

Preferential Environmental Conditions for Bipolar Disorders in Crete, Greece, 2008-2012: Local Versus Distant (After the Great 2011 Tōhoku Japan Earthquake) Triggering ($M < 3$) Microseismicity

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Abstract

There is strong evidence that both physical and anthropogenic electromagnetic radiation, at various bands of electromagnetic spectrum, affect human health and life in many ways. In particular, in previous studies we have demonstrated that the rate N_{BIP} of bipolar disorder patient admissions to IPU/UoC, Heraklion, Greece, was strongly related to the number N_E of small earthquakes, between the years 2008 - 2010. We have also provided strong observational evidence that the effect of the microseismicity on the major mental disorders in Crete, i.e. bipolar disorders and schizophrenia, are mediated through the Ultra Low Frequency (ULF) electromagnetic (EM) waves radiated at the Hellenic arc (the boundary of the Eurasian and African tectonic plates). The aim of the present paper is to confirm our previous findings between 2008 - 2010 by expanding the time-period examined to five years, i.e. 2008 - 2012, given that in March 2011 a giant M9.1 earthquake (EQ) occurred in Japan followed by a period of large EQs in the vicinity of its epicenter and dynamically triggered small earthquakes around the globe. Based on our analysis, we infer that (a) N_{BIP} and N_E continue to be strongly correlated ($r = 0.559$, $p < 0.001$) during the whole time period 2008 - 2012, (b) the seismological profile in Greece changed after the Japan March 2011 EQ (in particular between May-December 2011) compared to the previous time interval examined, (c) the highest mean monthly values $\langle N_E \rangle$ and $\langle N_{BIP} \rangle$ during the 5-year interval 2008 - 2012 were recorded in Greece-Minor Asia after the Japan March 2011 EQ, along with high earthquake activity in Japan ($\langle N_E \rangle = 374$ versus $\langle N_E \rangle = 188.5$ after the EQ; $\langle N_{BIP} \rangle = 9.5$ versus $\langle N_{BIP} \rangle = 6$ before the EQ). A comparison of seismicity in Greece and Japan during the time period examined (2008 - 2012) suggests that most probably the change in the seismological profile in Greece after May 2011 (in particular between May-December 2011) is an effect of the dynamically triggering microseismicity caused by the distant Japan earthquakes. We finally infer that both local and remotely triggered microseismicity significantly affected the frequency of bipolar disorders hospital admissions in Crete during the time period 2008 - 2012 and that the correlation between N_{BIP} and N_E shows a more complex correlation pattern after the Japan 2011 earthquake most probably due to the microseismicity-induced ULF EM radiating energy to the bipolar disorder patients by distant microseismicity (not only near Crete). The results suggest that in some seismological regions like Crete, patients with bipolar disorders may be affected by locally generated microseismicity, as well as by a distant giant earthquake (and its subsequent great earthquakes even for several months after its occurrence) and by remotely transferred microseismicity. New approaches based on electromagnetic protection may be beneficial for patients with bipolar disorder, in particular, after a giant earthquake at large distances. However, more work is needed to further examine our present results.

Keywords: Bipolar disorder; Bioelectromagnetics; ULF Health Effects; Remotely Triggered Earthquakes; Seismobiology; Mental Disorders

Introduction

Environmental electromagnetism and bipolar disorders

In general, electromagnetic phenomena have been confirmed as affecting both humans [1-10] and animals [11-13]. Mood disorders encompass a large group of mental disorders, in which a pathological mood is the dominant symptom. The main mood disorders, i.e. depression and bipolar disorder are frequent with a life-time prevalence of 15% and about 1.5%, respectively [14]. They usually have a chronic course, which may lead to a significant disability for the patient and cause a high burden to the family/care givers [15,16].

The pathophysiology of mood disorders is still, to some extent, unknown and previous research has related it to multiple factors. Several previous studies have provided significant evidence that depression and bipolar disorders are related with some physical environmental conditions. Seasonable effects on depression and bipolar disorders are well known [17], which suggest some dependence on the physical environment. In addition, some observational studies have provided evidence that enhanced frequency of psychotic disorders is related with times of strong geomagnetic activity and microseismicity (enhanced rates of very small earthquakes; i.e. $M < 3$ earthquakes) [18-21]. Both physical phenomena, geomagnetic storms and microseismicity, transfer quasi-static or ultra low frequency (ULF) electromagnetic fields from either space or the lithosphere, respectively [22,23], which affect human mental health and behavior [18-21,24,25].

Furthermore, all organisms, including humans, are exposed to the influence of different types of EM fields, characterized by distinct physical parameters. All electrically powered devices and transmission lines generate the low frequency (usually 50 or 60 Hz). On the other hand, electronic devices, such as mobile phones, television sets or radio transmitters, emit electromagnetic radiation with high frequencies (from 300 MHz to 300 GHz). High energy radiation of this type causes a thermal effect that may increase the temperature of tissues and organs and also cause serious damage to cells. Several studies have provided significant evidence that anthropogenic electromagnetic radiation in the ULF frequency band is responsible for enhanced frequency of depression-like symptoms, higher rates of suicide, anxiety, hostility and paranoia [26,27].

More recently, we have shown that acute admissions of patients with bipolar disorder in Crete, Greece [24,25] are strongly dependent on ULF radiation-induced by microseismicity at the boundary of the African and the Eurasian tectonic plates [21], the so-called Hellenic arc. However, small earthquakes are also known to be generated not only by local intrinsic microseismicity, but also by “remotely triggered events” [28] caused by distant great earthquakes.

In this study, we extend our previous investigation on the relation between bipolar disorders and local intrinsic microseismicity to a relation of bipolar disorders with the microseismicity triggered by “remotely triggered events” following the giant March 11, 2011 M9.1 Japan earthquake.

If a relation of enhanced frequency of bipolar disorders after some time from the occurrence of a distant great earthquake can be established, some special protection of bipolar patients could be planned and performed.

Microseismicity triggered by distant great earthquakes

The earthquake motion consists in general of several sets of vibrations, whose amplitude and period range within wide limits. Increases in seismicity have been widely observed at varying distances from the source area following large earthquakes. The increased number of earthquakes are usually called aftershocks if the area is within a rupture length of the main shock and called “remotely triggered events” if they are well beyond that distance [28].

A number of studies have presented evidence that remotely triggered earthquakes are caused by the dynamic stress changes associated with transient seismic waves, typically the high- amplitude S and/or surface-wave arrivals [29]. The association of triggered earthquakes with dynamic stress changes [31] is in contrast to aftershocks, which have been assumed to be caused primarily by local, static stress changes associated with fault movement.

Aiken., *et al.* in [32] explored how the 27 February 2010 M8.8 Maule, Chile main shock was triggered at 6,000 km away and just 46 days after the 12 January 2010 M7.0 Haiti earthquake. A remotely triggered earthquake or a “distant earthquake” sometimes is considered a seismic disturbance, whose epicentral distance from a given station is over some 2,000 km or 1,500 miles. Gomberg and Davis found instances of an abrupt, temporary increase in the rate of small earthquakes ($M < 3$) due to dynamic stresses from eight regional earthquakes with magnitudes between $M = 6.6 - 7.7$ at distances up to 2,500 km [33] and Pankow [34] reported triggered earthquakes with magnitude $M < 3.2$, which occurred more than 3,000 km after the Denali fault M7.9 earthquake, on 3 November 2002.

Deloray., *et al.* [35] investigated two $M > 5.5$ -triggered events off the east coast of Japan in the days after the 2012 M8.6 Indian Ocean earthquake. Furthermore, we note that although rapid triggering of $5 < M < 7$ earthquakes occur only within 1,000 km from a great earthquake [36], the great earthquakes can trigger seismicity at very large distances. For instance, the great ($M9.3$) December 26, 2004 Indian Ocean earthquake triggered remote earthquakes as far away as Alaska [37].

Seismic activity naturally occurs on active fault systems due to tectonic stressing between plate boundaries. But sometimes tremor and earthquakes can be triggered, as we mentioned, by transient stress changes associated with the passing seismic waves of earthquakes, the so called “dynamic triggering”. This process has been observed worldwide in a wide range of tectonic environments [31,32].

Omori mentions earthquake motion propagated to 5,400 miles far from Tokyo or from Pacific Ocean to South America, the Atlantic and the Indian Oceans [38], while Parson and Velasko noted that large earthquakes may trigger “remotely triggered events” elsewhere [36]. In particular, Congalez., *et al.* performed a global search for seismicity potentially triggered by the seismic waves from the 2011, M9.0, Tohoku-Oki, Japan Earthquake by using seismograms from global seismic networks and they found potential cases of instantaneous triggering in the United States, Russia, China, Ecuador and Mexico, while for tremors they found evidence for triggering in Taiwan, Cuba, United States and Armenia [39].

Since in [21,24,25] we presented a strong positive correlation between psychotic disorders and small ($M < 3$) earthquakes in Crete, Greece, between 2008 - 2010, we wanted to examine (a) whether a distant giant earthquake like the one in Japan on March 11, 2011 triggered small earthquakes at the Hellenic arc (the boundary between the African and the Eurasian tectonic plates) and, consequently (b) if bipolar disorders in Crete were related to “remotely triggered events” from the Japan, March 2011 M9.1 EQ.

Methodology and Data

To investigate the possible correlations between seismic activity and health problems in humans, in [21,24,25] we selected the island of Crete, Greece, as a suitable test area. In fact, this area is characterized by high seismicity, given that it is a major part of the Hellenic Arc and Trench system at the boundary which marks the active subduction of the African lithospheric plate beneath the southern margin of the Eurasian plate [40]. In [21], we noted that during the first seven months of 2008 the Hellenic Arc was ruptured by a series of four strong main shocks [40] measuring magnitudes larger than 6, whereas only one large EQ occurred during the rest of the time interval (August 2008-December 2010).

The sample of our study derived retrospectively from the admissions of patients hospitalized in the Psychiatric Inpatient Unit of the University Hospital of University of Crete, in Heraklio [IUP/UoC], between 2008-2012 with a primary diagnosis of bipolar disorder, based on the electronic database of the hospital, as previously described in details [17,20]. The Psychiatric Unit consists of two wards, i.e. the “acutely ill ward” and the “short stay ward”. It should be noted that the IUP/UoC is the only public mental health inpatient unit in the

Eastern part of the island, with a reference population of about 400,000 inhabitants. Diagnosis of bipolar disorder was based on clinical evaluation by the attending psychiatrists of the Unit based on DSM-IV-TR criteria [41].

In [21], EQs of magnitude $M > 2$ occurring in the area determined by the geographical coordinates $21^{\circ}\text{E} - 29^{\circ}\text{E}$ and $32.5^{\circ}\text{N} - 38^{\circ}\text{N}$ that were considered for our analysis, between the years 2008 - 2010. In the present study we extend our analysis to a period of 5 years by extending our initial time period by a two year interval, i.e. from January 2008 - December 2010 to January 2008 - December 2012. In addition, since we wanted to check the possible effect of “remotely triggered events” caused by the catastrophic $M9.1$ 2011 Japan EQ we considered a much larger geographic region. The EQ data were obtained from the European Mediterranean Seismological Centre (<http://www.emsc-csem.org>), as in [21].

Observations

Bipolar disorder patient admissions in IUP/UoC and seismicity near Crete

In [21] we investigated the effect of small earthquakes on admissions of patients with mental disorders to the IUP/UoC, during the period November 2008 - December 2010, using “peak to peak” correlation analysis and found that the rising trend of small earthquakes over time ($\beta = 5.848, p < 0.001$) was paralleled with a similar, rising trend of admissions of bipolar disorder patients ($\beta = 0.298, p < 0.001$), while no such trend was noted for hospital admissions of patients with schizophrenia. Focusing on small earthquakes (magnitude 2-4.5) and using Ordinary Least Square (OLS) regression we also found a positive association between the number of earthquakes N_E and the number of admissions of both schizophrenia ($r = 0.484, p = 0.039$) and bipolar disorder patients ($r = 0.703, p < 0.001$). However, the effect on the bipolar disorder patients was found to be much stronger compared to the effect on the schizophrenia patients ($p < 0.001$ vs $p = 0.039$). Additional tests during the period November 2008-December 2010 confirmed that patients with bipolar disorders are the most sensitive patients to changes of microseismicity (small magnitude earthquakes, i.e. $M < 3$) [21].

Since the microseismicity-induced EM ULF radiation is more effective on bipolar disorder patients than on other psychotic patients [25], in this study we focus on bipolar disorder patients admissions in IUP/UoC. For this reason, in figure 1 we extend the comparison between the monthly number of earthquakes N_E and the monthly number of admissions of bipolar disorder patients N_{BIP} to a period of 5 years by extending our initial time period by a two-year interval, i.e. from January 2008 -December 2010 to January 2008 -December 2012.

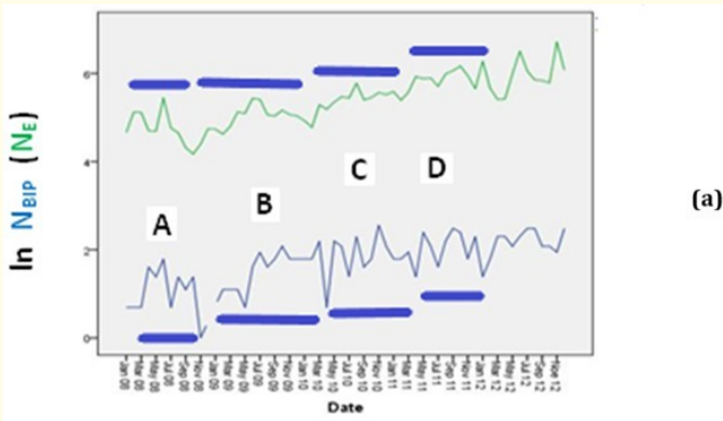


Figure 1: (a) Peak to peak analysis of the monthly course of the natural logarithm(\ln) of total admissions (acute and short-term units) of Bipolar Disorder Patients [N_{BIP} blue line] and the natural logarithm (\ln) of the number of earthquakes of magnitude $M \geq 2$ in the region surrounding Crete [N_E /green line] for the years 2008 - 2012 [14]; Distinct almost simultaneous increases in $\ln(N_{BIP})$ are indicated by the bars A, B, C and D, (b) As in figure 1a but for N_{BIP} versus N_E . It is evident an abrupt change to very large monthly numbers of (small) earthquakes N_E , after the giant ($M9.1$) Japan March 2011 earthquake, from May 2011 to the end of 2012.

Figure 1a shows the peak to peak analysis of the natural logarithm (\ln) of the monthly course of total admissions (acute and short-term units) of bipolar disorder patients (N_{BIP} /blue line), and the natural logarithm (\ln) of the number of earthquakes of magnitude $M \geq 2$ (N_E /green line) in the region surrounding Crete [21], for the years 2008 - 2012. This figure suggests that the enhanced microseismicity during the intervals marked as A, B, C and D are related with increases in the number of admissions of bipolar disorder patients N_{BIP} (panel a). Furthermore, the slopes of the two lines are: upper line $\beta = 0.023$, $p < 0.001$ and lower line $\beta = 0.029$, $p < 0.001$. These values suggest a positive association between the number of earthquakes N_E and the number of admissions of bipolar disorder patients.

Furthermore, from figure 1b it is evident that there is an abrupt change in very large monthly numbers of (small) earthquakes N_E , after the giant ($M9.1$) Japan March 2011 earthquake, i.e. from May 2011 to the end of 2012; the number of $M \geq 2$ earthquakes N_E around Crete ranged between ~ 150 - ~ 300 before April 2011, whereas N_E showed a much more variable profile later, with intense peaks ranging between values as high as ~ 400 - ~ 800 earthquakes per month.

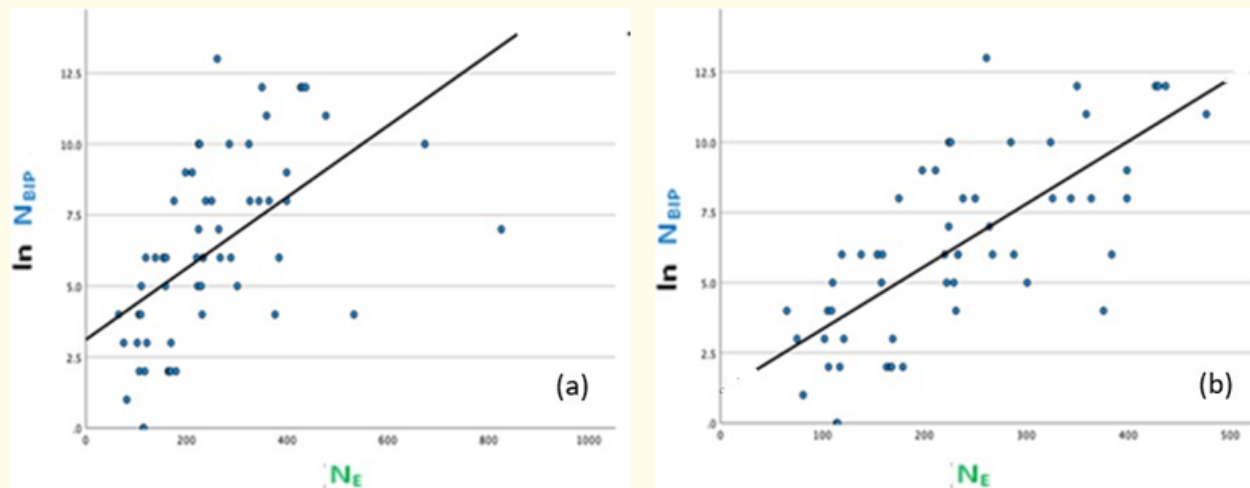


Figure 2: Ordinary Least Square (OLS) regression of the total number of admissions of bipolar disorder patients (N_{BIP}) against the total number of earthquakes (N_E) of magnitude $M \geq 2$ during the period 2008 - 2012 for the total of the 60 points/months (panel a, $r = 0.559$, $p < 0.001$) and for the sample when the three points of highest N_E (>500) were left out (panel b, $r = 0.722$, $p < 0.001$).

In figure 2 we present the two fitted linear lines between the total number of admissions of bipolar disorder patients N_{BIP} and the total number of earthquakes N_E of magnitude $M \geq 2$ during the period 2008-2012 obtained by using the OLS regression [42]. We found a positive association between the monthly number of earthquakes and the monthly number of admissions of bipolar disorder patients (panel a, $r = 0.559$, $p < 0.001$). When the three points of highest N_E (>500) were left out, we found a stronger and more significant correlation between the monthly number of earthquakes N_E and the monthly number of admissions of bipolar disorder patients N_{BIP} (panel b, $r = 0.722$, $p < 0.001$). This is explained by the fact that the three values are far away from the rest affecting the slope of the line, leading to a smaller correlation.

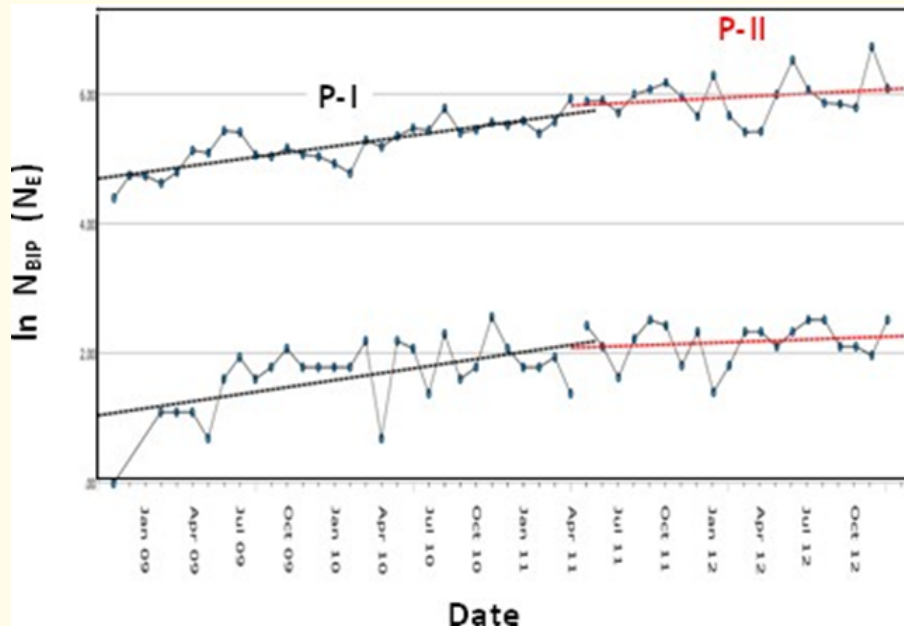
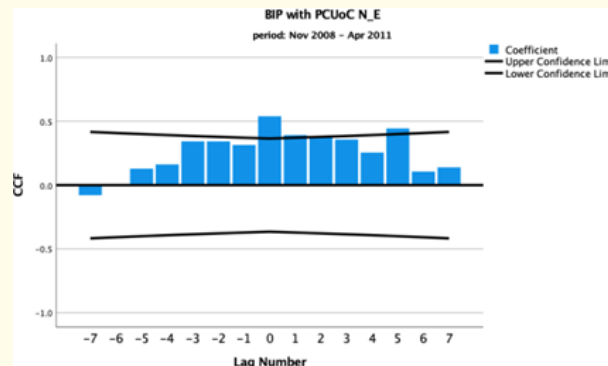
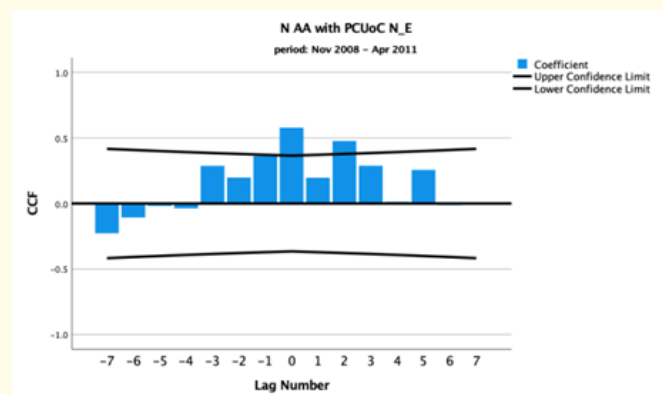


Figure 3: Linear fit of $\ln(N_{BIP})$ versus $\ln(N_E)$ per period (drawing done by manual merging of 4) for the time interval November 2008-April 2011 (Period P-I; black fitting line) and, after the M9.1 March 2011 Japan earthquake, between May 2011-December 2012 (Period P-II; red fitting line). In general higher NBIP and NE were recorded in P-II than in P-I, but the fitting lines in the two time intervals show significant different slopes.

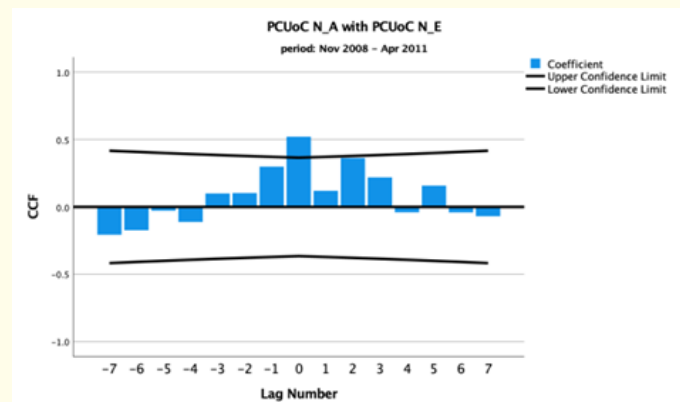
In figure 3 we compare the natural logarithm of the bipolar disorder patient admissions with the natural logarithm of small ($M \geq 2$) earthquakes for a period before and another period after the giant M9.1 2011 Japan earthquake. In particular we fitted linear lines between the $\ln(N_{BIP})$ versus $\ln(N_E)$ (drawing done by manual merging of 4) for the time interval November 2008-April 2011 (Period P-I) and, between May 2011-December 2012 (Period P-II). We see that both the rate N_{BIP} of bipolar disorder patient admissions and the number N_E of small ($M \geq 2$) earthquakes significantly increase after May 2011. The mean monthly values $\langle N_E \rangle$ and $\langle N_{BIP} \rangle$ in the Crete area were evaluated to be $\langle N_E \rangle = 374.5$ (s.d = 144) and $\langle N_{BIP} \rangle = 9.5$ (s.d. = 2.46) after the Japan earthquake (Period II) versus $\langle N_E \rangle = 188.5$ (s.d = 67.5) and $\langle N_{BIP} \rangle = 6$ (s.d. = 3) before the EQ (Period I). We see that the mean monthly number of earthquakes in the Crete area increased by a factor as high as 2 after the 2011 Tōhoku Japan earthquake, while the mean monthly of bipolar disorder patient admissions by a factor ~ 1.6 . We hypothesize that the smaller increasing factor in the bipolar disorder patient admissions ($n = 1.6$) compared to that of the mean monthly number of earthquakes ($n = 2$) is related to the much variable profile of seismic activity during Period II (s.d = 144 in P-II versus s.d = 67.5 during P-I). It is also worth noting that N_{BIP} and N_E present weaker slopes, which are not significant, between May 2011-December 2012 (P-II) (upper line $\beta = 0.009$, $p = 0.495$ and lower line $\beta = 0.012$, $p = 0.333$) than during the time interval November 2008-April 2011 (P-I) (upper line $\beta = 0.036$, $p = 0.003$ and lower line $\beta = 0.033$, $p < 0.001$), which are very significant.



(a)



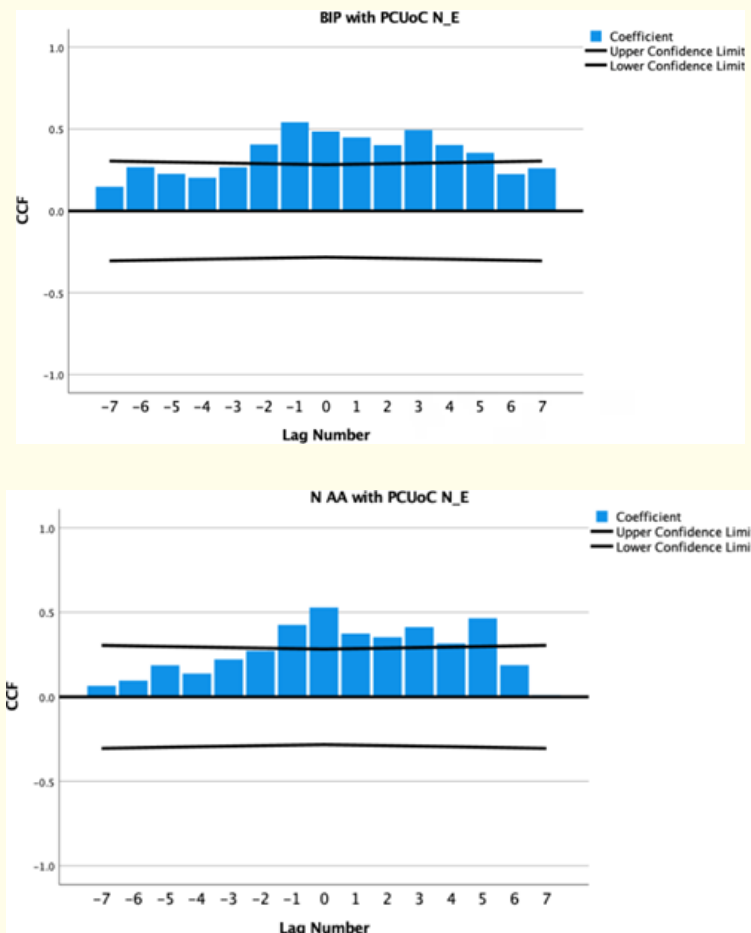
(b)



(c)

Figure 4: Estimated cross-correlation coefficients and associated 95% confidence intervals for the period November 2008 - April 2011 between the number of earthquakes of magnitude $M \geq 2 N_E$ and the monthly admission rates: (a) NBIP for the bipolar disorder patients, (b) N_{AA} for the total "acute" admissions (patients diagnosed with bipolar disorder and schizophrenia, admitted in the acute ward) and (c) NA for the total admissions to IPU/UoC (PCUoC), Greece (patients diagnosed with bipolar disorder and schizophrenia, admitted in the acute and the short stay wards).

Figure 4 shows the estimated cross-correlation coefficients and associated 95% confidence intervals for lags $k = 0, \pm 1, \pm 2, \dots, \pm 7$ between monthly admission rates for bipolar disorder patients to IPU/UoC (PCUoC in figure 4) N_{BIP} and the number of earthquakes of magnitude $M \geq 2 N_E$ for the period November 2008-April 2011. More details about the method of estimating the cross-correlation coefficient and the calculated 95% confidence intervals are given in [43]. We see that the highest correlation occurred ($r = 0.539$, $p = 0.002$) at zero time lag ($k=0$), although significant correlations above the 95% confidence levels are also seen at lags with $k = +1, +2$ and $+5$. Figure 4b is similar to figure 4a, but for the total acute admissions (patients diagnosed with bipolar disorder and schizophrenia admitted in the acute ward) in the same time interval (when in general microseismicity prevailed in Greece), in contrast to the period February-July 2008, when an unusual storm of great earthquakes occurred in Greece [21,25]. Figure 4b reveals a high correlation between N_{AA} and N_E at zero time lag ($r = 0.579$, $p < 0.001$). There are also significant correlations above the 95% confidence intervals at lags with $k = -1$ and $+2$. Finally, figure 4c is similar to figure 4a, but for the total admissions to IPU/UoC, Greece (patients diagnosed with bipolar disorder and schizophrenia admitted to the acute and the short stay wards). Figure 4c shows the highest correlation ($r = 0.521$, $p = 0.003$) at zero time lag ($k=0$). There exists a significant correlation at lag $k = +2$ as well.



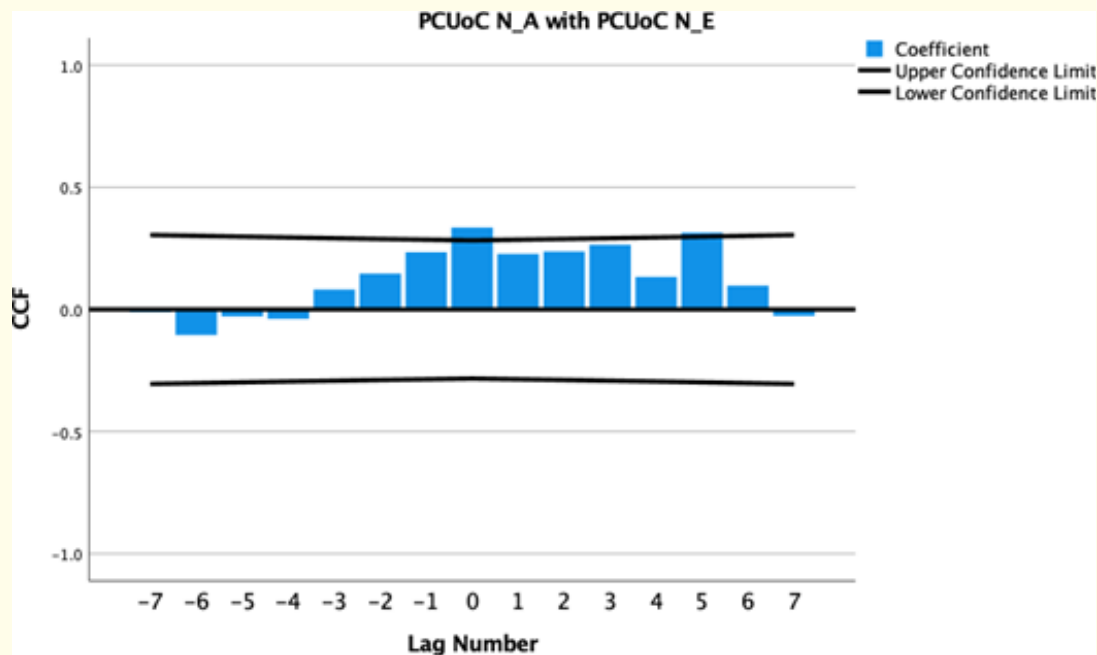


Figure 5: This is similar to figure 4, but including the whole period from November 2008 to December 2012. The estimated cross-correlation coefficients for the bipolar disorder patients and the total acute admissions are significant over seven months, which are much wider than the profiles shown by the bipolar disorder patients and total acute admissions presented in figure 4.

Figure 5a shows the estimated cross-correlation coefficients and associated 95% confidence intervals for lags $k=0, \pm 1, \pm 2, \dots, \pm 7$ between monthly admission rates for bipolar disorder patients to IPU/UoC (PCUoC in figure 5) and the number of earthquakes of magnitude $M \geq 2 N_E$ for the period November 2008-December 2012. It is apparent that there is a high correlation at zero time lag ($k=0$) ($r = 0.485$, $p < 0.001$). Other significant correlations above the 95% confidence intervals exist at lags $k = -2, -1, +1, +2, +3, +4$ and $+5$. Figure 5b is similar to figure 5a, but for the total acute admissions in the same time interval. It is clear that there is a high correlation at zero time lag ($k=0$) ($r = 0.529$, $p < 0.001$). Finally, figure 5c is similar to figure 5a, but for the total admissions to IPU/UoC, Greece in the same time interval. Figure 5c shows the highest correlation ($r = 0.336$, $p = 0.017$) at zero time lag ($k = 0$). There is a significant correlation at $k = +5$.

Special seismological characteristics in Greece between May - December 2011

From the comparison of figure 4 and 5 we see that there is an obvious spreading of seven months (high significant correlations) in the lag of N_{BIP} against N_E during 2010-2012, in contrast to the period November 2008 - April 2011, where there are only three or four significant correlations.

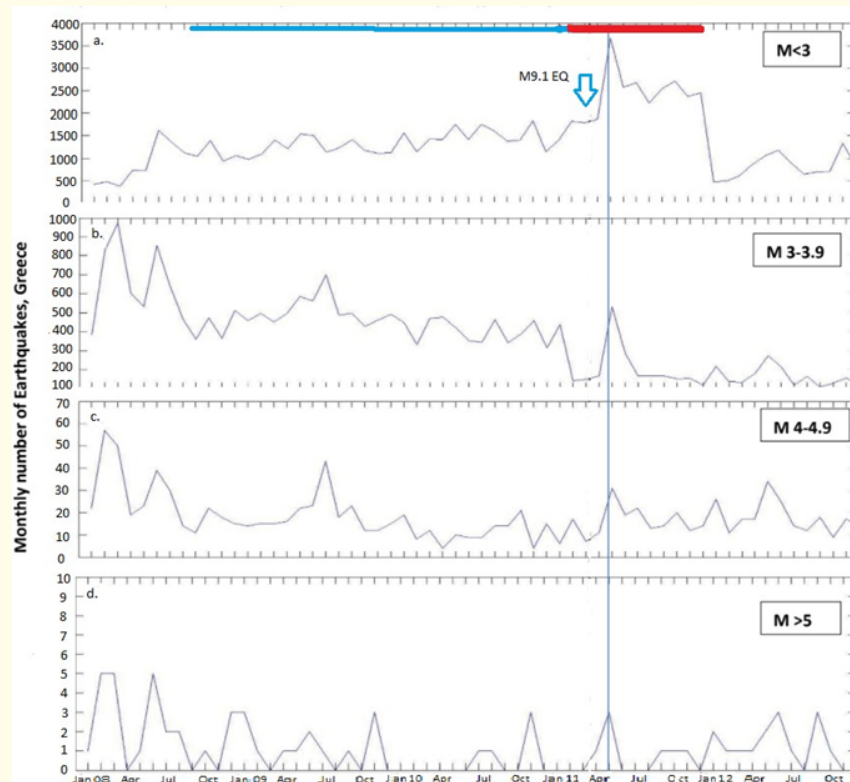


Figure 6: The number of EQs NE in and around Greece in four successive ranges of magnitude M . Different seismological patterns can be seen during the time period February-December 2011 - January 2012 (P2: blue horizontal line) compared to the previous one, from August 2008 to February 2011 (P1: red horizontal line).

In figure 6 we display the number of EQs in a large area including Greece ($19^{\circ} \leq \theta \leq 32^{\circ}$, $31^{\circ} \leq \varphi \leq 46^{\circ}$) in four successive ranges of magnitude M , that is $M < 3$, $3 \leq M \leq 3.9$, $4 \leq M \leq 4.9$, $M > 5$ (panels a-d). The normal blue line in figure 6 indicates an enhanced microseismicity starting in May 2011 ($M < 3$; panel a), which remained at very high levels until at least January 2012 (panel a). Since on March 11, 2011 the giant M9.1 Japan earthquake occurred, the question is whether this long duration increased microseismicity in and near Crete was a normal local intrinsic phenomenon or a remotely triggered effect of the March 11, 2011 Japan earthquake. This is an interesting query, because if the second case is true, then increased admissions of patients with bipolar disorder might be expected in remote seismogenic regions after a giant earthquake, due to remotely triggered small earthquakes.

In order to check this possibility, in figure 6 we compare the number of earthquakes of various magnitudes in and around Greece (panels a-d) during a 5-year time interval, from January 2008 to December 2012. We can easily see that during the time period February/ March - December 2011/January 2012 (P2: blue horizontal line) the seismicity appears different features compared to the previous one, that is from August 2008 to February 2011 (P1: red horizontal line). In particular: (i) During P2 the monthly number of very small ($M < 3$)

EQs $N_{M<3}$ gradually increase from February to May 2011 by a factor of 2.5, that is from a level of a monthly number of ~ 1500 EQs during P1 to a number of 3750 EQs in May 2011 and remains at a high level of ~ 2500 EQs by the end of 2011 (panel a). At the same time interval the monthly number of EQs in the magnitude range $3 \leq M < 3.9$ decreased, in general, by a factor of 3, that is from ~ 450 to a level as low as ~ 150 EQs (except for the months of May and June). (ii) A peak in the number of earthquakes of all magnitudes was recorded in May 2011 (panels a-d), (iii) The frequency of strong ($M \geq 4$) earthquakes in panels c and d show a similar profile all the time from September 2008 to December 2012 and, consequently, does not follow any similar pattern change as in the small EQs in the range $M < 3$ and $3 \leq M < 3.9$ (panels b and c); the time period with a “storm of earthquakes” of high magnitudes between February - July 2008 was a phenomenon of local origin, according to the relative scientific literature [Papadopoulos, 2009], and (iv) Three earthquakes with magnitude $M > 5$ occurred in May 2011 along with the increase of the number of smaller EQs.

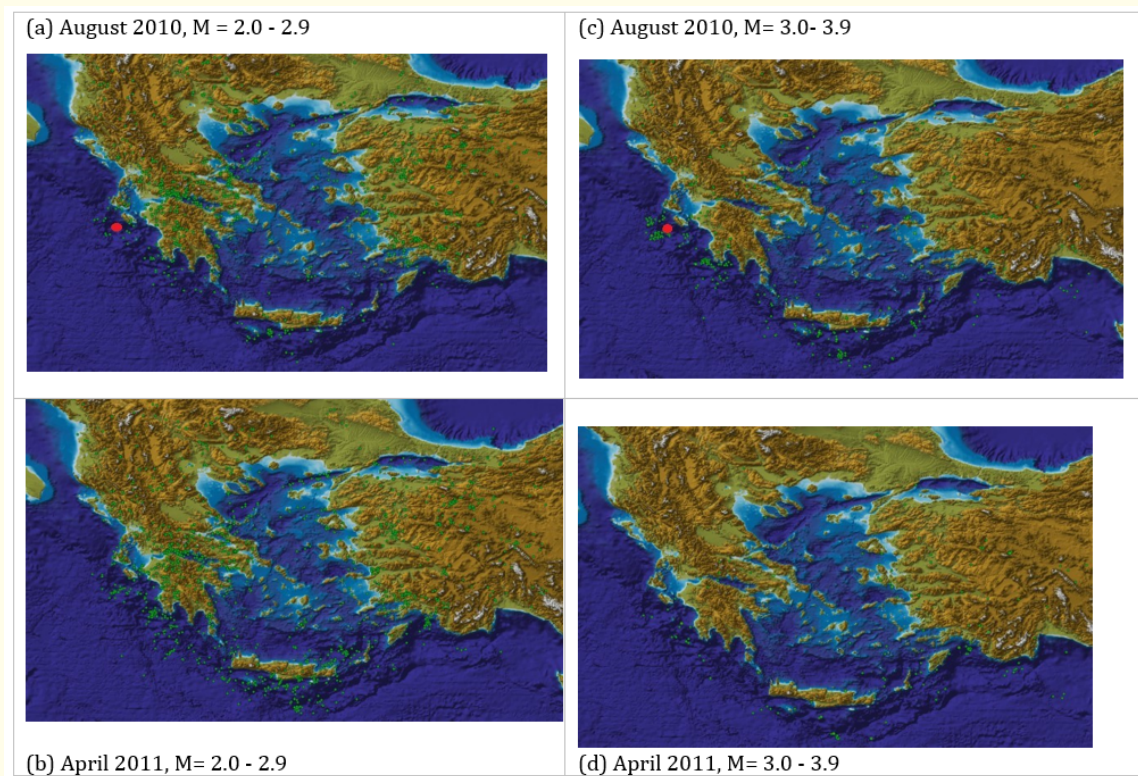


Figure 7: Distribution of earthquake epicenters (green solid circles) in a region including Greece, for August 2010 and April 2011 and in two successive earthquake magnitude ranges: (a) August 2010, $M = 2.0 - 2.9$, (b) April 2011, $M = 2.0 - 2.9$, (c) August 2010, $M = 3.0 - 3.9$ and (d) April 2011, $M = 3.0 - 3.9$. The number of very small earthquakes ($M = 2.0 - 2.9$) increases and the number of small ($M = 3.0 - 3.9$) earthquakes decreases in April 2011 compared to the earthquakes which occurred in August 2010. This change reflects a different seismological pattern in Greece after the March 2011 M9.1 Japan earthquake, in comparison with the pattern found in previous times (November 2008 - March 2011).

Figure 7 displays representative geographical distribution of earthquake epicenters in the region considered in Figure 6 before and after the March 2011 M9.1 Japan earthquake. In particular, earthquake distribution is presented for August 2010 and April 2011 in two successive earthquake magnitude ranges: (a) August 2010, $M = 2.0 - 2.9$, (b) April 2011, $M = 2.0 - 2.9$, (c) August 2010, $M = 3.0 - 3.9$ and (d) April 2011, $M = 3.0 - 3.9$. An inspection in figure 7 reveals a different seismological pattern in Greece after the March 2011 M9.1 Japan earthquake, in comparison with the pattern found in previous times (November 2008 - March 2011). It is evident that the number of very small earthquakes ($M = 2.0 - 2.9$) increases and the number of small ($M = 3.0 - 3.9$) earthquakes decreases in April 2011 compared to the earthquakes occurred in August 2010.

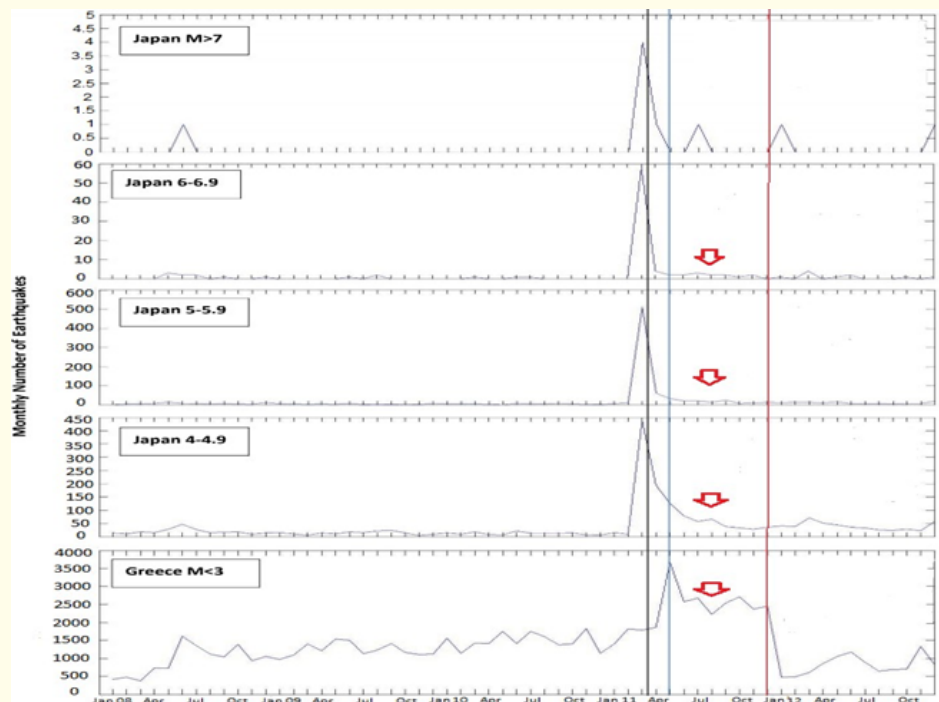


Figure 8: The number of EQs in Japan in four successive magnitude with $M \geq 4$ in Japan (panels a-d) compared to the number of small ($M < 3$) EQs in Greece (panel e). The monthly number of very small ($M < 3$) EQs in Greece increased highly after two months from the M9.1 Japan earthquake and its subsequent strong earthquake activity by the end of 2011.

In figure 8 we compare the number of great EQs in Japan with the small earthquakes in and around Greece, as in figure 6. In particular, we compare the number of great EQs in Japan in four successive earthquake magnitude ranges, that is between $4 \leq M \leq 4.9$, $5 \leq M \leq 5.9$, $6 \leq M \leq 6.9$ and $M > 7$ (panels a-d) with the number of $M < 3$ EQs in Greece (panel e; as in panel d of figure 4). From figure 5 we see (i) A distinct peak in the number of great EQs in Japan during March and April, (ii) Aftershocks with magnitudes 4-6.9 in Japan until at least the end of 2011, (iii) A two-month delay of the peak of small EQs in Greece compared to the peak in N_E in Japan, (iv) An increase in N_E in both the large EQs in Japan (panels a-c) and of small EQs in Greece (panel e) during the whole period May-December 2012.

Summary and Discussion

Seismic waves from large earthquakes have been shown to trigger seismicity in large distances from a main shock, and this is termed remotely or dynamically triggered seismicity. This phenomenon has already been discussed in the introduction. Several investigators used seismograms from global seismic networks and an event catalogue confirmed that (i) earthquakes and tremors instantaneously triggered during the passing of the seismic waves, as well as (ii) statistically significant changes in global seismic rates after the passing of the waves.

Potential cases of instantaneous triggering of the giant M9.1 March 2011 Japan earthquake were reported in the United States, Russia, China, Ecuador and Mexico, while evidence of tremors triggering was found in Taiwan, Armenia, Cuba and the United States. In addition, a potential case of delayed triggering of larger magnitude earthquakes (including a M5.2) was reported for Baja California, Mexico [39]. In general, large earthquakes may dynamically cause “remotely triggered events” elsewhere [36], while, in particular, [39] confirmed earthquake triggering in the United States, Russia, China, Ecuador and Mexico, Taiwan, Cuba, United States and Armenia after the 2011, M9.0, Tohoku-Oki, Japan catastrophic earthquake.

In the present study we extend our previous findings on the relation between the rate of bipolar disorder patients admissions in the Psychiatric Inpatient Unit of the University of Crete (IUP/UoC) N_{BIP} and small ($M \geq 2$) earthquake rate N_E [14,17,20] from a 3-year time interval (2008- 2010) to a 5-year interval (2008-2012), which includes the time of the giant and catastrophic M9.1 March 2011, Tohoku-Oki, Japan, earthquake.

The data we presented in figure 6 and 7 provided us with the opportunity to extract significant information on the presence of small earthquakes in the territory of Greece and in particular in the region surrounding the island of Crete associated with great earthquakes in Japan, which followed the giant M9.1, Japan 2011 EQ.

The main result from the extension of our previous studies from a 3-year time interval to a 5-year interval was rather to be expected on the basis of our previous results [21,24,25]. We found that the level of bipolar disorder patients admission number N_{BIP} in Crete followed the increase of the $N_{E\text{ level}}$; i.e. time interval May-December 2012 (P-II) compared to the time period from November 2008 to April 2011 (P-I).

The second novel finding of the present study is that the seismological profile of Crete/Greece was different during P-II to during P-I. In particular, the seismological data suggest that during the time period May-December 2012 seismicity appeared different features in Greece compared to the previous one (from November 2008 to February 2011). The fact that the monthly number of very small ($M < 3$) EQs increased, whereas the monthly number of EQs in the magnitude range $3 \leq M < 3.9$, in general, decreased in Greece during the time period May- December 2012, while an enhanced activity in great EQs was in process in Japan strongly supports the hypothesis of a dynamically triggered seismicity with its origin in Japan after the giant M9.1, Tohoku-Oki, March 2011 EQ. The remote triggered small EQs in Greece, after the Japan 2011 giant EQ, are consistent with the reports that remote triggered effects were recorded almost over the whole planet, including the United States, Russia, China, Ecuador and Mexico [39].

The third characteristic finding of our present study is that the correlation between the monthly number of admissions of patients with bipolar disorder N_{BIP} and the monthly number of small (i.e. $M \geq 2$) earthquakes N_E in Crete do not show the same peak-to-peak pattern during P-I and P-II (Figure 1, 4 and 5); the cross correlation results between N_{BIP} and N_E show the highest correlation at zero time lag ($k=0$) during P-I but not during P-II (Compare figure 4 with figure 5). The correlation coefficients between N_{BIP} and N_E are significant (values are outside the 95% confidence interval) during time interval May-December 2012 at zero time lag ($k = 0$), as in P-I, but also at

lags with $k = -2, -1, +1, +2, +3, +4$ and $+5$ as well. Given that our daily analysis in summer 2010 demonstrated a 2-day delay of the acute mental disorder (bipolar and schizophrenia) admission rate with the small earthquake rate and the ULF radiated energy [17], the lag of some months between N_{BIP} and N_E during P-II definitely suggests the existence of two different patterns of seismicity - bipolar disorder relationship. We believe that the destruction of the picture of a very short time influence of the microseismicity-induced ULF EM radiating energy to the bipolar disorder patients during P-II is due to the distant sources radiating ULF energy. This phenomenon most probably was caused by "remotely triggered events" following the Japan 2011 high seismicity affecting the population in Crete from great distances.

Finally, we can infer that the positive correlation between the monthly admissions to the IPU/UoC in Crete, Greece, and the monthly number of earthquakes, between November 2008 - December 2012, reflects the influence of both the locally intrinsic microseismicity at the boundary of the Eurasian and the African tectonic plates (and the whole Greek territory) and the remotely triggered microseismicity (due to a series of great EQs following the giant M9.1, Tohoku-Oki, Japan 2011 EQ) on human bipolar disorders.

Conclusion

In the present paper we extended our previous work [21,24,25] based on three-year data (2008 - 2010) to a five-year study, i.e. from the year 2008 to the year 2012. In our previous studies we have demonstrated that the rate NBIP of bipolar disorder patient admissions to the Psychiatric Inpatient Unit of the University of Crete (IPU/UoC), were strongly related to the number of small earthquakes N_E , between the years 2008 - 2010, due to Ultra Low Frequency (ULF) waves radiating at the Hellenic arc, which is the boundary of the Eurasian and African tectonic plates. The ULF radiation is a characteristic feature of small earthquakes. However, we did confirm a correlation of the number of small EQs with the admission number of patients with bipolar disorder (and schizophrenia) and the ULF radiation recorded above Crete detected by the satellite DEMETER. This check was done by using daily averaged data in both the rate of bipolar and schizophrenia disorder patient admissions to the IPU/UoC, during the time period June to August 2010. The comparison of the three time series has shown a time delay of 2 days between the temporal profile of the admission number of patients and both the number of small EQs and the ULF radiation [24].

Our present data analysis suggests that the Greek seismological features changed from two months after the March 11, 2011 giant M9.1 earthquake throughout the end of 2011, while at the same time period great ($M < 6.9$ and some $M > 7$) earthquakes continued to occur in Japan. This characteristic change along with our results in [21] suggest that we can recognize three intervals with different seismological characteristics in Greece and corresponding differentiation in the rate of admissions of patients to IPU/UoC, Heraklion, Greece, during the 5-year time period 2008 - 2012.

The effect of electromagnetic Ultra Low Frequency/Extra Low Frequency radiation on patients with mental disorders and especially mood disorders has been previously demonstrated by many studies. However, underlying mechanisms explaining these associations are still unexplored. Several theories have attempted to explain these associations. Studies have reported that electromagnetic radiation affects neurotransmitter release and activity in neural synapses [44,45]. Furthermore, more recently Ultra Low Frequency/ Extra Low Frequency radiation has been related to having an effect on specific brain structures, such as the pineal gland, reducing melatonin secretion, which in turn modifies the secretion of neurotransmitters such as serotonin and dopamine in other cortical and limbic areas of the brain associated with hallucinations [46-49]. Furthermore, other studies have related electromagnetic radiation to changes in the hypothalamus, a significant brain area for the regulation of energy homeostasis and circadian rhythms [50]. Finally, electromagnetic fields appear to be associated with structural changes in hippocampus and mammillary bodies, parts of the limbic area, and principal brain structures involved with mood and behavior regulation [51-54].

In our present study we argued that the enhanced number of small earthquakes in Greece during the period May - December 2012 were “remotely triggered events” caused by great earthquakes in Japan.

Furthermore, we demonstrated that at the same time interval (May - December 2012) with the highly enhanced microseismicity, the rate N_{BIP} of bipolar disorder patient admissions to IPU/UoC increased (Figure 1, time interval A), as in the case of three other major time intervals (B, C, D), which were examined in detail in our previous works [21,25].

Furthermore, the comparison of N_{BIP} and N_E continues to show a strong correlation ($r = 0.559$, $p < 0.001$) during the whole time period 2008 - 2012, as during the shorter time period 2008 - 2010 ($r = 0.703$, $p < 0.001$). It is worth noting that, when the monthly admissions to the Acute Care Unit of the IPU/UoC N_{BIP} was compared with the monthly number of earthquakes N_E during the time period 2008-2012, a stronger and significant correlation was found ($r = 0.722$, $p < 0.001$).

We note that the novel result of the present study is that we found a good observational evidence that, besides the almost continuous intrinsic local microseismicity at the Hellenic arc, the boundary of the Eurasian and the African plates as well as a remotely triggered microseismicity by the Japan 2011 giant earthquake and its aftershocks significantly affected, albeit with a different pattern, the frequency of bipolar disorder relapses in Crete (during the examined time period 2008 - 2012).

Although additional tests should be done to further check the possible increase of bipolar disorders in Crete as well as in other highly seismological regions all over the globe, the present study may suggest that some special (i.e. electromagnetic) protection for bipolar patients could be addressed, planned and performed in seismological regions like Crete, which are remotely affected by distant giant earthquakes for several significant time intervals (probably some days/months) after their occurrences. A further investigation of the possible prediction of environmental conditions which affect patients with bipolar disorder, at least in active seismological regions, may provide a better quality of life for a significant part of the general population. It would be also very important to proceed with brain's electromagnetic investigation (EMG) in mentally healthy people and in patient suffered from bipolar disorders in correlation with the distance from the main seismic locus and the local geomagnetic activity.

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