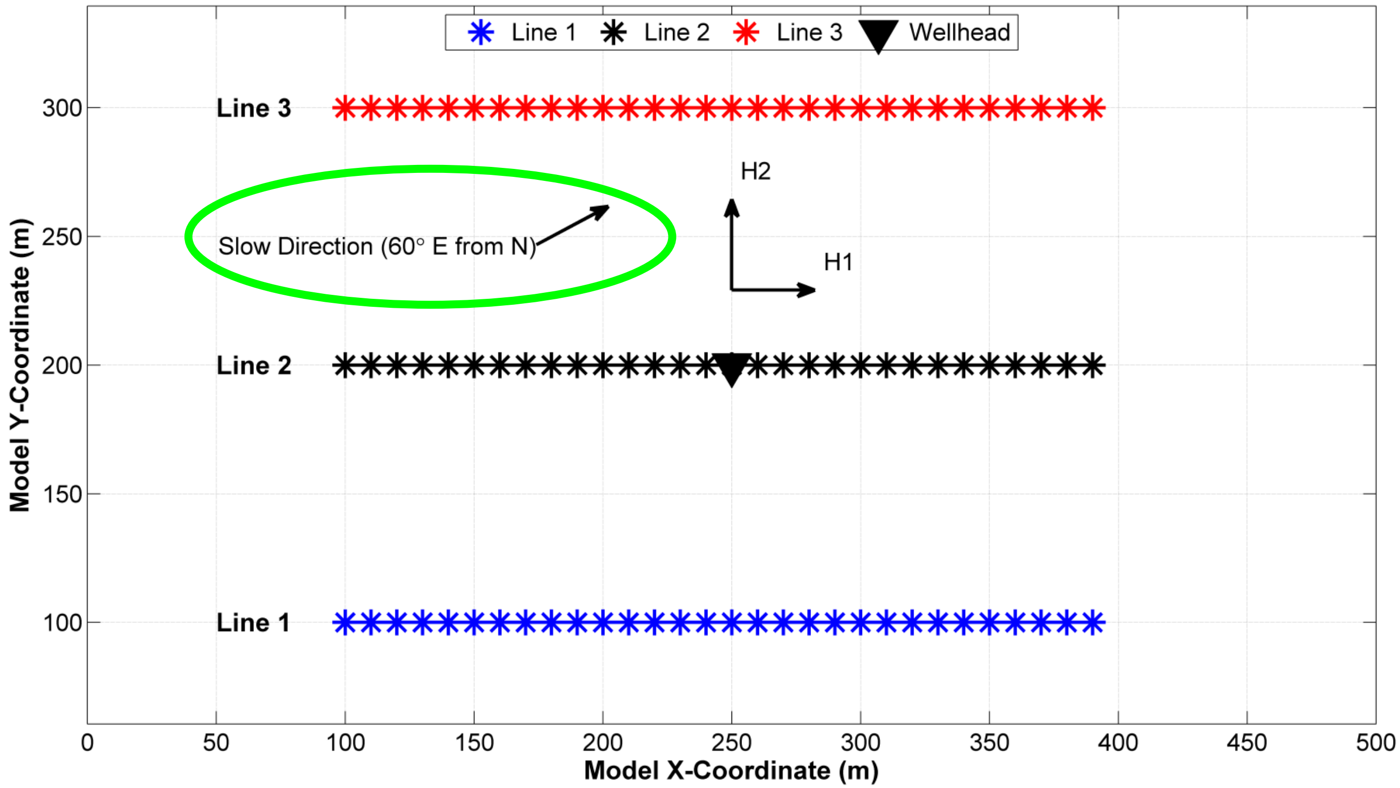


Anisotropy (HTI)



Adapted from Thomsen (1986)

Finite Difference Model



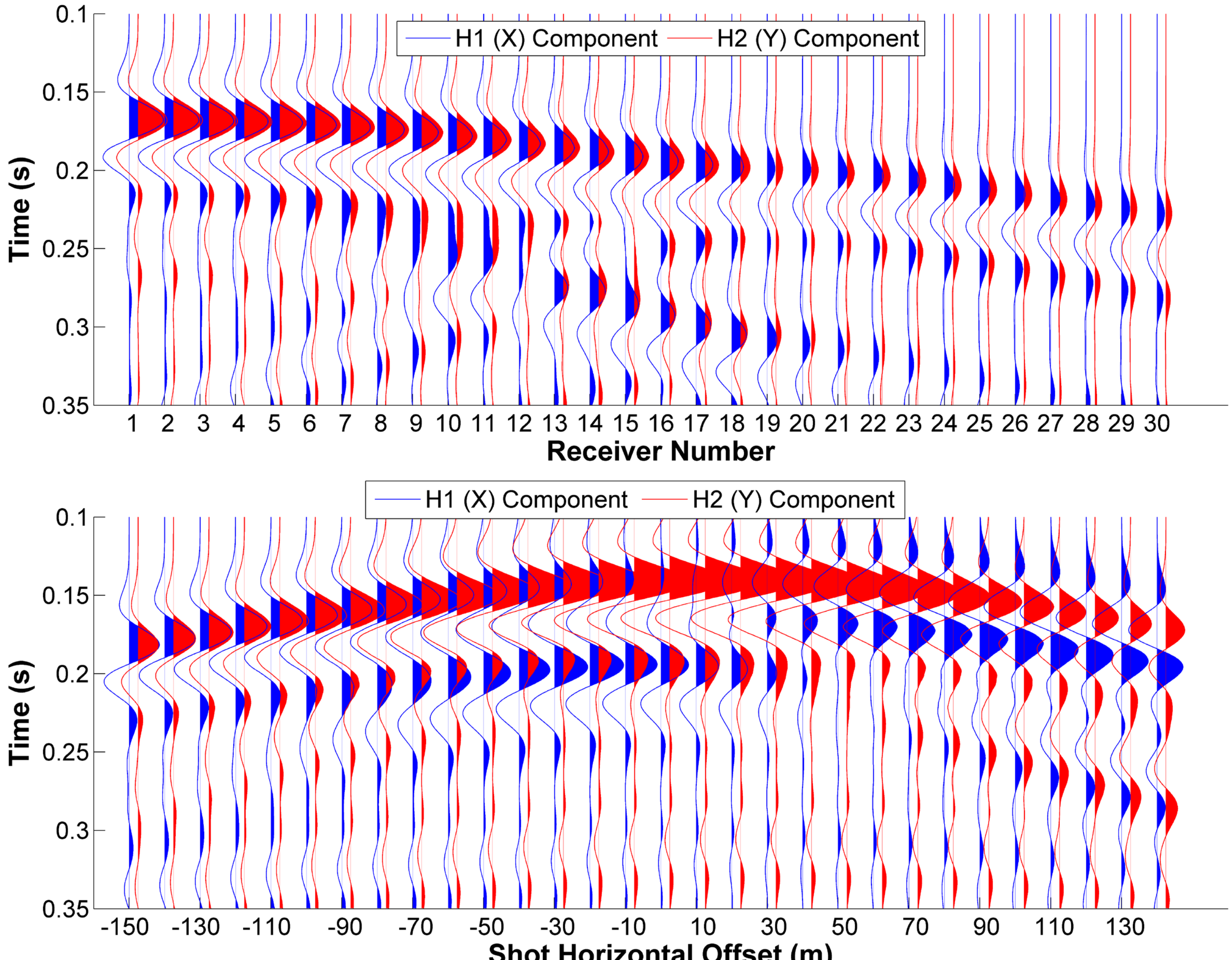
30 receivers
10-300 m
(10 m spacing)

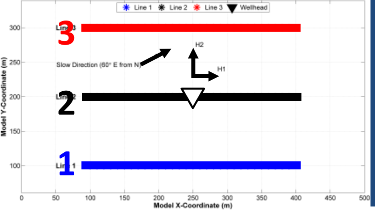
Layer 1 V_P=2000 m/s
Layer 1 V_S=1000 m/s
Layer 2 V_P=2900 m/s
Layer 2 V_S=1740 m/s

Layer 1 ε=0.1
Layer 1 δ=0.025
Layer 1 γ=0.1
Depth at well=180 m

90 shots (30 per line)
10 m spacing

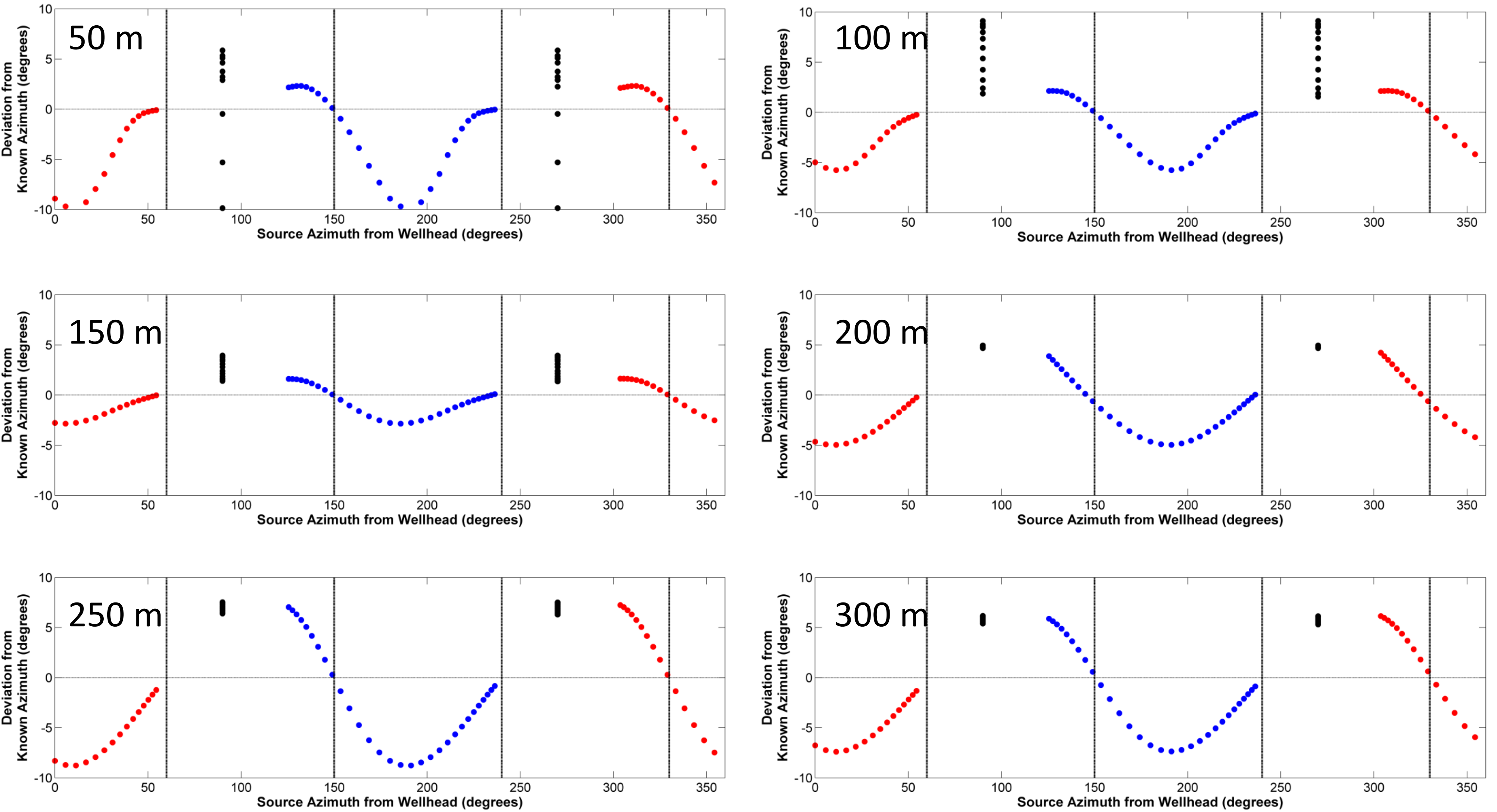
Shot and Receiver Gathers

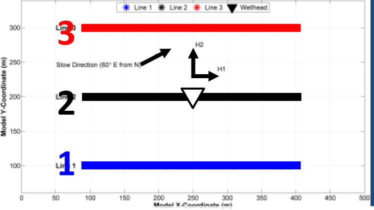




Orientation vs. Azimuth

Range: +/- 10°





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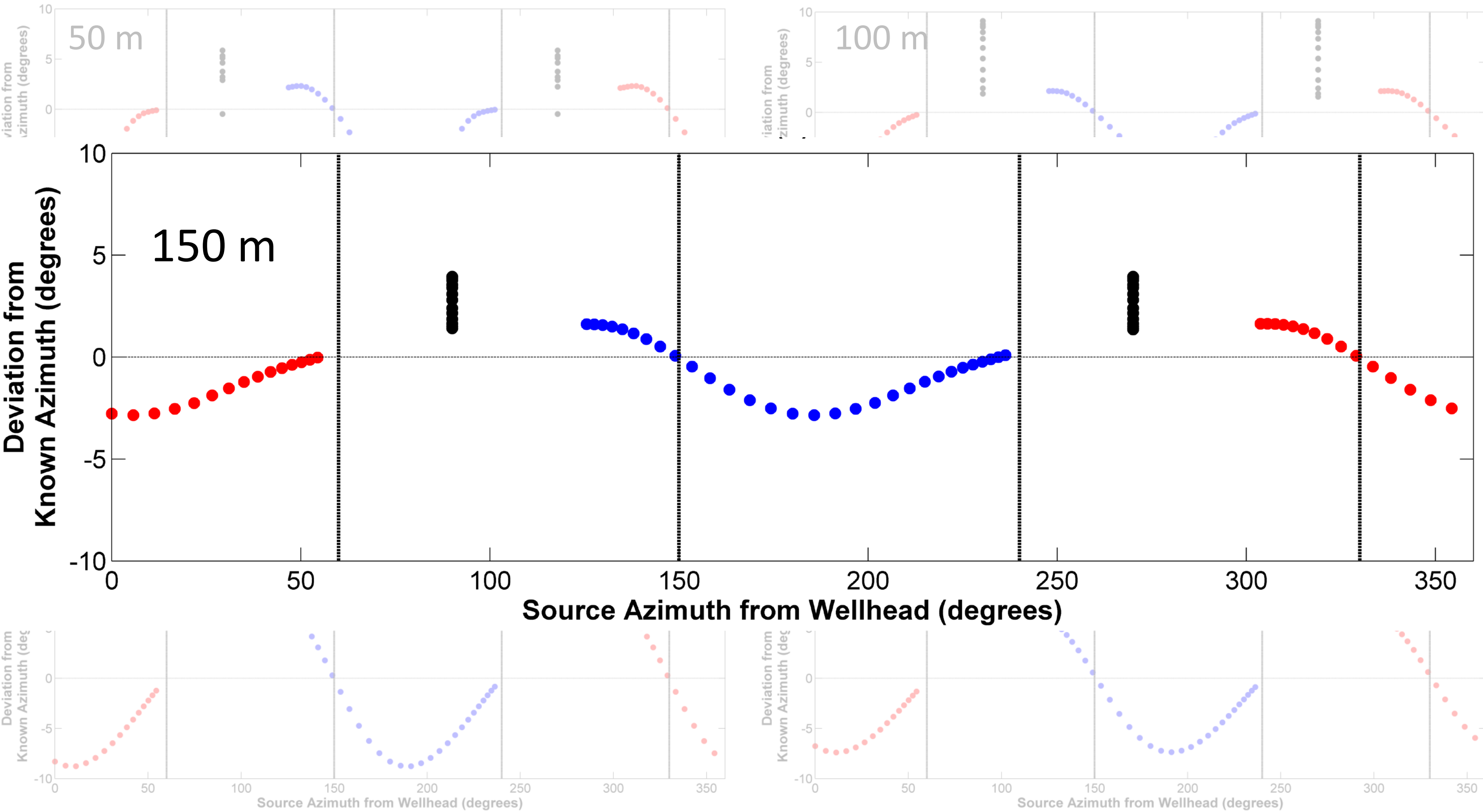
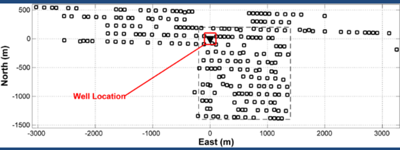
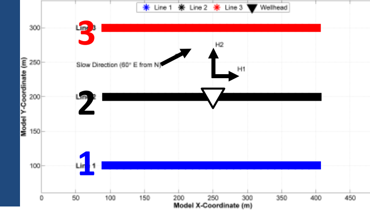
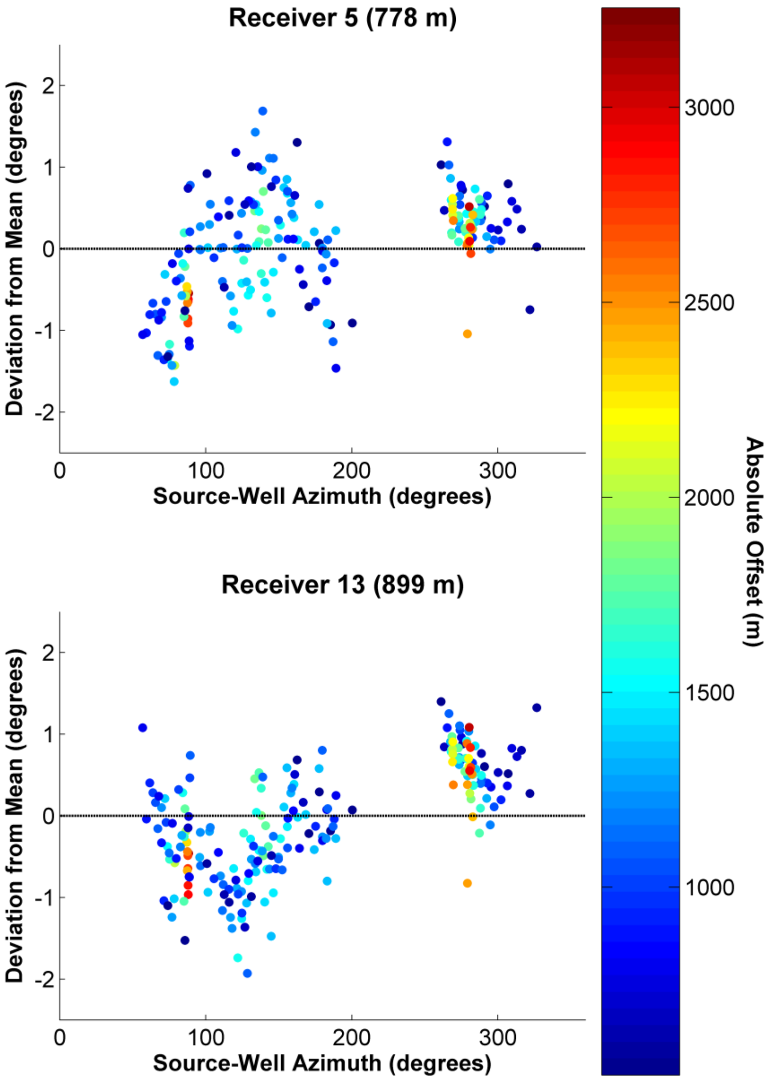
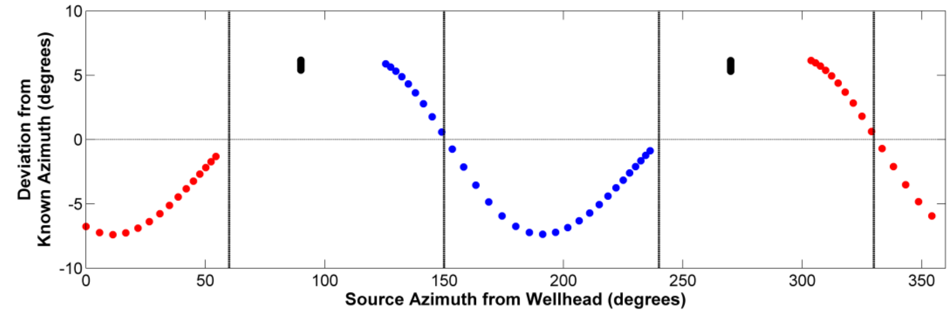


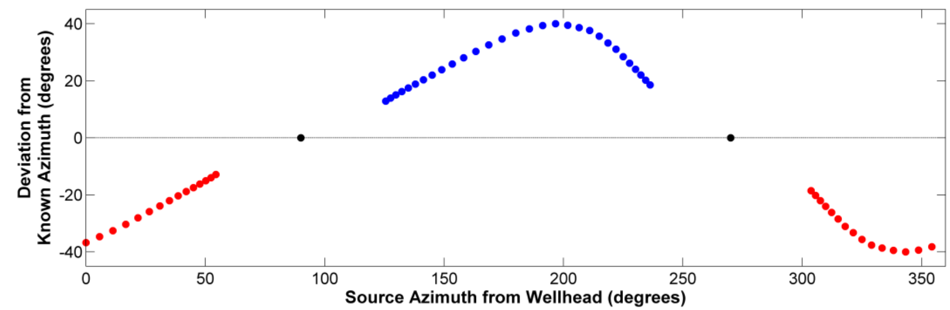


Signatures from Dip or HTI?









Conclusions: Objective 1

Determine optimal **survey design** for calibration

- Source locations nearer than 1/2 receiver depth increase scatter; optimal offset range between 1-2 times receiver depth.
- Scatter:
  - 2D (all/far offsets): 5.22°/0.67°
  - 3D (all/far offsets): 2.41°/1.74°

Conclusions: Objective 2

Characterise and quantify the effects of **lateral raybending** and **seismic anisotropy** on geophone orientation azimuth calibration

- Lateral raybending: one-cycle sinusoid over azimuth (zero updip and downdip)
- Azimuthal anisotropy: two-cycle sinusoid over azimuth (zero in fast and slow directions)
- Deviation patterns from lateral raybending possible match in Lousana case study

Acknowledgements

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