GITEC-TWO FINAL SCIENTIFIC REPORT

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1. WP 3 New techniques to model tsunami propagation

1.1. WP 3.3 New Techniques to Explore Tsunami Run-up and Flooding

Modelling run-up and flooding needs, besides refined numerical models, very high-resolution bathymetries and topographies. The IGN has the responsibility of providing these data to the project. In the work programme it was planned to collect data during the first year, transforming them into digital data set in the second year. In the first year the IGN completed the entire process for the most interesting area (Cádiz and vicinity), establishing a methodology that could be later applied to any other area of interest.

Topography data: Digital Topographic Model 1:25.000 (DTM25)

To elaborate the DTM25 (Fig. 1) two qualitatively different sources of altimetric data have been used, depending on the available information for each area:

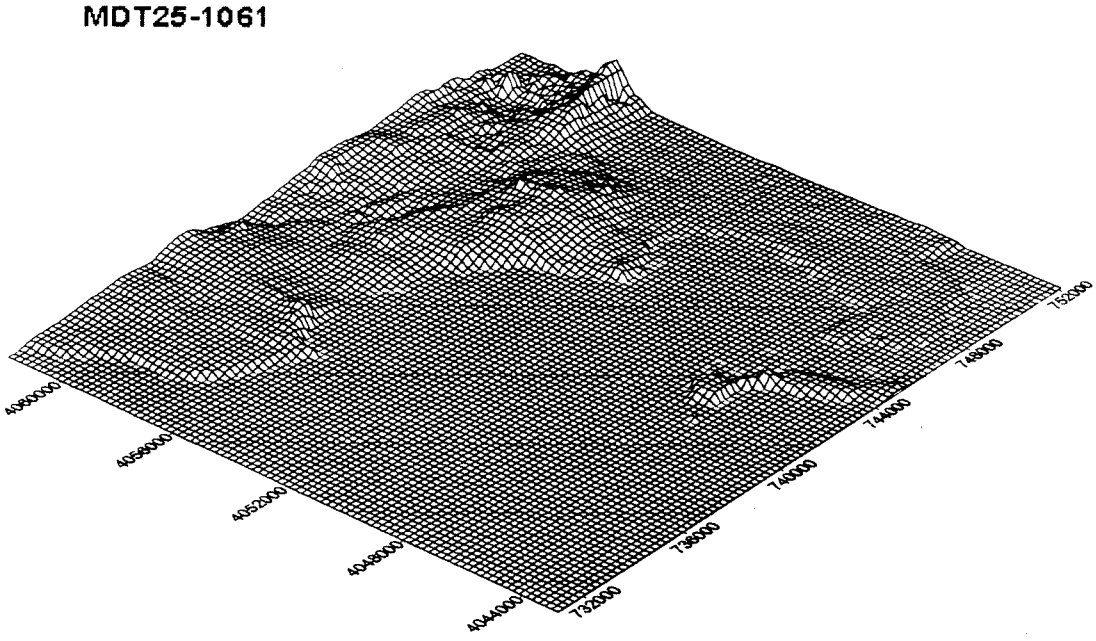

Figure 1. Extract of the DTM25 (Gulf of Cádiz zone).

For the southern cartographic pages the numerical files come from digital photogrammetric restitution. They are three-dimensional files containing contour lines,

reference points and hydrography (used to assure his consistence with the final model). The calculated accuracy is 1.5m in altitude and 2.5m in planimetric coordinates.

For the northern pages the numerical information comes from the National Topographic Map 1:25.000, obtained from classical cartography. They are two-dimensional files containing contour lines and reference points, their theoretic accuracy being 1/4-1/3 of the contour interval, i.e., 2.5-3.3m.

The preliminary process to calculate each cartographic page includes: joining original data from adjacent pages; testing the contour lines continuity between adjacent pages; searching and correcting all kind of mistakes, such as contour lines discontinuity, wrong levels, equidistance loss, inconsistency between contour lines and reference points, etc.

To elaborate the model the program SCOP (Stuttgart Contour Program) has been employed, that was developed by the Stuttgart University and commercialized by the German company INPHO GmbH. This program is based on least squared interpolation. To calculate the level of a node of the grid the algorithm takes into account the levels of all the points in a near field. These levels are weighted by means of a function inversely proportional to the distance. In order to follow the surface shape with sufficient continuity and smoothness, this function is established for each node by a previous analysis of spatial autocorrelation in the near field.

Once a first version of the DTM25 of a page has been calculated, several perspectives are drawn, and a visual control is carried out. This way residual errors are easily and quickly detected because of the sharp peaks in the elevations and depressions. Next step is correct the detected errors in the original data and to calculate the final model for this page.

After generating the model for one page, the result is subjected to a quality control by a different person, which basically consists of checking that:

. - the format for each file is correct
. - the coastline is adequately delimited by a chain of the grid nodes with level zero
. - there is no node of the grid without assigned level, due to erroneous lack of data
. - there is no level with negative or unreasonable value
. - the overlap is enough to ensure the continuity between adjacent pages
. - there is no sharp jump in the assigned levels

Finally the errors found are corrected, repeating the calculations if necessary.

One of the most difficult aspects to solve in the process is the one that appears when composing data from photogrammetry with data digitized from a map.

The technical parameters of the model are:
Levels recorded in metres above the sea level in Alicante; geodetic reference system: ED50, datum Potsdam; reference ellipsoid: international (Hayford); planimetric coordinates: UTM (the pages calculated are in the 29 zone).

Comparing this procedure with one similar carried out by the IGN at a 200.000 scale, the error can be estimated in 1.5m for pages from photogrammetry and 3m (less than 1/3 contour interval) for pages from maps.

The DTM25 is presented in ASCII, in a matrix format arranged in rows, so that every element corresponds to the altitude of one point of the grid with four integers and one decimal. All the elements in a row have the same coordinate Y, being 25m the distance between them. Similarly, all the elements in a column have the same coordinate X, being 25m the distance between them.

The first line of the file is a headline that includes: page number; SW corner UTM coordinates (metres), i.e., minimum coordinates X and Y of the grid; EN corner UTM coordinates (metres), i.e., maximum coordinates X and Y of the grid; UTM zone; file length, in bytes; projection employed and reference ellipsoid.

Bathymetry data

The digital bathymetry for the area between 37° and 34° and between 11° and 5° has been obtained at two different scales: 200m grid up to at least 23km distance from the coast and 5km grid from here up to 200km, at least (Fig. 2).

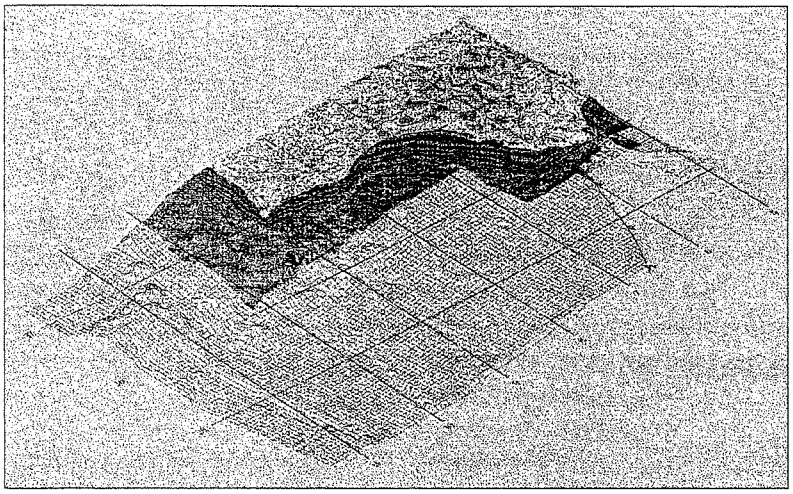

Figure 2

As the starting point the maps of the Servicio Hidrográfico de la Marina have been used. These maps are in Mercator projection and their scales are approximately, depending on the parallel, 1:750.000 and 1:500.000.

The methodology followed for the two grids has been the same, and basically the same one adopted to produce the topographic data set, though a little more simplified.

The first step has been to digitize the isolated points and the bathymetric curves appearing in the maps. The bathymetric curves are not equidistant (10m, 30m, 100m, 200m, 500m, 1000m, 2000m, etc.) and change from a map to another. Next the coordinates obtained are transformed from Mercator projection to UTM projection, in order to make geometric computations much easier.

The last step is an interpolation procedure. It has been developed a program, simpler that the one employed for the topography, based on the inverse of the distance method. In this method four points (one for each quadrant) are taken. These points are the closest to the one whose Z value is to be calculated and a weight is given to their heights (inverse of the distance) (Fig. 3). In this case, taking more points per quadrant is not useful since it only would twist the result.

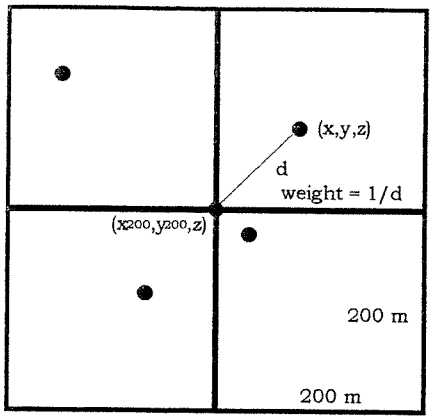

Fig. 3: Illustrative diagram of the inverse of the distance method, showing the selection.

The 200m grid approximately corresponds to a 1mm grid in the original maps, and because of the dispersion of the points in such maps, a great error could be expected. For this area the seabed has few topographic changes (very smooth relief) and the applied method and the final scale are good enough.

In order to calibrate the modelling programs, real run-up and flooding data are needed. A table with numerical real data of the flooding produced by the 1755 tsunami along the Spanish coasts has been completed and provided to the LDG group (Fig. 4, Fig. 5).

Place	H (m) wave height	Horizontal Runup (m)	Runup and Rundown	Notes
Algeciras (Cádiz)	-	?	(- +)	
Almonte (Cádiz?)	-	-	-	
Armoia (Orense)	3	-	-	estuary
Ayamonte (Huelva)	-	-	5	
Baiona (Pontevedra)		62	2nd greatest?	estuary
Betanzos (La Coruña)	-	-	-	estuary
Bolullos Par del Condado (Cádiz)	-	-	-	liquefaction
Cádiz (Cádiz)	-	-	-	
	-	33	3	
	6	40	5	
	6	40	-	
Cantillana	-	-	-	river/P 205
Carballeda de Avia (Orense)	-	-	-	river
Chiclana de la Frontera (Cádiz)	2 h_{opt}	?	3 [1]	[1]each one bigger than previous
	-	?	-	well(8-10 varas)
Chipiona (Cádiz)	?	?	-	
Conil (Cádiz)	?	6358	-	mirar cota
Corcubión (La Coruña)	1.5	-	more than 2	
Estepona (Málaga)	-	0	-	anomalous
Ferrol (La Coruña)	-	-	-	harbour ↓
Guadalquivir	-	-	-	river
Huelva	-	11144.6 ?	-	along the river
Isla de León, San Fernando (Cádiz)	?	?	?	
Jabalquinto (Jaen)	1	-	-	
Jerez de la Frontera (Cádiz)	-	-	-	
Jimena de la Frontera (Cádiz)	-	-	-	
La Coruña	-	0	4	
La Redondela (Huelva)	La Tula beach (2786)	-	-	
Lepe (Huelva)	-	-	3	

Place	H (m) wave height	Horizontal Runup (m)	Runup and Rundown	Notes
Lora del Río (Sevilla)	-	7	-	
Málaga	?	-	-	
Marbella (Málaga)	-	28	-	
Mellas y Ribela (Orense)	-	7	-	
Medina Sidonia (Cádiz)	-	-	-	
Moguer (Huelva)	-	11144.6 ?	-	along the river
Monterrey (Orense)	-	-	-	
Montoro (Córdoba)	-	?	-	
Niebla (Cádiz?)	-	-	-	
Orense (Orense)	-	-	-	
Pontevedra	high tide	-	3	
Puerto de Santa María (Cádiz)	-	-	-	
	8	56	-	
	16	-	-	
Puerto Real (Cádiz)	-	2.5	-	
Quintela de Leirado (Orense)	-	2	-	
Rivadavia (Orense)	-	-	-	
Rivas de Sil (?)	-	0.6	-	
Rota (Cádiz)				
San Lucar de Barrameda (Cádiz)	?	1393	?	
San Roque (Cádiz)	-	-	-	
Santander	-	0	3	
Santiago (La Coruña)	-	-	-	
Sevilla	-	-	-	
Tarifa (Cádiz)	-	167	-	
Velga (Orense)	-	-	-	
Vejer de la Frontera (Cádiz)	-	8358 ?	-	along the river
Villarino do Campo (Orense)	-	-	-	
Vivero (Lugo)	-	-	3	

Figure 4. 1755 tsunami flooding data in the Spanish coasts.

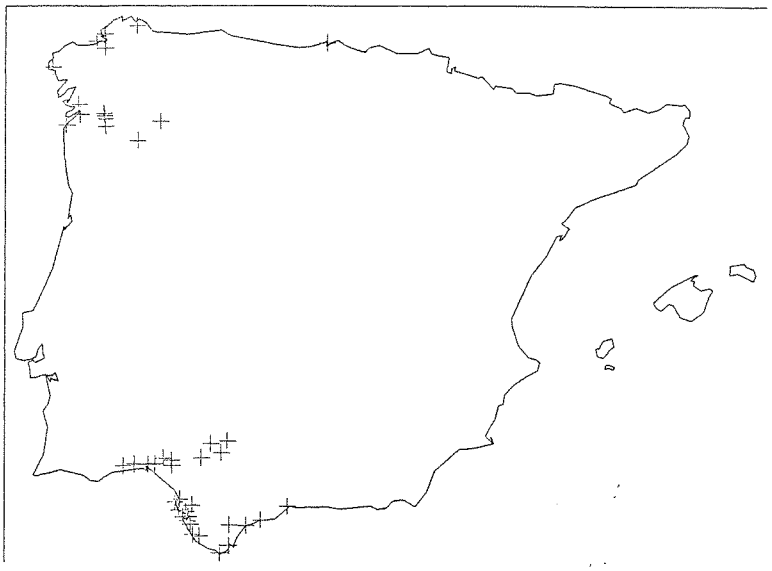

Figure 5. Places with 1755 tsunami information.

1.2. WP 3.3 New Geological Techniques for Tsunami Run-up and Run-up Mechanisms

Concerning this point the work of the IGN was basically to give assistance to the CU team who during September 1997 achieved a field investigation in Huelva.

In order to give this team an image of the area before the 1755 Lisbon earthquake and prepare the field investigation, a search for historical cartography has been carried out and some maps have been found:

. - Andalucia Nova (1606)
. - Li regni de Granata et d'Andalucia (1696)
. - Bahía de Cádiz (1812)
. - Cádiz (1868)

17th century maps are not very useful, because their scale is scarce. 19th century maps have a very convenient scale, but they are later than the Lisbon earthquake. As historical cartography is a really interesting subject not only for this project, but also for other investigations, it is foreseen to continue searching in this matter.

2. WP 4 Tsunami observation

2.1. WP 4.1 Sensors to Record Tsunamis

In the section "Role of participants" of the Work Programme, is said that the IGN will operate in order to improve the Spanish tide-gauge network. In Spain, besides the IGN, three institutions have tide-gauge networks: Puertos del Estado (PE), Instituto Español de Oceanografía (IEO) and Instituto Hidrográfico de la Marina (IHM) (Fig. 6, Fig. 7). These four institutions are now involved in a National Programme -Red Integrada de Mareógrafos RIMA- whose objective is to harmonize the different operative tide-gauge networks in Spain and modernize them. The coordinator/principal researcher and a researcher of IGN-GITEC-TWO group participate in the IGN group of the project RIMA.

SPANISH TIDE-GAUGE NETWORK

	STATION	INSTITUTION (OWNER)
1	BILBAO	PE
2	SANTANDER	IEO
3	SANTANDER	PE
4	GIJÓN	PE
5	CORUÑA	IGN
6	CORUÑA	IEO
7	CORUÑA	PE
8	VILLAGARCÍA	PE
9	VIGO	PE
10	VIGO	IEO
11	HUELVA	PE
12	SEVILLA	PE
13	BONANZA	PE
14	CÁDIZ	IEO
15	CÁDIZ	IHM
16	TARIFA	IEO
17	ALGECIRAS	IEO
18	MÁLAGA	IEO
19	MÁLAGA	PE
20	ALMERÍA	IGN
21	ALICANTE (I-II)	IGN
22	VALENCIA	PE
23	BARCELONA	PE
24	CIUDADELA	IEO
25	PALMA DE MALLORCA	IEO
26	CEUTA	IEO
27	ARRECIFE	IEO
28	LAS PALMAS	IEO
29	LAS PALMAS	PE
30	STA. CRUZ DE TENERIFE	IGN
31	STA. CRUZ DE TENERIFE	PE
32	STA. CRUZ DE LAS PALMAS	IEO

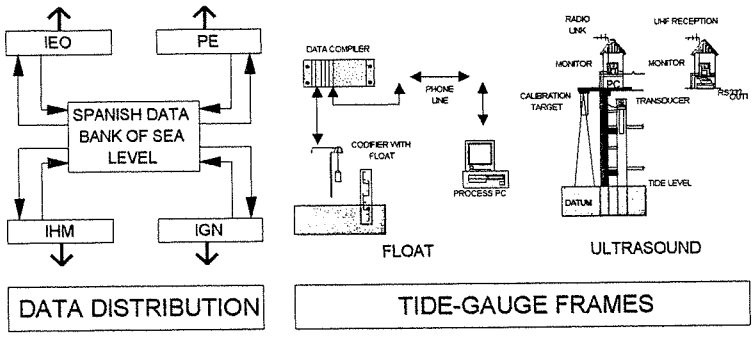

Figure 6. Spanish tide-gauge network.

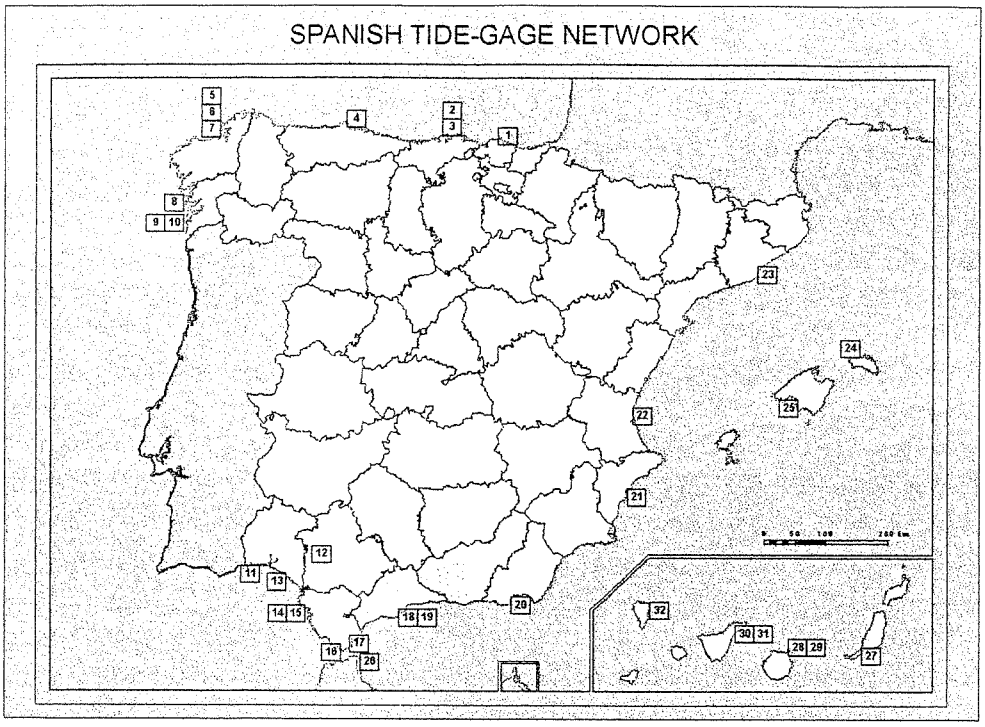

Figure 7. Spanish tide-gauge network.

2.2. WP 4.3 Updating Tsunami Catalogue

In this SubPackage the IGN takes the responsibility of two different tasks: 1755 Lisbon earthquake and updating the European tsunami catalogue for the events affecting the Spanish coasts.

1755

A summary of the new information extracted from the work by Dr. Fernando Rodriguez de la Torre entitled "Recopilación de informes manuscritos sobre los efectos en España del terremoto del 1 de noviembre de 1755" related to the effects of the tsunami due to this earthquake on the Spanish coast was done. The subject of this work is based on the gathered hand-written statements compiled by The Spanish National History Library.

The new summarised information includes on the one hand the tsunami effects on the north Spanish coast and references about the related inundated areas and, on the other hand, the tsunami damages on the south-west Spanish coast with new references about the inundated areas, the possible liquefaction due to both earthquake and tsunami and the effects on the rivers.

A monograph (M. L. Campos Romero, 1992) focusing on the effects of the tsunami, resulting from this earthquake, on the south-west coast of the Iberian Peninsula, has been published by the IGN. The data used in this work were mainly taken from the manuscripts gathered in the Spanish Royal Academy of History.

The documentation of the Spanish Royal Academy of History, about this subject, is simply a synthesis of the original "corpus" compiled in the Spanish national History Library. This is the reason why the effects on other parts of the Spanish coastline (Cantabrian and Galician coasts) have not been taken into account, except for the document related to Corcubión (r.n. 308) which is included in the Spanish Royal Academy of History statements.

Nevertheless, in the original documents of the Spanish National History Library, a more detailed information about the tsunami effects is given. Thus, statements about the north-western tsunami, attenuated and not catastrophic, on the north-west coast are available, e.g.: Baiona (r.n. 140 and 141), Betanzos (r.n. 177), Corcubión (r.n. 308), La Coruña (r.n. 321), Pontevedra (r.n. 694) and Santander (r.n. 763). In the case of El Ferrol (r.n. 359), the tsunami is not mentioned but some data about the impression of the crew of a ship located forty leagues to the west of the Cape Finisterre are referred to.

In relation to the information about the damages caused by the tsunami on the south-west Spanish coast, the whole compendium of the Spanish National History Library gathers numerous references, which obviously will not be included here.

Data referring to the Gulf of Cádiz, from Ayamonte (r.n. 122) to Tarifa (r.n. 842), should be highlighted and especially the descriptions about the damage in Cádiz (r.n. 219, 221, 224, 226 and 228), Chiclana de la Frontera (r.n. 281), Chipiona (r.n. 286 and 287), Huelva (r.n. 421 and 555), Puerto de Santa María (r.n. 705, 706 and 708) and Sanlúcar de Barrameda (r.n. 751).

In the whole compiled material there are many references to liquefaction phenomena either due to the earthquake, Bolullos Par del Condado (r.n. 555), Bonares (r.n. 621), Lepe (r.n. 471), La Redondela (r.n. 720), etc., or possibly due to the tsunami waves, Isla Mayor del Guadalquivir (r.n. 812), Moguer (r.n. 555). Descriptions about the eruption of water and dark, smelly sands and opening of holes or craters in the soil are very commonly in the areas next to the epicentre.

Data about the change of the rivers in different ways are present in these documents. A flow decrease in water running, a swell rise on the river or an unnatural increase in the water level following a decrease of it are common in the whole compiled information.

For instance, the Miño River changes in Melías, Ribela (r.n. 642) and Quintela de Leirado (r.n. 643); the Duero River in Tordesillas (r.n. 850) and Zamora (r.n. 973); the Tajo River in Talavera de la Reina (r.n. 834 and 838); the Guadiana River changes in Medellín (r.n. 549), Valverde de Mérida (r.n. 914), Villanueva de la Serena (r.n. 943) and in Badajoz (r.n. 132). The Guadalquivir River has changes in Jabalquinto (r.n. 439), Linares (r.n. 465), Montoro (r.n. 588), Lora del Río (r.n. 260), Posadas (r.n. 698) and Sevilla (r.n. 802 and 812).

There is no sense in mentioning every reference but it is necessary to comment that data not only for the main rivers but even for the smaller ones are reported in the compendium. These changes on the rivers produced by the tsunami are referred to both the north-west and south-west coast and even on the Moroccan coast.

Spanish coasts catalogue

To elaborate the tsunami catalogue for Spain the first step was to elaborate a preliminary list of all the events that could have been tsunamis. After preparing the preliminary list the next step has been to search the bibliography and documents available for these events. This information was revised in order to transform the list in the final catalogue. For this task it was also necessary to work with the catalogues of other countries, especially Portugal.

The work started from several tsunami lists and earthquake catalogues which include the effects descriptions:

. - Campos[1]: this is the more complete tsunami list for the Iberian coasts, including the Mediterranean coasts. It also provides some descriptions.
. - Soloviev[2]: this tsunami catalogue contains three tsunamis in Spain (1755, 1790 and 1860).
. - Munuera[3]: this earthquake catalogue does not bring new information to Campos and Galbis.
. - Rodríguez[4]: it is a very systematic and useful study for earthquakes and tsunamis in the 19th century.
. - Chaouche[5]: in this paper there are four earthquakes that produced tsunami in the Mediterranean Sea.
. - Galbis[6], S. Navarro-Neumann[7]: they are the classical earthquake catalogues for Spain.

It is included this preliminary list, (Fig. 8) with the following information related with the sources from where they have been taken:

[1] Campos Romero, M. L.(1992): El riesgo de tsunamis en España. Análisis y valoración geográfica. Instituto Geográfico Nacional.

[2] Soloviev, S. L. (1990) : Tsunamigenic zones in the Mediterranean Sea. Natural Hazards, 3, 183-202.

[3] Munuera, J. M.(1963): A Study of Seismicity on the Peninsula Ibérica Area. Technical Note n°1 Inst. Geográfico y Catastral.

[4] Rodríguez de la Torre, F.(1990): Sismología y sismicidad en la Península Ibérica durante el siglo XIX. Tesis Doctoral.

[5] Yelles Chaouche, A.(1991): Coastal Algerian Earthquakes: a potencial risk of tsunamis in western Mediterranean. Science of Tsunami Hazard vol.9, n°1.

[6] Galbis Rodríguez, J. (1932): Catálogo sísmico de la zona comprendida entre los meridianos 5 E y 20 W y paralelos 45 y 25 N. Inst. Geográfico y Catastral.
Galbis Rodríguez, J. (1940): Catálogo sísmico de la zona comprendida entre los meridianos 5 E y 20 W y paralelos 45 y 25 N. Inst. Geográfico y Catastral.

[7] Sánchez Navarro-Neumann, M. (1921): Lista de los terremotos más notables sentidos en la Península Ibérica desde los tiempos remotos hasta 1917 inclusive, con ensayo de agrupación en regiones y periodos sísmicos. La estación sismológica y el observatorio astronómico de Cartuja (Granada).

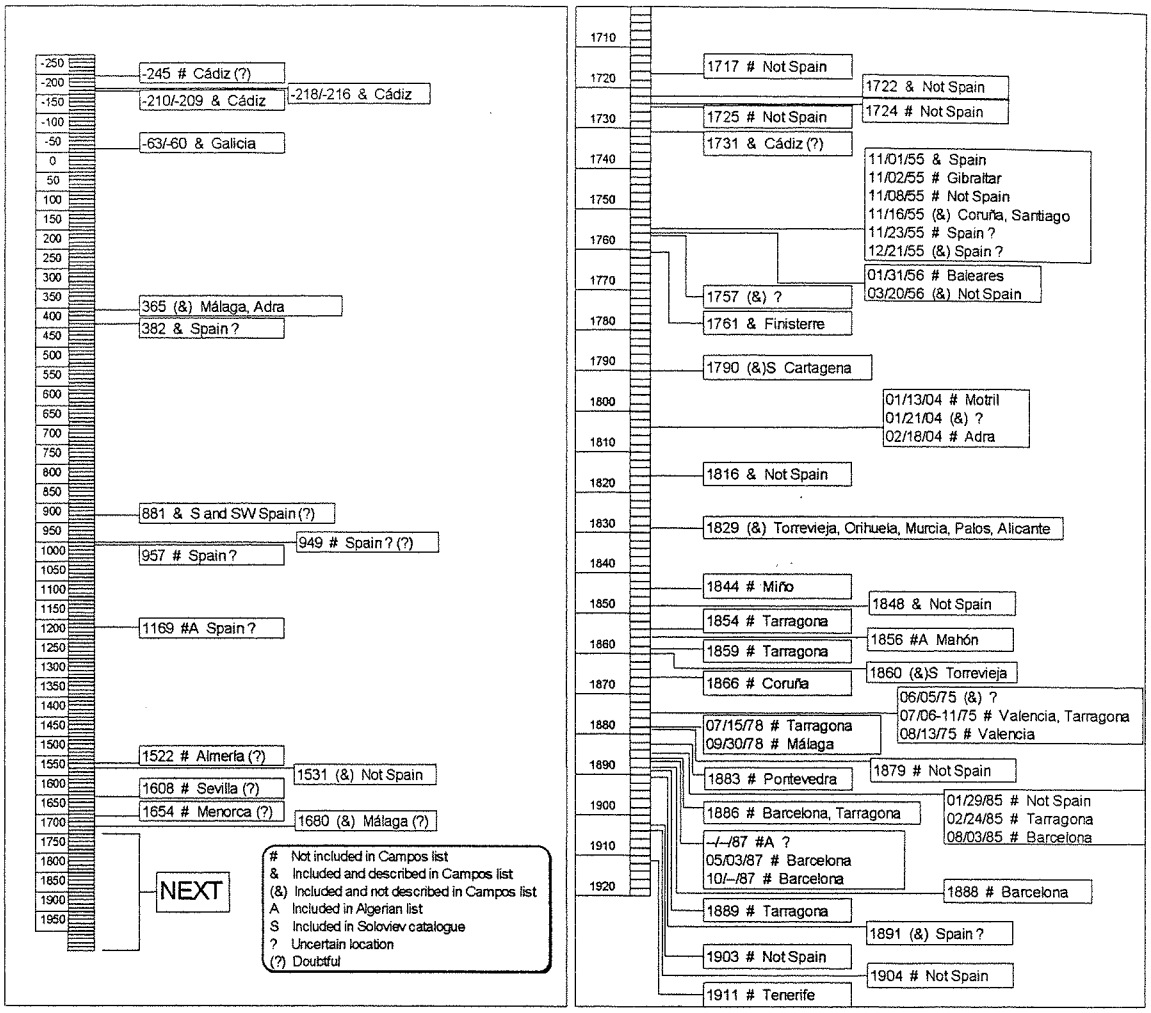

Figure 8. Possible tsunami list.

#	Events not included in Campos list
&	Events included and with some descriptions in Campos list
(&)	Events included but not described in Campos list
A	Events referred in Chaouche paper
S	Events included in Soloviev catalogue

Referring to the events themselves two symbols appear:

?	Events that probably have been tsunamis, but whose location is uncertain
(?)	Events probably felt in the Spanish coasts, but that are not clearly described as tsunamis.

The second stage for the catalogue elaboration was a search of available bibliography and documents, and a carefulness revision of all this information. Beside the data relating to the Spanish coasts, some data concerning other countries were found.

For the instrumental period, tide gauge record data bank of the IGN was revised in order to find tsunami records (Fig. 9). The records found were scanned and the images, joined with the earthquake data, were included in a special file (Fig. 10).

EARTHQUAKE	I.G.N. TIDE GAUGE STATION ACTIVE	TIDE GAUGE RECORD	COMMENTS
8 - V - 1.939 Azores	None	-	
25 - XI - 1.941 Atlantic	*Tenerife*	*Tenerife*	*Lost*
9 - IX - 1.954 Alborán	Alicante	Alicante	
	La Coruña	-	*Lost*
	Tenerife	*Tenerife*	*Nothing esteemed*
15 - III - 1.964 Cádiz	*Alicante*	-	*Lost*
	La Coruña	-	*Lost*
	Santander	-	*Lost*
	Tenerife	Tenerife	
28 - II - 1.969 Atlantic	*Alicante*	*Alicante*	*Nothing esteemed*
	La Coruña	La Coruña	
	Santander	Santander	*Original lost. Photocopy.*
	Tenerife	Tenerife	*Original lost. Photocopy.*
26 - V - 1.975 Atlantic	Alicante	Alicante	
	La Coruña	La Coruña	
	Tenerife	Tenerife	
14 - VIII - 1.978 Cádiz	Alicante	Alicante	
10 - X - 1.980 Maghreb	Alicante	Alicante I	
		Alicante III	

Figure 9. IGN tide gauge records studied.

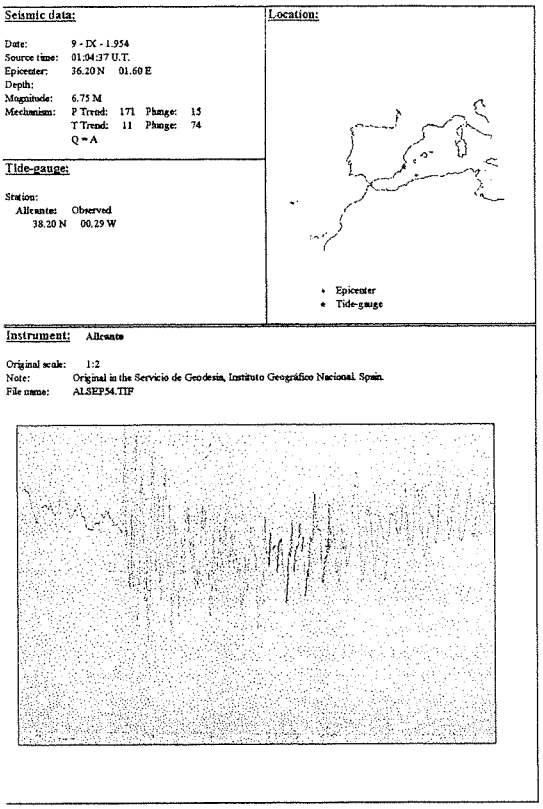

Figure 10. Special file for records found.

The last step was a new revision of the data, but this time under the criteria established for the GITEC Catalogue. After this critical revision twenty events have proved to be reliable tsunamis, and have been thus included in the GITEC Tsunami Catalogue, with all the references and descriptions.

Three events happened before our era and another one in the 9th century. After that tsunami there is a lack of events -or information- up to 1680. Six events in the 18th century, four in 19th century and five in this century have been recovered.

The area of study comprises not only the Spanish coasts (A2 and M3 regions) but also the tsunamis observed or originated on the African Western Mediterranean coasts (M3). To sum up, eleven of the tsunamis included were observed on the Atlantic Spanish coast -most of them were also observed on the Portuguese coast- and the rest took place in the Mediterranean Sea. Five of the events were observed in Algeria.

Earthquakes have been the main cause of the tsunamis observed in the studied area: 11 of them were submarine earthquakes, 5 earthquake-associated and 2 were marine slide earthquakes. It is worth mentioning the special case of the 1706 tsunami caused by a volcanic eruption in Tenerife, in the Canary Islands, unknown until now.

The biggest tsunami ever observed in Spain has been the very well known 1755 one, with tsunami intensity 6. With intensity 4 there are two in the catalogue: the one already mentioned of 1706, in Tenerife, and the well known of 1856.08.22, in Algeria, that was also observed in Spain -in Menorca, Balearic Islands-. The 1680, 1790 and 1856.08.21 tsunamis were observed with intensity 3. Other events have not been given intensity values as they have low reliability.

In Figure 11 the Quick-Look-Table of the events of the area -Spain and M3- is presented.

Tsunami Catalogue **Spain & M3**

Year	M	D	hh	mm	ss	Δ	Srg	Source_sub	Description	Rel	Cause	NN nn	EE ee	Δ	I	m	h	Vei	Runup	i
-218						2	A2	Cádiz	Tsunami in Cádiz	0	ER	36 12	-07 40							
-210						1	A2	Cádiz	Flooding in Cádiz	0	ER	36 00	-10 30	30						
-60						3	A2	SW Portugal	Flooded coasts	1	ER	36	-10		9.0					
881	06	10					A2	Cádiz	Sea retreat in South Spain	0	ER	36	-08							
1680	10	09	07				M3	Alboran sea	Sea rise (5m) in Málaga harbour	4	ER	36 30	-04 24		9.0					3
1706	05	05					A2	Canary Islands	Sea retreat/flooding at Garachico	3	VO	28 17	-16 37					2		4
1755	11	01	09	30		10	A2	SW Portugal	Catastrophic tsunami	4	ER	37	-10		11.0	8.5			1500	6
1755	11	02					A2	SW Portugal	Large ebb and flood in Gibraltar	0	ER	37	-10							
1755	11	16	15	30		2	A2	Coruña	Sea flux/reflux at La Coruña	2	ER									
1756	01	31					M3	Baleares	Flooded coast	0										
1790	10	09	01	15			M3	Alboran Sea	Flooding of Spain-Africa coasts	3	EA	35 42	-00 36		10.0					3
1804	01	13	17	45			M3	Alboran sea	Sea retreat in Almería Province	4	EA	36 50	-02 50		8.0					2
1856	08	21	21	30			M3	Algeria	Sea withdrawal-flooding at Jijel	4	EA	36 50	05 43							3
1856	08	22	11	40			M3	Algeria	Flooding at Jijel and Bougie	4	EA	36 50	05 43		8.0				500	4
1885	01	29	07	30			M3	Algeria	Sea level change in Algerian coasts	0	EA									
1954	09	09	01	04	37		M3	Alboran sea	Recorded by tide-gauges	4	ES	36 17	01 28		10.0	6.6				1
1969	02	28	02	40	32		A2	Gorringe Bank	Recorded on tide-gauges	4	ER	36 01	-10 57	01	7.0	7.3	22			1
1975	05	26	09	11	51		A2	AGFZ	Recorded on tide-gauges	4	ER	35 54	-17 36			7.9	15			1
1978	08	14	14	17	50		A2	Cádiz	Recorded on one tide-gauges	4	ER	36 22	-06 59	02		5.1	31			1
1980	10	10	12	24			M3	Algeria	Recorded on tide-gauges	4	ES	36 17	01 41		10.0	7.3	14			1

Figure 11. Tsunami Catalogue: Spain & M3.