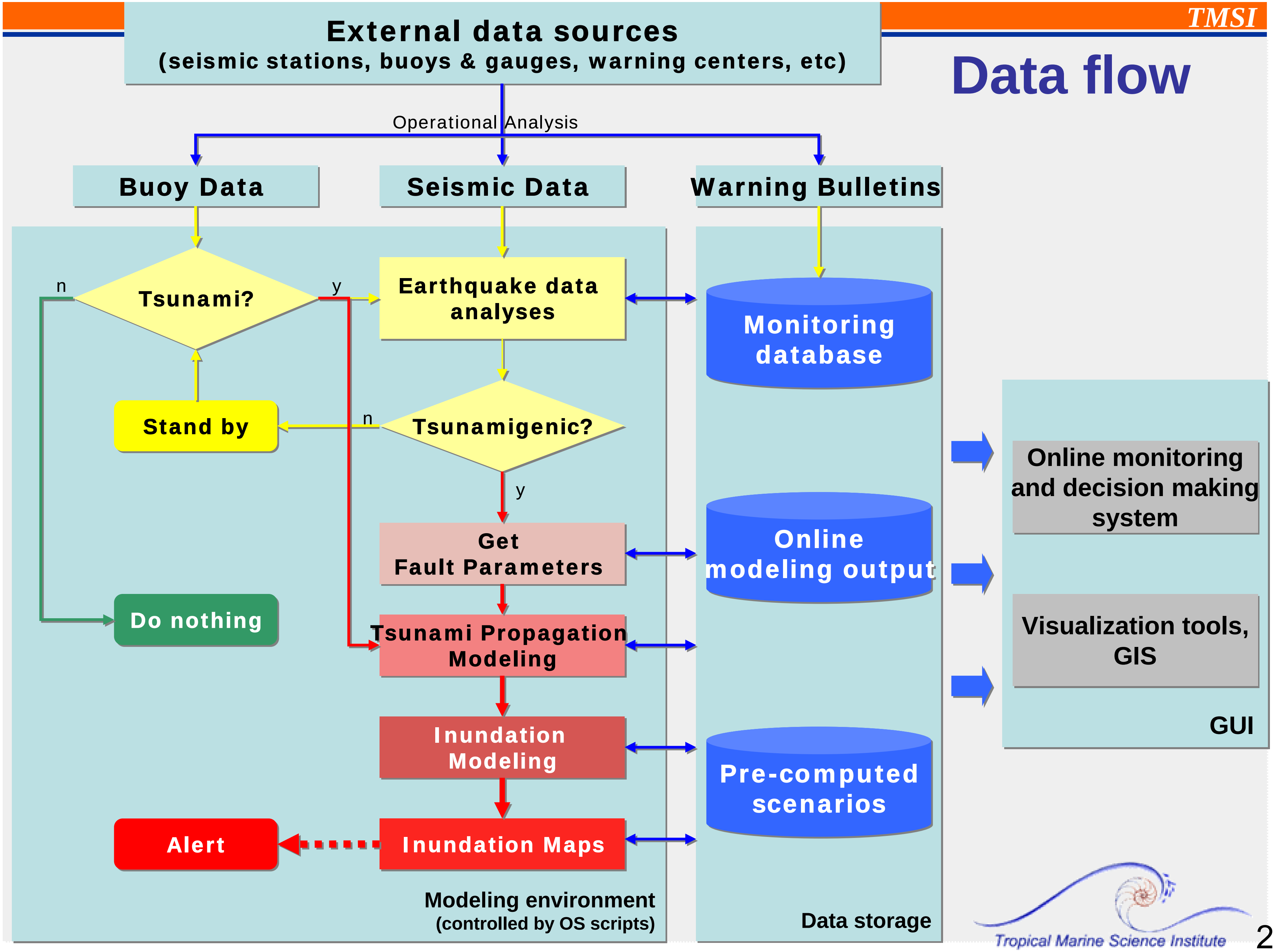
SINGAPORE TSUNAMI WARNING SYSTEM.
PROJECT MILESTONES

By Pavel TKALICH , DAO My Ha, CHAN Eng Soon
National University of Singapore

Data flow



External data sources
(seismic stations, buoys & gauges, warning centers, etc)

Operational Analysis

Buoy Data

Seismic Data

Warning Bulletins

Tsunami?

n

y

Earthquake data analyses

Stand by

n

Tsunamigenic?

y

Get Fault Parameters

Do nothing

Tsunami Propagation Modeling

Inundation Modeling

Alert

Inundation Maps

Modeling environment
(controlled by OS scripts)

Monitoring database

Online modeling output

Pre-computed scenarios

Data storage

Online monitoring and decision making system

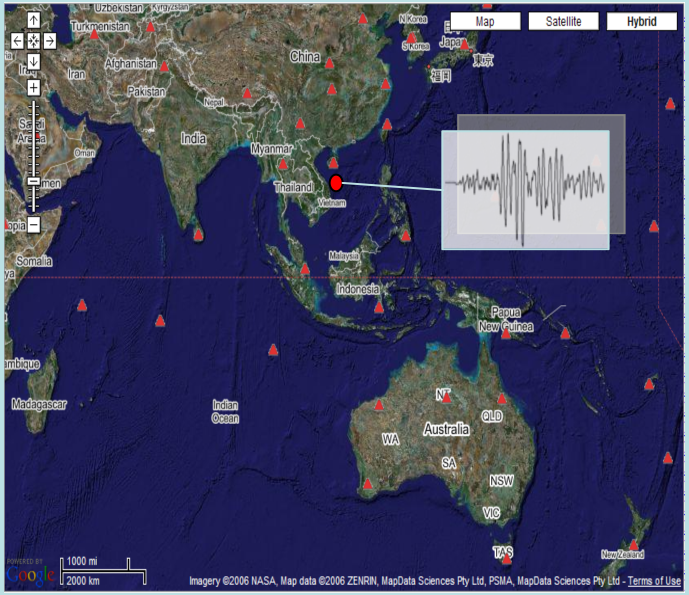
Visualization tools, GIS

GUI

EARTHQUAKE & TSUNAMI SENSORS AND TRIGGERS

I. Tsunami Warning Bulletins

II. Network map for Global Seismograph Network



Imagery ©2006 NASA, Map data ©2006 ZENRIN, MapData Sciences Pty Ltd, PSMA, MapData Sciences Pty Ltd - Terms of Use

III. Sea level data from buoys (DARTS)

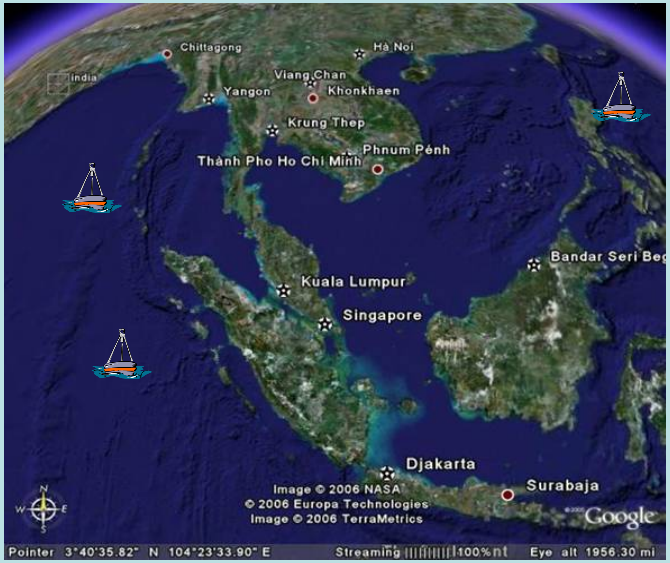


Image © 2006 NASA
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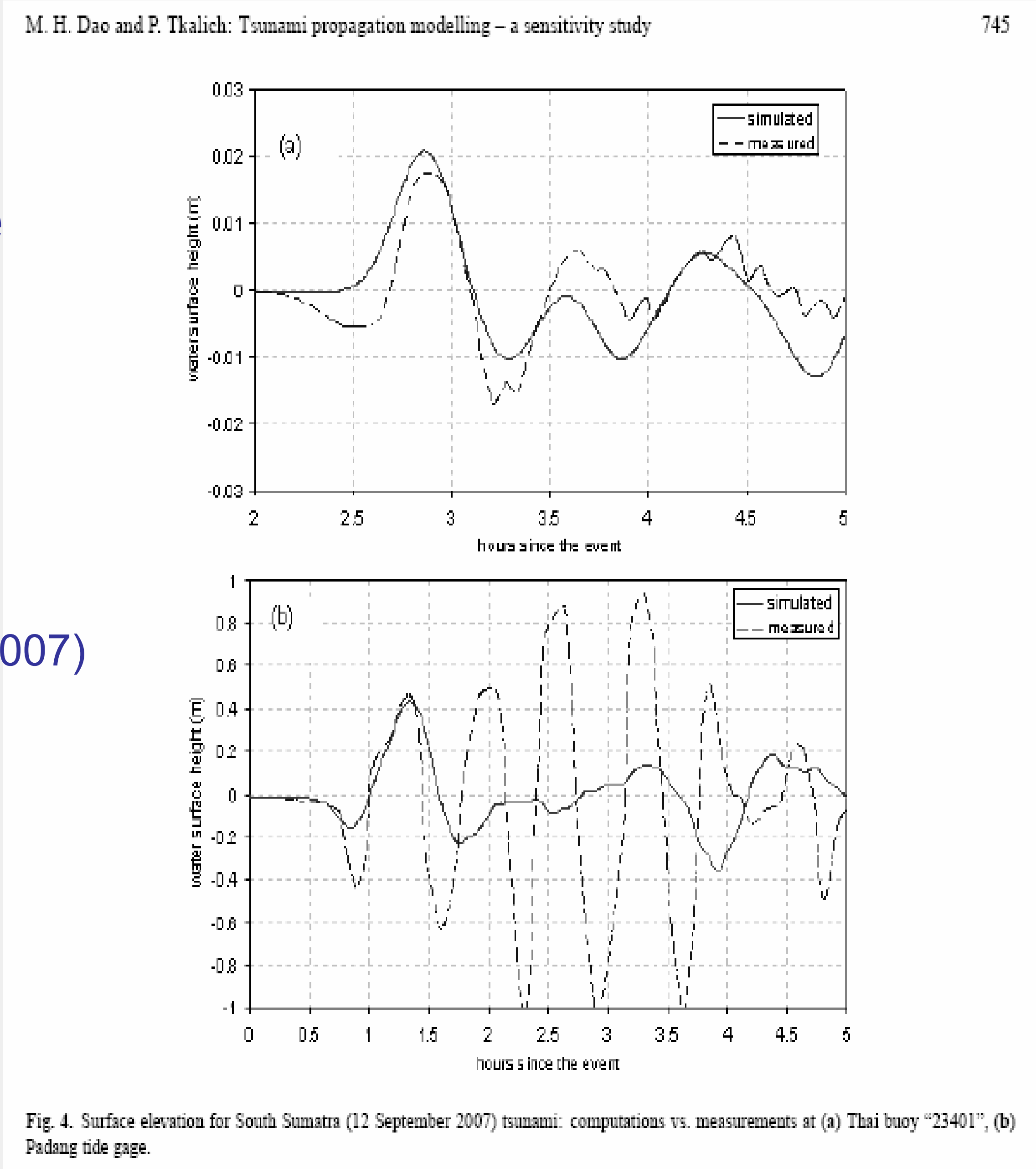
Image © 2006 TerraMetrics

8.4Mw earthquake off Bengkulu, South Sumatra (12 Sep 2007)

Nat. Hazards Earth Syst. Sci(2007) 7, pp. 741–754



M. H. Dao and P. Tkalich: Tsunami propagation modelling – a sensitivity study 745

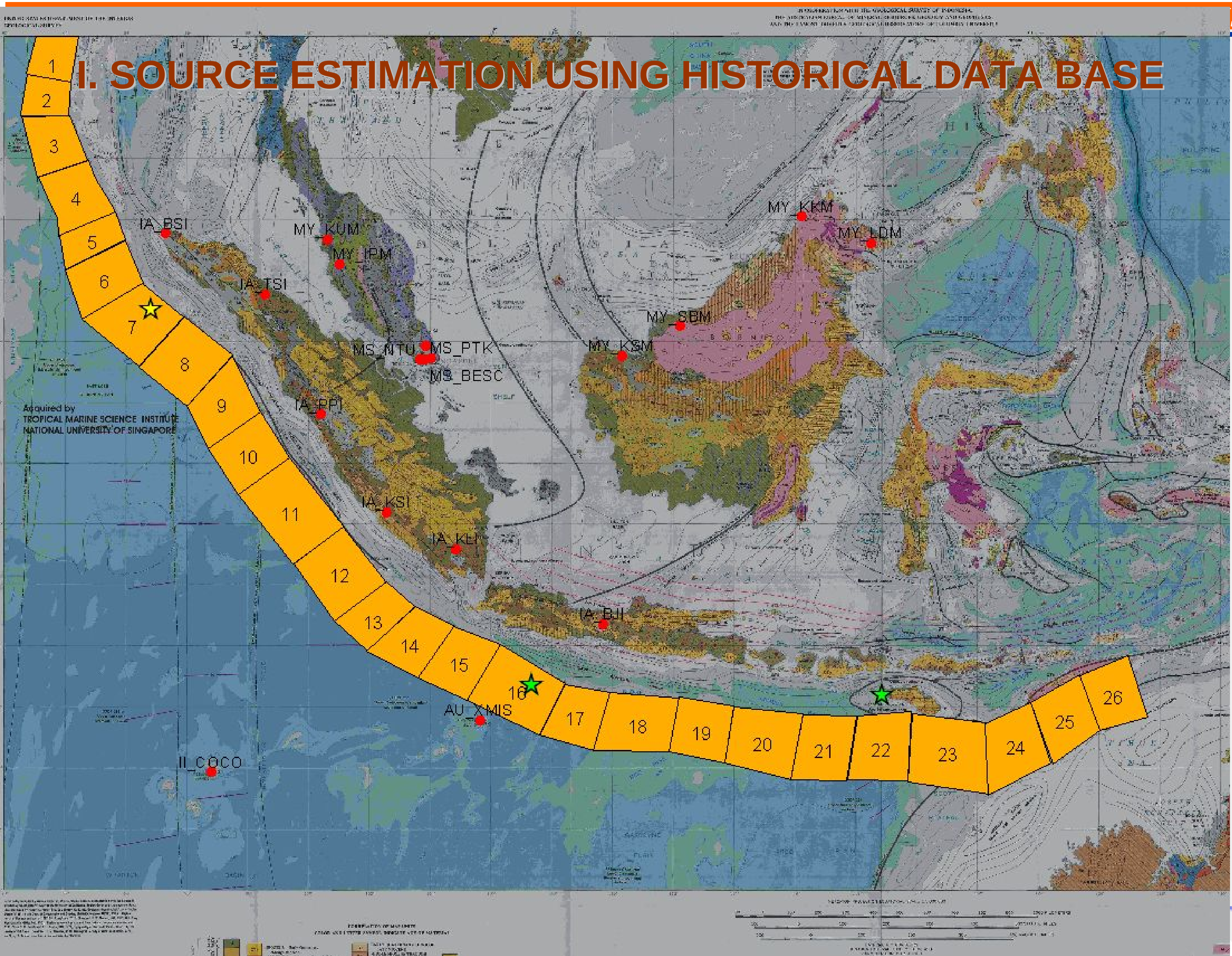
Fig. 4. Surface elevation for South Sumatra (12 September 2007) tsunami: computations vs. measurements at (a) Thai buoy "23401", (b) Padang tide gage.

The Antelope
Seismic Information System

ON-LINE SEISMIC DATA READING

The current generation of Antelope provides full functionality for seismic network and array operations and control, including real time data acquisition from field digitizers, interactive control of field equipment, system state-of-health monitoring, real time automated data processing (detection, picking, seismic event association, seismic event location, archiving). It also offers interactive and batch processing, information system functions, automated distribution of raw data and processed results, batch mode seismic array processing and a powerful development toolkit for extending and customizing the system.

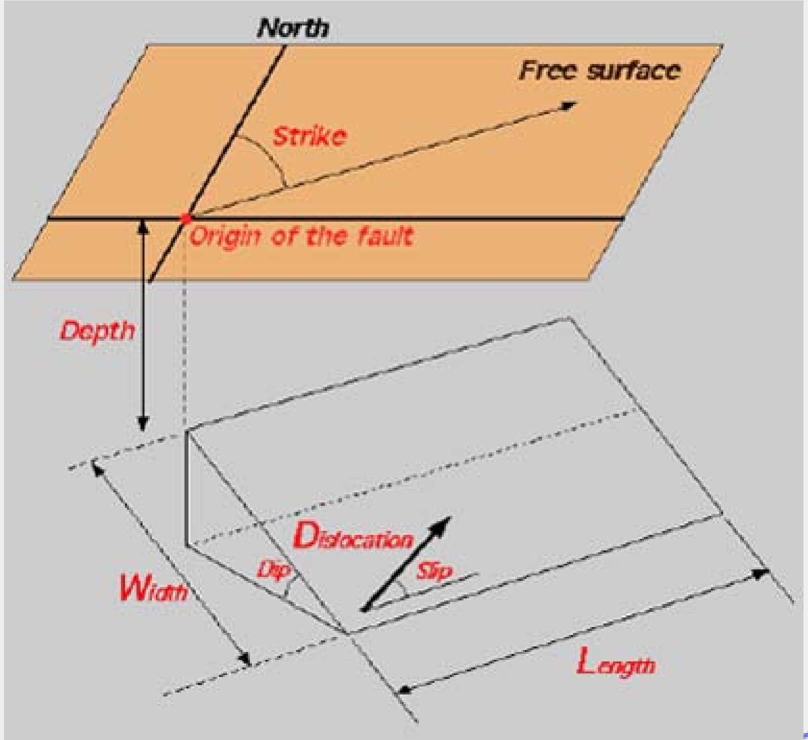
I. SOURCE ESTIMATION USING HISTORICAL DATA BASE



I. SOURCE ESTIMATION USING HISTORICAL DATA BASE

Fault model for earthquake-tsunami

- **For a submarine earthquake, the rupture typically has durations less than a minute, which is considered instantaneous compare to tens of minutes period of tsunami wave, thus dynamic effect is neglected**
- **Initial wave profile is assumed to be identical to the vertical static displacement of the sea floor.**
- **Typical fault parameters (based on Manshinha and Smylie (1971) or Okada (1985) fault model) :**
  - Fault origin (lat., long.)
  - Rupture duration, τ
  - Strike, θ
  - Dip, λ
  - Rake (Slip), δ
  - Depth, D
  - Length, L
  - Width, W
  - Dislocation, Δ



II. Computation of real time fault parameters from moment magnitude.

Chew Soon Hoe et al. (2007)

USGS solution

```
Strike=297, 113
Slip=  93, 90
Dip= 84, 6
Mo=8.1*10**26 dyne cm
MW 7.2
              -------
        --############---
      ####################-
    ########################-
  ################   ########--
 ################# T ##########-
 --###############   ###########
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 ----------   ------------------
  --------- P -----------------
    -------   ---------------
      ---------------------
        -----------------
             -------
```

Our solution

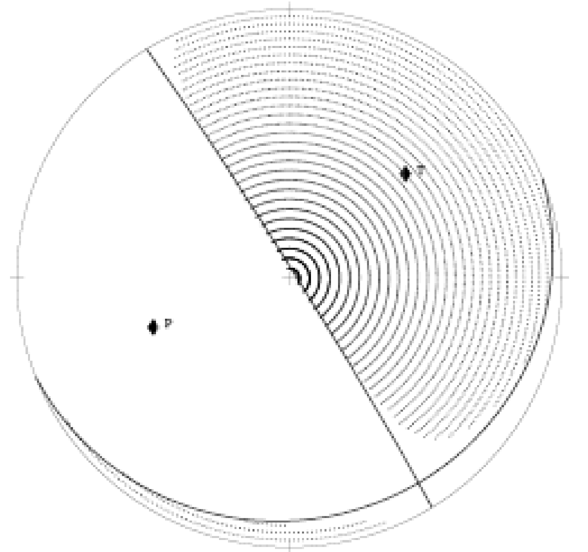
Strike=328 ; 68

Rake =-79 ; -170

Dip =88 ; 12

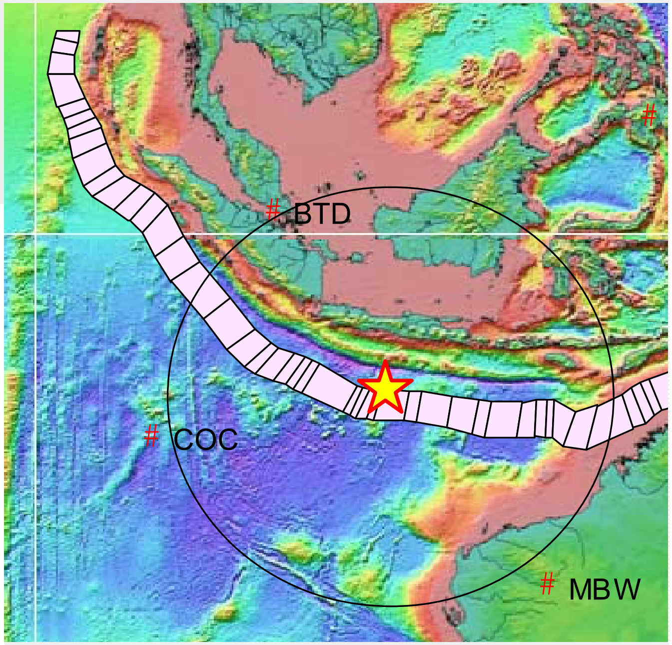
Mo =2.73e+26

Mw =6.9



Preliminary Results

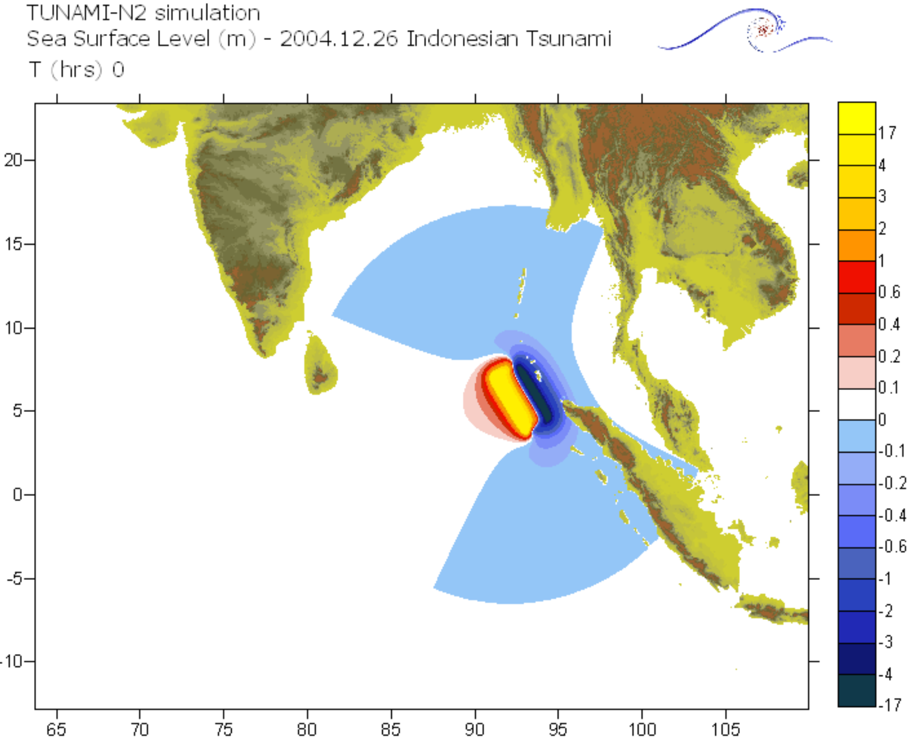
Java EQ (July 17, 2006)



Using 200+ stations, obtained only many hours after EQ!

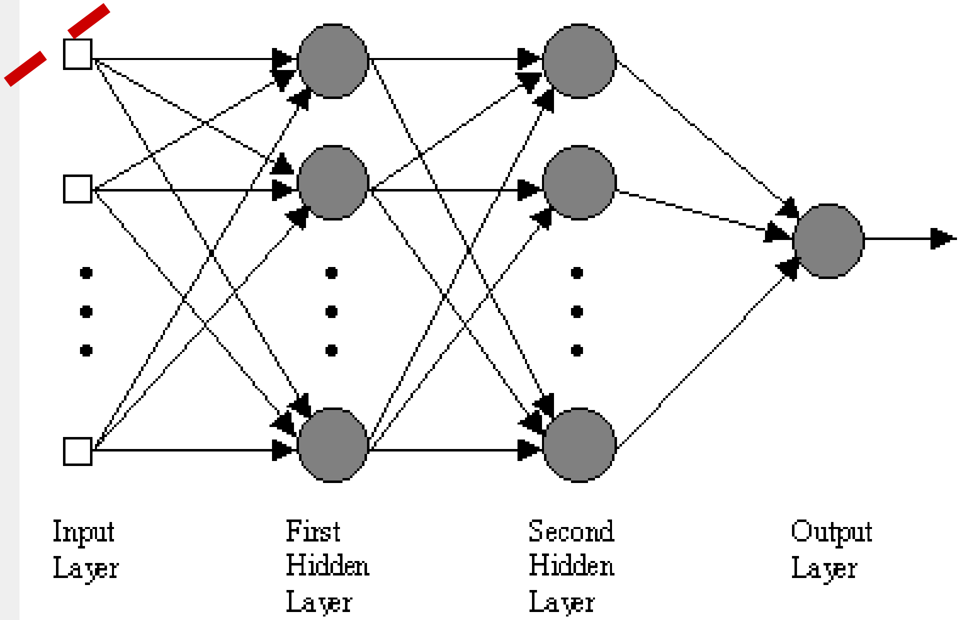
Our solution – which is similar to USGS results, with close-enough values of Mo and Mw, was obtained by analyzing signals from three stations within 12 minutes after EQ!

Tsunami propagation. NUS Scenarios

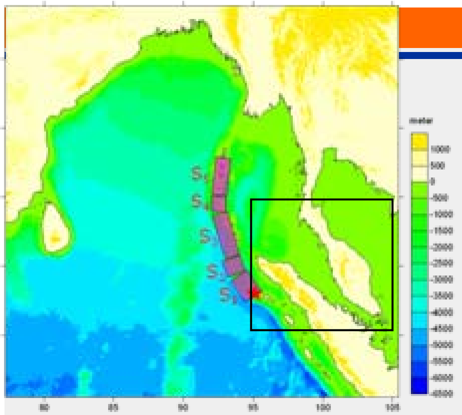

TUNAMI-N2 simulation
Sea Surface Level (m) - 2004.12.26 Indonesian Tsunami
T (hrs) 0

(TUNAMI-N2)

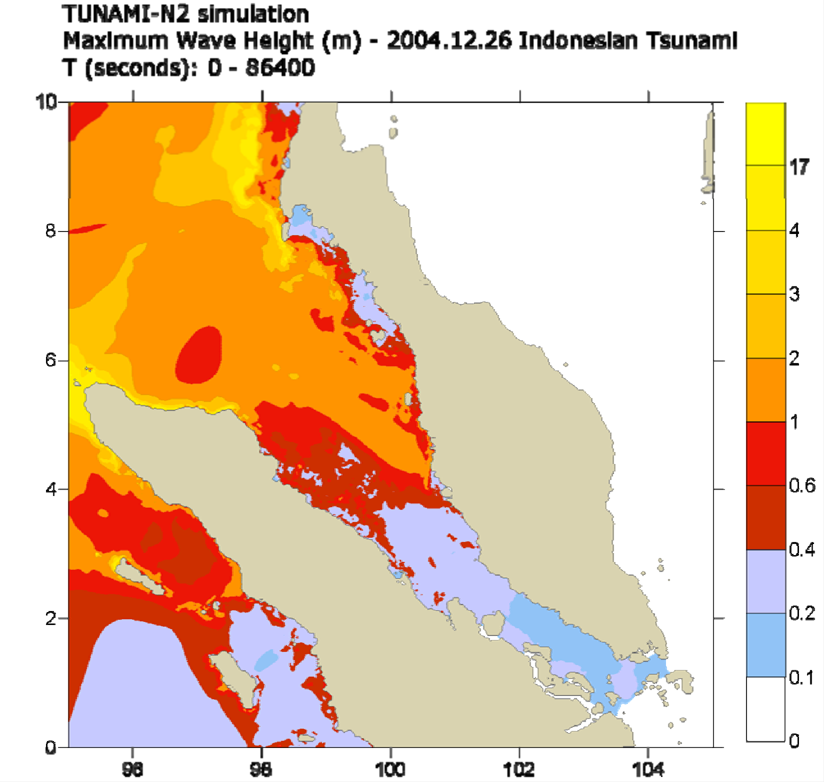
(TUNAMI-ANN)



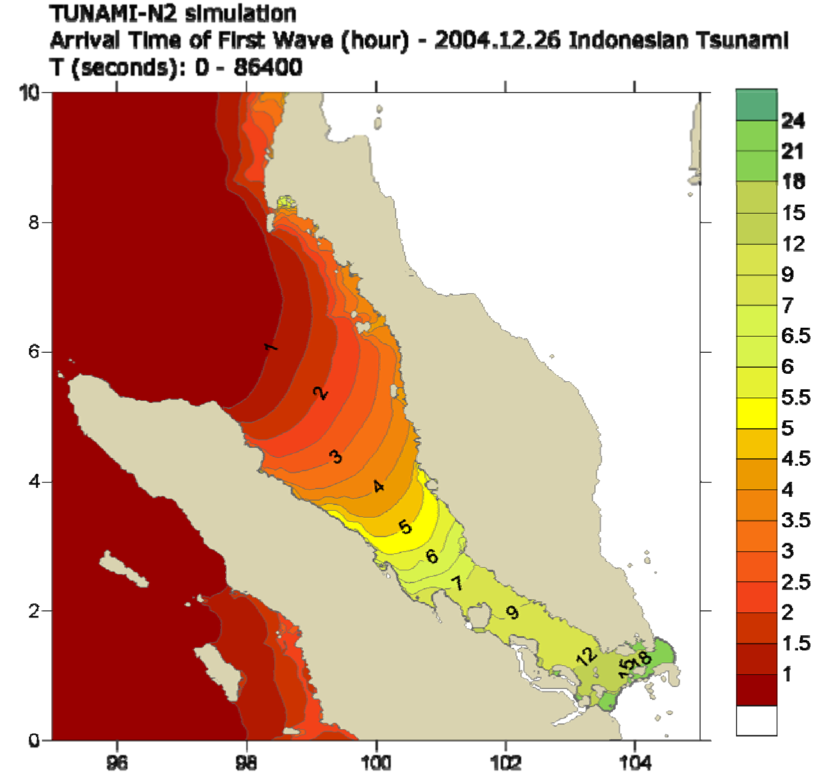
Artificial Neural Network (ANN)



Max wave height and travel time in Malacca Strait and Singapore

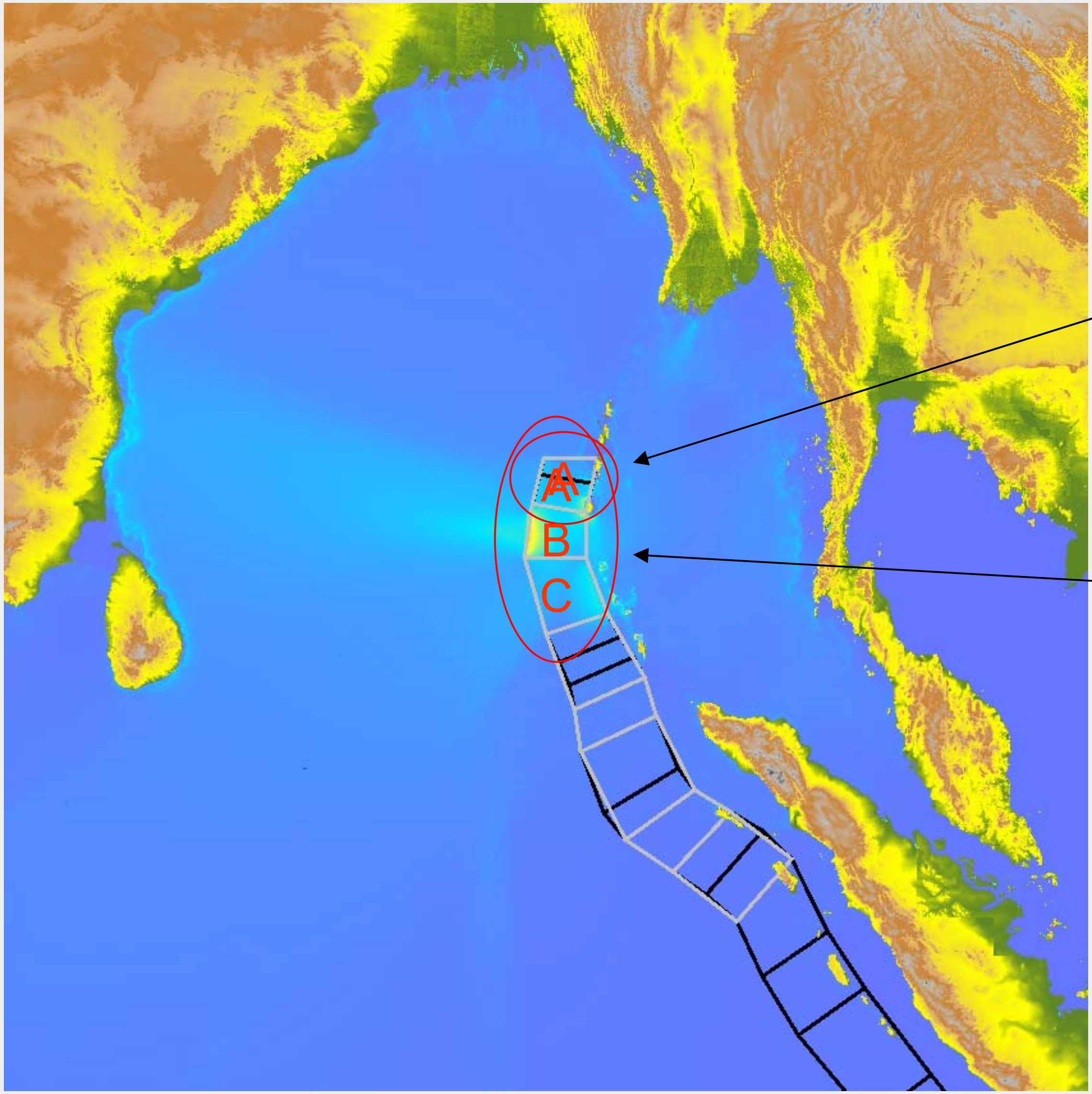


TUNAMI-N2 simulation
Maximum Wave Height (m) - 2004.12.26 Indonesian Tsunami
T (seconds): 0 - 86400



TUNAMI-N2 simulation
Arrival Time of First Wave (hour) - 2004.12.26 Indonesian Tsunami
T (seconds): 0 - 86400

Data Driven Model (ANN): NUS Scenarios



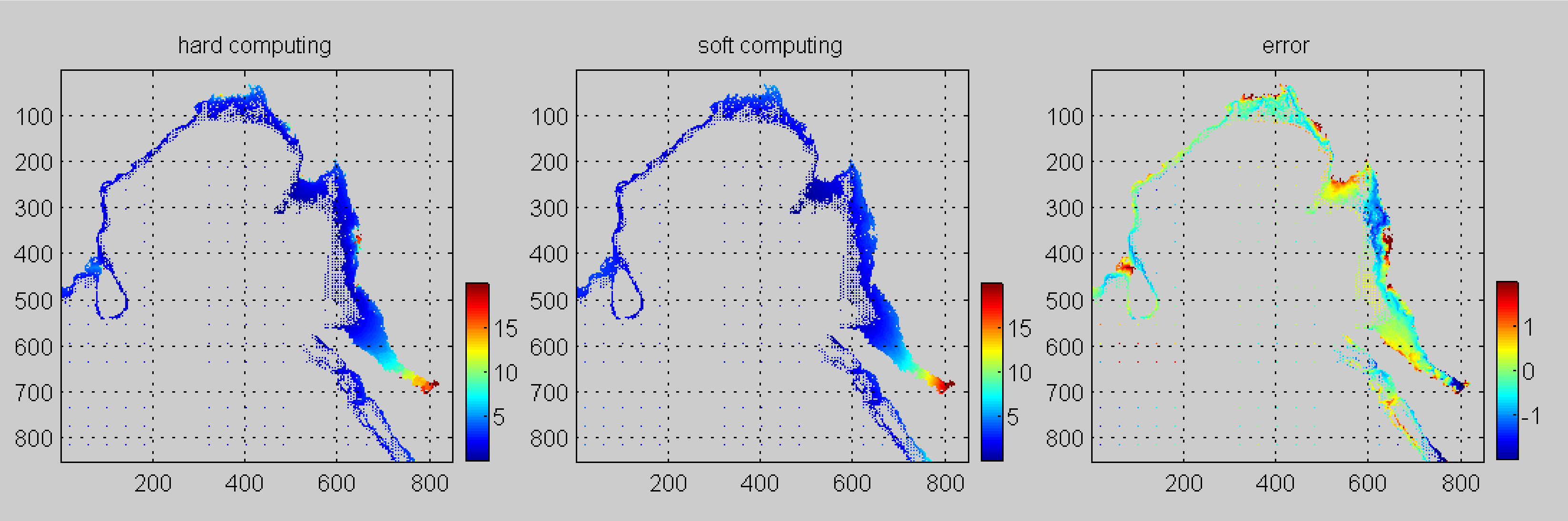
SCENARIO 1

SCENARIO 2

Segment A alone

Segments A, B and C together

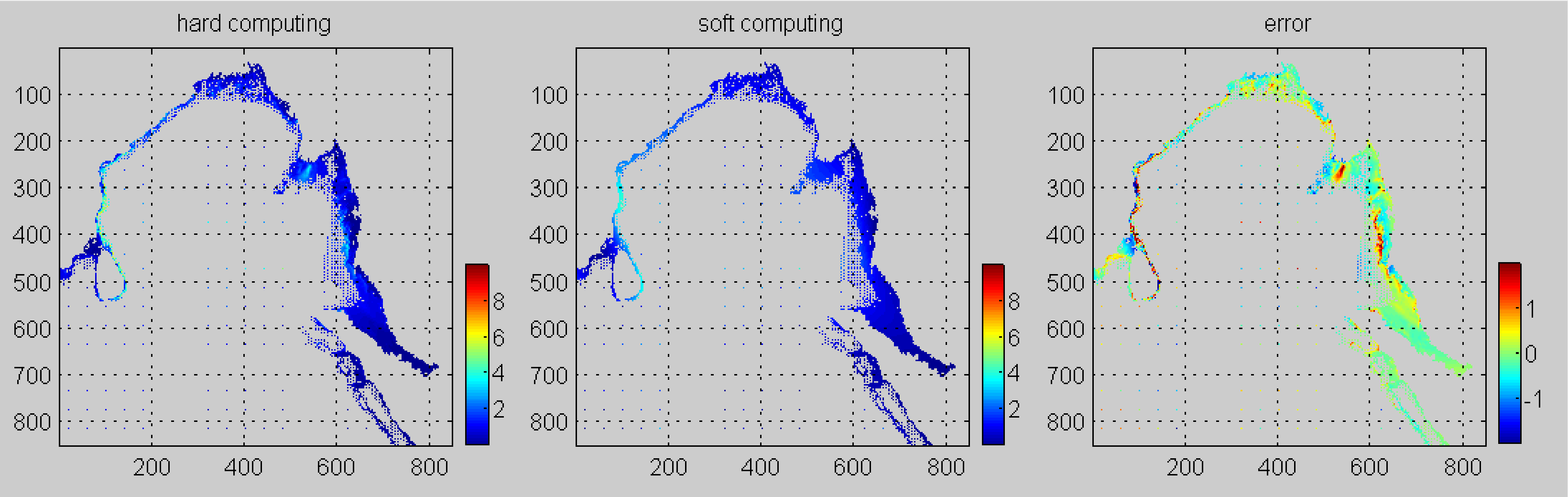
Results comparison (ANN)- Segment A, B & C


hard computing

soft computing

error

Wave Arrival Time (hours)


hard computing

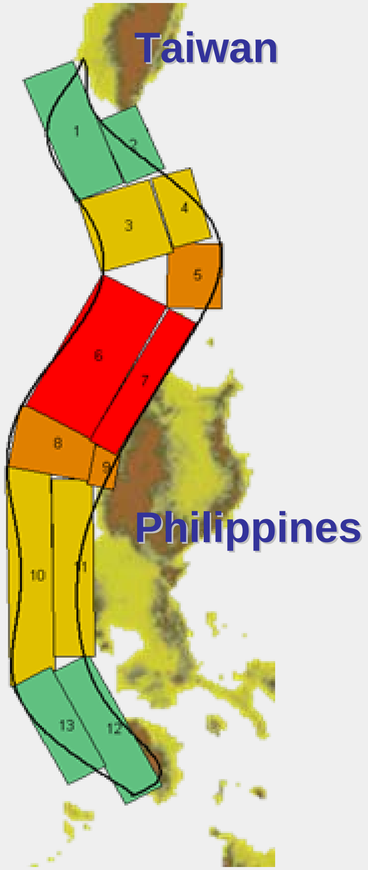
soft computing

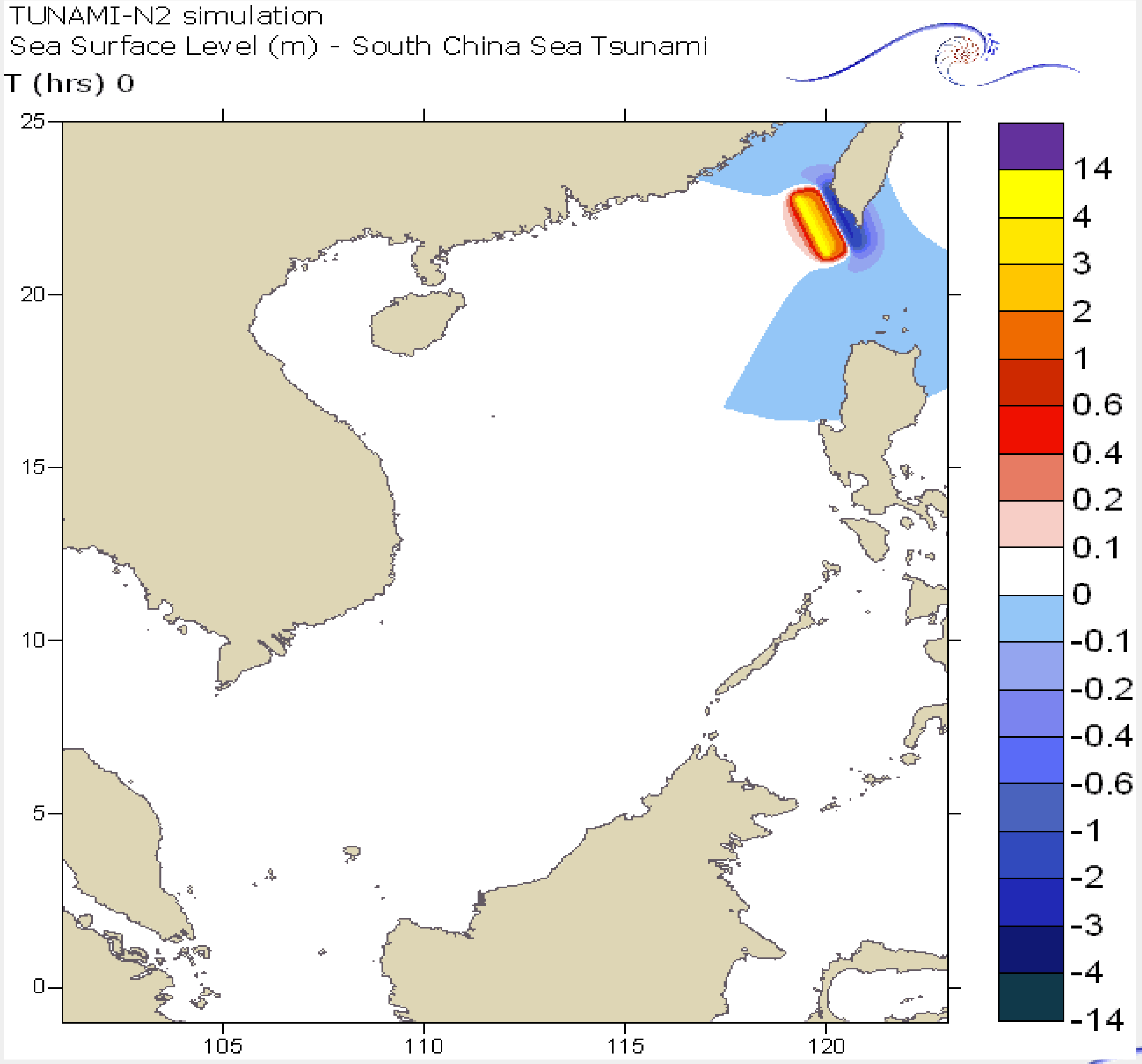
error

Maximum Wave Height (m)

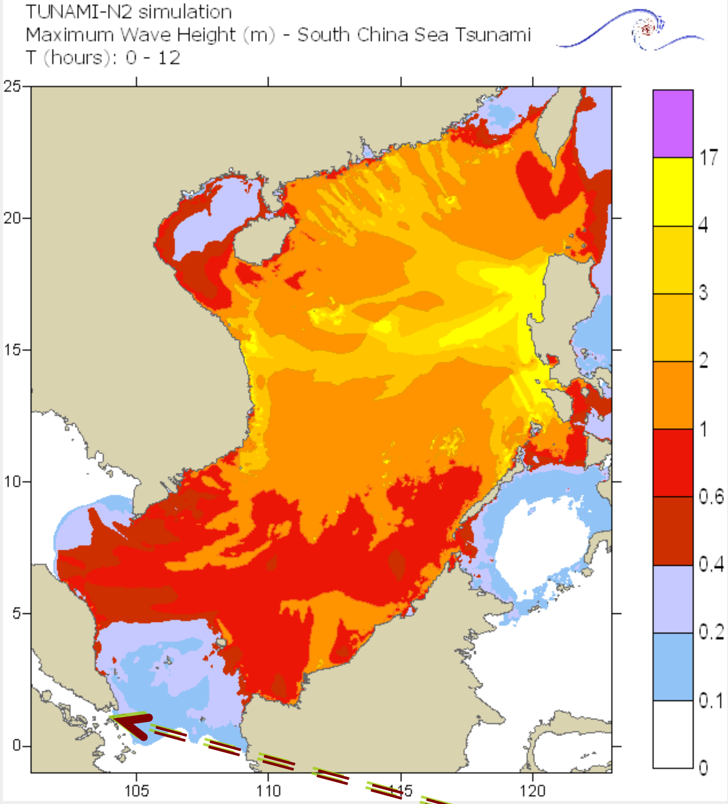
Earthquake occurs in Segments A, B & C – Scenario 117

Wave propagation, scenario A (NTU)

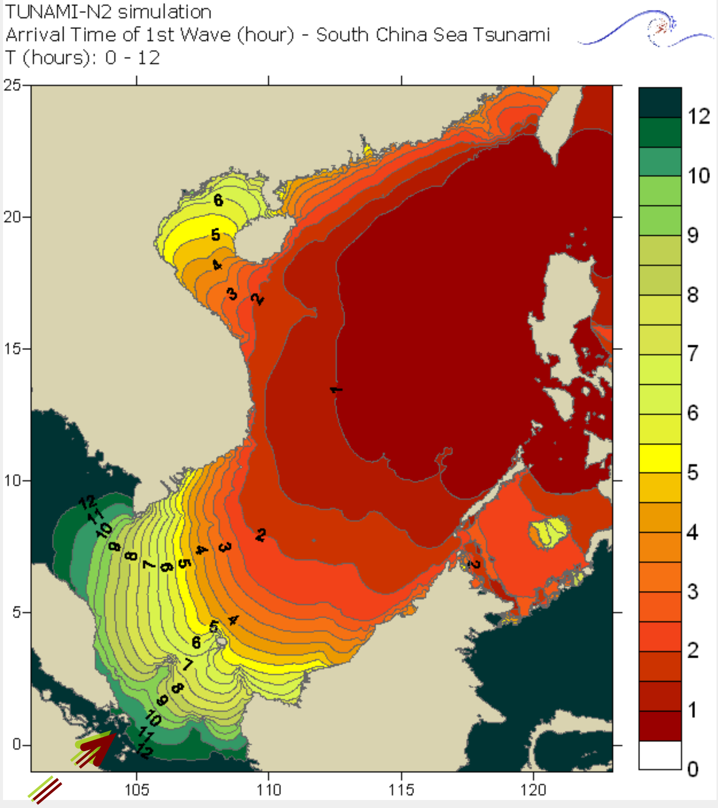




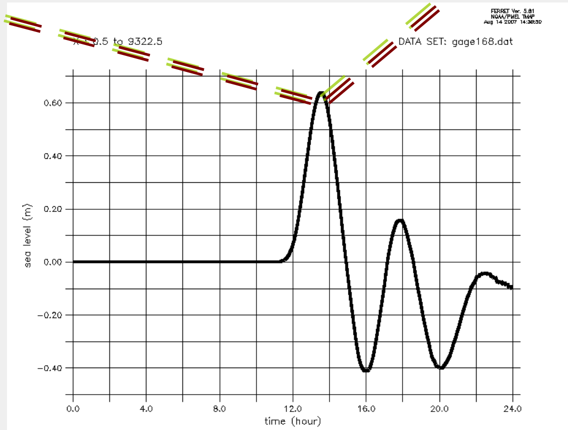
Max wave height & arrival time



TUNAMI-N2 simulation
Maximum Wave Height (m) - South China Sea Tsunami
T (hours): 0 - 12



TUNAMI-N2 simulation
Arrival Time of 1st Wave (hour) - South China Sea Tsunami
T (hours): 0 - 12

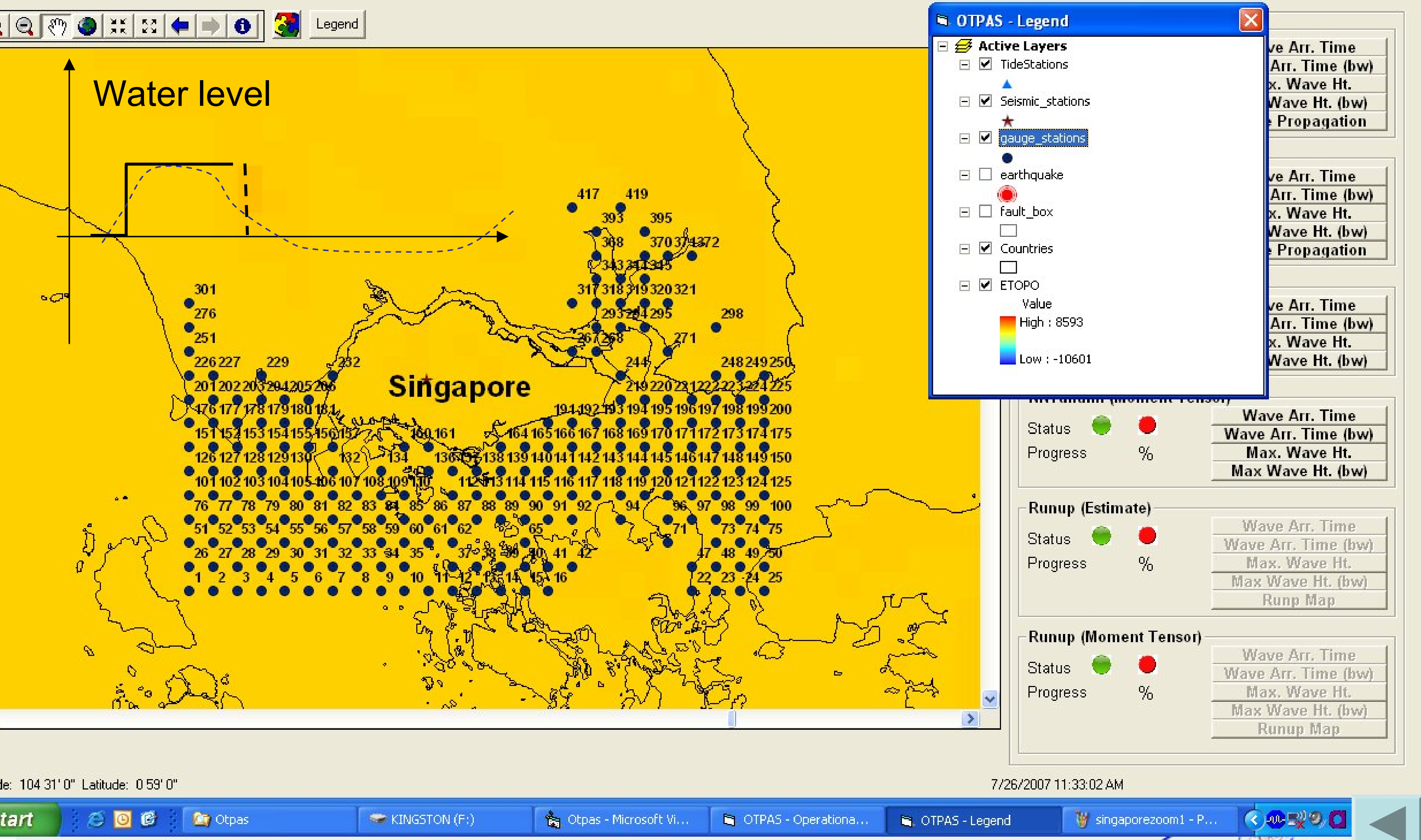


Sea level (m) at 104.010deg lon, 1.267deg lat (gage168)

Tropical Marine Science Institute

PROPAGATION → INUNDATION

OTPAS - Operational Tsunami Prediction and Assessment System



OTPAS - Legend

Active Layers
- ☑ TideStations ▲
- ☑ Seismic_stations ★
- ☑ gauge_stations ●
- ☐ earthquake ●
- ☐ fault_box ☐
- ☑ Countries ☐
- ☑ ETOPO
  - Value
  - High : 8593
  - Low : -10601

de: 104 31' 0" Latitude: 0 59' 0"

7/26/2007 11:33:02 AM

REDUCED-ORDER MODELS (DATA-DRIVEN)

PROPER ORTHOGONAL DECOMPOSITION METHOD

To formulate the reduced-order model, the output is represented as a linear combination of q basis vectors

$$y(x,t,\mathbf{w}) = \sum_{j=1}^{q} a_j(t,\mathbf{w})\phi_j(x)$$

The POD yields a data-driven basis that is using a set of solutions (snapshots) of an original high-performance numerical model or empirical data from any extensive data-base. In tsunami forecasting, snapshots can encode spatially-distributed sea surface elevation as a function of time.

TEST CASE. POD APPLICATION

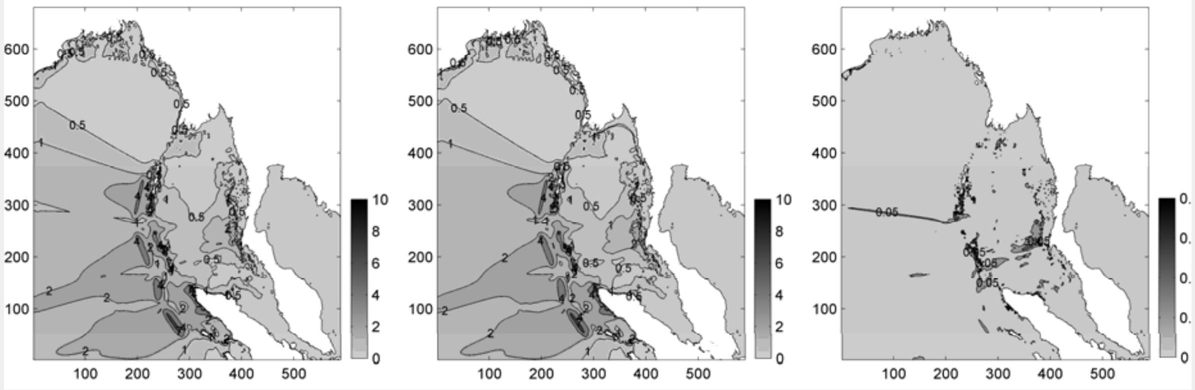


Figure 1. Maximum wave amplitude of scenario 5. Left: TUNAMI-N2; Middle: reduced-order model; Right: error. Color scale unit is meter. Horizontal and vertical axes represent grid numbers, grid-cell size is 2 minutes

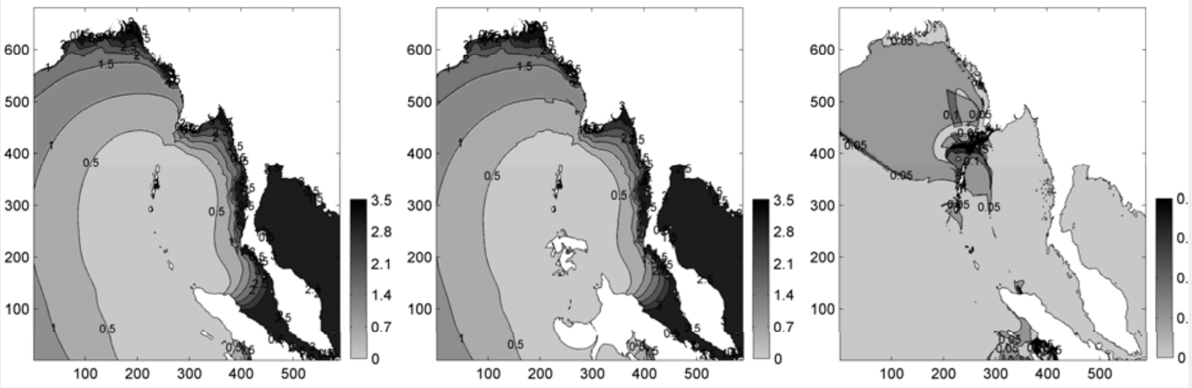


Figure 1. Travel time of scenario 5. Left: TUNAMI-N2; Middle: reduced-order model; Right: error. Color scale unit is hour. Horizontal and vertical axes represent grid numbers, grid-cell size is 2 minutes

BUOYS: DATA SOURCE AND WARNING TRIGGER

Proper Orthogonal Decomposition Method (POD)

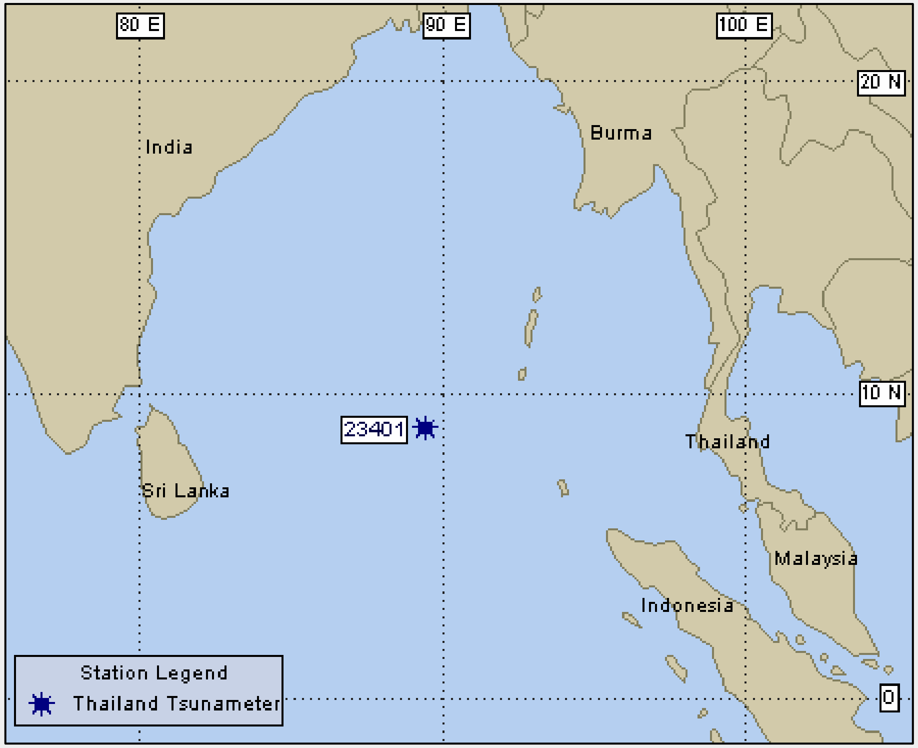
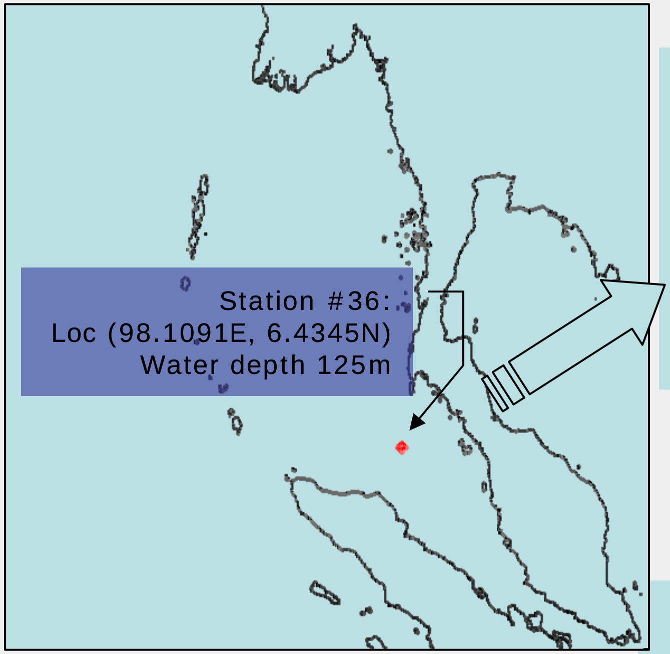


Figure . Station "23401" - 600 NM West-Northwest of Phuket, Thailand.

BUOYS: DATA SOURCE AND WARNING TRIGGER

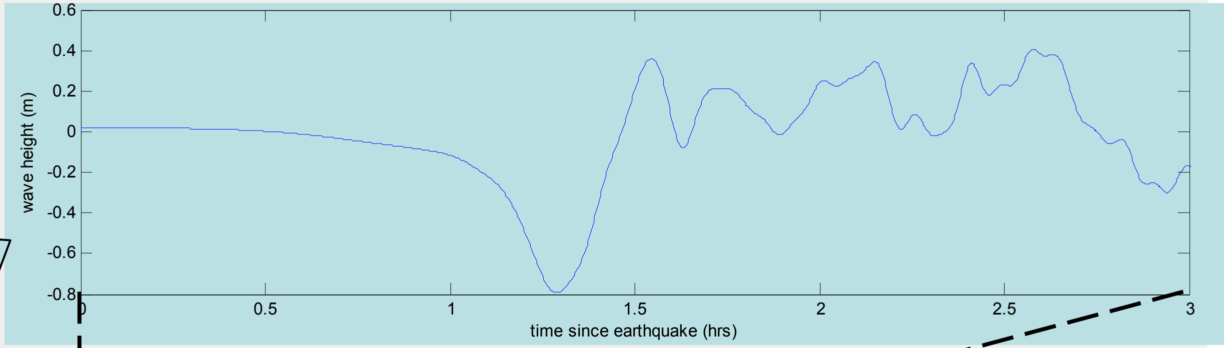
Proper Orthogonal Decomposition Method (POD)

Wave record at a fictitious station #36

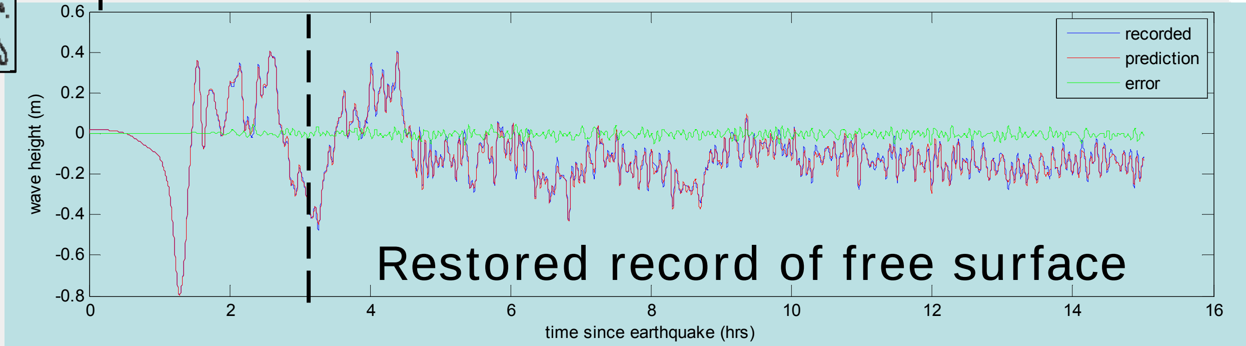


Station #36:
Loc (98.1091E, 6.4345N)
Water depth 125m

“Actual” record of free surface



Predicted wave height at station #36 by POD



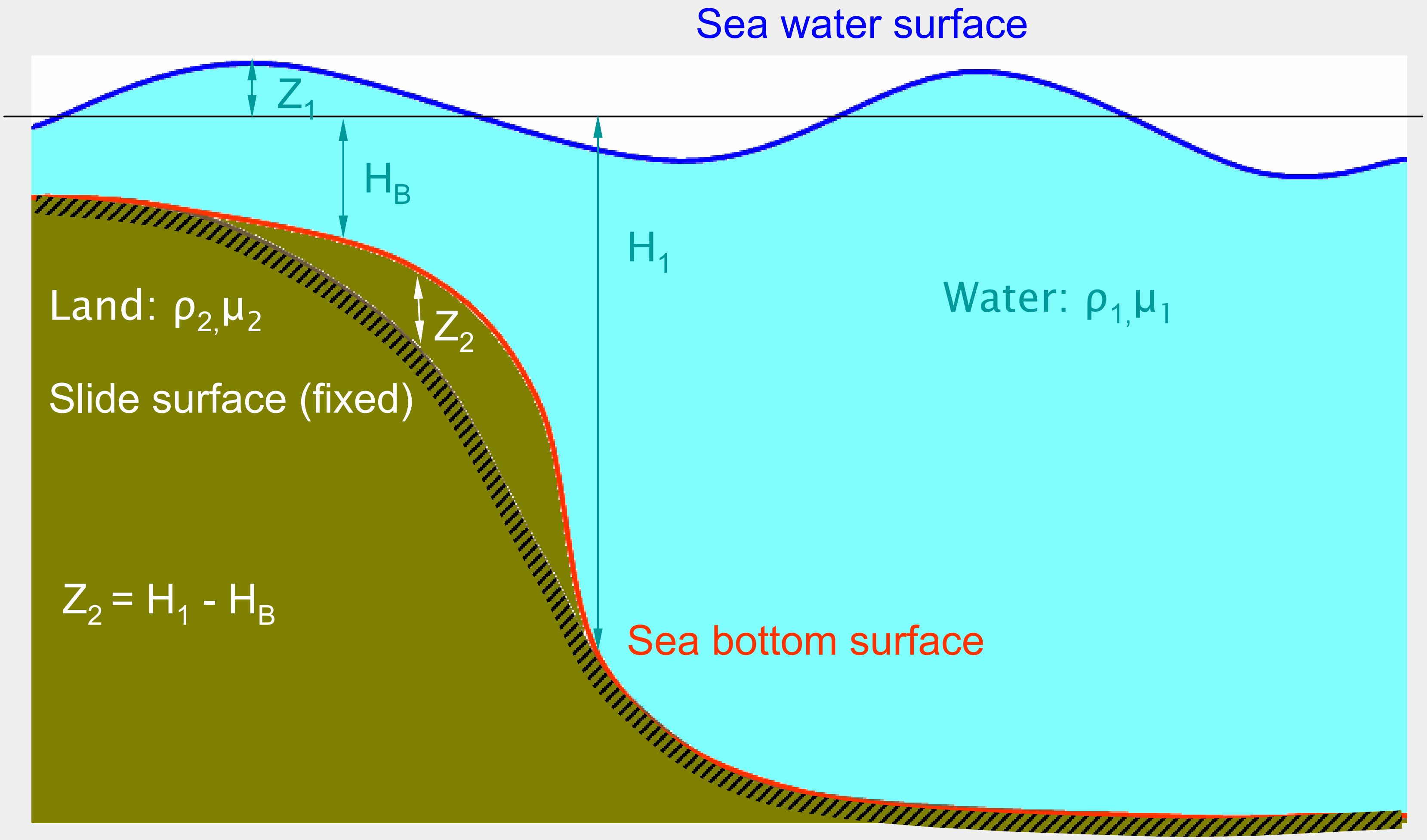
Restored record of free surface

LANDSLIDES AS TSUNAMI SOURCES

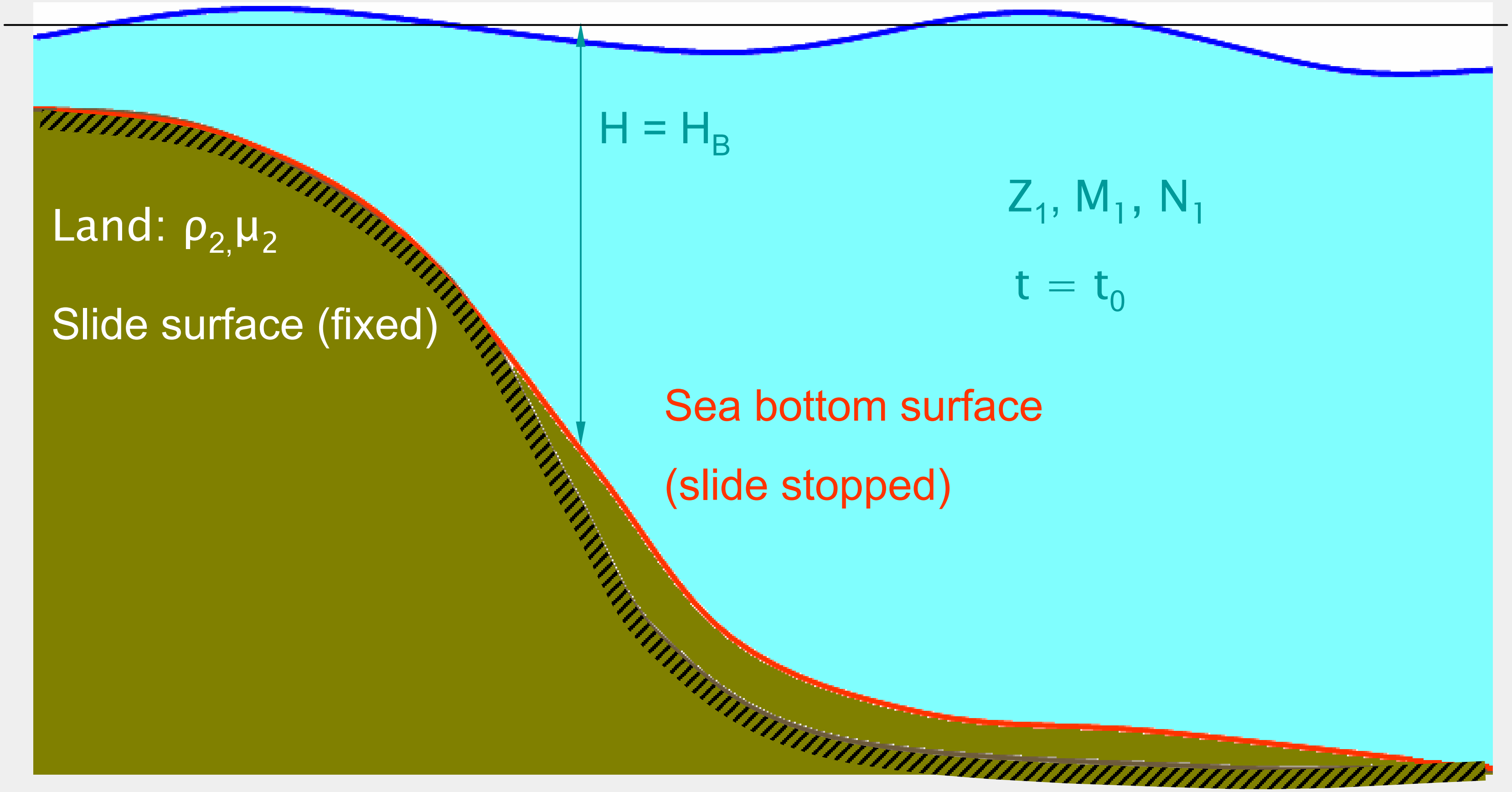
NTU: estimation of landslide parameters

NUS: computation of tsunami using two-layer model

TWO-LAYER formulation



TWO-LAYER formulation



Sea water surface

$H = H_B$

Z_1, M_1, N_1

$t = t_0$

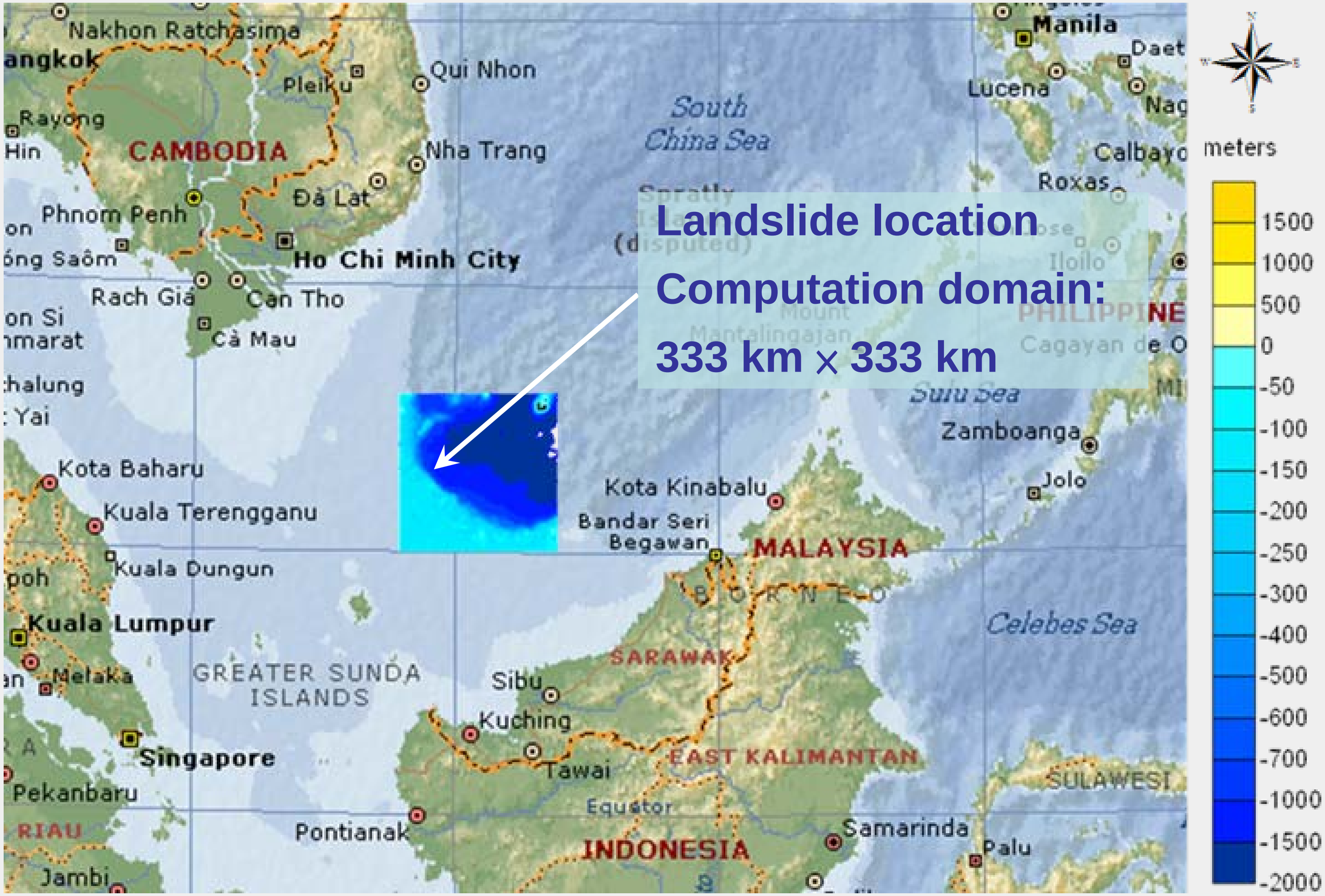
Land: $\rho_{2,} \mu_2$

Slide surface (fixed)

Sea bottom surface

(slide stopped)

Computation domain for TWO-LAYER



Landslide location

Computation domain:

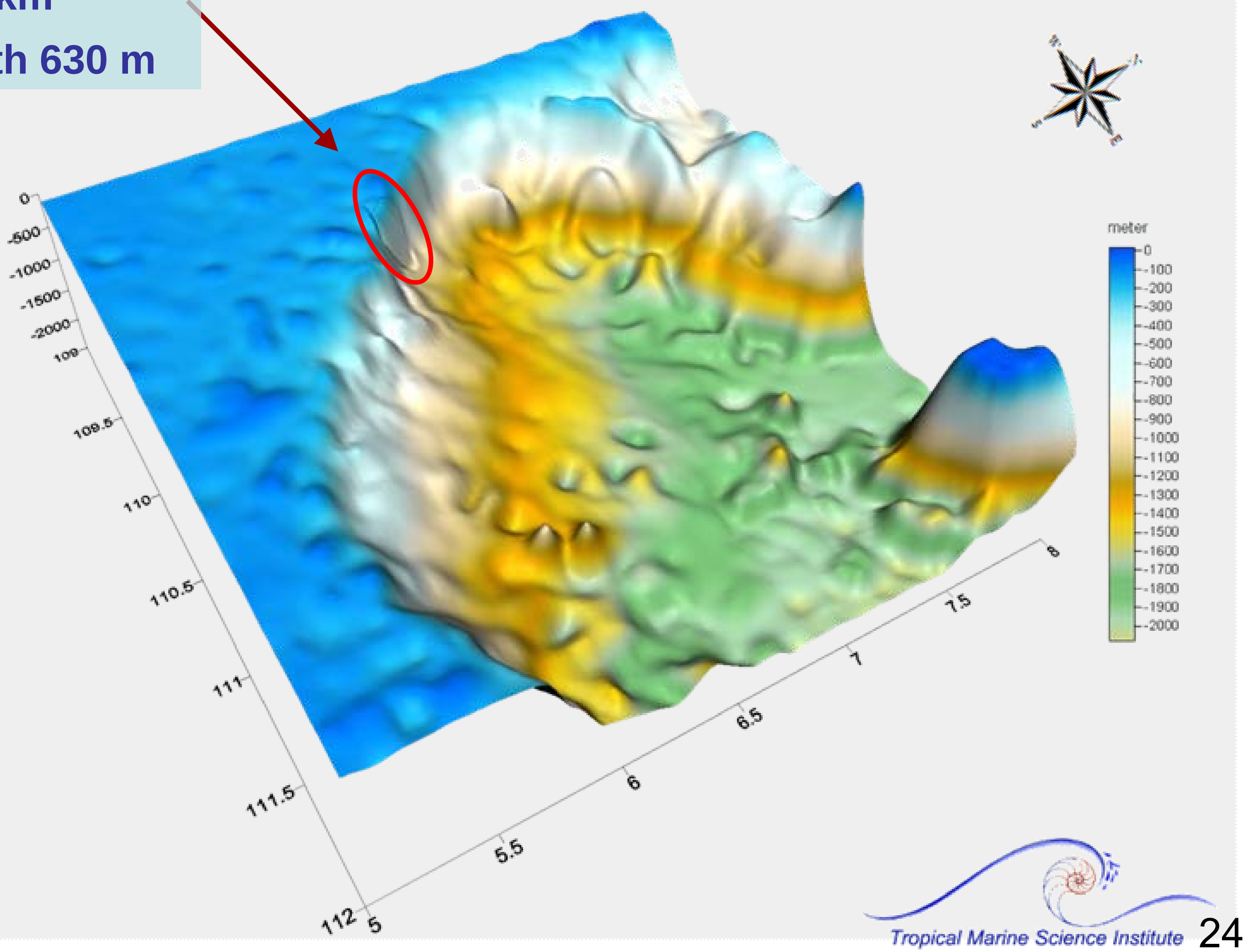
333 km × 333 km

Bathymetry and landslide source (by NTU)

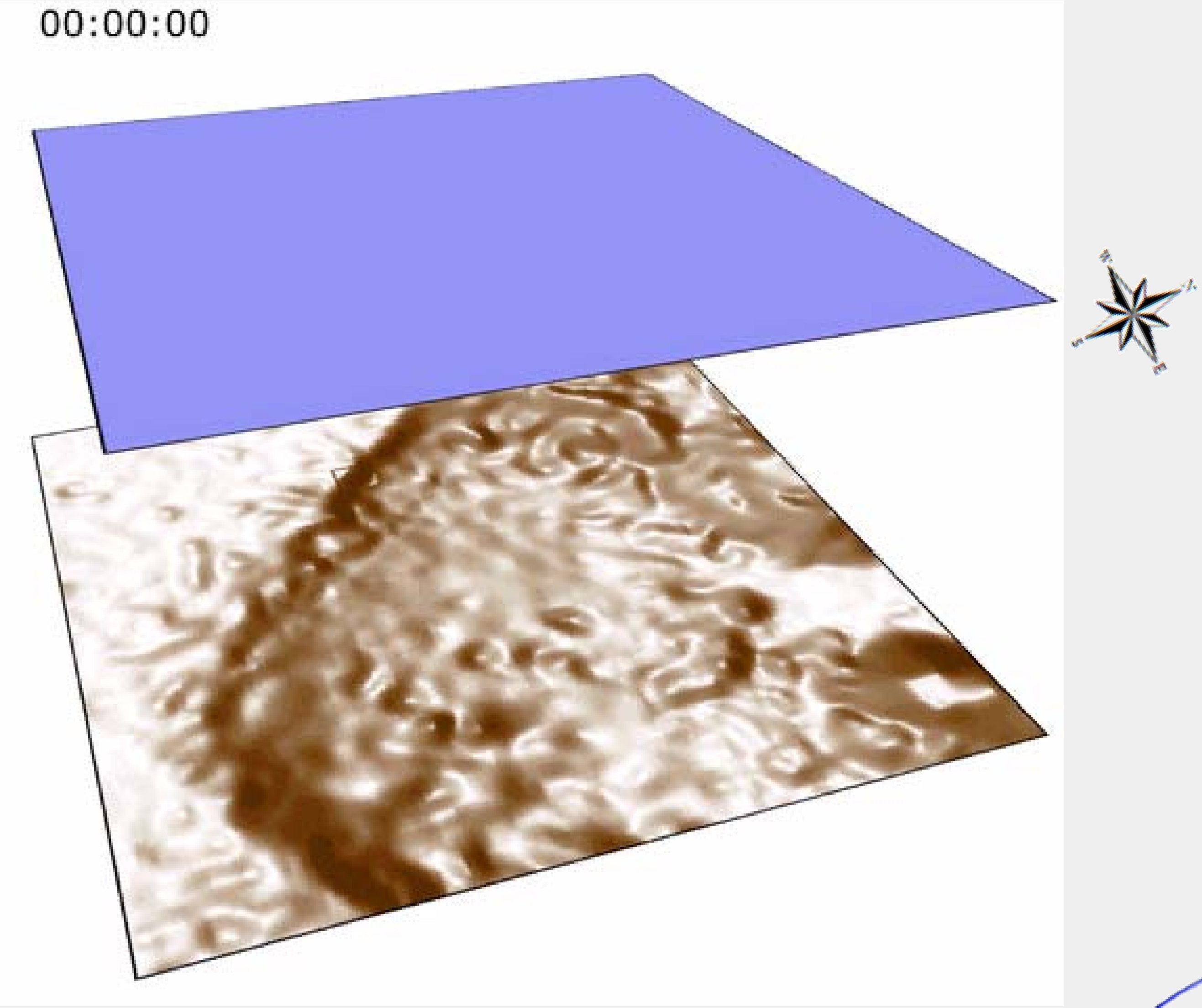
Landslide source (NTU)

Size: 10 km × 10 km

Max vertical depth 630 m



Result by TWO-LAYER model



SOME PUBLICATIONS ON TSUNAMI PROPAGATION AND FORECASTING

- TKALICH, DAO and CHAN (2007) “Tsunami propagation modeling and forecasting for early warning system”, Journal of Earthquake and Tsunami, Vol. 1, No. 1, pp.87–98
- DAO and TKALICH (2007) “Tsunami propagation modelling – a sensitivity study”, Nat. Hazards Earth Syst. Sci., 7, pp. 741–754
- TKALICH, DAO and CHAN (2007) “Tsunami Forecasting Using Proper Orthogonal Decomposition Method”, Journal of Geophysical Research – Oceans, submitted

Thank you