SALLE DU PARC (50 places)
9 novembre
Initiation à l'utilisation du code FMNEAR
B. Delouis
23 participants

Tour d’horizon rapide sur la méthode, quelques précautions d’usage, et son utilisation

Format des données en entrée et modèle de vitesse

Premiers retours sur l’installation / utilisation de la machine virtuelle ?

Démo (?) – Discussion, perspectives (suite…)

What is the “manual” semi-automated version of FMNEAR?

FMNEAR: Focal Mechanism using Near source seismic records

- Full waveform inversion (in displacement)
- Works with broadband and strong motion (accelerometers) records at local to regional distance (< 1500 km)
- Inverts for the double couple focal mechanism only (no CLVD, no isotropic part) ←→ shear ruptures on faults
- Different filtering bands may be used for the N, E, Z components of a given station
- Can cover a wide magnitude range: from Mw < 3 (favorable cases) to Mw > 8 thanks to the possibility to use either a point source or a linear finite source model
- Non linear inversion allowing the assessment of the uniqueness of the solution (index of confidence)

Reference : *Delouis, B., 2014. FMNEAR: determination of focal mechanism and first estimate of rupture directivity using near source records and a linear distribution of point sources, Bulletin of the Seismological Society of America, 104 (3),1479-1500. doi: 10.1785/0120130151*

FMNEAR is one of the the waveform inversion methods that you may be interested in:

- TDMT Time Domain Moment Tensor Inversion (Dreger and Helmberger, 1993; other Dreger references…)
- W-Phase inversion (Kanamori and Rivera, 2008)
- ISOLA (Sokos and Zaradnik, 2003)
- MecaVel (Martin Vallée)
- Méthode intégrée dans Seiscomp (Gempa)
- …

Introduction to the manual inversion (semi-automated approach)

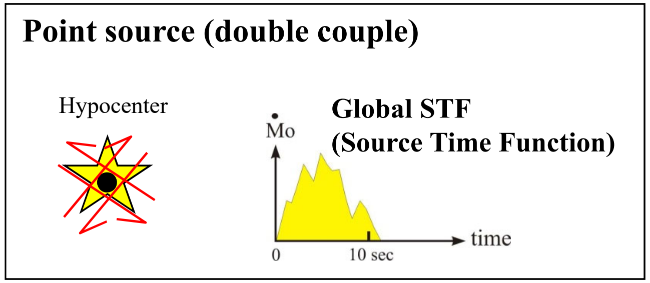
- ❑ Manual picking of the P wave
- ❑ Visual inspection of the waveforms *
- ❑ Semi-automated inspection of the waveforms for various filtering bands
- ❑ Definition of the filtering bands and stations to be incorporated in the inversion
- ❑ Launching the FMNEAR inversion proper
- ❑ Visual inspection of the result
- ❑ Possibility to loop back on filter definition and station selection
- ❑ Semi-automated exploration of hypocentral depth

If needed, the epicentral location and velocity model can be modified

* saturated and/or tilted signals should be identified. They should be later on discarded or used with precaution

Source model as a function of magnitude

If magnitude < 5.5 → point source



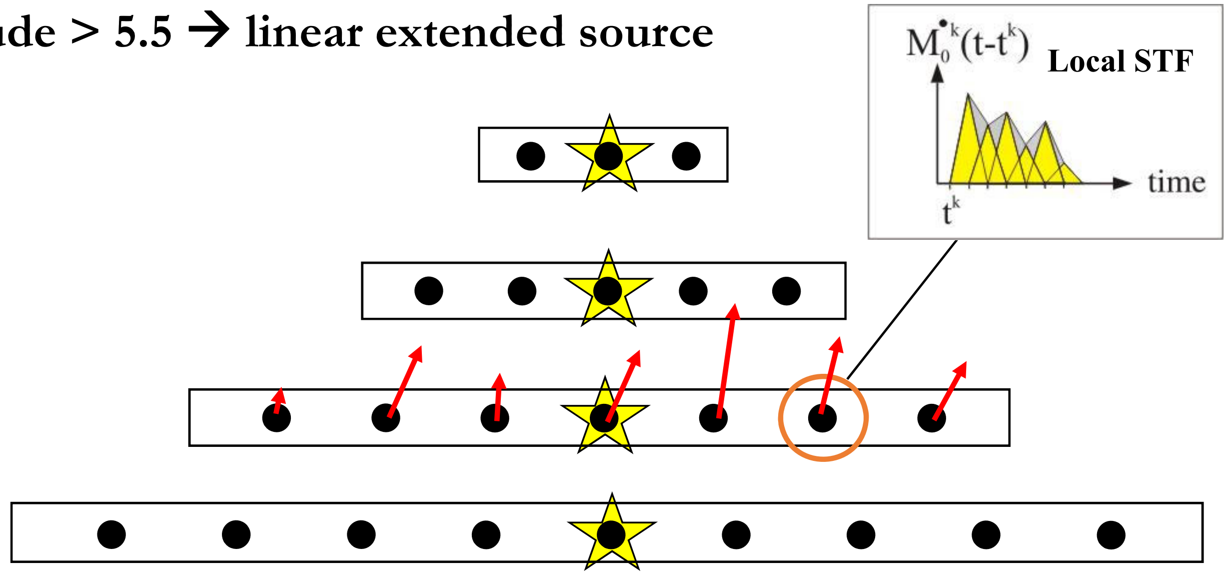
If magnitude > 5.5 → linear extended source

5.5 < M < 6

6 < M < 7

7 < M < 7.5

M > 7.5



Unknowns: focal mechanism (strike, dip, rake) and local STFs

Computation of synthetic seismograms : integration of the discrete wavenumber method by Bouchon (1981)

Velocity model : 1D model with planar layers

Misfit function : $$\mathrm{RMS} = \frac{\sqrt{\sum \mathrm{w(obs-cal)}^2}}{\sqrt{\sum \mathrm{w(obs)}^2}}$$ to be minimized

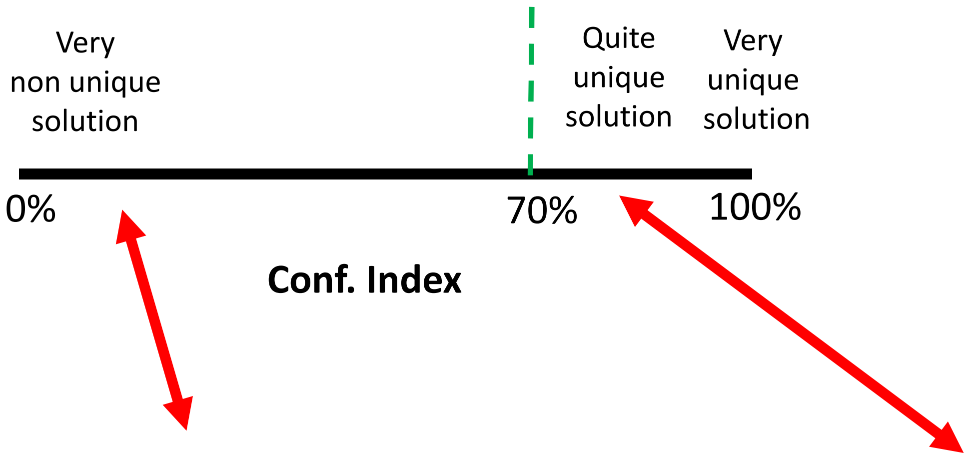
Station weighting 'w' : weight increases with distance to compensate amplitude attenuation. Closest stations more severely downweighted to handle possible error in the epicentral location

Bouchon, M. (1981). A simple method to calculate Green's functions for elastic layered media, *Bull. Seismol. Soc. Am.* 71, no. 4, 959–971.

The Confidence Index (0 – 100%)

A measure of the unicity of the solution for the focal mechanism (FM)

FMNEAR explores tens of solutions for the FM, each associated with its corresponding RMS misfit value

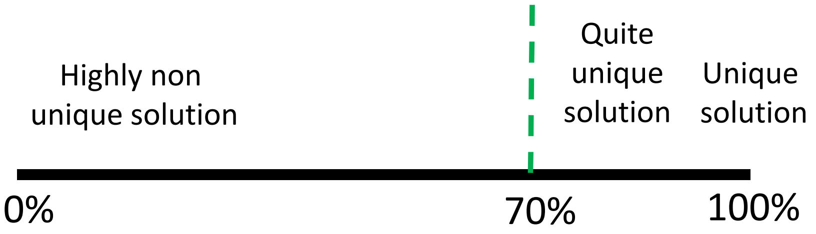


There are solutions with RMS close to the best RMS value but with focal mechanisms very different from that of the best solution. The solution is not unique and the confidence index is low.

All the focal mechanisms found with RMS values close to the best one are close to each other and to the best solution. The solution tends to be unique and the confidence index is high.

The Confidence Index:

a measure of the unicity of the solution for the focal mechanism (FM)

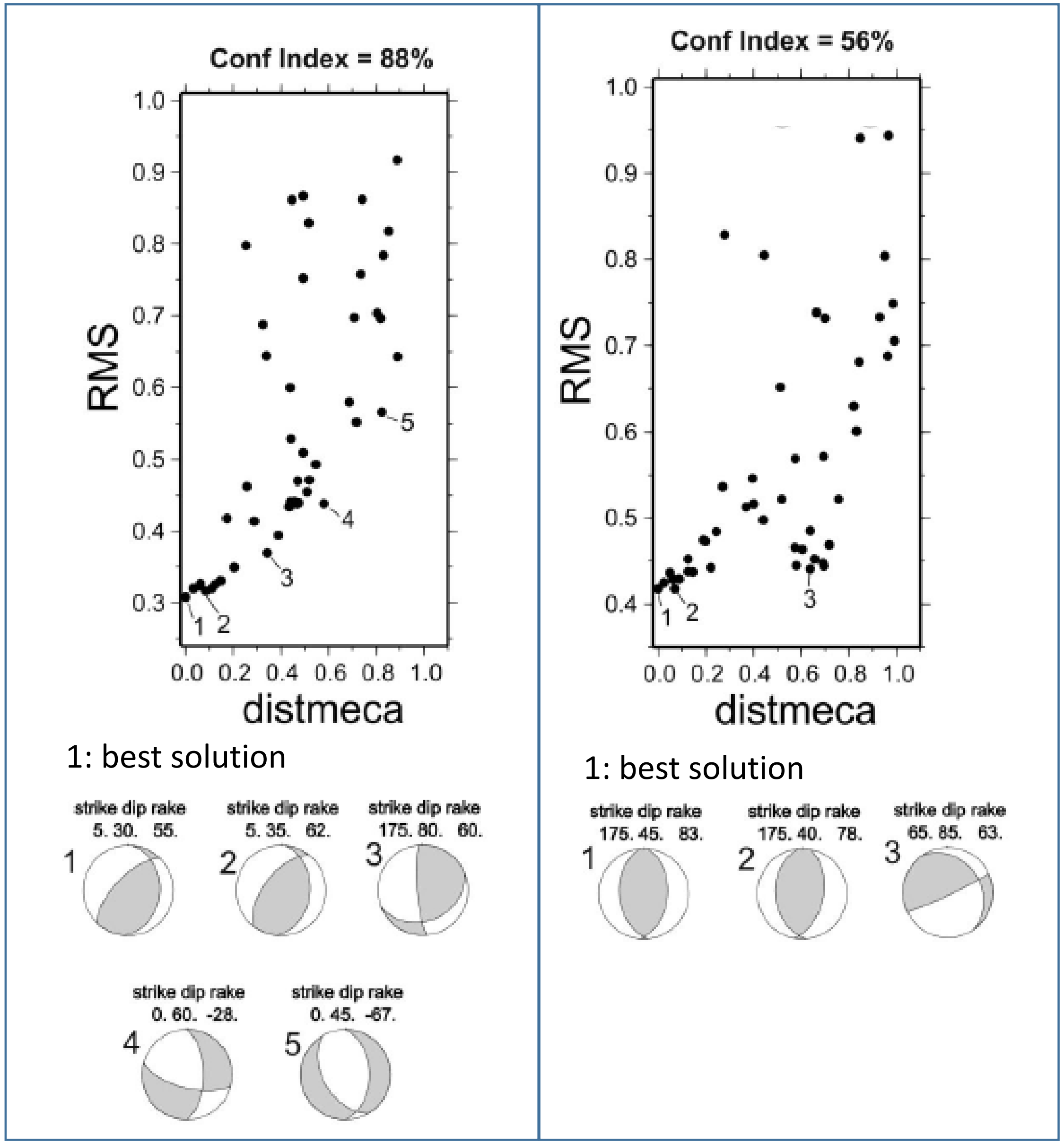


Conf. Index

distmeca:

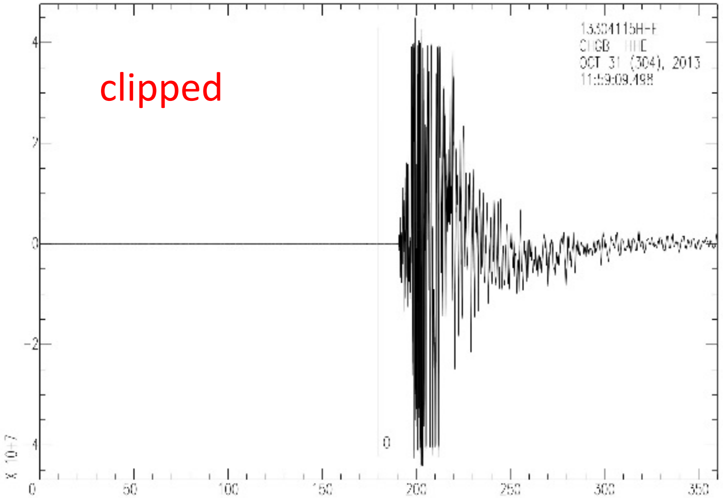
a measure of the distance between two focal mechanisms (FM)

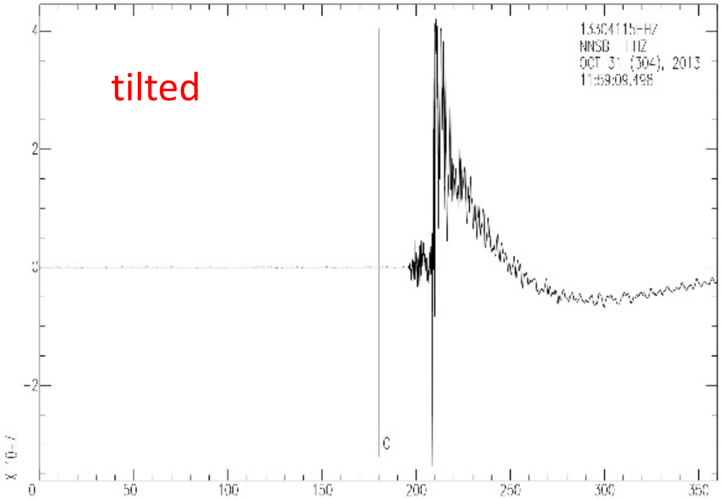
distmeca = 0 → identical FM
distmeca = 1 → opposite FM

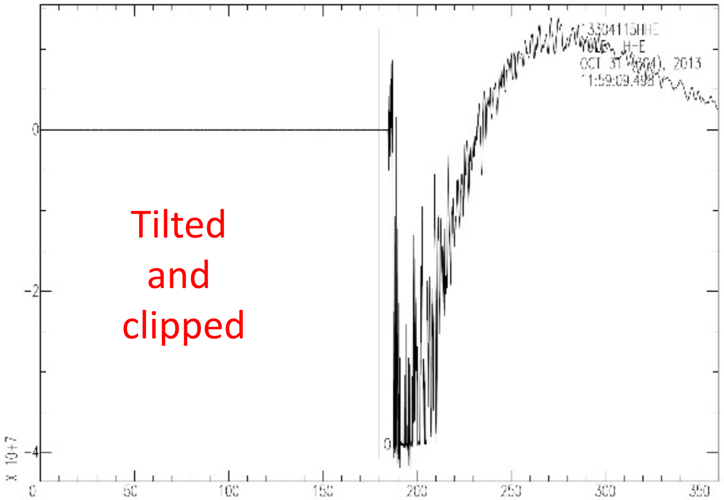


Special caution to clipped (saturated) and tilted signals

❑ Special caution to clipped (saturated) and tilted signals





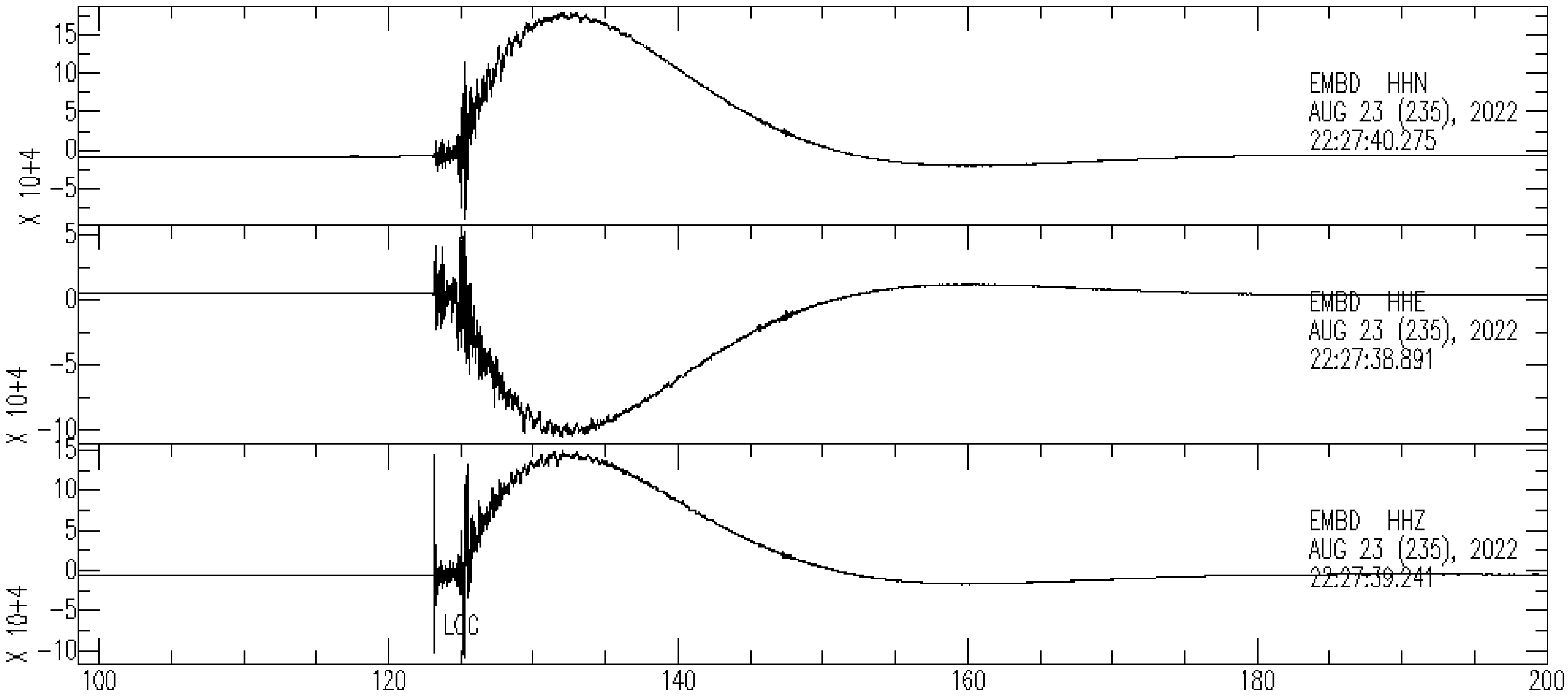


Broadband velocity

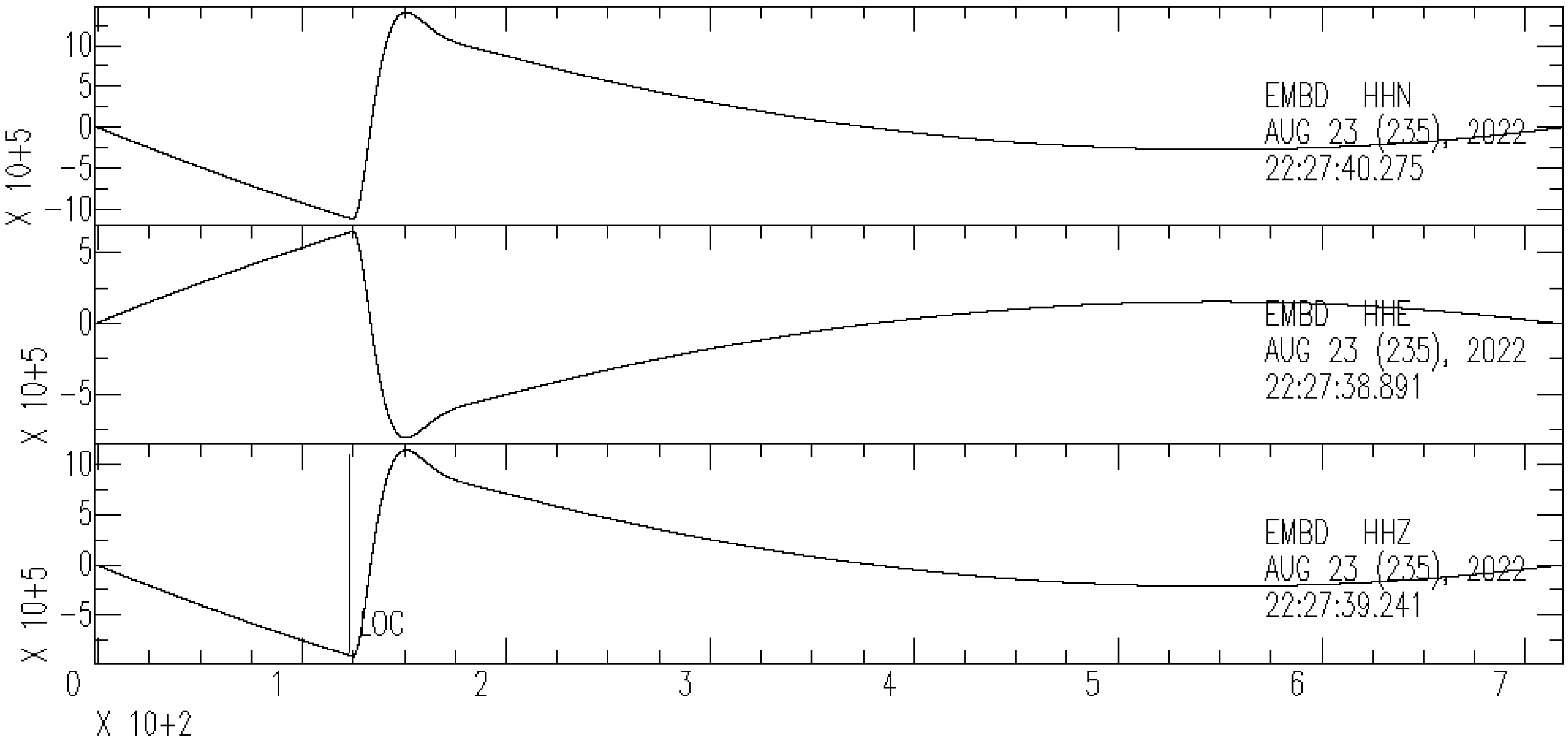
Case where tilting is clear in velocity

station EMBD at 12 km epicentral distance, EQ of Mw 2.8 in Switzerland

velocity



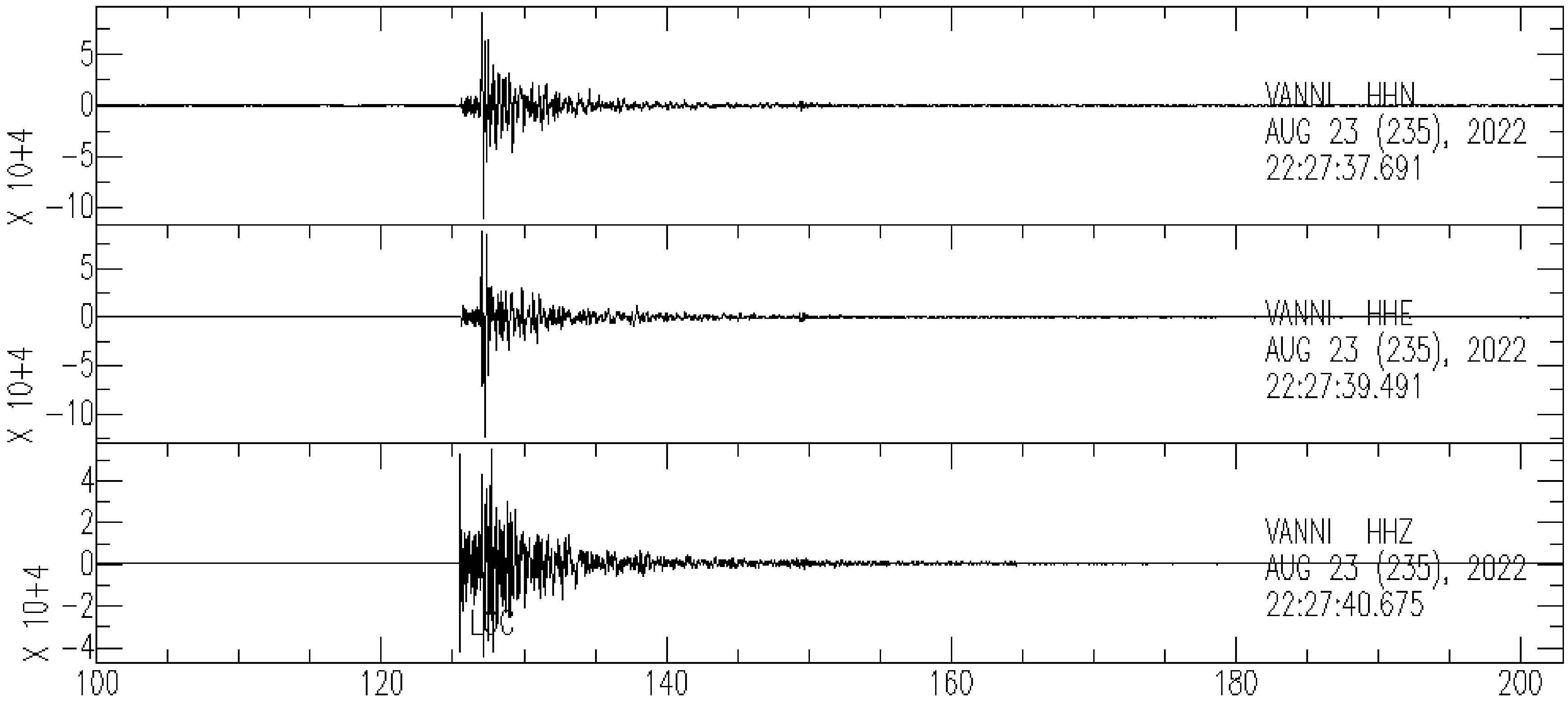
displacement



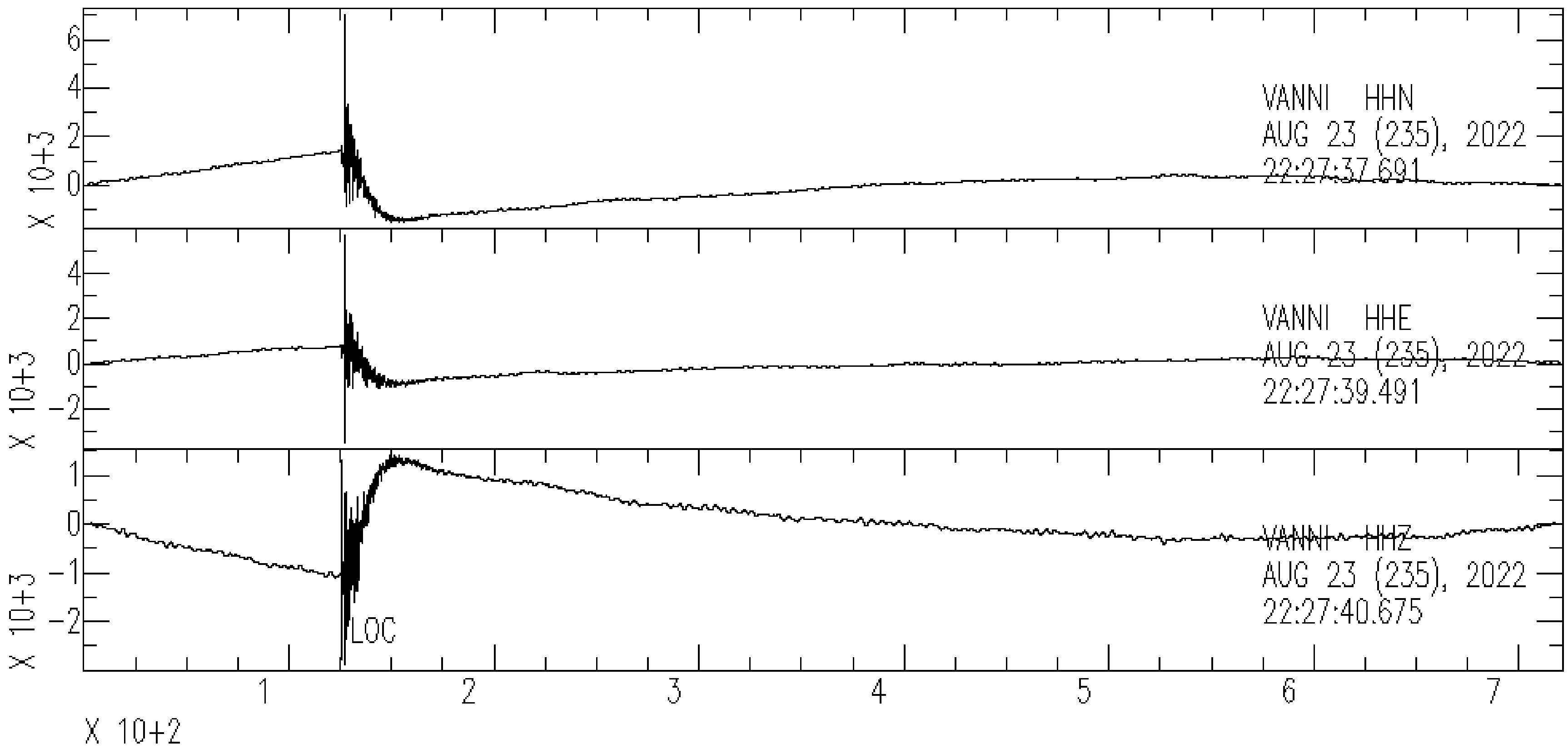
Case where tilting is not clear in velocity but appears in displacement

station VANNI at 12 km epicentral distance, EQ of Mw 2.8 in Switzerland

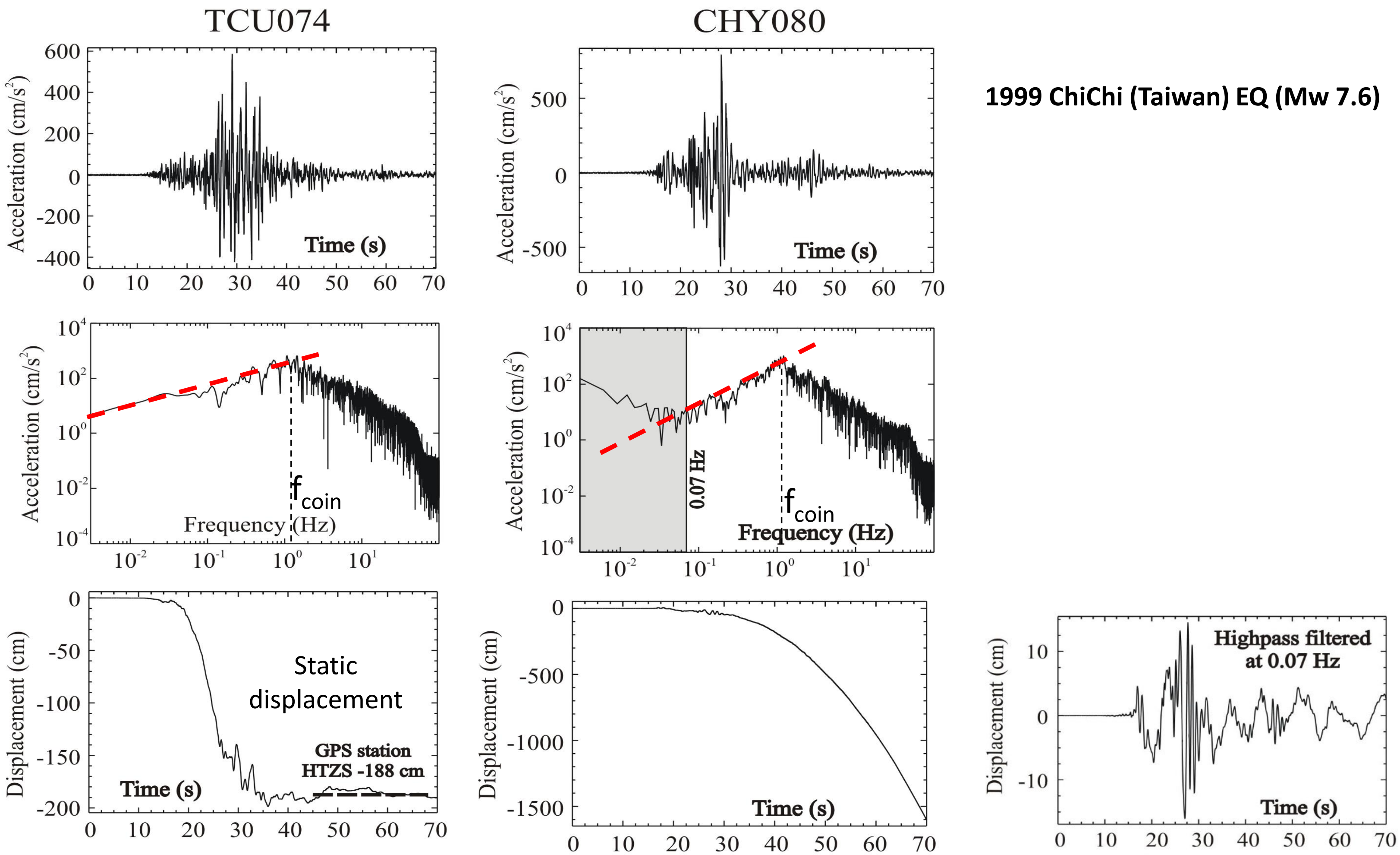
velocity



displacement



Accelerometers also can suffer tilt issue:



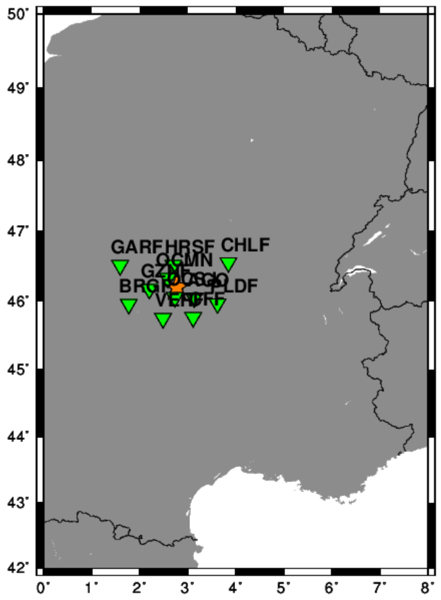
1999 ChiChi (Taiwan) EQ (Mw 7.6)

→ So, strong motion records have to be bandpass filtered as well

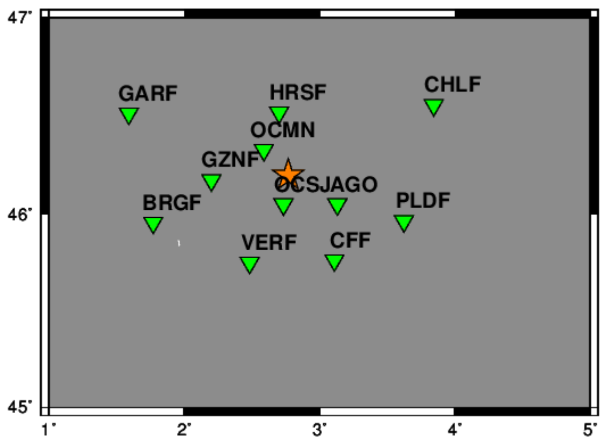
Bandpass filtering is necessary for two main reasons:

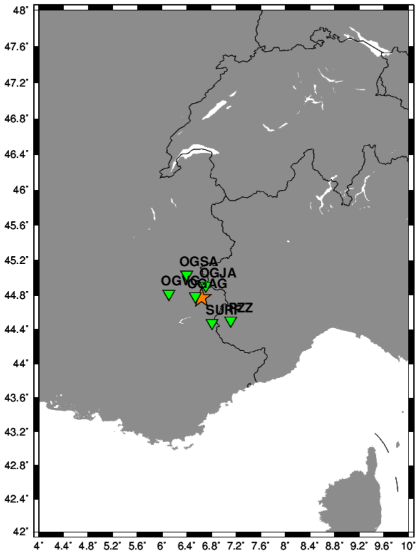
- To eliminate high frequencies that would require too detailed rupture and wave propagation models to be reproduced

- To eliminate low frequencies contaminated by noise

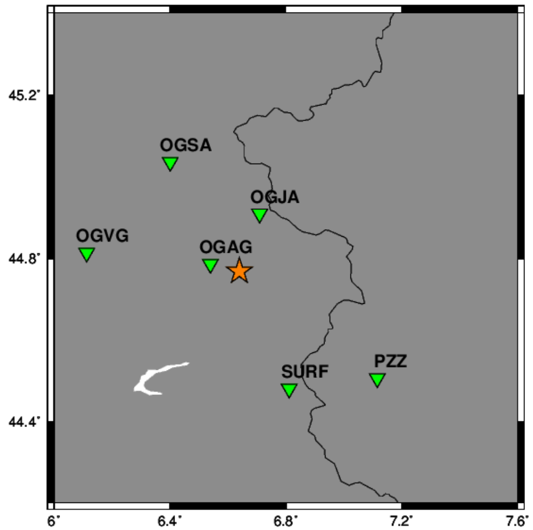


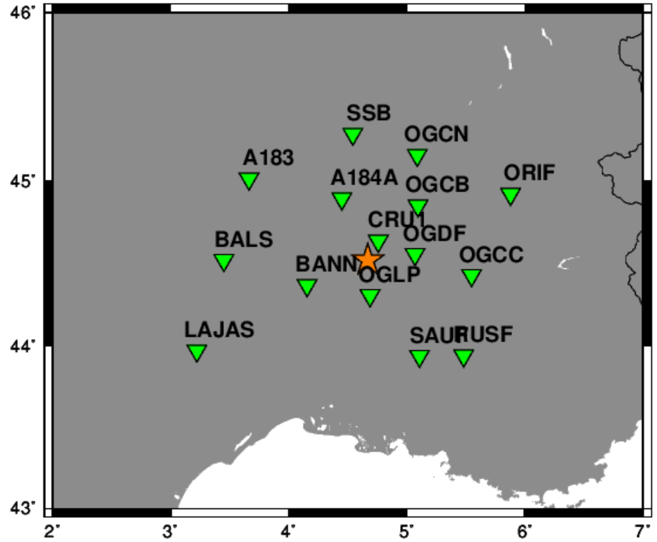
M4.0 Centre France
2022/05/09 11:13:40 UTC





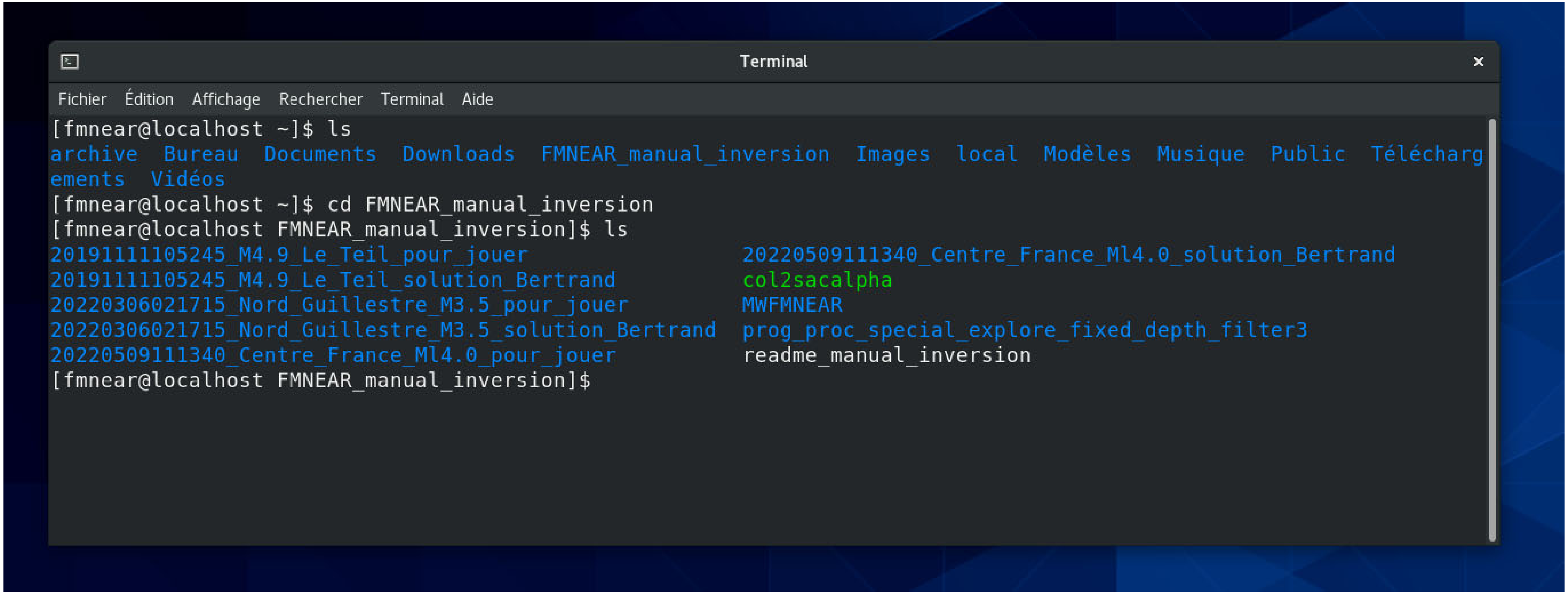
M 3.5 Alpes
2022/03/06 02:17:15 UTC



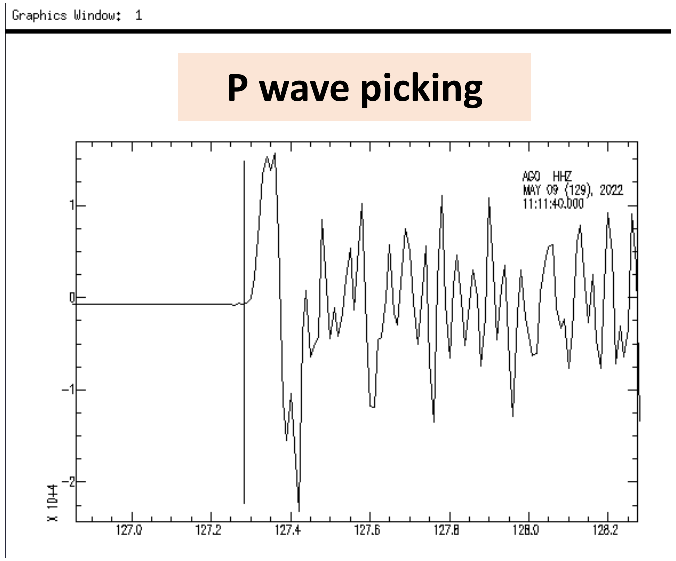


M 4.9 Le Teil
2019/11/11 10:52:45 UTC

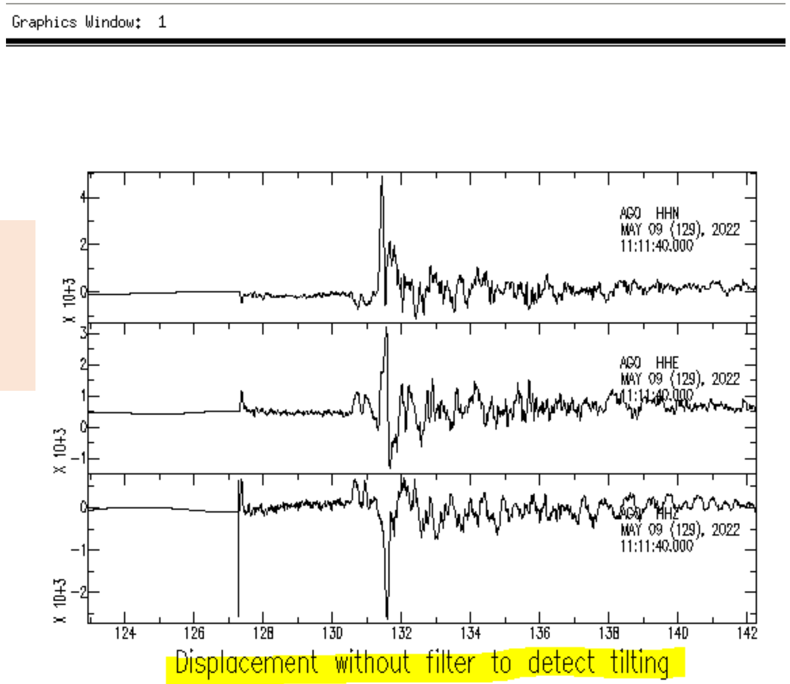
Trois exemples pour jouer


Terminal
Fichier Édition Affichage Rechercher Terminal Aide
[fmnear@localhost ~]$ ls
archive Bureau Documents Downloads FMNEAR_manual_inversion Images local Modèles Musique Public Télécharg
ements Vidéos
[fmnear@localhost ~]$ cd FMNEAR_manual_inversion
[fmnear@localhost FMNEAR_manual_inversion]$ ls
20191111105245_M4.9_Le_Teil_pour_jouer
20191111105245_M4.9_Le_Teil_solution_Bertrand
20220306021715_Nord_Guillestre_M3.5_pour_jouer
20220306021715_Nord_Guillestre_M3.5_solution_Bertrand
20220509111340_Centre_France_Ml4.0_pour_jouer
20220509111340_Centre_France_Ml4.0_solution_Bertrand
col2sacalpha
MWFMNEAR
prog_proc_special_explore_fixed_depth_filter3
readme_manual_inversion
[fmnear@localhost FMNEAR_manual_inversion]$

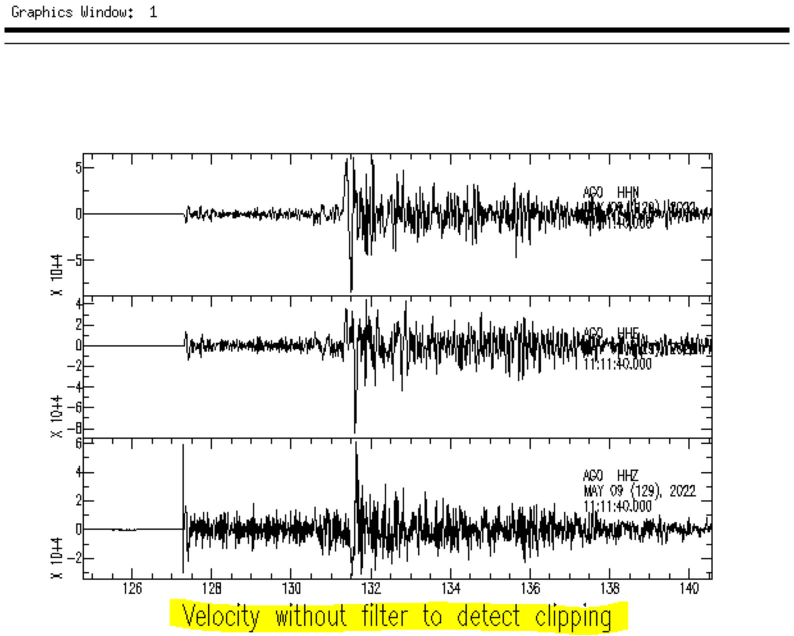
P wave picking



Identifying possible tilt



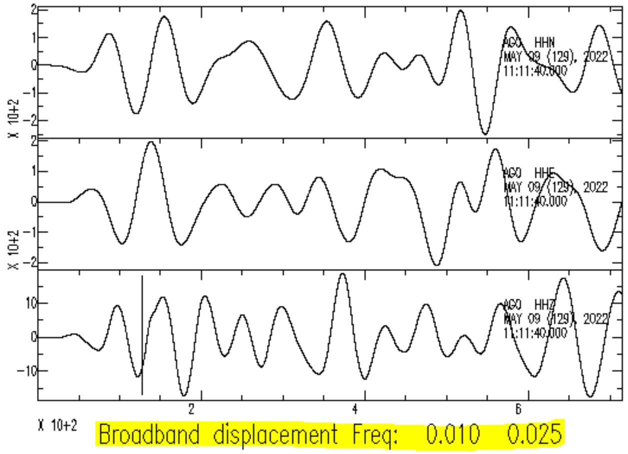
Identifying possible saturation



All semi-automated procedure

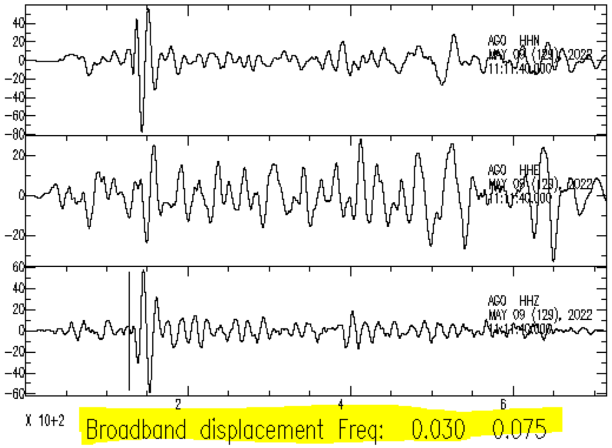
Graphics Window: 1

N, E, Z dominated by noise



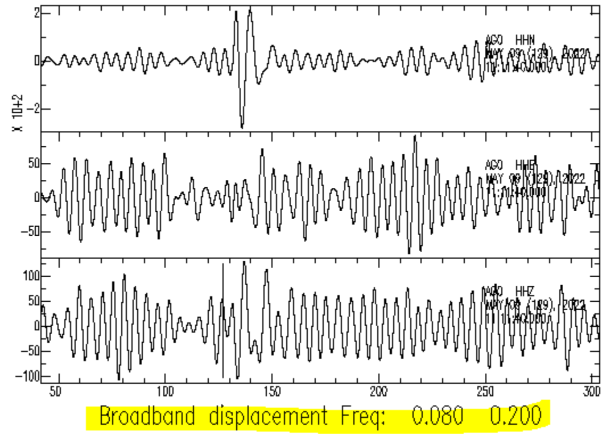
Graphics Window: 1

N and Z OK, E still noisy



Graphics Window: 1

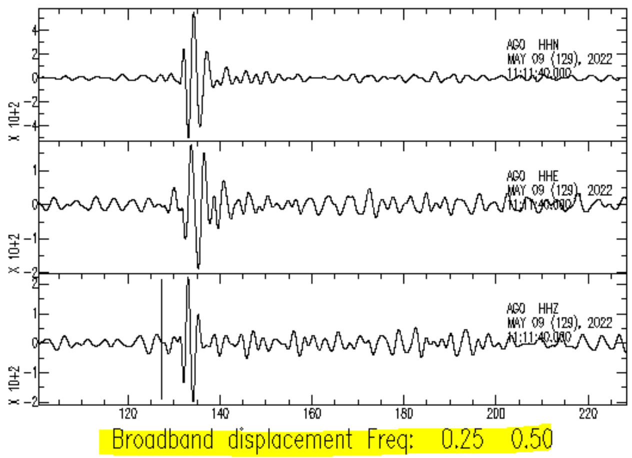
N partly noisy, E and Z very noisy



Semi-automated procedure running through filtering with increasing frequency bands

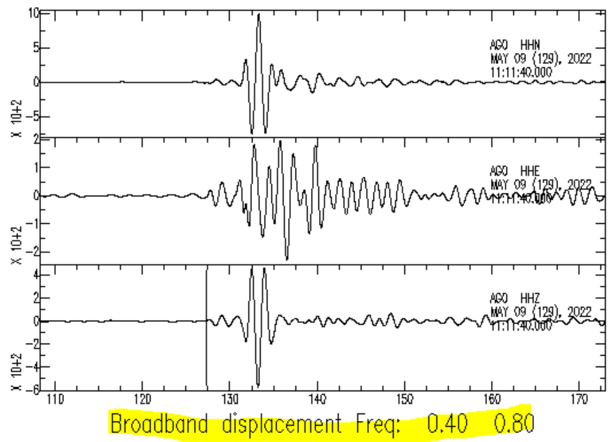
Graphics Window: 1

N, E, Z OK



Graphics Window: 1

N and Z OK, E too complex



Fill file "filter3" with the frequency band of filtering for each component

fmin (Hz) fmax (Hz)

```
0.03 0.075 001v  127.2837 1 vit AGO    N
0.20 0.400 001v  127.2837 1 vit AGO    E
0.03 0.075 001v  127.2837 1 vit AGO    Z
0.04 0.100 002v  135.2572 1 vit BRGF   N
0.04 0.100 002v  135.2572 1 vit BRGF   E
0.03 0.075 002v  135.2572 1 vit BRGF   Z
0.05 0.125 003v  131.1455 1 vit CFF    N
0.05 0.125 003v  131.1455 1 vit CFF    E
0.05 0.125 003v  131.1455 1 vit CFF    Z
0.03 0.075 004v  136.6363 1 vit CHLF   N
0.03 0.075 004v  136.6363 1 vit CHLF   E
0.03 0.075 004v  136.6363 1 vit CHLF   Z
0.03 0.075 005v  137.7521 1 vit GARF   N
0.04 0.100 005v  137.7521 1 vit GARF   E
0.04 0.100 005v  137.7521 1 vit GARF   Z
0.03 0.075 006v  129.2345 1 vit GZNF   N
0.03 0.075 006v  129.2345 1 vit GZNF   E
0.03 0.075 006v  129.2345 1 vit GZNF   Z
0.03 0.075 007v  127.9534 1 vit HRSF   N
0.03 0.075 007v  127.9534 1 vit HRSF   E
0.03 0.075 007v  127.9534 1 vit HRSF   Z
0.25 0.500 008a  125.6696 1 acc OCMN   N
0.25 0.500 008a  125.6696 1 acc OCMN   E
0.25 0.500 008a  125.6696 1 acc OCMN   Z
0.25 0.500 009a  125.1148 1 acc OCSJ   N
0.25 0.500 009a  125.1148 1 acc OCSJ   E
0.25 0.500 009a  125.1148 1 acc OCSJ   Z
0.04 0.100 010v  133.5145 1 vit PLDF   N
0.04 0.100 010v  133.5145 1 vit PLDF   E
0.04 0.100 010v  133.5145 1 vit PLDF   Z
0.04 0.100 011v  130.8331 1 vit VERF   N
0.04 0.100 011v  130.8331 1 vit VERF   E
0.04 0.100 011v  130.8331 1 vit VERF   Z
```

Define stations to be used in the inversion in file "tpobs"

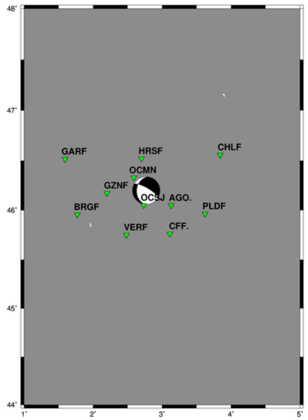
1 or 0 : used or unused

```
001v  127.2837 1 vit AGO
002v  135.2572 1 vit BRGF
003v  131.1455 1 vit CFF
004v  136.6363 1 vit CHLF
005v  137.7521 1 vit GARF
006v  129.2345 1 vit GZNF
007v  127.9534 1 vit HRSF
008a  125.6696 1 acc OCMN
009a  125.1148 1 acc OCSJ
010v  133.5145 1 vit PLDF
011v  130.8331 1 vit VERF
```

Tp (s) Stat

Launch the inversion

Visualize result file



M < 5.5, only one point source

Frequencies too low to constrain the STF

strike dip rake
300. 75. -119.

strike dip rake
300.0 75.0 -118.8 : best focal mechanism

RMS = 0.306

Selected depth: 19.0 km

33 = number of components
91 % : index of confidence

3.35 : Mw from waveform inversion

Epicenter used (lat,long): 46.200 2.770
Starting depth(km): 19.0

strike dip rake of the second nodal plane:
184.7 32.1 -29.1

****
****** quality: A ******
****

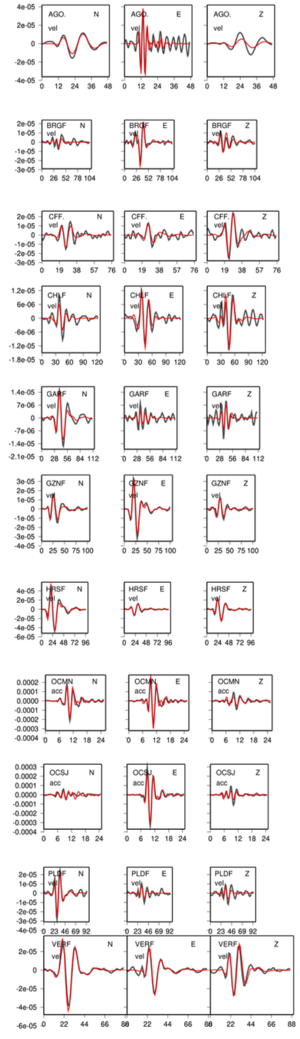
**** Signification of quality *******
A: focal mechanism STRONGLY CONSTRAINED
B: focal mechanism WELL CONSTRAINED
C: focal mechanism MODERATELY CONSTRAINED
D: focal mechanism WEAKLY CONSTRAINED
E: focal mechanism BARELY CONSTRAINED
F: focal mechanism NOT CONSTRAINED
****

Event directory:
/home/fmnear/FMNEAR_manual_inversion/20220509111340_Centre_France_Ml4.0

Date of computation:
mer. nov. 1 09:23:39 -03 2023

Method used: FMNEAR

!!!! AUTOMATIC COMPUTATION !!!!



Result text file

```
strike   dip    rake
300.0   75.0 -118.8 : best focal mechanism

RMS =   0.306

Selected depth:  19.0 km

        33 = number of components
91 % : index of confidence

3.35 : Mw from waveform inversion


Epicenter used (lat,long):   46.200    2.770
Starting depth(km):    19.0

strike   dip    rake   of the second nodal plane:
 184.7   32.1  -29.1

*************************
****** quality: A ******
*************************

**** Signification of quality *******
A: focal mechanism STRONGLY CONSTRAINED
B: focal mechanism WELL CONSTRAINED
C: focal mechanism MODERATELY CONSTRAINED
D: focal mechanism WEAKLY CONSTRAINED
E: focal mechanism BARELY CONSTRAINED
F: focal mechanism NOT CONSTRAINED
*****************************************
```

Explanation

strike, dip rake of nodal plane 1

Normalized RMS misfit (to be minimized)

Source depth used, as fixed in « locmag » file

Number of components included in the inversion
Index of confidence (unicity of the solution, best close to 100%)

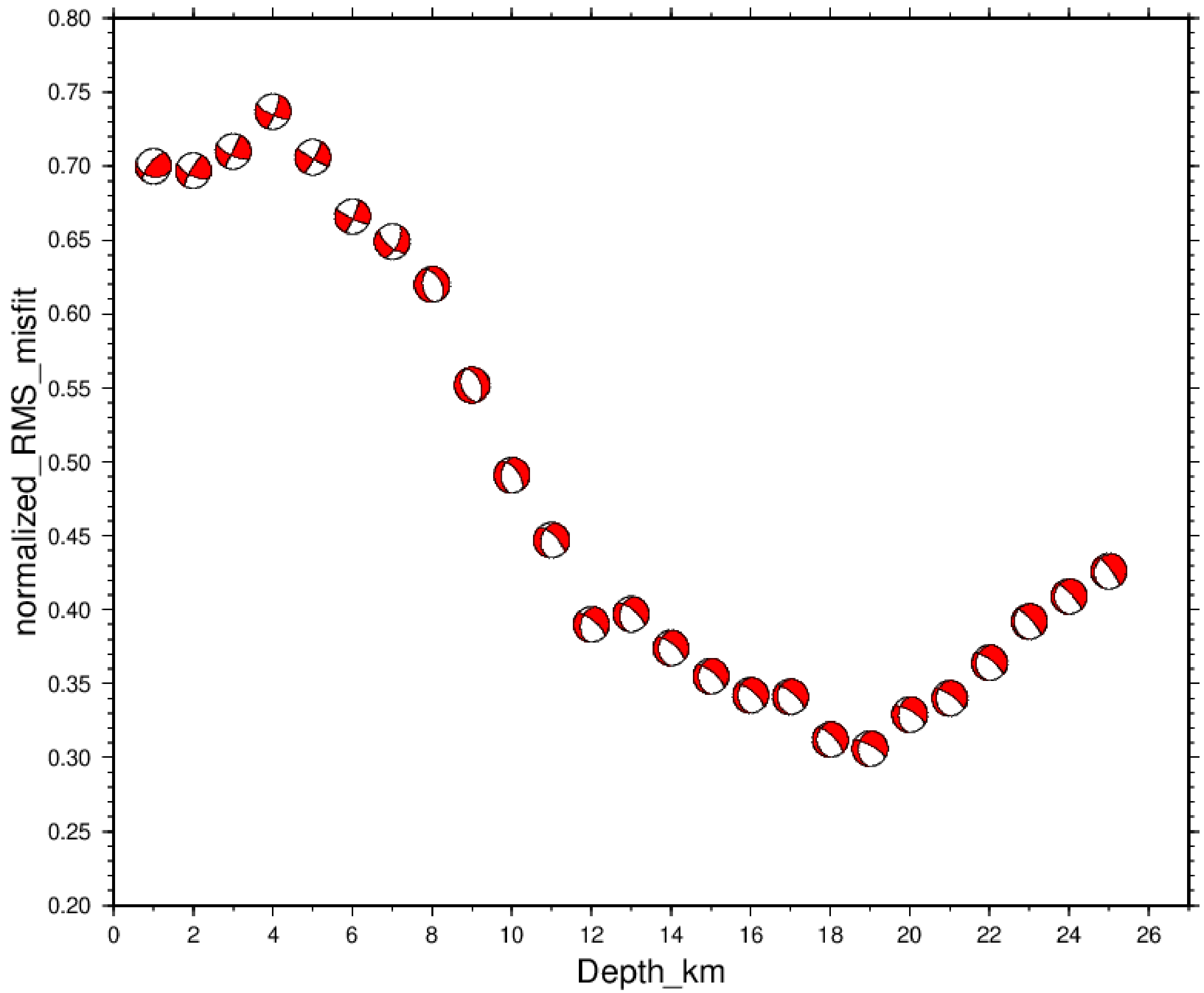
Final moment magnitude Mw

Epicenter used, as defined in « locmag » file
Starting depth = final depth in this version

strike, dip rake of nodal plane 2

Global quality (A to F)

Launch fine exploration of depth



Data preparation (data format) and velocity model

Data format and information needed: “ Data preparation for FMNEAR ”

Data consist in linux binary SAC files, one per component of each station. All three components (N, E, Z) (rem 1) should be provided. Ideally, they should include 120 to 180 s of pre-event signal (before earthquake origin time or before the first P wave arrival).

The SAC header variables stla, stlo, evla, evlo, evdp, scale, and mag should be filled.

stla: station latitude stlo: station longitude

evla: event latitude evlo: event longitude evdp: event depth (km)

All latitudes and longitudes should be in degrees. Latitude > 0 for North, latitude < 0 for South, longitude > 0 for East, longitude < 0 for West.

scale: sensitivity

Sensitivity is the factor by which amplitudes in counts should be divided to obtain amplitudes in m (meters). It corresponds to the overall amplification of the signal in the flat part (plateau) of the global response of a broadband seismic station. By broadband we include here broadband velocimeters and broadband accelerometers. The value of sensitivity is read on the vertical component only, and applied to all 3 components (it is assumed that the sensitivity is similar for all three components).

mag: a priori (initial) magnitude of the earthquake (M_w if known, otherwise any kind of magnitude determined for the earthquake).

NB: The SAC variable « lovrok » should be set to « true » for all channels (generally it is so, but if you generate yourself the SAC files from ascii files, this may not be the case). It permits to overwrite the file on disk.

The names of the SAC files should follow a specific format:

XX.STAT..HHN.XXXXX.XXXXX.SAC XX.STAT..HHE.XXXXX.XXXXX.SAC XX.STAT..HHZ.XXXXX.XXXXX.SAC for the three components in case of velocity. The letter after “HH” indicates the component (N, E, or Z).

NB: even if the record is originally a BH or LH channel, it should be HH in the final name of the SAC file.

XX.STAT..HNN.XXXXX.XXXXX.SAC XX.STAT..HNE.XXXXX.XXXXX.SAC XX.STAT..HNZ.XXXXX.XXXXX.SAC for the three components in case of acceleration. The letter after “HN” indicates the component (N, E, or Z).

NB: even if the record is originally a BN or LN channel, it should be HN in the final name of the SAC file.

STAT is the station name, it should be 3 to 5 letters long.

Take care to use double point after the station name.

Rem 1: The FMNEAR codes will not work properly if the components are not correctly oriented with the correct polarity (sign). The correct orientation and polarity corresponds to positive amplitude towards the North, East and Up.

Rem 2: Errors in the sensitivity values (scale parameter) will affect also the results

Format of the velocity model:

Here is the default velocity model:

```
5
  0.60     3.30     1.90     2.00    200.00  100.00
  1.40     4.50     2.60     2.30    350.00  175.00
  3.00     5.50     3.18     2.50    500.00  250.00
 25.00     6.50     3.75     2.90    600.00  300.00
  0.00     8.10     4.68     3.30   1000.00  500.00
```

The default model is contained in file “**model_vel_base**”. To change the velocity model, modify this file.

First line: number of layers. Accepted values are 1 to 10. Integer value.

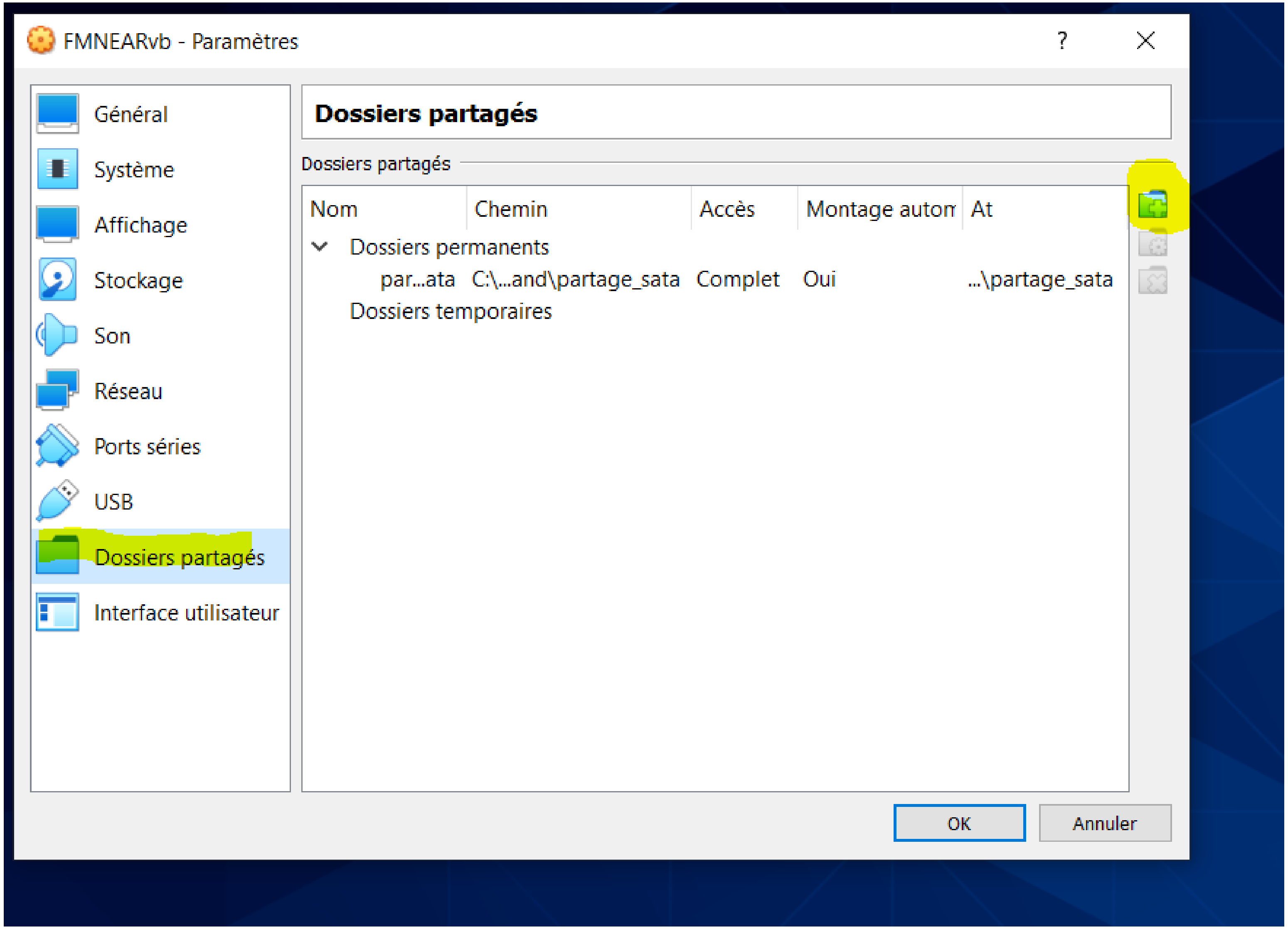
Next lines: layer thickness (km), Vp (km/s), Vs (km/s), density (g/cm^3), Q_p, Q_s. Real values. Spacing between values is free, as is the number of decimals. However, length of lines should not exceed 80 characters.

The last line with “0” thickness is for the mantle, considered as a half-space.

Take care not to include a blank line at the end of the velocity model, it will produce an error.

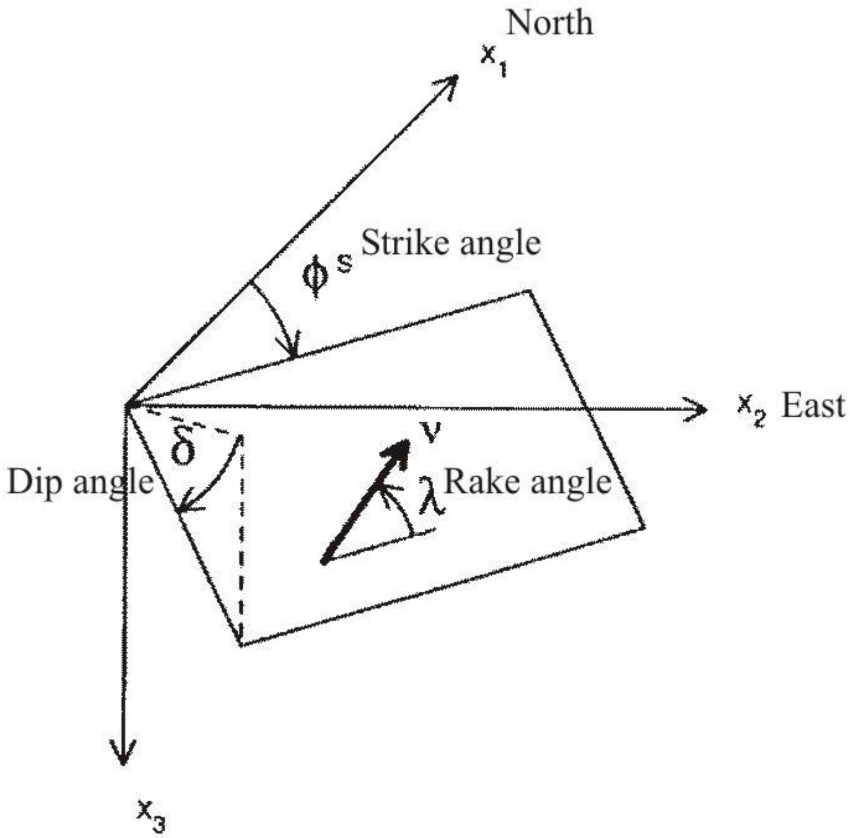
!!! The velocity model should not include velocity inversions. Velocity should be increasing with depth. Parts of the FMNEAR codes cannot handle velocity inversions, so that they will produce errors in the results !!!

Annexes

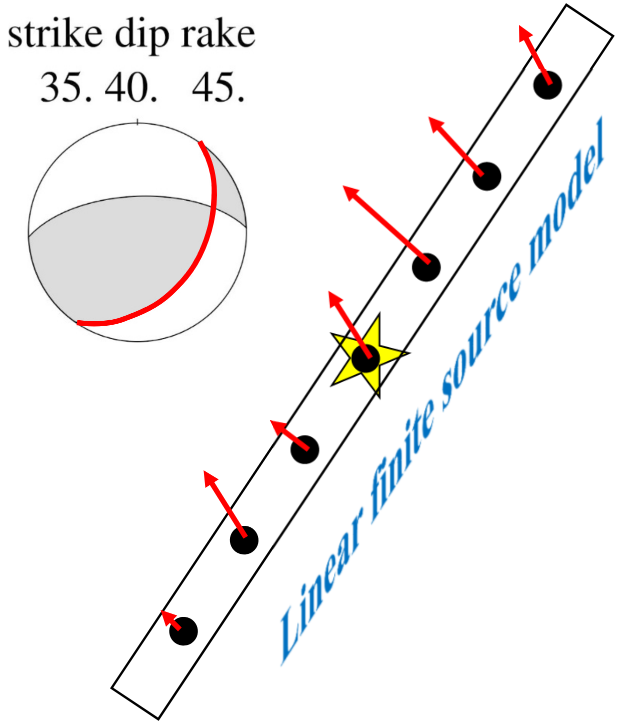


Possibilité d'ajouter des dossiers partagés

Au besoin, le mot de passe root est : fmnear



Example: testing of a line of point sources along strike N35°



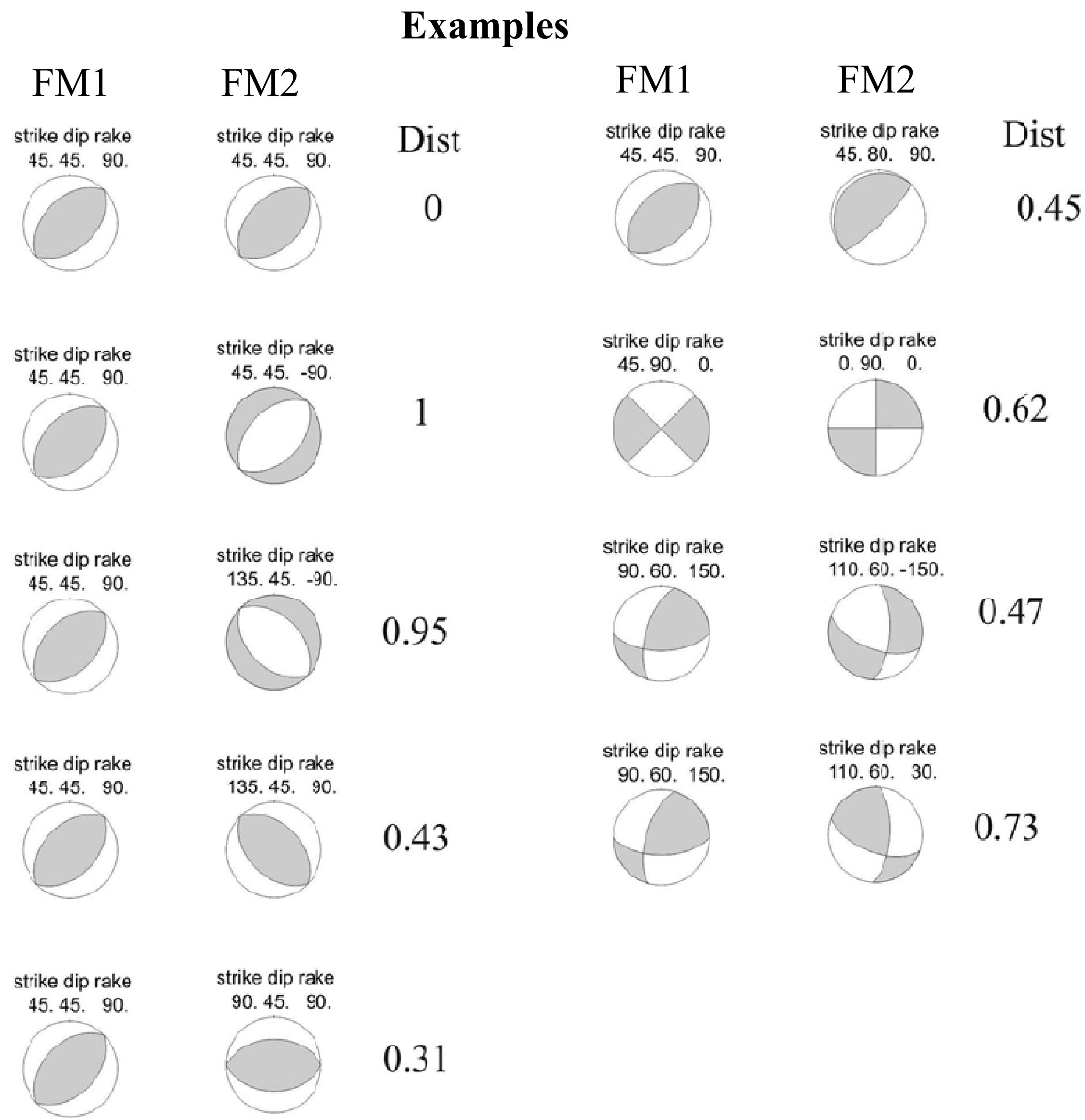
« distmeca »

$$\text{Distance (FM1 - FM2)} = \frac{1}{m} \sum^{m} \text{ABS} (amp_{FM1} - amp_{FM2})$$

ABS: absolute value
m: number of points sampling the focal sphere

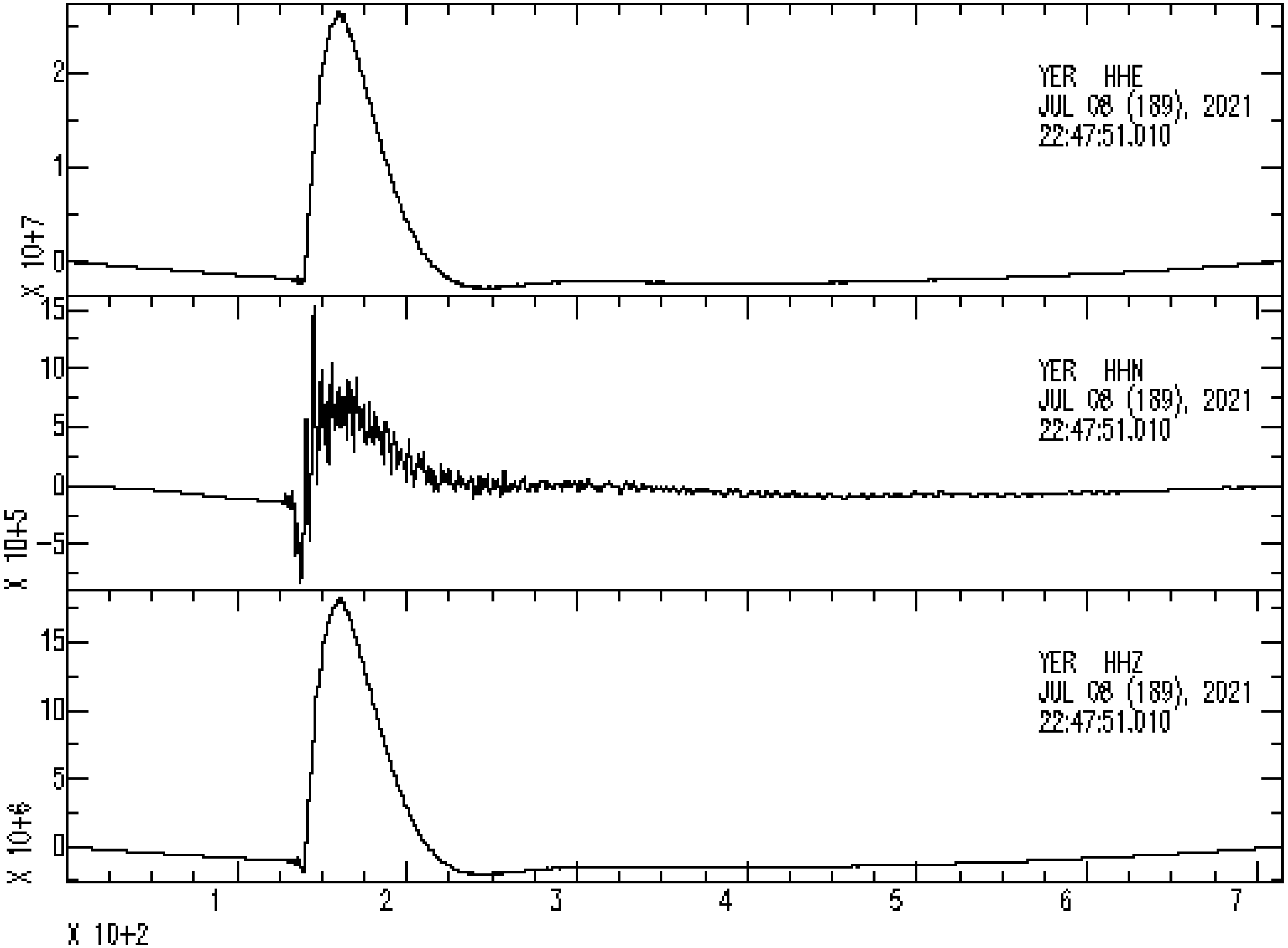
$ampFM = 2\,(\vec{v}.\vec{\gamma})\,(\vec{n}.\vec{\gamma})$ = radiation factor of the P wave*

$\vec{n}$: unit vector normal to the nodal plane
$\vec{v}$: unit slip vector on the nodal plane
$\vec{\gamma}$: unit vector defining the take-off direction



* Aki, K. and P. G. Richards (1980). *Quantitative Seismology*, Vol. 1, W. H. Freeman and Co., San Francisco, 512 pp.

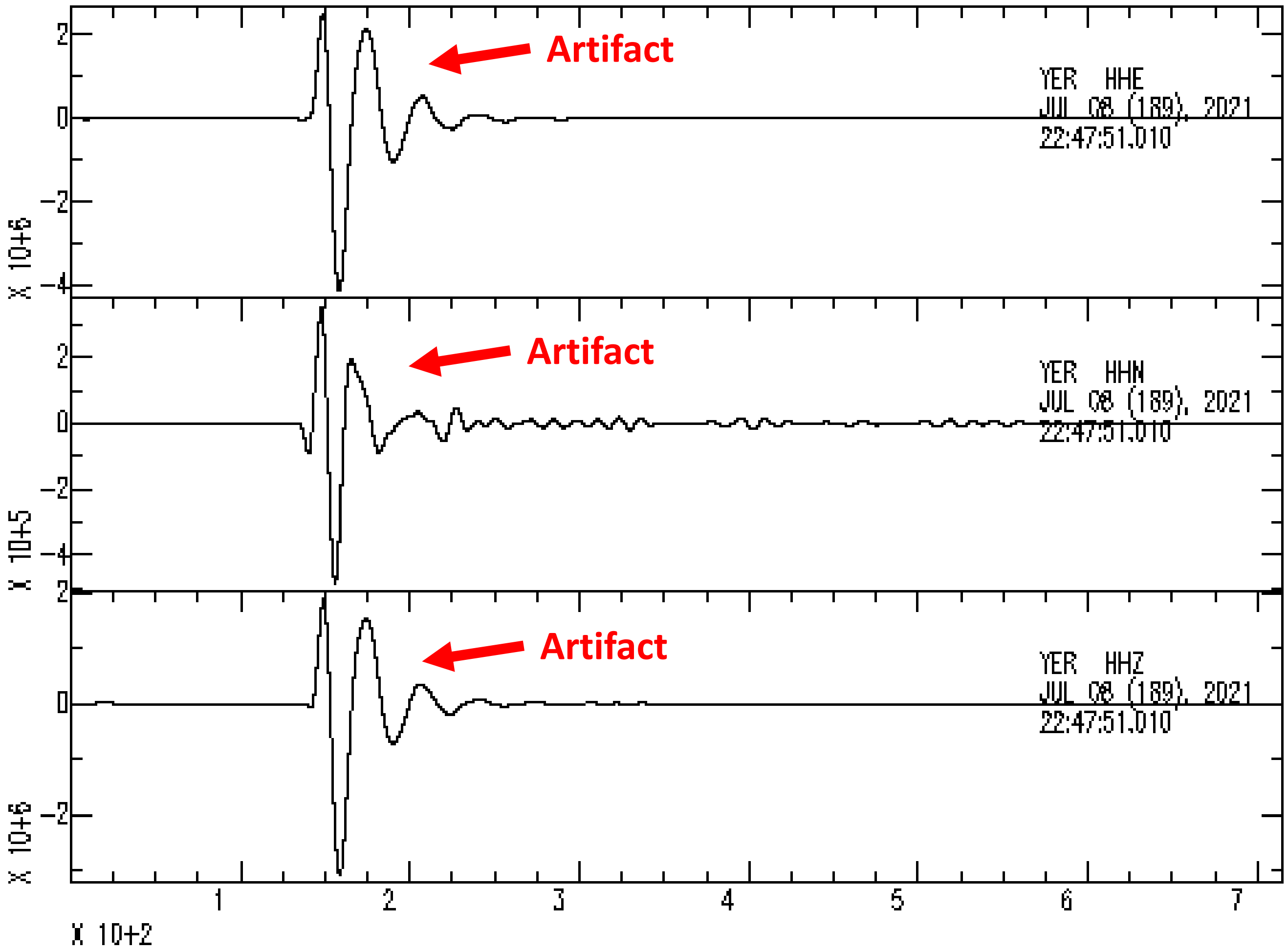
Mw 5.8 Nevada



Displacement records

all comp clearly tilted (mostly E and Z)

Mw 5.8 Nevada



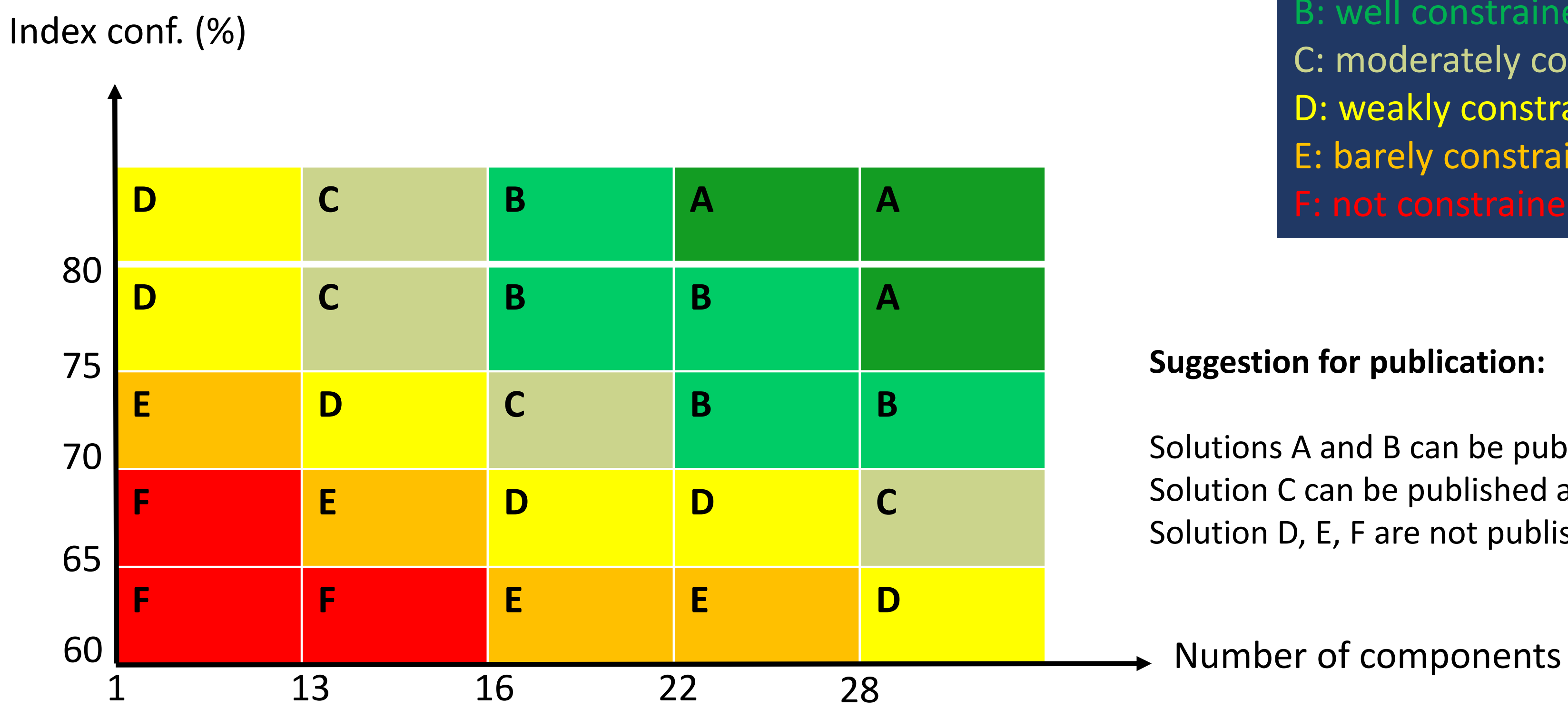
Displacement records

Same as previous slide
but filtered between 0.03 0.08 Hz

See that all components
show similar shapes, especially
E and Z.

And the much larger amplitudes
for E and Z, so that it is clear
that after passband filtering, the
amplitude is biased proportionally
to the importance of the tilt effect

A: strongly constrained
B: well constrained
C: moderately constrained
D: weakly constrained
E: barely constrained
F: not constrained



Suggestion for publication:

Solutions A and B can be published
Solution C can be published after visual inspection
Solution D, E, F are not published

Additional conditions:

- if qual=A or B and rms > 0.7 then qual=C
- if qual=A and rms > 0.65 then qual=B
- Conditions on primary and secondary gaps : if bad, cannot be better than C