TSUNAMI INUNDATION MAPPING PROJECT

Andrés Enríquez Olavarría
Errazuriz 254, Playa Ancha, Valparaíso, Chile
Telephone: +56 (032) 2266666
e-mail: aenriquez@shoa.cl
WEB Site: www.shoa.mil.cl

Abstract

The Hydrographic and Oceanographic Service of the Chilean Navy (SHOA), is the technical, official and permanent organism of the State of Chile responsible for the operation and maintenance of the National Tsunami Warning System, known as “Sistema Nacional de Alarma de Maremotos (SNAM)”.

As a fundamental support element of the above, SHOA started in 1997 the execution of the first step of the Tsunami Inundation Maps (CITSU project), which defines the probable flood level for the main urban zones and ports of the coast considering near field tsunamis. More than thirty maps have been produced since then. One of the the main goal of these maps, have a direct relation for mitigating the impact of tsunamis for urban planning in charge of local authorities, which let them to manage evacuation plans for citizen’s protection, in direct coordination with the National Emergency Office (ONEMI), preventing human lives lost and high cost of material resources.

Introduction

A tsunami event can be expressed by successive long waves capable to travel along a complete large ocean basin (e.g. Pacific Ocean) with high velocities, about 800 kilometers per hour, and affect significantly the coastal zones. The Pacific Ocean has a high occurrence in the record of disasters originated by tsunami events.

In Chile, the Hydrographic and Oceanographic Service of the Chilean Navy (SHOA, Servicio Hidrografico y Oceanografico de la Armada de Chile) is the technical, permanent and official office of the government, related with the responsibility of the function, operation and maintenance of the National Tsunami Warning System (SNAM, Sistema Nacional de Alarma de Maremotos) created by the Supreme Law Nº26 of January, 11 of 1966. In this context, the SHOA supported the systematic development of geophysical science of the tsunami phenomena and from the 1997 executes a operative project mainly oriented to the civil protection, called Tsunami Inundation Mapping Project.

To execute the project, the SHOA have the scientific, technical and computational capacity necessary to make the numerical modeling of different seismic and tsunamigenic scenarios and potential events associated to debris flows or landslides, e.g. the Aysen fjord tsunamigenic event in April 21 of 2007. Thereby, the Tsunami Inundation Mapping Project is a cartographic tool that defines the maximum tsunami inundation levels expected in the main urban and harbor zones of the Chilean shoreline.

In the preparedness and mitigation field of the tsunami impact, the tsunami inundation maps have a direct application in the urban and land management, and the generation of the evacuation plans and civil protection, supervised by the National Emergency Office of the

Interior's Ministry (ONEMI, Oficina Nacional de Emergencia del Ministerio del Interior), through the actions realized by the Regional Offices of Civil Protection and Emergency (OREMI) and the Local Civil Protection and Emergency Teams.

Objectives

Main objective

Support to the Civil Authorities in the preparedness and mitigation of the tsunami risk, generating Inundations Maps that shows the urban zones potentially threaten of the main harbors of the Chilean shoreline.

Specifics objectives

To applies the numerical modeling techniques to simulate historical tsunamigenics seismic events and landslides, with a high probability of occurrence in the study area.

To analyze the tsunami waves propagation in the far or near field to the coast zone and study their impact in the shoreline to describe the effects in harbors and coastal embayment.

To determine the horizontal extension and probability distribution of the wave's height in the shoreline.

To disseminate the information by the distribution of the Tsunami Inundation Maps to the civil or naval authorities in the different communities of the shoreline.

Methodology

In order to estimate the potential effects of the tsunami risk with tectonic source and the occurrence of events associated to debris flow or landslides in the coastal and island areas of Chile, different interdisciplinary studies has been executed involving geological, seismological and marine geophysics aspects (Lockridge, 1985, Lomnitz, 1970), that include the collection of topographic and bathymetric information, historical tsunami sources (Iida *et* al., 1967, Soloviev, 1974) and the calibration of the numerical modeling with *in situ* records of modern tsunami events (e.g. Valparaiso, 1985; Antofagasta, 1995 and Aysen, 2007).

The hydrodynamics factors associated to the numerical modeling of the historical tsunamis, together with the topographic, bathymetric and morphological records, specific for every region, gives a probabilistic character that can be modeled.

In this context, the numerical modeling allows discrimination between the different possible scenarios that may affect a specific region, in function of the source's localization: far or near field event, the seismotectonic parameters, the rupture mechanism and the tsunami generation.

The numerical models applied to execute the Tsunami Inundation Mapping, are the following:

a) TUNAMI-N: TIME Project (Tsunami Inundation Modeling Exchange), belonging to the Intergovernmental Oceanographic Commission (IOC). The model was design by Dr.

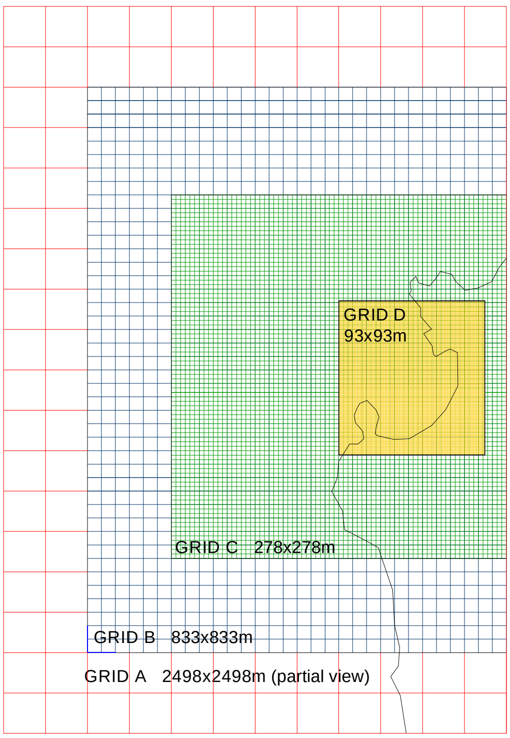
Nuobo Shuto at the Investigation Center and Disaster Control Centre, of the Tohoku University(Mansinha, 1971, Goto & Ogawa, 1982, Shuto, 1995)

b) TSUNAWI: Finite element numerical model used to simulate far field scenarios, where included the Coriolis factor. The model was developed by the Alfred Wegener Institute, Bremerhaven, Germany.

c) GEOWAVE: Numerical model composed by two separated routines:

TOPICS(Tsunami Open and Progressive Initial Conditions System), that generate the initial conditions based in six source types, included landslides, and FUNWAVE, a long wave propagation model that use the Boussinesq approach and include the wave breaking physics and the run up simulation. The model has been develop by Dr. Phillips Watts of the Applied Fluids Engineering Institute, California, USA (Grilli & Watts, 1999, Watts *et al*., 2003, Walder *et al*., 2003).

When the studied urban zone is identified and the historical, bathymetric, topographic and seismotectonic records are compiled, topobathymetric grids can be generated using some of the numerical models mentioned (Figure 1 & 2).



Bathymetric Sources:
Database CENDHOC (SHOA)
Electronic Nautical Charts (SHOA)
Digitized of Nautical Charts (SHOA)
Special bathymetry database: GEBCO 1’, ETOPO 1’, ETOPO 5’.

Topographic sources:
DEM from local cartographies.
DEM from aerial photographies.

SRTM Database (Shuttle Radar Topographic Mision) of 3 and 30 seconds of resolution.

Figure 1: Generation and nested of topobathymetric grids using TUNAMI – N2.

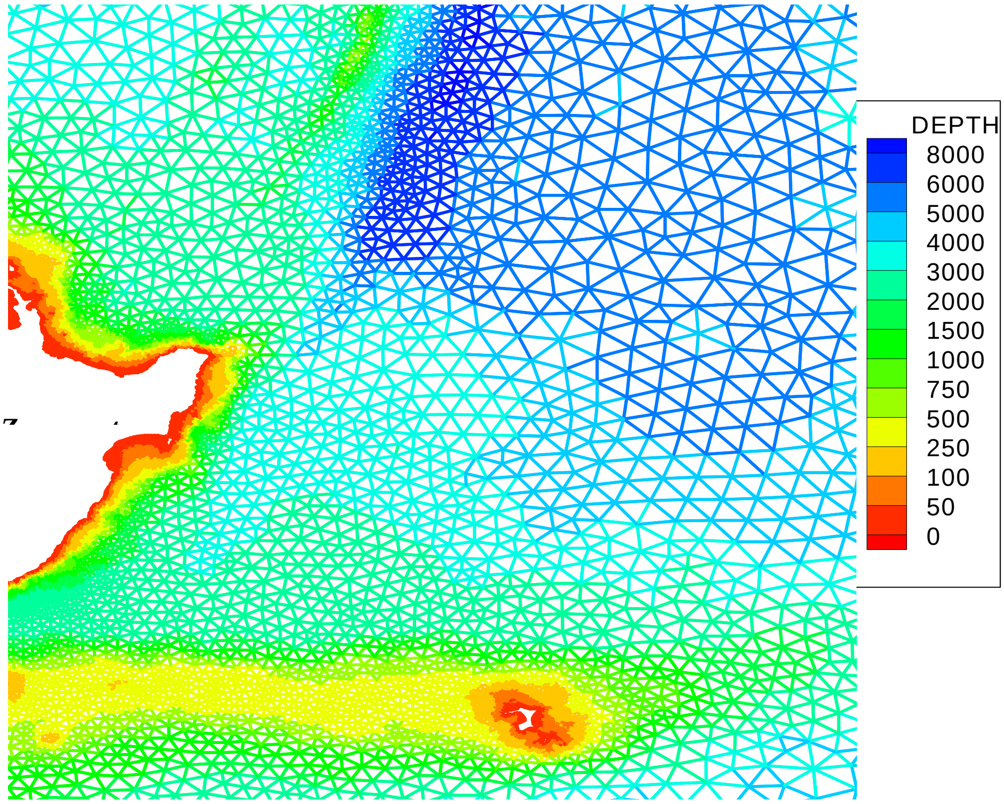


Figure 2: Triangular grids of irregular size to used in the finite element numerical model TSUNAWI.

In the second stage, the numerical modeling is executing on the basis of seismotectonic parameters selected. For example, the Figure 3 shows the numerical modeling performed in the bay of Arica, using two historical and different scenarios, the 1868 and 1877 tsunamis (Abe, 1975), whose seismotectonics parameters are detailed in the Table 1.

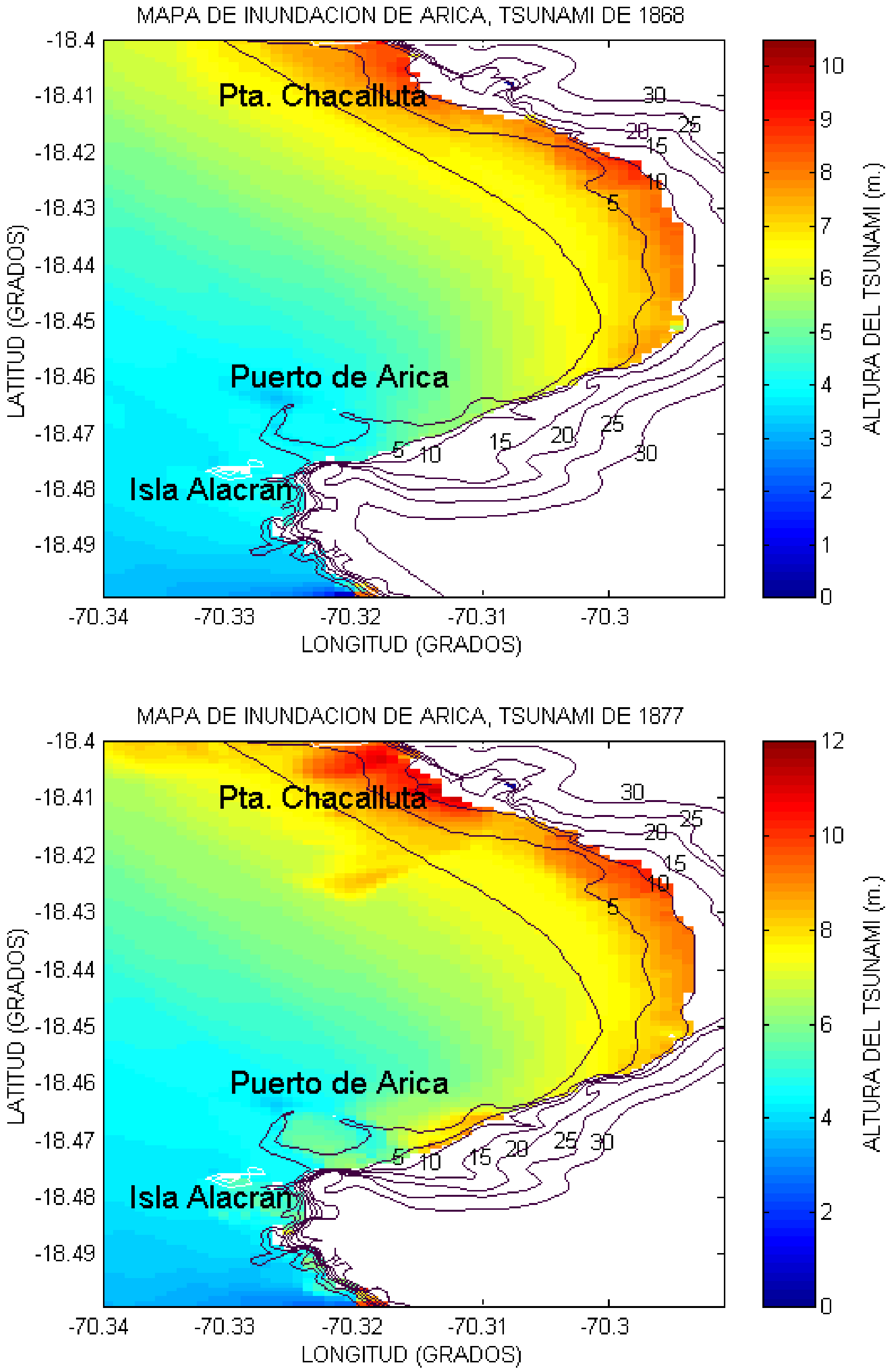


Figure 3: Inundations areas of Arica's bay to the tsunamis of 1868 (upper) and 1877 (lower).

Table 1: Seismotectonics parameters used in the numerical modeling of Arica’s bay.

SEISMOTECTONIC PARAMETERS	**TSUNAMI 1868**	**TSUNAMI 1877**
Source	19° Lat. S –71° Long.W	23° Lat. S -71° Long.W
Dislocation	12 m.	12 m.
Length	500 Km.	490 Km.
Width	150 Km.	150 Km.
Strike	300°	359°
Dip	18°	19°
Depth	10 Km.	10 Km.
Displacement angle	90°	90°

Results

The obtained results can be generated a Tsunami Inundation Map for an extreme event, according to the estimation of the recurrency periods of great coastal earthquakes in every region of the country.

The Tsunami Chart hold the neccesary information to the civil authority can generated the emergency plans, focused to implemented the tsunami signals in the inundation area and to make the evacuation ways. The Figures 4 and 5, show the Tsunami Inundation Maps for Antofagasta and Iquique, cities where reciently make emergency plans related with tsunami, on the basis to the information provide by SHOA, by other hand, the Table 2 give a list related with the produced maps and they distribution.

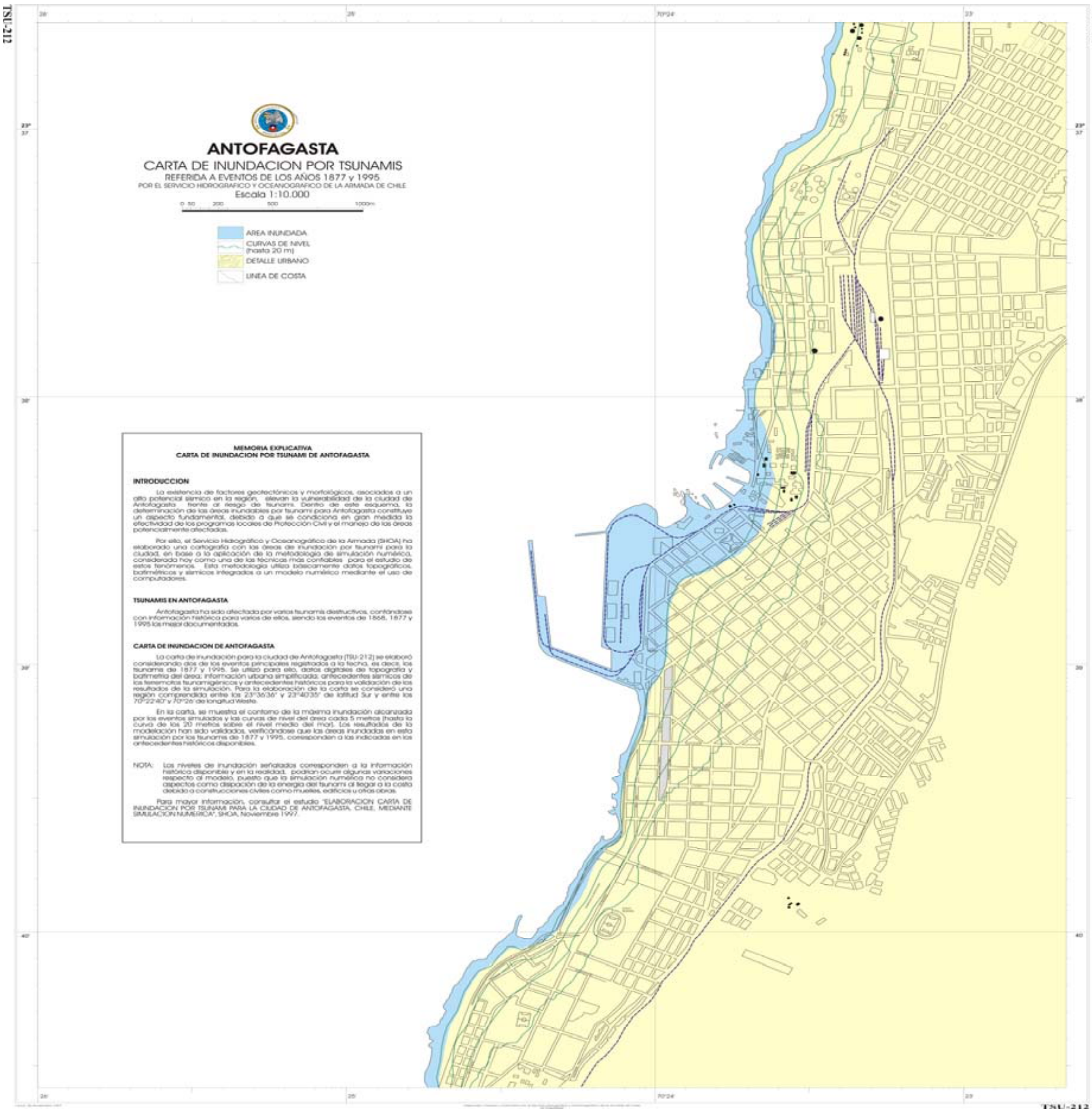


Figure 4. Antofagasta Tsunami Inundation Map

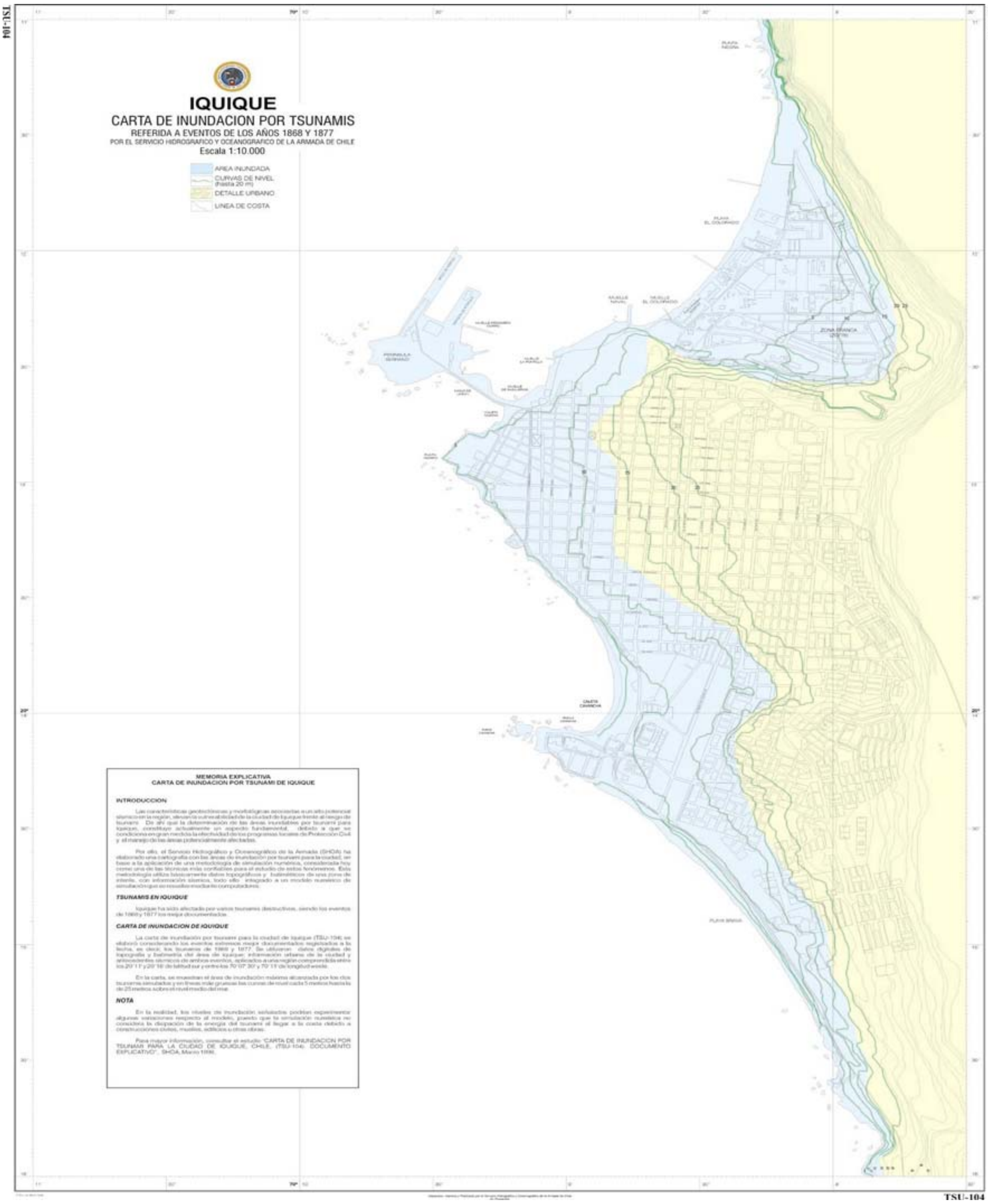


Figure 5. Iquique Tsunami Inundation Map.

Table 2. List of the Tsunami Inundation Map developed by SHOA.

COMMUNITY CITSU CHART	**EDITION YEAR**	**REFERENCE EVENT** **Richter Magnitude( )**	**MAXIMUM INUNDATIONS LEVELS(*) (refered to MSL)**
ARICA	1997	1868 (8,5) – 1877 (8,3)	12 – 15 m (*)
IQUIQUE	1997	1868 (8,5) – 1877 (8,3)	15 – 18 m (*)
TOCOPILLA	1999	1868 (8,5) – 1877 (8,3)	10 – 15 m (*)
MEJILLONES	1998	1868 (8,5) – 1877 (8,3)	15 – 18 m (*)
ANTOFAGASTA	1998	1868 (8,5) – 1877 (8,3)	7 – 10 (*)
TALTAL	2001	1877 (8,5) – 1922 (8,3)	5 – 7 m (*)
CHAÑARAL	2000	1922 (8,3)	5 – 6 m (*)
CALDERA	1999	1922 (8,3)	6 – 7 m (*)
HUASCO	2003	1922 (8,3)	7 – 10 m (*)
COQUIMBO LA SERENA	2001 2001	1922 (8,3) 1922 (8,3)	5 – 6 m (*) 6 – 7 m (*)
LOS VILOS	2002	1906 (8,6)	3 – 5 m (*)
PAPUDO	2003	1906 (8,6)	5 – 6 m (*)
QUINTERO	2003	1906 (8,6)	6 – 7 m (*)
VALPARAISO VIÑA DEL MAR	1999 1999	1906 (8,6) 1906 (8,6)	5 – 6 m (*) 6 – 7 m (*)
SAN ANTONIO ALGARROBO	2000 2000	1906 (8,6) 1906 (8,6)	7 – 8 m (*) 5 – 6 m (*)
CONSTITUCIÓN	2002	1906 (8,6)	6 – 7 m (*)
TALCAHUANO PENCO TOMÉ LIRQUÉN	2000 2000 2000 2000	1835 (8,2) 1835 (8,2) 1835 (8,2) 1835 (8,2)	7 – 8 m (*) 8 m (*) 7 – 8 m (*) 8 m (*)
SAN VICENTE	2004	1835 (8,2)	7 – 8 m (*)
CORONEL	2002	1835 (8,2)	10 – 12 m (*)
LEBU	2002	1835 (8,2)	10 – 12 m (*)
CORRAL	2000	1837 (8,5)	10 – 12 m (*)
ANCUD	2004	1837 (8,5)	8 – 10 m (*)
I. DE PASCUA	2006	1960 (9,5)	3 – 8 m (*)
PTO. AYSEN	2007	2007 (6,2)	5 – 8 m (*)

Conclusion

The Tsunami Mapping Project consolidated to SHOA as a service institution, well defined in national level, inside the Chilean Navy, and in the general community, as an organization of great scientific and technological relevance.

The population that live in the nearshore or in zones with significant tsunami inundation risk, has been favored, because the local authorities in coordination with the National Emergency Office, generate a number of activities with the goal of inform about the risk and the management of every city. For example, the cities of Arica and Antofagasta developed a series of tsunami drills in the area identified by the SHOA Tsunami Inundation Maps.

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