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# *Interactive comment on* "Signatures of the self-affinity of fracture and faulting in pre-seismic electromagnetic emissions" *by* S. M. Potirakis et al.

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Dear Referee 2,

First of all thank you for agreeing to review our article and for your efforts in doing so. Thank you also for being very clear in declaring that your background is on environmental time series analysis; this is probably the reason why your review isn't taking into account the particularities of kHz pre-seismic electromagnetic emissions time series, which are different from what is usual for environmental time series analysis. Moreover, probably due to the same reason, we are not sure of what you really mean and how should we reply to most of your comments and suggestions. Our analysis refers to

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a set of dynamic nonlinear processes which are relevantly fast changing in time (total duration is of the order of hours, or tens of hours). Finally, we are not sure of what do you mean by “precursor” and “activity”; it seems you separate our signal into two parts, the “precursor” and the “activity”, while our claim is that the whole signal (after the vertical broken green line) is a candidate precursor and the vertical broken red line just signifies that there are two phases (two epochs) in the specific signal, each one representing a different nonlinear process.

However, we will give short replies to all your comments:

General remarks:

You are talking about “the argument” throughout your review, but it is not clear to us what do you mean. In our manuscript you can find a number of different arguments referring to different issues. So it is not clear which of the arguments do you mean each time. Moreover, you should keep in mind that we are referring to just the kHz fracture-induced electromagnetic emissions (EMEs) and not both on MHz and kHz EMEs which were recorded prior to the Athens EQ, while, in addition, it should be noted that there is a long list of past papers in which we have analyzed in depth the Athens EQ MHz and kHz EMEs.

Given the opportunity, we would like to clarify that the validity of the fracture-induced electromagnetic emissions (EME) is checked in two ways:

The first condition is that strict criteria have to be satisfied before the classification of an emerged EME anomaly as a possibly EQ-related one by investigating for the existence of specific EQ-compatible features embedded in it. These features are summarized through a proposed four stages model for the preparation of an EQ by means of its observable EME activity, which has been recently put forward (please see the following papers:

Eftaxias, K. and Potirakis, S. M.: Current challenges for pre-earthquake electromag-



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netic emissions: shedding light from micro-scale plastic flow, granular packings, phase transitions and self-affinity notion of fracture process, Nonlin. Processes Geophys., 20, 771–792, doi:10.5194/npg-20-771-2013, 2013;

Eftaxias, K., Potirakis, S. M., and Chelidze, T.: On the puzzling feature of the silence of precursory electromagnetic emissions, Nat. Hazards Earth Syst. Sci., 13, 2381–2397, doi:10.5194/nhess-13-2381-2013, 2013;

Y. Contoyiannis, S.M. Potirakis, K. Eftaxias, L. Contoyianni: Tricritical crossover in earthquake preparation by analyzing preseismic electromagnetic emissions, Journal of Geodynamics, 84, 40-54, 2015, doi: 10.1016/j.jog.2014.09.015;

Donner, R. V., Potirakis, S. M., Balasis, G., Eftaxias, K., and Kurths, J.: Temporal correlation patterns in pre-seismic electromagnetic emissions reveal distinct complexity profiles prior to major earthquakes, Phys. Chem. Earth, 85/86, 44–55, 2015;

S. M. Potirakis, Y. Contoyiannis, N. S. Melis, J. Kopanas, G. Antonopoulos, G. Balasis, C. Kontoes, C. Nomicos, K. Eftaxias: Recent seismic activity at Cephalonia (Greece): a study through candidate electromagnetic precursors in terms of non-linear dynamics, Nonlin. Processes Geophys., 23, 223-240, 2016, doi: 10.5194/npg-23-223-2016).

In summary, the proposed four stages of the last part of the EQ preparation process and the corresponding EME observations, for which specific features have been identified using appropriate time-series analysis methods, appear in the following order: first stage: valid MHz anomaly; second stage: kHz anomaly exhibiting tricritical characteristics; third stage: strong avalanche-like kHz anomaly; fourth stage: electromagnetic quiescence. It is noted that, according to the aforementioned four-stage model, the pre-EQ MHz EME is considered to be emitted during the fracture of a part of the Earth's crust that is characterized by high heterogeneity. During this phase the fracture is non-directional and spans a large area that surrounds the family of large high-strength entities distributed along the fault sustaining the system. Note that for an EQ of magnitude approximately 6, the corresponding fracture process extends to a radius of approximately 120 km. The specific signal features that define a valid MHz anomaly or a valid strong avalanche-like kHz anomaly have been described in detail in the above mentioned papers. Please note that in the case of the EME observed prior to the Athens EQ (the kHz part of those EME are analyzed in the submitted paper), all the above requirements are fulfilled.

The second condition is that a sequence of MHz and kHz EMEs which emerge one after the other within a short time interval and each of them fulfills the criteria set within the above mentioned four-stage model should also be in consistency with other seismogenic precursors, before being classified as possibly EQ-related. Please note that this also happens for the EME observed prior to the Athens EQ (the kHz part of those EME are analyzed in the submitted paper).

Specific remarks, replies to corresponding Referee 2 comments:

(A) It is not clear to us what do you mean by hypothesis testing or why so long time series (you suggest 200 days) is necessary. Please, take into account two facts: first Greece is a highly active region in terms of geodynamics and more than one significant EQs are usually reported during a year, or even during a three months' time, and second it has been proven that our Zante observatory is sensitive to EQ preparation processes happening all over Greece, even in Italy. Please also note that in the meantime (from the time we submitted the specific paper, in 2014, and now), we have published an article which performs an analysis on an 123 days long excerpt of the same 10 kHz recording (Kalimeris, S. M. Potirakis, K. Eftaxias, G. Antonopoulos, J. Kopanas, C. Nomikos, Multi-spectral detection of statistically significant components in pre-seismic electromagnetic emissions related with Athens 1999, M = 5.9 earthquake, Journal of Applied Geophysics, 128, 41–57, 2016, doi:10.1016/j.jappgeo.2016.03.002.). Most of this article deals with spectral analysis based on a hypothesis testing, while an R/S analysis is also provided. Even in this article, no hypothesis testing is done in the R/S analysis case, since we perform a running-window analysis on successive non-overlapping 3000 samples long windows. When we perform a running window analysis, the objective is to evaluate the temporal evolution of persistence, fractal characteristics and complexity, dependent on the calculated signal characteristic. During seismically "quiet" periods, i.e., having a time distance of a few weeks from a main EQ event, these signal characteristics are clearly very different to the ones detected in the presented signal a few days prior to the main event, in the part we call a candidate precursor. Even if an anomaly was detected earlier this wouldn't be related to the specific main EQ; it would be probably related to another EQ that was preparing earlier. We have repeatedly clarified in our past papers that kHz anomalies related to EQ preparation appear a few days (up to -about- a week) before the EQ occurrence. Therefore, although we could perform the analysis for 200 days, we consider that the here presented part of the signal is enough to demonstrate the difference between a "quiet" electromagnetic recording and a recording carrying information related to EQ preparation processes.

Again, we cannot understand your point about "precursor" and "activity" (or "A" and "B"). The whole signal (after the vertical broken green line) is a candidate precursor and the vertical broken red line just signifies that there are two phases (two epochs) in the specific signal, each one representing a different nonlinear process. If you mean these two phases, then we have to clarify that these two phases are not always observed and this is dependent on the geological structure of the region where the EQ preparation process takes place (please see Y. Contoyiannis, S.M. Potirakis, K. Eftaxias, L. Contoyianni, "Tricritical crossover in earthquake preparation by analyzing preseismic electromagnetic emissions", Journal of Geodynamics, 84, 40-54, 2015, doi: 10.1016/j.jog.2014.09.015, and references therein). Nevertheless in all cases that both of them have been identified, they appear in the specific order.

(B) We understand your point, in a possible revision we should probably re-write some parts in simpler words and we should probably add more details in some other parts to make our article more easy-to-read for non-experts. However, we have no indication from you which parts were more difficult to follow; indicating us specific difficult-to-follow parts of the manuscript would greatly help us revise. Moreover, we don't understand what do you mean by “the argument”, or by “It is fine to have some of the analyses as ‘see ***’ so long as these actually allow one to work from data to methods to results.”, what do these asterisks stand for? Was it caused by reformatting of your text in copy-pasting to the online form? What did you intent to tell us?

(C) We could describe the way the recordings are done, although it has been presented in many of our past papers, and determine the uncertainty involved in our measurements. Specifically concerning the measurement accuracy we cannot see how would this information help. We consider this uncertainty as a “noise” contributing to the background noise inherent in our measurements. Actually, this “noise” is orders of magnitude lower in amplitude compared to the received electromagnetic background noise (man-made or from natural sources) at the location of the field experimental station. Details on the above issues can be found in the supplementary downloadable material available with our article “S. M. Potirakis, Y. Contoyiannis, K. Eftaxias, G. Koulouras, and C. Nomicos: Recent Field Observations Indicating an Earth System in Critical Condition Before the Occurrence of a Significant Earthquake, IEEE Geoscience and Remote Sensing Letters, 12(3), 631-635, 2015, doi: 10.1109/LGRS.2014.2354374.”

(D) We are aware of the drawbacks of the R/S and you are right we should mention them in a possible revision. However, please note that we employed R/S analysis because it is the only way to directly estimate Hurst exponent, without any model hypothesis for the data. The main reason was to prove that the candidate precursor follows the fBm model, by demonstrating that a direct estimation of Hurst exponent through the R/S method and an indirect estimation through the DFA method under the fBm hypothesis, and the spectral power law method under the fBm hypothesis, all lead to similar values, consistent to each other.

(E) We are also aware of the weak points of DFA and you are again right, we should mention them in a possible revision. However, we have seen that calculation of higher orders of DFA for the specific signal lead to similar results, and we should also mention that. Regarding the benchmarking you mention, first, there is no specific model describing the whole length of the analyzed data. You know that in the fBm time series case, for example, the employed methods provide different estimates depending on the value of Hurst exponent, but in our analysis the data are not characterized by a single Hurst exponent value. The data before the vertical broken green line, are background electromagnetic noise and there is no certainty if they can be described by a specific fBm model, the data between the vertical broken green line and the vertical broken red line are anti-persistent fBm, the data between the vertical broken red line and just before the occurrence of the EQ (these two strong EM bursts) are persistend fBm, and after those bursts we are not again sure if the time series can be described by an fBm model. Second, the focus of our paper is not on the (details of) use of different analysis methods and we consider that such a benchmarking analysis, if it was possible to be performed, would not only lengthen our paper but also defocus our paper.

(F) It would be easy, in a possible revision, to show some examples of the fits and include information about the details of the analysis (window length etc. in the figure captions). We didn't do it in the first version in order not to lengthen our paper.

All minor remarks could easily be covered in a possible revision.

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