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Evaluation of Tsunami Risk in the Great Lakes: Urban Planning and Outreach

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1 Statement of Research Need

Tsunami occurrences at the Great Lakes can endanger the 8 million annual swimmers who visit the coastal facilities (Austin et al., 2007). While these events frequently affect the coastline of the Lakes, they have not been adequately studied, which is evident in the very few existing scientific literature on the matter (Ewing et al., 1954; Hughes, 1954; Platzman, 1958, 1959; Donn, 1959; Bechle & Wu, 2014). However, according to the media outlet archives including Chicago Tribune, and Detroit Free Press (citations needed here), tsunamis have greatly affected the local community around the Great Lakes. Some of these events are the July 4, 1929 in Grand Haven, MI with 10 casualties (Matheny, 2017), June 26 and July 6, 1954 in Chicago, IL killing seven fishermen, July 4 (e.g. Ewing et al. 1954), 2003 near Sawyer in Berrien County, MI (Matheny, 2017) resulting in the death of seven swimmers, May 27, 2012 sweeping three swimmers into Lake Erie (Anderson, et al. 2015), September 8, 2018 killing one man and flooding the lakeside in Chicago , IL (CBS Local, 2018), and December 22, 2018 killing one man in La Porte, IN (CBS, 2018). Most of these events are called meteotsunamis and caused by meteorological phenomena. Studies have shown that atmospheric tsunamis alone can cause tens of millions of dollars in economic loss by inundating coastal towns (e.g. Vilibić et al., 2004; Orlić et al., 2010).

In the wake of recent climatic changes in the US, and more specifically in the Midwest, with extreme reported and forecasted weather conditions (e.g. Nehring, 2015-11-11; Prociv, 2015-11-27; Calfas, 2016-02-24; Mowry, 2016-09-01; Lewis, 2017-12-07; Irizarry, 2018-08-24; Wright, 2019-01-09; NWS, 2019-02-24), codification of efficient plans to address such imminent tsunami events is inevitable. Detailed scientific study of tsunamis in the Great Lakes will play an important role in drafting economic and social strategies in both short-term and long-term scales and increasing tsunami preparedness and resilience of the local community in the Great Lakes.

2 Project Goal and Objectives

While tsunamis recorded in the Great Lakes are all meteorological, one cannot rule out the possibility of landslide tsunamis as the Lakes all possess the main factors, i.e. slope, unconsolidated sediments, and trigger mechanism such as storms and distant earthquakes (e.g. Salaree & Okal, 2015, Salaree, et al. 2018) for submarine landslides. Therefore, the proposed research aims at studying both geological (i.e. landslides and earthquakes) and meteorological (i.e. from atmospheric changes in the Great Lakes) potential sources of tsunamis using state-of-the-art numerical simulations and a variety of data sets including lake bathymetry, earthquakes and submarine landslides. The proposed research will be carried out by a multi-disciplinary team from University of Michigan and Michigan State University, including new postdoc Amir Salaree (tsunami modeling), PI Yihe Huang (earthquake and wave propagation), co-PI Ali Zockaie (urban planning), and co-PI Brian Arbic (tsunami). We will also collaborate with NOAA Great Lakes Environmental Research Laboratory (GLERL) to use the most updated Great Lake model and contribute to the operational Great Lake Forecasting System. We will codify evacuation, traffic management, and urban plans based on the existing coastal infrastructure in the Lakes, with special attention to Lake Michigan, Lake Huron, and Lake Erie. The produced plans will be recommended to authorities for legislation and enactment in the coastal states. We will also use social media and organize public workshops in collaboration with City Halls and local schools to raise the public awareness of the investigated hazard and proposed mitigation plans.

3 Research Methods

3.1 Geological Tsunamis

We will therefore investigate the occurrence of potential tsunamis from both earthquake and submarine landslide sources using methods developed by Synolakis et al. (2002), Okal & Synolakis (2003), and Salaree & Okal (2015). In this framework, tsunami sources are considered as dislocation fields localized at the location of either the earthquake or landslide. The resulting deformation is calculated using elastic equations (e.g. Mansinha & Smylie, 1971) and then used by shallow-water hydrodynamic models to simulate the resulting tsunami in the form of propagating gravity waves (Titov et al., 2016). Potential loci of seismicity in this study will be extracted both from earthquake catalogs (e.g. Dziewonski et al., 1981; US Geological Survey, 2019) and studies on seismic sources in the Midwest (e.g. Li et al., 2007; Hough, 2014; Huang et al., 2017). Potential landslide sources are identified by calculating the steepest descent from topographic maps using methods similar to Salaree & Okal (2018).

3.2 Meteotsunamis

As the speed of tsunami propagation is directly proportional to water depth at any given point, tsunami speed in shallow basins such as the Great Lakes (with depths barely exceeding 400 m, NOAA (2019)) can be equal to high winds and create a phenomenon known as the Proudman resonance (Proudman, 1929). This will result in amplification of waves which may significantly affect coastal areas. These waves have been successfully modeled using mobile squalls of atmospheric pressure gradient that create corresponding disturbances in water (e.g. Rabinovich & Monserrat, 1998; Salaree et al., 2018). Simulation of tsunamis in both cases requires detailed information regarding water depth, or bathymetry in the Great Lakes, which can be obtained from sources such as the ETOPO (NOAA, 2019) and GEBCO (Fisher et al., 1982) models. We will perform a large set of possible scenarios (e.g. Salaree et al., 2018) and evaluate time series of calculated amplitudes at more than 1,000 coastal points around each lake to obtain maximum most probable hazard (Geist & Parsons, 2006). This information is then used in determining the cites exposed to highest tsunami risk to be considered for urban planning studies.

Preliminary results from meteotsunami and landslide tsunami simulations are shown in Figure 1.

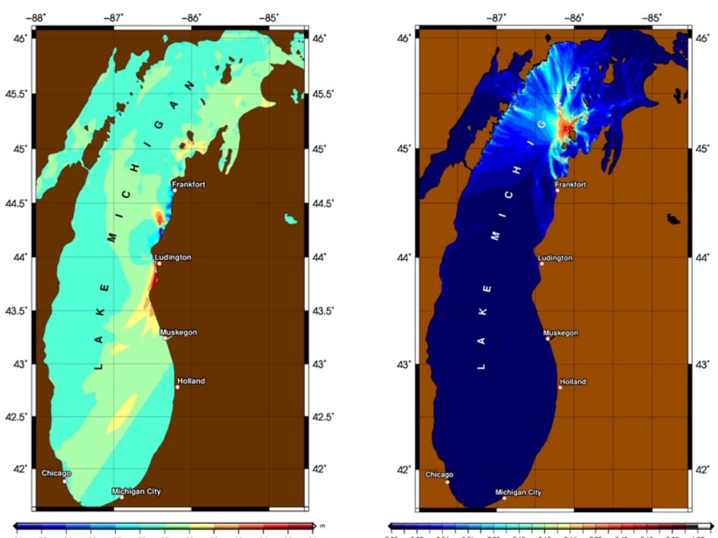

Figure 1. Preliminary results from simulations of *(left)* meteotsunami and *(right)* landslide tsunami. Maps are color-coded according to maximum tsunami waveheight in meters.

3.3 Urban Planning

Locations with highest tsunami risk need to be considered in urban planning studies. In these locations, depending on the risk and the distance from the shore line, various strategies need to be considered in response to the tsunami risk. In this regard three zones need to be defined as follows: immediate risk, medium risk, and safe zone. In each of these zones, particular strategies should be pre-planned by authorities to ensure a safe response to tsunami. These strategies can be categorized in two major groups. The first group is focused on evacuating residents from immediate and medium risk zones to safe zones when a warning is issued based on weather predictions and tsunami models. Thus, evacuation plans need to be designed for different available buffer times. A proper evacuation plan requires determining certain locations in the safe zone as destination of evacuees, assigning evacuees to one of the selected destinations in the safe zone, developing a schedule for evacuation for different locations in the immediate risk, and medium risk zones, and choosing the mode of evacuation (personal vehicles versus mass transit). A recent study, by PI Zockaie using traffic simulation, shows the importance of a proper evacuation plan in a large-scale evacuation for Long Island (NY), in response to superstorms such as Sandy that occurred in 2013 (Zockaie et al., 2014”). The second group considers strategies that may address only the immediate risk zone when there is no available buffer time for a large-scale evacuation. Preventing development in high risk locations, building short dams or shelters, and educating residents to response properly to tsunami are some of the strategies that can be considered. For both categories, in addition to plans that should be developed by authorities, the residents’ response is also crucial (e.g. evacuating based on schedule once the warnings are issued by authorities). As part of this project, for selected high tsunami risk cities, we will develop evacuation plans for different available buffer times, along with action plans for the second group as discussed above. A proper evacuation plan calls for simulating traffic for multiple scenarios. Traffic simulation requires developing a network model and estimate travel demand. PI Zockaie is an expert in transportation network modeling and will lead the research efforts in this domain.

3.4 Education and Outreach

We will disseminate the project results and raise the public awareness in facing tsunami hazard through the following three steps:

- We will organize educational workshops at City Halls and schools throughout the state. This, as is routinely conducted in tsunami hazard workshops (e.g. UNESCO, 2004; Connor, 2005; UNISDR, 2017), is extremely important in preparing the public, especially the younger generation to face the tsunami hazard and train them to participate in a future mitigation/evacuation procedure. The collaboration NOAA GLERL will be particularly important in this regard.

- Effective use of pedagogical frameworks for disaster studies can be extremely helpful in conveying the importance and implications of mitigating natural hazards to K-12 students (Alexander, 1991). In this approach, new technologies such as multimedia in interactive talks/lectures will be used (Songer et al., 2002).

- Social media platforms in networks such as Twitter and Facebook will be developed to ensure community safety though shared responsibility (Dufty et al., 2012) and to increase the hazard and mitigation awareness in young adults through entertaining multimedia products and informative snippets (Salaree, 2018).