UN Decade Collaborative Centre for COASTAL RESILIENCE

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA
DIPARTIMENTO DI FISICA E ASTRONOMIA "AUGUSTO RIGHI"

RegioneEmilia-Romagna

From Detection to Action: The Indian Tsunami Early Warning System

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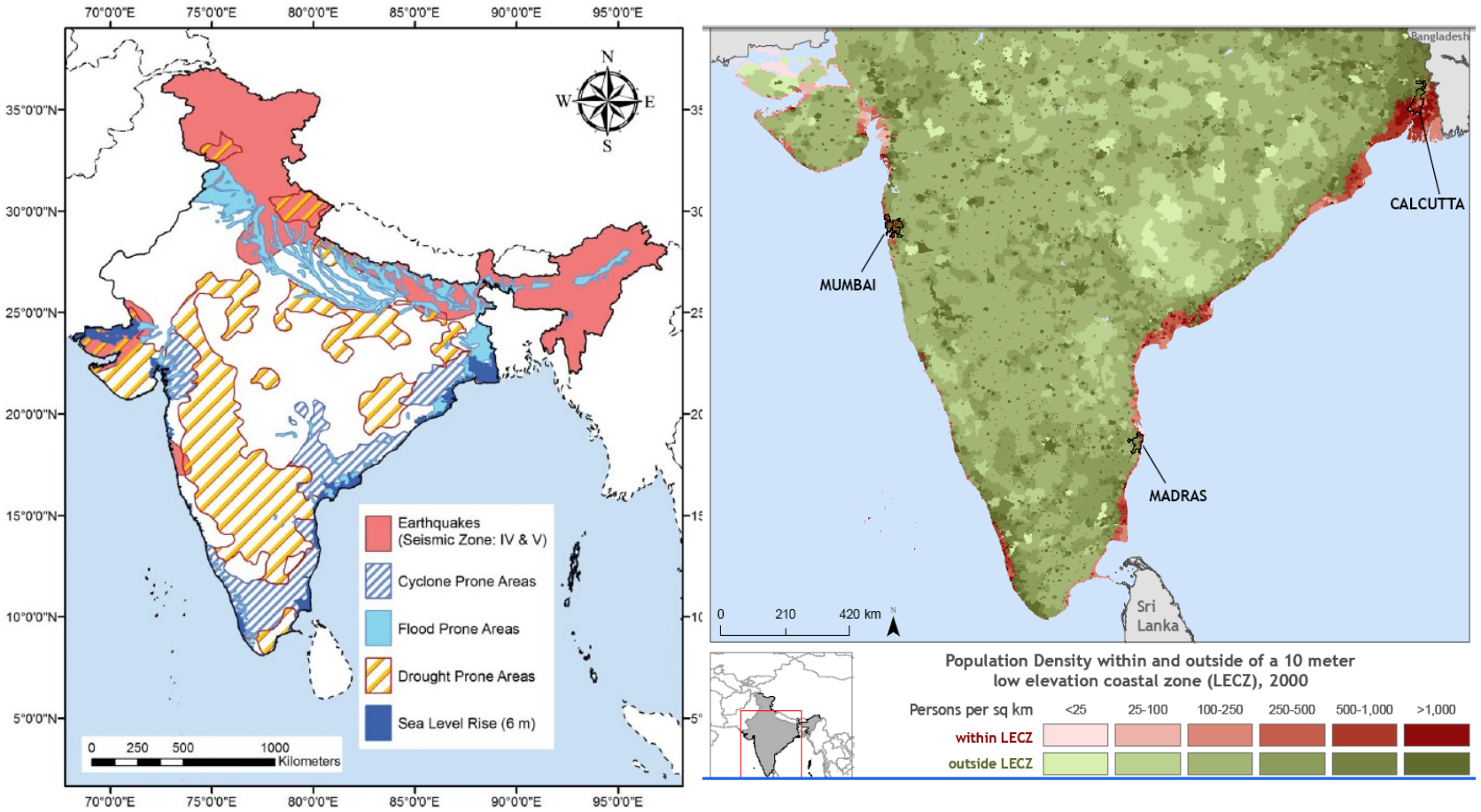
Palazzo Malvezzi - University of Bologna

INCOIS

Vulnerability of the Indian Coastline

- Around 250 million of India's population reside within 50 km of the 7500 km coastline
- Comprising 77 towns and cities including 3 megacities Mumbai, Calcutta and Chennai
- A report released by the UN Intergovernmental Panel on Climate Change (IPCC) had dire warnings for India stating that 12 coastal cities including Mumbai, Chennai, Kochi, Visakhapatnam could be submerged by the end of the century
- Frequent Cyclones - 13% of World's cyclones in the Seas around India (recent cyclones: Phailin, Hudhud, Fani, Amphan, Tauktae, Yass, Biparjoy, Michaung etc.
- Increased frequency and intensity of the disasters (cyclones, floods, storm surges etc.)



Courtesy: Chakraborty, 2016

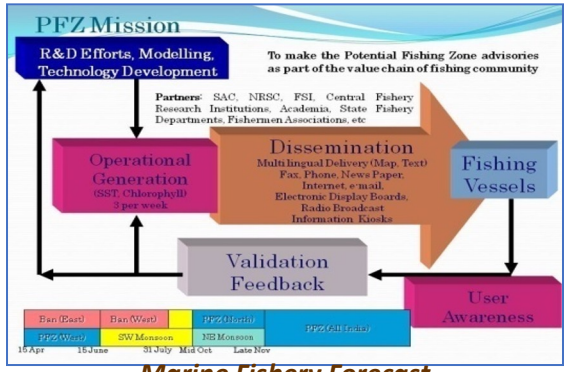
Oceanic Disasters

- Most of the coastal areas are low lying and vulnerable to oceanogenic disasters such as Tsunamis, Storm Surges, Sea-level rise, Coastal Erosion, High Waves etc.

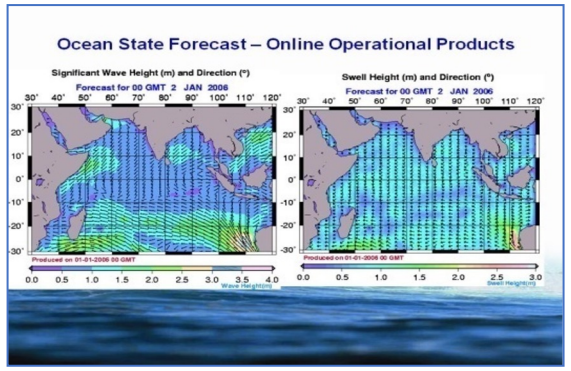
- Over 33 percent India's coastline under varying degree of erosion

Indian National Centre for Ocean Information Services

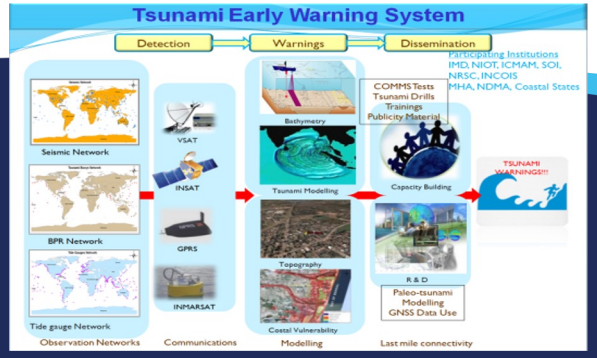
Operational Services to User community



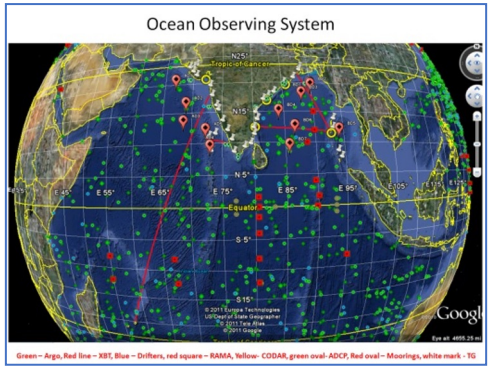
Marine Fishery Forecast

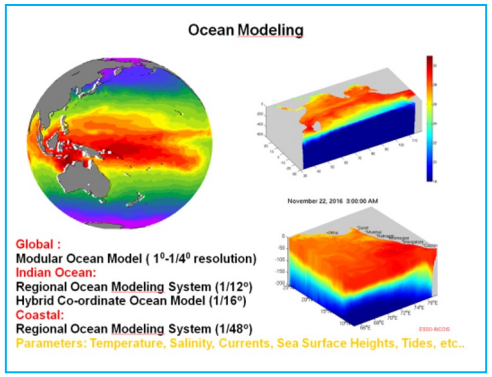


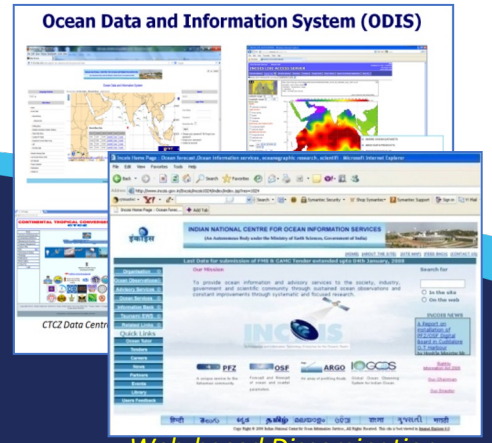
Ocean State *Forecast*



Tsunami *Early Warning Information*







Web-based Dissemination

Our Mission

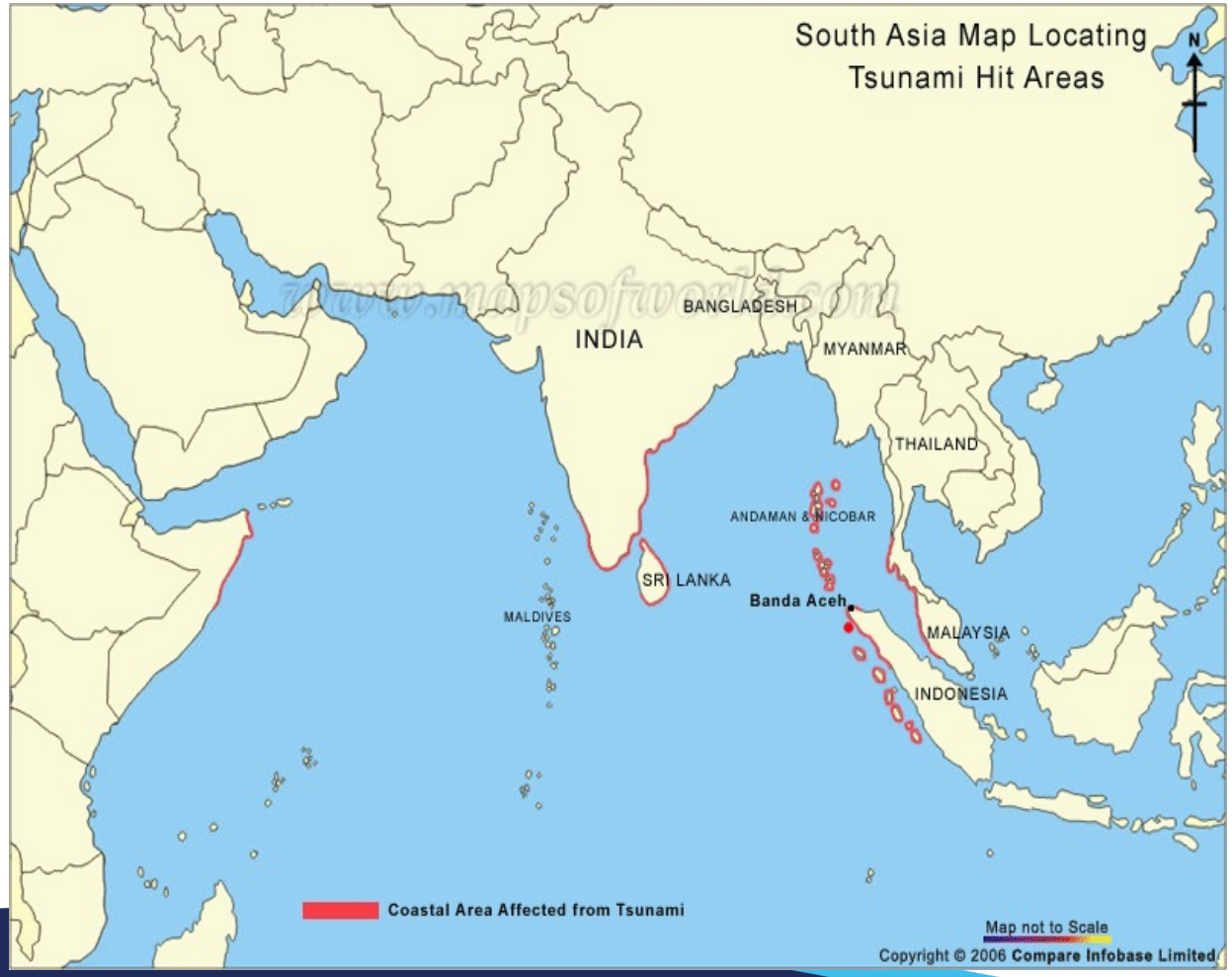
"Provide the Ocean Information and Advisory Services to Society, Industry, Government Agencies and Scientific Community through Sustained Ocean Observations and Constant improvements through Systematic and Focused Research".

Our Stakeholders

All those who depend on Sea for livelihood and those who live on the coastal regions

Fishermen; Coastal population; Navigators; Ports & Harbours; Maritime Industries (oil, shipping, Power..); Navy, Coast Guard, Marine Police; Disaster Management agencies; Coastal Tourism; State Administration; Academia and Researchers

The 2004 Indian Ocean Tsunami

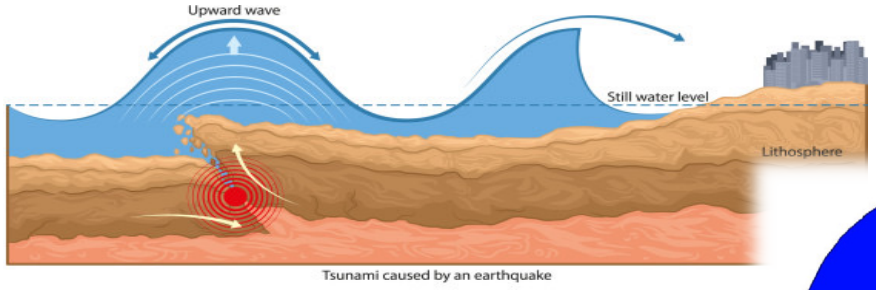


- December 26, 2004 - The worst tsunami in recorded history
- Magnitude 9.1 (third strongest earthquake ever recorded on a seismograph)
- Lasted about 10 minutes (longest lasting earthquake in history)
- ~2,30,000 confirmed dead and estimated damage > $7 billion
- Tsunami hit 14 countries
- Energy released equivalent to 23,000 Hiroshima-sized atomic bombs

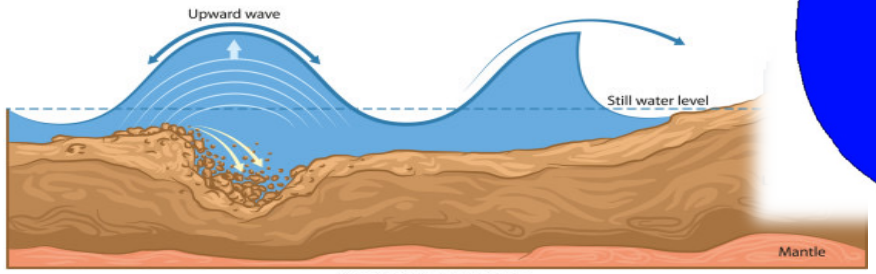
Reasons for huge loss…..

- Many nations in the Indian Ocean did not even recognize the word "tsunami"
- None had tsunami preparedness programs in place
- Absence of a Tsunami Early Warning System (TEWS) in the Indian Ocean
- Ignorance of the natural signs of a tsunami led to inappropriate actions

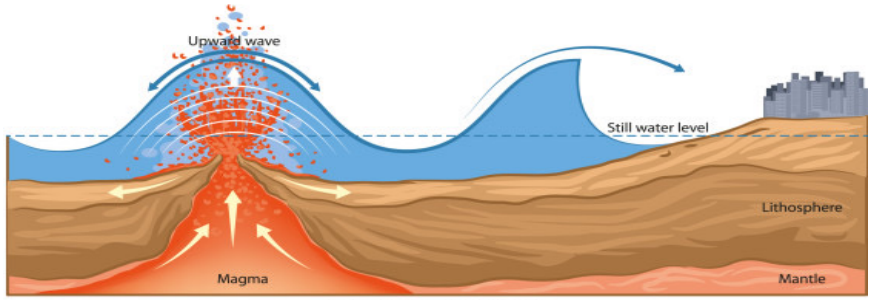
What is Tsunami?



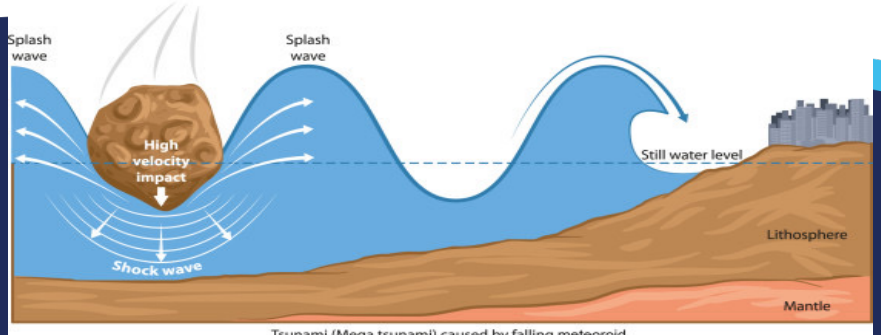
Tsunami caused by an earthquake



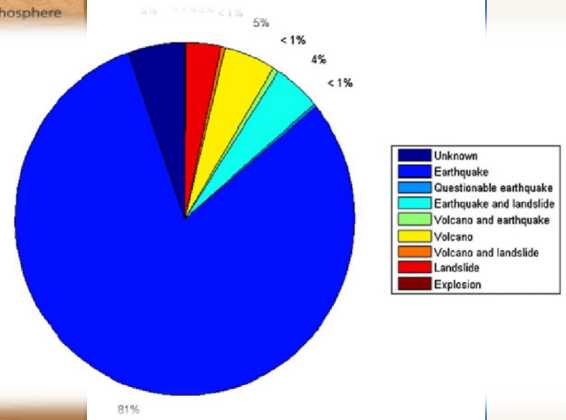
Tsunami caused by erosion



Tsunami caused by the volcano

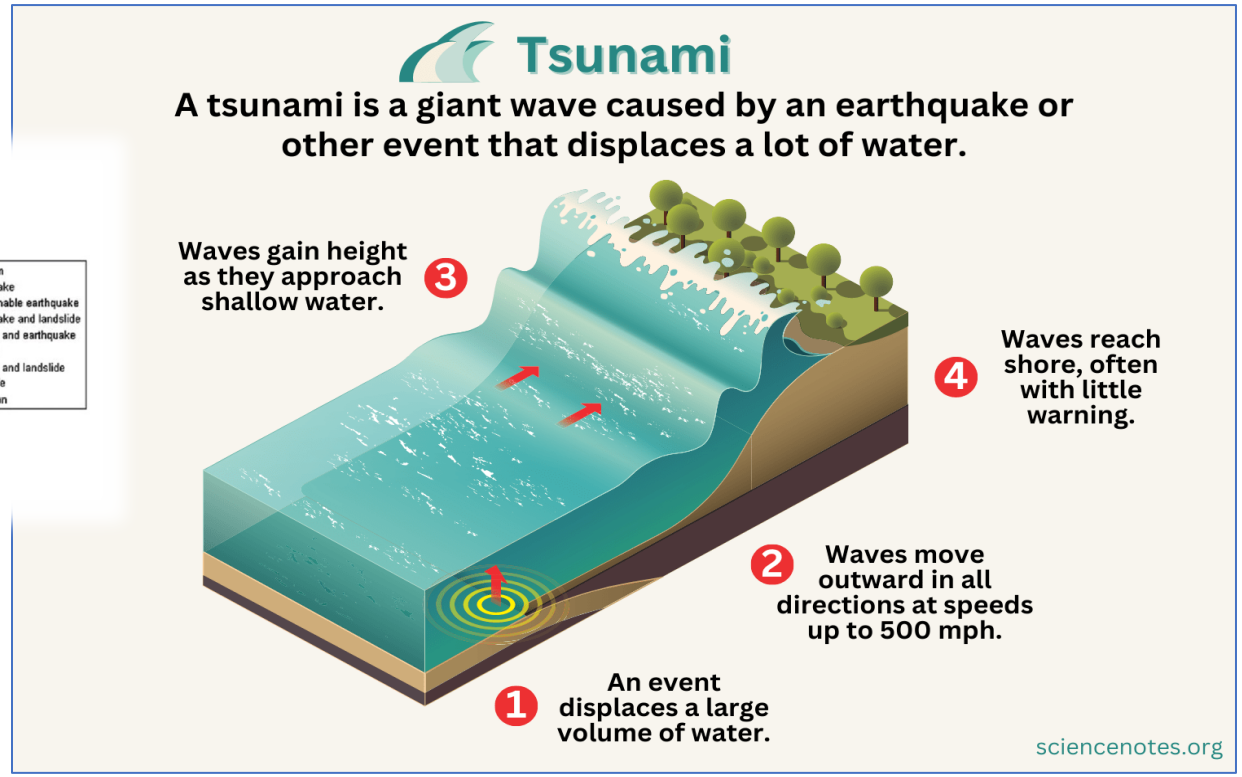


Tsunami (Mega tsunami) caused by falling meteoroid



Tsunami Sources

- Earthquakes
- Submarine/Coastal Landslides
- Volcanoes
- Meteorite impact



Tsunami Characteristics

- Length and Time Period
  - Long wave length (of several 100 km)
  - Periods of a few minutes to about an hour
- DEEP OCEAN tsunami has long wavelength, travels fast, small amplitude - doesn't affect ships
- AS IT APPROACHES SHORE, it slows. Since energy is conserved, amplitude builds up - very damaging

The FOUR Pillars

In line with UN “Early Warnings for All” (EWS4ALL) initiative from COP-27

Pillar 1

Disaster risk knowledge

Systematically collect data and undertake risk assessments

- Are the hazards and the vulnerabilities well known by the communities?
- What are the patterns and trends in these factors?
- Are risk maps and data widely available?

Pillar 2

Detection, observations, monitoring, analysis and forecasting of hazards

Develop hazard monitoring and early warning services

- Are the right parameters being monitored?
- Is there a sound scientific basis for making forecasts?
- Can accurate and timely warnings be generated?

Pillar 4

Preparedness and response capabilities

Build national and community response capabilities

- Are response plans up to date and tested?
- Are local capacities and knowledge made use of?
- Are people preapred and ready to react to warnings?

Pillar 3

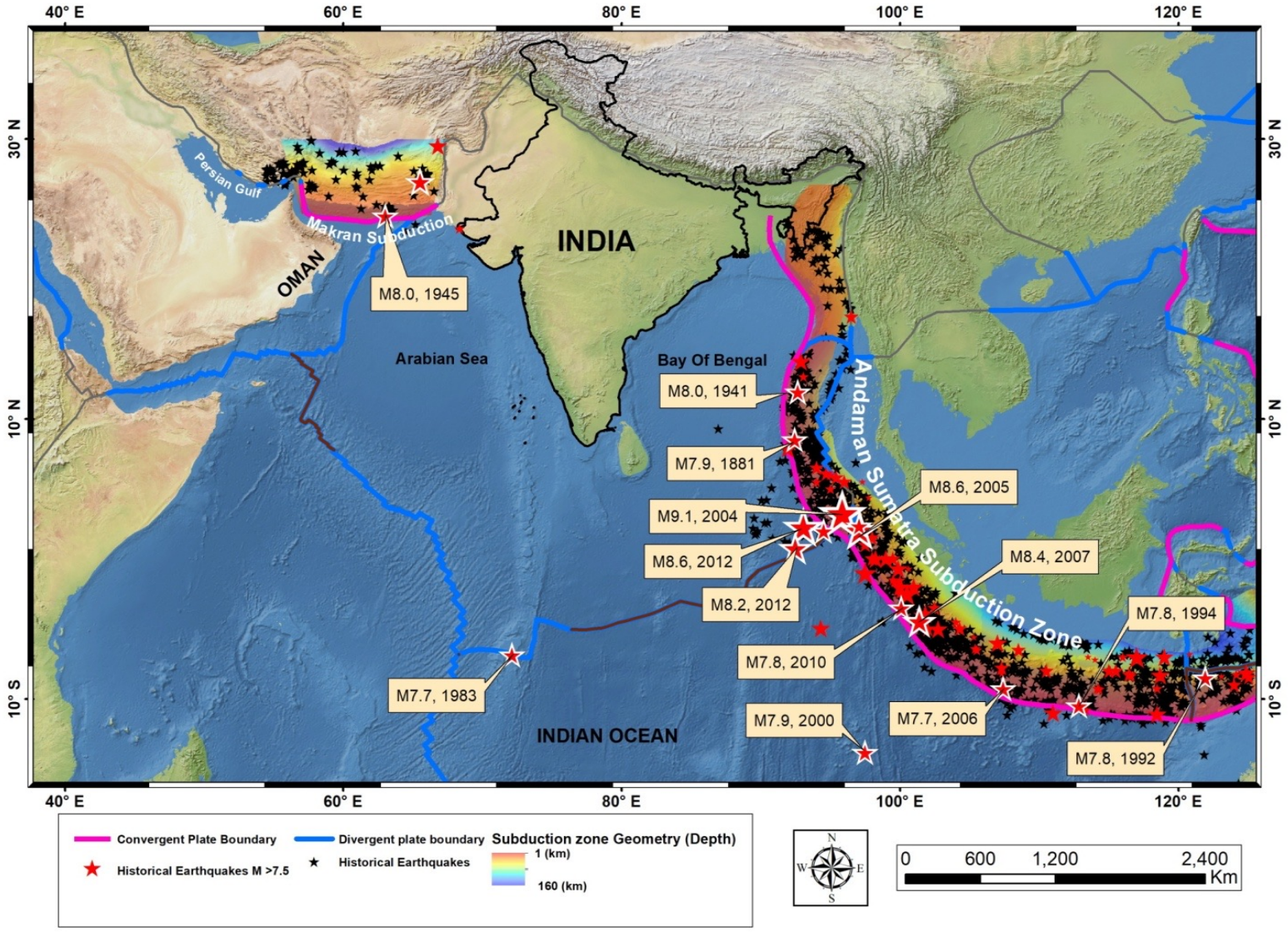
Warning dissemination and communication

Communicate risk information and early warnings

- Do warnings reach all of those at risk?
- Are the risks and warnings understood?
- Is the warning information clear and usable?

Courtesy WMO, 2023

Pillar 1: Potential Tsunamigenic Sources in the Indian Ocean



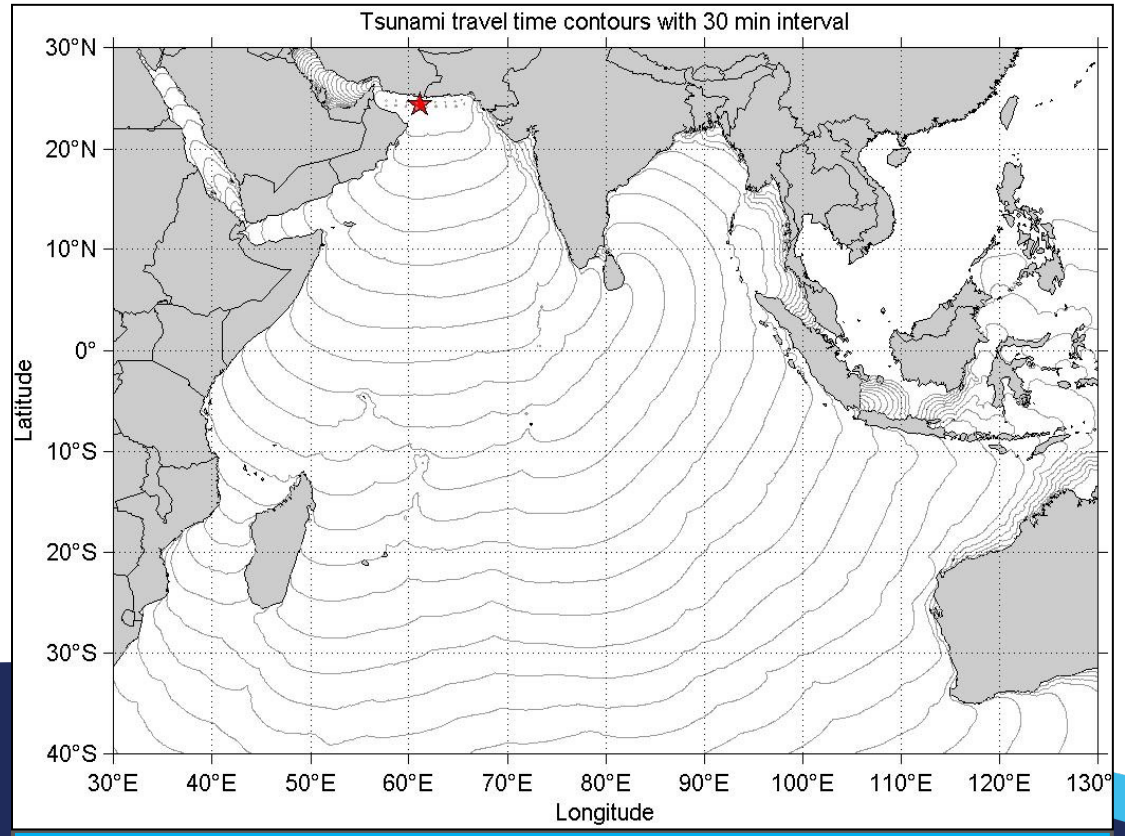
Major Subduction Zones

- Subduction Zone: Indian and Australian plates are moving north and eastward relative to Eurasian plate forming a convergent boundary
- Sumatra Andaman Subduction Zone (SASZ) – From Himalayan front southward through Myanmar, Andaman and Nicobar Islands, Sumatra, Java and the Sunda Islands (Sumba, Timor), to the north of Western Australia
- Sumatra Andaman Subduction Zone (SASZ) ~6000 km
- Makran Subduction Zone (MSZ) – lies between southeastern Iran and southwestern Pakistan
- Makran Subduction Zone (MSZ) ~900 km

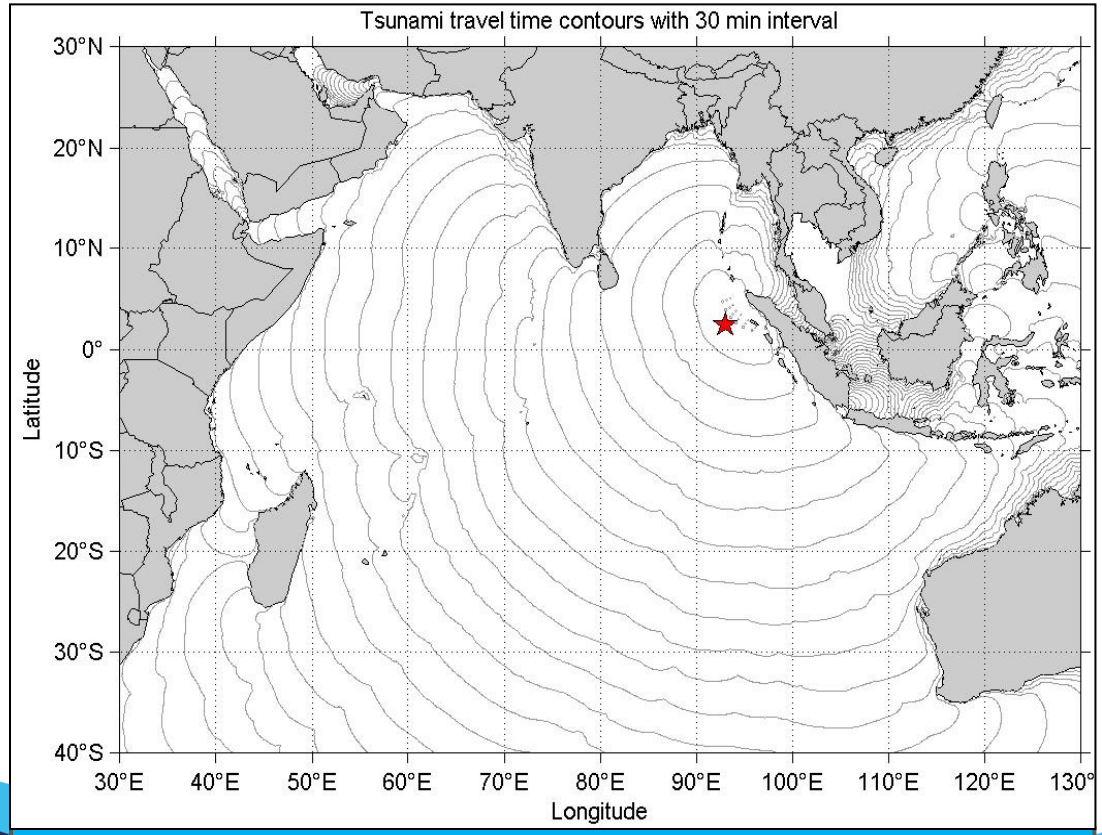
Pillar 1: Tsunami Risk Assessment

Tsunami Travel Times & Response time

- Depending upon the Earthquake location (Makran/Andaman-Sumatra Subduction Zone) the response time for evacuation of coastal population could range between 20 min to few hours.
- As Andaman & Nicobar Islands are situated right on subduction zone the available response time is very short

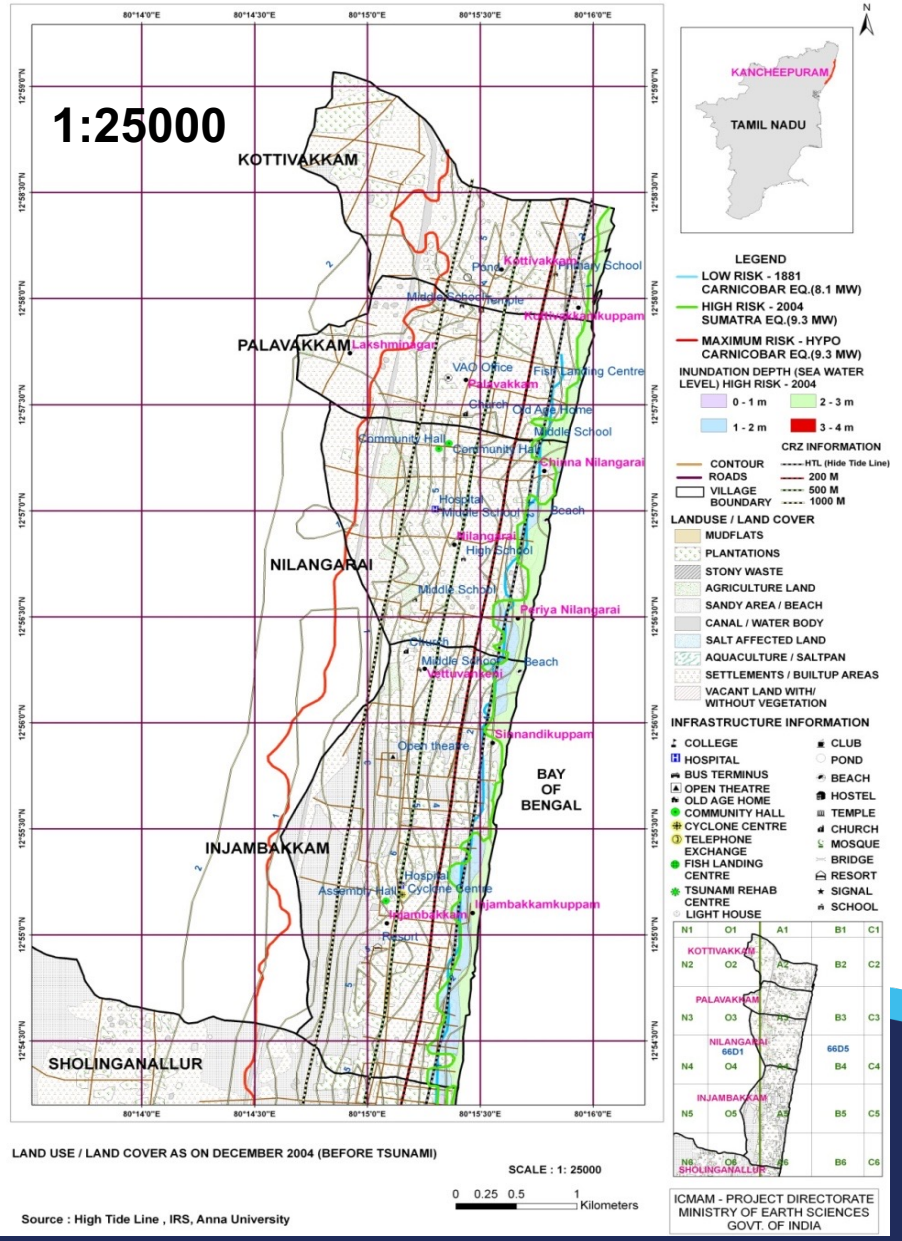


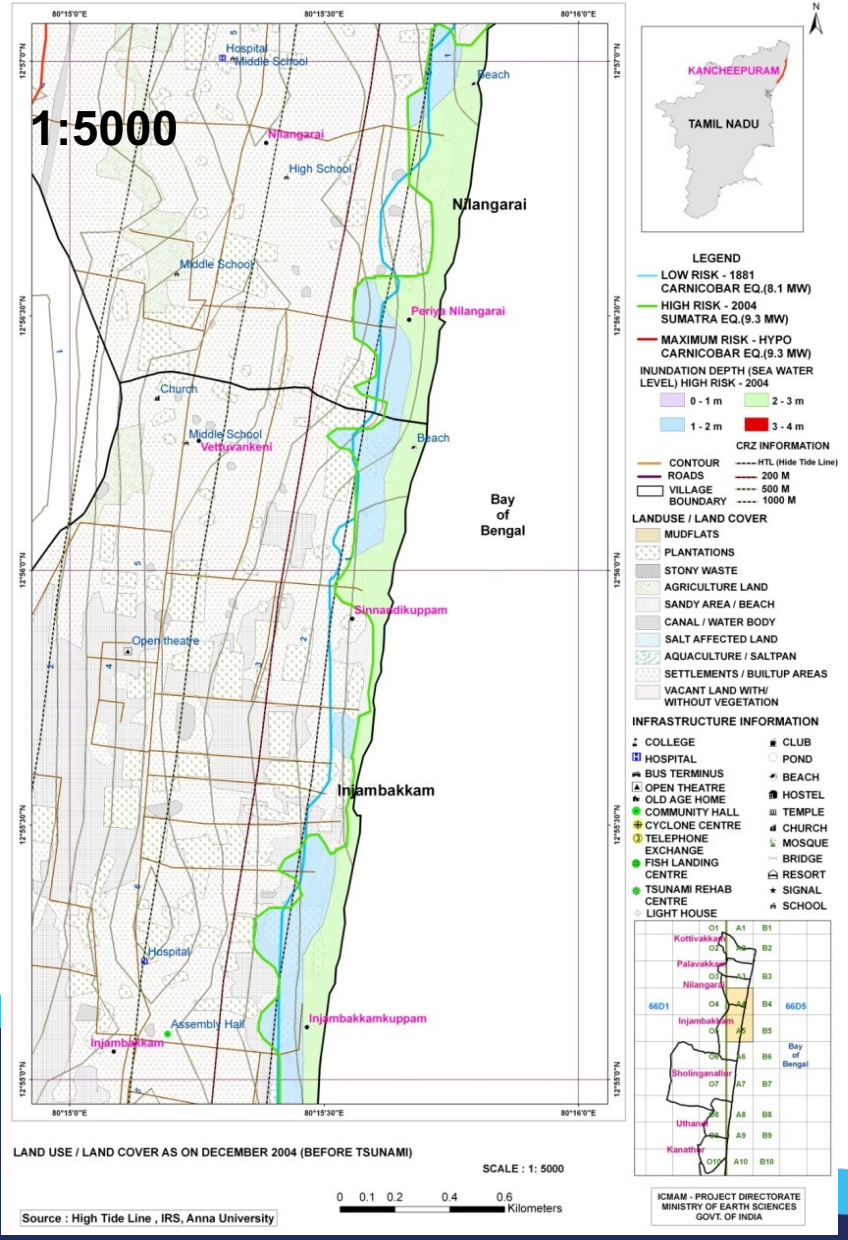
- If Earthquake occurs at Makran Subduction zone, Travel Time to nearest Indian Coast (Gujarat) are 2 to 3 hrs



- If Earthquake happens at Sumatra, travel times to nearest coast (A&N Islands) are 20 to 30 min
- For Indian main land travel times are 2 to 3 hrs

Pillar 1: Tsunami Vulnerability Mapping





I. Vulnerability classification

Low risk – Carnicobar Eq (8.1.Mw)
High risk – Sumatra Eq (9.3Mw)
Maximum risk – Hypo. Carnicobar Eq (9.3 Mw)

II. Inundation Depth

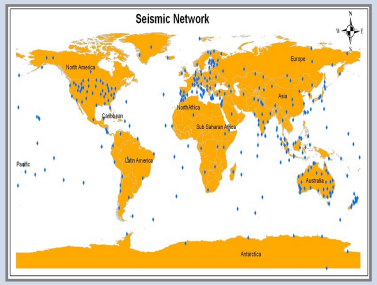
(sea water level due to Sumatra 2004)

III. Others details

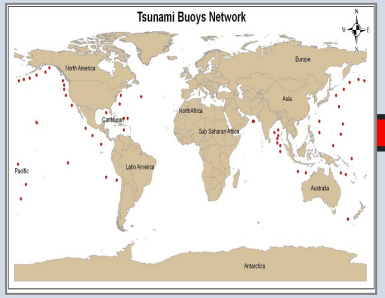
- **From Satellite Imagery (entire Village)**
  - **Landuse**
- **From DC images (upto 2 km from coast)**
  - **Elevation Contours**
  - **Infrastructure details**
  - **Trees**
  - **Roads**
  - **Railways**
  - **Buildings**
- **Secondary data**
  - **Cadastral boundaries and Survey Nos**
  - **Administrative boundaries**

Pillar 2: Indian Tsunami Warning System Architecture

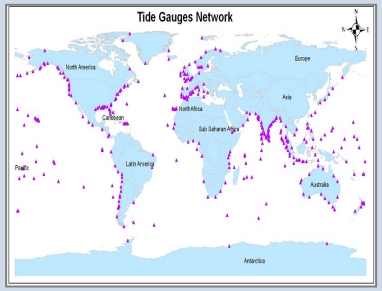
Detection → **Warnings** → **Dissemination**



Seismic Network



BPR Network



Tide gauge Network

Observation Networks

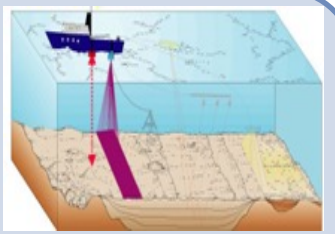
VSAT

INSAT

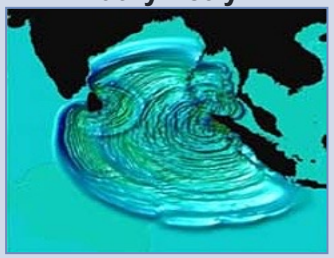
GPRS

INMARSAT

Communications



Bathymetry



Tsunami Modelling

Topography

Costal Vulnerability

Simulations

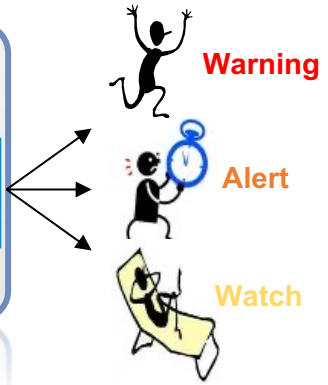
Participating Institutions
IMD, NIOT, ICMAM, SOI,
ISRO, NRSC, INCOIS
MHA, NDMA, Coastal States

Capacity Building

R & D

Last mile connectivity

National Warnings
National DMO
Local DMO
Media
Public



Pillar 2: Detection, Observations, Monitoring and Forecasting

➢ Seismic & GNSS Network:

- Real-Time Seismic Network of 17 stations and ~350 international stations
- Indian Seismic & GNSS Network around ~ 150 seismic and ~ 400 GNSS
- Capable of estimating earthquake parameters in less than 10 min
- 35 station GNSS Network in Andaman &Nicobar Islands

➢ Tsunami Buoy Network:

- INCOIS-NIOT established real-time network of 7 Tsunami Buoys
- Receives data from ~ 50 international real-time tsunami buoys
- Shares data from 7 Indian stations

➢ Tide gauge Network:

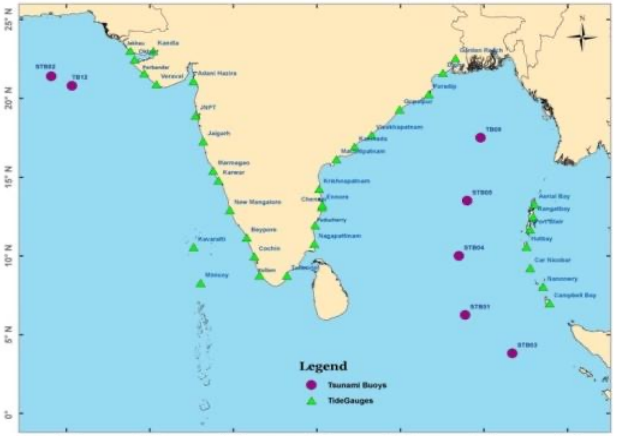
- INCOIS established real-time network of 36 tide-gauge stations
- Receives data from 300 international real-time tide-gauge stations
- Shares data from 8 Indian stations

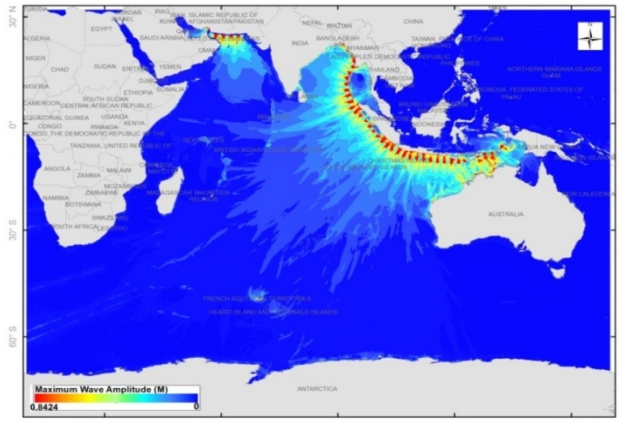
➢ Tsunami Modeling:

- Large Database of open ocean propagation scenarios
- ~1400 unit sources each of 100 X 50 km area representing rupture caused by EQ of M 7.5 with slip as 1m . Can be scaled up/down based on actual magnitude.
- Expected Wave Arrival & Amplitude forecasts at CFP and CFZs

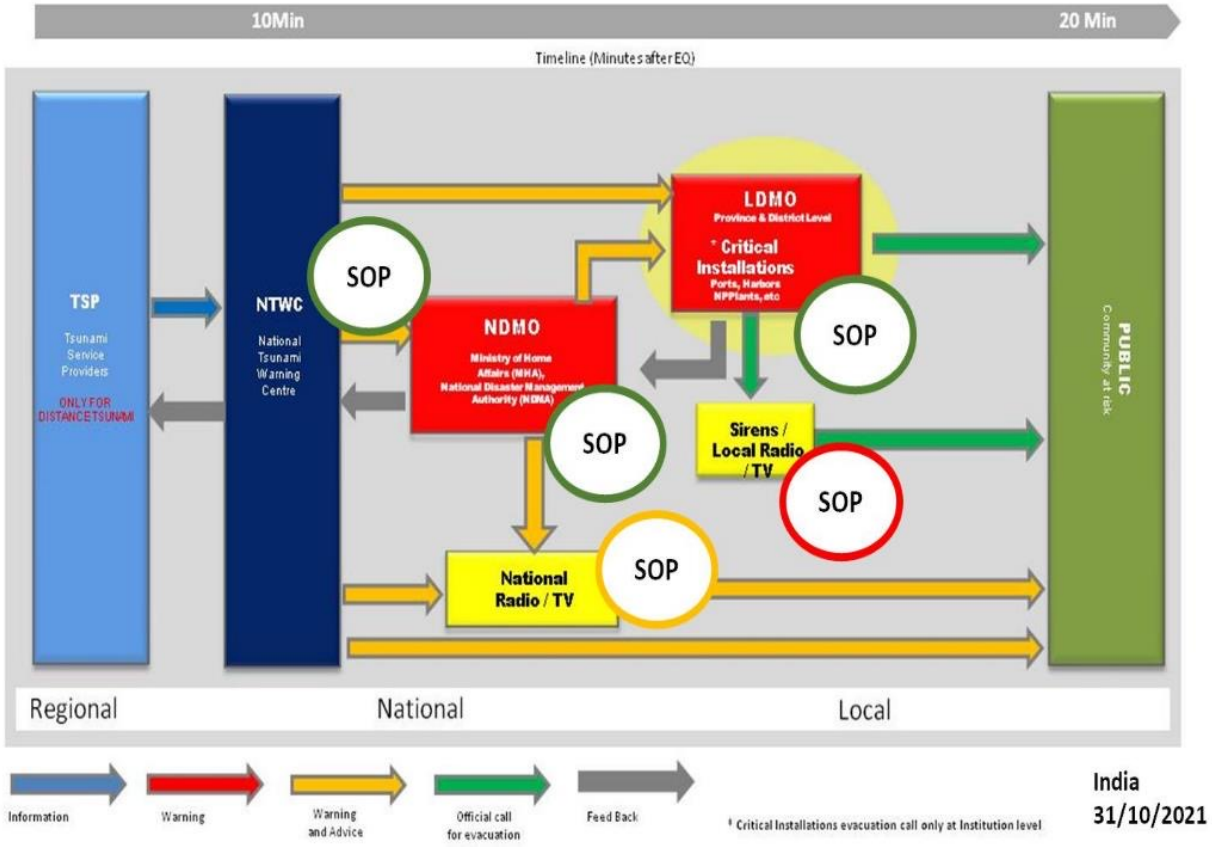
➢ 24 x 7 warning Centre:

- High Performance Computation & Advanced Communication Infrastructure





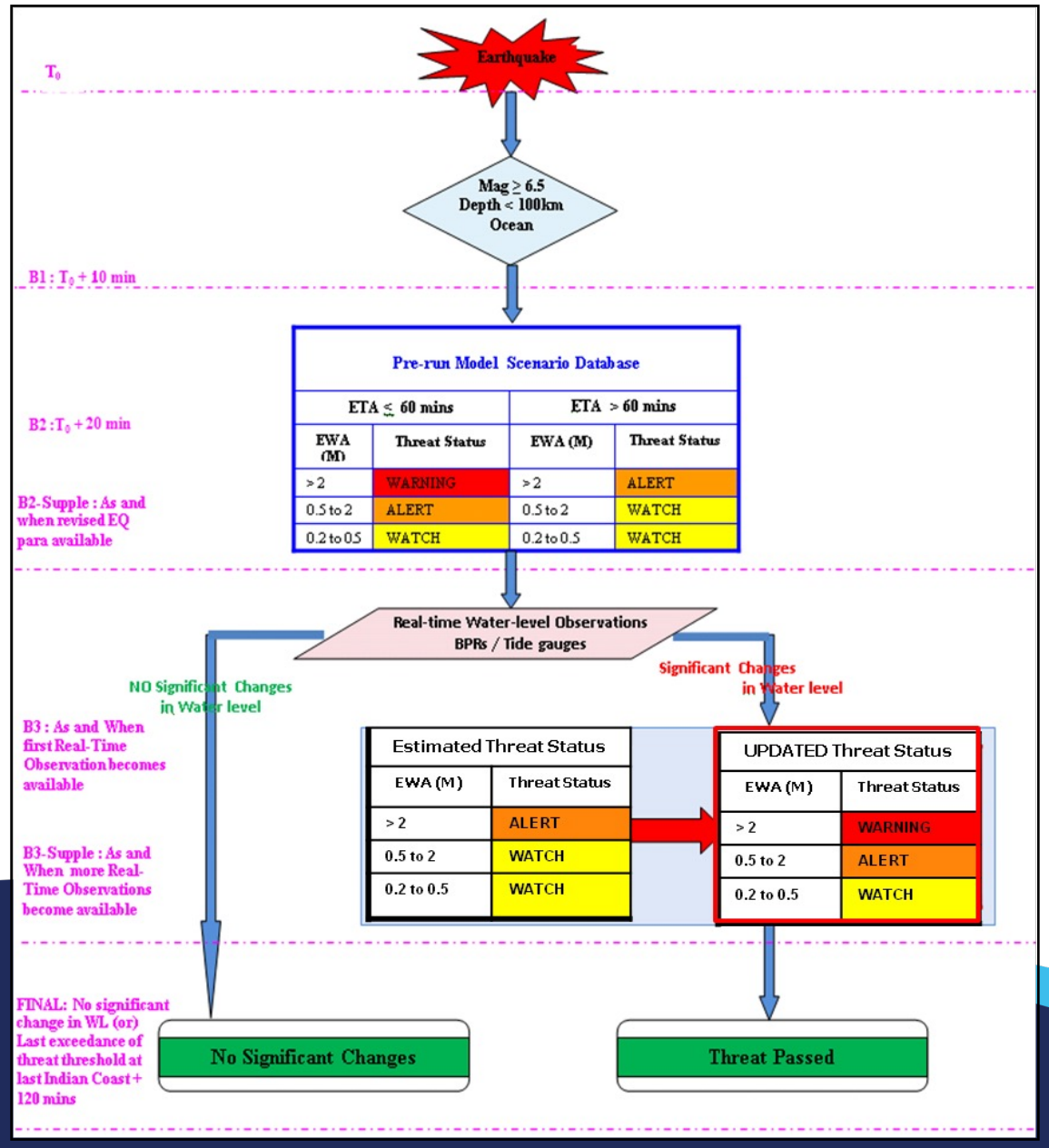
Pillar 3: Warning Dissemination and Communication



National Warning Chain

- National Tsunami Warning Centres (**NTWCs**), Disaster Management Organisations (**DMOs** at national, provincial, and local level), and **Broadcast Media**
- **Standard Operating Procedures (SOPs)** underpin each link.
- SOPs prepared and tested at national, provincial and local level. Media SOP is being tested.
- **Routine 6-monthly communication tests** Jun and Dec every year (email, GTS, SMS, Fax)
- Test national tsunami warning chain and SOPs in Mock Drills
- Recent mock drill was in October 2023

Pillar 3: Standard Operating Procedure of NTWC



- The Indian Tsunami Early Warning Centre (ITEWC) services for an event commence whenever an earthquake is recorded with M ≥ 6.5 within the Indian Ocean and M ≥ 8.0 outside of the Indian Ocean
- Uniquely designed SOP for generation of timely and accurate tsunami bulletins to handle both near-source and far-source coastal regions
- Based on proximity of a coastal zone to the tsunamigenic earthquake source regions and Expected Wave Heights from Models
- 4 Threat Levels corresponding to different public responses and mapped to NDMA guidelines

SOP – Public Response and Threat Levels in Bulletins

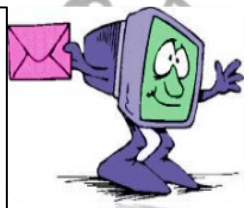
Threat Status	Action to be taken	Dissemination to
WARNING	Public should be advised to move inland towards higher grounds. Vessels should move into deep Ocean	MoES, MHA, NDMA, NCMC, NDRF Battalions, SEOC, DEOC, Public, Media
ALERT	Public should be advised to avoid beaches and low-lying coastal areas. Vessels should move into deep Ocean	MoES, MHA, NDMA, NCMC, NDRF Battalions, SEOC, DEOC, Public, Media
WATCH	No immediate action is required	MoES, MHA, NDMA, NCMC, NDRF Battalions, SEOC, DEOC, Media
THREAT PASSED	All clear determination to be made by the local authorities	MoES, MHA, NDMA, NCMC, NDRF Battalions, SEOC, DEOC, Public, Media

Pillar 3: Products and Dissemination

- **Notification Messages** are issued in **text** format (email and SMS)
- **Bulletins** are generated in both text and **HTML formats** on the websites (email and website)
- **Graphics** are generated in jpg or png format on the websites
- **Spatial** data is also available in dbf format on the websites

Multichannel, Multilingual, Geo-located, Social Media, Regular tests and Clear & Concise Messages

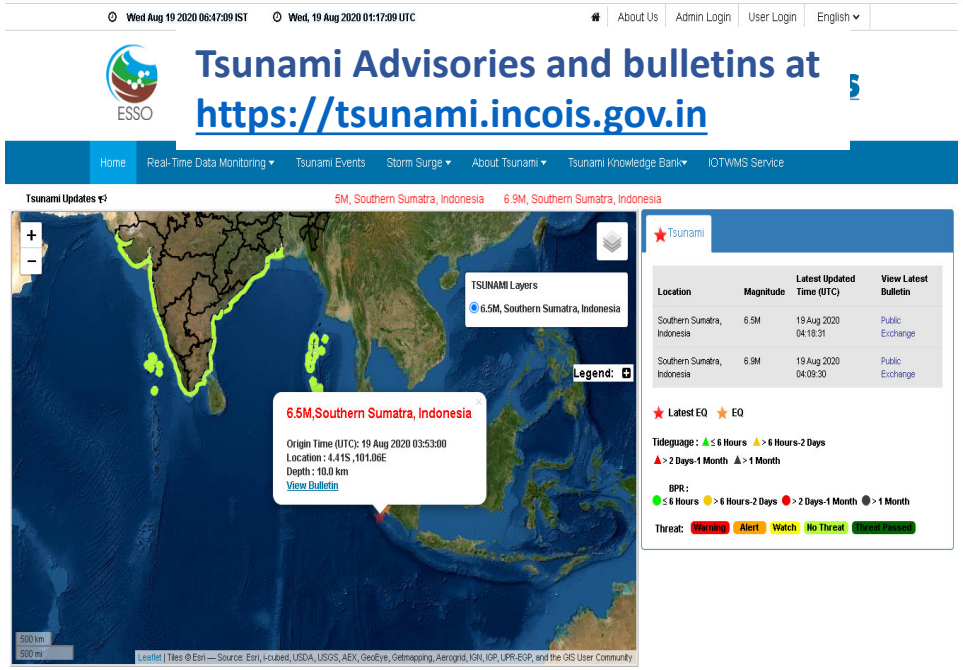
Fax

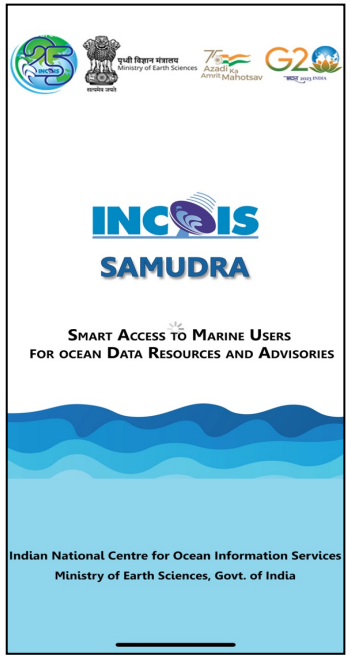


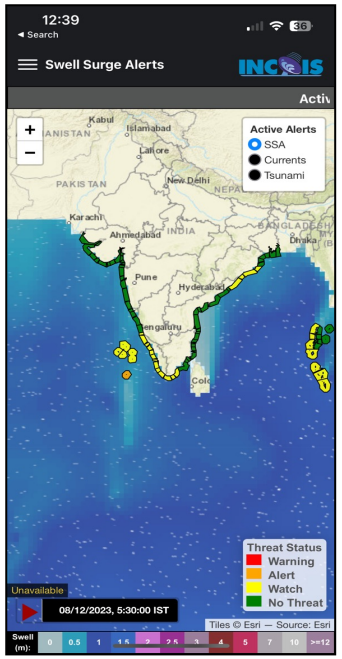
Email

SMS

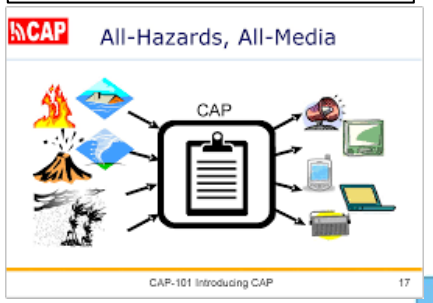
Web



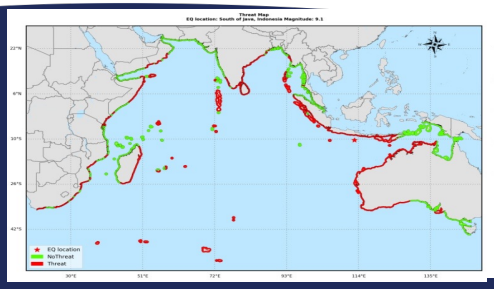




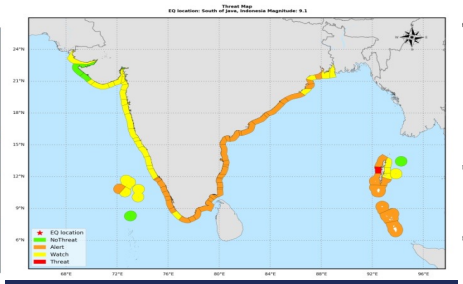
SAMUDRA" (Smart Access to Marine Users for ocean Data Resources and Advisories) The mobile app empowers users with real-time updates and critical alerts on oceanic disasters such as tsunamis, storm surges, high waves, swell surge alerts, etc.



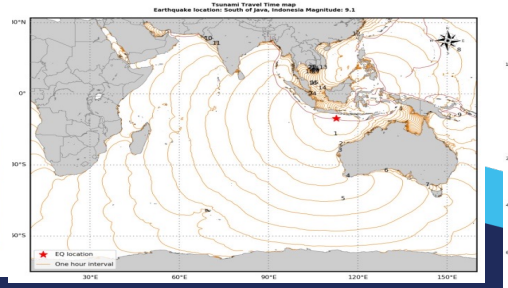
GTS



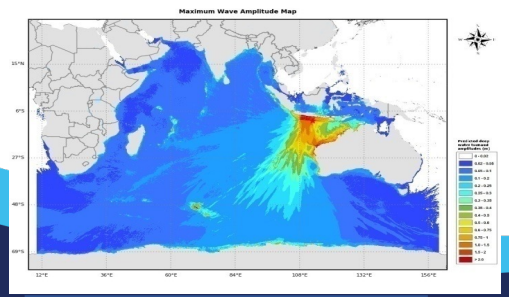
Tsunami Threat Map for Indian Ocean



Tsunami Threat Map for India



Tsunami Travel Time Map



Tsunami Amplitude Map

Pillar 4: Preparedness and Response

➢ SOP Workshops, Tabletop Exercises & COMMs test

- SOP Workshops For DMOs to build their own SOPs detailing actions to be taken upon receipt of bulletins from NTWC
- Tabletop Exercises to stimulate the development, training, testing and evaluation of Emergency Response Plans, SOPs and assess procedures followed
- Communication tests every 6 months to validate the dissemination and reception processes of advisories
- Awareness material in vernacular languages

➢ Mock Drills

- INCOIS conducts IOWave Tsunami mock exercises biannually in coordination with ICG/IOTWMS and conducts at National level mock exercises alternative years in coordination with National/State DMOs to strengthen the readiness to handle the emergency situations with stakeholders

➢ World Tsunami Awareness Day

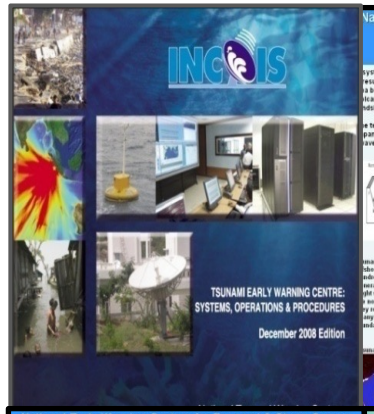
- Commemorates World Tsunami Awareness Day on 5th November and organize various activities

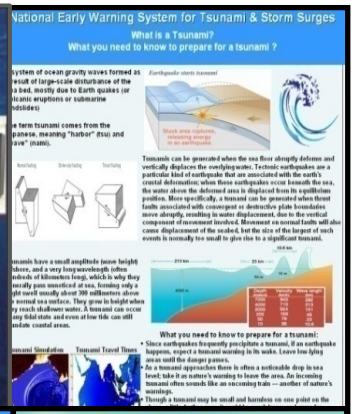


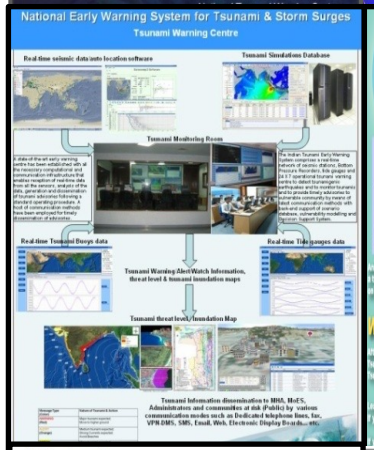


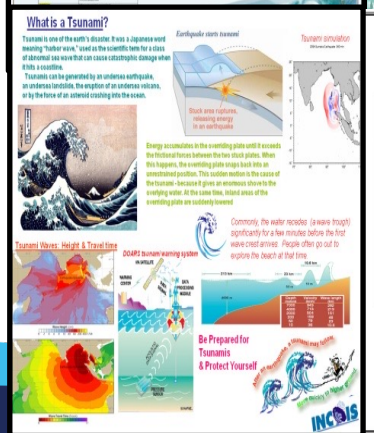


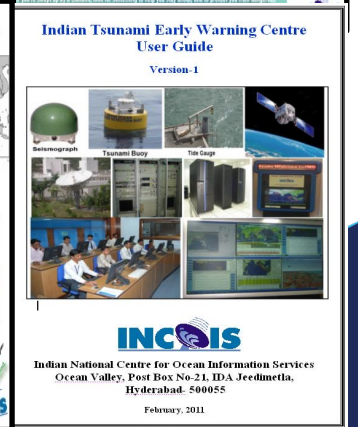








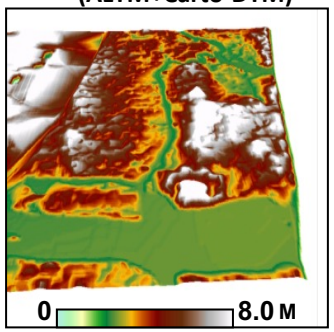


Pillar 4: Tsunami Ready Recognition

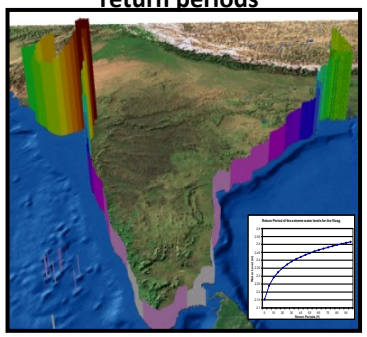
- The IOC-UNESCO Tsunami Ready Programme is a voluntary community performance-based programme
- Promotes tsunami hazard preparedness as an active collaboration of national and local emergency management agencies, community leaders and the public.
- To improve coastal community preparedness for tsunami emergencies, to minimize the loss of life and property
- India is the first implemented country Tsunami Ready programme in the Indian Ocean region

Coastal Multi-Hazard Vulnerability Assessment

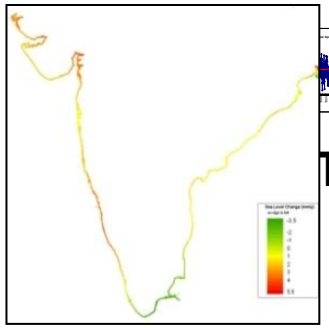
High Resolution Topography (ALTM+Carto-DTM)



Extreme Water Level and return periods



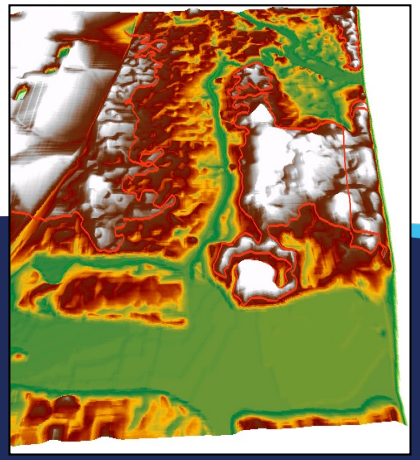
Sea-level Change Rate



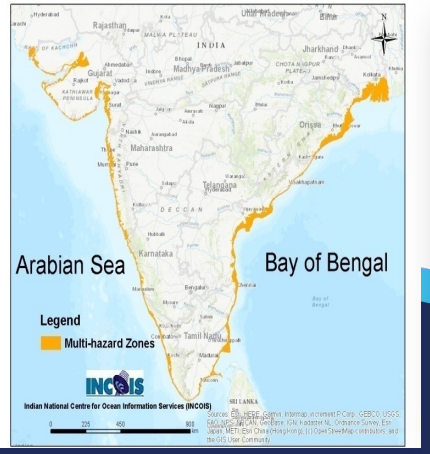
Shoreline Change Rate

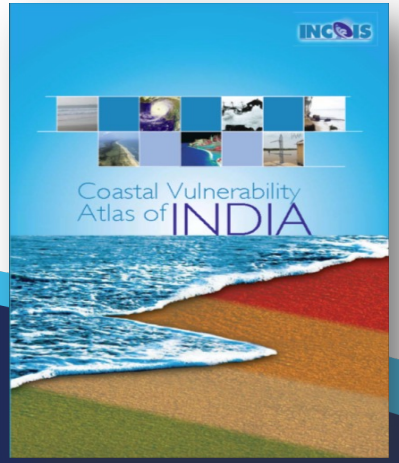
SYNTHESIZED SPATIAL OVERLAY ANALYSIS

Composite Multi-hazard Line



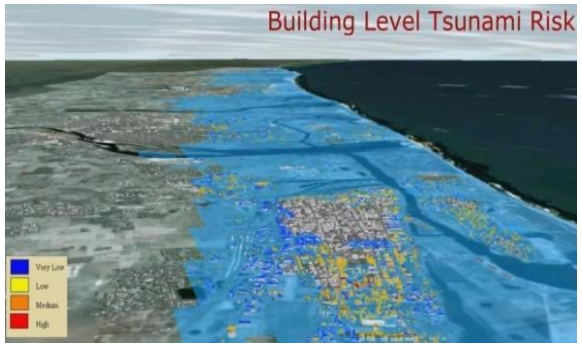
Multi-hazard Vulnerability Maps



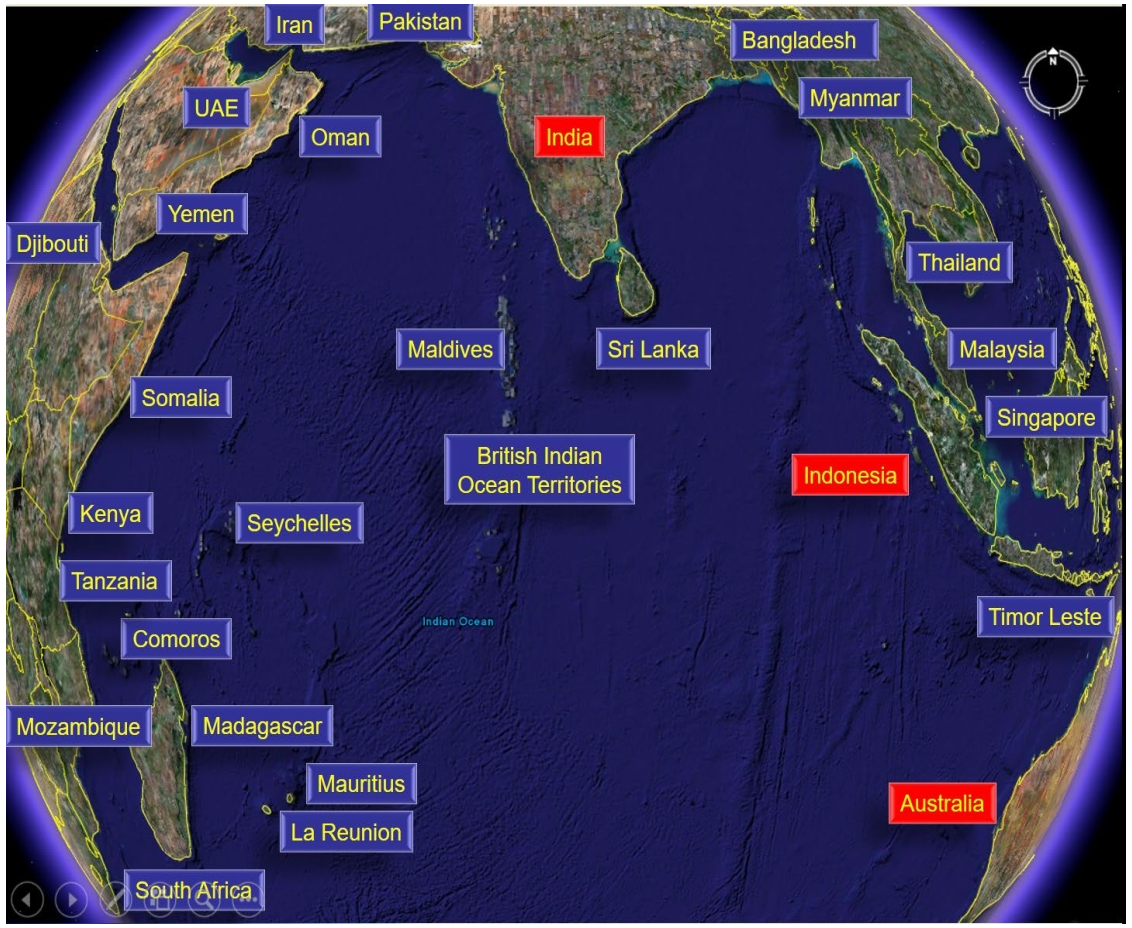


Coastal Inundation – 3D Mapping

- **Coastal Vulnerability Indices** Atlas covering Indian coast comprising 156 maps on 1:0.1 million scale have been prepared
- The multi-hazard mapping has been carried out using the parameters sea level change, shoreline change rate, elevation contours, extreme water level from tide gauges and the return periods of extreme events
- Realistic 3D models of the buildings along with the attributed details of the owner, address and other socio-demographic details.



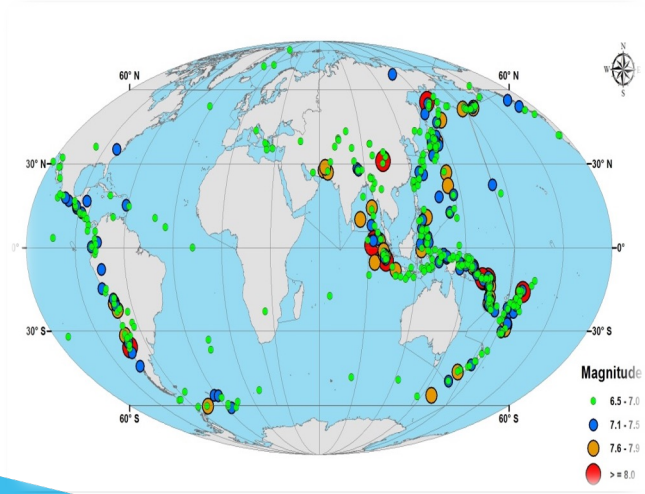
ICG/IOTWMS Tsunami Service Provider



The Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWMS) was formed in response to the tragic tsunami on 26 December 2004

In October 2011, ITEWC recognized as a Tsunami advisory Service Provider (TSP) along with Australia and Indonesia by IOC-UNESCO. Since then ITEWC providing services to all Indian Ocean member countries.

INCOIS is providing tsunami services to 27 member states in the Indian Ocean Region



ITEWC monitored 690 earthquakes (M>6.5) since its inception to till date

Region	No of Earthquake M≥6.5
Indian Ocean **(IO)**	102
Other than Indian Ocean (GO)	588

Challenges

Atypical Tsunami Sources

September 28, 2018 Palu Tsunami & December 22, 2018 Sunda Strait tsunami

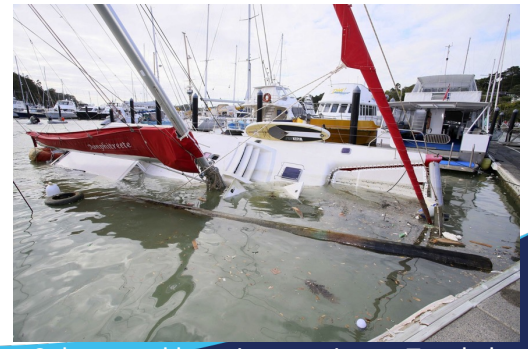
Submarine landslide, Liquefaction

- Deaths - 2,100; Missing 680; Injured 4,612; and Displaced 78,994
- Warning issued in 5 Minutes, first wave arrived in 3 minutes
- No time for communities to receive official warning
- No access to evacuation, no prior preparation of evacuations

Anak-krakatau Volcano eruption

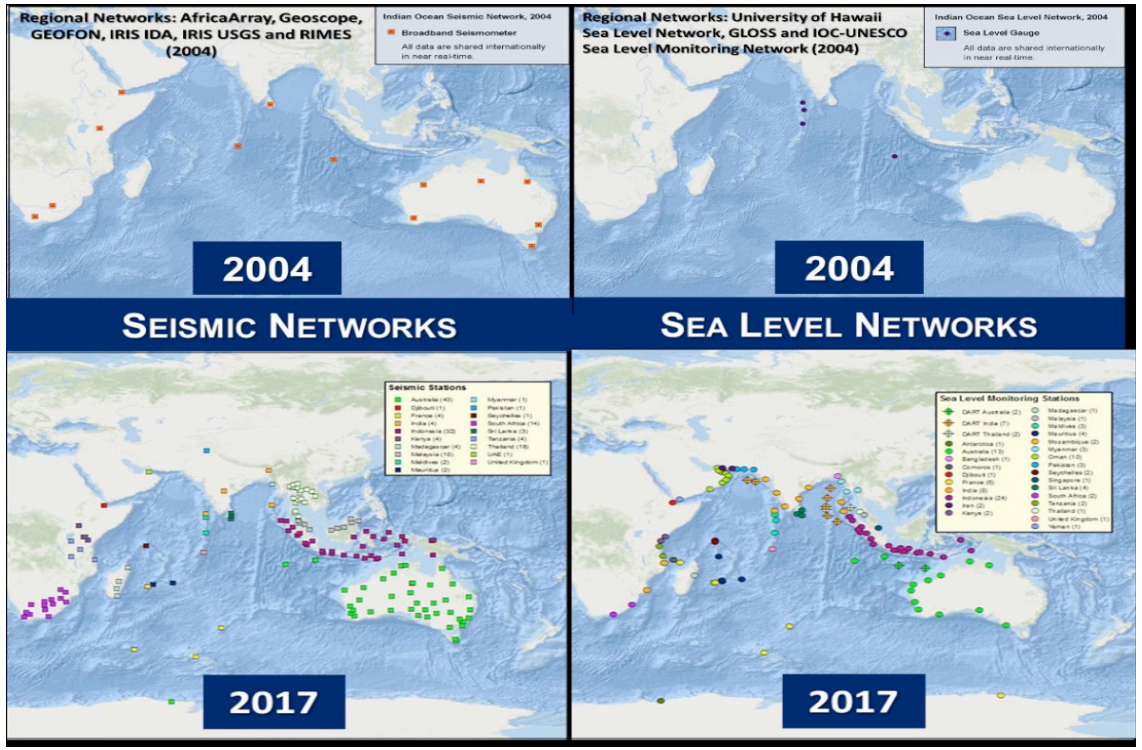
- Deaths - 430; Missing 128; Injured 1,459; and Displaced 5,695
- Caused by flank collapse due to eruption of Anak Krakatau volcano
- No Tsunami Early Warning issued
- Tsunami waves arrived in succession following the eruptions patterns, and avalanches.

2022 Hunga Tonga–Hunga Ha'apai eruption



Submerged boat in a marina at Tutukaka, New Zealand

Are We Ready?



Great progress in Tsunami Warning Systems since 2004

- 4 Regional Systems coordinated by the IOC UNESCO - PTWS, IOTWMS, CARIBE EWS, NEAMTWS
- IOTWMS – Network of 3 TSPs (Australia, India, Indonesia) and NTWCs

Several challenges evidenced by recent events

- Tsunami warning is a race against time - Uncertainties in tsunami warning
- Gaps in Warning and Response capabilities, especially for non-seismic and near-field sources
- Gaps in SOPs and Early Warning Chains
- Gaps in preparedness & response

Ocean Decade Tsunami Programme (2020-2030)

Observational & Technological Advances to reduce uncertainties

100 % at-risk communities prepared & resilient

2024 marks 20th Anniversary of the IOT + 2025 Midway to the ODTP

Thank you!