RECENT ENHANCEMENTS OF THE PMCC INFRASOUND SIGNAL DETECTOR

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Context

The Progressive Multi-Channel Correlation Method (PMCC), originally designed for seismic arrays, proved efficient at detecting low-amplitude, coherent infrasonic signals within incoherent noise (Cansi, 1995; Cansi and Klinger, 1997; Le Pichon and Cansi, 2003).

The PMCC detector was originally developed by the CEA/DASE and was installed in 2004 in the operational environment of the International Data Centre (IDC) of the Comprehensive nuclear Test-Ban Treaty Organization (CTBTO) in Vienna, Austria. PMCC has performed well in terms of detection sensitivity and robustness.

Atmospheric infrasound signals are observed across a wide frequency range (~0.01-20 Hz, Campus and Christie, 2010). We may consider three general frequency bands of interest:

- Above 0.5 Hz: impulse signals of natural or man-made origin, which may propagate over distances of several hundred kilometers.
- Between 0.1 and 0.5 Hz: microbaroms and isolated large remote events such as explosions, meteorites and volcanoes.
- Below 0.1 Hz: large-scale atmospheric disturbances such as mountain associated waves and auroral infrasound.

For each of these frequency bands, PMCC parameters must be optimized at a compromise between a low detection level and a low number of false alarms. One of the major differences between these configurations is the duration of the sliding time-window and the frequency band spacing.

For standard processing of IMS-type infrasound arrays, the window length required ranges from tens to hundreds of seconds. In previous releases of WinPMCC, the window length remained constant during a processing run. Hence, previous PMCC processing at the CEA/DASE was performed in multiple separate, independent runs with different target signal frequencies.

During the last 5 years, several changes have been made to enhance the PMCC source code at the CEA/DASE (WinPMCC) and at the IDC (DFX/Geotool-PMCC). Studies have shown the benefit of implementing an adaptive window length and log-spaced frequency bands (Brachet et al., 2010).

Frequency-dependent parameters

Figure 1 illustrates the window lengths and frequency bands considered in two separate standard PMCC processing runs used to target low- (0.02-0.5 Hz) and high-frequency (0.1-4 Hz) bands. This is compared to a new single processing run with log-spaced frequency bands (0.01-5 Hz) and window lengths that vary linearly with the period.

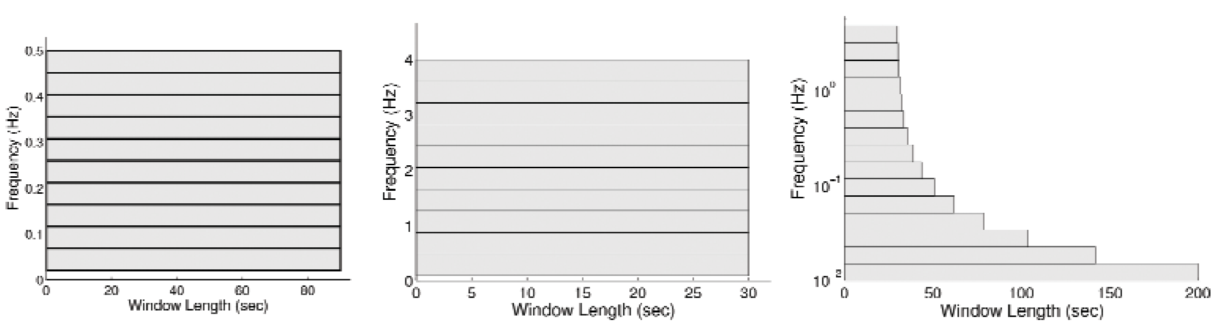

Fig 1. Examples of two 10-band standard configurations for low- and high-frequency processing (0.02-0.5 Hz and 0.1-4 Hz, left and middle respectively), replaced by a single configuration consisting of 15 bands with log-spaced filter parameters (0.01-5 Hz) and a variable window length.

In addition to the window length, bandwidth and filter parameters (filter order and ripple), the following detection parameters can now be adjusted as a function of frequency:

- TimeStep (s): overlap between two consecutive time windows is now defined as a fraction (%) of the window length.
- ThresholdNbSensors: minimum number of sensors required for detection.
- QLambda: threshold distance Q.λ for integration of a new sensor in a growing sub-network (aggregation of a new sensor if its distance from the barycentre of the growing sub-network is smaller than Q.λ).
- ThresholdConsistency (s): maximum consistency and threshold for detection.

Also, the parameters controlling the clustering of detections (pixels) into families can be varied as a function of frequency:

- ThresholdDate (s): maximum time difference between a pixel and a family.
- ThresholdDistance: maximum acceptable dimensionless Euclidean distance in the time-frequency-speed-azimuth domain when integrating a candidate pixel into a growing family.
- Sigma_t (s): maximum distance in time between a given pixel and a family. It must be higher than TimeStep, otherwise no integration of pixel in family can occur. If no more pixels can be integrated because of this condition, the family is closed.
- Sigma_f (Hz): maximum distance in frequency for integration of a pixel into a family.
- Sigma_a (°): maximum distance in azimuth for integration of a pixel into a family.
- Sigma_v (%): maximum distance in velocity for integration of a pixel into a family.

For full explanations of these parameters, the reader is referred to the WinPMCC User Manual.

Application to IMS data

Figure 2 presents an example of multi-year processing using a single log-spaced configuration (Figure 1) at IMS station IS22 (New Caledonia). Two main natural sources of infrasound waves are detected:

- Below 0.1 Hz, signals consistent with Mountain Associated Waves (MAW) generated by tropospheric wind flow over high mountain ranges are detected.
- From 0.1 to 0.4 Hz, microbaroms are continuously observed. In the southern hemisphere, microbarom signals (e.g., Garcés et al., 2004) are mainly produced by large swell systems and severe storms driven by strong continuous eastward surface winds, circulating along the Antarctic Circumpolar Current (ACC). When monitored over several years, a clear seasonal transition in the bearings along with the stratospheric general circulation between summer and winter is observed.
- Above 0.5 Hz, at backazimuths between 0-50°, persistent detections are associated with active volcanoes in the Vanuatu archipelago (Lopevi/Ambrym, and Yasur). As with microbaroms, seasonal azimuthal variations are observed. These volcanic signals arrive with unique backazimuth values and dominant frequencies resulting from differences in propagation (Le Pichon et al., 2005).

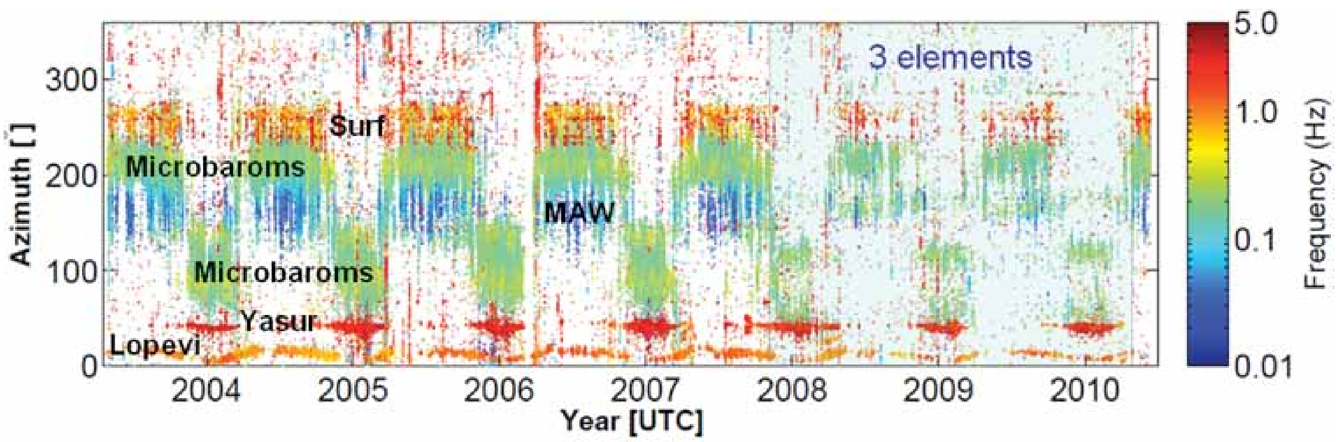

Fig. 2. PMCC processing of IS22 (New Caledonia) from 2003 to 2010 using the 15-band log-scaled filter parameters (0.01-5 Hz) and variable window length illustrated in Figure 1. From 2008 to 2010, the reduced detection capability is explained by a missing central array element.

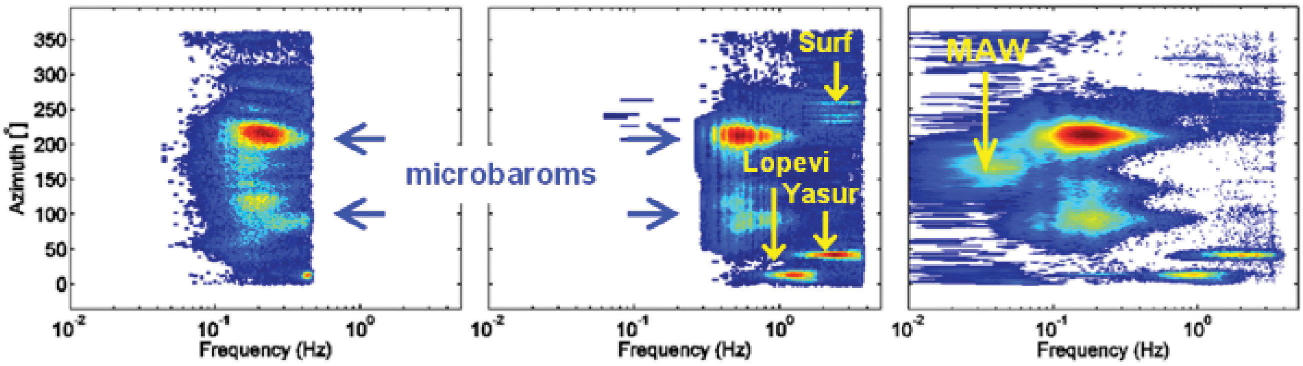

Fig. 3. Comparisons between processing results using two 10-band low- (0.02-0.5 Hz) and high-frequency (0.1-4 Hz) configurations (left and middle, respectively) and a 15-band log-spaced configuration (0.01-5 Hz, right). Warm colors correspond to increasing number of detections in frequency-azimuth space.

- Above 1 Hz, in the backazimuth range from 230–260°, signals are caused by surf action (e.g., Arrowsmith and Hedlin, 2005). Ocean waves from low-pressure systems in the south Pacific propagating towards New-Caledonia generate such signals when breaking on its reefs.

Figure 3 compares processing results from the standard low- and high-frequency configurations and the new log-spaced configuration (Figure 1) applied to IS22 2004-2006. The main results are:

- The main sources detected independently using the low- and high-frequency configurations are also clearly detected using the log-spaced processing (e.g., microbaroms, volcanoes and surf signals).
- With the high-frequency configuration, coherent microbarom signals are found up to 1 Hz, whereas in the log-spaced processing they are found between ~0.1-0.4 Hz. The log-spaced processing allows a more accurate estimation of signal frequency content, particularly at low frequencies.
- Between 20 and 50 s periods (0.02-0.05 Hz), during the austral winter, signals consistent with MAW are detected using the log-spaced processing. The corresponding backazimuths range from 180-200˚. These signals, perhaps produced over high mountain ranges in New Zealand, have also been reported at much larger range at IS55 (Windless Bight, Antarctica) (Wilson and Olson, 2003).

Conclusion

These results clearly show that the log-frequency-spaced implementation of PMCC is well-adapted for infrasound data processing across a wide frequency range (more than two decades) in a single processing run. There are several advantages to this new process:

- Only one processing run is necessary to cover the full frequency range of interest.
- There is no need to develop grouping methods for signals appearing in separate PMCC processing runs.
- A smoother, more continuous sampling of parameter frequency space (no discontinuities).
- Improved accuracy of estimated frequency dependent wave parameters (enables better source detection and discrimination).
- Shorter computation time (~1 week to process 2 years of data for one 4-element array on one Intel® Xeon® Processor X5460 @3.16 GHz Linux system).

The new release of the WinPMCC and PMCC detection algorithm software, running under Windows or Linux operating sytems, allows full configuration of filtering and detection parameters as described in this article and is now available by request.

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