Chapter 1

The sources of the two destructive earthquakes of 1693 retrieved by automatic inversions

F. Pettenati, F. Gentile & L. Sirovich
Istituto Nazionale di Oceanografia e di Geofisica Sperimentale – OGS, Trieste

Abstract

We automatically inverted the macroseismic intensity data set of the two destructive earthquakes of 1693 in SE Sicily, and retrieved the principal geometric and kinematic source parameters of the events. The inversion results obtained by the grid-search method are printed in the Journal of Seismology (Sirovich and Pettenati, 1999), and in the BSSA (Sirovich and Pettenati, 2001). Here, we repeated and improved these inversions by: 1) using different intensity catalogues, and 2) by applying a Niching Genetic Algorithm, NGA, to speed up the automatic inversions (Levine, 1996). So doing, we obtained solutions which are consistent with those already published. Our technique uses Voronoi polygons and our KF kinematic model (Sirovich, 1996, 1997; Pettenati et al., 1999). It was possible to invert the regional intensity patterns of these two earthquakes because their data sets (one intensity datum per site; sites with heterogeneous geology) are sufficiently uncontaminated by local seismic responses, and retain regional traces of source effects. The Jan. 9 and Jan. 11, 1693 sources - constrained by our inversions - form a NNE oriented segmented fault, approximately 60 km long; then, according to the different intensity data sets, the retrieved fault is steeply dipping towards ESE, or WNW, with rupture mechanism from pure strike-slip to 50% strike-slip and 50% dip-slip. This active structure would cross SE Sicily from the Hyblean Plateau to the coast of the Ionian Sea, south of the city of Catania. It is worth mentioning that this complex source best fits the regional distribution of damage observed in the field by various authors. At the limit of the negative error of the dip angle at depth, a value of 54° makes our line source for the Jan. 11 event compatible with the
trace of the Scicli-Ragusa-Monte Lauro active transcurrent fault found in the field, which outcrops 12-14 km to the west (Grasso and Reuther, 1988; see their Fig. 5). The retrieved complex source is compatible also with the orientation of the maximum horizontal geodynamical compressive stress, confidently measured in the area, as well as with an authoritative tectonic interpretation, independent from this study. The combined use of tessellation, of our KF model, and of the NGA genetic algorithm is promising for automatically inverting intensity data sets of preinstrumental earthquakes. Our automatic technique was recently validated by treating the data of a recent and well documented earthquake in the Great Los Angeles Region, California (Pettenati and Sirovich, 2003, Vol. 93, No. 1, pp. 47-60 by the BSSA).

**Keywords:** Sicily, 1693, microseismic intensity, source inversion, genetic algorithms.

## 1 Introduction

Regarding the theoretical basis, and the validation of our inversion technique, we refer to the papers mentioned in the Abstract. We stress that the work presented here is original, and that it was exclusively developed for the GNDT Catania2 Project. Thus, we inverted the new intensity data sets by Barbano and Rigano ([1]; in the EMS98 scale). According to our technique, we retrieved the following parameters: the Seismic Moment $M_0$, the epicentral coordinates, the depth of the nucleation, the fault-plane solution (strike, dip, and rake angles), the rupture length along strike (we call it positive length, $L_+$) and anti-strike (negative length, $L_-$), the along strike and anti-strike rupture velocity ($V_r$), the shear-wave velocity $V_s$ in the half-space. Regarding $V_r$ and $V_s$ we use the Mach Number concept; thus, we have a positive Mach Number, $Mach_+$, along strike, and a negative value in the opposite direction. We inverted both the intensities of the Jan. 9 event and those of the Jan. 11, 1693 main shock. Please note that the matter of the influence of site effects, and that of the relevance of the 1693 tsunami are thoroughly treated elsewhere (Sirovich and Pettenati [2, 3]). Barbano and Rigano [1] produced 31 data for the event of Jan. 9, and 179 for the main shock of Jan. 11. Given the physical limitations of our KF model (Sirovich [4, 5]), we inverted the data at epicentral distances shorter than 100 km, that is to say 27 data and 167 data, respectively for the two shocks. In Fig. 1, one can see the intensities of the earthquake of Jan. 9, 1693 from the CFTI catalogue by Boschi *et al.* [6], which were inverted by Sirovich and Pettenati [2]. Fig. 2 shows the intensities of the same event according to the new interpretation by Barbano and Rigano [1]. In Figs. 3 and 4 the reader can see the data of the Jan. 11, 1693 earthquake from CFTI, and by Barbano and Rigano [1], respectively. Our best fitting criterion in the source inversion is $\Sigma r^2$: the sum of the squared residuals $r$, where $r$ is equal to the intensity calculated by the KF model, minus the observed intensity (i.e. retrieved from historical documents). The absolute minimum variance models presented in Table 1 scored $\Sigma r^2 = 20$, and $\Sigma r^2 = 96$, respectively. Four demes (sub-populations) were used in each inversion to be able to find four minima.
Figure 1: The CFTI intensities (Boschi et al. [6]) of the Jan. 9, 1693 earthquake inverted by Sirovich and Pettenati [2].

Figure 2: The Barbano and Rigano [1] intensities of the Jan. 9, 1693 earthquake treated here for NGA source inversions.
Figure 3: The CFTI intensities (Boschi et al. [6]) of the Jan. 11, 1693 earthquake inverted by Sirovich and Pettenati [2].

Figure 4: The Barbano and Rigano [1] intensities of the Jan. 11, 1693 earthquake treated here by NGA source inversions.

2 Results

Our results are listed in Table 1. Note from Table 1 that the two sources, presently placed en-echelon, substantially agree with those which were found by the grid-search inversion technique (Sirovich and Pettenati [3]). Two results are
worthy of comment in detail. First, we refer to the strike angle of the fault-plane solution of the main shock. Note that, given our geometrical convention (Sirovich [5]), a strike angle of 200°, with the dip angle=77°, means that the rupture plane is steeply dipping towards WSW; and note that this plane does not substantially contradict the position of the plane previously obtained by Sirovich and Pettenati [3], which was sub-vertical (dip=80°) and NNE oriented (strike=28°). Then, we refer to the rake angle of the main shock (79°): this value is substantially different from those which were obtained by inverting the intensities reported by the CFTI catalogue (Boschi et al. [6]), and those by Barbano and Cosentino [7]. In fact, the present mechanism is mainly of the dip-slip type. We stress that this finding is a direct consequence of the new intensity data produced by Barbano and Rigano [1] which are considerably lower than before (see Barbano and Cosentino [7]; see Fig. 6 in Sirovich and Pettenati [2]) along the Ionian coast from the Etna area towards the city of Messina. This reduction of the elongation of the areas of XI, X, and of IX degrees towards NNE drives the genetic algorithm to the mechanism shown in Table 1.

Table 1:  Source parameters of the absolute minimum variance models of the two studied earthquakes, retrieved from automatic source inversions of intensity patterns by a Niching Genetic Algorithm.

<table>
<thead>
<tr>
<th>Earthquake PARAMETER</th>
<th>Jan. 9, 1693</th>
<th>Jan. 11, 1693</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude (°)</td>
<td>37.09 ±0.07</td>
<td>37.46 ±0.06</td>
</tr>
<tr>
<td>Longitude (°)</td>
<td>14.97 ±0.08</td>
<td>14.98 ±0.05</td>
</tr>
<tr>
<td>Depth (km)</td>
<td>10.0 ±1.7</td>
<td>25.1 ±2.3</td>
</tr>
<tr>
<td>Rupture length L (km)</td>
<td>total L = 19.5</td>
<td>total L = 50.6</td>
</tr>
<tr>
<td>L along strike</td>
<td>6.0</td>
<td>41.5</td>
</tr>
<tr>
<td>L anti-strike</td>
<td>13.5</td>
<td>9.1</td>
</tr>
<tr>
<td>Strike angle (°)</td>
<td>37* ±8</td>
<td>200* ±9</td>
</tr>
<tr>
<td>Dip angle (°)</td>
<td>70 ±8</td>
<td>77 ±4</td>
</tr>
<tr>
<td>Rake angle (°)</td>
<td>13 ±8</td>
<td>79 ±8</td>
</tr>
<tr>
<td>Mach number ([=V_r/V_s])</td>
<td>0.83 ±0.02</td>
<td>0.95 ±0.02</td>
</tr>
<tr>
<td>Mach along strike</td>
<td>(0.86 or 0.87) ±0.05</td>
<td>0.90 ±0.03</td>
</tr>
<tr>
<td>Mach anti-strike</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vs (km/s)</td>
<td>3.98 ±0.05</td>
<td>3.95 ±0.04</td>
</tr>
<tr>
<td>(M_0) ([10^{19}\text{ N\cdot m}])</td>
<td>0.31** ± 0.8</td>
<td>3.99*** ±0.055</td>
</tr>
</tbody>
</table>

¶ There is an unavoidable ambiguity of ±180°.

* In the adopted geometric convention, the plane is dipping to the right.

** Corresponds to M=6.25 in accordance to formula M=2/3\((\log M_0)-10.7\) (see: Stover and Coffman [12]; eq. 6).

*** As before, corresponds to M=7.03.

Figs. 5, 6 and Fig. 12 in Sirovich and Pettenati [3] show the structures of the multiparameter source spaces of this kind of geophysical inversion; those figures inform on the location of the minimum residuals. In this work, we directly address the reader to Figs. 5 and 6, where he can find the intensities which were synthetically produced by the minimum variance models of the Jan. 09, and
Jan. 11, 1693 earthquakes, automatically retrieved by the NGA inversions starting from the Barbano and Rigano [1] data.

Figure 5: Synthetic pseudo-intensities produced by the minimum variance source model automatically retrieved by NGA inversion of the Barbano and Rigano [1] data; Jan. 09, 1693 earthquake.

Figure 6: Synthetic pseudo-intensities produced by the minimum variance source model automatically retrieved by NGA inversion of the Barbano and Rigano [1] data; Jan. 11, 1693 earthquake.
3 Conclusions

We stress that the new source inversions presented in this paper are automatic, without constraints, and original. Also, it is worth mentioning that the source parameters retrieved by inverting the macroseismic intensities by Barbano and Rigano [1] substantially agree with those already found by inverting by the grid-search method, with tectonic constraints, the aforementioned previous catalogues. In particular, this agreement holds for the epicentral coordinates and the fault-plane solutions of the two earthquakes. The previous inversions identified a segmented source, in part mainly strike-slip (for the Jan. 9 shock) and in part 50% strike-slip and 50% dip-slip (Jan. 11); the present inversions identify an en-echelon structure in part strike-slip (Jan. 9) and in part dip-slip with a minor strike-slip component (Jan. 11). The differences come from the different intensity data sets which were inverted. However, the recurrence of these results for the two strong shocks of 1693 suggests that the solution of an inland complex source, crossing the Hyblean Plateau from SSW to NNE, is rather robust and stable.

References

