Tsunami Warning with Data Assimilation of Seafloor and Sea Surface Observations

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We are interested in the use of data assimilation methods for tsunami warning, and potential use of GNSS-derived ship height data in data assimilation to supplement sparse seafloor pressure measurements.

Most tsunami warnings rely on first locating and determining size of a large earthquake and then using a computer model to estimate the amplitude and timing of the resulting tsunami. However, with enough sensors, traditional forecasting methods can be supplemented by models continuously updated with real-time wave data. Progressive data assimilation has been used for many years in weather forecasting (Miller et al., 1994), and recently Maeda et al. (2015) adapted it to tsunami forecasting for eventual use with the Japan Trench (S-net) cabled network. In the tsunami data assimilation method, at every time step the tsunami wavefield for the current time step is approximated by numerically solving the shallow water equations using the wavefield at the previous time step (i.e. by a forward numerical simulation). In the assimilation step, the forecasted tsunami height is compared to that observed at the observing stations (seafloor pressure sensors or other instrument types), and this residual is used as a correction to bring the assimilated wavefield closer to the true wavefield. This method has been applied to seafloor pressure measurements from the Cascadia Initiative (Gusman et al., 2016) and the MOANA ocean bottom seismic network offshore New Zealand (Sheehan et al., 2019). The Cascadia Initiative and MOANA were both temporary standalone experiments that did not provide data in real time. The regional networks of cabled pressure sensors currently deployed off Japan and Cascadia provide data that can be used test data assimilation in real time. However, they have limited footprints and are unlikely to be replicated in many other regions of interest, and it is thus important to seek other sources of real time data that could be incorporated into the data assimilations.

One promising avenue to explore for obtaining more widespread coverage is sea surface height obtained from Global Navigation Satellite Systems (GNSS) on ships or wave gliders, which can be incorporated into the data assimilation. Foster et al. (2012) observed a 10 cm tsunami signal from the 2010 M8.8 Maule, Chile earthquake using the high rate GPS on a research vessel offshore Hawaii, and suggested that tsunami forecasting capabilities could be improved by ingesting precise shipping fleet GPS positions within a real-time operational framework. Subsequently, Inazu et al. (2016) demonstrated that the density of cargo ship traffic in the Nankai Trough would be sufficient for near-field tsunami forecasting. Mulia et al. (2017a), using the same Nankai Trough dataset, explored the optimal combination of traditional offshore geophysical instrumentation and ship-borne GPS.

Making use of existing infrastructure, in the form of the commercial shipping fleet, is a potential method to improve forecasting abilities. Inclusion of ship-borne GNSS sea surface height measurements may reduce the reliance on high-cost offshore arrays. Successful results would also clarify the need for high precision GNSS positioning of vessel traffic, particularly in regions of geophysical interest.

We are working with the US University Research Fleet to log raw GNSS data for measuring precise ship height and exploring its utility for tsunami data assimilation. Our hope is that the navigation systems that are already installed on the research vessels to provide position, attitude and heave data, can be cheaply configured to routinely collect a raw GNSS stream. If not, it may be necessary to install a dedicated GPS system on each ship. Either way, the raw GNSS data could be shared as open source data

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to support tsunami research using the mechanisms that have already been established for UNOLS underway data. We welcome collaboration from those interested in ship-based sea height measurements as well as those interested in tsunami data assimilation.

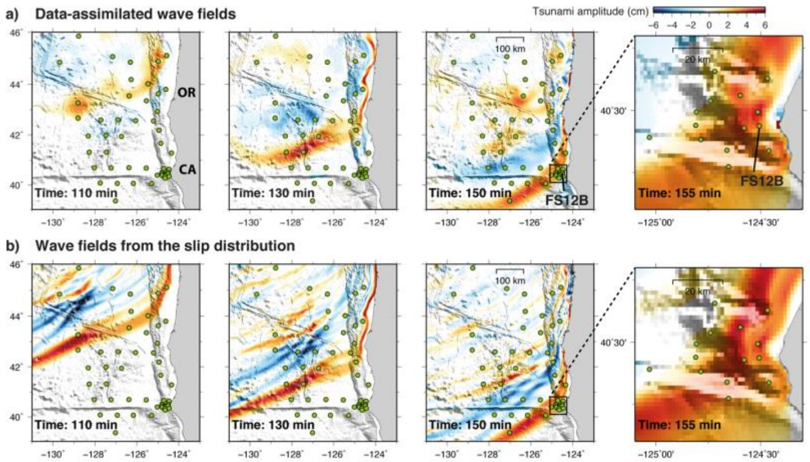

Figure 1. Tsunami propagation forecast offshore the Cascadia subduction zone using data assimilation of Cascadia Initiative seafloor pressure data (Gusman et al., 2016). (a) Wavefield at 110, 130, 150, and 155 minutes after the Haida Gwaii earthquake produced by tsunami data assimilation (DA). Green circles show the station distribution. (b) Wavefield at 110, 130, 150, and 155 min simulated from the estimated slip distribution of the 2012 Haida Gwaii earthquake.

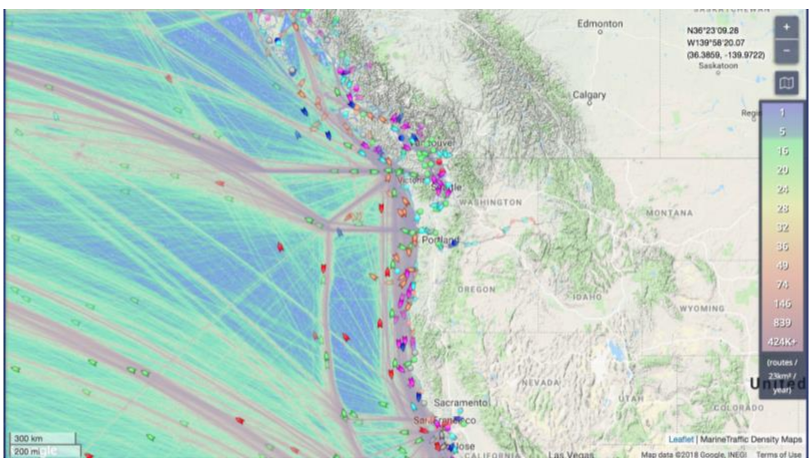

Figure 2: Ships and marine traffic density in the Cascadia region (MarineTraffic.com). Ships shown are a real-time snapshot from 9/7/18. Automatic Identification System (AIS) automatic tracking system used on ships provides information on movements of ships, though raw GPS is not routinely available. The marine traffic density highlights the major ports and shipping lanes in the Cascadia region.

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