India's Tsunami Warning System:

A Success Story

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NATIONAL GEOPHYSICAL RESEARCH INSTITUTE

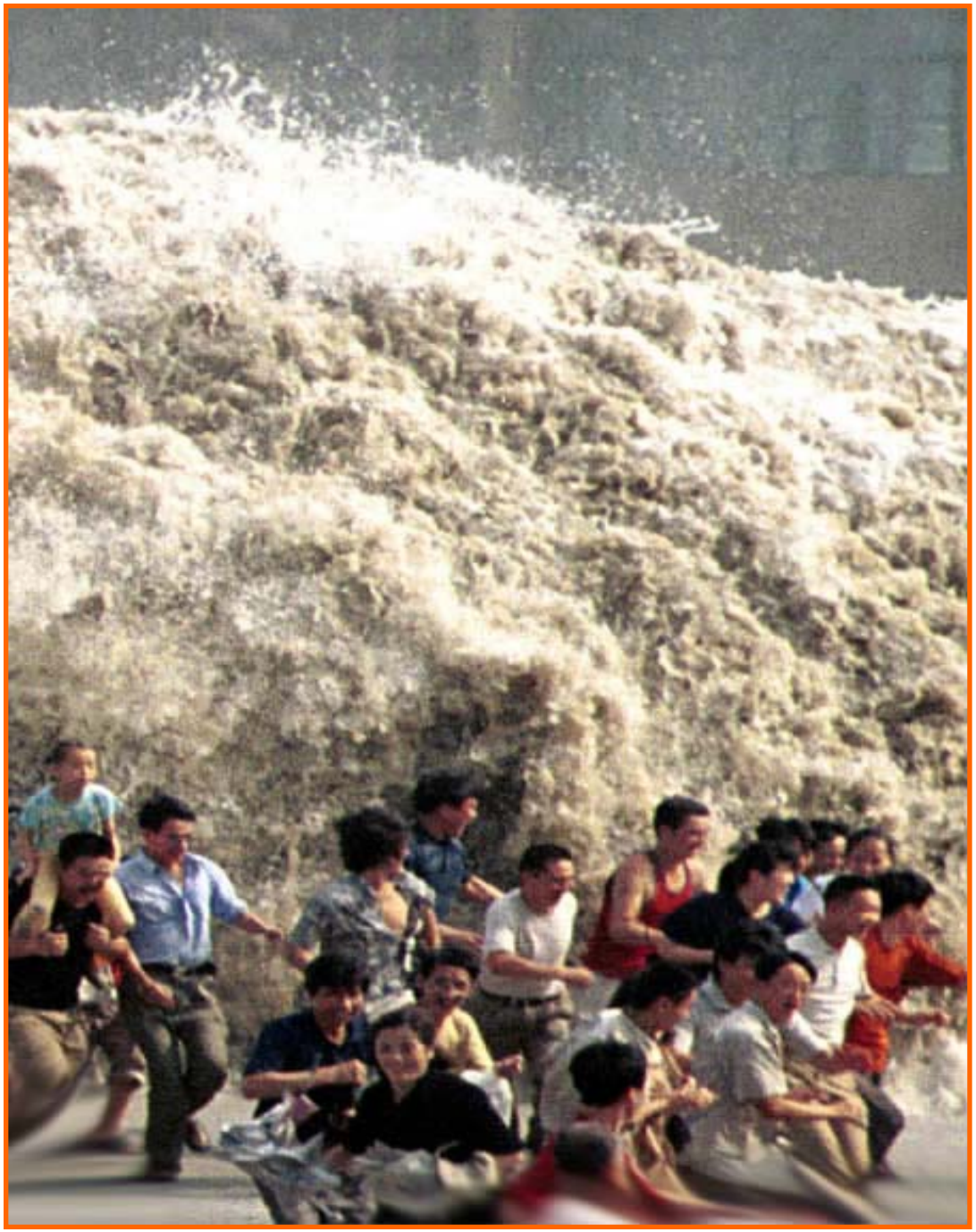
(COUNCIL OF SCIENTIFIC & INDUSTRIAL RESEARCH)

HYDERABAD – 500 007, INDIA

29th June, 2011

December 26, 2004

- **Most destructive tsunami ever experienced.**
- **Over 250,000 human lives lost.**
- **Unprecedented financial loss.**



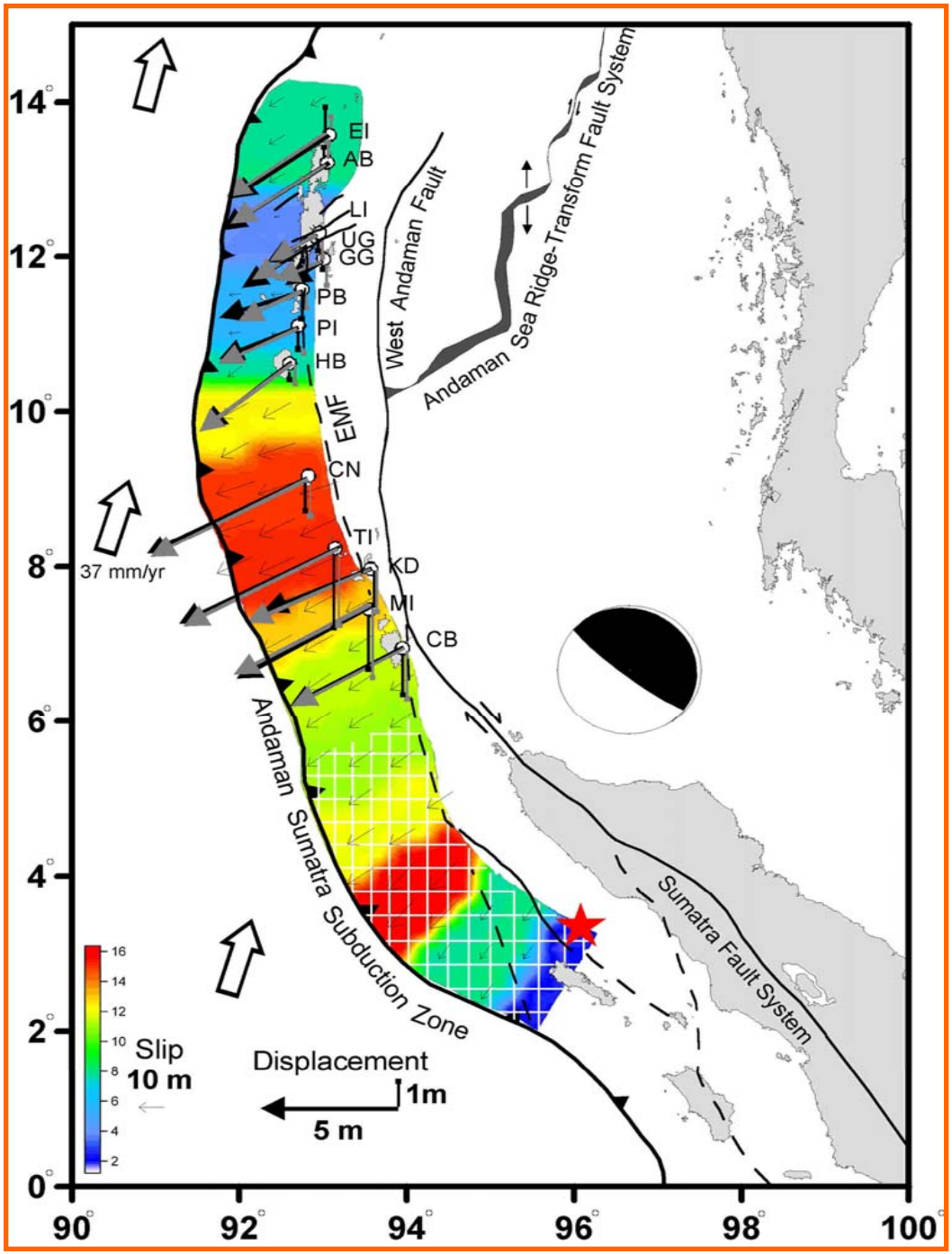

Banana
DANCE THE NIGHT


Marina Beach, Chennai


Marina Beach, Chennai


Marina Beach, Chennai


Kanyakumari


EI
AB
LI
UG
GG
PB
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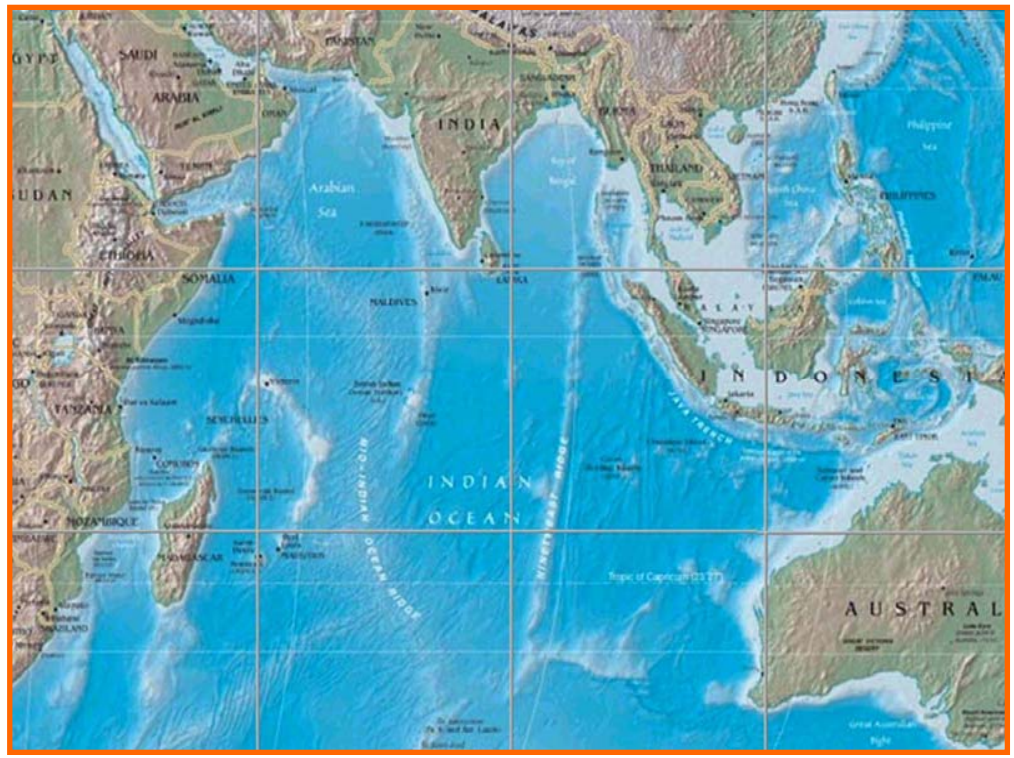
HB
EMF
CN
TI
KD
MI
CB
West Andaman Fault
Andaman Sea Ridge-Transform Fault System
37 mm/yr
Andaman Sumatra Subduction Zone
Sumatra Fault System
Slip
10 m
Displacement
1m
5 m
14°
12°
10°
8°
6°
4°
2°
0°
90°
92°
94°
96°
98°
100°

The Indian Ocean

- More than 50 Nations around
- Many are Developing Countries
- More than1.5 Billion Population
- More than 66,500 km coastline



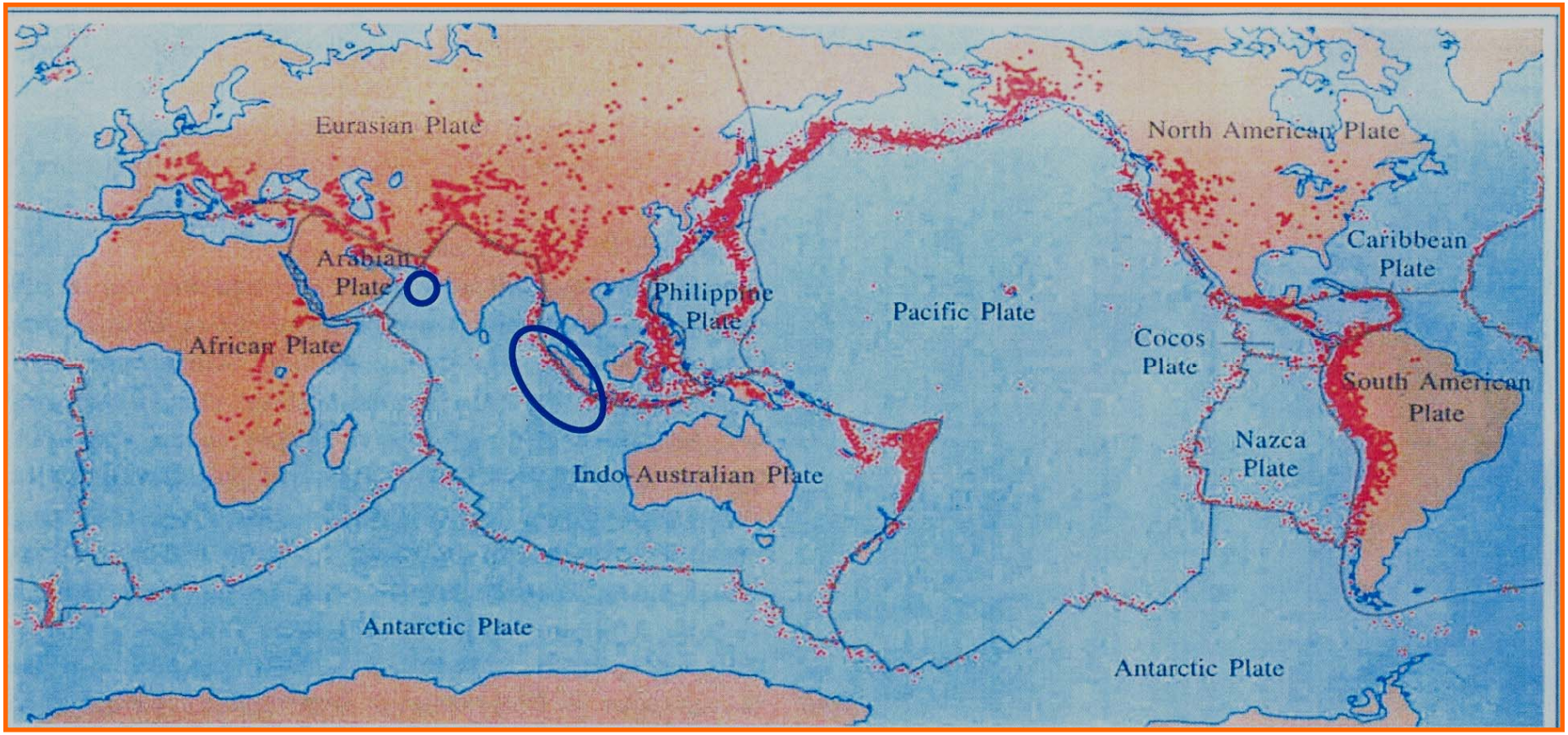


Diagram showing the distribution of earthquakes and major plate boundaries. It may be noted that globally, more than 75% of earthquake energy is released in the circum-Pacific belt, about 20% in the Alpine-Himalayan belt, and remaining 5% through the mid-oceanic ridges and other Stable Continental Region earthquakes. For a tsunami to hit Indian coast, it is necessary that a tsunamigenic earthquake occurs and its magnitude should be larger than M 7, and the possible locations of such events are enclosed in blue circle and ellipse.

An Early Warning System is imperative for the Indian Ocean to mitigate the loss of life and property due to Tsunamis and Storm Surges. The Indian Tsunami Early Warning System incorporates the needs of storm surge forecast too. The System design is based on end-to-end principle encompassing:

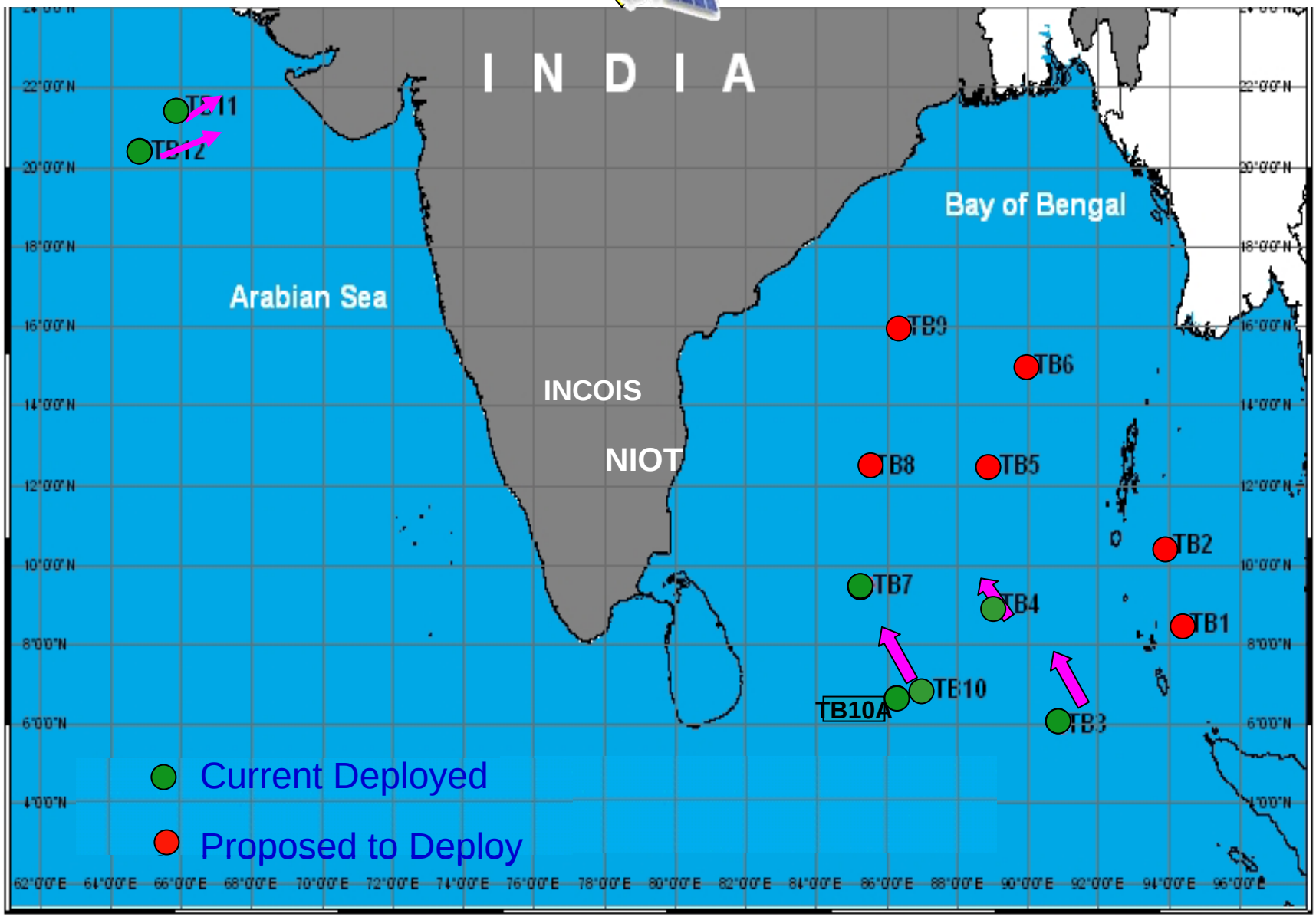
- Near-real time determination of earthquake parameters in the two known Tsunamigenic zones of Indian Ocean region, using a network of land-based Seismic Stations

- Establishing a comprehensive real time Ocean observational network comprising Bottom Pressure Recorders around the two Tsunamigenic zones, Tide Gauges, Radar-based Coastal Monitoring Stations etc.

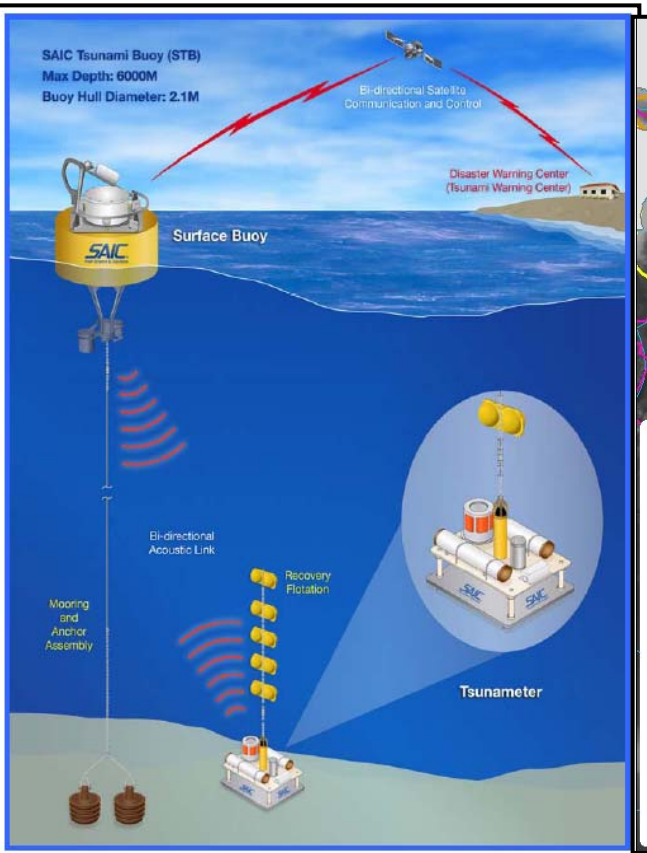
- **Developing numerical models for Tsunami and Storm Surges with all associated data inputs**
- **Generating Coastal inundation and Vulnerability maps**
- **Setting up a dedicated Tsunami Warning Centre (include Storm Surge) in India and operating it on 24x7 basis for generation of timely advisories**
- **Capacity building, training, education of all stakeholders**
- **International connectivity**

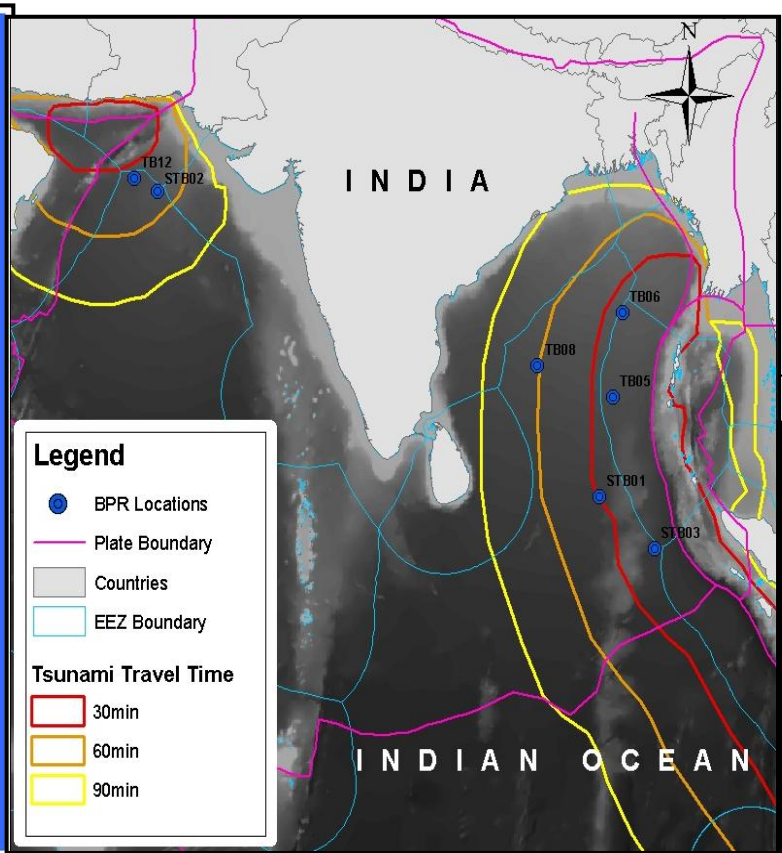
Deep Ocean Assessment and Reporting System for Detection of Tsunamis

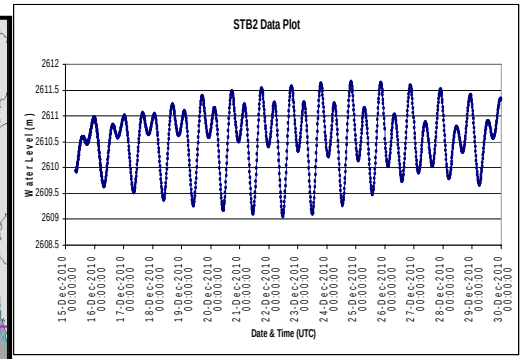
SATELLITE



Tsunami Buoys





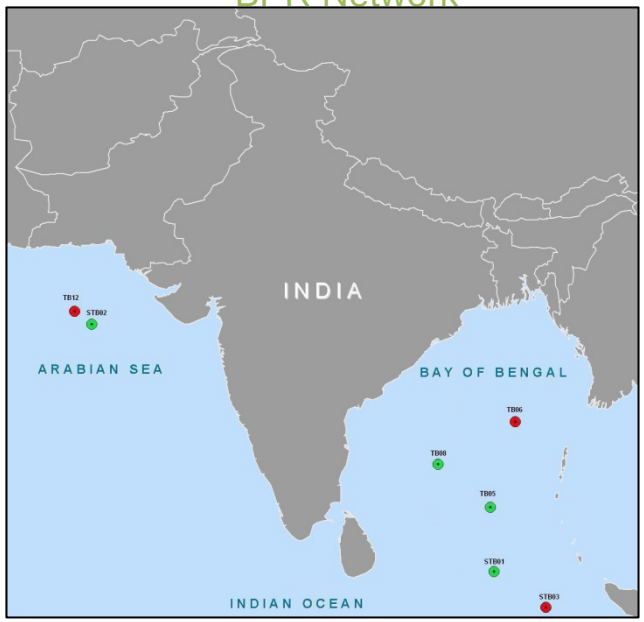


Revised locations of Tsunami Buoys

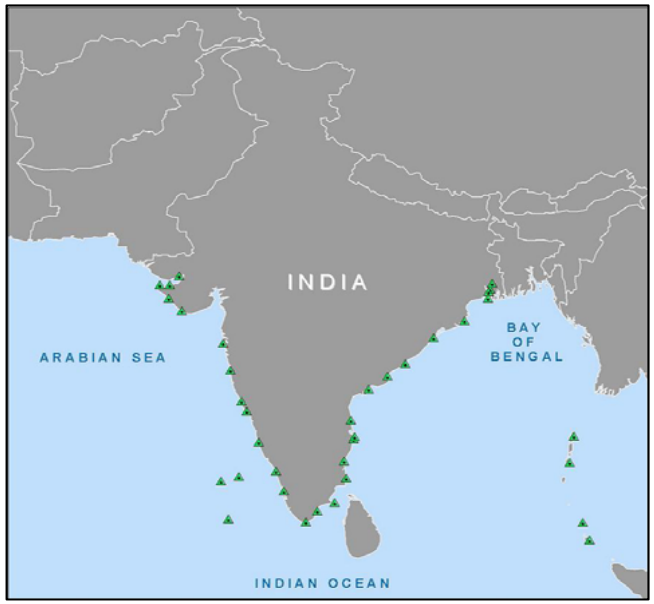
S. No.	Code	Lat (N)	Long (E)
1	STB01	06.25	88.8
2	STB02	20.8	65.3
3	STB03	03.8	91.7
4	TB05	11.0	89.5
5	TB06	15.0	90.0
6	TB08	12.5	85.5
7	TB12	21.4	64.1

Sea-level Network

BPR Network

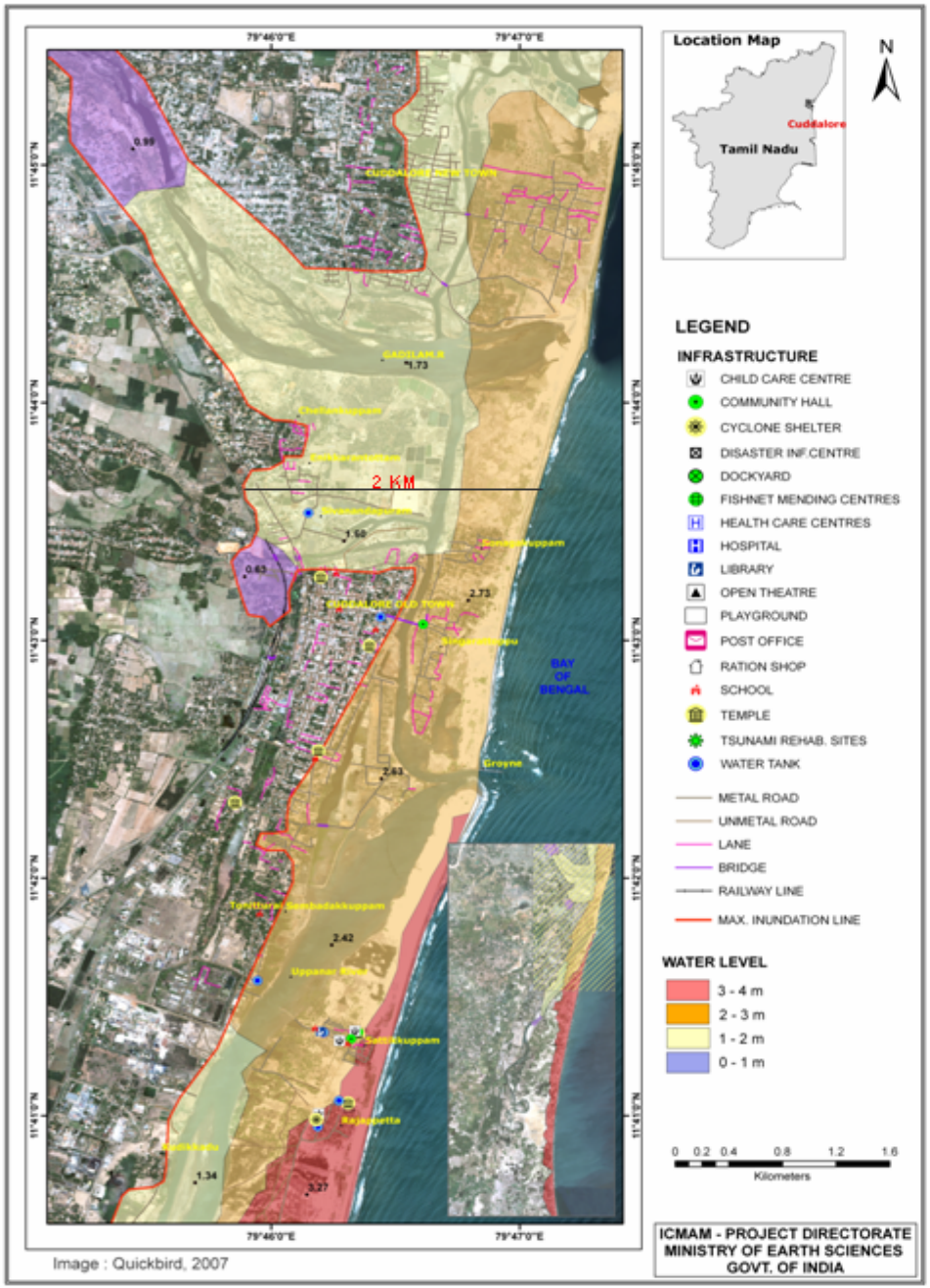


Tidegauge Network

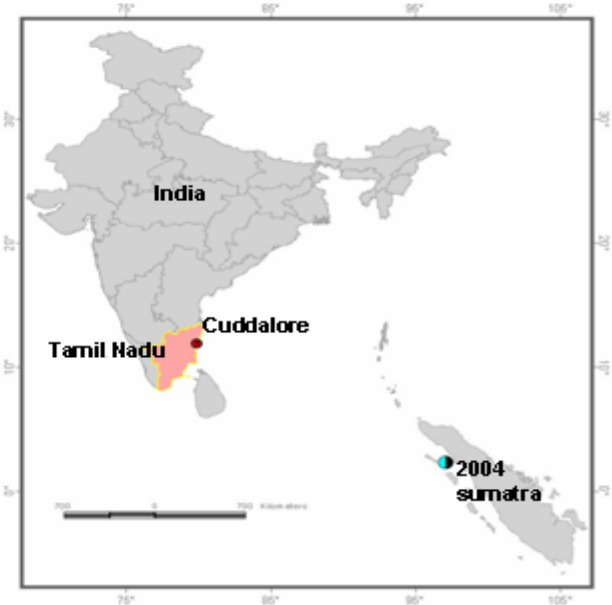


- **BPR Network**
  - Real-time BPR Network of 7 BPRs
  - BPR network is re-designed and optimized to 7
  - Two are deployed in Bay of Bengal & one in Arabian Sea
  - Data is being received at INCOIS & NIOT
- **Tidegauge Network**
  - Real-time Tidegauge Network of 36 Tideguages
  - 25 are operational
  - Communication through VSAT/INSAT/GPRS with average reporting frequency of 5 mins
  - Data is being received at INCOIS & SOI

Vulnerability Map of Cuddalore District



VULNERABILITY OF CUDDALORE DISTRICT (TN) TO DEC. 2004 SUMATRA TSUNAMI

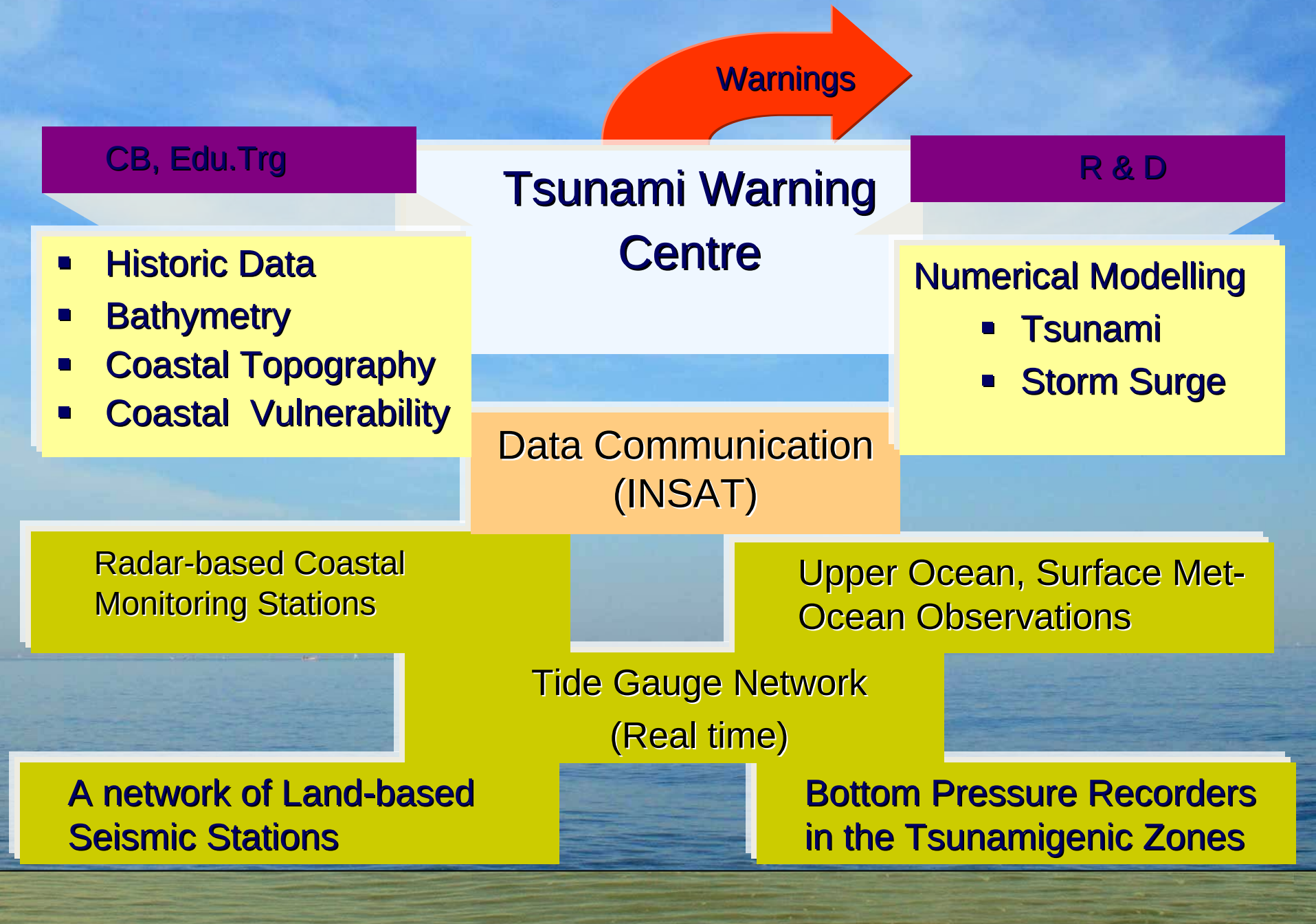


Location	: 95.85E, 3.32N
Magnitude	: 9.3 Mw
Slip Magnitude	: 15M
Strike Angle	: 345 deg.
Focal Depth	: 20km

Max. Inundation : 2 km

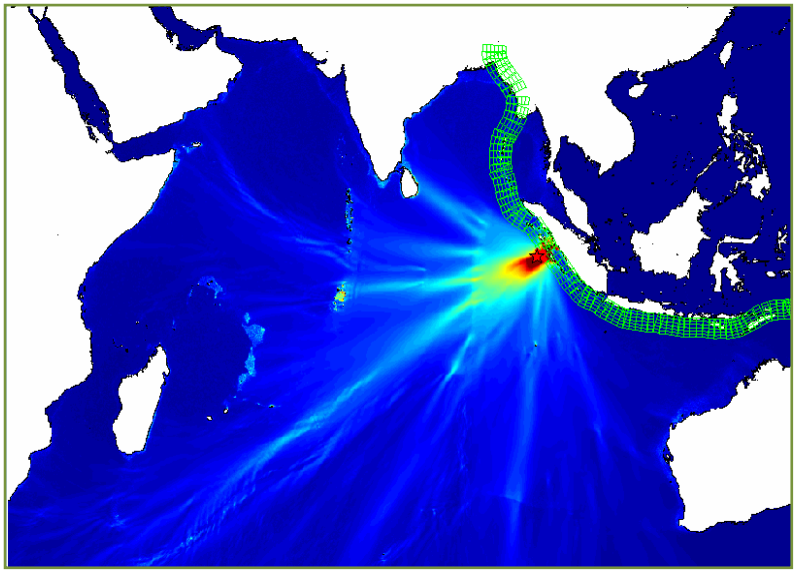
Max. water level : 3 – 4m

Components of the Indian Early Warning System

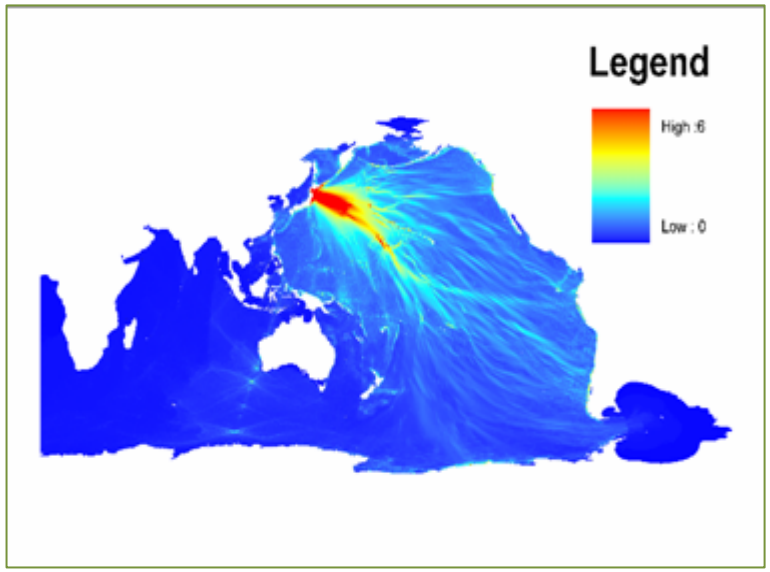


Tsunami Modelling – Scenario database

Indian Ocean Region



Global Ocean Region



- New improved procedure of 1000 unit sources covering all tsunamigenic sources in the Indian Ocean
- Each unit source is of 100 X 50 km area representing rupture caused by EQ of M 7.5 with slip as 1m
- Depending on EQ's location and magnitude basic unit source open ocean propagation scenarios are either scaled up or down
- Eliminates need for accessing huge database for matching scenario
- Rupture can be represented more realistically with multiple rupture zones of M 7.5, instead of a single uniform rupture zone
- Preparation of unit sources for global ocean is under process

SEPTEMBER 12, 2007

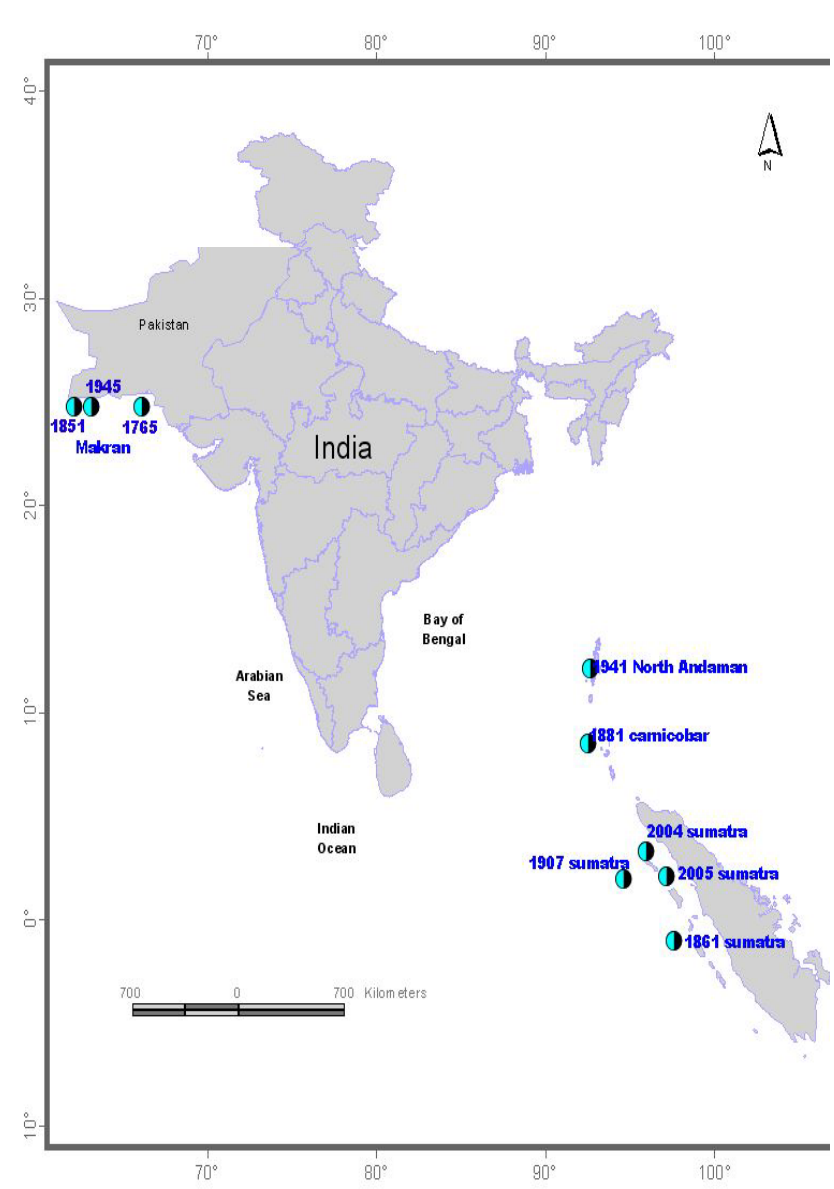
M 8.4, 4.521° S, 101.370°E

The Earthquake was shallow and large enough to generate a destructive tsunami. For the current EQ, an Alert was issued by INCOIS for the A & N Islands, which meant that 'No Evacuation' is required however, the public needs to be vigilant. This Bulletin was issued well within the stipulated SOP Timeline of 30 minutes

INCOIS generated a database of Model Scenarios considering various earthquake parameters. For the September 12, 2007 event scenario Ids 28.2 & 29.2 were picked from the scenario database. They were used to calculate the estimated travel time and run up heights at various coastal locations and water level sensors (Tide guages & BPRs and tidal stations as evident from the table below:

Location	Estimated Arrival Time (h)	Estimated water level (cm)	Observed Arrival Time (h)	Observed water level (cm)
Padang	1751	80	1754	60
Coco's Island	1748	40	1748	50
Sabang	1903	20	1903	30
TB 3	1903	2	1913	1
TB10A	1931	1	1941	2
TB10	1930	2	1945	1
Port Blair	2010	10	2013	8
Chennai	2105	20	2110	18

Tsunami Modelling – Coastal Inundation
Source Locations & Parameters used in the Models

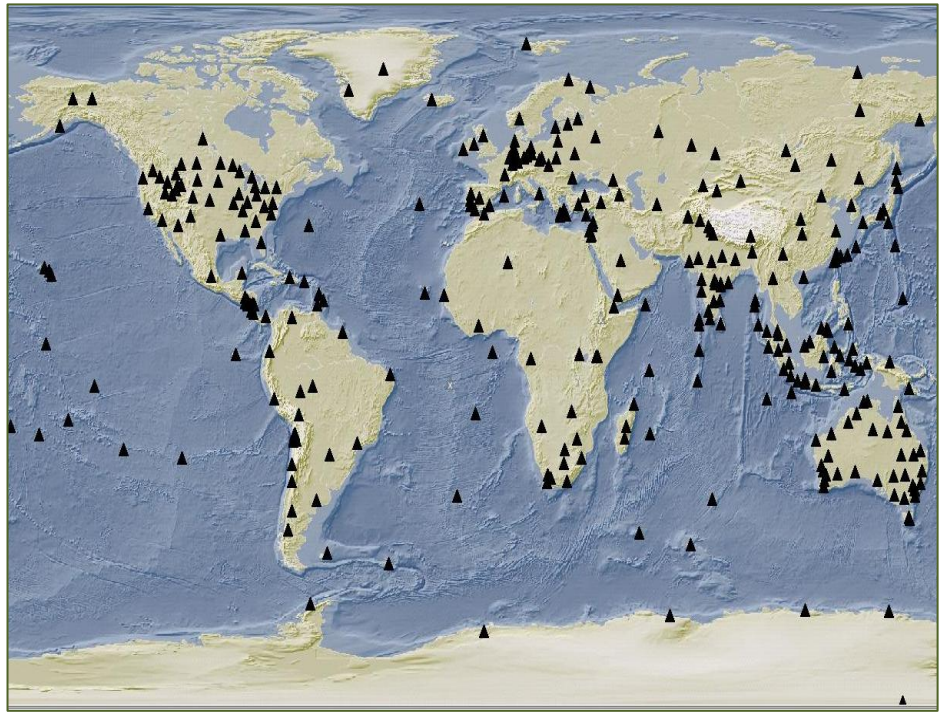


Parameters	Sumatra 2004	Car Nicobar 1881	Andaman 1941	Arakan 1762	Worst-Case	Worst-Case
Source	Sumatra	Car Nicobar	North Andaman	Arakan	Car Nicobar	North Andaman
Longitude	95.85^0 E	92.43^0	92.5^0 E	94.0^0	92.43^0	92.43^0
Latitude	3.32^0 N	8.52^0	12.1^0 N	19.0^0	8.52^0	8.52^0
Magnitude	9.3 Mw	7.9 Mw	7.7 Mw	8.8 Mw	9.3 Mw	9.3 Mw
Slip	15 m	5 m	5 m	10 m	15 m	15 m
Fault Length	1200 km	200 km	200 km	700 km	500 km	500 km
Fault Width	150 km	80 km	80 km	125 km	150 km	150 km
Strike Angle	345^0	350^0	20^0	320^0	345^0	345^0
Dip Angle	15^0	25^0	20^0	20^0	15^0	15^0
Rake Angle	90^0	90^0	90^0	90^0	90^0	90^0
Focal Depth	20 km	15 km	30 km	10 km	20 km	20 km

Seismic Network

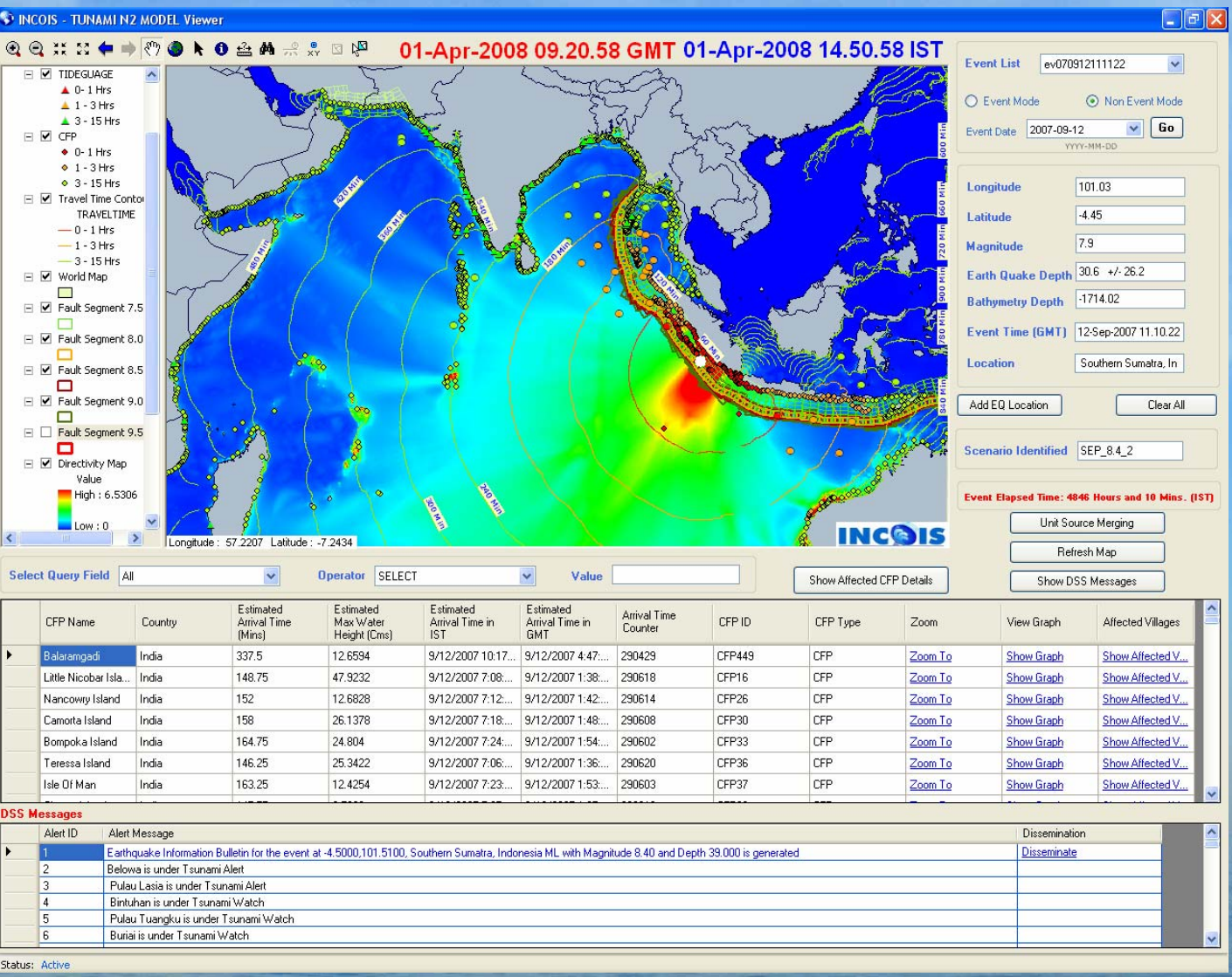
National Network

International Network



- Real-time Seismic Monitoring Network of 27 broadband seismic stations
- Seismic data from International stations (GEOFON / IRIS)
- Data Acquisition, Processing, Auto location and Archival using Response SeisComP 3.0 and Response Hydra 1.47
- Autolocation within 5 to 12 min of occurrence of an earthquake
- Reported and monitored 73 earthquakes of M > 6.5 (May 10 to Apr 11)
- EQ parameters matching well with those put out by USGS / GEOFON
- 10 More stations have been installed and VSAT connectivity for real-time data reception is under progress

Modelling for Operational Forecasting



CFP Name	Country	Estimated Arrival Time (Mins)	Estimated Max Water Height (Cms)	Estimated Arrival Time in IST	Estimated Arrival Time in GMT	Arrival Time Counter	CFP ID	CFP Type	Zoom	View Graph	Affected Villages
Balaramgadi	India	337.5	12.6594	9/12/2007 10:17:...	9/12/2007 4:47:...	290429	CFP449	CFP	Zoom To	Show Graph	Show Affected V...
Little Nicobar Isla...	India	148.75	47.9232	9/12/2007 7:08:...	9/12/2007 1:38:...	290618	CFP16	CFP	Zoom To	Show Graph	Show Affected V...
Nancowry Island	India	152	12.6828	9/12/2007 7:12:...	9/12/2007 1:42:...	290614	CFP26	CFP	Zoom To	Show Graph	Show Affected V...
Camorta Island	India	158	26.1378	9/12/2007 7:18:...	9/12/2007 1:48:...	290608	CFP30	CFP	Zoom To	Show Graph	Show Affected V...
Bompoka Island	India	164.75	24.804	9/12/2007 7:24:...	9/12/2007 1:54:...	290602	CFP33	CFP	Zoom To	Show Graph	Show Affected V...
Teressa Island	India	146.25	25.3422	9/12/2007 7:06:...	9/12/2007 1:36:...	290620	CFP36	CFP	Zoom To	Show Graph	Show Affected V...
Isle Of Man	India	163.25	12.4254	9/12/2007 7:23:...	9/12/2007 1:53:...	290603	CFP37	CFP	Zoom To	Show Graph	Show Affected V...

DSS Messages

Alert ID	Alert Message	Dissemination
1	Earthquake Information Bulletin for the event at -4.5000,101.5100, Southern Sumatra, Indonesia ML with Magnitude 8.40 and Depth 39.000 is generated	Disseminate
2	Belowa is under Tsunami Alert	
3	Pulau Lasia is under Tsunami Alert	
4	Bintuhan is under Tsunami Watch	
5	Pulau Tuangku is under Tsunami Watch	
6	Buriai is under Tsunami Watch	

Status: Active

Each simulation covers the entire Indian Ocean domain with 15 hours simulation time and a time step of 5 seconds. Out put profiles are generated at 30 m bathymetry for about 1800 coastal forecast points (CFPs) covering the entire Indian ocean rim countries including Tide Gauge & BPR locations

The TUNAMI N2 model is customized for Indian Ocean region

For operational forecast

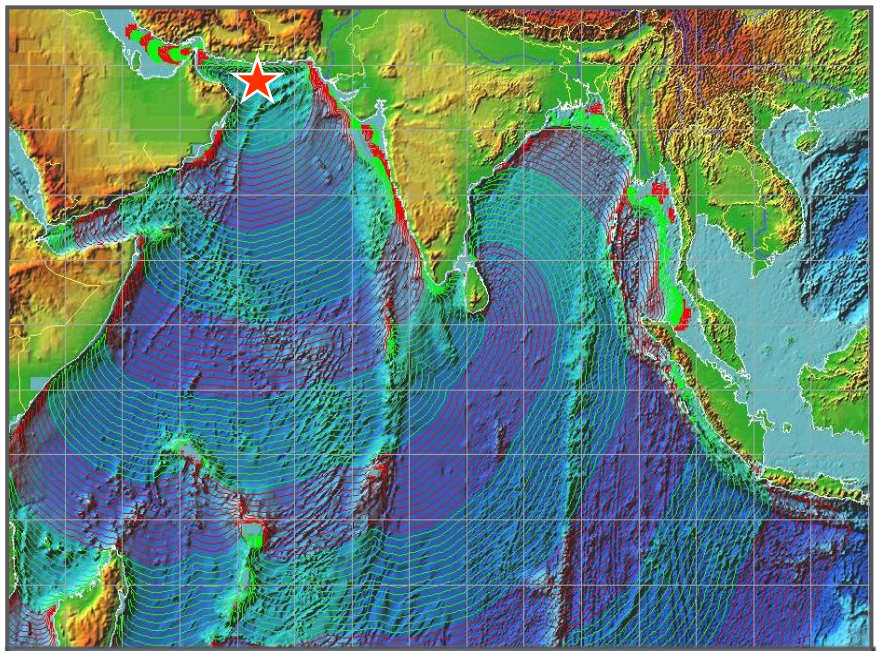
- **A large database of open ocean propagations scenarios**
- **For epicenters separated by 100 km all along two Tsunamigenic zone**
- **Scenarios for different magnitudes (6.5, 7.0, 7.5, 8.0, 8.5, 9.0 & 9.5) and depths (10, 20, 40, 60, 80 & 100 km)**
- **About 1000 “Base” unit source scenarios,**
- **‘On-Fly’ scenario generation using earthquake magnitude**

Tsunami Risk Assessment

Tsunami Travel Times & Response time

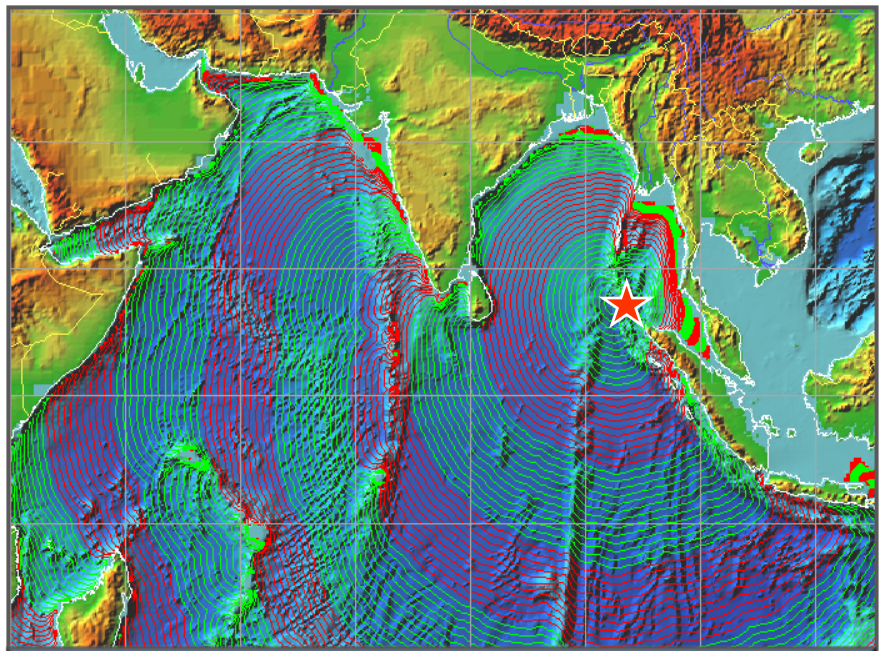
- Depending upon the Earthquake location (Makran/Andaman-Sumatra Subduction Zone) the response time for evacuation of coastal population could range between 10 min to few hours.
- As Andaman & Nicobar Islands situated right on subduction zone the available response time is very short

Makran Subduction Zone



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

Andaman-Sumatra Subduction Zone

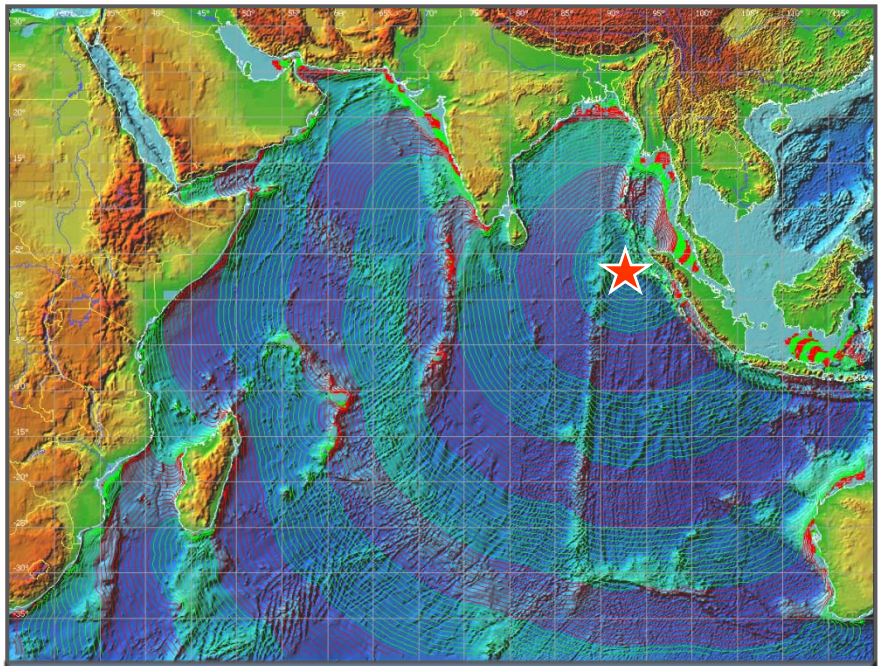


- **If Earthquake happens at Nicobar Islands , travel times to nearest coast (A&N Islands) are 20 to 30 min**
- **For Indian main land travel times are 2 to 3 hrs**

Tsunami Travel Times & Response time

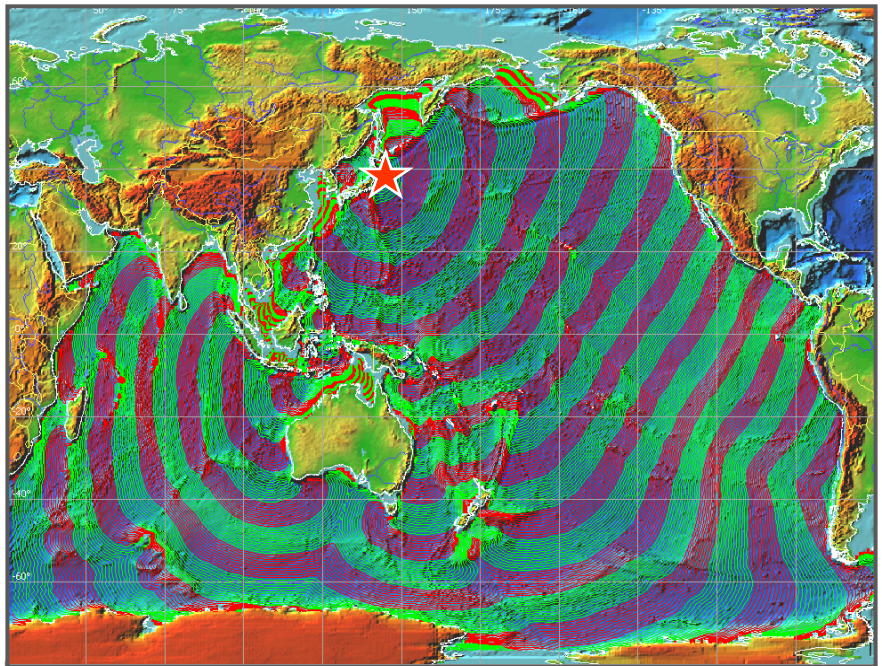
Recent Real Tsunami Scenarios

December 26, 2004 – Northern Sumatra



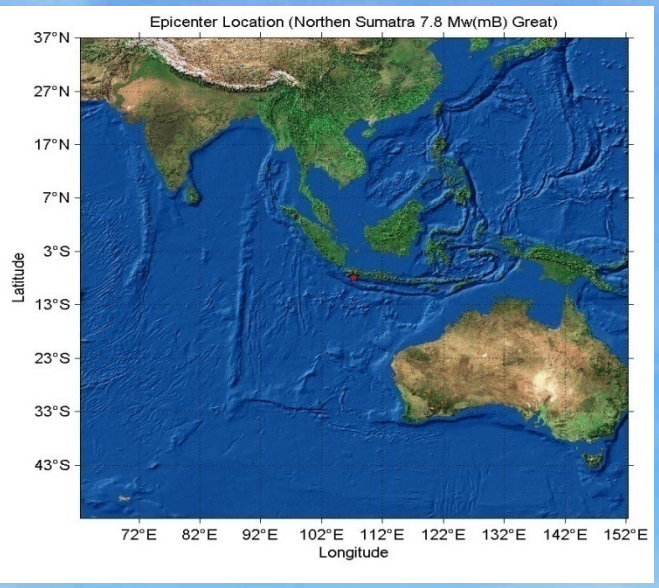
- For Northern Sumatra Event Travel time to Indira Point , A & N Islands was 20 min and to Chennai, Indian main land was 170 min

March 11, 2011 – Honshu, Japan



- In case of recent Japan tsunami, travel times for India were more than 14 hrs

Java Earthquake on 02 Sep 2009



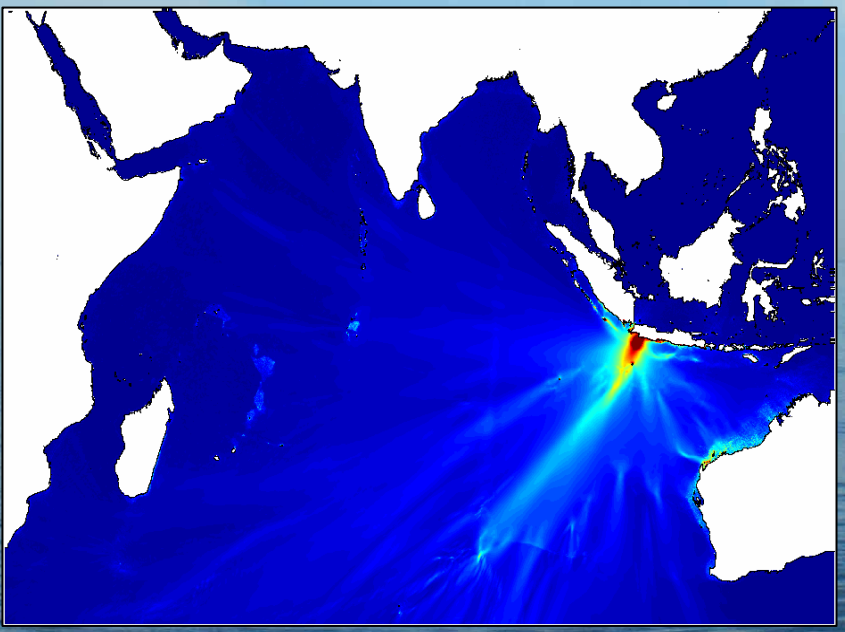
Java Earthquake of M7.8 on 02nd Sep 2009 at 07:55:03 (UTC)

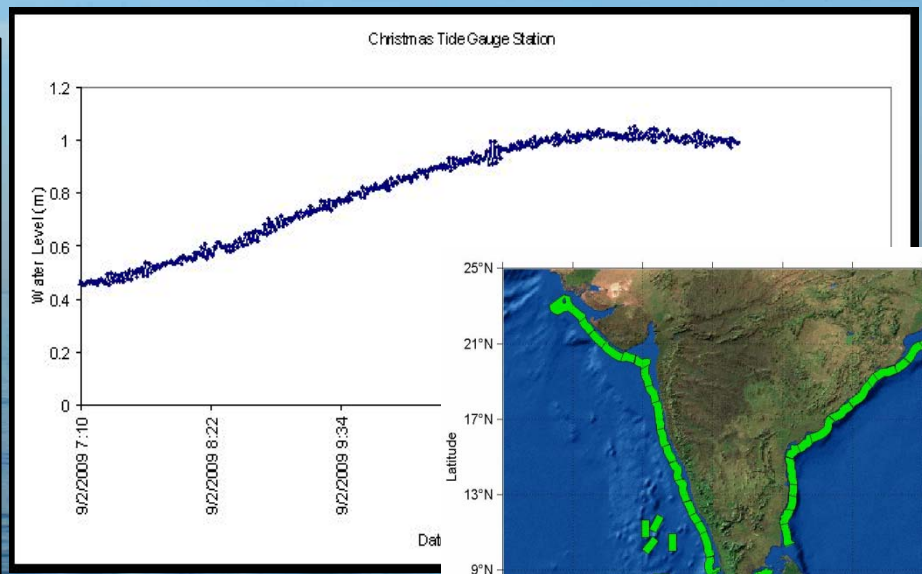
This event did not generate any water level changes in Indian Coasts.

Issued Bulletins

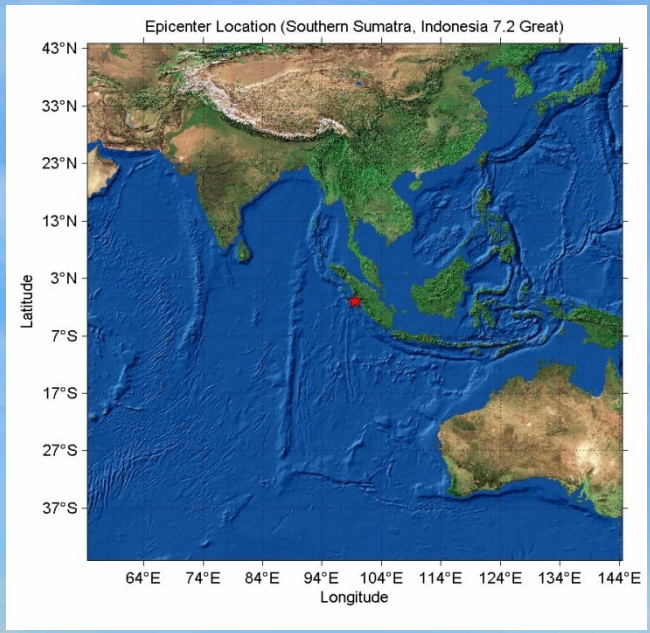
Bulletin No 1: Earthquake Information M7.8
Bulletin No 2: No Significant Water Level Changes
No tsunami threat for A& N Islands and India main Land

INCOIS	PTWC	JMA
Tsunami Evaluation: There is no tsunami for Indian Ocean Region	**Tsunami Evaluation:** PTWC issued Local tsunami watch for Indian Ocean. Later cancelled.	**Tsunami Evaluation:** JMA issued Local tsunami watch for Indian Ocean.





Southern Sumatra Earthquake on 30 Sep 2009



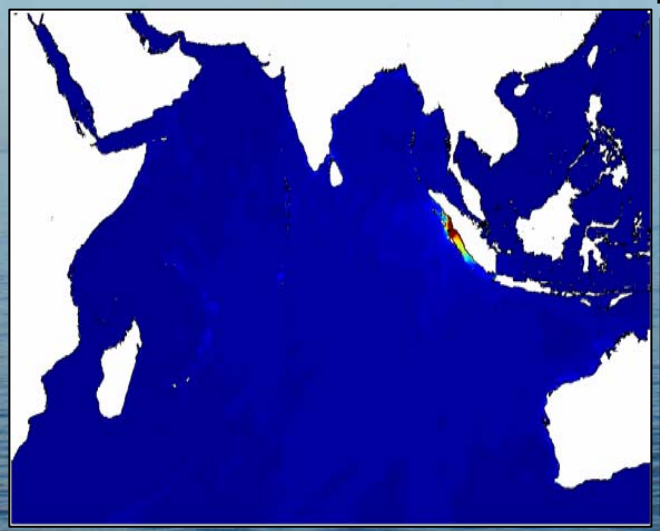
Southern Sumatra Earthquake of M8.0 on 30th Sep 2009 at 10:16:11 (UTC)

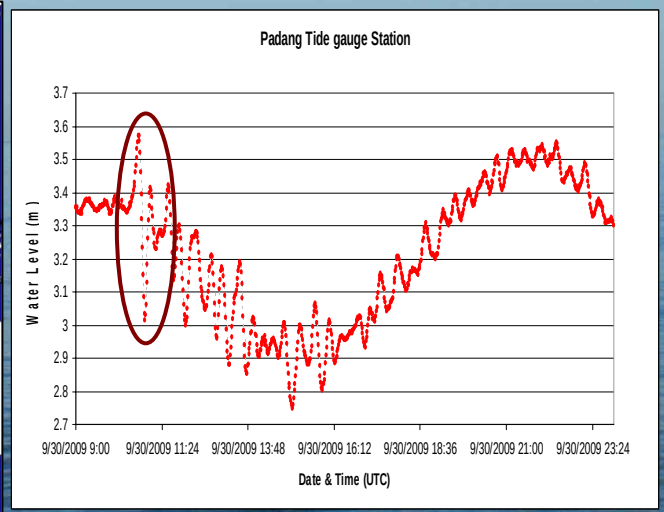
This earthquake generated a local tsunami near the epicenter especially at Padang, Indonesia (30 cm). This event did not generate any water level changes in Indian Coasts.

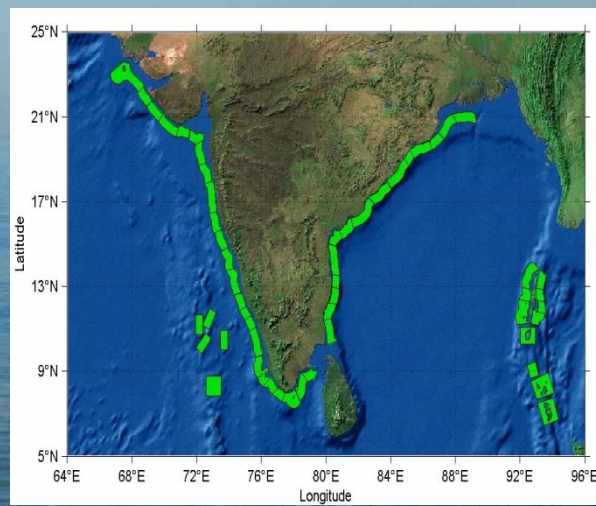
Issued Bulletins

Bulletin No 1: Earthquake Information M7.8
Bulletin No 2: No Significant Water Level Changes
No tsunami threat for A& N Islands and India main Land

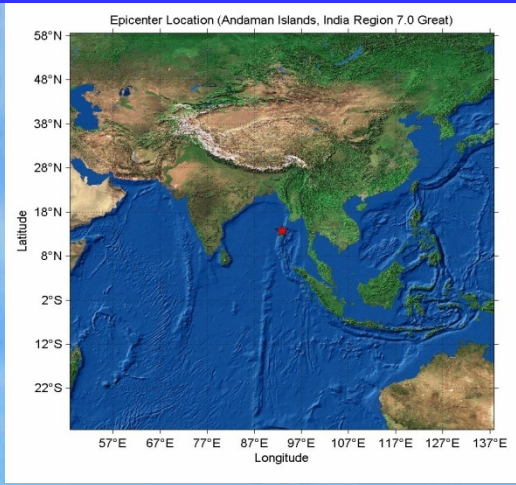
INCOIS	PTWC	JMA
Tsunami Evaluation: This earthquake generated a local tsunami near the epicenter especially at Padang, Indonesia (18 cm). This event did not generate any water level changes in Indian Coasts. There is NO tsunami threat for Indian Region	**Tsunami Evaluation:** PTWC issued watch for Indian Ocean. Later cancelled.	**Tsunami Evaluation:** JMA issued watch for Indian Ocean.







A&N Islands Earthquake on 30 Mar 2010



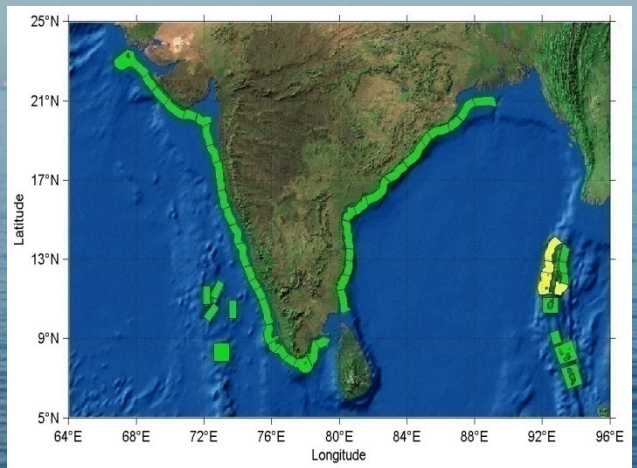
A&N Earthquake of M6.9 on 30th Mar 2010 at 16:54:50 (UTC)

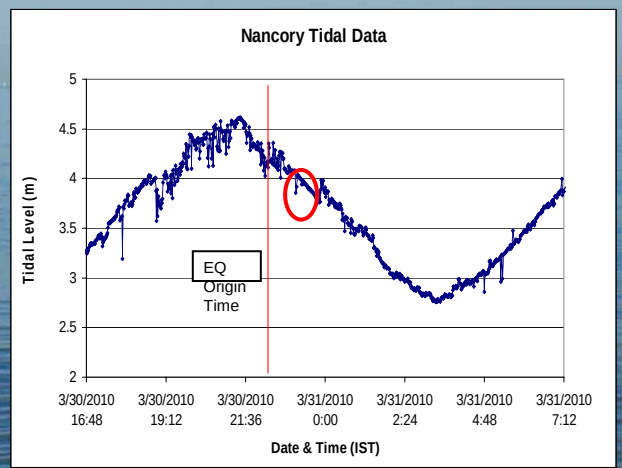
This event did not generate any water level changes in Indian Coasts.

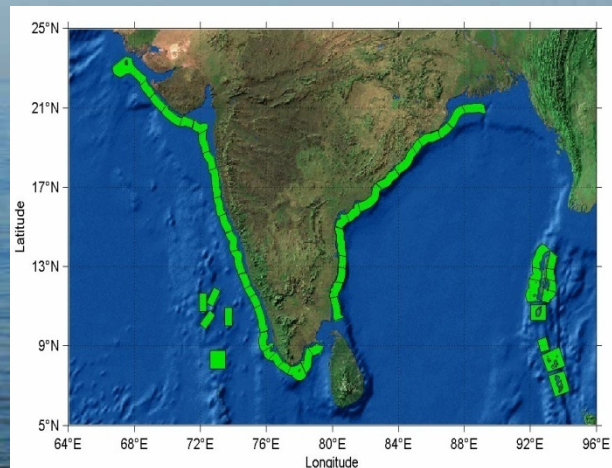
National Bulletins Issued

Bulletin No 1: Earthquake Information M7.0
Bulletin No 2: Watch for North Andaman; No threat for India Bulletin No 3: No Significant Water Level Changes
No tsunami threat for A& N Islands and India main Land

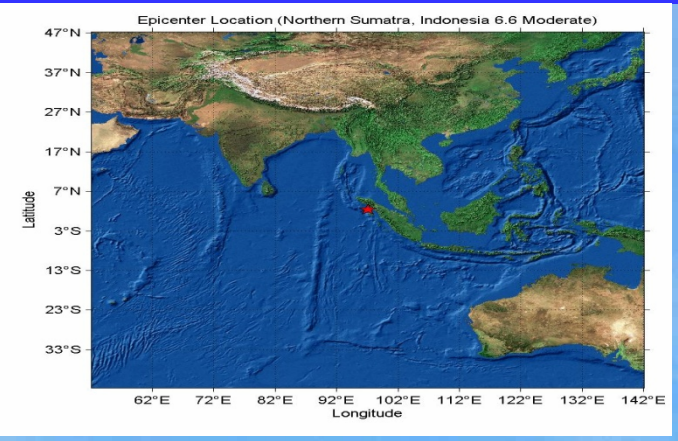
INCOIS	PTWC
Tsunami Evaluation: Model Simulations do not indicate any significant change in water level at the Indian coast. There is NO tsunami threat for Indian Region.	**Tsunami Evaluation:** PTWC issued "very small possibility of a local tsunami". Later cancelled.







Northern Sumatra Earthquake on 6 Apr 2010



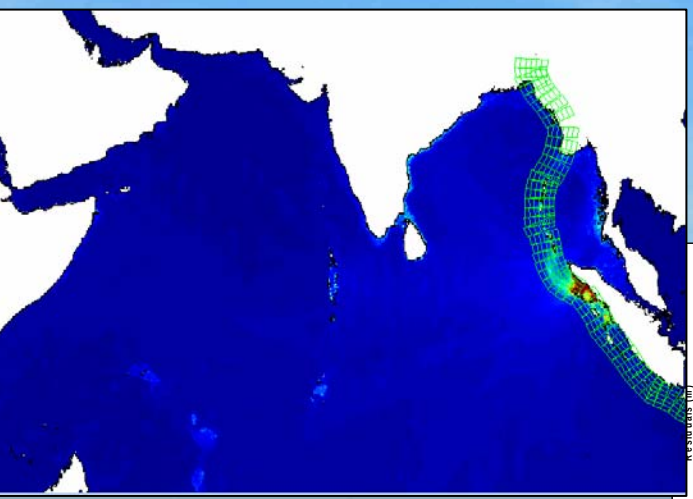
Northern Sumatra Earthquake of M7.7 on 6th Apr 2010 at 22:15:05 (UTC)

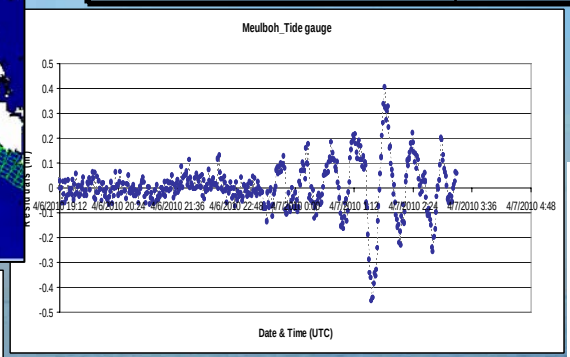
This earthquake generated a local tsunami near the epicenter especially at Meulboh, Indonesia (40 cm). Second bulletin issued 'based on PRE-RUN model scenarios, there is no tsunami threat for Indian Ocean'. This event did not generate any water level changes in Indian Coasts.

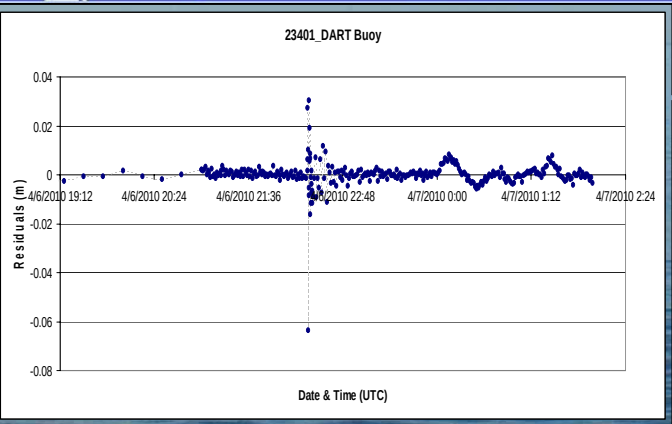
National Bulletins Issued

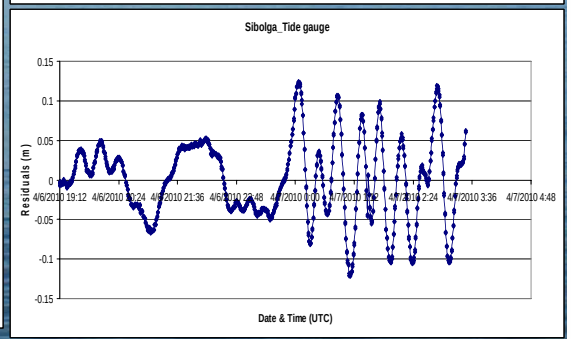
Bulletin No 1: Earthquake Information
Bulletin No 2: No Significant Water Level Changes
No tsunami threat for A& N Islands and India main Land

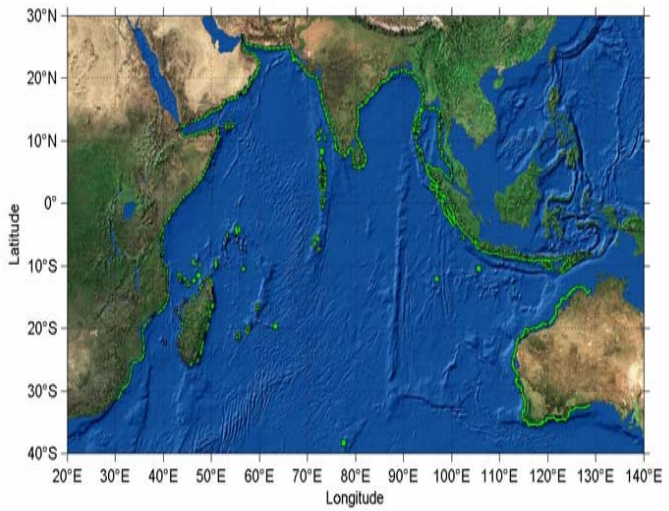
INCOIS	PTWC	JMA
Tsunami Evaluation: Based on PRE-RUN model Simulations, there is No tsunami threat for Indian Ocean.	**Tsunami Evaluation:** PTWC issued watch for Indonesia. Later cancelled.	**Tsunami Evaluation:** JMA issued Local tsunami watch effect for Indian Ocean.



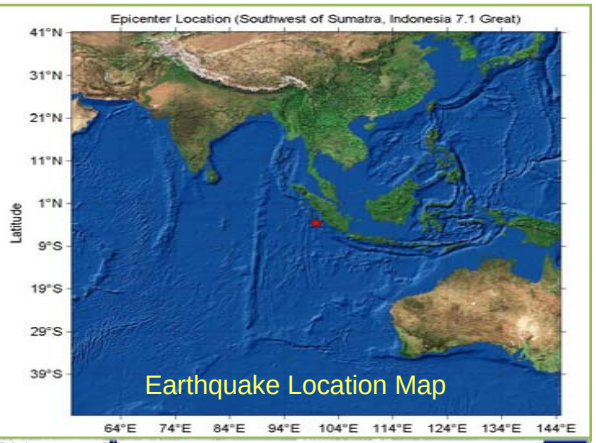


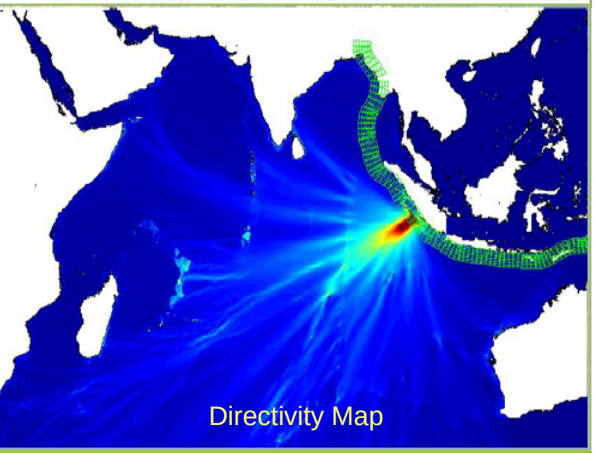


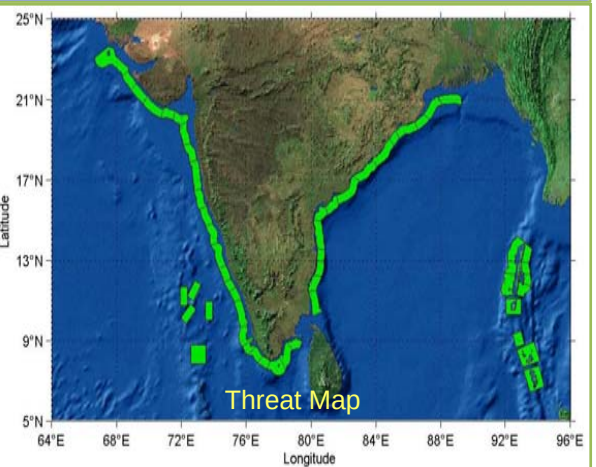




Major Events



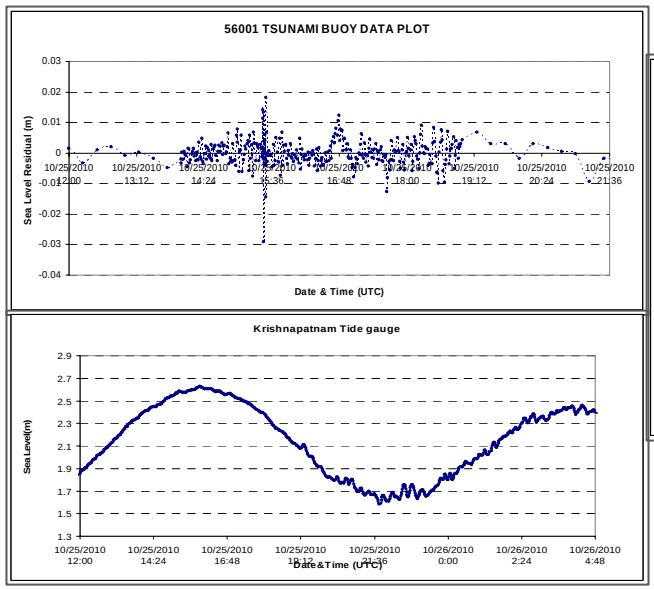


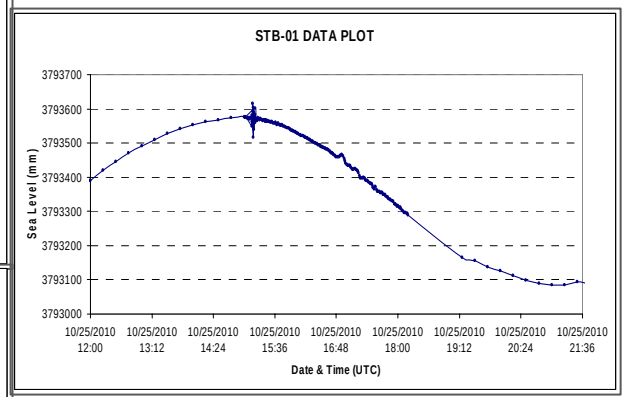


M 7.7 Southern Sumatra, Indonesia on 25 October 2010 14:42:20

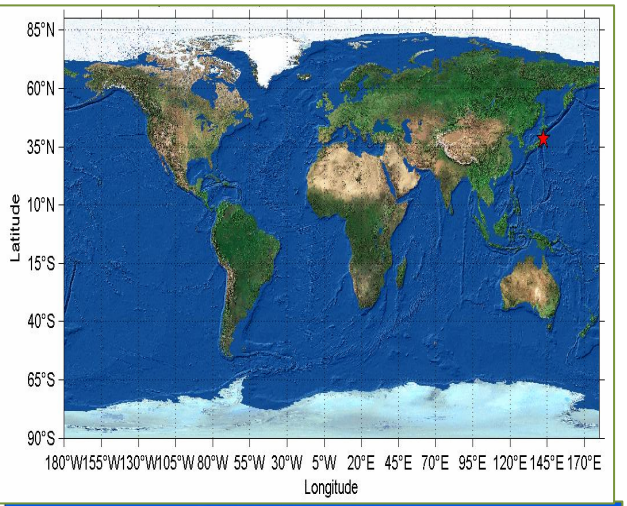
This earthquake generated a local Tsunami at the epicenter on Mentawai Island
This event did not generate any water level changes in Indian Coasts.

INCOIS	PTWC	JMA
Tsunami Evaluation: Based on PRE-RUN model Simulations, Tsunami threat does not exist for India.	Tsunami Evaluation: PTWC issued watch for Indian Ocean. Later cancelled.	Tsunami Evaluation: JMA issued A local tsunami watch for Sumatra, Jawa (Indonesia) & Cocos Island (Australia.

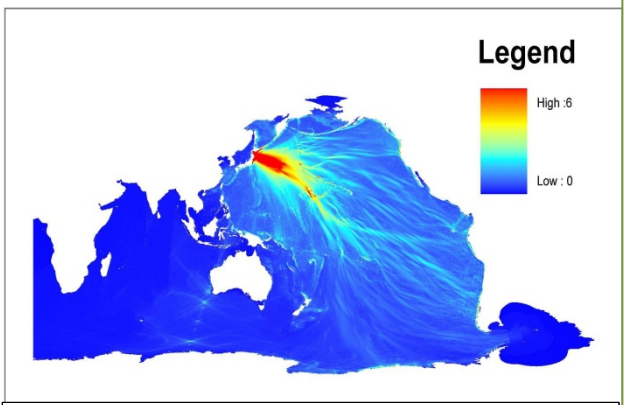


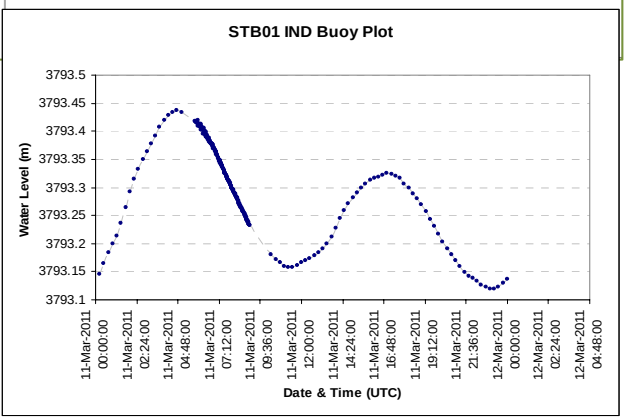


Major Events



Directivity Map_Honshu Japan



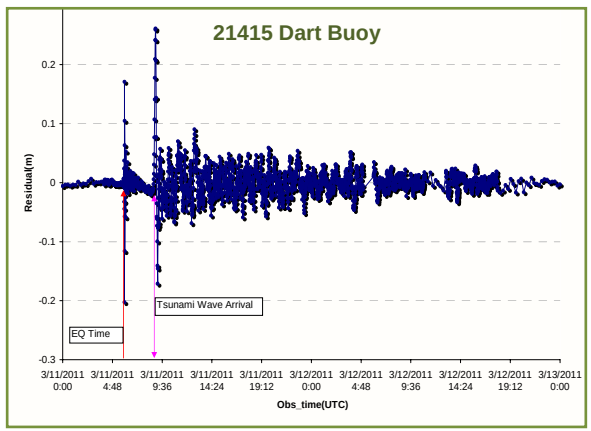


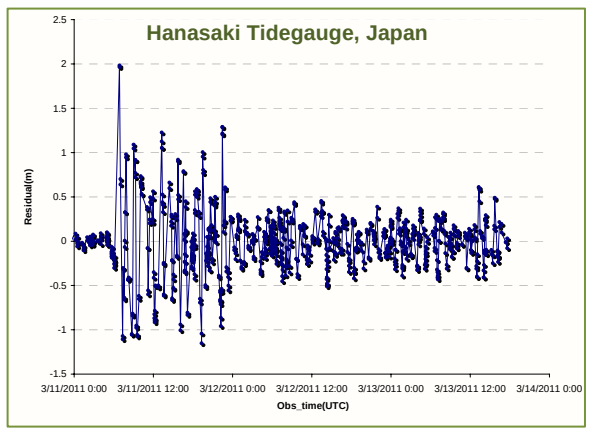
M 9.0, Honshu, Japan on March 11, 2011 at 05:46:23

This event generated a major tsunami in Japan

No water level changes in Indian Coasts.

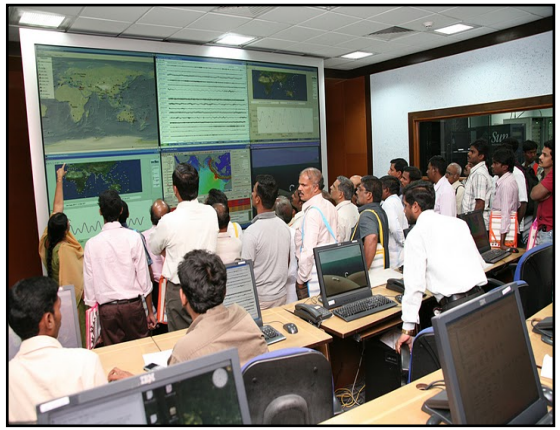
INCOIS	PTWC	JMA
Tsunami Evaluation: Based on historical earthquake and tsunami data, Tsunami Threat does not exist for Indian Ocean	Tsunami Evaluation: Expanding Regional Tsunami Warning for Japan, Russia, Marcus Is., N. Marianas A Tsunami Watch is in Effect For Guam, Wake Is., Taiwan, Yap, Philippines, Marshall Is., Belau, Midway Is., Pohnpei, Chuuk, Kosrae, Indonesia, Papua New Guinea, Nauru, Hawaii .	Tsunami Evaluation: Major Tsunami warning is in affect .for the Japan region.





Capacity Building, Education and Training







- **Conducted workshops, seminars, arranged trainings (national & international), participated in exhibitions**
- **Key Priorities**
  - Capacity building to public (especially in near-source vulnerable coastal areas) on responding to earthquakes & tsunami warnings
  - Capacity building to coastal administrators, disaster management officials and public on SOPs, use of tsunami inundation maps, etc.
  - Include disaster awareness and response related topics in primary, secondary and high school curriculum.

Capacity Building, Education and Training

Desktop Exercise for Indian Ocean Rim Countries held at INCOIS

Exercise Date & Time:
February 09, 2011 1030 IST (05:00 UTC)

Countries Participated:
Australia, Bangladesh, Comoros, India, Indonesia, Kenya, Malaysia, Madagascar, Maldives, Mozambique, Mauritius, Myanmar, Oman, Reunion, Sri Lanka, Tanzania, Thailand, Yemen

Exercise Time Format:
Abbreviated Time Format
0-30 min of Exercise Time in Real Time
After 1100 IST, 60 min of Real
Time is equal to 20 min in Exercise Time

Exercise Teams:
Team1: South East Asia
Team 2: South Asia
Team 3: East Africa
Team 4: Western Indian Ocean

Countries In Two Categories

- **In the Indian Ocean, countries fall in two broad categories: 1. Close to the source of tsunamigenic earthquakes, 2. Those located far away……..**

CONCLUDING REMARKS

- **India undertook a very ambitious project to set up an state of art Tsunami and Storm surge warning capability in a short time of 30 months. This was achieved by end of August 2007, and tested by September 12, 2007 earthquake. Over the last three years the system has performed satisfactorily.**

Thank You