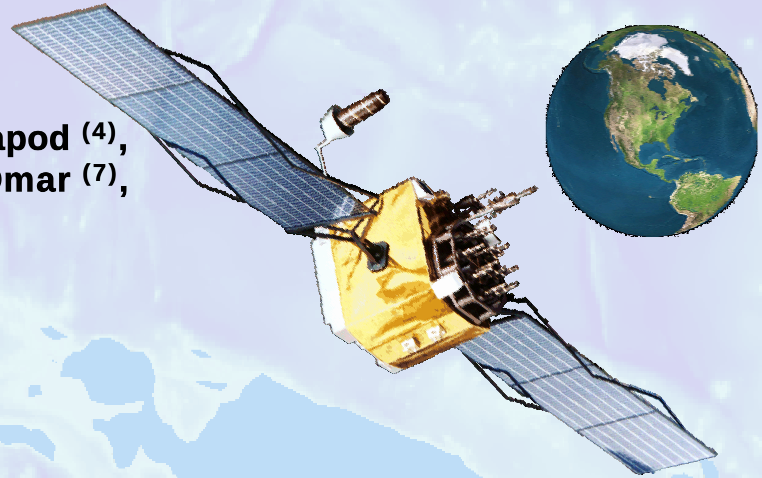
SEAMERGES:

GPS Measurements in S.E. Asia: Sundaland Motion and Deformation before and after the December 26th, 2004 Magnitude 9.0 Earthquake



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SEAMERGES:

Outline

- What is Crustal Motion?
- Tectonic Settings of S.E. Asia
- GPS for Geodynamic Studies
- Aim GPS Measurements in S.E. Asia?
- Geodetic GPS Network in S.E. Asia
- GPS Position Time Series
- Sundaland Motion and Deformation
- Sundaland Deformation: 26 December 2004
- Co-seismic Displacements from GPS
- Post-seismic Displacements from GPS
- Additional GPS Measurements in S.E. Asia
- Conclusive Remarks

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 (differently) for millions of years
- Plates are continuously (re)shaping the Earth’s exterior
- Geodynamic processes occur when plates converge/collide:
  - Earthquakes
  - Volcanic eruptions
  - Tectonically induced landslides
  - Tsunamis

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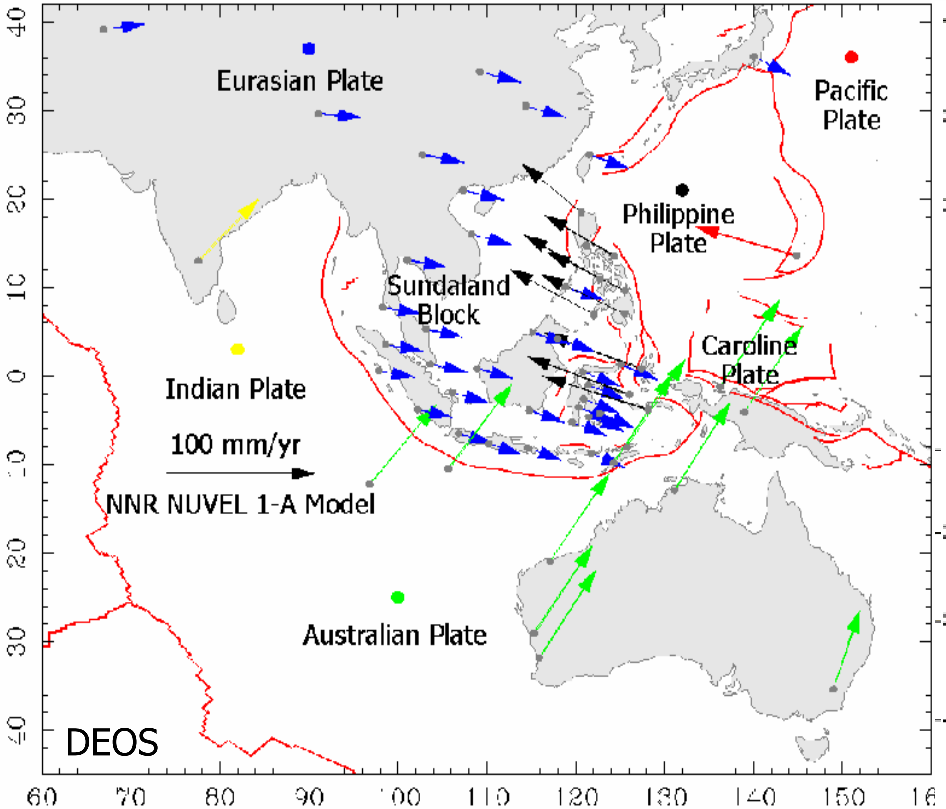
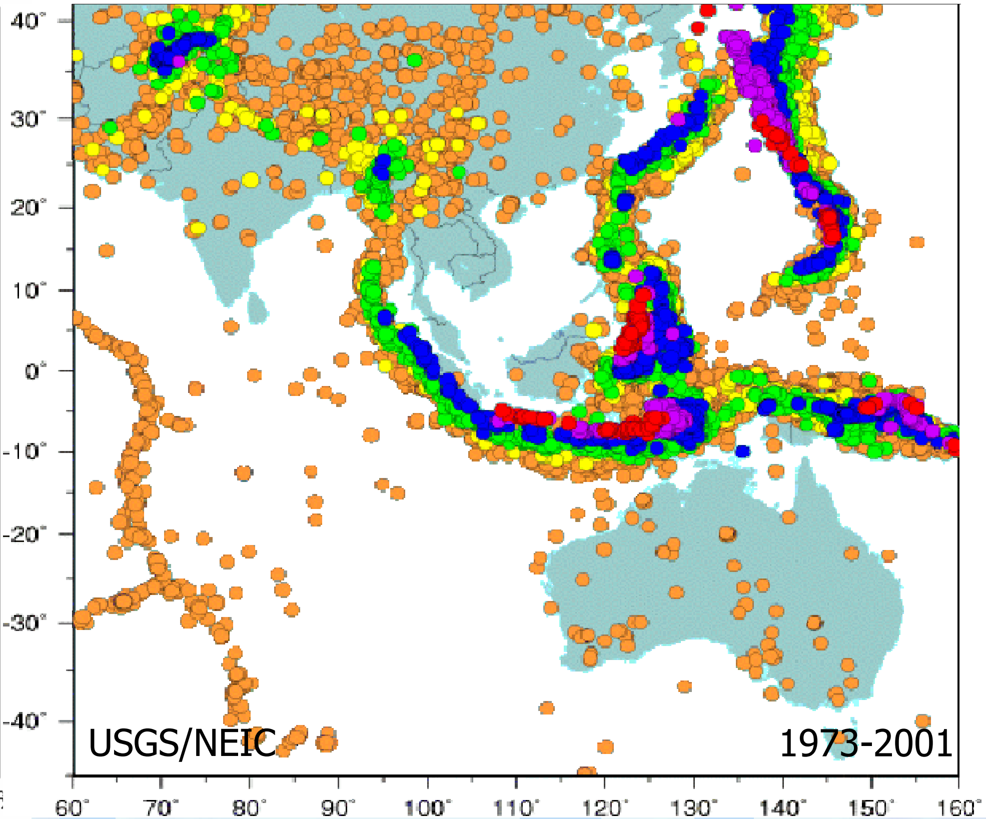
Tectonic Settings of S.E. Asia

Predicted Tectonic Plate Motions



Distribution of Earthquakes (Mw ≥ 5)

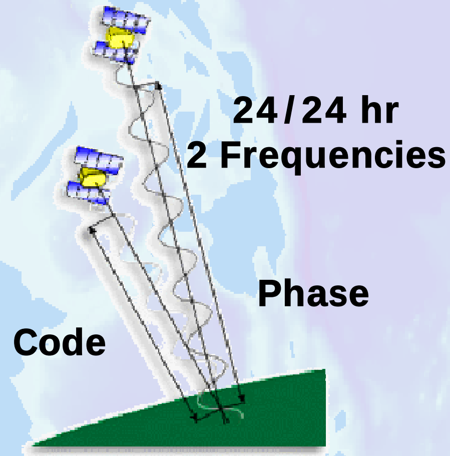


Convergence of Indian, Australian, Philippine and Sundaland plates

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
- Changes position in time give displacements or velocities

Aim 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

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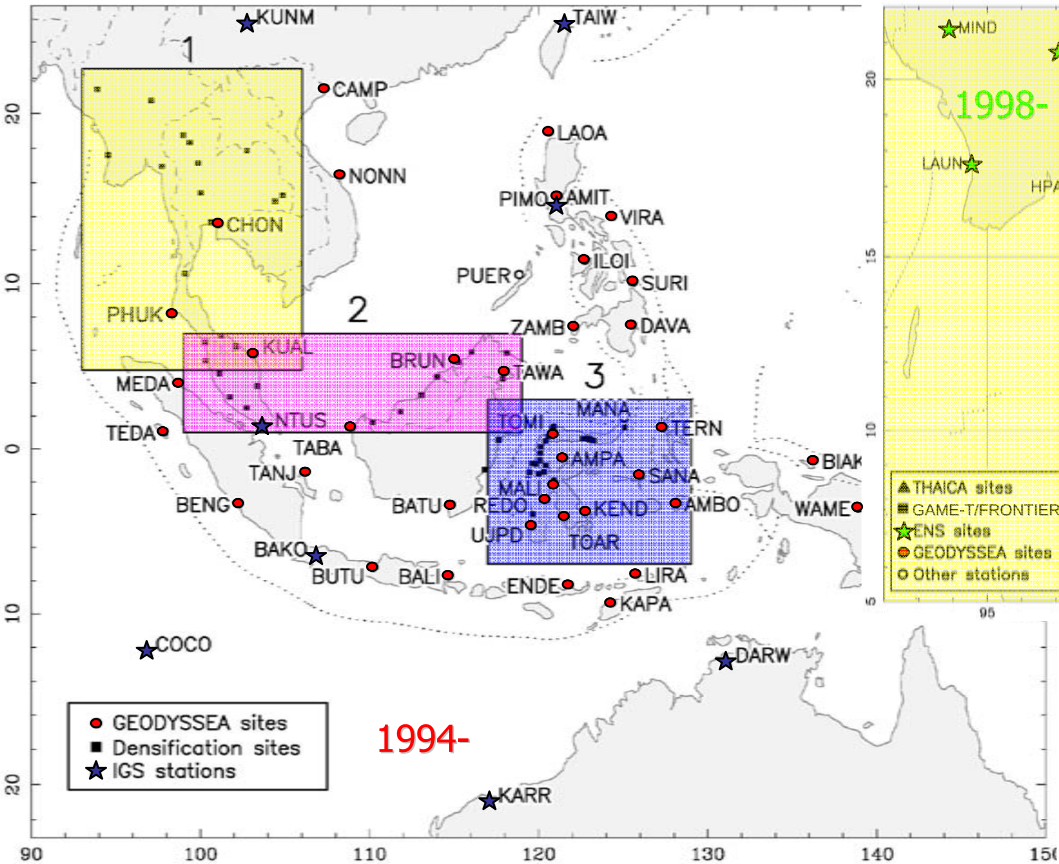
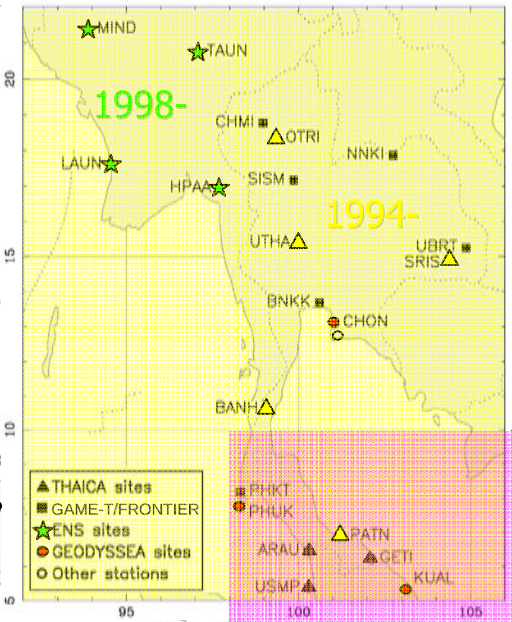
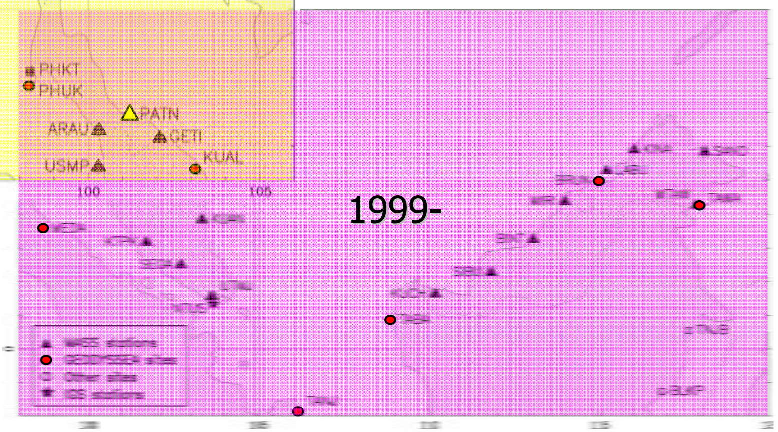
Geodetic GPS Network in S.E. Asia





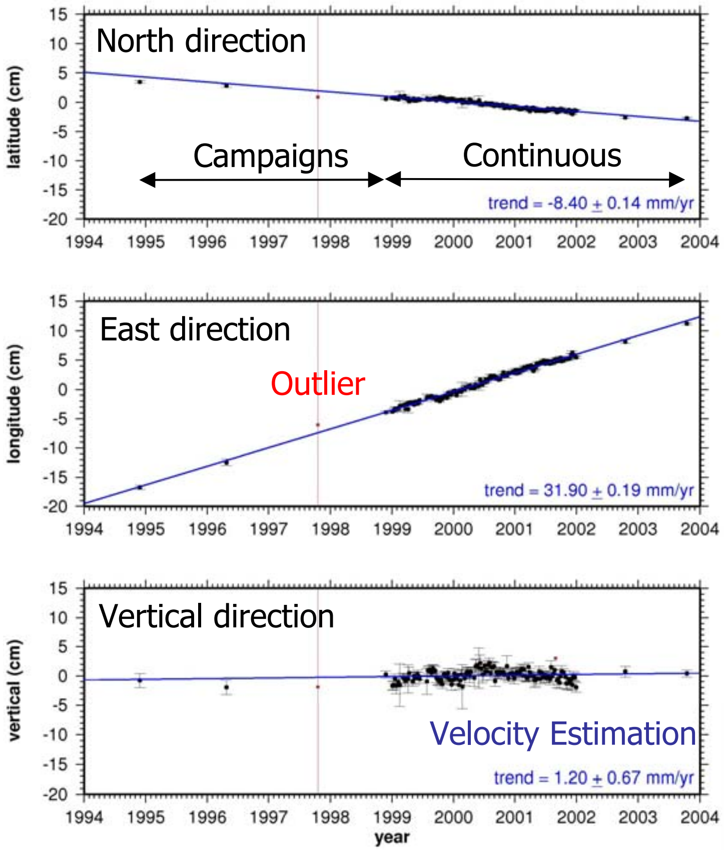


Phuket (PHUK) GPS point

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

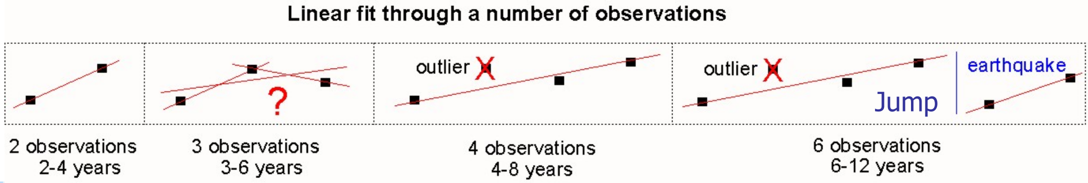
GPS Position Time Series

GPS point KUAL, Malaysia



Changes in time of (averaged) 3-D positions

Constructing time series from GPS campaigns



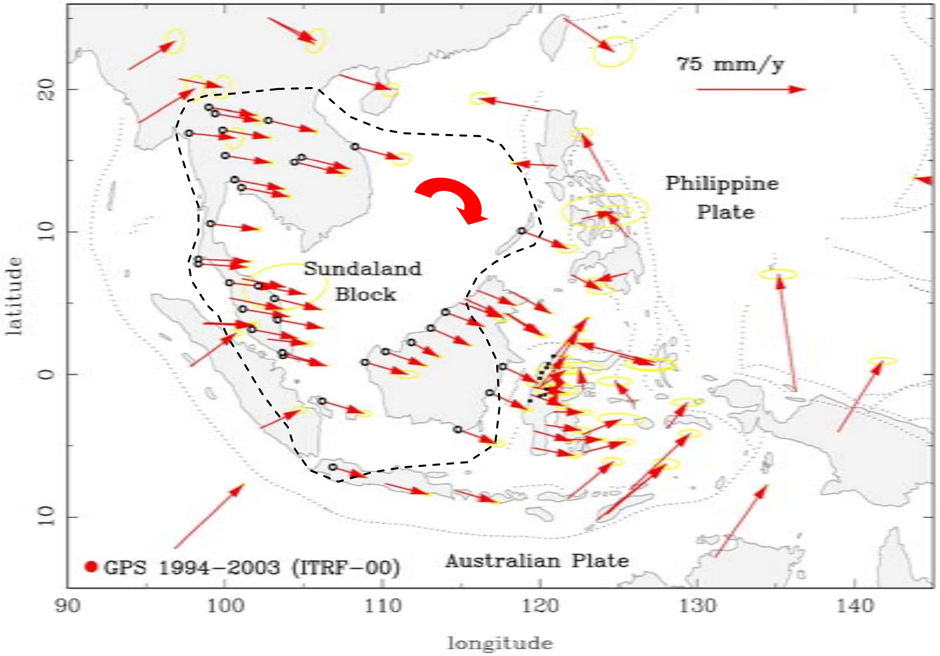
Overview GPS activities

1994-present

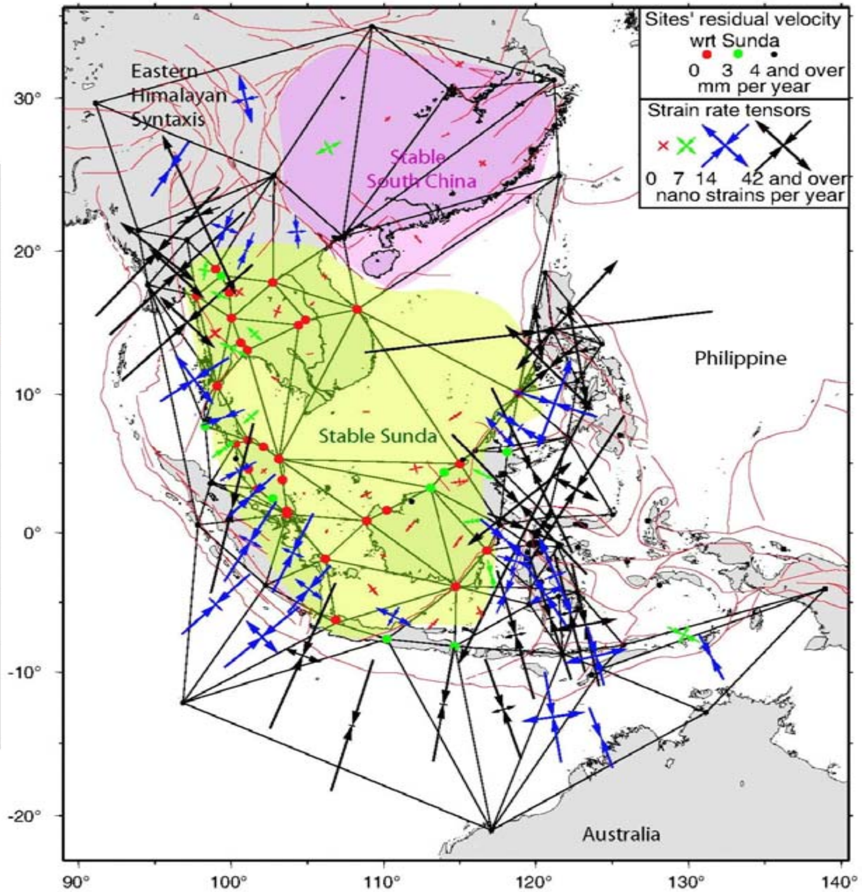
- GPS measurements EU-ASEAN partners
- Update GPS database S.E. Asia
- Merge all EU-ASEAN GPS data
- Include data global (IGS) GPS network
- High-precision (daily) network positions
- Map in global (ITRF) reference frame
- Estimate yearly position changes
- Update kinematical model S.E. Asia

Sundaland Motion and Deformation (1)

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

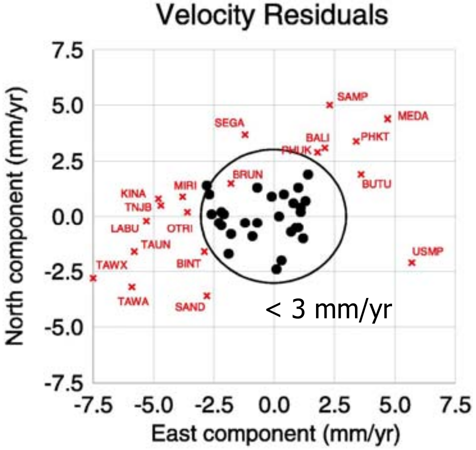


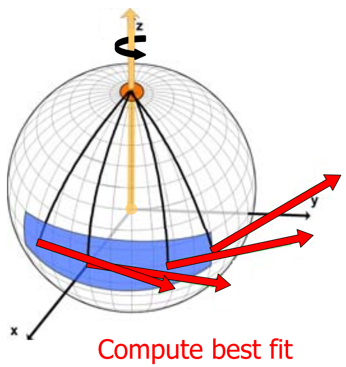
------ : boundaries stable 'rigid' Sundaland block



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

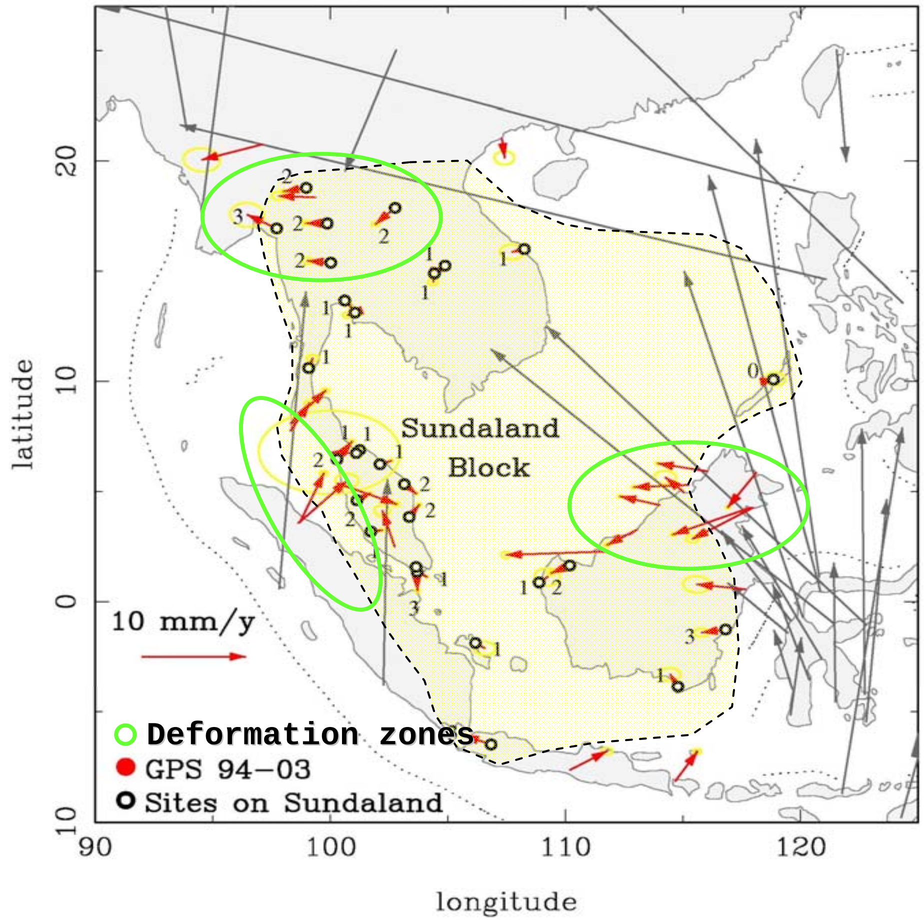
Sundaland Motion and Deformation (2)





Describe motion with a rotation pole vector

Reference	Reference frame	Sites used	Pole Rotation parameters Lat(° S)	Lat(° E)	°/Myr)
GEODYSSEA					
Wilson et al. [1998]	ITRF-94	12	31.8°	134.0°	-0.280°
Simons et al. [1999]	ITRF-96	12	43.0°	119.0°	-0.370°
Michel et al. [2001]	ITRF-97	10	56.0°	77.0°	-0.339°
SEAMERGES	ITRF-00	28	48.9°	85.8°	-0.341°
Others					
Sella et al. [2002]	ITRF-97	3	38.9°	93.1°	-0.393°
Kreemer et al. [2003]	NNR	9	47.3°	89.8°	-0.392°
Bock et al. [2003]	ITRF-00	16	49.8°	84.1°	-0.320°



History Sundaland rotation pole parameters

GPS velocities S.E. Asia w.r.t. Sundaland

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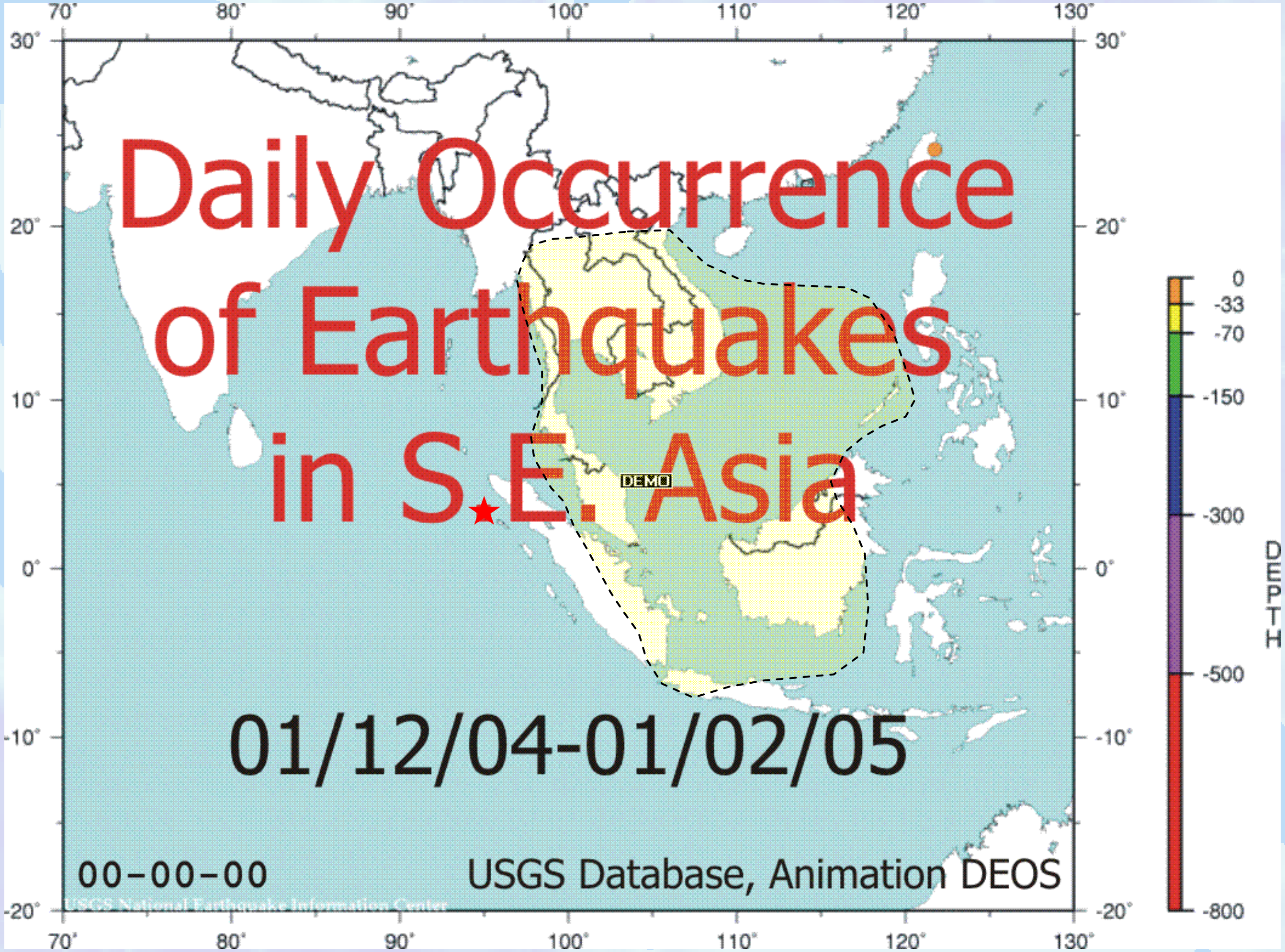
Sundaland Deformation: 26 December 2004 (1)



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Sundaland Deformation: 26 December 2004 (2)

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

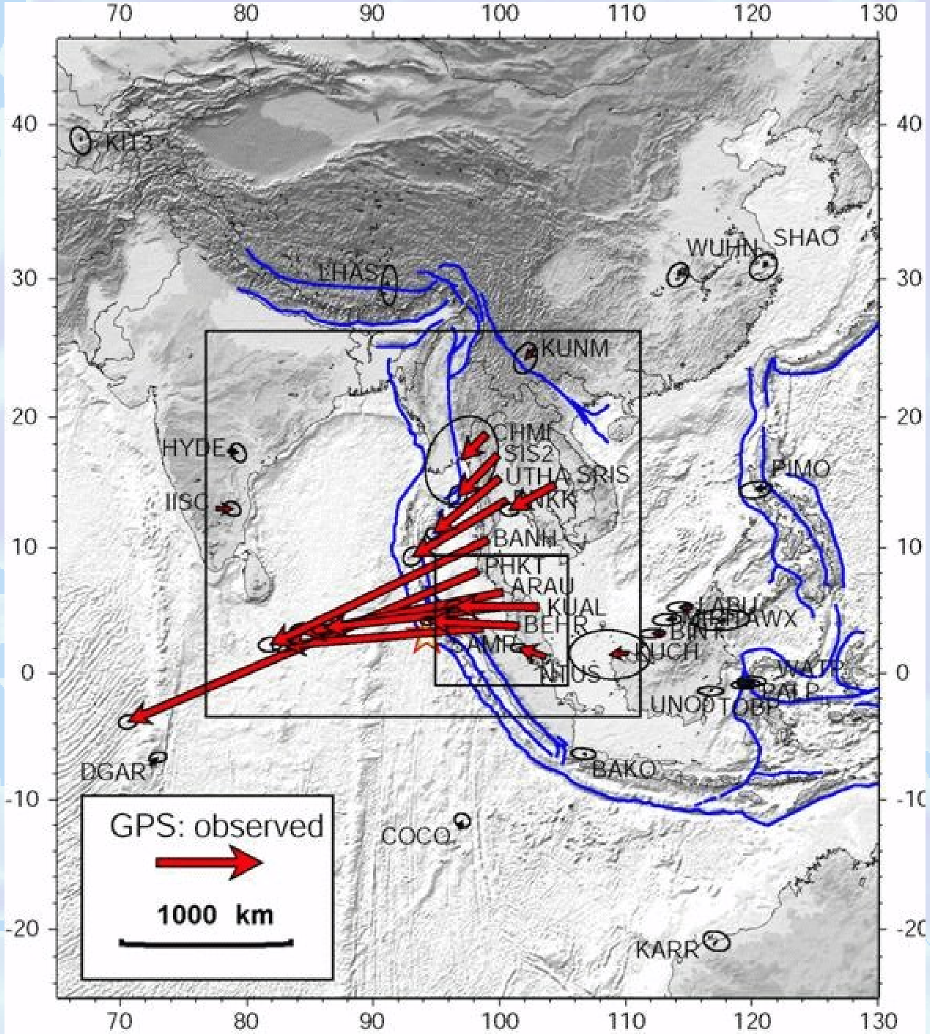
After Mw 9.0 Earthquake:

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

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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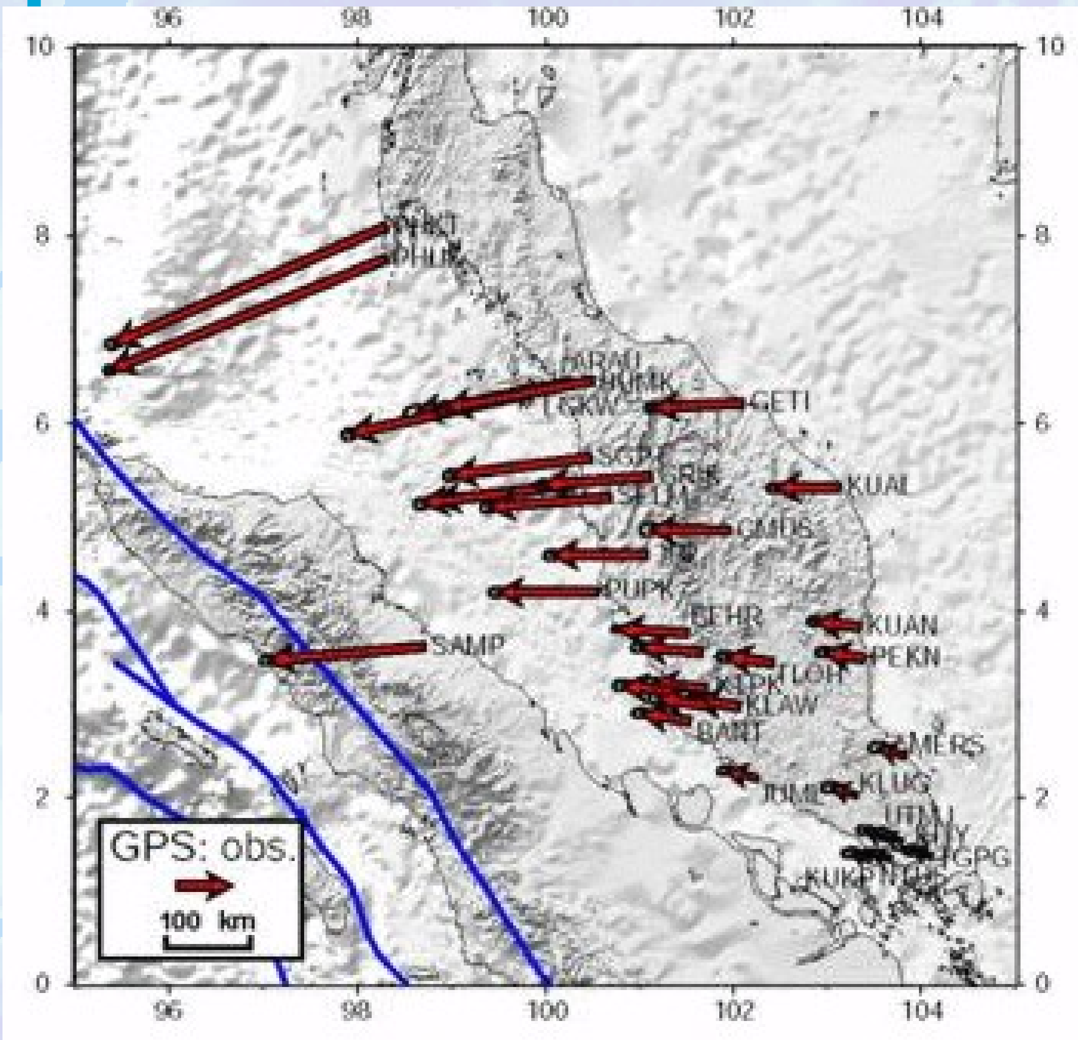

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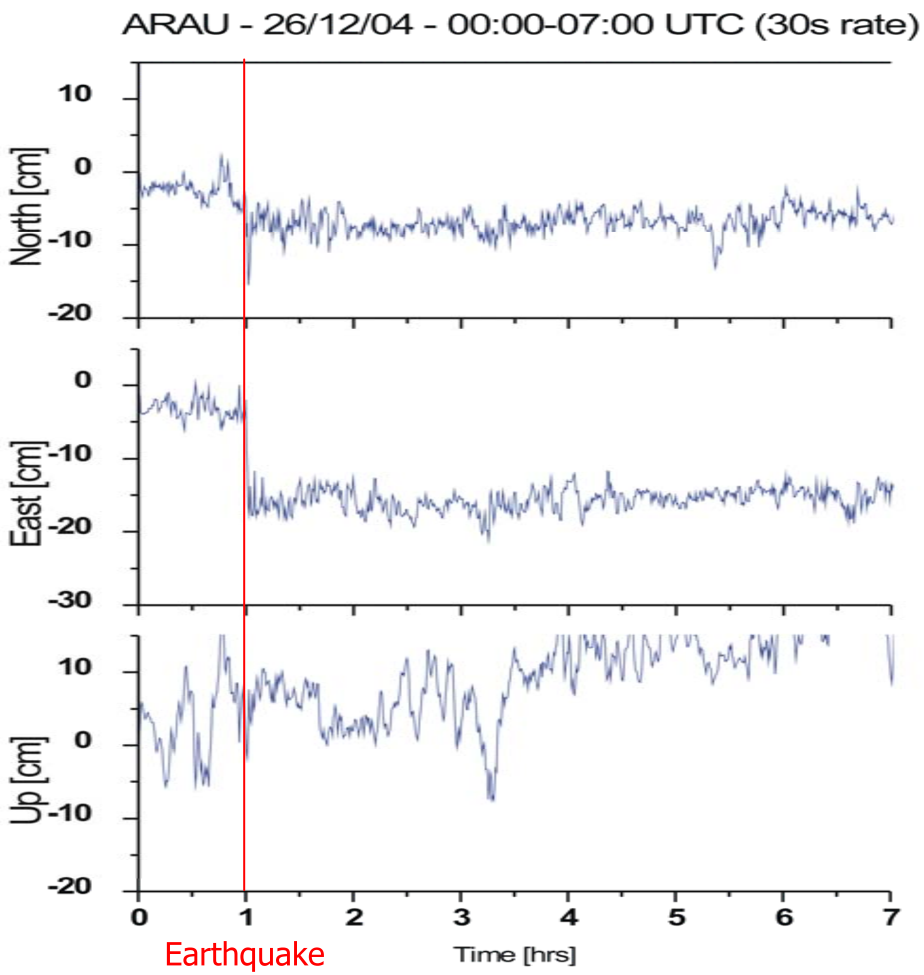
Co-seismic displacements from GPS

- Kinematic solution:
  - Position changes during day
  - Position update each 30 s
  - Accuracy ± 2 cm (horizontal)
  - Feasible for any GPS location

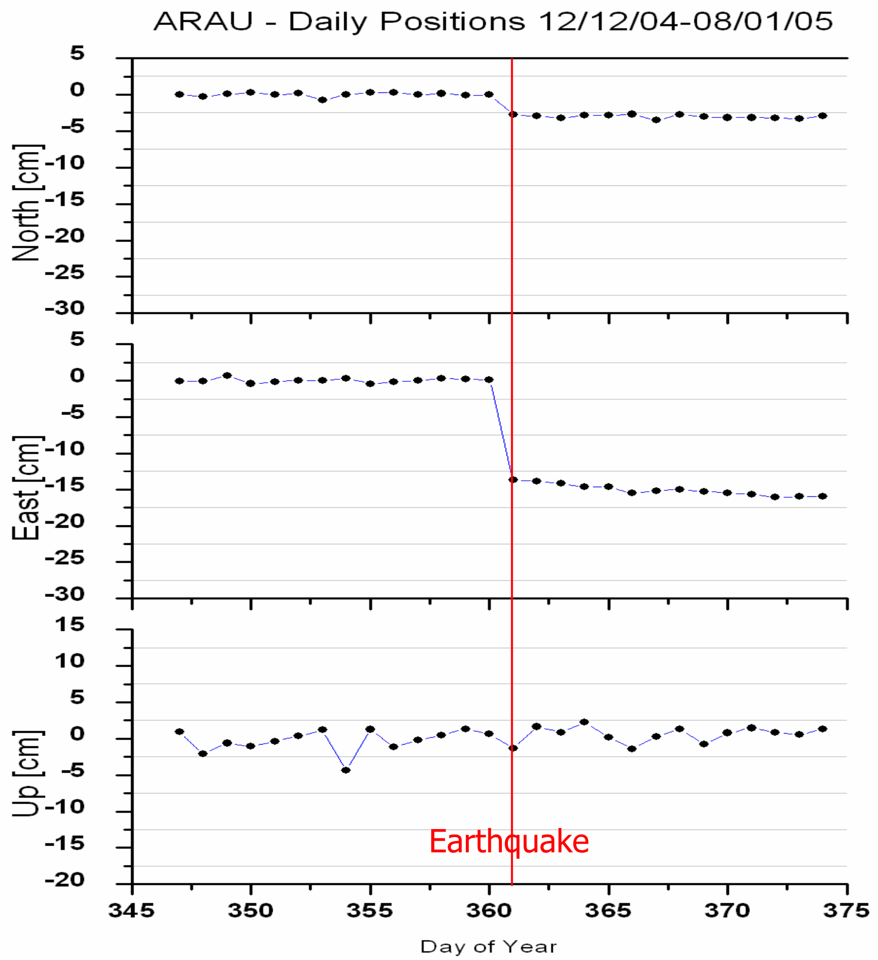
- Unique results:
  - At more than 40 locations
  - Changes up to 25 cm in 3 min
  - Start/end co-seismic motions
  - Low frequency quake signals
  - At distances over 2000 km
  - Input to earthquake model



Post-seismic displacements from GPS

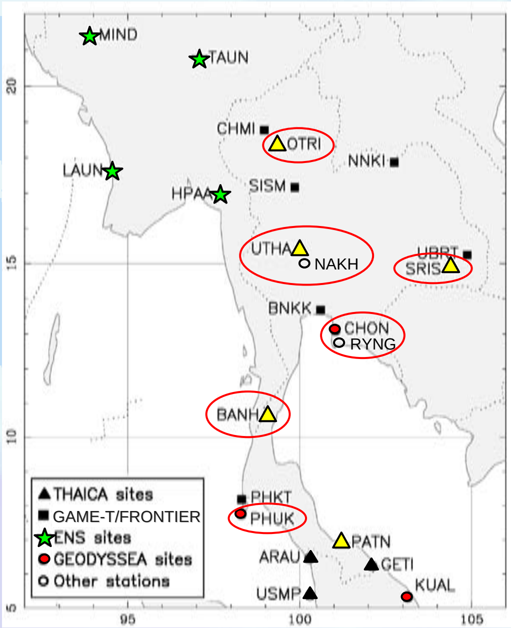
- Daily solutions after earthquake:
  - Position changes per day
  - Compare with average before
  - Accuracy ± 5 mm (horizontal)
  - Follows co-seismic motion

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



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

Conclusive Remarks

- Sundaland motion and deformation was well defined before 26/12/04.
- The Mw 9.0 earthquake has generated significant deformation of Sundaland, on a scale never before seen with GPS (> 2000 km).
- A unique combined GPS solution for the region has been computed, which shows intriguing co- and post-seismic deformation patterns.
- The entire geodetic networks of Malaysia and Thailand are internally deformed up to 35 cm (on continue to deform).
- The presented GPS results will allow a better modelling of the earthquake mechanism, and it's future impact on the region.
- The SEAMERGES EU-ASEAN partners have responded quickly: A special (internal) scientific report on the earthquake/tsunami has prompted (external) partners to collect/provide and analyze valuable GPS data.