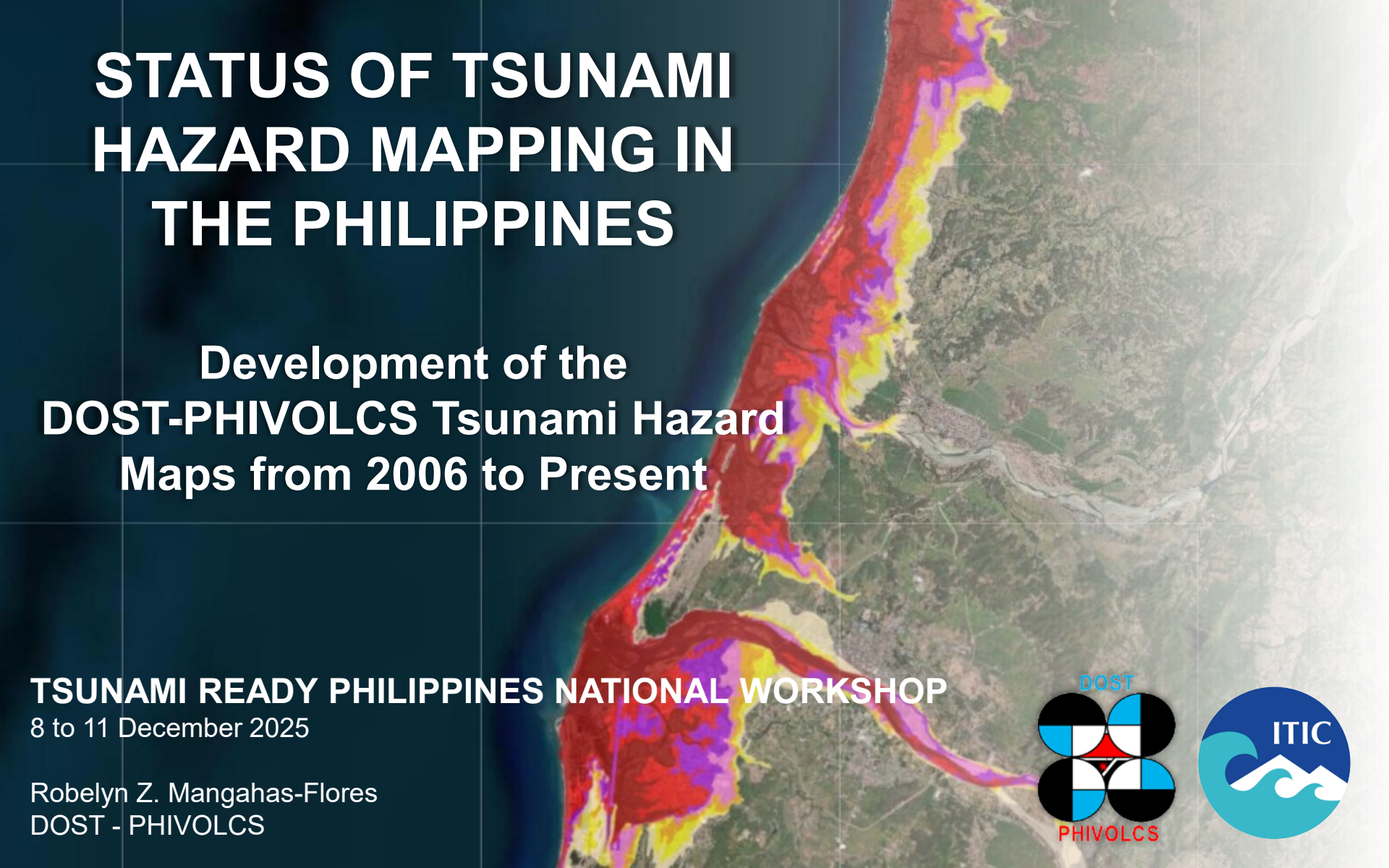
STATUS OF TSUNAMI HAZARD MAPPING IN THE PHILIPPINES

Development of the DOST-PHIVOLCS Tsunami Hazard Maps from 2006 to Present

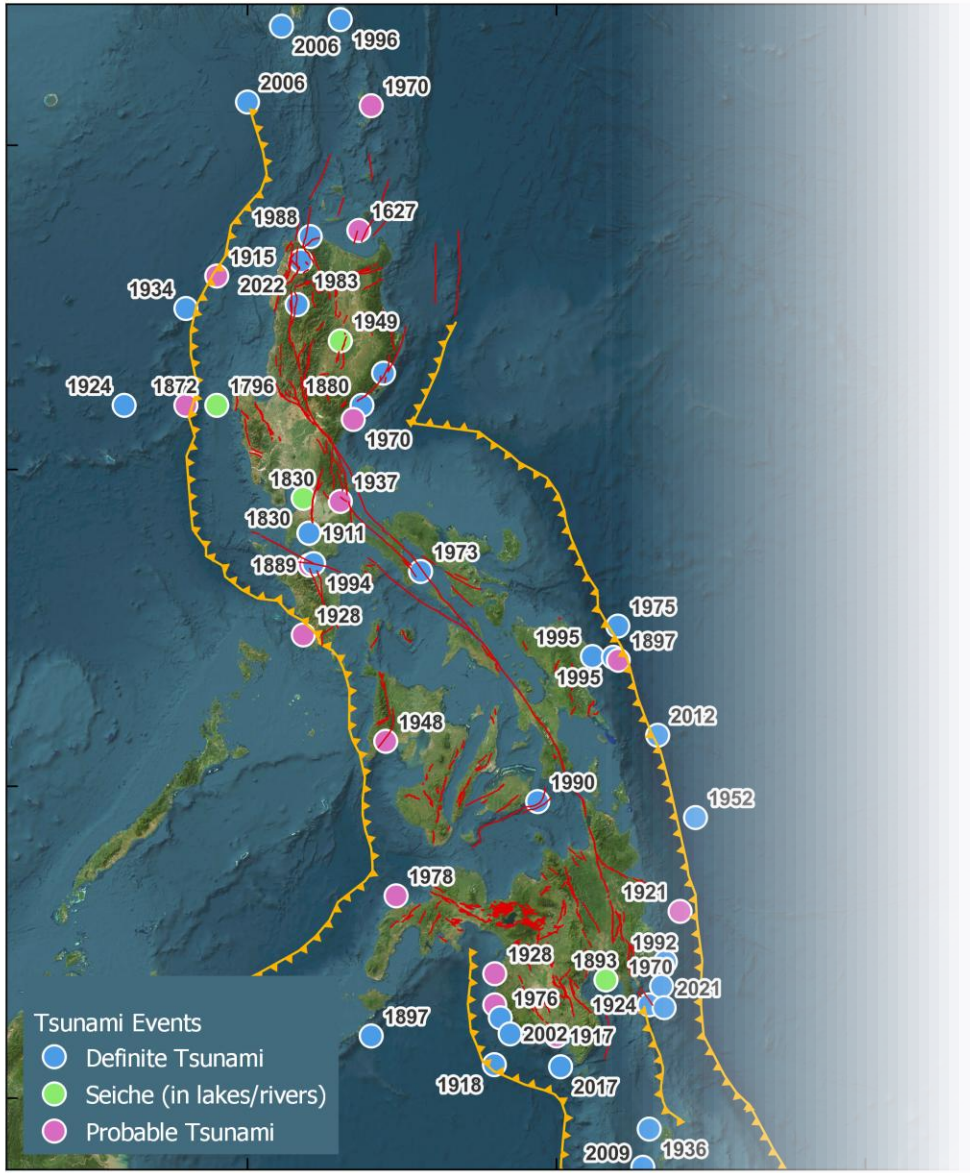


TSUNAMI READY PHILIPPINES NATIONAL WORKSHOP
8 to 11 December 2025

Robelyn Z. Mangahas-Flores
DOST - PHIVOLCS

DOST
PHIVOLCS

ITIC



Seismicity of the Philippines

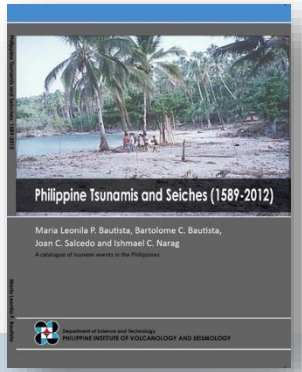
- 20 earthquakes are recorded per day on the average
- 4-5 felt earthquakes per week
- 100-150 felt earthquakes per year
- ~ 100 destructive earthquakes in the past 400 years
- 41 confirmed tsunami events based on historical accounts and earthquake events catalogues from 1828 to 2012

Historical Tsunamis

Mw8.1 August 17 1976
Moro Gulf Tsunami
(~11m wave height)

M 7.1 November 15 1994
Oriental Mindoro Tsunami
(~6m wave height)

Ms 7.1 & Ms 7.5 May 17 1992
Eastern Mindanao Tsunami
(~6m wave height)

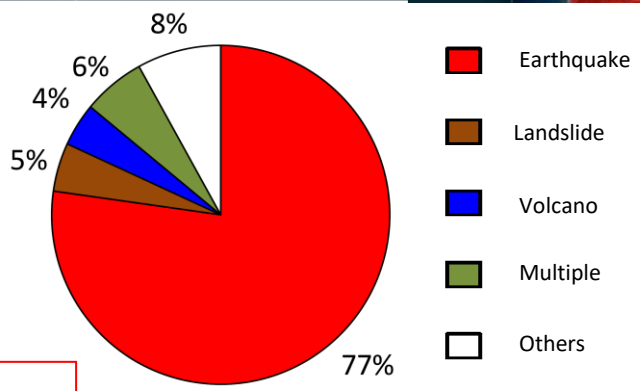


(1) Earthquake

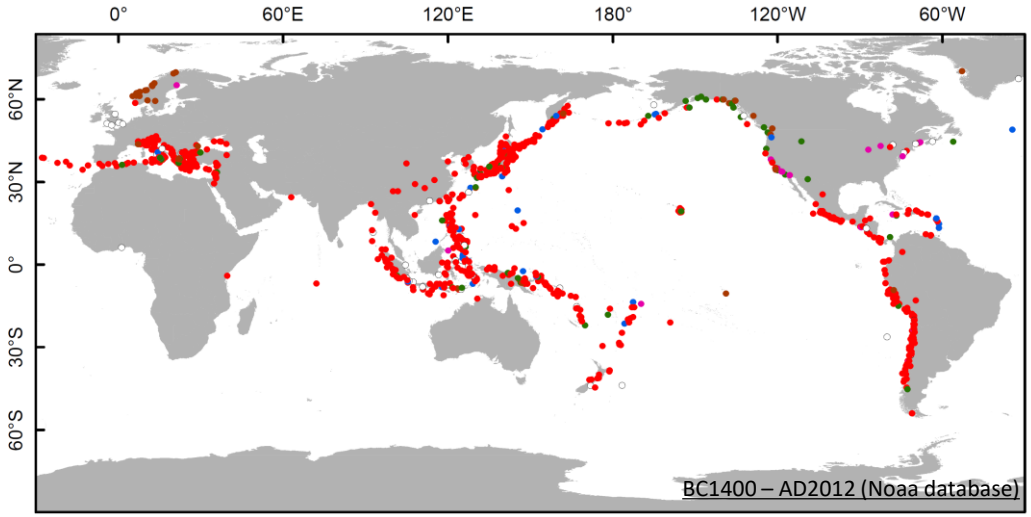
(2) Landslide

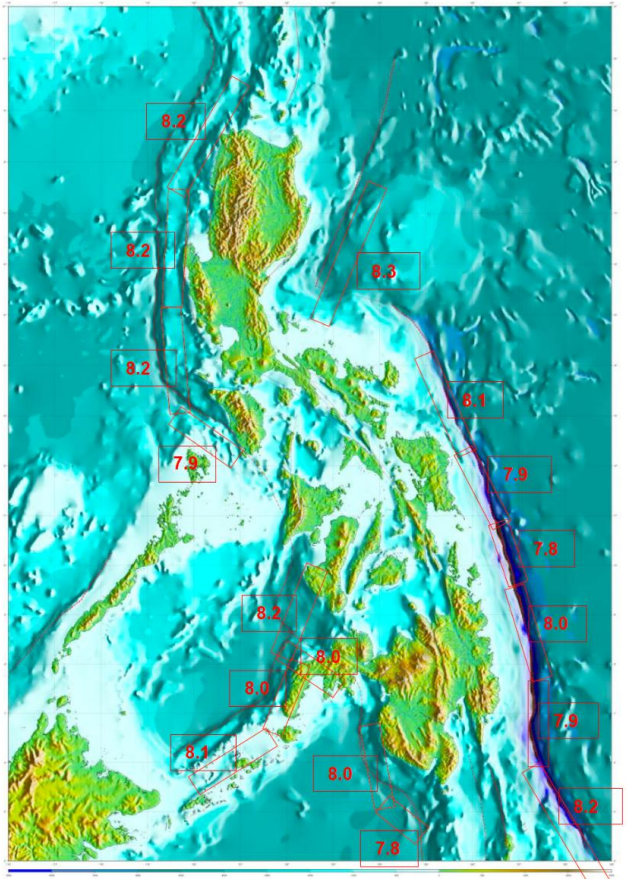
(3) Volcanic activities

(4) Others (Meteorite impact etc.)



77% of tsunami is generated by earthquakes

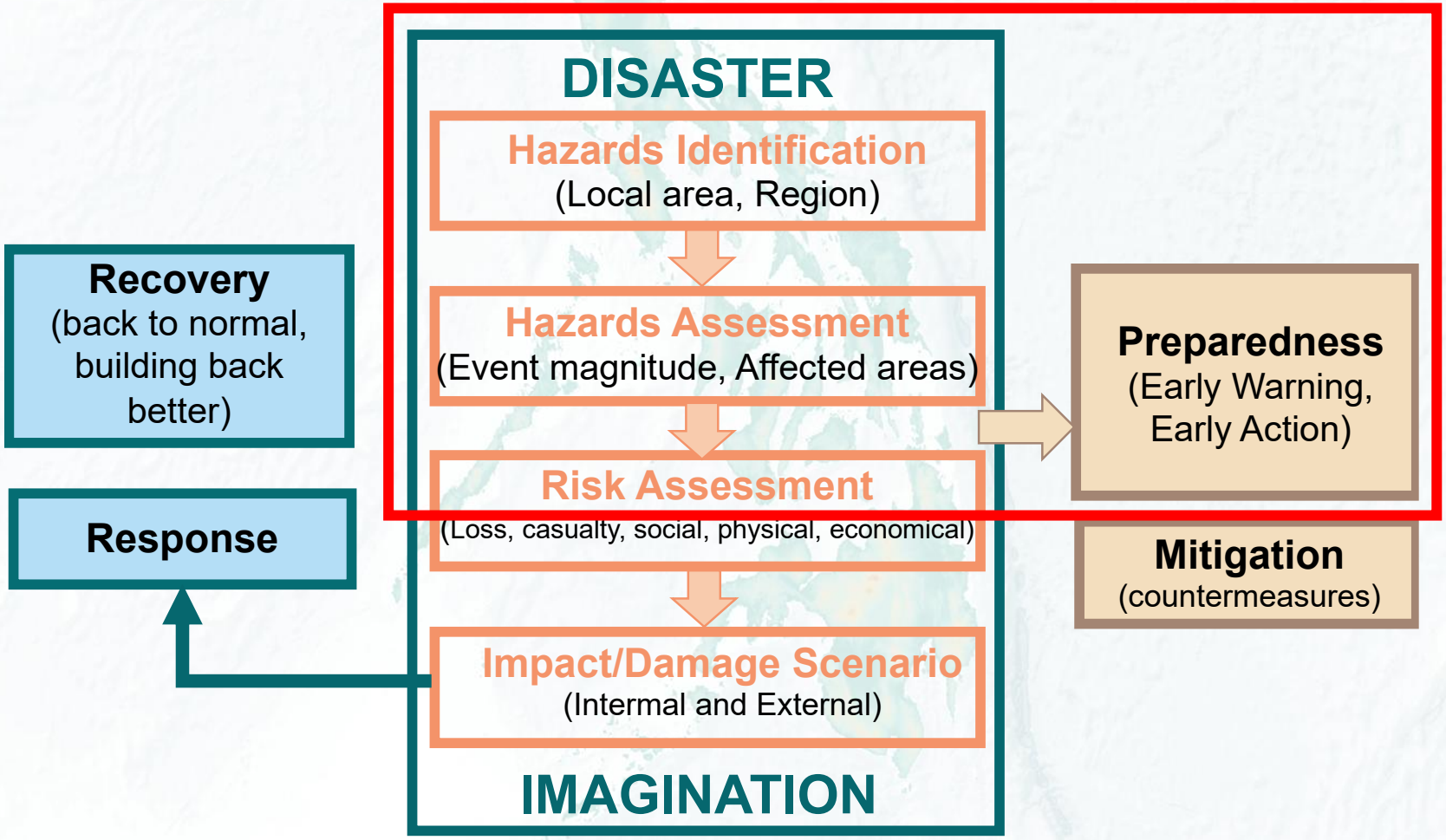




Cruz-Salcedo, 2010

PHIVOLCS

PHILIPPINE DISASTER RISK MANAGEMENT



TSUNAMI HAZARD MAPS

Tsunami Inundation Maps

refers to ***cartographic (paper) maps, spatial imagery, interactive and static web-based maps,*** *and other digital maps that delineate the* ***landward extent of flooding (inundation)*** *from tsunami waves.*

(Tsunami Modeling and Mapping: Guidelines and Best Practices, NOAA)

I	ASSESSMENT (ASSESS)
1	**ASSESS-1**. Tsunami hazard zones are mapped and designated.
2	**ASSESS-2**. The number of people at risk in the tsunami hazard zone is estimated.
3	**ASSESS-3**. Economic, infrastructural, political, and social resources are identified.

TSUNAMI HAZARD MAPS

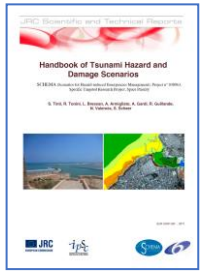
Regional Tsunami Hazard Scenarios

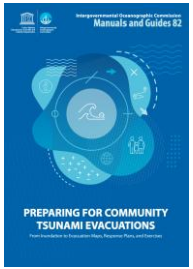
Local Tsunami Hazard Scenarios

Tsunami Damage Scenarios / Risk Assessment

Environmental Damage Scenarios

Evacuation Maps



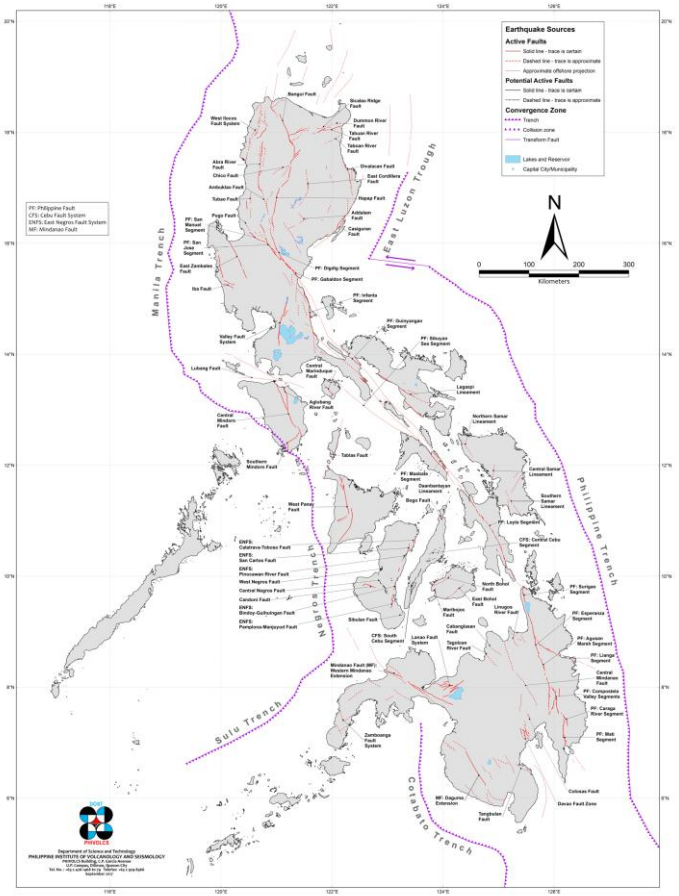


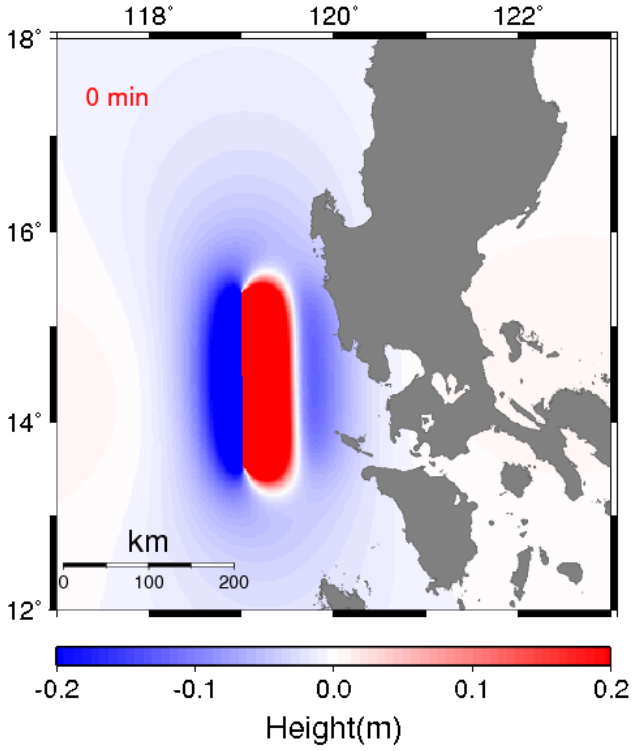
DOST PHIVOLCS

Two types of tsunamis, source, lead time and warning mechanism in place

Type	Source	Lead time	Warning mechanism in place
LOCAL	Trench or fault in Philippine region, usually less than 200 km from shoreline	2 – 20 minutes	Community-based must rely on natural signs such as moderate to intense shaking in coastal area, unusual water level rise or fall
DISTANT Regional or Trans-Pacific	Trench or fault outside the Philippine region (ex. Japan, Hawaii, Chile)	1 – 24 hours	International Centers Pacific Tsunami Warning Center, NW Pacific Tsunami Advisory Center

LOCAL TSUNAMI





There will be less time (a few minutes) for warning in case of locally-generated tsunamis – which are more often.

Tsunamis generated in distant locations will generally give people enough time for tsunami warning.

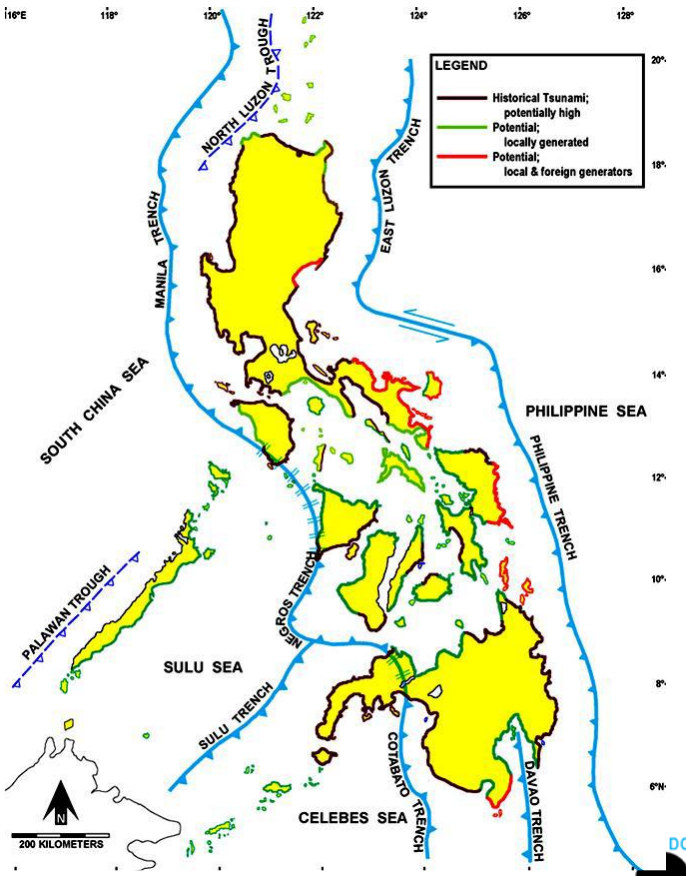
PHIVOLCS DATA RECEIVING CENTER


PACIFIC TSUNAMI WARNING CENTER (Photo Credits: NOAA)

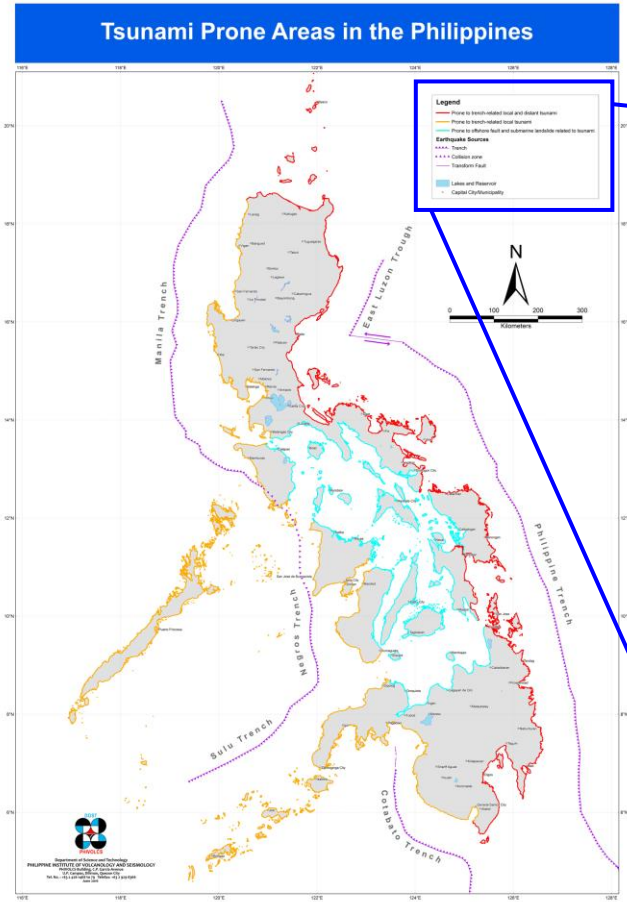
2004 Tsunami Hazard Map of PHIVOLCS

Indicative Tsunami Hazard Map for the Philippine Archipelago

- Describes tsunamis that can affect coastal communities
  - Tsunami Potentially High (Historical Tsunamis)
  - Potential
    - Local generators
    - Local and foreign generators



Indicative Tsunami Hazard Map of PHIVOLCS



Legend

- Prone to trench-related local and distant tsunami
- Prone to trench-related local tsunami
- Prone to offshore fault and submarine landslide related to tsunami

Earthquake Sources

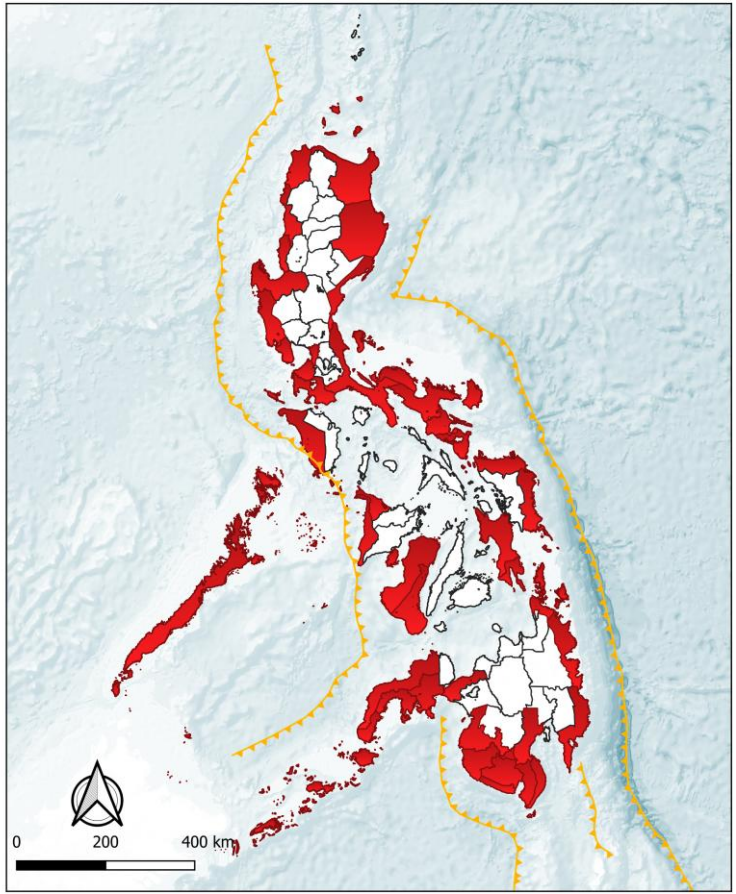
- Trench
- Collision zone
- Transform Fault

- Lakes and Reservoir
- Capital City/Municipality

2006-2007 DOST-GIA

Produced maps for provinces facing major trenches:

- Philippine Trench
- East Luzon Trough
- Manila Trench
- Negros-Sulu Trench
- Cotabato Trench

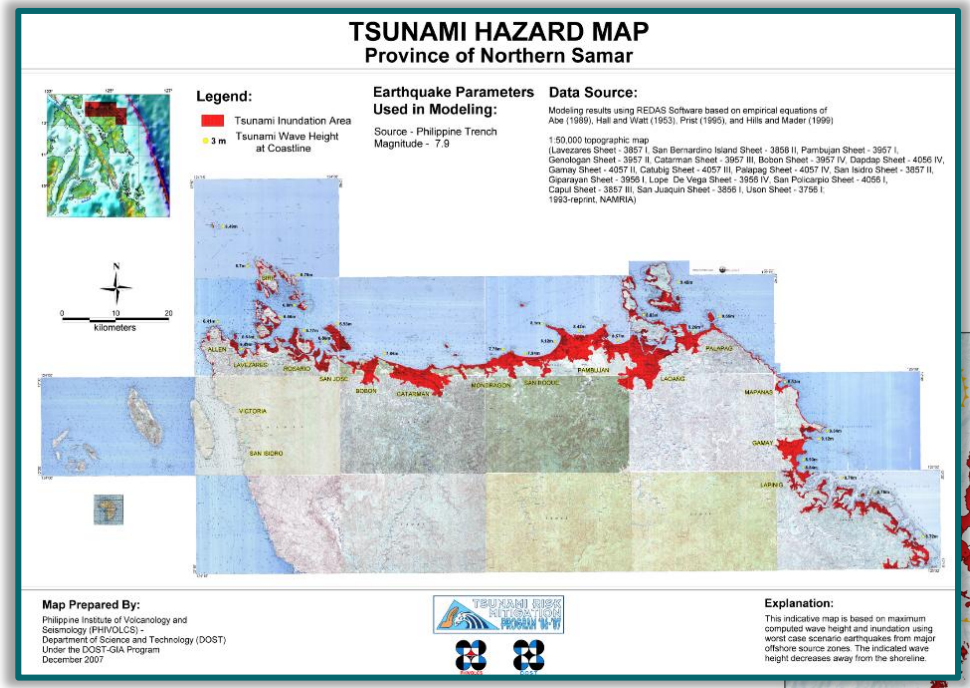


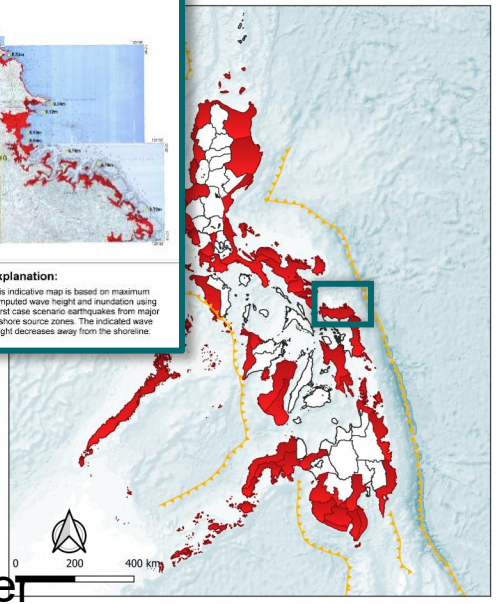
Tsunami Hazard Maps of 45 Provinces were generated based on wave heights computed from empirical equations (Abe, 1989), the input parameters are:

1) the shortest distance to the shore from a known active seismotectonic structure
2) the maximum credible earthquake for that particular structure based on historical seismicity and fault length (whichever is higher)

2006-2007 DOST-GIA

- Shows 1 color tsunami hazard symbology (red) = Tsunami Inundation Area
- Shows wave height information based on empirical equations of Abe (1998).

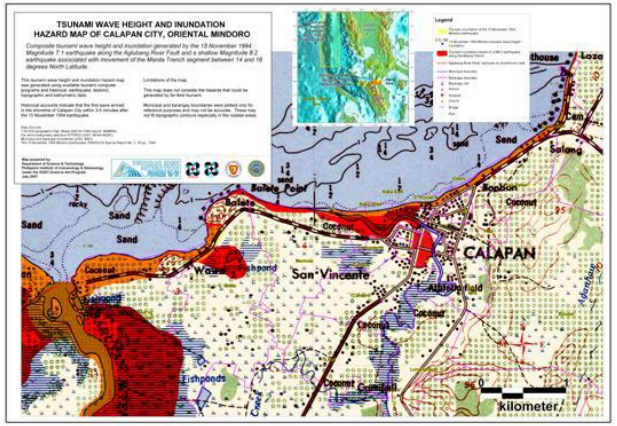


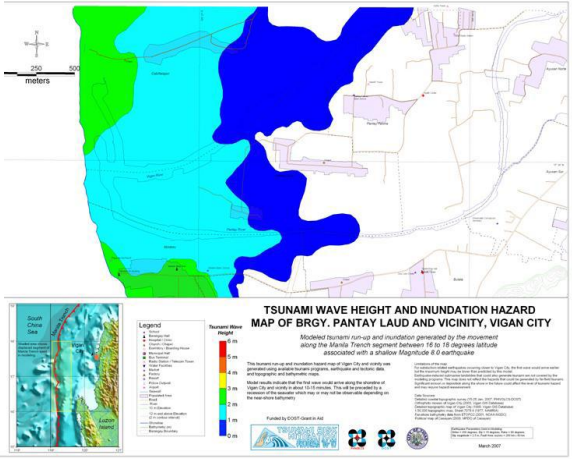


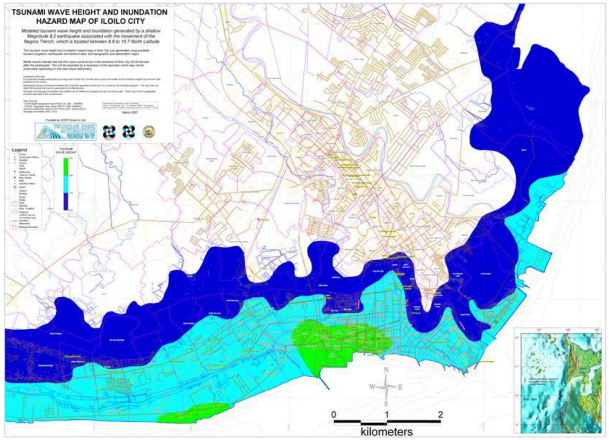
For wave heights,
the input parameters are:

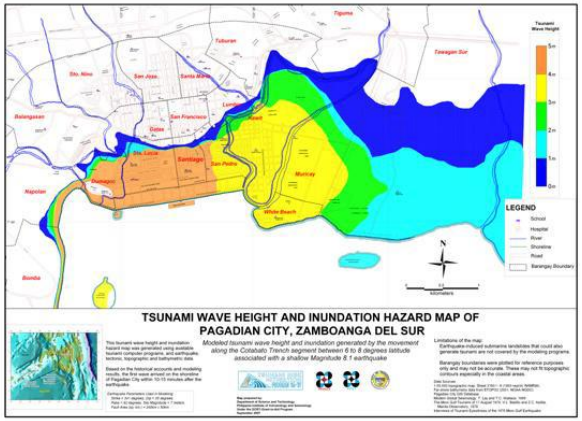
1) the shortest distance to the shore from a known active seismotectonic structure
2) the maximum credible earthquake for that particular structure based on historical seismicity and fault length, whichever is higher

2006-2007 DOST-GIA









Detailed Tsunami Hazard Map for 4 Local Pilot Sites were produced using simulated tsunami using numerical modeling method (in TUNAMI N2) in 1:5,000 scale:

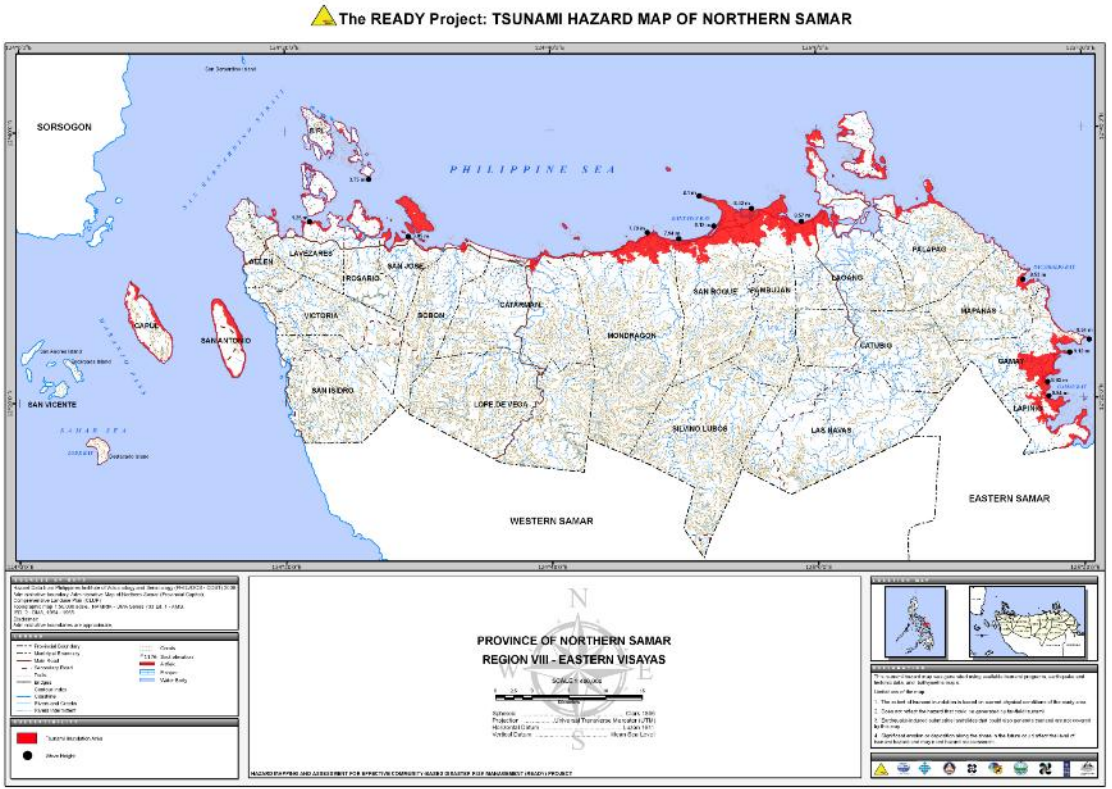
- Vigan City

- **Northern Oriental Mindoro**
- **Iloilo City**
- **Pagadian City**

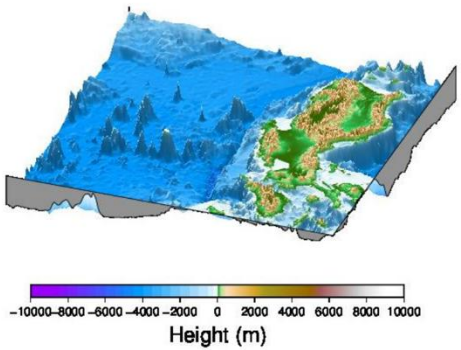
DOST PHIVOLCS

2006-2013 READY Project

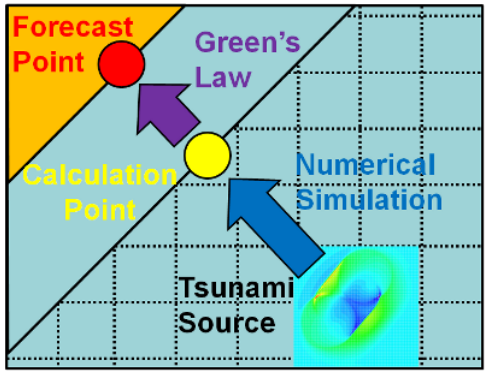
The generated tsunami hazard maps are part of the project named ***"Hazard Mapping and Assessment for Effective Community-Based Disaster Risk Management",*** dubbed as the "***READY" Project,*** as part of the Multi-hazard Mapping and Risk Assessment Component.



2006-2013 READY Project



Bathymetry:
ETOPO/GEBCO (1-minute)



Modeling (TUNAMI-N2) or
Empirical Equations

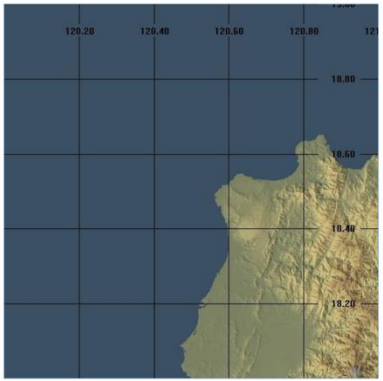
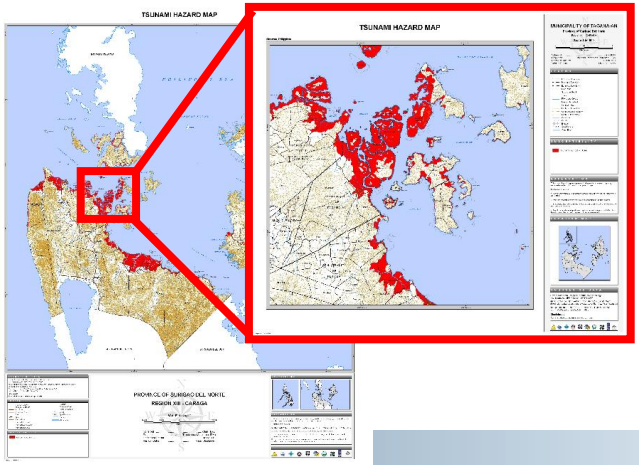


Figure 10. Topography from SRTM 3-arc second data.

Topography: SRTM Data
(Elevation-based,
"bathtub" method

- Shows 1 color tsunami hazard symbology (red) = Tsunami Inundation Area
- Shows wave height information based on ***empirical equations or modeling***



DOST PHIVOLCS

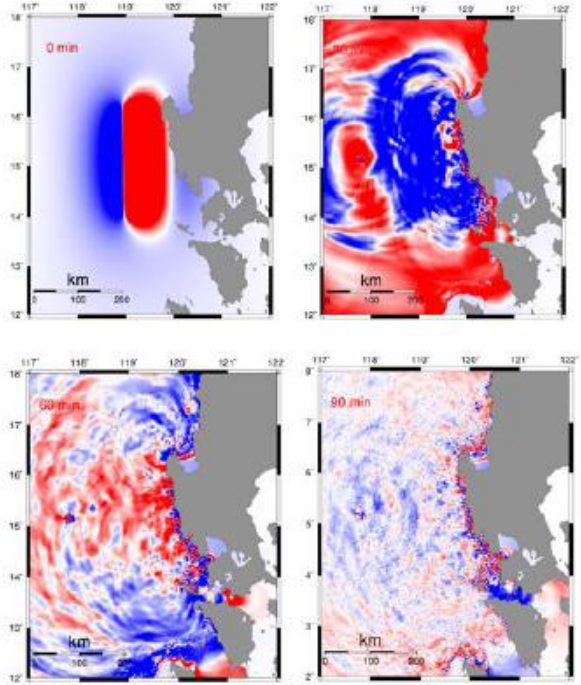
2012-2015 GMMA-READY

Metro Manila Tsunami Hazard Map

1. Shows graduated tsunami hazard symbology = Tsunami Inundation Depth

2. Show wave height information

3. Includes fieldwork data and information on elements at risk



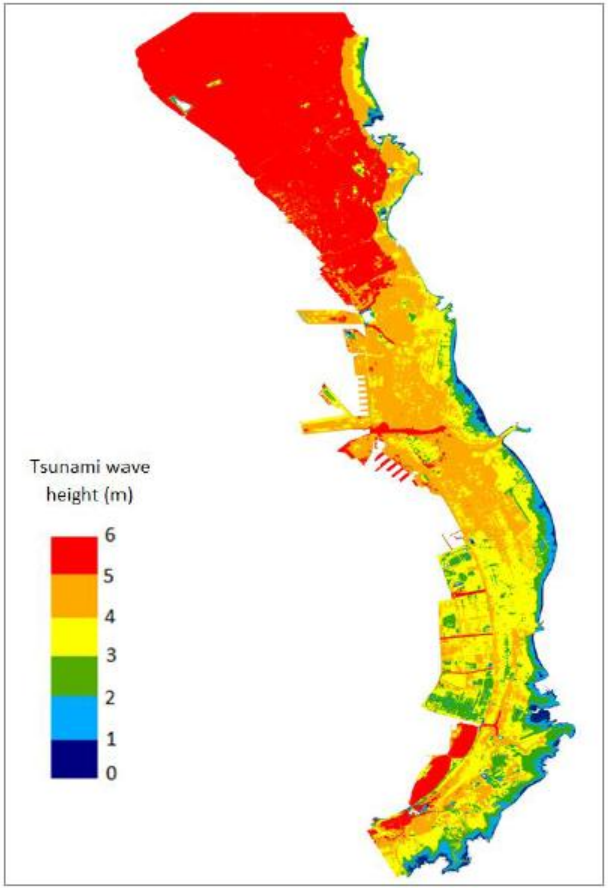


Figure 2.3.6.11. Tsunami inundation map for Metro Manila

Bathymetry Data: ETOPO
Topographic Data: 2013 Metro Manila LiDAR

PHIVOLCS

DOST-GIA & READY PROJECTS DISTRIBUTION

Region	Province	IEC Project	Year
1	Ilocos Norte		
	Ilocos Sur	DOST GIA Pilot Site	2008
	Pangasinan		
	La Union		
2	Batanes		
	Cagayan	READY/REDAS	2014
	Isabela		
3	Aurora	READY	2008
	Bataan		
	Zambales	READY	2009
	Pampanga	READY	2008

Region	Province	IEC Project	Year
4A	Quezon	(REINA)	2005
	Batangas		
	Cavite	READY	2008
	Laguna	READY	2008
4B	Mindoro Island	DOST GIA Pilot Site	2008
	Palawan		
5	Albay	READY	2014
	Camarines Norte		
	Camarines Sur		
	Catanduanes	READY	2015
	Sorsogon		

DOST-GIA & READY PROJECTS DISTRIBUTION

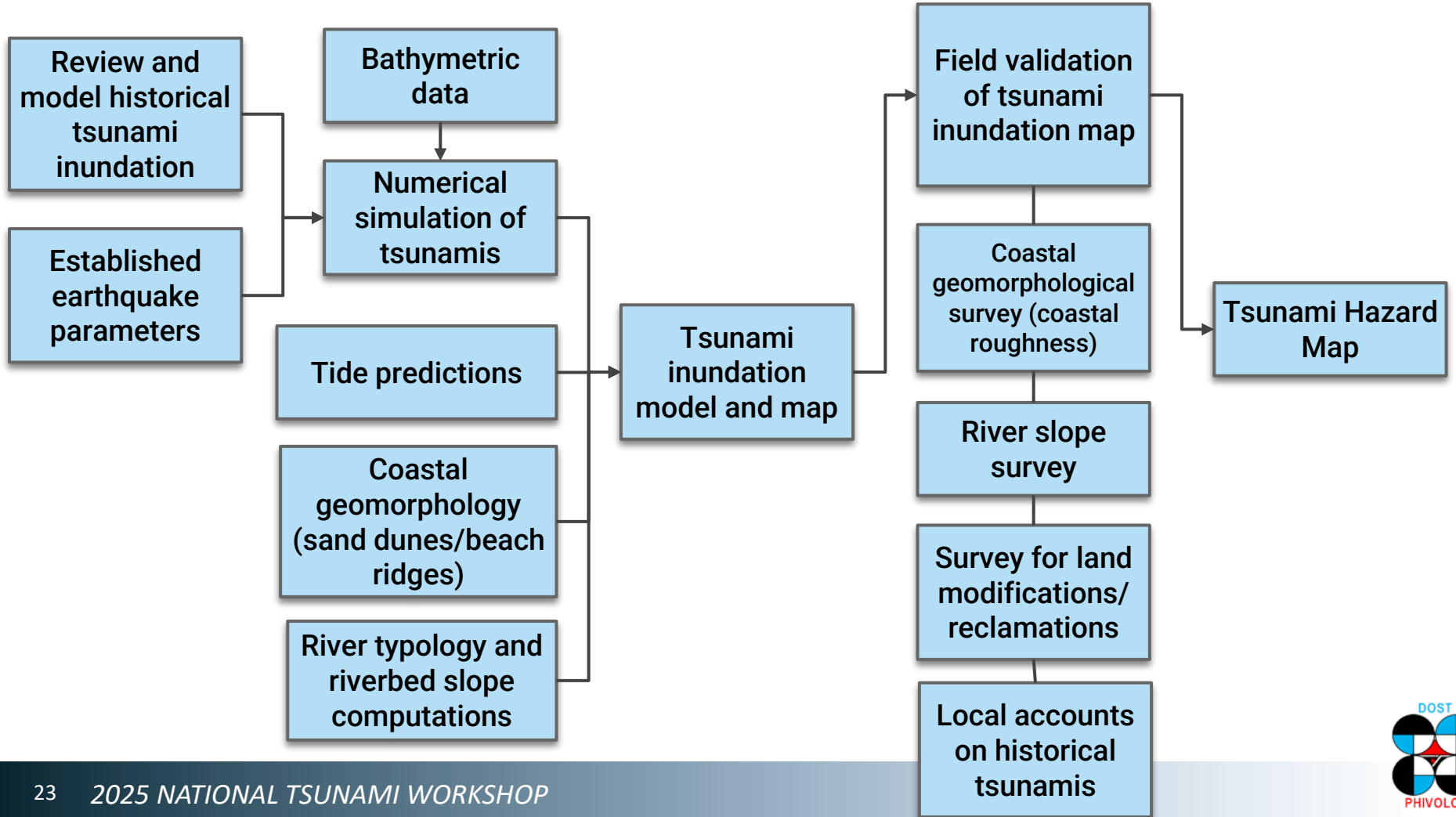
Region	Province	IEC Project	Year
6	Aklan		
	Antique	READY	2015
	Guimaras		
	Iloilo	DOST GIA Pilot Site	2
	Negros Occidental		
7	Bohol	READY	2008
	Negros Oriental		
	Siquijor		
8	Northern Samar	READY	2009
	Leyte Island	READY	2007
	Eastern Samar	READY	2099

Region	Province	IEC Project	Year
9	Zamboanga City		
	Zamboanga del Norte		
	Zamboanga del Sur	DOST GIA Pilot Site	2013
	Zamboanga Sibugay		
10	Camiguin		
	Lanao del Norte		
11	Davao del Sur		
	Davao Oriental		
12	Sarangani		
	South Cotabato		
	Sultan Kudarat		

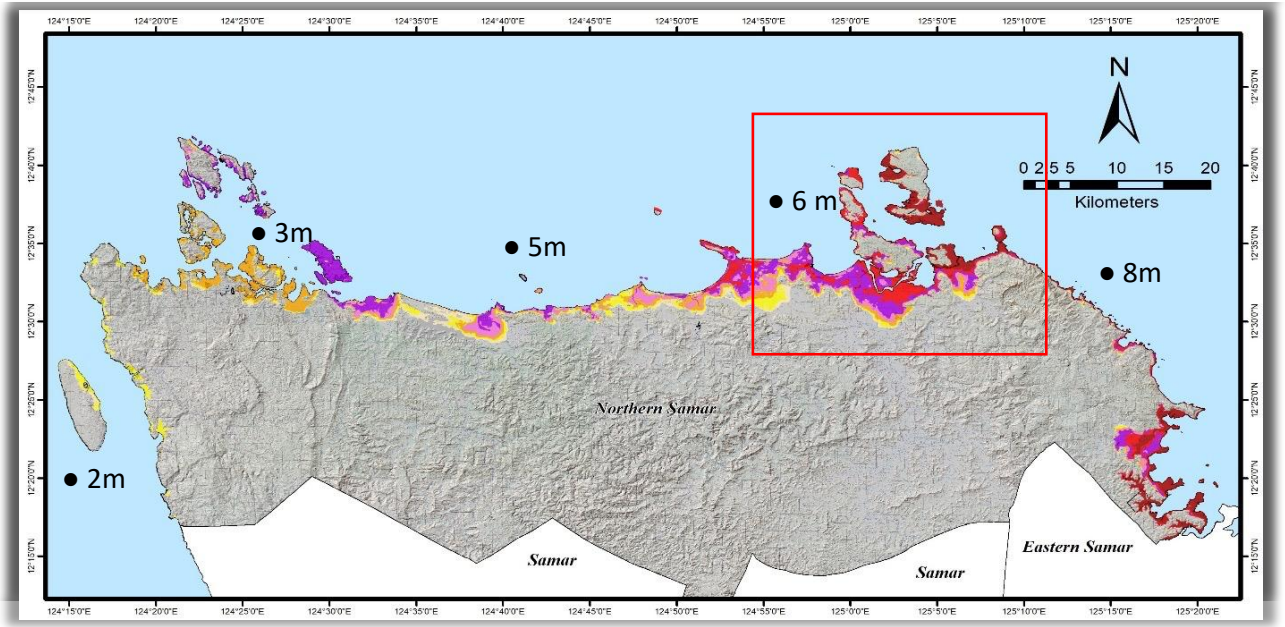
DOST-GIA & READY PROJECTS DISTRIBUTION

Region	Province	IEC Project	Year
13	Surigao del Norte	READY	2006
	Surigao del Sur	READY	2006
	Dinagat Islands	READY	2009
ARMM	Basilan		
	Lanao del Sur		
	Maguindanao		
	Sulu		
	Tawi tawi		

2019 to 2025 Tsunami Hazard Mapping Framework



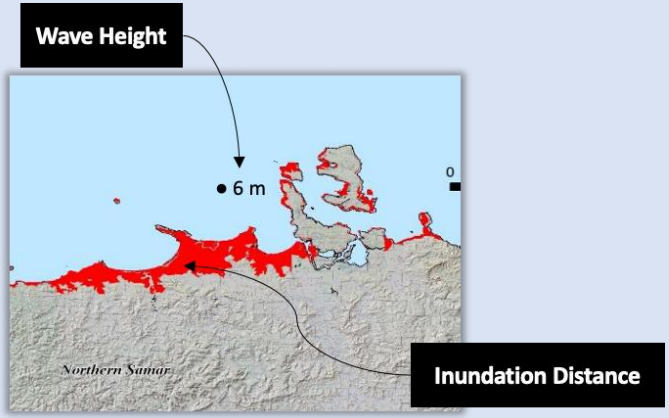
2019 to 2025 Tsunami Hazard Mapping Results



Graduated inundation colors = inundation depth

One inundation color = inundation area (prone areas)

Previously generated Tsunami Hazard Maps



Different methodologies, basemaps, and modeling software and empirical equations

2007 DOST-GIA Project:
Tsunami Propagation and Inundation: Empirical relations based

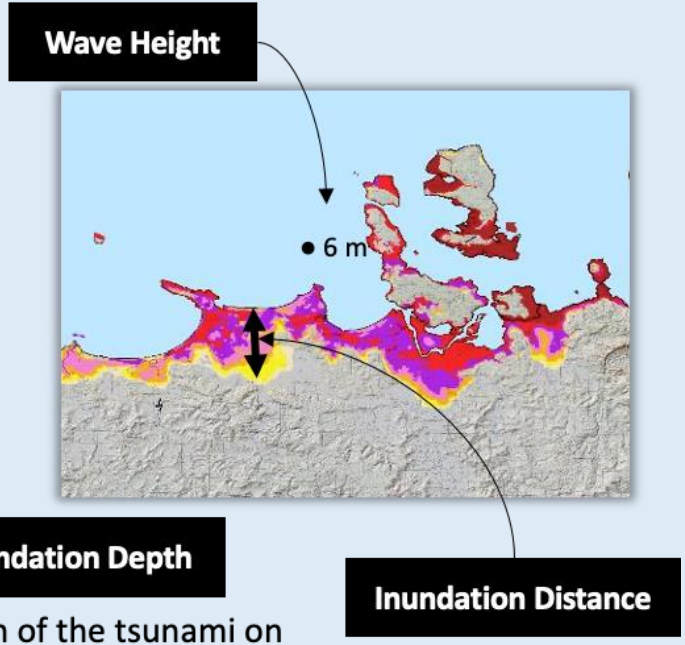
2013 READY Project:
Tsunami Propagation: Numerical Modeling-based (TUNAMI-N2), empirical relations; validated coastal roughness for some areas, some areas are not based on worst-case scenario

2016 TsuHaMEI:
Enhancement of 2007 DOST-GIA and READY Projects

2019 – Present:
EHM-Tsunami and TsuHMP: Tsunami Propagation: Numerical Modeling-based (JAGURS) - source to coast modeling approach; GIS-based tsunami inundation using IfSAR as basemap

Harmonized Tsunami Hazard Maps

DOST-PHIVOLCS



Depth of the tsunami on a specific area Represented by the colors

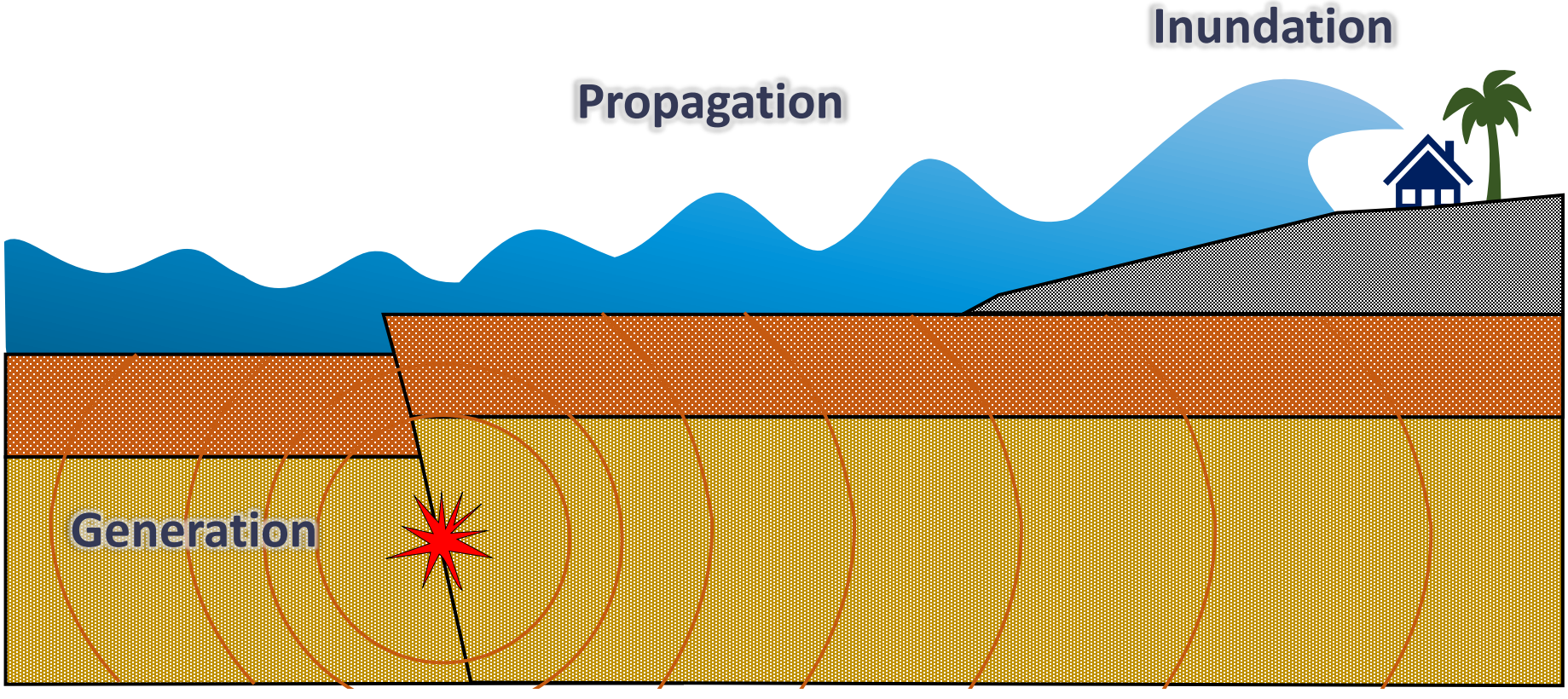
Harmonized methodologies, basemaps, modeling software and empirical equations using an improved methodology

BAKIT MAY IBA IBANG MAPA NG TSUNAMI ANG PHIVOLCS?

Habang gumaganda ang available na data, mas gumaganda din ang resolution ng tsunami hazard map. Patuloy na ini-improve ang mga tsunami hazard map upang makatulong sa communities.

Paano ginagawa ang mga mapa ng PHIVOLCS?

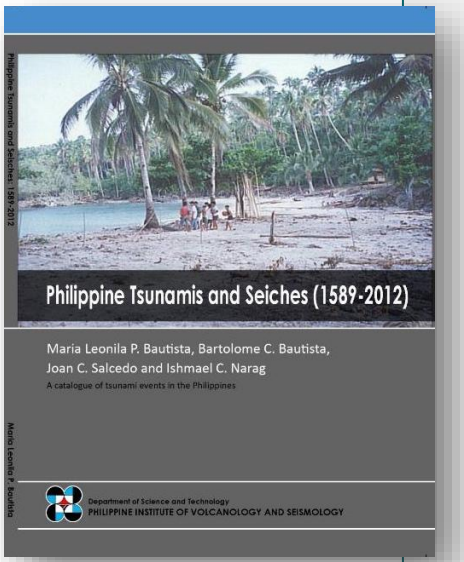
Stages of Tsunami

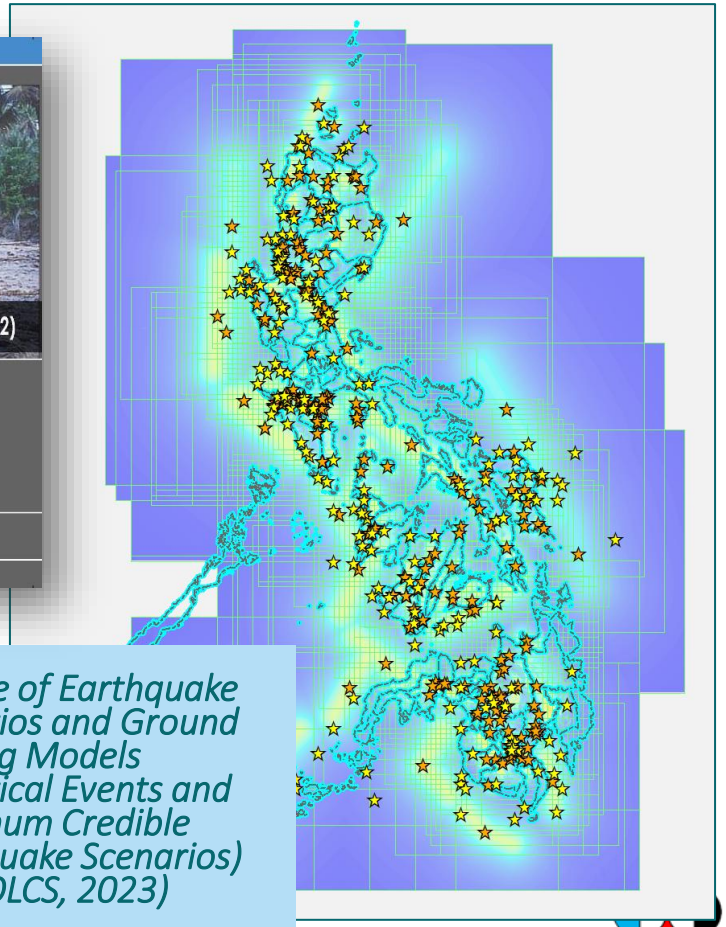


1. Database of wave heights of Historical Tsunamis and Earthquake Scenarios

Collection/ Database

- of Historical tsunami wave heights (Bautista, et al., 2012) and wave heights from previous/current modelling and hazard maps (READY/DOST-GIA Projects)
- of information on tsunami impacts that may give clues on historical tsunamis (deposits, boulders, etc.)





Archive of Earthquake Scenarios and Ground Shaking Models (Historical Events and Maximum Credible Earthquake Scenarios) (PHIVOLCS, 2023)

PHIVOLCS

1. Database of wave heights of Historical Tsunamis and Earthquake Scenarios

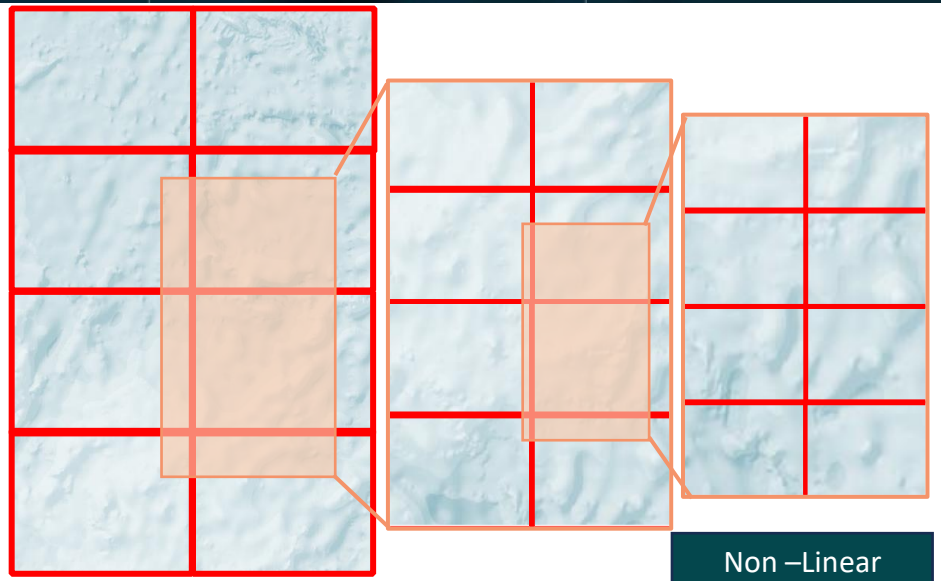
I. Collection/ Database

- of Historical tsunami wave heights (Bautista, et al., 2012) and wave heights from previous/current modelling and hazard maps (READY/DOST-GIA Projects)
- of information on tsunami impacts that may give clues on historical tsunamis (deposits, boulders, etc.)

Wave height	Subaerial			JBBT		
	Min	Max	Mean	Min	Max	Mean
Ht	0.15	1.30	0.46	0.68	7.38	2.46
Hs	0.61	5.82	1.85	2.74	29.50	9.85

Mangahas et al., 2021

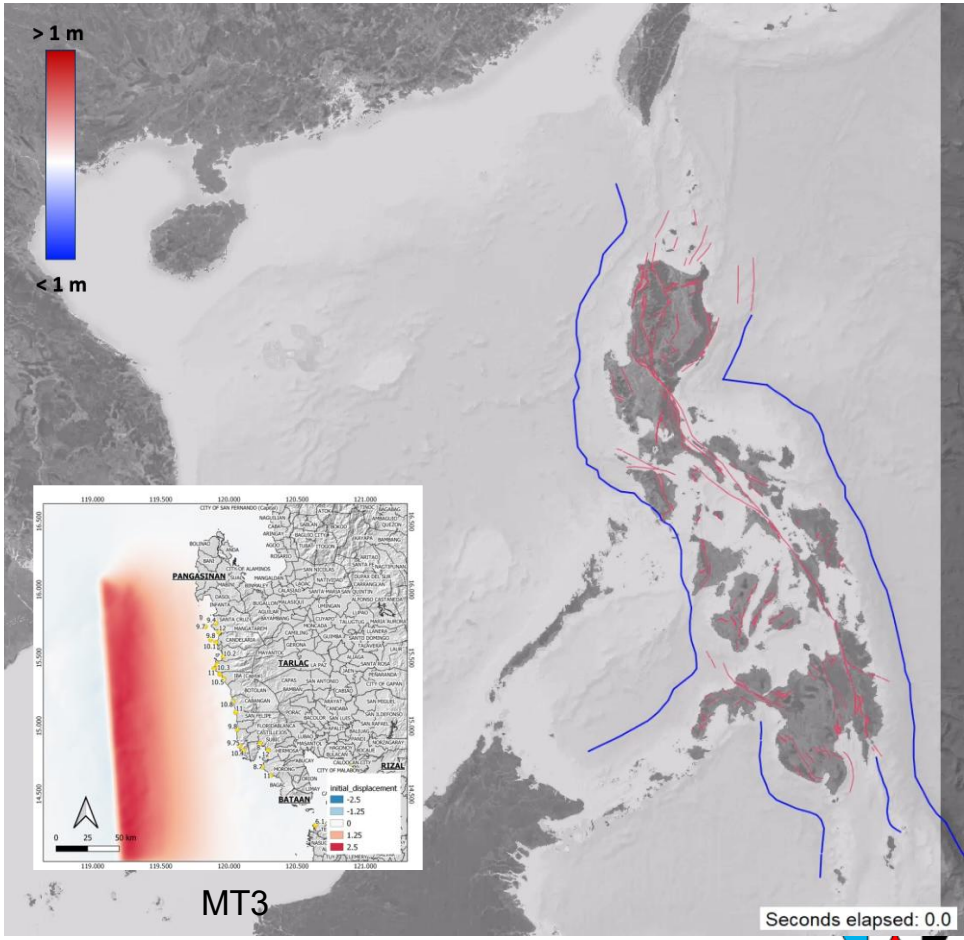
2. Generation of Models



Linear equations

Non –Linear Shallow Water Wave Equations

- Computational Limitations
- Bathymetric and topographic data cannot be used together due to differences in shoreline delineations
- **Wave heights are recorded up to the coast**



PHIVOLCS

3. Inundation (Bathtub method)

Mosaic all IfSAR data (.bil format) of each Province to create DEM & DTM

Generation of contours (polylines) from DEM reflecting the tsunami inundation heights

Conversion of contours (polylines) to inundation areas (polygons)

Creation of shoreline based on recent satellite images

Adjustment of inundation area based on present shoreline

Calculation of Maximum Tsunami Inundation Distance on Land using REDAS

$$X_{max} = (H_t)^{1.33} N^{-2} k$$

X_{max} = limit of landward incursion (meters)
N = Mannings n constant for surface roughness
k = a constant (0.06)

Calculation of Maximum Tsunami River Intrusion Distance using Tanaka, 2020

$$X_p = 48.4 S^{-0.71} \ (m)$$

X_p = limit of river incursion (meters)
S = riverbed slope

3. Inundation(Bathtub method)

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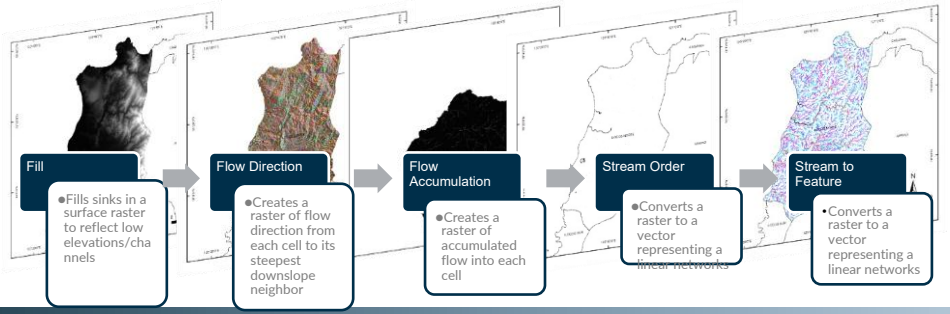
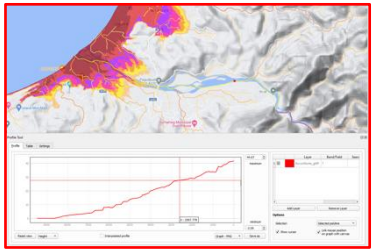
Calculation of Maximum Tsunami River Intrusion Distance using Tanaka, 2020

$$X_p = 48.4 S^{-0.71} \ (m)$$

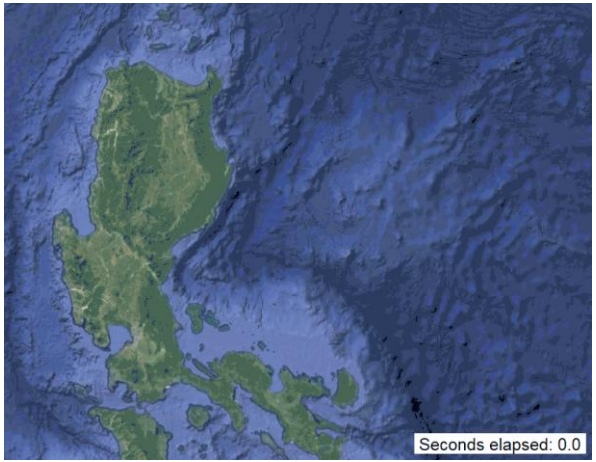
X_p = limit of river incursion (meters)
S = riverbed slope

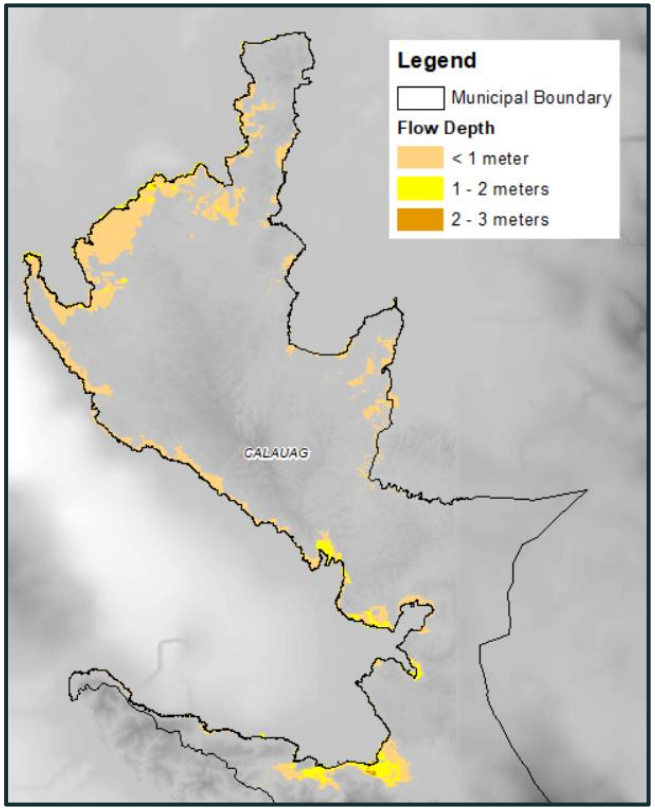
Hydrological Analysis (GIS) And River Bedslope Computation





3. Inundation(Modeling method)



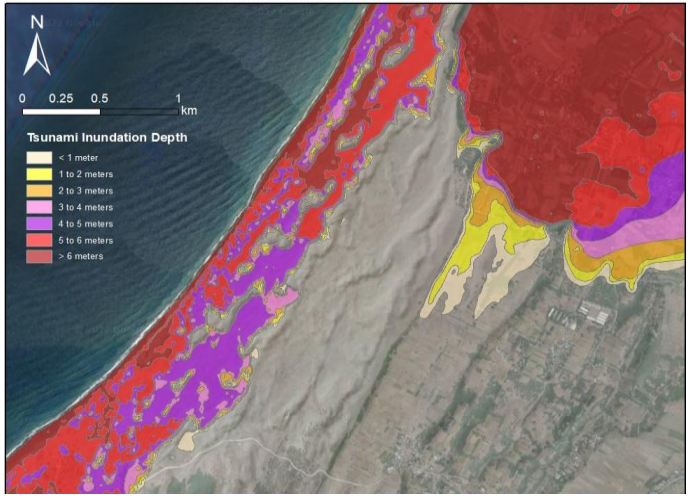


- Maximum height is in reference to Mean Sea Level (MSL)
- Subtract the IfSAR DEM elevation from the maximum height raster

- Cotabato City
- General Santos City
- Iloilo Province

RS Data

Analyzing topographic features that may serve as barriers to tsunami (beach ridge, sand dunes, etc.)



Video showing spatio-temporal analysis of a dune area in Laoag City, using series of Google Earth images.

High, not easily eroded and non-migrating sand dunes in Ilocos Sur acts as natural topographic barriers to tsunami.

Field Data: Coastal Roughness and elevation data

Field Data: Historical Tsunami

Mapping inundation extent of historical extreme wave event

WP2137

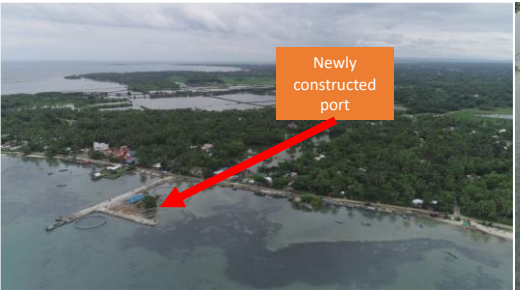
Inundation limit of the 1994 earthquake tsunami. Line of protruding rock outcrop observed near the shore, with a 0.5m height from mean sea level.

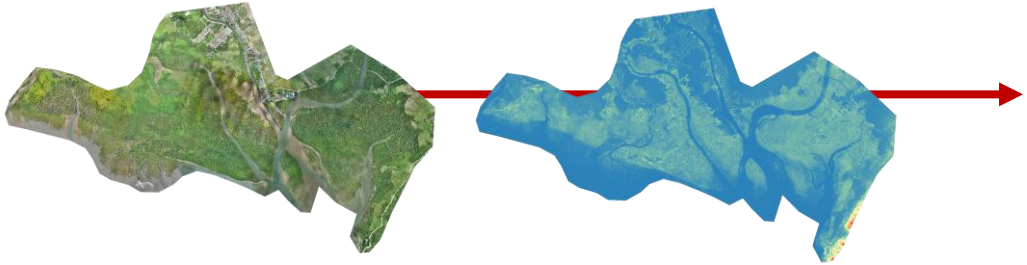
Interviews with locals and survivors (in photo: ZDS resident)

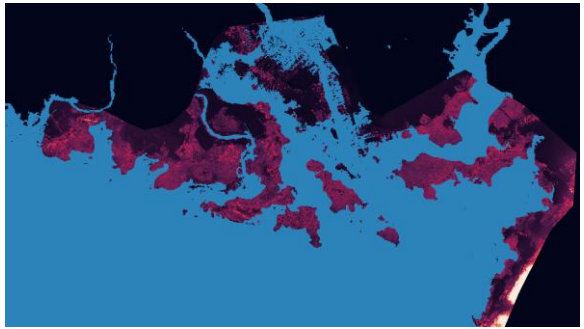
Field Data: Elevation Data

The RPAs technology are also used to verify current coastal extent for tsunami inundation maps in the Philippines as well as newly constructed ports and coastal communities.

Coastline delination







RPA derivatives (DTM, DSM, and Orthomosaic) for tsunami inundation modeling

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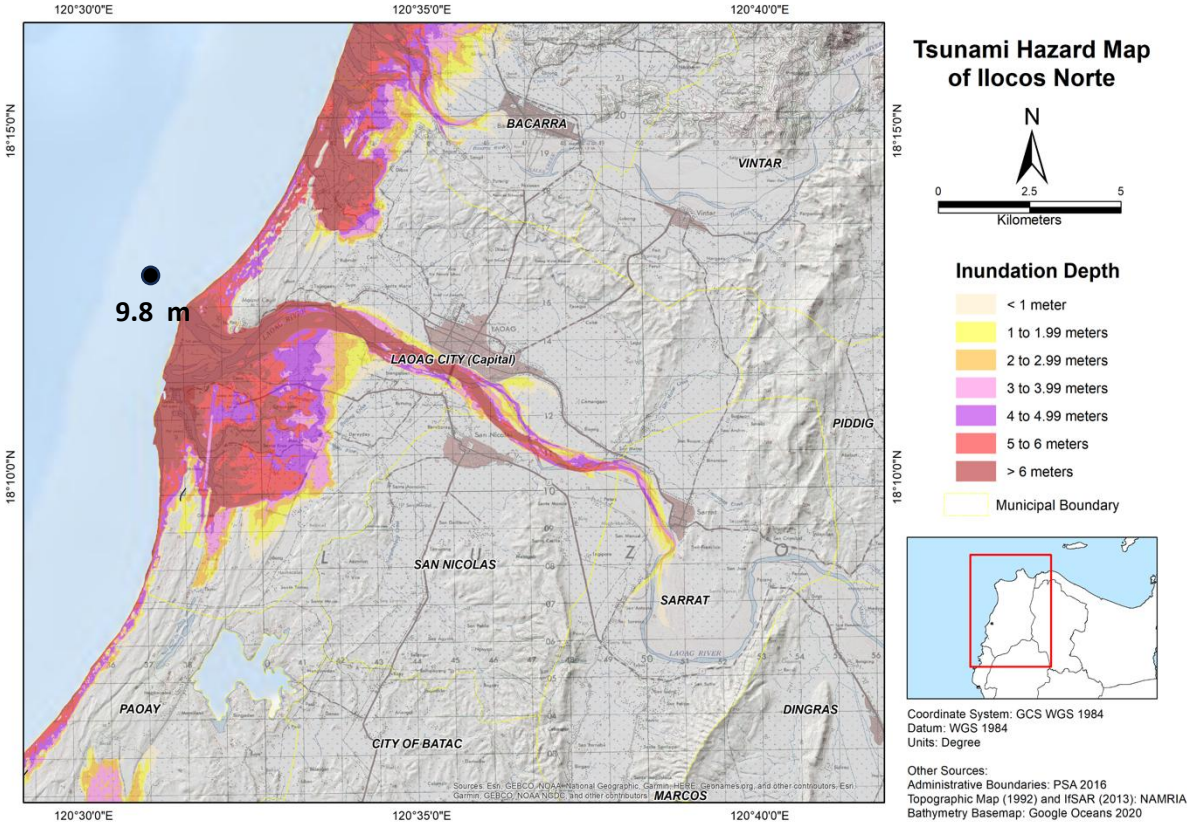
4. Results

- Graduated tsunami hazard maps utilizing the topographic contours generated from 5m x 5m resolution IfSAR DTM of the Philippines
- Graduated inundation colors help DRRMO to plan horizontal evacuation effectively (shortest distance away from the greatest inundation depths)
- Information on inundation depth allows decision for vertical evacuation



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Tsunami Hazard Map

Legend

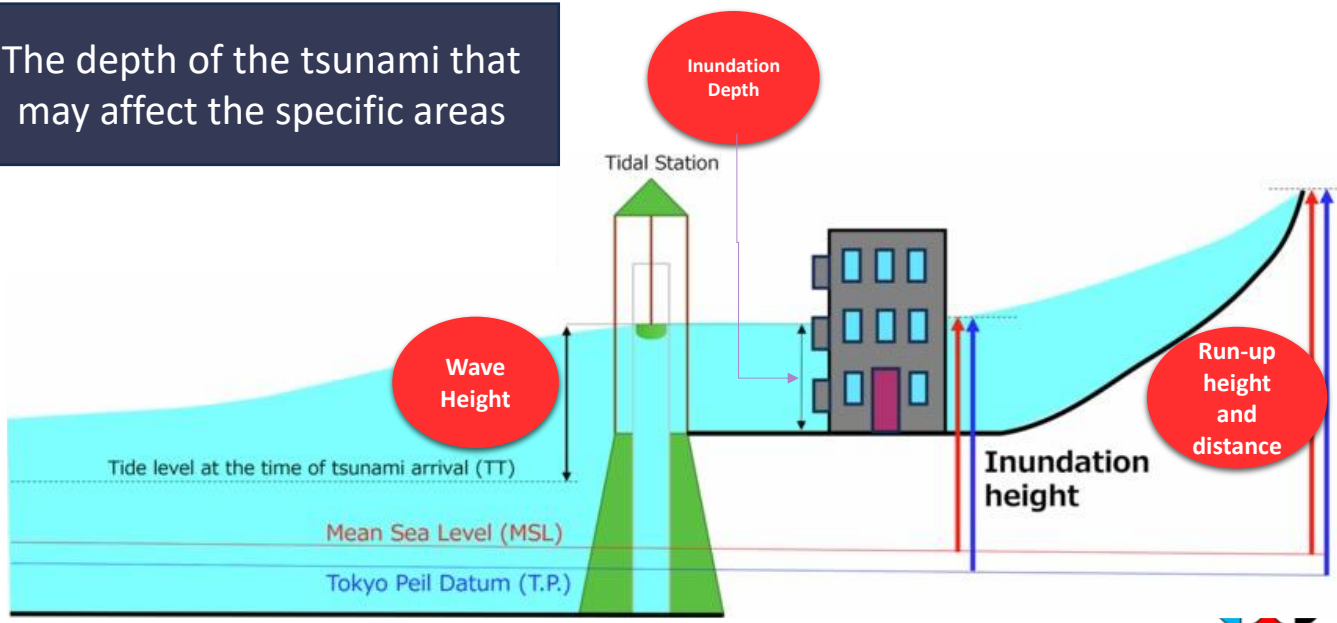
- Wave Height (in meters)

Tsunami Inundation

- < 1 meter
- 1 to 1.9 meters
- 2 to 2.9 meters
- 3 to 3.9 meters
- 4 to 4.9 meters
- 5 to 6 meters
- > 6 meters

Represents wave height that can be observed along the coast

The depth of the tsunami that may affect the specific areas



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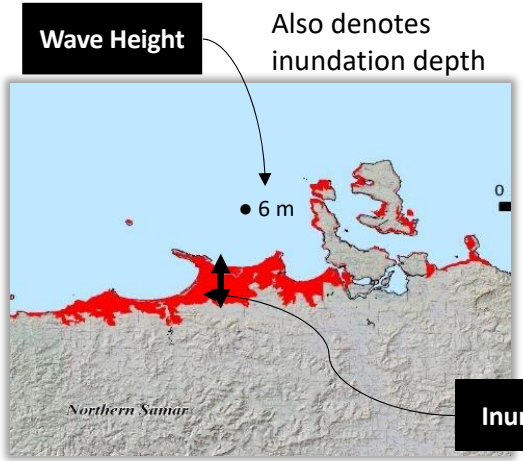
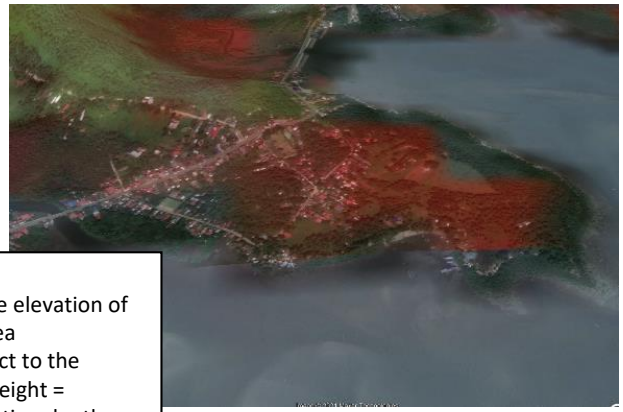
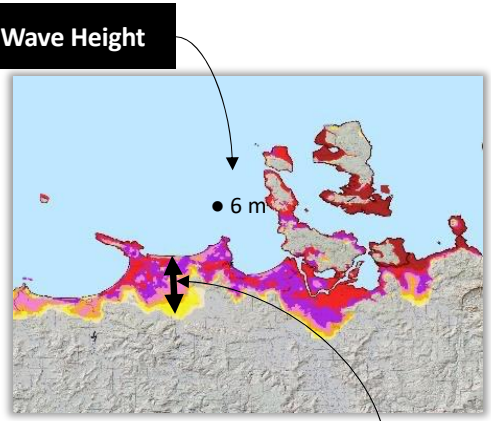
Interpreting Tsunami Hazard Maps





Tip:
- Get the elevation of the area
- Subtract to the waveheight = Inundation depth



Depth of the tsunami on a specific area Represented by the colors

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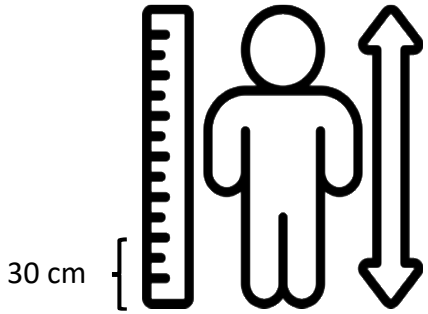
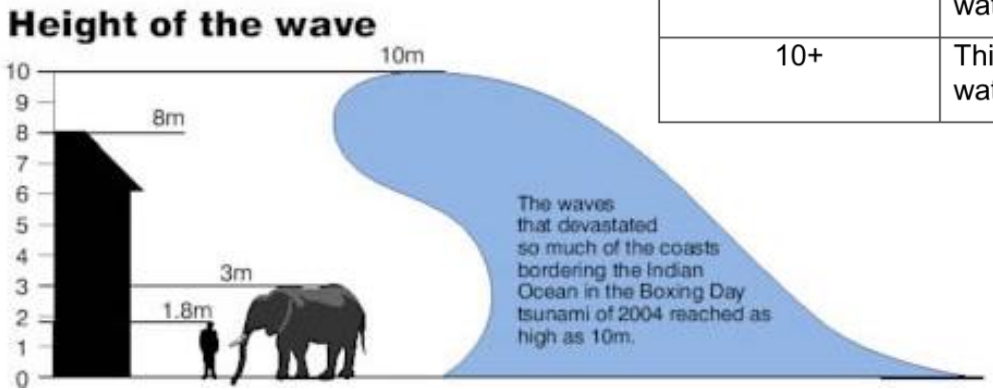
Inundation depth

Average: 160 cm



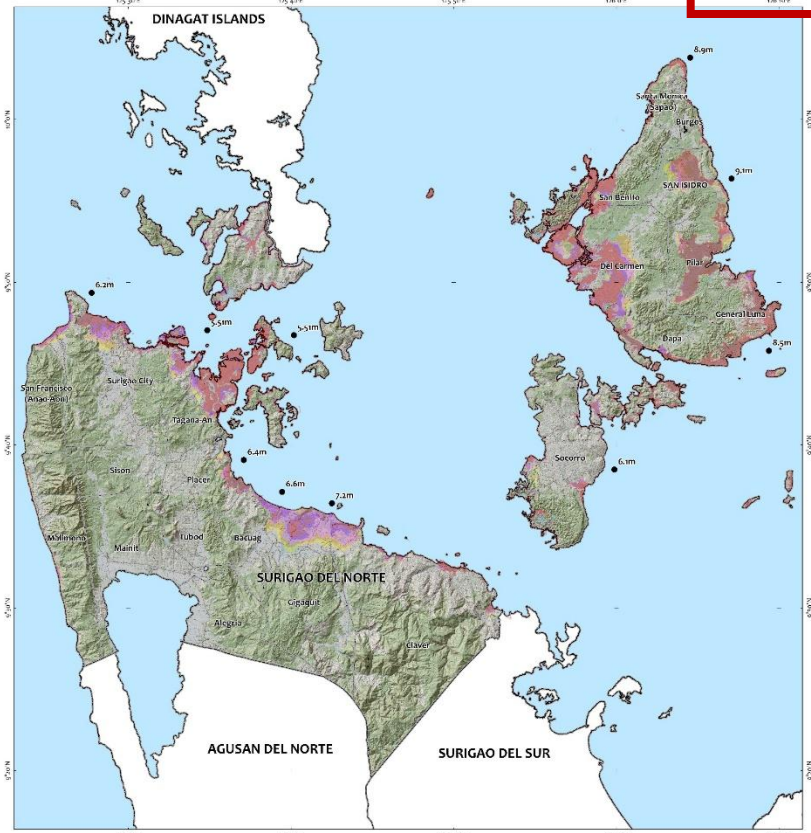
Inundation Height (meters)	Damage Description
1+	Most of the people caught by the tsunami may perish. People can lose their balance and vehicles begin to float in as little as 30 cm of water.
2+	More than half of structures may be completely damaged
3+	Evacuation will be difficult or not possible. More than half of structures may be completely damaged or washed away.
5+	Second floor and part of the third floor of buildings will be under water.
10+	Third floor and part of fourth floor of buildings will be under water. Many structures may be washed away.

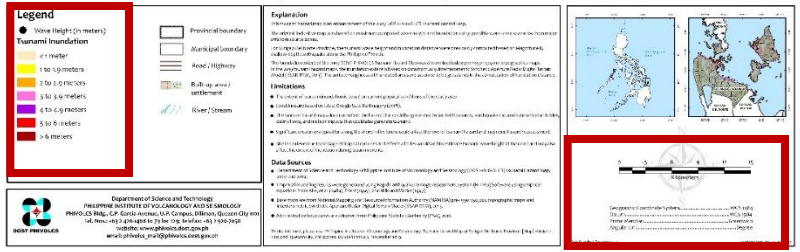
Inundation height in relation to damage it could cause



Tsunami Hazard Map
Province of Surigao Del Norte

Surigao Del Norte
1:115,000





Tsunami Hazard Map
Province of Surigao Del Norte

Surigao Del Norte
1:115,000

Legend

- Wave Height (in meters)

Tsunami Inundation

- < 1 meter
- 1 to 1.9 meters
- 2 to 2.9 meters
- 3 to 3.9 meters
- 4 to 4.9 meters
- 5 to 6 meters
- > 6 meters

N

0 3 6 9 12 15

Kilometers

S

Geographic Coordinate System.....WGS 1984
Datum.....WGS 1984
Prime Meridian.....Greenwich
Angular Unit.....Degree

ate Published: November 2019

Product Code: TSU-2019-166700-01

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Explanatory Text:

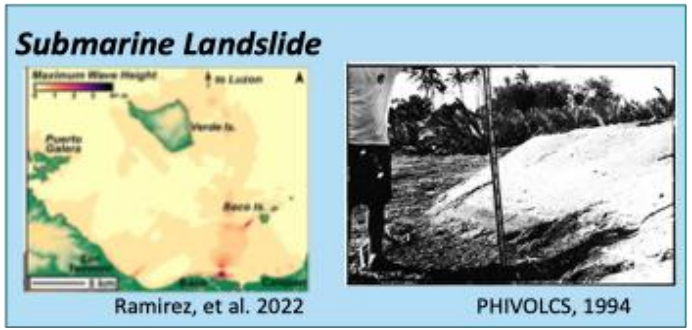
- This tsunami hazard map is based on ***maximum computed wave height and inundation*** using possible **worst-case scenarios** from major offshore source zones
- For different provinces, the tsunami wave height and inundation distance were computed based the maximum credible earthquake along the **nearest major offshore fault or trench**.

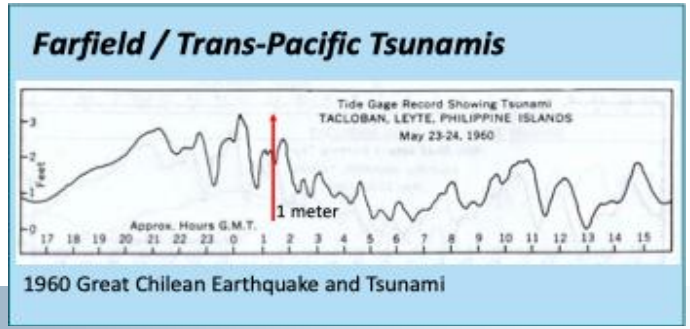
Limitations

- The extent of tsunami inundation is based on current physical conditions of the study area. **Coastlines are based on most recent Google Earth Satellite Imagery**.
- Significant erosion or deposition along the shore in the future could affect the level of tsunami hazard and may need hazard reassessment.

Limitations

- It does not reflect the hazard that could be generated by far-field tsunamis, earthquake-induced submarine landslides, debris flows, and meteor impacts that could also generate tsunami
- Rise in sea level due to passage of typhoon and effects of tides would add to estimated tsunami wave height at the coast and may also affect the extent of inundation during tsunami events.





(Ramos, 2022)

Historical Tsunami	3 m
From Coastal Boulders (min) (Ramos, 2022)	2.1 m
Model	**10 m**

(Mangahas-Flores, 2021)

Historical Tsunami	6 m
From Coastal Boulders (min)	1.5 m
Model	**5.5 m**

1994

Historical Tsunami	**8 m**
Model	4 m

2012

Historical Tsunami	**6 m**
Model	4 m

2023

Historical Tsunami	2 m
Model	**6 m**

1976

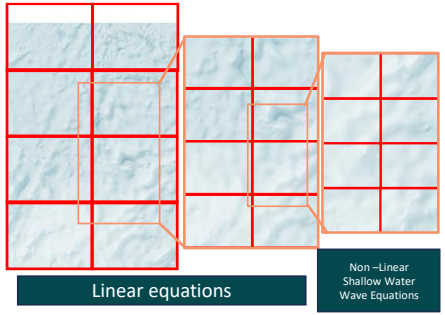
Historical Tsunami	**11 m**
Model	9 m

2023

Validation: Historical and Geological Evidences

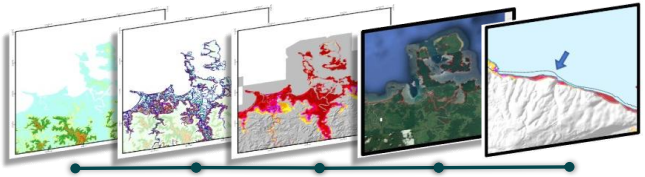
Challenges

Limited Computational Facilities



Limited bathymetry data

Dynamic Coastlines



Mosaic all IfSAR data (.bil format) of each Province to create DEM & DTM

Generation of contours (polylines) from DEM reflecting the tsunami inundation heights

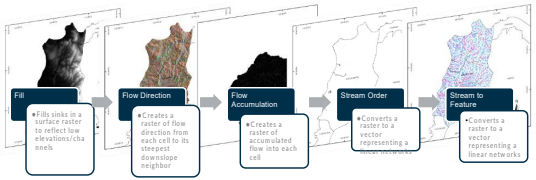
Conversion of contours (polylines) to inundation areas (polygons)

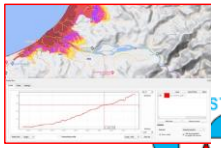
Creation of shoreline based on

Adjustment of inundation

Tedious and time-consuming Modeling or GIS Work

Hydrological Analysis (GIS) And River Bedslope Computation





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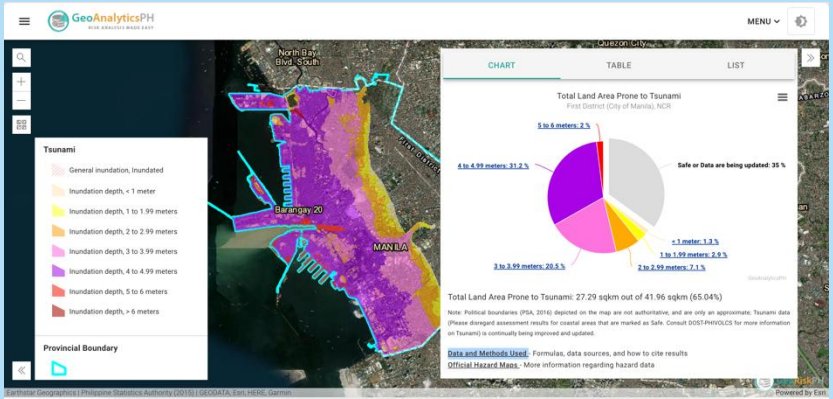
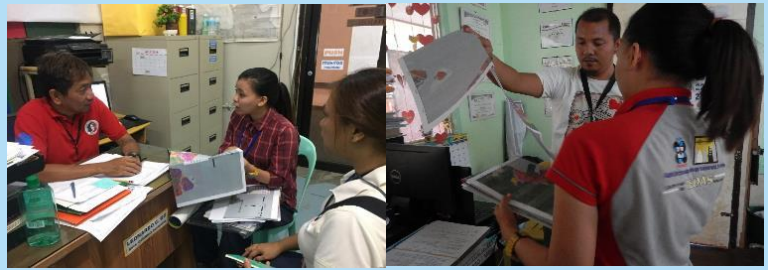
Applications and Implications



Geoanalytics PH (Automatic assessment of risk)



Information, Communication, and Education to Local Disaster Risk Reduction Managers and Communities

Sea-level monitoring and EWS equipment establishment

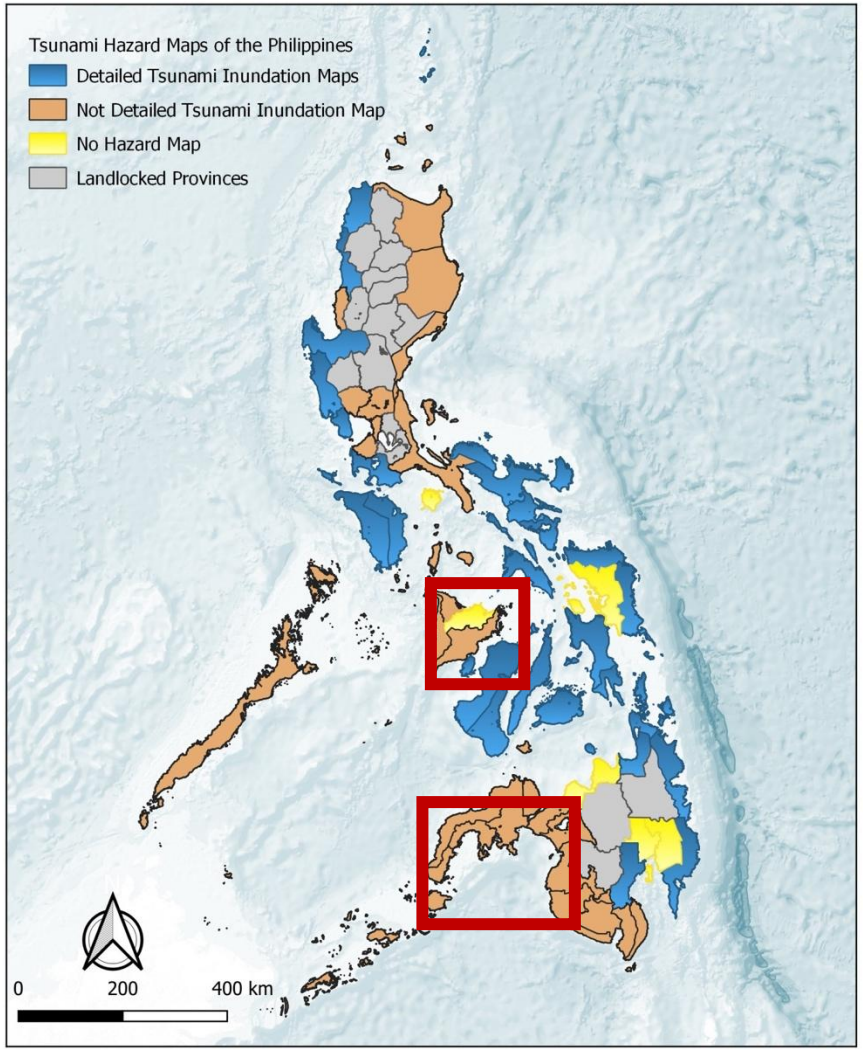
Evacuation planning and establishment of *community-based tsunami information and signages*

Way Forward:

Status of Tsunami Hazard Maps in the Philippines

STATUS	No. of Provinces
Not – Detailed (2006-2013)	**29**
Detailed (2019 onwards)	**30**
No Tsunami Hazard Map (Coastal Provinces)	**8**
Landlocked Provinces	15

- **Harmonized Tsunami Hazard Maps** in the Philippines using graduated tsunami hazard for all provinces
- Generate tsunami hazard map for 8 provinces within the archipelagic seas
- **Institutionalized research** on paleo- and historical tsunami deposits
- **Strengthened collaboration** between DOST-PHIVOLCS and Local Government Units



Thank you!

"The next disaster happens when we have forgotten the last one."