UNIVERSITÀ DEGLI STUDI DI TRIESTE

Applied seismology

Signal Processing

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SEISMIC MOTION PARAMETERS

Microseismic activity: characterized by vibrations of weak amplitude and very large periods such that they are not perceived by most common recording instruments (especially important for seismologists)

Strong motion activity: characterized by vibrations of such amplitude and period as to produce damage on environment and infrastructure and detectable with the most common instruments (e.g., amplitudes between **0.001 g** and **1 g** and frequencies between **0.06 Hz and 25 Hz**)

SEISMIC MOTION PARAMETERS

Assessing the effects of strong motion activity on a given site requires a quantitative and objective description of the seismic motion at the site:

- Three orthogonal components of translation
- Three components of rotation (generally neglected)

The components of translation are generally measured and recorded, e.g., in terms of acceleration (accelerograms), in analog or numerical form (in which case a sufficiently small step size, e.g., 0.01 s, is required to adequately represent each peak or inversion)

SEISMIC MOTION PARAMETERS

The information useful for engineering purposes to represent the seismic motion at the site is much less than that contained in a recording and concerns:

- the amplitude
- the frequency content
- the duration

such information must still be obtained from the recording, but it can be summarized in a series of parameters (seismic motion parameters)

Using appropriate laws (GMPE) it is possible to predict the variation of these parameters with epicenter distance.

N.B. Each parameter alone can describe one or more characteristics of seismic motion, but there is no parameter that can by itself fully describe it

AMPLITUDE OF SEISMIC MOTION

The most common and comprehensive, though overabundant, way of describing the magnitude of seismic motion is to use the entire time history of the motion in terms of acceleration, velocity and displacement, where one (usually acceleration) is measured directly and the others derived by successive integrations or derivations.

Generally in the accelerogram the predominant frequencies, i.e., to which the highest peaks correspond, are the high frequencies (at the peak the cycles of oscillation become thicker, i.e., have smaller periods), so it can be said that the significant part of the motion is concentrated at high frequencies; in the velocigram and even more so in the seismogram it tends to move more toward the low frequencies, i.e., at the peaks low frequencies are detected (the cycles "widen"). This is due to the filtering effect produced by the integration process.

AMPLITUDE OF SEISMIC MOTION

Peak acceleration (PGA):

highest peak (in absolute value) recorded for acceleration, generally calculated for one of the horizontal components (**PGHA**) and the vertical component (**PGVA**)

PGHA: is the most interesting and useful because.

1. horizontal acceleration is closely related to the dynamic forces induced on structures by an earthquake
2. it is possible to correlate (only indicatively, however) this peak with macroseismic intensity, so as to have an estimate of the PGA even for those earthquakes for which records are not available and ,known the isosism map, one can derive how the PGA varies with epicentral distance

PGVA: is the least interesting and useful being generally the most resistant structures to vertical dynamic stresses due to the force of gravity exerting a conservative role for stability purposes and is generally assumed: PGVA = 2/3 PGHA

Generally earthquakes characterized by high PGAs have been the most destructive, although if the peak is of short duration (corresponding to high frequencies) and the earthquake is of short duration, the damage is much more limited especially on certain structures

This parameter alone does not provide information on the duration of the motion and frequency content.

AMPLITUDE OF SEISMIC MOTION

Peak velocity (PGV):

highest peak (in absolute value) recorded for velocity and is generally calculated for one of the horizontal components (PGHV)

It is useful because:

1. since velocity is less sensitive to high-frequency motion components, it serves to characterize the amplitude of seismic motion at intermediate frequencies and is therefore useful in indicating damage potential for all those structures sensitive to the intermediate-frequency range (tall buildings, flexibles, bridges)
2. it is possible to correlate (only tentatively, however) this peak with macroseismic intensity

AMPLITUDE OF SEISMIC MOTION

Peak displacement (PGD):

highest peak (in absolute value) recorded by displacement is useful because:

1. since displacement is associated with the low-frequency components of motion, it serves to characterize the amplitude of seismic motion at low frequencies.

FREQUENCY CONTENTS

Frequency content describes how the amplitudes of seismic motion are distributed among the various frequencies.

it is useful if not indispensable because the dynamic response of structures depends strongly in addition to the amplitudes of applied loads on the relative frequencies in relation to their own natural frequencies, so the description of seismic motion and the effects produced can only be complete if it is accompanied by an analysis of the frequency content

Spectra of seismic motion

Any periodic function x(t) of period T_f can be expressed as a sum of simple harmonic functions with different frequency ω_n, amplitude C_n and phase ϕ_n:

$$x(t) = c_0 + \sum_{n=1}^{\infty} c_n sin(\omega_n t + \phi_n) \text{con}$$

$$c_0 = a_0; c_n = \sqrt{a_n^2 + b_n^2}; \phi_n = \tan^{-1}\left(\frac{a_n}{b_n}\right); \omega_n = \frac{2\pi n}{T_f}$$

$$a_0 = \frac{1}{T_f}\int_0^{T_f} x(t)dt$$

$$a_n = \frac{2}{T_f}\int_0^{T_f} x(t)\cos(\omega_n t)dt$$

$$b_n = \frac{2}{T_f}\int_0^{T_f} x(t)sin(\omega_n t)dt$$

Known the x(t) function, the corresponding Fourier series (Fourier transform) can be derived, and known the latter, the x(t) function (inverse Fourier transform) can be derived. Furthermore, since x(t) is generally a discrete function, the Fourier transform is also derived in discrete form (Fast Fourier Transform).

FREQUENCY CONTENTS

Fourier spectrum.

Expresses, as frequency or period varies, how the amplitudes or phases of individual harmonics derived from the Fourier transform vary.

FREQUENCY CONTENTS

Response spectrum.

Expresses the maximum response of a single-degree-of-freedom (SDOF) system to a particular input motion as the natural frequency, (or period) and attenuation ratio vary.

It is especially useful in the engineering field because it allows direct evaluation of the maximum response to seismic input of various structures, even if simplified.

The response spectrum reflects only indirectly the characteristics of the seismic motion, these being filtered through the response of the SDOF structure

1. the maximum response of the system can be expressed in terms of acceleration, velocity, or displacement; for each of these, the spectrum can be represented separately or in the same diagram by reporting the spectral velocity on the vertical axis and the natural frequency or period on the horizontal axis and the spectral acceleration and displacement on the inclined axes;
2. the Fourier spectra in terms of amplitude of and phase and that of power are sufficient to completely describe the seismic motion, while that of response tends more to assess its effects;
3. Denoted by u the displacement of the system and by ω_0 its attenuation the acceleration S_a, velocity S_v and maximum spectral displacement S_d can be approximated as follows:

$$S_d = |u_{max}|;\ S_v = |\dot{u}_{max}| = \omega_0 S_d = PSV;\ S_a = |\ddot{u}_{max}| = \omega_0^2 S_d = PSA;$$

DURATION

An accelerogram generally contains all accelerations recorded from the beginning of the event to the instant the instrument resumes recording only background noise, but for engineering purposes only the strong motion portion of the accelerogram is of interest so:

The duration of seismic motion (T_d) is understood to be the duration relative to the strong motion portion of the accelerogram and can be calculated:

- the time interval between the first and last exceedance of an acceleration threshold (usually 0.05 g);
- the time interval between instants when the total energy recorded is 5% and 95%;
- the reciprocal of the "corner" frequency of the Fourier spectrum

The duration has a significant influence on damage especially when it begins to be high due to the number of cyclic loads it produces to which both structures and soils are sensitive (cyclic degradation and liquefaction).
Duration is related to the time required to release the energy stored along the rupture surface.

OTHER SEISMIC PARAMETERS

Unlike the parameters seen so far, which are predominantly related to only one of the aspects of seismic motion, there are a number of other parameters that simultaneously reflect multiple aspects of seismic motion.

RMS acceleration RMS(a) defined as:

$$a_{rms} = \sqrt{\frac{1}{T_d}\int_0^{T_d}\left[a(t)\right]^2 dt} = \sqrt{\lambda_0}$$

- reflects both the frequency content and amplitude of seismic motion
- is particularly useful for engineering purposes since it is not affected by high-frequency peaks and depends on duration
- is, however, influenced by the criterion adopted to define the strong motion duration

OTHER SEISMIC PARAMETERS

<u>Arias intensity (Ia) defined as:</u>

$$I_a = \frac{\pi}{2g} \int_0^{\infty} [a(t)]^2 \, dt$$

- reflects both the frequency content and amplitude of seismic motion
- Is a velocity, generally expressed in m/s
- not affected by the criterion adopted to define the strong motion duration, depending on the entire duration

OTHER SEISMIC PARAMETERS

Effective peak acceleration (EPA)

defined as the average spectral acceleration derived over the period interval from 0.1 to 0.5 s divided by 2.5

OTHER SEISMIC PARAMETERS

intensity of Housner, IH

defined as:

$$I_H \doteq \int_{T_1}^{T_2} S_v(\tau)d\tau$$

where S_v is the pseudo-velocity spectrum, T_1 and T_2 are the extreme periods of the interval of integration considered (equal to 0.1 - 2.5 s in the standard definition).

Event: Socchiev - Origin time: 2024/04/05 12:28:32 Lat:46.358 Lon:12.816 Ml = 3.4 Agency: DPC

Seismic moment: 1.182e+14 Nm - Mw = 3.2 Agency: DPC

sta	chan	loc	dista	filter	PGA	EPA	PGV	PGD	PSA03	PSA10	PSA30	EC8	location
			km	Hz	cm/s*s	cm/s*s	cm/s	cm	cm/s*s	cm/s*s	cm/s*s		
AMPZ	HNE		6	0.4-50.0	6.93	1.32	0.09		2.69	0.14		na	Ampezzo (FVG)
AMPZ	HNN		6	0.4-50.0	5.65	1.97	0.09		5.90	0.31		na	Ampezzo (FVG)
AMPZ	HNZ		6	0.4-50.0	5.69	1.48	0.08		4.05	0.17		na	Ampezzo (FVG)
INVI	HNE		8	0.7-49.8	1.01	0.34	0.02		0.85	0.14		na	Invillino HAREIA
INVI	HNZ		8	0.7-49.8	1.07	0.32	0.02		0.55	0.07		na	Invillino HAREIA
PURA	HGE		9	0.4-49.1	2.37	0.96	0.05		1.30	0.09		na	Passo_Pura
PURA	HGN		9	0.4-49.1	2.15	1.11	0.07		2.51	0.23		na	Passo_Pura
PURA	HGZ		9	0.4-49.1	1.10	0.44	0.03		0.99	0.13		na	Passo_Pura
CHIE	HNE		13	0.8-49.9	6.31	1.28	0.09		1.97	0.09		na	Chievolis HAREIA
CHIE	HNN		13	0.8-49.9	5.95	0.81	0.08		0.91	0.07		na	Chievolis HAREIA
CHIE	HNZ		13	0.8-49.9	4.12	0.55	0.04		0.62	0.06		na	Chievolis HAREIA
TLM2	HGE		13	0.6-50.0	2.70	1.32	0.06		4.32	0.24		B	Tolmezzo2
TLM2	HGN		13	0.6-50.0	5.23	1.88	0.11		5.83	0.22		B	Tolmezzo2
TLM2	HGZ		13	0.6-50.0	1.89	0.70	0.04		1.47	0.06		B	Tolmezzo2
PRAD	HNE		13	0.5-50.0	2.95	0.67	0.04		1.04	0.07		na	Pradis
PRAD	HNN		13	0.5-50.0	2.48	0.71	0.04		0.67	0.08		na	Pradis
PRAD	HNZ		13	0.5-50.0	3.82	0.69	0.04		0.72	0.06		na	Pradis
OVAR	HNE		15	0.6-50.0	7.71	1.46	0.12		2.59	0.12		B	Ovaro
OVAR	HNN		15	0.6-50.0	11.00	1.11	0.11		2.57	0.12		B	Ovaro
OVAR	HNZ		15	0.6-50.0	5.35	0.73	0.08		0.76	0.10		B	Ovaro
PALA	HGE		15	0.3-49.9	1.38	0.48	0.03		0.99	0.14	0.01	na	Monte_Pala
PALA	HGN		15	0.3-49.9	1.56	0.58	0.03		0.92	0.13	0.01	na	Monte_Pala
PALA	HGZ		15	0.3-49.9	1.35	0.26	0.02		0.33	0.08		na	Monte_Pala
CESC	HNE		18	0.5-49.2	1.80	0.86	0.03		1.38	0.08		na	Cesclans
CESC	HNN		18	0.5-49.2	2.45	1.18	0.05		2.73	0.12		na	Cesclans
CESC	HNZ		18	0.5-49.2	3.01	0.53	0.03		0.91	0.05		na	Cesclans
AVS	HNE		19	0.3-49.8	1.23	0.17	0.01		0.24	0.03		C	Avasinis
AVS	HNN		19	0.3-49.8	1.75	0.15	0.01		0.23	0.04		C	Avasinis

dista = epicentral distance
filter = automatic band pass butterworth filter
EC8 = site classification (Eurocode from ITACA)

PGA,PGV,PGD = peak ground acceleration, velocity and displacement
EPA = effective ground acceleration (Kramer, 1996)
PSA03,PSA10,PSA30 = spectral acceleration (0.3, 1.0, 3.0 sec)

Event: Socchiev - Origin time: 2024/04/05 12:28:32 Lat:46.358 Lon:12.816 Ml = 3.4 Agency: DPC

Seismic moment: 1.182e+14 Nm - Mw = 3.2 Agency: DPC

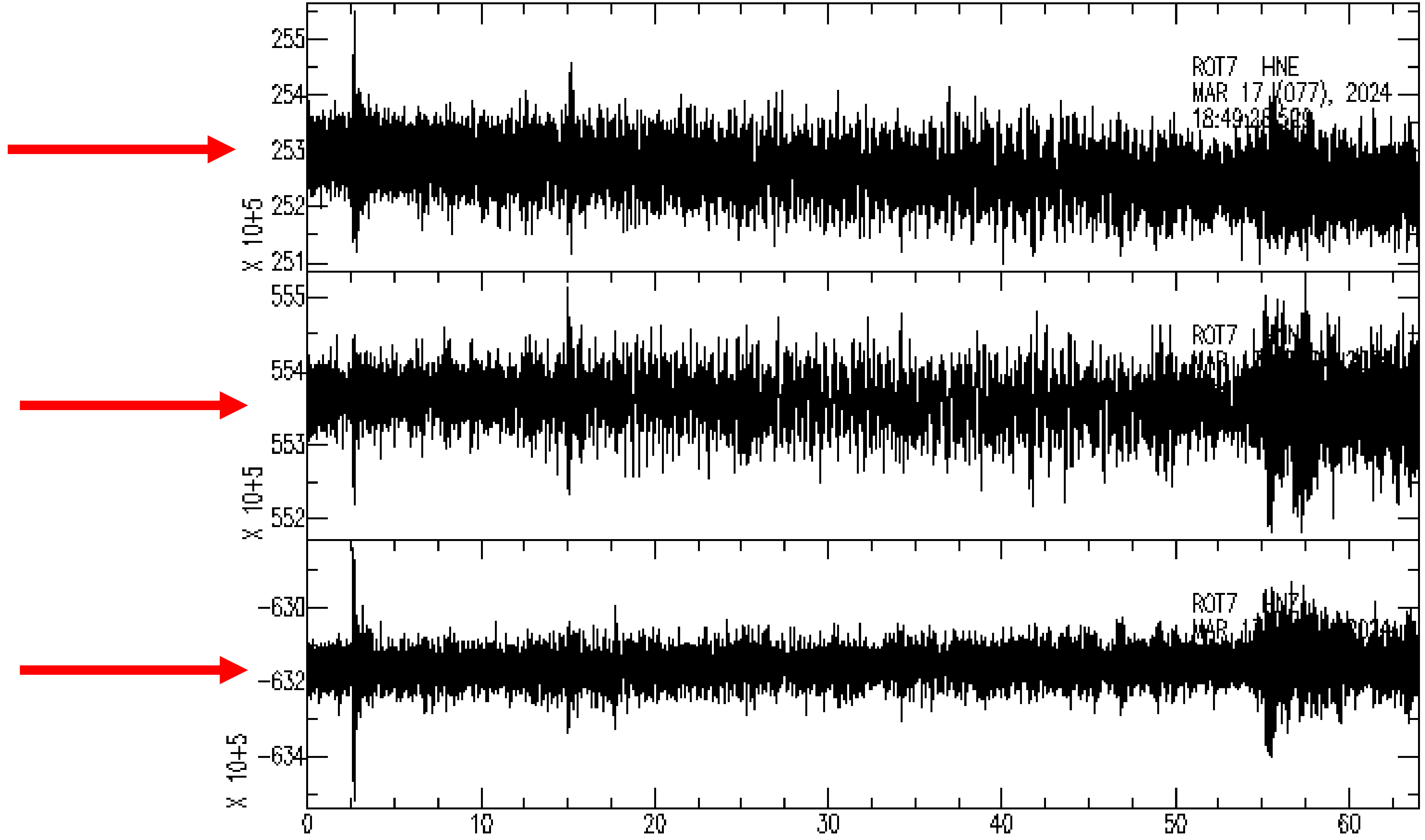
sta	chan	loc	dista	filter	Td	PGV/PGA	RMSA	v0	Pd	Id	Housner	Arias	EC8	location
			km	*Hz*	*s*	*s*	*cm/s*s*	*1/s*	*cm*s*	*cm/s*	*cm*	*cm/s*		
AMPZ	HNE		6	0.4-50.0	4.01	0.01	1.59	34.87		15.52		0.02	na	Ampezzo (FVG)
AMPZ	HNN		6	0.4-50.0	5.01	0.02	1.19	31.70		13.59		0.01	na	Ampezzo (FVG)
AMPZ	HNZ		6	0.4-50.0	3.85	0.01	1.43	39.53		17.28		0.01	na	Ampezzo (FVG)
INVI	HNE		8	0.7-49.8	5.17	0.02	0.20	29.76		9.81			na	Invillino HAREIA
INVI	HNZ		8	0.7-49.8	6.50	0.02	0.18	25.69		11.51			na	Invillino HAREIA
PURA	HGE		9	0.4-49.1	4.11	0.02	0.51	27.98		8.73	0.06		na	Passo_Pura
PURA	HGN		9	0.4-49.1	4.00	0.03	0.50	24.78		6.94	0.11		na	Passo_Pura
PURA	HGZ		9	0.4-49.1	4.84	0.02	0.25	34.67		10.88	0.05		na	Passo_Pura
CHIE	HNE		13	0.8-49.9	1.70	0.01	2.08	36.58		13.50		0.01	na	Chievolis HAREIA
CHIE	HNN		13	0.8-49.9	2.08	0.01	1.78	36.63		14.59		0.01	na	Chievolis HAREIA
CHIE	HNZ		13	0.8-49.9	2.57	0.01	0.92	42.80		12.35			na	Chievolis HAREIA
TLM2	HGE		13	0.6-50.0	5.36	0.02	0.62	23.88		12.06			B	Tolmezzo2
TLM2	HGN		13	0.6-50.0	3.75	0.02	1.01	28.27		6.78			B	Tolmezzo2
TLM2	HGZ		13	0.6-50.0	5.20	0.02	0.45	34.84		15.68			B	Tolmezzo2
PRAD	HNE		13	0.5-50.0	5.03	0.01	0.60	40.95		17.14			na	Pradis
PRAD	HNN		13	0.5-50.0	4.81	0.02	0.57	35.76		16.04			na	Pradis
PRAD	HNZ		13	0.5-50.0	4.36	0.01	0.71	34.44		13.77			na	Pradis
OVAR	HNE		15	0.6-50.0	3.06	0.02	1.46	39.28		7.26		0.01	B	Ovaro
OVAR	HNN		15	0.6-50.0	1.86	0.01	1.97	30.11		5.72		0.01	B	Ovaro
OVAR	HNZ		15	0.6-50.0	4.57	0.01	0.99	36.14		10.65			B	Ovaro
PALA	HGE		15	0.3-49.9	10.90	0.02	0.24	21.47		18.09	0.05		na	Monte_Pala
PALA	HGN		15	0.3-49.9	10.28	0.02	0.28	24.51		17.64	0.05		na	Monte_Pala
PALA	HGZ		15	0.3-49.9	6.33	0.02	0.29	37.57		19.45	0.02		na	Monte_Pala
CESC	HNE		18	0.5-49.2	6.84	0.02	0.40	21.77		17.54			na	Cesclans
CESC	HNN		18	0.5-49.2	5.86	0.02	0.48	18.43		11.85			na	Cesclans
CESC	HNZ		18	0.5-49.2	5.50	0.01	0.53	31.12		15.31			na	Cesclans
AVS	HNE		19	0.3-49.8	10.69	0.01	0.23	43.43		31.86	0.01		C	Avasinis
AVS	HNN		19	0.3-49.8	10.90		0.34	48.62		53.60	0.01		C	Avasinis

dista = epicentral distance
filter = automatic band pass butterworth filter
Td = duration (Trifunac and Bardy, 1975)
PGA,PGV = peak ground acceleration and velocity

RMSA = root mean square acceleration
v0 = intensity of zero crossing
Pd = Saragoni index
Id = damage factor

Housner = Housner spectral intensity
Arias = Arias intensity
EC8 = site classification (Eurocode8 from ITACA)

Remove mean


255
254
253
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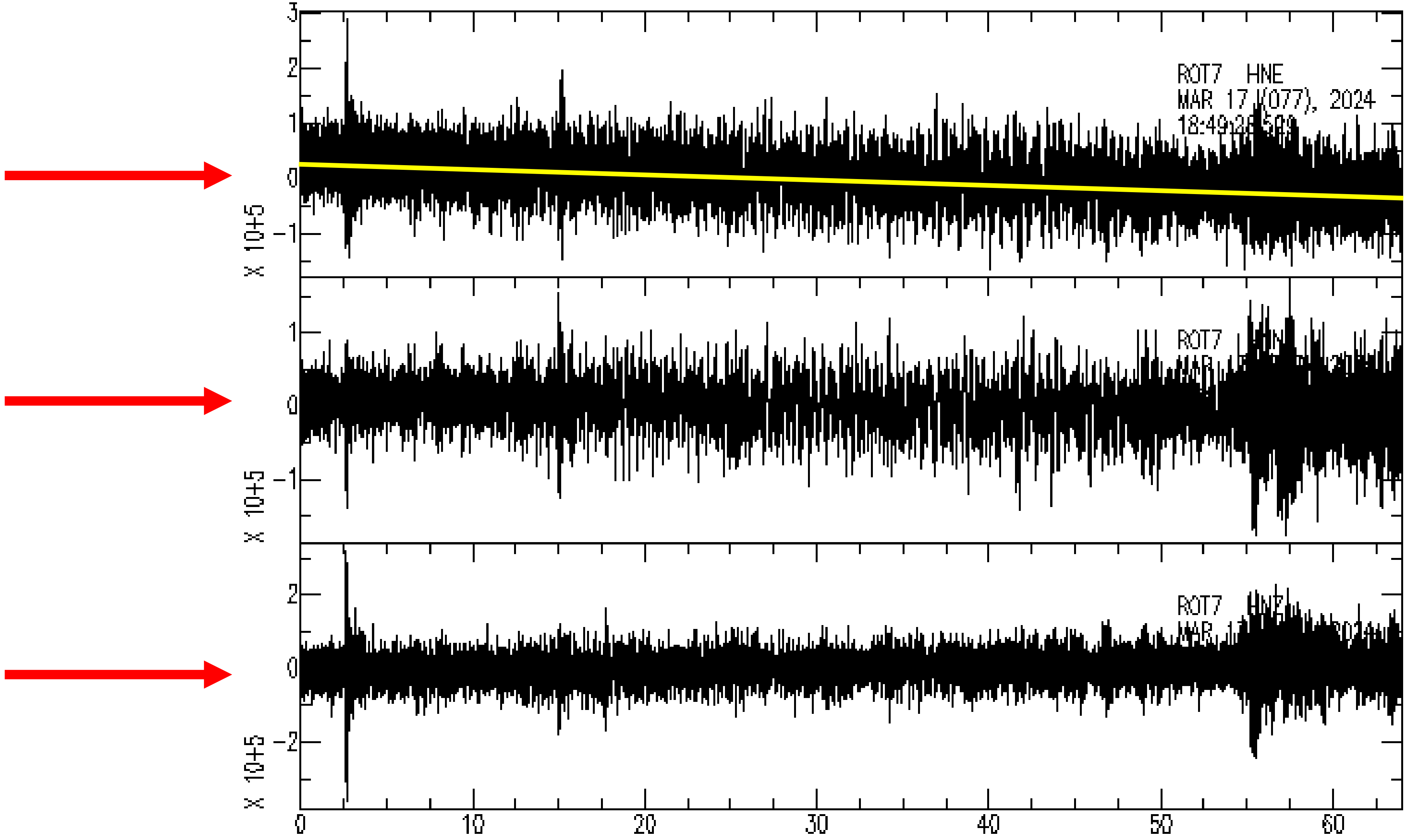
X 10+5
ROT7 HNE
MAR 17 (077), 2024
555
554
553
552
X 10+5
ROT7
-630
-632
-634
X 10+5
ROT7
0
10
20
30
40
50
60

Remove mean


ROT7 HNE
MAR 17 (077), 2024
ROT7
ROT7
X 10+5
X 10+5
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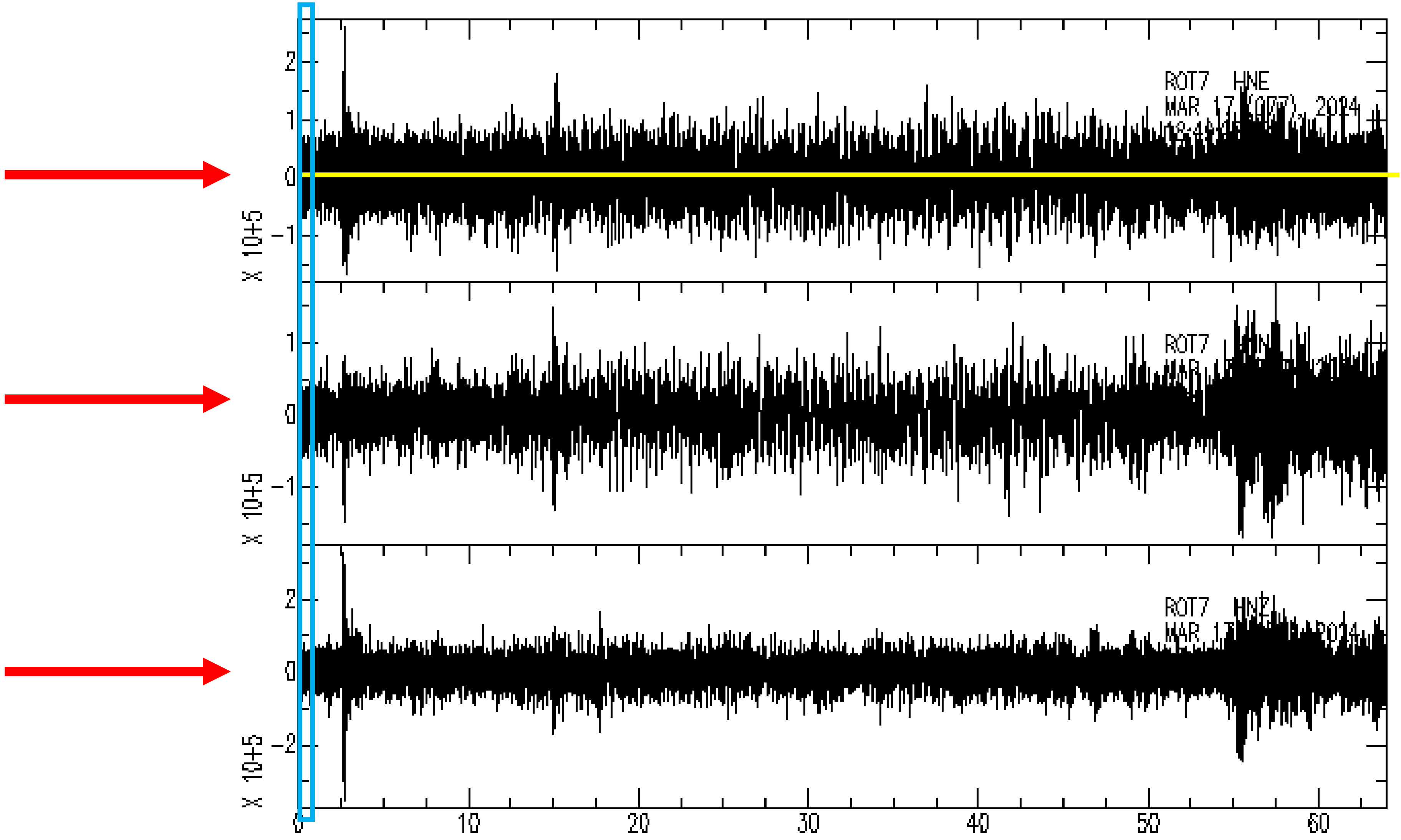
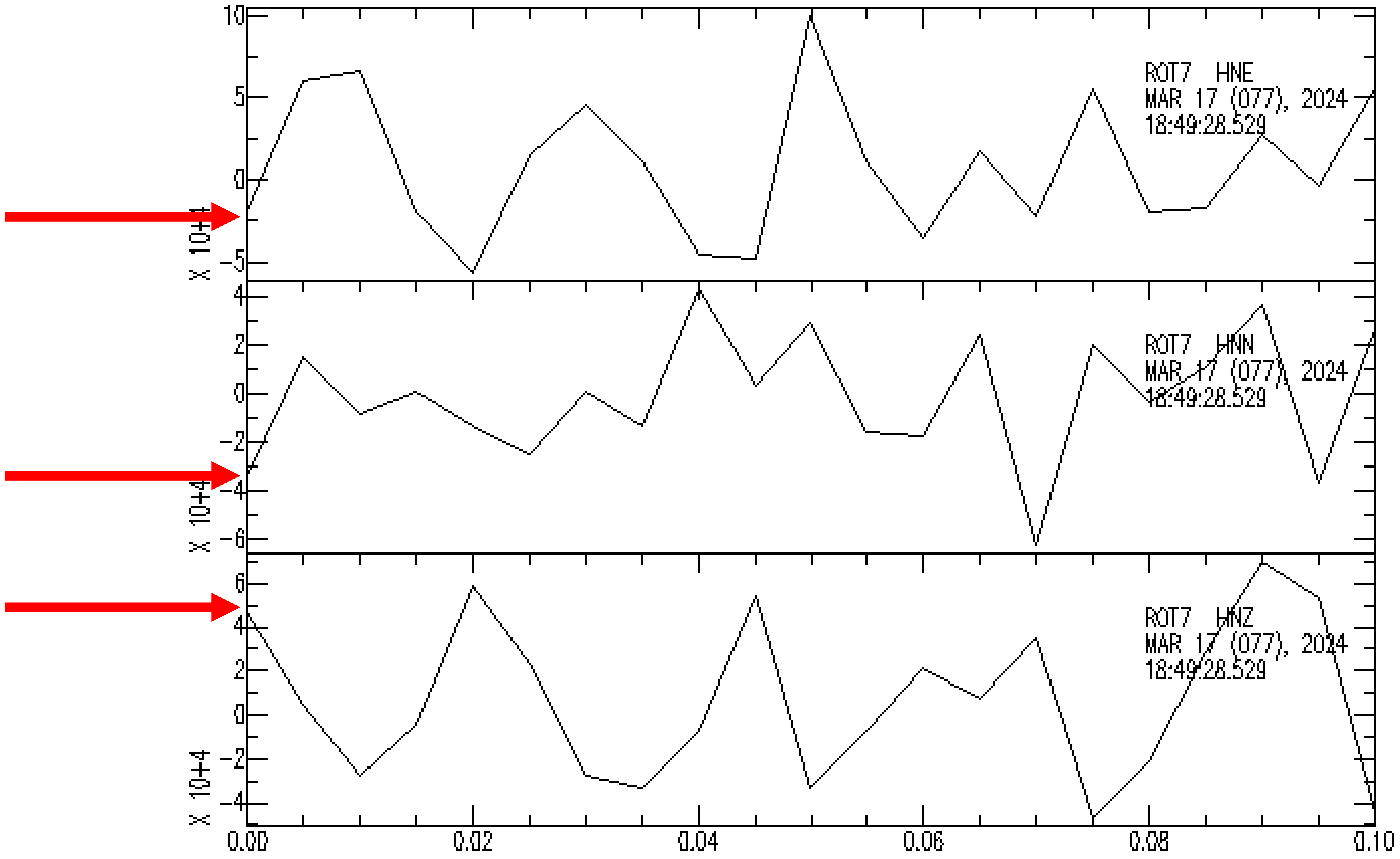
0
10
20
30
40
50
60

Remove trend



tapering


ROT7 HNE
MAR 17 (077), 2024
18:49:28.529
ROT7 HNN
MAR 17 (077), 2024
18:49:28.529
ROT7 HNZ
MAR 17 (077), 2024
18:49:28.529
X 10+1
X 10+4
X 10+4
10
5
0
-5
4
2
0
-2
-4
-6
6
4
2
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-2
-4
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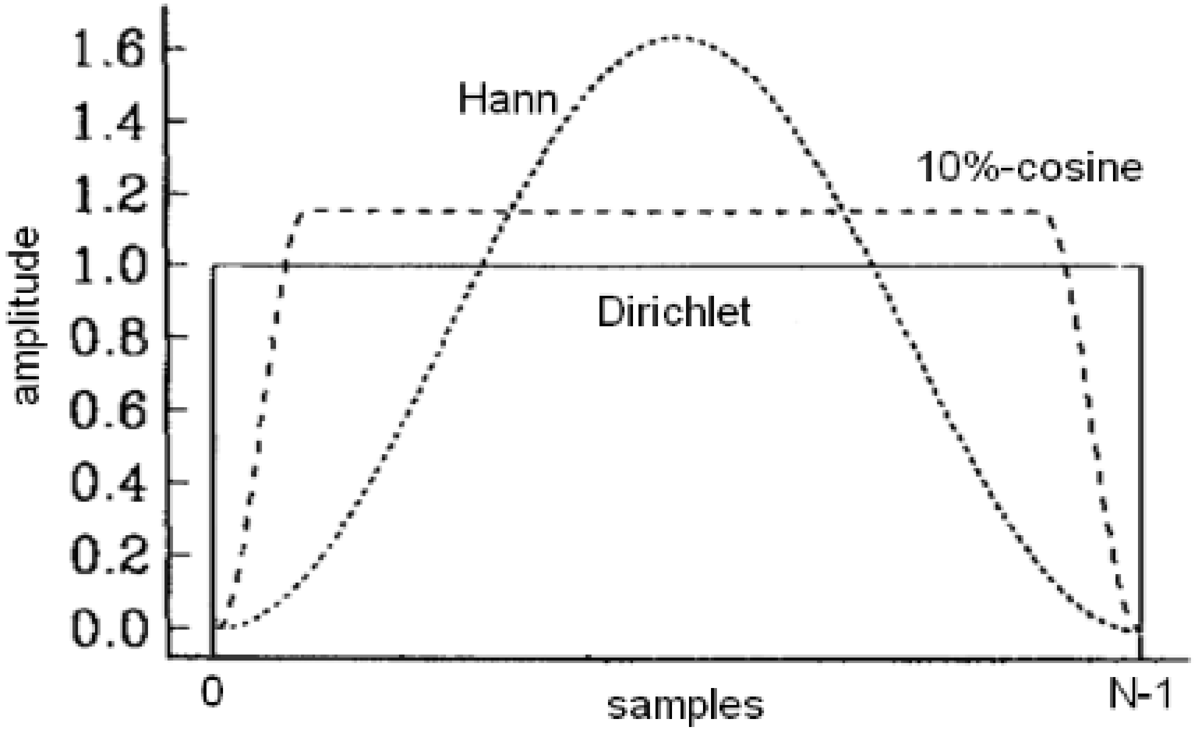
0.02
0.04
0.06
0.08
0.10

Tapering of windowed time series



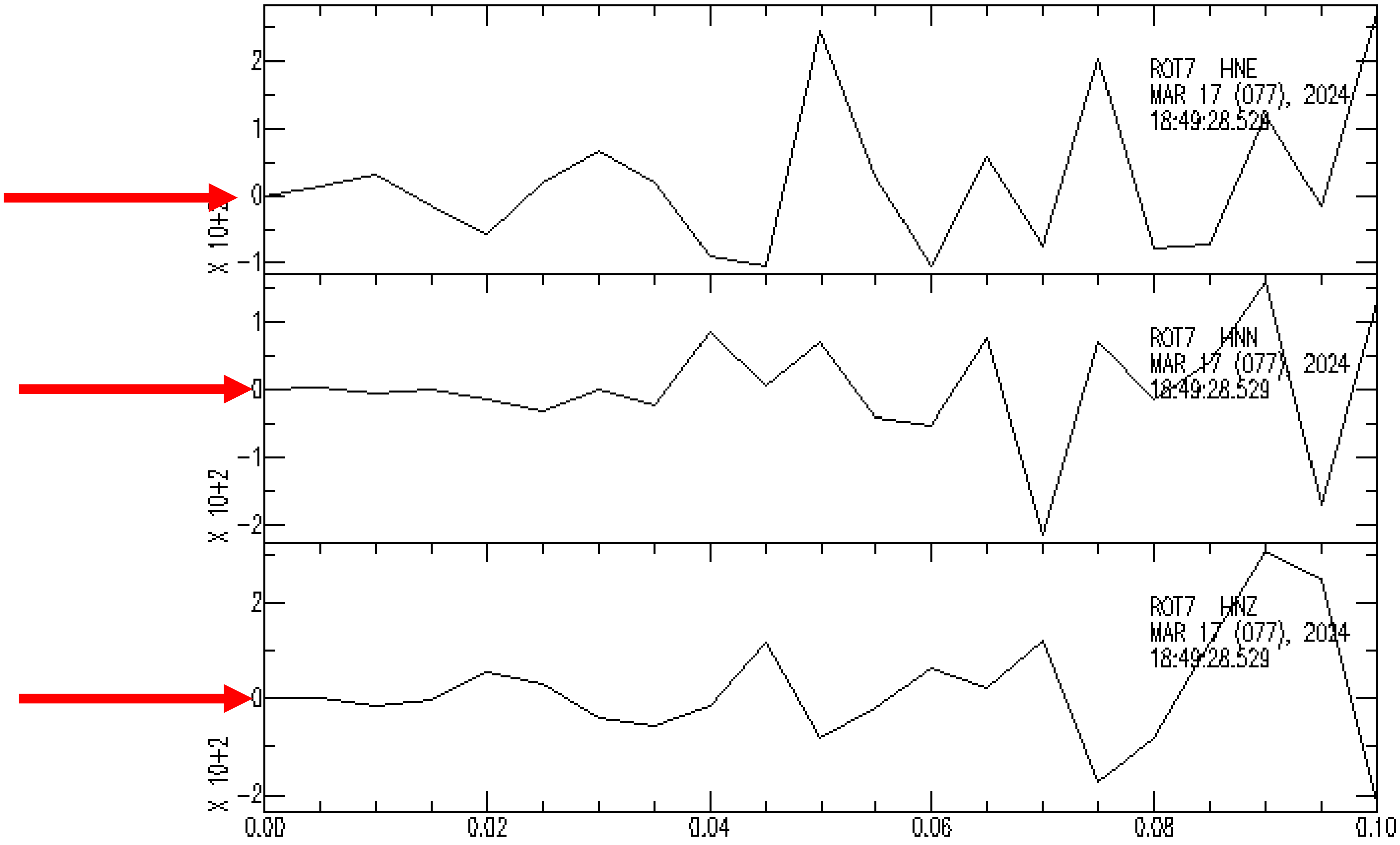
Comparison between the Dirichlet sharp-edged rectangle window function with two common taper functions.

Tapering of windowed time series

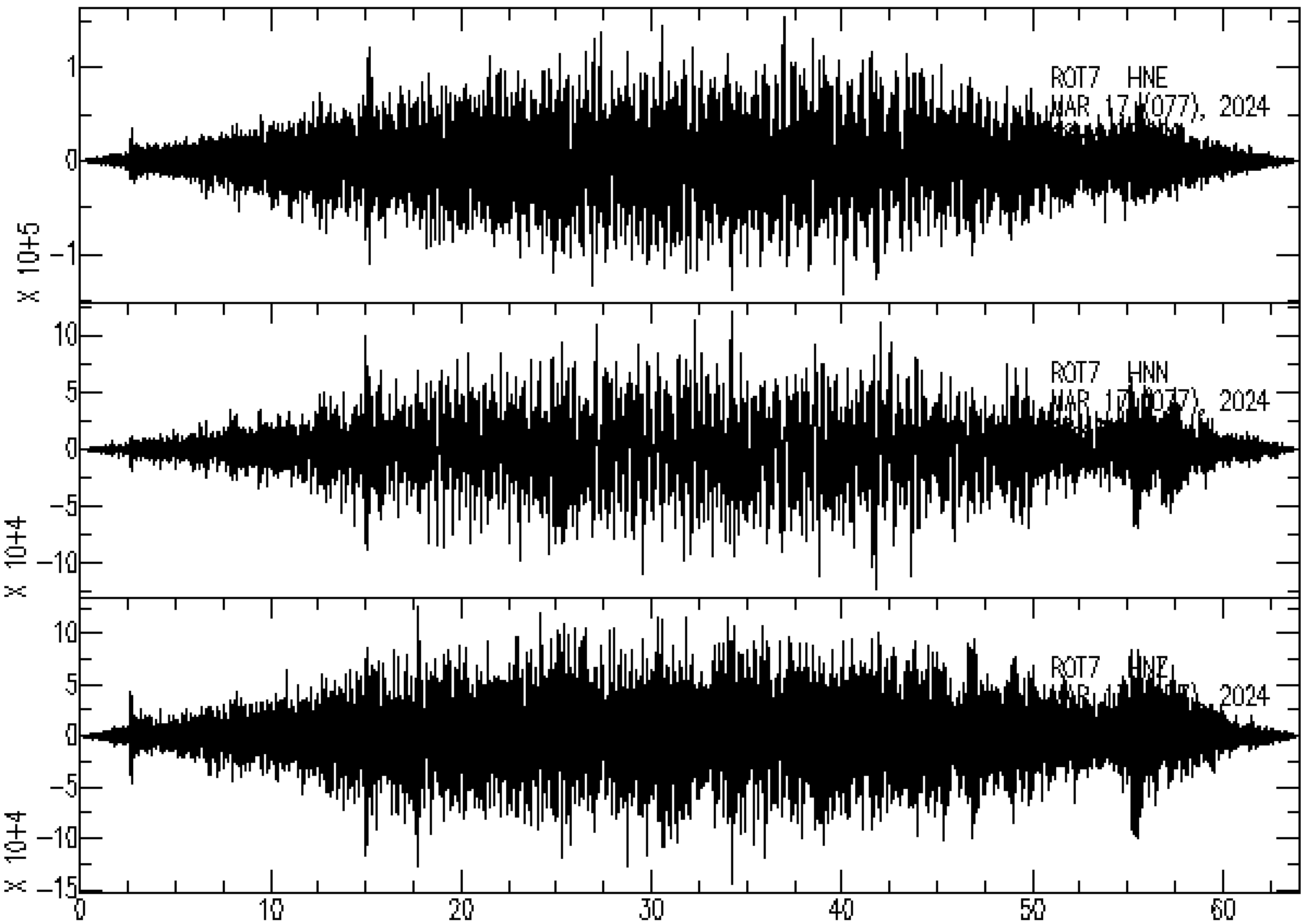
$$c(t) = \begin{cases} \frac{1}{2}\left(1 - \cos\frac{\pi}{a}t\right) & \text{for } 0 \le t \le a \\ 1 & \text{for } a \le t \le (1-a) \\ \frac{1}{2}\left(1 - \cos\frac{\pi}{a}(1-t)\right) & \text{for } (1-a) \le t \le 1 \end{cases}$$

with time *t* and taper ratio *a*

Tapering
cosine

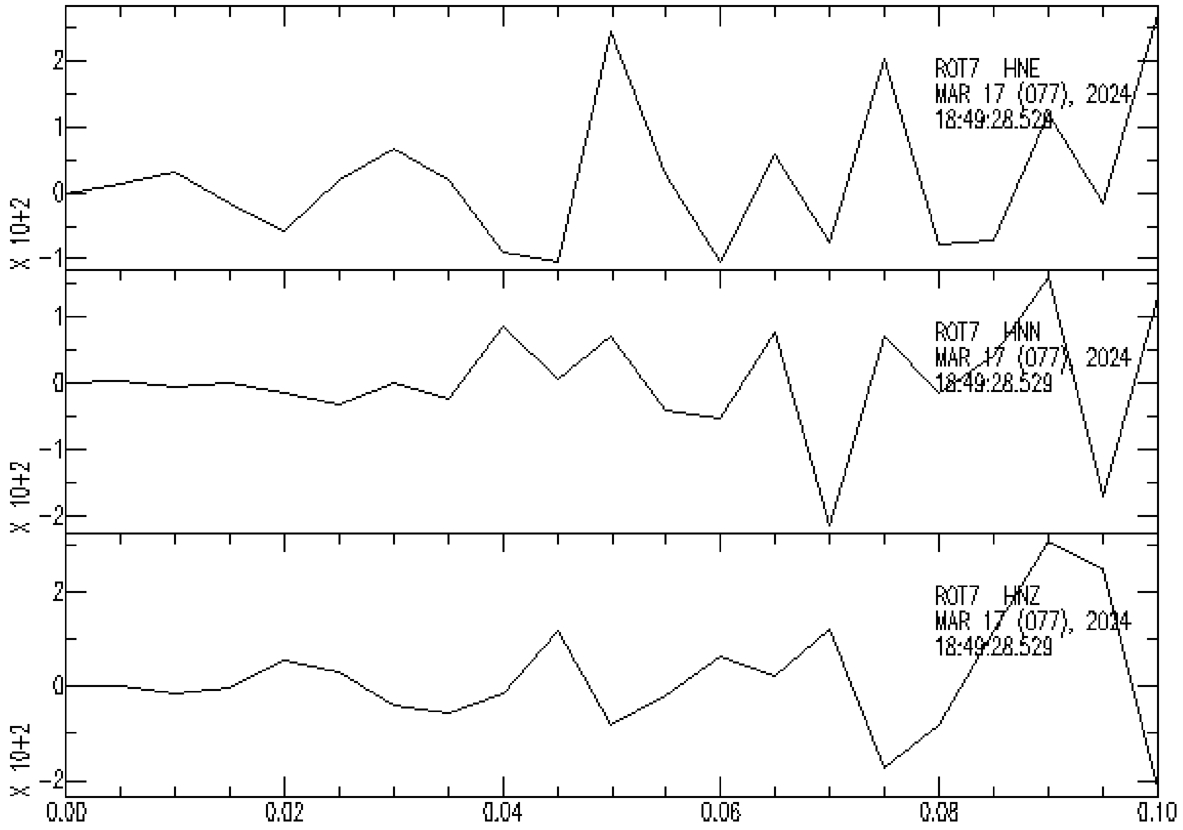


Tapering
cosine

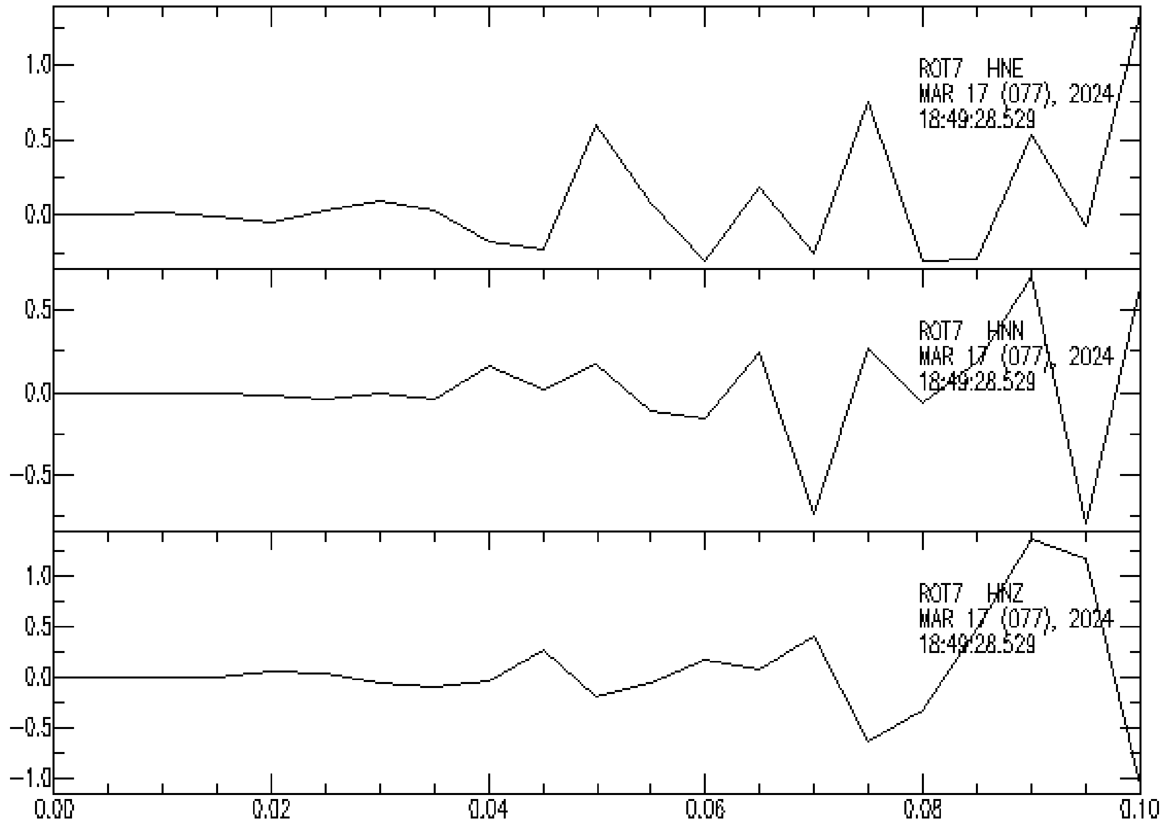


Tapering

cosine

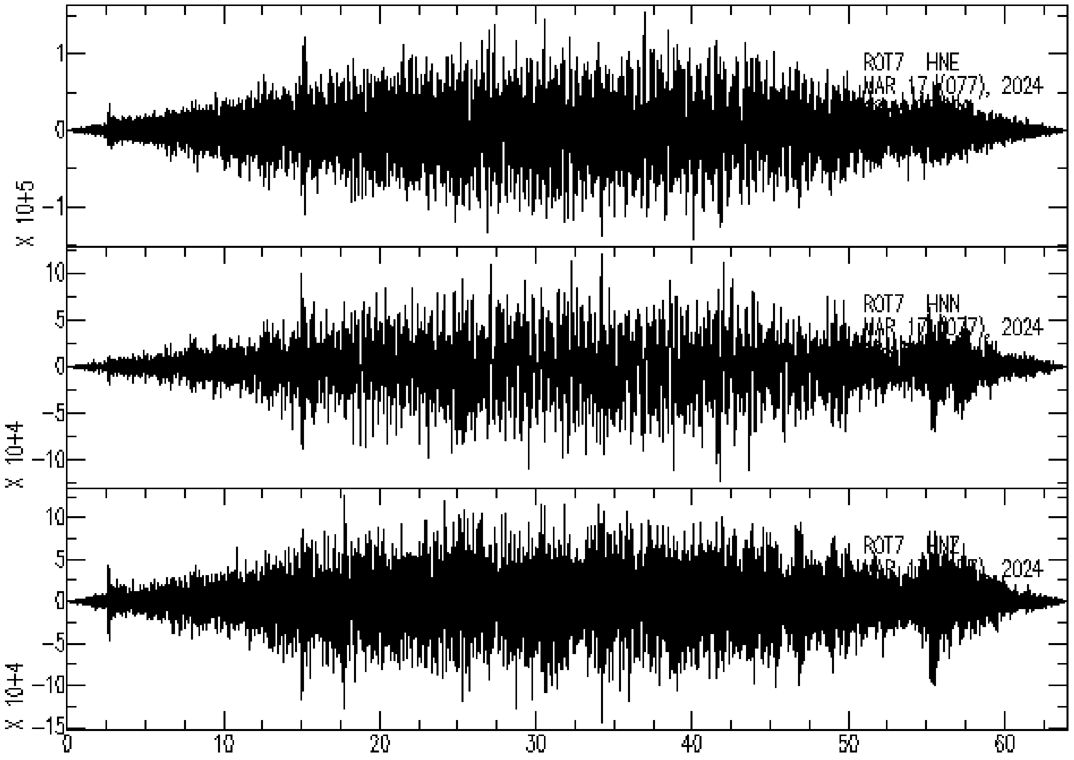


hanning

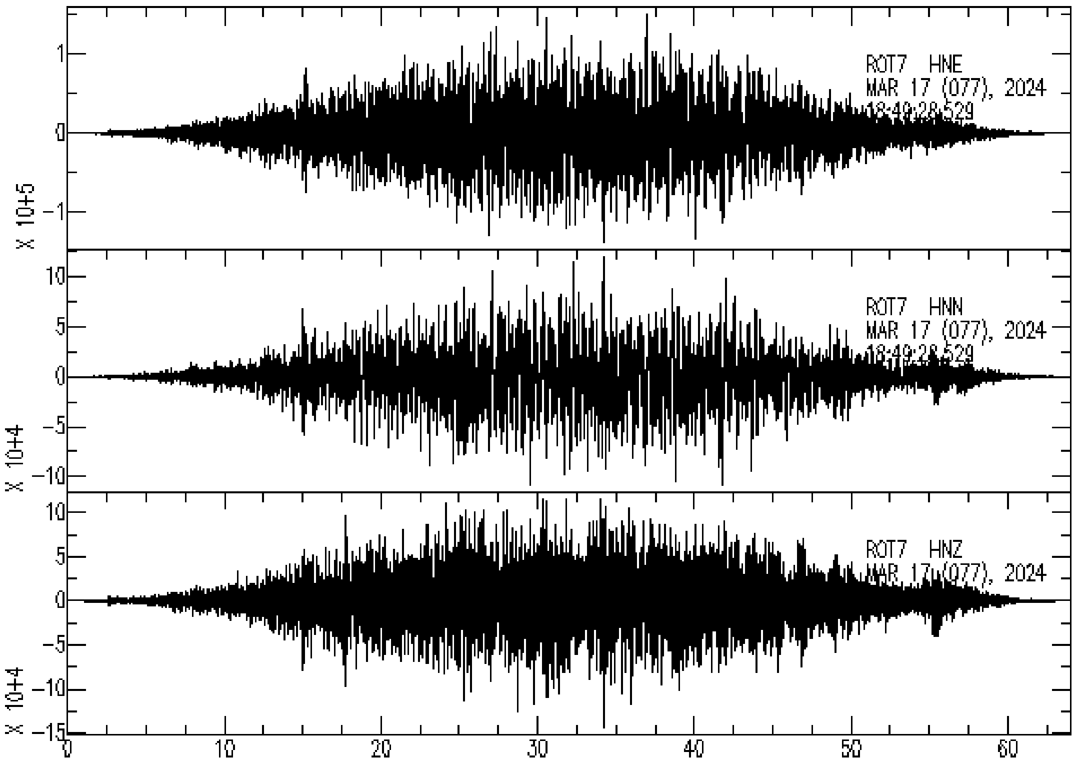


Tapering

cosine

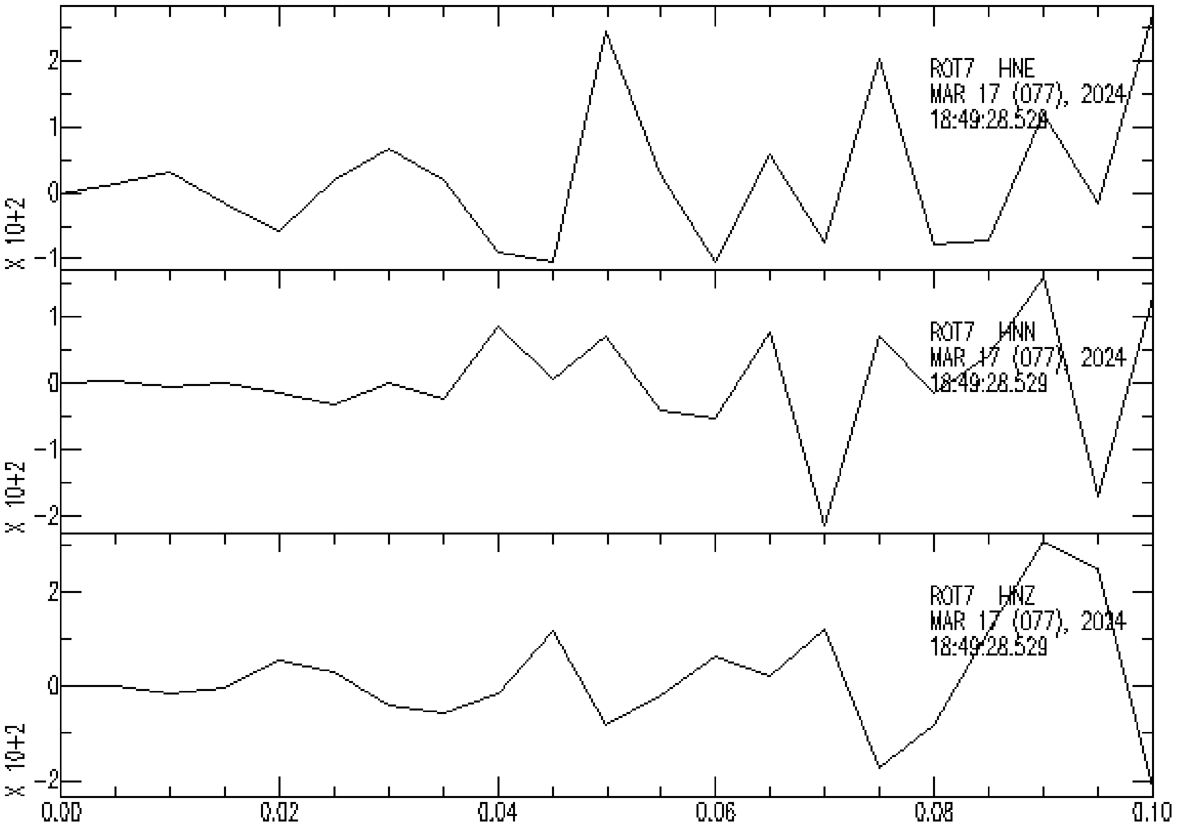


hanning

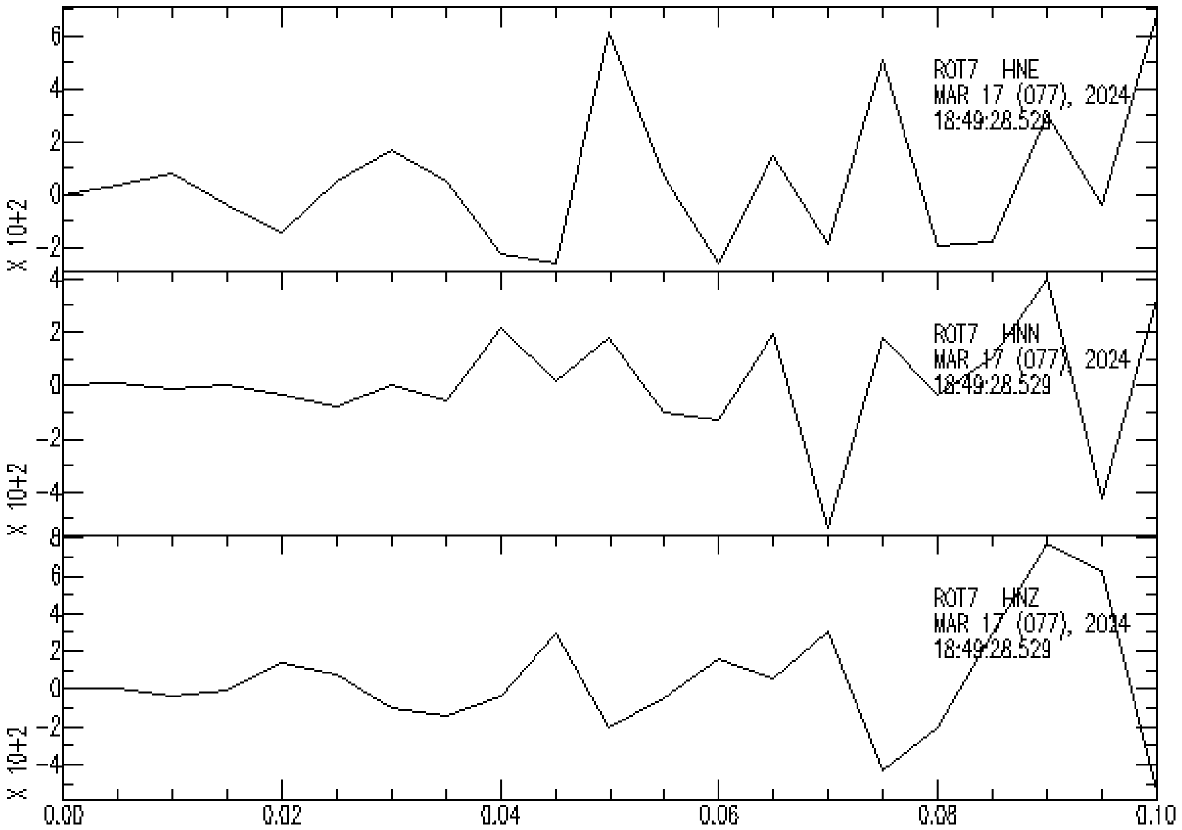


Tapering

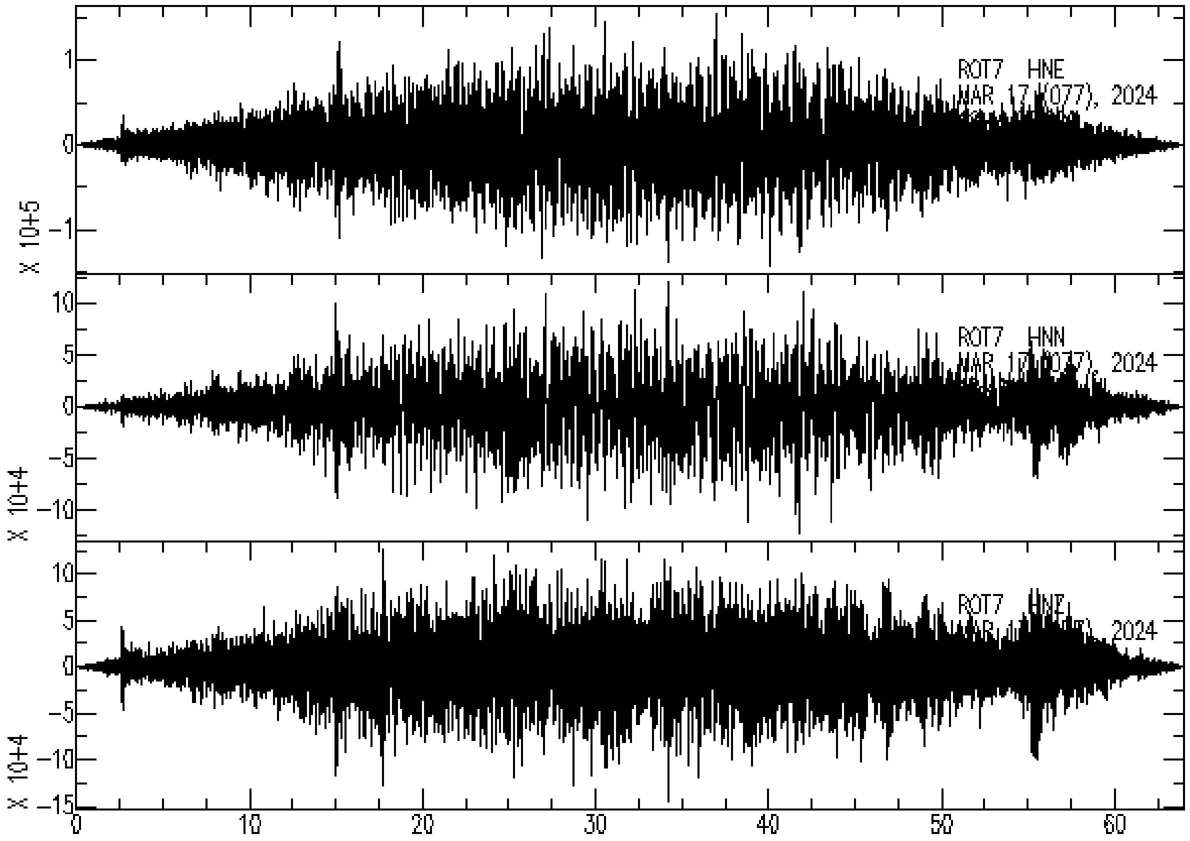
Cosine – with 0.5



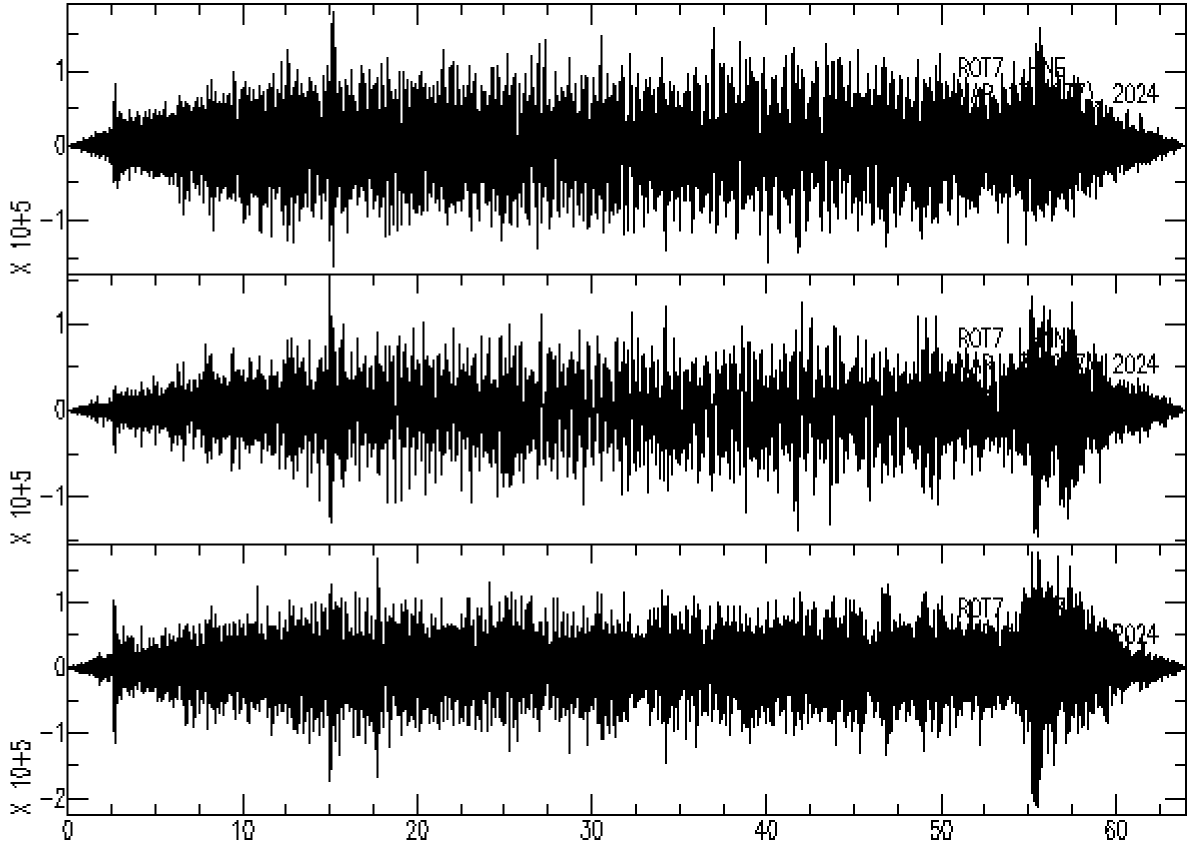
Cosine – with 0.2



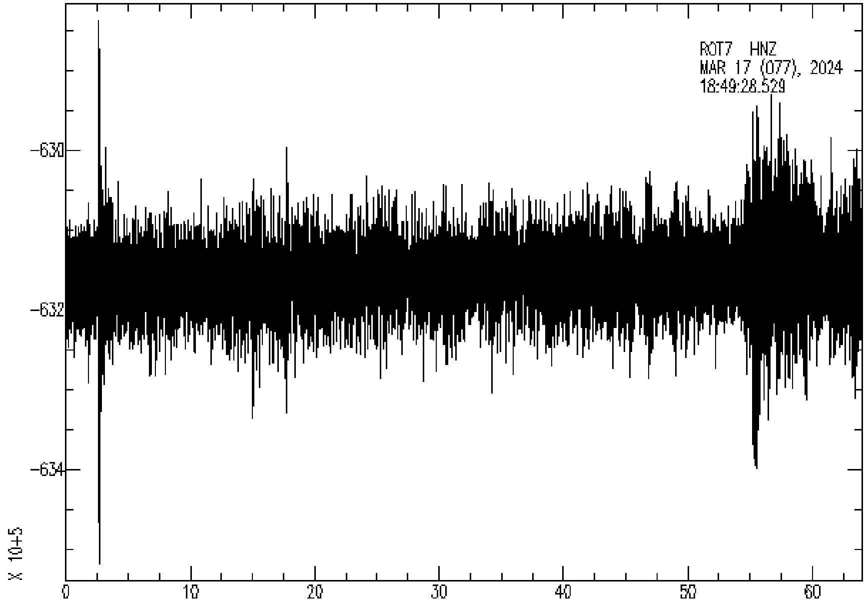
Cosine – with 0.5

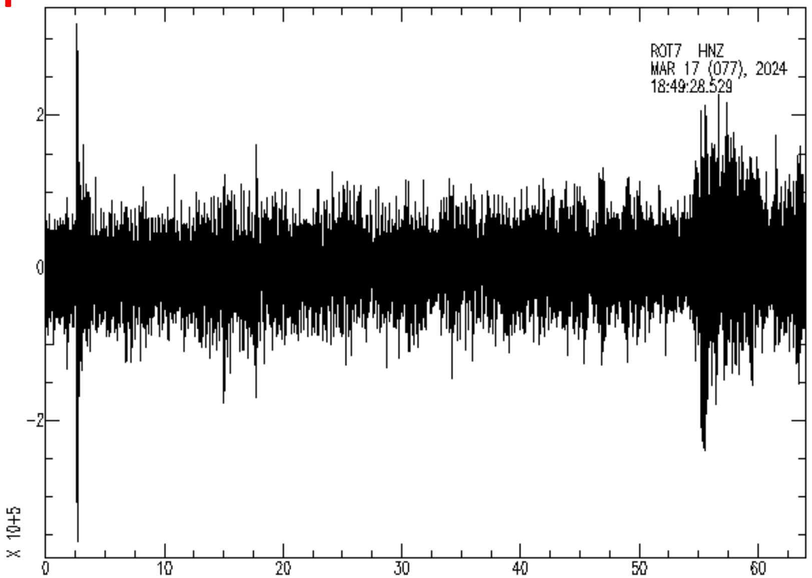


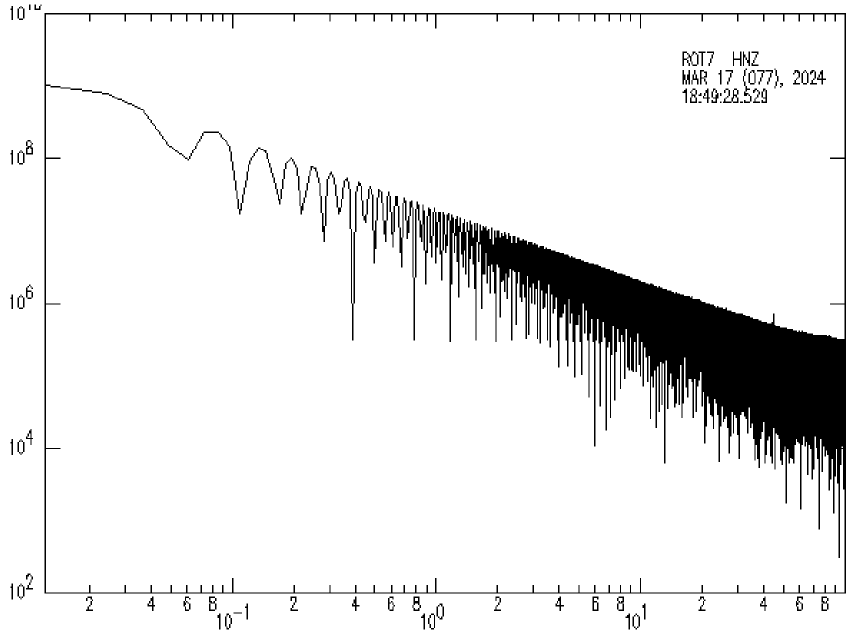
Cosine – with 0.2

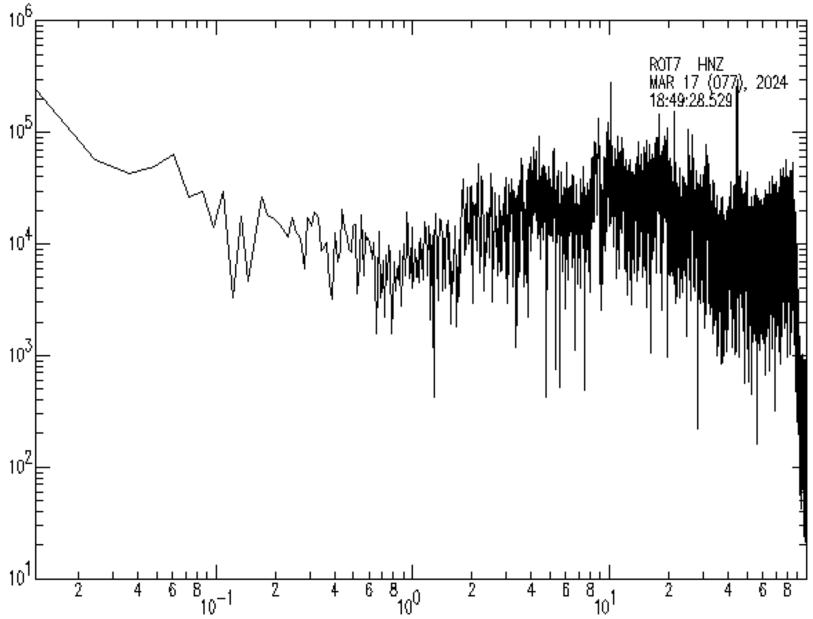


Effect of removing the mean on the FFT

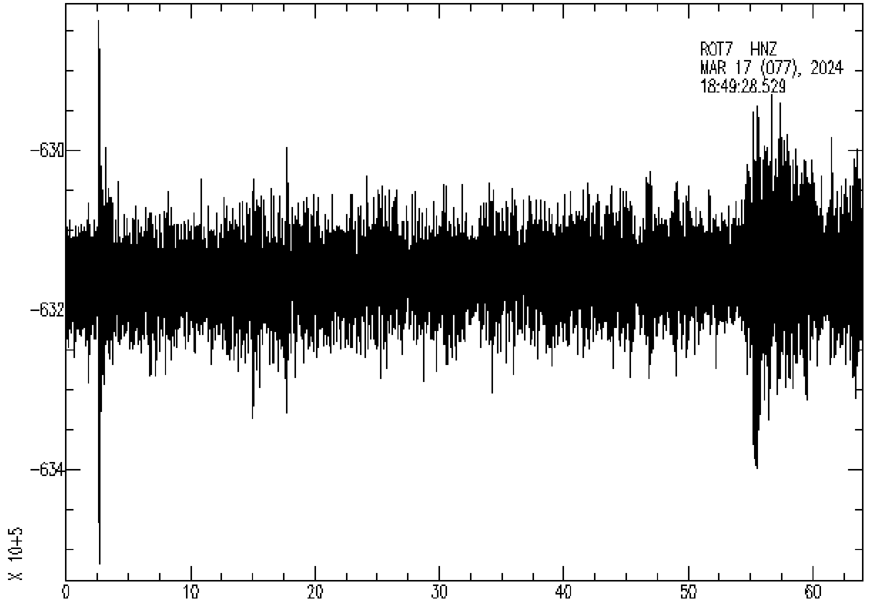


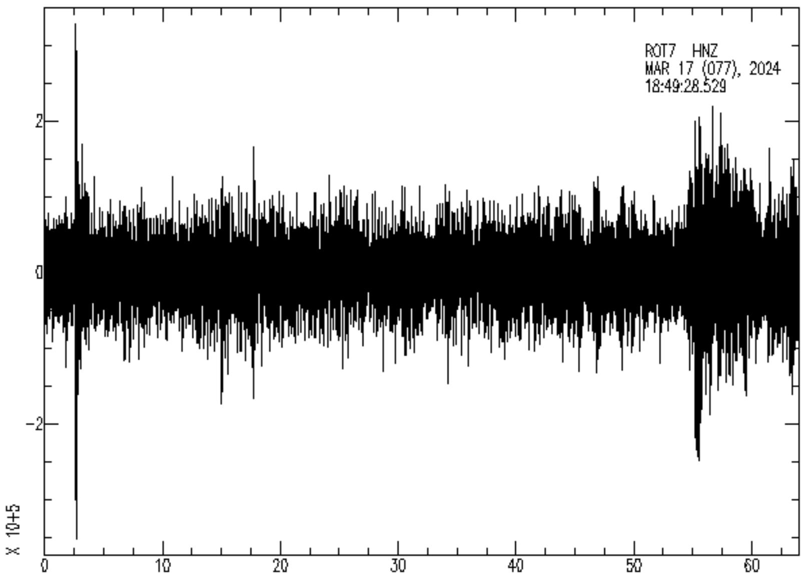


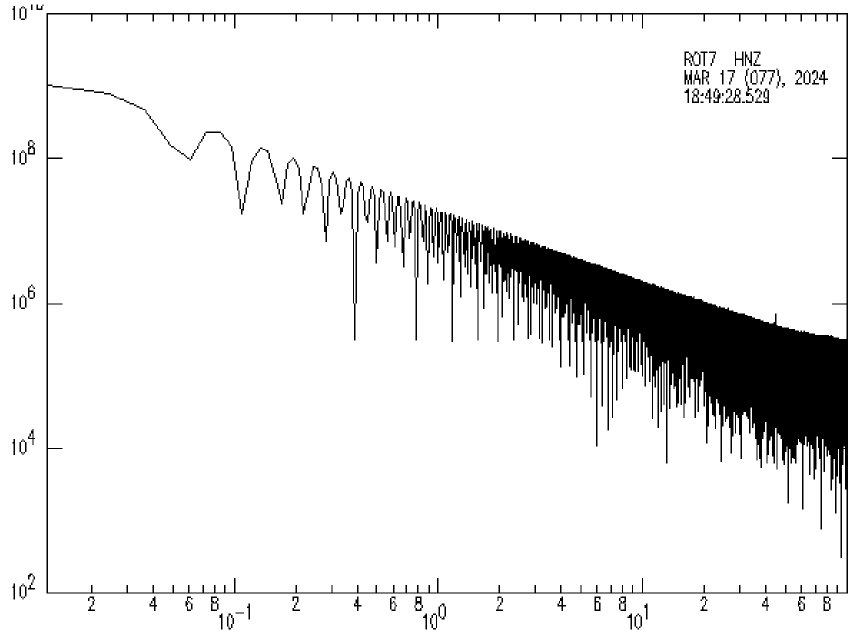


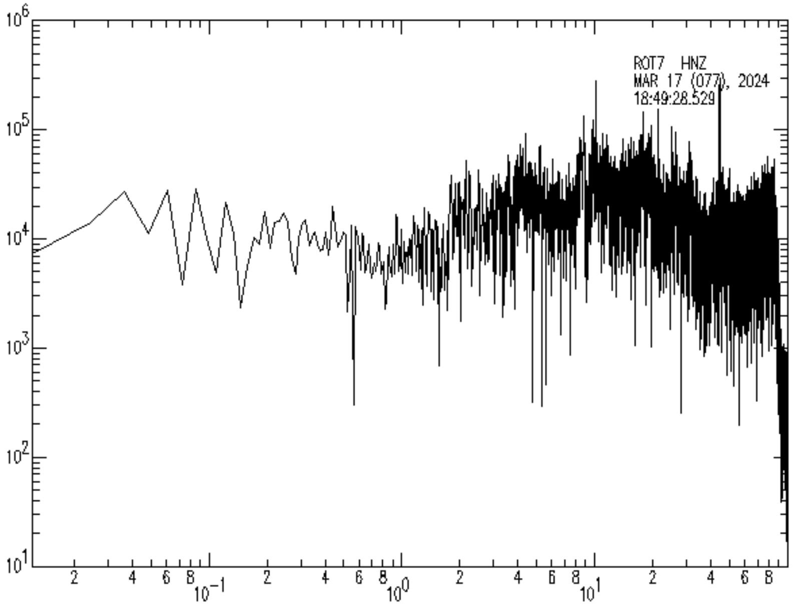


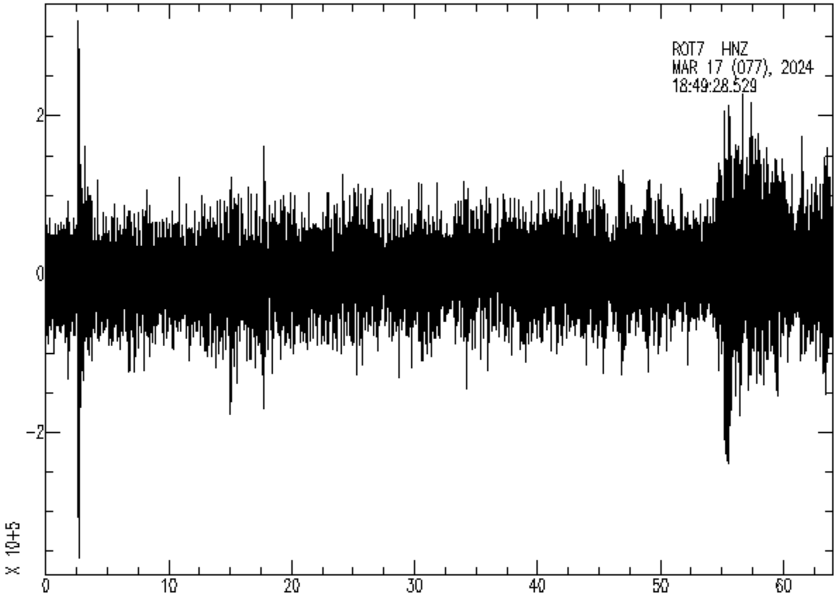
Effect of removing the trend on the FFT



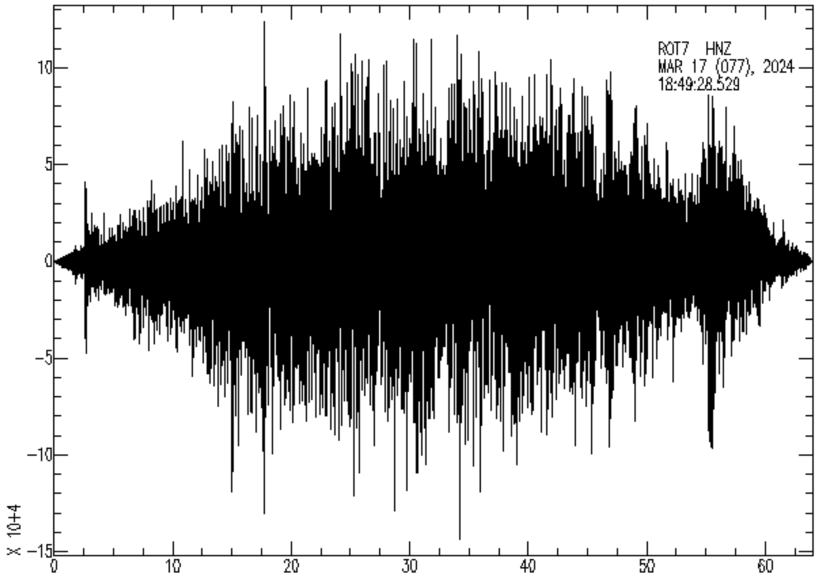


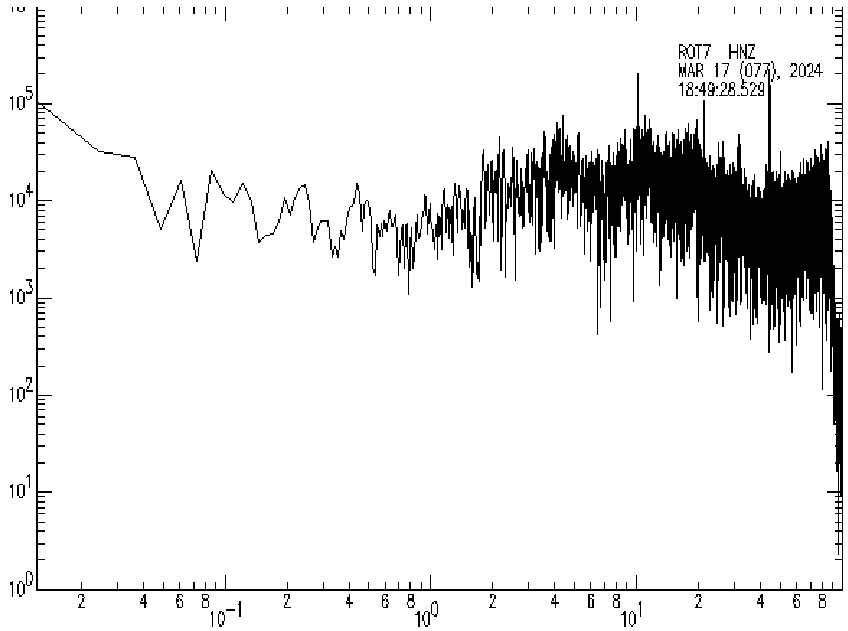




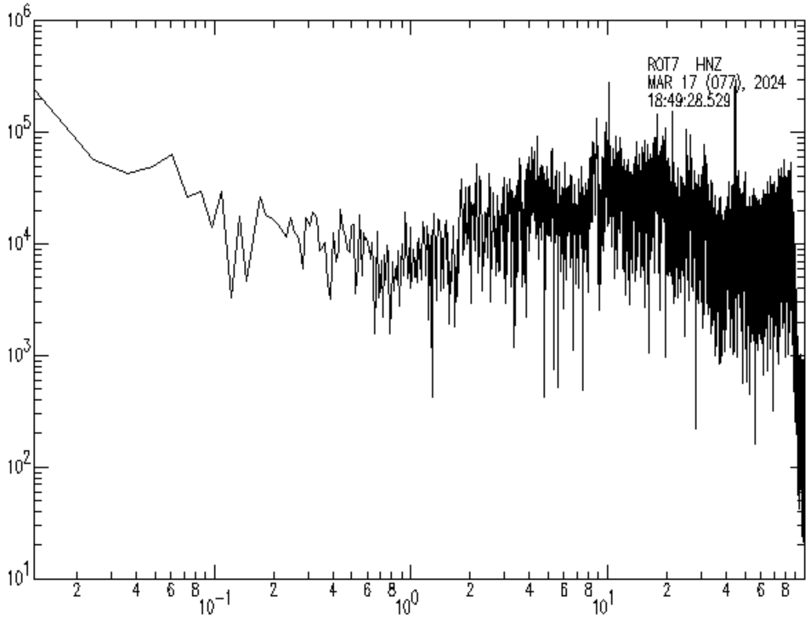


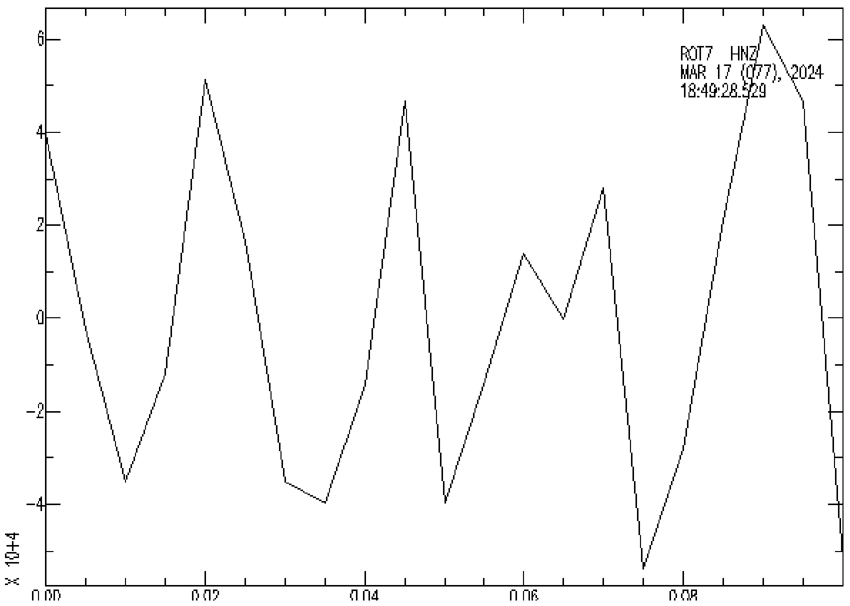
Effect of removing the mean on the FFT

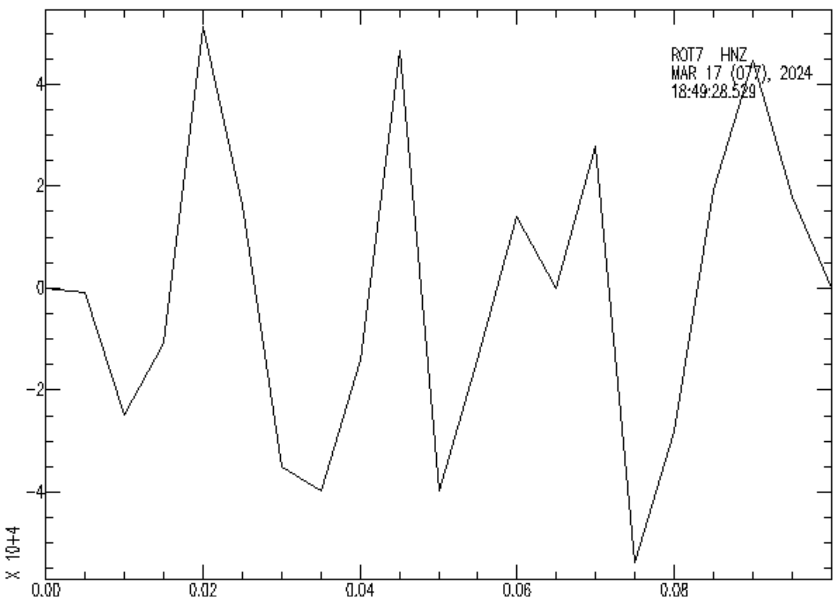


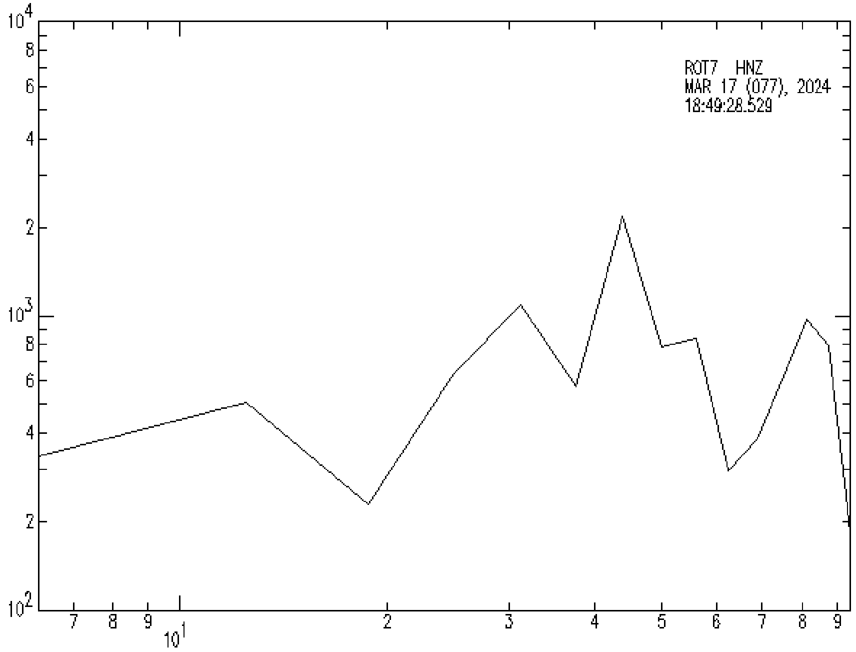


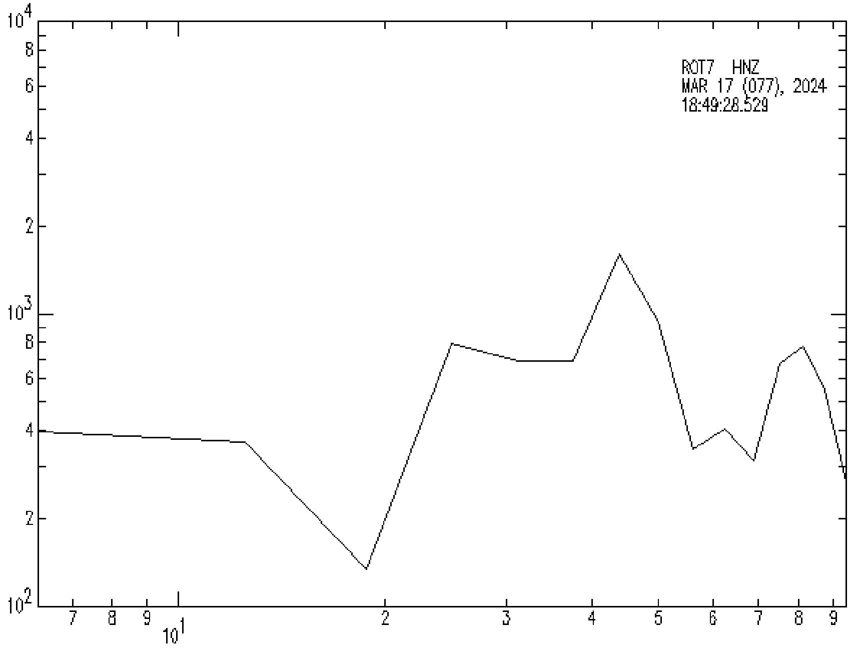
Effect of tapering and removing the mean on the FFT




ROT7 HNZ
MAR 17 (077), 2024
18:49:28.529
X 10+4


ROT7 HNZ
MAR 17 (077), 2024
18:49:28.529
X 10+4

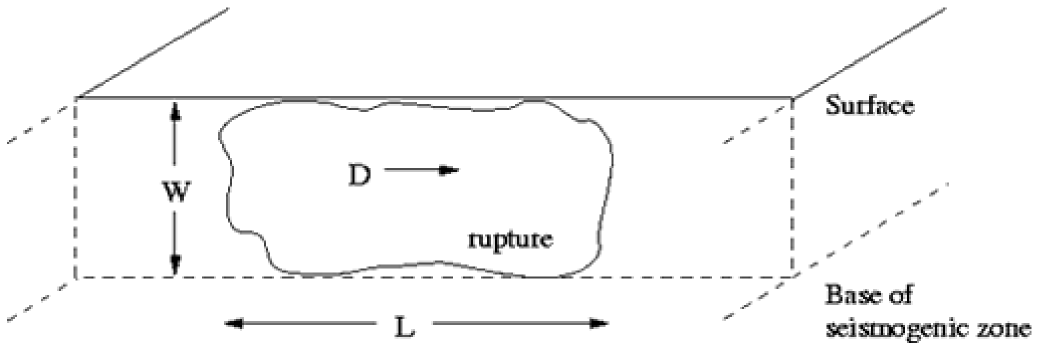

ROT7 HNZ
MAR 17 (077), 2024
18:49:28.529


ROT7 HNZ
MAR 17 (077), 2024
18:49:28.529

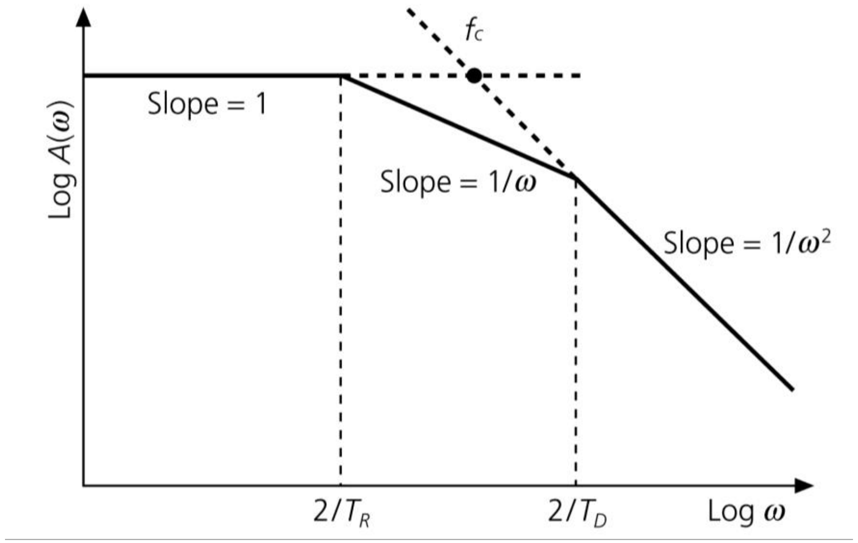
$$Sforzo = \mu \times deformazione \quad \rightarrow \quad F/S = \mu \bar{u}/L \quad \rightarrow \quad FL = \mu \bar{u} S$$

$$\boxed{M_0 = \mu \bar{u} S}$$

Il momento sismico è il prodotto dell'area della superficie di faglia che si rompe, dello spostamento medio lungo tale superficie e di una costante, una misura della proprietà elastica della roccia (ovvero la sua facilità di deformazione) chiamata **modulo di rigidità**.



Il momento sismico è una misura dell'intensità di un terremoto basata sull'area di rottura della faglia, sulla quantità media di slip e sulla forza necessaria per superare l'attrito che tiene unite le rocce sfalsate dalla faglia.
Il momento sismico può anche essere calcolato dagli spettri di ampiezza delle onde sismiche.



Approximation of the amplitude spectrum of a trapezoidal box car function:

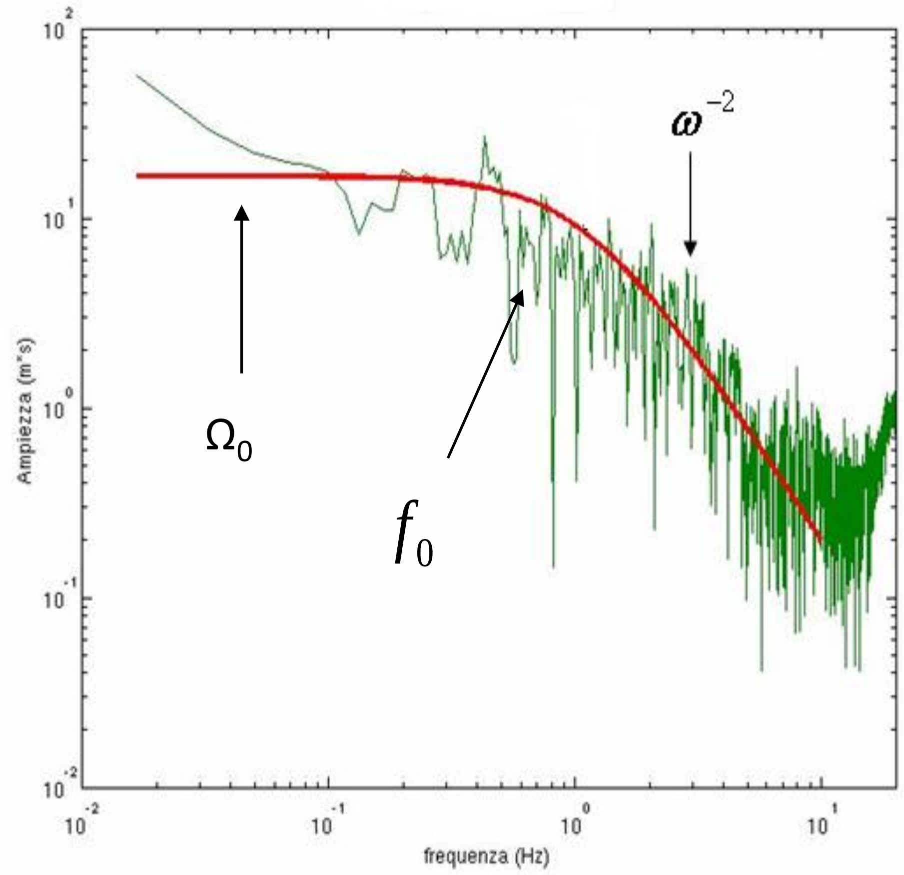
$$\log|A(\omega)| =$$

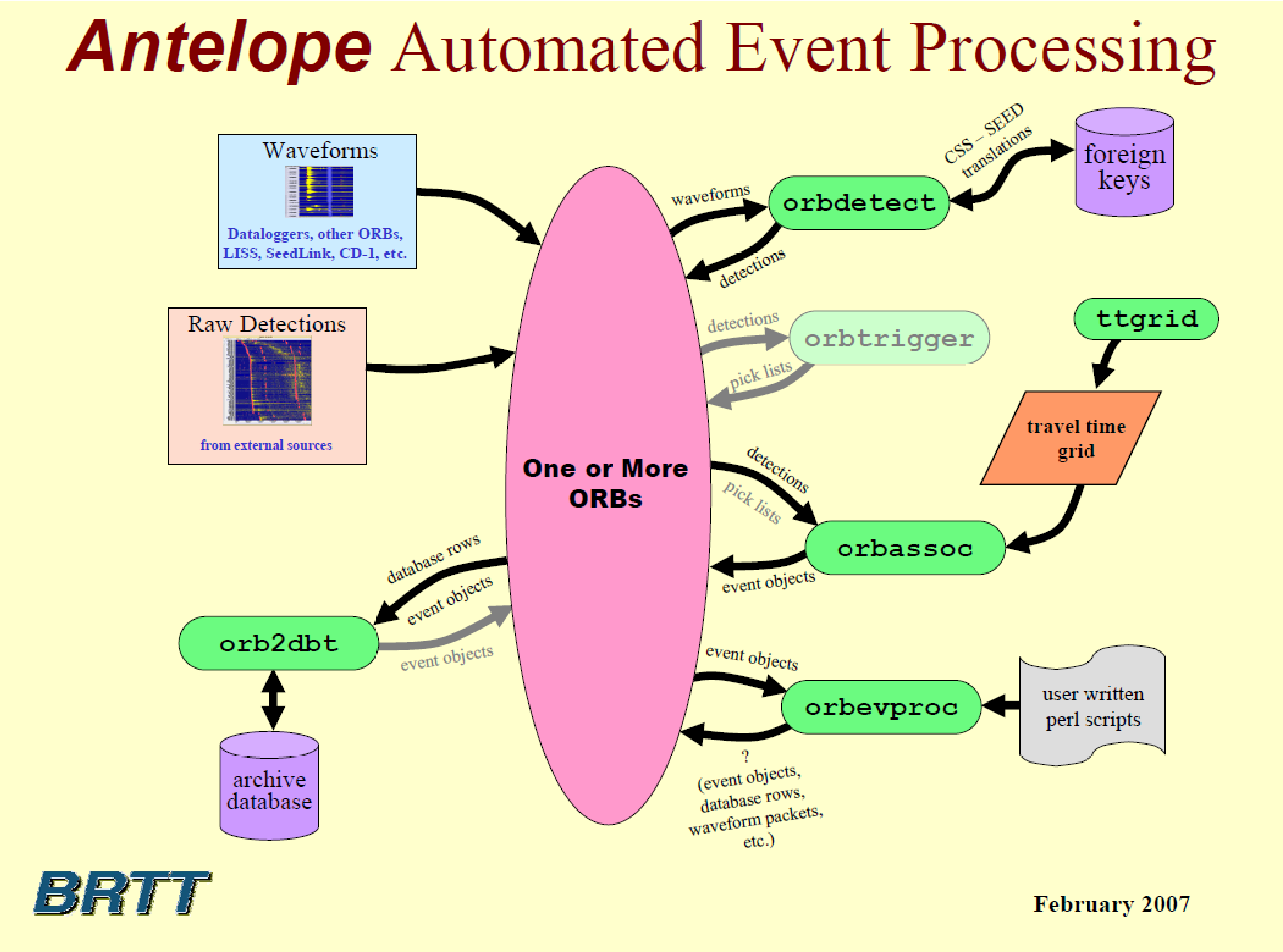
$$= \begin{cases} \log M_0 & \omega < 2/T_R \\ \log M_0 - \log(T_R/2) - \log\omega & 2/T_R < \omega < 2/T_D \\ \log M_0 - \log(T_R T_D/4) - 2\log\omega & 2/T_D < \omega \end{cases}$$

The spectrum os often defined in terms of the "corner frequencies"

- Lo SPETTRO DI SORGNTE è piatto e pari al momento sismico a periodi superiori alla frequenza di taglio $2/T_R$.
- Decadimento al di sotto della frequenza di taglio.
- La frequenza di taglio si sposta verso sinistra (frequenza più bassa) per terremoti più intensi con faglie più lunghe.

$$M_0 = 4\pi\rho R\beta^3\Omega_S(\omega \to 0)/\Re_{\Theta\Phi}$$




Antelope Automated Event Processing
Waveforms
Dataloggers, other ORBs, LISS, SeedLink, CD-1, etc.
Raw Detections
from external sources
One or More ORBs
waveforms
orbdetect
detections
CSS – SEED translations
foreign keys
detections
orbtrigger
pick lists
ttgrid
travel time grid
detections
pick lists
orbassoc
event objects
database rows
event objects
orb2dbt
event objects
archive database
event objects
orbevproc
user written perl scripts
?
(event objects, database rows, waveform packets, etc.)
BRTT
February 2007