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

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

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Deep chamber</th>
<th>Shallow chamber</th>
<th>Shallow chamber geometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF1</td>
<td>shoshonite</td>
<td>phonolite</td>
<td>oblate</td>
</tr>
<tr>
<td></td>
<td>1% CO₂ - 2% H₂O</td>
<td>0.3% CO₂ - 2.5% H₂O</td>
<td></td>
</tr>
<tr>
<td>CF2</td>
<td>shoshonite</td>
<td>phonolite</td>
<td>prolate</td>
</tr>
<tr>
<td></td>
<td>1% CO₂ - 2% H₂O</td>
<td>0.3% CO₂ - 2.5% H₂O</td>
<td></td>
</tr>
<tr>
<td>CF3</td>
<td>shoshonite</td>
<td>phonolite</td>
<td>spherical</td>
</tr>
<tr>
<td></td>
<td>1% CO₂ - 2% H₂O</td>
<td>0.3% CO₂ - 2.5% H₂O</td>
<td></td>
</tr>
<tr>
<td>CF4</td>
<td>shoshonite</td>
<td>phonolite</td>
<td>oblate</td>
</tr>
<tr>
<td></td>
<td>1% CO₂ - 2% H₂O</td>
<td>0.1% CO₂ - 1% H₂O</td>
<td></td>
</tr>
<tr>
<td>CF5</td>
<td></td>
<td></td>
<td>prolate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.1% CO₂ - 1% H₂O</td>
<td></td>
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</tbody>
</table>
Numerical simulation – Observation

- 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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Max. Time Simulated: \( \approx 7.5 \) hr
Numerical simulation – Results

• 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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Instrumental Network

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

- Time window analysed
  - Seismic swarm (October-November 2006)
Raw monitoring data

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  - 3 strainmeters (2004-2005) [Scarpa, 2007]
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Data processing

- Atmospheric pressure and Tidal effects removed
  - cleanstrain+ [Langbein, 2010]
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  - $3.7 \cdot 10^{-5}$ Hz
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Matched filtering

- Proc. Strain
- Real Strain
- Earthquakes

Match Filt. corr
- Earthquakes

Synth. Strain

Time (hr)

Match value

Norm. value

0.4
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4

10/20/06 10/21 10/22 10/23 10/24 10/25 10/26 10/27 10/28 10/29

60
40
20
0

10/20/06 10/21 10/22 10/23 10/24 10/25 10/26 10/27 10/28 10/29
Matched filter
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]
QUARTO - 1st November

- High resemblance (time-domain)
- Plateau $3 \cdot 10^{-4}$ Hz
- Peak $6 \cdot 10^{-4}$ Hz (frequency-domain)
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• 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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• 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.
... in addition
... in addition

- Cross correlation
- Frequency Spectrum
... in addition

QUAR - 21/10/2006

- ESD (dB/Hz)
- Frequency (Hz)
- Normalized Strain
- Pseudo-Frequency (Hz)

QUAR - 01/11/2006

- ESD (dB/Hz)
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... in addition

MRUS - 21/10/2006

MRUS - 01/11/2006

- Processed
- Synthetic

Normalized Strain

Pseudo-Frequency (Hz)

- Processed
- Synthetic

Normalized Strain

Pseudo-Frequency (Hz)

- Processed
- Synthetic

Normalized Strain

Pseudo-Frequency (Hz)

- Processed
- Synthetic

Normalized Strain

Pseudo-Frequency (Hz)

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