NTHMP FY15 Grant Project Narrative

Project Name/Title:	Modeling Tsunami Inundation and Hazard for the U. S. East Coast (Phase 4)
Project Dates:	September 1, 2015 – August 31, 2017
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Executive Summary

In contrast to the long history of tsunami hazard assessment on the US West coast and Hawaii, tsunami hazard assessment along the eastern US coastline is still in its infancy, in part due to the lack of historical tsunami records and the uncertainty regarding the magnitude and return periods of potential large-scale events (e.g., transoceanic tsunamis caused by a large Lisbon 1755 type earthquake in the Azores-Gibraltar convergence zone, a large earthquake in the Caribbean subduction zone in the Puerto Rico trench (PRT) or near Leeward Islands, or a flank collapse of the Cumbre Vieja Volcano (CVV) in the Canary Islands). Moreover, considerable geologic and some historical evidence (e.g., the 1929 Grand Bank landslide tsunami, and the Currituck slide site off North Carolina and Virginia) suggests that the most significant tsunami hazard in this region may arise from Submarine Mass Failures (SMF) triggered on the continental slope by moderate seismic activity (as low as M_w = 6 to the maximum expected in the region M_w = 7.5); such tsunamigenic landslides can potentially cause concentrated coastal damage affecting specific communities (Grilli et al., 2009, 2014; ten Brink et al., 2014).

In FY10-12, we began the process of hazard analysis and inundation map development for the U. S. East Coast. Simulating tsunami sources from the PRT, CVV and Azores-Gibraltar convergence zone (Grilli et al., 2010; Abadie et al., 2012; Harris et al., 2012, Tehranirad et al., 2015; Grilli and Grilli, 2013a,b,c), together with a number of relevant near-field SMFs (Grilli et al., 2014), we concentrated on developing tsunami inundation maps (maximum envelope) for continuous coastal areas located North of Ocean City, MD (Tehranirad et al., 2014) to Cape Cod, MA, plus Myrtle Beach, SC (excluding major bays or estuaries such as Chesapeake Bay, Delaware Bay, Hudson River, Long Island Sound and Narragansett Bay). In FY13, we extended the range of this mapping effort southward to include the communities of Virginia Beach, VA, Savannah, GA, and Miami Beach, FL. Work done in this area will eventually provide detailed tsunami hazard mapping inputs for a number of the larger east coast coastal communities, and the overall modeling effort should provide an indication of possible additional communities needing

attention as well as a sufficient background for providing guidance on determining hazard levels for non-modeled communities. In the current FY14, we are addressing several important issues as part of a set of three prioritized tasks:

(i) We are doing an investigation of dynamic tidal effects on tsunami behavior. Several high population locations on the East Coast are located in regions, which are strongly affected by estuarine tidal flows, with prominent examples being New York, NY and Norfolk, VA. Both of these areas have been modeled as part of FY10-12 or FY13 work, but these investigations do not take into account any potential effects of the tidal conditions Based on this work, we will assess whether a combined tide-tsunami scenario could be treated as a simple linear combination of tide and tsunami, or whether there are significant nonlinearities in the superposition that potentially lead to more hazardous conditions than would be expected from linear superposition alone.

(ii) Having so far modeled landslide tsunamis as resulting from extreme Currituck SMF proxies, we are further refining our set of sources used for east coast modeling, mainly by (1) extending the suite of candidate continental margin SMF sources to include a broader set of cases from the geological record, (2) performing a broader range of simulations for the CVV volcanic cone collapse based on events which are less extreme than the presently utilized 450 km^3 slide volume, and (3) examine the role of our modeling approach in determining the hazard associated with each event. We will use this broader range of source conditions as a basis for starting to reexamine several of the most-impacted communities identified in FY10-12 and FY13 work, with the goal of redoing more detailed mapping. This effort is coordinated with a multi-state group led by California, which is starting to work towards the development of improved capabilities in the area of landslide-generated tsunamis, both modeling and model benchmarking.

(iii) We started conducting a comparison of our previously developed inundation lines with published FEMA hurricane flood maps for selected areas we have directly modeled. The goal is to determine whether there is sufficient agreement between the two families of results to allow using the FEMA maps as proxies in areas where tsunami inundation maps have not yet been developed. Work to date on this task shows positive results, which has to two potential outcomes: first, where we find an agreement between the map products, the urgency for producing independent tsunami hazard maps in these communities can be reduced (particularly those believed to be less affected) and these local communities can start making determinations on hazard conditions and evacuation strategies based on the more familiar FEMA products. Secondly, a positive outcome allows us to use FEMA products as the fundamental resource for providing guidance in areas, which are not likely to be covered by a detailed NHTMP modeling effort. We have also approached this problem by comparing low-resolution model predictions offshore, which are available for the entire coastline, to high resolution inundation results onshore, which are available for our areas mapped in FY10-13. Development of guidance based on these approaches is pending and will be closely coordinated with the Gulf States, who will be working with the same basic information.

In FY15, we are proposing 3 tasks, which are either new (Task 1) or continuations/completion of earlier efforts (Tasks 2 and 3). Specifically:

In Task 1, we would organize and conduct a tsunamigenic landslide model benchmarking and validation workshop in the summer 2016, on behalf of NTHMP/MMS and on the model of earlier NTHMP model benchmarking workshop (Galveston, 2011; Portland, 2015). The expected outcome would be a set of community accepted benchmark tests for validating models for landslide tsunami generation. We would develop extensive workshop documentation and a web-based repository for benchmark data, model results and workshop documentation. An external evaluator would be brought in to review the proposed benchmarks, workshop plans, and outcome, and provide a neutral opinion as of the stated performance of the various models being benchmarked and validated.

In Task 2, continuing our FY14 effort, we would further refine and extend the set of potential SMF sources along the Atlantic margin, and apply new source modeling techniques for tsunami activity in the North Atlantic. As part of an established URI/USGS collaboration, we would integrate USGS's latest field information on SMF sources in our work, and site, characterize and parameterize new relevant extreme SMF sources in our geographic area (including the Florida straight; Chaytor et al., 2014). We would then conduct screening simulations with the newer SMF tsunami generation models developed (Ma et al., 2013, 2015; Kirby et al., 2014). Results of these simulations would be compared to the SMF proxy approach used so far to develop inundation maps. On this basis, we would extend the number and distribution of size of our SMF sources in order to obtain a more nuanced set of input to hazard mapping results, particularly near the northern and southern edges of our study area. We would in parallel continue to examine the role of the modeling approach (i.e., solid slide, debris flow, heavy fluid flow,…) in determining the tsunami hazard associated with each event. Finally, completing work initiated in FY14, we will perform a broader range of simulations for the CVV flank collapse, based on events, which are less extreme than the presently utilized extreme 450 km^3 slide volume.
As part of this task, we would also collaborate in the initial phase of a multistate project on "Improving tsunami warning for landslide tsunamis" proposed by California. The task also aligns with Task 1, which will lead to new benchmarks for SMF tsunami models.

In Task 3, as there is a vast area of the coastline to cover, we would continue our current FY14 effort of assessing tsunami hazard for unmodeled East Coast sites. We would be collecting additional FEMA flooding maps and comparing those to our existing modeling effort. We would continue applying the testing method developed during FY14 to objectively compare the FEMA and NTHMP maps and infer information for the unmodeled areas. We will further be carrying out a study of how east coast continental geometry contributes an overall control on the alongshore distribution of tsunami wave height, rendering predicted inundation levels potentially insensitive to exact nature and location of tsunami source events.

Similar to our earlier work during FY 10-12, FY13 and FY14, modeling in this project will be carried out using a set of models developed at the University of Delaware, including FUNWAVE-TVD, a Boussinesq model for tsunami propagation and inundation simulations, in Cartesian or spherical coordinates (Shi et al., 2012a; Kirby et al., 2013) and NHWAVE, a RANS three-dimensional, sigma-coordinate model for simulating fully non-hydrostatic short wave response to large scale ground motion (Ma et al., 2012, 2013, 2015; Kirby et al, 2014). FUNWAVE and NHWAVE are open source, publically available models, which have been benchmarked according to NTHMP standards (Tehranirad et al, 2011, 2012; Shi et al, 2012b) for use in NTHMP-sponsored work. Both codes are efficiently parallelized using MPI and use a one-way coupling methodology, allowing for large scale computations of tsunami propagation and coastal impact to be performed in a series of nested grids of increasingly finer resolution. Both models deal with breaking dissipation via a TVD algorithm and also implement bottom friction. As in previous work, we will use NHWAVE to compute the initial tsunami waves generated from SMF sources (both translational slides and rotational slumps) and, once the tsunamigenic part of the SMF is complete, we will continue simulating tsunami propagation in FUNWAVE. While we have been so far only considering rigid SMFs in our work, which are believed to yield worst case scenario SMF tsunamis, the most recent version of NHWAVE makes it possible to simulate deforming slides (Ma et al., 2013, 2015; Kirby et al, 2014). We will begin to assemble a set of model results based on deforming slide calculations, pending anticipated parallel efforts towards benchmarking the codes for NTHMP work. The modeling work to date provides a reasonably comprehensive coverage of tsunami impact along the US Northeast coast, as indicated in Figure 1. More work would need to be done to provide complete coverage of the Southeast, beyond the level of coverage in the present effort.

The three tasks indicated here are primarily intended to support the MMS outcome "Tsunami hazard assessment that supports informed decision making in tsunami-threatened communities." Tasks 1 and 2 address the MMS strategy to "Develop new tsunami hazard products to assist the maritime community and meet emergency management and other NTHMP customer requirements". Task 3 addresses the specific MMS strategy to "Develop expected inundation limits for communities which are not provided with high resolution inundation maps".

Background

The proposing team of Kirby and Shi (UD), and S. Grilli and A. Grilli (URI) has been conducting NTHMP-funded work starting in FY10 (A. Grilli since FY12) and continuing to the present. Work to date has been entirely in the area of modeling inundation resulting from potential coseismic, submarine mass failure (SMF) and volcanic cone failure events, in support of the goal of developing tsunami inundation maps for coastal communities. FY10-12 project work centered on development of an initial set of tsunami sources and high resolution mapping of DEMs stretching from Ocean City, MD to Cape Cod. FY13 work was aimed at additional modeling of regions further to the south, including Virginia Beach VA, Savannah, GA, and Myrtle Beach, SC using existing sources, and Miami FL and vicinity using a SMF source based on the West Bahama Banks (Mulder et al., 2012). This last study leverages a collaboration with U. Miami, who have performed the initial analysis and modeling of the source. FY14 involves a continuation of the mapping effort, with the development of extreme SMF proxy sources. New work is also being conducted to: (i) estimate tsunami inundation risk and magnitude in the not-yet-mapped areas, based on FEMA maps developed for storm surge; (ii) study and model tsunami-tide interactions in estuaries and harbors with strong tidally-induced flow (e.g., Chesapeake Bay, Hudson River, New York Harbor), and evaluate how this affects tsunami inundation. Project work on sources has been documented in a series of reports and peer-reviewed papers, which are available at http://www.udel.edu/kirby/nthmp.html. Inundation reports and map products for FY10-12 work are in draft stage and will be distributed to stakeholders for evaluation shortly. These reports provide guidance on accessing modeling results, stored as raster based data sets in ArcGIS format. Tabulated results include inundation limits, inundation depths, maximum velocities and maximum momentum fluxes for initially dry areas, and maximum elevation, velocity and vorticity for initially submerged areas.

The PIs have extensive experience in tsunami model development and application to ocean scale propagation, SMF generation mechanisms, and inundation modeling. Kirby and Grilli developed the first fully-nonlinear Boussinesq model, and this theory served as the basis for the first open source, publically available version of such a model, FUNWAVE (Wei et al., 1995). FUNWAVE has recently been extensively revised in order to improve its accuracy in performing simulations of tsunami runup and inundation (Shi et al., 2012a), and it has been extended to include a spherical coordinate system, with Coriolis effects, for use at ocean scale (Kirby et al., 2013). The model has been fully documented and benchmarked (Shi et al., 2011; Tehranirad et al., 2011) according to

NTHMP standards (Synolakis et al, 2007; Horrillo et al., 2014). The PIs have also been instrumentally involved in the development of methods for performing simulations of either solid or deforming submarine mass failures (SMF) using Navier-Stokes solvers, with either high resolution VOF modeling (Abadie et al., 2010, 2012), or a more efficient, lower resolution surface and terrain following model (Ma et al., 2012, 2013). This latter model, NHWAVE, has been used for SMF simulations in the FY10-12, FY13 and FY14 work, and has been benchmarked for NTHMP use (Tehranirad et al., 2012) using a solid slide. The model has recently been extended to include granular slide modeling (Ma et al, 2015) and has been tested against multiple data sets for subaerial slide configurations. The PIs have made a number of significant contributions to the understanding of wave generation by SMFs, and the group has carried out highly accurate simulations of near and far-field response to seismic tsunami events including the 2004 Indian Ocean event (Grilli et al, 2007; Ioualalen et al, 2007) and the 2011 Tohoku event (Grilli et al, 2013; Kirby et al, 2013; Tappin et al, 2014).

In this box, provide the title of each task, listed in order of priority.

The tasks listed should reflect priorities for sustainment of current activity and participation in NTHMP supported projects and should be consistent with the NTHMP Strategic Plan.

Explain carefully how this new grant will not overlap or duplicate any work under current NOAA grants which, with no-cost extensions, could overlap in time periods for execution.

Task 1: Tsunamigenic Landslide Modeling Benchmark Development, Validation Workshop and Workshop Documentation

Subtask 1: Establish community accepted benchmark tests for validating models for landslide tsunami generation.

Subtask 2: Organize and conduct a model validation workshop.

Subtask 3: Develop workshop documentation and a web-based repository for benchmark data, model results and workshop documentation.

This is an entirely new task that does not overlap with any other existing activity funded by NTHMP.

Task 2: Refinement and extension of potential SMF sources and source modeling techniques for tsunami activity in the North Atlantic

Subtask 1: Collaborate with USGS to include latest field information on SMF sources, and site, characterize and parameterize new relevant extreme SMF sources in our geographic area (including the Florida straight). Conduct screening simulations with the newer SMF tsunami generation models developed. Compare results of these simulations to the SMF proxy approach used so far to develop inundation maps.

Subtask 2: Based on results of Subtask 1, extend the number and distribution of size of our SMF sources in order to obtain a more nuanced set of input to hazard mapping results, particularly near the northern and southern edges of our study area.

Subtask 3: Examine the role of the modeling approach (i.e., solid slide, debris flow, heavy fluid flow,…) in determining the tsunami hazard associated with each event.

Subtask 4: Perform a broader range of simulations for the CVV flank collapse, based on events which are less extreme than the presently utilized extreme 450 km^3 slide volume.

While this work is a continuation of earlier work initiated in FY10-12, and continued in FY13 and FY14, each of these proposed subtasks is distinct from work undertaken in earlier work funded by NTHMP.

As part of Task 3, we would also take part in the initial phase of a multistate project on "Improving tsunami warning for landslide tsunamis" proposed by California. This priority also aligns with Task 2 on detection and early warning of SMF tsunamis. Finally, the priority also ties up with Task 1, which will lead to new benchmarks for SMF tsunami models.

Task 3: Tsunami Hazard Assessement for Unmodeled East Coast Sites

Subtask 1: We will continue collecting FEMA flooding maps and comparing those to our existing modeling effort. We will continue applying the testing method developed during FY14 to objectively compare the FEMA and NTHMP maps and infer information for the unmodeled areas.

Subtask 2: We will carry out a thorough analysis of the degree to which the east coast's broad continental shelf controls the spatial distribution of tsunami hazard.

Work under this priority continues work initiated during FY14, with an additional focus on analyzing the effect of the east coast's broad continental shelf on controlling regional tsunami hazards.

Work in Task 1 will lead to new landslide tsunami model benchmarks and establish the relevance and accuracy of existing models, which is a requirement of the NTHMP Strategic Plan.

Work in Task 2 will address important shortcomings of our work to date for the modeling of landslide tsunamis (i.e., only solid underwater slides and proxy-SMFs where considered), by including more relevant field-based information and using models that better simulate the physics of complex SMFs (e.g., deforming, fluid-like, debris,..). Also, east coast tsunami hazard is currently dominated by the extreme CVV flank collapse, which may be unrealistic and have a very long return period. The new proposed work will revisit and refine this important source scenario.

Work in Task 3 will indicate whether existing model results will be sufficient for providing guidance for hazard assessment for the remainder of the coast that is not modeled yet at a high resolution, or whether there are additional areas that are likely to be in need of high resolution modeling.

Task Project Narratives

Task 1: Tsunamigenic Landslide Modeling Benchmark Development, Validation Workshop and Workshop Documentation

In its FY2009 Strategic Plan, the NTHMP required that all numerical tsunami inundation models be verified as accurate and consistent through a model benchmarking workshop/process. This was completed in FY2011, but only for seismic tsunami sources and in a limited manner for idealized solid underwater landslides. Recent work by various NTHMP states/areas, however, has shown that landslide tsunami hazard may be dominant along significant parts of the US coastline, as compared to hazards from other tsunamigenic sources.

- Along the US east coast, a large volcanic subaerial landslide tsunami on La Palma (Canary Islands) is the dominant, albeit long return period, tsunami source (Abadie et al., 2012; Harris et al., 2012, Tehranirad et al., 2015). Many large underwater landslide scars, some a few 10Ka old, have been mapped by USGS (ten Brink, et al., 2008, 2014) along the continental shelf slope and Atlantic Margin; more recent USGS work (Chaytor et al., 2014) also shows large potential landslides in the Florida straight. Earlier work has shown that many of these landslides would have been strongly tsunamigenic (Grilli et al., 2009, 2014a). In 1929, in this broad geographic area and oceanic margin, a large landslide tsunami was actually triggered off of the Grand Banks by a M7.1 local earthquake (Fine et al., 2005).

- In the Gulf of Mexico, the majority of the tsunami inundation mapping work that is being done as part of NTHMP is based on a few major underwater landslide sources (also mapped by USGS; ten Brink, et al., 2008) (Horrillo, et al., 2013).

- In California, Oregon and Washington states, while both local and far-field seismic sources likely dominate tsunami hazard, many large historical landslides have been mapped which were likely to be strongly tsunamigenic. Notable examples in California include the Goleta slide off of Santa Barbara (Greene et al., 2006) and the Big Sur slide in the Monterey Canyon (Greene and Ward, 2003). Recent work on the Tohoku 2011 tsunami (e.g., Tappin et al., 2014) indicates that very large megathrust earthquakes (such as anticipated in the future for the Cascadia subduction zone), may also trigger very large landslides which could contribute significant additional wave activity in addition to the co-seismic tsunami. Hence, their study, siting and modeling should be done ahead of time, in preparation for such large seismic events.

- In Alaska, numerous landslides, both underwater and subaerial, have been triggered by large earthquakes (e.g., the M9.2 1964 event) and artesian flows, and have caused tsunamis with significant local runup and inundation. In this region, the most notable such event is the Lituya Bay 1958 subaerial slide that triggered a tsunami in a narrow fjord, causing over 500 m runup on the other side of the fjord (Fritz et al., 2001, 2009; Weiss et al., 2009).

- In Hawaii, larger landslides associated with volcano flank motion and collapse have occurred (e.g., Kalapana 1975; Day et al., 2005) causing significant runup. Such events will continue to occur in the future as a result of the continuous build up and weathering of volcanoes.

- In Puerto Rico, a number of large historical landslide tsunami events have been mapped by USGS and modeled (e.g., in the Mona passage; Lopez-Venegas et al., 2008).

In past years, there has been considerable model development and benchmarking activity for seismically induced tsunamis, in particular within the auspice of NTHMP (e.g., the Galveston benchmarking workshop for tsunami elevations in 2011, NTHMP, 2012; Horrillo et al. (2013) as well as the upcoming Portland workshop for tsunami velocities in 2015). For landslide tsunamis, however, both the model development and benchmarking efforts have been lagging. In 2003, the east coast NTHMP PIs were co-organizers of a NSF sponsored landslide tsunami workshop in Hawaii, and a similar follow-up workshop took place on Catalina island in 2006. Since then, to our knowledge, no similarly large and comprehensive benchmarking workshops have been organized. In 2011, following the NTHMP model benchmarking workshop, J. Horrillo organized a landslide tsunami workshop devoted to a review of the state-of-the-art in modeling. Later that year, the USGS Woods Hole group (U. ten Brink, J. Chaytor, and E. Geist) organized a similar workshop, during which the state-of-the-art in field work, geology, PTHA, and landslide tsunami modeling were reviewed.

A decade ago, investigators were satisfied with modeling solid block landslides (e.g., Grilli et al., 1999, 2002, 2005; Lynett and Liu, 2003; Watts et al., 2003, 2005; Liu et al., 2005) and benchmarking experiments were developed for those and used for tsunami model benchmarking (in particular as part of the Galveston workshop; Enet and Grilli, 2007). More recently developed models simulate deformable slides and solve both more complete sets of equations (dispersive, non-hydrostatic, Navier-Stokes) and consider subaerial or submarine slides as heavy fluids (e.g., Abadie et al., 2010, 2012; Horrillo et al., 2014), flows induced by sediment concentration (Ma et al., 2013), or granular flow layers (Ma et al., 2015). A number of recent laboratory experiments have modeled tsunamis generated by subaerial landslides made of gravel (Fritz et al., 2004; Heller and Hager, 2012; Mohammed and Fritz, 2012) or glass beads (Viroulet et al., 2014), but, to our knowledge, there are no experimental benchmark data for deforming underwater landslides that are initiated underwater, but some relevant experiments are in preparation to this effect.

Following discussions at a recent meeting, the NTHMP MMS subcommittee recommended that a landslide tsunami model benchmarking workshop be organized in the near future. In response to this recommendation, this proposal seeks funding from NTHMP to conduct such a workshop, on the model of the one organized in Galveston in 2011 and the upcoming workshop in Portland in 2015. To help with preparing the workshop scientific program, a small committee led by the two PIs will be formed in large part composed of NTHMP-MMS members. The committee will meet during upcoming MMS meetings and conduct conference calls to identify an agenda for the workshop and select a set of relevant landslide tsunami benchmarks (analytical, numerical, experimental, field). While these are not yet determined, recent experiments with granular/glass bead flows for subaerial landslide will be likely experimental benchmark candidates; the 1998 Papua New Guinea landslide tsunami (Tappin et al., 2008) could also serve as a field benchmark candidate. Some solid block underwater landslide experiments could also serve as benchmarks. A workshop webpage will be built, as a receptacle for the benchmark information and data, as well as other practical information regarding the workshop. The committee will help select a workshop date to coincide with an NTHMP meeting. To allow for enough preparation time and also for some ongoing experiments to be completed, the targeted date for the workshop is summer 2016, preceding or following the regular NTHMP/MMS summer meeting. Once the workshop date is set, the benchmarking data will be posted a few months ahead of time, and, at the same time, potential participants will be invited to attend the workshop and given information on how to access the data. These participants will be in part NTHMP modelers and investigators (about 10), together with a group of selected experts and graduate students (about 15). Participants will be invited to simulate as many benchmarks as possible (with a minimum set to warrant financial support to attend the workshop), using their own model, and results will be compared during the workshop, and discrepancies with the benchmarking data discussed. Although this may be more difficult to do than for seismic tsunamis, participants will be asked to attempt to reach a consensus at the end of the workshop, on both acceptable modeling approaches (and associated models) for various types of landslide tsunamis and acceptable levels of discrepancies with various types of benchmarking data. Finally, the scientific committee will prepare a workshop proceedings and a manuscript for publication in a peer-reviewed journal based on the workshop findings (as done for the Galveston workshop; Horrillo et al., 2014). In order to provide an independent assessment of benchmark development and model evaluation, we will engage an outside reviewer to evaluate all stages of the process above. This step is provided for in the budget as an unspecified contract, with the external reviewer to be chosen early in the process in order to allow him or her to take part in every stage of the process. The bulk of benchmark development, organization of the workshop, and reporting of results will be handled by the proposing team.
List all NTHMP Strategic Plan Outcome and Strategies that this task addresses. 1. Tsunami hazard assessment that supports informed decision making in tsunami-threatened communities (MMS)   a. Continue to ensure all models funded by NTHMP meet the NOAA standards for inundation models as defined in NOAA-NTHMP (2012a) (MMS)

b. Ensure models used for NTHMP-funded work is shared (MMS)	
Date of expected completion 5/17	• Develop and document a set of benchmark tests for landslide tsunami models • Conduct a model validation workshop to test the accuracy of models available to the NTHMP community • Assess the shortcomings of existing modeling approaches in relation to observational data • Document results in the form of a report and a summary paper, and develop a web site to provide open access to results and benchmark data.
	Task 1 Total Cost: **$88,531**

Task 2: Refinement and extension of potential SMF sources and source modeling techniques for tsunami activity in the North Atlantic:

Sources used in initial mapping efforts for the East Coast consisted of far-field seismic sources (Puerto Rico, Grilli et al., 2010, Grilli and Grilli, 2013c; Azores-Gibraltar convergence, zone, Grilli and Grilli, 2013a), a far-field subaerial source (flank collapse of the Cumbre Vieja Volcano, CVV; Abadie et al., 2012; Harris et al., 2012, Tehranirad et al., 2015) and several near-field SMF sources on the US continental margin, in the form of Currituck slide proxies (Grilli et al., 2015). To date, FY10-14 work, mainly confined to the Northeast, has used a family of Currituck-like sources as SMF proxies with various source locations dictated by the presence of an adequate sediment supply to support the size of the event (Grilli et al., 2015). FY13 work further to the south utilized a Cape Fear-like slide proxy with a probable maximum size. In FY14 we are modeling an additional event located on the West Bahamas Bank carbonate platform.

All our NTHMP-related slide modeling to date has been based on a solid slide model developed in house by Ma et al (2012) and benchmarked against a solid slide experiment by Enet and Grilli (2007). The assumption that all underwater landslides behave as a single solid mass may not be applicable to all types of realistic slides, and may also strongly overestimate landslide tsunami risk (this effect of slide deformation in reducing tsunami amplitude was already pointed by Grilli and Watts, 2005). Consequently, in this task, we would like to put in effort to:

1. Extend the number and distribution of size of our slide sources in order to obtain a more nuanced set of input to hazard mapping results, particularly near the northern and southern edges of our study area,
2. Examine the role of the modeling approach (i.e., solid slide, debris flow, or heavy fluid flow) in determining the tsunami hazard associated with each event.
3. Perform a broader range of simulations for the CVV flank collapse based on events which are less extreme than the presently utilized extreme 450 km^3 slide

volume (Abadie et al., 2012).

The USGS Woods Hole group has recently been conducting field work to better map and parameterize SMF sources along the Atlantic margin, including the Florida straight (ten Brink et al., 2014; Chaytor et al., 2014). The URI investigator and his colleagues have a cooperative agreement with the USGS Woods Hole group and prior contacts indicate that they (in particular Dr. Chaytor) are interested in doing collaborative work as part of this task, and are willing to share their most recent SMF source information with us. On this basis, in FY15, we will identify, site and parameterize relevant SMF sources, and estimate their failure mode (i.e, slide/slump, rigid/debris flow,…) in order to define the most relevant modeling strategy. This could include some limited slope stability analyses. Based on the new field data we will perform screening SMF tsunami generation simulations, first assuming rigid slumps as in prior work with NHWAVE, and then using the latest NHWAVE implementations (Ma et al., 2013, 2015) which model slides either as dense suspensions or granular flows. We will thus quantify how using the most relevant model adapted to the SMF type and mechanism (i.e., solid or not very deformable for slumps, deforming for slides, and even debris flows) affects tsunami generation. Results will be compared to the earlier proxies we simulated, and relevant new worse case scenarios will be selected for further modeling. It should be noted that this methodology also applies and can inform similar work that needs to be performed in other states (e.g., California) and also is relevant for preparing the SMF benchmarking workshop (Task 1); hence, there are numerous synergies here (see below). More specifically, for each of the SMF sources considered here, we propose to perform simulations for both solid slides, and using a slide model based on a depth-integrated, deformable slide layer lying below the usual NHWAVE perfect fluid layer (Kirby et al., 2014; Ma et al., 2015). The purpose of this work is to determine whether solid slide modeling provides an overly conservative view of resulting tsunami events, as discussed further below. The results for the increased range of SMF events, and for the choice of deforming vs. solid slides, would be used to re-examine the hazard mapping results for two heavily impacted communities, to be determined later.

As part of this task, we would also take part in the initial phase of a multistate project "Improving tsunami warning for landslide tsunamis" proposed by California. Landslide tsunamis play a dominant role in the hazard estimates for the East Coast, and we are concerned both with the warning technology (with warning times being much smaller for SMF tsunamis) and with the impact of choice of modeling technique on the resulting size of modeled events. In particular, we would like to provide a comparison of events for our chosen sources (as well as other sources of generic nature or in specific geographic locations) based on using solid translating slides vs. arbitrarily deforming slides. Results in hand from other related projects indicate that simulations based on solid, non deforming slides can be dramatically over-conservative. There is also a need for establishing benchmark tests for the deformable slide cases, as this modeling approach plays a strong part in several state and region NTHMP modeling efforts; this is work also needed as part of the proposed landslide tsunami benchmarking workshop (Task 1).

Echoing the description of a multi-state effort proposed through the State of California's NTHMP FY14 proposal, we would coordinate with CA and additional partners to:

- Evaluate and improve the criteria used by the Tsunami Warning Centers for minor-moderate earthquake and landslide sources. This warning criteria issue is a major concern along the highly populated, central and southern California coastlines. California is working closely with Alaska, Puerto Rico, and the East and Gulf Coast states, which face a similar hazard, to develop tsunamigenic landslide benchmarks and hold a model validation workshop by 2016 (see Priority 1). Work with other entities (besides USGS) to evaluate appropriate locations for undersea landslide investigations to compare with the above analysis and use toward eventual WCS recommendation of protocol development by the tsunami warning centers; these other entities include states/territories with similar local source issues: Alaska, Puerto Rico, East Coast, and Gulf Coast. Part of this analysis will also lead to the creation of new benchmarks for tsunamigenic landslide modeling through the NTHMP and ultimately to a model benchmark workshop.
List all NTHMP Strategic Plan Outcome and Strategies that this task addresses. 1. Tsunami hazard assessment to support informed decision making in tsunami-threatened communities (MMS) a. Develop inundation maps for all communities with high tsunami hazard as defined by state tsunami programs MMS) b. Develop expected inundation limits for communities, which are not provided with high-resolution inundation maps. (MMS)

Date of expected completion 8/16	• Based on recent USGS field work, site, characterize and parameterize new relevant extreme SMF sources in the Atlantic margin. • Based on simulations using newer SMF tsunami generation models, evaluate the relevance and update the SMF proxy approach used so far to develop inundation maps. • Extend the number and distribution of size of SMF sources in order to obtain a more nuanced set of input to hazard mapping results, particularly near the northern and southern edges of our study area. • Establish the role of the modeling approach (i.e., solid slide, debris flow, heavy fluid flow,…) in determining the tsunami hazard associated with each event. • Obtain a broader range of simulations for the CVV flank collapse, based on events which are less extreme than the presently utilized extreme 450 km^3 slide volume.
	Task 2 Total Cost: **$135,484**

Task 3: Tsunami Hazard Assessment for Unmodeled East Coast Sites:

The U.S. East and Gulf Coasts are frequently impacted by large storm systems such as tropical cyclones and Nor'easters, and as a result there has been extensive effort made to develop probabilistic inundation maps for storm-driven coastal flooding. These maps cover the same areas under consideration in NTHMP modeling and mapping efforts, and are already extensively developed for the entire region, with extensive efforts either ongoing or recently completed to update the modeling database and resulting maps in several FEMA regions. (These studies have also been the source for high resolution DEM's in several areas not covered by the NGDC tsunami DEM's, such as New York City and adjacent areas in New Jersey and Long Island (NY)). FEMA flooding maps will be collected for the entire East Coast and then systematically compared to existing NTHMP modeling efforts. The task is expected to not be entirely straightforward, as estuaries and other types of embayments can be resonators of low frequency storm surge responses, leading to increasing surge with distance from ocean entrances, whereas they typically serve as filters for tsunami motions, attenuating the tsunami signal over these same distances. Our strategy would likely be to examine the correspondence between FEMA and NTHMP results on directly exposed ocean shorelines, and then account for likely tsunami attenuation effects further up rivers or estuaries using medium resolution modeling.

In addition, geometric features of shelf geometry are known to lead to focusing effects in incident tsunami waves, leading to alongshore variations in tsunami response that are not likely to be mirrored by surge responses to traveling storm systems. To address this, we will examine the correspondence between low resolution model results offshore and detailed model results onshore in mapped areas in order to provide an additional baseline for unmapped areas.

In order to provide a test of the resulting methodology, we will use a training set and test set approach. Guidelines will be developed based on a set of about 50% of our total set of modeled DEM's (the training set), and then the guidelines will be applied to the remaining set of modeled DEM's and compared to model results there (the test set). In the event that the test produces accurate results (as indicated by a to-be-determined criterion), the methodology will then be suggested for use as the regular NTHMP guidance for hazard determination in unmodeled East Coast areas. A "learning machine algorithm" approach could be evaluated to help identifying similar patterns in both types of maps and defining a relevant criterion to do so.

We will coordinate closely with the Gulf Coast region in developing the methodology, as that region has undergone the same detailed analysis for hurricane storm surge and is affected by similar types of potential tsunami events. No formal multi-state proposal exists on this topic to date.

List all NTHMP Strategic Plan Outcome and Strategies that this task addresses.

1. Tsunami hazard assessment to support informed decision making in tsunami-threatened communities (MMS) a. Develop expected inundation limits for communities, which are not provided with high-resolution inundation maps. (MMS)	
Date of expected completion 8/16	• An extended comparison of FEMA flooding maps with our existing modeling effort, to objectively compare the FEMA and NTHMP maps and infer information for the unmodeled areas. • Additional assessment of controls on general coastal hazards resulting from continental shelf geometry for the US East Coast
	Task 3 Total Cost: **$24,330**

COLLABORATION AND SYNERGIES

1. Collaboration is defined as two or more grantees working on the same project in their respective states. Collaboration does not include merely sharing resources or information with each other. This section of the Project Narrative is about jointly-funded NTHMP grant activities shared among one or more NTHMP grant partners.

   If there are no jointly-funded shared priorities/tasks with another NTHMP Grantee, then check this box and leave the rest of this page blank:

   ___ No jointly-funded priorities or tasks with any other NTHMP Grantee.

2. List any tasks within any priorities above that will be directly worked on collaboratively with any other NTHMP grantee. State the priority and task number from your grant as well as the name of the other NTHMP grantee and its specific priority and task number for this same activity. For this activity to count as being collaborative, your Priority/Task must also appear on your collaborative partner's FY15 NTHMP Grant Narrative in this same space.

This grant Task #	Grant partner name & Task #	Short description of collaborative task/priority
Task 3 subtask 1	Gulf of Mexico Task 3	Using FEMA and state flooding and storm surge maps as surrogates for NTHMP inundation maps
Task 2 subtask 3	California (multi-state) Task 6	Assess effect of modeling approach on hazard prediction for landslide sources

3. Describe with whom and how you will work collaboratively on the priority(ies)/task(s) listed in the table above.

We will work with Juan Horrillo's group at TAMUG to develop the methodology for using FEMA flood map products or individual states' storm surge evacuation maps as a means for providing guidance for tsunami inundation and evacuation planning in areas lacking hi-resolution NTHMP modeling. (Work continuing from FY14).

We will work with the California group and other potential multi-state partners on determining the effect of landslide model choice on the resulting estimates of tsunami hazard for a variety of source configurations. Landslide models can be based on a wide variety of assumed physical behavior. UD and URI are heavily involved in the development of these models, and assessing the effect of model choice on our own East Coast results is a crucial activity for us. We would like to extend this to settings, which are of interest to California and other states, and can carry out the computational work as part of our own effort.

Summary of Task Plan

FY14 Milestone Schedule (September 1, 2015 – August 31, 2017)

Task	Key Milestone	Expected Month/Year of Completion	Requested Funding
Task 1: Tsunamigenic Landslide Modeling Benchmark Development, Validation Workshop and Workshop Documentation			
Establish community accepted benchmark tests for validating models for landslide tsunami generation	Final choice of suite of benchmarks for workshop use	**2/16**	
Organize and conduct model validation workshop	Workshop conducted in conjunction with summer MMS meeting	**8/16**	
Develop workshop documentation and web-based repository	Publication of workshop report, launch of website	**5/17**	
		Subtotal Task 1:	**$88,531**
Task 2: Refinement and extension of potential SMF sources and source modeling techniques for tsunami activity in the North Atlantic			
Collaborate with USGS to include latest information on SMF sources		**12/15**	
Extend number and distribution of sizes of SMF sources to obtain a more nuanced set of input to hazard mapping results		**3/16**	
Examine role of modeling approach in determining tsunami hazard		**6/17**	
Perform a broader range of simulations for CVV flank collapse		**8/16**	
		Subtotal Task 2:	**$135,483**
Task 3: Tsunami Hazard Assessment for Unmodeled East Coast Sites			
Continue work comparing FEMA flood zone maps and state storm evacuation maps to NTHMP inundation maps (work in conjunction with Gulf of Mexico)		**8/16**	
Evaluate degree to which continental shelf reduces dependence on source location for east coast hazards		**8/16**	
		Subtotal Task 3:	**$24,330**
		Total FY2014 Grant Request:	**$248,344**

Grand Total of Award Request: $248,344

BIOGRAPHICAL SKETCH
James T. Kirby
Edward C. Davis Professor of Civil Engineering
Center for Applied Coastal Research
Dept. of Civil and Environmental Engineering
University of Delaware, Newark, DE 19716
Phone: (302) 831-2438; Fax: (302) 831-1228
E-mail: kirby@udel.edu

A. Professional Preparation

Brown University	Engineering	Sc. B., 1975
Brown University	Engineering	Sc. M., 1976
University of Delaware	Civil Engineering	Ph. D., 1983

B. Appointments

Edward C. Davis Professor of Civil Engineering, University of Delaware, 2003 to present.
Professor, Department of Civil and Environmental Engineering, University of Delaware, 1994 to 2003.
Joint appointment in College of Earth, Ocean and the Environment, 1994 to present.
Visiting Professor, Grupo de Dinamica de Flujos Ambientales, Universidad de Granada, 2010, 2012. Associate Professor, Dept. of Civil and Environmental Engineering, University of Delaware, 1989 to 1994.
Associate Professor, Dept. of Coastal and Oceanographic Engineering, University of Florida, 1988 to 1989.
Assistant Professor, Dept. of Coastal and Oceanographic Engineering, University of Florida, 1984 to 1988.
Assistant Professor, Marine Sciences Research Center, SUNY Stony Brook, 1983 to 1984.

C. Products

1. Abdolali, A., Cecioni, C., Bellotti, G. and Kirby, J. T., 2015, "Hydro-acoustic and tsunami waves generated by the 2012 Haida Gwaii earthquake: modeling and in-situ measurements", *J. Geophys. Res: Oceans*, **120**, 958-971, doi:10.1002/2014JC010385..
2. Tehranirad, B., Harris, J. C., Grilli, A. R., Grilli, S. T., Abadie, S., Kirby, J. T. and Shi, F., 2015, "Far-field tsunami hazard on the western European and US east coast from a large scale flank collapse of the Cumbre Vieja volcano, La Palma", resubmitted to *Pure and Applied Geophysics*.
3. Ma, G., Kirby, J. T., Hsu, T.-J. and Shi, F., 2015, "A two-layer granular landslide model for tsunami wave generation: Theory and computation", *Ocean Modelling,* under revision.
4. Abdolali, A., Kirby, J. T. and Bellotti, G., 2015, "Depth-integrated equation for hydro-acoustic waves with bottom damping", *J. Fluid Mech.*, **766**, R1, doi:10.1017./jfm.2015.37
5. Grilli, S. T., O'Reilly, C., Harris, J. C., Tajalli Bakhsh, T., Tehranirad, B., Banihashemi, S., Kirby, J. T., Baxter, C. D. P., Eggeling, T., Ma, G. and Shi, F., 2015, "Modeling of SMF tsunami hazard along the upper U. S. East Coast: Detailed impact around Ocean City, MD", *Nat. Hazards*, **76**, 705-746, doi: 10.1007/s11069-014-1522-8.
6. Tappin, D. R., Grilli, S. T., Harris, J. C., Geller, R. J., Masterlark, T., Kirby, J. T., Shi, F., Ma, G., Thingbaijam, K. K. S. and Mai, P. M., 2014, "Did a submarine landslide contribute to the 2011 Tohoku tsunami?", *Marine Geology*, **357**, 344-361.
7. Kirby, J. T., Shi, F., Tehranirad, B., Harris, J. C. and Grilli, S. T., 2013, “Dispersive tsunami waves in the ocean: model equations and sensitivity to dispersion and Coriolis effects”, *Ocean Modelling*, **62**, 39-55.
8. Grilli, S. T., Harris, J. C., Tajalibakhsh, T., Masterlark, T. L., Kyriakopoulus, C., Kirby, J. T. and Shi, F., 2013, “Numerical simulation of the 2011 Tohoku tsunami based on a new transient FEM co-seismic source", *Pure and Applied Geophysics*, **170**, 1333-1359.
9. Ma, G., Kirby, J. T. and Shi, F., 2013, "Numerical simulation of tsunami waves generated by deformable submarine landslides", *Ocean Modelling*, **69**, 146-165.
10. Ma, G., Shi, F. and Kirby, J. T., 2012, "Shock-capturing non-hydrostatic model for fully dispersive surface wave processes", *Ocean Modelling*, **43-44**, 22-35.

11. Shi, F., Kirby, J. T., Harris, J. C., Geiman, J. D. and Grilli, S. T., 2012, "A high-order adaptive time-stepping TVD solver for Boussinesq modeling of breaking waves and coastal inundation", *Ocean Modelling*, **43-44**, 36-51.
12. Grilli, S. T., Dubosq, S., Pophet, N., Perignon, Y., Kirby, J. T. and Shi, F., 2010, "Numerical simulation of co-seismic tsunami impact on the North Shore of Puerto Rico and far-field impact on the US East Coast: a first-order hazard analysis", *Nat. Haz. Earth Sys. Sci.*, **10**, 2109-2125.
13. Waythomas, C. F., Watts, P., Shi, F. and Kirby, J. T., 2009, "Pacific basin tsunami hazards associate with mass flows in the Aleutian Arc of Alaska", *Quaternary Science Rev.*, **28**, 1006-1019.
14. Long, W., Kirby, J. T. and Shao, Z., 2008, "A numerical scheme for morphological bed level calculations", *Coastal Engineering*, **55**, 167-180.
15. Grilli, S. T., Ioualalen, M., Asavanant, J., Shi, F., Kirby, J. T. and Watts, P., 2007, "Source constraints and model simulation of the December 26, 2004 Indian Ocean tsunami", *J. Waterway, Port, Coastal and Ocean Engineering*, **133**, 414-428.
16. Ioualalen, M., J. A. Asavanant, N. Kaewbanjak, N., Grilli, S. T., Kirby, J. T. and Watts, P., 2007, "Modeling of the 26th December 2004 Indian Ocean tsunami: Case study of impact in Thailand", *Journal of Geophysical Research*, **112**, C07024, doi:10.1029/2006JC003850.
17. Day, S. J., Watts, P., Grilli, S. T. and Kirby, J. T., 2005, "Mechanical models of the 1975 Kalapana, Hawaii earthquake and tsunami", *Marine Geology*, **215**, 59-92.
18. Watts, P., Grilli, S. T., Kirby, J. T., Fryer, G. J. and Tappin, D. R., 2003, "Landslide tsunami case studies using a Boussinesq model and a fully nonlinear tsunami generation model", *Natural Hazards and Earth System Sciences*,**3**, 391-402, 2003.
19. Kennedy, A. B, Chen, Q., Kirby, J. T., and Dalrymple, R. A., 2000, "Boussinesq modeling of wave transformation, breaking and runup. I: One dimension", *J. Waterway, Port, Coastal and Ocean Engineering*, **126**, 39-47.
20. Chen, Q., Kirby, J. T., Dalrymple, R. A., Kennedy, A. B. and Chawla, A., 2000, "Boussinesq modeling of wave transformation, breaking and runup. II: Two horizontal dimensions", *J. Waterway, Port, Coastal and Ocean Engineering*, **126**, 48-56.

D. Synergistic Activities

1. Editorial service including Associate Editor, Journal of Engineering Mechanics (1994-1995), Editor, Journal of Waterway, Port, Coastal and Ocean Engineering (1996-2000), Editor, Journal of Geophysical Research – Oceans (2003-2006) and Editor-in-Chief, Journal of Geophysical Research – Oceans (2006-2009).
2. Member, Coordinating Committee and Mapping and Modeling Subcommittee of the National Tsunami Hazard Mitigation Program (2008-present).
3. Member, Board of Directors, American Institute of Physics (2011-2013).
4. Lead developer of a number of widely used public domain models for surface wave processes, including the surface wave transformation programs REF/DIF and FUNWAVE, the nearshore community model NearCoM for wave-driven circulation, and the recently developed surface and terrain following nonhydrostatic model NHWAVE.
5. Developer of course content for several University of Delaware graduate level courses including CIEG 672 Ocean wave mechanics, CIEG 872 Advanced ocean wave mechanics (textbook under development), CIEG 681 Ocean wave spectra (textbook under development), and CIEG 684 Introduction to nearshore modeling techniques (new course)

E. Collaborators and Other Affiliations

Present Collaborators: Chris Baxter (URI), Stephan Grilli (URI), Tom Hsu (UD), Fengyan Shi (UD), Chris Summerfield (UD), Tobias Kukulka (UD), Gangfeng Ma (ODU), Chris Chickadel (UW), W. Rockwell Geyer (WHOI), Merrick Haller (OSU), Jeffrey C. Harris (URI), James M. Kaihatu (Texas A&M), Jamie MacMahan (NPS), Tim Masterlark (ND School of Mines), Alex Sheremet (UF), Ad Reniers (Delft UT).
Ph.D. Thesis Advisor: Robert A. Dalrymple, Dept. of Civil Engineering, Johns Hopkins University.
Graduate and Postgraduate Advisees (41 total graduate advisees)
Dongming Liu (2008-2009); James Kaihatu (1994, Texas A&M), Changhoon Lee (1994, Sejong Univ.), Ge Wei (1997, unknown), H. Tuba Özkan-Haller (1997, Oregon St U), Mauricio Gobbi (1998, Fed. Univ. Parana), Arun Chawla (1999, NWS), Shubhra Misra (2005, Chevron), Wen Long (2006, U MD), Joseph Geiman (2011, Johns Hopkins ARL), Gangfeng Ma (2012, Old Dominion U), Zhifei Dong (expected 2014), Babak Tehranirad (expected 2015), Morteza Derakhti (expected 2015), Saeideh Banihashemi (expected 2016), Ali Abdolali (2014-)

Biographical Sketch for Stephan Grilli

Name: Stephan T. Grilli Title: Distinguished Professor
http: www.oce.uri.edu/_grilli Address: Dpt. Ocean Engng., URI, Narragansett, RI 02882
Tel./Fax.: (401) 874-6636/-6837 Email: grilli@oce.uri.edu

A. Professional Preparation :

M.S. (1980, Civil Engineering); Registered Professional Civil Engineer (1980); M.S. (1983, Physical Oceanography); Ph.D (1985, Ocean Engng.; advisor Prof. A. Lejeune), all from Univ. of Liège (Belgium) (all *summa cum laude*). Post-doctoral work (1985-87), Univ. of Liège (Belgium)

B. Permanent positions :

2011-present, *Professor* (joint appointment), U. of Rhode Island, Grad. School of Oceanography
2002-2008, *Chairman*, University of Rhode Island, Dept. of Ocean Engng.
1998-present, *Distinguished Professor*, University of Rhode Island, Dept. of Ocean Engng.
1996-1998, *Distinguished Assoc. Professor*, University of Rhode Island, Dept. of Ocean Engng.
1993-1996, *Associate Professor*, University of Rhode Island, Dept. of Ocean Engineering.
1991-1993, *Assistant Professor*, University of Rhode Island, Dept. of Ocean Engineering.
1987-1991, *Research Assistant Professor*, University of Delaware, Dept. of Civil Engineering.
1985-1987, *Research Associate* (F.N.R.S.), University of Liège (Belgium).

C. Visiting positions :

2007, 2014, *Research Director*, C.N.R.S., University of Toulon, LSEET, France (Spring 07, 14).
2005, *Invited Professor*, U. of Braunschweig, Institute for Civil Engng., Germany (January 05).
1999, *Visiting Senior Scientist*, University of Nice, Institut Nonlin´eaire, France (Spring 99).
1998-present, *Visiting/Invited Prof.*, Univ. of Toulon, LSEET Laboratory, France (1-3 m./year).
1996, *Visiting Professor*, University of Nantes, Ecole Centrale, France (January 06).
1991, *Visiting Scholar*, U. of Cantabria, Dept. of Water Science and Tech., Spain (April/June 91).

D. Selected Relevant Publications : (http://www.oce.uri.edu/ grilli/resume.html; h-index: 35)

1. Grilli, S.T., Ioualalen, M, Asavanant, J., Shi, F., Kirby, J. and Watts, P. (2007). Source Constraints and Model Simulation of the 12/26/04 Indian Ocean Tsunami. *J. Waterw. Port Coast. Ocean Engng.*, **133**(6), 414-428.
2. Ioualalen, M. , Asavanant, J., Kaewbanjak, N., Grilli, S.T., Kirby, J.T. and P. Watts (2007). Modeling the 12/26/04 Indian Ocean tsunami: Case study of impact in Thailand. *J. Geoph. Res.*, **112**, C07024.
3. Tappin, D.R., Watts, P., Grilli, S.T. (2008). The Papua New Guinea tsunami of 1998: anatomy of a catastrophic event. *Natural Hazard and Earth System Sc.*, **8**, 243-266.
4. Grilli, S.T., Taylor, O.-D. S., Baxter, D.P. and S. Maretzki (2009). Probabilistic approach for determining submarine landslide tsunami hazard along the upper East Coast of the United States. *Marine Geology*, **264**(1-2), 74-97, doi:10.1016/j.margeo.2009.02.010.
5. Grilli, S.T., S. Dubosq, N. Pophet, Y. P´erignon, J.T. Kirby and F. Shi (2010). Numerical simulation and first-order hazard analysis of large co-seismic tsunamis generated in the Puerto Rico trench: near-field impact on the North shore of Puerto Rico and far-field impact on the US East Coast. *Natural Hazards and Earth System Sciences*, **10**, 2109-2125.
6. Abadie, S., J.C. Harris, S.T. Grilli and R. Fabre (2012). Numerical modeling of tsunami waves generated by the flank collapse of the Cumbre Vieja Volcano (La Palma, Canary Islands) : tsunami source and near field effects. *J. Geophys. Res.*, **117**, C05030.
7. Grilli, S.T., Harris, J.C., Tajali Bakhsh, T.S., Masterlark, T.L., Kyriakopoulos, C., Kirby, J.T. and and Shi, F. (2013). Numerical simulation of the 2011 Tohoku tsunami based on a new transient FEM co-seismic source: Comparison to far- and near-field observations. *Pure and Appl. Geophys.*, **170**, 1333-1359, doi:10.1007/s00024-012-0528-y .

8. Kirby, J.T., Shi, F., Tehranirad, B., Harris, J.C. and Grilli, S.T (2013). Dispersive tsunami waves in the ocean: Model equations and sensitivity to dispersion and Coriolis effects. *Ocean Modell.*, **62**, 39-55, doi:10.1016/j.ocemod.2012.11.009.
9. Horrillo J., Grilli S.T., Nicolsky D., Roeber V., and J. Zhang (2014). Performance Benchmarking Tsunami Operational Models for NTHMP's' Inundation Mapping Activities. *Pure and Applied Geophysics*, 1-16 doi: 10.1007/s00024-014-0891-y (published online 7/25/14).
10. Tappin D.R., Grilli S.T., Harris J.C., Geller R.J., Masterlark T., Kirby J.T., F. Shi, G. Ma, K.K.S. Thingbaijamg, and P.M. Maig (2014). Did a submarine landslide contribute to the 2011 Tohoku tsunami ?, *Marine Geology*, **357**, 344-361 doi: 10.1016/j.margeo.2014.09.043 (published online 9/28/14; open access).
11. Grilli S.T., O'Reilly C., Harris J.C., Tajalli-Bakhsh T., Tehranirad B., Banihashemi S., Kirby J.T., Baxter C.D.P., Eggeling T., Ma G. and F. Shi (2015). Modeling of SMF tsunami hazard along the upper US East Coast: Detailed impact around Ocean City, MD. *Natural Hazards*, **76**(2), 705-746,, doi: 10.1007/s11069-014-1522-8 (published online 11/15/14).
12. Tehranirad, B., Harris, J. C., Grilli, A. R., Grilli, S. T., Abadie, S., Kirby, J. T. and Shi, F., 2015, "Far-field tsunami hazard on the western European and US east coast from a large scale flank collapse of the Cumbre Vieja volcano, La Palma", resubmitted to *Pure and Applied Geophysics*.

E. Synergistic Activities:
1. Various tsunami hazard assessment projects for critical coastal infrastructures (e.g., nuclear powerplants and maritime facilities). Proprietary studies.
2. Appointed member of the US *National Research Council Marine Board* (2010-), leader of sub-committee on critical coastal infrastructure resilience; East Coast co-representative on the US *National Tsunami Hazard Mitigation Program* mapping and modeling committee (2010-2013).

F. Current collaborators: Prof. M. Benoit (Univ. Paris East, France); Profs. C.A. Gu´erin, F. Nougquier, M. Saillard and Ph. Fraunie (Univ. of Toulon, France); Prof. S. Abadie (Univ. of Pau et Pays de l'Adour, France); Prof. M. Benoit (Lab. St Venant; Univ. Paris East); Prof. F. Dias (Ecole Normale Sup´eriqure, Paris, France); Prof. J.T. Kirby (Univ. of Delaware); Professor T.L. Masterlark South Dakota School of Mines); Prof. D. Tappin (British Geological Survey, UK); Prof. Krafczyk (Tech. U.. Braunschweig, Germany).

G. Media outreach: Featured on local, national, and international media (TV, radio, newspaper science sections) regarding extreme waves and tsunamis (e.g., Discovery channel, PBS-National Geographics Intl., US Weather Channel, BBC-TV/radio, ABC/NBC, CNN International, History Channel, DE-NPR,. . .).

I. Thesis advisor and postgraduate-scholar sponsor: (past 5 years : 2 post-doc, 20 graduate students) : Taylor Asher (MS, URI), Amir Banari (current PhD student, URI); Benjamin Biausser (PhD; Technip, France), Myriam El Bettah (current PhD student, URI), Kevyn Bollinger (MS, URI), Sara Dubosq (current PhD student, U. of Toulon, France), Yann Drouin (MS; Ecole Centrale, Nantes, France), Francois Enet (PhD, URI; Alkyon Inc., Holland), Christophe Fochesato (PhD; Ecole Normale Sup´erieure, France), Nate Greene (MS, URI; Raytheon, RI), Richard Gilbert (MS; McLaren Inc., NY), Philippe Guyenne (PhD; U. of Delaware, DE), Jeff Harris (PhD, URI; Laboratoire St Venant, Paris), Stefan Maretzki (MS, URI; Germany), Kristy Moore (MS, URI; NUWC, RI), Yves Perignon (MS; PhD, ECN, Nantes, France) Matt Schultz (MS, URI; Woods Hall Engineering Inc.), Tayebeh S. Tajali-Bakhsh (current PhD student, URI).

Professional Societies : AGU, ASCE, ISOPE, MTS; 7 scient. awards in Belgium, France and US

Fengyan Shi

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C. Professional Preparation

Wuhan University of Science and Technology, Physics, Sc. B., 1984
Ocean University of Qingdao, Physical Oceanography, Sc. M., 1991
Ocean University of Qingdao, Environmental and Physical Oceanography, Ph. D., 1995
University of Delaware, Center for Applied Coastal Research, Postdoc, 1999-2003

D. Appointments

Research Associate Professor, Department of Civil and Environmental Engineering & Center for Applied Coastal Research, University of Delaware, 2012 - present
Research Assistant Professor, Department of Civil and Environmental Engineering & Center for Applied Coastal Research, University of Delaware, 2007 - 2012
Associate Scientist, Center for Applied Coastal Research, University of Delaware, 2004 – 2007
Associate Professor, Institute of Estuarine and Coastal Research, East China Normal University, 1997 – 1998

E. Publications

(i) Five most closely related to the proposed project

- Tappin, D. R., Grilli, S. T., Harris, J. C., Geller, R. J., Masterlark, T., Kirby, J. T., Shi, F., Ma, G., Thingbaijam, K. K. S. and Mai, P. M., 2014, ``Did a submarine landslide contribute to the 2011 Tohoku tsunami?", *Marine Geology*, 357, 344-361.

- Ma, G., Kirby, J. T. and Shi, F., 2013, ``Numerical simulation of tsunami waves generated by deformable submarine landslides", *Ocean Modelling*, 69, 146-165.

- Kirby, J. T., Shi, F., Tehranirad, B., Harris, J. C., and Grilli, S. T., 2013, "Dispersive tsunami waves in the ocean: model equations and sensitivity to dispersion and Coriolis effects", *Ocean Modelling* , 62, 39-55.

- Shi, F., Kirby, J. T., Harris, J. C., Geiman, J. D. and Grilli, S. T., 2012, "A high-order adaptive time-stepping TVD solver for Boussinesq modeling of breaking waves and coastal inundation", *Ocean Modelling*, 43-44, 36-51.

- Ma, G., Shi, F. and Kirby, J. T., 2012, "Shock-capturing non-hydrostatic model for fully dispersive surface wave processes", *Ocean Modelling*, 43-44, 22-35.

(ii) Five most recent publications

- Shi, F., Vittori, G. and Kirby, J. T., 2015, ``Concurrent correction method for modeling morphological response to dredging an offshore sandpit", *Coastal Engineering* , 97, 1-10.
- Grilli, S. T., O'Reilly, C., Harris, J. C., Tajalli Bakhsh, T., Tehranirad, B., Banihashemi, S., Kirby, J. T., Baxter, C. D. P., Eggeling, T., Ma , G. and Shi, F., 2015 "Modeling of SMF 54 tsunami hazard along the upper U. S. East Coast: Detailed impact around Ocean City, MD", *Nat. Hazards*, DOI 10.1007/s11069-014-1522-8.
- Keshtpoor, M., Puleo, J. A., Shi, F. and Ma, G., 2015,``3D Numerical Simulation of Turbulence and Sediment Transport within a Tidal Inlet", *Coastal Engineering*, 96,13-26.
- Chen, J., Shi, F., Hsu, T.-J., and Kirby, J. T., 2014,``NearCoM-TVD - a quasi-3D nearshore circulation and sediment transport model", *Coastal Engineering,* 91, 200-212
- Ma, G., Shi, F., Hsiao, S.-C., and Wu Y.-T.,2014, ``Non-hydrostatic modeling of wave interaction with porous structures", *Coastal Engineering*, 91, 84-98

D. Synergistic Activities

Convener and chair of session of nearshore processes at AGU 2008 Fall Meeting
Session chair of 32nd international conference of coastal engineering, 2010
Editorial board of the scientific world journal - oceanography

F. Collaborators and Other Affiliations

(i) Collaborators

Patrick Barnard(USGS), Chris Chickadel(UW), Steve Elgar(WHOI), Li Erikson(USGS), Jody Eshleman(NPS), Stephan Grilli(URI), Merrick Haller(OSU), Daniel Hanes(SLU), Jeffrey L. Hanson(ASACE), Rob Holman (OSU), Raleigh Hood (U. Maryland), Evamaria Koch(U. Maryland), Jamie MacMahan(NPS), Tim Masterlark(U. Alabama), Natalie Perlin(OSU), Roger Newell(U. Maryland), Elizabeth North(U. Maryland), Ad Reniers(UM), Larry Sanford (U. Maryland), Chris Sherwood(USGS), Richard P. Signell(USGS), John C. Warner(USGS), Phil Watts(App. Fluid Engr.), Chris Waythomas(USGS), Chris Sommerfield(UD)

(ii) Graduate and Postgraduate Advisees

Master graduate student: Yunfeng Chen (graduated 2010, Educational Testing Service, co-advise with Kirby)

PhD students: Jian Shi, Guoxiang Wu, Jialin Chen (co-advise with Hus), Mohammad Keshtpoor (co-advise with Puleo)

Post-doc: Wenzhou Zhang (Xiamen University)

(iii) Ph.D. Thesis Advisor:

Shizuo Feng, Department of Physical Oceanography, Ocean University of Qingdao.

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Education

University of Delaware, USA, 2000, Ph.D. in Climatology
University of Liège, Belgium, 1984, M.S. in Oceanography
University of Liège, Belgium, 1983, B.S. in Geography and B.S. in Education (summa cum laude)

Experience

2014-present: Associate Research Professor, Department of Ocean Engineering (OCE), University of Rhode Island (URI)
2006–2014: Assistant Research Professor, OCE-URI
2004-2005: Research Scientist, OCE-URI.
2003-2005 : Independent Consultant in Environmental Engng., Narragansett, RI.
2002-2003 : Research Scientist, Applied Sciences Associates, Narragansett, RI.
2000-2002 : Post Doctoral researcher, OCE-URI.
1993-2000 : Independent Consultant, Narragansett, Rhode Island.
1988-1991 : Research Assistant in Climatology, University of Delaware.
1984-1987: Research/Teaching Assistant/Lecturer in regional planning. Department of Geography, University of Liège (Belgium).

Professional Societies/Honors

2010-2012: Appointed member of the National Research Council (NRC) "Marine and Hydrokinetic Energy Technology Assessment" committee, of the National Academies.
2010-: Member of the "American Geophysical Union".
2007-: Member of the "International Society for Offshore and Polar Engineers".
1992-98: Member of the "American Geographical Society".
1988-1989 : Lefranc Foundation Travel/Research scholarship, University of Liège (Belgium).

Book

Marine and Hydrokinetic Energy Technology Assessment Committee, 2013. National Research Council. *An Evaluation of the U.S. Department of Energy's Marine and Hydrokinetic Resource Assessments*. Washington, DC: The National Academies Press, 154 pages, 978-0-309-26999-5, http://www.nap.edu/catalog.php?record_id=18278.

Selected Recent Journal and refereed Proceedings Articles

Tehranirad B., Harris J.C., Grilli A.R., Grilli S.T., Abadie S., Kirby J.T. and F. Shi, 2015. Far-field tsunami hazard in the north Atlantic basin from large scale flank collapses of the Cumbre Vieja volcano, La Palma. *Pure and Applied Geophysics*, 34pps. (resubmitted).

Grilli, A.R., Grilli S.T., David, E. and C. Coulet 2015. Modeling of tsunami propagation in the Atlantic Ocean Basin for tsunami hazard assessment along the North Shore of Hispaniola. To appear in *Proc. 25th Offshore and Polar Engng. Conf.* (ISOPE15, Kona, HI, USA. June 21-26, 2015). Intl. Society of Offshore and Polar Engng., 8 pps.

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Grilli, A.R. and M.L. Spaulding 2013. Offshore wind resource assessment in Rhode Island waters. *Wind Engineering,* **37**(6), 579-594, doi:10.1260/0309-524X.37.6.579.

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Gemme, D.A., Bastien, S.P., Sepe R.B., Montgomery J., Grilli S.T. and Grilli A.R. 2013. Experimental Testing and Model Validation for Ocean Wave Energy Harvesting Buoys. In *Proc. IEEE Energy Conversion Congress and Exposition* (ECCE13, Denver CO, September, 2013), paper 1407, 337-343

Grilli, A.R., Lado, T., and M. Spaulding 2012. A protocol to include ecosystem services in a wind farm cost model. *J. Environmental Engineering* **139**(2), 176-186, doi:10.1061/(ASCE)EE. 1943-7870.0000599.

Grilli, A.R., Lado, T. and M.L Spaulding 2011. Ecosystem services typology: a wind farm siting tool. In *Proc. 21th Offshore and Polar Engng. Conf.* (ISOPE11, Maui, HI June 19-24, 2011), 525-532, Intl. Society of Offshore and Polar Engng.

Grilli, S.T., Grilli, A.R., Bastien, S.P., Sepe, Jr., R.B., and M.L. Spaulding 2011. Small Buoys for Energy Harvesting: Experimental and Numerical Modeling Studies. In *Proc. 21st Offshore and Polar Engng. Conf.* (ISOPE11, Maui, HI, USA, June 19-24, 2011), 598-605, Intl. Society of Offshore and Polar Engng.

Grilli, A.R., Spaulding, M.L. and C. Damon 2010. Methods for Wind Farm Siting Optimization: New England Case Study. In *Proc. 20th Offshore and Polar Engng. Conf.* (ISOPE10, Beijing, China, June 20-25, 2010), 727-734, Intl. Society of Offshore and Polar Engng.

Spaulding, M.L., Grilli, A.R., and C. Damon 2010. Application of technology development index and principal component analysis and cluster methods to ocean renewable energy facility siting. *J. Marine technology Soc.*, **44**(1), 8-23.

Bastien, S.P., Sepe, R.B., Grilli, A.R., Grilli S.T., and M.L. Spaulding 2009. Ocean Wave Energy Harvesting Buoy for Sensors. In *Proc. IEEE Energy Conversion Congress and Exposition* (ECCE09, San Jose CA, September, 2009), **3**,718-3,725, doi: 978-1-4244-2893-9/09/.

Selected Recent Research reports

Grilli A.R. and S.T. Grilli, 2013. Modeling of tsunami generation, propagation and regional impact along the U.S. East Coast from the Azores Convergence Zone. *Research Report no.* **CACR-13-04**. NTHMP Award, #NA10NWS4670010, US National Weather Service Program Office, 20 pp.

Grilli A.R. and S.T. Grilli, 2013. Far-Field tsunami impact on the U.S. East Coast from an extreme flank collapse of the Cumbre Vieja Volcano (Canary Island). *Research Report no.* **CACR-13-13**. NTHMP Award, #NA10NWS4670010, US National Weather Service Program Office, 13 pp.

Grilli A.R. and S.T. Grilli, 2013. Modeling of tsunami generation, propagation and regional impact along the upper U.S East coast from the Puerto Rico trench. *Research Report no.* **CACR-13-02**. NTHMP Award, #NA10NWS4670010, US National Weather Service Program Office, 18 pp.

Grilli S.T., Tajalli-Bakhsh, T.S., Grilli, A.R. and J. Harris 2012. Fine grid simulations of tsunami hazard along the Mozambique coast. *Technical Report for Phase III.* Ocean Engineering, University of Rhode Island, 52 pps.

SUPPLEMENTAL MATERIAL

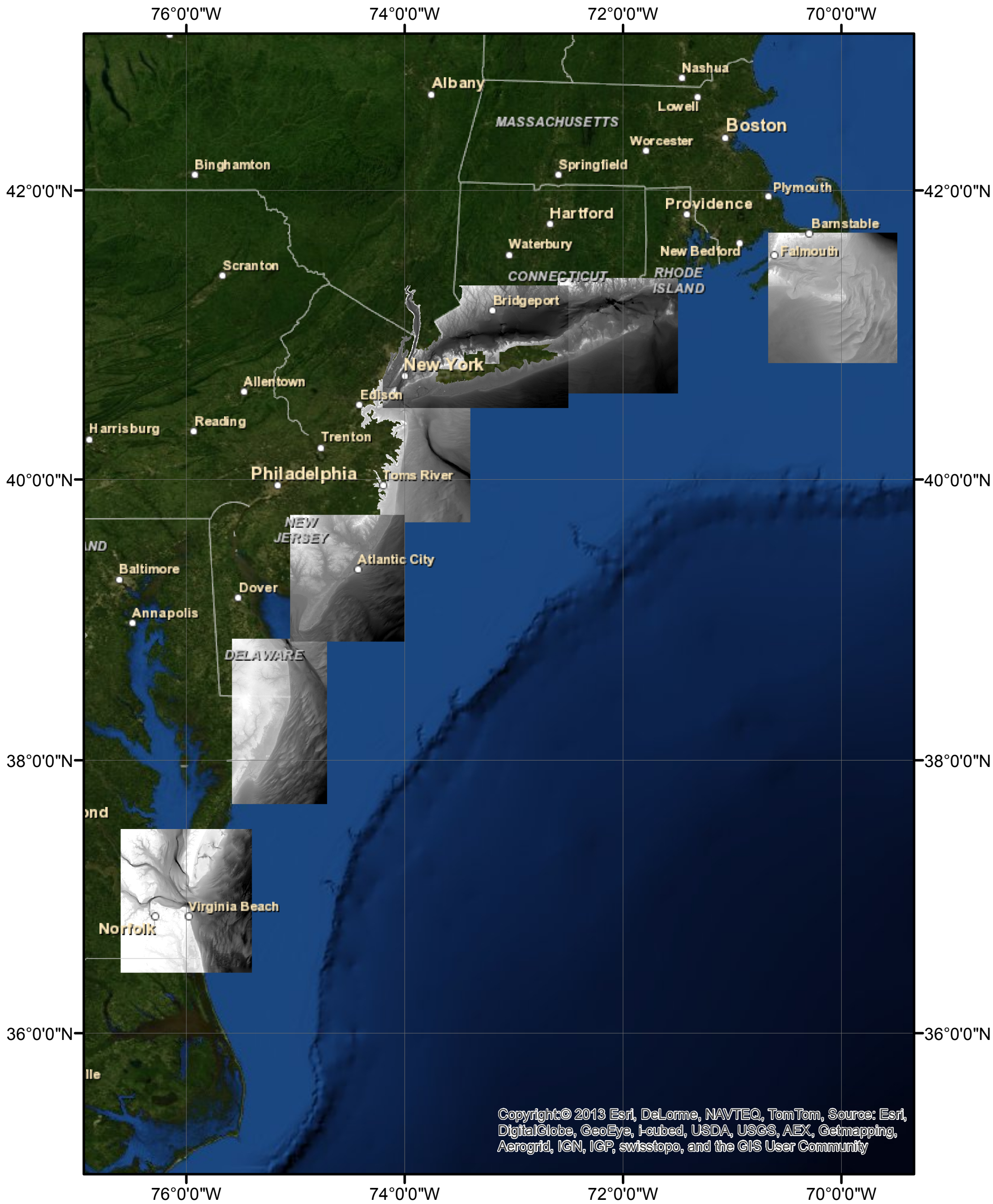

Figure 1. Northeast US DEM coverage for FY10-12 (Ocean City, MD; Atlantic City, NJ, Northern New Jersey, New York City and Western Long Island, Montauk (Eastern Long Island) and Martha's Vineyard/Nantucket) and FY13 (Virginia Beach). All DEM's are NGDC Tsunami DEM's except for Northern New Jersey, New York and Western Long Island, which are derived from FEMA Region 2 DEM's.

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