Limiting the effects of earthquakes on gravitational-wave interferometers

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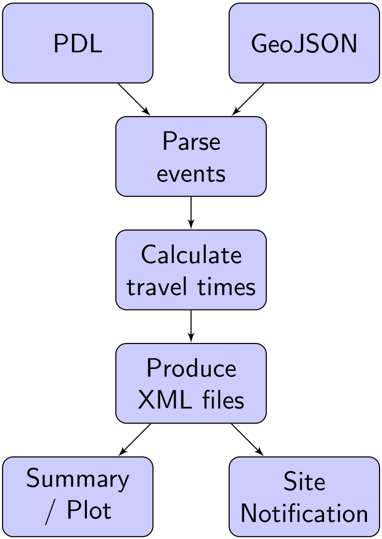
Introduction

1. The detectors are susceptible to teleseismic events, which can significantly impact a detector's duty cycle.
2. Here we describe an early-warning system for gravitational-wave observatories, which relies on near real-time earthquake alerts provided by the U.S. Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA).
3. Our initial results indicate that by using detector control configuration changes, we could regain duty cycle otherwise lost during earthquake events.

Pipeline


PDL
GeoJSON
Parse events
Calculate travel times
Produce XML files
Summary / Plot
Site Notification

Notices

1. Warning system relies on the most preliminary notices of earthquakes currently available generated by worldwide networks of seismometers.
2. USGS provides preliminary estimates of the location providing latitude, longitude, and depth of each event.
3. These solutions are distributed through USGS's Product Distribution Layer (PDL), which has been configured to receive notifications for all located earthquakes worldwide.

Site Notification

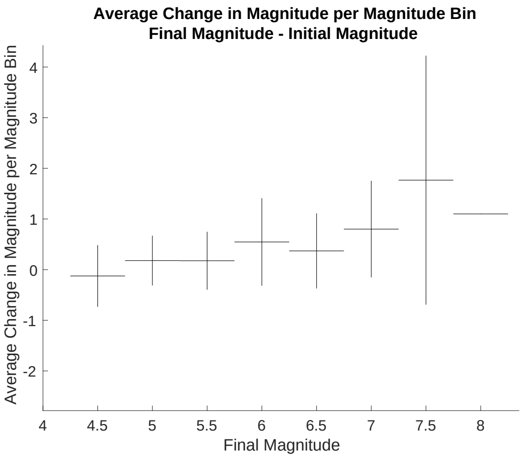
1. We use the ground velocity at the site and time-of-arrival predictions to create warnings for the detectors.
2. The algorithm analyzes the recent notifications and places a threshold on the predictions.
3. We provide a set of variables that contains the following information: amplitude prediction, probability of lockloss, earthquake time-of-arrival.

We estimate the amplitude of the surface waves, $\mathrm{Rf}_{\mathrm{amp}}$, at the sites using the equation

$$\mathrm{Rf}_{\mathrm{amp}} = M \frac{\mathrm{a}}{f_c^b} \frac{e^{-2\pi h f_c / c}}{r^d} \tag{1}$$

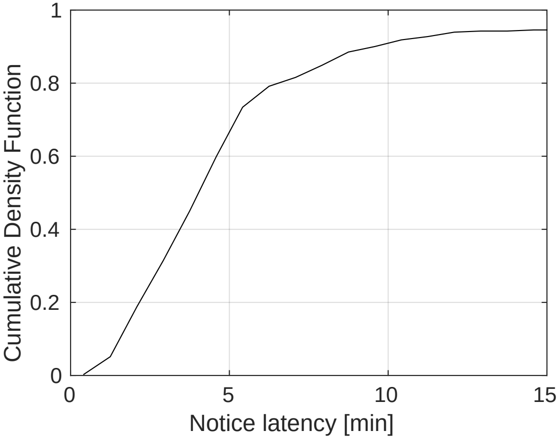
where $f_c = 10^{2.3 - M/2}$ is the corner frequency of the earthquake, M is the magnitude of the earthquake, h is the depth, r is the distance to the detectors, and c is the speed of the surface-waves, all in SI units.

Comparison of initial versus final magnitude estimates



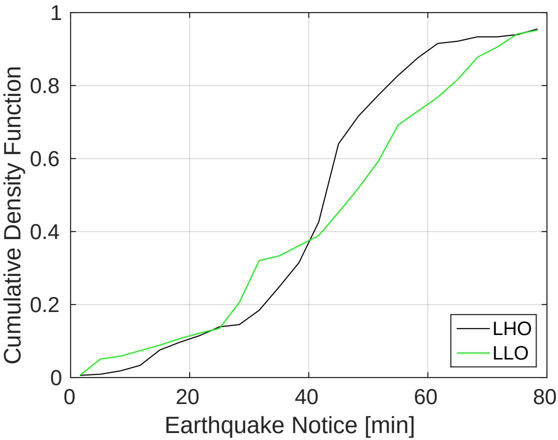
(a) Comparison of initial versus final magnitude estimates.

Time delay - initiation of fault rupture and generation of the PDL client notification.



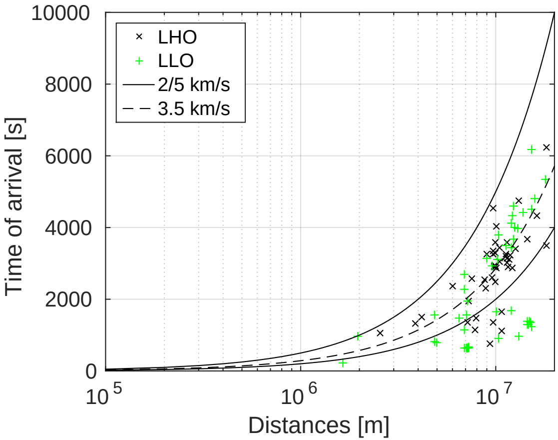
(b) Time delay - initiation of fault rupture and generation of the PDL client notification.

Time delay - generation of the PDL client notification and surface wave arrivals.



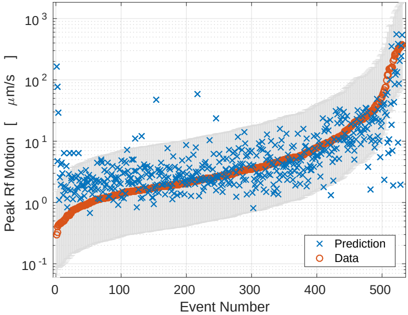
(c) Time delay - generation of the PDL client notification and surface wave arrivals.

Time of arrivals



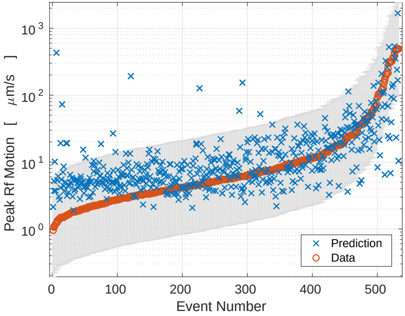
(d) Time of arrivals

Fit of peak velocities (LHO)



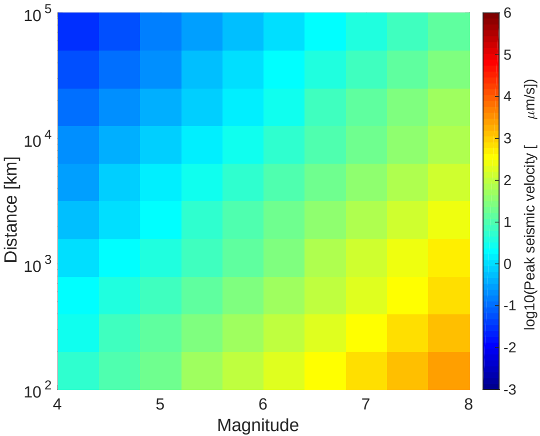
(e) Fit of peak velocities (LHO)

Fit of peak velocities (LLO)



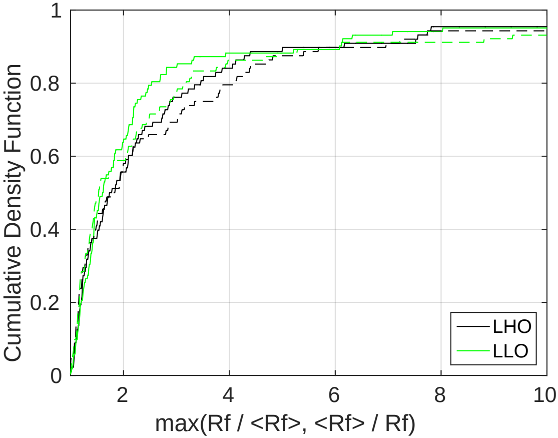
(f) Fit of peak velocities (LLO)

Predicted peak ground velocity as a function of magnitude



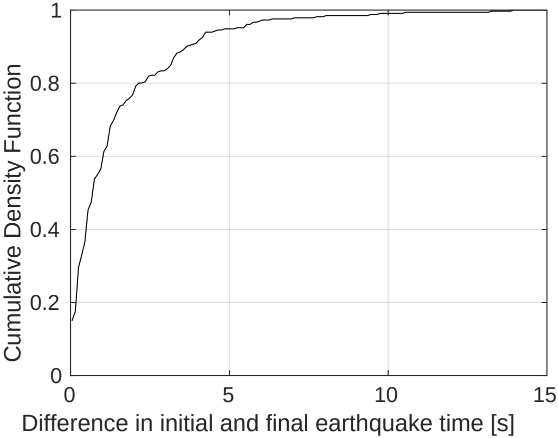
(g) Predicted peak ground velocity as a function of magnitude

Performance of estimation of peak velocities seen during O1 at the interferometers



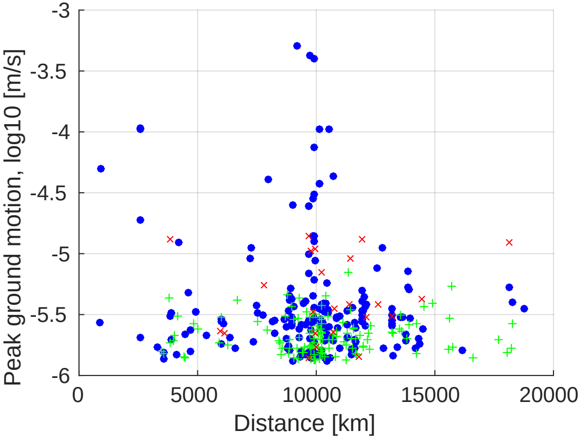
(h) Performance of estimation of peak velocities seen during O1 at the interferometers

Difference between the initial and final estimates of the earthquake time



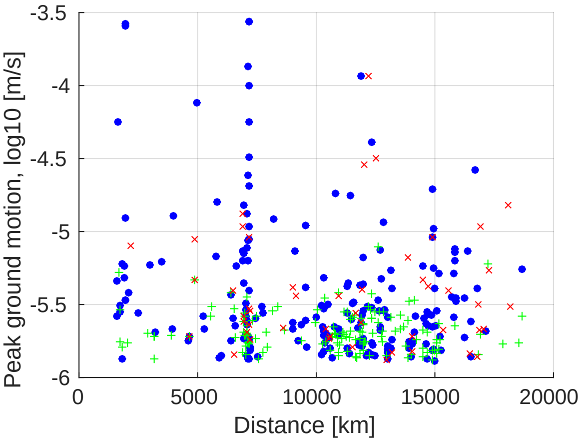
(i) Difference between the initial and final estimates of the earthquake time.

Lockloss as a function of predicted peak velocity vs. earthquake distance (LHO)



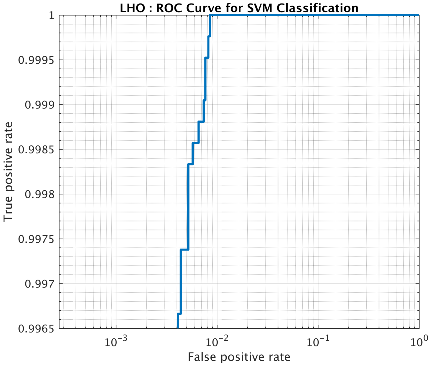
(j) Lockloss as a function of predicted peak velocity vs. earthquake distance (LHO)

Lockloss as a function of predicted peak velocity vs. earthquake distance (LLO)



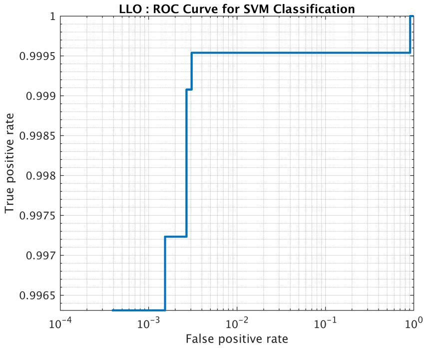
(k) Lockloss as a function of predicted peak velocity vs. earthquake distance (LLO)

Performance of different machine learning classifier (LHO)



(I) Performance comparison of different machine learning classifiers (LHO)

Performance of different machine learning classifier (LLO)



(m) Performance comparison of different machine learning classifiers (LLO)

Current Status

1. *Seismon* is running reasonably well at LHO/LLO, with inputs to EPICs channels and the like.
2. Currently using any earthquakes that come as tests by keeping the configuration the same and seeing what happens. Keith Thorne at LLO and Dave Barker at LHO are maintaining the codes there.
3. Virgo has installed and is running the code, and there is some debate about how to best use the output there.

To-Do List

There is much to do going forward ...

1. Updated amplitude fits using O1-O2 data. There is also the idea of using available IRIS data to make global fits, we have files containing 2015-2016 data for this that are being looked at.
2. Code or function for lockloss probability calculation
3. Generating lists of lock state (to do better than just locked vs. not locked) as we use in our current analysis.
4. Understanding what frequency band we most care about for lockloss (the seismic modeling community needs more information than just the broadband which we use for our empirical analysis)
5. Control configuration changes