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Scope of work & tools of the trade

“The analysis of earthquake sequences and swarms provides useful hints to identify and characterize the seismogenic structures of an area, to investigate earthquake source properties, to study the propagation of seismic waves, and to investigate the recurrence of earthquakes...” (Barani et al., 2013, GNGTS)

Seismogram cross-correlation

DD location – Hypo DD (Waldhauser and Ellsworth, 2000, BSSA)

Microquake detection – STA/LTA algorithm

*Microquake*: earthquakes of very low magnitude (often lower than zero) and short durations (rarely longer than ten seconds)
Sampeyre swarm: overview

- 550 earthquakes were recorded and located by the RSNI network in the period Oct-Nov 2013
- including the micro-seismicity detected through an STA/LTA-based algorithm, the number of events goes up to approximately 3250!
- approximately 200 events exceeded a local magnitude (ML) of 1.0
- only two earthquakes exceeded ML = 3.0, reaching up to ML = 3.2
Major shocks felt in the past:
1883 Pinerolo earthquake (Io = IV-V MCS, Mw = 4.4)
1887 Dronero earthquake (Io = IV-V MCS; Mw = 4.1)
1905 Alta Savoia earthquake (Io = VIII-VIII MCS; Mw = 5.6)
1914 Tavernette earthquake (Io = VII MCS; Mw = 5.4)

The Varaita Valley never experienced a swarm with a so high number of events
<table>
<thead>
<tr>
<th>Start time</th>
<th>Duration</th>
<th>Area</th>
<th>N° of events</th>
<th>Max mag. (ML)</th>
<th>Average depth (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013-06-21*</td>
<td>2 months</td>
<td>Lunigiana – Alpi Apuane (MC)</td>
<td>2113</td>
<td>5.1</td>
<td>4.4</td>
</tr>
<tr>
<td>2013-04-14</td>
<td>3 days</td>
<td>Val di Taro (PR)</td>
<td>31</td>
<td>2.3</td>
<td>12.3</td>
</tr>
<tr>
<td>2013-01-25*</td>
<td>3 months</td>
<td>Garfagnana (San Pellegrino) (LU)</td>
<td>469</td>
<td>4.8</td>
<td>13.9</td>
</tr>
<tr>
<td>2011-10-02</td>
<td>30 days</td>
<td>Santo Stefano d'Aveto (GE)</td>
<td>43</td>
<td>4.0</td>
<td>9.7</td>
</tr>
<tr>
<td>2011-09-19</td>
<td>11 days</td>
<td>Appennino Parmense (PR)</td>
<td>132</td>
<td>3.6</td>
<td>13.6</td>
</tr>
<tr>
<td>2008-12-23*</td>
<td>3 days</td>
<td>Appennino Reggiano (RE)</td>
<td>86</td>
<td>5.2</td>
<td>17.6</td>
</tr>
<tr>
<td>2008-03-01</td>
<td>5 days</td>
<td>Firenzuola – Appennines (FI)</td>
<td>93</td>
<td>4.2</td>
<td>8.3</td>
</tr>
<tr>
<td>2006-04-02</td>
<td>2 days</td>
<td>Fivizzano – Lunigiana (MC)</td>
<td>25</td>
<td>2.3</td>
<td>8.2</td>
</tr>
<tr>
<td>2006-04-01*</td>
<td>10 days</td>
<td>Pontremoli – Lunigiana (MC)</td>
<td>33</td>
<td>3.8</td>
<td>9.7</td>
</tr>
<tr>
<td>2000-06-10</td>
<td>2 days</td>
<td>Garfagnana (MC)</td>
<td>74</td>
<td>1.8</td>
<td>13.0</td>
</tr>
<tr>
<td>1995-10-10*</td>
<td>21 days</td>
<td>Aulla – Lunigiana (MC)</td>
<td>107</td>
<td>4.9</td>
<td>6.4</td>
</tr>
<tr>
<td>1982-10-18</td>
<td>8 days</td>
<td>Appennino Parmense (PR)</td>
<td>98</td>
<td>3.7</td>
<td>9.4</td>
</tr>
</tbody>
</table>
Sampeyre swarm: W.S.A.

The aim is to obtain the minimum number of families that allows us to correctly reproduce the spatial distribution of earthquakes and, particularly, to identify the group of impulsive events observed visually.

1. **Earthquake selection**: $M_l \geq 1$, $\text{GAP} \leq 180^\circ$, ERH & ERZ < 5km
   
   *The No. earthquakes reduces to 118*

2. **Waveform filtering** from 2 to 12Hz

3. **Cross-correlation** performed on pairs of 2.2s signals (including both the P-wave and S-wave onsets)

4. **Definition of multiplets** ($C_{\text{min}} = 72\% + \text{Bridging Technique}$)
Besides those of DOI and PZZ, differential times are also calculated for the stations of RRL, BHB, and STV.

**DD solutions are found by means of a weighted least-squares procedure**
Lunigiana sequence: W.S.A. & DD location

1. Earthquake selection: $M_l \geq 1$, GAP $\leq 200^\circ$, ERH & ERZ $< 5$ km
   
   No. earthquakes reduces to 824

2. Waveform filtering from 2 to 12 Hz

3. Cross-correlation performed on pairs of 2s (FIVI and EQUI stations) or 3s signals (SARM and GRAM)

4. Definition of multiplets ($C_{min} = 72-80\%$ + Bridging Technique)
1. Microseismicity is detected (through an STA/LTA-based algorithm) to increase the completeness of the family data sets

2. Microquakes (with S/N ≥ 2.44) are joined to Family 1 and 2 through seismogram cross-correlation:
   - 592 events are associated to Family 1
   - 280 events are associated to Family 2

\[ \text{Mc} \approx -0.3 \]

![Strong P-wave pulse!!!](image)
1) Magnitude “behavior”

![Graph showing magnitude behavior for Family 1 and Family 2.]

2) Energy radiation

![Graphs showing energy radiation for Family 1 and Family 2.]

Sampeyre swarm: other clues of distinct sources
**Conclusions**

- The work has strengthened the results of various research studies about the capability of seismogram cross-correlation and double-difference location in characterizing the seismogenic process of an area.

- These methods have been once more proved to be effective tools for the definition of the seismogenic structures in terms of location and orientation. Moreover...

- ...they are of great importance to characterize surface fault lineaments but assume a greater importance in areas where seismicity is triggered by deep structures with no clear geological evidences.

- Concerning the case study of the Sampeyre swarm, our work has also pointed out that investigating changes of the $b$-value within the rock volume involved in a seismic process may help in identifying structural and rheological heterogeneities.

- Generally, a decreasing $b$-value with depth corresponds to an increasing stress level. However, given the small difference in depth between the two earthquake families identified within the Sampeyre swarm, fault heterogeneity, variation of rheological properties, and pore pressure variation appear more reasonable causes for $b$-value variation.