Subtraction of Newtonian Noise

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Abstract

Often times when measuring for gravitational waves detectors pick up gravitational disturbances from local sources (Newtonian noise). This causes a problem. Desired measurements are polluted with this Newtonian noise (NN) and in order to view data accurately the noise must be subtracted out. At the former Homestake mine in Lead, South Dakota seismic noise, from which NN originates, is rather low in underground locations. Research here has several main goals, two of which are investigating how to subtract NN from GW measurements and determining if this is done more efficiently at underground locations or above ground ones like at Hanford, Washington and Livingston, Louisiana. Progress has been made in both goals, but improvements, including the set up of the seismic array and how to subtract NN with filters, are still needed. This entire operation will span over many years and during this summer of 2010 small, but effective, modifications to the seismic array, advances in NN knowledge, and comparison of the systems used in the array will be made. It is expected modifying geophones to sense low frequencies will allow Hanford and Livingston to sense low frequencies which will eventually lead to NN filters at these locations and may provide cheaper instrumentation than the seismometers used at Homestake if it is found geophones also work well underground.

I. Introduction

Newtonian noise originates at a distance from a test mass [2]. This creates a problem, as test masses are part of a more complex system measuring gravitation waves and NN mixing in with the data collected by gravitational wave detectors (GWD's) skews the data [4]. Since NN comes from quite a distance (often kilometers away) [2] before being measured by a GWD, its source is often difficult to locate [2] resulting in the inability to filter it out from the data (as can be done with other types of noise) [4]. For studying elimination techniques the Laser Interferometer Gravitational Wave Observatory has set up seismic stations at the former Homestake mine in Lead, South Dakota. This location was chosen due to its tendency to decrease seismic noise at locations deep underground [4] making it a candidate for measuring gravitational waves more efficiently if it is shown subtracting NN here is less difficult than at Hanford and Livingston [2,5].

The seismic stations currently set up for studying NN are in a plane-like array with one Güralp CMG-40T at 300ft down in the mine, one Nanometrics T-240T at 800ft, three Nanometrics T-240's at 2000ft, and one Nanometrics T-240, one Güralp CMG-40T, and one Streckeisen STS-2 at 4100 ft [3] (see figure 1). The ideal environment for each is an isolated one [3]. LIGO has already constructed several of these. Each seismometer is put on a concrete platform and isolated from its surroundings with thermal and acoustic insulation panels [3]. The panels, however, are not perfect. Only one of the 4100ft stations reads off data that can be used since the other two have too much air flow around causing the seismometers to pick up the air waves that "tamper" with the data. Seismic stations like these need to be moved to a better location [3]. Each station also needs its readout system fixed [2] and others also need to be relocated and redesigned. More detail will be given about this process in Section II with a timeline in Section III.

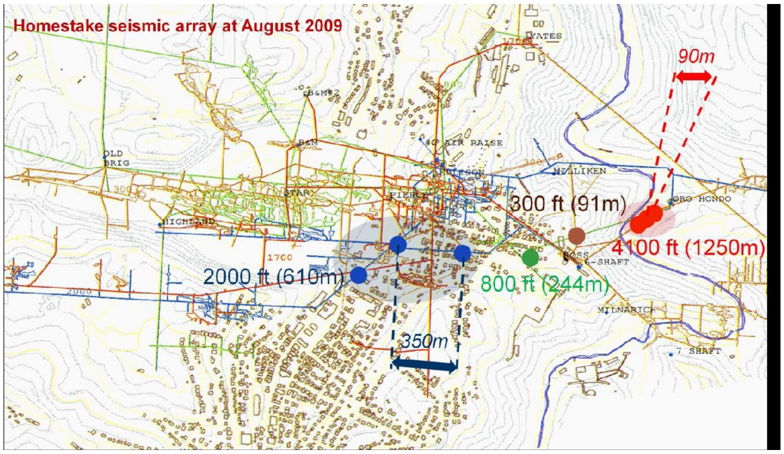

Figure 1: Location of the 8 seismic stations at the former Homestake Mine in Lead, South Dakota. Each dot represents a station at the specified underground level [6].

Once this is achieved the array must be altered from its planar form to a three-dimensional one as this will make it easier to hone in on NN locations [2]. When this array is completed the studying of seismic noise can continue. Studying it can lead to many advances for LIGO, one being a better understanding of how NN is generated from seismic noise [2,4]. The more discovered about this, the more that is found out about NN and how to construct filters for subtracting it. Just how this subtraction will be carried out is another question: will constructing a filter to subtract the noise as waves are measured suffice, or will it be necessary to build a system which subtracts the noise after the waves are measured [2]? Concurrently it will be possible to look at the seismometers and determine which works best of the three types. Right now it appears the T-240 is best, but with price factored in this may change [2]. This is also explained in more detail in Section II with a timeline in Section III. Once the experiment at Homestake is completed a new, but related, experiment begins at Pasadena. Advanced LIGO uses geophones at its Hanford and Livingston site to measure and subtract seismic noise form GW measurements and it is proposed to have the sensitivities of these brought down enough to read NN [2] as NN is read at rather low, sensitive frequencies [5] and is a major contributor to unnecessary detections during measurements. Successful modification would make it possible to use geophones for NN filtering at Hanford and Livingston in the future and, if these work well underground, will offer a cheaper solution to NN filtering at Homestake since geophones are less expensive than the seismometers used there [2].

II. Plan of Action

The seismic stations are set up in a rather plane-like array (refer to Figure 1). There is some three-dimensionality to it, but not enough to make it noticeable over the dominating planar array [2]. This array needs to be converted into a fully three-dimensional one because a planar array is not sufficient for analyzing the three-dimensional propagation of seismic fields [2]. Studies of NN are at early stages; not much is known about it [2,5]. As seen by Figure 2 Homestake seismic noise is about 1-2 orders of magnitude less than at Hanford during noisy times [6]. Since the noise at Homestake is so much lower in this comparison a three-dimensional array of seismometers potentially allows for more effective NN analysis here. This is discussed in more detail later in this section.

Changing the array involves a couple of steps. First, the current seismic stations will be fixed. All the stations need the readout system modified since the system gives off quite a bit of measured electronic noise that is unwanted [2]. The system is essentially the same at each: the seismic signal is pre-amplified before an 18bit digital-to-analogue converter reads it [2] and using optical fiber communication a timing-distribution system synchronizes the stations [2,3].

Recently, a "master clock" using a GPS antenna was installed for the system but is not fully functioning at this moment [2]. This summer, to improve the readout system, two main objectives will be carried out. First, the "master clock" will be put into working condition so the data-acquisition system is improved. This way the timing signal used for controlling the sampling of seismic signals will operate with better accuracy [2]. Second, coils and capacitors will be used directly at the stations [2] to "tweak" readout systems on site.

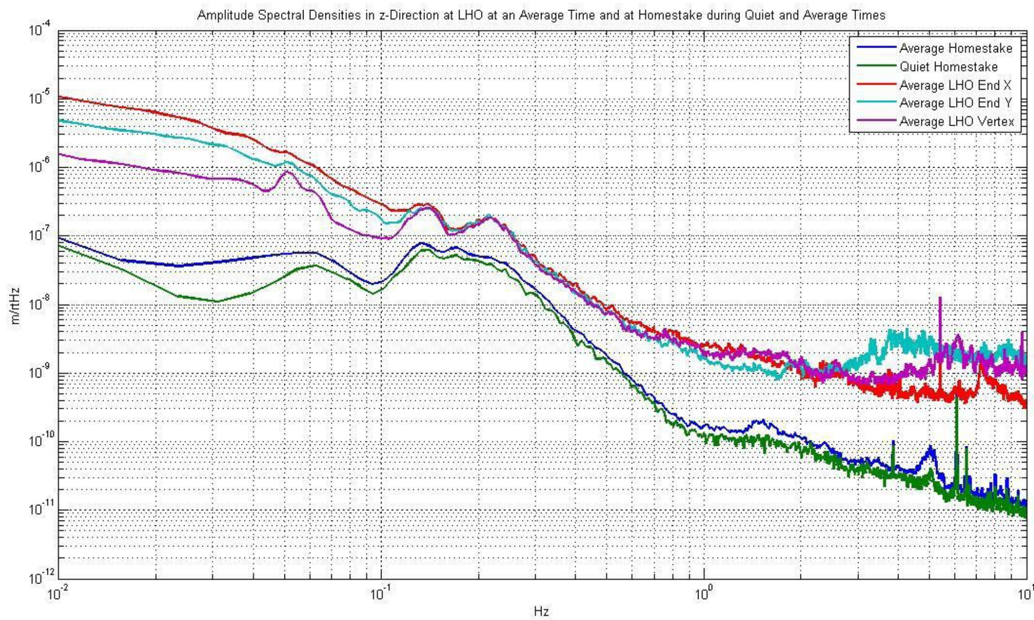

Figure 2: This graph shows how noise during noisy and quiet times varies from Homestake to Hanford. As can be seen, in each case, Hanford has much more noise during both events [6].

The 800ft stations have been marked to be rebuilt as well [3]. Redesign, however, is not a priority and will occur only if time permits [2]. The B and C stations at the 4100ft level have been marked for relocation and redesign [3]. Redesign will wait [2] and relocation will be described soon. The 4100ft A station is working very well and while not a priority improving the design of the station and small details of its readout could lead to it working even better [3].

Once the seismic stations are fixed the construction of a three-dimensional array will begin. As mentioned above two of the seismic stations at the 4100ft level are marked for relocation [3]. These will be the first stations moved. Following this three seismometers brought from Pasadena will be placed [2]. Afterwards an expensive seismometer will be set up with a newly designed 24bit analog-to-digital converter to be used in its readout system [2]. This seismometer will determine if this readout system gives off less electronic noise as the other seismometers [2] and if it seen the noise is much less than with the 18bit analog-to-digital converters investment in it may be made in the future [2]. When a location has been found for these in a suitable 3-D array seismic wave propagation studies begin.

Homestake, as mentioned earlier, has world record low amounts of seismic noise deep underground [6]. Figure 3 shows how the amount of seismic noise it has does not vary much during quiet and noisy times while at Hanford the noise will vary as much as 3 orders of magnitude [6]. A hypothesis suggests measuring seismic noise underground and making predictions of NN based off these measurements at Homestake will be easier, as NN may be more consistent at these depths [5], hence easier to model, but this must be tested [2]. Filters using algorithms have been made to subtract noise such as falling bricks or a car starting from GW data [2,3], but since not too much is known about NN GWD's have yet to be constructed with filters for subtracting it from GW data [6]. By making models of the noise based off predictions of it from seismic wave measurements, filters for subtracting NN from GW data will be produced for Advanced LIGO in the future. These filters, however, will first go through tests to find the answer to an essential question before many of these new GWD's are produced: will it be best to filter NN as gravitational waves are measured, or will it be best to wait until the waves, polluted with NN, are measured, and then subtract it out [2]? As time progress and more knowledge of NN is found at both aboveground and underground LIGO locations it will be determined if NN filtering is best done above or below ground; however, this is many years way.

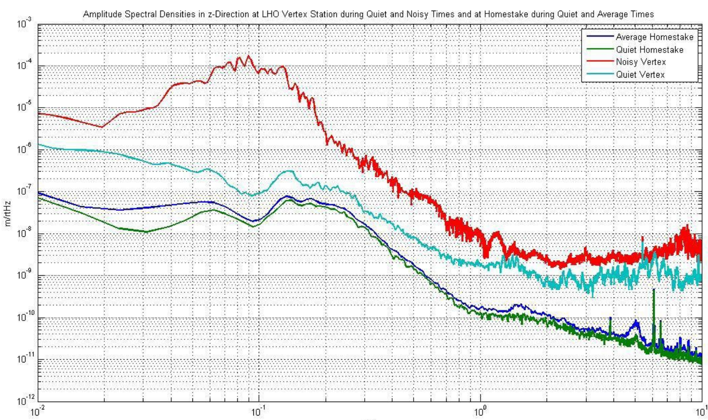

Figure 3: This graph shows how noise varies at both Homestake and Hanford. As seen by the graph, noise at Homestake is essentially the same during loud and quiet times, while at Hanford loud times have noise up to 3 magnitudes greater noise than during quiet times [6].

During these seismic wave propagation studies it will be convenient to look at the different seismometers in the setup and decide which functions and produces results best. Right now the T-240 (see Figure 4), CMG-40T, and STS-2 are used at Homestake. All produce sufficient results when functioning properly, but the T-240 is preferred over the others [2] while the CMG-40T, the cheapest of the three [6], is the least preferred [2]. If a CMG-40T breaks it must be sent back to England for repair [2]. This is hardly worth the time and money for an instrument that is not preferred over the others. The T-240 is very good at reading small seismic waves crucial for understanding NN [2], but in terms of performance is on the same level as the STS-2 [2]. It must be understood many seismometers will be placed in the 3-D array over the years [2], so careful comparison of these two must be made to decide if the more expensive one is really worth the investment over the other. Saving money, however, is what it all comes down to [2], and if the CMG-40T is the only option then it may become the dominating seismometer in the array.

Figure 4: A Trillium T-240 at the 2000ft level surrounded by the thermal acoustic box to isolate it from its surroundings [1].

Following Homestake refitting geophones used at Hanford and Livingston will begin in Pasadena. The main goal is to bring geophone sensitivity to lower levels so the instrument can read lower frequencies of seismic waves [2]. This way Hanford and Livingston can begin modeling NN with much better precision with the ultimate goal of subtracting the noise from GW measurements with new generation GWD's. This will contribute to determining if this subtraction is done better above or below ground as well. To modify a geophone for sensitivity at low frequencies, a low noise environment must be found [2] so it can attempt to measure these low frequencies. The geophone will then be worked on with parts taken out, replaced, and added. Following this models of noise it should read at these frequencies will be compared to what it actually measures [2]. The geophone will then be modified accordingly and the process will continue until it operates as desired.

Geophones, which operate like seismometers, happen to be less expensive than the seismometers used at Homestake [2]. If modification is successful testing geophones underground at Homestake will then take place. If it is observed these work well here there will be a cheaper option than the seismometers [2] for the huge 3-D array that will be in the making at Homestake.

III. Timeline

It is unknown just when the arrival and departure from Homestake will occur, so presented here is a basic timeline:

- For Homestake, one week is needed to set up the three new seismometers. If time permits it will be possible to relocate one or two of the 4100ft stations [2]. During the second week the readout system's timing signal will be modified [2]. Any other modifications and studies of seismic wave propagation and modeling NN will occur if time permits.
- Refitting the geophones at Pasadena will take 10 + weeks [2]. The initial refitting of one will take a few days and modeling the noise it should measure in a low noise environment will take one or two. Following this it will take a day to test and compare what the geophone actually measures to the model. It is not expected the first test will be near perfect, nor the third nor fourth test. Weeks will then be spent working on the geophone and testing it and comparing results to the model.

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