Signature of magmatic processes in ground deformation signals from Campi Flegrei (Italy)

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What?

- Comparison between strain records and synthetic ground deformation caused by magma mixing
- Detection of magma dynamics from analyses of ground deformation signals at active volcanoes in ULP (*Ultra-Long-Period*) band 10^{-4} Hz to 10^{-2} Hz [*Longo,2012*]

Why?

- Magma re-juvenation has been identified as the trigger of past eruptions at Campi Flegrei [*Tonarini et al., 2009*]
- New method to approach from short to medium term volcanic hazard forecast

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Outline

- Synthetic dataset
- Monitoring dataset
- Methods & analysis
- Concluding remarks

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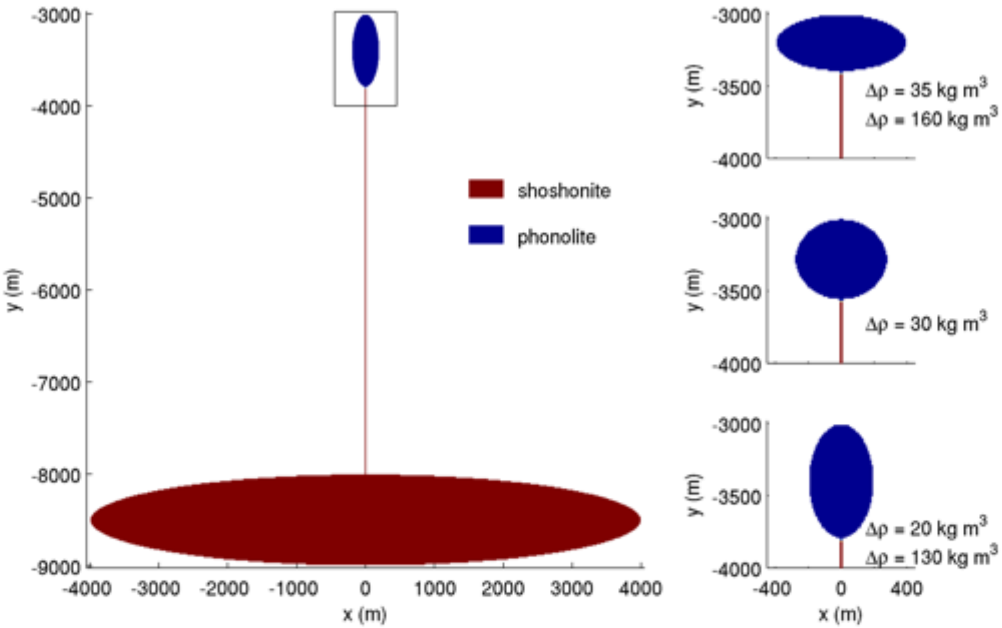
Numerical simulation – Set up

Synthetic dataset

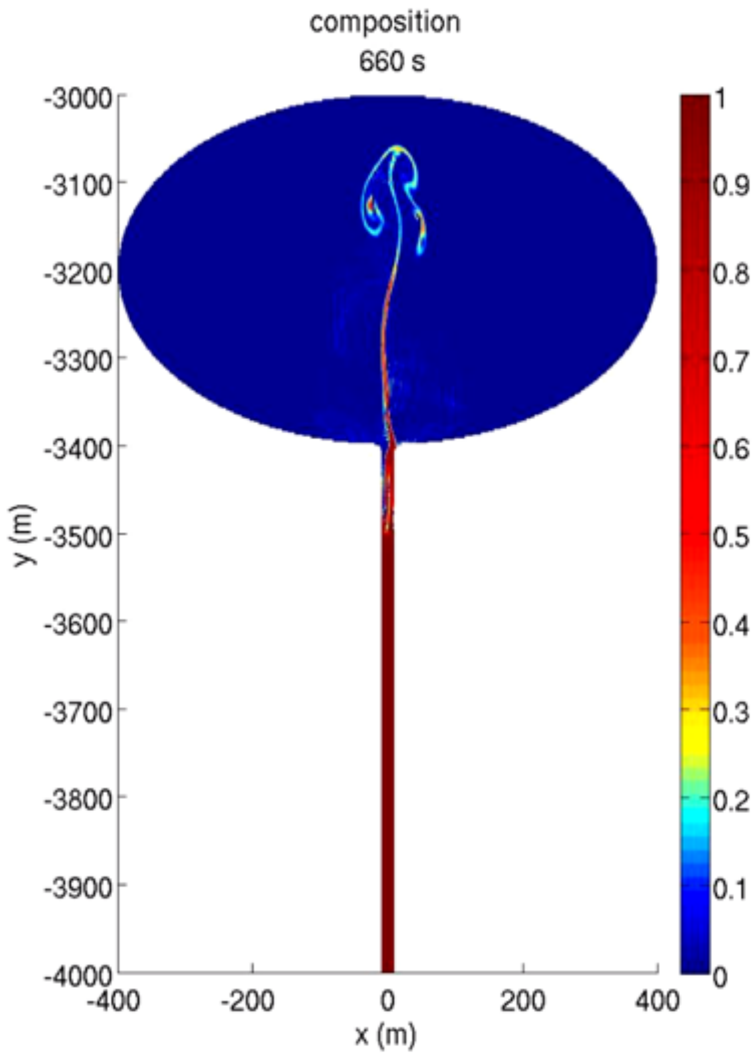
- Magma chambers:
  - different geometries of shallow chamber
  - different magma compositions: *phonolitic* (shallow) , *shoshonitic* (deep)
  - different volatile content (shallow chamber)



Simulation	Deep chamber	Shallow chamber	Shallow chamber geometry
CF1	shoshonite 1% CO_2 - 2% H_2O	phonolite 0.3% CO_2 - 2.5% H_2O	oblate
CF2	shoshonite 1% CO_2 - 2% H_2O	phonolite 0.3% CO_2 - 2.5% H_2O	prolate
CF3	shoshonite 1% CO_2 - 2% H_2O	phonolite 0.3% CO_2 - 2.5% H_2O	spherical
CF4	shoshonite 1% CO_2 - 2% H_2O	phonolite 0.1% CO_2 - 1% H_2O	oblate
CF5	shoshonite 1% CO_2 - 2% H_2O	phonolite 0.1% CO_2 - 1% H_2O	prolate

Numerical simulation – Observation

Synthetic dataset



- magma arise in the conduit
- magma mixing & mingling driven by buoyancy and density contrast [*Montagna, 2015*]
- no more relevant dynamics changes

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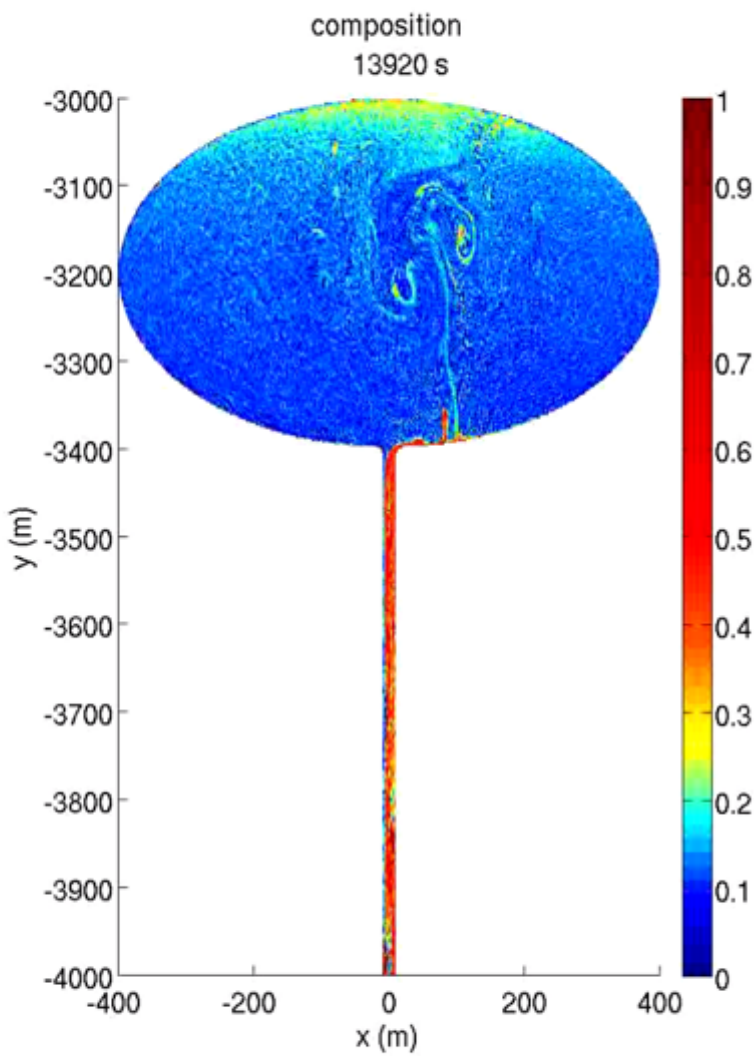

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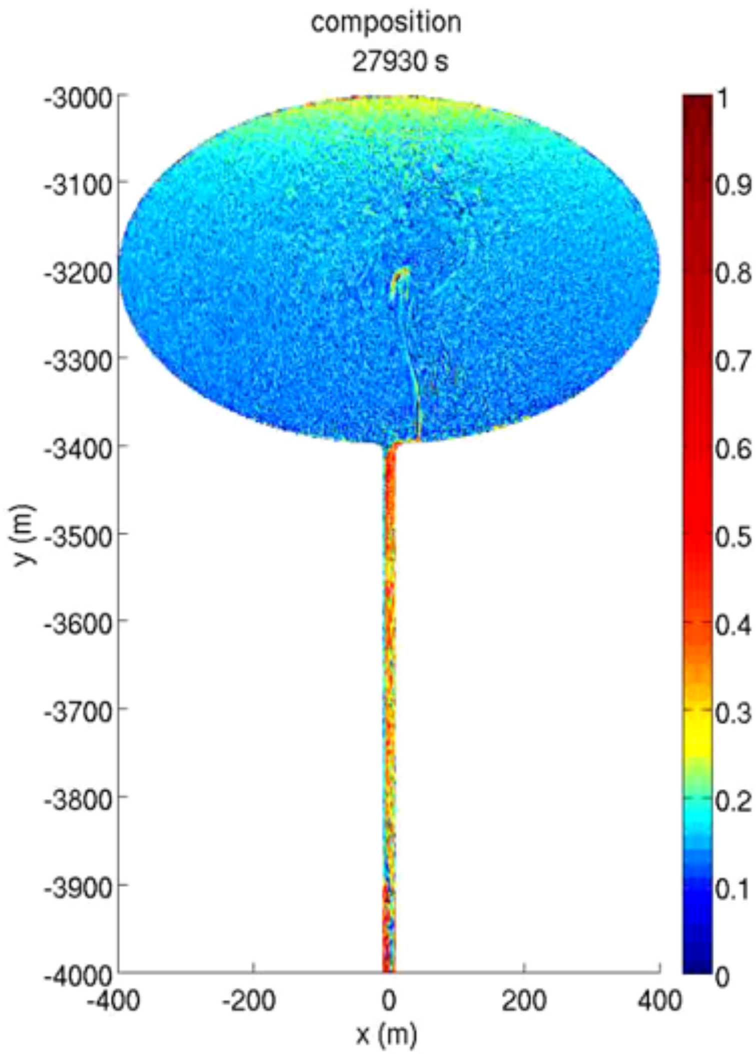

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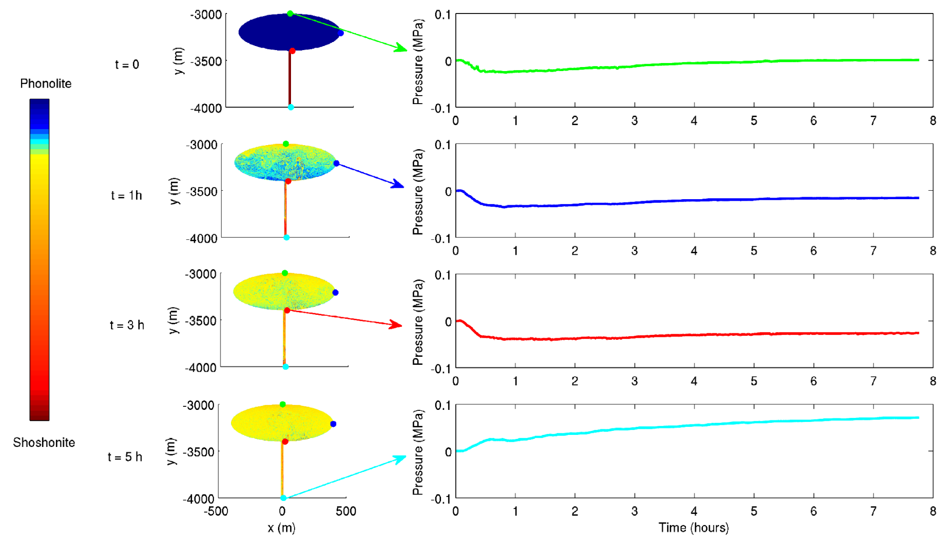
Max. Time Simulated:
≅ 7.5 hr

Numerical simulation – Results

Synthetic dataset

- Direct observable
  - pressure time series at the chamber's boundaries



- Strain
  - full band ground deformation signal
  - Green's function
  - homogeneous medium
  - *one-way* coupling

- Template signal
  - cross-correlation single traces
  - high pass filtering: $3.7 \cdot 10^{-5}$ Hz
  - **used for comparison with real data**

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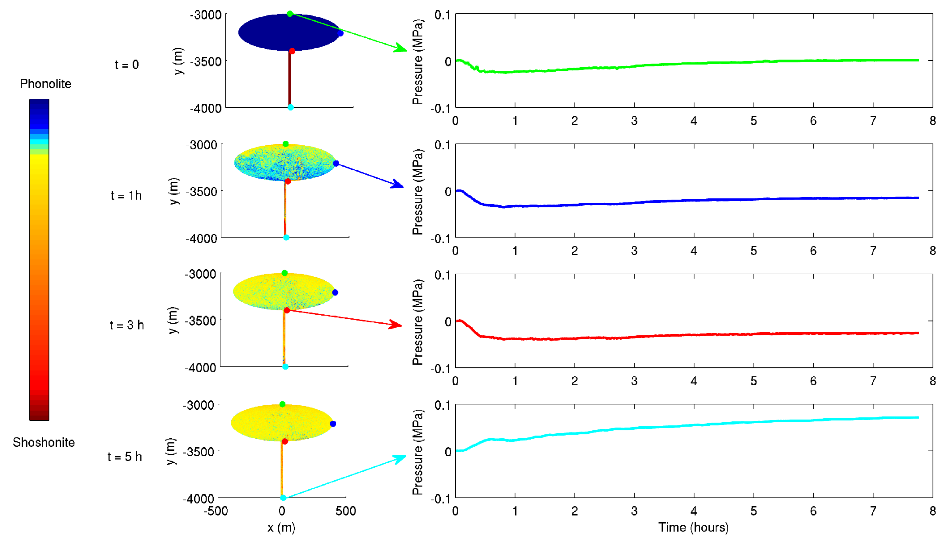

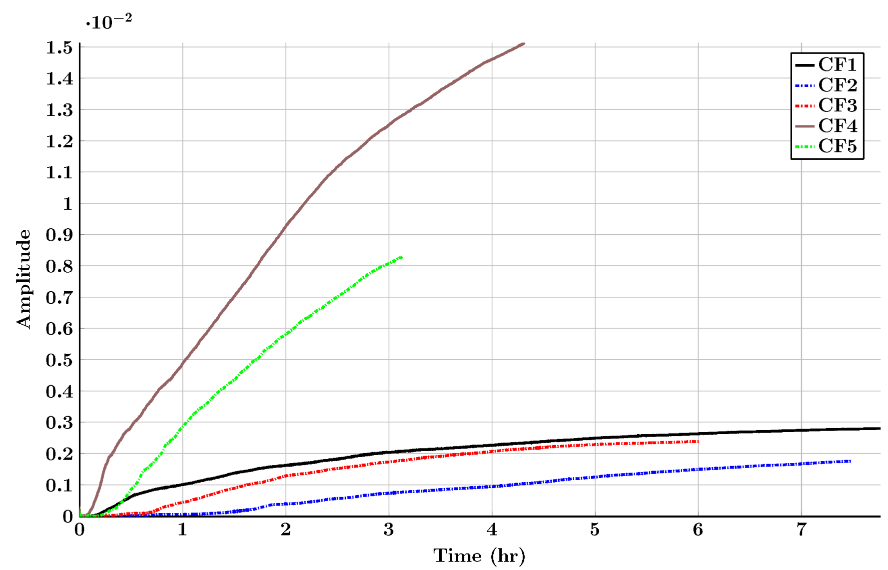

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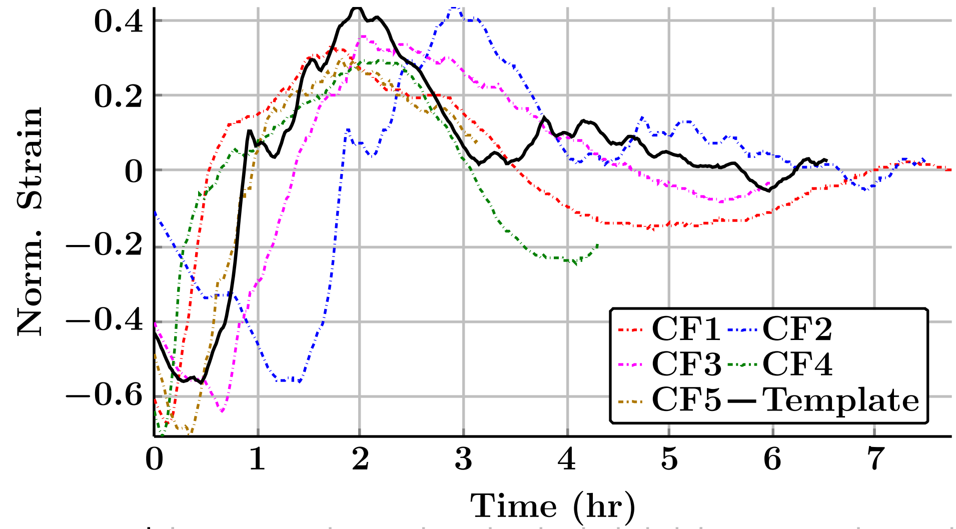

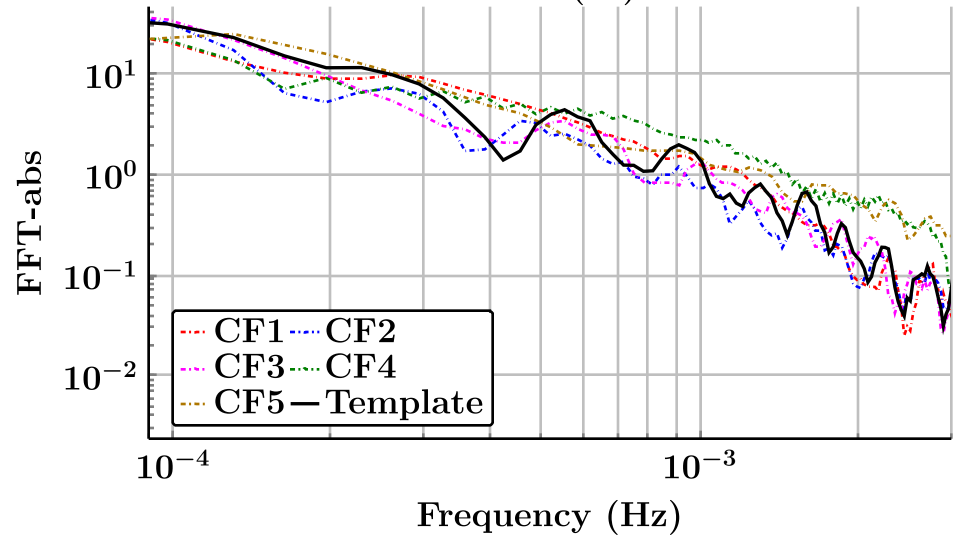

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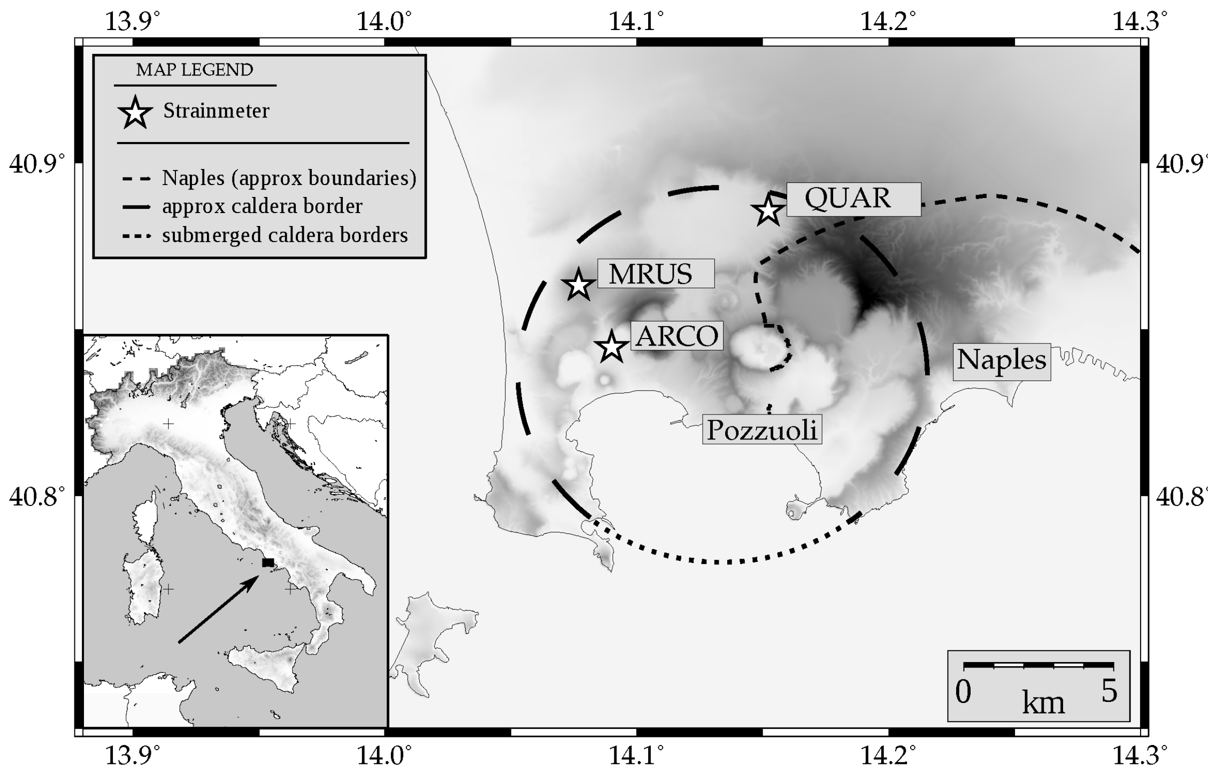
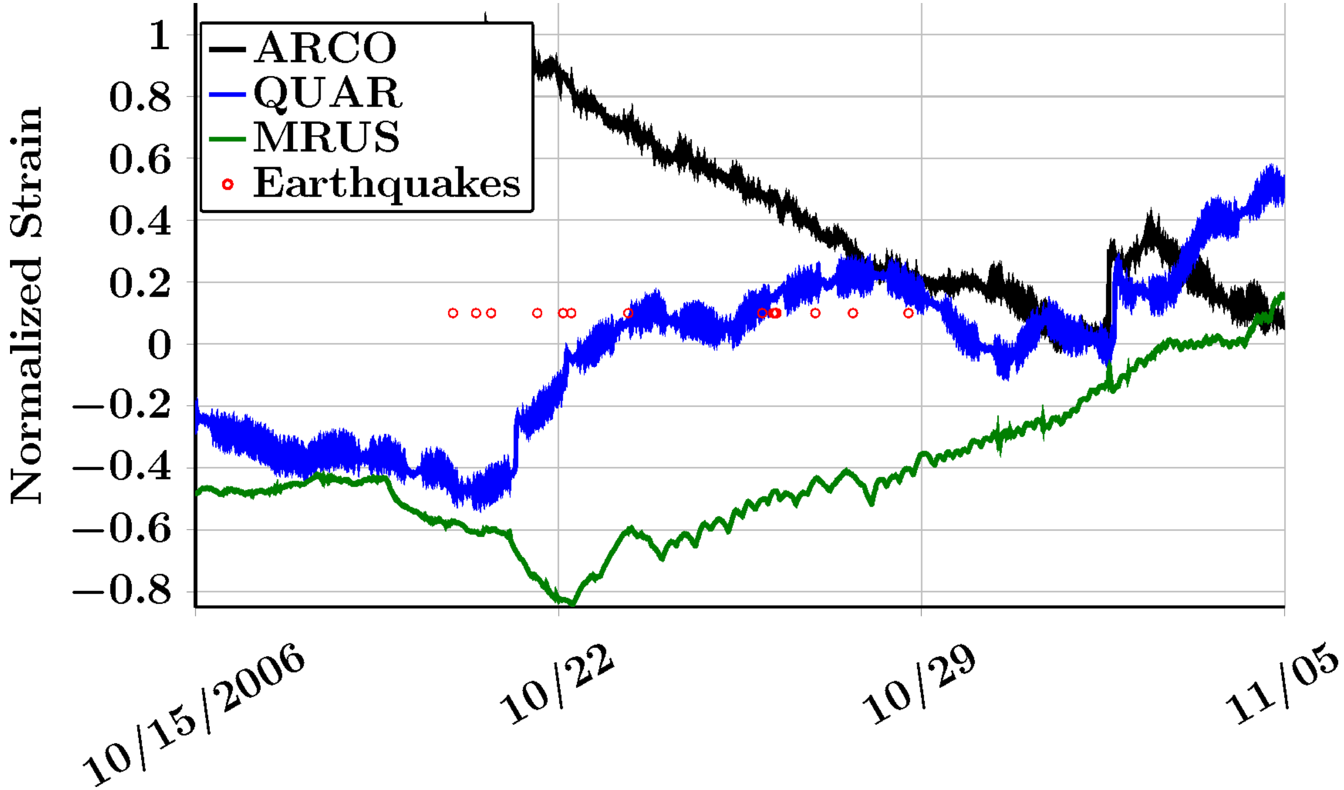
Instrumental Network



- Università di Salerno
  - 3 strainmeters (2004-2005) [*Scarpa, 2007*]
  - 2 tiltmeters (2008-2009)

- Time window analysed
  - Seismic swarn (October-November 2006)

Raw monitoring data



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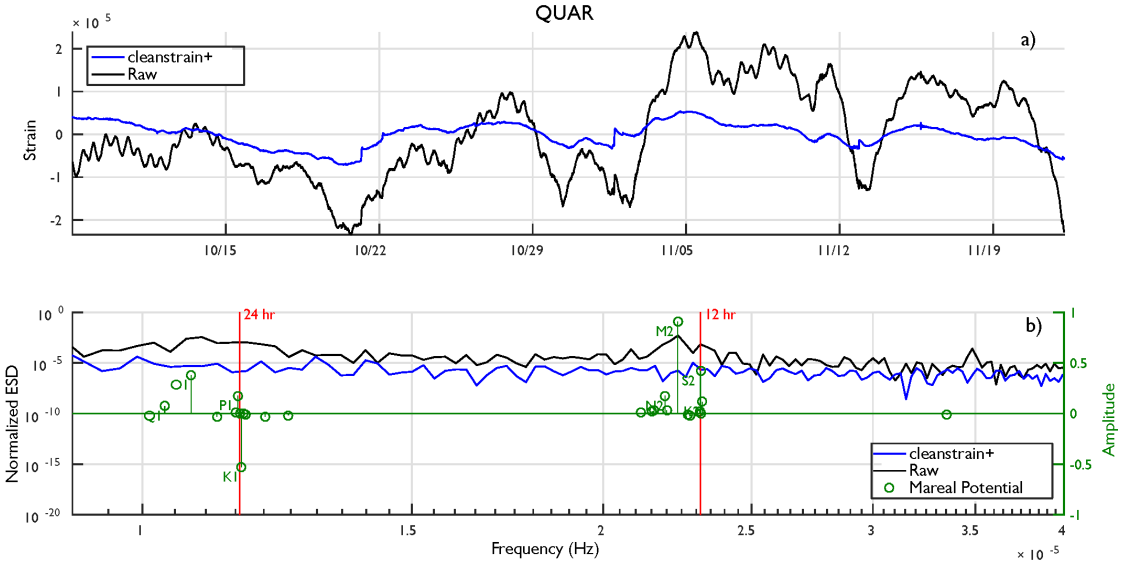
Data processing

Monitoring dataset



- Atmospheric pressure and Tidal effects removed
  - cleanstrain+ [*Langbein, 2010*]

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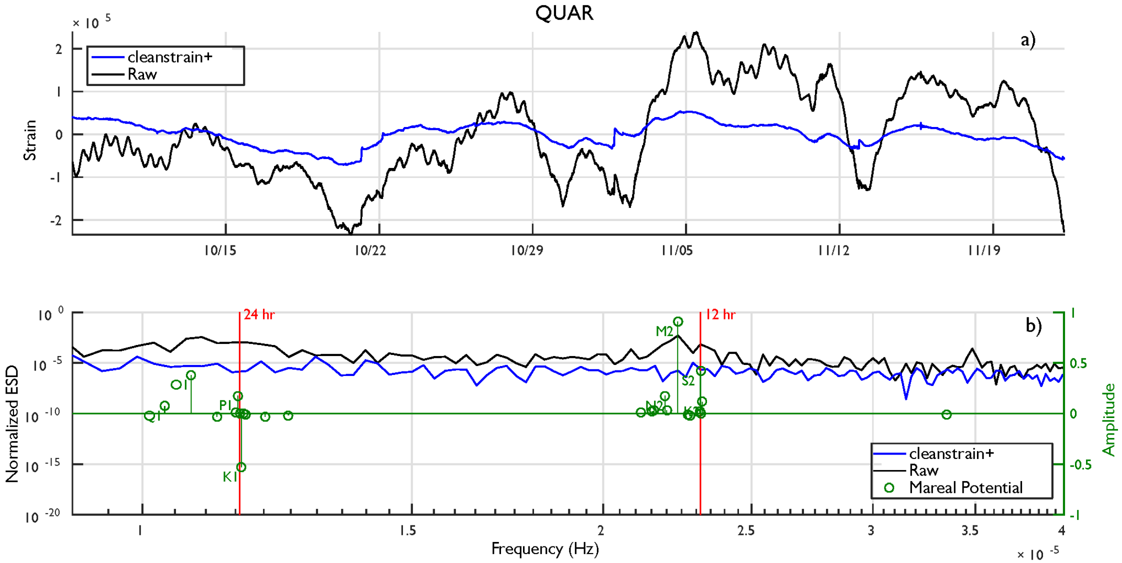

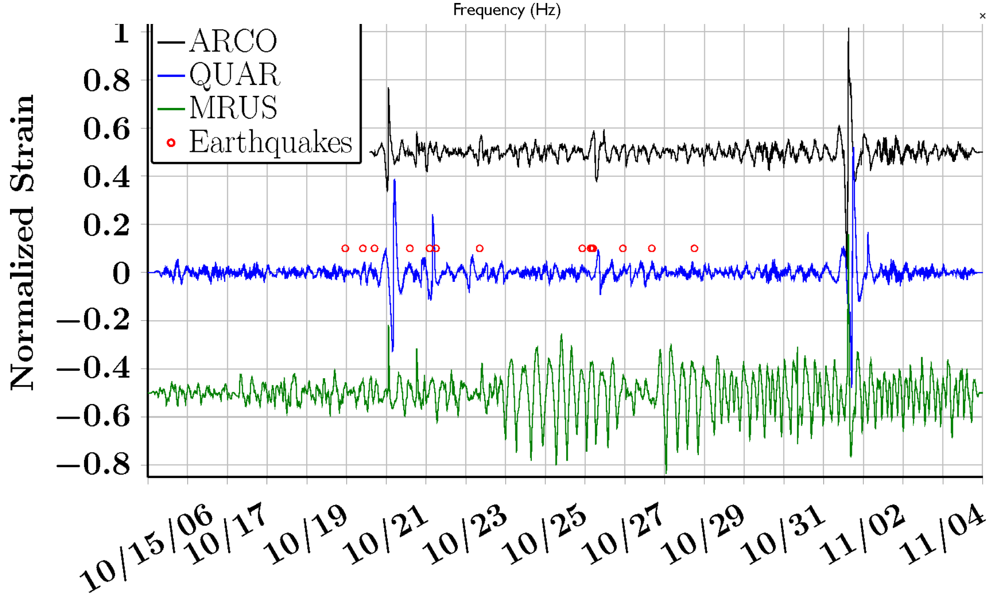

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- Highpass filtering
  - $3.7 \cdot 10^{-5}$ Hz

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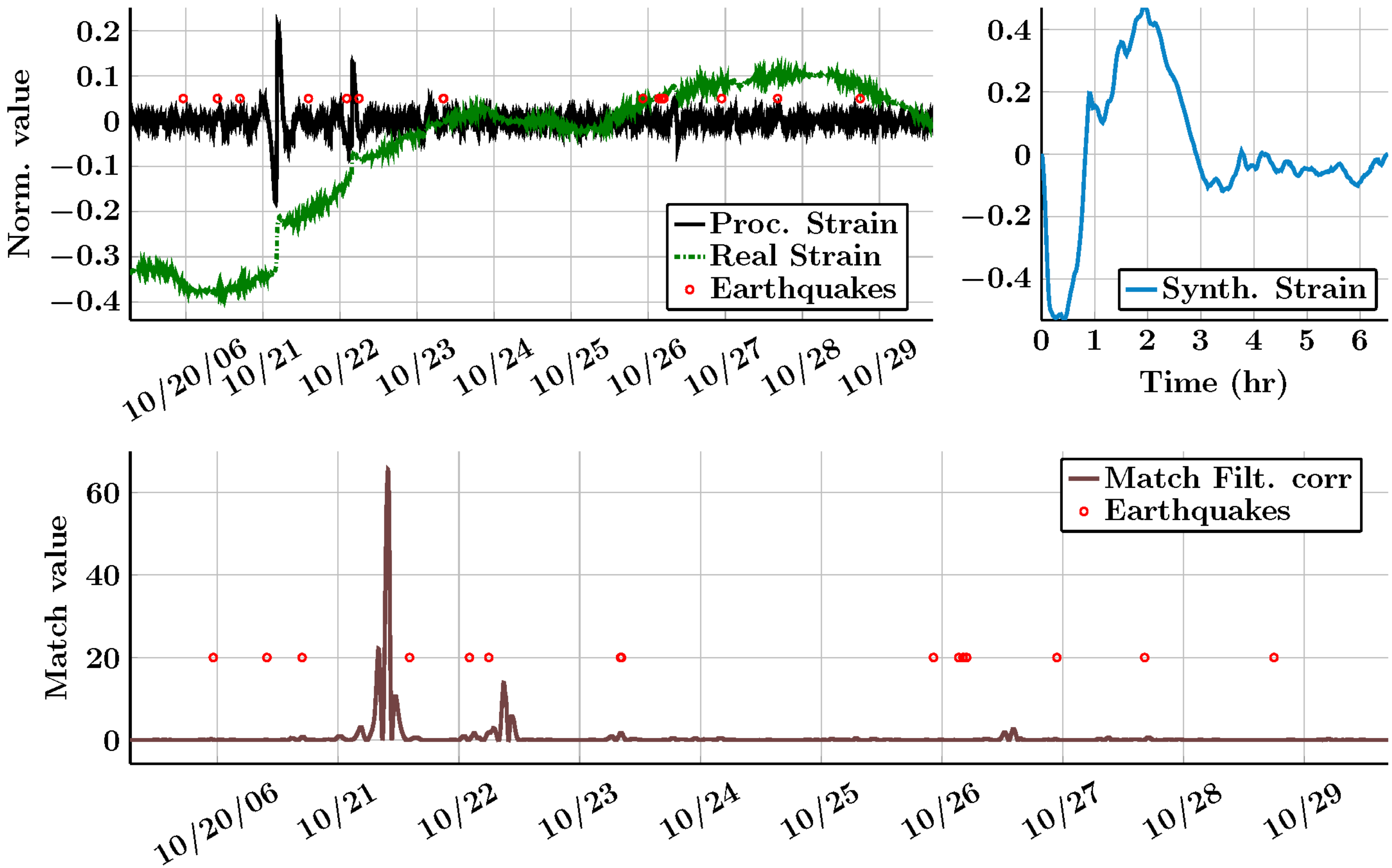
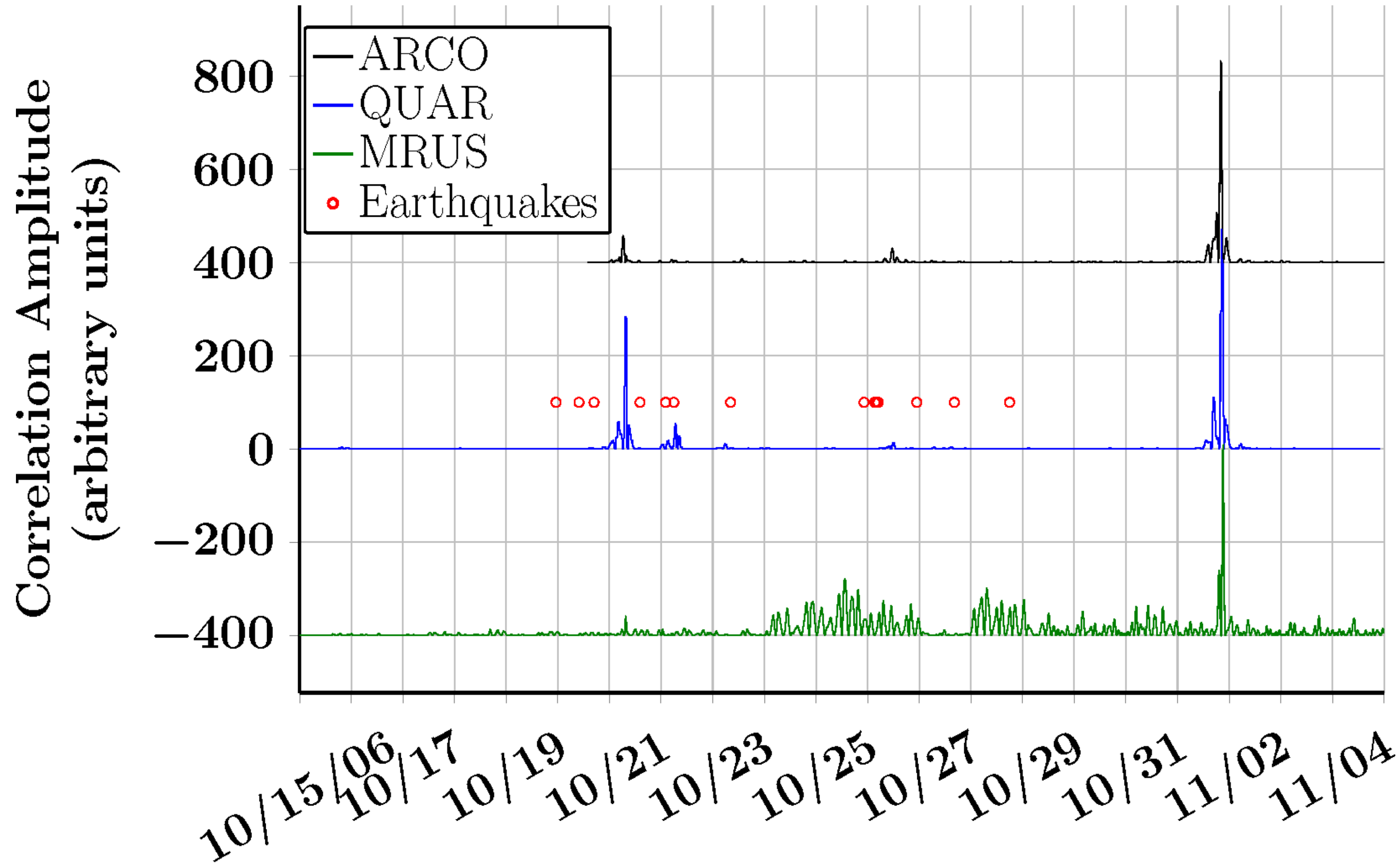
Matched filtering



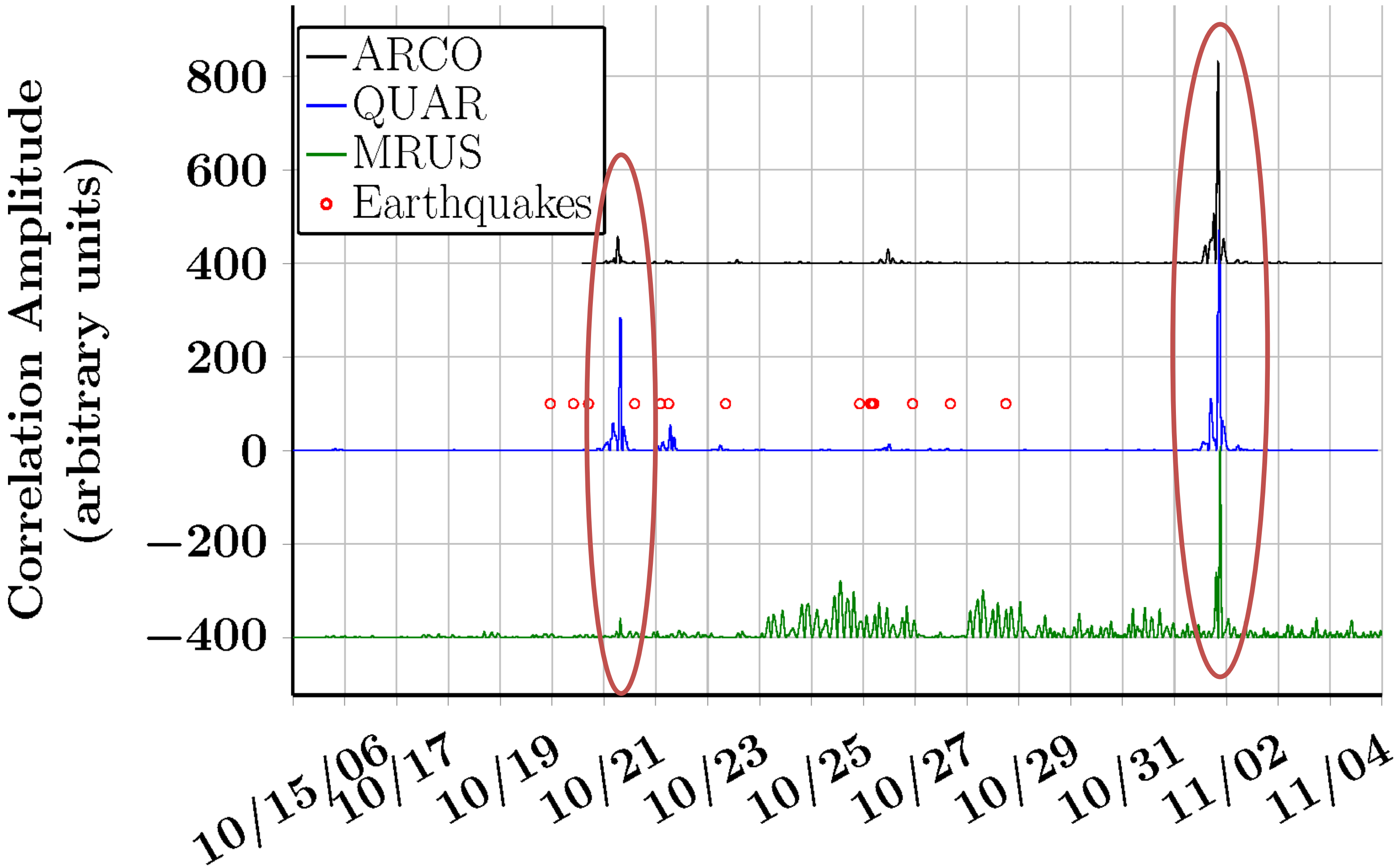
Matched filter

Methods & analysis

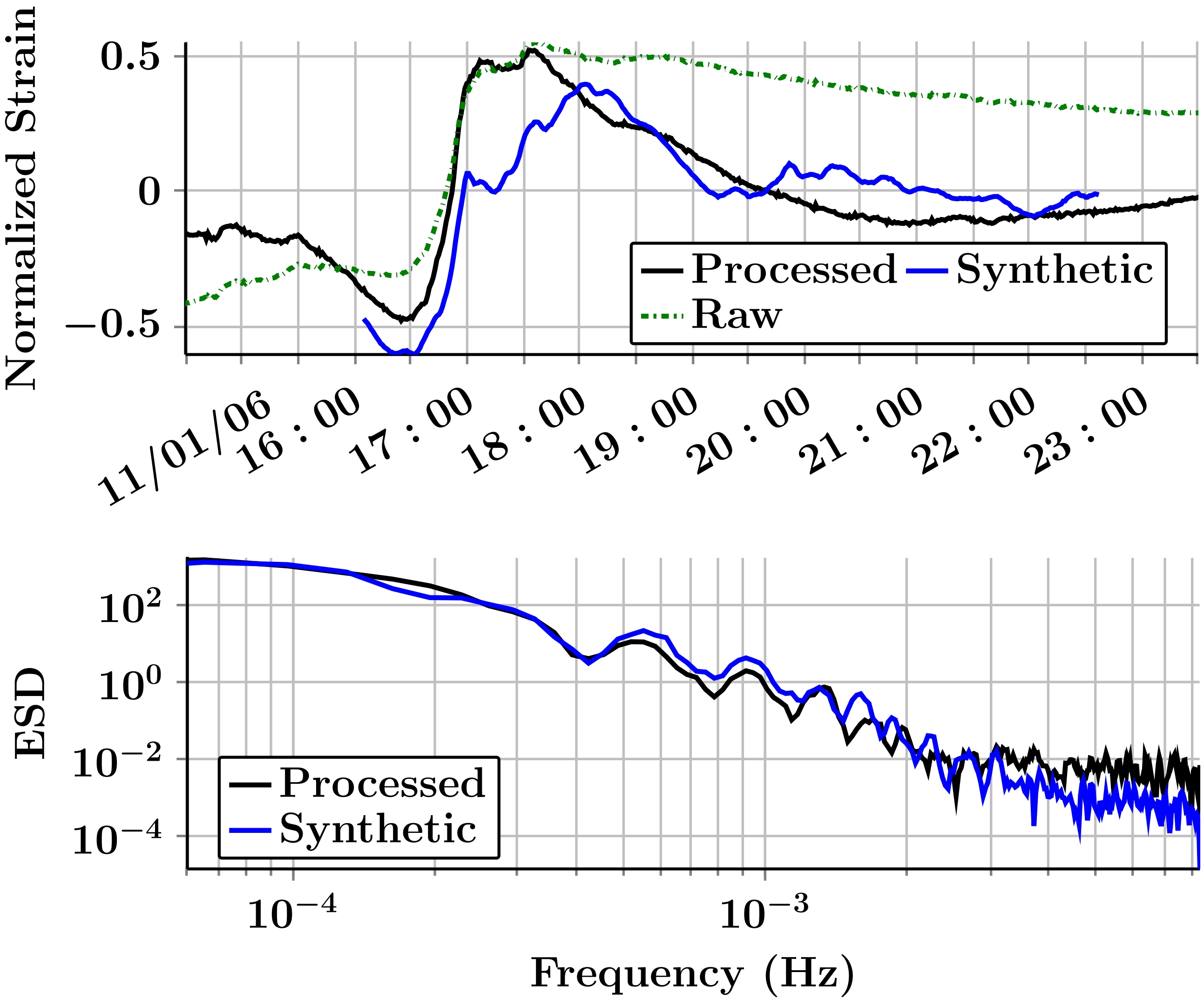


Matched filter

- High similarity transient: 21th Oct. + 1st Nov. 2006



QUARTO - 1st November



- High resemblance *(time-domain)*
- Plateau $3 \cdot 10^{-4}$ Hz
- Peak $6 \cdot 10^{-4}$ Hz *(frequency-domain)*
- Wavelet Transform *(time-frequency domain)* [*Torrence*, 1998]

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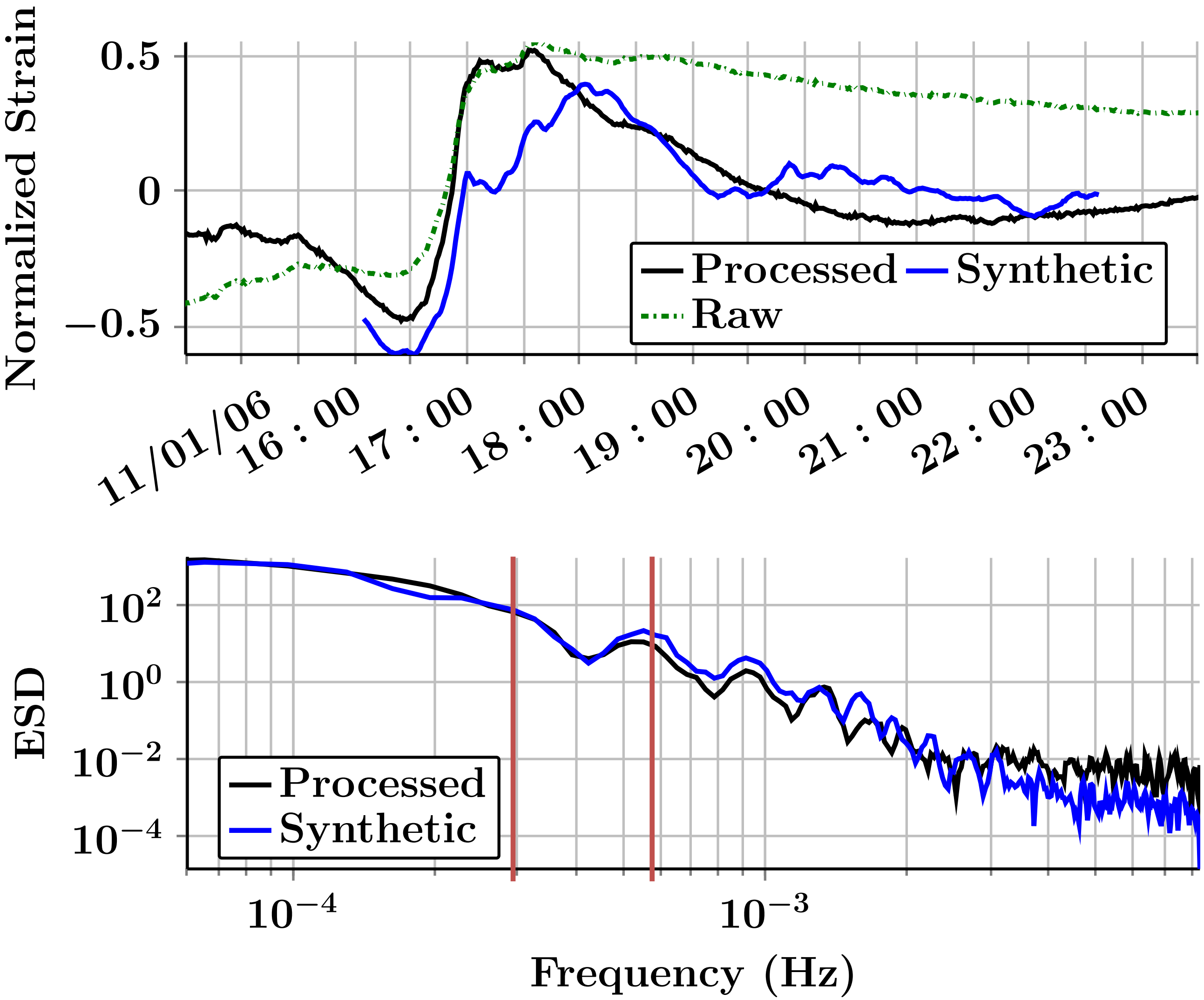

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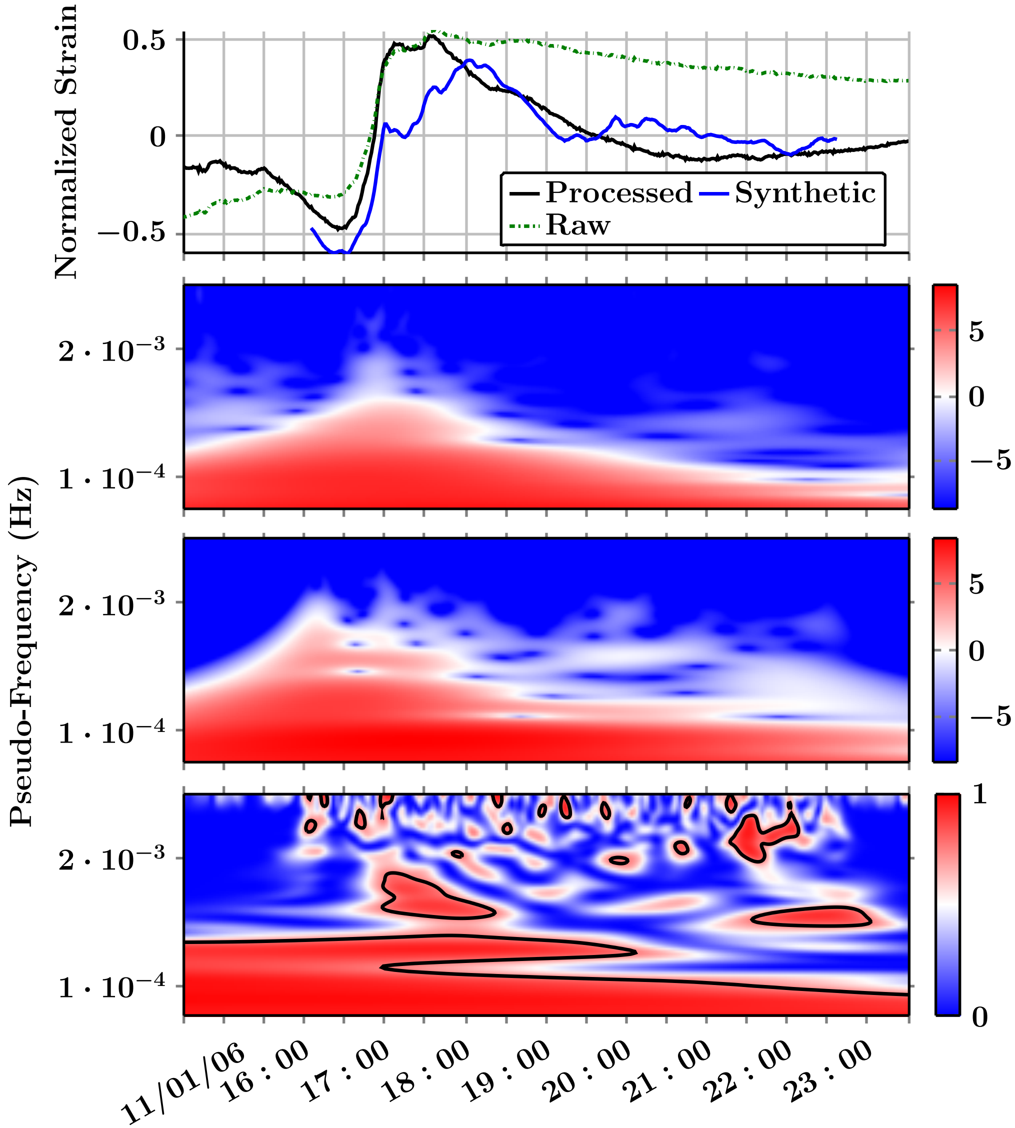

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Take home …

- Synthetic ground deformation signals show characteristic features both in time and frequency domain
- These features can be identified in monitoring data *(matched filter, wavelet transform …)*
- Monitoring data could record signals linked to shallow magmatic processes *(ie. ULP band)*

… to be continued ?

- Compare tiltmeters data
- Seek different time windows
- Enhanced numerical simulation *(i.e. seismicity , CF hydrothermal system …)*

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References

- Grinsted, Aslak, John C. Moore, and Svetlana Jevrejeva. "Application of the cross wavelet transform and wavelet coherence to geophysical time series." *Nonlinear processes in geophysics* 11.5/6 (2004): 561-566.
- Langbein, John. "Computer algorithm for analyzing and processing borehole strainmeter data". In: *Computers & Geosciences* 36.5, (2010): 611–619.
- Longo, Antonella et al. "Magma convection and mixing dynamics as a source of ultra-long-period oscillations". In: *Bulletin of volcanology* 74.4, (2012a): 873–880.
- Longo, Antonella, et al. "A finite element Galerkin/least-squares method for computation of multicomponent compressible–incompressible flows."*Computers & fluids* 67 (2012b): 57-71.
- Montagna, CP, P Papale, and A Longo. "Timescales of mingling in shallow magmatic reservoirs". In: *Geological Society,London,Special Publications* 422, (2015): SP422–6
- Scarpa, Roberto, et al. "New borehole strain system detects uplift at Campi Flegrei." *Eos, Transactions American Geophysical Union* 88.18 (2007): 197-203.
- Torrence, Christopher, and Gilbert P. Compo. "A practical guide to wavelet analysis." *Bulletin of the American Meteorological society* 79.1 (1998): 61-78.
- Tonarini, Sonia, et al. "Geochemical and B–Sr–Nd isotopic evidence for mingling and mixing processes in the magmatic system that fed the Astroni volcano (4.1–3.8 ka) within the Campi Flegrei caldera (southern Italy)." *Lithos* 107.3 (2009): 135-151.

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Signature of magmatic processes in strainmeter records at Campi Flegrei (Italy)

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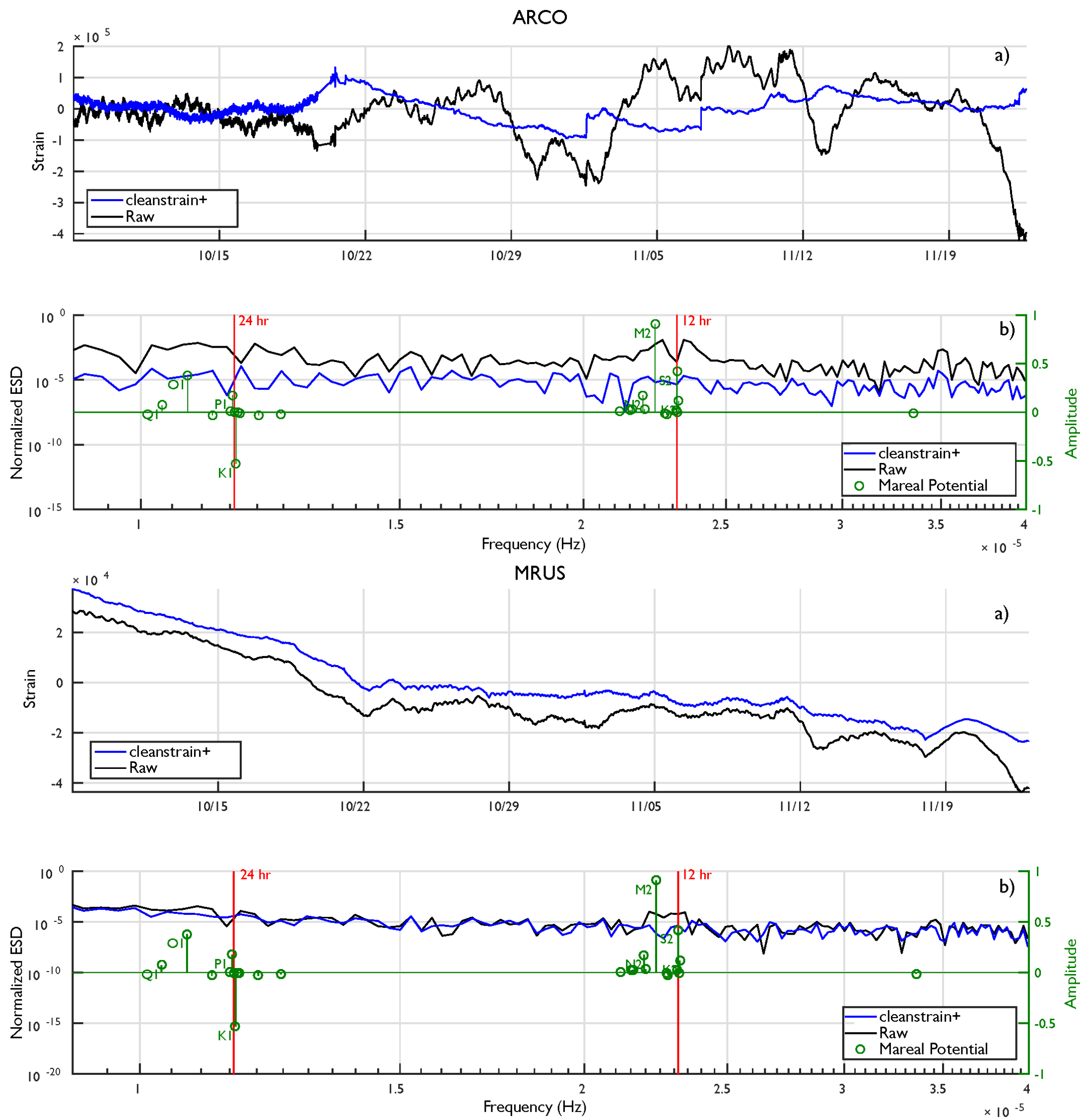
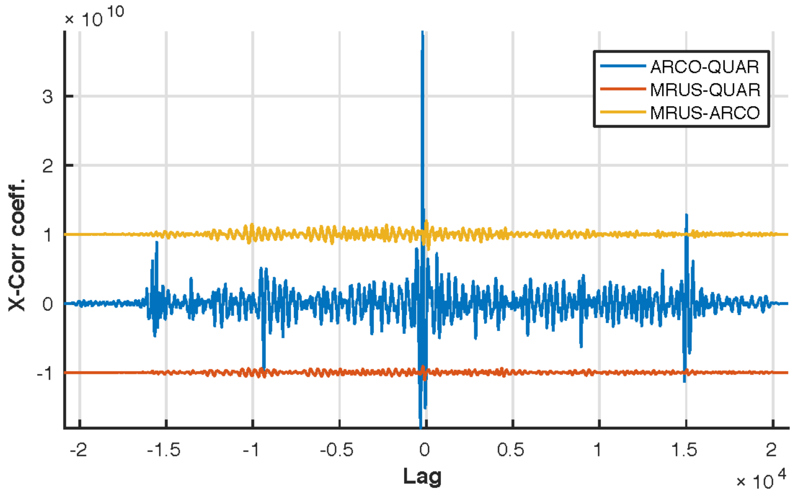
Key Points:
- Comparison between strain records and synthetic ground deformation caused by magma mixing
- Identification of transients where similarity is large indicating magma

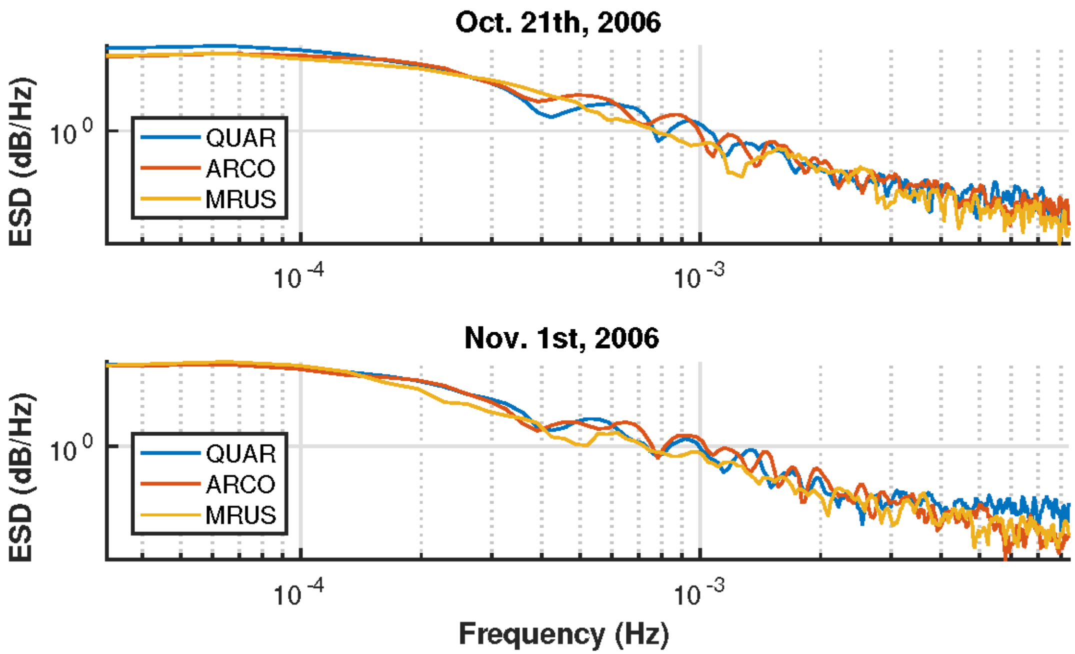
… in addition


ARCO
a)
Strain
cleanstrain+
Raw
10/15
10/22
10/29
11/05
11/12
11/19
b)
24 hr
12 hr
Normalized ESD
Amplitude
Frequency (Hz)
cleanstrain+
Raw
Mareal Potential
MRUS
a)
Strain
b)
Normalized ESD
Amplitude
Frequency (Hz)

… in addition

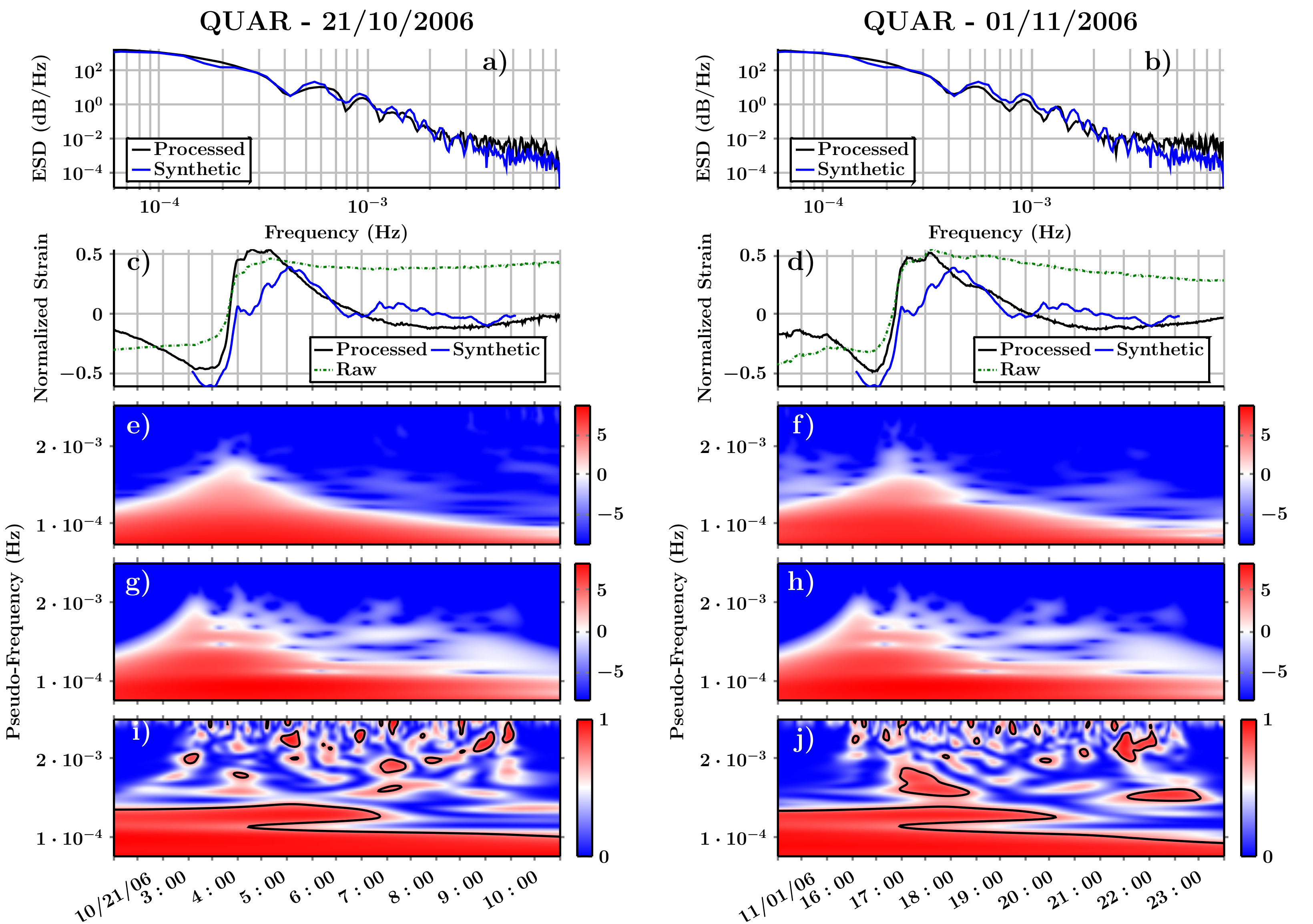


- Cross correlation



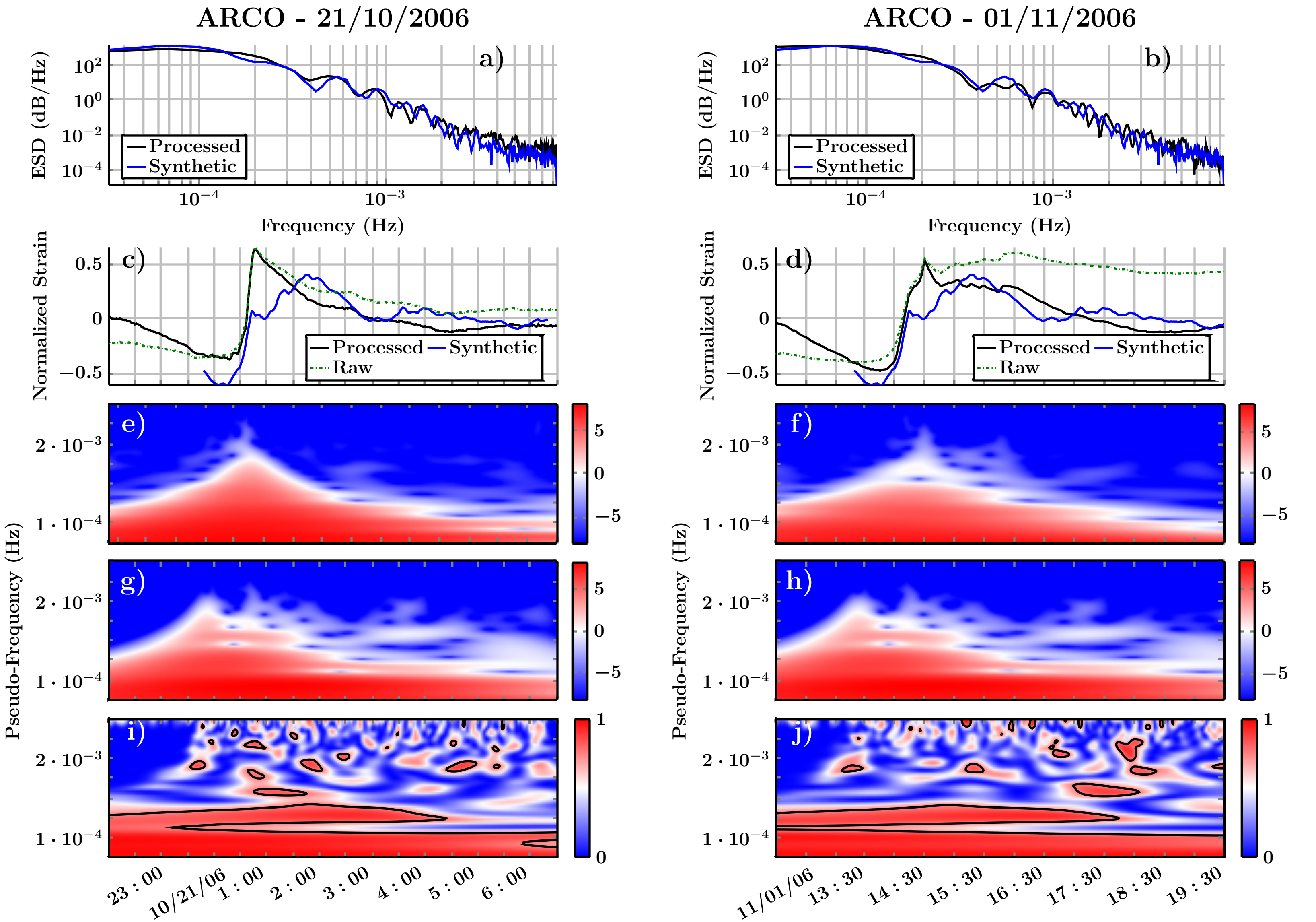
- Frequency Spectrum

… in addition

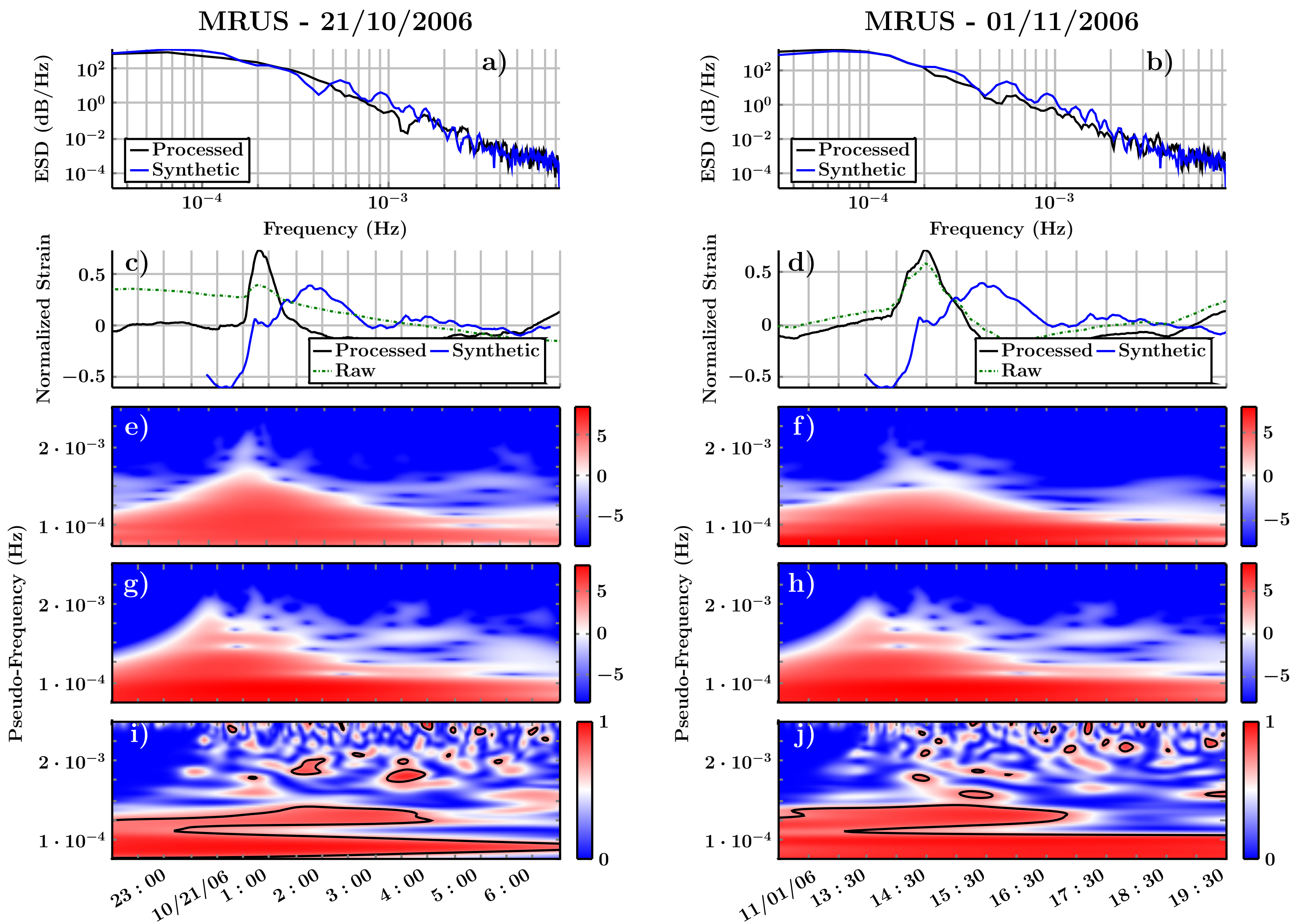


QUAR - 21/10/2006
QUAR - 01/11/2006
a)
b)
c)
d)
e)
f)
g)
h)
i)
j)
ESD (dB/Hz)
Frequency (Hz)
Processed
Synthetic
Raw
Normalized Strain
Pseudo-Frequency (Hz)
10/21/06
3 : 00
4 : 00
5 : 00
6 : 00
7 : 00
8 : 00
9 : 00
10 : 00
11/01/06
16 : 00
17 : 00
18 : 00
19 : 00
20 : 00
21 : 00
22 : 00
23 : 00

… in addition


ARCO - 21/10/2006
ARCO - 01/11/2006
a)
b)
c)
d)
e)
f)
g)
h)
i)
j)
ESD (dB/Hz)
Frequency (Hz)
Processed
Synthetic
Raw
Normalized Strain
Pseudo-Frequency (Hz)
23 : 00
10/21/06
1 : 00
2 : 00
3 : 00
4 : 00
5 : 00
6 : 00
11/01/06
13 : 30
14 : 30
15 : 30
16 : 30
17 : 30
18 : 30
19 : 30

… in addition



MRUS - 21/10/2006
MRUS - 01/11/2006
a)
b)
c)
d)
e)
f)
g)
h)
i)
j)
ESD (dB/Hz)
Frequency (Hz)
Processed
Synthetic
Raw
Normalized Strain
Pseudo-Frequency (Hz)
23 : 00
10/21/06
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2 : 00
3 : 00
4 : 00
5 : 00
6 : 00
11/01/06
13 : 30
14 : 30
15 : 30
16 : 30
17 : 30
18 : 30
19 : 30