Earth tides can trigger shallow and intermediate depth earthquakes

Speaker : Shao Yilien

References

- Cochran, E. S., Vidale, J.E. Sachiko T. (2004) Earth tides can trigger shallow thrust fault earthquakes. Science, vol 306, 1164-1166

- N. Cadicheanu, M. van Ruymbeke, and P. Zhu (2007) Tidal triggering evidence of intermediate depth earthquakes in the Vrancea zone (Romania). Nat. Hazards Earth Syst. Sci., 7, 733-74

一. Introduction

二. Method(1) - the tidal potential phase angles of earthquakes

三. Method(2)- a tidal-stress time series that includes the solid Earth tide and an ocean-landing component.

四. Conclusion

Introduction

- It can triggering an earthquake by tidal when the stress in the focal area is near the critical level (Tananka et al., 2006)
- Earth tide are deeply modulated signals which depend on the Sun and Moon's orbital parameters.
- The response of a seismic zone to tidal periodicities depends on its specific geology, tectonic history and stress accumulation mechanisms in this region.
- The tidal modulation tendencies in seismic activity could help explain some aspects on the physical mechanism of rupture forming.

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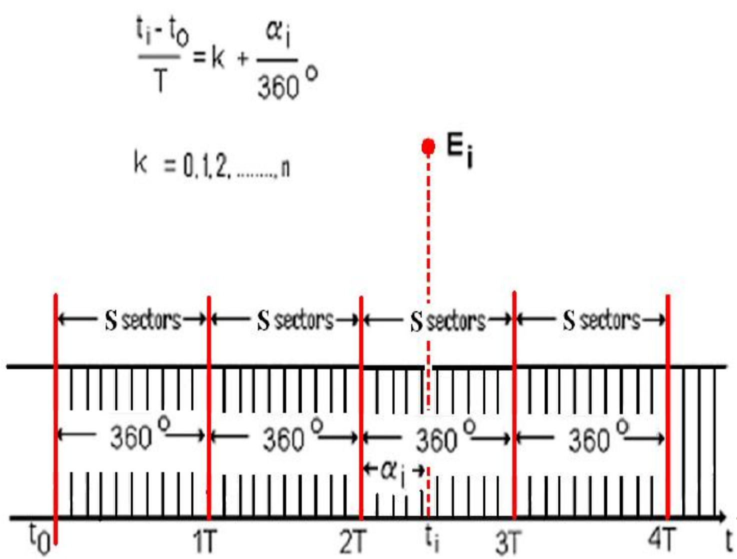
The tidal potential phase angles

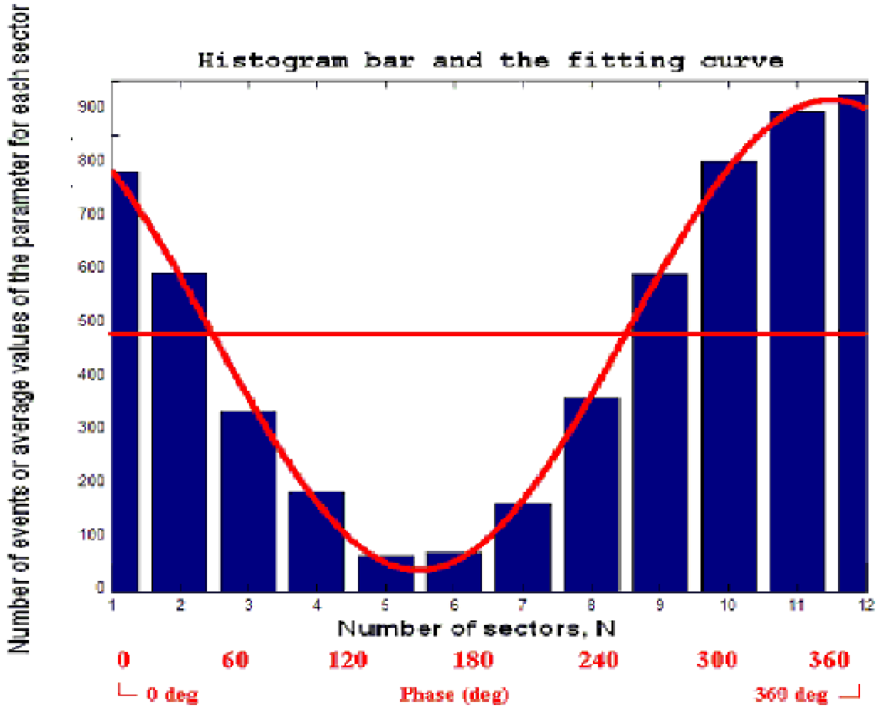
- Cadicheanu et. al studied mainly the semidiurnal tidal components because the gravitational tidal forcing is a force, which could affect the dynamic processing at such depths.
- They computed the *M*2 and *S*2 tidal phase angle of each earthquake and attribute gravity vales at moment of earthquake occurrence which was calculated from a local model by Tsoft (Van Camp and Vauterin, 2005).

Earth tide component	Doodson argument	Angular frequency (°/h)	Periodicity (h)	Amplitude (microgal)
*S*2	273.555	30.000000	12.000000	42.286
*M*2	255.555	28.984104	12.421000	90.812

Methods(1)

- Compute the tidal potential phase angles of earthquakes
- A stacking analysis method named HiCum (Histogram Cumulating) is applied to compute the tidal potential phase angles of earthquakes.



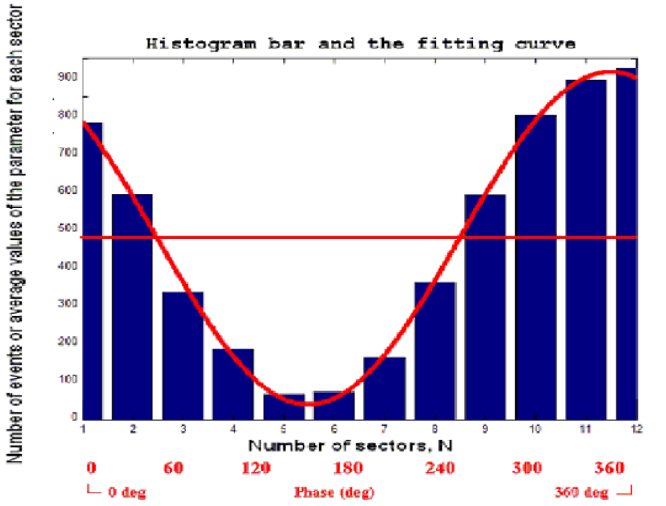


Methods(1)-statistical tests

- Schuster's tests

$$D^2 = \left(\sum_{i=1}^{N} \cos \alpha_i \right)^2 + \left(\sum_{i=1}^{N} \sin \alpha_i \right)^2$$

D: vectorial sum



$$p_S = \exp\left(-\frac{D^2}{N} \right)$$

- Permutation tests

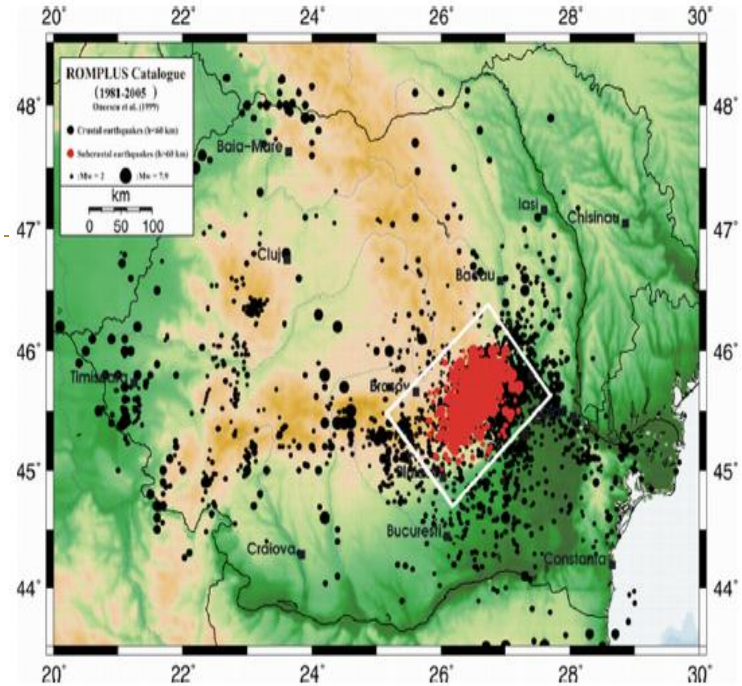
$$p_P = \left(\sum_{l=0}^{m} A_l \right) / r$$

A_l: HiCum on each permutation distribution of amplitude

$A_l > A_0$ (l=1,2,3,…m where m $\leq$ r)

Data(1)

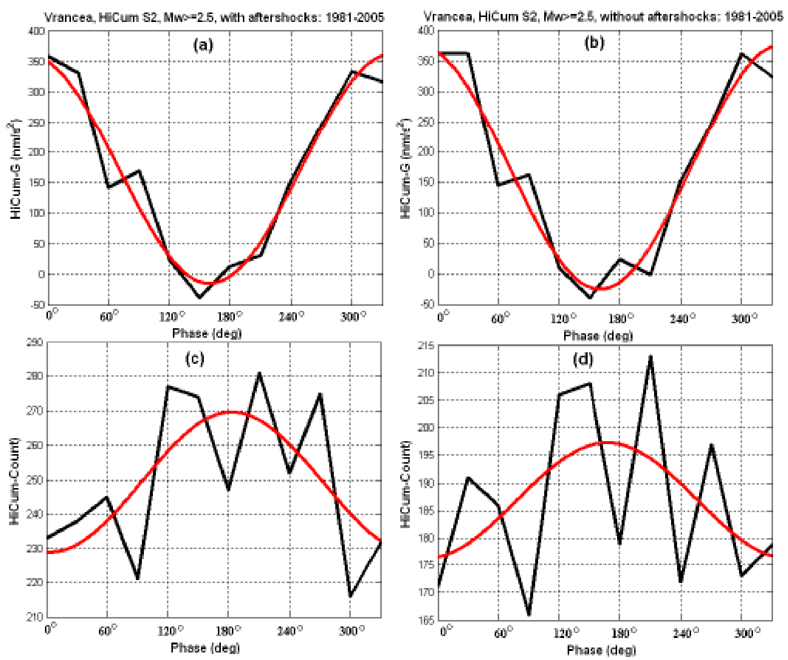
- Vrancea zone (Romania)
- RomPlus catalogue from the National Institute of Earth Physics of Bucharest
  - 45°-46°N, 25.5°-27.5°E
  - Mw ≧2.5
  - 60 km ≦Focal depth≦ 300 km

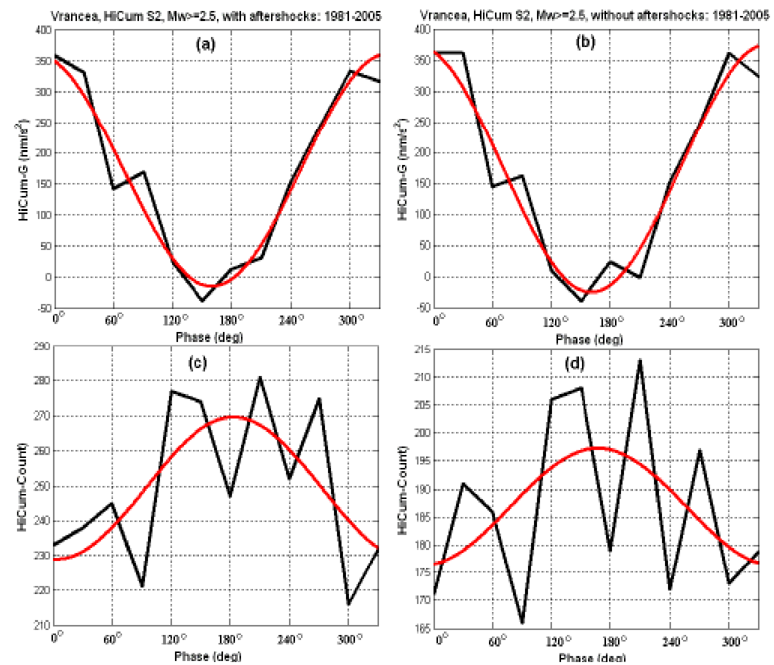


Wave	With aftershocks		Without aftershocks	
$M2$	p_s=79.46%	p_p=79.48%	p_s=66.77%	p_p=70.88%
$S2$	p_s=0.86%	p_p=3.54%	p_s=15.78%	p_p=10.22%

Result(1)

- The distribution of gravity values and earthquake numbers as a function of tidal phase angle.

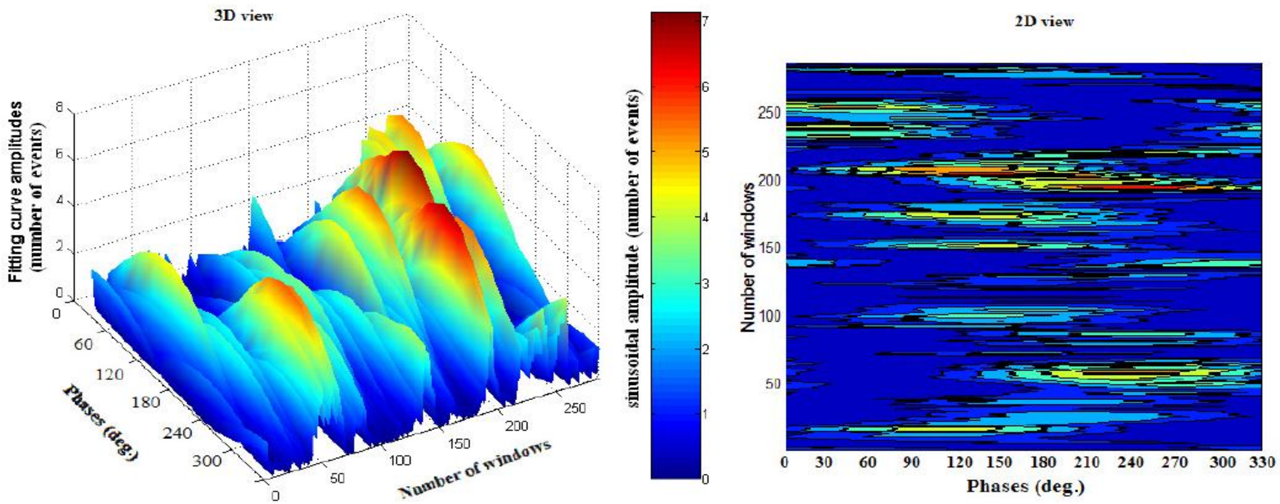




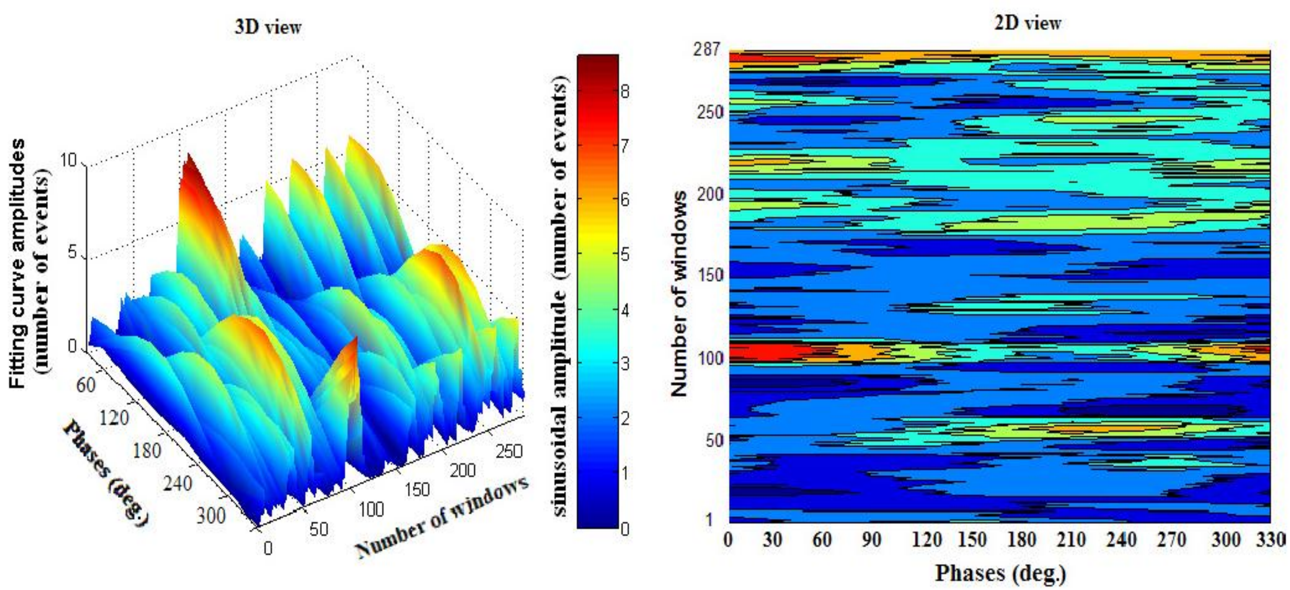
- In these case, the event distributions should be considered as random.
- It means that the processes induced by tidal triggering have a non repetitive long term pattern.

- In order to evaluate the possible correlations between earthquake occurrence and the semidiurnal tidal wave in a shorter time interval, a sliding window algorithm was developed.

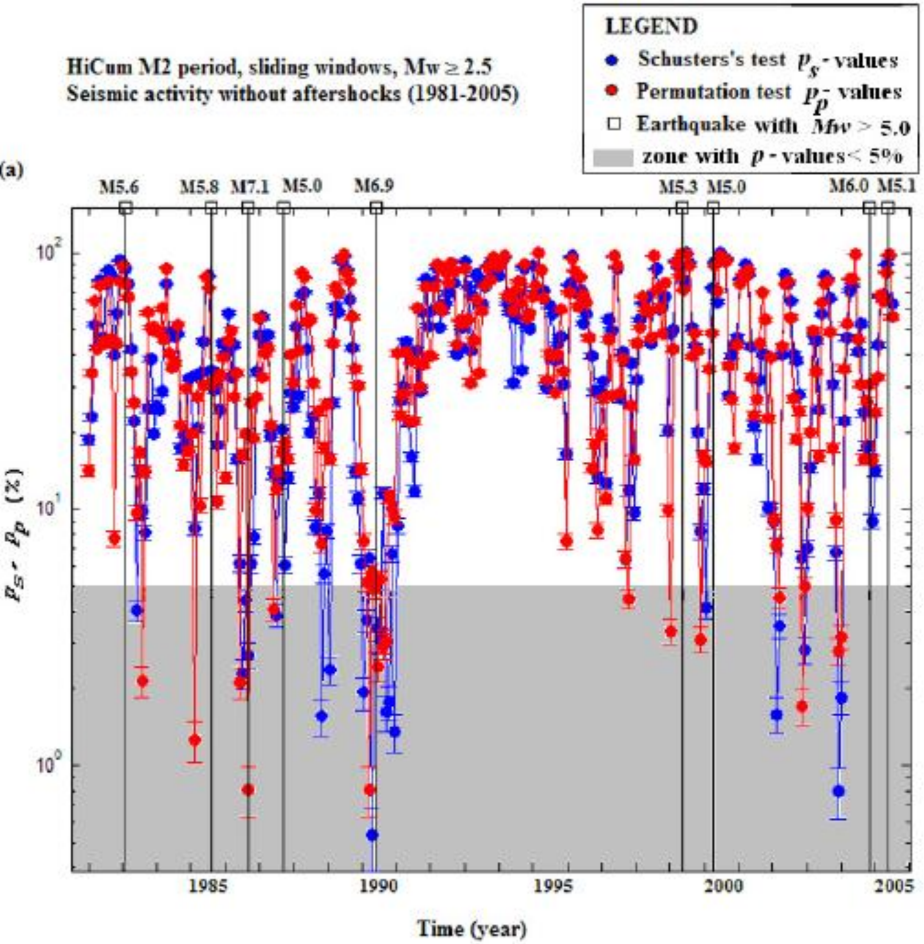
Vrancea - HiCum S2 in moving time windows of 365.25 days shifted by 30 days, Mw≥2.5, without aftershocks: 1981-2005

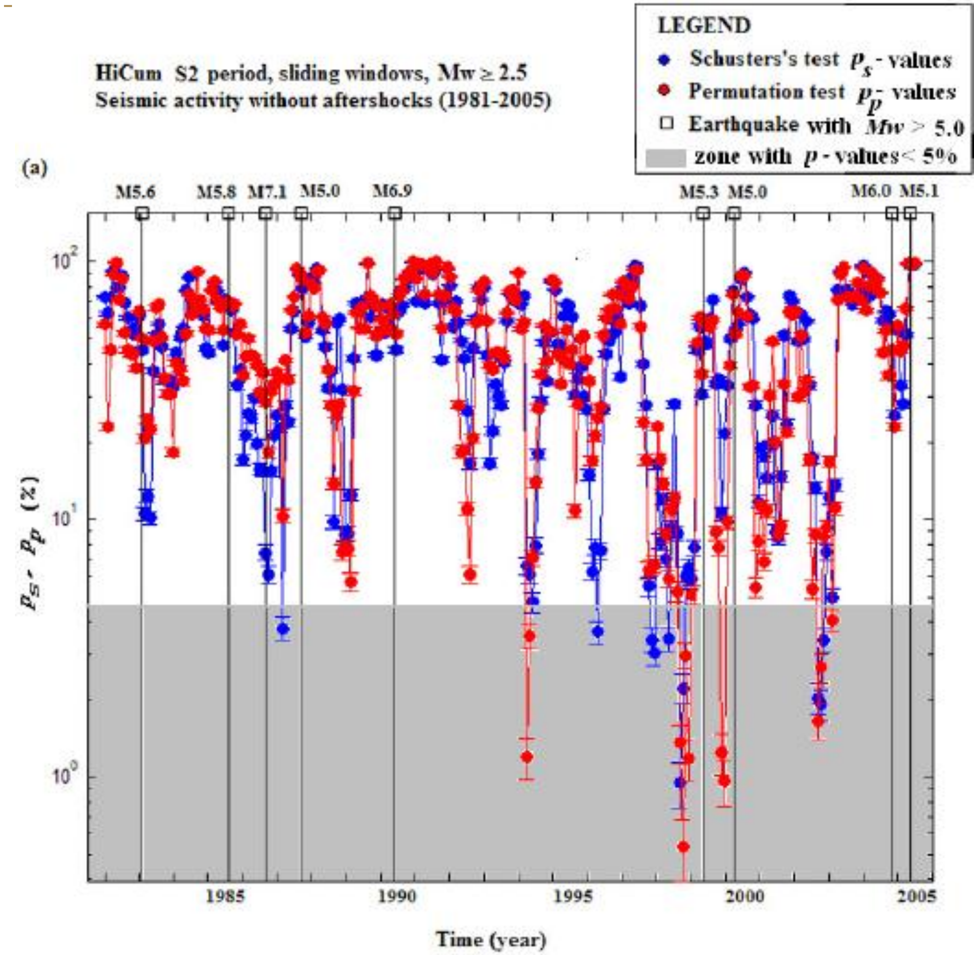


Vrancea - HiCum M2 in moving time windows of 365.25 days shifted by 30 days, Mw≥2.5, without aftershocks: 1981-2005



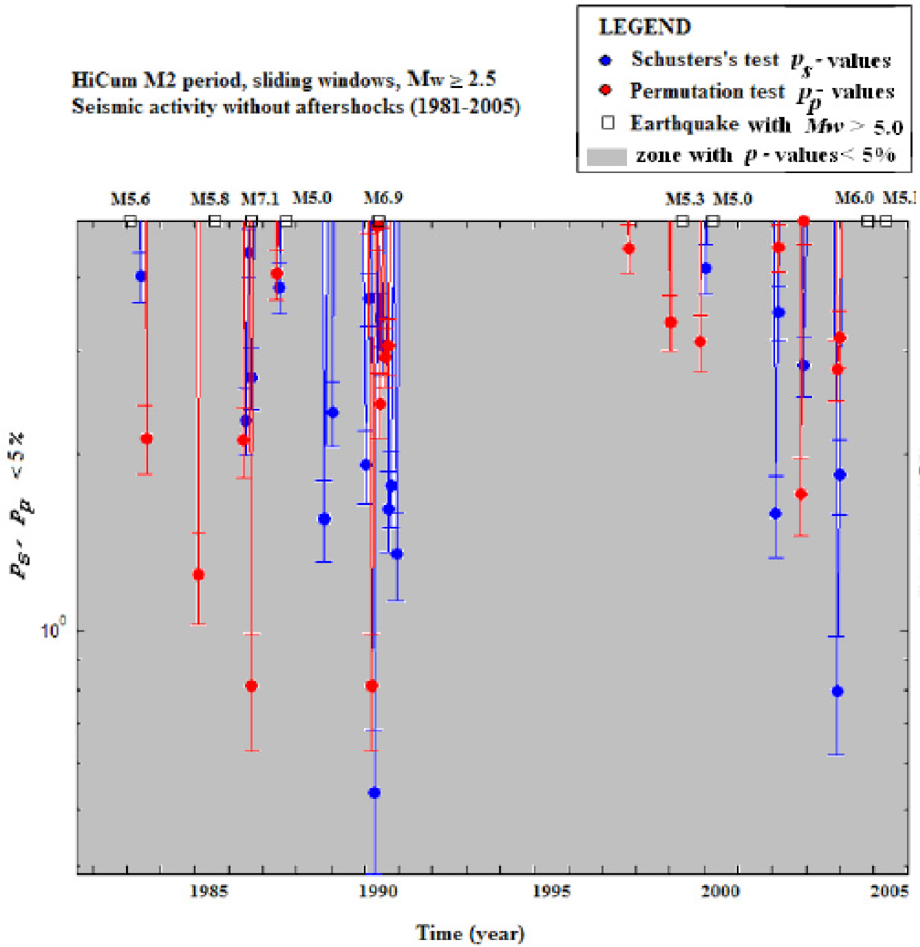
Each distribution was evaluated by Shuster's and Permutation tests

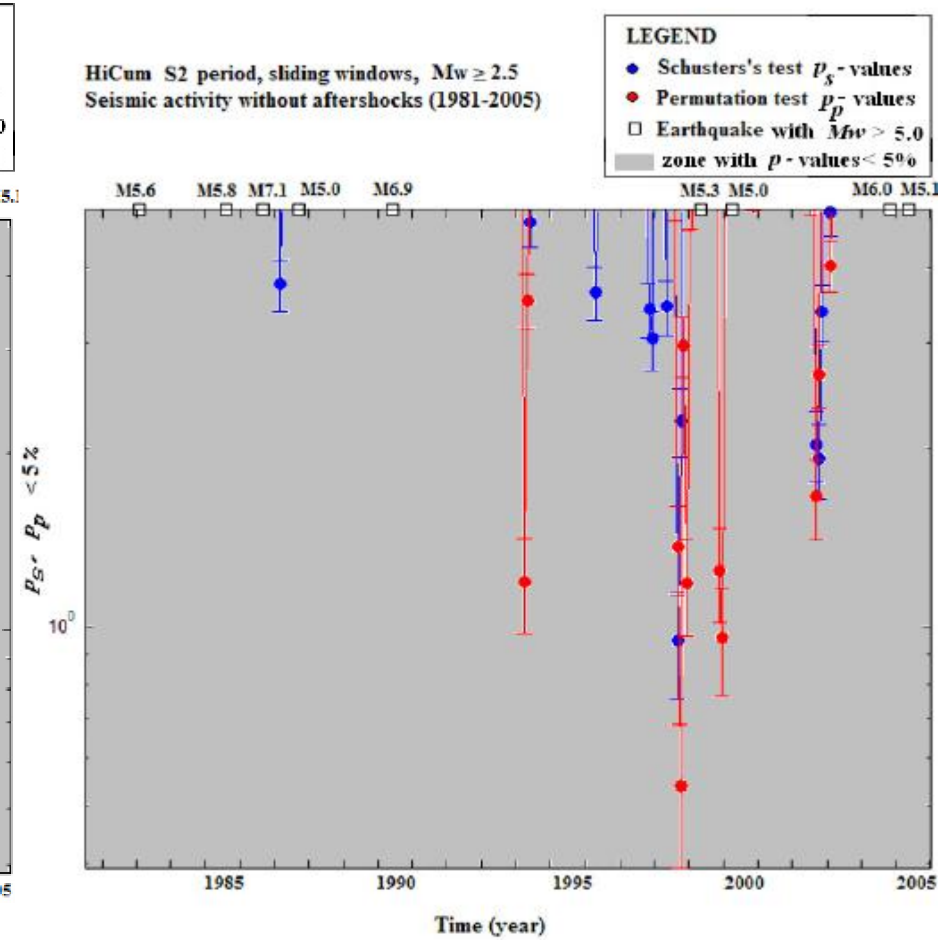




- Temporal variation of the p_s -value (blue) and p_p-value (red) in every sliding window for HiCum with an M2 (left) and S2 (right) period. The vertical bar represents the standard deviation of the p_s and p_p-values.

p_s and p_p-values are plotted in real time





- Similar phenomena were also repoted in the study of the Tokai region earthquakes (Tanaka et al., 2006)

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四. conclusion

- Earthquake-tide correlations have been observed to be small or nonexistent in normal crust; however, correlations have been shown in shallow, possibly hydrothermal or magma-related areas. (Tolstoy 2002 and O. Saar 2003).
- Cochran et. al take advantage of accurate accounting of ocean tides and a large data set of earthquake focal mechanisms with fairly well known fault phase to look for a correlation.

Data(2)

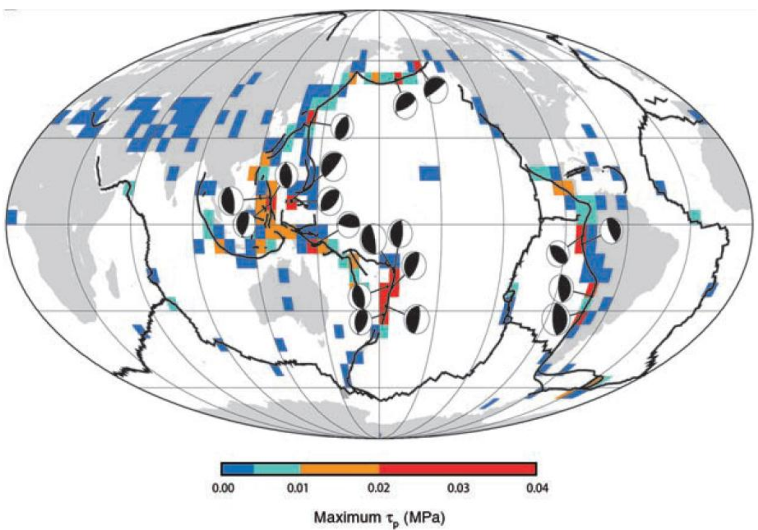
- Harvard Centroid Moment Tensor (CMT) catalogue
  - 0 km ≦ Focal depth ≦ 40 km
    - These earthquakes are in regions with the largest tidal stresses
    - Shallow events are under lower confining pressures, so tidal stress may be proportionally more influential
    - a larger influence of the ocean loading component
  - Reverse-type earthquakes
    - In subduction zones, ocean loading tends to be largest and low-angle thrust events are most common.

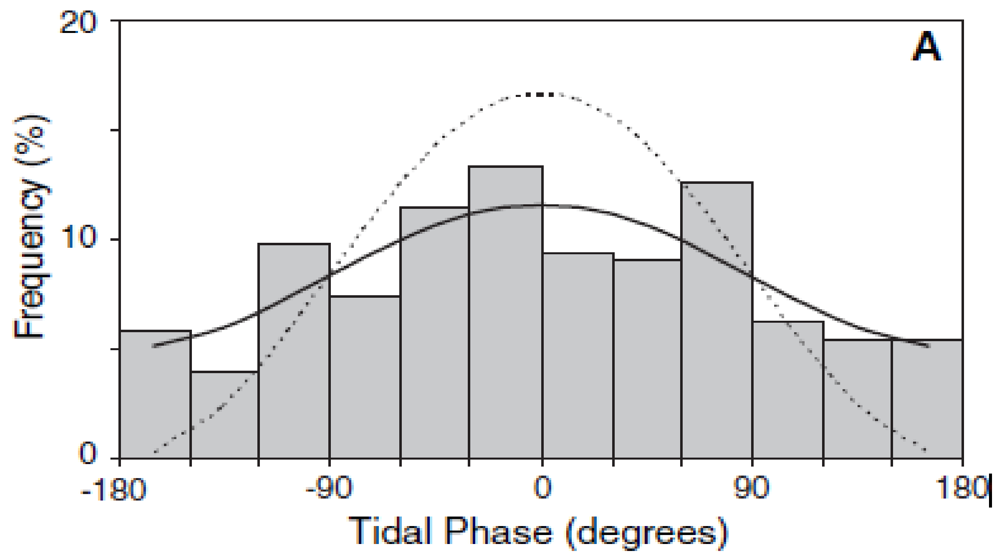
Method(2)

- Calculated a tidal-stress time series that includes the solid Earth tide and an ocean-landing component.
- Shear failure under compressive stress can be described by the Coulomb criterion
  - $\tau_c = \tau + \mu\sigma_n$
  - τ : shear stress; σ_n : normal stress; μ : the coefficient of friction
- Statistical tests
  - Binomial test
  - Schuster' s test

Tidal phase angle

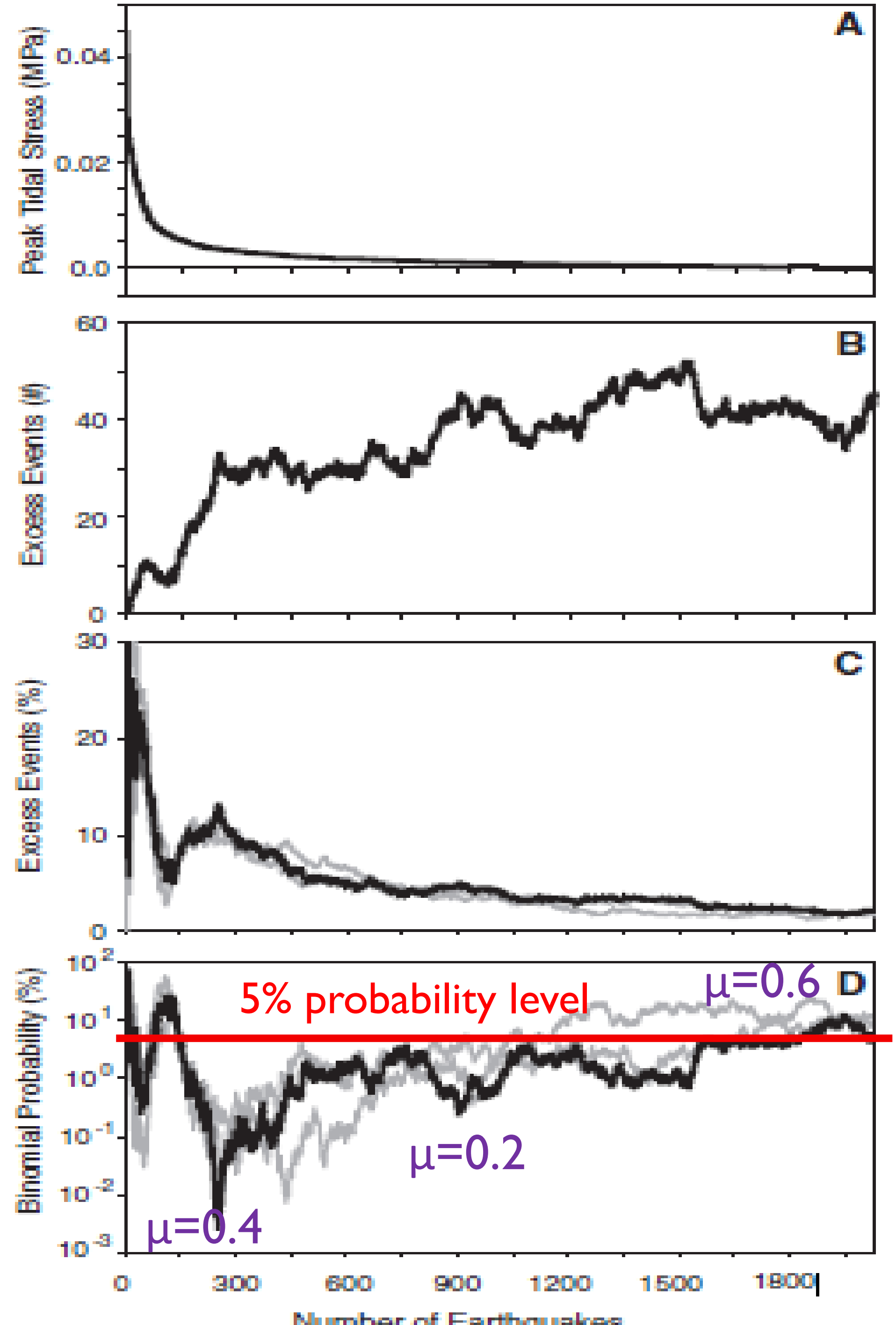
- Calculated the tidal phase angle (Θ) between -180 ° and 180°
- defined the average of the tidal stress amplitudes at the peaks just before and after each earthquake to be the peak tidal stress τ_p
- 0 ° phase is defined to be at the time of maximum stress that can promote failure.





Correlation with the tides is found for shallow-dipping thrust events

- (A) Plot of peak tidal stress τ_p versus total number of event N_{tot}
- (B) plot of the number of excess N_{enc} during times of higher stress versus N_{tot}
  - N_{enc} the number of events with -90 ° <Θ <90 °
- (C)percentage of N_{ex} versus N_{tot}
  - $N_{ex} = [N_{enc} – (N_{tot}/2)]/N_{tot}$
- (D)binomial probability versus for =0.2, 0.4, and 0.6.

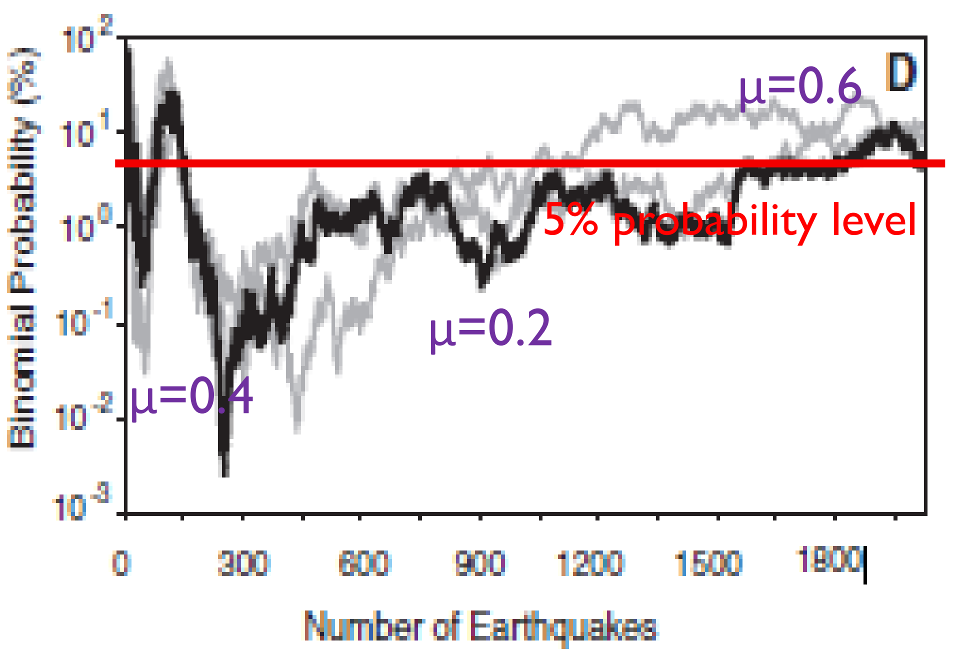


Result

- The most highly correlated 45 events are the most highly stressed, and most are shallow, with 41 events at or above 15 km depth.
- The next 100 events are not as highly correlated and tend to be deeper, with only 45% the earthquakes at or above 15 km depth.
- Tidal stress amplitudes decay with depth, so event depth and tidal stress amplitude are not independent

Events	Binomial (%)	*P* value (%)	N_{ex} (%)	θ_{peak} (degrees)
$\mu = 0$ (shear)	4.38	10.36	5.6	−22.2
$\mu = 0.2$	0.1439	0.6253	9.6	−1.2
$\mu = 0.4$	0.0032	0.0157	12.8	0.2
$\mu = 0.6$	0.0942	0.3265	10.0	6.0
$\mu = \infty$ (normal)	0.4688	3.677	8.4	15.8

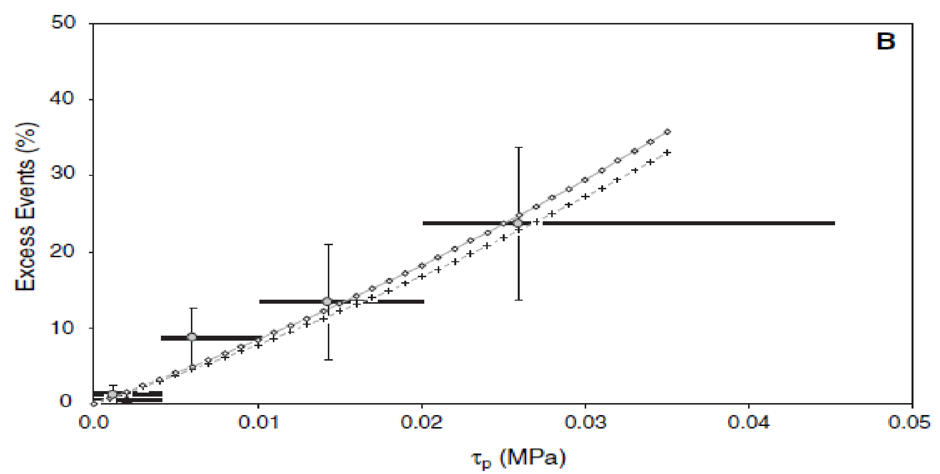
Comparison of coefficients of friction. Data are shown for the 250 events with the highest calculated tidal stress (τ_p) given different values of the coefficient of friction (μ)



Result

- On the basis of the earthquake-tide correlation observed, we have tried to estimate the tidal stress amplitude required to trigger an earthquake.
- The percent of Excess events, N_{ex}
  - N_{enc} the number of events with $-90^{\circ} < \Theta < 90^{\circ}$
  - $N_{ex} = [N_{enc} - (N_{tot}/2)]/N_{tot}$

Data set	τ_p (MPa)	N	N_{ex} (%)
Global thrust	>0.02	19	23.7 ± 10.10
Global thrust	0.01 to 0.02	41	13.4 ± 7.52
Global thrust	0.004 to 0.01	155	8.7 ± 3.95
Global thrust	<0.004	1,813	1.2 ± 1.17
California strike-slip	<0.004	27,464	0.60 ± 0.30



Both global thrust events and California strike-slip events are shown for various peak Coulomb stress ranges (τ_p)given a coefficient of friction μ =0.4

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Conclusion

- A systematic temporal pattern related to the decrease of the p-value precedes the occurrence for larger earthquakes in the Vrancea seismic region. This pattern could be considered as a kind of precursor.
- The possible physical consequences of the tidal effect could constrain the research on the seismic source characteristics and their dynamical patterns.
- We could imagine that for seismic zones, tidal modulation of fluid pressure is acting before the rupture process.
- The observed trend of increased triggering with higher imposed tidal stress can be well fit to friction theories of rate- and state-dependent friction and stress corrosion.

Thanks for your attention