MICROSEISMIC RESEARCH AT CREWES

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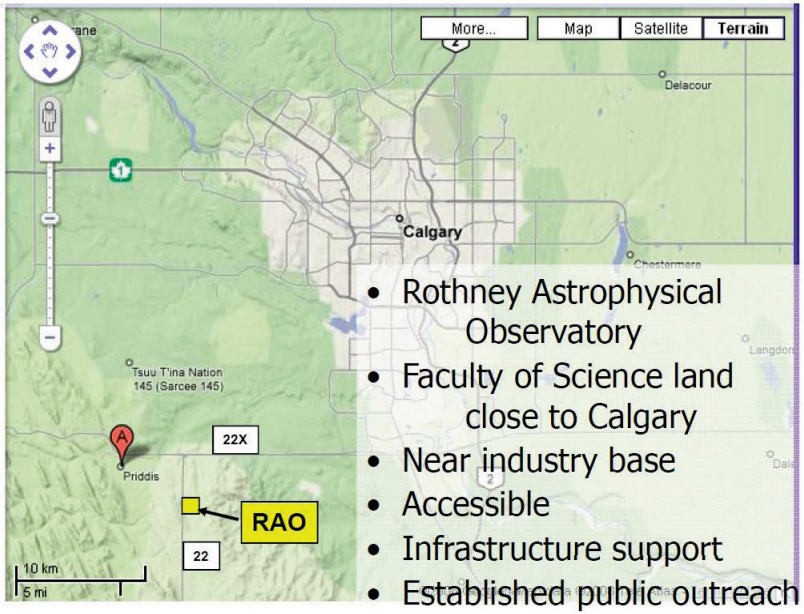
CREWES

OUTLINE

- Introduction / Motivation
- Automatic Time Picking
- Hypocenter Location using noisy data
  - Hodogram/back-azimuth analysis
  - Nonlinear Optimization
    - Levenberg-Marquardt inversion
    - Direct search (GA and PS)
- Summary and Conclusions.

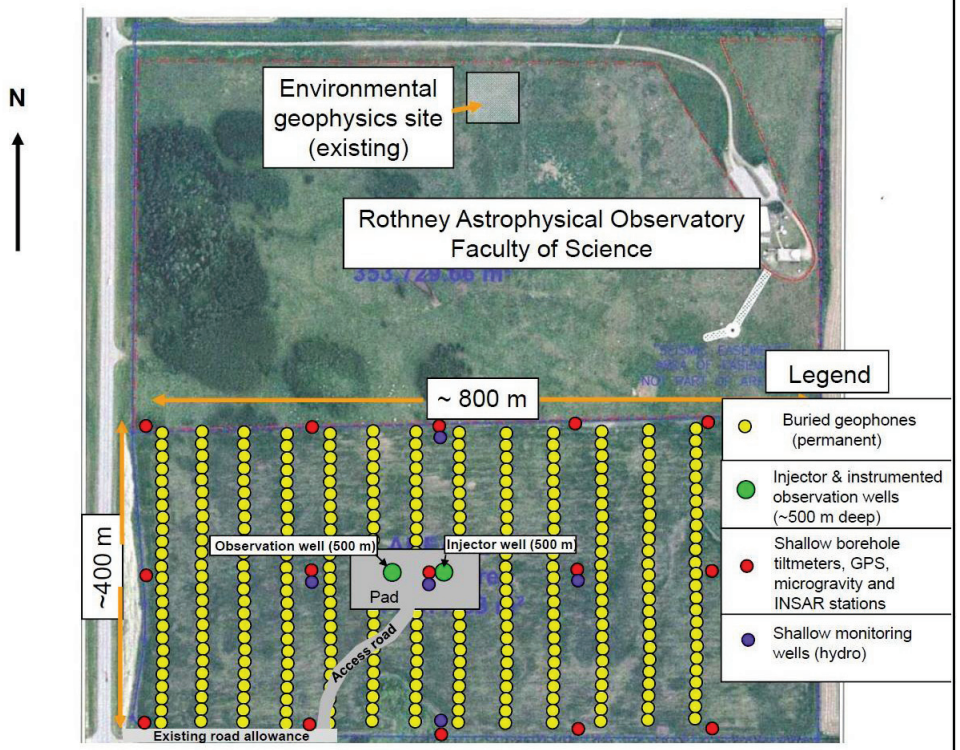
Motivation

UofC field test & training centre



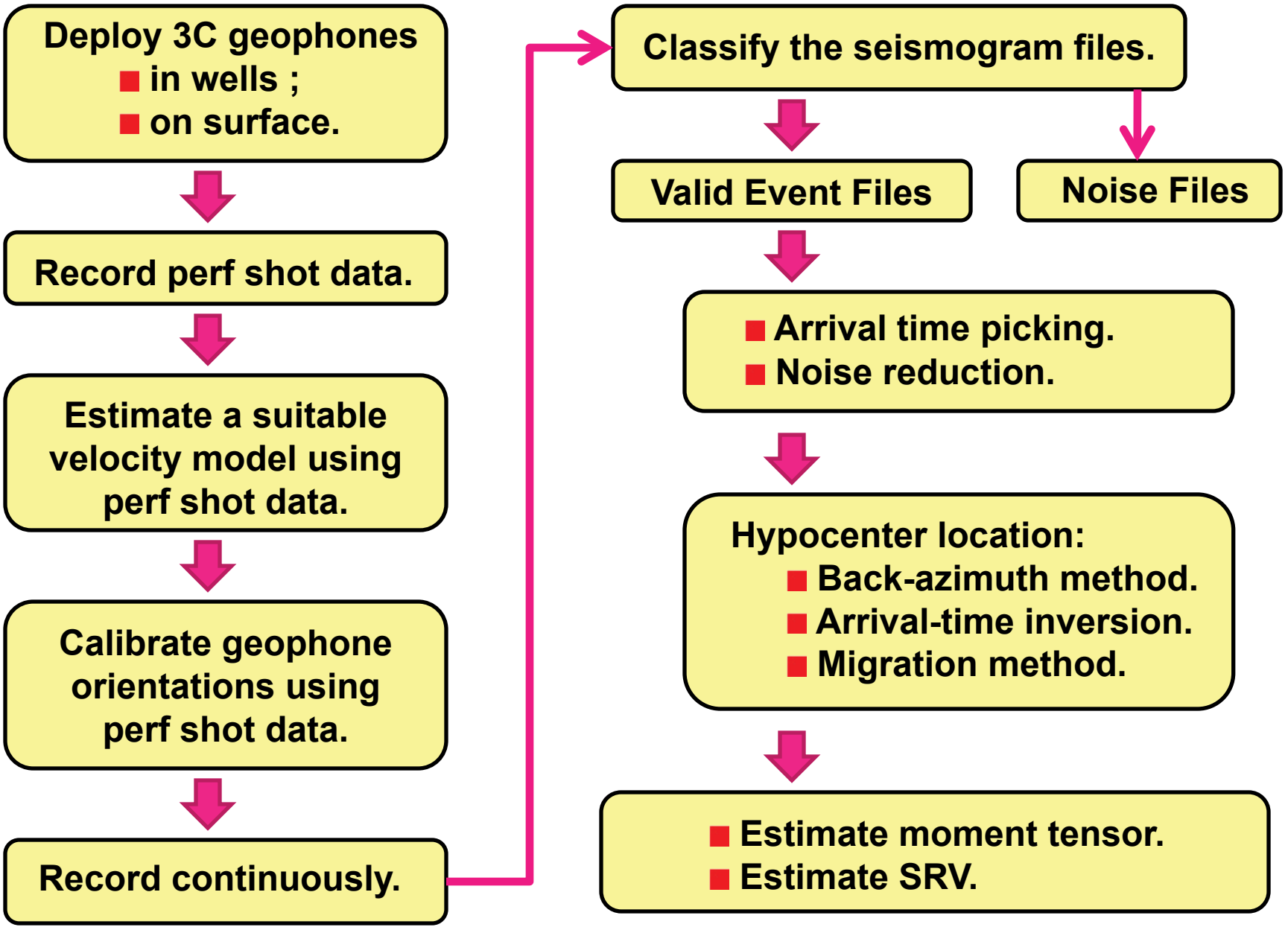
- Rothney Astrophysical Observatory
- Faculty of Science land close to Calgary
- Near industry base
- Accessible
- Infrastructure support
- Established public outreach

www.google.ca



(images courtesy of D. Lawton)

Microseismic Monitoring



FAST AUTOMATIC TIME PICKING

Develop the MER (modified energy ratio) technique for automatic time picking and compare with the standard STA/LTA method.

STA/LTA Ratio

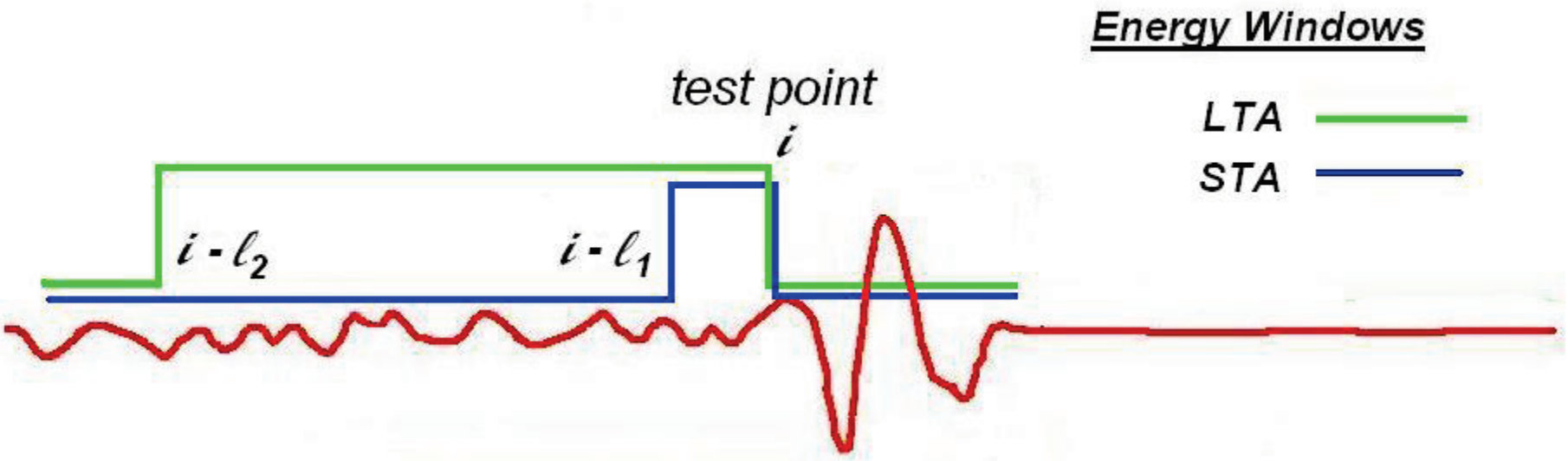
$$STA = \sum_{j=i}^{i-l_1} grm(i)^2 / l_1$$

Short-term average

$$l_2 = 10 * l_1$$

$$LTA = \sum_{j=i}^{i-l_2} grm(i)^2 / l_2$$

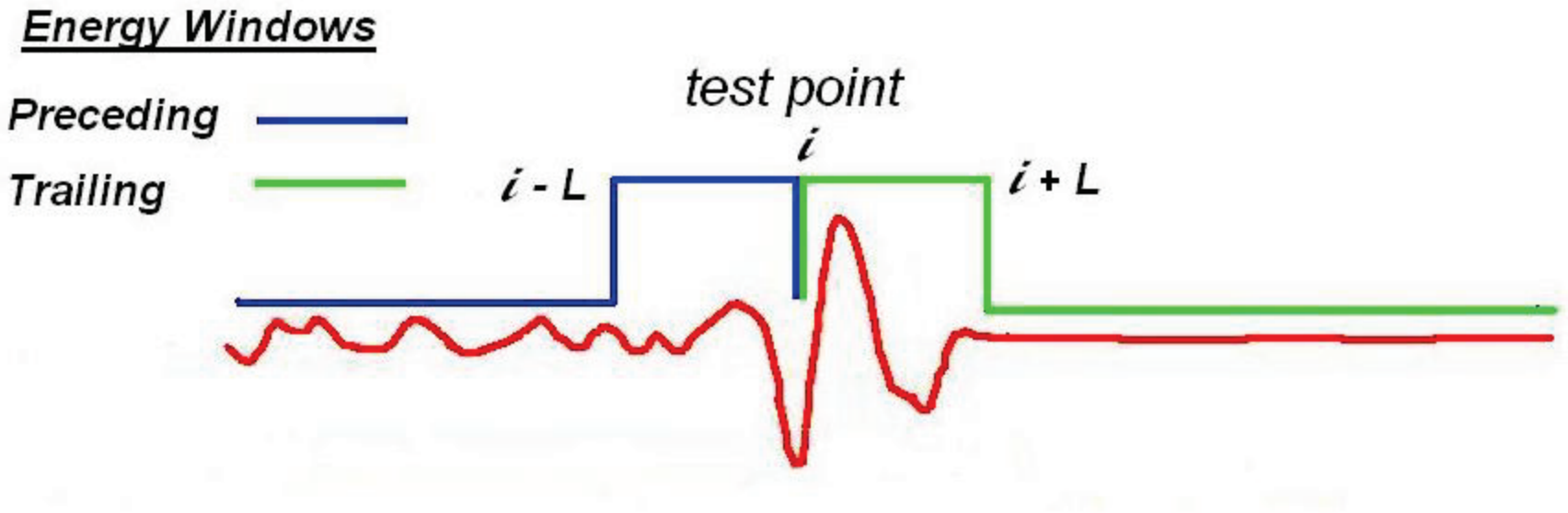
Long-term average

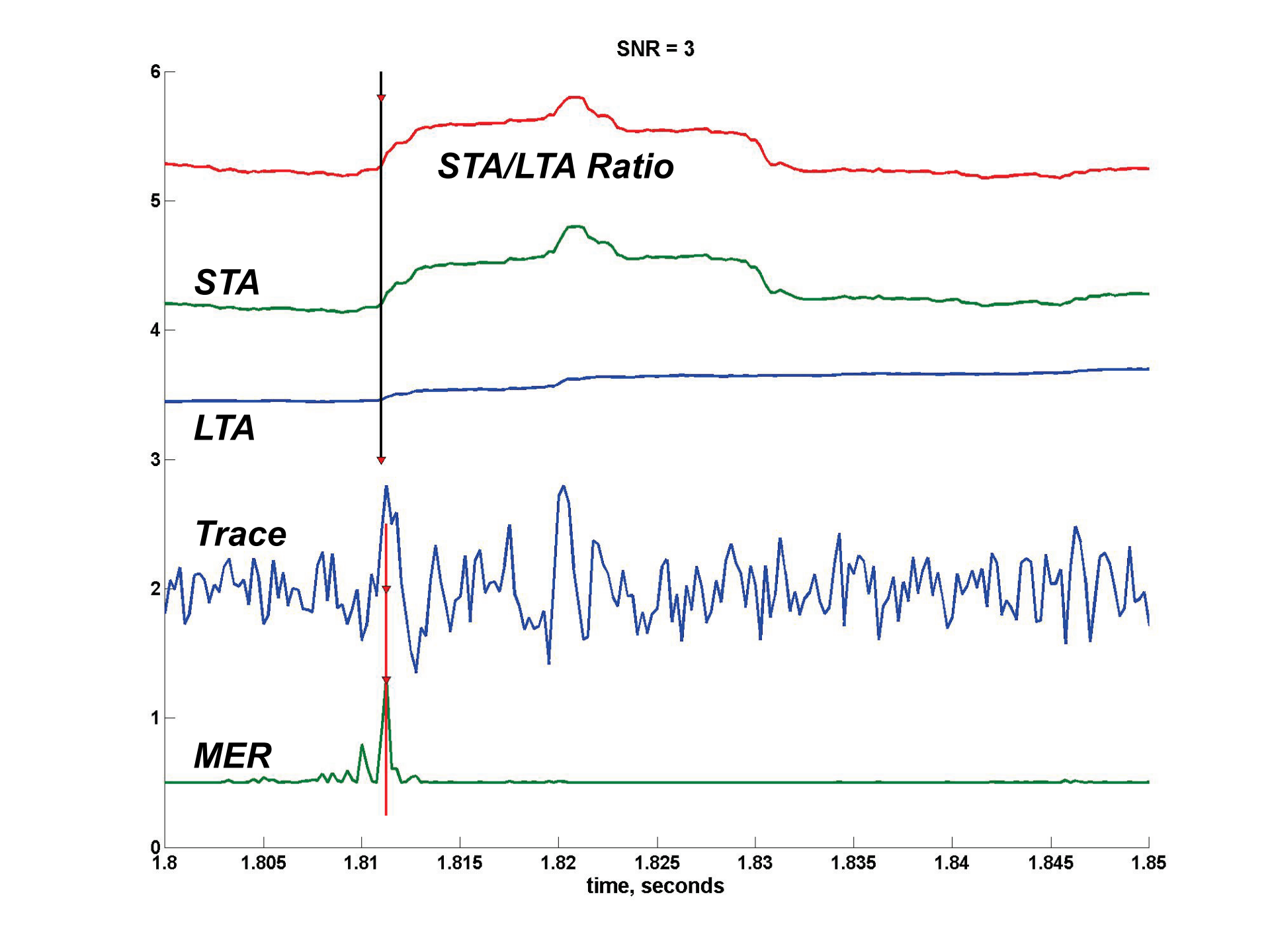


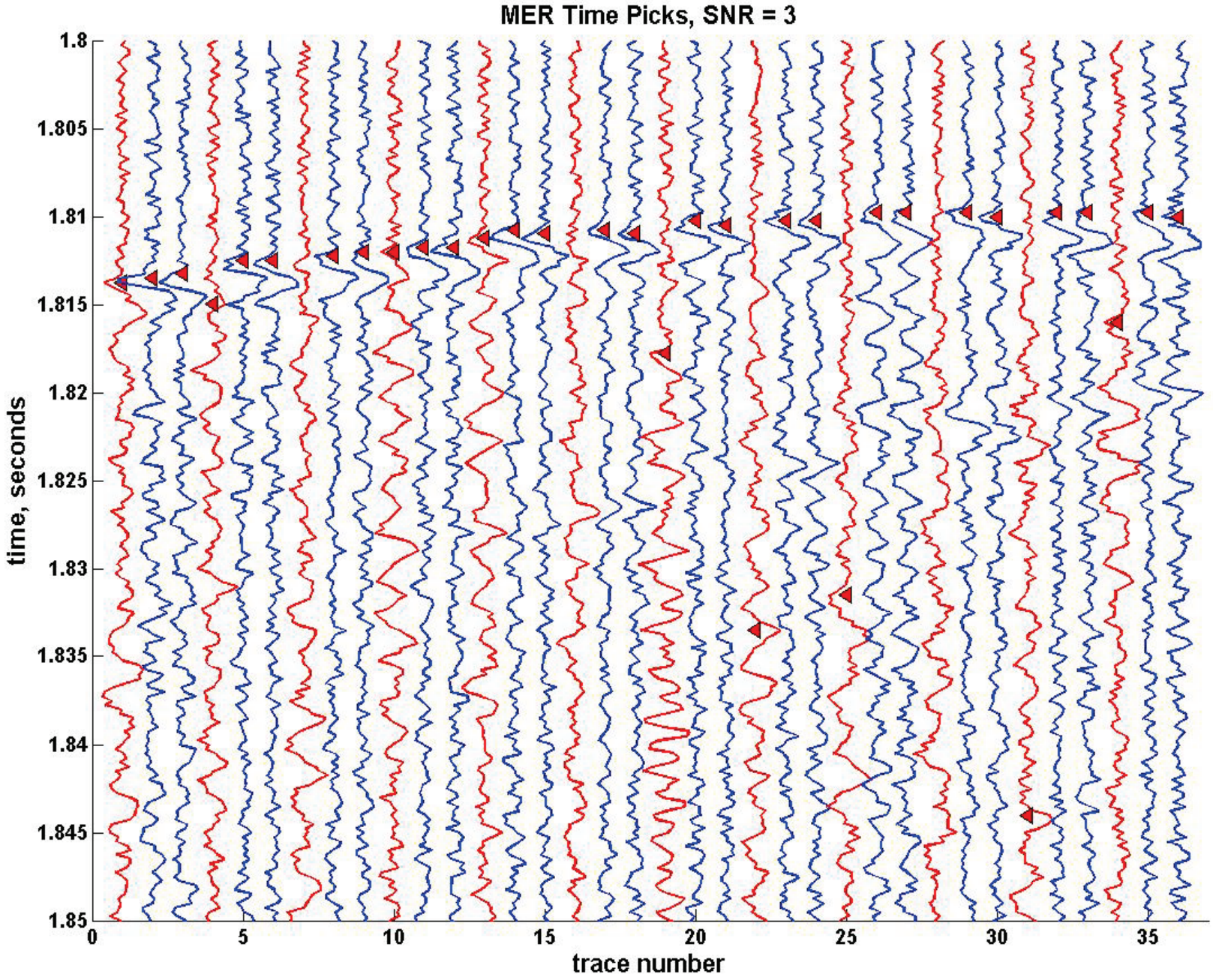
Modified Energy Ratio

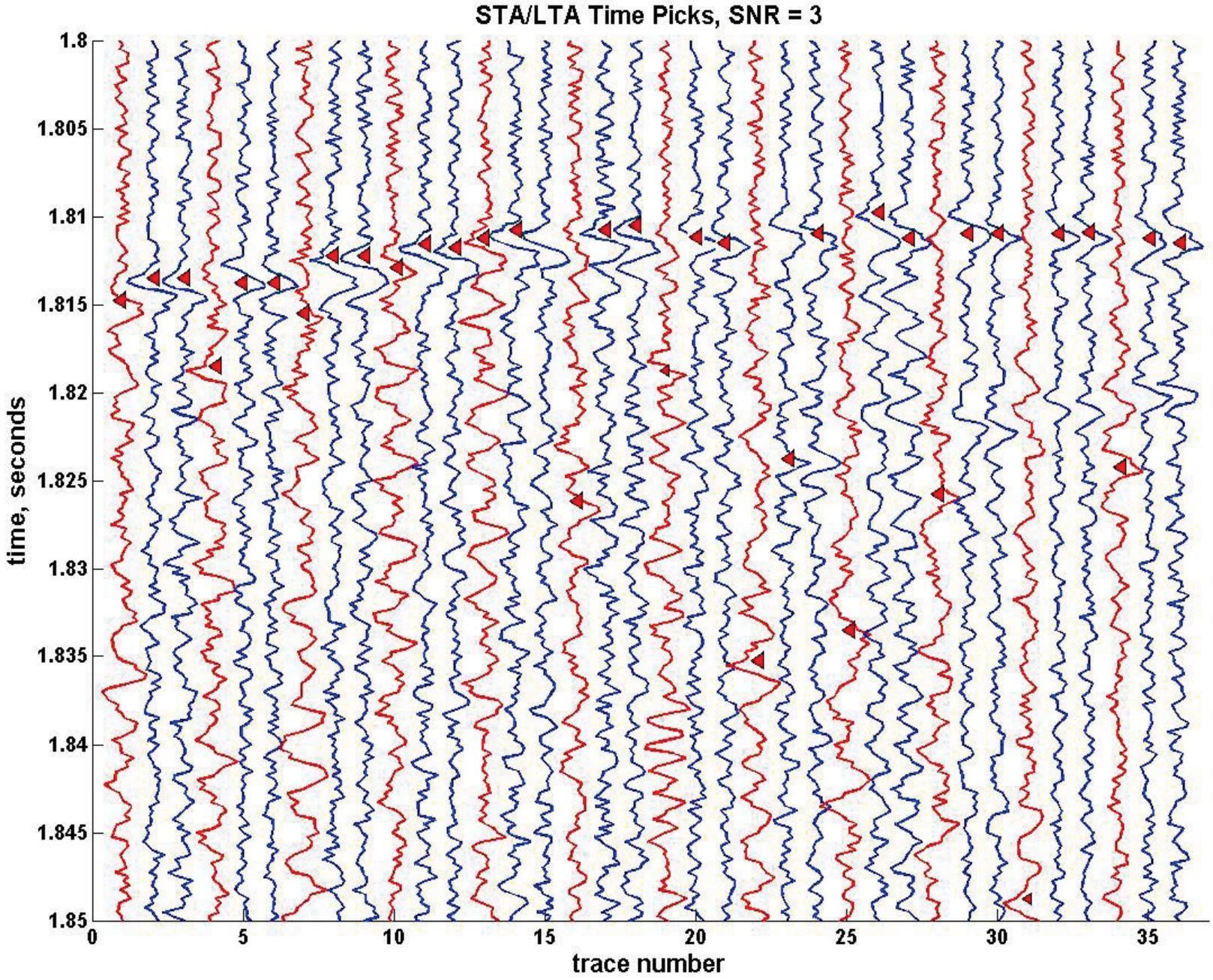
$$er(i) = \sum_{j=i}^{i+L} grm(j)^2 \Big/ \sum_{j=i-L}^{i} grm(j)^2$$

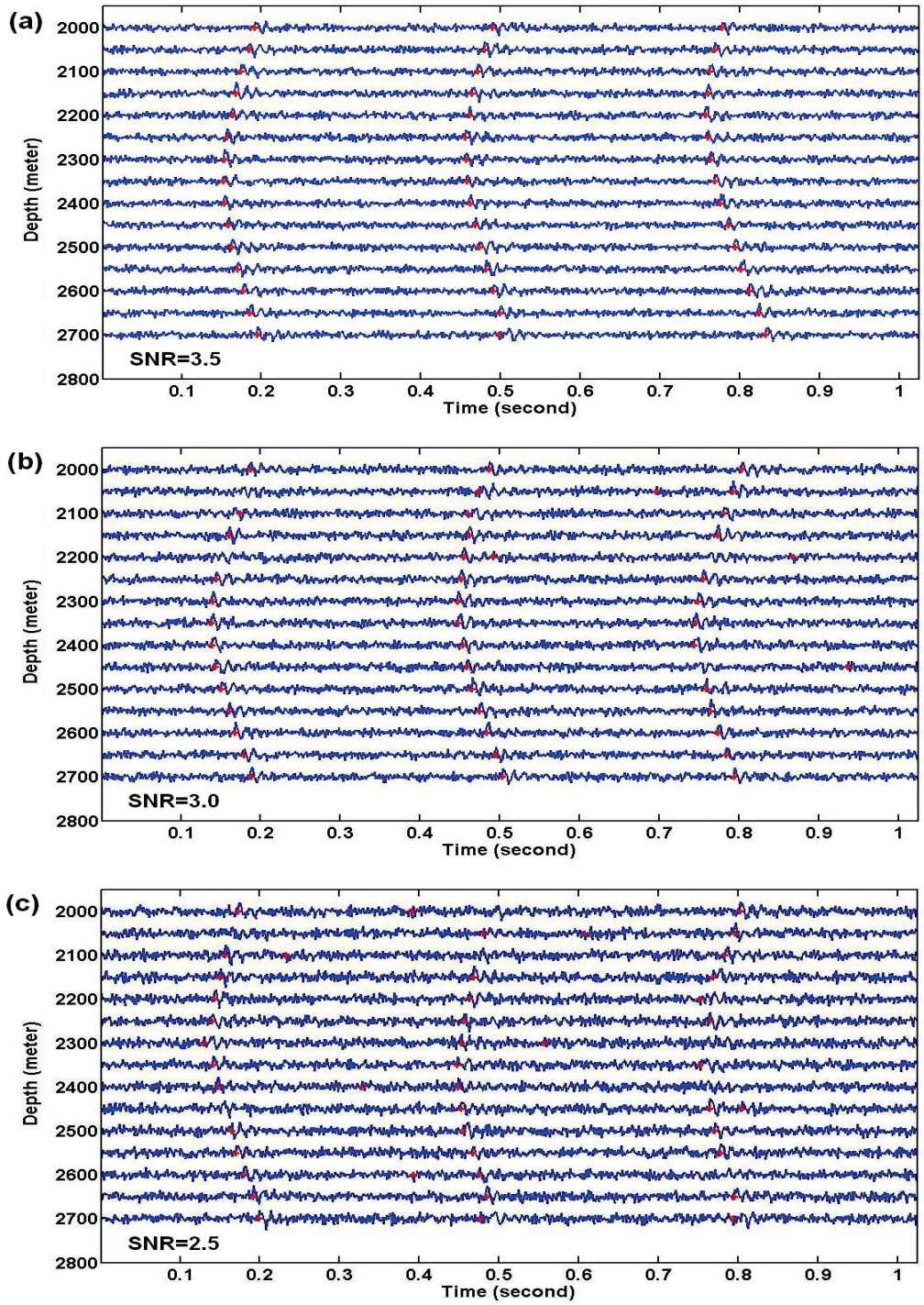
$$mer(i) = [er(i) * abs(grm(i)]^3$$

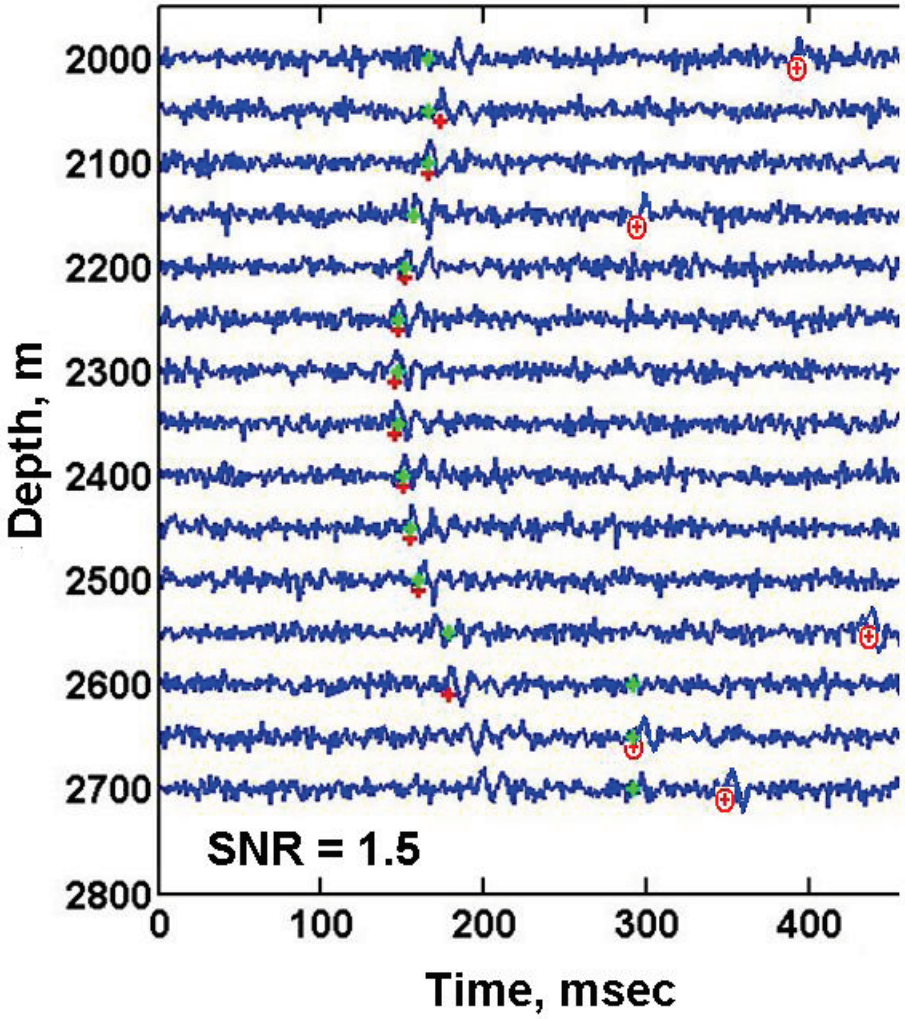


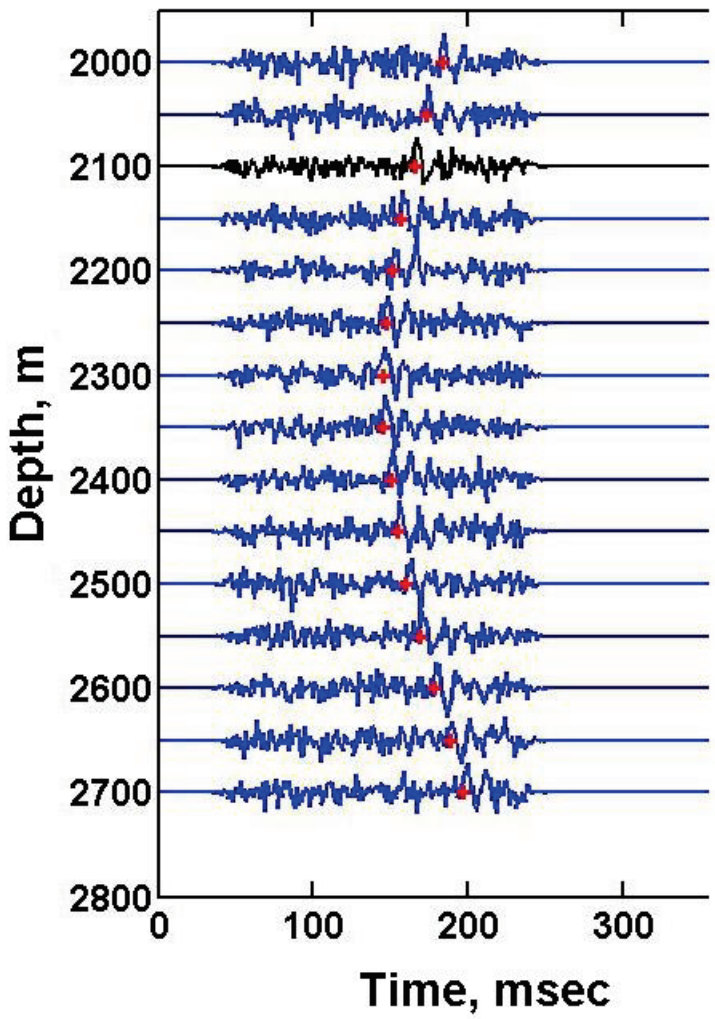

SNR = 3
STA/LTA Ratio
STA
LTA
Trace
MER
6
5
4
3
2
1
0
1.8
1.805
1.81
1.815
1.82
1.825
1.83
1.835
1.84
1.845
1.85
time, seconds


MER Time Picks, SNR = 3
time, seconds
trace number
1.8
1.805
1.81
1.815
1.82
1.825
1.83
1.835
1.84
1.845
1.85
0
5
10
15
20
25
30
35


STA/LTA Time Picks, SNR = 3
time, seconds
trace number
1.8
1.805
1.81
1.815
1.82
1.825
1.83
1.835
1.84
1.845
1.85
0
5
10
15
20
25
30
35


(a)
Depth (meter)
2000
2100
2200
2300
2400
2500
2600
2700
2800
SNR=3.5
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Time (second)
(b)
Depth (meter)
2000
2100
2200
2300
2400
2500
2600
2700
2800
SNR=3.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Time (second)
(c)
Depth (meter)
2000
2100
2200
2300
2400
2500
2600
2700
2800
SNR=2.5
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Time (second)

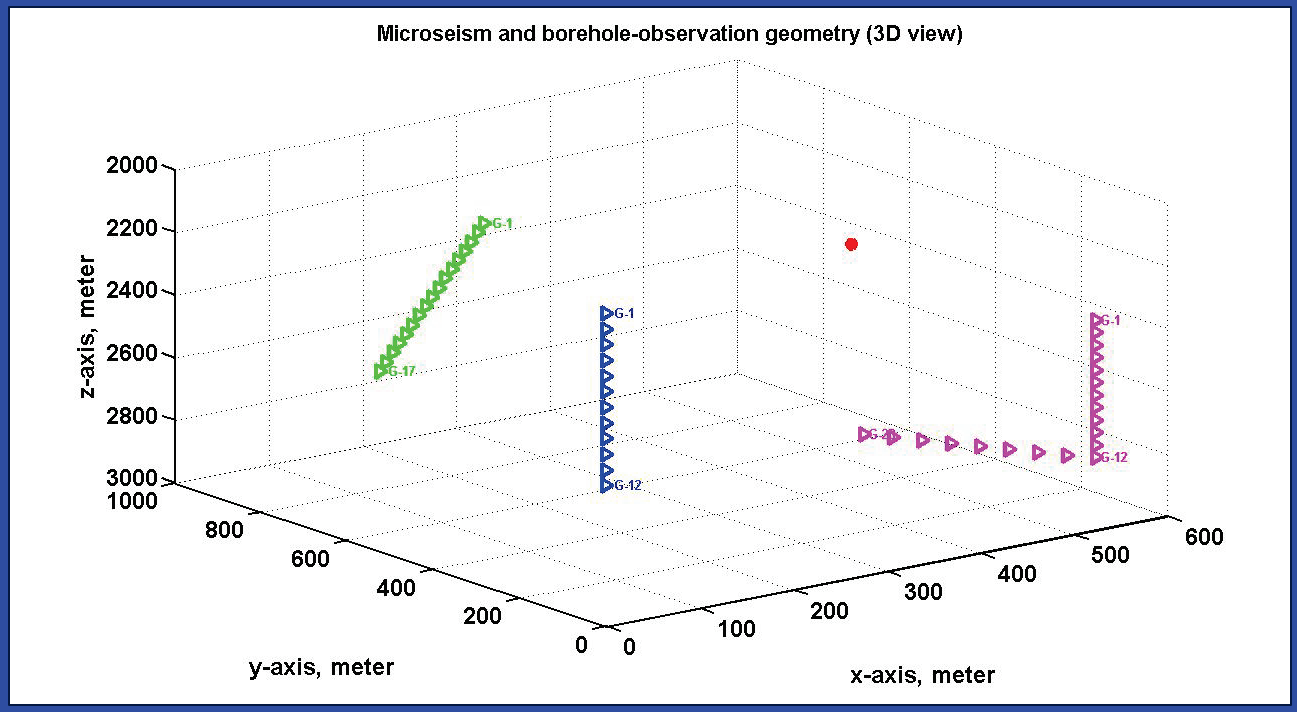

2000
2100
2200
2300
2400
2500
2600
2700
2800
Depth, m
SNR = 1.5
0
100
200
300
400
Time, msec

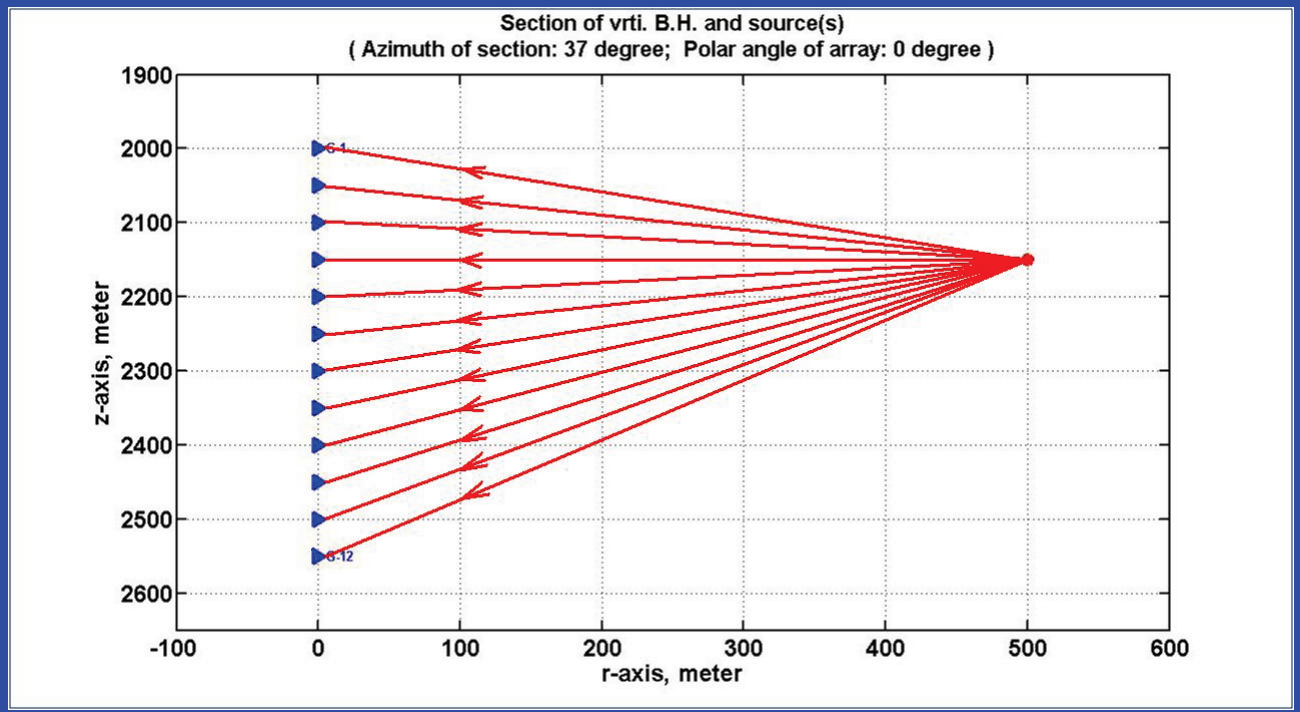

2000
2100
2200
2300
2400
2500
2600
2700
2800
Depth, m
0
100
200
300
Time, msec

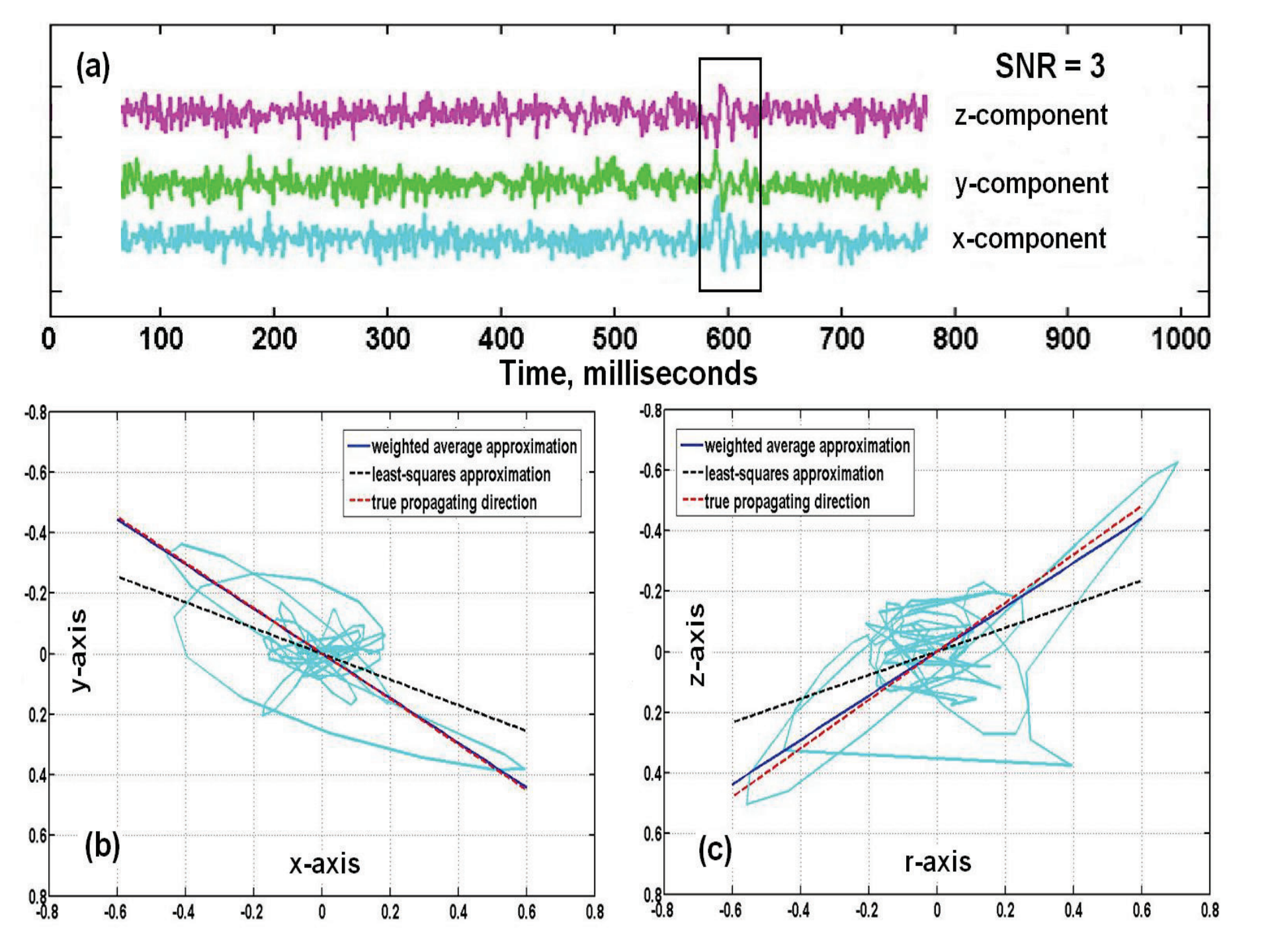
HODOGRAM / BACK-AZIMUTH METHOD FOR LOCATING HYPOCENTERS USING NOISY 3C MICROSEISMOGRAMS

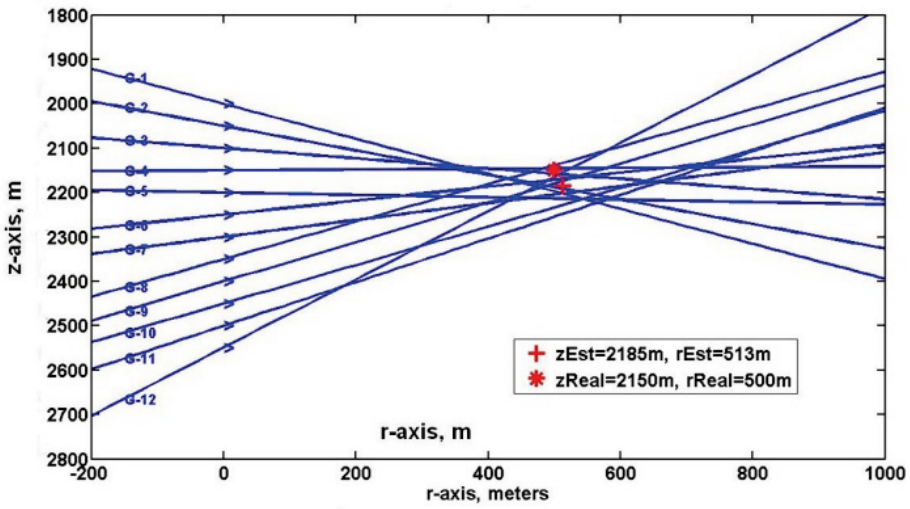
Develop techniques for mitigating the effects of random noise on location accuracy.

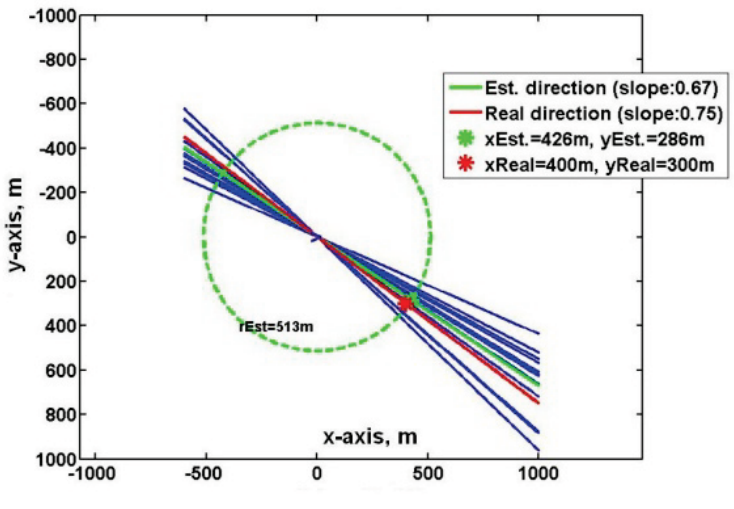
Test on synthetic seismograms generated for a layered-earth velocity model.

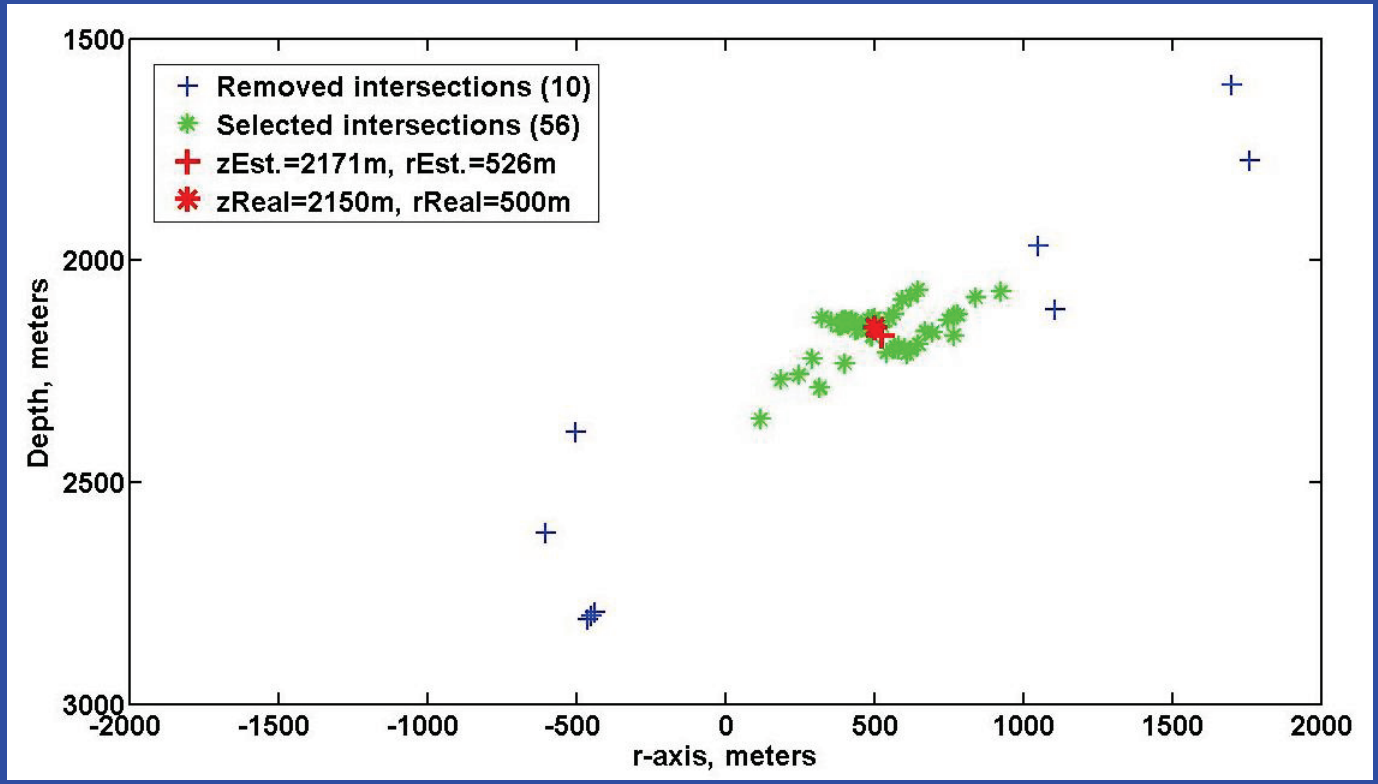

Microseism and borehole-observation geometry (3D view)
z-axis, meter
2000
2200
2400
2600
2800
3000
G-1
G-17
G-1
G-12
G-1
G-12
1000
800
600
400
200
0
y-axis, meter
0
100
200
300
400
500
600
x-axis, meter


Section of vrti. B.H. and source(s)
(Azimuth of section: 37 degree; Polar angle of array: 0 degree)
z-axis, meter
1900
2000
2100
2200
2300
2400
2500
2600
G-1
G-12
-100
0
100
200
300
400
500
600
r-axis, meter


(a)
SNR = 3
z-component
y-component
x-component
0
100
200
300
400
500
600
700
800
900
1000
Time, milliseconds
weighted average approximation
least-squares approximation
true propagating direction
y-axis
x-axis
(b)
weighted average approximation
least-squares approximation
true propagating direction
z-axis
r-axis
(c)

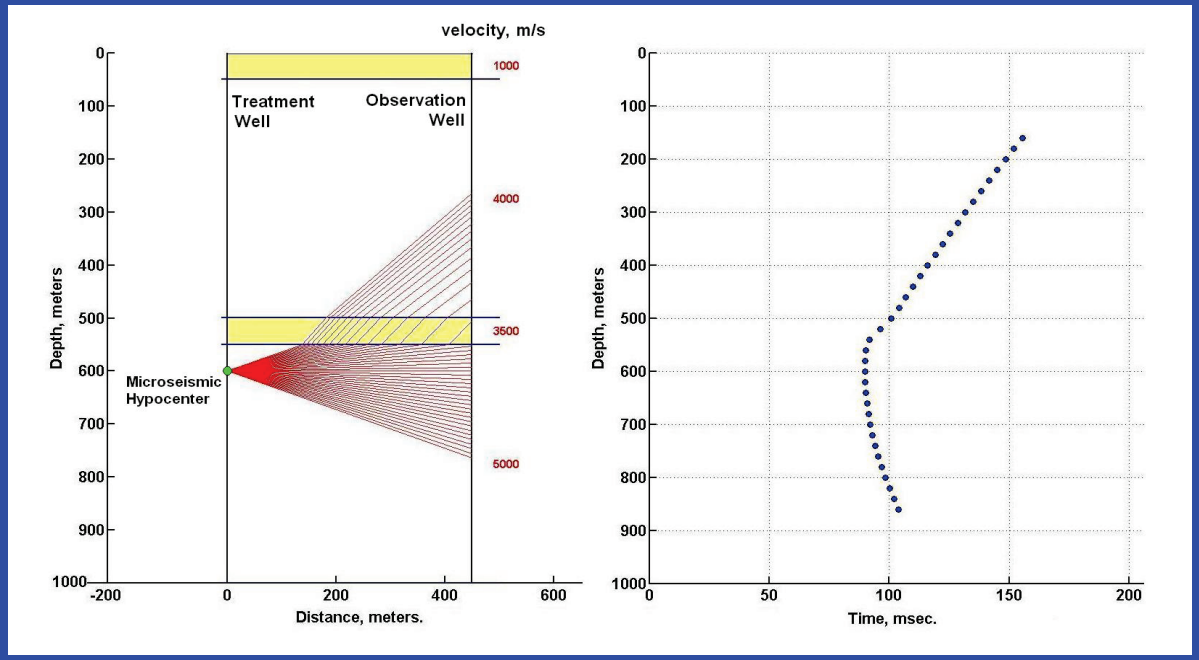

z-axis, m
r-axis, meters
r-axis, m
G-1
G-2
G-3
G-4
G-5
G-6
G-7
G-8
G-9
G-10
G-11
G-12
zEst=2185m, rEst=513m
zReal=2150m, rReal=500m

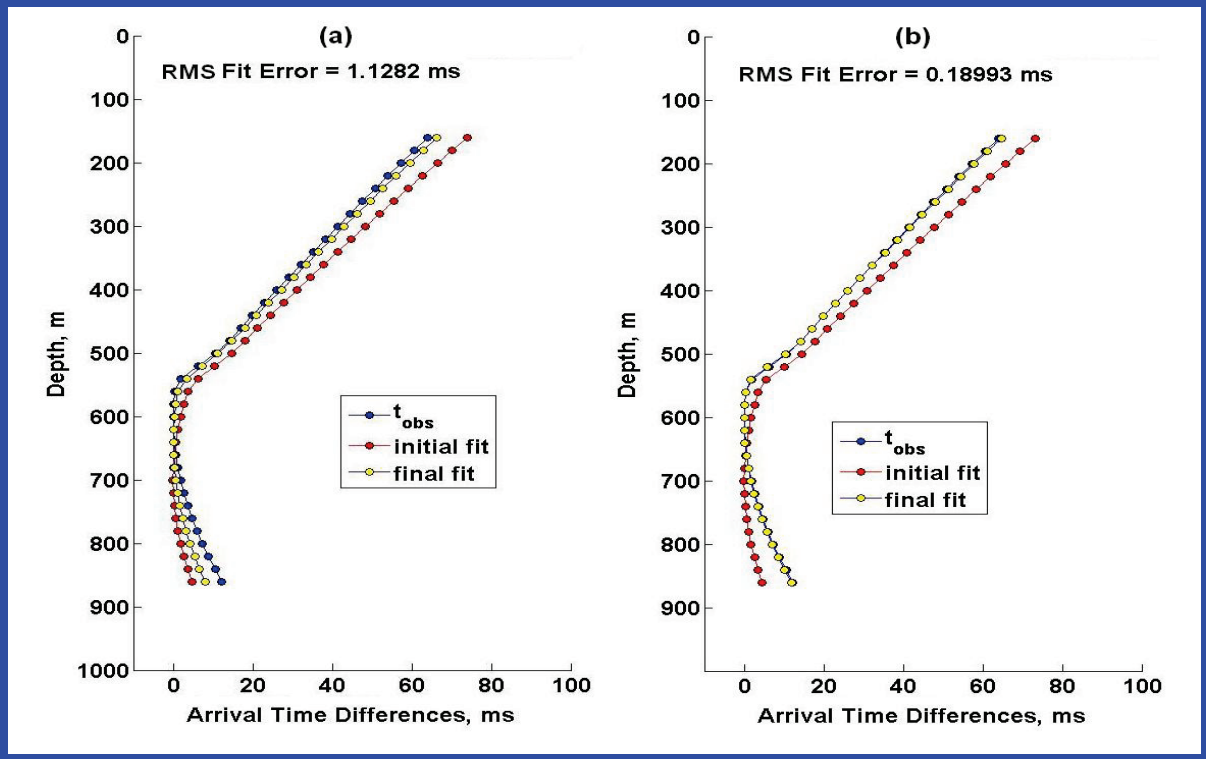

y-axis, m
x-axis, m
Est. direction (slope:0.67)
Real direction (slope:0.75)
xEst.=426m, yEst.=286m
xReal=400m, yReal=300m
rEst=513m

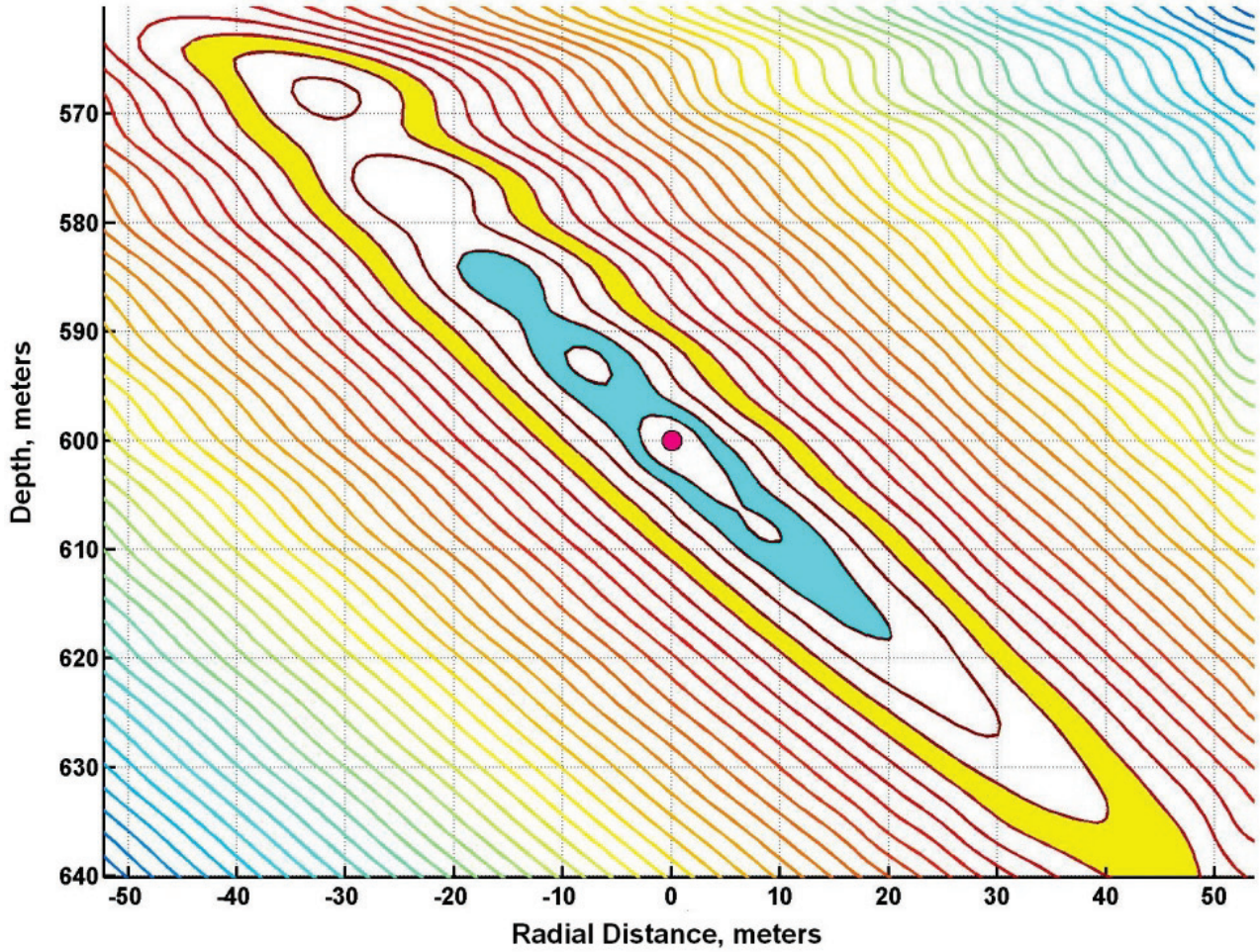

Depth, meters
r-axis, meters
Removed intersections (10)
Selected intersections (56)
zEst.=2171m, rEst.=526m
zReal=2150m, rReal=500m

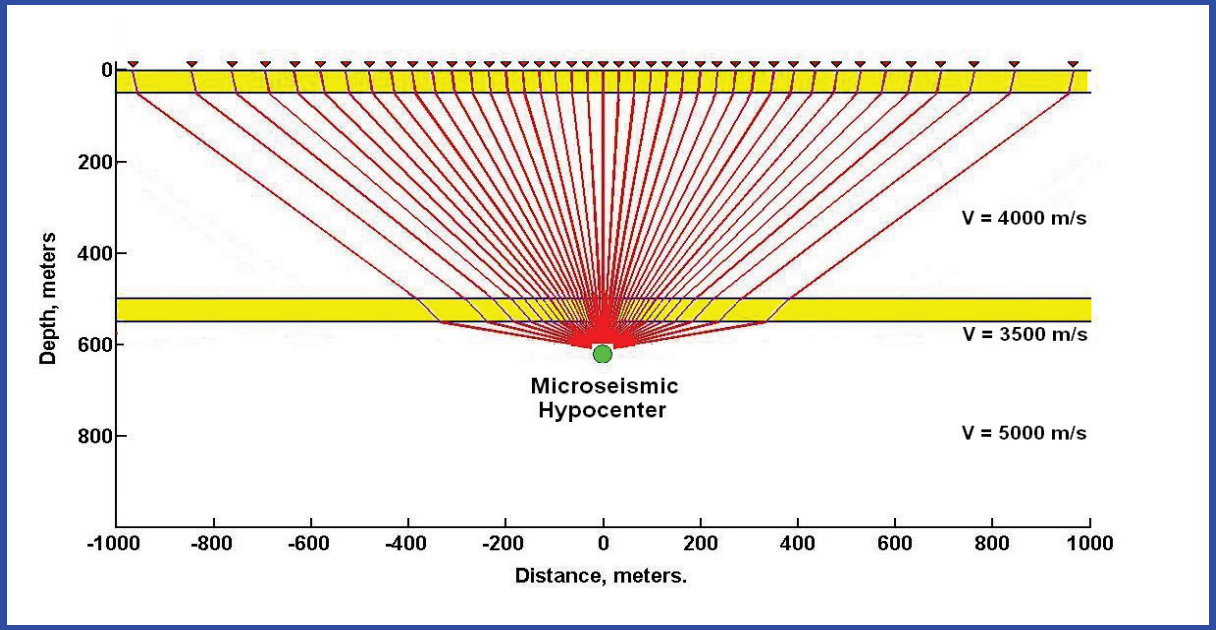
NONLINEAR OPTIMIZATION FOR HYPOCENTER LOCATION

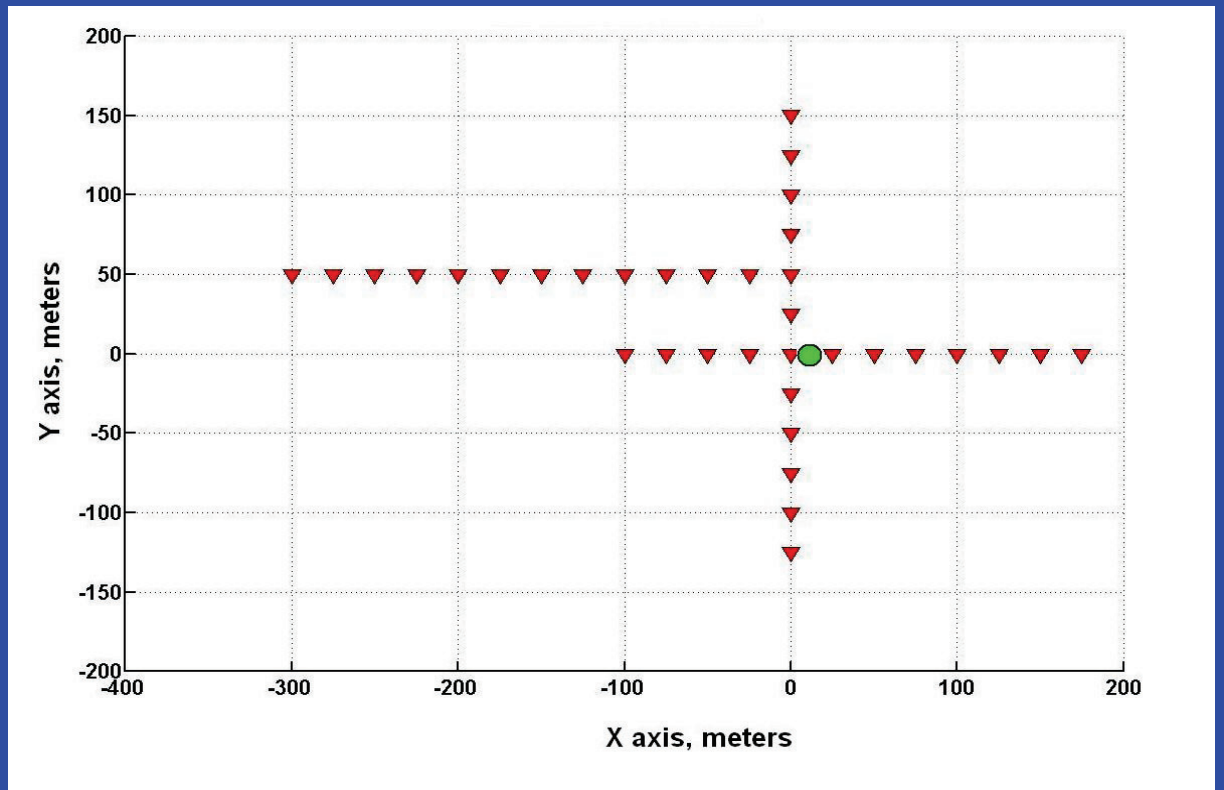
- *Invert observed arrival times for hypocenter coordinates (x_s, y_s, z_s).*
- *Gradient based method (Levenberg-Marquardt).*
- *Direct search methods (Genetic Algorithm and Pattern Search).*

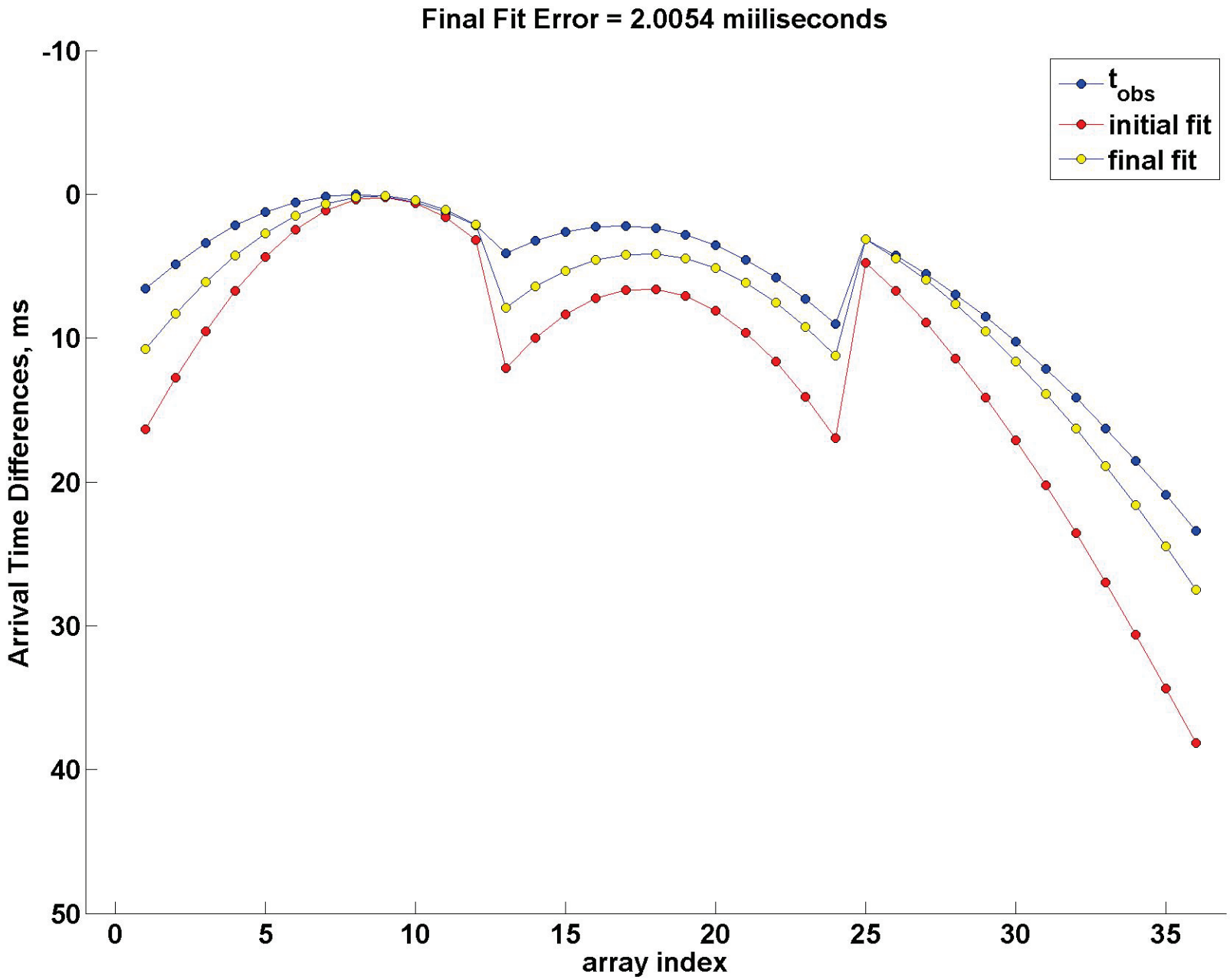

velocity, m/s
1000
4000
3500
5000
Treatment Well
Observation Well
Microseismic Hypocenter
Depth, meters
Distance, meters.
Time, msec.

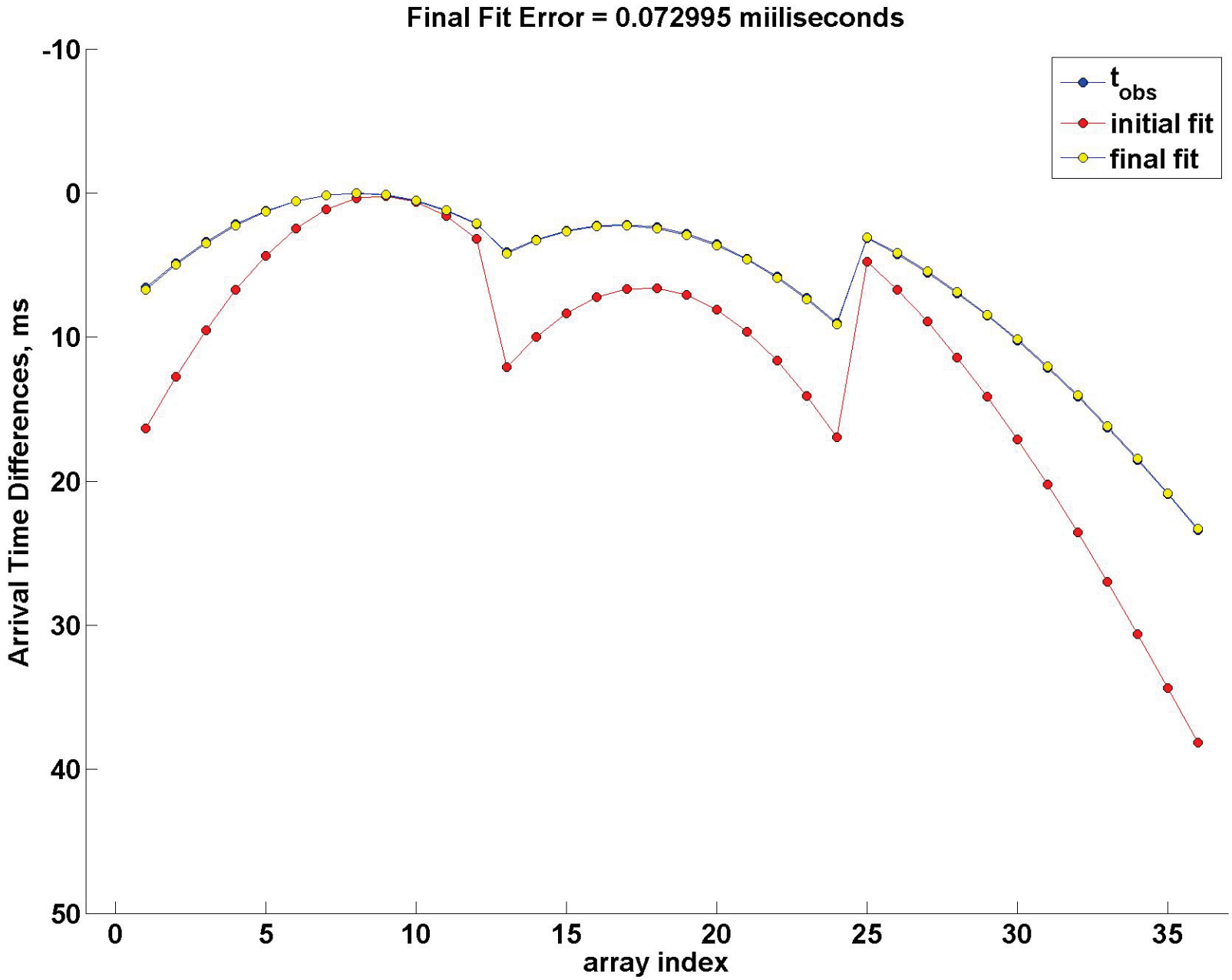

(a)
RMS Fit Error = 1.1282 ms
(b)
RMS Fit Error = 0.18993 ms
Depth, m
Arrival Time Differences, ms
t obs
initial fit
final fit

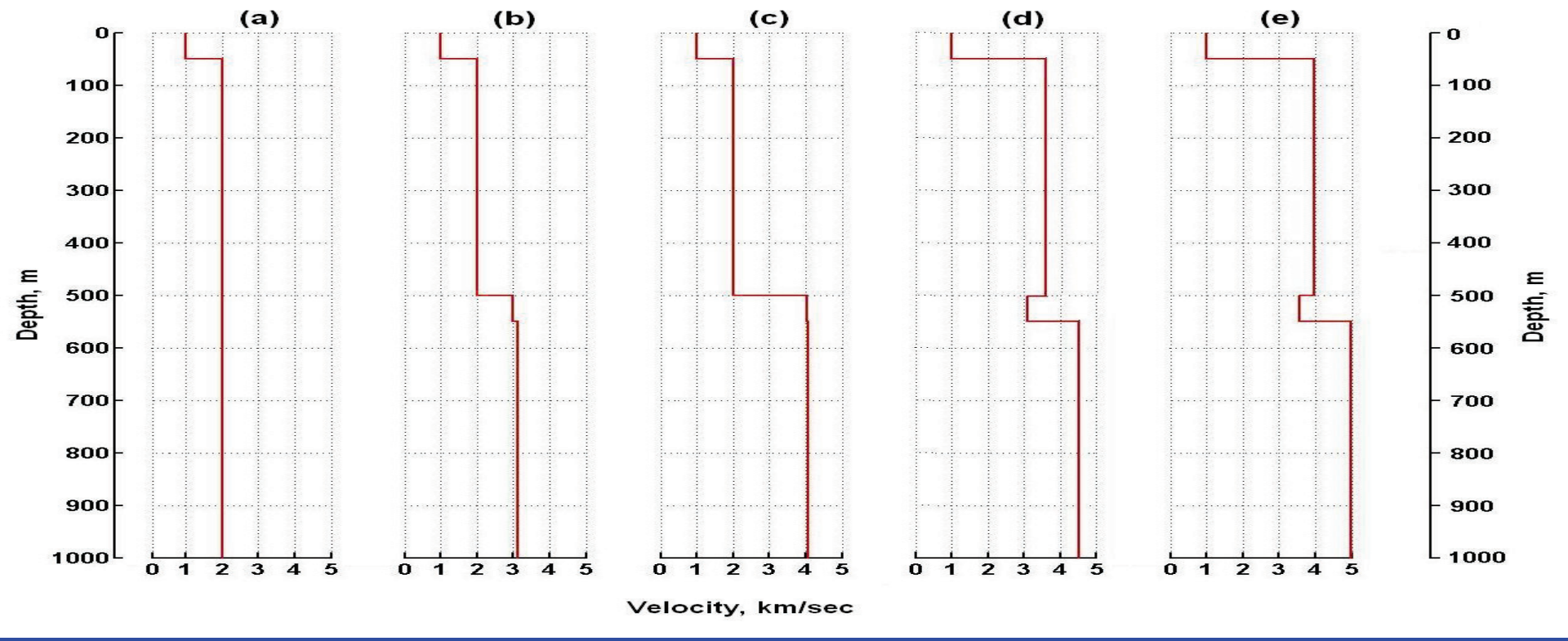

Depth, meters
570
580
590
600
610
620
630
640
-50
-40
-30
-20
-10
0
10
20
30
40
50
Radial Distance, meters

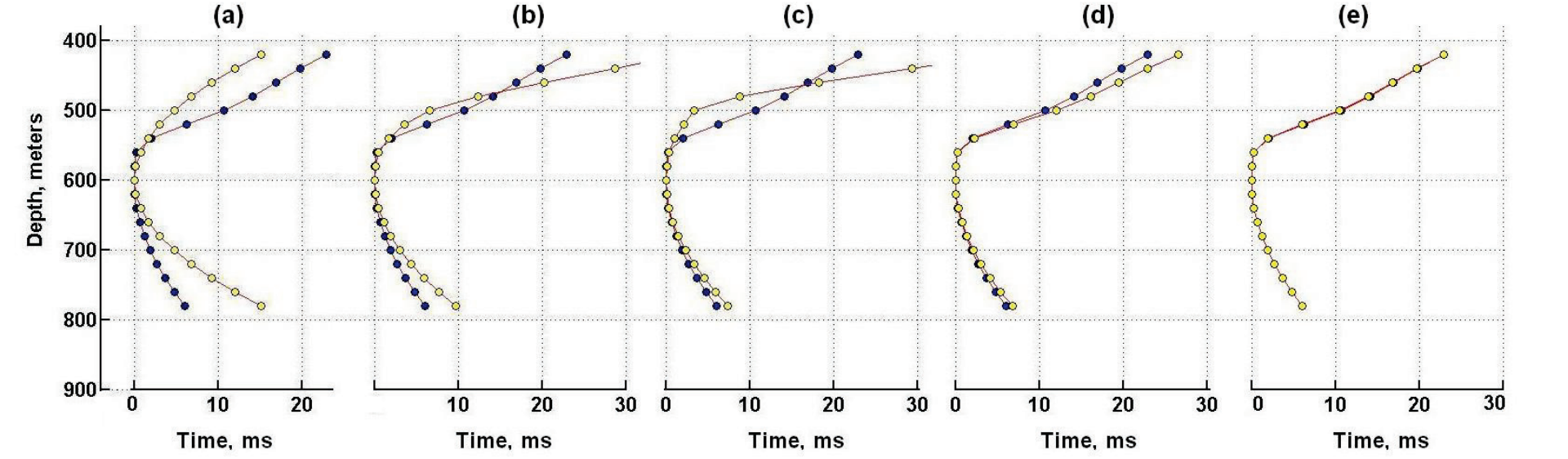

0
200
400
600
800
Depth, meters
V = 4000 m/s
V = 3500 m/s
V = 5000 m/s
Microseismic
Hypocenter
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
Distance, meters.


200
150
100
50
0
-50
-100
-150
-200
Y axis, meters
-400
-300
-200
-100
0
100
200
X axis, meters


Final Fit Error = 2.0054 miiliseconds
-10
0
10
20
30
40
50
Arrival Time Differences, ms
0
5
10
15
20
25
30
35
array index
t obs
initial fit
final fit


Final Fit Error = 0.072995 miiliseconds
-10
0
10
20
30
40
50
Arrival Time Differences, ms
0
5
10
15
20
25
30
35
array index
t obs
initial fit
final fit


(a)
(b)
(c)
(d)
(e)
Depth, m
Velocity, km/sec


(a)
(b)
(c)
(d)
(e)
Depth, meters
Time, ms

OTHER METHODS FOR LOCATING HYPOCENTER S

- *Apollonius spheres (Bancroft, 2007).*
- *Analytic method (Bancroft, 2009).*
- *Migration techniques (future work).*

SUMMARY AND CONCLUSIONS

- *For automatic time picking on noisy seismograms, our MER method is faster and more consistent than the STA/LTA method.*

- *With noisy 3C microseismograms, reasonably accurate hypocenter locations can be found using hodogram / back-azimuth analysis when we mitigate the effects of random noise.*

- *After comparing both gradient-based and direct search methods for inverting microseismic arrival time data, it appears that Pattern Search is the fastest and most efficient.*

ACKNOWLEDGEMENTS

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