Numerical Modeling of seismic wave propagation on Etna Volcano (Italy): Construction of 3D realistic velocity structures

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I. General Introduction
   a) Objectives
   b) Volcano seismic signals

II. Etna volcano
   a) Geographical and geological setting
   b) LP events case study De Barros (2011)

III. Model setting
   a) EFISPEC3D (Spectral element code)
   b) Topography and structural features implementation

IV. Results
   a) Real data and synthetics comparison
   b) Conclusions

V. Perspectives
Objectives

1) Simulation of seismic waves propagation
   a) Complex media
   b) Realistic detailed topography

2) Volcano structural properties

3) Volcano seismic source characterization

NEMOH (Numerical, Experimental and stochastic Modelling of vOlcanic processes and Hazard) is an Initial Training Network under the European Community FP7 → http://www.nemoh-itn.eu/
Volcano Seismicity

1. Forecasting of eruptions from direct interpretation of different seismic signals
2. Investigation of structural properties of volcanoes from physical observations

Volcano-seismic signals classification following Wasserman J. (2011)
Geographical setting

- **Tallest** volcano of Europe (3,343 m)
- 1,570 km$^2$ of covered area (45 km diameter) one of the **largest** world volcanoes
- Many suburban and urban (Catania ~ 7 $10^5$ inhabitants) communities live nearby the volcanic edifice → **High volcanic risk**!
Geological evolution

Four main volcanic phases which generated the volcanic edifice (Branca et al., 2004)

1. **Basal Tholeiitic phase**
   - Pre-Etnean gulf, submarine lava (pillow lava), Tholeiitic basalts
   - Timeline: 5.0 years

2. **Timpe phase**
   - Fissure eruptions, shield volcano, Thoeliitic to alkali basaltic lava
   - Timeline: 2.2 years

3. **Valle del Bove phase**
   - From fissures to centralized activity, effusive/explosive episodes, stratovolcano, first Etna edifice
   - Timeline: 1.1 years

4. **Stratovolcano phase**
   - Ellittico crater (3,800 m), 9 $10^3$ y edifice collapse (valle del Bove creation)
   - Mongibello crater (actually active)
   - Timeline: 0.6 years

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Present day
Tectonic context

Aeolian – Maltese fault system

Bousquet & Lanzafame (2004)
LP events
(June – July 2008)
De Barros (2011)

50 stations deployed
129 LP events recorded

Family 1
63 events

Family 2
66 events

0.2 – 1.2 Hz filtered signal
$\lambda \approx 600 – 5,000$ m

Very good spatial and azimuthal coverage!

Lava fountain occurred during the experiment
LP Inversion
(Family 2)
De Barros (2011)

Inversion performed in a Homogeneous velocity Model

QUESTION
How does the (unrealistic?) assumption for a homogeneous velocity model influence the inversion (and so the retrieved physical source mechanism)?

Retrieved source time function for 6 independents Moment Tensor components and 3 forces

Oriented $\Phi = 110^\circ$, $\theta = 60^\circ$

Moment $[1 \ 1 \ 2]$

Forces – only used to accommodate errors

Physical mechanism related to gas movements
EFISPEC3D
(De Martin, 2011)

Spectral Element Code (SEM)

- 3D seismic waves propagation in complex geologic media
- Topography implementation
- Elastic and Viscoelastic simulations
- Programmed in FORTRAN95 and MPI


Geometrical Models

- Velocity models based on the seismic tomography papers:

1. Cauchie & Saccorotti (2012) → very shallow velocity gradient
2. Patané et al. (2002) → velocity until depth
3. Cristiano et al. (2010) → Vs velocity structure

Localization of the two profiles (on the right), Patané (2002)

Seismic tomography performed on a seismic swarm occurred on Etna volcano in 2001, Patané (2002)
Geometrical Models

Homogeneous Surface (low vel.) Layer

Surface layer

Gradient model (100m)

Strong Gradient

Gradient model (60m)
Geometrical Models

- **Topography of Etna (100 m grid precision) implemented**
- **Four velocity structural models (increased complexity)**

<table>
<thead>
<tr>
<th>Model</th>
<th>Vp (m/s)</th>
<th>Vs (m/s)</th>
<th>ρ (kg/m³)</th>
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<tbody>
<tr>
<td>Homogeneous</td>
<td>2000</td>
<td>1175</td>
<td>2069</td>
</tr>
<tr>
<td>Surface (low vel.) Layer</td>
<td>866 / 2000</td>
<td>500 / 1175</td>
<td>1697 / 2069</td>
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<td>Gradient model (100m)</td>
<td>1645 → 4503</td>
<td>950 → 2600</td>
<td>1974 → 2539</td>
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<td>21 layers</td>
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<tr>
<td>Gradient model (60m)</td>
<td>744 → 4503</td>
<td>430 → 2600</td>
<td>1619 → 2539</td>
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<tr>
<td>36 layers</td>
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<table>
<thead>
<tr>
<th></th>
<th>CPUs</th>
<th>n° elements</th>
<th>Δt (s)</th>
<th>Comput. time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homogeneous</td>
<td>16</td>
<td>1.418 10⁶</td>
<td>0,004</td>
<td>16.3 h</td>
</tr>
<tr>
<td>Surface Layer</td>
<td>16</td>
<td>1.418 10⁶</td>
<td>0,004</td>
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<td>1.418 10⁶</td>
<td>0,004</td>
<td>16.3 h</td>
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<tr>
<td>Gradient model (60m)</td>
<td>48</td>
<td>2.272 10⁶</td>
<td>0,001</td>
<td>49.9 h</td>
</tr>
</tbody>
</table>
Geometrical Models
(examples (1))

- Homogeneous velocity model
Geometrical Models
(examples (2))

• *Surface (low-velocity) layer*
  200 – 300 – 400 m depths
Geometrical Models
(examples (3))

- Gradient velocity layer (100 m)
Geometrical Models
(examples (4))

- Gradient velocity layer (60 m)
Simulation Parameters

Receivers position

- 16 receivers in the near-intermediate field from De Barros (2011)

We have not data from far field stations. Future applications will be designed in order to test the influence of complex models on long-travel path waves
Simulation Parameters

Source time function

- **Full Moment tensor + 3 Single Forces solution**
  (the one found by De Barros (2011) in their inversion)
Comparisons

Homogeneous model

X-component & Z-component

Homogeneous Model - shallow source

Time (s)

Stations

NE

SW
Comparisons

Homogeneous vs Surface layer (400 m)

X-component
Comparisons

Homogeneous vs Surface layer (200 m)

X-component
Comparisons

Homogeneous vs Gradient (100 m)

X-component
Comparisons

Homogeneous vs Gradient (100 m)

Z-component
Comparisons

Homogeneous vs Gradient (100 m)
Near station (et82)
Comparisons

Homogeneous vs Gradient (100 m)

Far station (ecpn)
Comparisons

Homogeneous vs Gradient (60 m)

X-component
Comparisons

Homogeneous vs Gradient (60 m)
Near station (et82)
Comparisons

Homogeneous vs Gradient (60 m)

Far station (ecpn)
Conclusions

May a composite model be more accurate?

Gradient 100 m

Homogeneous

et82

Homogeneous?

ecpn

Velocity gradient?
Complex? Simple?

300 m

1,000 m

SW  NE
Comparisons

Homogeneous vs Hom + Gradient (60 m)

X-component
Comparisons

Homogeneous vs Hom + Gradient (60 m)
X-component
Perspectives

1) Production of Green Functions in more complex mediums including velocity gradient

2) Inversion of real data for different model scenarios

3) Extend the comparison to higher frequencies (~4 Hz)

4) Joint blind test with the INGV of Pisa and university of Dublin in order to test the influence of a priori model assumptions on synthetics data
Thank you for your attention!

Explosion on Etna volcano (10/11/2013), view of north flank. Shot taken from the village of Taormina (Sicily, Italy)
Summary

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a) Real data and synthetics comparison
b) Observations and results

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