Numerical Simulations of the 2004 Indian Ocean Tsunami – Runup and Inundation

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WHOI Workshop

Interactions between Tsunamis and Underwater Geological Processes

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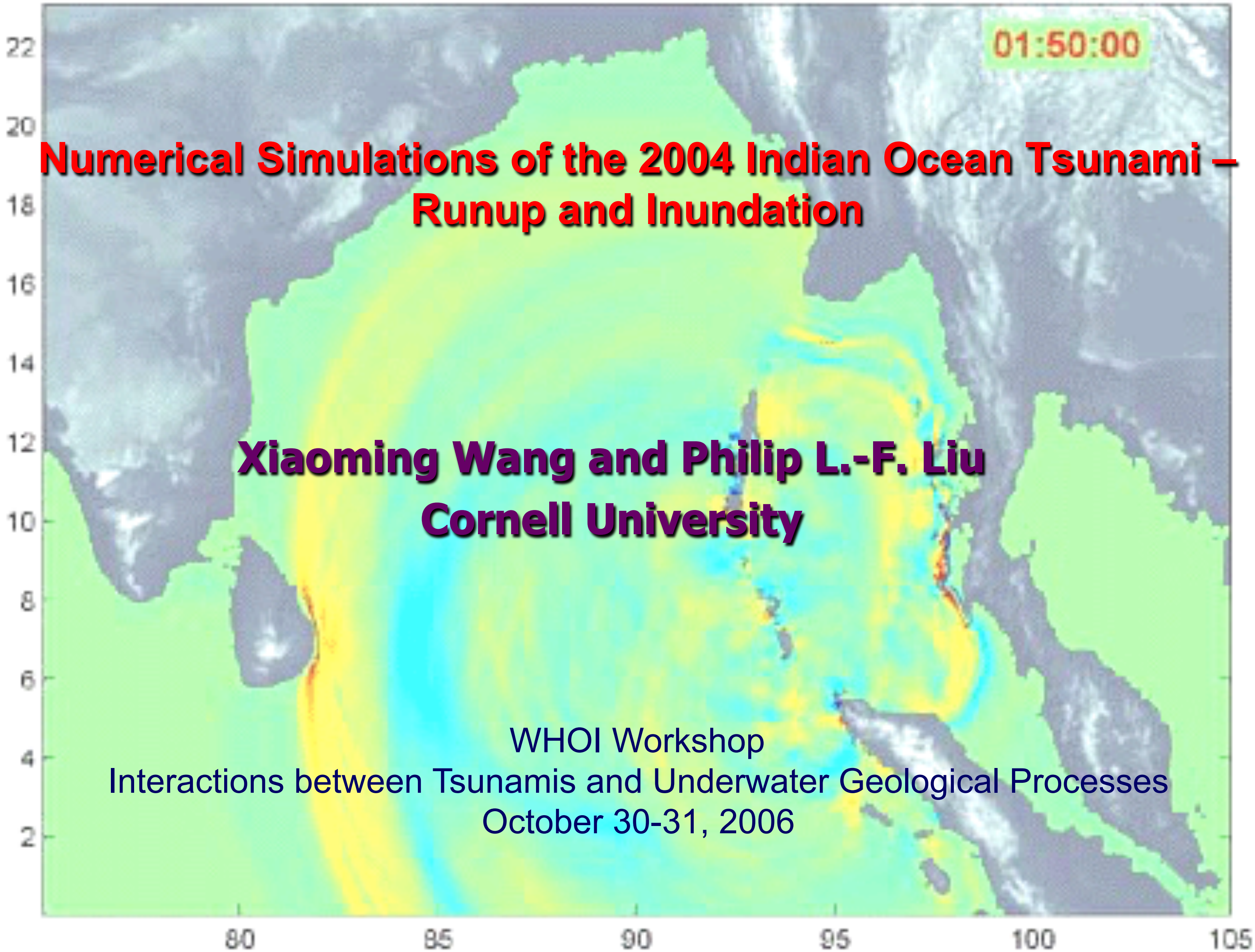


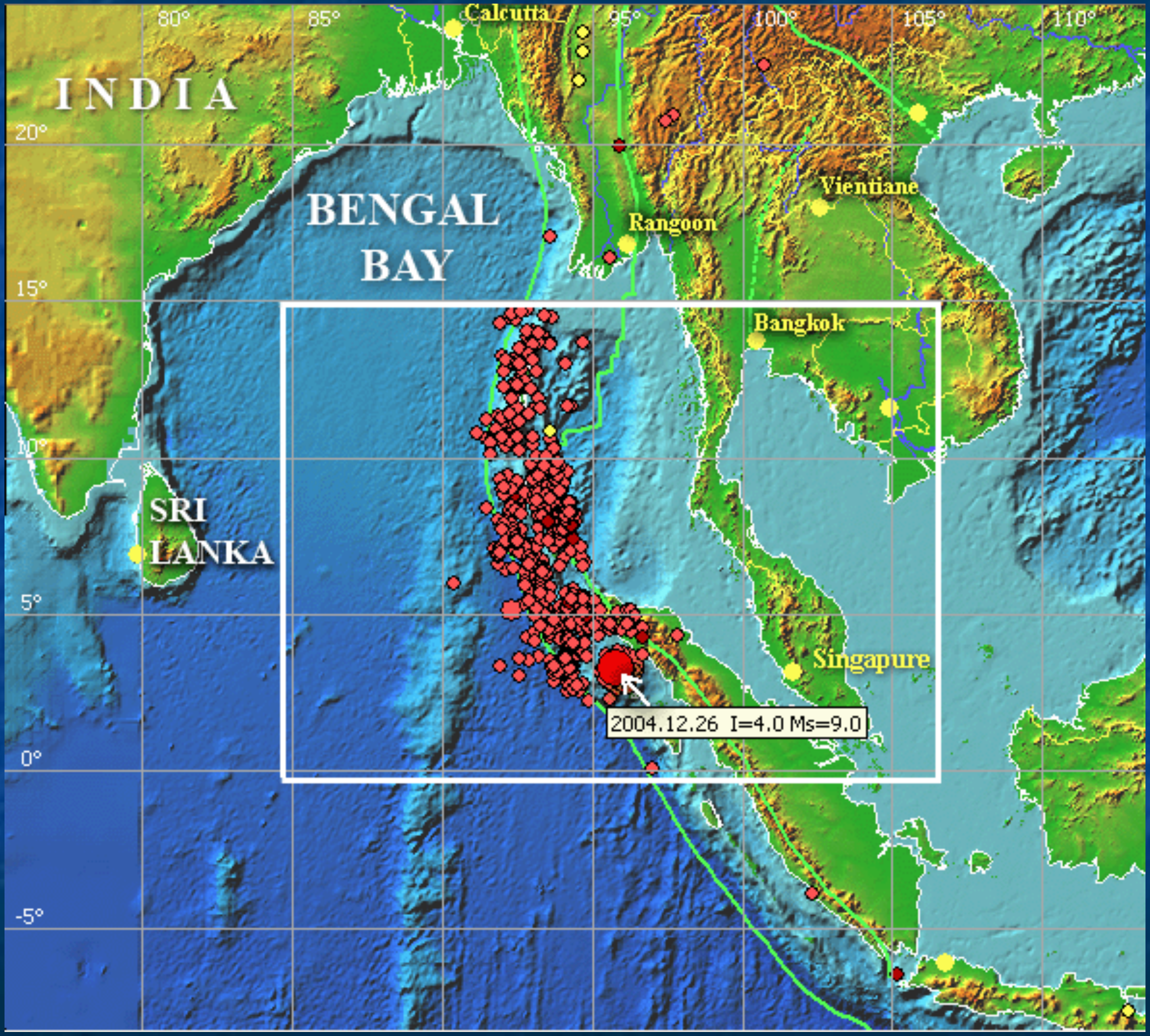
Outline:

1. Review of the general features of the 2004 Indian Ocean tsunamis

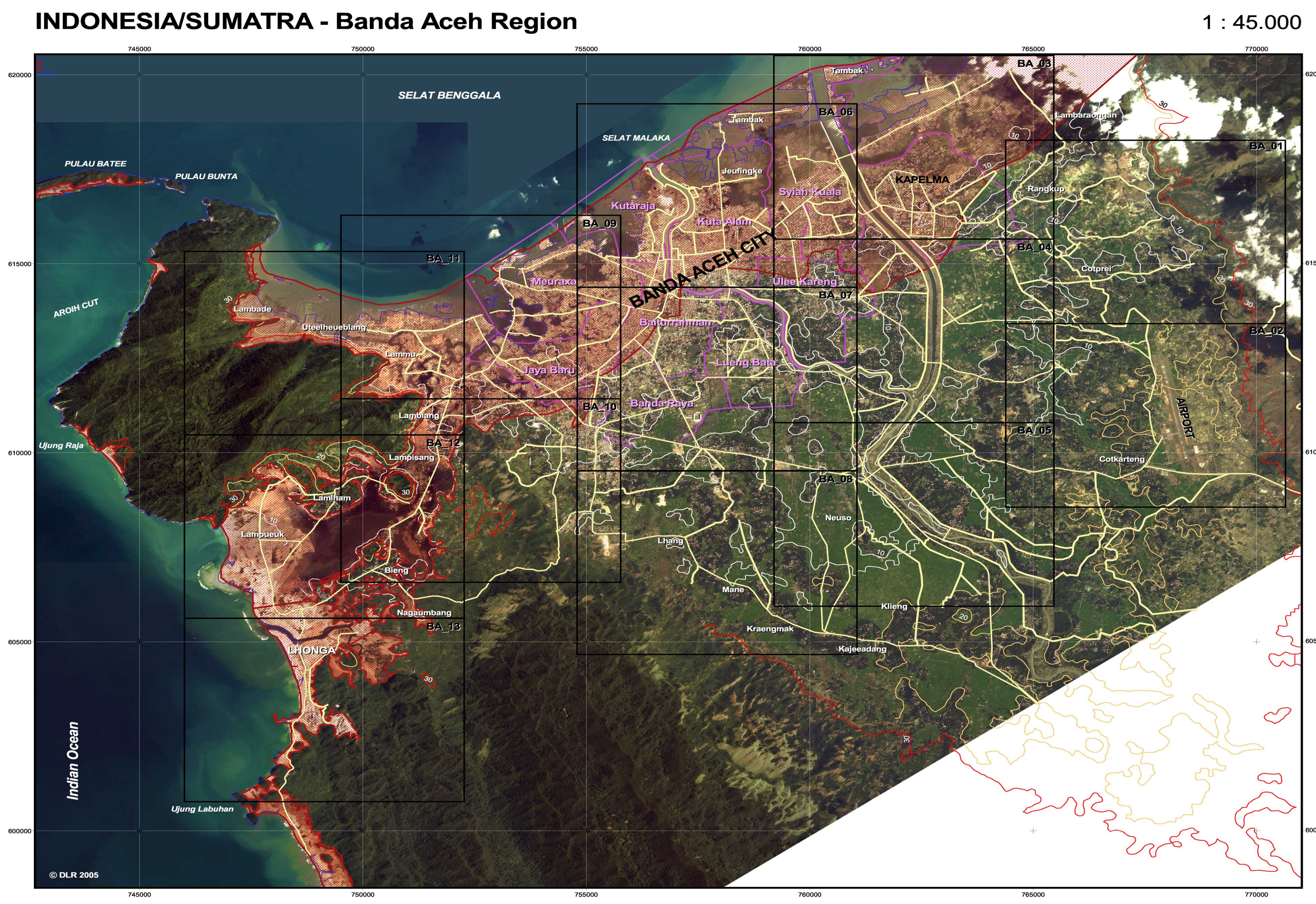
2. Numerical simulation results of runup and inundation in Trincomalee, Sri Lanka and Banda Aceh, Indonesia

3. Erosion and deposit

Epicenter and after shocks
2004 Sumatra Earthquake



Flooding and erosion at Banda Aceh

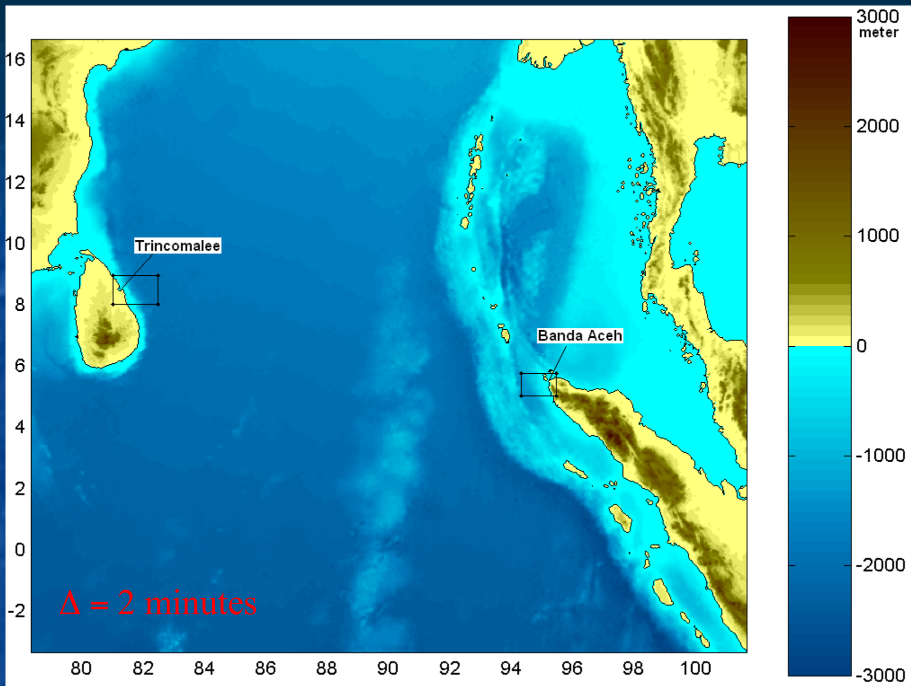


Banda Aceh North Shore

Southern Banda Aceh (Gleebruk: 31miles southwest of Banda Aceh)

Kalutara, Sri Lanka

COMCOT: Nested grid system

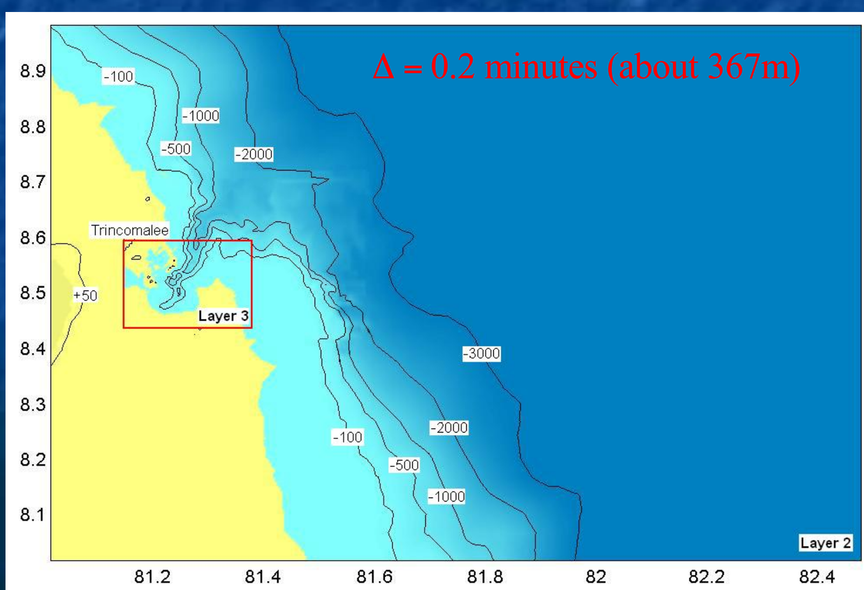


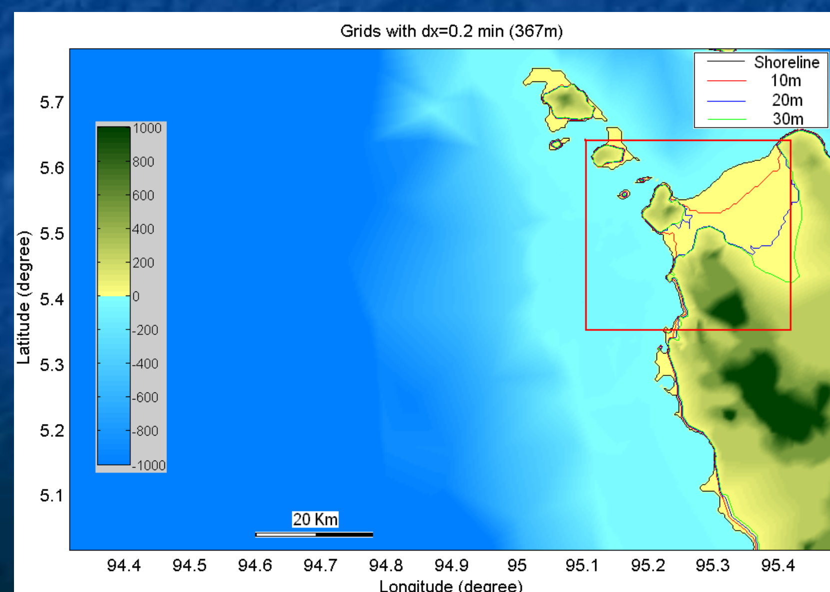
Linear Shallow Water Equations in Spherical Coordinates:

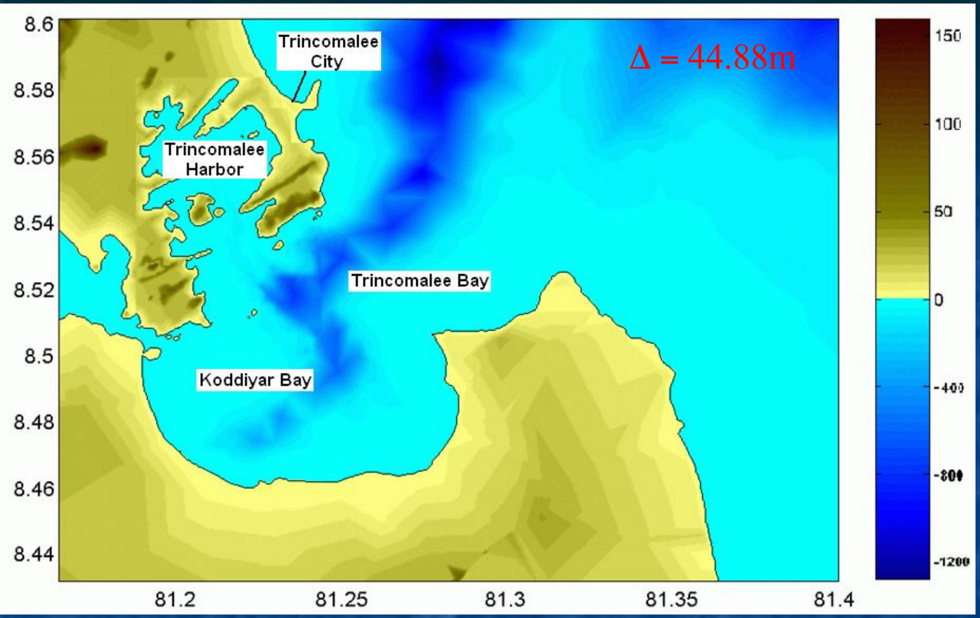
$$\frac{\partial \zeta}{\partial t} + \frac{1}{R\cos\varphi}\left[\frac{\partial P}{\partial \psi} + \frac{\partial}{\partial \varphi}(\cos\varphi Q)\right] = 0$$

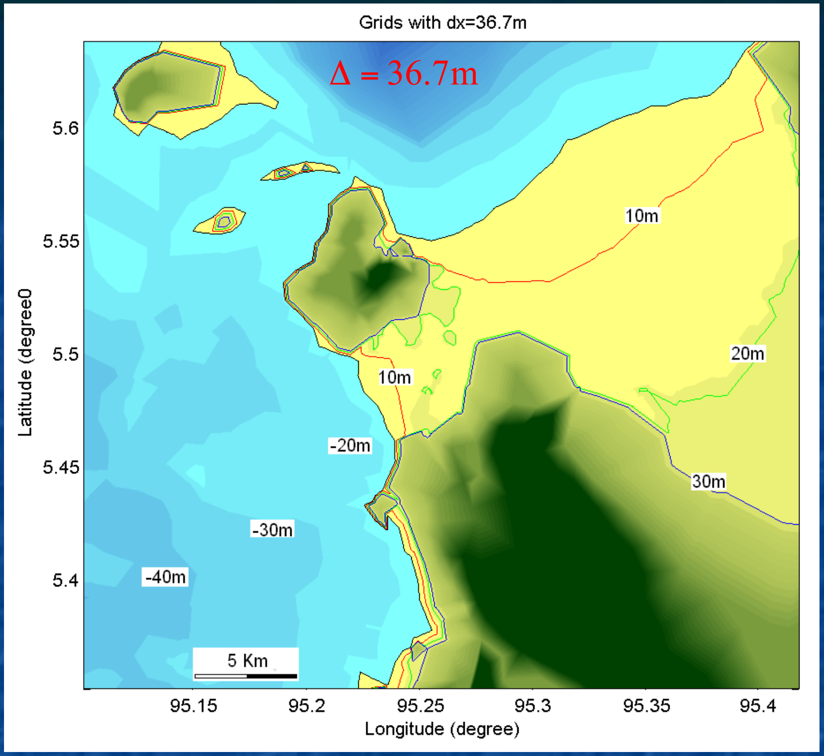
$$\frac{\partial P}{\partial t} + \frac{gh}{R\cos\varphi}\frac{\partial \zeta}{\partial \psi} - fQ = 0$$

$$\frac{\partial Q}{\partial t} + \frac{gh}{R}\frac{\partial \zeta}{\partial \varphi} + fP = 0$$









Non-linear Shallow Water Equations in Cartesian Coordinates:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial P}{\partial x} + \frac{\partial Q}{\partial y} = 0$$

$$\frac{\partial P}{\partial t} + \frac{\partial}{\partial x}\left(\frac{P^2}{H}\right) + \frac{\partial}{\partial y}\left(\frac{PQ}{H}\right) + gH\frac{\partial \zeta}{\partial x} + \tau_x H = 0$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{PQ}{H}\right) + \frac{\partial}{\partial y}\left(\frac{Q^2}{H}\right) + gH\frac{\partial \zeta}{\partial y} + \tau_y H = 0$$

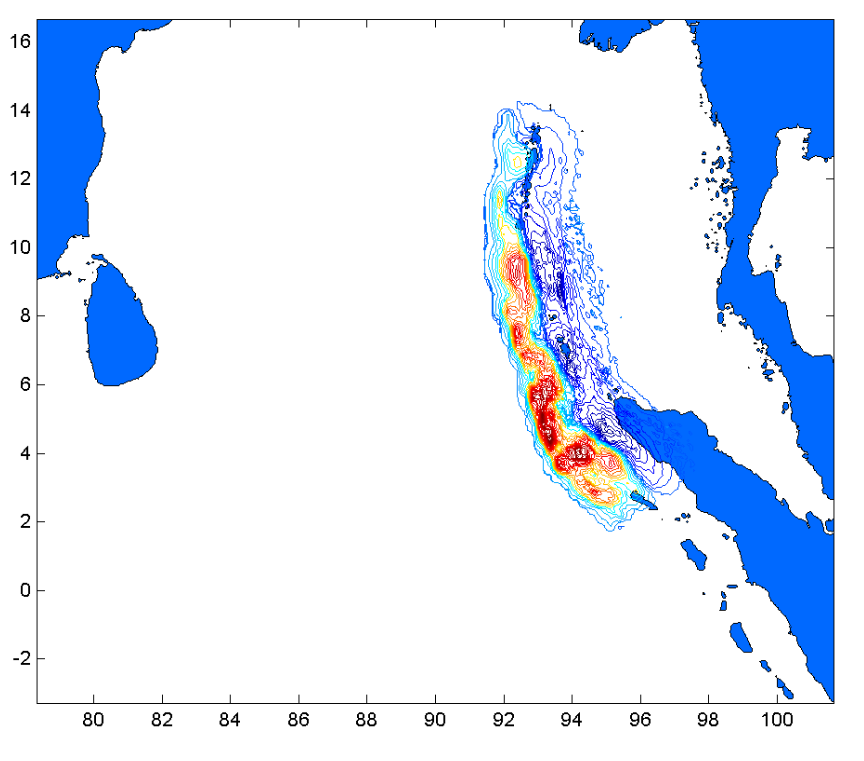
Bottom Frictional stress:

$$\tau_x = \frac{gn^2}{H^{10/3}} P(P^2 + Q^2)^{1/2}$$

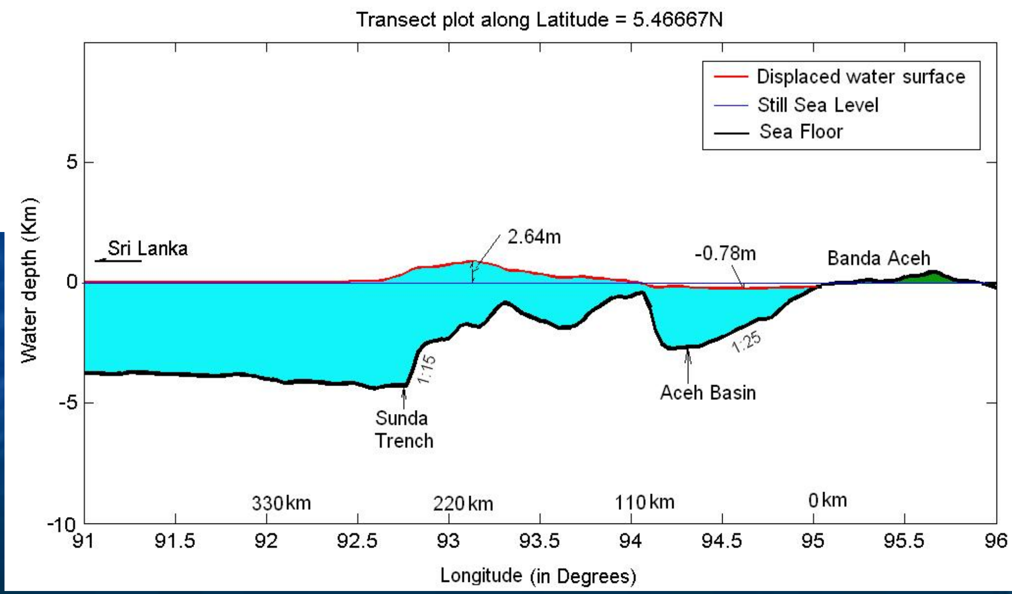
$$\tau_y = \frac{gn^2}{H^{10/3}} Q(P^2 + Q^2)^{1/2}$$

$$n = 0.02$$

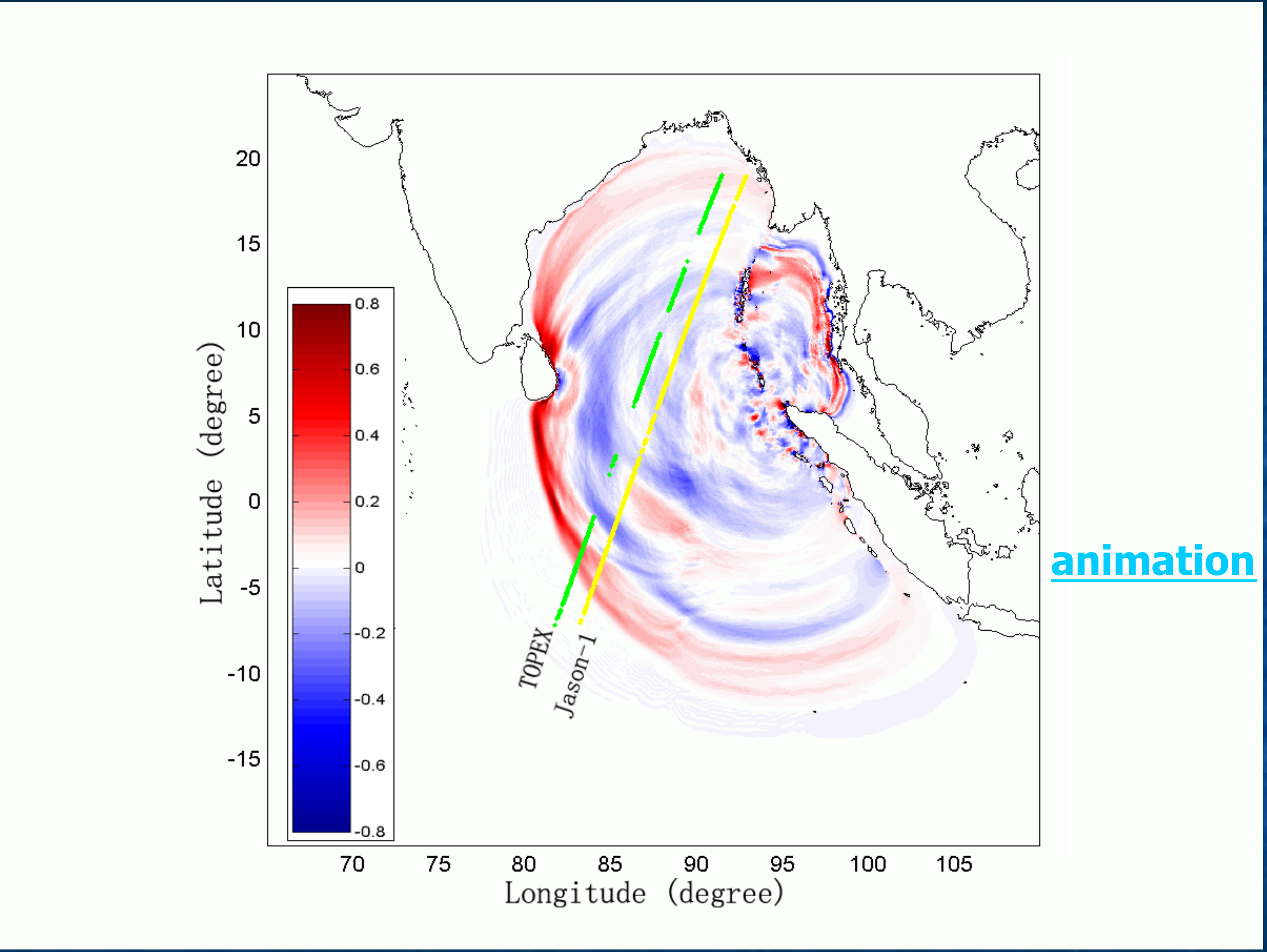
Initial Free Surface Profile



- Rupture speed: 2 ~ 3 km/s
- Rupture duration: 10 mins
- Fault Plane Width: 150 ~ 200km
- Maximum horizontal displacement: 20 m
- Maximum vertical displacement: 3 m



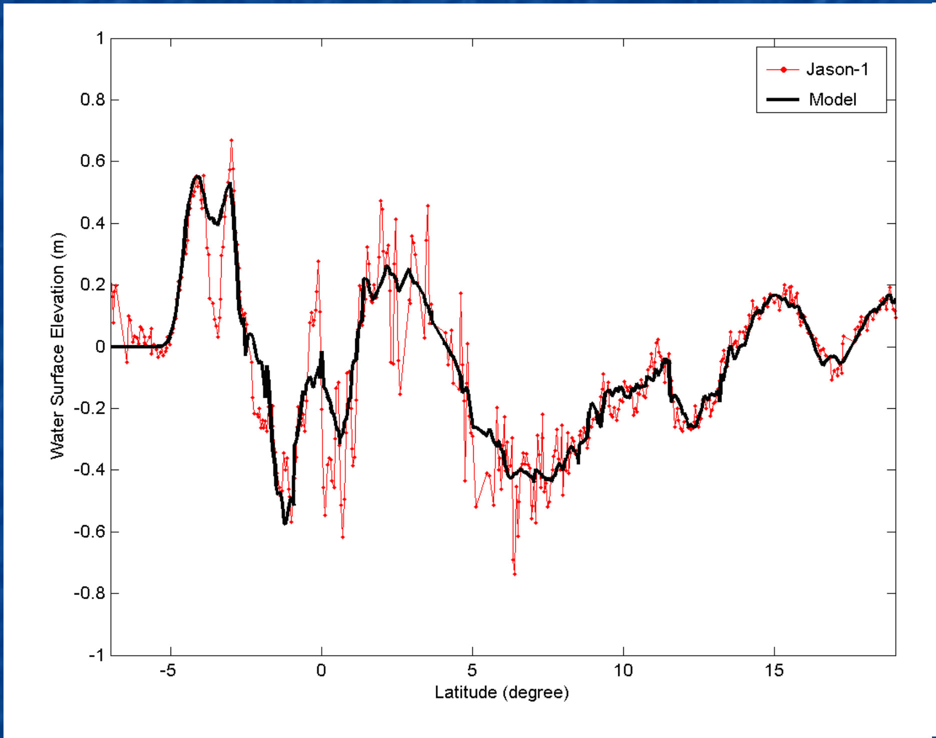
Satellite tracks for TOPEX and Jason-1

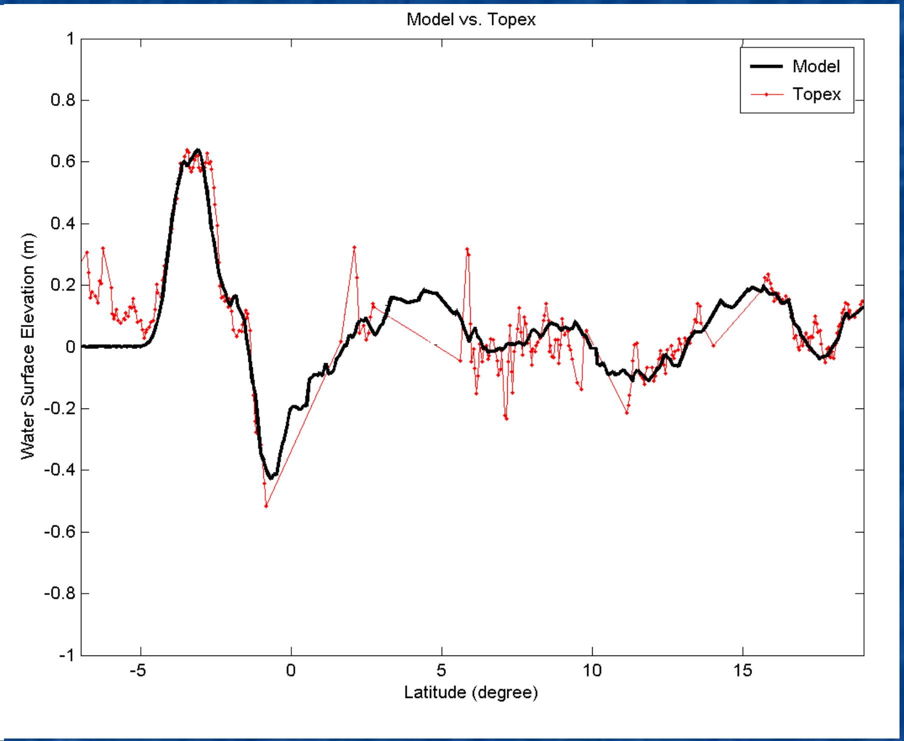


animation

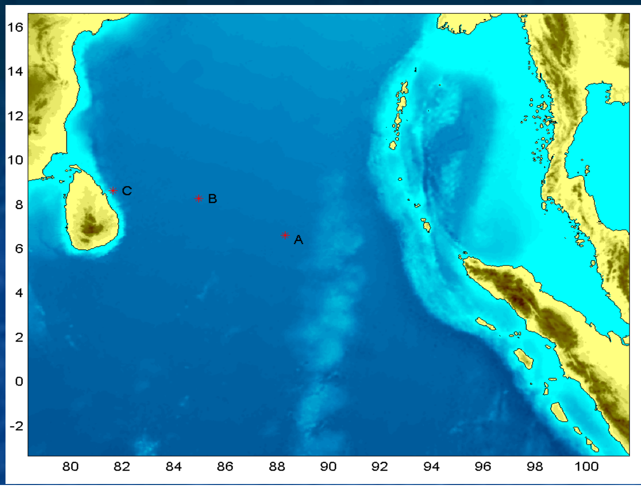
The colors indicate the numerically simulated free surface elevation in meter at two hours after the earthquake struck

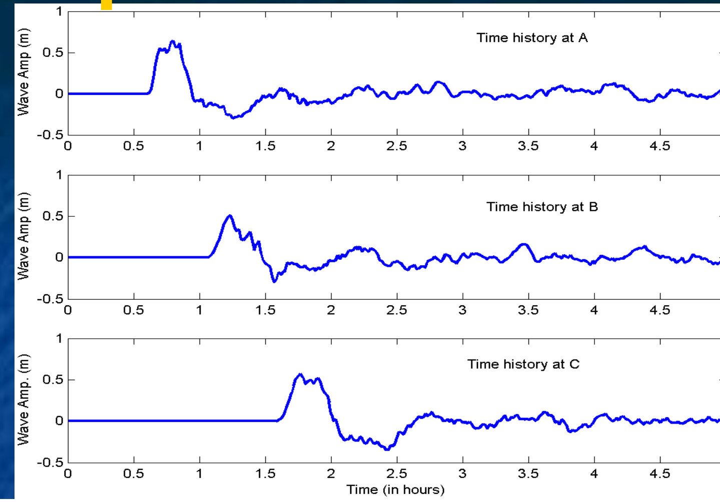
Comparisons between model results and Jason-1 measurements (left) and TOPEX measurements (right)

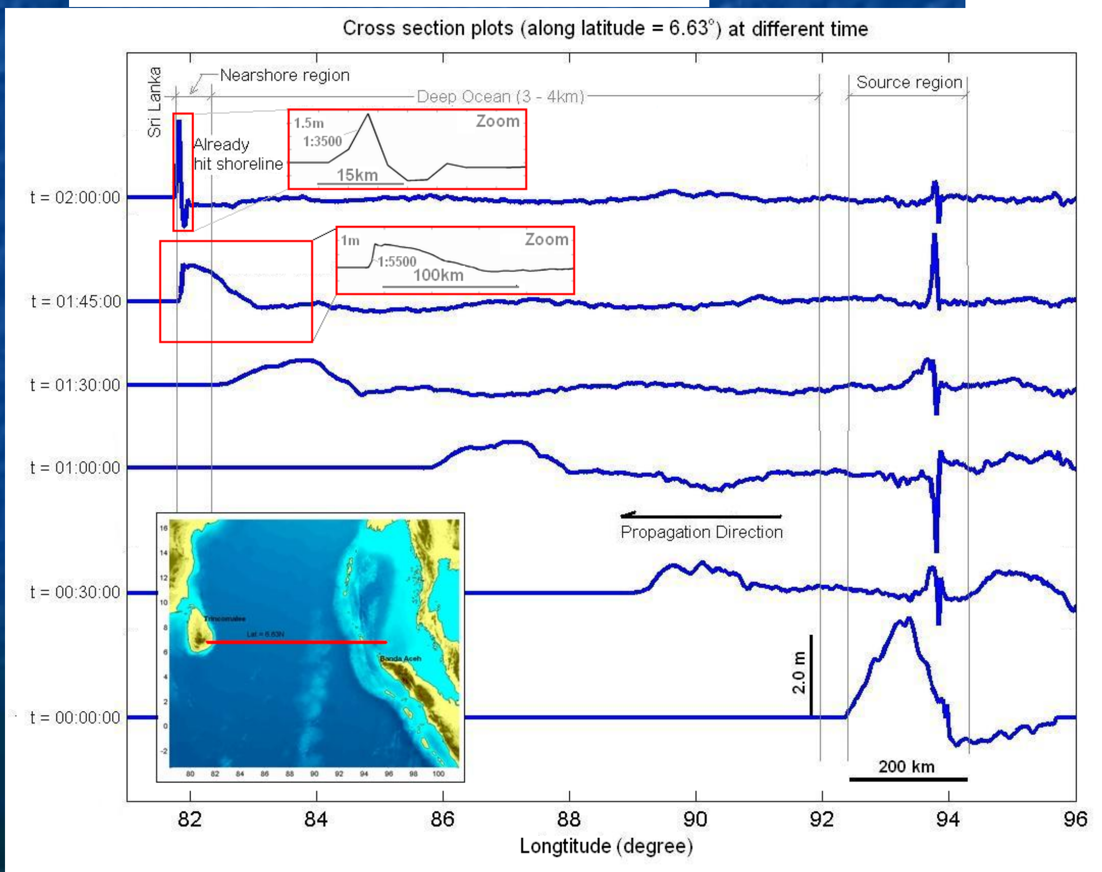




Tsunami characteristics in the open sea



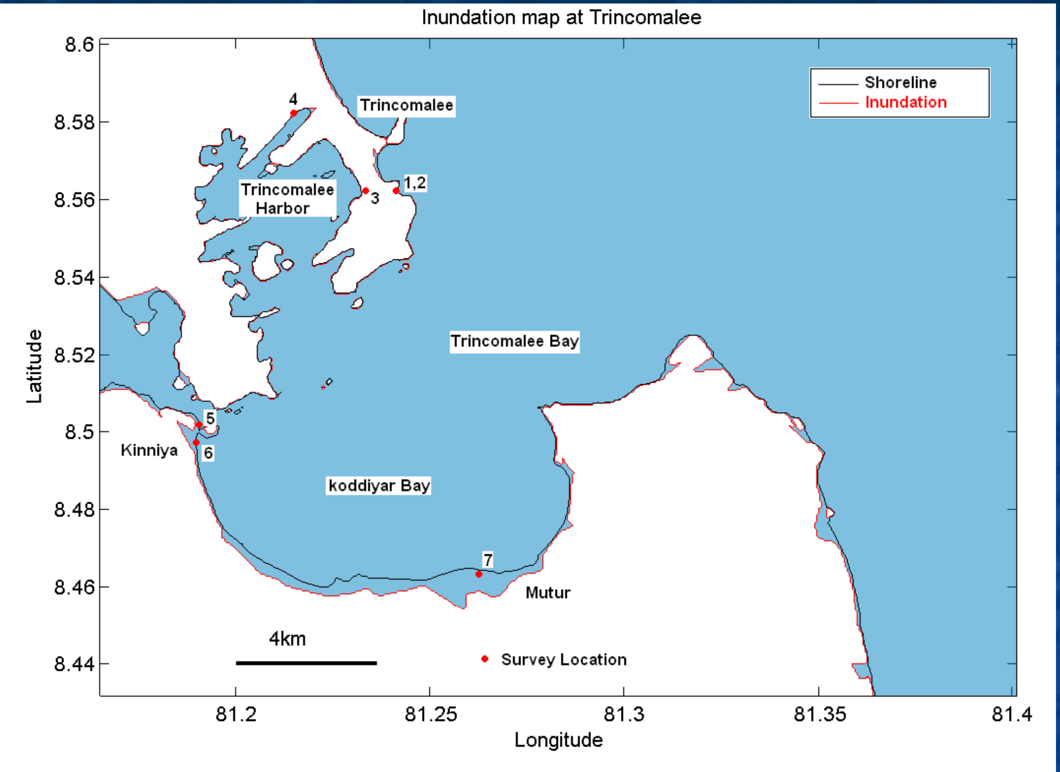


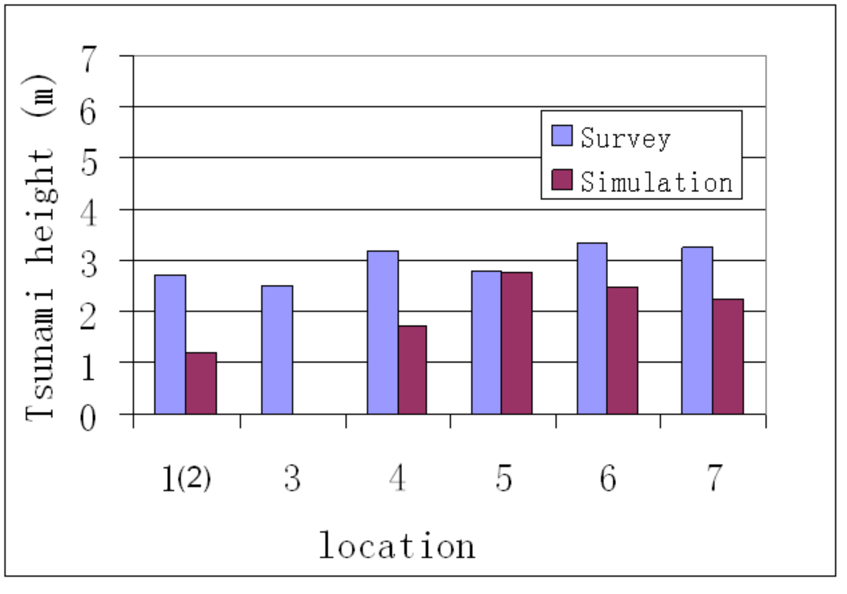


Snapshots of free surface profile along latitude = 6.63)

Linear Non-dispersive Waves

Tsunami inundation in Trincomalee (red line shows the inundation line)



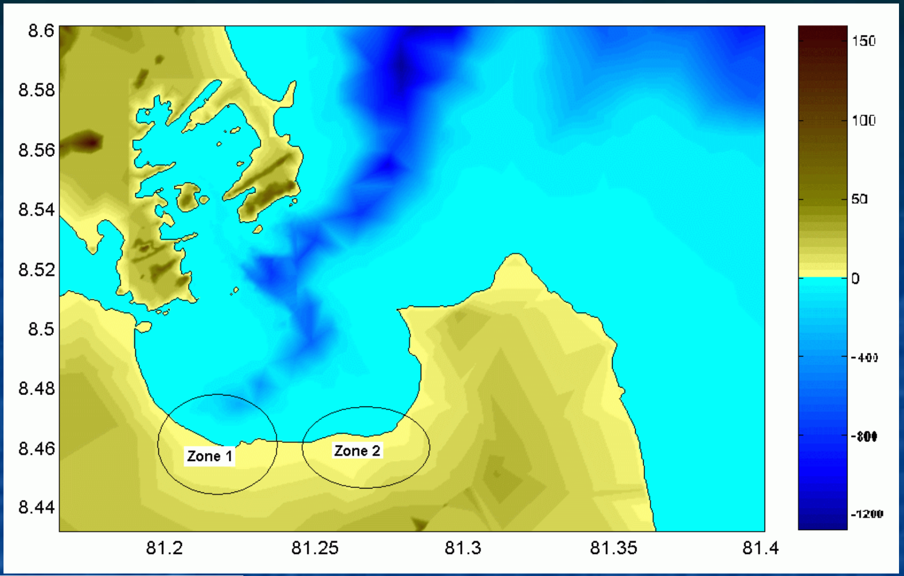


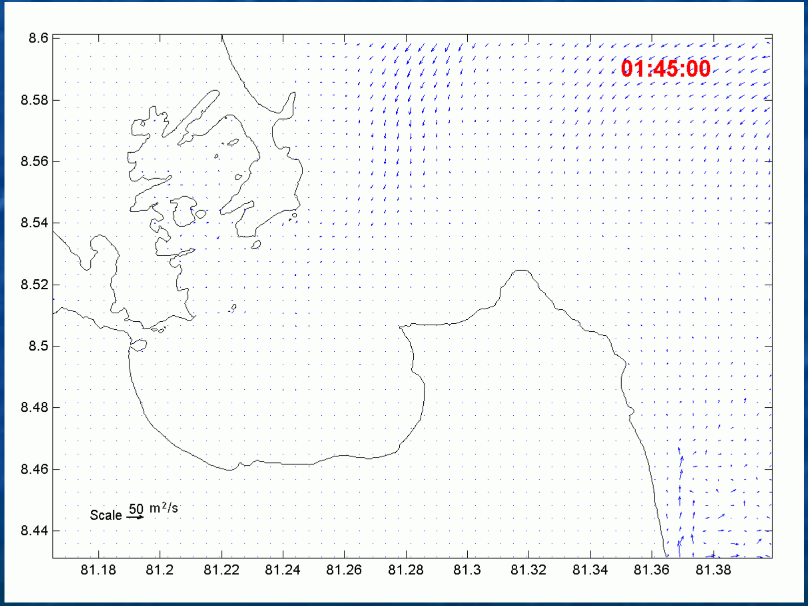
[Wave profile](#)

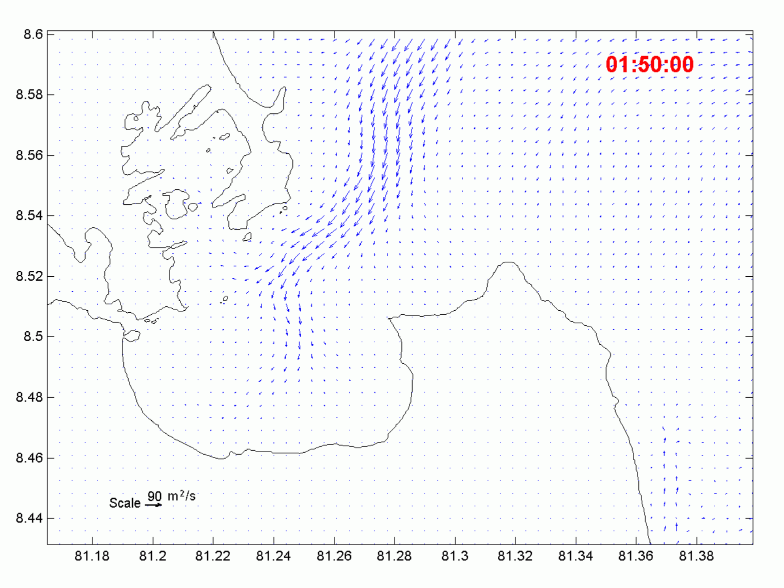
Comparisons between survey data and numerical results

[animation](#)

Local Bathymetry Effect

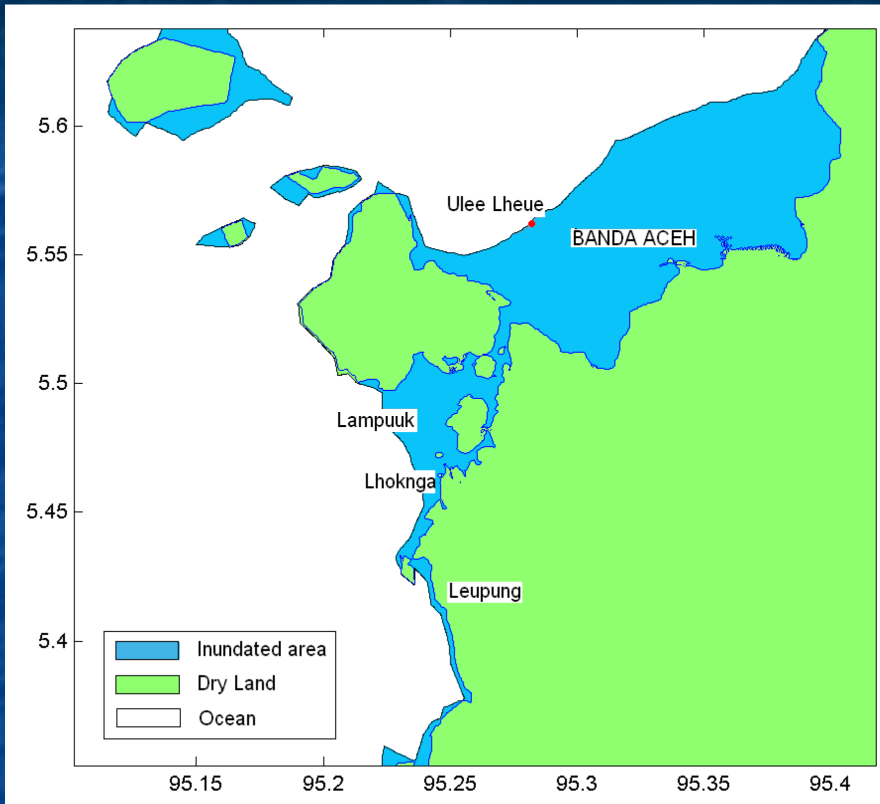


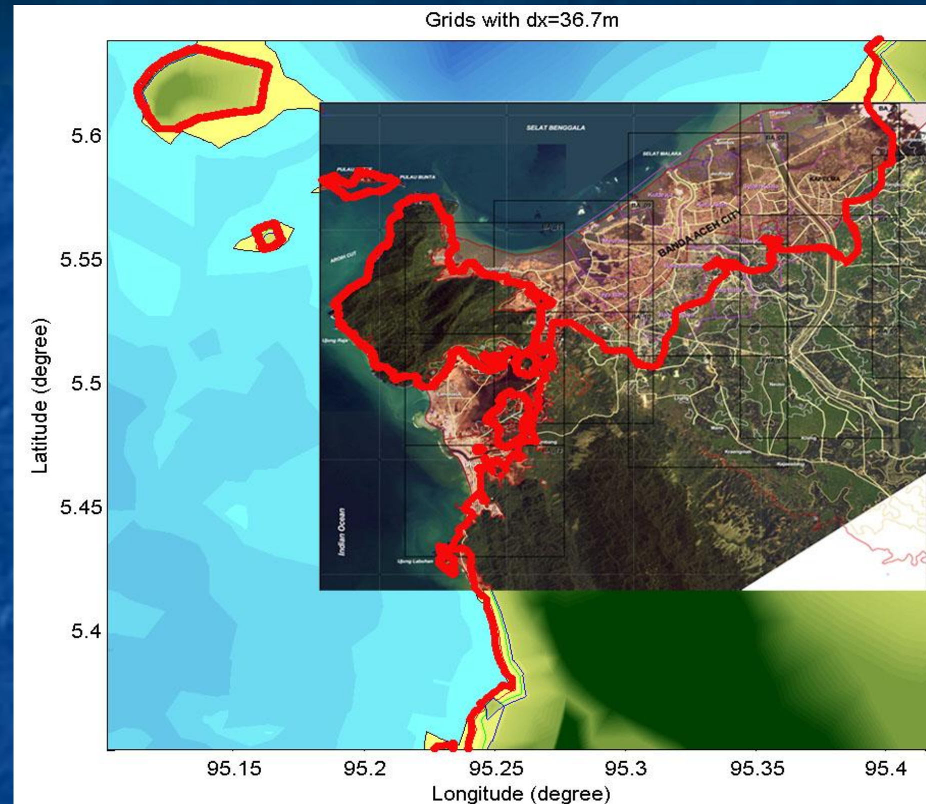




Mass fluxes inside Trincomalee bay

Tsunami Runup and Inundation in Banda Aceh

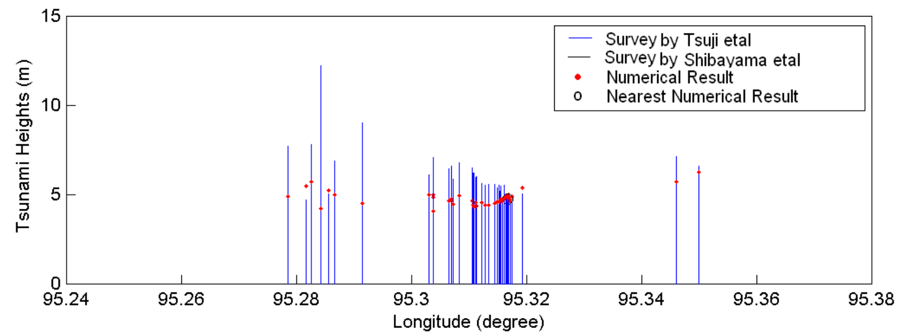


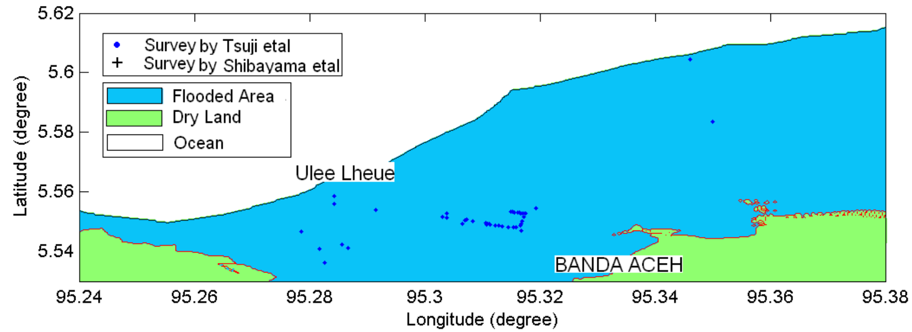


Calculated inundation area (left panel) and comparison with satellite image (right panel)

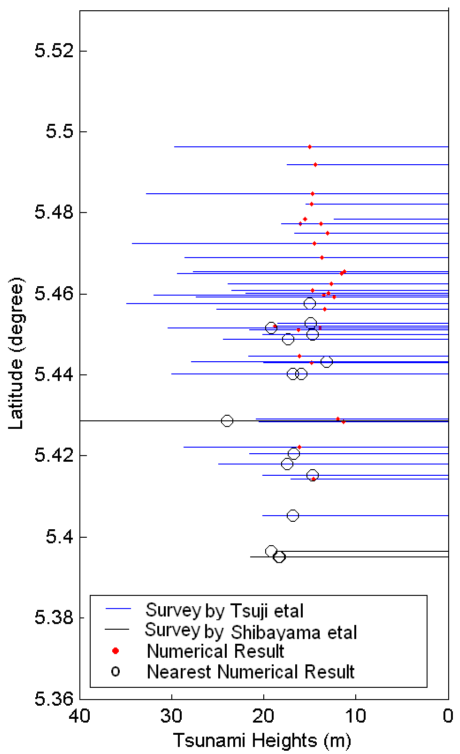
animation

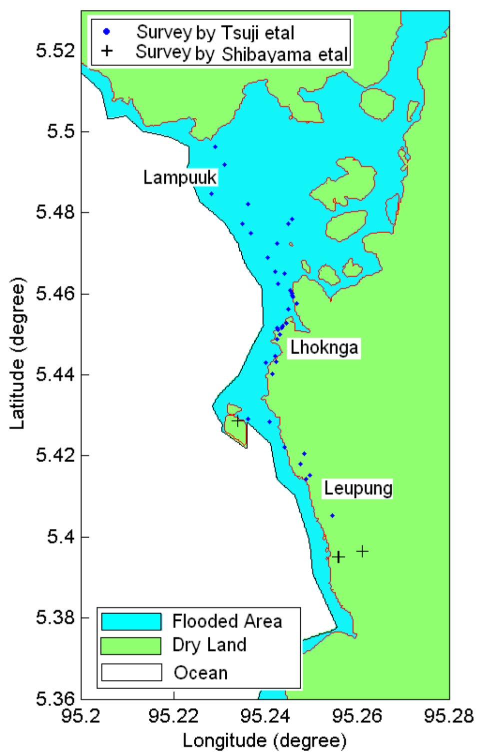
Calculated tsunami heights
at the Surveyed locations





North shore





West coast

Sediment transport

Shield parameter

$$\theta = \frac{\tau_b}{(\rho_s - \rho) g d_s},$$

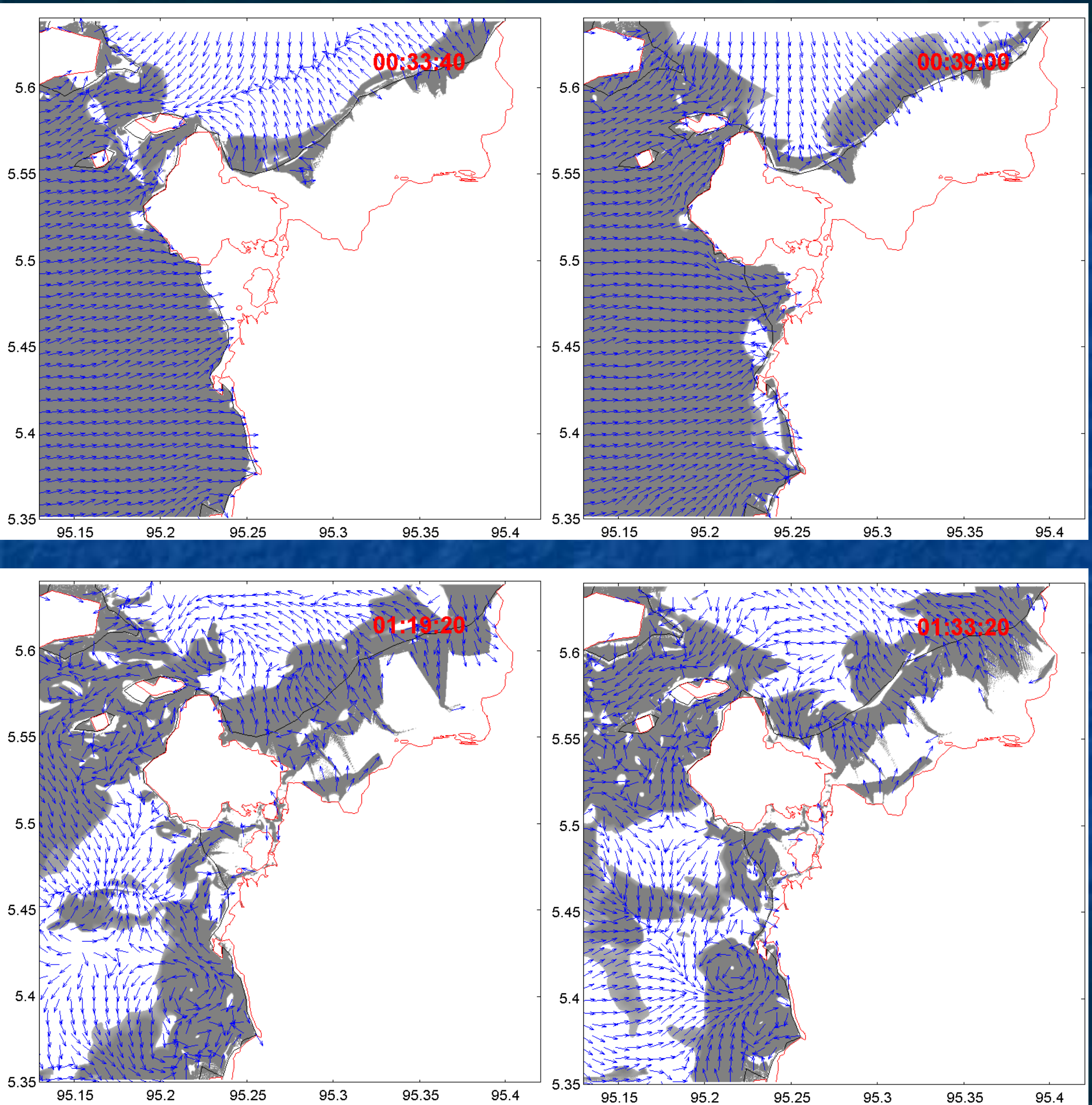
$$\tau_x = \frac{gn^2}{H^{10/3}} P(P^2 + Q^2)^{1/2}$$

$$\tau_b = \sqrt{\tau_x^2 + \tau_y^2}$$

$$\tau_y = \frac{gn^2}{H^{10/3}} Q(P^2 + Q^2)^{1/2}$$

$\theta > 0.06$: incipience of grain movement

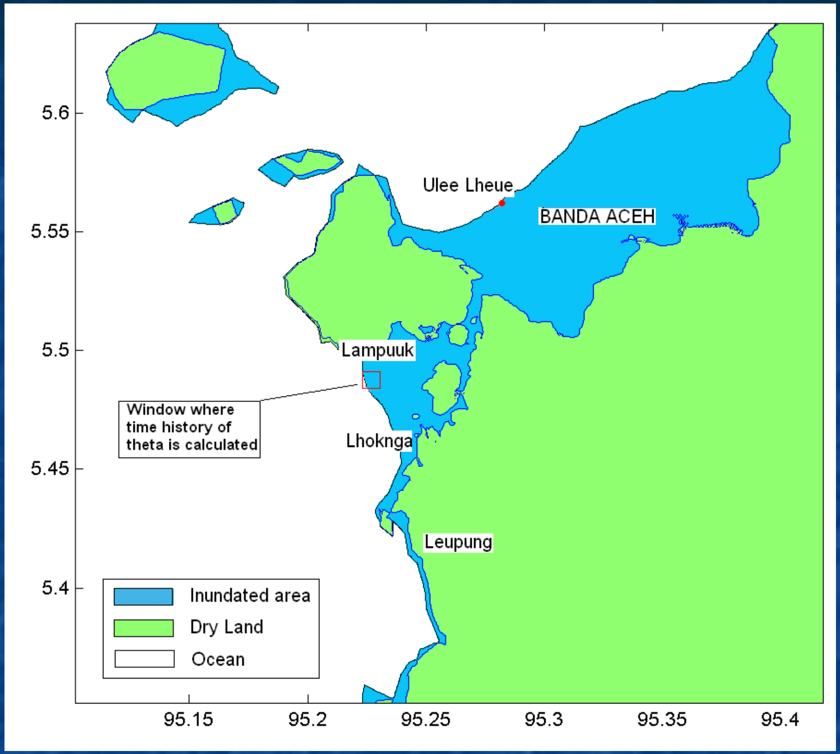
Sediment movement potential around Banda Aceh

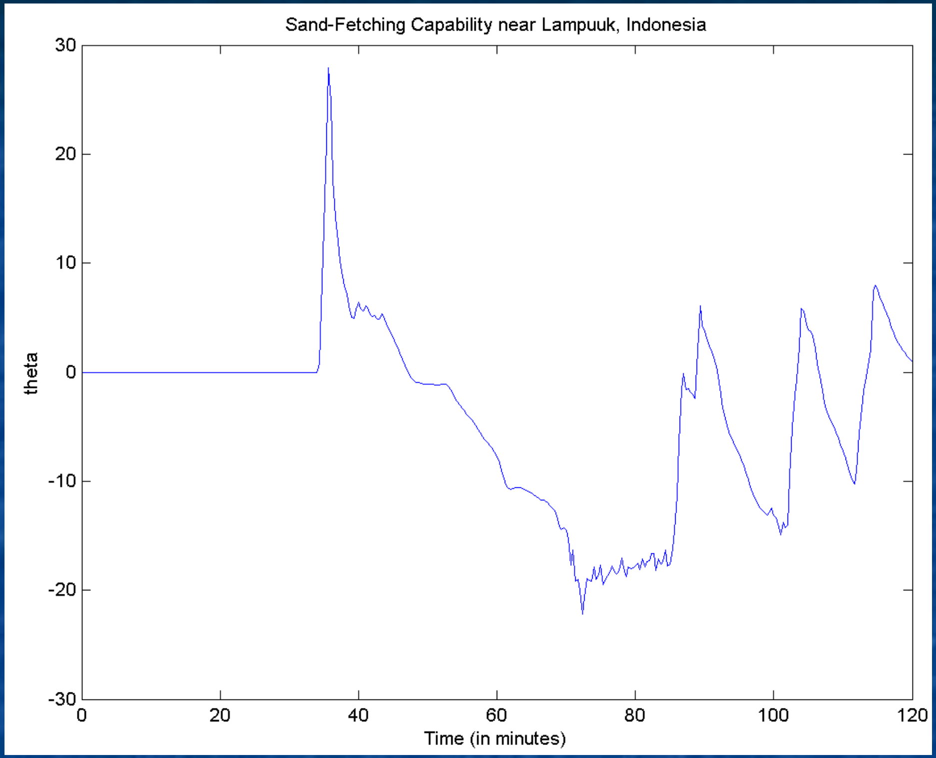


Gray color stands for regions where $\theta > 0.06$

Arrows denote the direction of bottom shear stress.

The clock shows the time after the main shock





Time history of *θ* averaged within an 800m-by-800m window near Lampuuk. Positive value means that the flow is in onshore direction and negative value means that the flow is in offshore direction.

Sediment erosion and deposit

Mass conservation

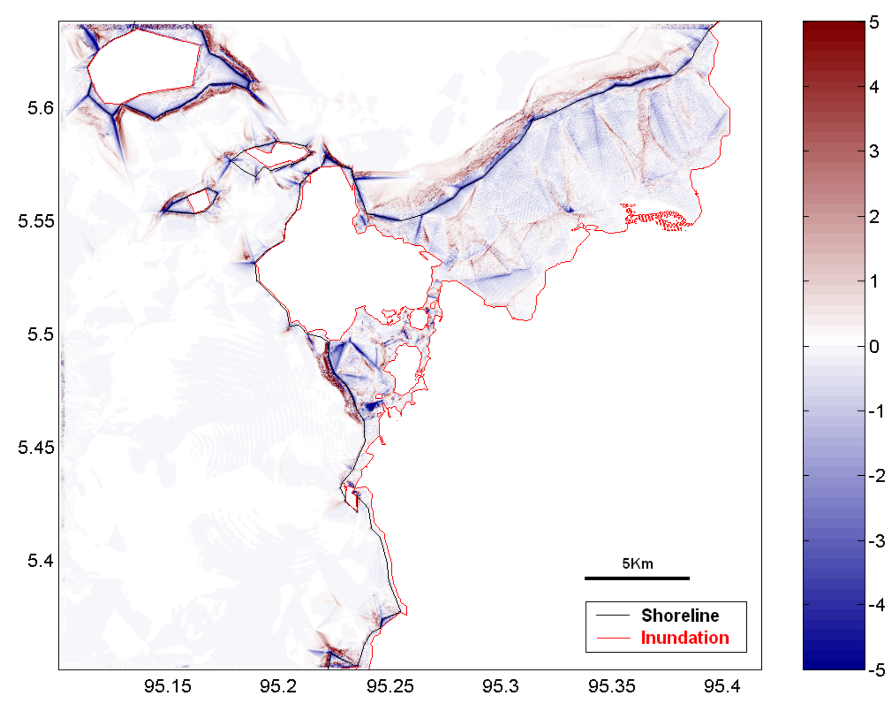
$$\frac{\partial h}{\partial t} + \frac{1}{1-\lambda} \nabla \cdot \vec{q} = 0$$

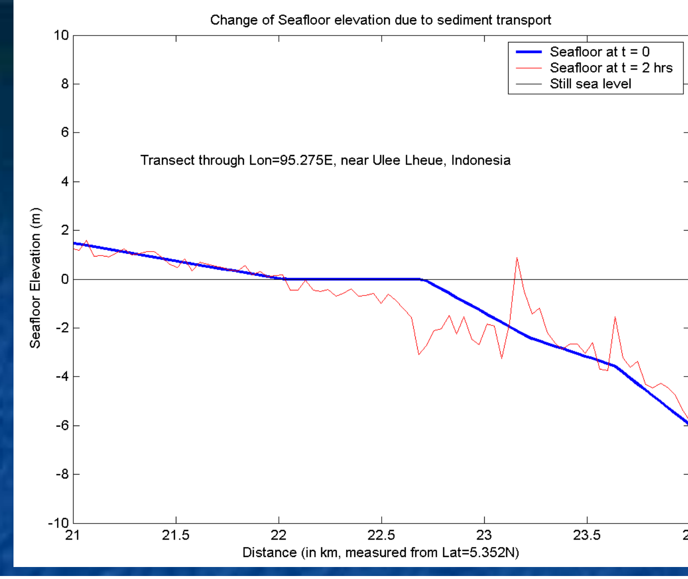
$$\vec{q} = 8 \sqrt{\frac{\rho_s - \rho}{\rho} g d_s} \left(\theta - \theta_c\right)^{3/2} \frac{\vec{u}}{|\vec{u}|}$$

porosity of sand (**λ =** 0.3)

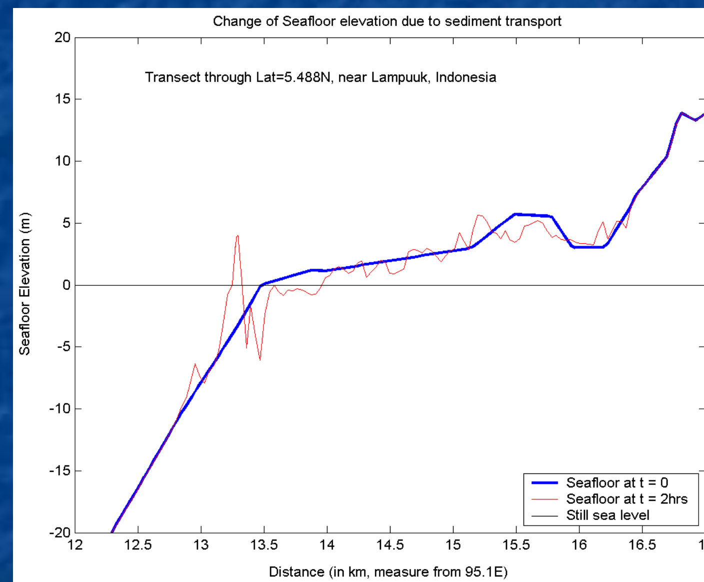
$\theta_c = 0.06$

mean sediment diameter
(d_s = 0.5mm)





Ulee Lheue

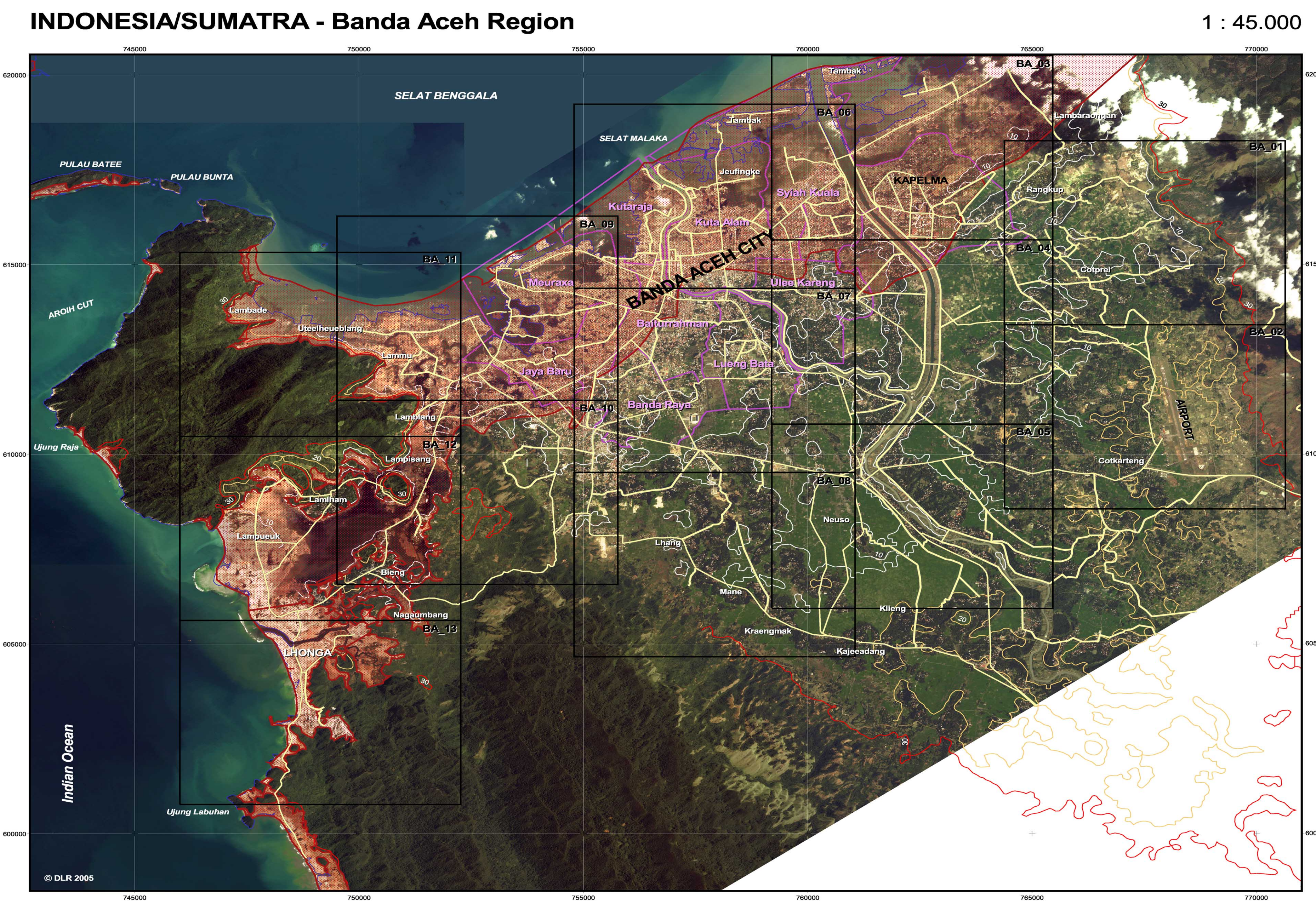


Lampuuk

Change of bathymetry and topography At Banda Aceh 2 hours after main shock. The color scale is in meters. Positive value means deposit and negative value Suggests erosion.

Transect of seafloor elevation. The thick blue line shows the original sea bottom and the red thin line denotes the calculated sea bottom 2 hours after the earthquake. Black line stands for the still sea level.

Flooding and erosion at Banda Aceh



Concluding Remarks

- COMCOT provides reasonable results for arrival time, wave height and runup;
- Shield parameter is used as an index for potential sediment movement;
- A simple sediment transport model is implemented, using the COMCOT results as an driving force.
- The sediment transport model needs to be improved and validated.