IV International Workshop on Gravitomagnetism and Large-Scale Rotation Measurement

Jun 14 – 16, 2023
Europe/Rome timezone

The **IV International Workshop on Gravitomagnetism and large-scale Rotation Measurement** (GRM) is devoted to the study of gravitomagnetism and high sensitivity angular rotation measurement, combining different fields of science: Earth science, General Relativity, and top sensitivity angular rotation devices as large Sagnac gyroscopes based on optical cavities, fibers and atoms.

The workshop will be in person. Online connection will be available for a limited number of participants.

Starts Jun 14, 2023, 9:00 AM
Ends Jun 16, 2023, 10:00 PM
Europe/Rome

Underground Geophysics at the *INFN Laboratori Nazionali del Gran Sasso* (*LNGS*)

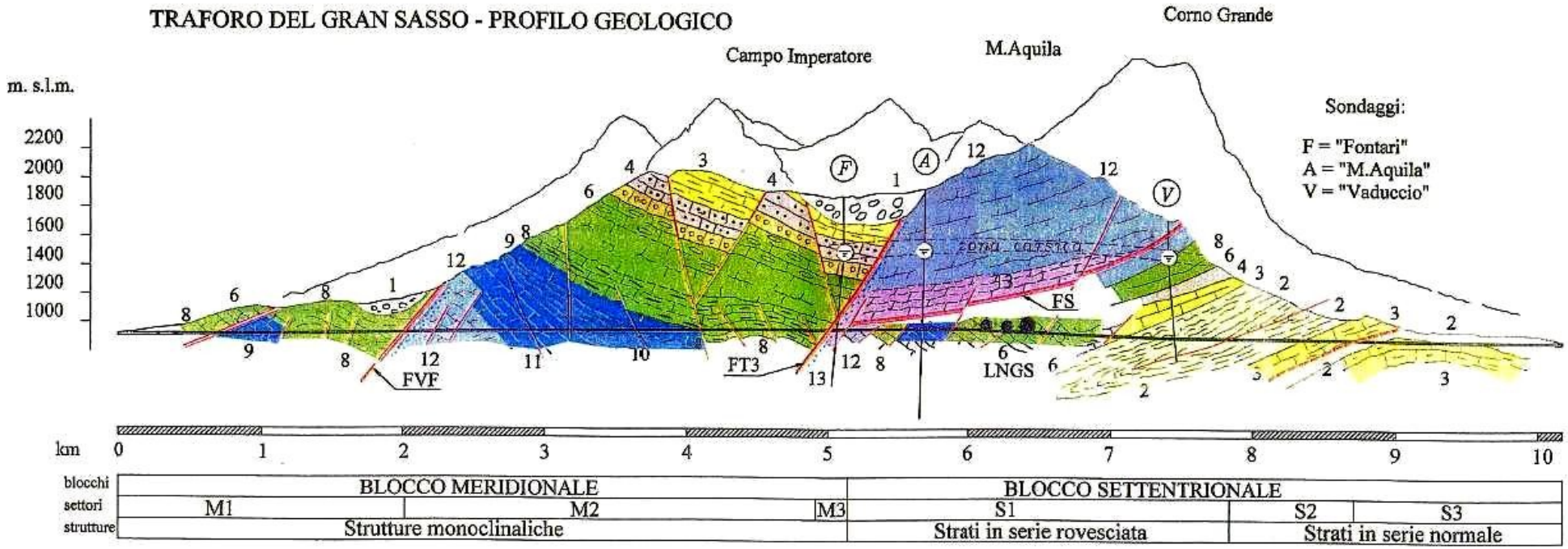
Gaetano De Luca
(INGV – Osservatorio Nazionale Terremoti)


Laboratori Nazionali del Gran Sasso - INFN


A
Laboratori Nazionali del Gran Sasso - INFN


Laboratori Nazionali del Gran Sasso - INFN

TRAFORO DEL GRAN SASSO - PROFILO GEOLOGICO



1 Depositi fluvio-glaciali - Quaternario

2 Marne arenacee "Flysch della Laga" - Miocene sup.

3 Calcari marnosi - Miocene medio

4 Calcari glauconitici - Miocene inf.

5 Calcari a macroforaminiferi - Oligocene

6 Calcari selciferi "Scaglia" - Cretaceo sup.

7 Calcari bioclastici massicci - Cretaceo sup.

8 Calcari selciferi a Radiolari - Cretaceo inf.

9 Calcari bioclastici massicci - Giurassico (Dogger-Malm)

10 Marne "Verde Ammonitico"-Giurassico (Lias sup.)

11 Calcari selciferi "Corniola"-Giurassico (Lias medio)

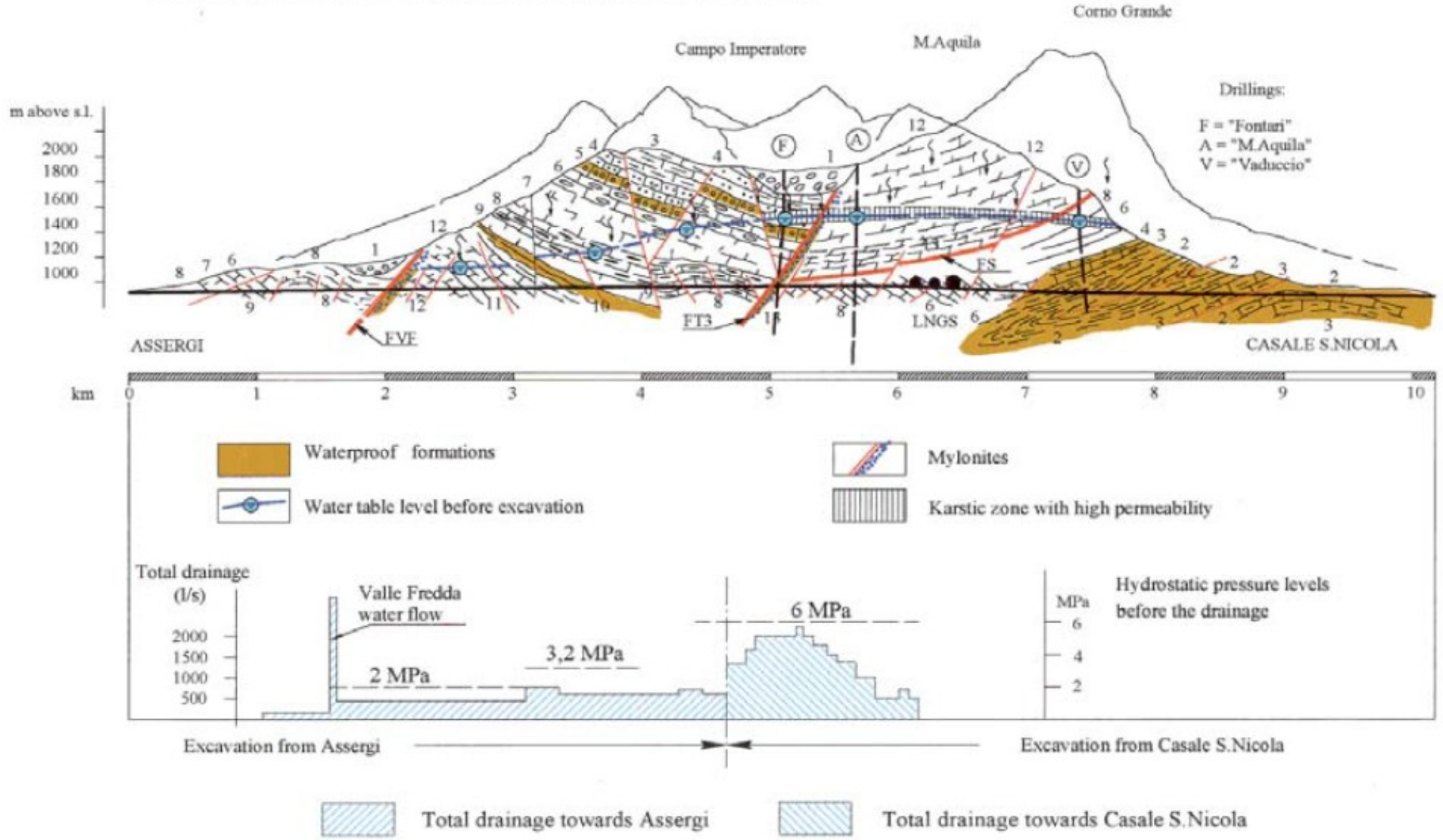
12 Calcari dolomitici "Calcare Massiccio" Giurassico (Lias inf.)

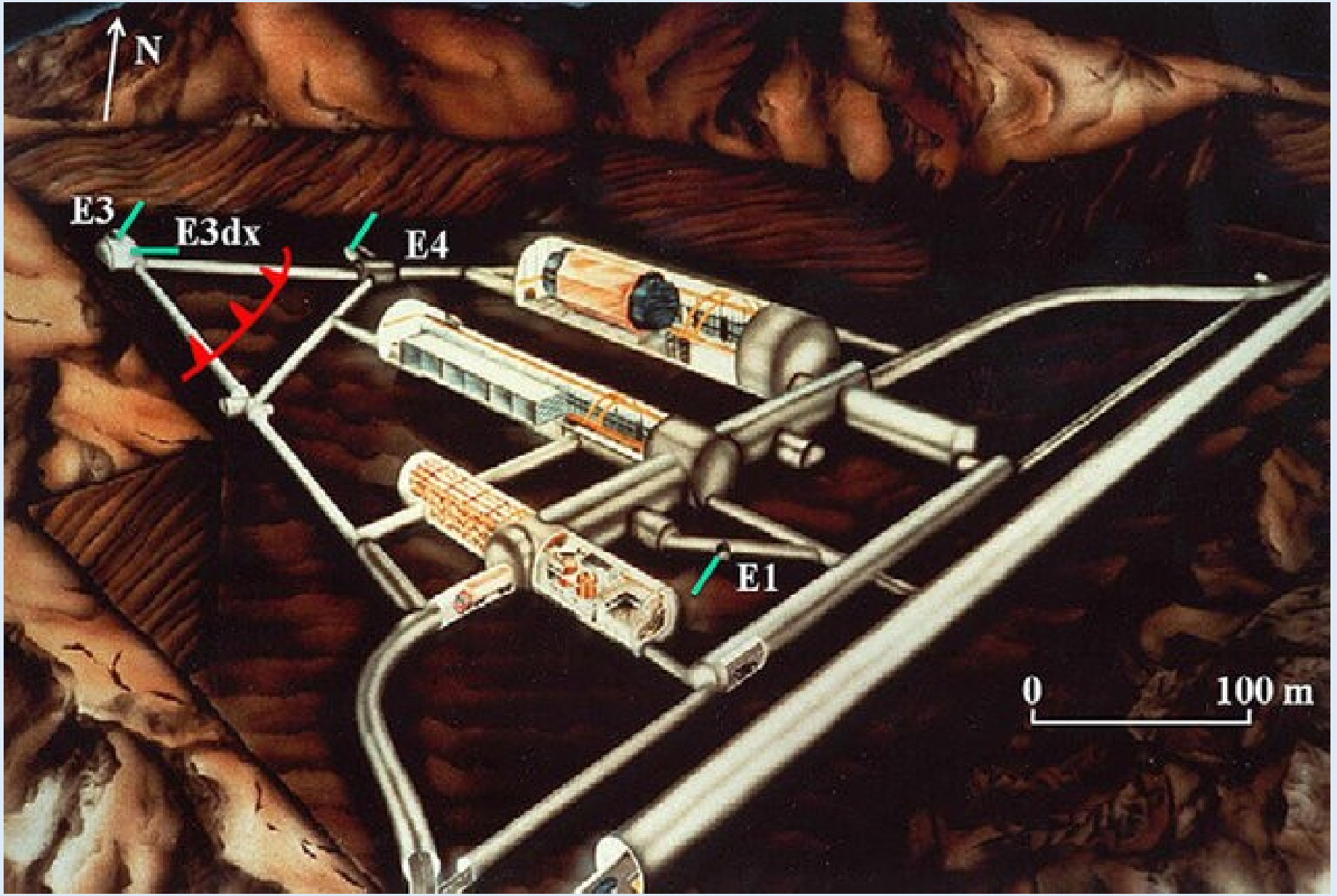
13 Dolomie - Trias sup.

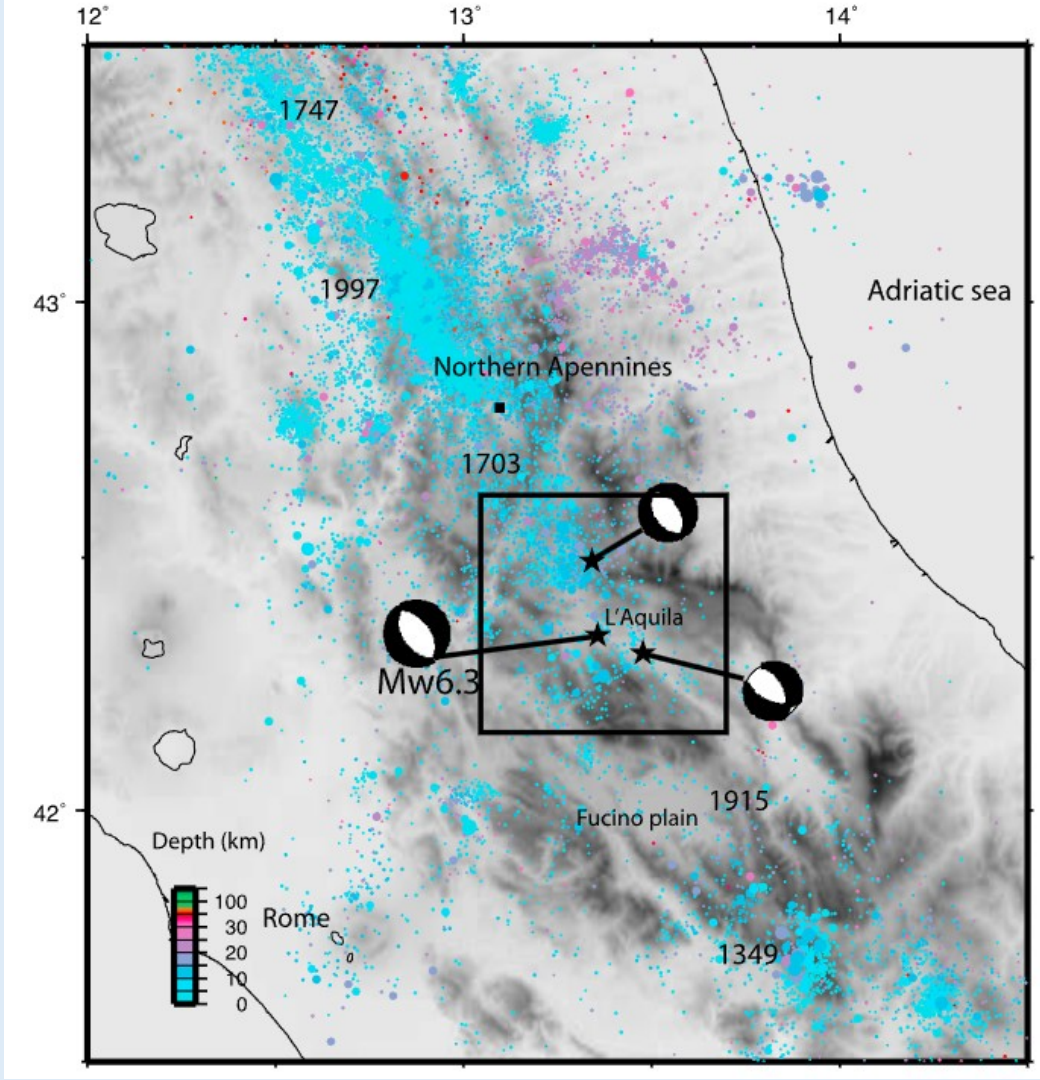
Faglie con milonite

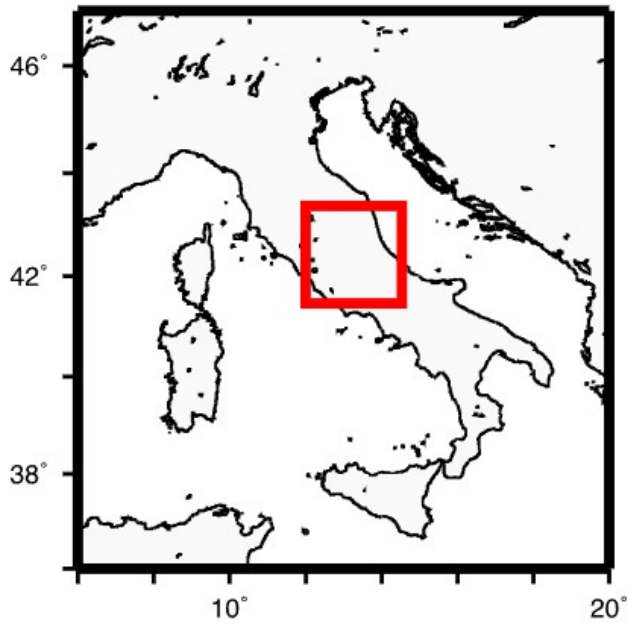
Faglie principali: FVF=faglia di "Valle Fredda" , FT3=faglia "Trasversale3" , FS=Faglia di sovrascorrimento

GRAN SASSO TUNNEL - HYDROGEOLOGICAL CROSS SECTION




N
E3
E3dx
E4
E1
0
100 m





GEOPHYSICAL RESEARCH LETTERS, VOL. 36, L18308, doi:10.1029/2009GL039627, 2009

The 2009 L'Aquila (central Italy) M_W6.3 earthquake: Main shock and aftershocks

C. Chiarabba,[1] A. Amato,[1] M. Anselmi,[1] P. Baccheschi,[1] I. Bianchi,[1] M. Cattaneo,[1] G. Cecere,[1] L. Chiaraluce,[1] M. G. Ciaccio,[1] P. De Gori,[1] G. De Luca,[1] M. Di Bona,[1] R. Di Stefano,[1] L. Faenza,[1] A. Govoni,[1] L. Improta,[1] F. P. Lucente,[1] A. Marchetti,[1] L. Margheriti,[1] F. Mele,[1] A. Michelini,[1] G. Monachesi,[1] M. Moretti,[1] M. Pastori,[1] N. Piana Agostinetti,[1] D. Piccinini,[1] P. Roselli,[1] D. Seccia,[1] and L. Valoroso[1]

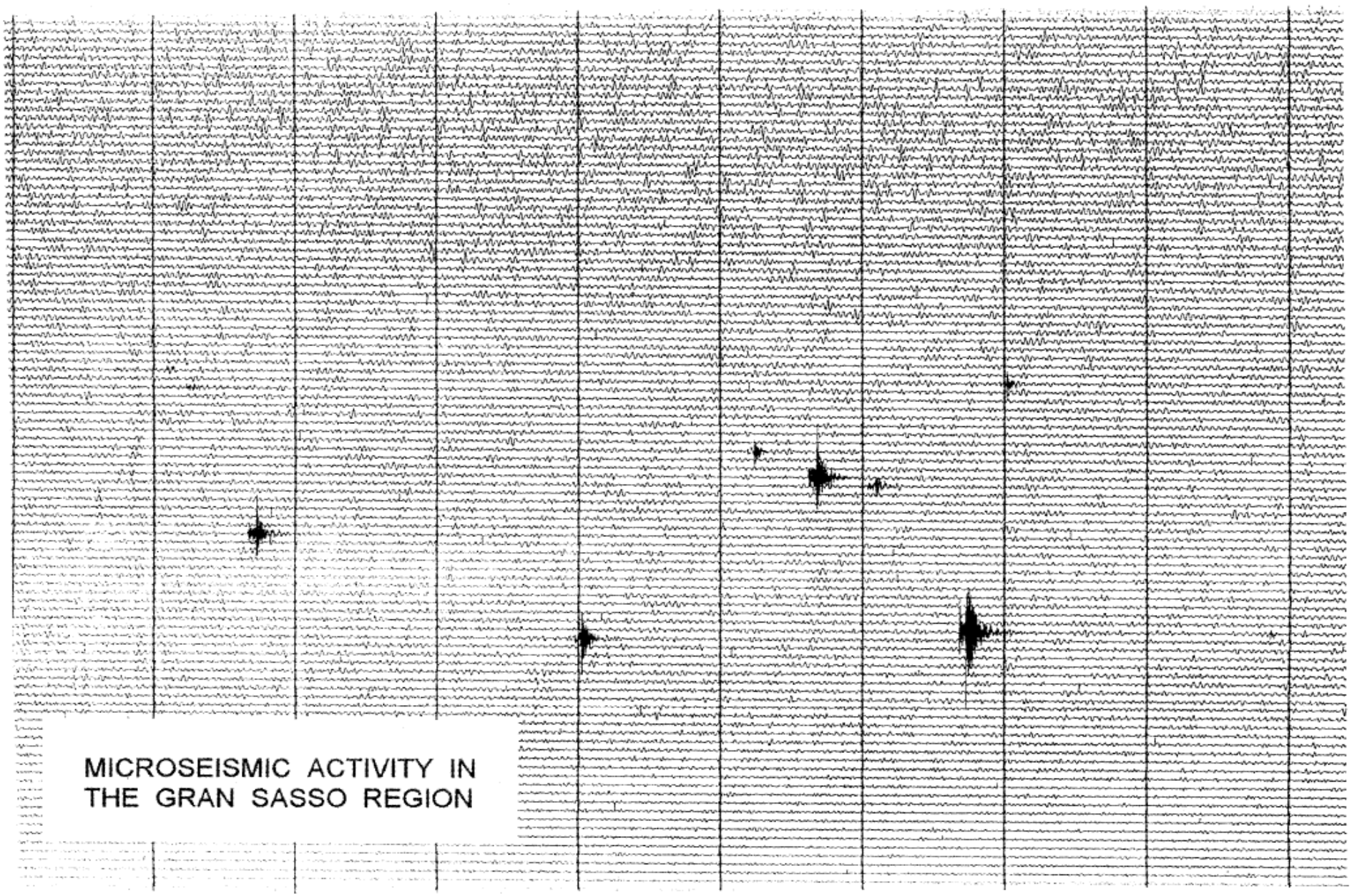
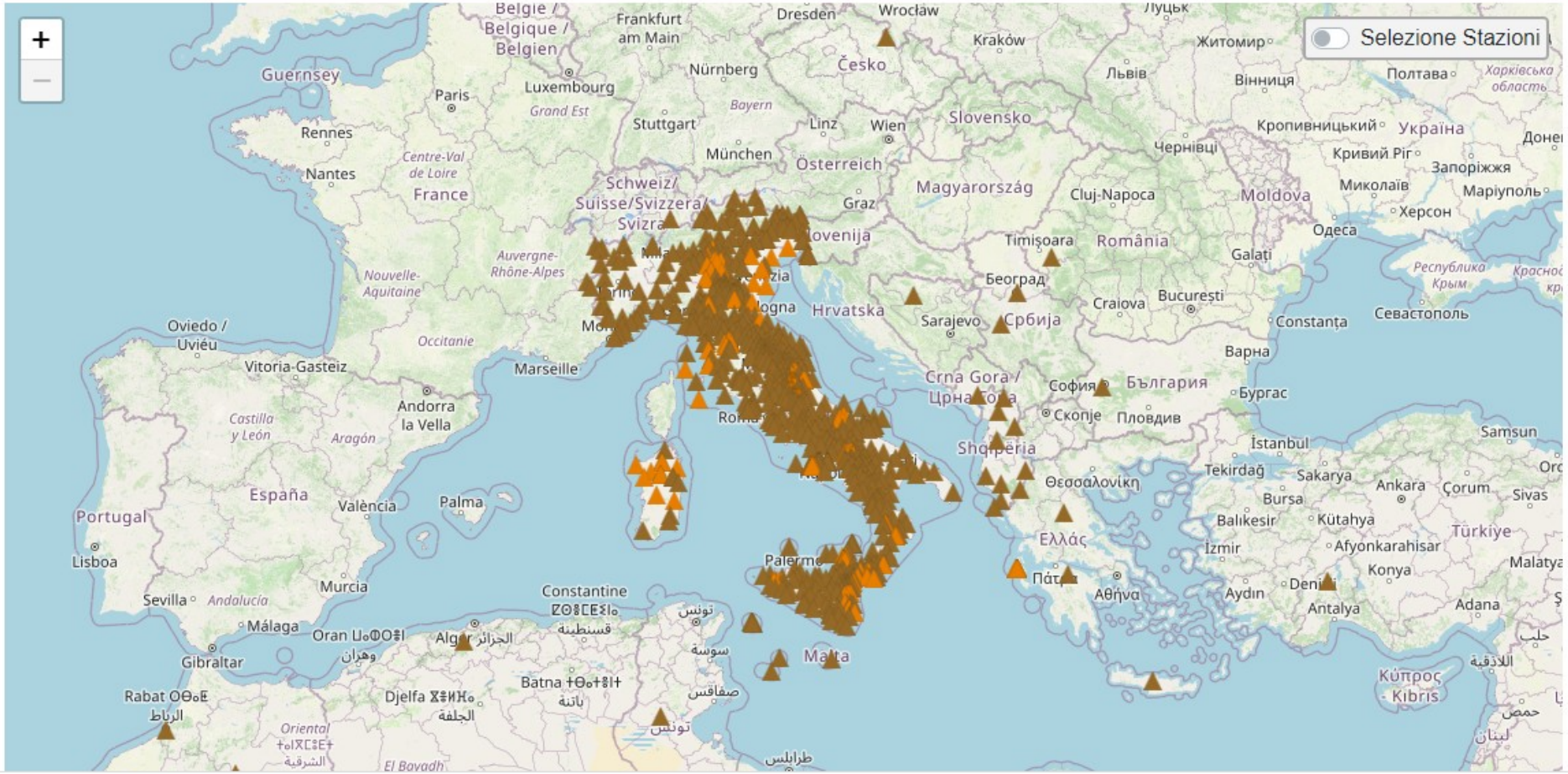
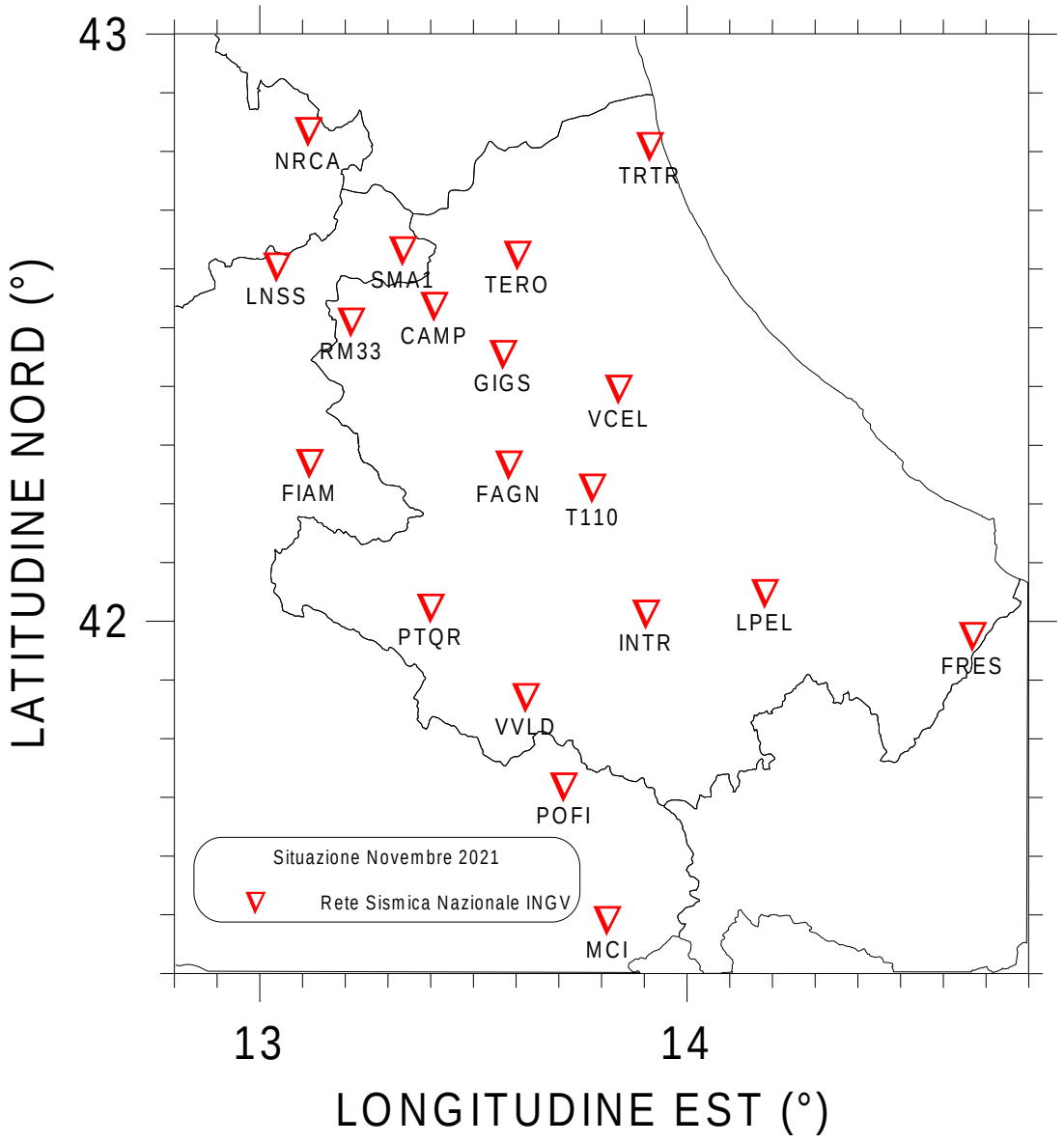


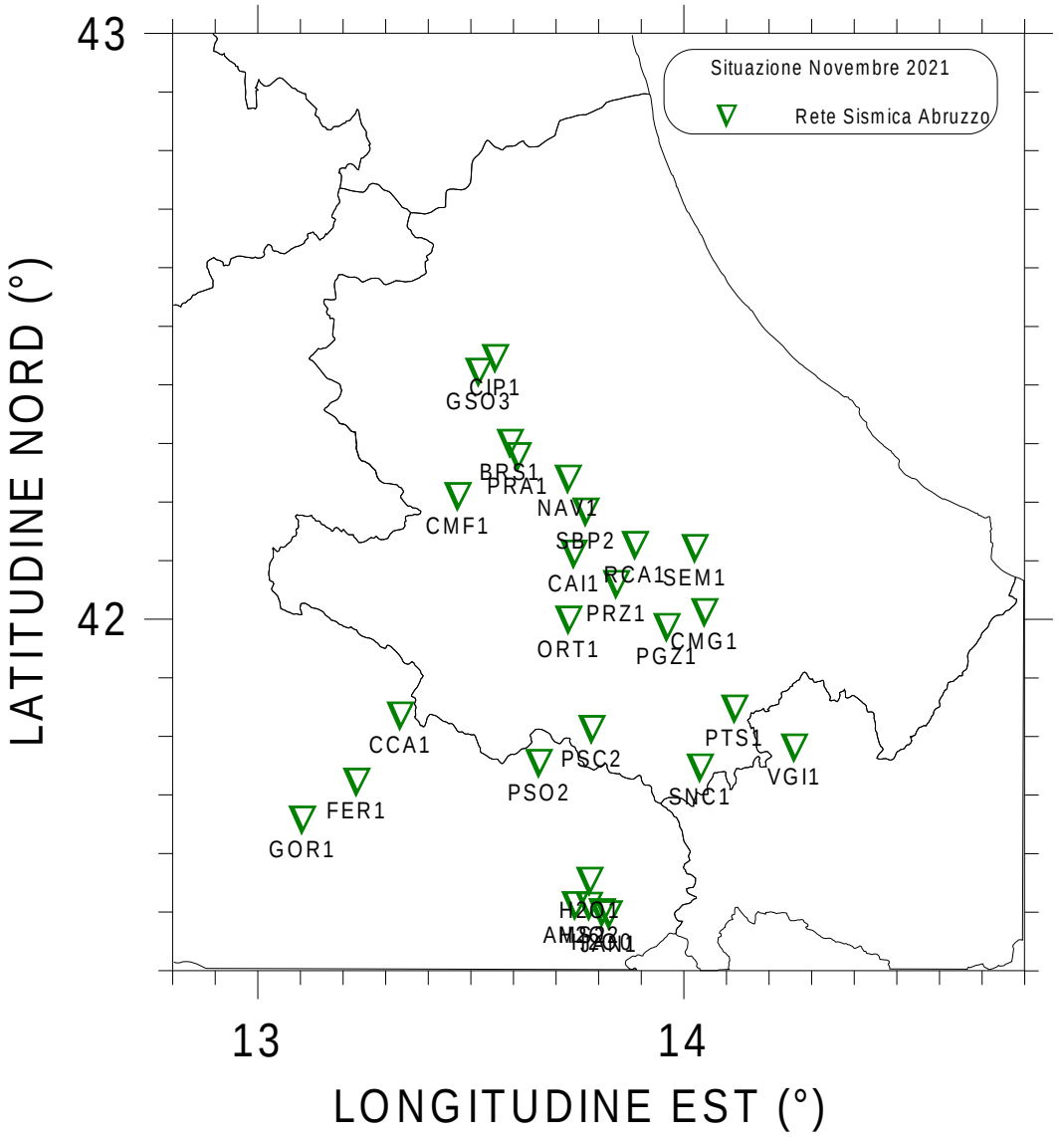
Fig. 1. Example of a drum record of microseismic activity at the end of February, 1992 in the Gran Sasso region.

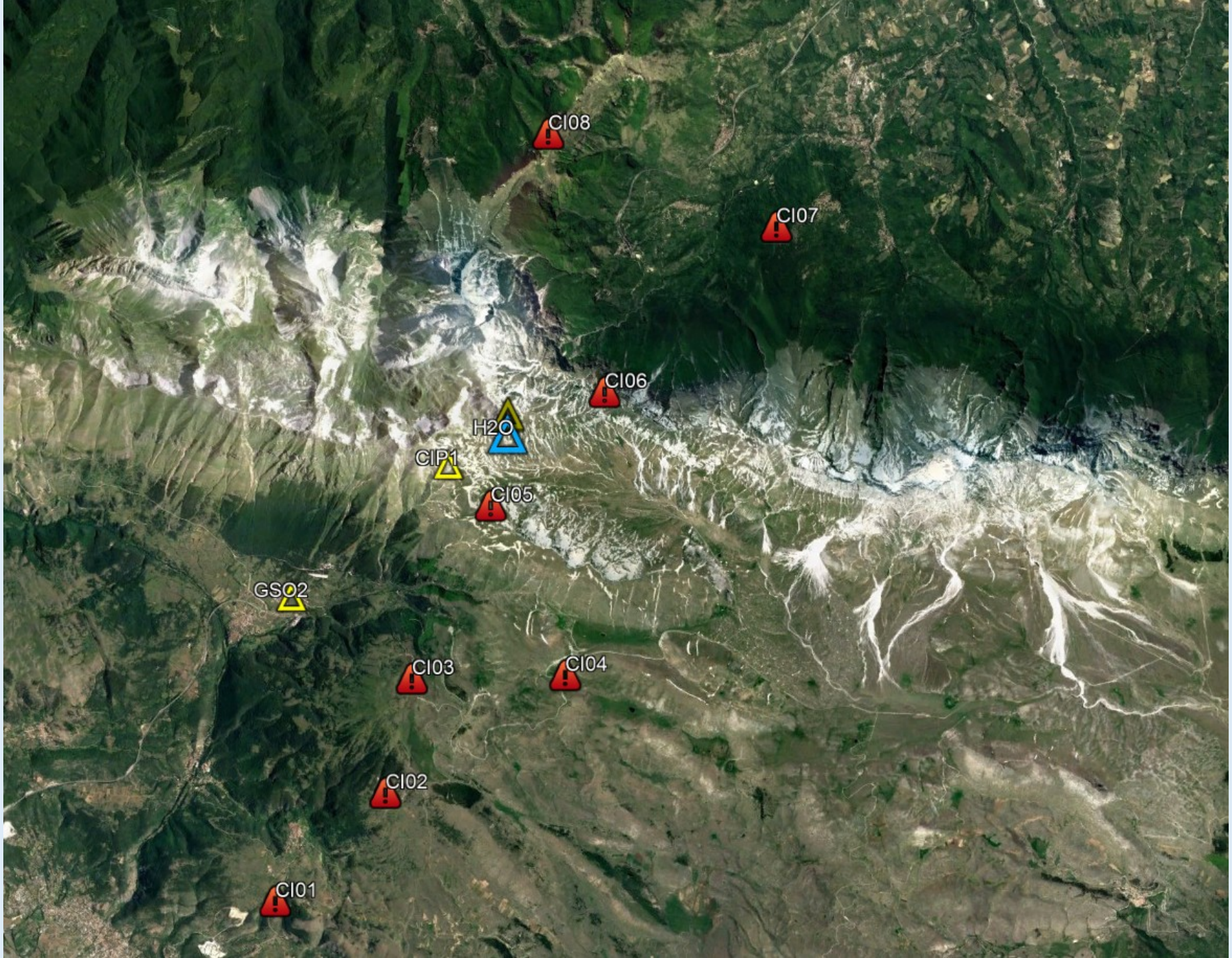
EIDA Italia
European Integrated Data Archives

Mappa interattiva



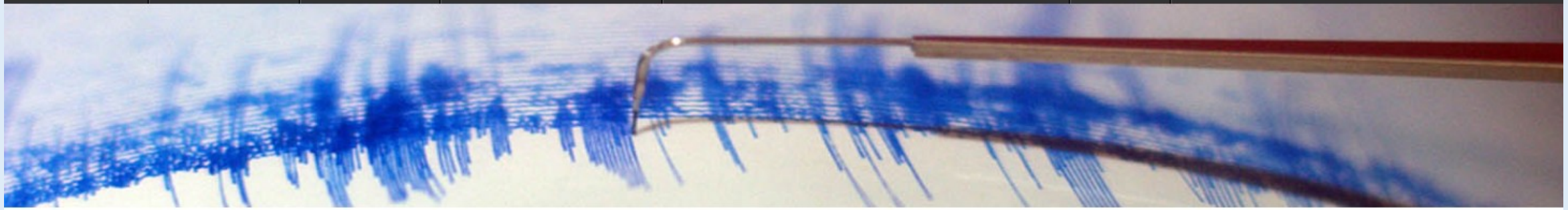

43
42
LATITUDINE NORD (°)
13
14
LONGITUDINE EST (°)
NRCA
TRTR
LNSS
SMA1
TERO
CAMP
RM33
GIGS
VCEL
FIAM
FAGN
T110
PTQR
INTR
LPEL
FRES
VVLD
POFI
MCI
Situazione Novembre 2021
Rete Sismica Nazionale INGV


43
42
LATITUDINE NORD (°)
13
14
LONGITUDINE EST (°)
Situazione Novembre 2021
Rete Sismica Abruzzo
CIP1
GSO3
BRS1
PRA1
NAV1
CMF1
SBP2
CAI1
PCA1
SEM1
PRZ1
ORT1
PGZ1
CMG1
CCA1
PTS1
PSC2
VGI1
PSO2
SNC1
FER1
GOR1


CI08
CI07
CI06
H2O
CIP1
CI05
GSO2
CI03
CI04
CI02
CI01

ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

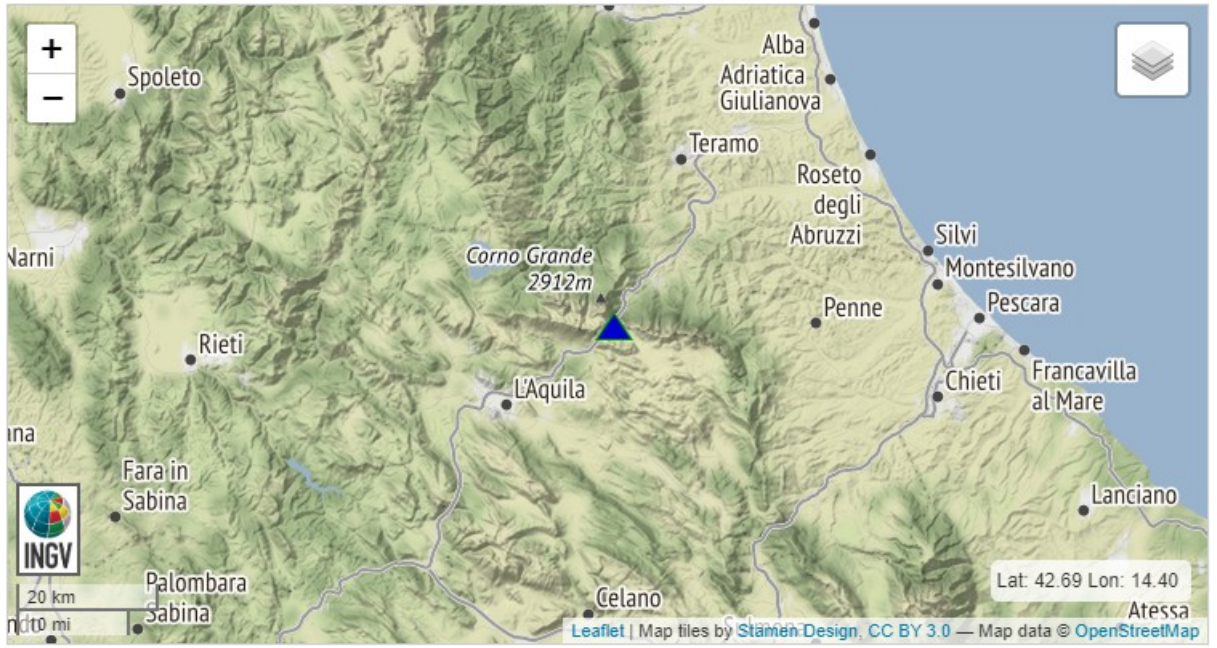
Earthquake list | Seismic networks | Real time data | Observatories and Centers | INGVterremoti | Site Guide | Contact



Seismic Station GIGS GIGS

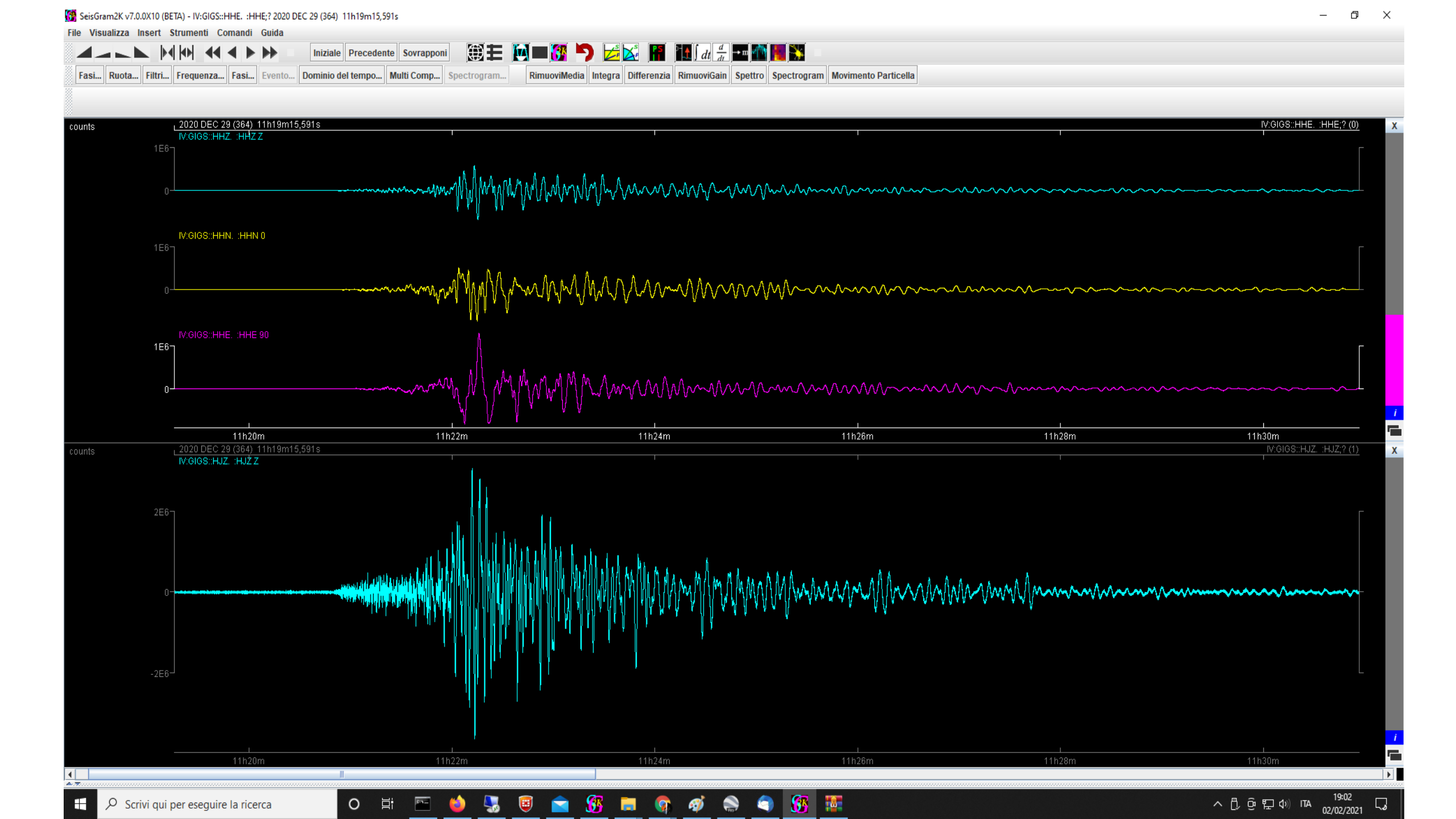
Network: IV
Start Date: 2015-02-16T12:17:00
End Date: --
Latitude: 42.453167
Longitude: 13.572833
Elevation: 960
Download StationXML

http://terremoti.ingv.it/instruments/station/GIGS#

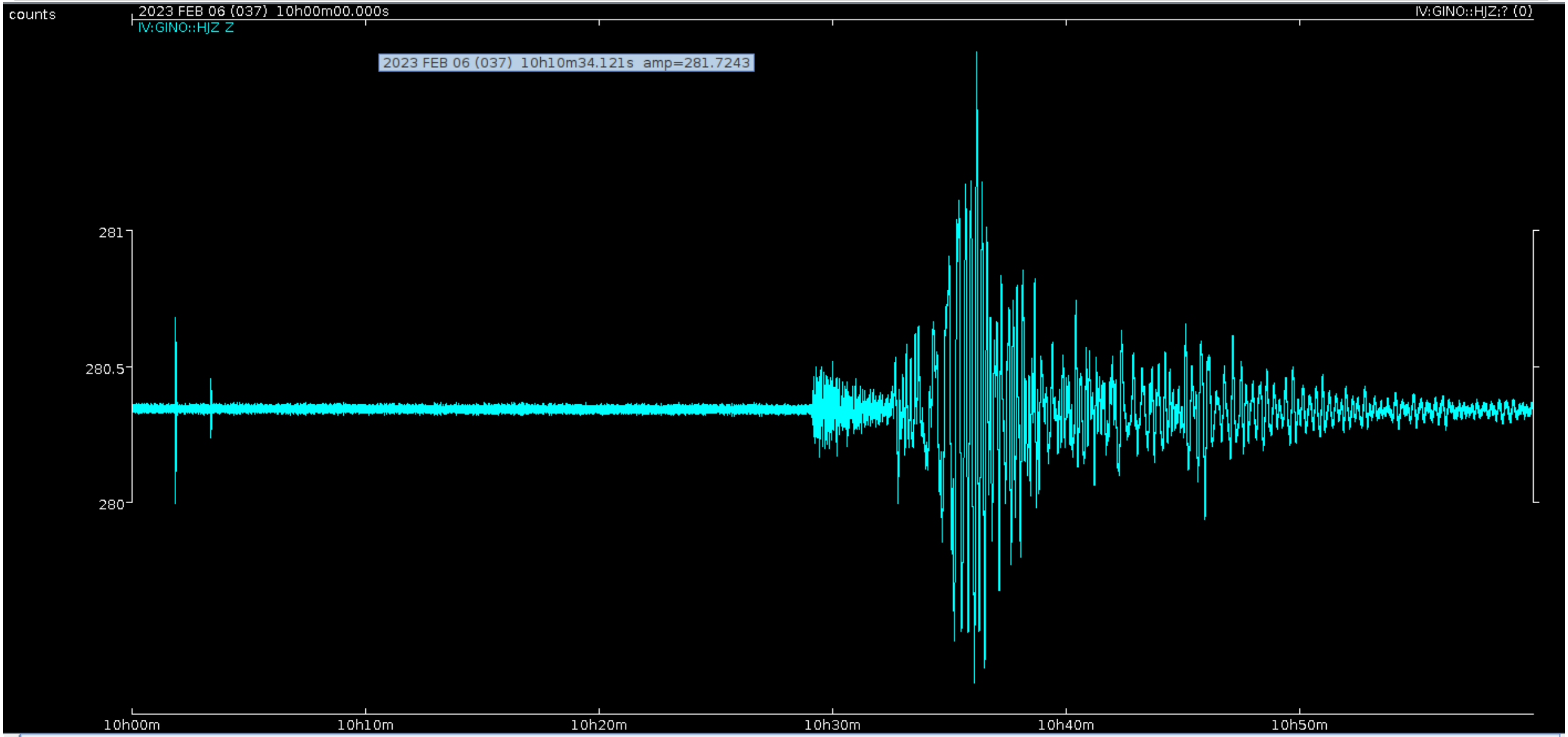


http://webservices.rm.ingv.it/fdsnws/dataselect/1/query?network=IV&station=GIGS&channel=H??&start=2020-12-29T10:00:00&end=2020-12-29T13:00:00

HHZ, HHN, HHE + HJZ


SeisGram2K v7.0.0X10 (BETA) - IV:GIGS::HHE. :HHE;? 2020 DEC 29 (364) 11h19m15,591s
File Visualizza Insert Strumenti Comandi Guida
Iniziale Precedente Sovrapponi
Fasi... Ruota... Filtri... Frequenza... Fasi... Evento... Dominio del tempo... Multi Comp... Spectrogram... RimuoviMedia Integra Differenza RimuoviGain Spettro Spectrogram Movimento Particella
counts
2020 DEC 29 (364) 11h19m15,591s
IV:GIGS::HHE. :HHE;? (0)
IV:GIGS::HHZ. :HHZ Z
IV:GIGS::HHN. :HHN 0
IV:GIGS::HHE. :HHE 90
1E6
0
11h20m
11h22m
11h24m
11h26m
11h28m
11h30m
counts
2020 DEC 29 (364) 11h19m15,591s
IV:GIGS::HJZ. :HJZ;? (1)
IV:GIGS::HJZ. :HJZ Z
2E6
0
-2E6
11h20m
11h22m
11h24m
11h26m
11h28m
11h30m
Scrivi qui per eseguire la ricerca
ITA
19:02
02/02/2021

2023-02-06 10:24:52	Mwpd 7.5	Turkey	28	38.09	37.27
2023-02-06 01:17:36	Mwpd 7.9	Turkey	20	37.20	37.06



ISTITUTO NAZIONALE
DI GEOFISICA E VULCANOLOGIA

INFN Istituto Nazionale di Fisica Nucleare

Creation of a multidisciplinary infrastructure dedicated to underground Geophysics at the INFN LNGS and a geophysics laboratory for the study of seismic precursors

1
Seismic Array Underground

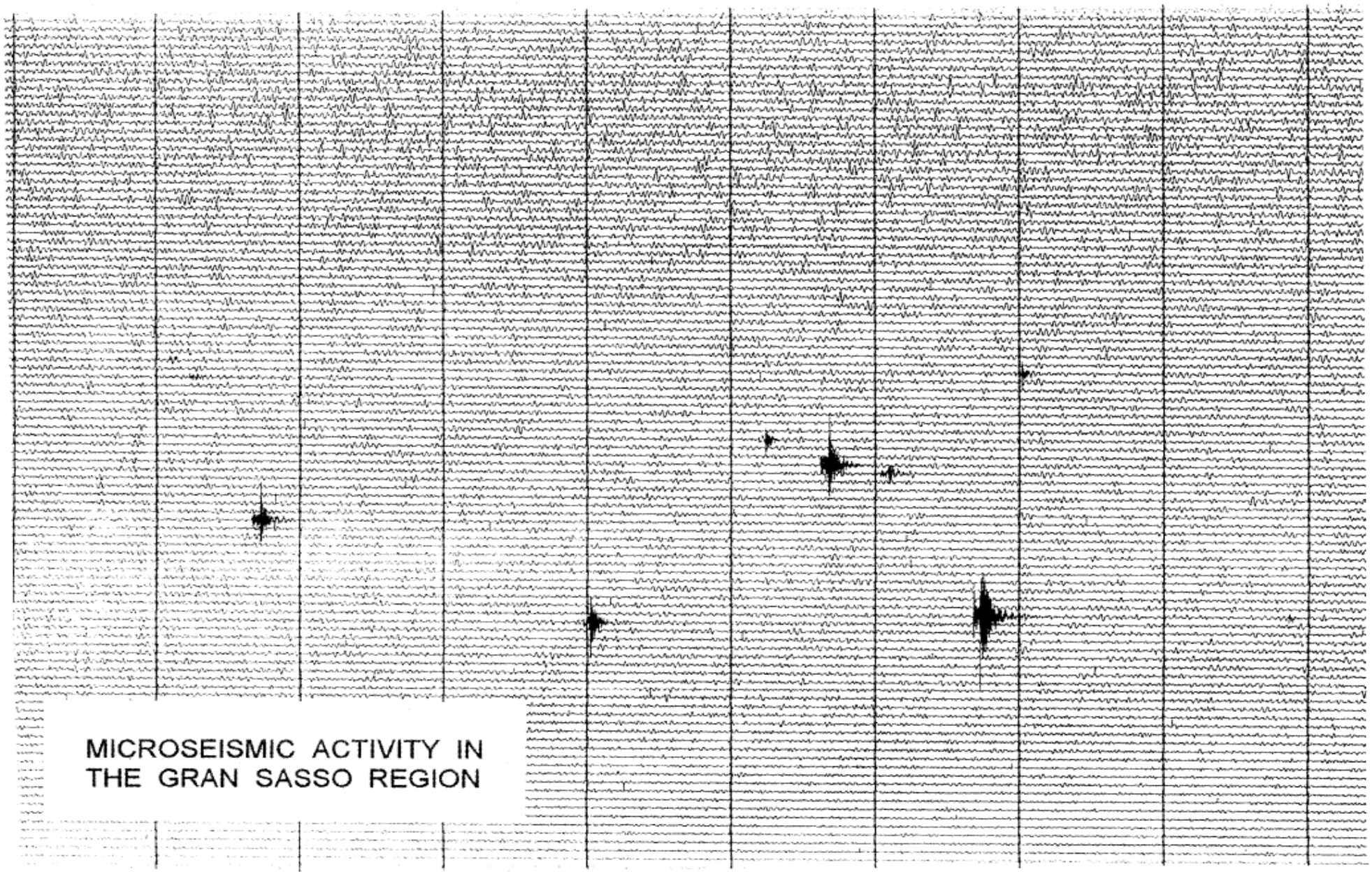


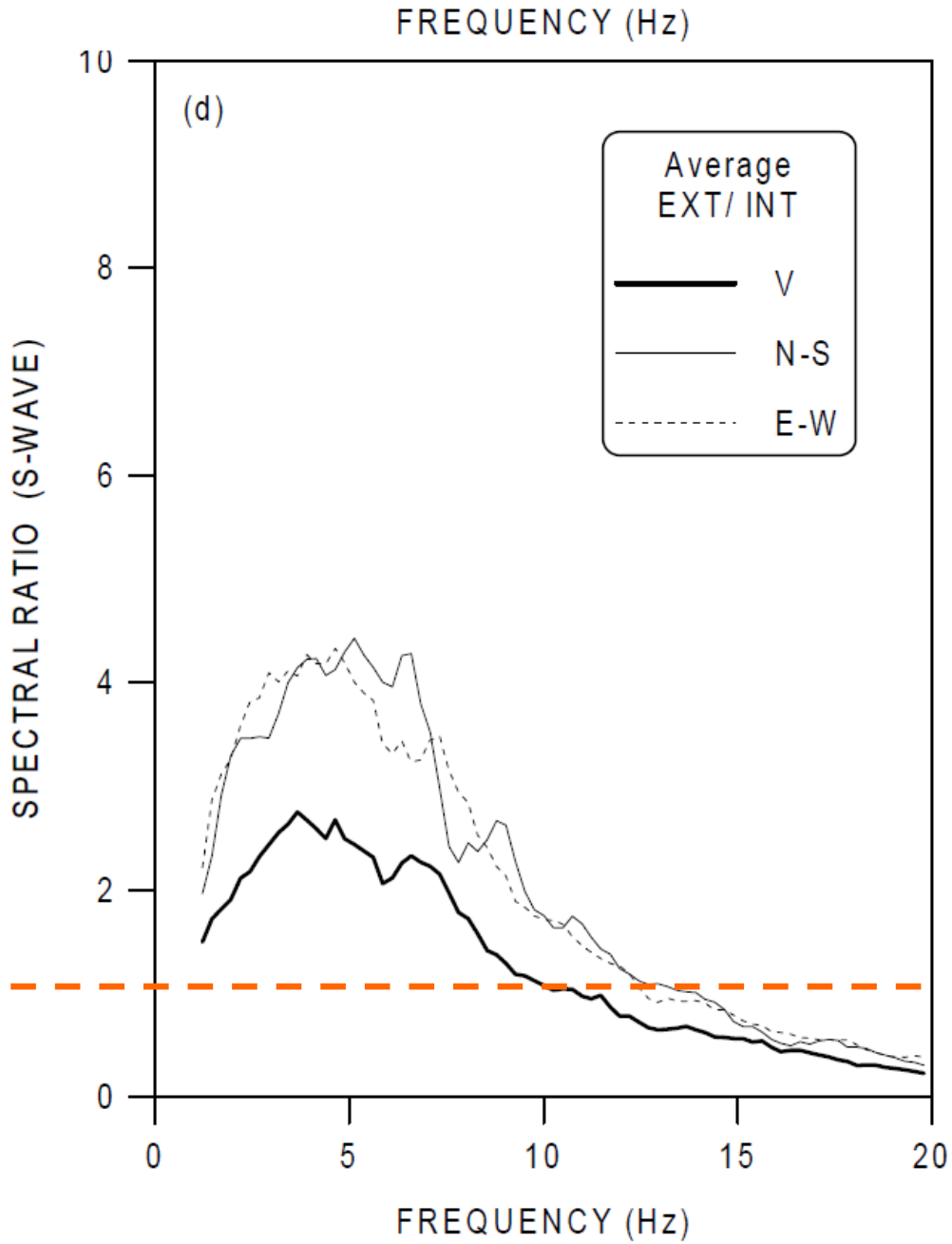
Fig. 1. Example of a drum record of microseismic activity at the end of February, 1992 in the Gran Sasso region.

Journal of Seismology **2:** 223–236, 1998.

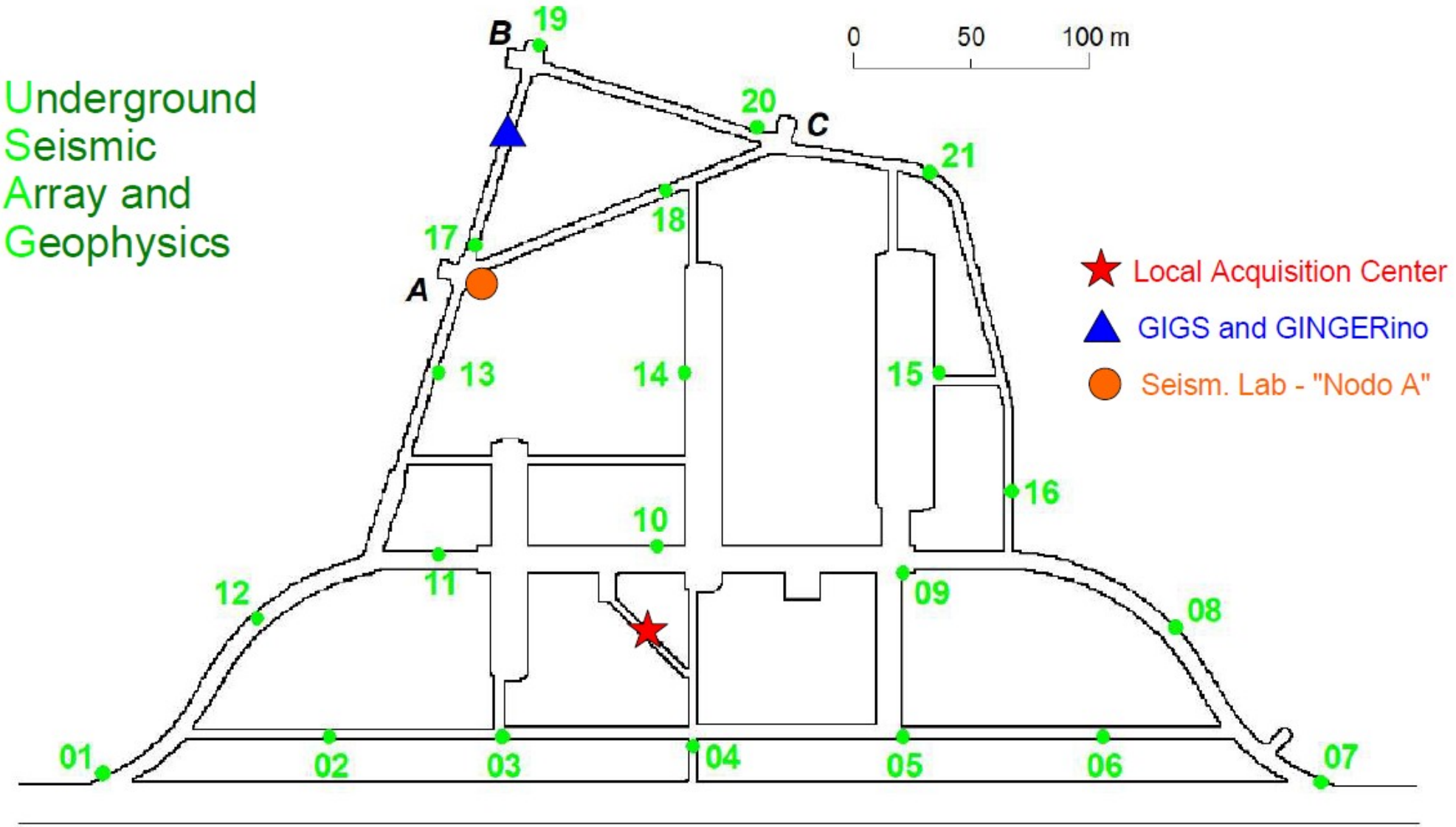
Site response study in Abruzzo (Central Italy): underground array versus surface stations

G. De Luca[1,5], E. Del Pezzo[2], F. Di Luccio[3], L. Margheriti[3], G. Milana[4] & R. Scarpa[1,5]

[1] *Università dell'Aquila, Dipartimento di Fisica, Via Vetoio, 67010 Coppito (L'Aquila), Italy*
[2] *Università di Salerno, Dipartimento di Fisica, Via S. Allende, 84081 Baronissi (Salerno), Italy*
[3] *Istituto Nazionale di Geofisica, Via di Vigna Murata 605, 00143 Rome, Italy*
[4] *Servizio Sismico Nazionale, Via Curtatone 3, 00185 Rome, Italy*
[5] *Laboratori Nazionali del Gran Sasso (LNGS-INFN), 67010 Assergi (L'Aquila), Italy*



Underground Seismic Array and Geophysics



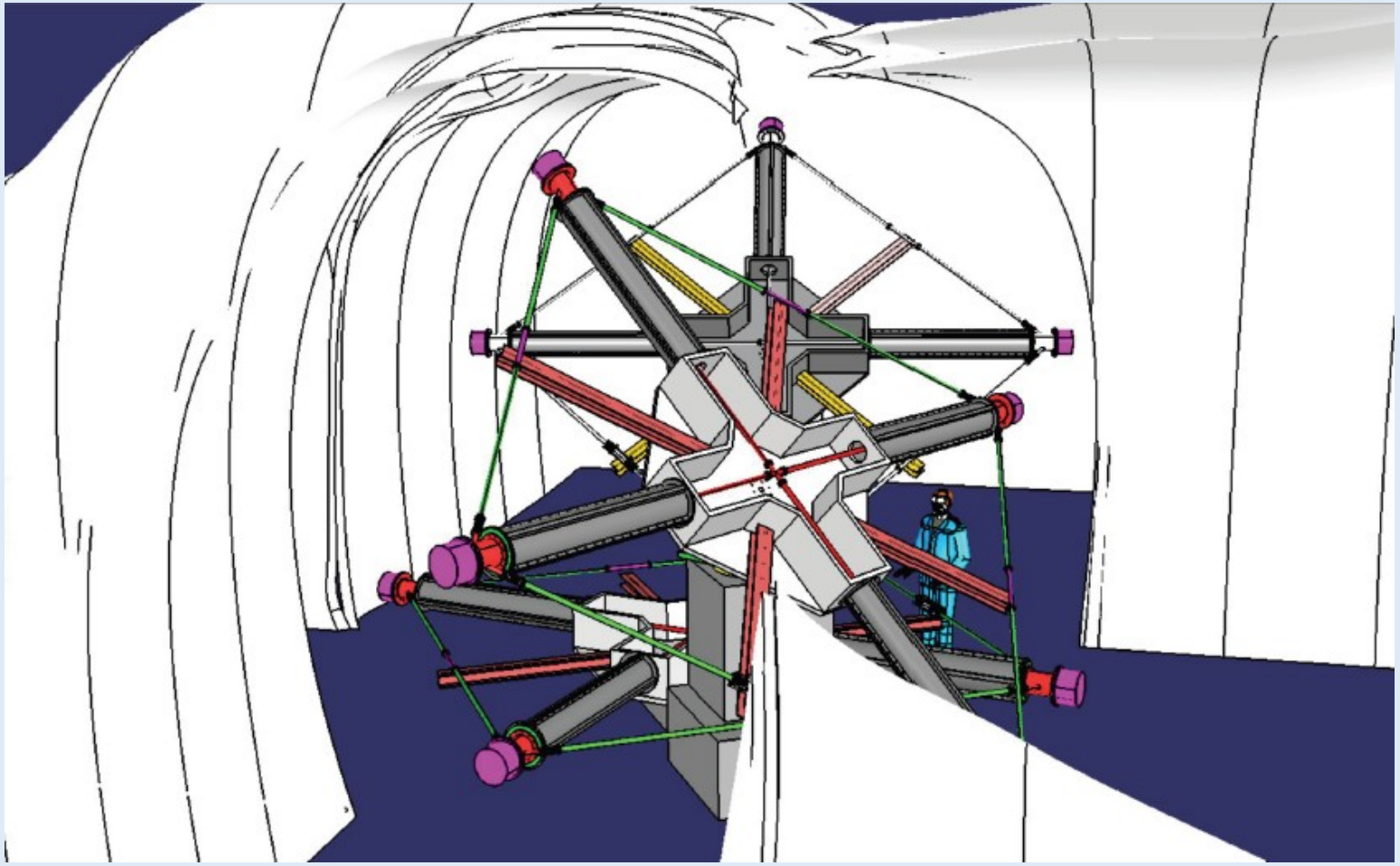
Site n. 06

Seismic Array

-Geometry (radar)
-Signals not impulsive
-Wavefield composition
-Correlation analysis
-Dispersion curve
-Staking
-S/N ratio
-Polarization analysis

2

Experiment: GINGER



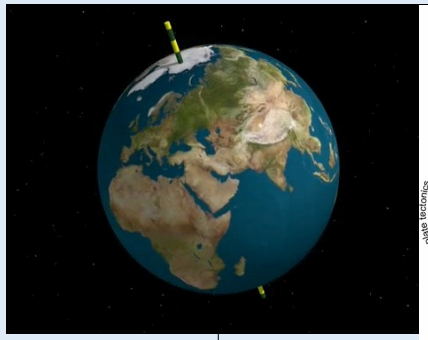
9:30 AM

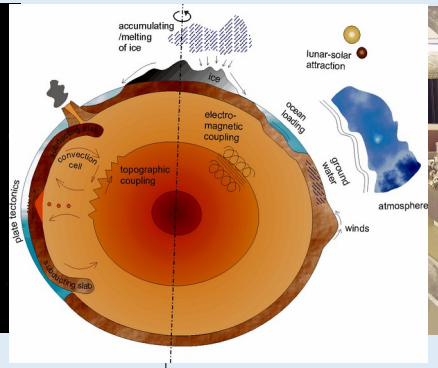
GInger

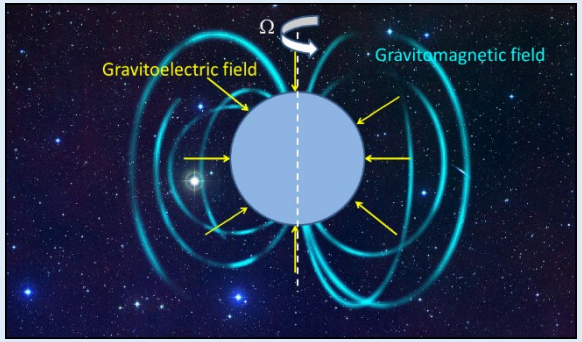
30m

GINGER (Gyroscopes In GEnereal Relativity -> Gyroscopes IN GEophysics and Relativity ?), array of ring laser gyroscopes (RLG), is entered the construction phase. The three-years plan is to install and to make operative 2 RLGs inside the underground Gran Sasso laboratory. One of the two will be oriented at the maximum Sagnac signal in order to evaluate the orientation, with respect to the instant angular rotation axis, of the second RLG, with vertical area vector. The apparatus, its plan, and its final target will be described.

Speaker: Angela Dora Vittoria Di Virgilio (Istituto Nazionale di Fisica Nucleare)







Sensibilità di «G»

10^{-4} 10^{-6} 10^{-8} 10^{-10} 10^{-12} 10^{-14} rad/sec

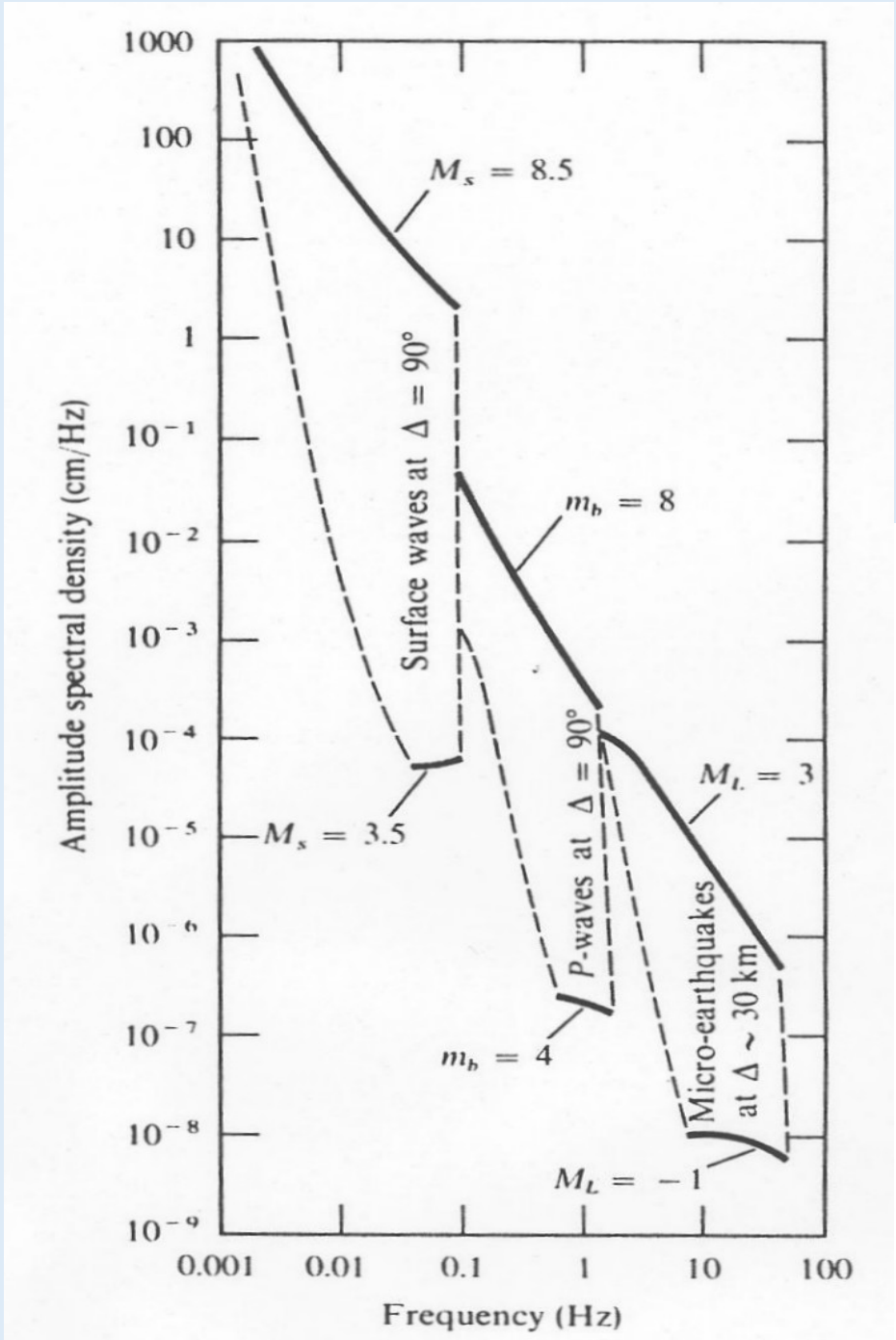
Giorno sidereo | Geofisica | Maree | Geodesia | Relatività generale

Geodetic-Geophysical topics (INFN-INGV cooperation)

1. Study of high frequency variations of Earth Rotation Parameters
   - Tidal variations of polar motion
   - High frequency UT1 variations (Oceans & Atmosphere tides)
2. Study of high frequency Earth’s axis nutation
   - Forced nutations
   - Free core nutation
3. Monitoring high frequency local tilt and Solid Earth Tides
4. Rotational seismology

Local and Regional Earthquakes	0.01 – 50 Hz
Earth Free Oscillations + Teleseismic	0.0001 – 2 Hz
Volcanic activity	(?) – 20 Hz
Oceanic Noise	0.01 – 1 Hz
Atmosferic pression, wind	days – Hz
Tides, local tilt	days
Acquifer, snow load	months/years

Deformations in volcanic and tectonic regions 20 Hz – months/years



two peaks:
~ 0.14 Hz and ~ 0.07 Hz

QUANTITATIVE SEISMOLOGY
Theory and Methods

VOLUME I

Keiiti Aki
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Paul G. Richards
COLUMBIA UNIVERSITY

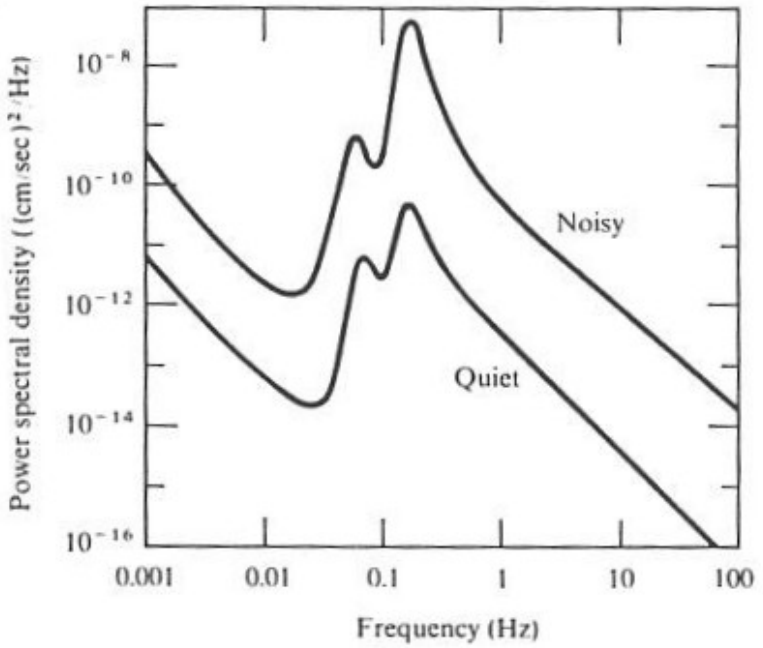
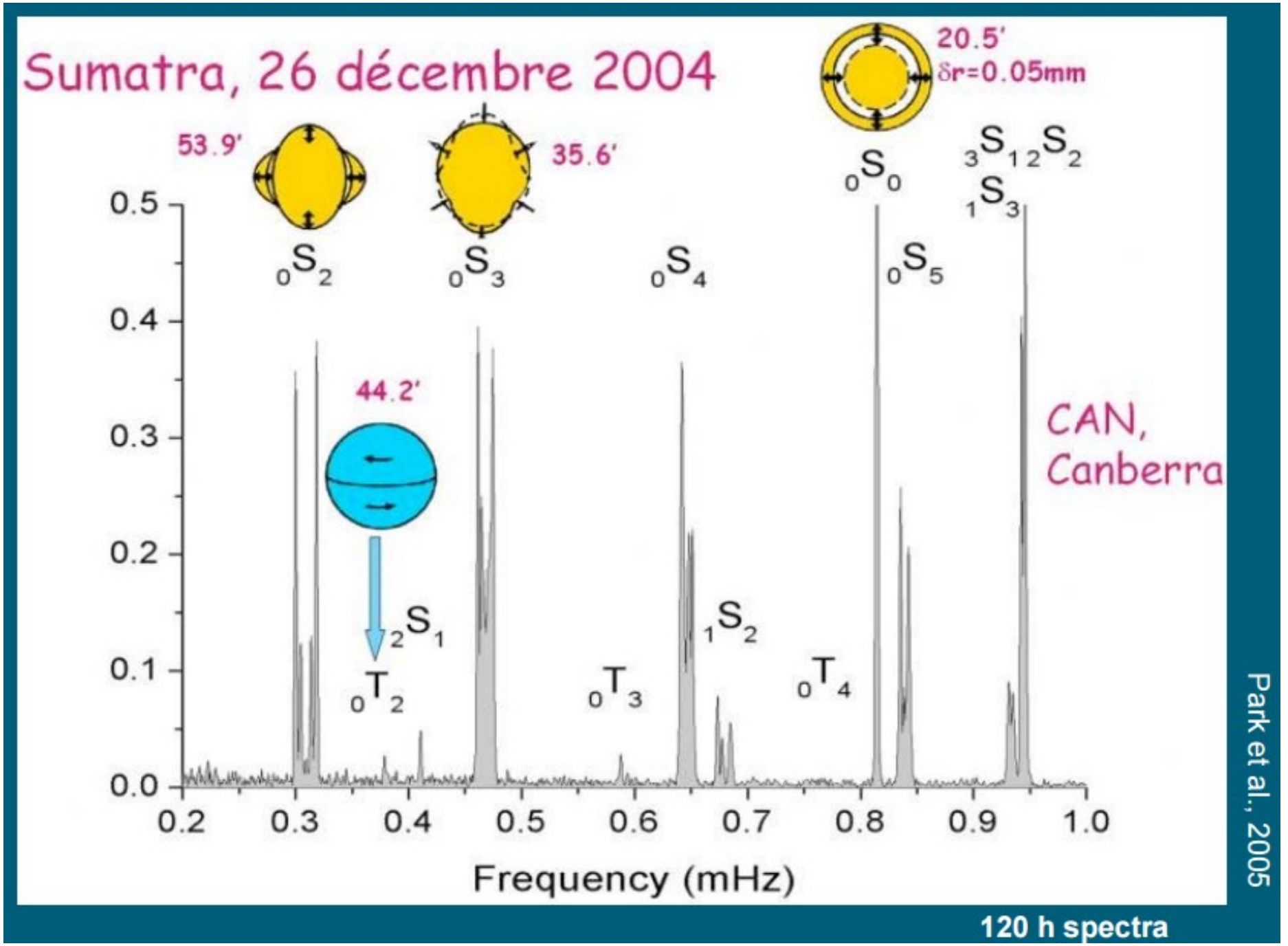
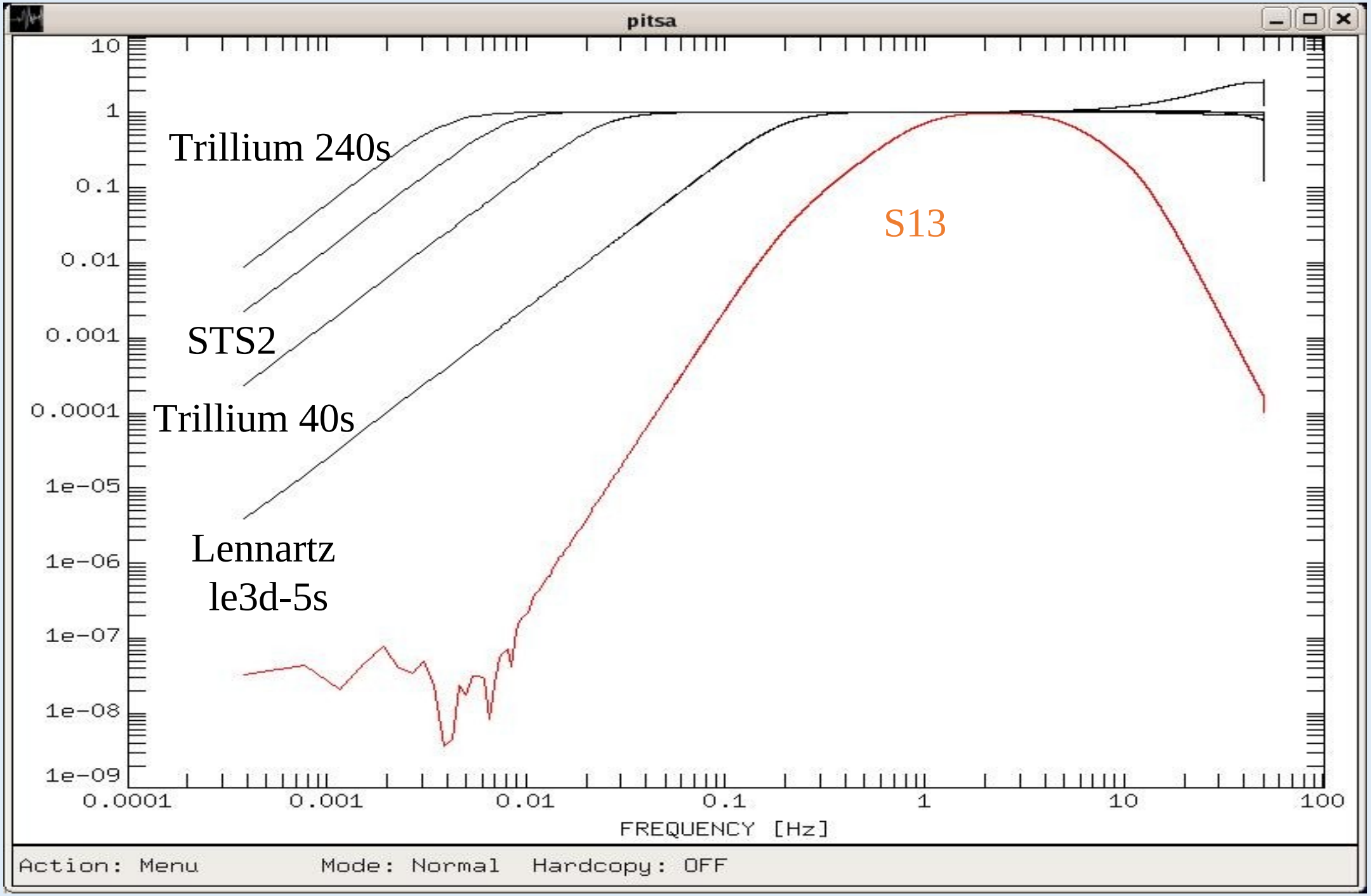


FIGURE **10.11**

Power spectra of ambient seismic noise at noisy and quiet conditions for a typical station on hard basement rock.


Sumatra, 26 décembre 2004
20.5'
δr=0.05mm
53.9'
35.6'
44.2'
$_0S_0$
$_3S_{12}S_2$
$_1S_3$
$_0S_2$
$_0S_3$
$_0S_4$
$_0S_5$
$_2S_1$
$_0T_2$
$_0T_3$
$_1S_2$
$_0T_4$
CAN, Canberra
0.0
0.1
0.2
0.3
0.4
0.5
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Frequency (mHz)
120 h spectra
Park et al., 2005


pitsa
Trillium 240s
STS2
Trillium 40s
Lennartz
le3d-5s
S13
10
1
0.1
0.01
0.001
0.0001
1e-05
1e-06
1e-07
1e-08
1e-09
0.0001
0.001
0.01
0.1
1
10
100
FREQUENCY [Hz]
Action: Menu
Mode: Normal
Hardcopy: OFF

3
Underground Seismometry Laboratory

Nodo A

Area utilizzata per «huddle test» e futura posizione di GIGS (rete sismica nazionale) con 360s + accelerometro

Sono stati in acquisizione continua un STS2 (verde) e un Broad-band ancora non in commercio (rosso) con banda 120 s – 50 hz

4 iGrav

1 nanoGal – 0.01 nm/s2

5:30 PM

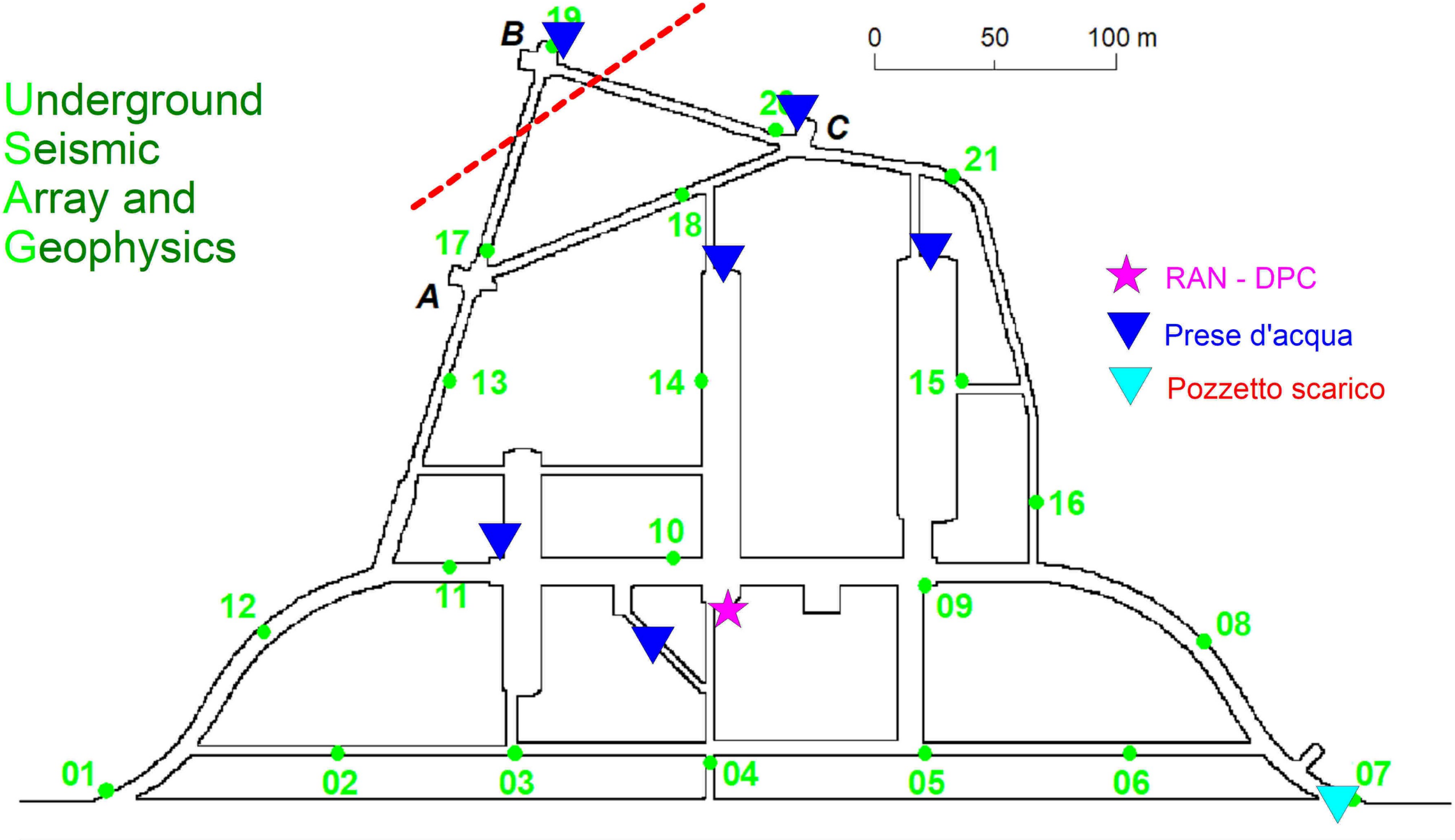
Gravimetry in the Italian area: future developments and perspectives 30m

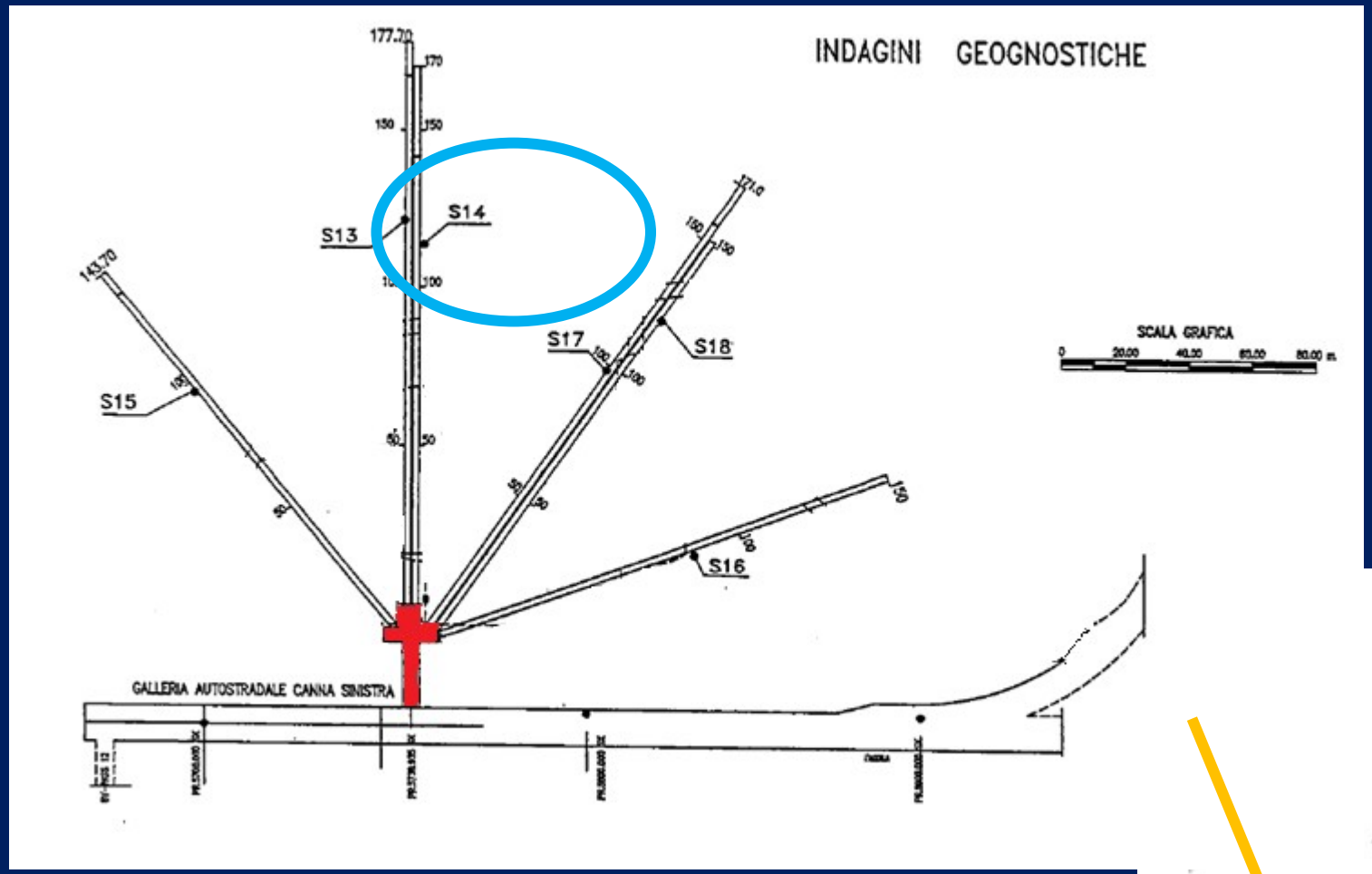
In Italy, gravimetry is largely carried out since '80 to study and monitoring active volcanoes of central-southern and insular Italy, but was not extensively applied in seismic areas, except in Central Italy, where gravity measurements have been performed since 2018, aimed to study the dynamics of the main tectonic processes, also including absolute stations already present and measured in the area for different purposes. Here we present the state-of-the-art of the gravimetry in Italy and the developments and perspectives. Specifically, in order to lay the foundations for a multidisciplinary approach to natural risk assessment, a large-scale gravity network in Italy, which in the most advanced development will consist of about 10 sites, homogeneously distributed throughout the country, is under realization. The network will allow for determining the temporal variations of the long-term and long-wavelength gravity field in seismic and volcanic areas. The sites will be equipped with absolute or relative gravimeters in continuous or pseudo-continuous recording (e.g. 1 measurement every week). For this purpose, superconducting gravimeters and atomic and ballistic absolute gravimeters will be used, the only instruments capable of providing a highly precise and stable signal even in the long term. This network, will supplements the newly established National Reference Gravimetric Network (G0) and the National Gravimetric Service in the planning stage

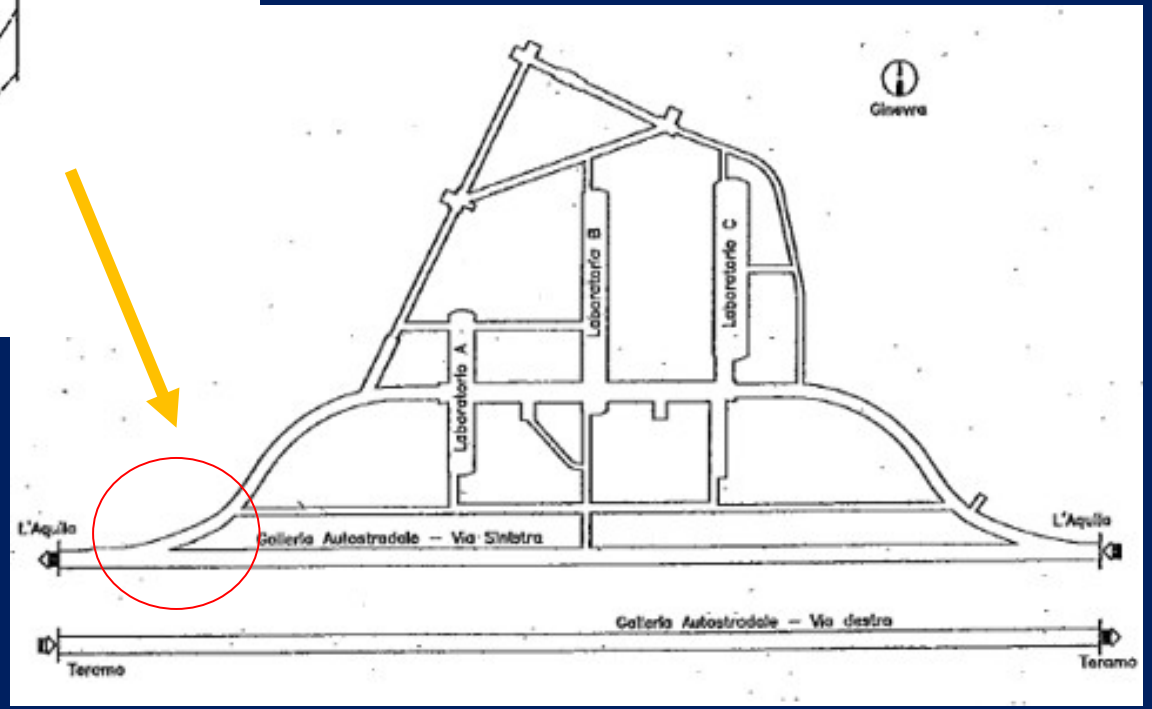
Speaker: Filippo Greco (INGV-OE)

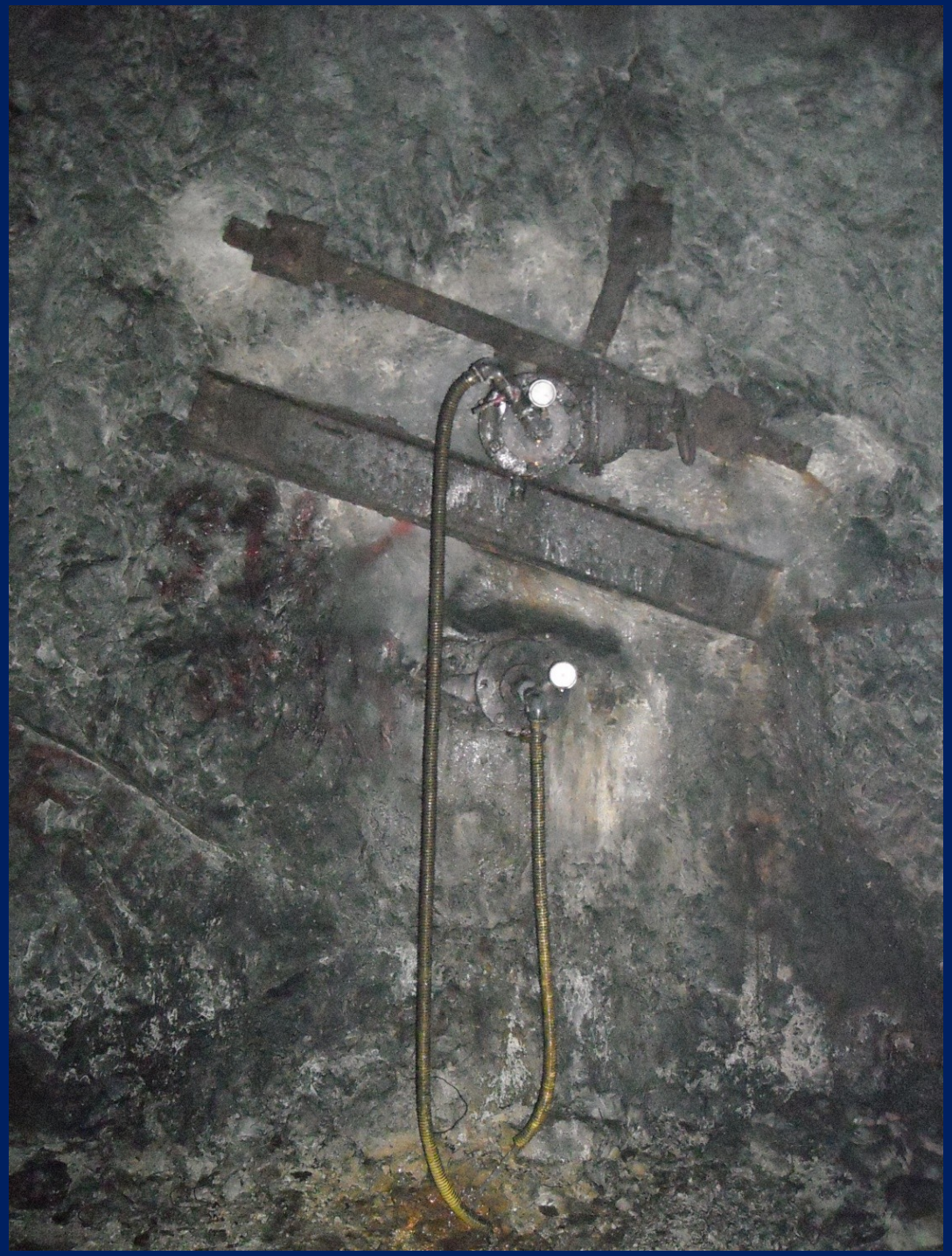
5
Physical and chemical monitoring of groundwater

Underground
Seismic
Array and
Geophysics

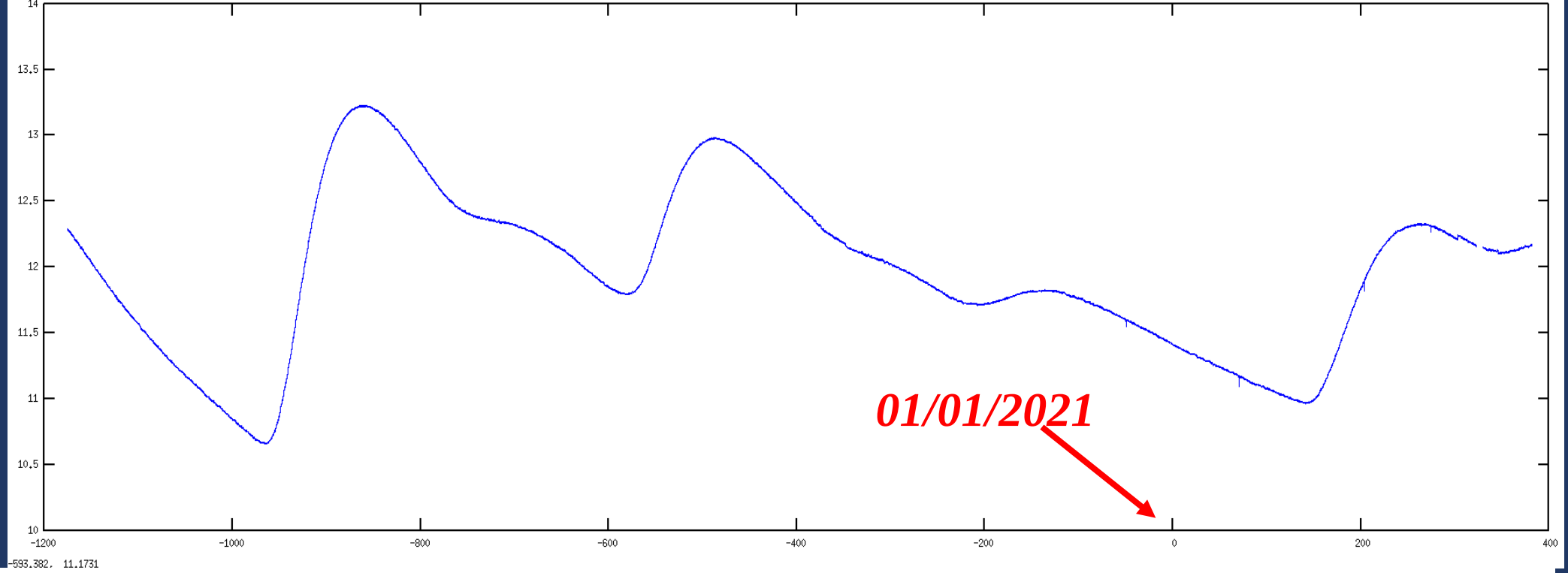



INDAGINI GEOGNOSTICHE
177.20
170
150
150
S13
S14
143.70
S15
S17
S18
S16
SCALA GRAFICA
0 20.00 40.00 60.00 80.00 m.
GALLERIA AUTOSTRADALE CANNA SINISTRA


Ginevra
Laboratorio A
Laboratorio B
Laboratorio C
L'Aquila
Galleria Autostradale – Via Sinistra
L'Aquila
Galleria Autostradale – Via destra
Teramo
Teramo




uk
PINT
usa
1 1/2
1
1/2
1 1/2
1
1/2
500
400
300
200
100


14
13,5
13
12,5
12
11,5
11
10,5
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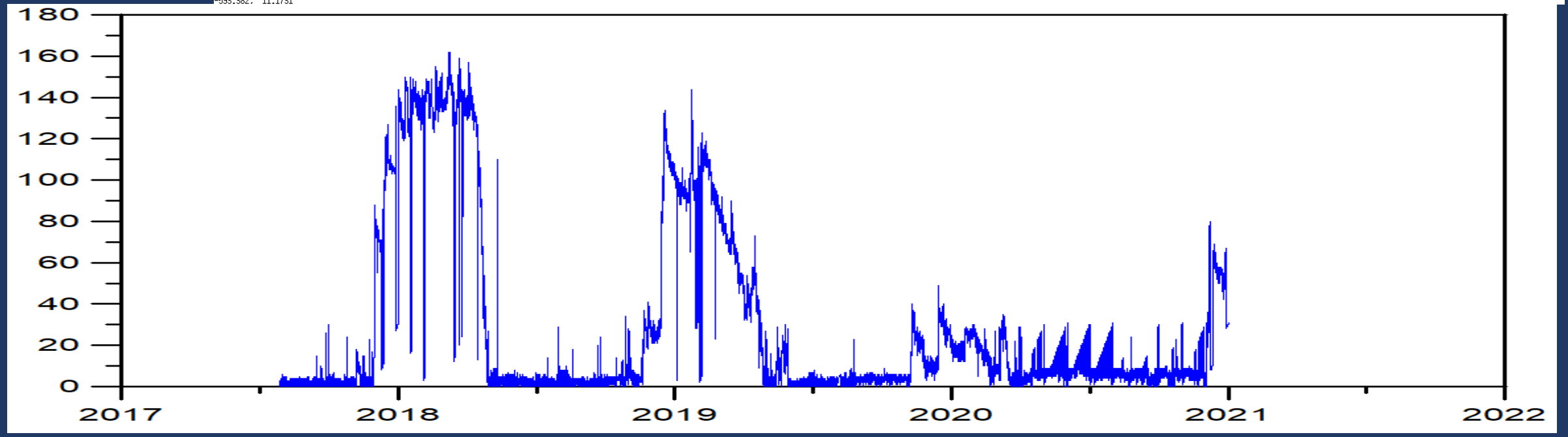
-1200
-1000
-800
-600
-400
-200
0
200
400
-593.382, 11.1731
01/01/2021


180
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140
120
100
80
60
40
20
0
2017
2018
2019
2020
2021
2022

https://www.nature.com/articles/s41598-018-34444-1

SCIENTIFIC REPORTS

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A record of changes in the Gran Sasso groundwater before, during and after the 2016 Amatrice earthquake, central Italy

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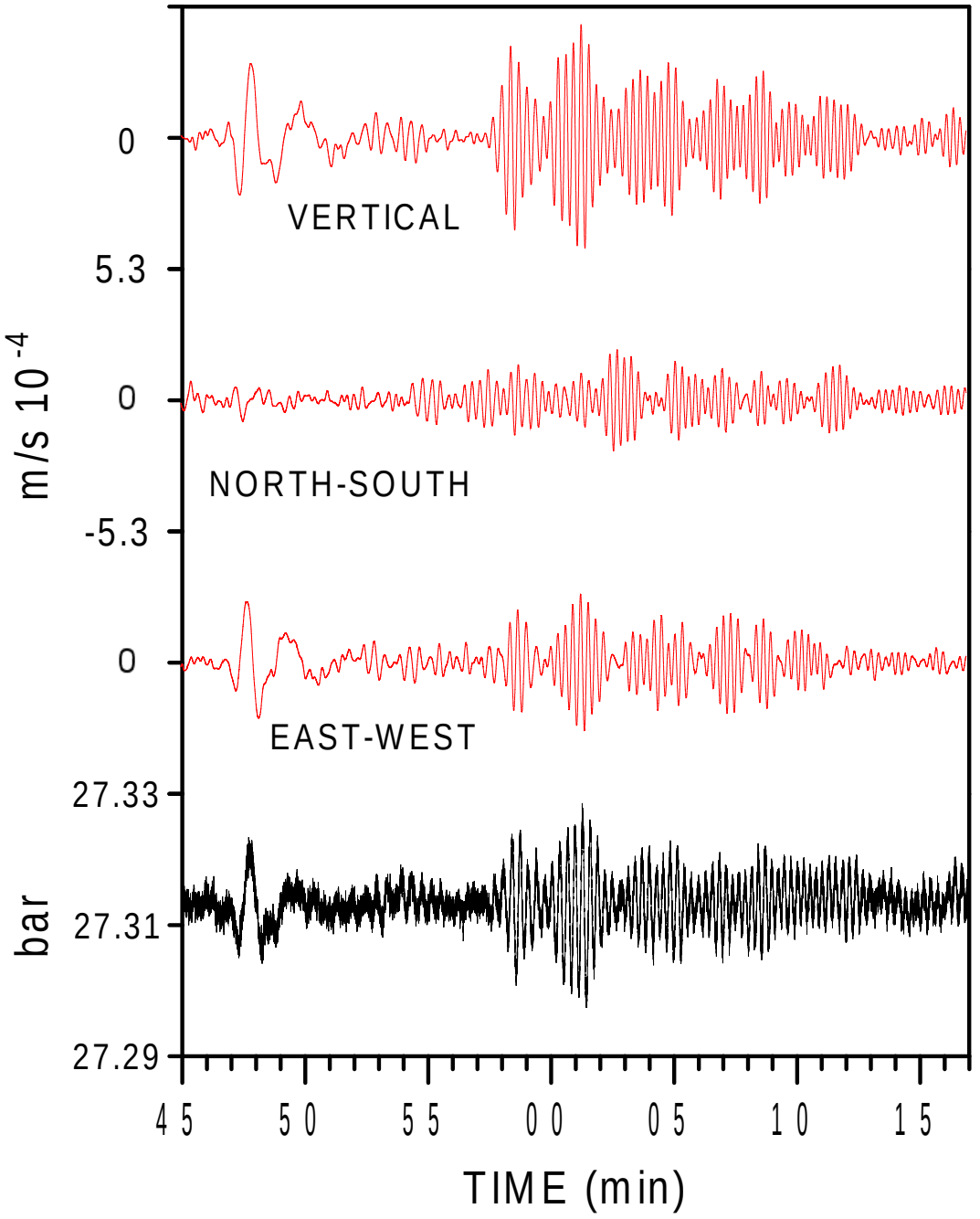
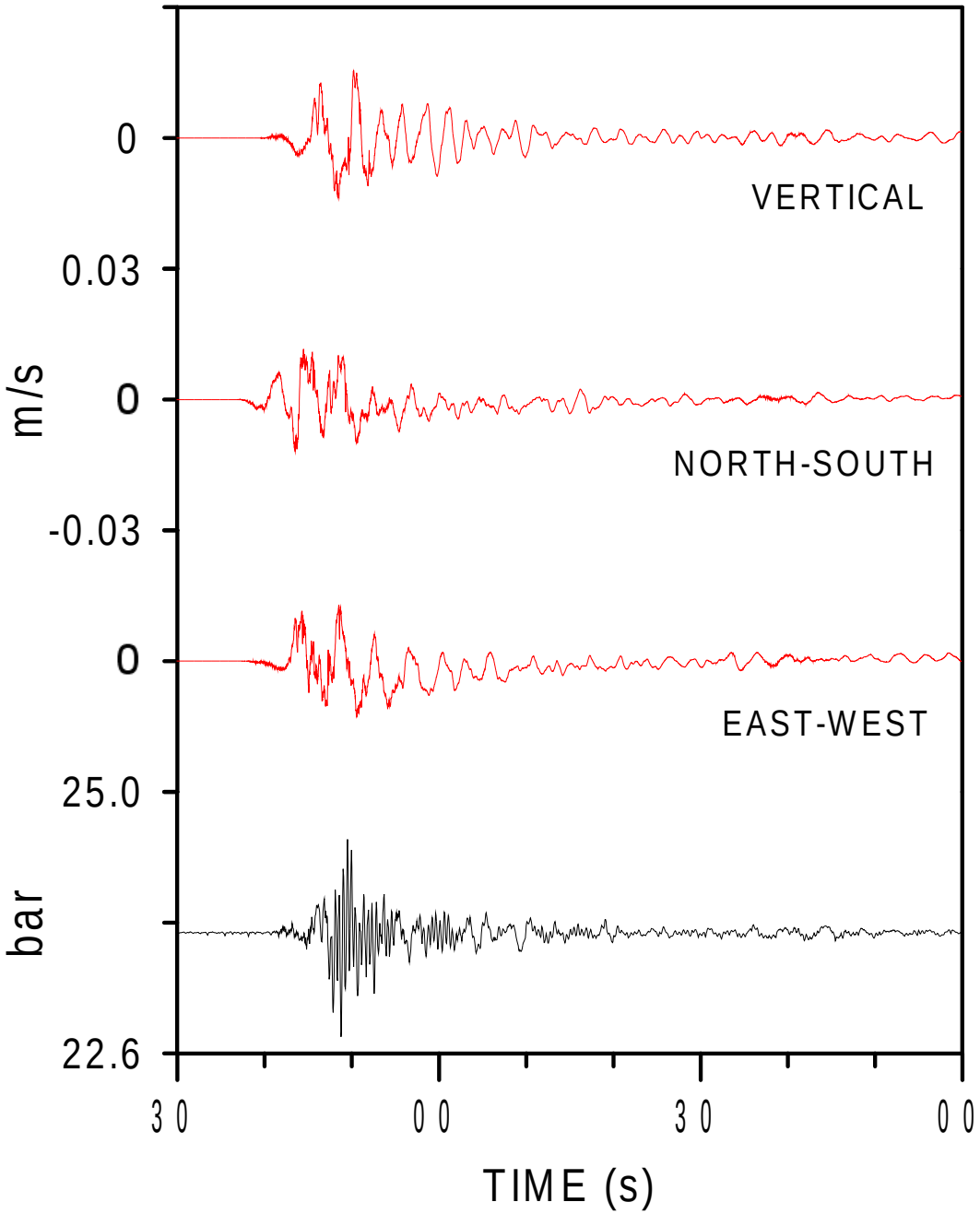
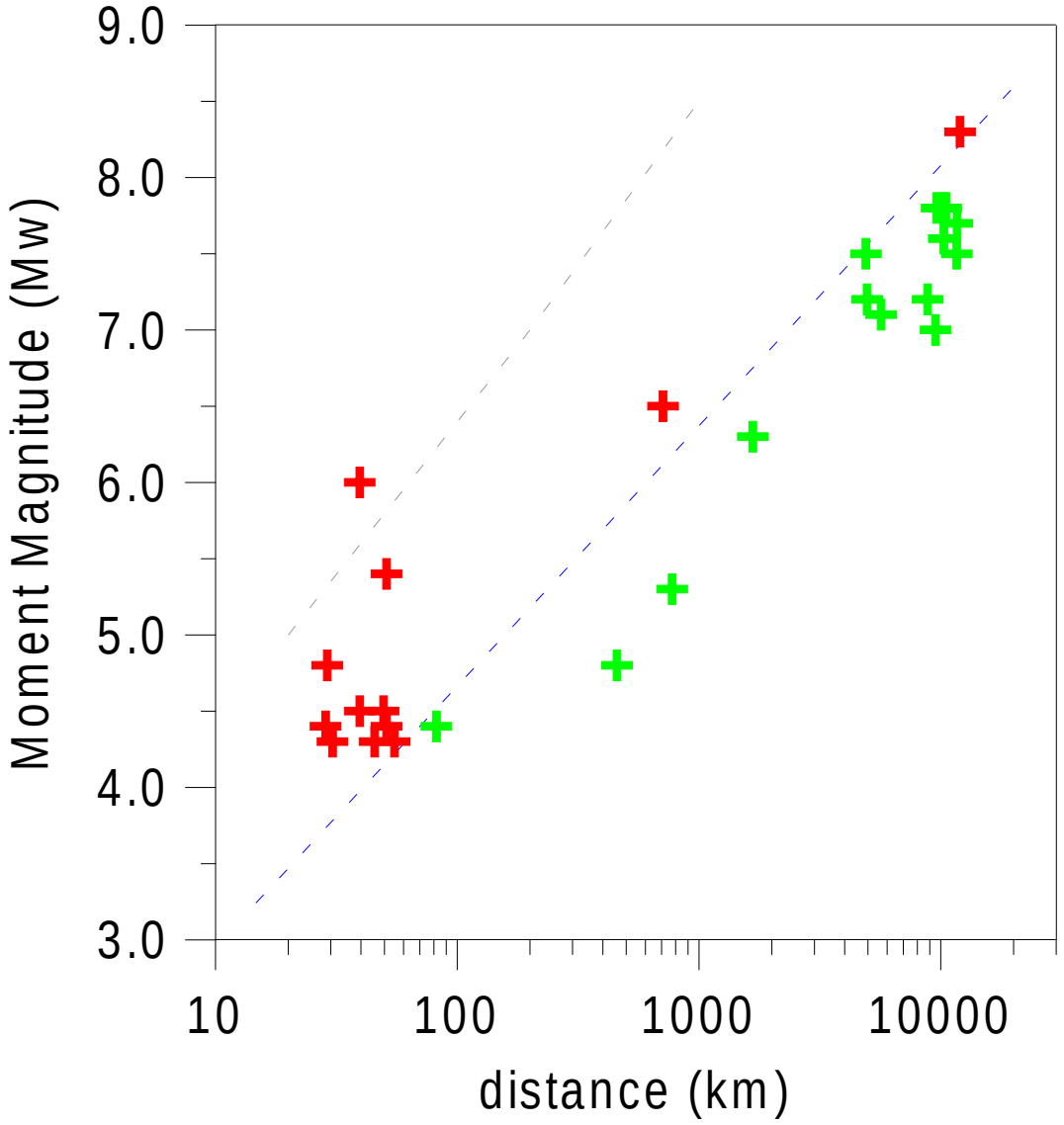
We performed continuous recordings (May 2015 – January 2017) of hydraulic pressure and electrical conductivity of groundwater in the 190 m-long horizontal S13 borehole drilled next to the deep underground laboratories of Gran Sasso (*LNGS-INFN*), located in the core of the Gran Sasso carbonate aquifer (central Italy) at a distance of about 39 km south-eastward from the 24 August 2016 Amatrice earthquake (6.0 M_w) epicenter. Using a 3-channel, 24-bit ADC we achieved a sampling rate of groundwater physical properties up to 50 Hz for each channel. We focused on the analysis of data recorded before, during and after the Amatrice earthquake, describing and discussing in detail the evidence for significant hydraulic pressure and electrical conductivity anomalies recorded before the main shock. We identified unambiguous signals in the hydraulic pressure data starting on 19 August, i.e. five days before the 24 August mainshock. A more careful analysis allowed us to detect the inception of a weak change up to 40 days before the Amatrice earthquake and a significant variation in the electrical conductivity data about 60 days before. The data revealed highly dynamic aquifer behaviour associated with the uprising of geogas probably related to the preparation stage of the Amatrice earthquake.



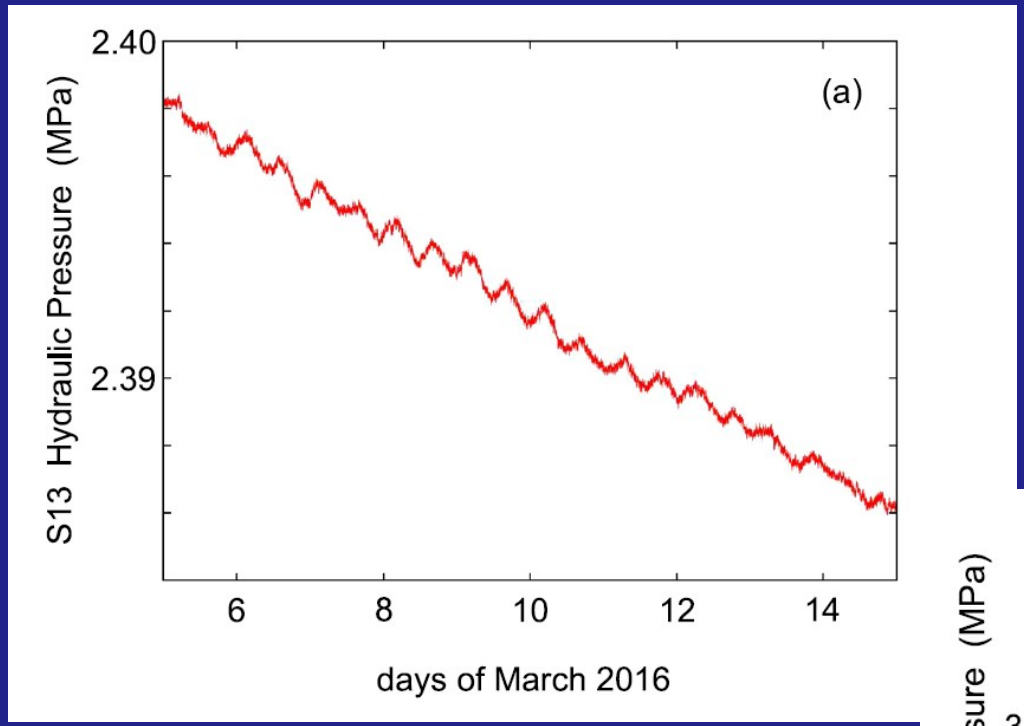
Chile earthquake of Sept 16th, 2015 (offshore Coquimbo – Mw 8.3). The red traces are the vertical, north-south and east-west components of Trillium 240 s sensor (GIGS) and the black trace is the water pressure signal (the velocity scales for red traces have the same values). Time scale starts from 23:45 (UT).

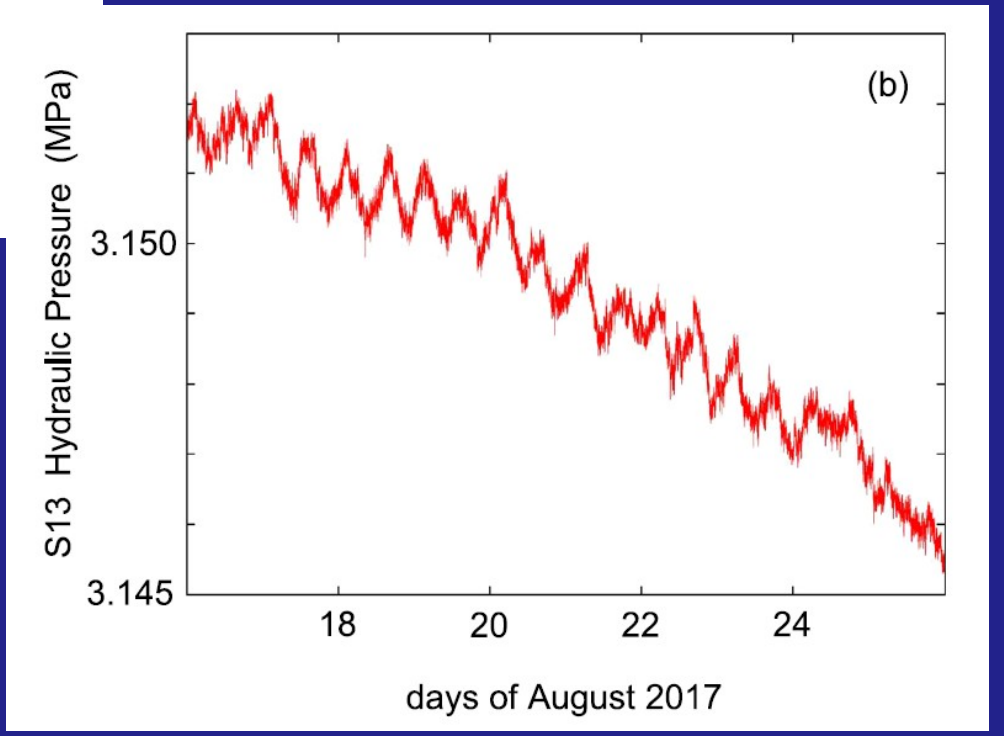


Amatrice-Accumuli earthquake (Central Italy) of August 24th, 2016 (Mw 6.0). The red traces are the vertical, north-south and east-west components of Trillium 240 s sensor (GIGS) and the black trace is the water pressure signal (the velocity scales for red traces have the same values). Time scale starts from 01:36:30 (UT)



Mw vs distance (km) of the 12 earthquakes collected by pressure sensor at S13 borehole from may 2015 to september 2016; the blue dashed line is an estimation of the detection level while the gray dashed line is the detection level from fig. 2 of Manga and Wang (2015). The green crosses represent earthquakes not observed in hydraulic pressure data.





Tidal signal in the hydraulic pressure data of S13 borehole. (a) data from 5 to 15 March 2016, about 6 months before the Amatrice earthquake; (b) data from 16 to 26 August 2017, about one year after the Amatrice earthquake.

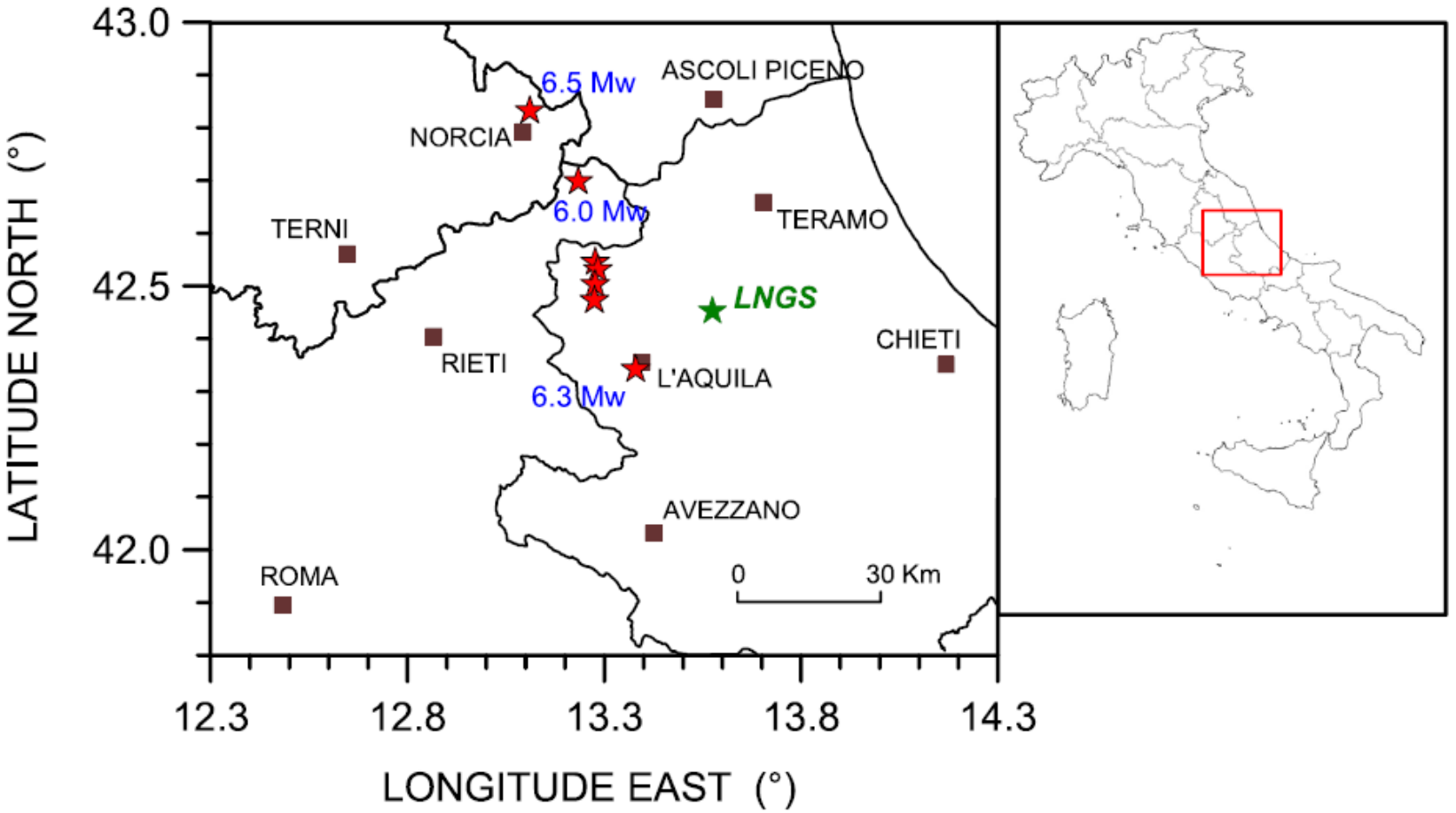
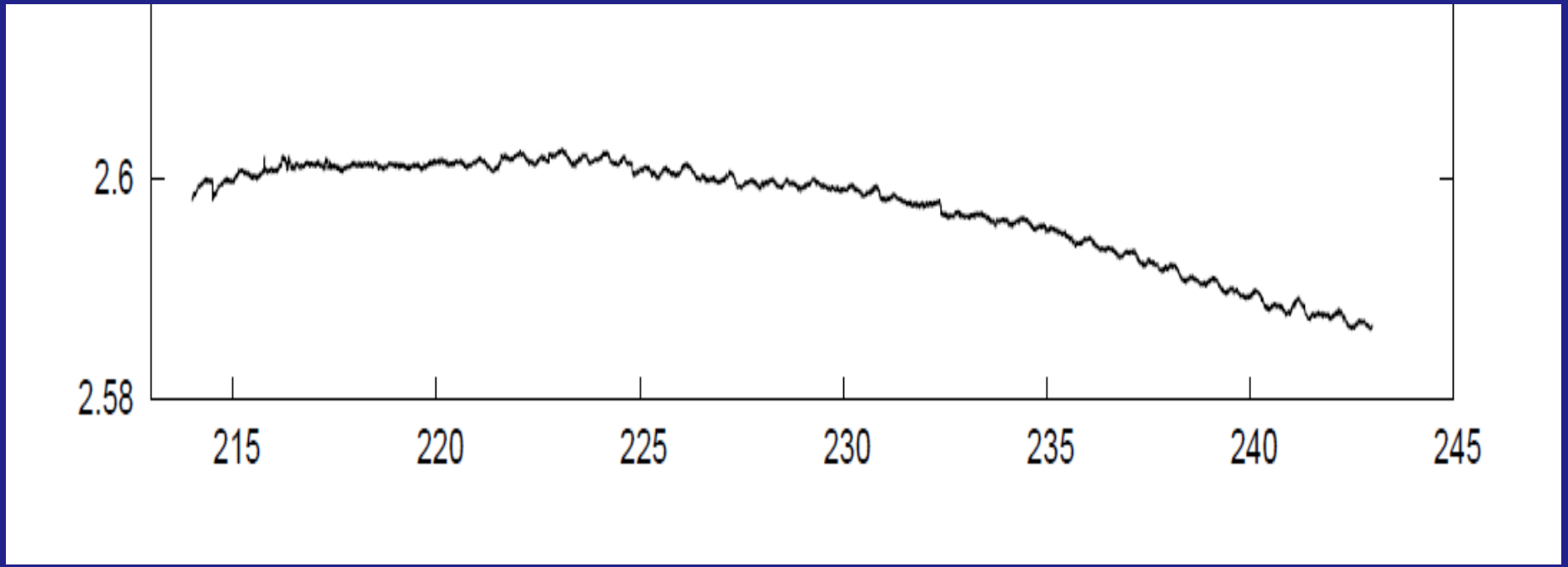
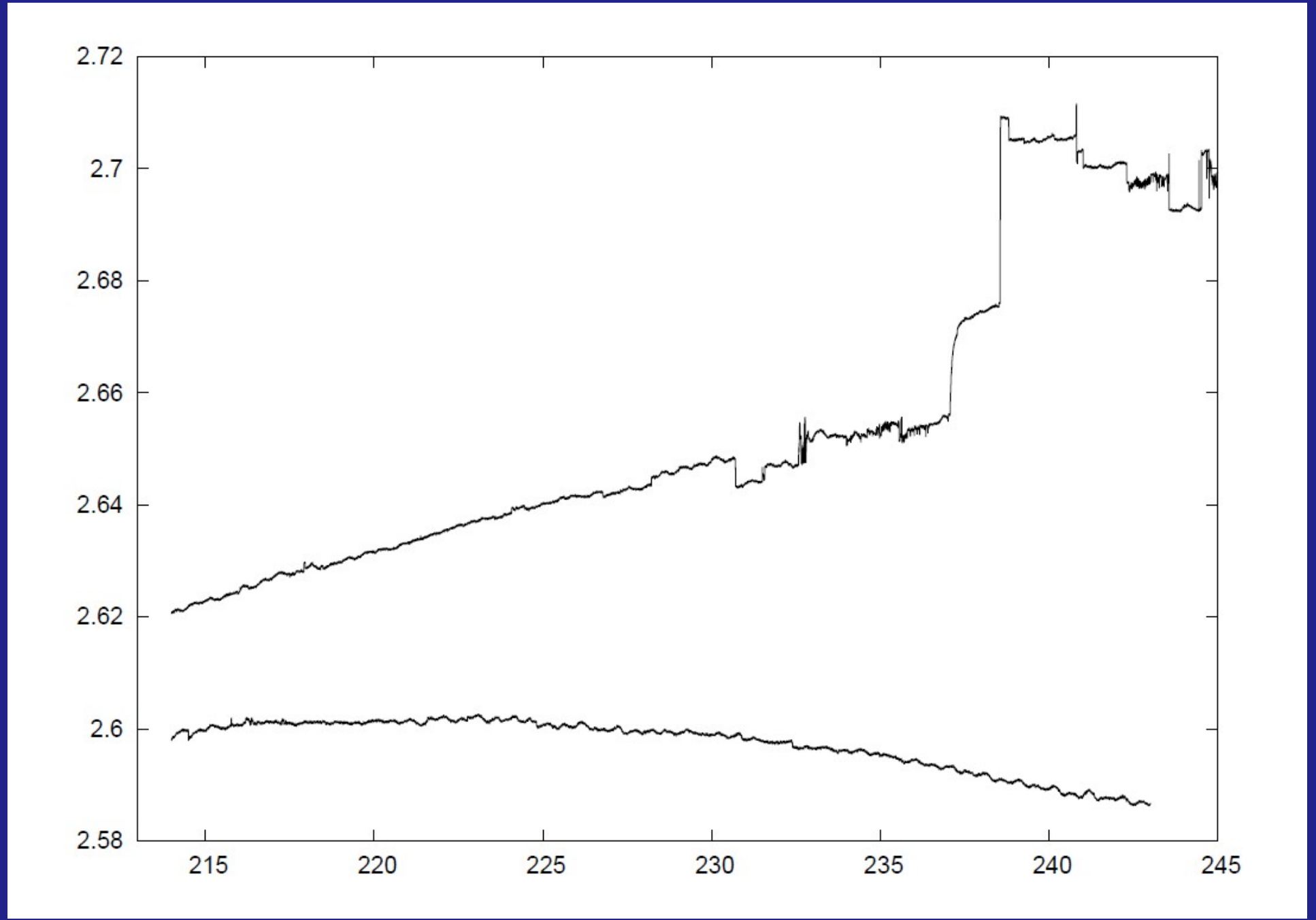


Figure 1. Main earthquakes location map, from Iside data-base[53], of August 2016–January 2017 period (http://cnt.rm.ingv.it/iside); brown squares represent principal towns in the area, black lines for regional boundaries, green star for *LNGS* (Laboratori Nazionali del Gran Sasso) of *INFN* (Istituto Nazionale di Fisica Nucleare) close to the S13 horizontal borehole (distance about 200 m); from northern: red stars for 6.5 M_w of 30 October 2016, 6.0 M_w of 24 August 2016, 5.1 M_w of 18 January 2017 (09:25:40 UT), 5.5 M_w of 18 January 2017 (10:14:10 UT), 5.4 M_w of 18 January 2017 (10:25:24 UT) and 5.0 M_w of 18 January 2017 (13:33:37 UT). We also show the L'Aquila earthquake of 6 April 2009 (6.3 M_w – 01:32:40 UT).

237 = 24 Agosto

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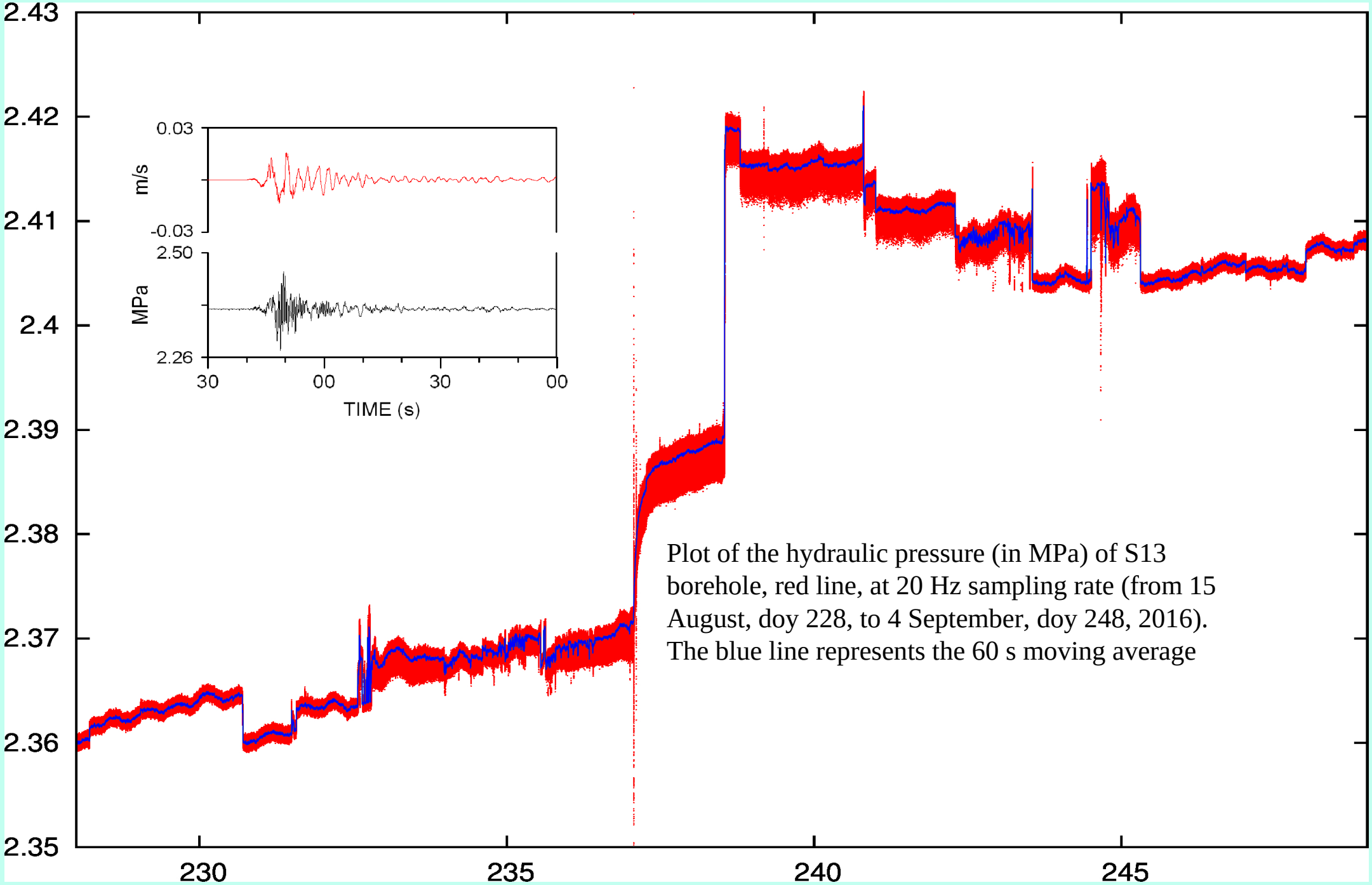
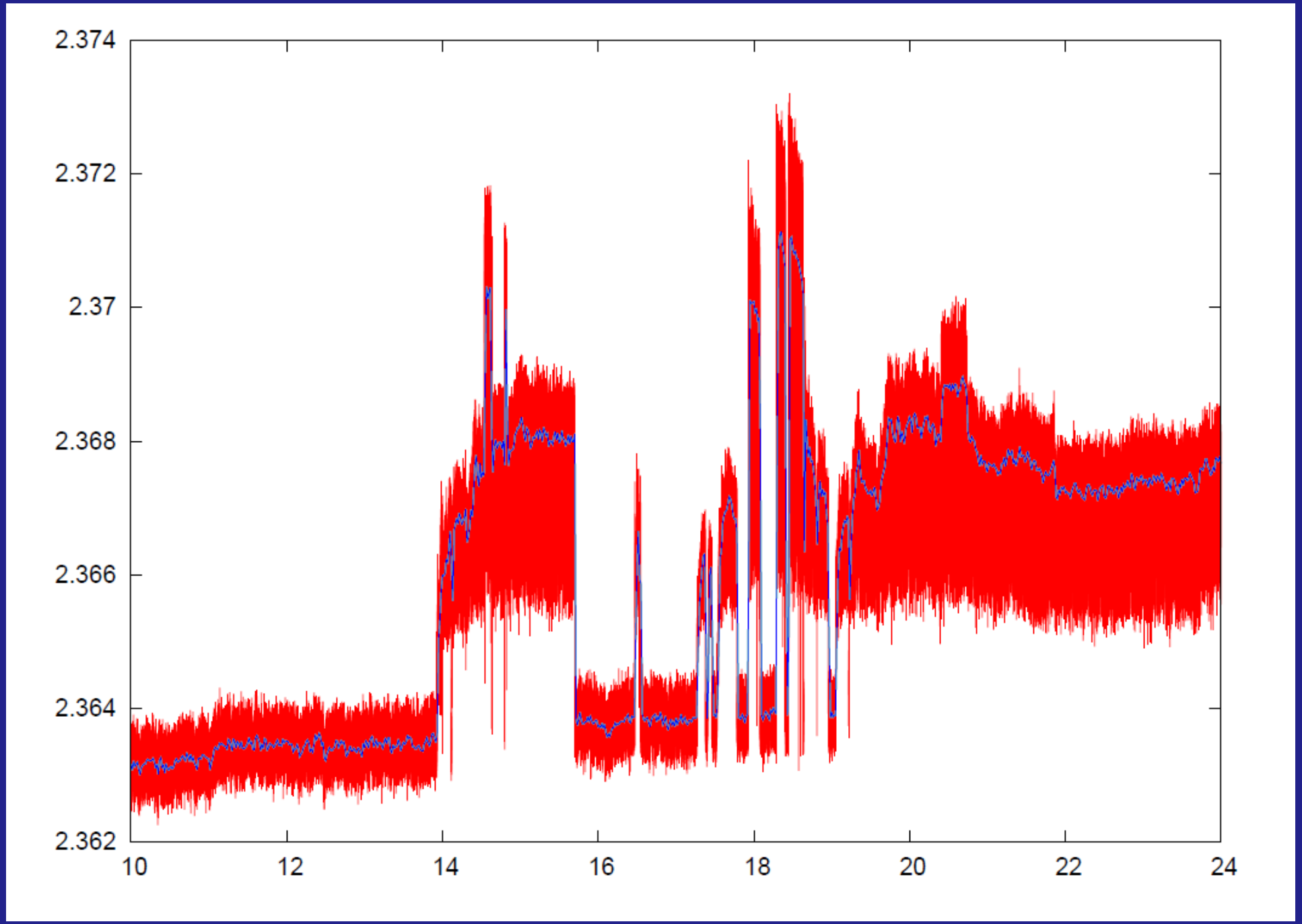
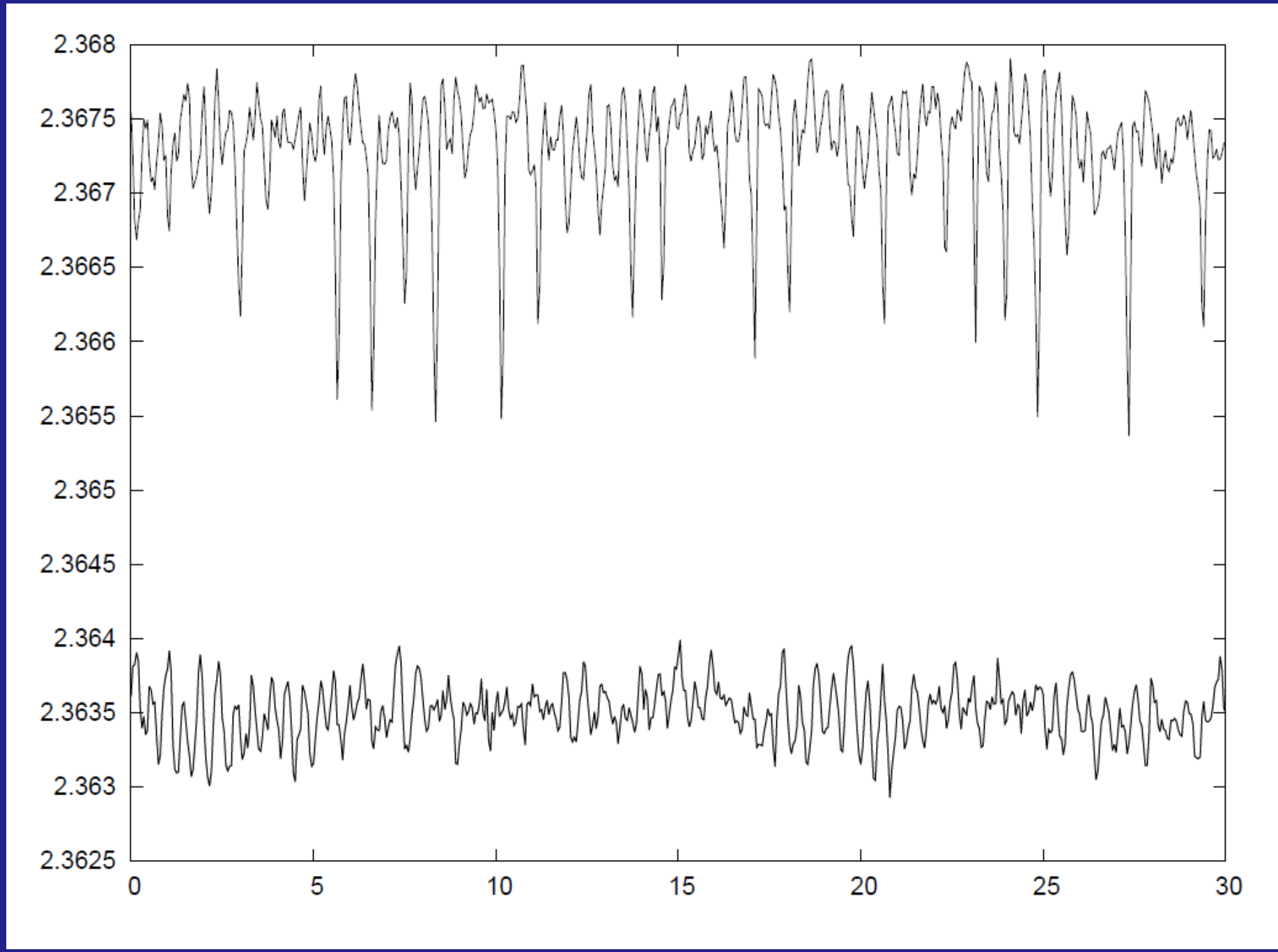
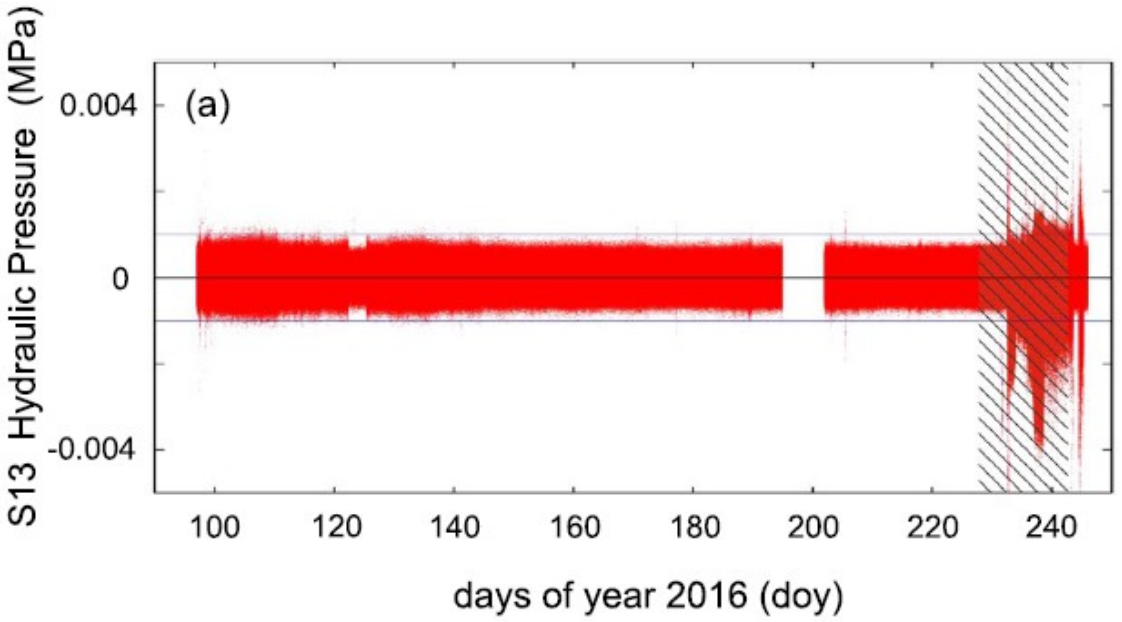
2.62
2.6
2.58
215
220
225
230
235
240
245

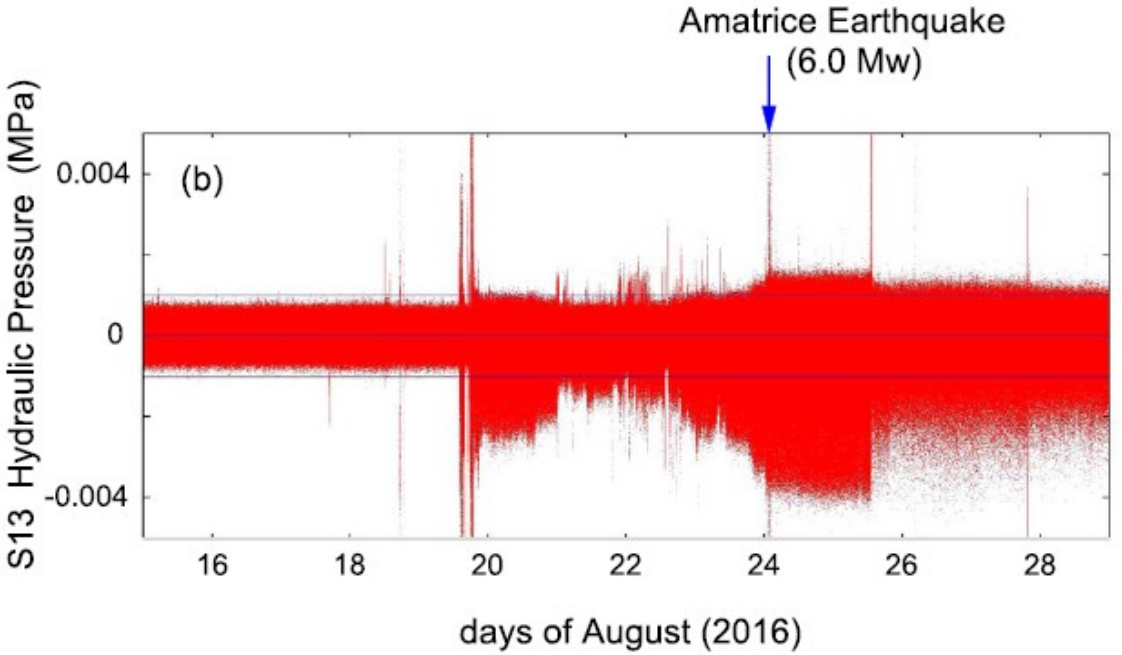


Plot of the hydraulic pressure (in MPa) of S13 borehole, red line, at 20 Hz sampling rate (from 15 August, doy 228, to 4 September, doy 248, 2016). The blue line represents the 60 s moving average


2.374
2.372
2.37
2.368
2.366
2.364
2.362
10
12
14
16
18
20
22
24

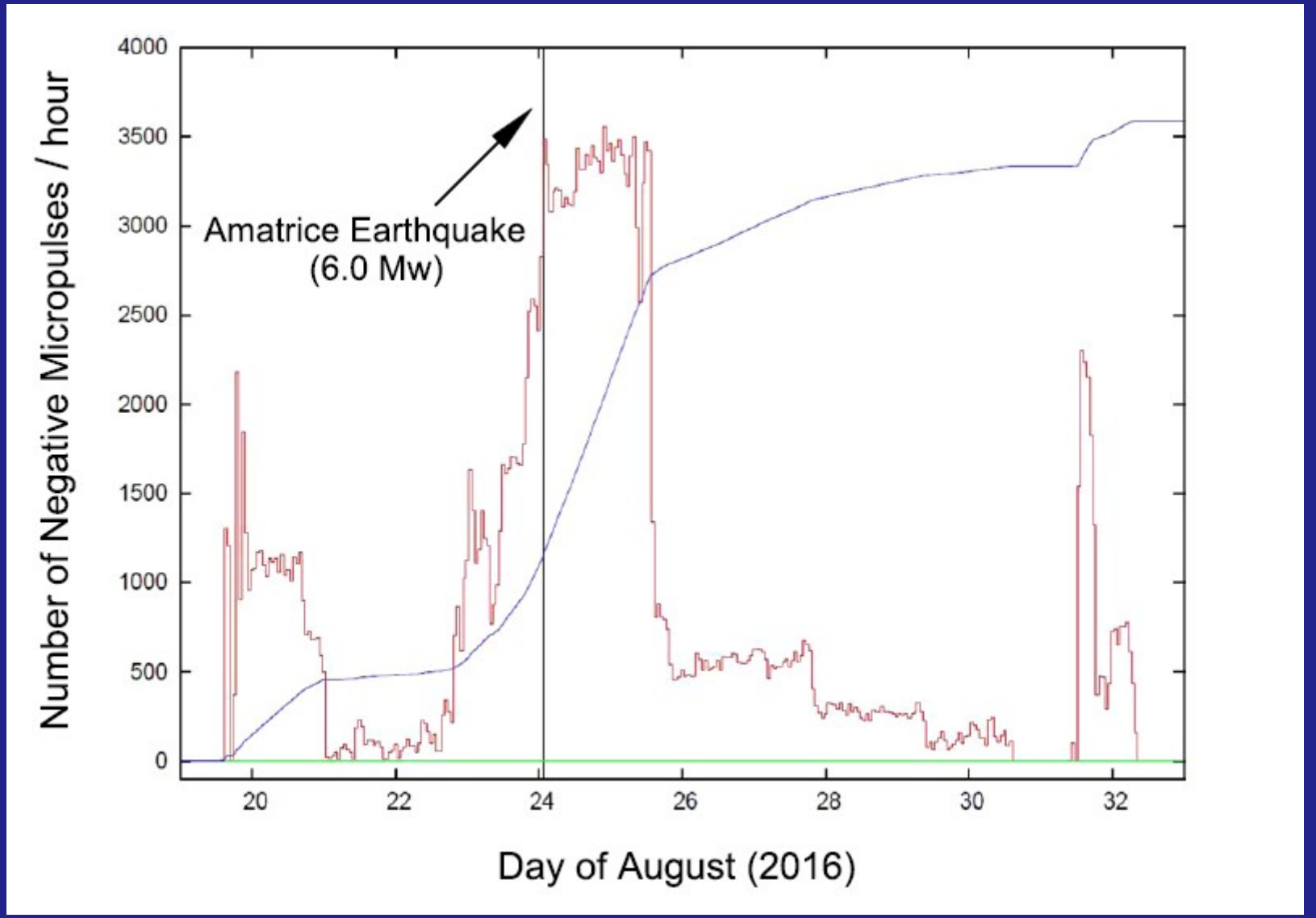

2.368
2.3675
2.367
2.3665
2.366
2.3655
2.365
2.3645
2.364
2.3635
2.363
2.3625
0
5
10
15
20
25
30



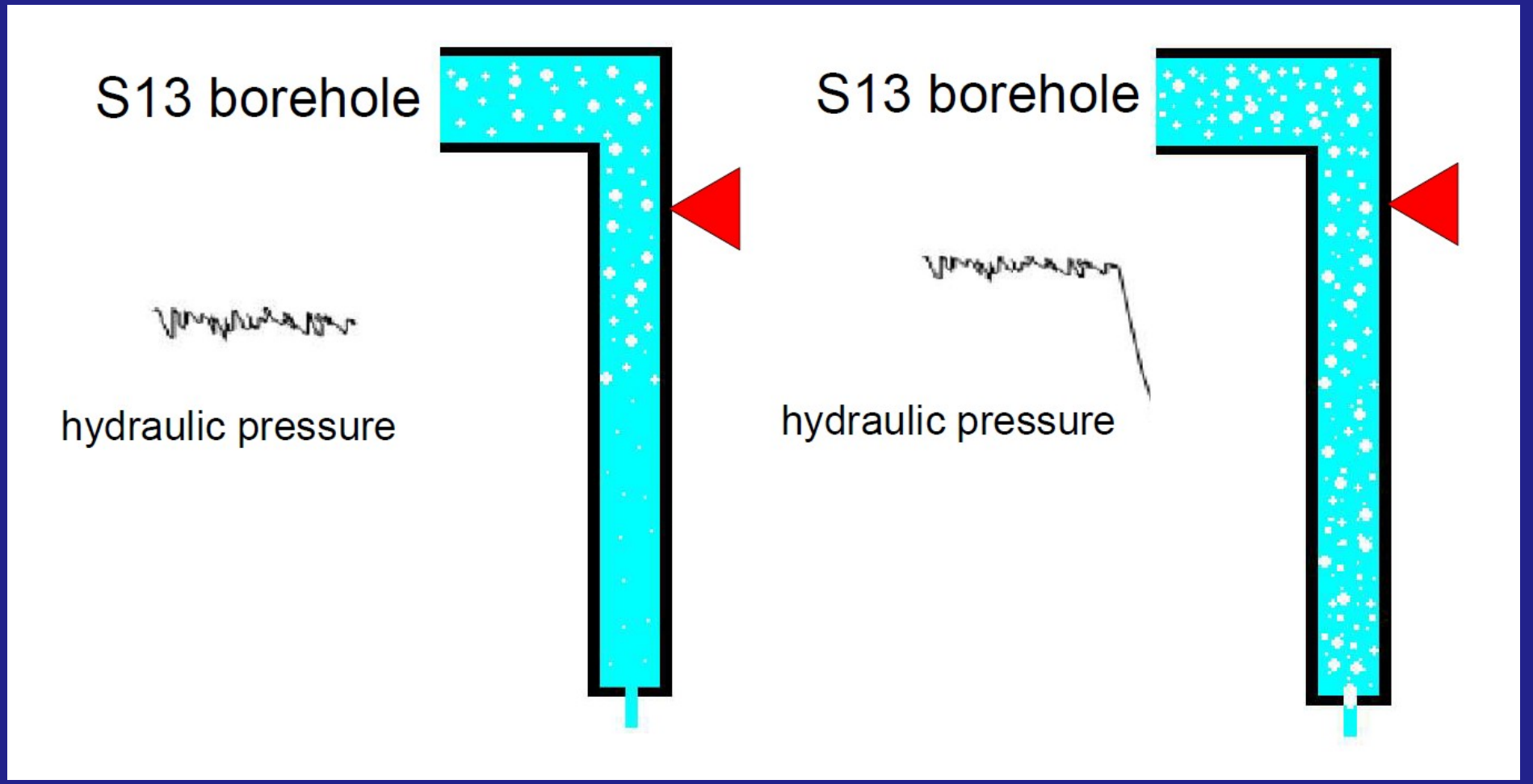


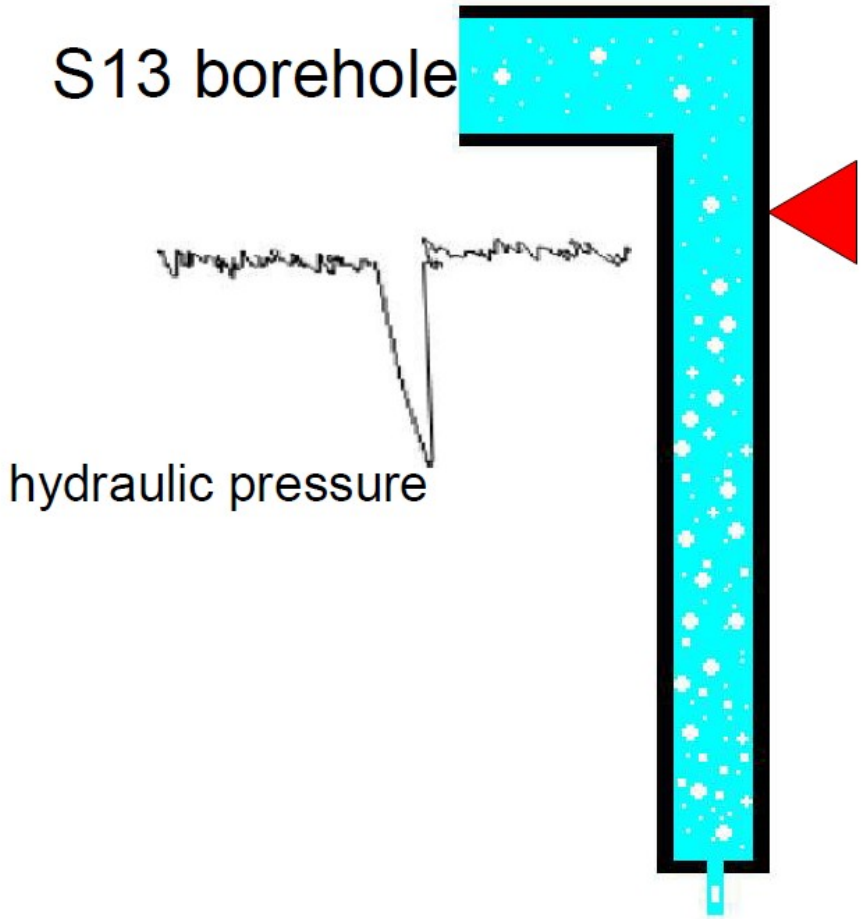
(a) Detrended of hydraulic pressure of S13 borehole from April to August 2016.

(b) Detrended of hydraulic pressure of S13 borehole from 15 (doy 228) to 29 August 2016 (doy 242), shaded rectangle in (a). The blue arrow in the top of (b) represents the Amatrice earthquake occurrence. In the period from May 2015 to March 2016 we did not observe any variations.



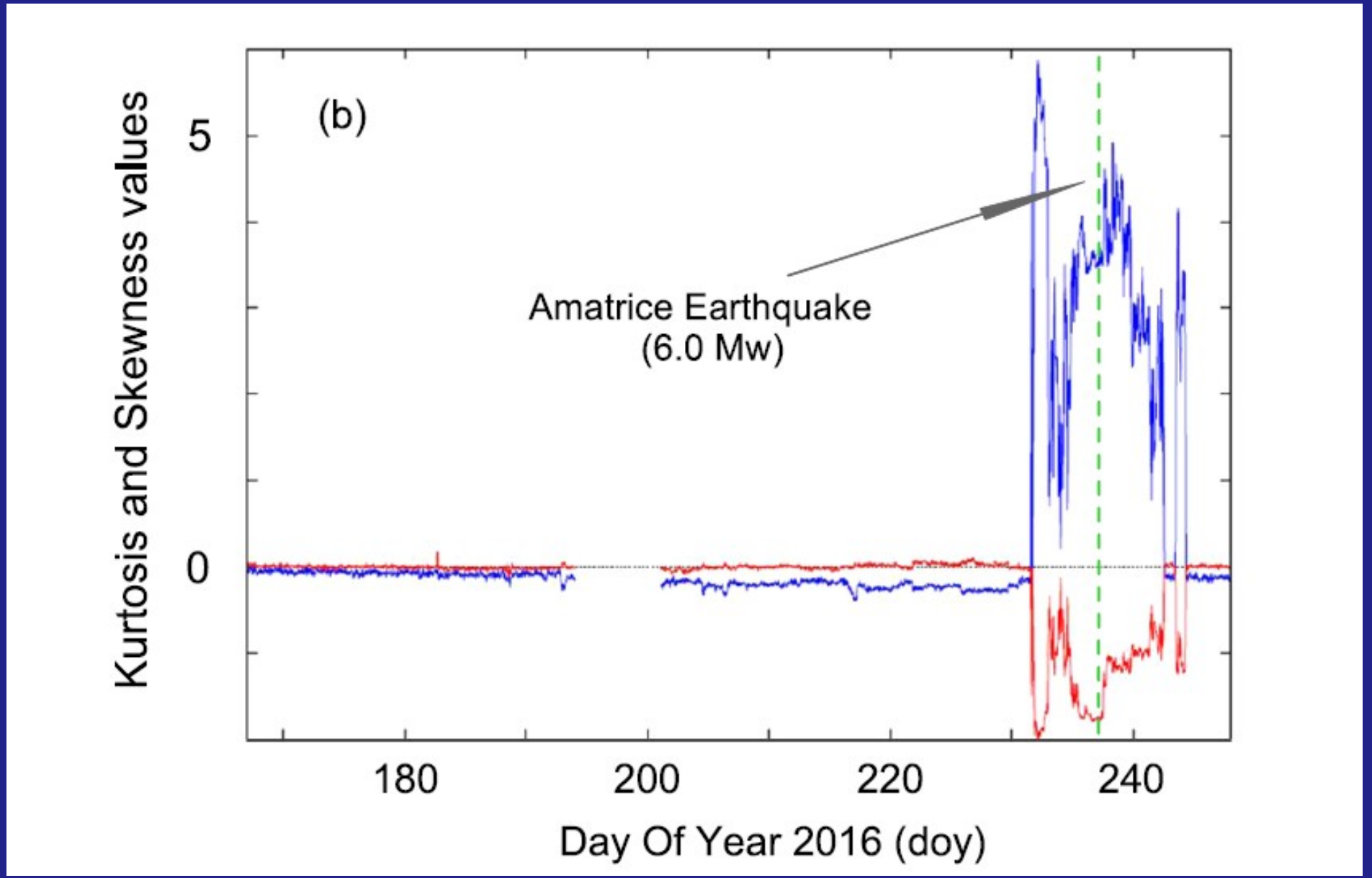
Number of negative micropulses (red line) each hour from 19 August (doy 232) to 2 September 2016 (doy 246), while the blue line shows the integral trend in arbitrary scale, black vertical line represents the Amatrice earthquake occurrence and green horizontal line is the zero level. In the period from May 2015 to July 2016 we did not observe any negative micropulses.


S13 borehole
hydraulic pressure
S13 borehole
hydraulic pressure

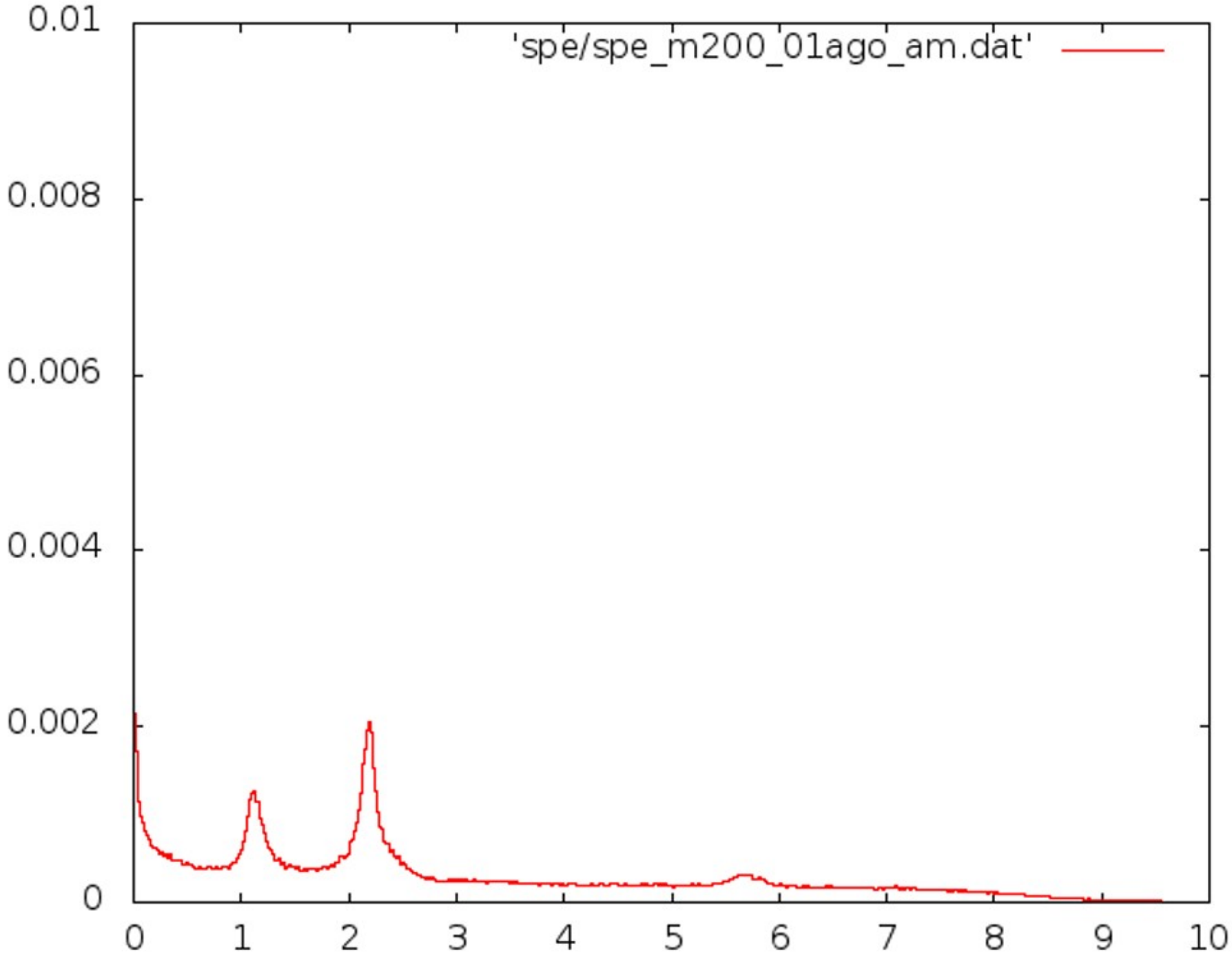

S13 borehole
hydraulic pressure

Statistical Analsis of time series of data:

- *average*
- *standard deviation*
- *skewness*
- *Kurtosis*



skewness $m_3/(m_2)^{3/2}$ kurtosis $(m_4/m_2^2 - 3)$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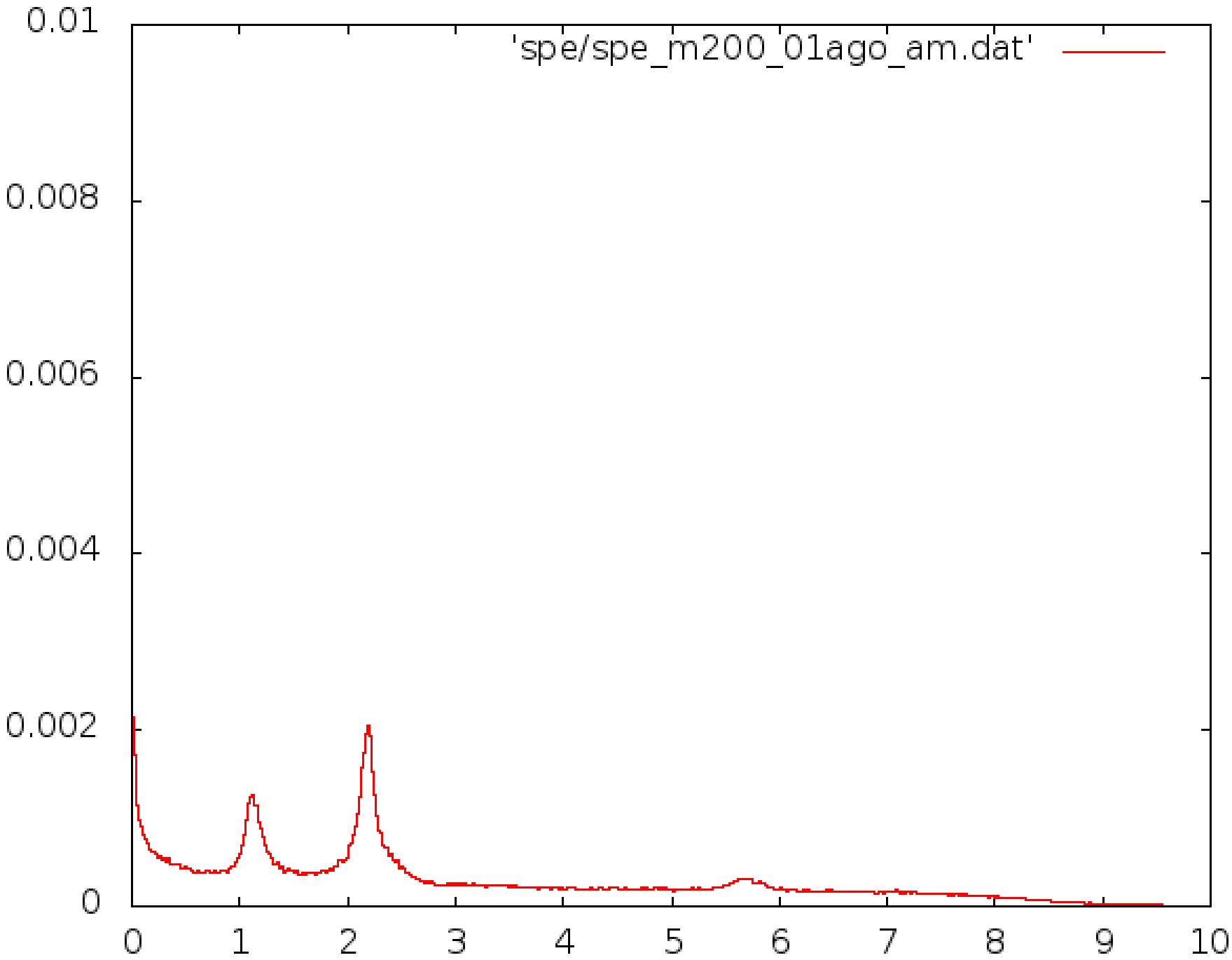
0.008
0.006
0.004
0.002
0
0
1
2
3
4
5
6
7
8
9
10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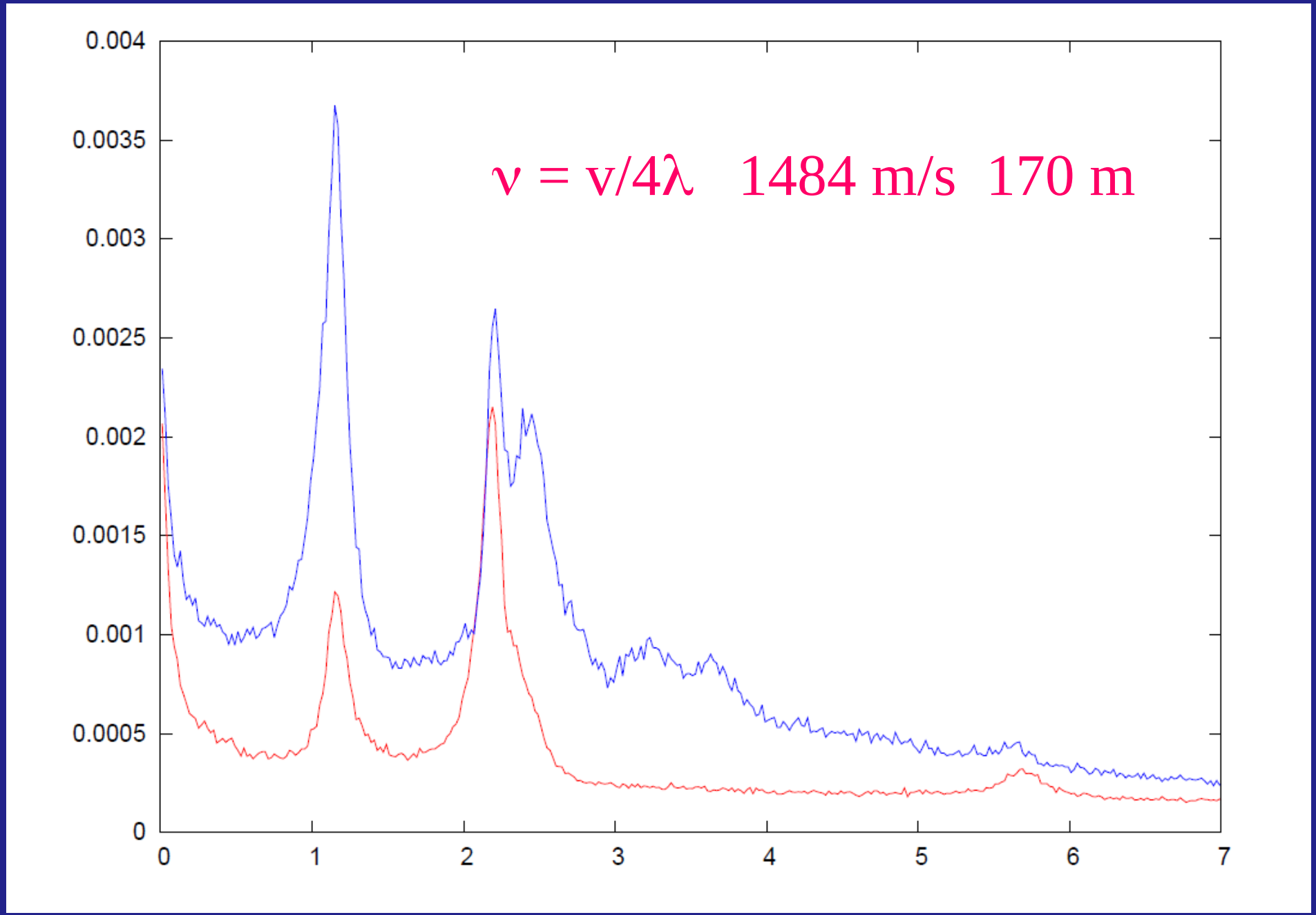
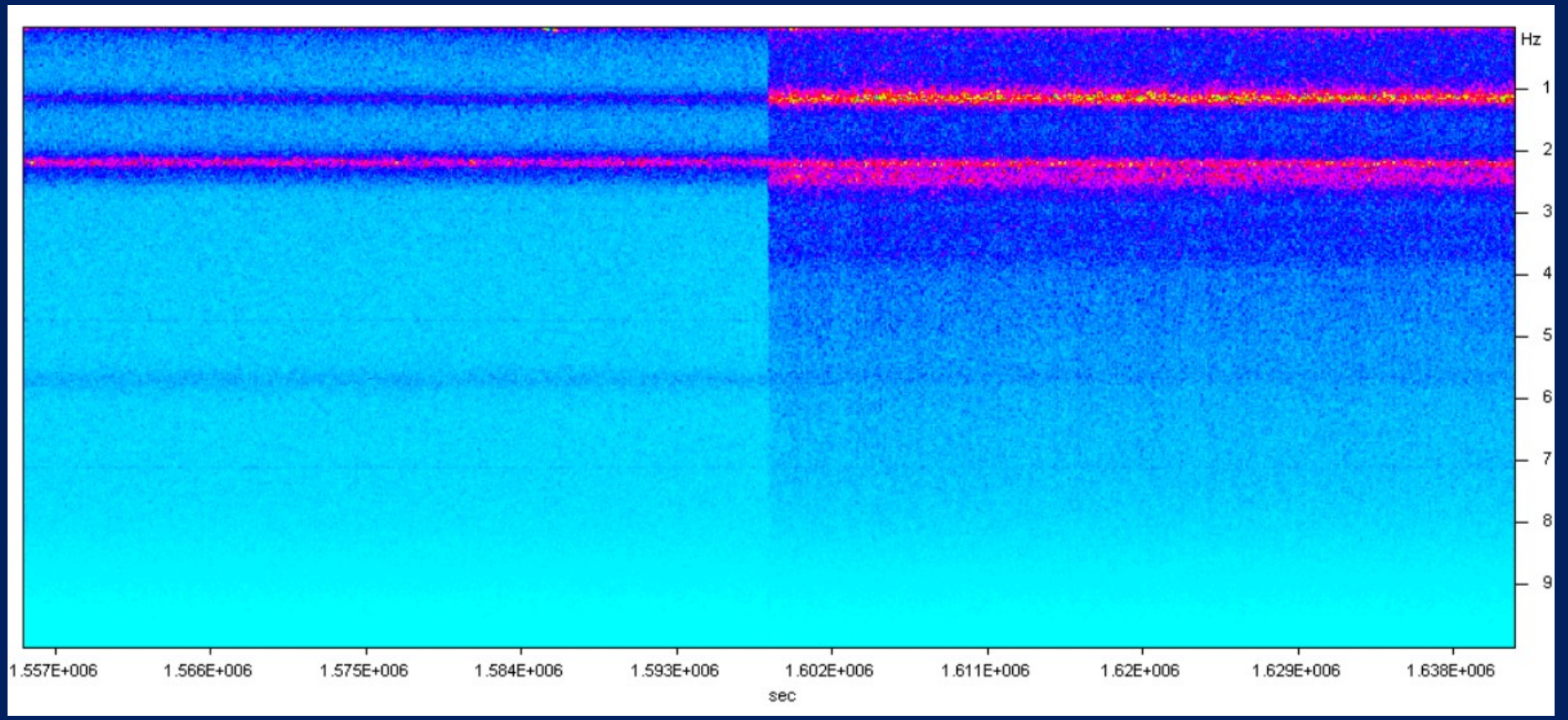
0.008
0.006
0.004
0.002
0
0
1
2
3
4
5
6
7
8
9
10

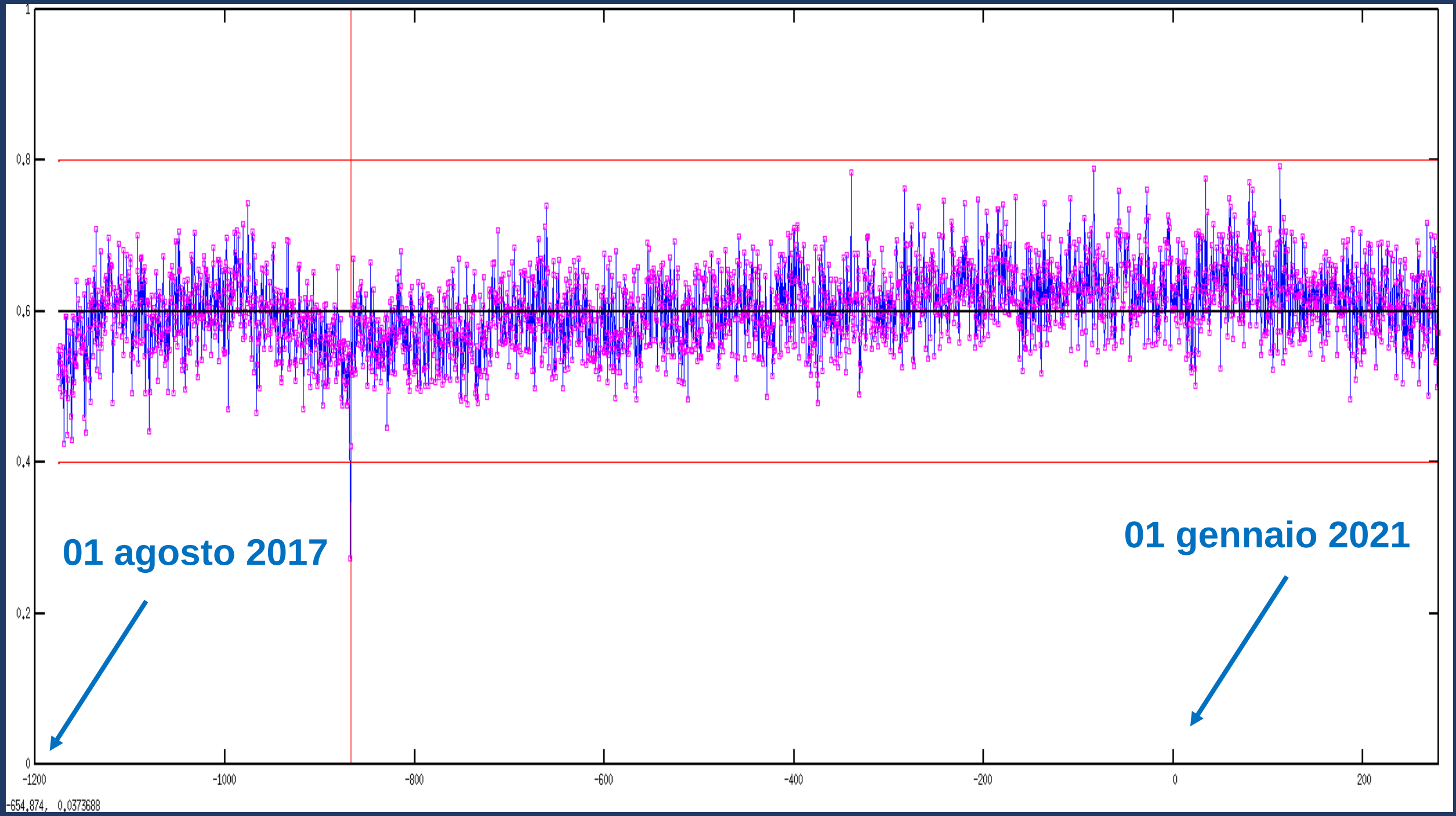

0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
0
1
2
3
4
5
6
7
ν = v/4λ 1484 m/s 170 m

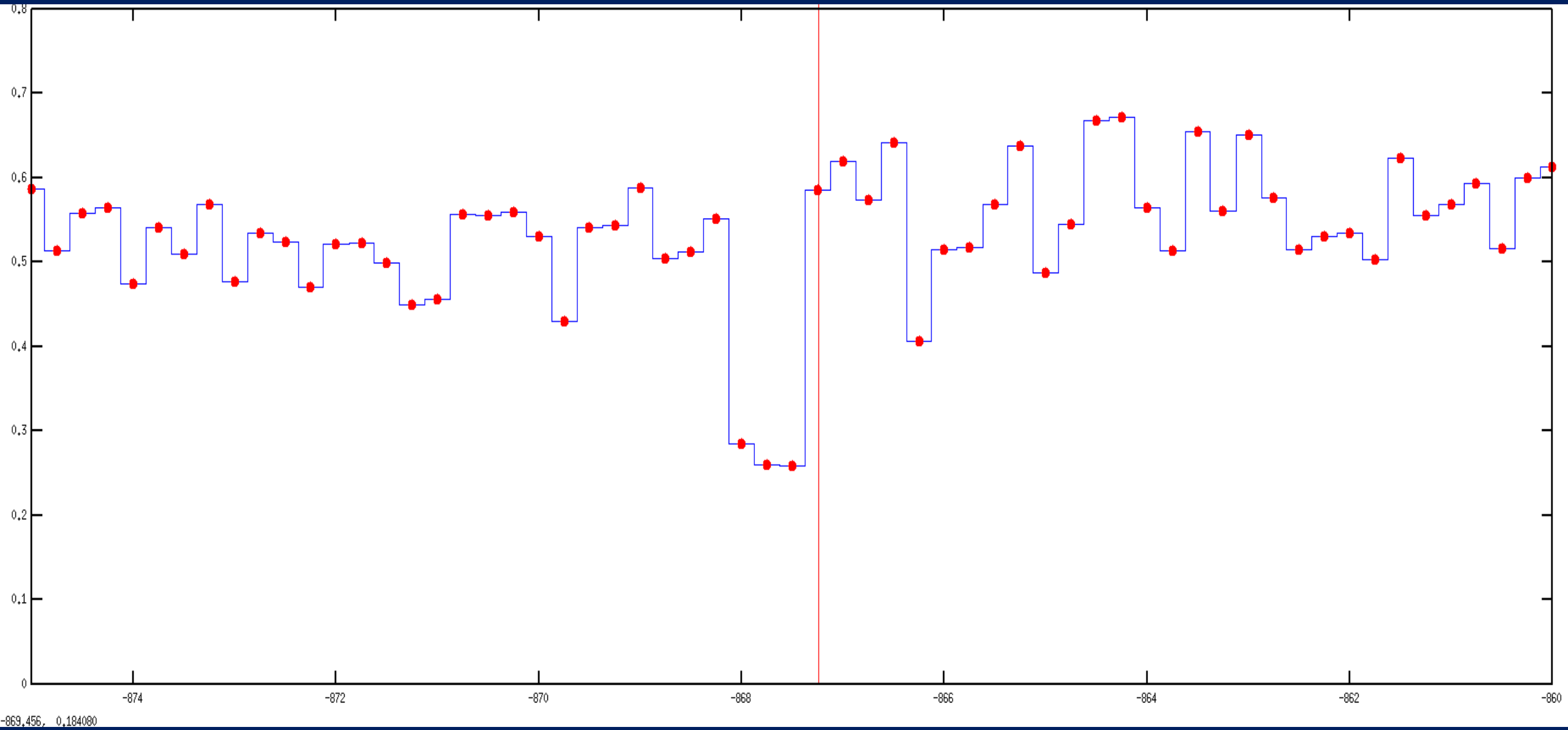

Hz
1
2
3
4
5
6
7
8
9
1.557E+006
1.566E+006
1.575E+006
1.584E+006
1.593E+006
1.602E+006
1.611E+006
1.62E+006
1.629E+006
1.638E+006
sec

Sopralluogo nella camera dei drenaggi nella mattinata del 13 ottobre 2016
particolare della colorazione dell’acqua prelevata dal sondaggio S13

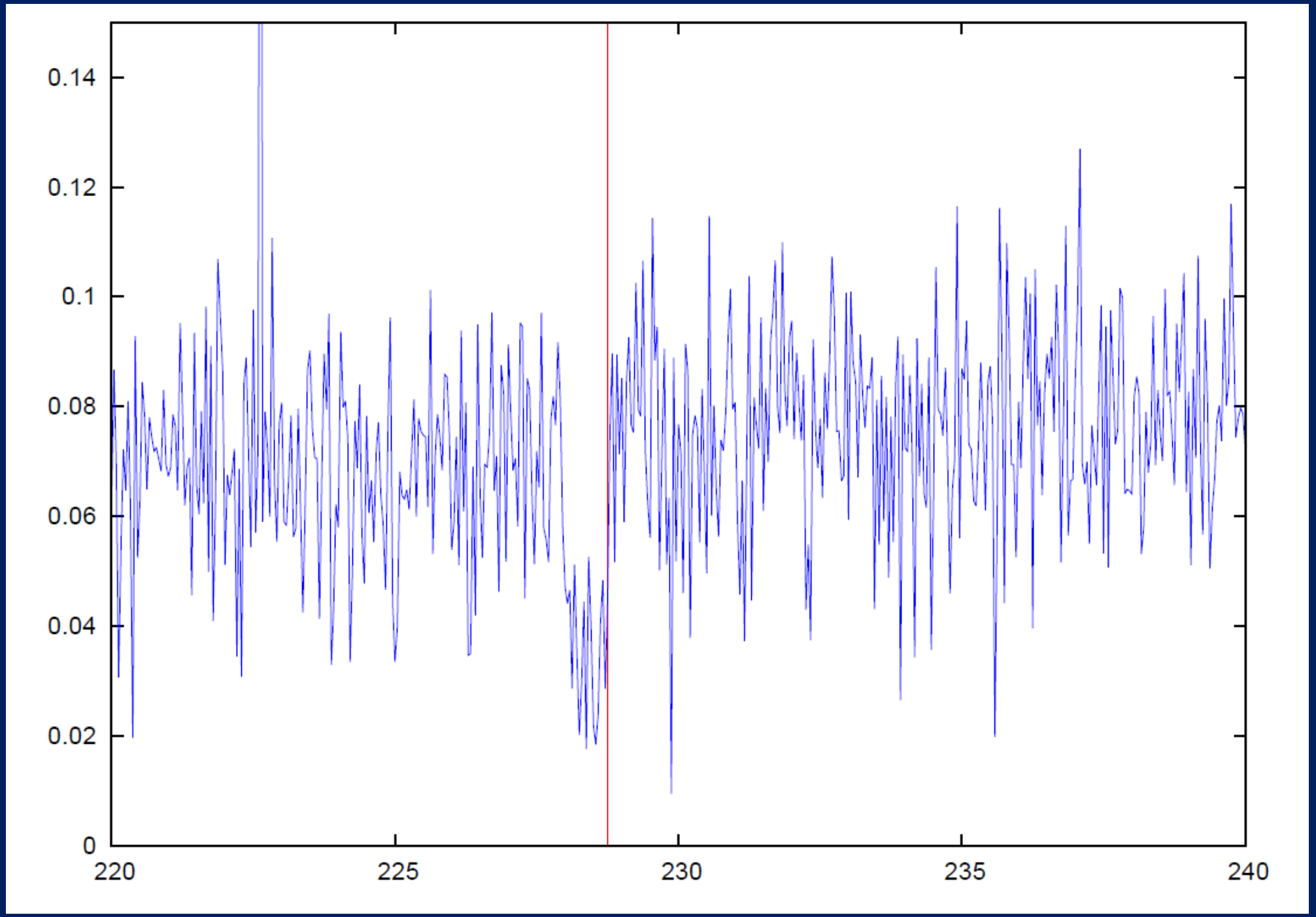
acqua del sondaggio S13
3 novembre 2016

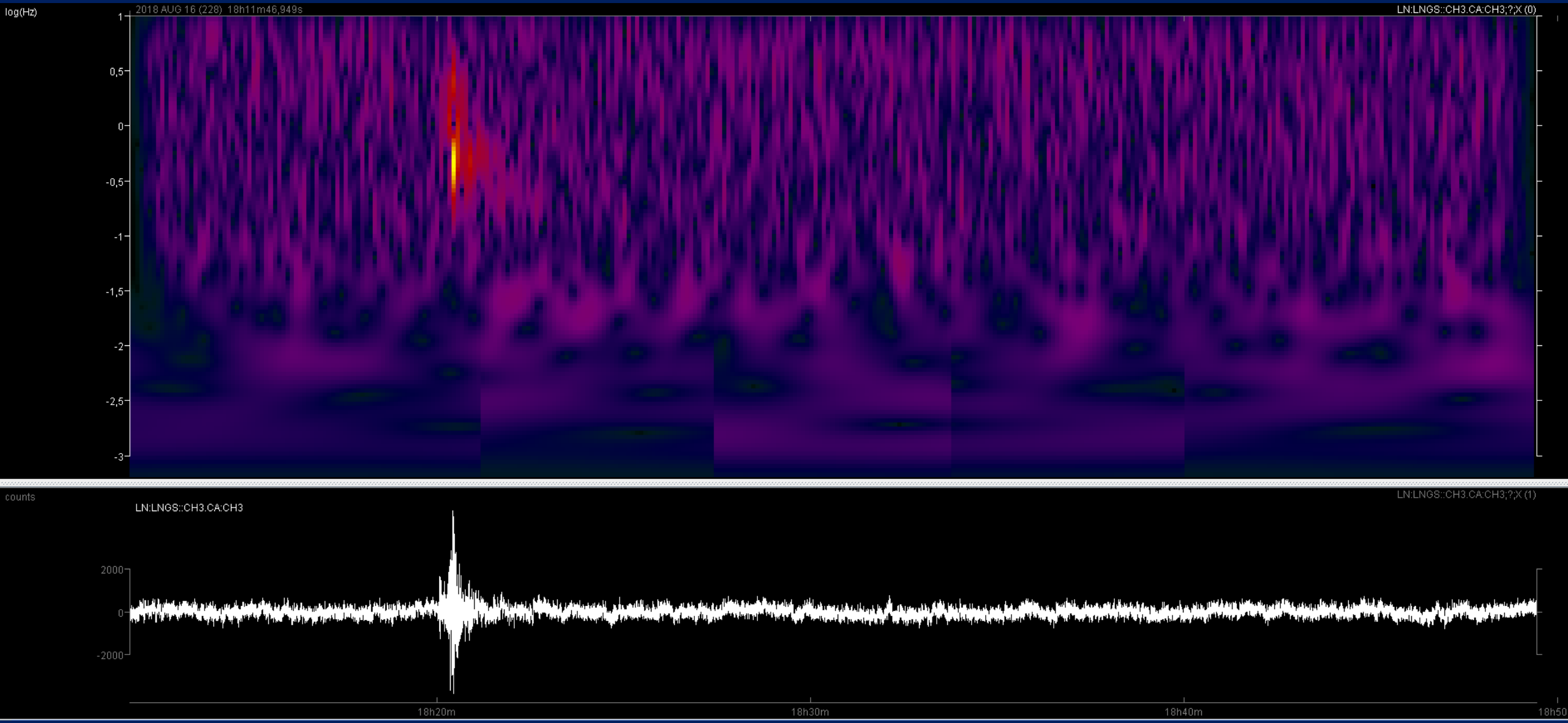

uk
PINT
usa
1 1/2
1
1/2
1 1/2
1
1/2
500
400
300
200
100


1
0.8
0.6
0.4
0.2
0
-1200
-1000
-800
-600
-400
-200
0
200
01 agosto 2017
01 gennaio 2021
-654.874, 0.0373688

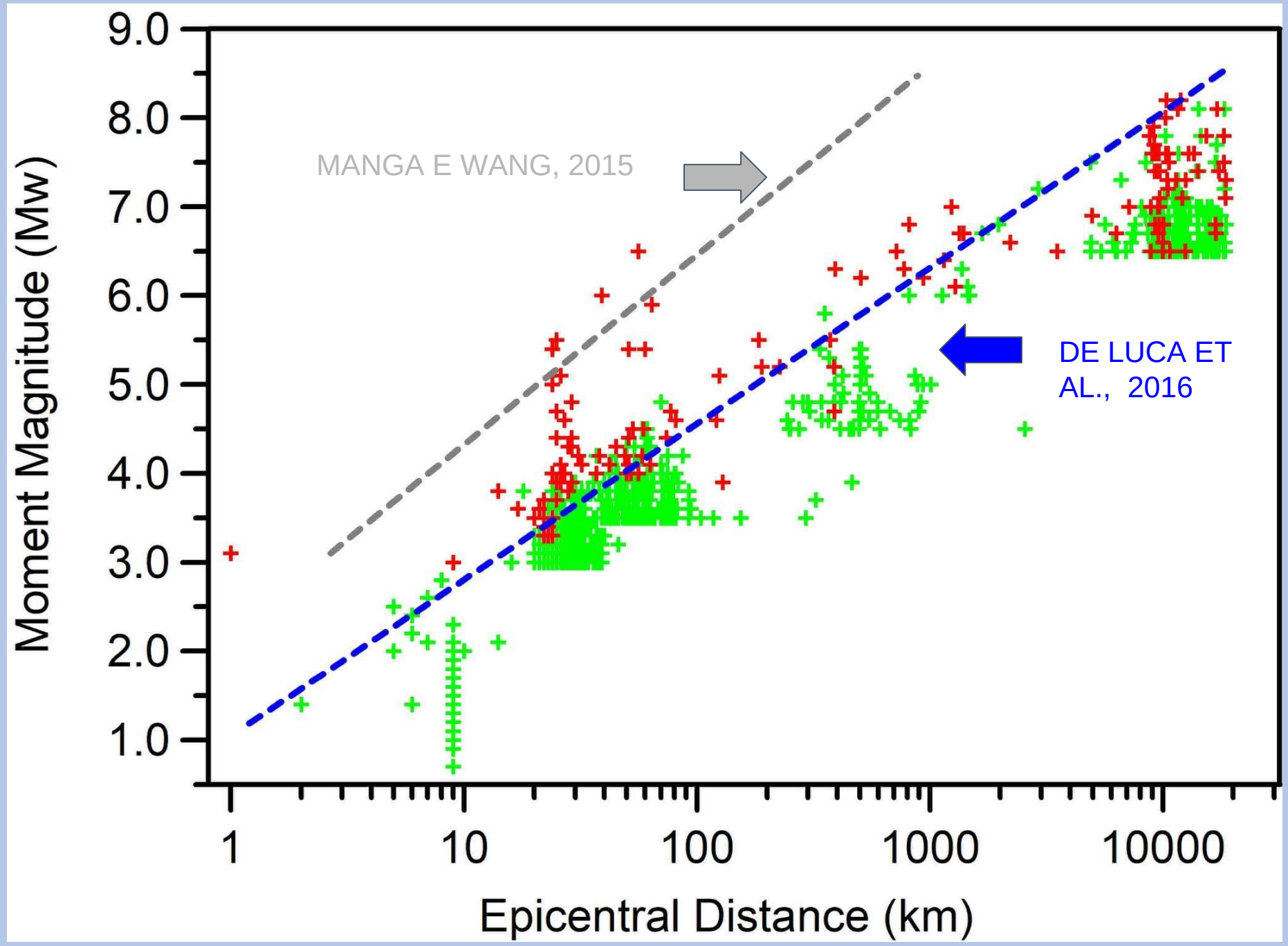


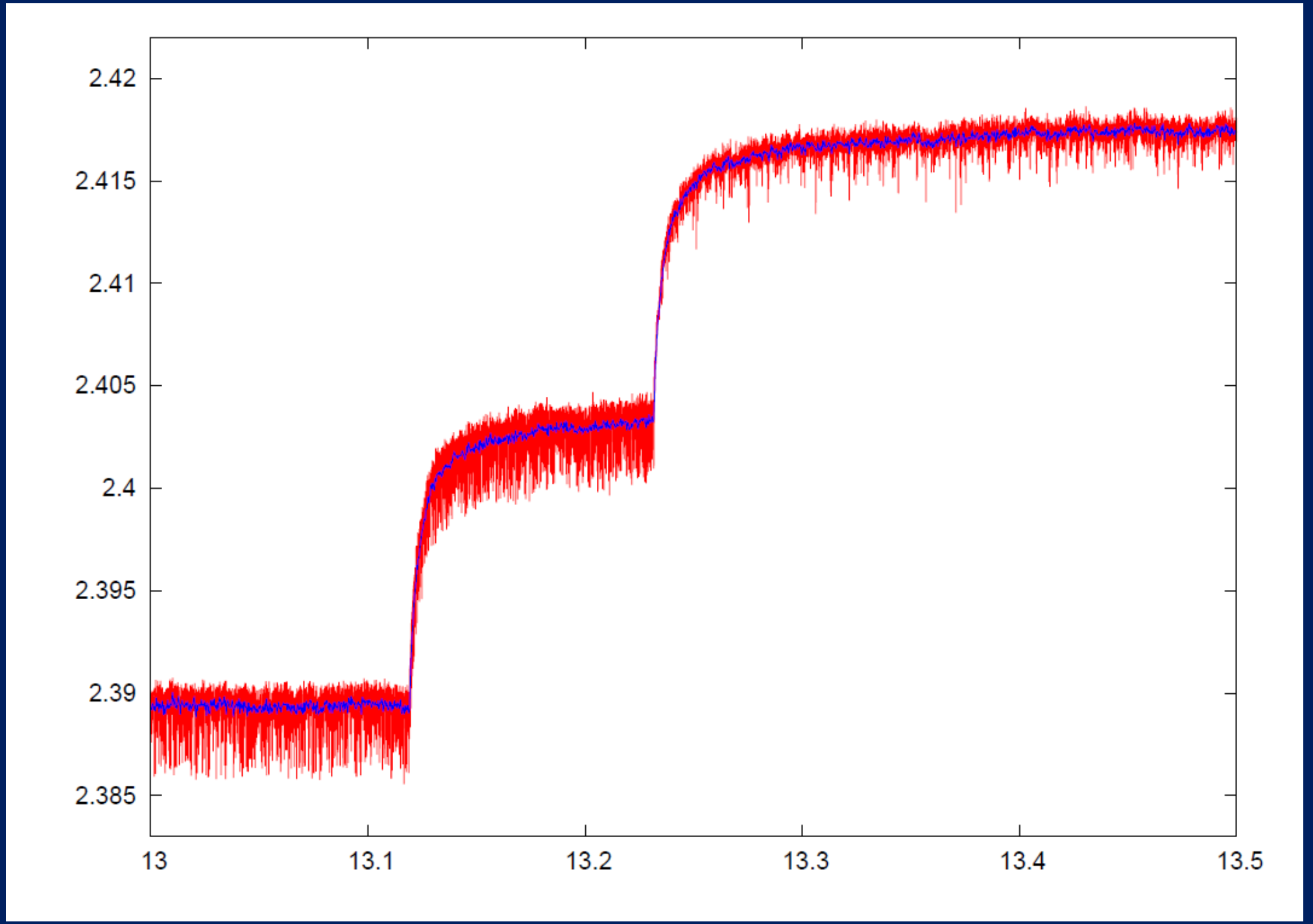
2018-08-16 20:19:04	Mw 5.1	4 km SE Montecilfone (CB)	20	41.87	14.87


0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
220
225
230
235
240


log(Hz)
2018 AUG 16 (228) 18h11m46,949s
LN:LNGS::CH3.CA:CH3;?;X (0)
1
0,5
0
-0,5
-1
-1,5
-2
-2,5
-3
counts
LN:LNGS::CH3.CA:CH3
LN:LNGS::CH3.CA:CH3;?;X (1)
2000
0
-2000
18h20m
18h30m
18h40m
18h50

0.3 – 1.0 Hz


9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
Moment Magnitude (Mw)
1
10
100
1000
10000
Epicentral Distance (km)
MANGA E WANG, 2015
DE LUCA ET AL., 2016
EVENTI NON RILEVATI DALL' ACQUIFERO
EVENTI RILEVATI DALL' ACQUIFERO


2.42
2.415
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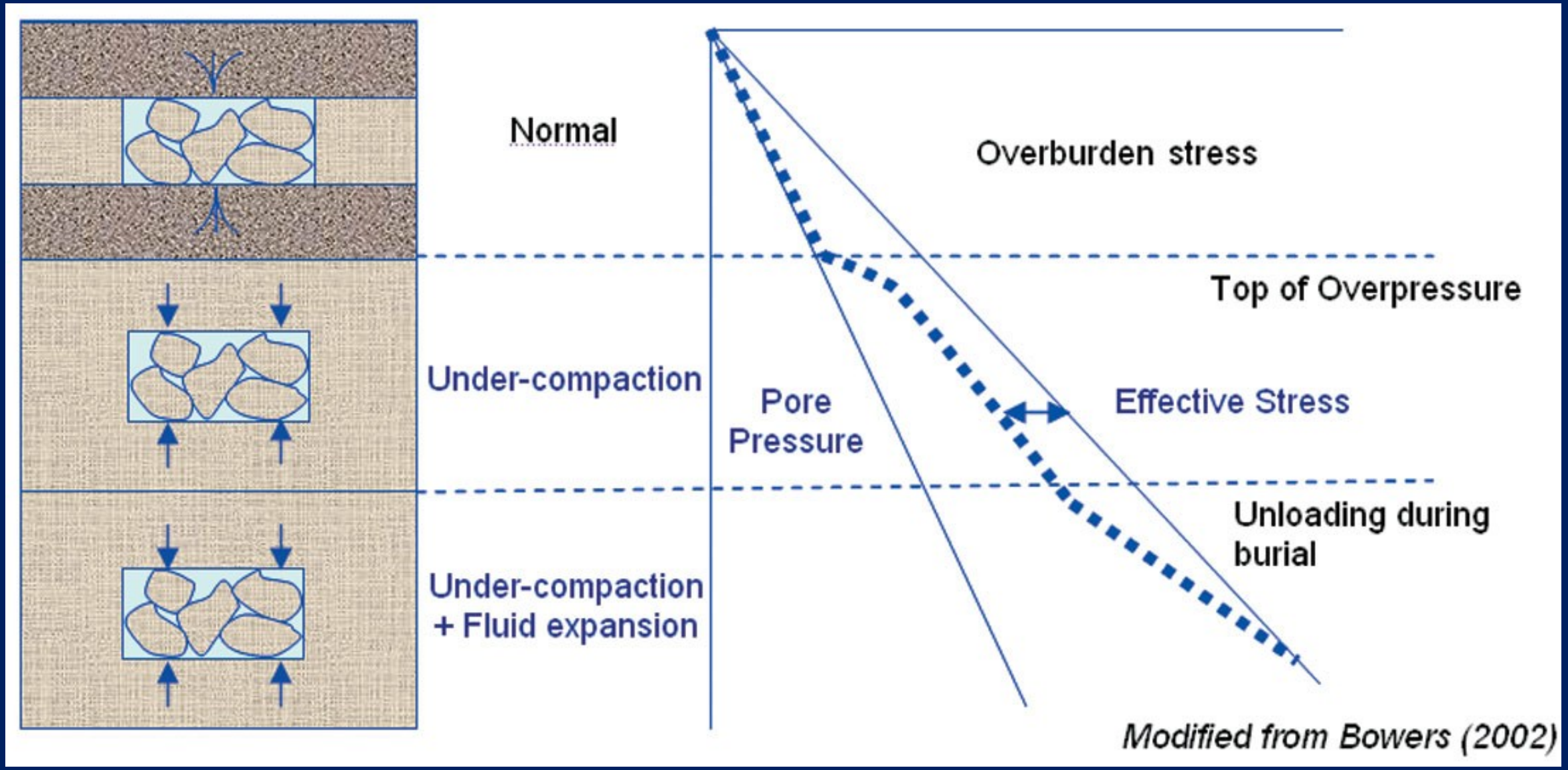
2.405
2.4
2.395
2.39
2.385
13
13.1
13.2
13.3
13.4
13.5


Normal
Overburden stress
Top of Overpressure
Under-compaction
Pore
Pressure
Effective Stress
Unloading during
burial
Under-compaction
+ Fluid expansion
Modified from Bowers (2002)