Sensitivity measurements for locating microseismic events

John C. Bancroft, Joe Wong, and Lilly Han

CREWES/University of Calgary

CREWES-2009

NSERC

Outline:

- Commercials
  - Papers
  - EOM
  - Modelling with diffractions
- Microseismic
- Apollonius
- Coplanar
- Collinear
- Vertical array

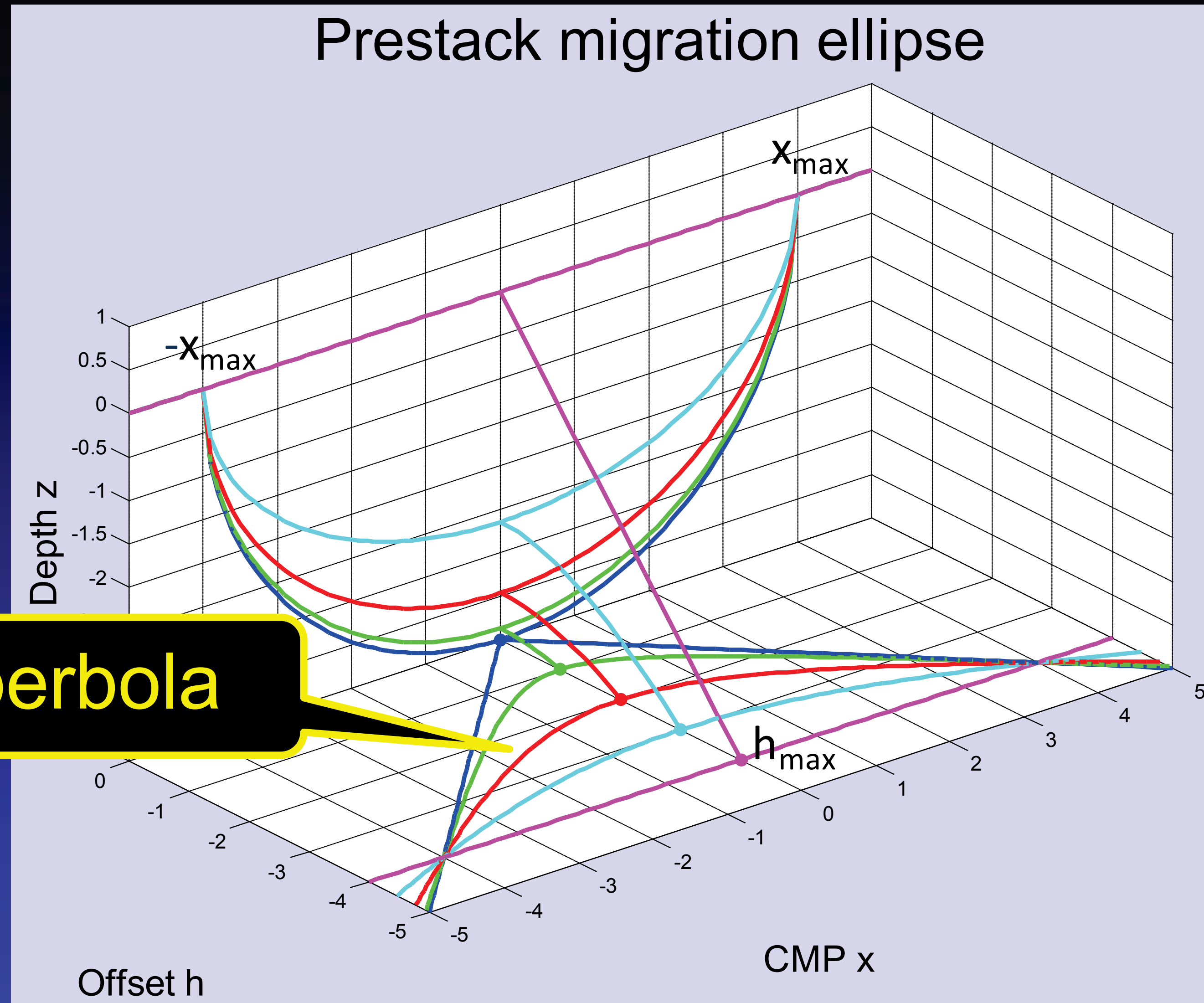
Naser Yousef-Zadeh

- Least-squares migration
- Multigrid approach

Baolin Qiao

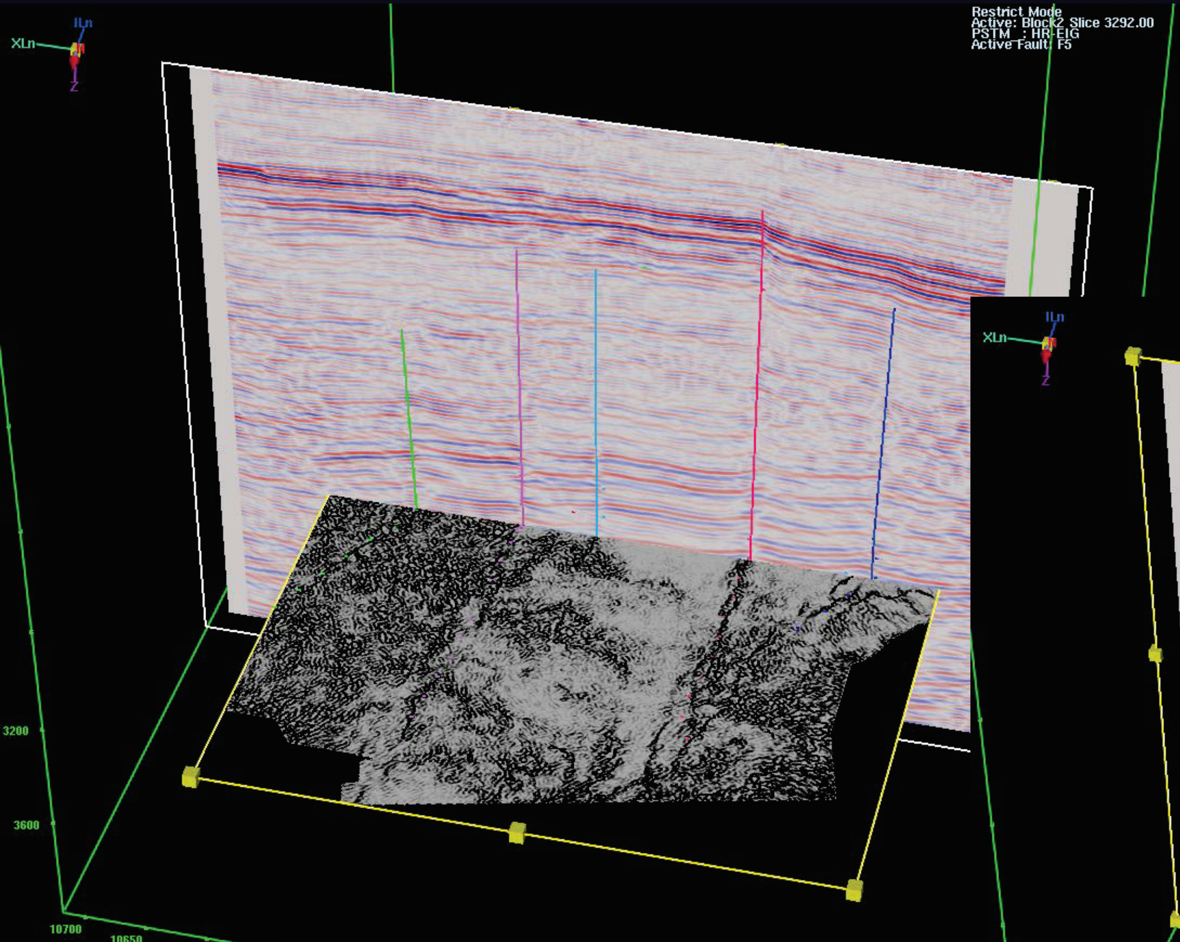
- PSPI migration
- Microseismic
  - Covariance matrix approach

EOM



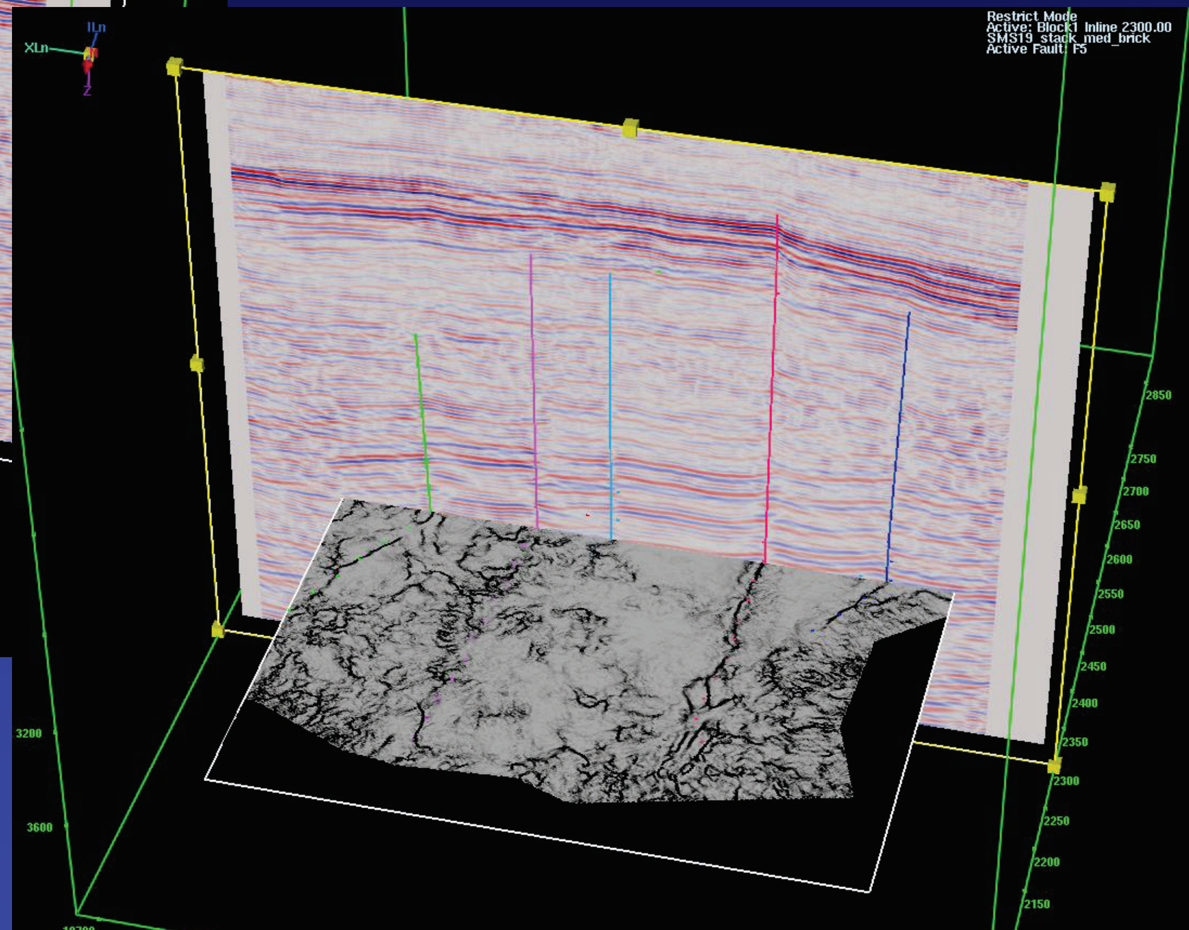
EO hyperbola

EOM

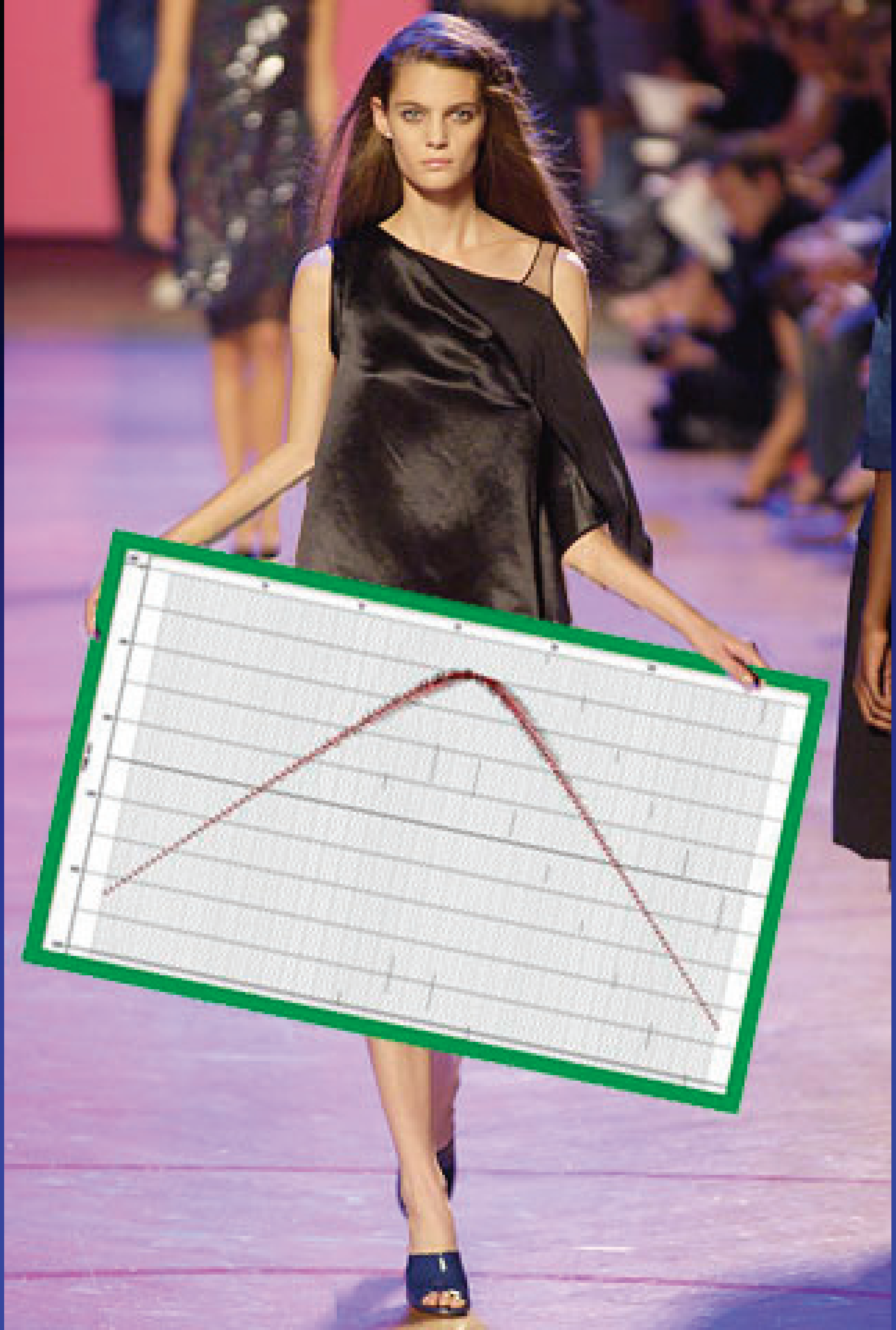


Conventional prestack migration

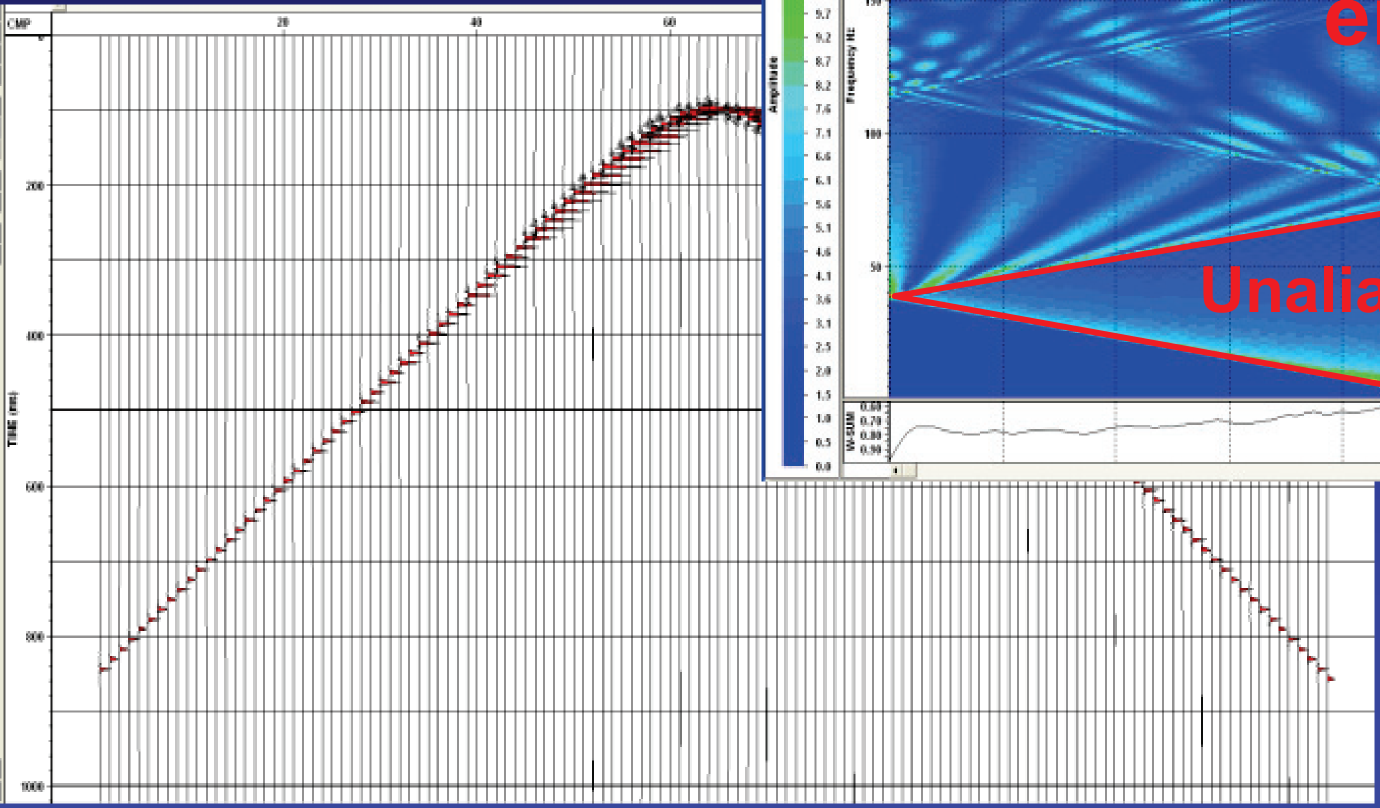
EOM

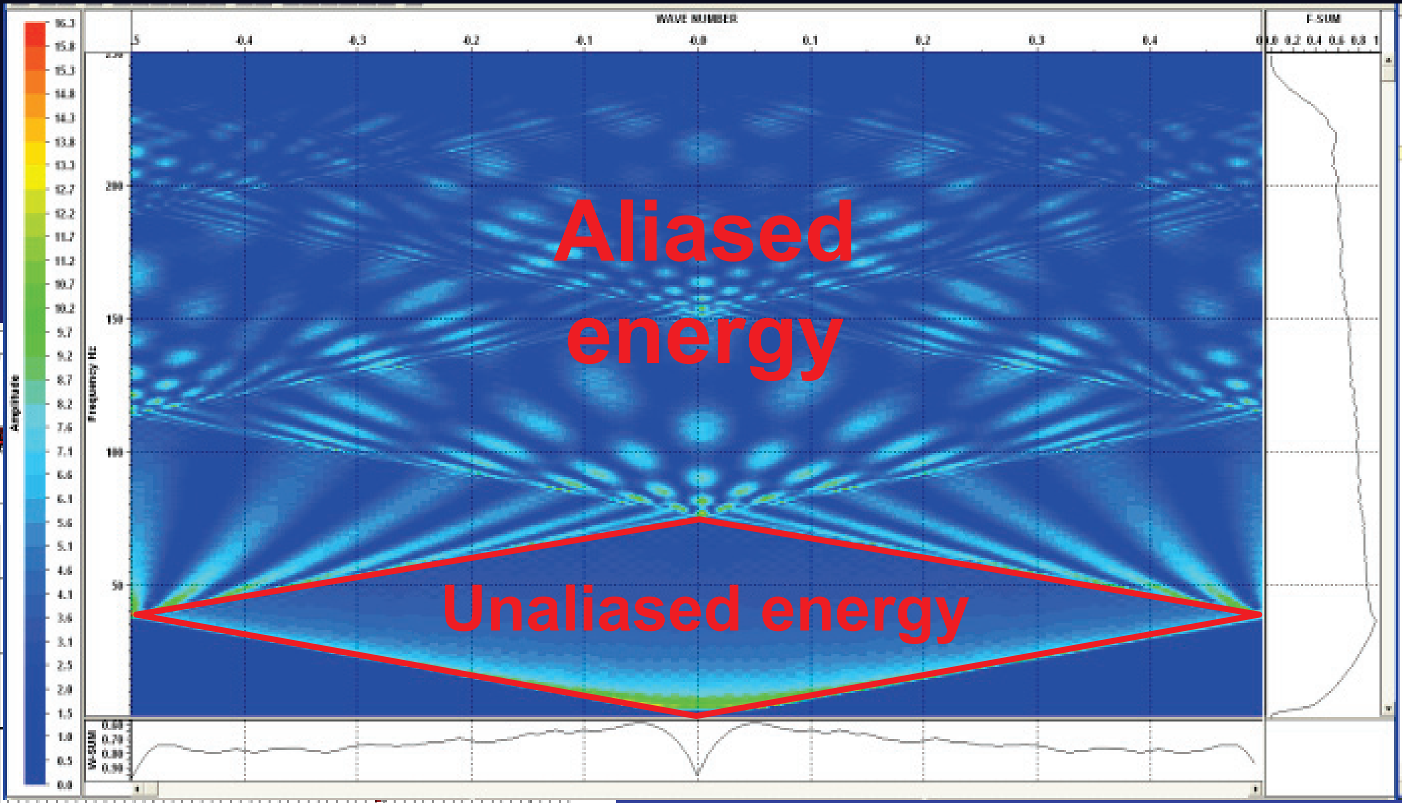


Modelling with diffractions



Modelling with diffractions



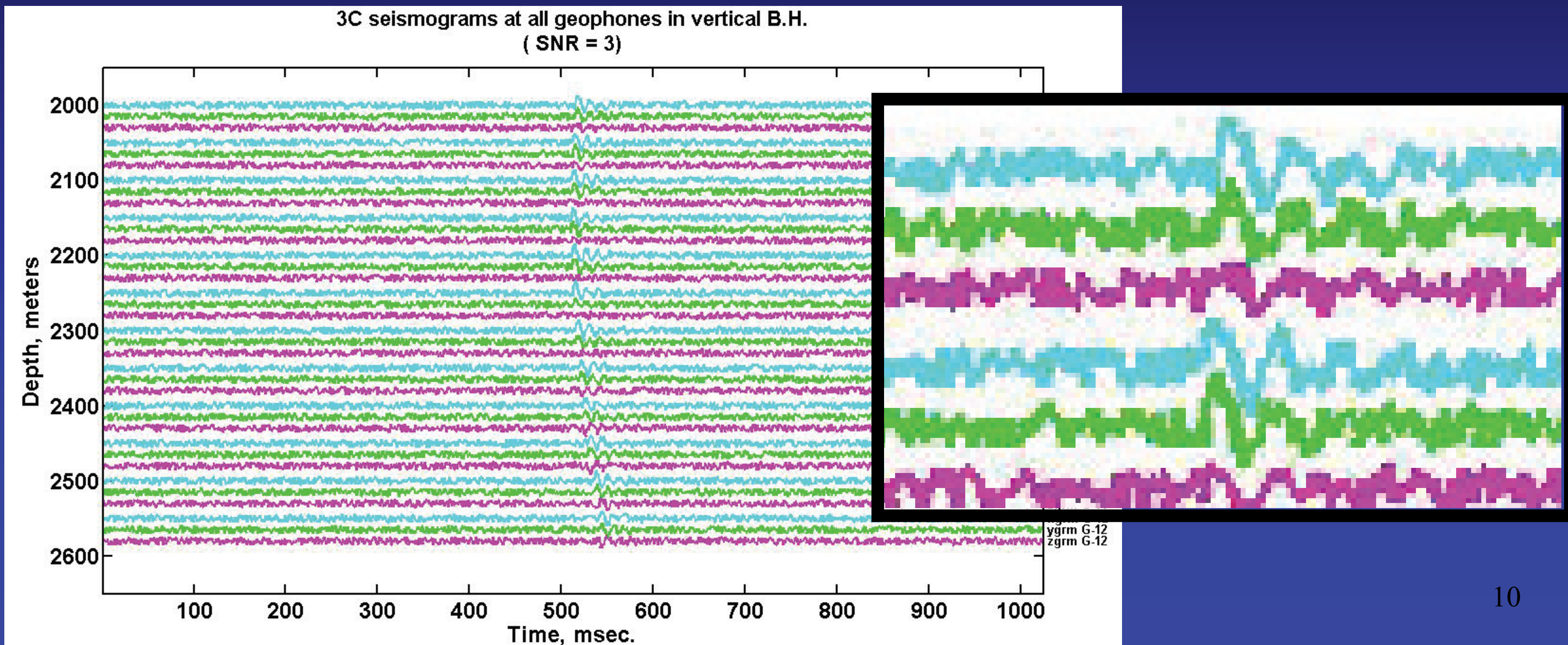


Microseismic work:

- Location and clock-time of a microseism
- Analytic solutions
- Part of a larger system of receivers
- Simple model: constant velocity (RMS OK)
- Evaluate the sensitivity of receiver clock-times
- Help set standards for estimating first arrival clock-times

Receiver clock-times: Joe and Lilly

- Difficult to identify absolute clock-times of an event
- Greater relative accuracy between associated traces
- How accurate do we need to be?



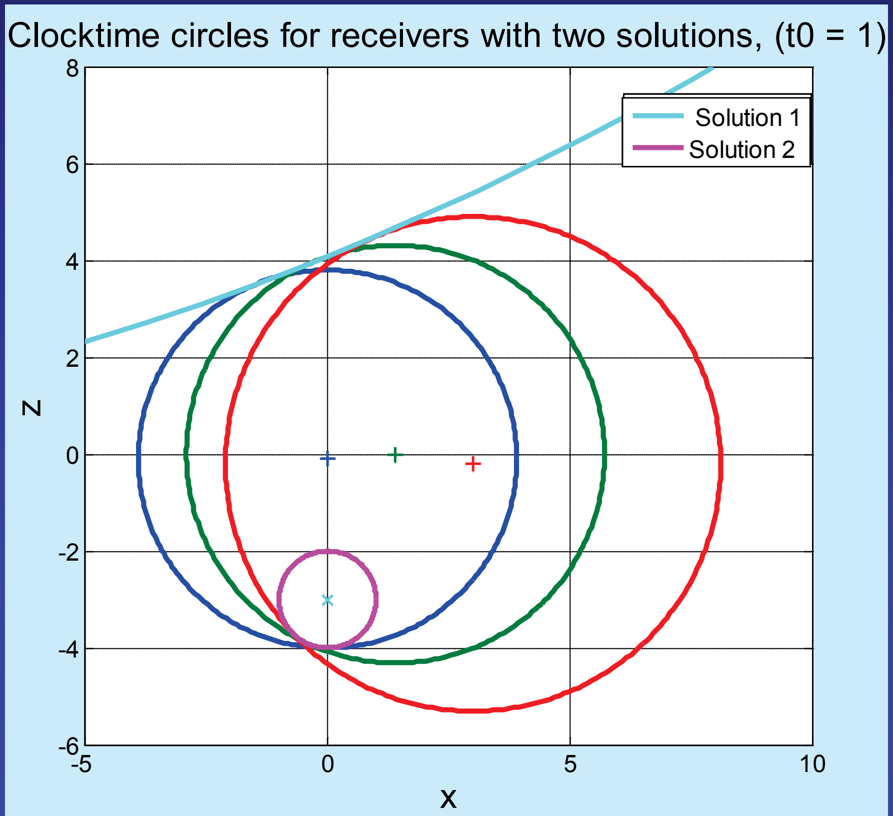
Analytic methods:

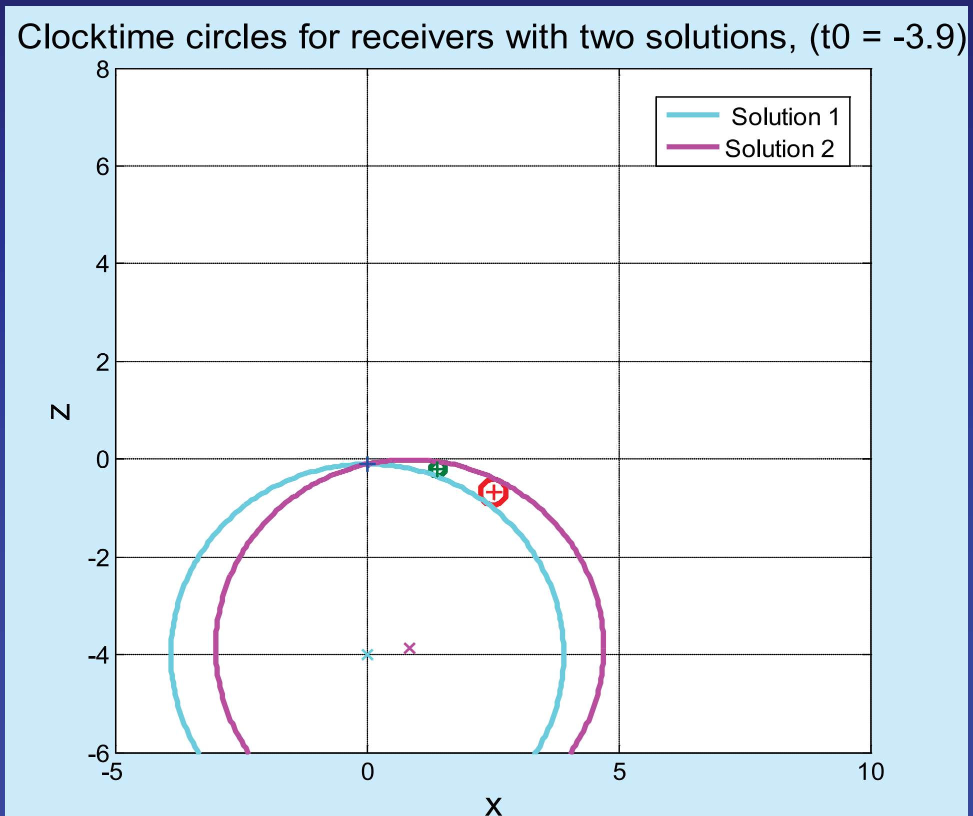
- (1) Apollonius solution
  - Four arbitrarily located receivers
  - No coplanar
  - No collinear
- (2) Four coplanar receivers on square grid at the surface
- (3) Three collinear equally spaced receivers

- Perturb the receiver clock-times … jitter
- Simple visual analysis of the distribution

(1) Apollonius method

- Two solutions
- Both are possible
- Can be difficult to choose the correct solution

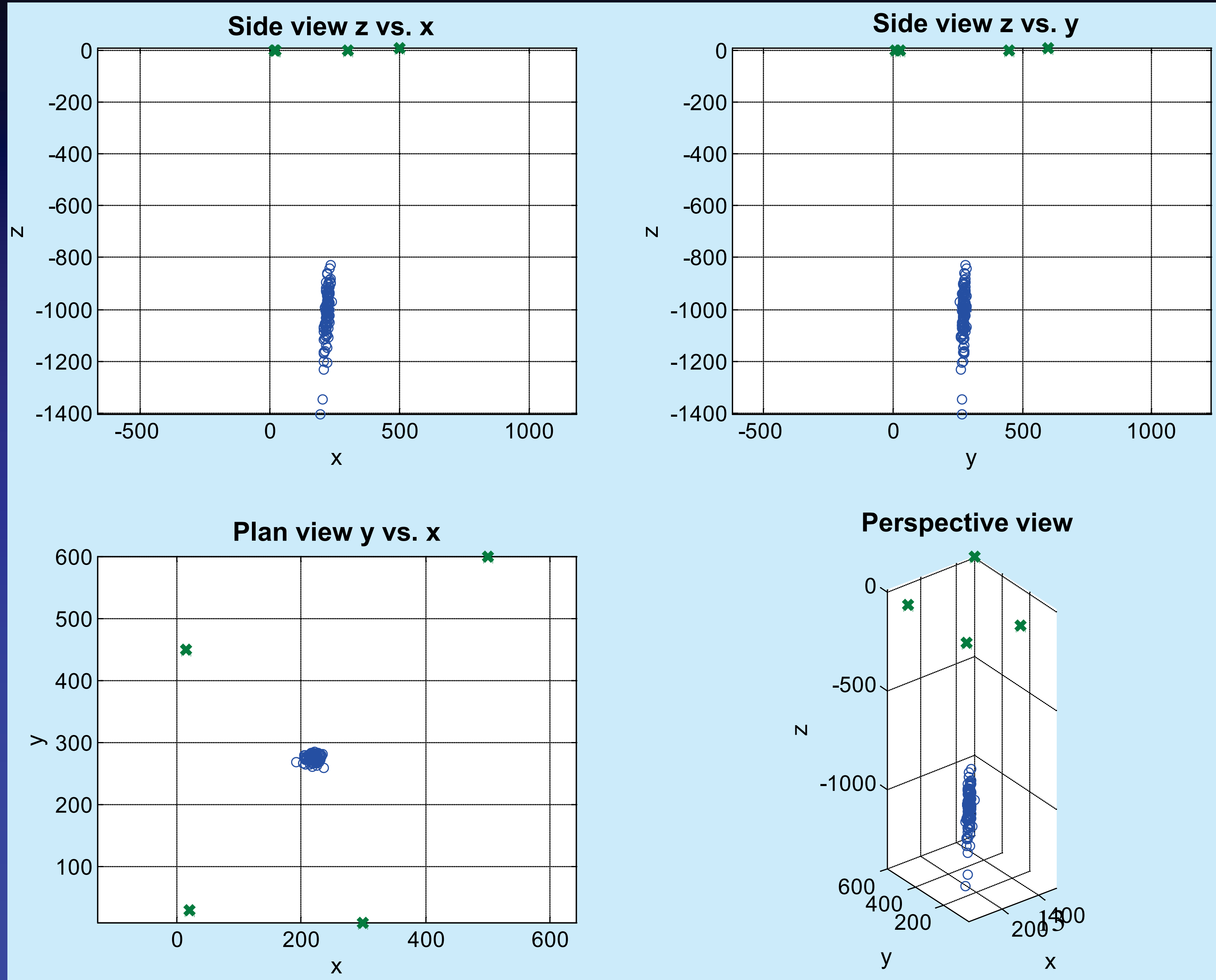




(1) Apollonius method

- Gaussian noise
- 100 trials
- Std = 0.1 ms
- z_s = 1000m

Elongated cloud of source estimates



Error in the source location

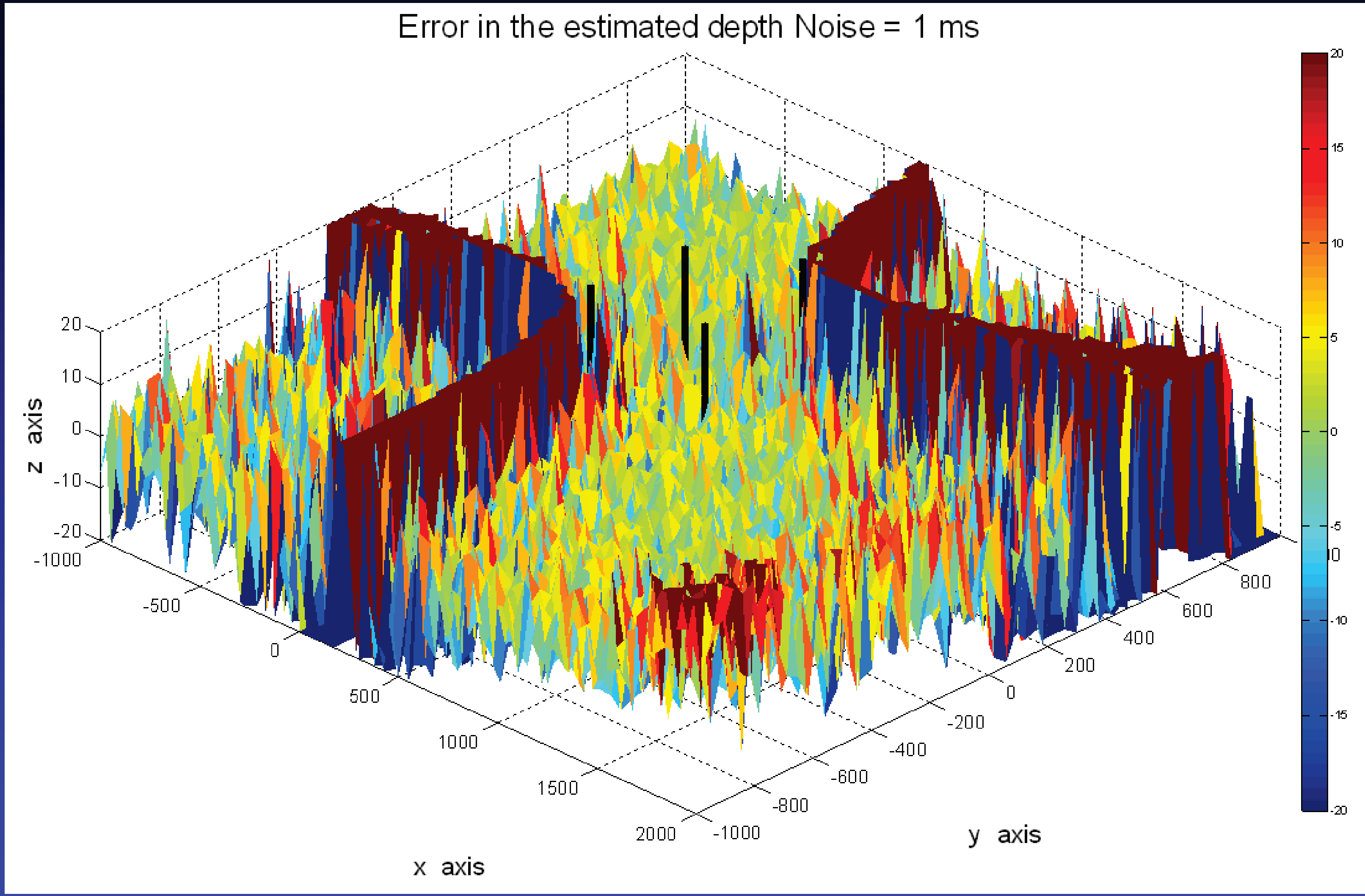
Depth 500 m

Noise 1 ms

-1000 < x <2000

-1000 < y <1000

Display ± 20 m



(2) Four receivers on a square grid

$$t_0 = \frac{t_1^2 - t_2^2 - t_3^2 + t_4^2}{2\left(t_1 - t_2 - t_3 + t_4\right)}$$

$$x_0 = \frac{v^2\left[2t_0\left(t_2 - t_1\right) - \left(t_2^2 - t_1^2\right)\right] + h^2}{2h}$$

$$y_0 = \frac{v^2\left[2t_0\left(t_3 - t_1\right) - \left(t_3^2 - t_1^2\right)\right] + h^2}{2h}$$

$$z_0 = -sqrt\left[v^2\left(t_1 - t_0\right)^2 - \left(x^2 + y^2\right)\right]$$

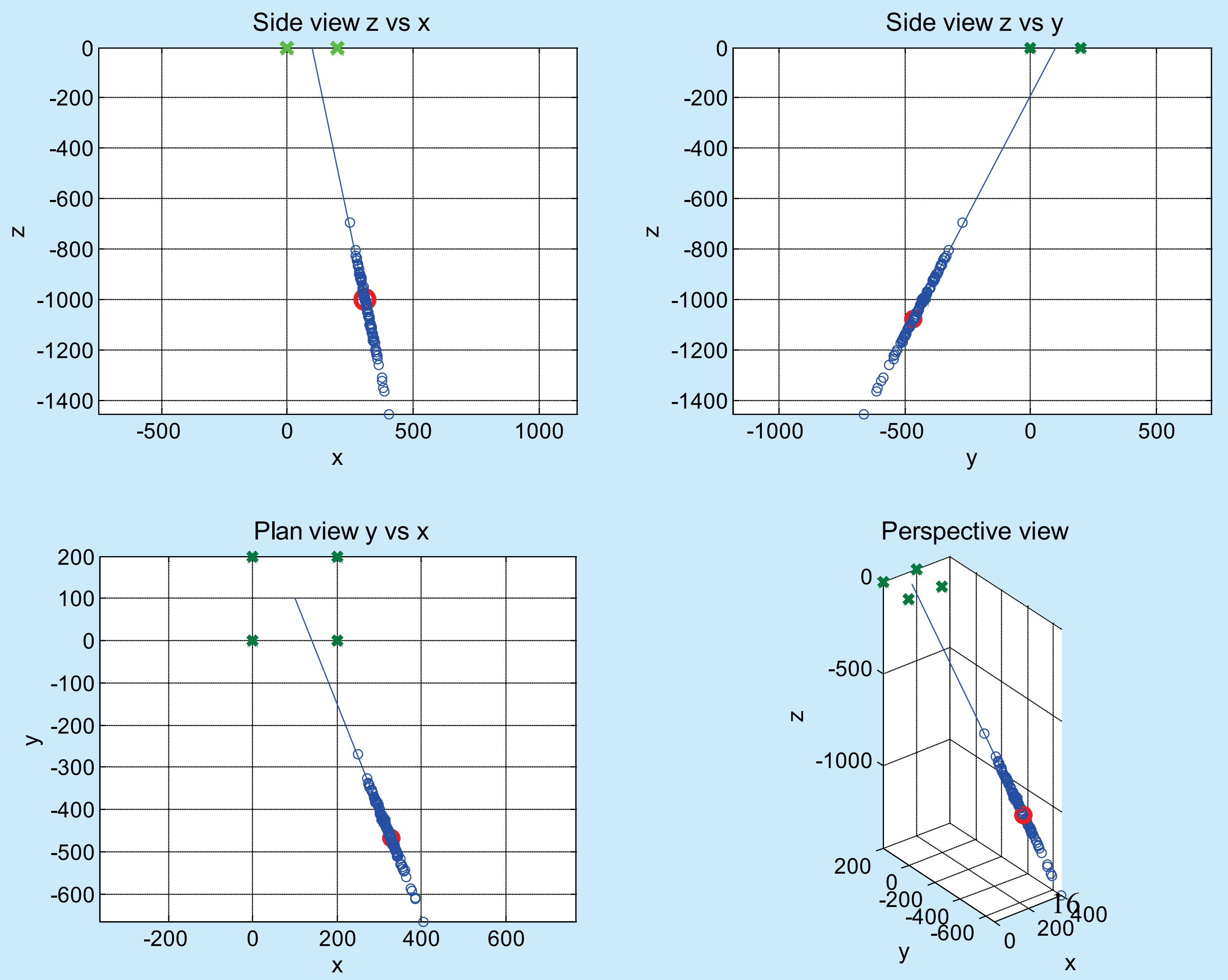
Simple equations

t_0 is independent of the geometry

Four receiver in a square on the surface

Std = 0.1 ms

Very sensitive to noise



Four receiver in a square on the surface

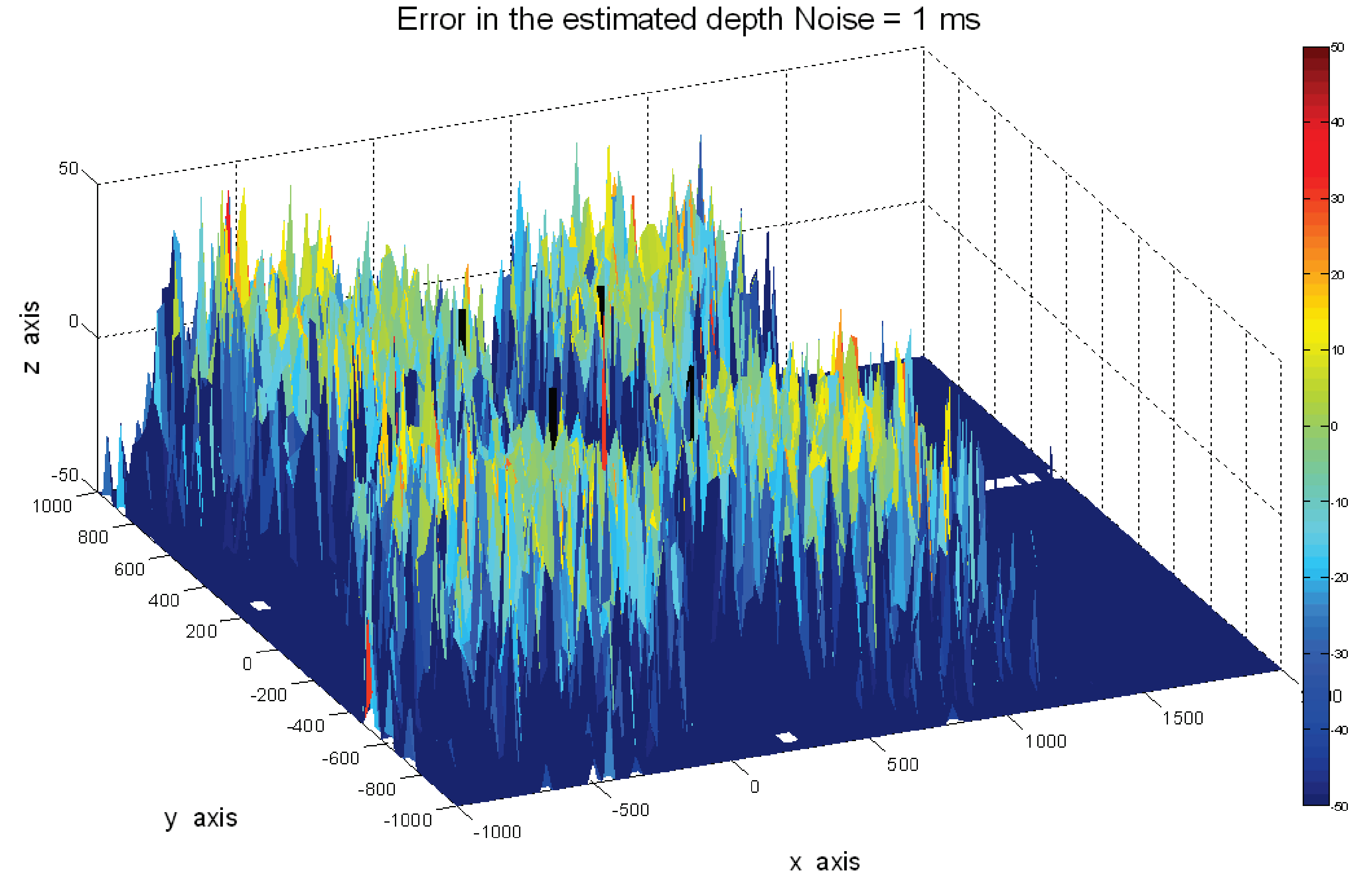
Depth 500 m

Noise 1 ms

-1000 < x <2000

-1000 < y <1000

Display ± 50 m



(3) Three vertical receivers

Only a 2D solution possible (no azimuth)

Radial and depth

Three receivers

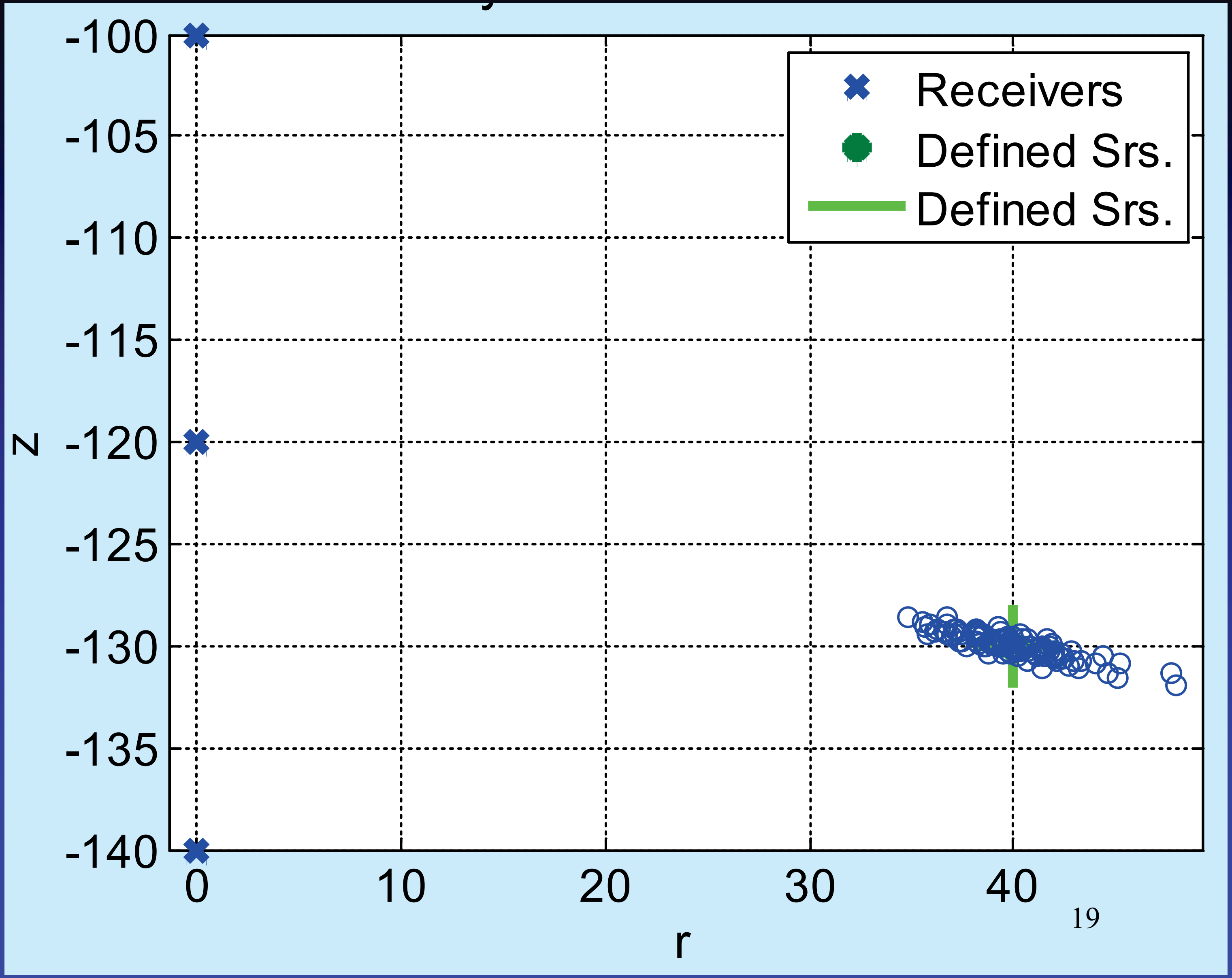
$$t_0 = \frac{t_1^2 - 2t_2^2 + t_3^2 - 2t_h^2}{2\left(t_1 - 2t_2 + t_3\right)}$$

$$r_0 = sqrt\left[v^2\left(t_1 - t_0\right)^2 - \left(z_1 - z_0\right)^2\right]$$

$$z_0 = \frac{1}{2h}\left[2t_0 v^2\left(t_2 - t_1\right) + v^2\left(t_1^2 - t_2^2\right) + h^2 + 2z_1 h\right]$$

Three vertical receivers

Std = 0. 1 ms

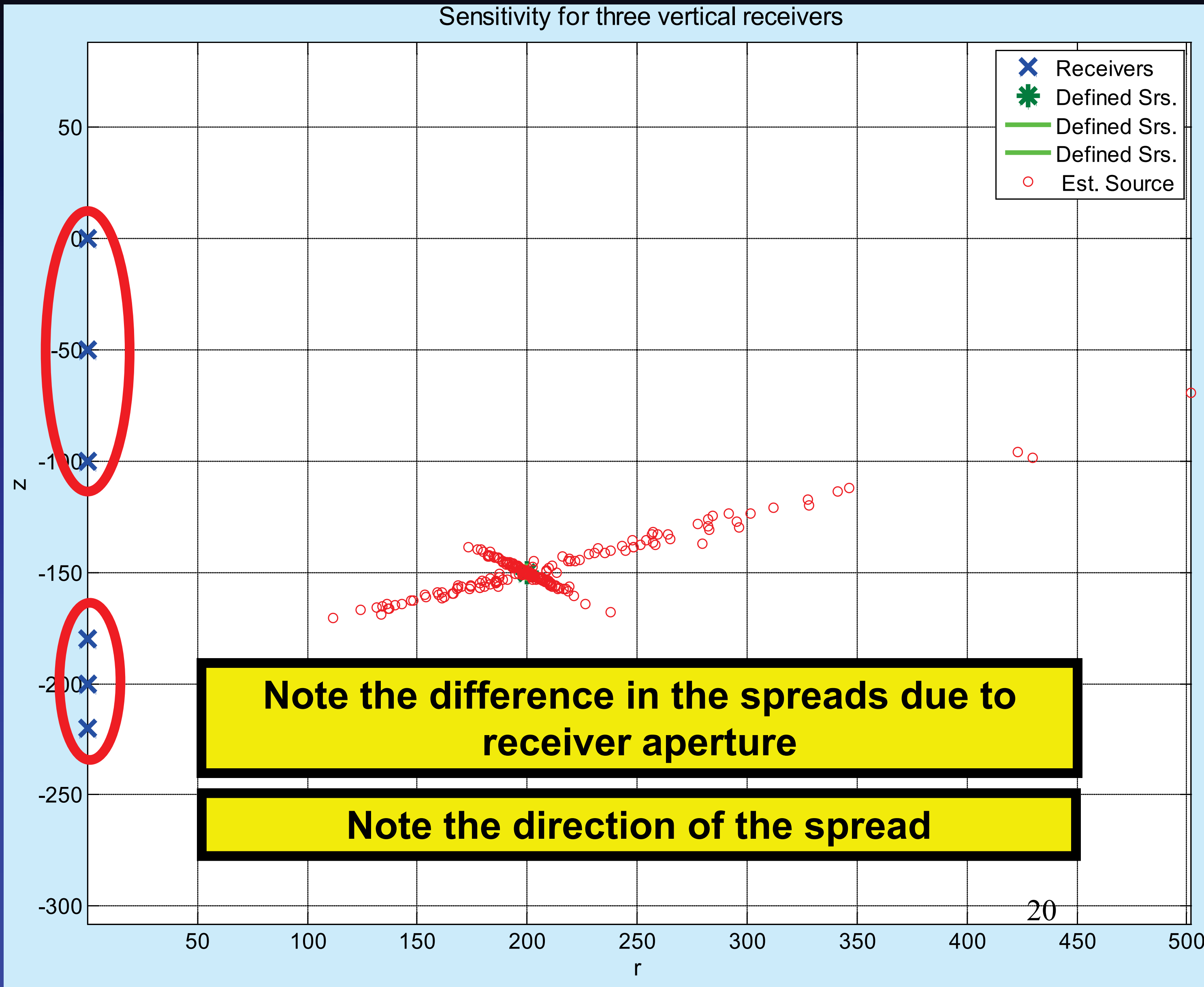


Two sets of 3 receivers

Std = 0. 1 ms

- 50 m spacing
- 100 m aperture

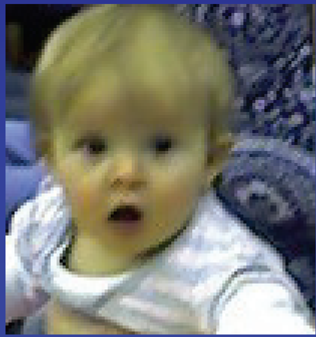
- 20 m spacing
- 40 m aperture



Vertical array of receivers

- Find combinations of three equally spaced receivers

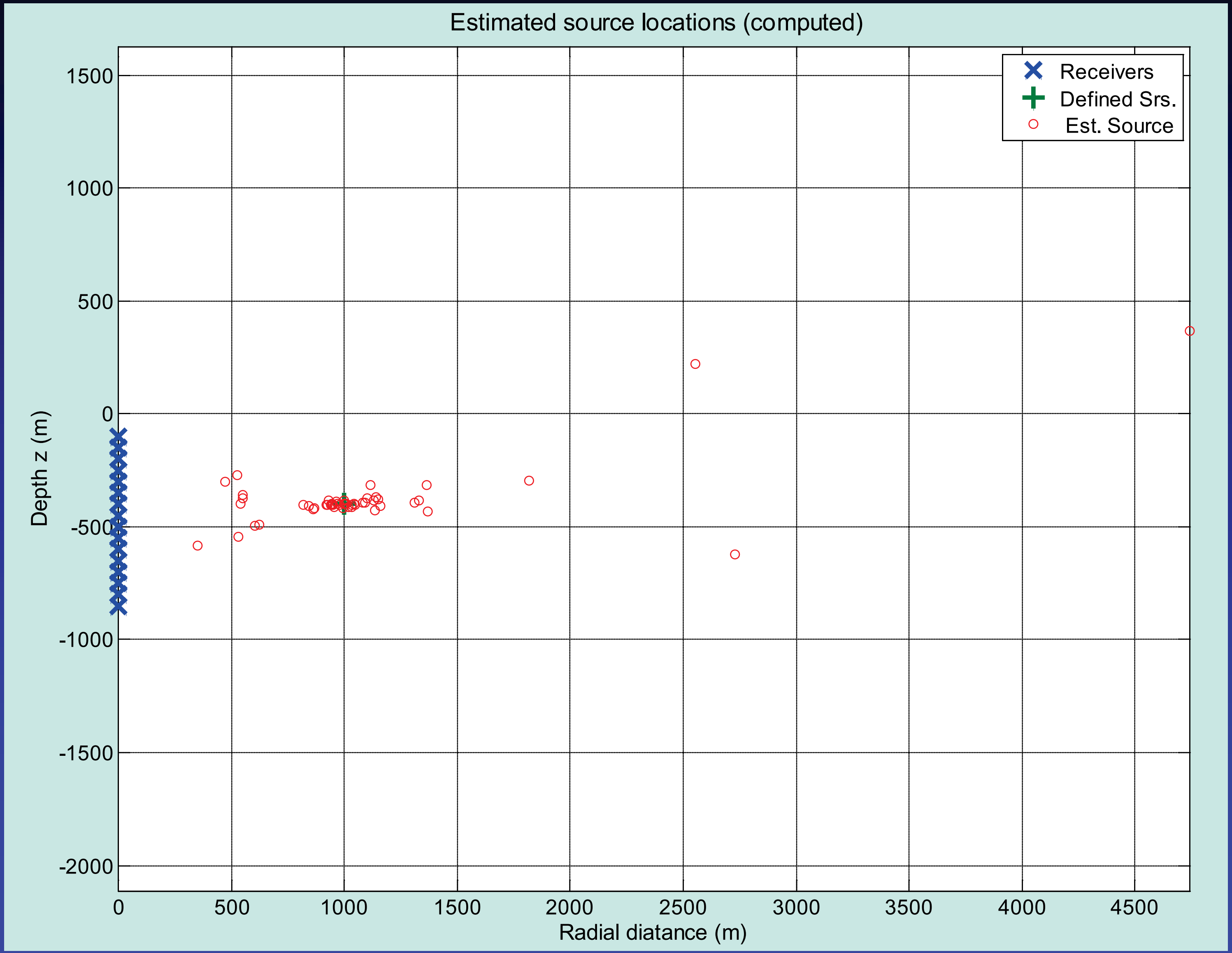
```
For 7 receivers, there will be 9 combinations,
 1    Rec..  1   2   3
 2    Rec..  1   3   5
 3    Rec..  1   4   7
 4    Rec..  2   3   4
 5    Rec..  2   4   6
 6    Rec..  3   4   5
 7    Rec..  3   5   7
 8    Rec..  4   5   6
 9    Rec..  5   6   7
```



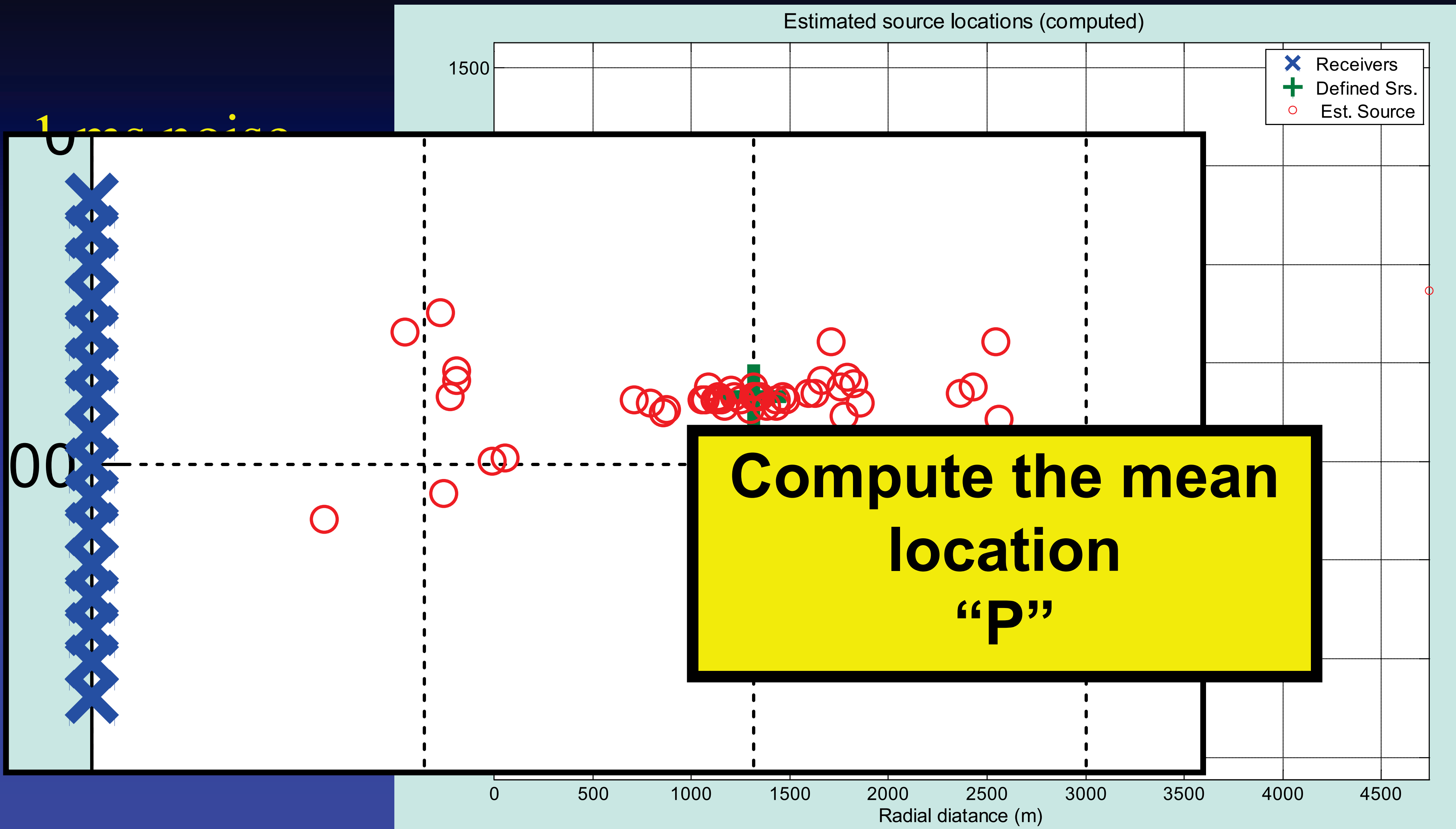
16 receivers, 56 combinations

1 ms noise

56 estimated solution

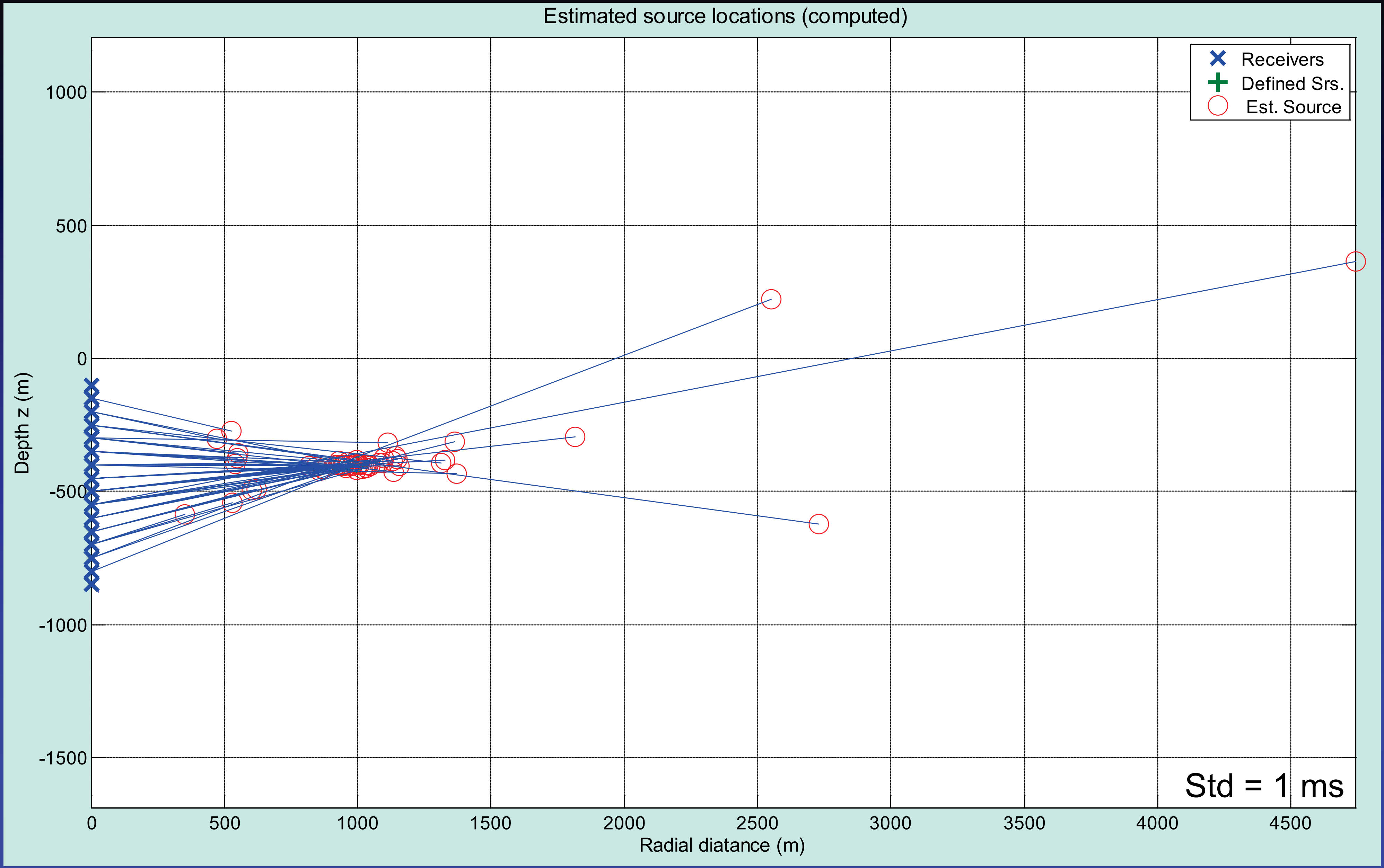


16 receivers, 56 combinations

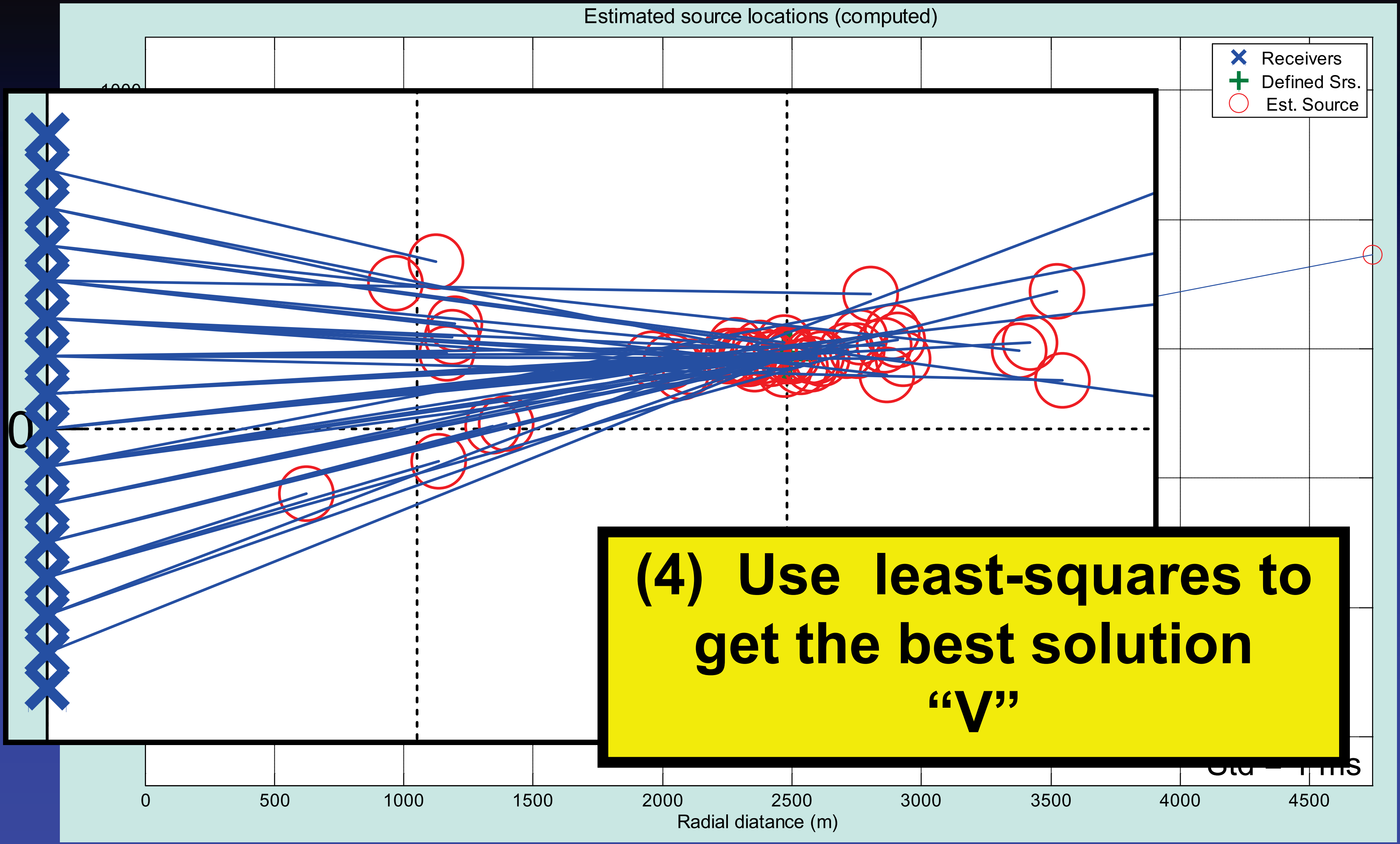


Compute the mean location "P"

Notice the vectors from source to center of receivers



Notice the vectors from source to center of receivers



(4) Use least-squares to get the best solution "V"

Vertical array

- Two solutions
  - Direct point computation ($\boldsymbol{P}$)
  - Least-squares of the slope vectors ($\boldsymbol{V}$)
- 100 trials to get the mean and SD of the source location
  - Different noise on the receiver clock-times
- Vary the source location
- Plot the SD of the estimated source

- Vary the amplitude (SD) of the clock-time error

Comparing *P* and *V* solutions

<u>Noise 0.1 ms</u>

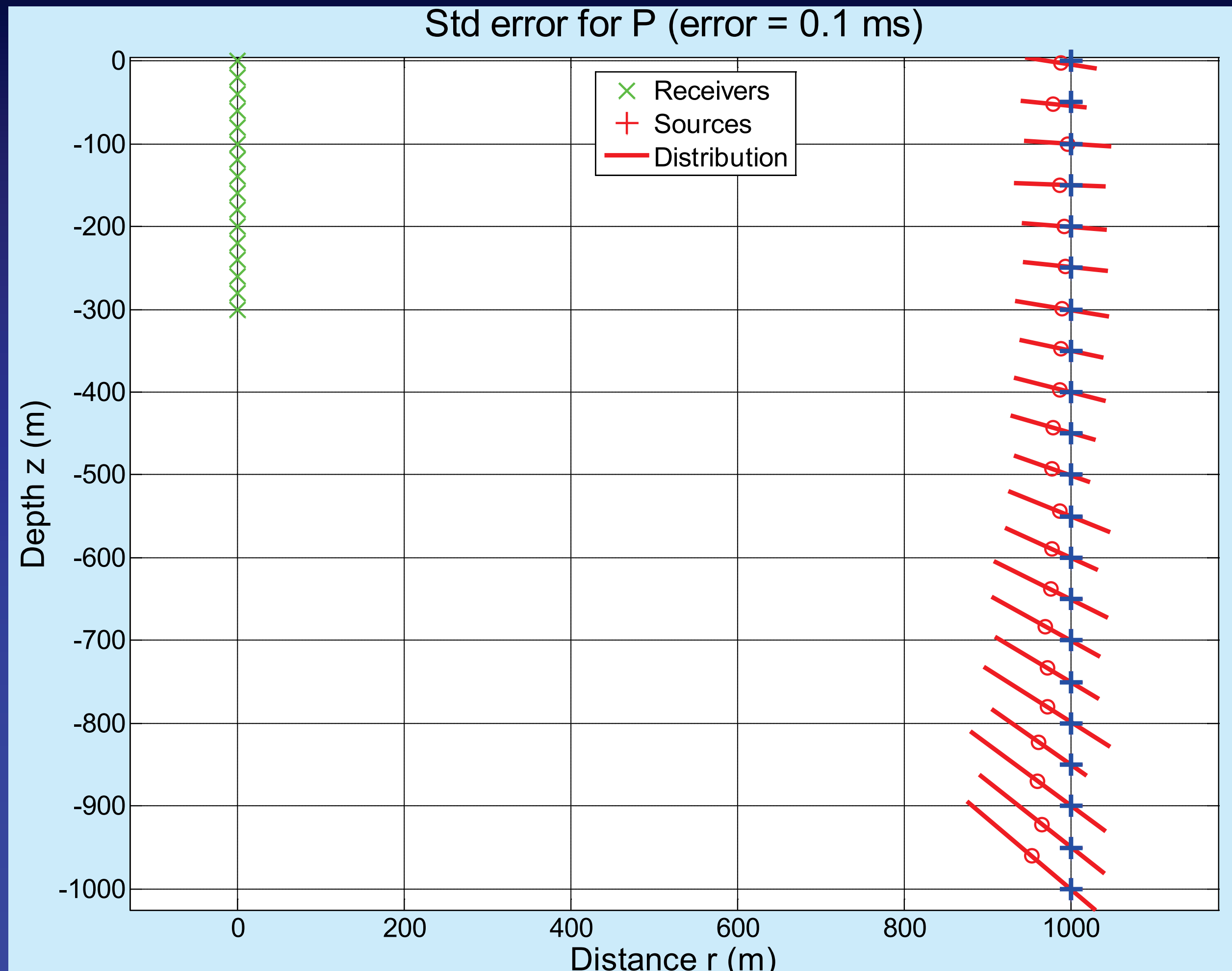
r = 1000m

V = 3000 m/s

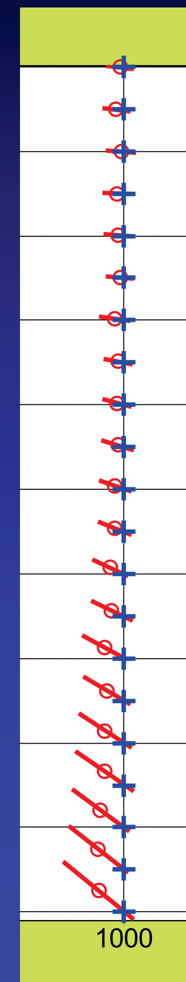
N = 16

$Z_{r\text{-}max}$ = 300 m

***P* solution**



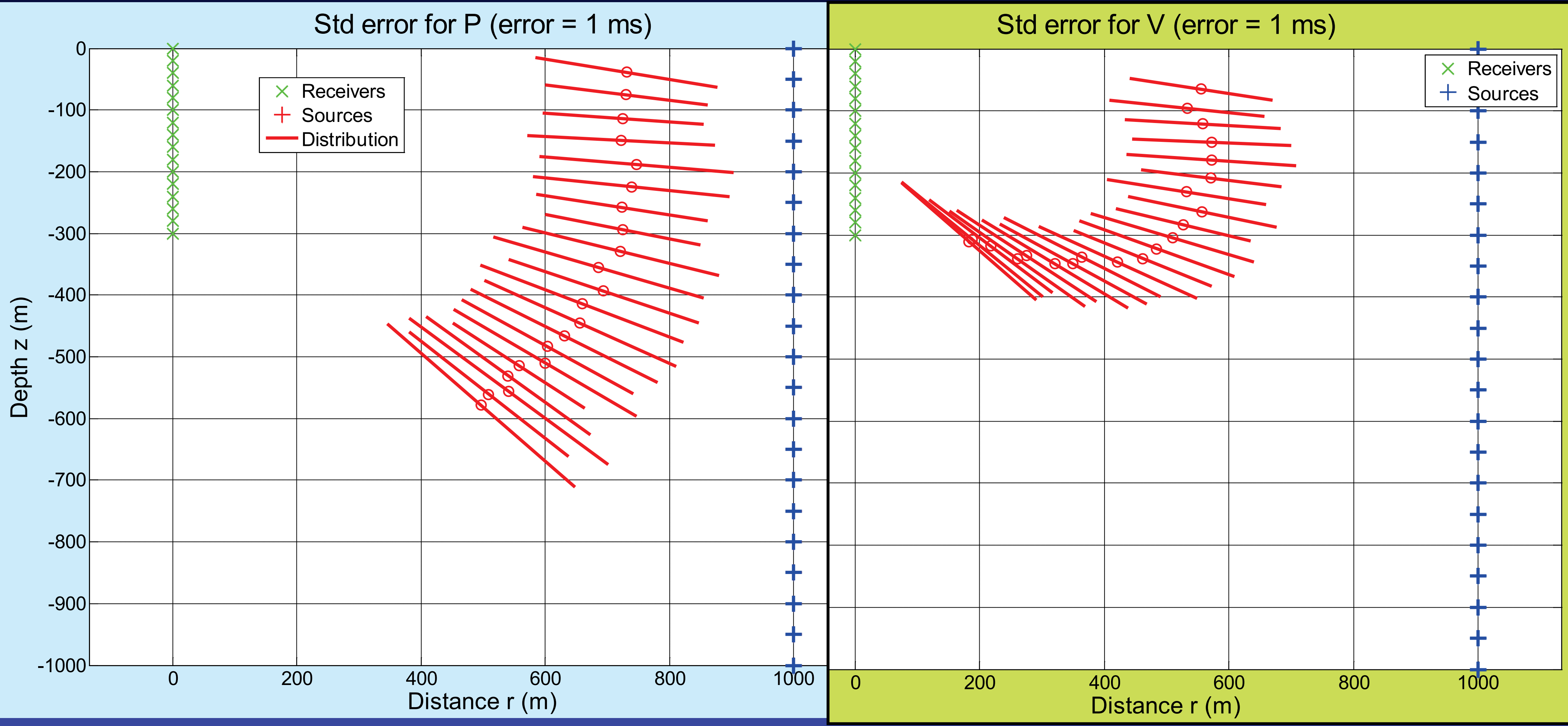
***V* solution**



Comparing *P* and *V* solutions

Noise 1.0 ms

***P* solution** | ***V* solution**



P - wave

Noise 1.0 ms

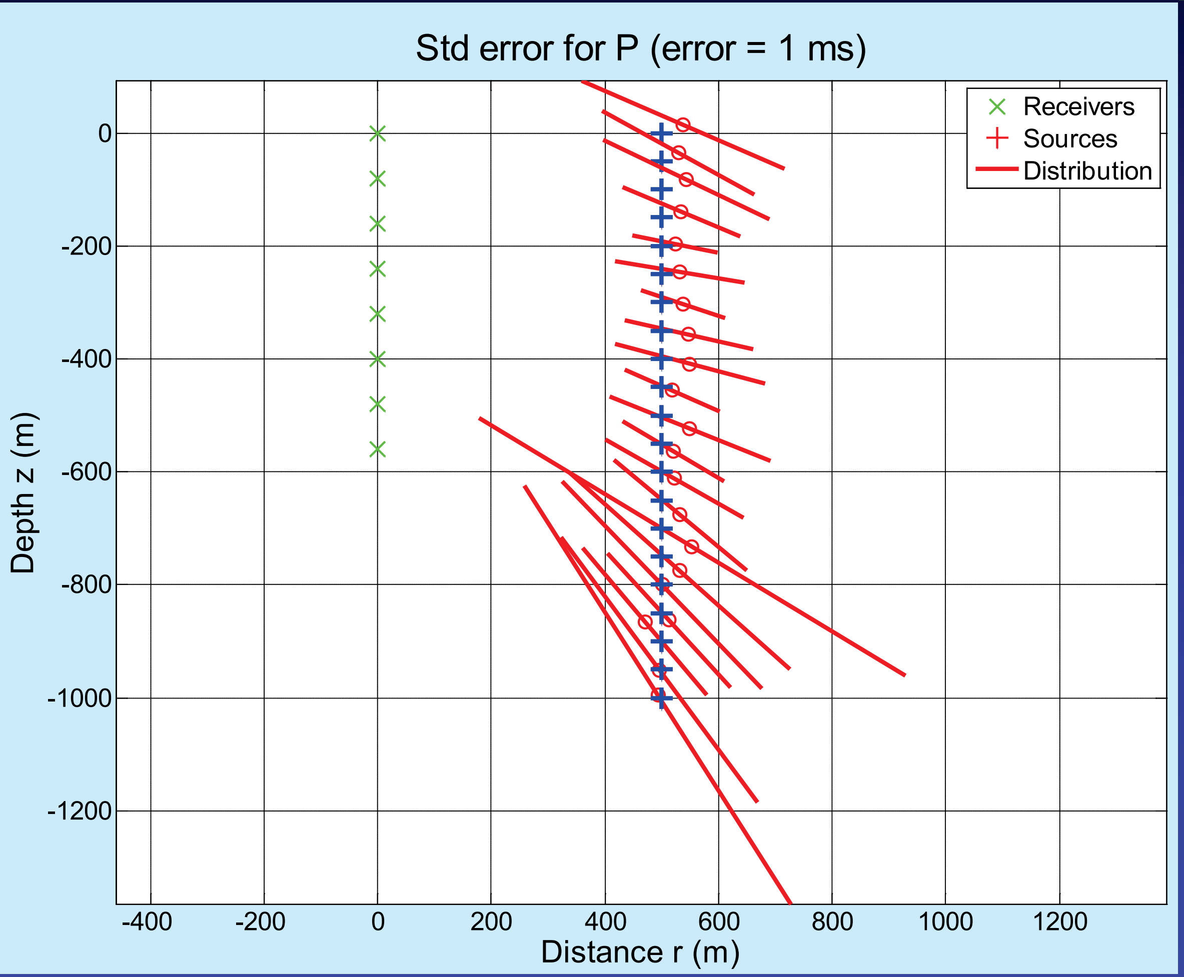
r = 500m

V = 3000 m/s

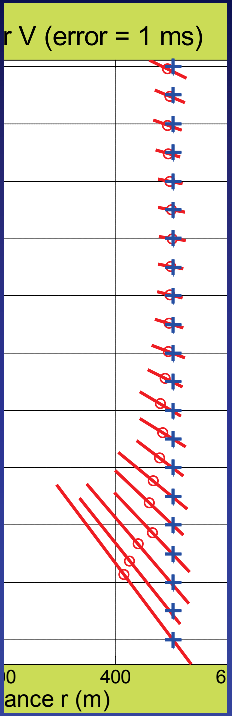
N = 8

$Z_{r\text{-}max}$ = <u>600 m</u>

***P* solution**



***V* solution**



S-wave (lower velocity)

Noise 1.0 ms

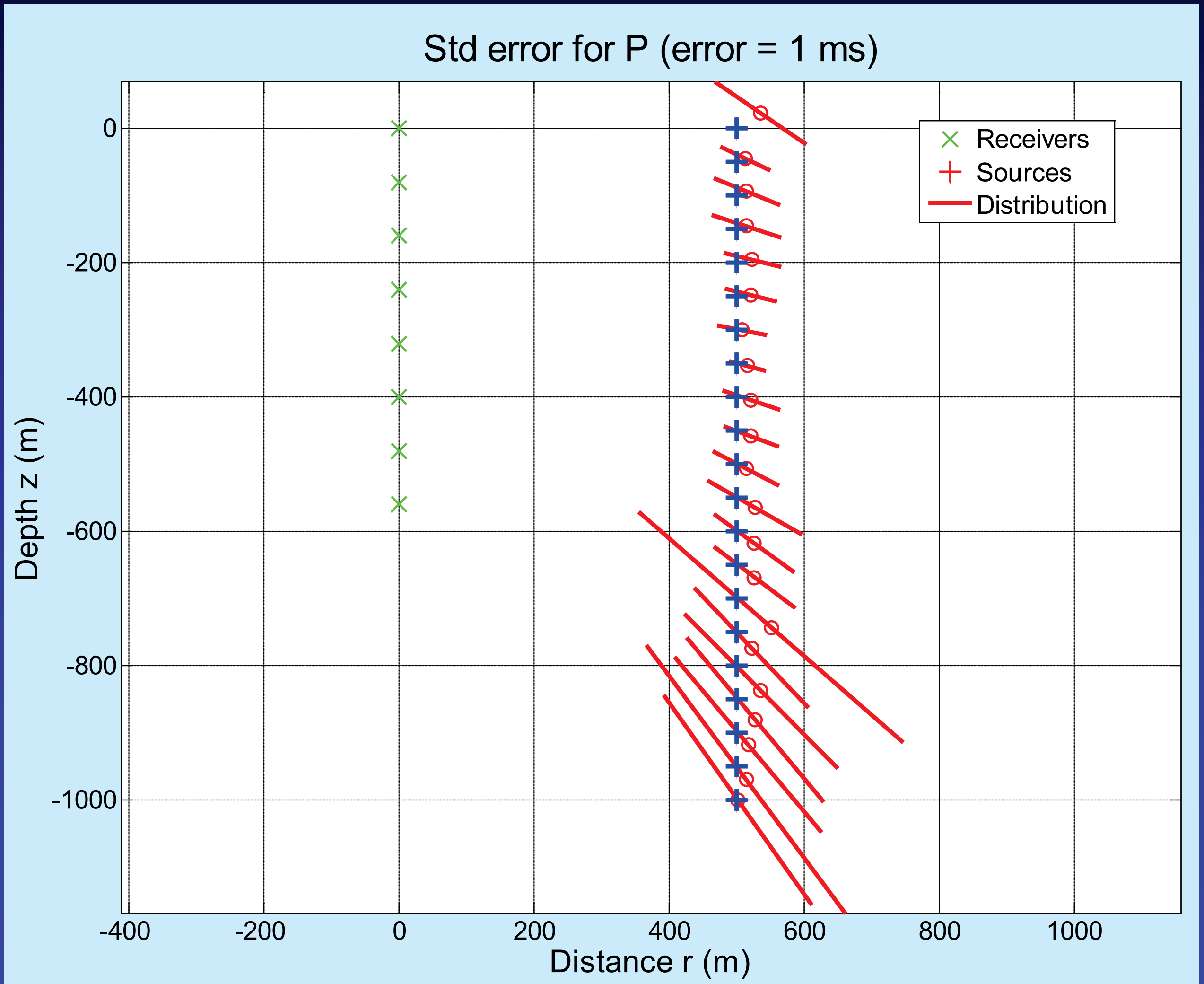
r = 500m

V = 1500 m/s

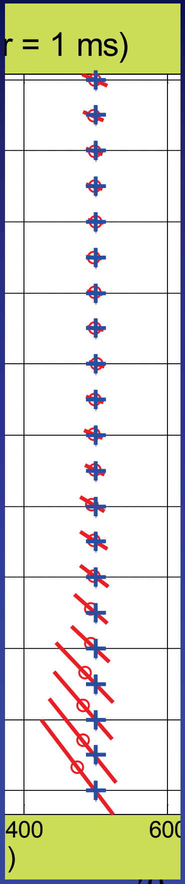
N = 8

$Z_{r\text{-}max}$ = 600 m

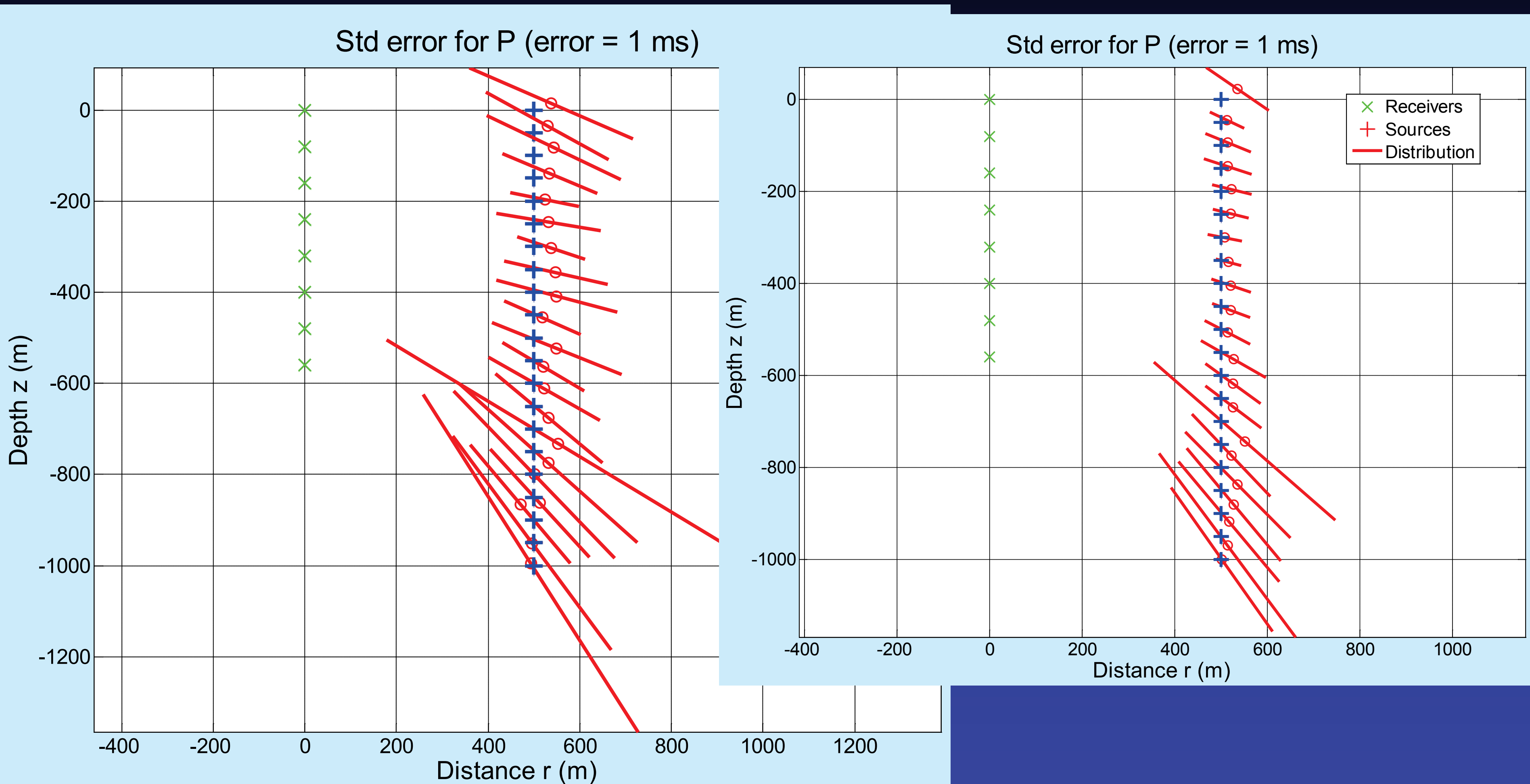
***P* solution**



***V* solution**

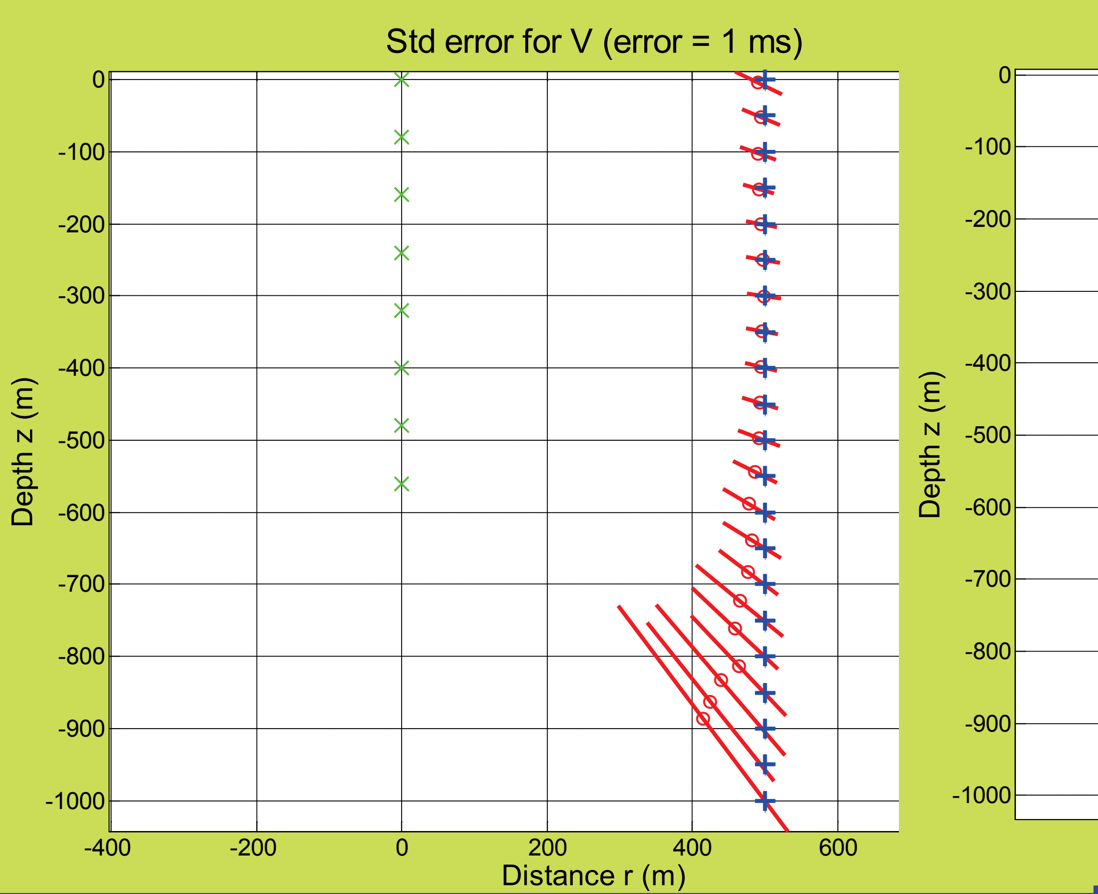


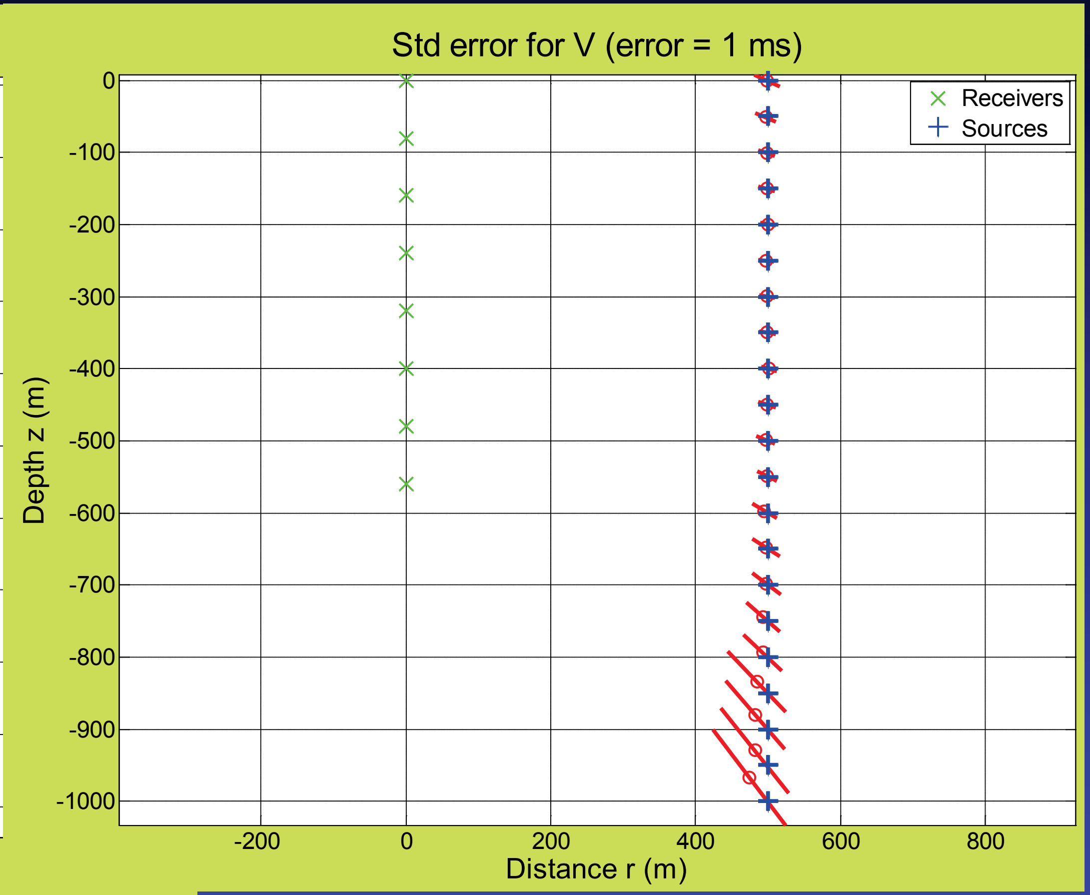
Compare *P*- and *S*-wave P solution



Vp = 3000 **Vs = 1500**

Compare *P*- and *S*-wave V solution



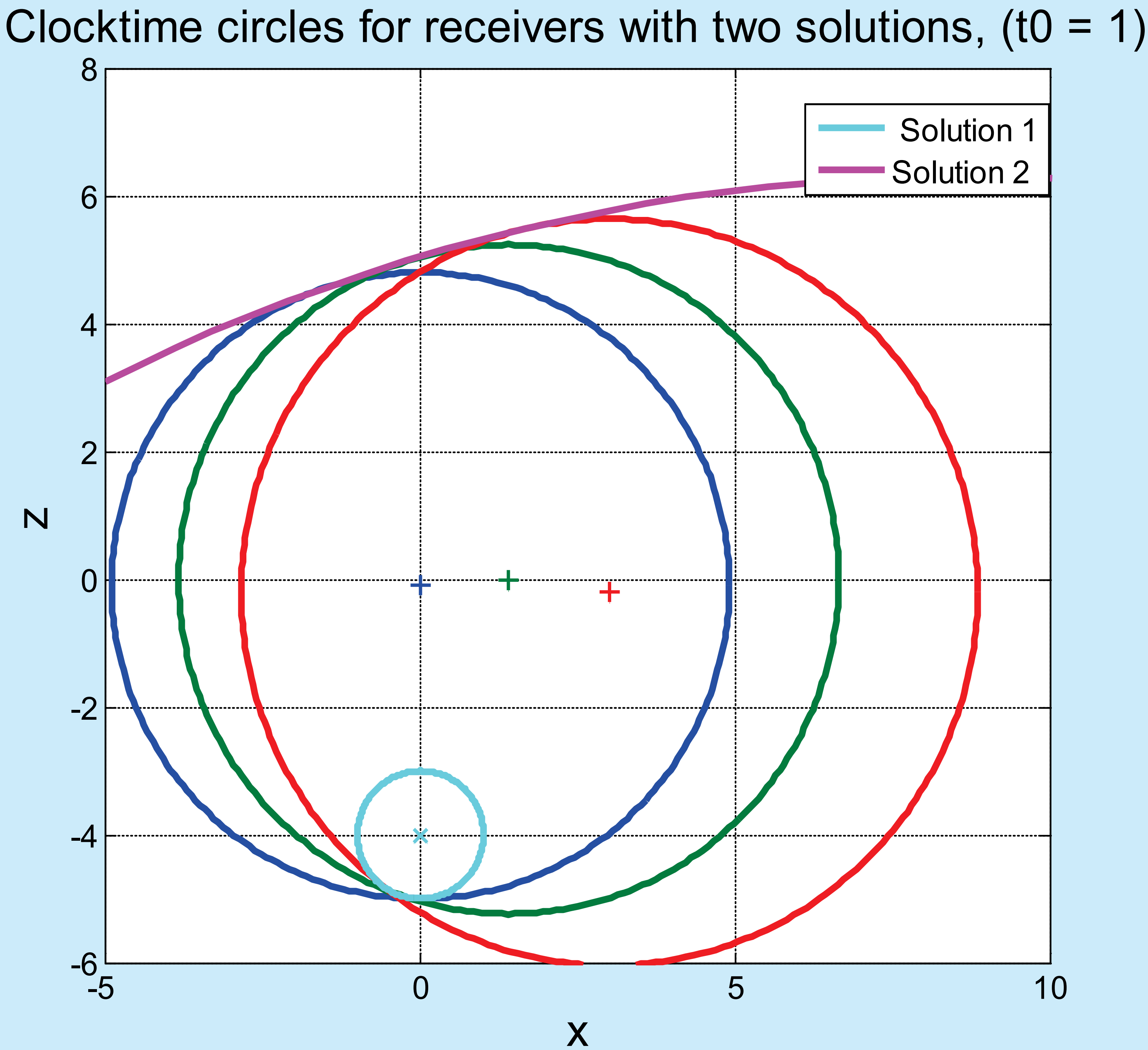


Vp = 3000 **Vs = 1500**

Conclusions and comments

1. Analytic solutions
2. Part of a larger grid system
3. Ideal conditions, constant velocity
4. Only error on the receiver clock-times
5. Least squares vector solution
6. Showed expected errors for vertical arrays

Thanks for your attention



Clocktime circles for receivers with two solutions, (t0 = 1)
Solution 1
Solution 2
8
6
4
2
0
-2
-4
-6
-5
0
5
10
z
x