New machine learning model improves early tsunami warnings

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A tsunami hazard zone sign in Tofino, B.C., reminds residents and visitors to move inland or head to higher ground in the event of of an earthquake. Credit: Katsu Goda/Western Science

History has a way of repeating itself. But unlike science, built on general principles and testable theories about the natural world, history examines past events and human actions using evidence and interpretation. This delineation is critical when predicting earthquakes and tsunami waves for Canada's west coast, as researchers just don't have the scientific data

required to make communities safe—at least not yet—so current calculations are informed by historic natural disasters in faraway places like Japan and Indonesia.

To counter this dearth of data, a new Western study buoyed traditional statistics with novel machine learning techniques, using artificial intelligence, to test early warning models for Tofino, B.C.—a popular surfing and tourist destination on Vancouver Island's west coast.

Overall, the collected data shows waiting longer to issue a tsunami early warning message performs better in terms of safely and orderly evacuating the most amount of people than a shorter response time. However, this approach is problematic as longer waiting times may make warning messages less effective and ultimately, more deadly for evacuees and emergency responders.

"Our models show when waiting times are too short, performances of the tsunami early warning models vary significantly in terms of success," said Katsuichiro Goda, Earth sciences professor and Canada Research Chair in Multi-Hazard Risk Assessment. "We need to continue collecting data and using multiple datasets to develop a robust tsunami early warning model for Tofino and other coastal communities on Vancouver Island."

Low topography, high risk

Tofino is at a high risk of tsunamis because of its location near the Cascadia Subduction Zone. Located 100-200 kilometers off the Pacific coast of North America, the Cascadia Subduction Zone is a convergent (tectonic) plate boundary capable of producing 9.0+ magnitude earthquakes and tsunamis that could reach 20-30 meters high.

Localized tsunamis, generated by earthquakes on the Cascadia

Subduction Zone, can reach Tofino within 15 to 20 minutes, leaving little time for warning. The community is actively working on tsunami preparedness, including the potential construction of tsunami towers.

"We don't have any data to check that our model and prediction are correct because no tsunami on record has ever hit Tofino. We can study historical cases, like Tohoku, to inform our models. And we now have a better idea of what may happen. What we don't know is how large it would be," said Goda. "But we know it's going to happen. It's not a matter of if, but when."

Mitigating deadly disasters

A series of deadly tsunami waves hit Tohoku, Japan on March 11, 2011. A 9.0 magnitude earthquake off the northeastern coast of Honshu, Japan's largest island, triggered the tsunami waves, causing nearly 20,000 deaths. The tsunami also set off a major nuclear accident at a power station along the coast.

"Early warnings for tsunamis are always a hot topic as the impact can be disastrous and deadly at the highest level," said Goda. "Tohoku is a classic example as it was so devastating. And of course, there was the 2004 tsunami in Sumatra. Those are the two major disasters that motivate me."

Born in Japan, Goda earned his master's degree in agriculture from Kyoto University before completing his Ph.D. in civil engineering at Western.

In the study, published by *Coastal Engineering Journal*, Goda showed random forest models—a machine learning algorithm that uses decision trees to make predictions—was the most accurate system when compared to neural networks, AI inspired by the human brain, and

multiple linear regression models, which are a traditional statistical method.

But Goda insists all tested models provide valuable data and should be utilized and cross-referenced.

"Multi-linear regression is the long-standing, baseline model that we've been using for decades to predict tsunamis," said Goda. "We need to start using more AI models to get better results, but they are more data-hungry and only perform better with more data."

And there lies another problem with predicting tsunamis for Tofino. While Canada's west coast relies, in part, on data from four ocean bottom sensors, deployed off Vancouver Island by Ocean Networks Canada (owned and operated by the University of Victoria), Japan's coastline is monitored by more than 150 off the coast of Tohoku alone.

"Japan has deployed more than 150 sensors. It's a very expensive system and no other country can afford that many," said Goda. "Ocean Networks Canada is monitoring four sensors around the clock that have been deployed in highly strategic locations, including one just off the coast of Vancouver Island.

"With that near-shore station, we should expect to get far better data. That was another motivation for the study, to demonstrate how much better we could warn of impending tsunamis if we had more data."

Perfect storm

Tofino, and its unique geographic location, is renowned for its mild climate, including year-round surfing opportunities. With more than 35 kilometers of sandy beaches, it attracts surfers of all levels, making it a paradise for beginners and experienced surfers alike.

Unfortunately, its exposed waterfront and low topography also make Tofino an ideal location for potential tsunami waves. In fact, a significant portion of the tourist hot spot's $2-billion worth of economic assets are at risk during a tsunami.

Goda studies at-risk coastal communities, including Tofino, Havana, Cuba and Bali, Indonesia, as the principal investigator of the Community and Infrastructure Resilience to Climate-geological Long-term Effects (CIRCLE) project. The interdisciplinary and international research initiative conducts multi-hazard impact assessments of physically interconnected infrastructures to better identify and protect vulnerable people and communities along the world's coastlines.

"The people of Tofino face a number of the challenges if a speedy evacuation was ever necessary, due to the single road connecting the town to Victoria and the potential for road flooding," said Goda.

Tofino is actively engaged in preparing for tsunamis, including running annual evacuation drills and tsunami early warning tests. Plans are also underway to build vertical evacuation towers in the town.

In another study, Goda and his collaborators outlined how seismic mapping for shaking and tsunami risks is necessary for coastal communities like Tofino that face imminent dangers from offshore earthquakes. Larger-scale seismic hazard assessments like the one Goda and partners produced require regional and local seismic hazard mapping, where the relative differences in seismic shaking across an area are identified and mapped. This process is known as microzonation.

Goda and post-doctoral scholar Nova Roosmawati are visiting Tofino in October for the town's next scheduled tsunami warning test, leading a workshop to share their latest research findings with community members. The team also has a workshop scheduled for September 11 in

Bali.

More information: Katsuichiro Goda et al, Effect of calibration data on performance of tsunami early warning model, *Coastal Engineering Journal* (2025). DOI: 10.1080/21664250.2025.2516324

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