The New Catalogue of Italian Tsunamis

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Abstract. A new Italian tsunami catalogue (ITC) is presented here. It contains 67 events, covering the period from the tsunamigenic Plinian eruption of Vesuvius (79AD) until today. It is the result of intense scrutiny of the original sources of data, and integrates and updates the tsunami catalogue by Tinti and Maramai (TMC) published in 1996. With respect to the TMC, six new events have been added and six have been eliminated, while the 61 events common to both catalogues have been all re-examined and re-evaluated. The ITC fits the criteria adopted for the catalogue of tsunamis in the European region in the framework of the EU projects GITEC (1992–1995) and GITEC-TWO (1996–1998). It is in the form of a digital database, that was implemented through the Visual FoxPro 6.0 DBMS with the main purpose of building a rigorous and easy-to-use working tool for scientists as well as for people involved in hazard and risk reduction in coastal areas. Through the main catalogue screen, the user is allowed to browse the database and to get all the information concerning a selected event (occurrence date, cause, detailed description, references, etc.). Furthermore, by means of functional buttons, the user can perform data extractions according to several key combinations (date, generation, sub-region, tsunami intensity, cause, etc.) and also access the related database of the references containing about 230 entries. In addition to data in the form of text, the ITC also includes a gallery of images documenting tsunami damage and a unique set of analogue tide-gauge records. A further section of statistics provides space and time distribution of the events, tables and histograms. The catalogue is available at the INGV web site http://www.ingv.it/italiantsunamis/tsun.html and can be freely downloaded.

Key words: Catalogue, digital database, Italy, statistics, tsunamis.

1. Introduction

Catalogues of tsunamis in the European seas have been assembled since the 1960s, first in the form of regional compilations (see papers by Galanopoulos, 1960, on tsunamis in Greece, and by Ambraseys (1962), on tsunamis in the Eastern Mediterranean), and then with a broader view (e.g., Antonopoulos, 1990; Soloviev, 1990, and Soloviev *et al.*, 2000, on tsunamis in the Mediterranean sea). In the 1990s the idea of assembling a catalogue covering all European tsunamigenic zones, which used the same criteria for the interpretation of historical sources, parameter estimation and data presentation, was conceived and implemented by a special working group created in the frame of the European Union projects GITEC (Genesis and

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Impact of Tsunamis on the European Coasts) and GITEC-TWO (Genesis and Impact of Tsunamis on the European Coasts – Tsunami Warning and Observations). The final result of their work was the first digital database of European tsunamis (Tinti, 1993; Tinti *et al.*, 1999a). Version 1.1 of the database was released in October 1998 under the name "GITEC Tsunami Catalogue" (see GITEC-TWO Final Scientific Report, 1999).

The first compilation of Italian tsunamis is mainly due to the tenacious work of Caputo and was published in the 1980s (Caputo and Faita, 1984; Bedosti and Caputo, 1986). That work had the relevant merit of outlining the significance of the tsunami problem for Italy. It showed that Italy is the second country of Europe after Greece to be affected by damaging tsunamis. But it had a notable drawback: data collection had been carried out by the authors deliberately with scarce analysis of the sources, since the prevailing logic was to gather as much material as possible and to leave the job of data scrutiny and interpretation to the reader. The effect was that more than 150 entries were included in the catalogue. A decade later, Tinti and Maramai (1996) applied the same criteria that were being established for the European GITEC catalogue to the Italian data. Their basic philosophy was totally diverse from Caputo et al.'s work, since it was based on the concept that one of the chief tasks of the compilers is to filter raw data by means of a prior minute examination of the sources. This careful examination led to a compilation of only 67 events, with the elimination of many entries of the previous catalogue due to a variety of reasons (double events, false events, etc.). The Italian tsunami catalogue presented in this paper (ITC for short) is the result of the research that was undertaken in the years since the end of the European project GITEC-TWO, and should be viewed as the continuation and completion of the studies that were the basis of the 1996 Tinti and Maramai catalogue (TMC).

2. What is a Tsunami?

It is not our intent to provide a general-purpose definition of a tsunami, but only to specify the definition that was adopted for compiling the ITC: "Tsunami is a series of sea waves generated by a large-scale source that can be 1) the sudden displacement of the sea floor due to tectonic dislocation, or 2) the motion of a body sliding along the sea floor". This means that basically the accepted primary tsunami causes are earthquakes and landslides, either entering the sea from the coast or starting underwater. On the other hand, volcanic activity is also taken into account as a possible tsunamigenic source since it may be associated with seismic shocks, the failure of a volcanic edifice (flank or caldera collapse), or with tsunamigenic pyroclastic flows or surges.

It is opportune to clarify that "large-scale" tsunamigenic sources are here considered those sources capable of exciting long water waves with periods in the order of tens of seconds or more. Though the above definition may appear either too generic or too trivial, nonetheless it serves as an effective criterion to decide

whether an event can be considered worthy of inclusion in the catalogue or not. In particular, attention is drawn to two categories of events that do not fit the ITC tsunami definition: (1) water waves generated by meteorological perturbations; (2) water waves excited by tsunamigenic-like sources in water basins other than the sea. Storm surges are the most common mechanism of large-amplitude sea wave generation, but these cannot be considered a tsunami since their period is smaller than 15 sec. However, fast moving large-scale atmospheric depressions are capable of exciting long water waves and seiches in coastal basins that possess hydrodynamic features not significantly different from tsunamis. Therefore, some researchers like calling them meteorological tsunamis. See Rabinovich and Monserrat (1996, 1998), for cases recorded in the Balearic Islands. As to the second class, closed basins like lakes and coastal lagoons are known to be as affected by earthquakes and mass slides as the open sea. Usually earthquakes excite the low-frequency eigenmodes of oscillations of the basins, while mass instabilities produce smaller-scale, but larger-amplitude waves that can also be catastrophic.

In Italy, ice-falls in glacial lakes (e.g., the lethal ice detachment that occurred in 1996 in the Miage glacier described by Tinti *et al.*, 1999b), rockfalls, and slumps in alpine lakes are not rare events. One of the most tragic events that ever occurred in the recent history of Italy is the Vajont catastrophe. On 9th of October 1963 a huge rockslide detached from Mount Toc filling the reservoir formed by a dam in the Vajont valley. The enormous splash almost emptied the lake displacing most of its water beyond the dam, which resisted the impact. The water was channelled violently into the narrow valley downstream from the dam and soon reached the large valley of the Piave river where it swept out several villages. The flood destroyed almost everything along its path killing more than 2000 people (see the thorough reconstruction by Hendron and Patton, 1985).

Since neither meteorological seiches nor water waves produced in lakes fulfil the tsunami definition we have adopted here, the ITC does not include events of this kind. But we are conscious that they deserve proper attention both by scientists and by people involved in protection from natural hazards.

The final remark of this section regards waves generated by the impact of meteorites on the ocean. No such cases have ever been recorded in the world in historical times, though evidence of catastrophic inundations attributable to the crash of extraterrestrial objects on our planet in geological times is abundant (see Toon *et al.*, 1997); hence, whether or not our tsunami definition embraces this mechanism is totally inconsequential for the ITC.

3. The Basic Structure of the Catalogue

The Italian Catalogue of Tsunamis is a digital data base that was built by means of the Microsoft Visual Foxpro 6.0 Database Management System (DBMS) and runs on PC platforms Windows 95, Windows 98, Windows 2000 as well as the latest Windows operating systems. It contains data on 67 tsunamis affecting the

Figure 1. Main user interface of the Italian Tsunami Catalogue (ITC). The Main Screen (MS) displays event 66 of the database which corresponds to a tsunami that occurred in 1990 in eastern Sicily, that was observed at Augusta and was caused by an intensity VIII and magnitude 5.4 earthquake.

Italian seas, the first of which is the tsunami that was generated by the large Plinian eruption of Vesuvius. This eruption destroyed Pompei and other Roman villages in 79 AD; it was recounted by the Roman writer Plinius Junior, whose description is the first historical account of a natural catastrophe made with a scientific approach. The complete list of the events is given in the Appendix A.

The main user interface of ITC is the Main Screen (MS) depicted in Figure 1. As may be seen, it is formed by six informative boxes providing data on a selected event, and by a number of functional buttons, by means of which the user can perform operations on the database, and have access to ancillary tables and data sets. The example given in Figure 1 concerns a tsunami that occurred in 1990 in association with an $I = 8.0$ (MCS scale) earthquake that occurred in eastern Sicily close to the town of Augusta. The box in the upper left corner of the MS supplies the event identification code (66), which is a number used by the database software to point to the entry, as well as the event reliability (4), that is an important parameter on which details will be given later. Information on the date and place of the tsunami occurrence, the generating mechanism, and the tsunami size (maximum run-up observed in cm, tsunami intensity and tsunami magnitude) are provided in other specific boxes that are entitled respectively "Date information", "Region information", "Source information" and "Tsunami information".

An on-line help facility can be utilised by the user to get more details on the parametric scheme adopted in the catalogue. For example, after clicking on the button called "Map", the user obtains the map of the 15 sub-regions into which the Italian coasts have been subdivided within ITC, displayed in Figure 2. Notice that Liguria (Italy) and Côte d'Azur (France) are considered as a unique tsunamigenic sub-region since usually tsunamis generated in the Ligurian sea affect the coasts of both areas. Notice also that the Sardinia coasts are not taken into account, since no event is known to have been generated there. A further example of what can be obtained through the on-line help is the screen reproduced in Figure 3, obtained by clicking on the underlined word "Cause" in the "Source information" box. It explains the code used in ITC to specify the generating cause of the tsunami. Observe that there are different codes for tsunamigenic mass failures, distinguishing cases where sliding is due to pure gravitational instability from cases where the rupture is triggered by earthquakes or by volcanic eruptions.

A short summary displayed in the MS provides an essential description of the phenomenon, but additional details can be obtained through the "Description" button located in the bottom box of the MS. Figure 4 shows the Description window that opens after clicking this button. The user finds here an account of the causal event and everything that is known about the tsunami, together with all the references available for the case. References are provided by means of the name of the author (or of the first of the authors) followed by rxxx where xxx is the numeric code identifying the work in the ancillary References Database (RD). In this example, the user learns that the main reference to the 1990 Augusta tsunami is found in the work by De Rubeis et al. with code r207 (see Figure 4). Then he can access the RD by means of the functional button called "References" on the bottom line of the MS (see Figure 1) and query the database by making use either of the above reference code or of the author name, to discover that De Rubeis *et al.*'s work (1991) is a contribution contained in a special Internal Report of the ING (today INGV) published soon after the earthquake.

Other functions can also be activated. For example, the "Extraction" button allows the user to select a list of events by using various extraction keys or combination of keys (year, sub-region, cause, reliability, intensity). In addition, through the command found on the right side of the MS, the user can order the entries by year, identification code, sub-region or cause code, and then browse the database back and forth by pressing the left- and right-arrow keys. Moreover, the box "Search" in the lower right corner of the MS helps one find a given event in the ITC by entering its year of occurrence in the data entry window; in response the system will sort the entries in chronological order and point to the first event of the specified year. The user can then advance to the following events by pressing the right-arrow key. Providing all the details on how to use the catalogue goes beyond the scope of this paper, and it is believed that the account given here suffices to help the reader grasp the main concept, structure and facilities of this tool.

Figure 2. Map showing the location of the 15 ITC sub-regions. It is displayed after the ITC user presses the button "Map" on the MS.

4. Tsunami Size

Estimating the size of a complex phenomenon like a tsunami or an earthquake by means of a parametric scale is difficult and maybe even debatable. It is nonetheless a recognised need and a common practice, and size parameters are considered by most people to be the most relevant parameters to search for in catalogues of natural events. The ITC uses intensity and magnitude to quantify a tsunamigenic earthquake and uses the explosivity index VEI (Simkin *et al.*, 1981) to quantify a volcanic eruption. With regard to tsunamis, the 6-degree intensity scale by Sieberg and Ambraseys (Ambraseys, 1962) is used to quantify the effects of a tsunami on coasts and structures. An intensity = 1 tsunami is very light and only visible on
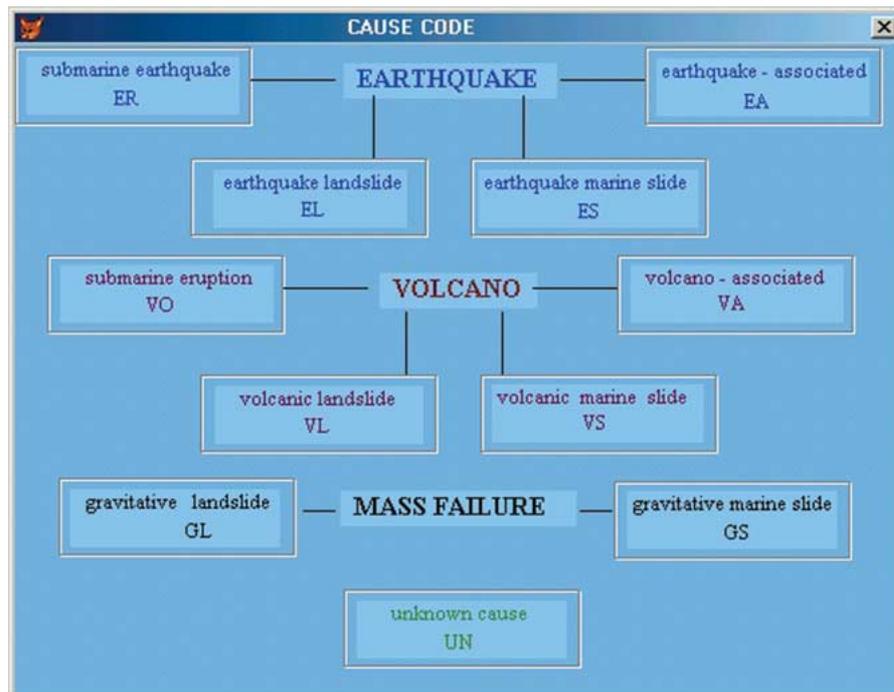
Figure 3. Sketch explaining the cause code adopted in the ITC. It is obtained by clicking on the underlined word "Cause" of the MS, while the MS remains in the background.
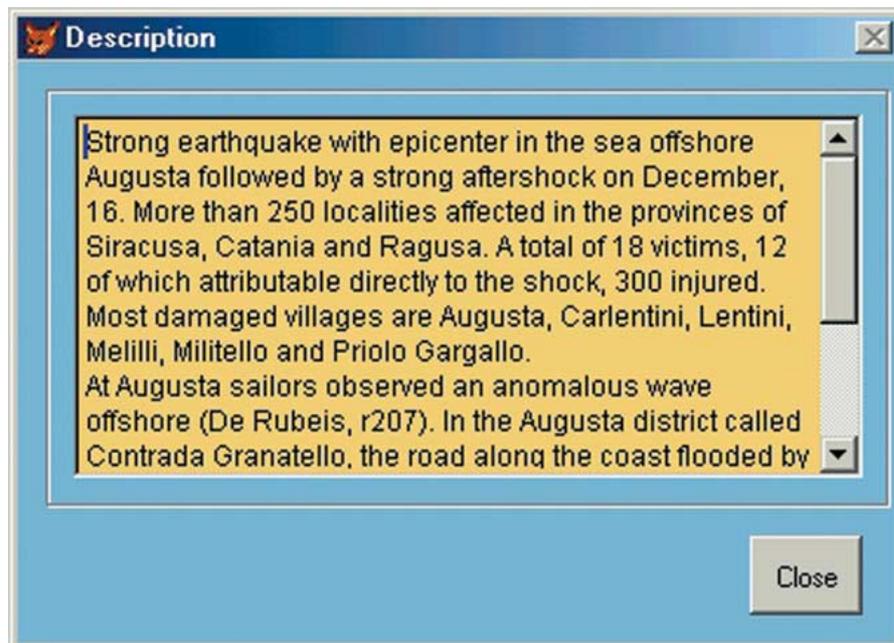

Figure 4. After pressing the button "Description", the Description window is displayed on the ITC Main Screen. It contains more details on the event and the related references.

tide gauge records, while at the top of the scale an intensity = 6 tsunami is capable of causing large disasters with total destruction of man-made structures, extensive flooding, many casualties, etc.

The magnitude is a parameter not frequently used in tsunami catalogues. In a way analogous to the earthquake magnitude, the magnitude of a tsunami conveys information about the strength of the source rather than the effects of the waves. Murty and Loomis (1980) introduced a magnitude scale suitable for tsunamis produced by earthquakes based on the initial potential energy of a tsunami E_P. Their formula is simple:

Tsunami Magnitude = 2 (Log E_P − 19)

where E_P is given in erg and may be calculated by means of the expression:

$$E_P = \frac{1}{2} \int \rho g h^2 ds.$$

Here the integral is extended over the whole tsunami source area, ds is the infinitesimal area element, ρ is the water density and h is the vertical displacement of the ocean surface from the still level. Their idea is that the sudden dislocation of the sea floor has the effect of vertically displacing the sea water, and consequently, the ocean gains potential energy. At the end of the quake, the sea water is out of equilibrium and the potential energy gained is available for the propagation of tsunami waves. This point of view is justified by numerous hydraulic experiments (see the fundamental work by Hammack, 1973) and is commonly adopted by tsunami modellers, who are accustomed to taking a water wave profile similar to the sea floor dislocation and a null initial velocity as initial conditions for their numerical simulations (e.g., Tinti *et al.*, 1995). This concept cannot be applied to the generating mechanism other than for submarine earthquakes, and therefore no tsunami magnitude has yet been suggested for waves generated by landslides or pyroclastic flows.

In the ITC, the Murty and Loomis expression has been adopted and computed for those tsunamis for which studies aimed at identifying the parent fault and the related seismic focal parameters are available in the literature. The procedure is as follows: once the fault is given, the solid earth surface displacement h_E is calculated through the classical Okada's model, under the hypothesis of a homogeneous Earth with a flat surface and of a rectangular uniform-slip fault (see Okada, 1992), then the sea surface displacement h is posed equal to h_E in the submarine portion of the source, and integrated according to the equation given previously. The magnitude values obtained in this manner are displayed in Table I. It is worth noting that the constant 19 appearing in the formula was chosen by Murty and Loomis in such a way as to get similar values for both the tsunami magnitude and the magnitude of the associated earthquake. It was calibrated for the large events in the Pacific Ocean with M_W about 8 or higher, and leads to very discrepant values for smaller

Table I. Tsunami magnitude table. Tsunami magnitudes have been computed only for the 5 cases listed in this table, for which the needed focal parameters of the parent earthquakes could be estimated. Fault data are in accordance with tsunami numerical simulations performed by Tinti and Piatanesi (1996), Tinti *et al.* (2001), Tinti and Gavagni (1995). Piatanesi and Tinti (2002), and Tinti and Armigliato (2000) for the cases respectively listed in rows 1 to 5 of the table

Event subregion: Date	Lon*	Lat*	Depth (m)	Length (km)	Width (km)	Strike (°)	Dip (°)	Rake (°)	Slip (m)	E_p (erg)	M_L
Gargano: 30 Jul 1627	15.25	41.88	100	35	20	0	90	270	1.3	2.12×10^{18}	−1.4
Eastern Sicily: 11 Jan 1693	15.33	37.07	2000	50	15	166.5	90	90	6.2	1.41×10^{20}	+2.3
Tyrrh. Calabria: 5 Feb 1783	15.92	38.20	100	50	35	233	60	270	1.0	1.29×10^{18}	−1.8
Tyrrh. Calabria: 8 Sep 1905	16.01	38.73	100	30	20	245	80	270	2.5	1.61×10^{19}	+0.4
Messina Straits: 28 Dec 1908	15.53	38.07	4000	45	18	11.5	29	270	1.42	6.06×10^{18}	−0.4

* Co-ordinates of the mid point of the upper border of the assumed fault.

Table IIa. Reliability scale of the Italian Tsunami catalogue

Reliability	Description	Cause	Tsunami	Sources
4	Definite Tsunami	×	×	×
3	Probable Tsunami	×	×	/
2	Questionable Tsunami	×	/	×
		/	×	×
		□	×	×
1	Improbable Tsunami	×	/	/
		/	×	/
		□	×	/
0	Very Improbable Tsunami	/	/	×
		/	/	/
		□	/	×
no	No Tsunami	All other combinations		

earthquake sources which are the rule for Italy. Therefore, it is not surprising that the tsunami magnitudes in Table I are so small.

5. Tsunami Reliability

Reliability of the entries in the ITC were been graded according to the 5-degree modified Iida scale that was introduced by Tinti and Maramai (1996) in the TMC, and ranges from degree 0, equivalent to a "very improbable tsunami", to degree 4 corresponding to a "definite tsunami". The reliability is a very important parameter which helps the catalogue user judge the quality of the data. Unfortunately, it was only recently introduced into tsunami catalogues and was sporadically used in the past. There is no doubt that it is inevitably the result of the judgement of the experts assembling the database and is therefore intrinsically subjective, but subjectiveness can be tempered if some criteria are defined and coherently applied to the data.

The approach for determining reliability that was outlined in the TMC was better defined for the ITC. It consists of taking into account and rating separately different elements or categories of the data, namely: (1) what is known about the tsunami cause, (2) what is known about the tsunami itself, and (3) what is known about the documentary sources. Each category is rated on three levels, and then the final reliability is obtained by combining these partial scores according to the scheme given in Table IIa.

Table IIb clarifies the basis for the reliability score attribution, but deserves some comments, especially with regard to the columns "Tsunami" and "Sources". Considering the former, we point out that not all of the descriptions of anomalous behaviour of the sea following a potentially tsunamigenic event (namely

Table IIb. Meaning of the symbols

Symbol	Cause	Tsunami	Sources
□	No information	No specific information	Very Posterior
/	Scarce/uncertain information	Scarce/uncertain specific information	Posterior
×	Good information	Good Specific information	Coeval

earthquake, volcanic eruption or landslide) can be considered as descriptions of tsunamis. For example, accounts of sea agitation, or of seamen feeling their boats hit from below by anomalous shocks, concern phenomena that are not peculiar to a tsunami, and hence cannot be taken as proof of a tsunami occurrence. For this purpose, at least some specific characteristics of a tsunami have to be reported, such as observations of long-period waves and oscillations, of large sea retreat or flooding, etc. In view of this, if no data can be found that are specific to a tsunami from the available sources, the attributed rate is "□". On the other hand, if such data exist, then the rate is "/" or "×" depending on their quality and clarity. With regard to the documentary sources, emphasis is put on the delay between the event occurrence and the date of the source; considering that time elapsing may corrupt and confuse memories, reliability is taken to decrease with increasing delay. Hence, the score is given on the basis of the time interval separating the event and the oldest available source. If the event and the source are coeval, the score is "×"; if the source is very subsequent, which means that the author or authors lived several generations later (i.e. several tens of years or centuries), the score is "□"; and for an intermediate delay, the score is "/". Appendix B provides the list of all the events in the ITC with the partial rates attributed in the three categories and the resulting value of reliability.

6. Tsunami Images

The ITC contains a small gallery of images that can be accessed by means of the "Images" button placed in the bottom string of the MS (see Figure 1). These figures have been gathered from the literature and the documentary sources, scanned and later refined in order to improve their quality. They are pictures documenting damage produced by tsunamis, or records of analogue tide-gauges. A sample of these can be seen in Figures 5–7. Figure 5 displays mareograms of the tsunami that occurred in 1887 in the Liguria-Côte d'Azur region recorded by gauges in the ports of Nice and of Genoa. They are also reproduced in a recent study by Eva and Rabinovich (1997) who performed numerical simulations of the tsunami and spectral analysis of the experimental records. Figure 6 reproduces the gauge records of the ports of Palermo, Napoli and Civitavecchia capturing the tsunami of the 28 December 1908, which is one of the most destructive tsunamis that
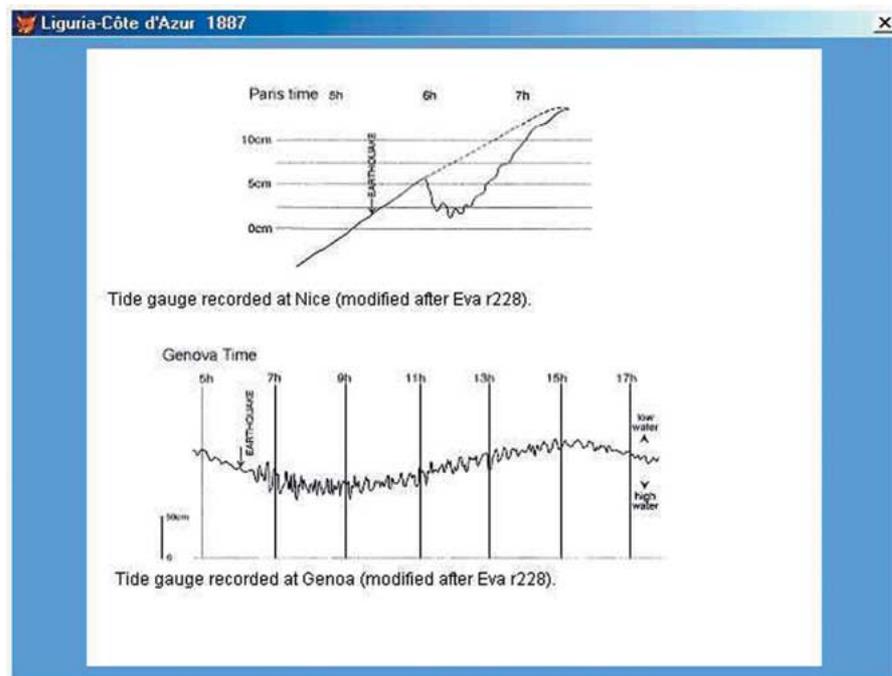
Figure 5. Signals of the 1887 tsunami recorded by tide-gauges located in Nice and in Genoa. Scanned image belonging to the ITC gallery.

ever occurred in Italy. They are taken from the monograph by Giovanni Platania (1909) who made a very accurate post-event survey on the Sicily and Calabria coasts affected by the tsunami, and collected all the available tide-gauge records by personally contacting the port authorities in charge of the operation. As may be seen, the gauge in Palermo was not functioning at the time of the tsunami attack, but when it was put in operation a few hours later it was still able to record the trace of the tsunami perturbation. Figure 7 displays the signals recorded by the gauges placed at Faro (Sicily) and at Messina, due to a tsunami of volcanic origin that occurred in 1919 and was observed in many places in the southern Tyrrhenian sea. The records are from the work of Gaetano Platania (1922), who quotes the tsunamigenic explosion of 1919 in a scientific account of the eruption of Stromboli in May 1922.

7. Tsunami Statistics

The total number of events in the ITC is 67, which is quite low and does not permit sophisticated statistical analyses. It is however possible to compile valuable frequency tables, histograms and space distribution maps. Some are available in the ITC and can be accessed by means of the "Statistics" button in the MS. The first frequency table, displayed in Table III, gives the time distribution of events per
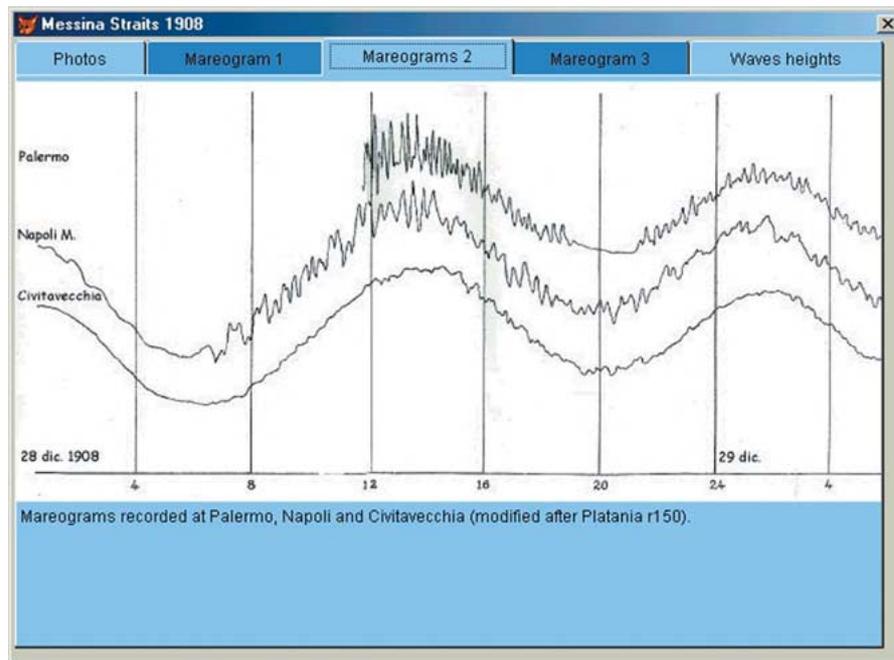
Figure 6. Scanned image of 3 tide-gauge records of the 1908 Messina Straits tsunami. This image is displayed by selecting the item "Mareograms 2" from the 5-item menu on the top of the screen.
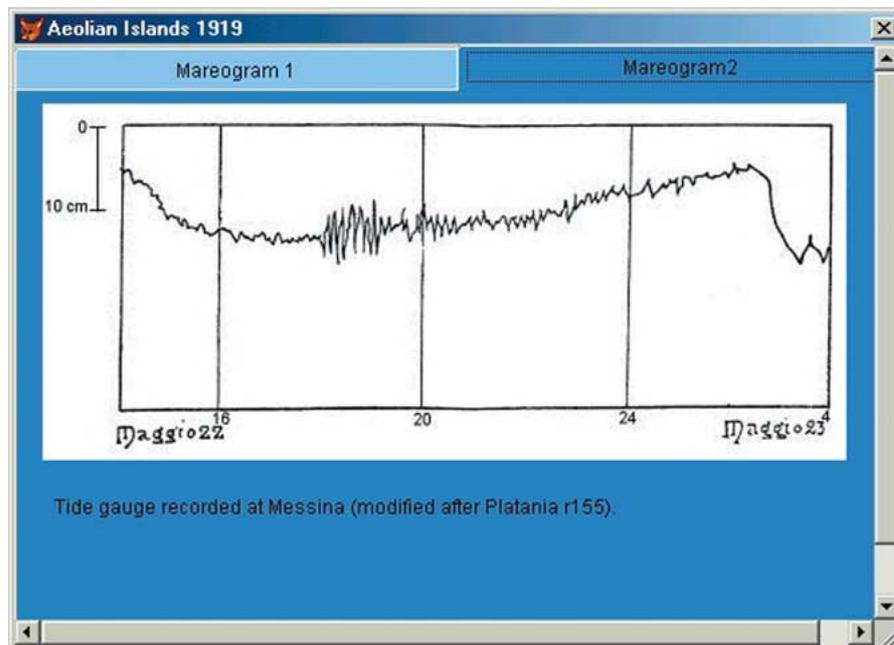
Figure 7. Picture of the record of the 1919 tsunami taken at Messina. The user can obtain this image by selecting the item "Mareogram 2" from the 2-item menu on the top of the screen.

Figure 8. Space distribution of the events of the catalogue: circles indicate the place of occur-
rence. When more events occurred in the same place, the numbers beside circles indicate the
total amount of events.

reliability classes. The last column of this table shows the frequencies of reliability
and indicates that most entries in the catalogue are definite or probable tsunamis,
having been attributed reliability values of 4 (37 events) or 3 (two events). This
property is common to all columns on the right side of the table, corresponding
to the last three centuries, which is an obvious effect of data tending to be more
abundant and less equivocal as time advances and science progresses. The time
distribution is rather unequal. Only three entries are found prior to 1300 and only
six prior to 1600. But in later times, the total number of entries per century is rather
stable (on average 15). This certainly means that ITC is far from complete until the
16th century, and gives some hints on the possible completeness of the catalogue
in the following times.

Table III. Time distribution of events per reliability class

Reliability	Time 0–1000	1001–1300	1301–1600	1601–1700	1701–1800	1801–1850	1851–1900	1901–1950	1951–2002	Total
0				1	2	1				4
1					1	2			1	4
2	1	1	2	4	4	3	2	2	1	20
3					2					2
4		1	1	5	7	7	3	8	5	37
Total	1	2	3	10	16	13	5	10	7	67

The space distribution of the events is displayed in the map of Figure 8 and can also be grasped from Table IV which gives the time distribution of events per sub-region. The sub-regions with the highest frequencies are Campania and Liguria-Côte d'Azur, with activity peaking in the 19th century. It can also be observed that most tsunamis affect the broad area covering the southern Tyrrhenian and northern and eastern Sicily coasts (corresponding to five ITC sub-regions, namely Tyrrhenian Calabria, Aeolian Islands, Messina Straits, Northern Sicily and Eastern Sicily): here as many as 29 events are concentrated, 20 of which have the highest reliability degree (3 or 4).

Table V shows the time distribution of the intensities. Notice that there are no intensity 1 events in ITC (these events are only perceptible on instrumental records), as a consequence of the deprecable lack of coverage of the Italian seas by tide-gauges tuned on tsunami time frequencies. Apart from this, frequencies decrease with the intensity, as expected (see the rightmost column of the table), although this is not strictly respected in all time windows (see the other columns), probably due to random fluctuations that are more common in small samples. In total, 26 events have intensity ≥ 3, which are tsunamis capable of producing at least some damage to boats and coastal structures. The events with intensity 5 and 6, which are the highest intensity values in the Sieberg-Ambraseys scale, are large tsunamis causing severe damage over extensive segments of the coast and victims. The events with intensity 6 are the 6 February 1783 and the 28 December 1908 tsunamis which were both in the Messina Straits sub-region. The former was due to an earthquake probably located in the Messina Straits, that caused a huge rocky portion of Mount Pací to collapse into the sea. The consequent generation of high waves affected villages close to the northern entrance of the Straits and killed more than 1500 people on the beach of Scilla in Calabria (see the coeval reports by Sarconi, 1784, and Minasi, 1785, and the revision study by Tinti and Guidoboni, 1988). The second was unequivocally of seismic origin. It followed a catastrophic earthquake which devastated eastern Sicily and the southern Calabria villages, and had an estimated toll of victims larger than 60,000. It is the tsunami with the most abundant documentation in the ITC, in terms of original documents, minutely detailed reports, monographic studies, tide-gauge records, and recent scientific contributions, which were aimed at identifying the seismic source and simulating the tsunami generation and attack (see Tinti and Giuliani, 1983a and 1983b; Piatanesi *et al.*, 1999; and Tinti and Armigliato, 2000).

The frequencies of the tsunamigenic causes (see Figure 3 for acronyms) given in Table VI reveal that the vast majority of tsunamis are determined by earthquakes, which is common to all the regional catalogues in the world, that a smaller proportion are engendered by volcanic activity and that very few are induced by mass failure due to mere gravity load. One such example is the 1979 tsunami. It was caused by the submarine slope failure that occurred concomitantly with the construction works to enlarge the airport of Nice, and affected the surrounding coasts with waves as high as 3 meters. From the table it can be seen that four low-

Table IV. Time distribution of events per sub-region

Sub-regions	Time								
	0–1000	1001–1300	1301–1600	1601–1700	1701–1800	1801–1850	1851–1900	1901–1950	1951–2002	Total
North Adriatic			1							1
Central Adriatic				1			1		1	3
Gargano				1	1		1			3
Apulia					1					1
Ionian Calabria					1	2		1		4
Eastern Sicily		1	1	2		1			1	6
Sicily Channel					1	1				2
Northern Sicily				1	1	1		1		4
Messina Straits				1	2			1		4
Aeolian Islands								5	3	8
Tyrrhenian Calabria				1	4		1	1		7
Campania	1	1		2	2	3		1		10
Latium					1					1
Tuscany				1	1	1				3
Liguria-Côte d' Azur			1		1	4	2		2	10
Total	1	2	3	10	16	13	5	10	7	67

Table V. Time distribution of events per intensity class. There are 66 assigned intensities instead of 67, since no intensity value could have been attributed to the 1889 Gargano tsunami, due to the lack of specific details on wave effects on the coasts. This event treated by Baratta (1901) was recently revised by Tinti *et al.* (1995)

Intensity	Time									Total
	0–1000	1001–1300	1301–1600	1601–1700	1701–1800	1801–1850	1851–1900	1901–1950	1951–2002	
1										0
2	1	1	2	6	12	9	1	4	4	40
3			1	2	3	2	3	4	1	16
4		1				2		1	1	5
5				2					1	3
6					1			1		2
Total	1	2	3	10	16	13	4	10	7	66

Table VI. Frequency of tsunami generation causes

Reliability	Cause EA	ER	EL	VS	VA	VL	GS	GL	UN	Total
0–4	30	17	1	5	7	1	1	1	4	67
3–4	17	12	1	4	2	1	1	1	–	39

reliability events have been accepted in the ITC, although their cause is unknown. This is however in agreement with the adopted reliability scheme provided in Table IIa. The cases involved are a few events for which the reported descriptions contain elements that are distinctive of a tsunami, and either occurred in sea regions where submarine mass failures can be reasonably assumed as the generating mechanism (see the 1809 event), or took place in remote periods when accounts of earthquakes or volcanic activity are quite sporadic and the corresponding catalogues are largely incomplete (see the example of the 1112 event in the Gulf of Naples).

8. Elimination and Addition of Entries

The analysis of the data sources that was performed to compile the ITC and the systematic application of the reliability scheme discussed in previous sections, led to the conclusion that several accounts describe events that cannot be considered tsunamis and cannot be included in a tsunami catalogue. The analysis was focussed particularly on the events of the last two centuries, for which possible accounts have been intensively searched for in newspapers, gazettes, and magazine archives. Because the user of the catalogue may find it useful to know both the events and the reason for their exclusion from the database, a special section has been added in the ITC that can be accessed by means of the MS "False events" button. Table VII provides the list of 45 false events of the 19th and 20th centuries and some related statistics. They have been excluded from ITC for various reasons, the most frequent being that information on the cause and on the tsunami is confusing or does not exist in the documents (which is the condition coded as TC in the table legend). Notice that all of these false events were included in the Caputo and Faita compilation, and that as many as six events were also included in the TMC. Most of these are related to phenomena taking place in the Liguria-Côte d'Azur sub-region: since all six were rated low-reliability events in the TMC (reliability 0 in five cases, and reliability 2 in one case), downgrading them to "no tsunami" can be considered a minor change.

The ITC has been enriched by adding six new entries, three of which are definite cases of tsunamis (reliability 4). These cases are the 1988 tsunami that occurred as a consequence of a landslide from the flank of the volcanic island of Vulcano (Tinti *et al.*, 1999c); the December 1990 tsunami in eastern Sicily, which followed an

Table VII. False events. The events removed from TMC are marked with an aster-
isk. The rightmost column contains the partial reliability scores justifying the event
elimination according to the scheme given in Table IIa

Year	Month	Day	Sub-region	Exclusion reason	C	T	S
1774*	09	24	Tuscany	BC		/	/
1802	01	04	Central Adriatic	M	×		/
1804	07	31	Campania	TC	/		/
1806	08	26	Latium	T	×		/
1809	07	27	Campania	TC		/	/
1812	06	28	Liguria Côte d'Azur	TC		/	/
1813	04	07	Central Adriatic	S	×		
1813*	06	19	Campania	D			
1816	11	12	Liguria Côte d'Azur	TC			/
1818*	12	09	Liguria Côte d'Azur	TC	/		/
1819	01	08	Liguria Côte d'Azur	S	×		×
1820	07	23	Liguria Côte d'Azur	TC			×
1822	03	20	Northern Sicily	TC			/
1822	04	10	Eastern Sicily	T	×		
1824			Campania	TC			/
1826	03	18	Central Adriatic	S	×		/
1828	07	20	Liguria Côte d'Azur	TC			
1831	05	26	Liguria Côte d'Azur	T	×		×
1831	07	02	Sicily Channel	T	×		/
1838	08	10	Central Adriatic	T	×		/
1843	10	11	Sicily Channel	TC		×	
1845	06	18	Messina Straits	TC			/
1846	09–10		Tuscany	TC			/
1846	12	03	Tuscany	T	×		/
1850	04–05	10	Tuscany	TC			/
1851	12	16	Tuscany	TC			/
1852	02–06	11	Tuscany	TC			/
1854	12	29	Liguria Côte d'Azur	S	×		×
1862	11	24	Liguria Côte d'Azur	M			×
1870	10-11			TC			
1871	01	17	Liguria Côte d'Azur	TC			×
1876	12	23	Liguria Côte d'Azur	M			×
1880	04	25	Liguria Côte d'Azur	T	×		×
1885*	01	16	Liguria Côte d'Azur	M			×
1886*	11	11	Liguria Côte d'Azur	M			×
1886*	12	17	Liguria Côte d'Azur	M			×
1892	11	15	Latium	S	×		×

Table VII. Continued

Year	Month	Day	Sub-region	Exclusion reason	C	T	S
1894	12	27	Aeolian Islands	S		×	×
1895	11	01	Latium	T		×	×
1896	10	16	Liguria Côte d'Azur	S		×	×
1903	05	13	Northern Sicily	TC		×	/
1914	01	15	Tuscany	T		×	×
1919	10	22	Latium	S		×	×
1939	01	27	Aeolian Islands	S		×	×
1941	03	16	Northern Sicily	T		×	×

D = Duplication of another event. M = Waves due to a meteorological perturbation. T = No tsunami data. TC = Neither tsunami data nor indication of the possible cause. BC = No mention of tsunami effects on coheval sources and lack of knowledge on the possible cause. S = Event with seismic origin for which no accounted evidence on the occurrence of a tsunami can be found.

earthquake with an offshore source that affected more than 250 villages and killed 18 people (see De Rubeis *et al.*, 1991, and the MS screen displayed in Figure 1); and the 30 December 2002 tsunami occurred in Stromboli as the consequence of a sequence of landslides in the Sciara del Fuoco subaerial and submarine flank, associated with an intense eruption period. This very recent tsunami caused large destruction on the northern coast of Stromboli that was attacked by waves as high as 8-10 meters in several places, but killed no people since it occurred fortunately in winter season, i.e. in a season when the island is usually not populated by the tourists that are conversely so numerous in summertime. This tsunami has been extensively studied (see e.g., Bonaccorso *et al.*, 2003; Maramai *et al.*, 2003; Tinti *et al.*, 2003), and has shown the need for continuous monitoring of the stability of the north-east sector of the volcano and for the emplacement of a tsunami warning system to alert the population of Stromboli and of the neighbouring islands of the archipelago.

9. Conclusions

The Italian Tsunami Catalogue improves and updates the previous tsunami catalogue by Tinti and Maramai (1996). The data base spans a time interval of 2000 years, but it is largely incomplete in the first millennium AD for which only one event (79 AD Vesuvius eruption tsunami) is included, attaining completeness possibly only in the last three centuries. Most of the entries have a high level of reliability (3–4), though the documentation is generally scarce and is abundant only for a few cases (for example the Messina Straits tsunami of 1908). Tsunamis reported to have produced some damage (intensity 3 or larger) are the vast majority, but the known cases of severely damaging or catastrophic tsunamis (intensity 5

and 6) are very few. The relatively modest proportion of tsunamis causing large effects on the coastlines can be easily explained by the fact that most Italian coasts remained deserted or almost uninhabited for a very long time. Since the level of coastal occupation and development has increased steadily in recent years in Italy, as in many other countries of the Mediterranean sea, vulnerability of coastal zones has also increased. Therefore the action of future tsunamis having the same magnitude as the past intermediate-intensity events can be expected to be much more damaging. Southern Italy sub-regions emerge as the ones most prone to damaging tsunamis; in particular the areas embracing the Straits of Messina, including southern Tyrrhenian and eastern Sicily, are the most exposed, which is in agreement with previous analyses. Earthquakes are the most frequent cause of Italian tsunamis, but cases related to volcanic activity of Stromboli, Vulcano and Vesuvius cannot be overlooked. Tsunamigenic mass failures are infrequently reported, but they are potentially more capable of producing locally disastrous waves, and should therefore be taken into serious account when envisaging scenarios of future disasters.

The ITC is a digital data base and can be downloaded freely in its present version from the INGV at the address http://www.ingv.it/italiantsunamis/tsun.html. As occurs for all catalogues, especially for those in digital form, it is under a process of continuous maintenance, revision and updating. Our future work will mainly aim at (1) extending the catalogue time interval by including the results of research on pre-historical and on paleotsunamis that is being undertaken by several groups; (2) enriching the catalogue gallery by including more data on tsunami effects, records and simulations; (3) updating the reference data base by accounting for new contributions of the scientific community; and (4) making attempts to reduce catalogue incompleteness prior to 1700.

Acknowledgments

Appendix A

List of the tsunamis of the Italian Tsunami Catalogue

Id Code	Year	Month/Day		Sub-region	Reliability	Cause	Tsu int	Tsu mag
1	79	8	24	Campania	2	VA	2	
2	1112	6	20	Campania	2	UN	2	
3	1169	2	4	Eastern Sicily	4	ER	4	
4	1329	6	28	Eastern Sicily	2	VA	3	
5	1511	3	26	North Adriatic	2	EA	2	
6	1564	7	20	Liguria-Côte d'Azur	4	EA	2	
7	1613	8	25	Northern Sicily	1	EA	2	

8	1627	7	30	Gargano	4	EA	5	−1.4
9	1631	12	17	Campania	4	VA	2	
10	1638	3	27	Tyrrhenian Calabria	2	EA	2	
11	1646	4	5	Tuscany	4	EA	3	
12	1649	1		Messina Straits	1	EA	3	
13	1672	4	14	Central Adriatic	4	ER	2	
14	1693	1	9	Eastern Sicily	2	ER	2	
15	1693	1	11	Eastern Sicily	4	ER	5	+2.3
16	1698	5	14	Campania	2	VA	2	
17	1703	2	2	Latium	0	EA	2	
18	1703	7	2	Liguria-Côte d'Azur	2	ER	2	
19	1714	6	30	Campania	0	VA	2	
20	1726	9	1	Northern Sicily	4	EA	2	
21	1727	7	4	Sicily Channel	2	ER	2	
22	1731	3	20	Gargano	4	EA	2	
23	1742	1	19	Tuscany	4	ER	2	
24	1743	2	20	Apulia	2	EA	2	
25	1760	6	16	Campania	2	ER	2	
26	1783	2	5	Tyrrhenian Calabria	4	EA	3	−1.8
27	1783	2	6	Messina Straits	4	EL	6	
28	1783	2	7	Tyrrhenian Calabria	1	EA	2	
29	1783	3	1	Tyrrhenian Calabria	3	EA	2	
30	1783	3	28	Tyrrhenian Calabria	3	EA	2	
31	1784	1	7	Ionian Calabria	4	ER	3	
32	1784	1	19	Messina Straits	4	ER	3	
33	1805	7	26	Campania	4	EA	2	
34	1808	4	2	Liguria-Côte d'Azur	2	EA	2	
35	1809	7	3	Liguria-Côte d'Azur	2	UN	2	
36	1813	5	17	Campania	1	VA	2	
37	1817	1	14	Sicily Channel	1	EA	2	
38	1818	2	20	Eastern Sicily	4	EA	2	
39	1818	2	23	Liguria-Côte d'Azur	2	EA	2	
40	1823	3	5	Northern Sicily	4	ER	4	
41	1828	10	9	Liguria-Côte d'Azur	4	EA	3	
42	1832	3	8	Ionian Calabria	4	EA	3	
43	1836	4	25	Ionian Calabria	4	EA	4	
44	1846	8	14	Tuscany	4	EA	2	
45	1847	8	26	Campania	0	UN	2	
46	1875	3	17	Central Adriatic	4	ER	3	
47	1887	2	23	Liguria-Côte d'Azur	4	ER	3	
48	1888	7	30	Liguria-Côte d'Azur	2	EA	2	
49	1889	12	8	Gargano	2	ER		
50	1894	11	16	Tyrrhenian Calabria	4	EA	3	
51	1905	9	8	Tyrrhenian Calabria	4	EA	3	+0.4
52	1906	4	4	Campania	4	VA	2	
53	1907	10	23	Ionian Calabria	4	EA	3	
54	1908	12	28	Messina Straits	4	ER	6	−0.4
55	1916	7	3	Aeolian Islands	4	EA	2	
56	1919	5	22	Aeolian Islands	4	EA	3	
57	1926	8	17	Aeolian Islands	2	VO	2	
58	1930	9	11	Aeolian Islands	4	VO	3	

59	1940	1	15	Northern Sicily	2	EA	2
60	1944	8	20	Aeolian Islands	4	VO	4
61	1954	2		Aeolian Islands	1	VO	2
62	1968	4	18	Liguria-Côte d'Azur	4	ER	2
63	1978	6	21	Central Adriatic	2	UN	4
64	1979	10	16	Liguria-Côte d'Azur	4	GS	3
65	1988	4	20	Aeolian Islands	4	GL	2
66	1990	12	13	Eastern Sicily	4	ER	2
67	2002	12	30	Aeolian Islands	4	VL	5

Appendix B

Partial Reliability scores (5th–7th column) and Reliability (8th column) of the ITC entries. The reliability categories are denoted by C (cause), T (tsunami) and S (source): see text and Table IIb for details.

Id code	Year	Month	/Day	C	T	S	Reliability
1	79	8	24	×	/	×	2
2	1112	6	20		×	×	2
3	1169	2	4	×	×	×	4
4	1329	6	28	/	×	×	2
5	1511	3	26	/	×	×	2
6	1564	7	20	×	×	×	4
7	1613	8	25	×	/	/	1
8	1627	7	30	×	×	×	4
9	1631	12	17	×	×	×	4
10	1638	3	27	×	/	×	2
11	1646	4	5	×	×	×	4
12	1649	1		×	/	/	1
13	1672	4	14	×	×	×	4
14	1693	1	9	×	/	×	2
15	1693	1	11	×	×	×	4
16	1698	5	14	/	×	×	2
17	1703	2	2	/	/	/	0
18	1703	7	2	/	×	×	2
19	1714	6	30	/	/	×	0
20	1726	9	1	×	×	×	4
21	1727	7	4	×	/	×	2
22	1731	3	20	×	×	×	4
23	1742	1	19	×	×	×	4
24	1743	2	20	×	/	×	2
25	1760	6	16	×	/	×	2
26	1783	2	5	×	×	×	4
27	1783	2	6	×	×	×	4
28	1783	2	7	×	/	/	1
29	1783	3	1	×	×	/	3
30	1783	3	28	×	×	/	3
31	1784	1	7	×	×	×	4
32	1784	1	19	×	×	×	4

33	1805	7	26	×	×	×	4
34	1808	4	2	/	×	×	2
35	1809	7	3		×	×	2
36	1813	5	17	/	×	/	1
37	1817	1	14	/	/	×	1
38	1818	2	20	×	×	×	4
39	1818	2	23	/	/	×	2
40	1823	3	5	×	×	×	4
41	1828	10	9	×	×	×	4
42	1832	3	8	×	×	×	4
43	1836	4	25	×	×	×	4
44	1846	8	14	×	×	×	4
45	1847	8	26		/	×	0
46	1875	3	17	×	×	×	4
47	1887	2	23	×	×	×	4
48	1888	7	30	/	×	×	2
49	1889	12	8	×	/	×	2
50	1894	11	16	×	×	×	4
51	1905	9	8	×	×	×	4
52	1906	4	4	×	×	×	4
53	1907	10	23	×	×	×	4
54	1908	12	28	×	×	×	4
55	1916	7	3	×	×	×	4
56	1919	5	22	×	×	×	4
57	1926	8	17	×	/	×	2
58	1930	9	11	×	×	×	4
59	1940	1	15	×	/	×	2
60	1944	8	20	×	×	×	4
61	1954	2		×	/	/	1
62	1968	4	18	×	×	×	4
63	1978	6	21		×	×	2
64	1979	10	16	×	×	×	4
65	1988	4	20	×	×	×	4
66	1990	12	13	×	×	×	4
67	2002	12	30	×	×	×	4

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