Data Quality studies for low frequency non-stationarity present in LIGO science data

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Abstract

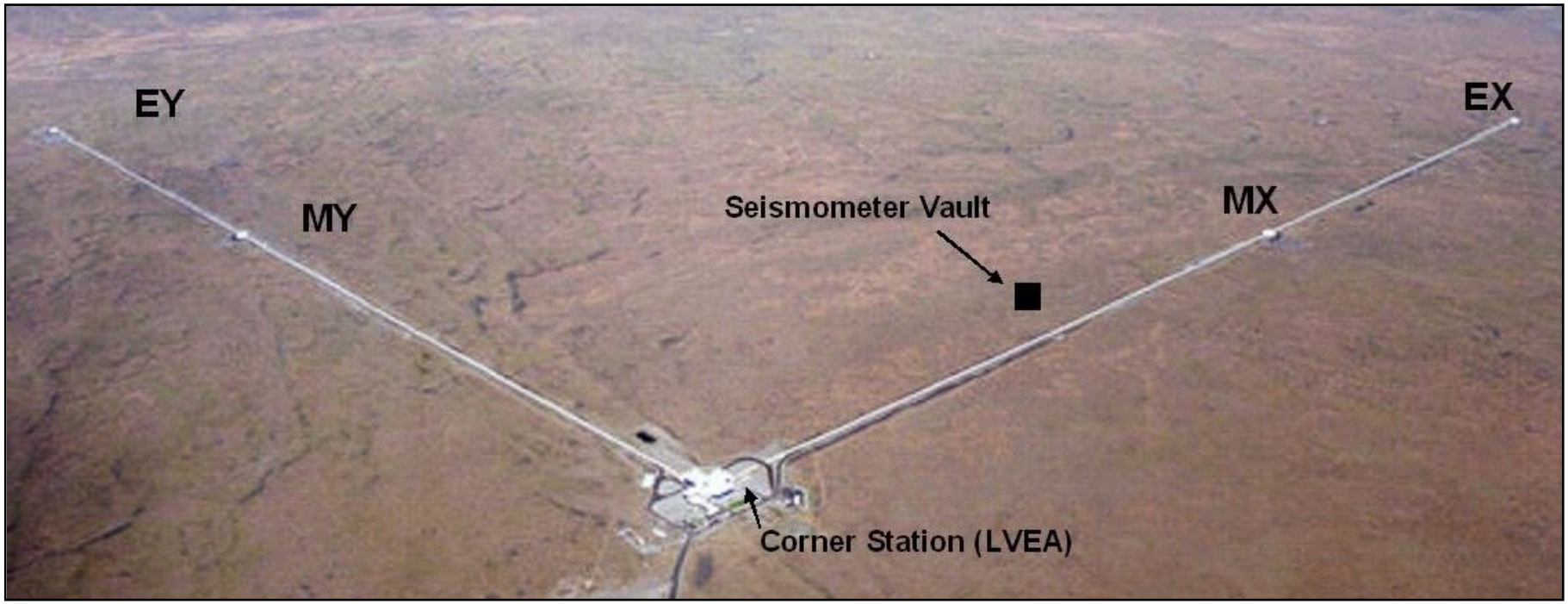
One of the important issues in detector characterization and noise analysis in gravitational wave (GW) detection by ground-based instruments is the seismic background. “NoiseFloorMon” is a data monitoring tool (DMT) that has been developed to help characterize the effect of seismic activity on the gravitational wave channels at both LIGO sites, and to identify instances of low-frequency non-stationarity. Cross-correlation measurements between the GW channel and seismic sensors that exceed a median-based threshold serve as pointers to time intervals of non-stationarity. Highest threshold crossings are recorded on a daily basis and the events are followed-up using time-frequency visualization methods of both the GW channel as well as the environmental channels involved. These events are also compared with existing figures of merit (FOM) and data quality (DQ) flags to find further correlations with other possible sources across the detector and in the environment. An example of the method is shown with LIGO S4 data.

Introduction

- NoiseFloorMon[1] is a median-based noise floor tracker in operation at LIGO-Livingston and LIGO-Hanford
- The monitor tracks slow non-stationary epochs as opposed to glitches or sharp transients.
- The monitor was developed in 2005 and tested on-site and has been in operation throughout S5 and S6
- **The goal of the analysis is to indentify low frequency non-stationary epochs in the gravitational wave channel that are associated with seismic channels.**

[1](i) Environmentally induced nonstationarity in LIGO science run data, Robert Stone and Soma Mukherjee, Classical and Quantum Gravity, 26, 204021-31, 2009.
(ii) Development of a DMT monitor for tracking slow non-stationarities present in LIGO science data. Soma Mukherjee for LIGO Science Collaboration, Journal of Physics conference series, 32, 44-51, 2006.

PEM Channels



- NoiseFloorMon records cross-correlation values between the main gravitational wave channel and the physical environmental monitor channels at the locations shown above.

Coupling between the seismic and gravitational wave channels

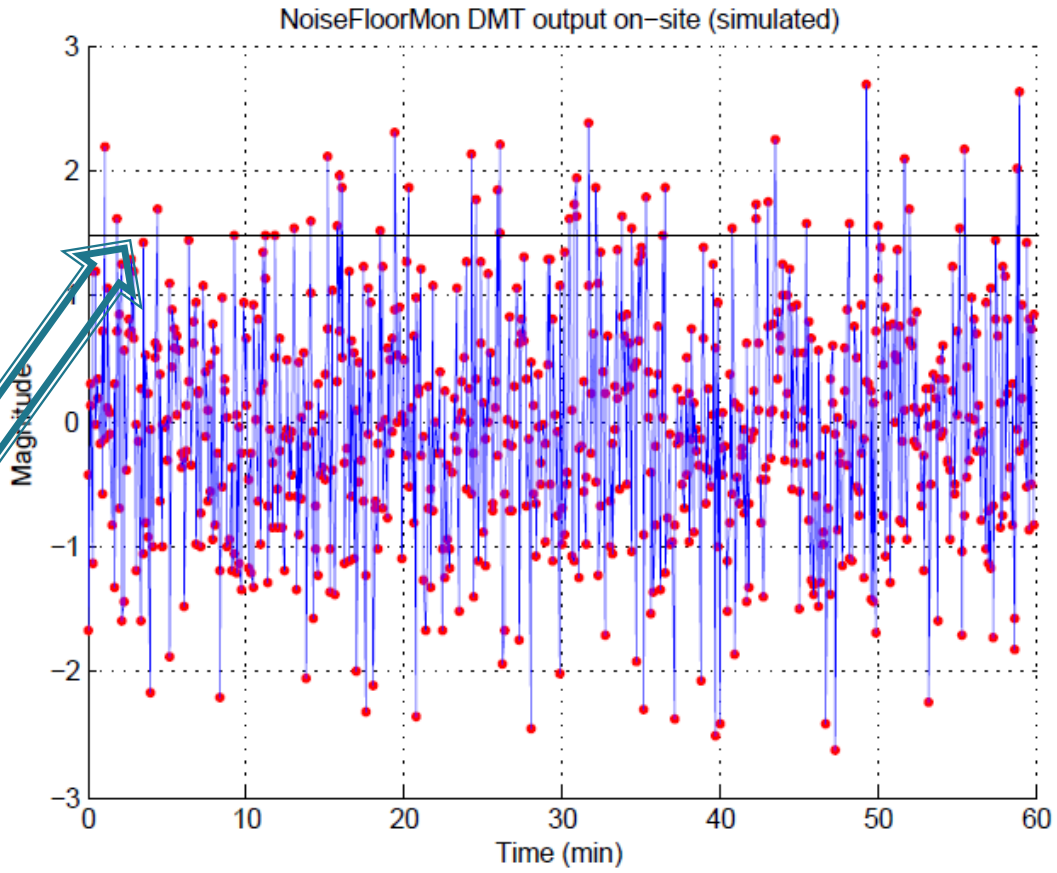
- The mechanism by which seismic activity affects the gravitational wave channel is not completely understood.
- Low frequency seismic motion can appear as glitches in the gravitational wave channels through a process known as upconversion.[2]
- Studies indicate a correlation between changing current direction in suspension system coils and low frequency nonstationarity[3]

[2] Schofield, 2009, LIGO Document G0900877-v3

[3]Garofoli, 2009, LIGO Document G0900990-v2

NoiseFloorMonDMT

- The cross-correlation between the gw and seismic channels is monitored in 0-16 Hz, 16-32 Hz, 32-64 Hz, and 64-128 Hz bands to narrow the search for low frequency disturbances.
- An adaptive threshold to indicate nonstationarity is set. Minute trends are recorded.



Online output of the NoiseFloorMon DMT

Auxiliary Channels

H0:PEM-

EX_SEISX	EY_SEISX
EX_SEISY	EY_SEISY
EX_SEISZ	EY_SEISZ
LVEA_SEISX	MX_SEISY
LVEA_SEISY	MY_SEISX
LVEA_SEISZ	MY_SEISY
MX_SEISX	MY_SEISZ
MX_SEISZ	

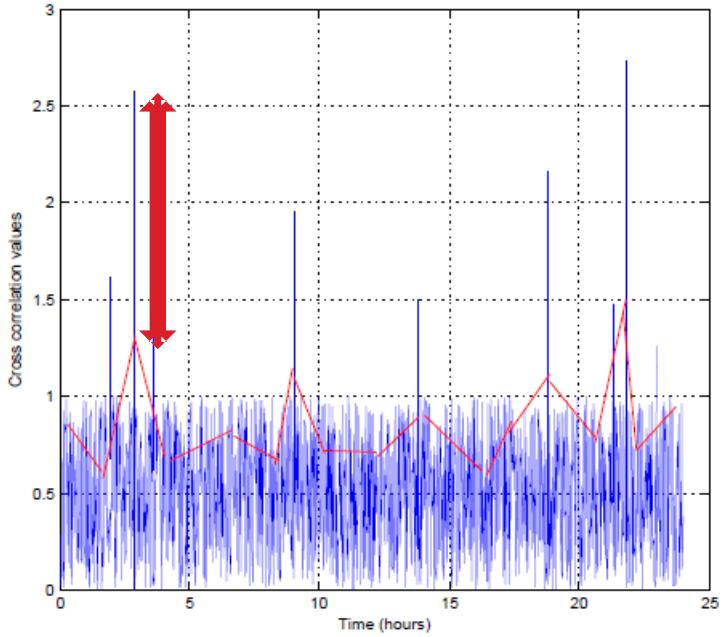
L0:PEM-

EX_SEISX	EY_SEISX
EX_SEISY	EY_SEISY
EX_SEISZ	EY_SEISZ
LVEA_SEISX	LVEA_SEISY
	LVEA_SEISZ
There are no mid-tube seismometers at LLO	

Output is produced for cross-correlations between the gravitational wave channel and the channels listed above in each of the four different frequency bands.

Offline Analysis

- A median-based algorithm is used to set the threshold for offline analysis.
- The top 10 threshold crossings across all seismic channels are identified daily. The criterion used is the distance from the threshold as indicated by the arrow.
- The following pipeline shows the connection between the online and offline analyses.



Simulated output of NoiseFloorMon offline analysis

Pipeline

Online analysis shows threshold crossings denoting nonstationary time periods

The maximum excursion outside the threshold is recorded every minute. These excursions are accessed for use in the offline analysis.

DMT OUTPUT

Merge frame files from repository containing intervals of interest

Generate time series and tf plots around threshold crossings

ID non-stationarity in GW channel

DATA QUALITY FLAGS generated according to non-stationarity in GW channel

ID top 10 threshold crossings across all channels and frequencies per day

ID Seismic Correlations between PEM and GW channel

ID Daily trend in GW channel

OFFLINE ANALYSIS

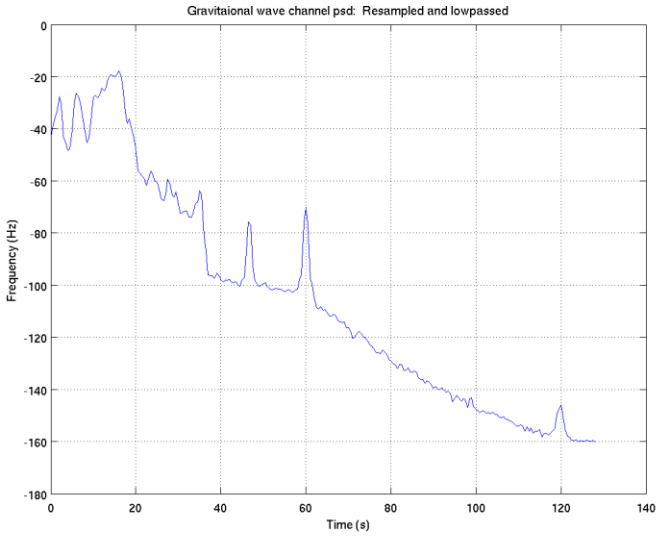
ID those times observatory was in data-collecting mode (science segments)

Data Quality Flags

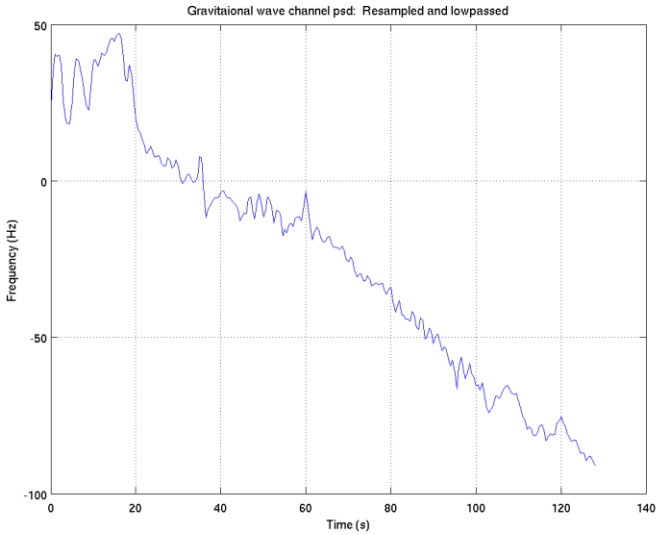
- Data quality flags indicate conditions that affect the quality of the gravitational wave data. The flags are categorized by severity.
- The most severe flags indicate the data is unusable. The least severe flags indicate that the data should be analyzed within limits dictated by the prevailing conditions.
- Data quality flags indicating nonstationary epochs are generated at the end of the NoiseFloorMon pipeline. Gravitational wave data should be analyzed with the understanding that seismic activity produced periods of noisefloor nonstationarity.

Data Conditioning Process

- The gravitational wave data is downsampled twice and lowpassed to eliminate high frequency noise that would dominate the sample.
- The gravitational wave channel power spectral density provides information about lines in the data.



*In this sample there are prominent lines at 48 Hz, 60 Hz and 120 Hz.



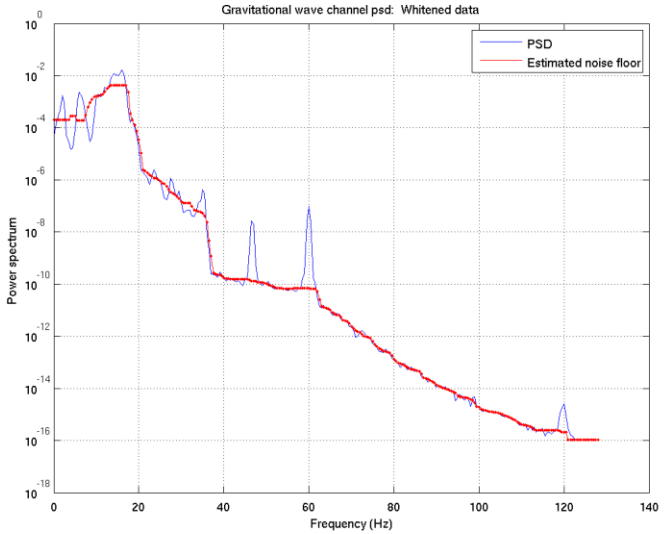
*In contrast to the left-hand plot, increased seismic activity on this day caused fluctuations throughout the spectrum .

*LIGO S4 data

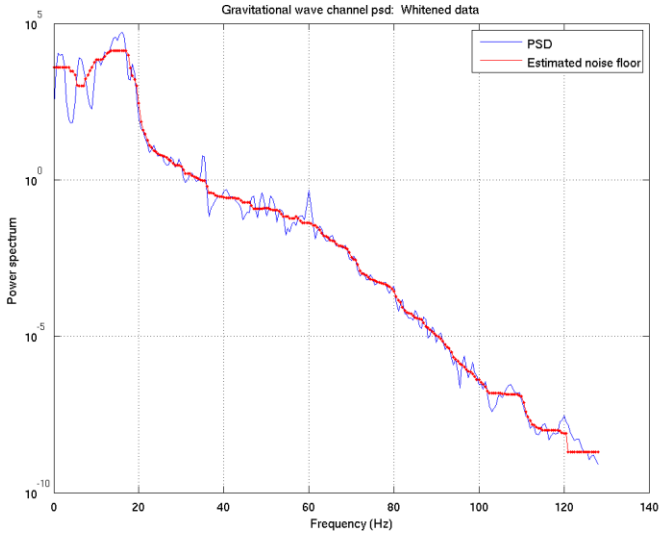
Determining the noisefloor

- We define the noisefloor as the spectrum that results when known lines are removed.

- A **median-based noisefloor tracker**[4] is applied to the spectra. A median is determined for a group of points and applied to the data.



Typical seismic activity

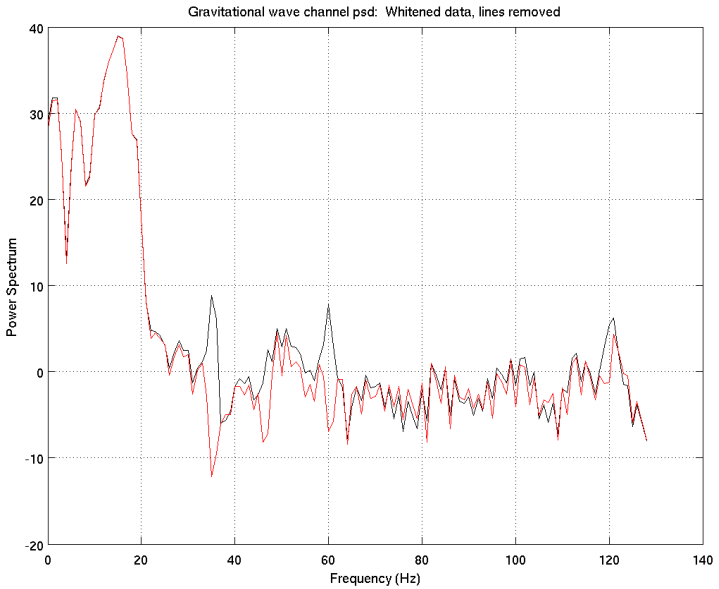


Increased seismic activity

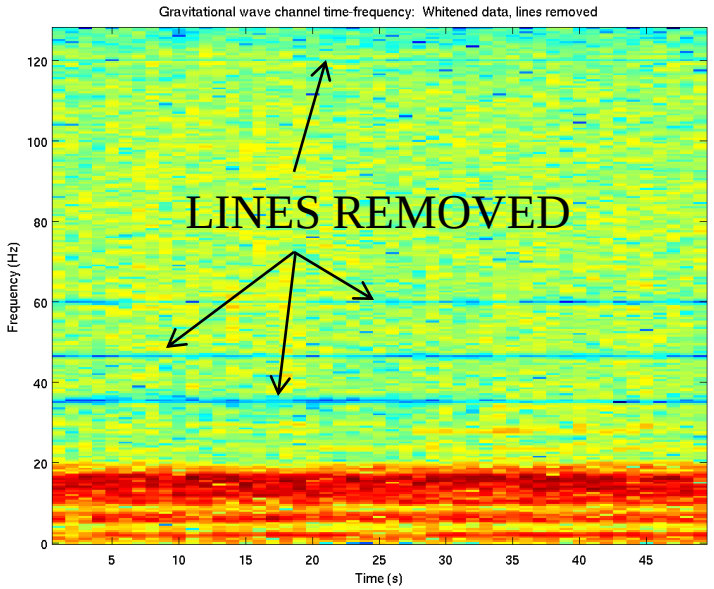
[4]Median based noise floor tracker : robust estimation of noise floor drifts in interferometric data. Soma Mukherjee, Classical and Quantum Gravity, 20, S925-S936,2003

LIGO S4 data

Data whitening and line elimination

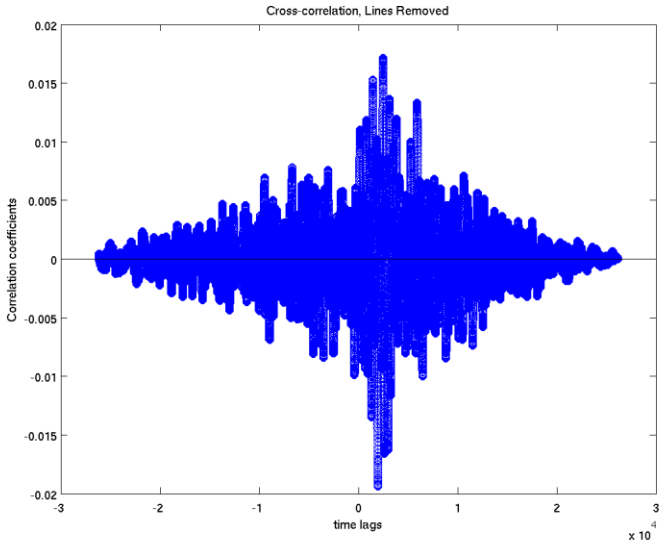


The black curve shows the original spectrum before data whitening. The red curve shows how whitening removes the lines.



The time-frequency representation of the data clearly shows the known lines notched out. This is how we define the noisefloor.

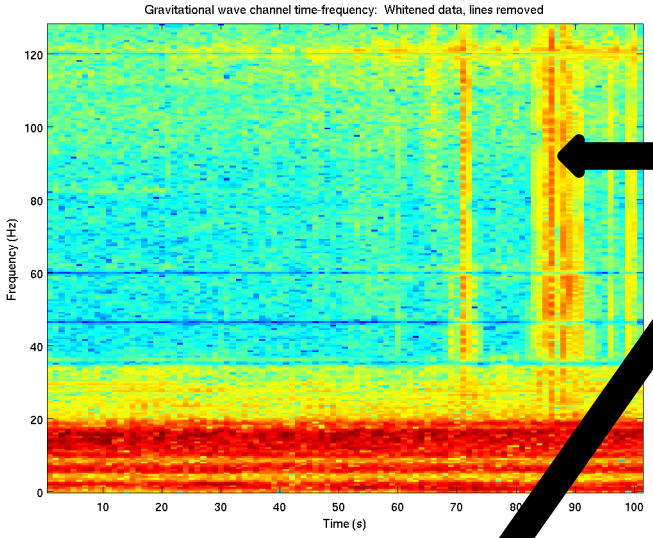
Cross-correlation between seismic channel and gravitational wave channel

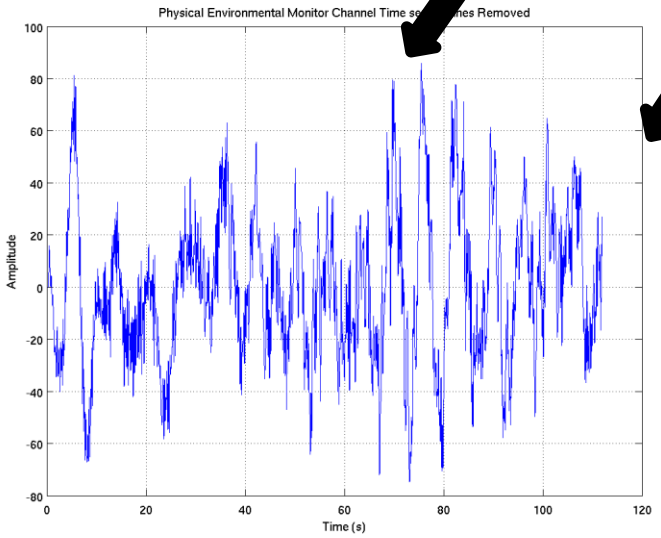


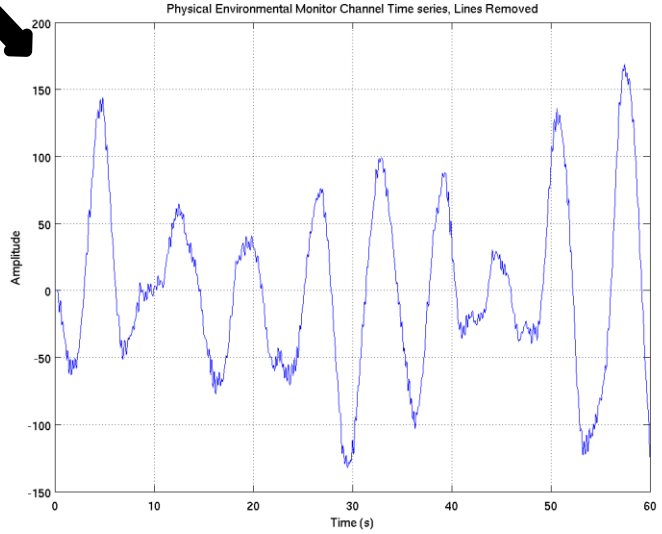
- The cross-correlation near zero lag indicates strong correspondence between the gravitational wave and the seismic channel.

- The NoiseFloorMon data monitoring tool determines the cross-correlations between all the seismic channels and the main channel across the four different frequency bands. This example is from the 0-16 Hz band.

The effect of seismic activity on the gravitational wave channel



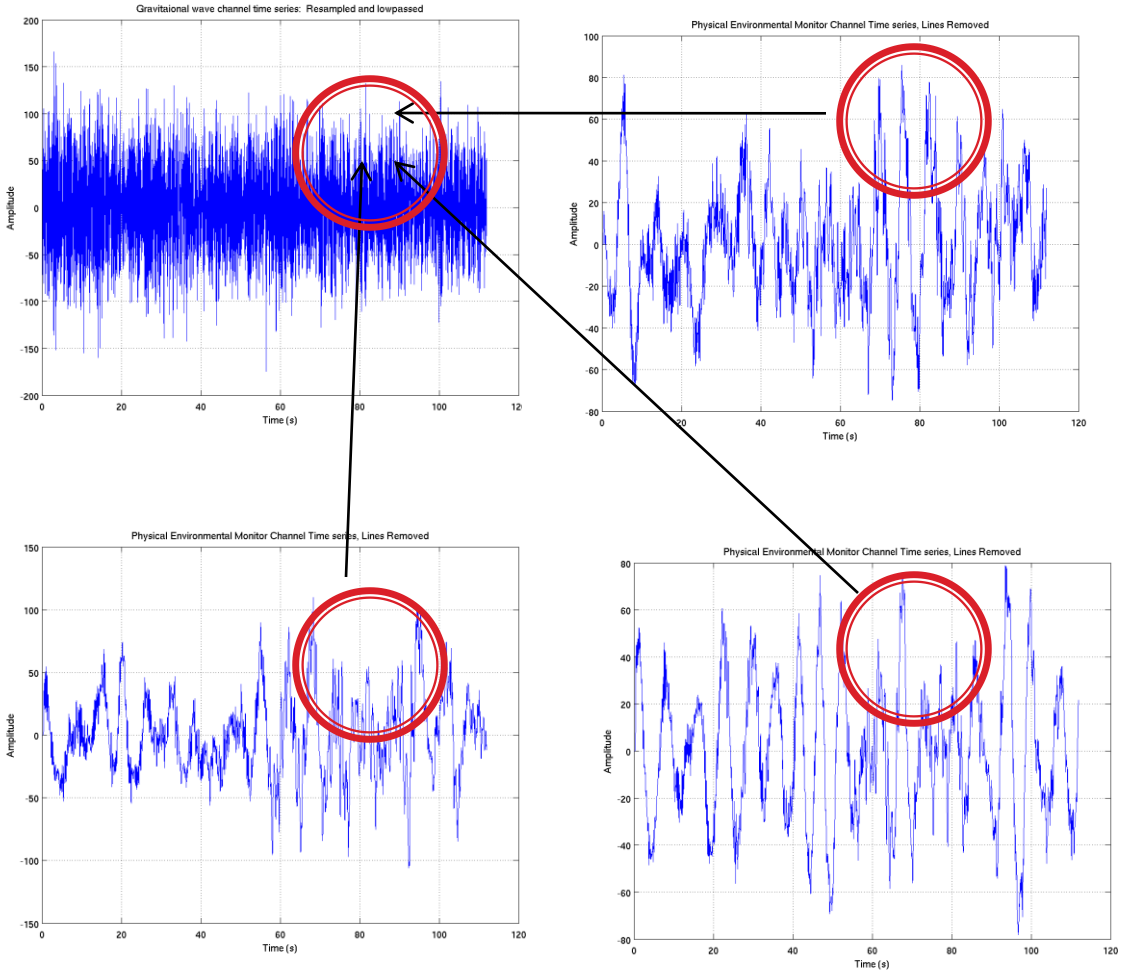




- The increased seismic activity is manifested in the gravitational wave channel.
- The seismometer channel data is shown on a day with lower seismic activity for comparison.

LIGO S4 data

Next step in seismic studies



- Our goal is to use a correspondence algorithm[5] that filters out correspondences between a model set (the main channel) and data sets (the PEM channels) by producing a cluster of strong data associations.

- We hope to more completely identify the parameters of seismic activity that have the greatest impact on the gravitational wave channel.

[5]Lowe, D.G., Object recognition from local scale invariant features, Proc. ICCV, pp. 1150-7, 1999

Conclusions and future work

- The NoiseFloorMon analysis can provide valuable insight into the coupling between the gravitational wave channel and low frequency seismic activity.
- The offline analysis illustrates the effect of the low frequency seismic activity on the time series and time-frequency representations of the data.
- Future goals include a more detailed look at the morphology of the gravitational wave data and physical environmental monitor data sets to better understand the coupling.