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Seismic and Infrasound Monitoring of Cyclones in the Indian Ocean, SIMCIO

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1- Intoduction and motivation

In the South-Western of Indian Ocean basin, tropical cyclones occur every year from December to April. As they move over the oceans, cyclones generate strong swells that may represent large sources of microseismic and infrasound noise. A dominant source of noise in the oceans is generated by standing waves, issued from the interaction of two swells of similar periods propagating in opposite directions. Such stationary waves, that may developed within tropical cyclones, generate pressure variations through the water column down to the ocean floor, and create seismic waves that propagate as surface waves (Rayleigh waves) in the oceanic crust and that may be recorded by seismic stations, even at large distances. In the meantime, these stationary waves generate microbaroms' sources that travel in the atmosphere and that are well recorded by infrasound stations.

2- Scientific objectives

We propose to use these two independent observables for tracking cyclones in the SW Indian Ocean, by analyzing data from an infrasound array located at the OPAR / Maido observatory, and from seismic stations from the OVPF volcano observatory.

The objective is to well-known the relationship between sources and oceanic swell during a passage of the storm by using two different techniques (seismic and infrasound).

3- Methodology and experimental set-up

For the seismology, a large number of stations is maintained by OVPF in La Réunion to monitor the volcano activity and will be accessible for the project. Microseisms are generally split into primary (PM) and secondary microseisms (SM). SM, on which we focus this study, have half the period of ocean waves (typically between 3 and 10s) and are induced by a second-order pressure fluctuation generated by interference of swells of similar periods travelling in opposite directions (Longuet-Higgins 1950). SM source regions are detected and located in the ocean basins by techniques such as polarization analyses (Schimmel et al. 2012) in the time-frequency domain and to determine their backazimuth.

For the infrasound, a small aperture array station is operational at the OPAR since Nov. 2014, and will benefit from the CEA expertise on data processing, modelling and interpretation. To locate azimuth of the sources , Progressive Multi-Channel Correlation (PMCC) algorithm [Cansi, 1995] is applied to Maïdo infrasound data, for the duration of the dataset (January 08-21). Infrasound caused by ocean activity is detected at all infrasound arrays in the frequency band 0.1–0.5 Hz, with a peak period of 5 s. Such infrasound signals are called ''Microbaroms'' and are caused by the non-linear interaction of ocean swells in the open ocean [Benioff and Gutenberg, 1939; Posmentier, 1967]. Ocean related infrasound at higher frequencies (1–5 Hz) also is observed, and is thought to be related to surf breaking at the shore [Kerman, 1988].

The complementary networks of seismic and infrasound stations available at the OPAR and the OVPF observatories provide the unique opportunity to combine independent seismological (solid-Earth) and infrasound (atmosphere) observables of a common phenomenon that occur in the heart of the cyclones.

First, as a test case, following the preliminary processing performed by Alexis le Pichon (CEA), we propose to analyze the signature of the cyclone Bansi that passed in the SW Indian ocean in January 2015 and that had a clear signature in both the infrasound and seismic data from La Réunion observatories. We will quantify the variations of amplitude of both the seismic and infrasound signals in the "secondary" frequency band (i.e., between 3 and 10 s of period) during the passage of Bansi. The analysis of the polarization of both signals will allow determining the noise source azimuths by these independent observables.

4- Preliminary results and conclusions

4-1 Seismic results

Two seismic stations (MAID and SALA) located in reunion island (Fig1) are used during the processing for the time period covering the cyclone's passage.

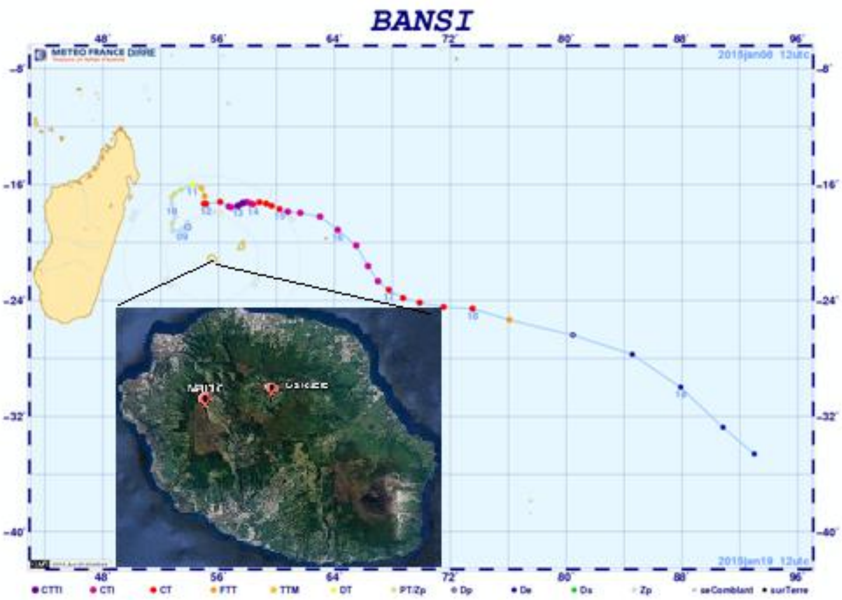

Figure1: Track nad intensity of cyclone Bansi and the two seismic stations(MAID, SALA)

Figure 2 shows histograms of number of detection variation (rigth) for each azimuth (left) during storm period (bottom). We see that microseism sources are clearly not punctual but cover certain angle. It means that sources are dispersed in large region around the cyclone. We observe a sismilarity of detections over the time and a good correlation of azimuth for the two stations MAID and SALA. Many detections are observed at SALA than at MAID station. From January 8 to 12, sources are near the storm and located between 0° and 50° of azimuth at MAID station and dispersed from surrounding the storm 300° -60° for SALA. Generally, they are removed from the storm from January 12 at the two stations, around 110° for MAID and 250° to 100° for SALA.

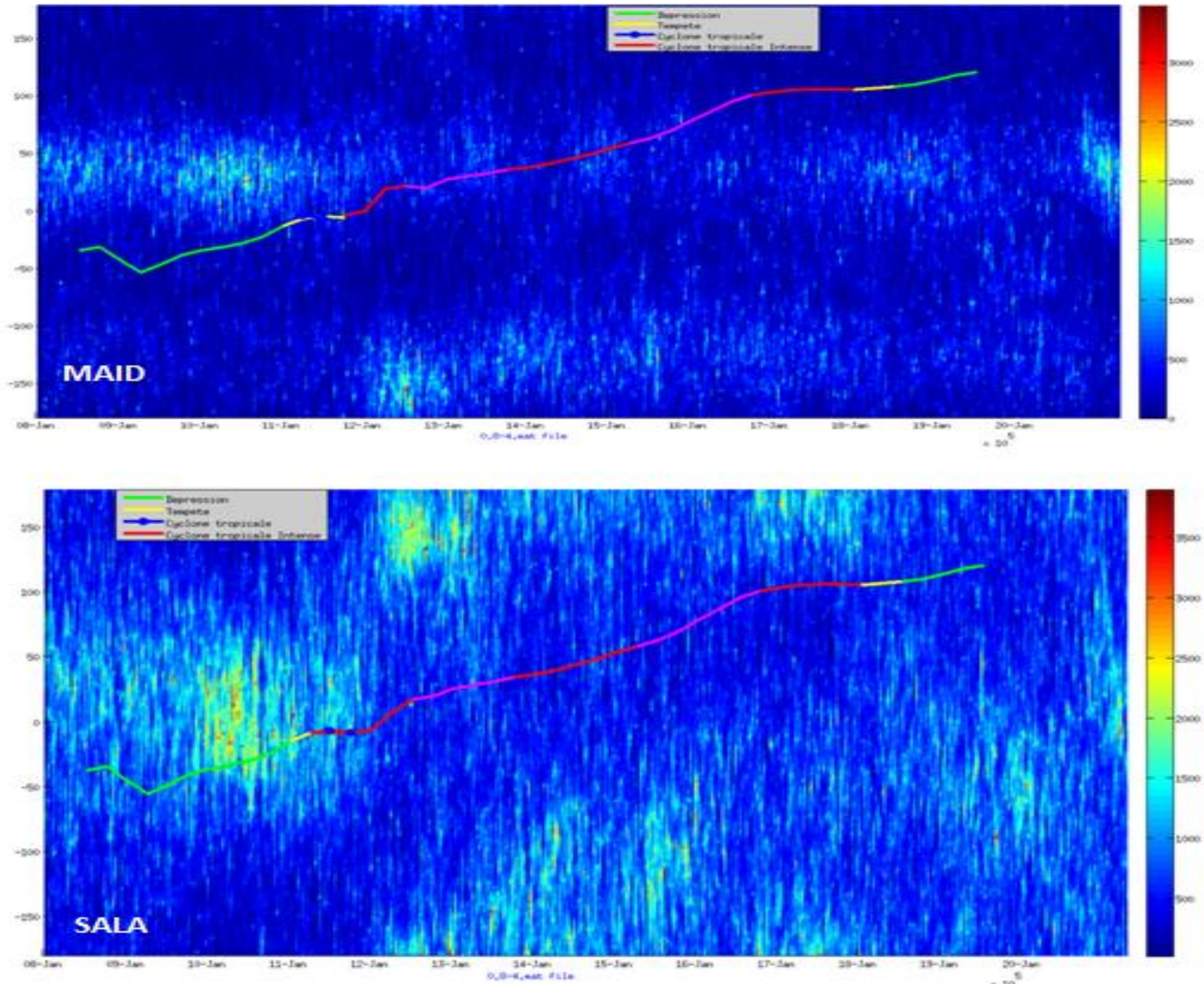

Figure2: Histogram of detection of secondary seismic noises for the seismic stations MAID and SALA with the track of Bansi.

4-2 Infrasound results

Two type of sources are observed at infrasound station (Maido), microbaroms (blue) and surf (red) (fig 3, top). Microbaroms in the 0.1-0.5 Hz frequency band with cyclone’s track are observed from January 11 to 17 (fig 3, bottom). From January 15 to January 16 they are surrounding the storm between 20° to 120° of azimuth and removed from the cyclone’s track elsewhere. Many detections of microbarom sources are observed from January 15.

Note that infrasound station at Maïdo is located near the beach at ~15km, so surf related infrasound has been observed at higher frequencies (1-5Hz) (Garce´s et al., 2003; Le Pichon et al., 2004a). The exact cause of surf infrasound is still unknown but it may be due to the compression or expansion of air resulting from breaking waves collapsing, impacting against a cliff or a shallow reef. At They are mostly observed from January 12 at range of azimuth 0° -90° but few detections from January 8 to 12 at 90°-180° and around 300°.

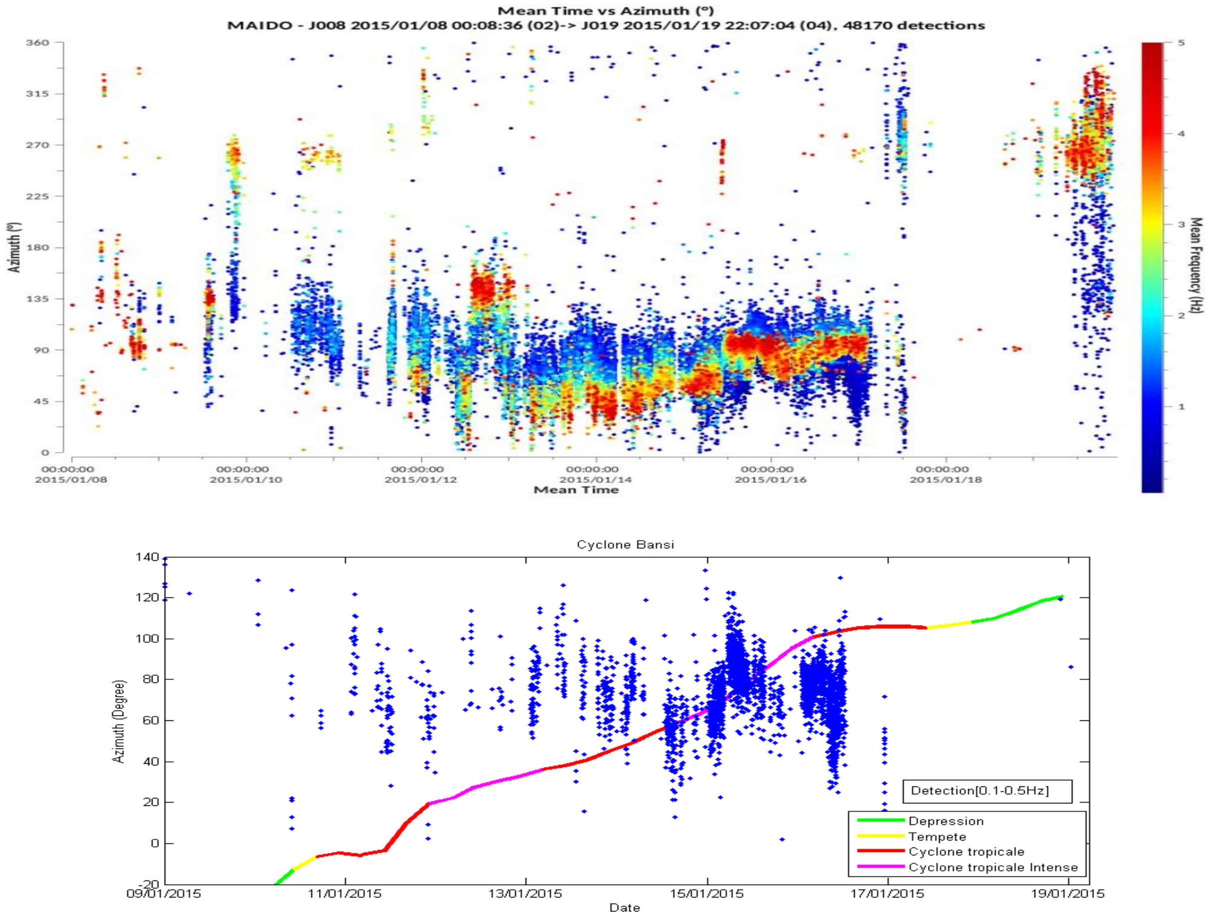

Figure 3: Histogram of detection of microbaroms and surf sources (top) and microbaroms with track of Bansi(bottom)

To conclude, during the period of cyclone, infrasonic and microseismic sources can be detected. For the seismic, Polarization analysis can locate the secondary microseim source. Microbarom sources are detected by infrasound station during the passage of the storm. For the station located near the coast, infrasound sources from surf also are observed

5- Multidisciplinary approach

The geophysics group at the University of Antananarivo (IOGA) are experts in infrasound and in analysing microbaroms to retrieve the source azimuths of these standing waves in the ocean and to locate them by triangulation. Seismologists from the University of La Réunion and from the OVPF developed these last years expertises in analysing the signature of cyclones through the study of amplitude and polarization of microseismic noise. The project will also benefit of the expertises developed by the OSU-R and by the LACy in the cyclone and ocean wave modelling.

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The major impact of this collaboration is to make advances in combining infrasound and seismic data to locate and to track tropical cyclones. The results will be part of the thesis of project leader and should be published in an international journal.

The physical access of this colleague from Antananarivo University to the OSU-R infrastructures is also important to strengthen regional cooperation around the subject of the natural risks and particularly those related to cyclones. Cyclones modelling, monitoring and the associated risks are indeed the focus of the RENOVRISK program carried by researchers from the OSU-R that will be submitted to the FEDER – INTER-REG program in 2016 and that will include the colleagues from both the IOGA and the meteorological services from Madagascar.

6- Outcome and future studies

Second, we propose to enlarge the view and to incorporate seismic and infrasound data from regional networks (infrasound stations are available in Madagascar and Africa and seismic stations in La Réunion, Mauritius and Madagascar). This will allow to locate the sources of noise by triangulation and to track their displacements as the cyclone is moving and changing of dynamics.

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