"Earthquake Potential Model Around Sunda Arc"

-Developing Model for Sumatra Plate Margin-

Most Material Was Presented JSPS Meeting at ERI, August, 2007 and Ministry Research & Technology of Indonesia on September 2007

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Geophysics Working Group-FIKTM-ITB Bandung

" Our Main Purpose "

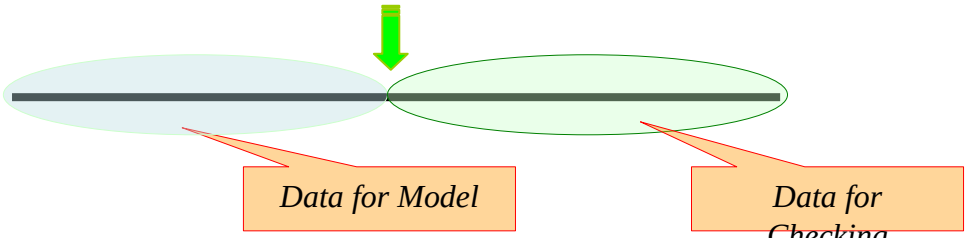
" Our main purpose and motivation is
to understand and managing future possible dissaster caused by Earthquake "

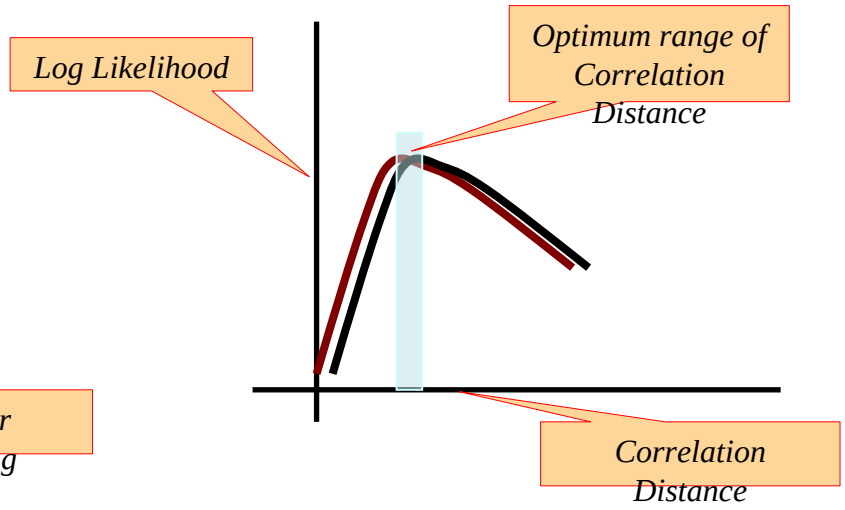
Earthquake Potential Model Is Modeling Possibility Of The Earthquake Event and It can be Expressed as Seismic Moment rate or Their Accumulations or Probability of Occurrence for the Several Decade of Time

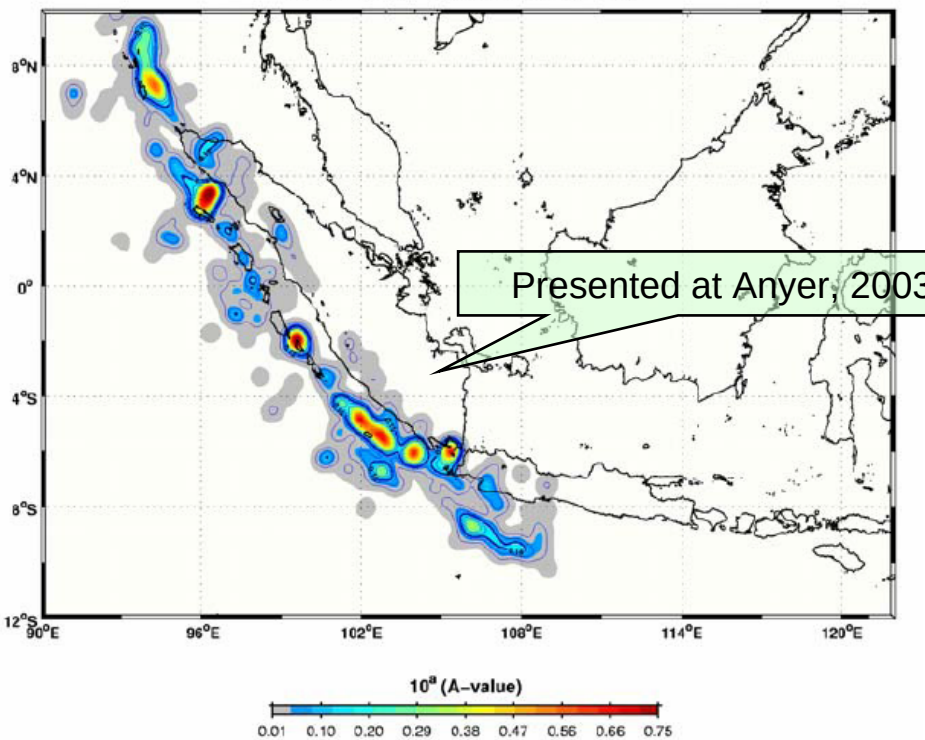
" Data "

" Earthquake, Fault, GPS or Zoning "

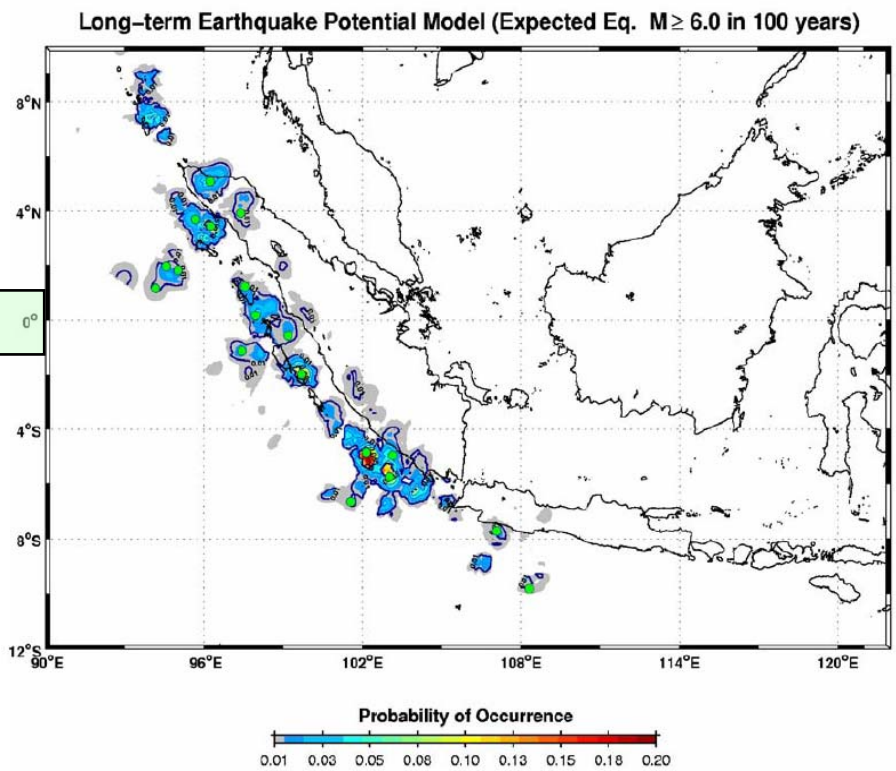
Model Based on Eq-Cat (2003)



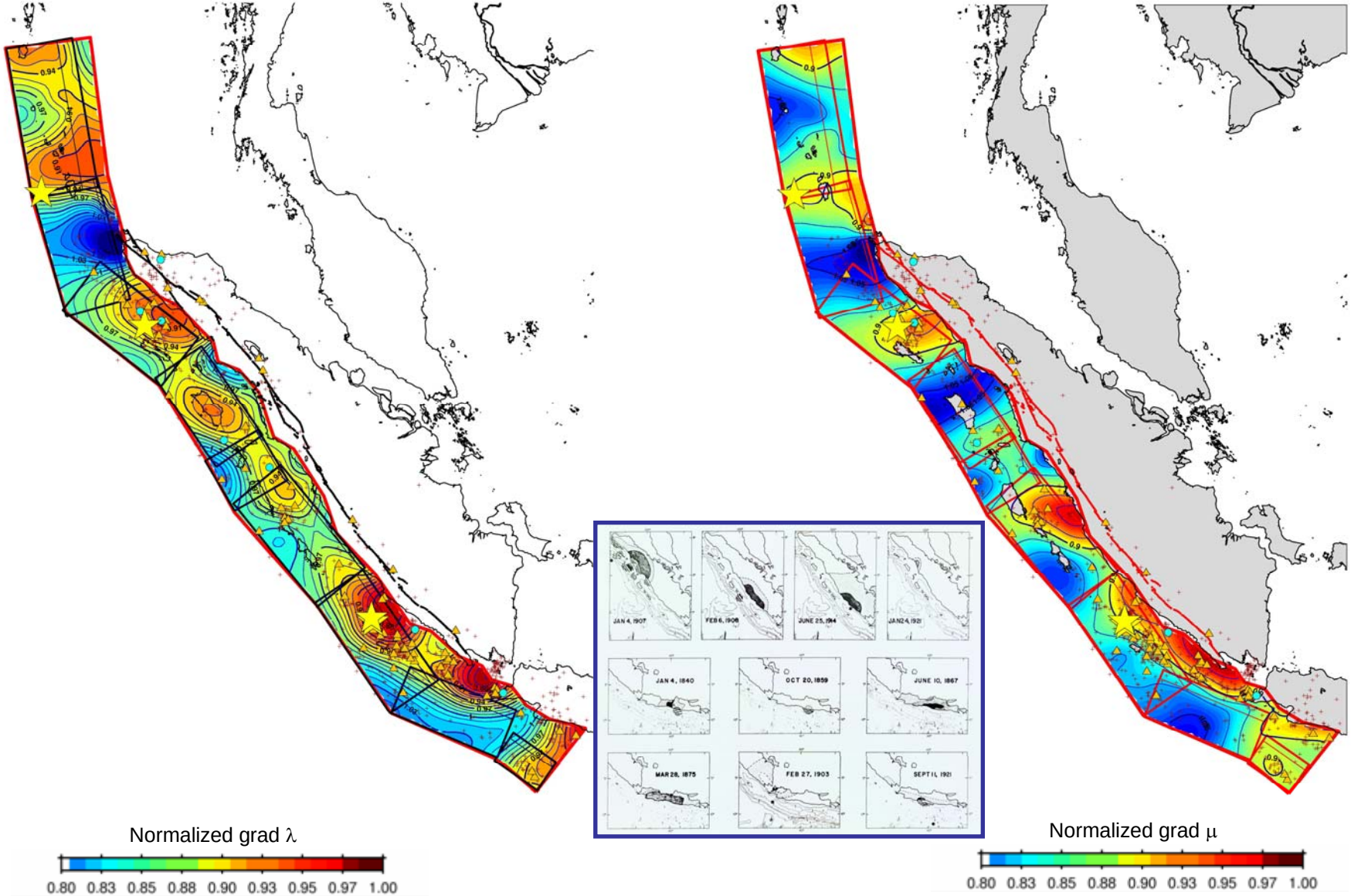




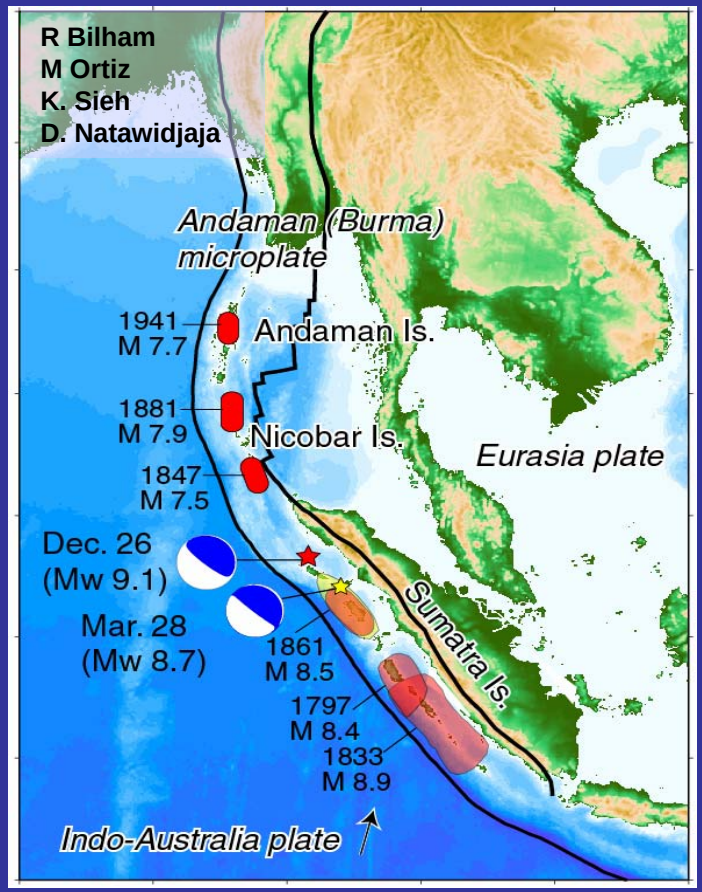
Presented at Anyer, 2003



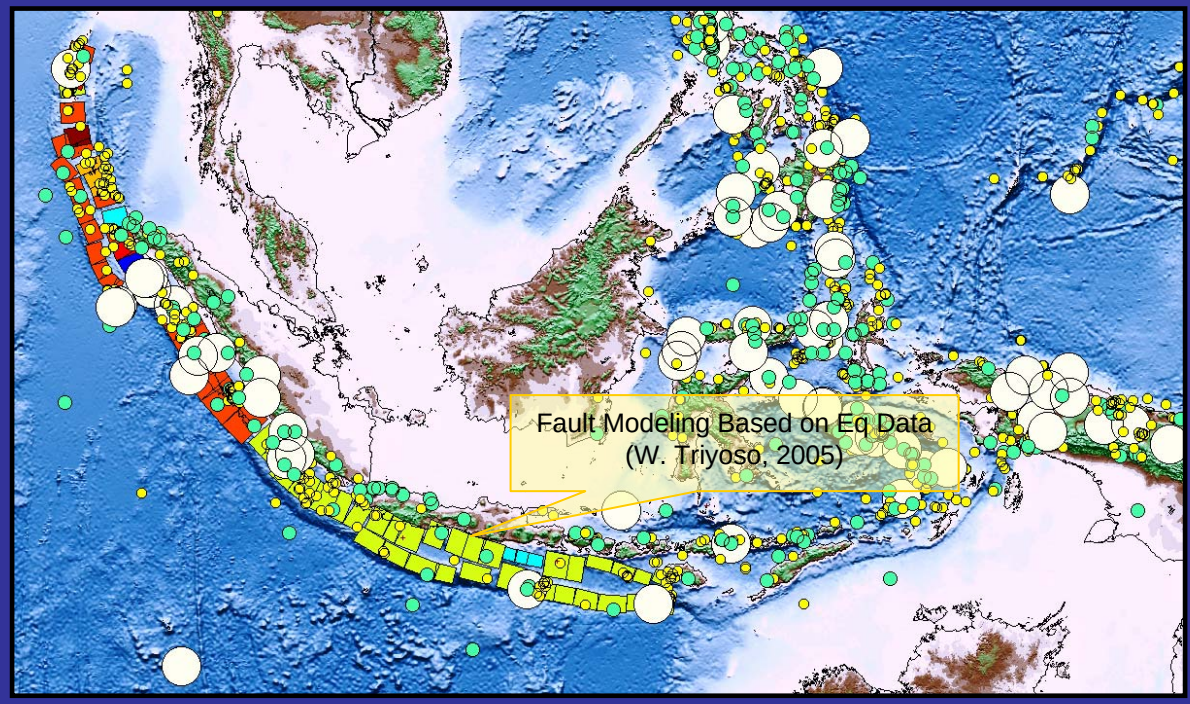
Result Based on Seismic Tomography Data (2004)



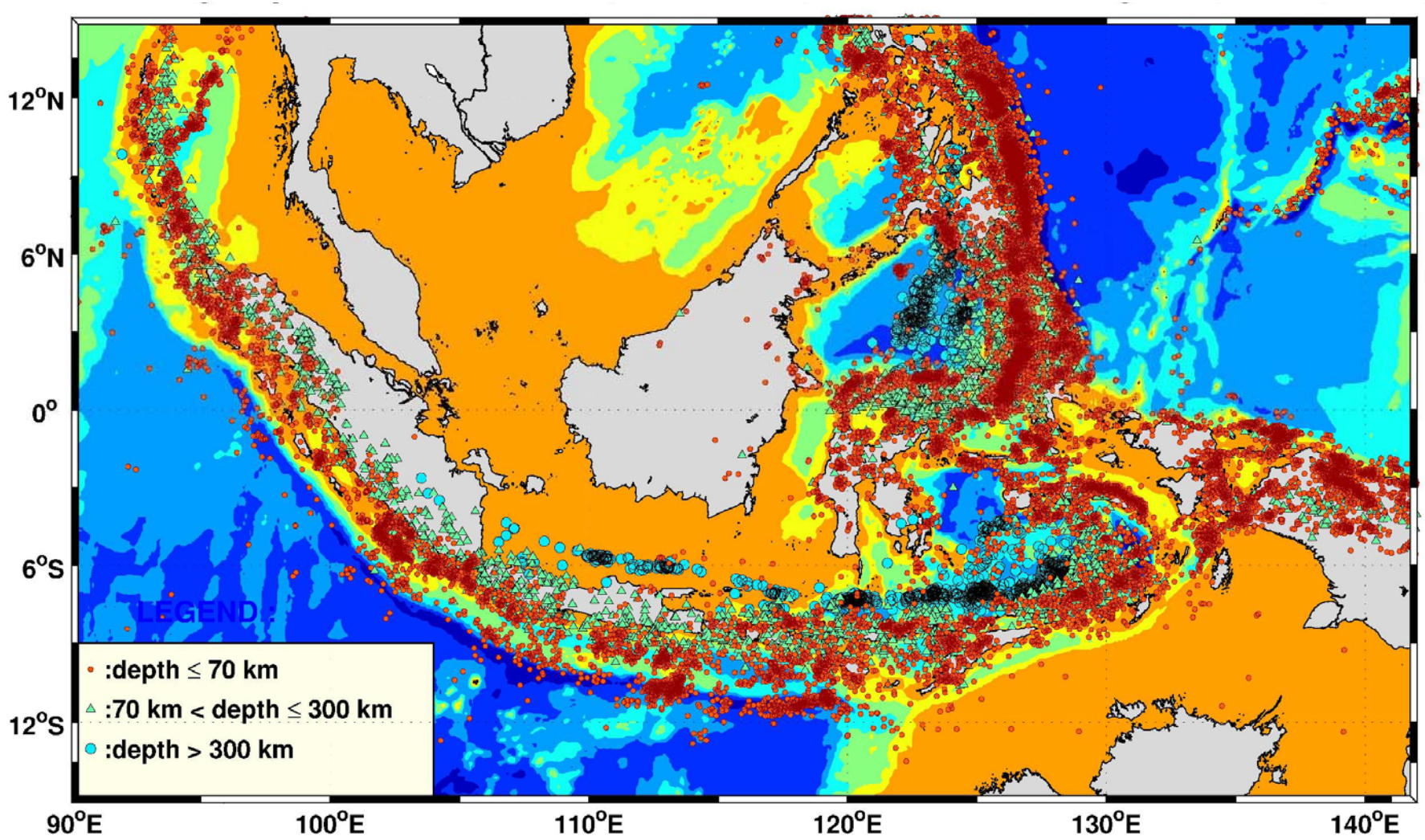
' Historical Large Earthquake ~ 1700 - 2005 '



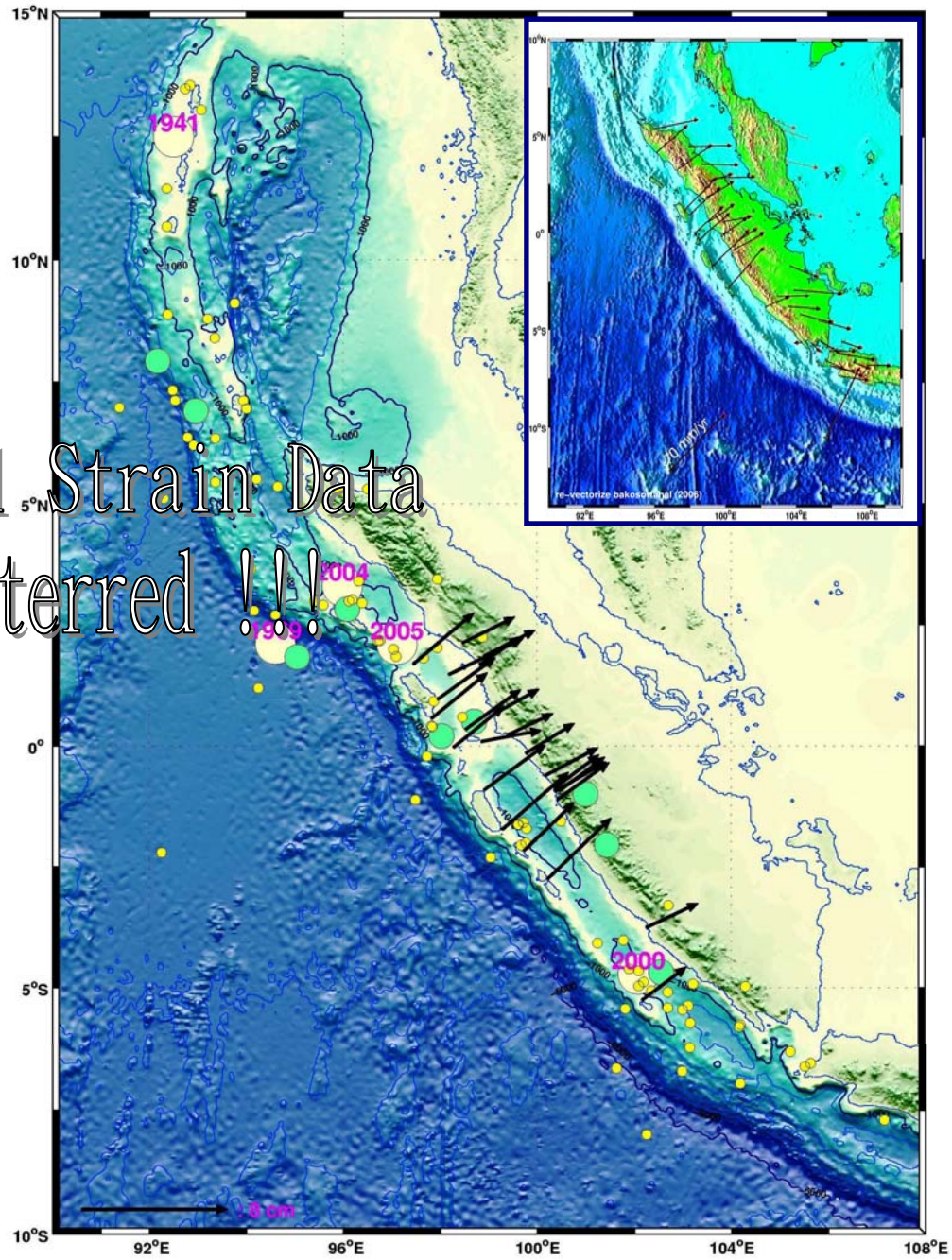
'Our Historical Earthquake seems to be short and it may not be complete'



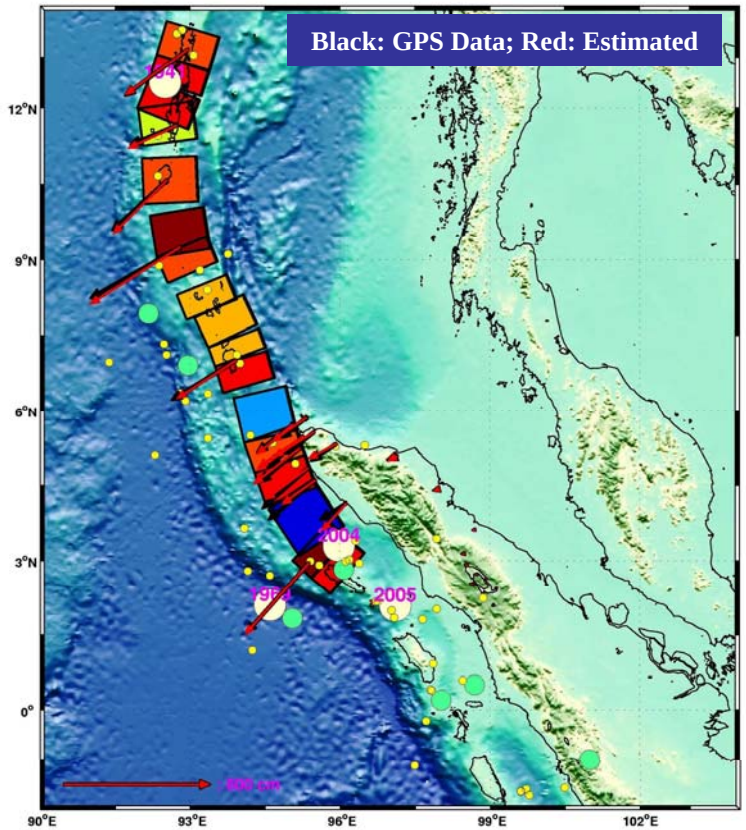
" Earthquake Catalog Data (1964-2000, After Engdahl) "

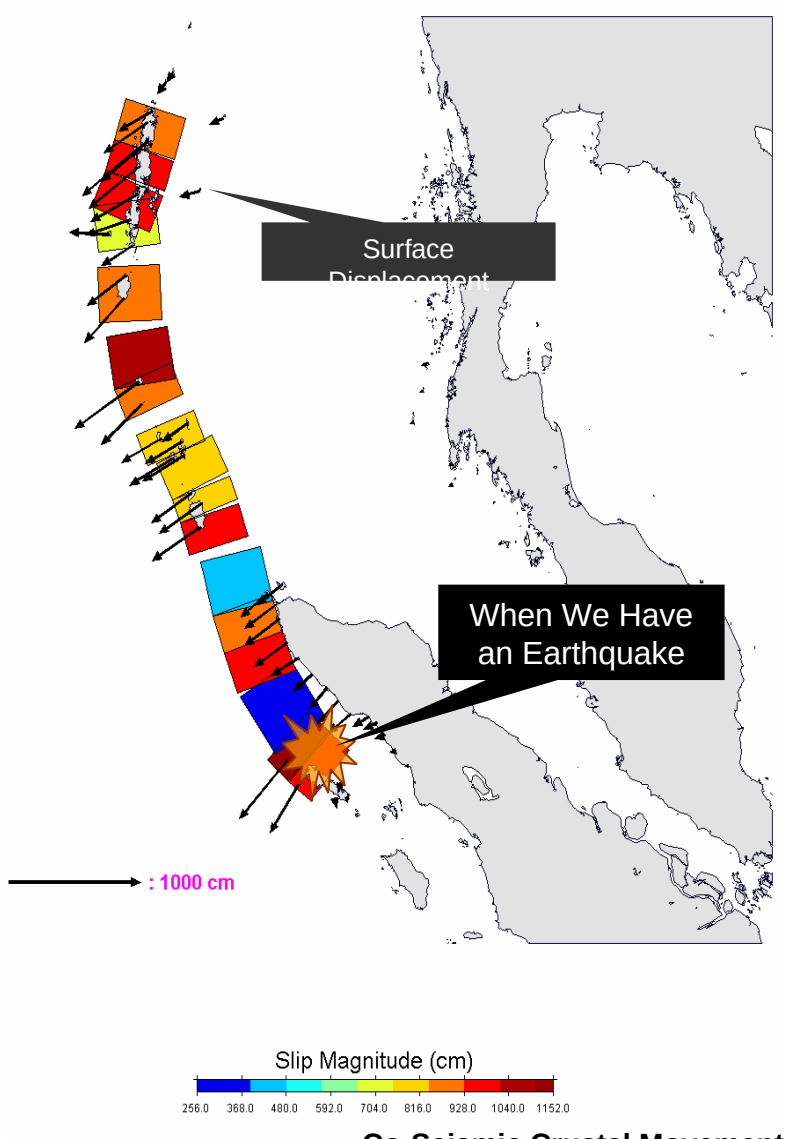


The Fact of Our Surface Crustal Strain Data So Sparse & Clusterred !!!



Learning Based on Present Day Event !!!



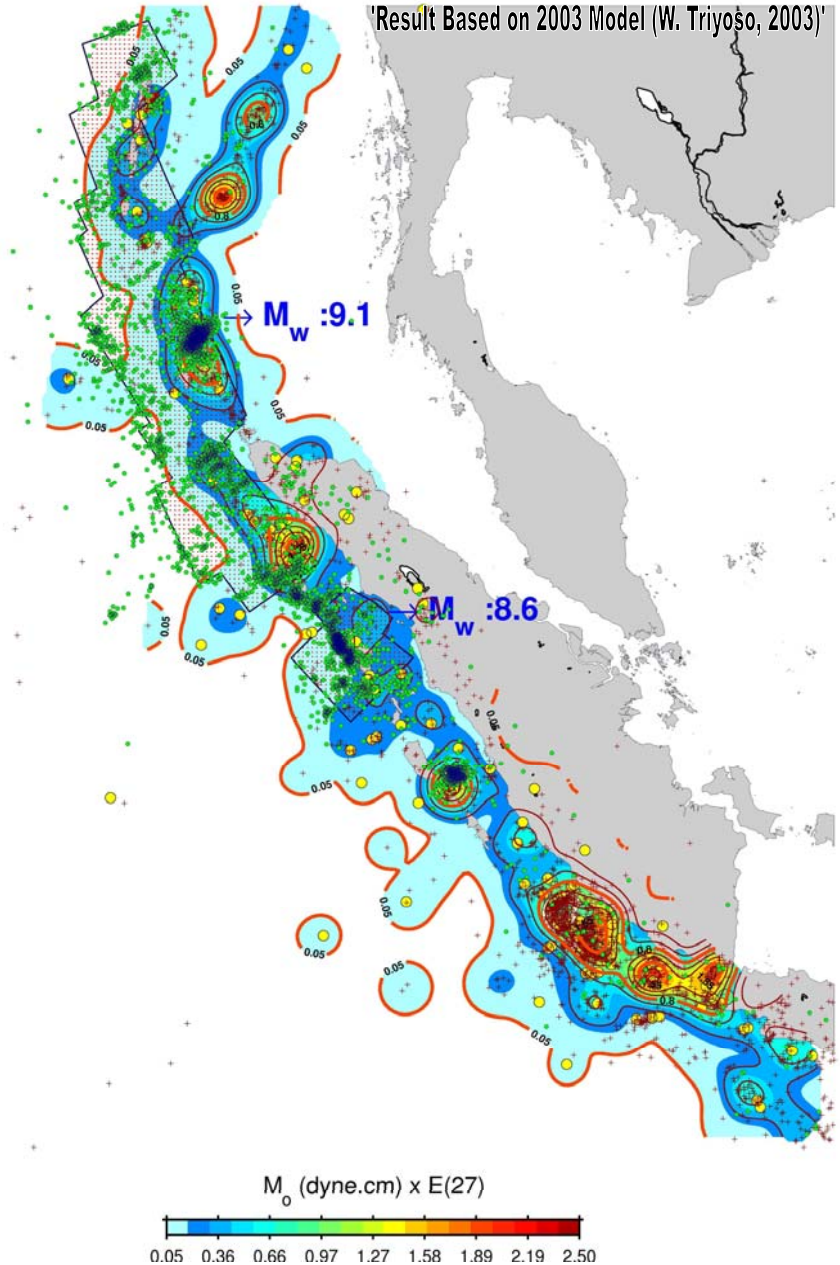


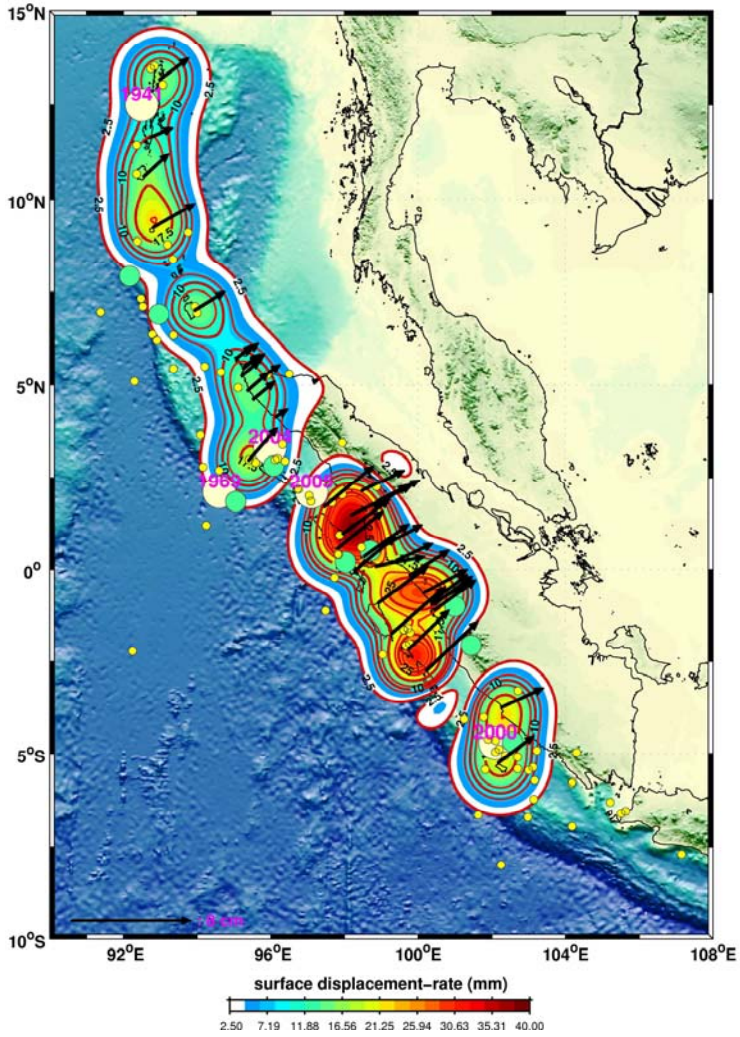
Co-Seismic Crustal Movement

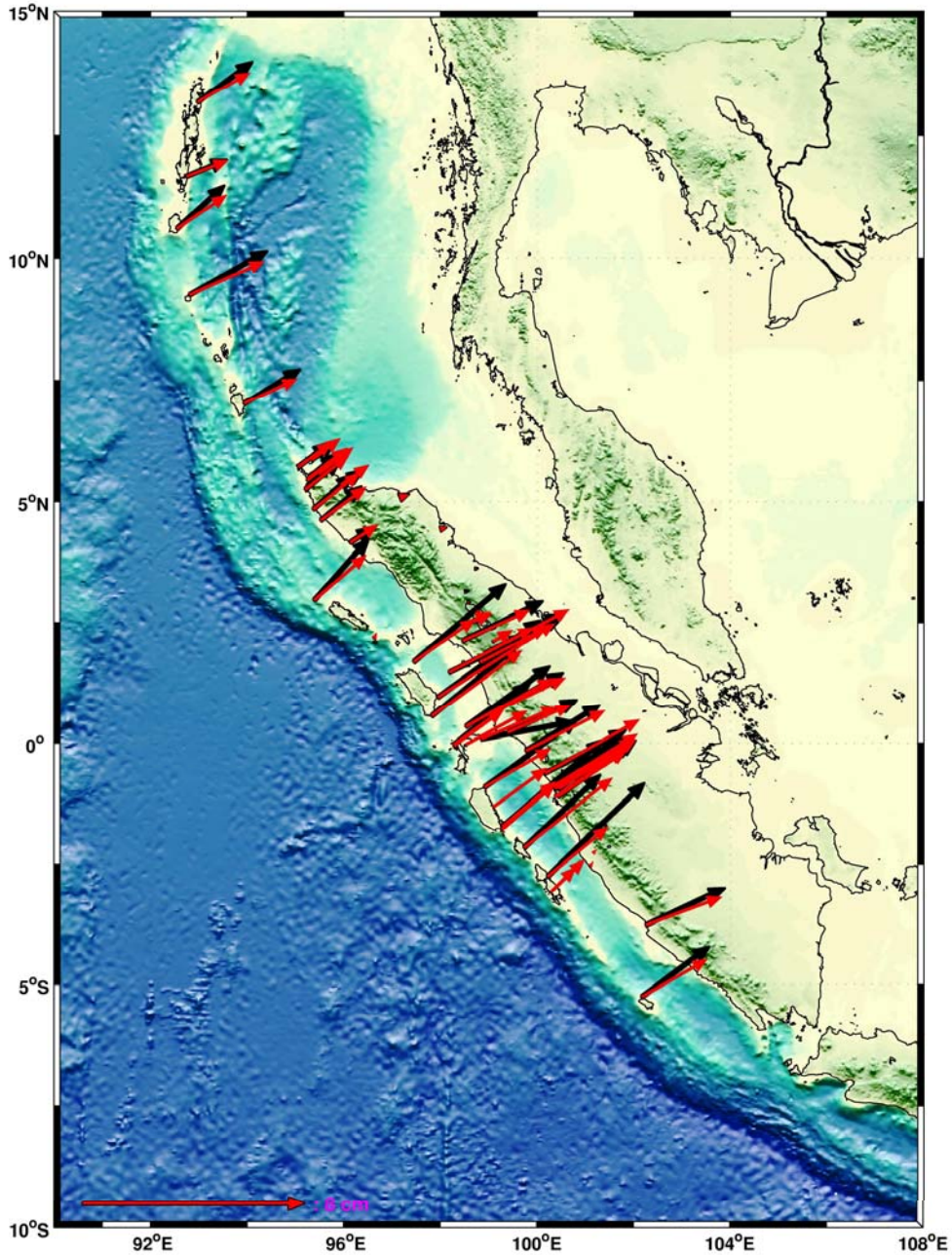
Based on GPS data, We Can Model the Fault Plane solution of an Earthquake Event using Elastic-Half Space Model (W. Triyoso, 2005)

~ 300 years Seismic Moment Accumulation Based on Shallow Earthquake Catalog Data of 1964-1999

I really Forced
to assign of following the Basic Assumption
of No Strain Deficit or Surplus !!!!



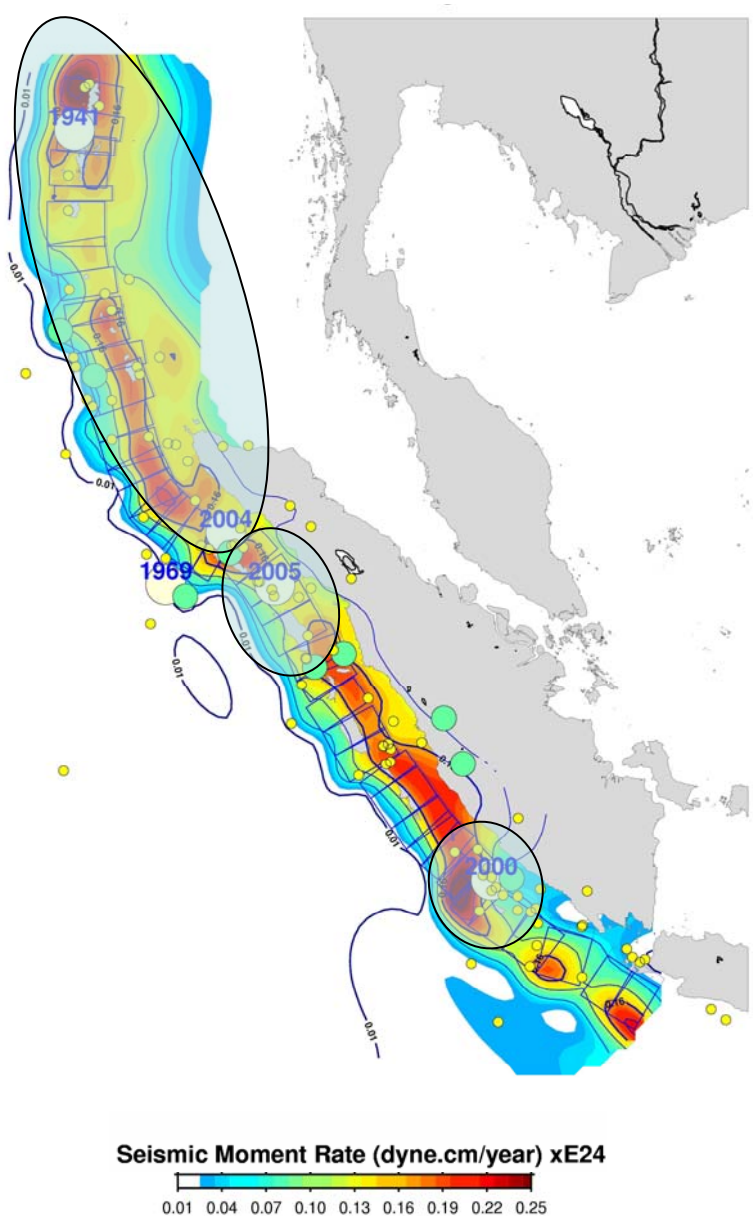




Pre-Seismic GPS Modeling

Using LSQR-Method, here I try to Model Pre-Seismic GPS Data to estimate Slip-Rate of Shallow Crustal Movement at any point (Black=Data; Red=Estimated by LSQR)

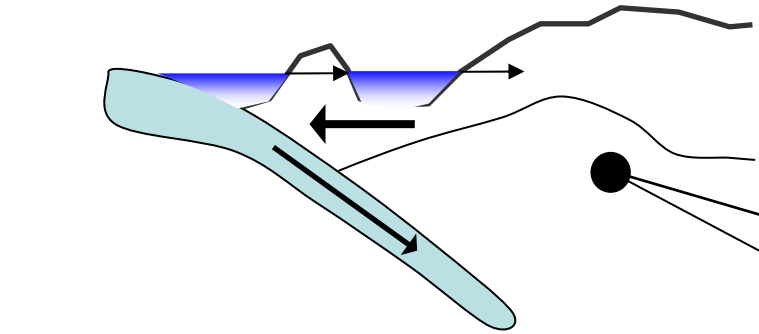
- **Modeling Multi Segment Fault Patch, Gives us the Feature of Seismic Activity and Seismic Moment Rate Loading (W. Triyoso, 2005)**

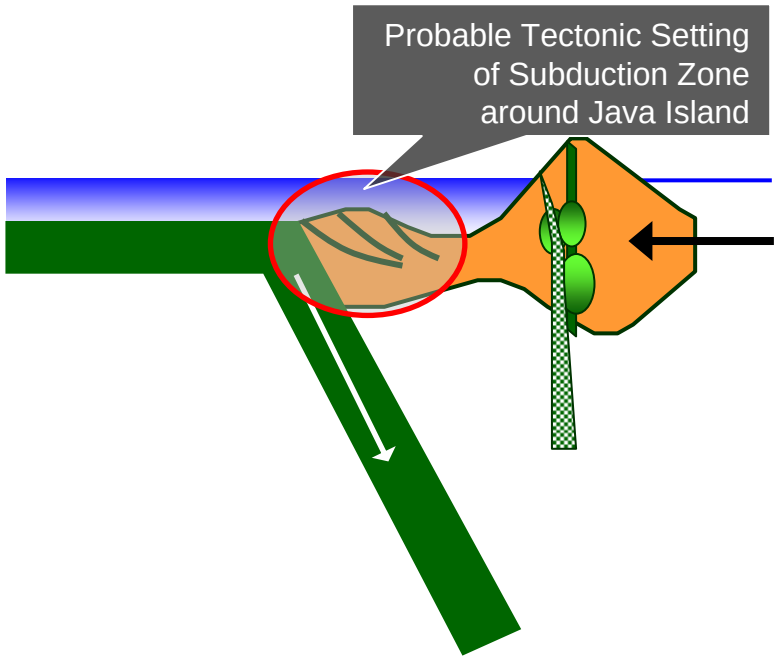


By The Fact Surface Curtal Strain Data Could Tell US Something …But at present is really Sparse ….
So …What we can do next?

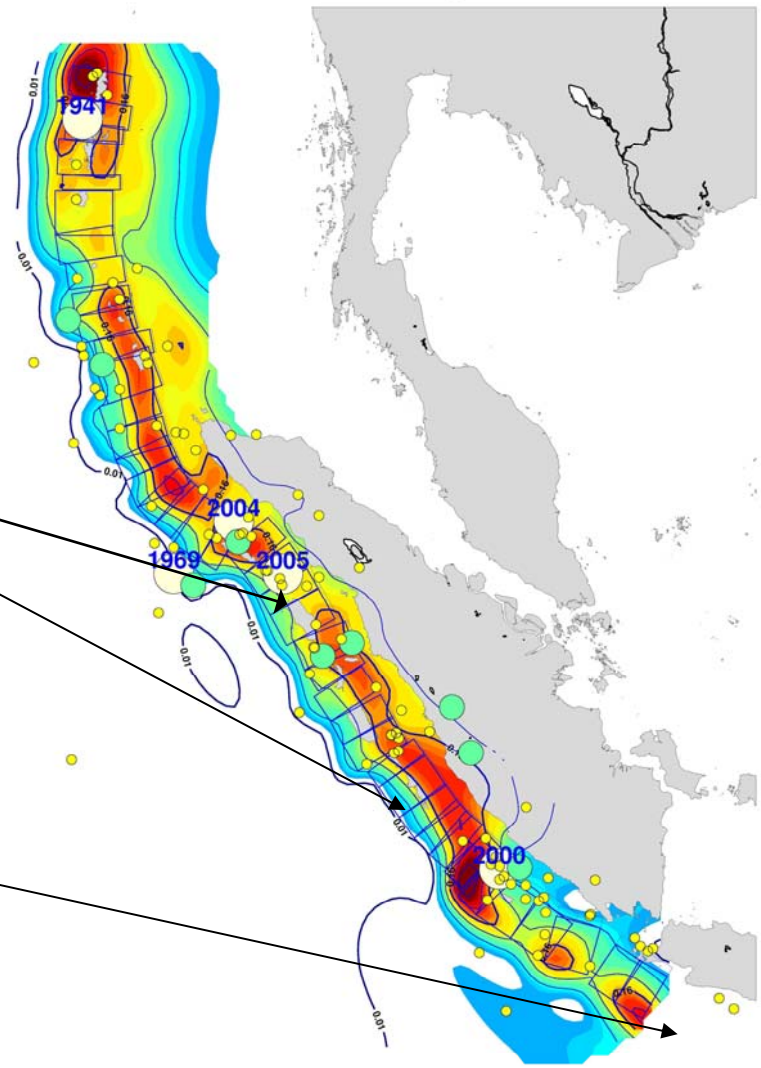
Since Our Surface Strain Data is Sparse, …
Then I came up with IDEA of Combining of Surface Crustal Starin Data with Present Day Instrumentally Recorded Earthquake catalog

Exploring GeoStatistic Modeling





Probable Tectonic Setting of Subduction Zone around Java Island



Seismic Moment Rate (dyne.cm/year) xE24

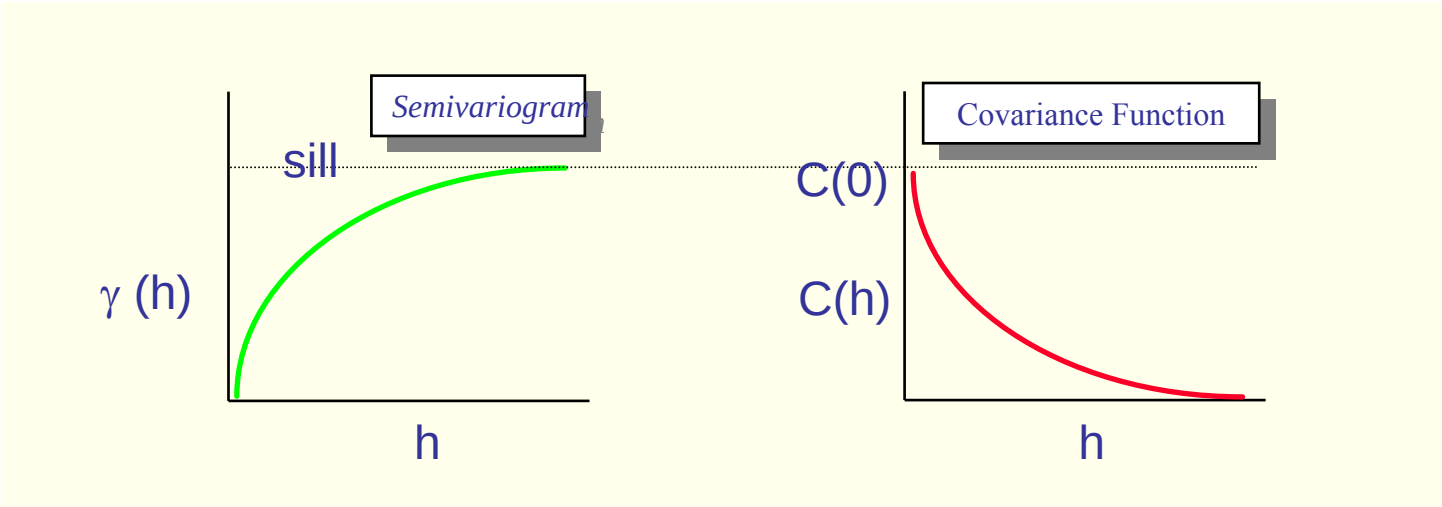
0.01 0.04 0.07 0.10 0.13 0.16 0.19 0.22 0.25

Semivariogram - Covariance

- Dataset 1 = dataset 2

  $\Rightarrow$ Autocovariance of each bin offset could be estimated based on semivariogram

$$C(h) = C(0) - \gamma(h) \qquad C_{model}(h) = C(0) - \gamma_{model}(h)$$

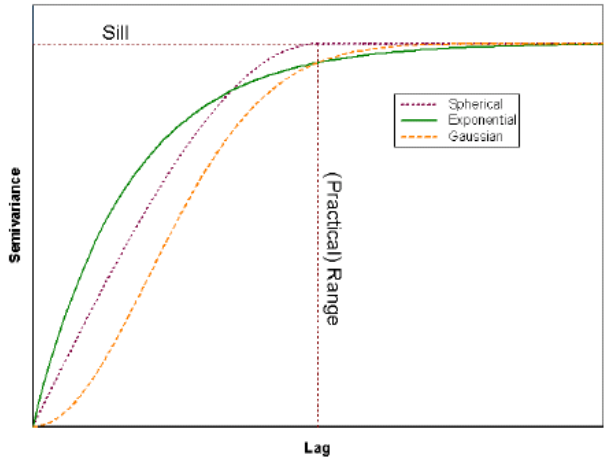


Model Of Semivariogram

- Spherical

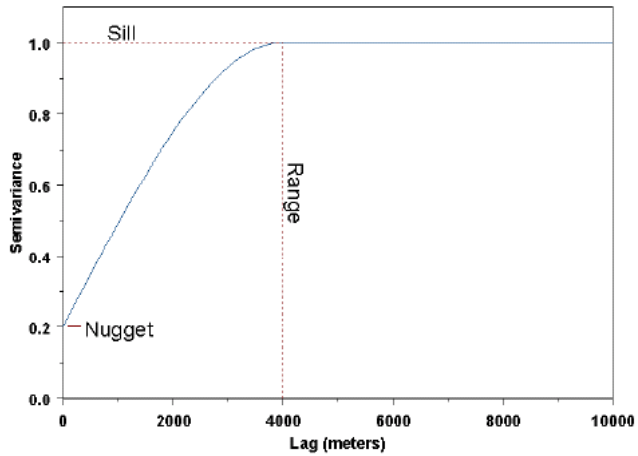
$$\gamma_{\text{model}}(h) = c\left(1\frac{1}{2}\left(\frac{h}{a}\right) - \frac{1}{2}\left(\frac{h}{a}\right)^3\right) + \gamma_0, \quad h \le a$$

$$\gamma_{\text{model}}(h) = c + \gamma_0, \quad h \ge a$$



- Gaussian

$$\gamma_{\text{model}}(h) = c\left(1 - e^{-\left(\frac{h}{a}\right)^2}\right) + \gamma_0$$



- Exponential

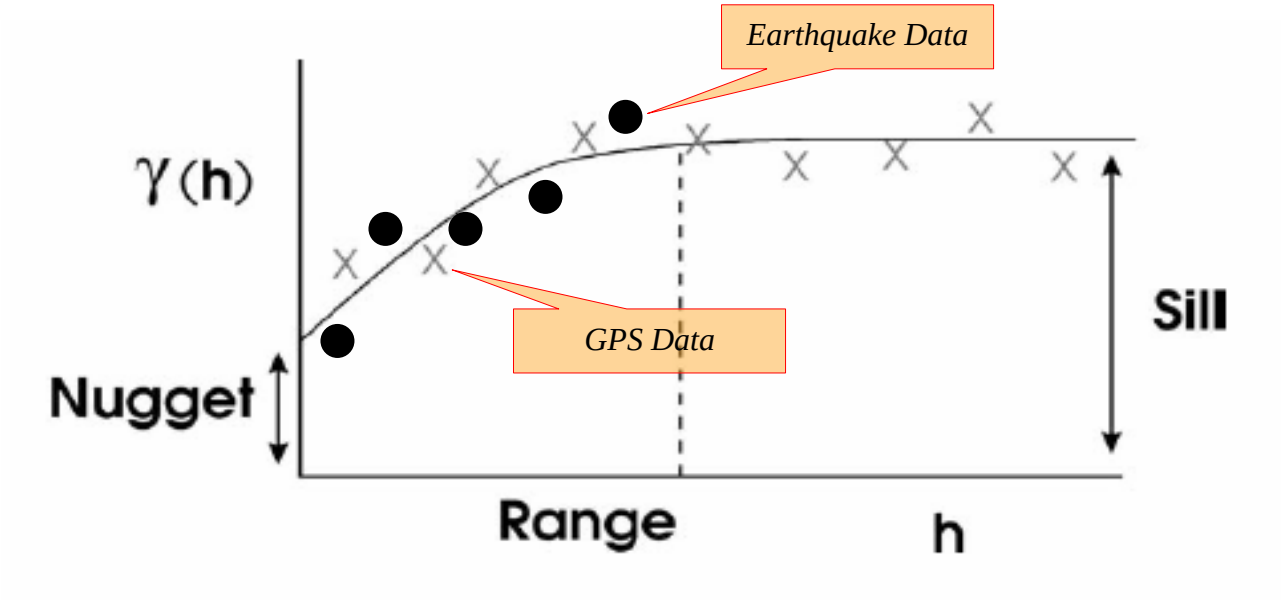
$$\gamma_{\text{model}}(h) = c\left(1 - e^{-\frac{h}{a}}\right) + \gamma_0$$

γ_0 : *Nugget,* value of *semivariogram* at zero *offset*

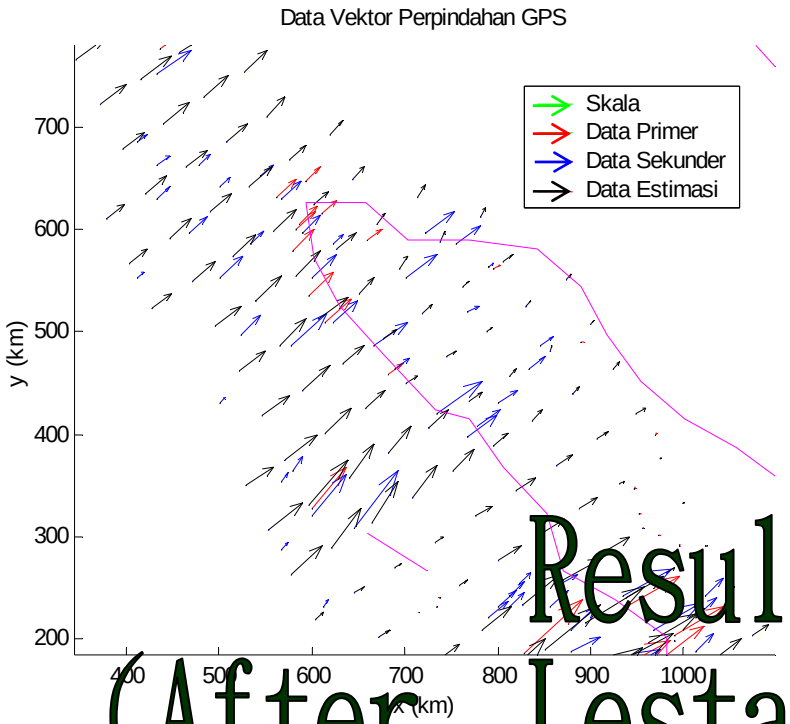
a : *Range, offset* value when *semivariogram reach the maximum value*

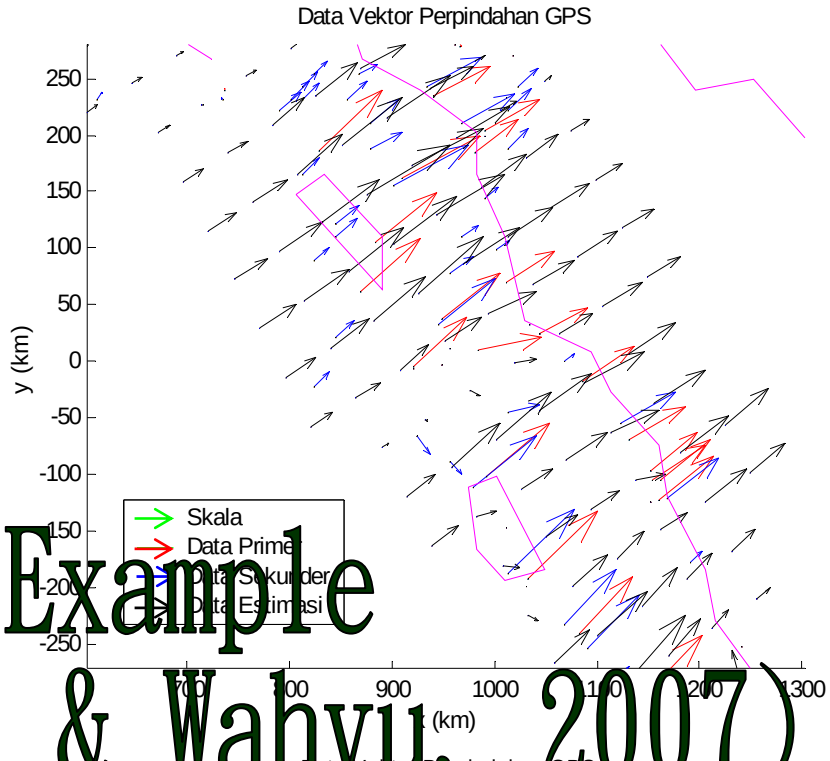
c : *Sill,* value of maximum of *semivariogram*

" The Main Idea of Combining Data "

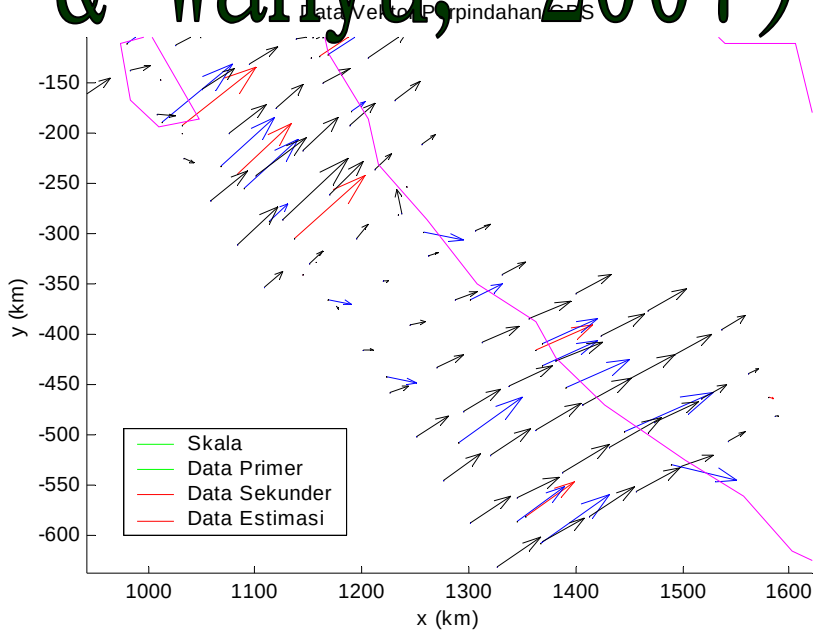


" To create smaller bin size based on earthquake catalog and probably could act as a trend function "



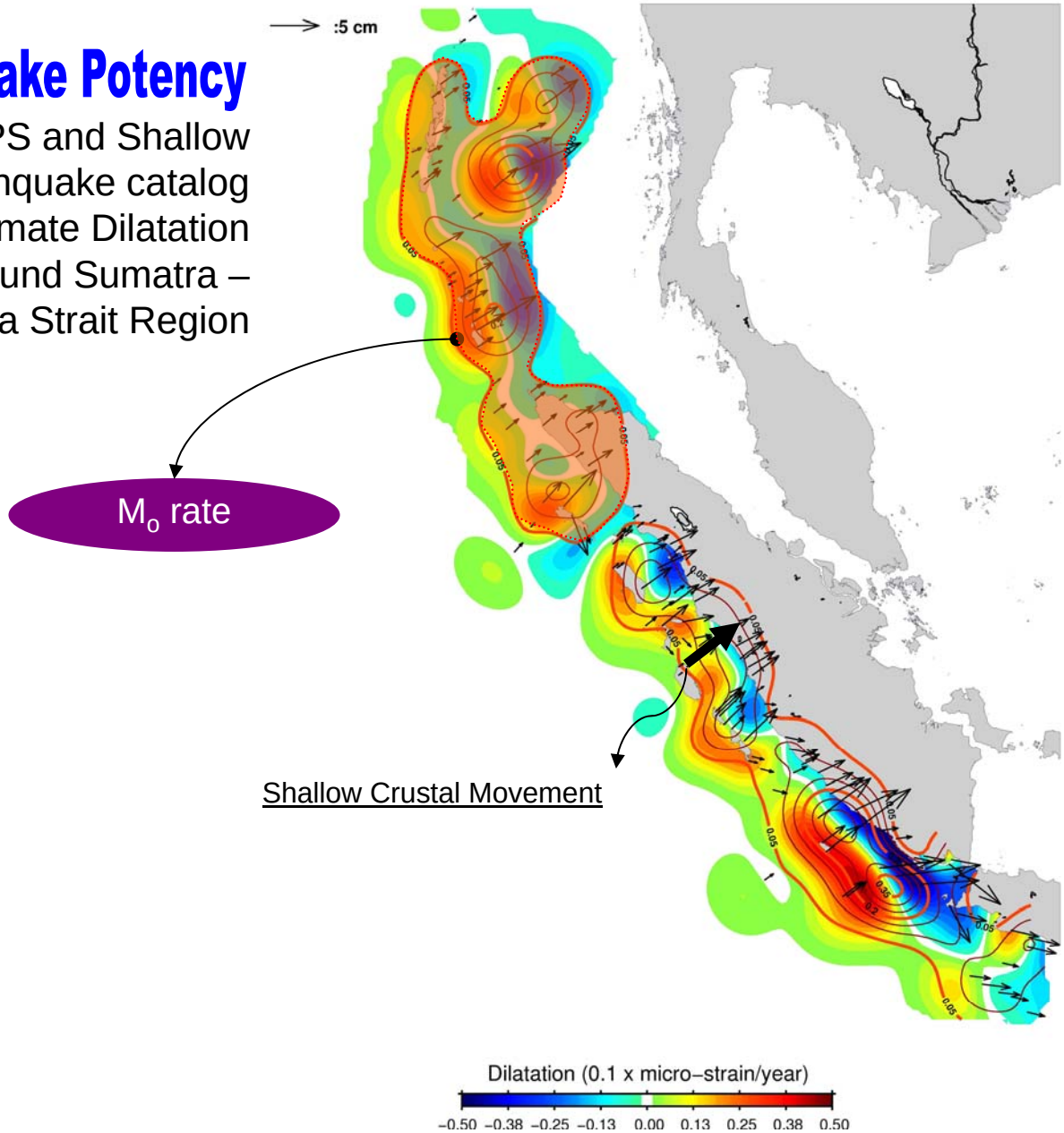


Result Example (After, Lestari & Wahyu, 2007)



Understanding The Earthquake Potency

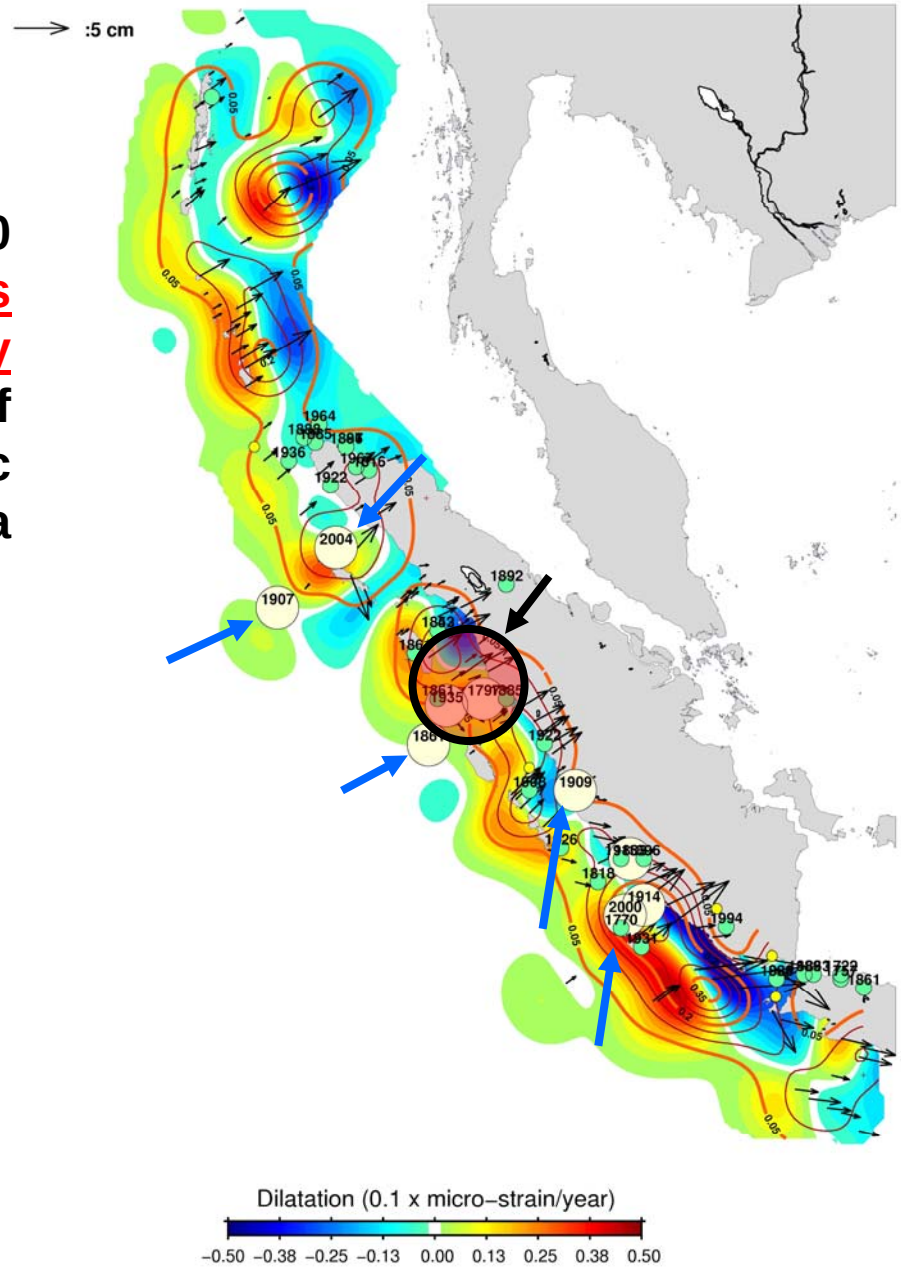
On the basis of Combining GPS and Shallow Instrumentally recorded earthquake catalog data of 1964-1999, I try to Estimate Dilatation rate & Seismic Moment Rate around Sumatra – Sunda Strait Region



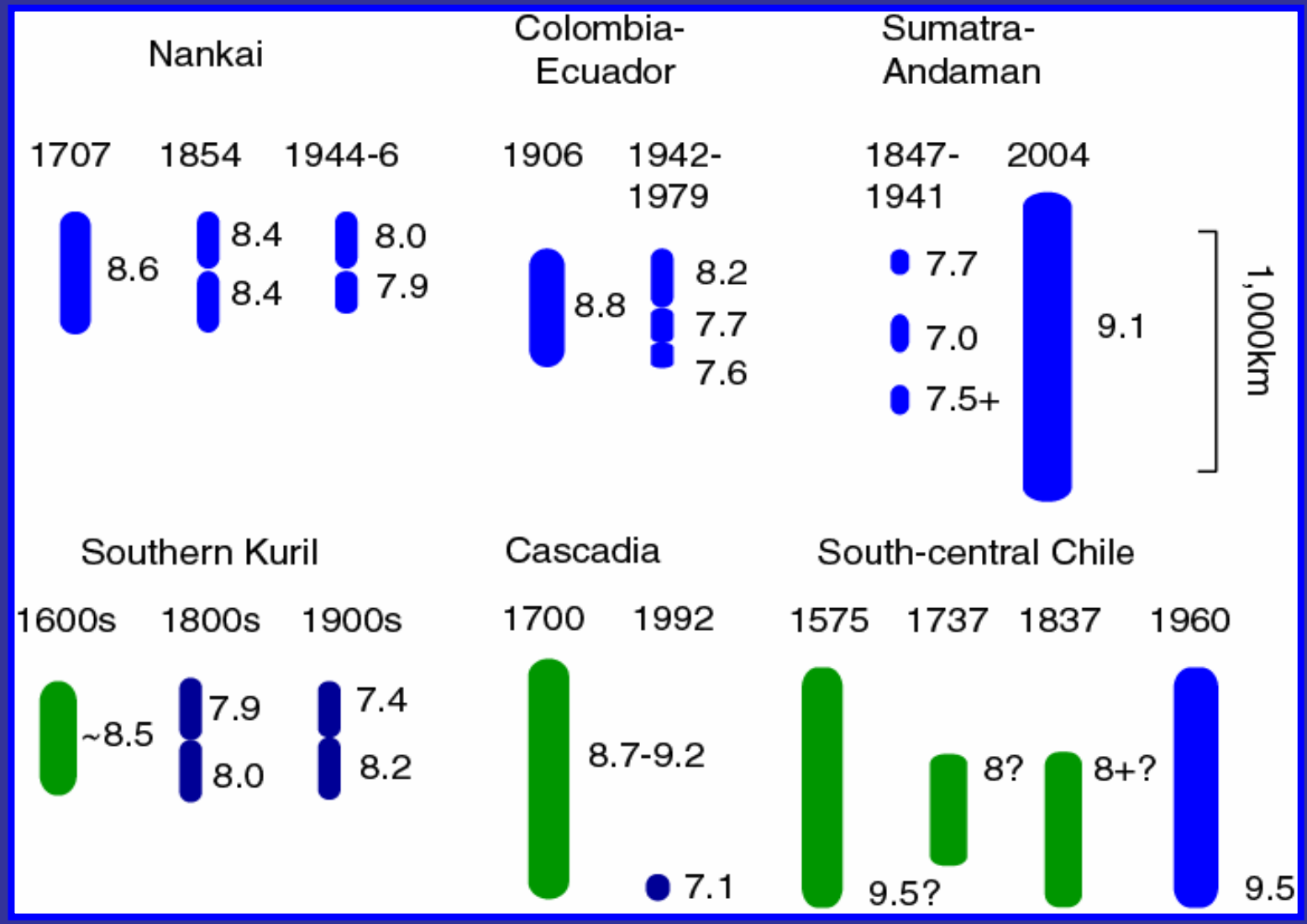
Earthquake Potential Model

Understanding The Earthquake Scenario

Overlapping with almost more than 200 years Large Shallow Earthquake, it seems likely that the both data could say something in the purpose of understanding The Seismotectonic Behaviors around the Study Area



Variability of Subduction Zone Earthquake



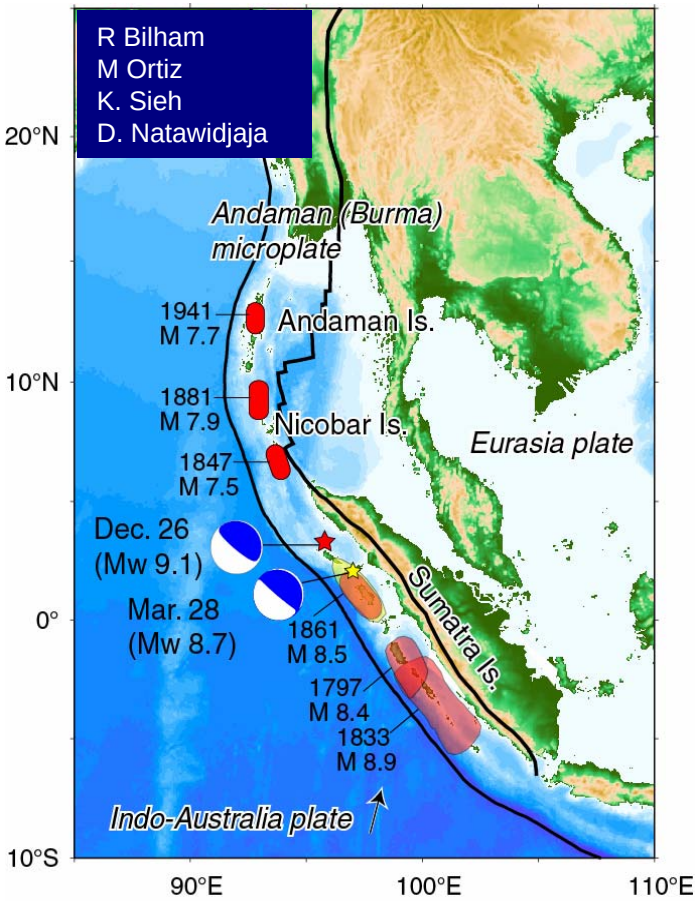
After, Satake, K. and B.F. Atwater (2006)

Summary (After Satake & Atwater, 2006)

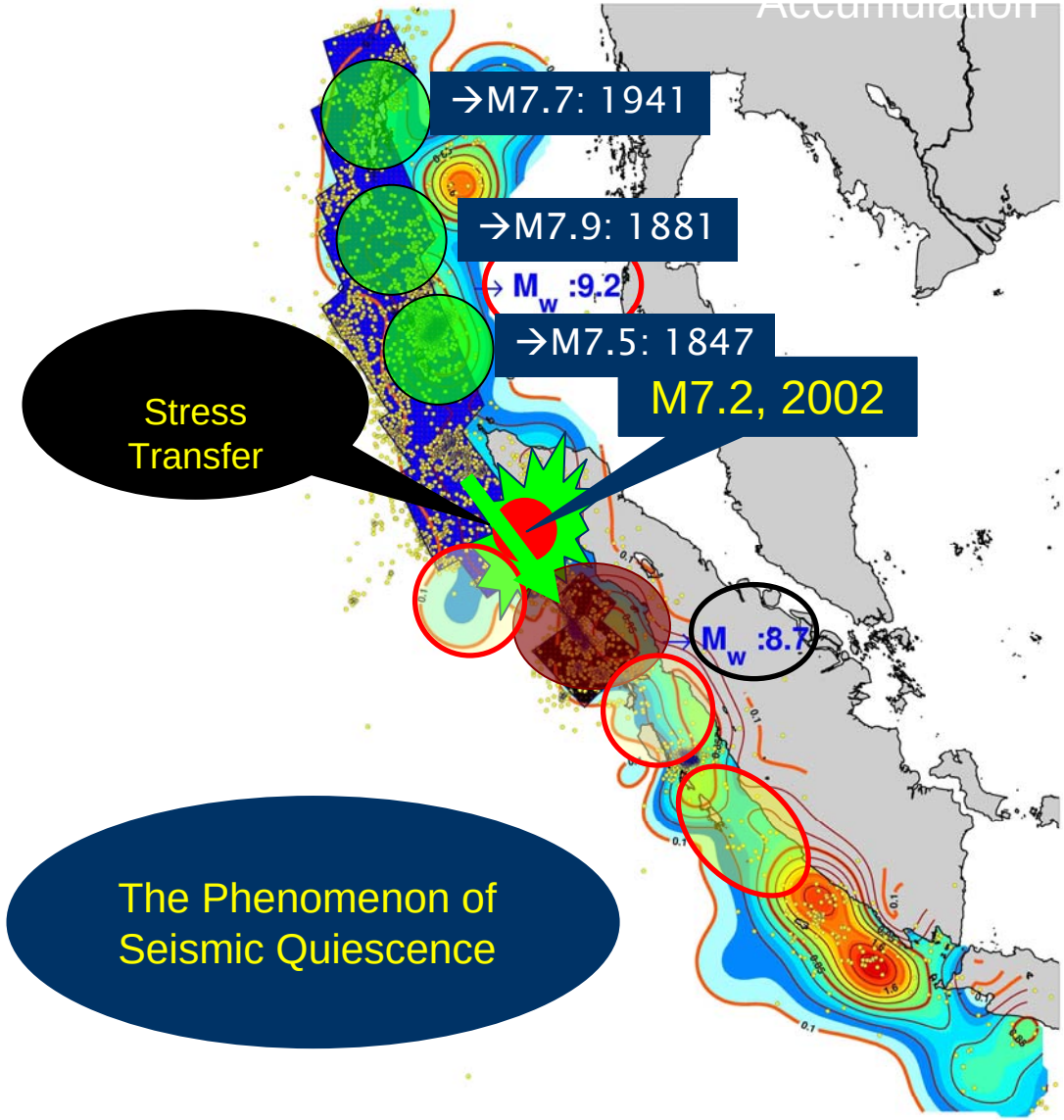
1. The 2004 Sumatra-Andaman Earthquake (Mw~9) occurred where only M<8 events were historically recorded.
2. Coastal paleoseismological studies indicate similar variability in earthquake. size at subduction zones in Chile, Cascadia and Japan (Kuril trench, Sagami and Nankai troughs).
3. The interval of such giant, or multi-segment events are 300 to 500 yrs.
4. More studies are ongoing in Sendai Plain, along Nankai trough, Andaman Islands and Myanmar.

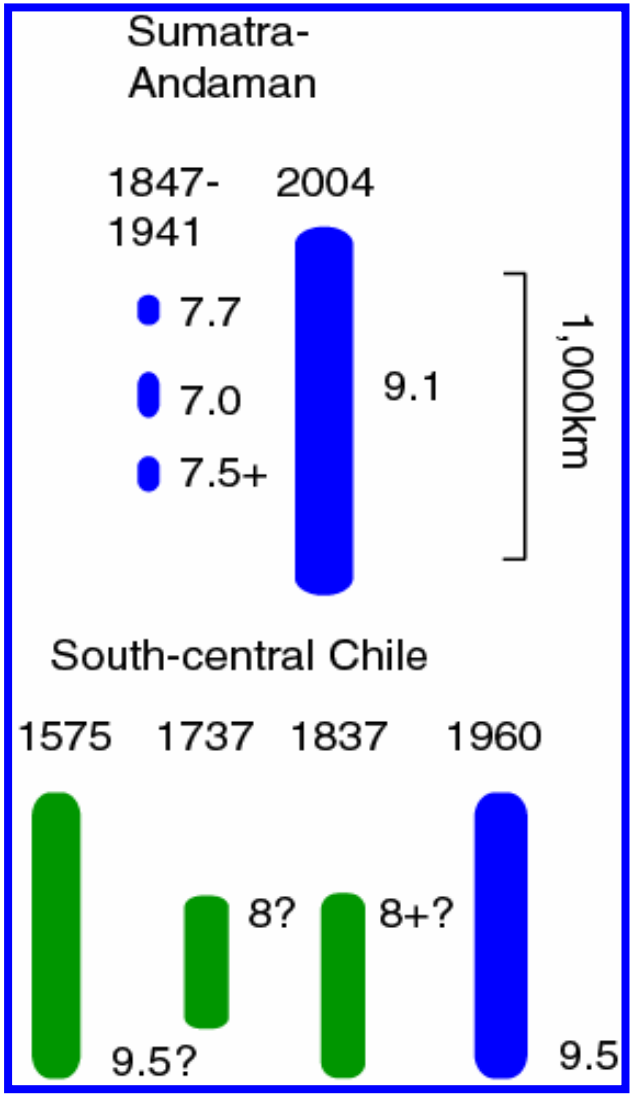
Satake, K. and B.F. Atwater
Long-term perspectives on giant earthquakes and tsunamis at subduction zones
Annual Reviews of Earth and Planetary Sciences, 2007, in press.

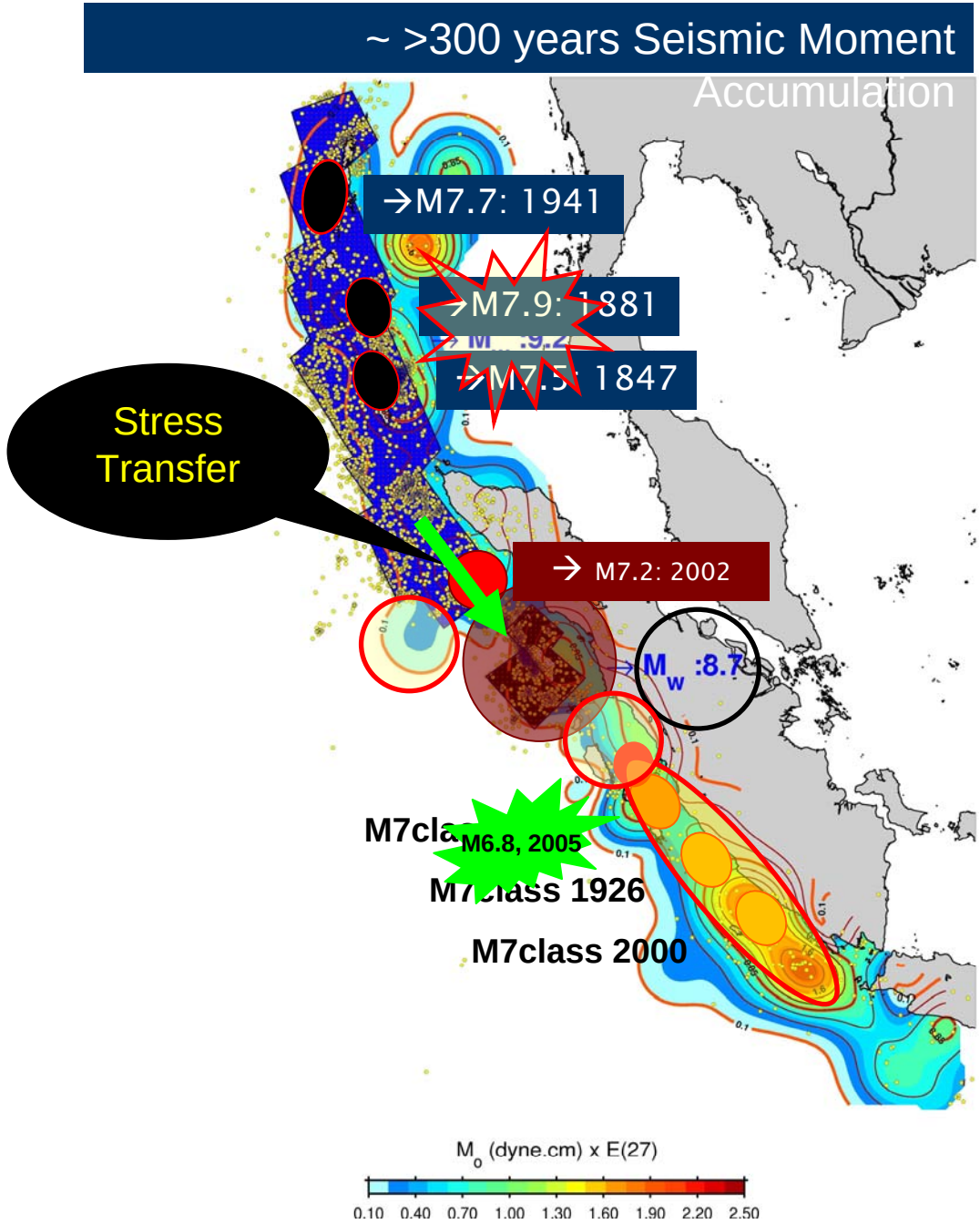
" Understanding The Possibility "



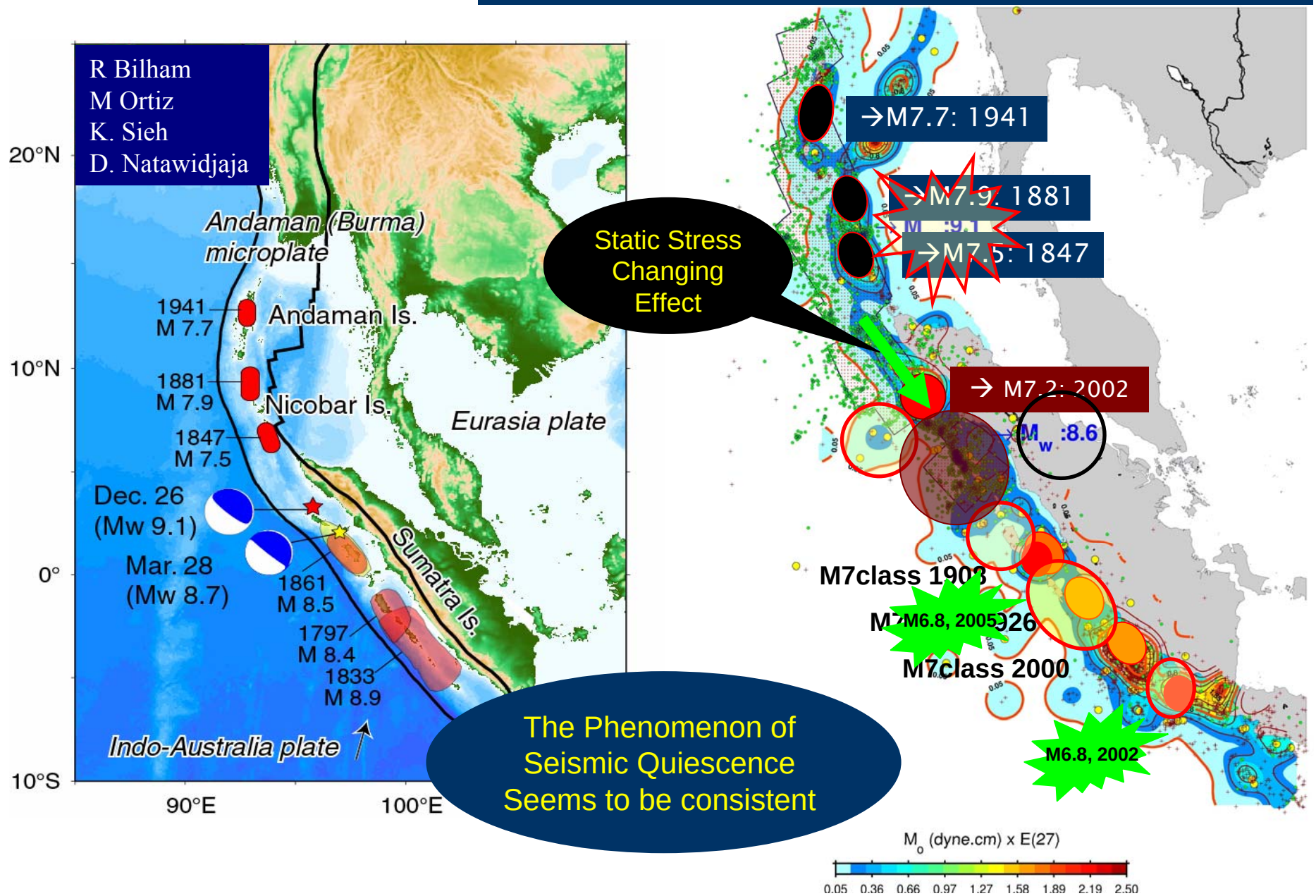
~ >300 years Seismic Moment Accumulation




Sumatra-
Andaman
1847-
1941
2004
7.7
7.0
7.5+
9.1
1,000km
South-central Chile
1575
1737
1837
1960
9.5?
8?
8+?
9.5

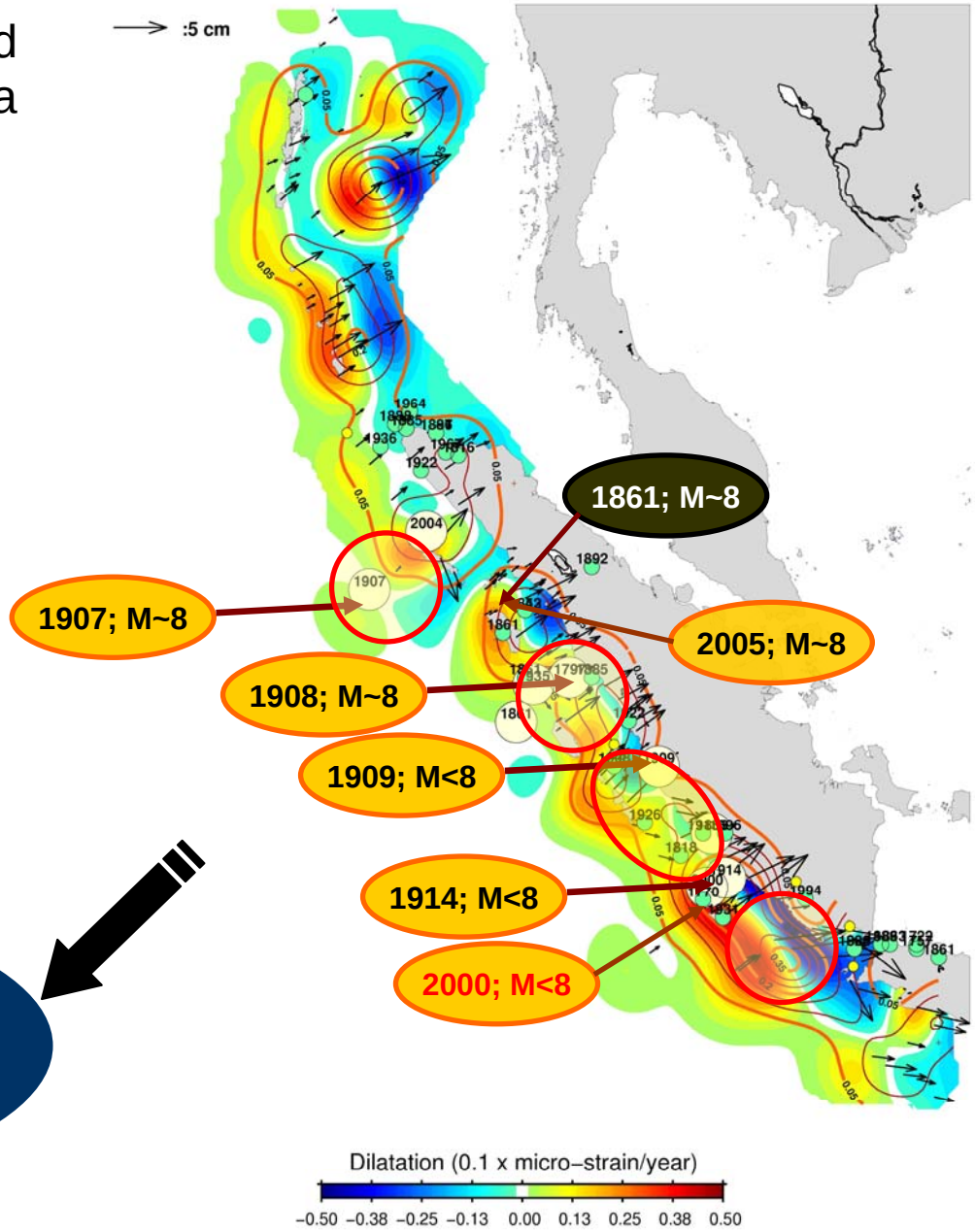

~ >300 years Seismic Moment Accumulation
→M7.7: 1941
→M7.9: 1881
→M7.5: 1847
Stress Transfer
→ M7.2: 2002
→ M$_w$:8.7
M6.8, 2005
M7class 1926
M7class 2000
M$_0$ (dyne.cm) x E(27)
0.10 0.40 0.70 1.00 1.30 1.60 1.90 2.20 2.50

~ 300 years Seismic Moment Accumulation Based on Shallow Earthquake Catalog Data of 1964-1999



Tracing back to ~ 100 years Historical Large EQ Event

Considering to ~ 100 years ago based on the Historical Large Earthquake Data



This Phenomenon leads Us
As the Guidance of ~ 100 years
Seismic Gap Hypothesis

' The Clue '

1. We are in a search the algorithm for understanding seismotectonic behaviour of the a part of Sunda Arc Region

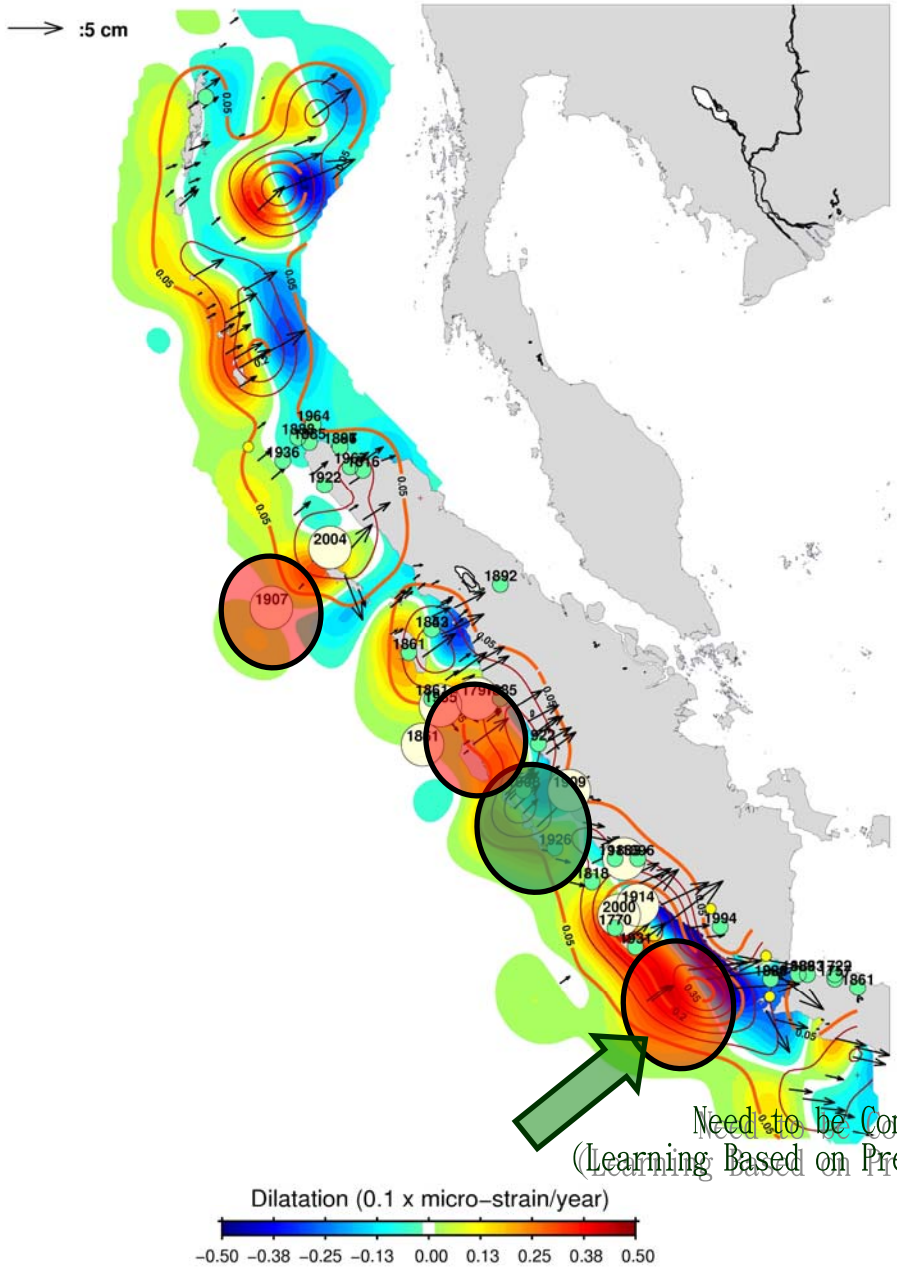
2. More reliable method seems likely could be developed

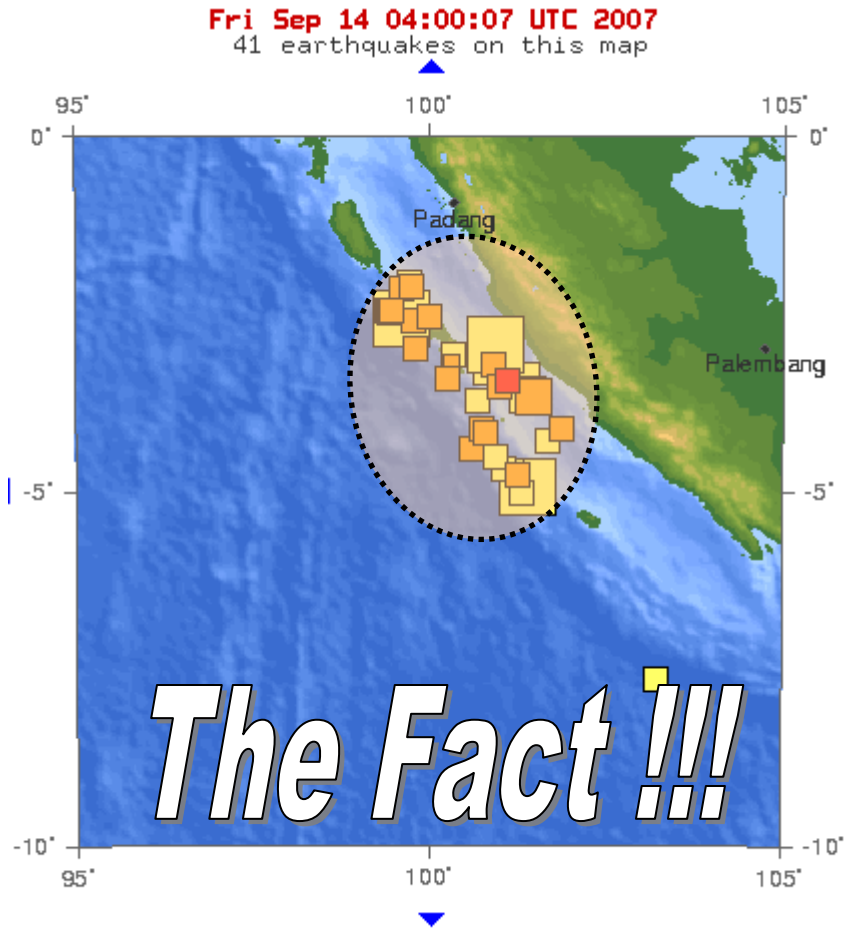
3. Seismic & Tsunami hazard Study and Analysis along off the coast Sumatra-Sunda strait should be constructed very carefuly

" Understanding The Possibility "

Evolution of My Scientifical Understanding Based on Present Day Event

Compression – Dilatation Rate Map

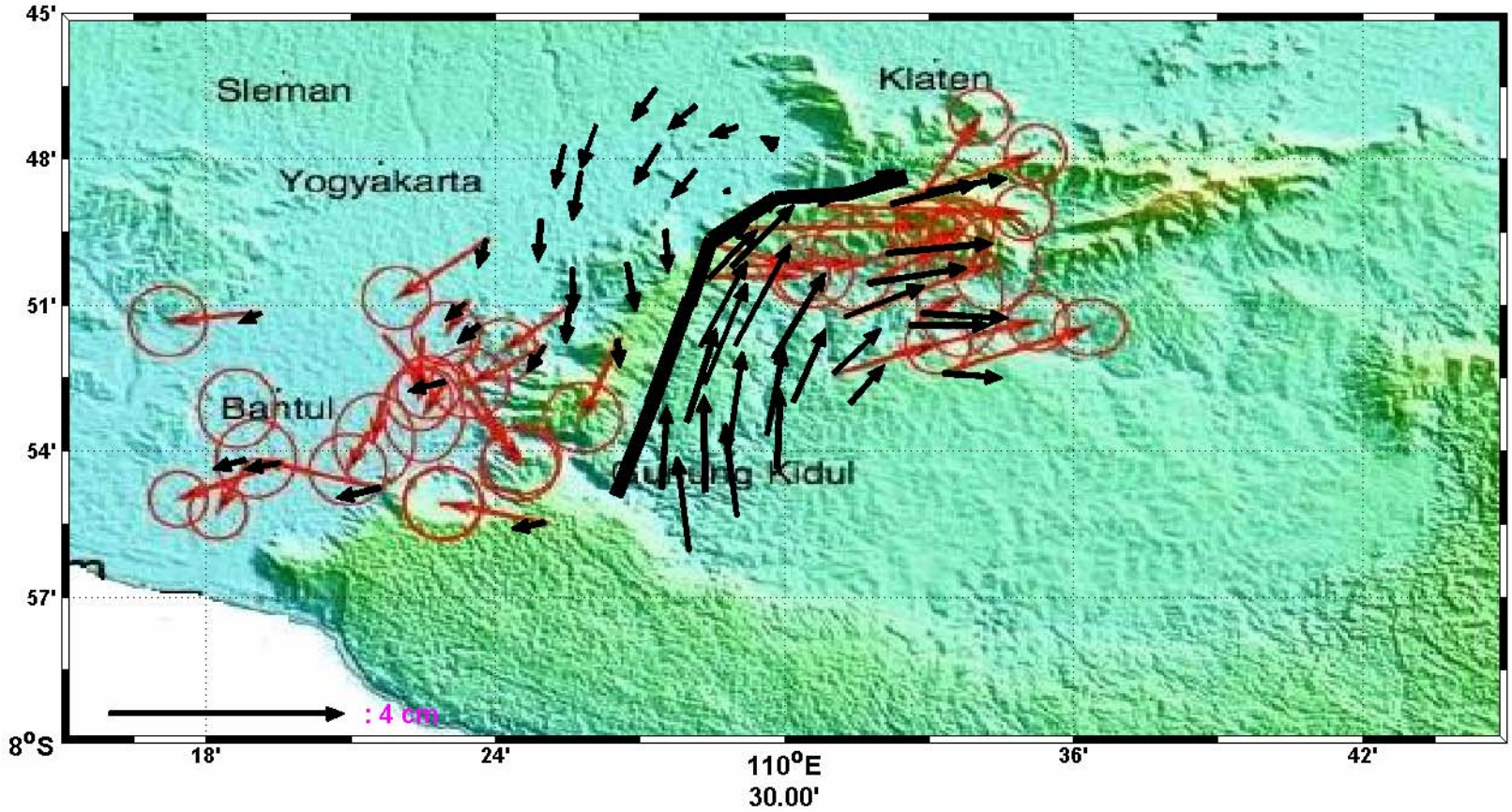




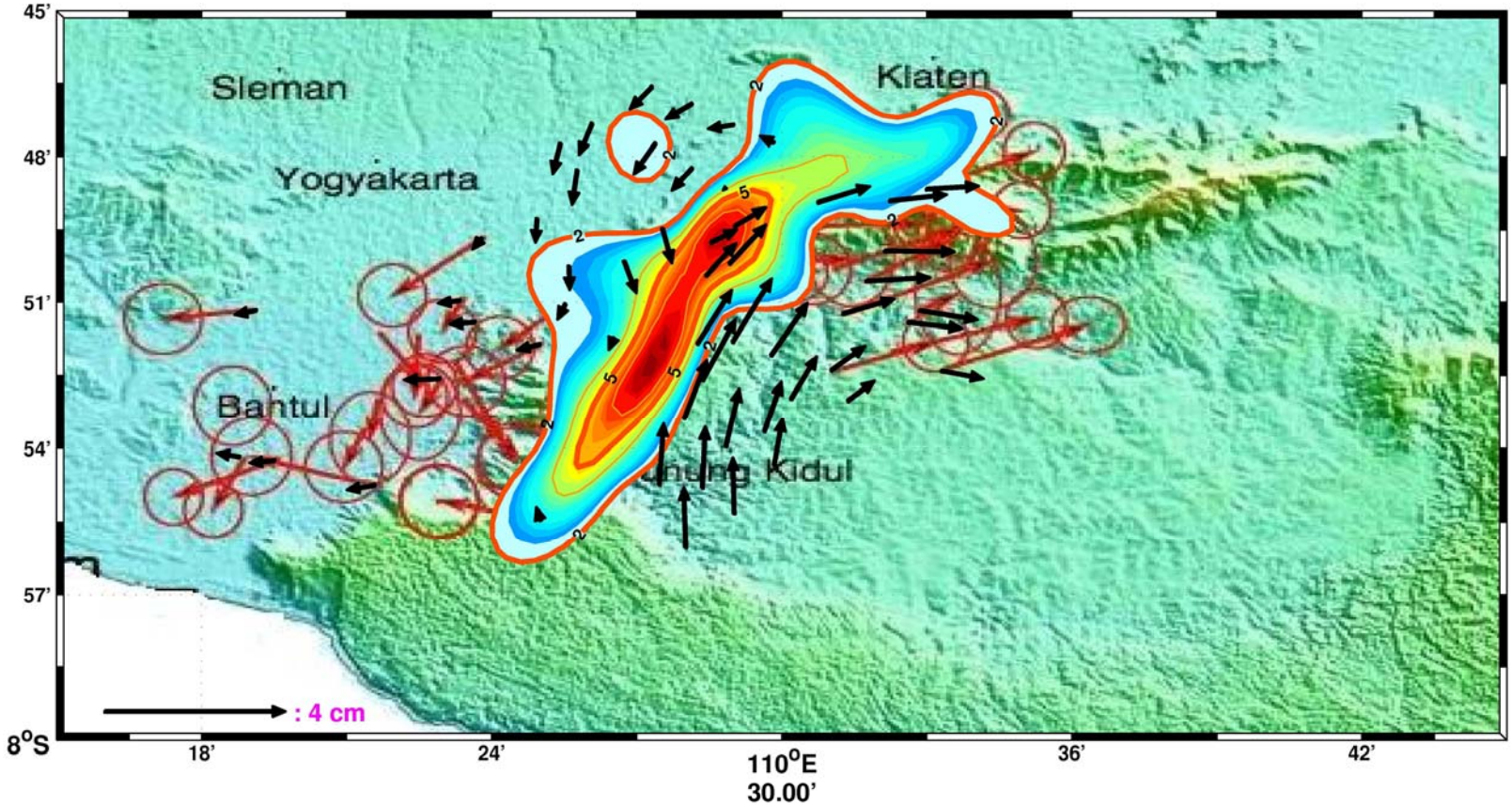
The Fact !!!

Need to be Considered More !!!!
(Learning Based on Present Day Crustal Dynamic)

Application for Jogja Earthquake (Central Java)



Maximum Shear Strain



Max. Shear (0.1xMicro−Strain)

2.00 2.63 3.25 3.88 4.50 5.13 5.75 6.38 7.00

Something '-Perhaps-' Very Important

Message to My Government

My Understanding about Crustal Dynamic seems to be Changed!!!

After Strain Released, There is something really hiding… It is about Healing Process Of Fault In Crustal Volume!!!. The Geological Evidence, Perhaps Give Us An Understanding of The Existence Based on Historical Asperity But Scenario and The Series in term of Mechanism Of Strain Released is Perhaps Evolve with State & Time.

From This Basis, We really Need to Record Surface Crustal Strain Continuously, … Do not ever STOP Monitoring ……

First proposal of joint research project

If we can rely on this hypothesis, it is very important to study the slip distributions of past plate-boundary earthquakes.

" What could be DONE "

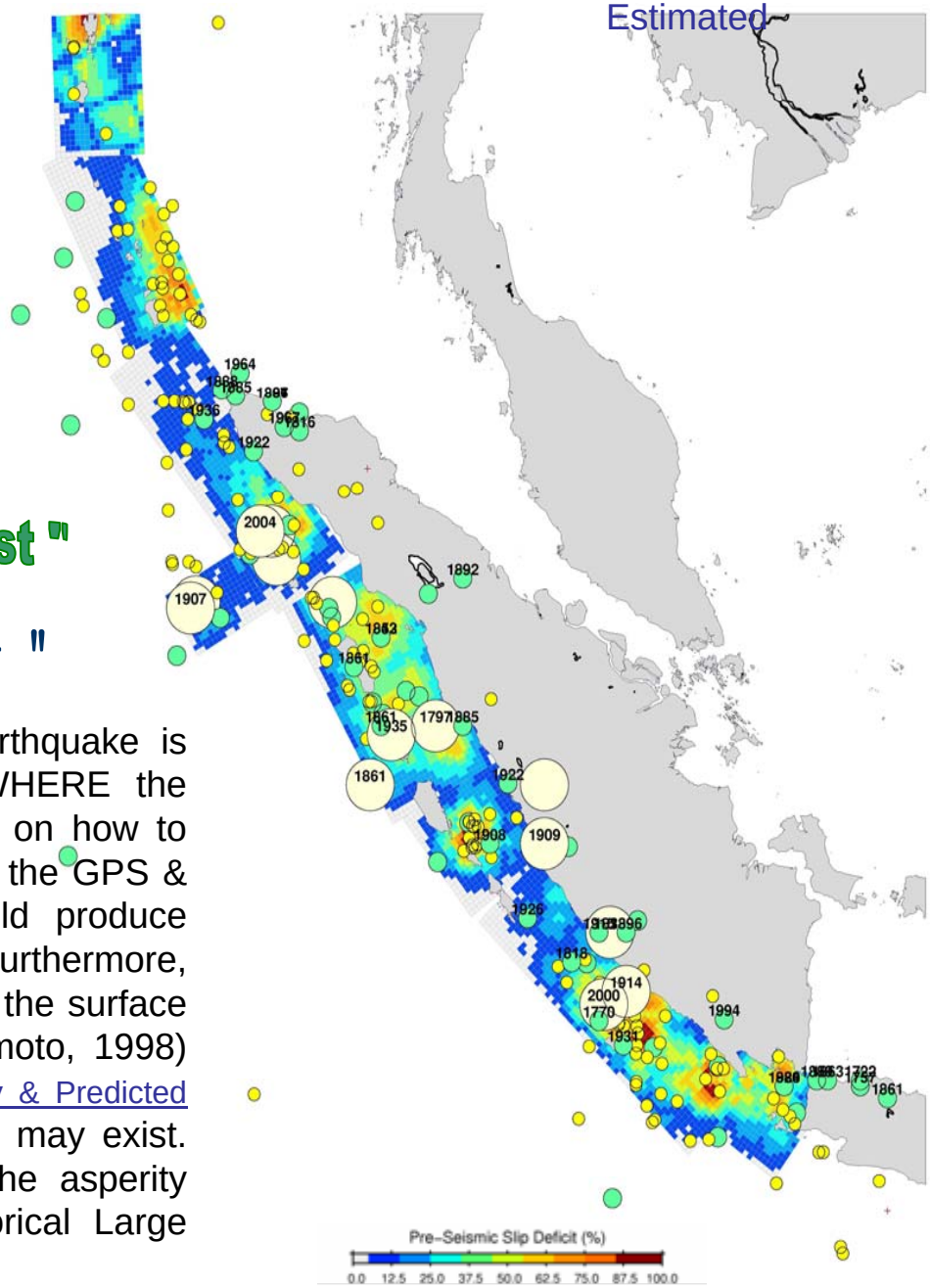
- We will retrieve historical seismograms in Off Coast Sumatra Island.
- We will carry out source process inversions for the slip distributions using them as well as teleseismic, geodetic and tsunami data.

First Trial Based on GeoStat Data

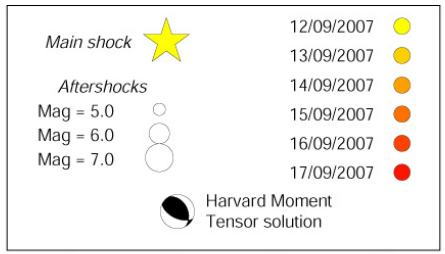
" The Basic Earthquake Forecast "

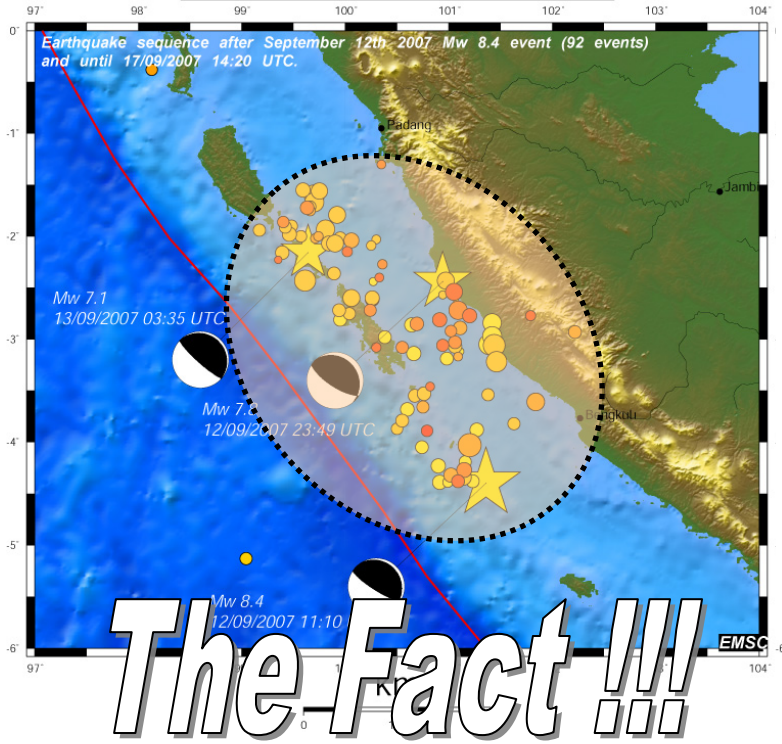
" Estimating The Asperity "

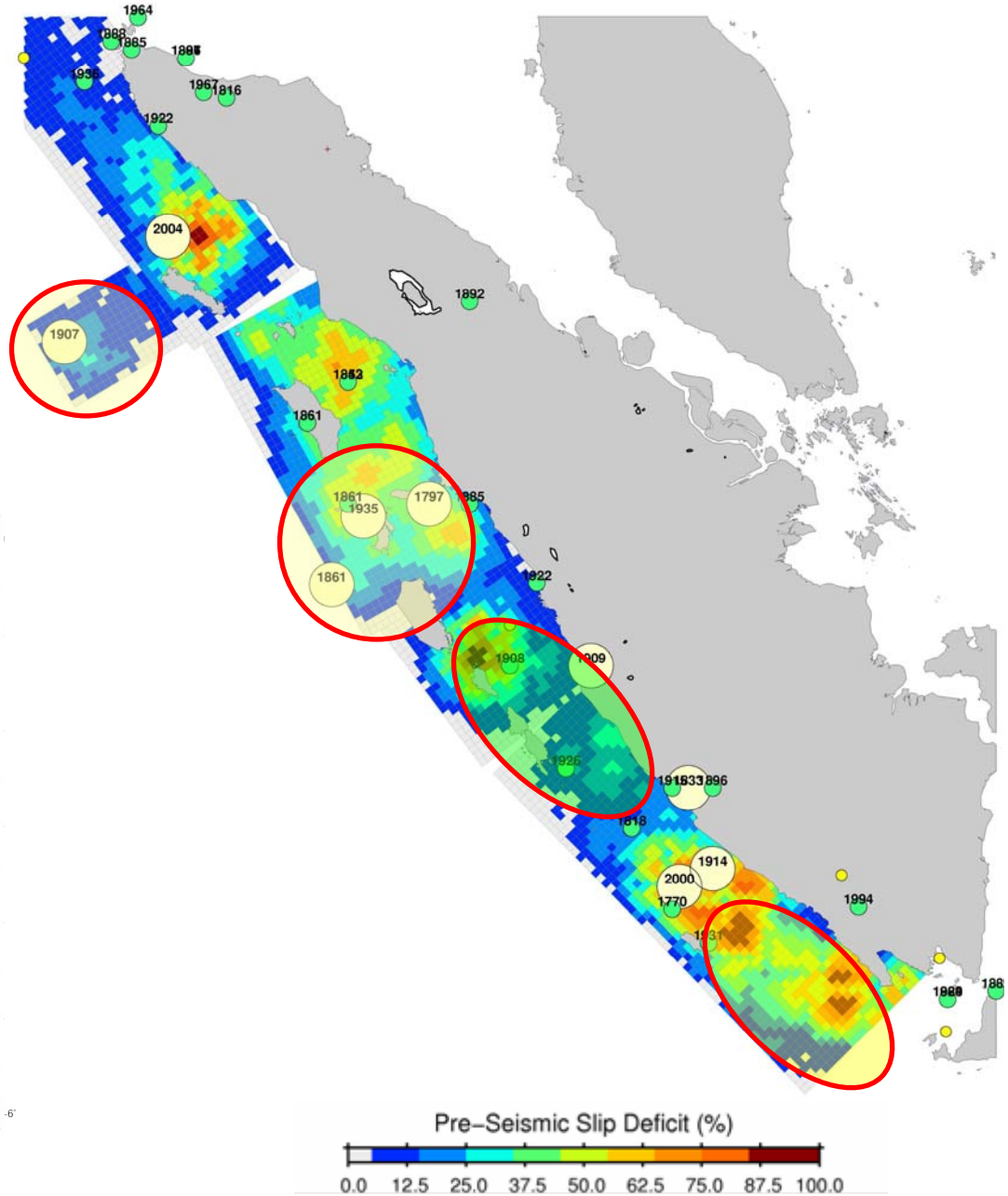
The best way to forecast the Next Coming Earthquake is probably by understanding the possibility of WHERE the asperity may take a place. Continuing, our work on how to model the seismotectonic behaviors by combining the GPS & shallow crustal Earthquake Data then we could produce displacement estimated over entire the surface. Furthermore, by following a simple algorithm on how to inverse the surface displacement into the surface fault-plane (Hashimoto, 1998) we basically could estimate the probable Asperity & Predicted Pre-Seismic Slip Deficit where high locking probably may exist. Here is the example of our simple result on the asperity estimation overlay with almost 200 years Historical Large Earthquake Catalog …



Understanding The Rest of Possible Locking (W. Triyoso, 2006)







The Fact !!!

Collaboration Research LIPI-ITB-Cambridge & GFZ

Period of research: 2008/2009 (detailed dates to be determined)

Proposal to LIPI in support of an application for a research permit
Project Title: Seismicity and deep structure of the Sumatra subduction zone

Proposer: *Dr Frederik Tilmann (University of Cambridge)*
Bullard Laboratories
University of Cambridge
Madingley Road
Cambridge CB3 0EZ
United Kingdom
Phone: +44 1223 765545, Fax: +44 1223 360779
Email: tilman@esc.cam.ac.uk
Nationality: German DOB: 25th February 1972

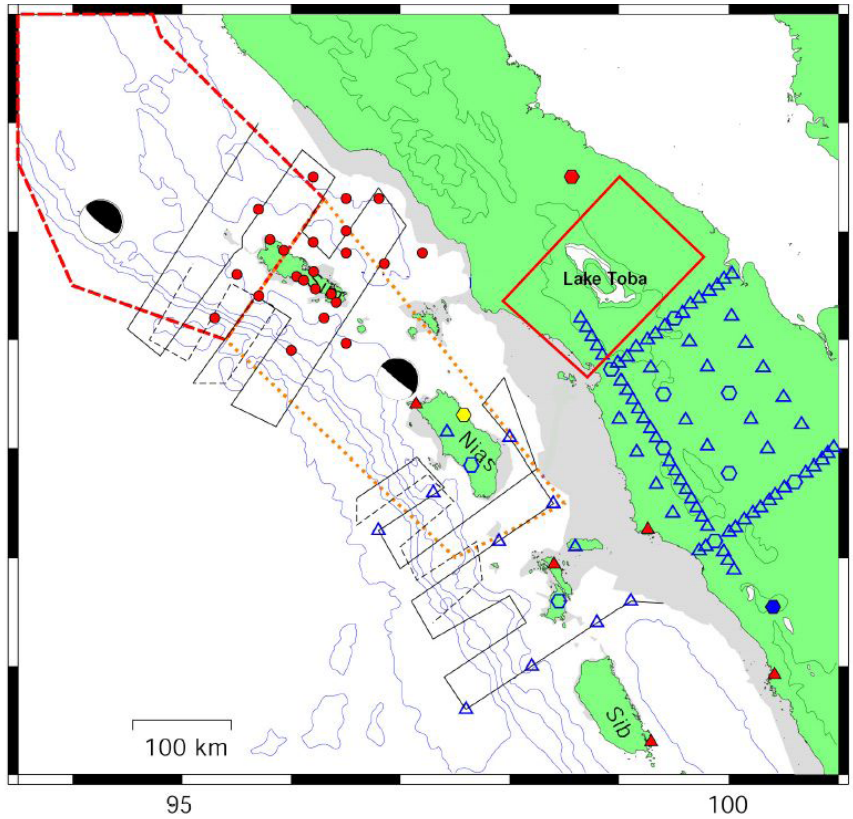
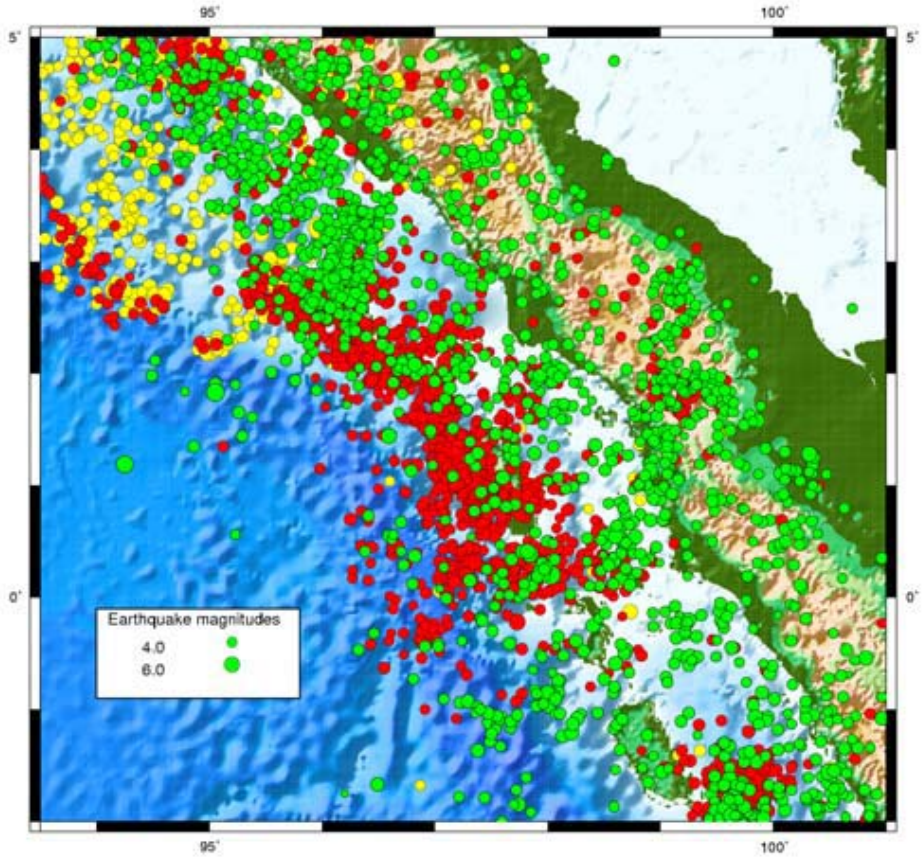


Figure 1 Schematic layout of planned experiment in the context of past and planned seismic experiments and permanent stations. The blue open symbols on land represent schematically planned station sites for the deployment in this proposal. Blue open symbols at sea represent stations to be deployed during the planned Sumatra segmentation 1 cruise. Actual locations will be modified to take account of logistical and site constraints, and possibly new results of rupture models. Blue open triangles on land – passive array stations (short period – CMG 6T; 6-12 months deploymen). Blue open hexagons – broadband stations (CMG 3T – 12 month deployment). and OBS (~8 months deployment). Red square: approximate outline of area for where 3-C geophones will be deployed for 4-6 months. Blue open triangles at sea – long term OBS stations. Solid lines – seismic refraction shooting profiles. OBS stations and refraction profiles are planned for cruise Sumatra Segmentation 1 in May 2008. Red triangles-vertical short period stations
(Caltech). Solid hexagons – permanent broadband stations (BMG, GEOFON, JISNET). Red circles – OBS and land stations from Simeulue & SEACAUSE experiments (3-5 month deployment in 2005/06).

(a)

(b)



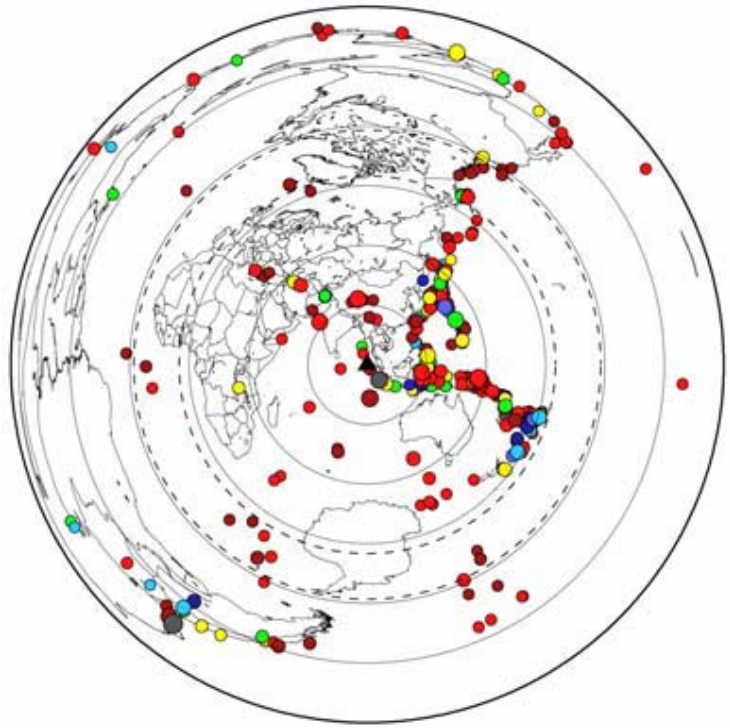


Figure 2 (a) Seismicity in the area of the proposed experiment (NEIC catalogue): Green: events 1/1/1970-26/12/2004; yellow: events 26/12/2004-27/3/2005. Red: Events 28/3/2005-20/4/2006. Based on the Gutenberg Richter distribution of earthquakes prior to December 26, 2004 we estimate that we will record approximately ~750 local events with magnitudes M>2 within or near the dense network (6 months deployment). (b) Global seismicity M>5.8) during one year (here 2000). During 6 months typically around 70 events with M>5.8 occur in the distance range suitable for receiver function analysis, and ~25 in the distance range suitable for analysis of shear wave splitting of SKS and SKKS phases..

A Research Progress in Understanding The Earthquake Potency of The Whole Sunda Arc & Its Implication to Probabilistic & Deterministic Earthquake Hazard (W. Triyoso, 2007)