# Earthquake Location and Tomography with Differential Traveltime Data

by William Menke
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acknowledging the contributions of

David Schaff
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Felix Waldhauser
*L.D.E.O.*

and the late
Sigurdur Rognvaldsson
*Icelandic Meterological Office*

*What you can measure:*

arrival times of P and S
waves from an earthquake
observed at at a station

*What you want to learn*
*when you locate an earthquake*

the location (x, y, z) and
orgin time To of the earthquake

*and when you do tomography*

the P velocity Vp(x,y,z)
and S velocity Vs(x,y,z)
of the earth

*arrival time*

*not the same as*

*a travel time !*

A car arrived in town at 1 PM
traveling at 60 m.p.h.

*Where did it start?*

*A car arrived in town after*
*traveling an hour at 60 m.p.h.*

*Where did it start?*

*Vs correlates strongly with Vp:*

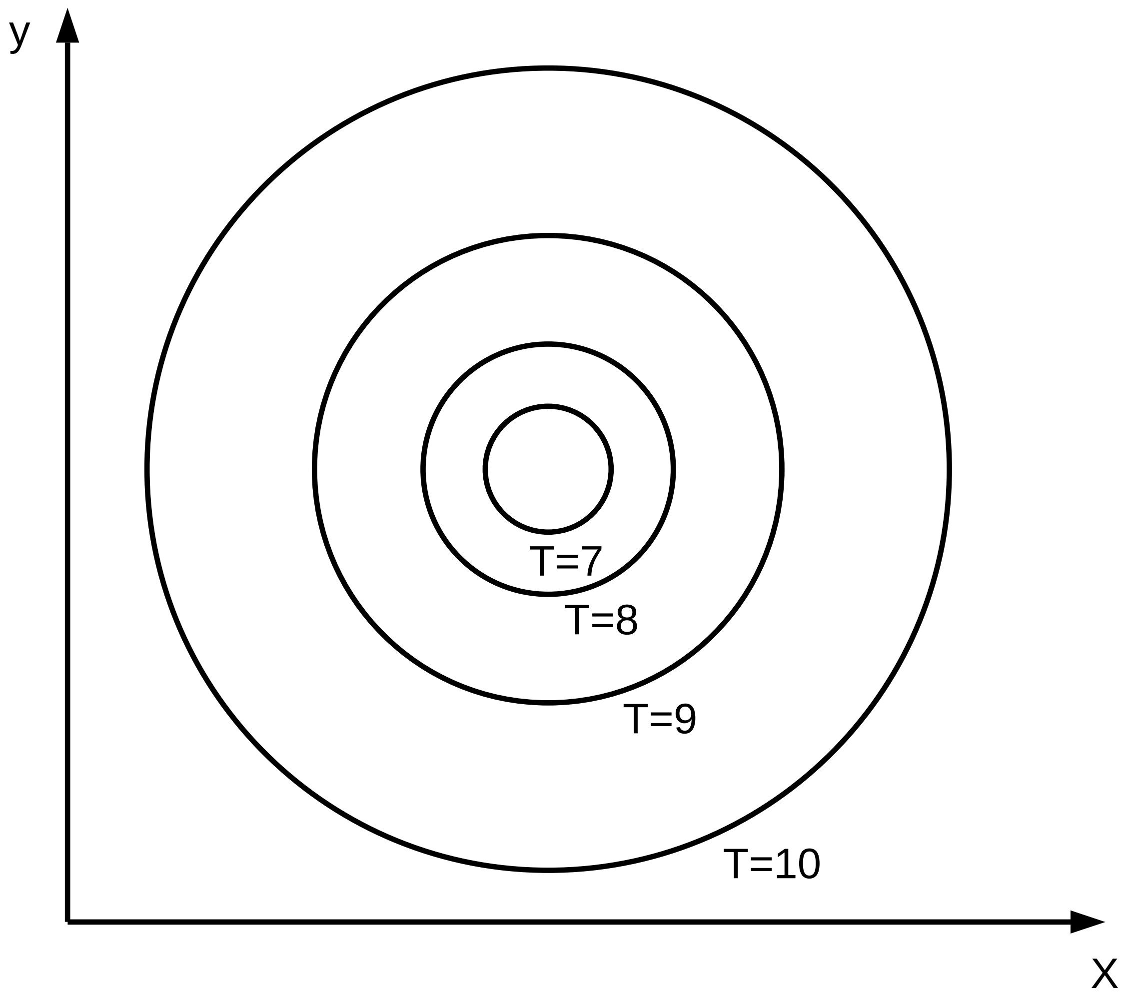
*Vp = sqrt[ ( k + 1.33 mu ) / rho ]*

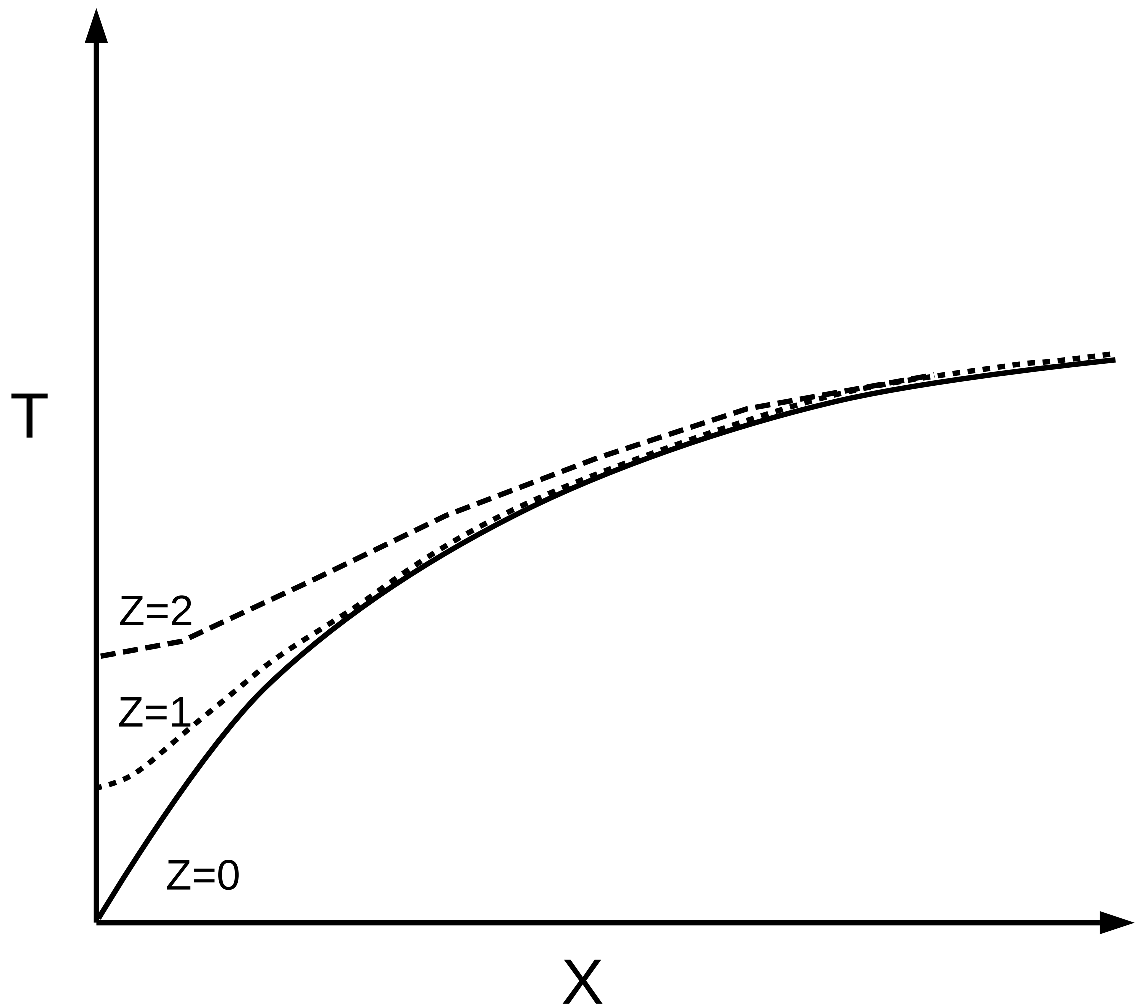
*Vs = sqrt[ mu / rho ]*

the ratio Vp/Vs has a fairly
limited range of values

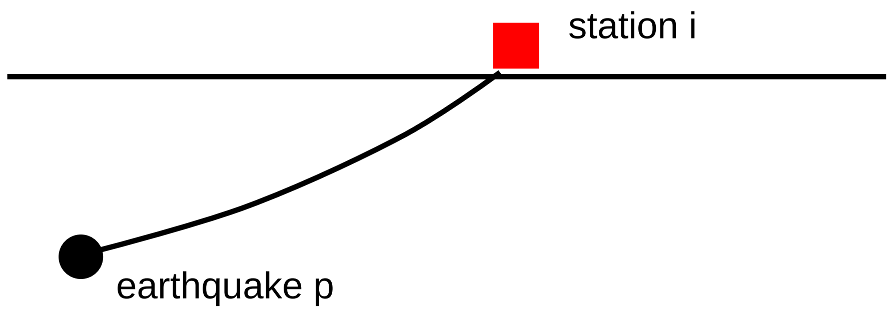
most rocks 1.7 < Vp/Vs < 1.8

partailly molten rocks
Vp/Vs can be as high as 2.0

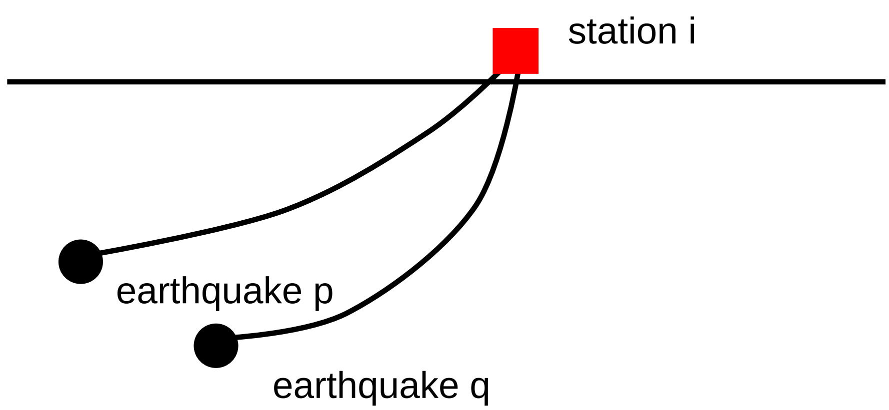

y
T=7
T=8
T=9
T=10
X


T
Z=2
Z=1
Z=0
X

# standard arrival time Tpi




# differential arrival time DTpqi



Disadvantages in using only

$$DTpqi = Tpi - Tqi$$

1) loss of information about mean origin times

$$Tpi = TTpi + Topi$$

$$Tqi = TTqi + Toqi$$

$$DTpqi = (TTpi-TTqi) - (Topi-Toqi)$$

2) subtraction amplifies noise

$$var(DTpqi) = var(Tpi) + var(Tqi)$$

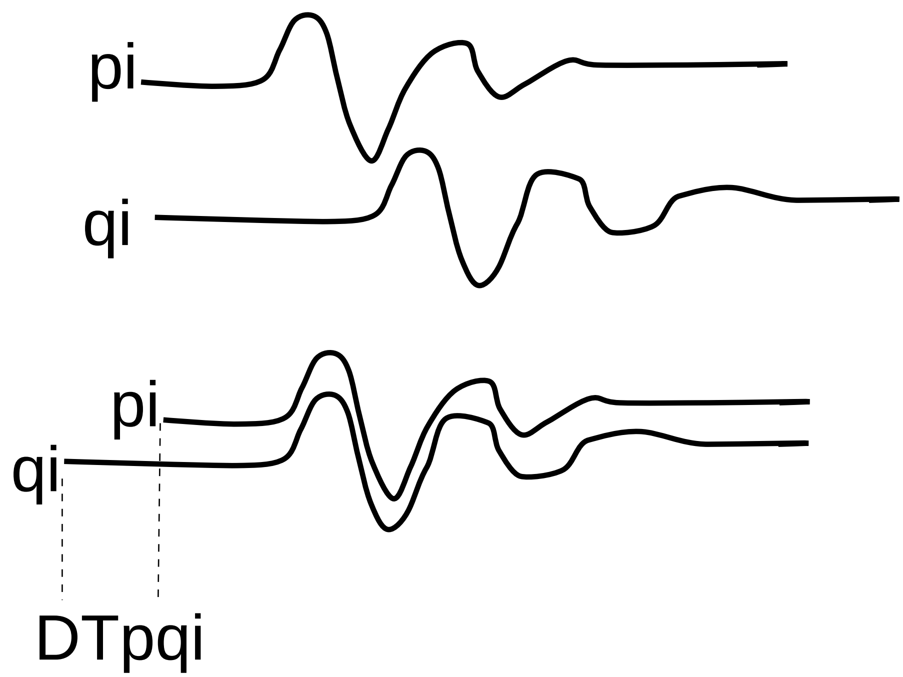
3) Weird corrlelations

$$DTpqi = DTpri - DTqri$$

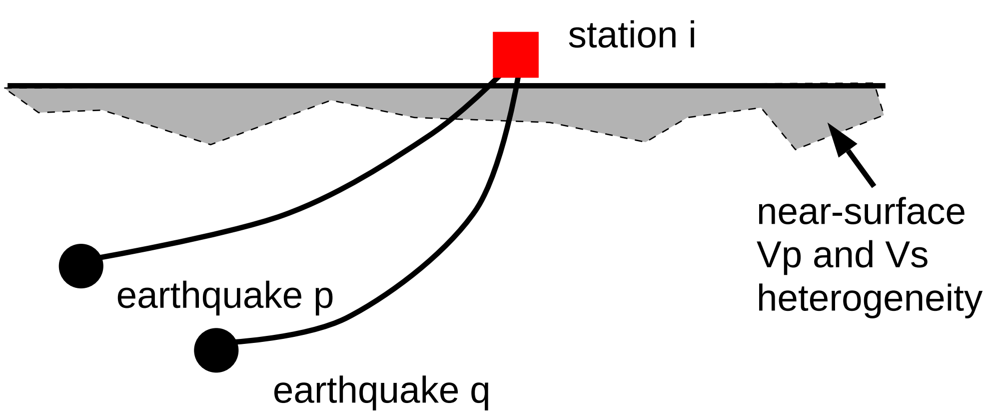
Advantages in using only

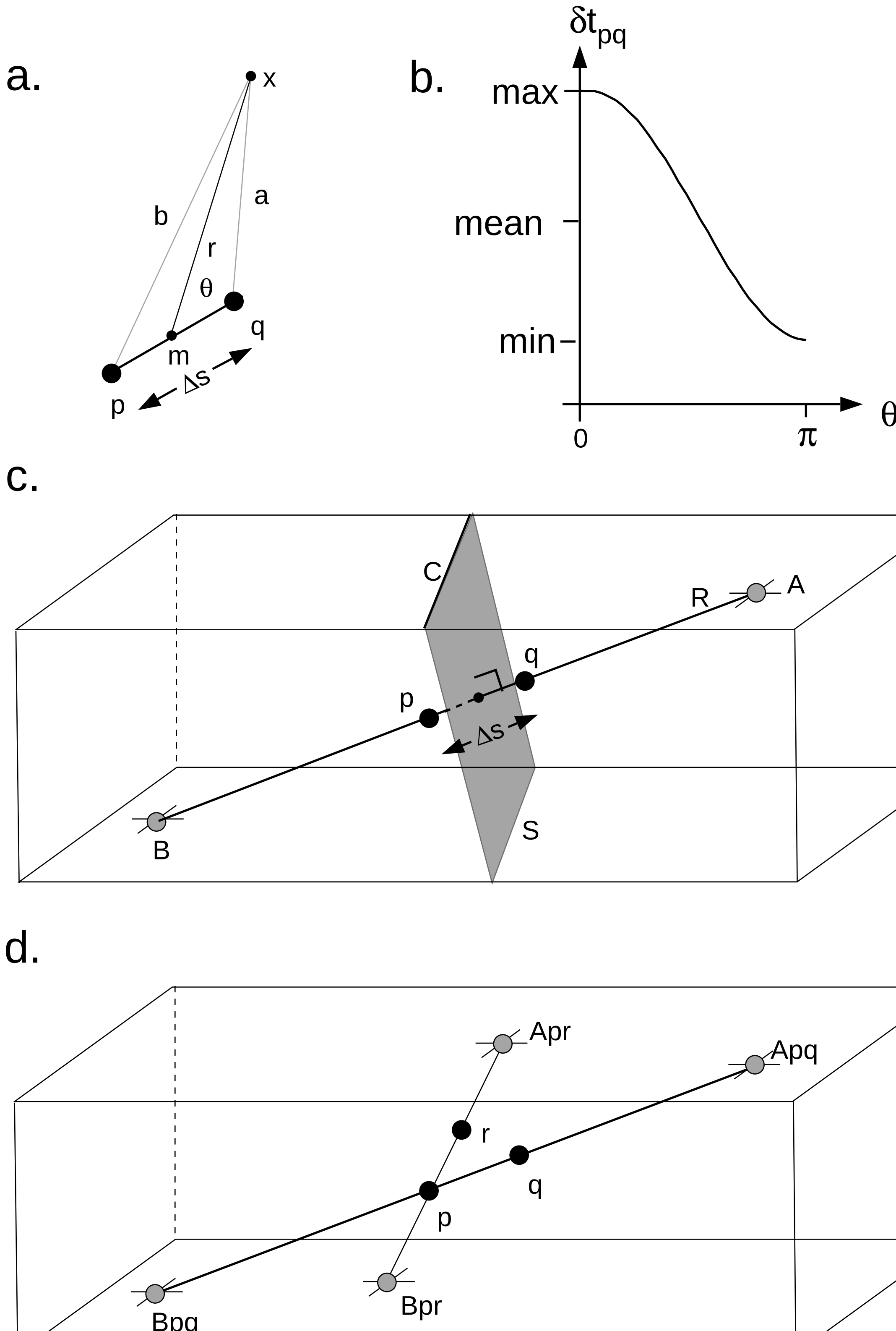
DTpqi = Tpi - Tqi

1) use cross-correlation

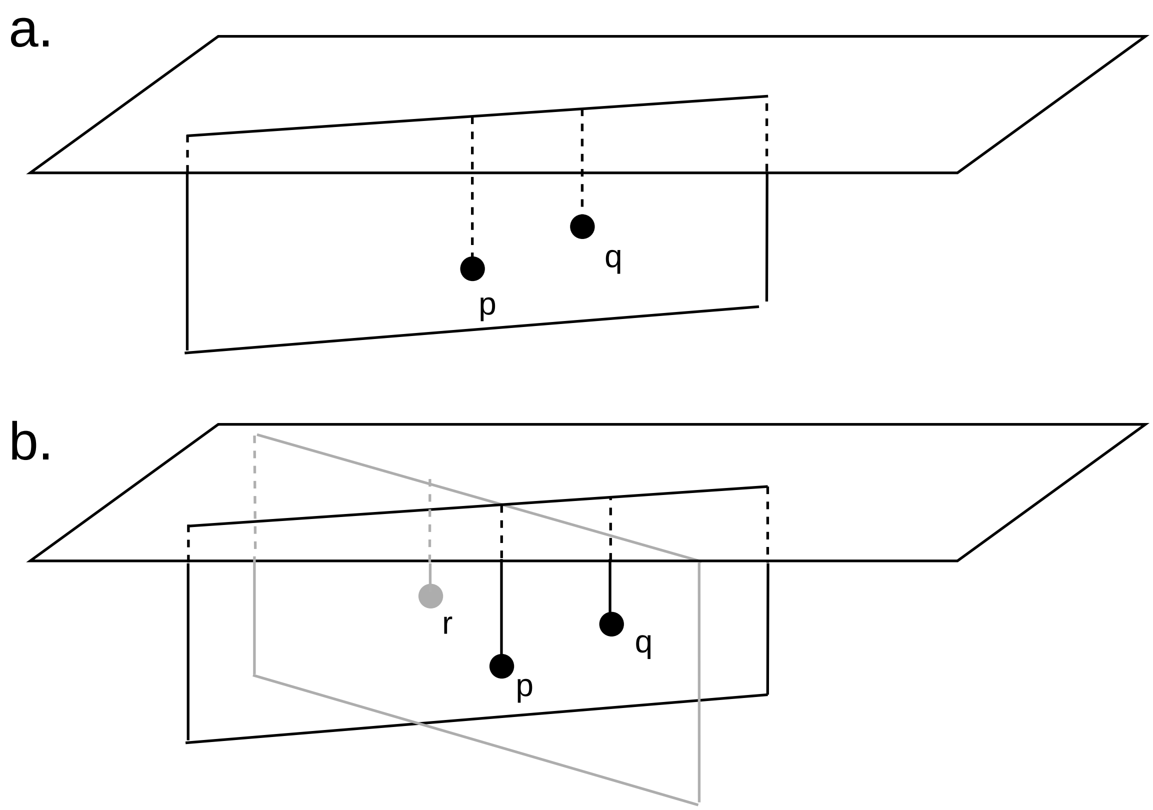


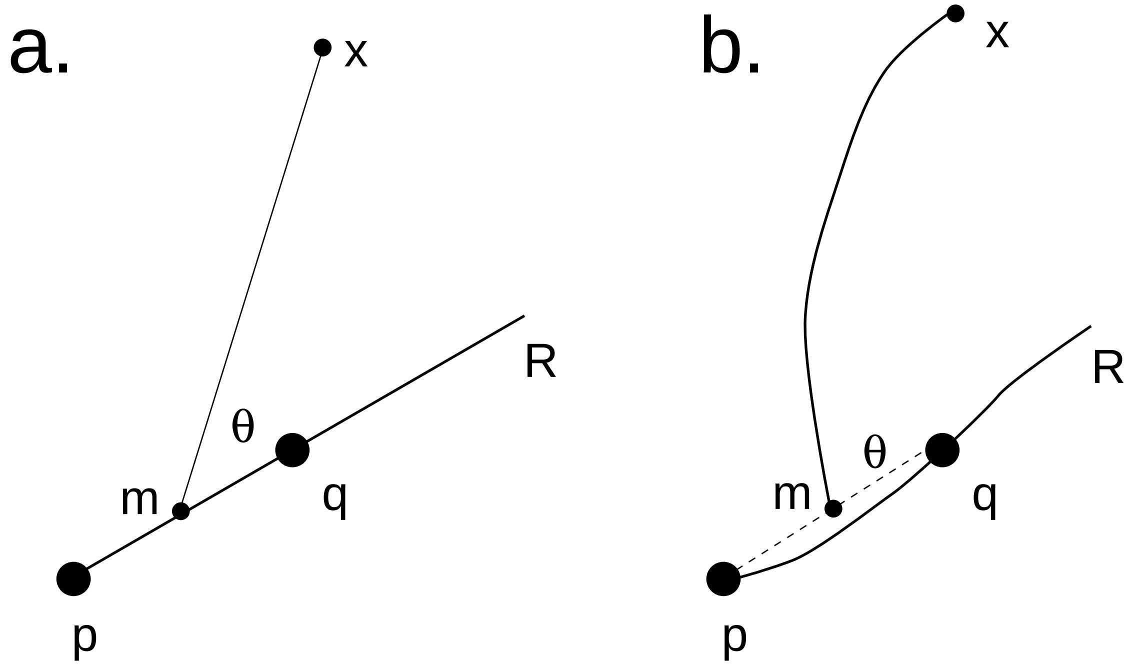

2) cancelation of near-station velocity model errors lead to better predictions of traveltime

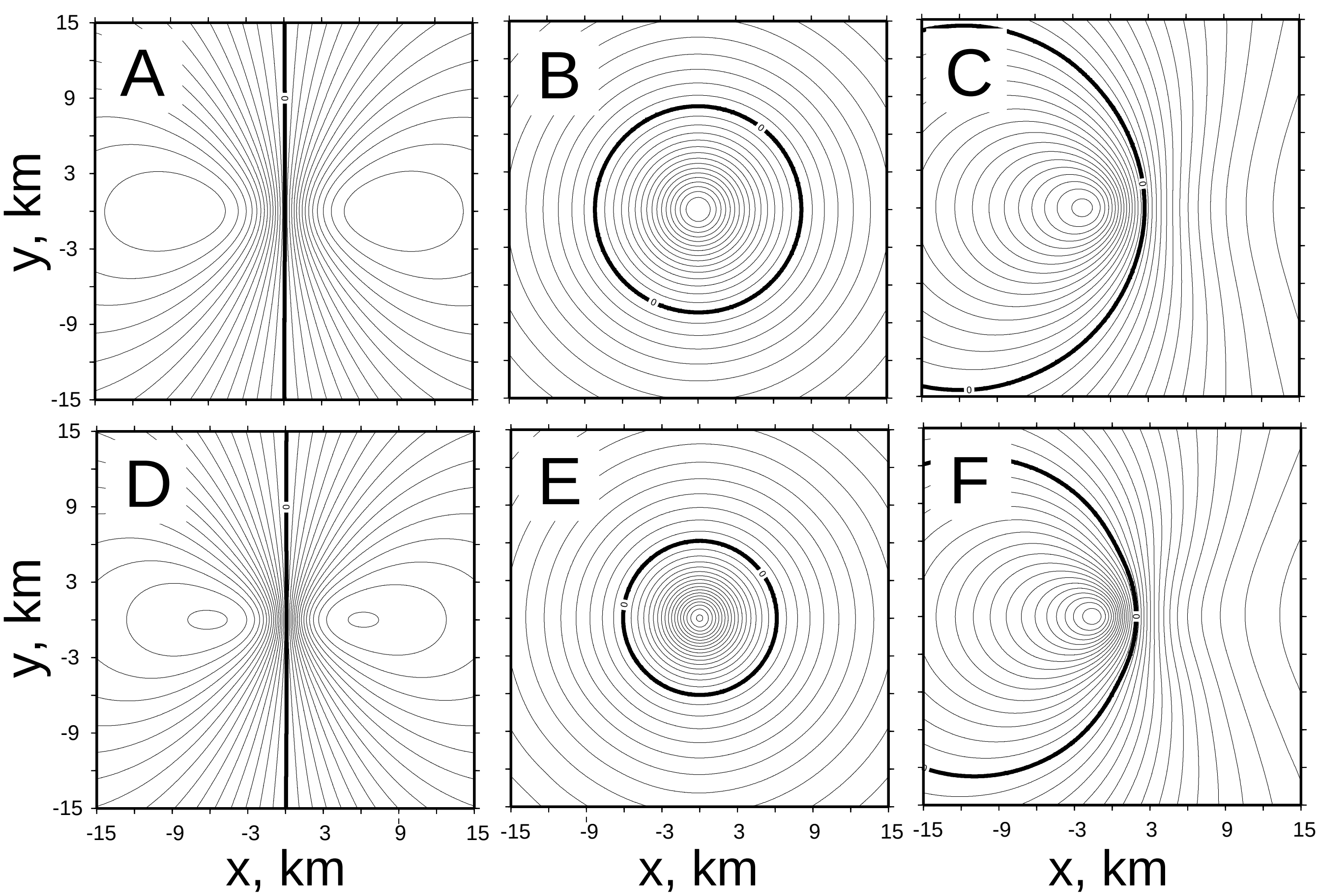


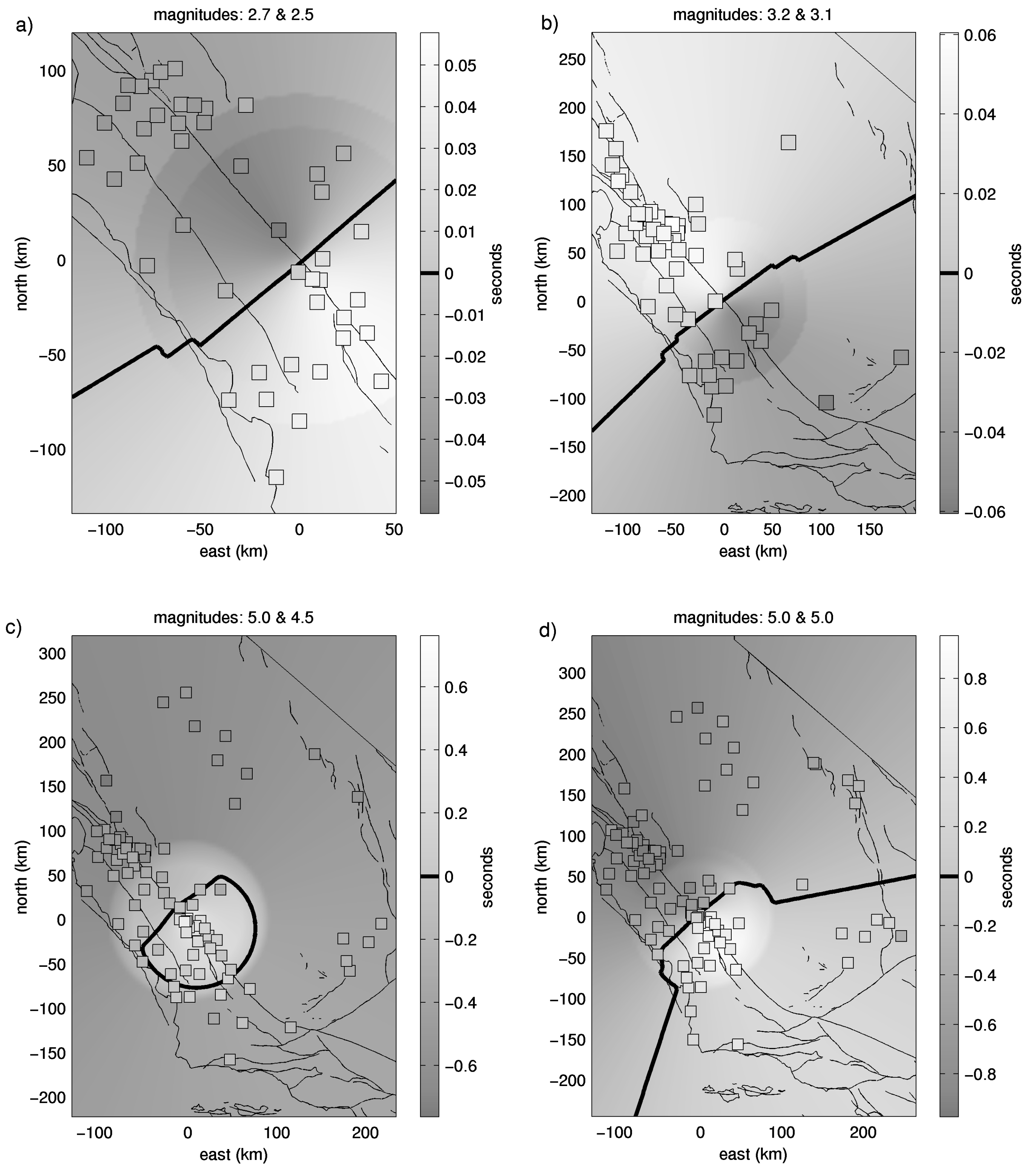


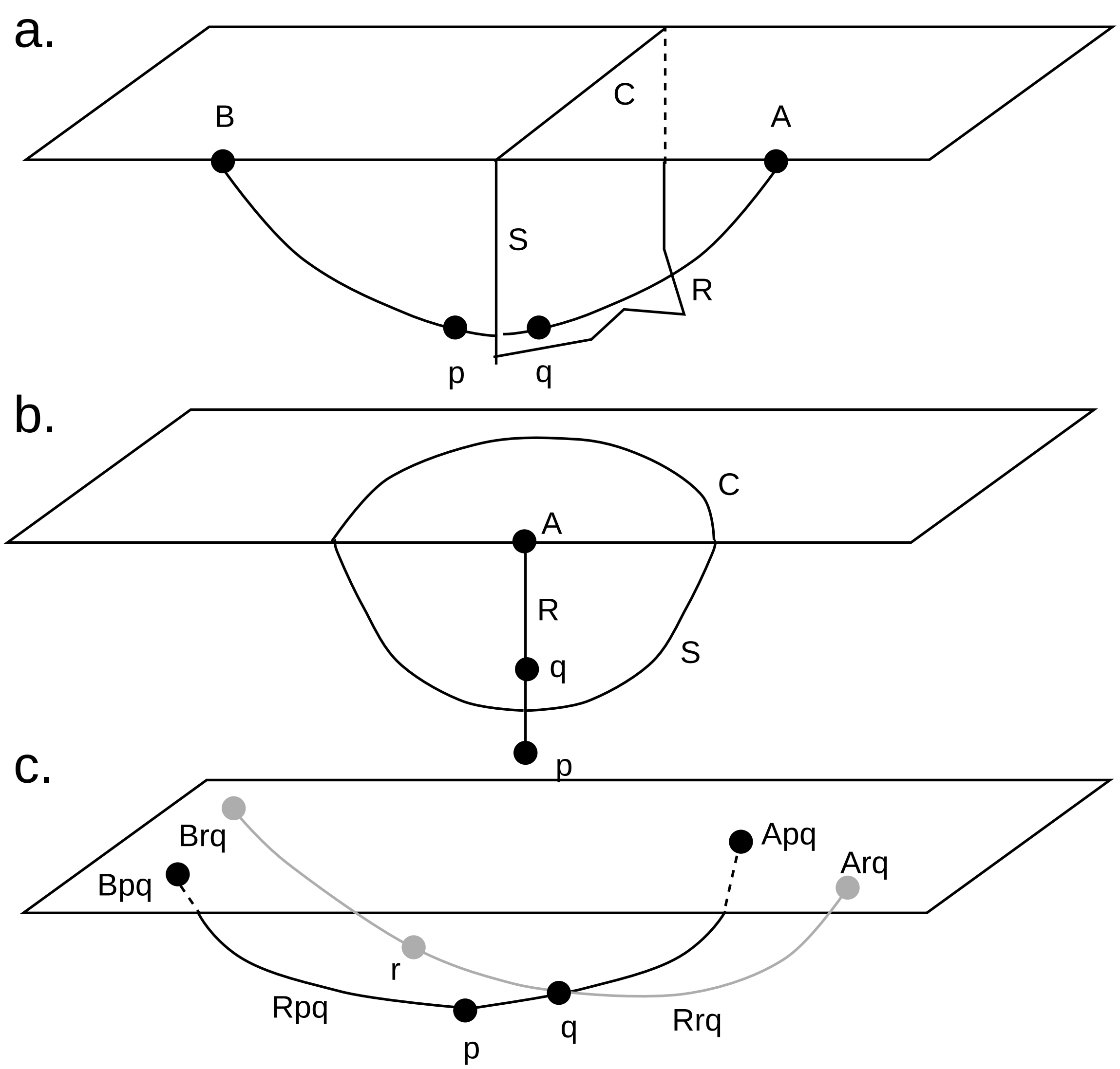
a.
x
a
b
r
θ
q
m
p
Δs
b.
δt_pq
max
mean
min
0
π
θ
c.
C
R
A
q
p
Δs
B
S
d.
Apr
Apq
r
q
p
Bpq
Bpr


a.
q
p
b.
r
q
p

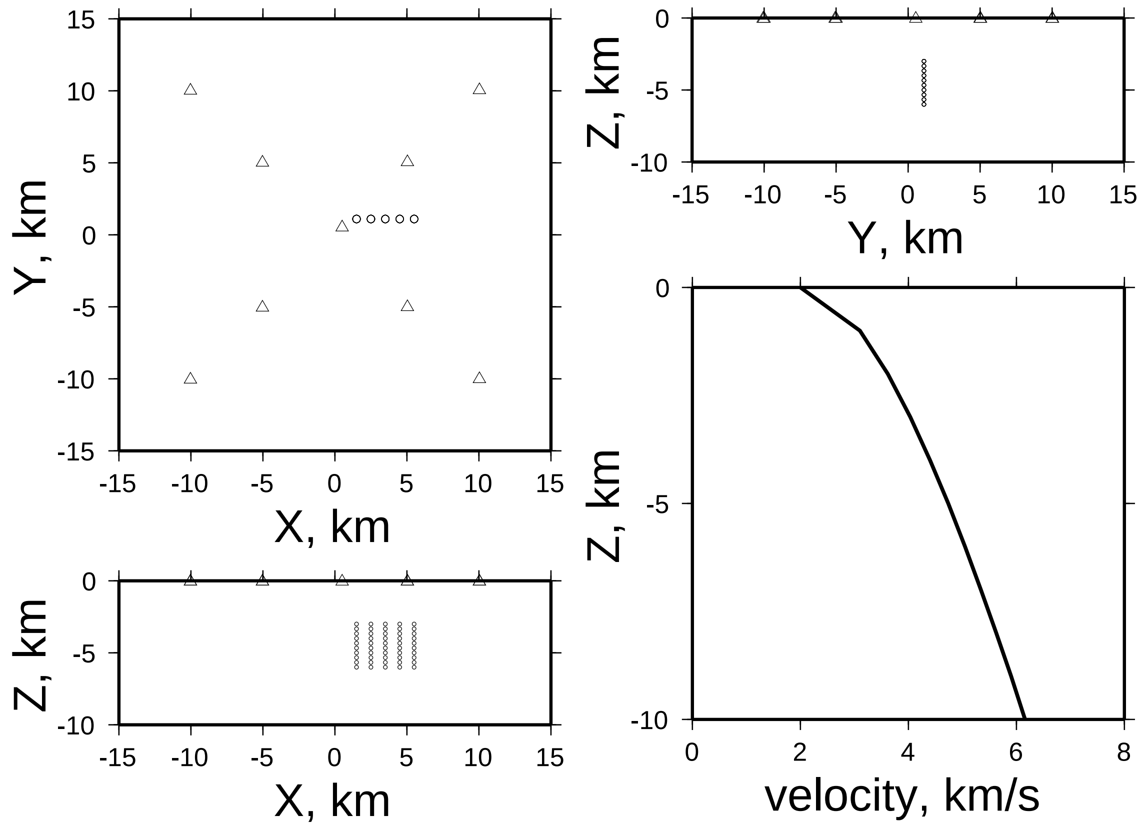

a.
x
R
θ
m
q
p
b.
x
R
θ
m
q
p


A
B
C
D
E
F
y, km
x, km
15
9
3
-3
-9
-15
0

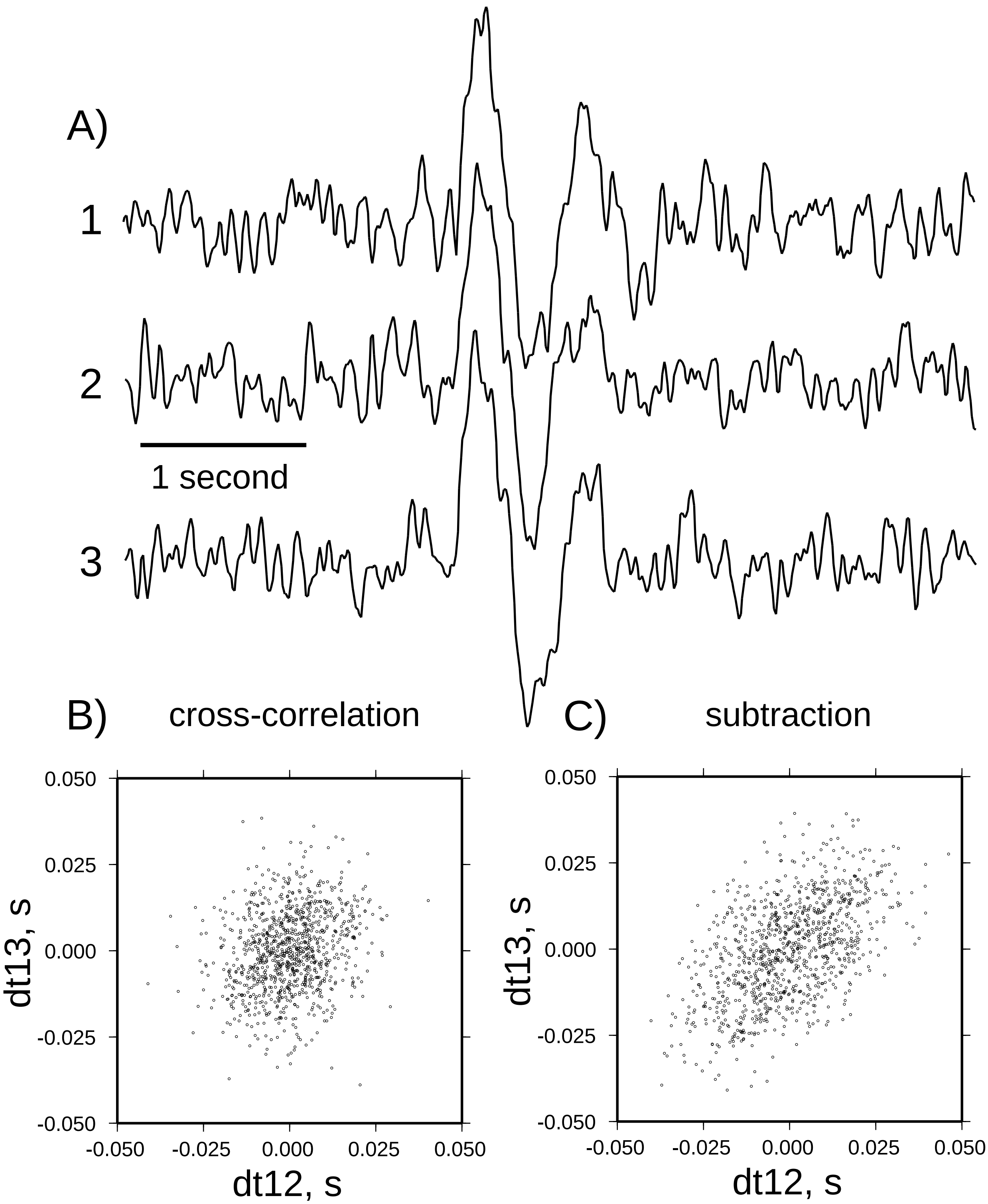

a)
magnitudes: 2.7 & 2.5
north (km)
east (km)
seconds
b)
magnitudes: 3.2 & 3.1
north (km)
east (km)
seconds
c)
magnitudes: 5.0 & 4.5
north (km)
east (km)
seconds
d)
magnitudes: 5.0 & 5.0
north (km)
east (km)
seconds

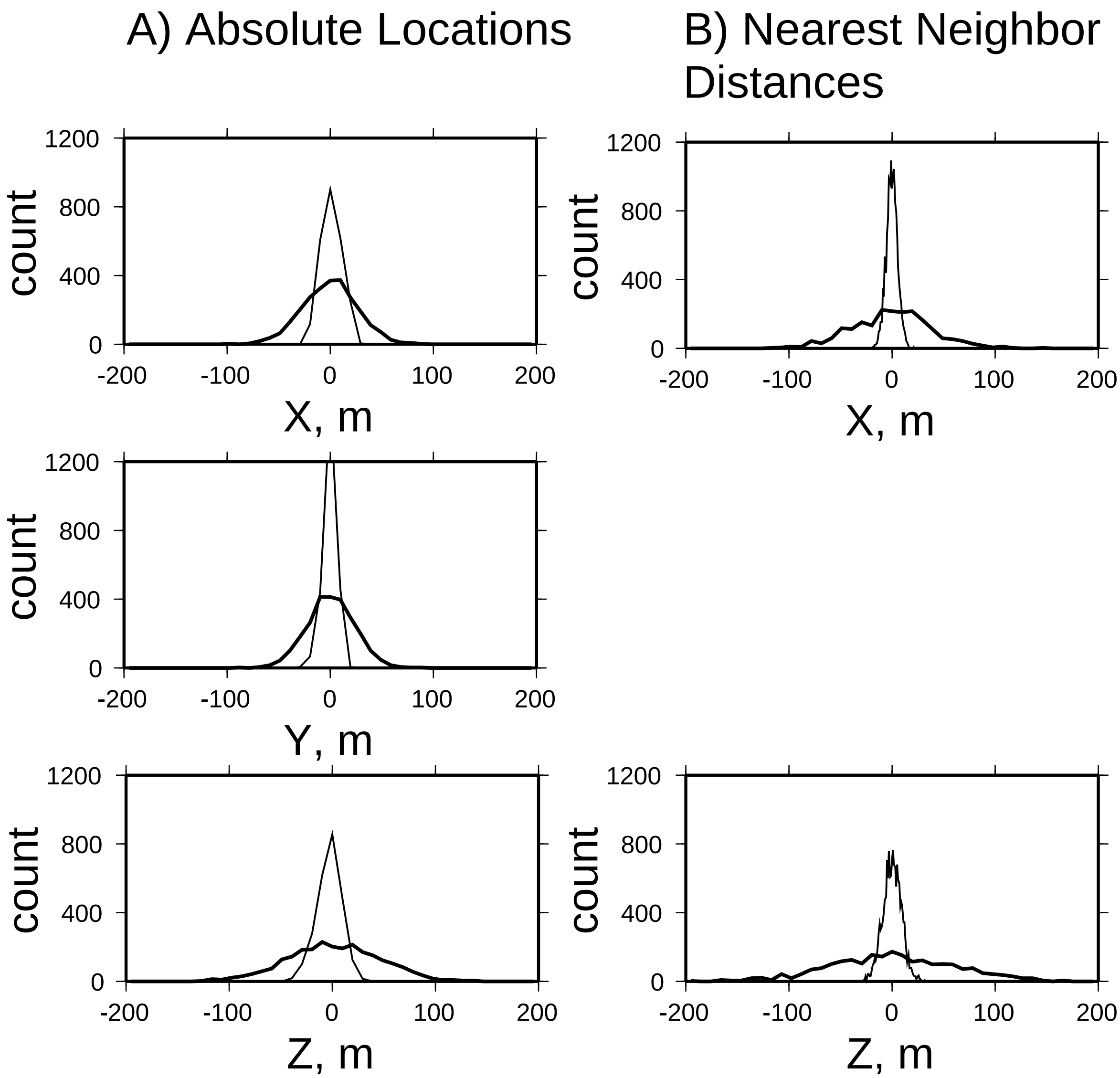


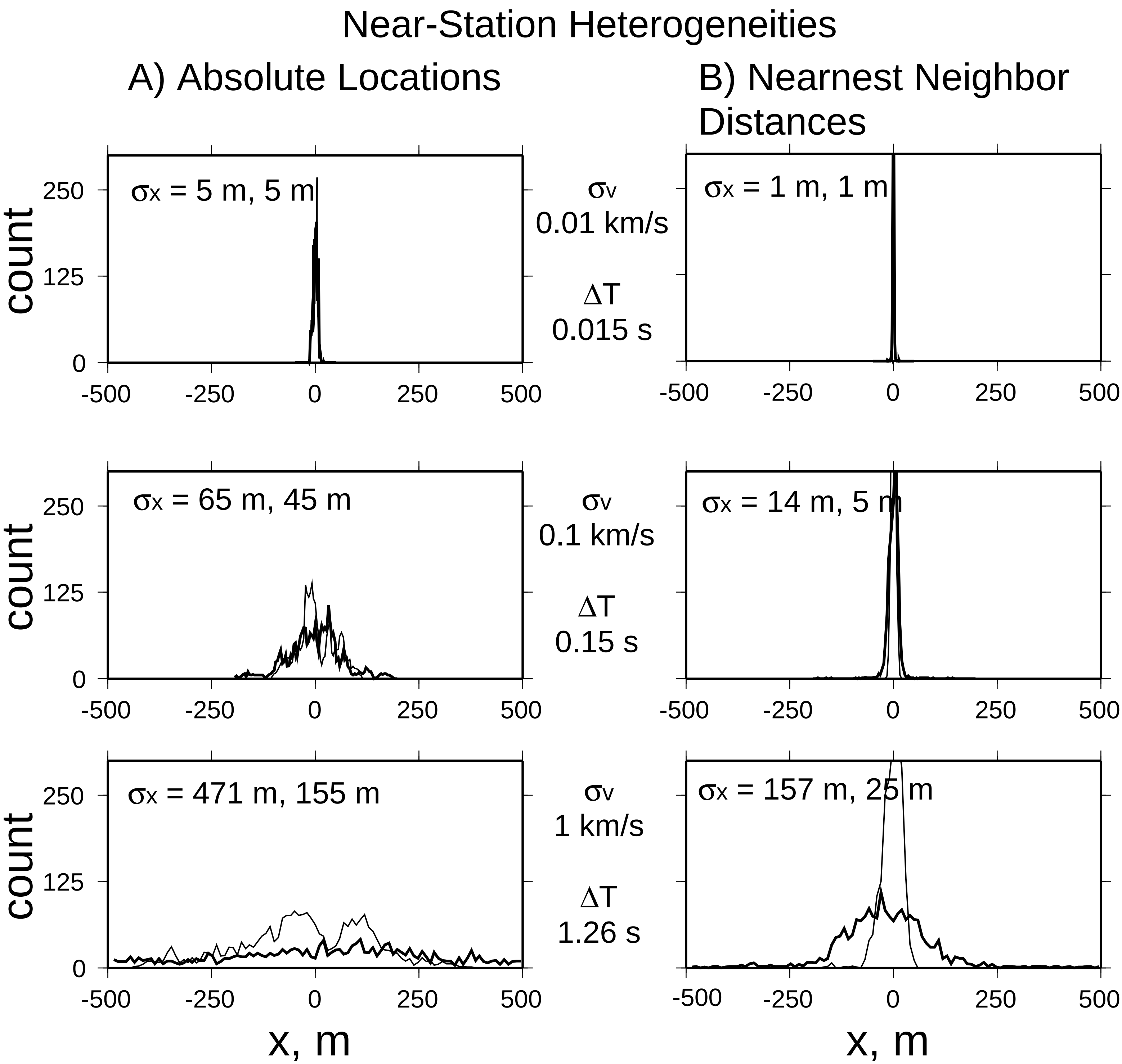
a.
C
B
A
S
R
p
q
b.
C
A
R
S
q
p
c.
Brq
Apq
Arq
Bpq
r
Rpq
q
Rrq
p

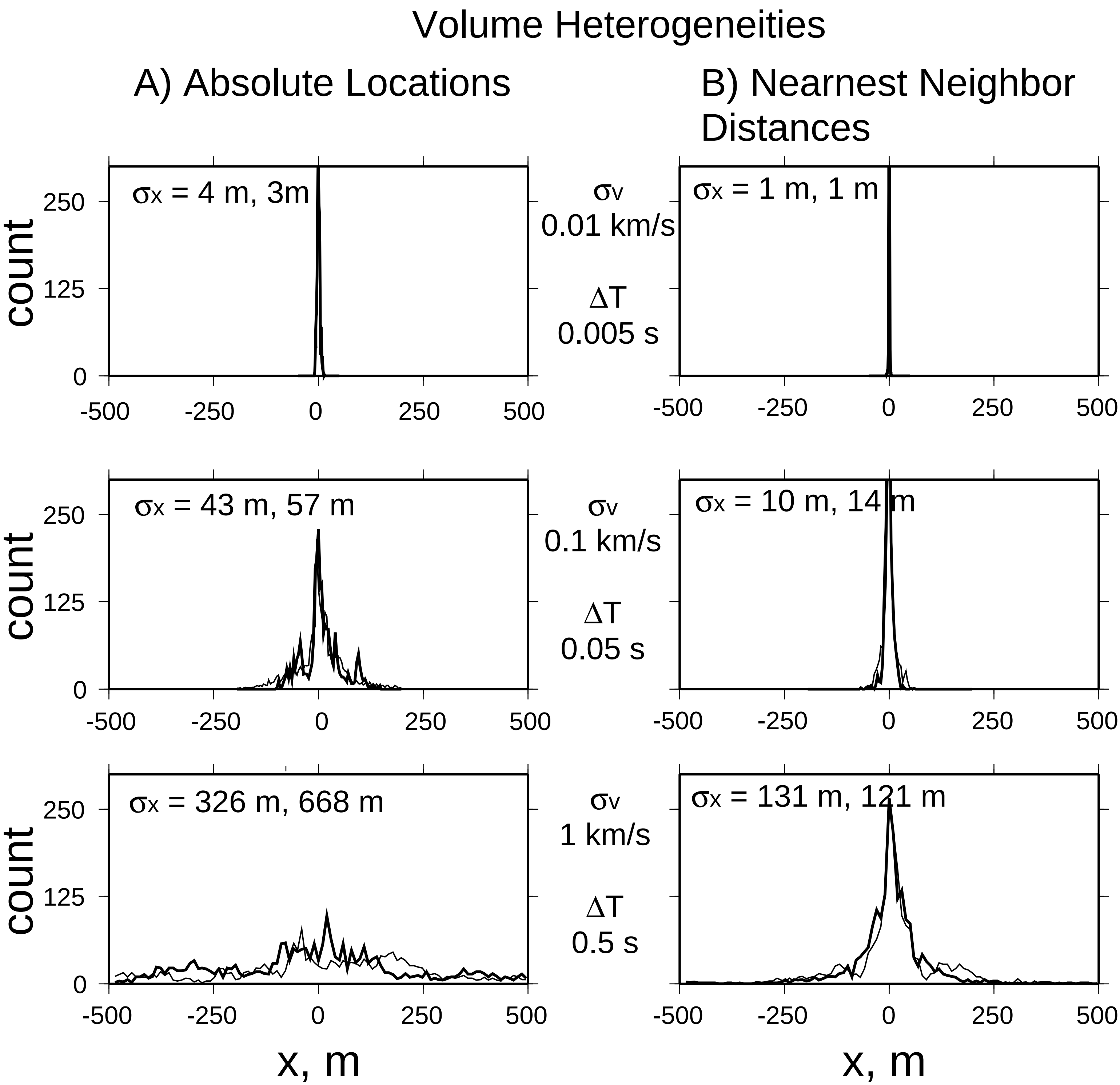


Y, km
X, km
Z, km
Y, km
Z, km
X, km
Z, km
velocity, km/s

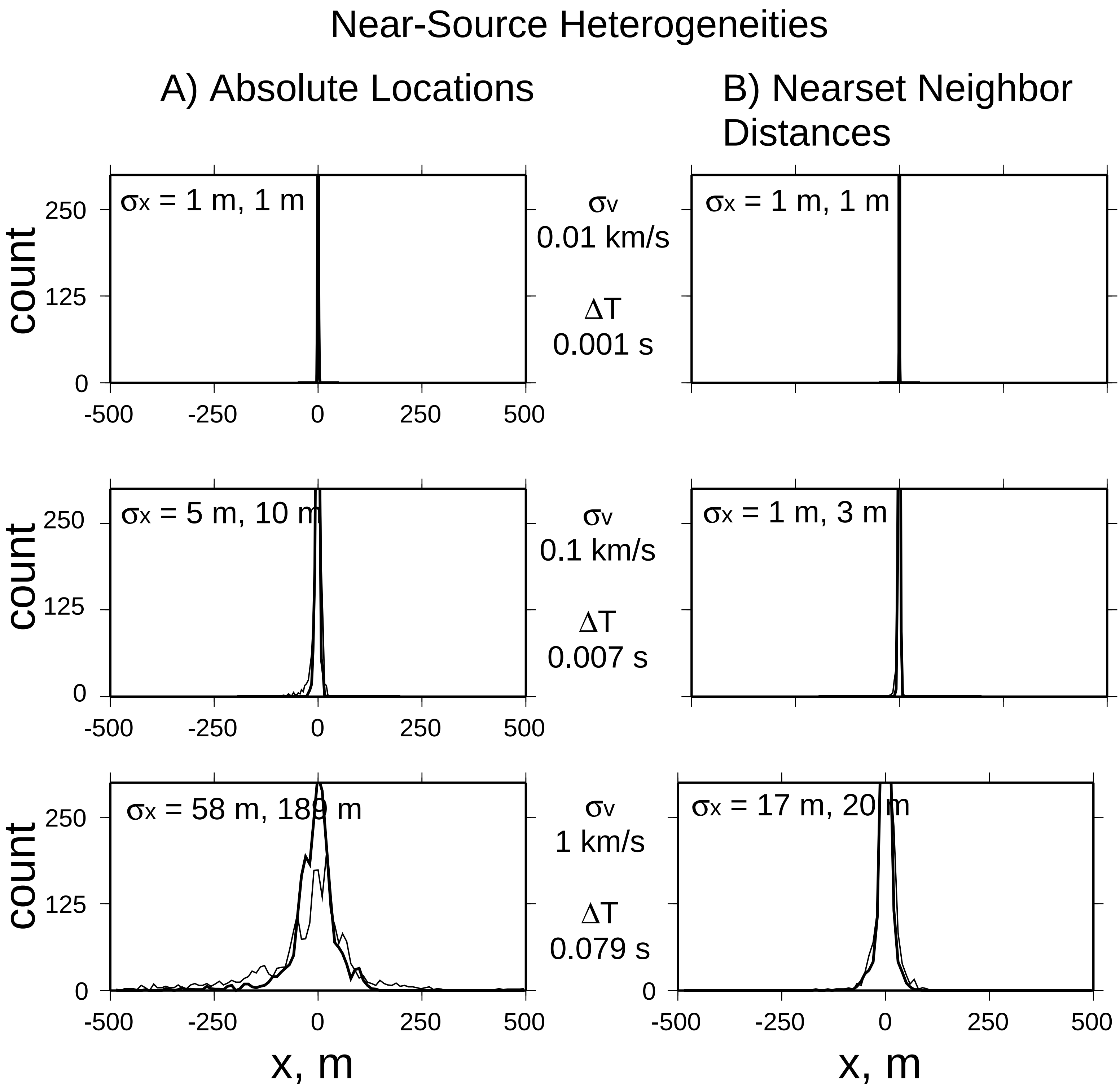

A)
1
2
3
1 second
B)
cross-correlation
C)
subtraction
0.050
0.025
0.000
-0.025
-0.050
-0.050
-0.025
0.000
0.025
0.050
dt13, s
dt12, s


A) Absolute Locations
B) Nearest Neighbor Distances
count
X, m
Y, m
Z, m
1200
800
400
0
-200
-100
0
100
200

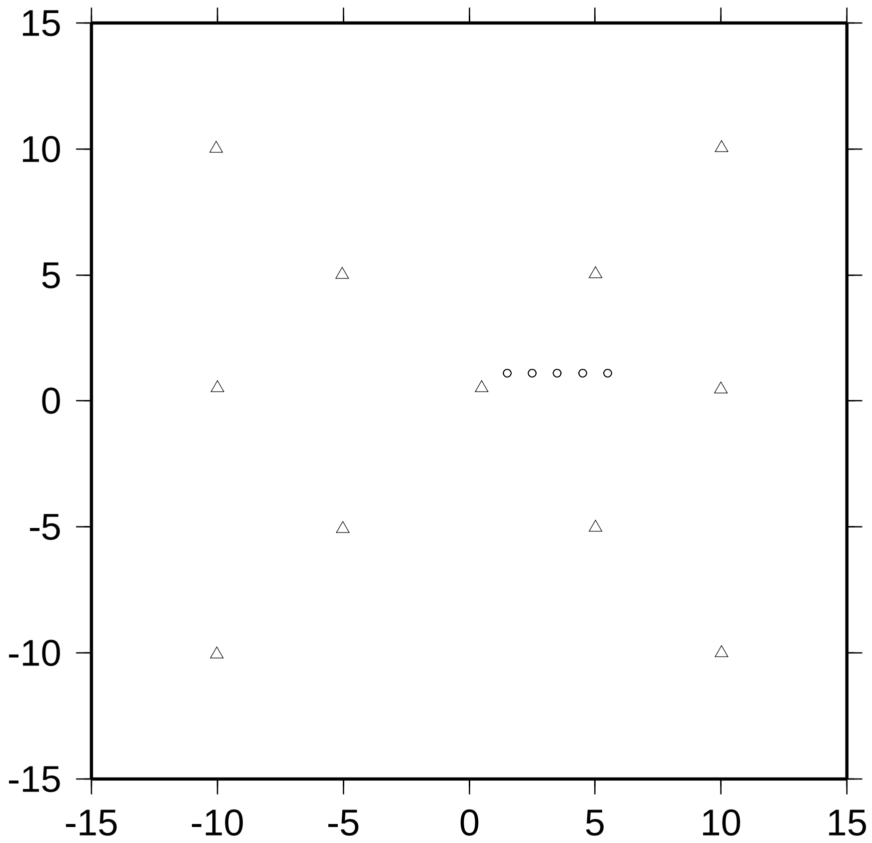

Near-Station Heterogeneities
A) Absolute Locations
B) Nearest Neighbor Distances
count
σx = 5 m, 5 m
σv 0.01 km/s
ΔT 0.015 s
σx = 1 m, 1 m
σx = 65 m, 45 m
σv 0.1 km/s
ΔT 0.15 s
σx = 14 m, 5 m
σx = 471 m, 155 m
σv 1 km/s
ΔT 1.26 s
σx = 157 m, 25 m
0
125
250
-500
-250
0
250
500
x, m



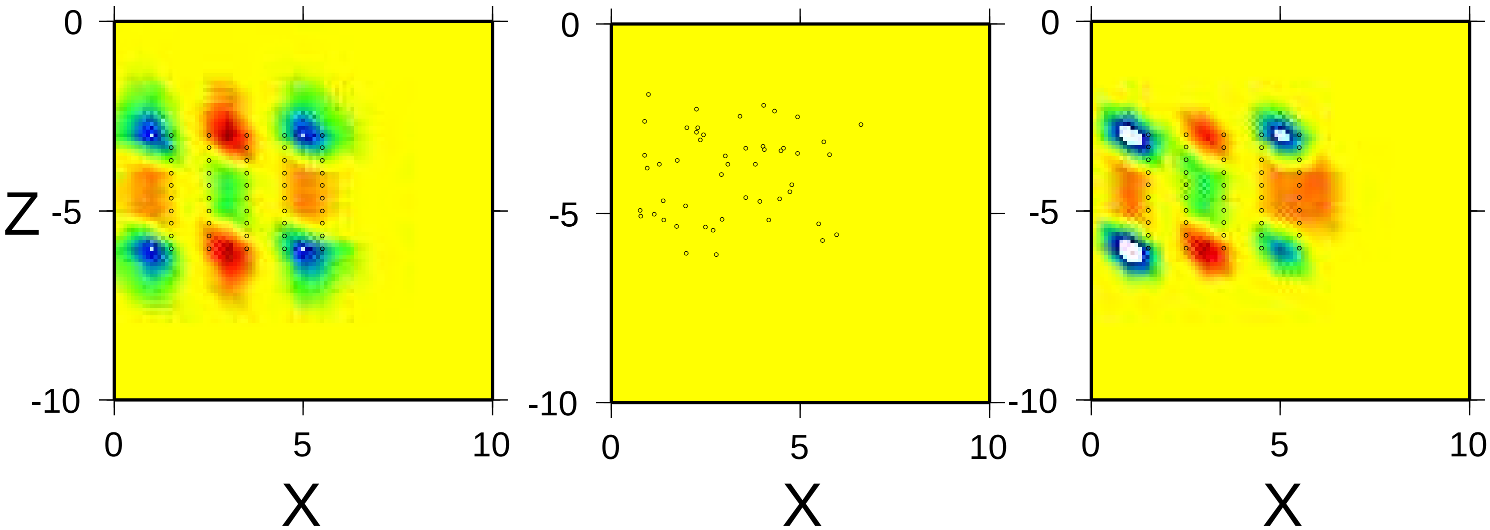
Volume Heterogeneities
A) Absolute Locations
B) Nearest Neighbor Distances
σx = 4 m, 3m
σv 0.01 km/s
ΔT 0.005 s
σx = 1 m, 1 m
σx = 43 m, 57 m
σv 0.1 km/s
ΔT 0.05 s
σx = 10 m, 14 m
σx = 326 m, 668 m
σv 1 km/s
ΔT 0.5 s
σx = 131 m, 121 m
count
x, m



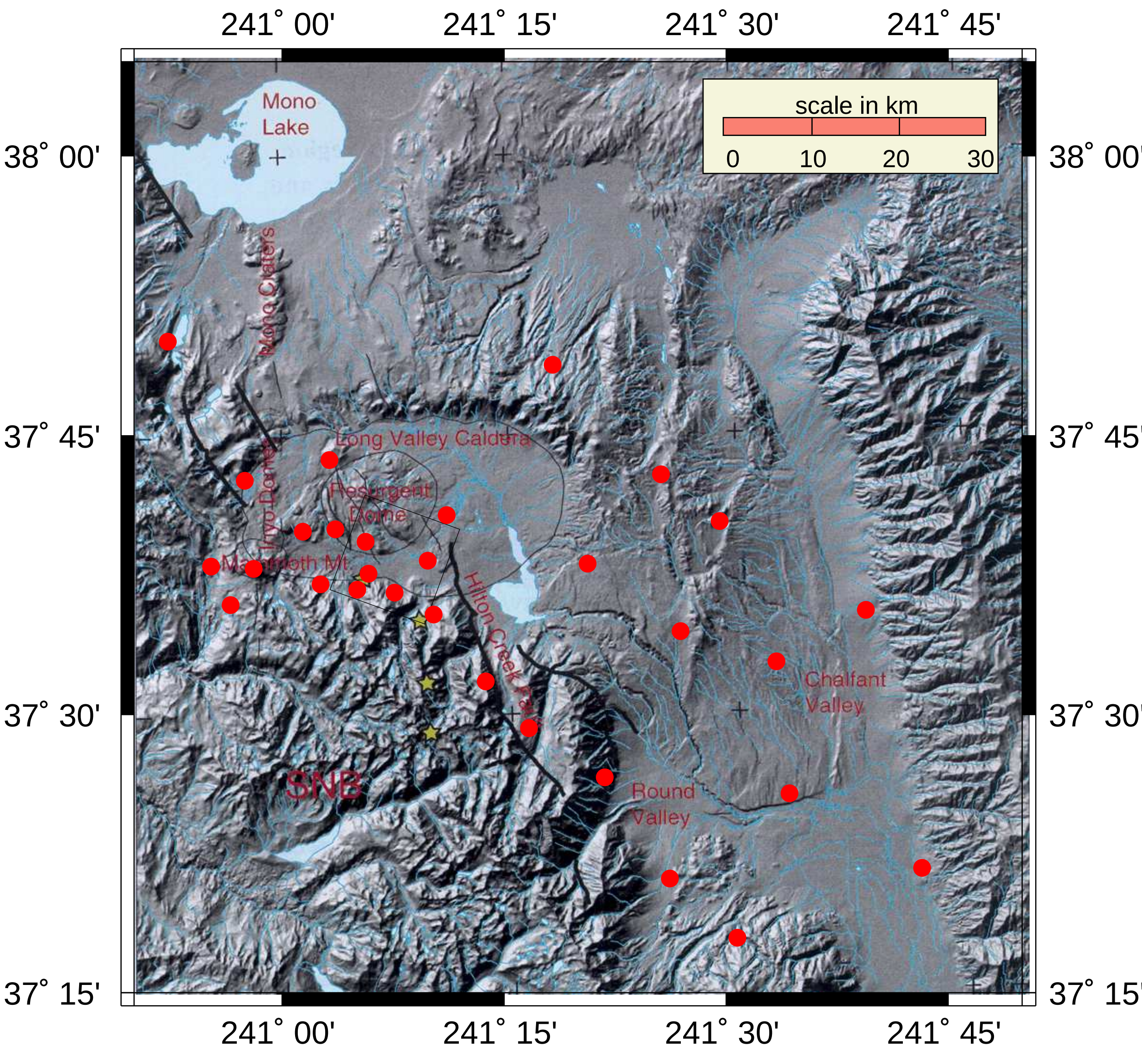
Near-Source Heterogeneities
A) Absolute Locations
B) Nearset Neighbor Distances
σx = 1 m, 1 m
σv 0.01 km/s
ΔT 0.001 s
σx = 1 m, 1 m
σx = 5 m, 10 m
σv 0.1 km/s
ΔT 0.007 s
σx = 1 m, 3 m
σx = 58 m, 189 m
σv 1 km/s
ΔT 0.079 s
σx = 17 m, 20 m
count
0
125
250
-500
-250
0
250
500
x, m



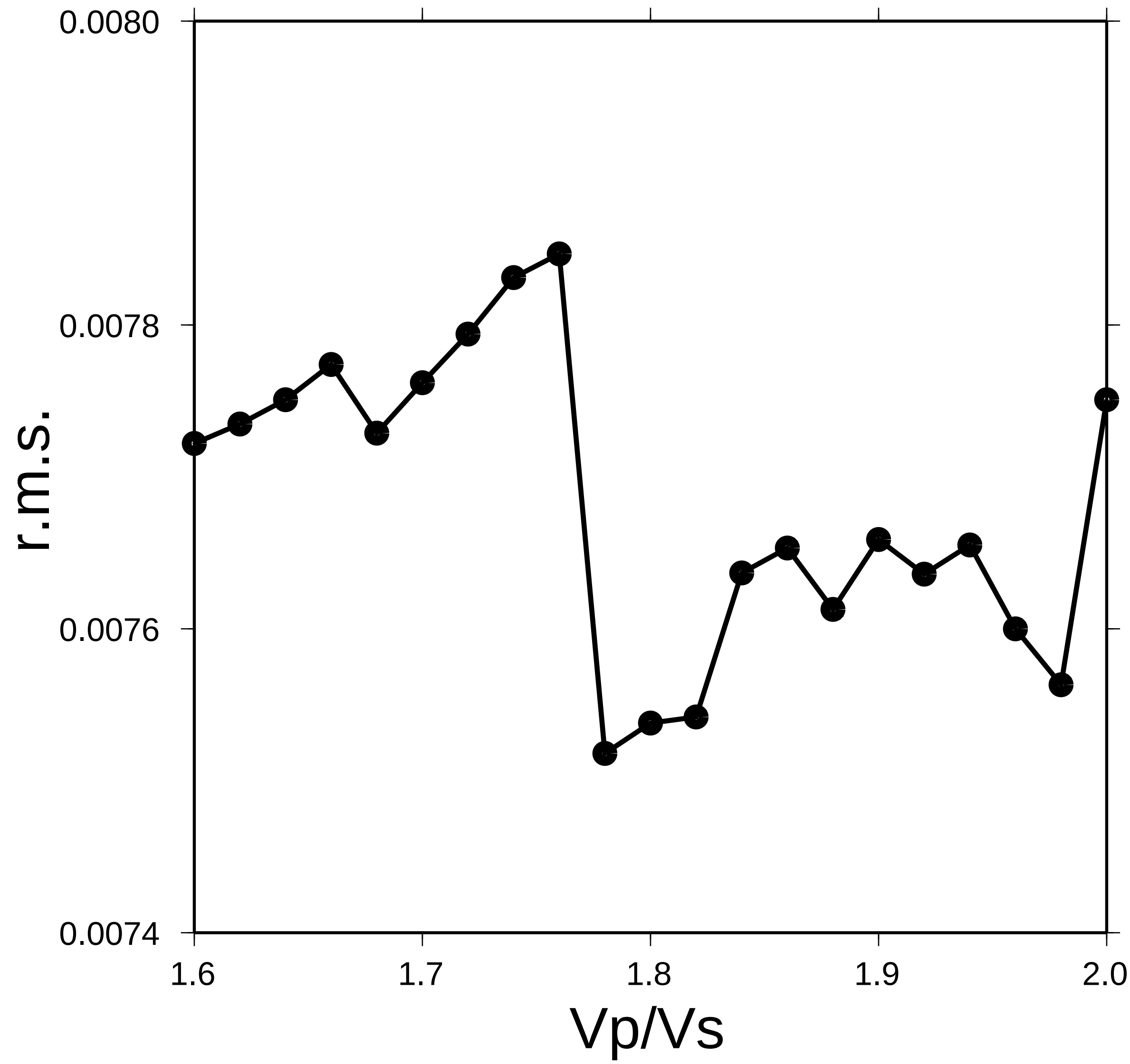
15
10
5
0
-5
-10
-15
-15
-10
-5
0
5
10
15



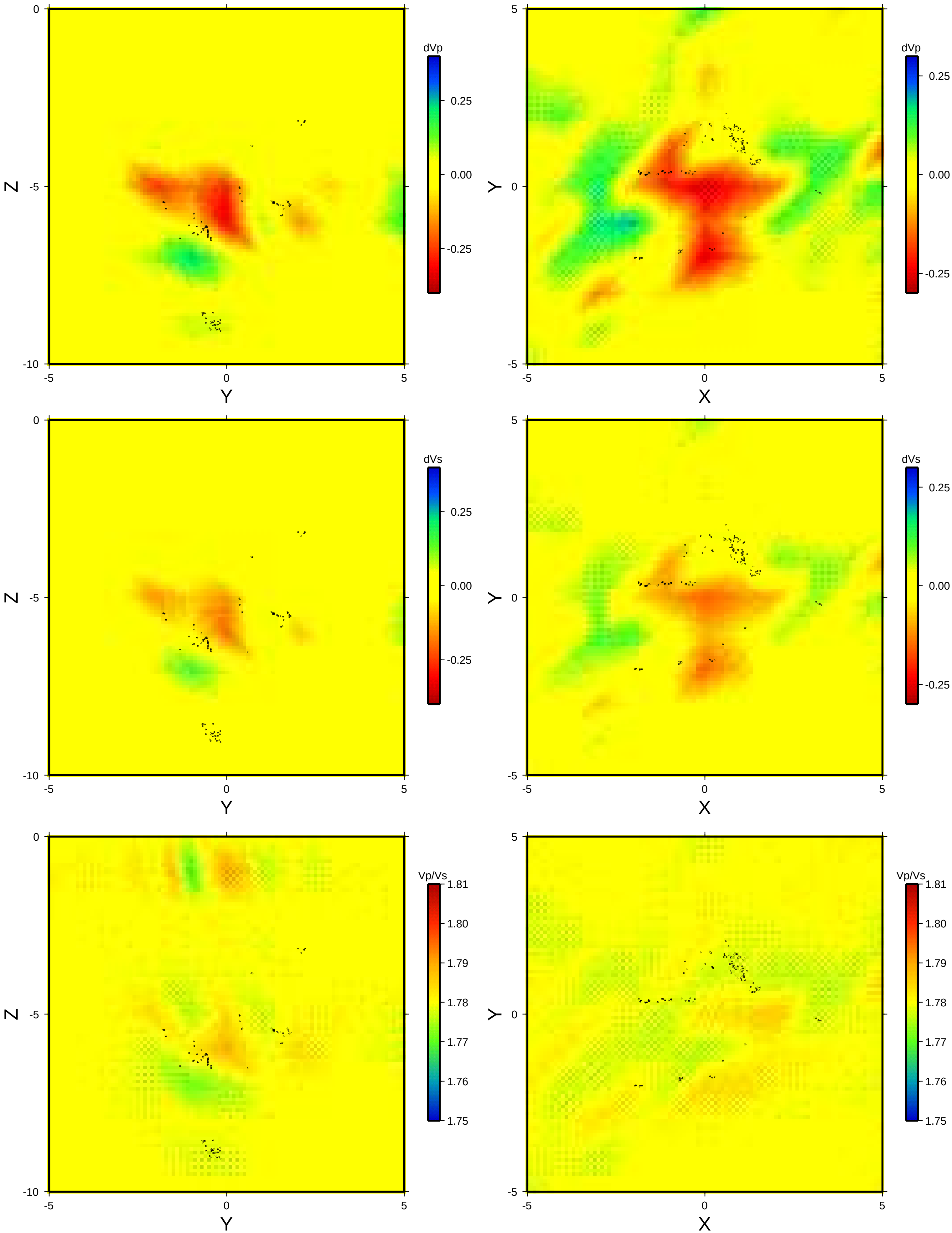
0
-5
-10
Z
0
5
10
X
0
-5
-10
0
5
10
X
0
-5
-10
0
5
10
X



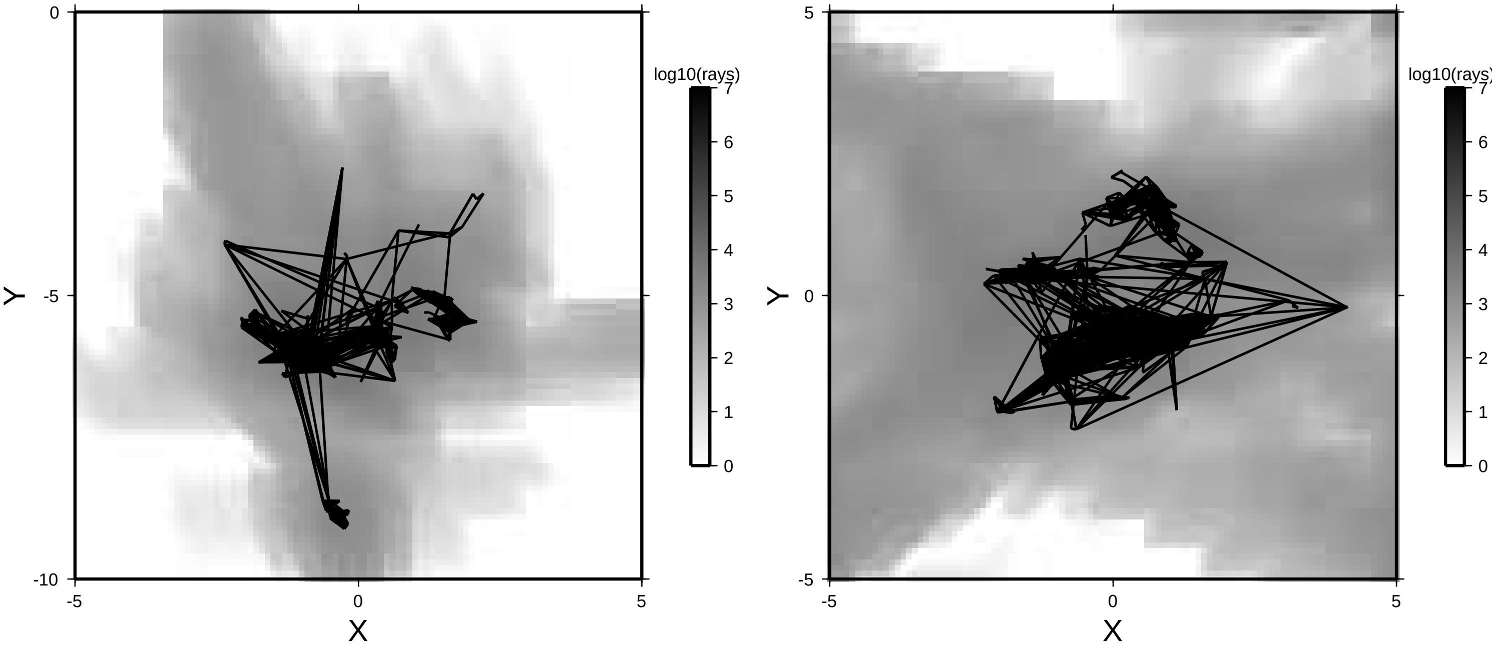
241° 00'
241° 15'
241° 30'
241° 45'
38° 00'
37° 45'
37° 30'
37° 15'
Mono Lake
scale in km
0
10
20
30
Mono Craters
Long Valley Caldera
Inyo Domes
Resurgent Dome
Mammoth Mt
Hilton Creek Fault
Chalfant Valley
Round Valley
SNB



0.0080
0.0078
0.0076
0.0074
r.m.s.
1.6
1.7
1.8
1.9
2.0
Vp/Vs



dVp
0.25
0.00
-0.25
Z
Y
X
dVs
Vp/Vs
1.81
1.80
1.79
1.78
1.77
1.76
1.75
0
-5
-10
5


log10(rays)
0
1
2
3
4
5
6
7
Y
X
0
-5
-10
-5
0
5
log10(rays)
Y
X
5
0
-5
-5
0
5

# Conclusions

1. Earthquakes locations obtained using differential data are as good or better than locations obtained using traditional arrival time data and should be used in preference to the traditional methodology.

2. Noise characteristics of differential data, and especially degree of correlation of overlapping pairs is still very murky. More research on this topic is needed.

3. Simultaneous eqrthquake location and tomography using differential data works, for example, when applied to Long Valley, CA dataset. However the 10% improvement traveltime residuals, from 7.5 to 6.9 ms is modest at best. More experience is needed to build confidence in the tomographic images.