Stress Perturbations along Sumatra Island due to Mega-Earthquake Occurrences

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Introduction and Motivation

A large earthquake plays an important role in perturbing the stress properties e.g., maximum stress orientation, stress loading and relaxation zone [1,2].

According to the cumulative seismicity rate along Sumatran subduction based on International Seismological Centre (ISC) Bulletin, it shows that there are 4 great earthquakes (Mw > 8) i.e., 2004 Sumatra-Andaman event, 2005 Nias-Simeulue event and twin events of 2012 off west coast of Sumatra. Regarding this issue, it becomes an interesting issue for identifying the in-situ stress properties and its evolution due to mega-earthquakes occurrence.

As a result of this study, we expect our outcomes could be used to better understand about the mechanisms of stress rotation due to great earthquake in order for assessing the post-seismic hazard analysis.

Methodology : stress inversion and Coulomb stress changes

In this study, we first apply the stress inversion to retrieve the principle in-situ stress orientation prior and after 2004 event within some segments defined from seismogenic volume. We run the stress inversion using iterative joint inversion technique proposed by [3] which applied on 652 focal mechanisms catalog compiled by Global CMT and ISC. Based on cumulative seismicity rate (Figure 1), we divided the time period into two intervals i.e., from June 1976 to November 2004 (background rate) and from December 2004 to August 2017 (After 2004 event)

For modeling the stress changes, we used the co-seismic slip data from [4,5,6] to produce static Coulomb failure stress (ΔCFS) model of each great earthquake. We utilized COULOMB3.3, an open-source software from USGS for computing the stress changes following a fault slip [1,2].

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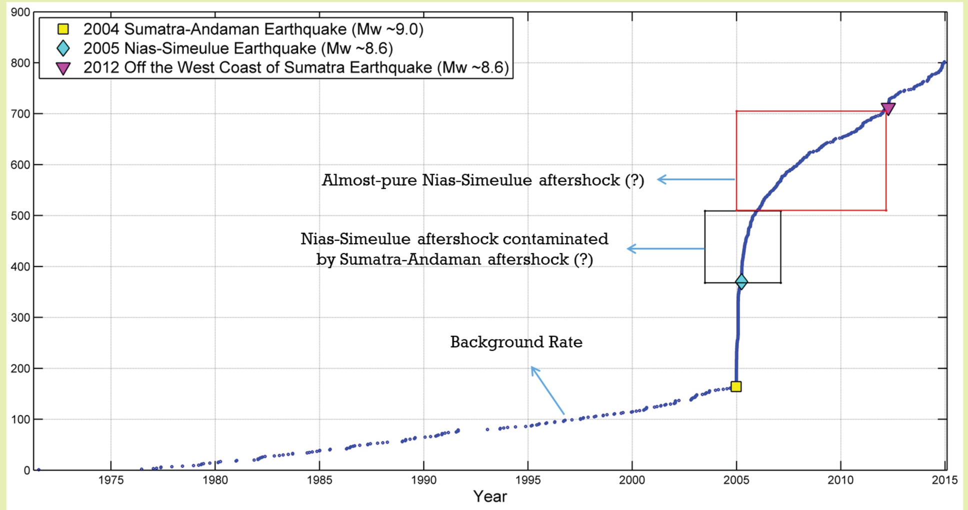
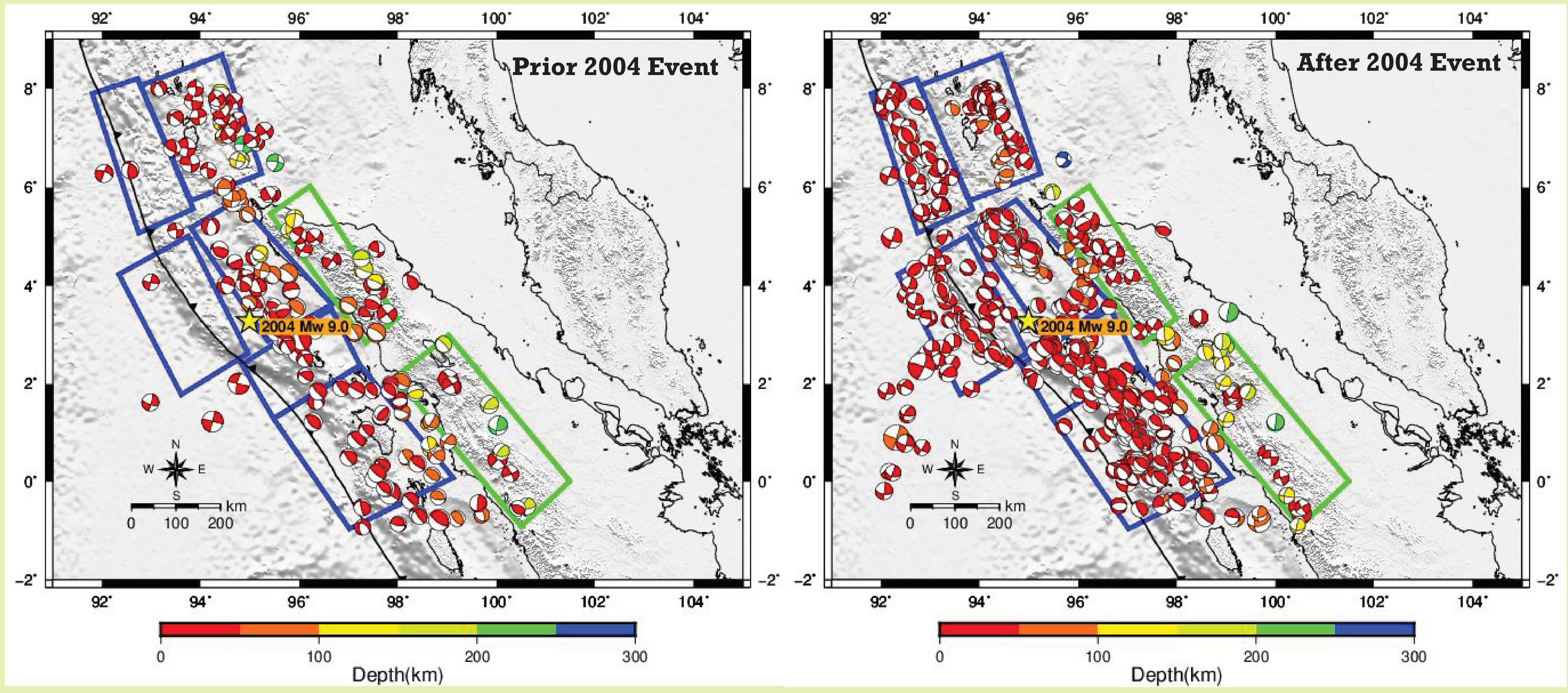
Cumulative Seismicity Rate and Focal Mechanisms Distribution





Stress Inversion Result

Tabel 1. Stress inversion result from background rate

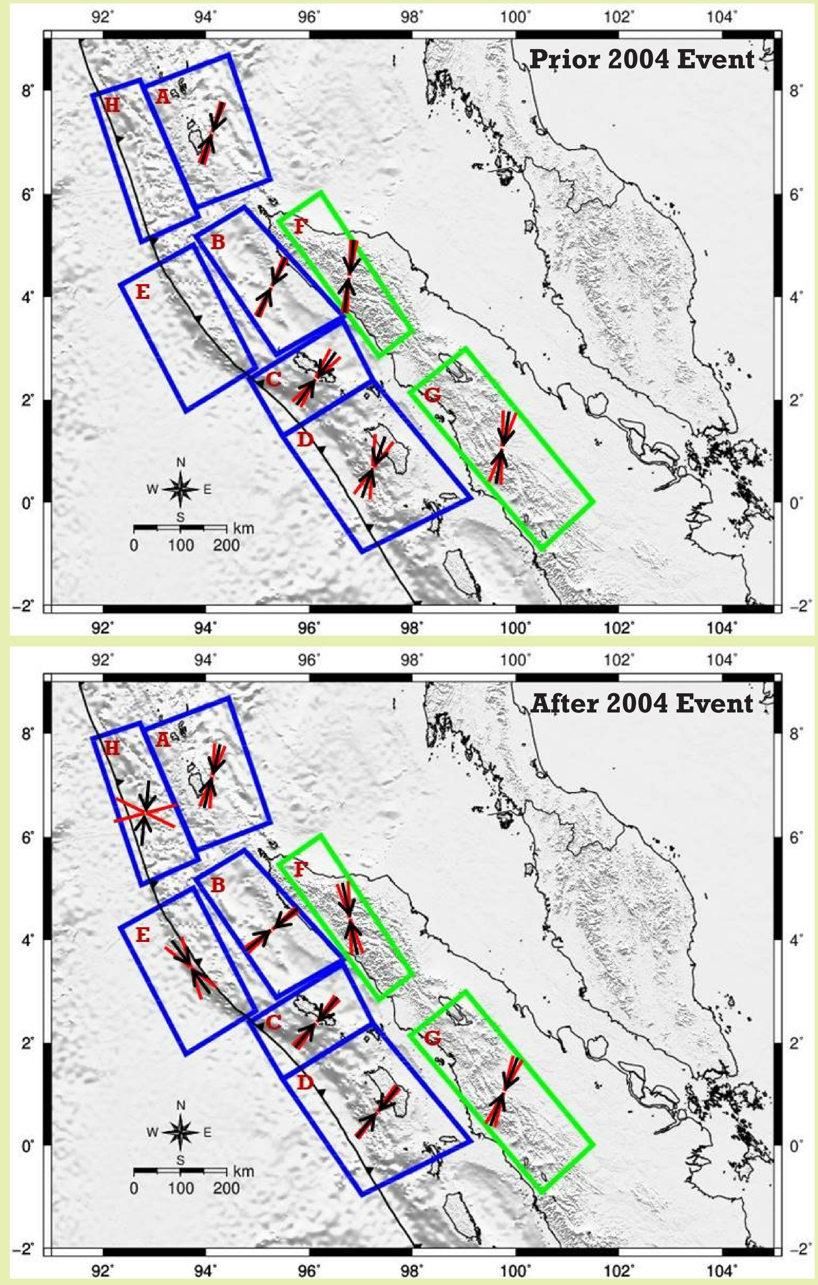
Segment	Orientation		
	σ_1(°) azimuth/plunge	σ_2(°) azimuth/plunge	σ_3(°) azimuth/plunge
A (30 data)	17.5/1.7 ± 1.9	200.5/88.2 ± 7.6	107.5/0.1 ± 7.4
B (25 data)	203.1/27.5 ± 1.5	305.7/22.8 ± 2	69.5/52.9 ± 1.6
C (14 data)	215.3/31.7 ± 7.2	308.6/5.4 ± 14.7	47.3/57.7 ± 15.3
D (20 data)	201.3/25.4 ± 17.5	293/3.5 ± 19.1	30.3/64.3 ± 11.7
F (12 data)	6/6.3 ± 1.1	97/8.3 ± 8.6	239.4/79.5 ± 8.7
G (6 data)	189.9/5.7 ± 3.8	99.6/3.2 ± 6.7	340.5/83.5 ± 6.6

Note: the errors showed the maximum differences between stress inversion without given uncertainty and with uncertainty.

Tabel 2. Stress inversion evolution toward 2004 Sumatra-Andaman earthquake

Segment	Orientation		
	σ_1(°) azimuth/plunge	σ_2(°) azimuth/plunge	σ_3(°) azimuth/plunge
A (118 data)	14/18.4 ± 3.7	240/64.4 ± 3.9	109.8/17.2 ± 1.5
B (121 data)	231.8/30.3 ± 1.1	141.1/1.3 ± 1.5	48.9/59.6 ± 1.2
C (48 data)	217/22.6 ± 1.3	310.8/9 ± 1.3	61.2/65.4 ± 0.8
D (139 data)	217.4/38.1 ± 0.8	309.1/2.1 ± 2.1	41.7/51.8 ± 2.1
E (49 data)	325.5/15.1 ± 10	55.8/0.9 ± 10	149.3/74.8 ± 1.7
F (22 data)	347.1/24.7 ± 3.3	199.2/61.5 ± 1.4	83.4/13.3 ± 3.2
G (12 data)	19/7.5 ± 2	248/78.6 ± 2	110.1/8.4 ± 1.7
H (27 data)	185.6/20.9 ± 70	292.9/38 ± 70.7	73.4/44.7 ± 2.1

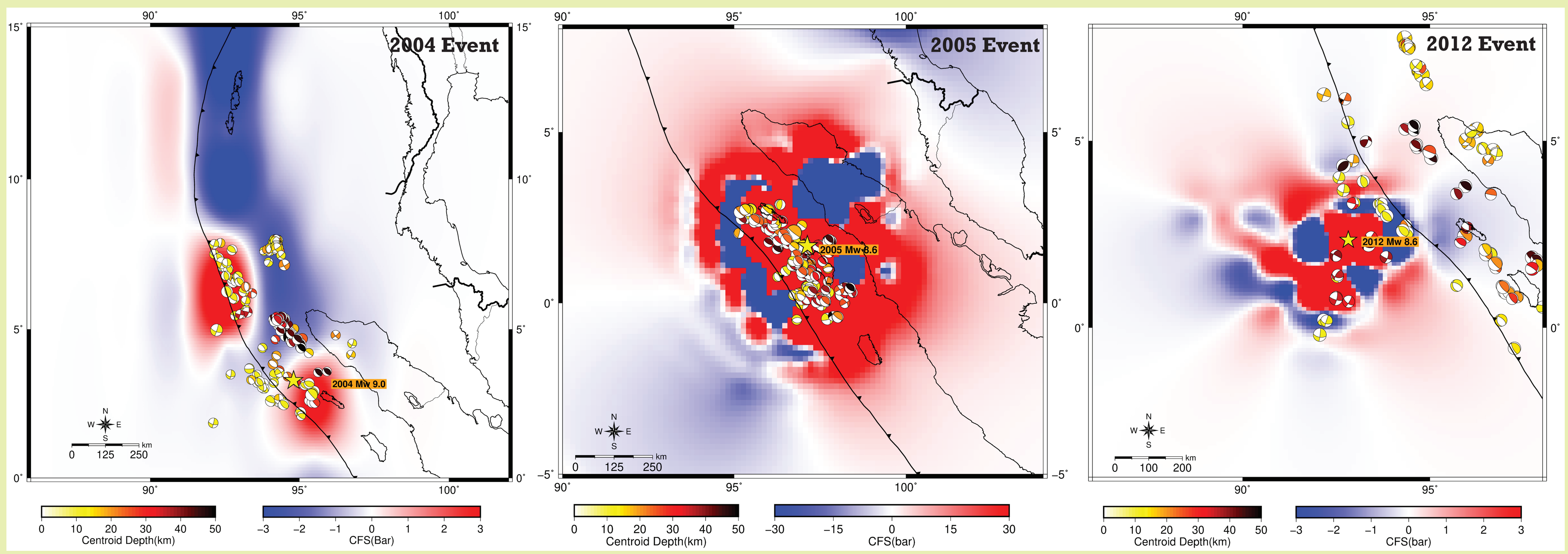
Note: the errors showed the maximum differences between stress inversion without given uncertainty and with uncertainty.



The evolution of maximum stress orientation after 2004 earthquake exhibited remarkable changes on segment B and D (see Table 1 and 2) with the difference of orientation approximately ~30° and ~16° respectively.

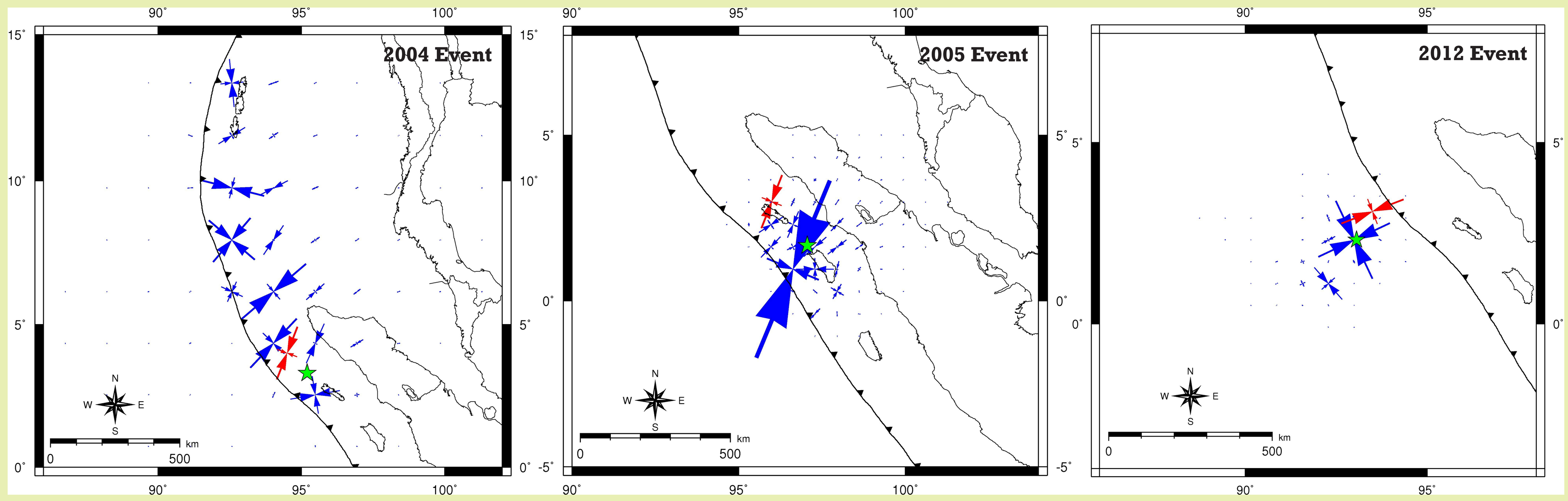
The acuracy of stress inversion depends on the number of focal mechanisms inverted and on the noise level in the data [3]. Thus, the inversion results on Sumatran fault (segment F and G) could possibly yield uninterpretable result due to low data quantity.

Coulomb Failure Stress (ΔCFS) Model



ΔCFS models of large earthquake showed that most of the aftershocks focal mechanisms distribution consistent with the area of increased ΔCFS and few aftershocks focal mechanisms occurred on stress shadow zone.

Mainshock Principal Stress Orientation



To better understand the influence of mega-earthquake in perturbing the background stress orientation, we calculated co-seismic principal stress orientation and found that the 2004 and 2012 events yield a difference direction supporting the result of stress inversion after mega-earthquake.

Conclusion

Principal stress orientations estimated in this study adequately reveal the changes in maximum stress orientation after the occurrence of mega-earthquake. The most noticeable changes lie within segment B and D which suggesting the rotation of maximum stress direction point out the location of the corner of Sumatera Island and the surrounding of Nias Island.

The high stress accumulation of ΔCFS models seems to support the rupture propagation of co-seismic slip. Based on the analysis of mainshock principal stress orientation, it shows the difference of background stress orientation in respect to the co-seismic stress orientation. This difference indicates that large earthquake could possibly perturb the background stress field in Sumatra subduction evinced from alike pattern of stress orientation after 2004 event.

Future Works

- Propose accurate fault plane solution from seismogenic zone based on Mohr-Coulomb criterion
- Modeling Coulomb stress transfer for background rate and after large earthquakes occurrence using proposed fault plane solution
- Mapping future event zones according to existences of mega-earthquake (Mw > 8)

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