

Tsunami – Unit-3

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A **tsunami** (pronounced soo-NAA-mee) is a series of waves (called a "wave train") generated in a body of water by a abrupt disturbance that vertically displaces the water column.



Lisbon, Portugal Tsunami of 1755

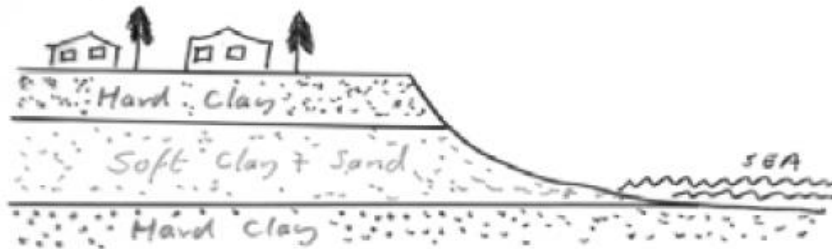
HOW TSUNAMIS ARE CAUSED ?

- **Huge submarine Earthquakes**
- **Submarine landslides**
- **Submarine volcanic eruptions**
- **Fall of huge sheets of ice**
- **Fall of giant meteorites**

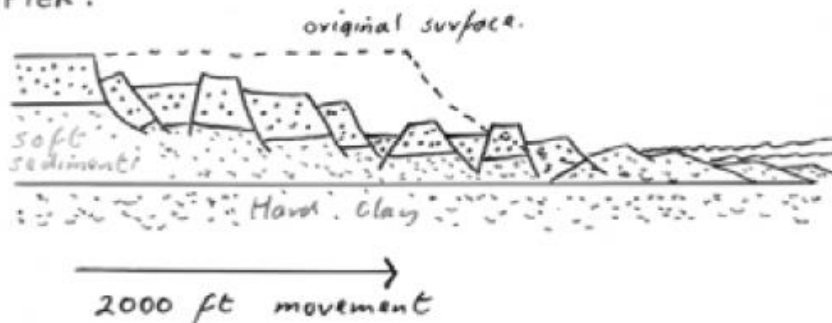
Most prominent are the Earthquake triggered Tsunamis

Landslide at Turnagain Heights, Alaska, 1964

BEFORE:



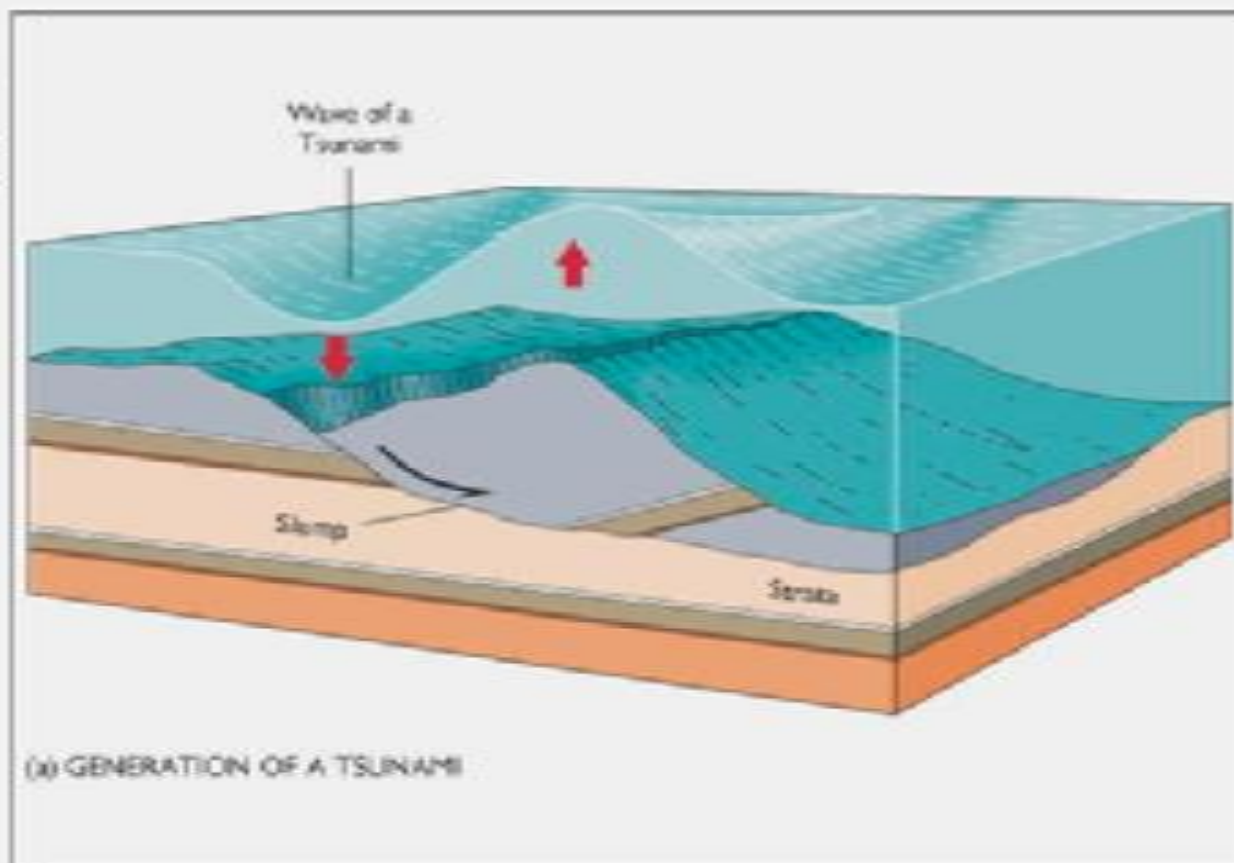
AFTER:



A very good example of liquefaction

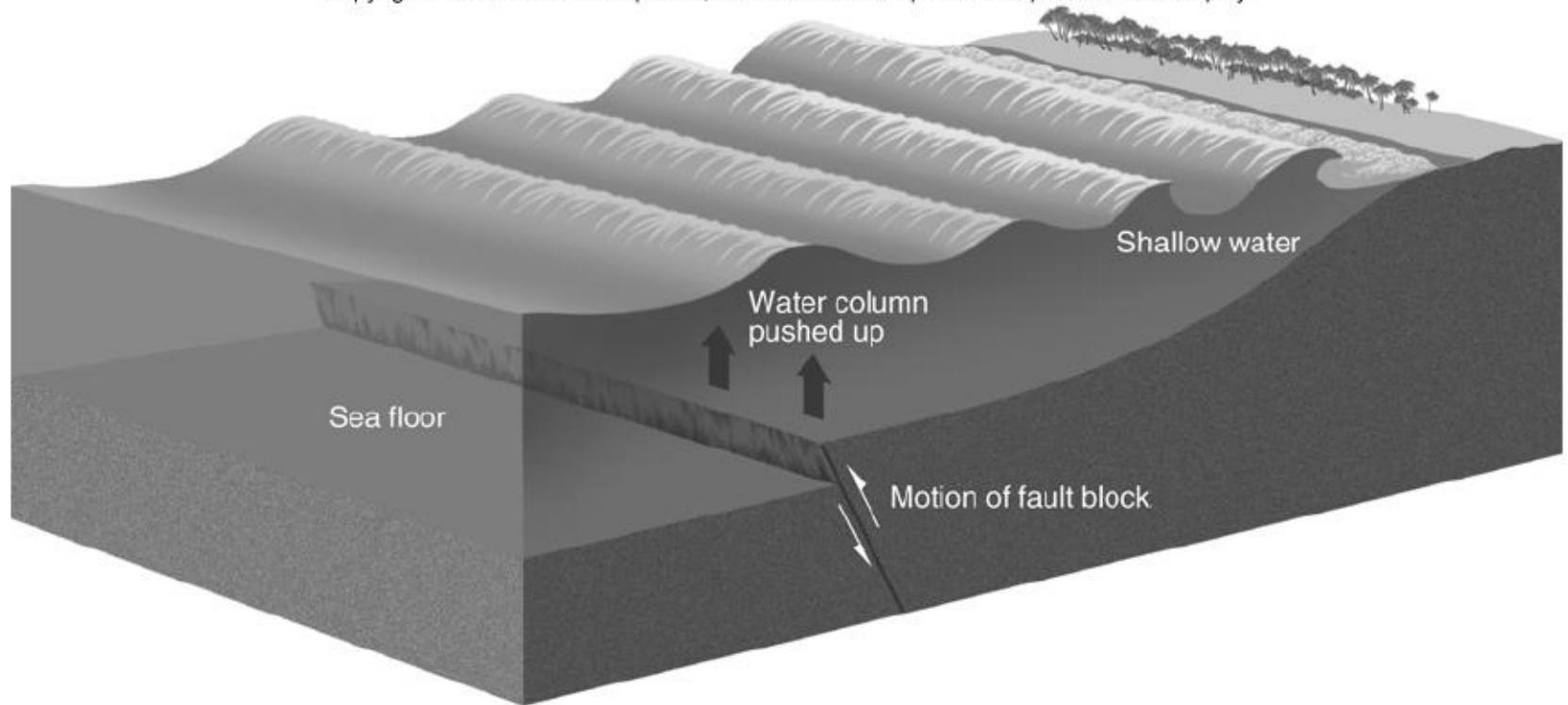
Slumping of a large mass of sediment disturbs the overlying water surface and produces a series of flat, long-period waves.

Figure 7.13a



Generation of a Tsunami by Faulting

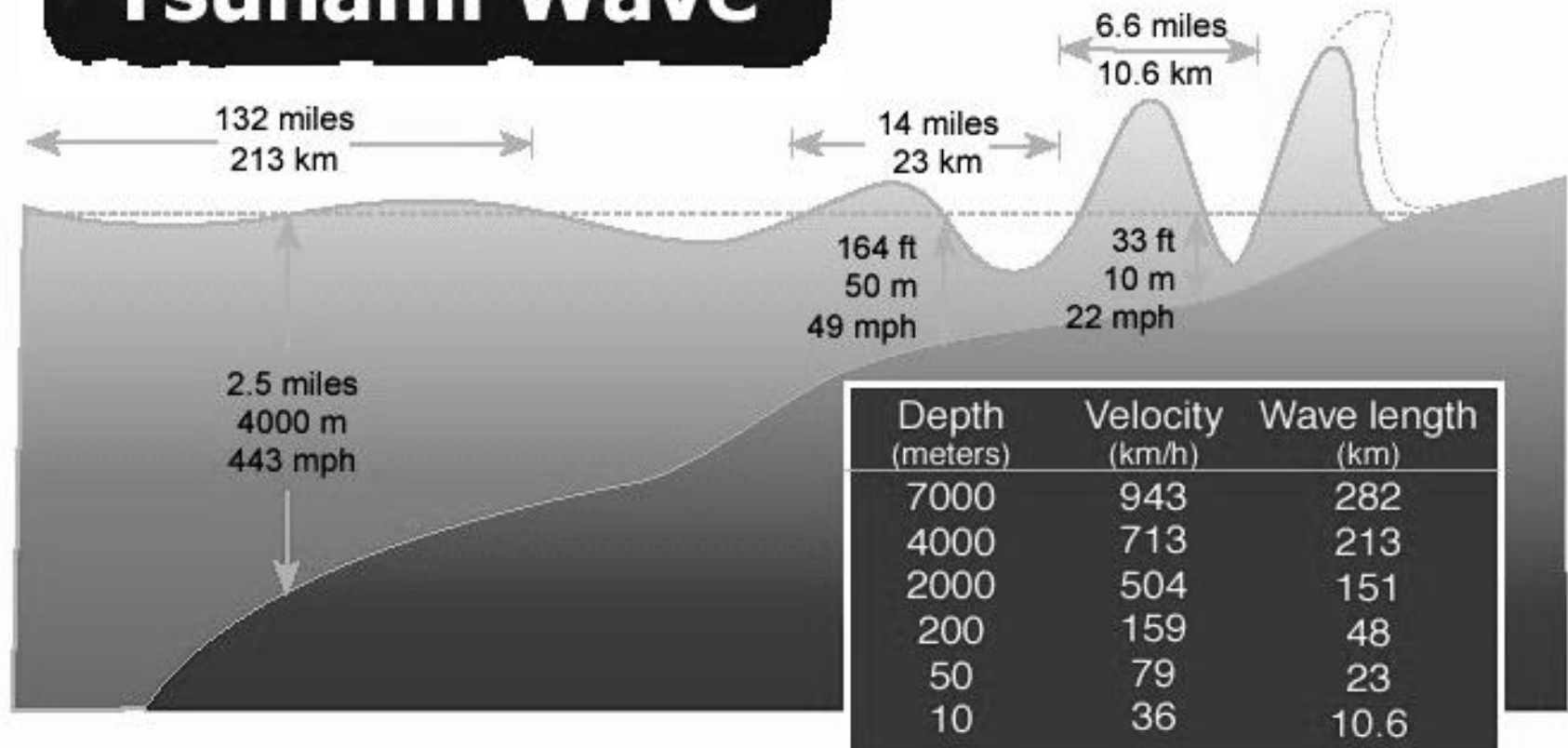
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Characteristics

- ❖ Move at high speeds
- ❖ Can travel enormous distances with little energy loss
- ❖ Can cause damage thousands of miles from its origin
- ❖ May be several hours between its creation and its impact on the coast

Tsunami Wave



As it enters shallow water, tsunami wave speed slows and its height increases, creating destructive, life-threatening waves.

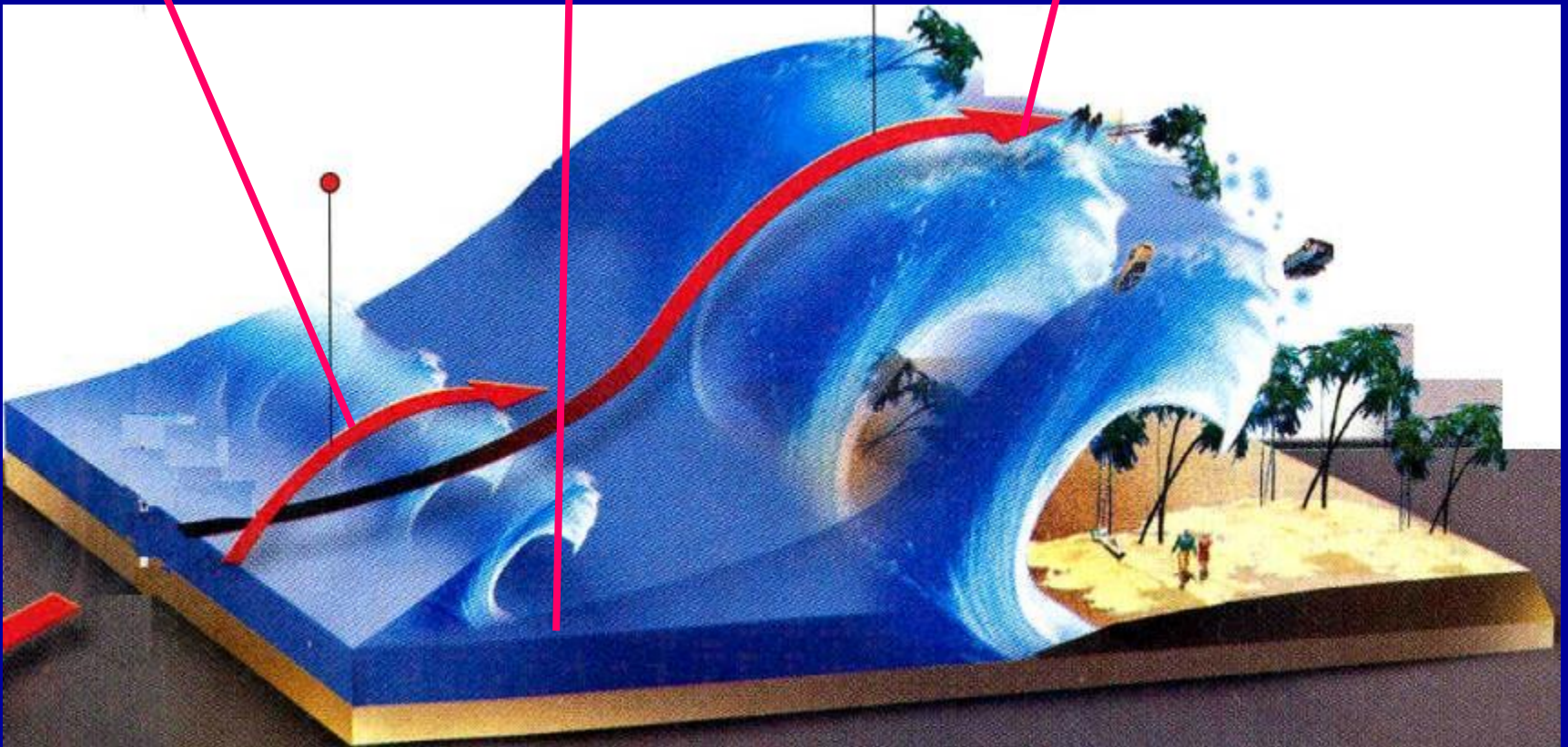
Depth (miles)	Velocity (mph)	Wavelength (miles)
4.4	586	175
2.5	443	132
1.2	313	94
635 ft	99	30
164 ft	49	14
33 ft	22	6.6

Triggering Mechanism of Tsunamis

Height - 1m
Speed - 700 km/h

Self Margin

Height - 10m
Speed - 40 km/h



Calculating the Tsunami Wave Speed

$$\begin{array}{l} \text{Tsunami} \\ \text{Wave} \\ \text{Speed} \end{array} = \sqrt{GD}$$

G = gravity (980 cm/sec²)

D = depth in centimeters

Assume an earthquake occurs in a deep ocean trench at a depth of 6 km, then:-

$$\begin{array}{l} \text{Tsunami} \\ \text{Wave} \\ \text{Speed} \end{array} = \sqrt{980 \times 6 \times 100,000}$$

$$= \sqrt{588,000,000}$$

$$= 24,249 \text{ cm/sec}$$

$$\text{or } 24,249 / 100,000 \times 60 \times 60 \text{ km/hr}$$

$$\begin{array}{l} \text{Tsunami} \\ \text{Wave} \\ \text{Speed} \end{array} = 871 \text{ km/hr} \quad (540 \text{ miles/hr})$$

EARTHQUAKE BELT

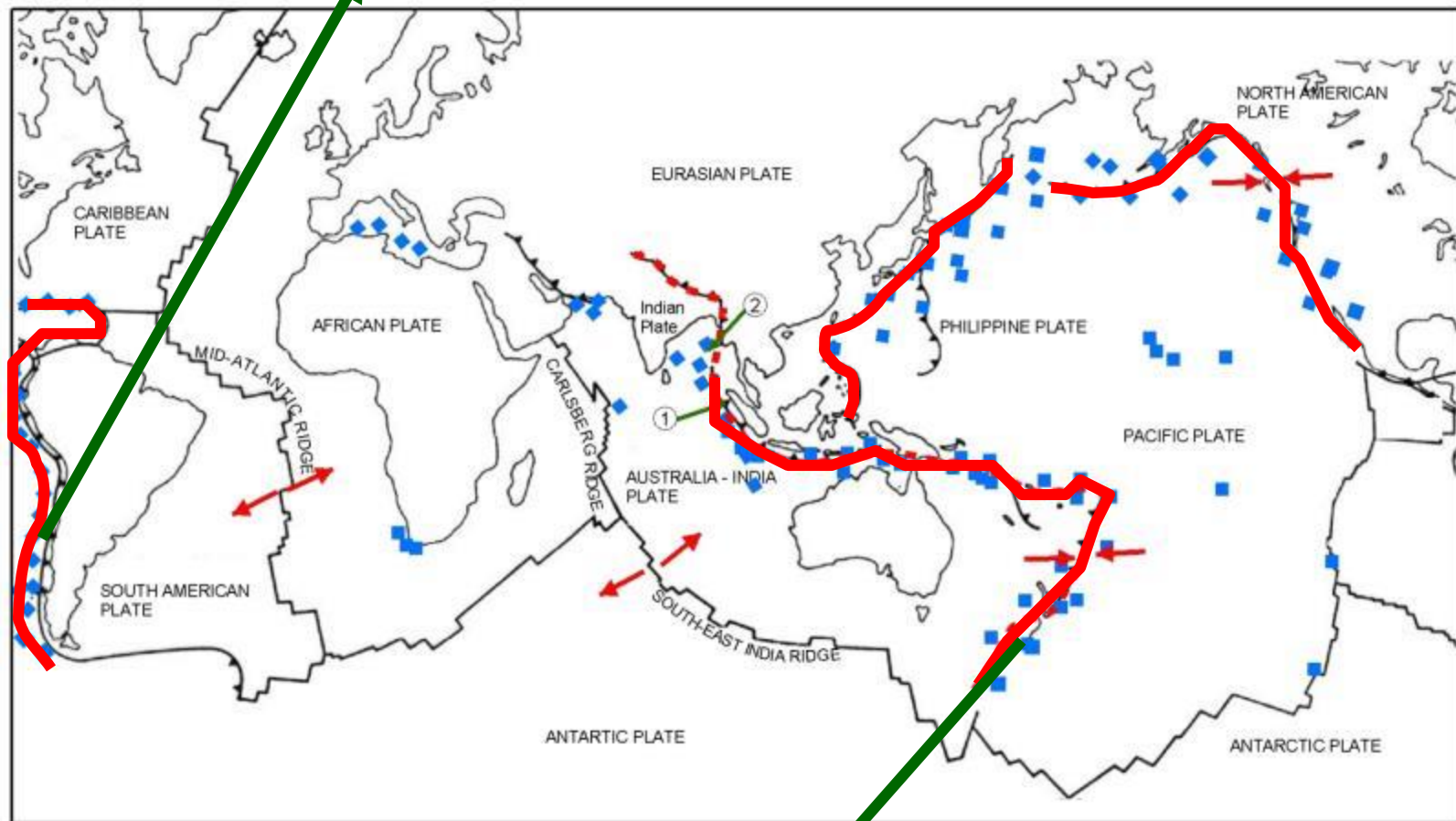


Fig.1 PRESENT POSITIONS OF CONTINENTS - PLATE BOUNDARIES - MAJOR TSUNAMIS EVENTS

- ←→ Divergent Plate Boundaries →← Convergent Plate Boundaries
... Indo-Burma-Sumatra Subduction Zone ■ Seismically Triggered Tsunamis Belts
① & ② 26th December 2004 Sumatra Earthquake and the Triggered Earthquakes in Andaman

TSUNAMIS PROVINCES

PAST TSUNAMIS OF SUMATRA REGION

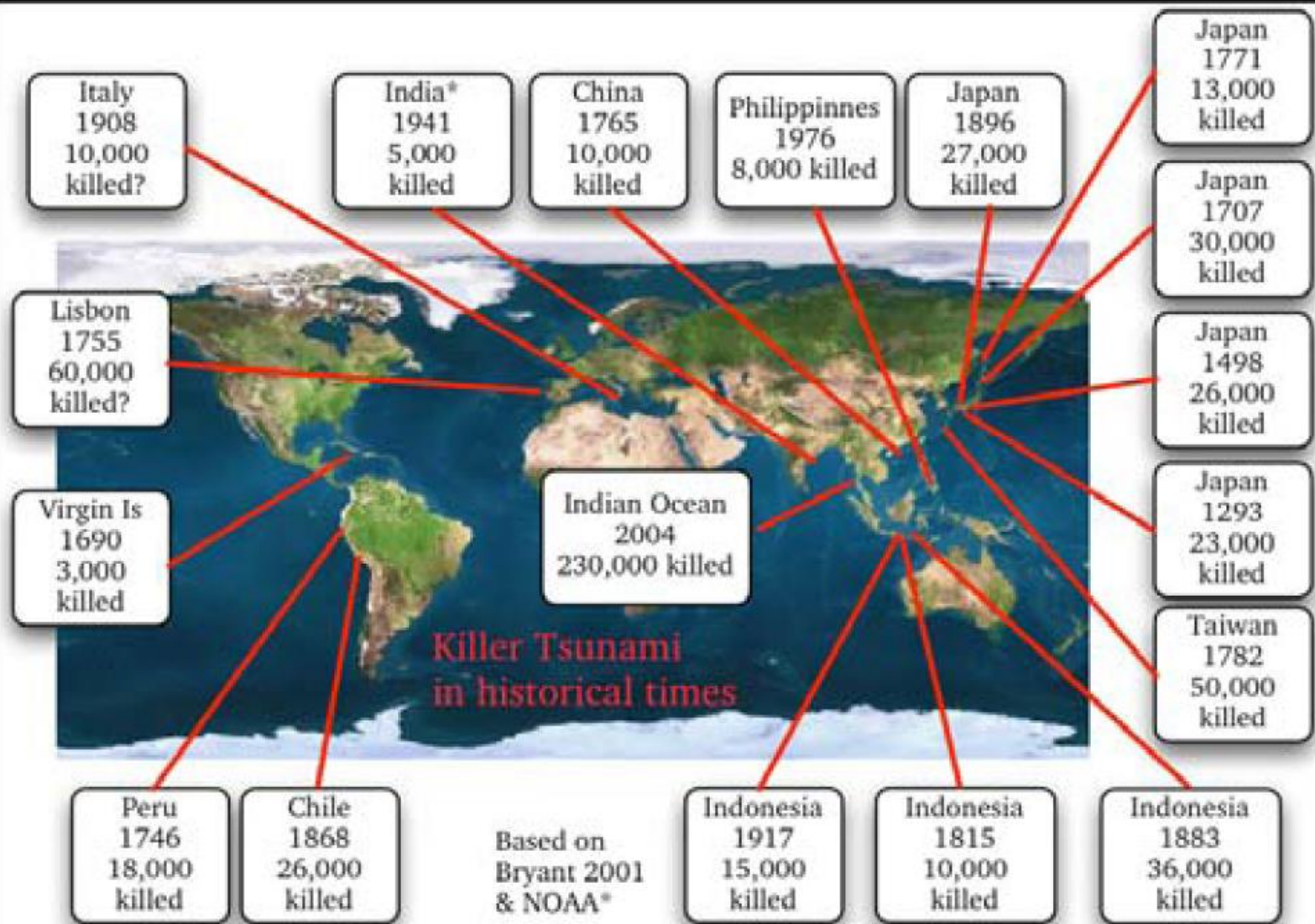
❖ 10, December 1797

❖ 24, November 1833

❖ 05, January 1843

❖ 06, February 1861

❖ 02, June 1994



Michael Paine, Australian Spaceguard Survey - updated 24 Jan 05

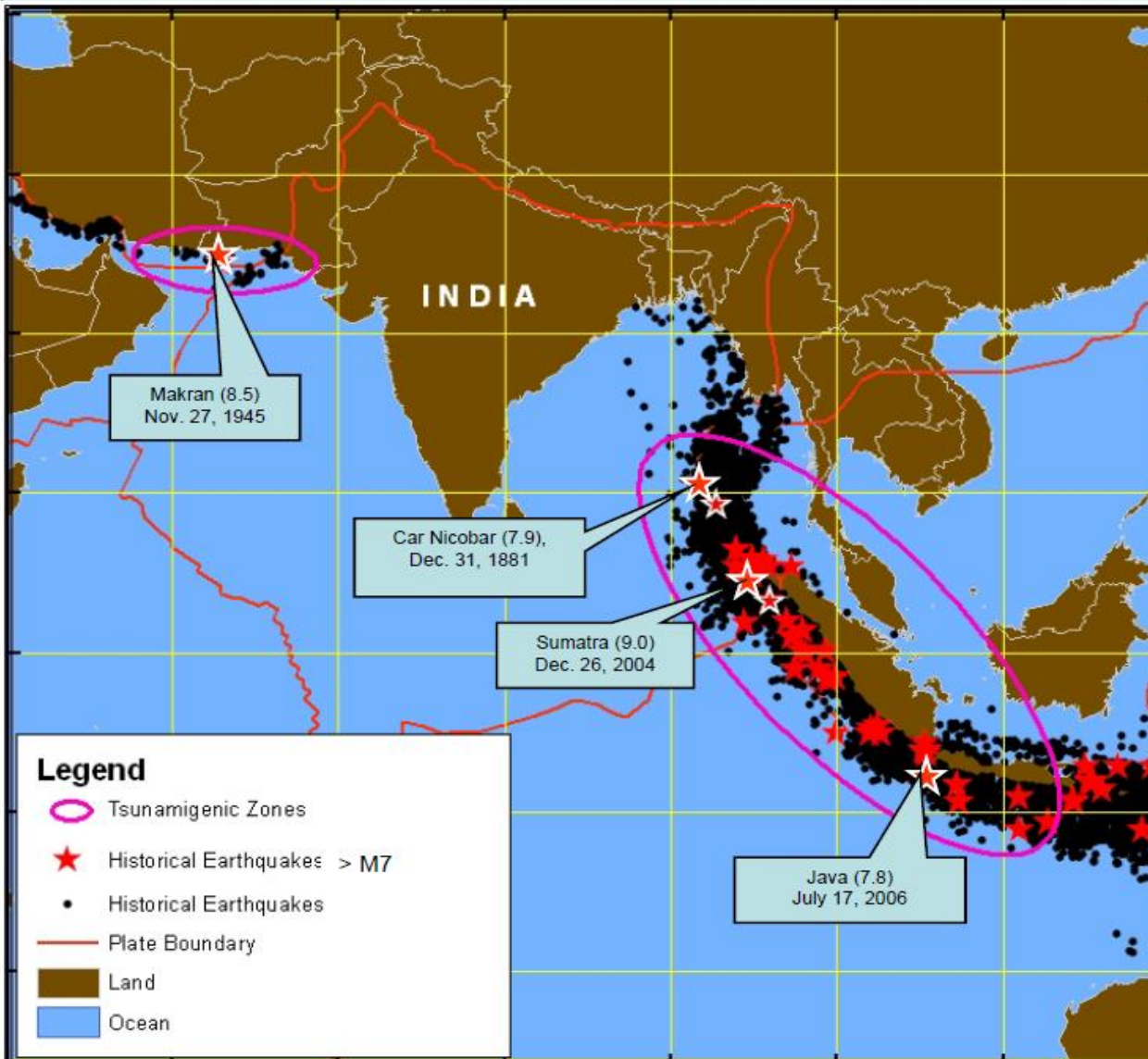
TSUNAMIS OF

26 DECEMBER 2004

DRIFTING OF INDIAN SUBCONTINENT



Risk Assessment - Historical Earthquakes & Tsunamis



Tsunamis are primarily caused due to large undersea 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. Possible locations of such events are enclosed in ellipse

Earthquakes with Slow Rupture Velocities are most efficient Tsunami Generators

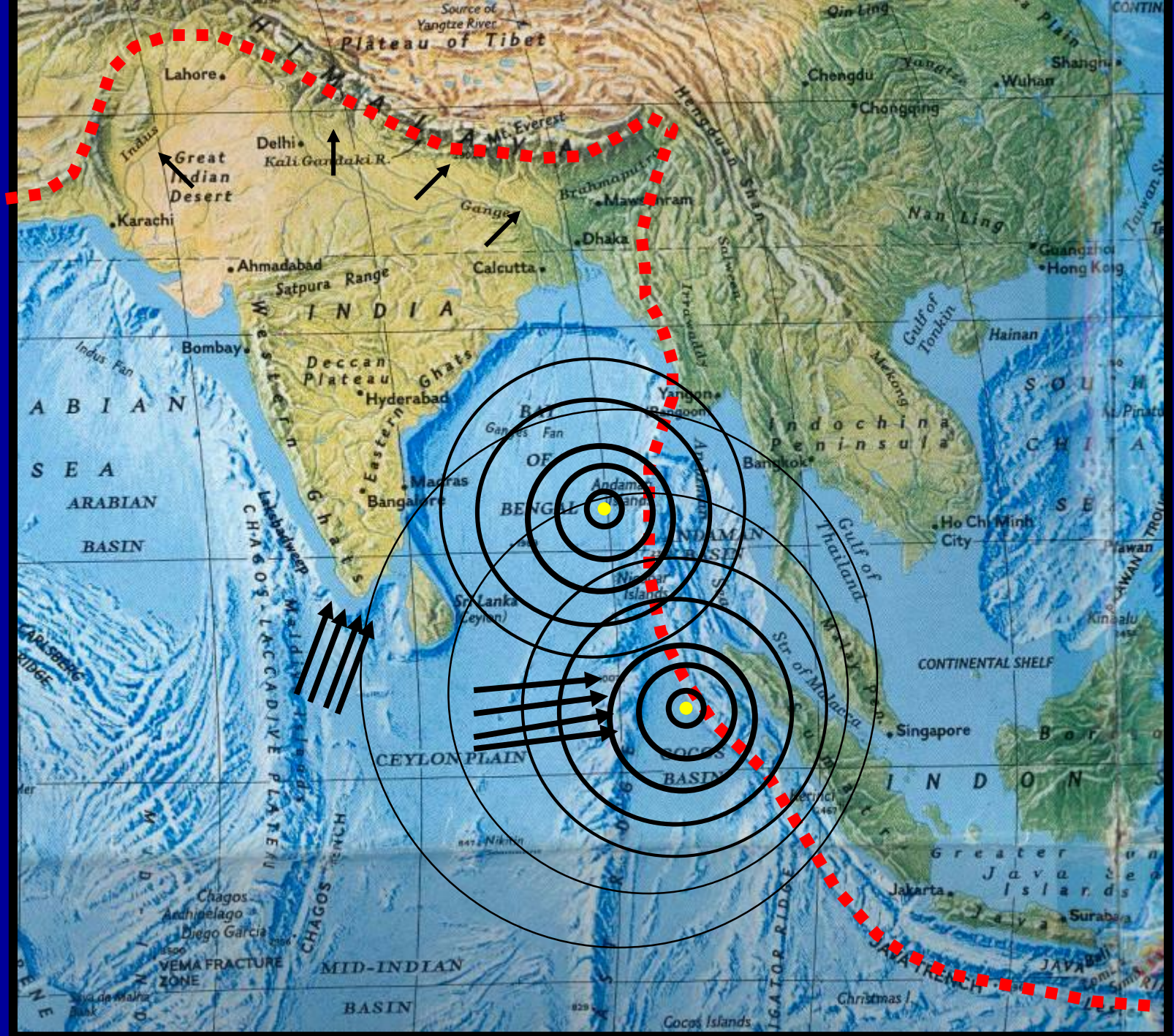
75% of earthquake energy is released in the circum-Pacific belt – 900 Tsunamis in 20th Century

20% in the Alpine-Himalayan belt – 6 Tsunamis in 20th Century

Historical Tsunami in India

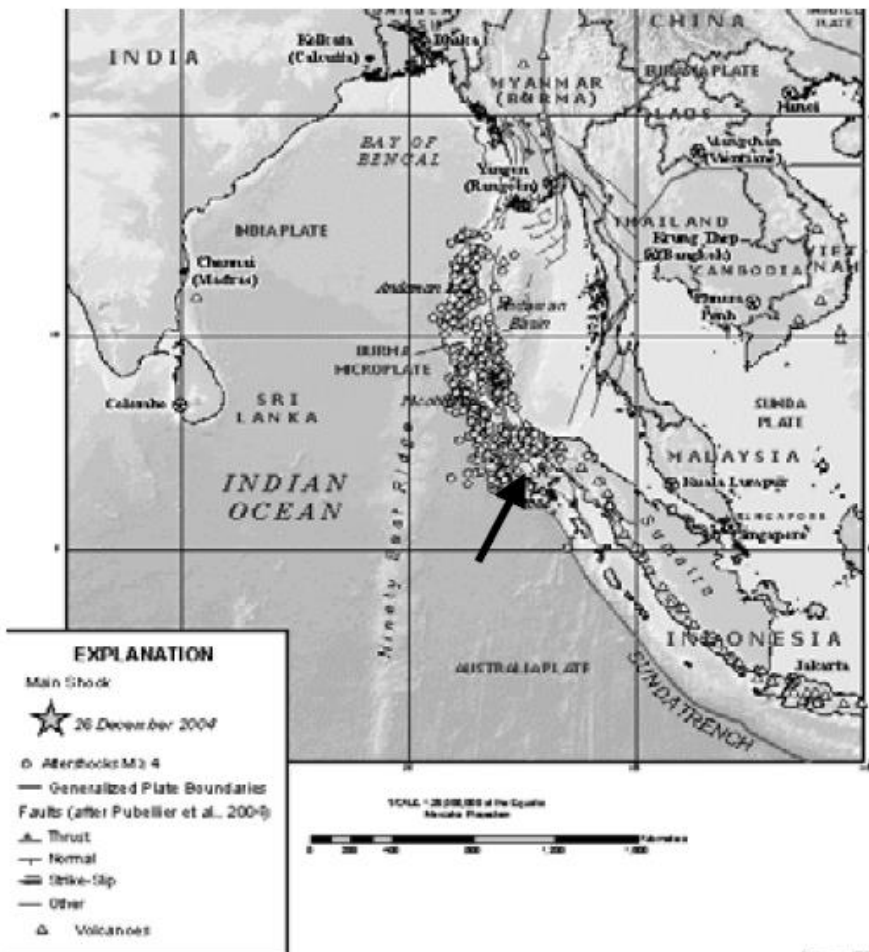
12 Apr, 1762 (BoB EQ) – 1.8 M
31 Dec, 1881 (Car Nicobar EQ)
27 Aug, 1883 (Krakatoa) – 2 M
26 Jun, 1941 (Andaman EQ)
27 Nov, 1945 (Makran EQ) – 12 M
26 Dec, 2004 (Sumatra EQ)

Landslides, Volcanoes & Meteor Impacts can also generate Tsunamis

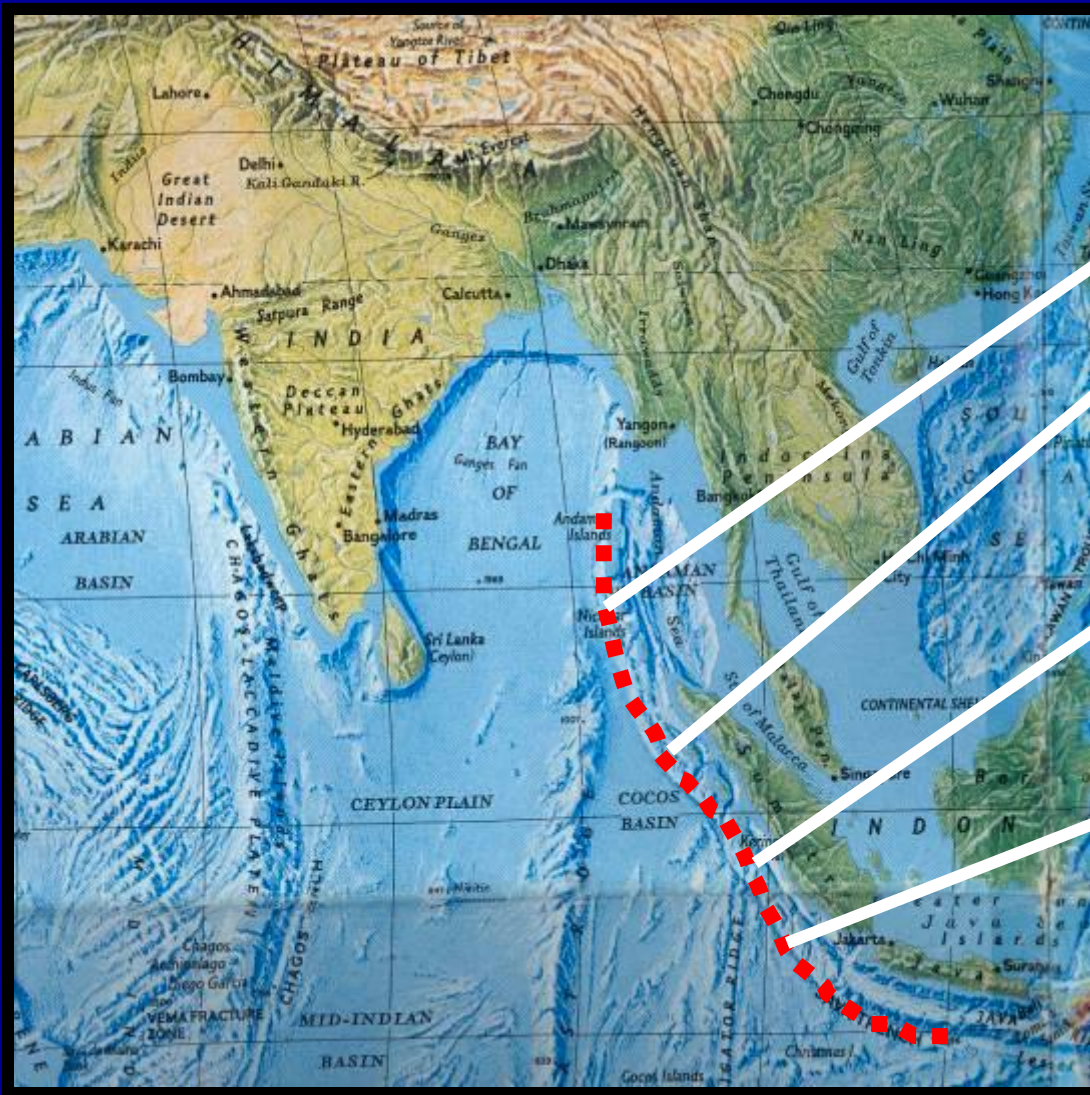


Sumatran Earthquake and Tsunami

December 26th, 2004



- Megathrust along subduction zone between Australian plate and Burma and Sunda microplates.
- 1200 km long displacement zone, most of which occurred 500 km N.W. of epicenter.
- Maximum of 20 m displacement
- Magnitude 9.0
- Fourth largest earthquake since 1900 A.D. and largest since 1964 Alaska earthquake.
- Equivalent to 475 megatons of TNT (23,000 Nagasaki A-bomb).
- Triggered a massive tsunami



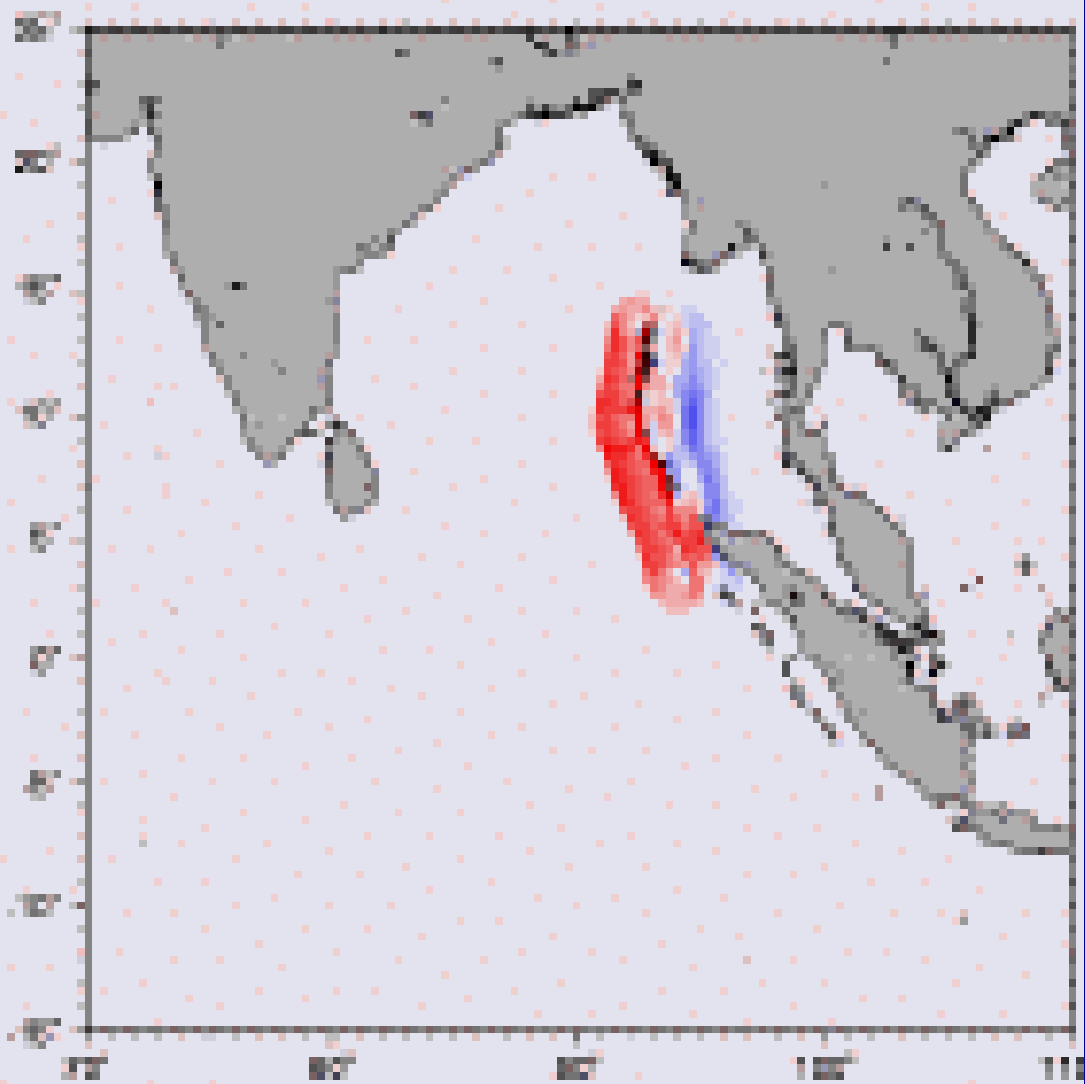
Length of subduction – 1200 km

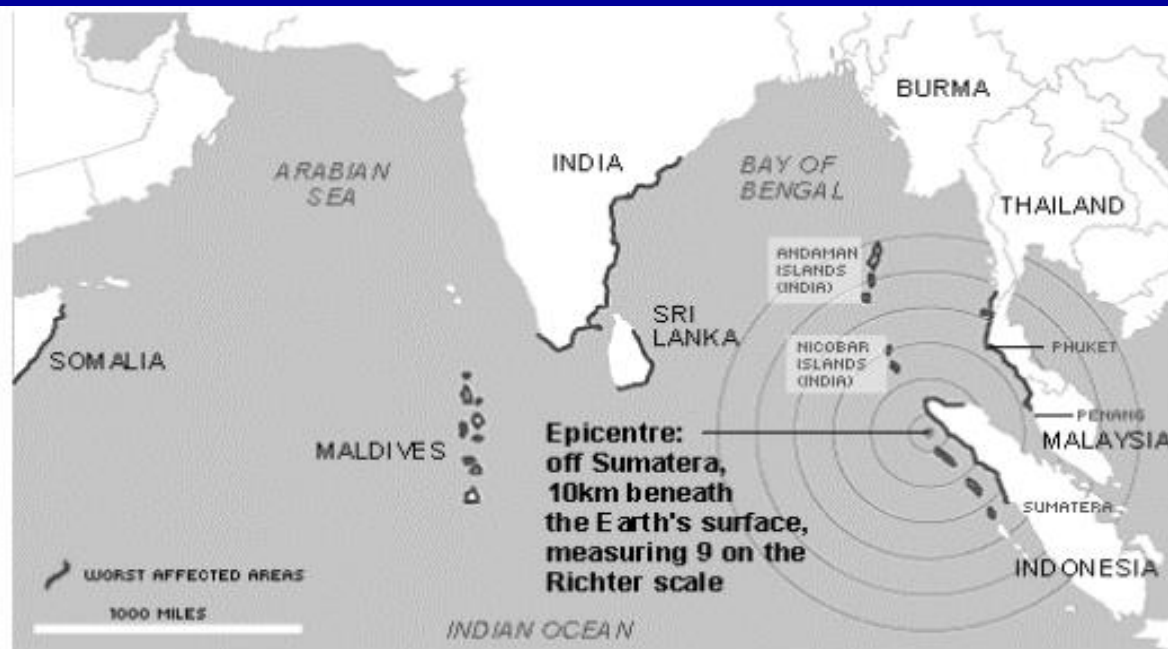
Width of rupture – 100 km

Depth of subduction – 15mts

**Energy released – 4.75 Lakh
Kiloton = 23,000 Hiroshima
bombs**

2004 Sumatra Earthquake CFE slice





Tsunami traveled across entire Indian Ocean, affecting Indonesia, Malaysia, Thailand, India, Sri Lanka, Maldives, Somalia, Madagascar and Tanzania. Maximum wave height was about 25 m (80 ft).

Travel Times

India ~ 2 hours

E. Africa ~ 7 hours

TSUNAMIS IN THAILAND





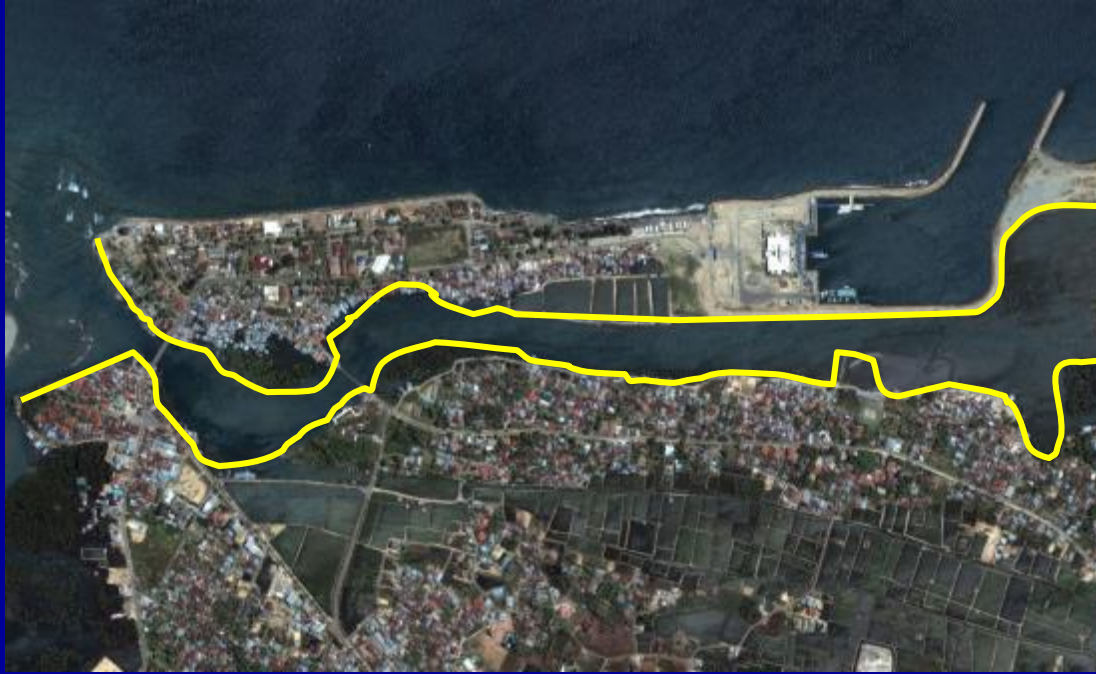




TSUNAMIS IN INDONESIA



BANDA BEACH



BANDA_ACEH_NORTHERNSHORE

June 23 2004



Dec 28 2004

INDONESIA



January 13 2003



December 29 2004

TSUNAMIS IN INDIA

CHENNAI MARINA BEACH



CHENNAI MARINA BEACH



TSUNAMI AFFECTED ENNORE – FISHING HARBOR



Tsunami - 2004

Part of Chennai City

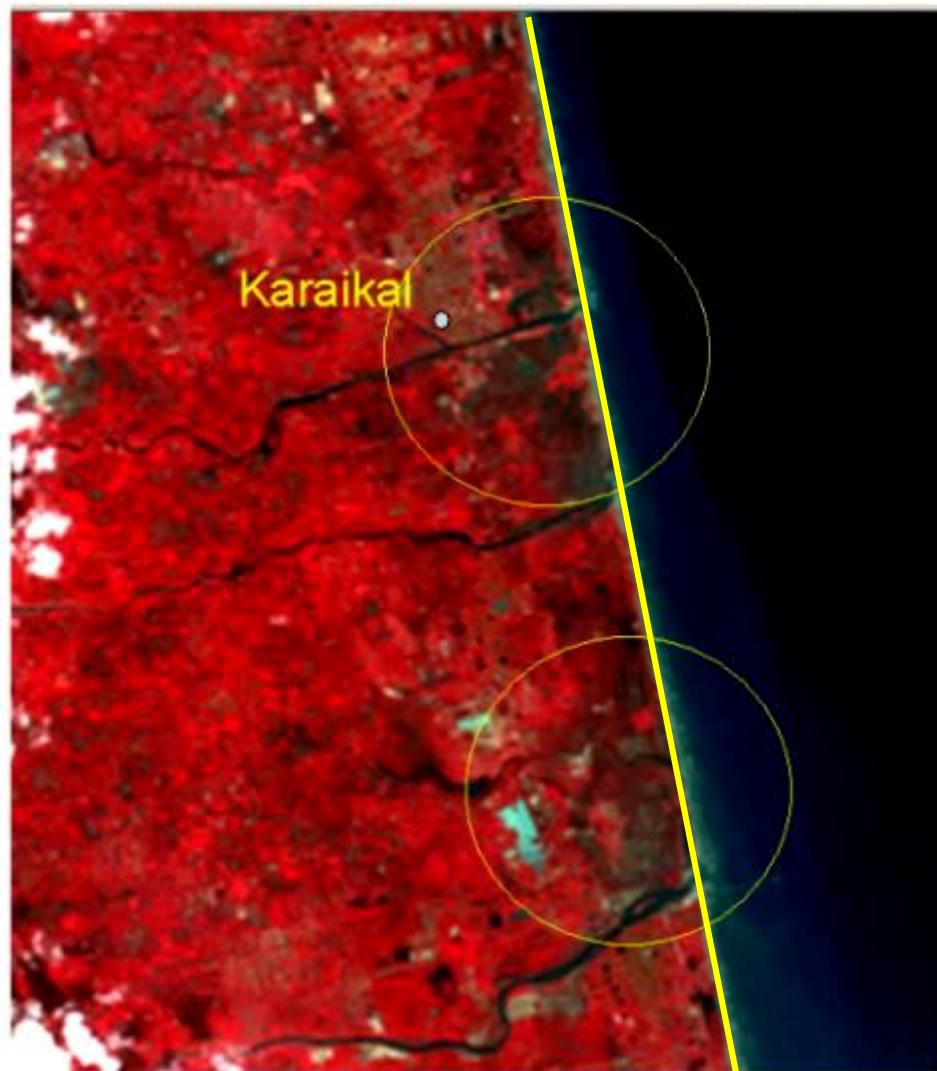
IRS-P6 L4 MX Image of 12-Jan-04

IRS-P6 L4 MX Image of 27-Dec-04

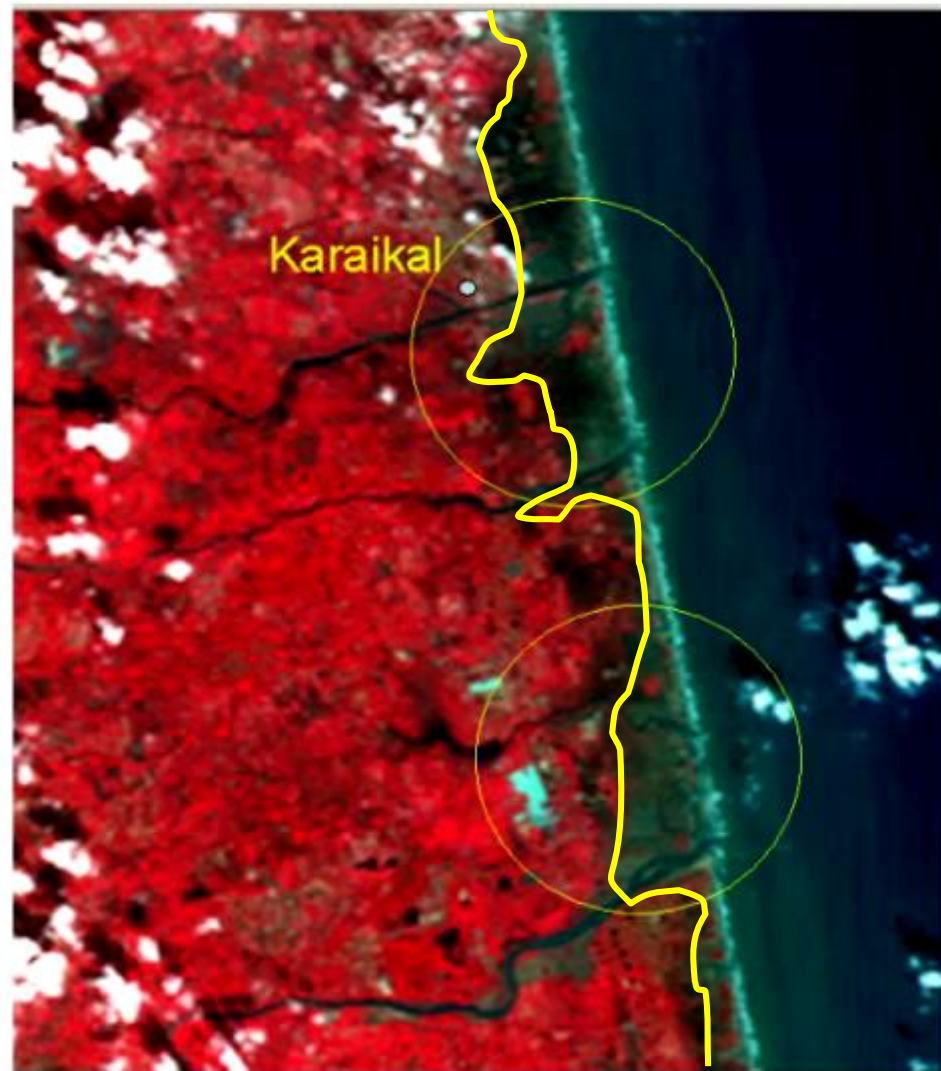


IRS P6 AWIFS Data

18 December 2004



28 December 2004





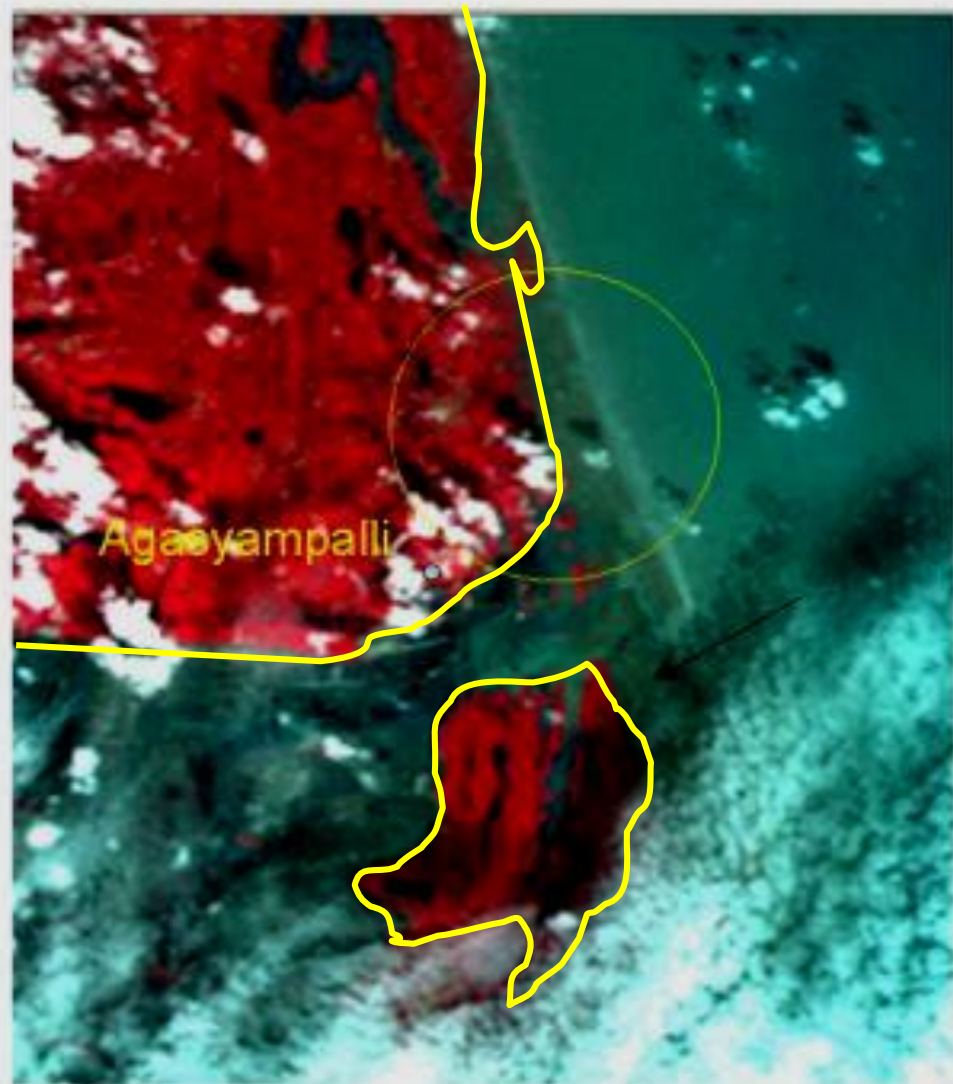
Nagapattinam

IRS P6 AWIFS Data

18 December 2004



28 December 2004



VEDARANNIYAM

Method of Splitting Tsunami (MOST) Model

Tsunami modeling using MOST proceeds in three distinct stages:

A Deformation Phase generates the initial conditions for a tsunami by simulating ocean floor changes due to a seismic event.

A Propagation Phase propagates the generated tsunami across deep ocean using Nonlinear Shallow Water (NSW) wave equations.

An Inundation Phase simulates the shallow ocean behavior of a tsunami by extending the NSW calculations using a multi-grid “run-up” algorithm to predict coastal flooding and inundation.

MOST simulations using all three phases require the following sets of input data:

- **The amount and distribution of the sea-floor dislocation, induced by a seismic event.**
- **Gridded bathymetric data information for the open ocean propagation.**
- **A set of gridded Digital Elevation Models (DEM) containing bathymetry and topography for use during the inundation phase. The set consists of one DEM that contains bathymetric and topographical information, and two DEMs that contain bathymetrical information and optional topographical information.**

Table 3 MOST Digital Elevation Model Grids Data Requirements

MOST Simulation Phase	Detailed Bathymetry	Detailed Topography
Deformation	Required	Not Required
Propagation	Required	Not Required
Inundation:		
Grid A (Outer)	Required	Optional unless run-up enabled
Grid B (Intermediate)	Required	Optional unless run-up enabled
Grid C (Inner)	Required	Required

Table 4 MOST Digital Elevation Model Grids Spatial Resolution

MOST Stage	Recommended Resolution	Lowest Required Resolution*
Deformation/Propagation	1 arcminute (~1800 m)	4 arcminutes (~7300 m)
Inundation:		
Grid A (Outer)	36 arcseconds (~1080 m)	2 arcminutes (~3600 m)
Grid B (Intermediate)	6 arcseconds (~180 m)	18 arcseconds (~500 m)
Grid C (Inner)	≤ 1 arcsecond (≤ 30 m)	2 arcseconds (60 m)

*Note: Equivalent meter value on the Equator.

Table 6 Some Recommended Sources of DEM Data

Coverage	Sources	Type	Links
Global	ETOPO2	bathymetry, topography	http://www.ngdc.noaa.gov/mgg/global/global.html
	GEBCO	bathymetry, topography	http://www.ngdc.noaa.gov/mgg/gebco/gebco.html
U.S. and its territories	NOAA	bathymetry, topography, shoreline, datum	http://www.ngdc.noaa.gov/ http://www.nos.noaa.gov/
	USGS	topography, photography, bathymetry	http://seamless.usgs.gov/
	USACE	bathymetry, shoreline	http://www.usace.army.mil/
	State agencies, universities	various	various
Local region	Local Agencies	various	various

Seismic Inputs

Significant changes to the ocean floor along a fault plane are characterized by a strike, a dip, a slip or rake angle of the fault plane; the ocean floor slip magnitude (dislocation) along the fault plane trace; and the epicenter of the seismic event responsible for the undersea deformation.

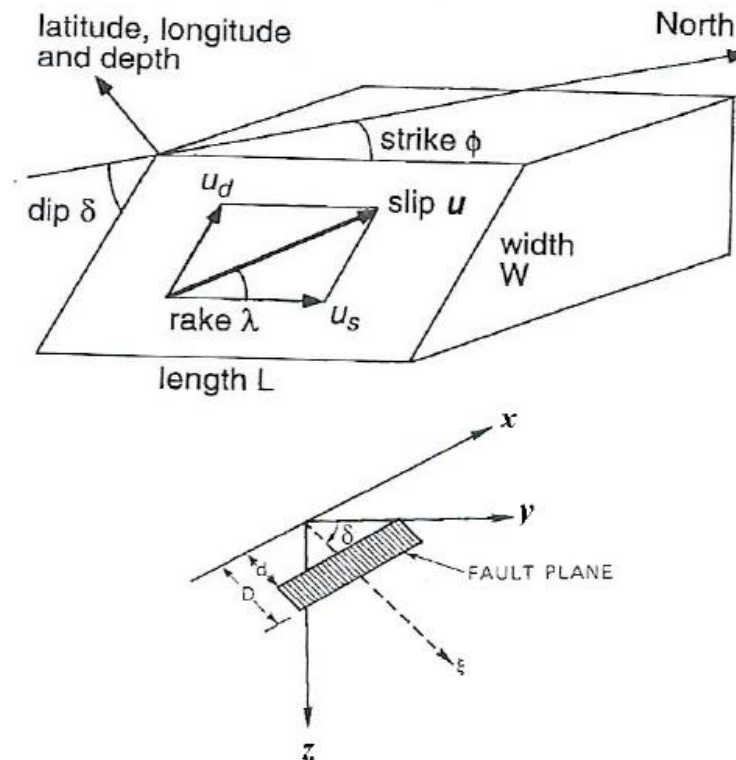


Figure 3: Earthquake Fault Parameters and Geometry System

Sea floor dislocation due to a rupture along a fault is expressed in terms of a [deformation rectangular area](#)—a region of ocean bottom bisected by the [fault trace](#), with an orientation determined by the [strike](#) angle.

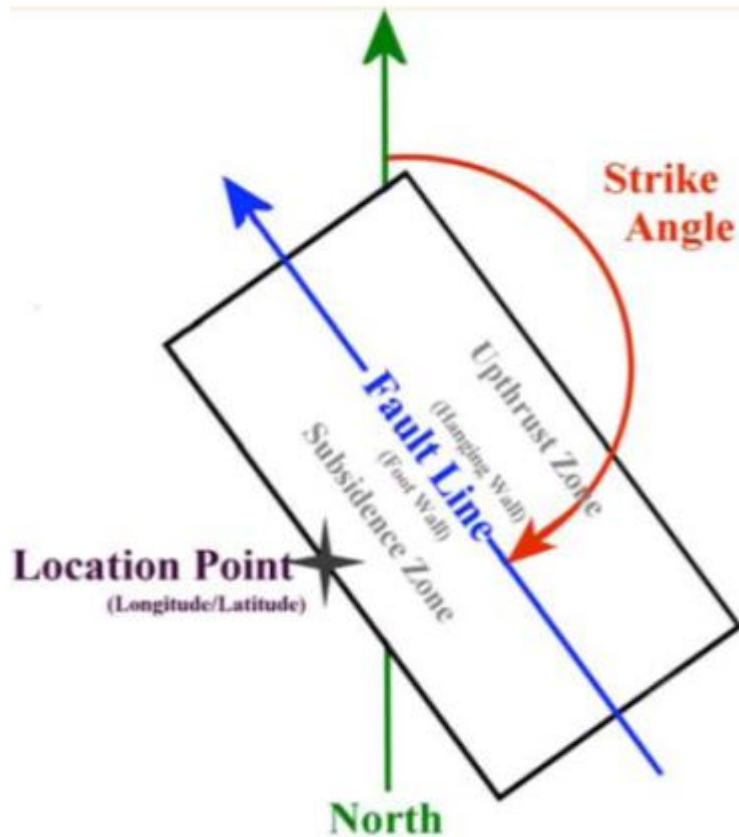


Figure 4: Deformation Rectangle

The fault line projects through the center of the deformation rectangle and divides the rectangle into a region of upthrust on the hanging wall side of the fault, and a region of subsidence on the foot wall side of the fault. The center of the deformation rectangle side parallel to the foot wall (on the subsidence side of the rectangle) is its location point or location reference—the point referred to by the longitude and latitude of the rectangle.

Using Multiple Deformation Rectangles

A given deformation rectangle should closely conform to a particular disruption occurring on the ocean floor. To model a real-world seismic fault, you need to decompose the rectangle into multiple deformation rectangles that are as contiguous and non-overlapping as possible.

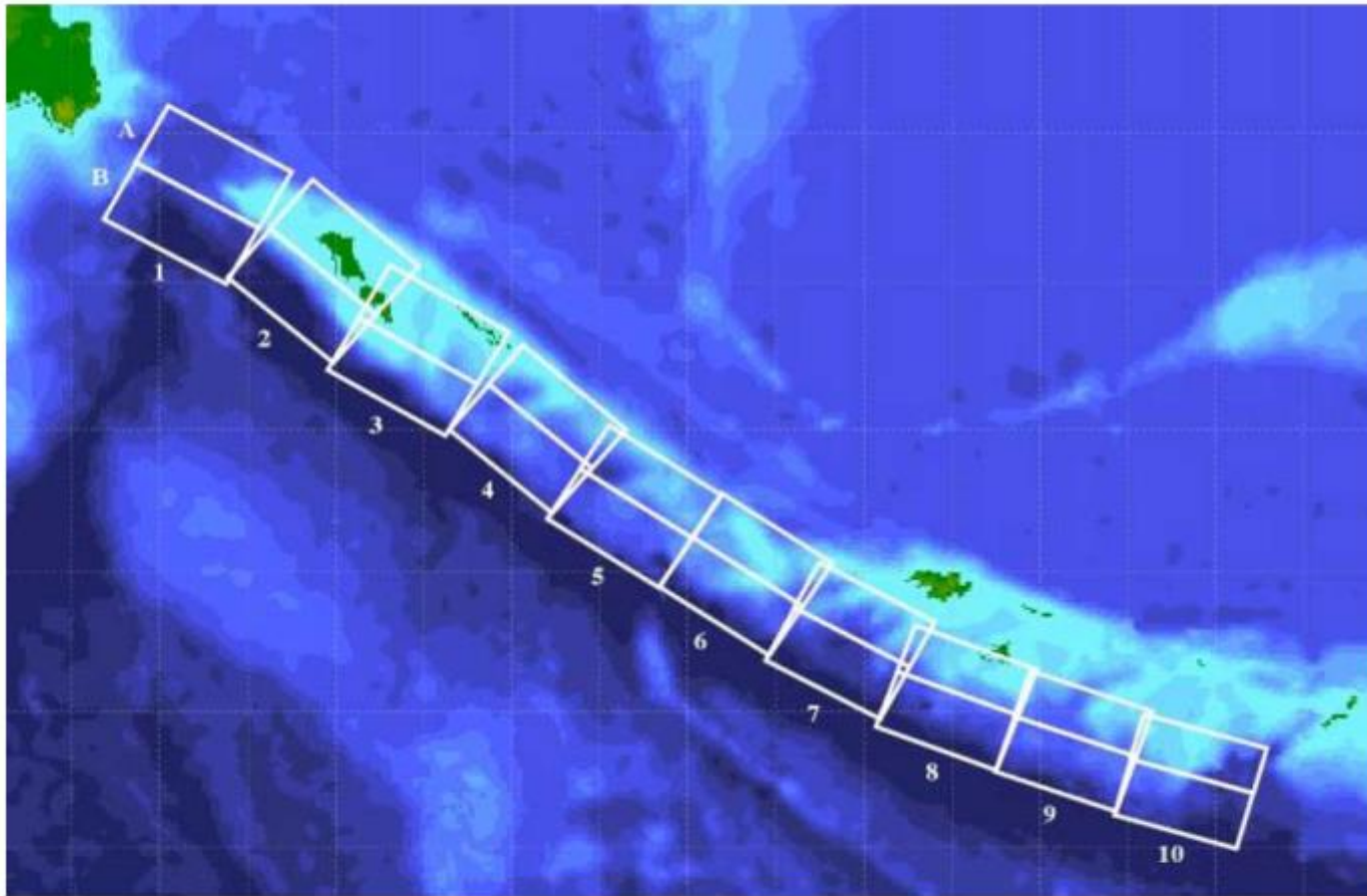


Figure 5: Fault Decomposed to Reformation Rectangles

Seismic Data Inputs to deform

The specification of a deformation rectangle and the size (in terms of nodes on a DEM finite difference grid) of a target sub-grid region on the ocean surface provide the seismic input data to **deform**.

A deformation rectangle is defined using the following parameters:

- latitude of the deformation rectangle
- longitude of deformation rectangle (in East degrees)
- length of deformation rectangle (in km)
- width of deformation rectangle (in km)
- seismic [epicenter](#) depth (in km)
- [slip magnitude](#) (in m)
- [strike angle](#)
- [dip angle](#)
- [rake angle](#) (also known as the [slip angle](#))

All of these values are supplied to the *stdin* of **deform**.

Deformation Phase Outputs



**Projection of Deformation Rectangle to
Deformation Phase Output Area**

Propagation Phase Modeling

The Propagation Phase models the open-ocean evolution of a tsunami using a depth-integrated version of Nonlinear Shallow Water (NSW) wave equations in two spatial and one temporal dimension. The output of a Propagation Phase calculation—the wave's height, and zonal and meridional velocities—is saved for selected time steps and provides the initial and boundary conditions for Inundation Phase.

Ocean Displacement Inputs to Propagation Phase

The ocean displacement inputs to **propagation** are created by **deform**. These inputs define the initial tsunami wave state and provide forcing functions to Propagation Phase calculations.

All Deformation Phase output produced by **deform** and used as input to the Propagation Phase must be calculated using the same DEM data set that was used as input to **propagation**.

Multiple Deformation Phase outputs can be used as inputs to **propagation**. This allows the decomposition of complicated undersea faulting into several deformation rectangles. Ocean surface displacements due to a deformation rectangle are mapped to a subsection (maximum size 500 x 500) of the nodes that make up the DEM finite difference grid

The MOST propagation model uses a numerical dispersion scheme and the non-linear shallow-water wave equations in spherical coordinates, with Coriolis terms (Murty, 1984):

$$h_t + \frac{(uh)_\lambda + (vh\cos\phi)_\phi}{R\cos\phi} = 0$$

$$u_t + \frac{uu_\lambda}{R\cos\phi} + \frac{vu_\phi}{R} + \frac{gh_\lambda}{R\cos\phi} = \frac{gd_\lambda}{R\cos\phi} + fv$$

$$v_t + \frac{uv_\lambda}{R\cos\phi} + \frac{vv_\phi}{R} + \frac{gh_\phi}{R} = \frac{gd_\phi}{R} - fu,$$

where λ is longitude, ϕ is latitude, $h = h(\lambda, \phi, t) + d(\lambda, \phi, t)$, $h(\lambda, \phi, t)$ is the amplitude, $d(\lambda, \phi, t)$ is the undisturbed water depth, $u(\lambda, \phi, t)$, $v(\lambda, \phi, t)$ are the depth-averaged velocities in the longitude and latitude directions, respectively, g is the gravity acceleration, f is the Coriolis parameter ($f = 2\omega\sin\phi$), and R is the Earth radius. In the MOST model, these equations are solved numerically using a splitting method similar to that described by Titov (1997).

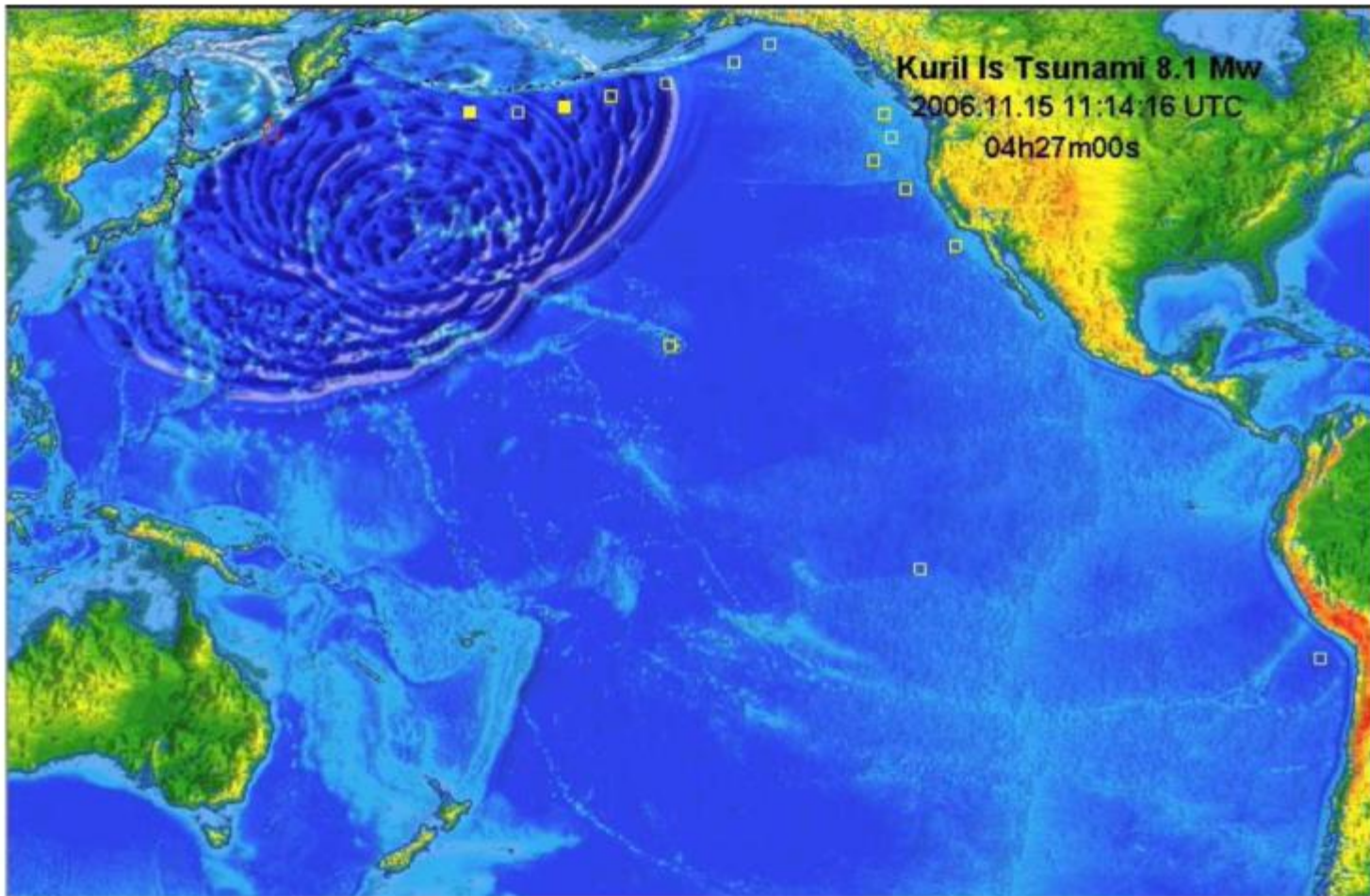
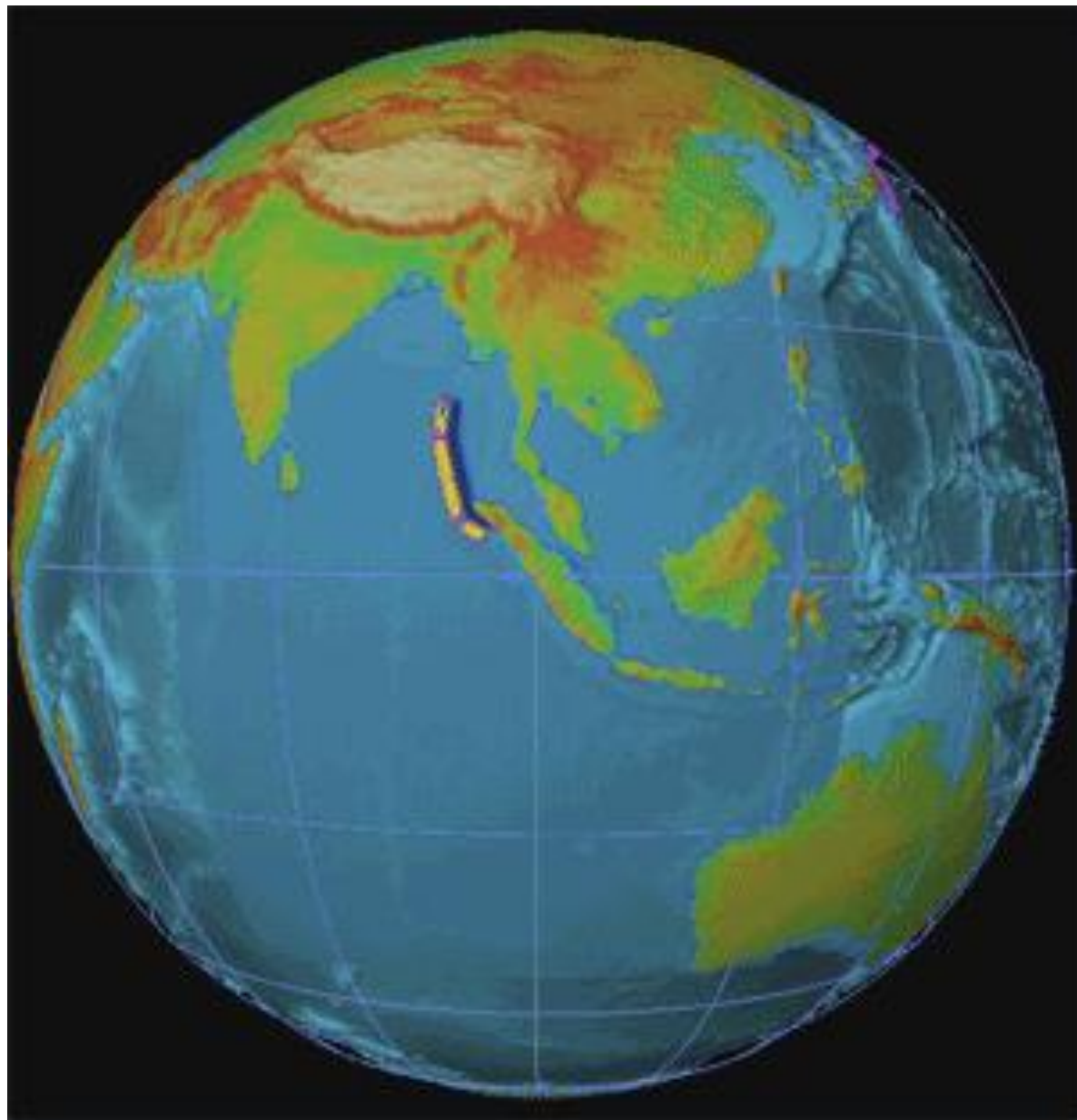


Figure 8: DEM and Tsunami Propagation

The propagation executable produces three output files, each containing the time-stepped evolution of one of the three components of the wave equations solution. These tsunami components are:

- Wave height in centimeters.
- Meridional velocity in centimeters/second.
- Zonal velocity in centimeters/second.



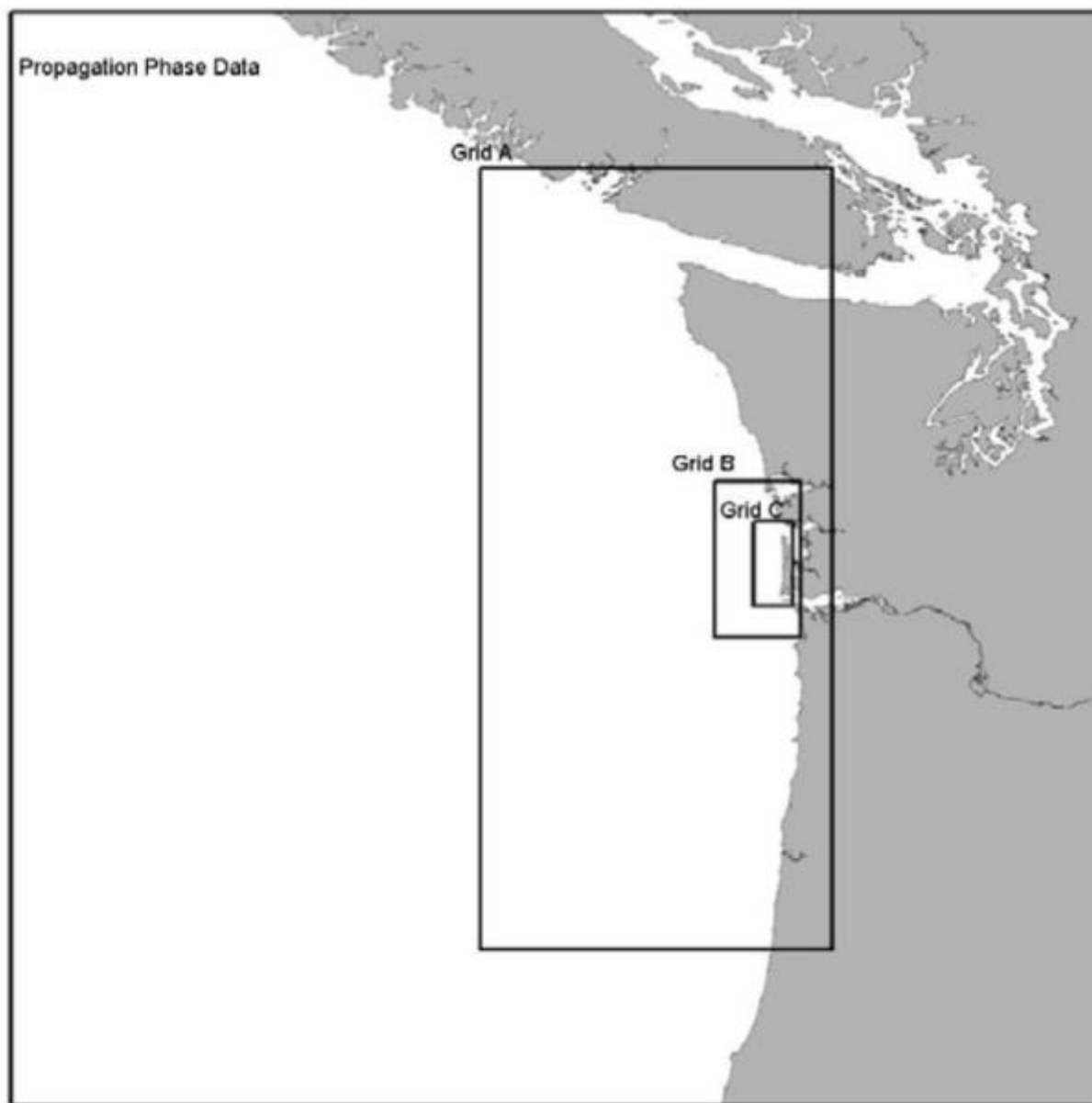
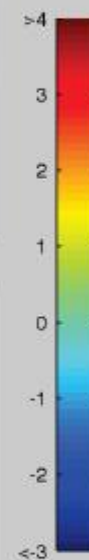
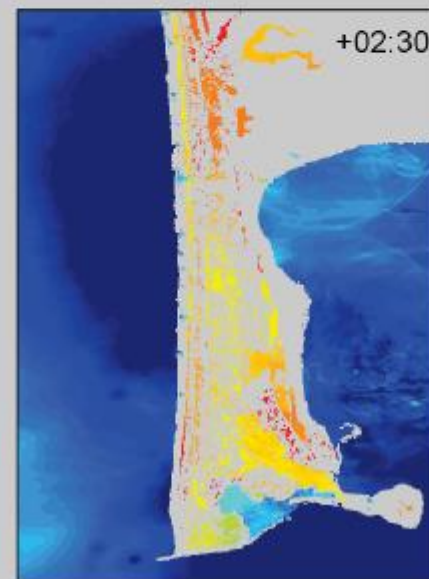
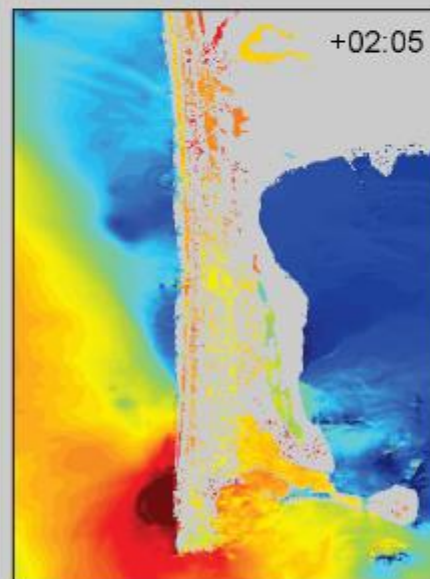
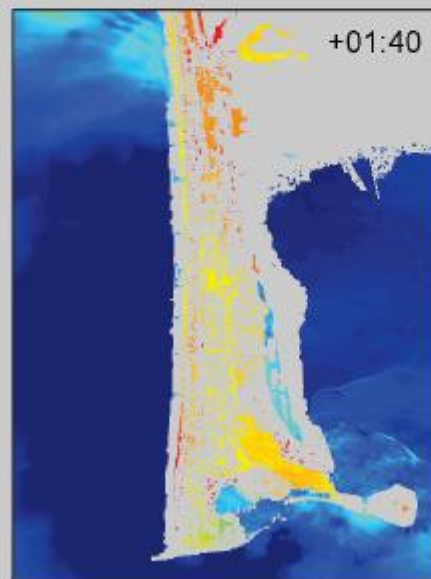
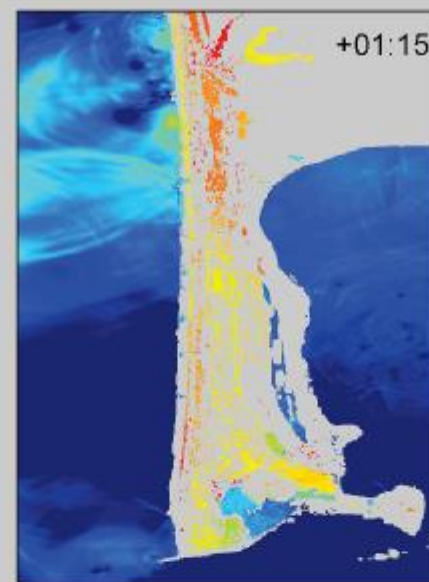
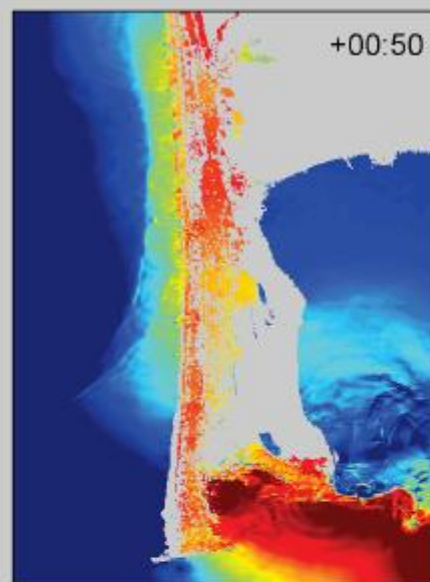
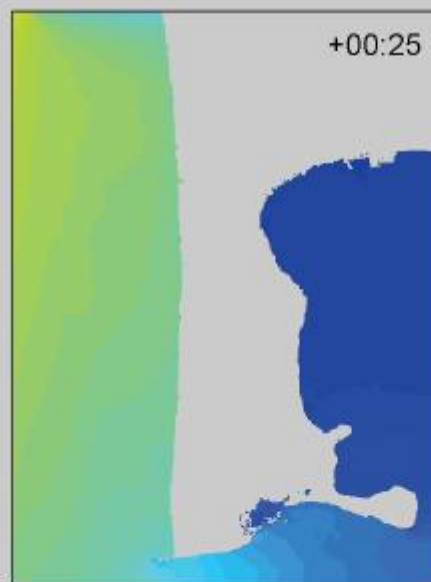


Figure 9: Propagation Phase and Inundation Phase Data Grids



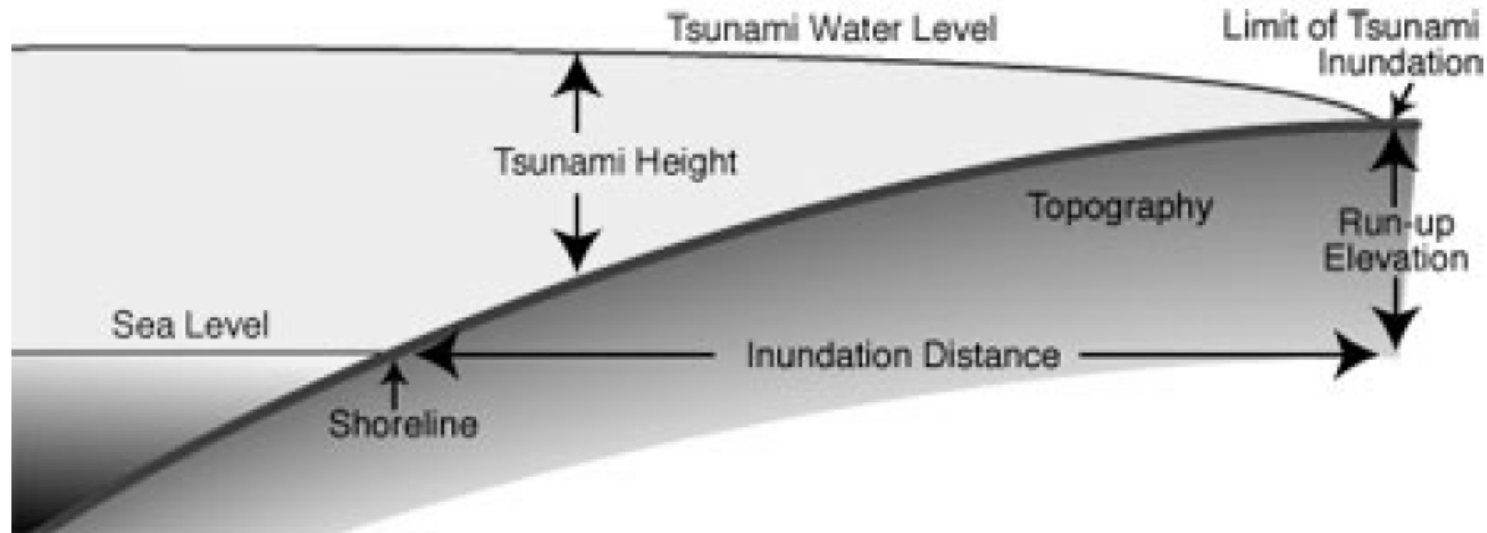
Inundation Phase Modeling

The inundation executable models shoreline tsunami behavior, including onshore run-up. Tsunami behavior is modeled using input from propagation, the depth-integrated NSW wave equations computed on a set of nested DEM grids, and a run-up algorithm to predict onshore flooding.

Inundation Phase output includes wave height, zonal velocity, and meridional velocity for each of the nested NSW calculations. The output is saved for selected time steps

RUNUP AND INUNDATION MAPPING

Tsunami run-up is the height above sea-level at the most inland location that the water penetrates.



Inundation distance is the distance inland from the normal shoreline that the water penetrates.

Inundation distance depends on the slope of the land extending down to the shoreline and the run-up elevation.

RUN UP MAPPING

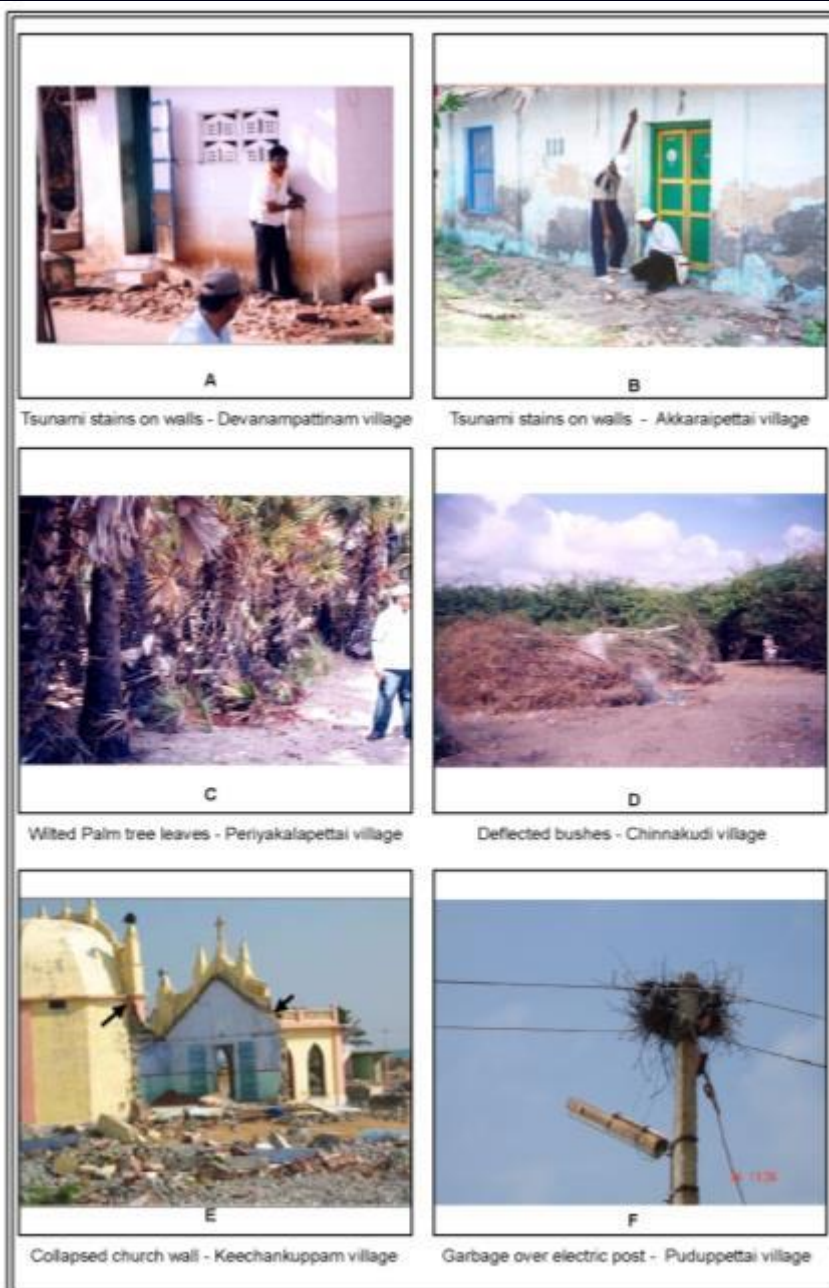


Fig.4.5 Run up mapping

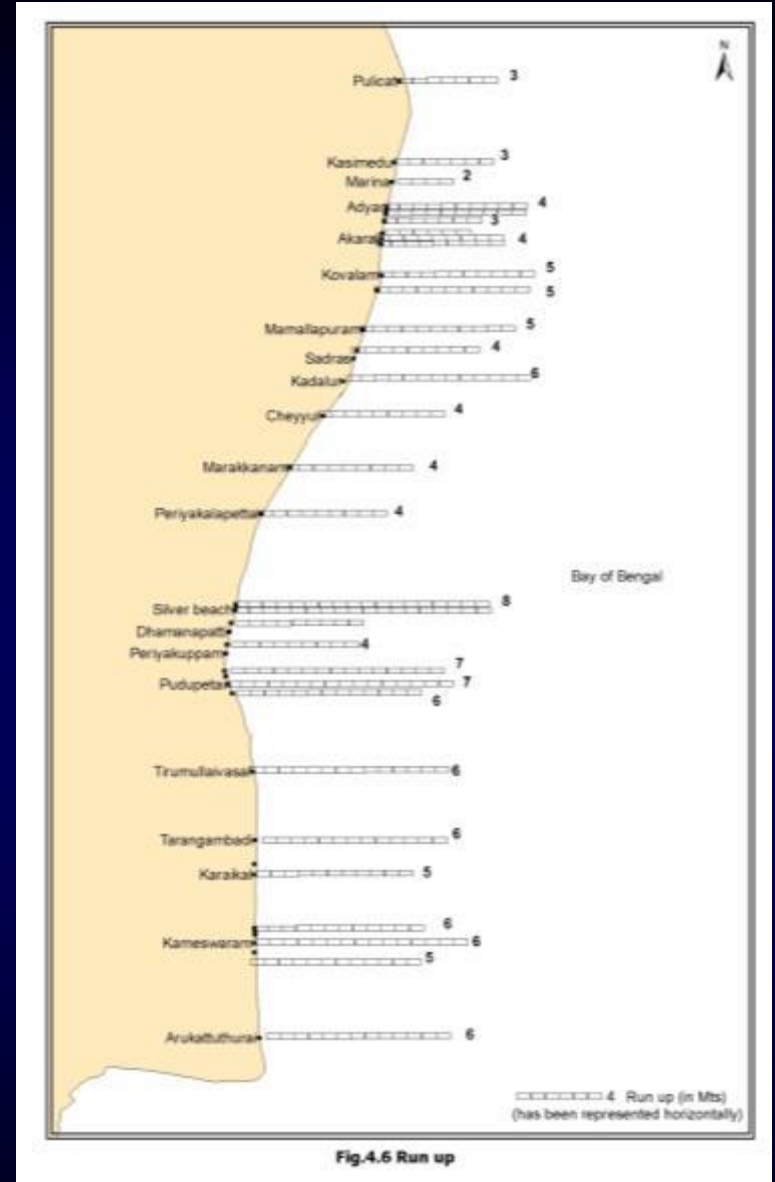


Fig.4.6 Run up

The extent of vertical rise of sea water during tsunami is called as run up

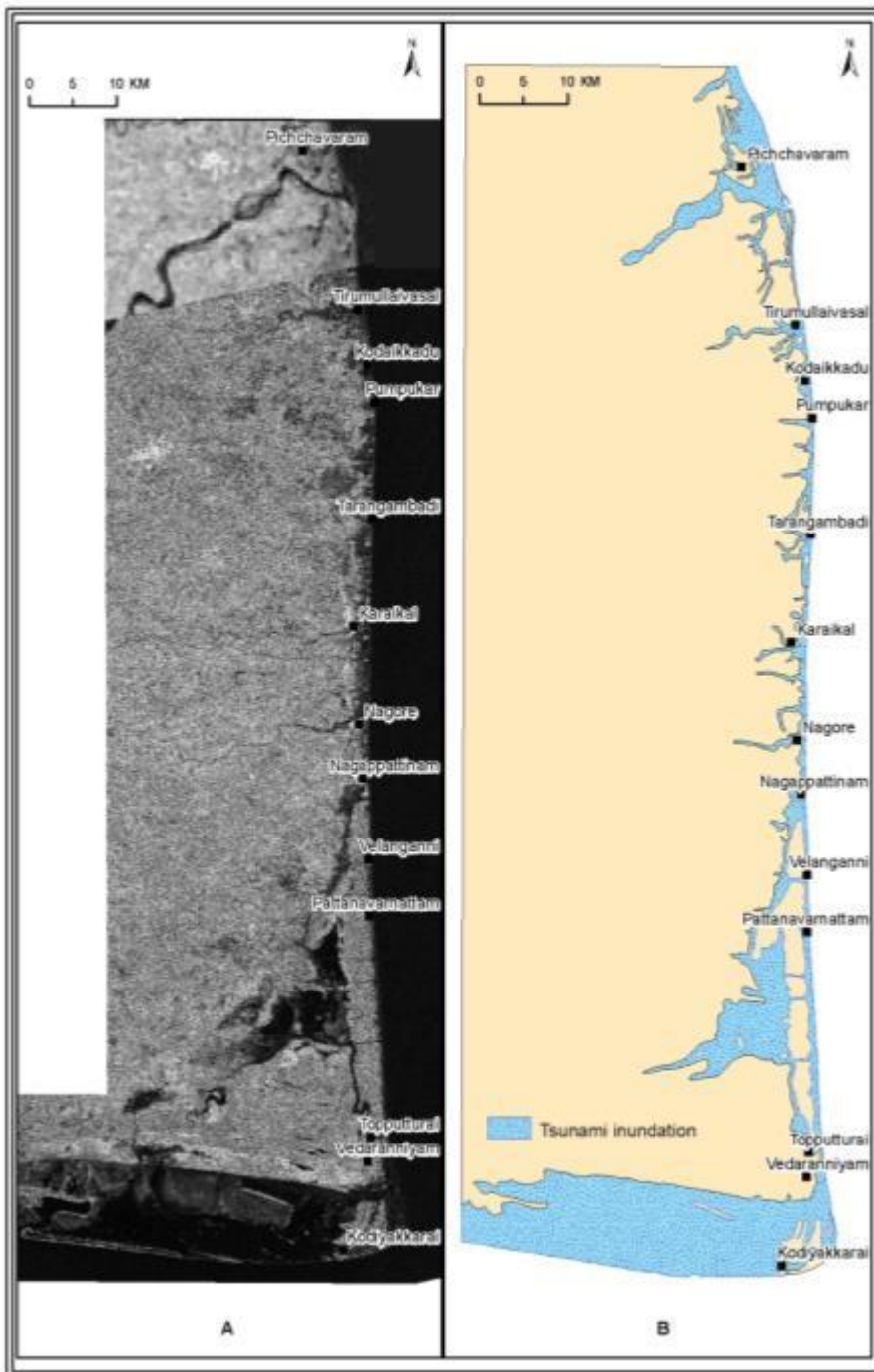


Fig.4.7 ENVISAT- Tsunami inundation

INUNDATION MAPPING

The lateral extent up to which the tsunami waters inundated into the inland is called as inundation

The microwave data of ENVISAT possesses strong credibility in mapping the tsunami inundated areas in the form of fine texture and darker tone (due to moisture content).



Immediately after the tsunami 2004, the digital ortho photography was done through a special flight by the Survey of India on 28-12-2004 (just two days after the tsunami) covering a width of 2 km across the east coast of India in the tsunami affected states of Andhra Pradesh and Tamil Nadu.

As these digital ortho photographs have vividly and precisely displayed the inundation pattern, the same were used for selected areas wherever the ENVISAT data did not give much clarity.

Some sample ortho photographs of parts of Nagapattinam area

Fig.4.8 Digital ortho photograph of Nagapattinam area showing tsunami inundation



(A) Thrown off boats along railway track - Nagore



(B) Thrown off boats - Cuddalore old town



(C) Thrown off boats - Muvakkarai village



(D) Collapsed railway line - Nagore



(E) Collapsed railway line - Nagore railway station



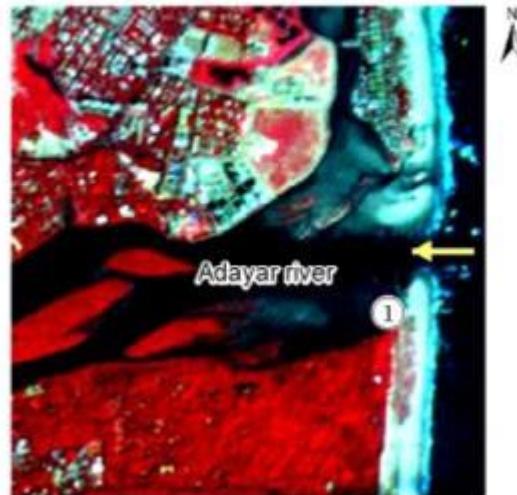
(F) Thrown off boats - Vanjiyur village

Apart from preparing tsunami inundation maps using satellite data and the digital ortho photographs, field based mapping was also done so as to check and update the interpreted data and also to collect data on the types of damages / imprints left by the tsunami so as to bring out the ferocity, the pattern of inundation and the responses of the various geo and anthropogenic systems

Fig.4.10 Field photographs showing imprints of tsunami



(A) IRS P6 Image - 12 January 2004 (pre tsunami)



(B) IRS P6 Image - 27 December 2004 (post tsunami)



(C) IRS P6 - 12 January 2004 (pre tsunami)



(D) QUICKBIRD PAN 31 December 2004 (post tsunami)

Fig.4.11 Pre and Post tsunami changes in river mouths in the form of breakage of bay mouth bars



(A) Eroded beach - Cuddalore



(B) Eroded beach being under protection
- Pudupettai village (Nagapattinam area)



(C) Eroded beach with relict beach ridge (1)
- Uppanar river Vellangani (Nagapattinam area)



(D) Flattened beaches - Therkupoyyur village
(Nagapattinam area)



(E) Tsunami inundated Marina beach (Chennai area)



(F) Dumping of black sand - Tharangambadi
(Nagapattinam area)

Fig.4.12 Flattened and inundated beaches



(A) Tsunami cut terraces in Uppanar river - Nagapattinam



(B) Tsunami casted sediments in Uppanar river - Nagore

Fig.4.13 Tsunami cut terraces and tsunami casted sediments



(A) Damaged houses - Pudukkuppam village



(B) Collapsed huts - Tirumullaivasal village



(C) Aerial view of tsunami incurred Keechakupam village



(D) Collapsed wall - Nagore



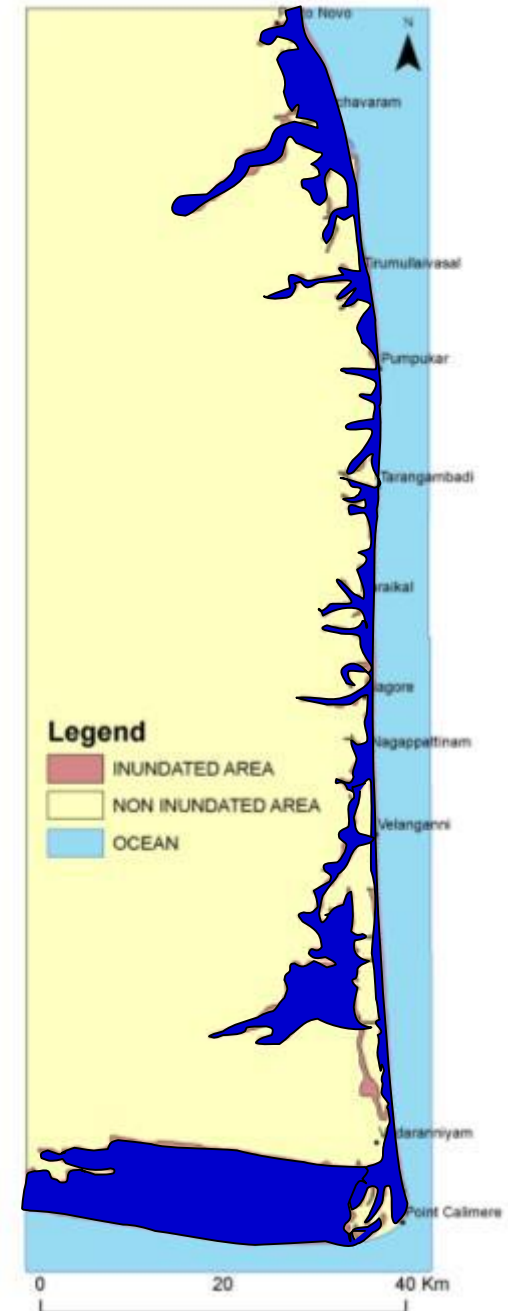
(E) Tsunami slurry encircled temple - Akkaraipettai village



(F) Garbage accumulation - Nagore railway station

Fig.4.9 Field photographs showing imprints of tsunami

NAGAPATTINAM INUNDATION MAP



TRAILS OF TSUNAMI AND COASTAL GEOMETRY



Deflected Pillars in Samiyapettai village (Nagapattinam area)



Deflected plants in Palar region



Deflected plants in Tharangambadi region

Fig.4.21 Trails of tsunami

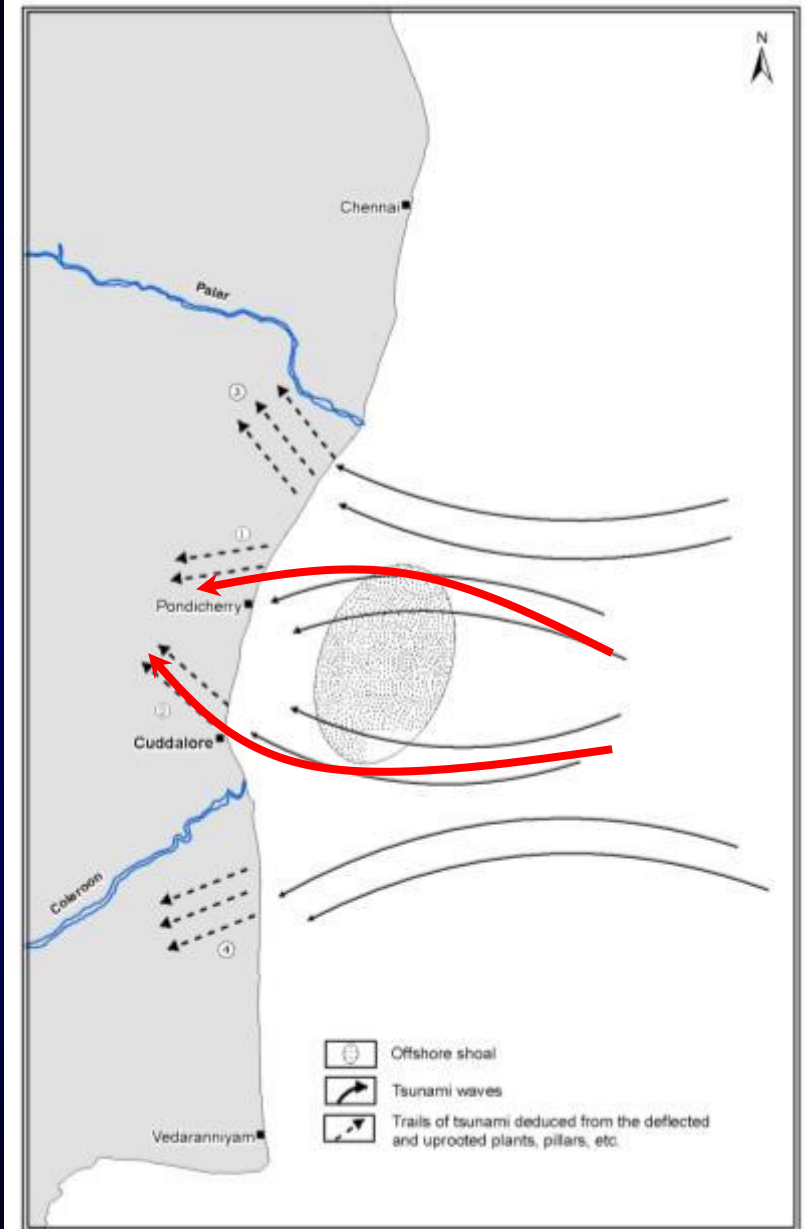


Fig.4.22 Correlation of tsunami trails and coastal geometry

SPATIAL MODELLING

INUNDATION

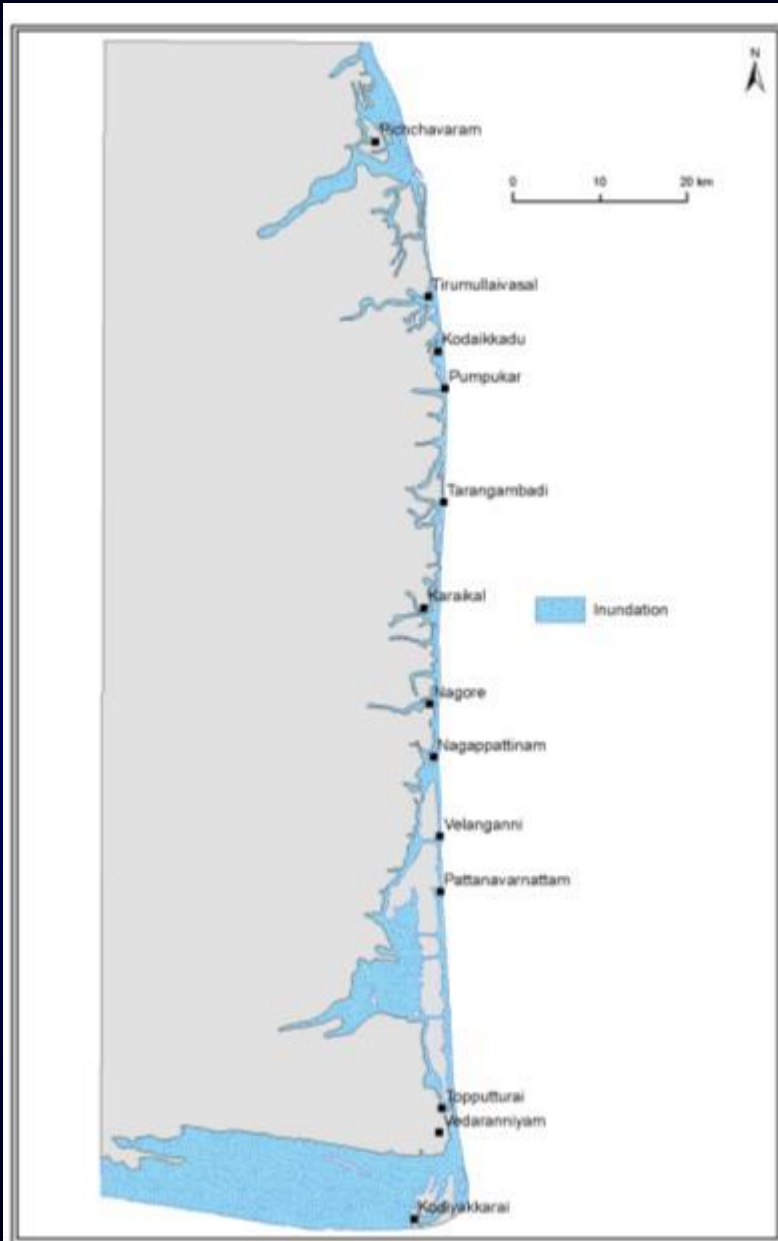


Fig.4.23 Tsunami inundation - deduced from ENVISAT satellite data and field surveys

GEOMORPHOLOGY

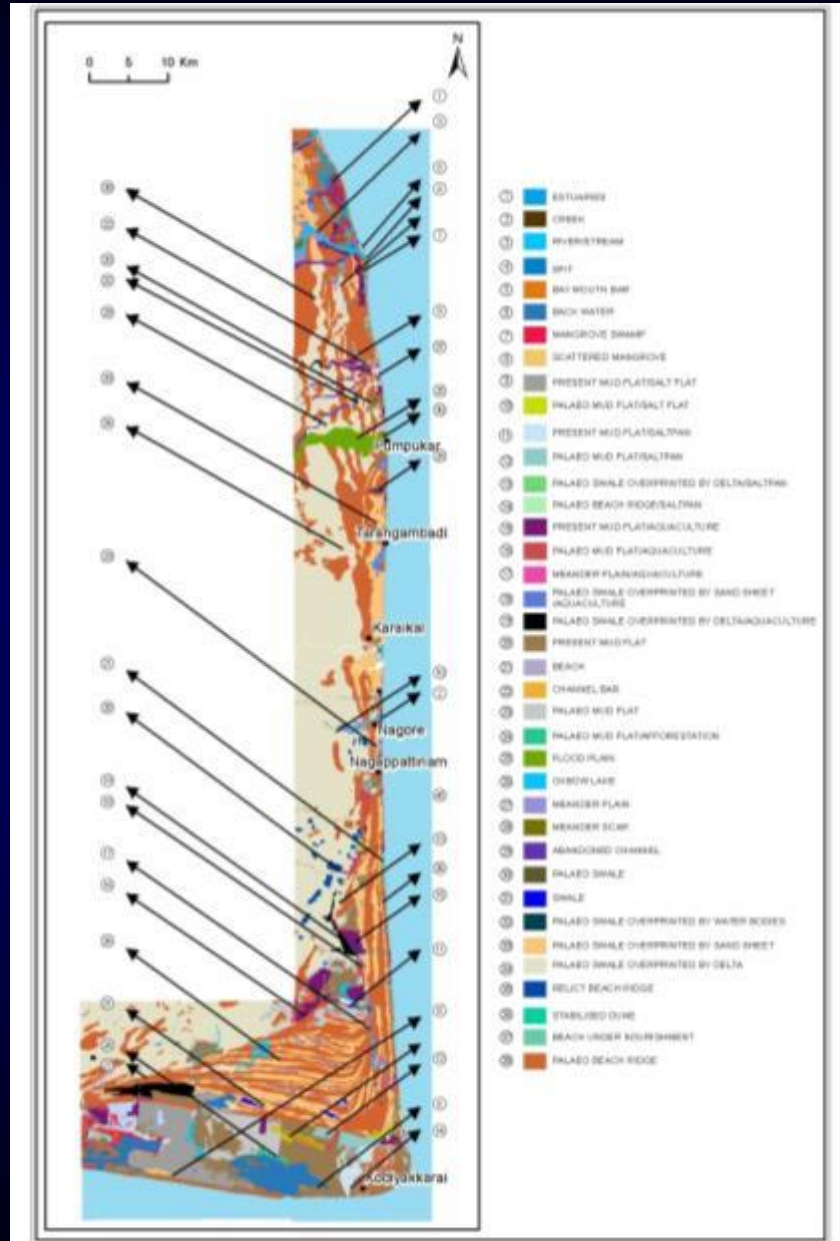
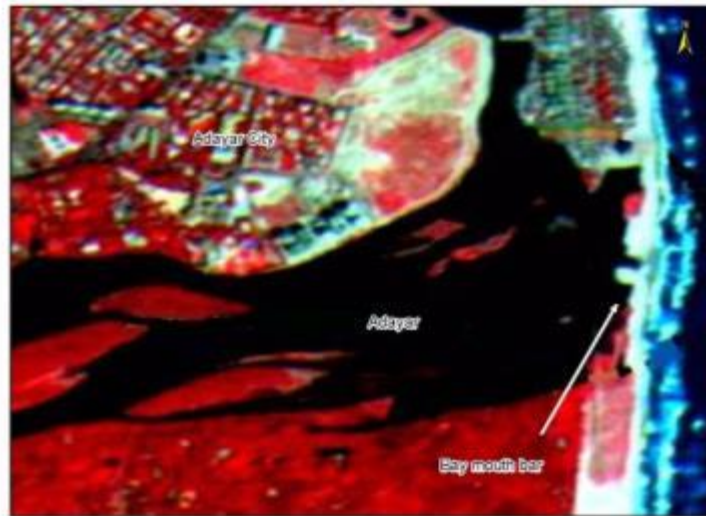


Fig 4.24 Coastal geomorphology - Nagapattinam district

INUNDATION Vs COASTAL GEOMORPHOLOGY

Sl.No	Type	Total Area (Sq.Km)	Inundated Area (Sq.Km)	Area Percentage of Damages/ Inundation
1	Estuary	9.3673	8.5064	90.73
2	Creek	5.8658	4.9523	84.43
3	River/Stream	25.1271	20.3298	80.90
4	Spit	0.0632	0.0632	100
5	Bay Mouth Bar	0.8385	0.8385	100
6	Backwater	54.5797	50.8881	93.23
7	Palaeo Beach Ridge /Saltpan	0.2121	0.0521	24.56
8	Present Mud Flat	42.4373	31.8239	74.99
9	Palaeo Mud Flat	17.5041	11.0008	62.84
10	Meander Plain/Aquaculture	3.0085	2.6073	86.66
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
29	Channel Bar	0.7514	0.7514	100
30	Palaeo Mud Flat	78.5035	64.7661	82.50
31	Palaeo Mud Flat /Afforestation	2.1897	2.1897	100.00
32	Abandoned Channel	10.0656	2.2330	22.18
33	Palaeo Swale	0.3793	0.3002	79.15
34	Swale	7.3481	6.7735	92.18
35	Relict Beach Ridge	16.0938	3.2216	20.01
36	Stablised Dune	2.4850	1.5251	61.37
37	Beach Under Nourishment	7.9765	6.0355	75.66
38	Palaeo Beach Ridge	533.9091	58.1556	10.89

BAY MOUTH BAR - FACILITATOR



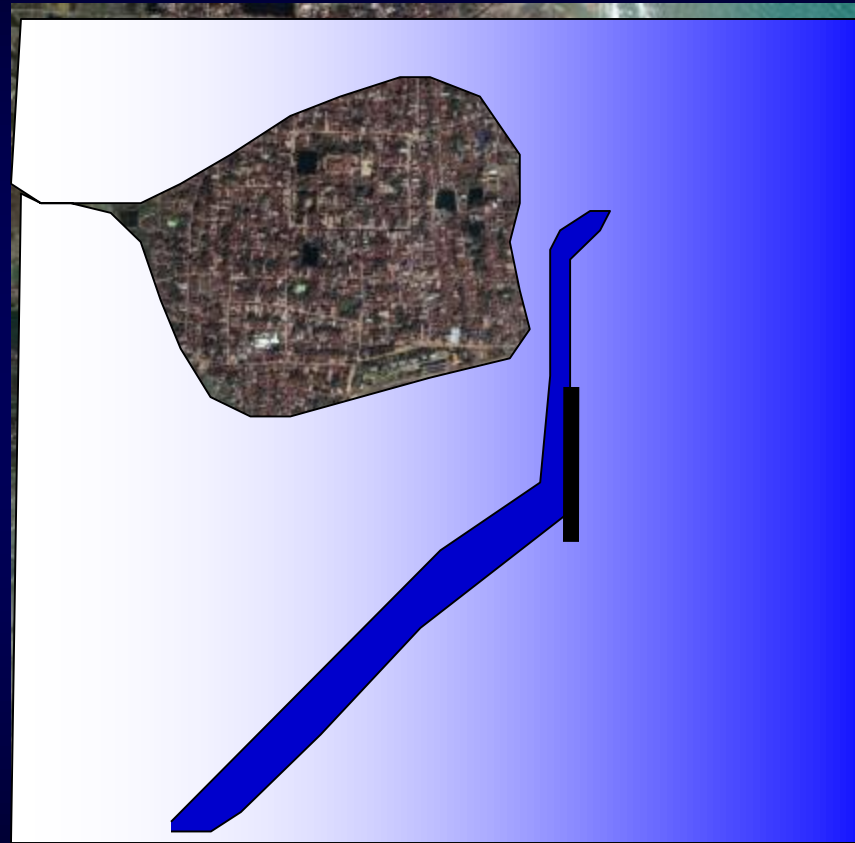
(A) Adayar River Mouth - IRS P6 Image - 12 January 2004



(B) Adayar River Mouth - IRS P6 Image - 27 December 2004

Fig.4.25 Bay mouth bars - Facilitators

ARREST OF RIVER MOUTH



MUD FLAT - FACILITATOR



(A) IRS P6 PAN merged satellite data showing tsunami inundated mudflat at Kodaikkadu village south of Tirumullaivasal



(B) Stony embankment at Kannaki temple (Pumpuhar)

Fig.4.28 Mudflats - Facilitators of tsunami inundation - remedial measures

RIVER & CREEK - CARRIER

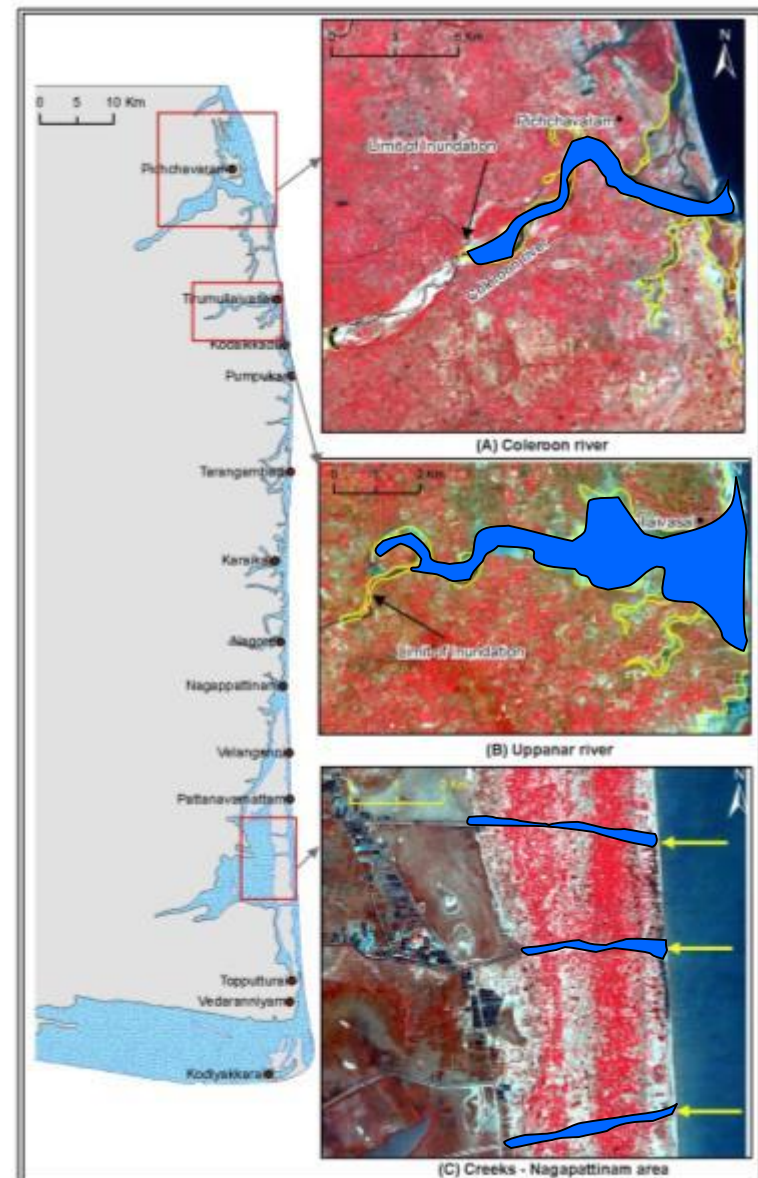


Fig.4.29 IRS P6 image showing rivers and creeks - carriers of tsunami surge

BACKWATER – ACCOMODATOR BEACH - ABSORBER



Fig.4.30 IRS P6 PAN merged image showing backwater - accommodators of tsunami surge



Fig.4.31 Photograph showing Marina beach - absorbers of tsunami surge

DESTRUCTION OF BEACH RIDGE

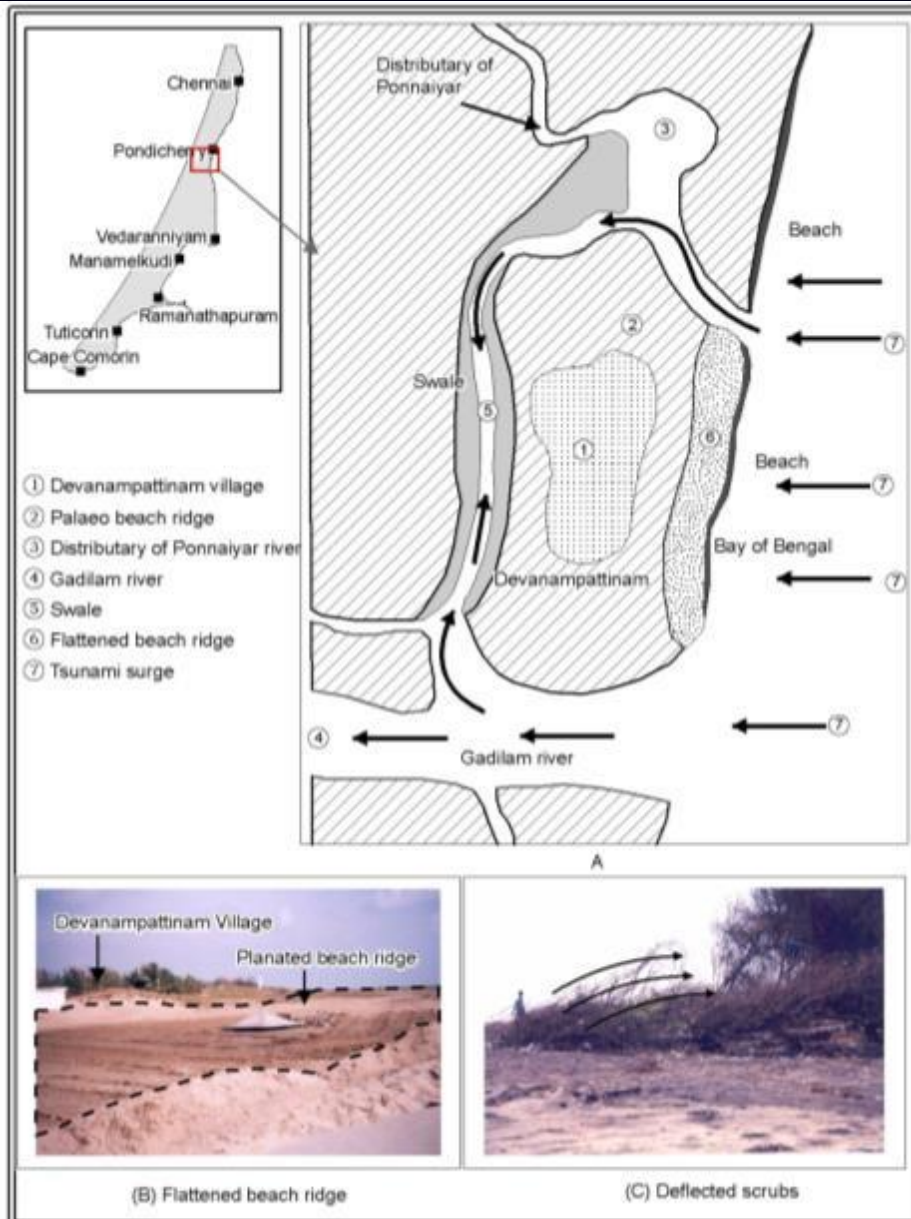


Fig.4.32 Devanampattinam damage due to beach ridge destruction

GEOMORPHOLOGY vs TIDAL INUNDATION – MITIGATION STRATEGIES

(Few examples)

S.No	Geomorphic Features	Mitigation Strategies
1	<i>FACILITATORS</i> a)River mouths, creek mouths, Bay mouth bars and spits b)Mudflats and saltpans	➤To be left as such / or dredged ➤No vegetation / afforestation in bay mouth bars / spits ➤Keep the river / creek mouths open and avoid arresting of river / creek mouths by walls ➤Settlements if at all developed must be only on the southern bank of the rivers in the coastal areas of the state. ➤Mangroves development in mudflats ➤Regulating measures to minimize the faster growth of saltpans ➤Dumping of boulders and creation of protection embankments in between mudflats / saltpans and the sea

2	CARRIERS Creeks and rivers/streams	➤ Keep mouths open ➤ Afforestation along banks ➤ Boulder embankment along low lying banks ➤ Avoid settlements in low lying banks of rivers / streams ➤ Promotion of mangroves
3	ACCOMMODATORS Estuary, backwaters, mangrove swamp, palaeo mudflat and swale	➤ Mouths to be kept open ➤ Afforestation of mangroves in the mangrove swamps and in peripheral parts of the backwaters and rims of the swales. ➤ Boulder embankment along the rim of the backwaters and mangrove swamps. ➤ Mangroves creations in palaeo backwater ➤ Radial outward drainages from the Palaeo backwaters to the Palaeo mudflats, afforestation and promotion of bird sanctuary

4	<i>ABSORBERS</i> Beaches	➤Existing beach nourishment by afforestation with deep rooted trees ➤Beach growth propagation by constructing groins at suitable locations and nourish such beaches too by afforestation.
5	<i>BARRIERS</i> Palaeo and Relict beach ridges	➤Intensive Afforestation through casuarina and cashew

GEOMORPHOLOGY vs TIDAL INUNDATION – MITIGATION STRATEGIES

(Few examples)

Bay Mouth Bars	→ Facilitators	→ Not to be affected or Utilized
Mudflats / Salt pans	→ Facilitators	→ Protective boulders embankments → Mangroves
River mouths	→ Carriers	→ Keep the mouth open with out obstruction / blocking
Creeks	→ Carriers	→ Mangrove vegetation
Backwaters / Palaeo mudflats	→ Accommodators	→ Radial out ward drain in mud flats, vegetation, bird sanctuary
Beaches	→ Absorbers	→ To be nourished
Beach Ridges	→ Barriers	→ To be nourished/Afforested

LINEAR MODELLING – RUN UP VS OFFSHORE SYSTEMS

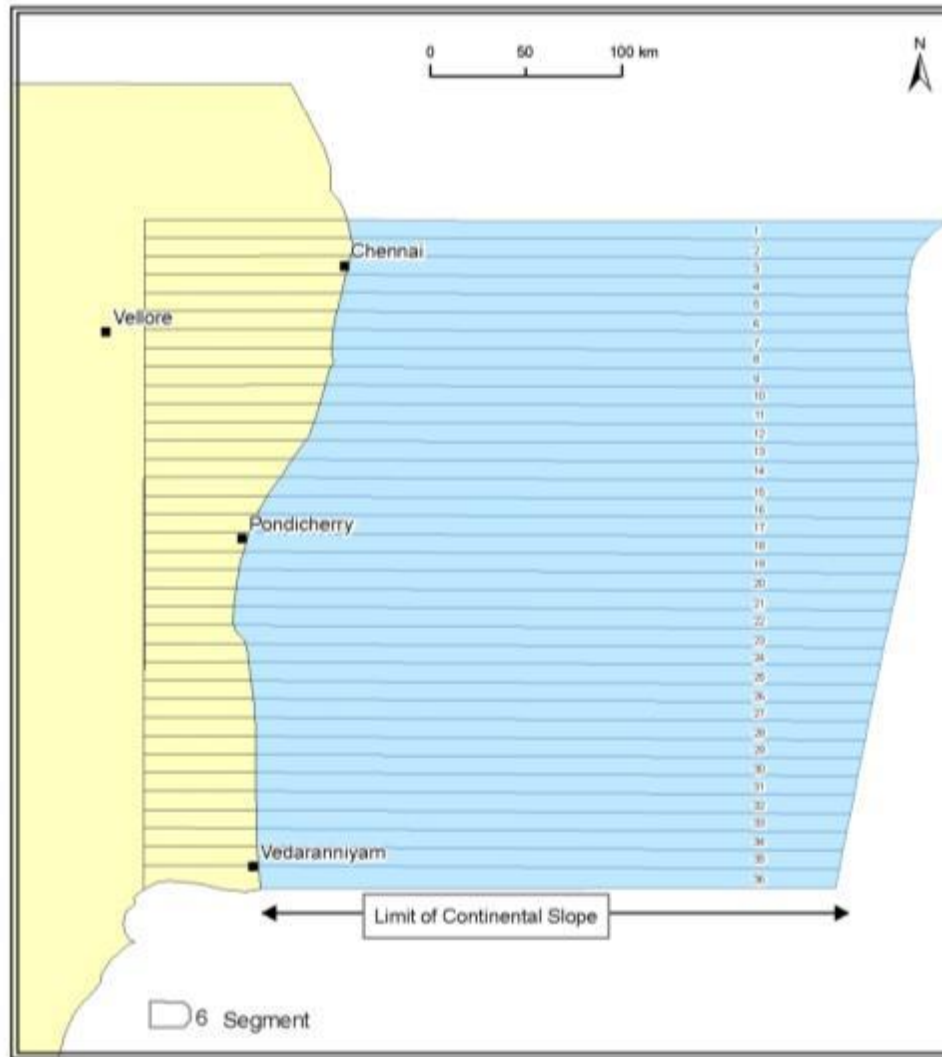


Fig.4.33 Sampling segments

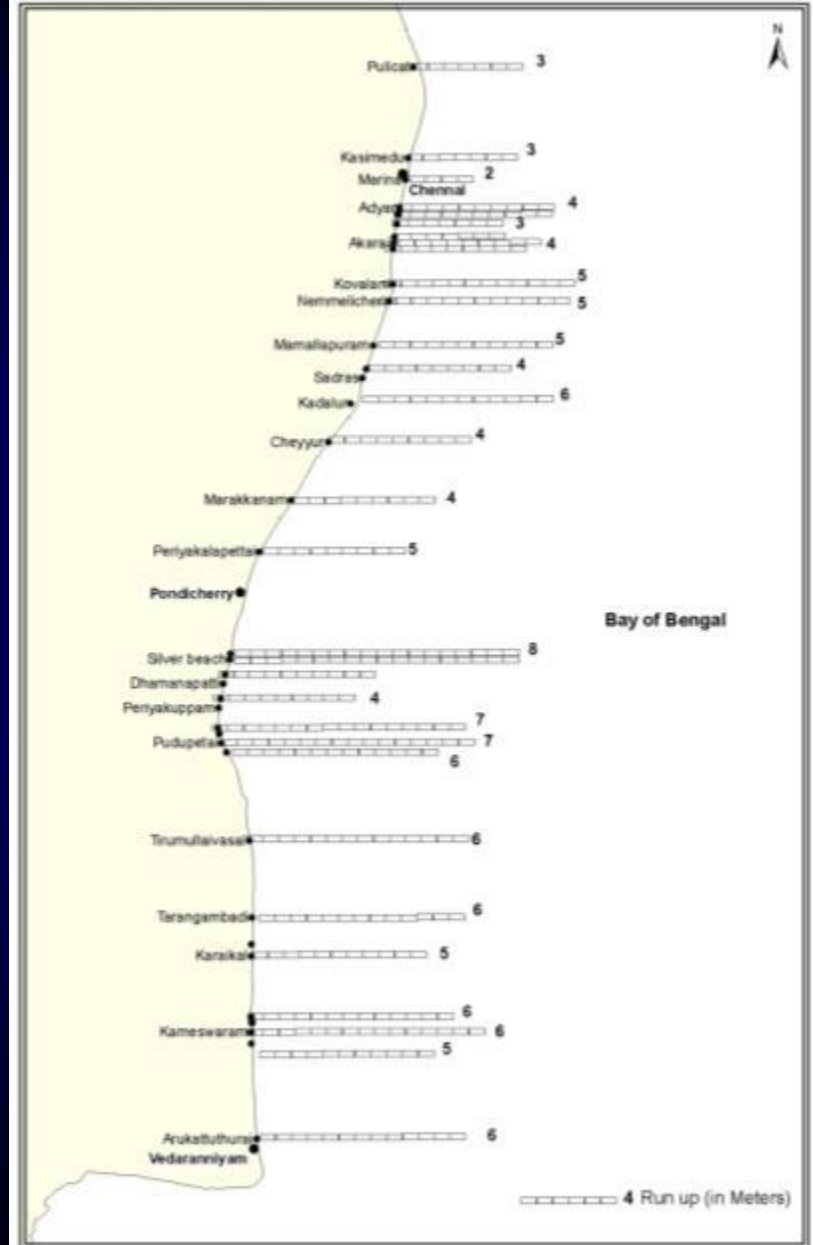


Fig.4.34 Run up (in 36 Segments)

Offshore Geosystems Scenario

The database on offshore geosystems viz: continental slope and continental shelf were generated by mapping the features from NATMO atlas.

Further, using the ETOPO satellite data which provides information on the sea bed topography,

the continental slope was sub divided into

- Shallow (2 to 20 m/km) gradient

- Moderate (21 to 80 m/km) gradient and the

Continental shelf into

- Shallow (2 to 20 m/km) gradient,

- Moderate (21 to 80 m/km) gradient and

- Steep (> 80 m/km) gradient (Fig. 4.35)

Offshore Geosystems

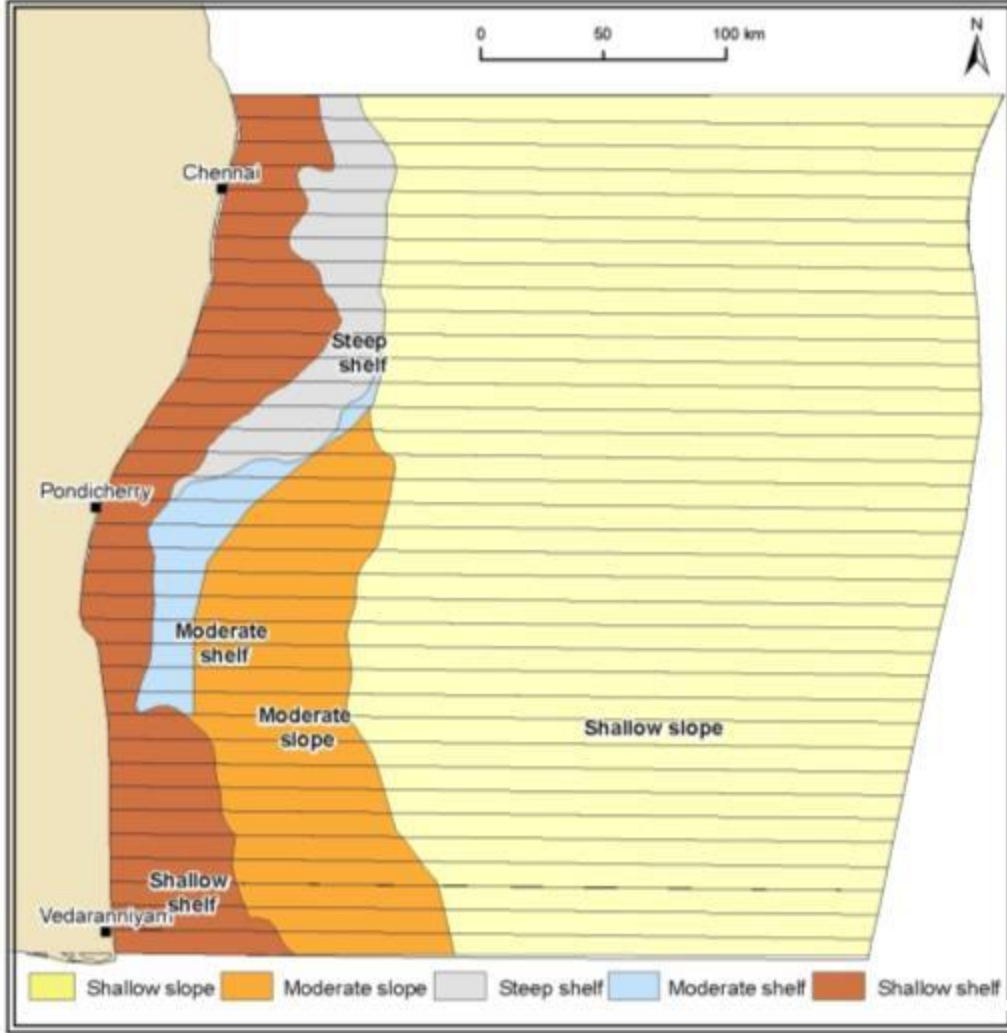
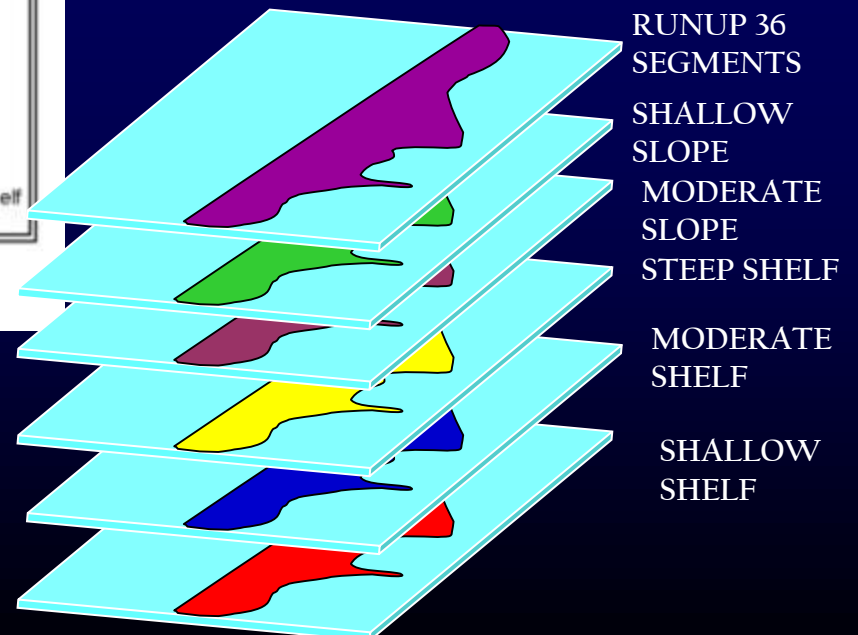


Fig 4.35 Offshore geosystem scenario

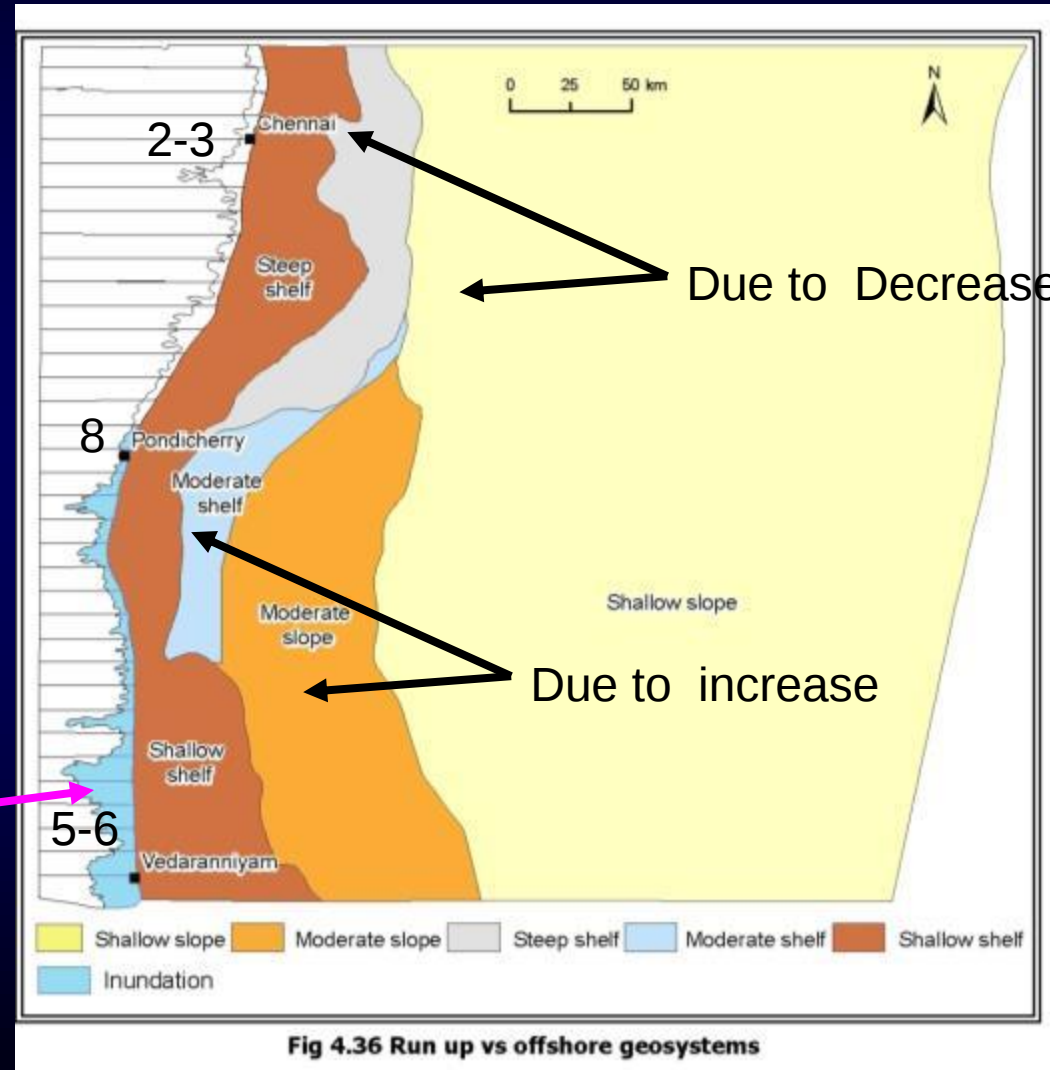


Variable	Factor 1	Factor 2	Factor 3
RUN UP	.29057	-.02231	-.95420
SH SLOPE	-.74633	.55282	.08377
MOD SLOPE	.94522	.09717	-.23228
ST SHELF	-.87936	-.15855	.27077
MOD SHELF	.29819	.87240	-.09397
SH SHELF	.14308	-.92373	-.07788

The run up increases with increase in the area of moderate continental slope and moderate continental shelf and The run up increases with decrease in the areas of shallow continental slope and steep continental shelf.

Run up increases

EIGEN VECTORS



PICTORIAL REPRESENTATION

LINEAR MODELLING – INUNDATION UP VS ONSHORE SYSTEMS

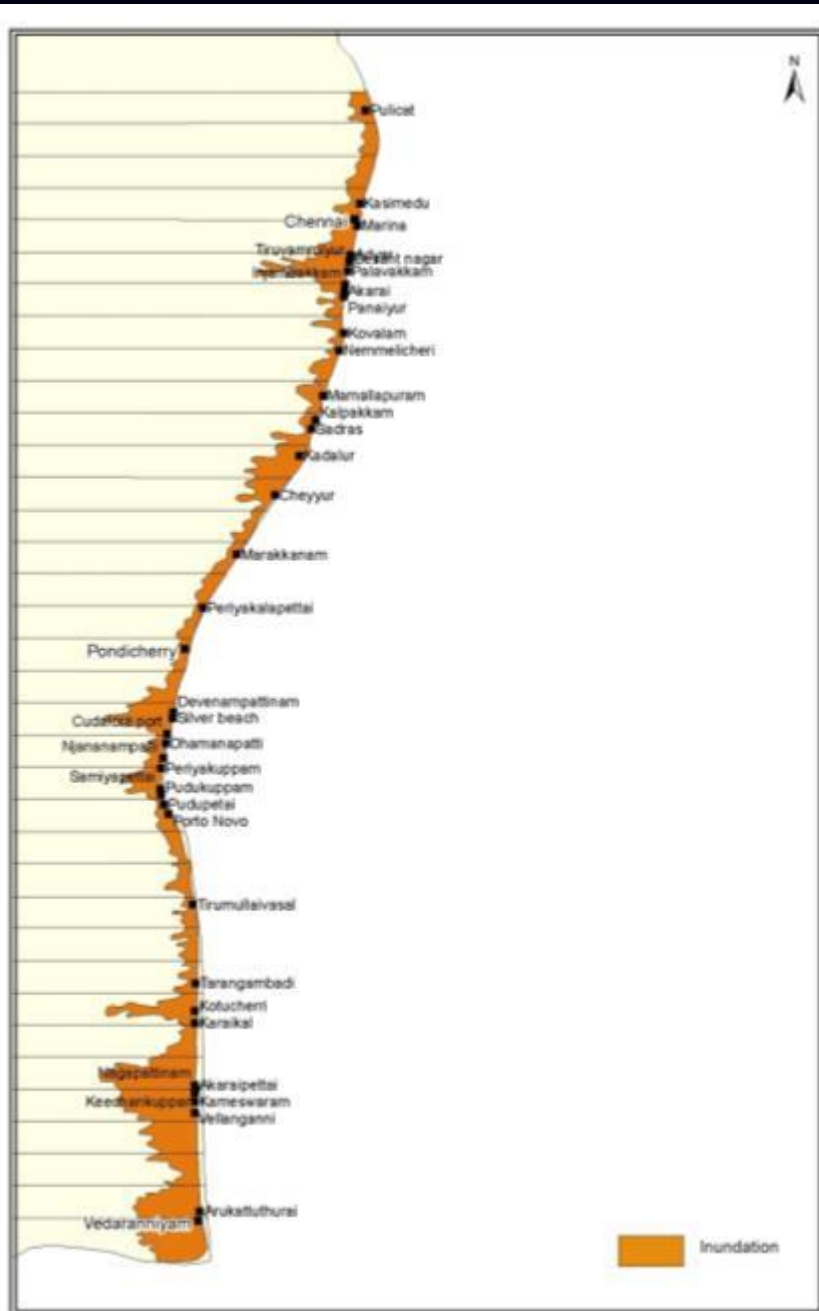


Fig 4.37 Inundation pattern

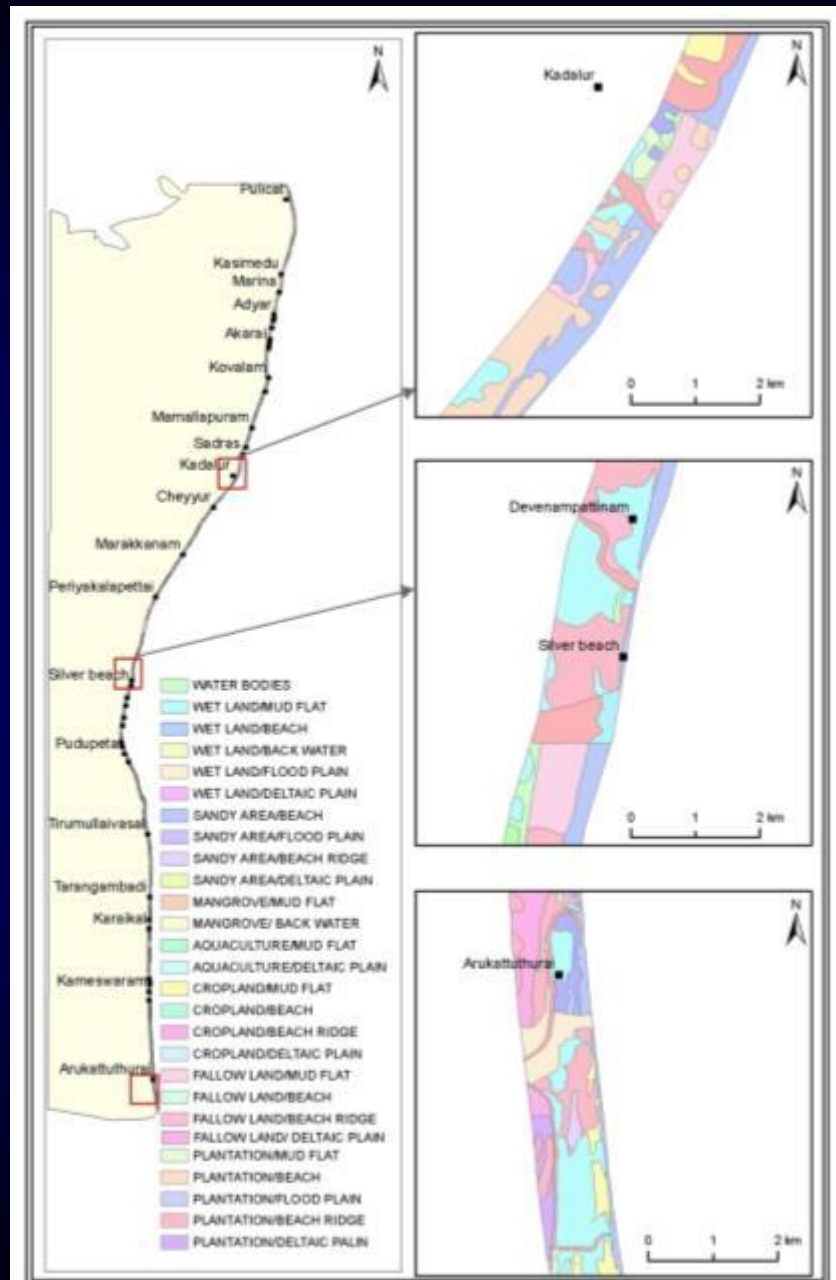


Fig. 4.40 Integrated geomorphology and landuse / land Cover

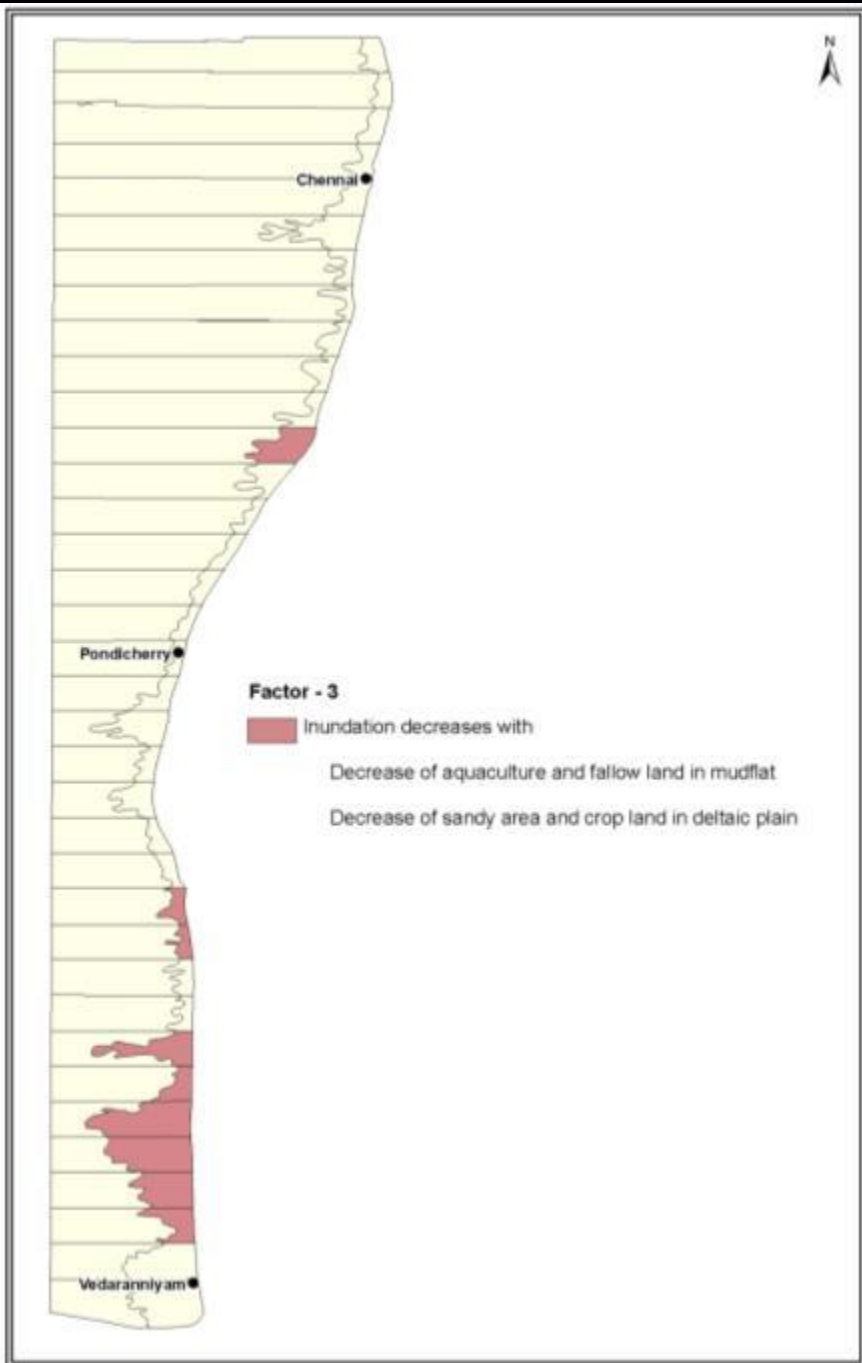


Fig.4.41 Inundation vs coastal geosystem (Factor -3)

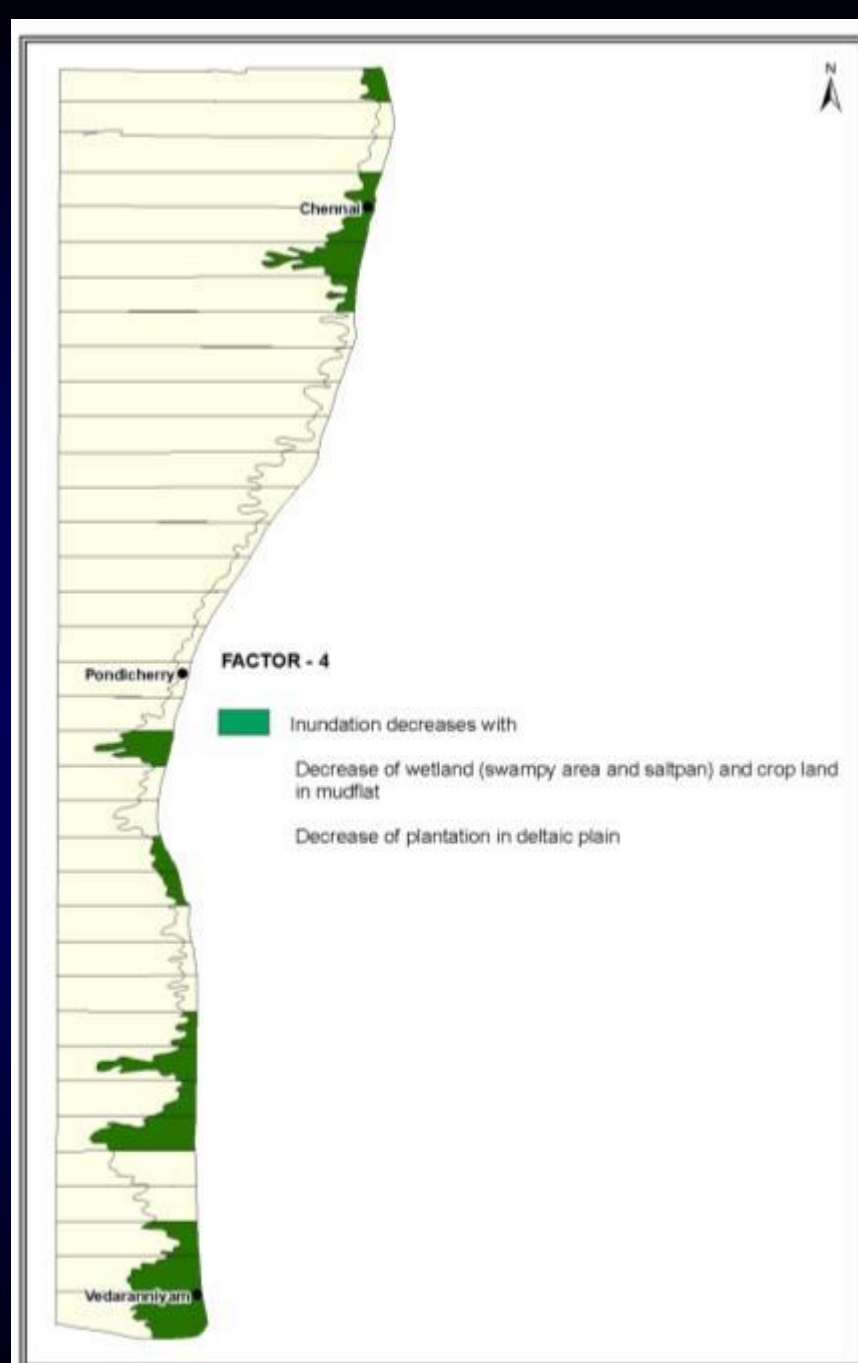


Fig.4.42 Inundation vs coastal geosystem (Factor - 4)

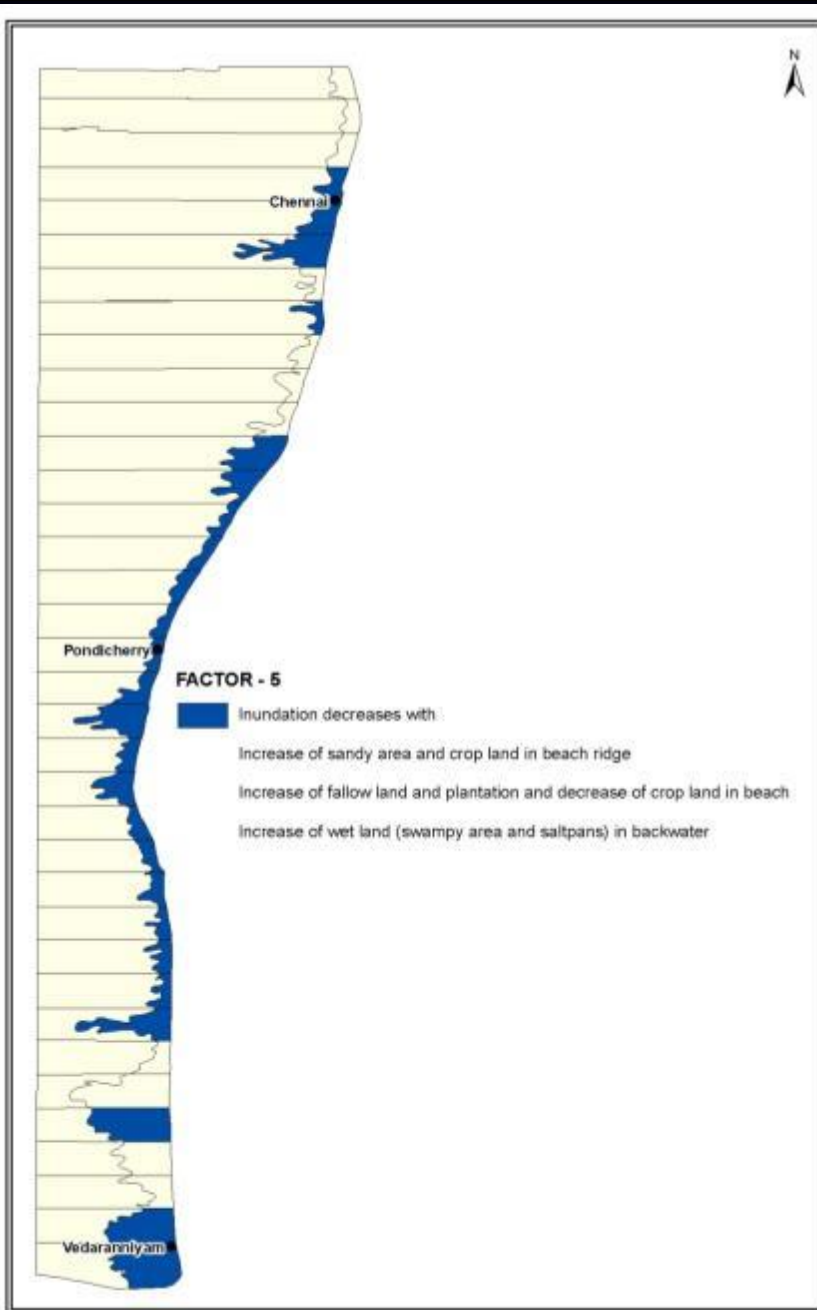


Fig.4.43 Inundation vs coastal geosystem (Factor 5)

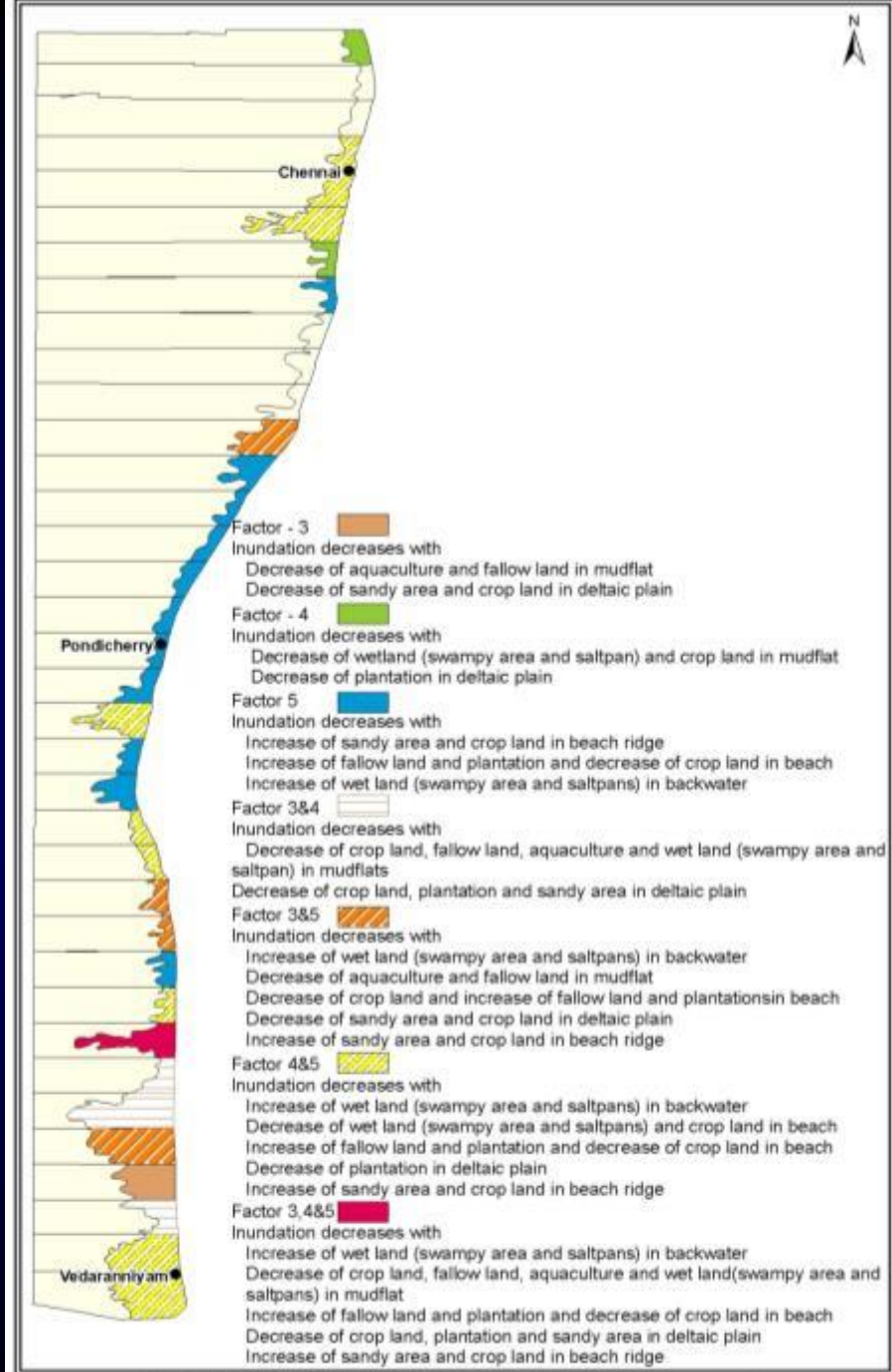


Fig.4.44 Inundation vs coastal geosystem (Integrated output)

INUNDATION DECREASES WITH

Increase in aerial extent of

Backwater and Wetland (which would have accommodated the tsunami surge)

Beach ridge with sandy area (which would have absorbed the tidal waves)

- Beach ridge with Plantation (which would have dissipated and acted as barriers),

Beach with sandy area and beach with plantations (which would have absorbed as well as dissipated).

MITIGATION STRATEGIES

Creating water bodies in deltaic plains, so that surge will be get accommodated

Mangrove afforestation in suitable wetlands, so as to dissipate the tsunami energy.

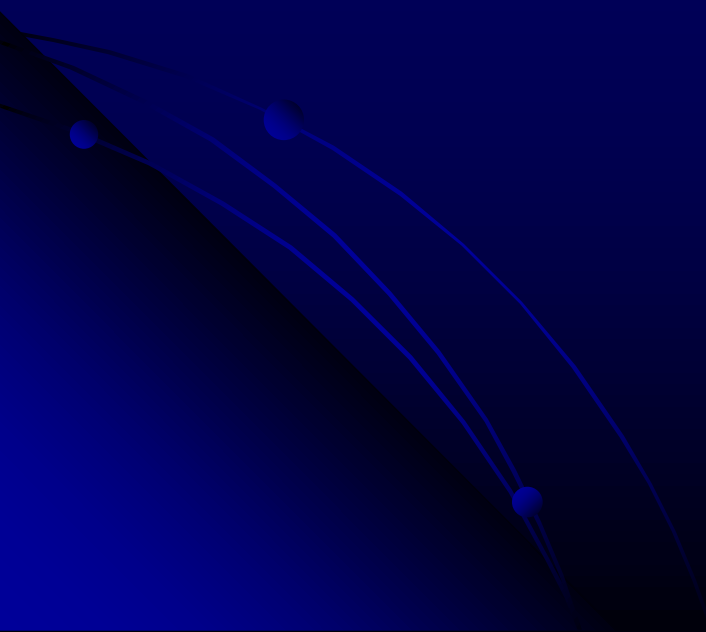
Increase aquaculture in mudflats and deltaic plains and create plantations in flood plains so that tsunami energy will be dissipated.

Decrease crop land in mudflat, fallow land in beach ridges in order to act as Barriers

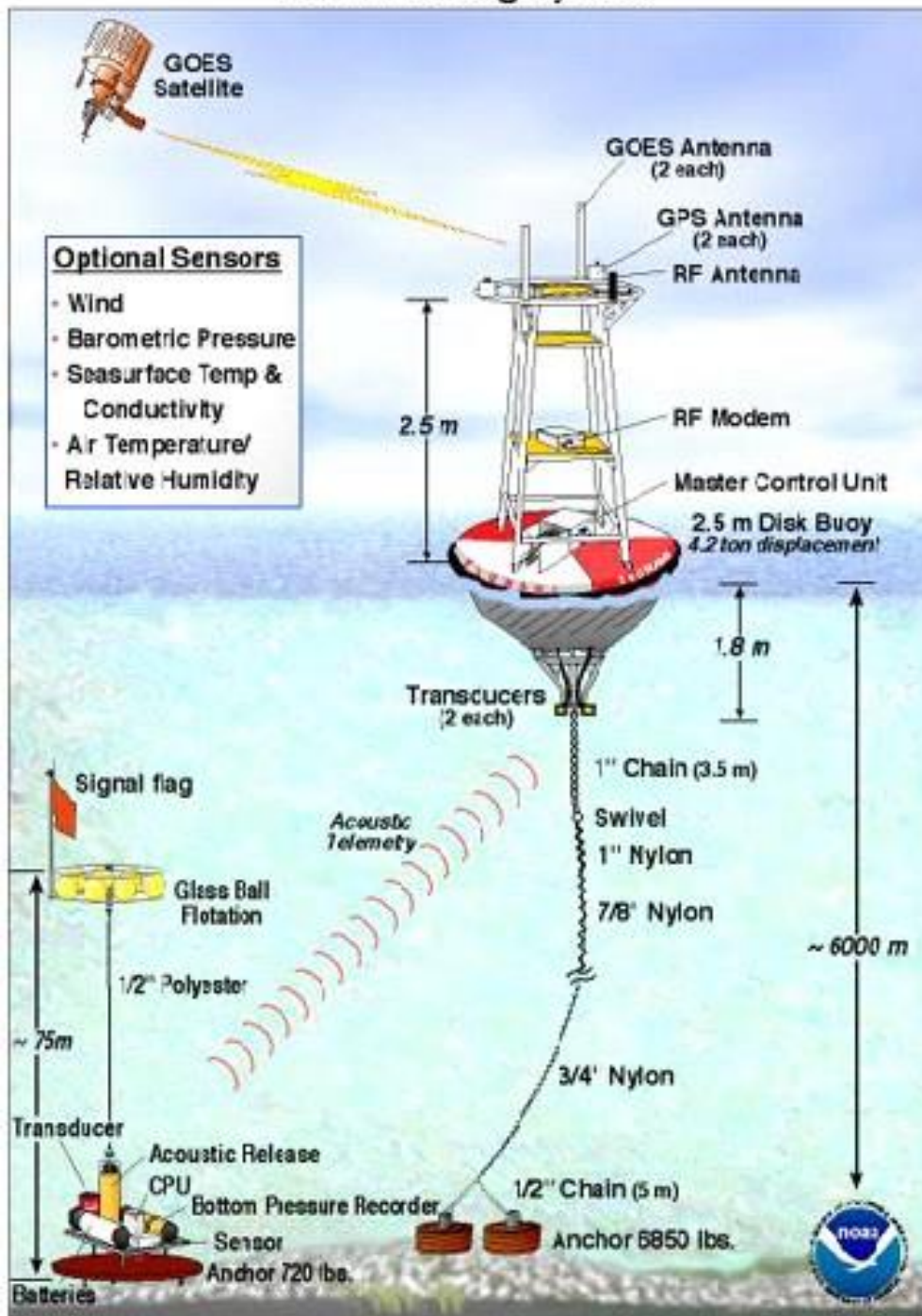
CONCLUSION

- From the above analysis it is evident that the geosystems have responded the tsunami surge in unique fashion
- Through visual interpretation the response of coastal geometry to tsunami was brought out
- Through Spatial modelling the geomorphic features were classified as carriers, facilitators, accomodators, absorbers and barriers and accordingly mitigation strategies were eolved
- Similarly the linear modelling has brought out an unique land use / land cover based mitigation strategies.
- Through which the damages can be minimised

TSUNAMI WARNING SYSTEM



DART Mooring System



WARNING SYSTEMS

The DART project was developed by the NOAA Pacific Marine Environmental Lab (PMEL) and brought into operational use by the NOAA National Data Buoy Center (NDBC) in October 2003.

The DART project is an ongoing effort to maintain, improve the capability for the early detection, real-time reporting of tsunamis in the open ocean and reduce costly false alarms (González et al 1998).

The DART buoy system comprises two parts: the bottom pressure recorder (BPR) and the surface buoy with related electronics. The BPR is capable of detecting and measuring tsunamis with amplitude as small as 1 cm in 6000 m of water (Eble and Gonzalez 1991).

The BPR uses a pressure transducer to make 15 seconds averaged measurements of the pressure exerted on it by the overlying water column.

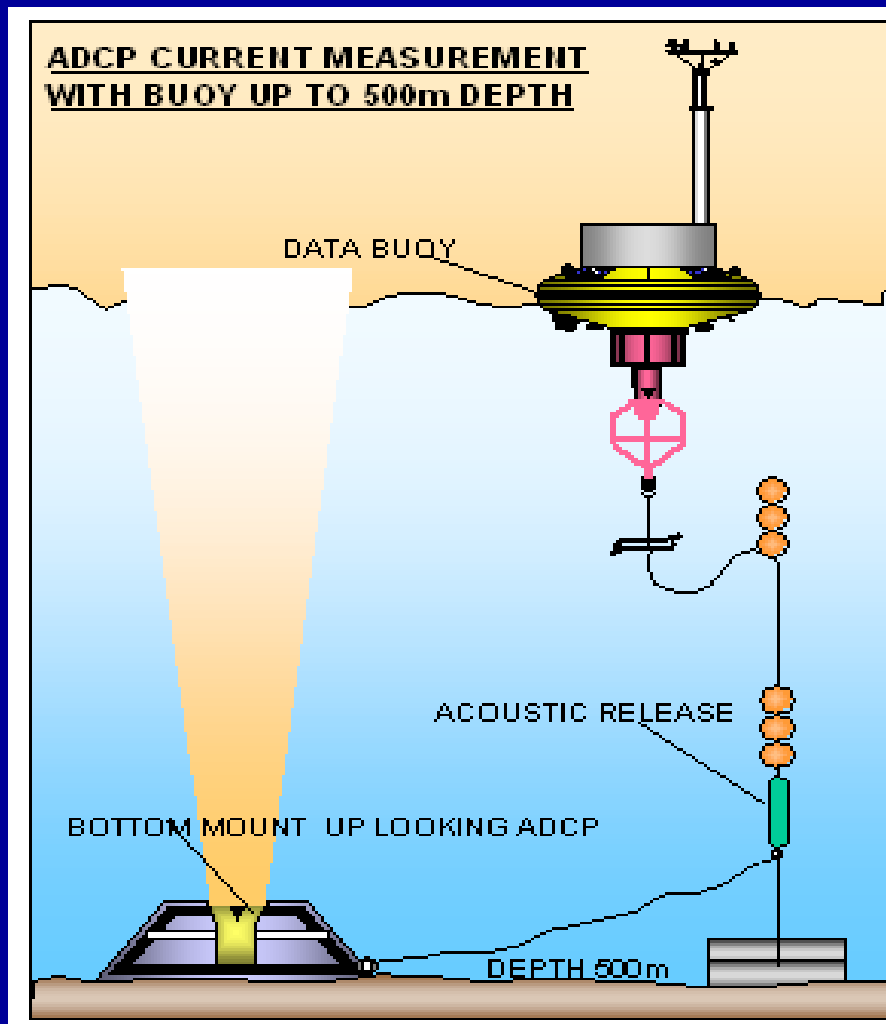
Data is transmitted from the buoy via an acoustic modem, and from the buoy via the Geostationary Orbiting Earth Satellite (GOES) Data Collection System.

Under normal conditions (no tsunami) the BPR sends data hourly comprising four 15-minute values, which are single 15-second averages.

An algorithm running in the BPR generates predicted water height values and compares all new samples with predicted values. If two 15-second water level values exceed the predicted values the system will go into the Tsunami Response Mode.

The data are then relayed via a satellite link to ground stations, which prepare the signals for immediate dissemination to the NOAA Tsunami Warning Centers, the NDBC and PMEL.

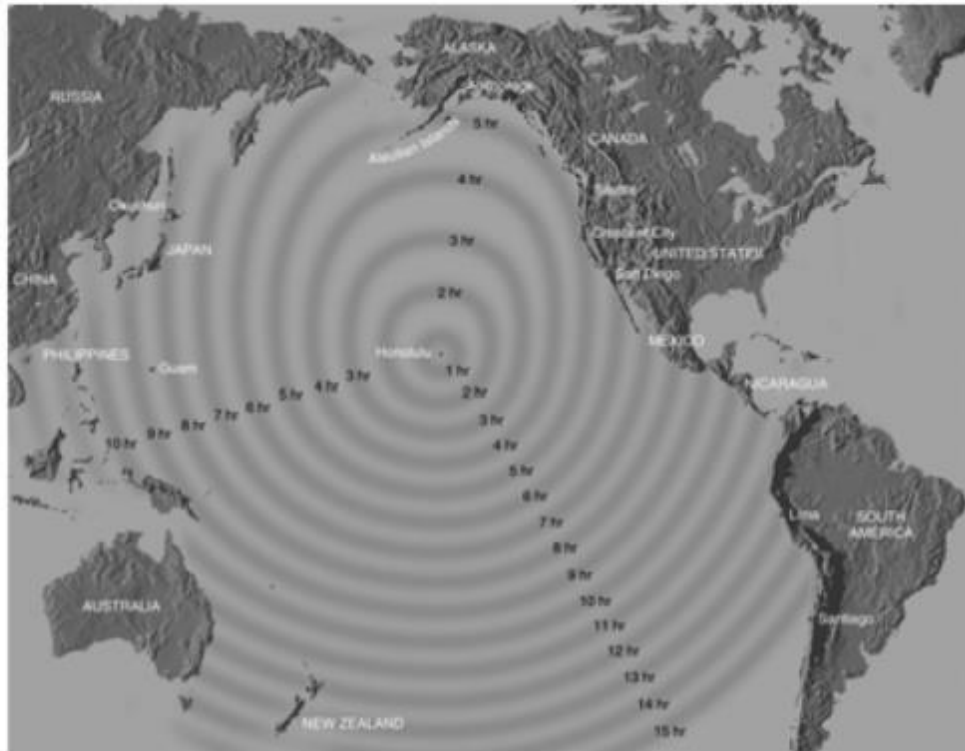
NOAA geophysicists use the data to determine the size of the wave, what areas may be at risk, and if a watch or warning is necessary. The DART research experience over the last 10 years indicates that these real-time systems are capable of detecting deep ocean tsunamis with amplitudes as small as one cm.



Current Meter Mooring

The velocity of tsunami currents can be measured using a current mooring which can give the current pattern of the water column triggered by the Tsunamis. Till now our nation don't have dedicated current meter mooring that can provide valuable information about the current pattern and its characteristics in Indian Seas especially during extreme events like cyclones and tsunamis. It is proposed to install 10 nos. of current meter moorings.

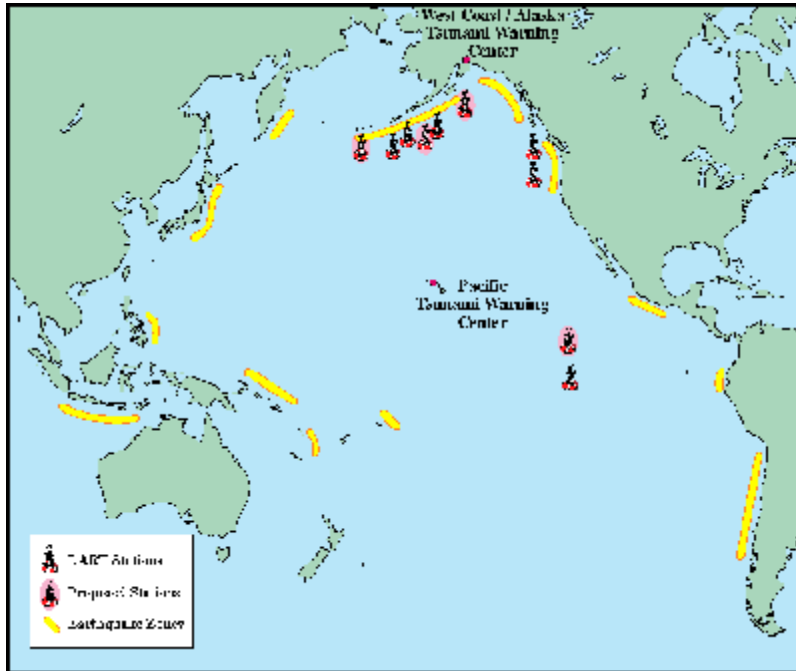
Tsunami Warning System



Times taken for tsunamis to reach Hawaii from certain locations

The tsunami warning system was established in 1946 following a devastating tsunami in Hawaii. Pacific Ocean-wide network of:-

- Seismic Station
- Tsunami Buoys
- Coastguards
- Civil defense

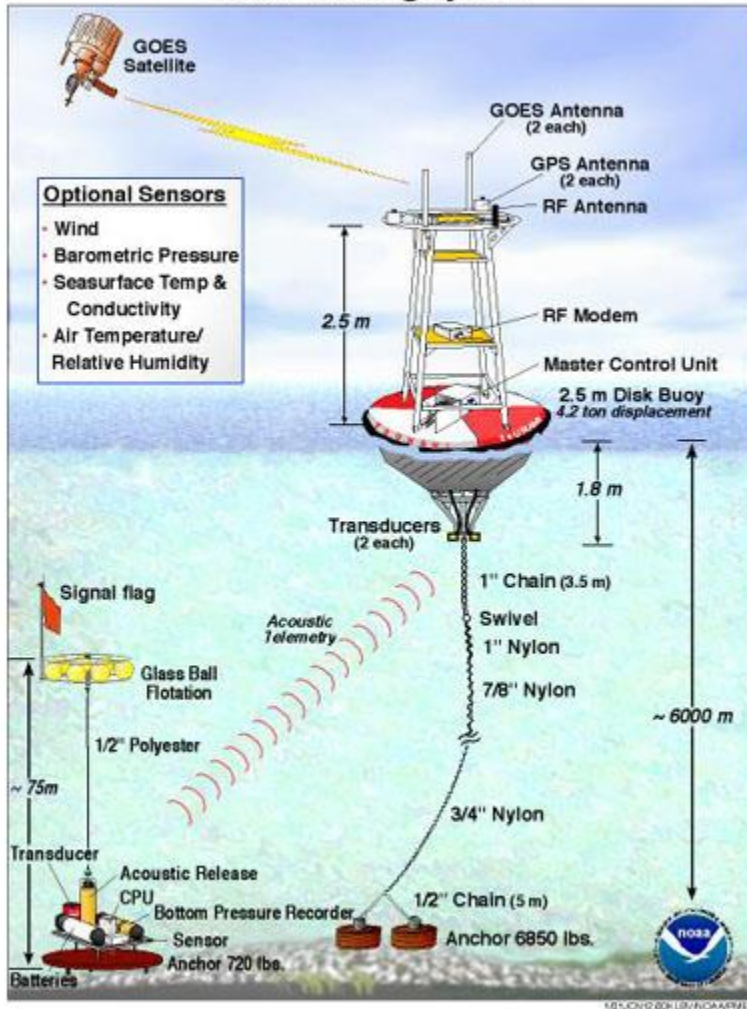


As part of the [U.S.National Tsunami Hazard Mitigation Program \(NTHMP\)](#), the DART Project is an ongoing effort to develop and implement a capability for the early detection and real-time reporting of tsunamis in the open ocean. DART is essential to fulfilling NOAA's national responsibility for tsunami hazard mitigation and warnings. Project goals are:

- 1) Reduce the loss of life and property in U.S. coastal communities.
- 2) Eliminate false alarms and the high economic cost of unnecessary evacuations.

DART stations are sited in regions with a history of generating destructive tsunamis to ensure early detection of tsunamis and to acquire data critical to real-time forecasts. Buoys shown on the accompanying map represent an operational array scheduled for completion in 2003.

DART Mooring System



A DART system consists of a seafloor bottom pressure recording ([BPR](#)) system capable of detecting tsunamis as small as 1 cm, and a moored surface buoy for real-time communications. An acoustic link is used to transmit data from the BPR on the seafloor to the surface buoy. The data are then relayed via a GOES satellite link to ground stations, which demodulate the signals for immediate dissemination to NOAA's Tsunami Warning Centers and PMEL.

<http://www.pmel.noaa.gov/tsunami/Dart/Flash/CODEframe4DART.html>