<u>Final Report</u>
Jia Yoong Chong
1001 204 252
ESS392
Aug 23rd 2018

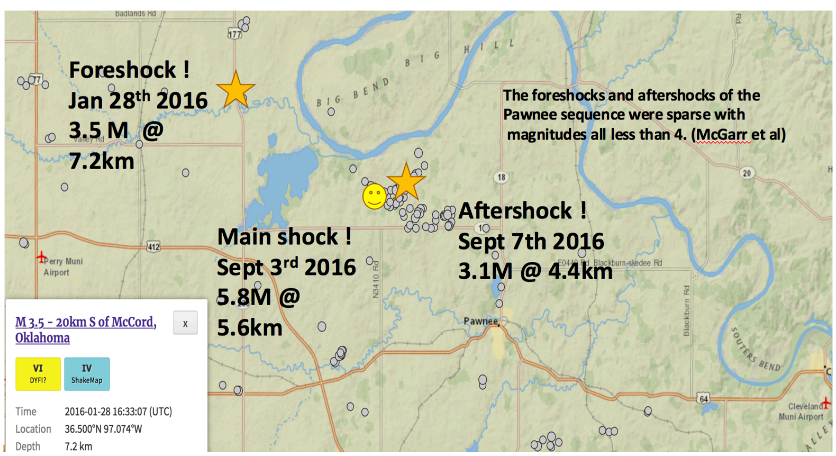
<u>Introduction:</u>

In this final report, I have included minor corrections from previous reports, data screening processes, main shock inversion results and discussions. In addition, the summary of the workflow has been outlined in the presentation slides.

To note, I have primarily focused on main shock - Pawnee event - although I have done inversions on 1 foreshock and 1 aftershock events; however, the synthetics fitted very poorly. Both of the magnitude are less than 3.7M. Recalling, events less than such magnitude would be harder to yield decent inversion results. Due to time constraint, I excluded the two events in this study, but hopefully I can come up with better inversion result that is consistent with the focal mechanism (as shown from USGS website) for thesis project.

<u>Question:</u>
Maybe require even stricter data screening or other rules of thumbs to remove the noisy stations?

<u>Events Location:</u>

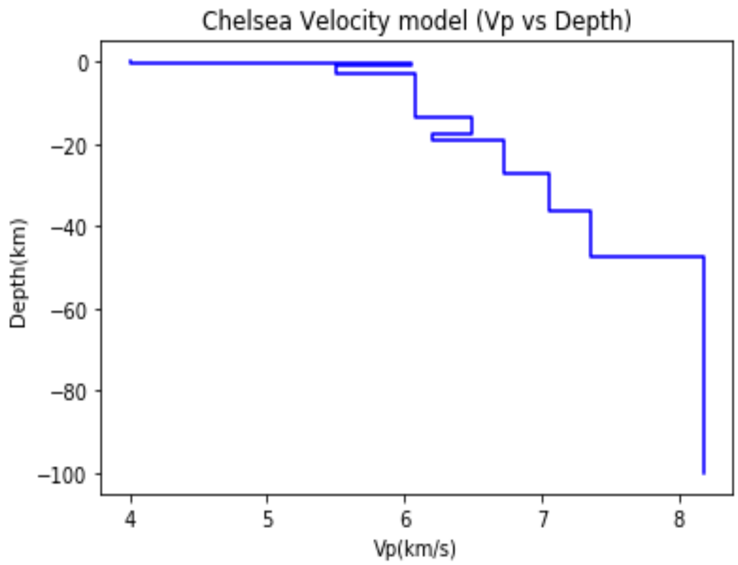


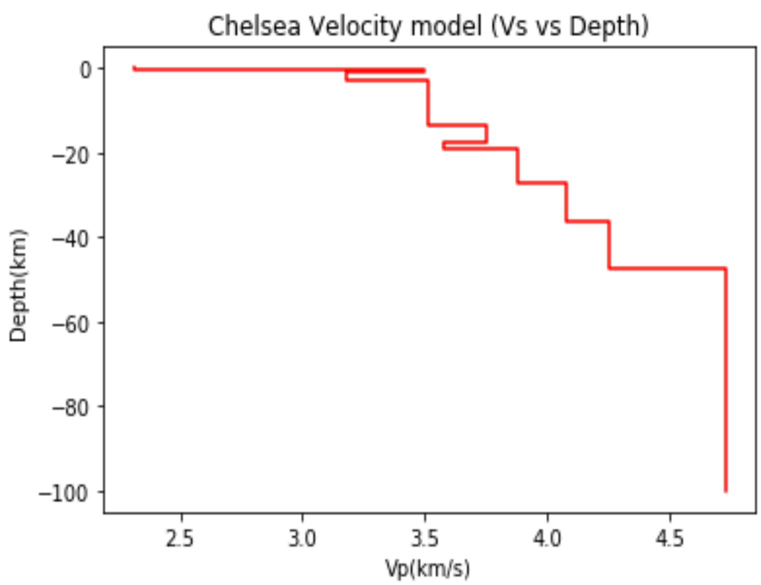
The above map shows the location of the foreshock, main shock and aftershock. The distance between foreshock and main shock is around 14km. While the distance between aftershock and main shock is around 1km.

Study location: latitude [33.7,37.02] and longitude [-98.96, -96.11].
Time: 1st Jan 2016 – 31st Dec 2016.

Velocity Model:

Below is a plot of Chelsea velocity model from seismic refraction. To note, I have included the plot as a correction from Report 2.0. To compute green's function, intermediate layers have been combined and their velocities averaged.





The two plots show velocity model of Chelsea region, ~170km away from main shock epicenter.

.

Data Acquisition & Preparation:

The three-component waveforms recording are from following network:
- USGS Networks (GS)
- Oklahoma seismic network (OK)
- Central and Eastern US Network (N4)
- Rapid response for Fairview aftershock in Oklahoma (Y9)
- Seismicity near the Nemaha fault in northern Oklahoma (XR)

In this study, the max radius the stations covered is set to 3 degrees, with the furthest station at 298km away from epicenter.

With the Chelsea velocity model, we can now use FK package to compute green's functions. It is also necessary to rotate the three-component seismograms and filter the time series. Lastly, as specified in cap.pl, the units are converted from m to cm. Below shows the filtering process that are included in process_data_to_sac.py script.

Filtering process used in process_data_to_sac.py:

1.) Anti-aliasing filter before interpolation (delta = 0.05)
    - T_min = 0.25s
    - T_max = 100s

    - f_min = 1/T_min
    - f_max = 1/T_max

2.) Remove instrument response from stream
    - water level = 50
    - output = 'VEL'

3.) Linearly detrend and remove the mean from the stream.
4.) Apply bandpass filter for the stream.

Data Screening:

Data screening is important when it comes to events of larger magnitude because closer stations (Pawnee event) may exhibit clipping or poor signal-to-noise ratio. Below is an example of a station that we went through that has poor signal to noise ratio and actually showed the clipped portion. However, in the graph shown below after running screen event script, it does not show clipped portion of the higher amplitude of the signal.

So in making inversions for other events (foreshock and aftershock) , it's hard to visually determine which stations displays bad results. Although I tried to use the low SNR ratio as a guideline to remove the stations, still my inversion result displays poor fitting.

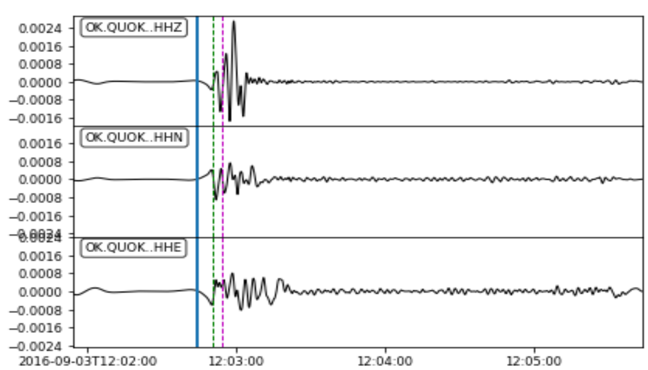
Question:
Are there any specific displaying tools that could show the clipped waveforms? Because the graph below is obtained right after I ran screen_event_data.py script. However, on the other day after we ran the script, we both saw stations that are clipped on display. I might have missed something?

I tried the following commands on SAC again but it's still hard to discern clipping on the waveform:

```
SAC> r *.*.*.??[RTZ].sac
SAC> mul 100
SAC> interp delta 0.05
SAC> p1
```

Screening Guidelines:

1.) Removal of low signal to ratio for Pnl (below 1.0) & Surface waves (below 1.5).
2.) Removal of visible clipping waveforms.



The above seismogram recordings exhibit poor signal to noise ratio.

Moment Tensor Inversion

Filtering parameters used in prepare_for_gcap.py:

- pnl_tmin = 3.5s
- pnl_tmax = 12.5s

- surf_tmin = 10s
- suf_tmax = 20s

- dist_scale = '-D0.5/1/0.5'
- plot_scale = '-P0.3/45' # amplitude adjusted later in cap_auto.bash

- body_surf_shift = 'S2/5/0' #time shift allowance 2/5s
- window = '-T30/70' #filter windows 30s/70s

- min_dist_pnl = 85km #min distance to start separate Pnl & Surface wave.
- max_dist = 500km

Source Mechanism Parameter:

Below table shows the source mechanism parameters used in grid search, which is the existing default values as stated in cap.pl.

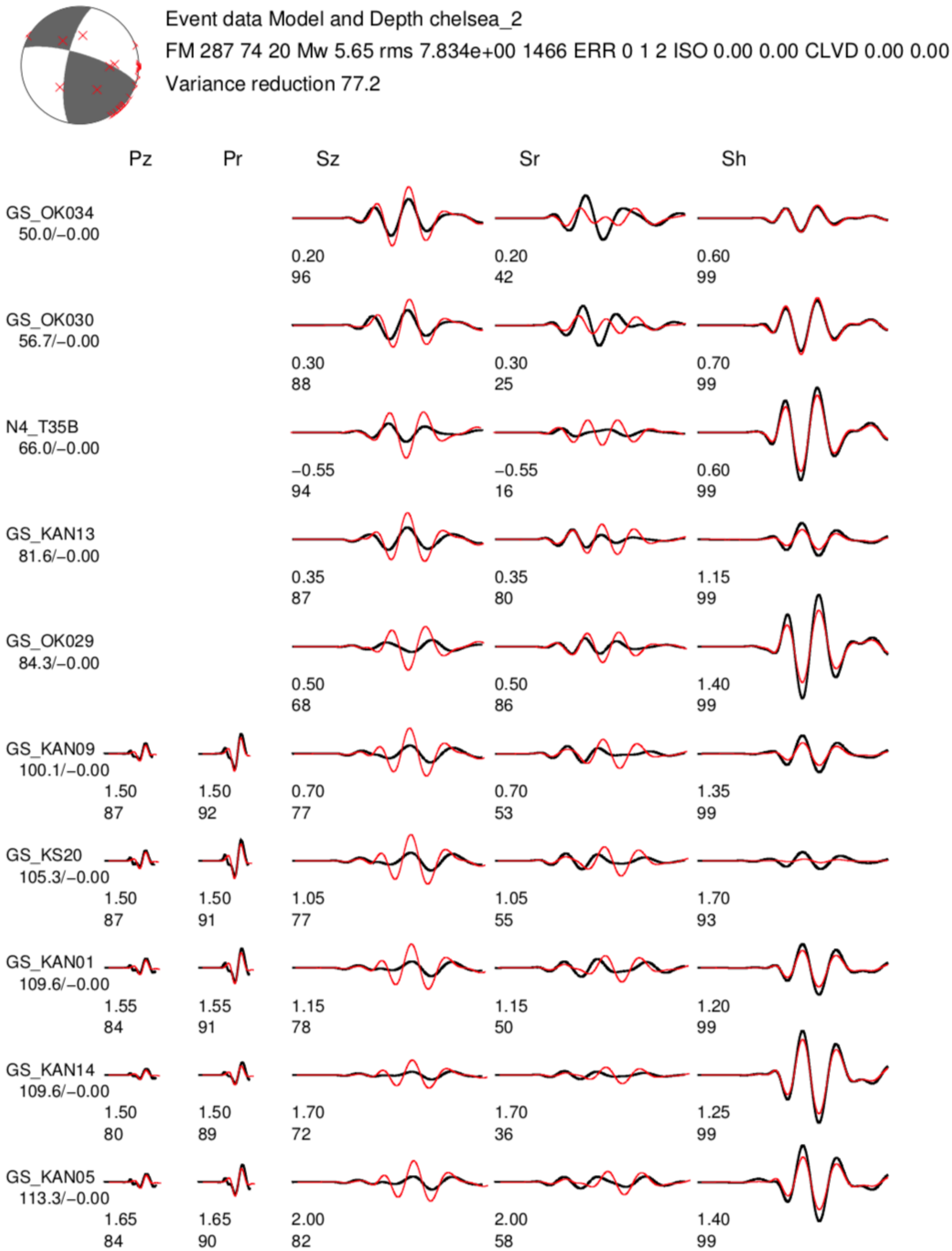
Parameter	Range	Step Size
MW	[1,10]	0.1
Strike	[0,360]	1
Dip	[0,90]	1
Rake	[-180,180]	1
Depth	[2km,7km]	1km

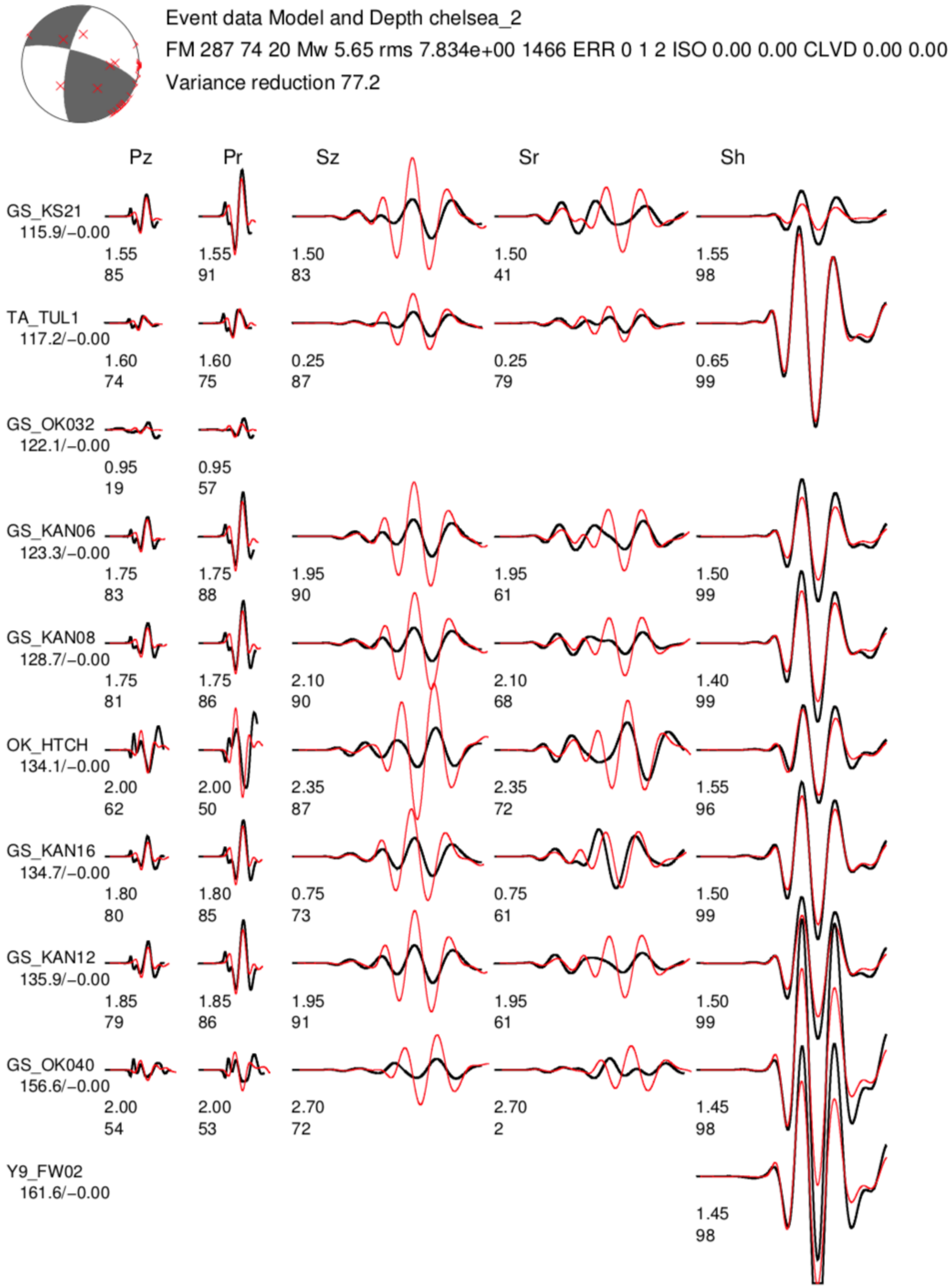
After the first round of inversion, the stations with poorer fit are input into bad-fit-station.txt. The weight coefficients for different windows can also be adjusted in weight.dat files. The inversion is repeated again to yield better results.

Note that the amplitude for the synthetics & observed waveforms are adjusted accordingly to make it easier to view the results.

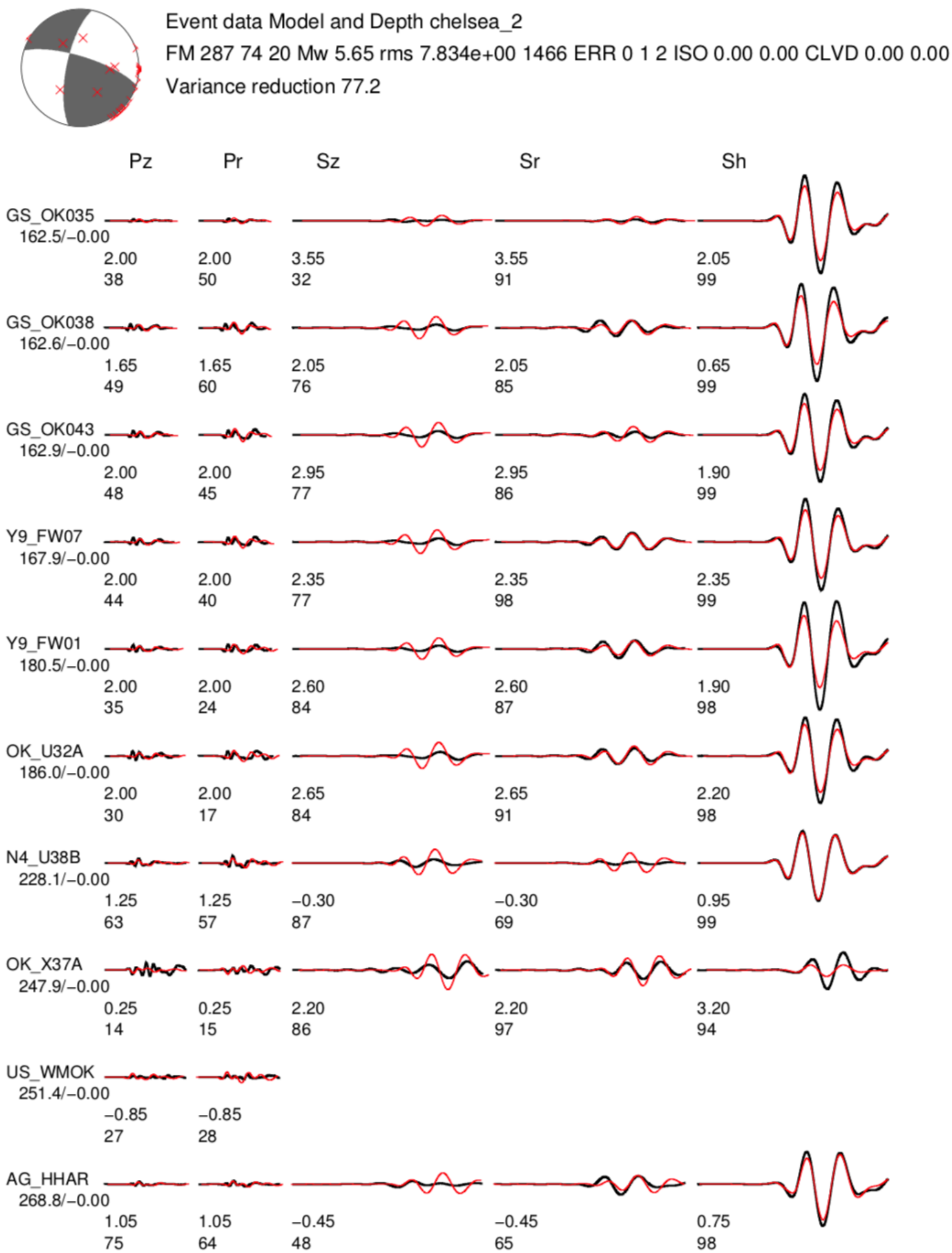
Inversion Result:

Inversion result at depth 2km.

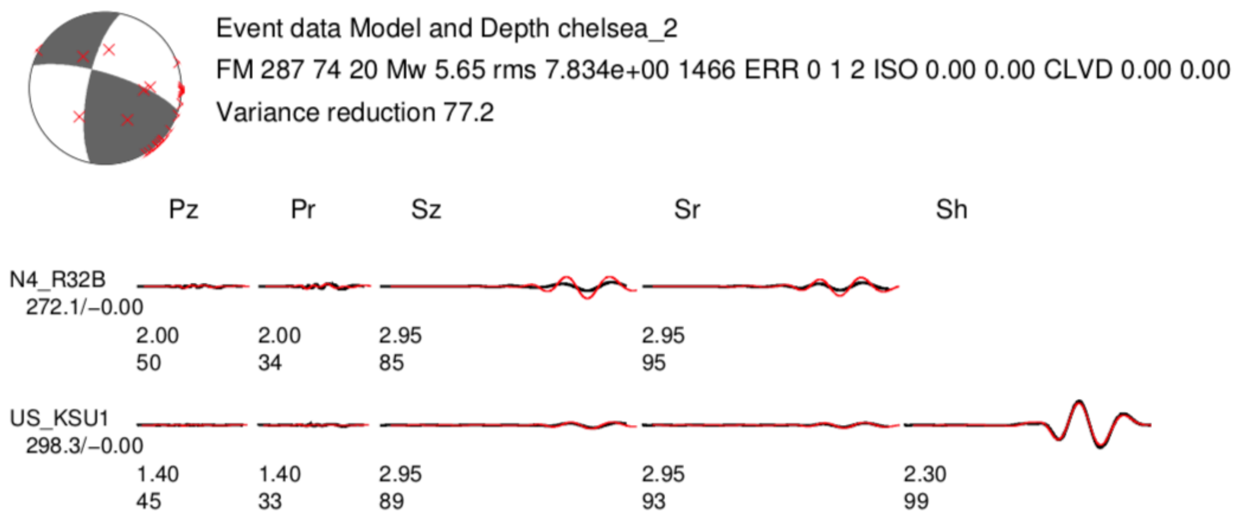




Event data Model and Depth chelsea_2
FM 287 74 20 Mw 5.65 rms 7.834e+00 1466 ERR 0 1 2 ISO 0.00 0.00 CLVD 0.00 0.00
Variance reduction 77.2
Pz
Pr
Sz
Sr
Sh
GS_KS21
115.9/-0.00
1.55 85
1.55 91
1.50 83
1.50 41
1.55 98
TA_TUL1
117.2/-0.00
1.60 74
1.60 75
0.25 87
0.25 79
0.65 99
GS_OK032
122.1/-0.00
0.95 19
0.95 57
GS_KAN06
123.3/-0.00
1.75 83
1.75 88
1.95 90
1.95 61
1.50 99
GS_KAN08
128.7/-0.00
1.75 81
1.75 86
2.10 90
2.10 68
1.40 99
OK_HTCH
134.1/-0.00
2.00 62
2.00 50
2.35 87
2.35 72
1.55 96
GS_KAN16
134.7/-0.00
1.80 80
1.80 85
0.75 73
0.75 61
1.50 99
GS_KAN12
135.9/-0.00
1.85 79
1.85 86
1.95 91
1.95 61
1.50 99
GS_OK040
156.6/-0.00
2.00 54
2.00 53
2.70 72
2.70 2
1.45 98
Y9_FW02
161.6/-0.00
1.45 98

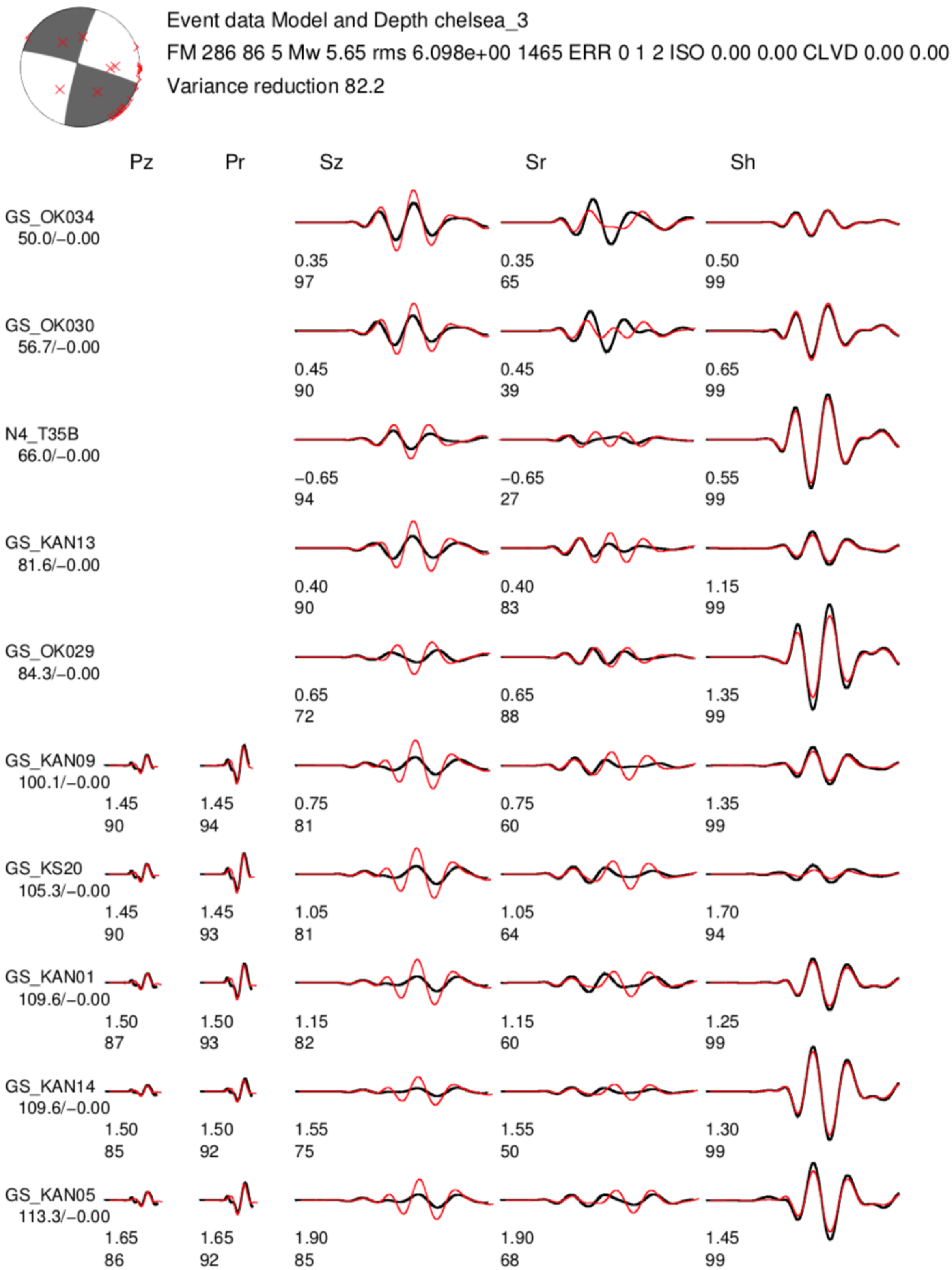


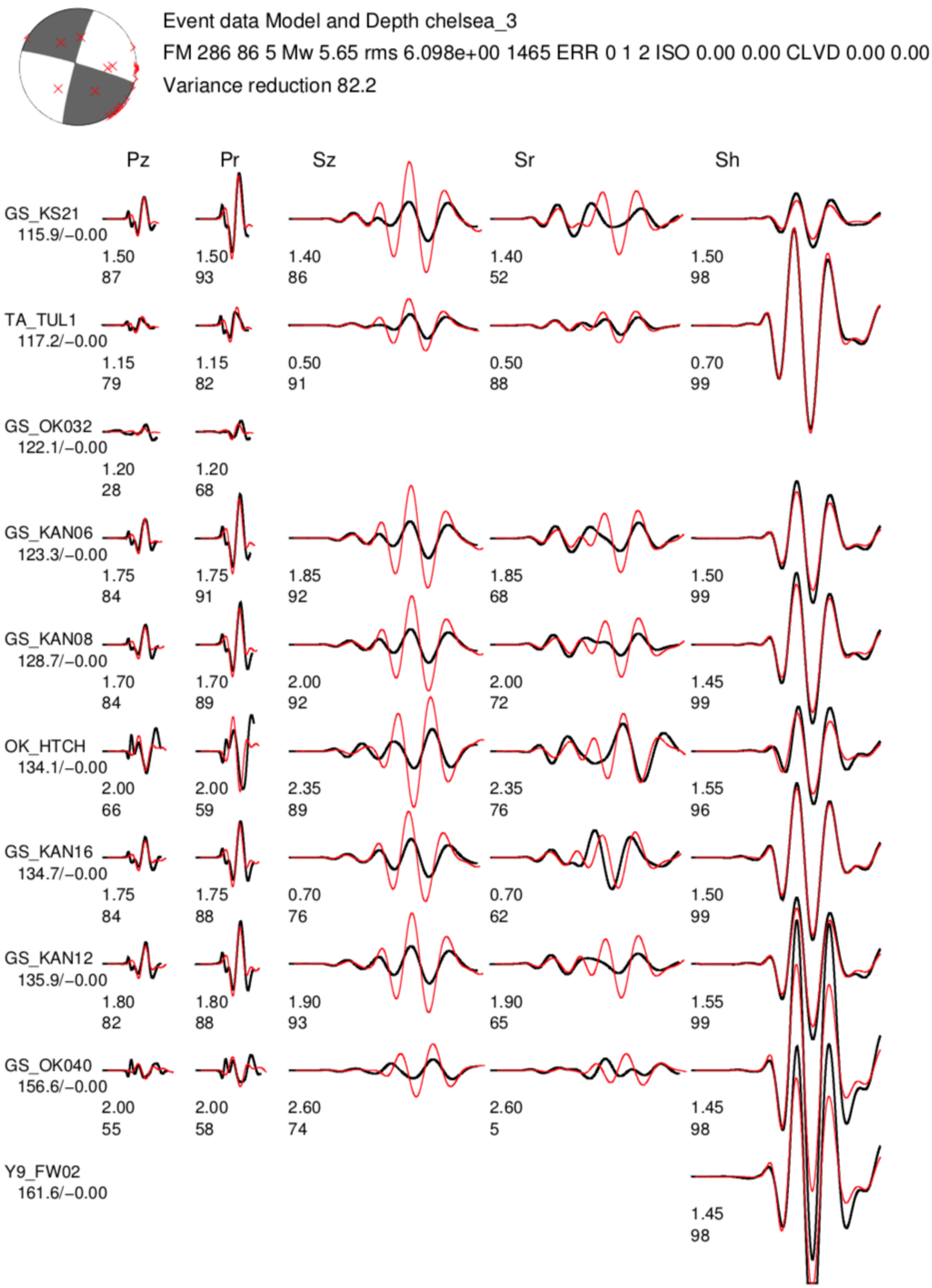
Event data Model and Depth chelsea_2
FM 287 74 20 Mw 5.65 rms 7.834e+00 1466 ERR 0 1 2 ISO 0.00 0.00 CLVD 0.00 0.00
Variance reduction 77.2
Pz
Pr
Sz
Sr
Sh
GS_OK035
162.5/−0.00
2.00 2.00 3.55 3.55 2.05
38 50 32 91 99
GS_OK038
162.6/−0.00
1.65 1.65 2.05 2.05 0.65
49 60 76 85 99
GS_OK043
162.9/−0.00
2.00 2.00 2.95 2.95 1.90
48 45 77 86 99
Y9_FW07
167.9/−0.00
2.00 2.00 2.35 2.35 2.35
44 40 77 98 99
Y9_FW01
180.5/−0.00
2.00 2.00 2.60 2.60 1.90
35 24 84 87 98
OK_U32A
186.0/−0.00
2.00 2.00 2.65 2.65 2.20
30 17 84 91 98
N4_U38B
228.1/−0.00
1.25 1.25 −0.30 −0.30 0.95
63 57 87 69 99
OK_X37A
247.9/−0.00
0.25 0.25 2.20 2.20 3.20
14 15 86 97 94
US_WMOK
251.4/−0.00
−0.85 −0.85
27 28
AG_HHAR
268.8/−0.00
1.05 1.05 −0.45 −0.45 0.75
75 64 48 65 98

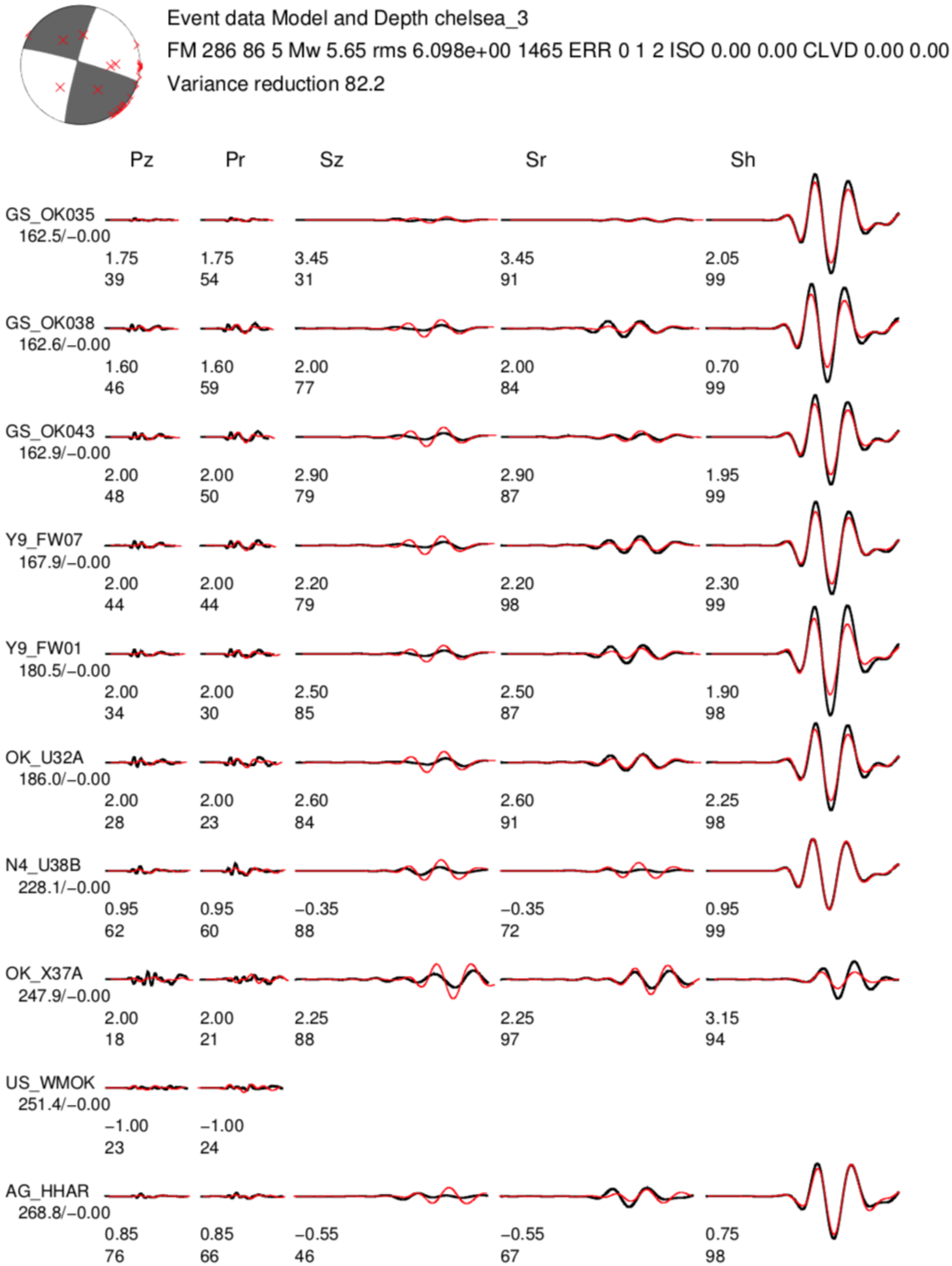


Event data Model and Depth chelsea_2
FM 287 74 20 Mw 5.65 rms 7.834e+00 1466 ERR 0 1 2 ISO 0.00 0.00 CLVD 0.00 0.00
Variance reduction 77.2
Pz
Pr
Sz
Sr
Sh
N4_R32B
272.1/−0.00
2.00
50
2.00
34
2.95
85
2.95
95
US_KSU1
298.3/−0.00
1.40
45
1.40
33
2.95
89
2.95
93
2.30
99

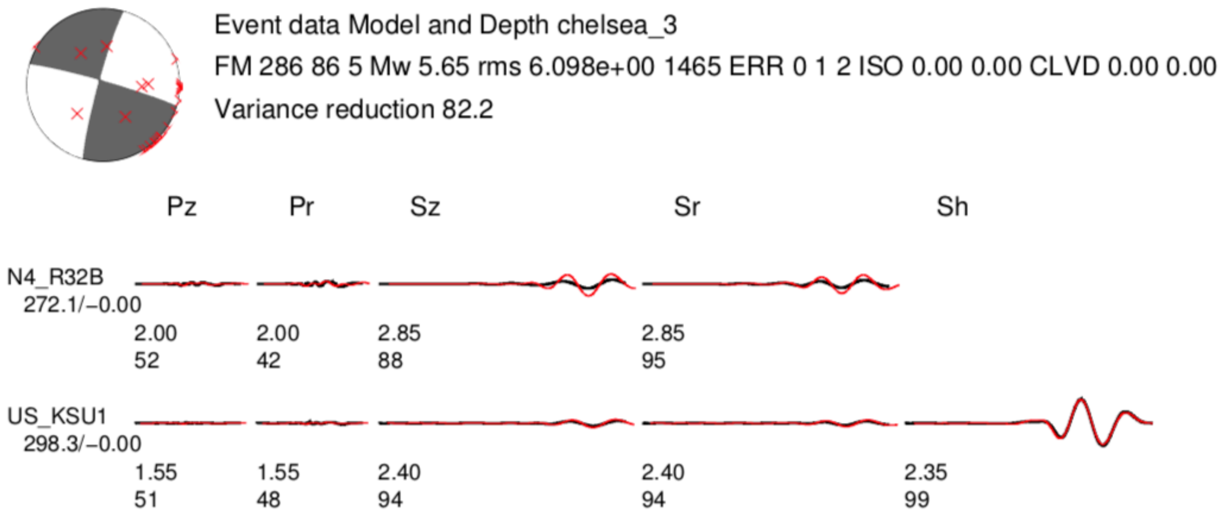
Inversion Result at depth 3km



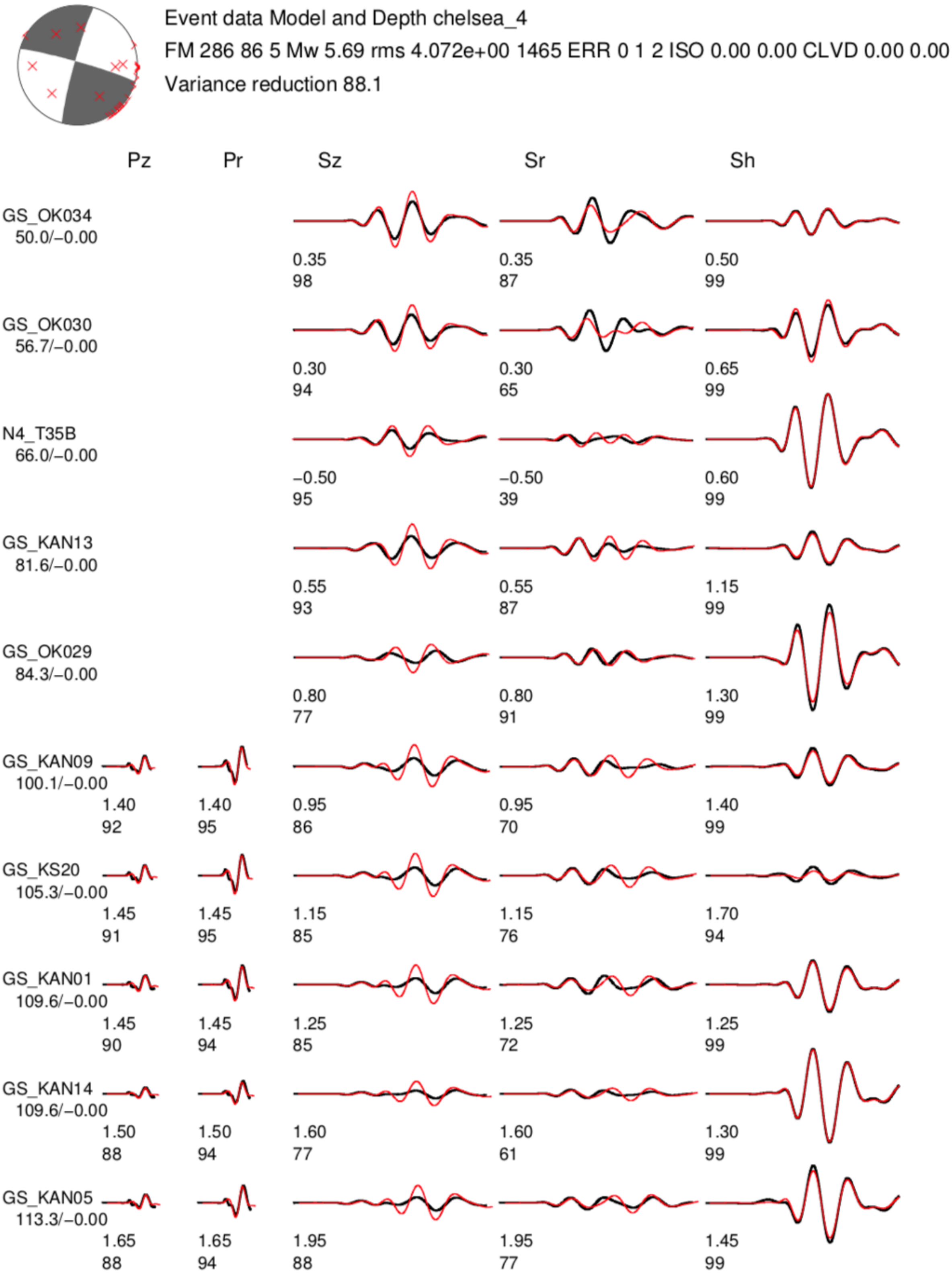

Event data Model and Depth chelsea_3
FM 286 86 5 Mw 5.65 rms 6.098e+00 1465 ERR 0 1 2 ISO 0.00 0.00 CLVD 0.00 0.00
Variance reduction 82.2
Pz
Pr
Sz
Sr
Sh
GS_KS21
115.9/-0.00
1.50 87
1.50 93
1.40 86
1.40 52
1.50 98
TA_TUL1
117.2/-0.00
1.15 79
1.15 82
0.50 91
0.50 88
0.70 99
GS_OK032
122.1/-0.00
1.20 28
1.20 68
GS_KAN06
123.3/-0.00
1.75 84
1.75 91
1.85 92
1.85 68
1.50 99
GS_KAN08
128.7/-0.00
1.70 84
1.70 89
2.00 92
2.00 72
1.45 99
OK_HTCH
134.1/-0.00
2.00 66
2.00 59
2.35 89
2.35 76
1.55 96
GS_KAN16
134.7/-0.00
1.75 84
1.75 88
0.70 76
0.70 62
1.50 99
GS_KAN12
135.9/-0.00
1.80 82
1.80 88
1.90 93
1.90 65
1.55 99
GS_OK040
156.6/-0.00
2.00 55
2.00 58
2.60 74
2.60 5
1.45 98
Y9_FW02
161.6/-0.00
1.45 98

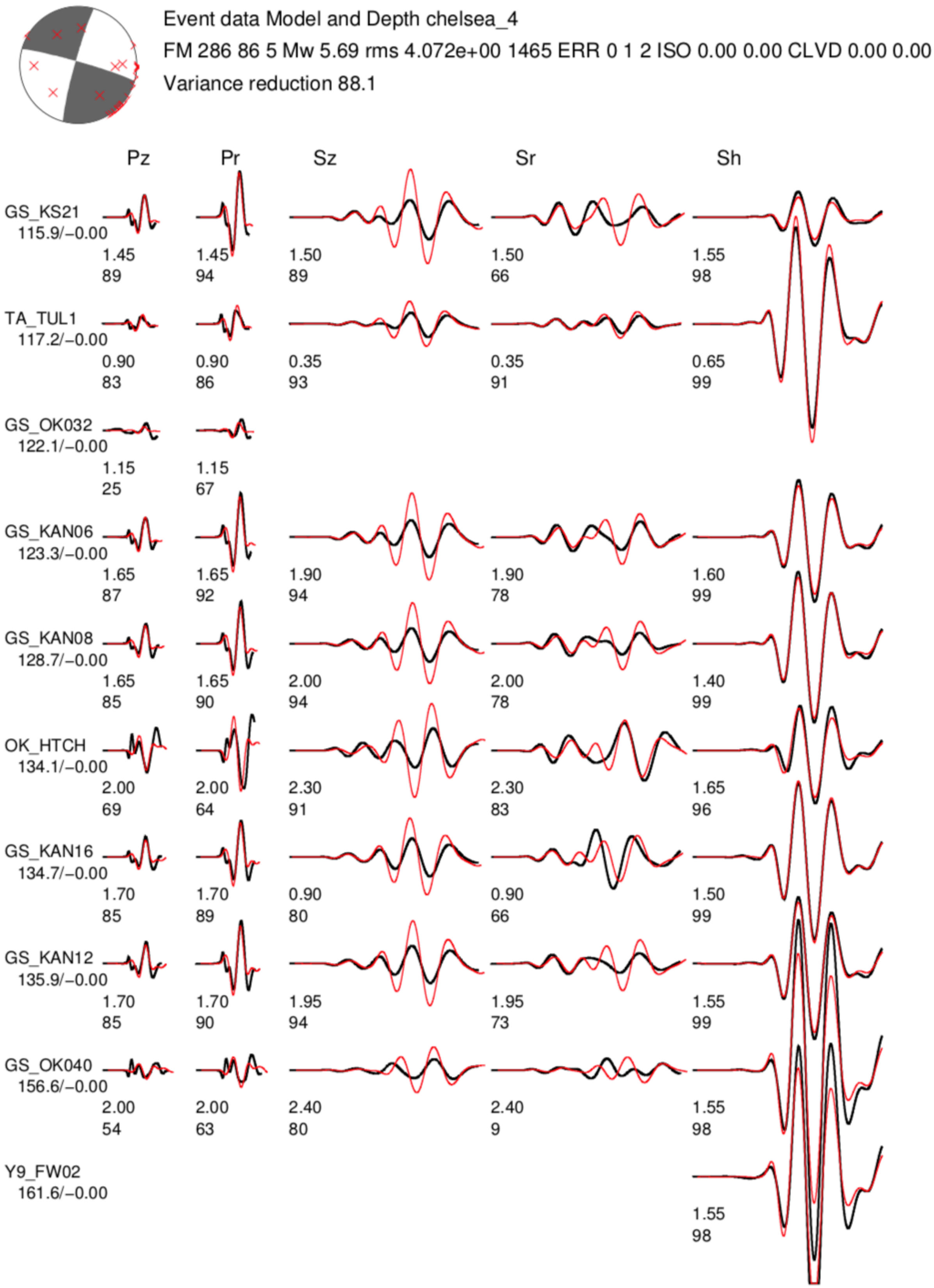


Event data Model and Depth chelsea_3
FM 286 86 5 Mw 5.65 rms 6.098e+00 1465 ERR 0 1 2 ISO 0.00 0.00 CLVD 0.00 0.00
Variance reduction 82.2
Pz
Pr
Sz
Sr
Sh
GS_OK035
162.5/−0.00
1.75 1.75 3.45 3.45 2.05
39 54 31 91 99
GS_OK038
162.6/−0.00
1.60 1.60 2.00 2.00 0.70
46 59 77 84 99
GS_OK043
162.9/−0.00
2.00 2.00 2.90 2.90 1.95
48 50 79 87 99
Y9_FW07
167.9/−0.00
2.00 2.00 2.20 2.20 2.30
44 44 79 98 99
Y9_FW01
180.5/−0.00
2.00 2.00 2.50 2.50 1.90
34 30 85 87 98
OK_U32A
186.0/−0.00
2.00 2.00 2.60 2.60 2.25
28 23 84 91 98
N4_U38B
228.1/−0.00
0.95 0.95 −0.35 −0.35 0.95
62 60 88 72 99
OK_X37A
247.9/−0.00
2.00 2.00 2.25 2.25 3.15
18 21 88 97 94
US_WMOK
251.4/−0.00
−1.00 −1.00
23 24
AG_HHAR
268.8/−0.00
0.85 0.85 −0.55 −0.55 0.75
76 66 46 67 98

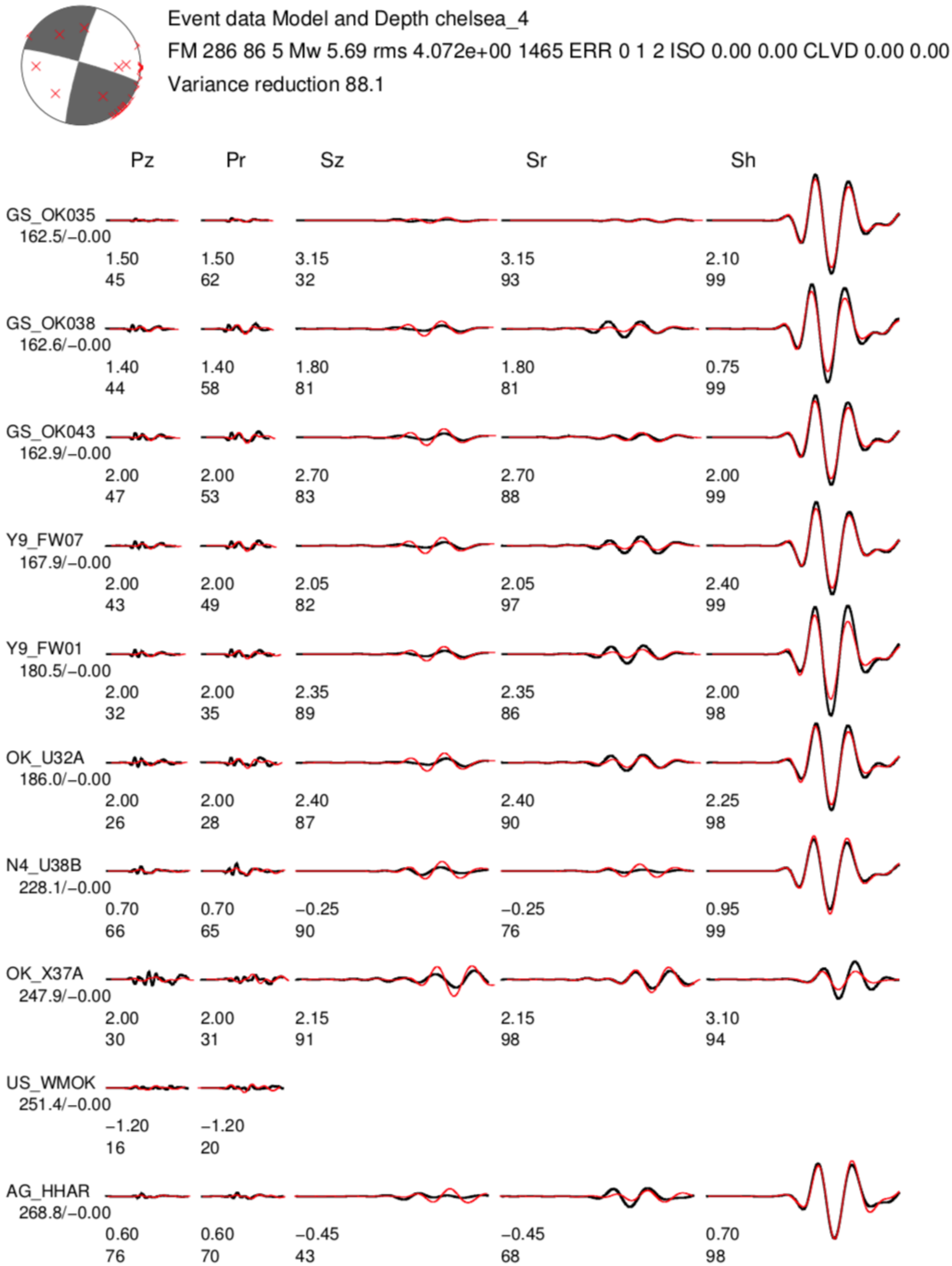

Event data Model and Depth chelsea_3
FM 286 86 5 Mw 5.65 rms 6.098e+00 1465 ERR 0 1 2 ISO 0.00 0.00 CLVD 0.00 0.00
Variance reduction 82.2
Pz
Pr
Sz
Sr
Sh
N4_R32B
272.1/−0.00
2.00
52
2.00
42
2.85
88
2.85
95
US_KSU1
298.3/−0.00
1.55
51
1.55
48
2.40
94
2.40
94
2.35
99

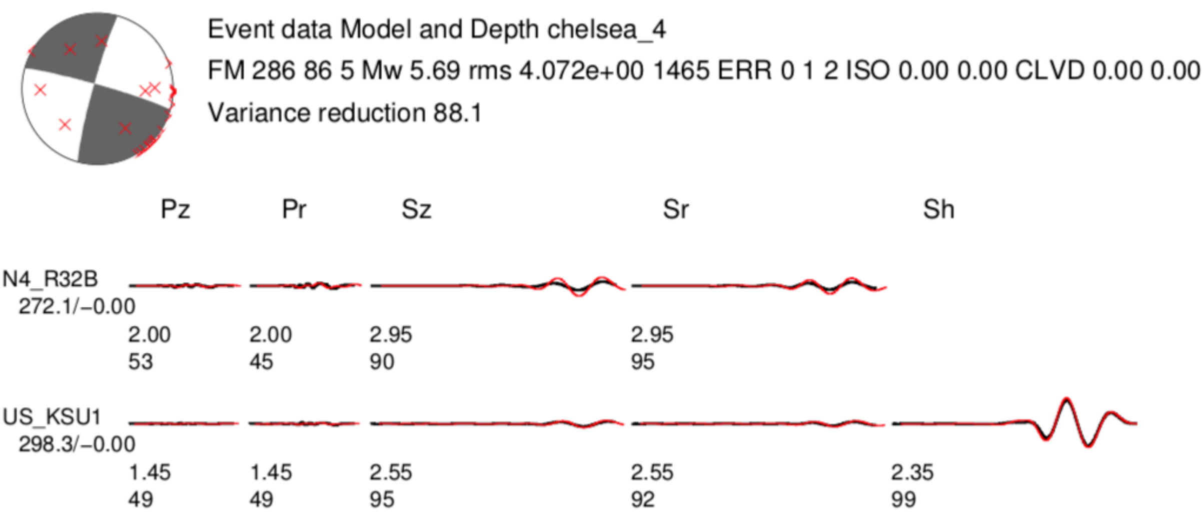
Inversion Result at depth 4km



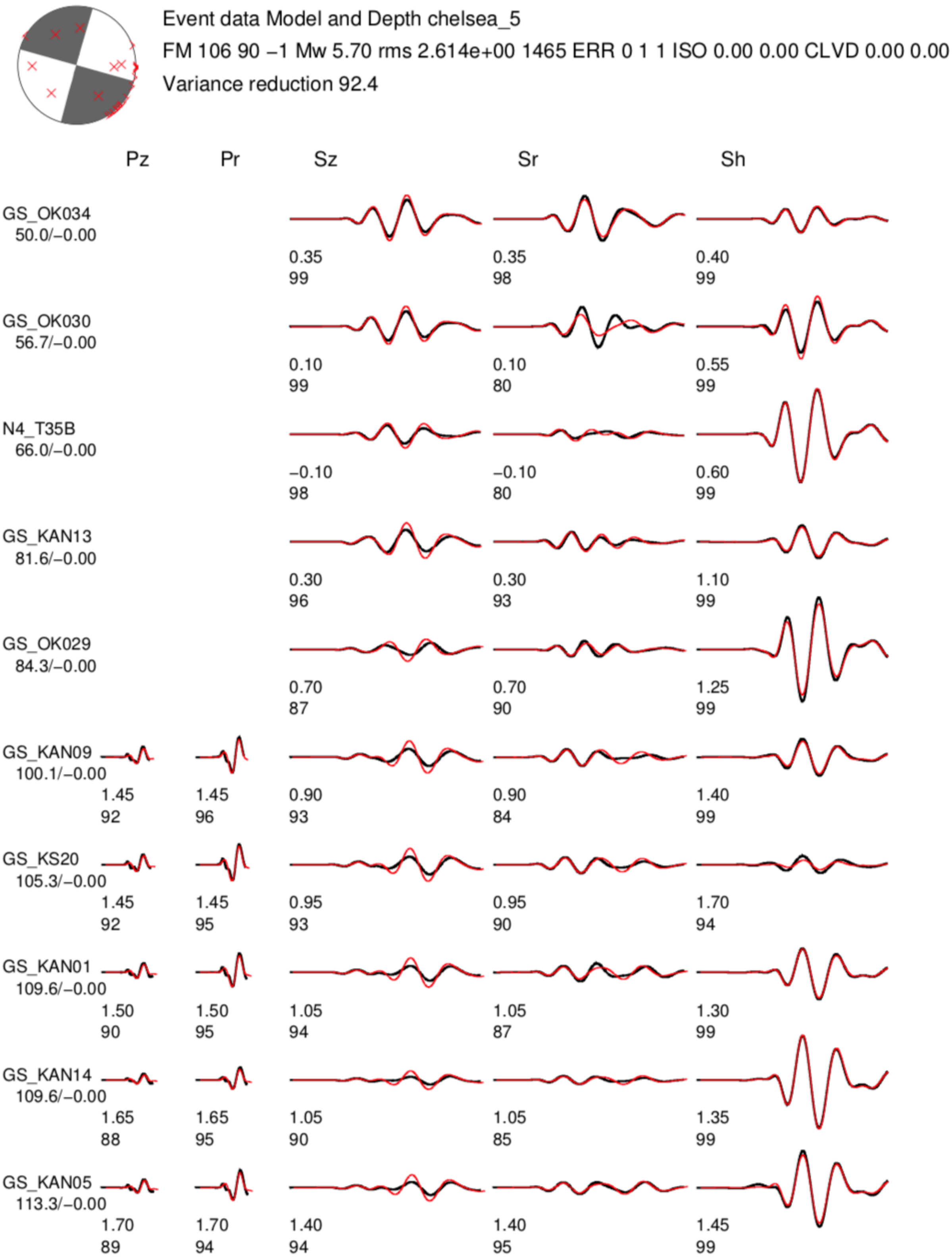


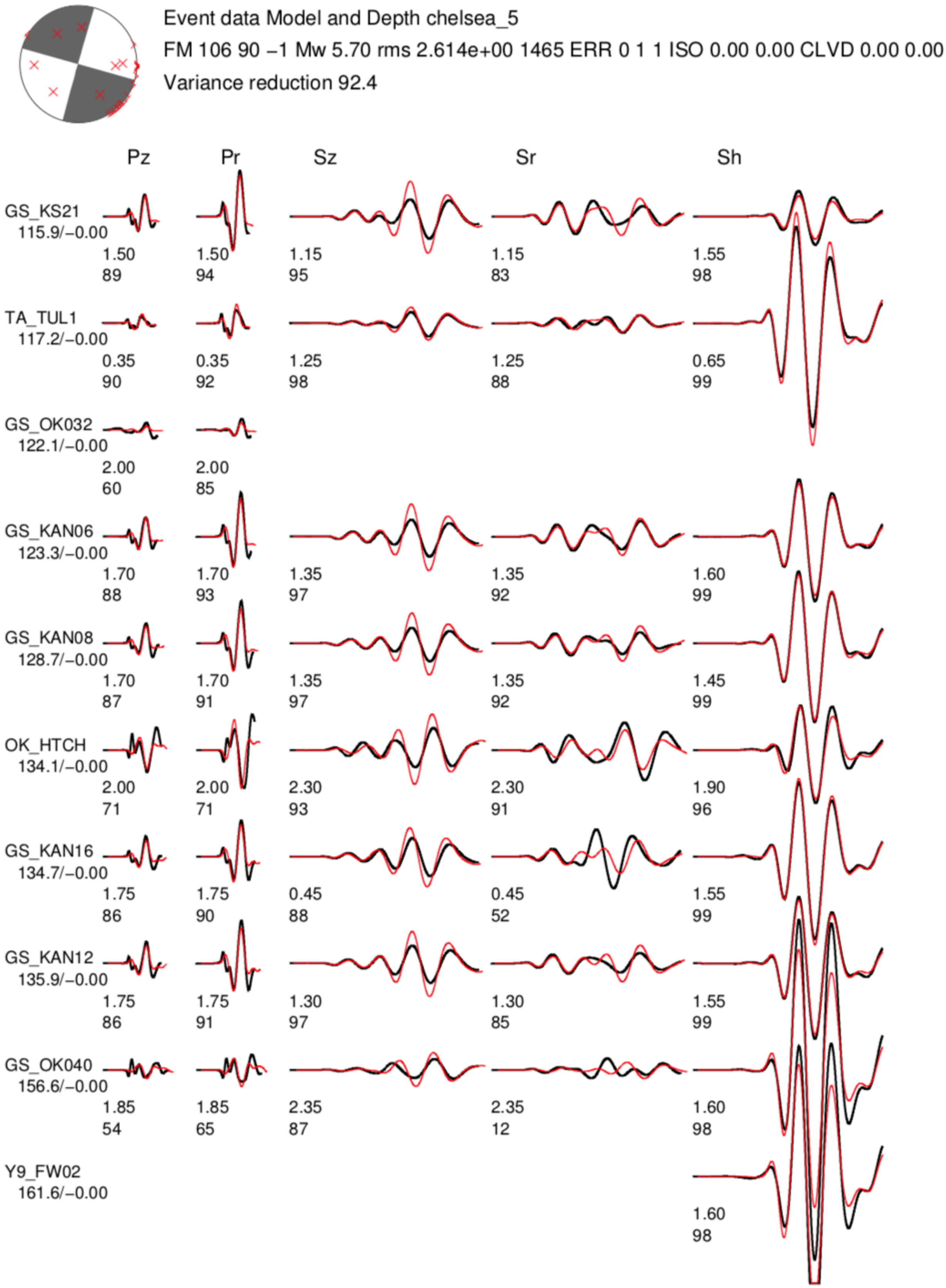
Event data Model and Depth chelsea_4
FM 286 86 5 Mw 5.69 rms 4.072e+00 1465 ERR 0 1 2 ISO 0.00 0.00 CLVD 0.00 0.00
Variance reduction 88.1
Pz
Pr
Sz
Sr
Sh
GS_KS21
115.9/−0.00
1.45 89
1.45 94
1.50 89
1.50 66
1.55 98
TA_TUL1
117.2/−0.00
0.90 83
0.90 86
0.35 93
0.35 91
0.65 99
GS_OK032
122.1/−0.00
1.15 25
1.15 67
GS_KAN06
123.3/−0.00
1.65 87
1.65 92
1.90 94
1.90 78
1.60 99
GS_KAN08
128.7/−0.00
1.65 85
1.65 90
2.00 94
2.00 78
1.40 99
OK_HTCH
134.1/−0.00
2.00 69
2.00 64
2.30 91
2.30 83
1.65 96
GS_KAN16
134.7/−0.00
1.70 85
1.70 89
0.90 80
0.90 66
1.50 99
GS_KAN12
135.9/−0.00
1.70 85
1.70 90
1.95 94
1.95 73
1.55 99
GS_OK040
156.6/−0.00
2.00 54
2.00 63
2.40 80
2.40 9
1.55 98
Y9_FW02
161.6/−0.00
1.55 98

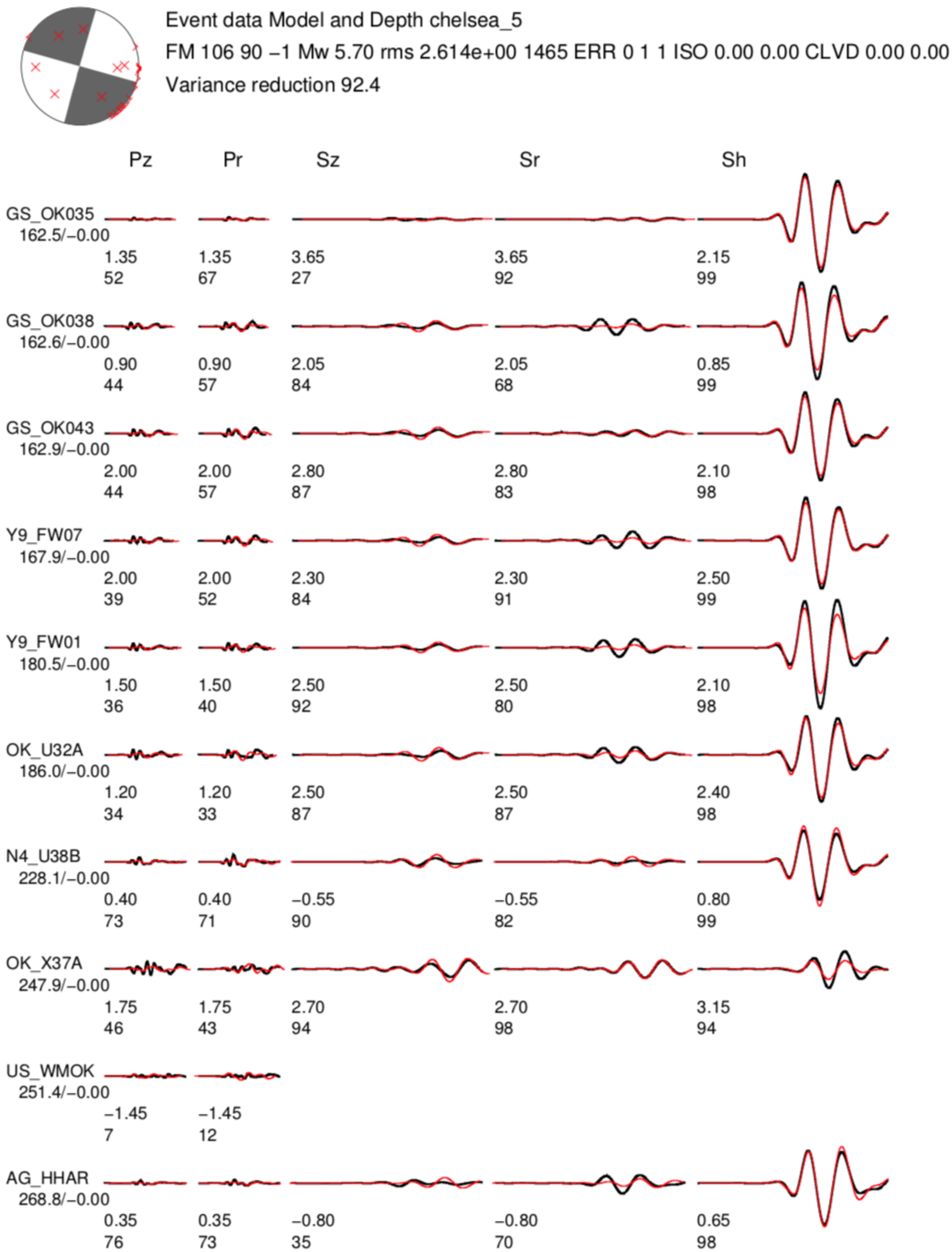

Event data Model and Depth chelsea_4
FM 286 86 5 Mw 5.69 rms 4.072e+00 1465 ERR 0 1 2 ISO 0.00 0.00 CLVD 0.00 0.00
Variance reduction 88.1
Pz
Pr
Sz
Sr
Sh
GS_OK035
162.5/−0.00
1.50 1.50 3.15 3.15 2.10
45 62 32 93 99
GS_OK038
162.6/−0.00
1.40 1.40 1.80 1.80 0.75
44 58 81 81 99
GS_OK043
162.9/−0.00
2.00 2.00 2.70 2.70 2.00
47 53 83 88 99
Y9_FW07
167.9/−0.00
2.00 2.00 2.05 2.05 2.40
43 49 82 97 99
Y9_FW01
180.5/−0.00
2.00 2.00 2.35 2.35 2.00
32 35 89 86 98
OK_U32A
186.0/−0.00
2.00 2.00 2.40 2.40 2.25
26 28 87 90 98
N4_U38B
228.1/−0.00
0.70 0.70 −0.25 −0.25 0.95
66 65 90 76 99
OK_X37A
247.9/−0.00
2.00 2.00 2.15 2.15 3.10
30 31 91 98 94
US_WMOK
251.4/−0.00
−1.20 −1.20
16 20
AG_HHAR
268.8/−0.00
0.60 0.60 −0.45 −0.45 0.70
76 70 43 68 98

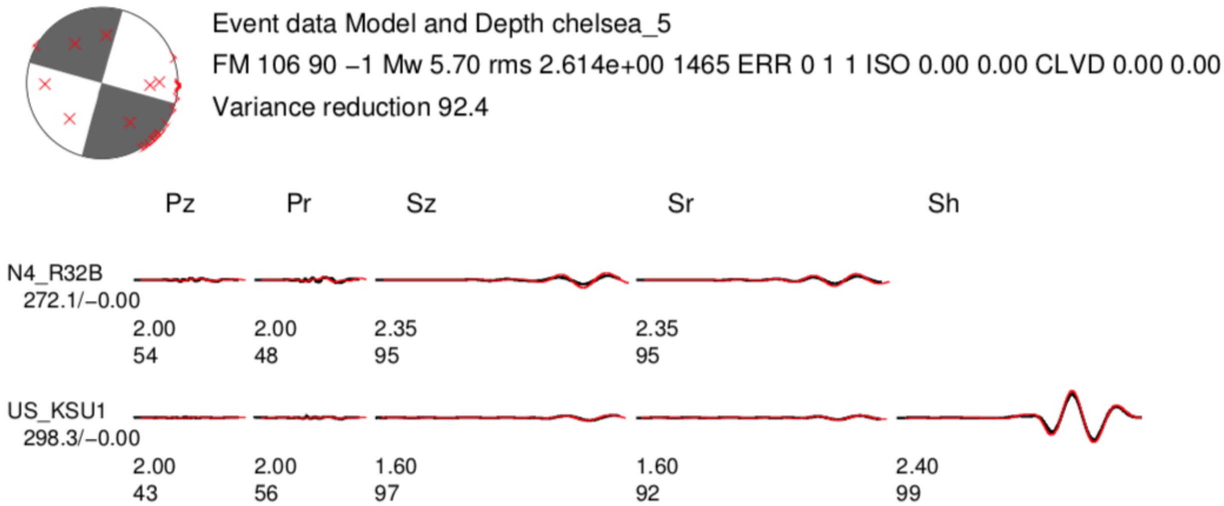

Event data Model and Depth chelsea_4
FM 286 86 5 Mw 5.69 rms 4.072e+00 1465 ERR 0 1 2 ISO 0.00 0.00 CLVD 0.00 0.00
Variance reduction 88.1
Pz
Pr
Sz
Sr
Sh
N4_R32B
272.1/−0.00
2.00
53
2.00
45
2.95
90
2.95
95
US_KSU1
298.3/−0.00
1.45
49
1.45
49
2.55
95
2.55
92
2.35
99

Inversion Result at depth 5km:

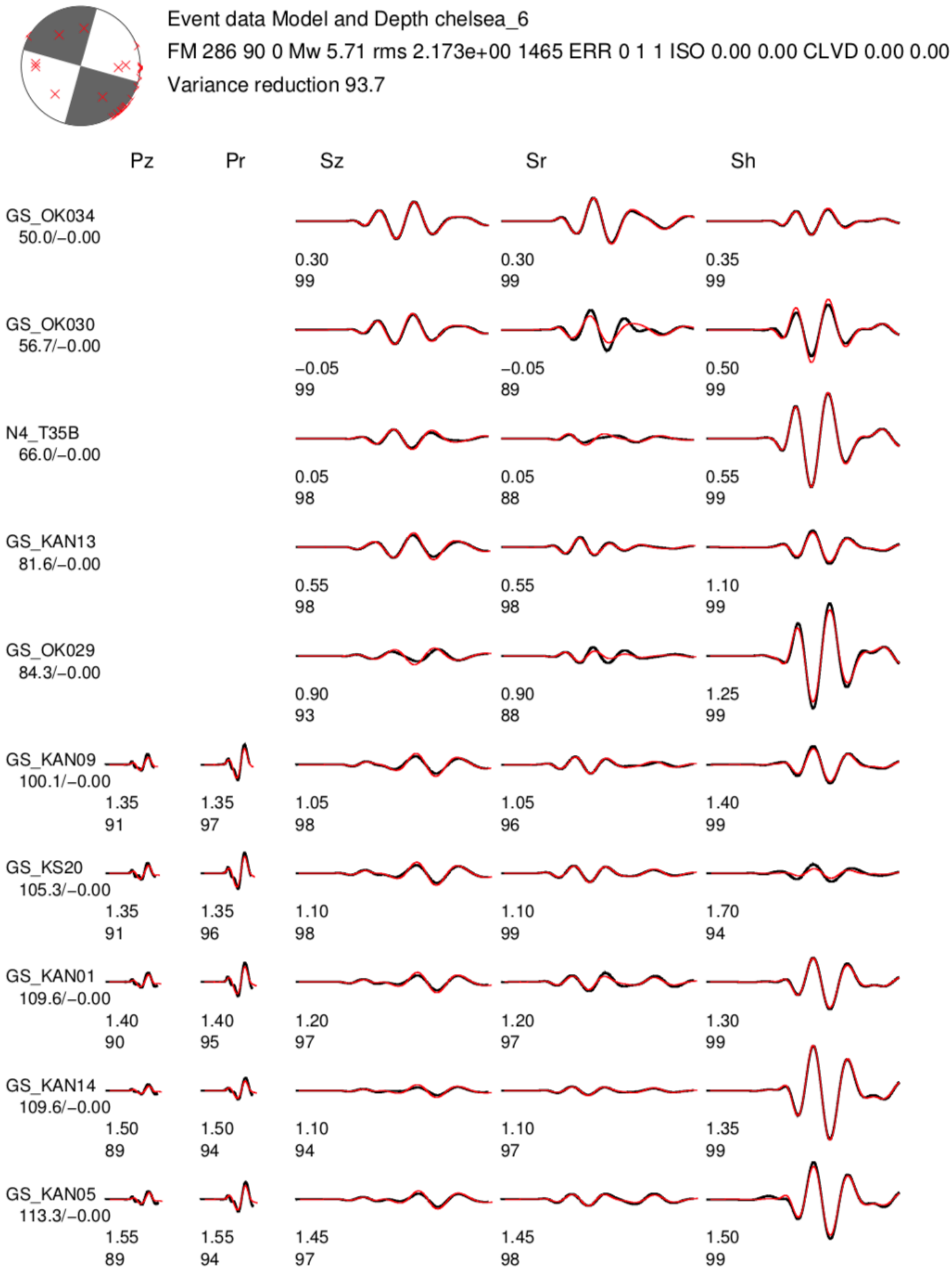


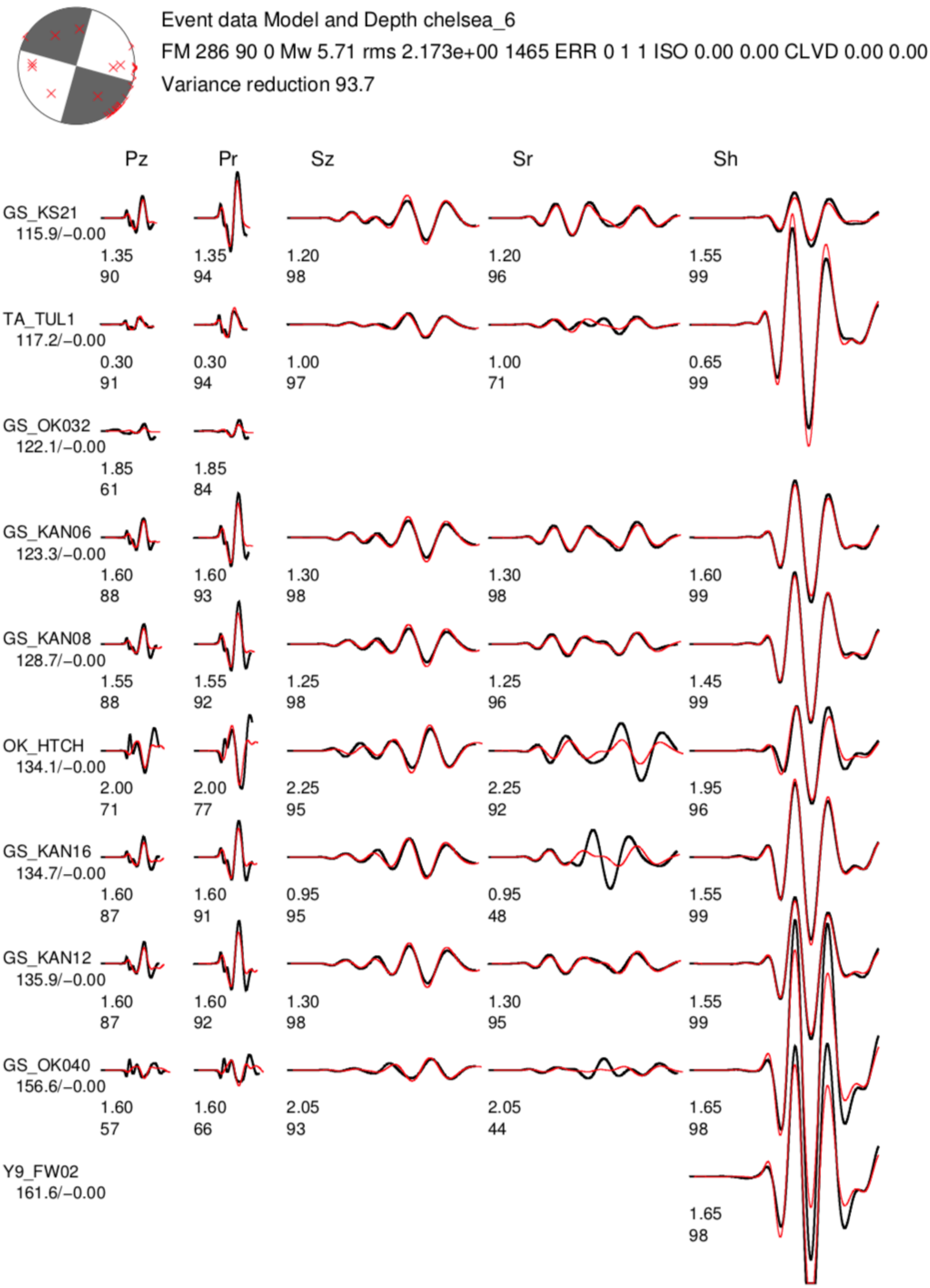

Event data Model and Depth chelsea_5
FM 106 90 −1 Mw 5.70 rms 2.614e+00 1465 ERR 0 1 1 ISO 0.00 0.00 CLVD 0.00 0.00
Variance reduction 92.4
Pz
Pr
Sz
Sr
Sh
GS_KS21
115.9/−0.00
1.50
89
1.50
94
1.15
95
1.15
83
1.55
98
TA_TUL1
117.2/−0.00
0.35
90
0.35
92
1.25
98
1.25
88
0.65
99
GS_OK032
122.1/−0.00
2.00
60
2.00
85
GS_KAN06
123.3/−0.00
1.70
88
1.70
93
1.35
97
1.35
92
1.60
99
GS_KAN08
128.7/−0.00
1.70
87
1.70
91
1.35
97
1.35
92
1.45
99
OK_HTCH
134.1/−0.00
2.00
71
2.00
71
2.30
93
2.30
91
1.90
96
GS_KAN16
134.7/−0.00
1.75
86
1.75
90
0.45
88
0.45
52
1.55
99
GS_KAN12
135.9/−0.00
1.75
86
1.75
91
1.30
97
1.30
85
1.55
99
GS_OK040
156.6/−0.00
1.85
54
1.85
65
2.35
87
2.35
12
1.60
98
Y9_FW02
161.6/−0.00
1.60
98

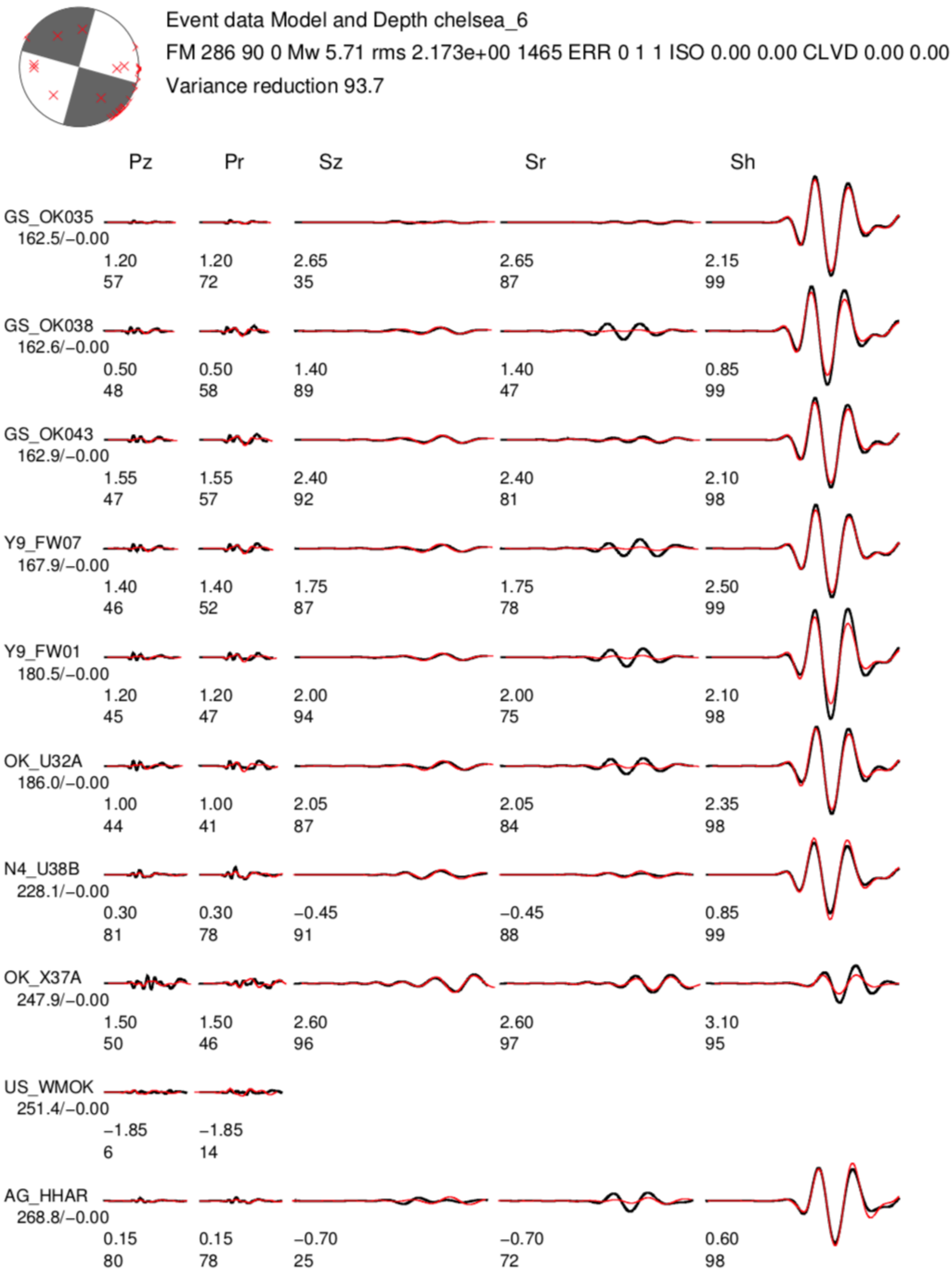

Event data Model and Depth chelsea_5
FM 106 90 −1 Mw 5.70 rms 2.614e+00 1465 ERR 0 1 1 ISO 0.00 0.00 CLVD 0.00 0.00
Variance reduction 92.4
Pz
Pr
Sz
Sr
Sh
GS_OK035
162.5/−0.00
1.35 1.35 3.65 3.65 2.15
52 67 27 92 99
GS_OK038
162.6/−0.00
0.90 0.90 2.05 2.05 0.85
44 57 84 68 99
GS_OK043
162.9/−0.00
2.00 2.00 2.80 2.80 2.10
44 57 87 83 98
Y9_FW07
167.9/−0.00
2.00 2.00 2.30 2.30 2.50
39 52 84 91 99
Y9_FW01
180.5/−0.00
1.50 1.50 2.50 2.50 2.10
36 40 92 80 98
OK_U32A
186.0/−0.00
1.20 1.20 2.50 2.50 2.40
34 33 87 87 98
N4_U38B
228.1/−0.00
0.40 0.40 −0.55 −0.55 0.80
73 71 90 82 99
OK_X37A
247.9/−0.00
1.75 1.75 2.70 2.70 3.15
46 43 94 98 94
US_WMOK
251.4/−0.00
−1.45 −1.45
7 12
AG_HHAR
268.8/−0.00
0.35 0.35 −0.80 −0.80 0.65
76 73 35 70 98


Event data Model and Depth chelsea_5
FM 106 90 −1 Mw 5.70 rms 2.614e+00 1465 ERR 0 1 1 ISO 0.00 0.00 CLVD 0.00 0.00
Variance reduction 92.4
Pz
Pr
Sz
Sr
Sh
N4_R32B
272.1/−0.00
2.00
54
2.00
48
2.35
95
2.35
95
US_KSU1
298.3/−0.00
2.00
43
2.00
56
1.60
97
1.60
92
2.40
99

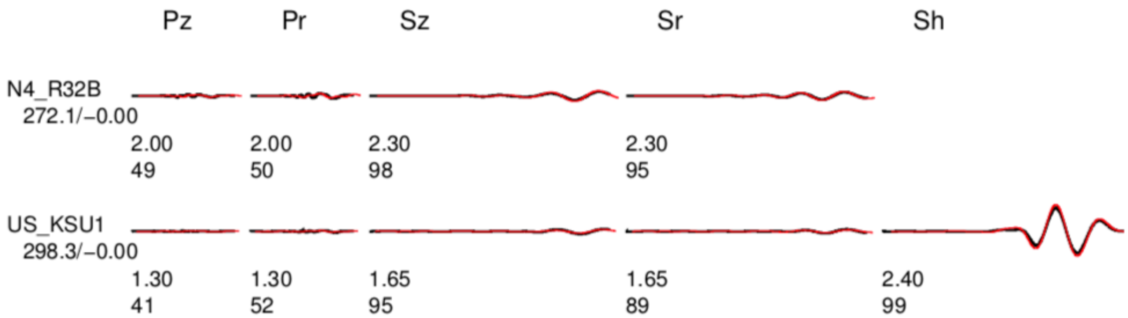
Inversion Result at depth 6km:



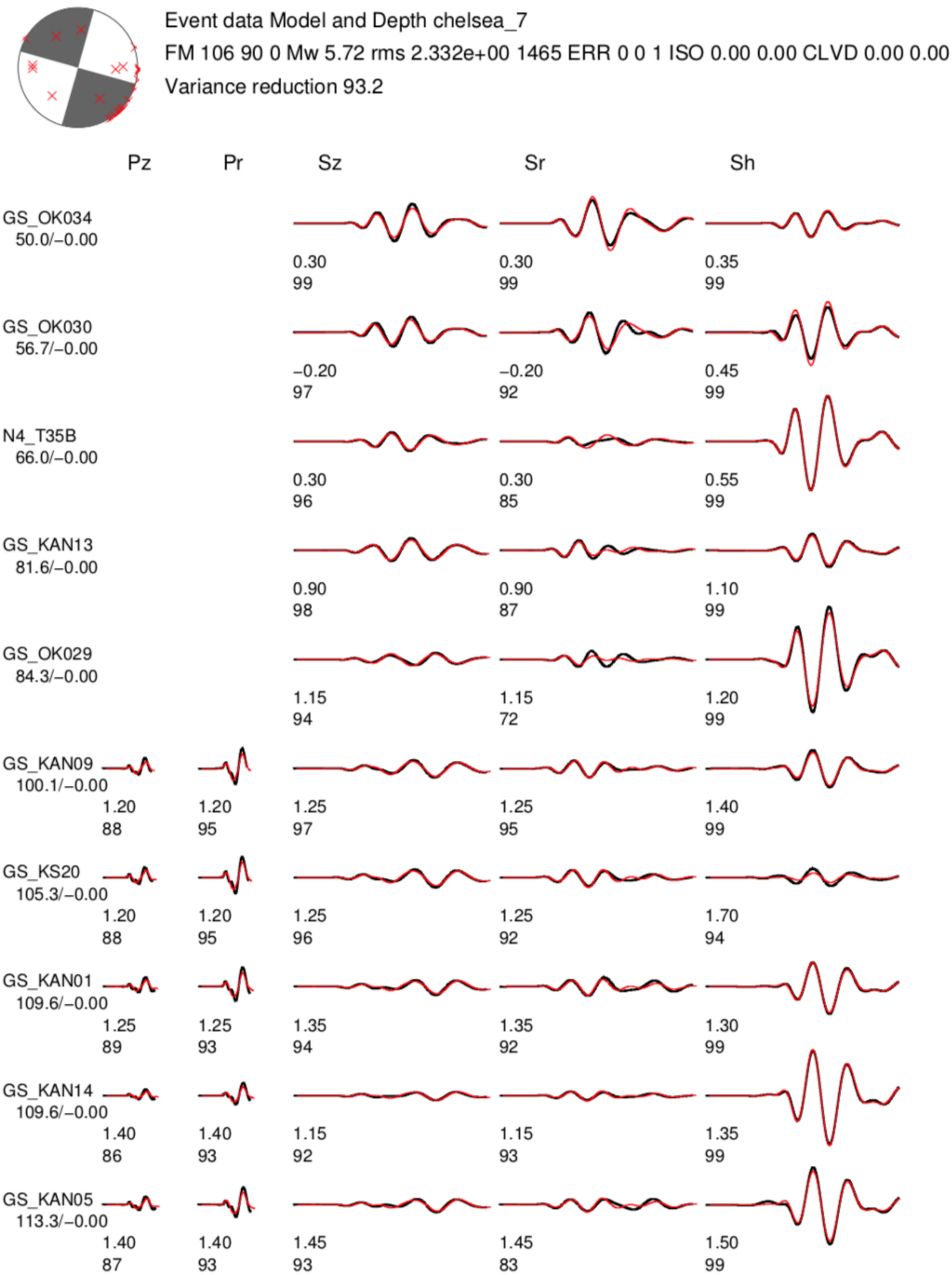

Event data Model and Depth chelsea_6
FM 286 90 0 Mw 5.71 rms 2.173e+00 1465 ERR 0 1 1 ISO 0.00 0.00 CLVD 0.00 0.00
Variance reduction 93.7
Pz
Pr
Sz
Sr
Sh
GS_KS21
115.9/−0.00
1.35
90
1.35
94
1.20
98
1.20
96
1.55
99
TA_TUL1
117.2/−0.00
0.30
91
0.30
94
1.00
97
1.00
71
0.65
99
GS_OK032
122.1/−0.00
1.85
61
1.85
84
GS_KAN06
123.3/−0.00
1.60
88
1.60
93
1.30
98
1.30
98
1.60
99
GS_KAN08
128.7/−0.00
1.55
88
1.55
92
1.25
98
1.25
96
1.45
99
OK_HTCH
134.1/−0.00
2.00
71
2.00
77
2.25
95
2.25
92
1.95
96
GS_KAN16
134.7/−0.00
1.60
87
1.60
91
0.95
95
0.95
48
1.55
99
GS_KAN12
135.9/−0.00
1.60
87
1.60
92
1.30
98
1.30
95
1.55
99
GS_OK040
156.6/−0.00
1.60
57
1.60
66
2.05
93
2.05
44
1.65
98
Y9_FW02
161.6/−0.00
1.65
98

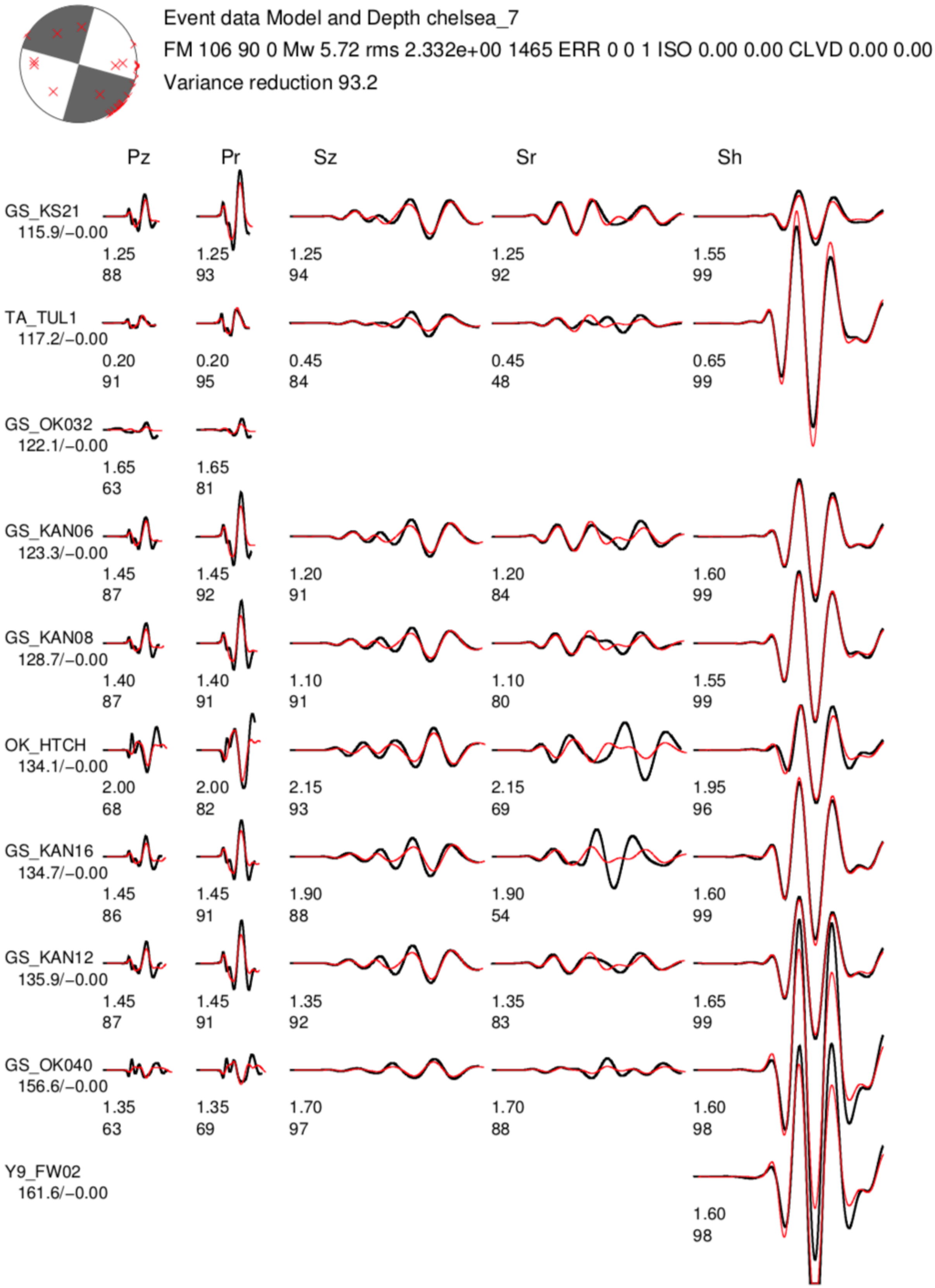

Event data Model and Depth chelsea_6
FM 286 90 0 Mw 5.71 rms 2.173e+00 1465 ERR 0 1 1 ISO 0.00 0.00 CLVD 0.00 0.00
Variance reduction 93.7
Pz
Pr
Sz
Sr
Sh
GS_OK035
162.5/−0.00
1.20 1.20 2.65 2.65 2.15
57 72 35 87 99
GS_OK038
162.6/−0.00
0.50 0.50 1.40 1.40 0.85
48 58 89 47 99
GS_OK043
162.9/−0.00
1.55 1.55 2.40 2.40 2.10
47 57 92 81 98
Y9_FW07
167.9/−0.00
1.40 1.40 1.75 1.75 2.50
46 52 87 78 99
Y9_FW01
180.5/−0.00
1.20 1.20 2.00 2.00 2.10
45 47 94 75 98
OK_U32A
186.0/−0.00
1.00 1.00 2.05 2.05 2.35
44 41 87 84 98
N4_U38B
228.1/−0.00
0.30 0.30 −0.45 −0.45 0.85
81 78 91 88 99
OK_X37A
247.9/−0.00
1.50 1.50 2.60 2.60 3.10
50 46 96 97 95
US_WMOK
251.4/−0.00
−1.85 −1.85
6 14
AG_HHAR
268.8/−0.00
0.15 0.15 −0.70 −0.70 0.60
80 78 25 72 98

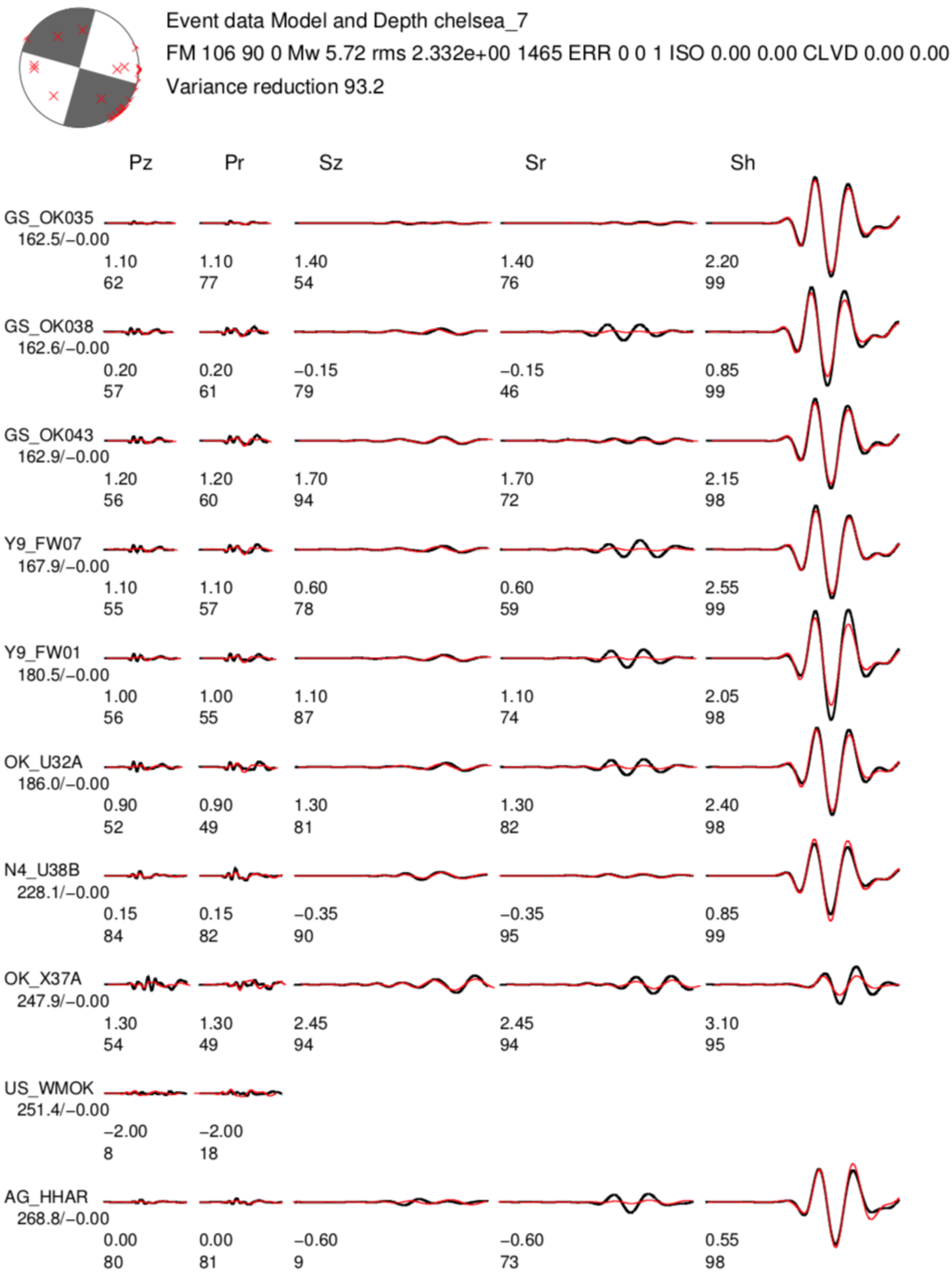
Event data Model and Depth chelsea_6
FM 286 90 0 Mw 5.71 rms 2.173e+00 1465 ERR 0 1 1 ISO 0.00 0.00 CLVD 0.00 0.00
Variance reduction 93.7



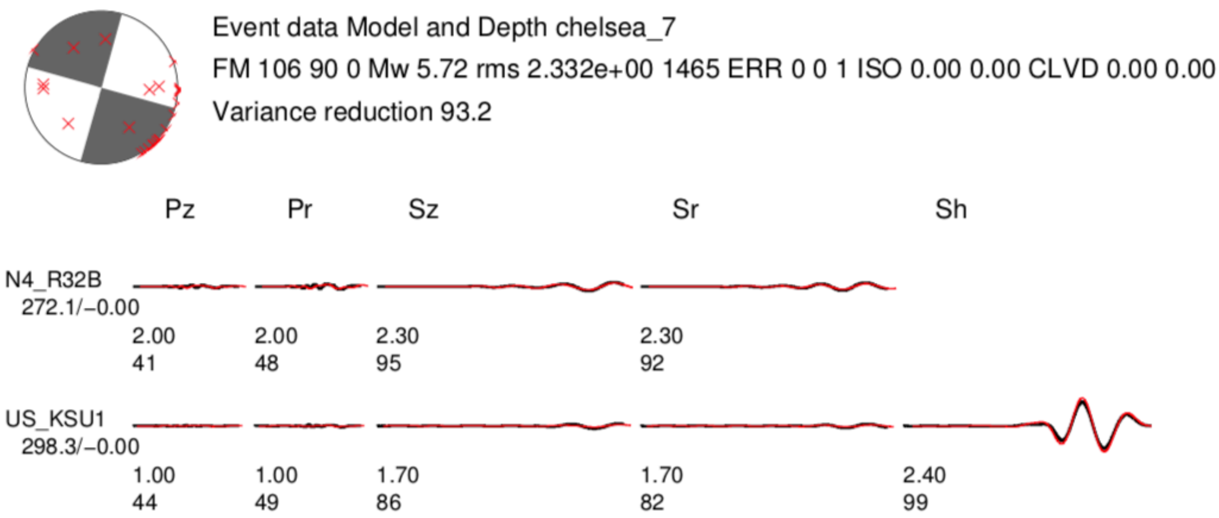
Inversion Result at depth 7km:



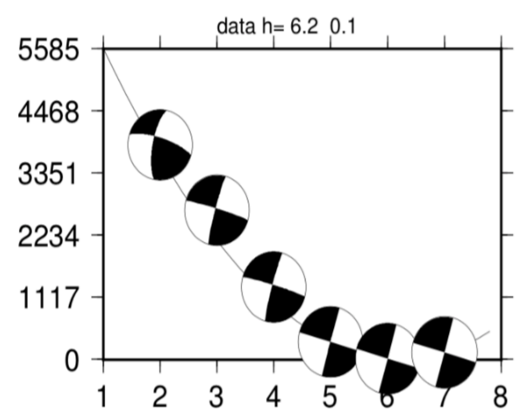

Event data Model and Depth chelsea_7
FM 106 90 0 Mw 5.72 rms 2.332e+00 1465 ERR 0 0 1 ISO 0.00 0.00 CLVD 0.00 0.00
Variance reduction 93.2
Pz
Pr
Sz
Sr
Sh
GS_KS21
115.9/-0.00
1.25 88
1.25 93
1.25 94
1.25 92
1.55 99
TA_TUL1
117.2/-0.00
0.20 91
0.20 95
0.45 84
0.45 48
0.65 99
GS_OK032
122.1/-0.00
1.65 63
1.65 81
GS_KAN06
123.3/-0.00
1.45 87
1.45 92
1.20 91
1.20 84
1.60 99
GS_KAN08
128.7/-0.00
1.40 87
1.40 91
1.10 91
1.10 80
1.55 99
OK_HTCH
134.1/-0.00
2.00 68
2.00 82
2.15 93
2.15 69
1.95 96
GS_KAN16
134.7/-0.00
1.45 86
1.45 91
1.90 88
1.90 54
1.60 99
GS_KAN12
135.9/-0.00
1.45 87
1.45 91
1.35 92
1.35 83
1.65 99
GS_OK040
156.6/-0.00
1.35 63
1.35 69
1.70 97
1.70 88
1.60 98
Y9_FW02
161.6/-0.00
1.60 98



Event data Model and Depth chelsea_7
FM 106 90 0 Mw 5.72 rms 2.332e+00 1465 ERR 0 0 1 ISO 0.00 0.00 CLVD 0.00 0.00
Variance reduction 93.2
Pz
Pr
Sz
Sr
Sh
GS_OK035
162.5/−0.00
1.10 1.10 1.40 1.40 2.20
62 77 54 76 99
GS_OK038
162.6/−0.00
0.20 0.20 −0.15 −0.15 0.85
57 61 79 46 99
GS_OK043
162.9/−0.00
1.20 1.20 1.70 1.70 2.15
56 60 94 72 98
Y9_FW07
167.9/−0.00
1.10 1.10 0.60 0.60 2.55
55 57 78 59 99
Y9_FW01
180.5/−0.00
1.00 1.00 1.10 1.10 2.05
56 55 87 74 98
OK_U32A
186.0/−0.00
0.90 0.90 1.30 1.30 2.40
52 49 81 82 98
N4_U38B
228.1/−0.00
0.15 0.15 −0.35 −0.35 0.85
84 82 90 95 99
OK_X37A
247.9/−0.00
1.30 1.30 2.45 2.45 3.10
54 49 94 94 95
US_WMOK
251.4/−0.00
−2.00 −2.00
8 18
AG_HHAR
268.8/−0.00
0.00 0.00 −0.60 −0.60 0.55
80 81 9 73 98



Best-fitting focal depth:



y-axis: Variance
x-axis: Depths

The above graph shows inversion result for focal depths from 2km to 7km, with 1km step size each. The computed moment magnitudes range from 5.65Mw to 5.72Mw, slightly smaller than catalog's magnitude of 5.8Mw. Grid-search on depth shows that best-fitting focal depth is 6km, achieving highest variance reduction of 93.7% and magnitude of 5.71Mw.

Discussion:

Jia's Fault Parameter AT 6.0KM DEPTH

Strike: 286

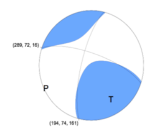
dip: 90

Rake: 0

Event Magnitude

5.71 M

VS

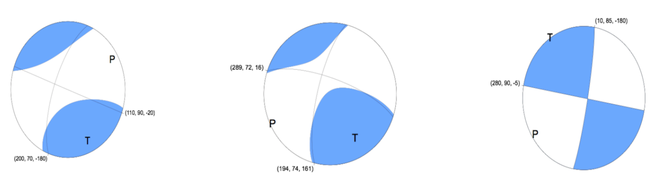


- **USGS's Fault Parameters AT 5.6KM DEPTH**
- Strike: 289
- dip: 72
- Rake: 16
- **Event Magnitude**
- 5.8 M

In this study, the generated focal mechanism has two possible candidate planes that would be responsible for the earthquake. According to our moment tensor solution, fault plane that is likely to cause the earthquake has strike of 286, dip of 90 and rake of 0. Its orthogonal plane, known as auxiliary plane, would also have produced the same seismic waveform. In this case, it is necessary to determine the fault plane with suggested moment tensor solutions and local geology.

Preliminary focal mechanism solutions suggest either as left lateral striking east southeast or on right lateral fault striking north-northeast. (Grandin R. et al) In this case, our focal mechanism suggests a left-lateral strike slip fault with East- SE –West-NW trending and vertical fault. This is quite similar with the moment tensor solution as listed on USGS website and findings of McGarr.

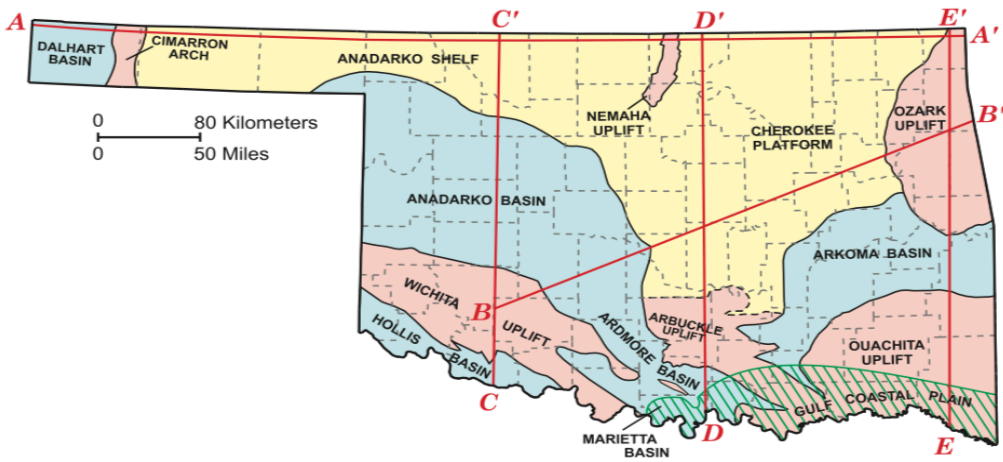
Foreshock	Mainshock	Aftershock

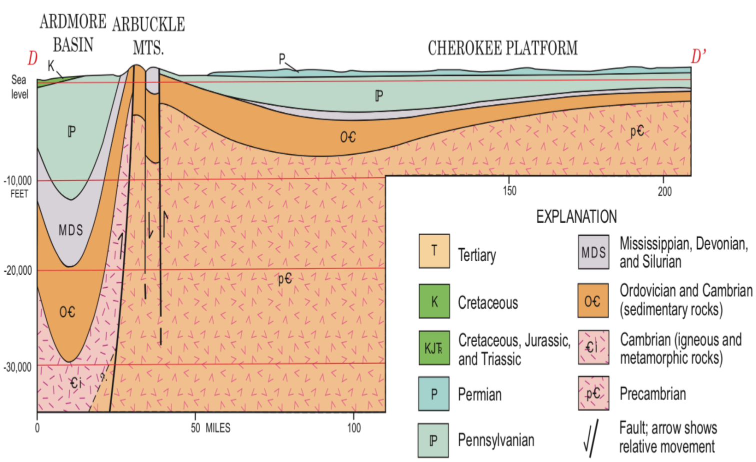


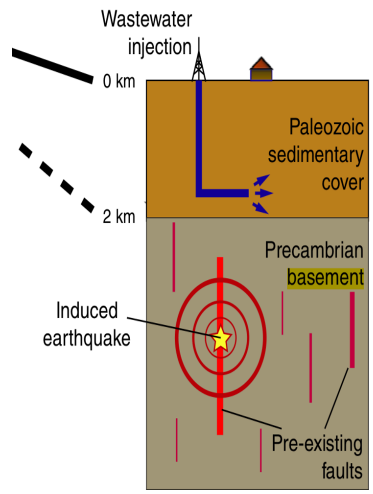
Jan 28th 2016 **3.5 M** **Depth: 7.2km**	**Sept 3rd 2016** **5.8M** **Depth: 5.6km**	**Sept 7th 2016** **3.1M** **Depth: 4.4km**

The above diagram shows the focal mechanism of foreshock, main shock and aftershock as obtained from USGS website.

In addition, the main shock focal mechanism is also in agreement with alignment of foreshock and aftershocks events as shown below. The focal mechanisms of these events suggest a left-lateral ESE-WSW trending fault. One study shows that Pawnee main shock was largely the result of left-lateral slip across an unmapped fault, striking west- northwestward. (Yeck et al.)







The above diagrams show the geology and cross section of the Oklahoma region. (Johnson K.)
The lower right diagram illustrates the possible existing faults buried beyond depth of 2km. (Grandin)

The Pawnee sequence events is likely to be a result of destabilization of fault 3-4km below the depth range where wastewater was injected. Increased injection rate within 10km surrounding Pawnee area may have activated the faults within. Stresses have slowly accumulated until largest seismic moment release on 3rd Sep 2016. Notice that the depths where Pawnee seismic events happened are usually in the range from 4km to 8km (USGS). Fault is likely to be buried within the Precambrian basement beneath the Paleozoic sedimentary pile where wastewater is injected. (Grandin. R. et. al.)

Conclusion

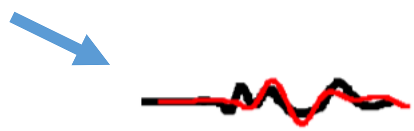
To conclude, inversion result of main shock Pawnee event suggests left-lateral strike slip faulting focal mechanism, consistent with that of aftershock and foreshock. The earthquake depths range of the Pawnee sequence events is also consistent with the injection depth within Precambrian layer. GCAP method offers a reliable result for point source mechanism inversion in terms of focal mechanism, depth and magnitude.

Feedback/Commentaries:

Feedback:

- Would the Pnl wave considered acceptable if the synthetic ignores the smaller waveform pattern and fit into the larger pattern instead? Because it makes sense that the synthetics should also match up with the smaller waveform pattern too. (C. Lin)

  Example:



- Group by polarity of Pnl waves to produce better inversion. (S.H.)
- Experiment with “lowpass” or other filtering. (S.H.)

Acknowledgement

I would like to express my gratitude for Dr. Qinya & Yiru for helping me understand the workflow and motivations of the projects better. And I appreciate feedbacks and commentaries from the audiences: ChuangXin, Dr. Shu Huei, Mostafa, Bahareh and Song Xin.

References

Grandin R., Vallee M., Lacassin R. (2017). Rupture Process of the Mw5.7 Pawnee, Oklahoma, Earthquake from Sentinel-1 InSAR and Seismological Data. Seismological Research Letter. Vol.88, Number 3. doi:10.1785/0220160226

Johnson K. S. (2008). Geologic History of Oklahoma. Oklahoma Geological Survey, Educational Publication 9:2008.

McGarr A., and J. Barbour Andrew. (2017). Wastewater Disposal and the Earthquake Sequences During 2016 Near Fairview, Pawnee and Cushing, Oklahoma. AGU Geophysical Research Letter, 10.1002/2017GL075258

Holland A. (2011). Examination of Possibly Induced Seismicity from Hydraulic Fracturing in Eola Field, Garvin County, Oklahoma. Oklahoma Geological Survey, Open-File Report, OF1-2011

USGS. (2016). M 3.5 -20km S of McCord, Oklahoma. Retrieved from https://earthquake.usgs.gov/earthquakes/eventpage/us20004vb5#executive

USGS. (2016). M 5.8 -14km NW of Pawnee, Oklahoma. Retrieved from https://earthquake.usgs.gov/earthquakes/eventpage/us10006jxs#executive

USGS. (2016). M 3.1 -14km NW of Pawnee, Oklahoma. Retrieved from https://earthquake.usgs.gov/earthquakes/eventpage/us10006ml1#executive

Yagi Y.. Seismic Source Mechanism. Retrieved from: http://www.geol.tsukuba.ac.jp/~yagi-y/text/Source_meca_v0.7.pdf

Yeck, W. L., Hayes, G. P., McNamara, D. E., Rubinstein, J. L., Barnhart, W. D., Earle, P. S., & Benz, H. M. (2017). Oklahoma experiences largest earthquake during ongoing regional wastewater injection hazard mitigation efforts. Geophysical Research Letters, 44, 711–717. https://doi.org/10.1002/2016GL071685