UNESCO/IOC – NOAA ITIC Training Program in Hawaii (ITP-TEWS Hawaii)
TSUNAMI EARLY WARNING SYSTEMS
AND THE PACIFIC TSUNAMI WARNING CENTER (PTWC) ENHANCED PRODUCTS
TSUNAMI EVACUATION PLANNING AND UNESCO IOC TSUNAMI READY PROGRAMME
15-26 September 2025, Honolulu, Hawaii

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. TWCs)
- **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

- **1975 to Sept 2025 - 150 tsunamis > 1m, 56 deadly (69 since 1960)**
- **Since 2004 - 24 deadly tsunamis (15 Pacific, 6 Indian Ocean)**
  - Dec 2004 Indian Ocean (227,899 lives)
  - Jul 2006 Java (802 lives)
  - Apr 2007 Solomon Islands (50 lives)
  - Sep 2009 Samoa (192 lives)
  - Oct 2010 Mentawai (431 lives)
  - Feb 2010 Chile (156 lives)
  - Mar 2011 Japan (18,428 lives)
  - Feb 2013 Solomon Islands (10 lives)
  - Sep 2018 Palu (4340 lives)
  - Dec 2018 Anak Krakatau volcano (437)
  - Jan 2022 Hunga Tonga – Hunga Ha'apai volcano, Tonga (6 lives)

Other tsunamis

- May 1960 Chile (2226 lives)
- Jul 1998 Papua New Guinea (1636 lives)
- 1983 / 1993 Japan (100/208 lives)
- 1992 Nicaragua, 2006 Java (170/802 lives)
- 2006 Tonga
- 2016 Kaikoura, NZ
- 2025 Honduras (Caribbean)

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

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
- Impact to American Samoa, Samoa, and Tonga (Niuatoputapu) – deaths, damage

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

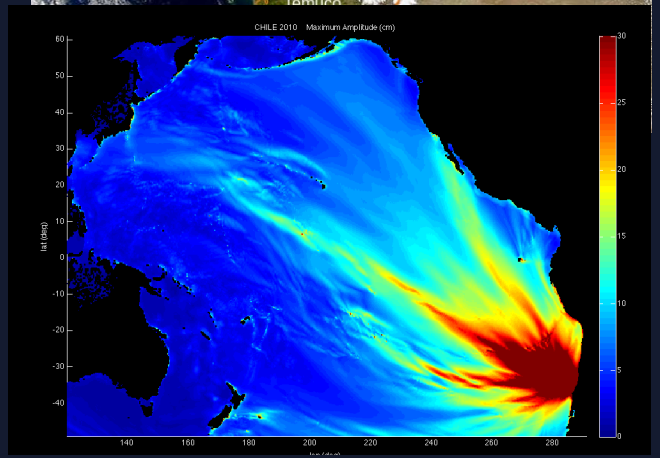
Maule Tsunami – 27 February 2010

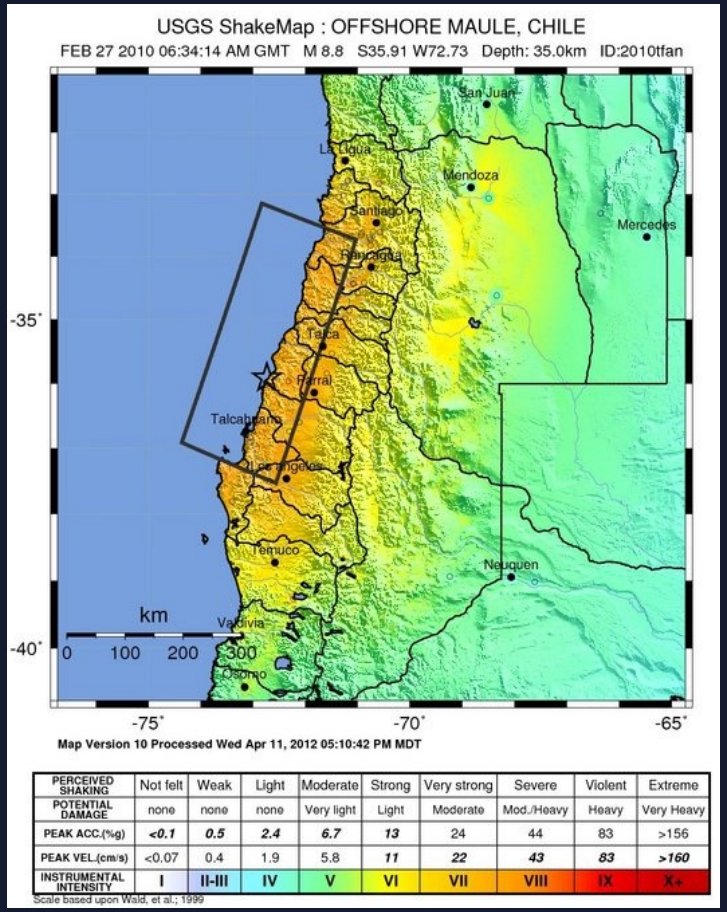
- Mw 8.8
- 156 tsunami, 455 earthquake
- 334 am (dark)
- Tourist high casualty, end-of summer celebration (Constitucion, Isla Orrego, mouth of Maure River)

Lessons Learned

- Older people remembered 1960
- Seismic strengthening so fewer EQ-caused deaths

TERREMOTO Y TSUNAMI CHILE 27 DE FEBRERO DE 2010





PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<0.1*	*0.5*	*2.4*	*6.7*	*13*	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	*11*	*22*	*43*	*83*	*>160*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

ARMADA DE CHILE
200 AÑOS

TERREMOTO Y TSUNAMI CHILE 27 DE FEBRERO DE 2010

ARMADA DE CHILE
200 AÑOS

LECCIONES APRENDIDAS

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.

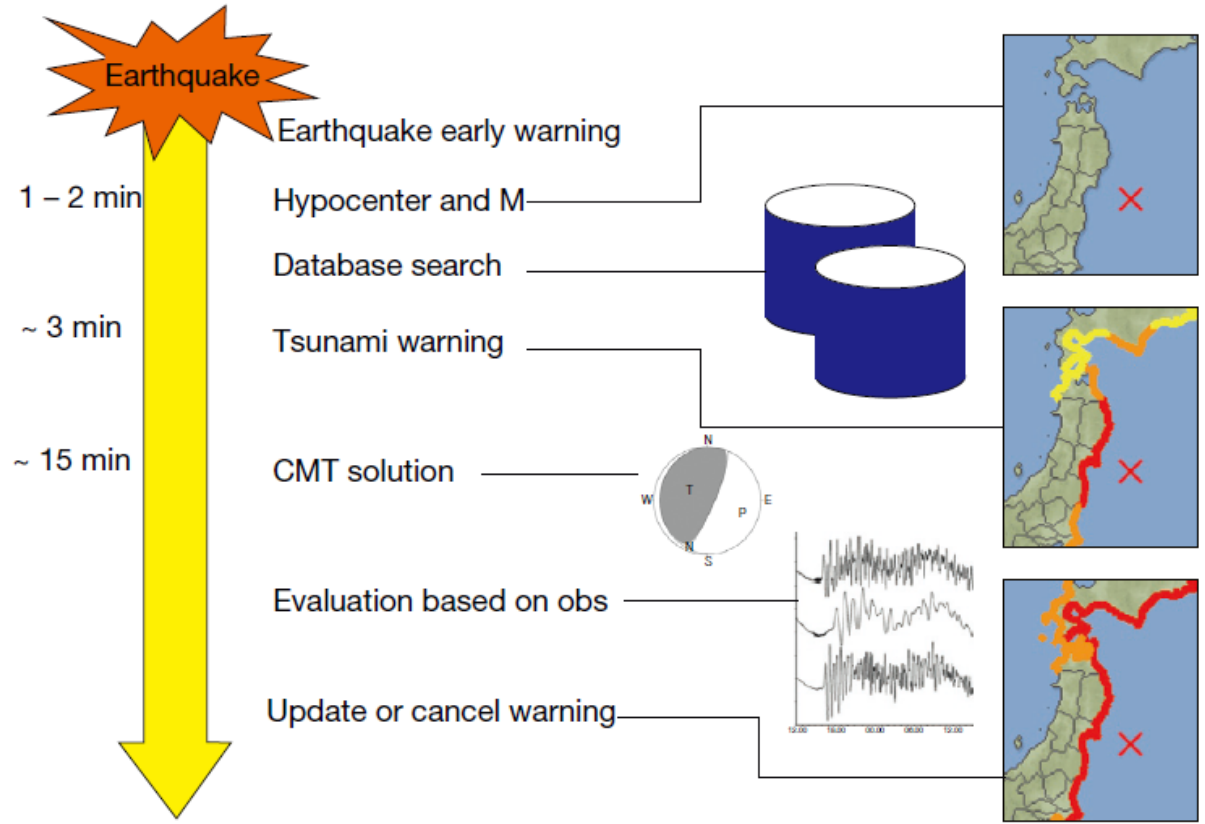
Japan Tsunami – Mar 2011

- 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

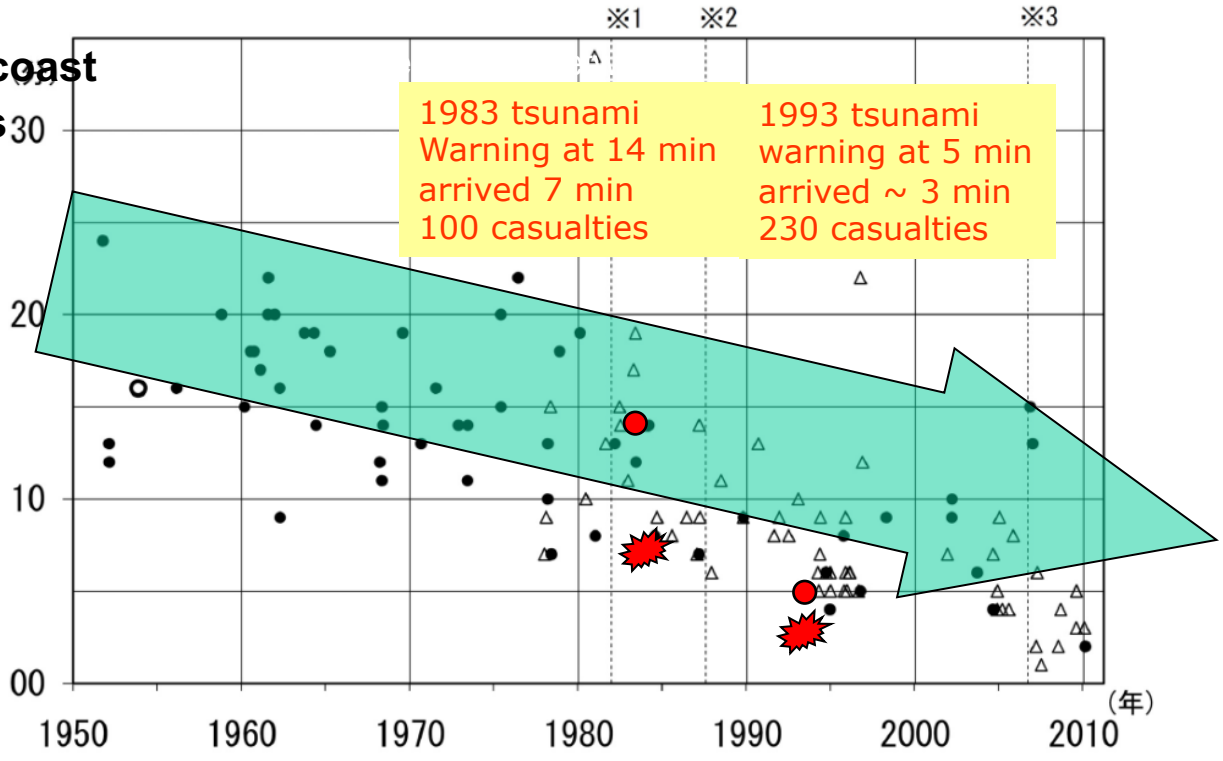
- Expect 1000-yr event
- Conservative first alert message
- Study/address how to motivate right actions

Tsunami Warning System of Japan (JMA)

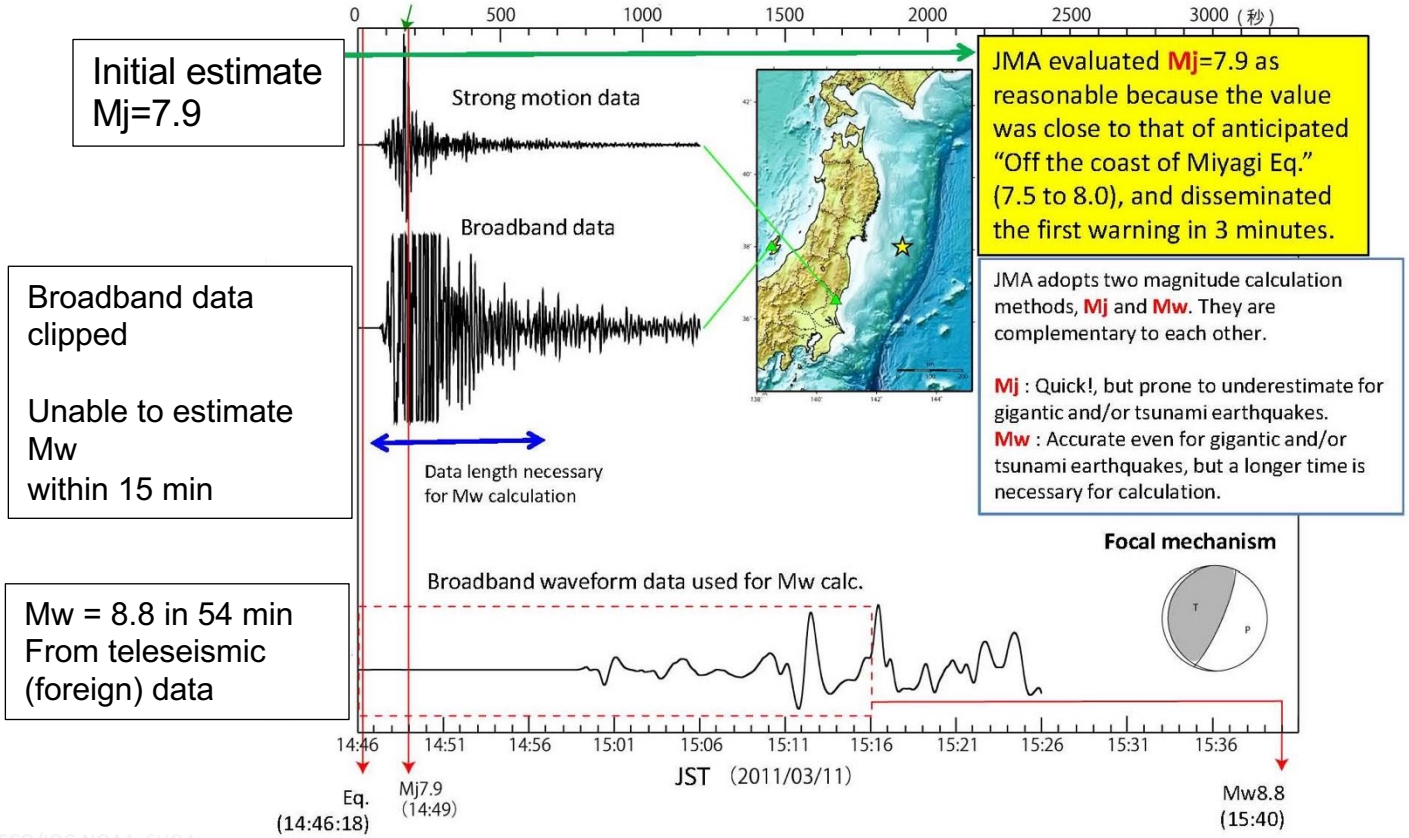


Tsunami Warning System of Japan (JMA)

1941- for Sanriku coast
1950- entire Japanese coast
1960- far-field tsunamis



Tsunami Warning on March 11, 2011



Tsunami Warning from JMA

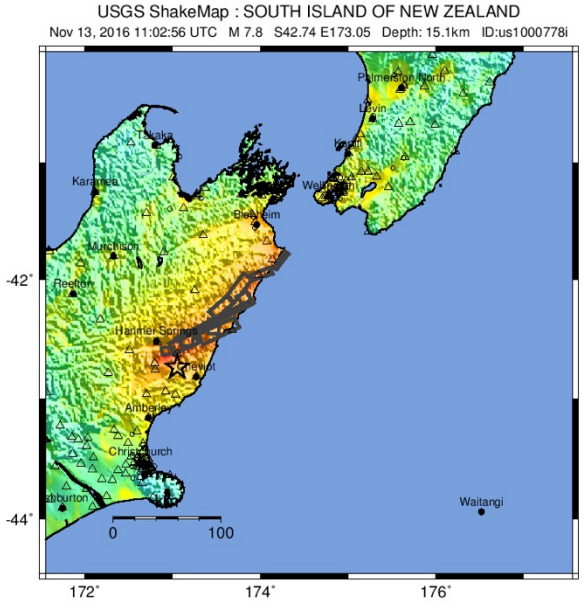
Time	after Eq.	M	Seismic Intensity and Tsunami Warning
14 : 46	0		Earthquake
14 : 49	3 min	7.9	Tsunami Warning: 6 m Miyagi, 3 m Iwate and Fukushima
15 : 14	28 min	7.9	Tsunami Warning: > 10 m Miyagi, 6 m Iwate, Fukushima
15 : 30	44 min	7.9	Tsunami Warning: > 10 m Iwate, Fukushima, Ibaraki, Chiba
12th 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

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 north
- 7m tsunami occurred

Lessons Learned

- Assume conservative earthquake source size
- Conservative first alert message
- Sea level gauges detect

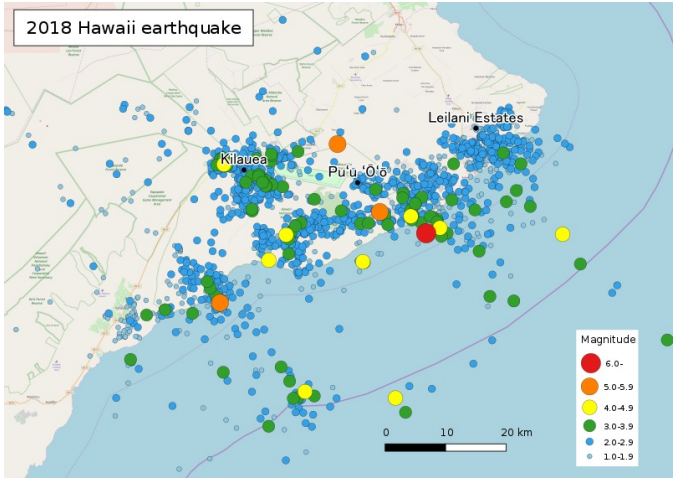


Hawaii Tsunami – May 2018

- Mw 6.9 earthquake – minimum PTWC threshold for a local tsunami warning
- PTWC initial Mw was 6.0, then 6.4, then 6.9
- 0.4 m tsunami observed on nearest gauge

Lessons Learned

- Used to relying on ml
- Special application of Mw required
- Better to wait a few extra minutes to get it right



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**
- **Currently, detect then warn**
- **Increase awareness**
- **Multi-hazard EW**

Hunga Tonga – Hunga Ha'apai Tsunami – 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 in March 2022

Lessons Learned

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

In Conclusion …

- Every tsunami is unique and provides new information to improve warning and response
- Problem is dynamic – detection, evaluation, forecasting, and alerting technologies keep changing. Information types, volume, flow, integrity becoming increasing challenging
- Atolls / small islands are PTWC TSP challenge as forecast site specific, requires high-res bathy – scenarios most critical
- Continuing challenges in communications (robust, remote, low cost to reach all)
- Coastal vulnerabilities change with increasing coastal populations and infrastructure, including adaptation to climate change
- Community-empowerment (champions) key to sustaining preparedness and awareness, esp where tsunamis very infrequent.
- Sharing practices, experience, and knowledge is essential activity that improves system

Thank You
Muchas Gracias

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