The LSC Glitch Group : Monitoring Noise Transients during the fifth LIGO Science Run

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Abstract. The LIGO Scientific Collaboration (LSC) "glitch group" is part of the detector characterization effort, consisting of members of the burst and inspiral analysis teams and detector experts. Goals of the glitch group during the fifth LIGO science run (S5) included (1) offline assessment of the detector data, with focus on noise transients, (2) veto recommendations for the analysis teams and (3) reports to the commissioning team of any anomalies seen in gravitational wave and auxiliary channels. These goals were achieved through off-site data analysis shifts and the examination of loud transients found by online burst and inspiral search algorithms, using customized event visualization tools. Other activities included the study of auto-correlation of transients, stationarity of the detector noise and various flavors of vetoes. This article shall provide an overview of these activities around the S5 LSC run.

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1. Introduction

The "glitch group" is one of the subgroups of the Detector Characterization Committee within the LIGO Scientific Collaboration (LSC). The term "glitch" implies some sort of a malfunction. In this paper we shall use the term "glitch" to denote any short-duration noise transients in the gravitational wave channel as well as transients in other auxiliary channels. Such noise transients are a source of background for burst and inspiral analysis searches and if they are loud enough could knock the detectors out of science mode. The glitch group was set up in 2003 to characterize these noise transients. It mainly consists of members from the burst and inspiral analysis groups as well as various detector experts and operators from both the LIGO sites at Hanford and Livingston. There is also substantial interaction between the glitch group and other detector characterization sub-groups such as Calibration, Data Quality, Dataset Reduction, Environmental Disturbances, Hardware Injections. This article will focus on the main activities of the glitch group during the fifth LIGO science run ("S5") which started in November 2005 and ended in October 2007 [1]. In Sect. 2, we describe the various activities of the glitch group. Then we shall outline the functioning of the glitch group (Sect. 3) and provide details of a typical glitch shift (Sect. 4). Finally, we shall conclude by highlighting some of the post-S5 activities (Sect. 7). This paper will mainly focus on the methods, functioning, goals and logistics of the glitch group and will not present any results.

2. Goals of the glitch group

The glitch group provided a forum for off-site brainstorming and assessing the performance of the LIGO detectors during S5. This would complement any realtime investigations and troubleshooting done onsite. We also provided guidance to the burst and inspiral analysis groups in their analysis of data. Here we outline the various tasks performed by glitch group members :

- Classification and data mining of triggers in the gravitational wave and auxiliary channels, using parametric and non-parametric techniques to see presence of structures in higher dimensional space [2].
- Creation of data quality epochs to identify periods where the behavior of the detectors was different.
- Identification of data quality intervals to flag periods of data which cannot be used for analysis.
- Veto analysis by looking for statistically significant correlations (on an event by event basis) between the gravitational wave and auxiliary channels.
- Looking for coupling caused by an injected gravitational wave signal (into the interferometer hardware) with auxiliary channels. This is known as "veto safety" and is done to ensure that we would not veto a real gravitational wave signal (with data from auxiliary channels).

- Scanning of outlier triggers (from burst and inspiral searches) with customized event visualization tools (See Sect. 5)
- Investigation into the causes of lock loss (which ends a stretch of data when a detector is in science mode) of the interferometers.
- Listening to glitches in audio files generated from filtered time-series data of the gravitational wave and auxiliary channels.
- Looking for incorrect or corrupted data from auxiliary interferometric and environmental channels. Some of these channels are used to create data quality intervals for analysis purposes and hence it is also important to check the sanity of data from these auxiliary channels.
- Other miscellaneous malfunctions in the data acquisition stream which could affect the smooth functioning of the detectors during a science run or affect science analysis (such as segment numbers not in sequential order, absence of some critical channels needed for smooth detector operation, etc).
- Study of peaks in the auto-correlation of events (which could potentially be a signature of micro-seismic noise).
- Study of a variety of environmental effects such as wind, micro-seismic noise, effects of dump trucks, thunderstorms, acoustic noise from airplanes and helicopters, etc.

3. Functioning of the glitch group

Members of the glitch group conducted offsite glitch shifts, with each shift covering 3-4 days of data taking. Results from these glitch shifts were discussed in weekly telephone conferences (which ranged from thrice a week near the start of S5 to once a week towards the end). Highlights from these shifts were also presented on a weekly basis in the run coordination and detector characterization telephone calls. Sometimes detailed specialized investigations were carried out by individual glitch group members. All shift reports as well as links to any specialized investigations were documented in an online electronic notebook hosted at University of Wisconsin, Milwaukee.

4. Details of a glitch shift

Various glitch members analyzed LIGO data with many near-online algorithms, with latency ranging from few hours to a day. Some of these were run using the Data Monitoring Tool (`DMT`) environment within LIGO. The `DMT` is a set of monitor programs and other software that runs continuously to monitor aspects of LIGO data quality, display status information and record data quality statistics. The goals of these pipelines ranged from searches for gravitational wave signals from unmodelled bursts and inspirals to studies of detector noise. A typical glitch shift mainly consisted of monitoring the outputs of all these analyses. The list of all such programs is as follows :

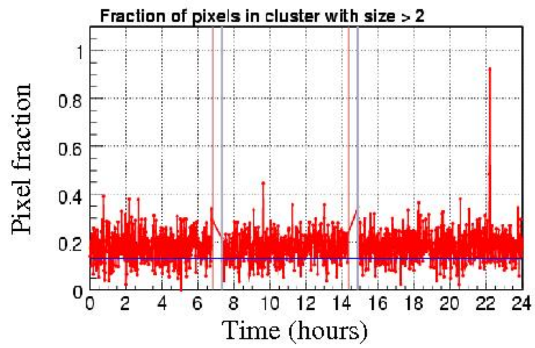

Figure 1. Pixel Fraction from `BurstMon` as a function of time

- `Block-Normal` : `Block-Normal` is a search algorithm designed to look for short-duration unmodelled gravitational wave bursts. It is based on a time domain search of the data and uses a Bayesian statistics figure of merit to select candidate events [3]. During a glitch shift, we mainly looked at single interferometer outliers from `Block-Normal` using event visualization tools.
- `BurstMon` : `BurstMon` is the DMT tool for monitoring the burst detection performance of LIGO detectors and is closely related to `Waveburst` algorithm [4] used for untriggered gravitational wave burst searches from S2 onwards. This monitor produced 3 figures of merits : a measure of the rate of non-stationarity, real-time detector sensitivity to various astrophysical waveforms, and noise variability in various frequency bands. For the glitch shifts we looked at all 3 figures of merit. A plot from one of these figures of merit is shown in Fig. 1.
- `InspiralMon` : Online inspiral searches were done using matched-filter based searches for compact object mergers between 1-3 $M_\odot$ using second order post-Newtonian stationary phase templates [6]. All triggers within a 15 s time-window were clustered into one set. The results were displayed in the control room every minute. During the glitch shifts, we usually looked at these single interferometer inspiral triggers with signal-to-noise ratio greater than 15 using event visualization tools.
- `NoiseFloorMon` : `NoiseFloorMon` is a monitor to detect slow drifts in the noise floor [5]. During S5, it was applied to the gravitational wave channel as well as various seismic channels. During glitch shifts we typically looked at minute trends of threshold crossings and cross-correlations with seismic channels.
- `KleineWelle` : `KleineWelle` [7] is a single interferometer event trigger generator. It is based on the dyadic wavelet decomposition of a time-series. The wavelet transform provides time-frequency localization of signal energy represented by the wavelet coefficients of the decomposition. During S5, `KleineWelle` was run in near-realtime (and offline) on both the gravitational wave channel and a variety of auxiliary channels for the 3 LIGO detectors as well as GEO. A whole variety

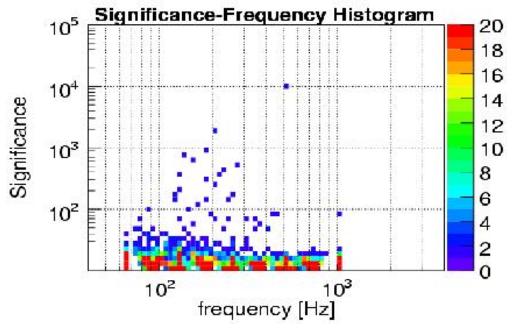

Figure 2. A plot of `KleineWelle` significance vs frequency as a function of time

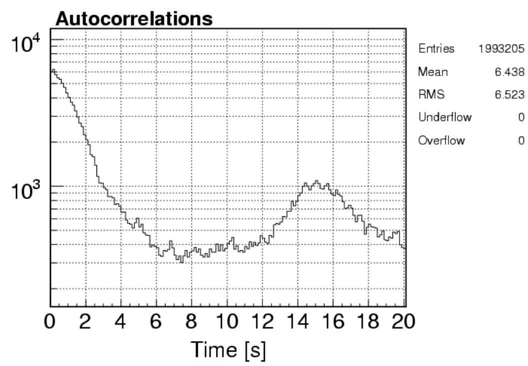

Figure 3. Auto-correlogram of the `KleineWelle` triggers

of diagnostic plots were produced based on these triggers. Multi-dimensional classification analysis was also done using these triggers [2]. Some plots such as the trigger rate for a given channel with low and high thresholds could be produced using a graphical web-based interface. During the glitch shifts, we typically looked at both double-coincident (between the 2 LIGO Hanford interferometers) and triple-coincident `KleineWelle` triggers using event visualization tools. We also looked at various other diagnostic plots such as auto-correlation of triggers, the histograms of trigger times (within a hour) etc, significance of the triggers as a function of time and frequency, etc. Any anomalous peaks seen in the auto-correlation plots is usually due to enhanced micro-seismic noise. Some of these plots are shown in Fig. 2 and 3.

- `Q-online` : The `Q-online` pipeline is an online multi-resolution time-frequency search for statistically significant excess signal energy. It is equivalent to a templated matched filter search, whose basis functions are sinusoidal Gaussians of varying central time, central frequency, and Q (where Q is the quality factor). More details on the Q-transform are provided in Ref. [8]. This was run online on all the 3 LIGO detectors as well as VIRGO and GEO. During the glitch shifts, we usually looked at the trends of the triggers from `Q-online` pipeline (See Fig. 4) and

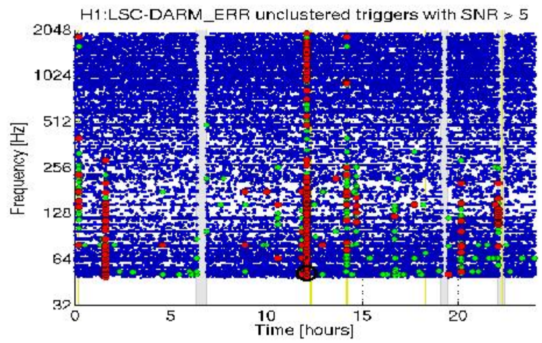

Figure 4. A plot of triggers from Q-online as a function of time

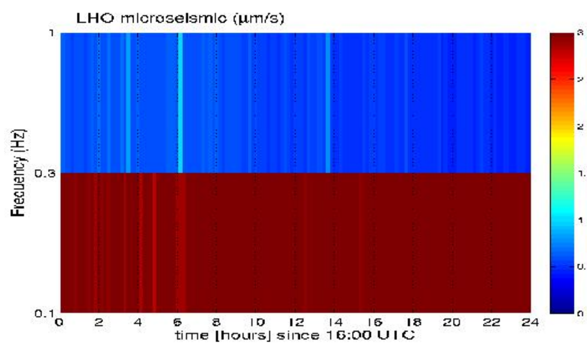

Figure 5. Spectrogram of micro-seismic noise in the 0.1 - 1 Hz band at Hanford

a scan of the loudest event within an hour.

- Miscellaneous : Besides the above near-online analysis, we also studied some other online figures of merit (which are usually produced in realtime in the control room) such as the effective distance to which LIGO is sensitive to binary neutron star inspirals, as well as environmental factors like wind, band-limited seismic noise, etc. See Fig. 5 for a plot of micro-seismic noise usually looked at during these shifts.

An automated script was written to collect highlights from all the above analysis on a single webpage. In the glitch teleconferences, the person on shift that week presented a detailed shift report highlighting any interesting findings.

5. Event visualization tools

Since S4, we have been using various event visualization tools to get better insight into the behavior of detectors at any particular time of interest. This was done by providing a snapshot of the various LIGO auxiliary and environmental channels (including the gravitational wave channel) at a given time. This is similar to various event display tools routinely used in high energy physics experiments to depict the tracks of particles. Usually these times of interest included times of outliers from the burst

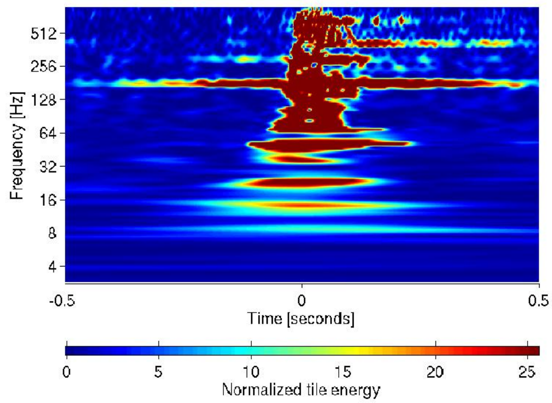

Figure 6. One output plot from the `QScan` of a glitch in the voltmeter channel, after the application of linear predictive error filter.

and inspiral algorithms. However we also used these event visualization tools to look at hardware signal injections, interesting double and triple coincident events, gamma-ray-burst arrival times, environmental injections, etc. These tools provided valuable insight into the behavior of the detectors at a given time and helped pin down any "smoking gun" cause of loud glitches and sources of lock-loss. Here we describe the two tools used extensively in S5 :

- `QScan` : `QScan` is an event visualization tool used to investigate multiple detector channels around times of interest. `QScan` produces "Q spectrogram" displays, which are based on the same transform as that used by the `Q-online` analysis. For statistically significant channels, `QScan` produces thumbnails of the time-series and "Q spectrograms" in 3 different time-windows (± 0.5 sec., ± 2 sec., and ± 8 sec.) on a single webpage. The list of channels to look at can be fixed with a user-specified configuration file. This tool has been extensively used in the control room by operators and scientific monitors to diagnose lock-losses and is also used to look at the various channels in the VIRGO detector. A `QScan` of a glitch in the voltmeter channel is shown in Fig. 6.
- `Event-Display` : The `Event-Display` is another web-based event visualization tool which shows the time-series and frequency spectrograms of a fixed set of channels along with various diagnostic information on the state of the detectors at that time, and output from the `Parameter Estimation` [9] code. One aspect of these spectrograms is that the intensity in a given time-frequency bin was normalized by the median. One example of this type of specialized spectrogram of a glitch in the calibration channel is shown in Fig. 7.

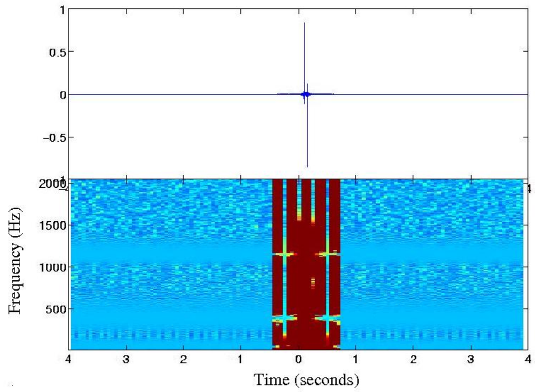

Figure 7. Superposed time-series and median-normalized spectrogram as it appears in the `Event-Display` of a glitch in the calibration channel, after the application of linear predictive error filter.

6. Impact of the glitch group efforts

During S5, the glitch group provided an offline forum for discussing the day-to-day performance of the LIGO detectors. The glitch group provided valuable feedback from a data analysis perspective which was responsible for the success of the S5 science run. These investigations also led to the creation of many new data quality flags which will be used for analysis results with S5 data. The identification of noise transients is particularly important for the development of vetoes for the burst and inspiral search efforts. Similar work has been conducted by the LSC in the past [10, 11, 12]; veto development continues to be an important motivation for the glitch characterization work with the S5 data.

Some new `DMT` monitors were written based on glitch group findings. Moreover, there was valuable feedback provided to the detector experts who conducted a variety of onsite investigations. Some new interferometric transfer functions were measured based on observed correlations between the gravitational wave and an auxiliary channel by various glitch group members. The glitch group looks forward to pursuing all these activities in the future.

7. Post-S5 activities

Due to the long duration of S5 run, work is still in progress to wrap up all the S5 related glitch group efforts. The most important S5 related task still in progress is the creation of data quality flags and this is being done in collaboration with members from the Data Quality group. Another major effort is to do follow-ups of interesting coincident events from burst and inspiral searches to assess their statistical significance. After S5, there were a few externally induced glitches and environmental injections. Some work has started using event visualization tools to characterize these glitches. We are also providing guidance to the Dataset Reduction group regarding choice of channels and sampling rates which need to be archived for the current Astrowatch program and future LIGO science runs.

8. Acknowledgments

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