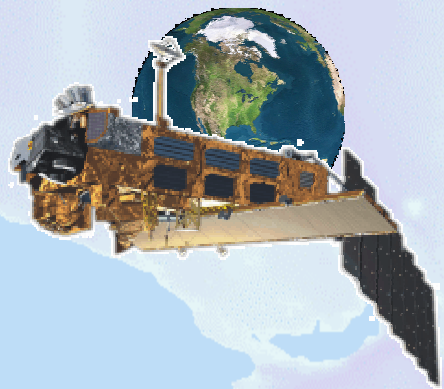
The 26 December 2004 Sumatra earthquake and the tsunami seen by satellite altimeters and GPS

Research in the scope of the 'South East Asia: Mastering Environmental Research with GEodetic Space techniques' (SEAMERGES) project

An ASEAN-EU University Network Programme (AUNP) project



SEAMERGES partners:

Delft University of Technology (DUT), Delft, Netherlands

Ecole Normale Superieure (ENS), Paris, France

Chulalongkorn University (Chula), Bangkok, Thailand

Universiti Teknologi Malaysai (UTM), Kuala Lumpur, Malaysia

Institut Teknologi Bandung (ITB), Bandung, Indonesia

Presented by: Boudewijn Ambrosius, on behalf of Ernst Schrama, Wim Simons, Christophe Vigny Remko Scharroo, Walter Smith and Vasily Titov

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Introduction: DEOS

- DEOS: *Delft institute for Earth Observation and Space Systems*
- DEOS is highly specialized in the application of space observation techniques to study the physics of the Earth and other planets and moons
- The expertise is focussed on satellite missions, which require extremely precise knowledge of the satellite trajectory
- Examples are the Global Positioning System (GPS), Radar Altimetry (RA) satellites and gravity field missions (Champ, Grace and Goce)
- Applications include deformation of the Earth's crust due to tectonic processes and sea-level changes and variability
- DEOS has been involved in GPS studies of Southeast Asia since 1993
- DEOS has developed and maintains the satellite Radar Altimeter Database System (RADS)
- DEOS has acquired unique data of the 26 December 2004 earthquake and tsunami from GPS and RA

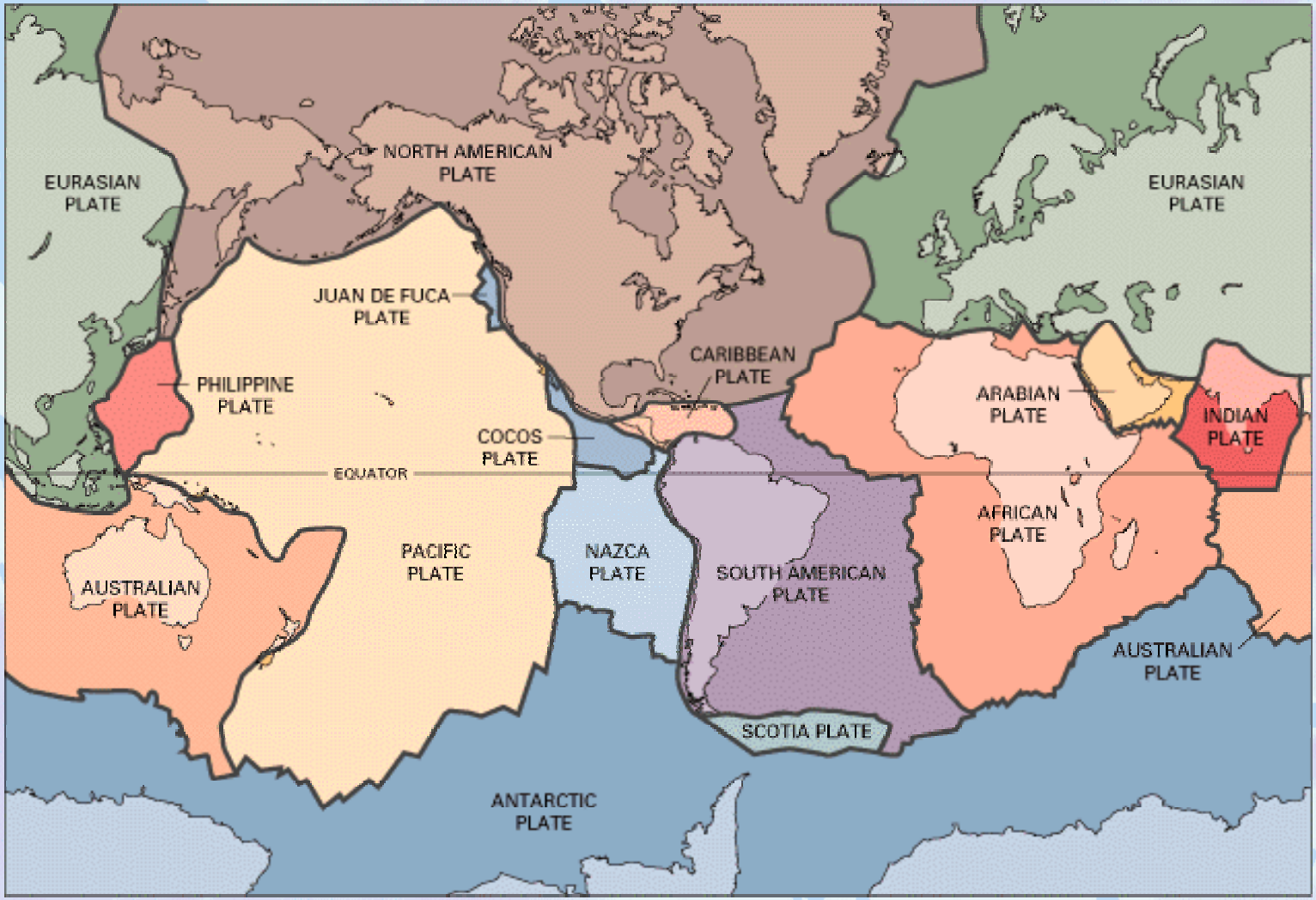
Introduction: SEAMERGES

- SEAMERGES: *South-East Asia: Mastering Environmental Research with GEodetic Space techniques*
- Project in the ASEAN-EU University Network programme (AUNP) of the European Committee (EC)
- Started 1 January 2004 and will run for two years
- University and research groups from the Netherlands, France, Indonesia, Malaysia and Thailand
- Seminars on the applications of the Global Positioning System (GPS), Interferometric SAR (InSAR) and Satellite radar ALTimetry (SALT)
- Exchange knowledge, methods and data for cooperative research projects targeted at the South-East Asian region

What is Crustal Motion?

- Earth's crust is made up of more than 20 tectonic plates
- Plates 'float' on the 'fluid' interior of the Earth
- Plates are moving relative to each other for millions of years
- Relative velocities range up to 10 cm/yr at plate boundaries
- Plates are continuously (re)shaping the Earth's exterior
- Geodynamic processes occur when plates converge/collide:
  - Earthquakes
  - Volcanic eruptions
  - Tectonically induced landslides
  - Tsunamis

Global plate tectonics



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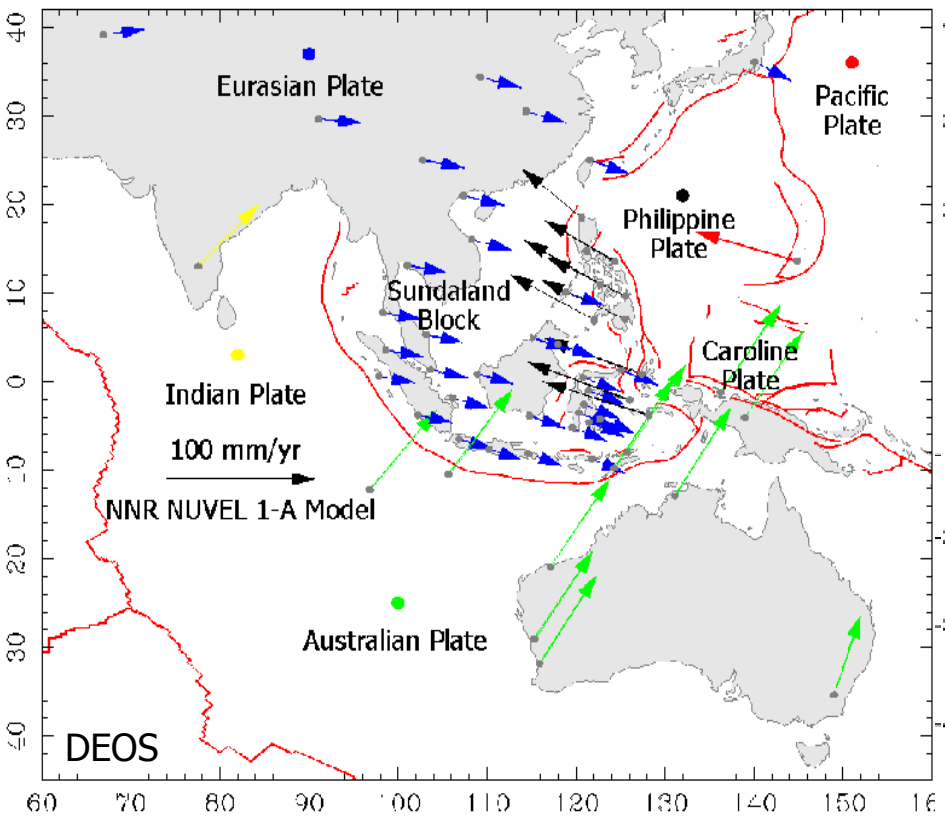
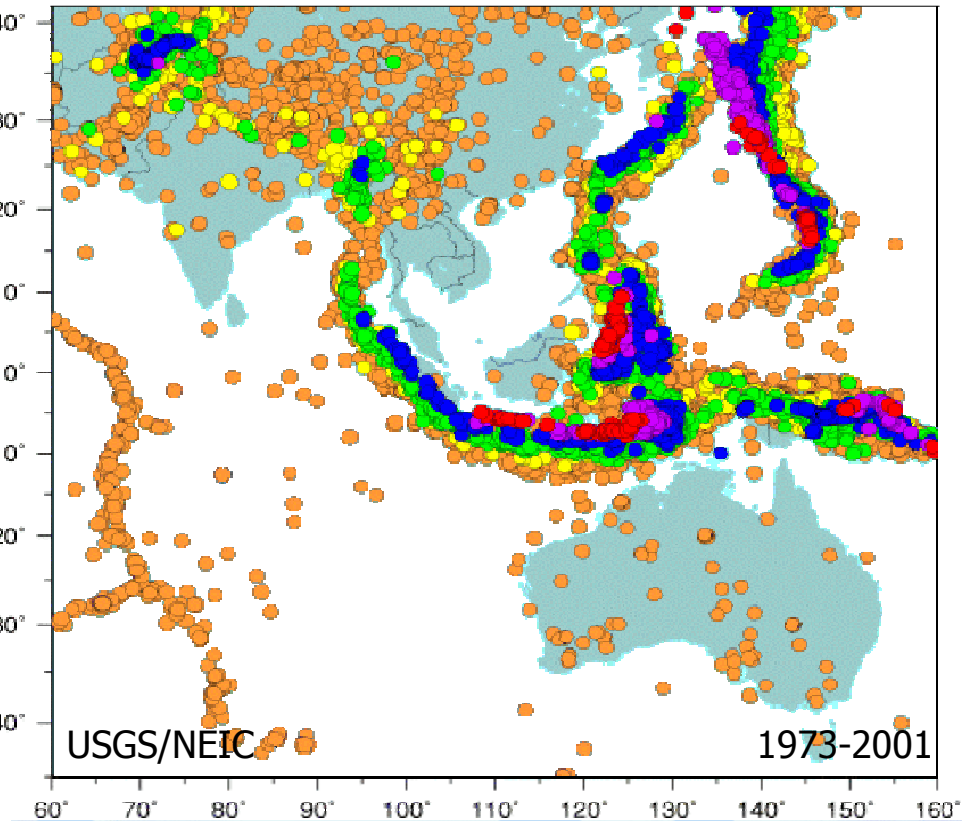
Tectonic Setting of SE Asia

Predicted Tectonic Plate Motions



Distribution of Earthquakes (Mw ≥ 5)



Convergence of Indian, Australian, Philippine and Sundaland plates

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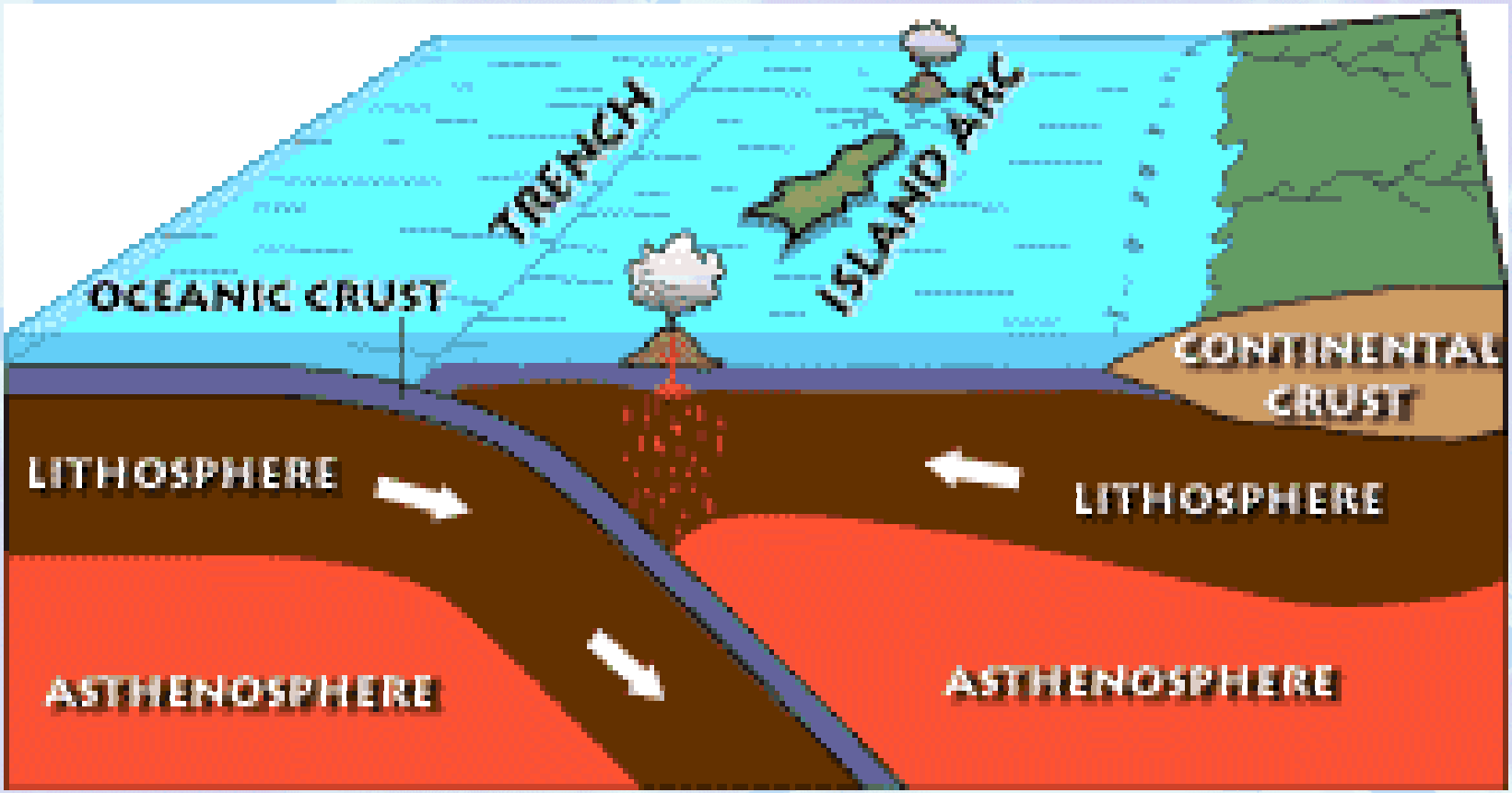
Subduction



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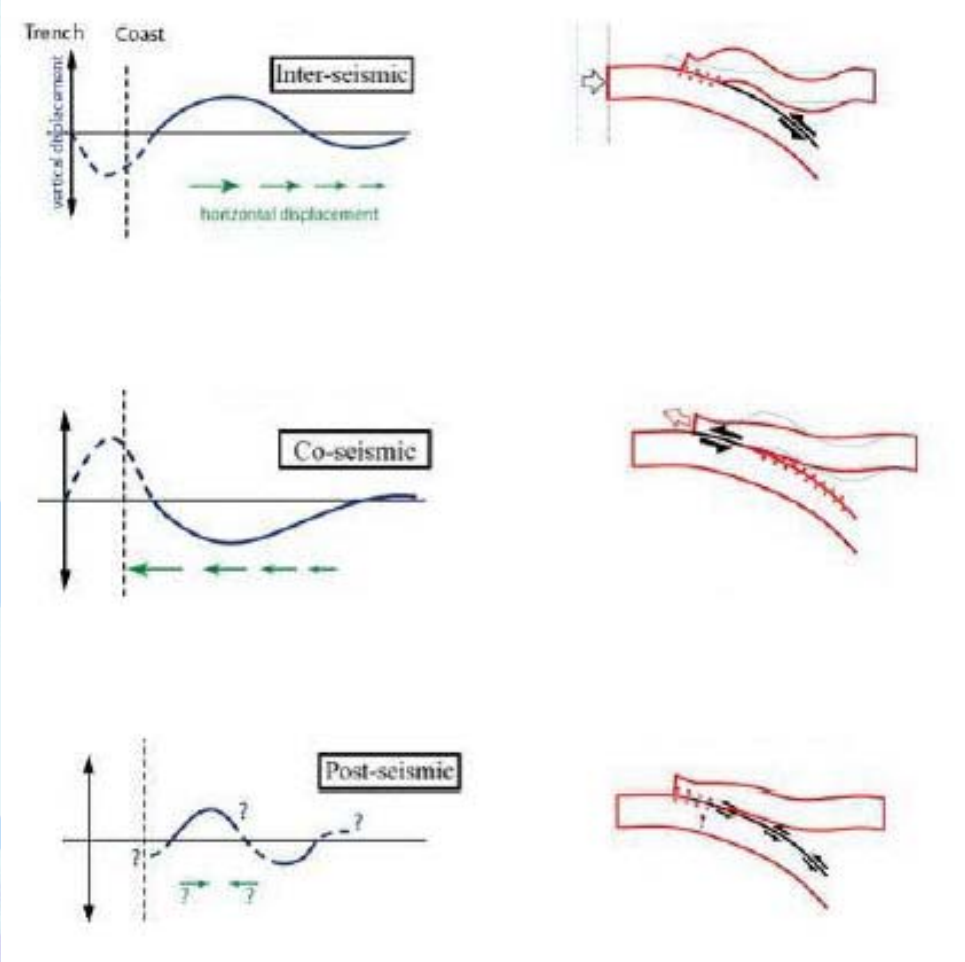
The subduction earthquake cycle



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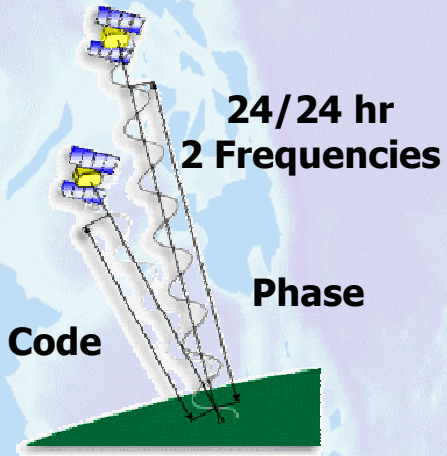
GPS for Geodynamic Studies

GPS (24+) Constellation

GPS Signals Transmitted



Geodetic GPS Receivers

- Measure stable GPS points continuously or in campaign style
- Use scientific high-precision GPS software (GIPSY, GAMIT,…)
- Compute (daily) positions with **millimetre** accuracy
- Temporal position changes indicate displacements or velocities

Setting up a GPS campaign station

The DEOS permanent GPS station at Nanyang Technical University in Singapore (NTUS)

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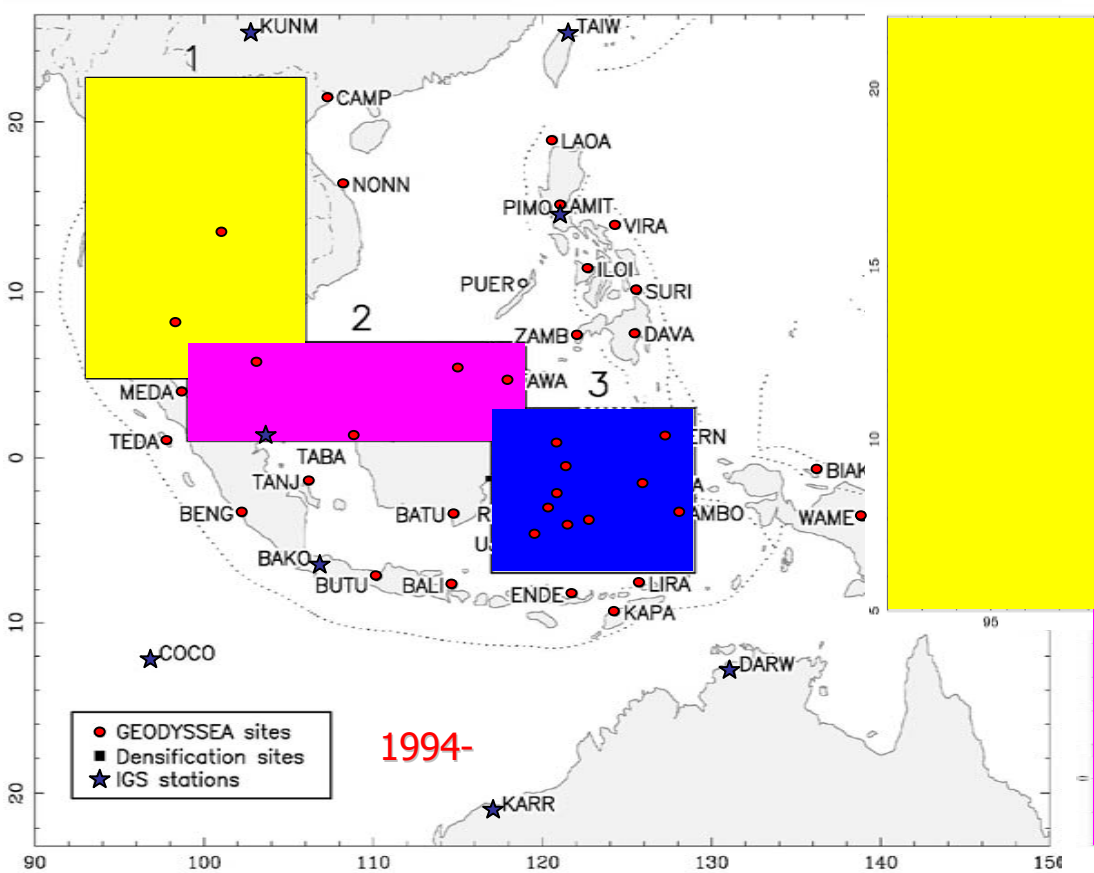
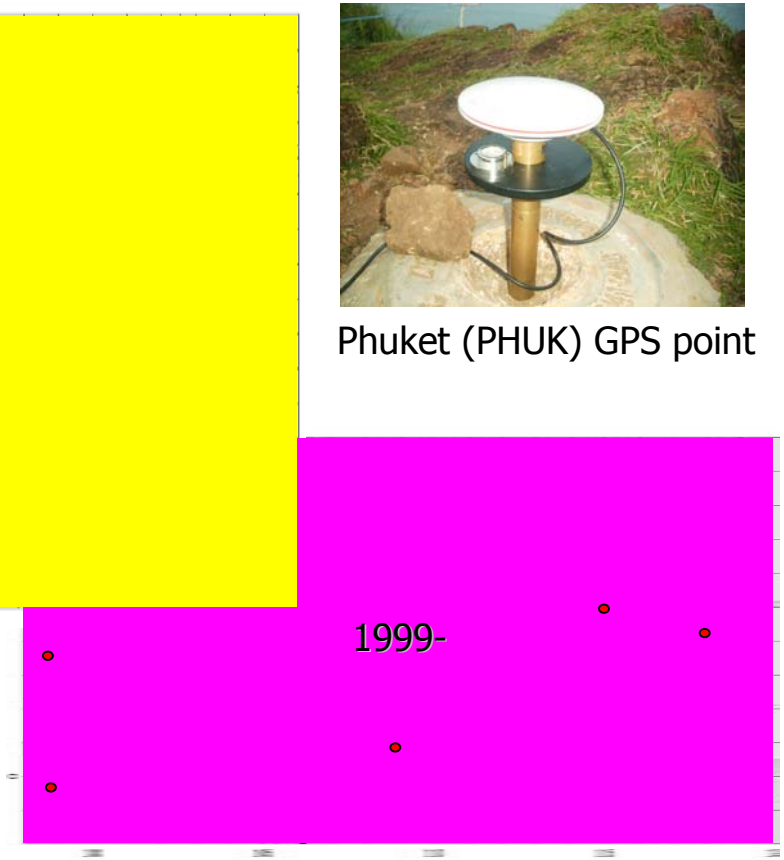
Original aim of the GPS Measurements in S.E. Asia

1) Define the (absolute) motion of the Sundaland block
   - Covers most of S.E. Asia, moving at 2.5-3.5 cm/yr
   - Remeasure/expand EU-ASEAN GEODYSSEA network
   - Include (high-quality) ASEAN GPS networks
2) Define the deformation zones and Sundaland boundaries
   - Regions that move different than 'rigid' Sundaland
   - Remove the absolute motion from the GPS velocities
3) Study specific natural hazard areas in S.E. Asia
   - Monitor (near real-time) behaviour of tectonic faults
   - Earthquake related pre-/co-/post-seismic motions

Geodetic GPS Network in S.E. Asia



Phuket (PHUK) GPS point



GPS network size in S.E. Asia: 100+ points (2003)

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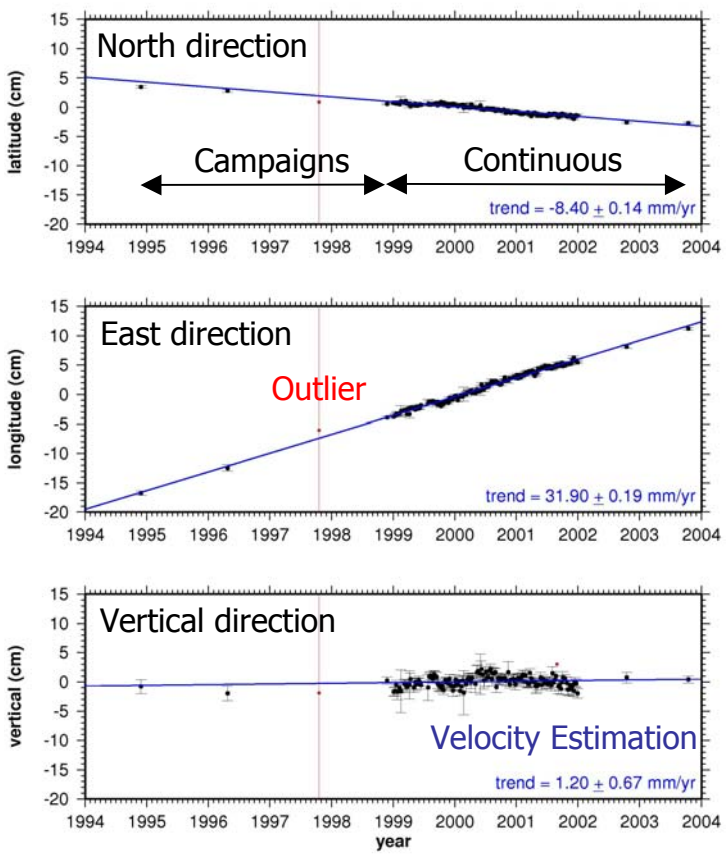
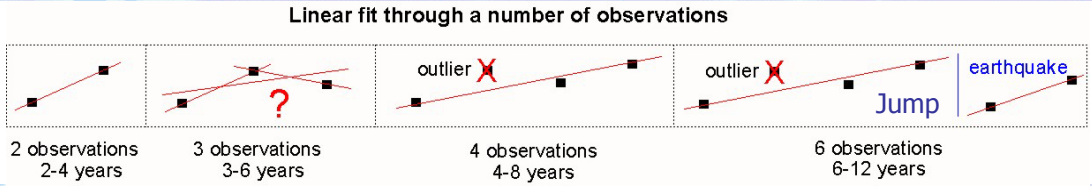
GPS Position Time Series

GPS point KUAL, Malaysia



Changes in time of (averaged) 3-D positions

Constructing time series from GPS campaigns



Overview GPS activities

1994-present

- GPS measurements EU-ASEAN partners
- Update GPS database S.E. Asia
- Merge all EU-ASEAN GPS data
- Include data global (IGS) GPS network
- High-precision (daily) network positions
- Map in global (ITRF) reference frame
- Estimate yearly position changes
- Update kinematical model S.E. Asia

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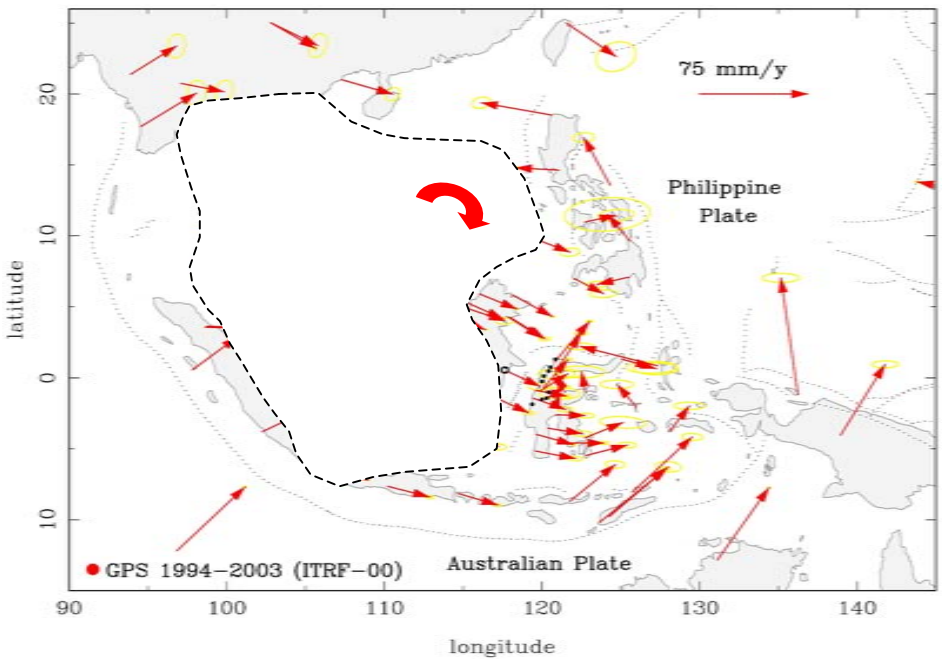
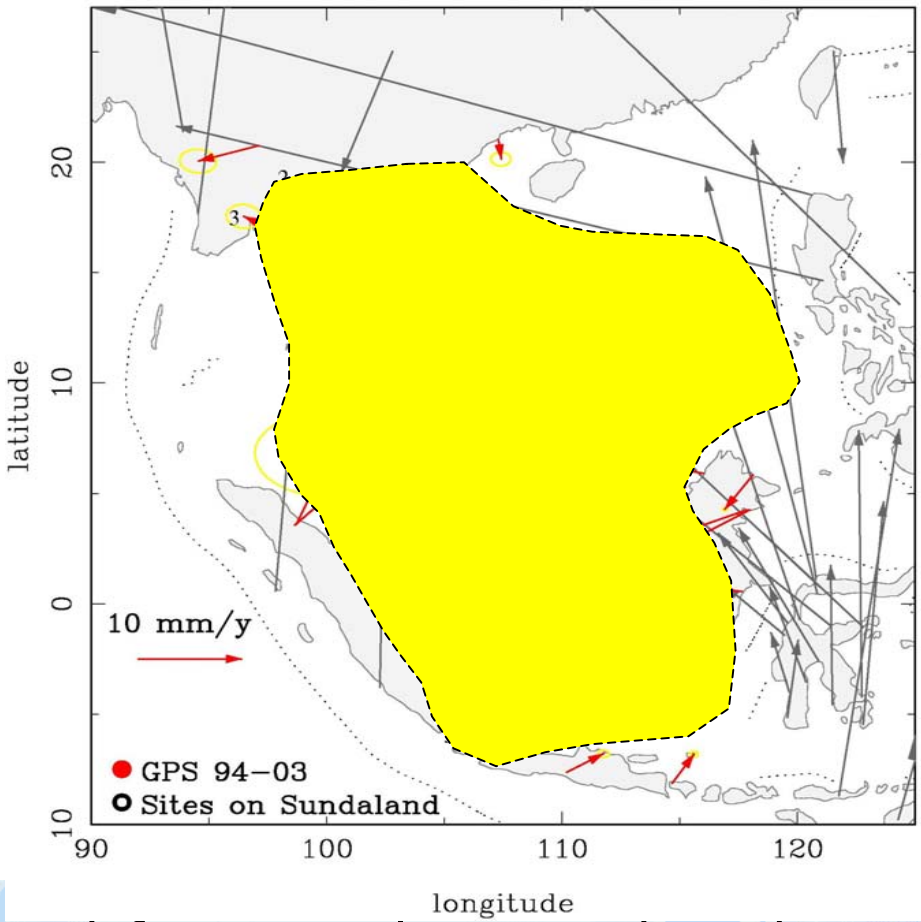
Sundaland Motion and Deformation from GPS

GPS Velocities S.E. Asia (1994-2003)
Global Reference Frame (ITRF-2000)



------- : boundaries stable 'rigid' Sundaland block



- Sundaland has rigid core, but significant deformation close to its boundaries

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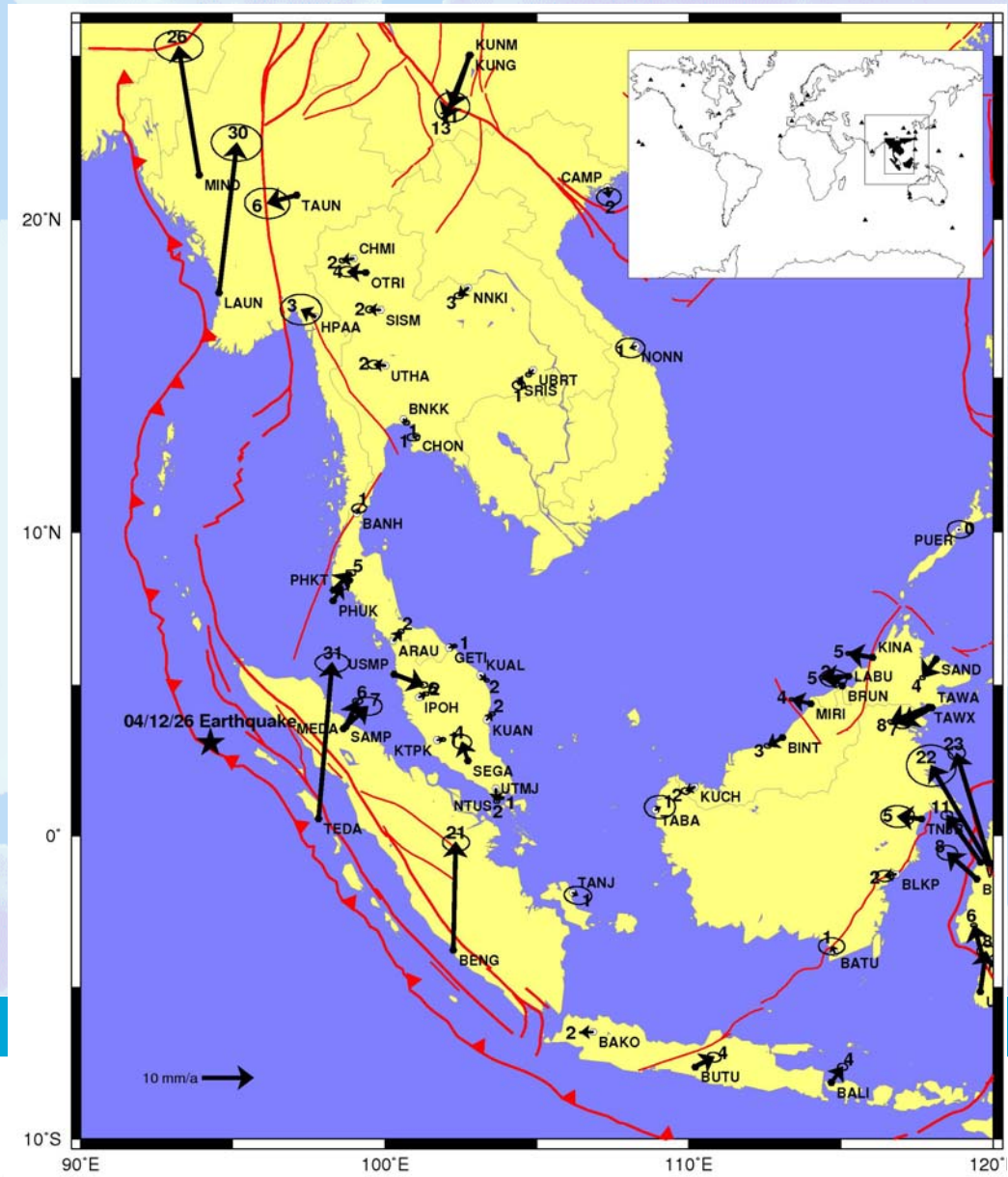
Sundaland deformation before the earthquake



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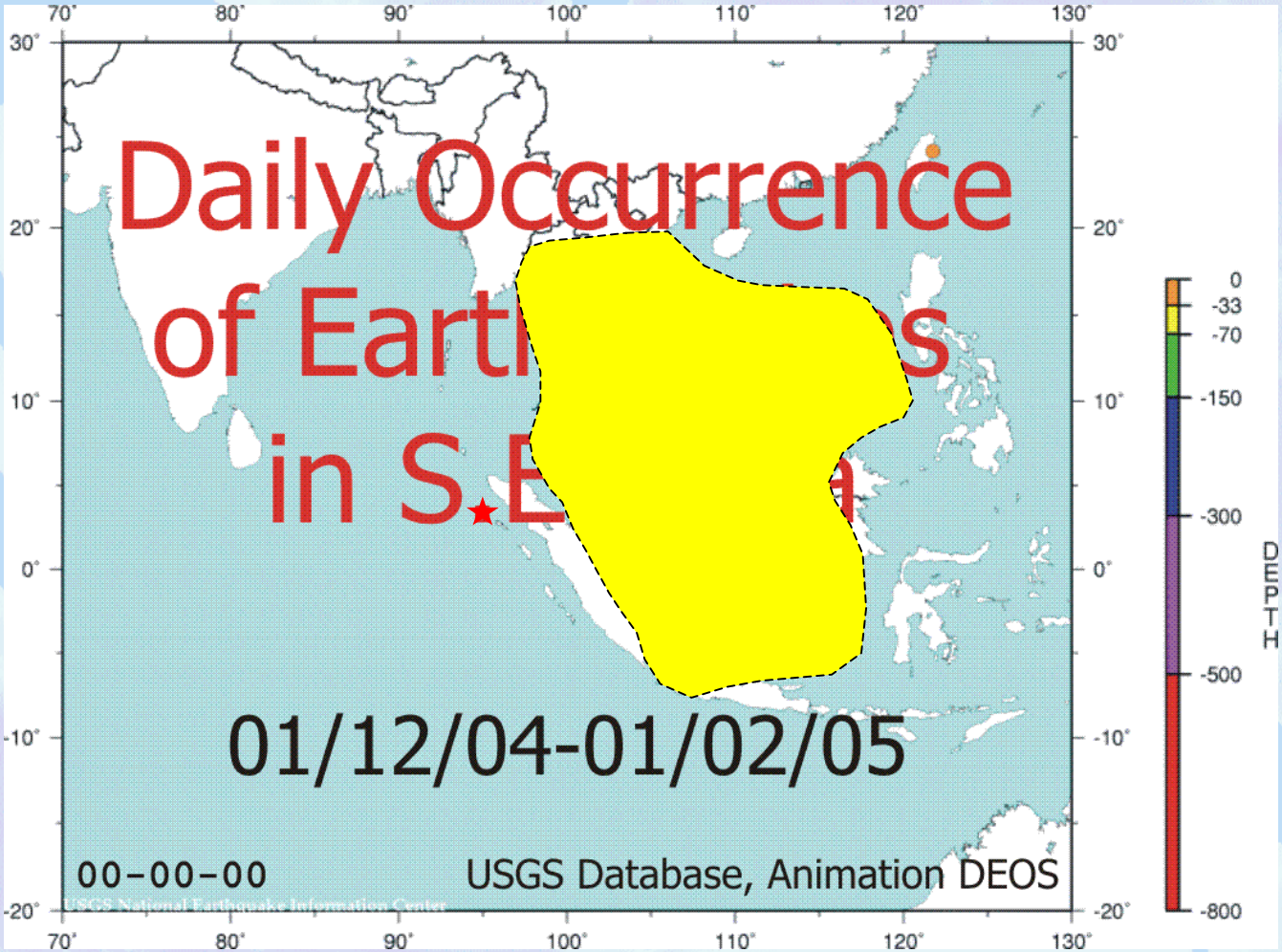
Daily occurrence of earthquakes in SE Asia



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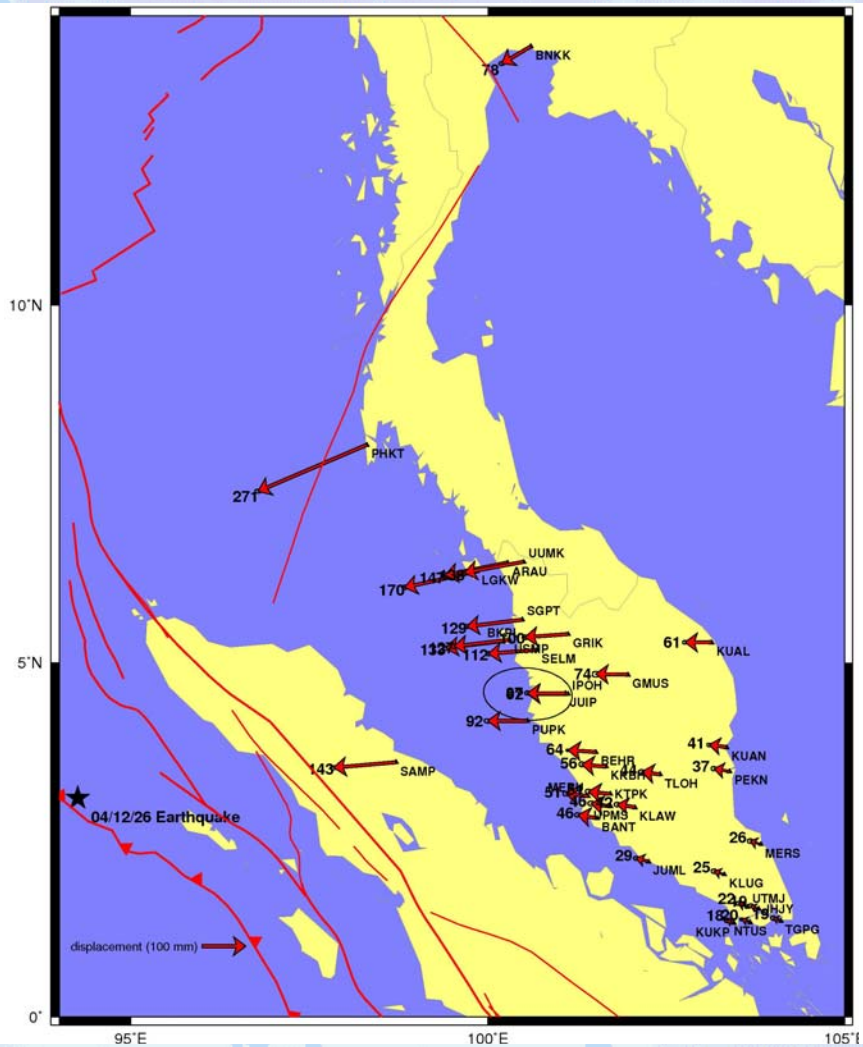
Co-seismic displacements from GPS

- Permanent GPS data:
  - Thailand (4)
  - Malaysia (36)
  - Indonesia (5)
  - Singapore (1)
  - Other countries (9)
  - Outside region (21)

- Unique solution:
  - 14 days pre-/post-quake
  - Combined solution
  - Global reference frame
  - Accuracy ± 2 mm
  - Input earthquake model



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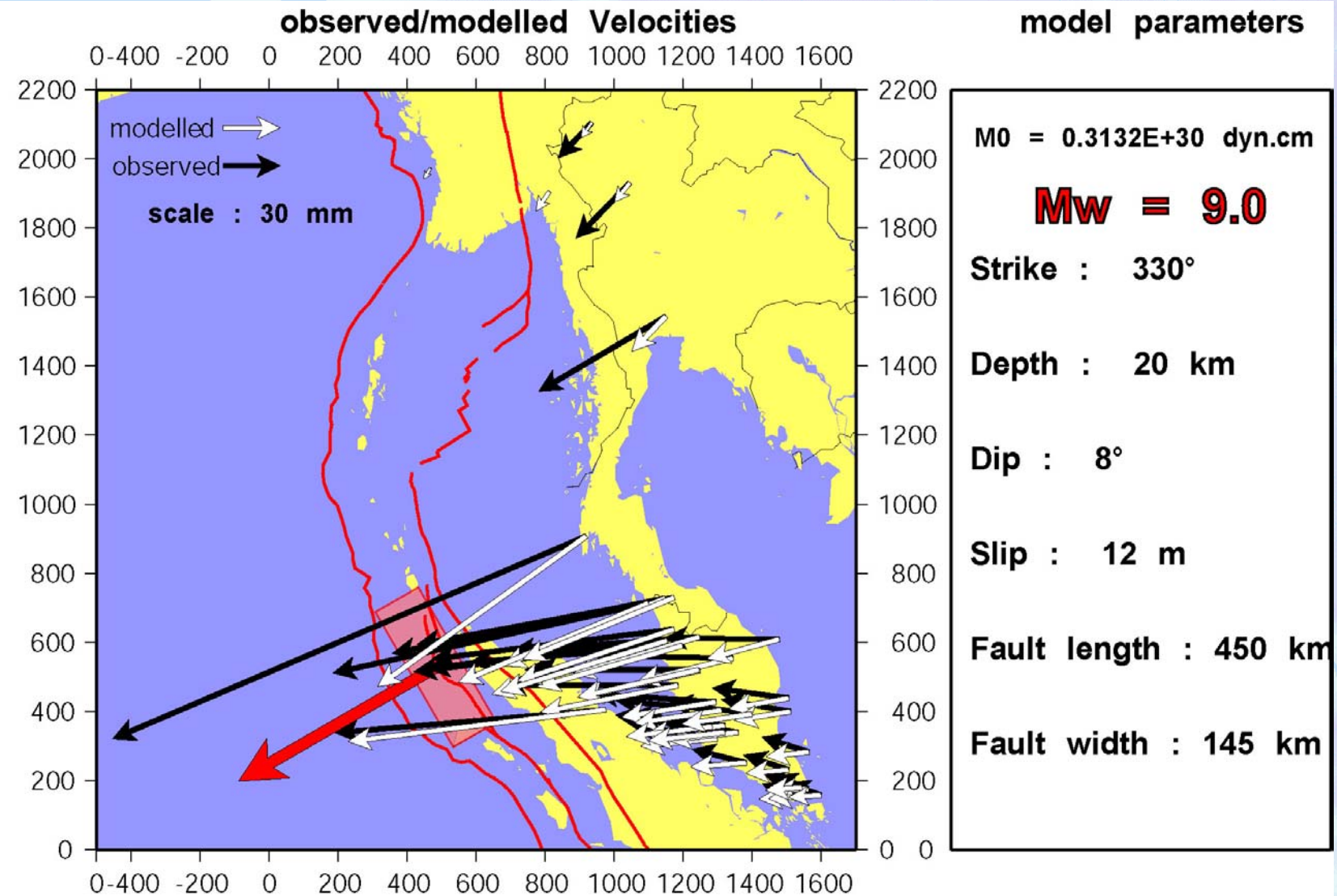

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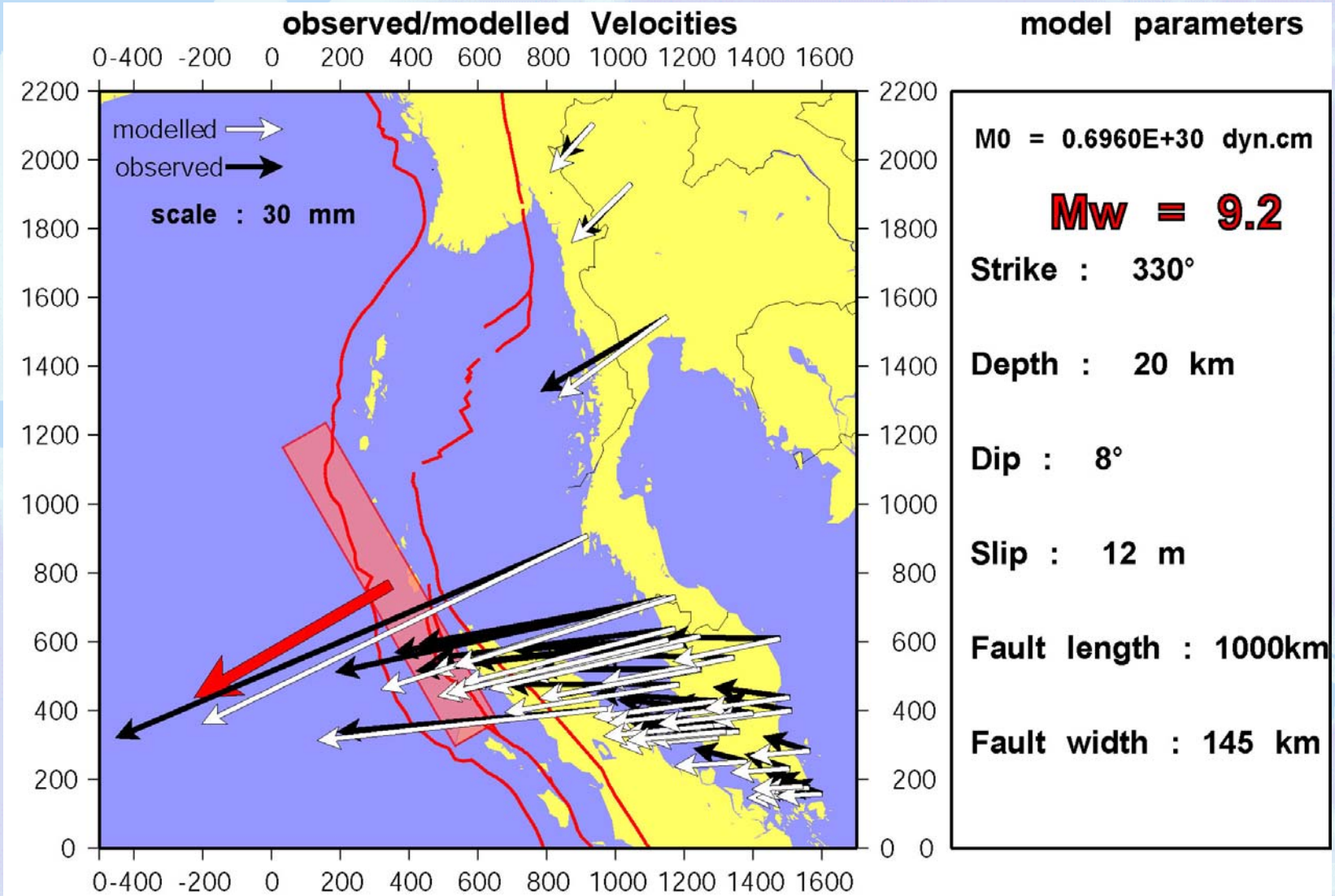

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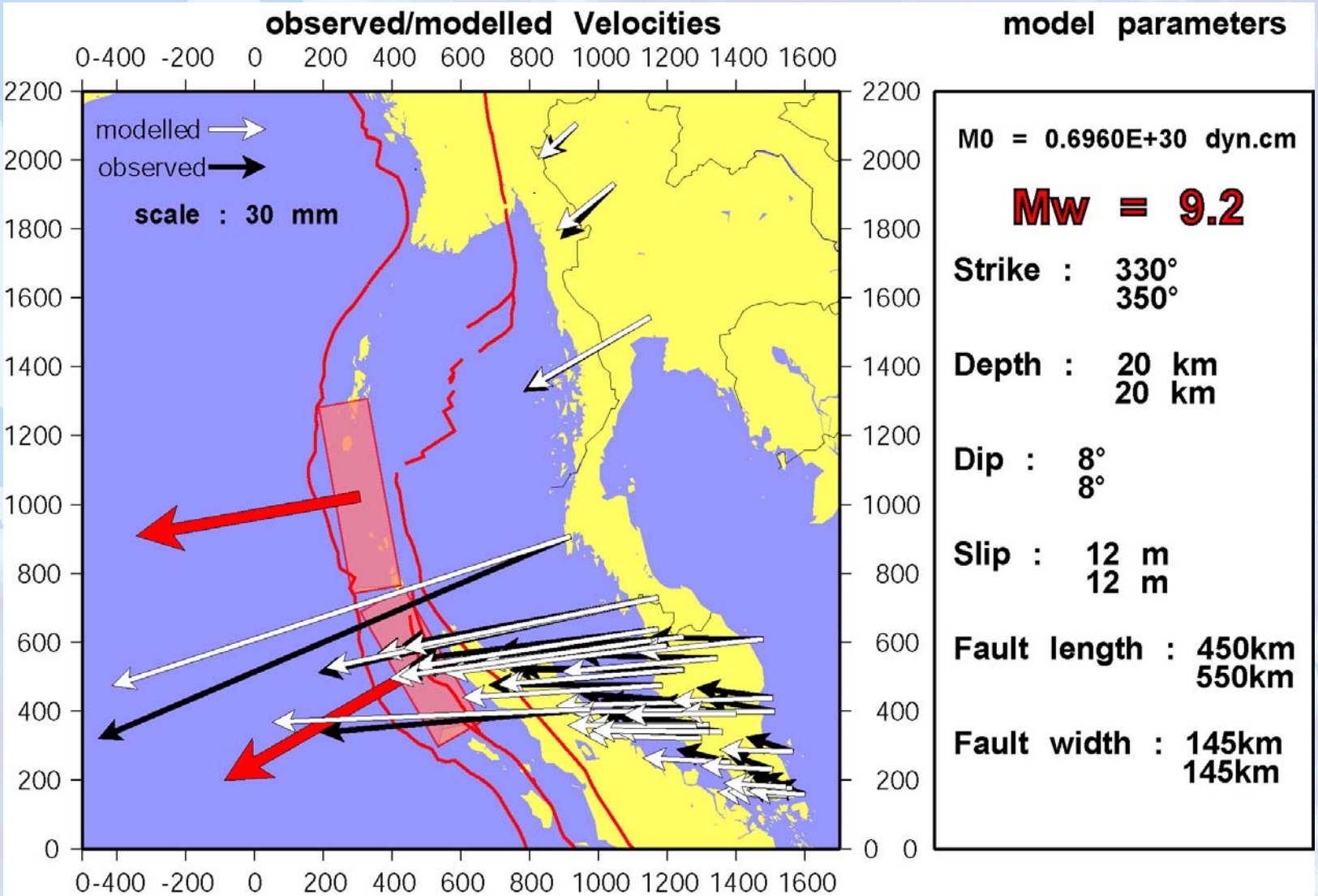

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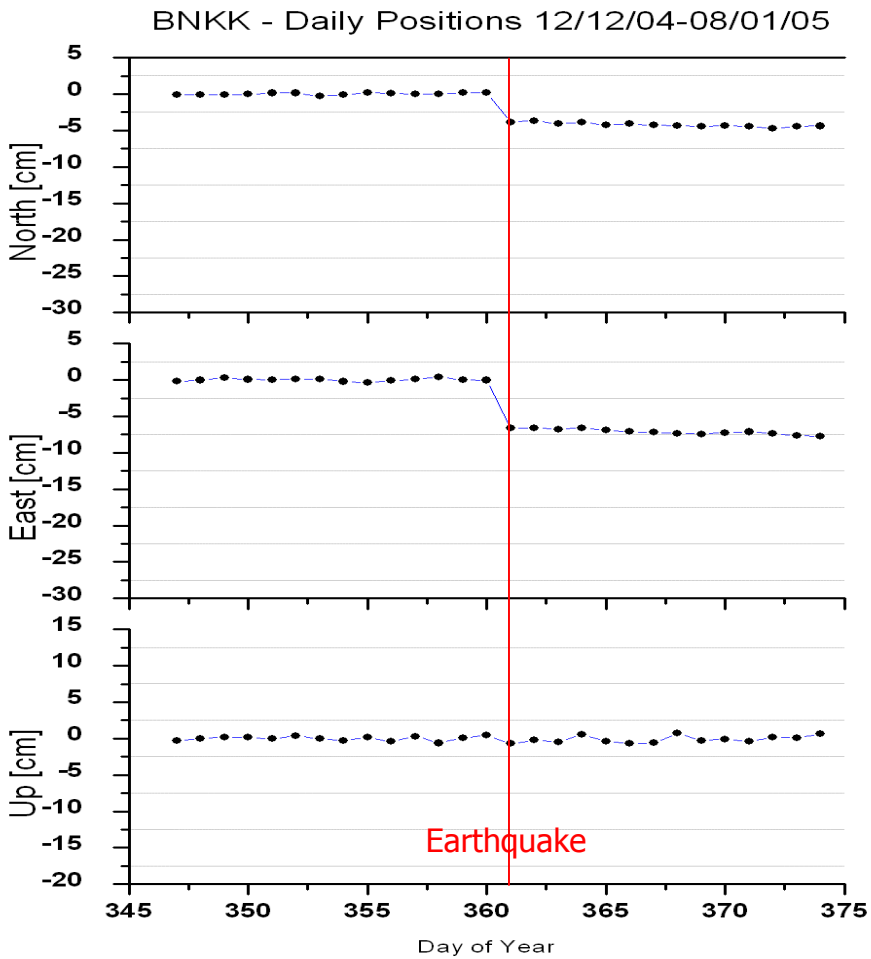
Post-seismic displacements from GPS

- Daily solutions after earthquake:
  - Position changes per day
  - Compare with average before
  - Accuracy ± 5 mm (horizontal)
  - Follows co-seismic motion

- Unique results:
  - At more than 11 locations
  - Up to 4.5 cm in 2 weeks
  - At distances over 1500 km
  - Input to earthquake model



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Sundaland Deformation

Before Mw 9.0 Earthquake:

- Sundaland stable with rigid core, deformation at edges
- GPS sites positions & velocities well known (2-3 cm/yr)

During Mw 9.0 Earthquake:

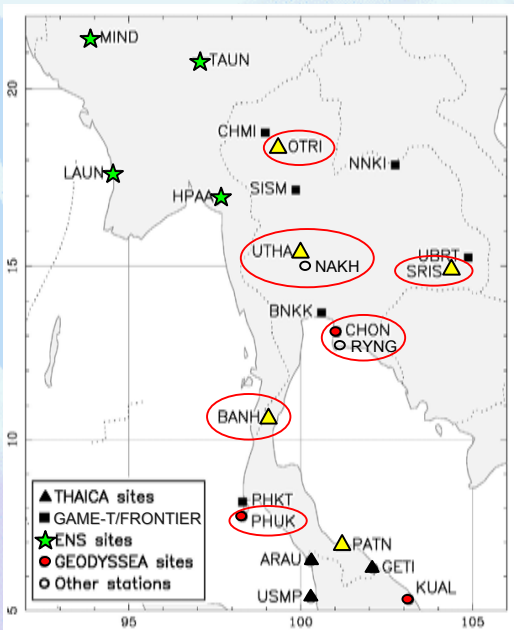
- Sundaland deforms further than 2000 km inside core
- Co-seismic displacements (up to 20 cm/min)
- GPS network is deformed, new positions unknown

After Mw 9.0 Earthquake:

- Sundaland continues to deform significantly
- Post-seismic displacements (initially up to 1 cm/day)
- GPS network continues to deform for months->years

Additional GPS Measurements in S.E. Asia

- GPS Campaigns urgently needed:
  - Indonesia and Thailand
  - Further densify displacement field
  - Post-seismic 'pollutes' co-seismic
  - Only at points measured before quake



GPS Campaign Thailand (10-15 February 2005)

Phuket (PHUK) GPS point

Co-seismic
+
Post-seismic
+
(Steady-state)
on 15/02/2005

Promthep Cape, Phuket, Thailand

Nearby Tsunami damage

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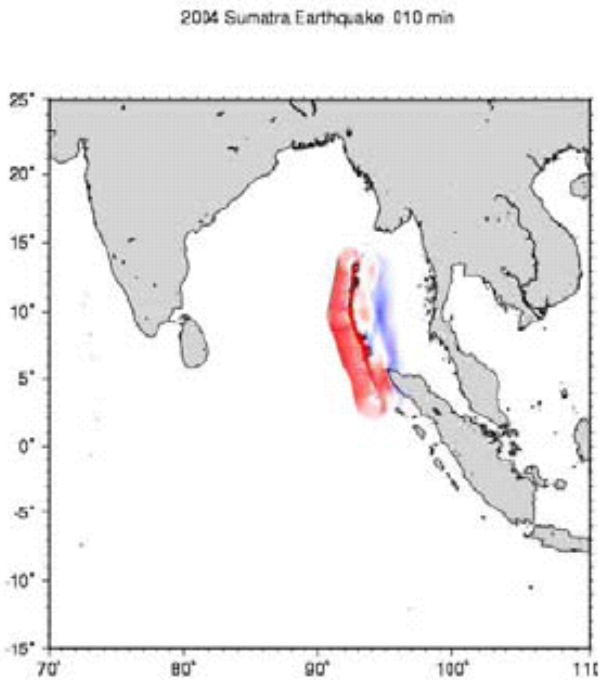
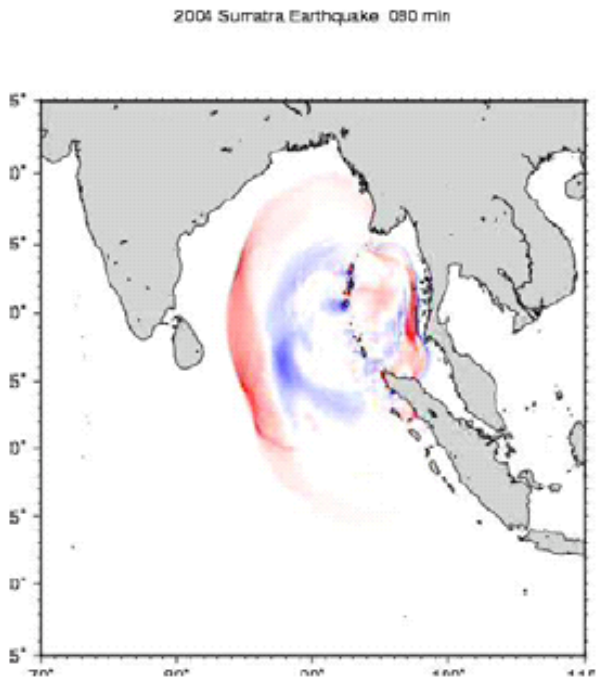
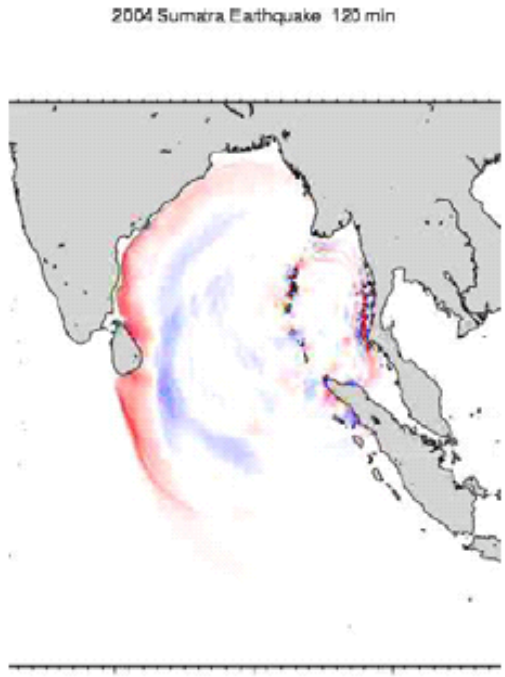
Tsunami propagation







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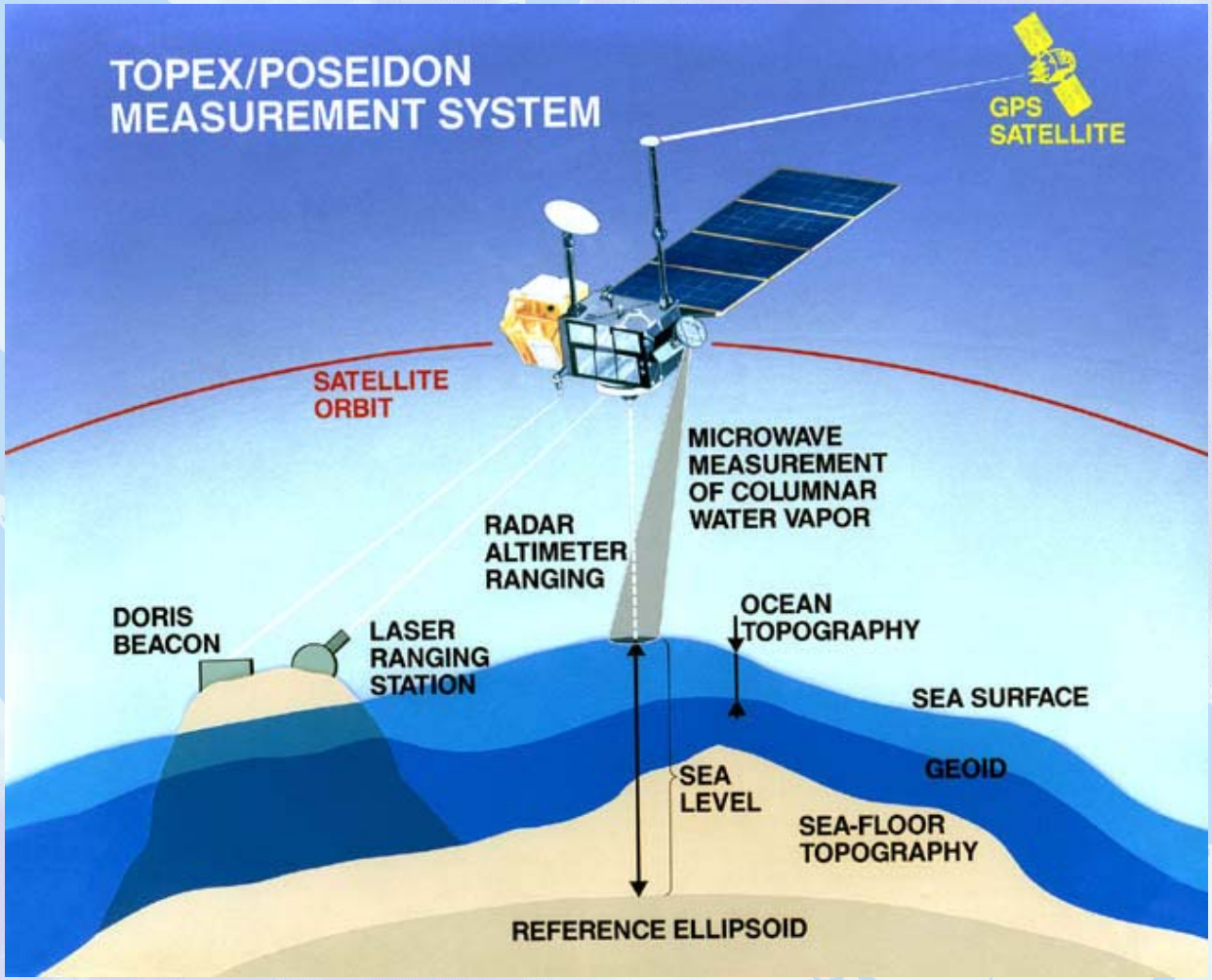
Satellite altimetry



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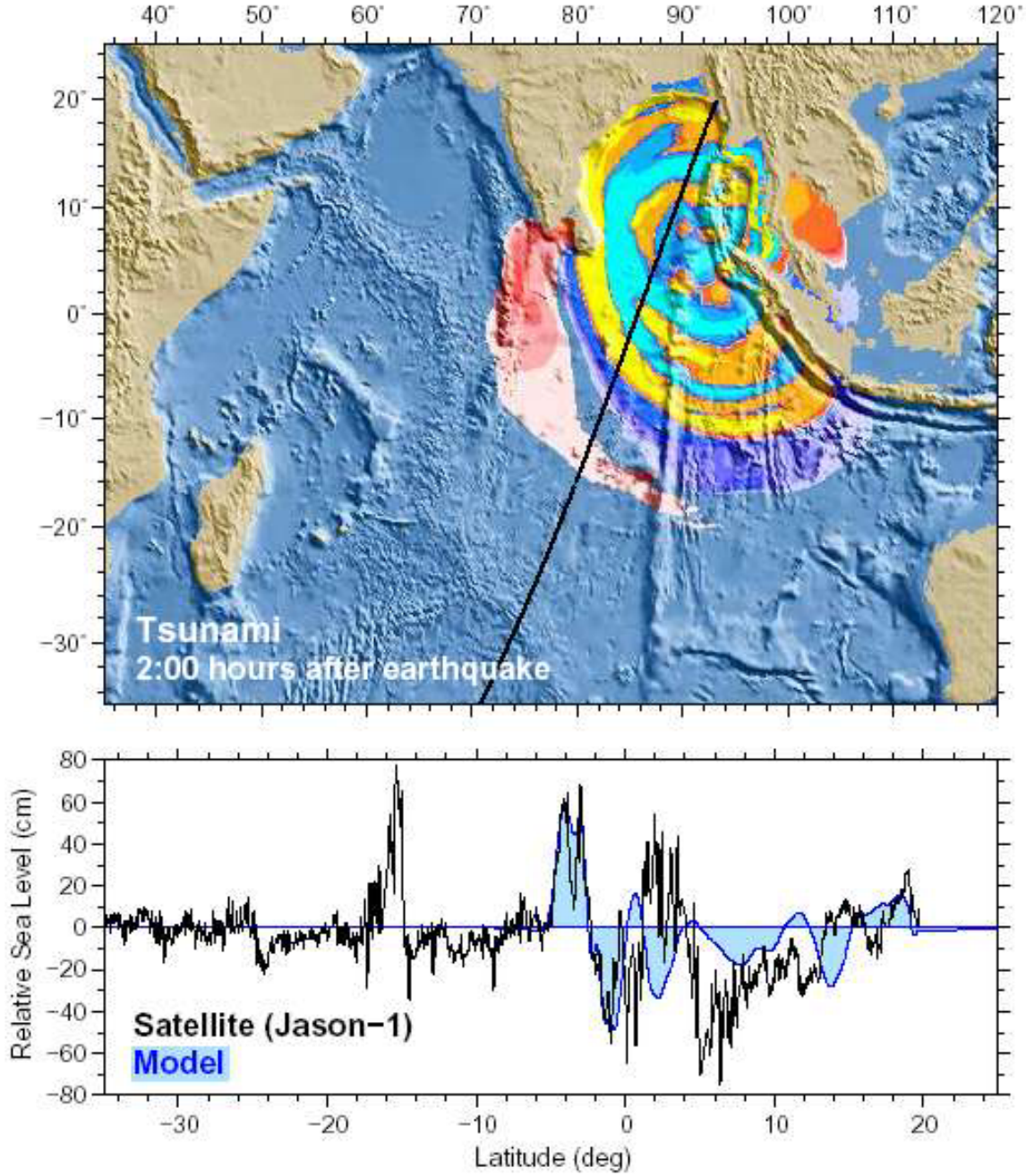
Radar Altimeter Database System

- Satellites: ERS-1, ERS-2, TOPEX/POSEIDON, ENVISAT, JASON-1, GFO, ??
- Altimeter data consists of (level 1)
  - Satellite position and time information
  - Orbit altitude from Precision Orbit Determination
  - Observations altitude, swh, sigma0, radiometer
  - Added corrections (wettrop, drytrop, iono, IB, tides, SSB)
  - Editing flags
  - Etc.
- There are several data providers (CLS, ESA, US Navy…)
- All information is collected in a database (=RADS)
- Derived information (level 2 and up)
- Several users of level 1 and 2 data



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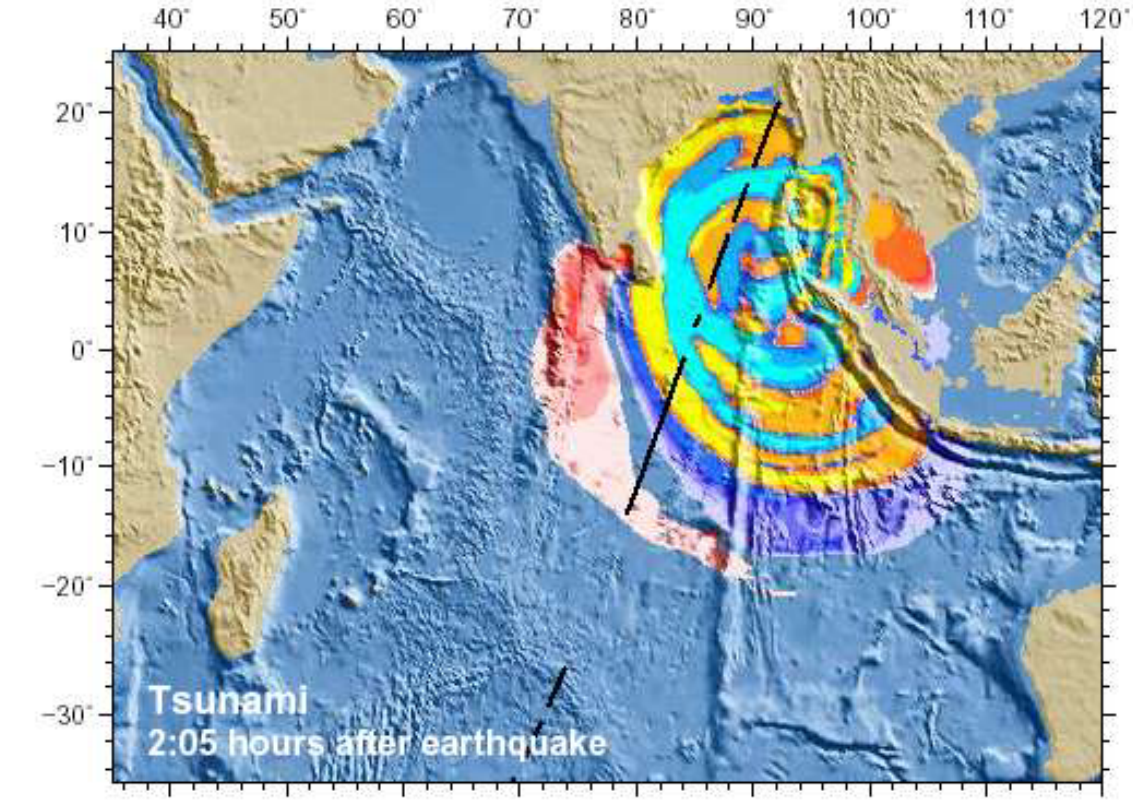

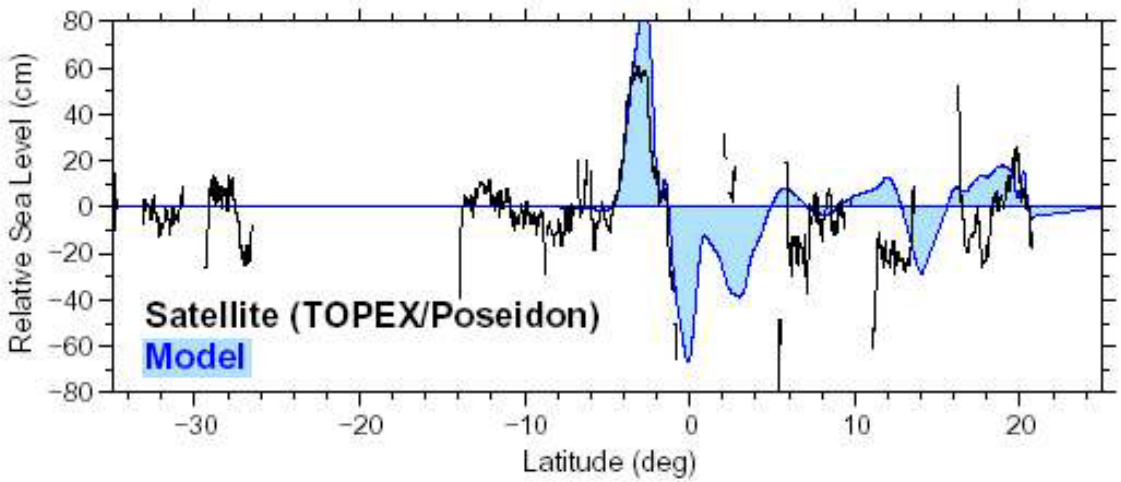

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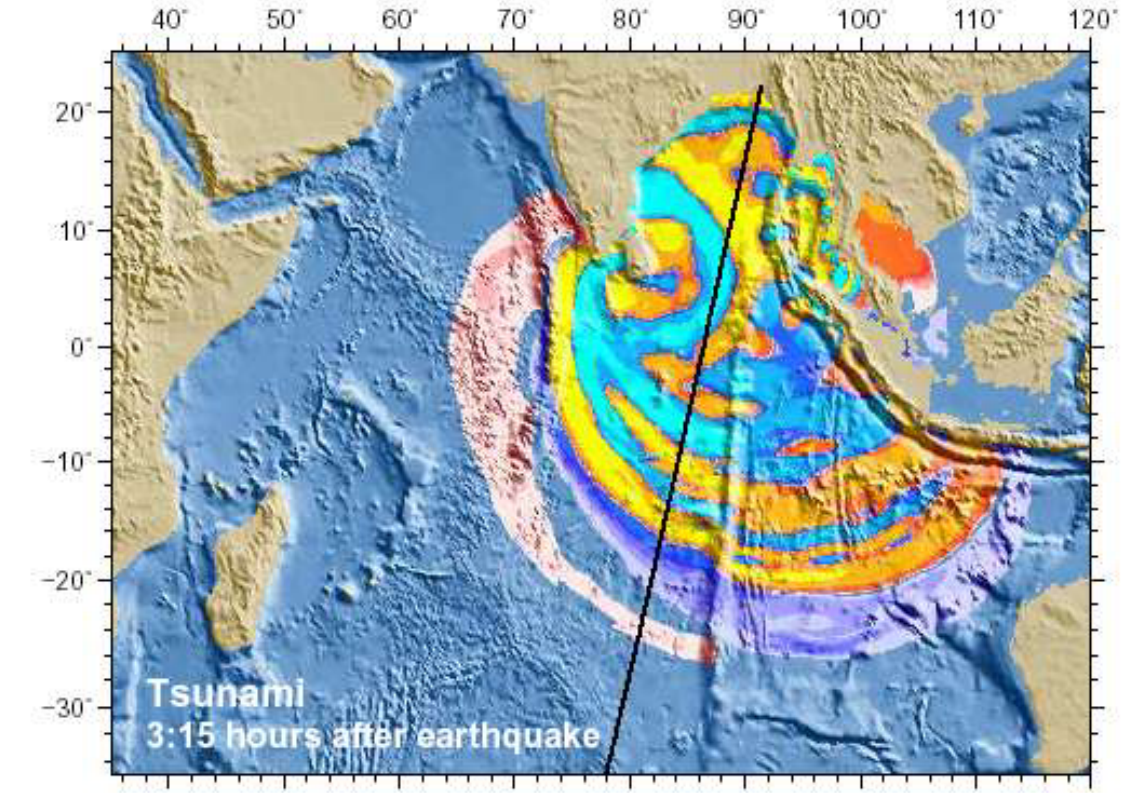

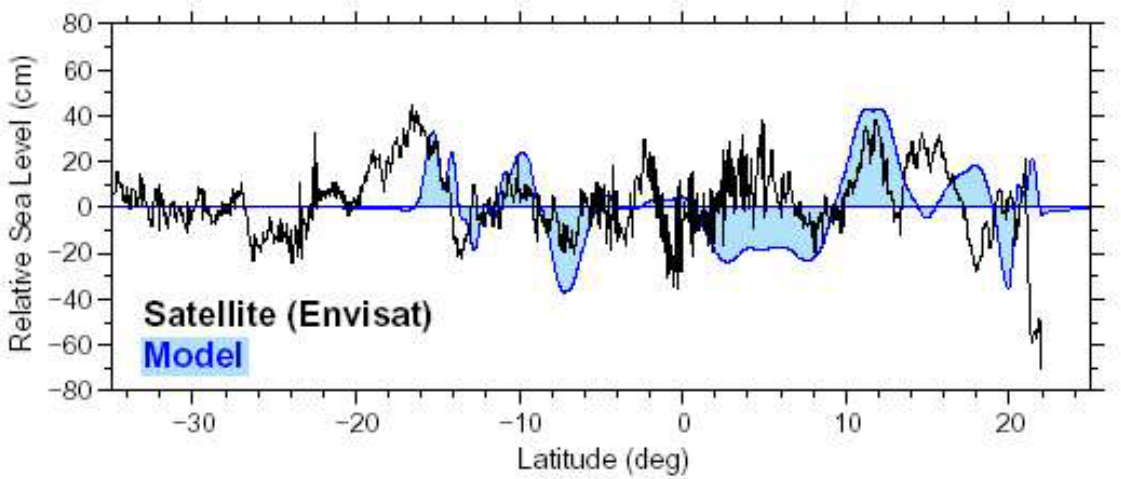

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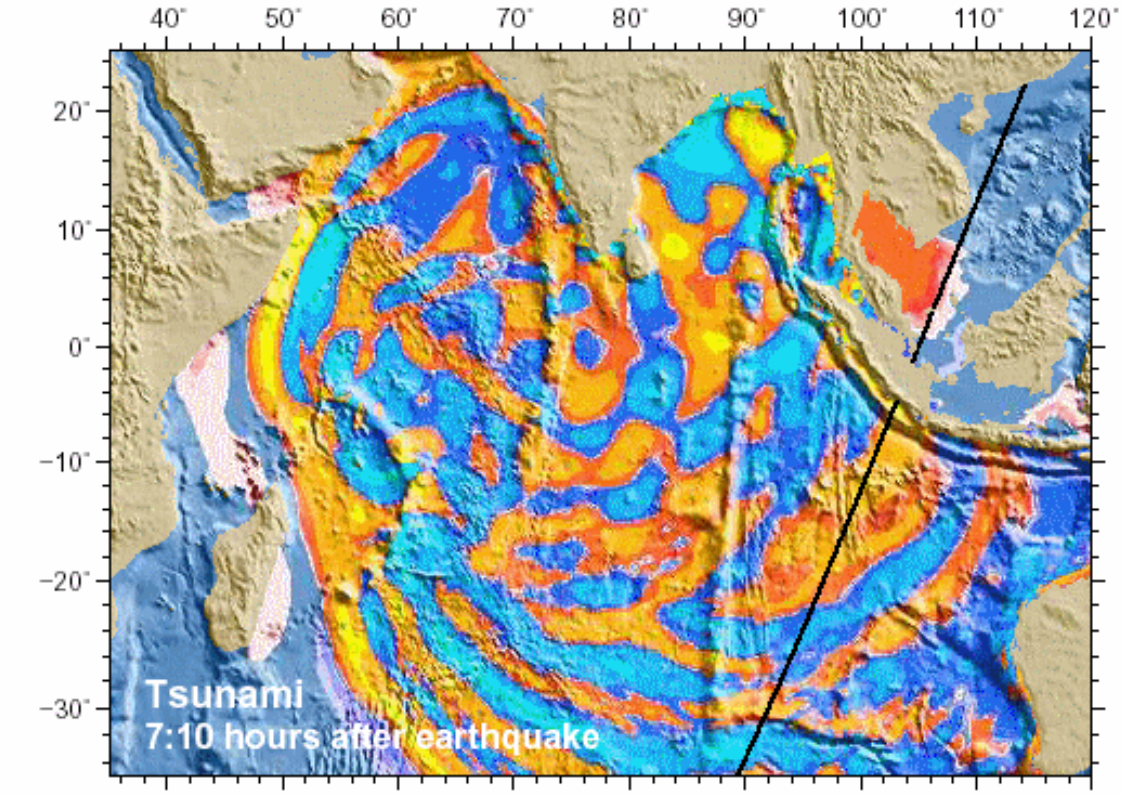

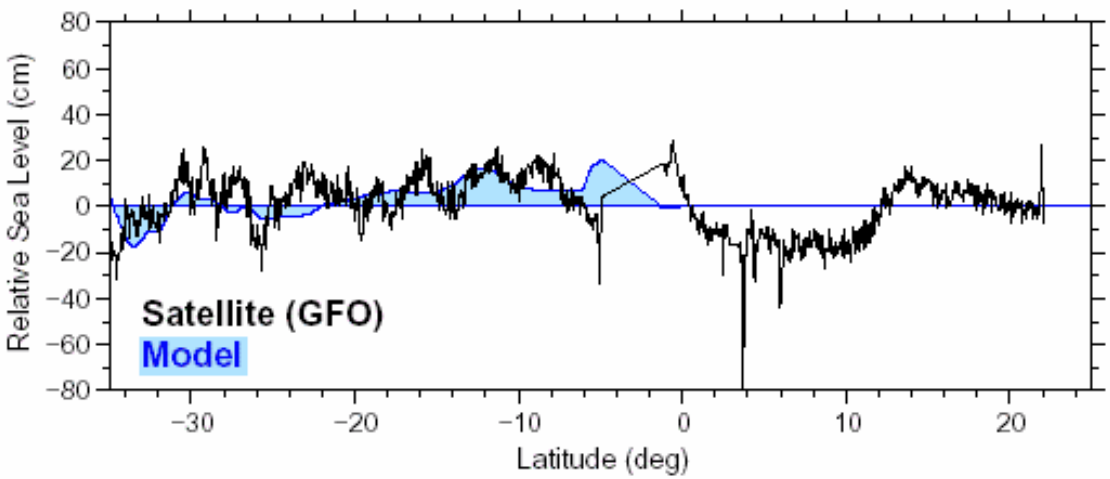

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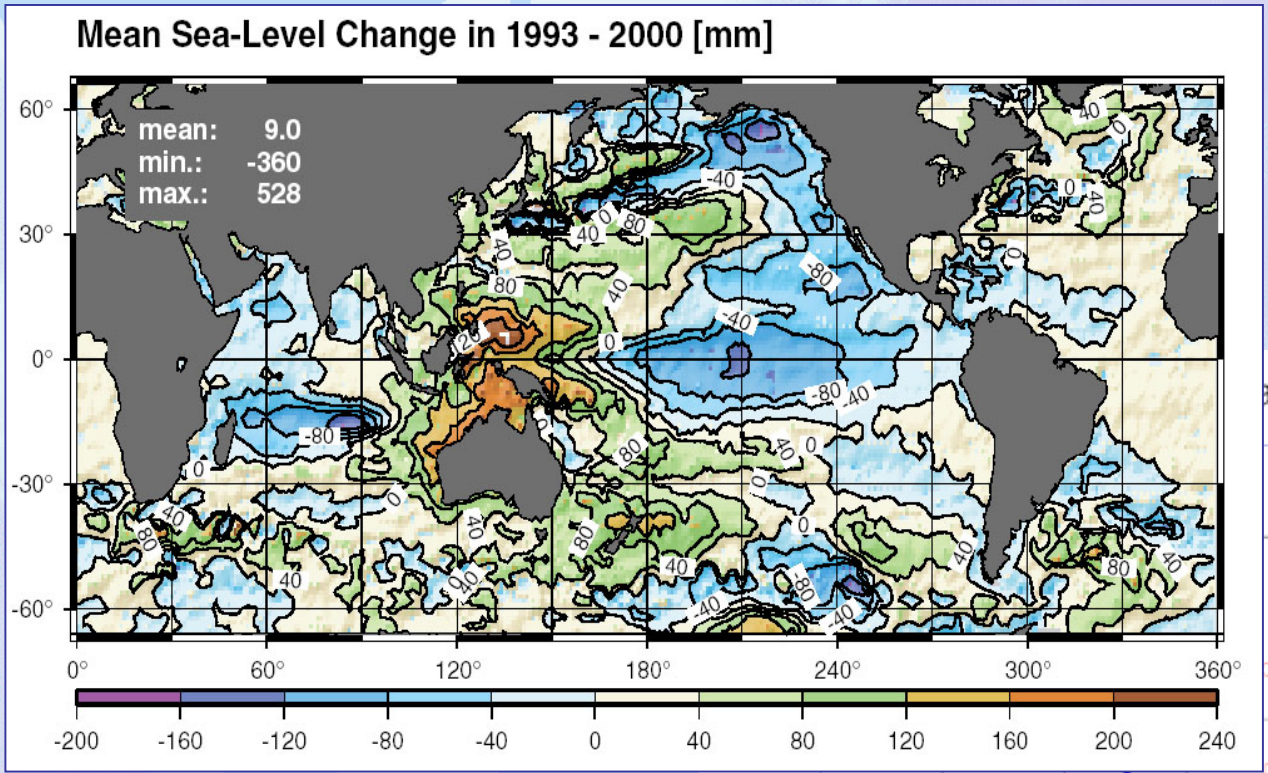
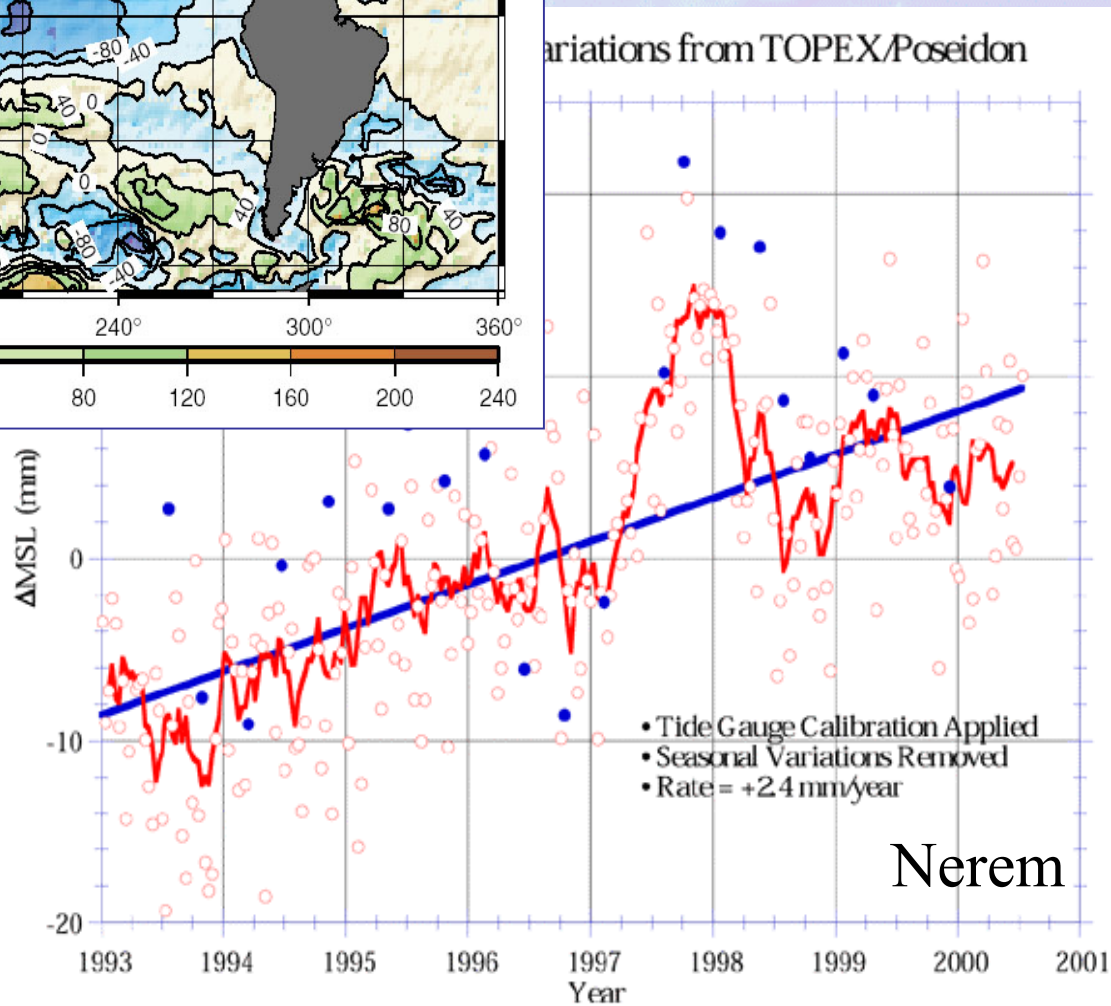
Sea level change





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SEAMERGES: South-East Asia Mastering Environmental Research with GEodetic Space techniques

SEAMERGES Themes: Global Positioning System | Interferometric SAR | Satellite Altimetry | Research projects

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SEAMERGES Themes:
1.Global Positioning System
2.Interferometric SAR
3.Satellite Altimetry
4.Research Projects

Final Workshop

Contact webmaster

Introduction

SEAMERGES is a project funded under the ASEAN-EU University Network programme (AUNP), human resource development component, by the European Committee (EC) that started 1 January 2004 and will run for two years. The participants are university and research groups from the Netherlands, France, Indonesia, Malaysia and Thailand who are involved in geodetic education and geodetic research. The project entails a number of seminars on the applications of the Global Positioning System, Interferometric SAR and satellite radar altimetry: exchanged knowledge, methods and data will then be used to define and carry out research projects targeted to the South-East Asian region.

Summary

The **aim** of the SEAMERGES project is the transfer of knowledge, expertise and technology to SE-Asia to locally enable higher-level geodetic research and initiate implementation of applications for water management and risk assessment. It also aims at stimulating scientific cooperation among the different Asian countries. The initial **target groups** consist of selected staff and students of 3 local universities: the Institut Teknologi Bandung in Indonesia, the Universiti Teknology Malaysia in Malaysia, and the Chulalongkorn University in Thailand. **Main activities** include theoretical and training courses in 3 geodetic techniques (HRD), the setup of interdisciplinary research (pilot) projects involving all partners, and the organization of a final international symposium. Besides the 3 university groups in SE-Asia (ITB, UTM, and Chula) the **partnership** includes DEOS (Delft University of Technology, Netherlands) and ENS (Ecole Normale Superieure, France).

Objectives

1. Transfer moderate and expert scientific knowledge and associated technologies in the field of earth-oriented space research to the ASEAN countries, which are tailored to their needs;
2. Improve research capability in the participating ASEAN countries, which would in turn allow for better and mujtual beneficiary cooperation between ASEAN and EC countries on the higher-education and scientific research levels;
3. Encourage more comprehensive and efficient studies in the region of SE-Asia in the fields of space geodesy, geodynamics and the assessment and monitoring of environmental risks. These future ASEAN co-lead research projects should also stimulate the participation and the sharing and transfer of knowledge of other ASEAN countires not included in this project;
4. Help the ASEAN countries to become full and respected members of the international scientific community. Both direct (graduated students) and indirect (through research projects and technology spin-offs) also the civil and industrial community would benefit from the project's HRD and combined research efforts.

Contacts

To register interest and make comments or suggestions please contact Boudewijn Ambrosius or Wim Simons of DEOS of the Faculty of Aerospace Engineering, Delft University of Technology, Netherlands.

For more information please go to the documents section.

Conclusive Remarks

- The 05-12-26 mega-trust earthquake has released stress built up over a period of many decades
- GPS has provided unique information on the pre-seismic, co-seismic and post-seismic deformation of the region, resulting in a better modelling of the earthquake mechanism
- The rupture possibly has loaded other parts of the fault. It may be possible to monitor future stress accumulation by new GPS stations
- International collaboration in the scope of the SEAMERGES project has been invaluable in swiftly collecting and analyzing new GPS data
- The tsunami wave has been observed for the first time with RA. The data will be used to develop better models.
- We start to understand the Earth; we do not control it…..

- We extend our sympathy to the victims of the disaster and their relatives