On the variability of the coupling between some earth tides periodicities and earthquake triggering from three important seismic nest regions on Earth

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ABSTRACT

Currently, many studies confirm the involvement of Earth tides in the earthquake triggering at the regional level. On a global scale, however, this has not been found. Statistical approach plays an important role in the methodology of the correlation analyses. With the help of such method based on histogram cumulating, a specific technique for assessing the statistical parameter *p* of correlation between some earth tides periodicities and earthquakes was established.

The data base includes temporal series of intermediate-depth seismic events that took place from 1980 to 2012, corresponding to three seismic nest regions characterized by strong heterogeneities: Vrancea (Romania), Bucaramanga (Colombia) and Hindu Kush (Afghanistan).

Special attention is given to result validation of the correlation statistical parameter *p*, calculated in the temporal sliding windows and spatial sliding windows (statistical tidal tomography) by means of random synthetically time series.

Keywords: Earth tides, *p* correlation parameter, HiCum, tomography, seismic nest, random time series.

1. Introduction

In a seismic zone, geology and tectonics have a leading role in the energy accumulation process. Moon and Sun tidal attractions induce elastic deformations of the solid Earth corresponding to a stress variation usually with two orders larger than tectonic stress variation (Stavinschi and Souchay, 2003; Tanaka et al., 2006). But Earth tides stress modulation is energetically a non-cumulative process while the variation in tectonic stress leads to accumulation of such energy after a long time. Earth tides could influence also physical parameters related to important geophysical phenomena like atmospheric circulation, fluid flow (water, lava, etc.), thermo-mechanical or tectonic processes involved in crustal and sub-crustal stress accumulation.

This means that Earth tides could be a good candidate to influence the earthquakes triggering. But this fact has not yet been clearly demonstrated on a global scale even though the concept of tidal triggering is more than 110 years old (Ping Zhu, 2010; Emter, 1997; Schuster, 1897). But currently, many studies confirm the involvement of Earth tides in the earthquake triggering at the regional level (Cochran et al., 2004; Tanaka et al., 2002; Kasahara, 2002;

Tolstoy et al., 2002; Wilcock, 2001; Tsuruoka et al., 1995; Zugravescu et al., 1989; Souriau et al., 1982; van Ruymbeke et al., 1981; Heaton, 1975). The gravitational attraction of the Moon and Sun is the principal external force that modulates at the depth the intermediate (60 km to 300 km) and deep earthquakes (focal depth > 300 km) (Cadicheanu, 2008; Ismail-Zadeh, 2005). It could affect the dynamic of the Earth with periodicities in mainly diurnal and semi-diurnal band (Melchior, 1978).

The influences of the tidal semidiurnal waves on the intermediate depth seismic activity in Vrancea (Romania) were found previously (Cadicheanu et al., 2007). The analysis was extended to two other long time series of intermediate-depth earthquakes (Fig.1) in Vrancea (Romania), Bucaramanga (Columbia) and Hindu Kush (Afghanistan) nest seismic zones (Cadicheanu et al., 2008a). .

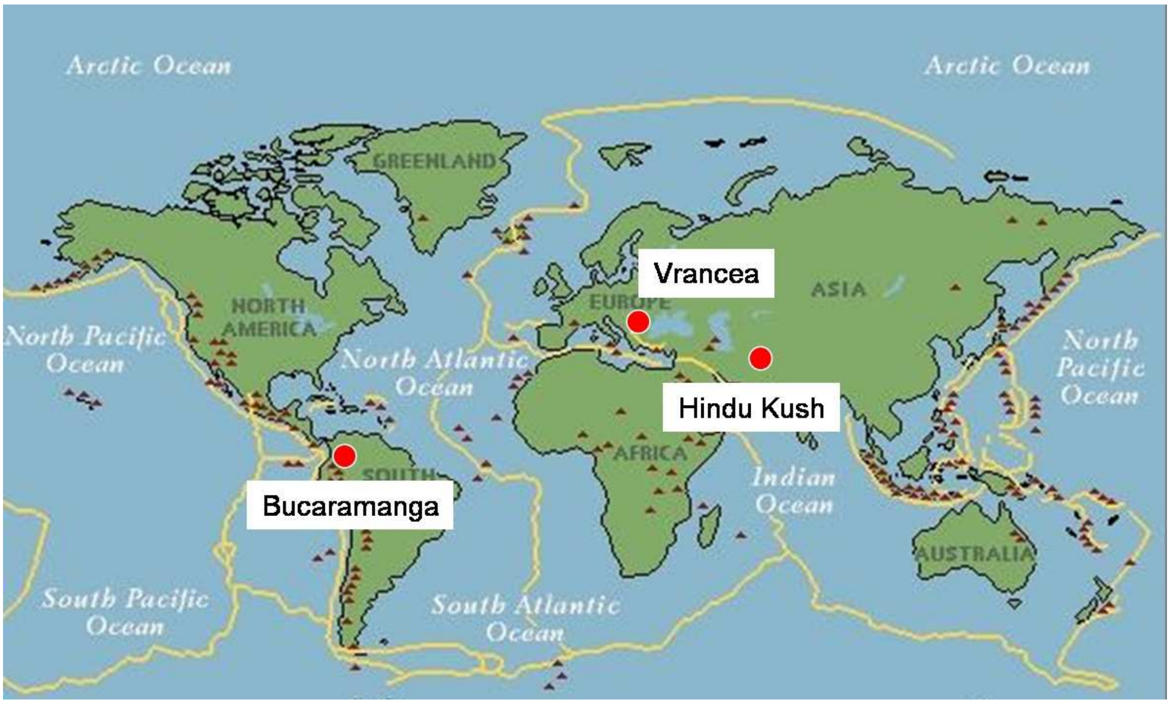


Fig.1. Geographical positioning of three seismic zones: Vrancea, Bucaramanga and Hindu Kush

2. Data

The input data for our study were obtained from RomPlus catalogue of seismic events occurred between 1980 and 2012 for Vrancea seismic zone (3604 intermediate events with $Mw \geq 2.9$), from IRIS catalogue for Bucaramanga seismic zone (3219 intermediate events with $Mw \geq 3.0$) and for Hindu Kush seismic zone (4662 intermediate events with $Mw \geq 3.6$). All the depth intermediate earthquakes were taken in account, main shocks and aftershocks also.

The nest intermediate-depth seismic activity represents the common feature of the three analyzed seismic zones (Zarifi and Havskov, 2003), tectonically very different.

These seismic zones are localized in the North hemisphere of the Earth and the catalogues cover the following geographical rectangles:

1) Vrancea (Romania): 45.0° – 46.0°N, 26.0° – 27.0°E,
2) Bucaramanga (Colombia): 5.0° - 9.5°N, 72.5° - 74.5°W and
3) Hindu Kush (Afghanistan): 35.0°N – 38.0°N, 68.0°E – 72.0°E.

3. Method

3.1. HiCum method and statistical tests of validation

In order to investigate the correlation between Earth tide *M2* component and seismic activity in the three seismic regions we have choose the histogram cumulating method (HiCum) applied on the events distributions (van Ruymbeke et al., 2003). This method is very efficient for the stable phenomena like Earth tides that represent an astronomical clock. The Hicum algorithm is capable to evaluate very precisely the amplitude of a periodical component included in a repetitive process. In the case of a random distribution of events such as a time series of earthquakes, we search for a specified periodicity *M2* in the seismic activity. Each event E_i occurred at time t_i is characterized by a phase α_i defined in the interval 360°, corresponding to the phase of a selected harmonic signal (Fig.2).

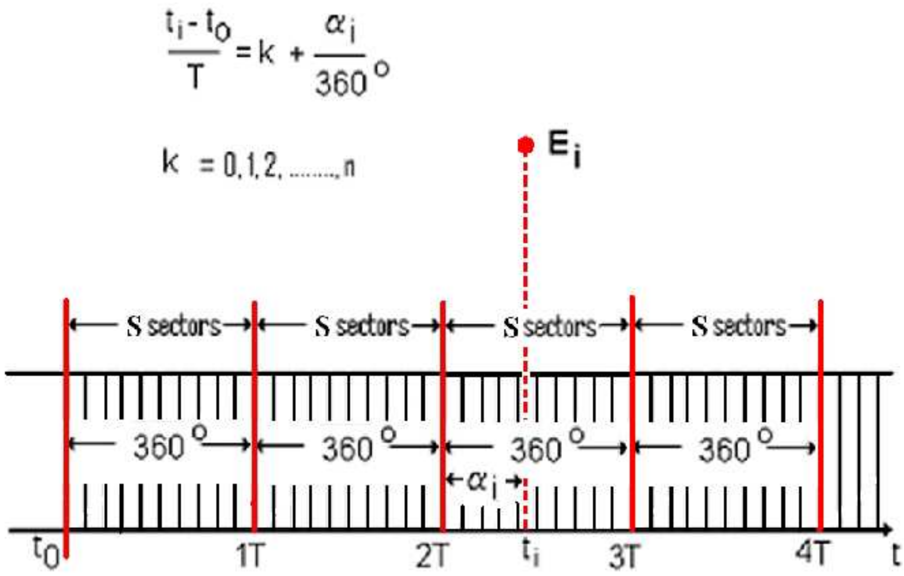


Fig. 2. Time series partition into selected time period T. An event E_i occurring at time t_i is defined by an angle α_i

The stacking analysis method HiCum consists in adjusting a cosine function to the histogram of the α_i (Fig.3.).

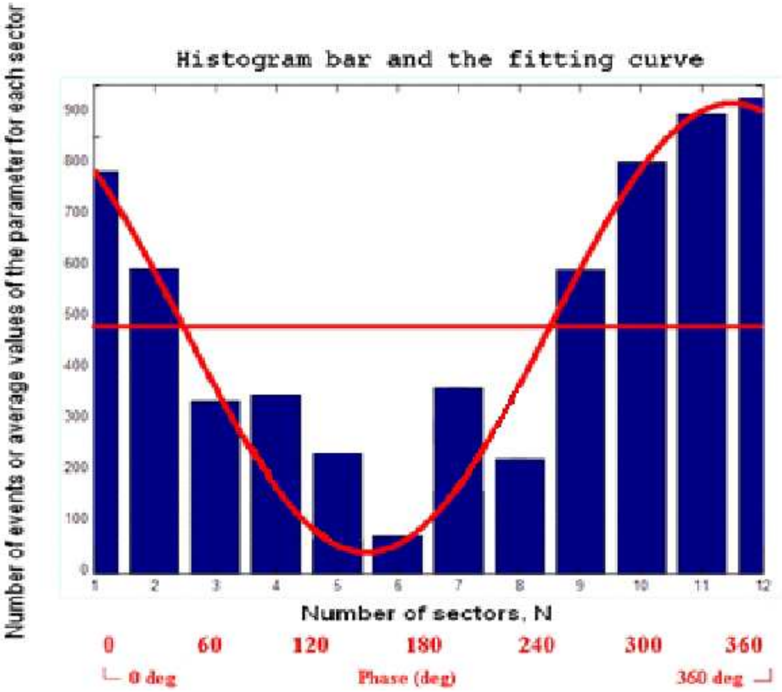


Fig. 3. The fitting curve of the HICUM stacking by a cosinusoidal function.

The amplitude and phase of this cosine show the relation, in terms of modulation, between the stacked events and the semidiurnal tidal component. The stacking function could be applied in sliding windows in the time domain, respectively in the space domain.
Shuster test is usually applied to analyze the correlation between earthquakes occurrences and a selected earth tide component by the coefficient *p*. It is evaluated for a specified significance level that characterizes the null hypothesis rejection (Schuster, 1897).

$$Ps = exp(-D^2/N) \qquad (1)$$

where *N* is the number of earthquakes and ***D*** represents the length of the vectorial sum of all unit length vectors defined by their angle phase.
But we concluded that Schuster test must be supplemented by another test capable to detect the staining of a random distribution aspect using, if is possible, a different mathematical approach. Permutation test (Pitman, 1938) was our second choice because it does not use any a priori assumption.

$$\text{for } A_j > A_0 \ (j=0,1,2\ldots\ldots m); \ \ p_p = m/n \qquad (2)$$

where *Aj* represents the amplitude of the sinusoids obtained for every permutation in the HiCum initial distribution (A_0 is the amplitude of the initial seismic event distribution), *n* is the number of permutation, $m \leq n$.
Thus, the parameter *p* used to validate the correlation was statistically defined by means of two independent statistical tests.

Our next approach investigated and validated the sensibility of a statistical parameter p to transient features around strong seismic events for *M2* component (Cadicheanu, 2008).

3.2 Temporal and 3D sliding windows

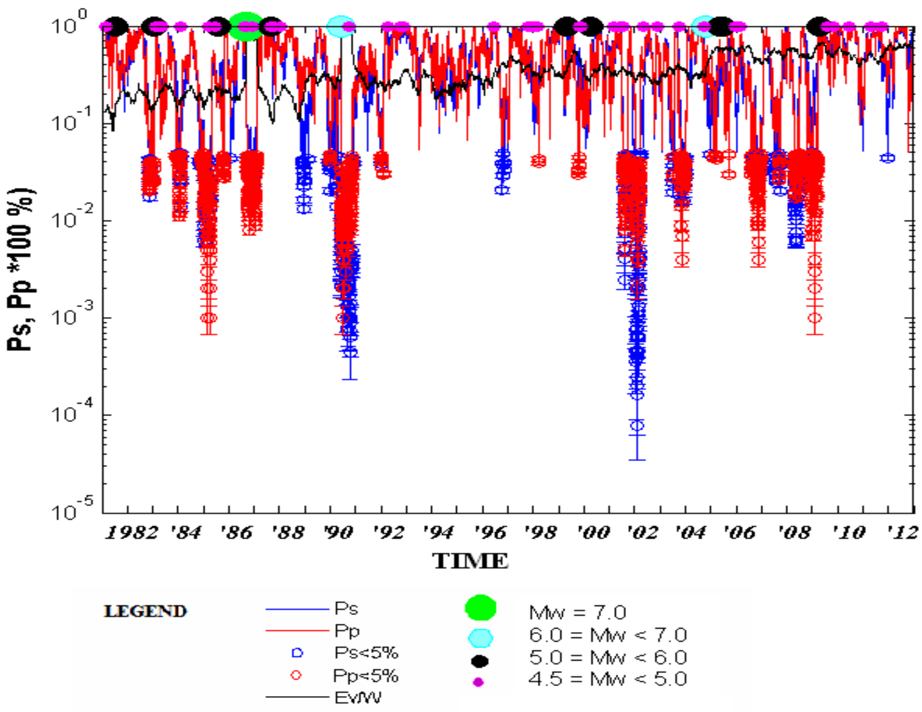
We introduce the temporal variability of the two statistical coefficients p applied on two kinds of temporal sliding windows defined respectively with constant time intervals shifted by a fixed number of *M2* Earth tide period, and windows containing constant number of events, N_{fix}, and shifted also by constant number of events. This number N_{fix} is obtained by an algorithm based on empirical Sturges (1926) formula (3).

$$K=(N_{max} - N_{min})/(1+3.22 *lg\ N_{tot}) \qquad (3)$$

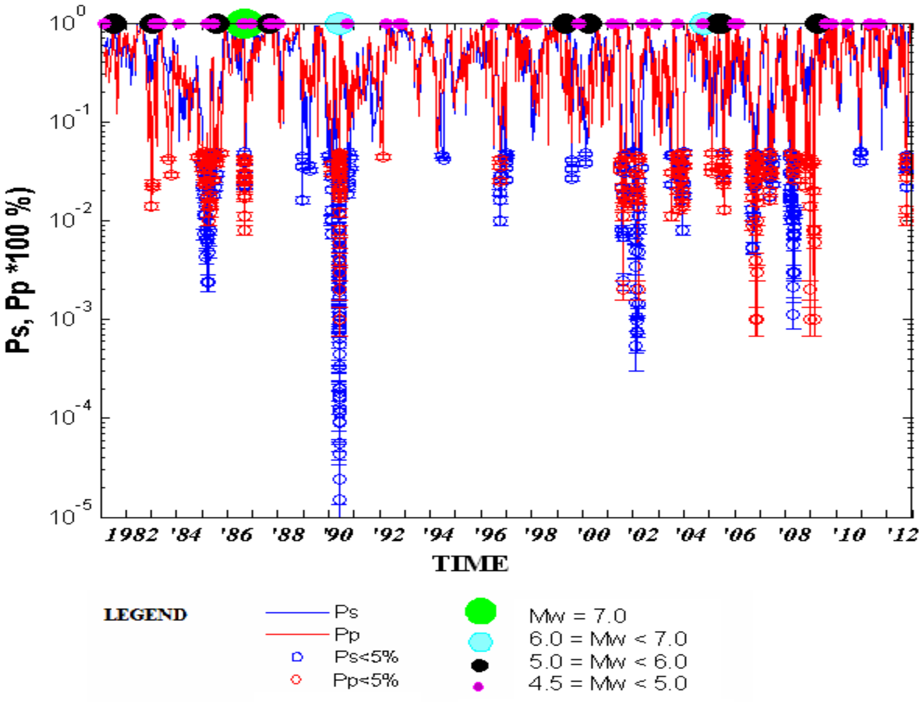
where K is the constant number of bin which characterizes the cumulative histogram resulted by stacking analysis , N_{max} and N_{min} are the maximum, respectively minimum number of events obtained by counting events in each window shifted by a fixed number of *M2* Earth tide period , and N_{tot} represents the total number of events. The average amplitude of all adjusting cosine functions applied to the cumulative histograms represents N_{fix}.

The p-values are plotted at the end of each window. For example, we choose the time series of intermediate-depth earthquakes that occurred in Vrancea seismic zone from 1980 to 2012 (3604 intermediate events with $Mw \geq 2.9$). (Fig. 4). We fund, for a fixed time interval of 170 days shifted by two M2 intervals (about one day), N_{max}= 150 events, N_{min}=1 event and $K=12$. The average amplitude for all adjusting cosine functions applied to the cumulative histograms of each sliding window gives the constant number of events N_{fix}=50 events.

In both cases the variation of p-values has the same behavior. This can be considered a good result concerning the choice of the method.



a)



b)

Fig. 4. Vrancea seismic zone exemple. Statistical coefficient p values for Schuster's test, p_S ,(in blue) and permutation test, p_P, (in red), marked with circles for p <5%. The magenta circles are for earthquakes with $4.5 \leq Mw < 5.0$. Earthquakes with magnitude $5.0 \leq Mw < 6.0$ are represented by black circles, with magnitude $6.0 \leq Mw < 7.0$ are represented by cyan circles and the green circle is for earthquakes with $Mw \geq 7.0$. The upper graph **(a)** shows results for the sliding windows defined by the fixed time interval 170 days shifted by two M2 intervals (about one day). The black curve represents the variation of the number of events in each window, E_V/W. The lower graph **(b)** corresponds to sliding windows with fixed number of events (N_{fix} = 50 seismic events) shifted with one event. In this case, black curve is not represented because $E_V/W=const= N_{fix}$, for every sliding windows we have the same number of events N_{fix}

In addition to the temporal sliding windows, we investigate the mentioned coupling between *M2* and intermediate-depth seismic activity using the new concept of *"3-D statistical tidal tomography"* (Cadicheanu et al., 2008). In this case, the p-coefficients are calculated for events located within box volumes (Fig.5) shifted in horizontal, respectively vertically plans. From statistical reasons only the series equal or larger than 25 events are considered. The dimension of the box is function of the average density of the seismic events in the considered area, the reported localization errors of the earthquake hypocenters and the minimum number of events required for statistical reason.

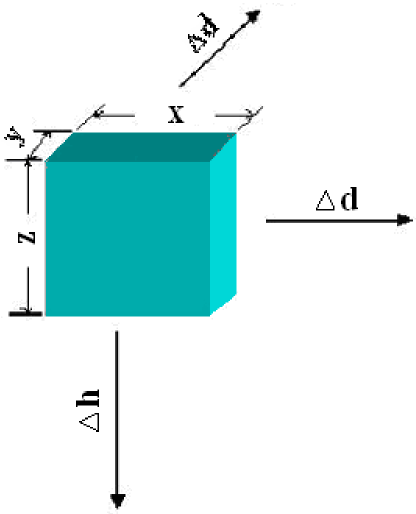
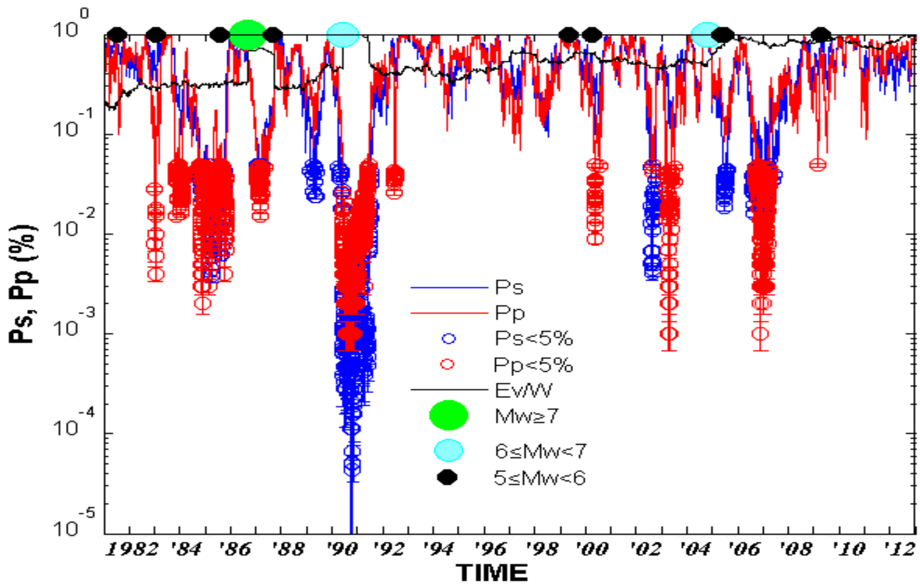


Fig. 5. The “statistical tidal tomography” map of *p* statistical coefficients is obtained when stacking function is applied to 3-D geometry following the earthquake distribution. The calculations are carried out for spatial box volume windows covering the entire hypocenter zone area. The horizontally and respectively vertically sliding steps are in according to the reported localization errors of the earthquake hypocenters.

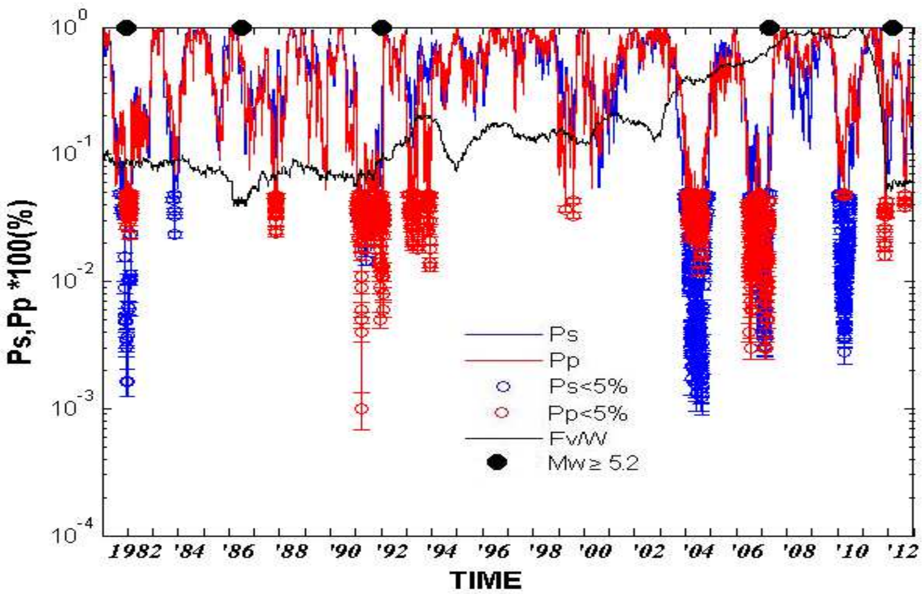
4. RESULTS AND DISCUSSION

Statistical *p* –values are calculated for each sliding window of a year shifted by two *M2* periods. A systematic temporal pattern of the *p*-values preceding or following the meaningful earthquakes was observed for the analyzed seismic zones (Fig.6). It is represented by a number of temporal windows, in which *p* –values are less than the 5% or express a frequent descending tendency toward smaller values of *p*. This behavior is observed from a few weeks in some cases, to a few years in other, before an important event or immediately after its occurrence.

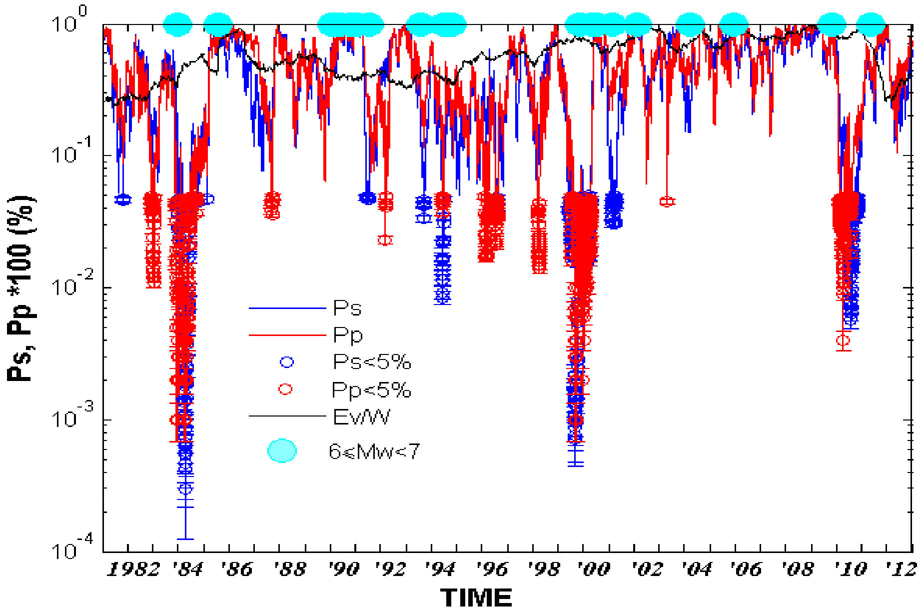
Therefore, we identify this feature for Vrancea (Romania) before the 1986, 1990 and 2004 large earthquakes ($Mw \geq 6.0$) and for the most part of earthquakes with $Mw \geq 5.0$ (Fig.6a). In Bucaramanga (Columbia) seismic region we observe this aspect before the 1981, 1992, 1992, 2007 and 2012 earthquakes (Fig.6b), but here the intervals between two successive large earthquakes are very shot comparing with Vrancea seismic zone. It means that the periods of energy recharge and release are not adequate for an earth tide triggering. The gravitational stress variation is not efficient in such a case where the main source of stress variations is each large event. We encounter a similar situation in Hindu Kush (Afghanistan) seismic region where the earthquakes with $Mw \geq 6.0$ are also frequent (Fig.6c).”


Ps, Pp (%)
TIME
Ps
Pp
Ps<5%
Pp<5%
Ev/W
Mw≥7
6≤Mw<7
5≤Mw<6

(a)


Ps,Pp *100(%)
TIME
Ps
Pp
Ps<5%
Pp<5%
Ev/W
Mw≥ 5.2

(b)



(c)

Fig.6. Statistical *p* value variations for the intermediate-depth seismic zones Vrancea (a), Bucaramanga (b) and Hindu Kush (c). Statistical coefficient *p* values for Schuster's test (in blue) and permutation test (in red) are marked with circles for p <5%.

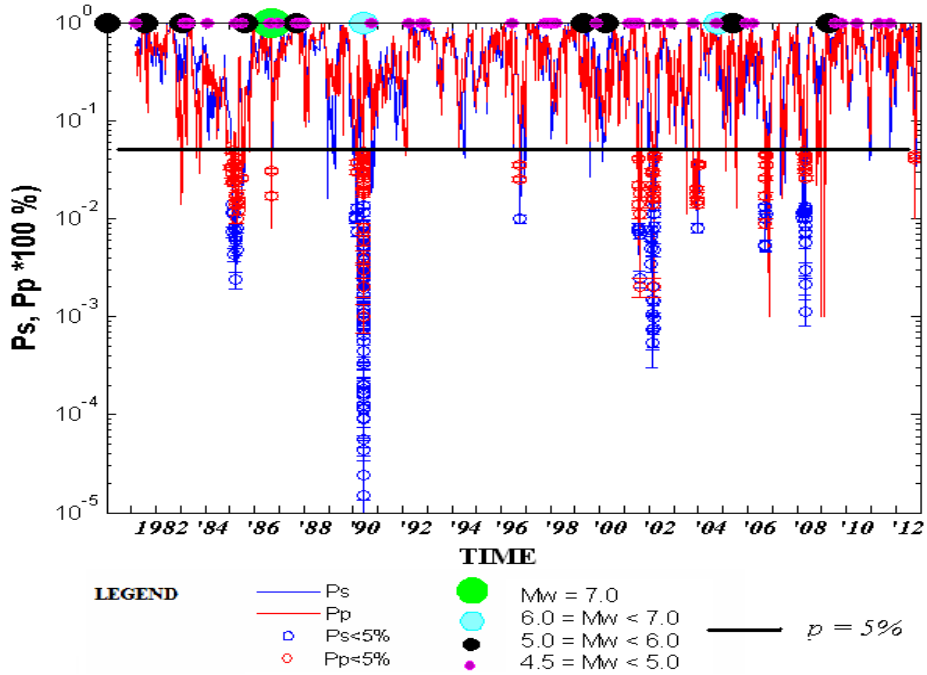
An important step of our approach was the result validation of the correlation statistical parameter *p* by means of random synthetically time series.

We have constructed hundred random synthetically time series of seismic events for each seismic zone taking in account the real intervals between two successive events from the observation series of earthquakes. We applied a randomization algorithm by permutation of these intervals and each time we calculated the correlation parameter *p* in the same way as for real data.

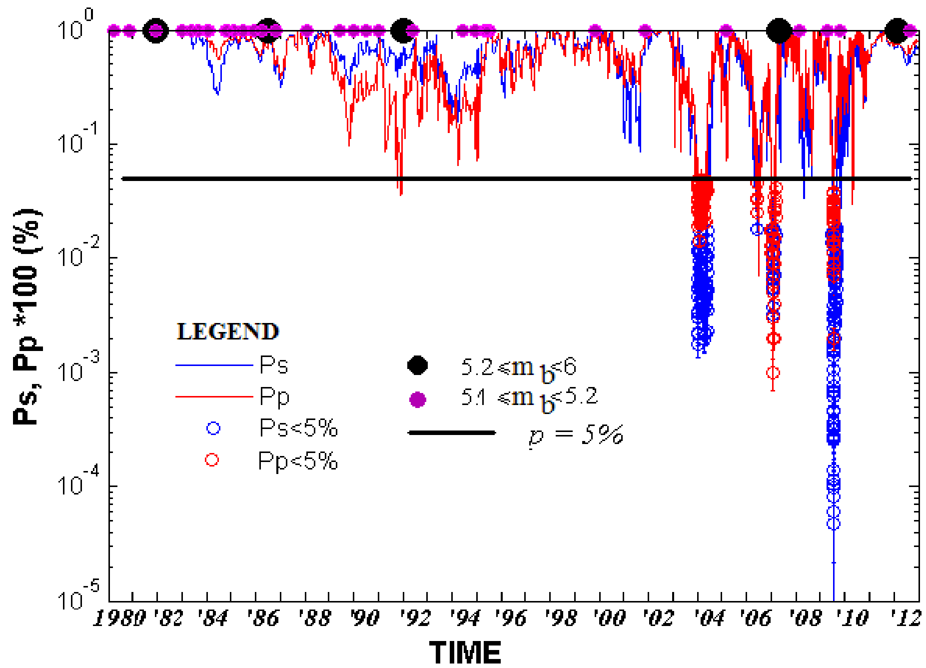
We calculated the average and the dispersion σ for the amplitude *A* of the fitting sinusoidal function in the all windows in which p<5% for random synthetically data. We considered the presence of correlation between seismic activity and earth tide component *M2* only in all the windows in which the following relation is true:

$$A_{\text{W\_eq}}\,(p<5\%) > \max\,(A_{\text{mean\_syn\_eq}}\,(p<5\%) + \sigma) \qquad (3)$$

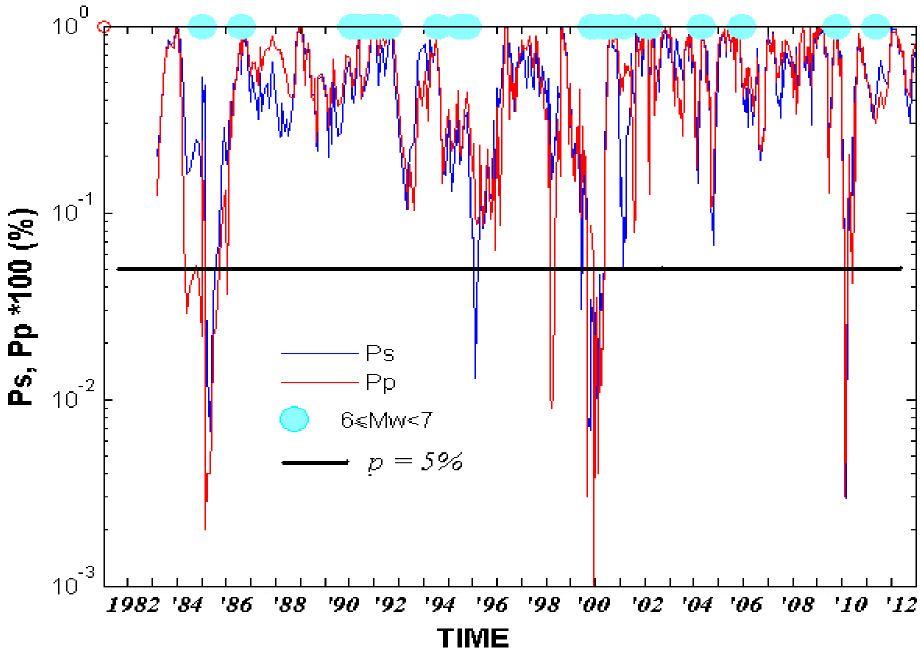
where, for a specified seismic area, $A_{\text{W\_eq}}$ is the amplitude of the fitting sinusoidal curve calculated for each real data window with p<5%, $A_{\text{mean\_syn\_eq}}$ represents the average amplitude of all fitting sinusoidal curve amplitudes of the windows with p<5% for each random synthetically series and σ the corresponding dispersion. We established the largest $A_{\text{mean\_syn\_eq}}$ value of the one hundred as the lower limit for validate the presence of correlation between *M2* earth tide component and seismic activity in the case of the time windows where p<5% (Fig.7).


Ps, Pp *100 %)
TIME
LEGEND
Ps
Pp
Ps<5%
Pp<5%
Mw = 7.0
6.0 = Mw < 7.0
5.0 = Mw < 6.0
4.5 = Mw < 5.0
p = 5%

(a)


Ps, Pp *100 (%)
TIME
LEGEND
Ps
Pp
Ps<5%
Pp<5%
p = 5%

(b)



(c)

Fig. 7. Validation of the correlation time windows between M2 earth tide component and seismic activity for Vrancea (a), Bucaramanga (b) and Hindu Kush (c) intermediate-depth seismic zones. Validated statistical coefficient p <5% values for Schuster's test p_S and permutation test p_P are marked with blue, respectively red circles. The black line delineates $p \leq 5\%$ zone of the p >5% zone. The p values of the figure 7a (Vrancea) correspond to sliding windows with fixed number of 50 seismic events shifted with one event, the p values of the figure 7b (Bucaramanga) correspond to sliding windows with fixed number of 125 seismic events shifted with one event while the p values of the figure 7c (Hindu Kush) correspond to sliding windows with fixed number of 150 seismic events shifted with 10 events.

We observe a good percentage of validation for Vrancea seismic region, fewer in Bucaramanga and not any window of correlation validated for Hindu Kush seismic region. We assume that gravitational processes are not the only dominating phenomenon neither in time nor in space. Other complex processes such as thermal or electromagnetic could play an important role in the triggering of earthquakes.

There are significant tectonical differences between the three seismic zones. Bucaramanga is characterized by a double process of oceanic subduction (Pulido, 2003). As regards Hindu Kush seismicity, it is affected by a dynamical process of continental subduction (Replumaz et al., 2013; Pegler and Das, 1998).

From this point of view, the Vrancea seismic region seems to be a good choice for the study of correlation between Earth tides and earthquakes. For this reason we have considered important to extend our temporal and spatial analysis in particular for this seismic area.

An attempt to analyze the p-value variations for Vrancea, 1934 -2007 in sliding windows of 365 days shifted by 50 days was also performed (Fig.8).

By applying the FFT to the 5th-order polynomial least squares fit of p-values, we obtain a quasi-long period of 17 years of correlation between earthquake occurrences and M2 tidal waves.
This period is in good agreement with the behavior of other characteristics of the seismic activity retrieved by Enescu et al.(1999): the same periodicity was observed concerning the magnitude limit values and fault plane solutions alternation. Intervals where the NE–SW orientation of the fault planes is dominant, maximum magnitudes are Mw_{max}>6.7, while in intervals dominated by the NW–SE orientation of the fault planes, maximum magnitudes are $Mw_{max} \leq 6.7$ (Fig.8).

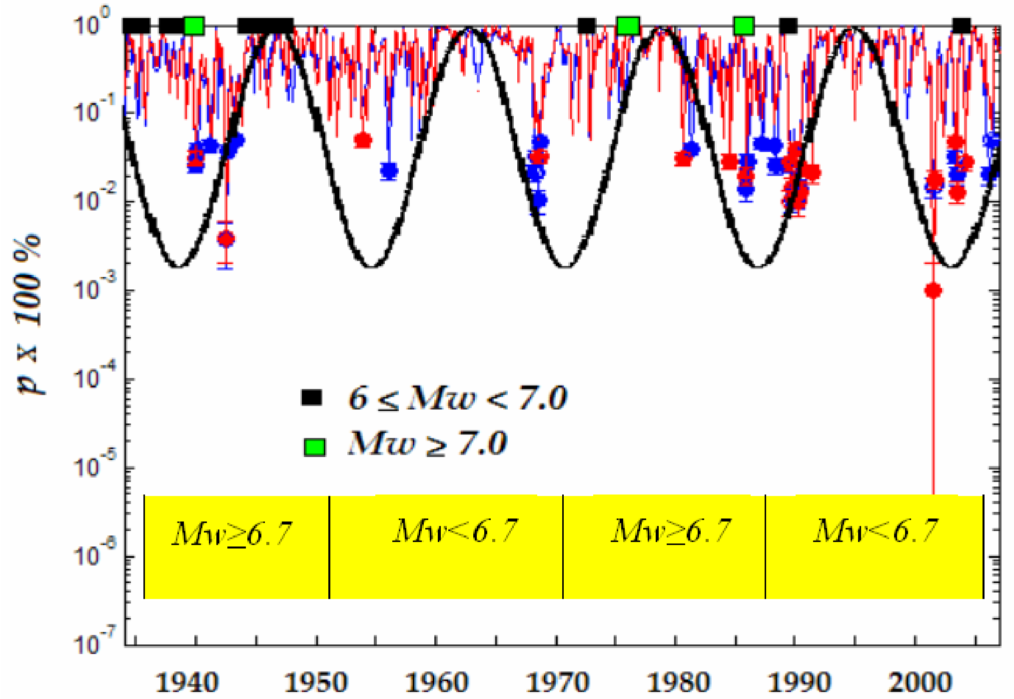


Fig. 8. p_s(blue line and circles) and p_p(red line and circles) -values variations for Vrancea seismic zone, 1934 - 2007 interval, in sliding windows of 365 days shifted by 50 days . A quasi-long period of 17 years in the variation of the *p*- value is pointed out. The same periodicity was observed by Enescu et al. (1999) concerning the magnitude limit values and fault plane solutions alternation. Intervals where the NE–SW orientation of the fault planes is dominant, maximum magnitudes are Mw_{max}>6.7, while in intervals dominated by the NW–SE orientation of the fault planes, maximum magnitudes are $Mw_{max} \leq 6.7$ (yellow rectangles separated by black lines).

4.1. 3-D statistical tidal tomography

To improve our observations on Vrancea seismic region we have extend in space the possibility of statistical parameter *p* applying the new concept of statistical tomography (Cadicheanu, 2008; Cadicheanu et al., 2008).

A "statistical tidal tomography" map for each intermediate-depth seismic zone is obtained when stacking function is shifted in 3D geometry following the hypocenter distribution. We assume that the tidal tomography patterns represent the response of the regional tectonic structure to the earth-tides.

The space distribution of the volumes in which the statistical parameter *p* of correlation is smaller than 5% agrees with the model of the distribution of seismicity for the Vrancea seismic zone (Radulian et al., 2008). Taking into account the assumption according to which gravitational forces dominate the volumes with p < 5%, we obtain a special map of their action on the Vrancea intermediate-depth seismic activity (Fig.9) maybe related to the torsion movement funded here by Stanica et al. (2004). Small white squares represent the positions of the elementary volumes in which p <5% and colorbar gives the number of earthquakes for each small elementary volume at different levels.

From tectonic point of view, among the three seismic regions, only Vrancea shows a peculiar feature related to the presence of a detached slab immerged into the asthenosphere (Ismail-Zadeh et al., 2005). Due to this greater freedom of movement in asthenosphere, the seismic volume will be more sensitive to the action of gravitational forces than other areas and thus to the action of the earth tides. But we observe that the coupling between earth tides and seismic activity is not constant. This means that any seismic region is subject to complex physical factors, not only gravitational, that impose various physical parameters measurements.

5. CONCLUSIONS

Different signatures of the p variation are observed in the neighborhood of the stronger earthquakes. Coupling tendencies between some earth tide components (semi-diurnal *M2* wave especially) and seismic activity for three important seismic regions of the world (Vrancea, Bucaramanga and Hindu Kush) are studied by means of the statistical p-value and validated by means of random synthetically time series. We suppose that statistical p-value, could have a potential capacity to identify the existence of transient features around strong seismic events.

In the triggering mechanisms, important factors could be: the variations of the heat flow distribution in the earth mantel, the fluid flow in the porous medium, in terms of physical characteristics of contact with magma in the areas of the crustal and sub-crustal discontinuity, the large seismic events and the earth tides that induce periodical variations of the gravitational forces at large scale. All these factors are capable to modify the energetic potential of a region inducing variations of the stress at the fault level. Our results confirm the existence of a structure and tectonic dynamics specific to each of the three analyzed areas.). In particular, in Vrancea region, the immerged seismic volume into the asthenosphere makes the seismic activity more sensitive to the action of gravitational forces than other similar areas and thus to the action of the earth tides.

In this context, Vrancea seismic region is the suitable zone for studies of the correlation between Earth tides and earthquake occurrences.

The relationship between seismic activities and tidal periodicities could be important to understand some characteristics of the analyzed seismic zones. In addition, the statistical coefficient p could have a potential capacity to identify the existence of transient features around strong seismic events (Bernard, 2001). Thus, the new concept and methodology of the statistical tidal tomography could reveal important features in the behavior of a seismic zone.

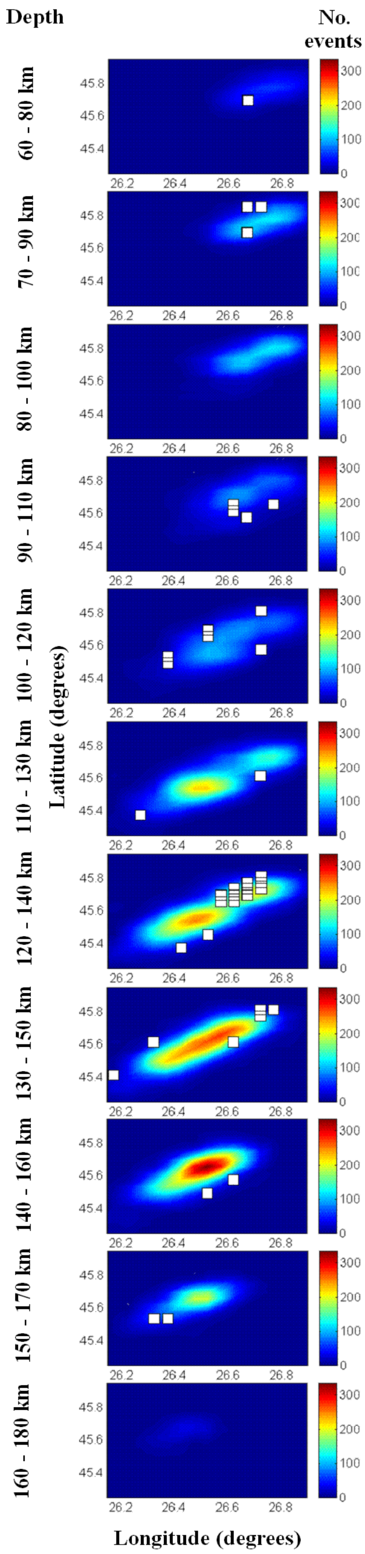


Fig. 9. Results of the statistical M2 tidal period tomography for the Vrancea seismic zone. Small white squares represent the positions of the elementary volumes with p <5% and colorbar gives the number of earthquakes for each small elementary volume at different levels.

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REFERENCES

Bernard, P., 2001. From the search of 'precursors' to the research on 'crustal transients'. Tectonophysics **338,** 225–232.
Cadicheanu, N., van Ruymbeke, M., Zhu, P., 2007. Tidal triggering evidence of intermediate depth earthquakes in the Vrancea zone (Romania), Nat. Hazards Earth Syst. Sci. 7, 733-740.
Cadicheanu, N., Zhu, P., van Ruymbeke, M., 2008. Spatial and temporal variations of the correlation coefficient between M2 and S2 earth tides components and earthquake occurrence for the intermediate-depth seismic activity zones. Acta Geod. Geoph. Hung. 43(2–3), 131–144.
Cadicheanu, N., 2008. Etude des influences gravimétriques induites par les marées terrestres sur l'activité sismique intermédiaire dans la zone de Vrancea. Doctoral Thesis. Université catholique de Louvain.
Cochran, E.S., Vidale, J.E., Tanaka, S., 2004. Earth tides can trigger shallow thrust fault earthquakes. Science 306, 1164–1166.
Emter, D., 1997. Tidal triggering of earthquakes and volcanic events. Lecture Notes in Earth, Sciences 66, 293-309
Enescu, D., Enescu, D.B., 1999. Possible cause – effect relationships between Vrancea (Romania) earthquakes and some global geophysical phenomena. Natural Hazards, Kluwwer Academic Publishers 19, 233–245.
Heaton, T. H., 1975. Tidal triggering of earthquakes. Geophys. J. R. Astron. Soc. 43, 307–326.
Ismail-Zadeh, A., Müller, B., Wenzel, F., 2005. Modelling of Descending Slab Evolution Beneath the SE-Carpathians: Implications for Seismicity. Perspectives in Modern Seismology Lecture Notes in Earth Sciences 105, 203-223
Kasahara, J., 2002. Tides, earthquakes and volcanoes. Science 297, 348–349.
Melchior, P., 1978. The Tides of the Planet Earth. Pergamon Press, New York.
Pegler, G., Das, S., 1998. An enhanced image of the Pamir-Hindu Kush seismic zone from relocated earthquake hypocentres, Geophysical Journal International 134 (2), 573–595.
Ping Zhu, Michel van Ruymbeke, Nicoleta Cadicheanu, 2009. A stacking method and its applications to Lanzarote tide gauge records. Journal of Geodynamics 48, 138–143
Ping Zhu, 2010. Analysis of very weak signals in seismic, climatic and tidal observations. Doctoral Thesis. Université catholique de Louvain.
Pitman, E.J.G., 1938. Significance tests which may be applied to samples from any population, Part III: The analysis of variance test. Biometrika 29, 322–335.
Pulido, N., 2003. Seismotectonics of the northern Andes (Colombia) and the development of seismic networks. Bulletin of the International Institute of Seismology and Earthquake Engineering, Special Edition, 69-76.

Radulian M., Popa M., Cărbunar O., Rogozea M., 2008. Seismicity patterns in Vrancea and predictive features. Acta Geod. Geoph. Hung. 43(2–3), 163–173.
Replumaz, A., Guillot, S., Villaseñor, A, Negredo, A.M., 2013. Amount of Asian lithospheric mantle subducted during the India/Asia collision. Gondwana Research 24, 936–945.
Schuster, A., 1897. On lunar and solar periodicities of earthquakes, Proc. R. Soc. Lond. 61, 455–465.
Souriau, M., Souriau, A., Gagnepain, J., 1982. Modeling and detecting interactions between Earth tides and earthquakes with application to an aftershock sequence in the Pyrenees. Bull. Seismol. Soc. Am. 72, 165–180.
Stanica, D., Stanica, M., Piccardi, L., Tondi, E., Cello, G.., 2004. Evidence of geodynamic torsion in the Vrancea zone (eastern carpathians). Rev. roum. GÉOPHYSIQUE, 48, 15–19.
Stavinschi, M. and Souchay, J., 2003. Some correlations between earthquakes and Earth tides, Acta Geod. Geoph. Hung. 38, 77-92.
Sturges, H. A., 1926. The choice of a class interval. Journal of the American Statistical Association 21, 65–66.
Tanaka S., Sato, H., Matsumura, S., Ohtake, M., 2006. Tidal triggering of earthquakes in the subducting Philippine Sea plate beneath the locked zone of the plate interface in the Tokai region, Japan. Tectonophysics 417, 69–80.
Tanaka, S., Ohtake, M., Sato, H., 2002. Evidence for tidal triggering of earthquakes as revealed from statistical analysis of global data. J. Geophys. Res. 107 (B10), 2211. doi:10.1029/2001JB001577.
Tolstoy, M., Vernon, F.L., Orcutt, J.A., Wyatt, F.K., 2002. Breathing of the seafloor: tidal correlations of seismicity at Axial volcano. Geology 30, 503–506.
Tsuruoka,H., Ohtake, M., Sato,H., 1995. Statistical test of the tidal triggering of earthquakes: contribution of the ocean tide loading effect. Geophys. J. Int. 122, 183–194.
van Ruymbeke, M., Ducarme, B., De Becker, M., 1981. Parameterization of the tidal triggering of earthquakes. B.I.M. 86, 5521-5544.
van Ruymbeke, M., Howard, R., Putz, P., Beauducel, F., Somerhausen, A., Barriot, J-P., 2003. An Introduction to the use of HICUM for signal analysis. BIM 138, 10955–10966.
Wilcock, W.S., 2001. Tidal triggering of microearthquakes on the Juan de Fuca Ridge. Geophys. Res. Lett. 28, 3999–4002.
Zarifi, Z., Havskov, J., 2003. Characteristics of dense nests of deep and intermediate depth seismicity. Advances in Geophysics 46, 237-278.
Zugravescu, D., Fatulescu, I., Enescu, D., Danchiv, D., Haradja, O., 1989, Peculiarities of the correlation between gravity tides and earthquakes. Revue Roumaine de Geologie, Geophysique et Geographie, Serie de Géophysique 33, 3-11.