Role of Observing Networks in Tsunami Early Warning

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Vulnerability of the World Coast to Oceanogenic Disasters



Source: Transboundary Water Assessment Programme (TWAP), 2015 and Fact Sheet, Ocean Conference, 2017

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What is a Tsunami

- Tsunami in Japanese means "harbor wave"
- A system of ocean gravity waves formed as a result of large-scale displacement of sea surface. Travel long distances without losing energy
- Long wave length (of several 100 km)
- $_{\odot}$ Periods of a few minutes to about an hour
- Travels 500 to 1000 km per hour with height of Less than a meter in the Deep Ocean
- About 30 km per hour with height of Grows to Tens of meters near shore



Distribution of confirmed tsunamis

by generation mechanism



Earthquake
Earthquake generated Landslide
Volcanic Eruption
Landslide
Other



2011 Tsunami & 2004 Tsunami



Tsunami Hazard

Tsunami Sources 1610 B.C. to A.D. 2020 From Earthquakes, Volcanic Eruptions, Landslides, and Other Causes



Tsunami Travel / Response Times

Red: 1-4 hour; yellow: 5-6 hour; green:7-14 hour; blue: 15-21 hour

Dec 26, 2004 Indian Ocean, EQ M 9.1 15 min to Indonesia with wave heights of more than 30 m 11 hours to cover whole Indian Ocean

> Nov I, 1755 Lisbon, EQ M 8.5 - 9.0 20 minutes to Lisbon with wave heights of 6 to 12 m

May 22, 1960 Chile EQ M 9.5 15 min to Chile with wave height 25 m 15 hours to Hilo, Hawaii with wave height 11 m 22 hours to Honshu, Japan with wave height 5.5 m

> Mar 27, 1964 Alaska EQ M 9.2 Tsunami wave heights in Alaska ~ 67 m Tsunami damage was reported in 20 countries, including Canada, Peru, New Zealand, Papua New Guinea and Japan.











NEAMTW:

- NWPTAC: Northwest Pacific Tsunami Advisory Center

- SCSTAC: Tsunami Advisory Center of the Ministry of National Resources

- PTWC: Pacific Tsunami Warning Center

- Pacific since 1965
- 2004 tsunami in Indian Ocean illustrated need for more
- In 2005, the IOC was mandated to establish three more TWS
 - ICG/IOTWMS
 - ICG/CARIBE-EWS
 - ICG/NEAMTWS
- All 4 Regional TWS are operational with 11 Tsunami Service Providers (TSP) – France, Italy, Portugal, Turkey, Greece, USA, Japan, China, India, Indonesia, Australia

Mediterranean Sea and North Eastern Atlantic

- CENALT: National Tsunami Warning Center
- INGV: Italy National Centre for geophysics and volcanology
- IPMA: Portuguese Sea and Atmosphere Institute
- KOERI: Turkey Kandili Observatory and Earthquake Research Institute of Istanbul
- NOA: Greece Hellenic National Tsunami Warning Center National Observatory of Athens (NOA)

Pacific Ocean

Caribbean Sea

- PTWC: Pacific Tsunami Warning Center

Indian Ocean

- INATEWS: Indonesia Tsunami Early Warning System
- ITEWS: The Indian Tsunami Early Warning Centre
- JATWC: Joint Australian Warning Tsunami Center

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Tsunami Detection, Warning and Dissemination



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Tsunami Warning System – The Three Pillars

Tsunami Risk Assessment

- Development of risk assessment and reduction guidelines
- Development of Hazard and Vulnerability Maps, workshops and trainings to DMOs

Detection, Warning and Dissemination

- Real-time monitoring
- Expansion of observation networks
- Establishment of Tsunami Service Providers for monitoring
- Establishment of NTWCs/TWFPs for issuing national warning
- SOP workshops & trainings

Tsunami Awareness and Preparedness

- Tsunami Information Centres
- Community awareness and response resources & training
- Tsunami Exercises & Communication Tests
- Community Evacuation Planning
- Tsunami Ready





Tsunami Warning – Status in the IOTWMS





- Great Progress since 2004
- Enhanced Observing Networks
- TSP & NTWC Framework
- * 651 earthquakes of magnitude \geq 6.5 in the Indian Ocean
 - 21 tsunamis in the Indian Ocean since 2004
 - Earthquake triggered 16
 - Largest was the 2004 Indian Ocean tsunami
- Uncertainties in tsunami warning, specially for near source, atypical events
- Strengthening the Downstream

Table 1		KPI #	Key Performance Indicator (KPI)	Target Value	Tsunami Service Provider		
					Australia	India	Indonesia
	Service Level 1 Earthquake Bulletin	1	Elapsed time from earthquake to issuance of first Earthquake Bulletin	10 min	13.7 min (12.5%)	11.3 (40.9%)	11.6 (64.1%)
		2	Probability of detection of Indian Ocean earthquakes with Mw>=6.8 (USGS final value)	100%	n/a	n/a	n/a
		3	Accuracy of earthquake magnitude	0.3	0.13 (94.3%)	0.16 (90.0%)	0.26 (69.2%)
		4	Accuracy of earthquake hypocenter depth	30 km	15.1 (86.7%)	15.6 (90.0%)	25.0 (74.4%)
		5	Accuracy of earthquake hypocenter location	30 km	16.5 (90.6%)	13.6 (86.6%)	26.5 (64.1%)
	Service Level 2 Threat / No Threat Bulletins	6	Elapsed time from earthquake to issuance of first Threat Assessment	20 min	22 min	25 min	38 min
		7	Probability of detection of tsunami above threat threshold	100%	n/a	n/a	n/a
		8	Accuracy of the tsunami forecast amplitude/height	Factor of 2	n/a	n/a	n/a

Observation Networks - Seismic



Seismic Network Response Map

Earthquake of M 8.5 Off coast of Northern Sumatra, on 12-Apr-2012 Tsunami threat issued based on EQ Information, Later cancelled after observing below-threshold water level changes¹⁰

Observation Networks – Sea level



Tide Gauge Network ~ 400



Tsunami Buoys Network ~50



Sea level Network Response Map





April I, 2014 Iquiue, Chile - DART buoy observations to constrain the model source



Other Science Applications of Sea Level Data







Pathways of barotropic waves in the IO The arrows represent the pathways of barotropic waves.

Observation Networks - Sea Level













Tsunami Warning - Challenges

Palu tsunami on September 28, 2018 and Sunda Strait tsunami on December 22, 2018





Submarine landslide, Liquefication

- Deaths 2,100; Missing 680; Injured 4,612; and Displaced 78,994
- Tsunami Warning issued by BMKG in 5 Minutes
- The first wave arrived in 3 minutes, earlier than the warning
- Complex Strike Slip Earthquake, Extensive Liquefaction, Coastal / Submarine
 Landslides, Bay
- Electricity and communication were cut off in 2 min after the earthquake
- No time for communities to receive official warning
- Lack of capacity in LDMO, Sirens weren't working
- No access to evacuation routes, no prior preparation of evacuations

Anak-Krakatau Volcano eruption

- Deaths 430; Missing 128; Injured 1,459; and Displaced 5,695
- Caused by flank collapse due to eruption of Anak Krakatau volcano
- No Tsunami Early Warning issued
- Tsunami waves arrived in succession following the eruptions
 patterns, and avalanches
- Tsunami confirmed only by recognizing wave anomaly at near-by tide-gauges



Other Observation Technologies

Ships as Sensors



Ionospheric Observations



Oil Platform Harvesting

LASER SENSOR (CU) HET SENSORS + 27 m EQUIP SHED (NEW VSAT DISH) HET BUBBLER2 (NOAA) BUBBLER1 (NOAA)

Infrasound

0.50

0.25

ALE

CG || 441

SKJI 160 km

MD51 226 km

CNJI 231 km

BBJI 289.km

and instantion

13:56 13:57 13:58 13:59 14:00 1 UTC on 22 Dec 2018

mah . As man

Coastal HF Radar



Altimetry (Satellite/Airborne)



Altimetr







Courtesy: Alexander Frolov et al 2021 (30th International Tsunami Symposium, Sendai, Japan)



Thank You