LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

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Downtime Accounting in S5

Daniel Hoak (LLO), Betsy Bland (LHO)

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of the LIGO Laboratory.

California Institute of Technology
LIGO Project – MS 18-34
1200 E. California Blvd.
Pasadena, CA 91125
Phone (626) 395-2129
Fax (626) 304-9834
E-mail: info@ligo.caltech.edu

Massachusetts Institute of Technology
LIGO Project – NW22-295
185 Albany St
Cambridge, MA 02139
Phone (617) 253-4824
Fax (617) 253-7014
E-mail: info@ligo.mit.edu

LIGO Hanford Observatory
P.O. Box 1970
Mail Stop S9-02
Richland WA 99352
Phone 509-372-8106
Fax 509-372-8137

LIGO Livingston Observatory
P.O. Box 940
Livingston, LA 70754
Phone 225-686-3100
Fax 225-686-7189

http://www.ligo.caltech.edu/

Downtime Accounting in S5

Between November 14, 2005 and October 1, 2007, the LIGO gravitational-wave detectors in Livingston, LA and Hanford, WA, operated in full-time data acquisition mode at design sensitivity. The science run (S5, for short) collected 8852 hours of triple coincidence data, or slightly more than one year. During this time, a variety of phenomena conspired to reduce the operating time of the detectors. This note is intended to provide a summary of these phenomena and a brief discussion of some conclusions from the data. All the results quoted here can be found in the detector electronic logbooks.

[During S5, the 2km detector at Hanford (H2) was extremely reliable and relatively impervious to most disturbances. Those phenomena that did reduce H2's livetime, such as earthquakes and commissioning breaks, are mostly included in the H1 accounting. We will neglect H2 for the remainder of this discussion.]

Methodology

For the two calendar years of S5, every moment of detector operation was assigned a category. The majority of detector time was spent acquiring data; for each instance not spent in science mode, a cause was determined based on information recorded in the detector logbooks and in the archived data, such as graphs of environmental sensors.

The categories used were the following:

Uptime is time the interferometer was in science mode. Science segments of any length are counted.

Calibration is time spent performing calibration studies. These were done periodically throughout the run.

Hardware & Software Failures is downtime due to equipment or software failures unrelated to commissioning. Examples are broken seismometers, electronics cards, or software processes that crashed and required a reboot.

Maintenance & Commissioning is downtime for planned detector maintenance and improvements. During S5, four hours were scheduled every Tuesday for invasive, periodic maintenance tasks, such as liquid nitrogen deliveries and groundskeeping. There were also a handful of extended commissioning breaks at both sites; these lasted for about a week and occurred once or twice a year. In addition, about 25 hours were allocated every month for discretionary studies.

The **Scripts** category includes time spent running the "up" and "down" scripts that take the instruments from lock-acquisition mode to the low noise detection mode. This required about ten minutes, each time the interferometer lost lock. Time was assigned to this category empirically, i.e., 600 seconds for each instance of lock-loss.

Wind includes downtime due to high winds. At Hanford, this is typically wind over 25-30 miles per hour. At Livingston, the seismic pre-isolation system is very sensitive to the low-frequency ground motion caused by wind. Typically, Livingston could not operate in science mode when the wind was gusting more than 15mph. (At Livingston, this category also includes downtime due to **Storms**.)

For Hanford, the **Seismic** category includes any source of ground motion that prevented the interferometer from normal operations. Mostly, this downtime is due to earthquakes. The seismic environment is more complicated at Livingston, and this category is expanded into different sources:

Microseism is the term used to describe the low-frequency (0.1-0.35 Hz) ground motion caused by ocean waves striking the continental shelf. This is worst in the winter months, due to storms in the Atlantic.

Earthquakes produce large amplitude, low frequency ground motion (0.03-0.1 Hz), although higher frequencies can be driven depending on the earthquake's size and location. Typically, a 6.0-magnitude earthquake on the western Pacific Rim (Russia, Japan, the Philippines, or Indonesia) will keep the Livingston interferometer out of lock for one or two hours. Events like these happen about once every two days.

Trains are a phenomenon unique to Livingston. Railroad tracks pass by the site about 1.75 miles south of the ETMY endstation, and freight trains move through Livingston three or four times a day. The largest trains occur regularly around 2am and around 7am, and typically take the interferometer out of low-noise operations for about half an hour.

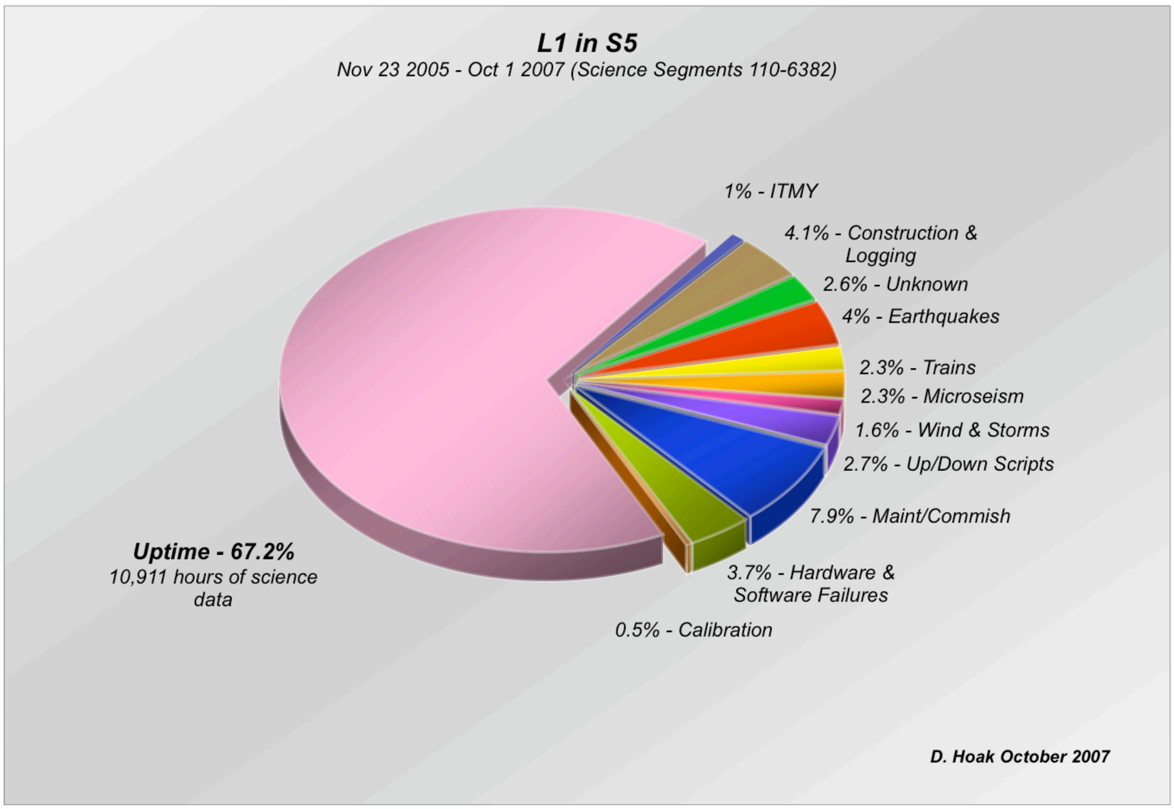
There are two other categories unique to Livingston. **SEC Construction** is downtime due to construction of the Science and Education Center near the corner station building, between November 2005 and October 2006. Data-taking operations had to be suspended during work hours due to elevated ground noise produced by construction equipment. (A small amount of downtime due to **Logging** local to the L1 site is included in this category.)

Also at Livingston was the **ITMY** incident in May 2006, when a series of dump trucks removing cement blocks from the SEC construction site shook the ITMY mirror enough to jam it up against its protective stops. A short vacuum incursion was required to free the mirror. The interferometer was down for about a week.

Finally, the **Unknown** category includes all downtime that could not be attributed to another category.

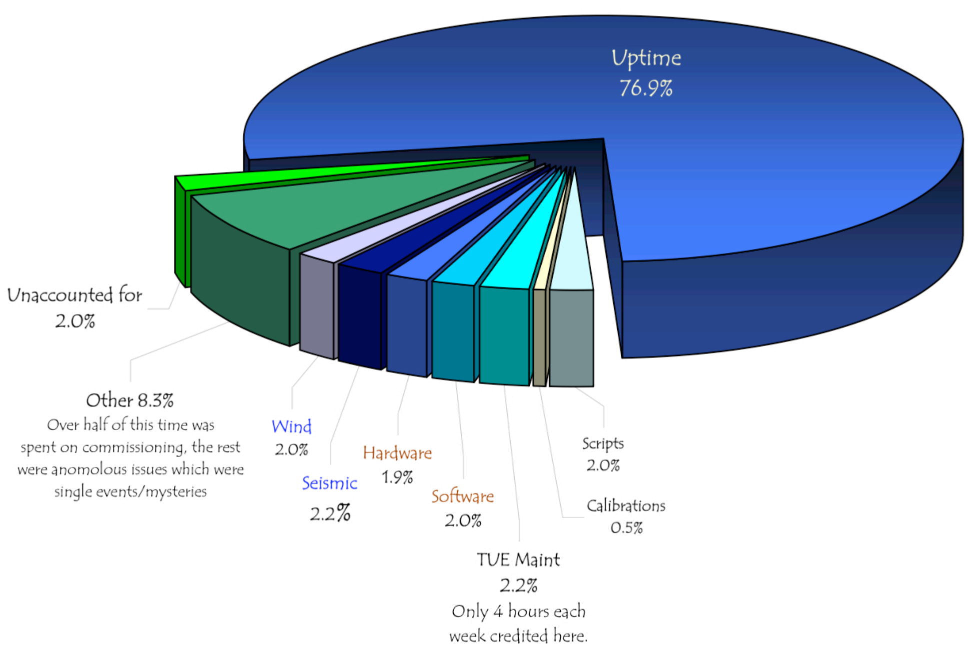
Results

The following pages contain the downtime pie charts for both sites. The original documents can be found in the detector electronic logs, on October 5, 2007, for Livingston, and May 28, 2007, for Hanford. (The last four months of the S5 run are not included in the Hanford results. Downtime at Hanford is less seasonally variable than at Livingston, so it's unlikely that the final results are much affected.)


L1 in S5
Nov 23 2005 - Oct 1 2007 (Science Segments 110-6382)
1% - ITMY
4.1% - Construction & Logging
2.6% - Unknown
4% - Earthquakes
2.3% - Trains
2.3% - Microseism
1.6% - Wind & Storms
2.7% - Up/Down Scripts
7.9% - Maint/Commish
3.7% - Hardware & Software Failures
0.5% - Calibration
Uptime - 67.2%
10,911 hours of science data
D. Hoak October 2007

S5 H1 Downtime

Data taken from elog and conlog and covers H1-35-3372, includes 3 commisioning periods.
Covers Nov 14, 2005 thru May 27, 07



BBland 5/28/07

Here are the percentages in tabular form:

Category	L1	H1
Uptime	67.2	76.9
Calibration	0.5	0.5
Hardware & Software Failures	3.6	3.9
Maintenance & Commissioning	7.9	10.5
Up/Down Scripts	2.7	2.0
Wind & Storms	1.6	2.0
Seismic	8.6	2.2
(Microseism)	2.3	--
(Trains)	2.3	--
(Earthquakes)	4.0	--
Unknown	2.6	2.0
SEC Construction	4.1	--
ITMY	1.0	--

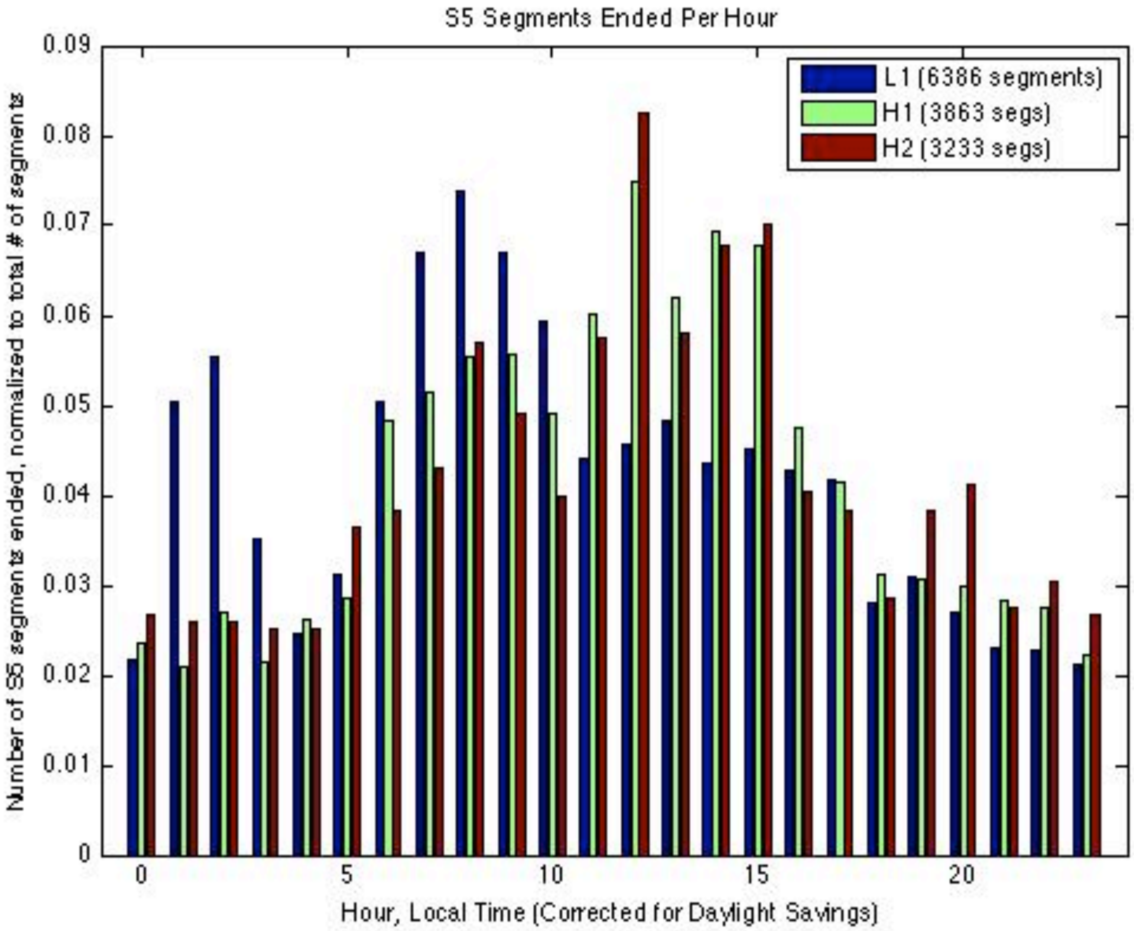
Discussion

Some caveats regarding the above plots:

- Sometimes, several things happen at once: a train may arrive during an earthquake, or there could be high microseism during a commissioning break. Since causes of downtime are independent of one another, the sum of all the categories should in theory be greater than 100%. Here, no attempt has been made to consider overlapping sources of downtime. (Mostly, this is because operators are not in the habit of recording events such as earthquakes and trains when the interferometer is already out of lock.)
- The accounting for sources of downtime only considers whether the interferometers were in science mode. Inevitably, some science data will be of poor quality and cannot be used in searches for gravitational waves. This amounts to a few percent of science data, depending on the interferometer and on the search.

Note that while uptime for the Livingston detector was much less than for Hanford, the difference is more than made up by the additional seismic noise at Livingston, plus the SEC construction and downtime due to ITMY. In other categories, the two sites are about equal. (Hanford presumably has more maintenance time because there is an additional interferometer to commission and maintain.)

In addition to the downtime accounting, the end times of science segments are an interesting guide to what typically prevents science-mode operations. The following histogram shows the number of segments ended for each interferometer per hour of the day:



Daytime hours (7am-5pm) are less amenable to data-taking due to human activity. Also, the Livingston detector has an excess of segments ended in the early morning hours. This is due to the train, which often arrives between two and three o'clock in the morning. (Another train arrives around 7am, but is mostly obscured by the daytime anthropogenic noise.)

Similar studies can be done for segments ended per minute of the hour and per second of the minute. These distributions are flat, which indicates there were no sources of detector instability (for instance, due to an hourly software job or timing problem) with a period of an hour or a minute.

Looking Ahead

It's not clear how much improvement we can expect in detector operating time in future science runs. Assuming no great changes are made to the alignment stabilization servos or the seismic isolation (none are planned), many factors will remain largely unchanged for Enhanced LIGO:

- Weekly maintenance will still be required.
- The up and down scripts will, if anything, become more complex and require slightly more time
- During S5, hardware and software failures for both sites were randomly distributed throughout the run. We can expect single-point electronics failures and software crashes to continue at about the same rate.
- Regular calibration of the detectors is important.
- Environmental factors, such as wind, earthquakes, and trains, will still be present. It's unclear how the upgrades for S6 will change the detector's sensitivity to environmental noise. The effects of low-frequency seismic noise may be slightly mitigated due to improved tidal servos, but phenomena like trains and large earthquakes will still reduce the operating time of the detectors. The effect of other enhancements on the stability of the detector, such as increasing the laser power and moving the DARM sensing chain to a seismically isolated platform, have yet to be evaluated.
- Downtime of Unknown provenance was consistently about 2% throughout S5 and will probably be the same in S6.

Based on the data from S5, we can estimate how much downtime is likely from each of these irreducible sources of noise:

	L1	H1
Maintenance	2.3	2.3
Scripts	2.7	2.0
Failures	3.6	3.9
Calibration	0.5	0.5
Seismic & Wind	10.2	4.2
Unknown	2.6	2.0
Total	21.9	14.9

(The 'Maintenance' category in the above table assumes 4 hours per week for invasive facilities work. The only sources of S5 downtime not included in the table above are commissioning outside of the weekly maintenance period and the SEC construction and subsequent ITMY incident at Livingston.)

From these numbers, we can estimate an upper limit on the operating time for each detector in S6. For H1, it will be difficult to do better than 85%; for L1, about 78%.