IS GEODETIC MEASUREMENT A USEFUL INDICATOR OF INTRAPLATE EARTHQUAKES?

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Abstract

The question of the reliability of GPS measurement as an index for intraplate seismicity is raised here. Geodetic measurement of slip rate along the Longmenshan Fault -a thrust structure that straddles the border of the Indo-Australian Plate and Eurasian Plate produced ?gures as low as 3mm/year, despite this low return, the magnitude 7.9 Wenchuan earthquake occurred along this fault. Similar pattern was discovered in both the New Madrid, South Carolina and Wabash seismic zones, where geodetic derived strain rates of less than 2mm/yr fail to account for the recurrence of magnitude 7 earthquakes every 500 years. Other intraplate settings like Europe, Australia, South Africa showed similar results, hence leading us to question how reliable a tool geodetic measurement is in predicting the likelihood of earthquakes occurring in the future. I conclude that seismic hazard assessment of intraplate earthquakes based solely on geodetic strain rate measurement and the location of occurrence of past (historic) earthquakes is spatially limited and could be misleading, this is because where strain release occurred (as past earthquakes) does not necessarily have to be the exact location where strain accrual for future earthquakes take place, as evidenced by the inability of the GPS strain rate to resolve seismic moment release in all of the seismic zones in Central-Eastern United States . Strain release in the future might occur on a distant unidentified fault through transient stress perturbation -one that might have been erroneously classified as ‘safe’ based on near-zero strain rate picked up by today‘s GPS measurements.

Is Geodetic Measurement a Useful Indicator of Intraplate Earthquakes?

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ABSTRACT

The objective of this work is to test the reliability of using GPS derived strain rate data as a proxy for seismicity. 2nd invariant horizontal strain rate and seismic moment plots were generated to show the spatial variations of these two parameters in both intraplate settings as well as plate boundary settings.
Plate boundary setting showed better correlation consistency, as places characterized with significant strain rate coincided with places of high released seismic moment. This correlation was discovered to dwindle from plate boundary setting through diffuse boundaries to intraplate settings. Stable continent regions such as central eastern United states and eastern Tibet showed very poor correlation of horizontal strain rate with seismic moment. A likely explanation for this, is the deficiency of loading from steady plate motion as is the case in plate boundary settings such as Italy, western Indonesia and western United states. Some of theses inconsistencies in intraplate settings can also be explained by other phenomena such as glacier isostatic rebound in Northeast United states, post seismic viscous relaxation in the New Madrid and Wabash seismic zones and waste-water injection in Oklahoma and Kansas.
It is concluded that geodetic derived strain rate data should be used as a proxy for seismicity in intraplate and diffuse plate boundary regions with caution so as to avoid overestimation or underestimation of seismic hazards in these regions.

METHODOLOGY [1,2,3]

2nd invariant horizontal strain rate

- The 2nd invariant horizontal strain rate was obtained using the formula :

$$\sqrt[2]{(\mathring{\varepsilon}_{\phi\phi}\mathring{\varepsilon}_{\phi\phi} + \mathring{\varepsilon}_{\lambda\lambda}\mathring{\varepsilon}_{\lambda\lambda} + 2\mathring{\varepsilon}_{\phi\lambda}\mathring{\varepsilon}_{\phi\lambda})}$$

- Where ϕ is the longitude and λ represents the latitude while the spatial derivatives of the interpolated velocity field represents the strain rate

$$\mathring{\varepsilon}_{\phi\phi} = \partial v_x/\partial x,\quad \mathring{\varepsilon}_{\lambda\lambda} = \partial v_y/\partial y,\quad \mathring{\varepsilon}_{\phi\lambda} = 1/2(\partial v_x/\partial y + \partial v_y/\partial x)$$

The interpolated velocity field was obtained from Kreemer et al. 2014 Global strain rate model and Kreemer et al. 2018.

Seismicity Moment

- Earthquake data used to estimate the seismic moment released span the 1960 to 2019. The data was obtained from National Earthquake Information Center (NEIC) catalog.

The seismic moment were estimated using (Hanks and Kanamori, 1979) moment magnitude relation: $M_w = 2/3 \log M_o - 6.03$

INTRAPLATE SETTING

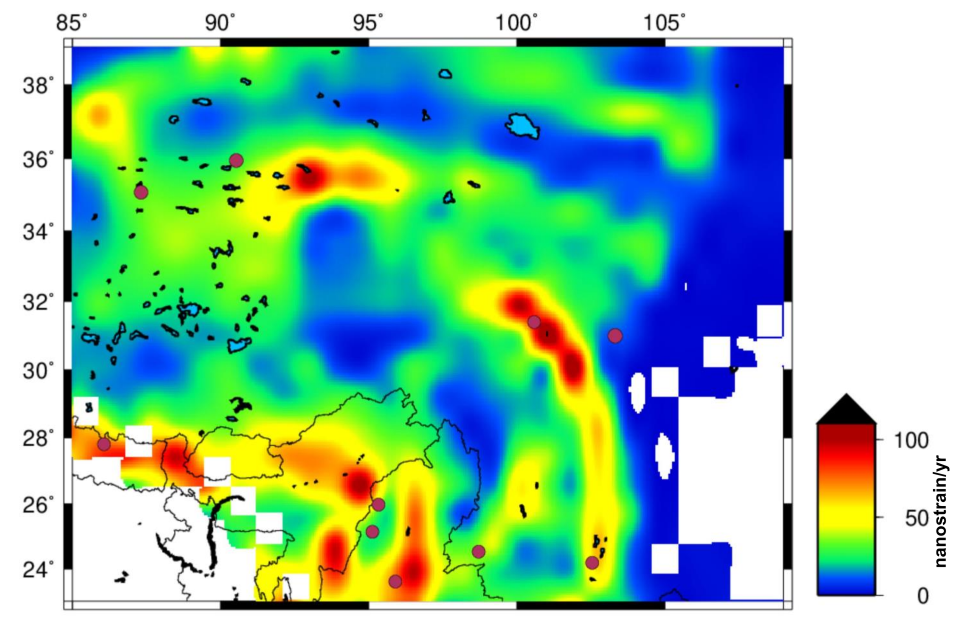

Fig. 5a Strain rate of Eastern Tibet

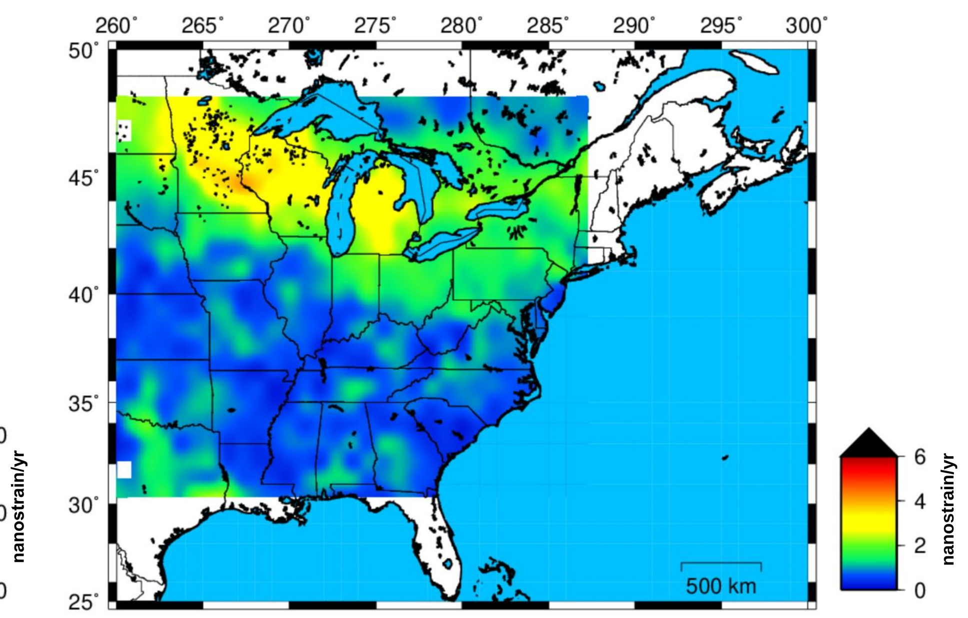

Fig. 6a Strain rate of Central Eastern United States

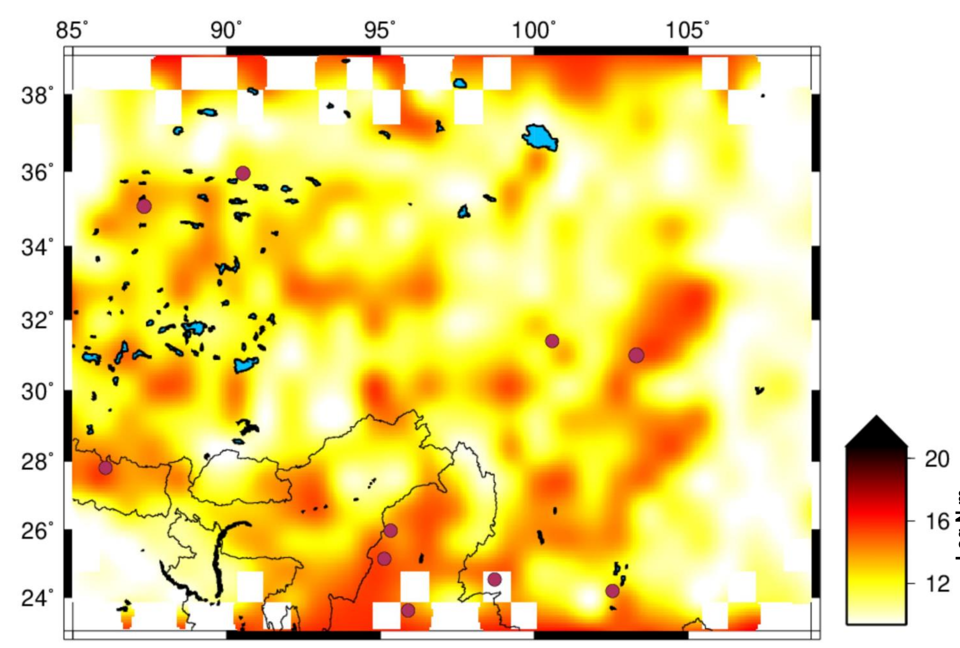

Fig. 5b Seismic moment of Eastern Tibet

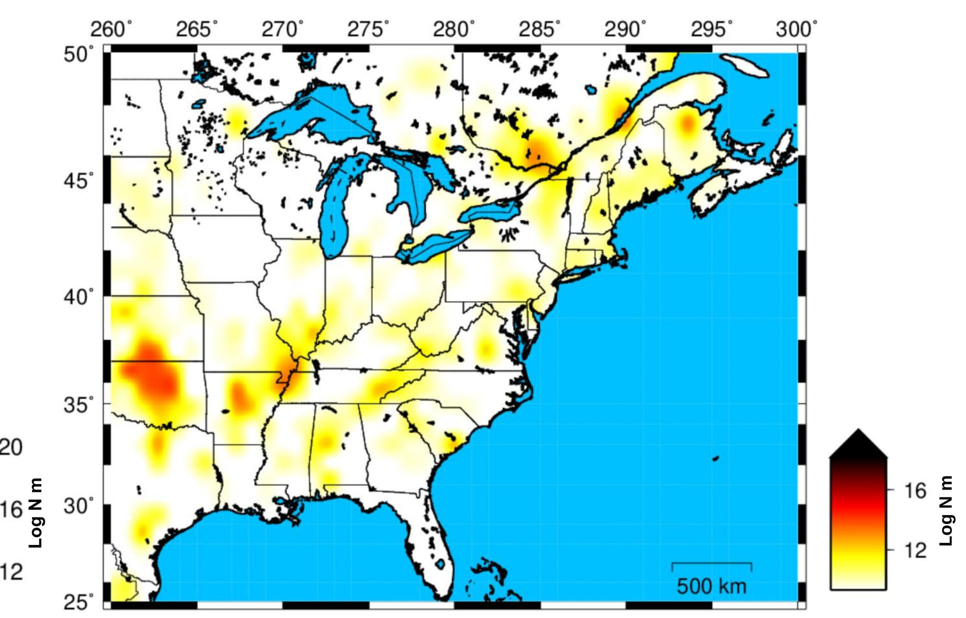

Fig. 6b Seismic moment of Central Eastern United States

INTERPRETATION [4,5]

- Features such as the Bitlis suture, the Zagros thrust, Makran trust, the eastern sections of the North and East Anatolia fault and the Alborz subduction are all identified as strain rate high in figure 1a . Other features such as the central Iranian plate interior and the Lut block are both characterized by low strain rates due to few sutures and fault lines that propagate through them. The regions of high strain rate correlate with regions of high seismic moment. This correlation decreases in the diffuse plate boundary that exist North of Himalayas.
- A fairly good correlation exist in the western United states, (figure 4 a and b) the correlation gradually decreases as you move away from the transform plate boundary to a more diffuse plate boundary (towards the basin and range). The san Andreas fault, the restraining bend as well as the Sierra Nevada granitic batholith are marked by strain rate high, while the great valley area is marked by a low. A similar situation is found in Italy were the subduction front that straddles Italy is picked up as both a strain rate and seismic moment high.
- Tectonic features such as the Altyn tagh fault, Kunlun fault, Kang ting fault and the Indus Sangpo suture are delineated by high strain rate that bound terranes North and South of the Tibetan Plateau (Fig 5a). A poor correlation exists between seismic moment and strain rate in the eastern section of the Tibetan plateau. Complex fault interaction, earthquake roaming (Liu and Stein 2016) and weak tectonic loading are believed to be some of the reasons for this poor correlation.
- Poor correlation between seismic moment and strain rate also exist in the central eastern United states(Figure 6a and 6b). The low recurrence frequency of earthquakes in this region is likely to be a major driver of this poor correlation. Some of the earthquakes that occur in the seismic zones in this region are likely due to post seismic viscous relaxation (Li et al. 2007). The Oklahoma earthquake swarm (a product of waste-water injection) that straddles Kansas and Oklahoma is not picked up by the strain rate data, thus emphasizing the deficiency of using geodetic strain rate as a proxy for seismicity in earthquake hazard assessment.

PLATE BOUNDARY SETTING

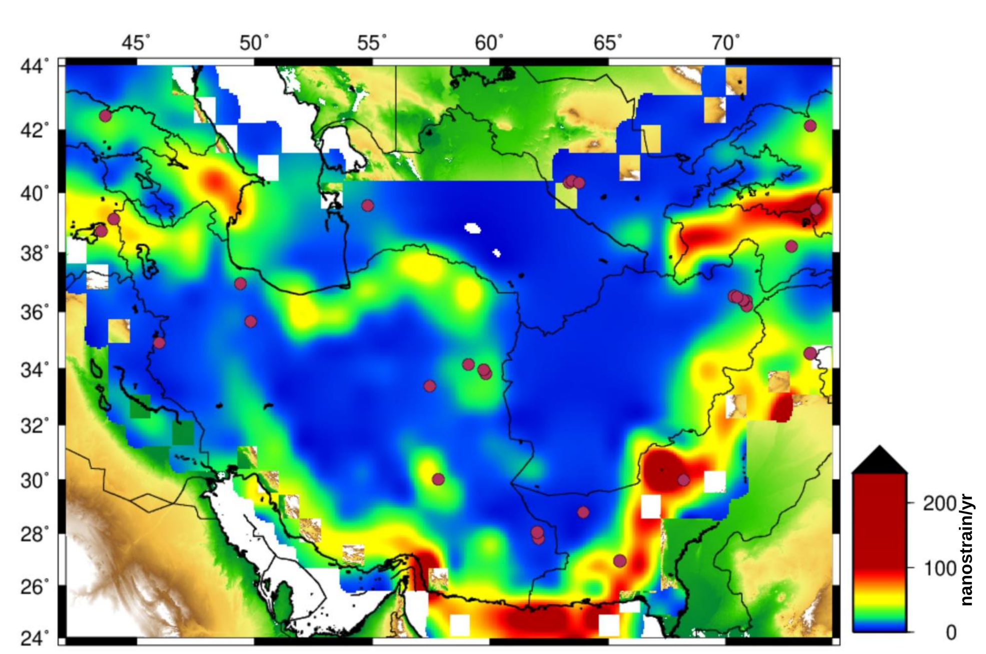

Fig. 1a Strain rate of the Middle east

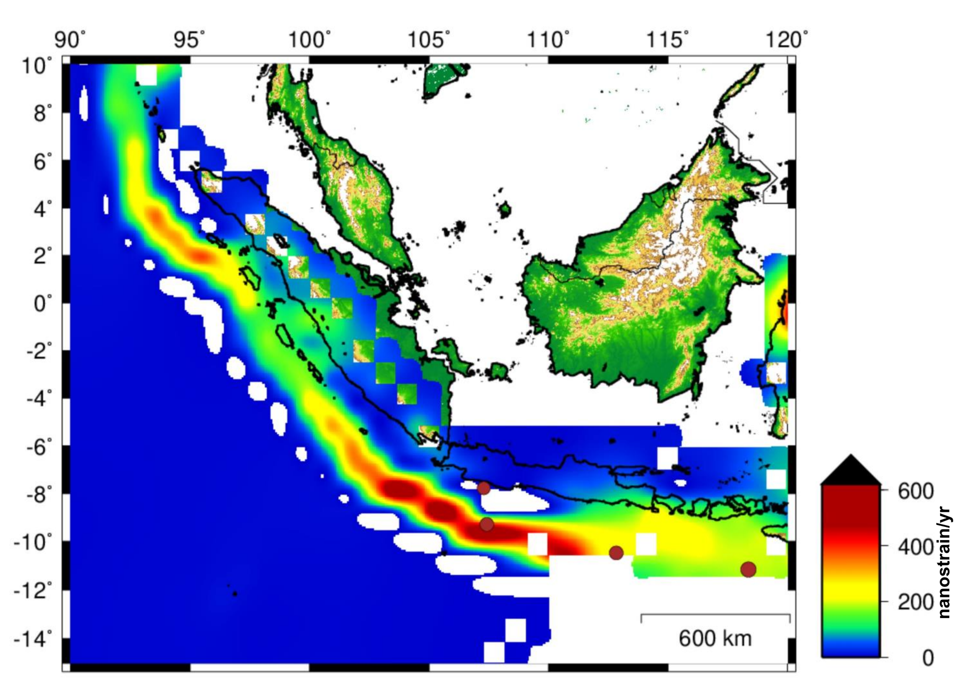

Fig. 2a Strain rate of Indonesia

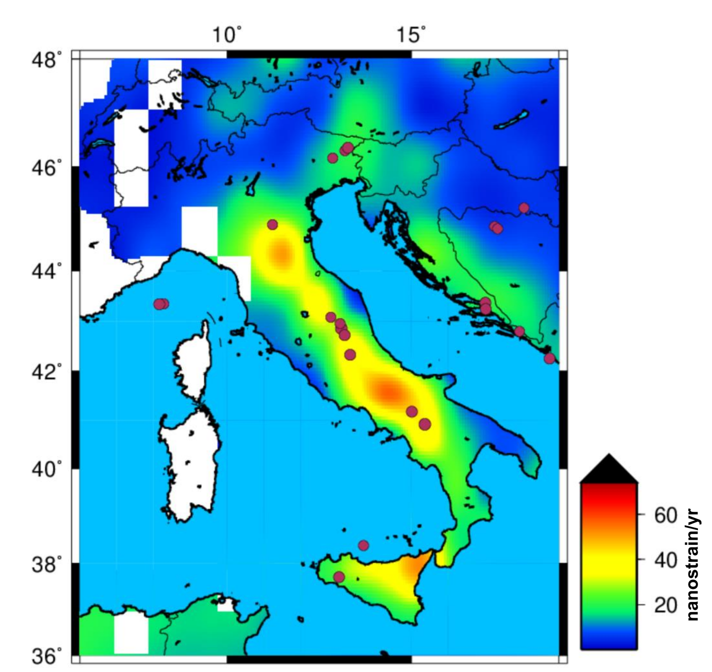

Fig. 3a Strain rate of Italy

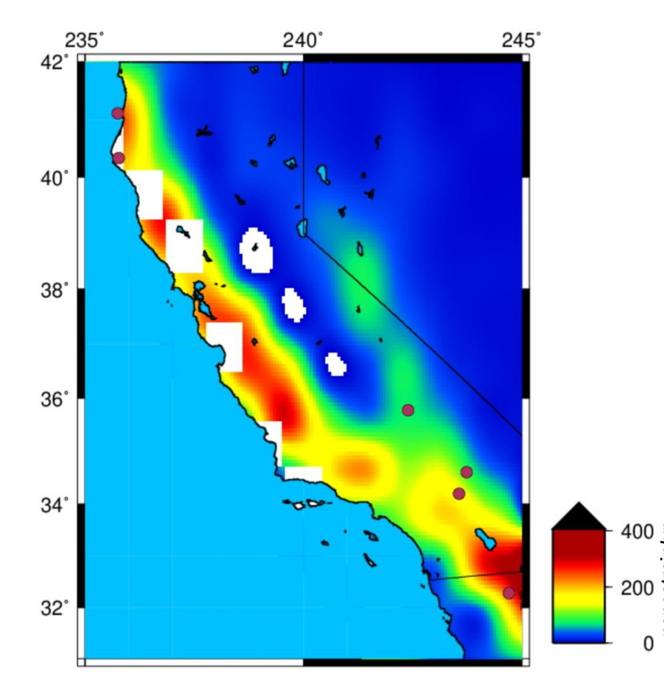

Fig. 4a Strain rate of Western United States

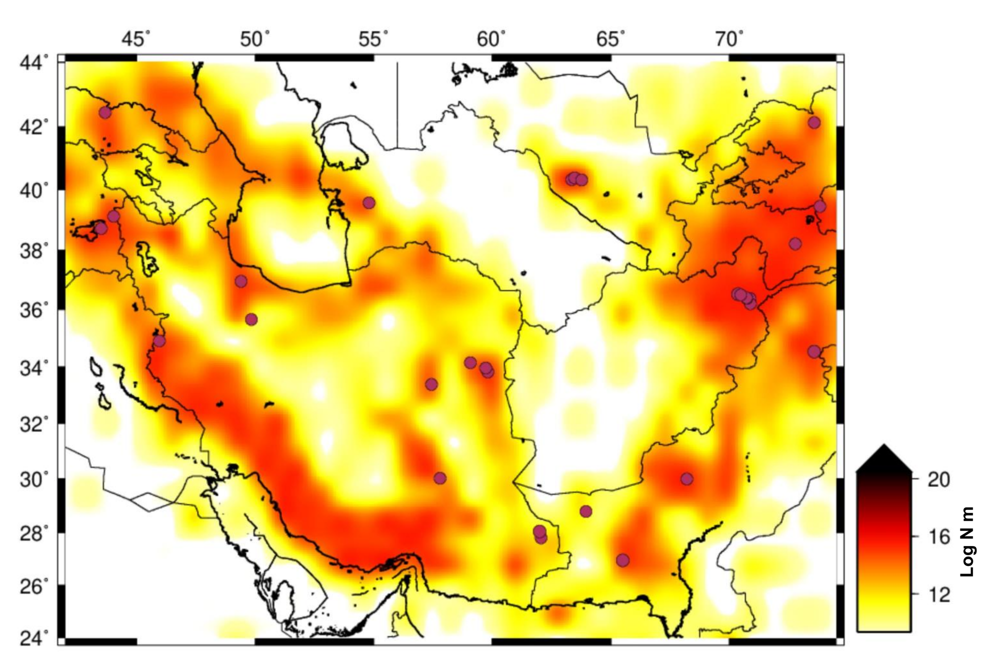

Fig. 1b Seismic moment of the Middle east

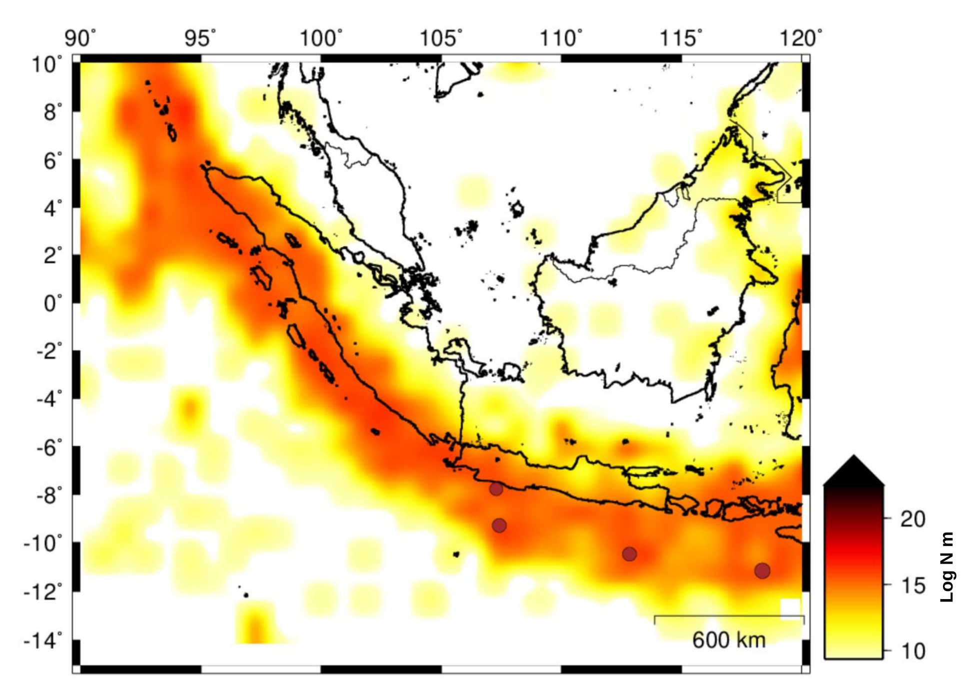

Fig. 2b Seismic moment of Indonesia

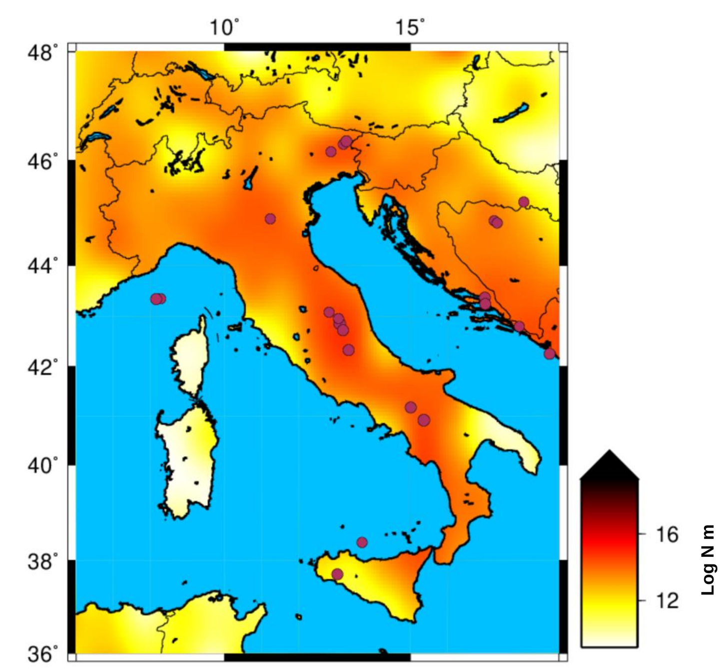

Fig. 3b Seismic moment of Italy

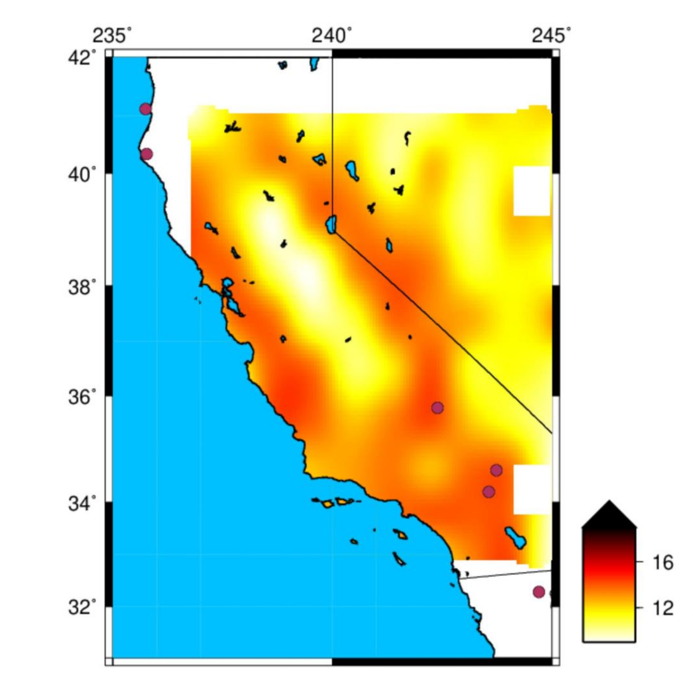

Fig. 4b Seismic moment of Western United States

CONCLUSIONS [5]

- The best seismic moment – strain rate correlation was achieved at plate boundary settings. This is the case because the steady relative plate motion at plate boundaries loads fault at constant rate thus leading to faster strain accumulation which is in turn is released as frequent recurring earthquakes.
- The seismic moment – strain rate correlation weakens as you move away from plate boundaries settings. These is slowly evident in diffuse plate boundaries like the basin and range,
- Intraplate settings such as Central Eastern United States as well as Eastern Tibet give the poorest correlation. Here, the faults in intraplate setting are usually not loaded directly by constant steady plate motion, but instead, slow far-field tectonic loading is usually accommodated by a complex dynamic system of interacting faults, thus creating a network whereby spatial roaming of large earthquakes between sets of interconnected faults is permitted (Liu and Stein 2016).

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