Characterizing the Temporal and Spatial Distribution of Earthquake Swarms in the Puerto Rico - Virgin Island Block

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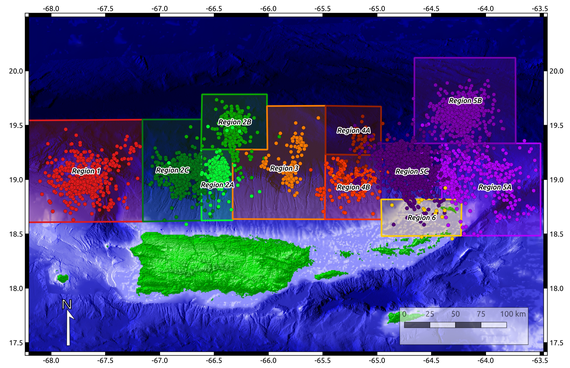
Introduction

This research identifies event clusters from the Puerto Rico Seismic Network catalog between 2005 and 2016, with magnitudes > 2.3 in the northern Puerto Rico - Virgin Islands block using a novel application of declustering algorithms. Identified clusters were classified into either earthquake swarms or seismic sequences. These results have identified 128 clusters which have been categorized into 11 distinctive regions based on their spatio-temporal distribution. Statistical analysis of these clusters has permitted insight into regional intra- and interplate dynamics.

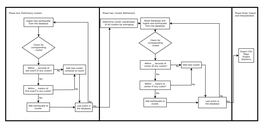


Region	R 1	R 2A	R 2B	R2C	R 3	R 4A	R 4B	R 5A	R 5B	R 5C	R 6	Totals
# Sequences	6	7	5	4	2	1	5	3	3	13	0	49
# Swarms	10	9	7	7	3	2	8	5	3	22	1	77
# Unknowns	0	1	0	0	0	0	0	1	1	0	0	3
Totals	16	17	12	11	5	3	13	9	7	35	1	129
NS Trend	3	5	3	6	1	0	7	0	1	8	0	34
NS-EW Trend	2	4	0	0	0	0	1	5	6	16	1	35
No Trend	11	8	9	5	4	3	5	4	0	11	0	60

Methods

A common objective in analyzing seismicity of an area is to remove background seismicity. However, this study to quantify clusters that are found in the background. In order to achieve this goal, we use a three-phase approach for data processing:

1. Declustering of the entire catalog based on the probabilistic algorithm of Marsan and Lengliné (2008).
2. Spatio-temporal classification and reintegration of main shocks to associated clusters.
3. Classification of earthquake clusters as either sequences or swarms and statistical analysis.



Some of the limitation of this methodology include small swarms detection (< 10 events) and events are limited to magnitudes above catalog completion.

Region Analysis

The algorithm developed for this study produces a series of graphs that allow the user to identify between earthquake sequence and seismic swarms. Figures 1 and 2 show typical examples of graphs of a seismic sequence and swarm, respectively. Data from each graph component for each cluster on a given region were extracted to generate graphs per region summarizing event history, slope distribution, time between events and probabilistic density map. Figures shown below are examples from Region 5C, where red are swarms and black are sequences:

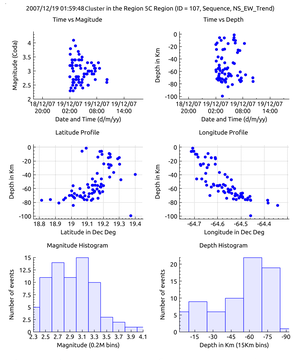


Figure 1: Example of output graphs produced by the algorithm for a typical earthquake sequence. Top panel show magnitude and depth as a function of time at left, and rigth, respectively. Central panel show slopes, and bottom panel shows histograms.

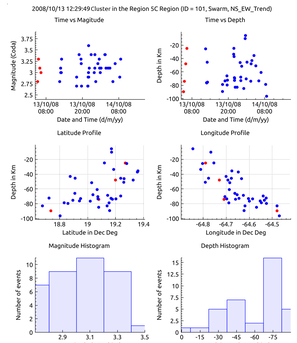


Figure 2: Example of output graphs produced by the algorithm for a typical earthquake sequence. Graphs are the same as for Figure 1. These graphs allowed for a quick visual inspection of the data.

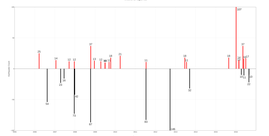


Figure 3: Example of a summary graph for Region 5C showing number of events as a function of time. Red represents swarms; black represents sequences.

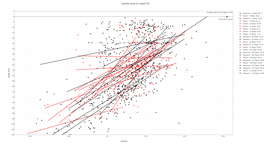


Figure 4: Latitudinal profile for the same region showing best fit slopes for each cluster. Red represents swarms; black represents sequences.

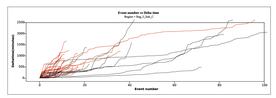


Figure 5: Behaviour of clusters with time. Example of the same Region 5C. Earthquake swarms (red) and sequences (black) tend to fall in specific areas suggesting a typical behaviour of the relationship in an event progression.

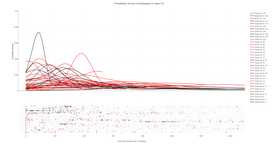


Figure 6: Probabilistic density map showing the likelihood of finding an event within the first 1500 min (25 hrs) of the beginning of a cluster.

Results

A great wealth of data has been produced by the analysis of this study. The first step to reduce results from this vast amount of data is to carry out spatial and temporal statistics. Arranging the data in space produced results that can be analyzed with spatial statistics, which shows the clustering activity in the Puerto Rico Trench and surrounding areas as it can be seen in Figure 7. Similarly, data can be arranged in time and its results analyzed with temporal statistics, which shows the average duration and number of earthquakes for clusters in this region (Figure 8). Finally, collapsing all of the slope data (as presented in Figure 4) along with the tectonic setting of the PRT allows to suggest the dip of the plate interface and observe its variation along the trench (Figure 9).

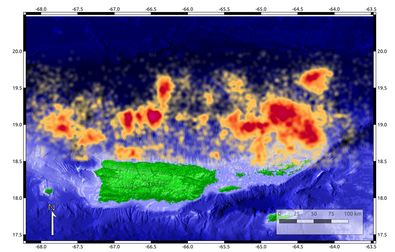


Figure 7: Heatmap showing the distribution of heightened seismic activity along the Puerto Rico Trench area. The highest density region occur at Region 2A, (light purple color), whereas the region containing the highest amount of clusters was the Sombrero Seismic Zone (Region 5).

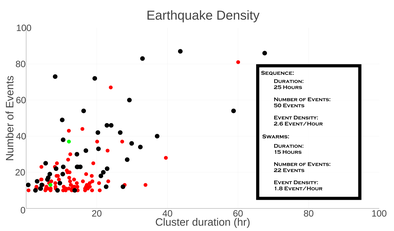


Figure 8: Relative earthquake density for small clusters (<100 events). Statistics of event duration, amount and density for swarms (red) versus earthquake sequences (black). On average, swarms group toward the lower numbers and shorter duration, whereas sequences have more events during longer duration.

Figure 9: Latitudinal variation of slab slopes in degrees along their longitudinal profiles. Inverted triangles are averages of individual clusters (circles). Apparent plate interface occurs at around 42^o with the largest variation occurring at the Sombrero Seismic Zone.

Region Analysis Cont'

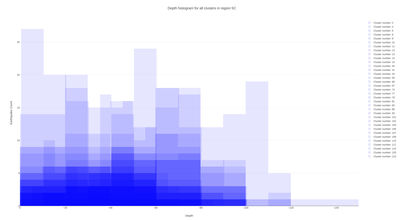


Figure 10: Heat histogram showing earthquake depth as a function of event number for all clusters within Region 5C. The transparency of each cluster distribution allows for visualizing the location where the majority of event depths (darker colors) plot for the region.

Conclusion

- Our analysis of 10 years of catalog seismic data indicate that the majority of earthquake clusters occurring within the PRT region fall into 11 distinct regions whose cluster centers and seismic activity are well defined.
- A statistical analysis indicate that swarms in the study area occur more frequently than seismic sequences, and the former last on average 15 hr whereas the latter last longer (1 day).
- Analyzing the depth distribution of events within each cluster allows us to quantify the depth to horizontal behaviour. The majority of the clusters exhibit a NS trend often coupled with an EW trend that is consistent with the regional subduction geometry of the region.
- Seismic cluster depth and spatial distribution yield an average plate interface slope of 42^o throughout the entire PRT.
- Ten years of data used for this spatio-temporal distribution study cannot be used to establish recurrence rates.

References

[1] David Marsan and Olivier Lengliné.
Extending earthquakes' reach through cascading.
Science, 319(5866):1076–1079, 2008.

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