Monitoring the seismic activity of Mayotte through image processing of fiber optic signals

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Motivation

In may 2018, a strong episode of seismicity started in Mayotte (Comoros archipelago), which was widely felt by the inhabitants of the island, in an area which was considered to be moderately active seismically. A year later, a new volcanic structure of 800m high was discovered 50km east of Mayotte during a scientific campaign (MAYOBS1, Feuillet et al., 2019). The seismicity is on-going to this day and is analyzed daily to monitor the activity of the volcanic structure.

The seismicity is monitored daily using the seismic stations installed on the island. Retailleau et al. (under review) developed a process to automatically detect and locate seismic events in real-time. Using a neural-network-based method we identified the main waves (P and S) that are generated by an earthquake and then propagate through the earth and are recorded by the different seismic stations. The arrivals are then associated as an earthquake and are used to locate the event. This process helped greatly to increase the number of earthquakes detected and located. However, the quality of data recorded by the land stations suffers a lot from anthropic noise.

In the last few years seismologists have increasingly used Distributed Acoustic Sensing (DAS) measurements. Using a DAS interrogator, a fiber optic cable can be used as a high sampling seismic network line, leading to an equivalent of a seismic sensor every 10m. Multiple studies showed that this data can be used in various contexts, to analyze seismic signals and to study the structure of the Earth (Zhan, 2020). On land, DAS recordings have been used to analyze Volcano-tectonic seismicity (Jousset et al., 2018) as well as anthropic signals (Lindsey et al., 2020). Measurements have also been made on fiber optic cables deployed on the seafloor, permitting to observe its subsurface as well as the signals generated by ocean waves (Lindsey et al., 2019).

We were able to record 10 days of DAS measurements in Mayotte on a fiber starting on the island and extending 40km offshore. With the seismicity still very active in the area numerous events were recorded with this high sampling method. These recordings have the great advantage to not suffer from human activity effects since the cable is deployed offshore. The extent of the fiber cable offshore also leads to measurements closer to the seismic activity linked to the Mayotte volcanic structure. Finally, the high density of measurements will permit highlighting small amplitude signals by combining the different arrivals.

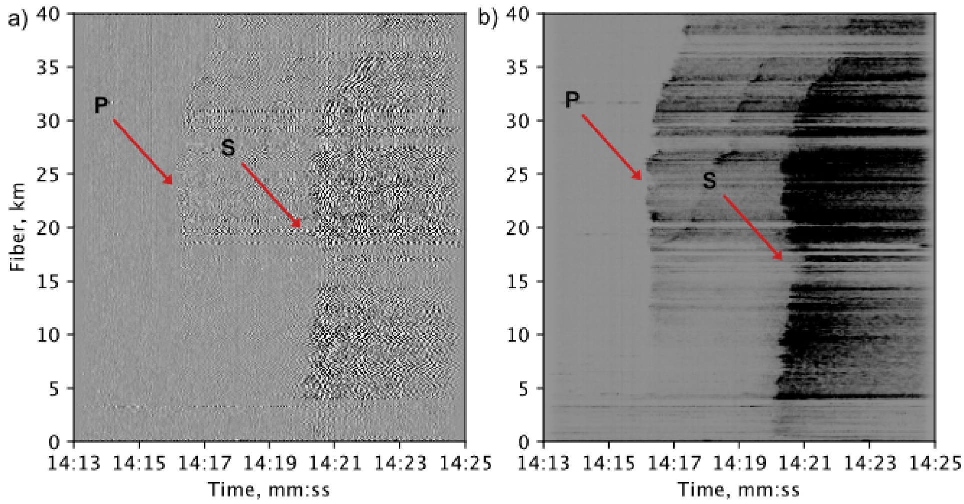

Figure 1 : Signals in time and distance from the beginning of the cable for the October 10, 2020 earthquakes. a) Represents the signals filtered between 5 and 30 Hz and b) their envelope.

Figure 1 represents the signals of a Volcano-Tectonic earthquake recorded on the Mayotte fiber optic cable. The figure shows that the measurement recovered very well these signals along most of the fiber. These signals can thus be very useful to monitor the seismicity of the area. While the high density of measurement will lead to more detailed information, it also implies that a large quantity of data has to be analyzed. For this reason, it is crucial to develop new methods to analyze these large datasets, and we propose to use image processing analyses.

Proposed work and implementation

Figure 1 shows the wavefronts of the two main arrivals generated by an earthquake. Both images show the same event. Figure 1a shows the signals with a simple band pass filter and Figure 1b represents the envelope of the signals. This shows that these images can be exploited for earthquake analysis and highlight different features..

The proposed work will be based on several incremental steps:

As a first step, we plan to consider active contour models (Niu et al., 2017) to locate the waves from a ground truth (approximate localization of P and S). Such models are widely used to extract regions in noisy images (e.g. in biomedical images, Lidar). They often required key points to initialize the fitting process near the region of interest (in this case the wavefront). We will choose these points from a polygonal approximation calculated on the given curves S and P.

Secondly, we want to consider an automatic localization of the starting points by considering a progressive search area (vertical patch) from the left to the right using homogeneous area criteria. Due to the specificity of the wave – high density – we also propose to study two effective strategies to approximate waves (Haar wavelet and multi-scale edge detectors). The underlying idea is to provide a set of possible curves before running the active model process. Such methods could also be extended to process a series of consecutive wavefronts (fast events).

Finally, we also plan to explore deep learning approaches (Khan et al., 2020) by considering ground truths (for instance from an expert evaluation of results achieved at the previous step) or an augmentation process by defining a set of possible wavefronts.

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