CAGMon Tool: Identifying and Diagnosing Coherent Associations and Causalities between Multi-channels of the Gravitational Wave Detector

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Abstract

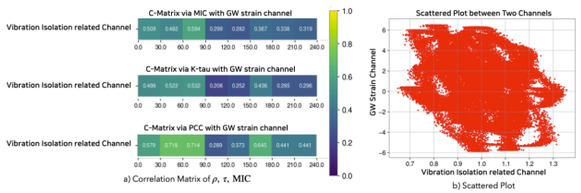
The gravitational-wave detector is a very complicated and sensitive collection of advanced instruments, which is influenced not only by the mutual interaction between mechanical/electronics systems but also by the surrounding environment. Thus, it is necessary to categorize and reduce noises from many channels interconnected by such instruments and environment for achieving the detection of gravitational waves because it enhances to increase of a signal-to-noise ratio and reduces false alarms from coincident loud events. For this reason, it is of great importance to identify some coherent associations between complicated channels. This study presents a way of identifying (non-) linear couplings between interconnected channels by using some correlation coefficients, which are applied to practical issues such as noises by hardware injection test, lightning strokes, and air compressor vibrations gravitational-wave detector.

Goal

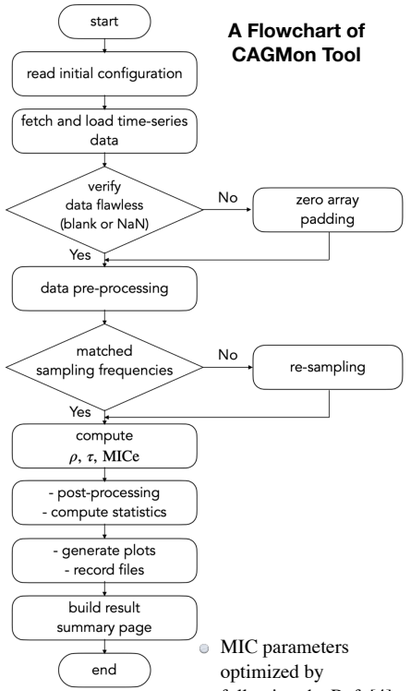
- To identify the association between GW channel and other auxiliary channels of instruments and environments monitoring devices that cause harmful transient or continuous noises
- To use three correlation measures - Pearson's correlation coefficient (PCC), Kendall's tau correlation (Ktau) and Maximal Information Coefficient (MIC)
- MIC determines the non-linear correlation between two random samples whereas other two indices provides linear relationship

Method

- PCC [1] : $\rho(x,y) = \dfrac{\sum_i (x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_i (x_i-\bar{x})^2 \sum_i (y_i-\bar{y})^2}}$
- Ktau [2] : $\tau(x,y) = \dfrac{(c-d)}{{}_nC_2}$ c: # of concordant pair, d: # of disconcordant pair
- MIC [3] : $MIC_e(x,y;\alpha,c) = \max_{ab<B(n)} \{\dfrac{\max I[*](S,k,l)}{\log_2 \min\{k,l\}}\}$



CAGMon Tool FOMs

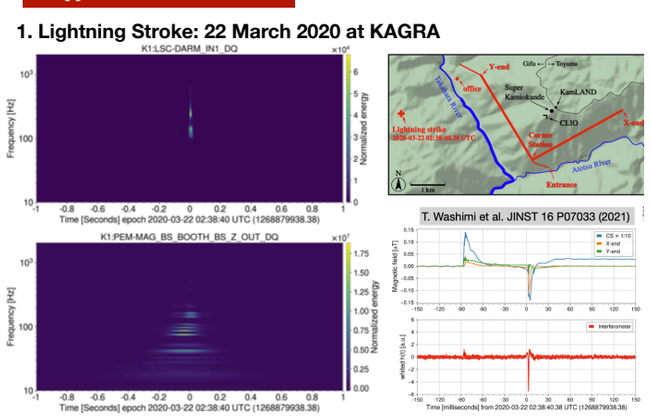


A Flowchart of CAGMon Tool

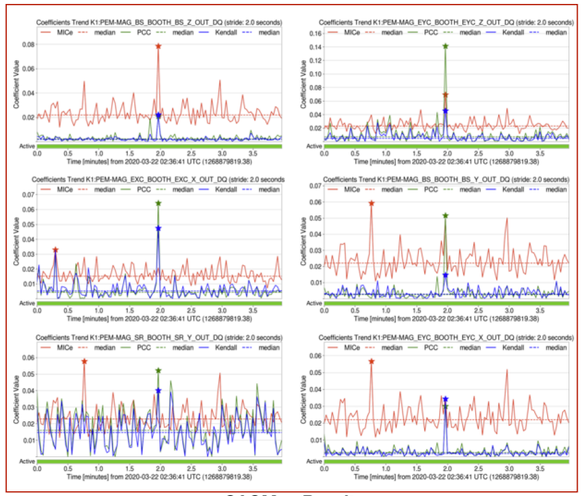
- MIC parameters optimized by following the Ref. [4]

Application to GW Data

1. Lightning Stroke: 22 March 2020 at KAGRA

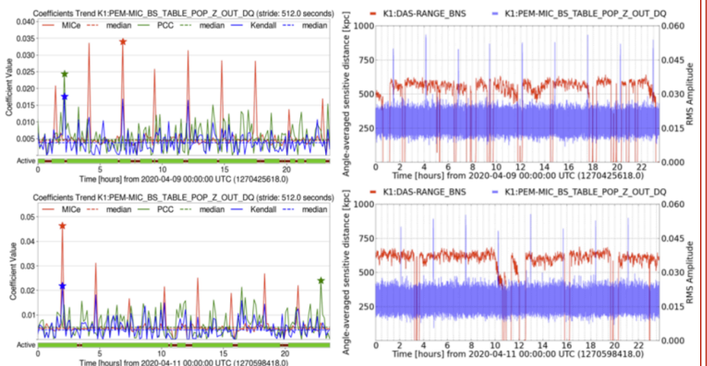


- Lightning Stroke found near KAGRA at 22 Mar. 2021 [5]
- Confirmed EM effect of Lightning propagated to KAGRA



CAGMon Results

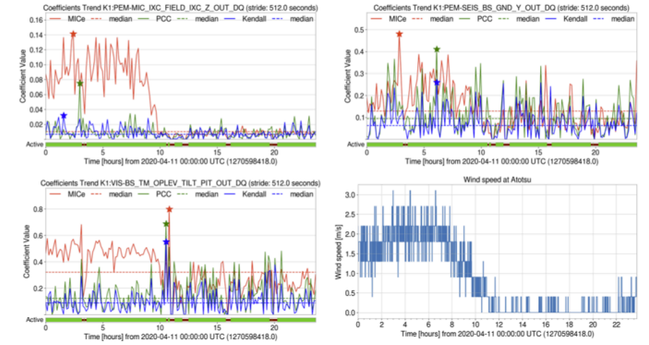
2. GW Sensitivity Range Drop by Air Compressor Periodic Noise



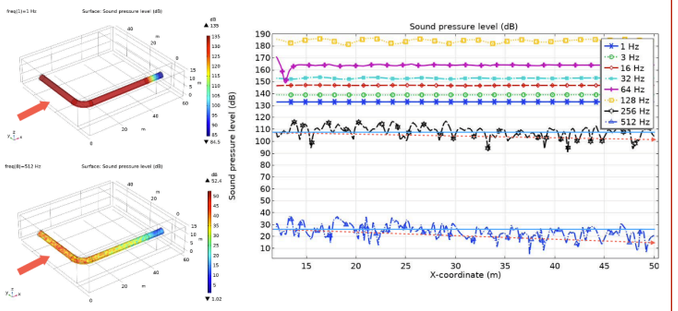
CAGMon Results **Periodic Range Drop**

- Correlated peaks with a harmonic f=26.5 in 2.58 hours/day
- Strong non-linear signature of both channels of GW and MIC channels
- New discovery found by CAGMon in KAGRA

3. Acoustic Noise induced by Strong Winds



- Strong winds found in a day time (9AM-7PM) between valley of IKENO Mt.
- PEM MIC channels are affected by this wind effects in the underground facilities
- Strong non-linear correlations between MIC-GW channels
- Seismic vibration by strong winds propagates to the tunnel of KAGRA, then excites the acoustic pressure level (FEM simulation below)



References

[1] K. Pearson, Biometrika 13, 25 (1920).
[2] M. G. Kendall, Biometrika 30, 81 (1938).
[3] D. N. Reshef, Y. A. Reshef, H. K. Finucane, S. R. Grossman, G. McVean, P. J. Turnbaugh, E. S. Lander, M. Mitzenmacher, and P. C. Sabeti, Science 334, 1518 (2011).
[4] P. Jung, S. H. Oh, Y.-M. Kim, E. J. Son, and J. J. Oh, arXiv:2107.03516 [astro-ph.IM].
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