Tsunamis and tsunami warning: Recent progress and future prospects

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Tsunamis are one of the most destructive disasters in the ocean. Large tsunamis are mostly generated by earthquakes, and they can propagate across the ocean without significantly losing energy. During the shoaling

process in coastal areas, the wave amplitude increases dramatically, causing severe life loss and property damage. There have been frequent tsunamis since the 21st century, drawing the attention of many countries on the study of tsunami mechanisms and warning. Tsunami records also play an essential role in deriving earthquake rupture models in subduction zones.

A recent paper entitled "Tsunamis and tsunami warning: recent progress and future prospects," by Dr. Chao An from Shanghai Jiao Tong University reviews the recent research progress on earthquake-generated tsunamis, from the aspects of tsunami generation, propagation, inversion and warning. The paper was published in *Science China Earth Sciences* recently.

On tsunami generation, the paper analyzes three assumptions adopted in tsunami modeling and the associated errors, i.e., neglecting earthquake rupture process, assuming sea surface profile mimics seafloor deformation, and ignoring water compressibility. On tsunami propagation, popular simulation techniques are based on shallow water wave equations or Bousinessq equations of weak nonlinearity and weak dispersion; the paper reviews research results on the effects of Earth elasticity, water compressibility and ocean stratification. On tsunami inversion, the paper summarizes popular inversion methods including finite-fault inversion, initial sea surface profile inversion and time reversal method.

Distance	Observations	Task	Warning Strategy	Problems	Possible Solution
Very Near Field	Strong motion Geodetic	Whether a tsunami is triggered	Estimate earthquake hypocenter, magnitude and focal mechanism; Determine if a tsunami occurs	Frequent false alarms	More near-source observations for direct evidence of a tsunami, .e.g., ocean-bottom pressure
Near Field	Strong Motion Geodetic Body Waves Surface Waves	Prediction of tsunami arrival time and wave height	(1) Use uniform slip models for prediction (e.g., tsunami scenarios) (2) Obtain finite-fault models by inversion	(1) Proper construction of uniform slip models (2) Finite-fault models based on seismic and geodetic data produce large errors to predict tsunami waves	Estimate the overall characteristics of earthquakes instead of detailed finite-fault models; Use simplified source models for prediction of tsunami.
Far Field					
Far Field	Strong Motion Geodetic Body Waves Surface Waves Tsunamis	Prediction of tsunami arrival time and wave height	Obtain finite-fault models by inversion of tsunami data and other data	Tsunami buoys are usually far from source. Near-field areas are not protected.	More tsunami buoys in potential source areas

Tsunami warning strategies according to source distance and available observations Credit: ©Science China Press

The paper points out that tsunami data are of essential importance to constrain earthquake rupture parameters, but it has limited spatial and temporal resolution. On tsunami warning, the paper concludes that tsunami buoys are the most reliable way for tsunami warning. Without tsunami buoys, it is potentially possible to obtain accurate tsunami predictions by estimating the overall earthquake rupture characteristics and constructing uniform slip models. Lastly, the paper briefly introduces the newly-developed method, i.e., Probabilistic Tsunami Hazard Assessment (PTHA), and points out that a possible improvement is to take regional geological structures into consideration.

By reviewing the most recent tsunami research, the following conclusions are obtained:

1. Since the 2004 Sumatra tsunami, there have been more and more tsunami measurements. As a result, a lot of research has been done and the research methodologies have been well developed. With the deployment of ocean-bottom pressure sensors, it is possible to investigate multiple physical phenomena in an earthquake-tsunami event.
2. By far tsunami buoys are still the most reliable ways of tsunami warning. If tsunami measurements are not available, one possible warning strategy is to estimate the overall characteristics of earthquakes use simplified uniform models to predict tsunami waves.
3. Probabilistic methods are developed for tsunami hazard assessment in addition to traditional deterministic methods. A possible improvement is to take regional geological structures into consideration.

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