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NON-LINEAR CRUSTAL DEFORMATION MODELING FOR DYNAMIC REFERENCE FRAME: A CASE STUDY IN PENINSULAR MALAYSIA

Wan Anom WAN ARIS, Tajul Ariffin MUSA, Kamaludin MOHD OMAR, Sohaimie RASIDI, Abdullah Hisam OMAR, Malaysia

EMBRACING OUR SMART WORLD WHERE THE CONTINENTS CONNECT: ENHANCING THE GEOSPATIAL MATURITY OF SOCIETIES

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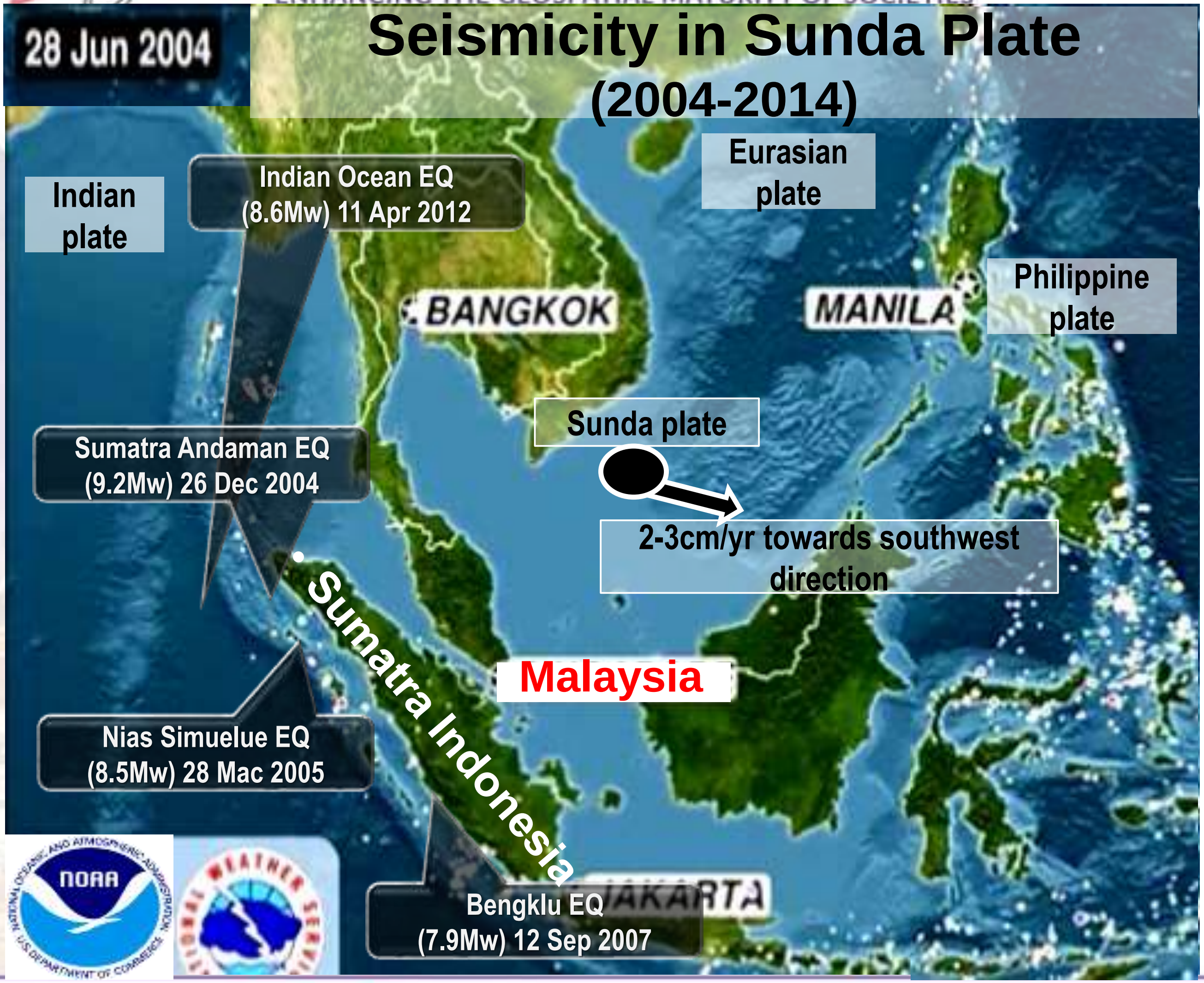
Seismicity in Sunda Plate (2004-2014)

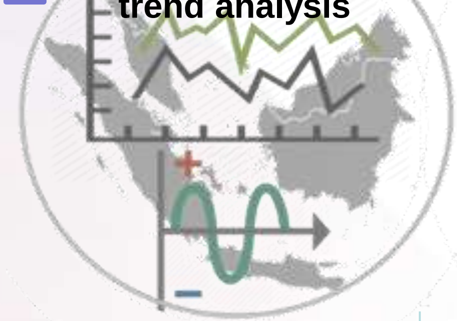


- Series of major EQ struck the Sundaland platelet since December 2004.
- The plate has been undergoing significant **co-seismic offset and post-seismic relaxation** deformation that affecting national geodetic reference frame for countries in the region such Indonesia, **Malaysia,** and Thailand.

Dynamic/ semi-dynamic Reference Frame Modelling (Malaysia)

Phase1

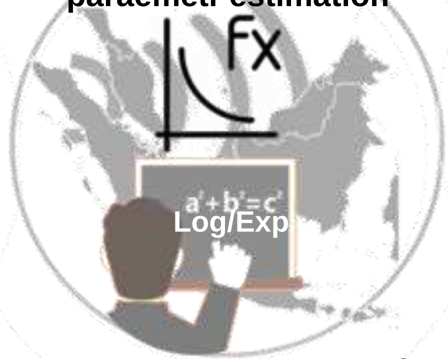
Crustal deformation trend analysis



Long-term and high precision crustal deformation profile generation in Sundaland

Phase2

Co- and Postseismic afterslip paraemetr estimation



Spatio-temporal analysis of co-seismic and post-seismic deformation in response of major earthquake in Sundaland

Phase3

Resolving Dynamic Reference Frame

Modelling geospatial of linear and non-linear crustal deformation for resolving time-dependent in geodetic reference frame

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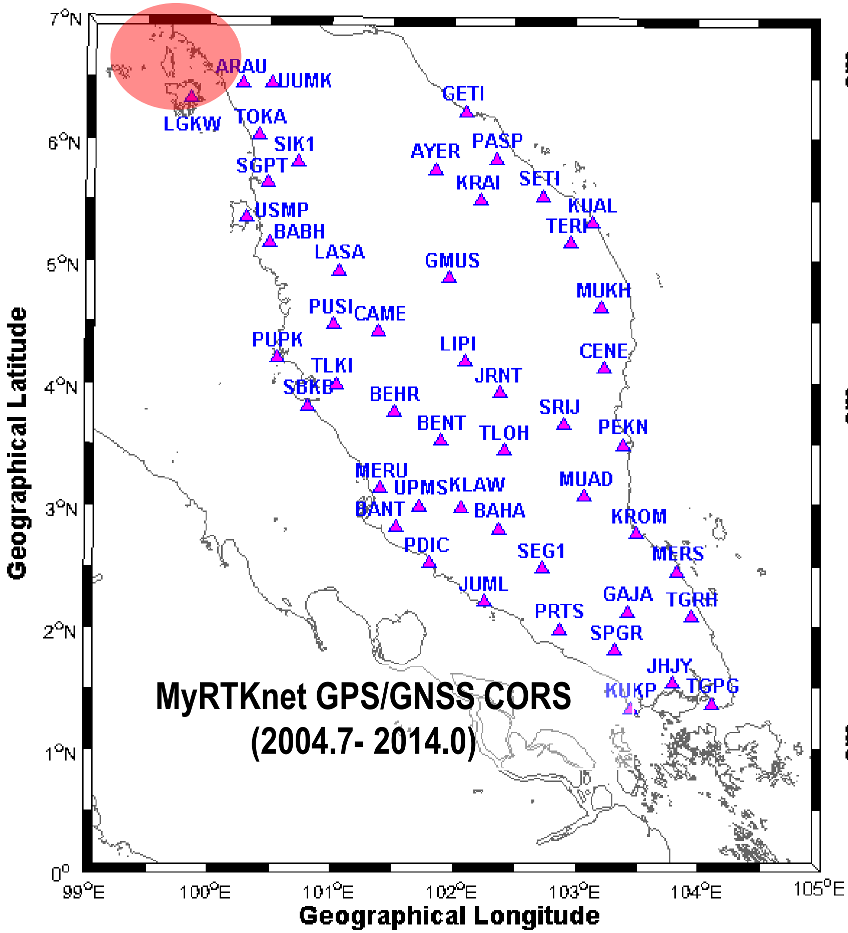
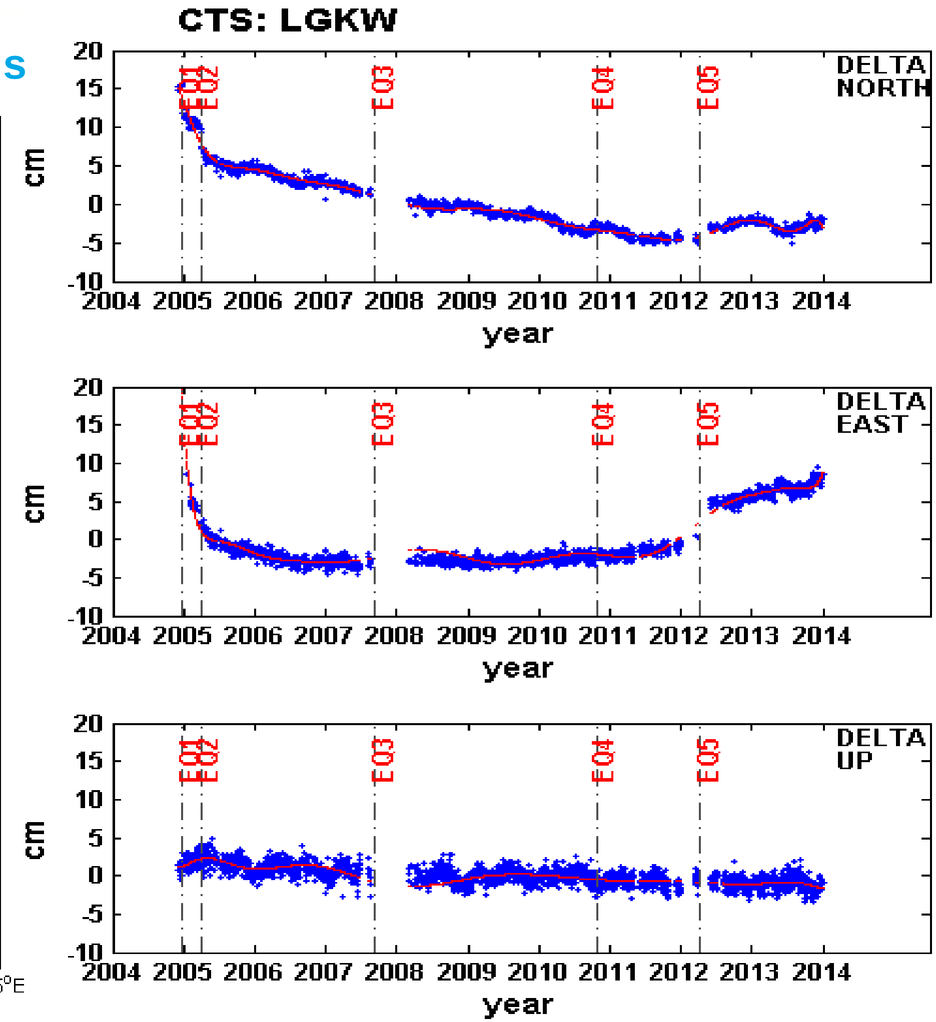
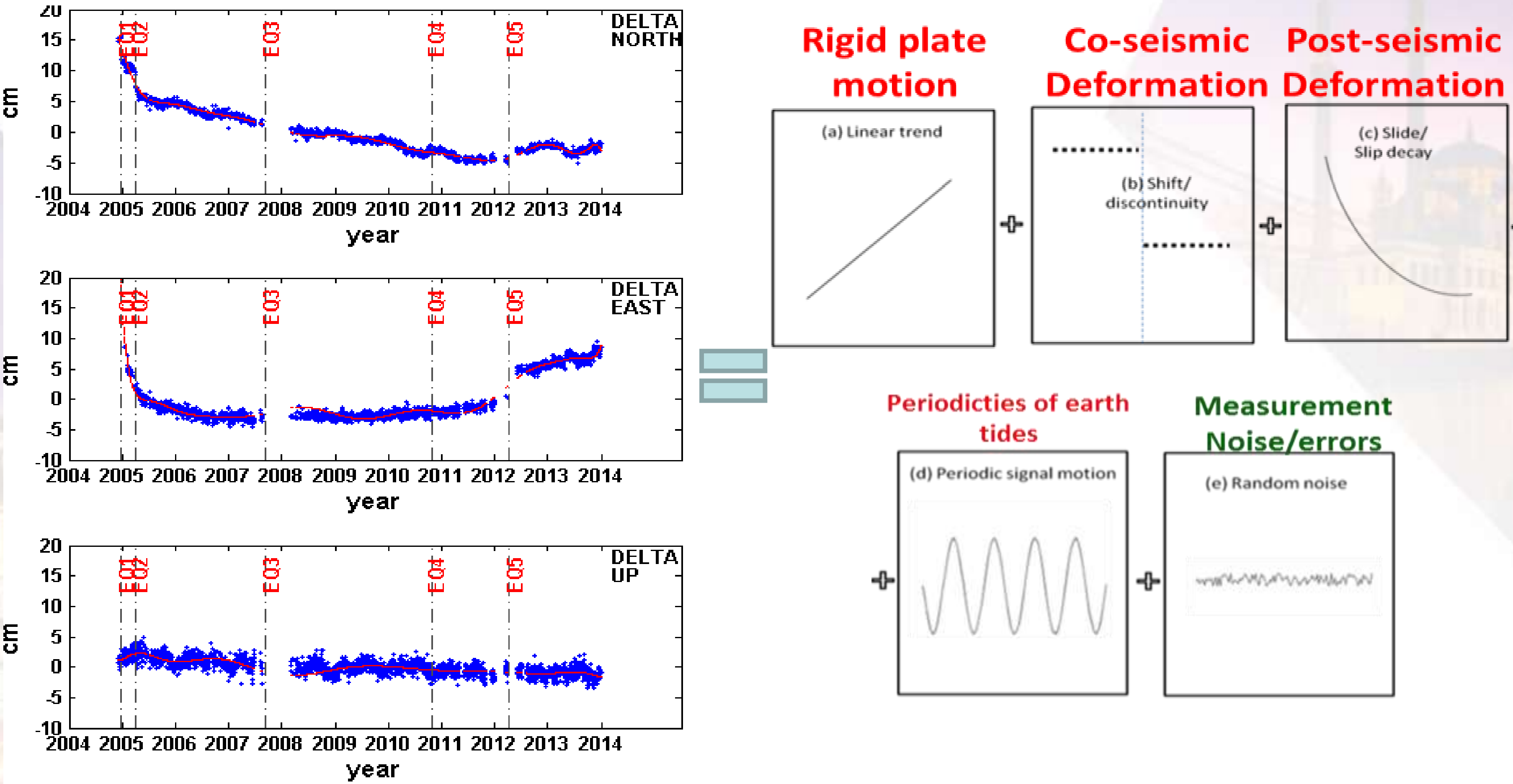
PHASE 1: Crustal deformation trend analysis



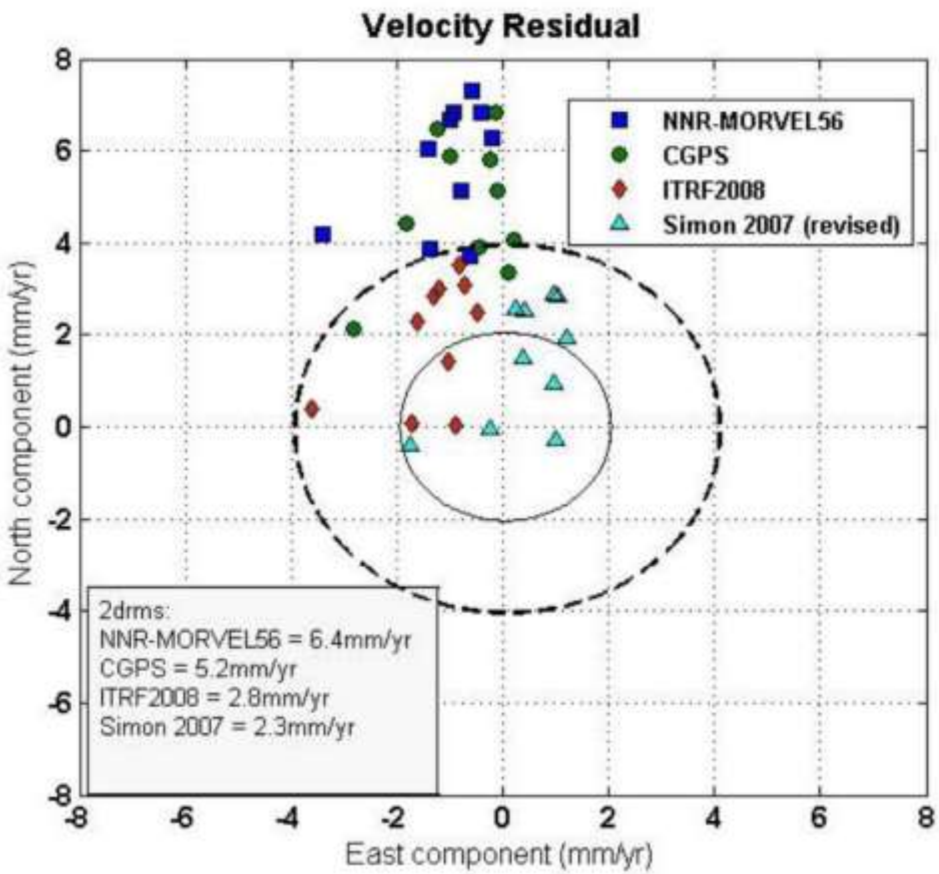


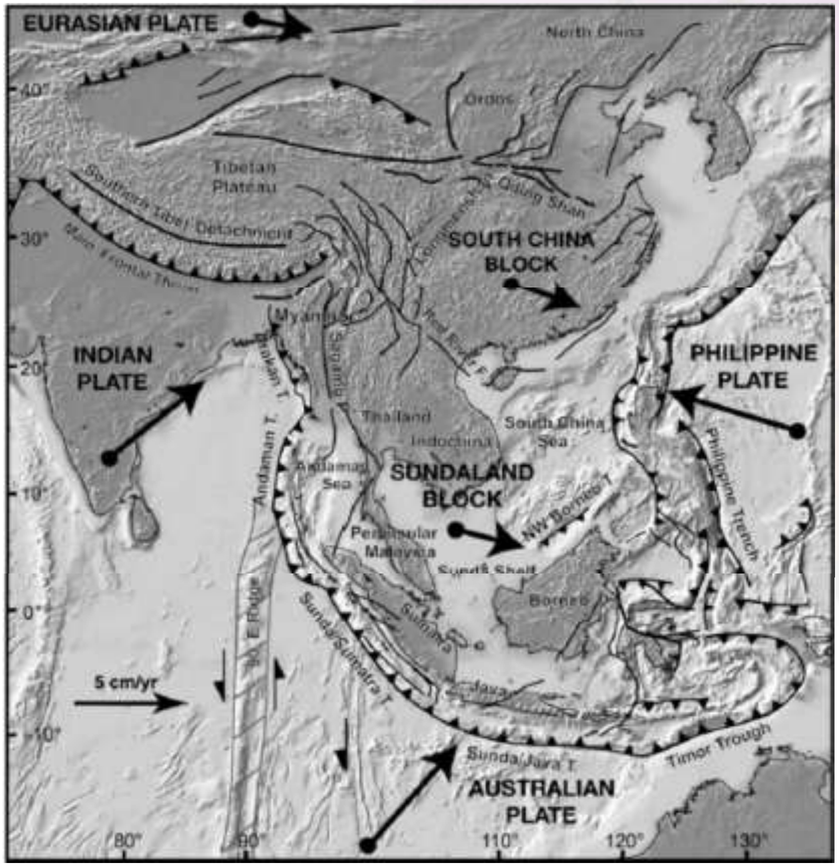
PHASE 1: Crustal deformation trend analysis



PHASE 1: Crustal deformation trend analysis

Selection of **Rigid Plate Motion** of Sunda





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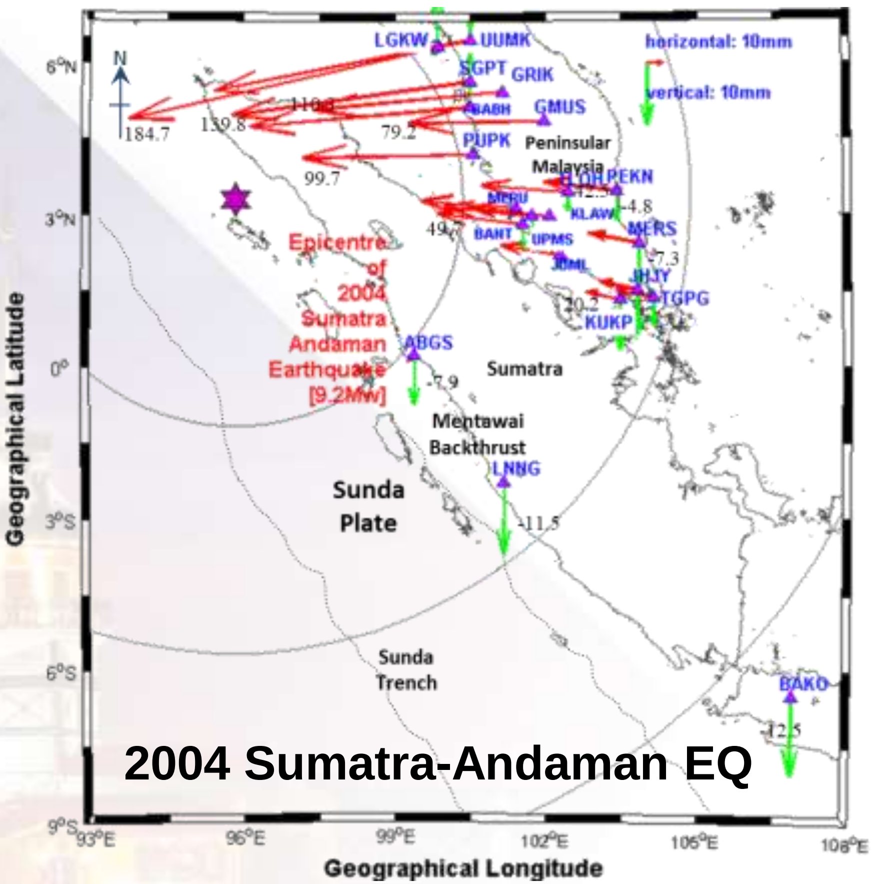
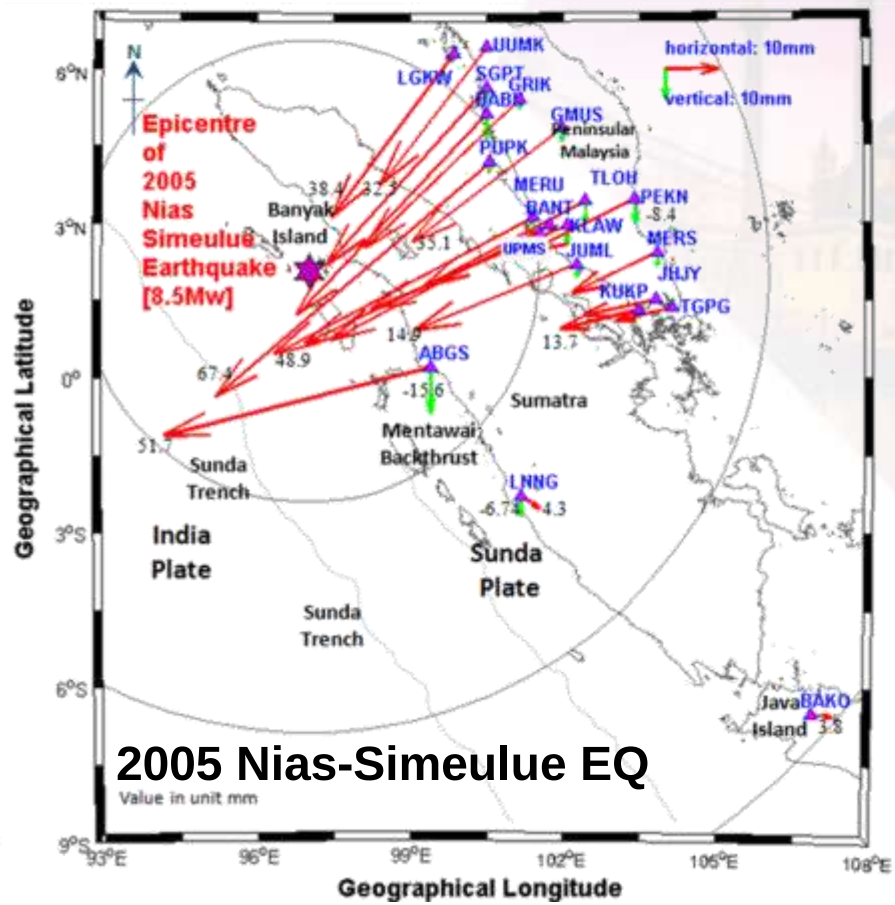
PHASE 2: Co- and Postseismic afterslip parameter estimation





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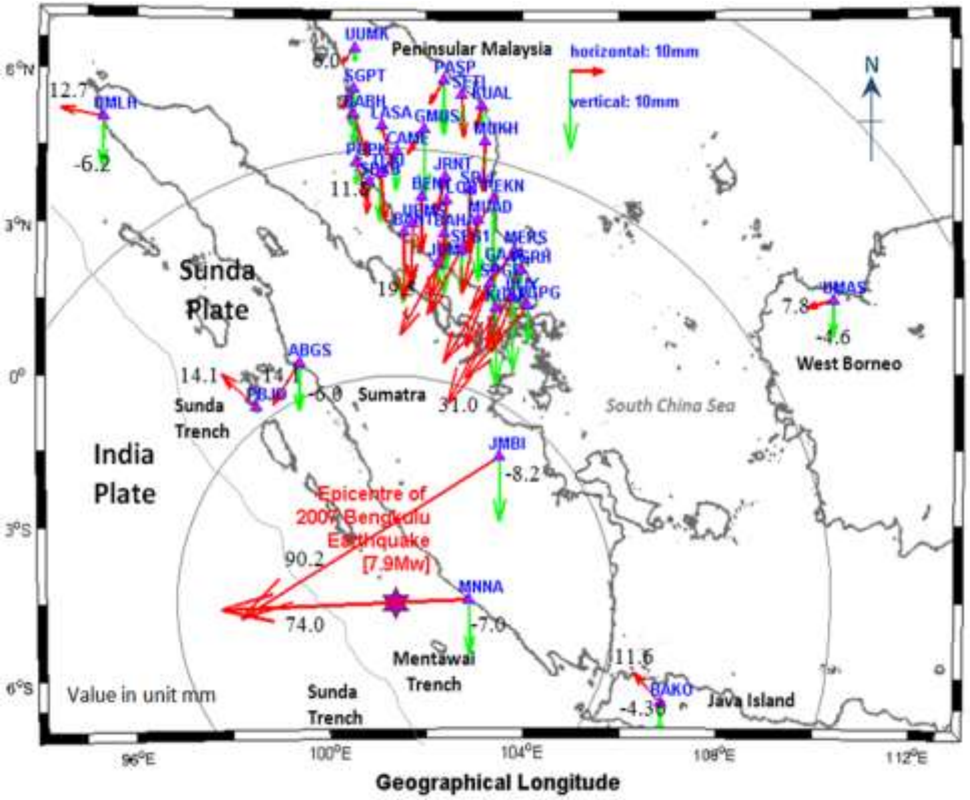
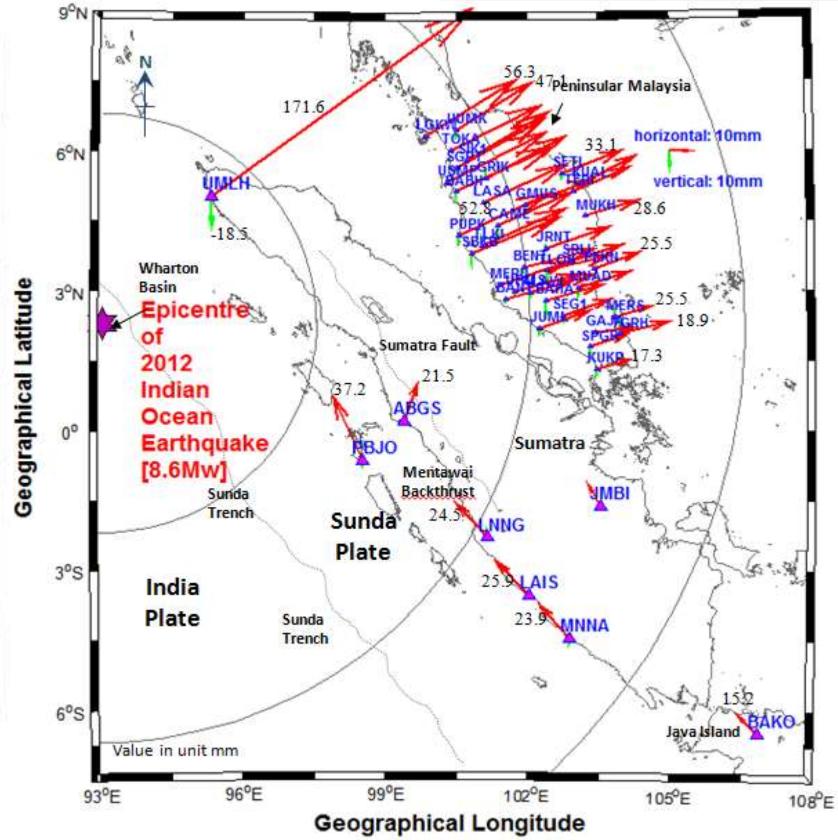


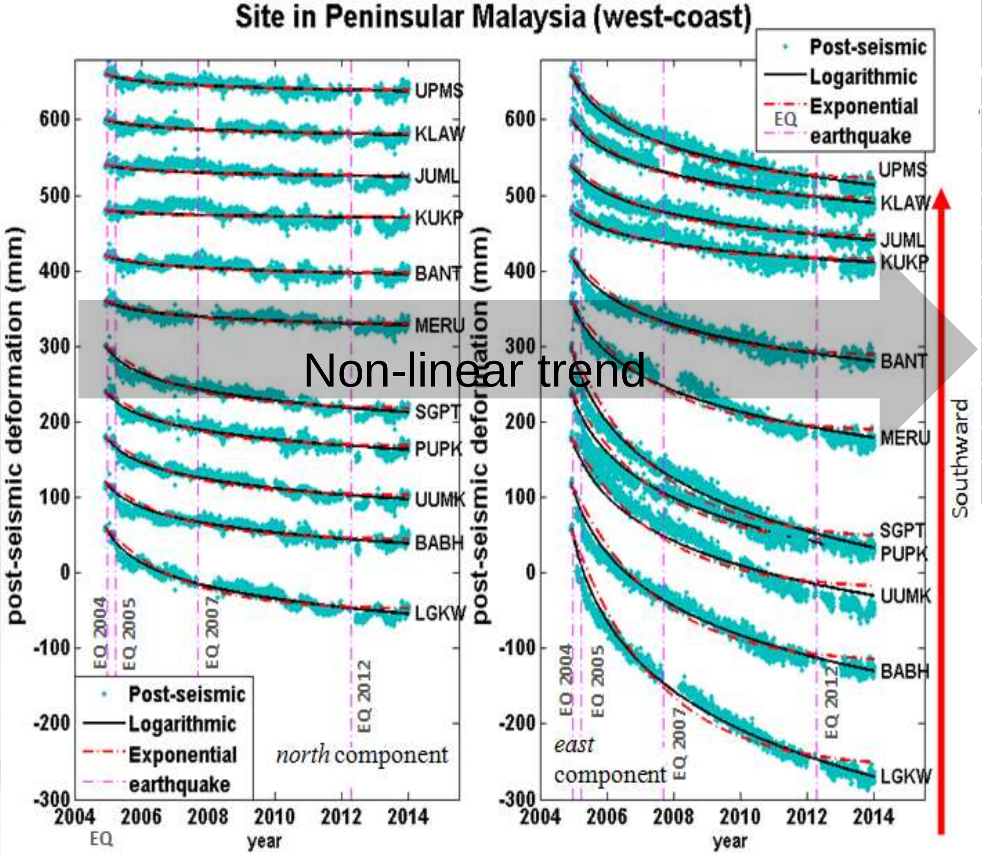
2007 Bengkulu EQ



2012 Indian-Ocean/ Wharthon Basin EQ

PHASE 2: Co- and Postseismic afterslip parameter estimation

Site	LOGARITHMIC (τ_{north} = 148.5days) (τ_{east} =204.1days)				EXPONENTIAL (τ_{north} = 819.3days) τ_{east} = 920.4days)			
	α_{north} (mm)	α_{east} (mm)	Horizontal (mm)	R^2 (mm)	α_{north} (mm)	α_{east} (mm)	Horizontal (mm)	R^2 (mm)
LGKW	-36.3	-116.0	121.5	0.9	-109.2	-320.0	338.1	0.9
BABH	-25.7	-87.9	91.5	1.0	-76.8	-241.1	253.0	0.9
UUMK	-26.3	-73.8	78.4	0.9	-78.6	-203.0	217.7	0.9
PUPK	-24.5	-75.4	79.3	0.9	-73.0	-206.8	219.3	0.8
SGPT	-27.7	-93.8	97.8	0.9	-83.0	-257.8	270.9	0.6
MERU	-10.1	-63.6	64.4	0.7	-30.3	-175.4	178.0	0.5
BANT	-7.8	-49.1	49.7	0.5	-23.2	-134.7	136.7	0.5
UPMS	-7.8	-49.1	49.7	0.5	-20.9	-141.2	142.8	0.5
KLAW	-6.3	-38.7	39.2	0.5	-18.7	-106.9	108.5	0.4
JUML	-4.8	-35.0	35.3	0.5	-14.3	-96.1	97.1	0.4
KUKP	-3.0	-24.2	24.4	0.4	-9.0	-66.4	67.0	0.4



$$u(t) = c + a\log_{10}(1 + t/\tau_{log})$$

Site	LOGARITHMIC (τ_{north} = 148.5days) (τ_{east} =204.1days)				EXPONENTIAL (τ_{north} = 819.3days) τ_{east} = 920.4days)			
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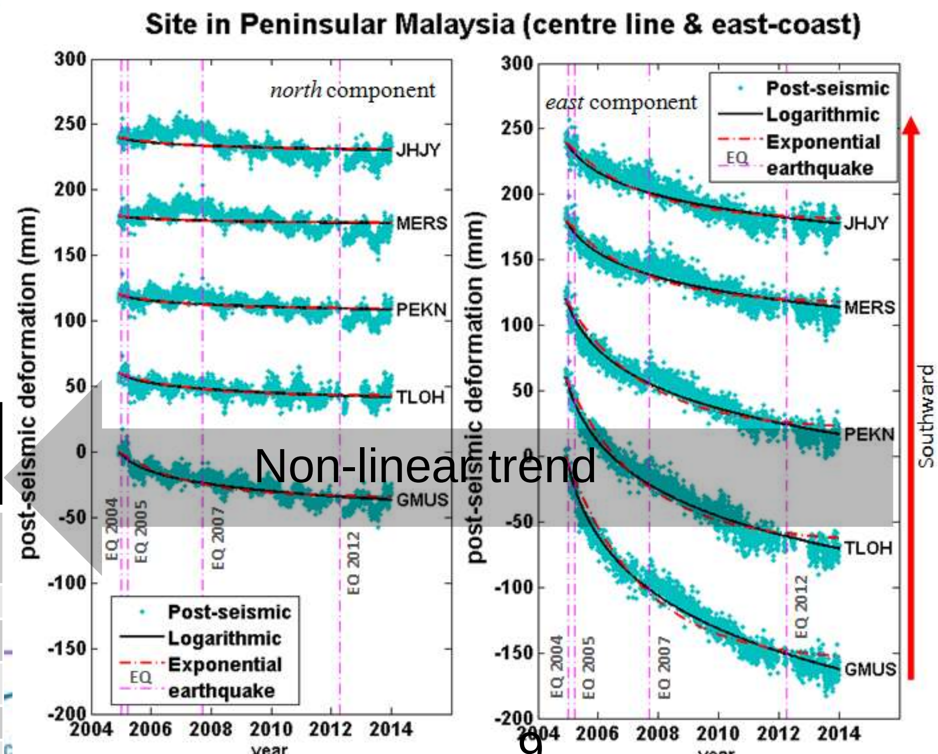
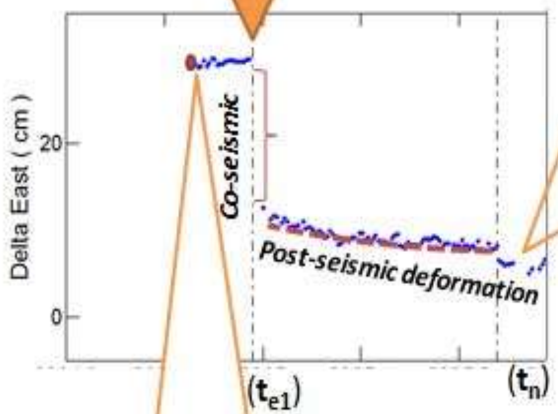


Phase 3: Resolving Dynamic Reference Frame

Time occurrence of earthquake (t_{e1})

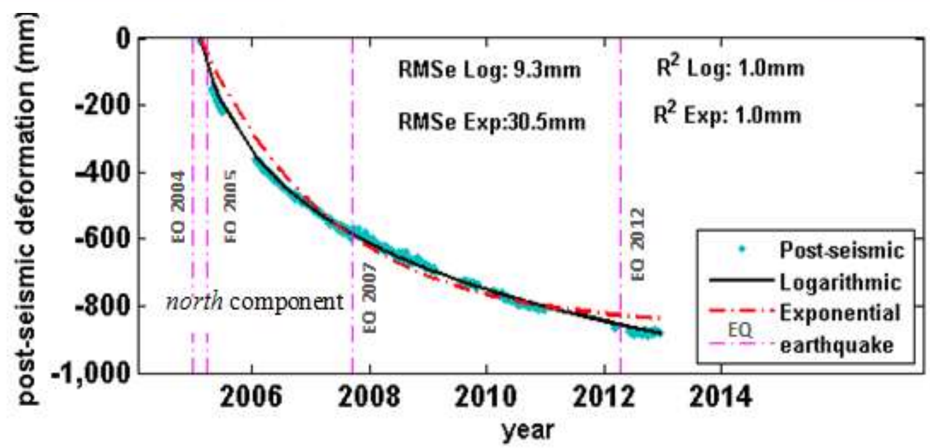


$P(t_0)$ = Initial ITRF coordinate of P at epoch 00

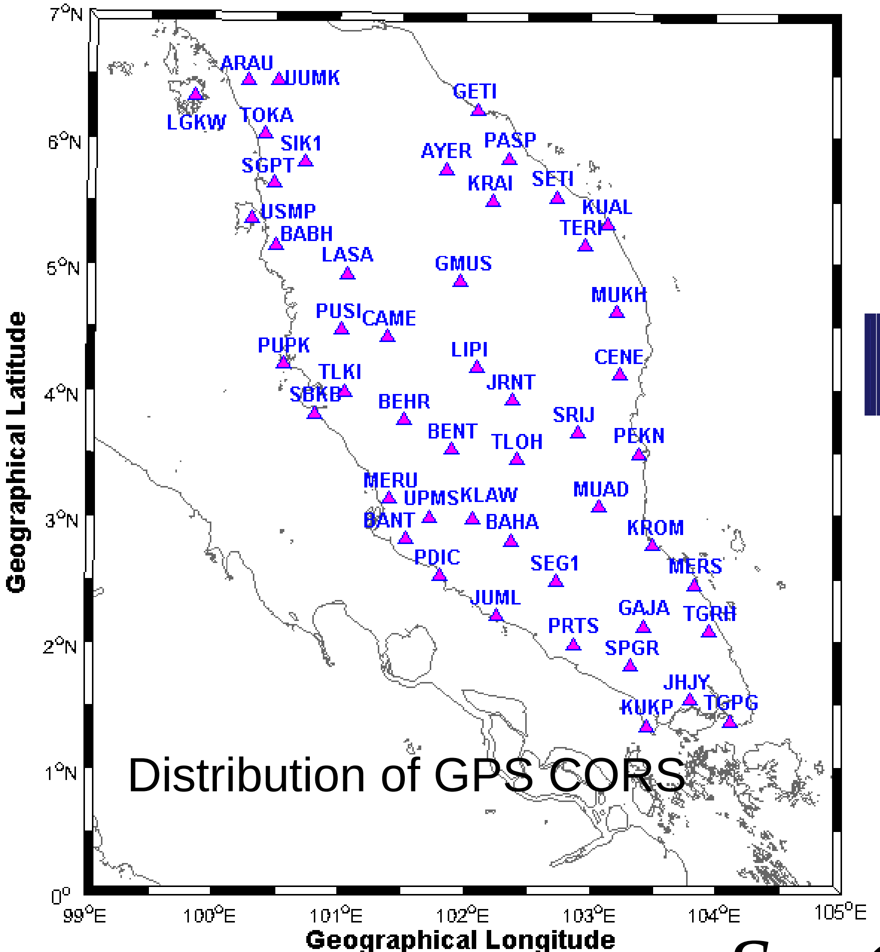
CSDM	Linear STDM	Non-Linear STDM

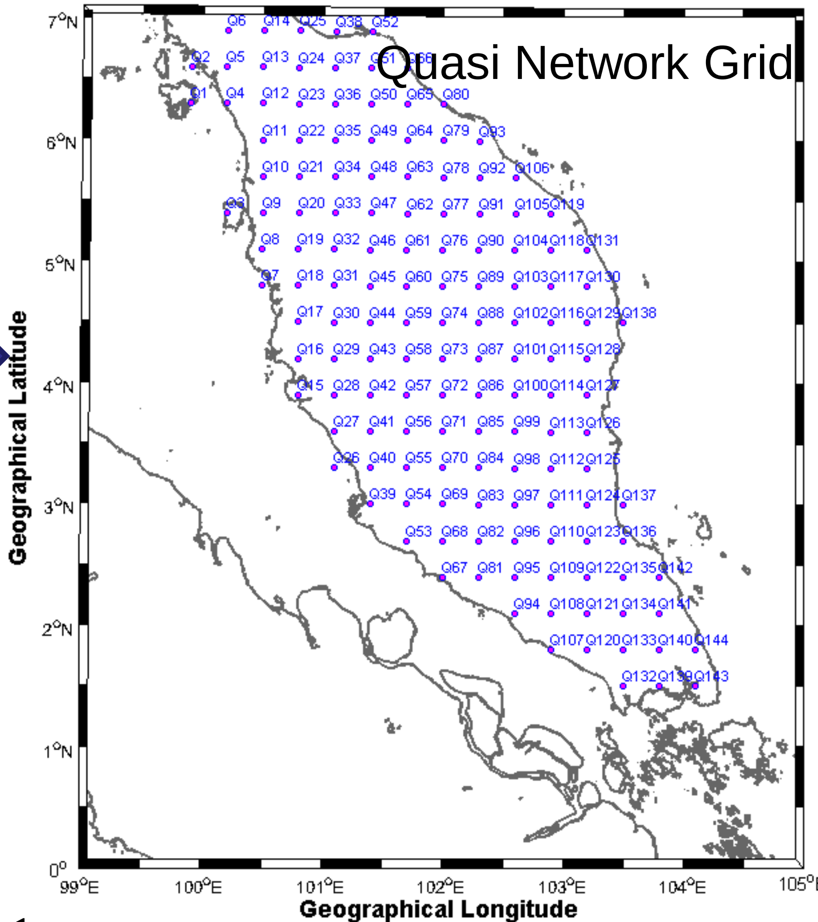
$$S^{p}_{te1,tn} = \boxed{C^{P}_{t_{e1}}} + \boxed{v^{P}_{(t_n - t_{e1})}} + \boxed{a^{P}_{e1} \log_{10}(1 + (t_n - t_{e1}) / \tau^{\log}_{e1})}$$

- Co-seismic displacement of point P at time $\mathbf{t}_{e1}$
- Plate rotation displacement of point P at time t_n. (Vp = inter-seismic site velocity at point P)
- Post-seismic displacement of point P at time $\mathbf{t}_n$ from $\mathbf{t}_{e1}$



Phase 3: Resolving Dynamic Reference Frame





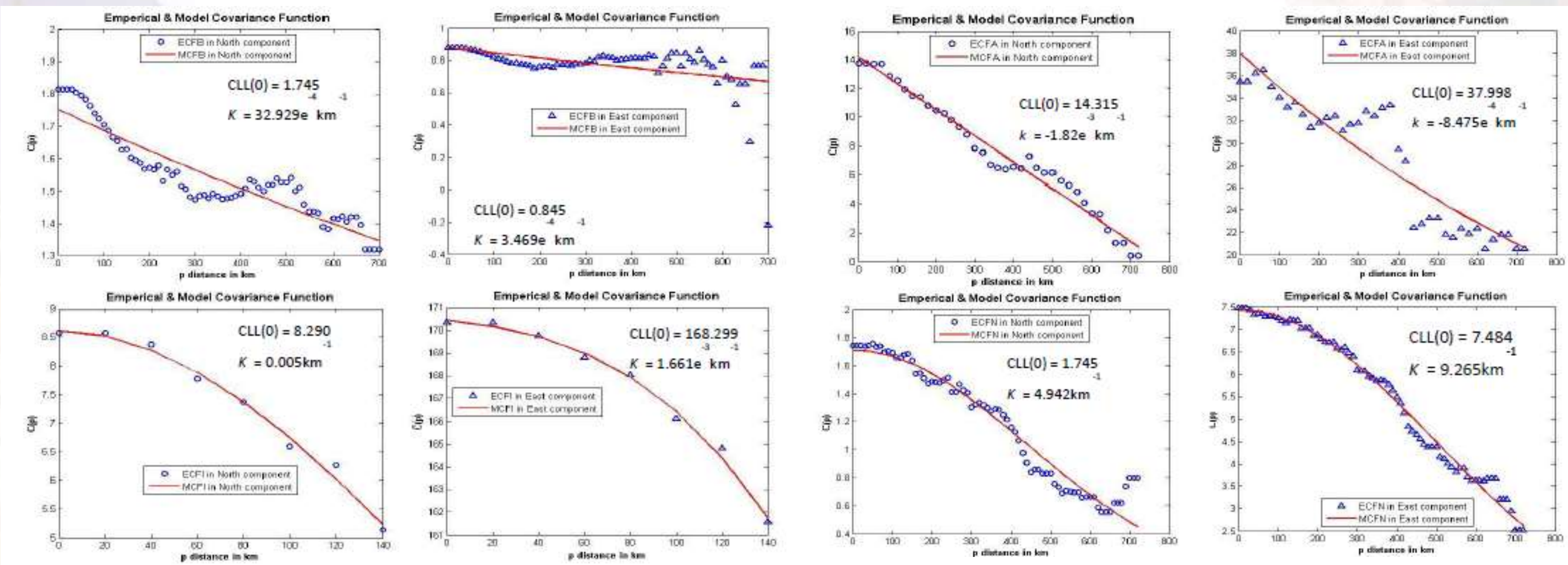
$$S = C_{SL} C_{LL}^{-1} L$$

- The crustal deformation after each earthquake event is considered as the signal to be estimated.
- By adopting **least square prediction technique** as expressed by Moritz, (1962); and Moritz, (1980), the predicted signal *S* (*i.e.,* co-seismic offset, post-seismic deformation parameter and site velocity) at the nearest point.

Phase 3: Resolving Dynamic Reference Frame

Empirical & Model Covariance Function

for each co-seismic offset, post-seismic amplitude, Sundaland's site velocity to enable for deformation signal prediction at Quasi Network Grid



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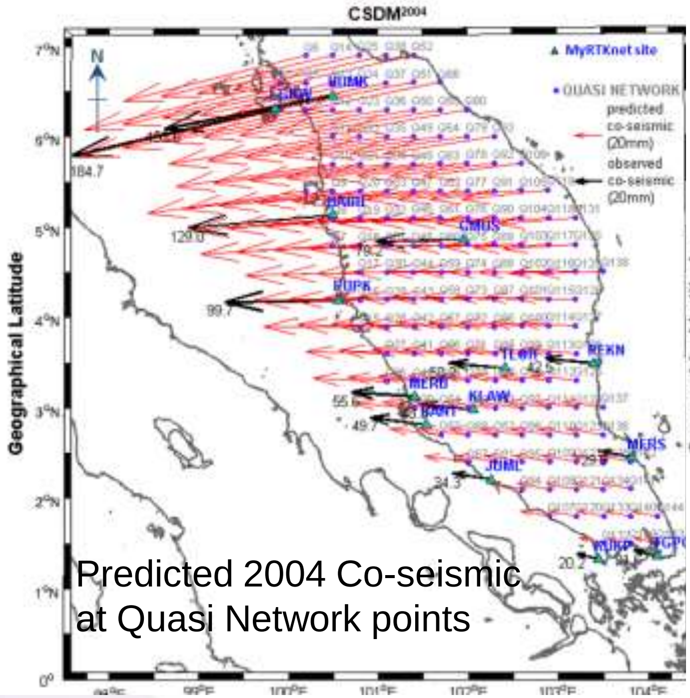
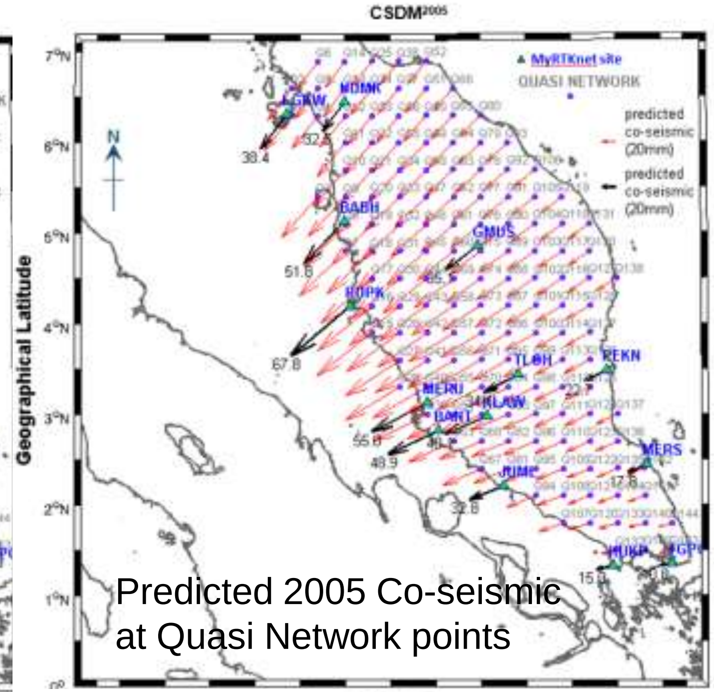
Phase 3: Resolving Dynamic Reference Frame

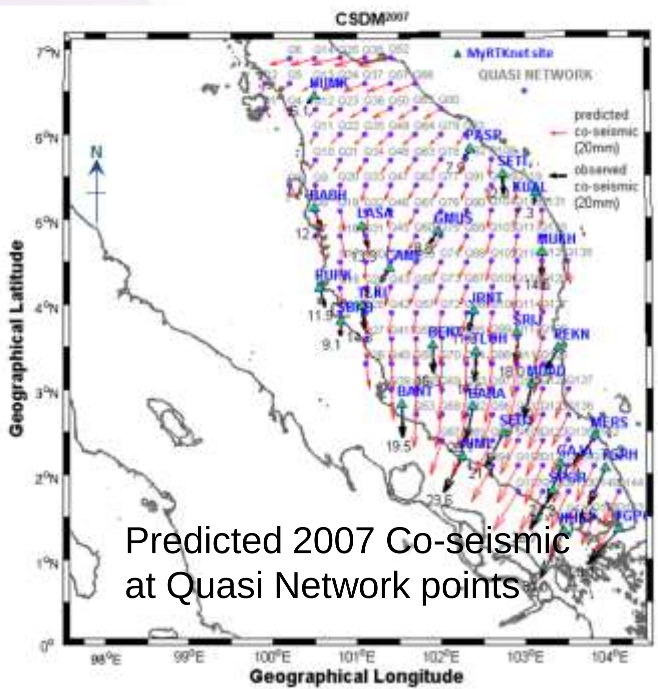
CSDM



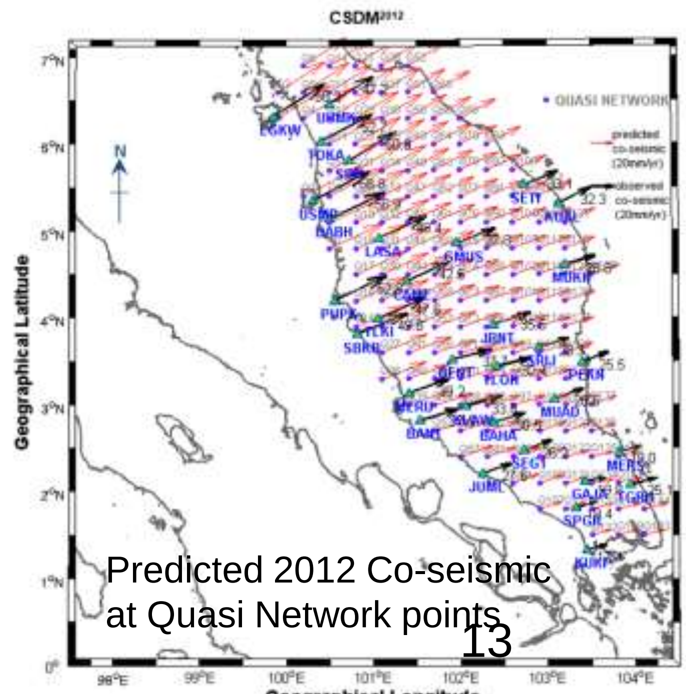
Predicted 2004 Co-seismic at Quasi Network points



Predicted 2005 Co-seismic at Quasi Network points



Predicted 2007 Co-seismic at Quasi Network points



Predicted 2012 Co-seismic at Quasi Network points

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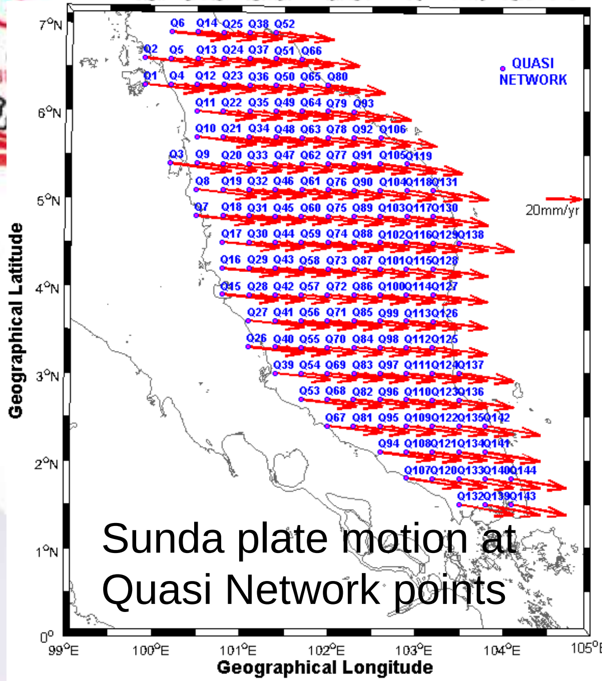
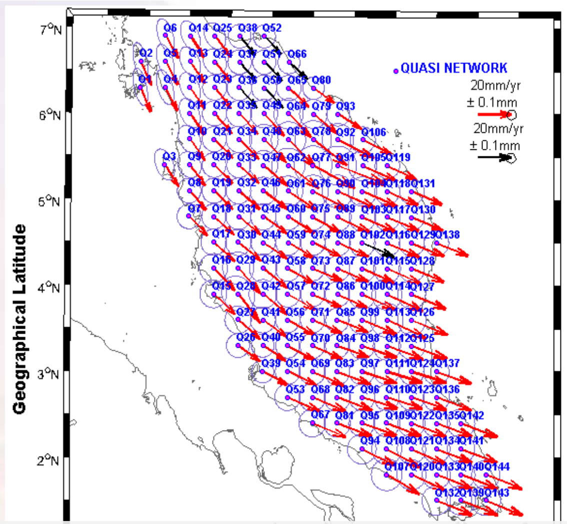
Phase 3: Resolving Dynamic Reference Frame

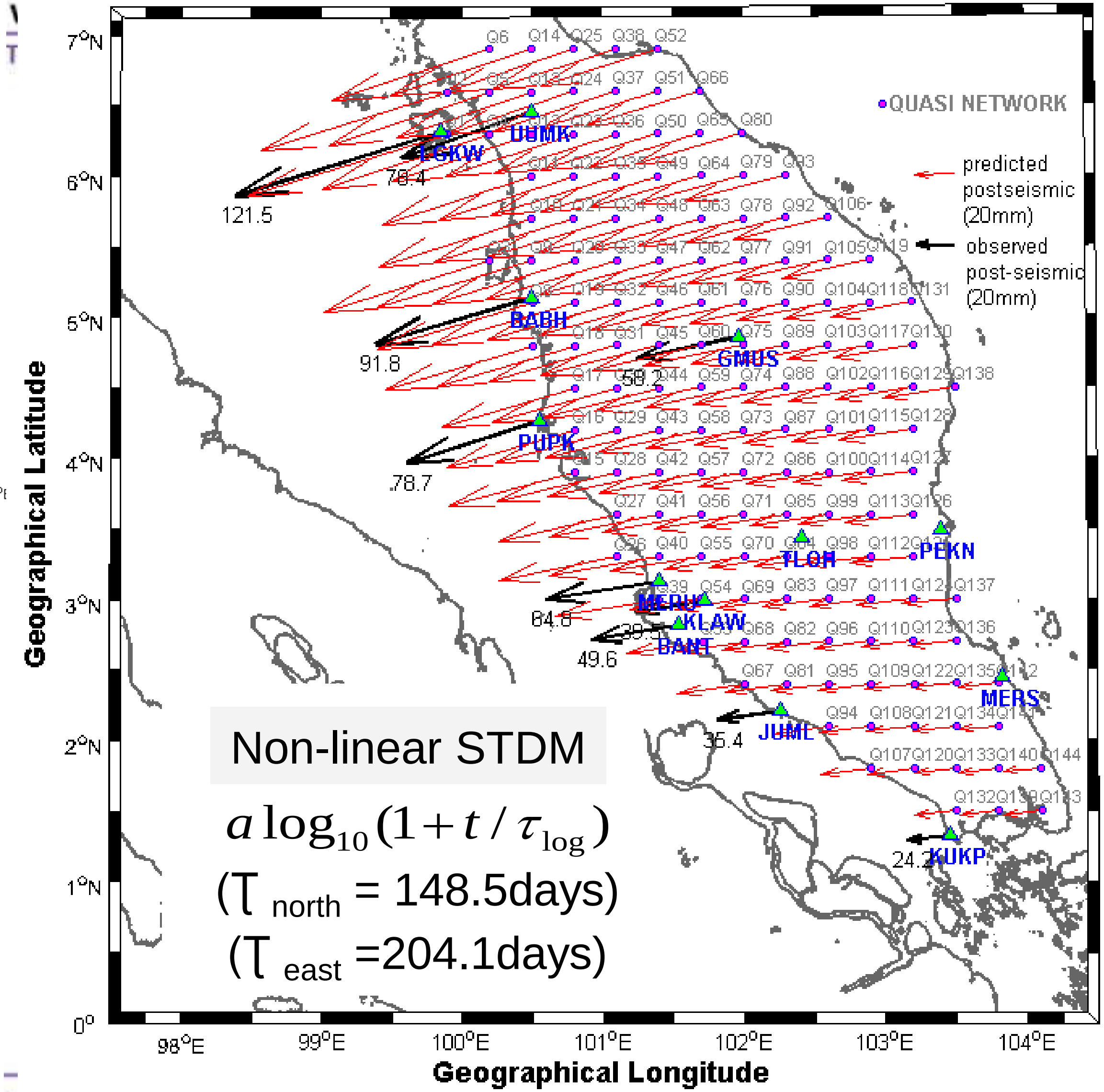
STDM



Sunda plate motion at Quasi Network points



Fitted piece-wise linear station velocity of STDM



Non-linear STDM

$$a \log_{10}(1 + t/\tau_{\log})$$

$(\tau_{north} = 148.5\text{days})$

$(\tau_{east} = 204.1\text{days})$

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Phase 4 -> to achieve 4th objective

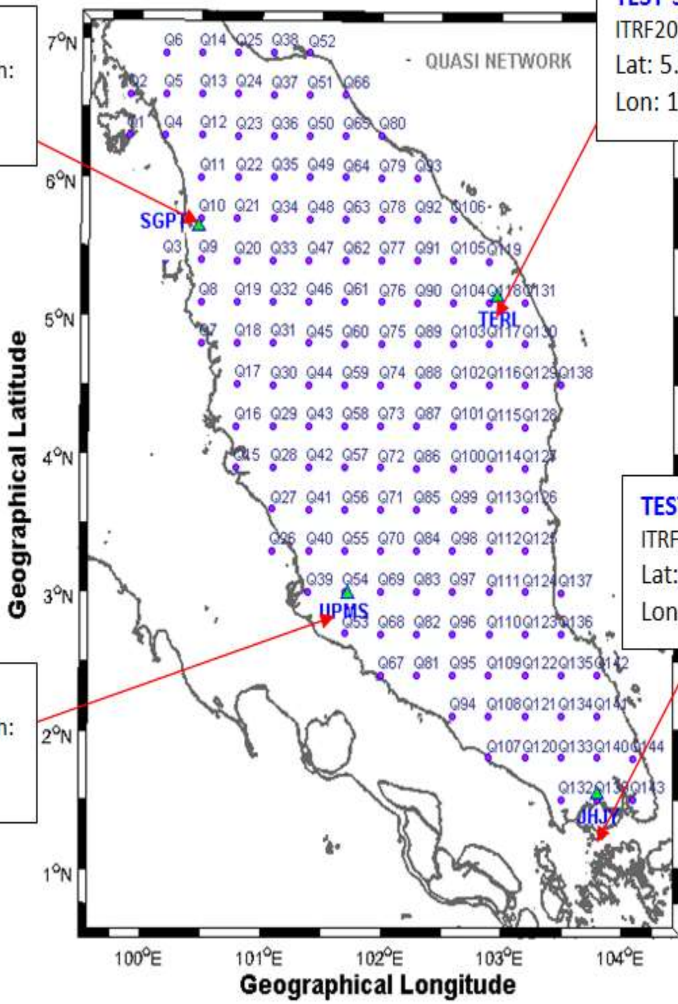
Phase 3: Resolving Dynamic Reference Frame (Assessment)

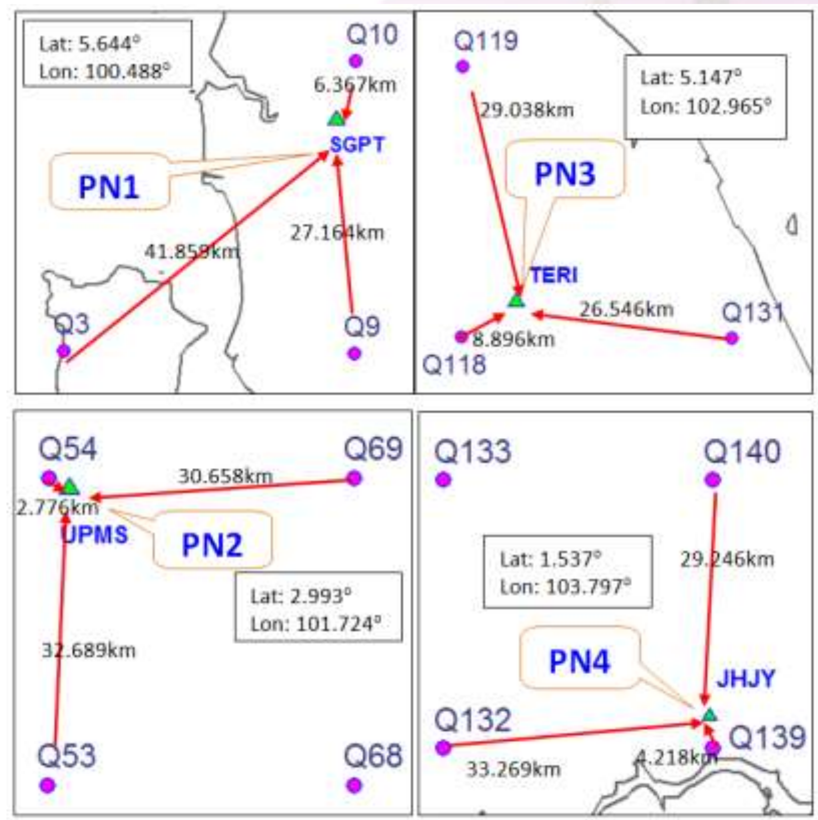
TEST 1: PN1
ITRF2008 location:
Lat: 5.644°
Lon: 100.488°

TEST 2: PN2
ITRF2008 location:
Lat: 2.993°
Lon: 101.724°

TEST 3: PN3
ITRF2008 location:
Lat: 5.147°
Lon: 102.965°

TEST 4: PN4
ITRF2008 location:
Lat: 1.537°
Lon: 103.797°

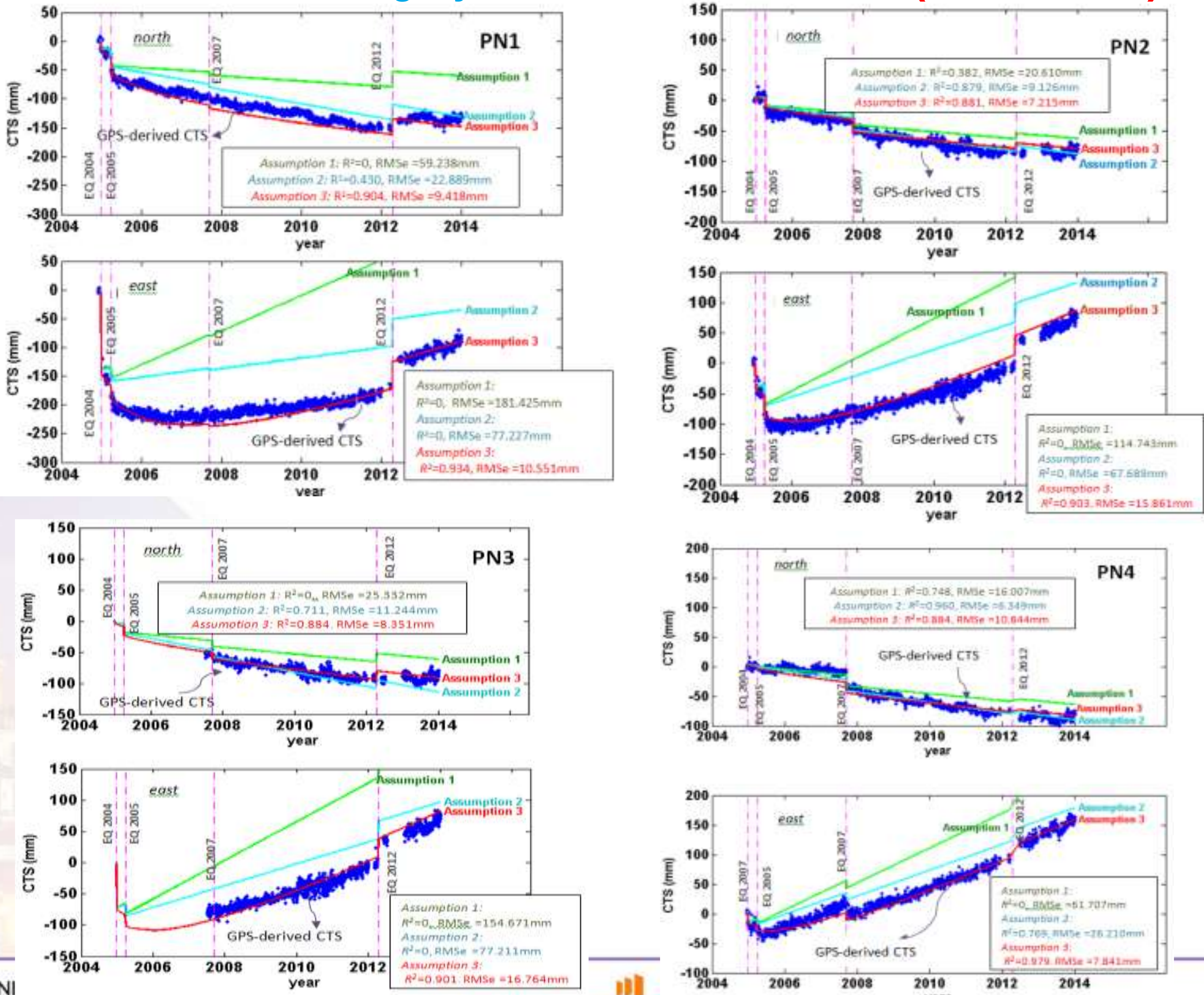




Phase 3: Resolving Dynamic Reference Frame (Assessment)

Assumption	Explanation	Temporal Trend of Crustal Deformation	STDM Models
Assumption 1	After the occurrence of major earthquakes in Sundaland, crustal deformation in Peninsular Malaysia still induced by **similar rotation of Sunda plate only.**	Linear STDM and CSDM correction	Sunda plate rotation
Assumption 2	After the occurrence of major earthquakes in Sundaland, crustal deformation in Peninsular Malaysia has changed and continually **moving as different plate entity apart from Sunda plate rotation**.	Linear STDM and CSDM correction	Fitted piece-wise linear station velocity
Assumption 3	After the occurrence of major earthquakes in Sundaland, crustal deformation of Peninsular Malaysia still **induced by the similar rotation of Sunda plates at it was before, but undergoing significant afterslip deformation (i.e., co-seismic and post-seismic).**	Non-linear STDM and CSDM correction	SuLin-STDM + PosNoLIn-STDM + CSDMs

Phase 3: Resolving Dynamic Reference Frame (Assessment)



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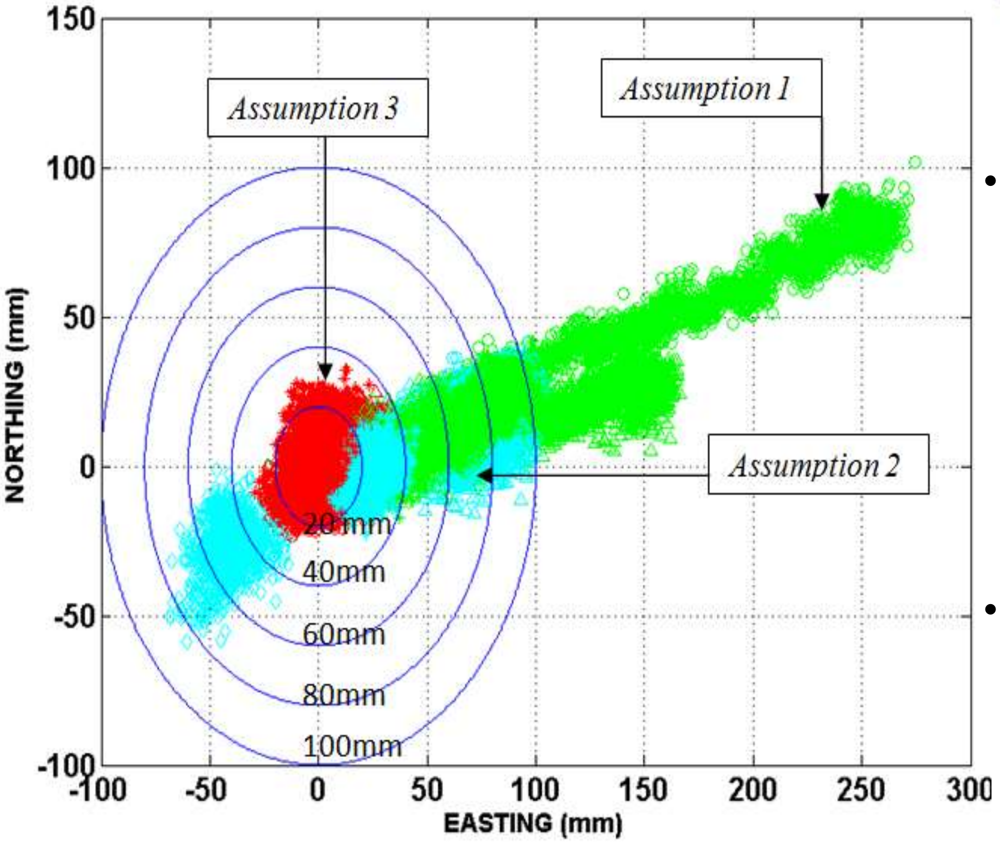

Concluding Remark

- The results indicate after the occurrence of major earthquakes in Sundaland, crustal deformation of Peninsular Malaysia is **still induced by the similar rotation of Sunda plates as it was before, but undergoing significant afterslip deformation that depicts non-linear crustal deformation over the region.**
- Therefore, the utilization of CSDM and non-linear STDM is appropriate to cope with dynamics reference frame due to non-linear crustal deformation.

~83% of simulated CTS from *Assumption 1* fall inside the 2cm limit, and ~17% fall between 2 and 4 cm. Meanwhile, 22% of simulated CTS from *Assumption 2* fall within 2 cm limit, and the other 78% were distributed from 2 to 10 cm.

Special Thanks to:

1) Universiti Teknologi Malaysia and Ministry of Higher Education (MOHE) under the FRGS Fund, Vote Number R.J130000.7827.4F962

UTM Universiti Teknologi Malaysia — Faculty of Geoinformation and Real Estate

2) Land Surveyors Board of Malaysia

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