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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).

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Discussion paper

1 Open Discussion

1.1 Response to reviewer S.D. Malone

Number: nhess-2015-273-RC1

1.2 General Comments

The rational for this study is very well stated and is convincing. It develops the usefulness of VT forecasting as well as its practicability in a specific volcanic setting and is a significant contribution to the area of operational earthquake forecasting.

1.3 Specific suggestions and comments

The title might be a bit better to include the word "Moving" before MRT and maybe even spell out "Mean Recurrence Time". I don't have strong feelings about this change.

Title. We have changed the title as suggested:

"Short-term volcano-tectonic earthquake forecasts based on a moving Mean-Recurrence-Time algorithm: the El Hierro seismo-volcanic crisis experience"

Introduction

line26: I take exception to the comment about "earthquake forecasting requiring answers to three questions: where, when, and how large?" This sounds more like "earthquake prediction". i.e. a deterministic approach rather than forecasting which MUST include some estimate of the likelihood of the possibly damaging event. Thus, indeed,

"where, when and how large" are important but just as important is "how likely".

Line 26 (new manuscript). We added "how likely" to the questions, as suggested.

Lines 50-54: These statements make it sounds as if forecasting large VT events is significantly different than forecasting an eruption. It seems to me that, while the exact same parameters might not be appropriate in these two cases, they still are never-the-less forecasts of a very similar nature and similarly useful.

Lines 51-53 (new manuscript). We changed the wording to make it more clear that the forecasting works for magma displacements, even if they do not reach the surface.

The previous text: "...nevertheless, this analysis cannot foretell definitively the occurrence of an eruption, as the magma injection and migration process may never reach the surface (Bell and Kilburn, 2012), although an increase in the probability of such an event must be considered".

It has been modified as follows: "...nevertheless, **in some cases** this analysis **may not** foretell the occurrence of an eruption, as the magma injection and migration process **that causes the stress concentration** may never reach the surface (Bell and Kilburn, 2012), although an increase in the probability of such an event must be considered".

2 El Hierro volcanic process

Lines âĹij60-90: I do not find any descriptions here of what VT ie. Volcano-tectonic (sometimes called Type-A) earthquakes are and how they may be different in this case from the more typical pre-eruption earthquakes that are often called low-frequency volcanic earthquakes or "Type-B earthquakes". In this case are ALL earthquakes considered VT events? At what depths do they occur? What is their frequency content? Was there any change in seismogram character just prior to the eruption of winter

2011-2012?

Lines 75-81 (new manuscript). We have added a paragraph describing the characteristics of the VT short-period earthquakes, and a figure (new figure 1) showing the waveforms and spectra of the typical VT shocks used in the analysis. We also explicitly remark that no LP earthquakes have been detected and that the only long-period signal detected was the sustained harmonic tremor caused by the submarine eruption.

The following paragraph has been added: "During the whole episode (2011-2015), only two types of seismicity have been observed: short-period volcano-tectonic (VT) earthquakes, with well-defined P and S phases, and a syn-eruptive long period tremor, patently related to the submarine magma effusion. No long-period (LP) earthquakes have been observed at any time. Here, we analyze the time evolution of the VT earthquakes occurrence rates, as they seem to have similar origins, related to rapid stress concentrations caused by magma intrusions. The VT events do not show significant changes in their waveforms or spectral contents along the duration of the whole episode, as illustrated in Figure 1".

The caption of the new Figure 1 is: "Characteristic VT earthquakes of the El Hierro seismo-volcanic process and their spectra. (A) Event recorded on 2011-09-27, before the eruption, at $\sim$ 6.3 km to the SE of the island center. (B) Event recorded on 2013-12-24, after the eruption at $\sim$ 10.4 km SW of the island center".

lines 145-155: Its not clear if your MRT calculations are based on the energy threshold or the >200 events threshold and if the latter what does the former have to do with anything?

Lines 154-155 (new manuscript). To clear up this ambiguity, we have rephrased the text.

Previous text: "In most cases, the time-window starts running when the cumulative en-

ergy released by a VT swarm reaches the 10^{11}J energy threshold of Yokoyama (1988)".

Modified as: "In most cases **an acceleration of the seismicity occurs** when the cumulative energy released by a VT swarm reaches **a value near** the 10^{11}J energy threshold of Yokoyama (1988)".

lines ∼155: The GRL algorithm explanation seems clear enough though its not clear if it always is run for a delta-T of five days or if once started it uses the previous 200 events. If it is the former, what happens when the number of events in a later 5 day period drops below 200?

Lines 162-164 (new manuscript). We have added two lines explaining that: "If the seismicity rate drops below 200 earthquakes in 5 days, the MRT algorithm would stop running. However, such a situation has never occurred during the El Hierro seismo-volcanic process".

lines ∼169 (Fig 5): Figure 5 of MRT is a great figure and very clear but many people are much more familiar with looking directly at GR plots with a regression line on them. A very useful additional figure might be examples of such plots for a period early in a sequence and one after the MRT drops below 10 days. This would give the reader a much better sense of the nature of the data and how the completeness magnitude might change and possibly influence the resulting a and b parameters.

Lines 177-179 (new manuscript). We have included a reference to another paper in which the alert levels associated to the MRT are described, and its evolution during the whole episode of unrest is plotted. To make more clear this question the following text has been added: "This method has been incorporated into a Volcanic Alert System, (described in García et al. 2014a), where the continuous evolution of the MRT over the whole unrest process is described".

3 Discussion and Conclusions

line âĹij200: Indeed, GRP techniques (or similar seismicity change parameters) have been attempted in many cases of tectonic sequences. The time scaling of short-term (hours-minutes) to long-term (years to decades) is not really the only issue. Rather it seems that orderly evolution patterns either don't occur or are very difficult to see. . . . at any time scale for most tectonic cases. I think your envisioning of the process at El Hierro is absolutely correct in that it is very different in time and spacial scale than most major tectonic systems. It is the superposition of the rapid concentrated magma related stresses on a background stress that makes for the rapid changes in the seismicity characteristics.

Lines 214-214 (new manuscript). We fully agree with your view of concentrated magma-related stresses makes for the rapid changes in the GR parameters. We have slightly changed the text to emphasize such concept.

Previous text: "In contrast, a similar method for tectonic earthquakes would require recognizing orderly evolution patterns of the GRPs over times scales of years to decades, making short-term forecasting non-viable (e.g. Jordan et al, 2011)... We envision the El Hierro process as the result of magma injections causing stress capable of triggering seismic swarms".

Modified text: "We envision the El Hierro process as the result of magma injections causing **rapid** stress **concentrations** capable of triggering seismic swarms".

line 219: Surely your MRT algorithm was not applied in real time to all five cases you illustrate. Certainly you must have had one or 2 sequences to recognize, develop the procedures and set the parameters before it was applied in real time. If not what was the basis for even trying it? Please clarify which ones resulted in a realtime notification. It might also be interesting for a sentence or two about the reaction of public officials

or the public to the notifications. Ie Did the notifications make any difference?

Lines 232-242 (new manuscript) You are absolutely right about this, and we regret not having included that important issue. A new paragraph has been added explaining that it was only during the last two VT crises that formal warnings based on the MRT algorithm were issued to the island authorities and to the Civil Protection officials

The new paragraph: "**It took the initial VT swarm crises to interpret the process and to recognize and develop the procedures and set the parameters of the MRT algorithm, which was first tested during the third crisis, when a significant reduction of the MRT was detected on 2012-06-05. A M4.2 VT earthquake occurred on 2012-07-03. From then on, the MRT algorithm run continuously in the background. It was not until the fourth** crisis that **a** formal warning **was** issued on **2013-03-26 communicating to** the island authorities and to the Civil Protection officials **the increased probability of a M5 earthquake for the following 8 days**, as described in García et al (2014a). **On 2013-03-31 a M4.9 occurred. In the next volcano-tectonic seismic crisis another formal warning was issued on 2013-12-22, communicating the increased probability of an earthquake exceeding M5 in the next 15 days. Further formal warnings were issued daily afterwards also indicating the increased probability of land slides and other eruption. On 2013-12-27, an M5.4 caused numerous landslides (García et al 2014a)**".

In general an excellent and very interesting paper. I do wonder if you know of, or have looked into any other volcano-tectonic situations where this technique could be applied, even in retrospect. Surely there are data from the literature or other published catalogs that you could easily apply your technique to or at least speculate about.

That is indeed a valuable suggestion. However it is not easy to accede to complete data bases of active Volcano-tectonic crises. We feel that it would be beyond the scope of the present paper. The final lines of the paper are an invitation to the interested

readers to apply the algorithm to similar situations.

Please also note the supplement to this comment:
http://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2015-273/nhess-2015-273-AC1-supplement.pdf

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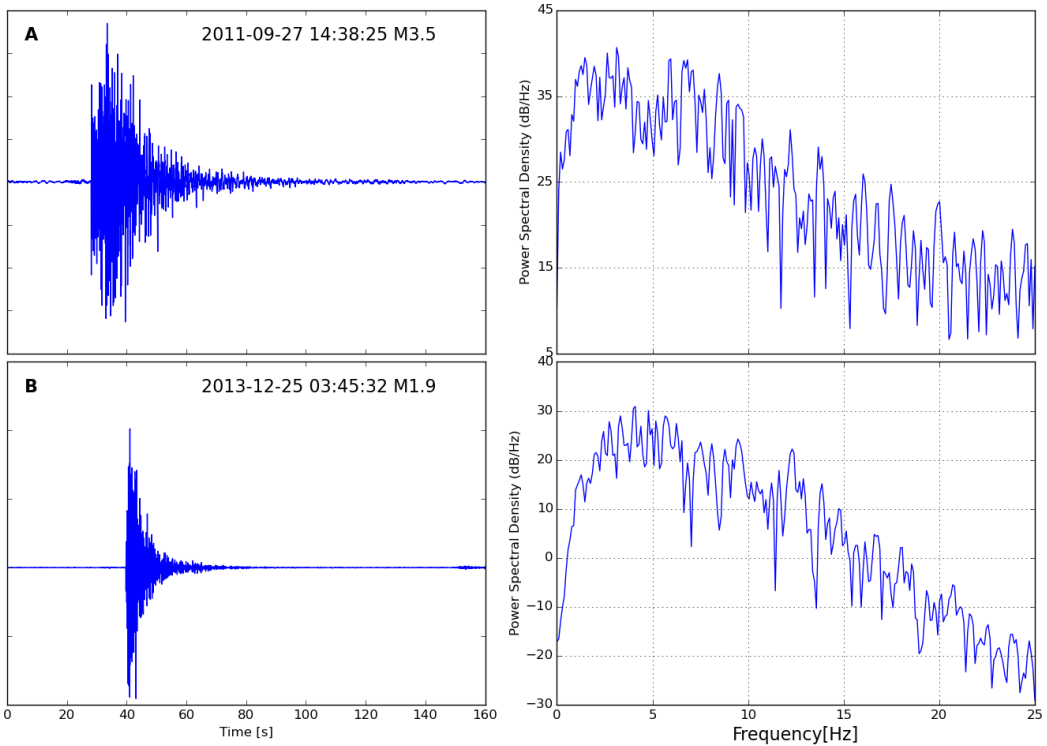

Fig. 1. Characteristic VT earthquakes of the El Hierro seismo-volcanic process and their spectra. (A) Event recorded on 2011-09-27, before the eruption, at $\sim$ 6.3 km to the SE of the island center. (B) Ev

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