POLE TIDE TRIGGERING OF SEISMICITY

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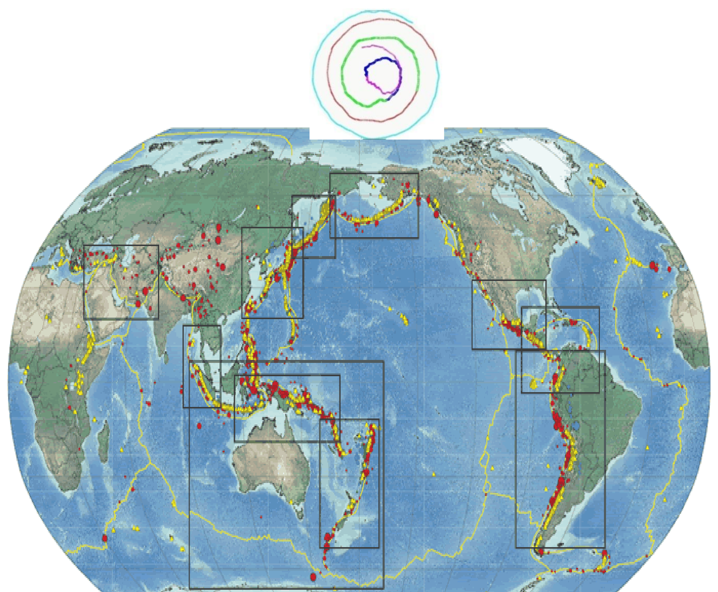
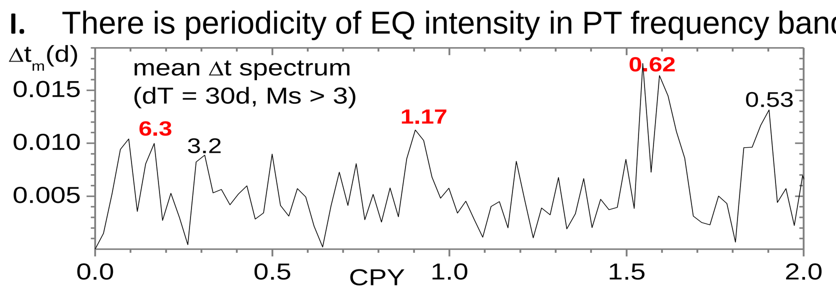


Abbreviations: PT – Pole tide, LST – Lunisolar tide
EQ – Earthquake
Used EQ data: CMT – Harvard Centroid-moment tensors catalogue (http://www.globalcmt.org)

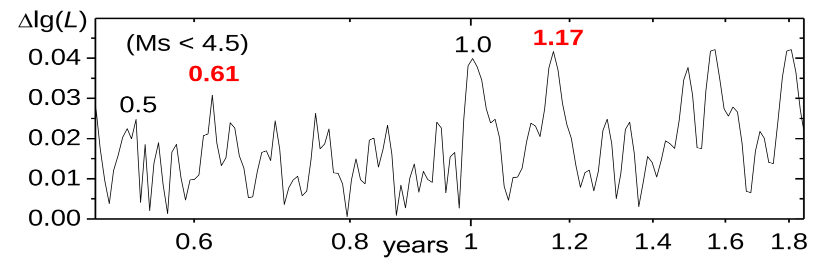
Motivation

I. There is periodicity of EQ intensity in PT frequency band.



NEIC data base (1973-2014)

Amplitude spectrum of EQ intensity (mean interval between EQ averaged in dT)

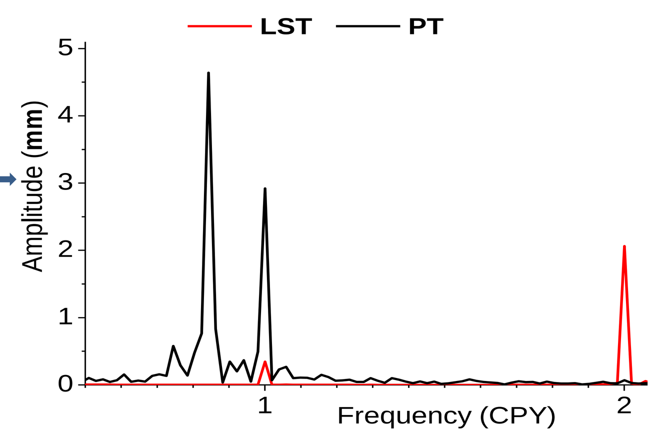


Increments of maximum logarithmic likelihood function (Δlg(*L*)) for periodic point EQ process. (Method of Lyubushin (1998) for detecting of hidden periodicities within flow of events)

The most obvious excitation factor of this EQ intensity variations is PT.

II. Excited stress variations in the crust by **PT < 1 kPa** and by **LST < 5 kPa**.
Why PT can trigger EQ but it is almost impossible to reveal EQ triggering by more power LST?
Because of PT is more powerful in low frequency.

Additionally according to *Sadovsky (1985)* the failure time t_n is depend on energy of seismic event E as $t_n \sim E^{1/3}$ and hence for magnitude M = 3.5 - 5.5 $t_n \approx 1\ A - 10$ years, that is to say t_n (preparation time) for weak EQ coincides with frequency band of PT induced stress variations.



Thus LST are added to stress accumulation process in fault zone as powerful high-frequency noise while PT acts as systematic, nearly synchronous component for a weak EQ.

III. The problem of EQ triggering was experimentally explored by *Beeler and Lockner (1999, 2003)*. The main conclusion of these papers is the next: *"The degree of correlation between failure time (t_n) and the phase of the driving stress depends on the amplitude and frequency of the stress oscillation and on the stressing rate. When the period of the oscillating stress is less than t_n, the correlation is not consistent with threshold failure models, and much higher stress amplitudes are required."*

At last some confirmation of the PT influence on seismic process can be found in the next papers:
- On the 6-Year Tsunami Periodicity in the Pacific. *B. Levin and E. Sasorova*, Izvestiya, Physics of the Solid Earth, 2002, Vol. 38, No. 12, p. 1030.
- Pole-Tide Modulation of Slow Slip Events at Circum-Pacific Subduction Zones. *Zheng-Kang Shen et al.*, Geoph.J.Int, 2007, V.53, 3, pp. 617 – 621.

The objective of this work is to estimate PT triggering of EQ.

Strain and stress excited by PT

Centrifugal PM perturbation in the potential ΔU (Wahr, 1985):

$$\Delta U(r,\lambda,\theta) = -0.5(\Omega r)^2 \sin 2\theta (X\cos\lambda - Y\sin\lambda),$$

Ω - the mean angular velocity of rotation of the Earth, r - geocentric distance to the station,
λ, θ - longitude and colatitude (90° - φ) of the station.

Corresponding displacement of station:

$$S_r = \frac{h}{g}\Delta U = -\frac{h}{2g}(\Omega r)^2[\sin 2\theta (X\cos\lambda - Y\sin\lambda)] \quad < 25\text{mm}$$

$$S_\theta = \frac{l}{g}\partial_\theta \Delta U = -\frac{l}{g}(\Omega r)^2[\cos 2\theta (X\cos\lambda - Y\sin\lambda)] \quad < 7\text{ mm}$$

$$S_\lambda = \frac{l}{g\sin\theta}\partial_\lambda \Delta U = \frac{l}{g}(\Omega r)^2[\cos\theta (X\sin\lambda + Y\cos\lambda)], \quad < 7\text{ mm}$$

h = 0.60267, *l* = 0.0836 – Love numbers for PT frequency. Positive displacement - upwards, south and east.

Strain tensor :

$$\varepsilon_{rr} = \partial_r S_r = -h\frac{\Omega^2 r}{g}[\sin 2\theta (X\cos\lambda - Y\sin\lambda)]$$

$$\varepsilon_{\theta\theta} = (\partial_\theta S_\theta + S_r)/r = (2l - h/2)\frac{\Omega^2 r}{g}[\sin 2\theta (X\cos\lambda - Y\sin\lambda)]$$

$$\varepsilon_{\lambda\lambda} = (\partial_\lambda S_\lambda/\sin\theta + S_\theta ctg\theta + S_r)/r = (l - h/2)\frac{\Omega^2 r}{g}[\sin 2\theta (X\cos\lambda - Y\sin\lambda)]$$

$$\varepsilon_{\theta\lambda} = (\partial_\lambda S_\theta/\sin\theta - S_\lambda ctg\theta + \partial_\theta S_\lambda)/2r = -l\frac{\Omega^2 r}{g}[\sin\theta (X\sin\lambda + Y\cos\lambda)].$$

Positive ε_{ii} – tension,
positive $\varepsilon_{\theta\lambda}$ – right-hand shift.

In view of free surface boundary condition (Melchior, 1978) $\tau_{rr} = \tau_{r\theta} = \tau_{r\lambda} = 0$, therefore stress tensor:

$$\tau_{\theta\theta} = 2\mu\varepsilon_{\theta\theta} + \Lambda\Sigma \quad < 0.9\text{ kPa}$$

$$\tau_{\lambda\lambda} = 2\mu\varepsilon_{\lambda\lambda} + \Lambda\Sigma \quad \le 0.9\text{ kPa}$$

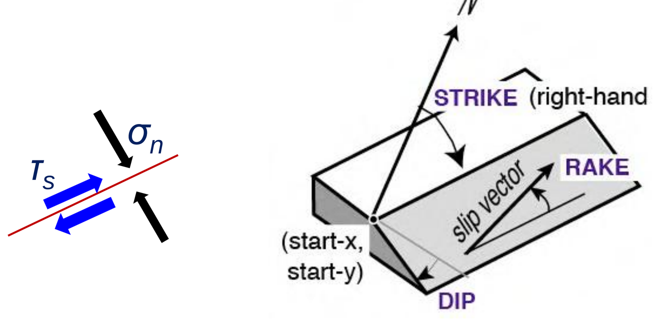
$$\tau_{\theta\lambda} = \mu\varepsilon_{\theta\lambda} \quad \le 0.1\text{ kPa}$$

where $\Sigma = \varepsilon_{rr} + \varepsilon_{\theta\theta} + \varepsilon_{\lambda\lambda}$ – dilatation, $\mu(d)$ - shear modulus, $\Lambda(d)$ – elastic modulus of the Earth (according *PREM, 1981*), d – depth of Earth's layer.

Hence normal and shear stresses:

$$\sigma_n^0 = \tau_{\theta\theta}\cos^2\alpha + \tau_{\lambda\lambda}\sin^2\alpha + \tau_{\theta\lambda}\sin 2\alpha$$

$$\tau_s^0 = 0.5(\tau_{\lambda\lambda} - \tau_{\theta\theta})\sin 2\alpha + \tau_{\theta\lambda}\cos 2\alpha.$$



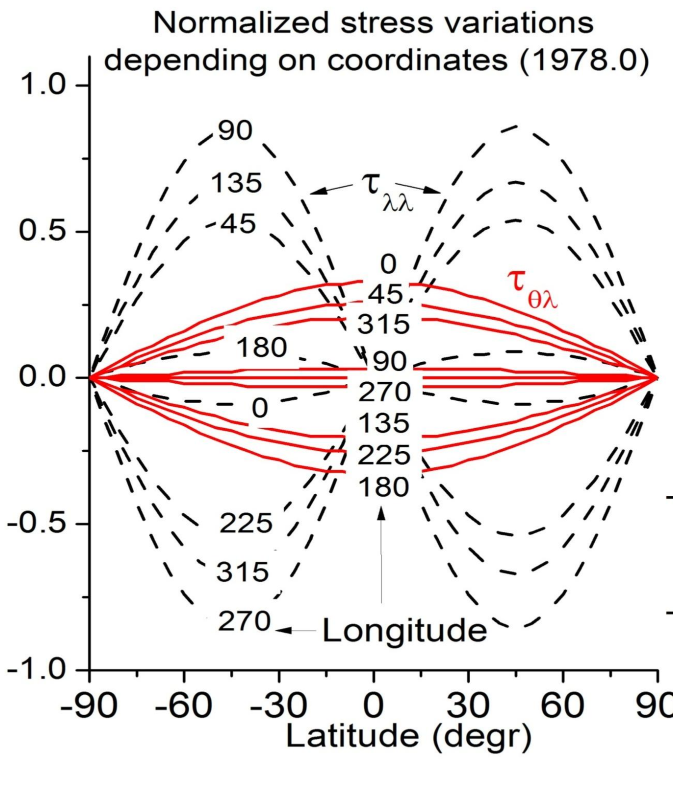
At last for free oriented fault (*Zhu P., 2013*):

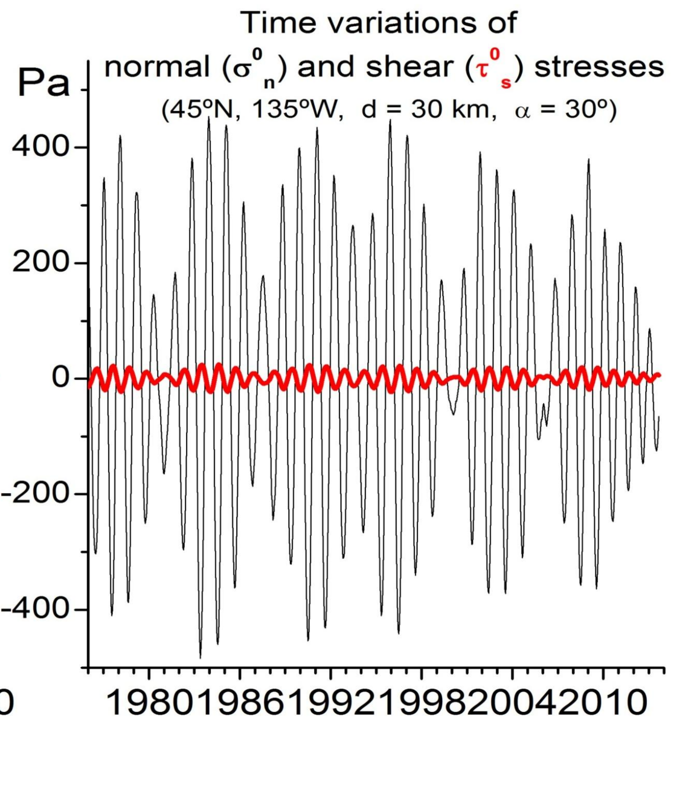
★
$$\sigma_n = \sigma_n^0 \sin^2\delta$$

$$\tau_s = \tau_s^0 \sin\delta\cos\psi + 0.5\sigma_n^0 \sin 2\delta \sin\psi.$$

where *α*, *δ*, *ψ* – strike, dip and rake angles of fault plane

Common view of coordinate and time dependences of PT induced stresses

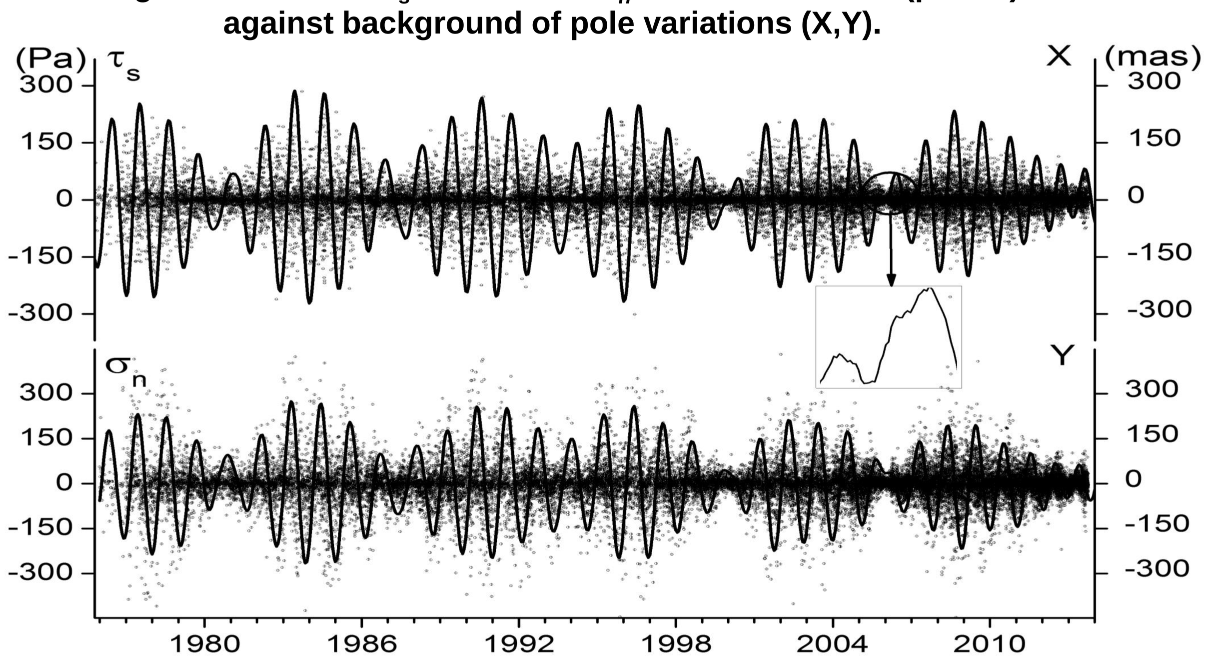




DATA and METHOD

There were used 32264 EQ events from CMT (1976-2014) to search the trace of PT in seismicity after declustering for events with *Mw* > 7.2 by (Uhrhammer, 1986): $\Delta d(km) = 1.2exp(0.8M_W - 1.0)$ and $\Delta t(days) = 1.2exp(0.8M_W - 2.9)$.

PT generated shear τ_s and normal σ_n stresses for CMT (points) against background of pole variations (X,Y).



It is obvious that approximately 90% of EQ events are indifferent to variations of Pole. The rest of events (~10%) repeat time variations of Pole. It is remarkable that ~ 10% events in CMT have magnitude Mw < 5.1.

Phases, β_i, of σ_n and τ_s were estimated for each EQ as a part between its previous and following max/min values in EQ coordinate point. EQ number N_ψ was counted in 30° phase boxes for next faulting type of EQ: **normal-slip (-120° < *ψ* < -60°), thrust-slip (60° < *ψ* < 120°), strike-slip (0° < |*ψ*| < 30°, 150° < |*ψ*| < 180°) and the rest – oblique strike-slip.**

PT induced stresses become extremely low (< 0.1 kPa) and its phases become misrepresent when Pole variations damping (< 100 mas). Therefore the data without this EQ events, ***r***, were researched separately.

Schuster (1897) and χ² statistic tests were used for assessment of significance of phase concentration near some particular phase. Null hypothesis on random distribution of phase β_i is rejected if probability $p_S = \exp(-R^2/N_\psi) \le p_{0.05}$ for Schuster test and $\chi^2 > \chi^2_{0.05} = 18.307$ for χ² statistic test,

where $R = \sqrt{C^2 + S^2}$, $C = \sum_{i=1}^{N_\psi}\cos\beta_i$, $S = \sum_{i=1}^{N_\psi}\sin\beta_i$.

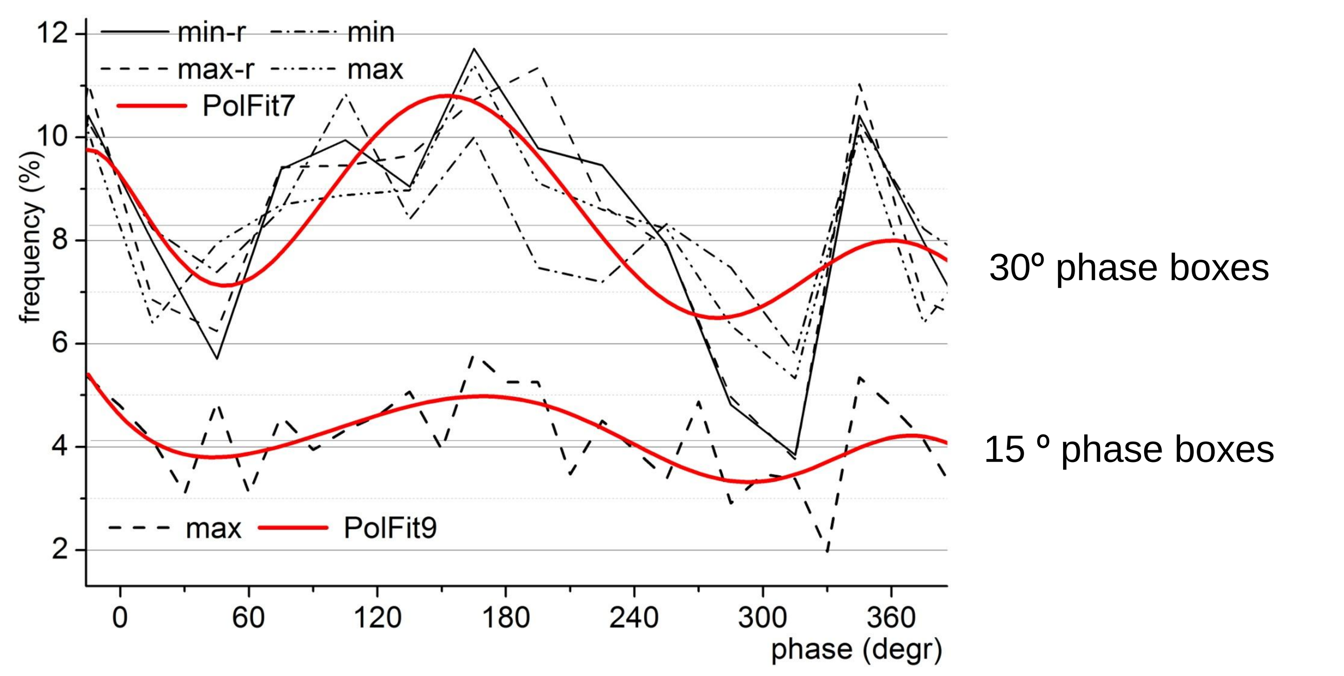
RESULTS

Estimated probability of PT induced shear stress influence on EQ occurrence with *d* < 70 km

M_w	4.0 – 5.0			5.0 – 5.5			5.5 – 6.0		
Faulting Type	N_ψ	p_s(%)	χ^2	N_ψ	p_s(%)	χ^2	N_ψ	p_s(%)	χ^2
normal	586	42.4	9.4	1457	60.3	10.5	440	22.3	9.3
(r)	317	86.3	10.8	1006	37.6	14.8	341	23.8	11.9
thrust	535	2.9	18.2	2890	2.6	16.6	1472	68.1	6.3
(r)	282	1.5	20.0	1976	2.2	15.8	1025	55.3	10.1
slip	816	78.2	12.5	3502	68.6	9.1	1666	17.7	14.0
(r)	434	53.1	11.9	2307	92.3	7.1	1329	21.8	16.6
oblique	488	31.1	17.1	2222	90.8	13.8	769	54.0	10.0
(r)	251	13.6	1.4	1580	61.1	10.5	616	17.5	12.0
total	2425	17.8	11.4	10071	13.3	13.4	4347	95.9	11.3

PT has an influence on seismic intensity of thrust EQ with M_W < 5.5 with confidence level 5%. Other faulting type EQ and EQ with M_W > 5.5 are indifferent relative to PT influence.

Frequency distribution of shear stress phase calculated for various variants of thrust EQ
(Convergence of these plots gives view on level of error of phase determination.)



There are two maxima of PT influence on thrust EQ near both extremes (min and max) of shear stress. <u>This result could explain the 0.6 year periodicity in seismic intensity</u>.

The PT influence on seismicity when Pole variation damping becomes actually noise as it was checked by independent estimations of χ^2 and p_s. <u>Therefore the PT is the most probable reason of 6-7 years periodicity in seismic intensity.</u>

Conclusions

- Pole tide influence on seismic intensity is revealed only for thrust type of EQ with 5% reliability.
- This influence falls with rise of *M* and vanishes for M_W > 5.5.
- There are two maxima of this influence approximately coinciding with both extreme of shear stresses. This result could explain 0.6-year spectral peak in seismic intensity.
- Pole tide influence on seismic intensity for time of Pole wobble damping (< 100 mas) is actually noise. This could explain 6-7 year periodicity in seismic process.
- Synphasing of shear and normal stresses for thrust faulting EQ type (see★ by *ψ* = 90º) could explain the exciting of these EQ by weak PT induced stress variations.

Literature:

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