



## Abstract

Spot Them All (STA), is the first localization software developed by the Laboratoire de Sismologie et Infrason (LSI) Madagascar. The objective of this study is to validate the results obtained from STA by comparing them with the published bulletin by GFZ and the revised (REB) by the CTBTO. Subsequently, focal mechanism analysis was performed in order to understand the source mechanism of the detected events. On the 15<sup>th</sup> of May 2018 around 15h48min, an unusual seismic event of magnitude 5.9 was detected in northwestern of Madagascar. Following that event, thousands of aftershocks were detected from that same area with more than twenty events per day. The program STA collects automatically data from IRIS, GEOFON, DASE, IMS, Africa Array, and Malagasy National Data Center (NDC) in near real time. The analysis showed that if we consider the GFZ's bulletin as reference, STA's bulletin is 90% accurate in longitudes and 96% in latitudes. However, CTBTO's REB showed 95% accuracy in longitudes and 97% in latitudes. Depth are fixed at 10km in the GFZ's bulletin and at 0km in the CTBTO's REB. STA's bulletin shows more constrain on events' depth, ranging from 0 to 135km. The earthquakes are generally located between latitudes 11.84°S and 14.18°S, and longitudes 44.8°E and 46.78°E. In addition, focal mechanism analysis shows that 59% of the event are generated from strike slip faults, 39% are normal fault and 2% are reverse faults. On 11<sup>th</sup> November 2018, another earthquake of 5.7 in magnitudes was detected and an extension northwest to southwest of earthquakes is observed. Because of that extension, we suggest that seismic activities recorded in the study area are from magma shift under the seabed or underwater volcanic eruption. Tomography analysis in that region is proposed to provide detailed information regarding the origin of those earthquakes.

## 2 Method

### Spot Them All (STA)

Developed by T. Rakotoarisoa, associate researcher at the Institute and Observatory of Geophysics of Antananarivo (IOGA) where the National Data Center (NDC) Madagascar is located, STA software is a C++ based program regrouping standard tools largely used by seismologist in a new and easy Graphic User Interface (Fig 4). To locate earthquakes, users can choose between Hypocenter, Hypo71. In focal mechanism analysis HASH, FFPIT are available. Spectral analysis and many more can be performed in a very friendly interface.



Figure 4: Spot them all

### Data

Figure 5 shows the seismic stations from which data (waveform) are automatically collected in near real time by the program. Data from primary, auxiliary and local stations are then synchronized in one user interface to ease the task of analysts.

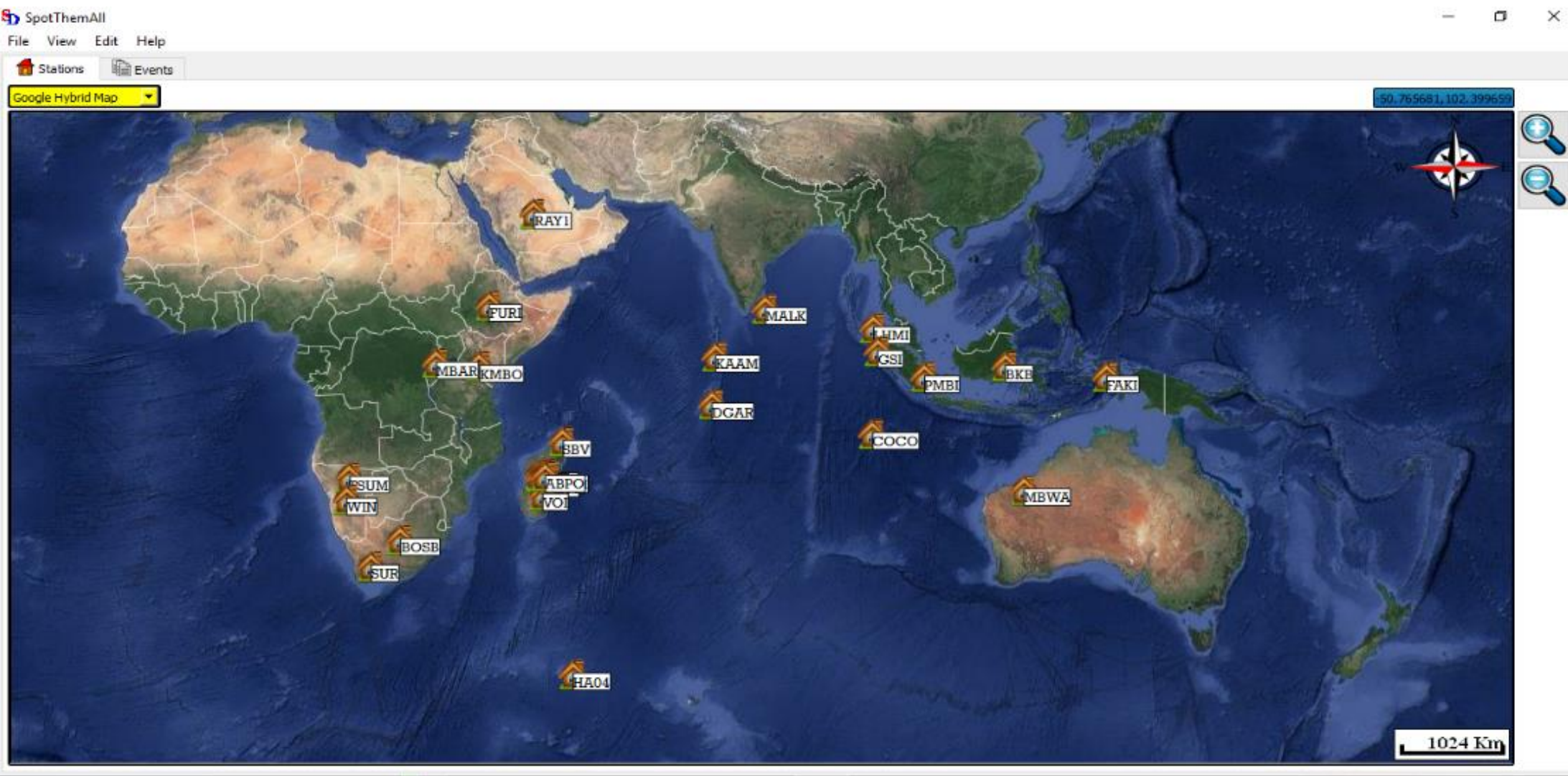


Figure 5: Seismic station which data are available in near real time using the STA

### Data processing

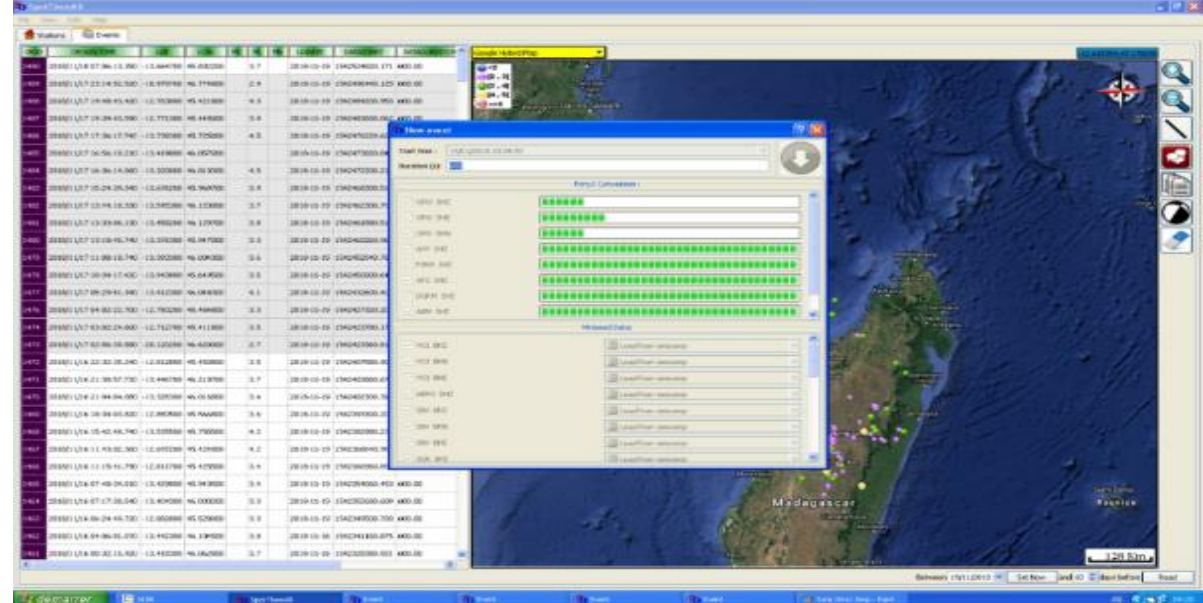


Figure 6: waveform conversion

Data are automatically collected from Local, IRIS, GEOPHONES, DASE, IMS and Africa Array network.... It is then saved in the STA's database and once the events are created by users the analysis can begin. STA can read most of the seismic data format (SAC, Miniseed, ascii, Seisan, seg, ...) and an automatic event location is available (Figure 6).

The following options are available on STA:

- Phase identification,
- Travel time
- Filter
- Magnitudes and coda magnitudes
- Spectral analysis
- Mapping



Figure 7: Phase identification and location in STA

- Focal mechanism analysis can be performed to identify the source mechanism for each events.

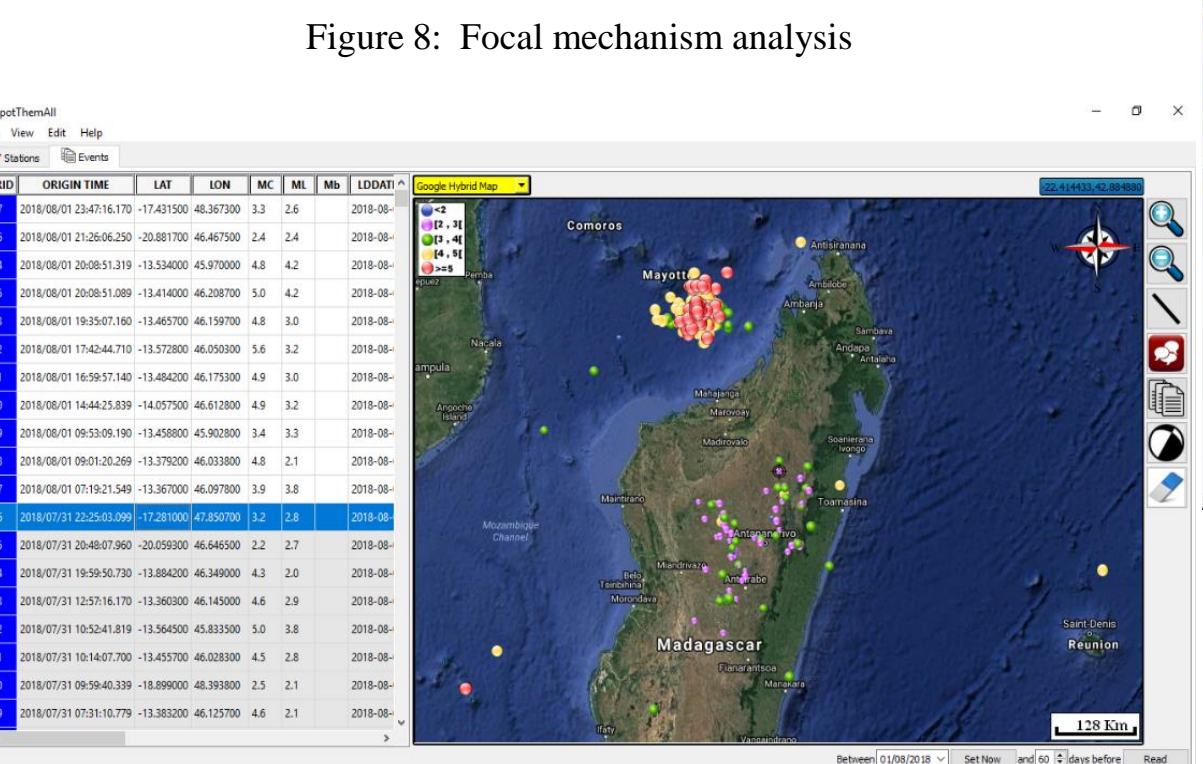


Figure 8: Focal mechanism analysis



Figure 9: Event location and focal mechanism solution

- The database and bulletins access are very simple

Figure 10: Bulletin and database access

## 3 Results

### STA Bulletin, REB (CTBTO) and GFZ

Considering the event on May 21<sup>st</sup>, 2018:

Bulletin	STA	GFZ	CTBTO
Origin time	00:47:11.5119	00:47:13	00:47:11.35
Latitude	-12.8773	-12.92	-12.826
Longitude	45.6393	45.71	45.6082
Depth (km)	0	0 fixed	10 fixed
Magnitudes	5.5	5.4	5.4

- GFZ means that the information has been collected from the GFZ's website <http://geofon.gfz-potsdam.de/einfo/list.php>.
- The Reviewed Event Bulletin (REB), by the CTBTO available for state signatories on [swp.ctbto.org](http://swp.ctbto.org).
- STA means that solution is calculated with STA

Figure 11 shows that the CTBTO and GFZ's results are within the error ellipse of the solution calculated

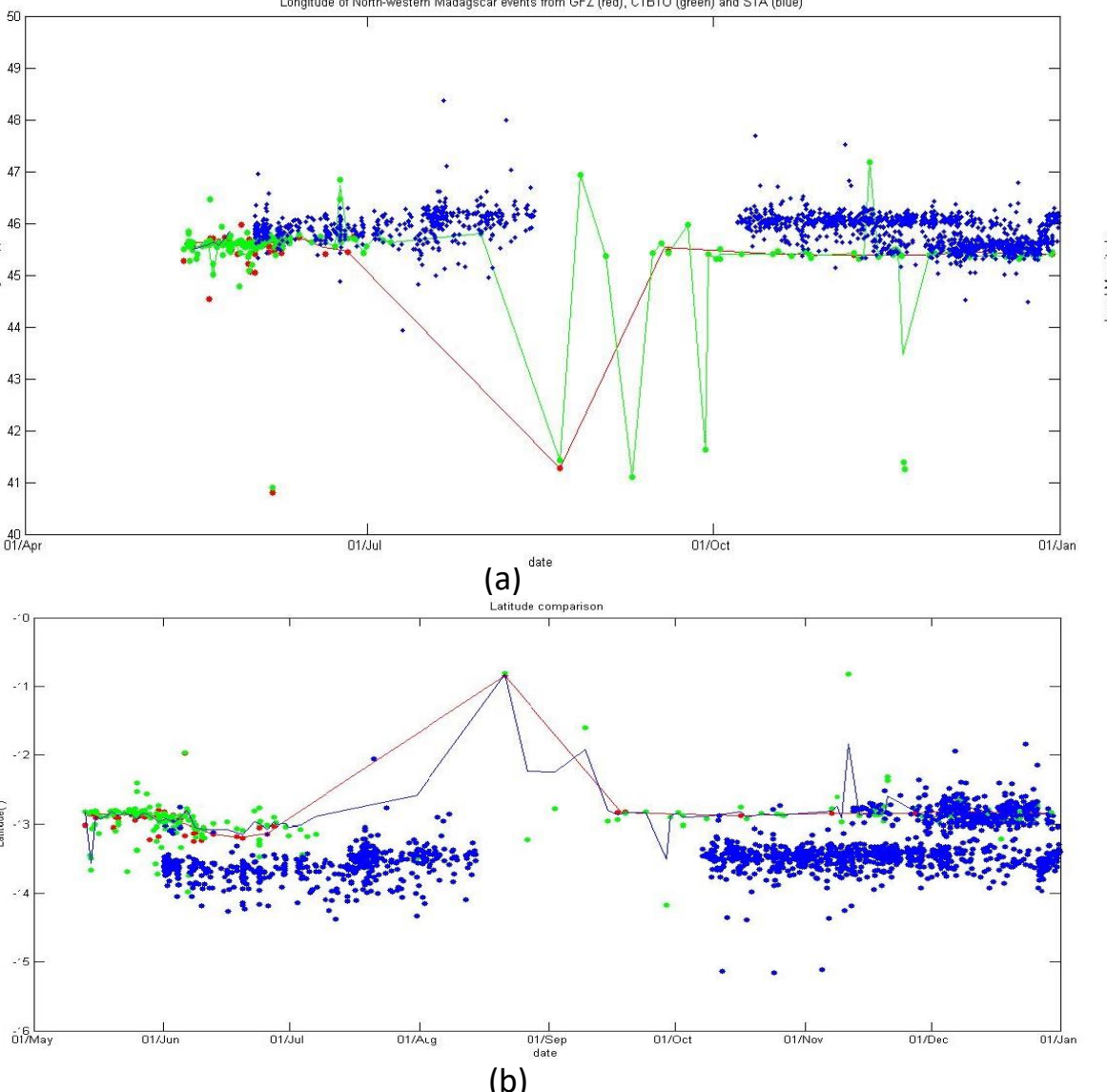


Figure 12: Longitude (a) and latitude (b) comparison from 3 different bulletin: STA (blue), CTBTO (green), GFZ (red)

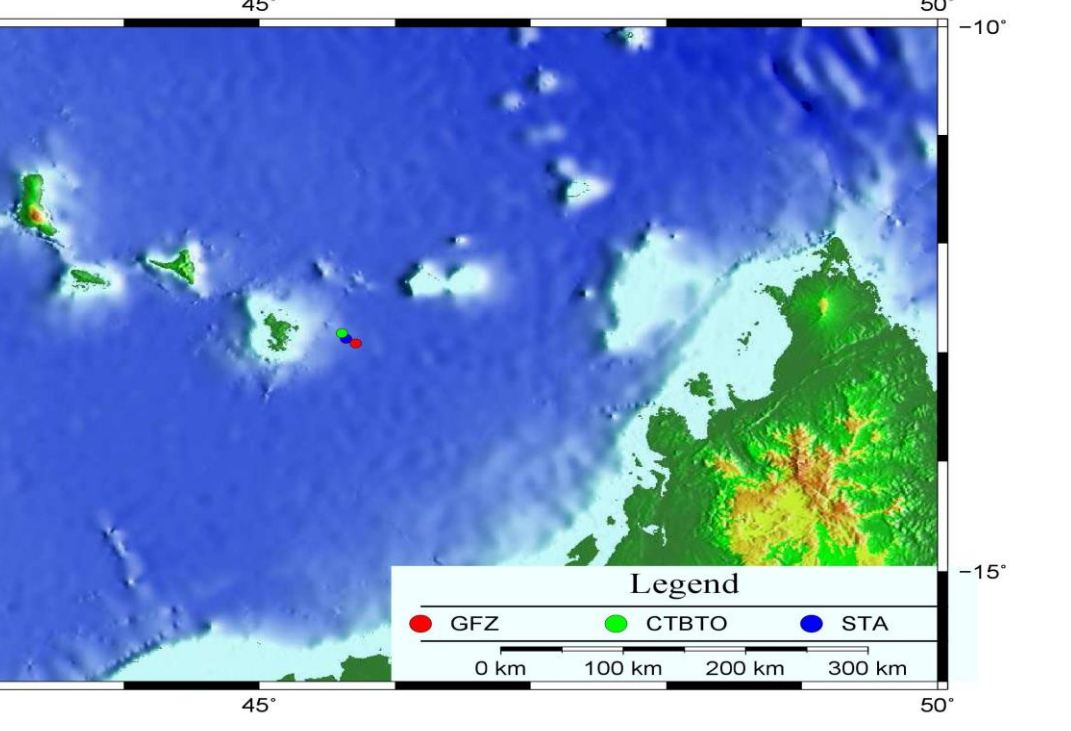


Figure 11: Location of the earthquake on 21st of May 2018. The red represents the location from the GFZ, the green is from the CTBTO and the black is from the STA

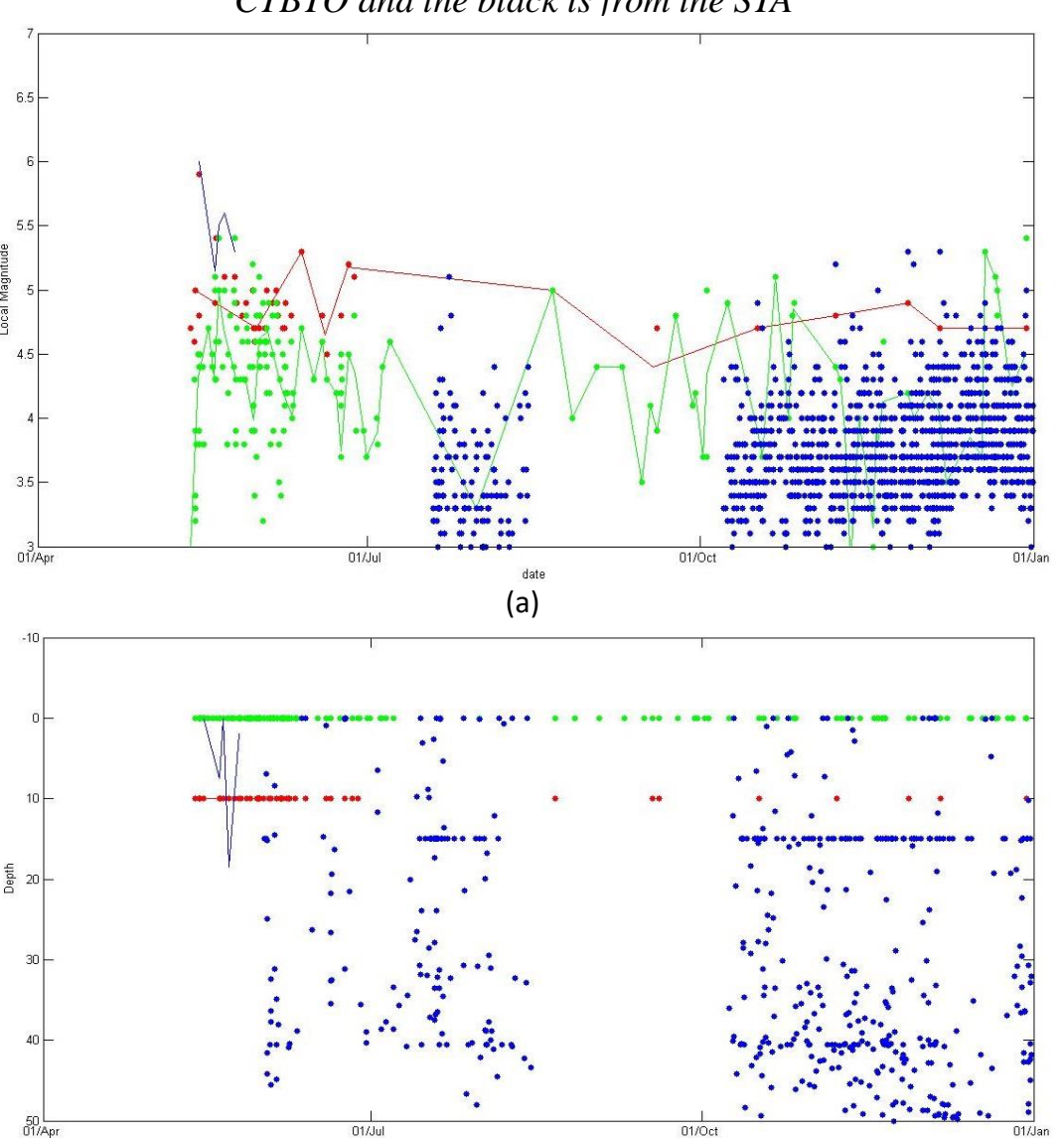


Figure 13: Magnitude (a) and depth (b) comparison from 3 different bulletin: STA (blue), CTBTO (green), GFZ (red)

- Considering the GFZ's bulletin as reference: The difference in Longitude and Latitude location is respectively between 0.01° (~1km) to 0.2° (~22km) and 0.001° (~100m) to 0.1° (~11km).
- Considering the CTBTO's bulletin as reference: The difference in Longitude and Latitude location is respectively between 0.01° (~1km) to 0.02° (~220m) and 0.001° (~100m) to 0.1° (~11km).

Figure 13 (a) shows that magnitude graph trend is the same for the 3 Bulletins. Figure 13 (b) shows that depth are fixed at 0km and 10km for the CTBTO and GFZ respectively. STA shows clear variations.

### Source Mechanim Solutions

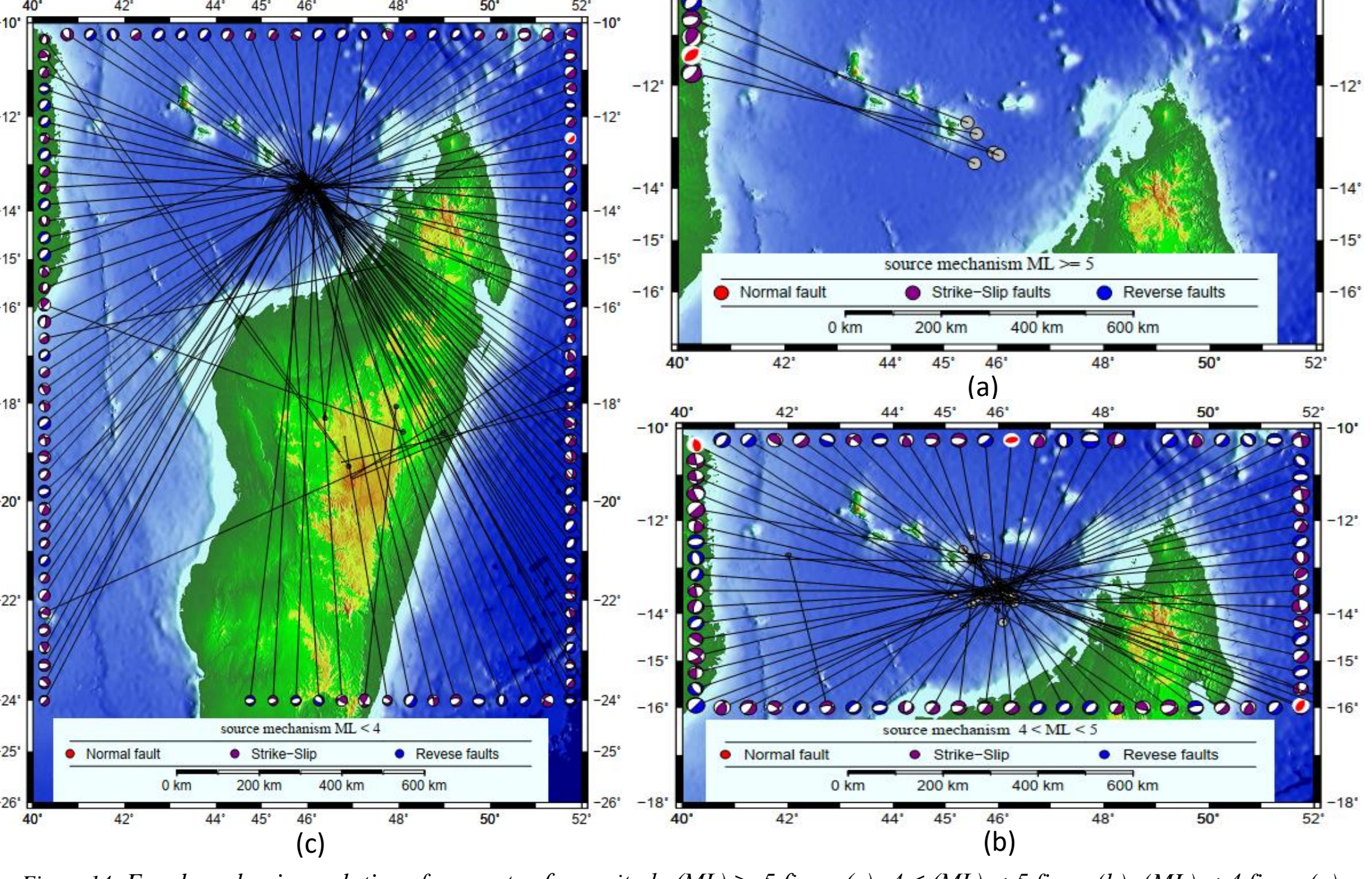
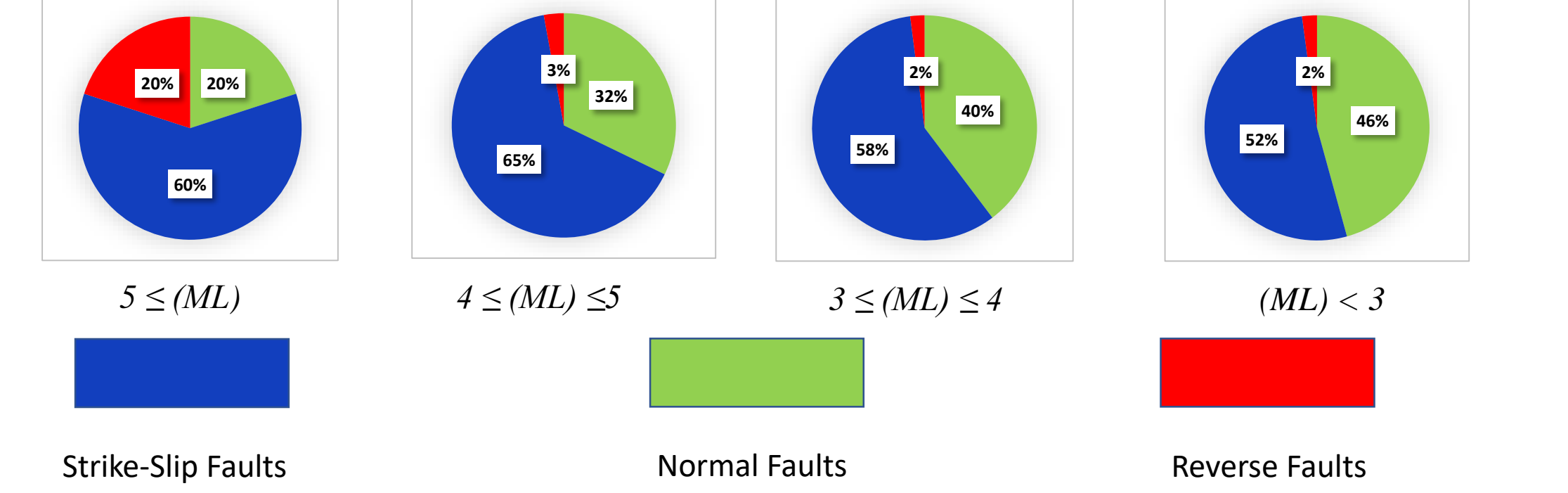


Figure 14: Focal mechanism solutions for events of magnitude (ML) ≥ 5 figure(a); 4 ≤ (ML) < 5 figure(b); (ML) < 4 figure(c)



## 4 Discussion

### Event locations

If we consider that the solutions from GFZ are the exact location of the event, in 94%, those locations are within the error ellips solutions calculated using STA. We can say that results obtained using STA are acceptable.

However, STA's accuracy is higher (96%) when we compare results obtained with the Revised Event Buletin (REB) of the CTBTO. STA is inspired from the Seiscomp software using some of the modules available in SEISAN software. Solutions are more close to the REB since it is obtained using Seiscomp??

Event though STA is still under development, we can say that event locations solutions can be trusted.

### Magnitudes

In general, events with magnitude ML < 4 are not listed in the REB and GFZ's bulletin. As a results, several events were detected only by STA. One of the advantage in using STA is that it uses all the local sismic stations. International, regional, and local stations are combined to provide more detectability of events occurring within and around Madagascar. Magnitudes of each event are very close to the other bulletin. However, in some cases, conversion are necessary in order to compare Local magnitude and body wave magnitudes.

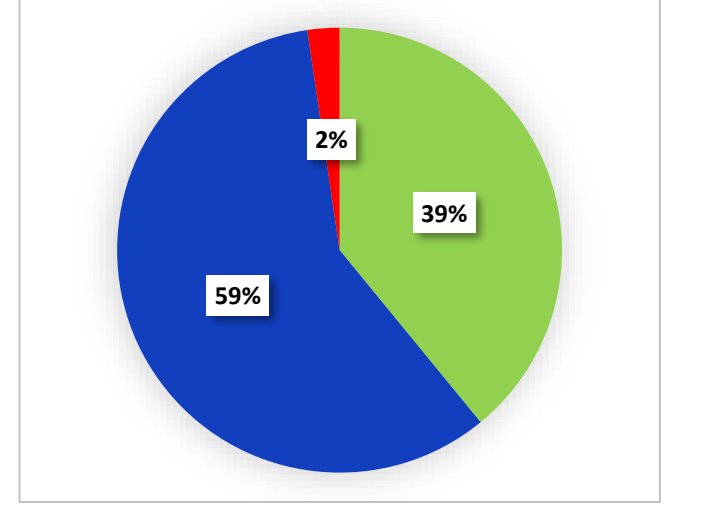
### Depth

STA's bulletin shows more constrain on events' depth, ranging from 0 to 135km. In fact, in REB bulletin depth are fixed at 0km. Mostlikely, events are consider as regional or distant. The same apply to the GFZ's bulletin where depth are fixed at 10km.

In STA, data from local stations are available, they give more control on the depth of events, it explains the constrain in comparison.

### Source mechanism

- In this study, we performed focal mechanism analysis of 906 earthquakes.
- 59% are from Strike-Slip faults,
- 39% are from Normal faults
- 2% are from Reverse faults.



## 5 Conclusion

Even if STA is still under development, we can affirm that the obtained results can be trusted. On 11th of November 2018, another event of ML=5.7 occurred and an extension northwest to southwest is observed (Figure 15).

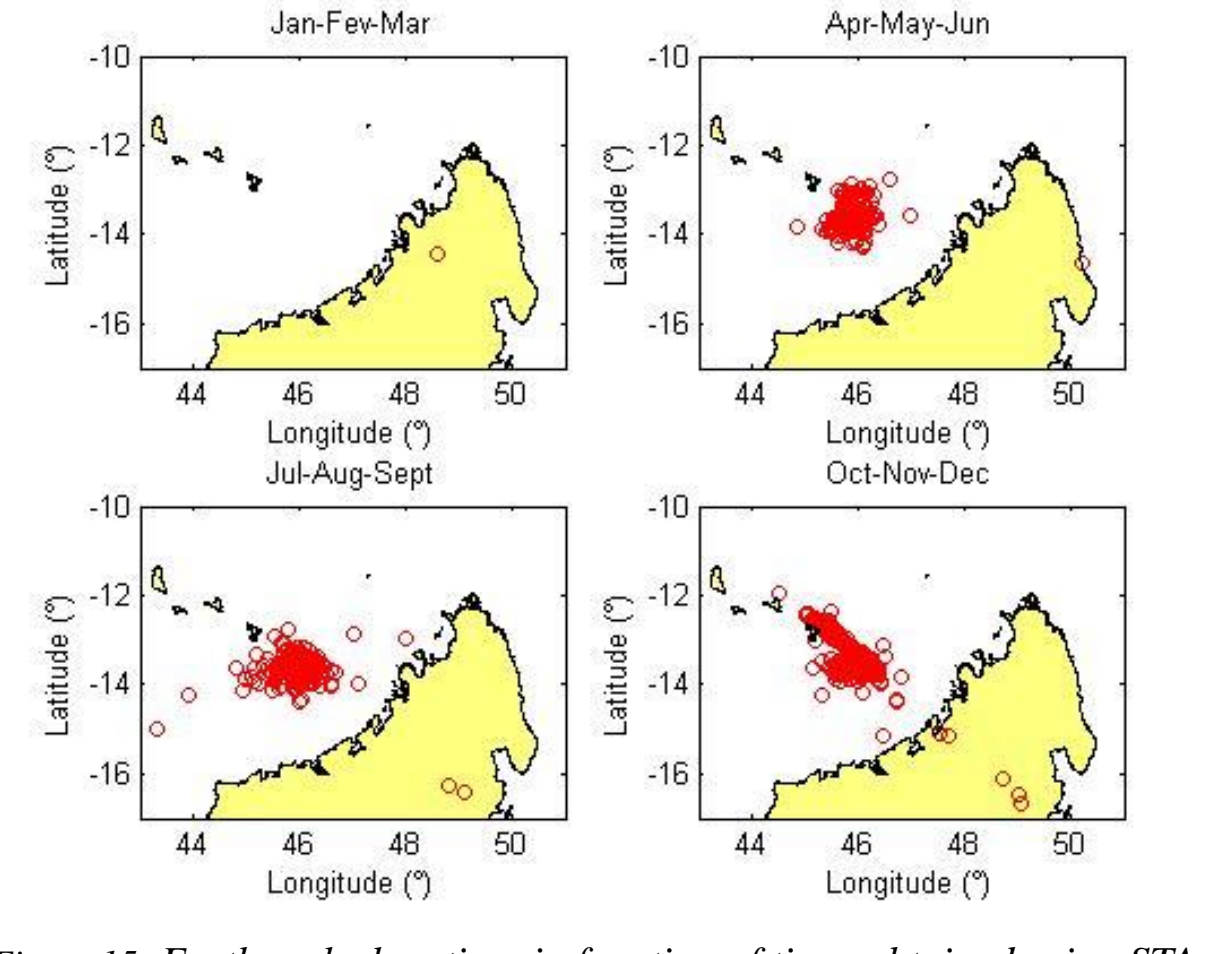


Figure 15: Earthquake location, in function of time, obtained using STA

### Future directions

According to the Institut National de L'information Géographique et Forestière, the Island is sliding more than 2.4 inches to the east and 1.2 inches to the south using GPS stations. A magma body is squishing its way through the subsurface near Mayotte (1, 2018). Tomography analysis in that region is proposed to provide detailed information regarding the origin of those earthquakes.

Figure 17: Ships spy the largest underwater eruption ever? [9]

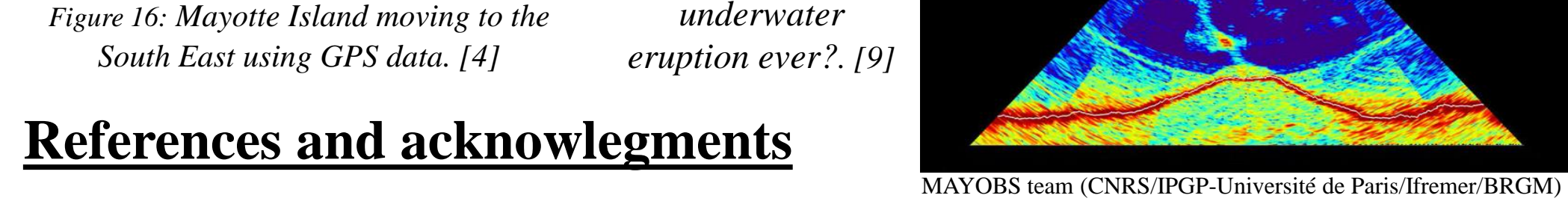


Figure 16: Mayotte Island moving to the South East using GPS data. [4]

### References and acknowledgments

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## 1 Introduction

### Research objectives

On May 15, 2018 at 15:48:05 (GMT), an earthquake of magnitude 5.9 occurred in the North-West of Madagascar. From previous study, the North-western of Madagascar has been classified in the 29<sup>th</sup> seismic zone of Madagascar (Figure 2) and belongs to the 8<sup>th</sup> Category (0.001 earthquake per kilometer) (J. Rakotomalala, 2007).

The BGRM (BGRM, 2018) defines these events as “earthquake swarm” which is an episode of multiple seismic events in a particular zone. In their report, the BGRM indicates that the seismic energy has weakened since July 2018, although some events are still being felt by the population. From the same report, it is mentioned that these events are not causing any major damage and too weak to generate tsunamis.

### Mayotte

Between Mozambique and the North tip of Madagascar, there are 4 volcanic islands aligned along a WNW-ESE direction (Michon, 2016). From the east to west it corresponds to Mayotte, Anjouan, Mohéli and the Grand Comoro (Figure 01).

### Sismicity of Madagascar

In 2007, Rakotomalala defined 29 seismic zones (Figure 2). In her report, those zones were established using two criteria which is the density and the magnitudes of seismic events between 1987 to 2010.

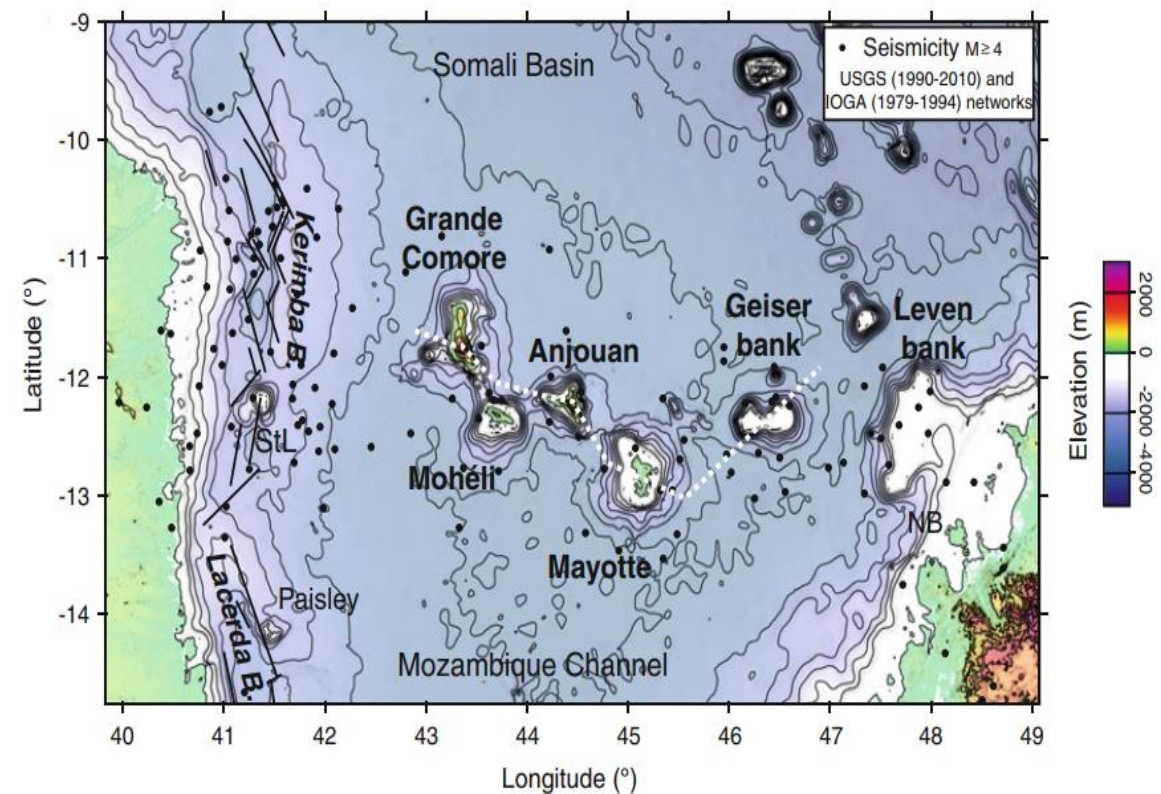


Figure 1: 4 Volcanic islands: Mayotte, Anjouan, Mohéli and the Grand Comoro (Michon, 2016)

Each seismic zones correspond to one of following characteristics:  
 low density and high magnitudes: Zone 2, 15, 24 and 26.  
 high density and low magnitudes: Zone 3, 5, 6, 7, 8, 9, 10, 11, 12, 14, 17, 18, 20, 22, 23, 25, 27 and 28.  
 high density and high magnitudes: Zone1,4,16,13,19,21 et 29.

CATEGORIES	DENSITY = d = per km <sup>2</sup>	Seismic Zones
I	0.095 ≤ d < 0.052	16-19-23
II	0.139 ≤ d < 0.288	17-18
III	0.063 ≤ d < 0.104	9-11-12-14
IV	0.003 ≤ d < 0.018	5-6-7-8-9-10-15-20
V	0.001 ≤ d < 0.009	22-23-25-27
VI	0.001 ≤ d < 0.037	1-2-3-4-13
VII	0.001	24-26
VIII		28-29

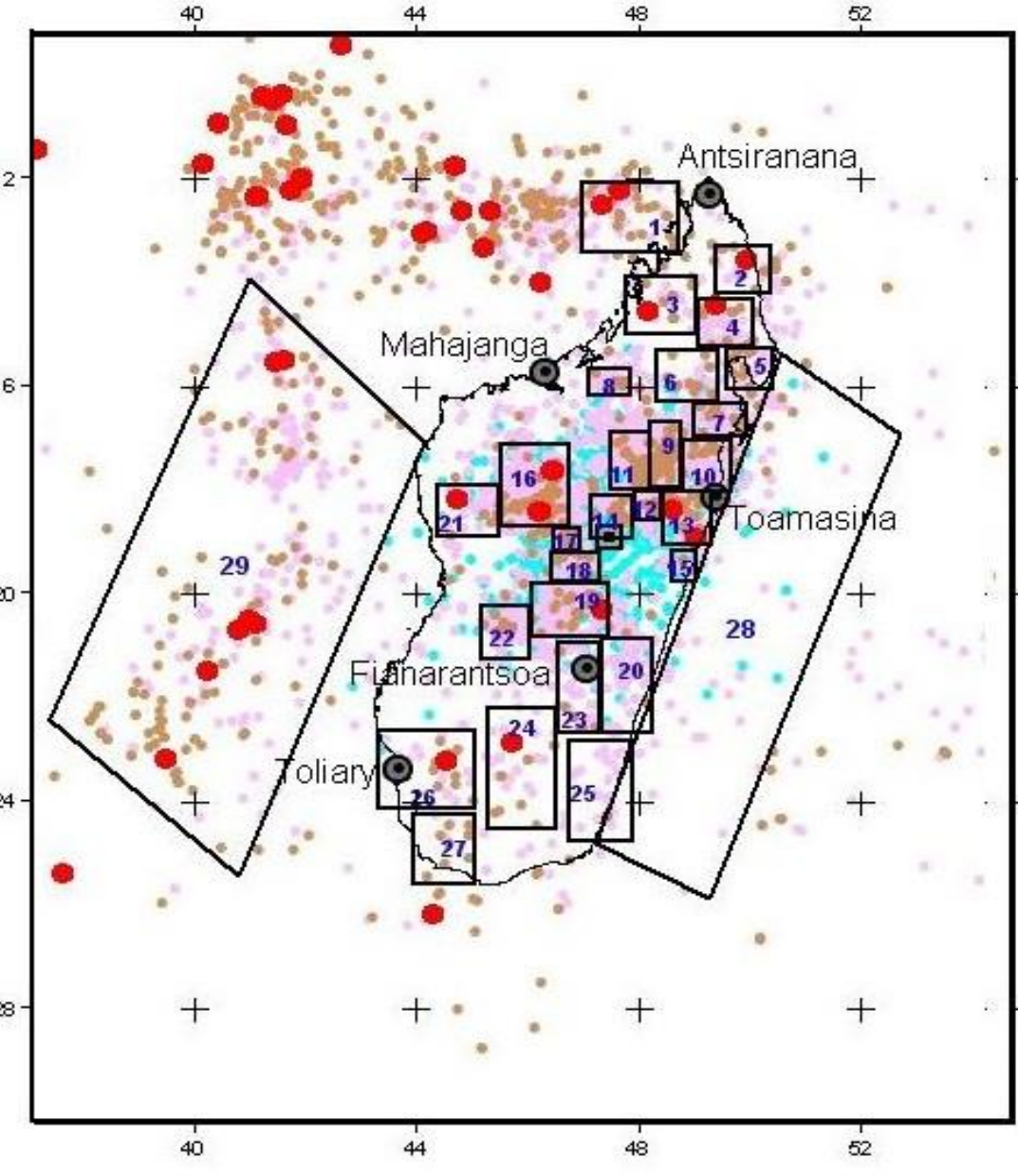


Figure 2: 29 seismic zones of Madagascar. (J.RAKOTOMALALA, 2007)

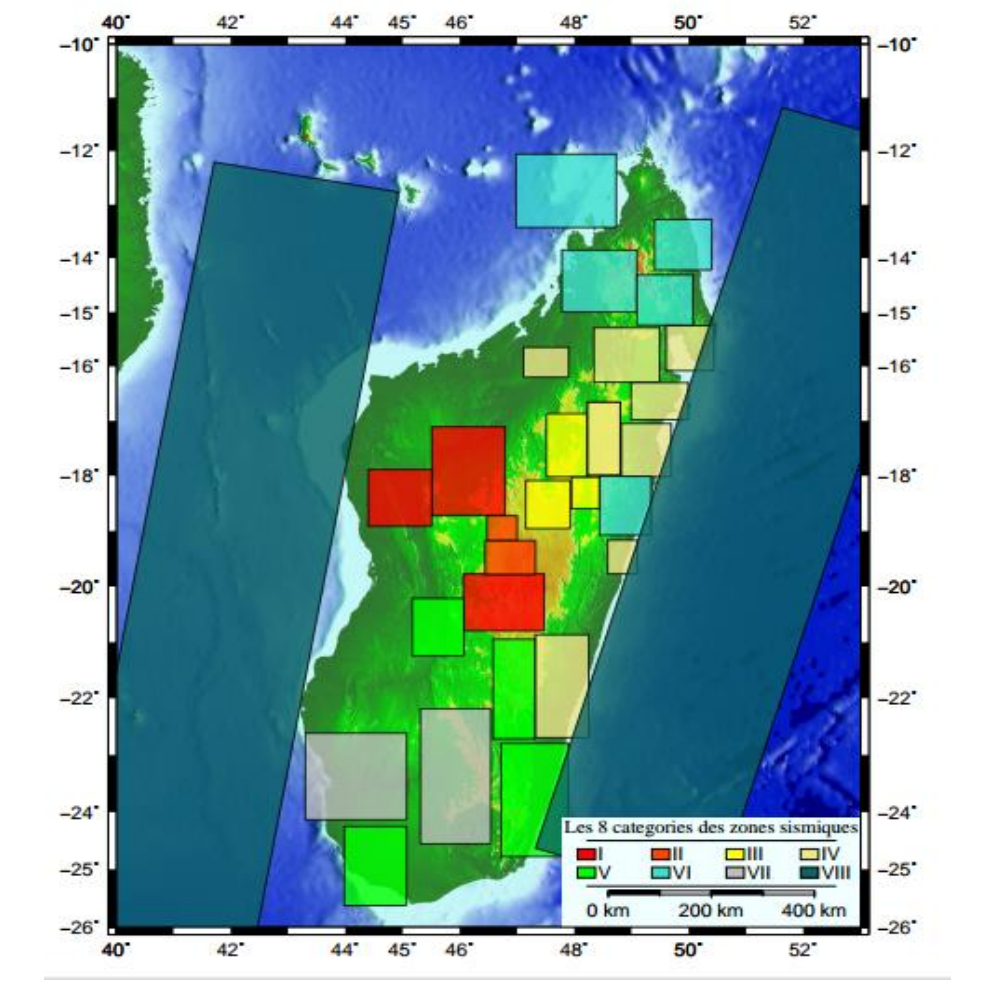


Figure 3: The 8 categories of the seismic zones (J.RAKOTOMALALA, 2007)

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