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An Approach to Geocentric Reference Frame Revision for Malaysia

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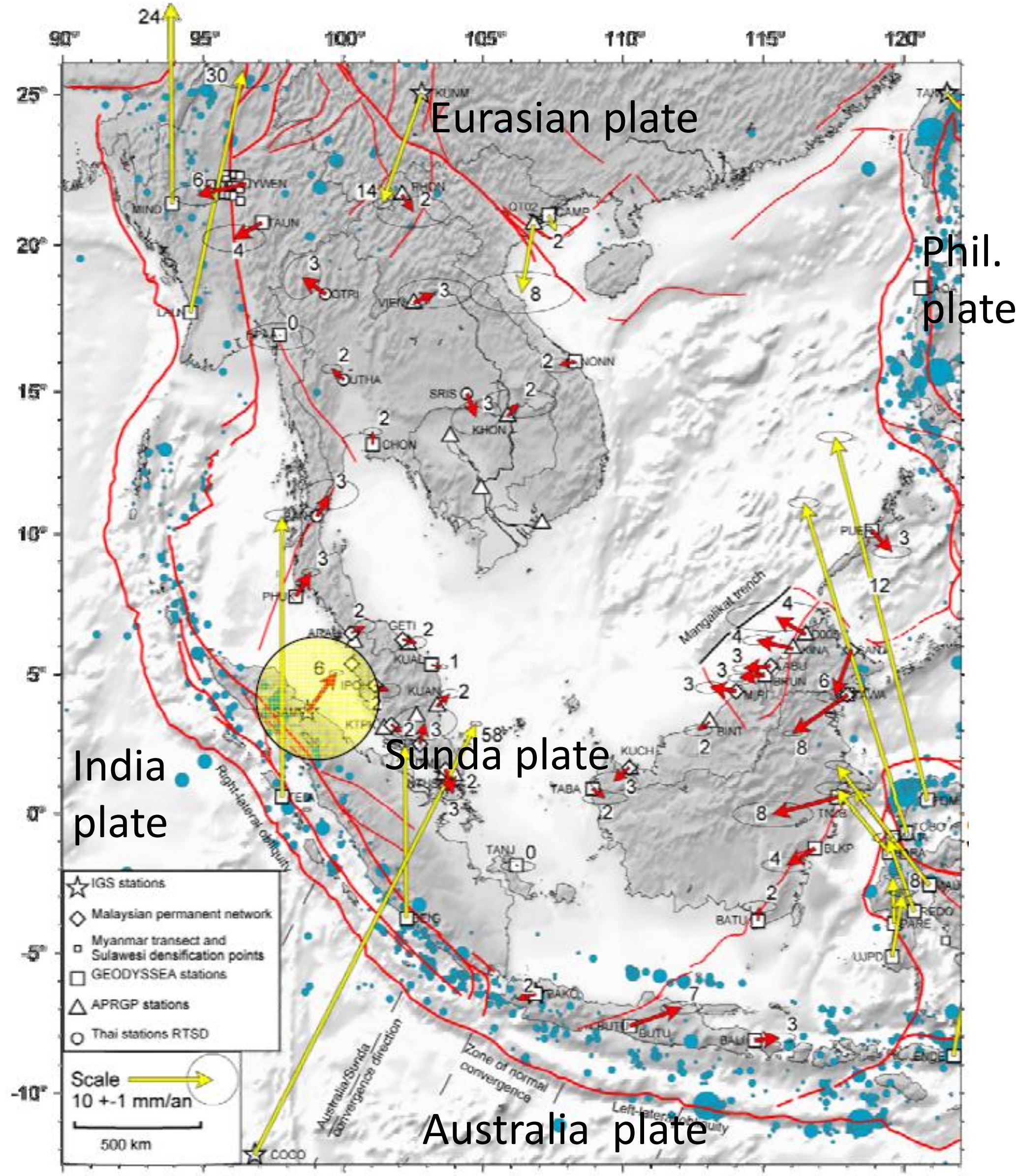
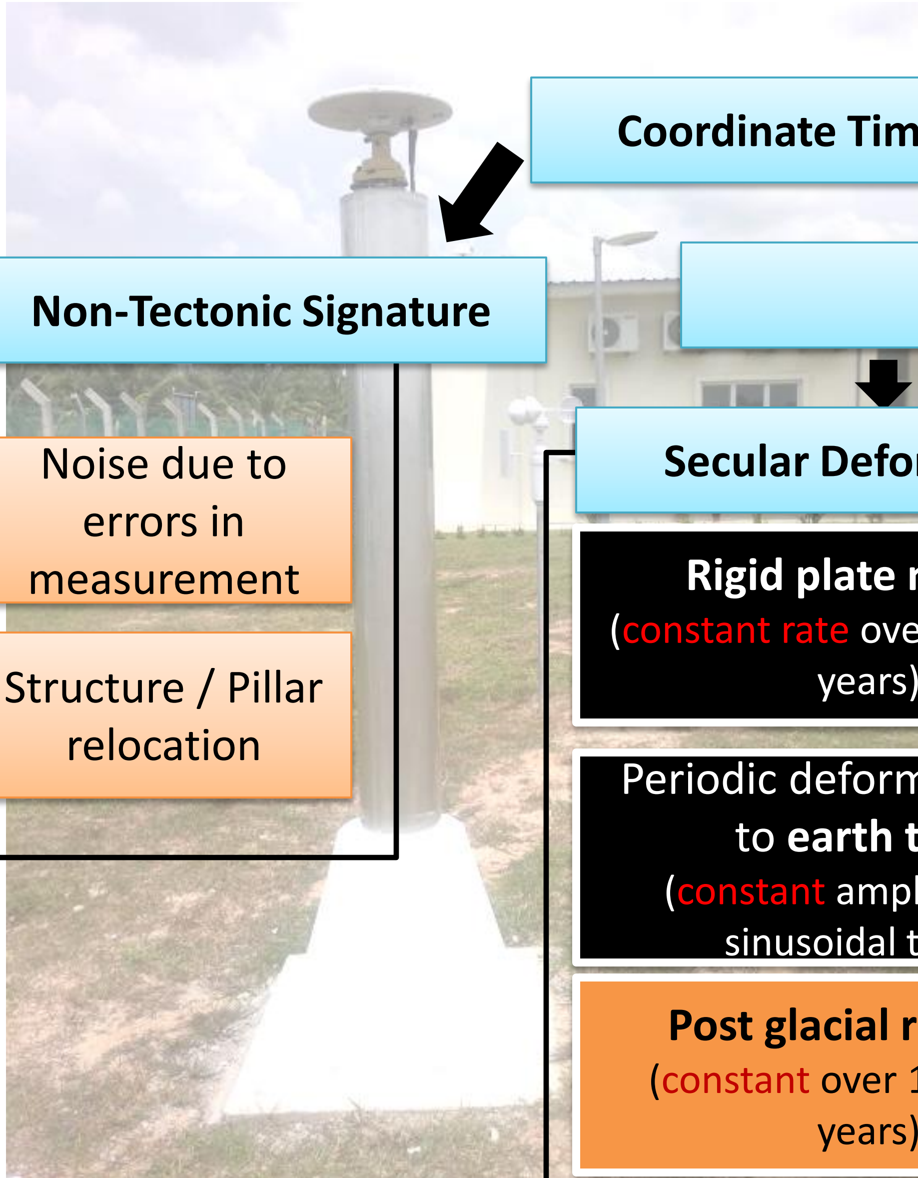
CONTENTS

Introduction

- Dynamic processes of the earth (e.g. earthquakes and long-term plate tectonic motions) are able to displace reference station coordinates.
- For instance, the 2004 Aceh megathrust earthquake significantly affects land displacements up to 10 cm in magnitude at a radius of 400 km away from the earthquake's epicentre (Vigny et al., 2005).
- Thus, it will considerably affect the reliability of a geocentric datum.



Tectonic Signature in ITRF Coordinate Time Series



Coordinate Time Series

Non-Tectonic Signature

- Noise due to errors in measurement
- Structure / Pillar relocation

Tectonic Signature

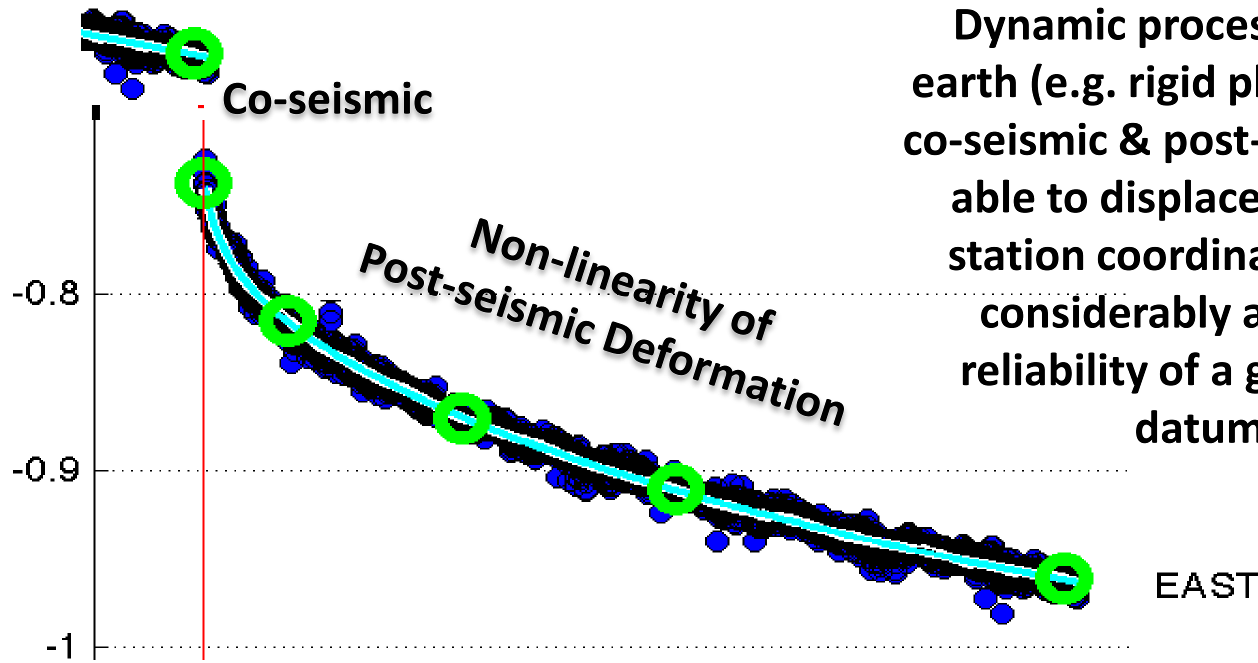
Secular Deformation

- **Rigid plate motion** (constant rate over 100 –1000 years)
- Periodic deformation due to **earth tides** (constant amplitudes of sinusoidal trend)
- **Post glacial rebound** (constant over 100 –1000 years)

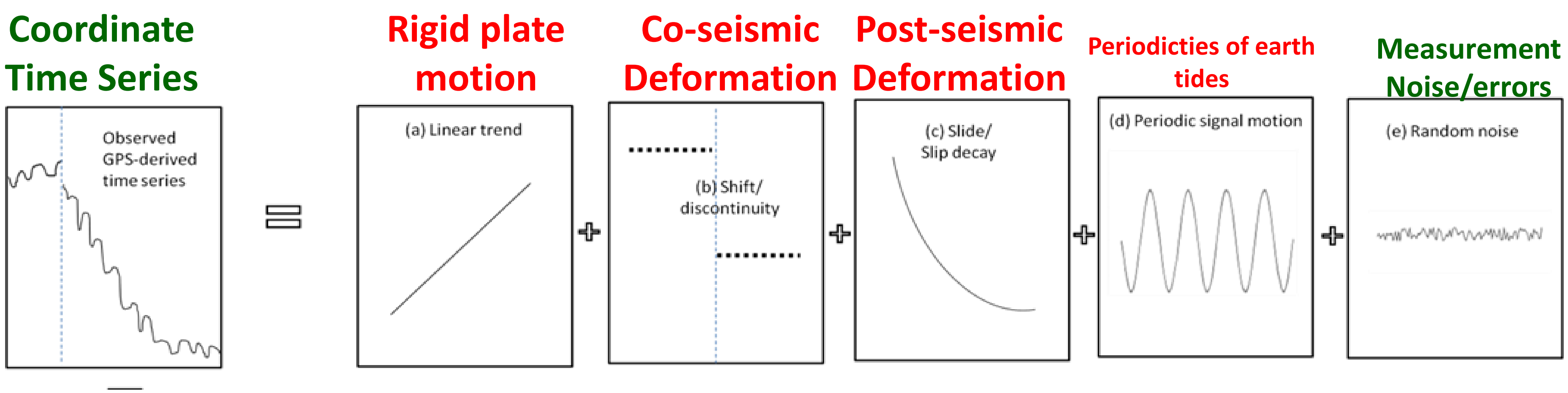
Non-Secular Deformation

- **Co-seismic deformation** (discontinuity from second to minute)
- **Post-seismic deformation** (logarithmic/exponential trend from hour to decades)
- Localized deformation (land subsidence)

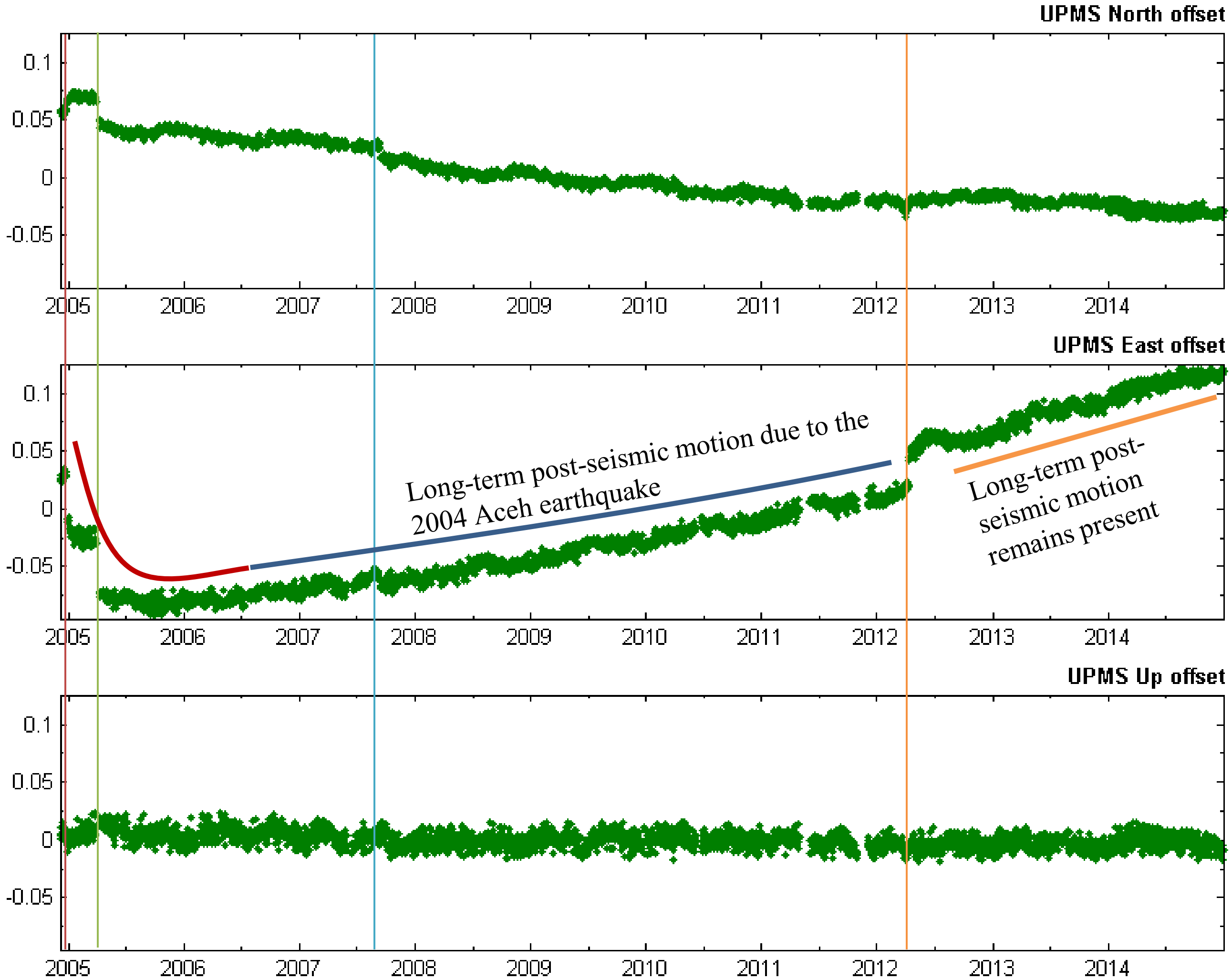
Tectonic Signature in ITRF Coordinate Time Series



Dynamic processes of the earth (e.g. rigid place motion, co-seismic & post-seismic) are able to displace reference station coordinates. It will considerably affect the reliability of a geocentric datum.



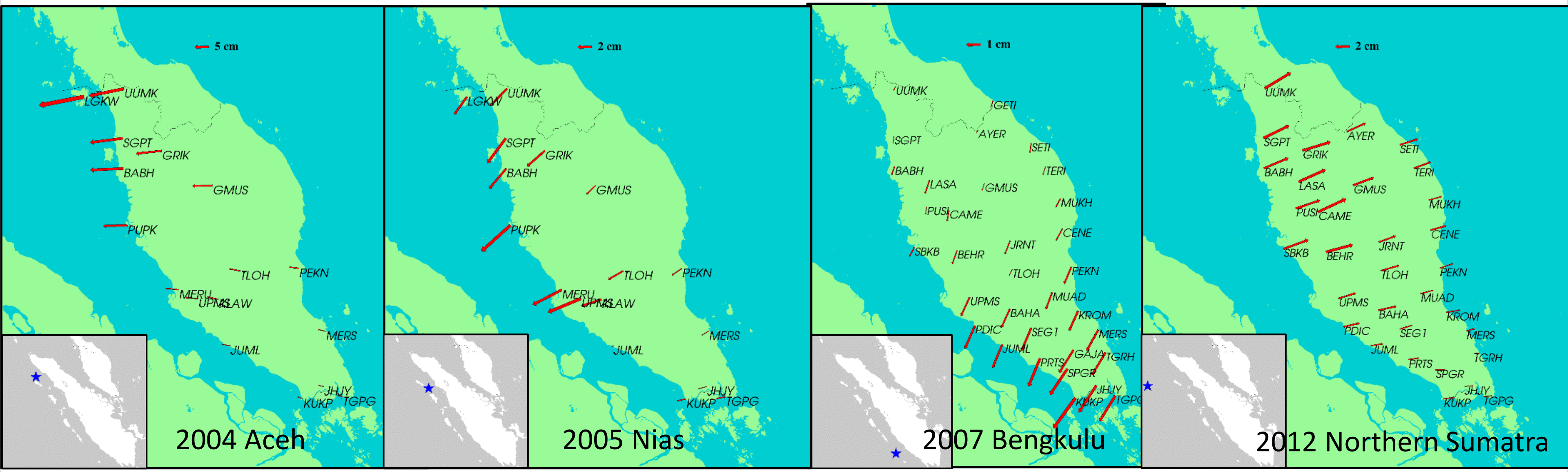
Tectonic Motion Analysis: Peninsular Malaysia



	26th December 2004 Aceh earthquake (9.2 Mw)
	28th March 2005 Nias earthquake (8.65Mw)
	12th September 2007 Bengkulu earthquake (7.9 Mw)
	11th April 2012 Northern Sumatra earthquake (8.6 Mw)

The Co-seismic displacement in Malaysia

Earthquake	Average Co-seismic Displacement of Peninsular Malaysia (cm) East Malaysia were < 10mm	
	North Region	South Region
2004 Aceh	13.1	2.6
2005 Nias	2.7	1.5
2007 Bengkulu	0.2	2.9
2012 Northern Sumatra	3.6	1.2



The Post-seismic displacement in Peninsular Malaysia

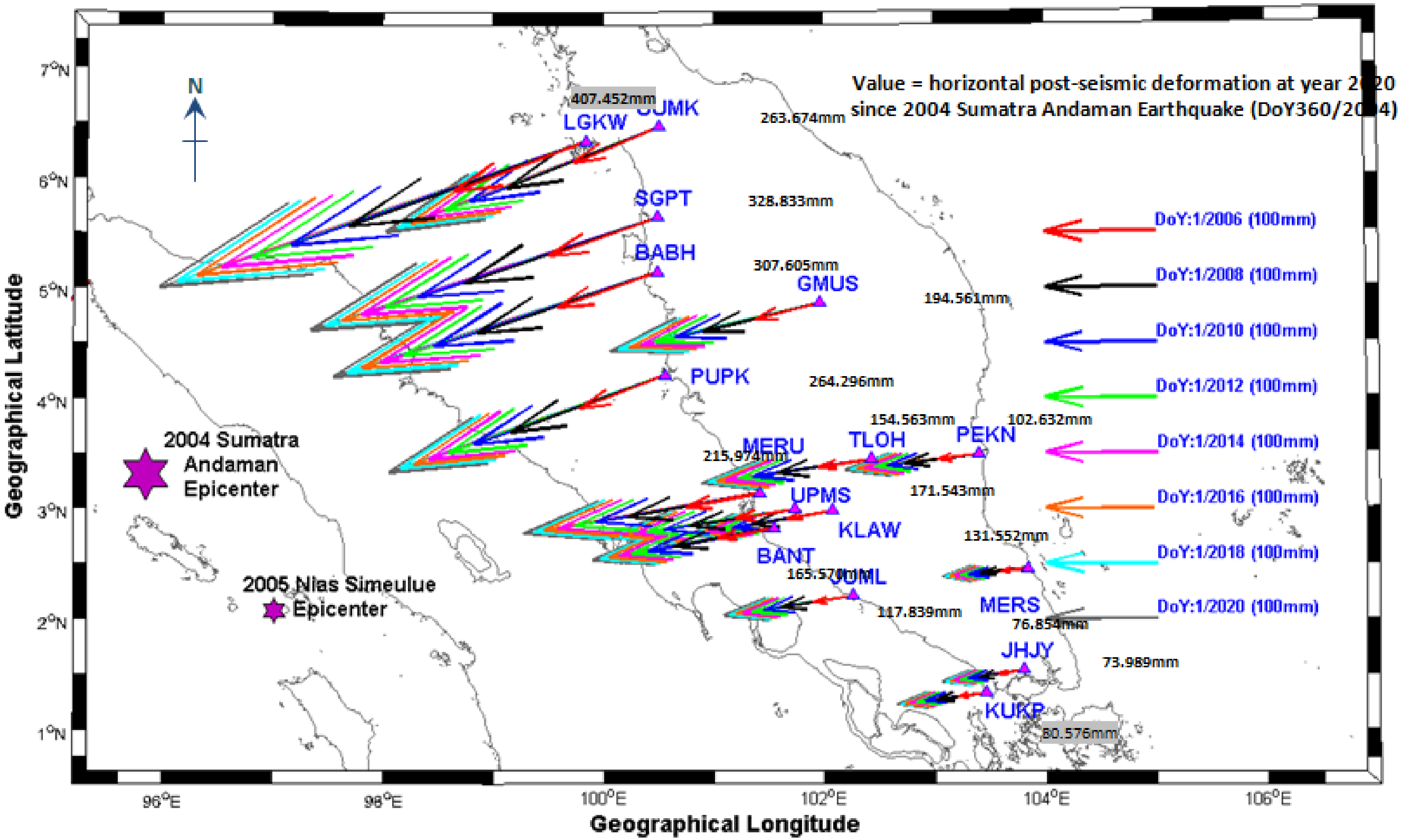
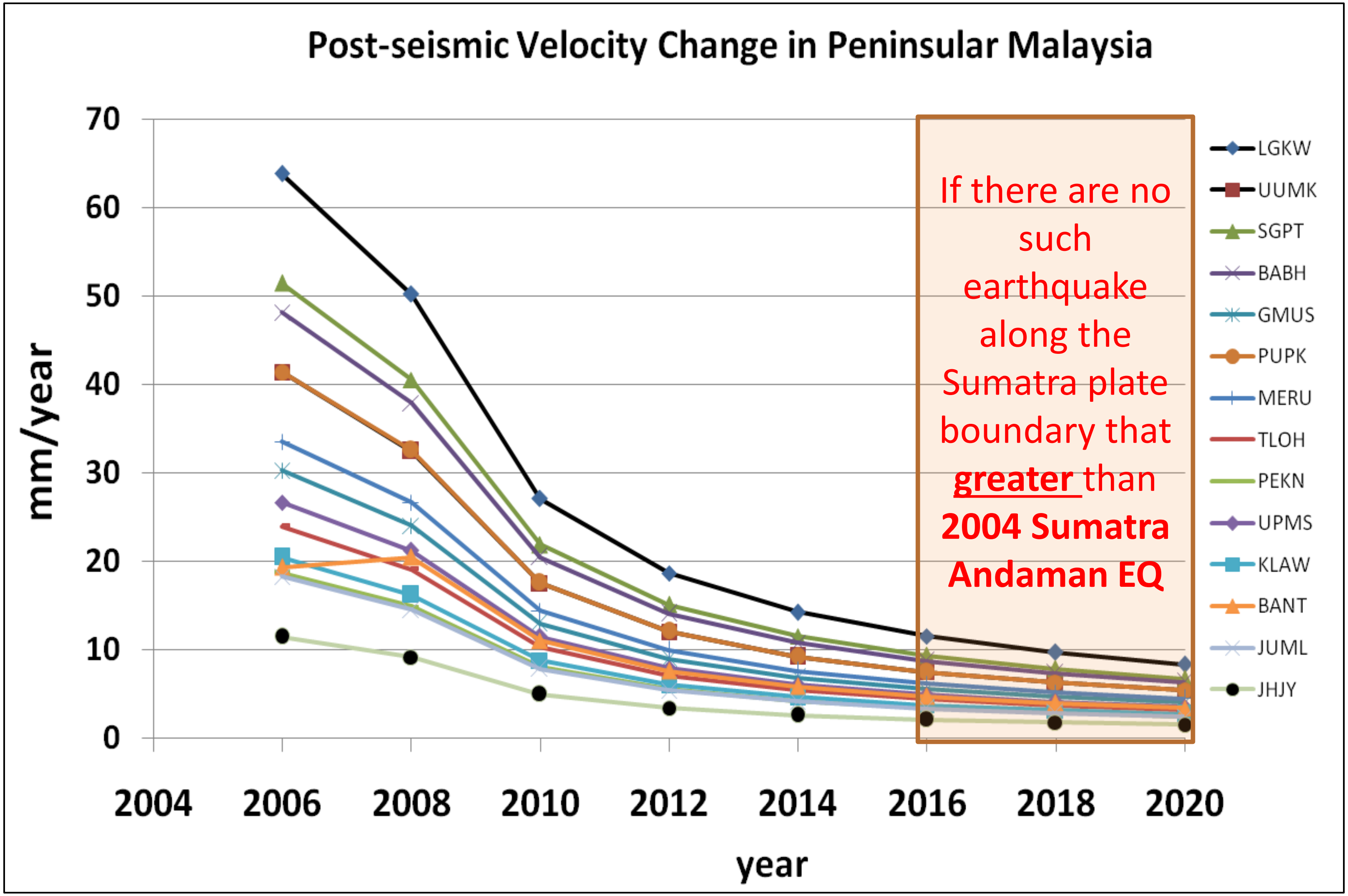


Figure 3.22: Prediction of afterslip post-seismic vector (2006-2020) in Peninsular Malaysia.

The Post-seismic displacement in Peninsular Malaysia



Status of GDM2000@2006

GDM2000@2000 established originally in 2000, then GDM2000@2006 was revised in 2006. The Revision approximately carried out more than 10 years ago has become non-geocentric due to the Peninsular Malaysia has further experienced secular & non-secular tectonic deformation effects within the period as follows;

(1) Continuous rotation of Sunda plate moves almost all MyRTKnet sites and passive network at 2-3cm/yr .This is caused by the pushing of the Indian and Australian plates towards Sunda plate at rates 45mm/yr and 59mm/yr, respectively.

(2) Significant transient slip due to 2004 Sumatra Andaman as well as subsequent (>Mw 8) earthquakes have caused centimeter level to submeter level co-seismic displacement for almost all MyRTKnet sites and passive network (CCI points).

(3) Long-term and complex post-seismic relaxation as experienced by the region causing non-linear of coordinate change at 1-1.5meter (logarithmic trend) over the time.

Status of GDM2000@2006

- Therefore,
  - What are the implications of non-geocentric datum?
  - What is the extent of deformation on the GDM2000 coordinates?
  - Should GDM2000 be revised?
  - What is the best approach for revision w.r.t. the current local plate tectonics?

Implications of a Non-Geocentric Datum

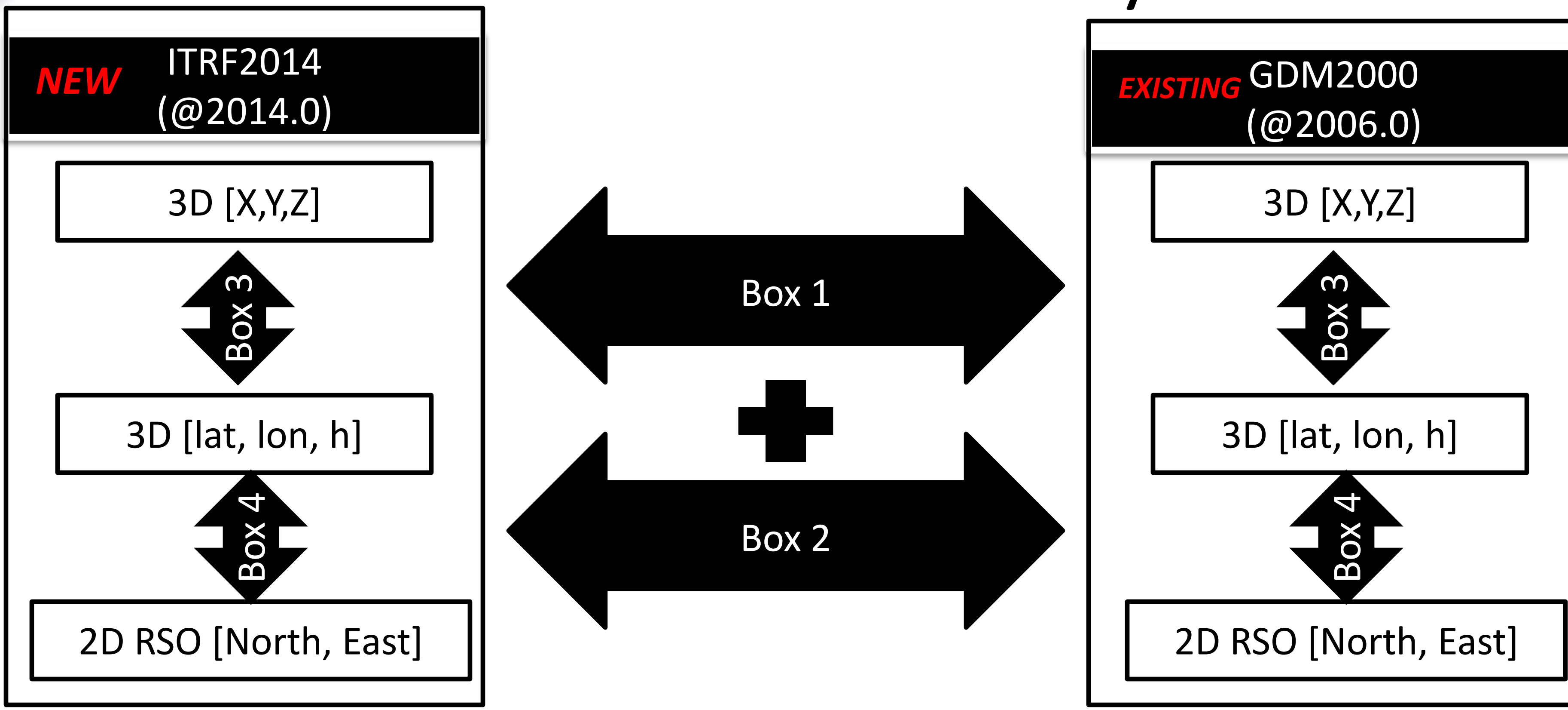
- The immediate implication: a non-geocentric datum does not represent the 'true' position of points.
- Consequently, this will introduce:
  - A coordinate bias, as the coordinates referenced to the national geocentric datum will be inconsistent with the GNSS orbit-referenced coordinates.
  - Thus, this would cause issues with absolute positioning using GNSS techniques, such as Precise Point Positioning (PPP), which is dependent on precise orbits.

Implications of a Non-Geocentric Datum

- A map conflict: absolute/differential positioning mismatch with base maps, e.g., affects navigation, oil and mineral exploration, agriculture, etc.
- Decreased accuracy of reference stations coordinates: transition problems in boundary zones of countries (Pinto, 2009).
- Moreover, limit scientific research and applications at the national-level that normally requires a reliable coordinates at the reference stations.

Resolving Geocentric Reference Frame in Malaysia

Resolving Geocentric Reference Frame in Malaysia



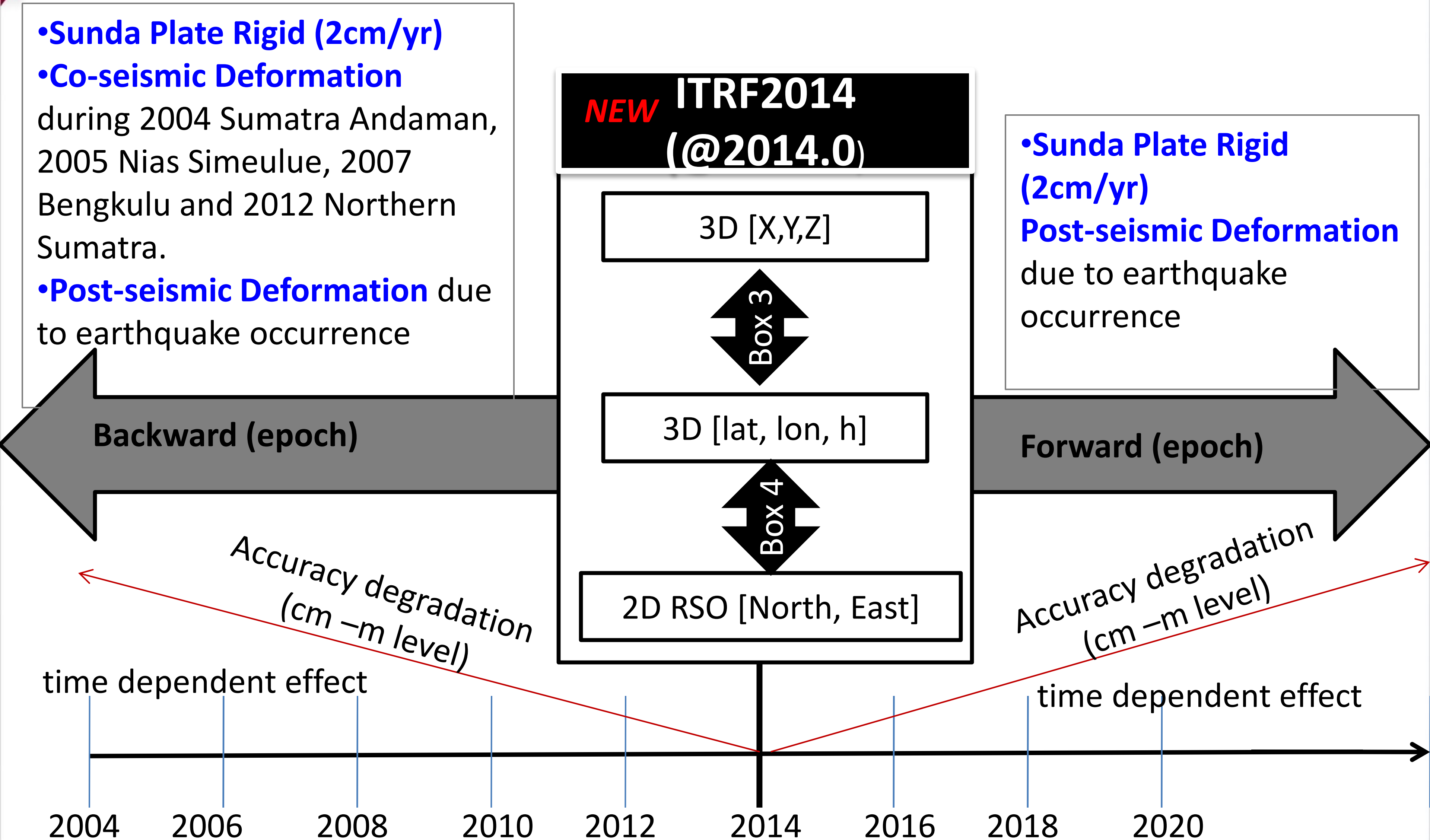
Box 1	7 parameters of Helmert Transformation (ITRF2014@2014.0– GDM2000@2006.0)
Box 2	3-Helmert residuals Helmert residuals (3 translation) between ITRF2014@2014.0– GDM2000@2006.0
Box 3	Coordinate conversion between 3D Cartesian – 3D geographical coordinate
Box 4	Coordinate Mapping from 3D to 2D mapping

NUM	NAME	FLG	RESIDUALS IN MILLIMETERS			
1	ARAU ARAU	A A	4.1	59.7	-37.4	M
2	AYER AYER	A A	-20.3	15.6	7.8	M
3	BABH BABH	A A	-10.5	21.9	7.5	M
4	BAHA BAHA	A A	-0.2	-8.0	-8.8	
5	BANT BANT	A A	-2.2	-15.4	16.1	M
6	BEHR BEHR	A A	-3.6	-5.2	-17.6	M
7	BENT BENT	A A	-2.2	0.6	-0.7	
8	CAME CAME	A A	-5.5	4.8	-3.5	
9	CENE CENE	A A	-2.4	-3.5	65.3	M
10	GAJA GAJA	A A	23.0	7.5	25.5	M
11	GETI GETI	A A	-9.8	14.8	11.3	M
12	GMUS GMUS	A A	-10.8	0.0	6.9	
13	GRIK GRIK	A A	-12.7	20.0	-2.4	M
14	JHJY JHJY	A A	18.1	-10.8	-14.0	M
15	JRNT JRNT	A A	0.6	1.2	-10.9	
16	JUML 22718M001	A A	10.6	-17.2	14.5	M
17	KLAW KLAW	A A	-5.1	-17.9	1.6	M
18	KRAI KRAI	A A	-39.8	-63.6	26.0	M
19	KROM KROM	A A	10.9	0.9	4.2	
20	KUAL KUAL	A A	-4.7	-4.7	-8.4	
21	KUKP KUKP	A A	26.3	-6.4	5.6	M
22	LASA LASA	A A	-8.1	9.0	-9.8	M
23	LGKW LGKW	A A	1.2	62.9	-2.0	M
24	LIPI LIPI	A A	-12.2	-3.5	36.6	M
25	MERS MERS	A A	7.6	-16.7	14.6	M
26	MERU MERU	A A	-15.8	11.1	65.7	M
27	MUAD MUAD	A A	5.5	0.0	2.6	
29	PASP PASP	A A	-8.9	15.8	6.3	M
30	PDIC PDIC	A A	7.3	4.1	2.1	
31	PEKN PEKN	A A	-6.5	-16.8	14.3	M
32	PRTS PRTS	A A	31.9	16.2	12.0	M
33	PUPK PUPK	A A	-2.2	1.6	3.6	
34	PUSI PUSI	A A	-4.3	4.5	-8.8	M
35	SBKB SBKB	A A	-3.3	-4.0	-8.3	M
36	SEG1 SEG1	A A	1.7	-0.5	11.8	
37	SETI SETI	A A	-9.8	10.3	-21.7	M
38	SGPT SGPT	A A	-10.7	33.5	4.5	M
39	SIK1 SIK1	A A	-19.6	29.6	16.8	M
40	SPGR SPGR	A A	26.4	7.2	4.1	M
41	SRIJ SRIJ	A A	18.3	-14.0	17.1	M
42	TERI TERI	A A	-2.6	11.0	-6.9	M
43	TGPG TGPG	A A	15.4	-13.0	27.2	M
44	TGRH TGRH	A A	20.7	5.4	2.4	M
45	TLKI TLKI	A A	12.8	2.9	49.7	M
46	TLOH TLOH	A A	-10.4	-14.5	2.5	M
47	TOKA TOKA	A A	-3.2	42.5	16.5	M
48	UPMS UPMS	A A	-3.2	-10.4	7.0	M
49	USMP USMP	A A	-1.4	30.8	-3.2	M
50	UUMK UUMK	A A	-6.3	51.6	9.6	M
	RMS / COMPONENT		6.2	3.6	7.1	

NUM	NAME	FLG	RESIDUALS IN MILLIMETERS			
1	MUKA MUKA	A A	-23.2	-10.7	-44.6	M
2	SARA SARA	A A	4.3	6.4	0.5	
4	BEAU BEAU	A A	0.4	-8.7	1.0	M
6	BELU BELU	A A	-1.2	-2.4	-3.6	
7	BIN1 BIN1	A A	-0.9	-0.1	-3.5	
9	KAPI KAPI	A A	-8.7	9.4	-14.2	
10	KENI KENI	A A	-2.2	-4.0	-4.6	M
11	KUDA KUDA	A A	-5.6	1.9	1.5	
12	LAB1 LAB1	A A	11.4	-7.8	-5.0	
13	LAWS LAWS	A A	4.5	-1.7	-61.2	M
14	MIRI MIRI	A A	4.6	-4.8	0.3	
15	MRDI MRDI	A A	-0.7	3.5	-15.1	M
16	MRDU MRDU	A A	-8.9	5.3	-29.8	M
18	NIAH NIAH	A A	-6.4	-12.9	-13.0	M
19	RANA RANA	A A	-171.7	254.0	-23.5	M
20	SAND SAND	A A	-35.5	8.5	-11.2	M
21	SEMA SEMA	A A	1.6	-1.2	6.3	
23	SIB1 SIB1	A A	-3.3	1.2	3.8	
24	TEBE TEBE	A A	0.2	0.0	4.9	
25	TENM TENM	A A	-2.1	-2.0	8.2	
26	TMBN TMBN	A A	-174.5	249.8	19.1	M
27	UMAS UMAS	A A	-107.6	226.4	-2.4	M
28	UMSS UMSS	A A	-118.4	245.4	-16.5	M
	RMS / COMPONENT		5.4	4.8	6.3	

- Helmert residuals between GDM2000 and GDM2000@2013.
- These results show that the GDM2000 coordinates are not stable as many stations as many stations depicts large residuals between 10 to 60 mm for Peninsular Malaysia and up to 250 mm for East Malaysia.

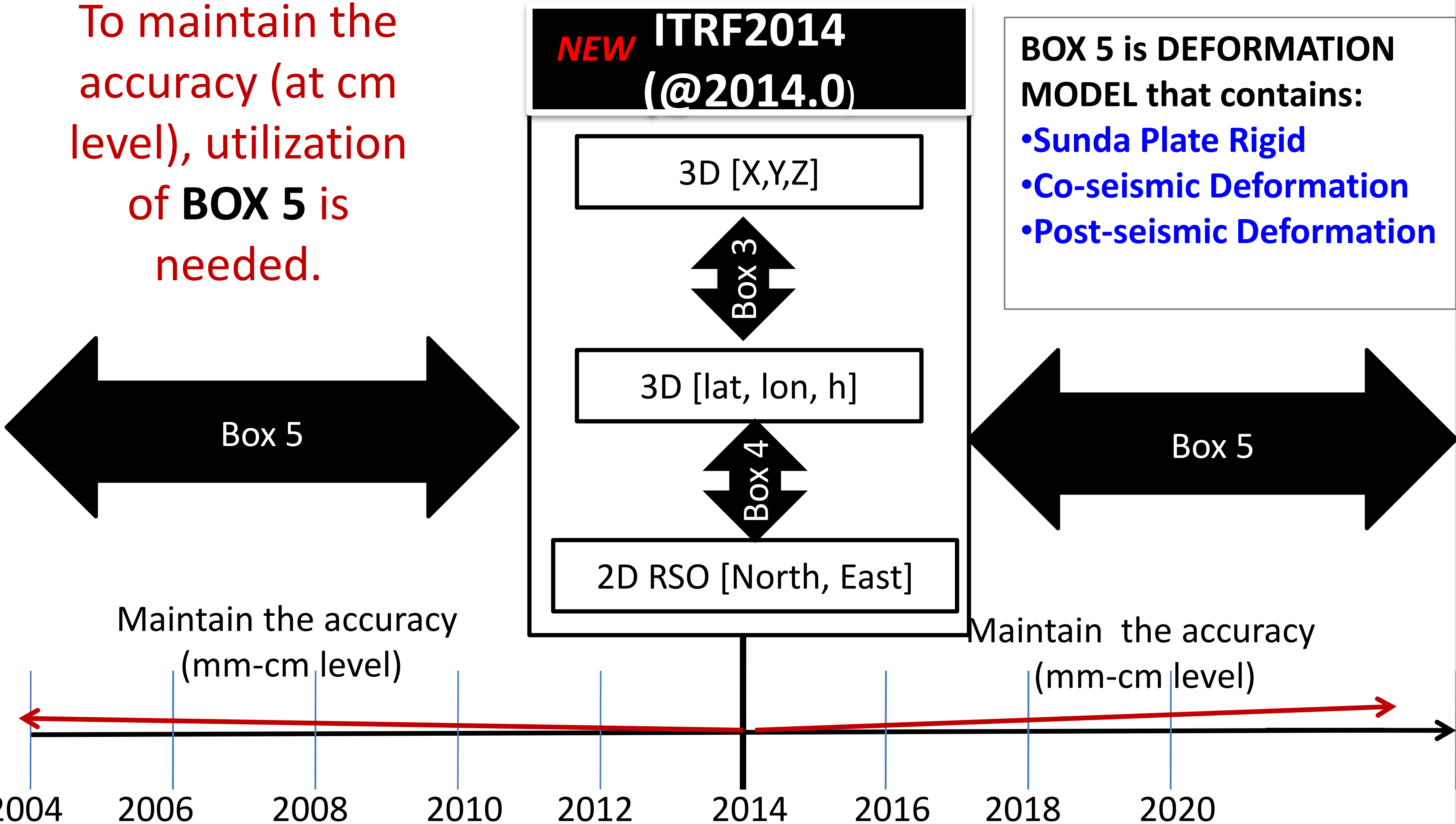
Defining coordinate of **ITRF2014** @different epoch



Defining coordinate of **ITRF2014 @different epoch**

To maintain the accuracy (at cm level), utilization of **BOX 5** is needed.

BOX 5 is DEFORMATION MODEL that contains:
- **Sunda Plate Rigid**
- **Co-seismic Deformation**
- **Post-seismic Deformation**



Mathematical function in BOX 5 that follow ITRF2014 approach

ITRF2014: Equations of post-seismic deformation models

After an Earthquake, the position of a station during the post-seismic trajectory, X_{PSD}, at an epoch t could be written as:

$$X_{PSD}(t) = X(t_0) + \dot{X}(t - t_0) + \delta X_{PSD}(t) \quad (1)$$

where $\dot{X}$ is the station linear velocity vector, and $\delta X_{PSD}(t)$ is the total sum of the post-seismic deformation (PSD) corrections at epoch t. For each component $L \in \{E,N,U\}$, we note δL the total sum of PSD corrections expressed in the local frame at epoch t:

$$\delta L(t) = \sum_{i=1}^{n^l} A_i^l \log\left(1 + \frac{t - t_i^l}{\tau_i^l}\right) + \sum_{i=1}^{n^e} A_i^e \left(1 - e^{-\frac{t - t_i^e}{\tau_i^e}}\right) \quad (2)$$

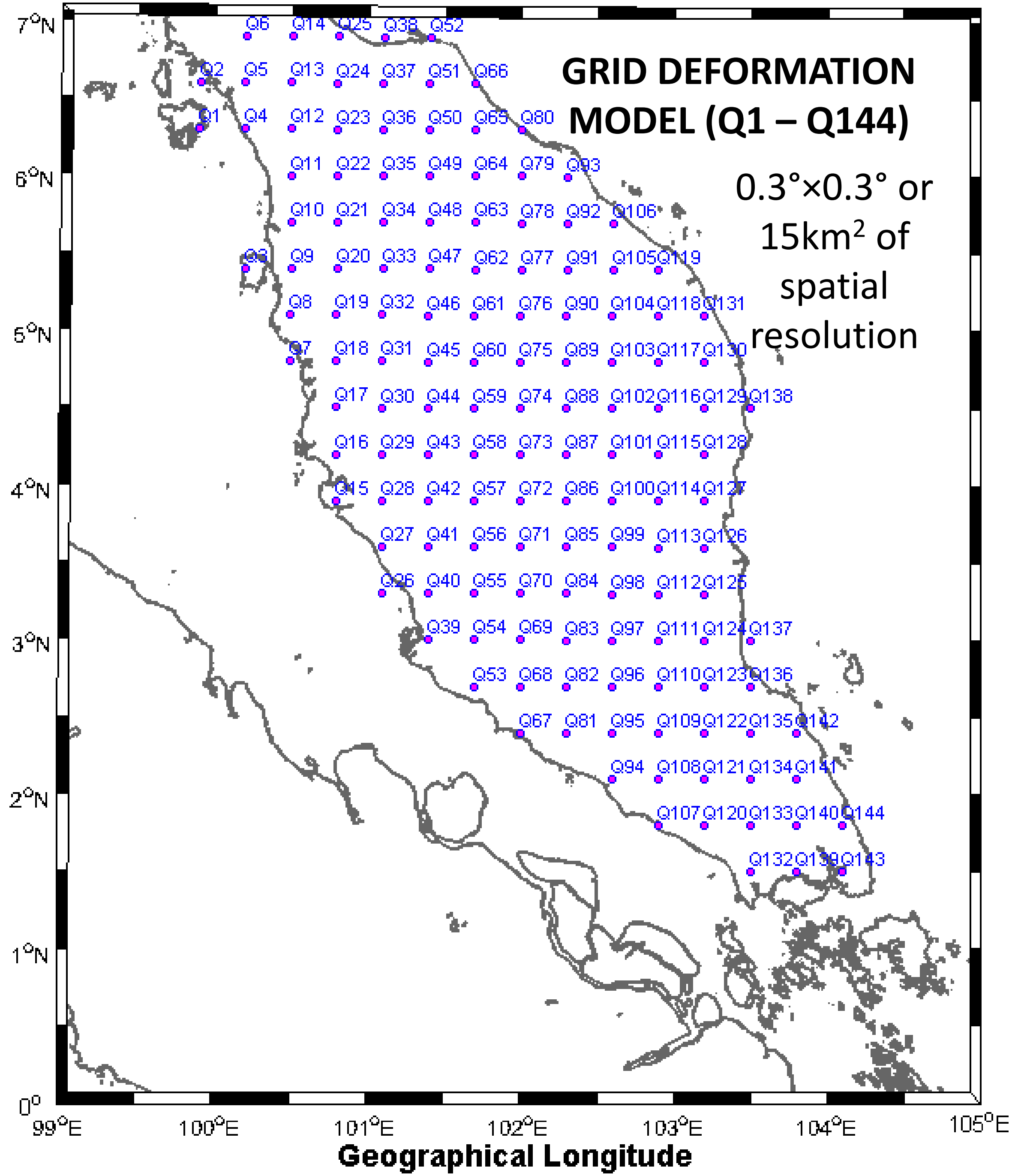
$$y(t_i) = y_0 + vt_i + \sum_{j=1}^{k} O_j c(t_i - t_q) + \sum_{j=1}^{k} a_j \log_{10}(1 + t/\tau_{\log})$$

- $y(t_i)$: Estimated Coordinate at time *i*
- y_0: Initial Coordinate ITRF (e.g ITRF2014.0 or GDM2000@2006.0
- vt_i: Rigid plate motion
- $\sum_{j=1}^{k} O_j c(t_i - t_q)$: Co-seismic Shift/ Deformation
- $\sum_{j=1}^{k} a_j \log_{10}(1 + t/\tau_{\log})$: Post seismic Deformation (PSD)

Box 5

Each grid (Q1 – Q144) contains parameter of :

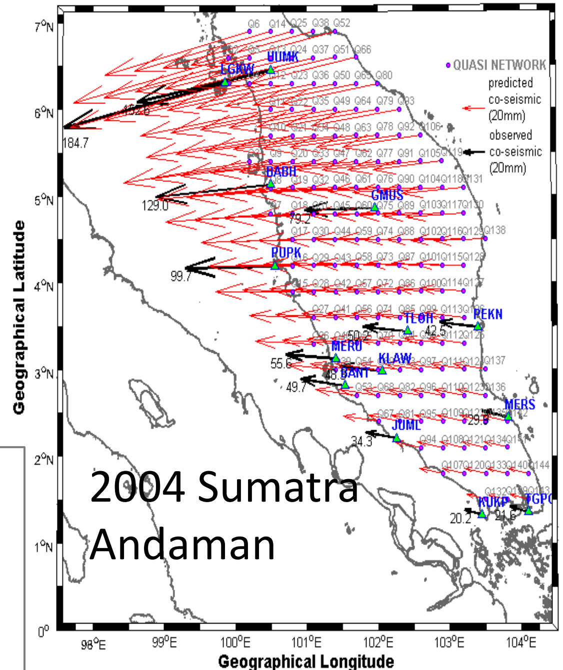
1. **Sunda Plate Rigid**
2. **Co-seismic Deformation**
3. **Post-seismic Deformation (PSD)**

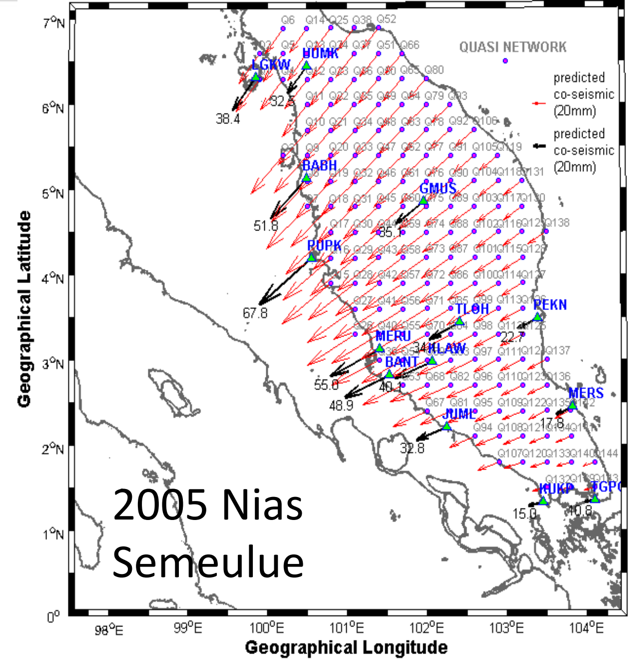


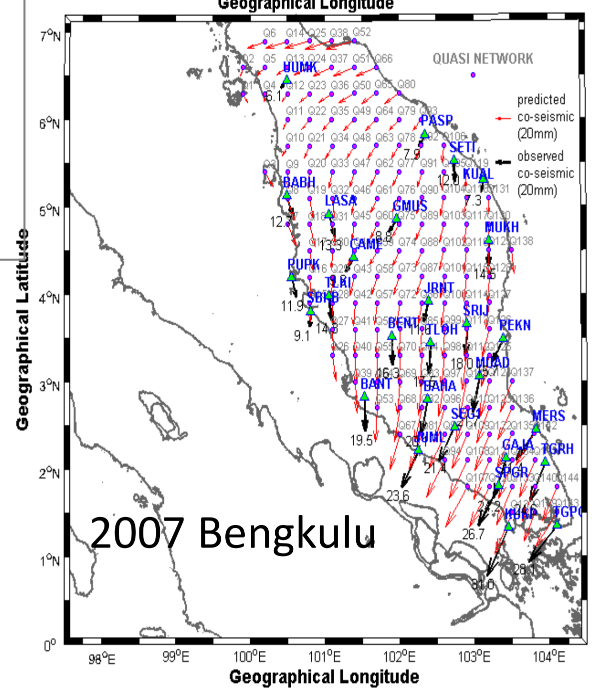
Box 5

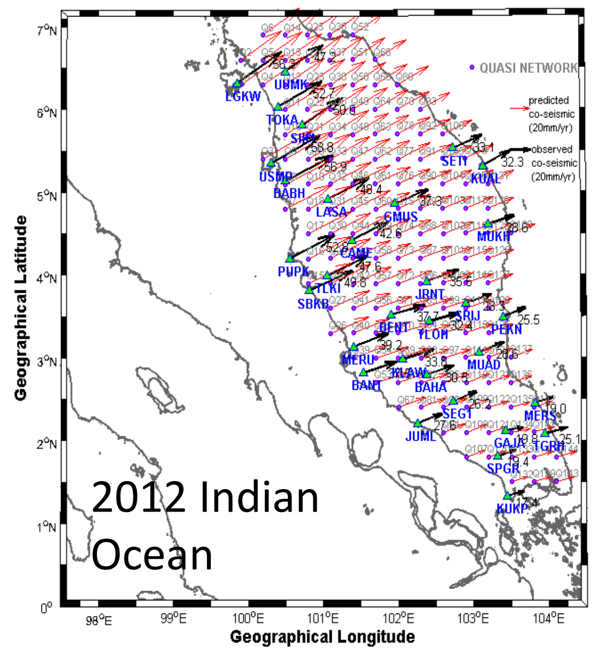
GRID DEFORMATION MODEL

- **Co-seismic Deformation**





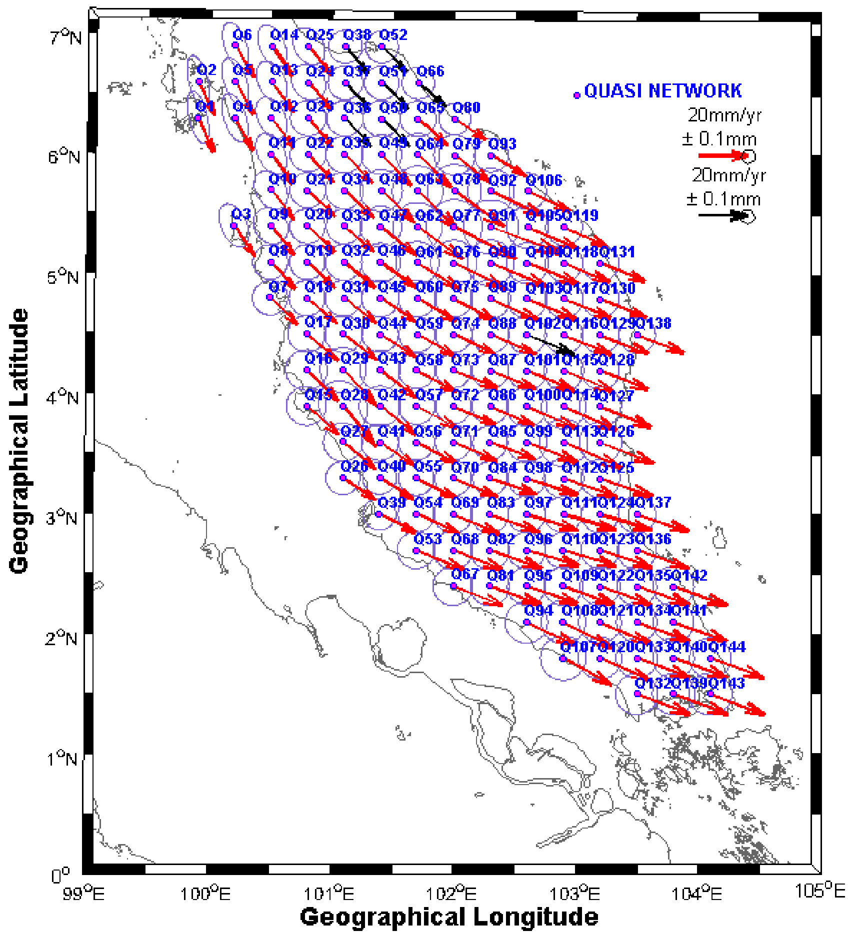




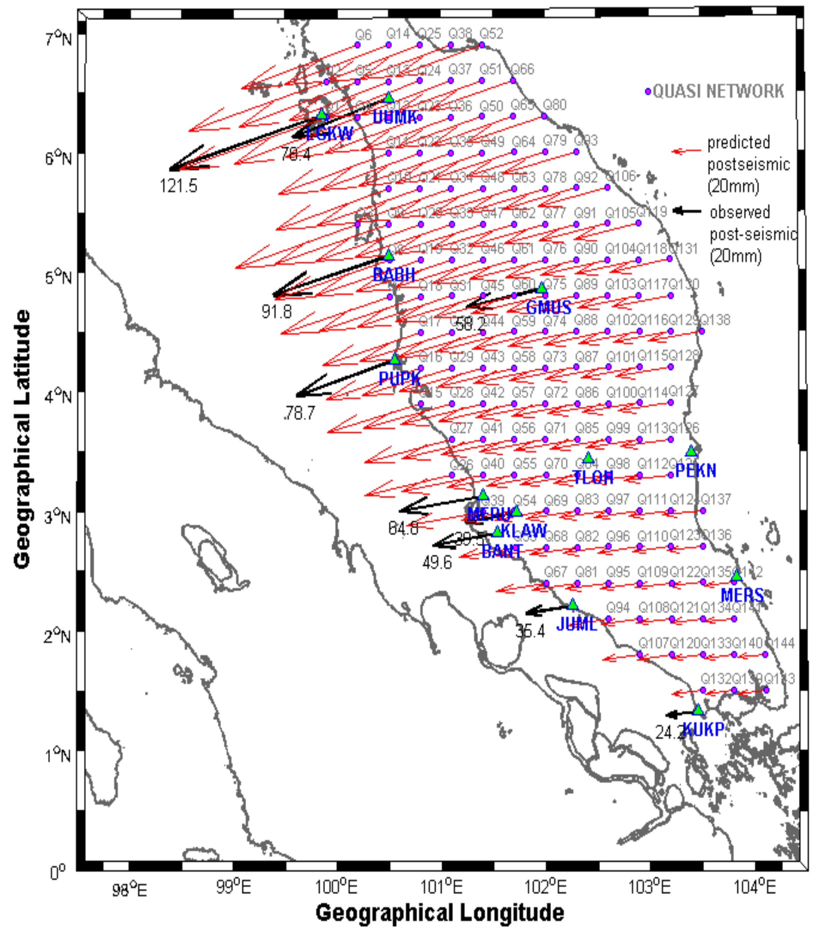
Box 5

GRID DEFORMATION MODEL

•Sunda Plate Rigid



Post-seismic Amplitude



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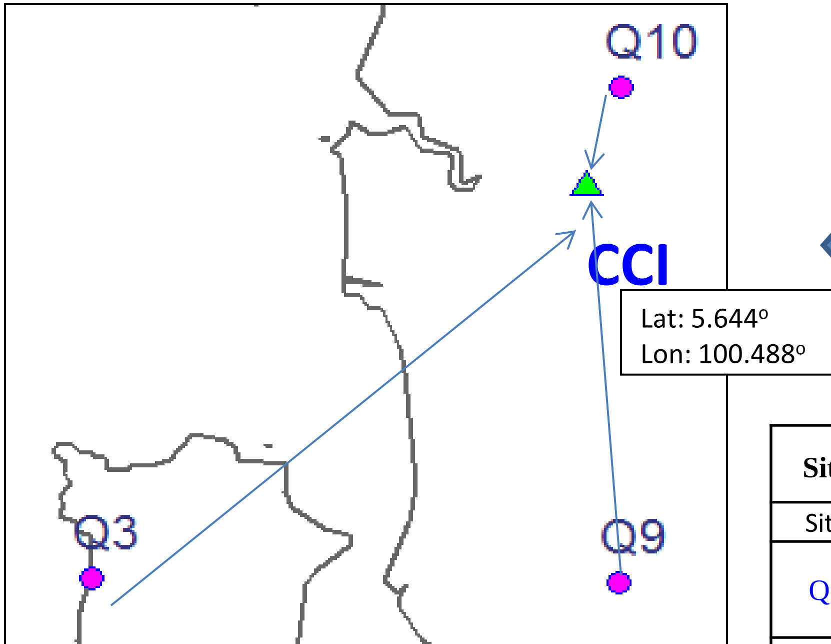
Box 5

GRID DEFORMATION MODEL

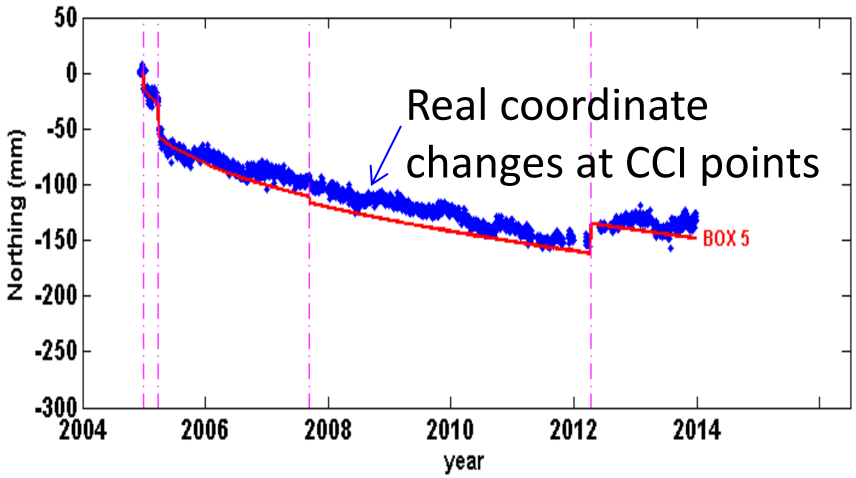


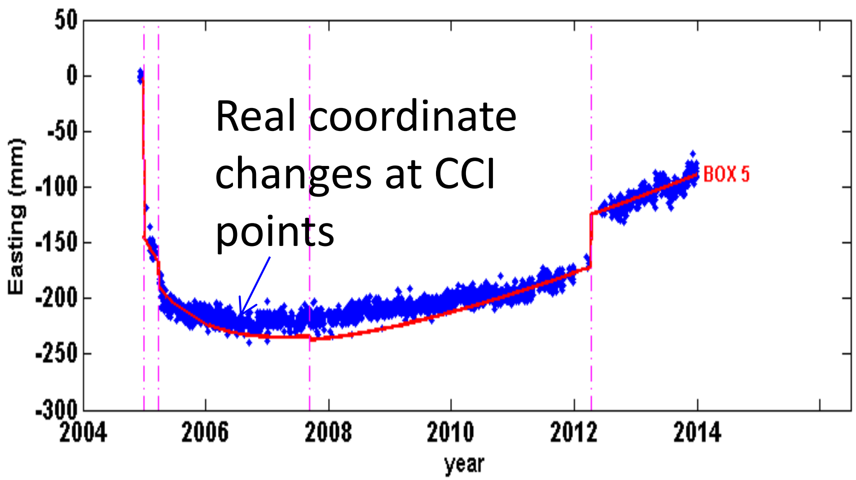
Parameter of Sunda Plate Rigid, co-seismic deformation & post-seismic deformation at CCI point can be interpolated from Q3, Q9 & Q10.

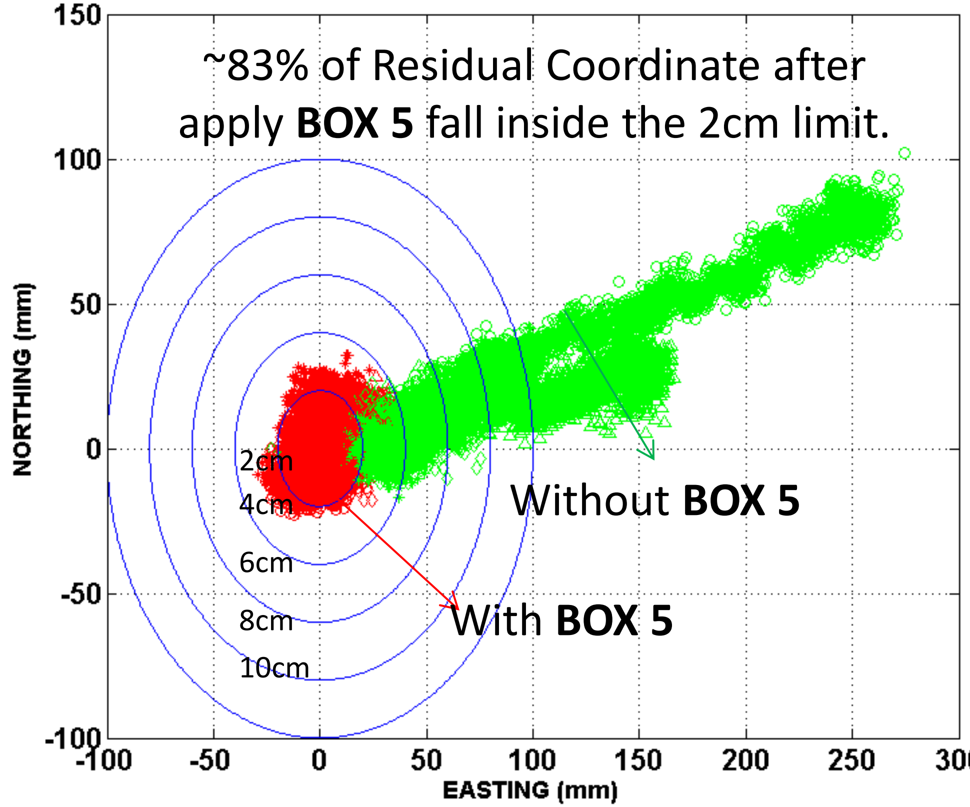
Site	component	RigidPlate Motion (mm/yr)	PSD (amplitude)	Co-seismic offset (mm)			
Site				2004 Eq	2005 Eq	2007 Eq	2012 Eq
Q3	N	-4.3	-28.7	-19.0	-35.5	-8.3	27.2
	E	30.9	-94.1	-140.6	-32.5	5.1	51.7
Q9	N	-4.4	-26.5	-15.2	-35.0	-8.7	26.1
	E	30.9	-87.8	-133.4	-32.7	0.5	49.5
Q10	N	-4.4	-27.1	-19.8	-32.5	-5.5	26.7
	E	31.0	-87.0	-139.5	-29.4	-3.4	46.4
CCI	**N**	**-4.4**	**-28.0**	**-19.1**	**-33.1**	**-5.6**	**26.9**
	E	**31.0**	**-94.0**	**-138.5**	**-30.2**	**-3.4**	**47.0**

Box 5

Residual Coordinate (Horizontal component) With VS Without BOX 5







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Concluding Remarks

- It is evident that significant deformation has occurred in Malaysia.
- Moreover, a new ITRF definition has been realized, i.e., ITRF2014.
- Therefore, it is necessary for a revision of GDM2000.
- The geocentric coordinates can be maintained via a time-dependent similarity datum transformation (**BOX 1 & BOX 2**) with crustal deformation model (**BOX 5**).
- The assessment using BOX 5 shows that ~83% of residual coordinate can achieved up to 2cm of accuracy by inclusion of linear and non-linear **of Plate Motion & Post-seismic Models**.