Applications of Remote Sensing Techniques to Identify Major Faults in the Island of Puerto Rico using SAR and SLAR images

Ashlyann Arana Morales[1], Daniel J. Mercado Rosario[2]

[1] Bo Tanama 1B Calle 1 Arecibo P.R, 00612-5578, ashlyann.arana@upr.edu

[2] #15 Calle Iglesia Quebradilla P.R, 00678, daniel.mercado1@upr.edu

Abstract

Studying geologic faults is essential for the mitigation of geologic hazards. Puerto Rico is located in a very active seismic zone, which makes it prone to earthquake activity and its effects. A great way to study these features is through remote sensing. Remote sensing offers a safe and budget efficient way to study and monitor geologic features. The use of active sensor imagery is encouraged, the Side-looking Airborne Radar (SLAR) in particular, is ideal to identify faults due to its capacity of bypassing the cloud and vegetation cover as well as penetrating the soil, allowing for the rock beneath to show (ideal for the tropics since the cloud cover is dense and the vegetation is vast, hiding the rock surface where the faults are expressed). The SLAR images were processed using the Environment for Visualizing Images (ENVI) software. The main challenge of this project was to be able to highlight the faults using this mean. Various techniques were employed in order to highlight the faults, including the Minimum Distance classification as well as the Synthetic Color Image tool. When using SLAR imagery to identify and highlight geologic faults, the Minimum distance supervised classification serves this purpose with more efficiency that the Synthetic Color Image tool. Using the interactive stretching to

enhance the raw SLAR image did not yield the desired results when the Minimum Distance and the Synthetic Color Image were applied.

Keywords: Remote Sensing, Faults, earthquakes, ENVI, SLAR

Introduction

Puerto Rico is a Caribbean island located in a highly active seismic zone, which makes it prone to seismic activity. For this reason we believe that identifying faults can be useful for hazard mitigation (i.e. if an area has high earthquake risks then constructions should be performed with the anti-seismic construction code in order to prevent a geologic disaster). We intend to identify and highlight (by employing different techniques using ENVI) known major geologic faults using SLAR images and then make a map using ArcGIS showcasing the faults and magnitude 5+ earthquake epicenters during the past 7 years (2005 - 2012) around Puerto Rico.

Every year our community is affected by geological hazard like earthquakes, debris flows, flooding, landslides, avalanches, etc. In order to help our community reduce these hazards it is of dire importance that we get to know and understand these geologic phenomenon and the factors that produce them. Each time one of these geological hazards takes place we have enormous property damage that leads to economic loss and in worse case scenarios, the loss of lives.

A fault is a fracture in the Earth’s crust where there has been significant displacement along the fracture caused by the Earth’s movement. These faults are classified into active (displacements is still taking place) and inactive faults (where displacement does not take place anymore) and are typically found along tectonic plate boundaries. Earthquakes are produced when the rock breaks in an active fault by releasing tension.

For this study we intend to use images taken by the Side-looking Aperture Radar (SLAR). This is an active sensors; this type of sensor differs from a passive sensor in that it broadcasts a pulse of energy directed at a portion of the Earth and receives the energy scattered back; contrary to a passive sensor that uses external energy sources such as the Sun. In this case, the beam of energy broadcasted by the sensor is in the microwave wavelength (1mm to 1m). This sensor is very useful since it has the capability of functioning in any kind of weather. Another great quality to this sensor is that it can escape the cloud cover, which makes it a good tool to study the tropical regions. One of the most interesting and useful qualities it provide is that it can also trespass the vegetation cover and even penetrate the soil allowing the underlying rock to be visible, which can be extremely useful to identify and analyze geologic features such as faults (Campbell and Wynne, 2011). All these features provided by the SLAR are perfectly adequate to identify faults in Puerto Rico; since this island is tropical it's always covered with clouds and full of vegetation which make this sensor perfect for the task since it can obviate it and see the underlying rock.

Material and Methods

The main objective of this project was to use active sensor imagery to identify and highlight major geologic faults (Appendix 1). We chose the images of Puerto Rico by the Side-looking Airborne Radar (SLAR) to do so. These images can be obtained for free at the USGS website dedicated to SLAR imagery of Puerto Rico (http://pubs.usgs.gov/of/2000/of00-006/htm/slar.htm). The images chosen showed the West, Center and East part of Puerto Rico (Fig. 1a - c). They were processed using the Environment for

Visualizing Images (ENVI) software, specifically the Minimum Distance supervised classification and the Synthetic Color Image.

Minimum Distance

Among the supervised classification methods is the Minimum Distance, which "uses the mean vectors of each ROI and calculates the Euclidean distance from each unknown pixel to the mean vector for each class; all pixels are classified to the closest ROI class unless the user specifies standard deviation or distance thresholds, in which case some pixels may be unclassified if they do not meet the selected criteria" (ENVI Tutorial – Classification Methods). For the purpose of this project, the technique used by (Luna-Rivera and Rodríguez, 2011) was used. It consists of choosing two different Regions of Interest (ROIs), one enclosing areas belonging to valleys and the other, mountainous areas (Figs. 2a – b). Once the Minimum Distance is applied, it outputs a flat bi-color image (Figs. 3a - c).

Synthetic Color Image

There are various techniques to work with active sensor imagery and among them is the Synthetic Color Image. This tool does a simple enhancement to black and white images to give them color. The way this works is that "ENVI changes the grayscale image into a color image by applying high pass and low pass filters to the image to separate high and low frequency information. Low frequency information is assigned to the hue, and high frequency information is assigned to the value, and a fixed saturation level is used. These hue, saturation, and value (HSV) data are transformed into red, green, and blue (RGB) space, producing a color image" (ENVI User's guide). The output is an image that contains enhanced large-scale features while retaining small details (ENVI User's guide)(Figs. 4a - c).

GIS application

In order to have an idea of the significant seismic activity in Puerto Rico's major faults the magnitude 5+ earthquake epicenters were plotted onto the SLAR mosaic of the island (found on the same website as the other SLAR images) to see if any of the earthquakes originated on these faults (Table 1). The earthquake data was obtained from the Puerto Rico Seismic Network's website (redsismica.uprm.edu). Also, a layer containing the major faults of Puerto Rico provided by the USGS (http://mrdata.usgs.gov/geology/pr/) was added on top of the SLAR composite of Puerto Rico (Fig. 5). Another image was done but with a polygon shapefile of Puerto Rico and its municipalities (Fig. 6).

Discussion

It is evident that SLAR is very useful to identify geological features, especially in tropical areas where there's a dense cloud cover and there is a significant amount of vegetation. At first, we indented to use the SLAR composite of Puerto Rico but in the first tries it was unquestionable that it couldn't be used for both the Minimum Distance classification and the Synthetic Color Image (SCI). The resulting images, in the case of Minimum Distance, did not show enhance textural details that could be used to detect faults (the image turned out a mess of red and yellow with the shape of the island rather than the island with red and yellow texture); in the case of SCI, the colors in the image seemed a bit random and the boundaries (where the separate images were connected was highlights) this lead to the possibility that the pixel values for one part of the image did not, necessarily, correspond to the other, which means that the techniques that we were going to use in ENVI were going to be affected, giving us incorrect results. With this in mind, the separate images used rather than the SLAR composite. The main purposed of our research was to highlight the major faults in Puerto Rico, which turned out to be successful.

To do this we employed several techniques in ENVI: atmospheric correction (Dark Subtract), interactive stretching, supervised classification (Minimum Distance) and Synthetic Color Image (SCI). The atmospheric correction was applied to the three images before doing any other adjustments; after this, the Minimum Distance classification and the SCI were applied. As a set of trial and error, the interactive stretching tool was also used, but turned out to be a problem for this project (the resulting images after processing them with the proposed techniques were useless for the purpose of this project) for which it was decided to use only the images corrected with the Dark Subtract.

Now, ¿which of these methods is more efficient when highlighting geologic faults or lineaments (topographic expressions of these (O'Leary et al. 1976)? There is no real answer to this question as both of the techniques were both successful and a failure to do so. Each of the three images processed with the Minimum Distance and the SCI gave different results (quality of highlight-wise). In the case of the image of the West side of Puerto Rico, the Minimum Distance classification gave impressive results. The resulting image shows a shift or a displacement in the texture of the mountains in the northwestern fault (Fig. 1a), precisely where the fault is going through (Fig. 3a). The southwestern fault was also highlighted with this technique. In the case of the SCI (Fig. 4a), it was a failure in highlighting the faults in the West Puerto Rico image. The northwestern fault could be appreciated due to the shift of purple and green hues but the southwestern fault was barely imperceptible. For the image of Central Puerto Rico, both techniques showed god results. The fault cutting diagonally through Puerto Rico (Fig. 1b) can be appreciated well in both images (Figs. 3b and 4b). For the Eastern side of Puerto Rico, both techniques yielded good results as well but SCI had the upper hand. There are two faults in this image (Fig. 1c), a southeastern fault and a northeastern fault. SCI was very successful at highlighting both faults (Fig. 4c) but the Minimum Distance classification showed a little trouble in highlighting the northern-most fault (it can be appreciated but is not highlighted as it had been expected). ¿Why did these methods gave out good and bad results? The reason for the minimum distance might be that there are noticeable textural changes where it was successful and little to no textural change where it was not. In the case of SCI, the reason for its intermittent success might have been due to the images pixel values since what SCI need to color the image is the frequency values stored in the image; the images are taken by the SLAR sensor at an angle and possibly not at a precise altitude which means that for the three images, the pixel values might differ significantly, affecting the frequency content that the SCI uses.

As an extra for the project, two maps containing the major geologic faults of Puerto Rico (shapefiles provided by the USGS) and the epicenters of the magnitude 5+ earthquakes from 2005 until 2012 (data provided by the Puerto Rico Seismic Network) (Figs. 5 and 6). It turns out that none of the epicenter fell on the faults; the closest, being near the major northern faults. There were some difficulties at the time of georeferencing the SLAR composite since it did not do so correctly (this can be appreciated in the West side where the faults do not go all the way to the shoreline) (Fig.5). Upon a closer look, the SLAR composite shows that the separate SLAR images do not fall into place completely as expected, which might have altered the shape of the island, therefore impeding a correct georeferenciation.

For a future project like this, it would be recommended that a larger range of magnitudes as well as a broader range or time is used for the earthquake points in order to have a wider scope of view; in geologic studies, wider ranges of data are better than short ranges. In the case of the Minimum Distance classification and the SCI, more experimentation is recommended since it turned out that they could be used to highlight faults but there are some inexact problems along with their processes.

Cited Literature

Campbell, J. B., Wynne, R. H., 2011, Introduction to Remote Sensing, ed. 5, The Gildford Press, p. 667.

Luna-Rivera, M., Rodríguez, J. J., 2011, Identificación de pliegues y lineamientos para hallar fallas geológicas en el área oeste de P.R. utilizando imágenes SLAR, Univeridad de Puerto Rico, Mayagüez. P. 1 - 10

O'Leary, D.W. Freidman, J.D., and Pohn, H.A. 1976. Lineament, linear, lineation: Some proposed new definitions for old terms. *Geological Society of America Bulletin*. 87: 1463-1469.

ENVI Tutorial – Classification Methods: http://www.exelisvis.com/portals/0/tutorials/envi/Classification_Methods.pdf

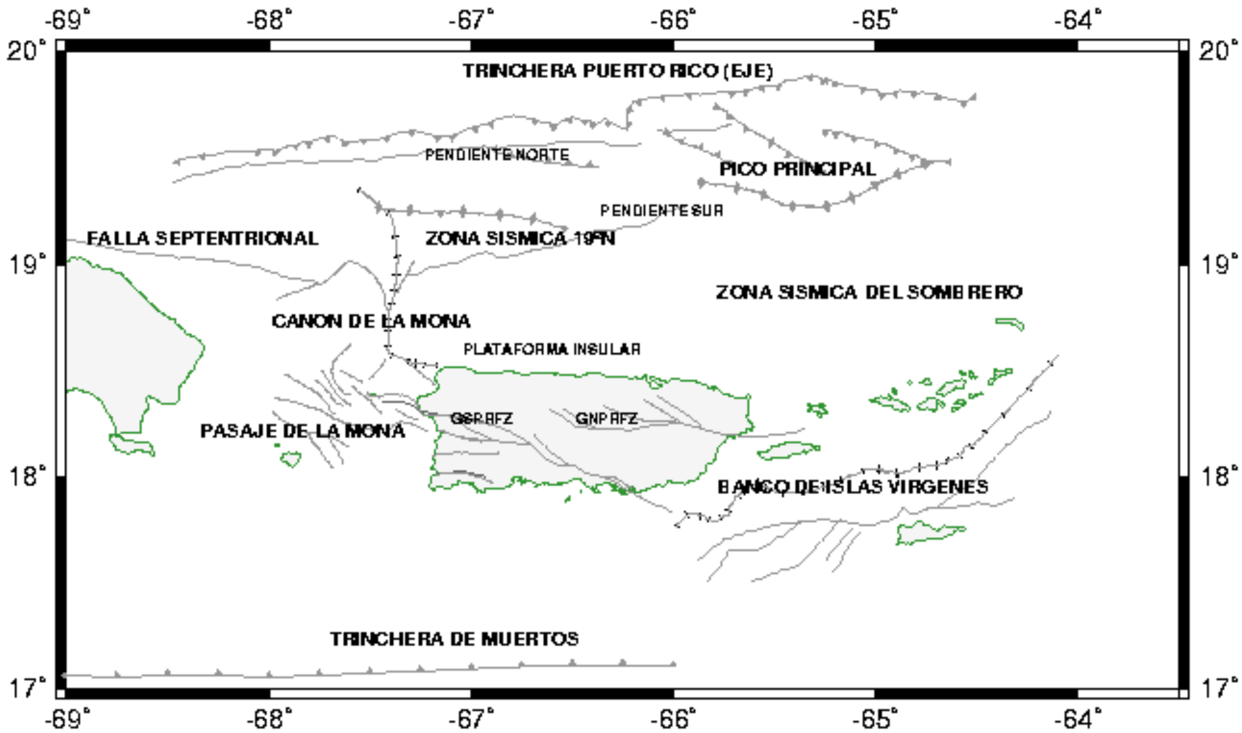
USGS SLAR Images of Puerto Rico: http://pubs.usgs.gov/of/2000/of00-006/htm/slar.htm

Puerto Rico Seismic Network: redsismica.uprm.edu

Mineral Resources On-Line Spatial Data – Geology of Puerto Rico: http://mrdata.usgs.gov/geology/pr/

ENVI User's guide – Synthetic Color Image: http://geol.hu/data/online_help/Creating_Synthetic_Color_Images.html

Appendix



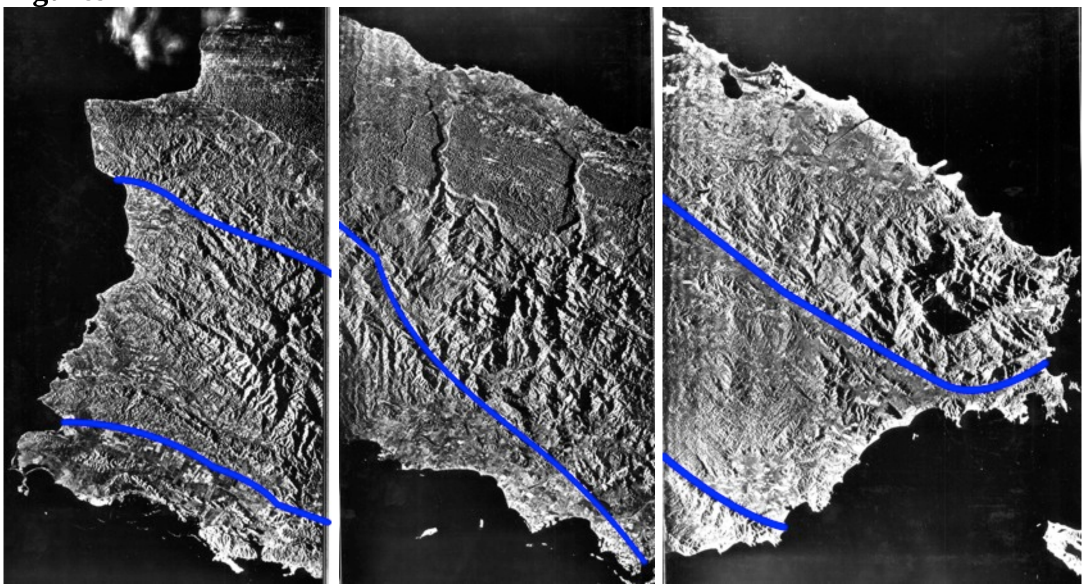
Appendix 1. Diagram fault lines of Puerto Rico and adjacent areas used as a reference fro this project. Provided by the Puerto Rico Seismic Network: (http://www.prsn.uprm.edu/English/information/sisnotas_zone.php).

Tables

Table 1. Here are magnitude 5 or more earthquakes and their epicenter's coordinates.

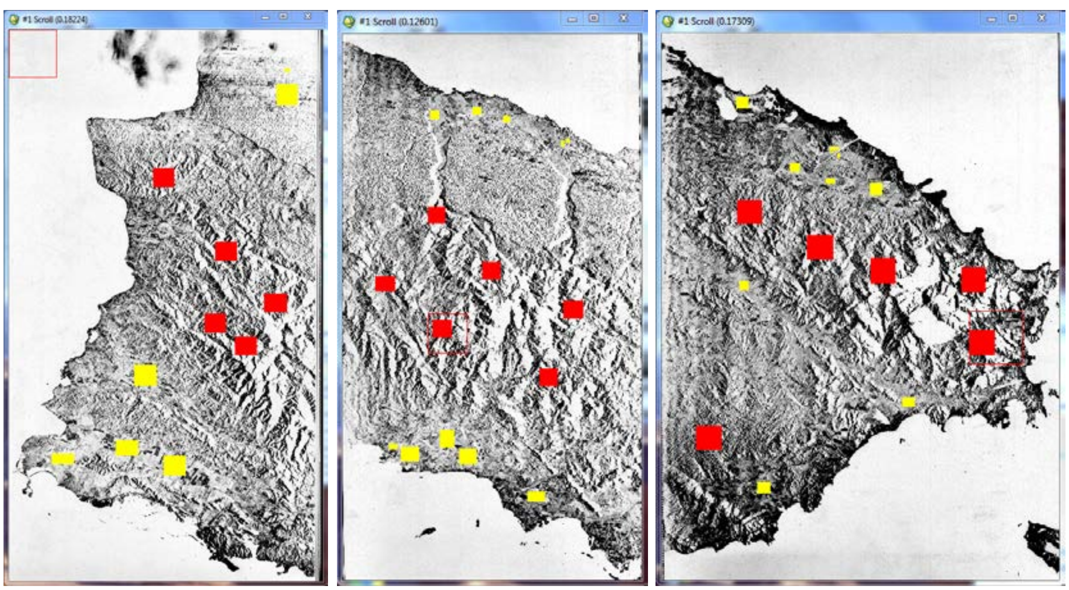
Magnitud del evento	Latitud	Longitud
5	19.664	-65.39
5.3	19.358	-63.787
5	19.022	-64.636
5	19.028	-66.902
6.1	19.282	-64.832
5.5	19.431	-66.383
5	19.07	-66.367
5.6	18.865	-64.699
5.2	18.733	-67.176
5.7	18.4	-67.07
5.53	18.207	-68.45
5.4	18.26	-66.135
5.37	19.033	-67.919
5.14	18.959	-64.264
5.2	19.0983	-66.7473
5.1	18.188	-67.37
5.3	18.1721	-67.3713
5.03	18.0528	-68.7623
5.2	19.7043	-64.257

Figures



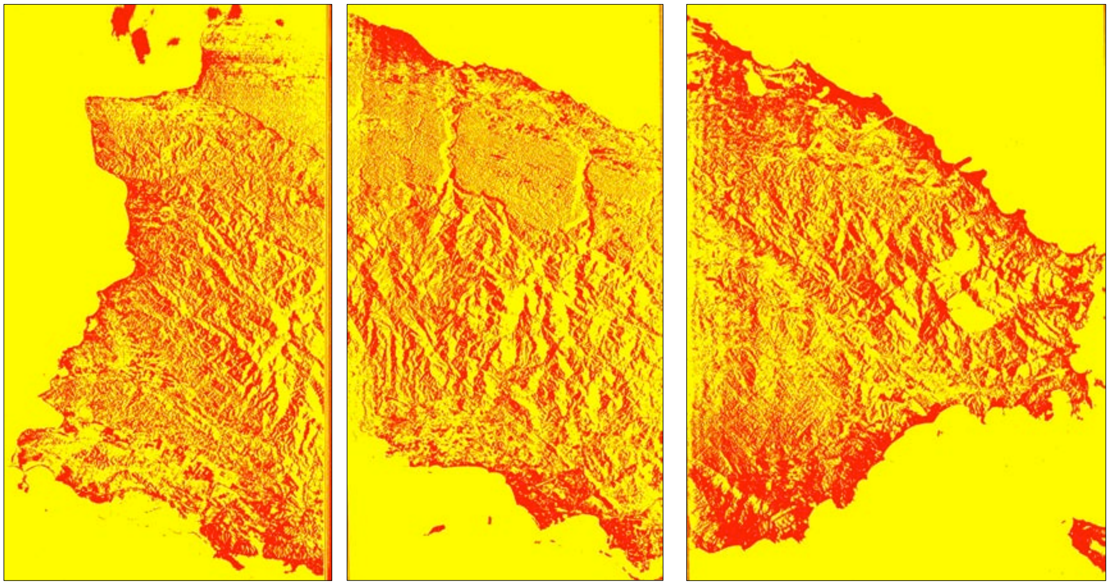
[a] [b] [c]

Figure 1. SLAR images from Puerto Rico with dark substrac atmospheric correction ((a) West side, (b) Central and (c) East). The blue lines correspond to major fault lines in Puerto Rico.



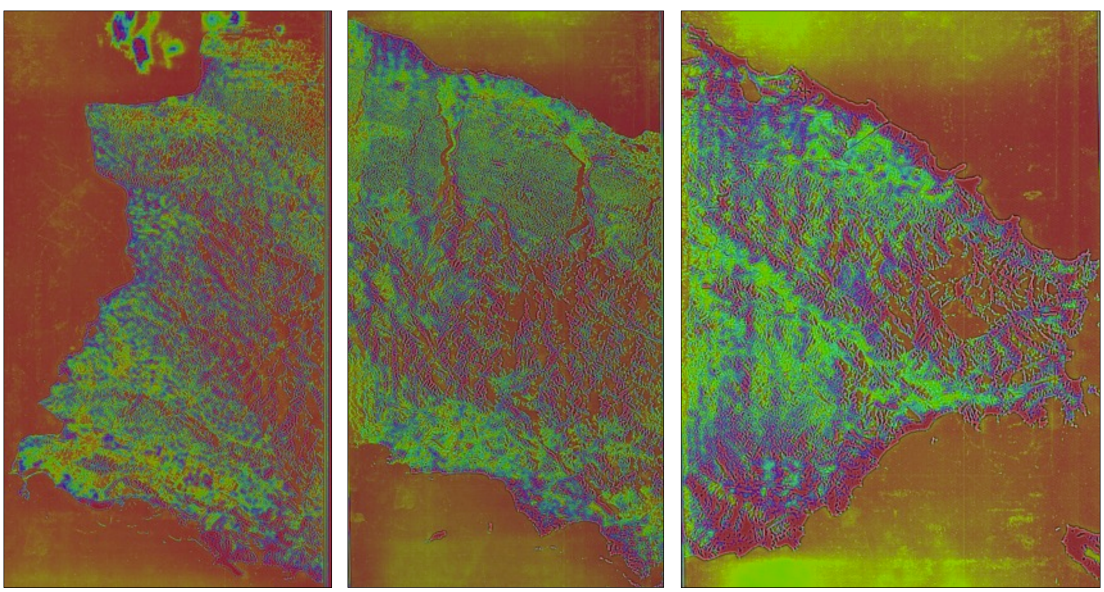
[a] [b] [c]

Figure 2. SLAR images from Puerto Rico ((a) West side, (b) Central and (c) East) with the selection of ROIs (red for mountainous areas and yellow for valles).



[a] [b] [c]

Figure 3. SLAR images from Puerto Rico ((a) West side, (b) Central and (c) East) processed with the Minimum Distance Classification.



[a] [b] [c]

Figure 4. SLAR images from Puerto Rico processed with the Synthetic Color Image: (a) West side, (b) Central and (c) East

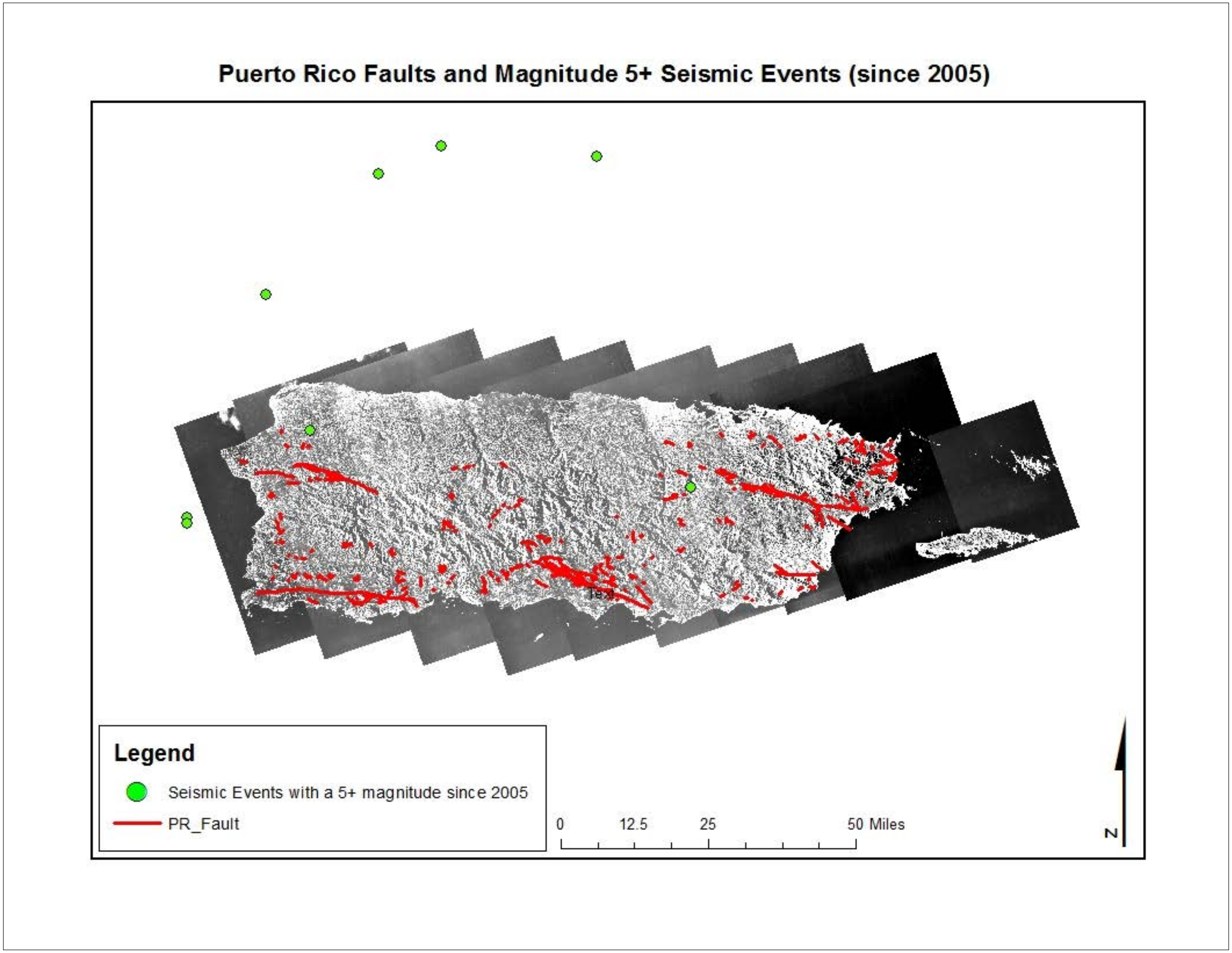


Figure 5. Faults (red lines) and magnitude 5+ earthquake epicenters (green dots) plotted over a SLAR composite from Puerto Rico.

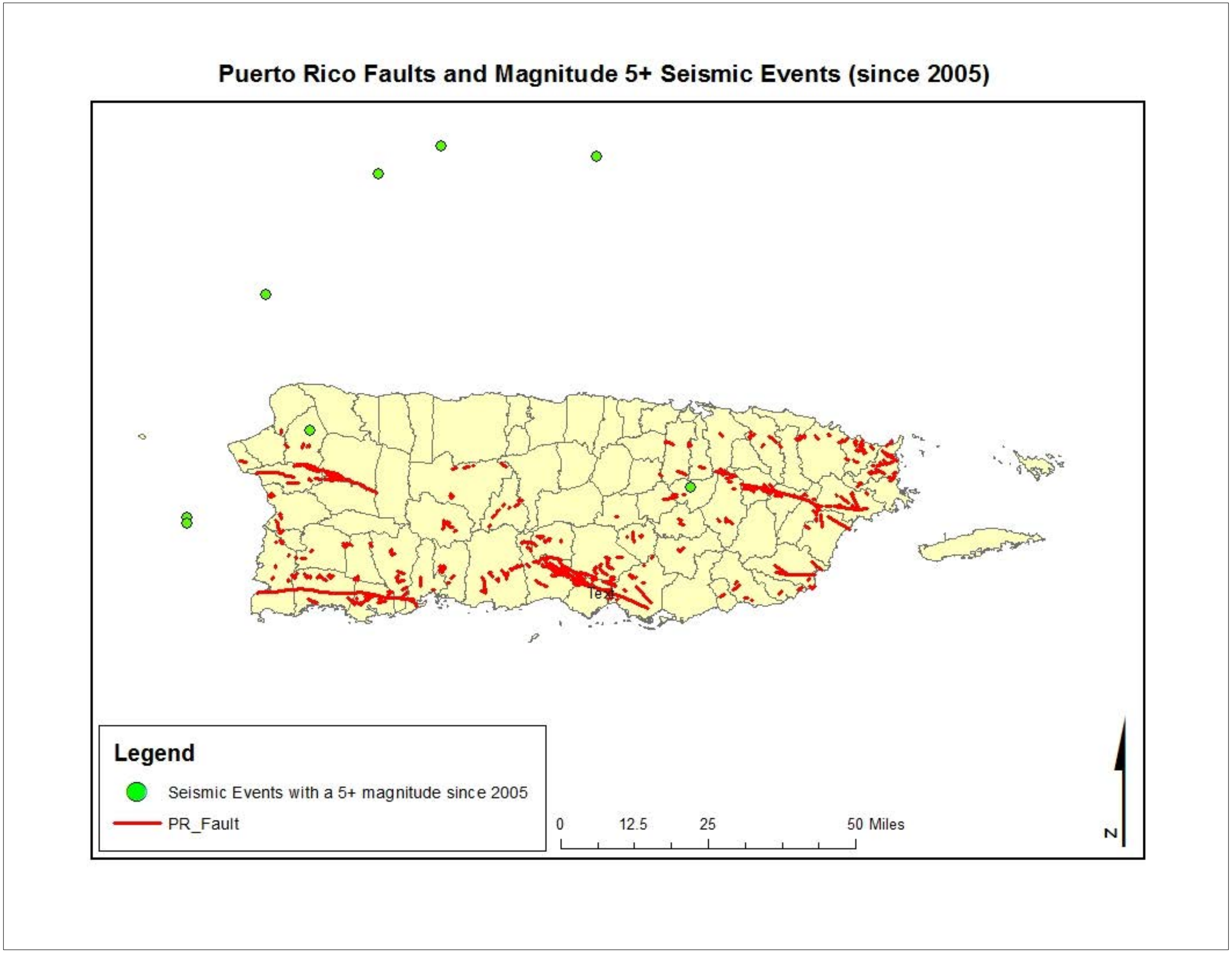


Figure 6. Faults (red lines) and magnitude 5+ earthquake epicenters (green dots) plotted over a municipal map of Puerto Rico.