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Discussions

# *Interactive comment on* "Short-term volcano-tectonic earthquake forecasts based on a MRT algorithm: the El Hierro seismo-volcanic crisis experience" *by* A. García et al.

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The authors are most grateful to the reviewer for his suggestions and recommendations that have greatly helped to improve our manuscript. Below, we have addressed (in normal typeface) all of the reviewer's comments (in italics).



## 1 Open Discussion

### 1.1 Response to reviewer 2, anonymous

Number: nhess-2015-273-RC2

### 1.2 General Comments

*First of all, please accept my apologies for being a bit late. In my opinion, in this paper there is a major problem, that makes the present results completely unreliable.*

The major problem pointed out by the reviewer is related to the apparent use of an inadequate method to calculate the Gutenberg-Richter parameters, i.e., using a Least-squares Regression Estimator, LRE) instead of a Maximum Likelihood Estimator (MLE). We would agree with the reviewer if the submitted results had been obtained with the LRE method. However, as we explain in detail in the following sections, we used the MLE to calculate the Gutenberg-Richter parameters (GRP). We indeed recognize our mistake in keeping the reference to the LRE in the original manuscript, which resulted from the real-time development of the algorithm during the seismo-volcanic crisis at El Hierro island. In the initial stages of the unrest we used several methods to calculate the Gutenberg-Richter parameters (GRP) (including the Least-squares Regression Estimator (LRE) and the r-cran libraries as SSLib: http://homepages.maxnet.co.nz/davidharte/SSLib/) to construct the MRT algorithm, obtaining similar results for the warning time-windows. Nevertheless, after testing the stability and efficiency of the different methods, we choose the Maximum Likelihood Estimator (MLE), and implemented a program in gcc C within the continuous monitoring process to automatically calculate the GRP with a Maximum Likelihood Estimator (following the methods of Tinti and Mualrgia, 1987, and Marzocchi and Sandri, 2003). The LRE was tested only at the initial stage of the unrest episode in July 2011. To make this clear, we have modified the manuscript (Section 2.1 in supplement-1) explaining with more detail the development of the algorithm, the test stages, and the procedures to issue the warnings.

1.3 Specific suggestions and comments

*The problem is the use of the Least Squares Regression estimation of the Gutenberg-Richter parameters (GRP), in particular of the b-value. This estimator produces STRONGLY BIASED b-values, and there is no justification in its use for this purpose, as its major assumptions are violated. This problem has been previously recognised and discussed in other papers (Page 1968, Bender 1893), among which one that the authors cite (Marzocchi and Sandri, 2003). In other words, Least Square regression produces fake variations (in space and/or in time) in the b-value, that are not real. Because of this, I cannot trust the results obtained, as they are based on a method to analyse the data that cannot be trusted. Another major problem is how the GRP are determined. If I understand correctly (Line 125) their determination is based on the cumulated form of the GRL. This produces further biases in the results.*

As explained above, we agree with the reviewer's comment on the LRE. We thus deleted the reference to that method in section 2.1. For more clarity we have explicitly included the MLE equations (Eqs. 4 and 5) used in the algorithm. The manuscript has thus been modified from line 158 as follows:

**Lines 163-173 (new supplement)** The MRT algorithm starts a forecast when a swarm of at least 200 earthquakes with M≥1.5 are detected in a time span of 5 days. Then, a completeness magnitude MC is calculated using the Maximum Curvature Method (MCM, Wiemer and Wyss, 2000). The GRP are estimated for each time-window using



a Maximum Likelihood Estimator (MLE) (Peishan et al, 2003; Bengoubou-Valerius and Gibert, 2013). In the final standard-C version of the software, we implemented a fast subroutine based on the equations of Marzocchi and Sandri (2003) to calculate the b-value:

$b = \frac{1}{\ln(10)\Delta M}\ln(p)$ (4)

where

$p = 1 + \frac{\Delta M}{\mu - Mc}$ (5)

and $\mu$ is the sampling average of the magnitudes, *Mc* is the cut-off (threshold) magnitude. We used a magnitude binning interval $\Delta M$ = 0.1.

*I encourage the authors in re-building their algorithm by: 1) using the not-cumulated GRL (that is: N(M) should be the number of events with magnitude equal to M)*

We do not quite agree with this comment. The Gutenberg-Richter law is defined using the cumulative distribution, i.e. with N(M) as the number of events exceeding a magnitude M. It is the standard form used in the international literature, and works well for our purpose. We do not see any reason to use the non-cumulative distribution.

*2) using only the MLE to determine b and a-values (as regards b-value, they can also use Bender 1983, or Tinti and Mulargia 1987, while for the a-value still Bender 1983 offers an option)*

As explained above, that is what we did in the original version. Unfortunately maintaining the remark on the early tests with the Least-squares Regression estimation may have created the impression that we used LRE for calculating the MRT's. We apologize for that. Figures 5 and 6 of the original manuscript (corresponding to figures 6 and 7 of supplement-1) were calculated with the MLE. This has been made explicit in section 2.1 and in the captions of the corrected supplement.

*3) careful checking equation 1 (I do not understand it... Isn't MRT the inverse of N(T)/DeltaT ? If so, I do not understand equation 1. If I misunderstood what MRT is, please explain better) Once these steps are carried out, if the authors still find a significant forecasting ability in their algorithm, I encourage them to re-submit the paper.*

To make the relation between the Gutenberg-Richter and the MRT clearer, we have extended the definition of the MTR in Section 2.1 as follows:

**Lines 130-142 (new supplement)** The Gutenberg-Richter Law (GRL, Gutenberg and Richter, 1944) scales the seismic activity, with respect to its magnitude, as:

$\log_{10}(N(M)) = a - bM$ (1)

where *N(M)* is the number of earthquakes with magnitude *M* or larger detected within a given region, in a certain time interval (Bender, 1983). In a process that remains stationary over a time interval $\Delta T$, the Gutenberg-Richter Parameters (GRP) *a* and *b* remain constant. Here, we use a time-dependent GRP to estimate the Mean-Recurrence-Time (MRT) of volcanic earthquakes having or exceeding given magnitudes, and thus the likelihood of major events occurring in the shorter time-scale



(hours to days). The MRT ($\tau_T$) between events with magnitude equal or greater than *M* may thus be estimated from Equation 1 as:

$N(M) = \frac{\Delta T}{\tau_T} = 10^{(a-bM)}$ (2)

The MRT may thus be calculated as:

$\tau_T = \Delta T \cdot 10^{(bM-a)}$ (3)

With this, we consider that all of the reviewer comments have been properly addressed. We have thus uploaded a corrected version in the supplement section.

Please also note the supplement to this comment:
http://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2015-273/nhess-2015-273-AC2-supplement.pdf

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