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TSUNAMI FIELD SURVEY OF THE 21st APRIL 2007
LANDSLIDE TSUNAMI IN AYSEN, CHILE
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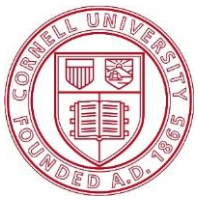

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RESEARCH

TSUNAMI FIELD SURVEY OF THE 21st APRIL 2007 LANDSLIDE TSUNAMI IN AYSEN, CHILE

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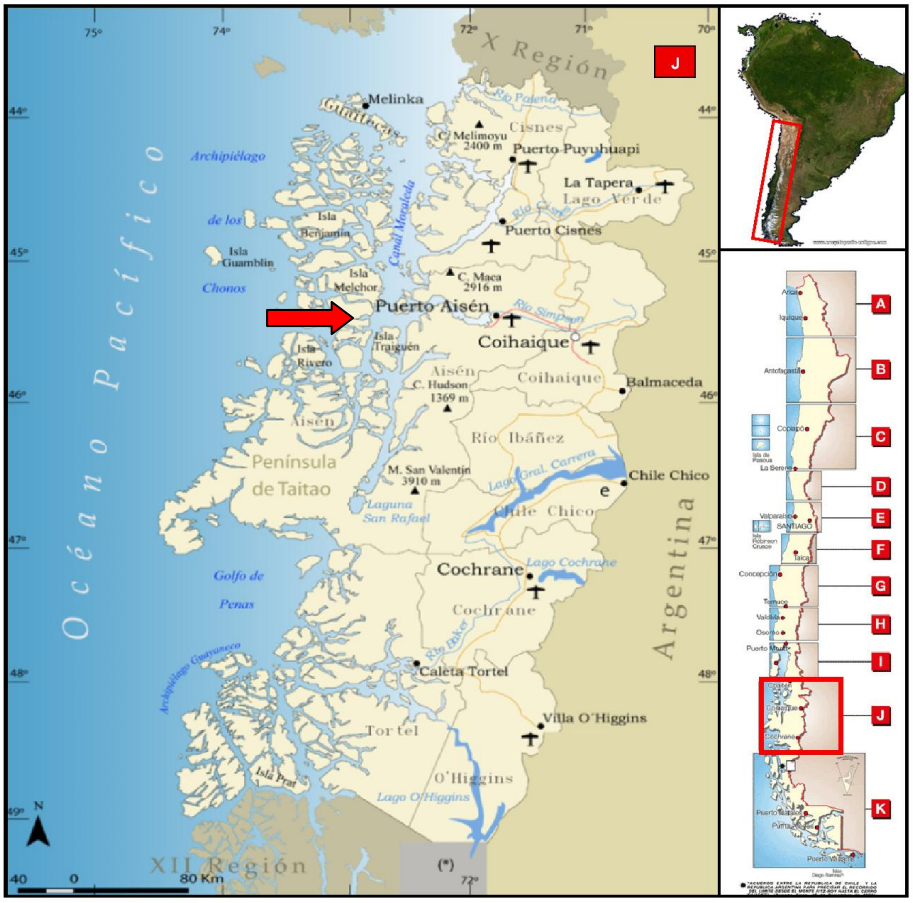
1 SCOPE OF THIS NOTE

This note is intended to provide the basic information required to model the 21st April 2007 tsunami generated by a series of landslides in Puerto Aysén, Chile (Figure 1). The landslides were triggered by a 6.2 earthquake following 2 months of intense seismic activity in Aysén fiord (Figure 2). The earthquake occurred at 13:53 (local time) and, as a consequence of the tsunami 10 people died, salmon cages were destroyed and houses in the fiord's coastline were washed away.

Figure 1: Location of Puerto Aysén, Chile.



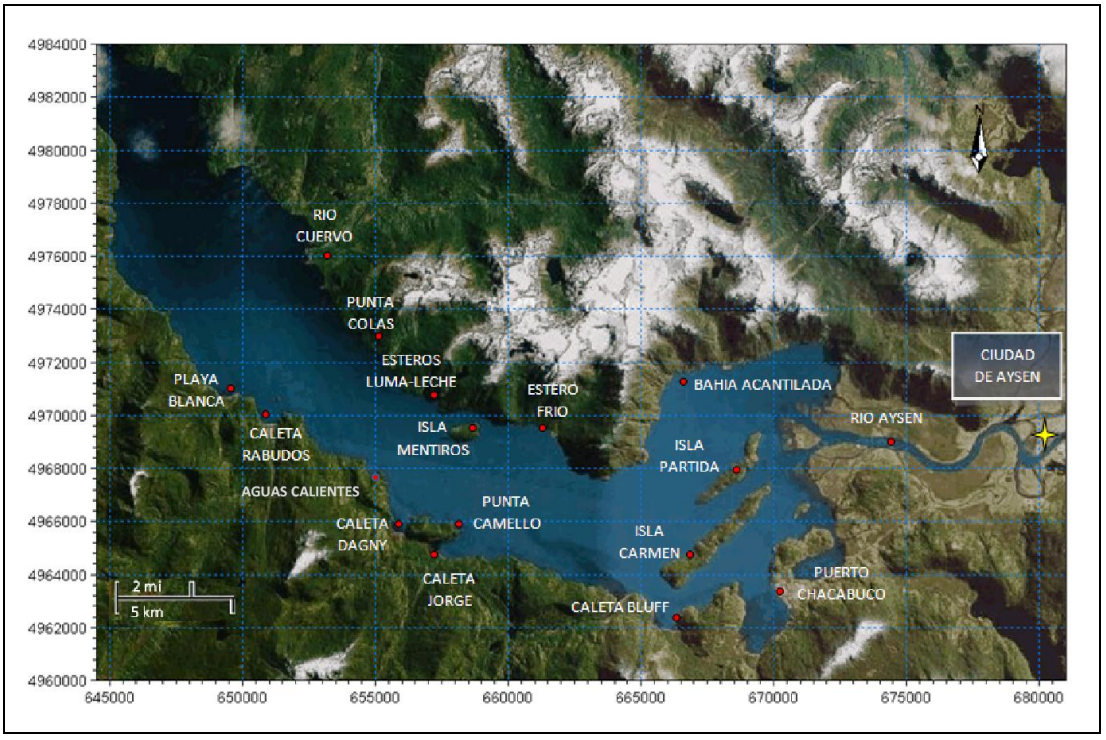
Source: Ocean Engineering Group. Universidad de Valparaiso.

The Ocean Engineering Group (OEG) at the University of Valparaiso compiled the information collected by different agencies (SHOA[1], SAF[2], SG[3] and SERNAGEOMIN[4]), carried out numerical models to reproduce this event and assessed the risk of other sources for landslide tsunami within the fiord. This note gives a brief explanation of the available data to numerical modelers who may be interested in studying this event, but gives no consideration to results found by the OEG. The detailed information is available on request at paw87@cornell.edu.

[1] SHOA: Chilean Hydrographic and Oceanographic Service
[2] SAF: Chilean Aero-photogrametric Service
[3] SS: National Seismological Service
[4] SERNAGEOMIN: National Geologic and Mining National Service

My opinion is that this information will be of great interest as this landslide event is probably one of the most well documented landslides tsunamis in history, as high quality bathymetric data, run-up records and even a tide gage record are available for its characterization. There is also complementary information in the form of photographs and videos which may be helpful to interpret the results.

Figure 2: Detailed map of Aysén fiord.



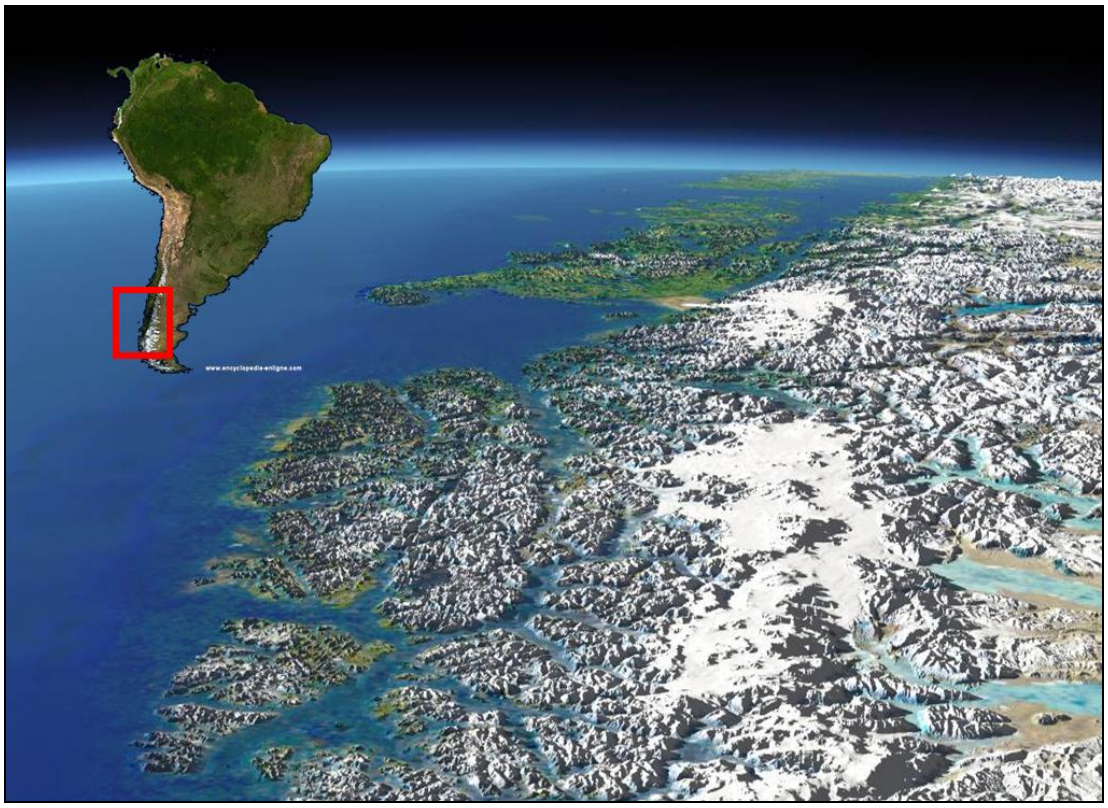
Source: Adapted from Google Earth.

2 DESCRIPTION OF THE SITE

Aysén fiord has an extension of 73 [km] and is connected with the Pacific Ocean by a complex network of channels (Figure 3 and Figure 4). The fiord is made up of many islands, rivers, bays, cliffs and is surrounded by mountains of up to 1300 [m], with steep slopes and abundant native vegetation.

Chacabuco is located in the eastern extreme of the Fiord (Figure 6), 15 [km] west of the small city of Aysén (Figure 5). Chacabuco is the only port for cargo vessels and cruises in the region, with a hinterland covering hundreds of kilometers. A tide gauge in this port recorded a maximum wave height of 0.83 [m] during high tide. The fiord is fed by Aysén River at its eastern extreme.

Figure 3: Satellite image of the Chilean fiords.



Source: Christoph Hormann (chris_hormann@gmx.de).

Figure 4: Aysén fiord in the proximity of Puerto Chacabuco.

Source: www.panoramio.com

Figure 5: Aerial view of Puerto Aysén.

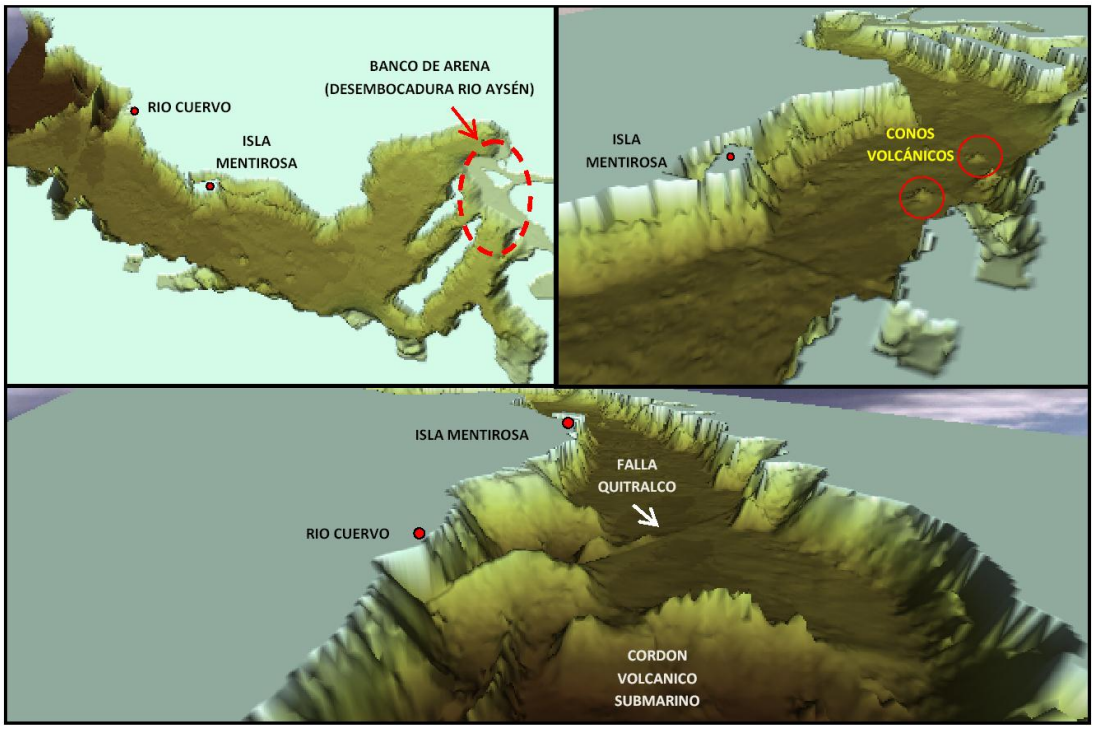
Source: www.panoramio.com

Figure 6: Aerial view of Puerto Chacabuco.

Source: www.panoramio.com

The fiord has an average depth of 147 [m] and an estuary highly stratified system, presenting two main basins and a postglacial esplanade formed as product of sliding slopes. These basins are limited by an underwater volcanic cord located near River Cuervo (Figure 7). The basin located west of the River Cuervo reaches maximum depths of approximately 300 [m], while the area located to the east has maximum depths of 220 [m]. In its final reach, Aysén river has a large sandbar and maximum depths not exceeding 4 [m].

Figure 7: Morphology of Aysén fiord.



Source: Ocean Engineering Group. Universidad de Valparaiso.

3 CHARACTERIZATION THE EVENT

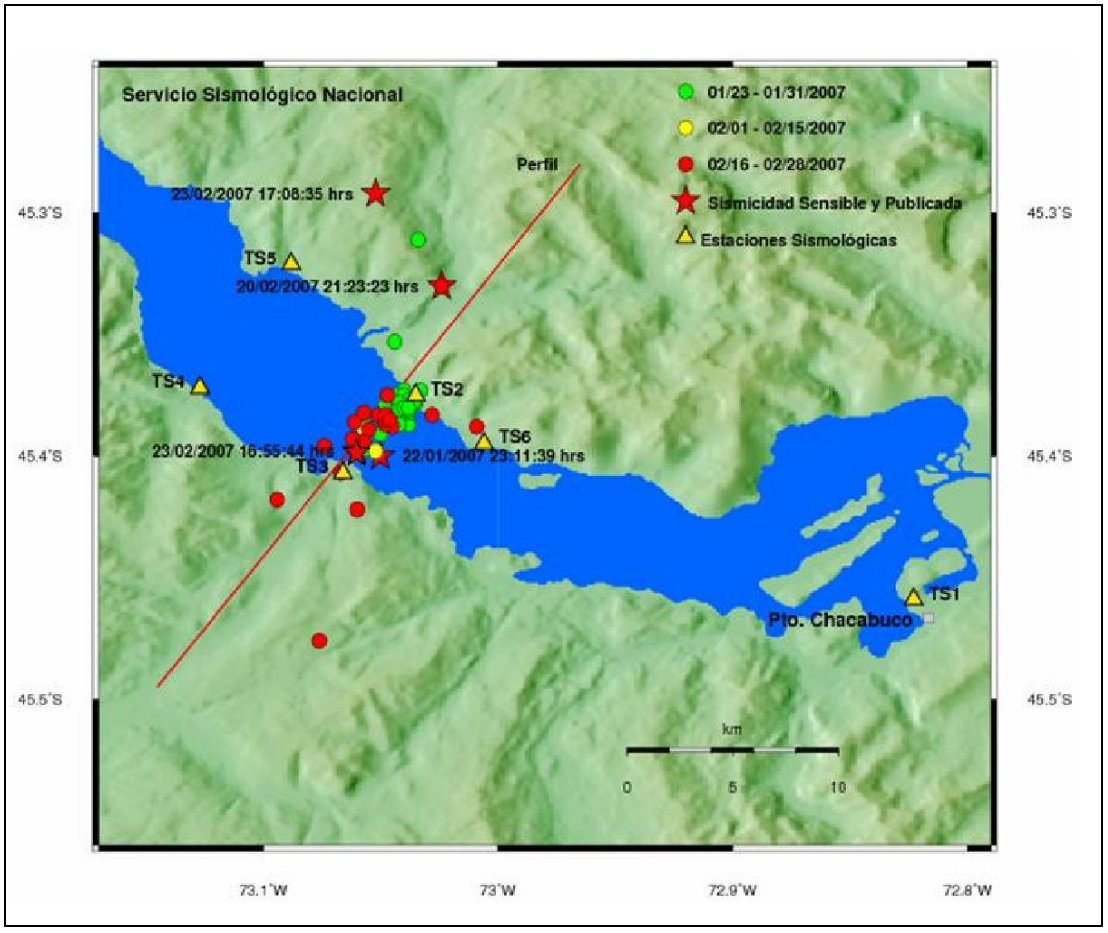
3.1 SEISMICITY AND LANDSLIDES

In the first months of 2007, an active seismic activity occurred in Aysén fiord (Figure 8). This main shock occurred on the 21st April 2007 at 13:53, local time, with a magnitude of 6.2. This shock, plus the steep slopes and a high precipitation in the region of around 4000 [mm/year], may have been responsible for triggering the landslides. A series of landslides occurred in the following sites

- Punta Cola (Figure 10)
- Esteros Luma y Leche (Figure 11 and Figure 12)
- Aguas calientes (Figure 13)
- Isla Mentirosa Norte (Figure 14)

Some details of the landslides obtained from SERNAGEOMIN are summarized in Figure 9:

Figure 8: Seismicity in Aysén fiord before the 21st April 2007.



Source: SSN

Figure 9: Parameters of the three main landslides.

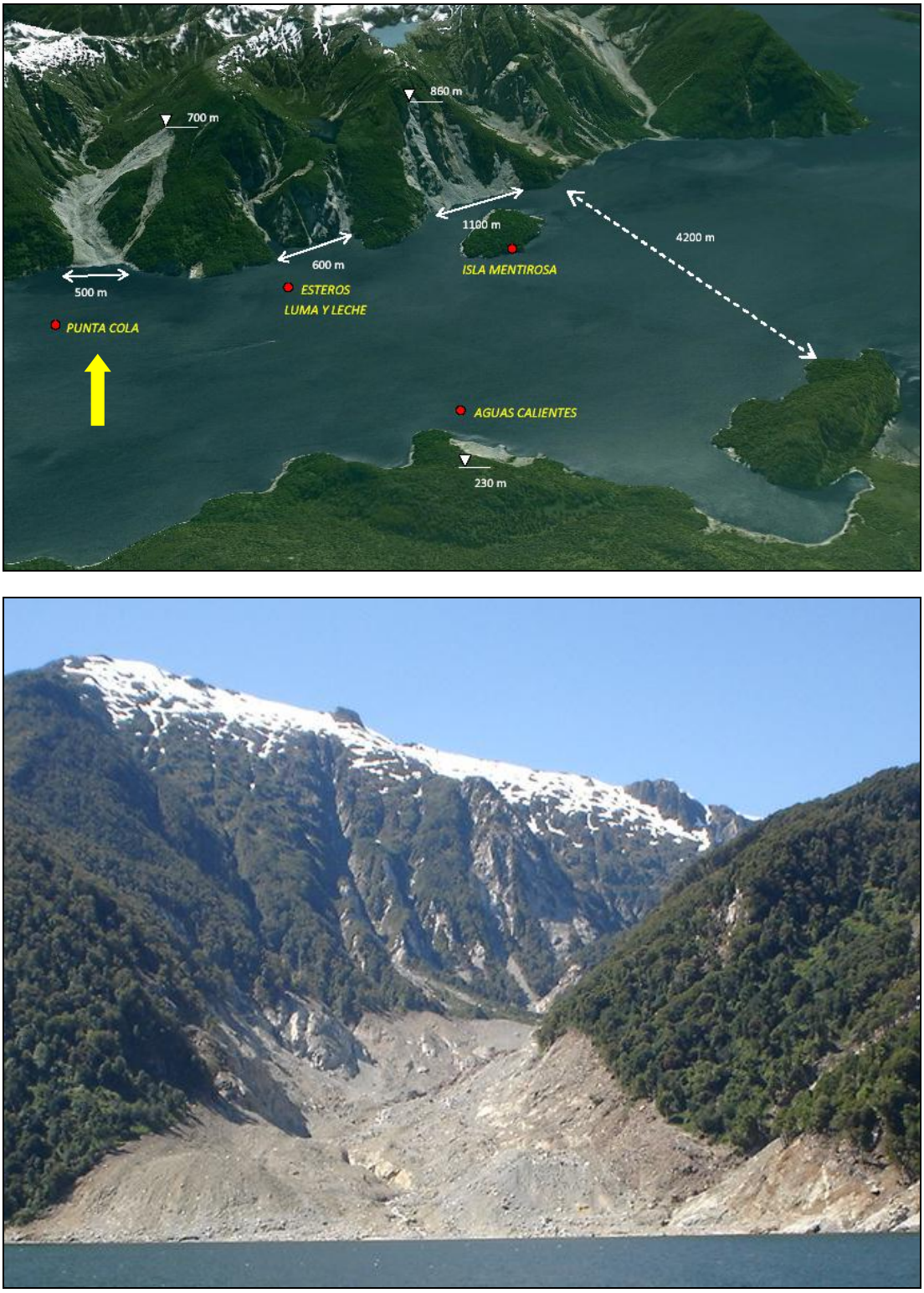
TABLA 4-1. Parámetros asociados a las remociones en masa.

PARÁMETROS	Deslizamiento de roca sector Isla Mentirosa Norte	Deslizamiento de roca sector Aguas Calientes Este	Flujo de distritos Quebrada sin nombre (Frente a sector El Tatio)
Volumen ingresado al agua [millones de m^3]	7 ± 1	1,7 ± 0,3	12 ± 2
Ángulo de ingreso al agua (grados)	40 ± 2	24 ± 2	8 ± 1
Posición centro de la masa que ingresó al agua (UTM, zona 18, SAD69)	658.950 4.970.140	655.500 4.967.355	655.670 4.971.890
Ancho de la masa que ingreso al agua (m)	1.000 ± 100	600 ± 50	250 ± 25
Velocidad máxima (m/s)	100 ± 10	34 ± 5	30 ± 5
Velocidad probable al ingresar al agua (m/s)	50 ± 5	17 ± 3	15 ± 3

Fuente: Sernageomin, 2007 (Ref. 24).

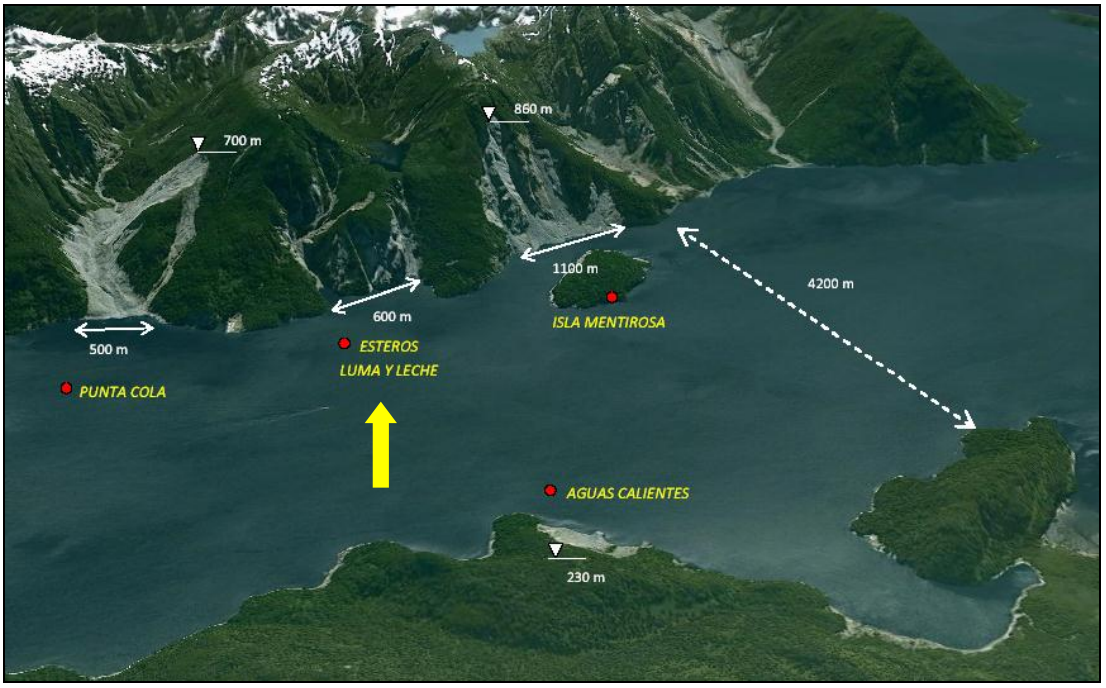
Source: SERNAGEOMIN

Figure 10: Landslide at Punta Cola.



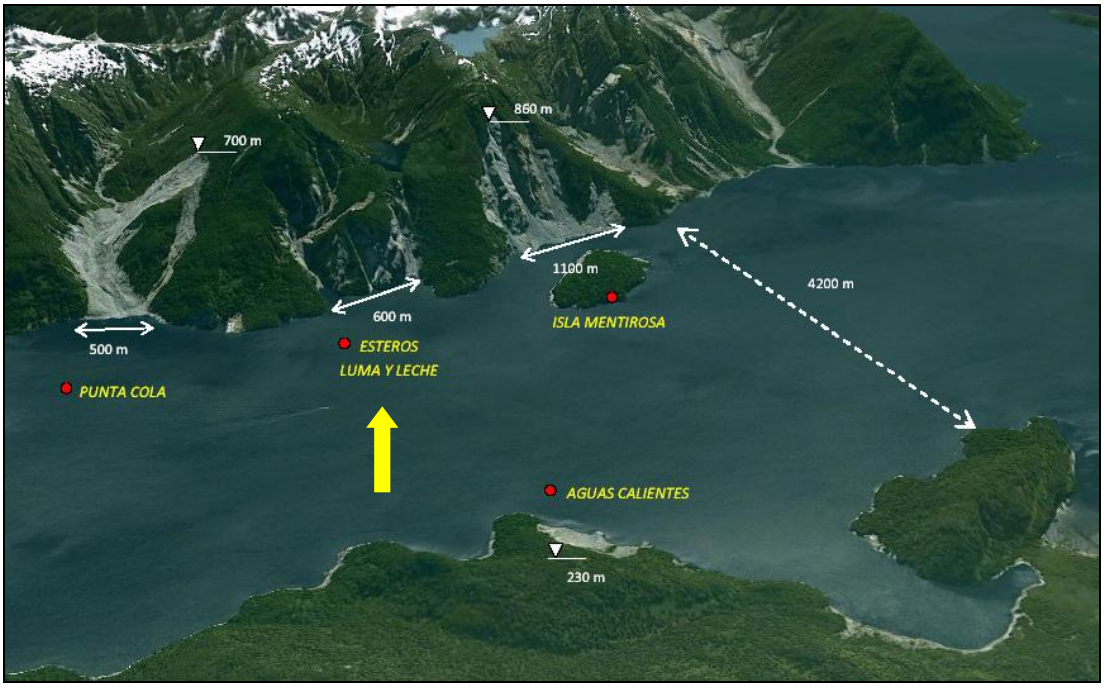
Source: www.panoramio.cl

Figure 11: Landslide at Esteros Luma y Leche.



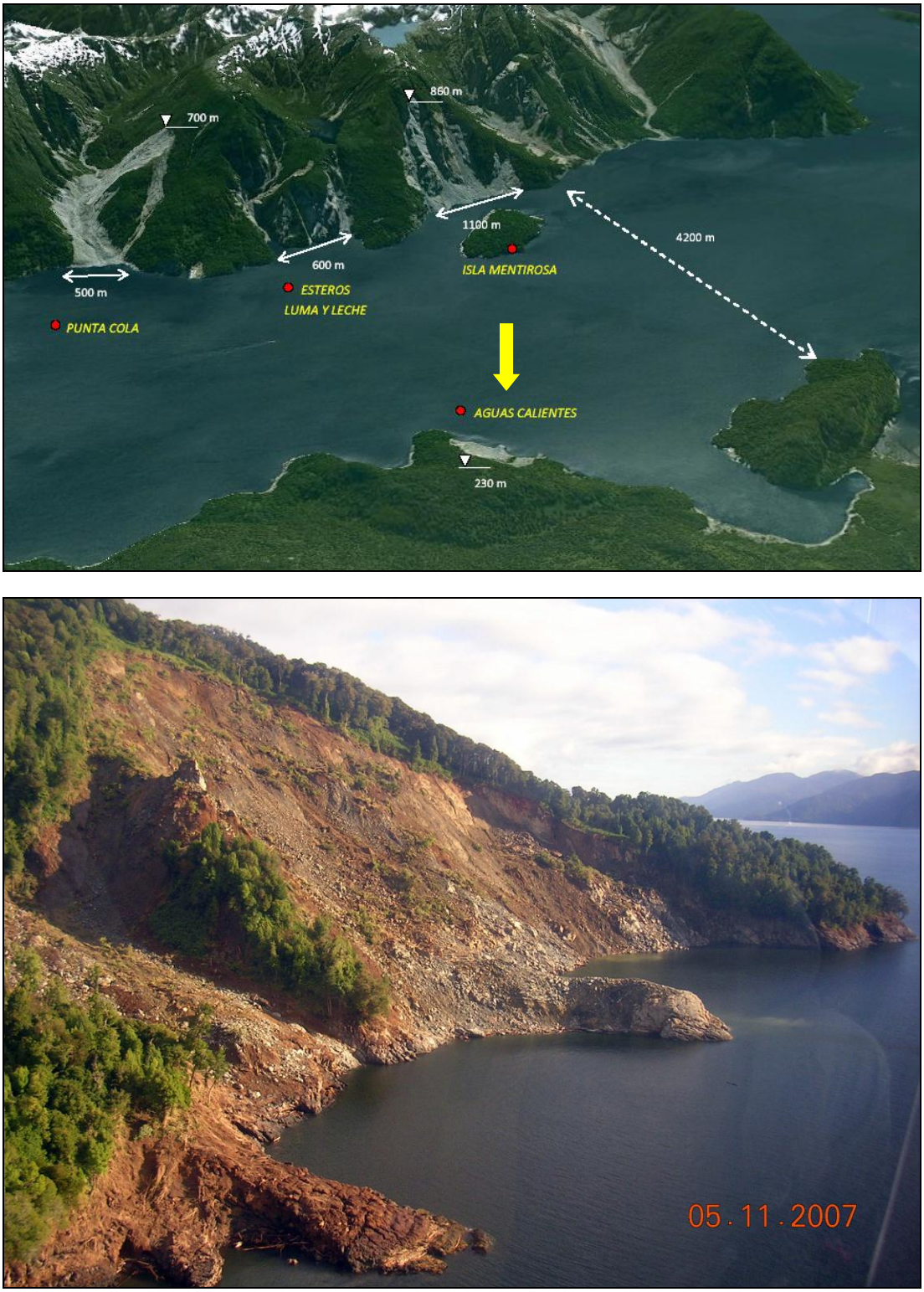
Source: www.panoramio.com

Figure 12: Landslide at Esteros Luma y Leche.



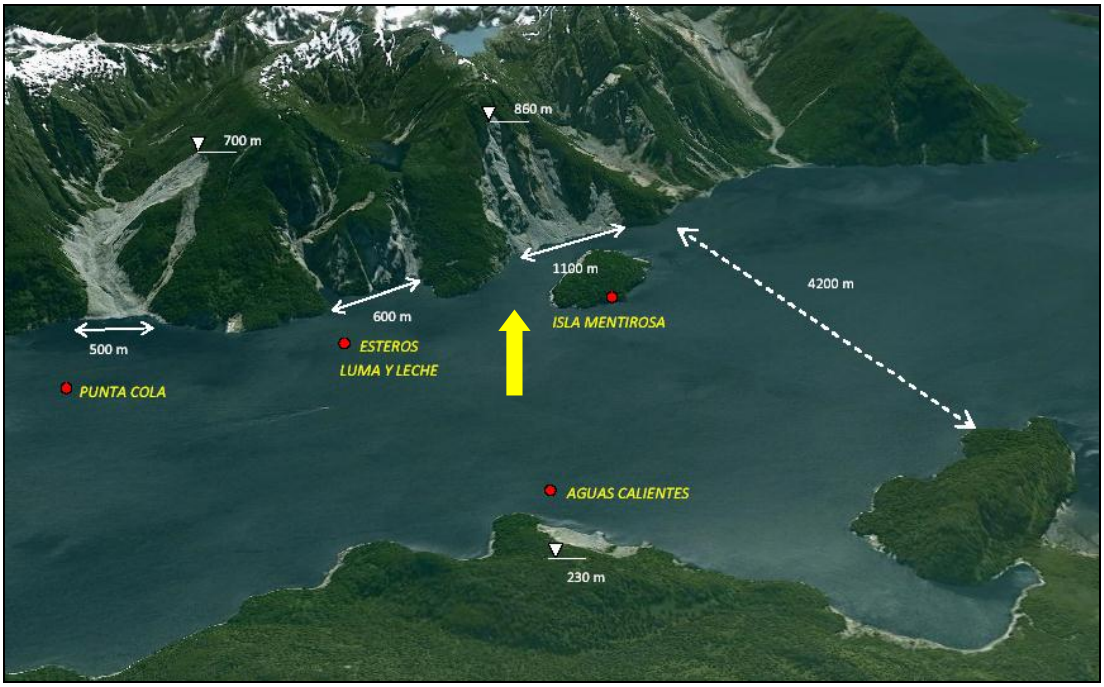
Source: www.panoramio.com

Figure 13: Landslide at Aguas Calientes.



Source: SHOA.

Figure 14: Landslide in front of Isla Mentirosa.

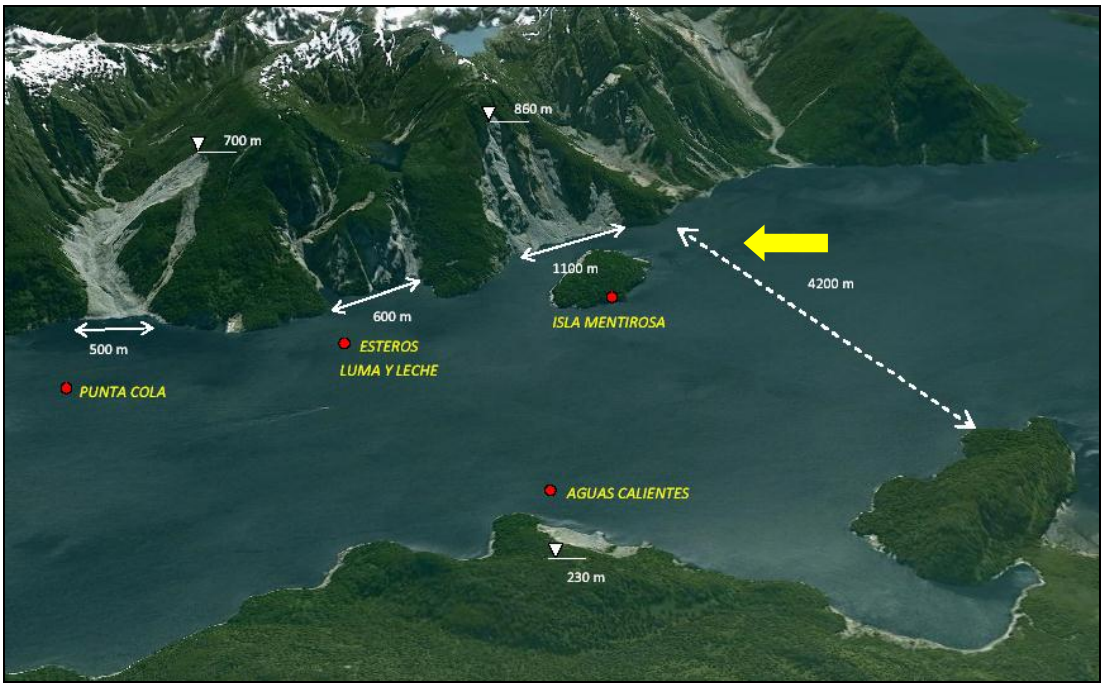


Source: www.panoramio.com

3.2 TSUNAMI

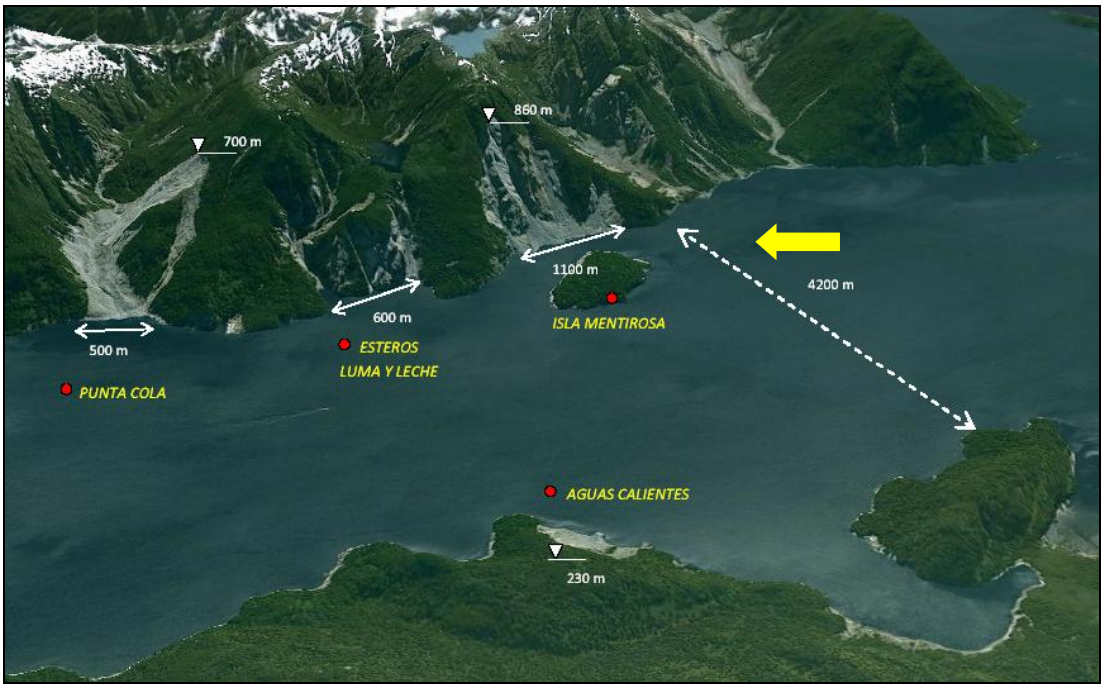
As a consequence of the landslide, a series of large waves were formed in the vicinity of Isla Mentirosa, where the maximum run-up reached 50 [m] roughly (Figure 15 and Figure 16). Due to the important depths in the fiord, the waves showed small amplitudes (Figure 17).

Figure 15: Formation of the initial tsunami wave.



Source: SHOA

Figure 16: Impact of the initial tsunami wave in Isla Mentirosa.



Source: SHOA

Figure 17: Tsunami propagating along Aysén fiord.

Source: www.panoramio.com

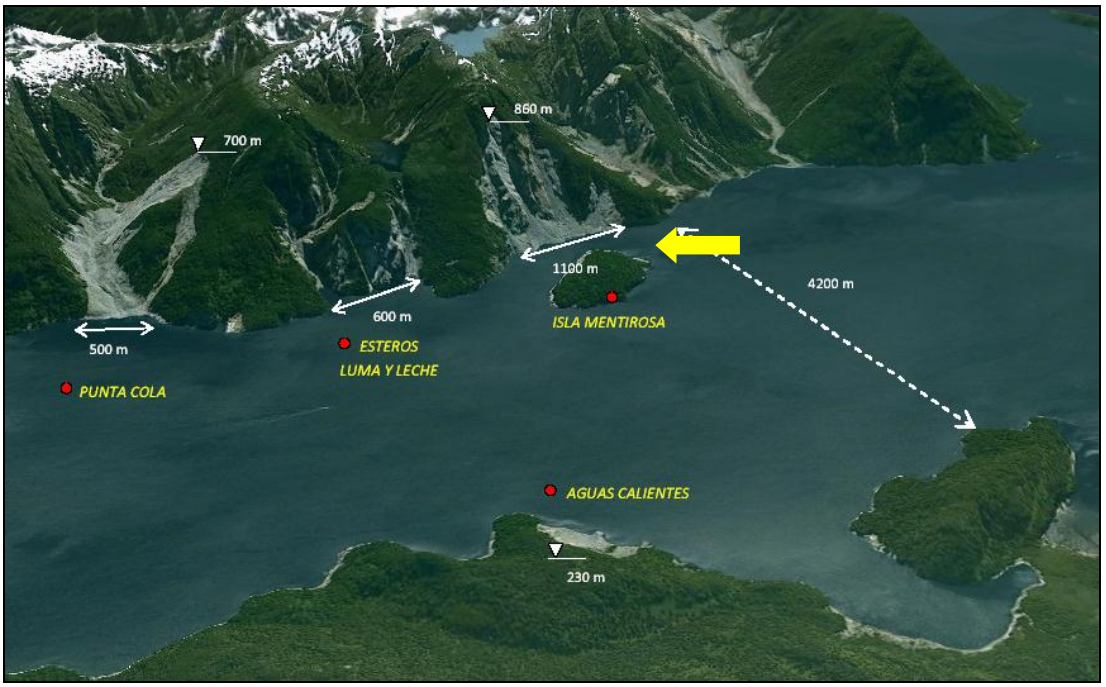
SERNAGEOMIN carried out a post tsunami survey measuring run-up (Figure 18). Apparently, no correction to tide is included in these values and no specific time and date for the measurement was included in the data. A maximum range in sicigy if roughly around 3 [m], but this information is easily accessible.

Figure 18: Run-up estimations by SERNAGEOMIN.

Source: SERNAGEOMIN

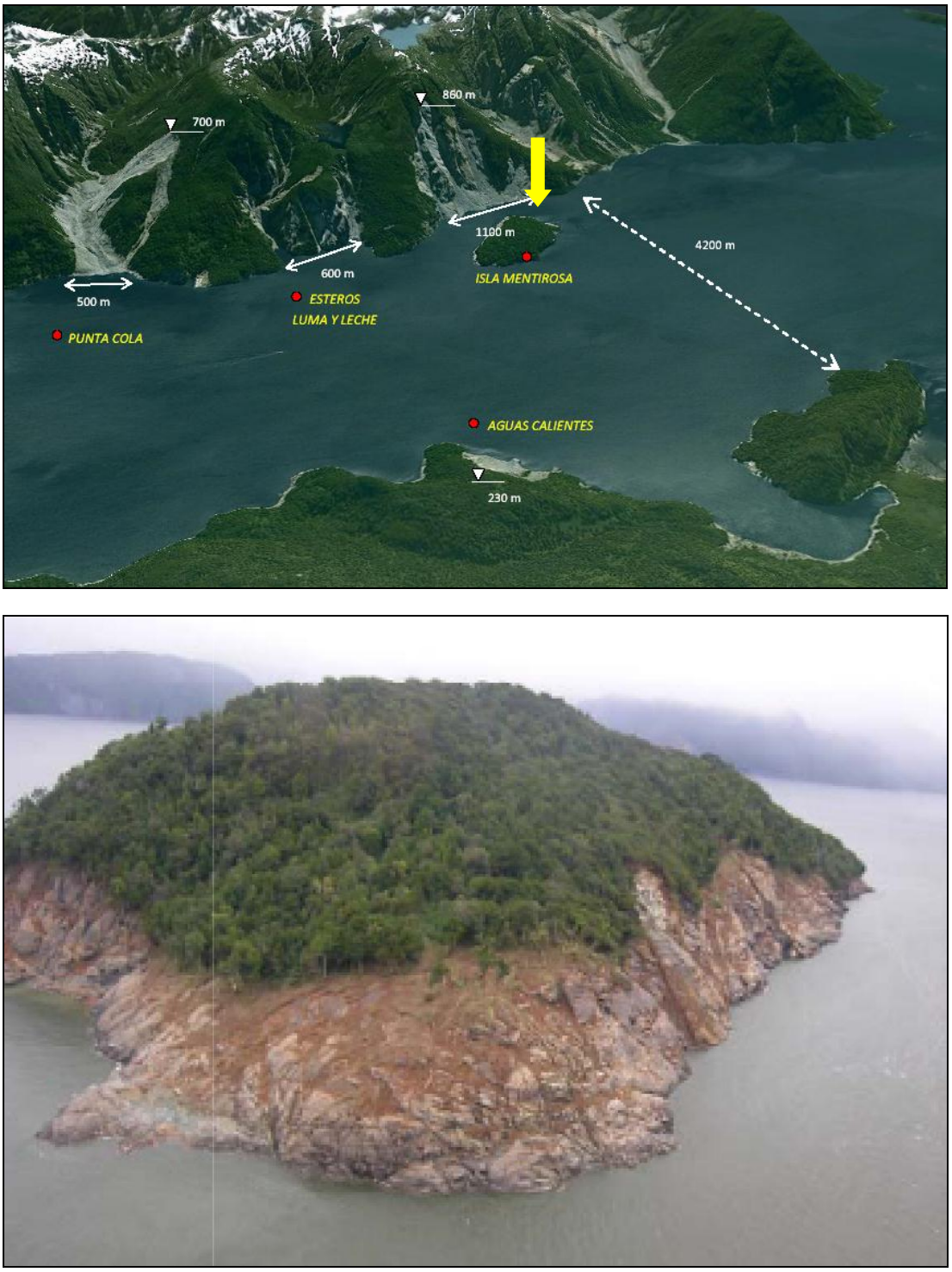
In Isla Mentirosa, run-ups reached up to 50 [m] as shown in Figure 19 and Figure 20.

Figure 19: Run-up in Isla Mentirosa.



Source: SHOA

Figure 20: Run-up in Isla Mentirosa.



Source: SHOA

Images of Estero Frio before and after the tsunami are depicted in Figure 21. According to SERNAGEOMIN (Figure 18), the run-up in this sector was of 6 [m].

Figure 21: Estero Frio before and after the tsunami.

FOTO 1-13. El antes y después del tsunami en el sector Estero Frío.

Fuente: SHOA, 2007 (Ref. 24).

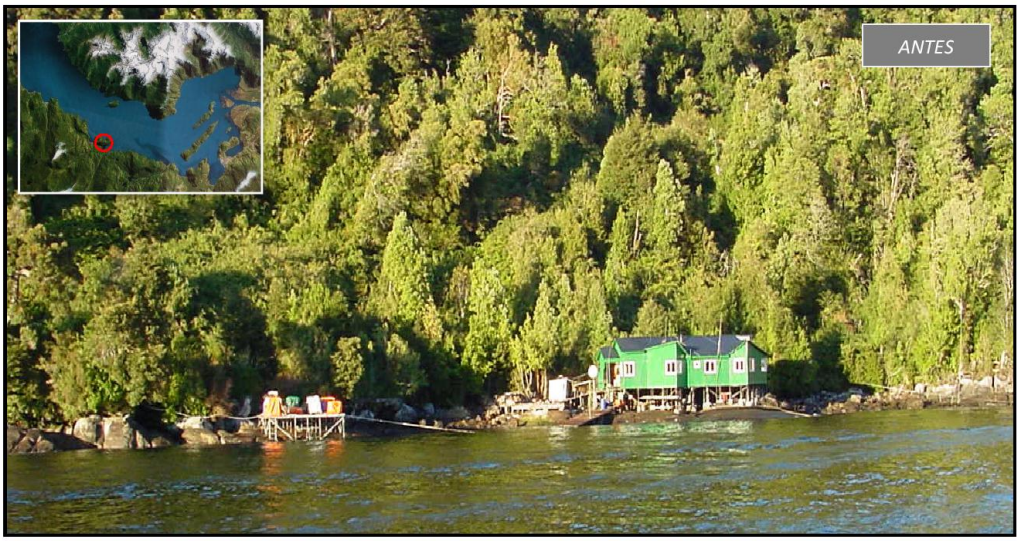
Fuente: SHOA, 2007 (Ref. 24).

Source: SHOA, 2007.

Images of Punta Camello before and after the tsunami are depicted in Figure 22. According to SERNAGEOMIN (Figure 18), the run-up in this sector was of 8 [m].

Figure 22: Punta Camello before and after the tsunami.

FOTO 1-14. El antes y después del tsunami en el sector Punta Camello.



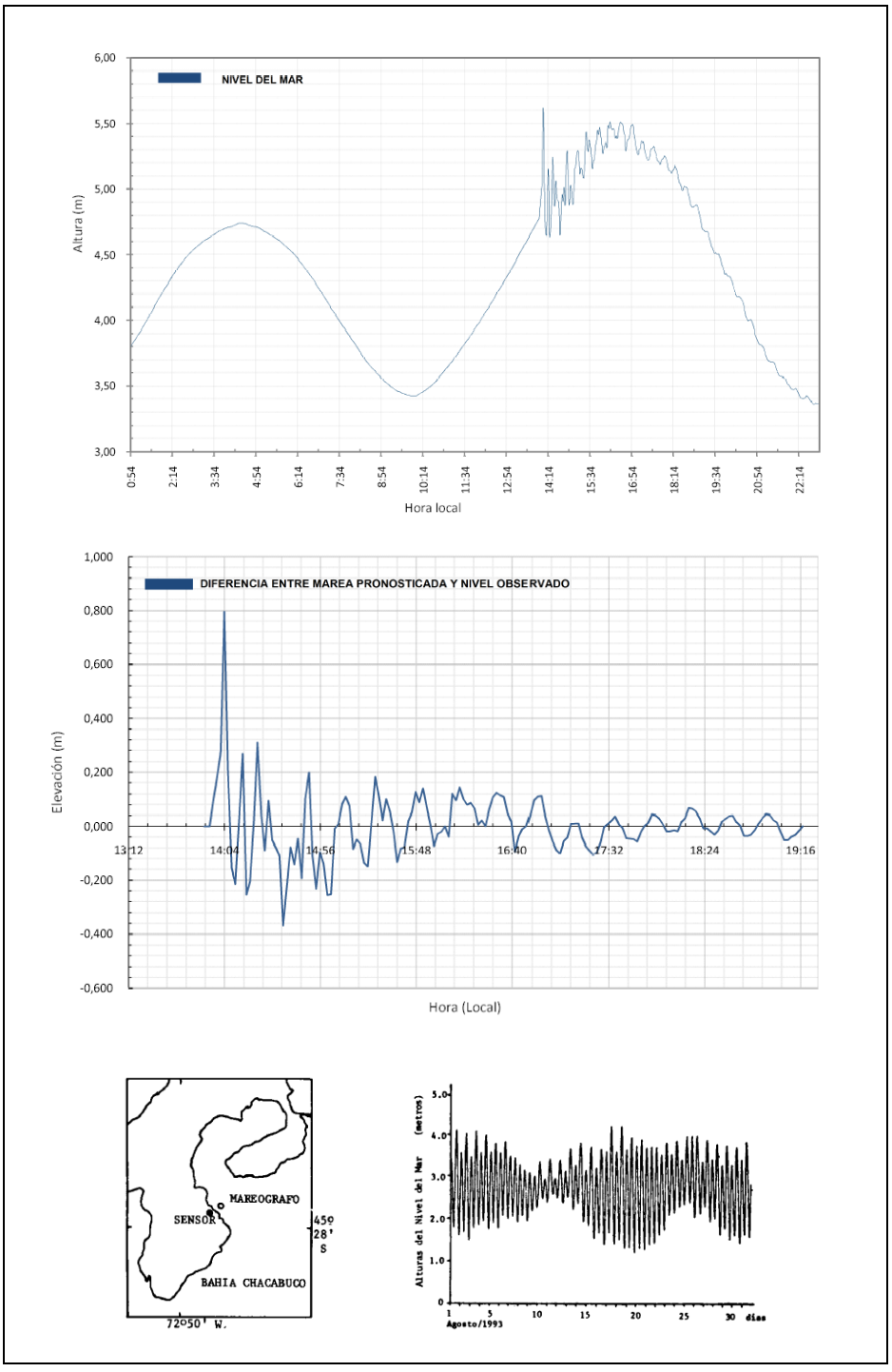
Fuente: SHOA, 2007 (Ref. 24).

Fuente: SHOA, 2007 (Ref. 24).

Source: SHOA, 2007.

A tide-gage recorded the tsunami in Puerto Chacabuco (Figure 23). The raw record and the filtered tsunami are shown in the upper and mid images. Lower images show the location of the tide gage and a record for August 1993, showing a maximum range in sicigy of 3 [m].

Figure 23: Tide record in Puerto Chacabuco.



Source: Adapted from SHOA and http://www.mares.io.usp.br/aagn/11o6.html.

4 AVAILABLE INFORMATION

4.1 BATHYMETRY

Bathymetry is available from the following sources:

- SHOA bathymetric chart N° 8610. Fiordo Aysén (Figure 24)
- SHOA bathymetric chart N° 8611. Bahia Chacabuco (Figure 25)
- SHOA bathymetric chart N° 8612. Rio Aysén (Figure 26)
- High resolution bathymetric survey, carried out by the Navy after the 21st April 2007 tsunami. Ship: PSG Cabrales. Monohaz and multihaz (Figure 27, region of high resolution data)

La amount of bathymetric data in the area of interest is of 854.000 points and the density is of roughly 1000 points per m^2 (Figure 27). Data was processes with UTM projection and datum Sad-1969, zone 18 south. A model of the consolidated bathymetric data in presented in Figure 28.

4.2 TOPOGRAPHY

Bathymetry is available from the following sources:

- SAF aerial survey. Scale 1:20.000 (may 2007)
- IGM geodetic survey. Scale 1:30.000 (may 2007)
- SHOA topographic maps. Scale 1:70.000 (1998)

La amount of topographic data in the area of interest is of 1.200.000 points and the density is of roughly 7000 points per m^2 (Figure 27). Data was processes with UTM projection and datum Sad-1969, zone 18 south. A model of the consolidated bathymetric data in presented in Figure 29.

Figure 24: SHOA bathymetric chart N° 8610. Fiordo Aysén.

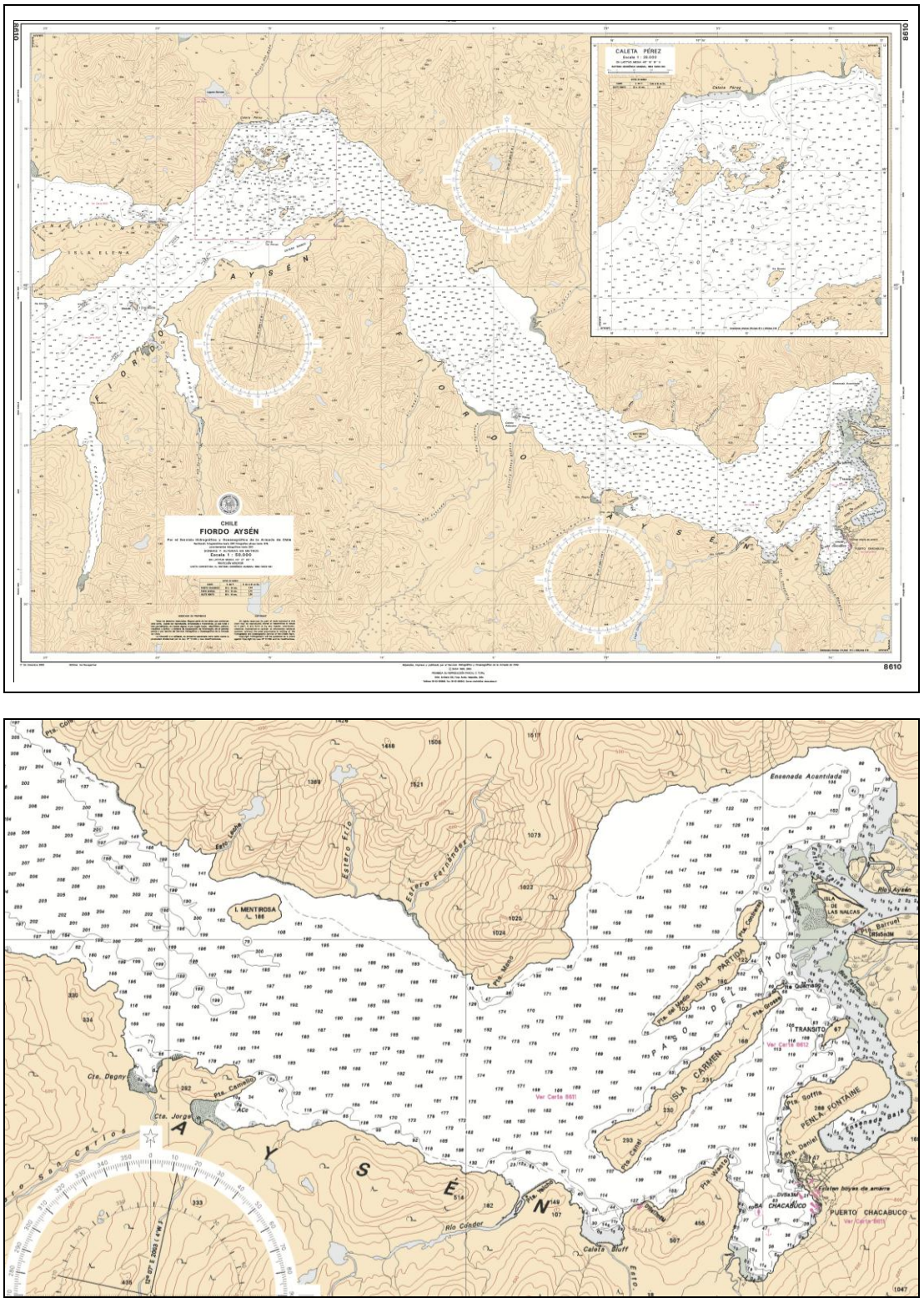
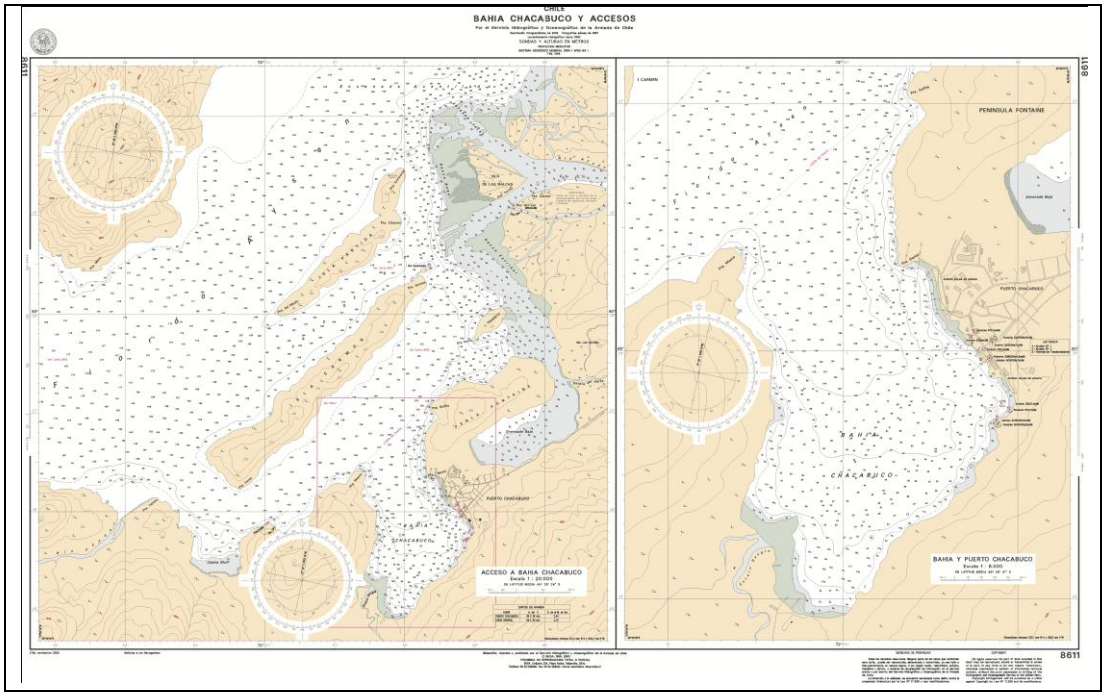


Figure 25: SHOA bathymetric chart N° 8611. Bahia y Puerto Chacabuco.



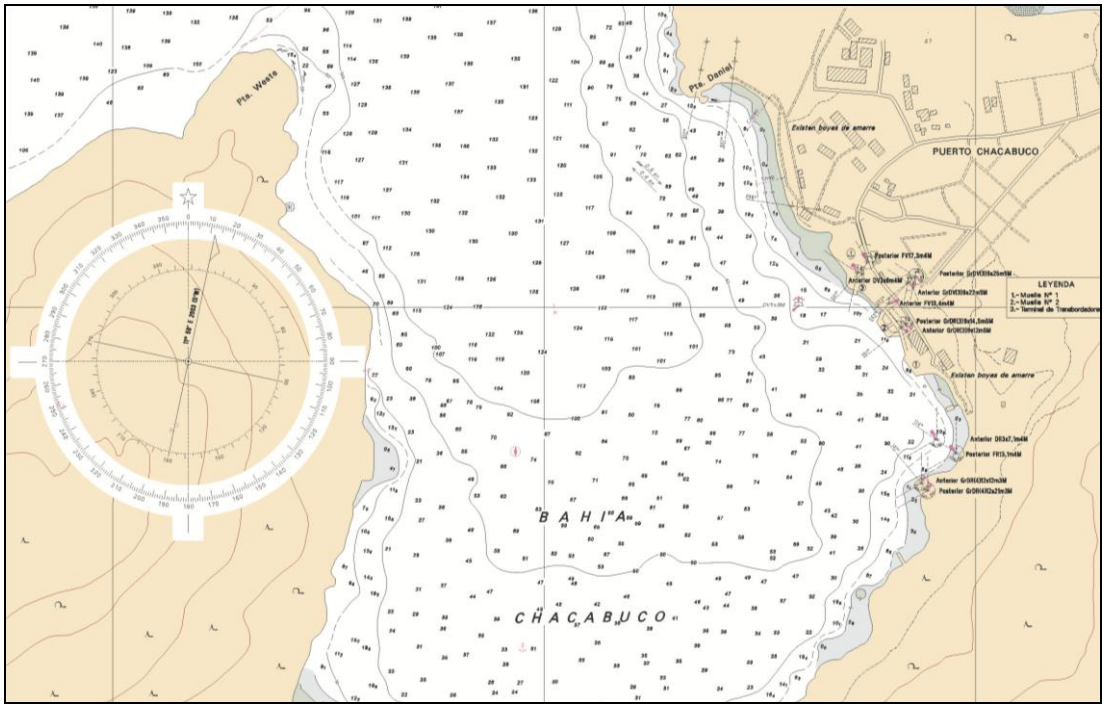


Figure 26: SHOA bathymetric chart No 8612. Rio Aysén.

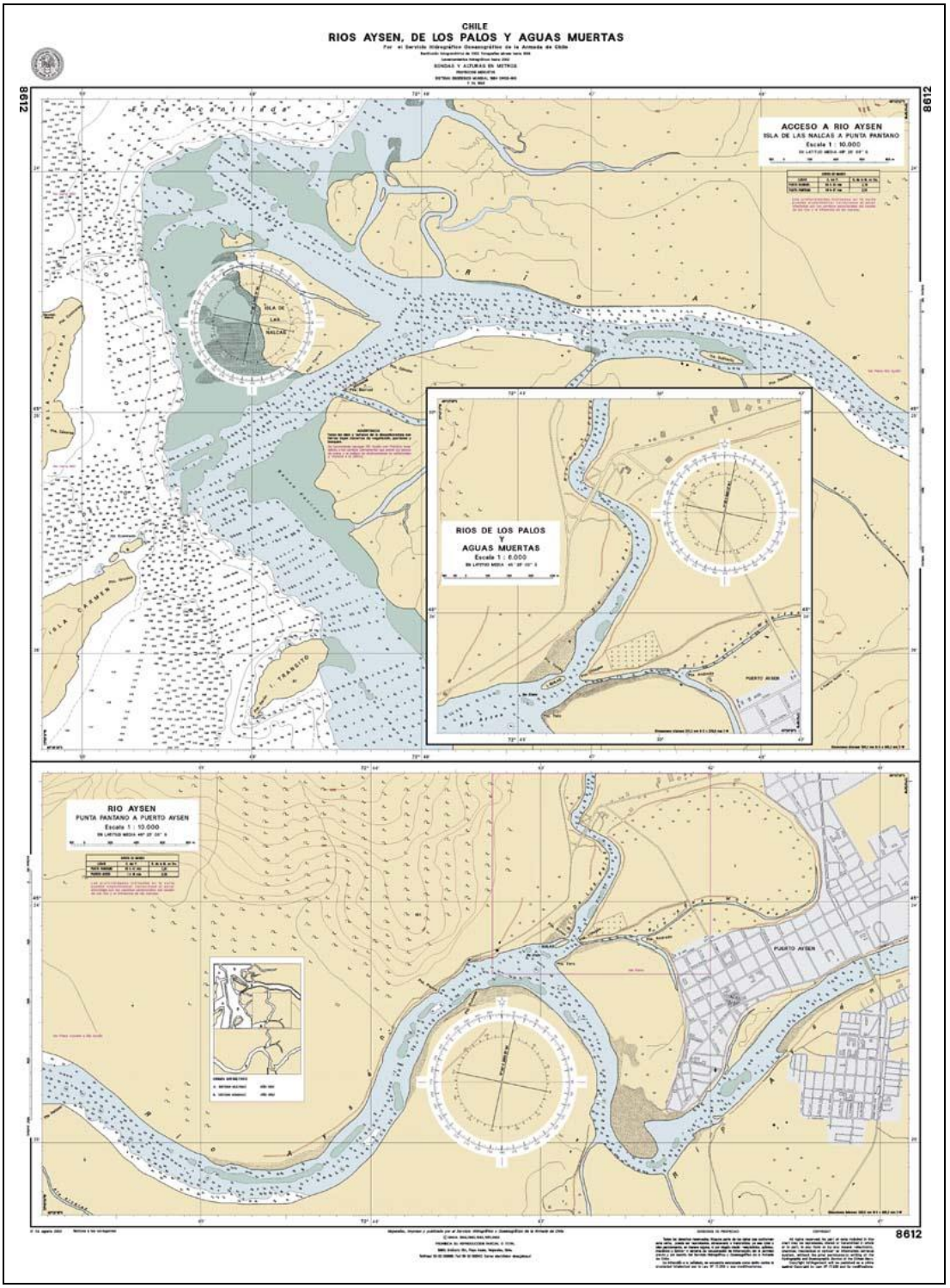


Figure 27: Consolidated bathymetric data. Higher resolution corresponds to post tsunami survey by PSG Cabrales.

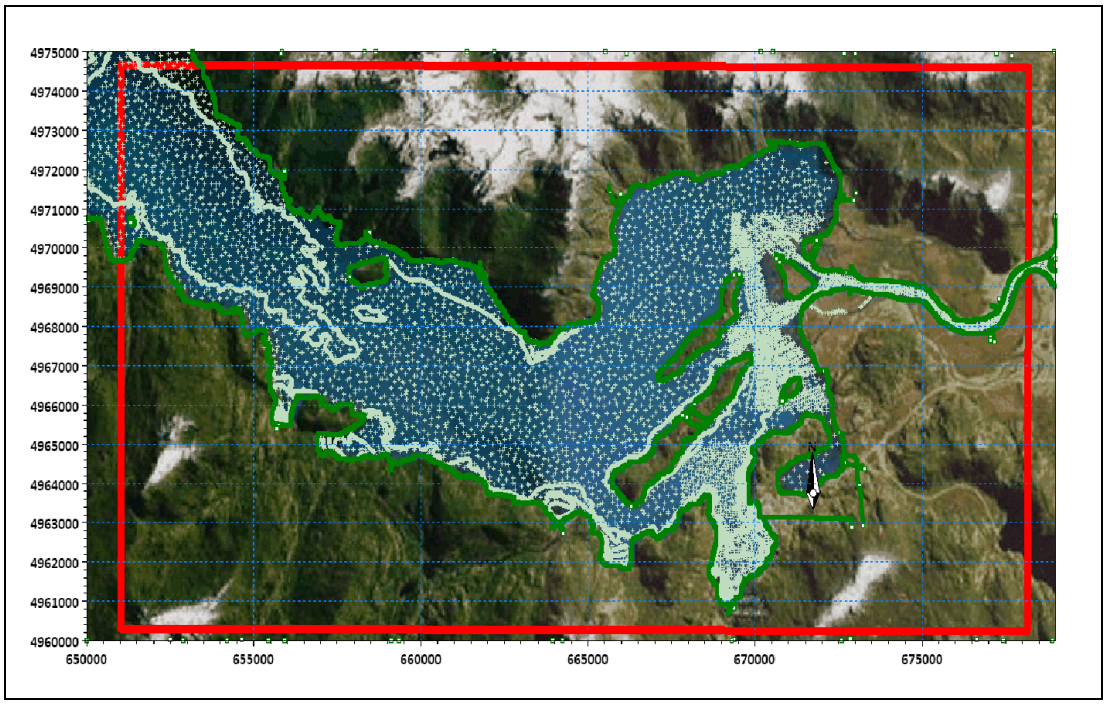


Figure 28: Bathymetric model carried out by Universidad de Valparaiso.

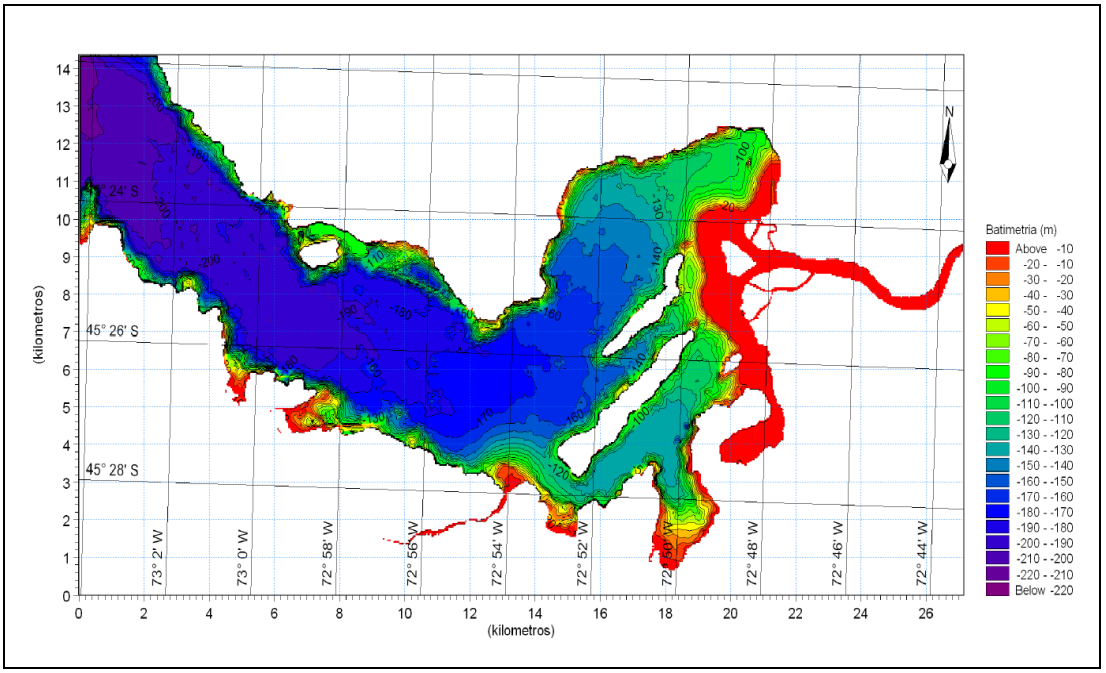
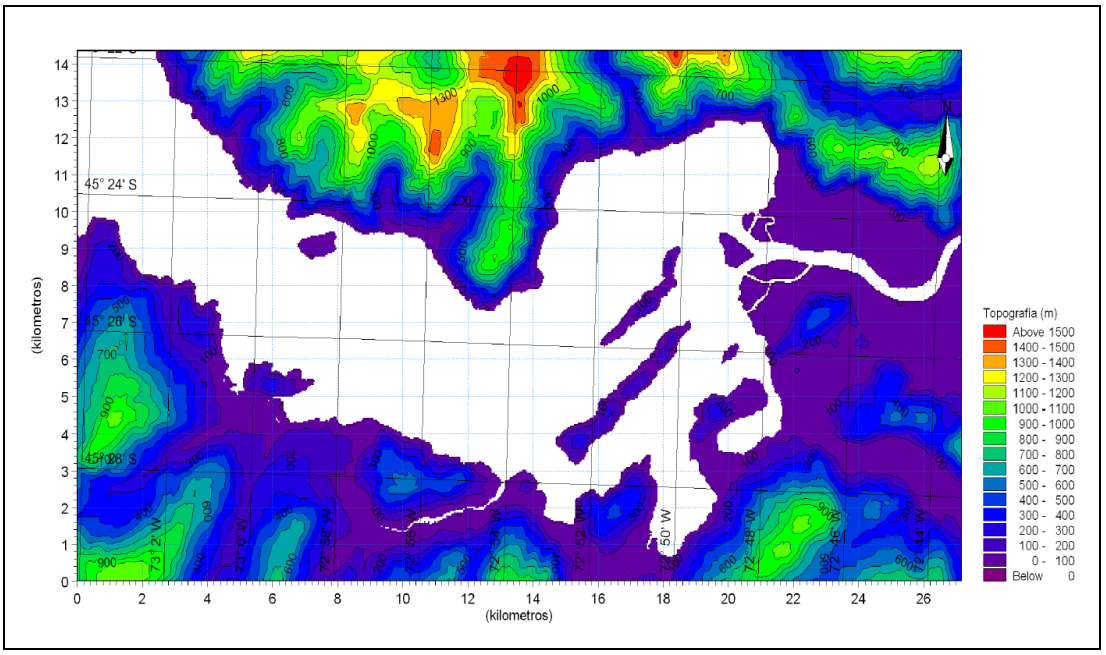


Figure 29: Topographic model carried out by Universidad de Valparaiso.

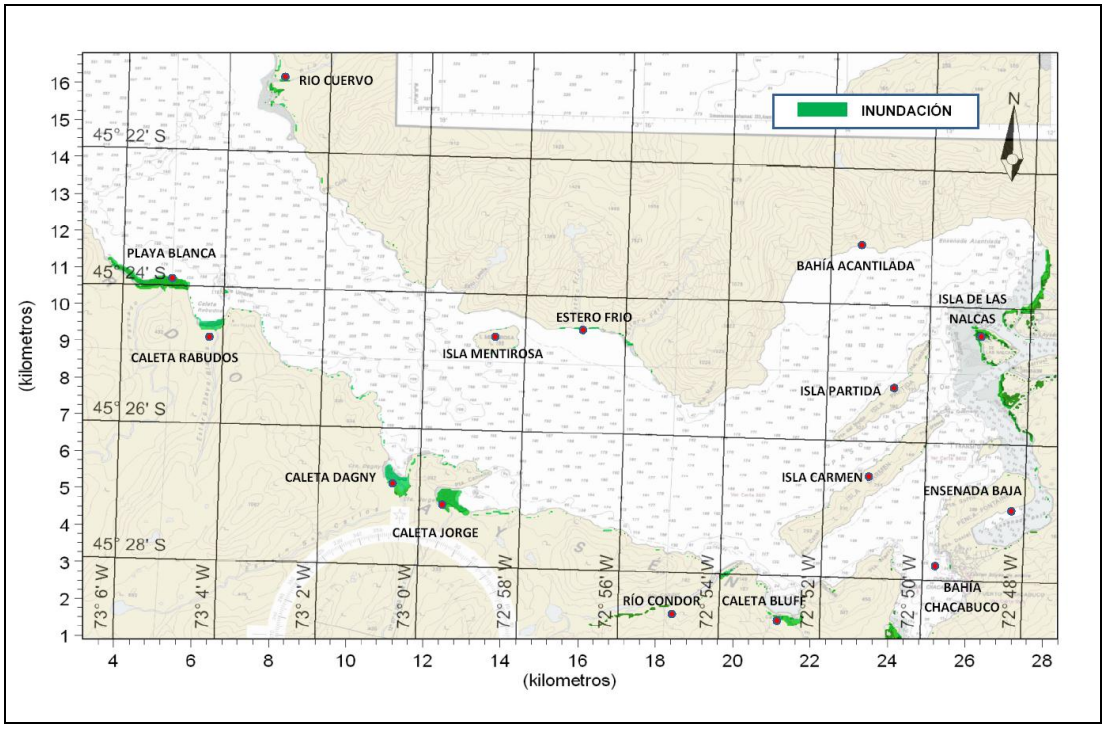


5 ASSESSMENT BY OCEAN ENGINEERING GROUP

As part of an undergraduate thesis as part of the fulfillment requirement to become Ocean Engineering, Francisco Riquelme (under the guide of the author) developed a series of 2D models of this tsunami, based on Mike 21 Flow Model and Mike 21 Boussinesq Wave Model. The whole text is in Spanish and is available on request. Some relevant results are summarized as follows:

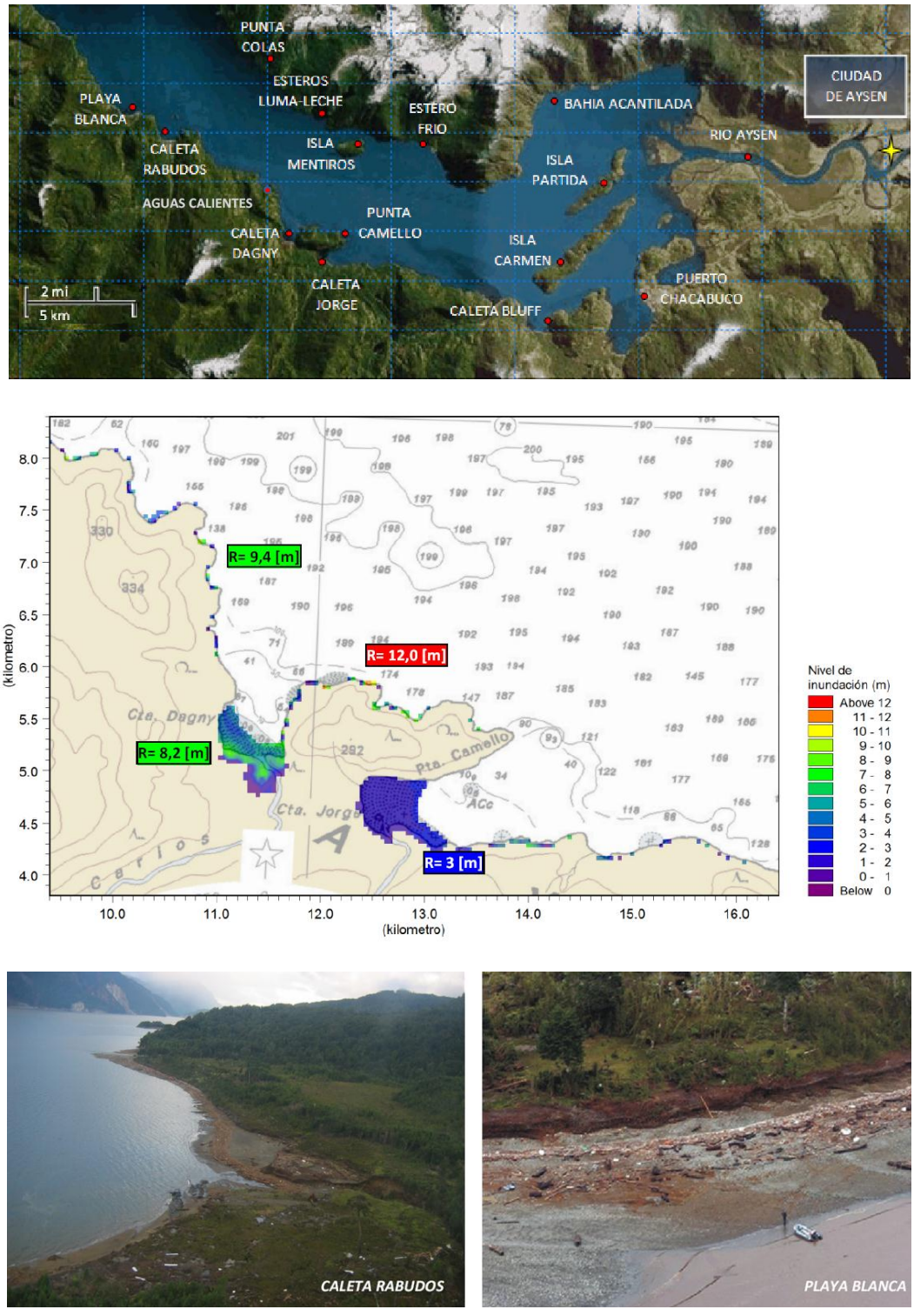
- Flooding extension in different coastal stations (Figure 30)
- Flooding extension in Playa Blanca and Caleta Rabudos (Figure 31)
- Results in different coastal stations for the 21st April 2007 tsunami (Figure 32)
- Estimated time of arrival for the 21st April 2007 tsunami (Figure 33)

Figure 30: Flooding extension in different coastal stations.



Source: Ocean Engineering Group. Universidad de Valparaiso.

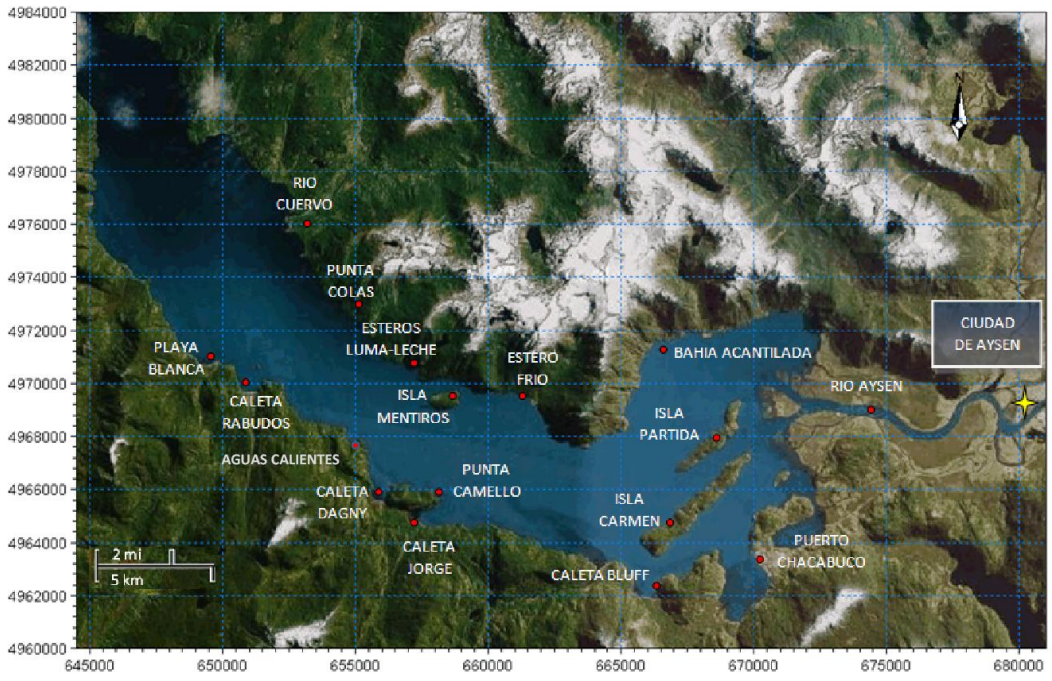
Figure 31: Flooding extension in Playa Blanca and Caleta Rabudos.



Source: Ocean Engineering Group. Universidad de Valparaiso.

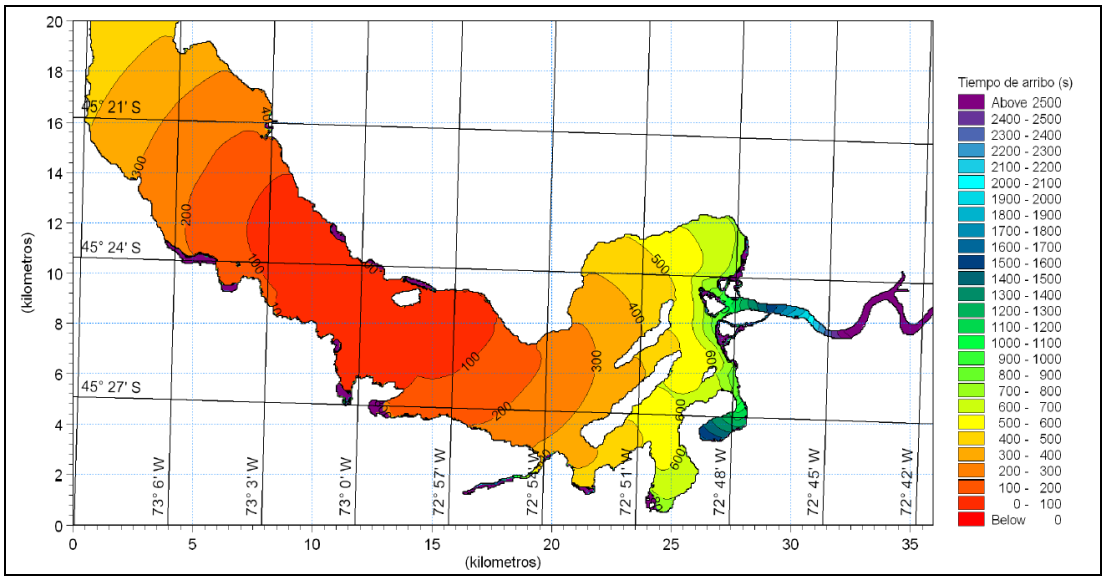
Figure 32: Results in different coastal stations for the 21st April 2007 tsunami.

SECTOR	INUNDACIÓN			PARÁMETROS DE LA ONDA			
	TIEMPO DE ARRIBO		ÁREA	RUN-UP	ELEVACIÓN	ALTURA	VELOCIDAD
	[Min]	[Segundo]	[m^2]	m	m	m	[m/s]
Playa Blanca	2,72	163	520.000	3,0	2,5	3,0	0,7
Caleta Rabudos	2,83	170	174.400	10,0	5,0	12,0	1,9
Caleta Dagny	1,23	74	312.000	8,2	5,0	8,0	6,6
Caleta Jorge	3,75	225	363.200	3,0	3,0	4,0	3,5
Isla Mentirosa	0,08	5	27.200	52,0	30,0	44,0	10,8
Estero Frio	0,47	28	65.600	14,0	8,0	18,0	4,0
Punta Yelcho	5,98	359	60.000	6,5	6,0	10,0	2,8
Caleta Bluff	7,67	460	148.800	4,6	1,6	6,0	2,7
Bahía Chacabuco	8,88	533	356.800	1,5	0,8	2,0	1,6
Alrededores de la desembocadura del río Aysén	13,83	830	672.000	2,5	2,0	3,8	0,3
Isla Carmen	5,53	332	22.400	3,5	3,4	4,0	0,6
Isla Partida	5,55	333	12.800	2,8	2,1	2,5	0,3
Isla de las Nalcas	11,00	660	150.400	1,6	1,5	2,0	2,6
Ensenada Baja	13,67	820	16.000	1,0	0,1	0,3	0,3



Source: Ocean Engineering Group. Universidad de Valparaiso.

Figure 33: Estimated time of arrival for the 21st April 2007 tsunami.



Source: Ocean Engineering Group. Universidad de Valparaiso.

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Ref. 2 Departamento de Geología Aplicada, Dirección Nacional de Geología (SERNAGEOMIN). (2007). "Estimación de parámetros de posibles remociones en masa que podrían afectar el sector de Bahía Acantilada en el fiordo Aysén, región de Aysén". Chile.

Ref. 3 Naranjo, J. A., Arenas, M., Clavero, J., & Lara, L. (2007). "Estudio preliminar de peligros por Remociones en Masa en la zona afectada por el sismo (MW 6,2) del 21de abril de 2007, región de Aysén". SERNAGEOMIN, Chile.

Ref. 4 Naranjo, J. A., Clavero, J., Moreno, H., & Basualto, D. (2007). "Crisis sísmica en la comuna de Puerto Aysén Enero-Febrero 2007". SERNAGEOMIN, Chile.

Ref. 5 Riquelme, F (2010).“Evaluación del tsunami por remoción en masa en Fiordo Aysén, Chile”. Memoria para optar al título de Ingeniero Civil Oceánico. Universidad de Valparaíso.

Ref. 6 Servicio Hidrográfico y Oceanográfico de la Armada (SHOA). (2007). "Carta de Inundación por Tsunami generado por Remociones en Masa. Puerto Aysén y Puerto Chacabuco". Chile.