Indian Tsunami Early Warning System

United Nations/India Workshop on use of Earth Observation Data in Disaster Management and Risk Reduction: Sharing the Asian Experience

Hyderabad, India

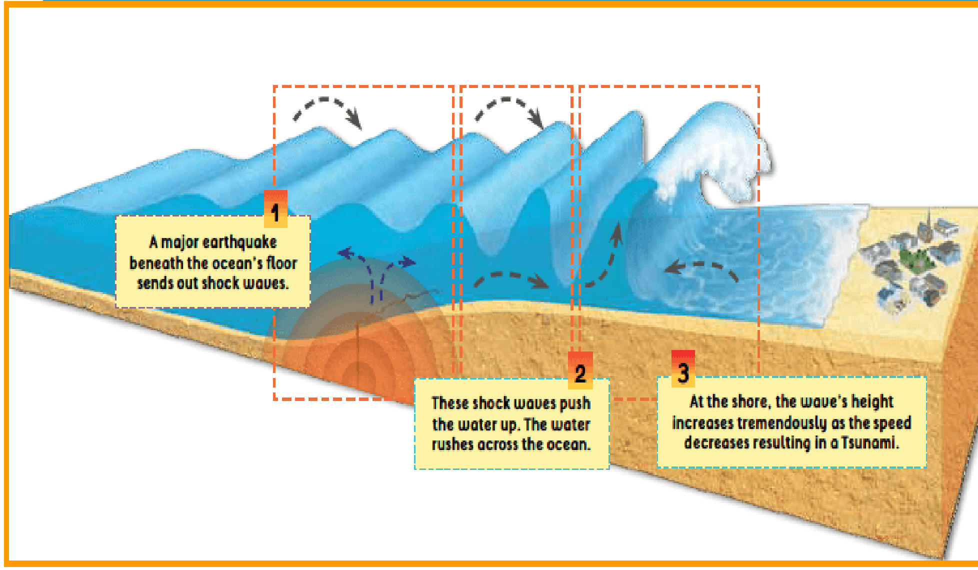
March 8-10, 2016

Sunanda M.V.

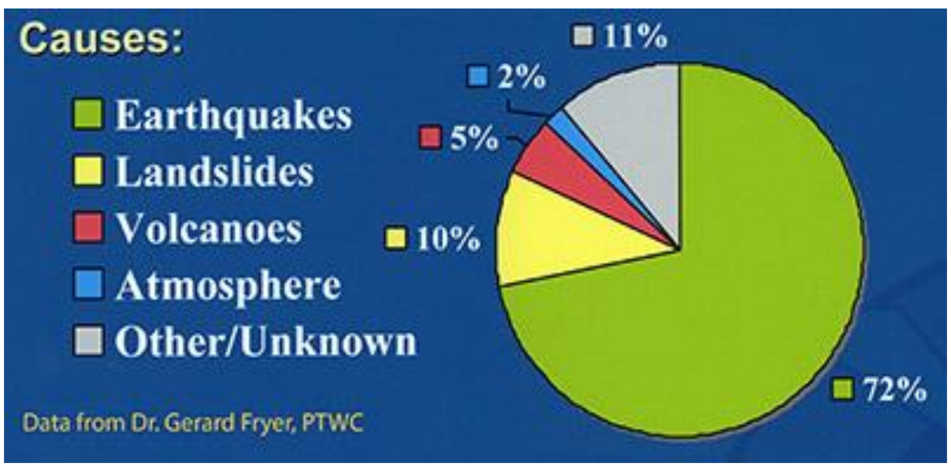
Indian Tsunami Early Warning Centre

INCOIS

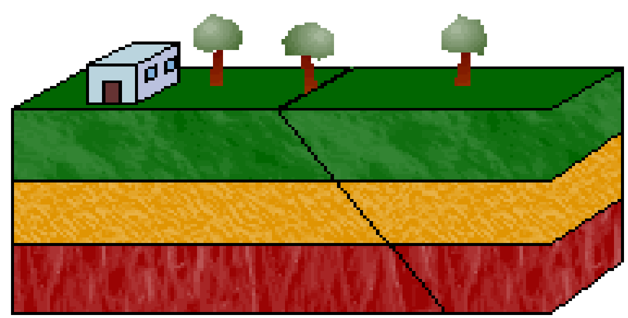
What is a Tsunami ?



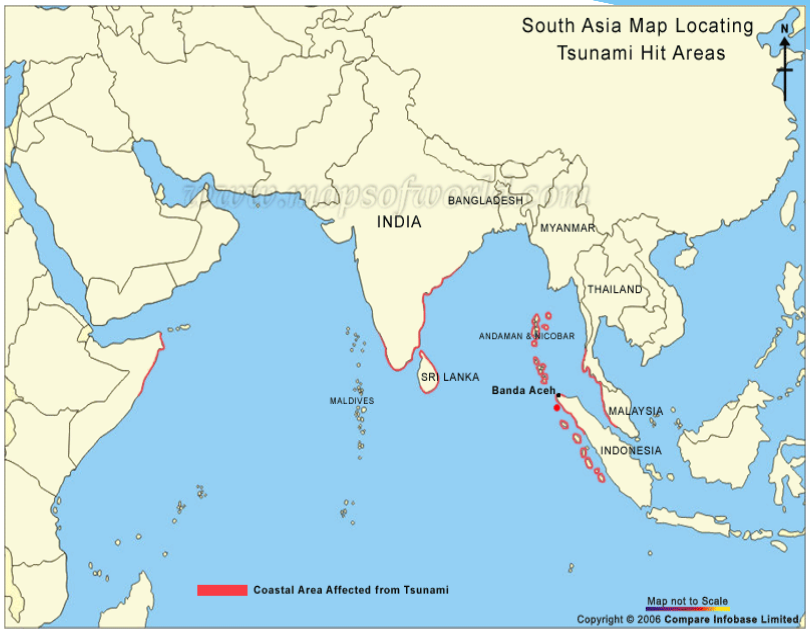
* A system of ocean gravity waves formed as a result of large-scale displacement of sea surface. Travel long distances without losing energy
* Length and Time Period
  - Long wave length (of several 100 km)
  - Periods of a few minutes to about an hour
* Speed proportional to square root of water depth
  - 500 to 1000 km per hour in Deep Ocean
  - About 30 km per hour near shore
* Height of Tsunami Wave
  - Less than a meter in the Deep Ocean
  - Grows to Tens of meters near shore



- NOT all earthquakes generate tsunamis
- Most generated at SUBDUCTION ZONES
- Magnitude > 6.5 and Depth < 100 km



Indian Ocean Tsunami of December 26, 2004



- The worst tsunami in recorded history on December 26, 2004
- Magnitude 9.2 (third strongest earthquake ever recorded on a seismograph)
- Lasted 10 minutes (longest lasting earthquake in history)
- 229,866 confirmed dead, which includes 42,883 missing and never accounted for
- More than $7 billion dollars damage

Reasons for huge loss…..

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

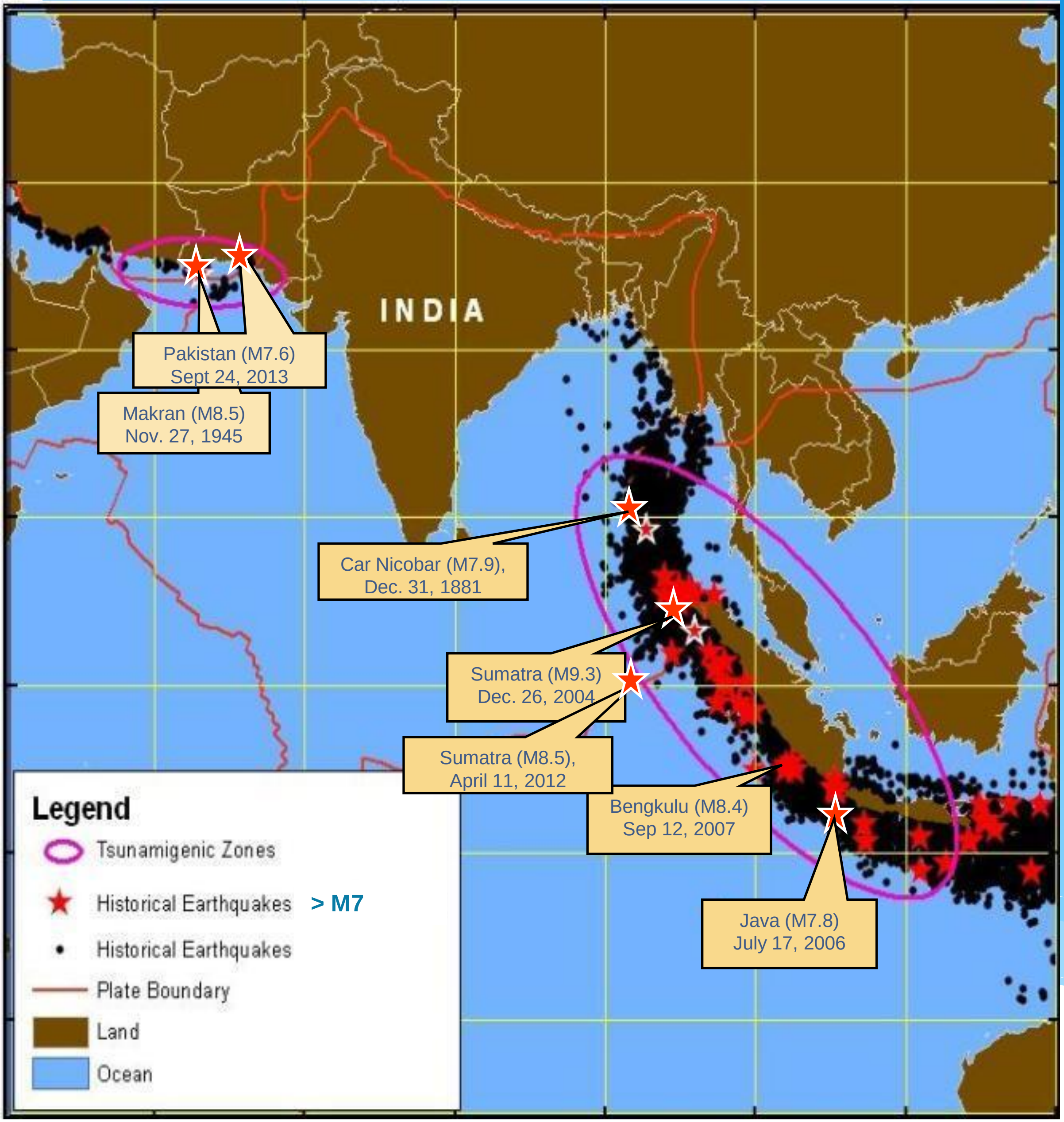
THE NEXT DESTRUCTIVE TSUNAMI

IT'S NOT IF, BUT WHEN

- **Risk Assessment**
- **Warning & Dissemination**
- **Preparedness**

Risk Assessment & Reduction

Risk Assessment



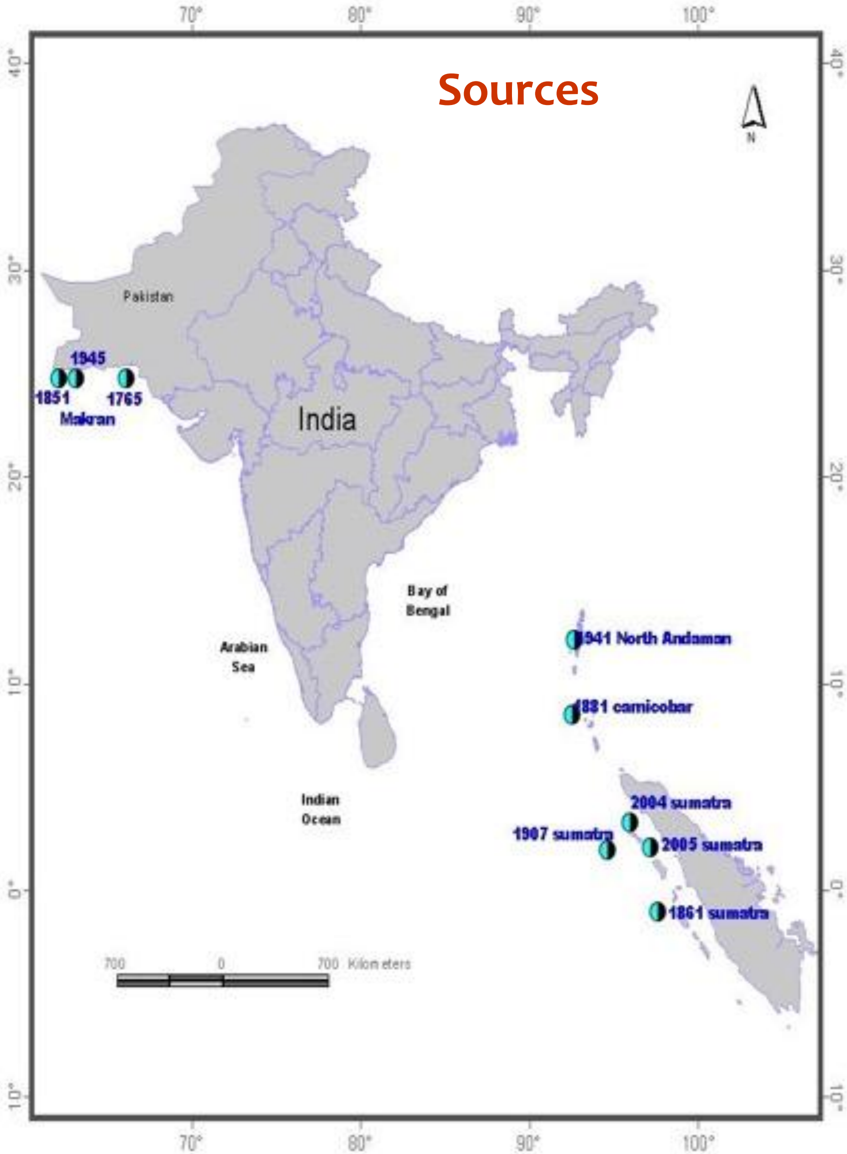
Historical Tsunamis in the Indian Ocean

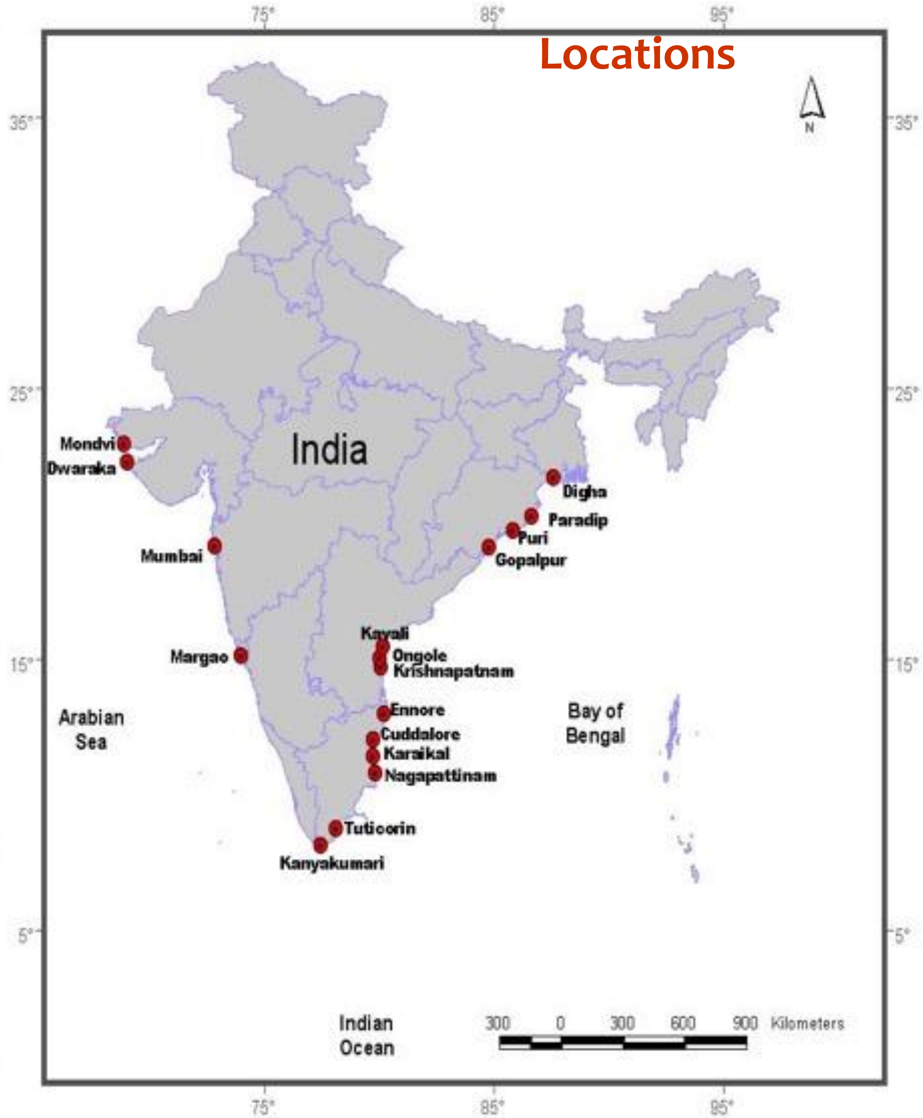
- 12 Apr, 1762 (BoB EQ) – 1.8 M
- 31 Dec, 1881 (Car Nicobar EQ)
- 27 Aug, 1883 (Krakatoa) – 2 M
- 26 Jun, 1941 (Andaman EQ)
- 27 Nov, 1945 (Makran EQ) – 12 M
- 19 Aug, 1977 (Sunda EQ) – 5 M
- 26 Dec, 2004 (Sumatra EQ) – 30 M
- 28 Mar, 2005 (Sumatra EQ) – 4 M
- 12 Sept, 2007 (Sumatra EQ) – 0.6 M
- 11 Apr, 2012 (Sumatra EQ) – 1 M

Tsunamigenic potential EQs for India

- Andaman-Sumatra & Makran subdution zones
- EQ Mag > 6.5
- Earthquakes under or near ocean
- Depth < 100km
- Vertical movement of the sea-floor

Simulated Tsunamigenic sources and Locations of Inundation modelling using RTK Topographic data

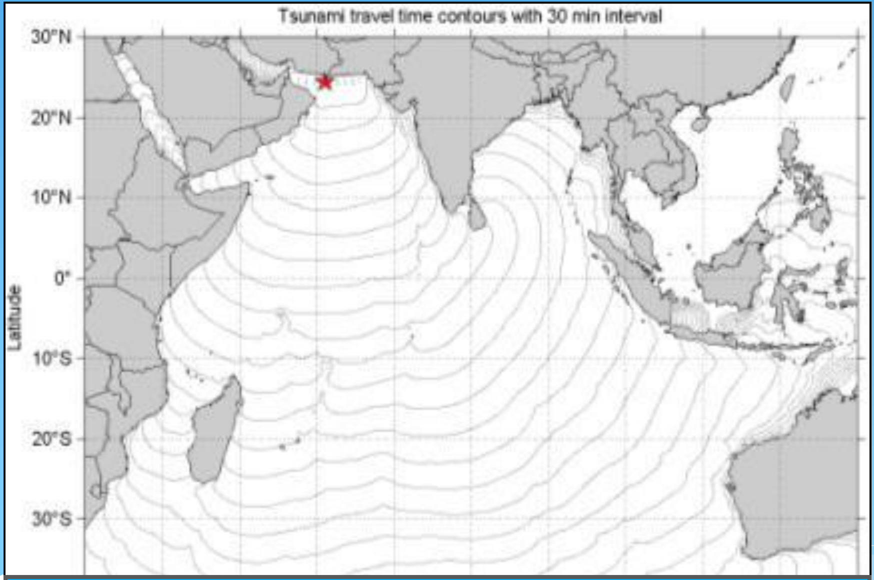




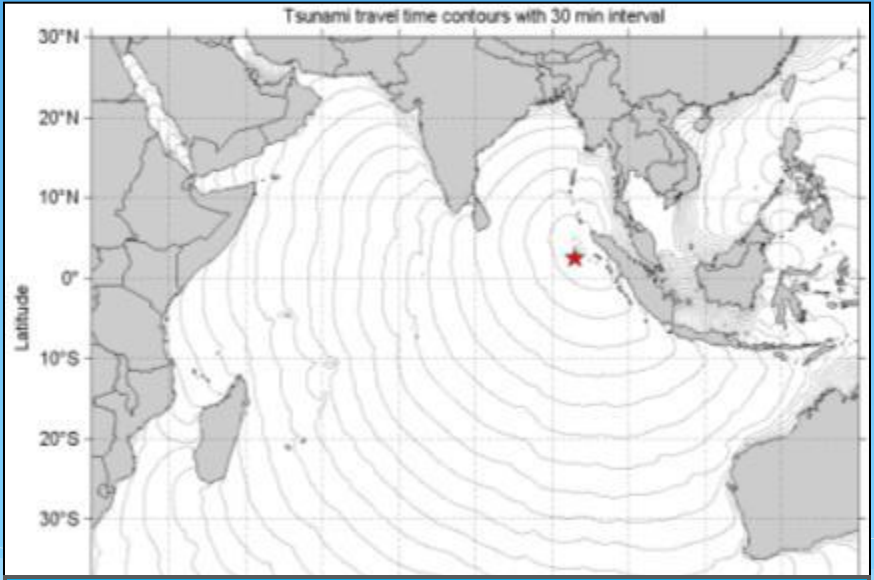
Risk Assessment

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**



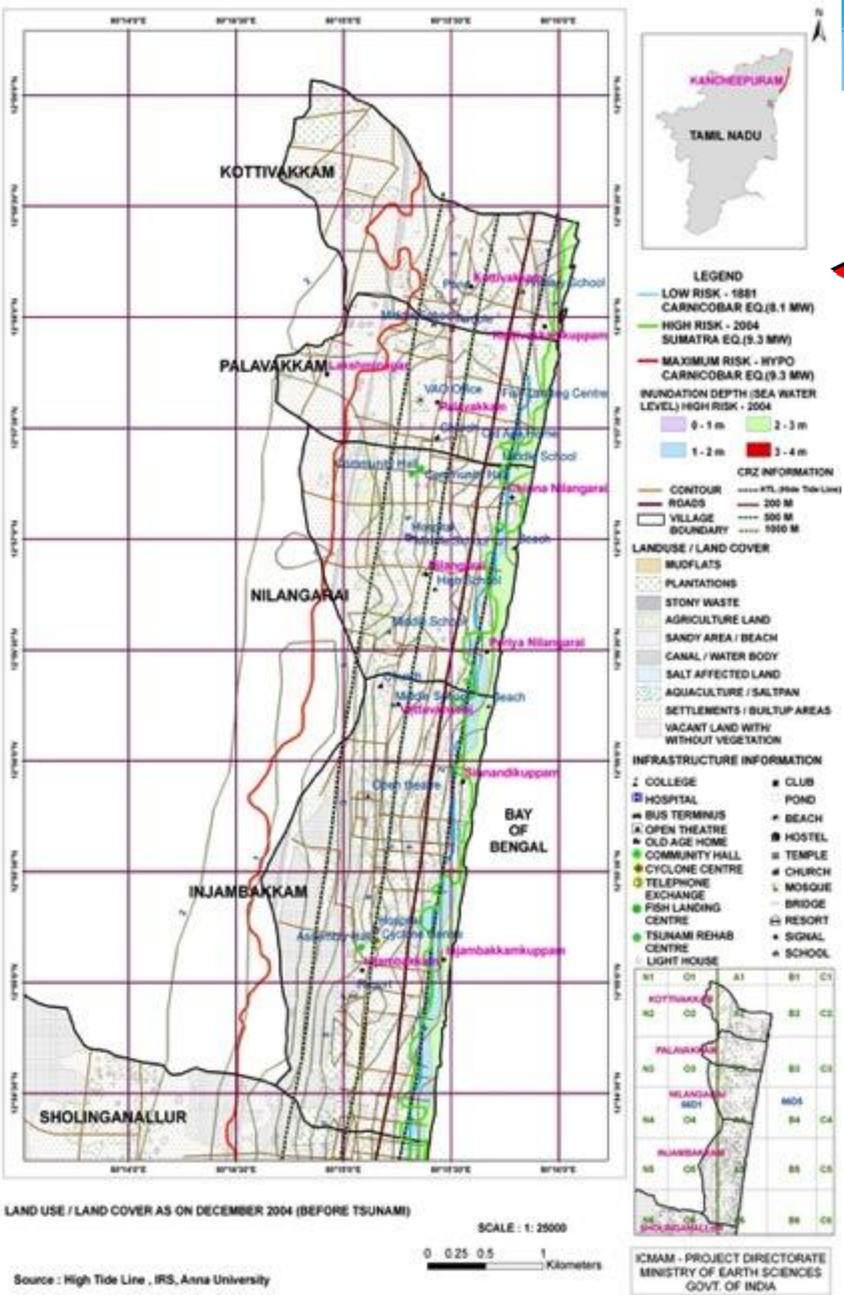
- If Earthquake occurs at Makran Subduction zone, Travel Time to nearest Indian Coast (Gujarat) are 2 to 3 hrs



- 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

Tsunami vulnerability map of Kancheepuram

1:25000



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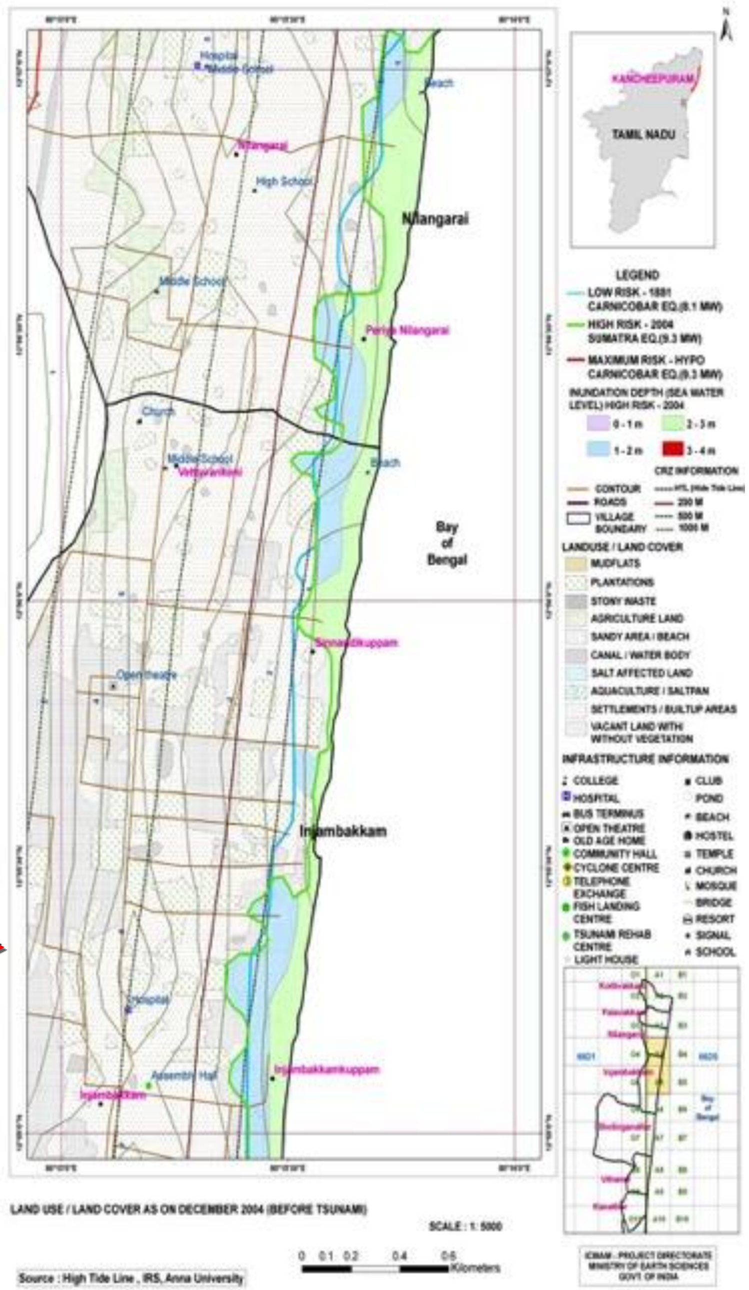
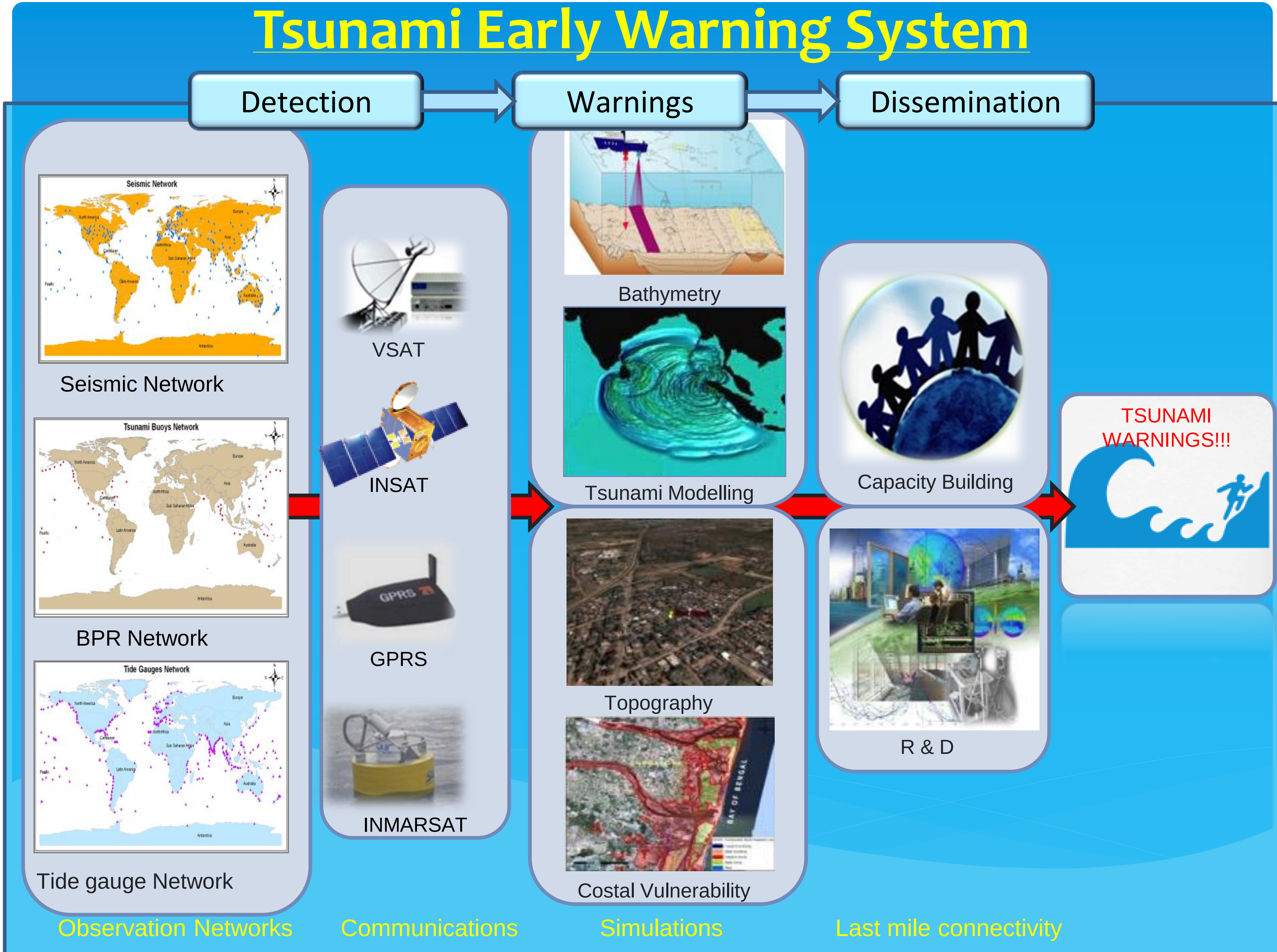


Inundation Map generated for Makran 1945 and Sumatra 2004.

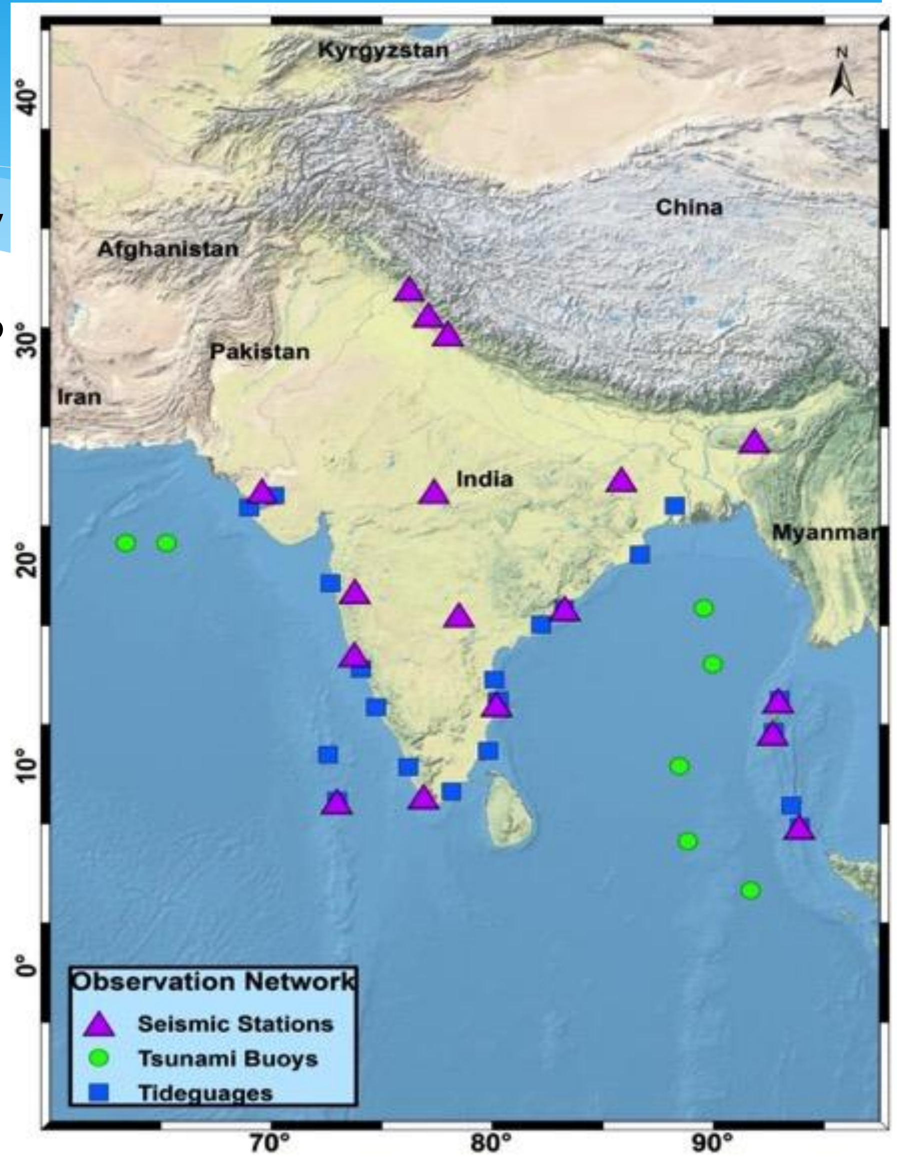
Detection, Warning and Dissemination


Tsunami Early Warning System
Detection
Warnings
Dissemination
Seismic Network
Seismic Network
Tsunami Buoys Network
BPR Network
Tide Gauges Network
Tide gauge Network
VSAT
INSAT
GPRS
INMARSAT
Bathymetry
Tsunami Modelling
Topography
Costal Vulnerability
Capacity Building
R & D
TSUNAMI
WARNINGS!!!
Observation Networks
Communications
Simulations
Last mile connectivity

Observational Network

- ➢ **Seismic Network**
  - ✓ 17 national broadband stations & around 300 International Stations
  - ✓ Network enhancement by establishing VSAT connectivity is under progress. Currently receiving data from 127 national seismic and GPS stations, it is being extended up to 500 stations
  - ✓ Establishing GPS & Strong Motion Accelerometer Network at Andaman & Nicobar Islands

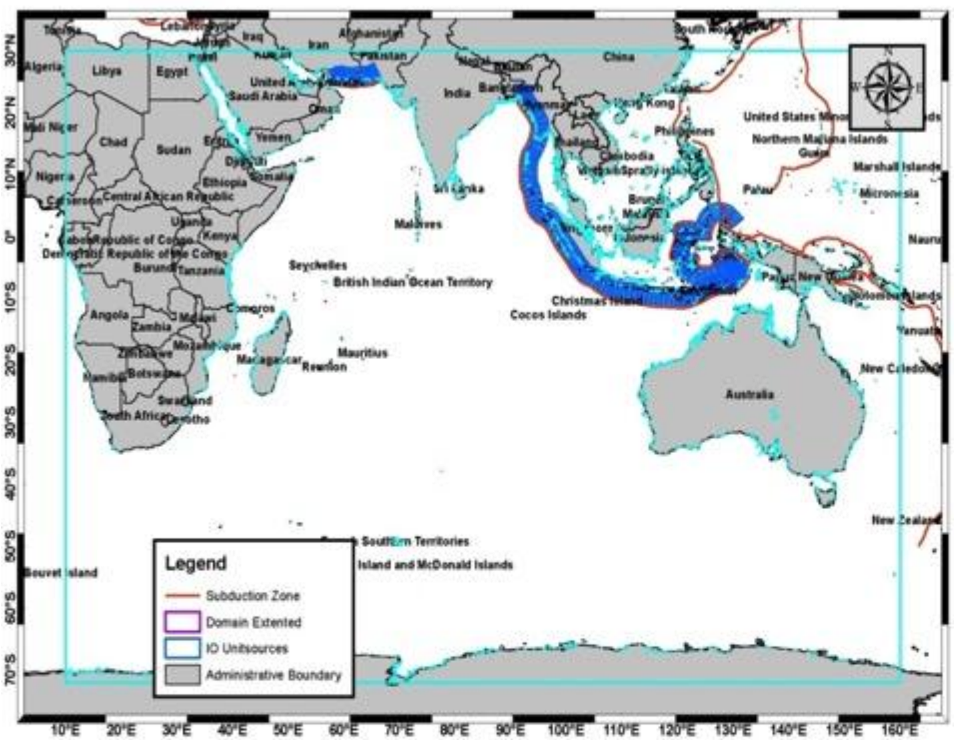
- ➢ **Sea-level Network**
  - ▪ Tsunami Buoys
    - Network of 7 Tsunami Buoys
    - 6 deployed, Five in Bay of Bengal & Two in Arabian Sea
    - Real-time data is being received at INCOIS and NIOT
  - ▪ Tide gauge Network
    - Network of 21 Tide gauges
    - 21 are operational and data receiving real time
    - Three types of Sensors at each location : Radar (RAD), Pressure (PRS) and Shaft Encoder (ENC)

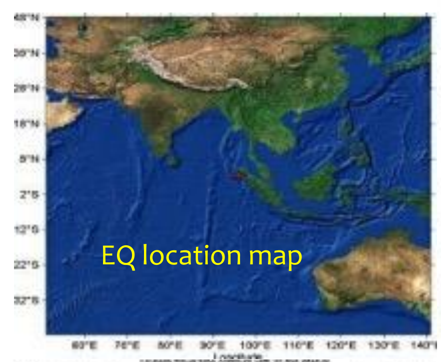


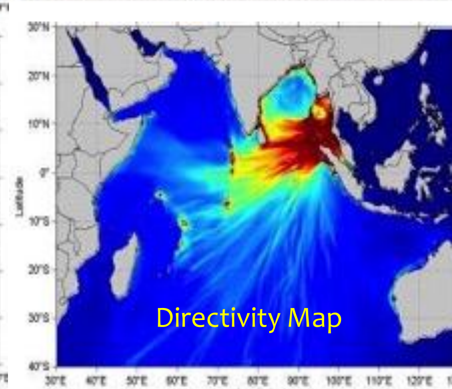
Tsunami Modelling

Open Ocean Propagation Database

- Model Domain with 3.2 million grids and scenarios covering Makran and Sunda subduction zones
- Each unit source of 100 X 50 km area representing rupture caused by EQ of M 7.5 with 1m slip
- Total simulation time increased from 15 hours to 25 hours for new domain of Indian ocean
- Depending on EQ's location and magnitude basic unit source scenarios are either scaled up or down
- Rupture is realistic with multiple rupture zones of M 7.5, instead of a single uniform rupture zone
- Expected Wave Arrival & Amplitude forecasts at all Costal Forecast Points (CFPs) in the Indian Ocean
- CFPs are then rendered to create threat profile for Coastal Forecast Zones (CFZs)

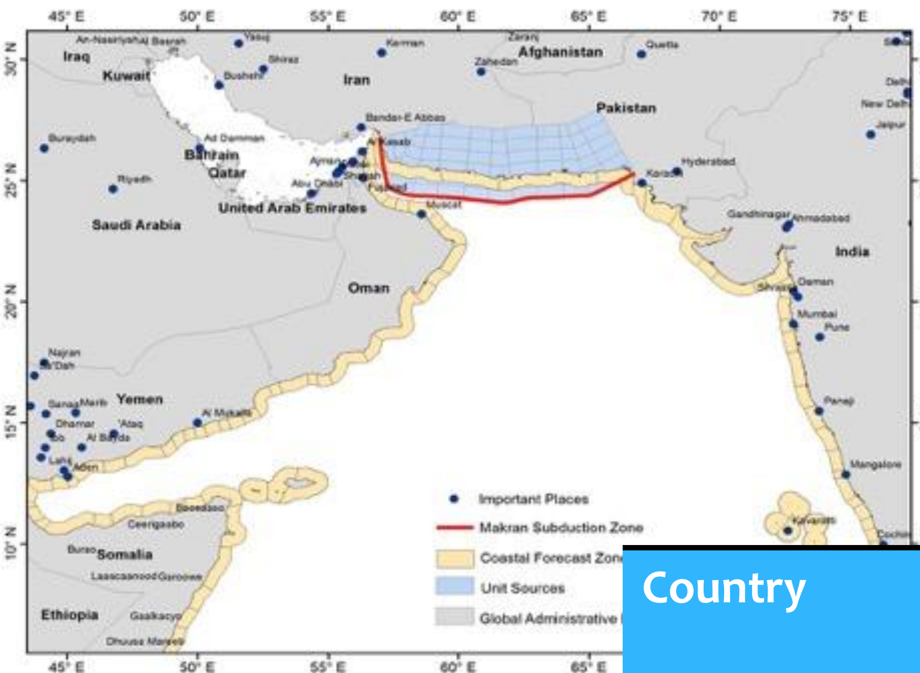


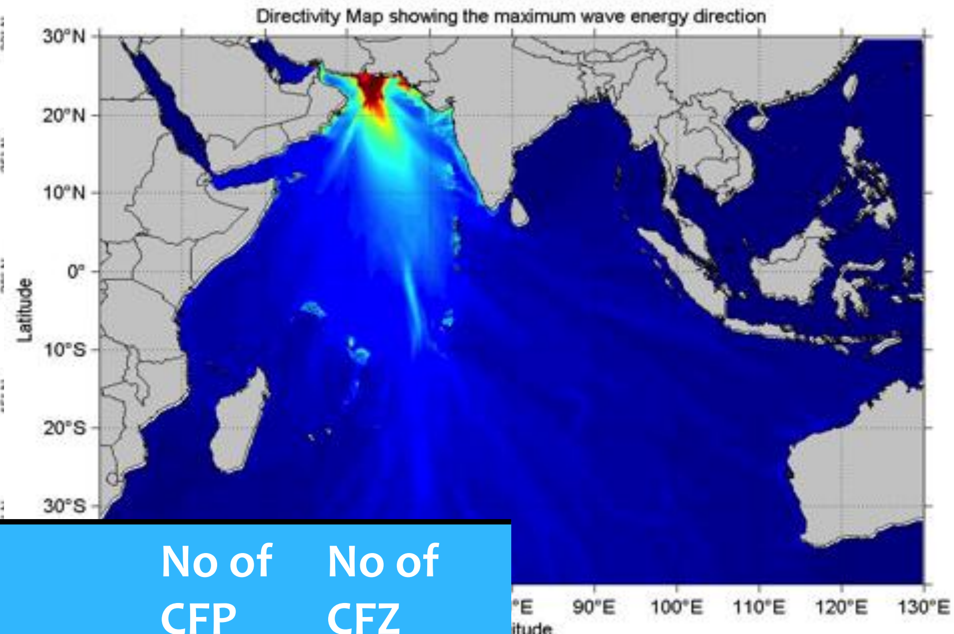




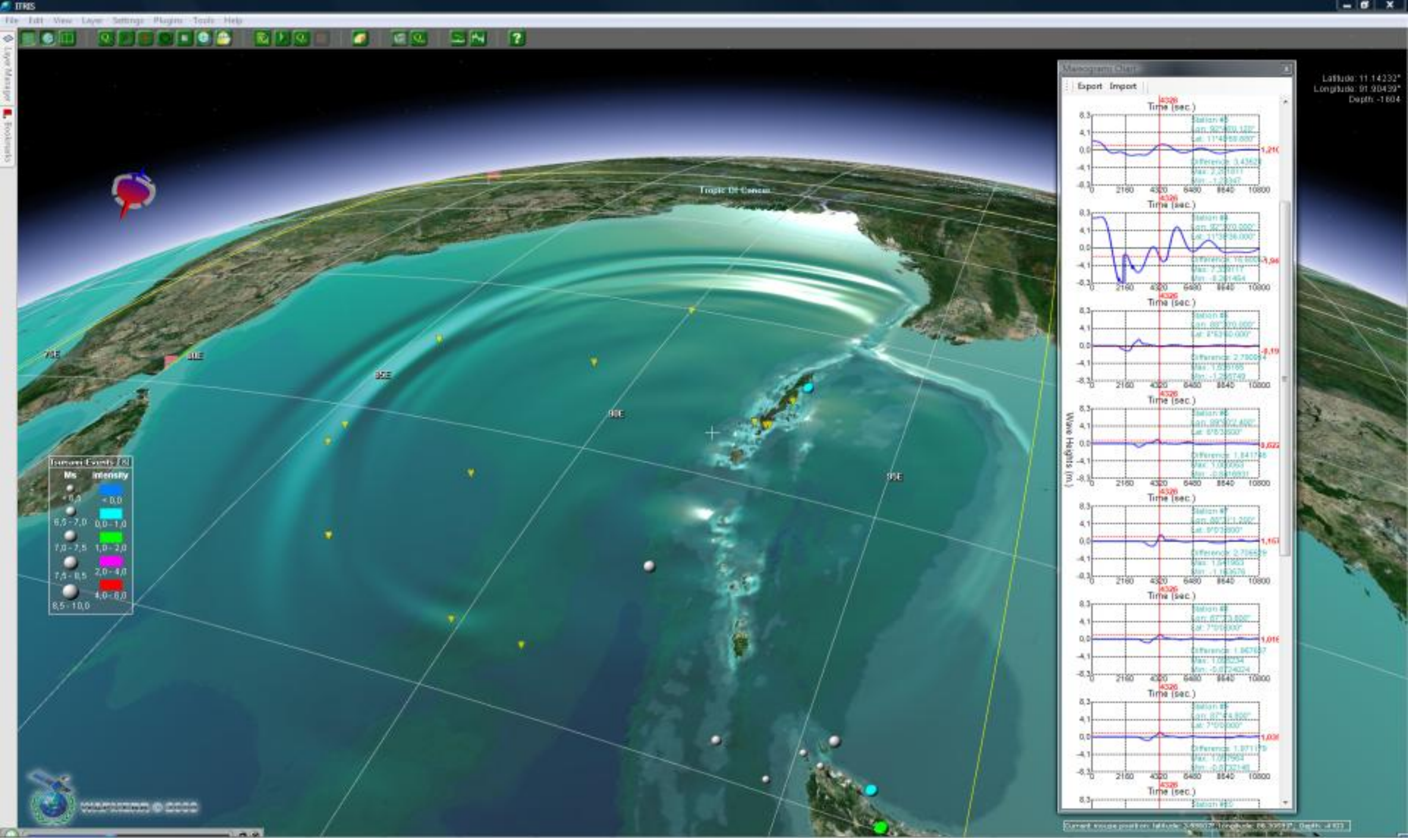
Tsunami Modelling

Makran Subduction zone

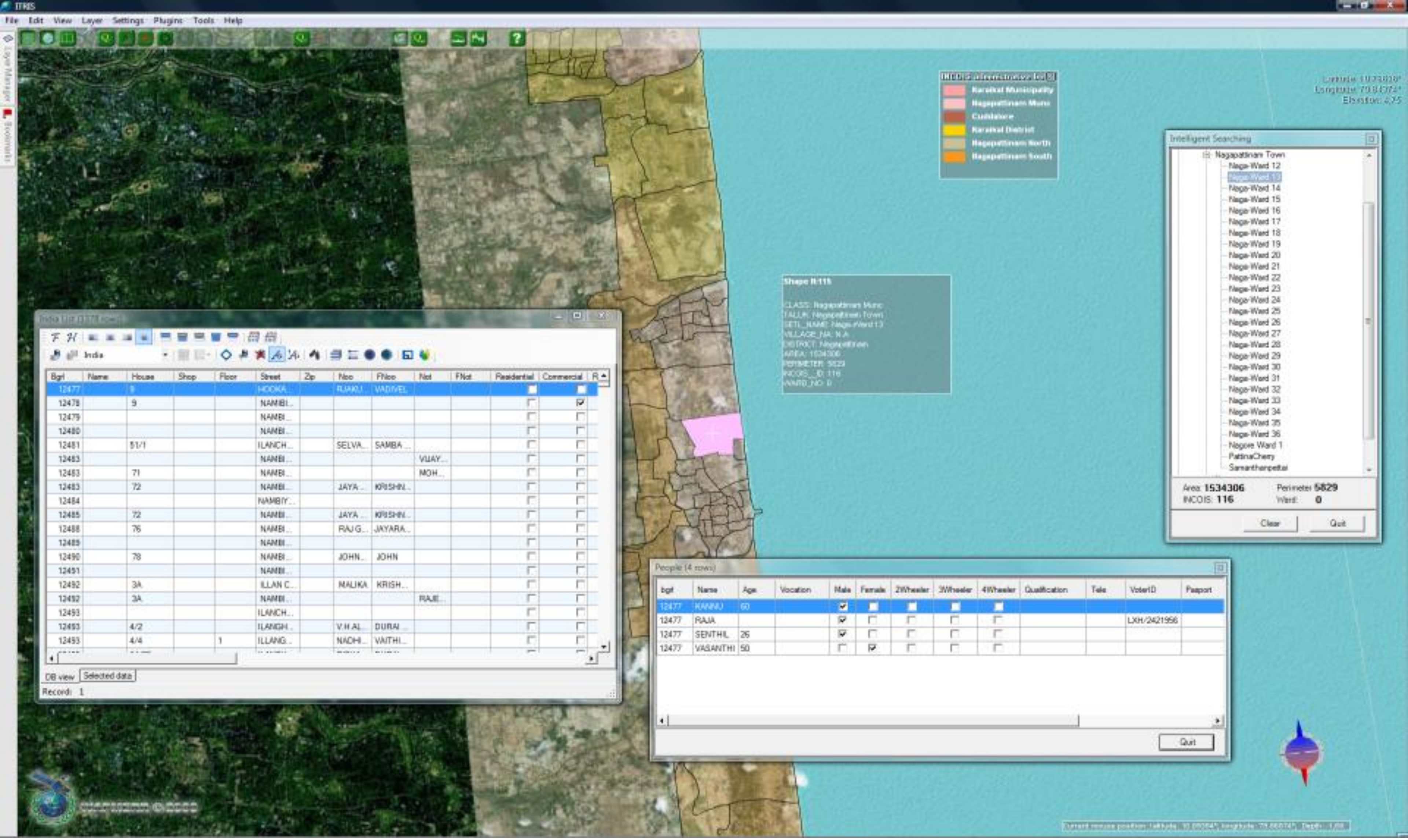




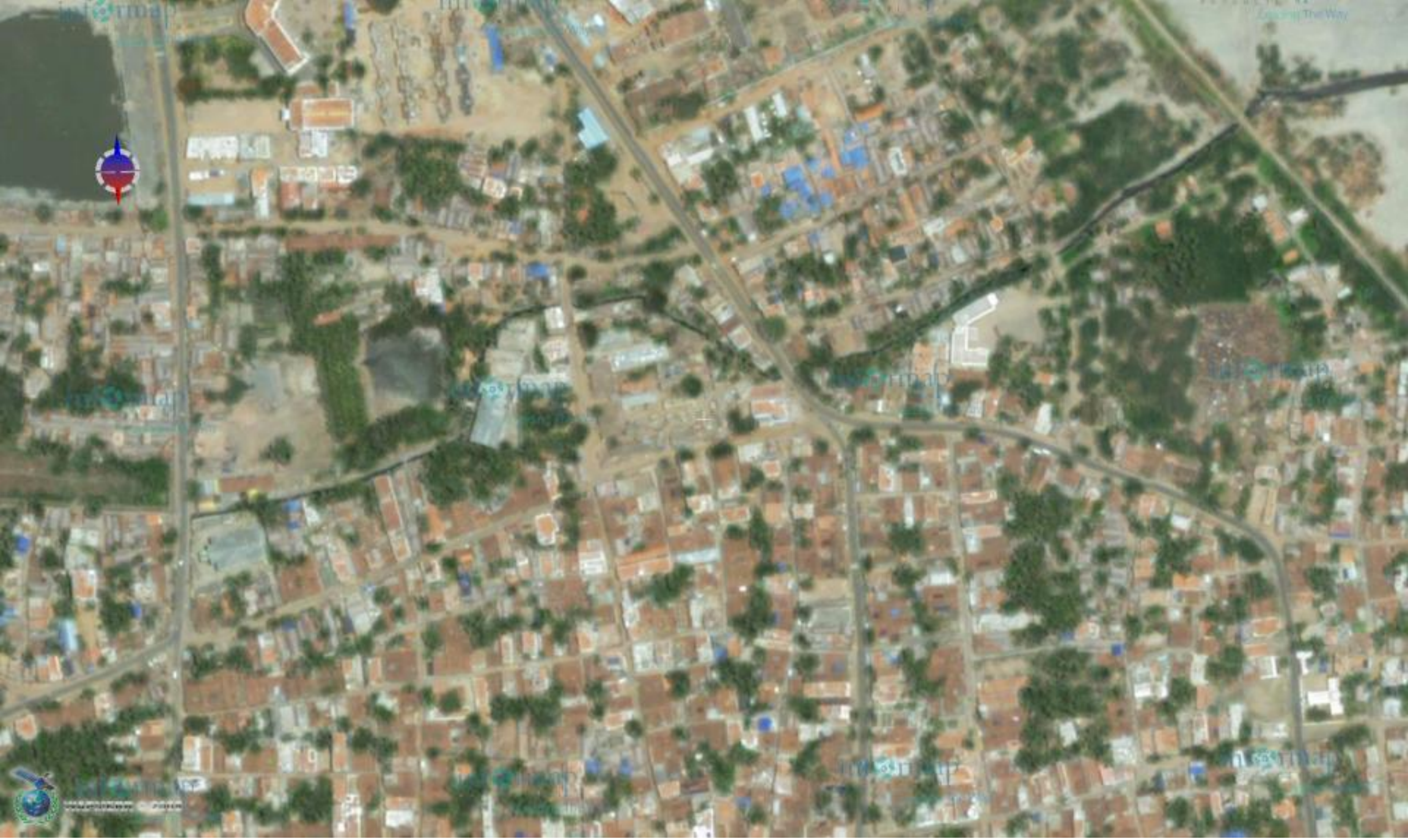
Country	No of CFP	No of CFZ
Pakistan	30	4
Oman	43	16
Yemen -	67	20
UAE -	17	2
Iran -	16	3
West coast of India	152	32



Numerical modeling of the tsunami propagation using ITRIS shell



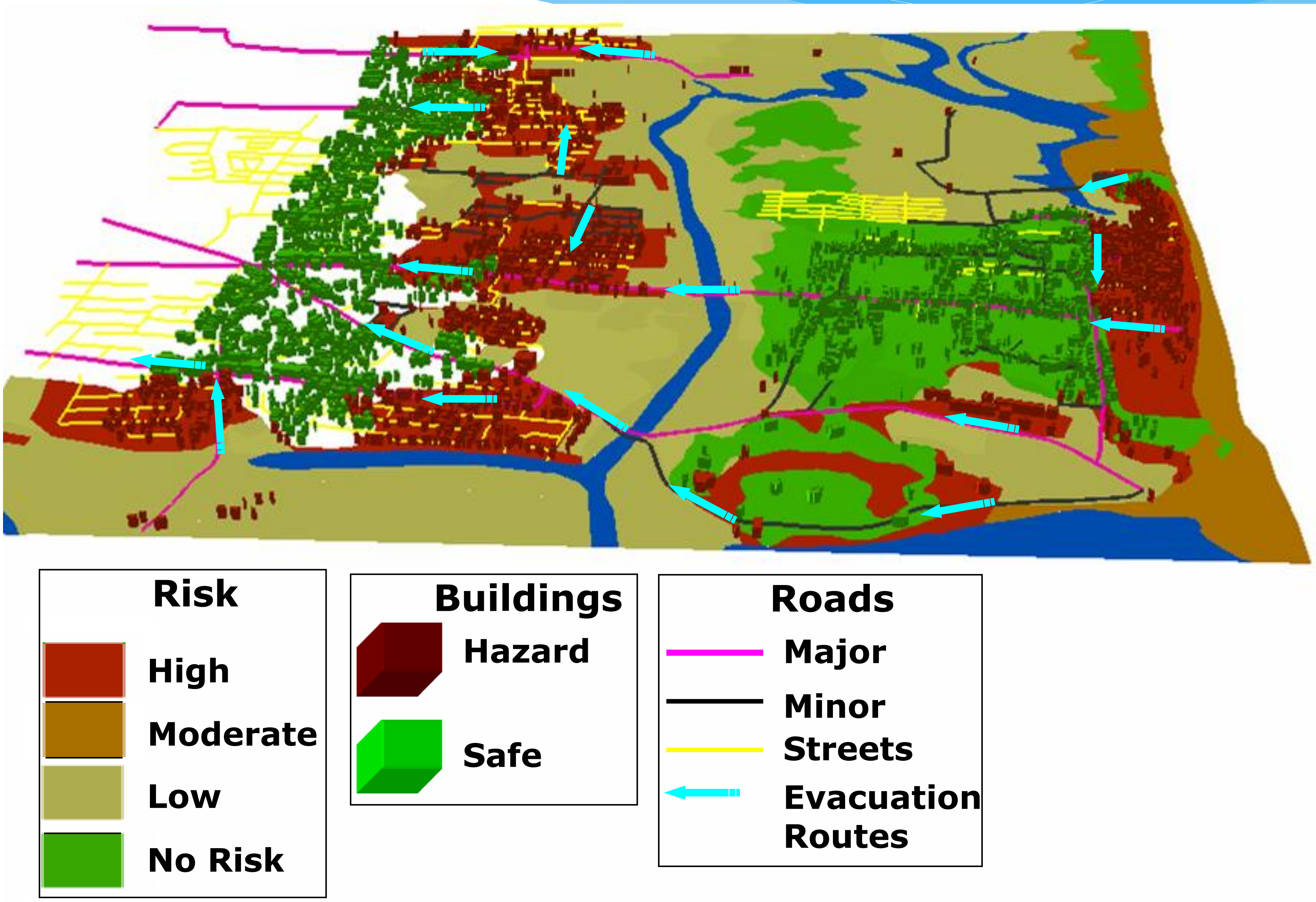
Administrative boundaries with the building, people and other information



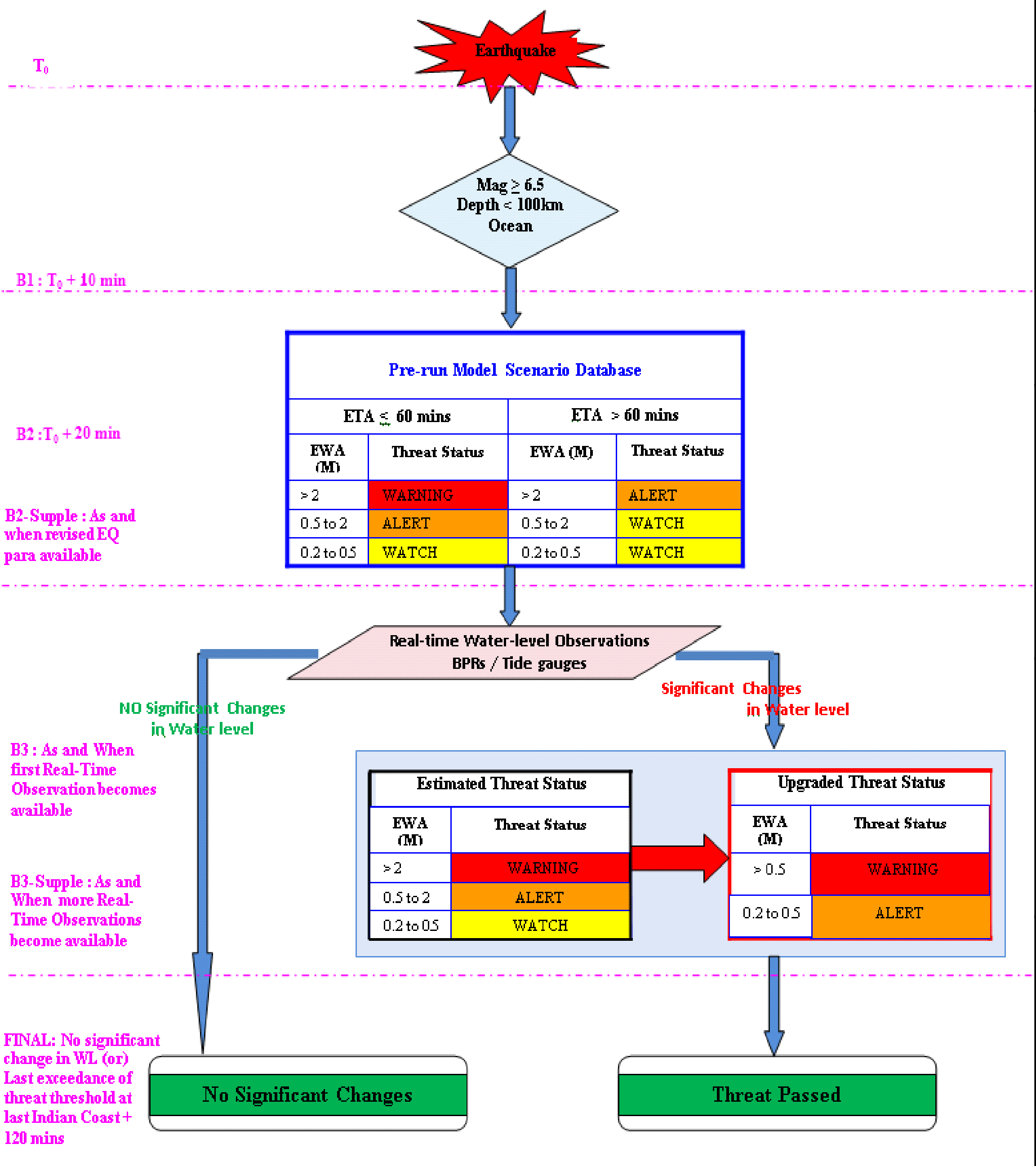
ITRIS allows to select any area of the Earth surface and zoom in on this area up to the highest resolution 60 cm (if a certain satellite imagery of the highest resolution is available)

Manipulation with realistic 3D models and textures of real buildings. Provides the possibility for including of real object images (peoples, items, signs) in a 3D model. The building brief (address, telephone, owner) appears in the pop-up information box. (This example is Nagapattinam India).

Evacuation Route

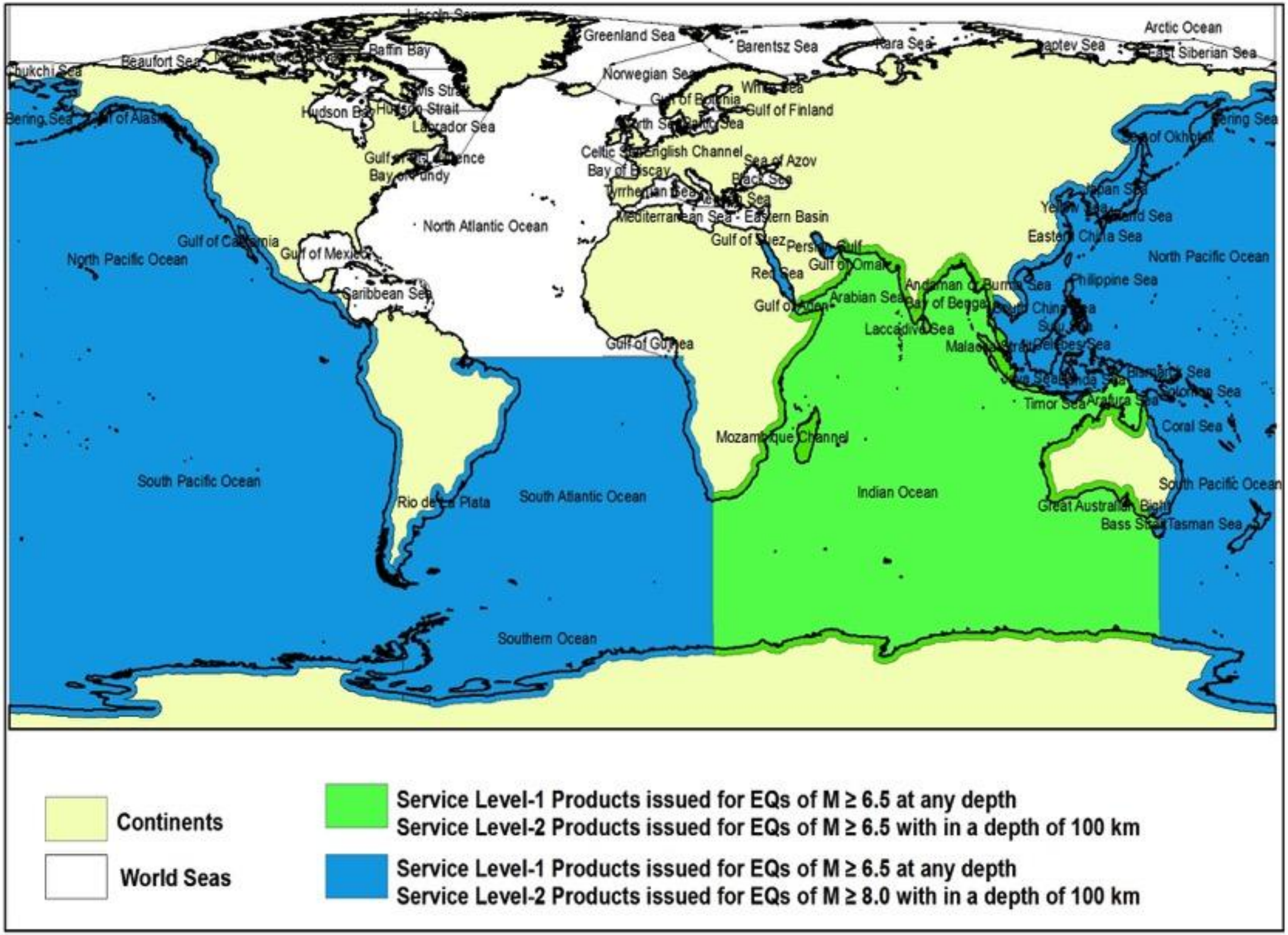


Standard Operating Procedure (SOP)



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

Earthquake Source Zone Map

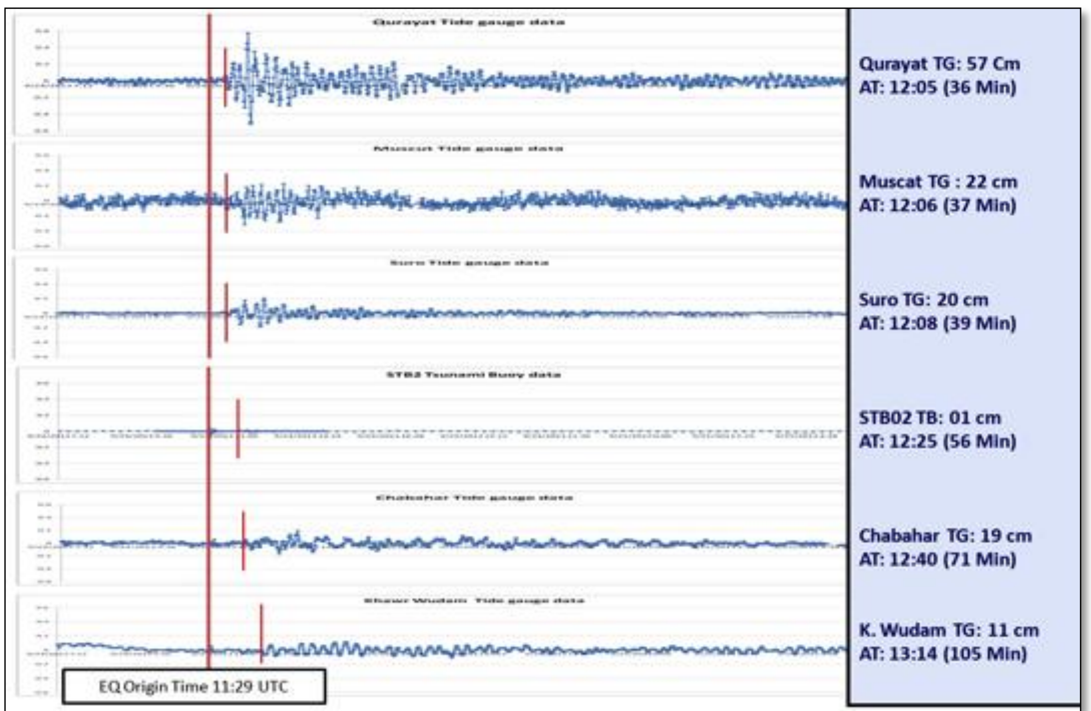


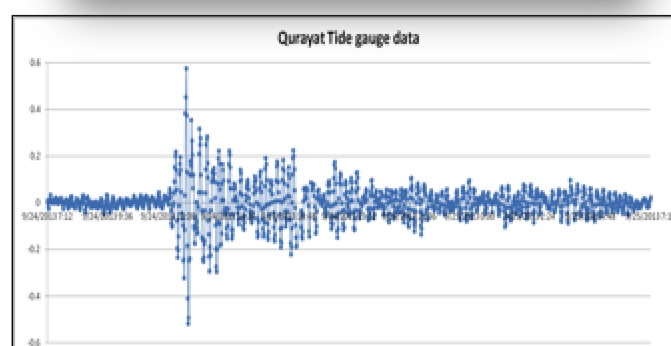
M 7.7 of 24 September 2013 Pakistan Event

M 7.7 of 24 September 2013 Pakistan Event #	57 cm at Qurayat Tide gauge in Oman

The earthquake occurred about 180 km inland from the Pakistan coast and generated a minor tsunami measuring about 57cm at Quarayat, 22cm at Muscat and 20cm at Suro, Oman. Indian Tsunami buoys (STB02 & TB12) in the north Arabian Sea were also got triggered due to the earthquake and recorded open-ocean sea-level variations of 1-2 cm. Water level variations due to this tsunami were detected and monitored successfully by the IOTWS TSPs. The water level changes, though insignificant, were very unusual considering that the earthquake was far inland. It is important that reasons be investigated for the triggering of minor tsunami and procedures be evolved for handling such unusual events.

Event	Elapsed Time of First EQ Bulletin (min)	Elapsed Time of First Threat Assessment Bulletin (min)	Threat Assessment		Number of Bulletins Issued	Threat Cancel Time (mins)
			Threat Zones and Countries	Highest Predicted Wave Amplitude		
Pakistan	11	16	No Threat	--	2	--

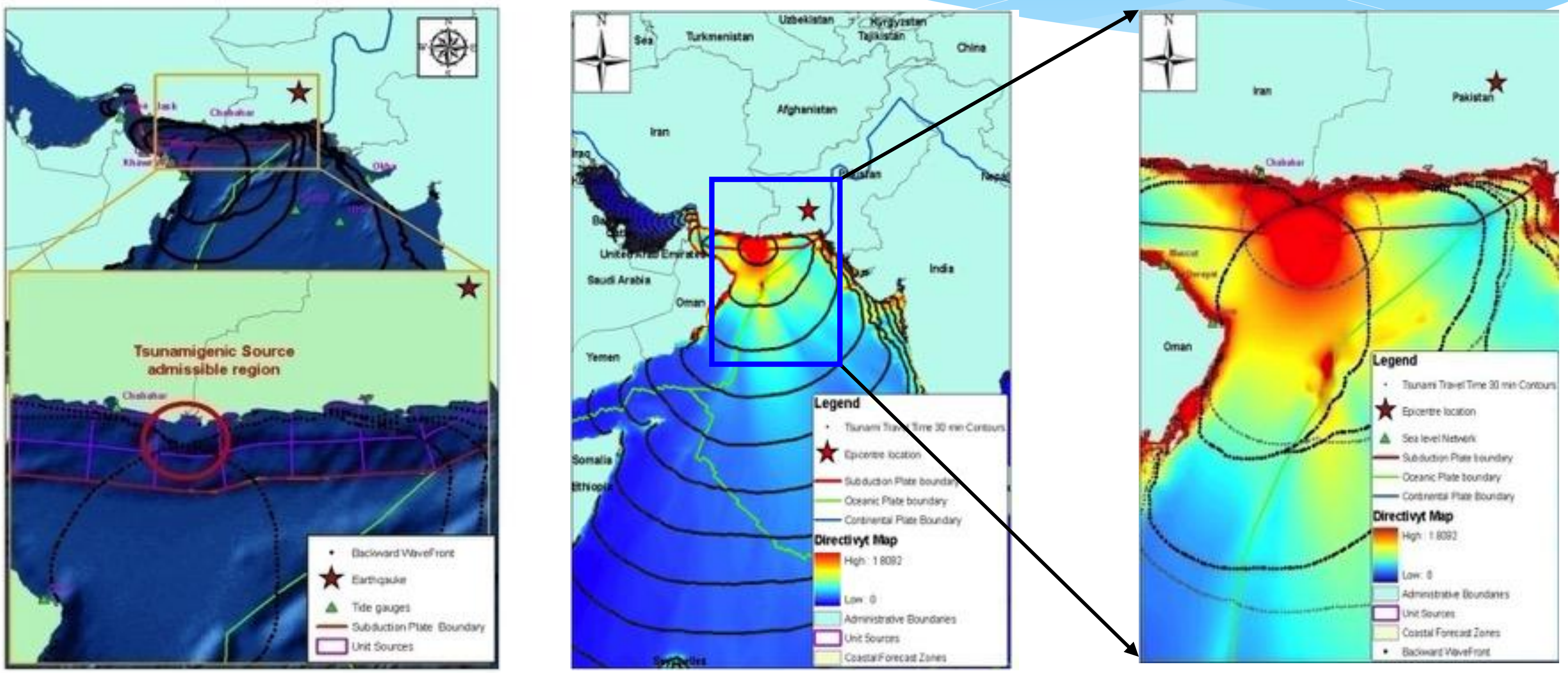




M 7.7 of 24 September 2013 Pakistan Event

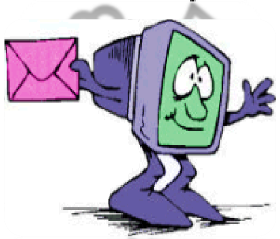
Admissible region of Tsunamigenic source of 24 Sep 2013 is identified using Backward ray tracing method

Backward Ray Tracing for Tsunami on 24Sep2013



Dissemination of Tsunami Bulletins

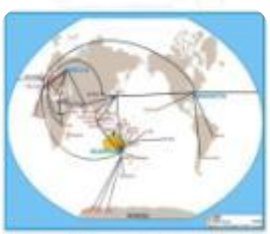
Fax



Email

SMS

Web



GTS

International Level
All 23 Indian ocean rim countries

National Level
MHA, NDMA, MoES, NDRF Head quarters, IMD & CWC

State Level
Principal Secretaries (Revenue) of Andaman & Nicobar Islands, Andhra Pradesh, Gujarat, Goa, Karnataka, Kerala, Maharashtra, Orissa, Tamilnadu, West Bengal, Lakshadweep and Puducherry

District Level
DROs of Srikakulam, Vizianagaram, Visakhapatnam, East Godavari, West Godavari, Krishna, Guntur, Prakasham, and S.P.S Nellore

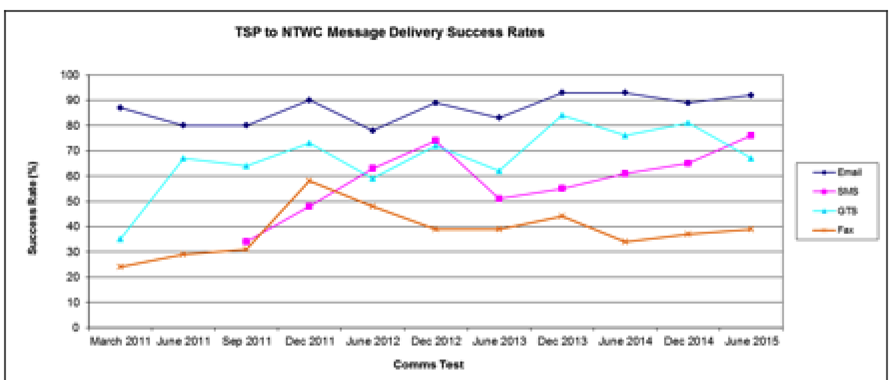
Institutional
1-10 NDRF Battalions, ALL control rooms of A&N Islands, HQWNC, HQENC, HQANC, HQSNC, NOIC Tamilnadu, Gujarat, West Bengal, NPCIL, Mumbai, Madras Atomic Power Station, Tarapur Atomic Power Station (1&2, 3&4), Kudankulam Atomic Power Unit, SHAR, MRCC, Coast Guards, Port Officers, Coastal Industries (Reliance) Media & Public subscriptions

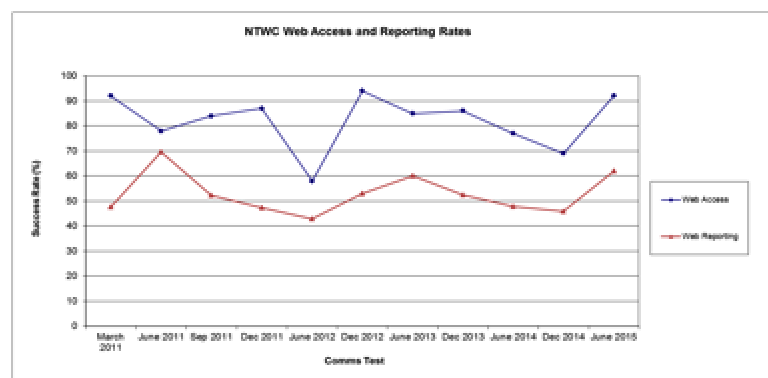
Awareness & Response

COMMs Tests & Tsunami Mock drill

- **Communication Tests**
  - December 10, 2014 (NTWCs)
  - June 10, 2015

TSP India NTWC Messages Delivery	Results of December 10, 2014	Results of June 10, 2015
GTS	81% (0-15 min)	80% (0-5 min)
FAX	41% (0-335 min)	47% (0-11 min)
Email	86% (0-95 min)	93% (0-17 min)
SMS	62% (0-397 min)	76% (0-9 min)
Web Access	69%	95%





Tsunami Mock Drills – IOWave14

Message Reception		
	Time Delay (minutes)	
Mode	**09 Sep, 2014**	**10 Sep, 2014**
Email	0 – 14	0 – 5
Fax	0 – 30	0 – 30
SMS	0 – 6	0 – 8

Time taken to notify public		
Activity	**Elapsed Time (in mins)**	
	Odisha	**Puducherry**
Making a decision on public warning (from time of receipt of warning)	10	20
Formulation of public notification (from time of decision)	5	15
Activation of public notification systems (from time of notification formulated)	5	15
Total Time	20	50

- Tsunami mock drill IOWave14 was conducted on 09 & 10September, 2014
- The exercises comprised two scenarios on successive days, one in the eastern Indian Ocean and the other in the North-western Indian Ocean
- The drill taken down to different levels, involving their field units, local officials, line departments and public, as appropriate
- Authorities executed village/community level evacuation in Puducherry and Odisha.

Tsunami SOP Workshop on Aug 26, 2015

Tsunami Standard Operating Procedure Workshop

- In preparation to the drill, INCOIS organized a tsunami **Standard Operating Procedure (SOP) workshop** on 26 August 2015 at INCOIS, total 51 officials participated in the workshop from
  - Disaster management authorities of 5 East coast states(provinces)
  - National Disaster Response Force
  - Indian Navy and coast guard

Mock Exercise Details:

Magnitude	:	9.0 Mw
Latitude	:	12.65 N
Longitude	:	93.50 E
Depth	:	10 km
Origin Time	:	0930 IST (0400 UTC)
Date	:	September 26, 2015
Region	:	Andaman Islands, Indi

- Tsunami exercise was conducted 4 hours (0930 to 1330 IST)
- 7 Tsunami bulletins disseminated through Email, Fax, SMS, Web

Table-top Exercise

Tsunami Mock Drill on Sept 26, 2015

- **Tsunami Mock Drill to East Coast of India**






- On 26 September 2015 tsunami mock drill conducted to East Coast of India, issued 7 bulletins during 0930 hrs to 1330 hrs
- Village level evacuations were carried out in few coastal districts of East Coast of India
  - 11 villages in Andhra Pradesh
  - 6 districts in Odisha
  - 1 village in Puducherry
  - 4 villages in Tamil Nadu
  - 6 villages in West Bengal

Challenges & New Initiatives

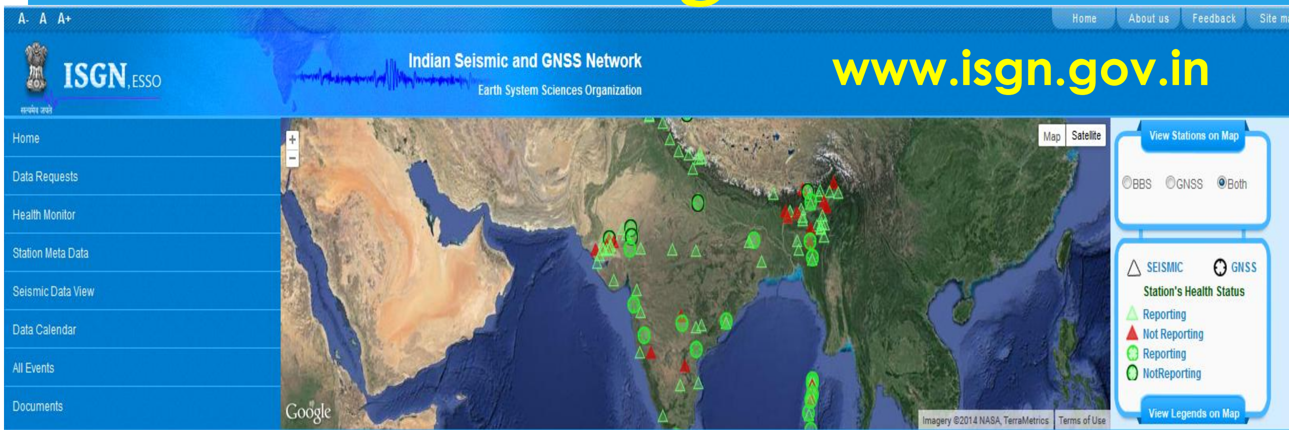
Some Challenges

- Under-estimation of Initial Magnitude and Tsunami wave heights
  - Tohoku-Oki Earthquake on March 11, 2011
  - Big challenge in case of large earthquakes especially for near-source regions wherein there is a requirement of very quick information
- Over-estimation of Forecasted Tsunami wave heights
  - Northern Sumatra Earthquake on April 11, 2012
  - Tsunami amplitude estimate " > 2m" at Andaman & Nicobar Islands, but observed 30 cm as the actual displacement was in horizontal direction. This is due to the consideration of thrust fault mechanism in the scenario generation
- Emergency Communication
  - Many remote coastal villages with failed electricity or telephone communications
- Non-Seismic Causes (submarine land slides, etc)

New Initiatives

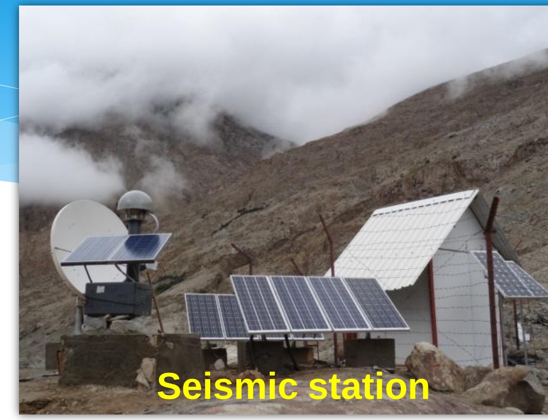
- Densification of Sensor Networks: Real-time GNSS & SMA Network at A & N Islands
- Modelling Enhancements (real-time modelling, water level inversion)
- Visualization and Analysis System for 2D and 3D Geospatial data (3DVAS)
- VSAT based Communication System for Emergency Operations Centres
- Integration of Storm Surge Forecast System

Enhancing Observation Network

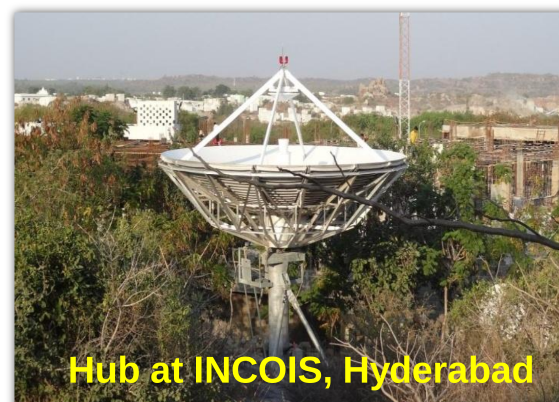


List of Events for past 30 days with magnitude > 6

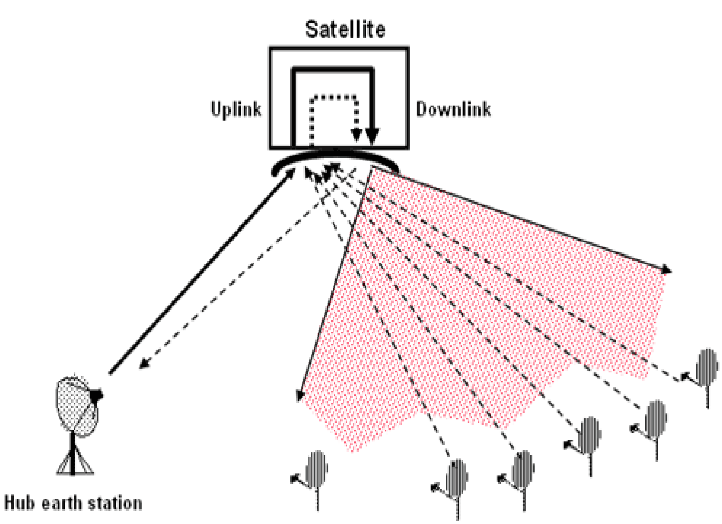
Origin Time (UTC)	Magnitude	Latitude	Longitude	Depth (KM)	Region Name
2014-03-19 00:34:14	6.1	5.2S	153.083E	10	New Ireland Region, P.N.G.
2014-03-18 21:26:48	6.1	20.005S	70.759W	10	Near Coast of Northern Chile
2014-03-17 05:11:36	6.4	20.044S	70.858W	10	Near Coast of Northern Chile
2014-03-16 21:16:30	6.8	19.886S	70.689W	10	Near Coast of Northern Chile
2014-03-15 23:51:31	6.3	5.572S	81.079W	10	Near Coast of Northern Peru
2014-03-15 08:59:21	6.1	14.109S	76.322W	10	Near Coast of Peru

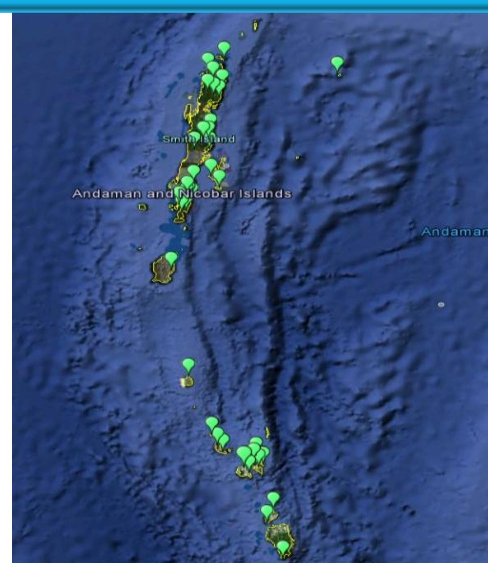

Seismic station


GNSS station


Hub at INCOIS, Hyderabad

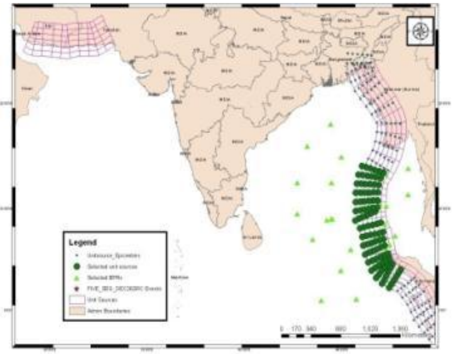
GNSS & Strong Motion Network at A&N Islands

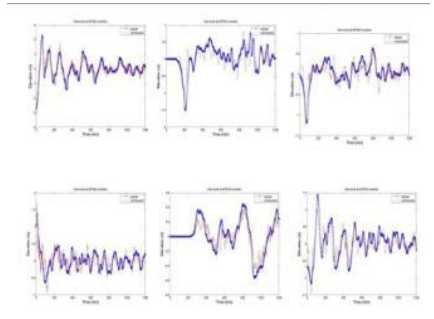




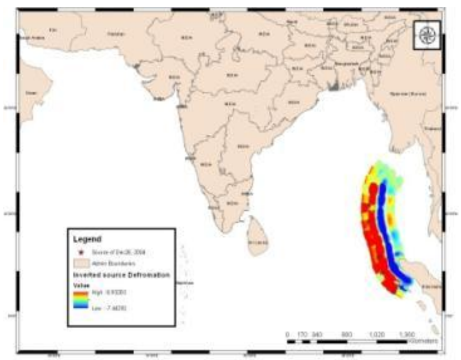
Modelling Enhancements

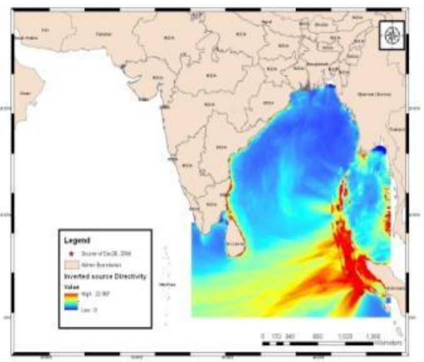
Real-time Water level inversion





Least Square Fit Analysis for Best Fit Five segment source VS Unit Sources



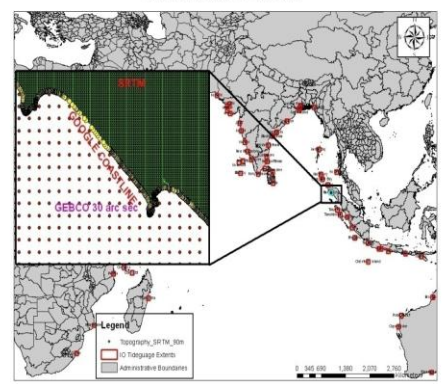


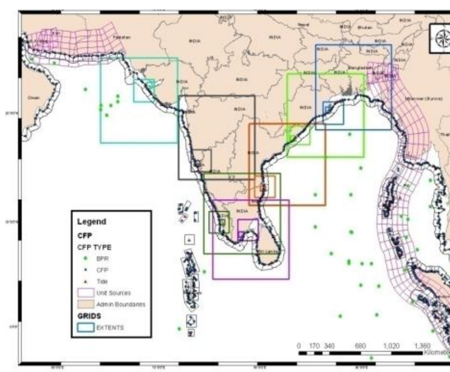
- Integration of Inversion module into DSS under progress
- Inversion for slip distribution at unit sources
- Least square fit analysis of green functions and residuals at BPRs
- The Planned BPR network will cover the sources at Andaman & Nicobar Islands

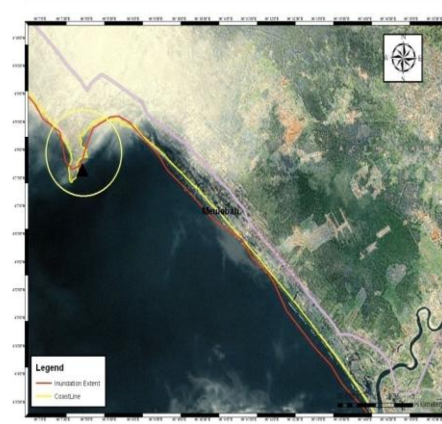
Modelling Enhancements

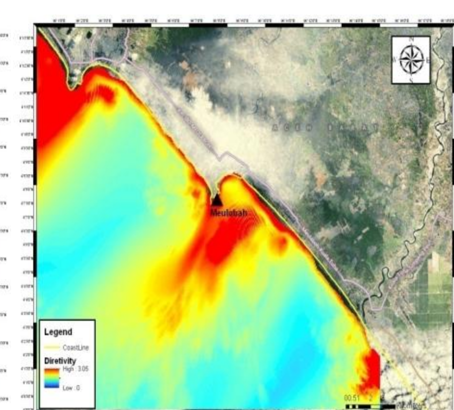
- **Total no of Indian Ocean Tsunamigenic sources: 2(Andaman &Sumatra, Makran)+7 (includes South China sea, Banda sea, Java sea, Celeb sea)**
- **Total no of Indian Ocean Unit sources: 1320**
- **New IO Domain Extent: 10E-160E**
- **Spatial Resolution: 2.5Km**
- **No Of Output Files For Each Scenario:1500 (25 hr)**

Data Preparation to setup SIM's



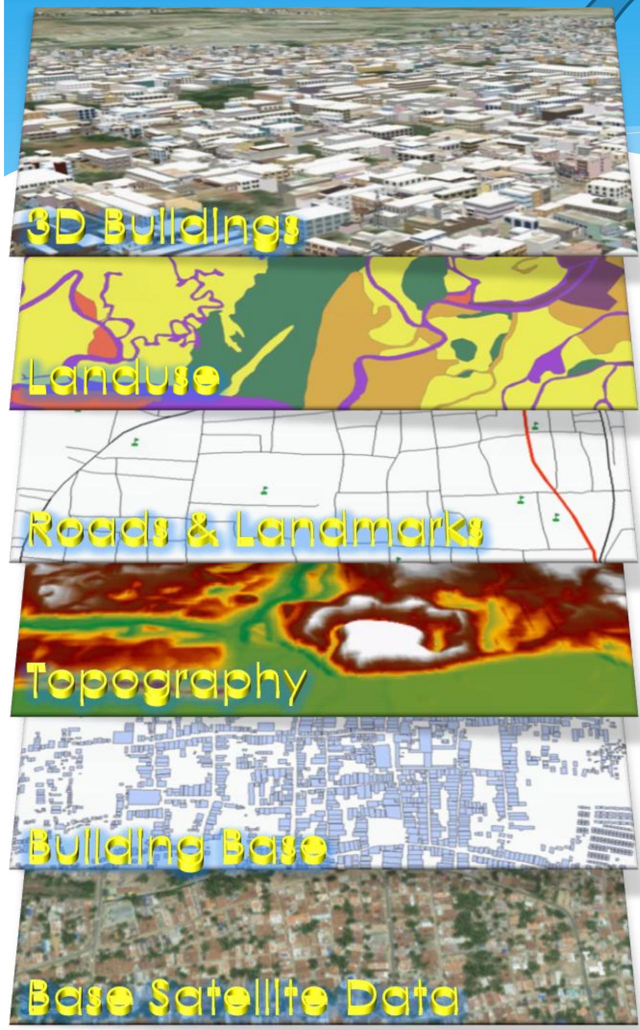


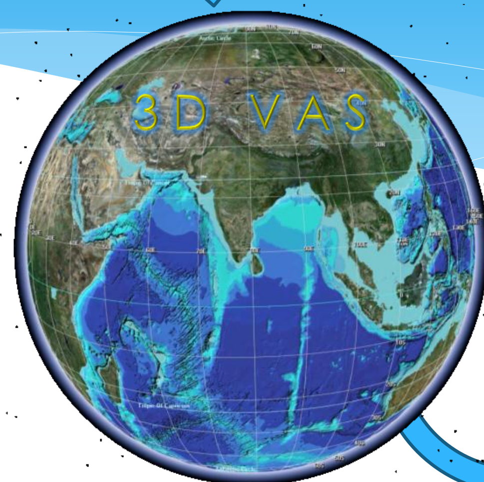




Visualization and Analysis System for 2D and 3D Geospatial data (3DVAS)

Generation of 3D GIS Maps



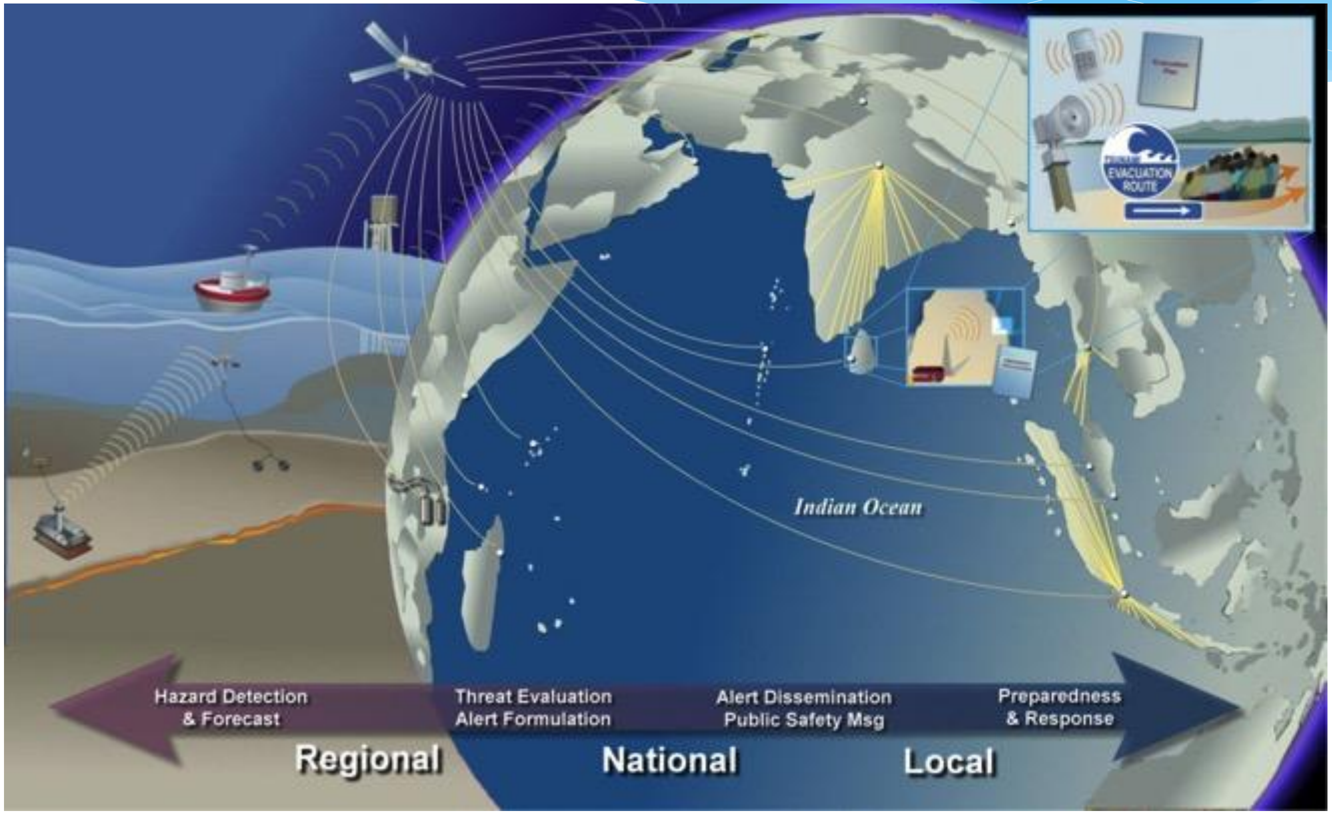


Base Maps, Hazard Maps, vulnerability maps, database of tsunami and storm surge inundation modeling results, event data, etc.

Ground Survey: GCP, Leveling, Field Photos, Socio-economic census, etc

Risk analysis and advisory

Vulnerability maps integrated with 3D GIS database will aid in making effective disaster management plans



Thank you!

www.incois.gov.in

Data Sharing

➢ Data Exchange from Indian Seismic & Sea level stations

- Real-time data sharing with the international community from
- Seismic stations operating at Minicoy, Port Blair and Shillong (available through the IRIS server)
- Tide gauges operating at Chennai, Cochin, Minicoy, Nancowry, Port Blair, and Visakhapatnam (available through the IOC sea level website)
- Six Tsunami Buoys -STB01, STB02, ITB05, ITB06, ITB09 and ITB12 (available through the NDBC website, ITEWC Website & FTP).