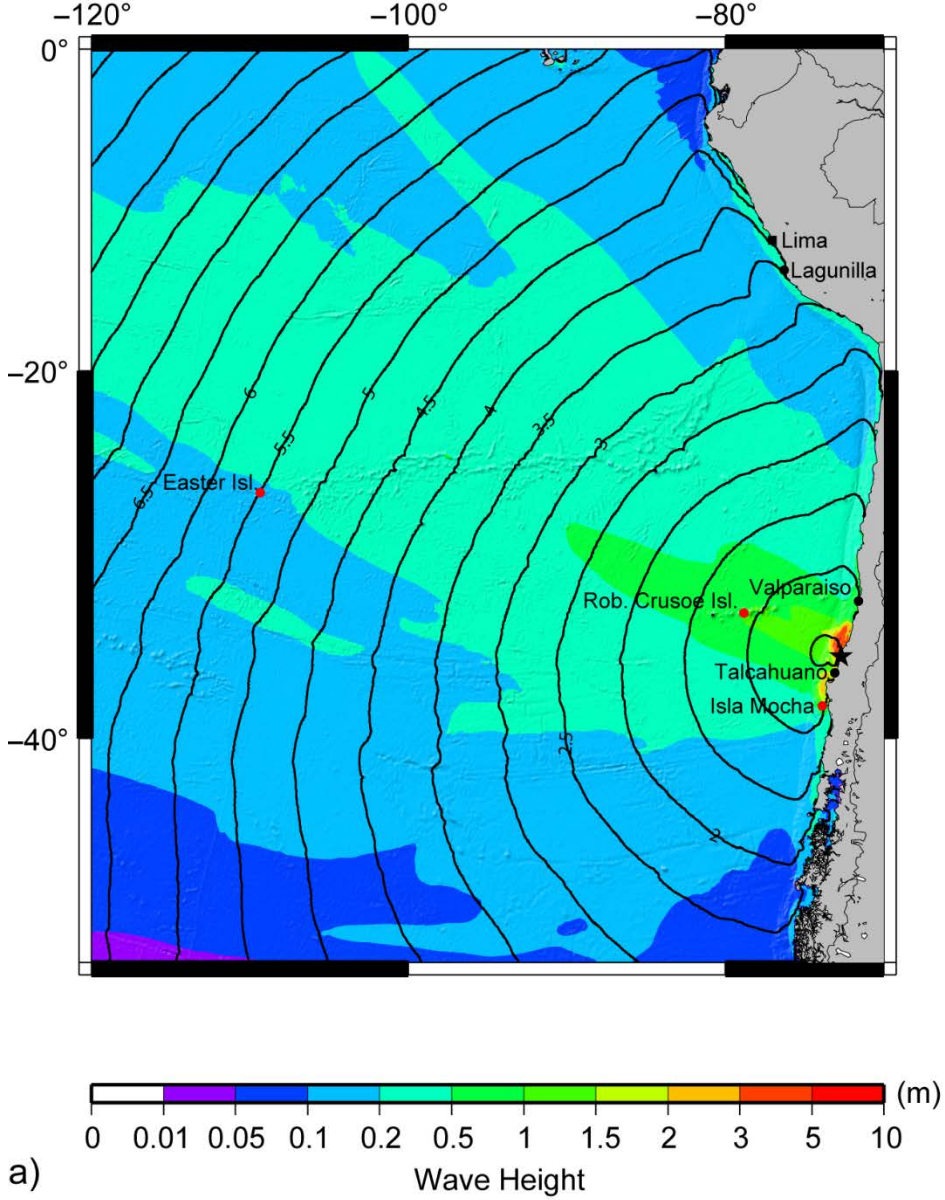
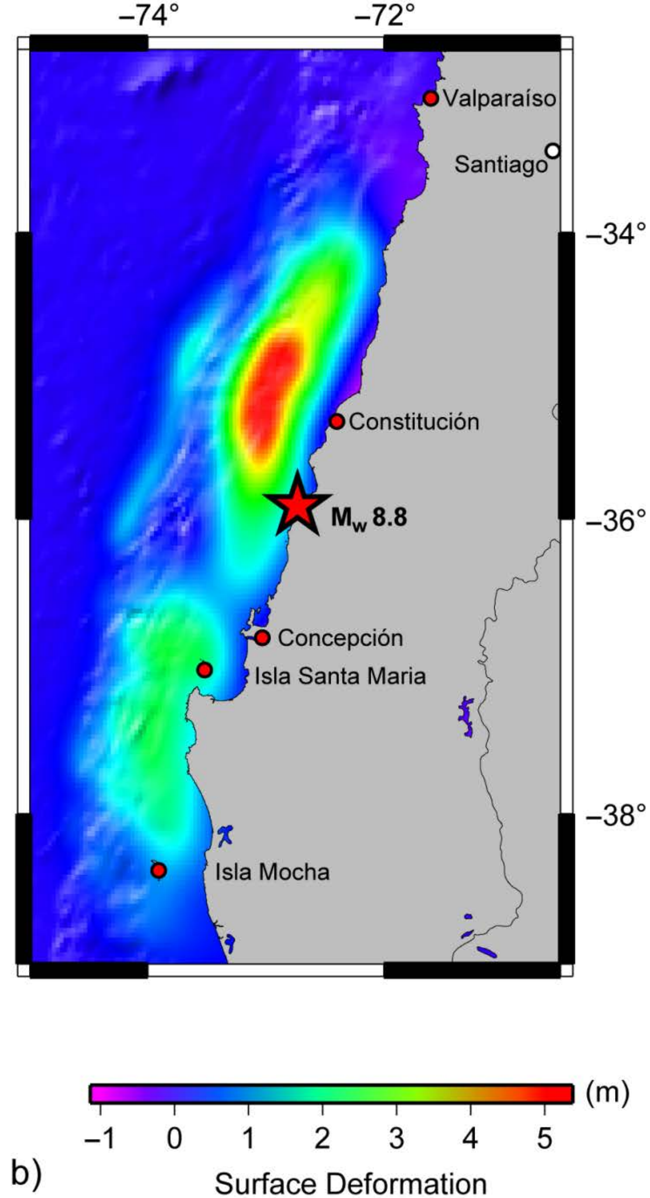
Seminario Internacional de Ingeniería y Operación Portuaria, Talcahuano, Chile, 8 Noviembre 2018

Tsunamis por maremotos en Chile y el Pacífico, deslizamientos en Tierra Verde y volcanes submarinos

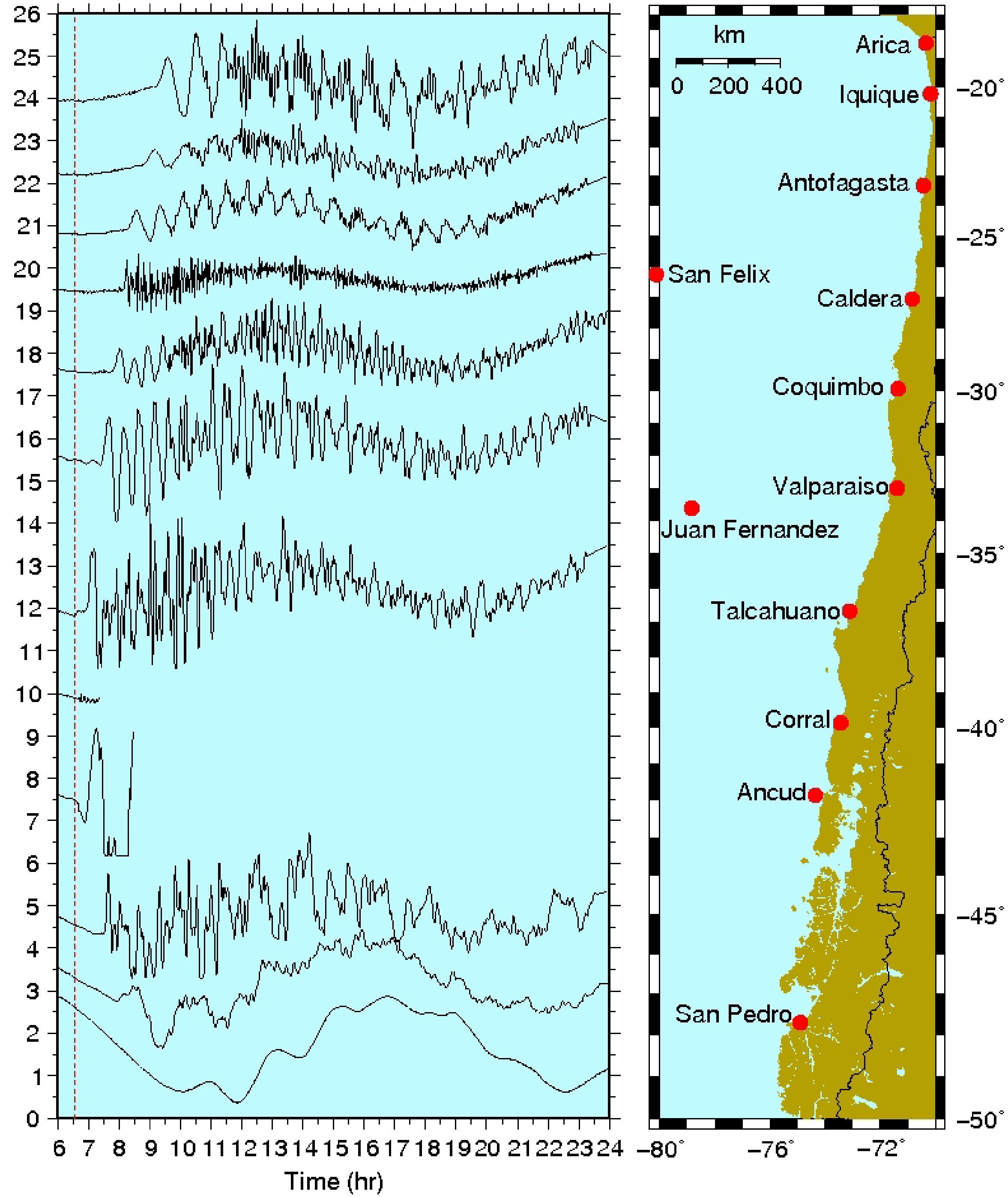
Dr. Hermann Fritz. Georgia Institute of Technology, USA

27 Feb 2010 Chile M8.8 Earthquake source and MOST tsunami modeling

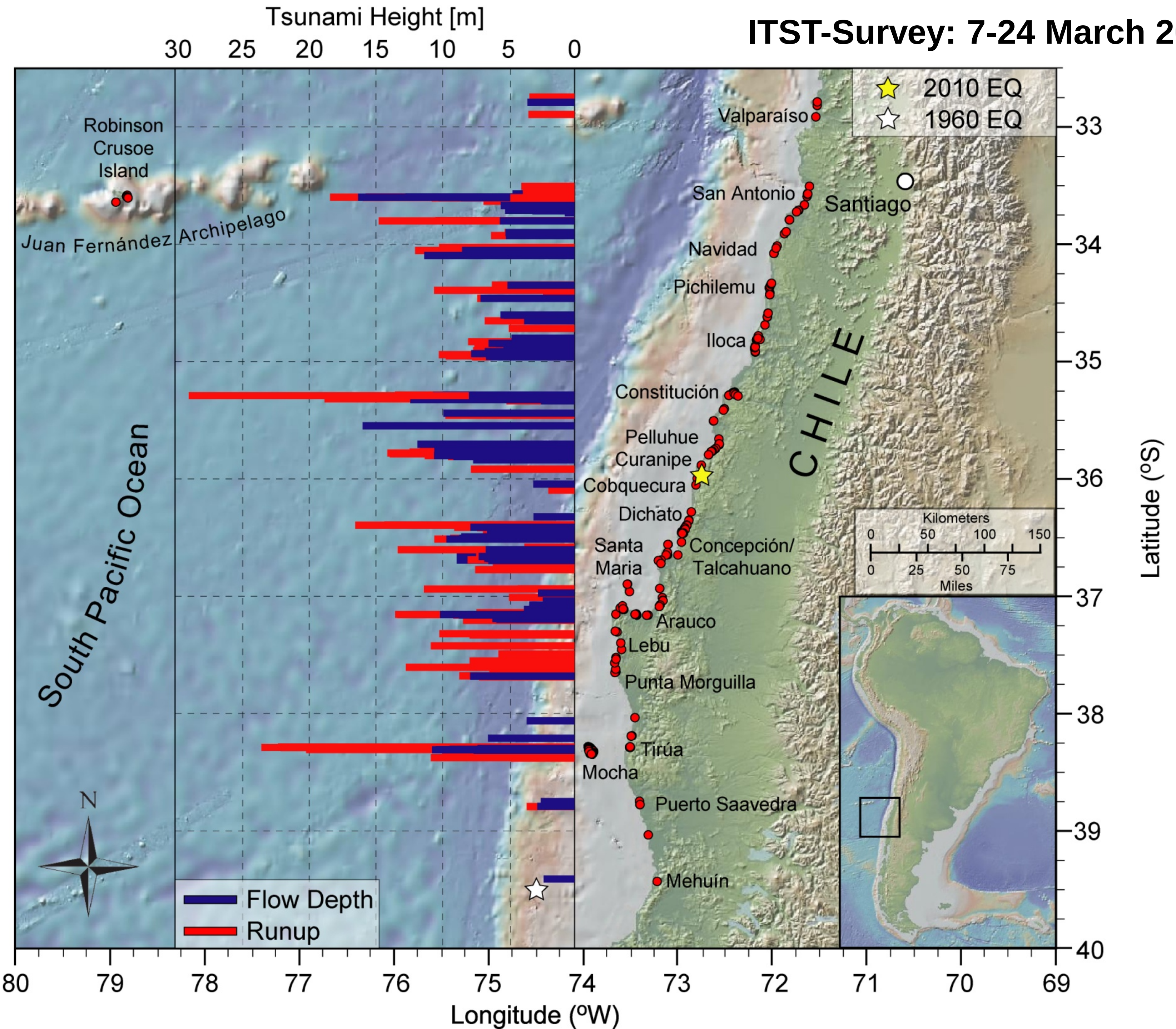


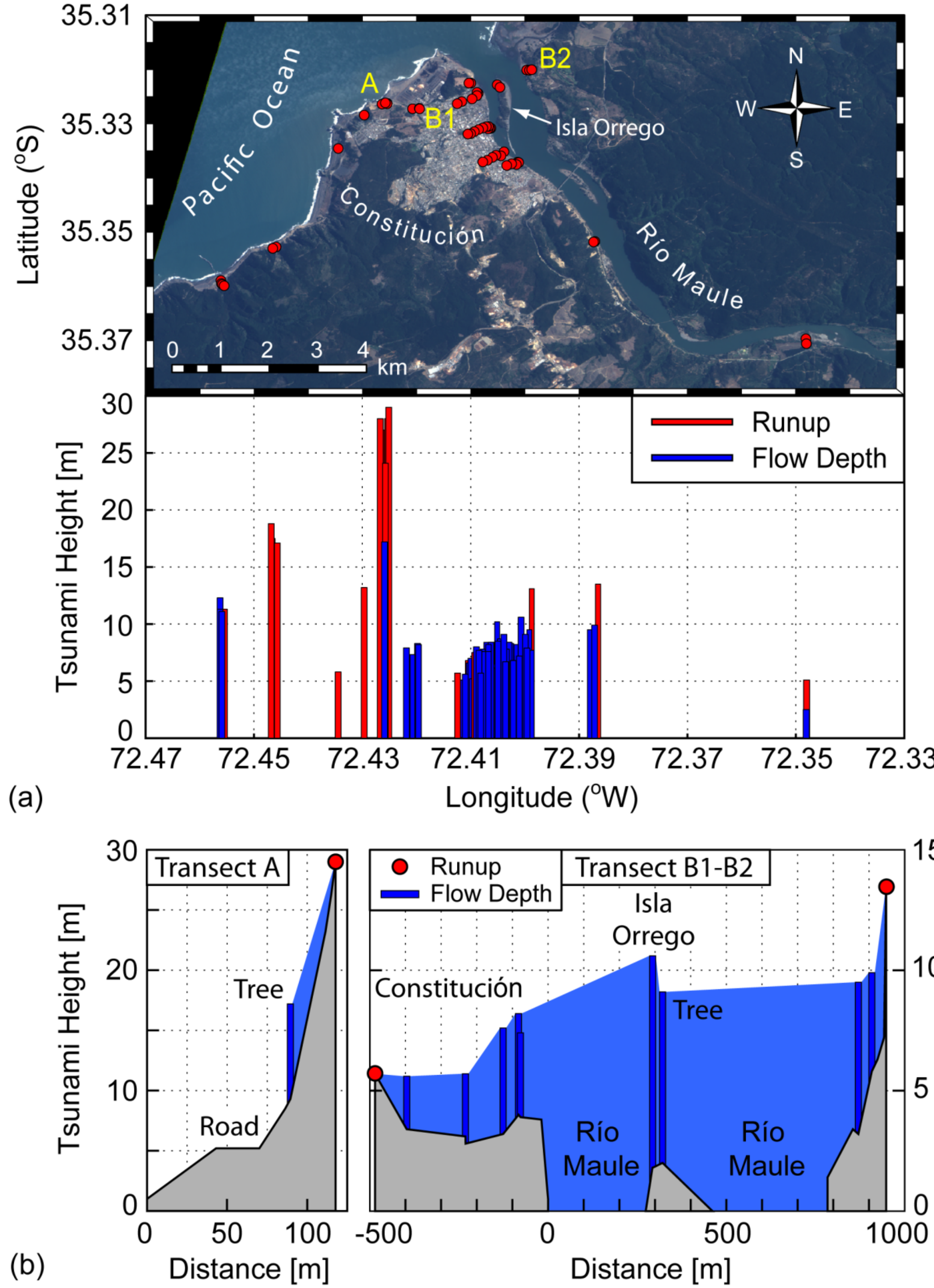


Tsunami Tide Gauge Recordings in Chile



ITST-Survey: 7-24 March 2010



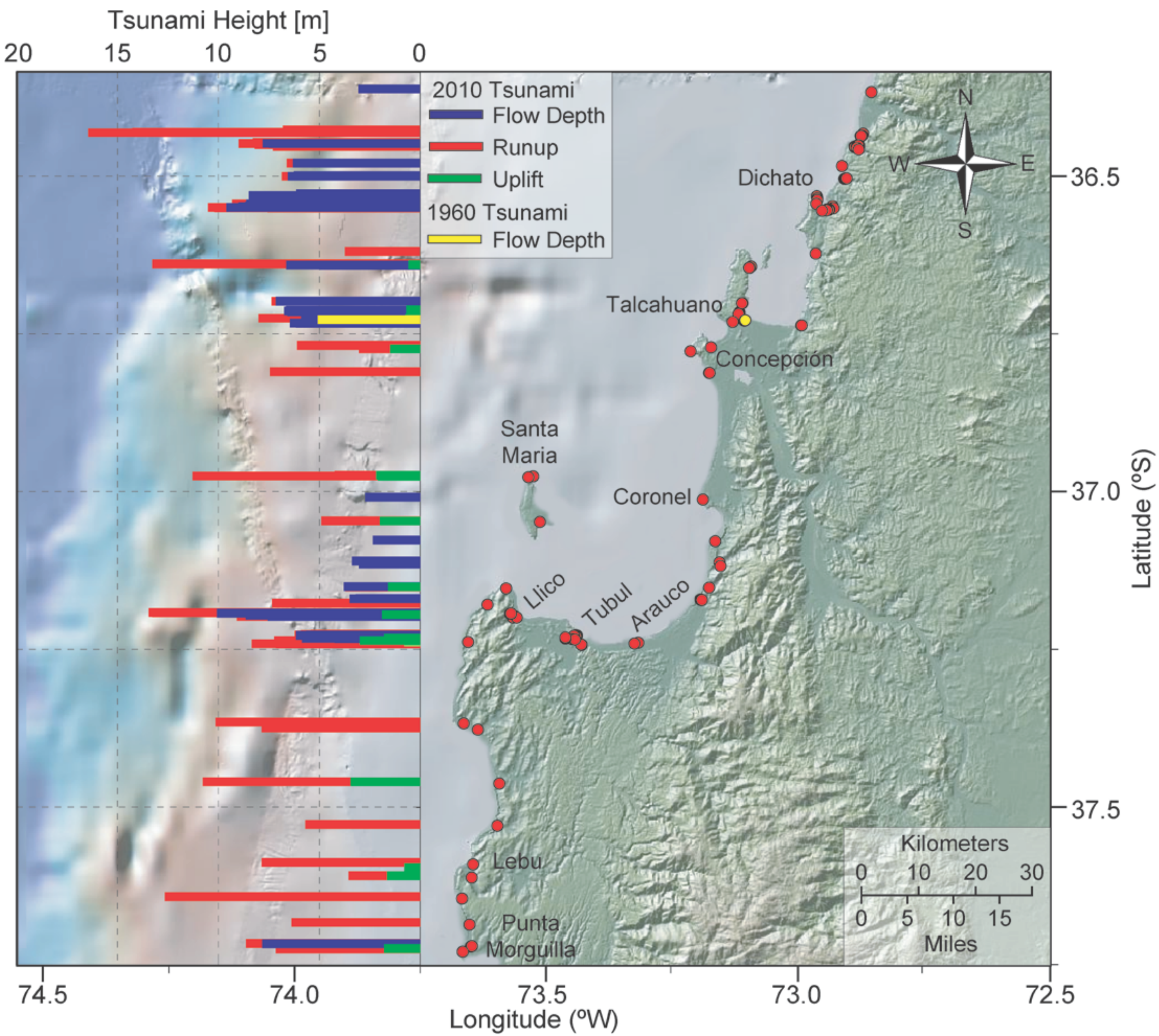


Constitución on the south shores of the Maule River estuary

Constitución – coastal tsunami variability

Constitución
Maule river
estuary
to 10 km
upriver

Dichato – Talcahuano – Arauco Peninsula



Dichato

Dichato

Talcahuano

1960 and 2010 tsunami flow depth measurements on residential house

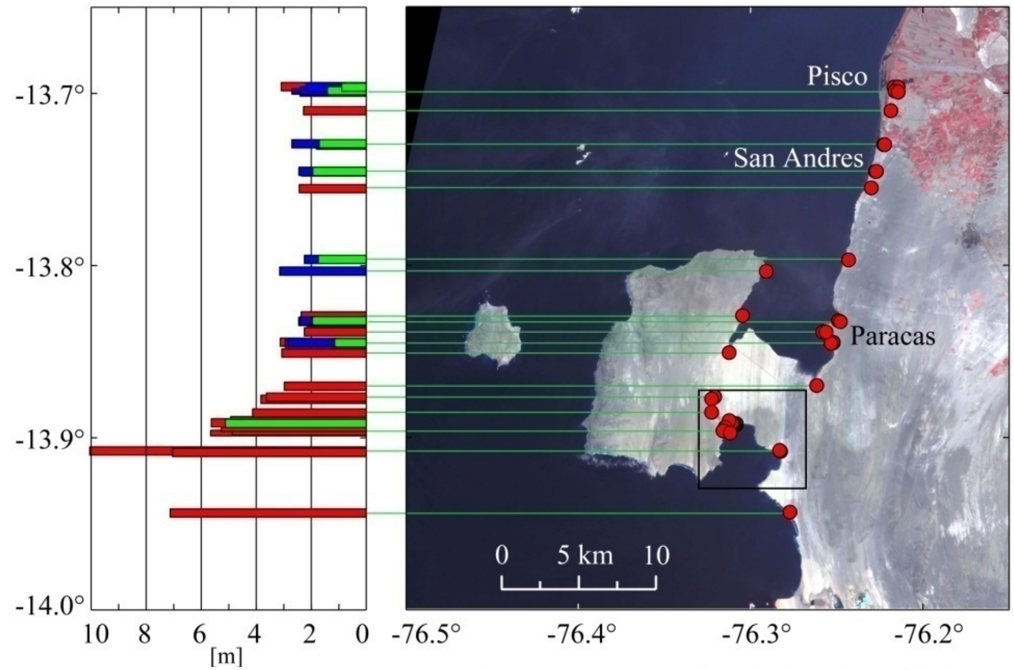

PAULA STEFANY
446
TALCA
PUERTO
SN VICENTE

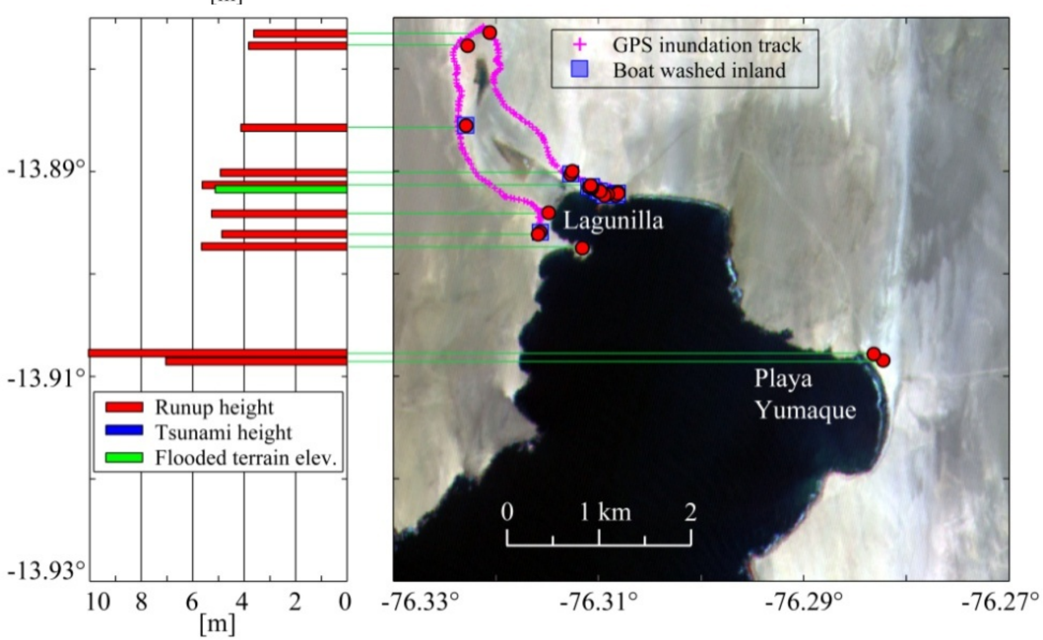

ASOC
GREMIAL
CALETA
INFIERNILLO
FUNDADA
1915

Isla Santa Maria - Uplift


Isla Santa Maria - Uplift

Lagunilla, Peru: 2007 Pisco and 2010 Chile Tsunami





Lagunilla 2007 - 3 tsunami-fatalities no earthquake fatalities

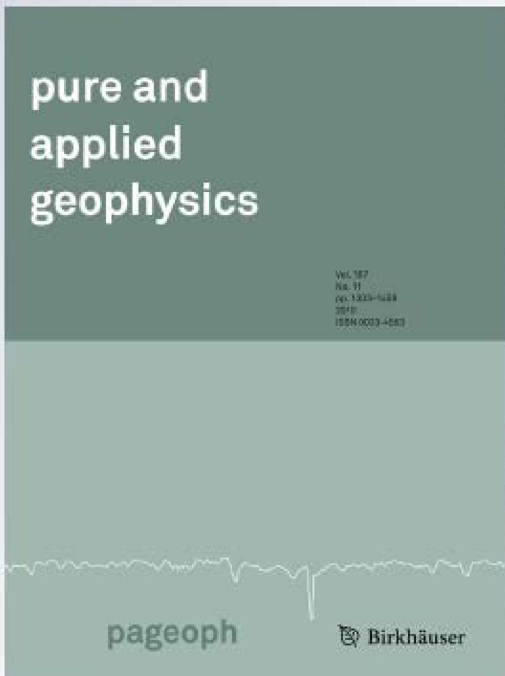
Field Survey of the 27 February 2010 Chile Tsunami

Hermann M. Fritz, Catherine M. Petroff, Patricio A. Catalán, Rodrigo Cienfuegos, Patricio Winckler, Nikos Kalligeris, Robert Weiss, et al.

Pure and Applied Geophysics
pageoph

ISSN 0033-4553
Volume 168
Number 11

Pure Appl. Geophys. (2011)
168:1989-2010
DOI 10.1007/s00024-011-0283-5



Springer

Acknowledgments

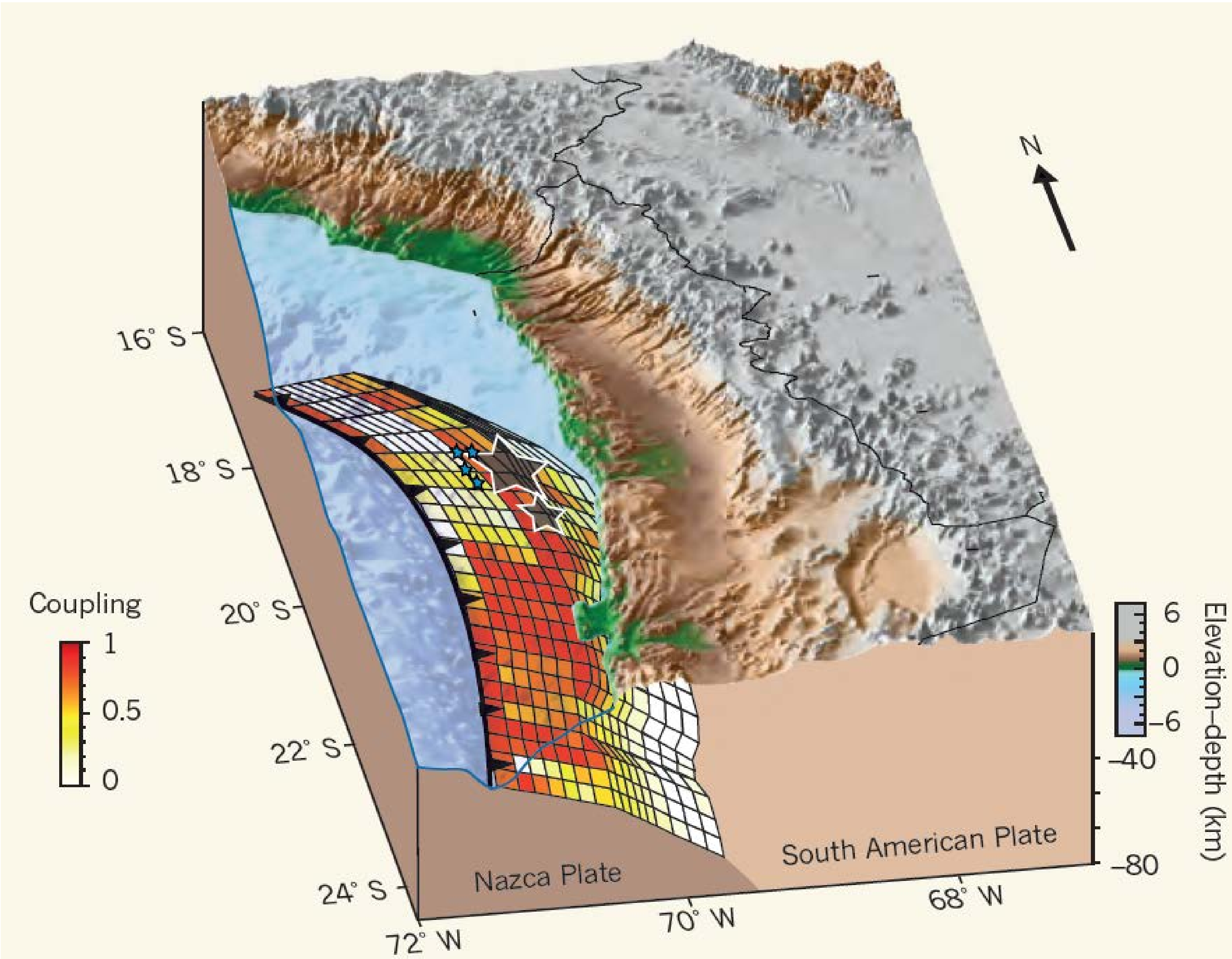
This work is supported by

- National Science Foundation NSF RAPID award CMMI-1034886 (Chile)

Any opinions, findings, and conclusions or recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of the National Science Foundation

National Science Foundation
WHERE DISCOVERIES BEGIN

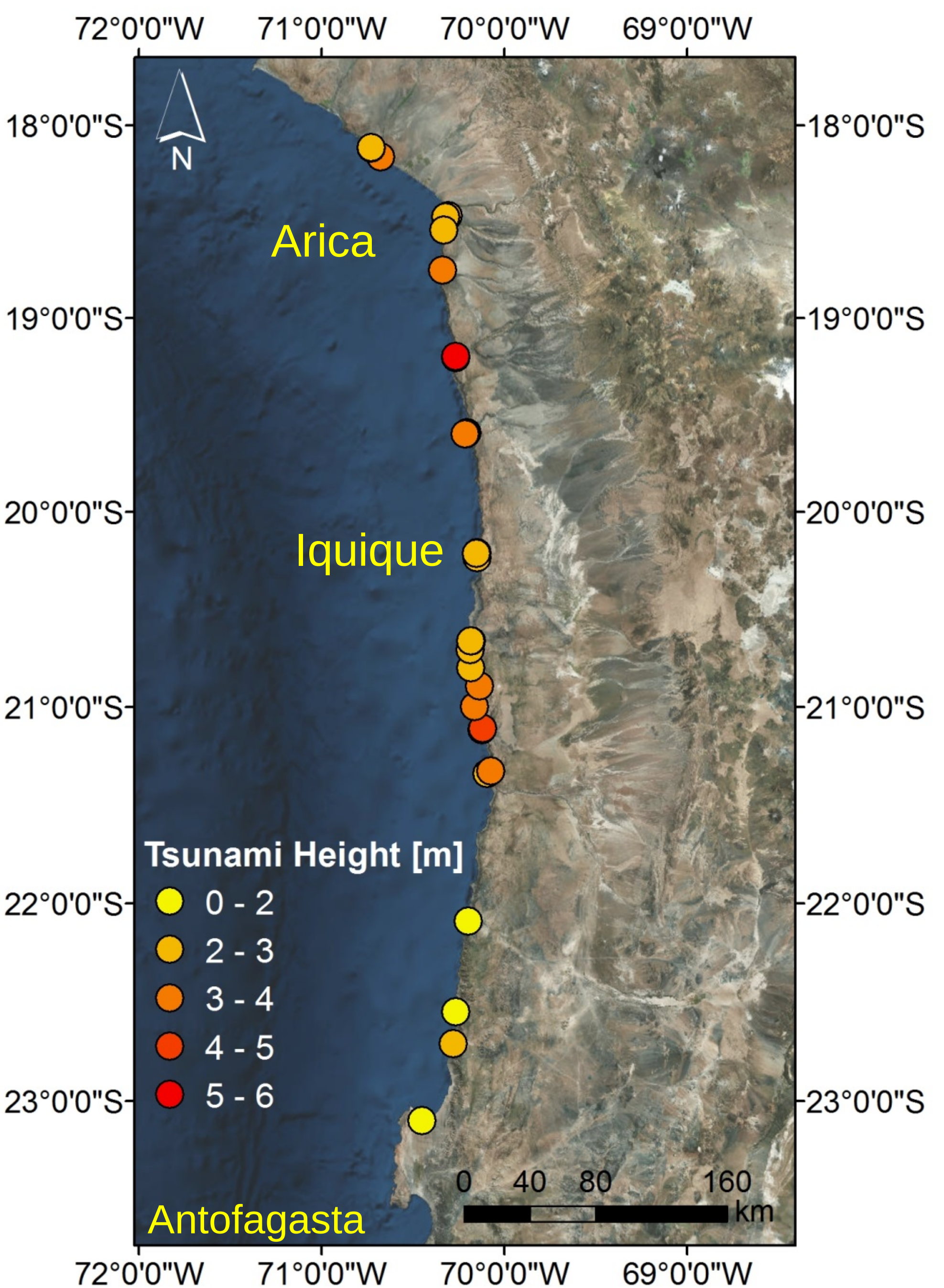
Chile M8.2, 1 April 2014



Chile M8.2
1 April 2014

Marcelo Lagos and I surveyed 600 km from Antofagasta to Vila Vila, Peru:

- Max Runup 5 m
- Max Inundation 150 m



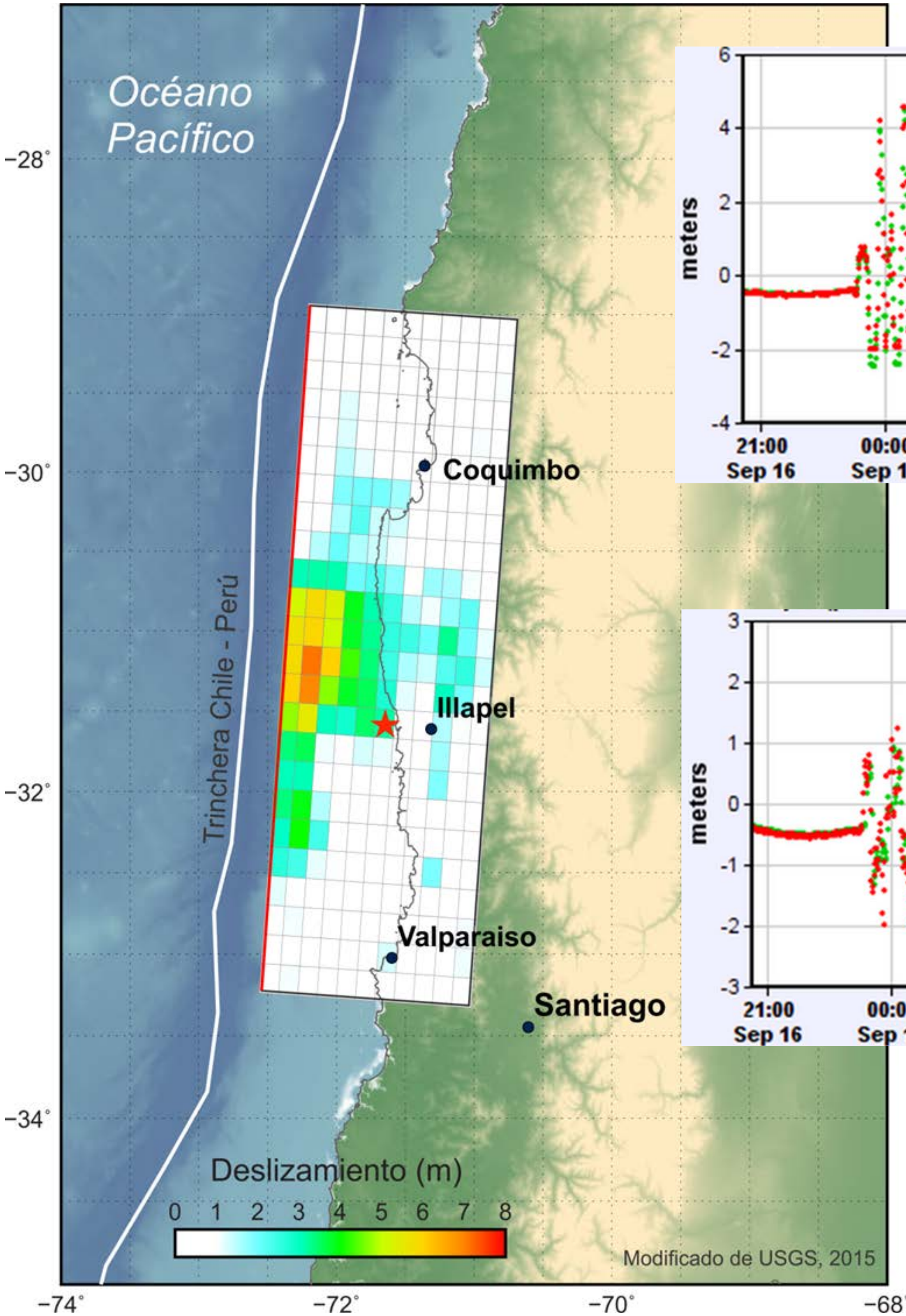
Chile M8.2, 1 April 2014

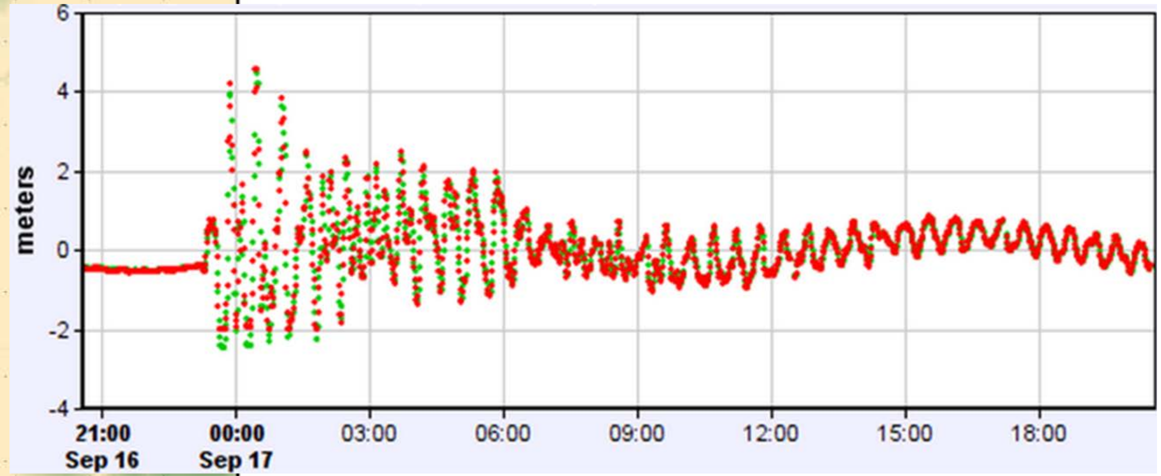



DART high and dry (22/09/2015)

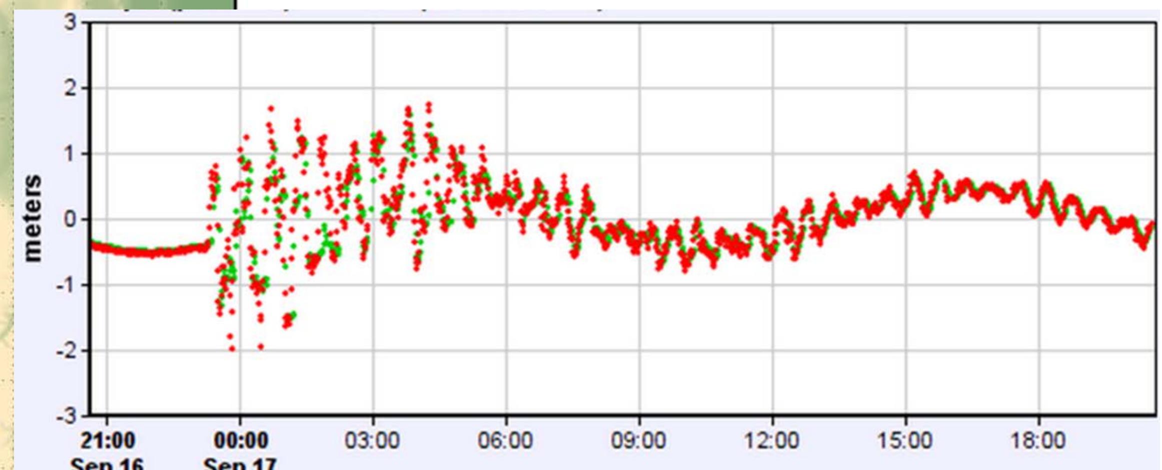
1 Million Evacuated....

…however few % were inside of flood zone!





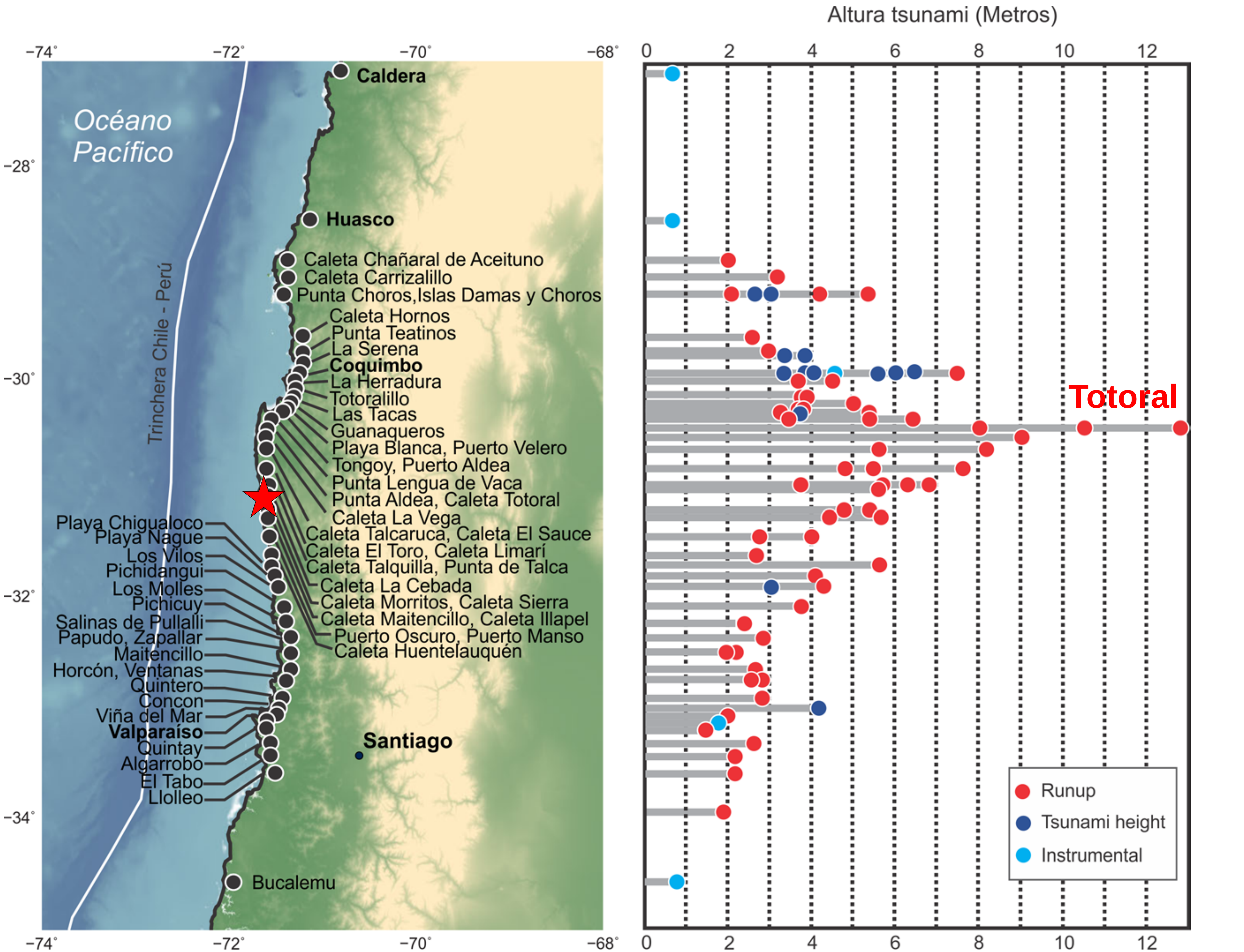
Coquimbo



Valparaíso

Tide Gauges

Field Survey 21-26 September 2015 with International Participant

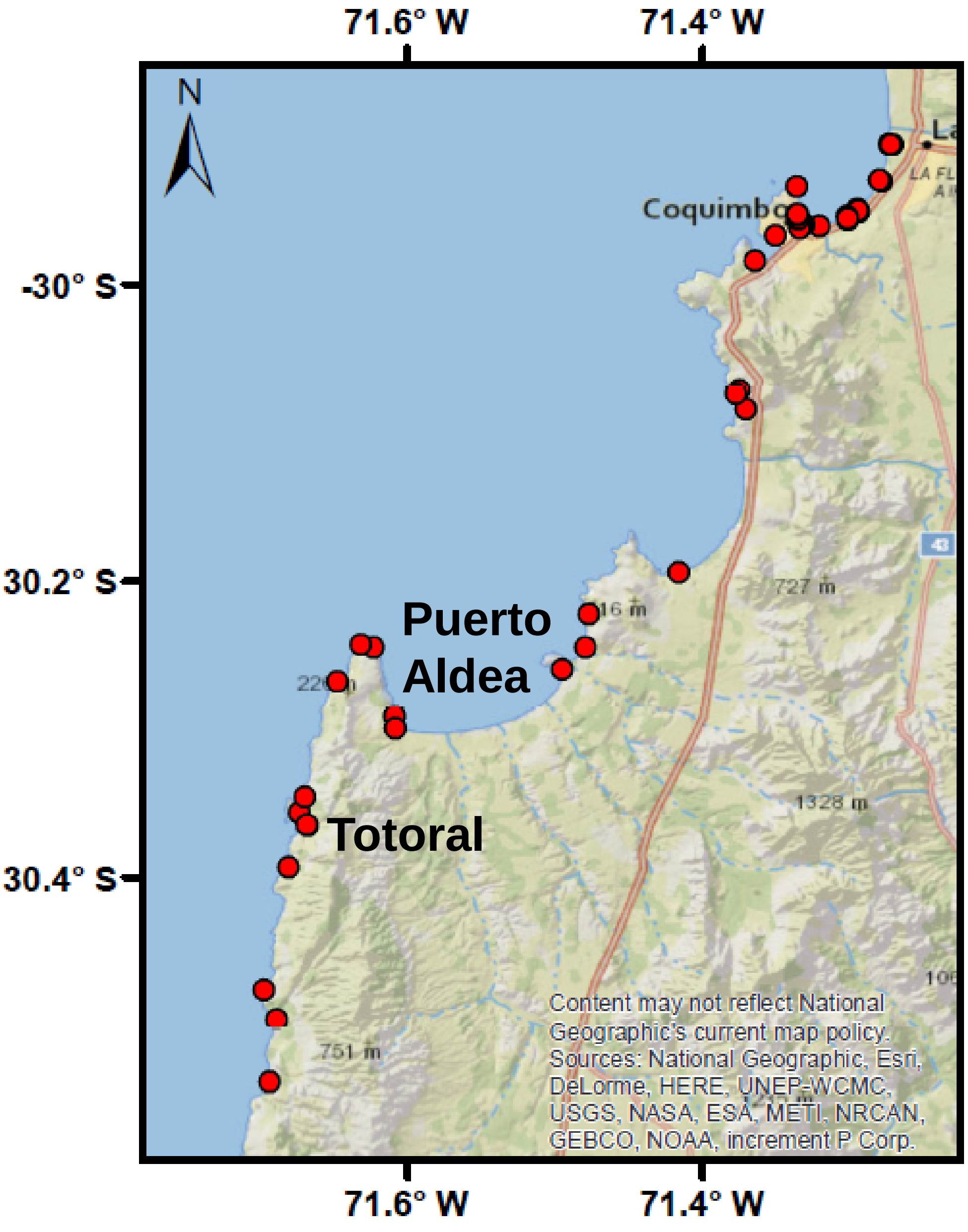


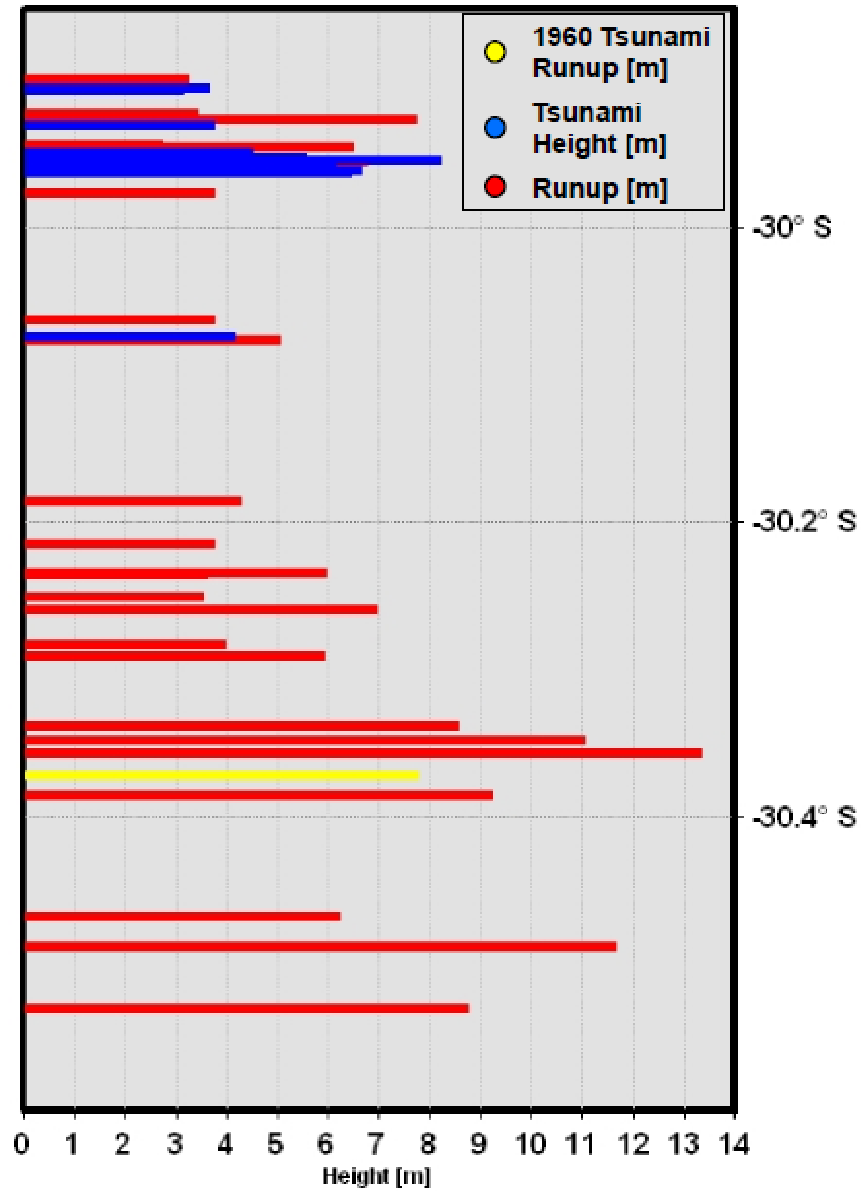
Fuente: Lagos & Fritz, 2015

Coquimbo – Post 16 September 2015 Tsunami

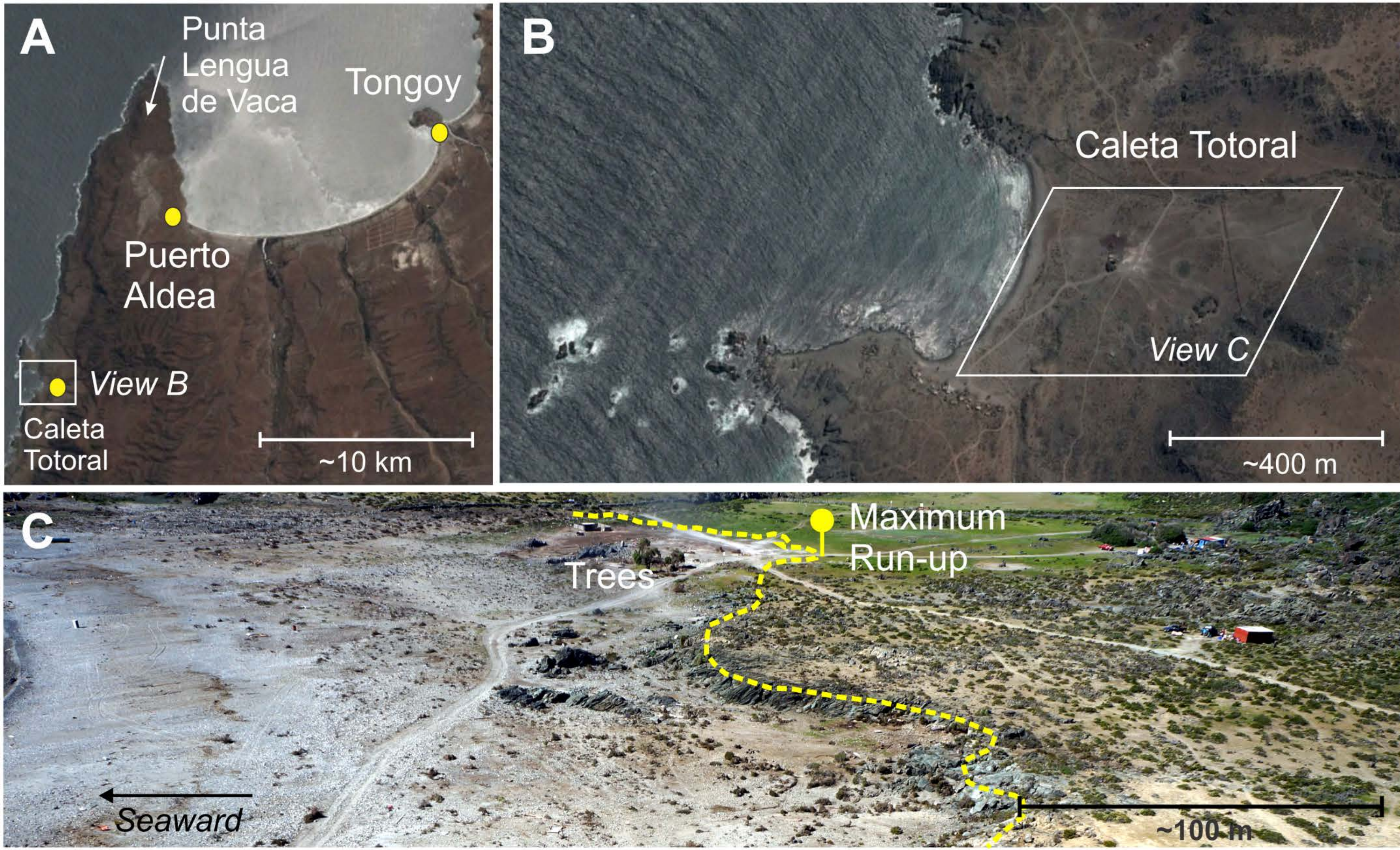
Coquimbo Fishing Boats on Costanera

La Serena – Coquimbo - Totoral





Caleta Totoral

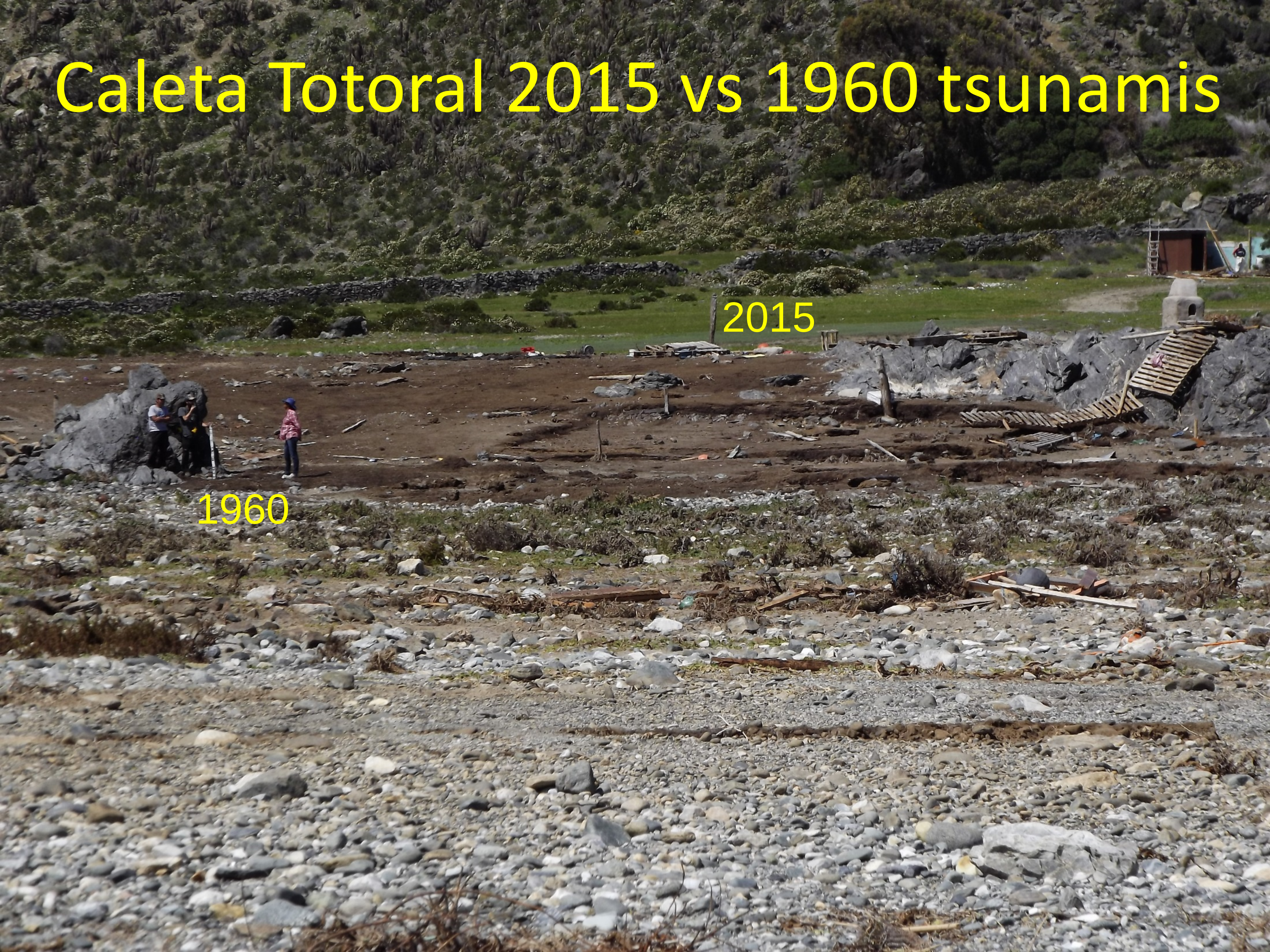


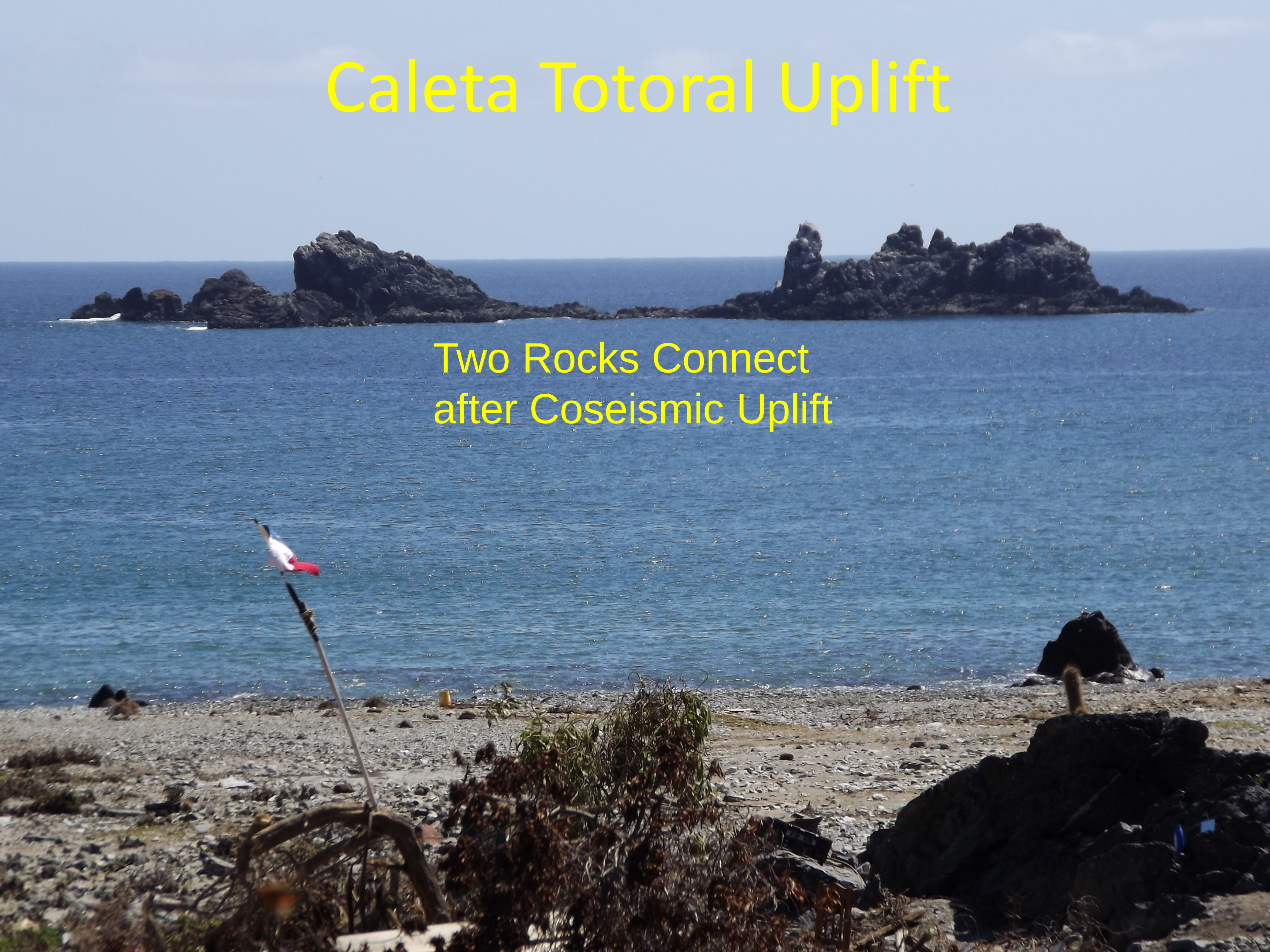

Caleta Totoral
Tree Damage

Caleta Totoral Eyewitness Interview

Fotografía: L. Carvalho, 2015

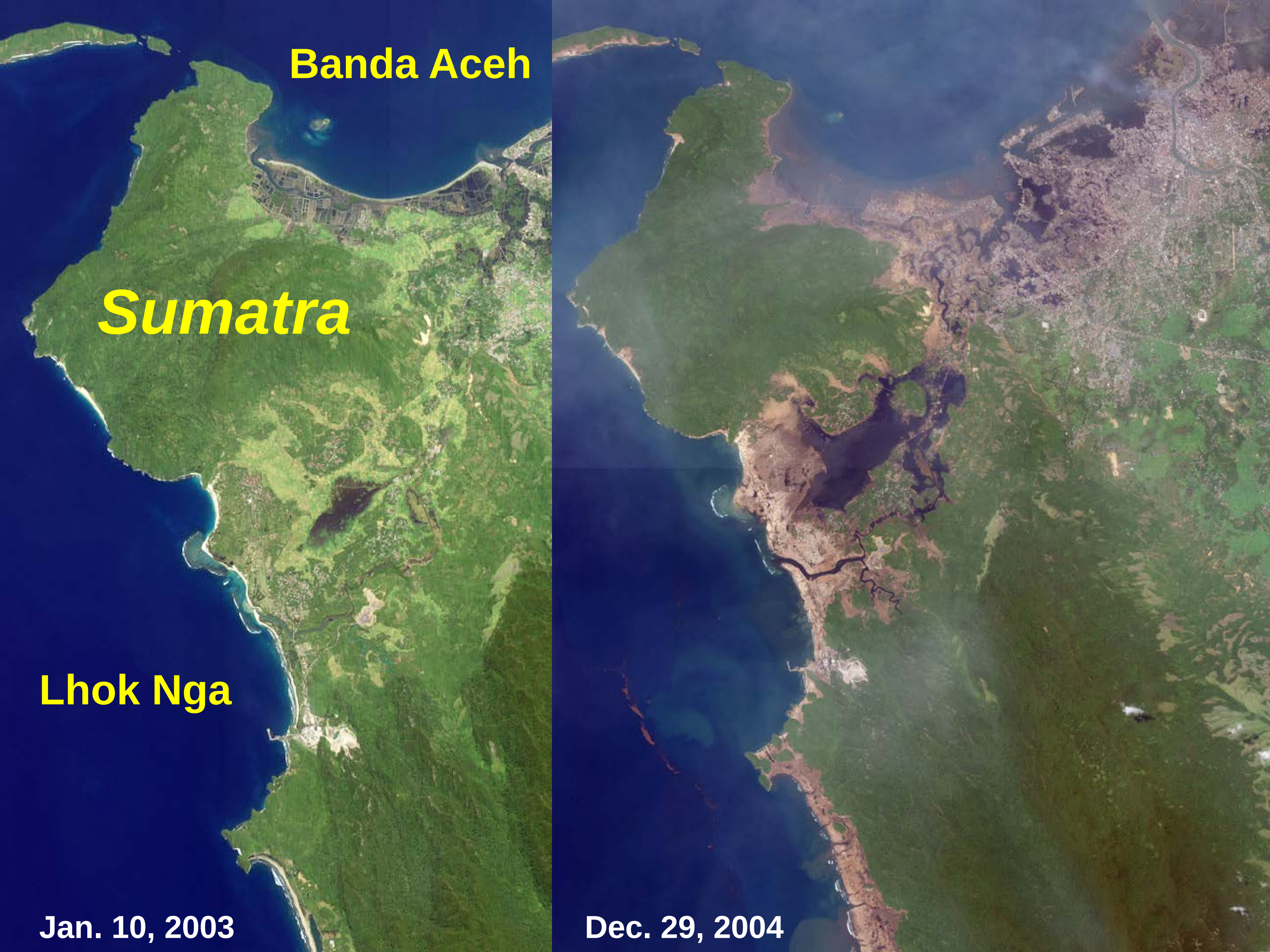
Testimonio de sobreviviente en Caleta Totoral


Caleta Totoral 2015 vs 1960 tsunamis
2015
1960

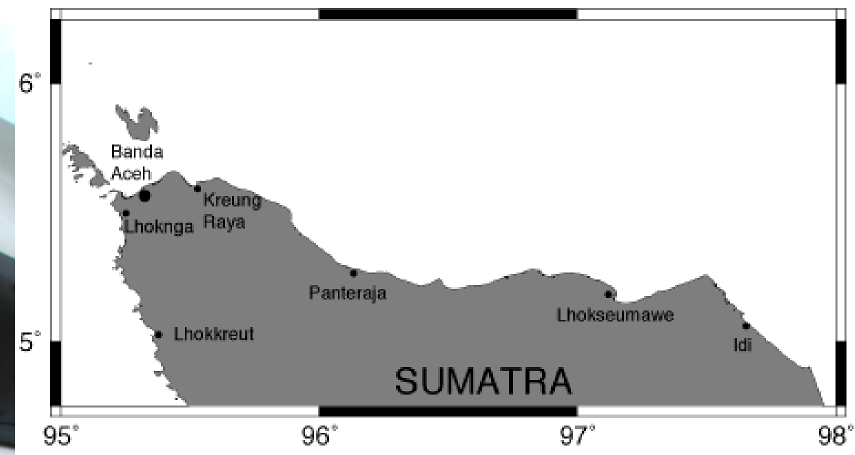

Caleta Totoral Uplift
Two Rocks Connect
after Coseismic Uplift

Chile 2015 tsunami

- EQ ground shaking as natural warning
- Tsunami arrives rapidly within minutes (“al tiro”) at coastlines closest to trench and high slip areas
- Even in 2015 the warnings did not reach many informal fishing settlements that are off the grid
- Spontaneous self evacuation contains fatalities
- Few direct tsunami victims
- Potential challenges in future events may arise from two evacuations in 2014 and 2015 of thousands of kilometers of Chilean Coastline….few in flood zone!
- surveyed 500 km of Chilean Coastline
- Max Runup 13 m, but additional bays with R > 11m


Banda Aceh
Sumatra
Lhok Nga
Jan. 10, 2003
Dec. 29, 2004


S-RNK
DANGER


6°
5°
95°
96°
97°
98°
Banda
Aceh
Kreung
Raya
Lhoknga
Panteraja
Lhokseumawe
Lhokkreut
Idi
SUMATRA


ZS-HJA
UN

Mosque at Lhok-Nga, Sumatra: Spontaneous Vertical Evacuation Site

In Lhok Nga 7000 of the town’s 8000 inhabitants lost their lives


Spontaneous Vertical Evacuation Site

30 July 2017

30 July 2017

- A 35-unit residential complex situated on the coast about 500 meters from the plant, and which housed roughly 100 employees and their families, was completely destroyed.
- 193 employees of the Banda Aceh cement plant were killed or reported missing, while 432 survived.

Rock hard cement filled the tilted vessels holds

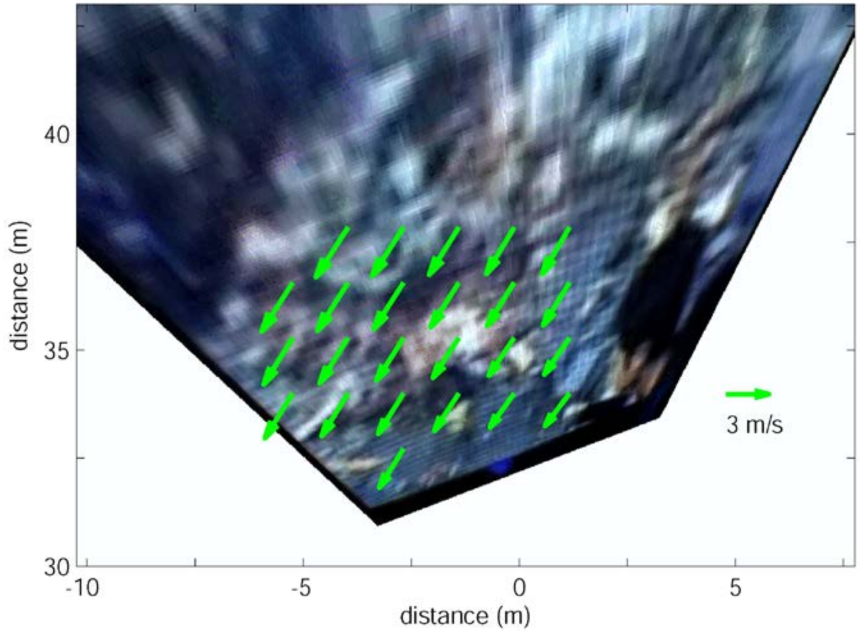
Banda Aceh


Grand Mosque
DUSUN TONGKOL
ULEE LHEUE
PEMILIK
TSUNAMI
26 DES 2004

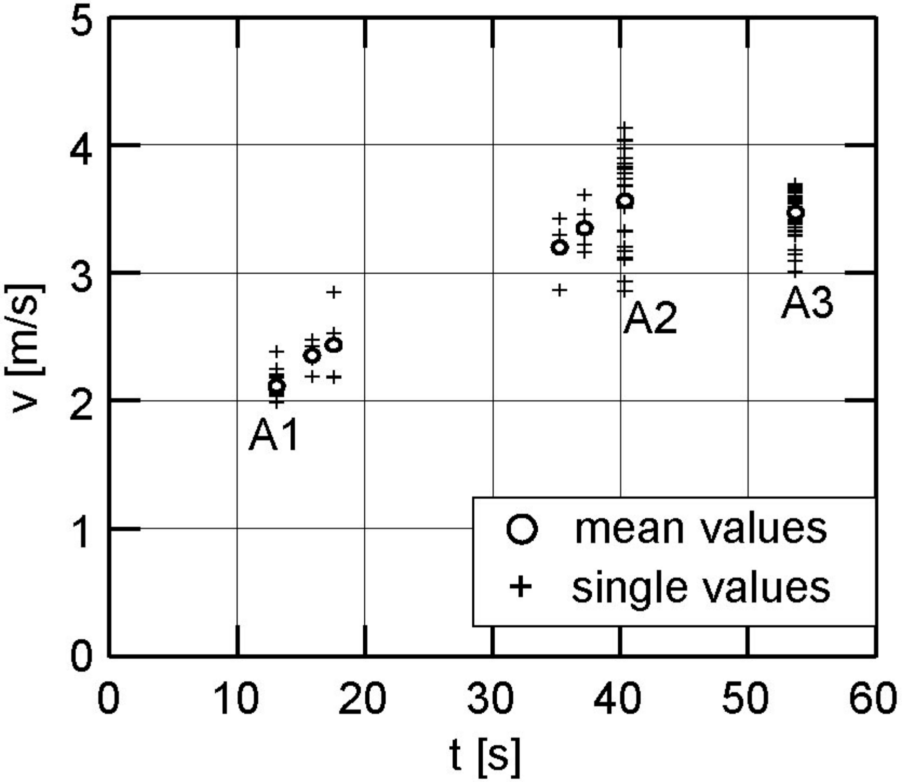
Survivor Video Analysis

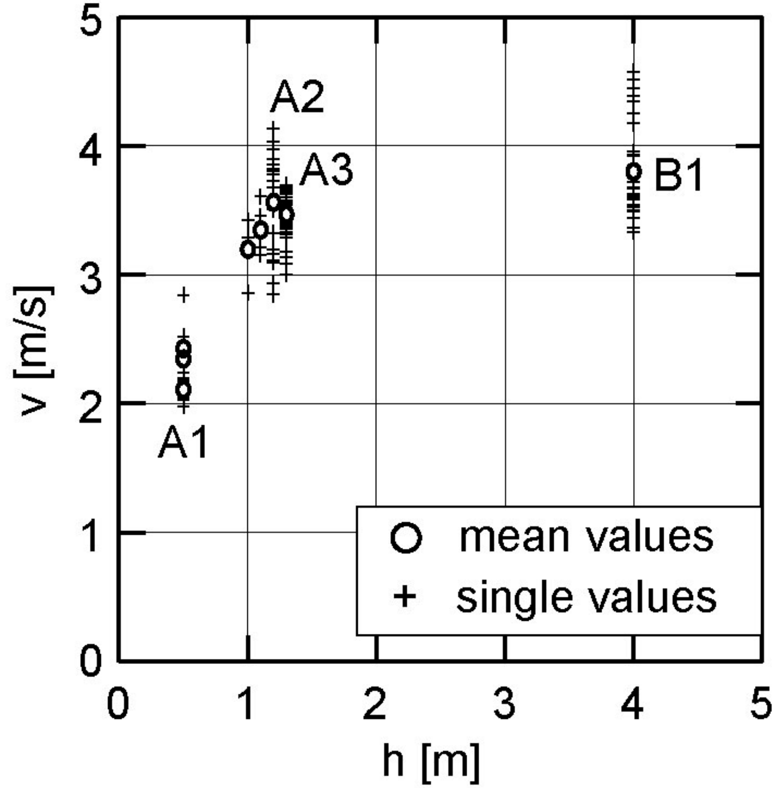
Evakuasi

Evakuasi



Fritz et al. (2006). 2004 Indian Ocean tsunami flow velocity measurements from survivor videos, *Geophys. Res. Lett.*, 33, L24605.



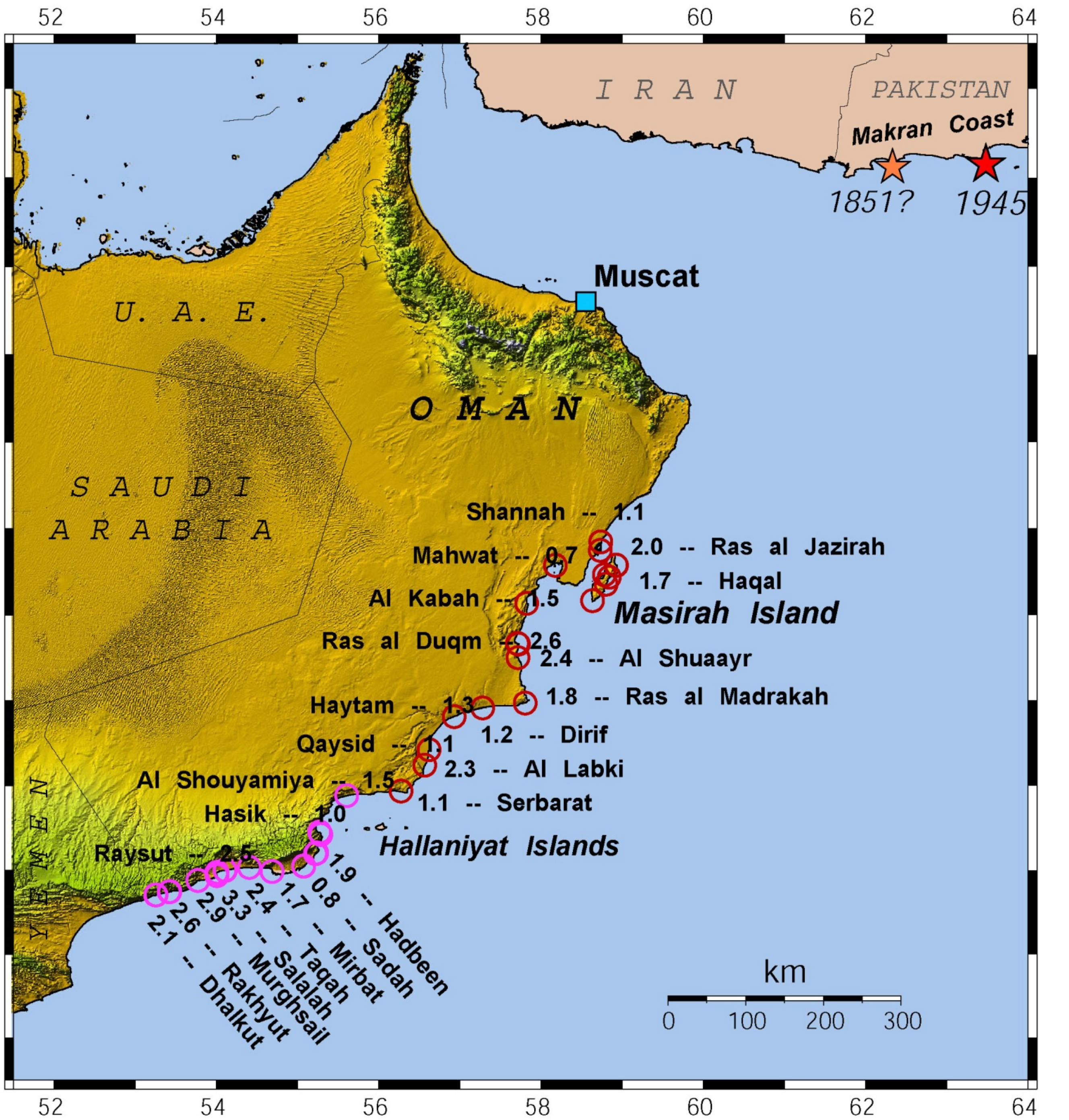



PLTD APUNG 1

2004 Indian Ocean Tsunami

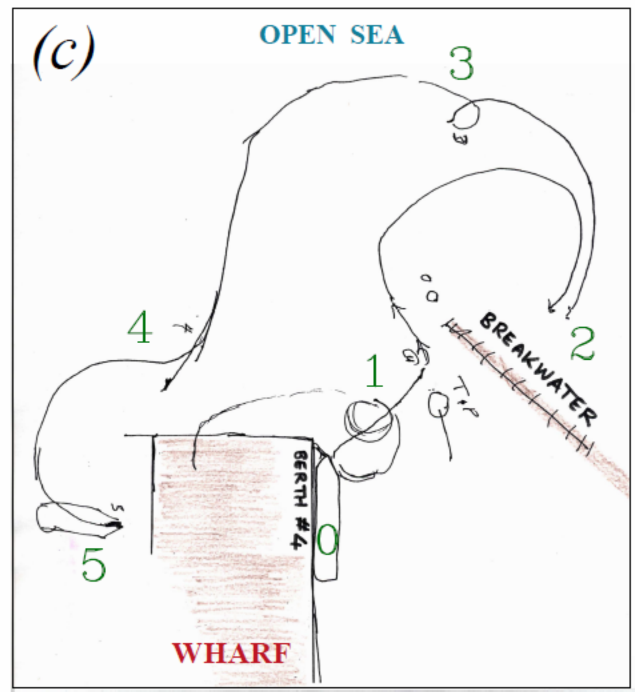
Runup Survey

Okal et al., 2006
Earthquake Spectra



Port of Salalah, Sultanate of Oman

Figure 6.: *(a):* Aerial photographs of the port of Salalah looking WSW *(a)* and WNW *(b)*. On these file photographs (www.salalahport.com), overprinted numbers are keyed to the description of the path of *Mandraki* (see Figure 7*c*), after she broke her moorings at Berth 4 (Position "0"). Also shown on *(a)* is Survey Site 1 in the old port.



2004 Indian Ocean Tsunami Currents

Figure 7.: *(a):* Photograph of *Maersk Carolina* moored at Berth 4 on 14 August 2005. This is a sister ship of *Maersk Virginia*, and is also essentially comparable to *Mandraki*. *(b):* Eyewitness interviewed by the team on 14 August 2005. *(c):* Sketch handwritten by the eyewitness, looking ENE (out to sea) and detailing the drift of *Mandraki*. Numerals show **(0)** initial position of *Mandraki* moored at Berth 4; **(1)** ship caught in strong eddy following rupture of moorings; **(2)** ship outside harbor approaching far side of breakwater; **(3)** subsequent loop outside harbor; **(4)** return to harbor; and **(5)** eventual grounding on sand bar East of harbor.

Duqm in 2005

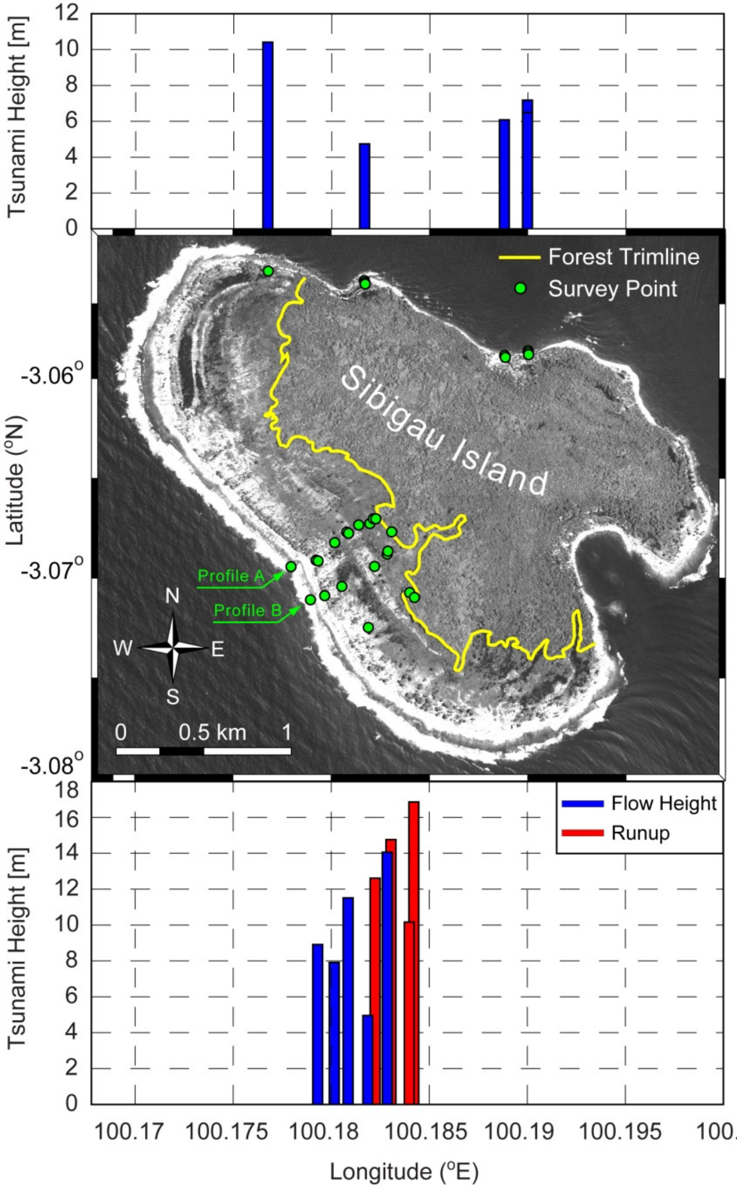
Port of Duqm – March 2015

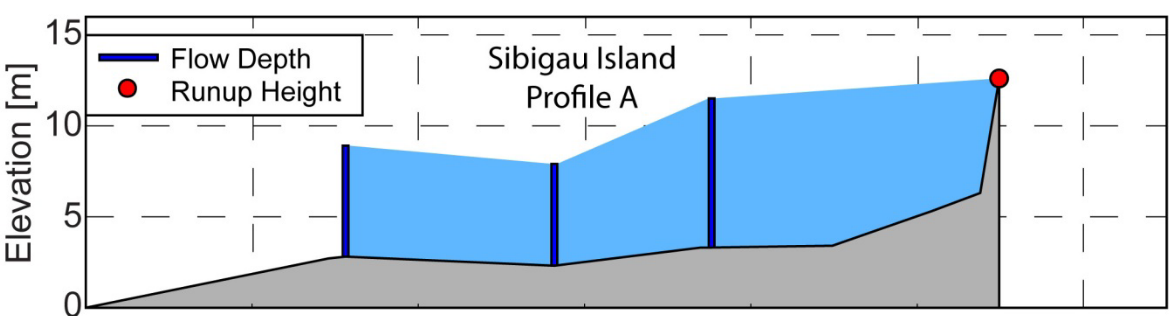
Port of Duqm

Liquid & Coal Berths
Bunkering
Approach Channel
4.6 Km
Royal Navy Berths
Harbour Basin
4.1 Km (2,250 x 350)
Commercial Quay Phase 1
Commercial Quay Phase 2
Dry Dock

Port of Duqm

Mentawai Islands, Indonesia 2010
Another Tsunami Earthquake





ITST 2018 Sulawesi Tsunami

- Hermann Fritz, GT
- Costas Synolakis, USC
- Nikos Kalligeris, UCLA
- Vassilis Skanavis, USC
- Philip Liu, NUS
- Pascal Guerin, Film

- **Fajar, Tadulako U**
- **Rizal, Tadulako U**
- **Gegar Prasetya, NTST**
- **Indonesian Film Crew**

ITST 2018 Sulawesi Tsunami

ITST 2018 Sulawesi Tsunami

ITST 2018 Sulawesi Tsunami

ITST 2018 Sulawesi Tsunami

ITST 2018 Sulawesi Tsunami

ITST 2018 Sulawesi Tsunami

ITST 2018 Sulawesi Tsunami

BMKG, Jakarta, Indonesia, 29. October 2018

ITST 2018 Sulawesi Tsunami

ITST 2018 Sulawesi Tsunami

ITST 2018 Sulawesi Tsunami

BMKG, Jakarta, Indonesia, 29. October 2018

ITST 2018 Sulawesi Tsunami

ITST 2018 Sulawesi Tsunami

ITST 2018 Sulawesi Tsunami

Earthquake source deformation (GSI)

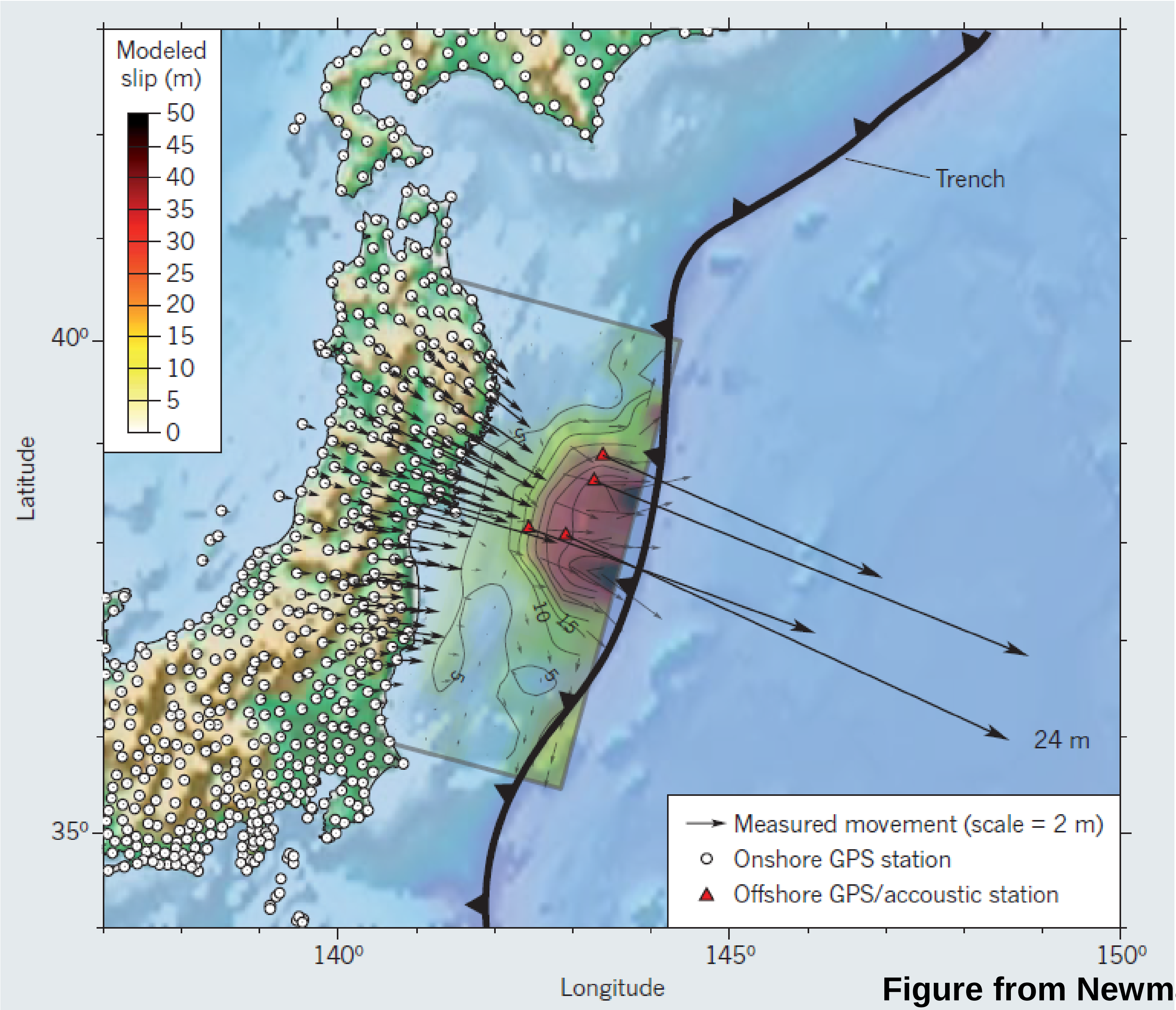
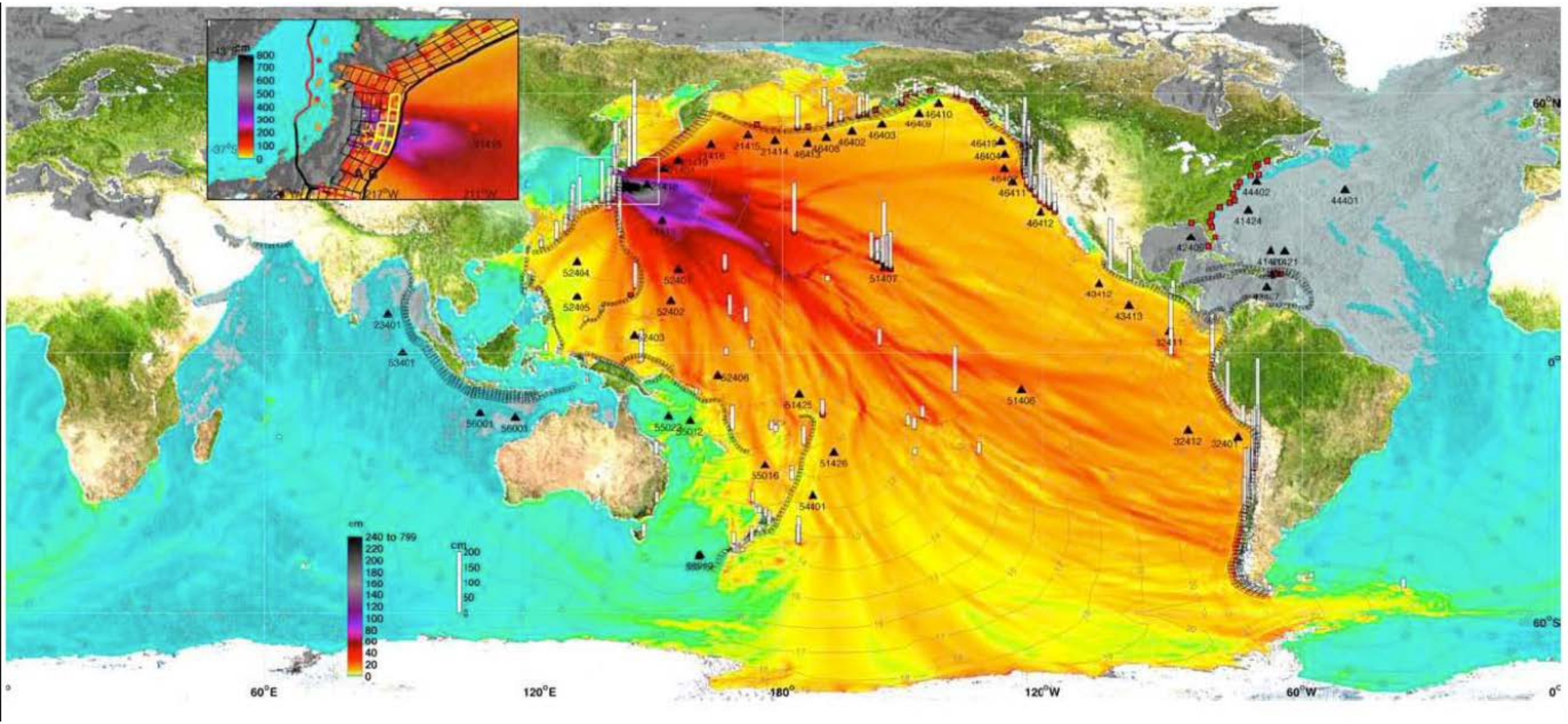
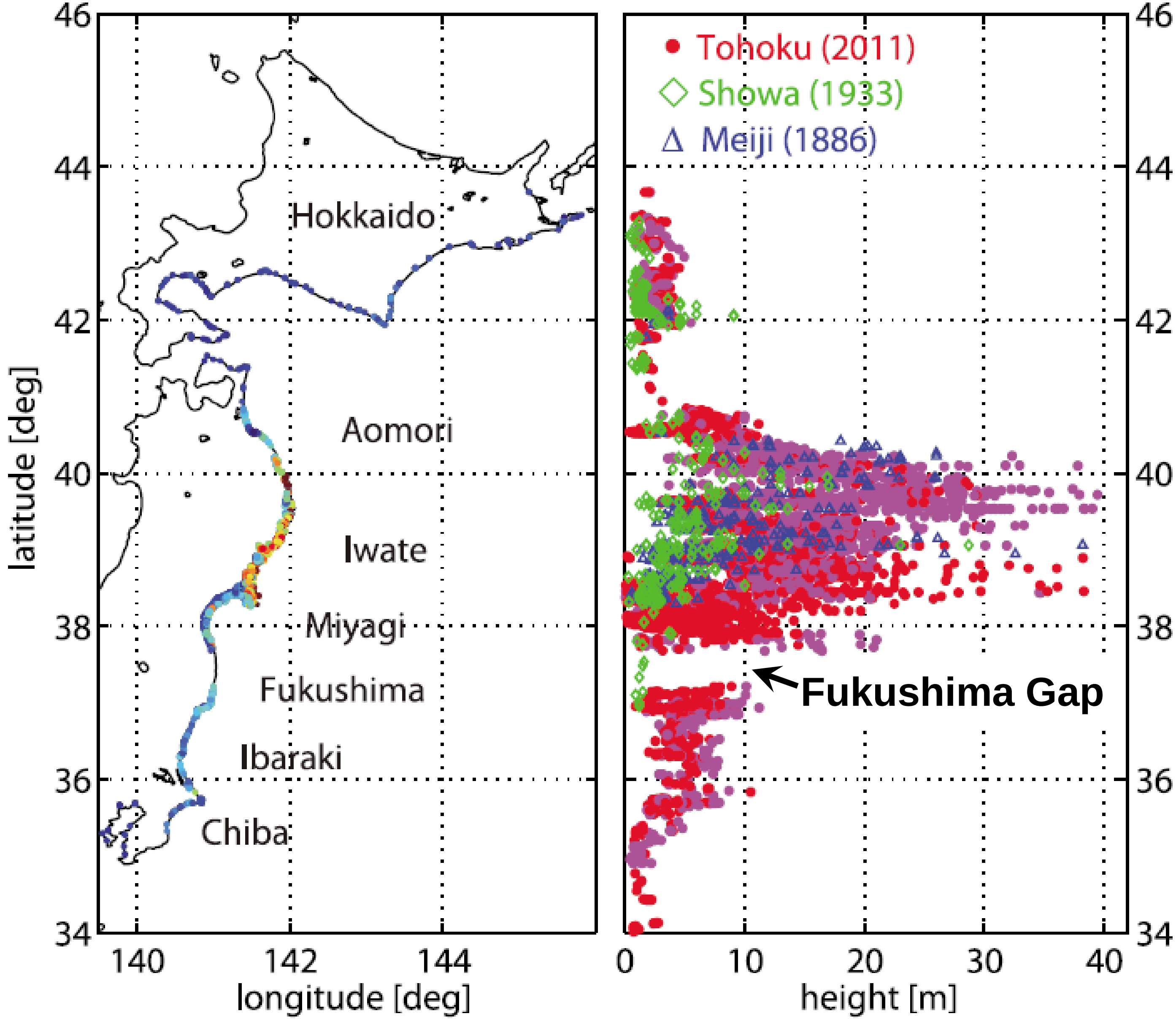


Figure from Newman, 2011

Pacific Basin Wide Tsunami Propagation (Modeling: NOAA, PMEL)

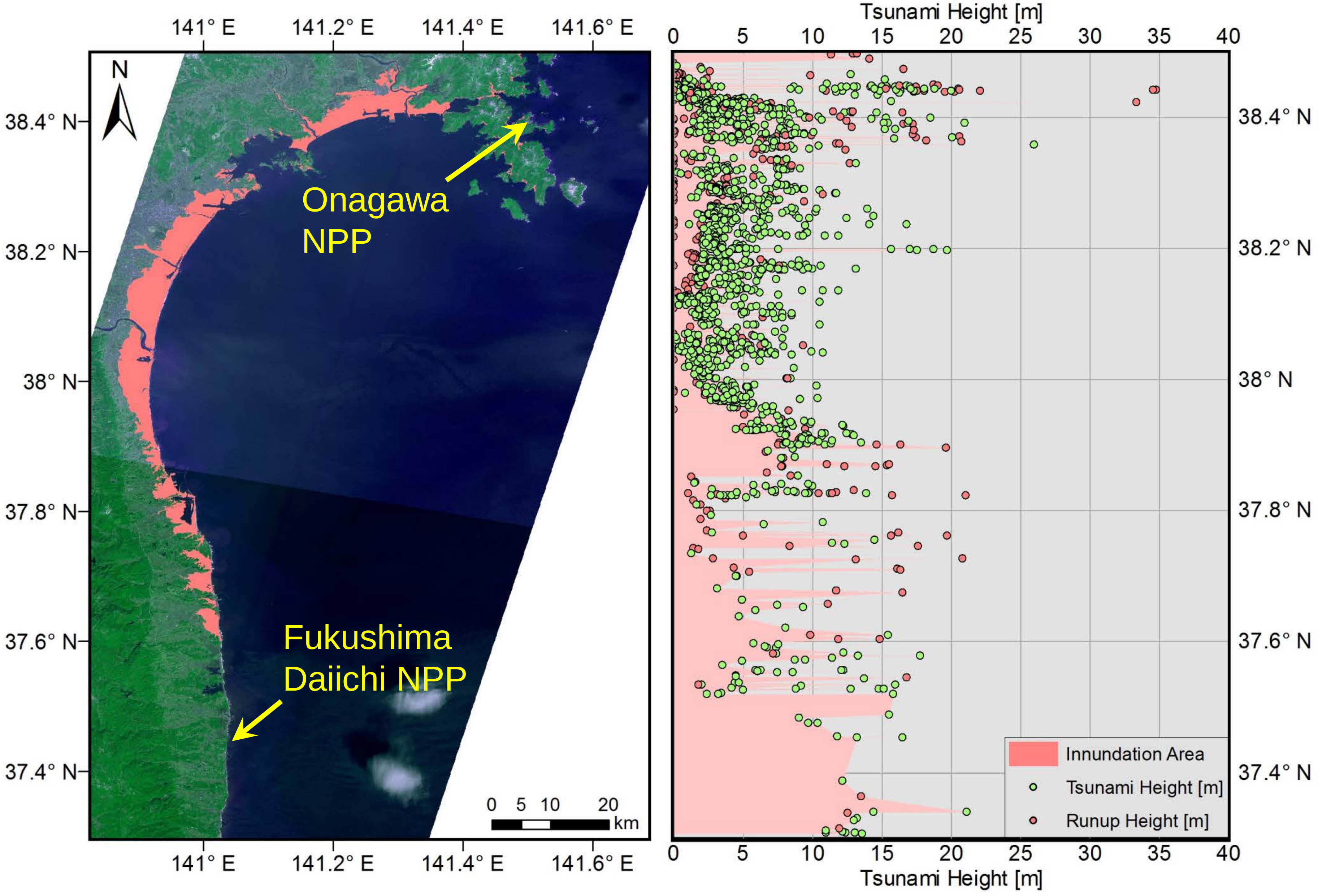


2011 Japan Tsunami Survey (TETJSG)



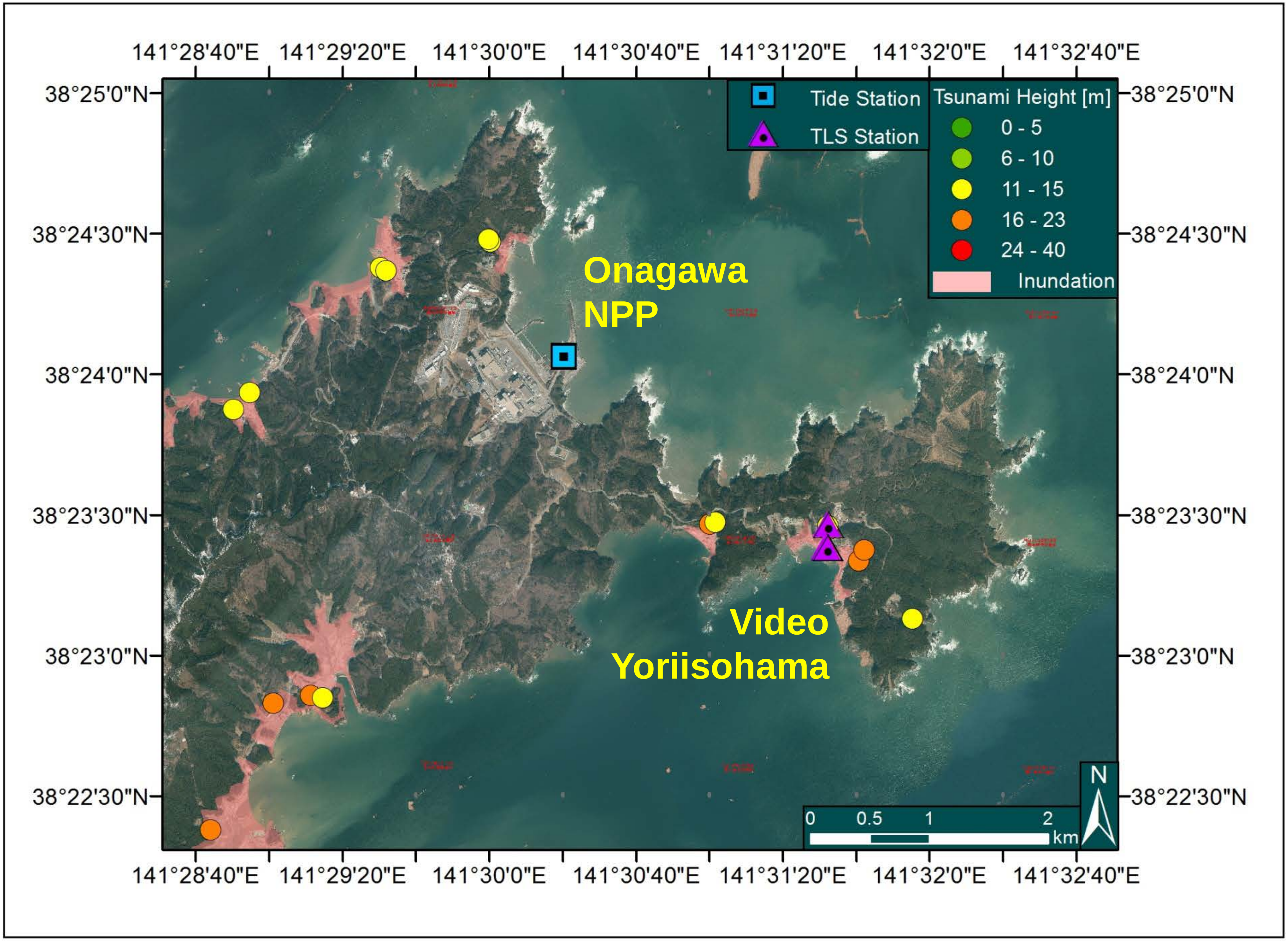
Mori et al., GRL, 2011 and CEJ, 2012

Onagawa NPP 110 km NNE of Fukushima 1

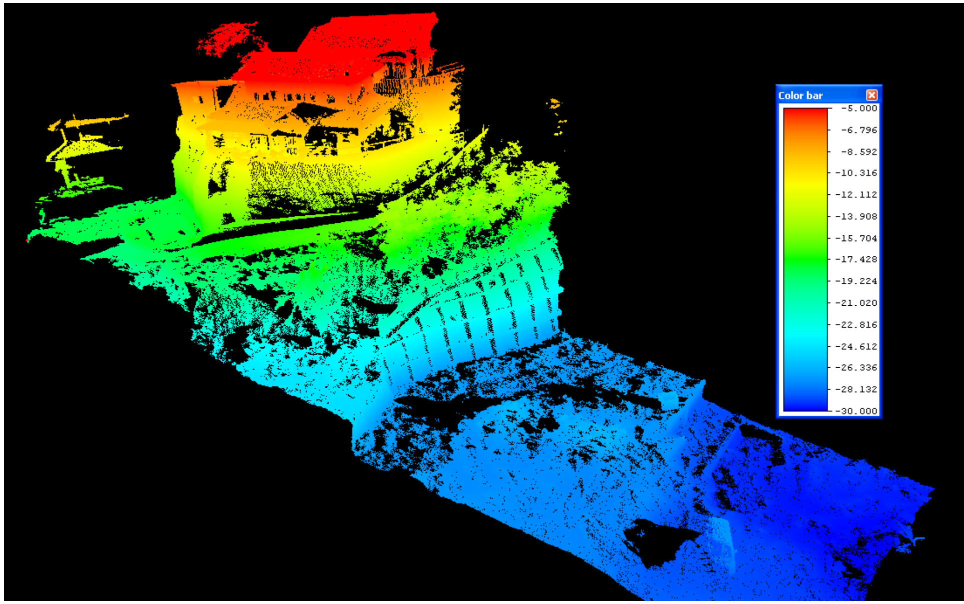


Onagawa – toppled engineered buildings

Onagawa Nuclear Power Plant (NPP) pressure gauge and Yoriisohama eyewitness video at 2km distance

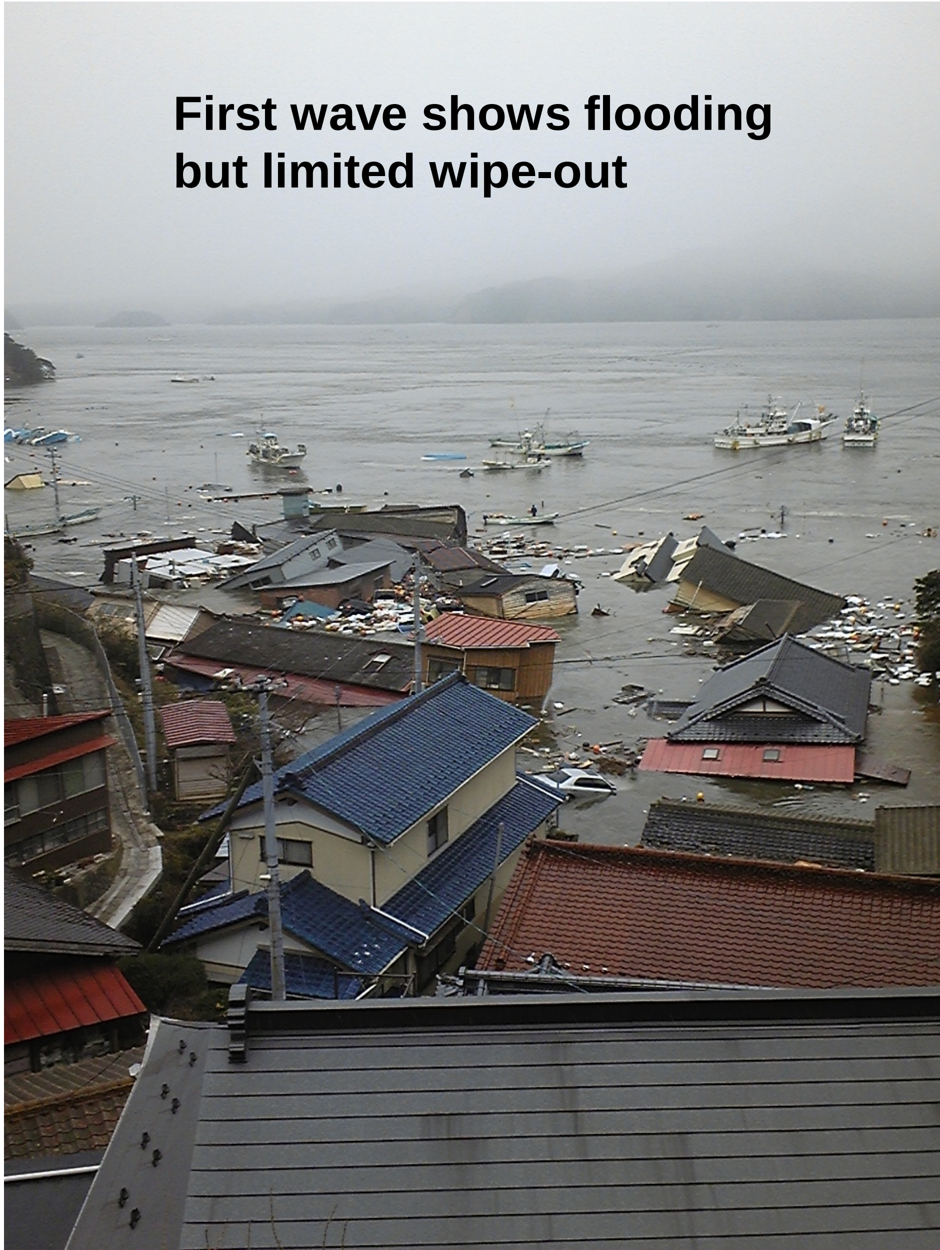


TLS scanning for detailed runup topography at Yoriisohama



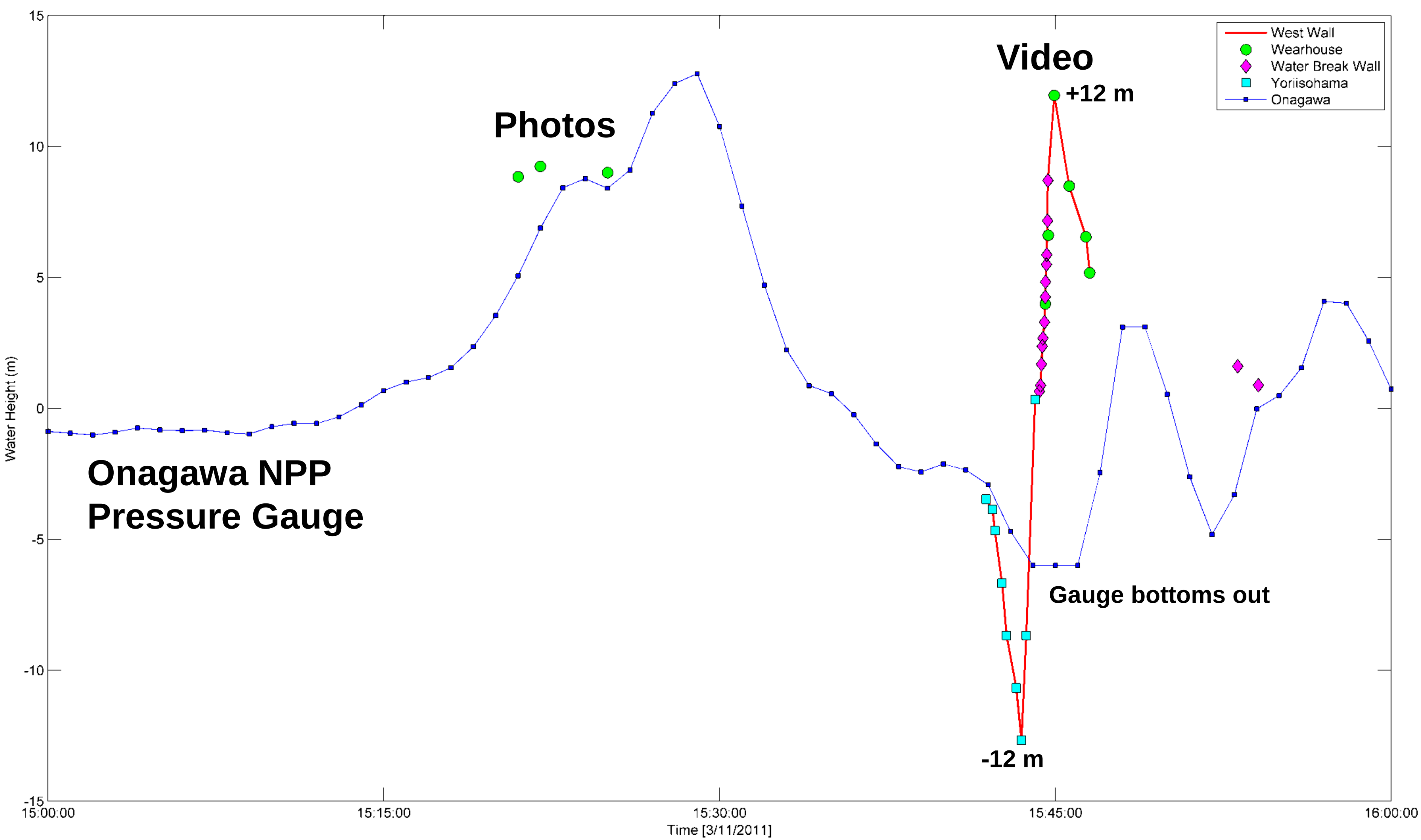
1^{st} wave eyewitness photos

Camera locations show survivor evacuating to higher ground!



Yoriisohama school girl video of 2nd wave

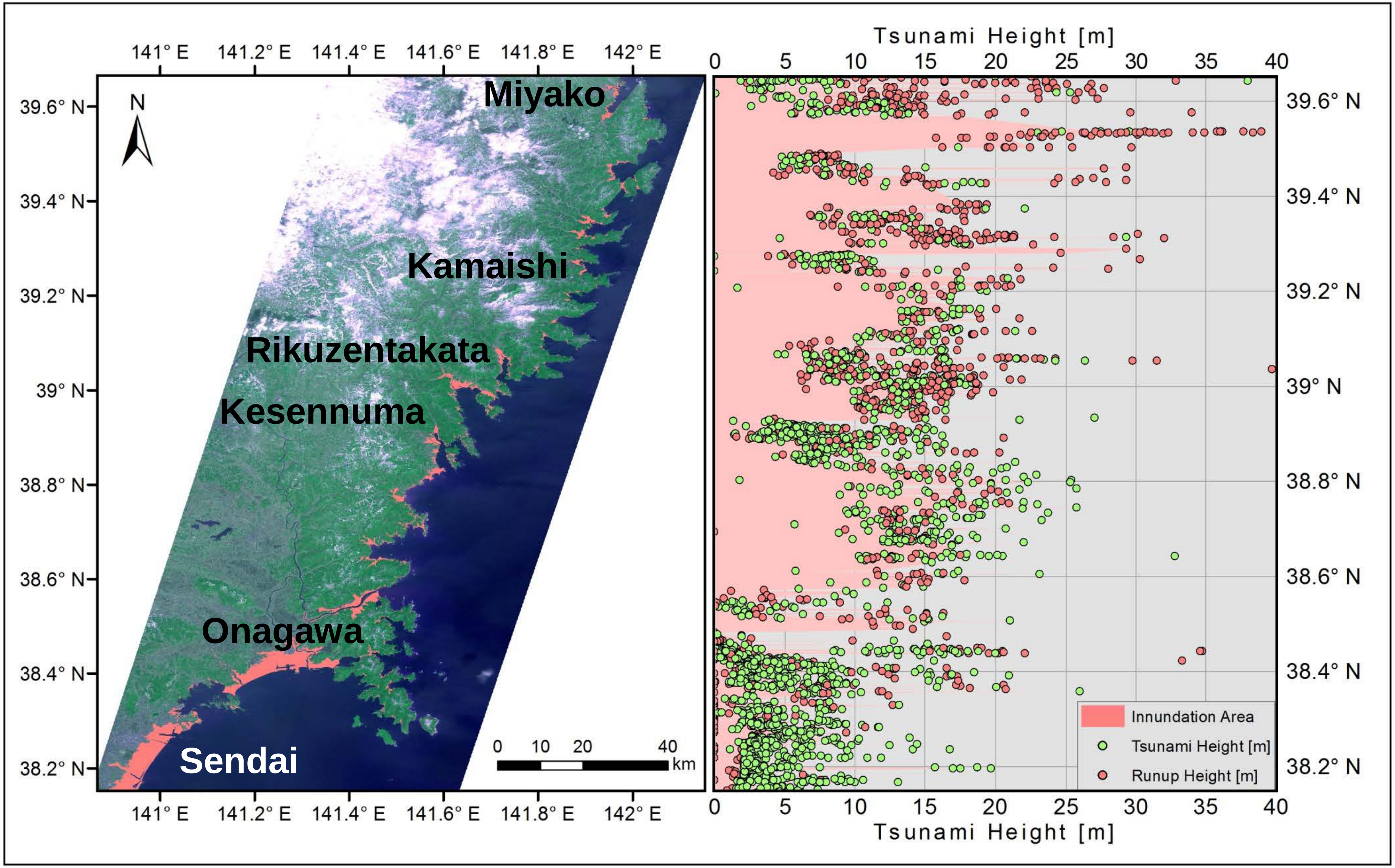
Yoriisohama video based hydrographs



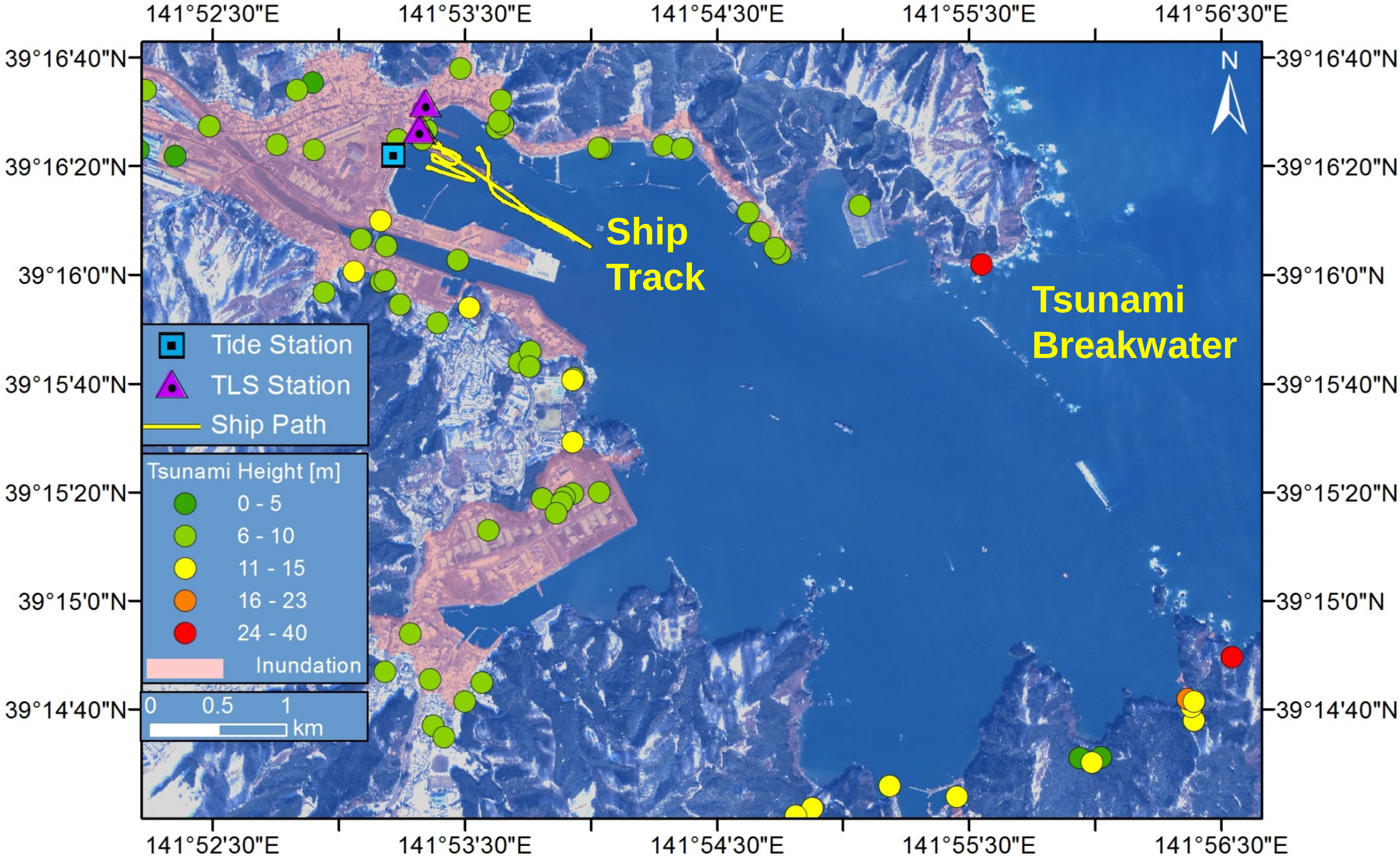
EQ + 30 min

EQ + 1 hour

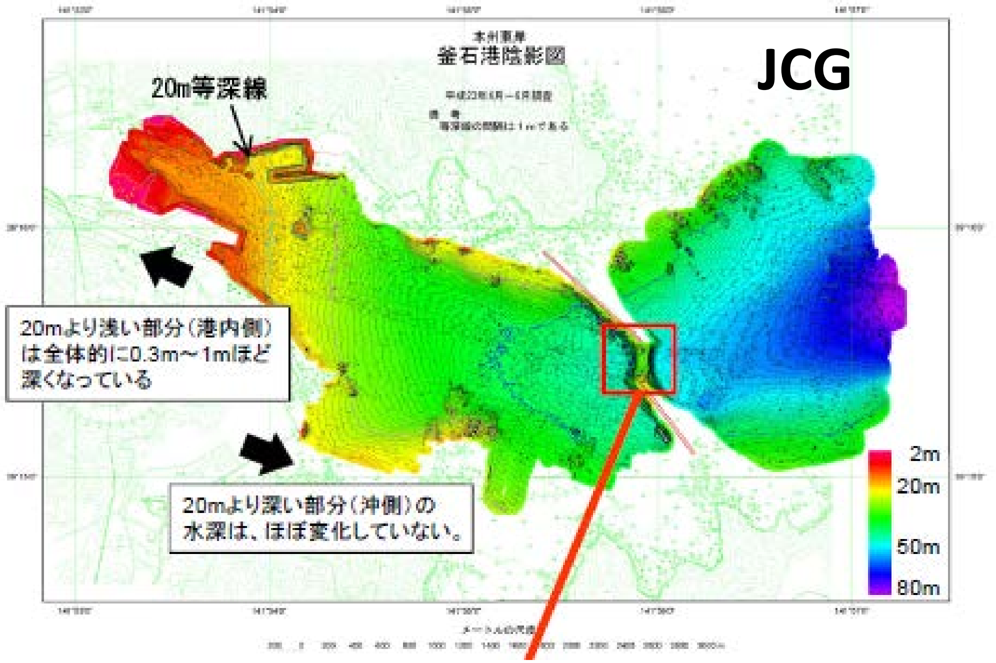
2011 Japan Tsunami Survey (TETJSG)

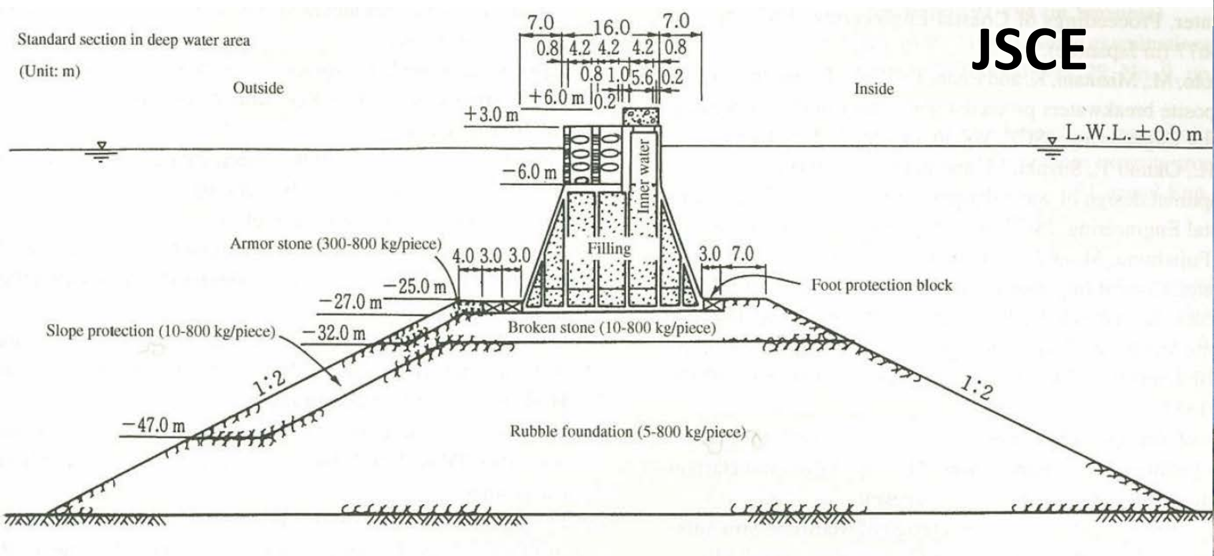


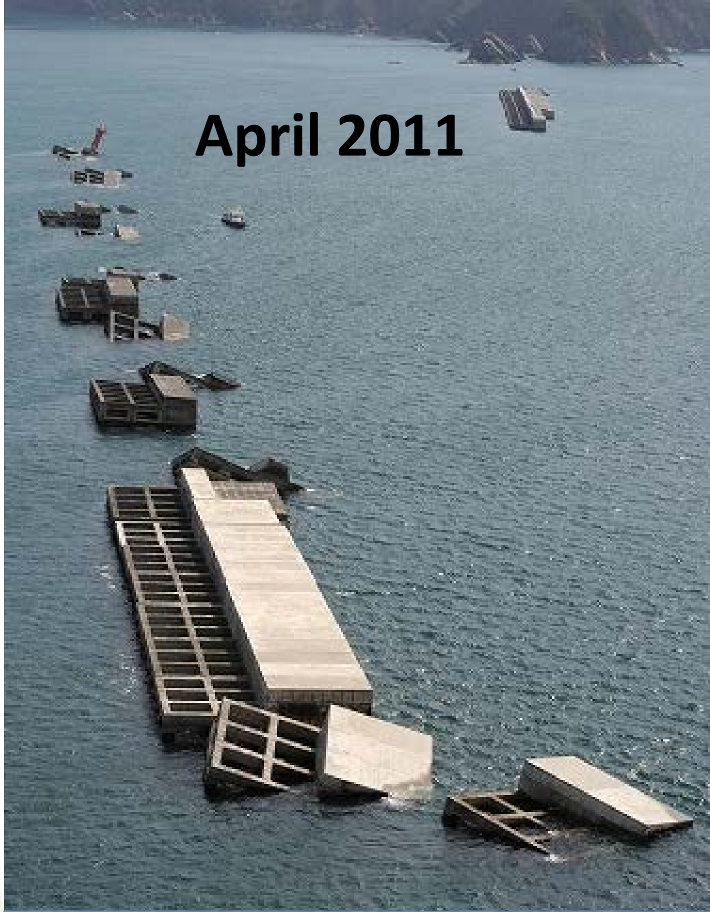
Kamaishi Bay with Tsunami Breakwater



Kamaishi Tsunami Breakwater



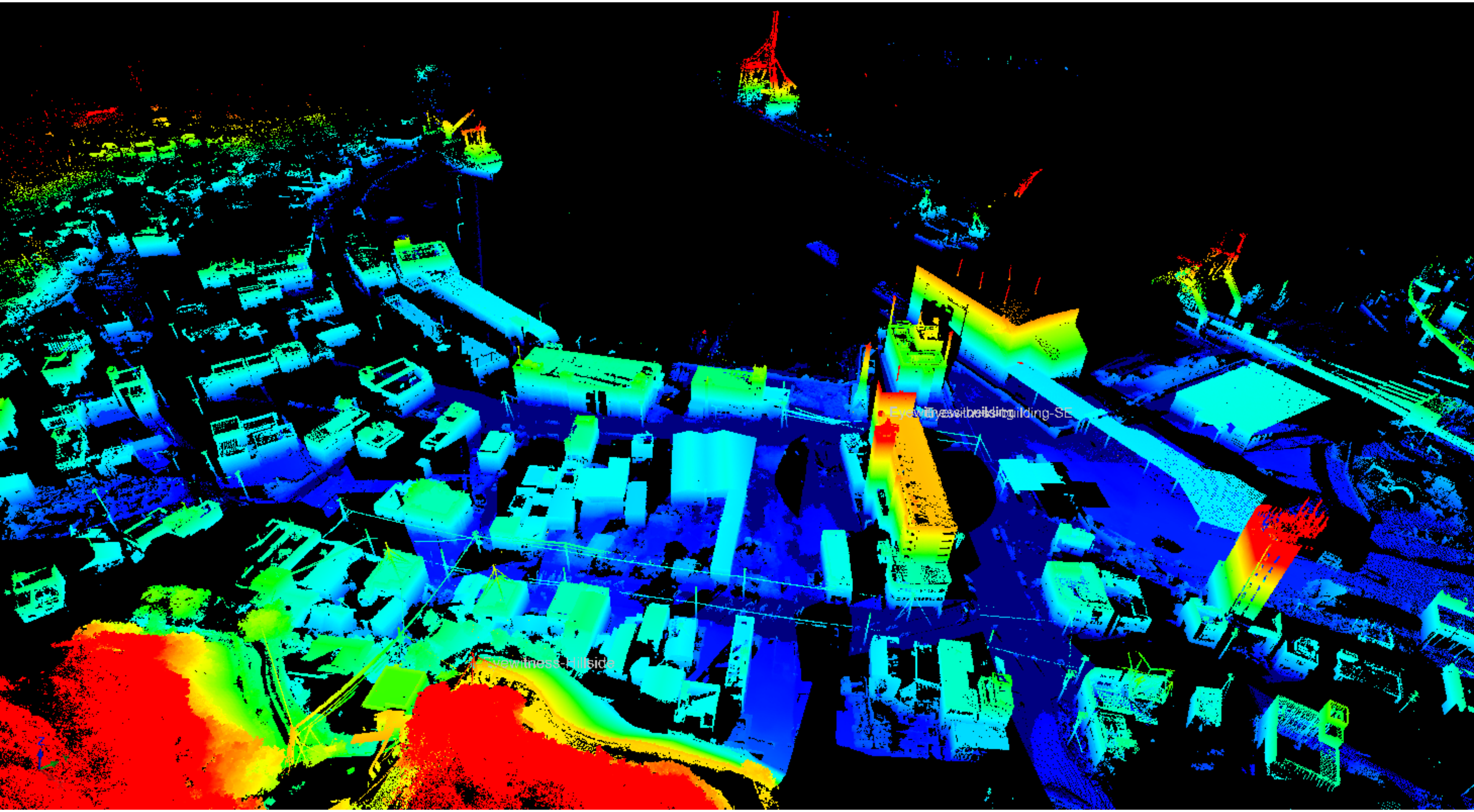




Kamaishi LIDAR survey June 2011

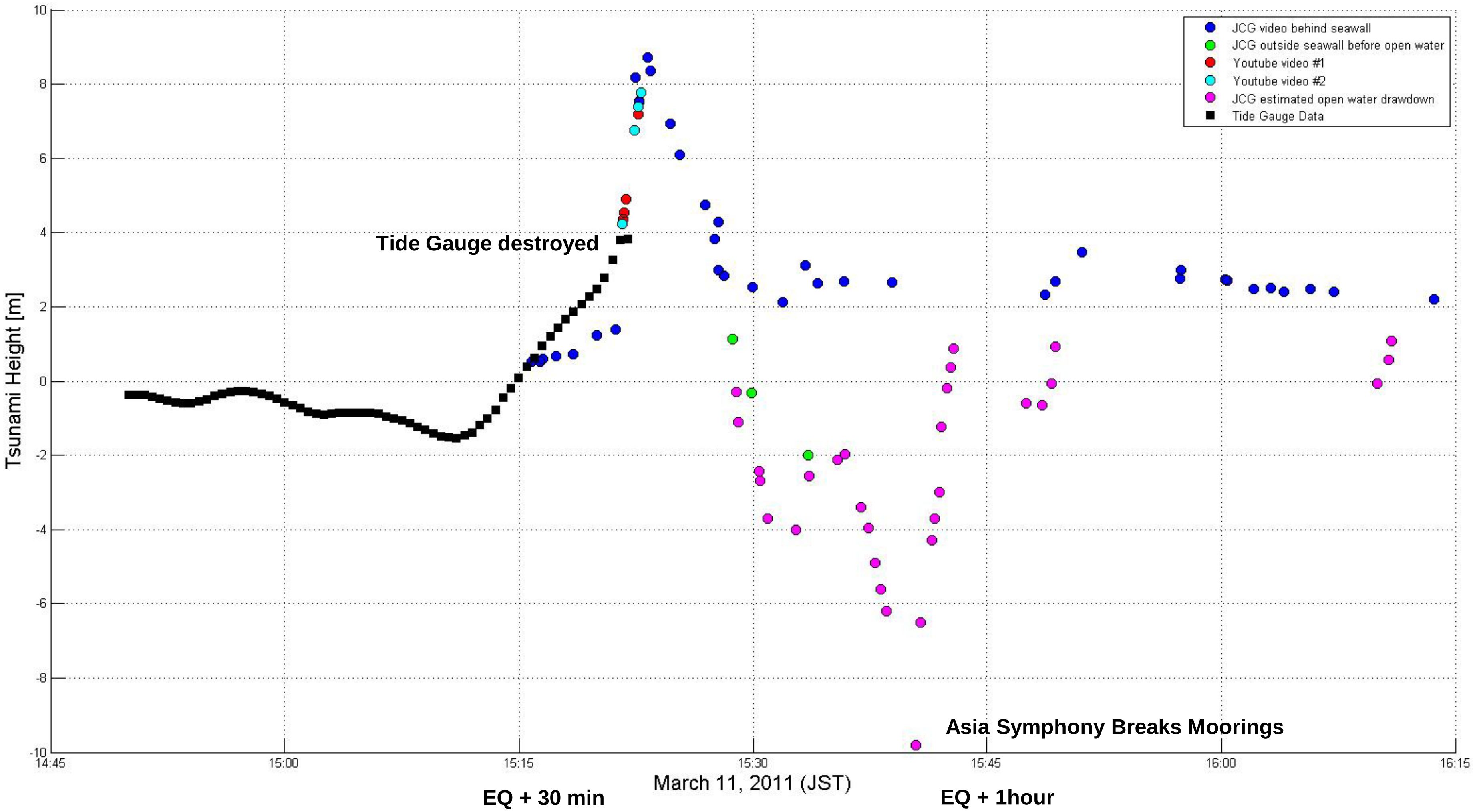

Kamaishi LIDAR survey June 2011

Kamaishi LIDAR survey June 2011

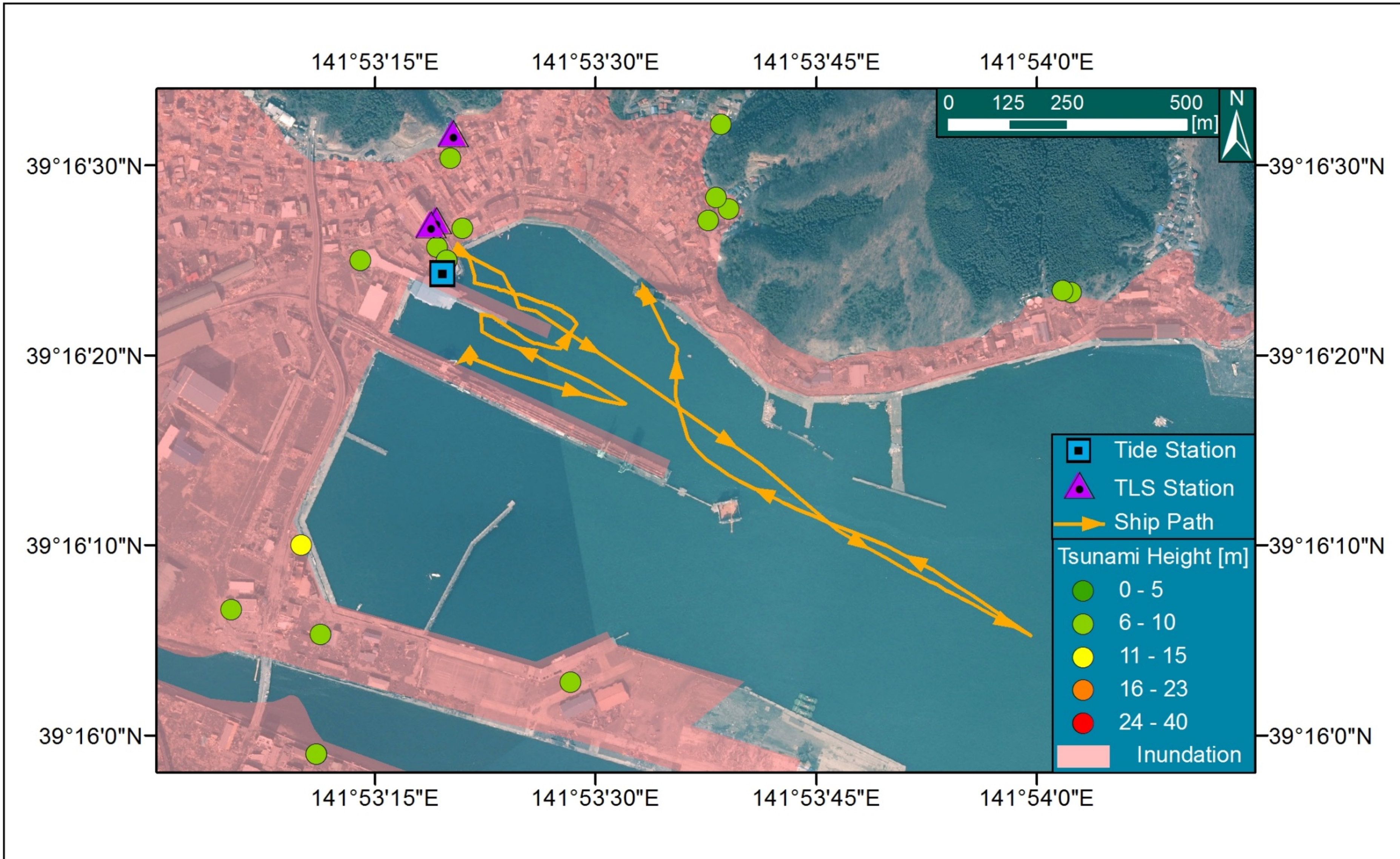


Dance of the Asia Symphony at Kamaishi

Kamaishi video based hydrographs



Dance of the Asia Symphony at Kamaishi



Japan 2011 tsunami

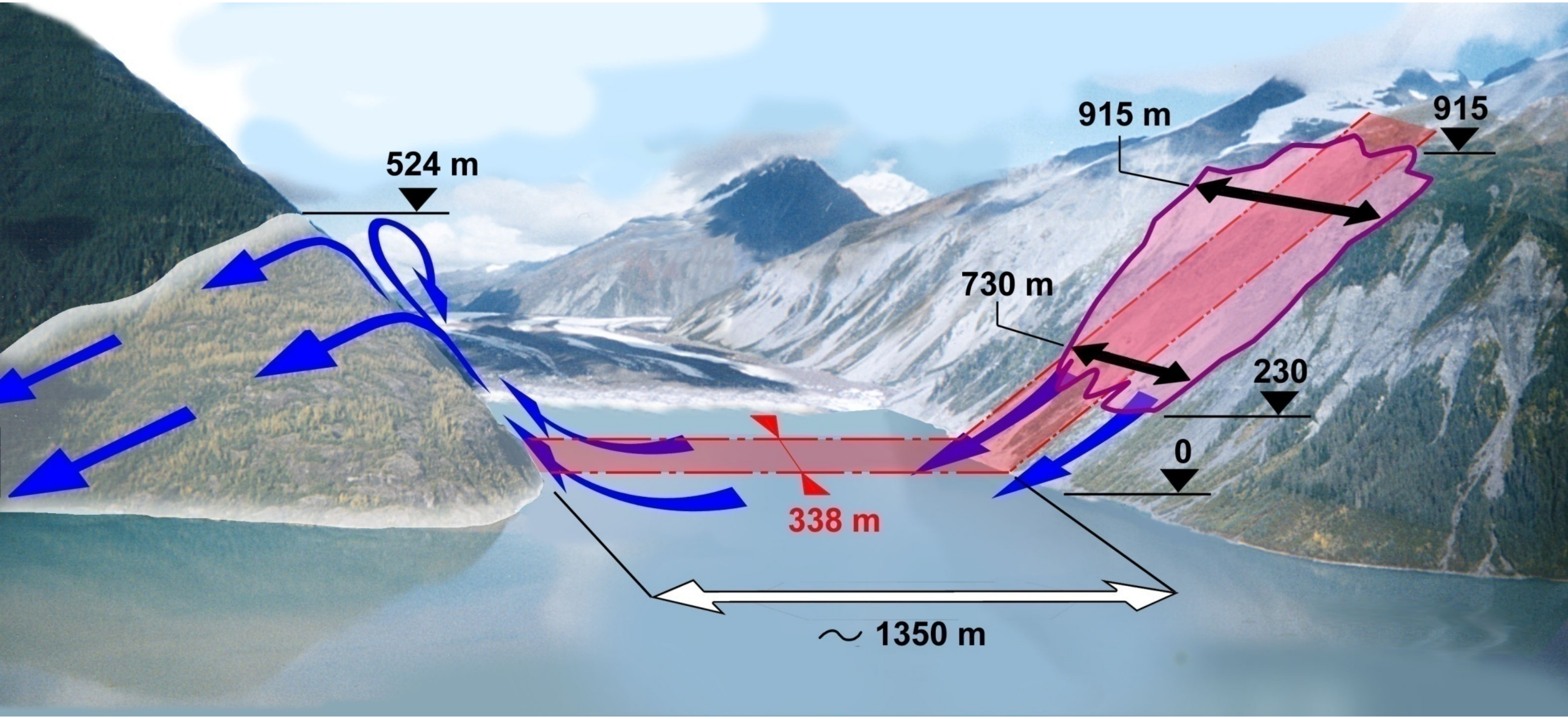
- EQ ground shaking as natural warning; spontaneous and mandated evacuation contains fatalities
- Coastal Defenses and vertical evacuation sites were designed for order of magnitude smaller events
- importance of community-based tsunami education and awareness programs (90% survival rate at Rikuzentakata).
- LiDAR at large scale during follow-up survey
- LiDAR data provide spatial coordinates of control points used for water level analysis, camera motion analysis, video rectification with DLT and PIV processing
- Tsunami runup overland flow exceeding 13 m/s at Yoriisohama
- Measured tsunami outflow velocities up to 11 m/s make navigation impossible


On top of Fjord Landslide in August 2007
Will the Landslide take off and when?
Cruise Ship

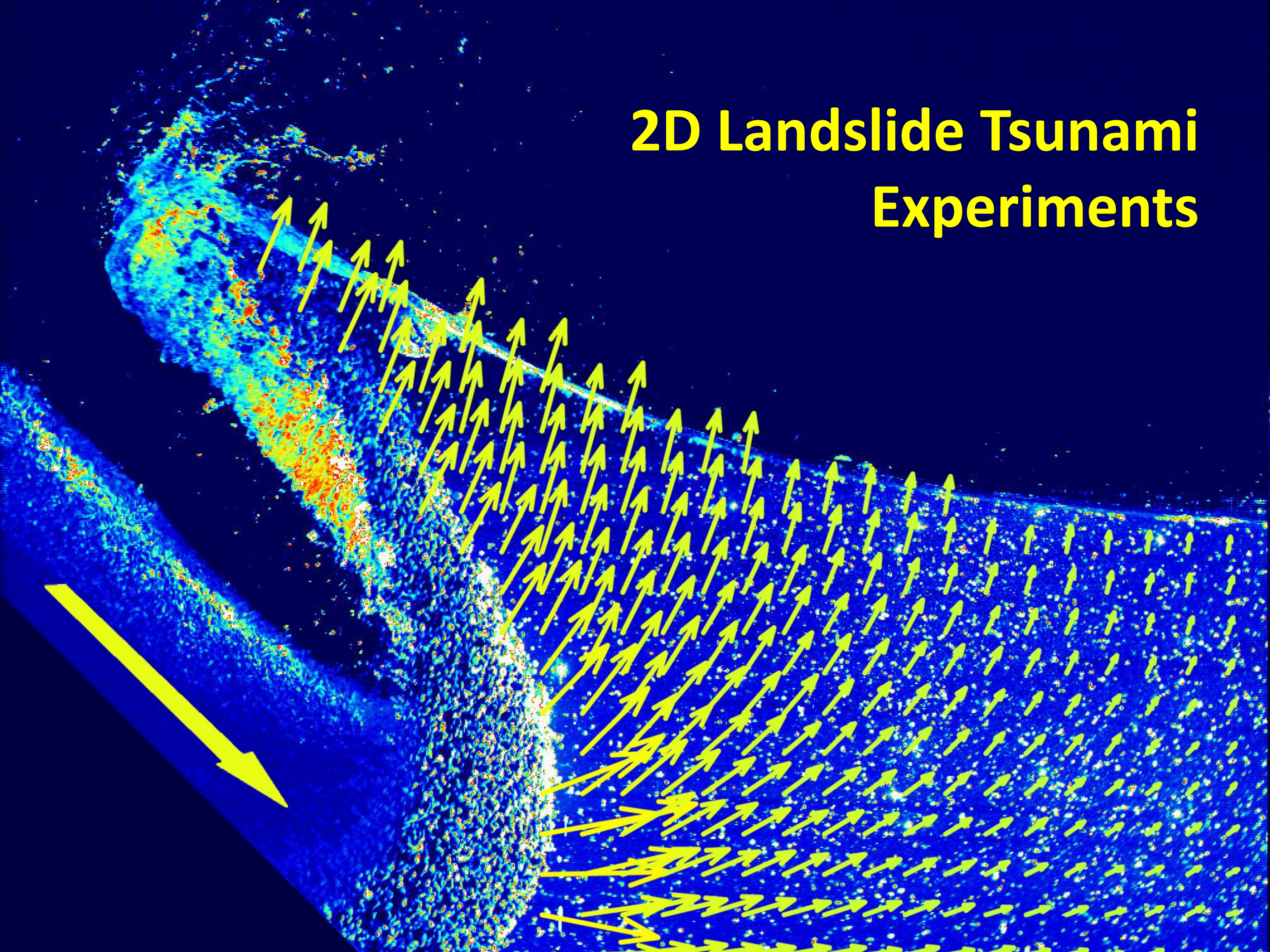
Lituya Bay, Alaska, 1958

Lituya Bay, forest trimline visible 50 years later

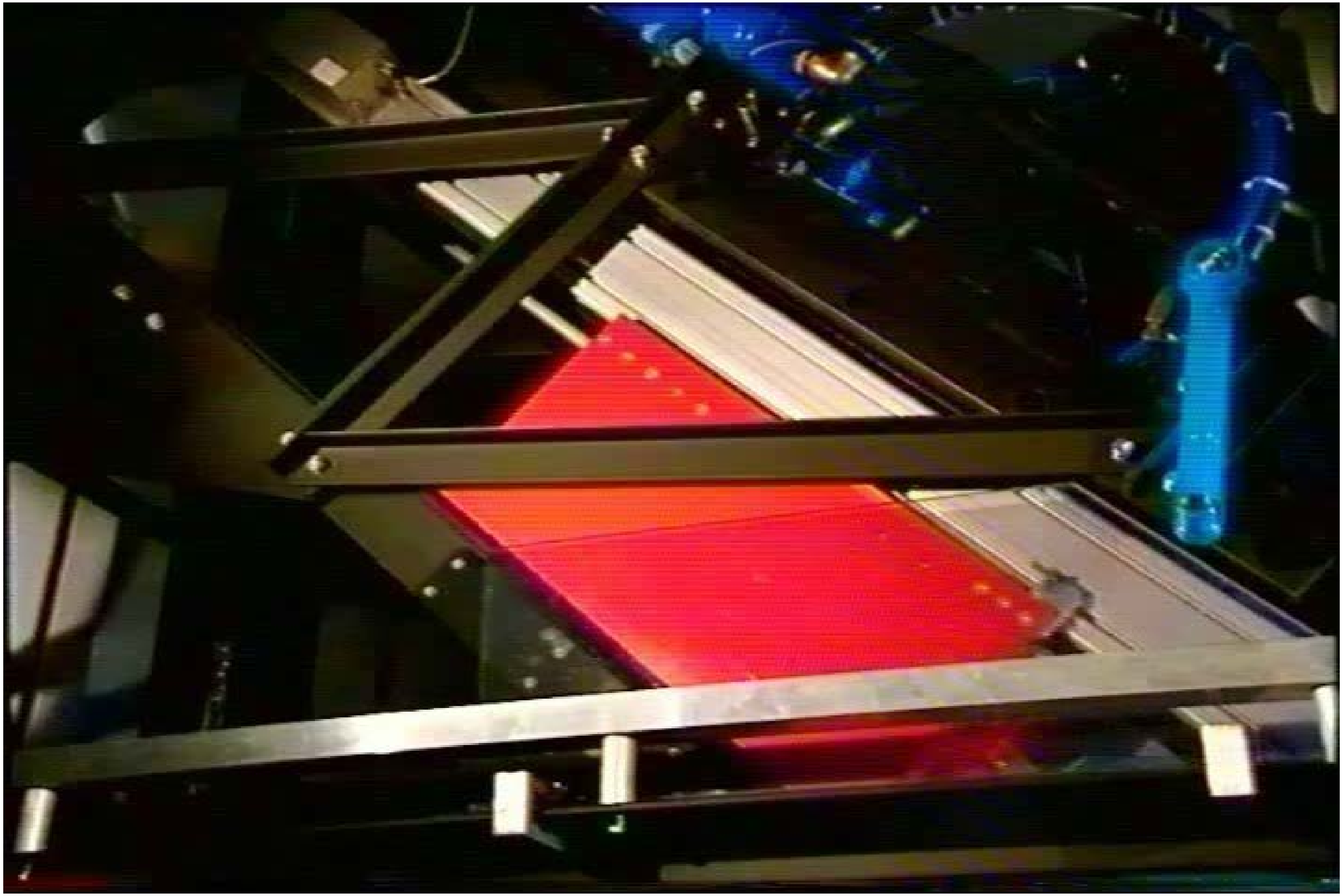
Lituya Bay impact and run-up site with 2D Experiment slice



Fritz H M, Mohammed F and Yoo J (2009), "Lituya Bay landslide impact generated mega-tsunami 50th anniversary", *Pure and Applied Geophysics*, 166(1-2): 153-175.


2D Landslide Tsunami
Experiments

2D Landslide Impact Experiment



Fritz, H.M., Hager, W.H., Minor, H.-E. (2004). Near field characteristics of landslide generated impulse waves. *J. Waterway, Port, Coastal, and Ocean Eng., ASCE*, 130(6):287-302.

3D Landslide Tsunami Experiments

Conical Island Experiment

Proc. R. Soc. A | Volume 472 | Issue 2188 | April 2016

ISSN 1364-5021 | Volume 472 | Issue 2188 | April 2016

PROCEEDINGS OF THE ROYAL SOCIETY A

MATHEMATICAL, PHYSICAL AND ENGINEERING SCIENCES

In this issue: The biophysical basis for the elastic secrets of the chameleon tongue

Exploring developments in and the need for better *ab initio* models of the climate system

Investigating stored electromagnetic energy and quality factor of radiating structures

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Oceans

RESEARCH ARTICLE

10.1002/2017JC012832

Runup of granular landslide-generated tsunamis on planar coasts and conical islands

Brian C. McFall[1,2] and Hermann M. Fritz[2]

[1]US Army Engineer Research and Development Center, Vicksburg, Mississippi, USA, [2]School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, Georgia, USA

Key Points:
- 3-D large-scale granular landslide-generated tsunami physical model experiments are conducted to study wave runup
- Predictive equations for laterally propagating edge wave characteristics are derived and opposing hill slope runup method is described
- The predictive wave and runup equations are benchmarked against the 2007 landslide-generated tsunami in Chehalis Lake, Canada

Correspondence to:
B. McFall,
Brian.C.McFall@usace.army.mil

Citation:
McFall, B. C., and H. M. Fritz (2017), Runup of granular landslide-generated tsunamis on planar coasts and conical islands, *J. Geophys. Res. Oceans*, 122, 6901–6922, doi:10.1002/2017JC012832.

Abstract Large-scale physical model experiments of tsunamis generated by granular landslides and volcanic flank collapses are conducted to study the wave runup on both the hill slope laterally adjacent to the landslide and an opposing hill slope. A pneumatic landslide tsunami generator was deployed on planar and convex conical hill slopes to simulate deformable landslides with various geometries and kinematics. On the landslide hill slope, maximum runup and rundown were observed in the landslide impact region followed by adjacent second maxima after the lateral waves were fully formed. The runup and rundown decayed asymptotically from the second maxima. In the conical island scenario, a localized runup amplification was measured on the lee side of the island. Outside the landslide impact region, the effects of the landslide granulometry on the lateral wave runup are minimal. The lateral wave runup on the planar hill slope was generally larger than on the convex conical hill slope outside the landslide impact region. The convex conical hill slope traps less lateral wave energy. The zeroth mode of the edge wave dispersion relation matched the first and second lateral waves on the planar hill slope and the first wave on the convex conical hill slope. Predictive equations for the laterally propagating wave characteristics are derived and a method to predict the runup on an opposing hill slope is presented. The predictive wave and runup equations are benchmarked against the 2007 landslide-generated tsunami in Chehalis Lake, British Columbia, Canada.

PROCEEDINGS A

rspa.royalsocietypublishing.org

Research

CrossMark

Cite this article: McFall BC, Fritz HM. 2016 Physical modelling of tsunamis generated by three-dimensional deformable granular landslides on planar and conical island slopes. *Proc. R. Soc. A* **472**: 20160052.
http://dx.doi.org/10.1098/rspa.2016.0052

Received: 20 January 2016
Accepted: 11 March 2016

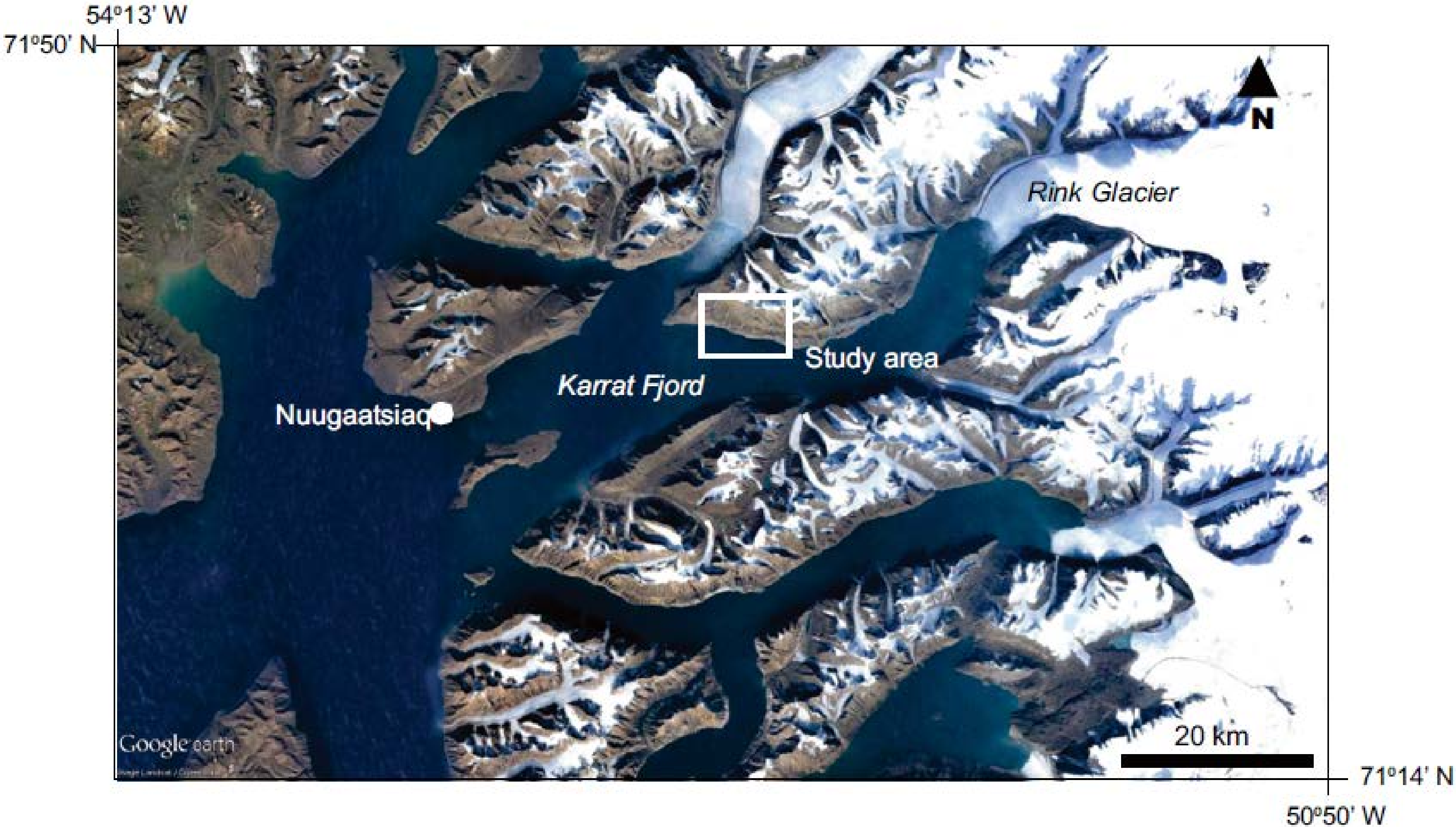
Physical modelling of tsunamis generated by three-dimensional deformable granular landslides on planar and conical island slopes

Brian C. McFall[1,2,†] and Hermann M. Fritz[2]

[1]US Army Engineer Research and Development Center, 3909 Halls Ferry Road, Vicksburg, MS 39180, USA
[2]School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332, USA

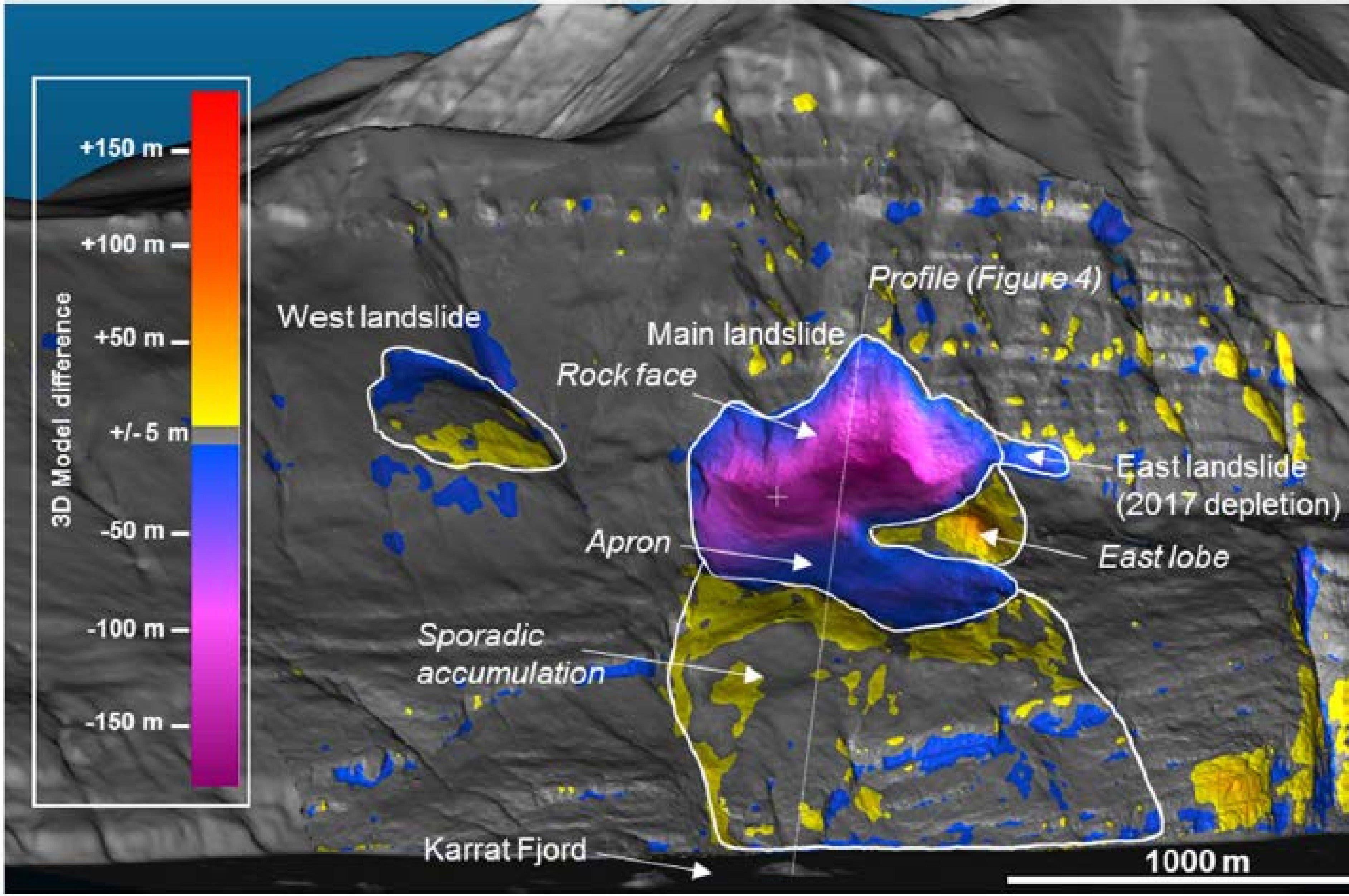
BCM, 0000-0001-9575-0012; HMF, 0000-0002-6798-5401

Karrat Fjord Landslide, Greenland 2017



Karrat Fjord Landslide, 3D model (OAP)

Karrat Fjord Landslide, 3D change detection



Karrat Fjord Landslide, 3D model (OAP)

Feature	$W \times L \times D$ (m, max)	Elevation range (m, approx.)	Volume (m^3, approx.)
Main landslide total depletion			58 M
Rock face	950 × 800 × 200	775–1270	46 M
Apron	900 × 600 × 30	580–775	12 M
Main landslide total accumulation			13 M
Sporadic	1200 × 900 × 10	0–660	10.5 M
East lobe	485 × 220 × 65	730–930	2.5 M
East landslide face	200 × 50 × 20	930–1010	0.4 M
Net (fjord-level)	1200 (w)	0	45 M
West landslide	500 × 650 × 30–80	940–1220	5 M (approx.)

Recent Landslides

Landslides
DOI 10.1007/s10346-017-0926-4
Received: 6 September 2017
Accepted: 17 November 2017

Dave Gauthier · Scott A. Anderson · Hermann M. Fritz · Thomas Giachetti

Karrat Fjord (Greenland) tsunamigenic landslide of 17 June 2017: initial 3D observations

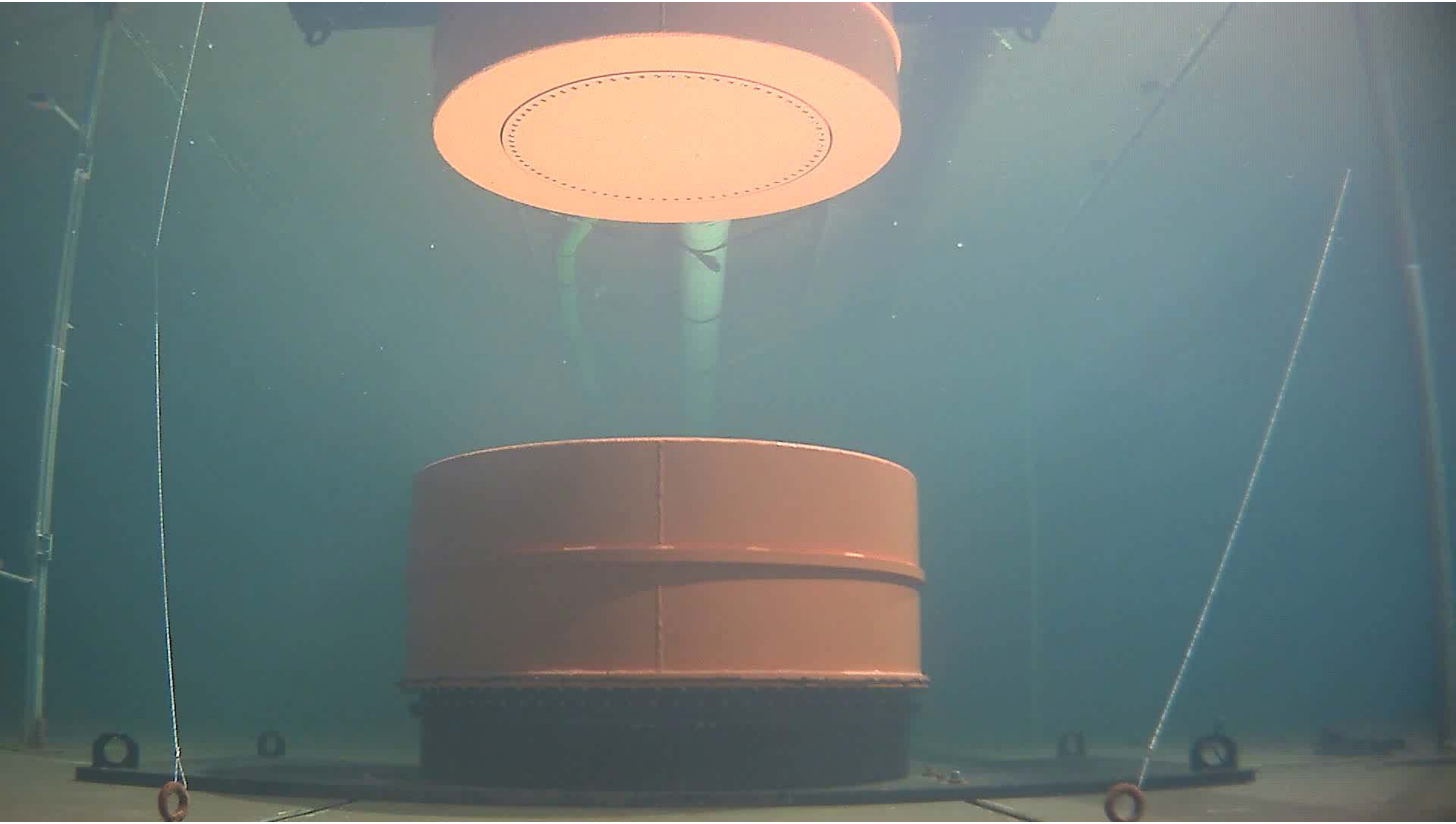
Karrat Fjord Landslide Tsunami Runup

Karrat Fjord Landslide Tsunami Runup

Karrat Fjord Tsunami, Nuugaatsiaq

Volcanic Tsunamis – Krakatau 1883

Tsunami Generation by Submarine Volcanic Eruption



Tsunami Generation by Submarine Volcanic Eruption

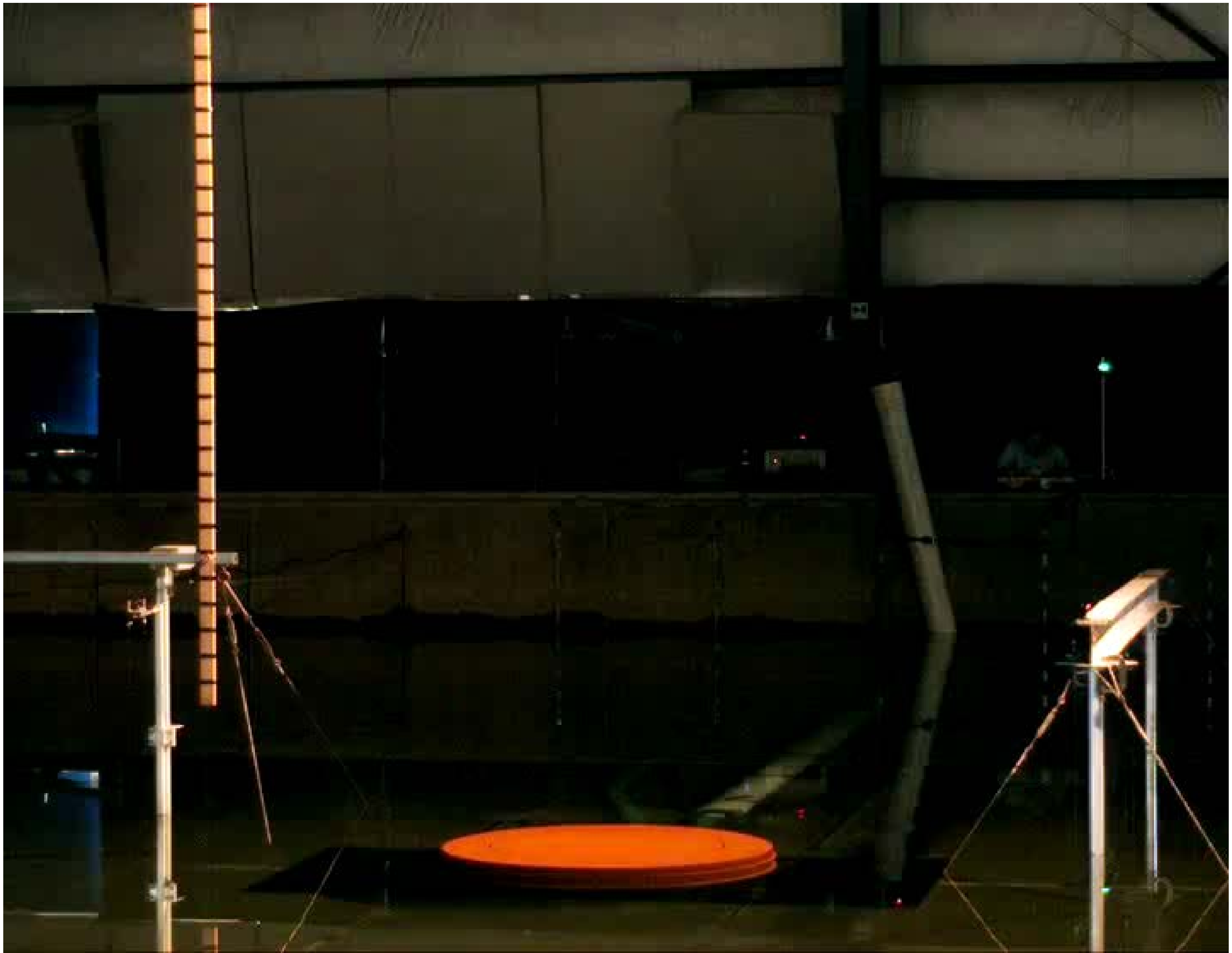



Photo:
April 11, 2011
Muchisimas Gracias!
Algunas Preguntas?