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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Outline

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• Tectonic Settings of S.E. Asia
• GPS for Geodynamic Studies
• Aim GPS Measurements in S.E. Asia?
• Geodetic GPS Network in S.E. Asia
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• 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
Tectonic Settings of S.E. Asia

Convergence of Indian, Australian, Philippine and Sundaland plates

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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
- 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
Geodetic GPS Network in S.E. Asia

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

GPS point KUAL, Malaysia

Constructing time series from GPS campaigns

Linear fit through a number of observations

Overview GPS activities

- 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)

Global Reference Frame (ITRF-2000)

• Sundaland has rigid core, but significant deformation close to its boundaries
Sundaland Motion and Deformation (2)

Describe motion with a rotation pole vector

<table>
<thead>
<tr>
<th>Reference</th>
<th>Reference frame</th>
<th>Sites used</th>
<th>Pole Rotation parameters</th>
</tr>
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<tbody>
<tr>
<td></td>
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<td></td>
<td>Latitude (°), Longitude (°), Rate (°/Myr)</td>
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<tr>
<td>Wilson et al. [1998]</td>
<td>ITRF-94</td>
<td>12</td>
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<td>ITRF-96</td>
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<td>Michel et al. [2001]</td>
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<td>SEAMERGES</td>
<td>ITRF-00</td>
<td>28</td>
<td>48.9°, 85.8°, -0.341°</td>
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<tr>
<td>Others</td>
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<tr>
<td>Sella et al. [2002]</td>
<td>ITRF-97</td>
<td>3</td>
<td>38.9°, 93.1°, -0.393°</td>
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<tr>
<td>Kreemer et al. [2003]</td>
<td>NNR</td>
<td>9</td>
<td>47.3°, 89.8°, -0.392°</td>
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<tr>
<td>Bock et al. [2003]</td>
<td>ITRF-00</td>
<td>16</td>
<td>49.8°, 84.1°, -0.320°</td>
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</tbody>
</table>

History Sundaland rotation pole parameters

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

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Sundaland Deformation: 26 December 2004

Daily Occurrence of Earthquakes in S.E. Asia

01/12/04-01/02/05

USGS Database, Animation DEOS
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
Co-seismic displacements from GPS

- Permanent GPS data:
  - Thailand (4)
  - Malaysia (36)
  - Indonesia (5)
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- Unique solution:
  - 14 days pre-/post-quake
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  - Accuracy ± 2 mm
  - Input earthquake model
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)

Nearby Tsunami damage

Promthep Cape, Phuket, Thailand

Phuket (PHUK) GPS point

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

26 + 9? cm
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.