Tsunami Modeling and Mapping: Guidelines and Best Practices

Part V: Modeling Landslide Tsunamis[1]

National Tsunami Hazard Mitigation Program

Mapping and Modeling Subcommittee

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Revised:

A key outcome specified in the National Tsunami Hazard Mitigation Program (NTHMP) 2013-2017 Strategic Plan was the development of "Tsunami hazard assessment that supports informed decision making in tsunami-threatened communities". Potential sources for tsunami hazards in U.S. coastal areas include tsunamis generated by local or large distant landslides. As a result, it has become necessary to develop guidelines and best practices for carrying out the modeling of tsunamis generated by landslides and other types of submarine mass failures (SMF), which are collectively referred to here as Landslide tsunamis. To achieve this goal, the NTHMP Coordinating Committee charged the Mapping and Modeling Subcommittee (MMS) in 2018 with establishment of guidelines for modeling landslide tsunamis. The Coordinating Committee further specified that, to ensure that tsunami inundation maps support informed decision making in tsunami-threatened communities, all NTHMP-funded models and new map products should meet these guidelines by 2021. The current NTHMP Strategic Plan further enforces the notion that all models and maps funded by NOAA/NWS grants should meet NTHMP guidelines except where they conflict with state/territory-mandated laws or policies.

Purpose

The purpose of this guidelines and best practices document is to establish minimum requirements that should be met to develop accurate, consistent, and cost-effective tsunami hazard and risk assessments across state and territorial coastal boundaries. Included here are guidelines for model inputs, outputs, and direction to ensure that a numerical code is properly applied. In addition to

[1] Formerly titled *Guidelines and Best Practices for Tsunami Inundation Modeling for Evacuation Planning*

this document, the MMS has developed *Tsunami Inundation Maps* and *Checklist for Evaluating Tsunami Modeling and Mapping Reports and/or Metadata*, a supplement containing content recommendations for metadata, project reports, or other forms of documentation related to model and map development (http://nws.weather.gov/nthmp/publications.html).

Moving forward, the MMS continues to review the activities previously specified every five years or as needed.

Intended Audience

These guidelines and best practices are intended for tsunami modelers and Digital Elevation Models (DEM) developers with the intent of providing the best attainable products to support informed decisions. These guidelines apply to federally funded NTHMP partners and may be adopted for use by other entities that are electing to do so.

Expected Results

The outcome of adherence to the guidelines and best practices set forth for landslide tsunami modeling will result in more uniform and understandable products. These guidelines and best practices may also serve communities or regions where formal tsunami mitigation efforts are in the development stage.

Landslide Tsunami Modeling Guidelines

In these guidelines, "landslide tsunami model" refers to the numerical computer code(s) used to simulate tsunami generation by subaerial or submarine landslide sources, possibly including propagation across a body of water, and inundation of normally dry land, both in the near- and far-field of such sources. These guidelines also address the input and parameters necessary to successfully model landslide tsunamis for chosen simulations or scenarios. Model inputs include, but are not limited to, the bathymetric and topographic DEMs and the tsunami source information that define credible local and distant tsunami scenarios for the susceptible coastline. The intent of these modeling guidelines is to support the development of landslide tsunami modeling products that further support clear, consistent inundation mapping and evacuation products. For NTHMP efforts:

- Modeling code(s) used should meet benchmark standards adopted by the NTHMP MMS following the Galveston January 2017 "Landslide Tsunami Model Benchmarking Workshop" (see: https://nws.weather.gov/nthmp/2017MMSLandslide/index.html). A summary of the tsunami inundation benchmark problems for landslide tsunami sources is provided at http://www1.udel.edu/kirby/landslide/problems.html . A list of the models that have met the desired accuracy criterion on these benchmarks and are in use for NTHMP efforts is provided at http://www1.udel.edu/kirby/landslide/models.html
  An important conclusion based on results of the 2017 NTHMP-MMS workshop is the recommendation that modelers use a non-hydrostatic (a.k.a. dispersive) numerical wave model.
- All landslide tsunami model codes used for NTHMP funded work should be accessible to interested users (e.g., available as open source on an archival webpage such as GitHub).
- Numerical models should be used appropriately with respect to domain of applicability (as identified by benchmarks). For instance, the landslide the landslide rheology should be considered and different models used for nearly rigid or highly deformable landslides. Model resolution should be selected in accordance with the size of the landslide and hence the wavelength of tsunami waves expected to be generated (e.g., landslide tsunami sources are typically of a smaller geographic extent as coseismic tsunami sources, requiring a higher resolution model grid). All modeling efforts and methodology for a given model or modeling group working on NTHMP mapping should be described and justified (i.e., in a peer-reviewed technical report or journal paper).
- Documentation of modeling effort in a specific area of US waters includes: input data, DEMs, tsunami source geometry, and assumptions about rheological parameters used, and samples of representative model output.
- Inputs for model runs used to generate inundation maps, or to generate input for subsequent propagation and inundation modeling, are to be archived and made available to ensure reproducibility, consistent with NTHMP's data management policy.

- Model should be used to simulate relevant tsunami events and their outputs compared against measurements and other local information where available. Lessons-learned from recent tsunamigenic landslides need to be evaluated, and applicability to relevant NTHMP sources in the selected study area needs to be assessed.
- A suite of relevant and credible tsunami sources, as determined by NTHMP members, in accordance with the Powell Center tsunami source meetings outcomes (once these will be released), should be considered for modeling of landslide tsunamis in US waters.
- At a minimum, model output should include the maximum predicted inundation in order to support mapping needs.

In cases where inundation calculations are to be carried out using the same model framework as used to calculate the initial landslide tsunami generation, as in cases where the targeted study area is in the extreme nearfield of the landslide source, the landslide tsunami model must also be certified for carrying out inundation studies in accordance with the *NTHMP Tsunami Modeling and Mapping: Guidelines and Best Practices, Part I: Tsunami Inundation Modeling* document.

Landslide Tsunami Modeling Best Practices

General

- The computational grid should be of a cell size sufficient to resolve the salient physical processes governing both landslide motion and resulting wave generation
- Landslide tsunami modeling should use the best available data and appropriate modeling techniques and be described in a peer-reviewed technical report and/or journal paper.
- Modeling should include DEMs developed from the highest resolution bathymetric and topographic data available for the area, be performed at an appropriate computational resolution to resolve the salient physical processes, and using credible source characterizations based on up-to-date geological analysis.
- Collaboration between tsunami forecast and inundation modeling groups is encouraged to provide the opportunity to identify and address unusual or significant differences in various model results that could impact inundation and/or forecast products.

Source Characterization

- Tsunami source selection should be based on credible tsunami generating scenarios, based on the geological record and assessment of slope stability and characteristics using site-specific information on sediment type and thickness in source areas. See recommendations of Powell center meetings (once these have been released).
- In the assessment of slope stability and tsunamigenic potential of the study areas, all relevant site-specific landslide triggering processes should be considered alone or in combination (e.g., overburden resulting from sediment accumulation combined with excess pore pressure, seismicity, volcanic processes, artesian processes).
- The NOAA Forecast Source Database (http://nctr.pmel.noaa.gov/propagation-database-access.html) should serve as the default distant source database for inundation modeling, recognizing that the depiction of potential tsunami sources will evolve and change.
- Source characterization should be as detailed as necessary to capture the relevant characteristics of the tsunami waves.

DEM Development

- DEMs for landslide tsunami generation are based on two types of data; existing bathymetry in areas of historic events, or existing bathymetry in areas that are expected to be at risk for subsequent failure.
- For potential events in areas with potential slide volumes in place on the present bathymetry, an assessment of slope stability and contributing geological factors should be carried out to obtain an estimate of failure surfaces and resulting initial slide volumes and shape (see recommendation of Powell center meetings once these are released). The fixed DEM bathymetry would be the existing bathymetry minus the estimated failure volume of the slide (e.g., Schambach et al., 2019
- In case no site-specific data is available to perform slope stability analyses, events can be selected from the geological record (e.g., ten Brink et al., 2014)
- For events taken from the geological record for use in hindcasts, it is necessary to reconstruct the initial pre-event bathymetry based on the geometry of failure scarps and the estimate of deposited volumes. The estimated slide deposit volume would then be

subtracted from the lower slopes of existing bathymetry and placed on the higher slopes in order to reconstruct an initial bathymetry. In this case, the fixed DEM bathymetry would thus be the present bathymetry minus the extracted slide deposit volume downslope, plus the reconstructed initial slide volume upslope (e.g., Grilli et al., 2019; Schambach et al., 2020).

- For cases where landslide tsunami generation is carried out in the same computation as nearfield inundation, a DEM vertical datum of Mean High Water (MHW) or alternative maximum flooding condition is recommended for inundation modeling conducted in support of evacuation planning (MHW is the vertical datum used by NOAA's National Centers for Environmental information (NCEI) to develop coastal DEMs for tsunami forecast and warning).
- DEM cell size should not be smaller than the source elevation data spacing of the most significant data sets (e.g., shallow-water hydrographic soundings or coastal LiDAR survey)—unless required to resolve important morphologic features.
- DEM source elevation data should be obtained in an area 5-10% larger than the DEM extents, to create a "data buffer" to avoid DEM edge effects or grid transition problems during gridding.
- Modeling of tsunami inundation should be performed using DEMs with cell sizes less than 3 arc-seconds (~90 meter), as DEM cell sizes coarser than this tend to degrade inundation modeling results.
- Topographic or bathymetric features, rivers, or community related features that are highly significant to modeling results should be communicated to the DEM development group. Once source data for the features are reviewed, options to ensure correct results can be presented to modelers for feedback.
- DEM source elevation data and development methodologies should be thoroughly documented in standards-compliant metadata records and technical reports.
- DEMs and associated documentation should be described and disseminated online to support use by other groups (e.g., NCEI's DEM Web Portal: https://www.ngdc.noaa.gov/mgg/coastal/coastal.html).

Model Parameters

- Landslide tsunami model runtime should be sufficient to allow for the generation of the portion of the resulting wave train containing waves of significant size.
- The computational grid domain should have enough extent to capture important tsunami wave dynamics. In particular, the domain should allow for the generated waves to propagate an adequate distance from the slide to eliminate significant 3D effects (i.e., strong variations in the vertical direction) so that the resulting wave may be introduced in 2D propagation models as initial conditions (e.g., Grilli et al., 2019; Schambach et al., 2019, 2020).
- To capture the contribution of high tidal conditions, models should be run at a minimum of MHW level conditions for a specific region.

This document is part of the "Tsunami Modeling and Mapping: Guidelines and Best Practices" series. All the documents in this series are available on the NTHMP website at http://nws.weather.gov/nthmp/publications.html:

- *Part I: Tsunami Inundation Modeling*
- *Part II: Tsunami Inundation Maps*
- *Part III: Tsunami Inundation Determination for Non-Modeled Regions*
- *Part IV: Tsunami Evacuation Maps*
- *Part V: Modeling Landslide Tsunamis*
- *Checklist for Tsunami Modeling and Mapping Reports and/or Metadata*

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