

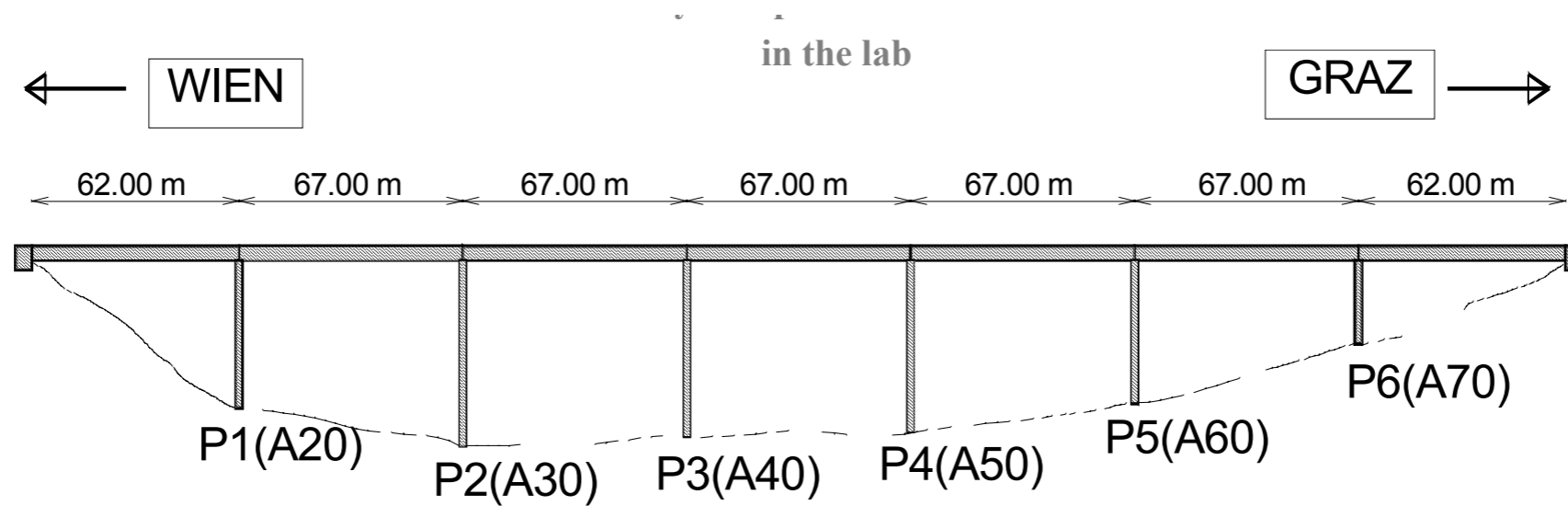
VAB Project (EC)

ADVANCED METHODS FOR ASSESSING THE SEISMIC VULNERABILITY OF EXISTING MOTORWAY BRIDGES

ARSENAL RESEARCH, Vienna, Austria; ISMES S.P.A., Bergamo, Italy;
ICTP, Trieste, Italy; UPORTO, Porto, Portugal; CIMNE, Barcelona, Spain;
SETRA, Bagnaux, France; JRC-ISPRA, EU.

Effects on bridge seismic response of
asynchronous motion at the base of bridge piers

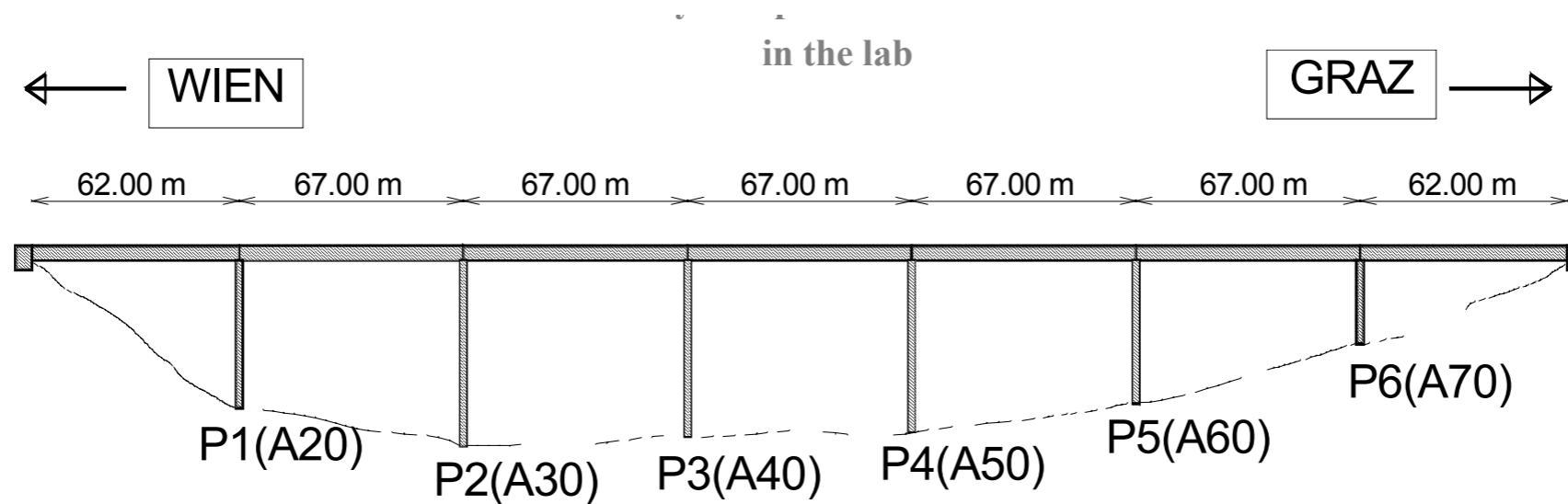
Warth bridge



Warth bridge



The bridge was designed for a horizontal acceleration of 0,04 g using the quasi static method.

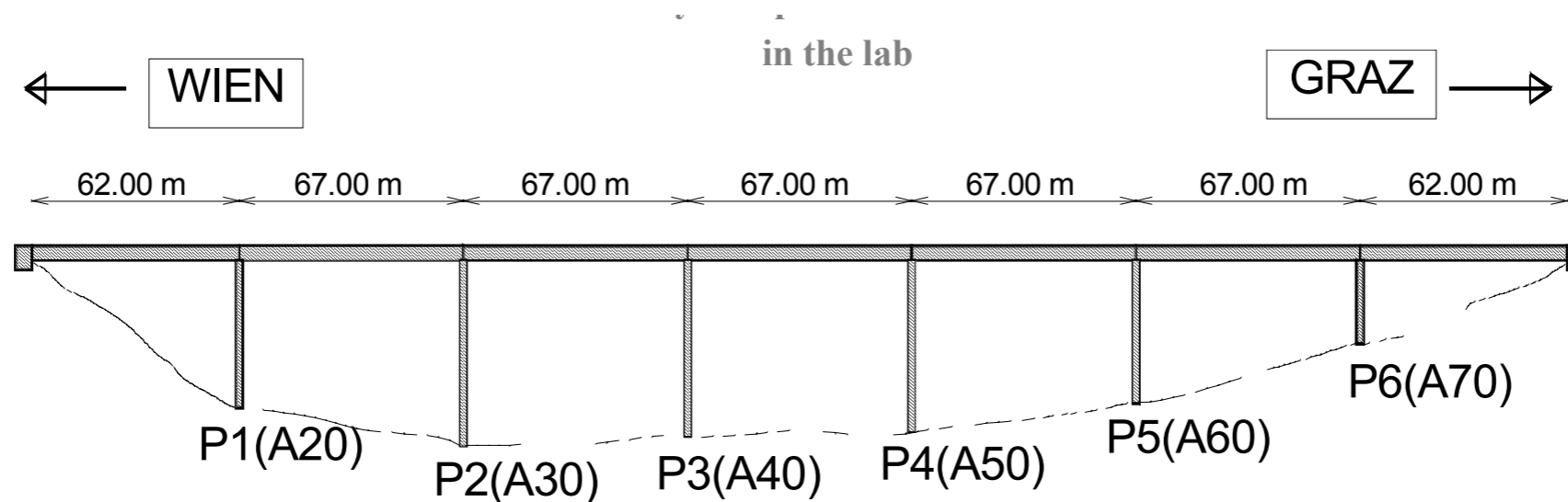


Warth bridge



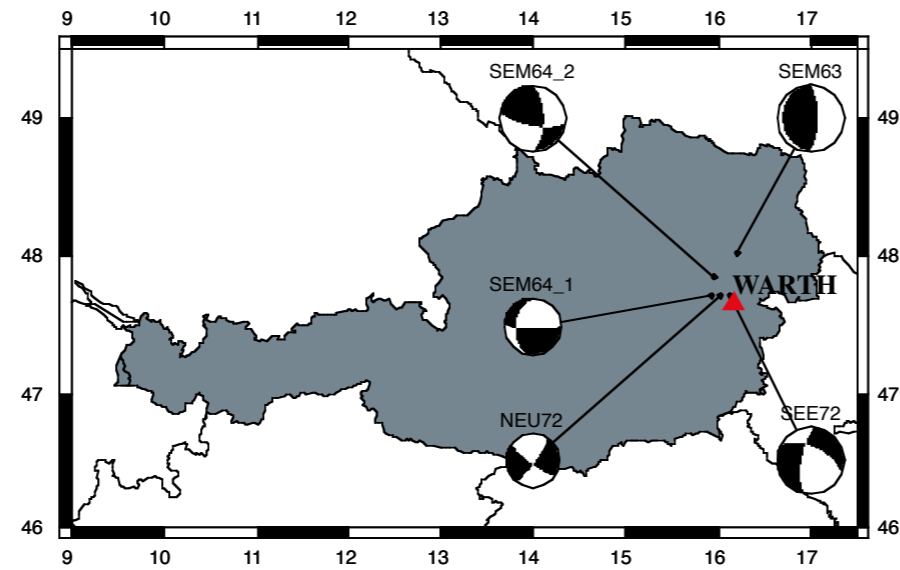
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According to the new Austrian seismic code the bridge is situated in zone 4 with a horizontal design acceleration of about 0,1 g: a detailed seismic vulnerability assessment was necessary.



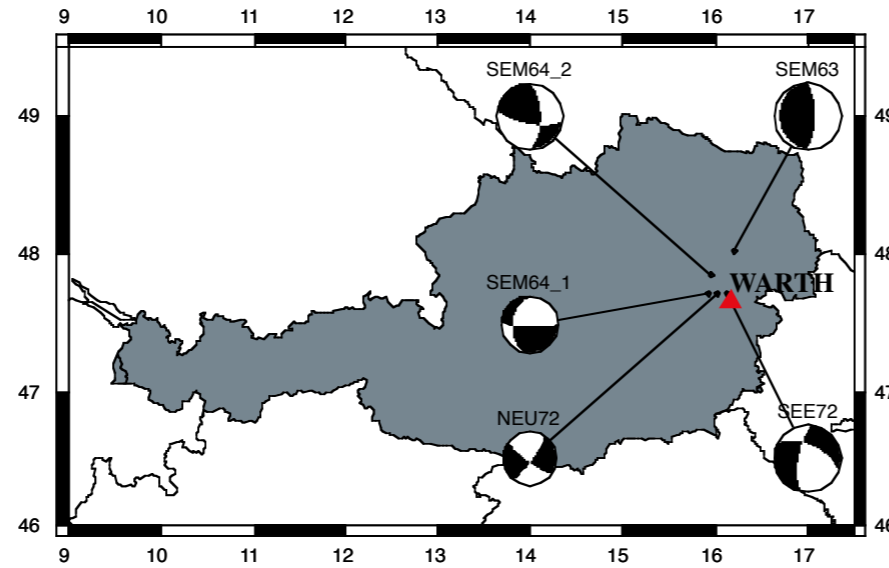
Warth bridge - Seismic sources

1) Database of focal mechanism



Warth bridge - Seismic sources

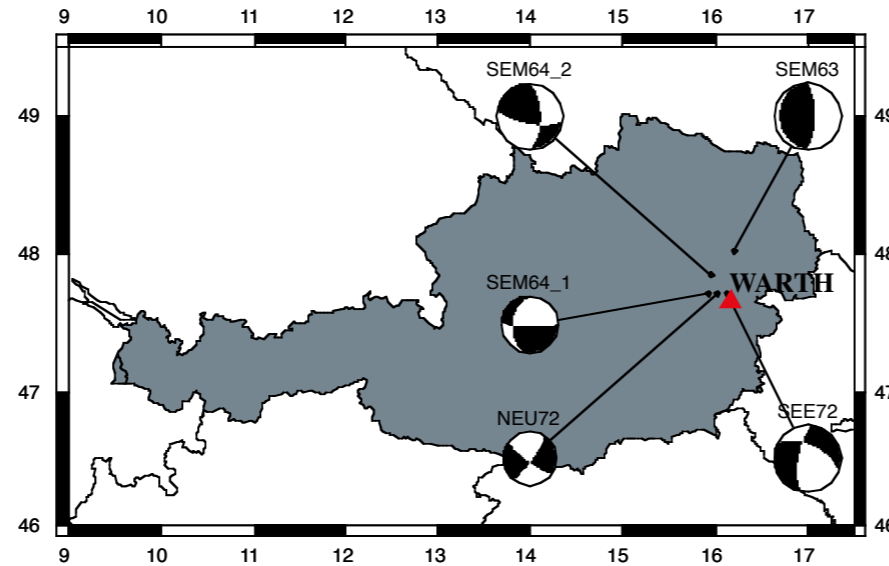
1) Database of focal mechanism



Maximum
Historical
Earthquake

Warth bridge - Seismic sources

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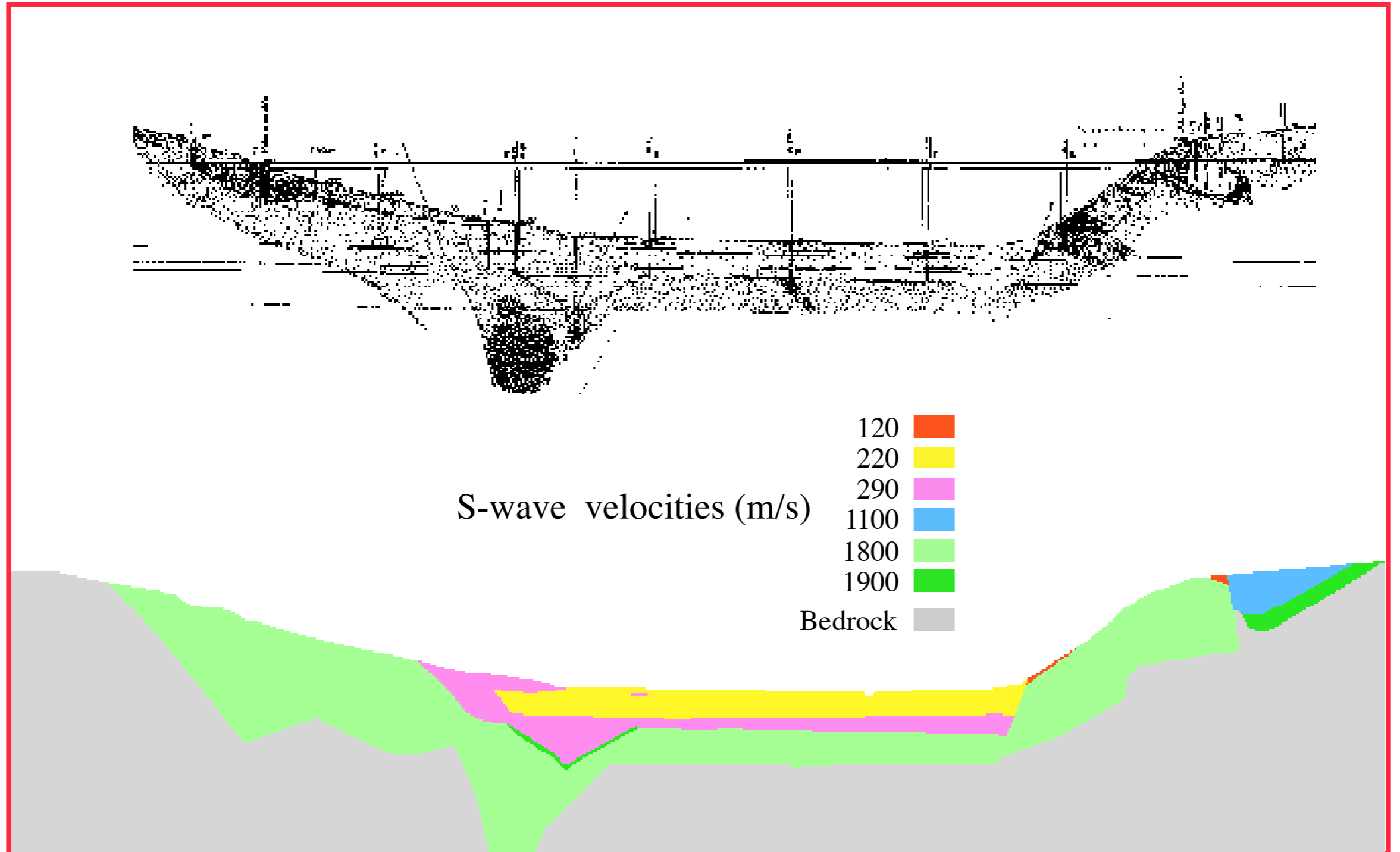


2) Parametric study on focal mechanism: strike dip rake depth

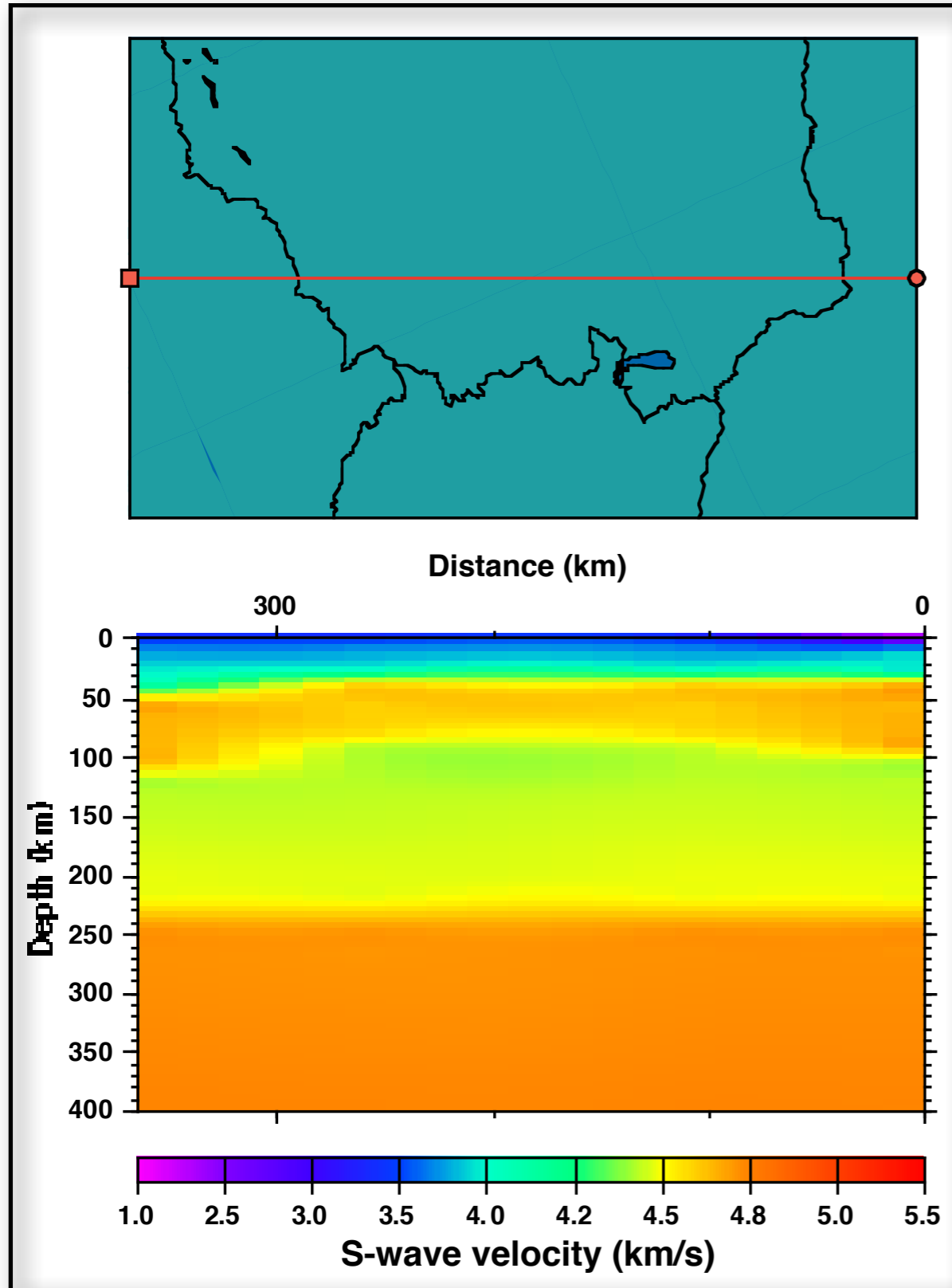
Maximum Credible Earthquake
Maximum Design Earthquake

Maximum
Historical
Earthquake

Initial LHM - Warth bridge - model

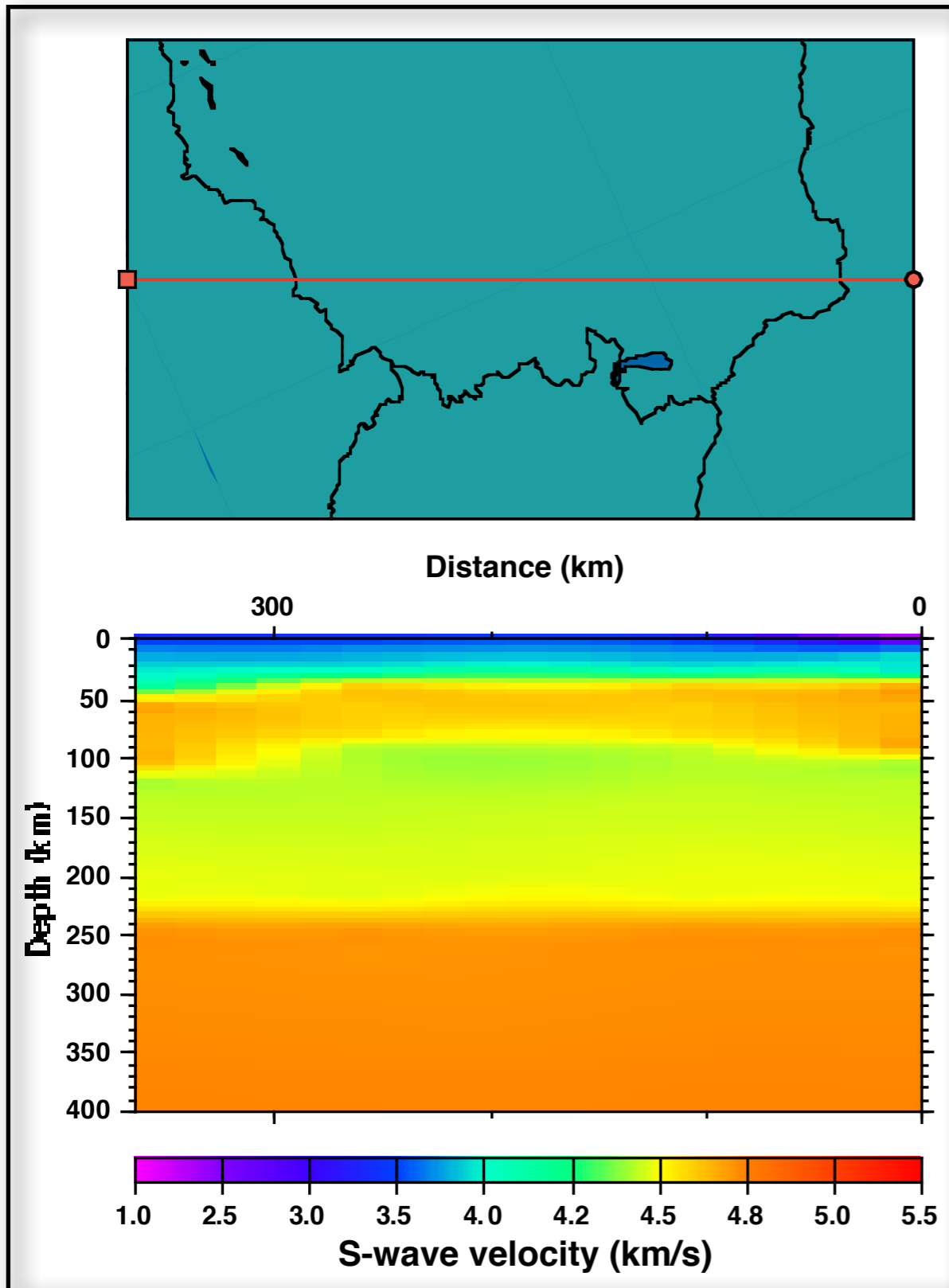


Warth bridge - Regional model

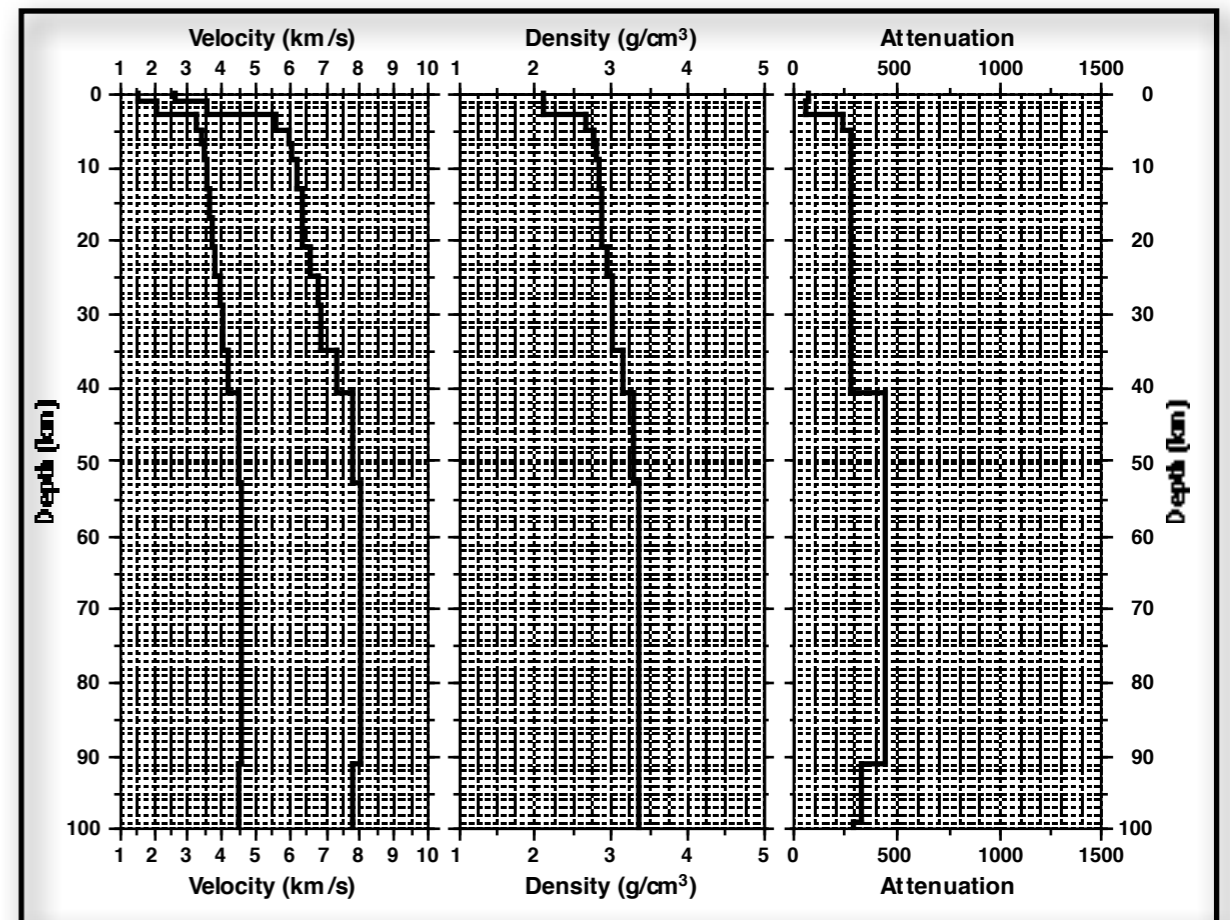


EUR I data set

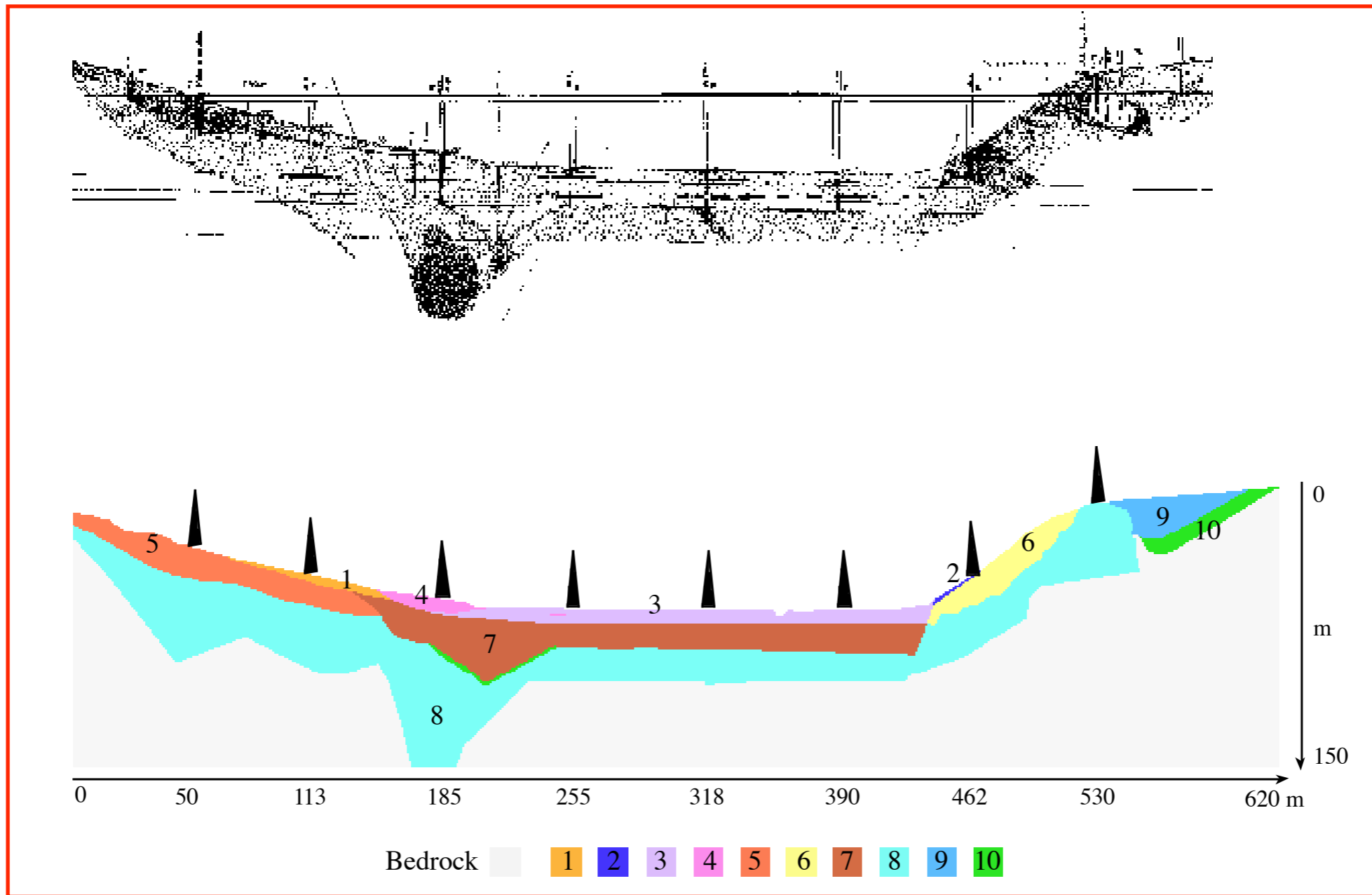
Warth bridge - Regional model



EUR I data set

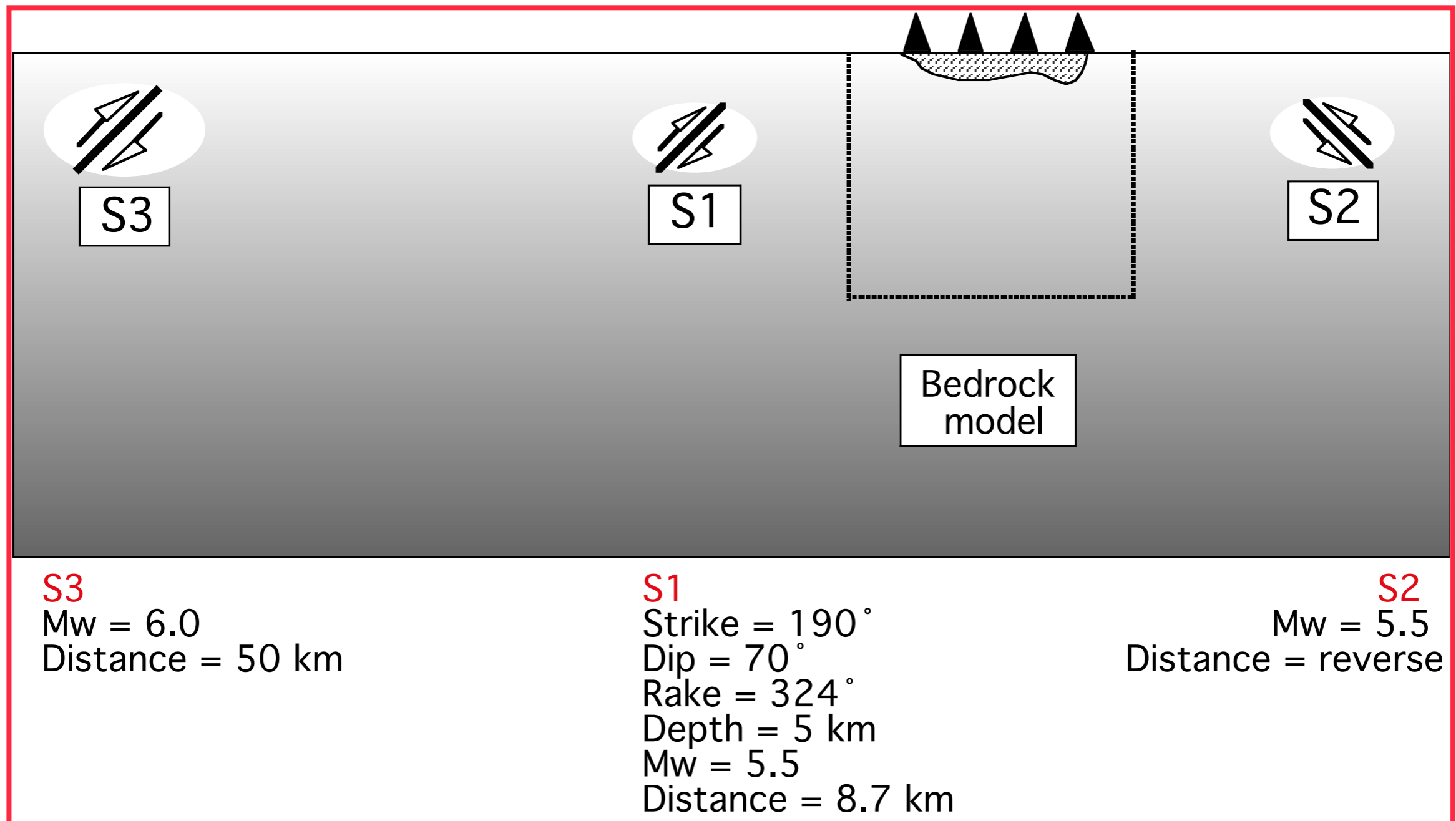


Warth bridge - Local model



Unit	Density g/cm ³	P-wave velocity km/s	Q _p	S-wave velocity km/s	Q _s
1	1.5	0.30	40.0	0.20	15.0
2	1.7	0.49	40.0	0.25	15.0
3	2.0	0.70	50.0	0.26	20.0
4	1.8	0.70	50.0	0.29	20.0
5	2.3	0.80	50.0	0.30	20.0
6	2.3	0.80	50.0	0.40	20.0
7	1.8	1.70	50.0	0.50	20.0
8	2.3	2.10	150.0	1.00	60.0
9	2.3	3.00	150.0	1.90	60.0
10	2.2	1.80	100.0	1.10	40.0

Different source-sites configurations



S3
M_w = 6.0
Distance = 50 km

S1
Strike = 190°
Dip = 70°
Rake = 324°
Depth = 5 km
M_w = 5.5
Distance = 8.7 km

S2
M_w = 5.5
Distance = reverse

COMPUTATION OF SEISMIC INPUT

PRELIMINARY COMPUTATION

INITIAL source and structural models
3 components of motion
Displacement, velocity, acceleration

FINAL COMPUTATION

FINAL source and structural models
3 components of motion
Displacement, velocity, acceleration

SEISMIC INPUT

- 1) 1D 10 Hz Parametric study
- 2) 2D 8Hz

DIFFERENTIAL MOTION

- 1) time domain
- 2) spectral domain

SITE RESPONSE

- 1) Fourier spectral ratios
- 2) Response spectral ratios

Parametric study I - towards MCE

All the focal mechanism parameters of the original source model have been varied in order to find the combination producing the maximum amplitude of the various ground motion components.

Longitude (°)	Latitude (°)	Focal Depth (km)	Strike (°)	Dip (°)	Rake (°)	Magnitude Ms (Mb)
16.120	47.730	18	190	70	324	5.5 (4.9)

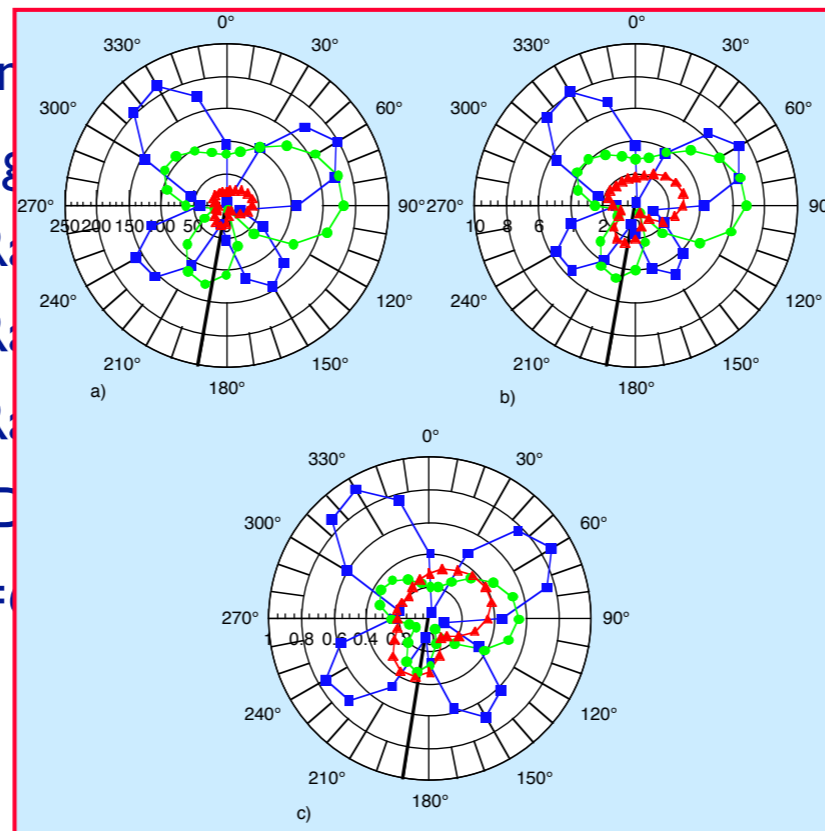
- 1) Strike angle (Depth=5km)
- 2) Rake angle
- 3) Strike-Rake angles variation (Dip=45°)
- 4) Strike-Rake angles variation (Dip=70°)
- 5) Strike-Rake angles variation (Dip=90°)
- 6) Depth-Distance variation
(Strike=60°, Dip=70°, Rake=0, 90°)

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 - 6) Depth-D
- (Strike=



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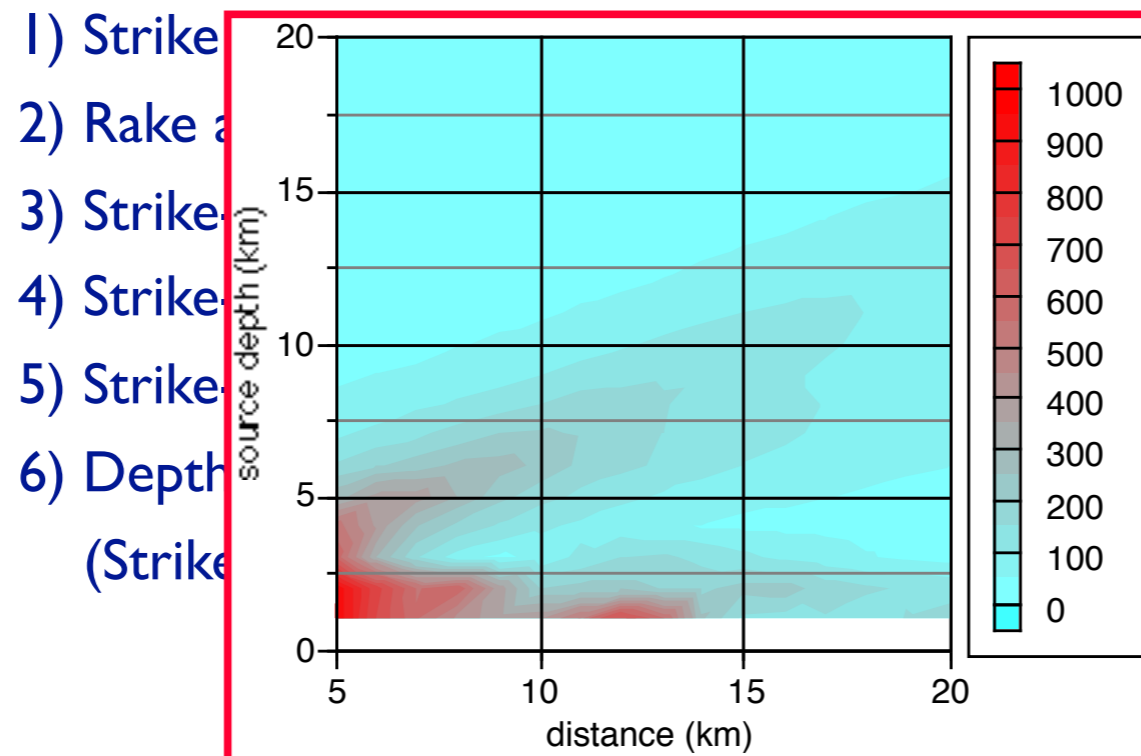
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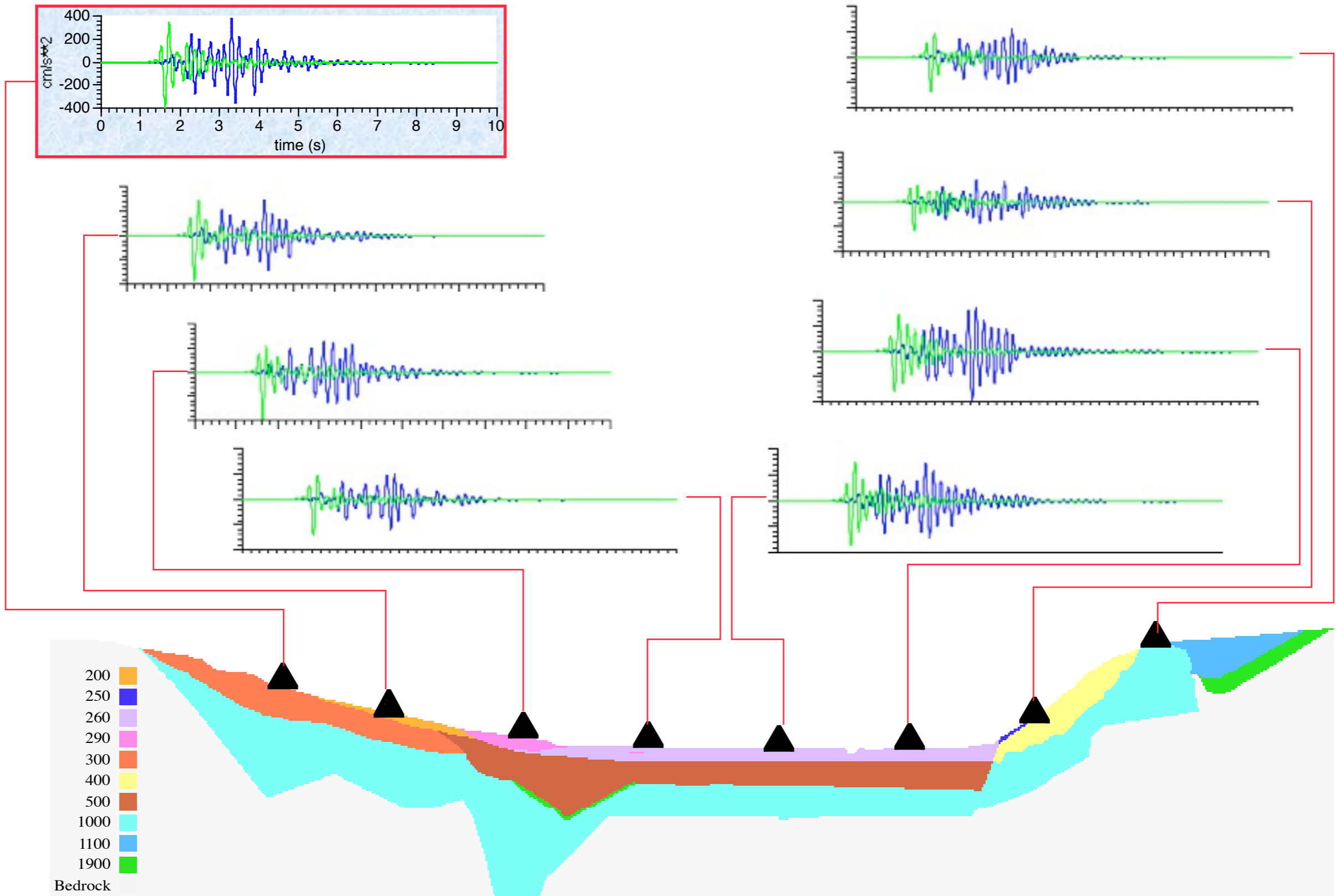
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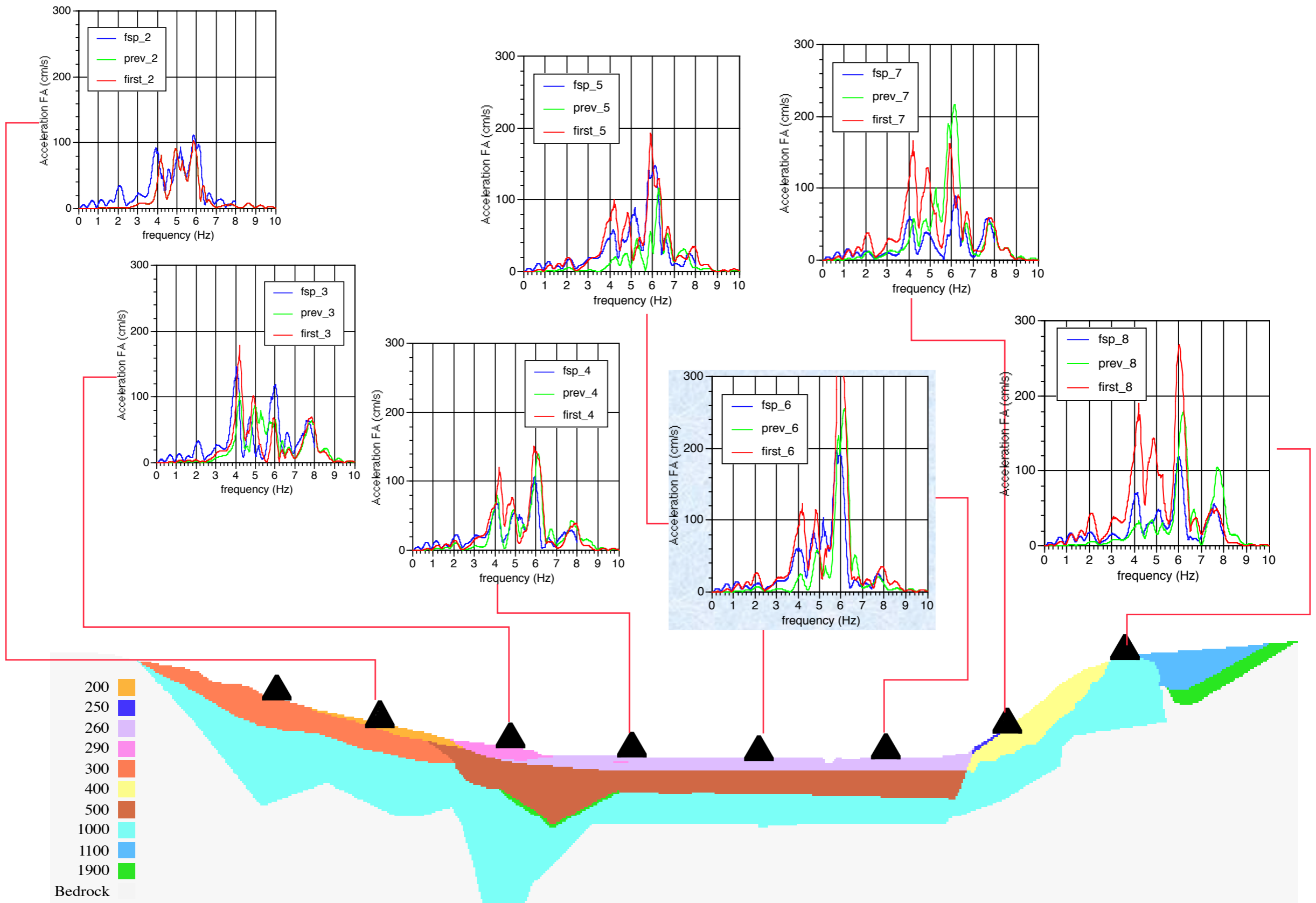
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Transverse accelerograms M=5.5, d=6km



Tranverse acceleration spectra

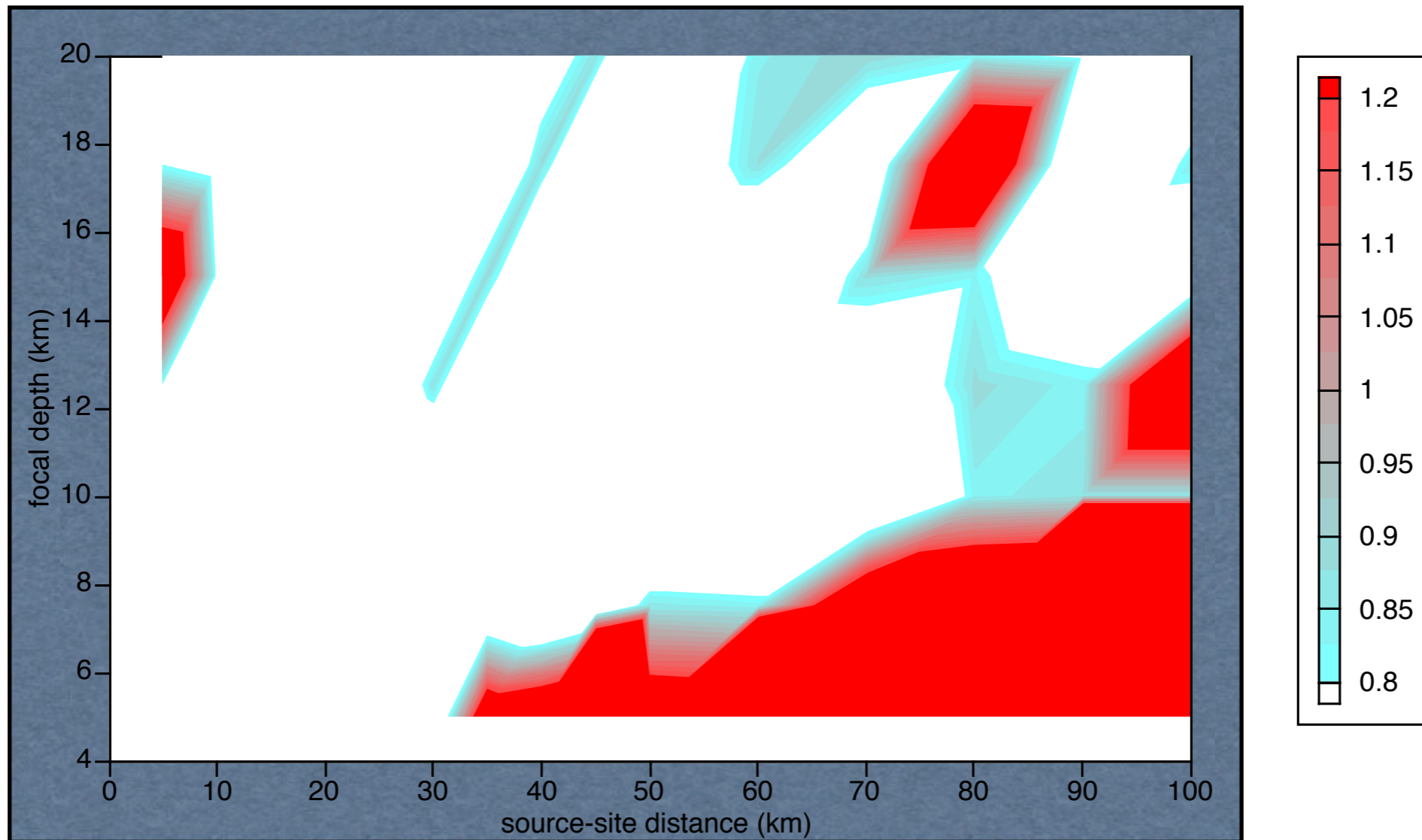


Parametric study 2 - towards 1 Hz

Another parametric study has been performed in order to find a seismic source-Warth site configuration providing a set of signals whose seismic energy is concentrated around 1 Hz, frequency that corresponds approximately to that of the fundamental transverse mode of oscillation of the bridge.

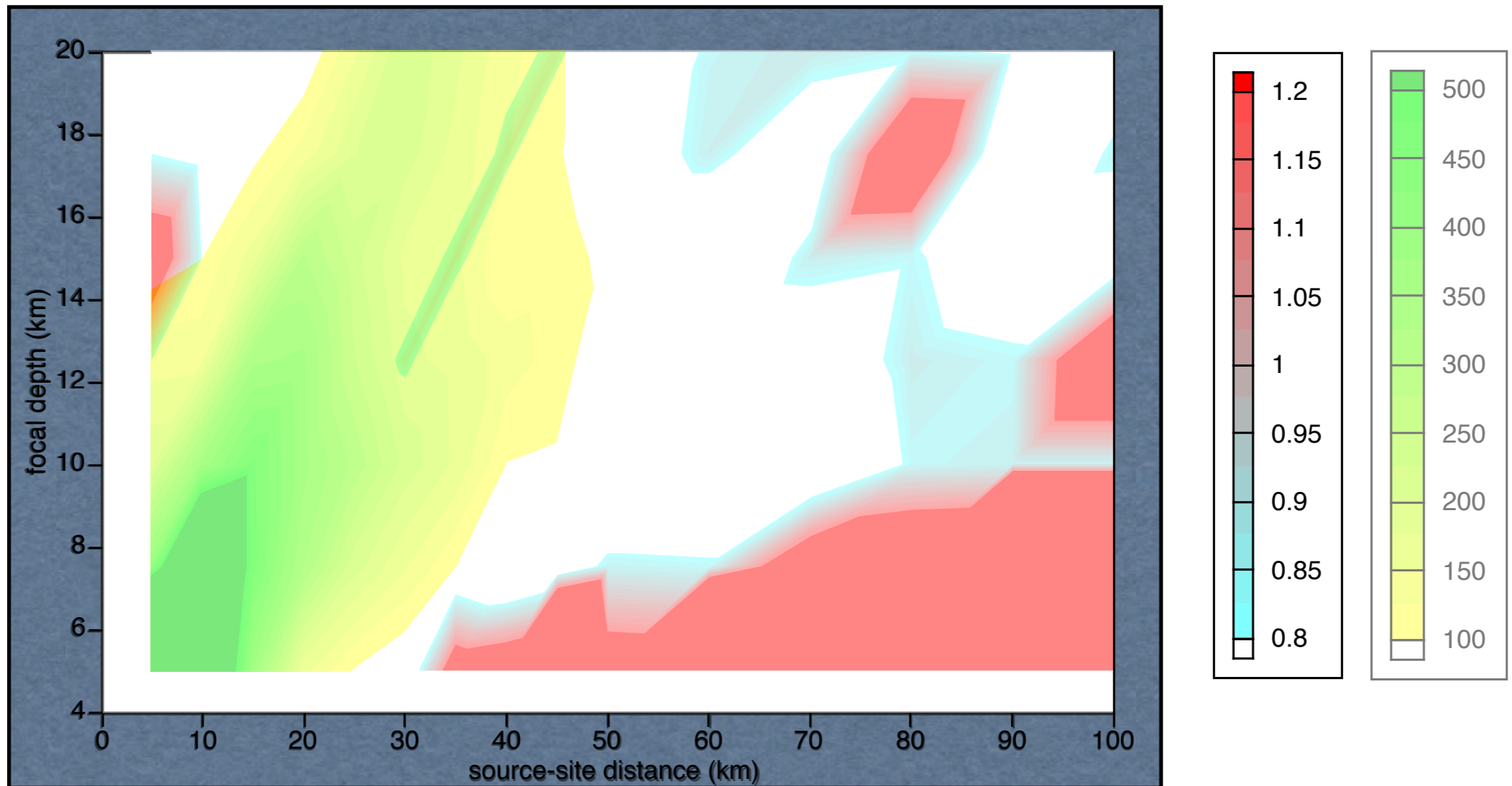
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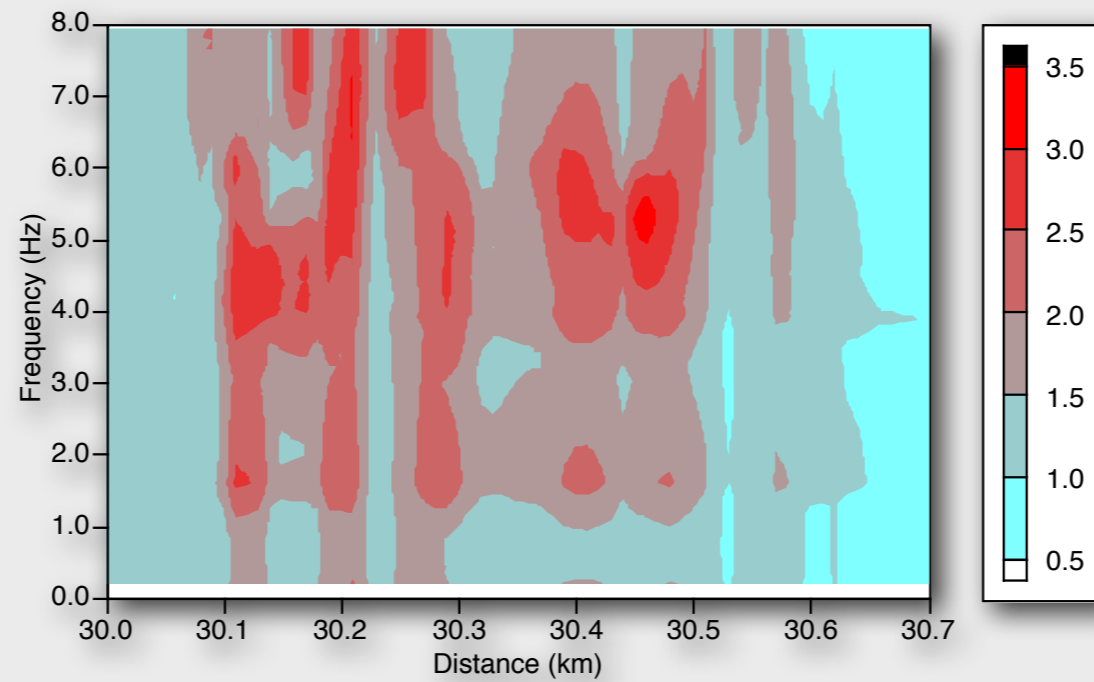
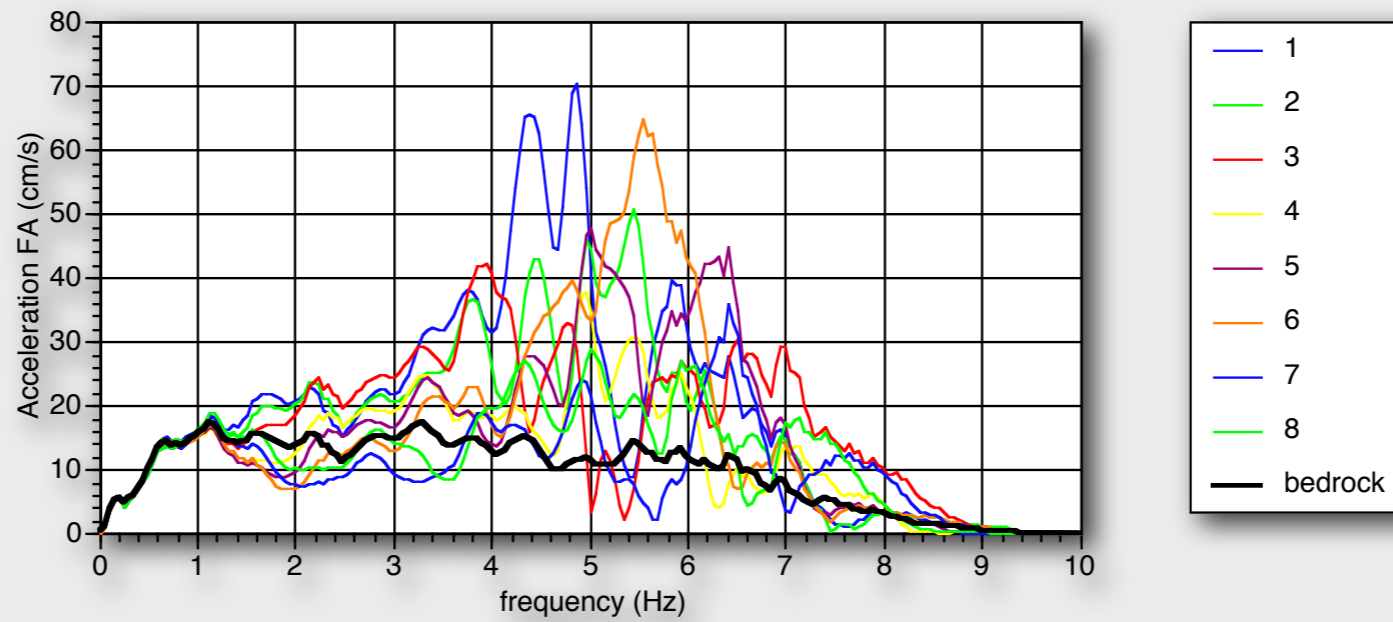
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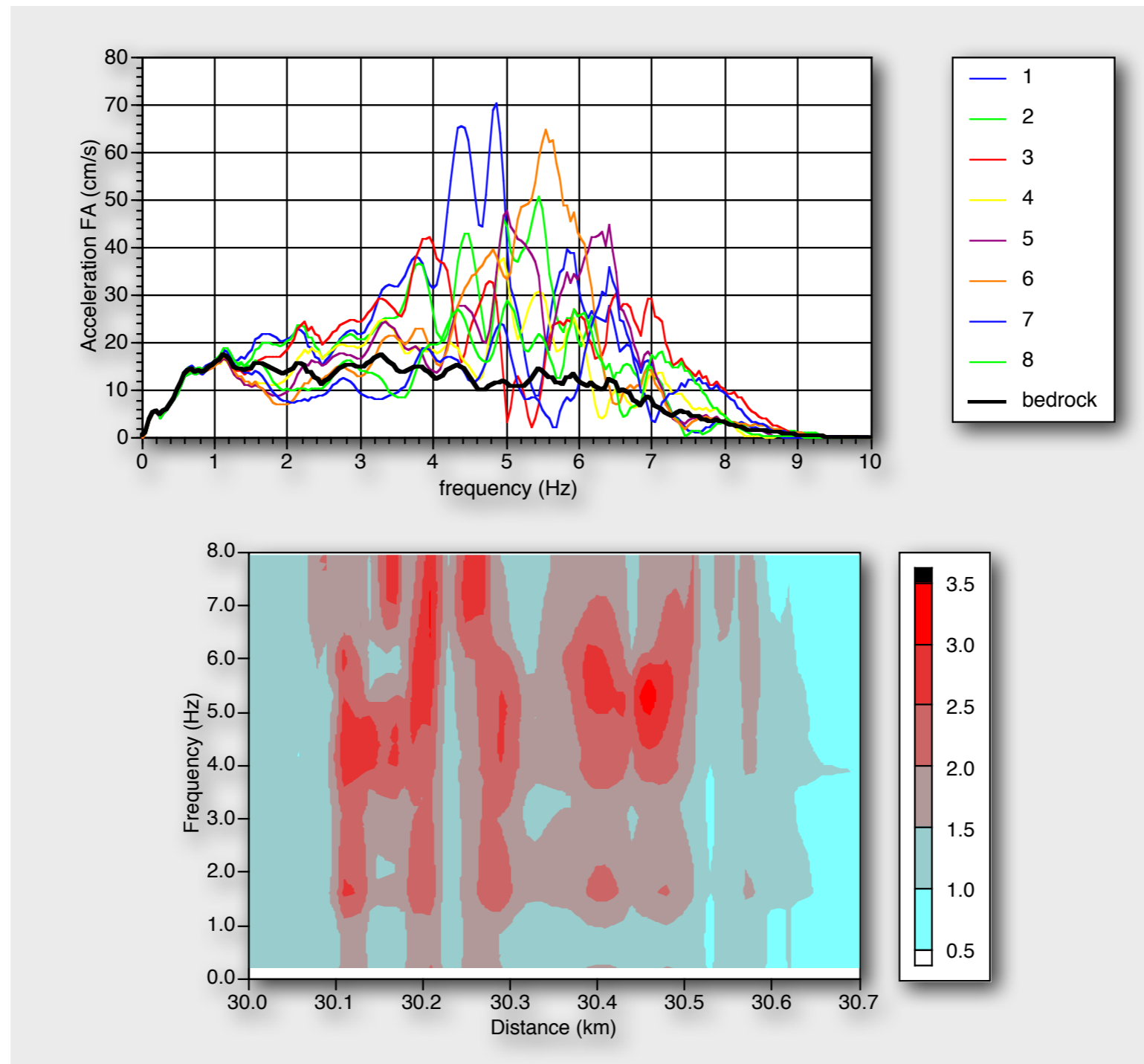


The results show that, in order to reach a relevant value of PGA (e.g. greater than 0.1g) in the desired period range (i.e. 0.8-1.2 s), an alternative and suitable configuration is a source **12 km deep at an epicentral distance of 30 km.**

Parametric study 2 - FS & RSR

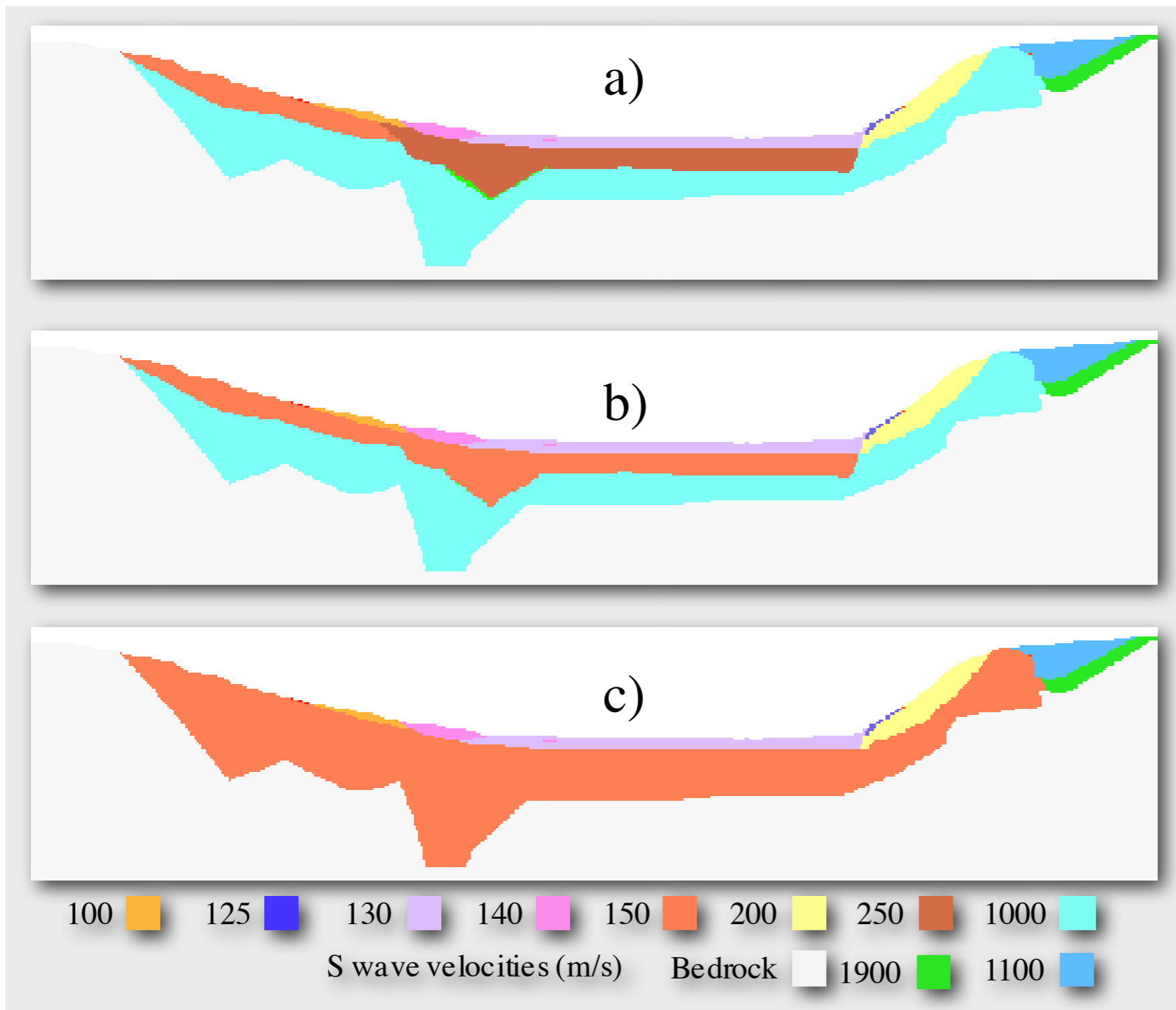


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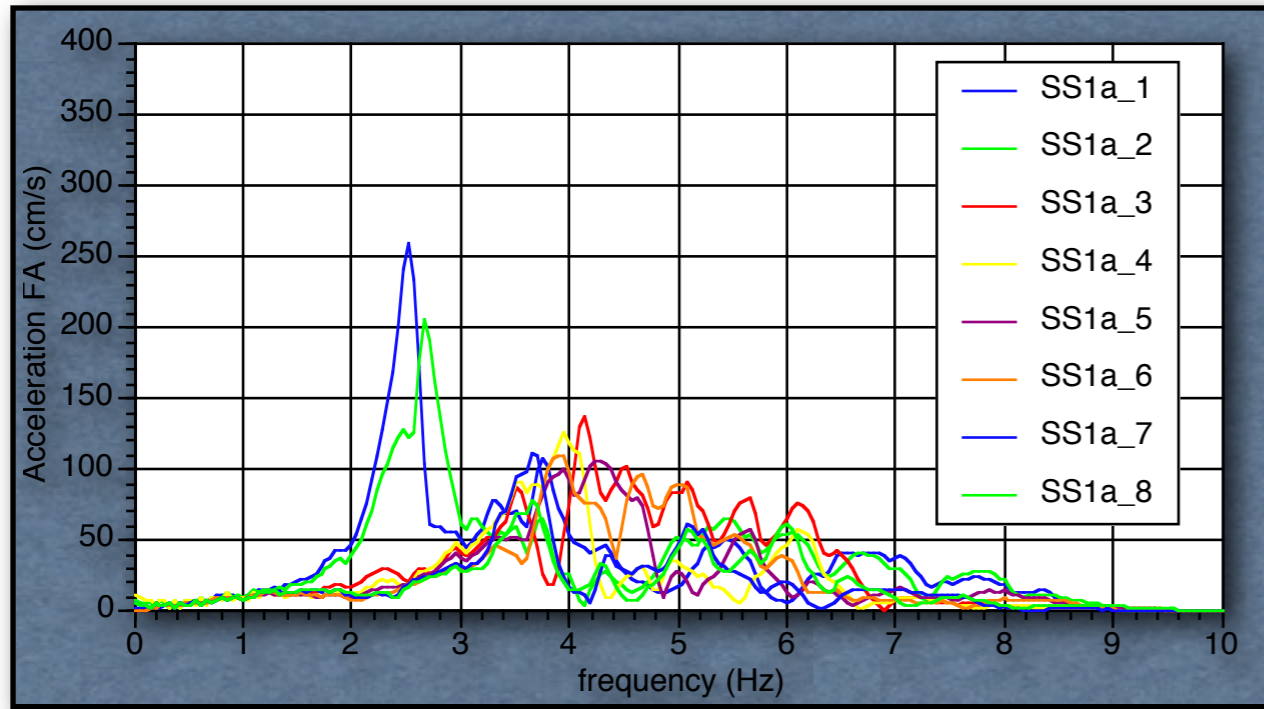


The results show that, the local structure beneath the Warth bridge greatly amplifies the frequency components between 3 and 7 Hz, i.e. a frequency range not corresponding to the fundamental transverse mode of oscillation of the bridge (about 0.8 Hz)

Parametric study 2 - towards 1 Hz (site)

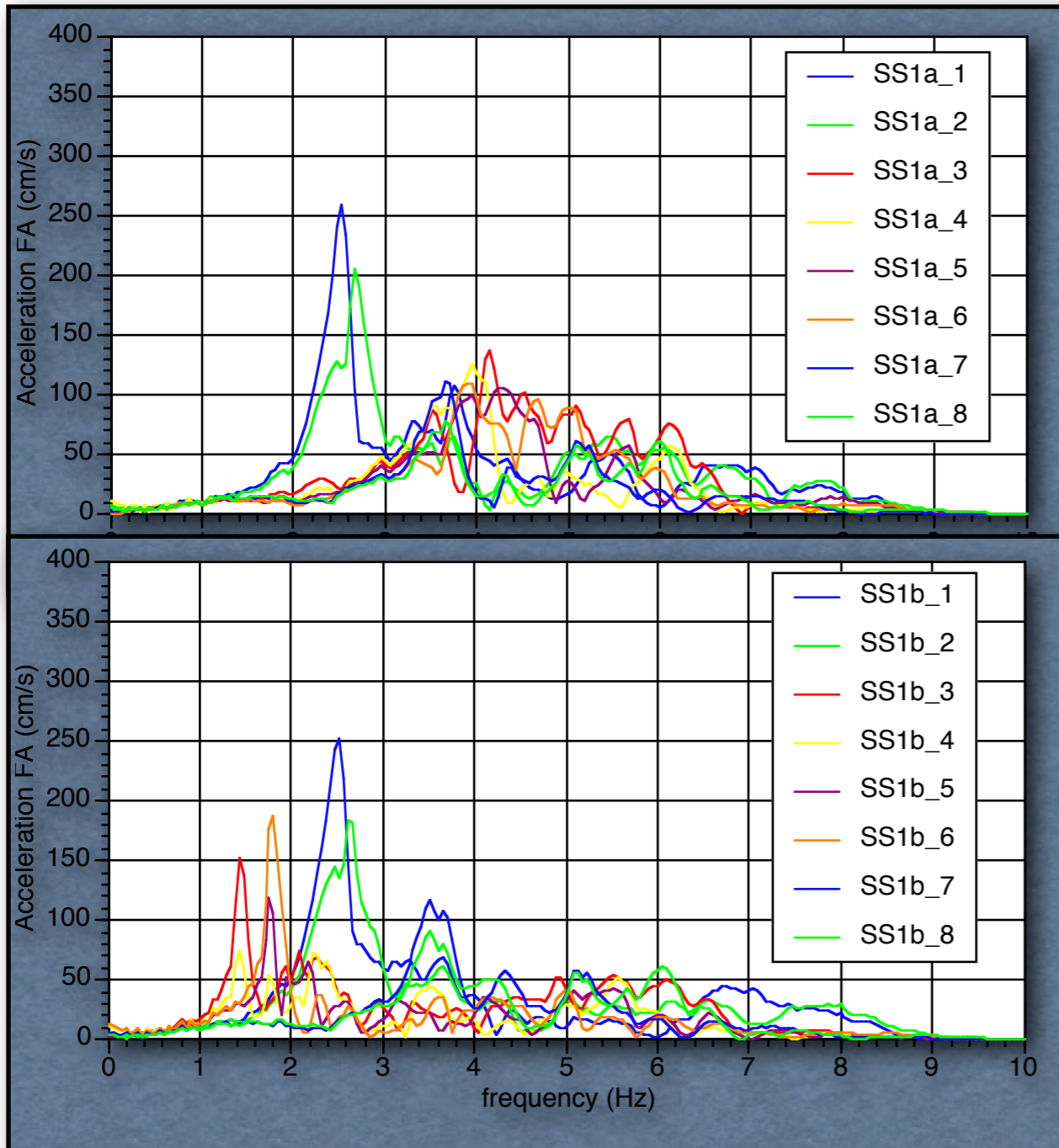


Local geotechnical models of Warth bridge section obtained lowering successively the S-wave velocities of the uppermost units

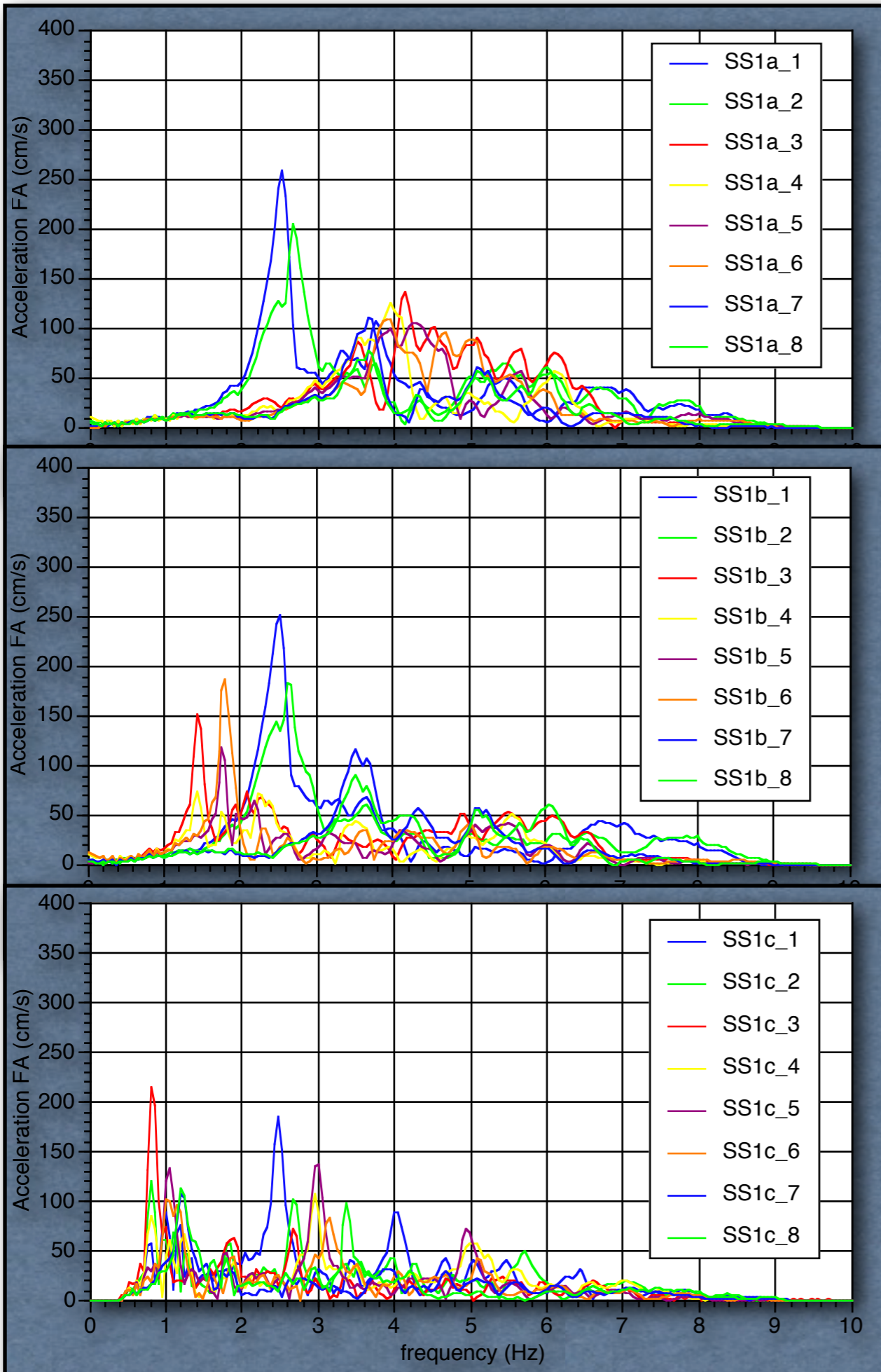


Fourier Amplitude spectra
M=5.5; d=8.6km; h=5km

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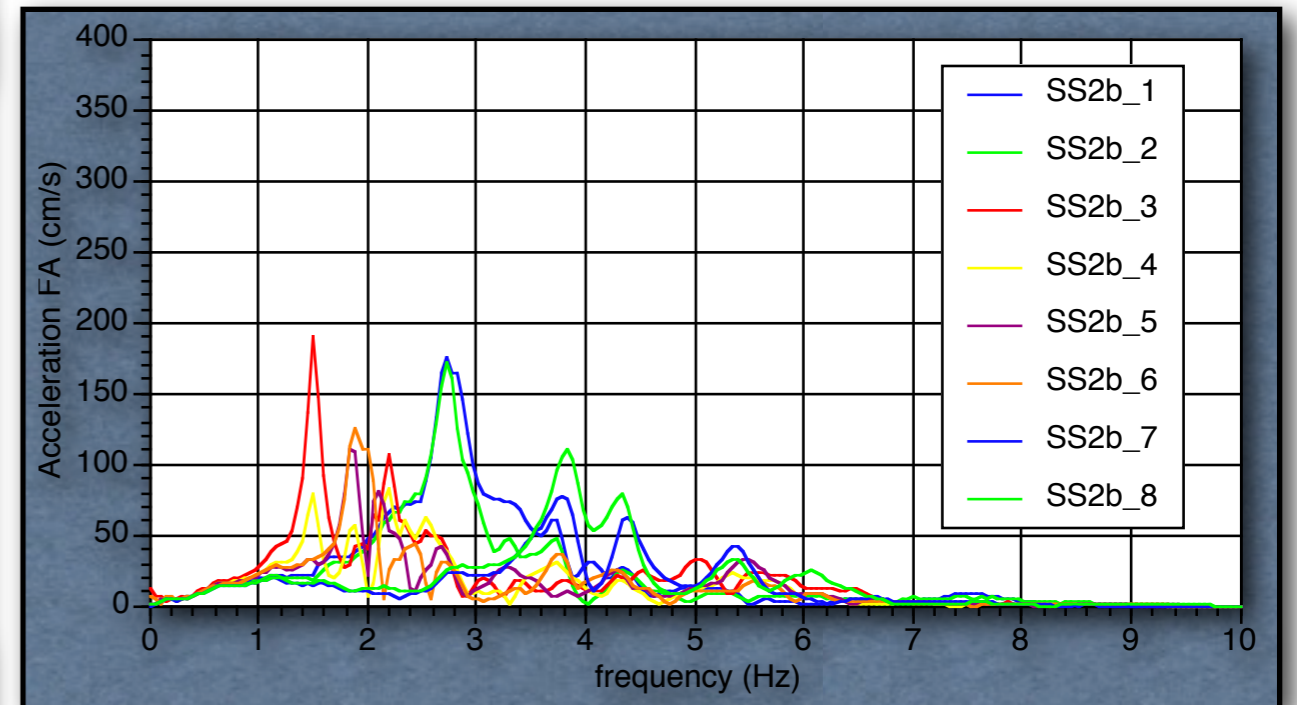
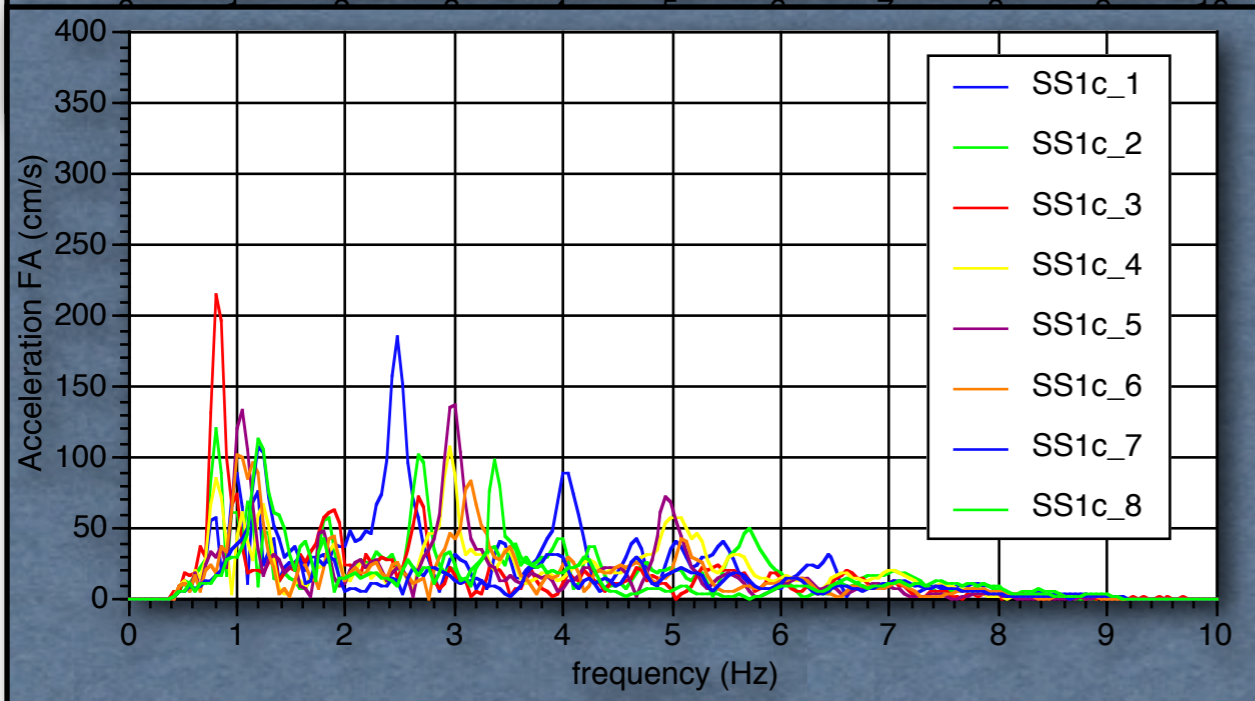
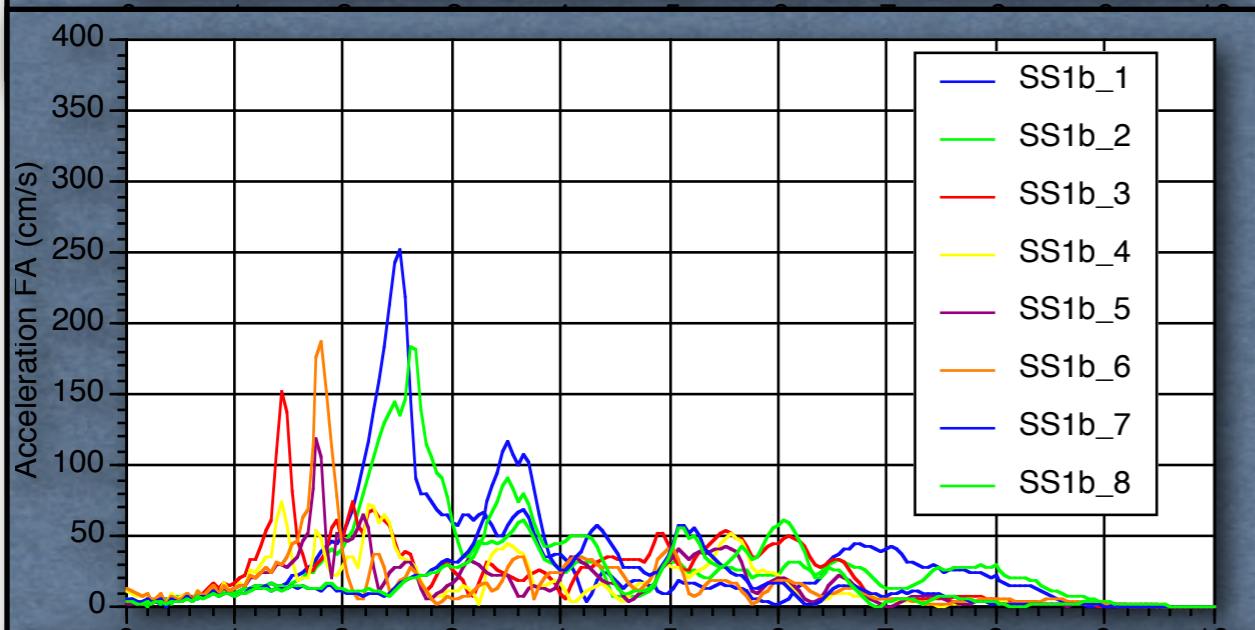
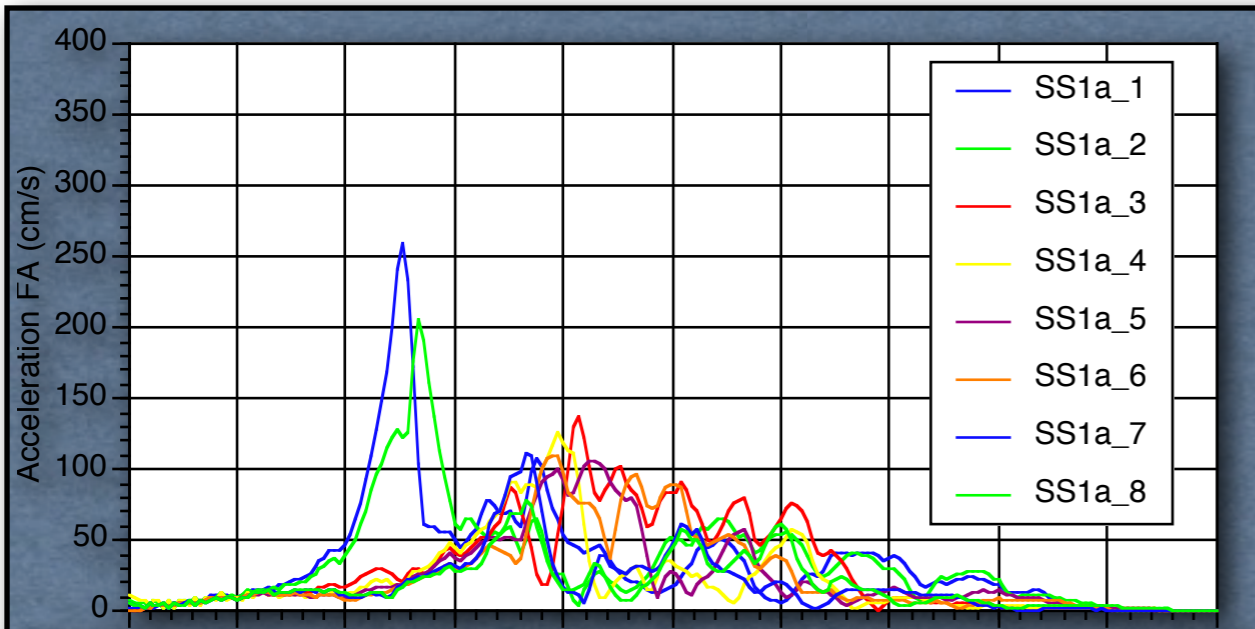


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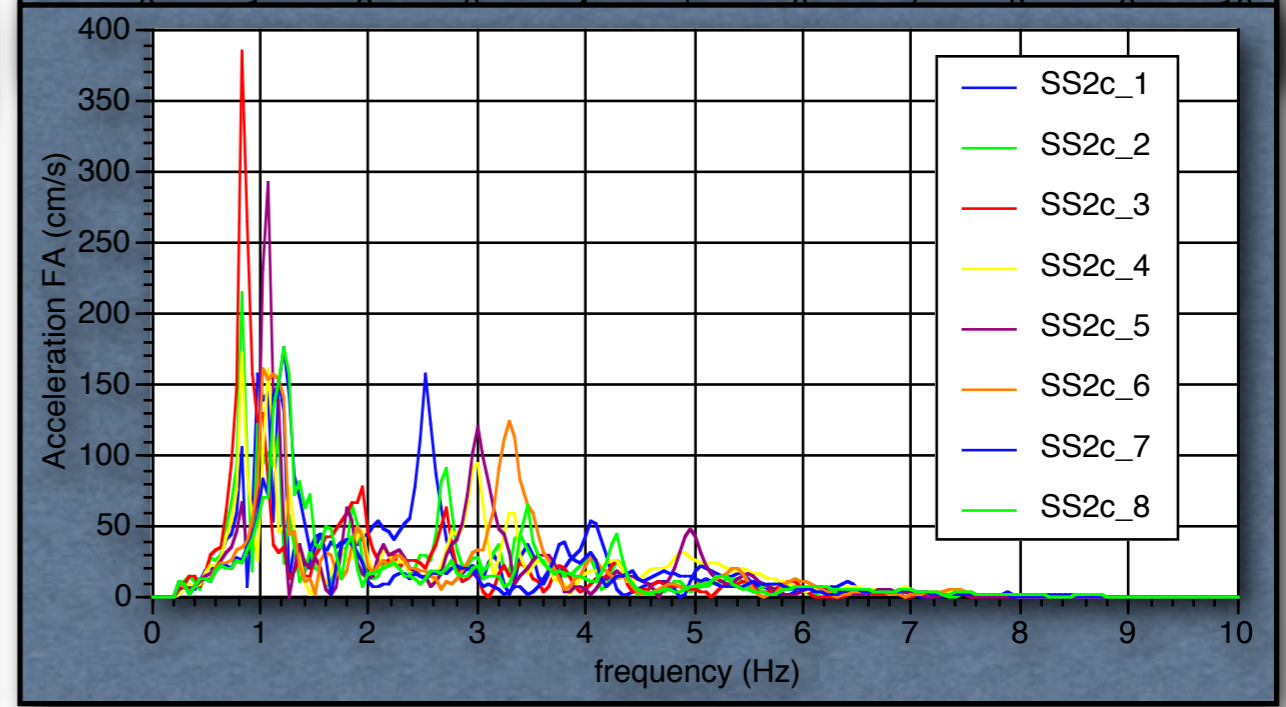
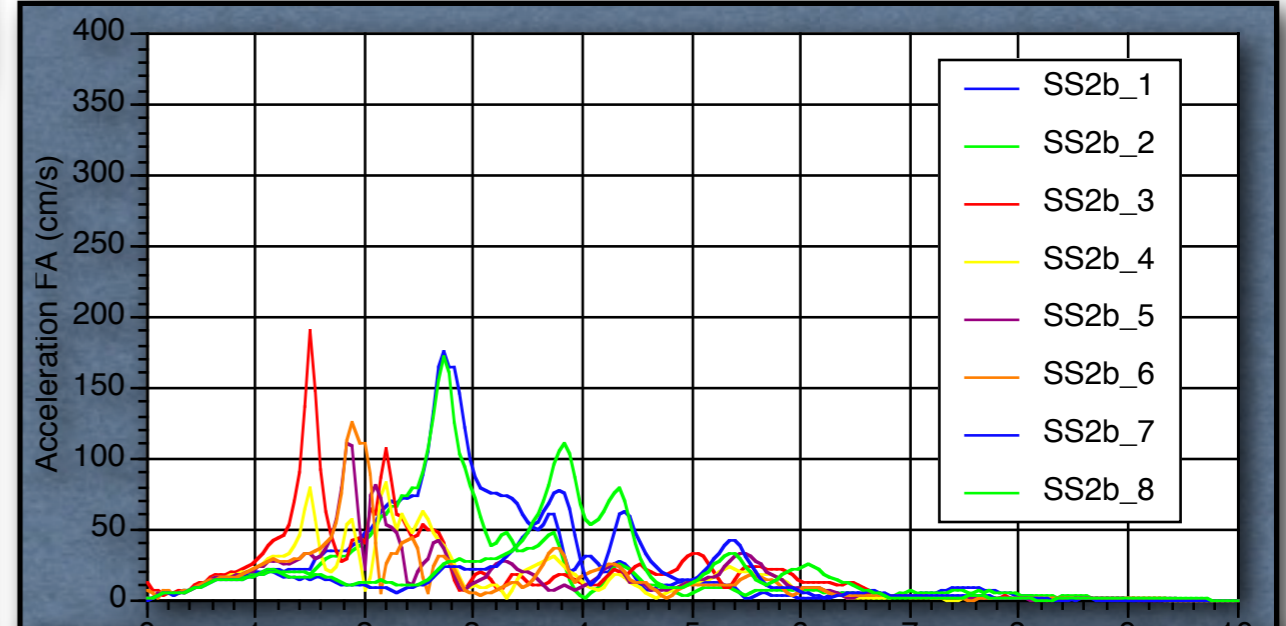
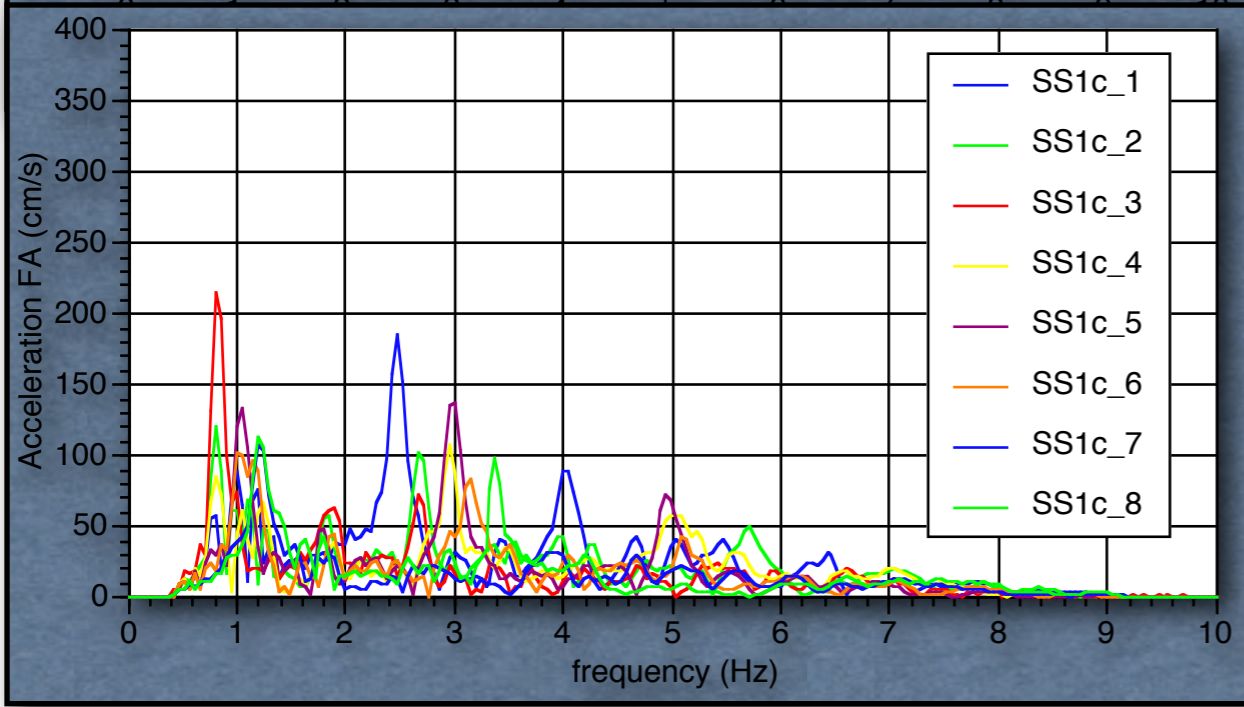
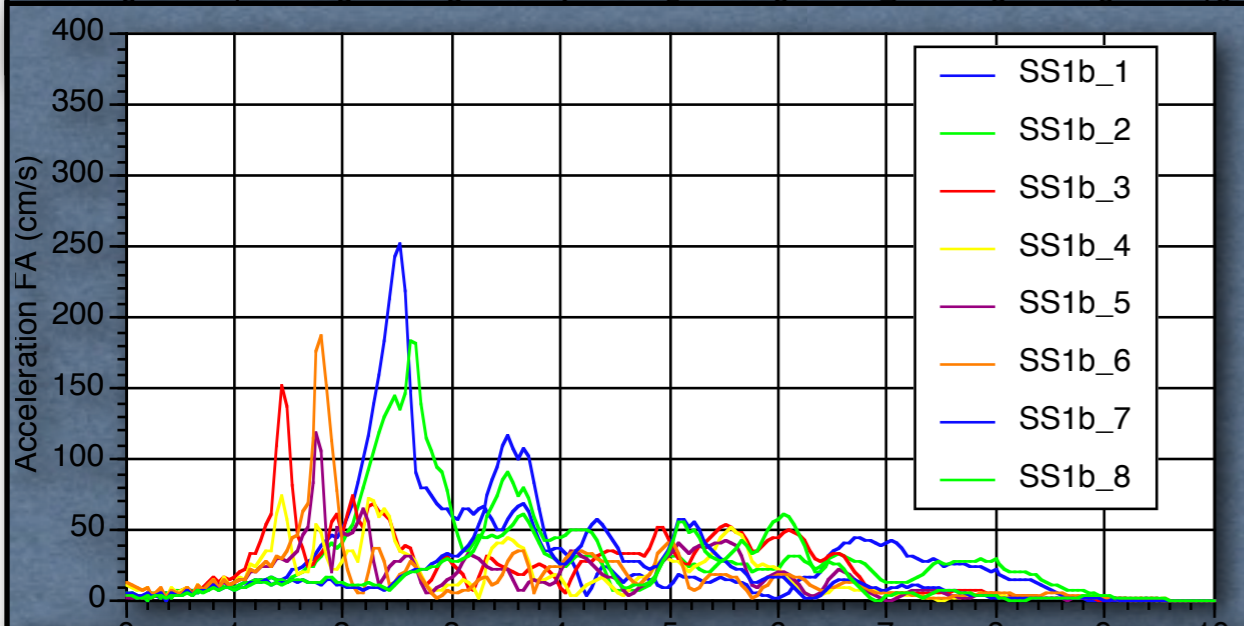
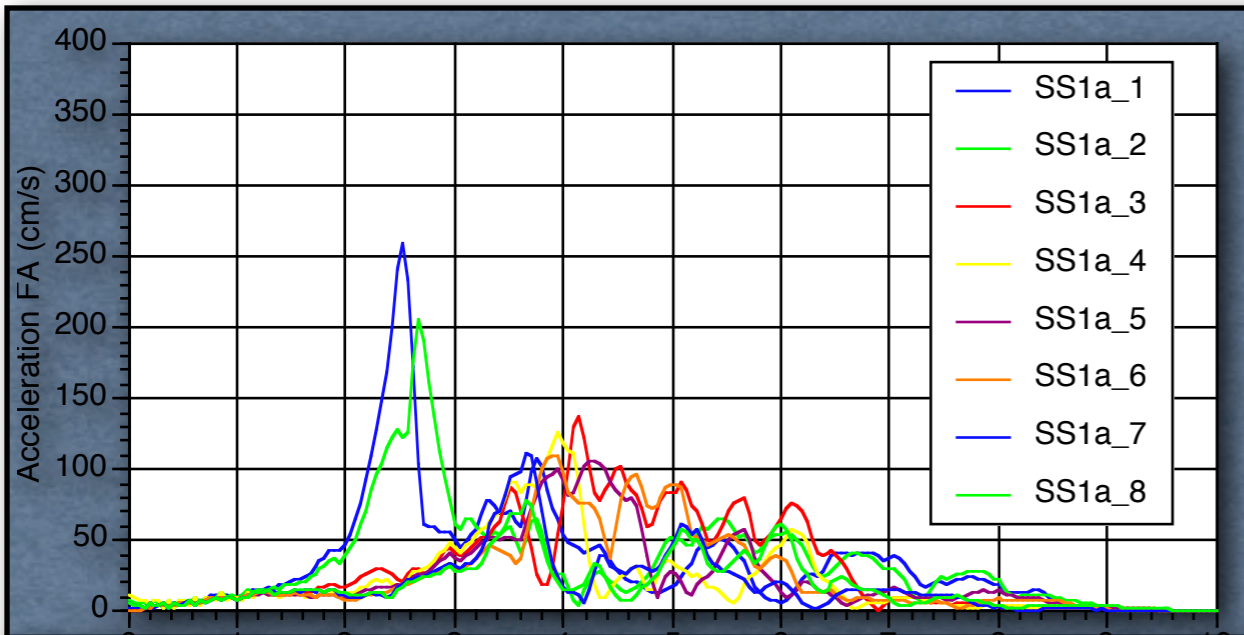
M=6.5; d=30.0km; h=12km



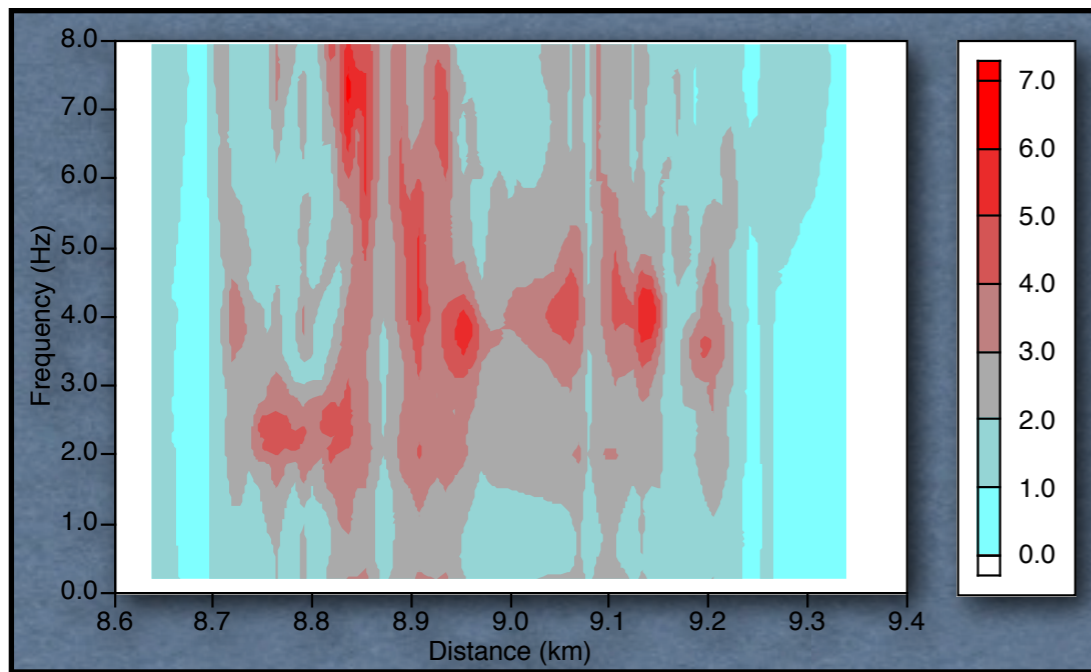
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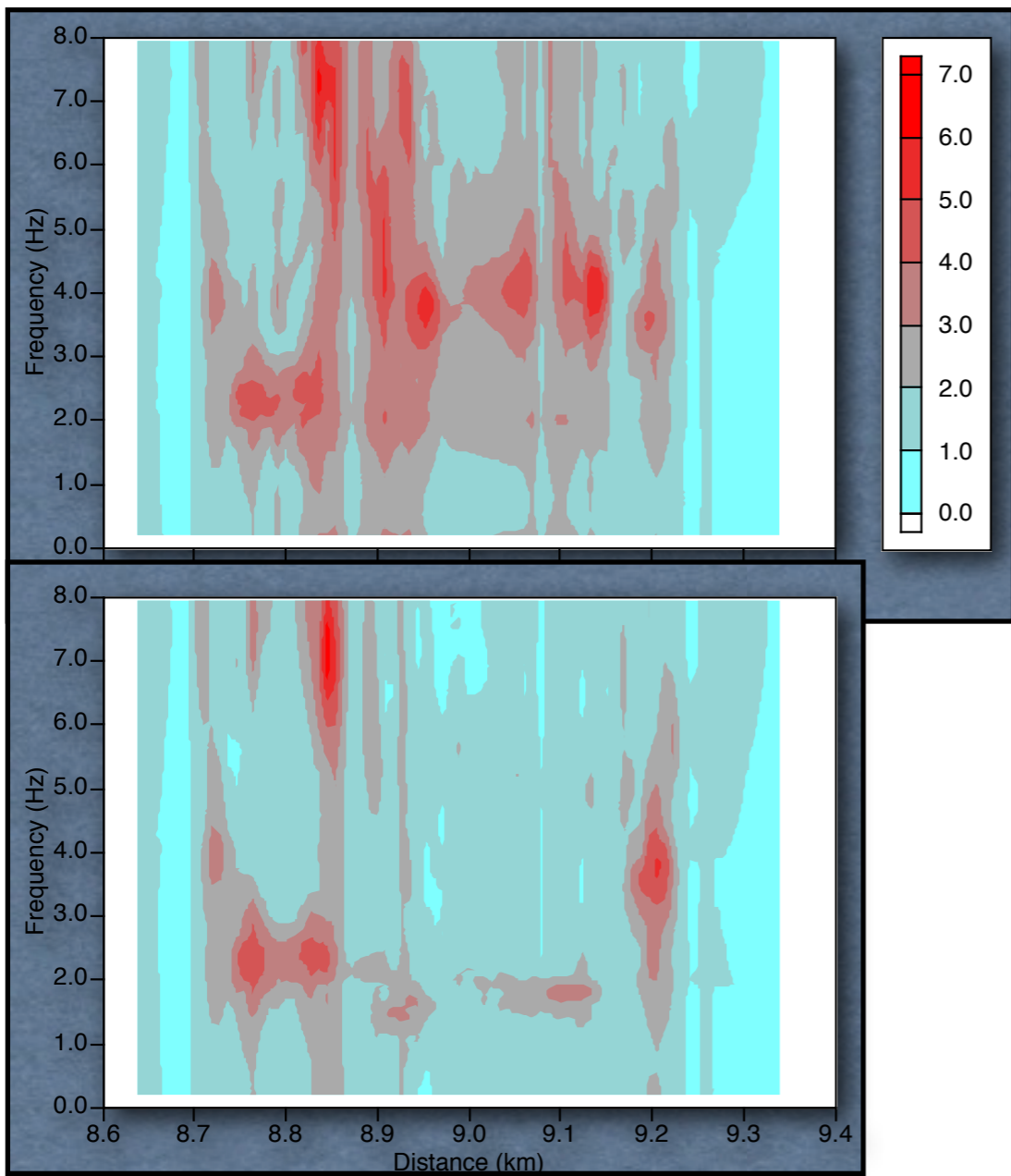
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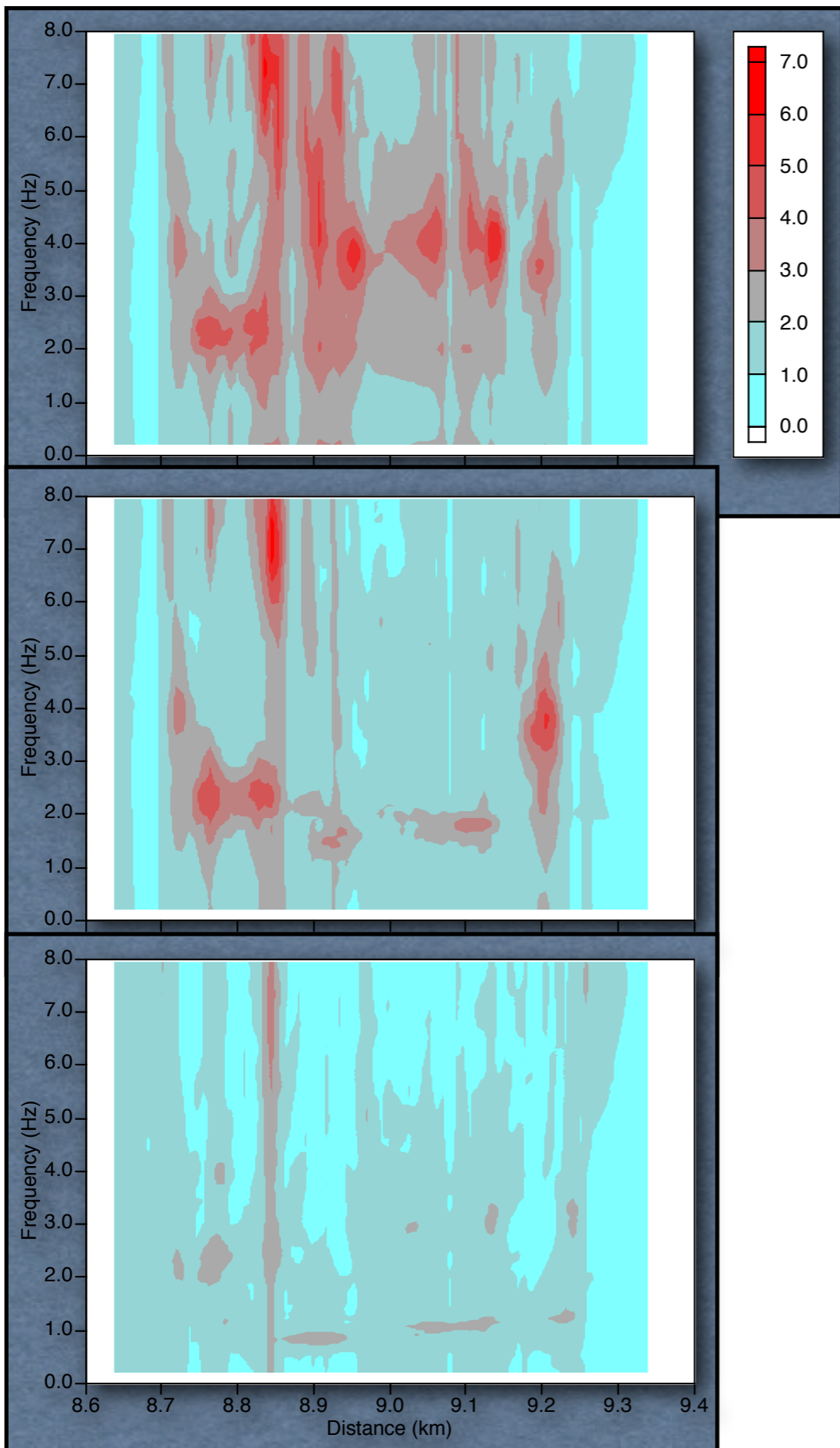
Site response estimation
 $M=5.5$; $d=8.6\text{km}$; $h=5\text{km}$



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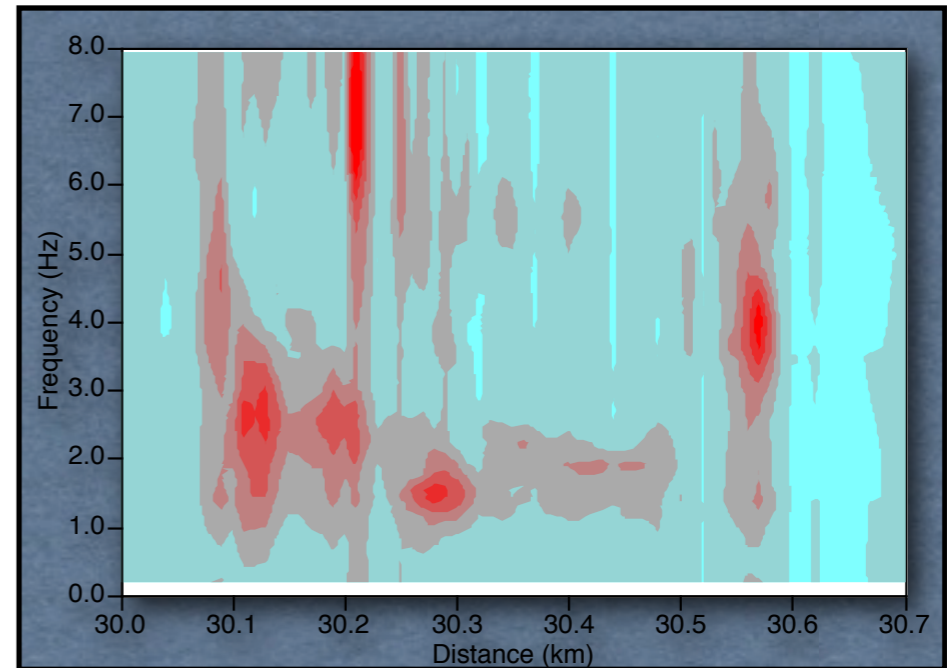
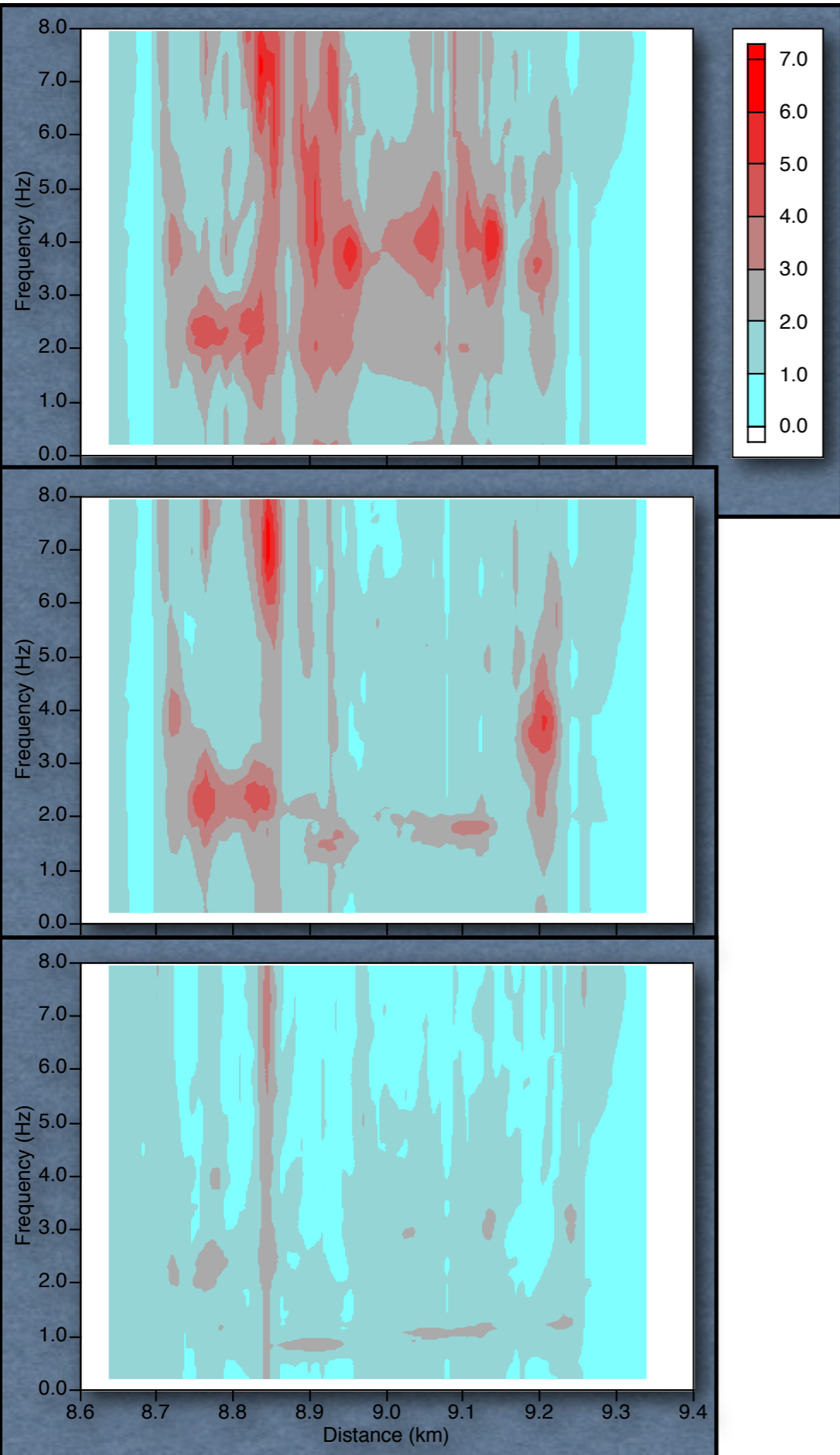


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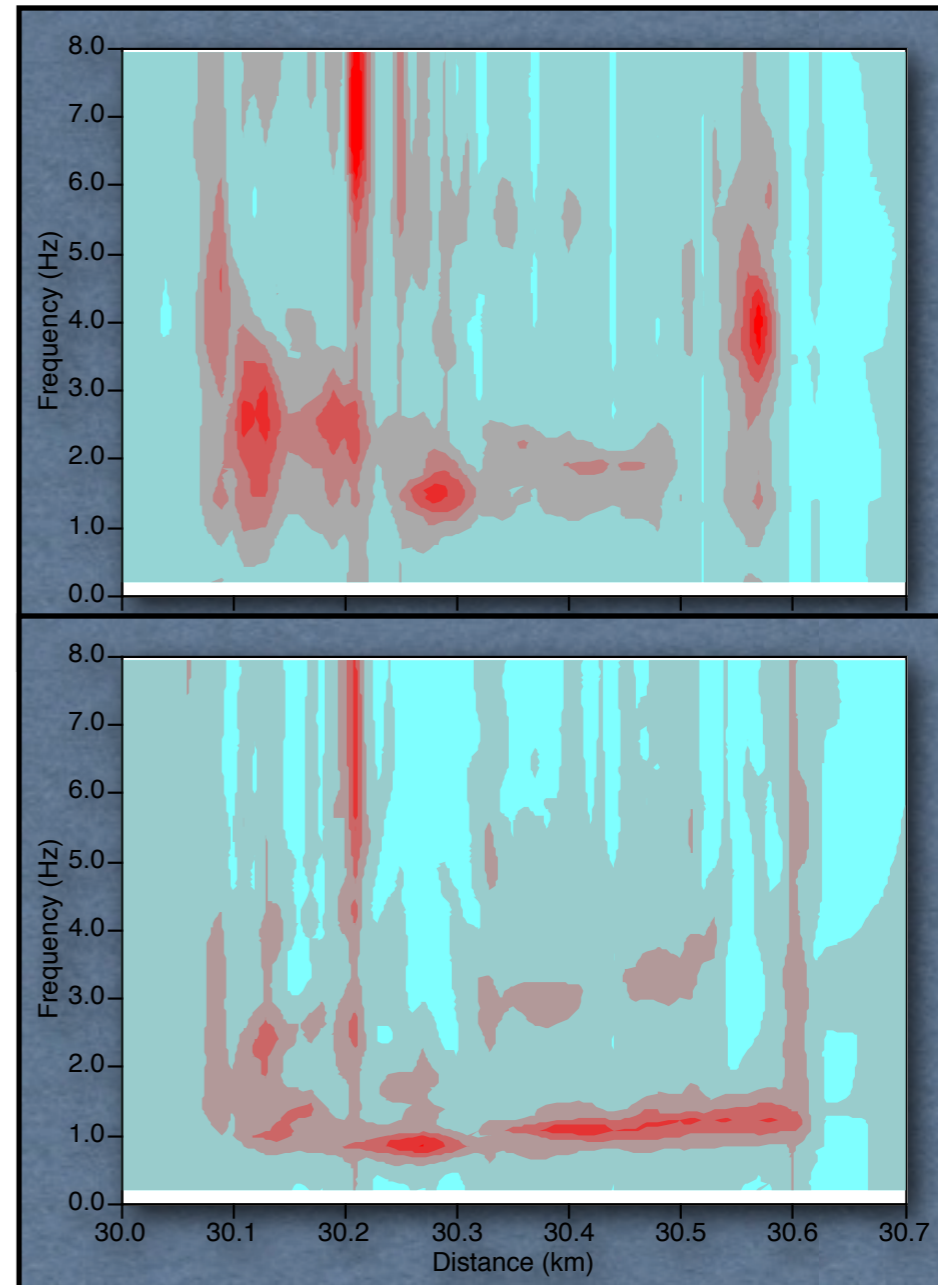
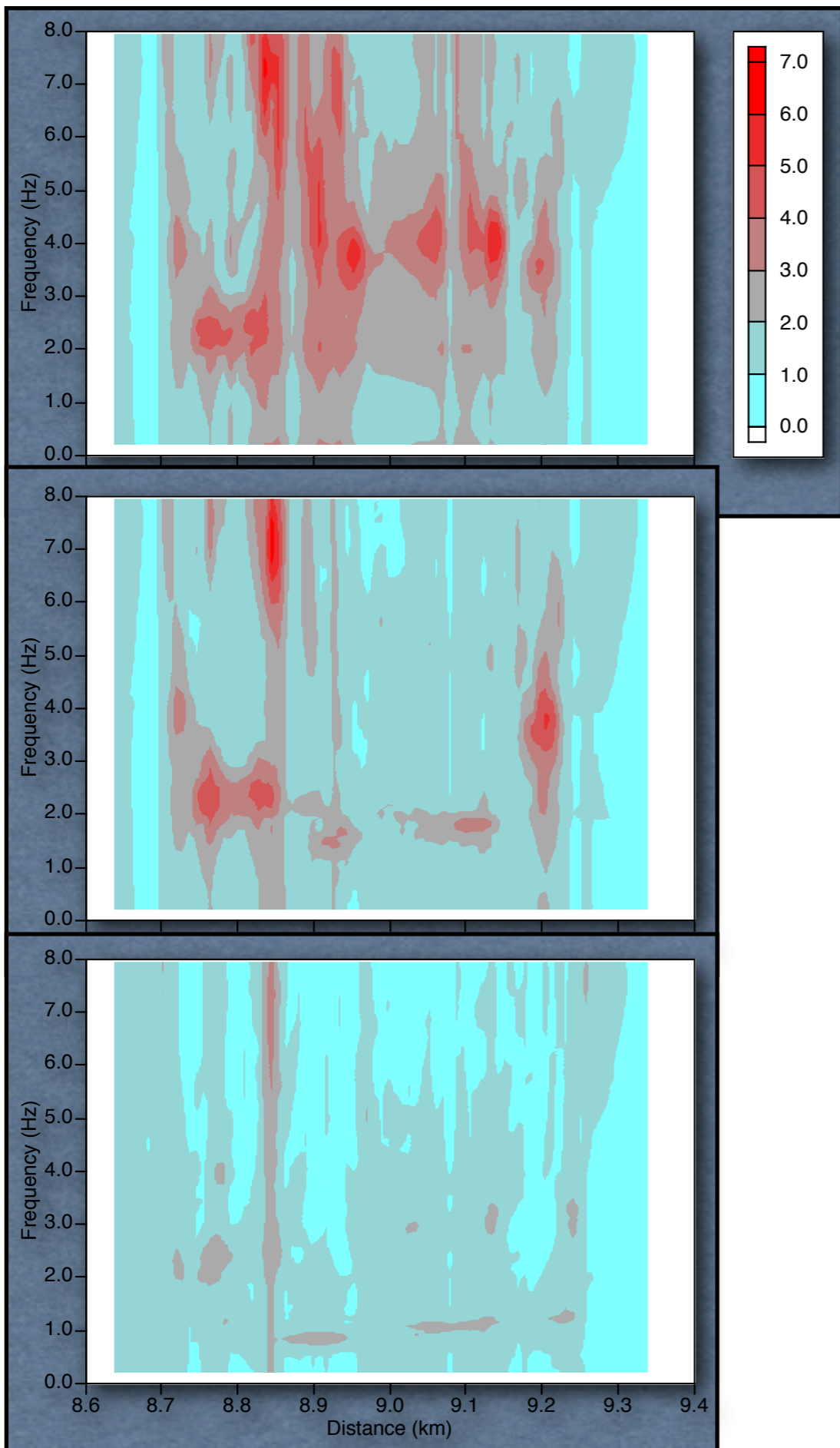
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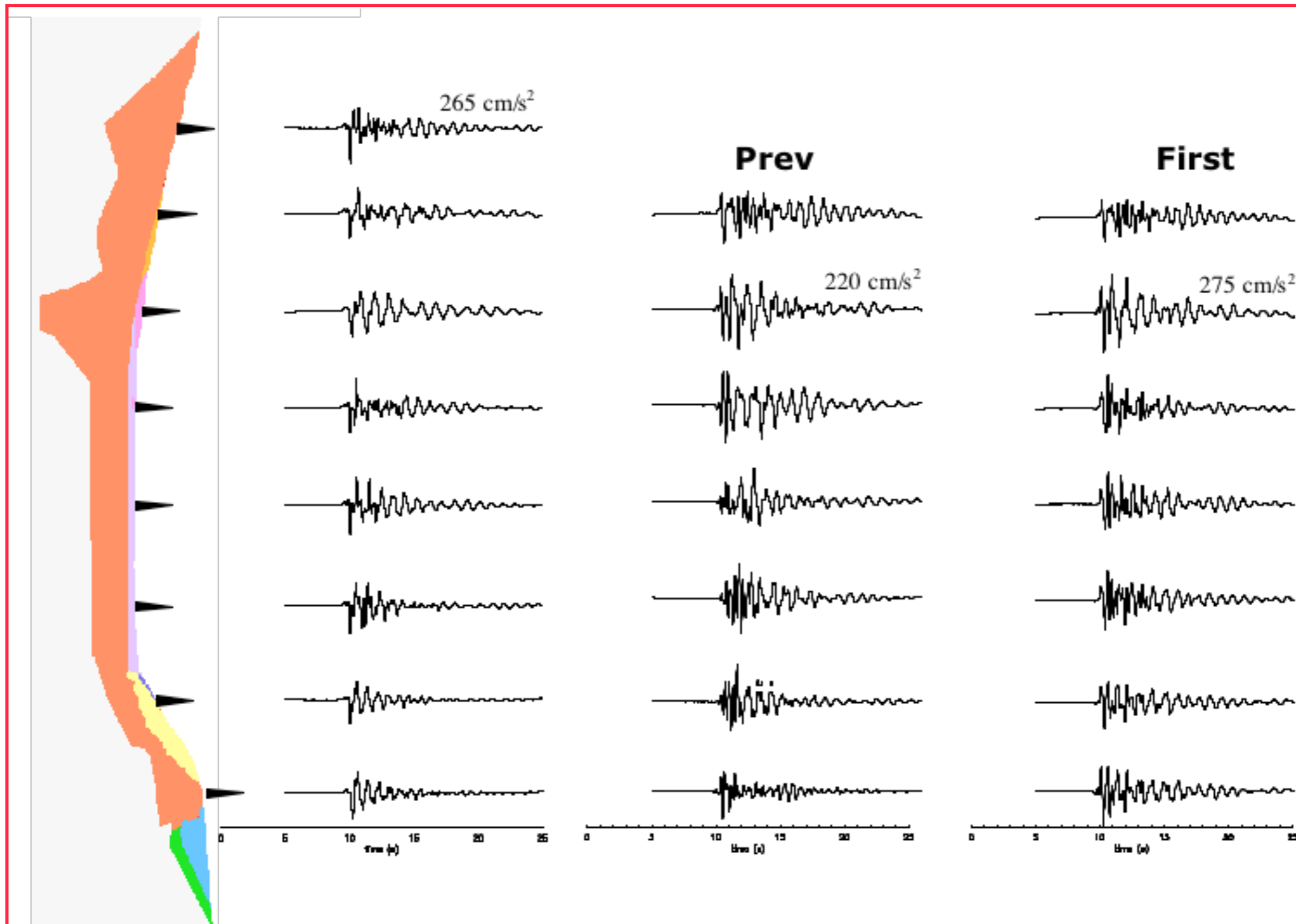


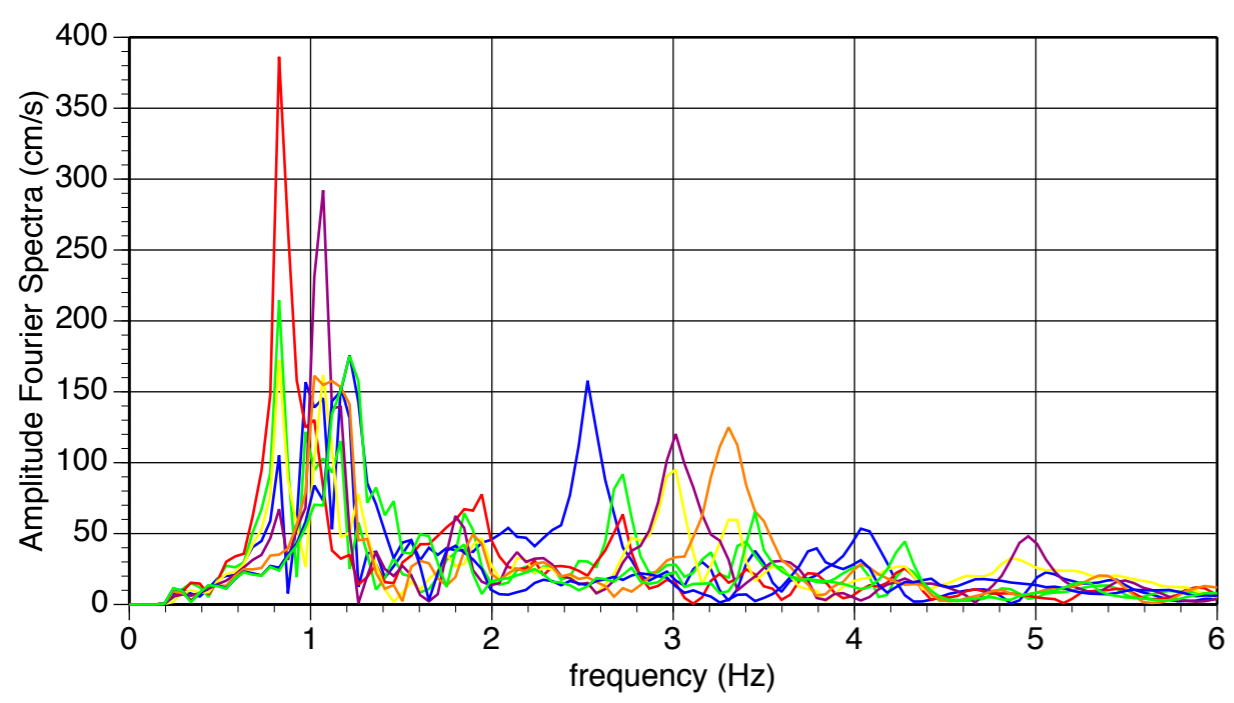
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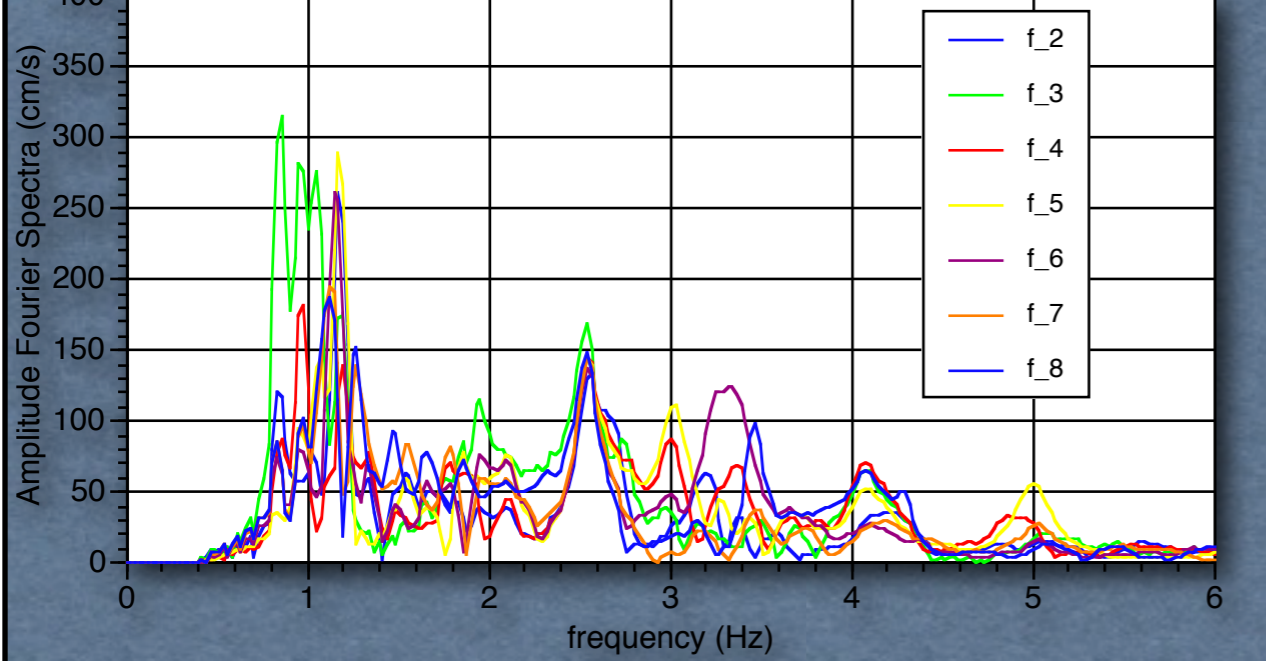
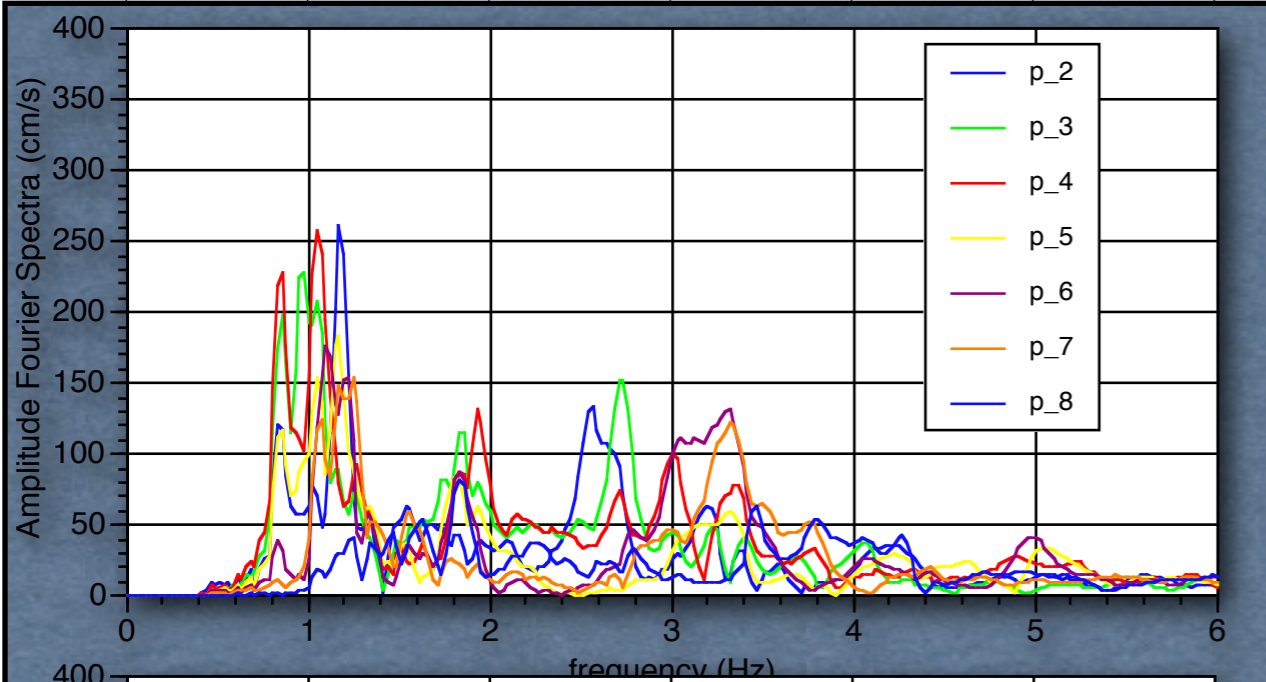
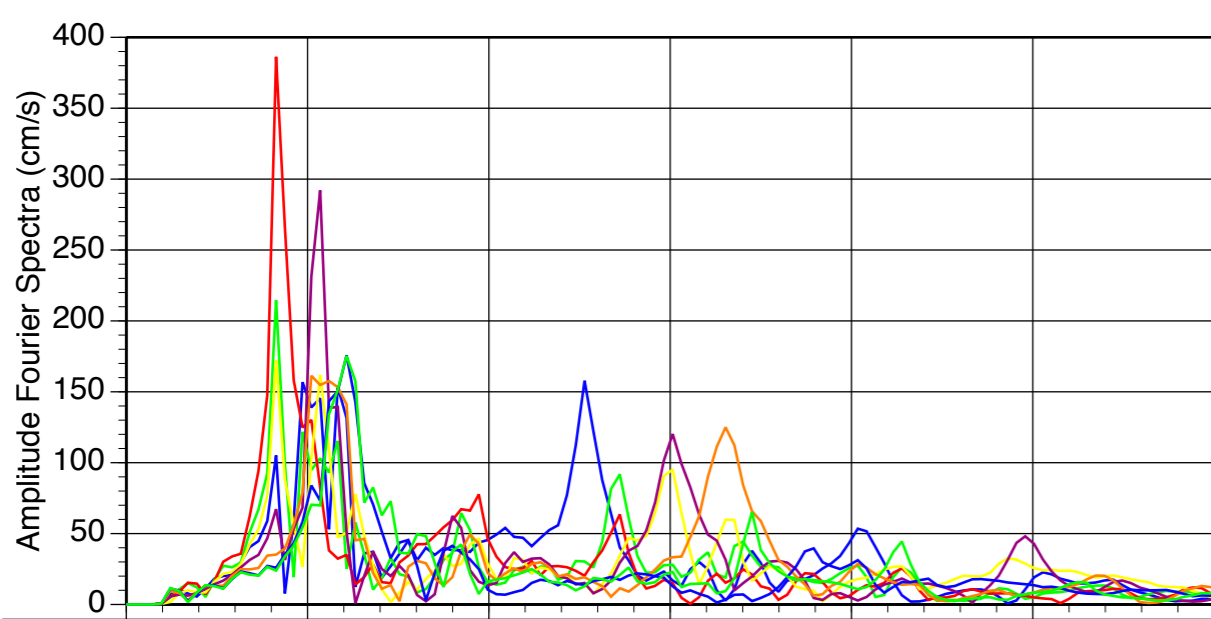
Synthetic accelerations and diffograms





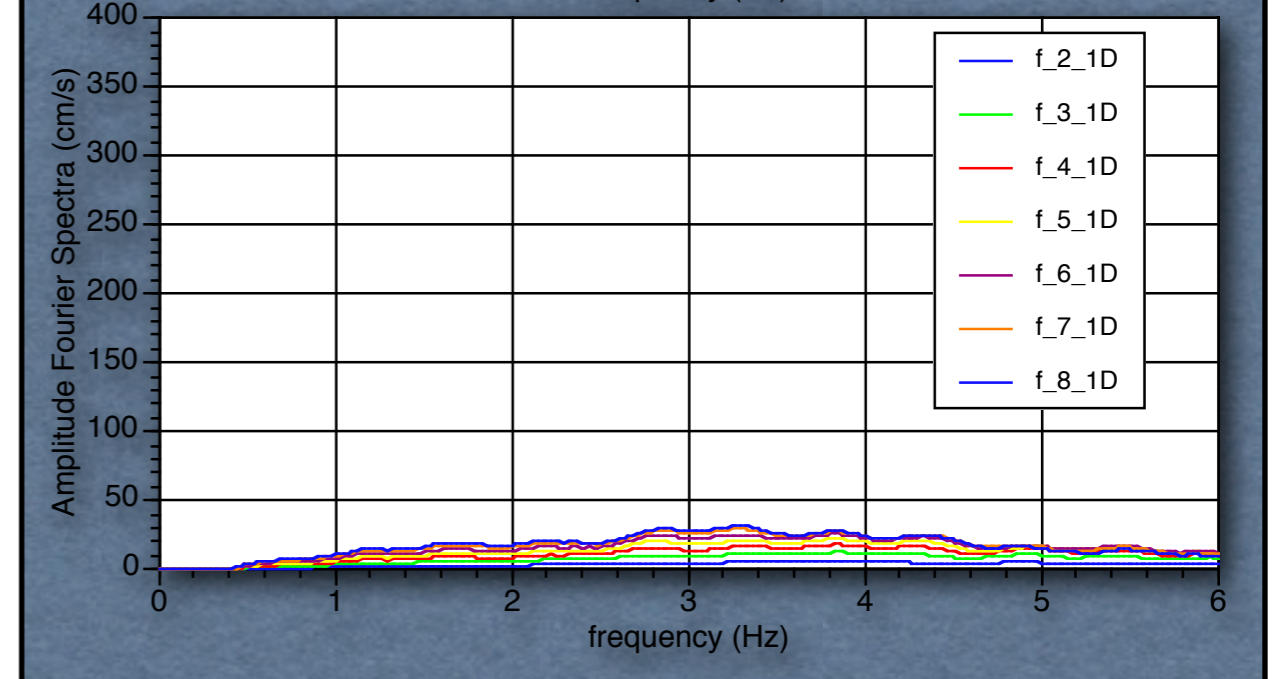
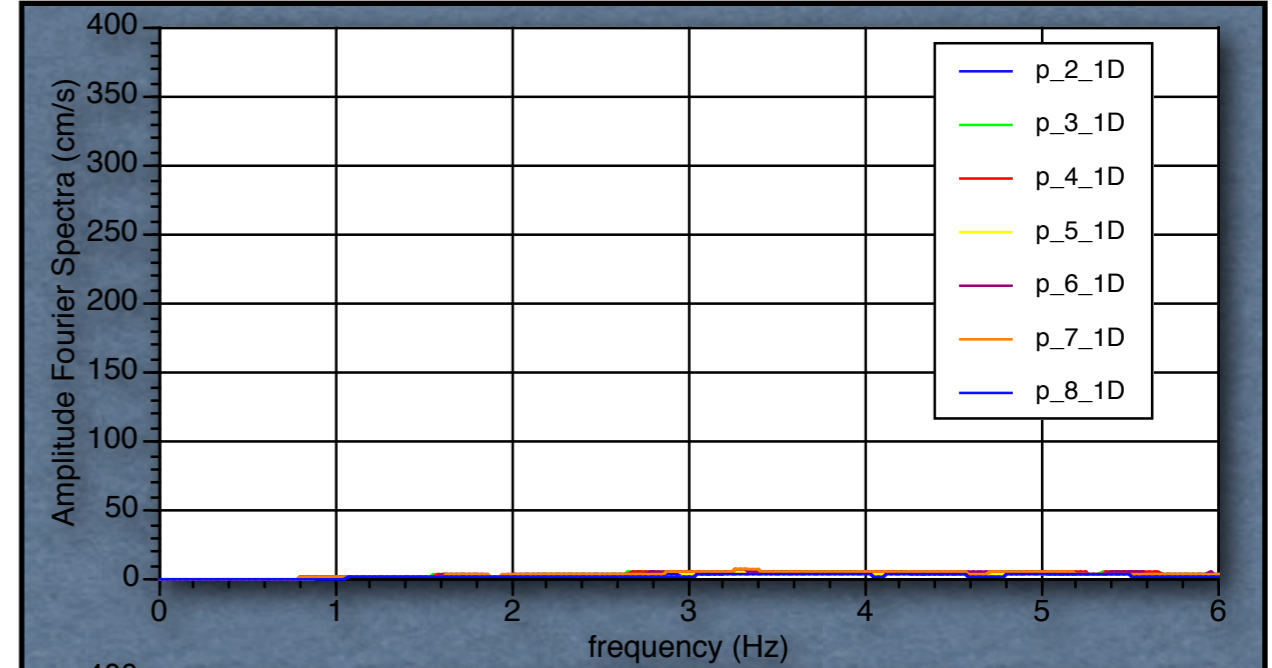
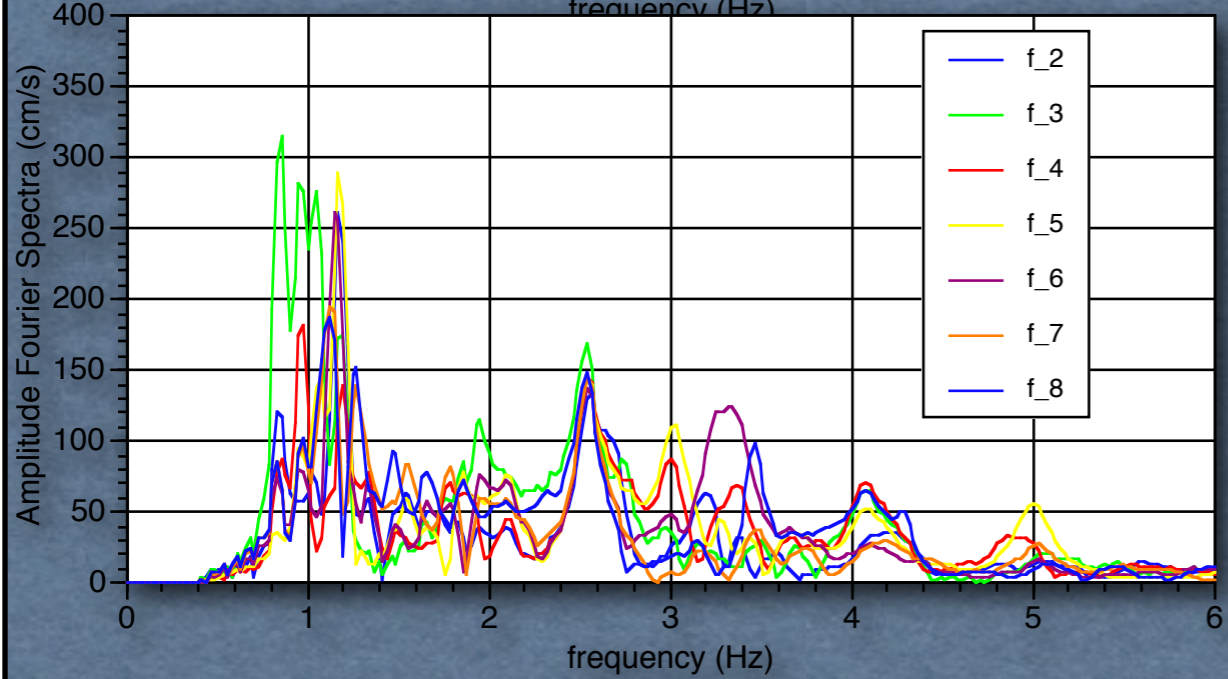
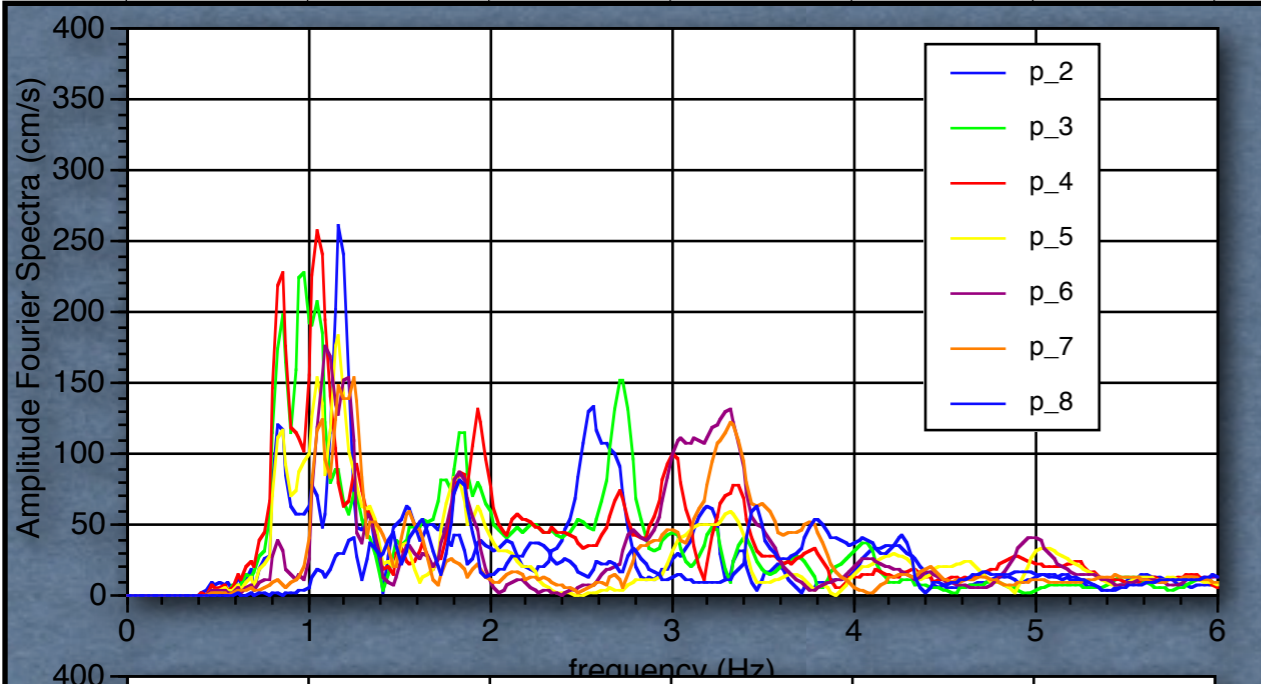
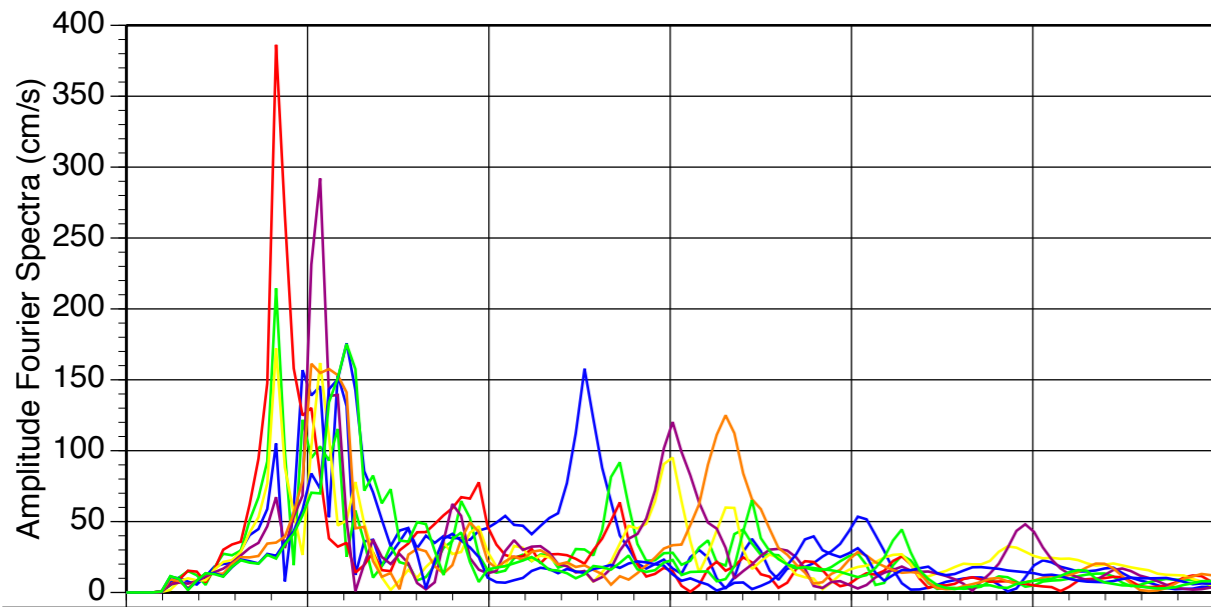
Fourier AS of
diffograms

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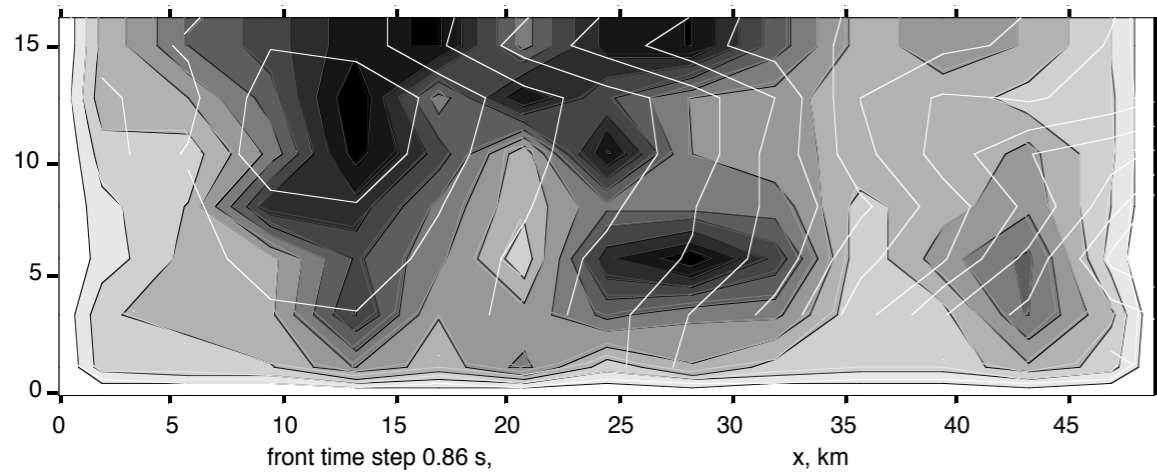


Fourier AS of diffograms

Bedrock

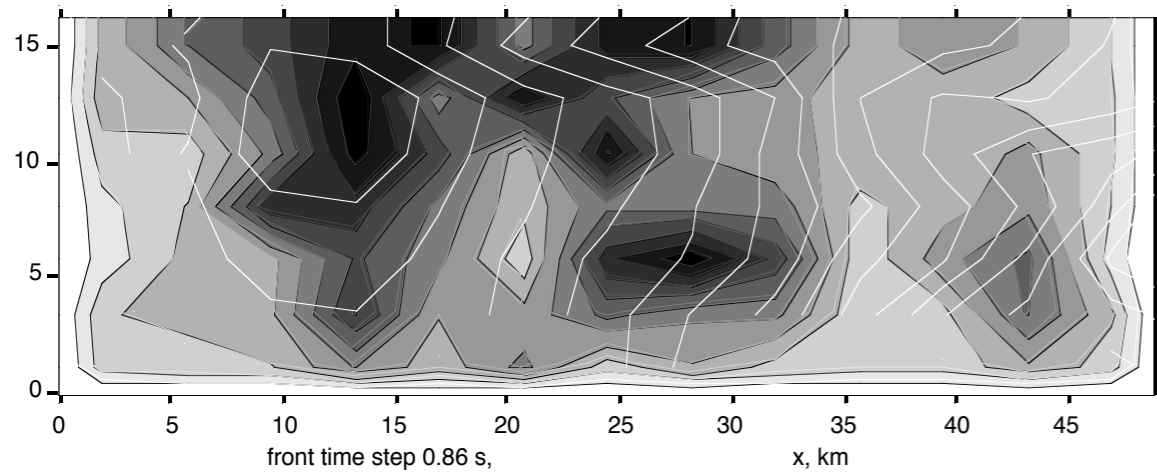


Extended source model



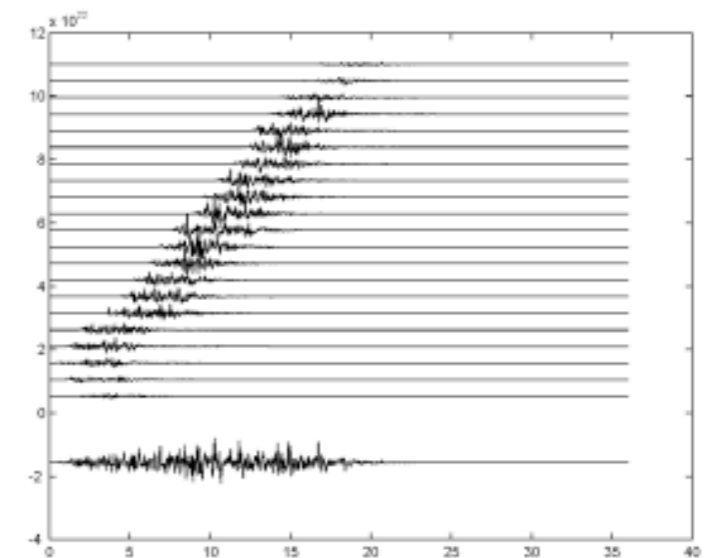
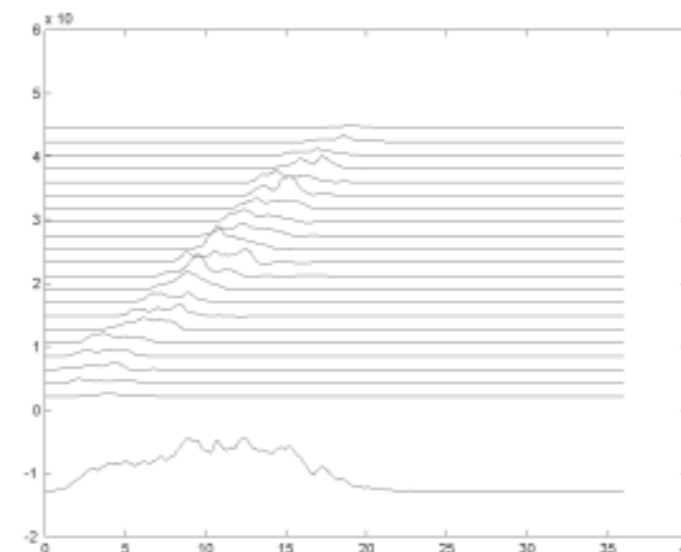
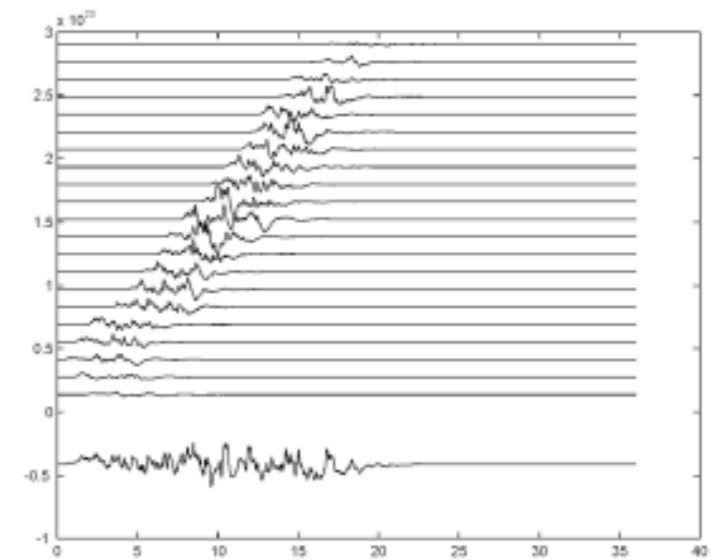
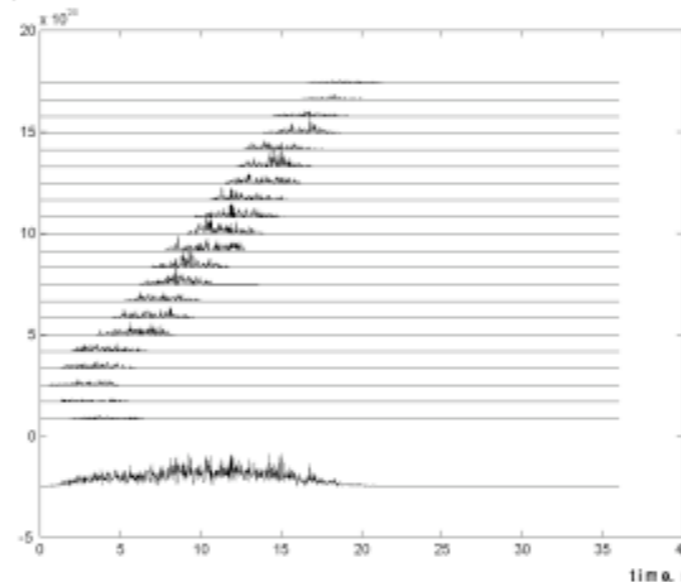
2-dimensional final slip distribution over a source rectangle, shown as a density plot. Preset magnitude value $M_w=7.0$. Rupture front evolution was simulated kinematically from random rupture velocity field.

Extended source model

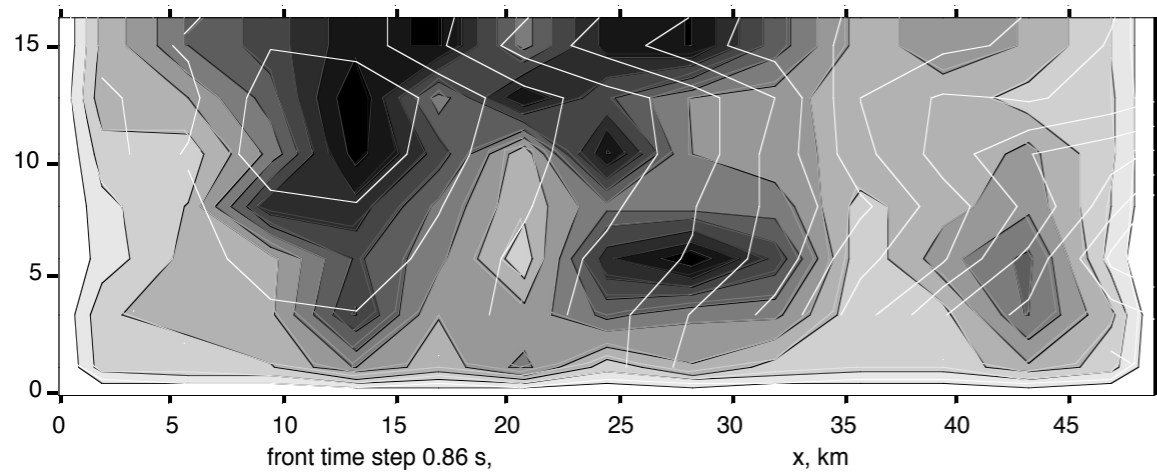


2-dimensional final slip distribution over a source rectangle, shown as a density plot. Preset magnitude value $M_w=7.0$. Rupture front evolution was simulated kinematically from random rupture velocity field.

Space-time histories for each of 21 subevents of the simplified “line” source model of a simulated $M_w=7$ earthquake, and sum over subevents, giving the entire-source far-field time function

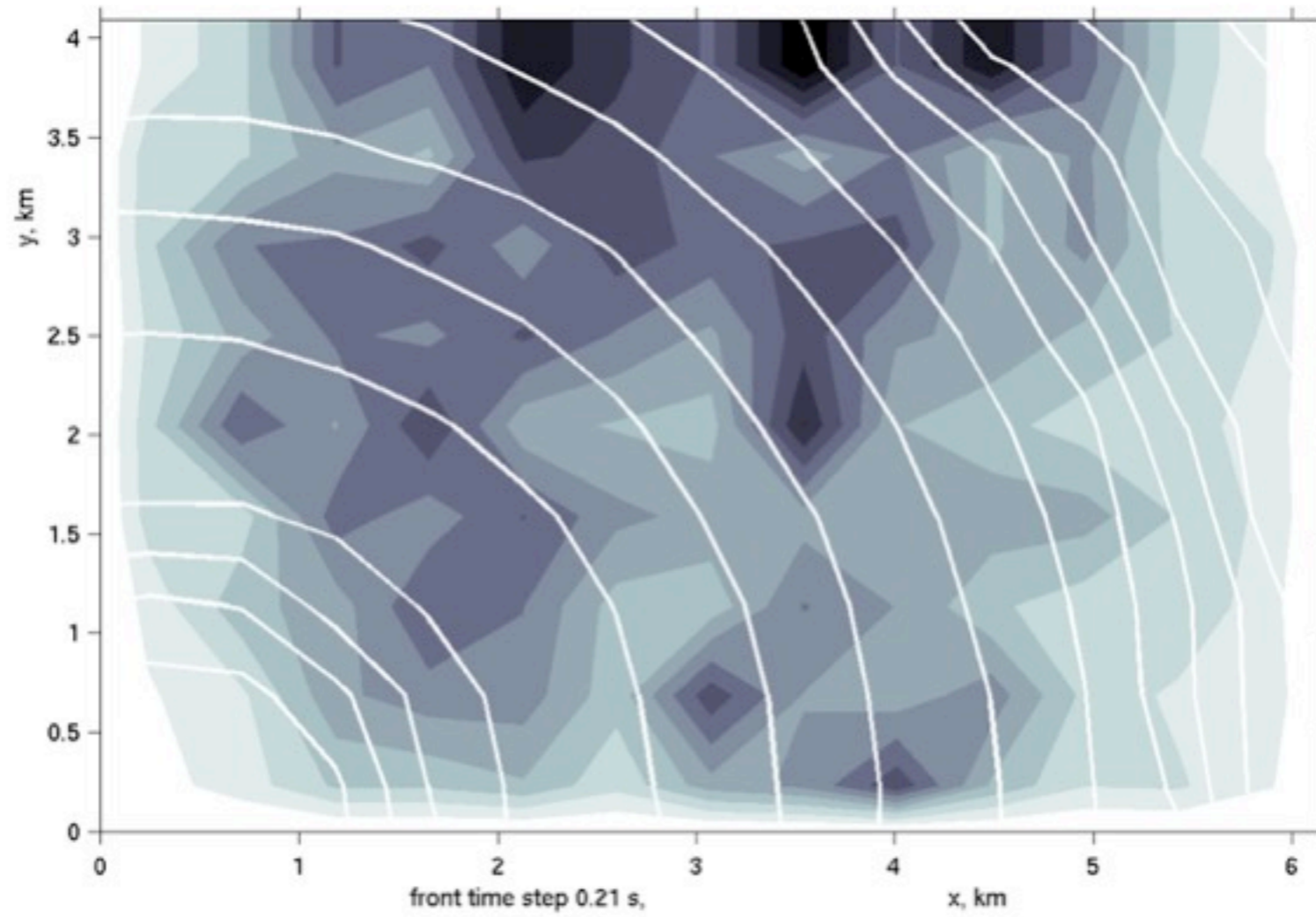


Extended source model



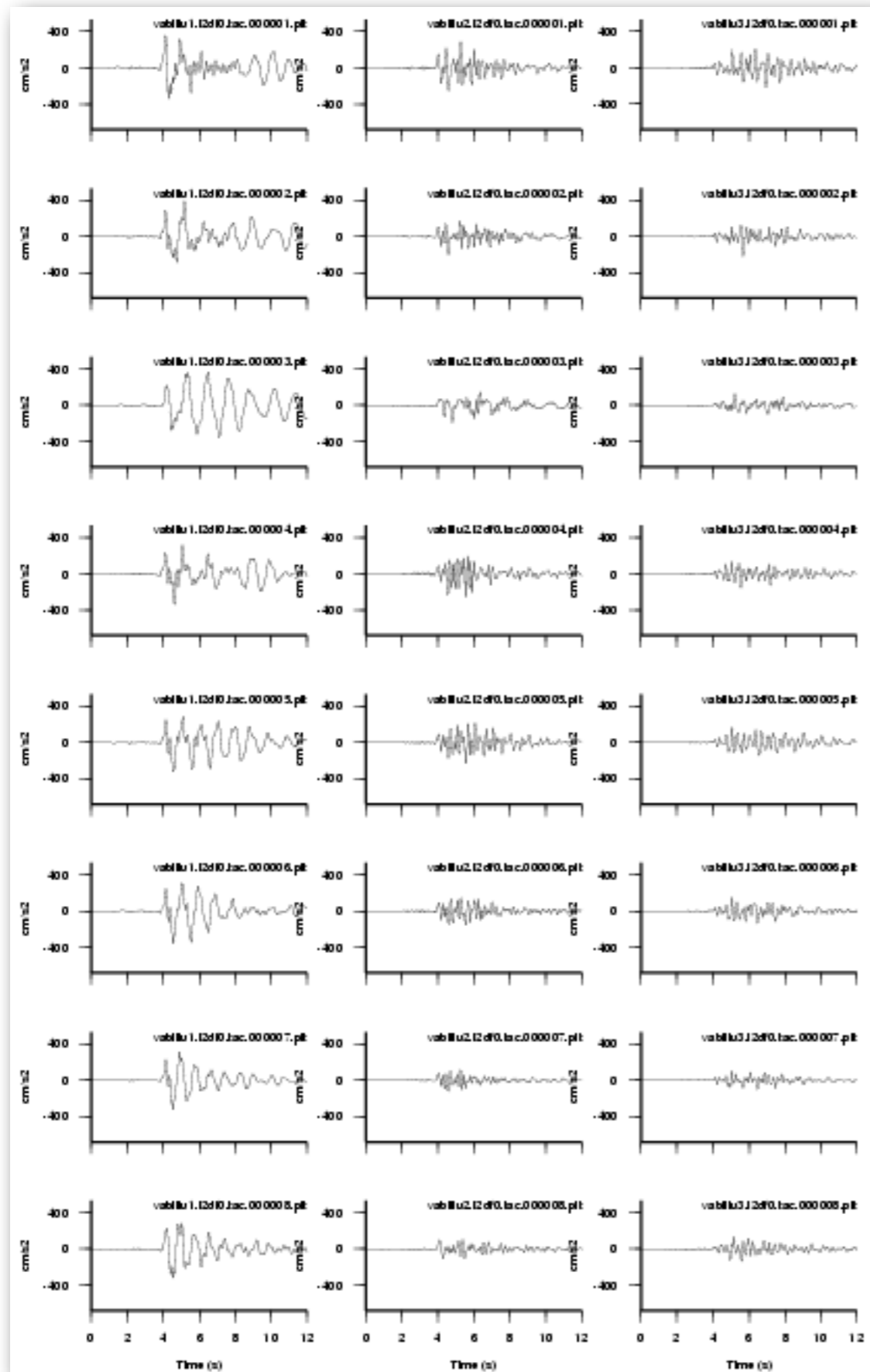
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Directivity parametric study

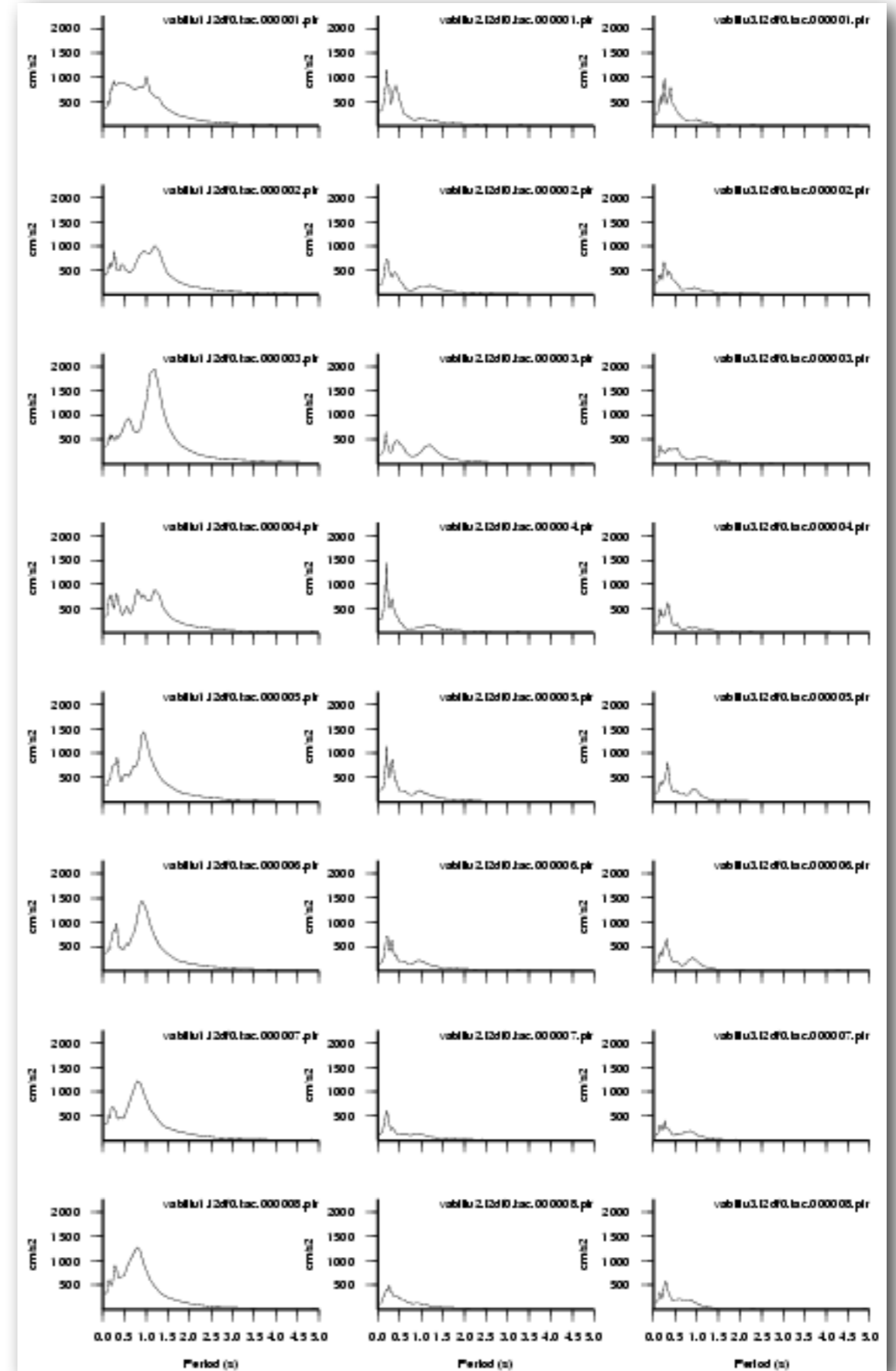
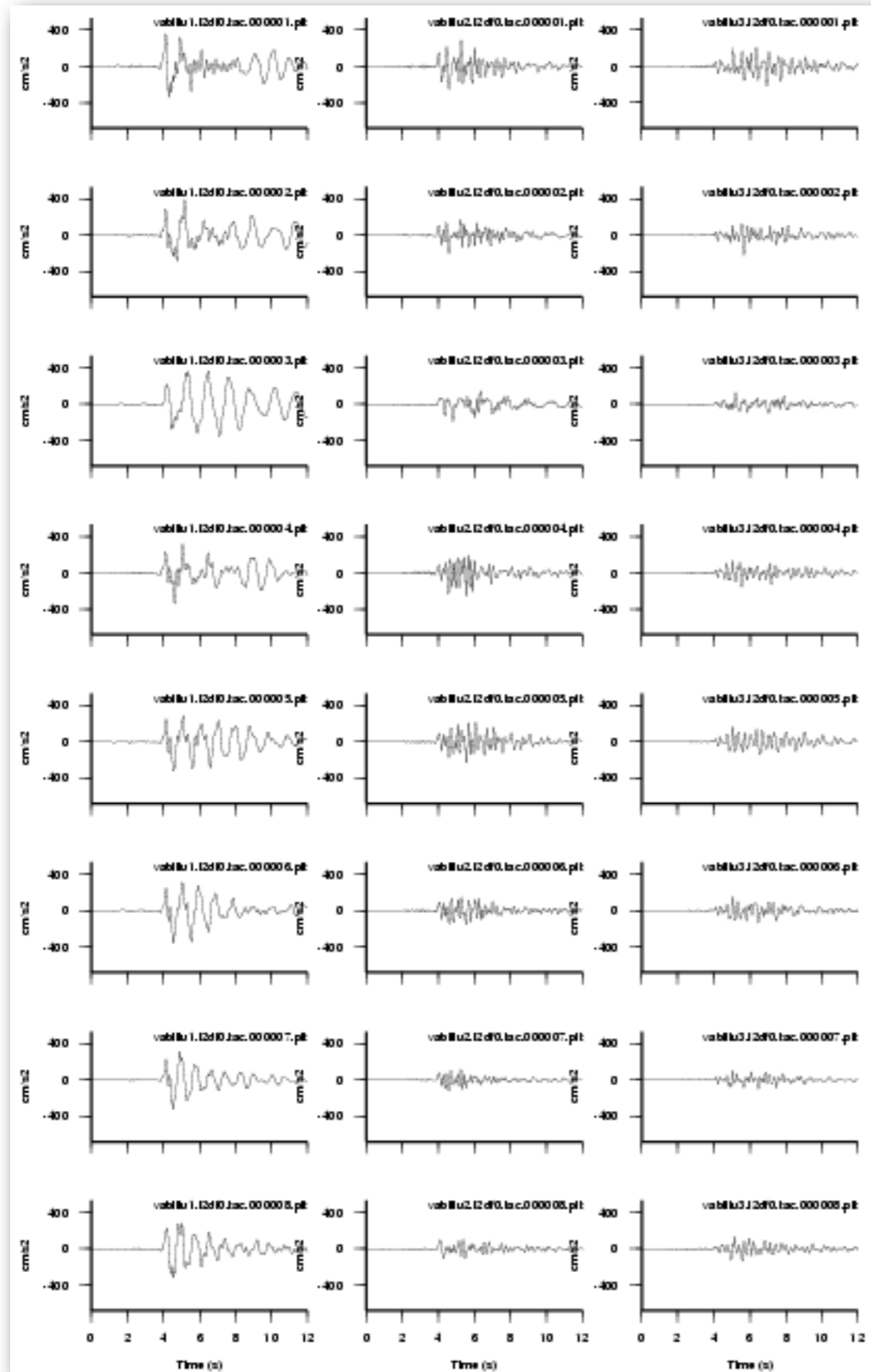


Directivity parametric study

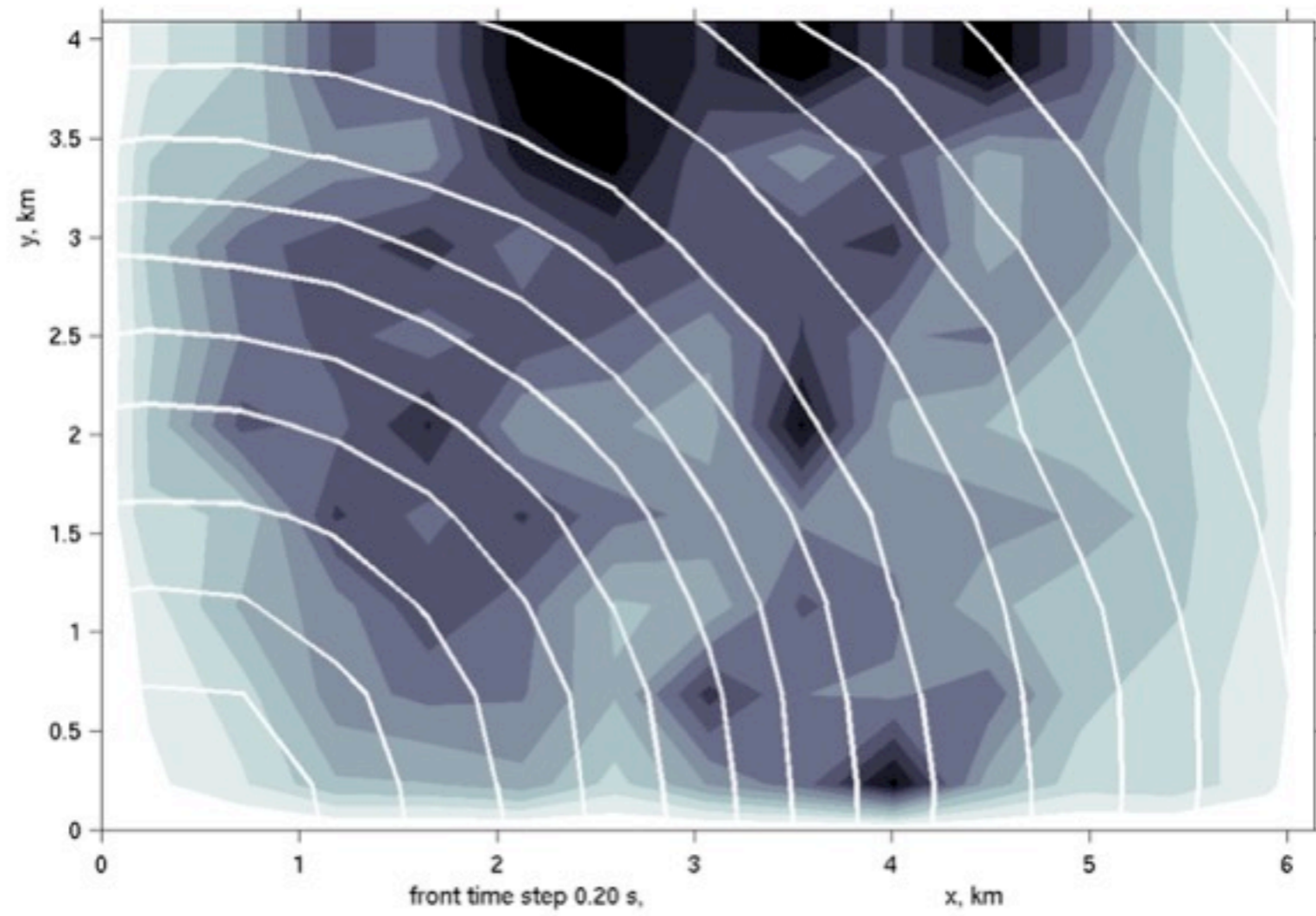
Directivity parametric study



Directivity parametric study

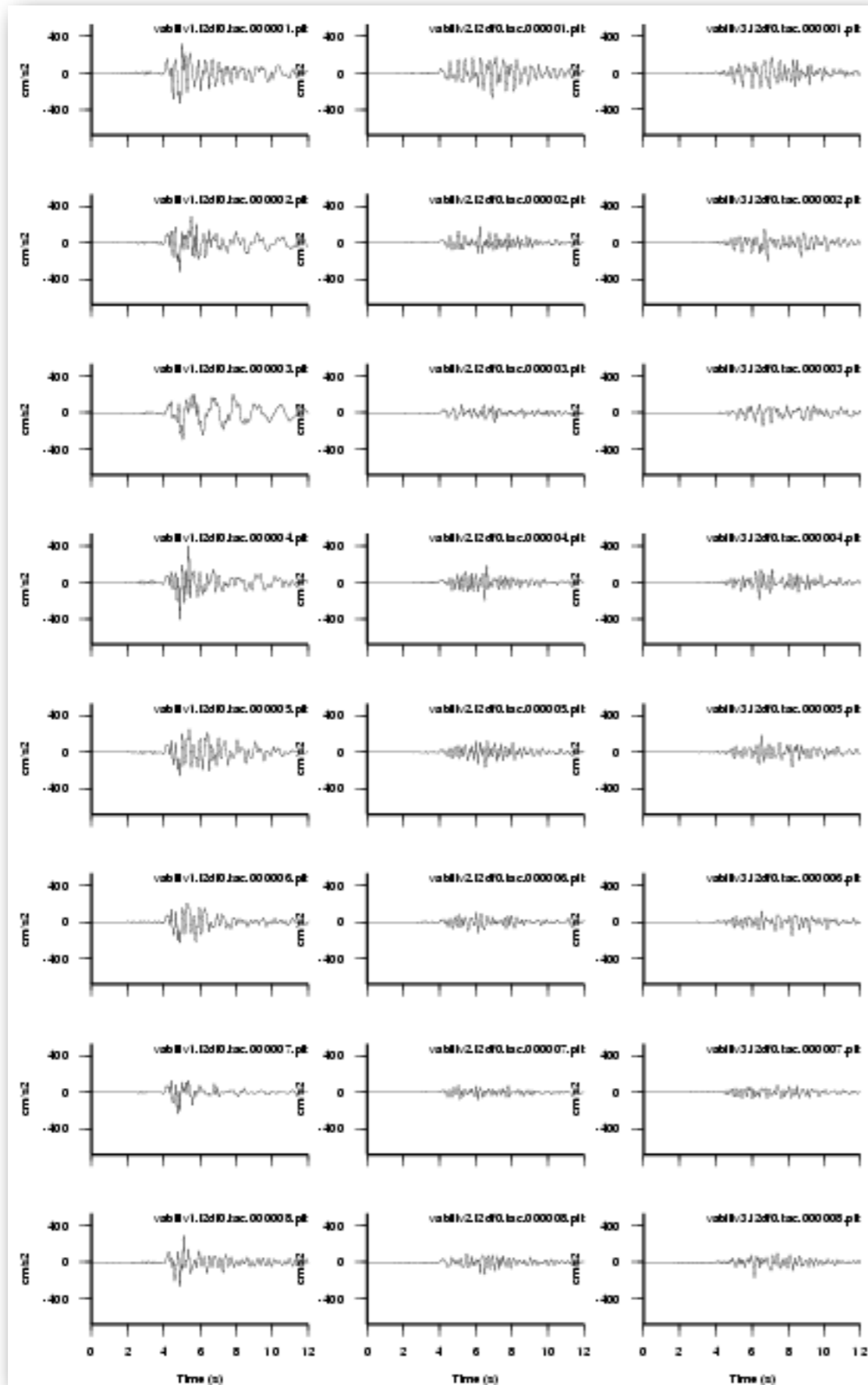


ESp towards directivity

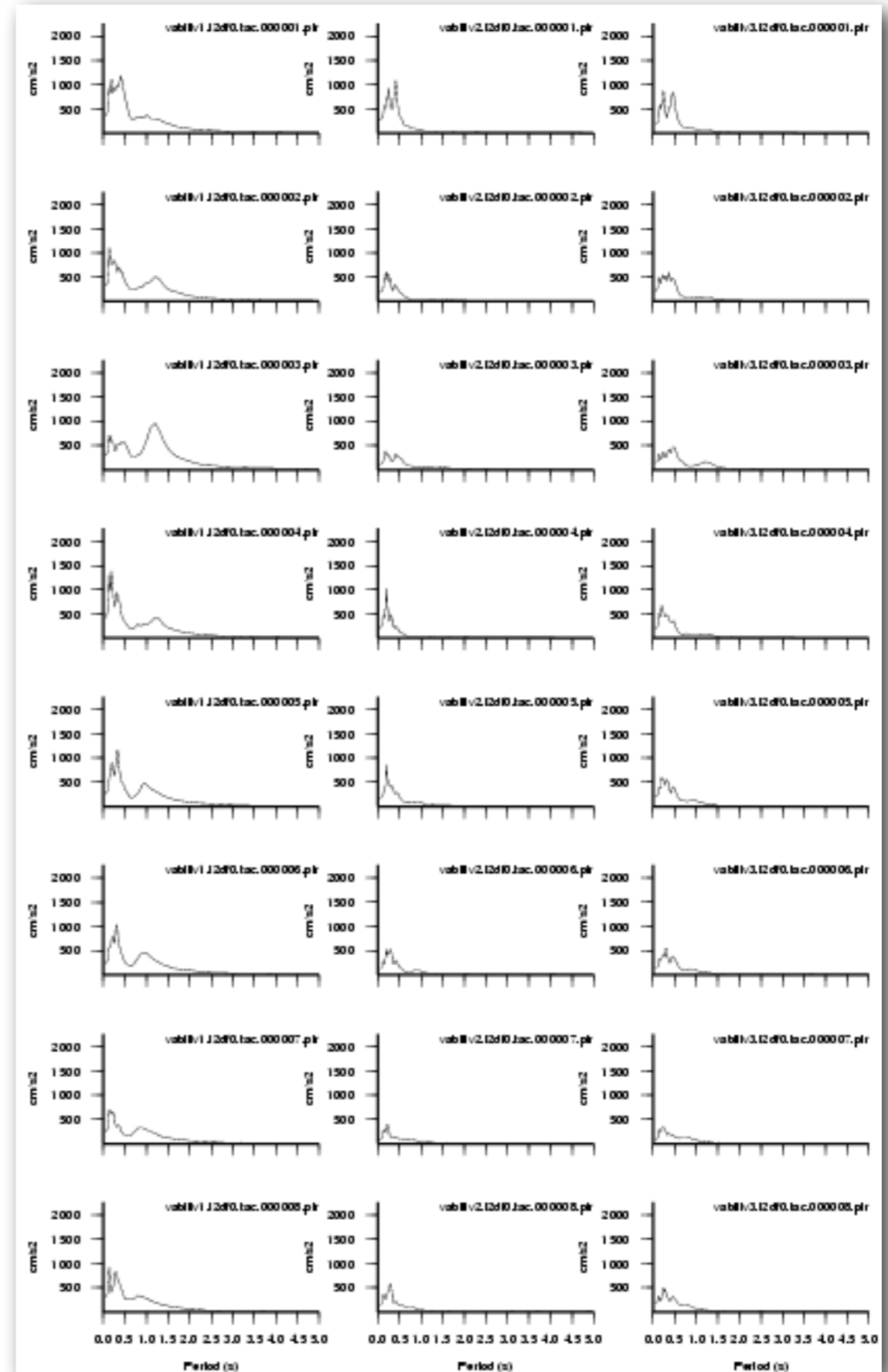
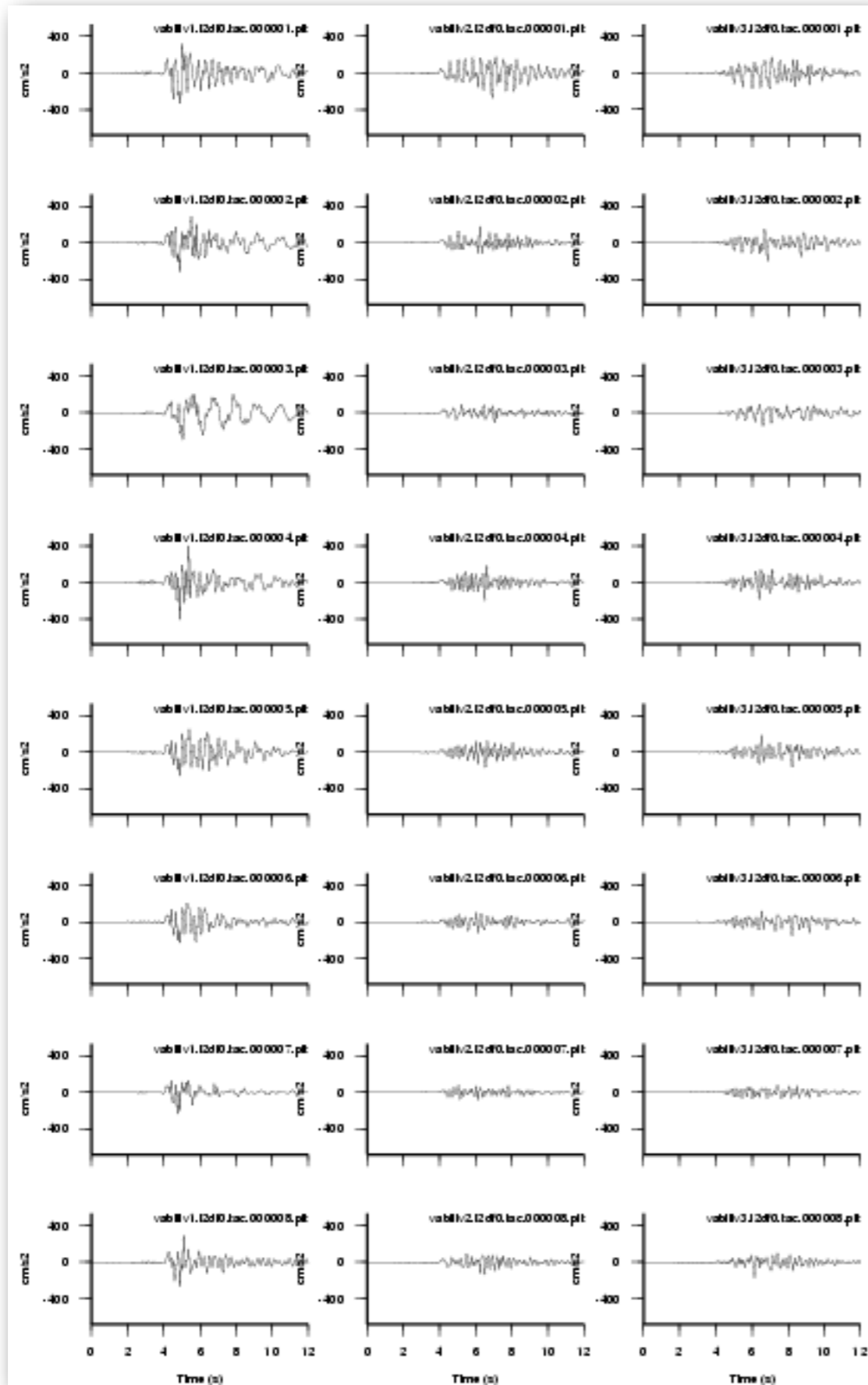


ESp towards directivity

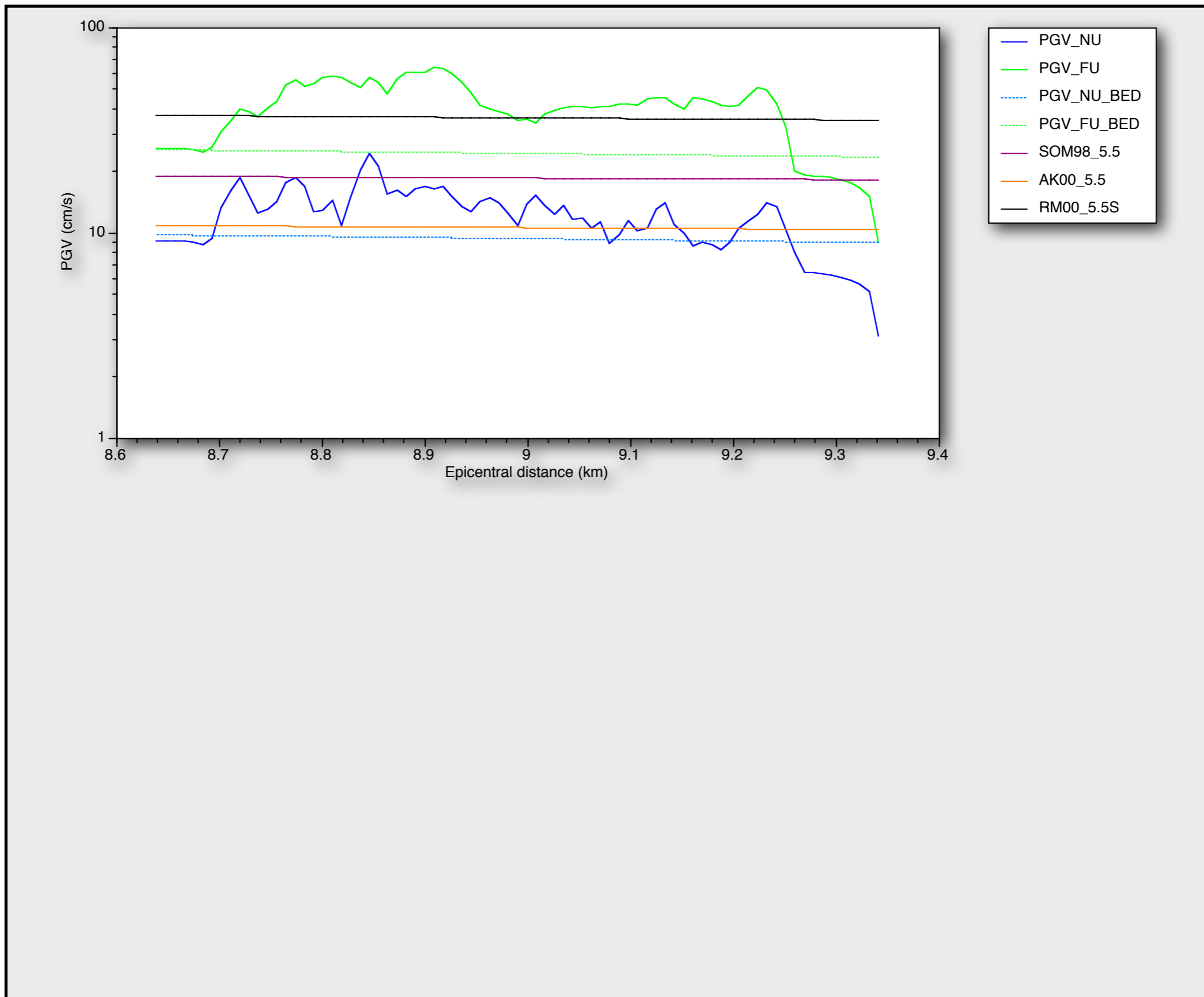
ESp towards directivity



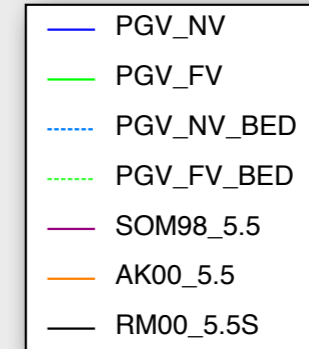
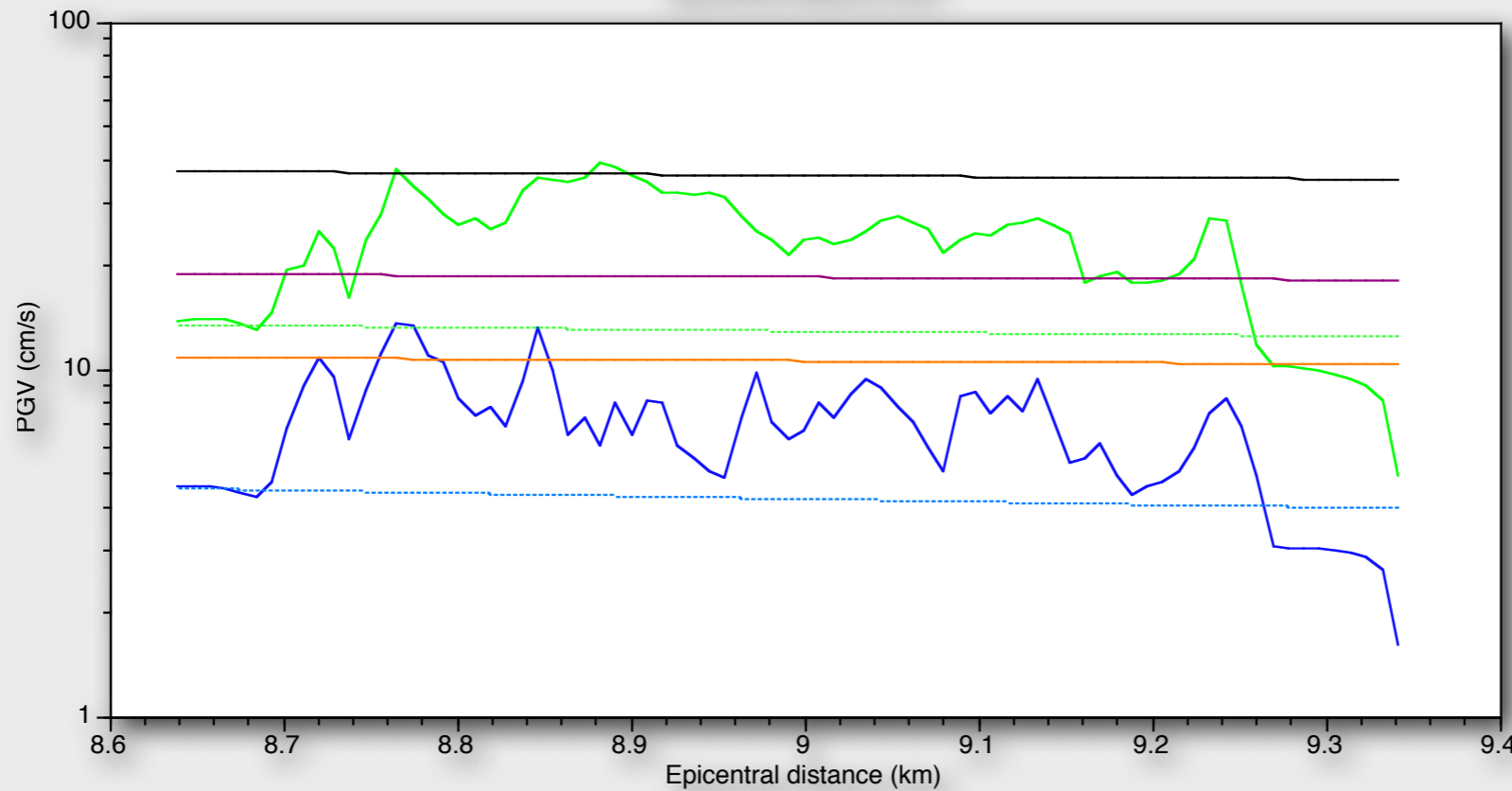
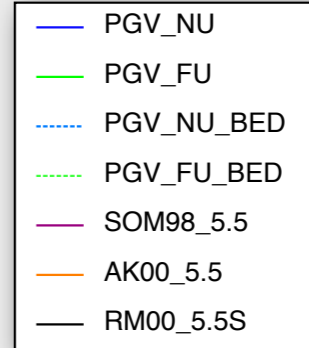
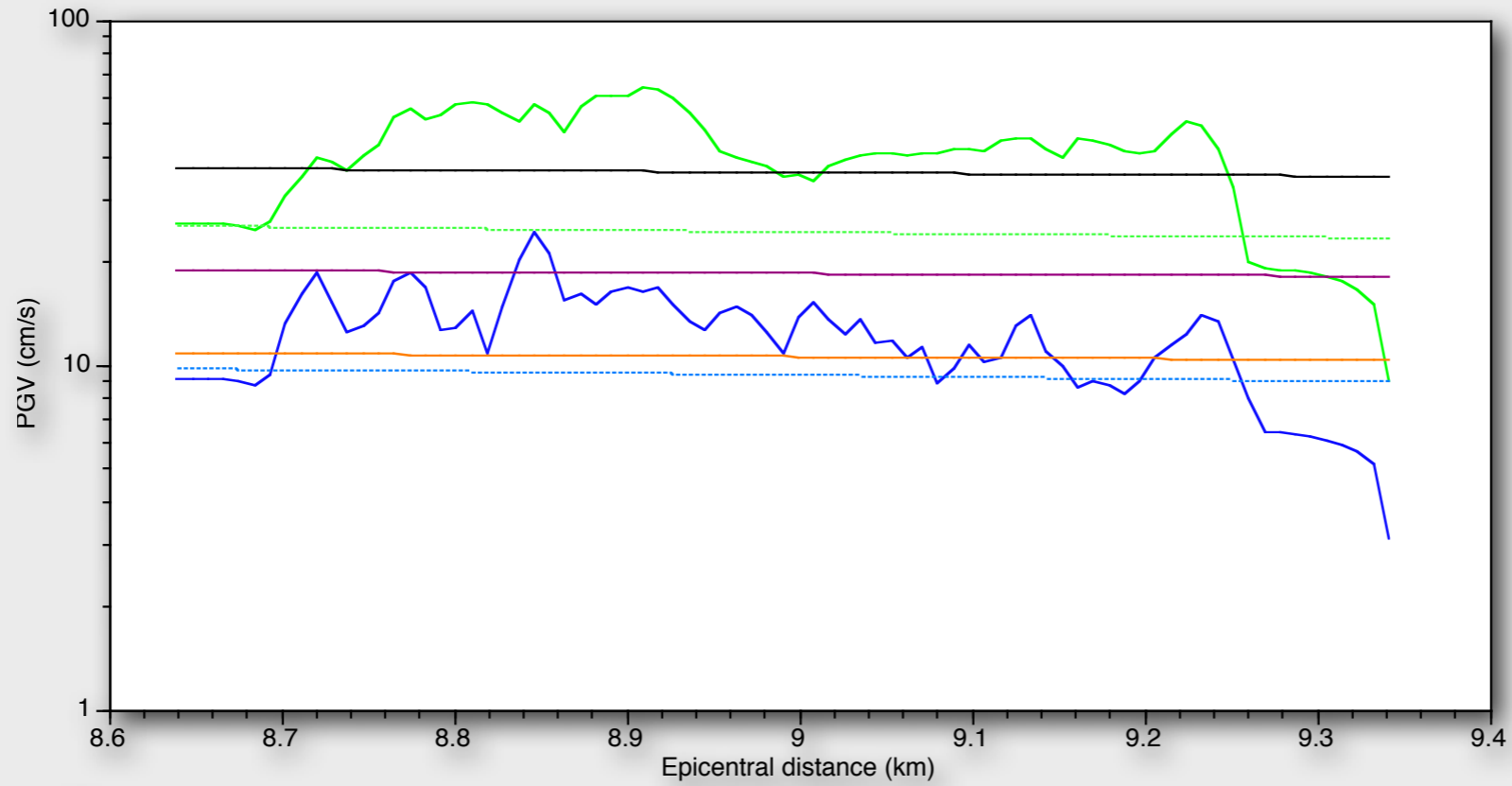
ESp towards directivity



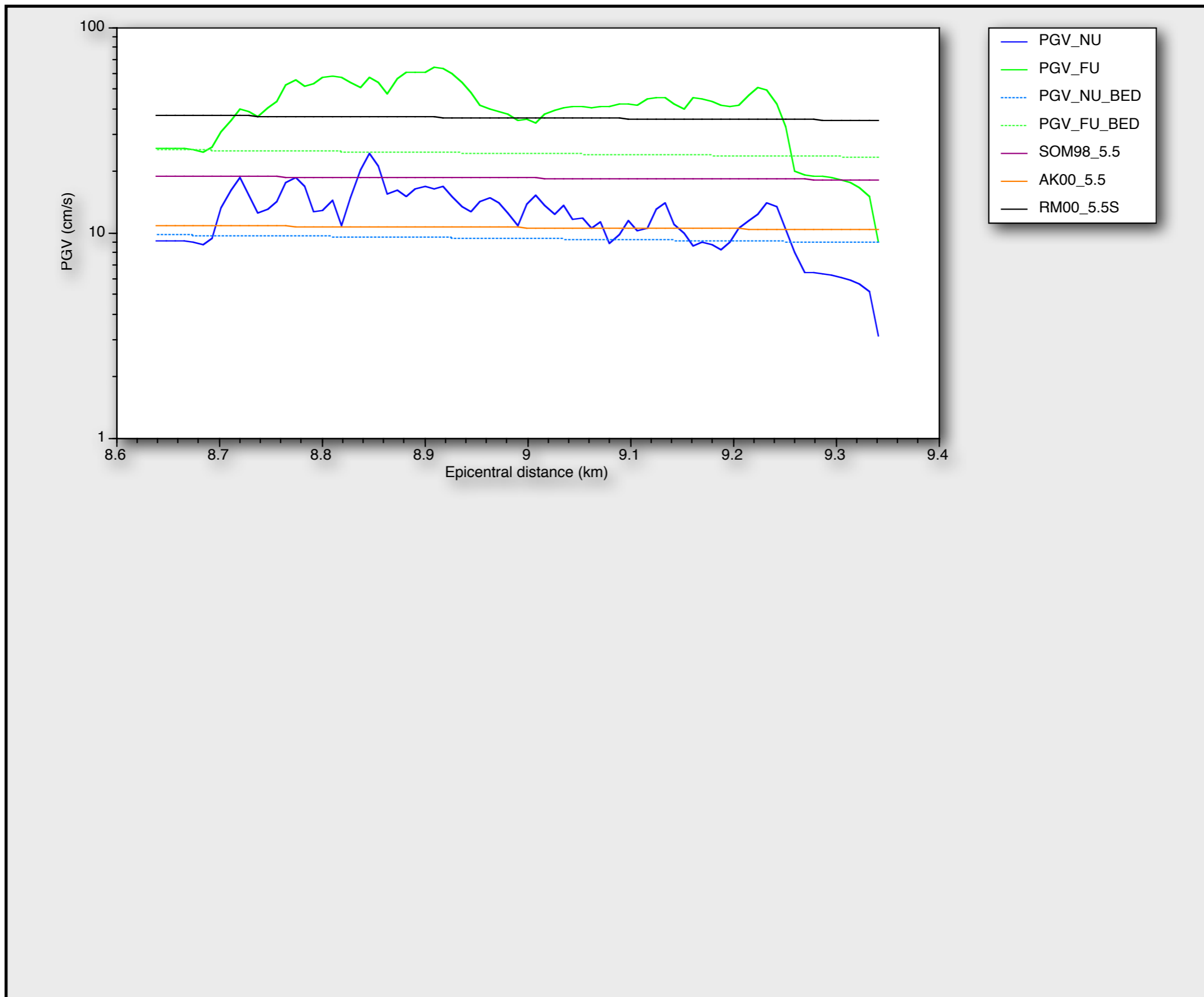
Directivity & PGV - PGA



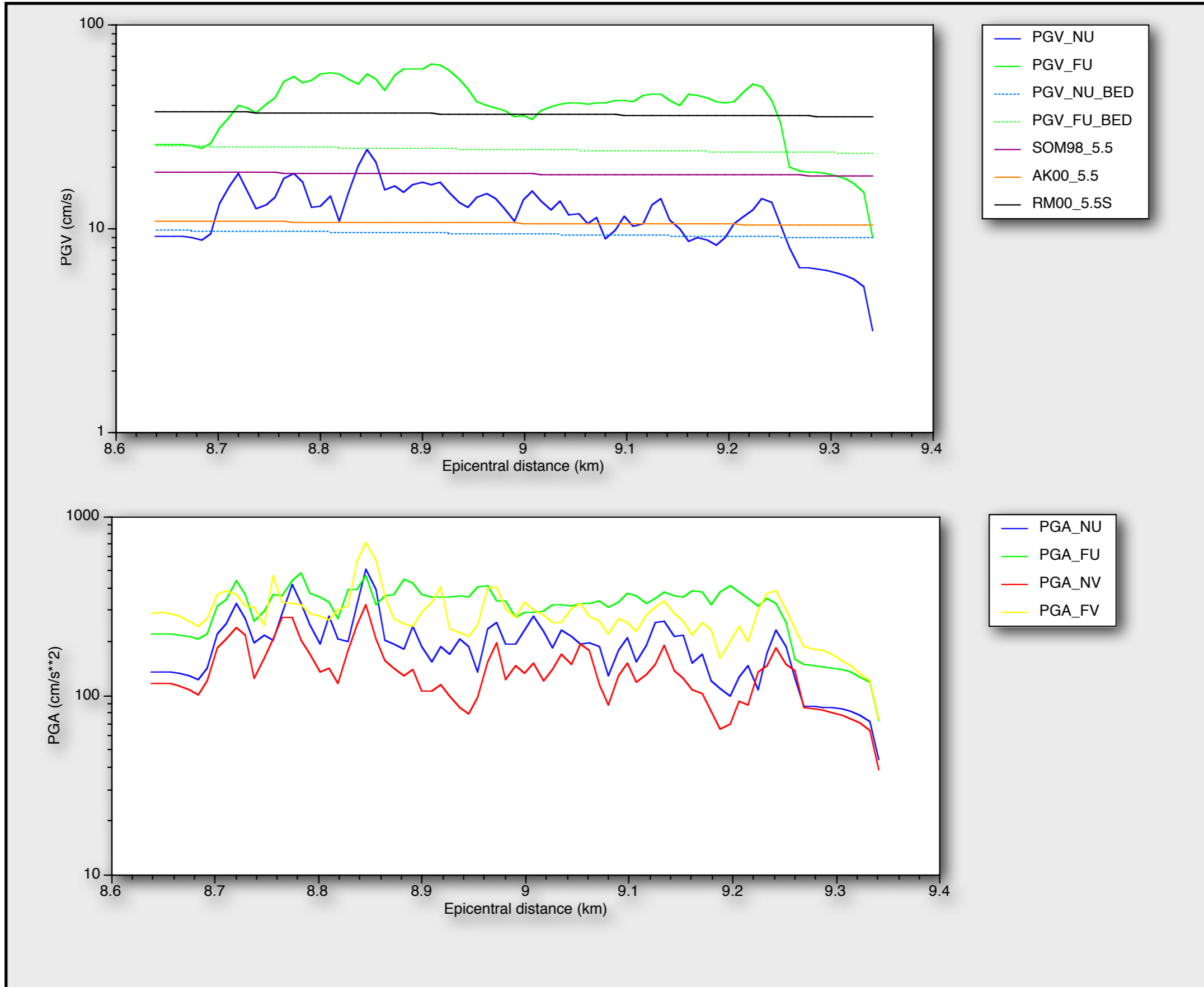
Directivity & PGV - PGA



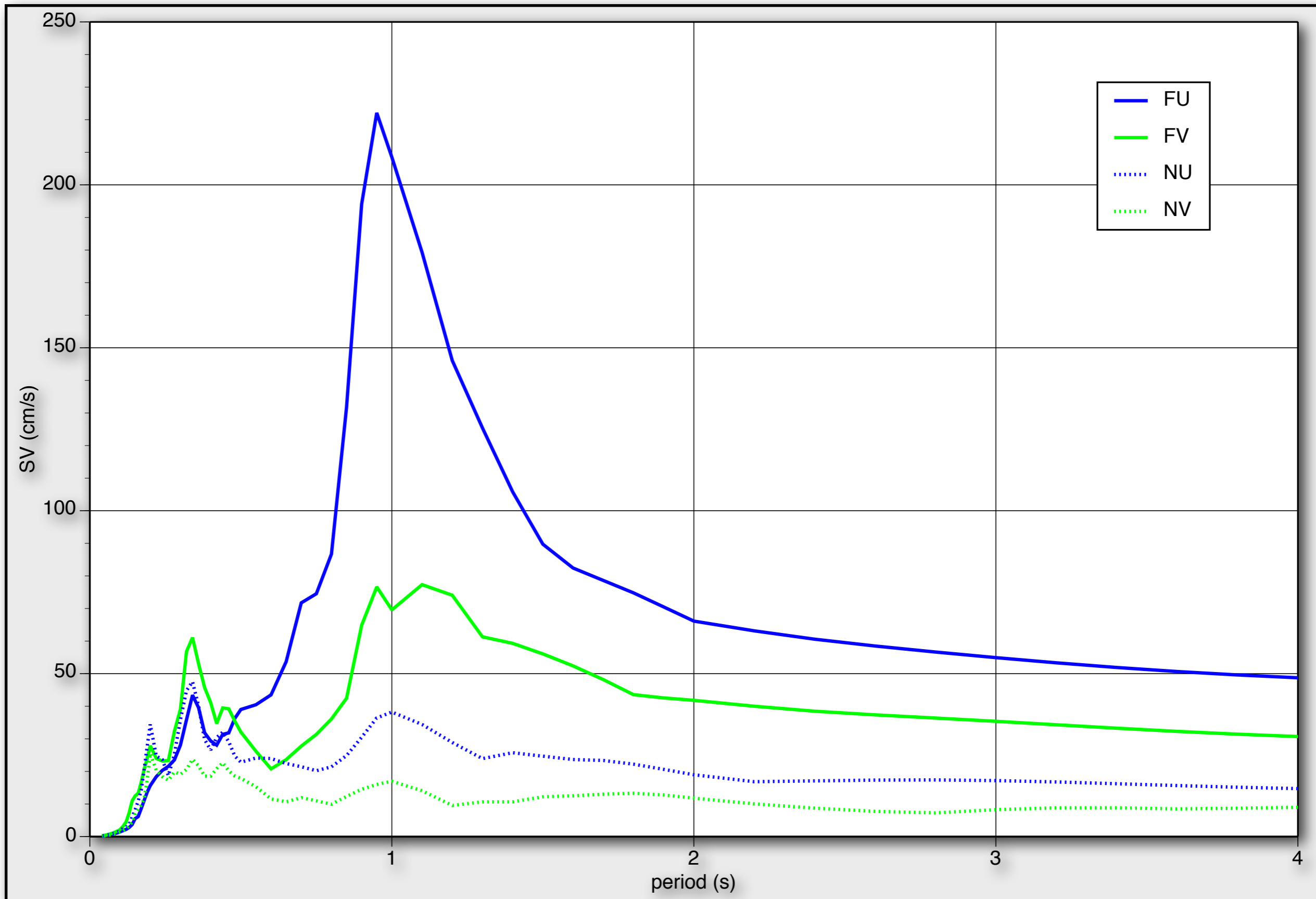
Directivity & PGV - PGA



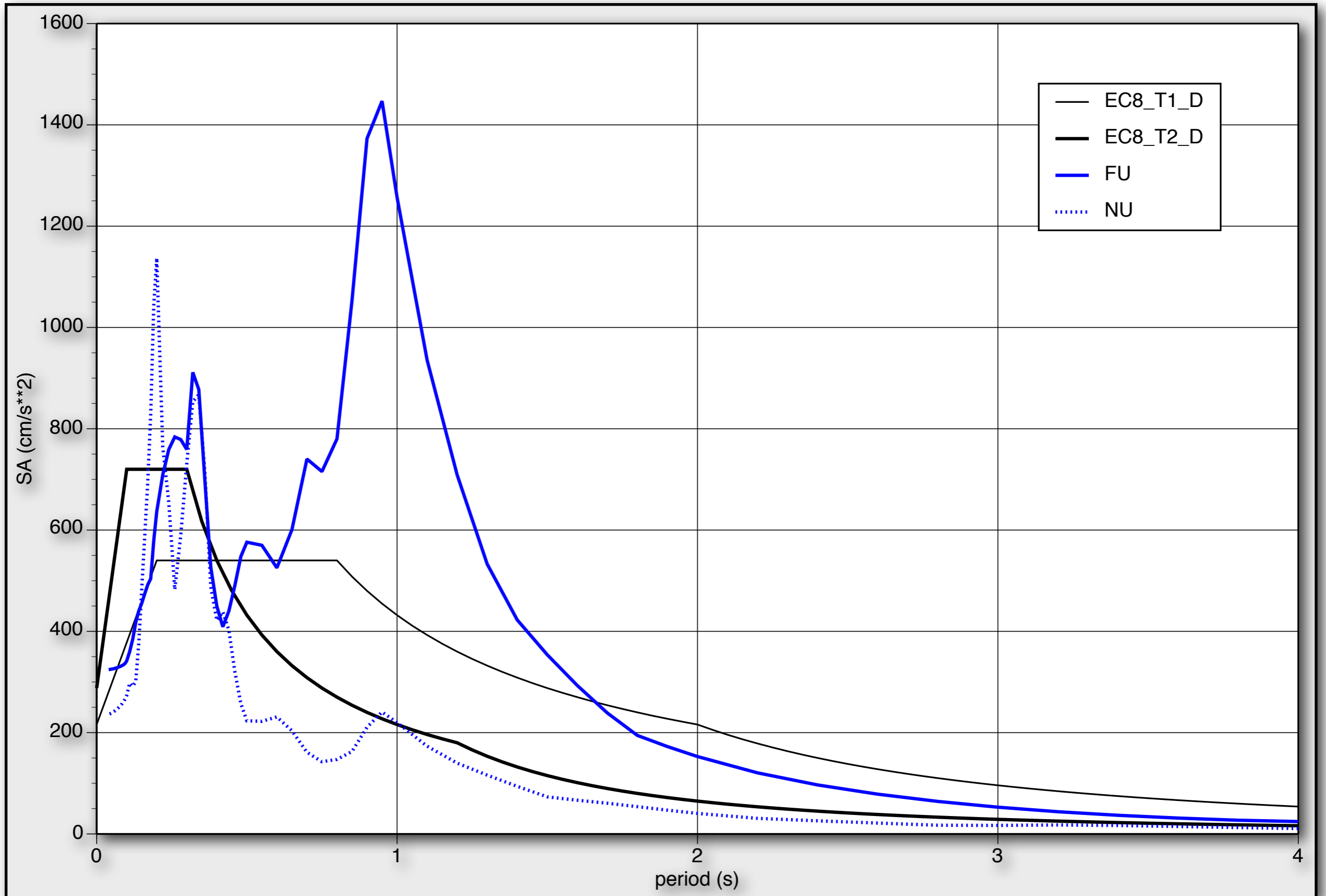
Directivity & PGV - PGA



Directivity & SV



Directivity & SA



Implementation of PSD tests

PSD WITH SUBSTRUCTURING

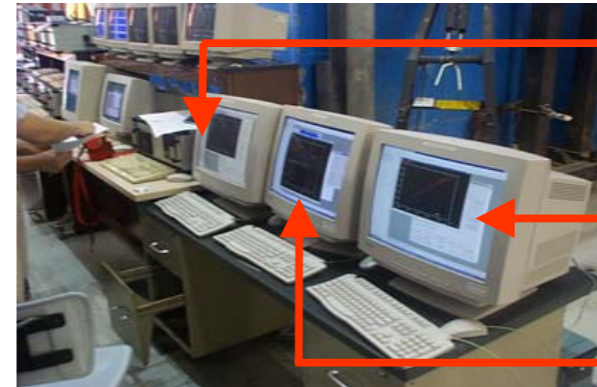
Application to the Warth Bridge, Austria



Construction of the large-scale bridge piers outside of the ELSA lab



Physical piers A40 & A70 in the lab



Numerical models for the substructured piers A20, A30

Numerical models for the substructured piers A50, A60

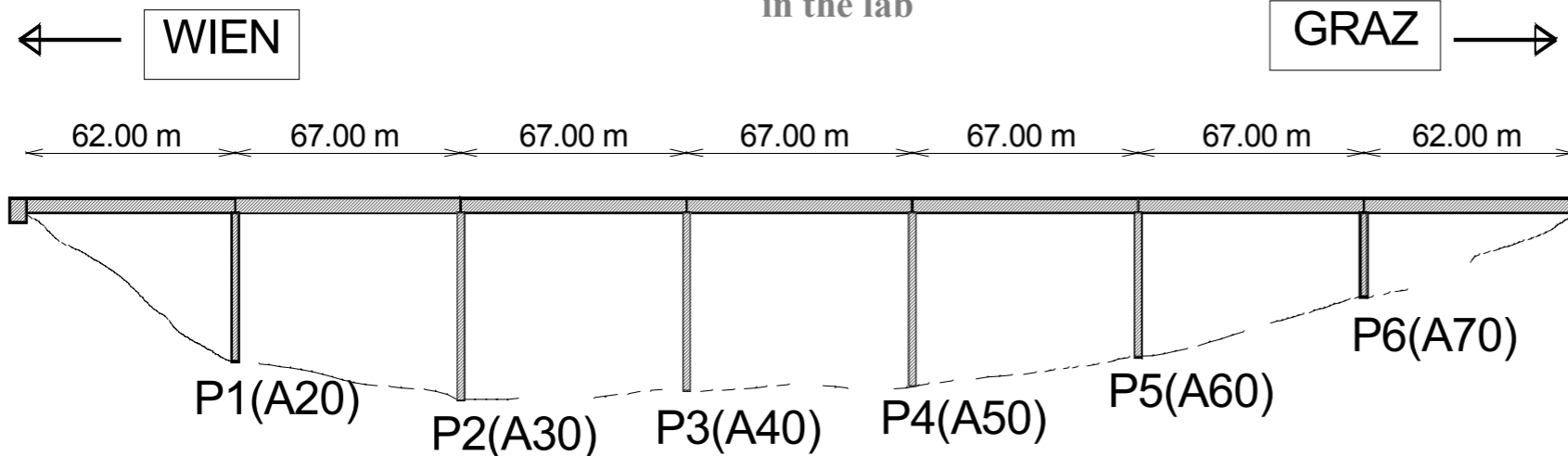
Numerical model for the deck and PSD master



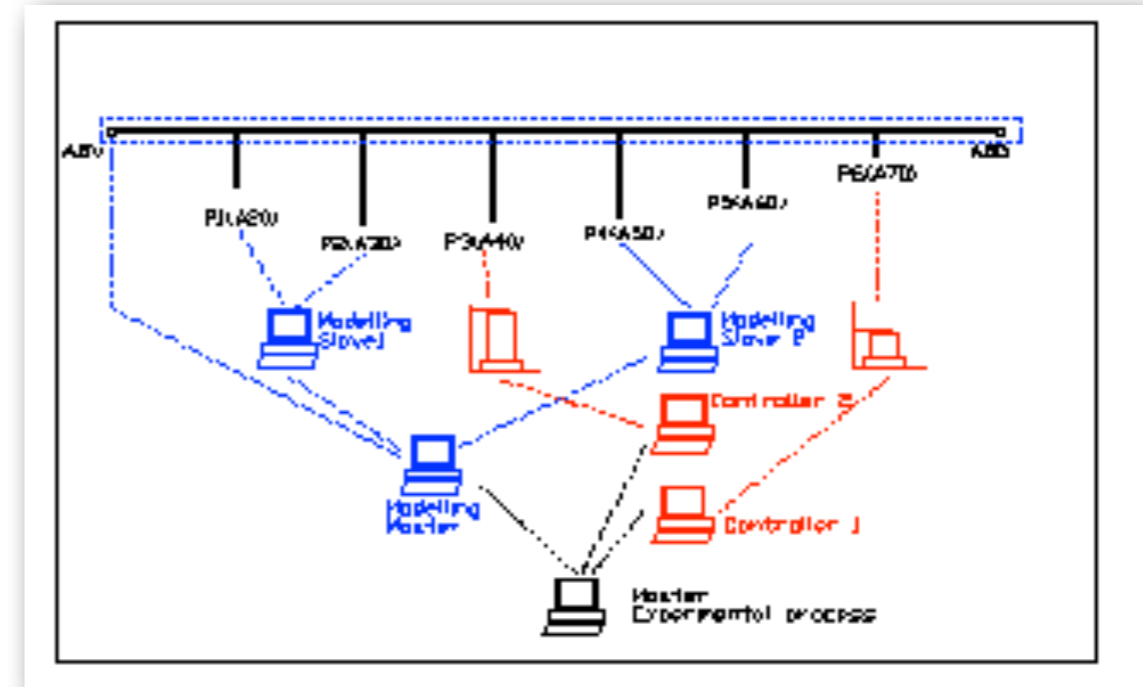
Master experimental process



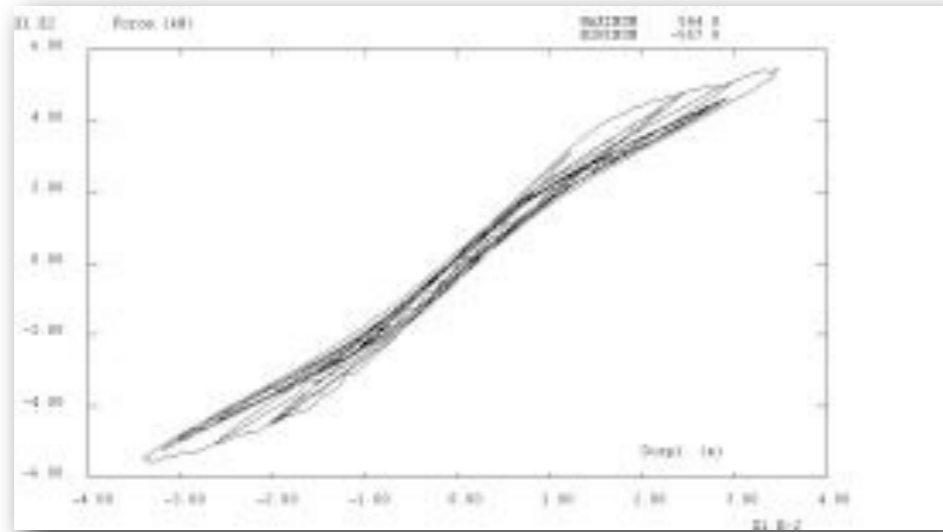
Warth Bridge



Implementation of PSD tests



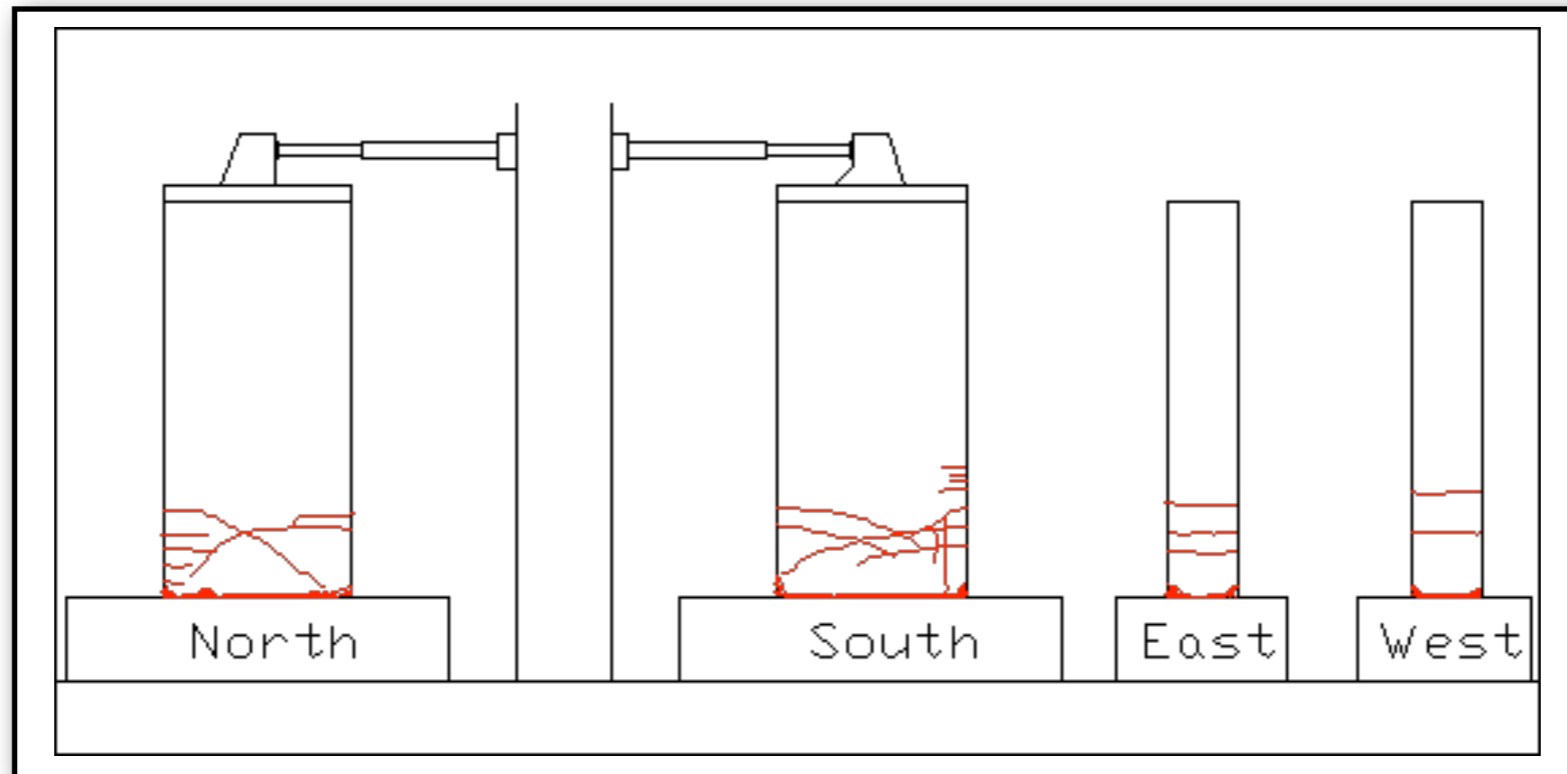
(a) physical piers in the lab, (b), schematic representation
(c) workstations running the PSD algorithm and controlling the test



Force-displacement for Low-level earthquake - experimental results Pier A40



Identification of insufficient seismic detailing. tall pier A40, buckling of longitudinal reinforcement at $h = 3.5\text{m}$



Damage pattern after the end of the High-Level Earthquake PSD test, short pier A70.