

# ISOLA course Brasilia 2013

2012 Montes Claros, Brazil seismic sequence

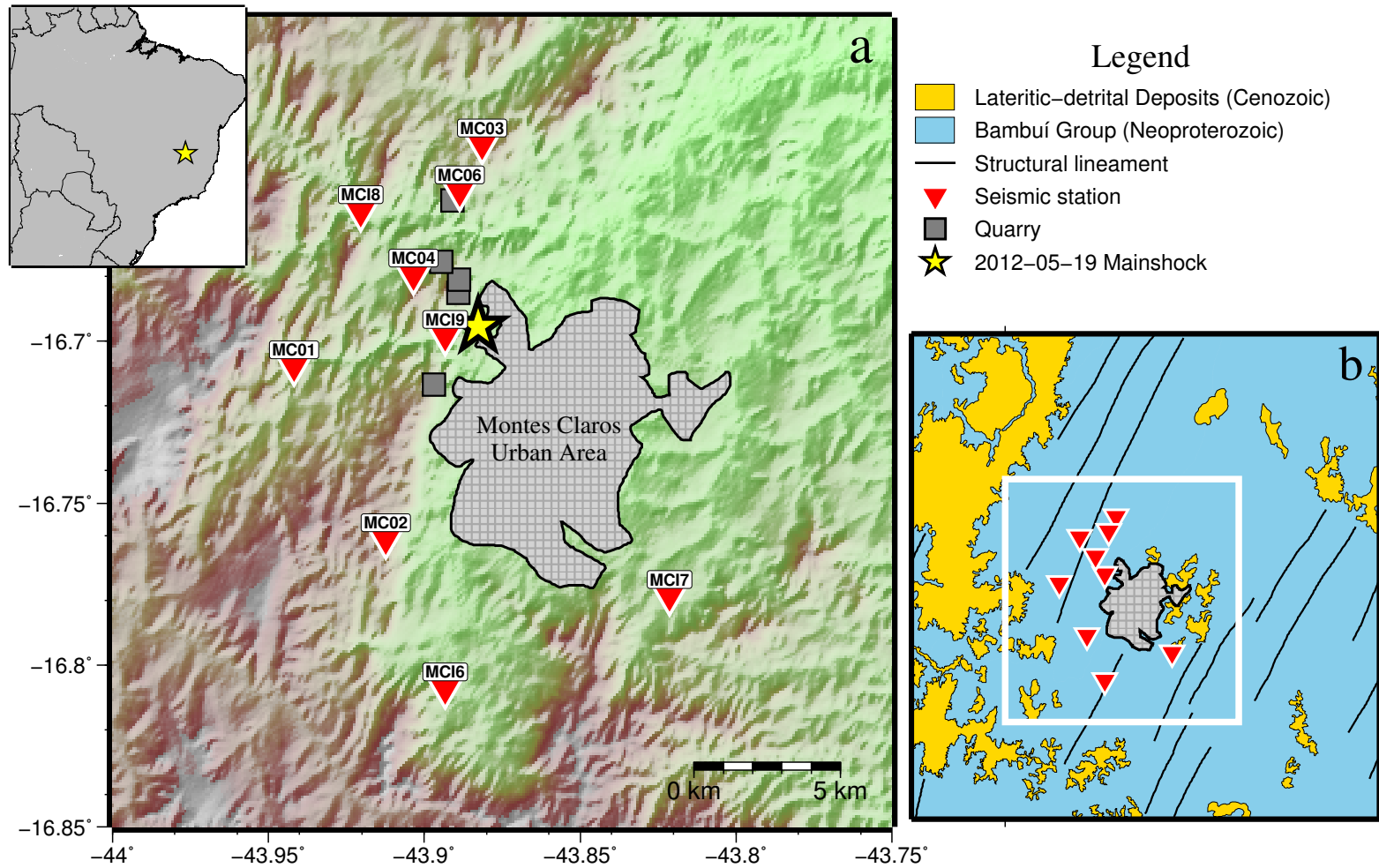
**Hans Agurto-Detzel**  
IAG - U. Sao Paulo

[h.agurto.detzel@gmail.com](mailto:h.agurto.detzel@gmail.com)



- On 19-May-2012, an earthquake  $M=4$  occurred in Montes Claros, central-east Brazil
- Shortly afterwards a local seismic network was deployed to study the aftershocks sequence
- Unknown nature and geometry of seismic source/fault
- Not enough stations for computation of focal mechanism through first motion polarities
- Solution: waveform modelling with **ISOLA**

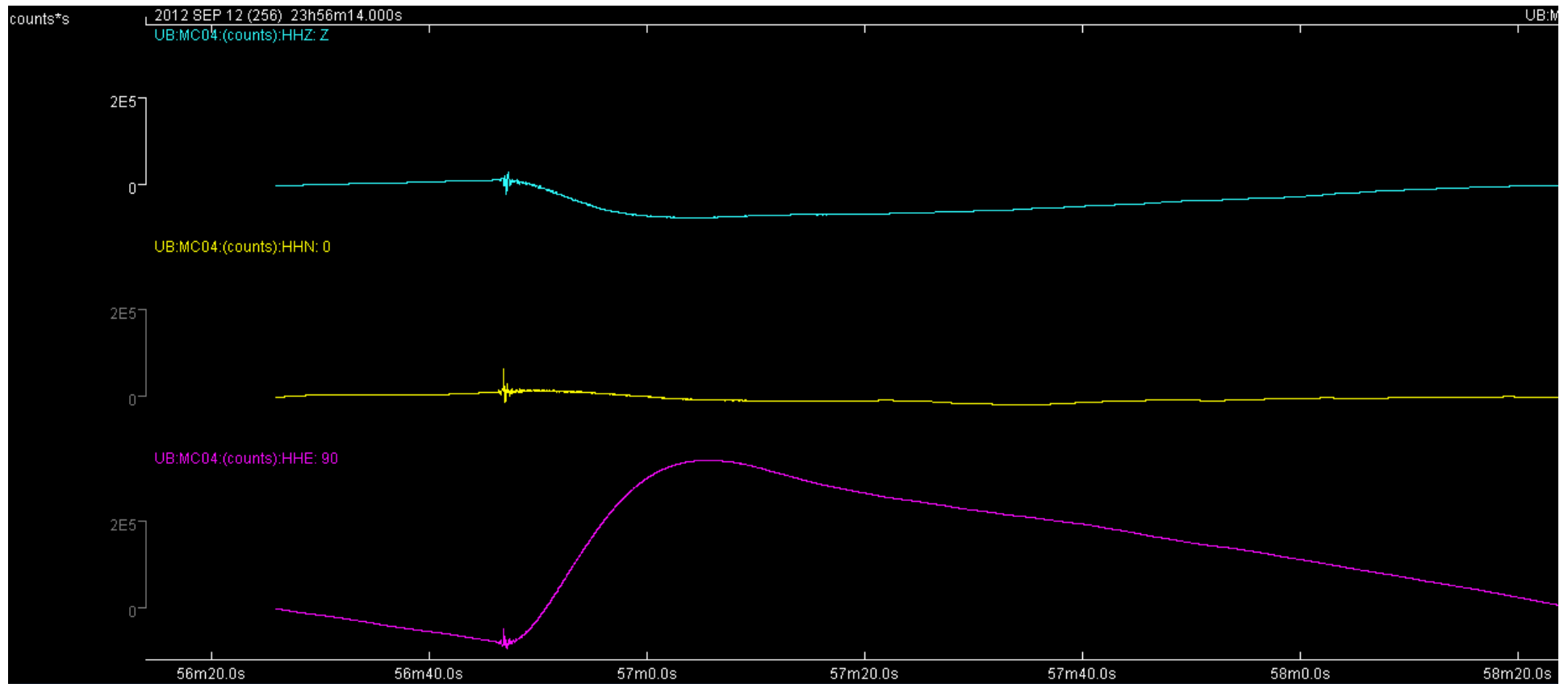
# Study Area



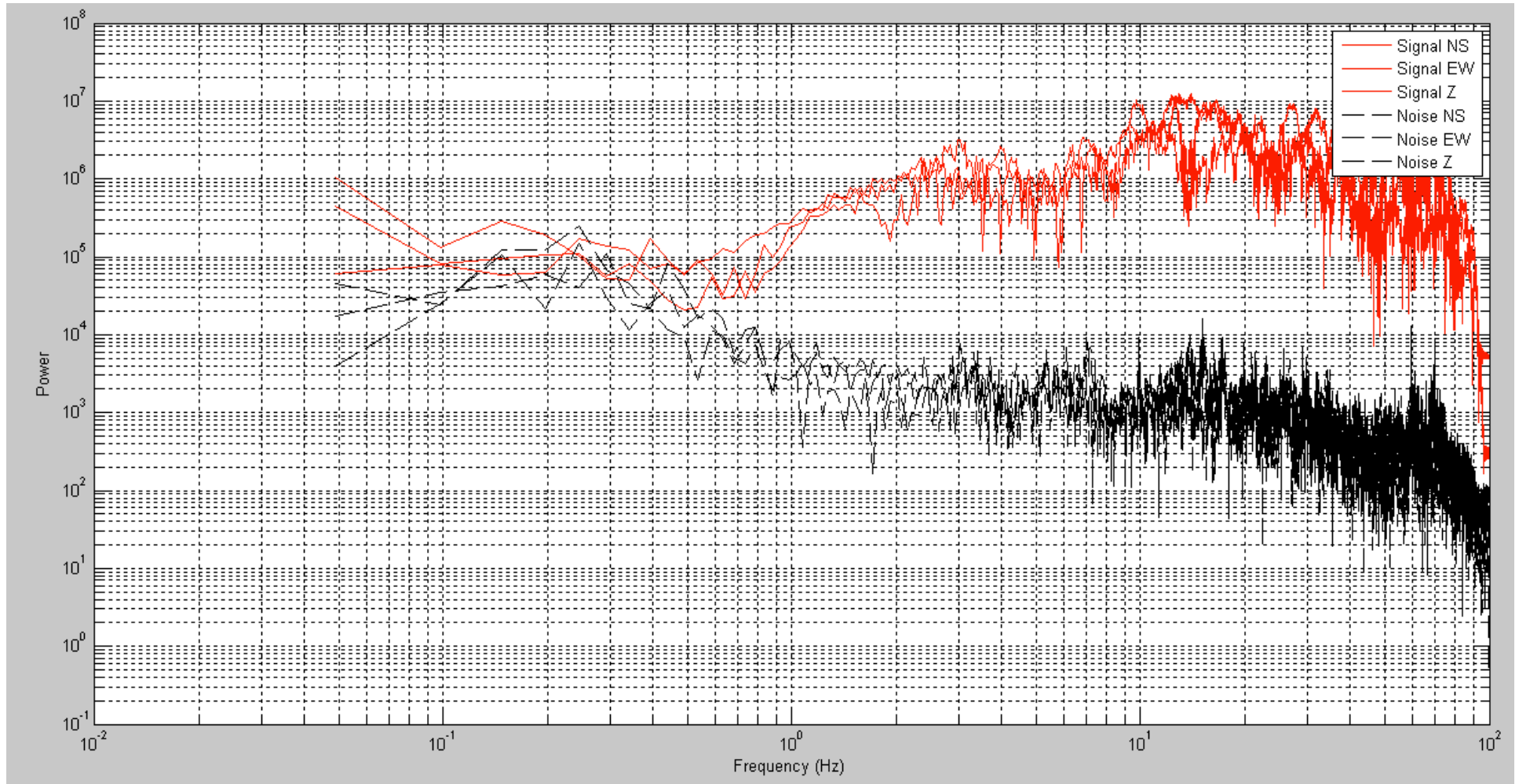
# Event info window for analysed aftershock

<b>Date</b> Date (YYYYMMDD) <input type="text" value="20120912"/>	<b>Location</b> Lat (Deg,Min) <input type="text" value="38.00"/> <input type="text" value="50.00"/> DDMM-> DDEG Lon (Deg,Min) <input type="text" value="21.00"/> <input type="text" value="50.00"/>		<b>Lat (N) (Dec.Degrees)</b> <input type="text" value="-16.7036"/> <b>Depth (km)</b> <input type="text" value="1.224"/> <b>Lon (E) (Dec.Degrees)</b> <input type="text" value="-43.8851"/>
<b>Origin Time</b> Hour <input type="text" value="23"/> Min <input type="text" value="56"/> Seconds <input type="text" value="45.681"/>	<b>Comments</b> Magnitude <input type="text" value="2.9"/> Location agency <input type="text" value="IAG"/>		
<b>Time Window Length (sec)</b> <input type="list" value="16.384"/> <input type="list" value="40.96"/> <input type="list" value="81.92"/> <input type="list" value="163.84"/> <input type="list" value="245.76"/> <input type="list" value="327.68"/> <input type="list" value="409.6"/> <input type="list" value="819.2"/> <input type="list" value="1638.4"/> <p>The chosen Time Window Length should be large enough to include the travel time from epicenter to stations plus the seismogram duration</p>			

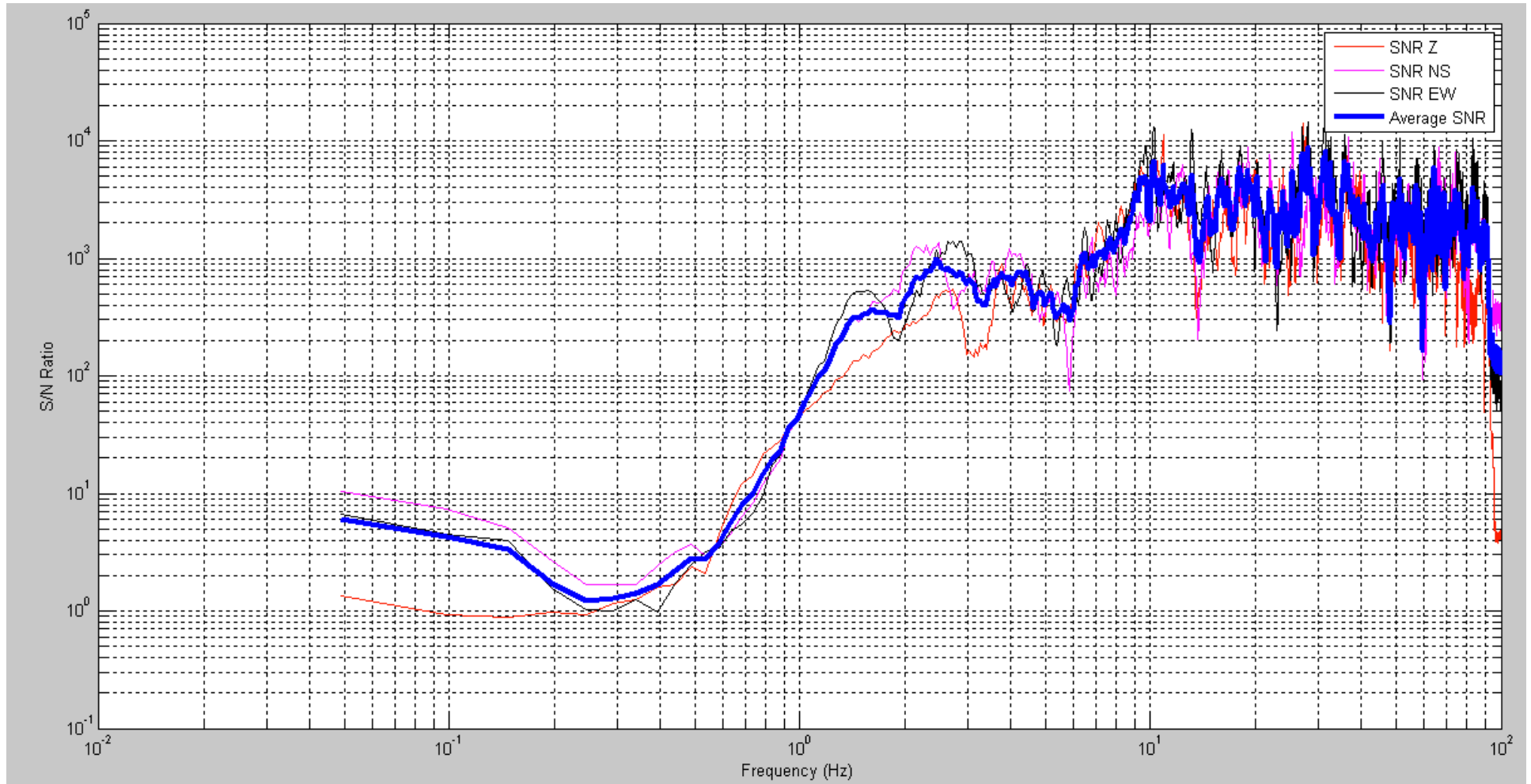
# Disturbances due to near-field effects in station MC04



# Example S/N Spectra Station MCI8



# S/N Spectra Station MCI8

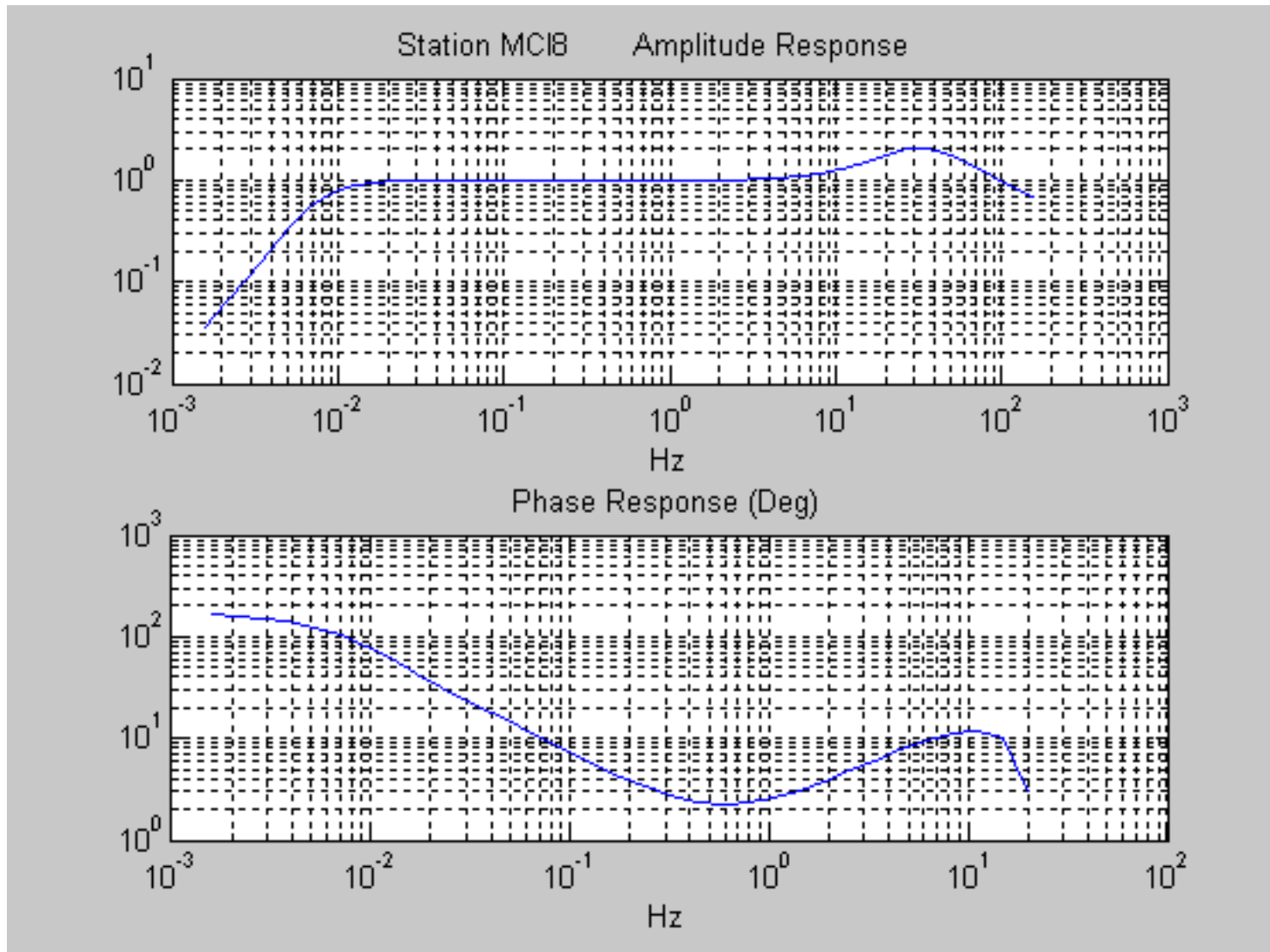


# P&Z Parameters

```
* NETWORK (KNETWK): BL
* STATION (KSTNM): MCI8
* LOCATION (KHOLE):
* CHANNEL (KCMPNM): HHZ
* CREATED : 2013-12-02T22:19:40
* START : 2012-05-29T00:00:00
* END : 2013-06-23T01:01:00
* DESCRIPTION : Montes Claros 8, MG (Fzda Vitoria)
* LATITUDE : -16.659670
* LONGITUDE : -43.920410
* ELEVATION : 696.0
* DEPTH : 0.0
* DIP : 0.0
* AZIMUTH : 0.0
* SAMPLE RATE : 200.0
* INPUT UNIT : M
* OUTPUT UNIT : COUNTS
* INSTTYPE : Trillium 120PA
* INSTGAIN : 1.201000e+03 (M/S)
* COMMENT : N/A
* SENSITIVITY : 4.804000e+08 (M/S)
* A0 : 4.113703e+09
* *****
ZEROS 6
      +0.000000e+00 +0.000000e+00
      +0.000000e+00 +0.000000e+00
      +0.000000e+00 +0.000000e+00
      -9.000000e+01 +0.000000e+00
      -1.607000e+02 +0.000000e+00
      -3.108000e+03 +0.000000e+00
POLES 8
      -3.852000e-02 +3.658000e-02
      -3.852000e-02 -3.658000e-02
      -1.780000e+02 +0.000000e+00
      -1.350000e+02 -1.600000e+02
      -1.350000e+02 +1.600000e+02
      -6.710000e+02 +1.154000e+03
      -6.710000e+02 -1.154000e+03
      -1.333890e+04 +0.000000e+00
CONSTANT +1.976223e+18
```

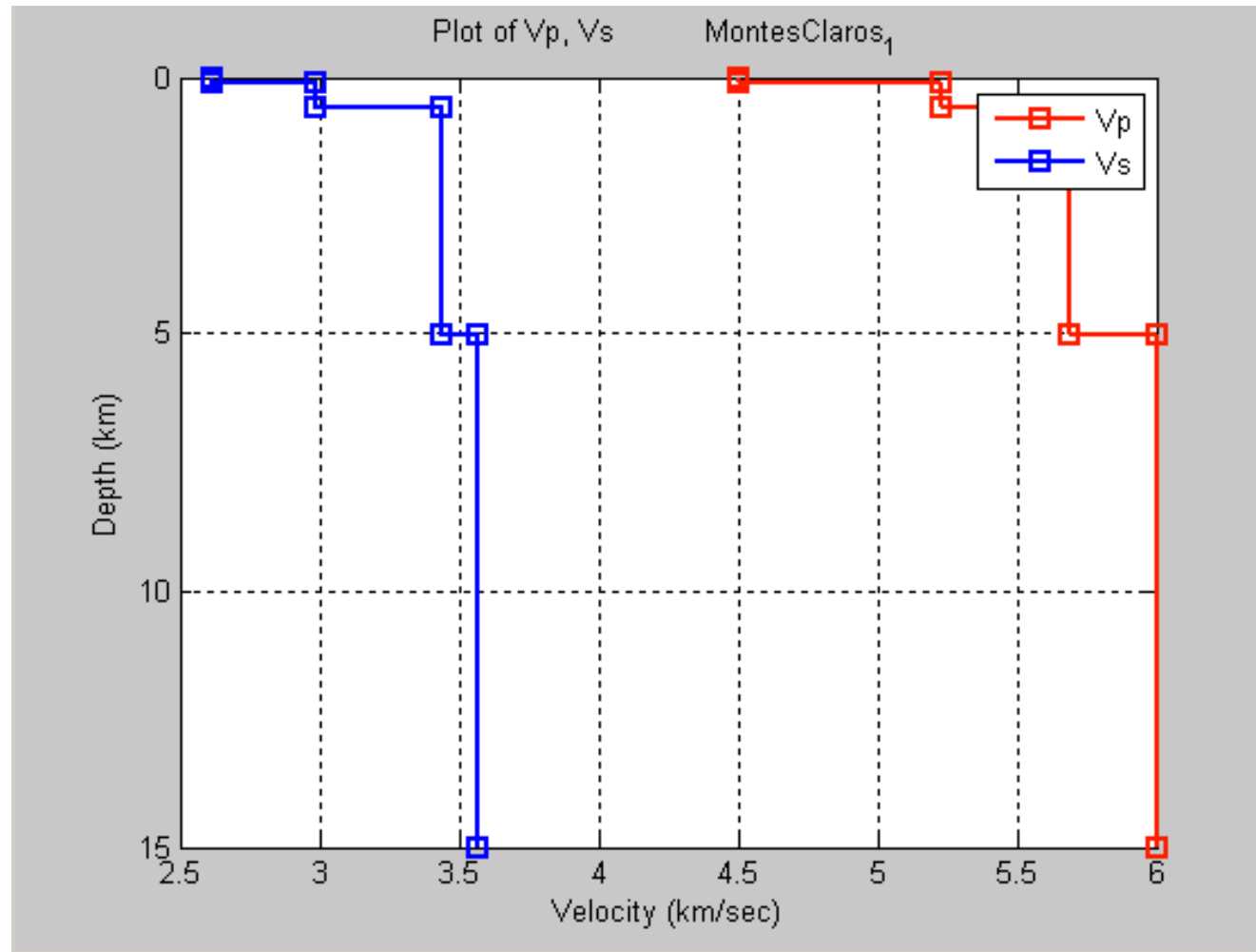


# P&Z Parameters



# Crustal Velocity Model

Previously obtained from simultaneous inversion with Velest



# Trial Sources

**Starting depth (km)**

0.2

**Depth step (km)**

0.4

**No of Sources (< 99)**

6

# Inversion window

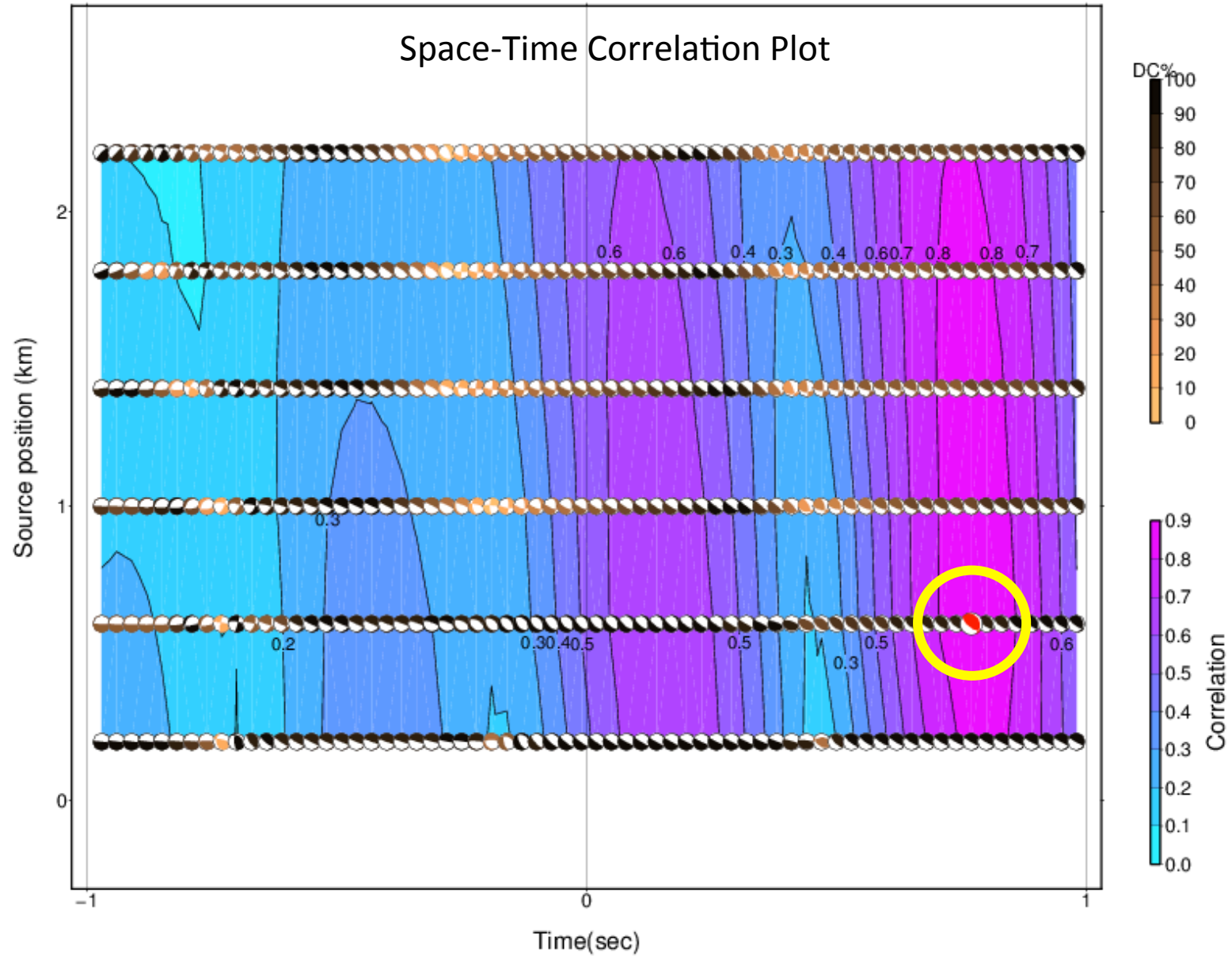
<p><b>Info</b></p> <p>Time Length <b>81.92</b></p> <p>No of Sources <b>6</b></p> <p>No of Stations <b>7</b></p> <p>Min Time shifts (sec) <b>-25</b></p> <p>Max Time shifts (sec) <b>25</b></p>	<p><b>Filter (Hz)</b> <input checked="" type="checkbox"/> Common for all stations</p> <p>filter (f1,f2,f3,f4); flat band-pass between f2, f3 cosine tapered between f1, f2 and between f3, f4</p> <p>f1 <input type="text" value="0.4"/> f2 <input type="text" value="0.41"/> f3 <input type="text" value="0.95"/> f4 <input type="text" value="1"/></p> <p>Plot S/N curves <input type="text" value="39"/></p> <p>S/N Ratio using f1 f4</p>	<p>Select Stations/Freq Band</p> <p>Compute Weights</p> <p>Reset Weights</p>																					
<p><b>Type of Inversion</b></p> <p><input type="radio"/> Full MT</p> <p><input checked="" type="radio"/> Deviatoric MT</p> <p><input type="radio"/> DC constrained</p> <p><input type="radio"/> Fixed mechanism</p> <p>Strike <input type="text" value="0"/></p> <p>Dip <input type="text" value="0"/></p> <p>Rake <input type="text" value="0"/></p>	<p><b>(dt) Time Search (sec)</b></p> <p><input type="text" value="-100"/> Start <input type="text" value="-1"/></p> <p><input type="text" value="3"/> Time Step <input type="text" value="0.03"/></p> <p><input type="text" value="100"/> End <input type="text" value="1"/></p> <p>Trial Time shifts</p>	<p><b>Run</b></p> <p><b>Exit</b></p>																					
<p><b>Number of Subevents</b> <input type="text" value="1"/></p>	<table border="1"> <tr> <td data-bbox="831 975 1077 1038"> <p>Plot Correlation diagram</p> </td> <td data-bbox="1084 975 1413 1038"> <p>Plot Scale X <input type="text" value="21"/></p> </td> <td data-bbox="1420 975 1749 1038"> <p>Results for Single source</p> </td> </tr> <tr> <td data-bbox="831 1043 1077 1107"> <p>Plot Correlation on map</p> </td> <td data-bbox="1084 1043 1413 1107"> <p>Plot Scale Y <input type="text" value="18"/></p> </td> <td data-bbox="1420 1043 1749 1107"> <p>Source Number <input type="text" value="1"/></p> </td> </tr> <tr> <td data-bbox="831 1112 1077 1176"> <p><input checked="" type="radio"/> Use Source Number</p> </td> <td data-bbox="1084 1112 1413 1176"> <p>Beachball Scale <input type="text" value="0.35"/></p> </td> <td data-bbox="1420 1112 1749 1176"> <p>Time limits <input type="text" value=""/></p> </td> </tr> <tr> <td data-bbox="831 1181 1077 1244"> <p><input type="radio"/> Use Distance-Depth</p> </td> <td data-bbox="1084 1181 1413 1244"> <p>Font size <input type="text" value="10"/></p> </td> <td data-bbox="1420 1181 1749 1244"> <p>Source limits <input type="text" value="6"/></p> </td> </tr> <tr> <td data-bbox="831 1249 1077 1313"> <p><input type="checkbox"/> Plot DC% contours</p> </td> <td data-bbox="1084 1249 1413 1313"> <p>Contour interval <input type="text" value="0.1"/></p> </td> <td data-bbox="1420 1249 1749 1313"> <p><input type="text" value="1"/></p> </td> </tr> <tr> <td data-bbox="831 1318 1077 1382"> <p><input checked="" type="checkbox"/> Draw Contours</p> </td> <td data-bbox="1084 1318 1413 1382"> <p>Beachball cut off % <input type="text" value="0"/></p> </td> <td data-bbox="1420 1318 1749 1382"> <p><input type="text" value=""/></p> </td> </tr> <tr> <td data-bbox="831 1386 1077 1442"> <p><input type="checkbox"/> Use fixed interval</p> </td> <td data-bbox="1084 1386 1413 1442"> <p>GMT Palette <input type="text" value="cool"/> <input type="checkbox"/> Invert Palette</p> </td> <td data-bbox="1420 1386 1749 1442"> <p><input type="text" value=""/></p> </td> </tr> </table>		<p>Plot Correlation diagram</p>	<p>Plot Scale X <input type="text" value="21"/></p>	<p>Results for Single source</p>	<p>Plot Correlation on map</p>	<p>Plot Scale Y <input type="text" value="18"/></p>	<p>Source Number <input type="text" value="1"/></p>	<p><input checked="" type="radio"/> Use Source Number</p>	<p>Beachball Scale <input type="text" value="0.35"/></p>	<p>Time limits <input type="text" value=""/></p>	<p><input type="radio"/> Use Distance-Depth</p>	<p>Font size <input type="text" value="10"/></p>	<p>Source limits <input type="text" value="6"/></p>	<p><input type="checkbox"/> Plot DC% contours</p>	<p>Contour interval <input type="text" value="0.1"/></p>	<p><input type="text" value="1"/></p>	<p><input checked="" type="checkbox"/> Draw Contours</p>	<p>Beachball cut off % <input type="text" value="0"/></p>	<p><input type="text" value=""/></p>	<p><input type="checkbox"/> Use fixed interval</p>	<p>GMT Palette <input type="text" value="cool"/> <input type="checkbox"/> Invert Palette</p>	<p><input type="text" value=""/></p>
<p>Plot Correlation diagram</p>	<p>Plot Scale X <input type="text" value="21"/></p>	<p>Results for Single source</p>																					
<p>Plot Correlation on map</p>	<p>Plot Scale Y <input type="text" value="18"/></p>	<p>Source Number <input type="text" value="1"/></p>																					
<p><input checked="" type="radio"/> Use Source Number</p>	<p>Beachball Scale <input type="text" value="0.35"/></p>	<p>Time limits <input type="text" value=""/></p>																					
<p><input type="radio"/> Use Distance-Depth</p>	<p>Font size <input type="text" value="10"/></p>	<p>Source limits <input type="text" value="6"/></p>																					
<p><input type="checkbox"/> Plot DC% contours</p>	<p>Contour interval <input type="text" value="0.1"/></p>	<p><input type="text" value="1"/></p>																					
<p><input checked="" type="checkbox"/> Draw Contours</p>	<p>Beachball cut off % <input type="text" value="0"/></p>	<p><input type="text" value=""/></p>																					
<p><input type="checkbox"/> Use fixed interval</p>	<p>GMT Palette <input type="text" value="cool"/> <input type="checkbox"/> Invert Palette</p>	<p><input type="text" value=""/></p>																					
<p><b>Time Function</b></p> <p><input checked="" type="radio"/> Delta</p> <p><input type="radio"/> Triangle <input type="text" value="4"/></p>																							

# Inversion window

Station MC04 was discarded for presence of near-field disturbances; components N and E of MCI7 were not used due to bad fitting of waveforms.

Stations	Components				f1	f2	f3	f4
<b>MC04</b>	<input type="checkbox"/> Use Station	<input type="checkbox"/> Use NS	<input type="checkbox"/> Use EW	<input type="checkbox"/> Use Z	0.4	0.41	0.95	1
<b>MC06</b>	<input checked="" type="checkbox"/> Use Station	<input checked="" type="checkbox"/> Use NS	<input checked="" type="checkbox"/> Use EW	<input checked="" type="checkbox"/> Use Z	0.4	0.41	0.95	1
<b>MCI8</b>	<input checked="" type="checkbox"/> Use Station	<input checked="" type="checkbox"/> Use NS	<input checked="" type="checkbox"/> Use EW	<input checked="" type="checkbox"/> Use Z	0.4	0.41	0.95	1
<b>MC02</b>	<input checked="" type="checkbox"/> Use Station	<input checked="" type="checkbox"/> Use NS	<input checked="" type="checkbox"/> Use EW	<input checked="" type="checkbox"/> Use Z	0.4	0.41	0.95	1
<b>MC03</b>	<input checked="" type="checkbox"/> Use Station	<input checked="" type="checkbox"/> Use NS	<input checked="" type="checkbox"/> Use EW	<input checked="" type="checkbox"/> Use Z	0.4	0.41	0.95	1
<b>MCI7</b>	<input checked="" type="checkbox"/> Use Station	<input type="checkbox"/> Use NS	<input type="checkbox"/> Use EW	<input checked="" type="checkbox"/> Use Z	0.4	0.41	0.95	1
<b>MCI6</b>	<input checked="" type="checkbox"/> Use Station	<input checked="" type="checkbox"/> Use NS	<input checked="" type="checkbox"/> Use EW	<input checked="" type="checkbox"/> Use Z	0.4	0.41	0.95	1

# Inversion Results



# Inversion Results

## MOMENT TENSOR SOLUTION

### HYPOCENTER LOCATION (IAG)

Origin time 20120912 23:56:45.681  
 Lat -16.7036 Lon -43.8851 Depth 1.224

### CENTROID

Trial source number : 2 (Fixed Epicenter inversion)  
 Centroid Lat (N)-16.7036 Lon (E)-43.8851  
 Centroid Depth (km) : 0.6  
 Centroid time : +0.77 (sec) relative to origin time

Moment (Nm) : 4.082e+012

Mw : 2.3

VOL% : 0

DC% : 86.6

CLVD% : 13.4

Var.red.:(for stations used in inversion):0.72 SNR CN FMVAR STVAR 39 2.7 17±8 0.09

Var.red.(for all stations) : 0.4

<b>Strike</b>	<b>Dip</b>	<b>Rake</b>	<b>Frequency band used in inversion (Hz)</b>
128	66	75	0.4 - 0.41 -- 0.95 - 1

<b>Strike</b>	<b>Dip</b>	<b>Rake</b>	<b>Stations-Components Used-Distance</b>
342	28	121	

<b>P-axis Azimuth Plunge</b>	<b>NS</b>	<b>EW</b>	<b>Z</b>	<b>D(km)</b>
229 20	-	-	-	3

<b>T-axis Azimuth Plunge</b>	<b>NS</b>	<b>EW</b>	<b>Z</b>	<b>D(km)</b>
12 65	+	+	+	6

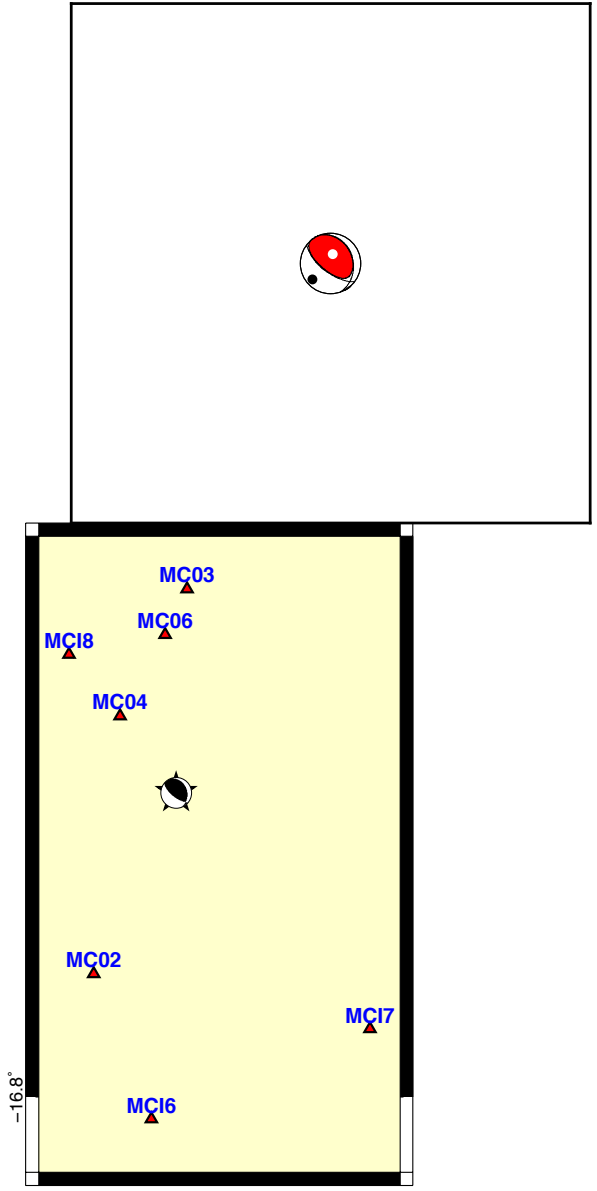
<b>Mr</b>	<b>Mt</b>	<b>Mp</b>	<b>NS</b>	<b>EW</b>	<b>Z</b>	<b>D(km)</b>
3.005	-0.922	-2.083	+	+	+	7

<b>Mrt</b>	<b>Mrp</b>	<b>Mtp</b>	<b>NS</b>	<b>EW</b>	<b>Z</b>	<b>D(km)</b>
2.441	-1.230	1.441	+	+	+	7

<b>Mr</b>	<b>Mt</b>	<b>Mp</b>	<b>NS</b>	<b>EW</b>	<b>Z</b>	<b>D(km)</b>
3.005	-0.922	-2.083	-	-	+	11

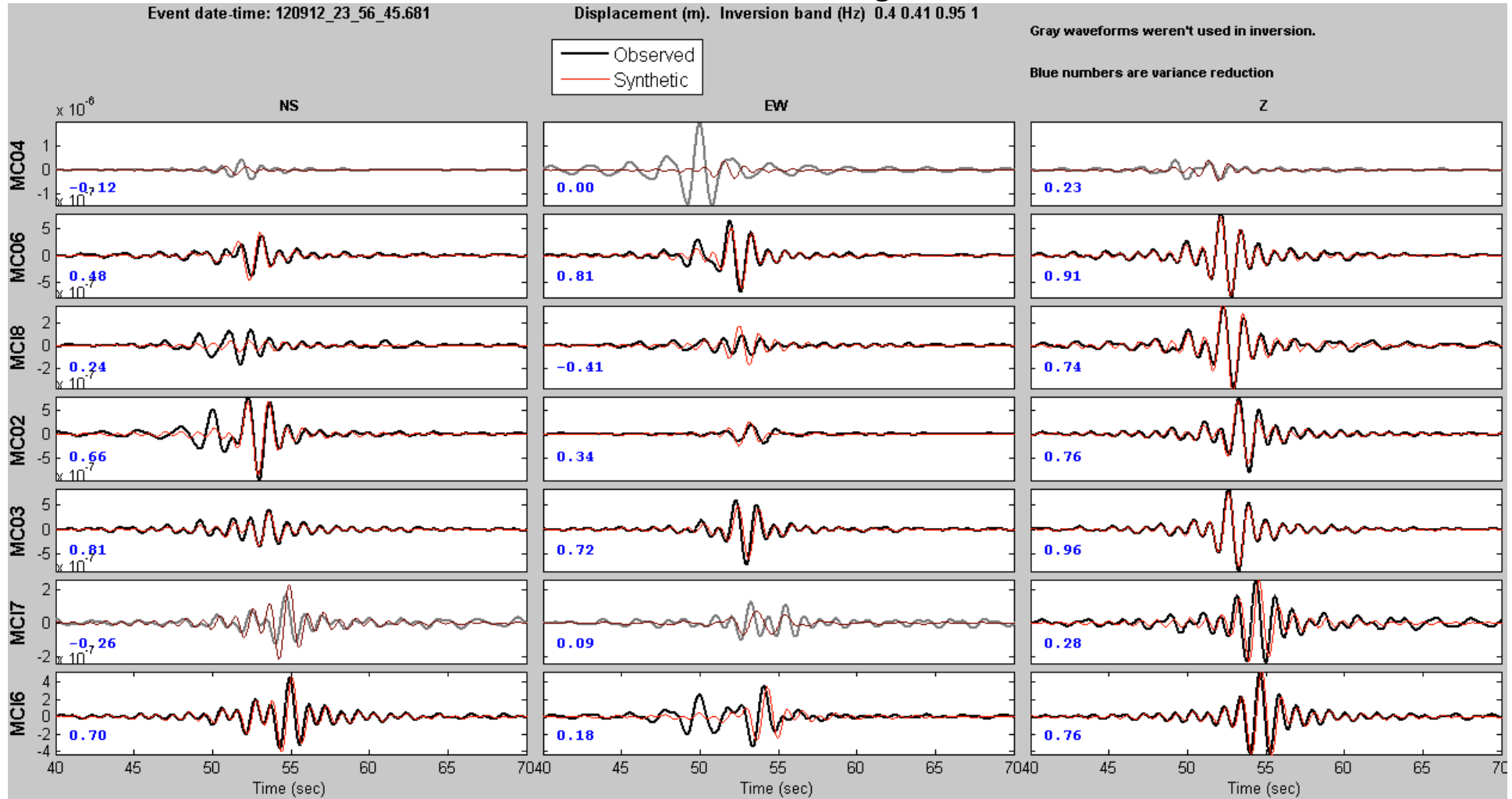
<b>Mrt</b>	<b>Mrp</b>	<b>Mtp</b>	<b>NS</b>	<b>EW</b>	<b>Z</b>	<b>D(km)</b>
2.441	-1.230	1.441	+	+	+	11

Exponent (Nm): 12



# Inversion Results

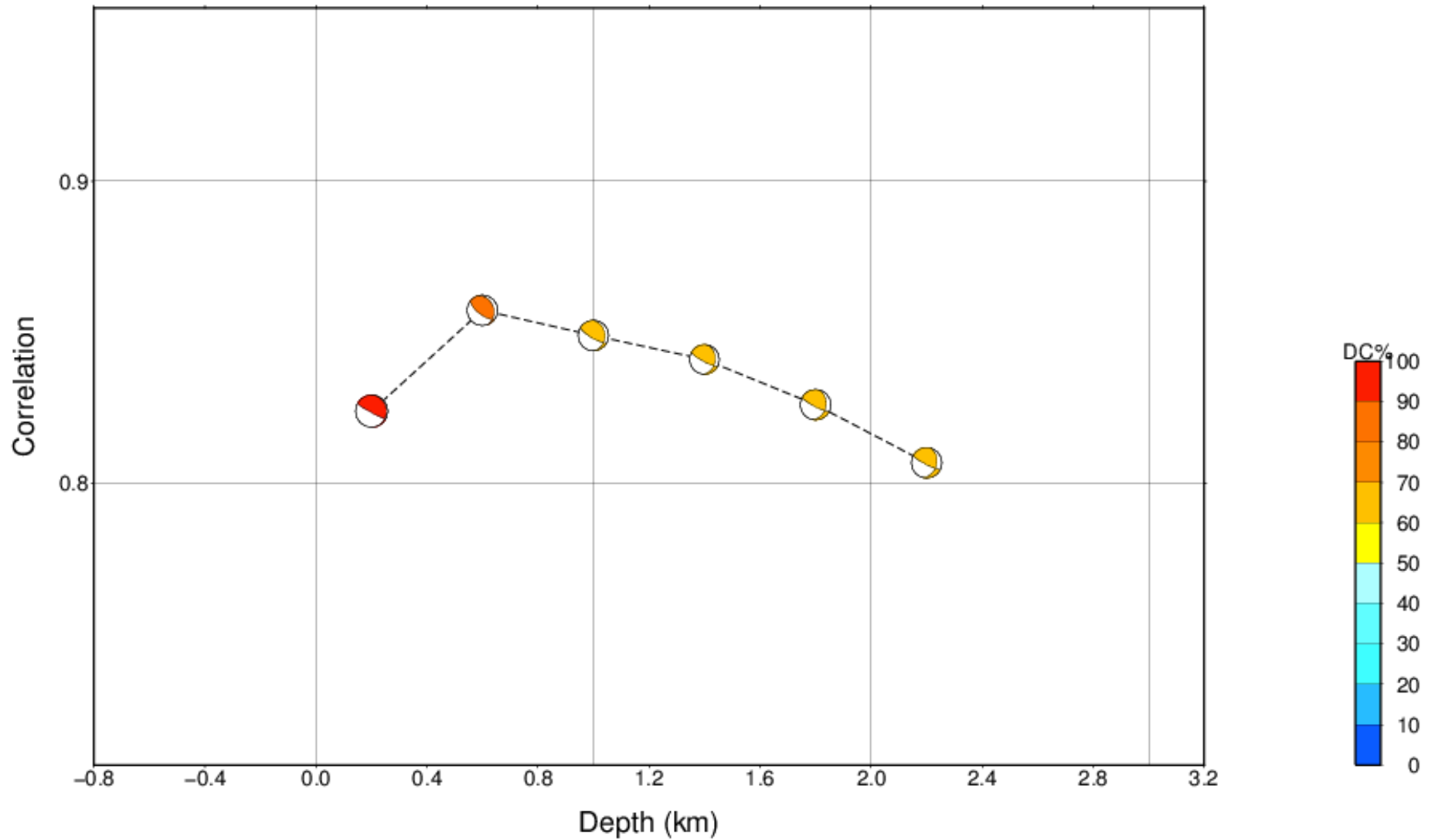
## Waveforms fitting



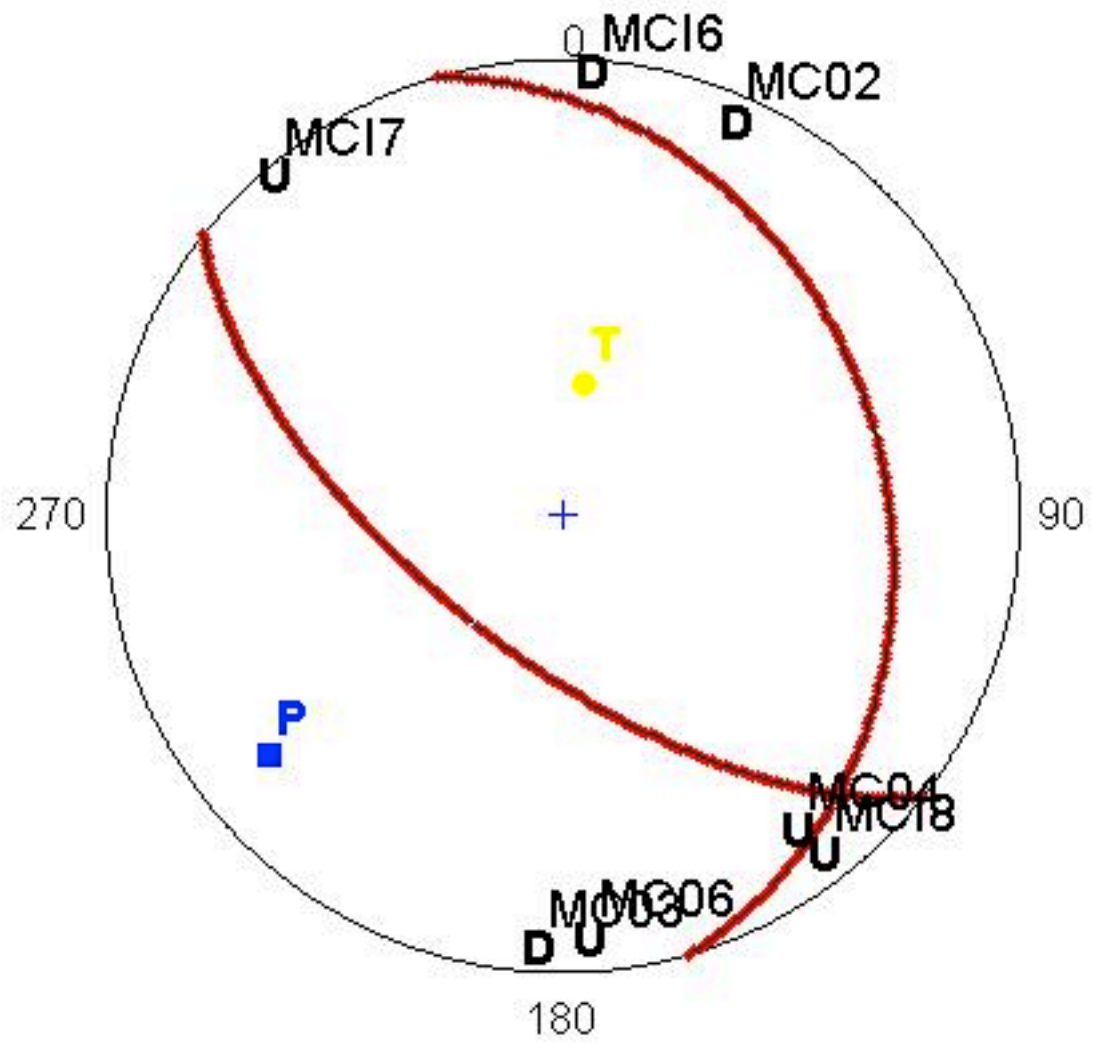


# Inversion Results

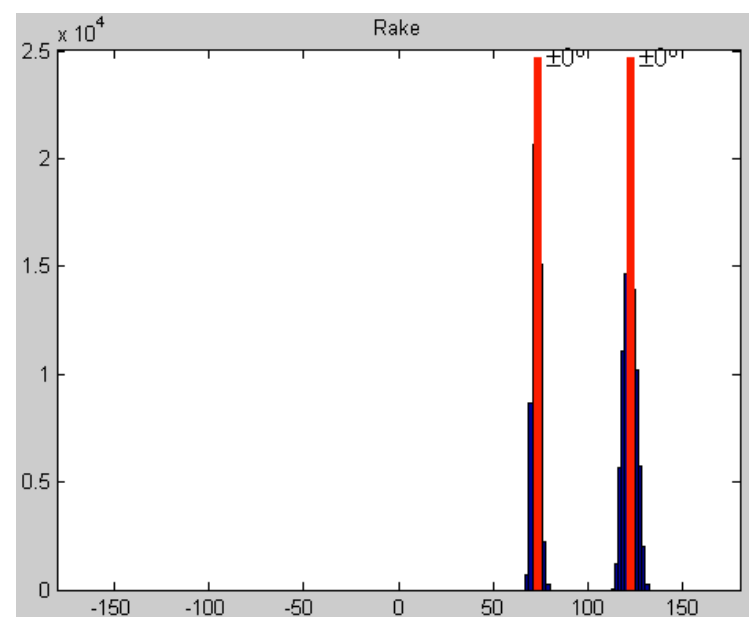
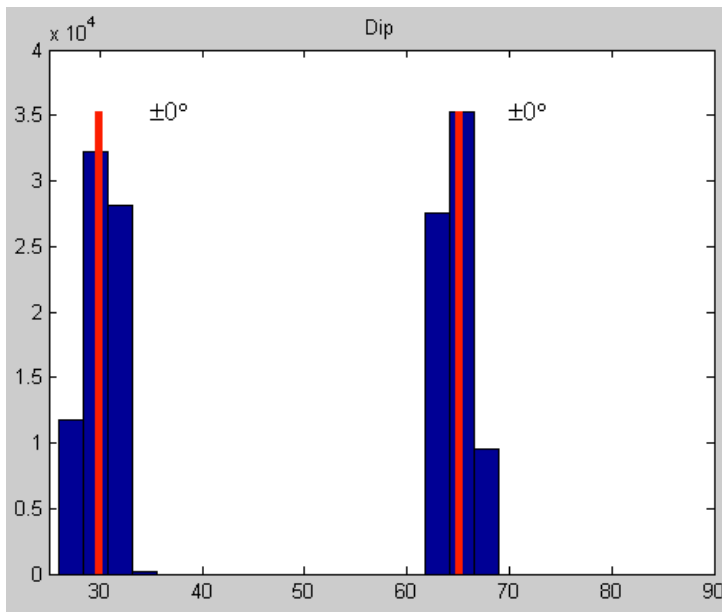
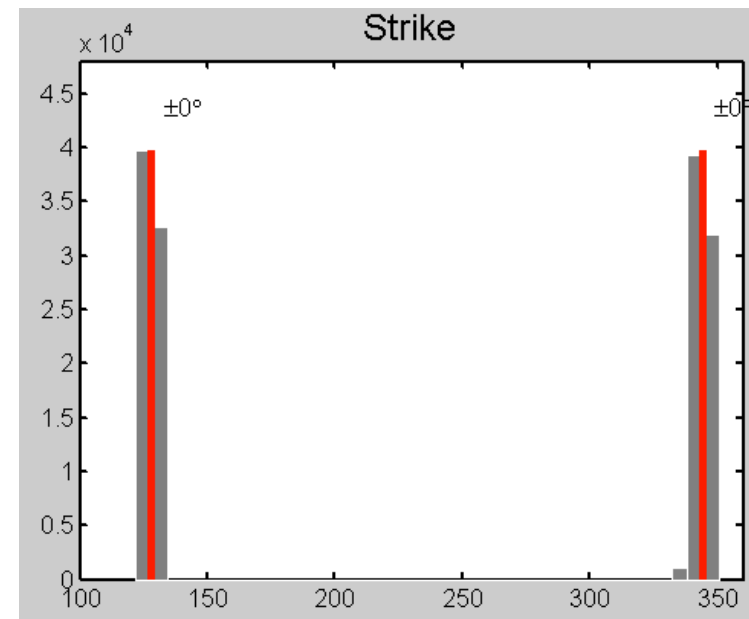
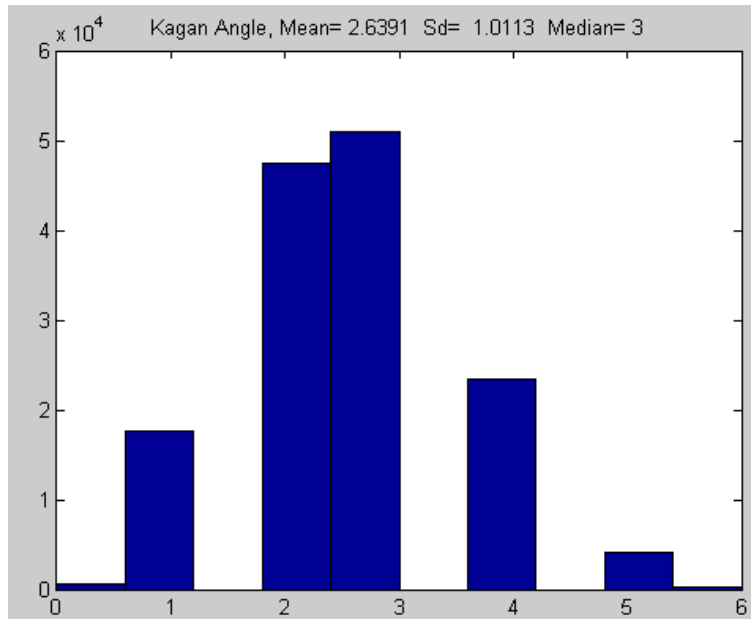
Correlation vs Depth Plot



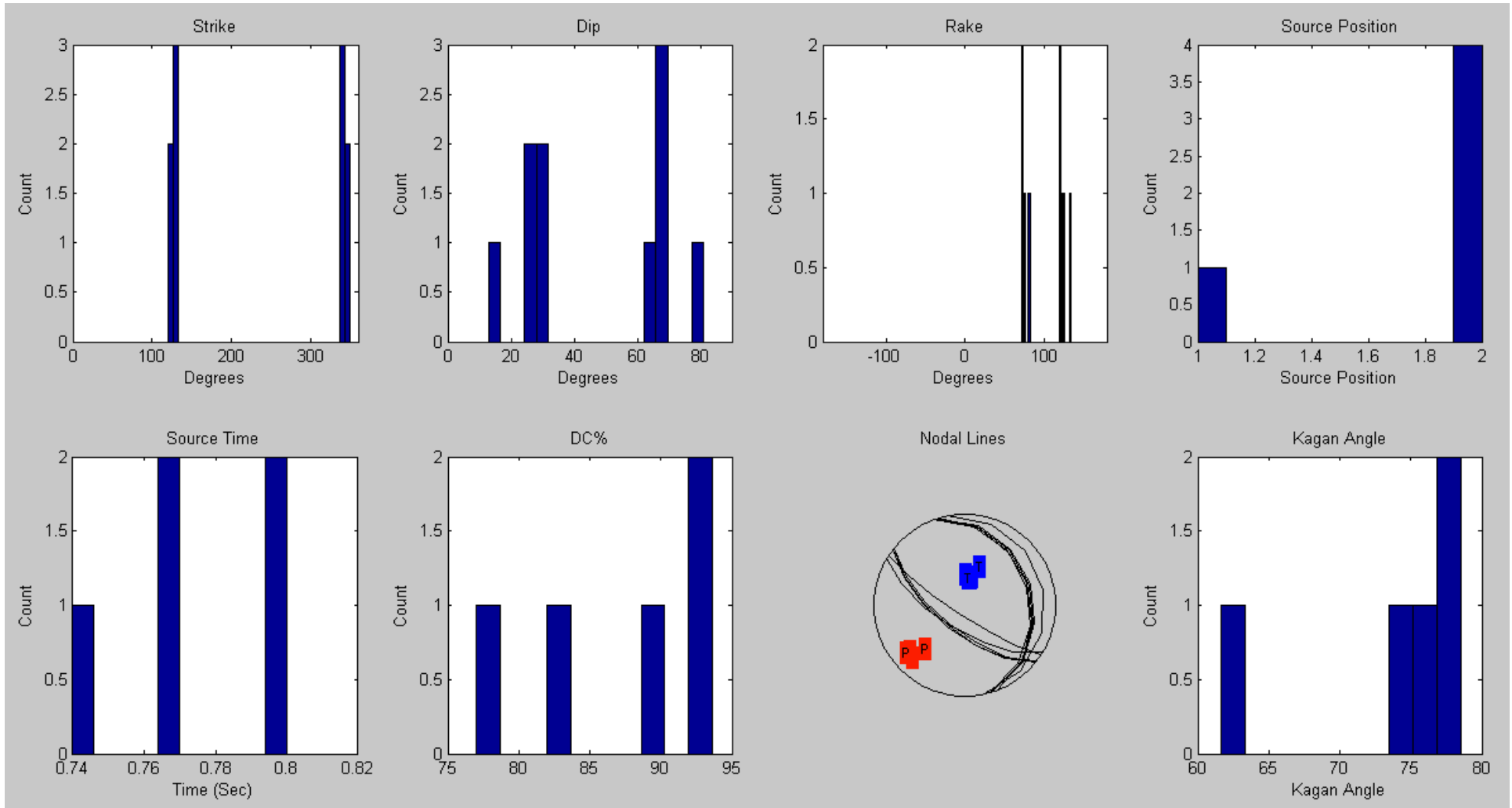
# Polarities check



# Some statistical tests...uncertainty estimation

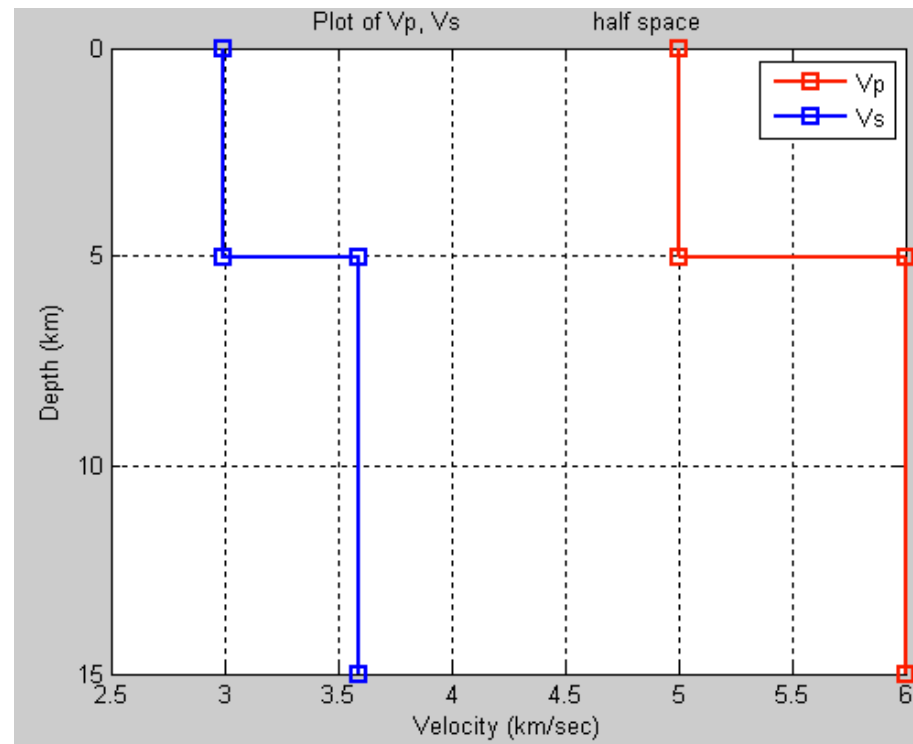


# Some statistical tests...Jackknifing



# Testing the importance of the velocity model

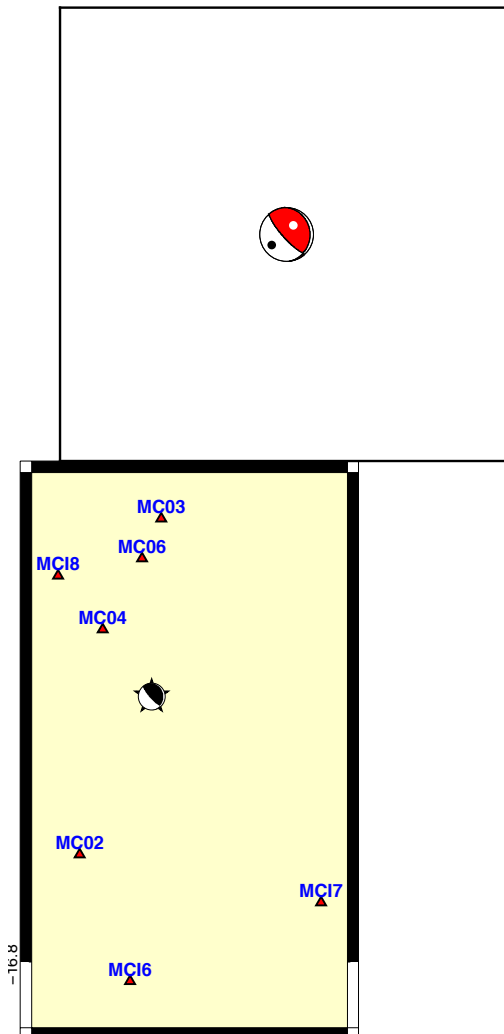
Using a simpler velocity model...



# Testing the importance of the velocity model

...we get different results:

- lower variance reduction
- different magnitude and centroid depth
- slightly different focal mechanism



## MOMENT TENSOR SOLUTION

### HYPOCENTER LOCATION (IAG)

Origin time 20120912 23:56:45.681  
 Lat -16.7036 Lon -43.8851 Depth 1.224

### CENTROID

Trial source number : 1 (Fixed Epicenter inversion)  
 Centroid Lat (N)-16.7036 Lon (E)-43.8851  
 Centroid Depth (km) : 0.2  
 Centroid time : +0.56 (sec) relative to origin time

Moment (Nm) : 4.784e+012

Mw : 2.4

VOL% : 0

DC% : 99

CLVD% : 1

Var.red.:(for stations used in inversion):0.32 SNR 49 CN 4.4 FMVAR 21±13 STVAR 0.10

Var.red.(for all stations) :0.32

Strike	Dip	Rake	Frequency band used in inversion (Hz)
138	78	81	0.4 - 0.41 -- 0.95 - 1
355	15	126	

Strike	Dip	Rake
138	78	81
355	15	126

P-axis Azimuth Plunge

235 32

T-axis Azimuth Plunge

37 56

Mrr	Mtt	Mpp
1.949	-0.162	-1.787
Mrt	Mrp	Mtp
3.007	-3.093	0.874

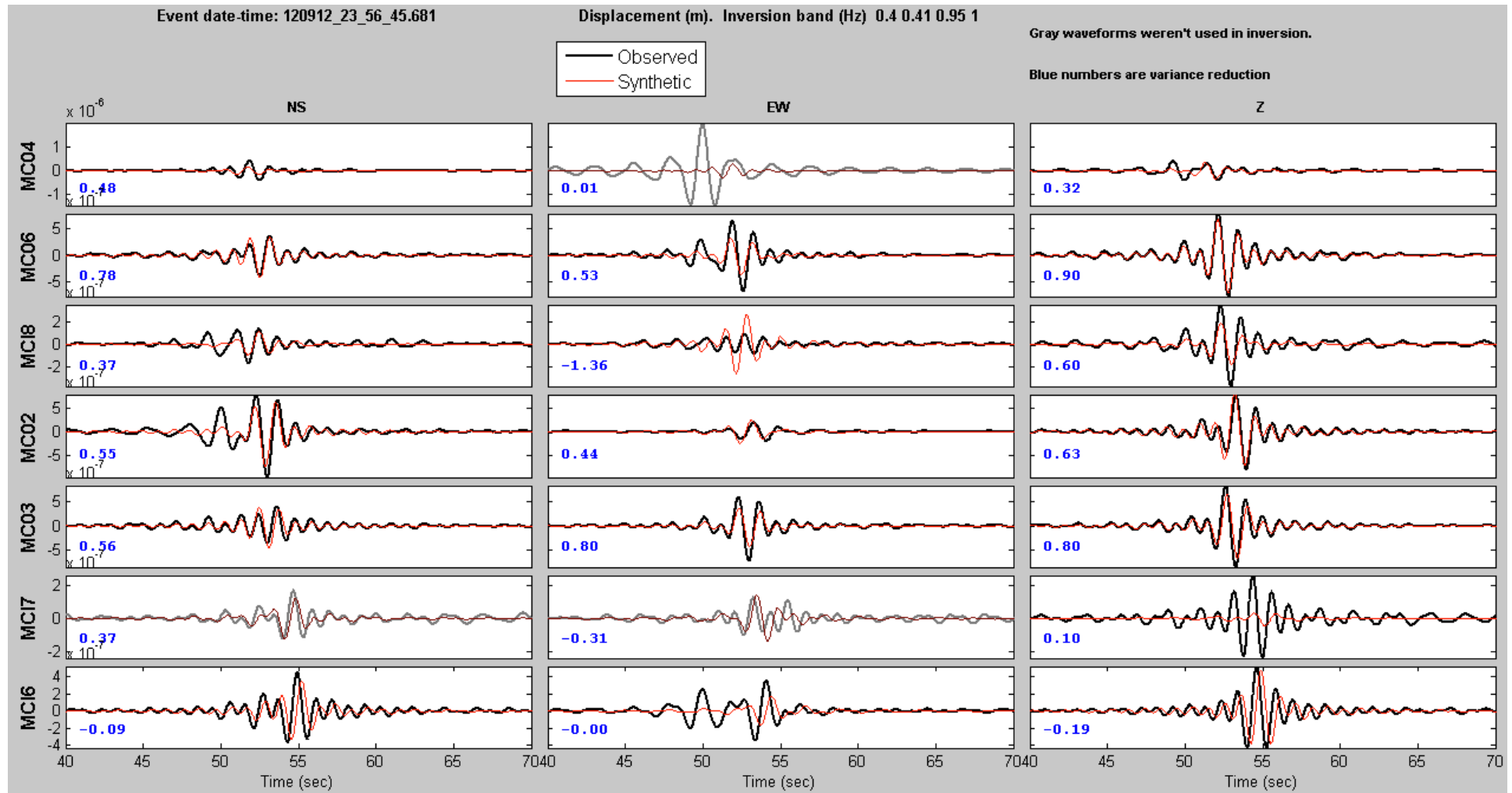
Exponent (Nm): 12

Stations-Components Used-Distance

NS	EW	Z	D(km)
+	-	+	3
+	+	+	6
+	+	+	6
+	+	+	7
+	+	+	7
-	-	+	11
+	+	+	11

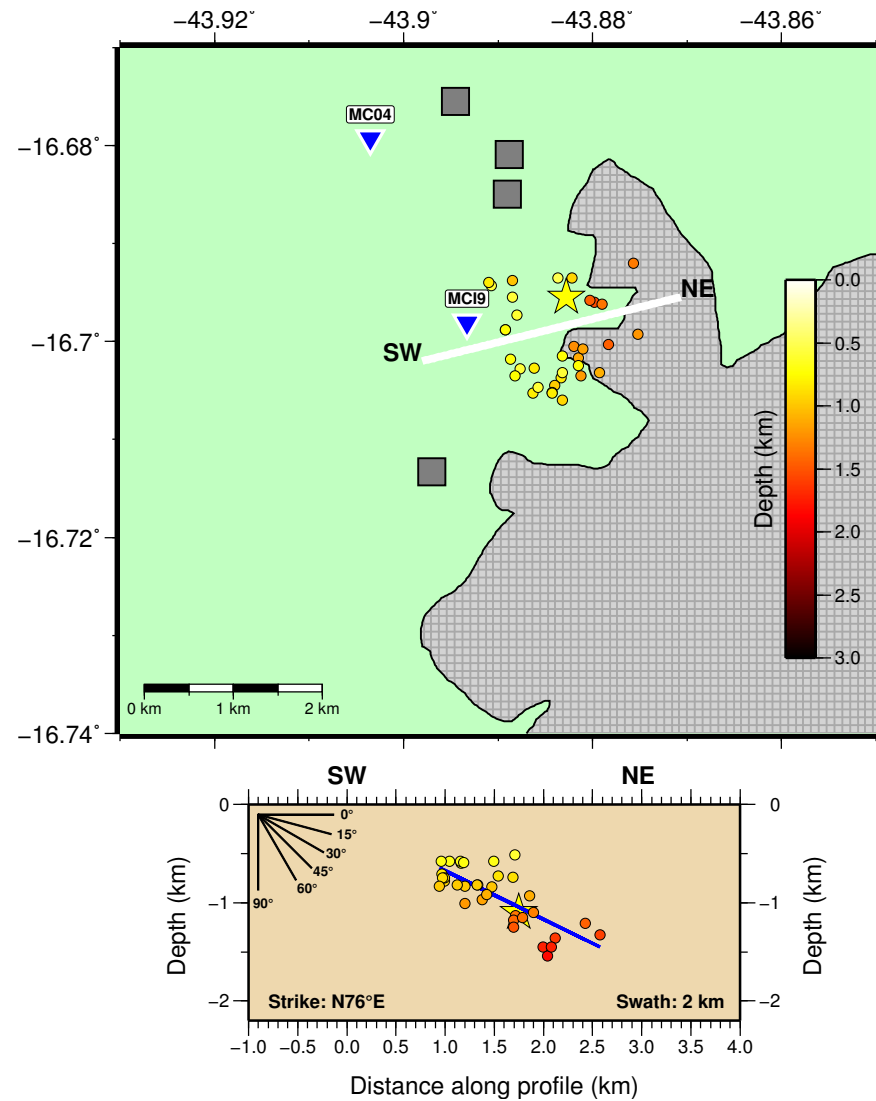
# Testing the importance of the velocity model

- slightly worse waveform fitting (still very good!)



# Discussion and Conclusion

Aftershocks distribution indicate NNW structure, dipping to the E, coinciding with one of the nodal planes of the obtained focal mechanism

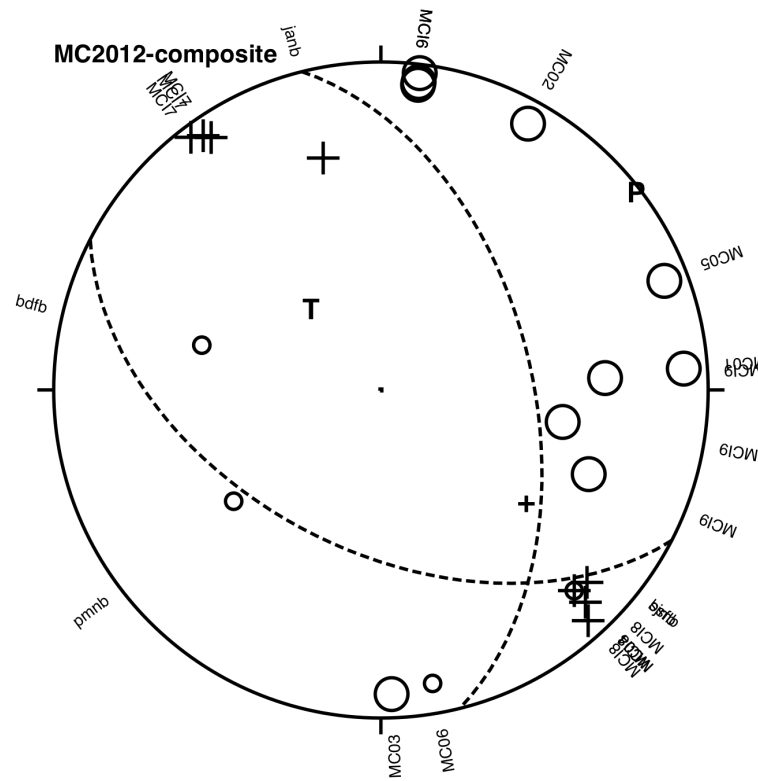


Agurto et al., 2014 (in prep)



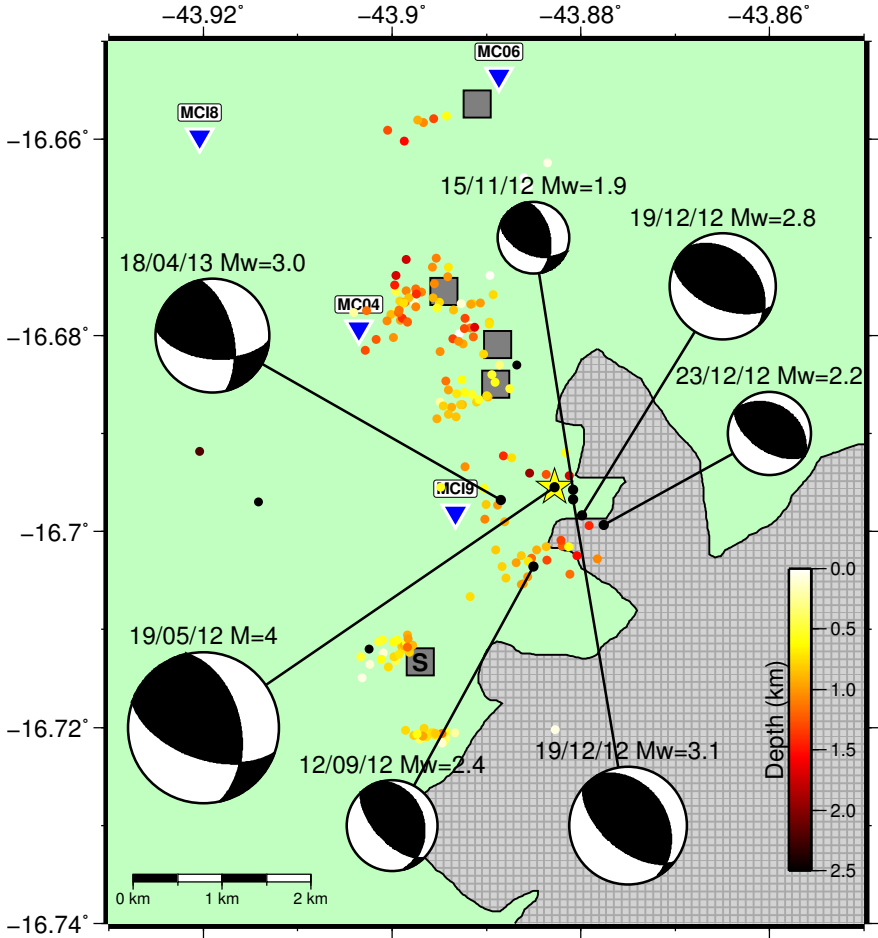
# Discussion and Conclusion

Mainshock composite focal mechanism from first motion polarities shows similar geometry...



# Discussion and Conclusion

Inversions performed on other aftershocks show consistency



## Discussion and Conclusion

- The 2012-2013 Montes Claros seismic sequence was originated on a previously unknown reverse fault NNW-striking, dipping to the E
- Inverted aftershocks moment magnitudes range 1.9 - 3.1  $M_W$ ; and suggest a relation  $M_W \approx M_R - 0.5$
- Successful usage of ISOLA software to determine moment tensor of local aftershocks down to  $M_W = 1.9$
- Detailed velocity model is an important (although not critical) aspect to consider, specially in cases of small earthquakes ( $M < 4$ ).