UNESCO/IOC – NOAA ITIC Training Program in Hawaii (ITP-TEWS Chile)
TSUNAMI EARLY WARNING SYSTEMS
AND THE PACIFIC TSUNAMI WARNING CENTER (PTWC) ENHANCED PRODUCTS
TSUNAMI EVACUATION PLANNING AND UNESCO IOC TSUNAMI READY PROGRAMME
19-30 August 2024, Valparaiso, Chile

Lessons Learned from past Tsunamis
Science, Warning, Response, Preparedness, Awareness

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No Common Sense for Tsunamis

- **Tsunamis are Not Common - Often 1st Time**
  - For individuals at risk
  - For government officials that must respond (incl TWC, DMO)
- **Tsunamis Can Be Learned From**
  - Tsunami wave characteristics from physics / models
  - Human response behavior from social science
- **Each Tsunami is Unique**
- **Warning / Response Planning Needs Imagination**
  - What situations might occur?
  - How to prepare/respond based on best science?
  - Procedures recorded in SOPs
- **Learn from the Past to Improve Future Response**

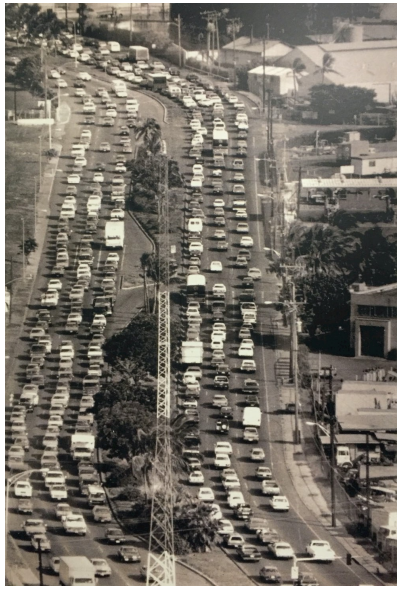
Recent Tsunamis to Learn From

Since 1991 - 38 deadly tsunamis
20 in Pacific (excl Indonesia), 3 each Chile, Japan and Peru, 13 Indonesia, 2 in Caribbean, 2 Mediterranean

- Sep, Dec 1992 Nicaragua, Flores, Indo (170, 1169 lives)
- July 1998 Papua New Guines (1636 lives)
- Dec 2004 Indian Ocean (227,899 lives)
- Jul 2006 Java (892 lives)
- Apr 2007 Solomon Islands (50 lives)
- Sep 2009 Samoa (192 lives)
- Feb 2010 Chile (156 lives)
- Oct 2010 Mentawai, Indonesia (431 lives)
- Mar 2011 Japan (18,428 lives)
- Sep 2018 Palu Indonesia (4340 lives, incl EQ)
- Dec 2018 Anak Krakatau, Indonesia (437)
- Jan 2022 Hunga Tonga, Hunga Ha'apai, Tonga (4 lives)

Hawaii – Evacuation Lessons

- **Aleutian Islands, M8.0, 7 May 1986**
  - **Massive traffic jam** on coast at travel time. Government sent everyone home
    New Instructions => stay put unless in evacuation zone. Walk to safety



- **Kuril Islands, M8.3, 4 October 1994**
  - **Schools closed due to warning**
  - Sunny day and surf coming up. 100s surfers in water at arrival time.
    Increase awareness - target surfers
  - 3 of 4 evacuations for non-destructive tsunamis. **Avoid term "false alarm" - tsunami did arrive. Use "non-destructive tsunami." Educate media and public on limitations**

September 1992 Nicaragua Tsunami

- Ms ~7 earthquake off the coast of Nicaragua
- Very little shaking along the coast
- Little or no tsunami expected, but
- Large tsunami struck – 116 lives lost

Lessons Learned

- Slow Earthquake
- Use Mw, not Ms
- Use slow discriminant
- Not always shaking
- Not that uncommon – ‘06 Java, ‘10 Mentawai

New Guinea Tsunami - Jul 1998

- Mw 7.1 earthquake – no tsunami expected, but
- Large tsunami impact – 2200 lives lost
- Probable cause was undersea landslide triggered by the earthquake

Lessons Learned

- Tsunami possibility after any large earthquake
- Roar from the sea may be only real warning

Sumatra Tsunami - Dec 2004

- Mw 9.2 earthquake – size not known for 4 hours
- Rupture direction and extent only known later
- Unrecognized hazard – nothing like this expected
- End-to-end alerting not possible

Lessons Learned

- Use new methods to measure huge quakes
- Techniques to quickly gauge rupture area
- Expect 1000-yr event
- Use forecast models
- End-to-end alerts

Tonga, M8.0, 03 May 2006

- **Media reports trigger unofficial and unnecessary evacuations in New Zealand**
  - PTWC bulletins designate countries in warning and watch as advice to countries
  - Media interpret as official warning to country, causing local NZ town to evacuate

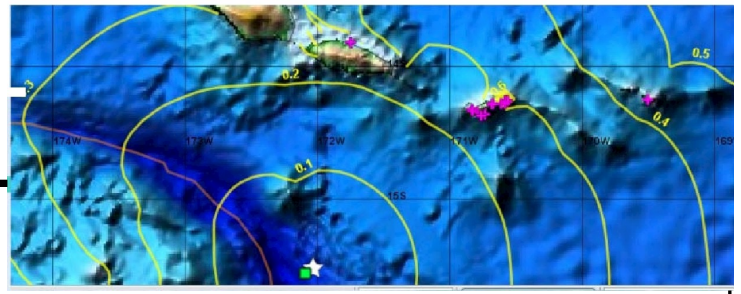
    PTWC bulletins modified to say official warning only from each country's agencies
- **Tonga Met Department doesn't receive PTWC warning due to power outage**
  - No backup power or communications

    Power I communications systems improved

Tonga Tsunami - 19 March 2009

- **PTWC reporting / receipt by TWFPs OK**
- **But difficulties with national to local dissemination**
  - Tonga - National Radio Broadcast Not during working hours (no one listening) Many did not know until cancelled!
  - American Samoa - Emergency Alert System not working, Phone/Fax lines choked
- **Nukualofa sea level gauge data 1-hr transmission interval too slow**

29 September 2009



- M8.1 earthquake and local tsunami
  - Strong shaking felt > 60 s, possible > 2 min
  - Tsunami arrived 10-20 min after EQ
  - Observed runup 16-17+ min Samoa, Am Samoa, Tonga
  - Extensive coastal damage (structures, reef destroyed)
  - Casualties (192): Samoa (149), Am Samoa (34), Tonga (9)
  - Complicated double event - irrelevant to public at time
- Early Warning
  - Existing international alert system (PTWC): 11 min for 1st unofficial estimate (16 min for official). Improve thru inti data sharing discussed since 2007
  - Local tsunami require immediate action - Don't wait!

South Pacific Tsunami – 29 September 2009

- **Mw 8.1 earthquake and local tsunami (12-20 min). Doublet (one subduction, 1 outer rise normal fault within minutes of each other,). Runup 16-17+ m**
- **Impact to American Samoa, Samoa, and Tonga (Niuatoputapu) – deaths** (192, Samoa(149), Am Samoa (34), Tonga (9), Damage Samoa (20% GDP)

Lessons Learned

- **Awareness works.**
- **AS: Disaster Preparedness Month, exercise was planned for that day; months before PTWC/ITIC briefed (15 min is minimum). Schoolteachers take charge - students to high ground (Poloa, Tula)**
- **Samoa: 2007 National Drill with evacuation maps, PSA EQ and Tsunami videos (AUSAID), ICG/PTWS in Apia Feb 2009**

29 Sept 2009 - South Pacific Tsunami

Samoa–American Samoa–Tonga: 192 deaths

- Pre-event awareness / education saved lives
  - For last decade, continuously
  - 2006, 2008 Pacific-wide tsunami exercise
  - Sept 2009 AS Disaster Preparedness month
- People heeded Natural Warning Signs
  - Earthquake shaking a 'wake-up' call
  - Small receding wave ~10 min after
- Tsunami coming
- Head inland and to high ground
- 1st large damaging wave 10-20 min after
- Few died returning before it was safe (to help)

Haiti, M7.0, 12 January 2010

- **Awareness**
  - **No tsunami warning signs in Haiti along beaches (like in other Caribbean countries).**
  - **Lack of tsunami education. Fishermen were taking photos and videos of draw-down of sea.**

Vital to educate locals and tourists about what to do.

- **Communications**
  - **Warning came in by telephone to police station that had already collapsed.**

Redundant communications and points of contact.

Maule Tsunami – 27 February 2010

- Mw 8.8
- 156 tsunami, 455 earthquake
- 330 am (dark)
- Weekend

Lessons Learned

- Older people remembered 1960, but…
- Seismic strengthening so fewer EQ-caused deaths
- Tourist high casualty (campground on island)

27 February 2010

- **M8.8** earthquake and local tsunami
  - Strong shaking felt for several minute!
  - Tsunami arrived 15-30 min after EQ
  - 156 tsunami deaths
  - Observed runups 10+ m, 50 m splash
  - Extensive coastal damage; destructive waves for 3-4 hrs
  - 'Few' casualties; good building codes
  - Coastal residents aware (remember 1960, signage/inund maps, educ, reminder 2005/2007), but not 'tourists'
- Early Warning
  - PTWC Regional (+10 min 1st unofficial, +12 official warn)
  - Local tsunami alerts require immediate action
    - Heed Natural Warnings - Do not wait for official ale
    - Preparedness, Education, Awareness key for succ e

Chile, M8.8, 27 February 2010

1. -77% of deaths (558) from earthquake, due primarily to collapse of adobe structures.
2. No specific communication protocols between NTWC and NDMO.
3. Lack of detailed checklist and SOP for evacuation.
4. Mass media not used to disseminate messages.
5. No clear chain of command from national to local levels.

Éste es el sector La Poza en Constitución, a orillas del río Maule. Antes del *tsunami* había casas particulares, como las de techo rojo a la izquierda, y estaban las dependencias de la capitanía de puerto (al medio).

Después de la destrucción causada por las olas del maremoto sólo se mantuvo en pie parte de la Casa de Botes, un moderno recinto municipal equipado con instalaciones para los cultores del canotaje. **C 12**

11 March 2011

- **M9.0 earthquake and local tsunami**
  - Strong shaking felt for several minutes
  - Tsunami arrived 20-30 min after EQ
  - 20,000+ tsunami deaths
  - Observed runups 10-25+ m, 38 m up valley, up to 5-6 km inland
  - Extensive structural damage, despite good building codes
  - Japan known for tsunami preparedness, but the tsunami wa bigger (bigger than 1896 / 1933 Sanriku.)
- **Early Warning**
  - JMA National (+3 min initial; +28 min upgraded warning)
    - EQ Early Warning worked, but problems with false aftershocks
    - GPS off-shore, surface buoy confirms ~15 min after eq
  - Local Warnings (sirens) work, but it is not enough
    - Heed Natural Warnings - Do not wait for official alerts
    - Education, Awareness key for success
  - Forecast justify evacuation (Japan, Hawaii, Chile) - How high?

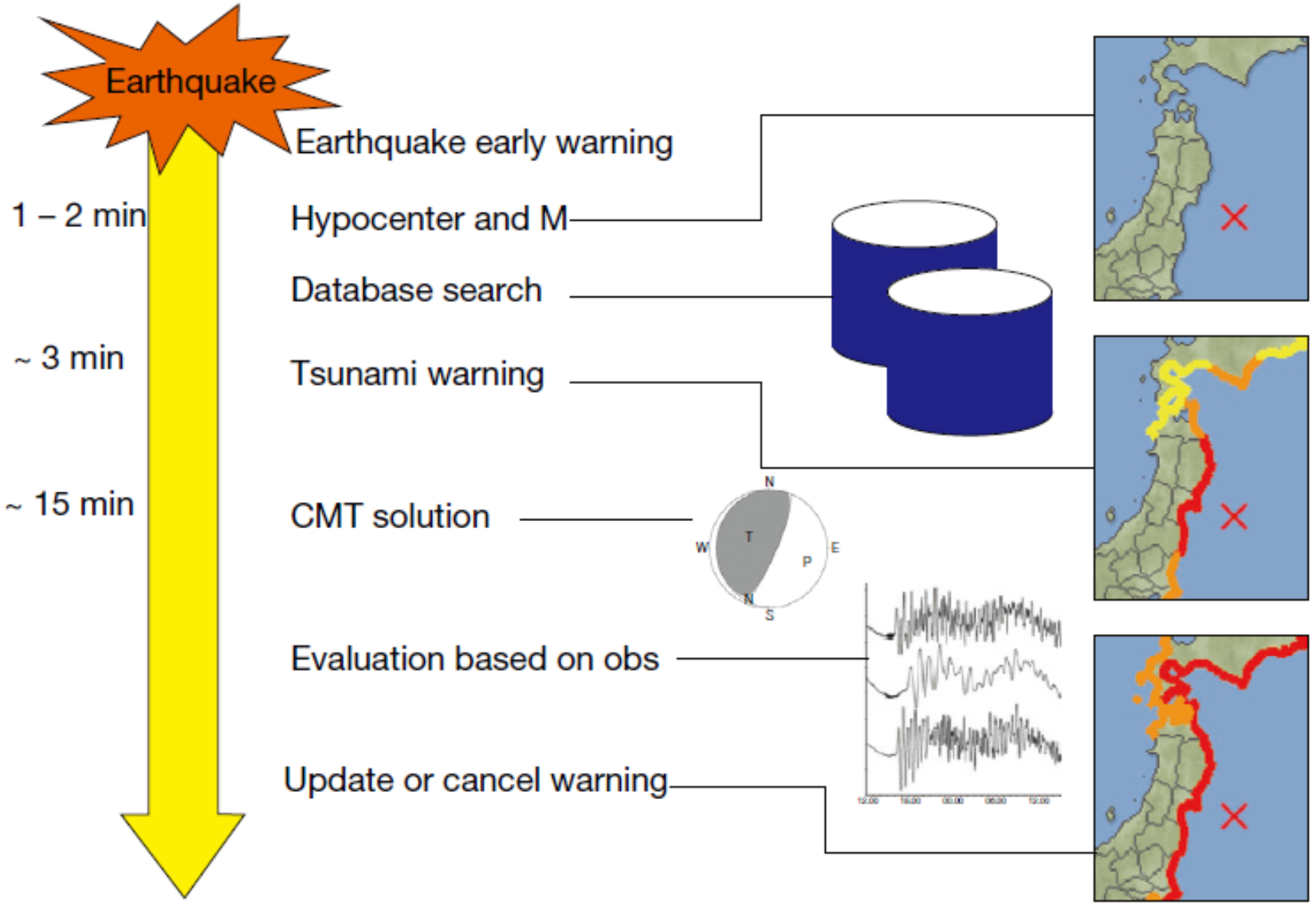
Japan Tsunami – Mar 2011

- Mw 9.0 earthquake – that big was not expected
- First alert in 3 min, but earthquake size and forecast tsunami impacts too small
- Human behavior – some did not evacuate

Lessons Learned

- Expect 1000-yr event
- Conservative first alert message
- Study/address how to motivate right actions

Tsunami Warning System (JMA)

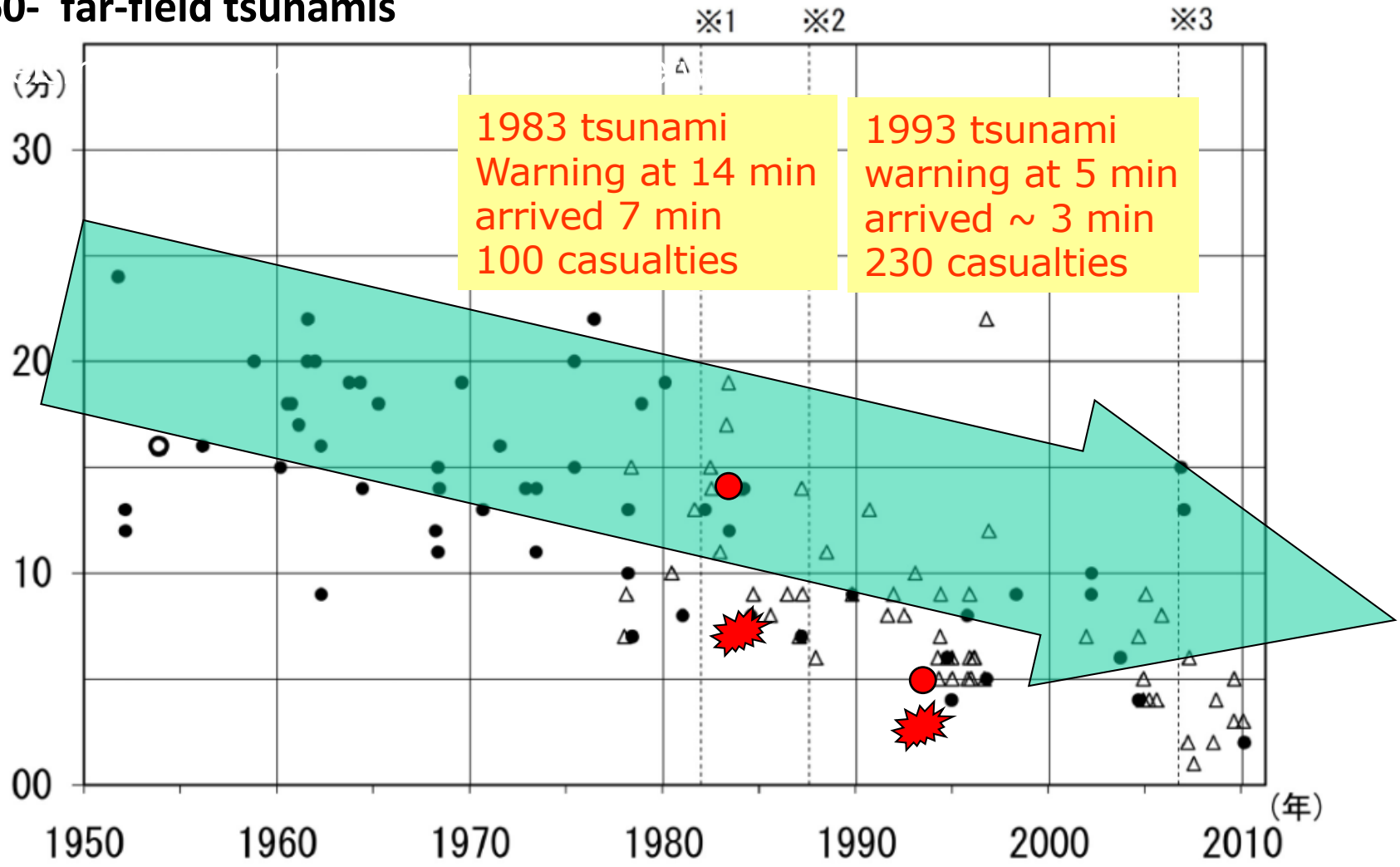


Tsunami Warning System of Japan (JMA)

1941- for Sanriku coast

1950- entire Japanese coast

1960- far-field tsunamis



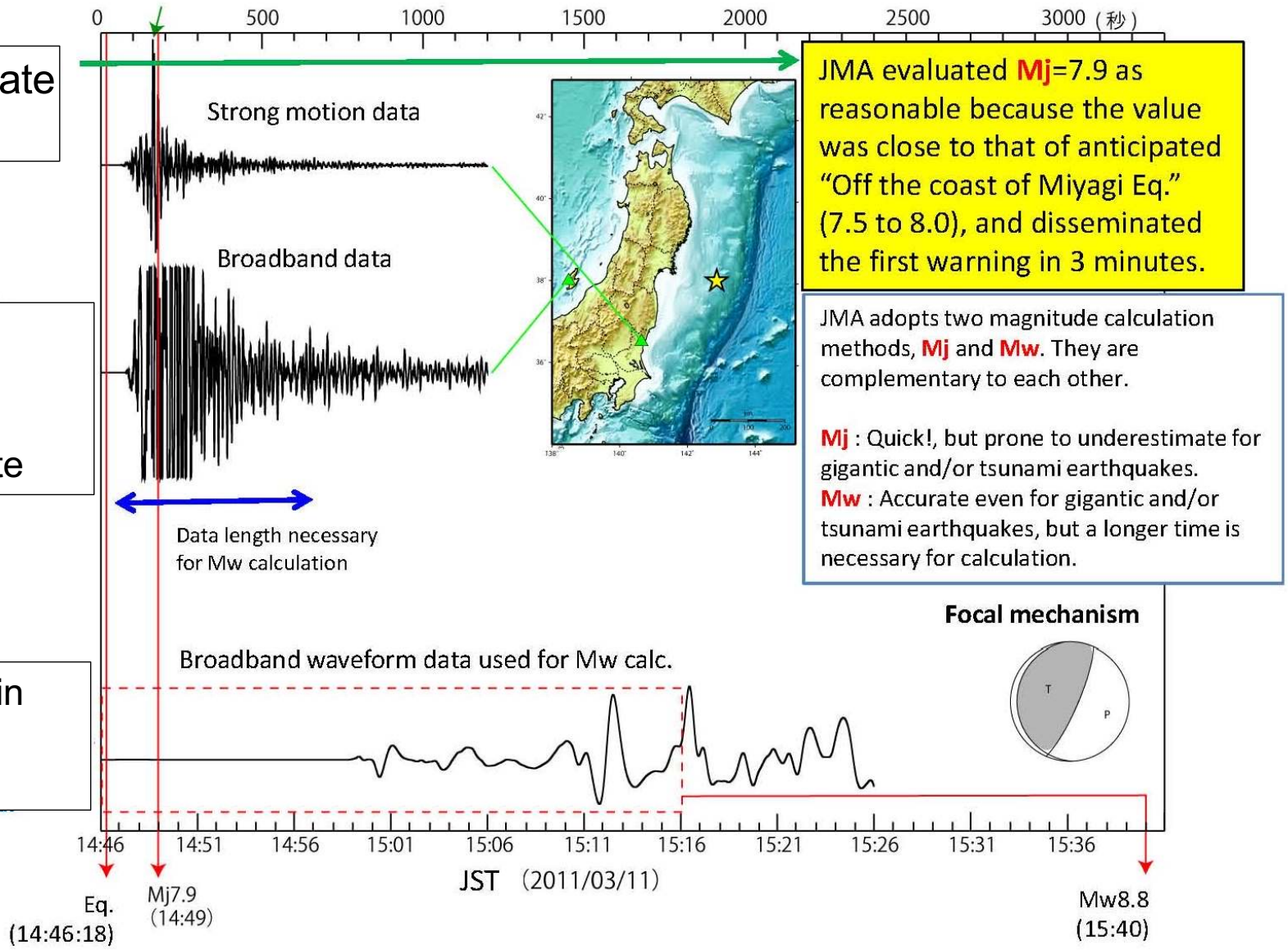
Tsunami Warning on March 11, 2011

Initial estimate
Mj=7.9

Broadband data clipped

Unable to estimate Mw
within 15 min

Mw = 8.8 in 54 min
From teleseismic (foreign) data



JMA evaluated **Mj**=7.9 as reasonable because the value was close to that of anticipated "Off the coast of Miyagi Eq." (7.5 to 8.0), and disseminated the first warning in 3 minutes.

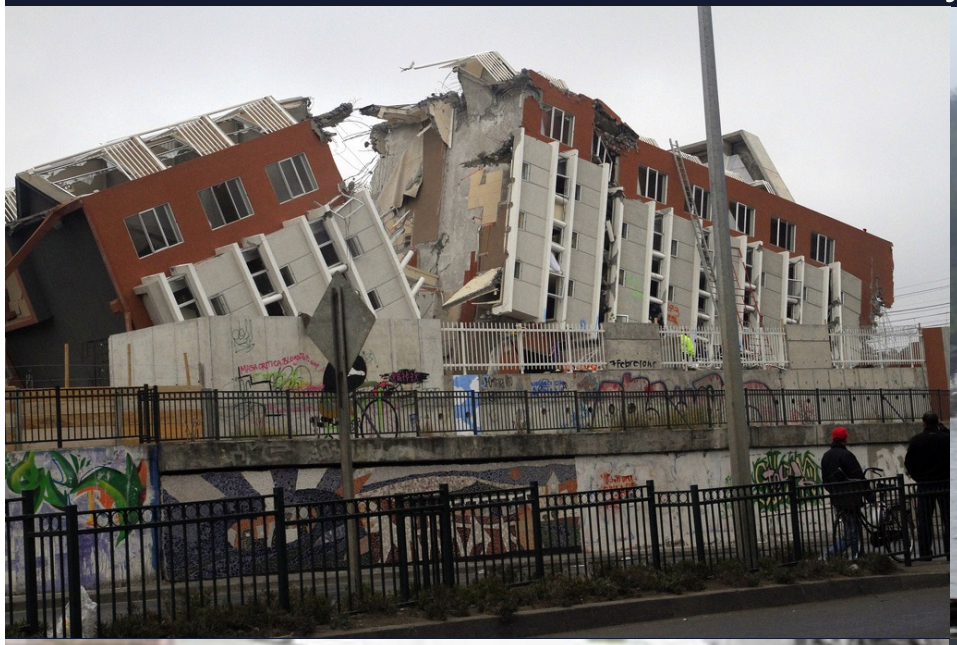
JMA adopts two magnitude calculation methods, **Mj** and **Mw**. They are complementary to each other.

Mj : Quick!, but prone to underestimate for gigantic and/or tsunami earthquakes.
Mw : Accurate even for gigantic and/or tsunami earthquakes, but a longer time is necessary for calculation.

Tsunami Warning from JMA

Time	after Eq.	M	Seismic Intensity and Tsunami Warning
14 : 46	0		Earthquake
14 : 49	3 min	7.9	Tsunami Warning: 6 m Miyagi, 3 m Iwate and Fukushima
15 : 14	28 min	7.9	Tsunami Warning: > 10 m Miyagi, 6 m Iwate, Fukushima
15 : 30	44 min	7.9	Tsunami Warning: > 10 m Iwate, Fukushima, Ibaraki, Chiba
12th 03 : 20	13 hrs	8.8	Tsunami warning or advisory for the entire coast of Japan
13th 07 : 30	1.5 days	8.8	Tsunami warning partially cleared
13th 17 : 58	2 days	9.0	Tsunami advisory all cleared

Maule Tsunami – 27 February 2010



MORE LESSONS LEARNED

27 DE FEBRERO DE 2010

- Importance of communications.
- Feedback of the information.
- Coordination of emergency agencies.
- Little clarity of the protocols.
- Population credibility in the information.
- Little knowledge about Tsunamis by the population.

- Importancia de las comunicaciones.
- Retroalimentación de la información.
- Coordinación de los organismos de emergencia.
- Poca claridad de los protocolos.
- Credibilidad de población en la información.
- Poco conocimiento acerca de los Tsunamis por parte de la población.

Melinka Tsunami – 25 December 2016

- Mw 7.6
- Small tsunami
- Xmas eve

Lessons Learned

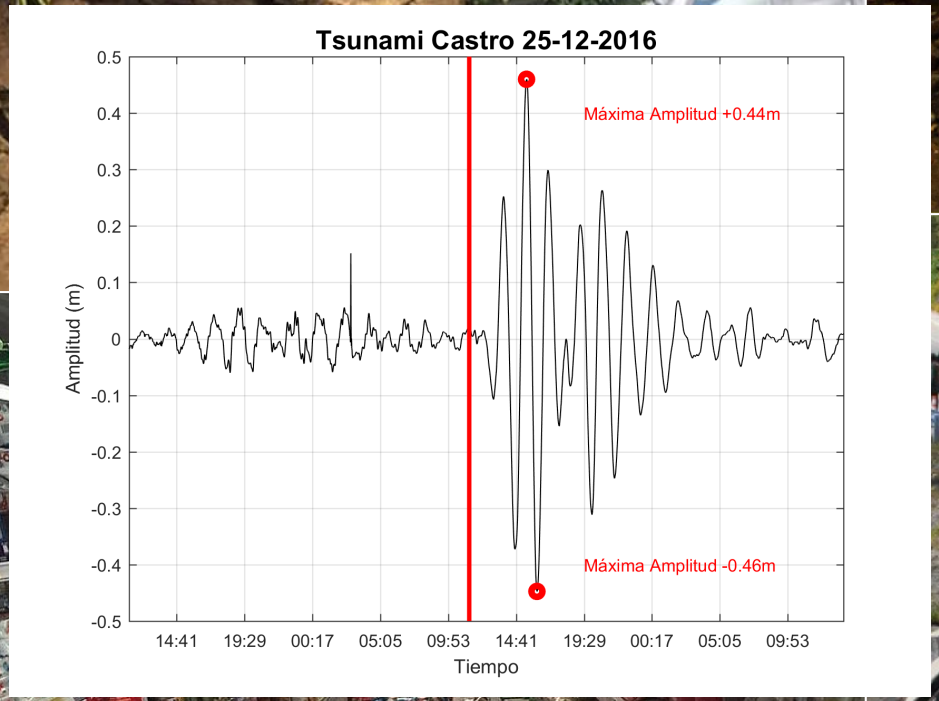
- 1st real situation implementation of SIPAT
- Lessons learned implemented
- Optimization of DRR

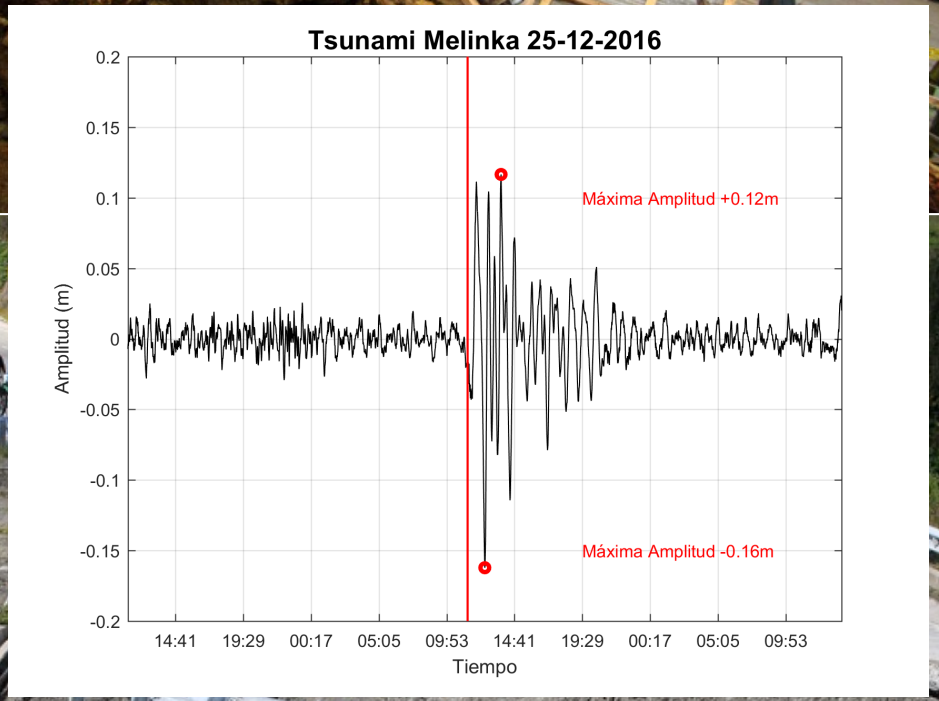
Melinka Tsunami – 25 December 2016

Localización estaciones	Amplitudes máximas observadas		Períodos (min)
	Tiempo (H.L.)	Amplitudes (m)	
Bahía Mansa	16:25 16:55	(+)0.16 (-)0.13	62
Ancud	15:43 16:22	(+)0.11 (-)0.13	88
Castro	15:26 16:09	(+)0.44 (-)0.46	67
Melinka	13:44 12:35	(+)0.12 (-)0.16	111

Servicio Hidrográfico y Oceanográfico de la Armada de Chile

Melinka Tsunami – 25 December 2016





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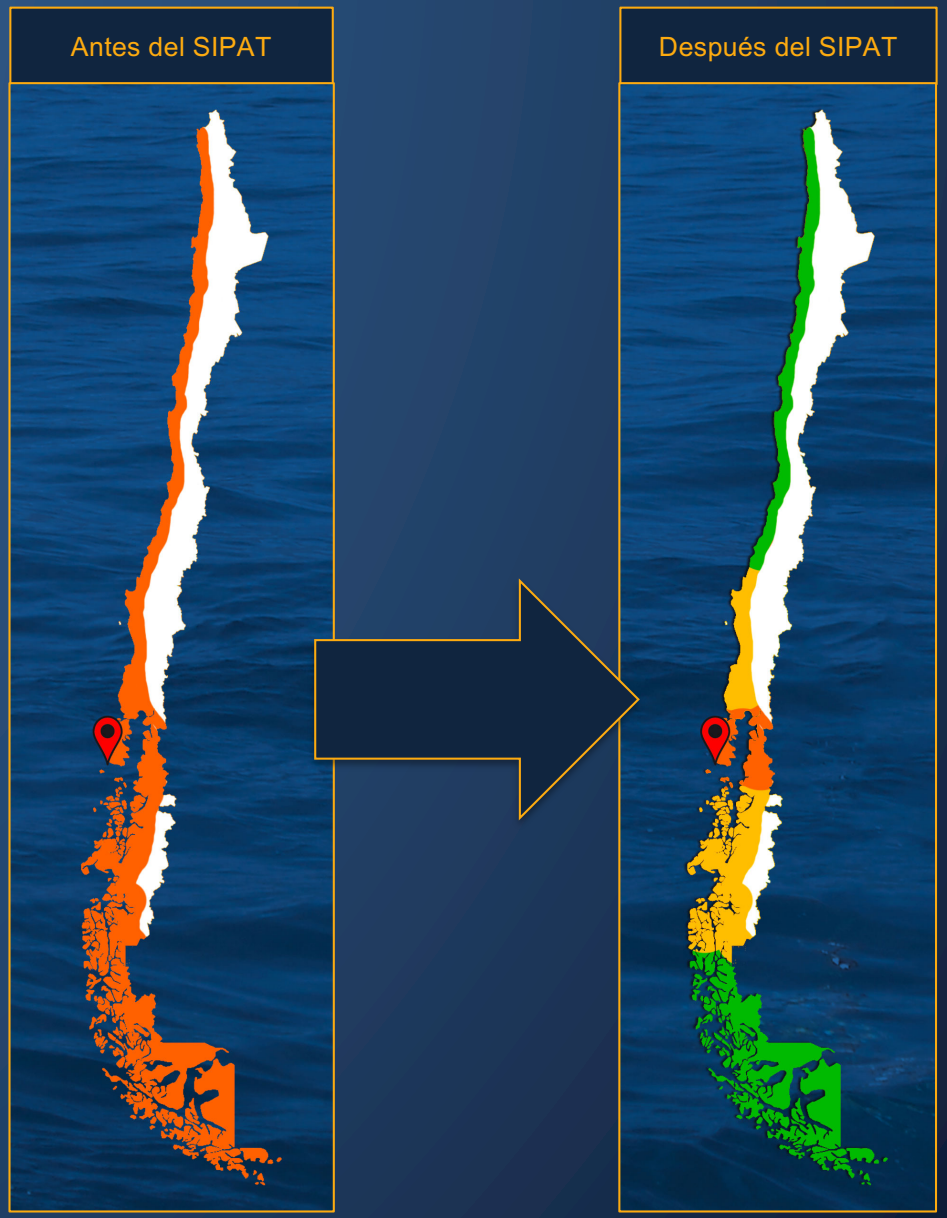
Melinka Earthquake 2016	
Magnitud	**7.6 (Mw)**
Fecha – Hora	25 de Diciembre de 2016 a las 11:22 hora local (14:22 UTC)
Epicentro	43.517° S; 74.391° W
Profundidad	20 km
Referencia Geográfica	89 km al NW de Melinka
Región	X Región de Los Lagos, Chile
Fuente	Centro Sismológico Nacional (CSN)



LESSONS LEARNED

25 December, 2016

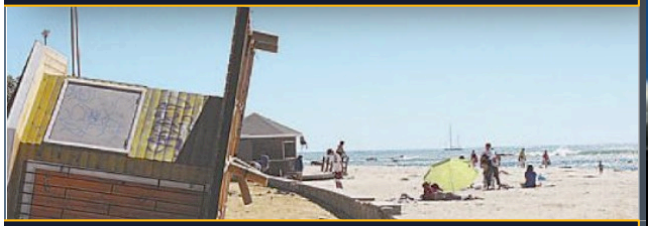
- Application of the Integrated Tsunami Prediction and Alarm System (SIPAT) successfully.
- Segmented evacuation, unlike before the SIPAT.
- Implementation of lessons learned (SOPs, coms, tech, sci, etc.).
- Keep improving!

- Aplicación del Sistema Integrado de Predicción y Alarma de Tsunami (SIPAT) exitosamente.
- Evacuación segmentada borde costero, evitando una evacuación completa como era antes del SIPAT.
- Implementación de lecciones aprendidas
- Segui mejorando

EARTHQUAKE AND TSUNAMI OF JAPAN, AND ITS EFFECTS ON CHILE 11 MARCH 2011

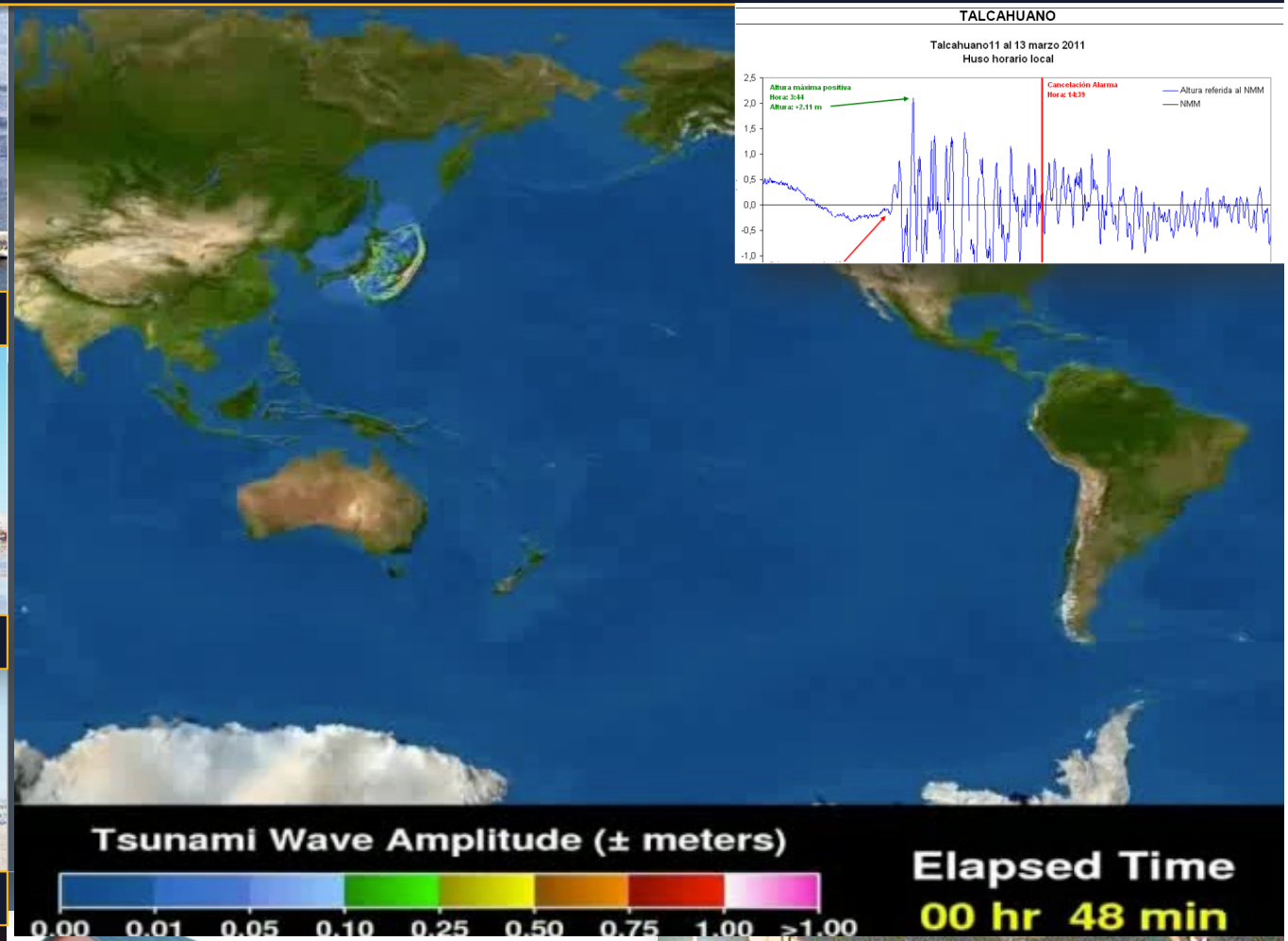
ARICA

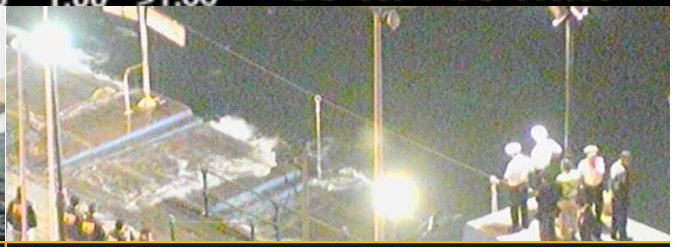
PUERTO VIEJO, CHAÑARAL



ALGARROBO

DICHATO





VALPARAÍSO

Servicio Hidrográfico y Oceanográfico de la Armada de Chile

Tsunami in Japan

Actions at TWC Ops room - CHILE









Servicio Hidrográfico y Oceanográfico de la Armada de Chile

LESSONS LEARNED

11 MARCH 2011

- Do not underestimate the power of nature.
- An event can be much larger than initial calculations.
- Little credibility of the authorities.
- Importance of timely evacuation (DR management)

- No subestimar el poder de la naturaleza.
- Un evento puede ser mucho mayor que lo calculado inicialmente.
- Poca credibilidad de las autoridades.
- Importancia de la evacuación oportuna (gestión de riesgo de desastres)

unesco
Intergovernmental
Oceanographic
Commission

Great East Japan Tsunami
Warning decision point, Evacuation, and Human Response

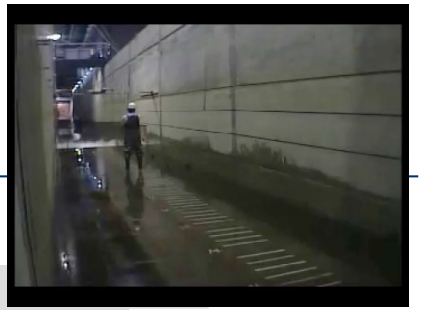
Deciding to issue warnings – Facts

- **JMA Warning timely,** incl wave forecast 3+ m (but was underestimate)
- **Small waves can be dangerous**
  Laboratory expts show waves 30 cm flow depth cause people to lose balance / cars to float
- **Swift-moving waves are dangerous**
  especially later waves as debris-laden rivers and/or walls of water.
- **Most people evacuated. Some did not.**
  Only 5% died, nonetheless, it was ~18,000

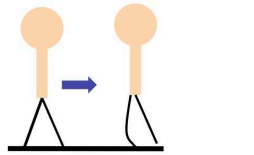
⇒ **NTWC DECISIONS MUST BE CONSERVATIVE (ENSURE SAFETY)**

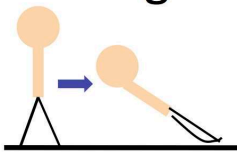
⇒ **FOR LOCAL, PUBLIC SELF-EVACUATES - DO NOT WAIT FOR NTWC**

Flow Depth – Humans



Preliminary Results:
Probability of falling or sliding
=> lose balance at 0.3 m (1 ft) depth





Arikawa, Japan PARI, 2010

Velocity > 2-3 m/s (7-11 km/hr, 4-7 mph, 4-6 kts)

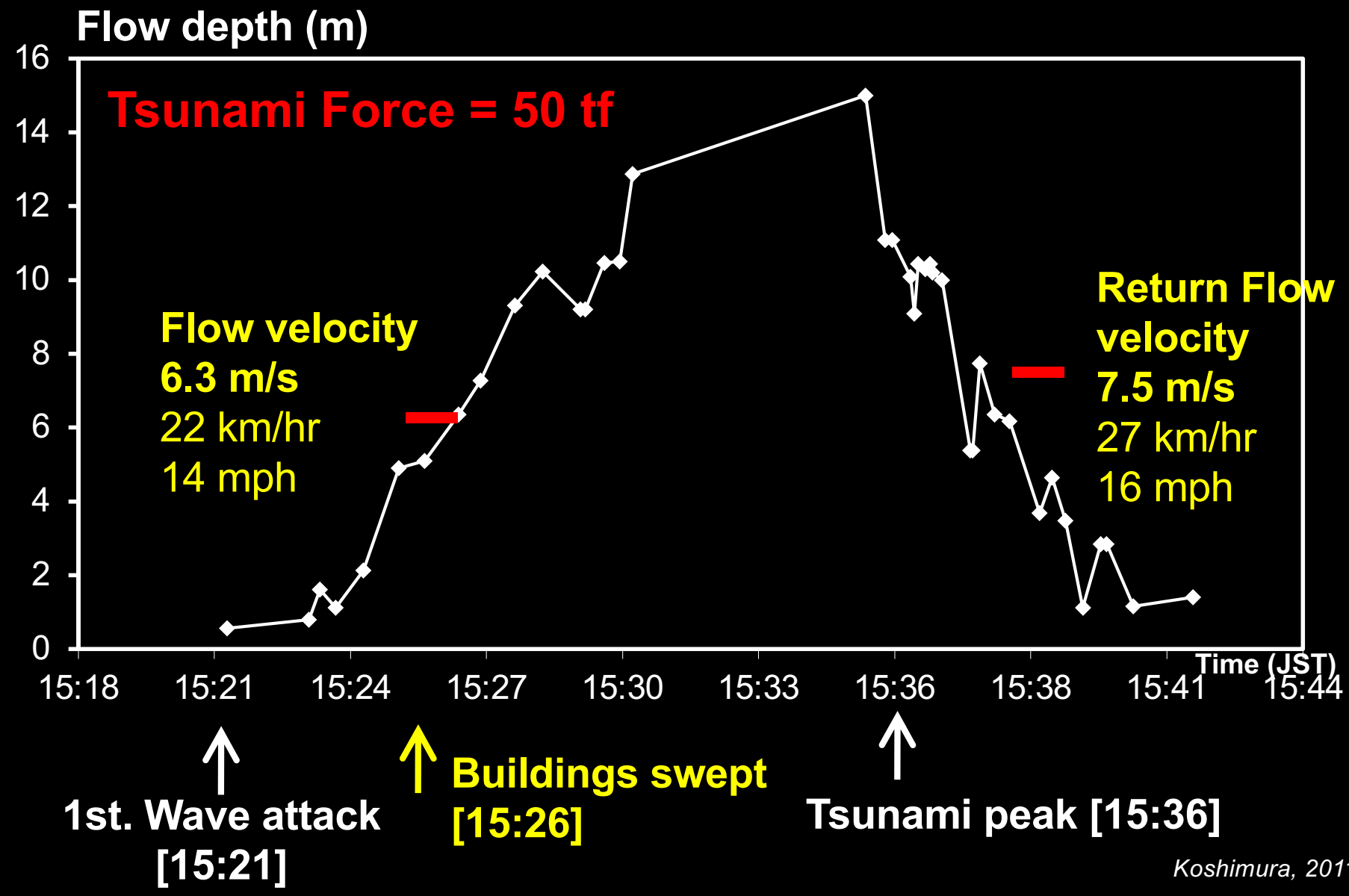
Onagawa, Miyagi Pref.

Koshimura, 2011

www.town.onagawa.miyagi.jp：
Fatality：455, Missing：739 (Pop.10,010). 12% of population were killed or missing.
Destroyed houses/buildings： 4432. 70% of houses in town was severely damaged.

Koshimura, 2011

Time series of tsunami inundation interpreted from video

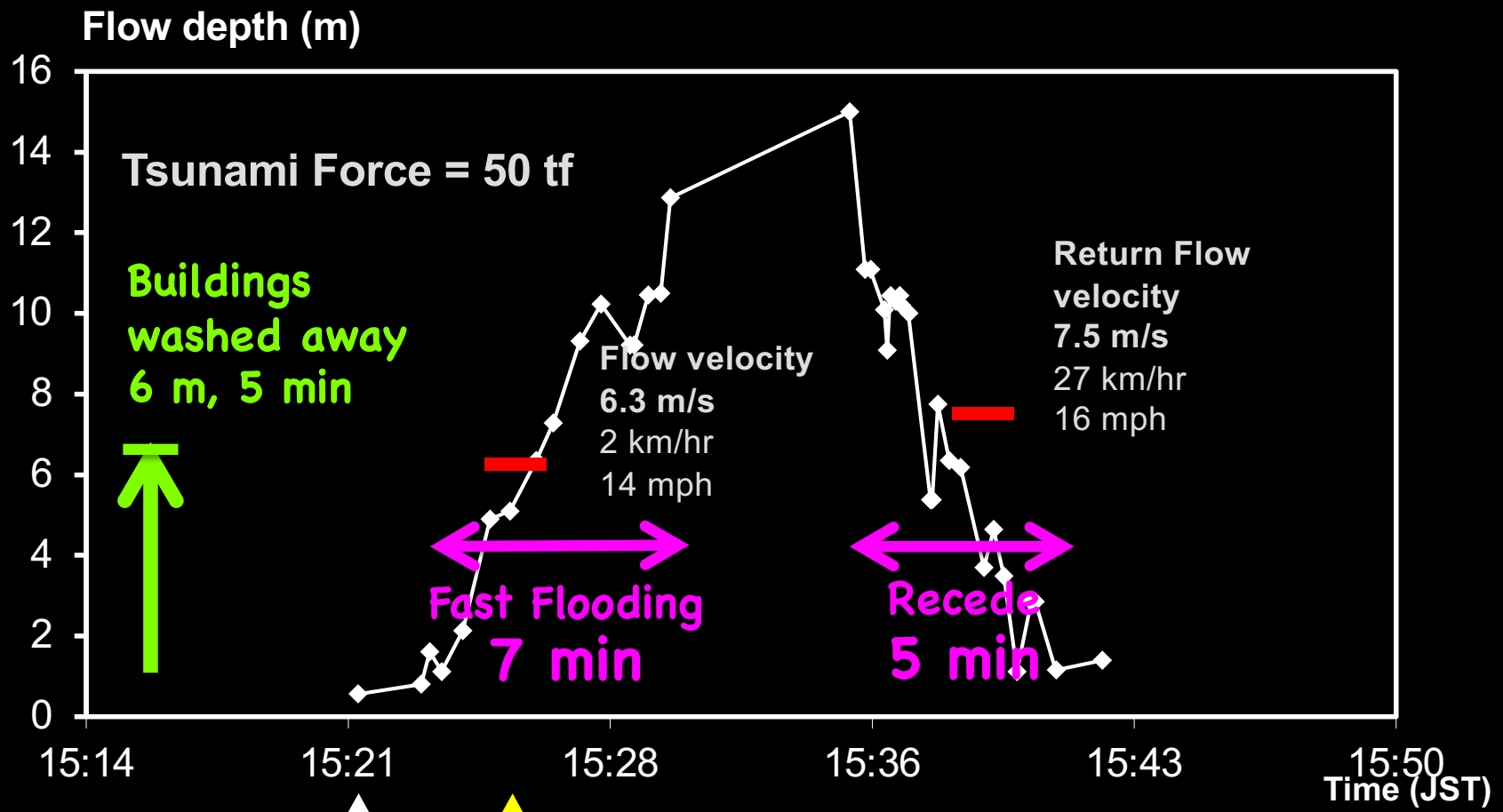


Koshimura, 2011

Onagawa, Japan

Koshimura, 2011

Time series of tsunami inundation interpreted from video



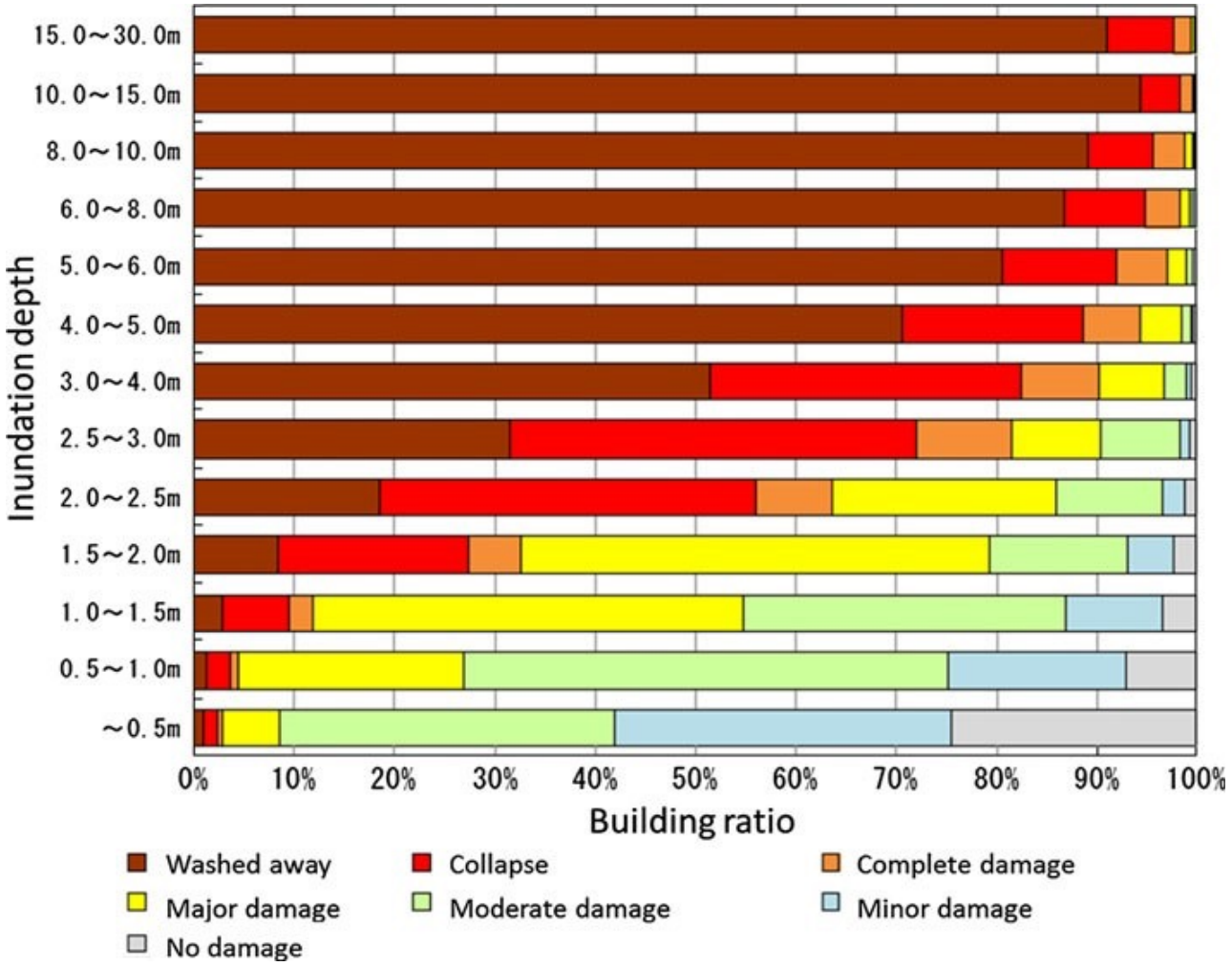
1st. Wave attack [15:21]

Buildings swept [15:26]

Tsunami peak [15:36]

Koshimura, 2011

Flow Depth - Building Damage



Suppasri et al., 2013

11 March 2011 Data: Fig. 2 Distribution of the total 251,301 building data surveyed by MLIT (2012) Ministry of Land, Infrastructure and transportation (MLIT): Survey of tsunami damage condition: http://www.mlit.go.jp/toshi/toshi-hukkou-arkaibu.html. Accessed 4 July 2012

Tsunami Impact - summary

Criteria to estimate damage by tsunamis

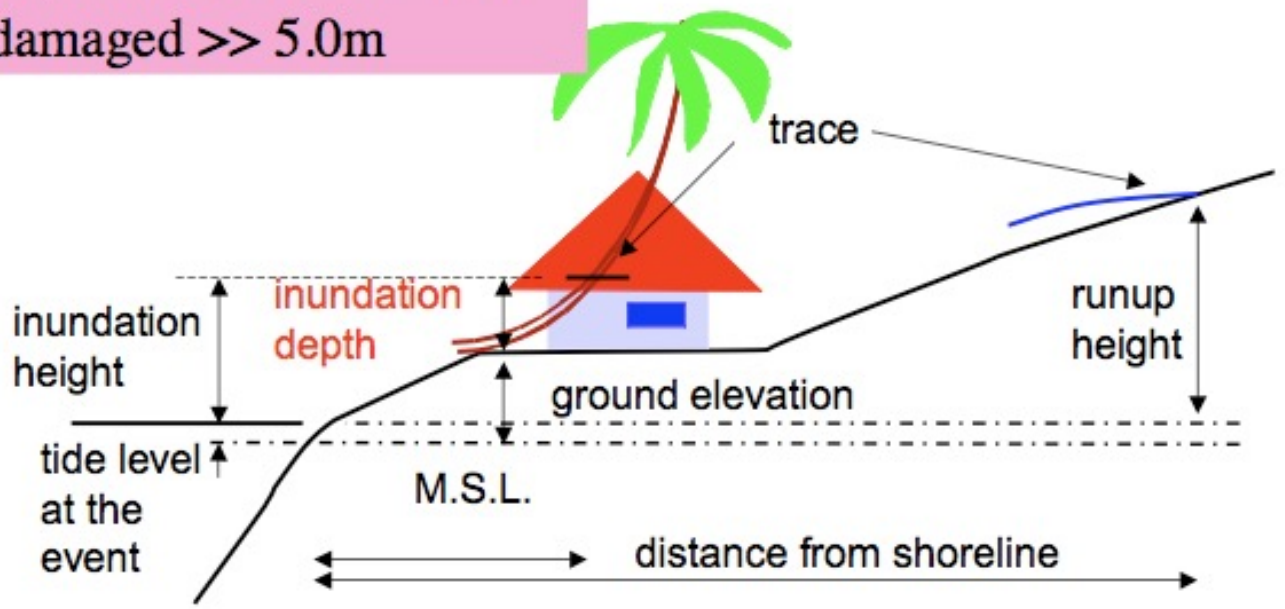
Inundation depth

Human: killed >> 50cm

House: partially damaged >> 1.0m

totally damaged >> 2-3.0m

Building: damaged >> 5.0m



Expect Fast Flooding
Have a Personal Plan

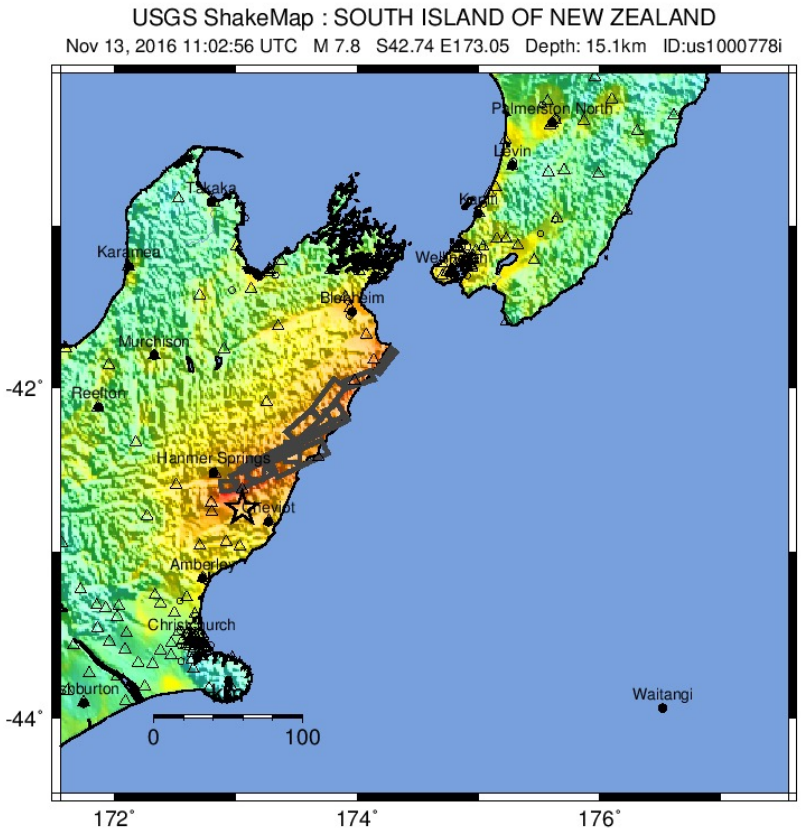
Sendai, Japan, March 11, 2011

New Zealand Tsunami – Nov 2016

- Mw 7.8 earthquake – epicenter inland
- New Zealand and PTWC evaluated as no tsunami threat
- Complex rupture – main slip 200km to N bi-lateral
- 7m tsunami occurred

Lessons Learned

- Assume conservative earthquake source size
- Conservative first alert message
- Sea level gauges detect 1 m offset Christchurch

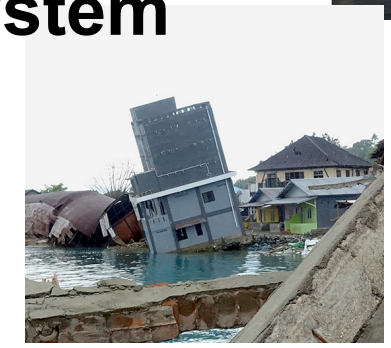


Non-seismic tsunami – 2018, 2022

- **Generated by landslide:**
  Aysen Fjiord 2007 (M6.2, 10 deaths)
  Palu 2018 (EQ subsidence, liquefaction)
- **Generated by volcanoes –**
  Krakatau 2018 (474 deaths) (1883, 35,000 deaths),
  Hunga Tonga, Hunga Ha'apai 2022 (4 deaths) –
  tsunami + lamb wave

Lessons Learned

- **Need to develop non-seismic Tsunami Early Warning System**
- **TW current: detect=>warn**
- **Increase awareness**
- **Multi-hazard EW**



Hunga Tonga – Hunga Ha'apai Tsunami – 15 January 2022

- Volcano eruption generated tsunami and atmospheric pressure wave that generated wave.
- Acoustic 'boom' heard in Alaska, wave observed in Caribbean, Atlantic, Indian Ocean
- 4 deaths locally, 1 in Peru (related to fuel unloading)
- PTWC ad hoc messages. No TW, nor forecast (models unknown)
- Interim HTTH PTWC response implemented - March 2022

Lessons Learned

- Must detect, then warn. But Volcano eruption has more lead time. 'Faraway' countries should monitor wave for potential threat.
- 14 January event 'pre-alerted'
- WTAD and other awareness made public aware

What to do … Know …

- **Tsunami Warning**
  - **Detect.** Have access to seismic data (or at least the earthquake information), 'other ways to find out'
  - **Know when:** Be able to est. likely wave arrival times
  - **Confirm.** Have access to sea level data for tsunami
  - **Science:** Understand the principles of tsunami generation and propagation and inundation

What to do … Know …

- **Tsunami Response**
  - **What dangerous and when:**
    - **Understand which local, offshore earthquakes likely to cause tsunamis because of their size and location**
    - **Understand likely distant tsunami sources**
  - **Alerting: Have many ways to reach varied customers (high-level, special sectors, public)**
  - **Prepare: Have evacuation maps that everyone understands. Conduct regular outreach. Exercise/test all components. incl communications**

What to do … Actions

Prepare and Establish in advance . .

1. Have SOPs for your organisation
2. Have SOPS across organisations
3. Test SOPs against scenarios and across organisations
4. Have good relationships with key people in all response organisations
5. Know who needs fast notification (how, what)
6. Know who to call for help (scale up)
7. Have a variety (redundant) of sources for information.
   "Bookmark" those sources

In Conclusion …

- Every tsunami is unique and provides new information to improve warning and response
- Problem dynamic – detection, evaluation, forecasting, alerting technologies keep changing. Information types, volume, flow, integrity are increasingly complex
- Forecast uncertainty. Atolls / small islands are PTWC TSP challenge as forecast site specific, requires high-res bathy – scenarios most critical
- Coastal vulnerabilities change with increasing coastal populations / infrastructure, incl adapt to climate change
- Community-empowerment (champions) key to sustaining preparedness and awareness, esp when tsunamis very infrequent.
- Sharing practices, experience, and knowledge is essential activity that improves system

UNESCO/IOC – NOAA ITIC Training Program in Hawaii (ITP-TEWS Chile)
TSUNAMI EARLY WARNING SYSTEMS
AND THE PACIFIC TSUNAMI WARNING CENTER (PTWC) ENHANCED PRODUCTS
TSUNAMI EVACUATION PLANNING AND UNESCO IOC TSUNAMI READY PROGRAMME
19-30 August 2024, Valparaiso, Chile

Lessons Learned from past Tsunamis
Science, Warning, Response, Preparedness, Awareness

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