Preliminary report for Cuadrilla Resources 13/01/2012

Seismik

Outline

- Location of the event of August 2nd, 2011
- Mechanism of the event of August 2nd, 2011
- Event August 8th, 2011?
- Detection on regional stations
- Comparison of master events 01/04, 27/05, 02/08/2011
- Detection range from local stations AVH and HHF

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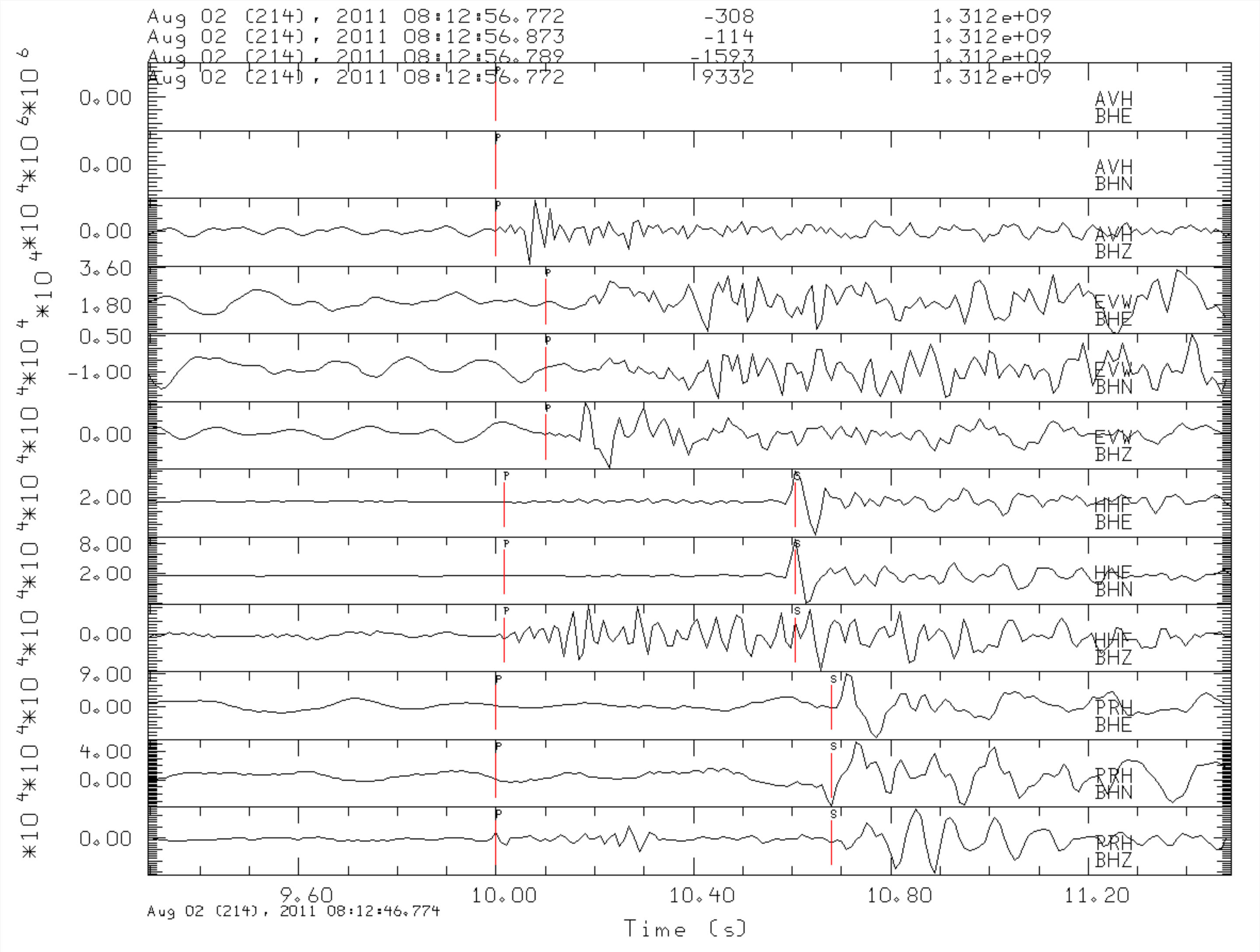
Location of the event 02/08/2011

Consistent picks

- Picks are consistent and RMS has fairly low value (~0.04)



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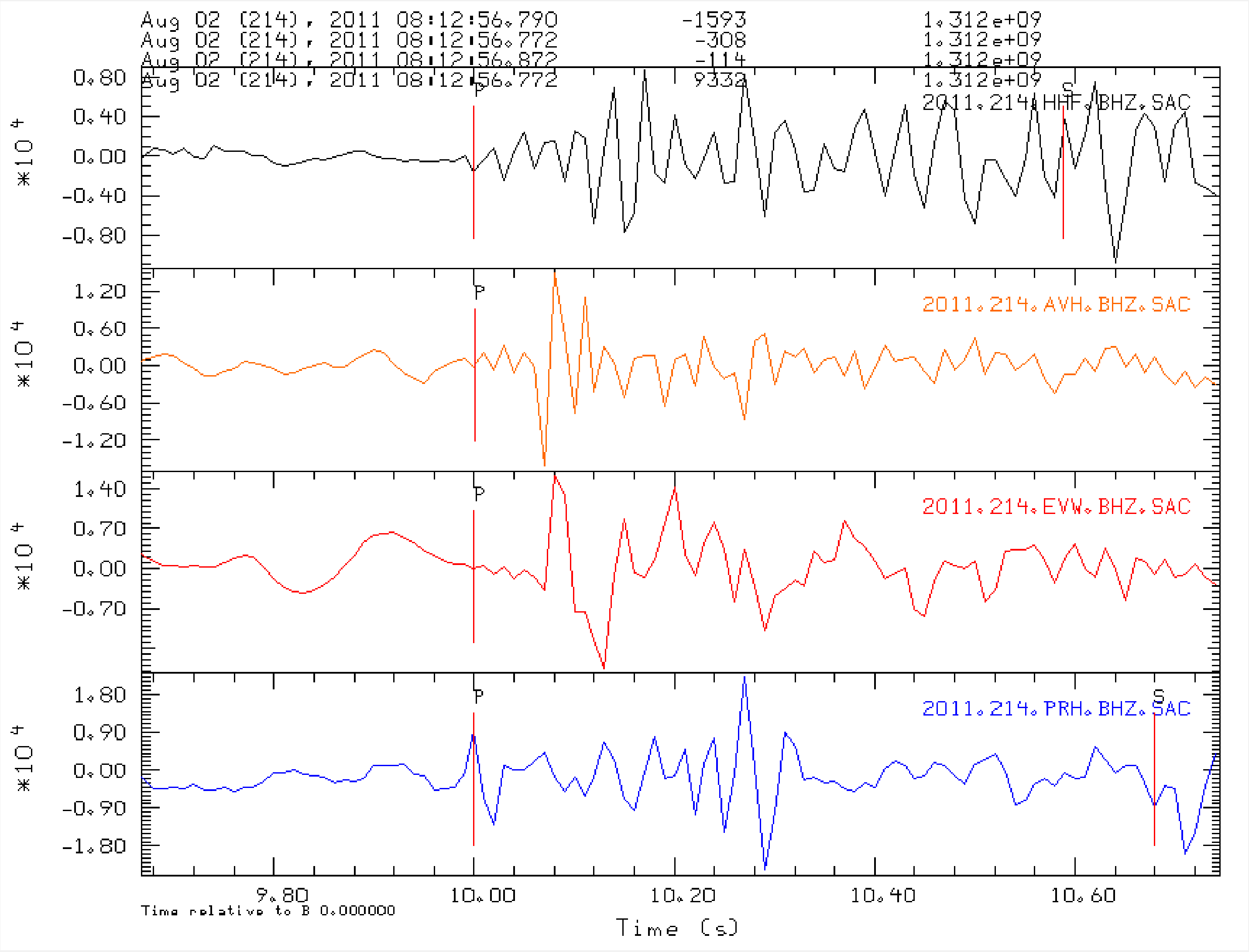
Consistent picks cross stations HHF, AVH, EVW and PRH

- Z comp. (P-wave) for event 2.8.2011 - HHF (black), AVH (orange), EVW (red), PRH (blue)



Location of event 02/08/2011

- Latitude 53.8225
- Longitude -2.9408

(WGS-84)

- Depth [km] 2.928

- RMS: 0.0407

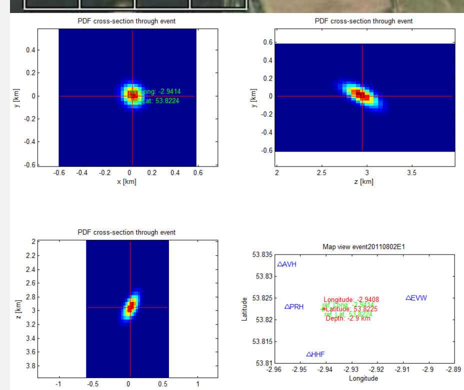
- PDF (ellipsoid of uncertainty)

main semi-axis	123 m
sec. semi-axis	108 m
azimuth of main semi-axis	140°
depth uncertainty	243 m

- Misfit [s]

AVH	HHF	EVW	PRH
0.049	0.045	0.017	0.073

- 4x P-wave and 2x S-wave
- Higher uncertainty at PRH station (geological heterogeneity)
- Layered isotropic velocity model



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Location of event 02/08/2011 with anisotropy of the wave propagation

- Greater delay between P and S arrival time on PRH can be possibly explained by the anisotropic medium (VTI type of anisotropy). Consistent with observed splitting

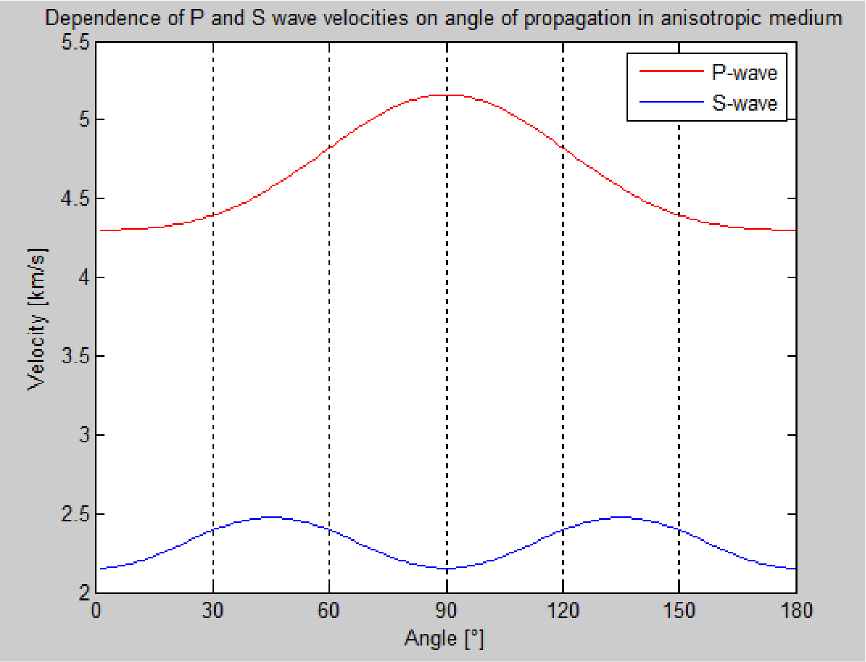
- No additional information on anisotropy strength

- We take guess for a typical shale VTI of effective coefficient:

  ε = 0.2 (i.e. approximately 20%)

  δ = 0.05

- RMS of location with anisotropy is slightly lower, event is located shallower and uncertainty is higher.



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Location of event 02/08/2011 with anisotropy of the wave propagation

- Latitude 53.8222
- Longitude -2.9425

(WGS-84)

- Depth [km] 2.933

- RMS: 0.0395

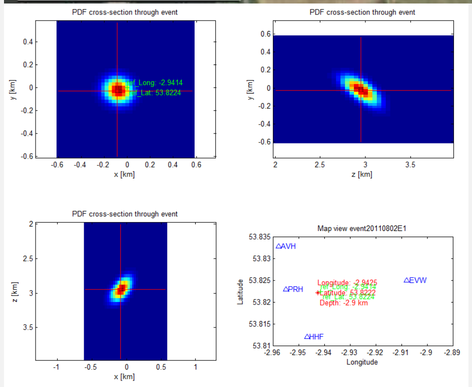
- PDF (ellipsoid of uncertainty)

main semi-axis	156 m
sec. semi-axis	139 m
azimuth of main semi-axis	150°
depth uncertainty	248 m

- Misfit [s]

AVH	HHF	EVW	PRH
0.048	0.041	0.016	0.071

- 4x P-wave and 2x S-wave
- Higher uncertainty at PRH station (geological heterogeneity)
- Layered anisotropic velocity model
- Anisotropy 20%

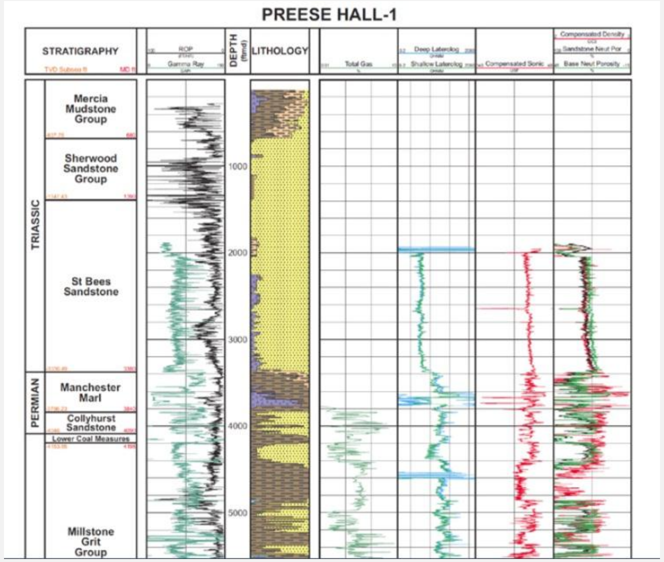


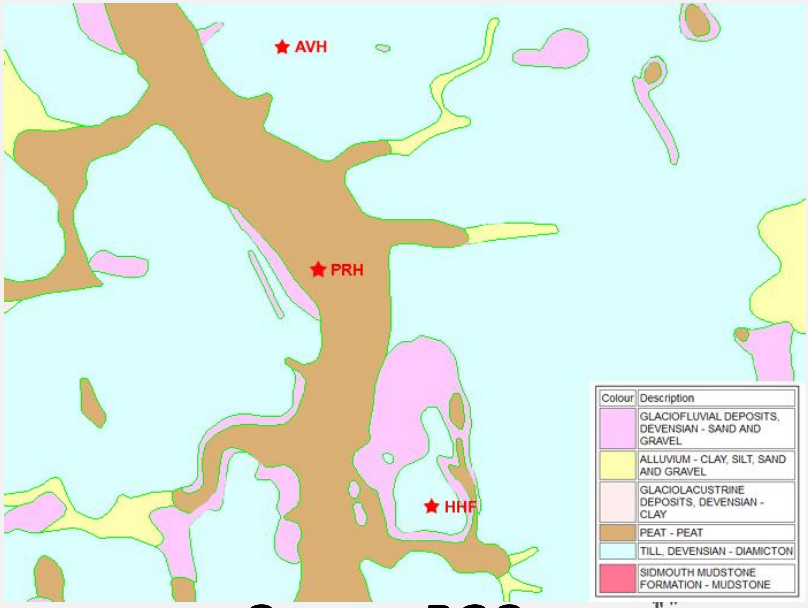
Location of event 02/08/2011
uncertainty of pick times on PRH station

- There is complicated geological situation. (unlikely simple layered isotropic or VTI medium)
- According to **geological maps and well log is there mudstone layer of** variable quality and thickness near surface. (It is below PRH and according to geological maps it is thinner below other stations)
- This layer has low wave propagation velocity and high Vp/Vs.

(*Reference:* CHANDLER, R J, BIRCH, N, and DAVIES, A G. 1968. Engineering properties of Keuper Marl. Construction Industry Research and Information Association Report, No. 13.)

- Due to this facts we decide to increase uncertainty of pick times on PRH station



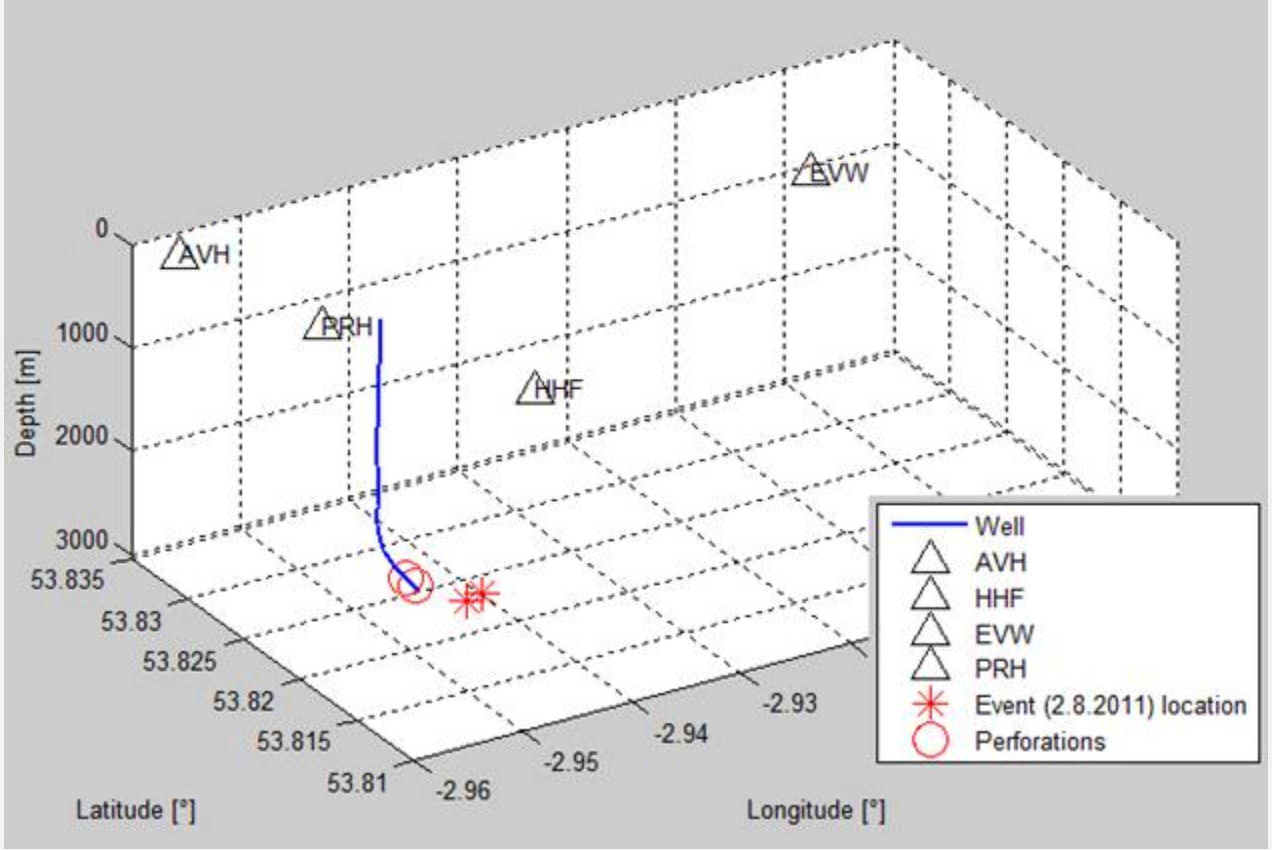


Source: BGS

Location of event 02/08/2011
Distance from the well

- Location of event 02/08/2011

	Distance from perforations [m]	Relative azimuth [degrees]
Location	400	86
Location with anizotropy 20%	300	90



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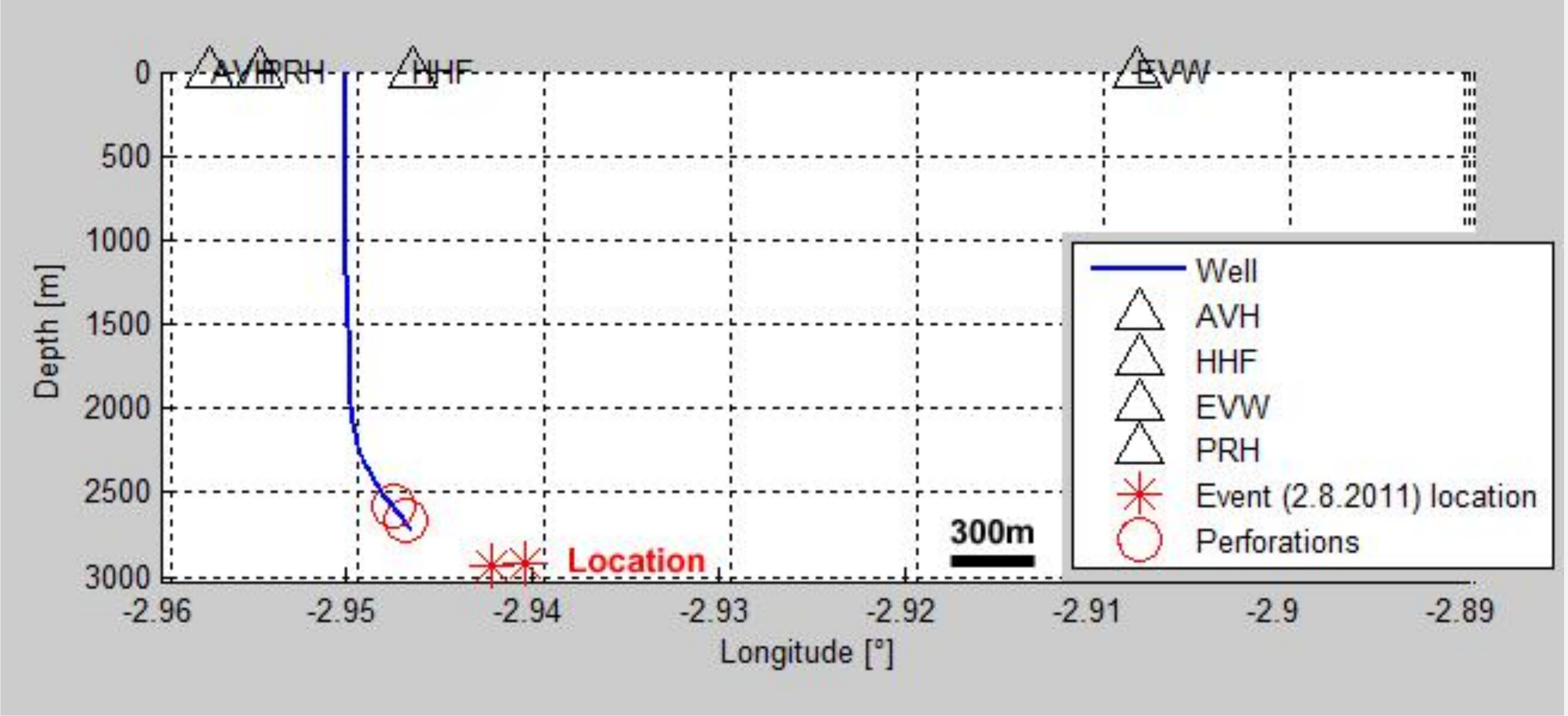
Location of event 02/08/2011
Distance from the well

- Location of event 02/08/2011

- Depth of events is 330-360m below perforations



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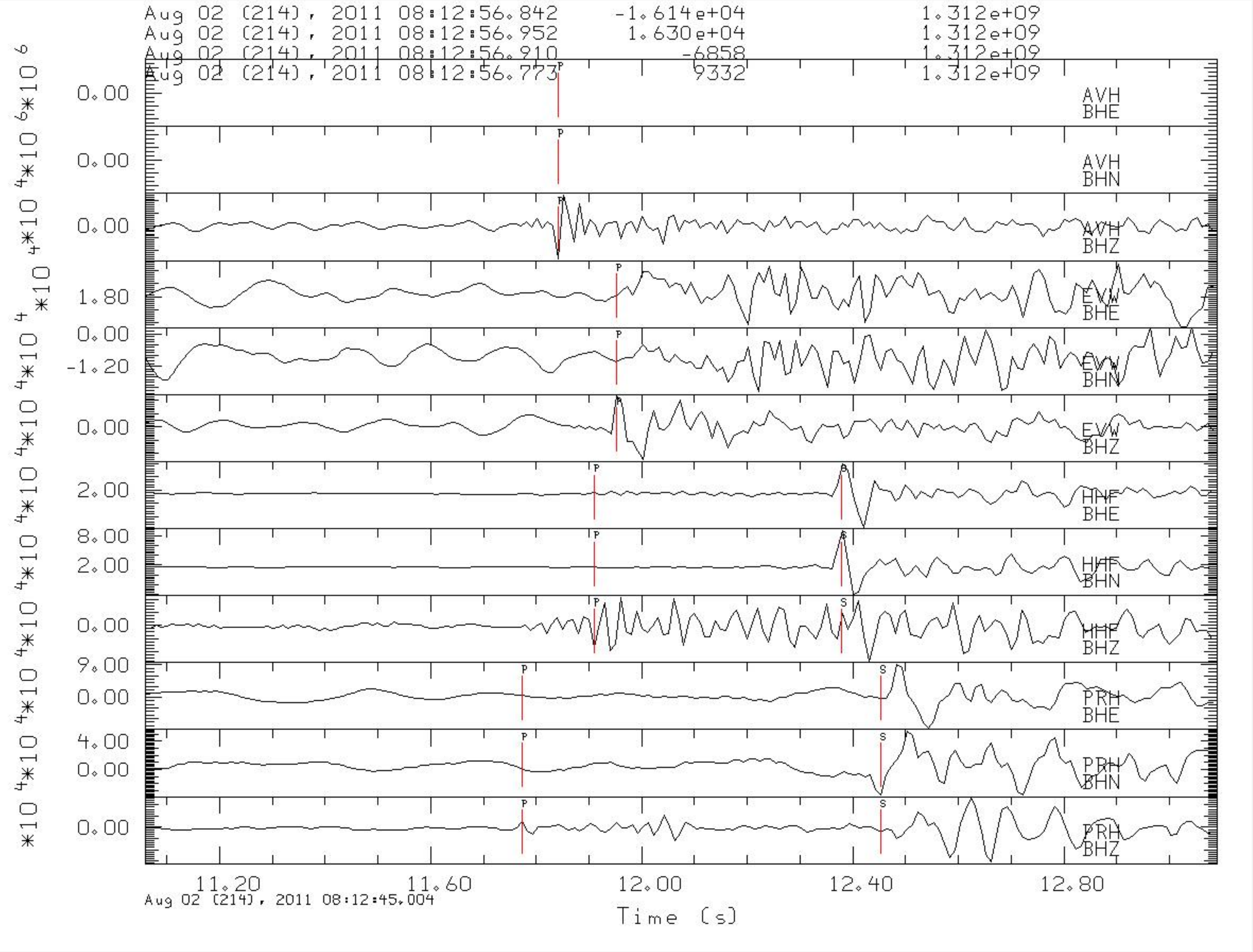
Location of event 02/08/2011 alternative picking

- Picks are consistent and RMS has value ~0.05



Location of event 02/08/2011 alternative picking results

	Lat (WGS-84)	Lon (WGS-84)	Depth [km]	RMS [s]
Alt. location	53.8219	-2.9399	2.593	0.052
Alt. location with anisotropy 20%	53.8216	-2.9410	2.569	0.050

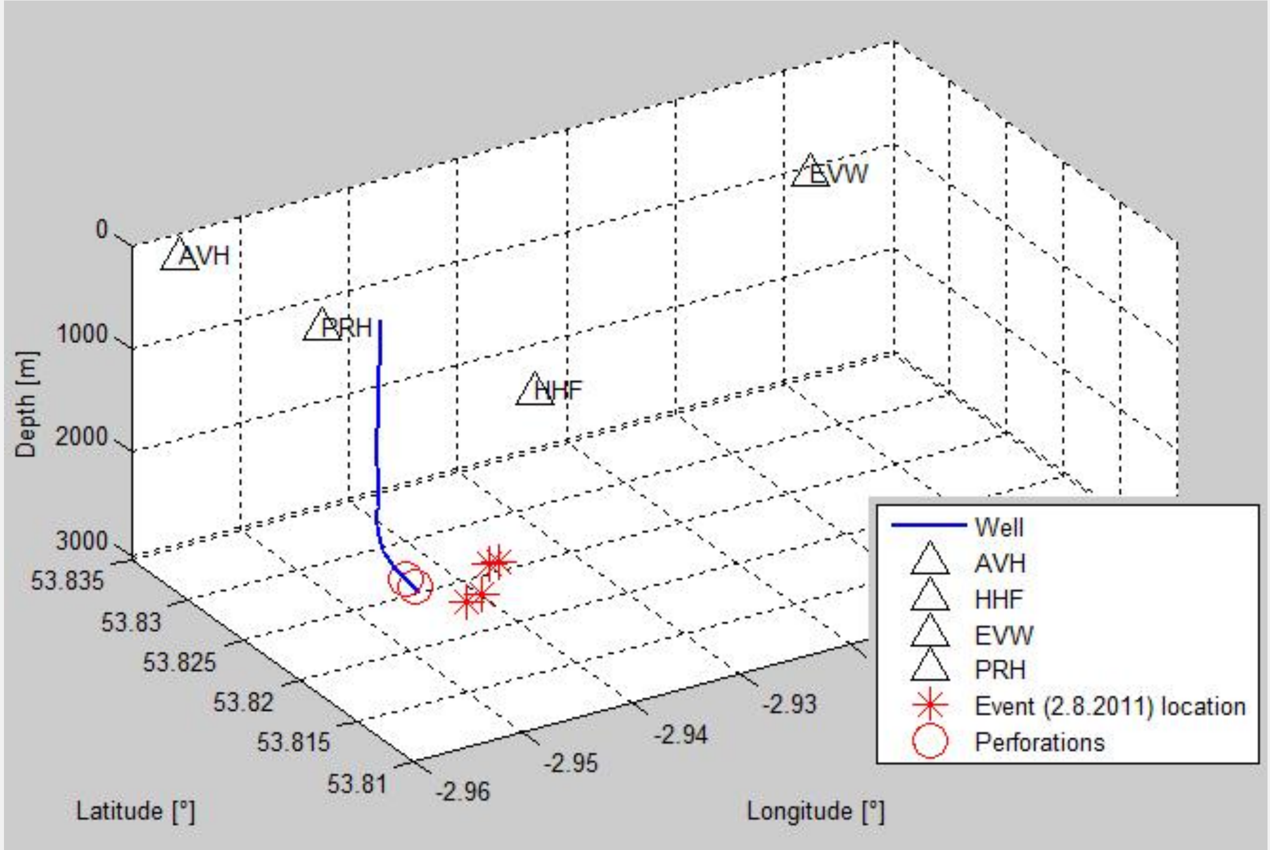
- There is more than one possible picking strategy. We believe, that strategy showed on previous slides is the best one, but there are some results of other possible picking strategy.

- Red – alternative location
- Green – alternative location with anisotropy 20%

Location of event 02/08/2011 alternative picking results – distance from the well

- **Alternative location of event 02/08/2011**

	Distance from perforations [m]	Relative azimuth [degrees]
Alternative location	470	94
Location with anizotropy 20%	400	100



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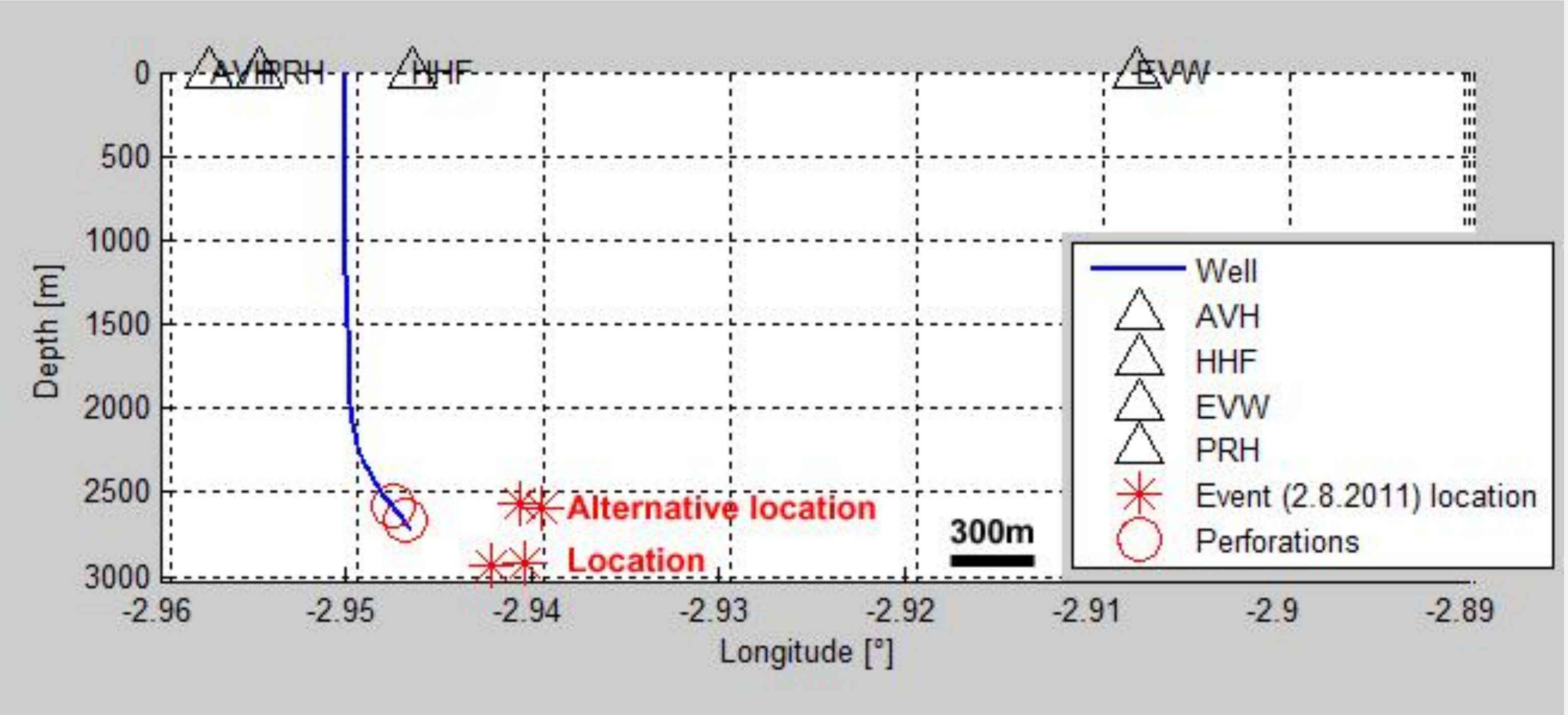
Location of event 02/08/2011
Distance from the well

- Alternative location of event 02/08/2011

- Depth of alternatively located events is exactly in the interval between the injection of 2nd and 4th stage



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Conclusions - location

- Location of event 02/08/2011 is in distance 300-500m (+/- 150 m) from the injection intervals of 2nd and 4th stage (to east).

- Depth of event is in range 2.5-3.0 km

- Relative azimuth from injection intervals to event is in range 85° to 100°

- The velocity model is most likely more complex than simple 1D isotropic layered model (arrivals on PRH)

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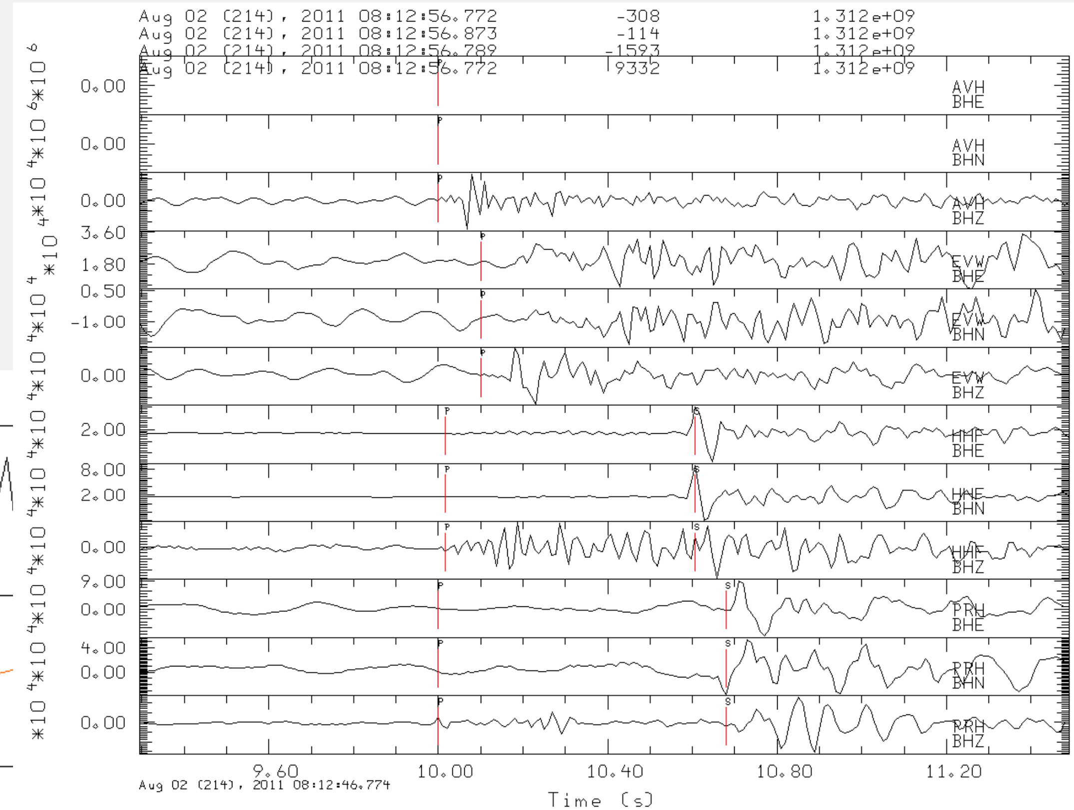
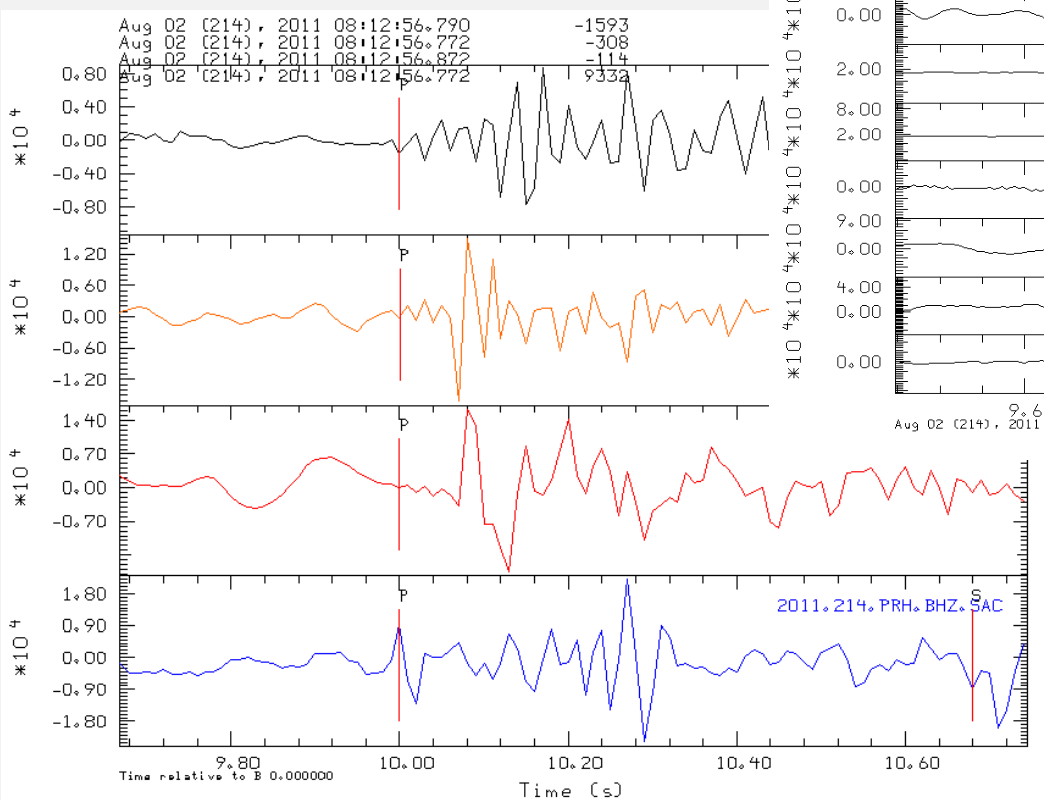
Mechanism of the event 02/08/2011

Mechanisms

S-wave picks – high confidence in polarity and amplitudes





P-wave picks – low confidence in polarity and amplitudes

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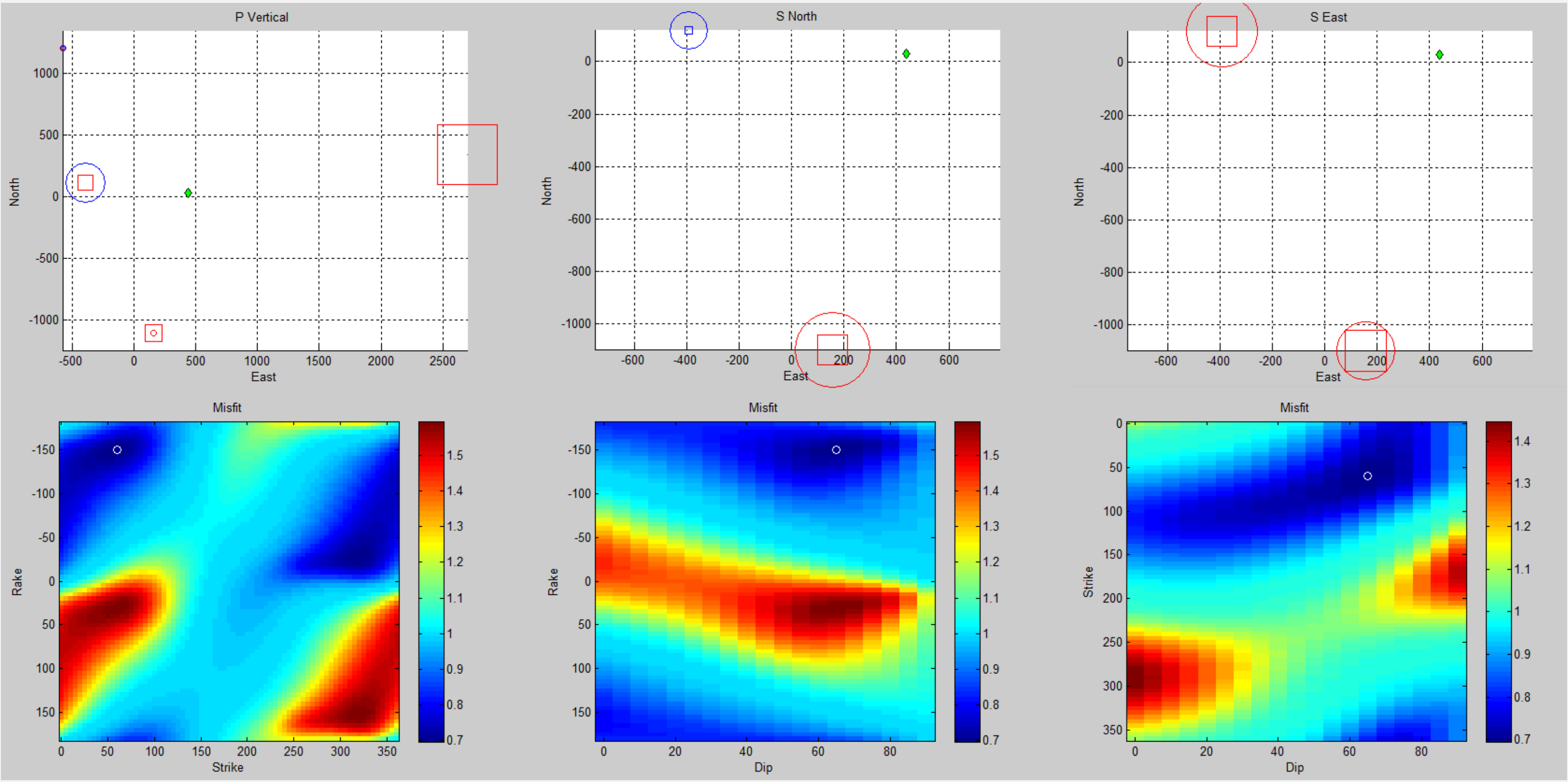
Mechanism of event 02/08/2011

- **The P-wave picks are not well explained by the inverted mechanism but provide at least relative ratio between P and S waves is.**
- Steeply dipping fault planes, however uncertainty is at least 20° for dip, strike and rake



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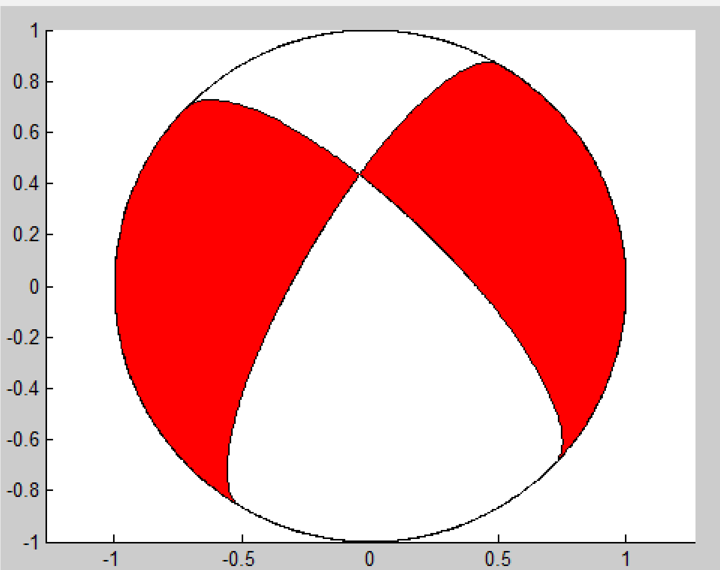
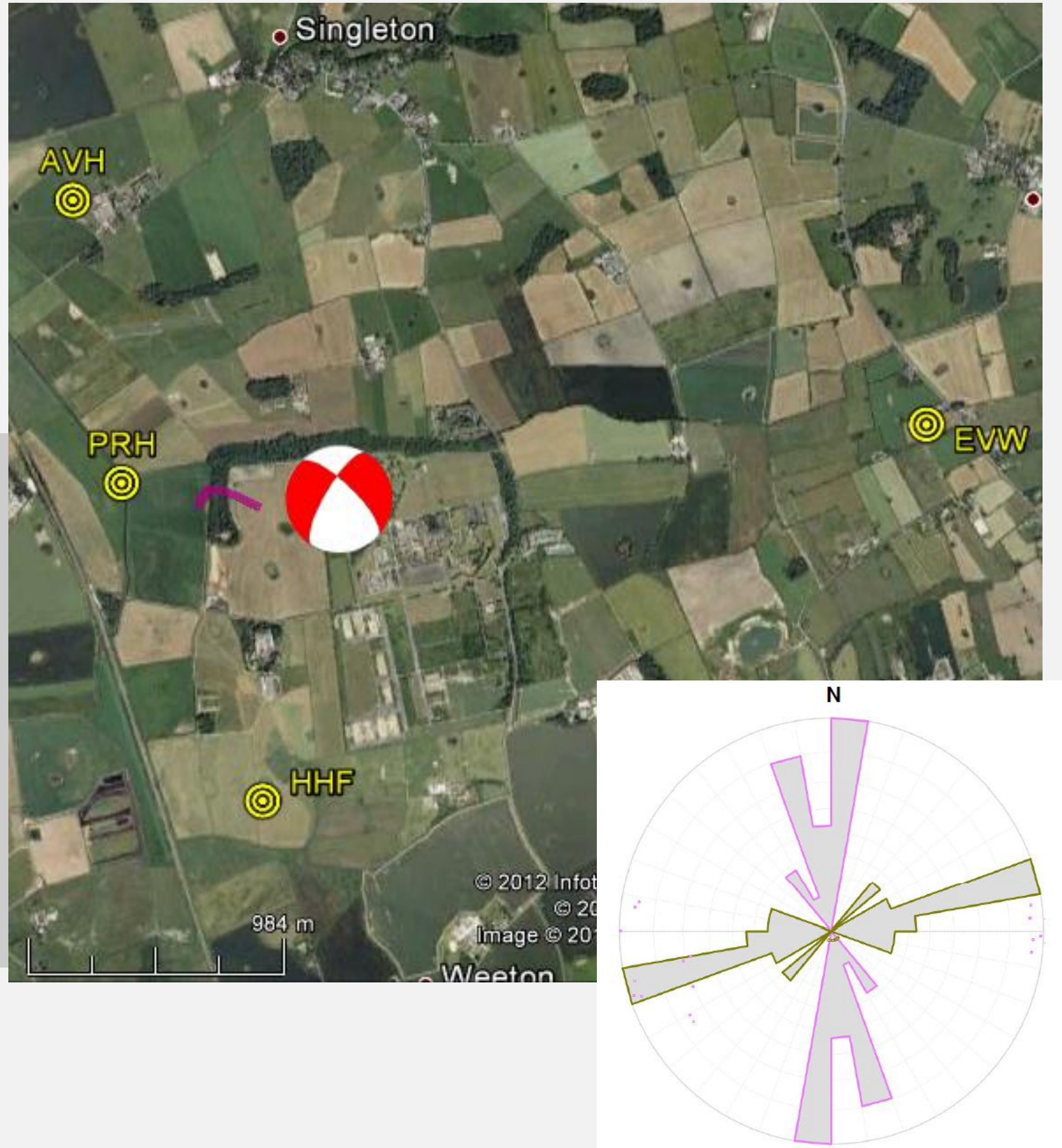
Mechanism of event 02/08/2011 - results

	Dip	Strike	Rake
Plane 1	63	316	-28
Plane 2	65	60	-150





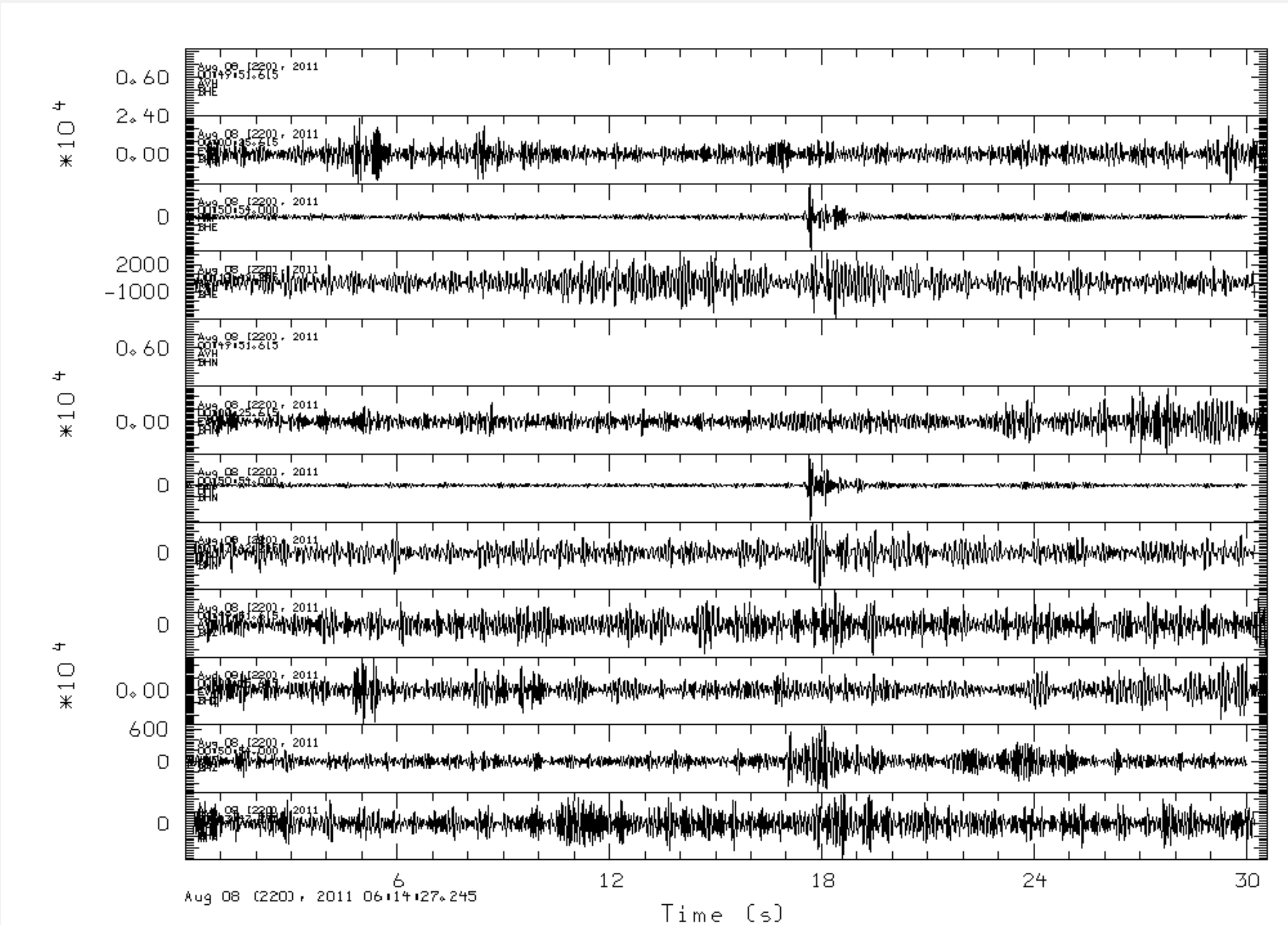
Conclusions
– mechanism of event 02/08/2011

- Focal mechanism of the event 02/08/2011 is transitional mechanism between strike-slip and normal fault.
- Dip is about 65°
- Strike is about 60°
- There is some uncertainty of the determination of mechanism

Event of 8/8/2011

False event found on HHF 08/08/2011 6:14:42   M=-1.0

- Is NOT present on other stations AVH, EVW, PRH. Picture sorted by cmp, stat
- Attempts to find it on PRH using 02/08/2011 8:12:55 as a master weren't successful
- **BUT: IS NOT THIS BECAUSE OF THE NOISE ON PRH?**



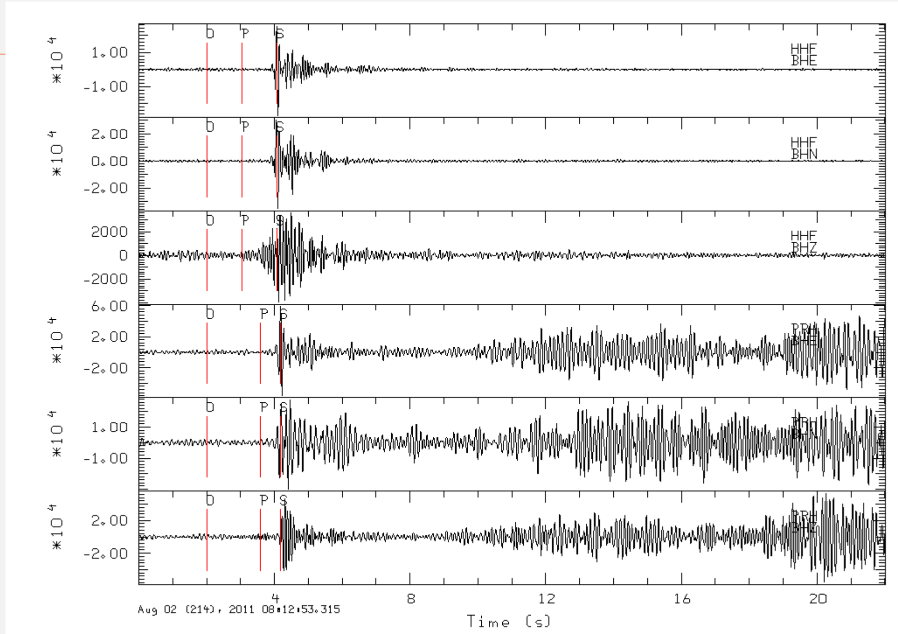
Seismik

False event found on HHF 08/08/2011 6:14:42   M=-1.0

02/08

HHF

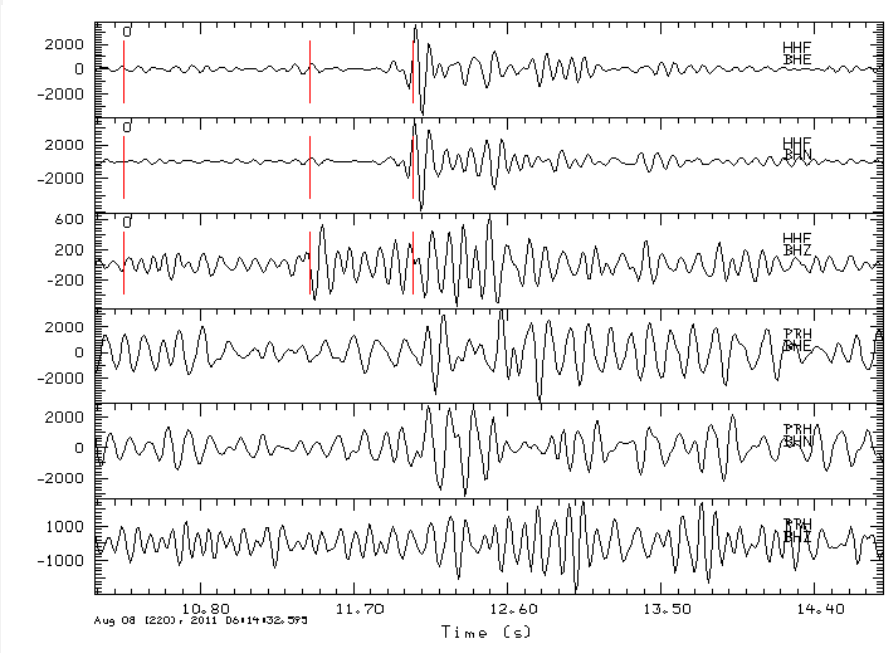
PRH



08/08

HHF

PRH



HHF		E	N	Z
02/08	signal	15000	20000	3000
08/08	signal	3000	4000	500
	signal ratio	0.2	0.2	0.167

PRH		E	N	Z
02/08	signal	30000	20000	30000
08/08	signal	3000	2500	2000
	expected signal	6000	4000	5000

Conclusion: false candidate

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Detection on regional stations

- Network detection using stations KESW, GAL1, WLF1, FOEL
- Control detection on days 26-27/05/2011
  - 6 events with M>0 found
- Detection on period 01/06-30/09/2011
  - 0 events found
- Detection on period 01/01-31/12/2010
  - 0 events found

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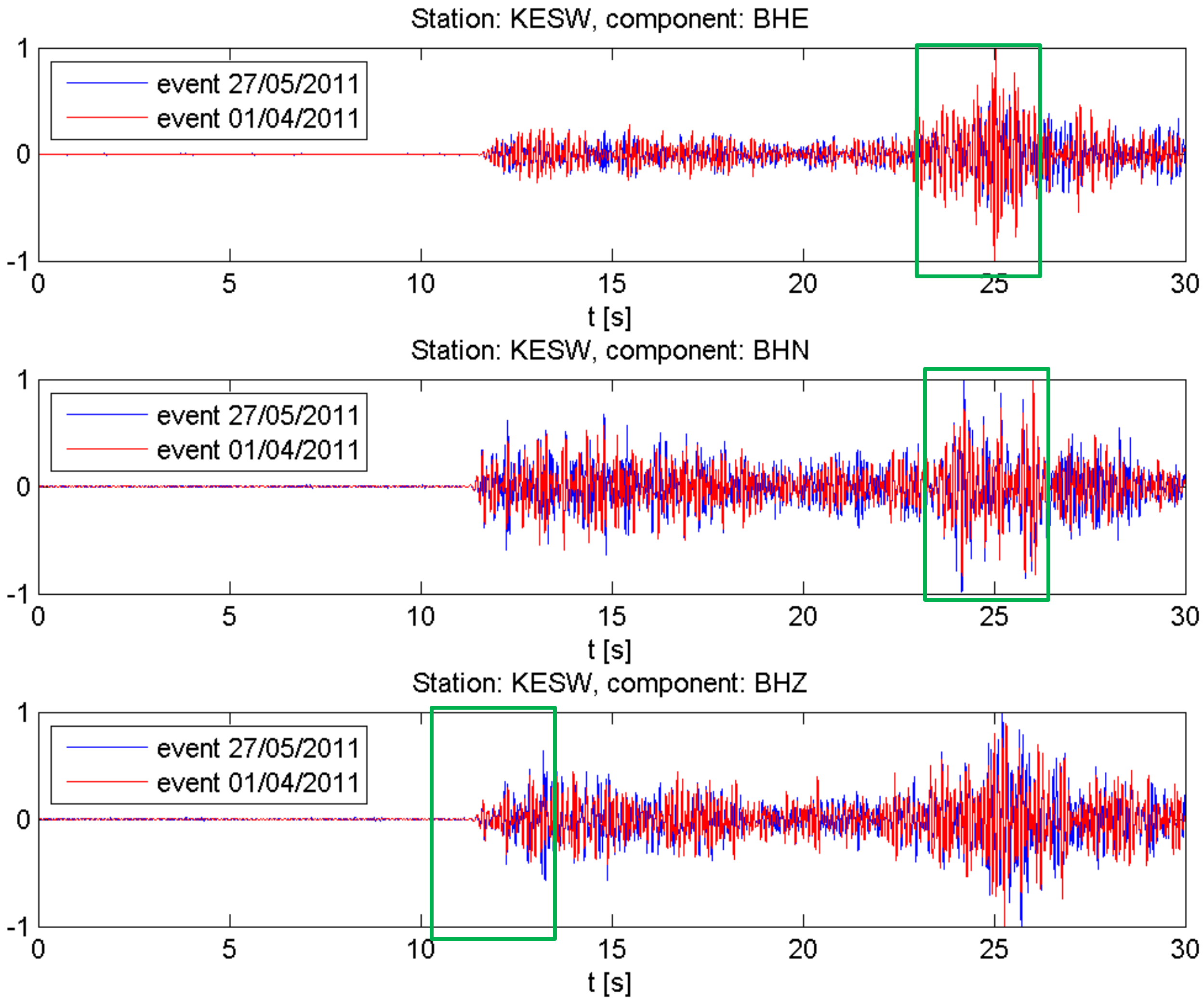
Comparing events

01/04/2011 vs 27/05/2011 on regional stations
27/05/2011 vs 02/08/2011 on local stations

- The aim – to show relationship between felt events of 01/04/2011 and 27/05/2011 and weak event of 02/08/2011
- We want to find events similar to the strongest ones (01/04/2011, 27/05/2011) using local stations
- But
  - on 01/04/2011 only data from regional stations are available
  - on 27/05/2011 only data from regional stations and HHF and AVH are available, AVH with vertical component only
  - on 02/08/2011 other local stations are available

- Are the waveforms similar?
  - Seismograms overlaid over the main S waveform
- Is there a difference in S-P?
  - Visual comparison of shift in P wave arrival
- If the events have similar waveforms, with no significant S-P difference than the 02/08 event can be used as a master

Waveforms KESW 01/04 vs 27/05/2011



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Synchronized on S-pick, waveforms start 25 seconds before S-pick

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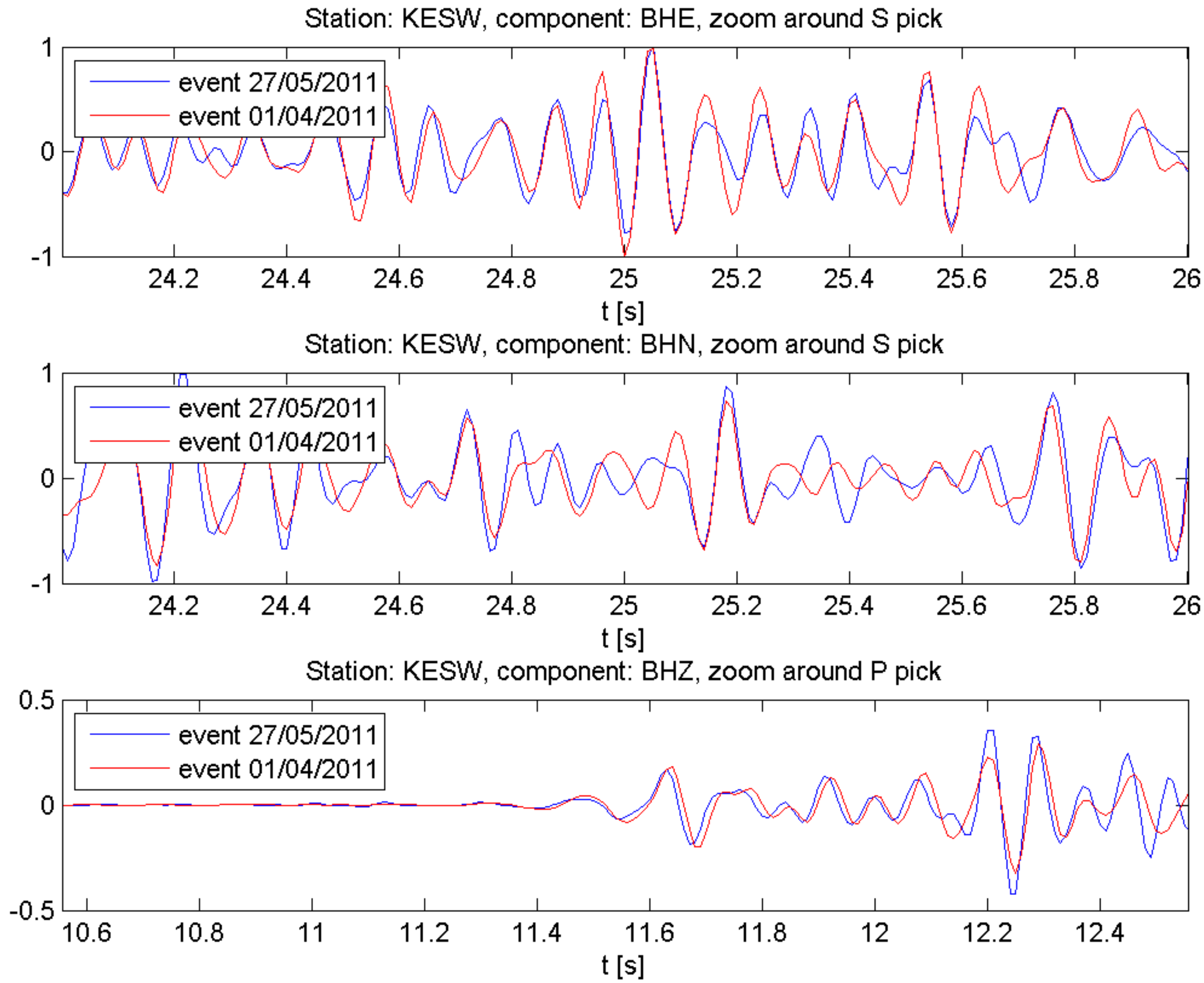
Waveforms KESW 01/04 vs 27/05/2011



Synchronized on S-pick, waveforms start 25 seconds before S-pick

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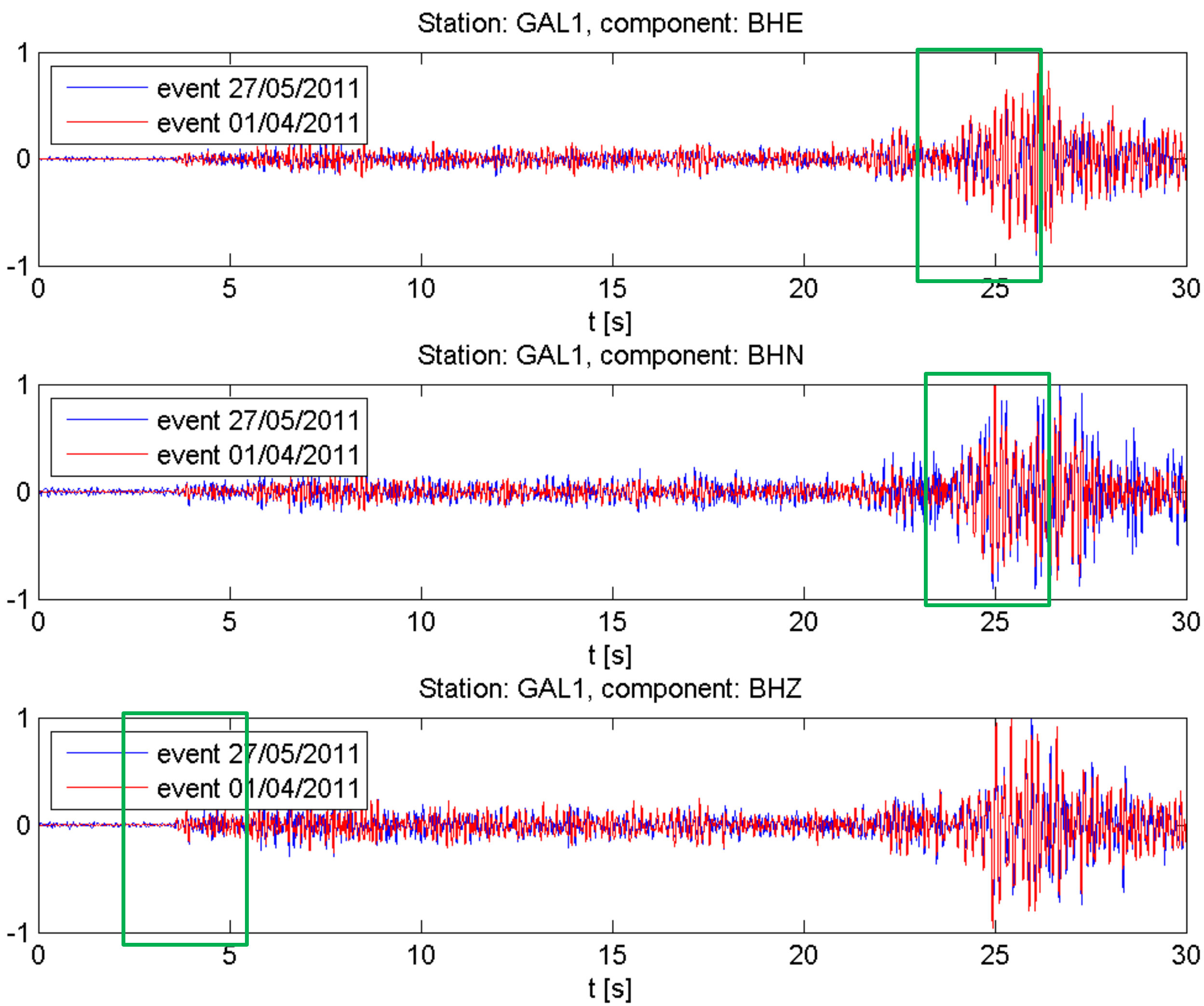
Waveforms GAL1 01/04 vs 27/05/2011



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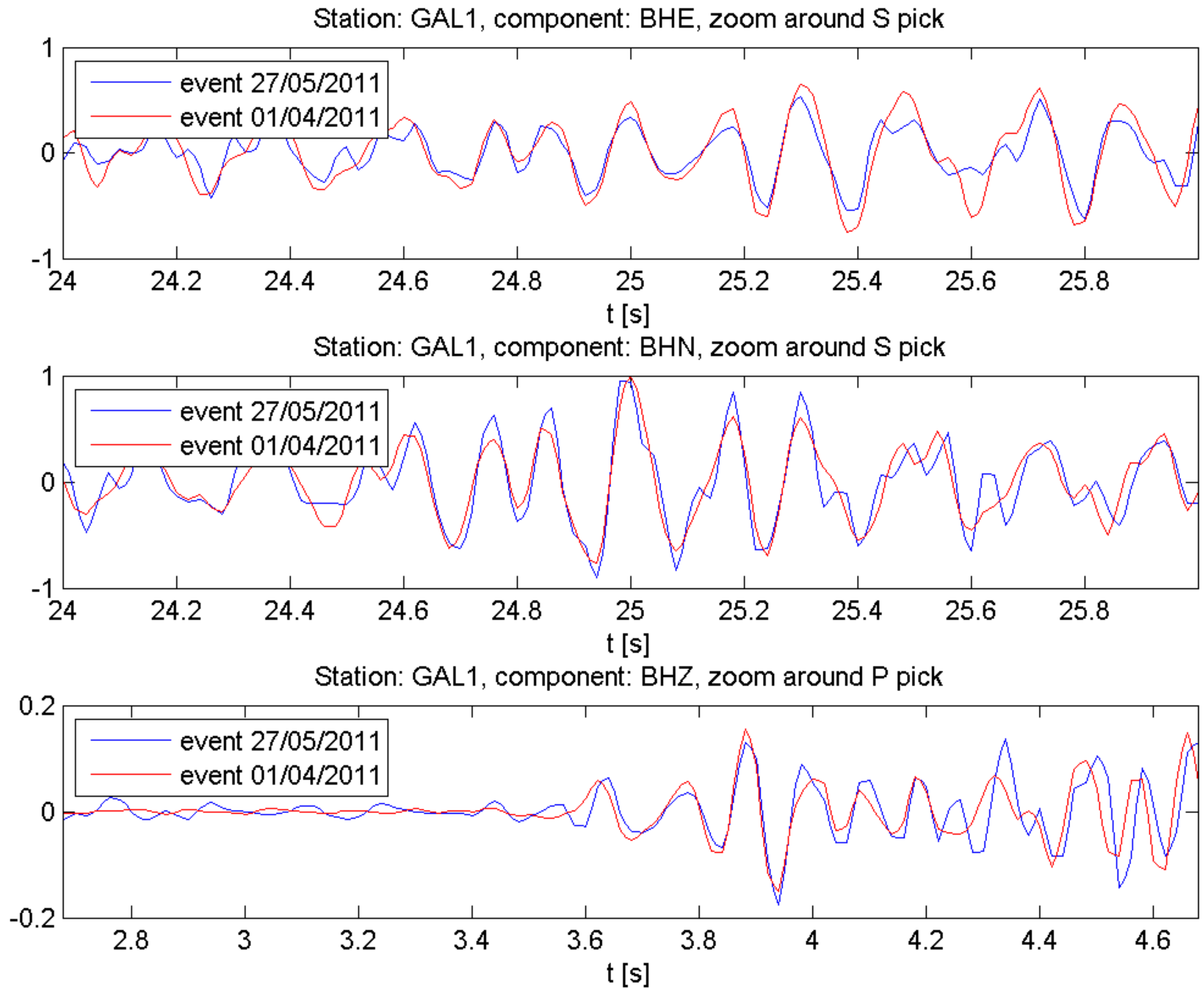
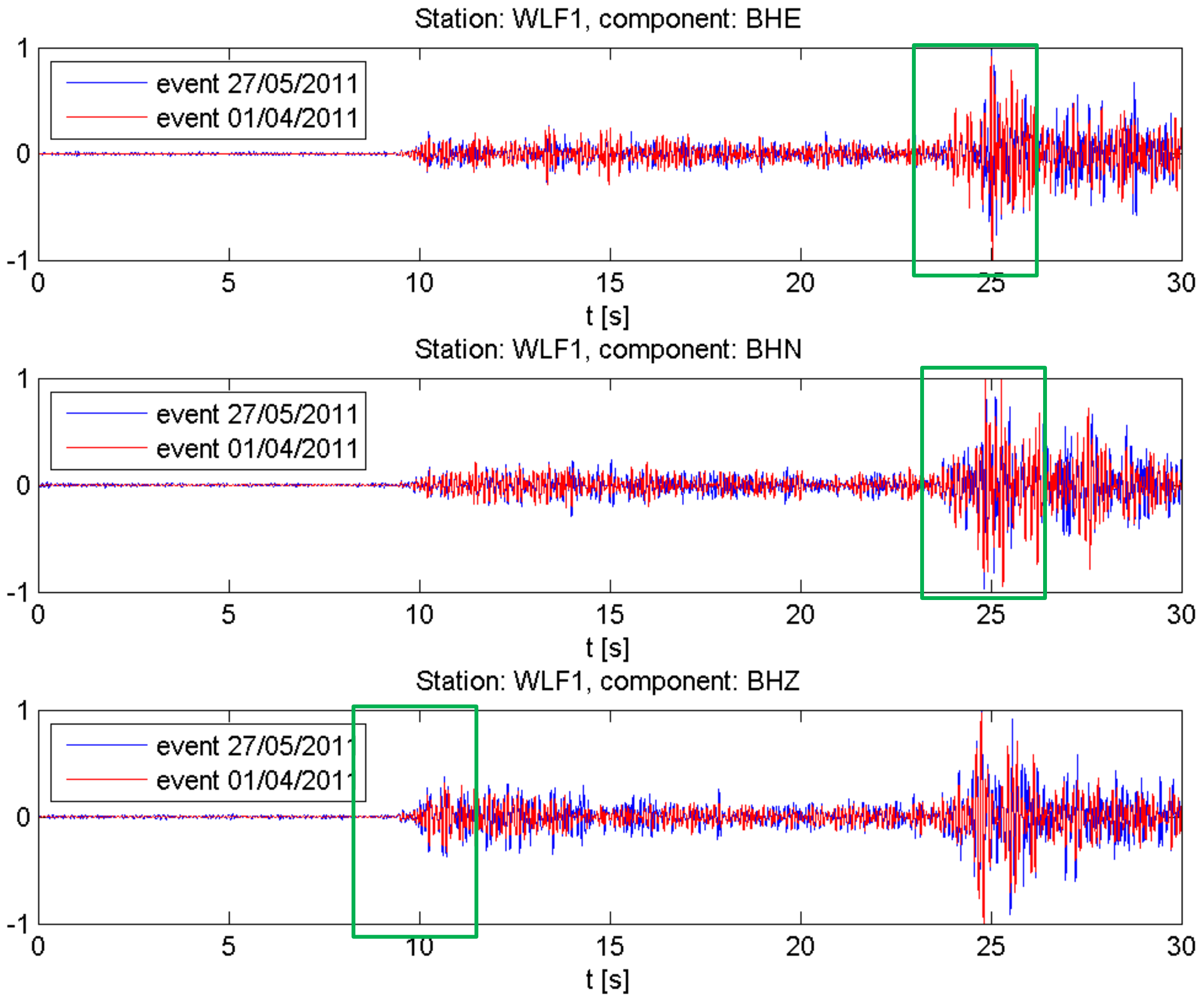
Synchronized on S-pick, waveforms start 25 seconds before S-pick

Waveforms GAL1 01/04 vs 27/05/2011



Synchronized on S-pick, waveforms start 25 seconds before S-pick

Waveforms WLF1 01/04 vs 27/05/2011



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Synchronized on S-pick, waveforms start 25 seconds before S-pick

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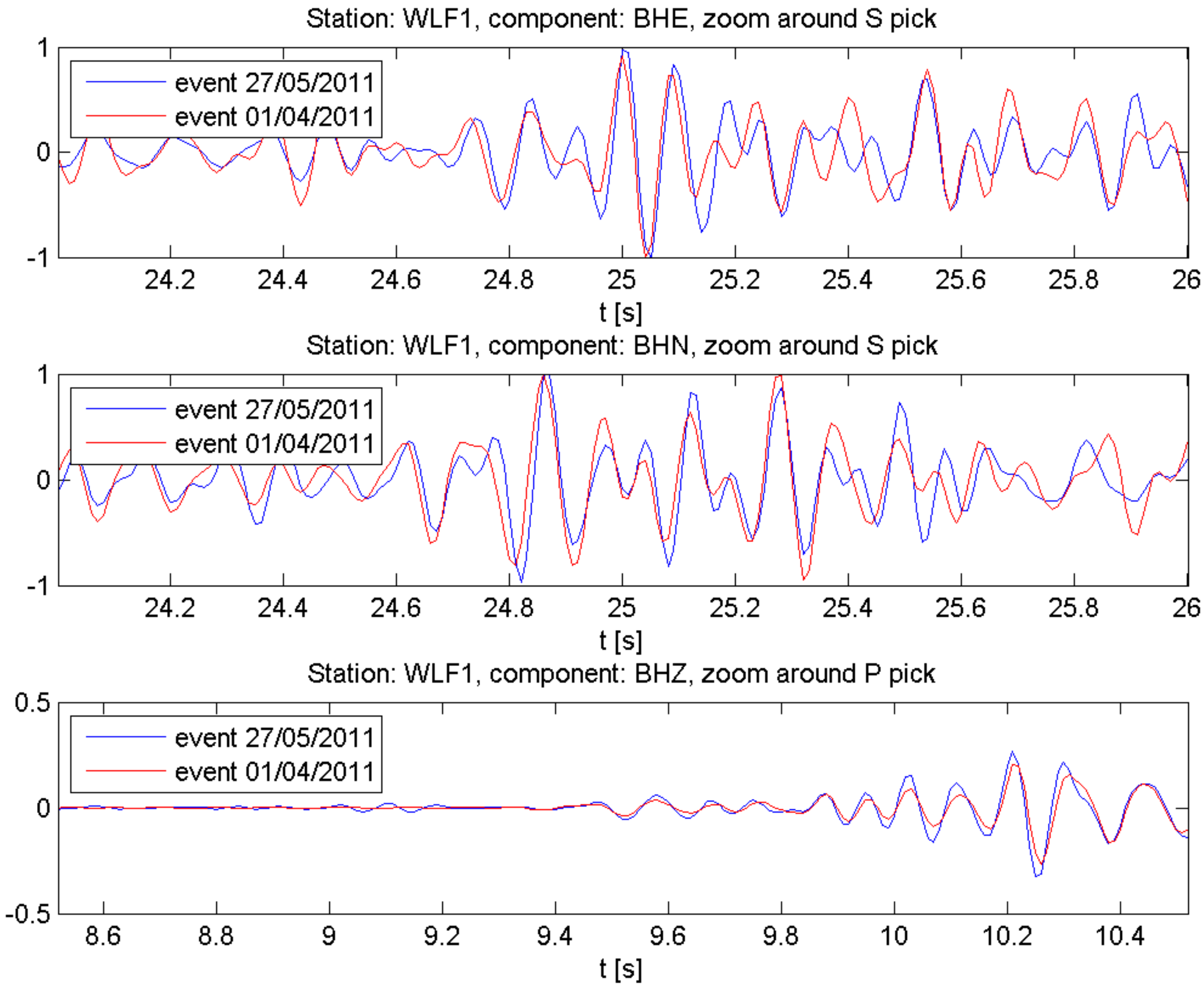
Waveforms WLF1 01/04 vs 27/05/2011



Synchronized on S-pick, waveforms start 25 seconds before S-pick

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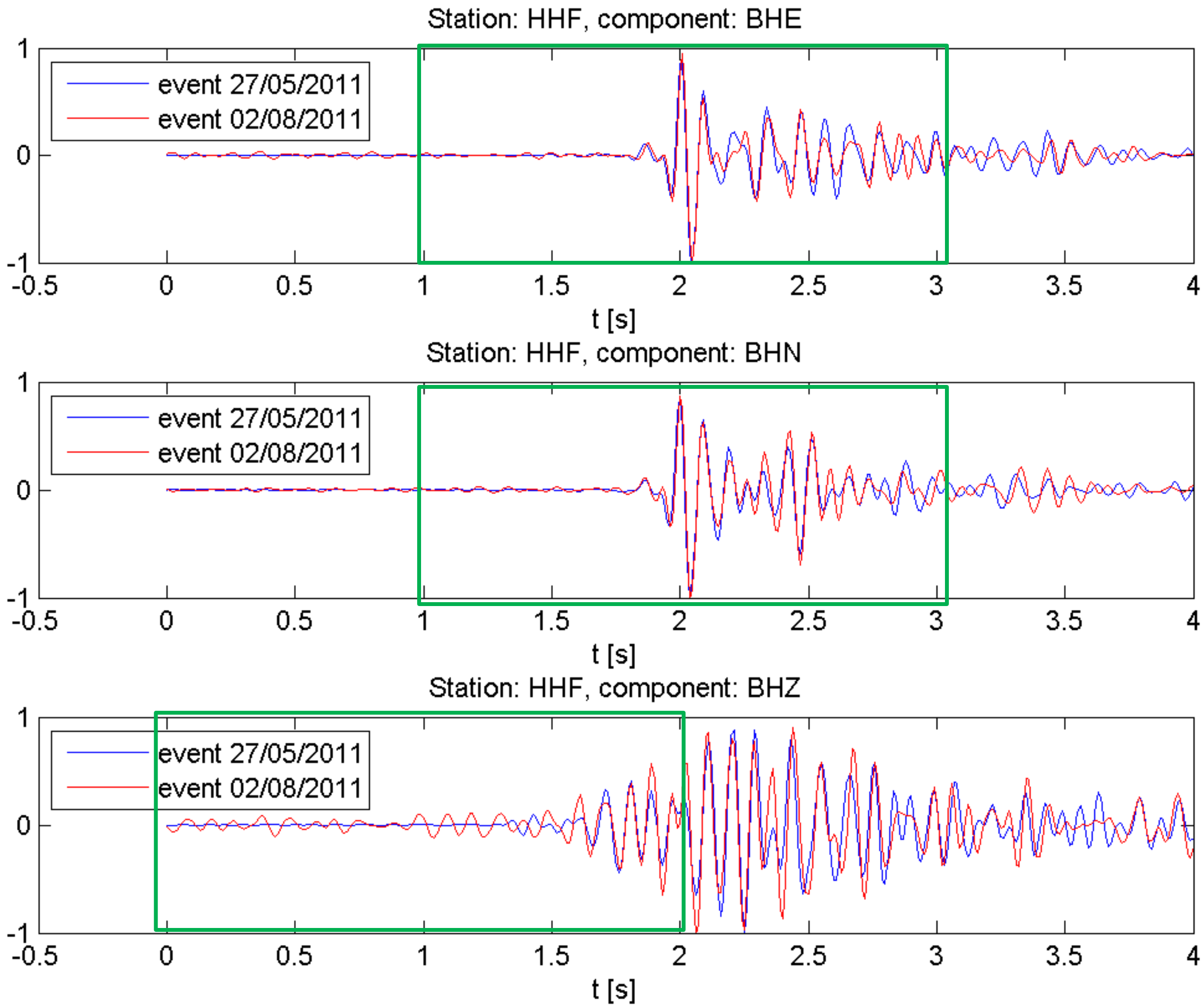
Waveforms HHF 27/05 vs 02/08/2011



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Filtered data (5-20 hz)
Synchronized on S-pick, waveforms start 2 seconds before S-pick

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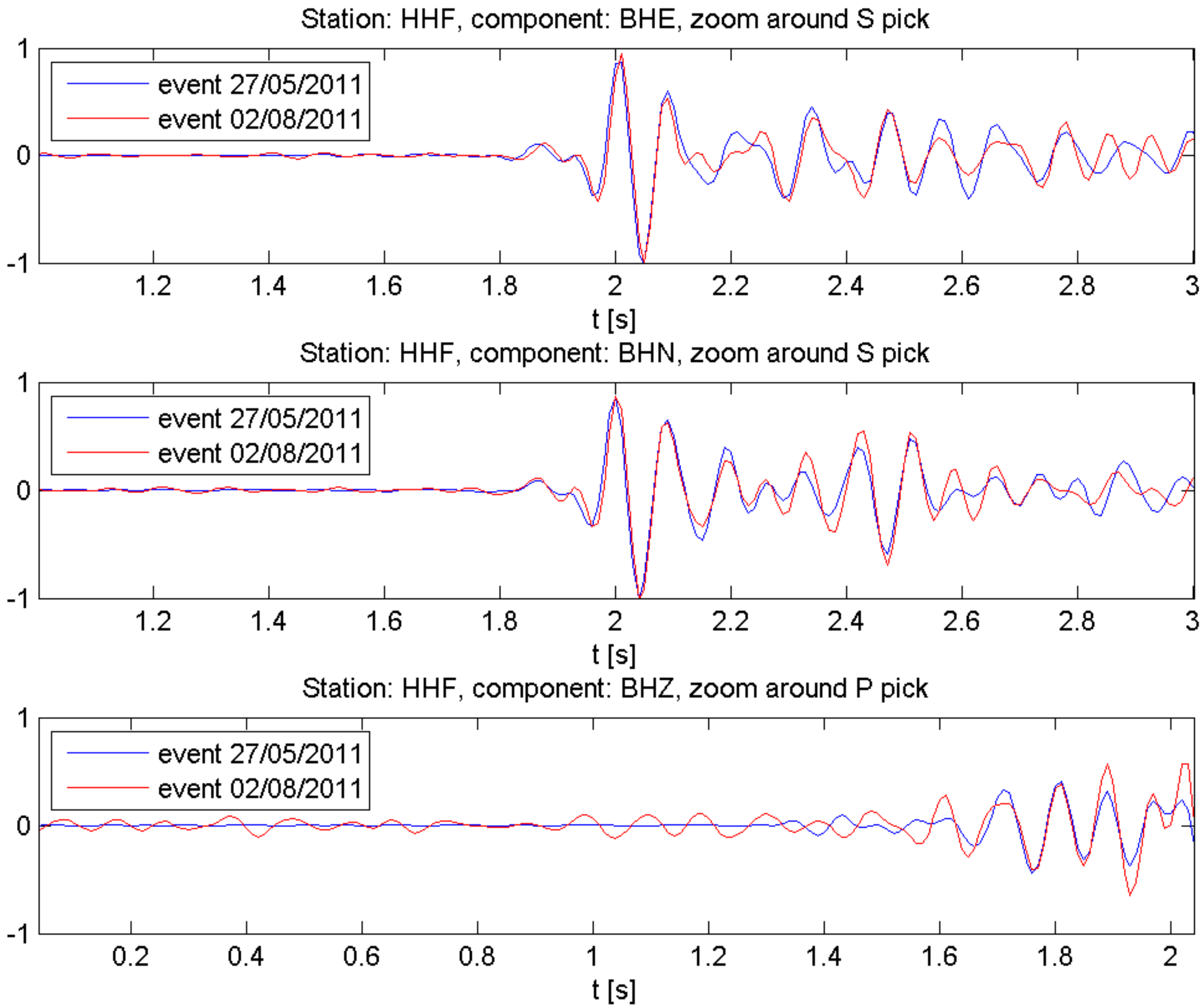
Waveforms HHF 27/05 vs 02/08/2011



Filtered data (5-20 hz)
Synchronized on S-pick, waveforms start 2 seconds before S-pick

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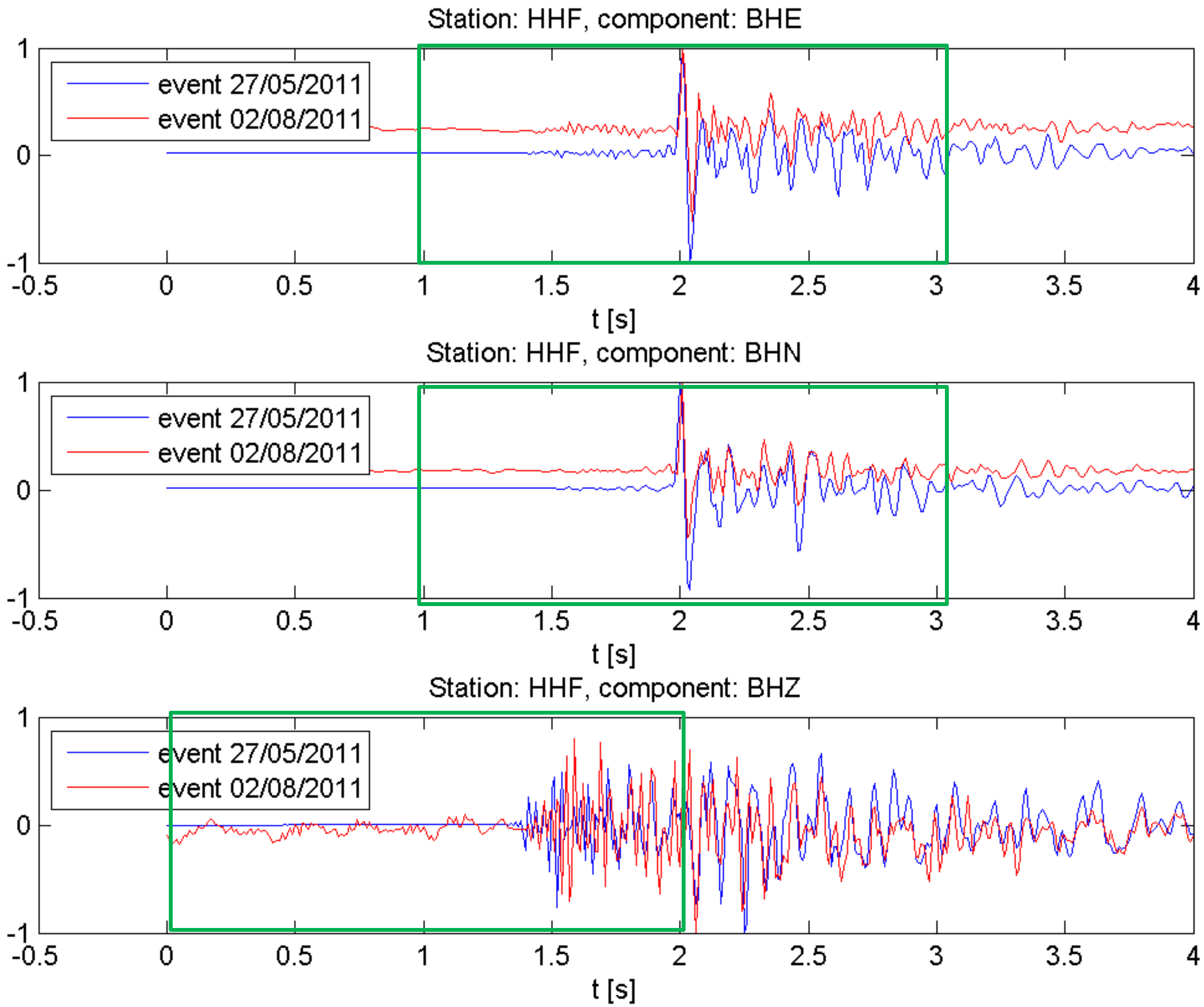
Waveforms HHF 27/05 vs 02/08/2011



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Raw data

Synchronized on S-pick, waveforms start 2 seconds before S-pick

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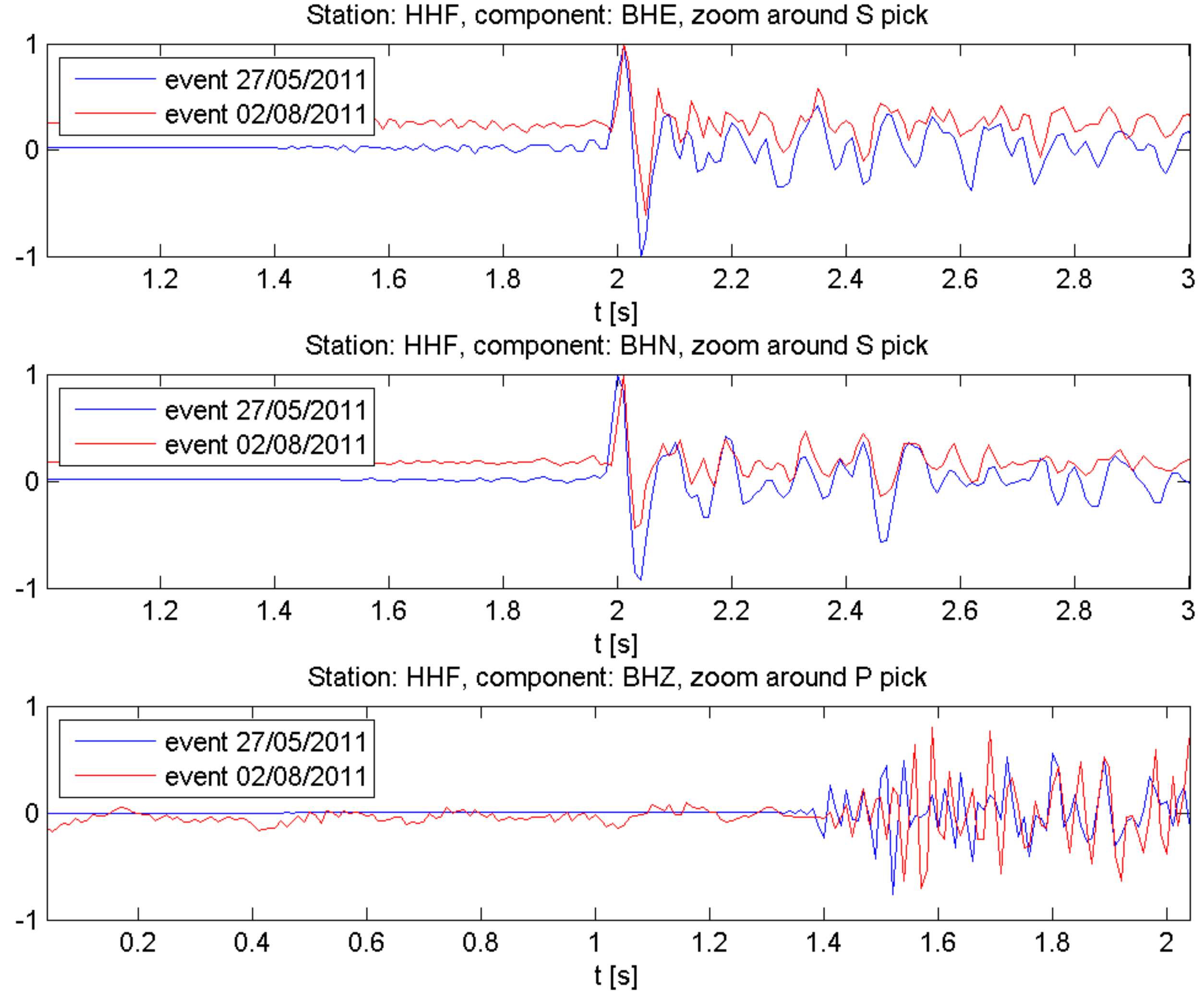
Waveforms HHF 27/05 vs 02/08/2011



Raw data

Synchronized on S-pick, waveforms start 2 seconds before S-pick

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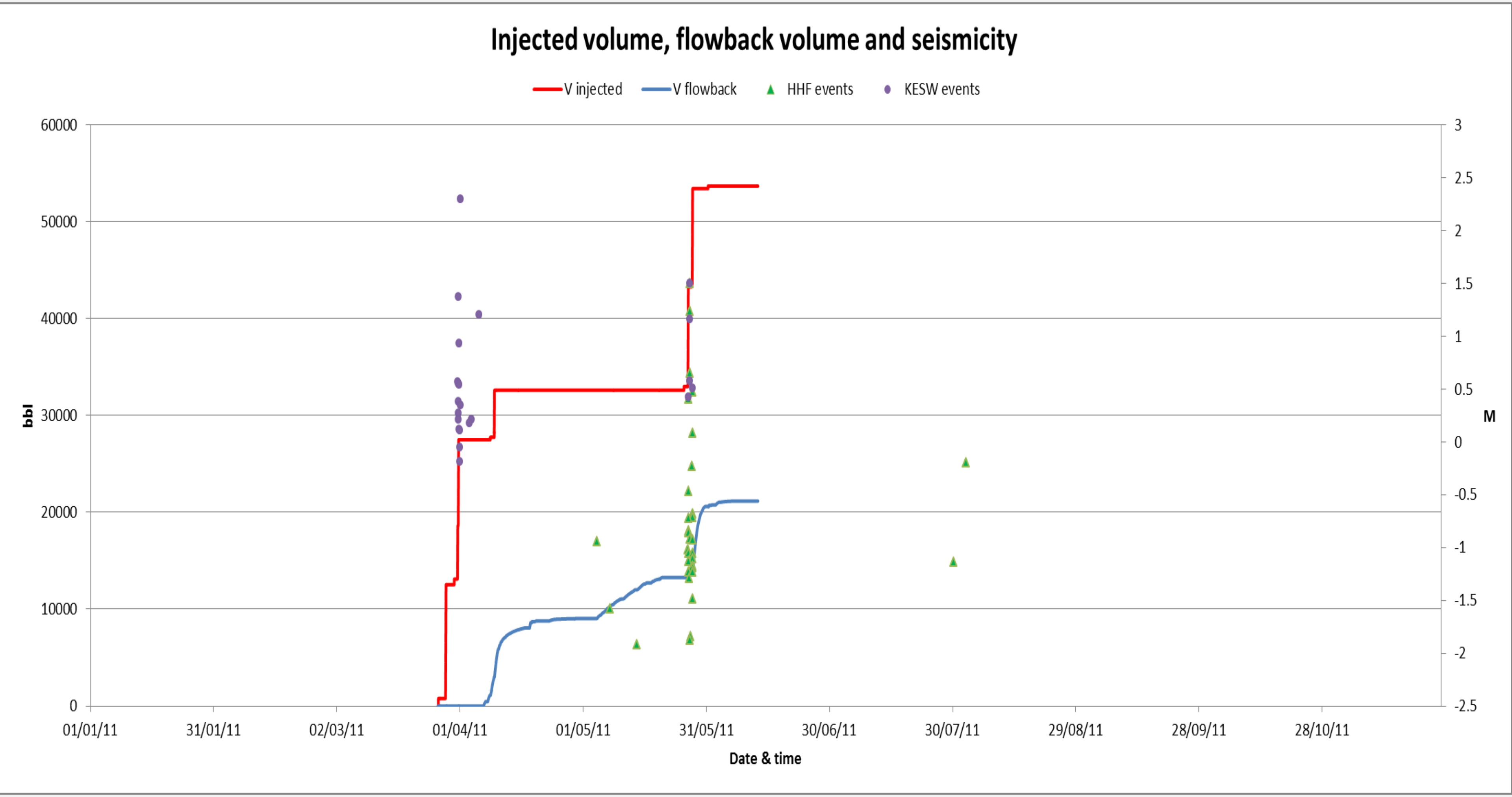
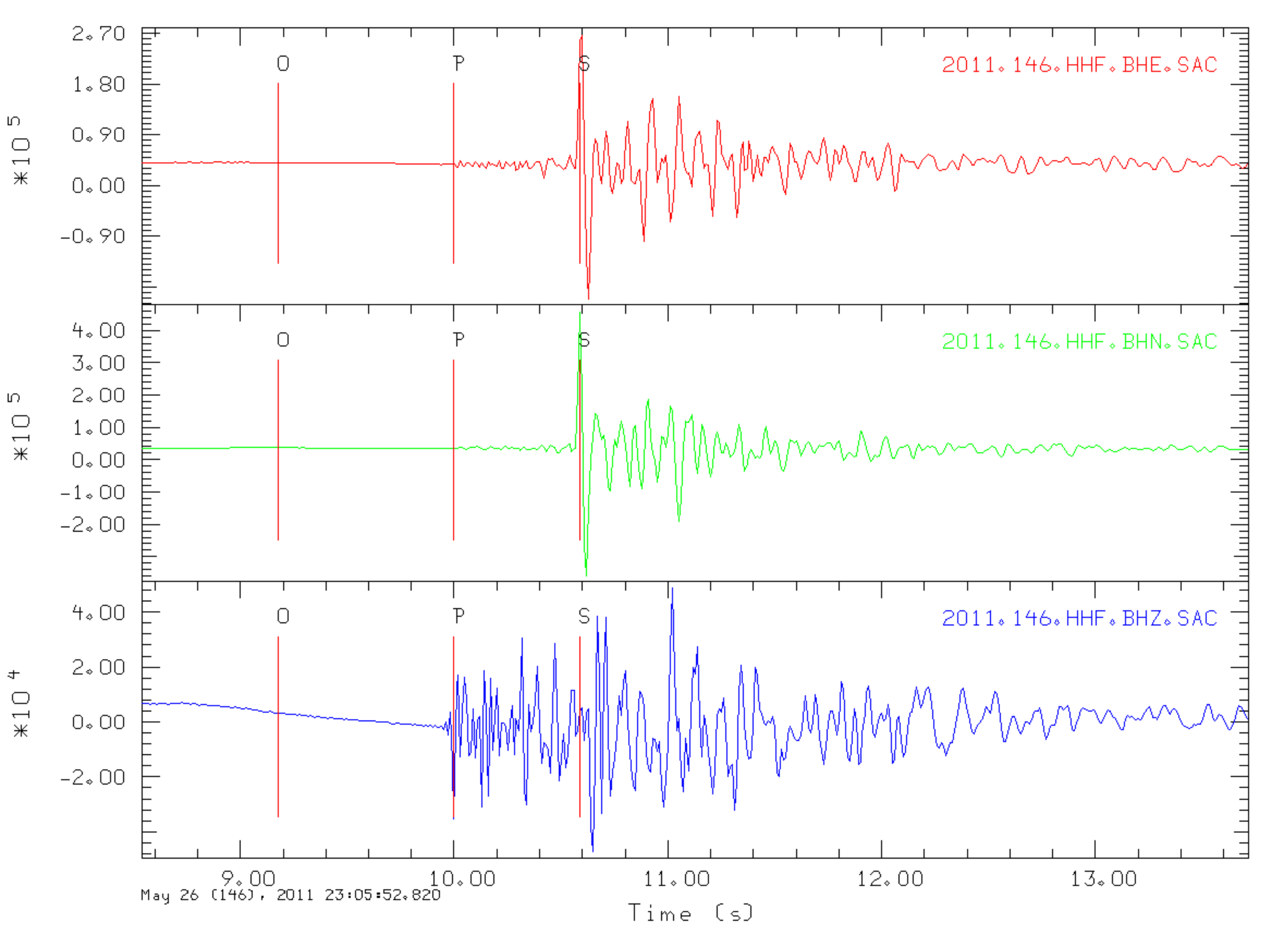
Injected volume, flowback volume and seismicity



Events detection range from local stations HHF and AVH

Comparison SNR of S-waves and P-waves
(event from 26/05/2011)

- E, N and Z components of HHF (raw data)
- SNR for P-waves is more then 3X smaller than SNR for S-waves



HHF S-wave
(E comp.)
SNR = **134**

HHF S-wave
(N comp.)
SNR = **105**

HHF P-wave
(Z comp.)
SNR = **30.2**

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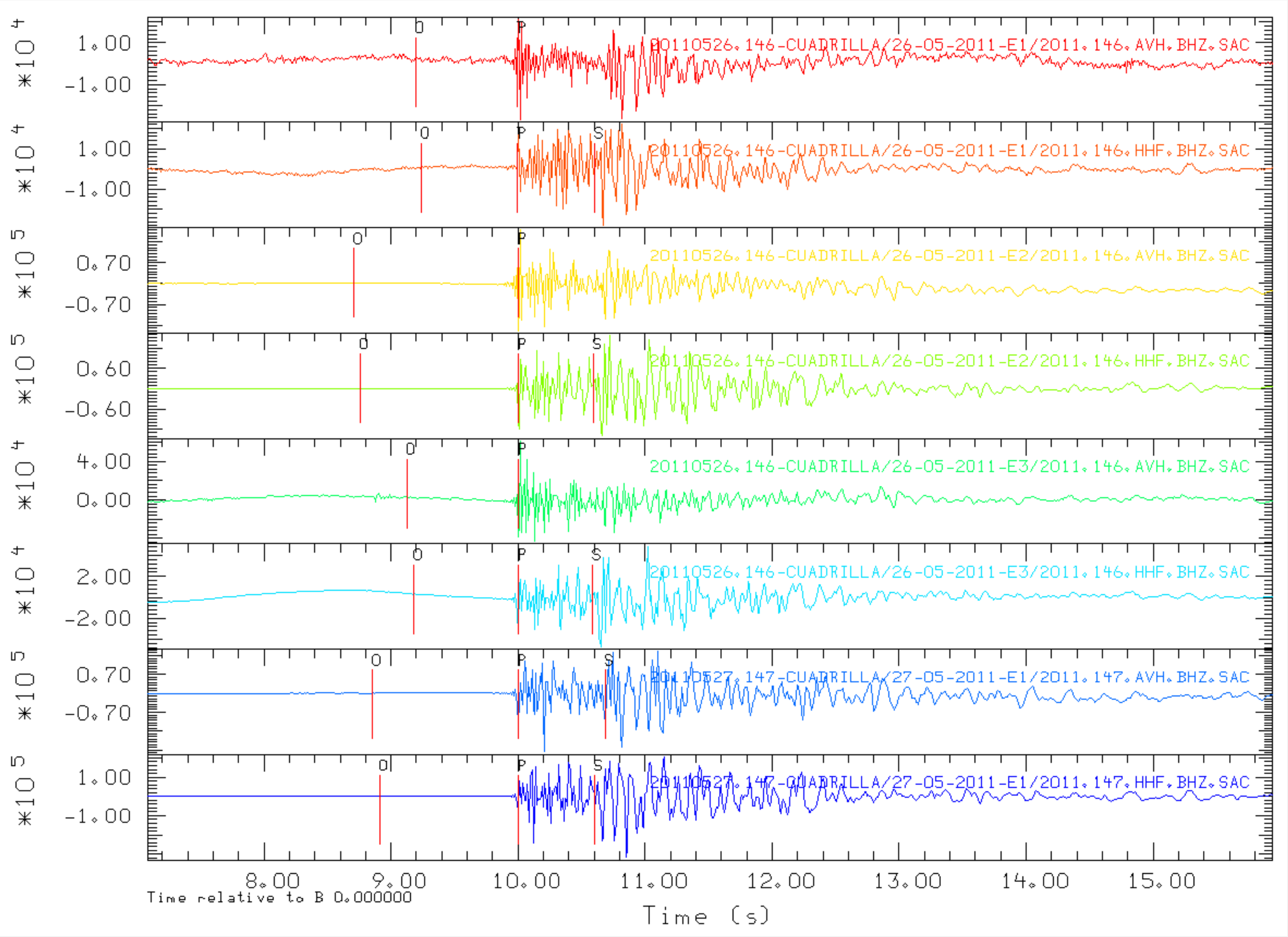
SNR of P-waves - raw data
(events from 26/05/2011 and 27/05/2011)

- Z comp. of AVH and HHF (P-wave arrivals) (raw data)



AVH event_1
SNR = **10.1**
M = 0.4

HHF event_1
SNR = **13.0**
M = 0.4

AVH event_2
SNR = **65.9**
M = 1.2

HHF event_2
SNR = **152**
M = 1.2

AVH event_3
SNR = **22.2**
M = 0.7

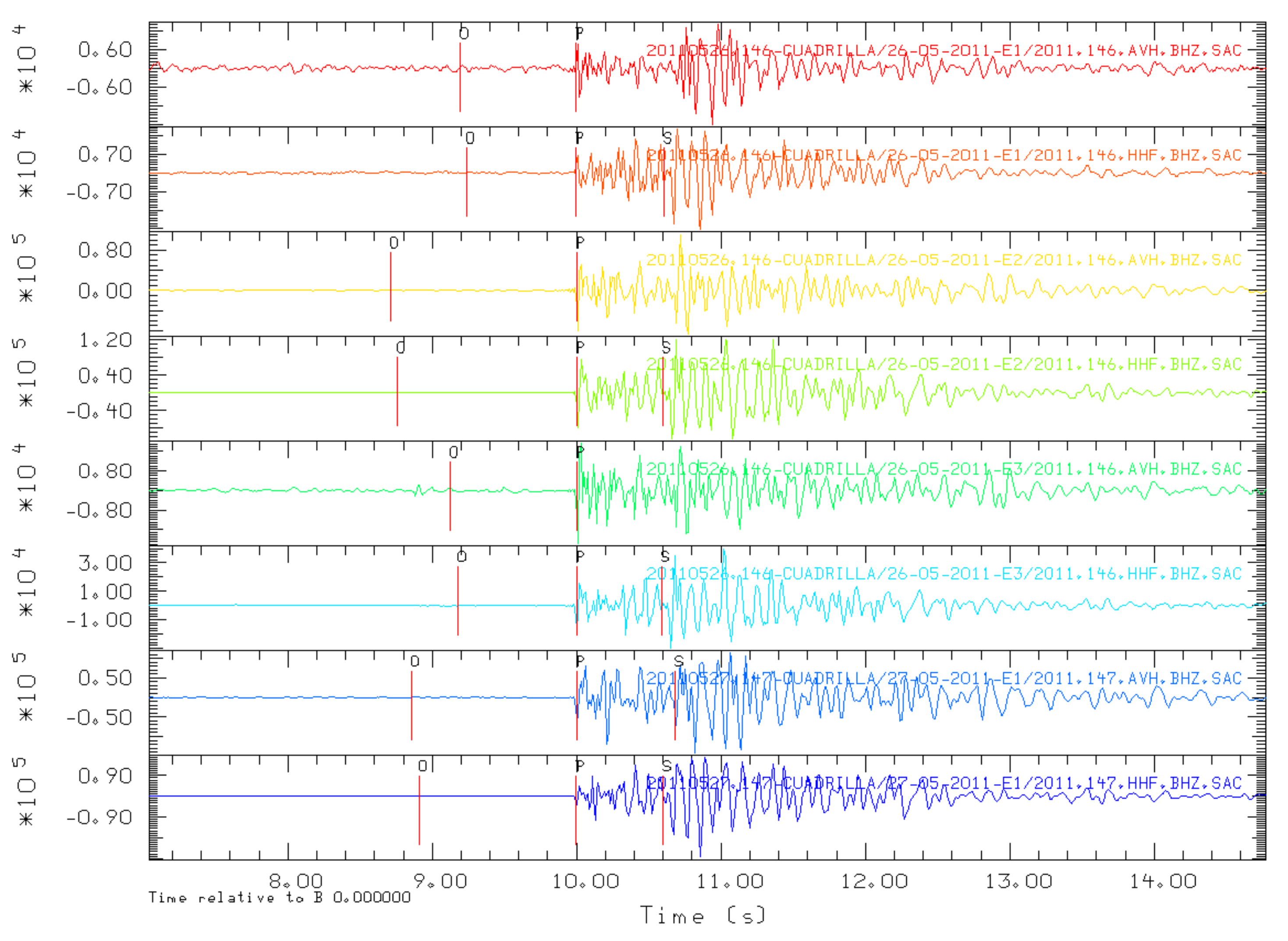
HHF event_3
SNR = **30.2**
M = 0.7

AVH event_4
SNR = **46.9**
M = 1.5

HHF event_4
SNR = **84.2**
M = 1.5

SNR of P-waves – 5 to 20 Hz
(events from 26/05/2011 and 27/05/2011)

- Z comp. of AVH and HHF (P-wave arrivals) (5Hz - 20Hz)



AVH event_1
SNR = **6.87**
M = 0.4

HHF event_1
SNR = **12.02**
M = 0.4

AVH event_2
SNR = **66.6**
M = 1.2

HHF event_2
SNR = **304**
M = 1.2

AVH event_3
SNR = **31.4**
M = 0.7

HHF event_3
SNR = **74.4**
M = 0.7

AVH event_4
SNR = **64.9**
M = 1.5

HHF event_4
SNR = **179**
M = 1.5

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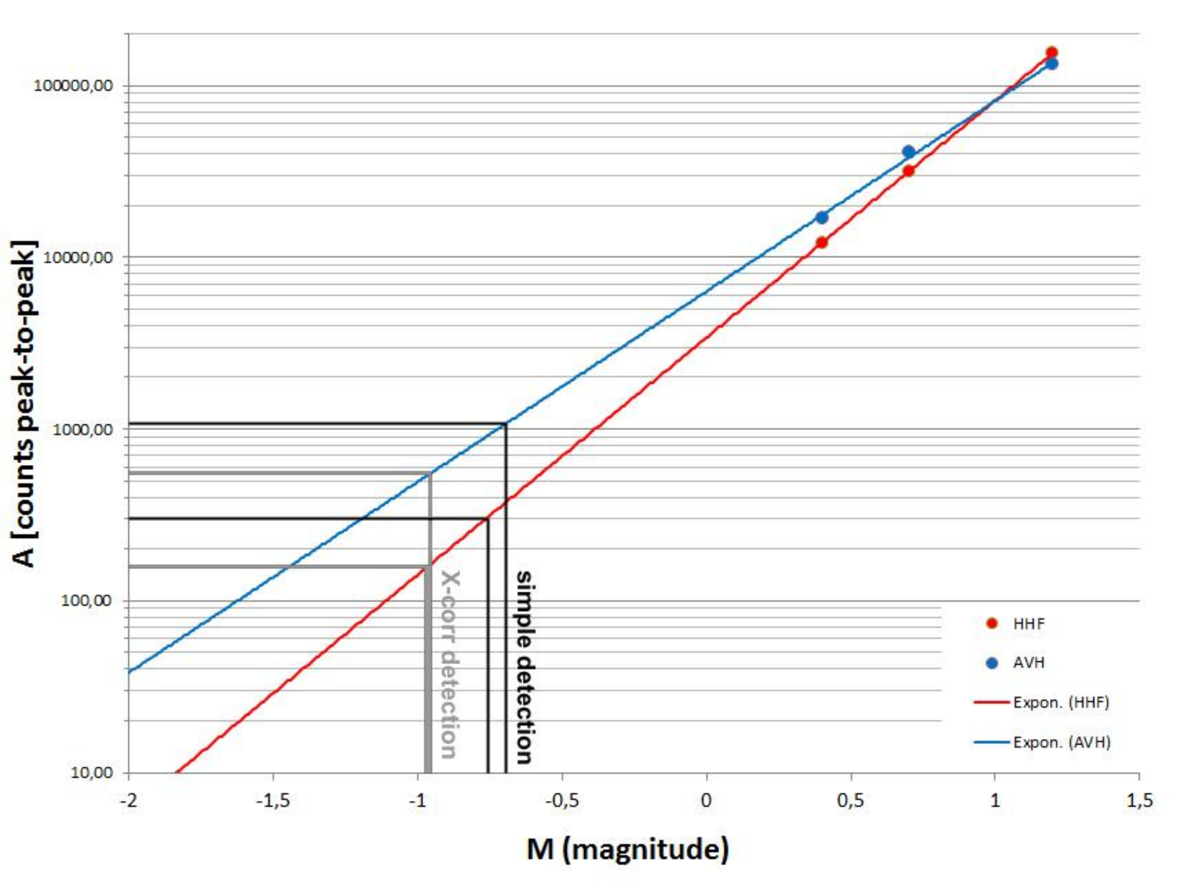
Predicted dependence of amplitude (at 5-20Hz) on magnitude

- If we assume events located in the same location dependence amplitude on magnitude is approximately exponencial.
- Predicted detectable magnitude from the stations AVH and HHF by simple detection is about -0.7 (SNR = 2; 5-20Hz) and about -1.0 with X-corr. Method (SNR = 1; 5-20Hz) .



- Noise level estimated like 2*mean of absolut values of noise signal
- Noise AVH = 546 counts
- Noise HHF = 150 counts

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Theoretical reliably detectable range of moment magnitude by simple detection with SNR = 2 (in depth 2500m)

Formula for the calculation of the moment magnitude M_w:

$$M_W = \frac{2}{3}(\log_{10}(M_0) - 9{,}1)$$

where M_0 is the moment tensor:

$$M_0 = \frac{4\pi\rho c^3 r\Omega_0}{U_\Theta}$$

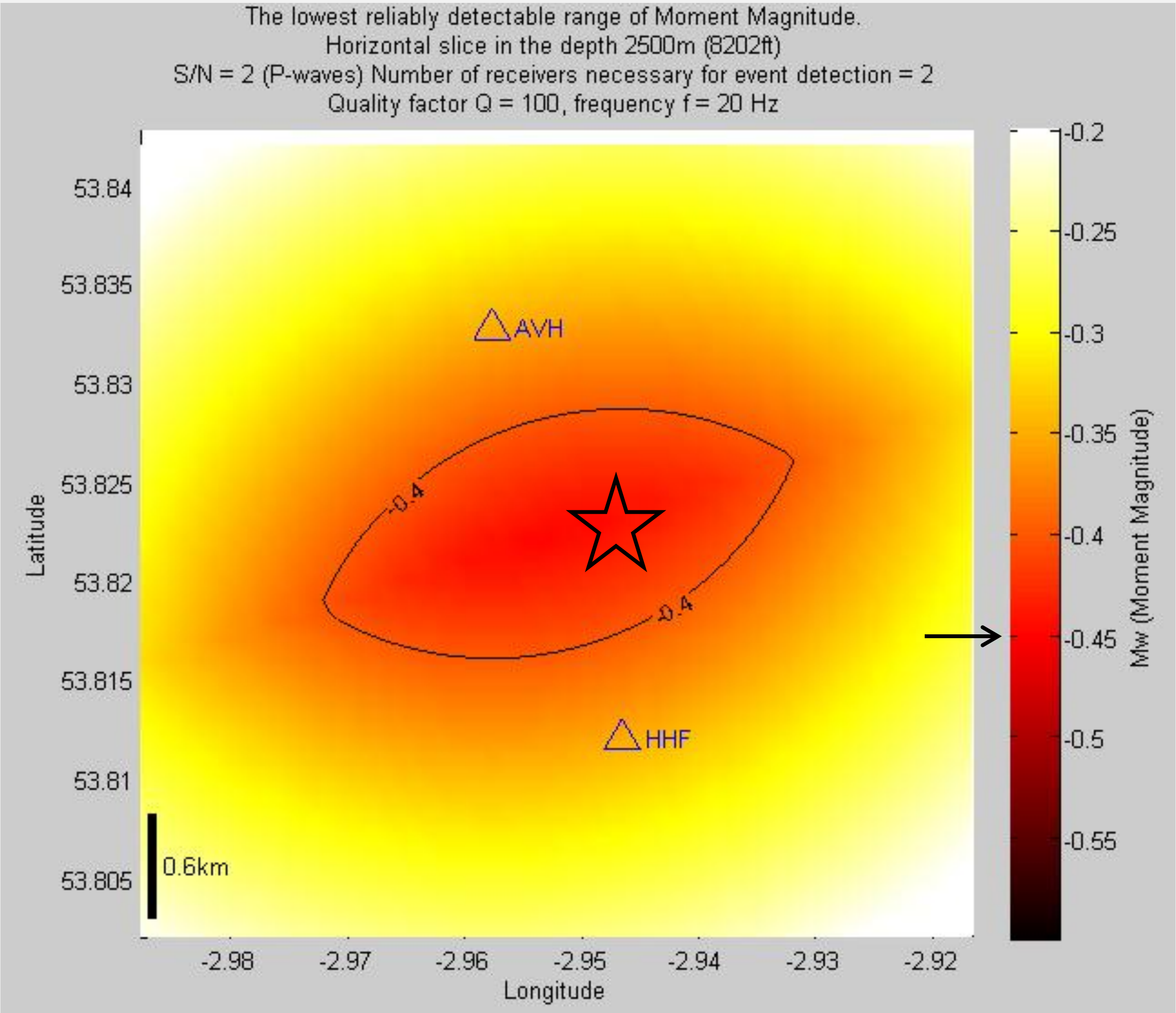
where r is distance from the source, ρ is density, c is the wave velocity and Ω_0:

$$\Omega_0 = \left(\frac{1}{2\pi f}\right)^2 A[m/s]$$

The amplitude in [m/s] is attenuated by:

$$A_{atten.} = \frac{A}{e^{-\left(\frac{\pi f r}{cQ}\right)}}$$

Q_p = 100
SNR = 2
Depth = 2500m



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Conclusions – detection range from only local stations HHF and AVH

- Computed theoretical reliable detectable range by simple detection method (SNR = 2) is M_w = -0.45
- Predicted detectable range by simple detection method (SNR = 2) from dependence of amplitude on relative magnitude is M = -0.7
- Predicted detectable range by X-corr. detection method (SNR = 1) from dependence of amplitude on relative magnitude is M = -1.0
- Completeness of catalog of an events from HHF and AVH stations can be down to M = -0.7
- The seismic activity close to the injection intervals can be well monitored by surface monitoring network.

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Plan

- Report
- Detection:
  - STA/LTA for other types of mechanisms
- Location:
  - Relative locations of 2 events
- Mechanism