NTHMP Project Narrative

Project Name/Title:	Modeling Tsunami Inundation and Hazard for the US East Coast (Phase 2)
Project Dates:	September 1, 2013 – August 31, 2014
Recipient Institution:	University of Delaware
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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.

In FY10-12, we have begun 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, together with a number of relevant near-field SMF, we concentrated on developing tsunami inundation maps (maximum envelope) for continuous coastal areas located North of Ocean City, MD 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 propose to keep developing inundation maps for the southern coastal areas along the US east coast, following the same methodology as well as studying areas near and into the mouth of the Chesapeake Bay.

While we were initially supposed to only model areas as far south as Georgia, after discussions with the NTHMP U.S. Gulf Coast group, we have extended the geographic range of our region of

responsibility to also include the Atlantic coast of Florida, thus effectively placing the state of Florida in two different NTHMP regions. This extension sets the context for one of the proposed tasks discussed next.

We propose to address two new tasks in FY13:

1. Inundation studies for Virginia Beach/Norfolk VA, Savannah GA and Jacksonville, FL using existing source information
2. Inundation studies for Miami Beach, FL, Palm Beach, FL and neighboring communities, using new sources developed for the West Bahama Banks.

Each of these tasks is described in detail below.

Similar to our earlier work during FY 10-12, 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 (Wei et al., 1995; Kennedy et al., 2000; Chen et al., 2000; Shi et al., 2012; 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). FUNWAVE and NHWAVE are open source, publically available programs, which have been benchmarked according to NTHMP standards (as part of the 2011 NTHMP benchmarking workshop, Galveston, TX) 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 in a series of nested grids of increasingly fine resolution. Both models deal with breaking dissipation via a TVD algorithm and also implement bottom friction. As in the FY10-12 work, we will use NHWAVE only 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 (Watts et al., 2003, 2005; Grilli and Watts, 2005; Day et al., 2005; Tappin et al., 2008), the most recent version of NHWAVE makes it possible to simulate deforming slides (Ma et al., 2013). Hence, in SMF cases where the rheology is unclear from the geology, we will continue assuming rigid SMFs since earlier modeling and scaling analyses showed that the key parameter in SMF tsunami generation (besides volume and submergence depth) is initial acceleration, and typical SMF deformation rates do no significantly affect these key tsunami features (Grilli and Watts, 2005). But if the work calls for simulating a debris flow (such as occurred during the 1929 Grand Bank event), our modeling tools can deal with this type of tsunami sources (Ma et al., 2013; Abadie et al., 2010, 2012).

As before, coseismic tsunami sources (e.g., Puerto Rico trench, Leeward Islands, or Lisbon 1755 sources in the Azores convergence zone) will be specified in FUNWAVE as an initial surface elevation mimicking the seafloor deformation, using Okada's (1985) method, which is a function of simple earthquake and fault zone parameters. This methodology has been successfully used in many earlier case studies (Grilli et al., 2007, 2010; Ioualalen et al., 2007; Karlsson et al., 2009).

It has become apparent during recent tsunami events that the residual flow field and persistent eddies set up by tsunami attack on harbors and other navigable areas can be quite damaging and dangerous to vessels and infrastructure, even in situations where tsunami runup and inundation is itself minimal. For example, Figure 1 (from Lynett et al., 2012) illustrates an example of a persistent eddy structure dominating an enclosed harbor for a significant amount of time past the point where harbor surging due to direct response to incident waves has subsided. At present, velocity fields and their persistence in open water or enclosed harbor areas are not typically examined as part of a hazard mapping effort, and different metrics for the hazards are required, such as measures of velocity or the expected time for motions to subside to a safe level. In the tasks proposed below, as well as in our ongoing work on FY10-12 tasks, we will collect information on flow fields and velocities in affected navigable inlets and harbor facilities that will be useful in future navigation hazard analysis.

Each of the subtasks described below involves a careful sequence of modeling steps. For each site studied, bathymetric data from various sources for deep and shallow water regions, as well as onshore DEM topography must be obtained, and this data must be merged via krigging into computational model grids. The configuration of distant sources must be reexamined in order to insure that conditions representing maximum impact at each site have been considered. This, in turn, requires rerunning some of these at oceanic grid scale. A thorough review of the literature on potential Grand Bahama Bank SMF events must be carried out, and additional work (particularly on the Cape Fear event) must be conducted in view of the more southerly locations of the sites under consideration in much of the proposed work. SMF sources are simulated using NHWAVE and may require grid sensitivity analyses. NHWAVE results are then interpolated onto onto FUNWAVE and coastal simulations are performed on a series of nested grids, leading to onshore inundation studies for each source in fine grids, calculation of maximum surface elevation envelopes, and development of inundation maps in GIS in proper format.

Background

The team of the University of Delaware (UD) and University of Rhode Island (URI) are presently involved in an FY10-12 NTHMP project aimed at providing the first round of tsunami hazard assessment and inundation mapping for the U. S. East Coast. During this effort, the team has conducted detailed simulations of a number of distant events affecting East Coast sites, including seismic events in the Hispaniola/Puerto Rico trench and the Azores Convergence Zone, a volcanic cone collapse (Cumbre Vieja, CVV) in the Canary Islands, and a number of submarine mass failure events (SMF) on the U.S. continental shelf margin. High resolution modeling of coastal inundation is presently being carried out for Myrtle Beach, SC and a continuous stretch of coastline running from Ocean City, MD north to Cape Cod, MA, with mapping underway for a limited subset of the region covered so far.

The PIs have extensive experience in tsunami model development and application to ocean scale propagation, submarine mass failure generation mechanisms, and inundation modeling. Kirby and Grilli developed the first fully-nonlinear Boussinesq model (Wei et al, 1995), and this theory served as the basis for the first open source, publically available version of such a model, FUNWAVE (Chen et al., 2000; Kennedy et al., 2000). FUNWAVE has recently been extensively revised in order to improve its accuracy in performing simulations of tsunami runup and inundation (Shi et al., 2012), 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., 2011a; Tehranirad et al., 2011) according to NTHMP standards (Synolakis et al, 2007). 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, is being used for ongoing SMF simulations in the FY10-12 work, and has been benchmarked for NTHMP use (Tehranirad et al., 2012). The PIs are also well established as tsunami scientists. Grilli has made a number of significant contributions to the understanding of wave generation by SMFs (Grilli and Watts 2005, for example) and the group has carried out highly accurate simulations of near and farfield 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, 2012; Kirby et al, 2013).

The proposed work represents new efforts related to the overall goal of examining and mapping hazards for the U.S. East Coast. Task 1 will utilize previously studied tsunami sources and events to study inundation in two heavily populated sites, which have not been considered under FY10-12 funding, including Virginia Beach, VA, Savannah, GA and Jacksonville, FL. Task 2 will consider previously unstudied sites in the State of Florida, including Miami and Palm Beach, using information from potential tsunami sources in the Florida Strait, which have not been previously studied in our applications to more northerly sites. In each of these tasks, we will collect the information needed for construction of NTHMP-compliant inundation maps, and, in the event that study areas include navigable coastal inlets or harbor facilities, we will also collect the information needed to aid in future development of navigational hazard charts. Each of these tasks represents a distinctly new set of efforts relative to the ongoing FY10-12 project. The tasks will be carried out by the same project team in conjunction with the FY10-12 work, which continues under no-cost extension. The combined funding does not overcommit any team member in terms of time allocation.

Capability 1: Threat/hazard assessments

Determine U.S. communities at risk, extent of future tsunami inundation, and tsunami vertical evacuation refuge heights

Task 1: *Perform inundation studies for Virginia Beach, VA, Savannah, GA and Jacksonville, FL:*

Our previous FY10-12 work (which will be ongoing in a no-cost extension) has examined distant seismic sources (Puerto Rico Trench and the Azores Convergence Zone), a distant volcanic cone collapse (Cumbre Vieja, Canary Islands) and a range of potential SMF events modeled after the Currituck and Cape Fear slides occurring in the geological record. This set of events provides the input for more detailed modeling of most sites on the exposed Atlantic coastline. In this task, we will use this existing set of sources to model inundation and, where appropriate, hazardous conditions in navigable waterways, at three additional populated areas on the exposed coastline; Virginia Beach, VA, Savannah, GA and Jacksonville/St. Augustine, FL. This work is divided into three subtasks as follows:

Task 1.1 *Inundation study for Virginia Beach, VA*: In this task, we will utilize sources studied previously in FY10-12 work to model inundation for Virginia Beach, VA. This subtask will utilize an existing NGDC DEM (Taylor et al., 2008a) as the basis for high resolution computations.

Task 1.2 *Inundation study for Savannah, GA*: In this task, we will primarily utilize sources studied previously in FY10-12 work to model inundation for Savannah, GA. The task will require additional new examination of the Cape Fear slide complex and it's possible influence on the South Atlantic region in a range of possible alternate locations with geologically similar properties to the historic event. Inundation modeling will be carried out using an available high resolution NGDC DEM (Taylor et al., 2008b).

Task 1.*3 Inundation study for Jacksonville/St. Augustine, FL*: This task will use existing source information together with Task 1.2 extensions to the Cape Fear source scenarios to study tsunami impact at the northern Florida region. DEM's for this region will have to be developed using bathymetry sources developed previously for storm surge simulations (usually by FEMA), leading to the higher cost for this individual task. (We are presently using a similar approach for the region from northern New Jersey to western Long Island, NY.)

These three study sites do not overlap any ongoing work in FY10-12.

Propagation and inundation modeling for all three subtasks will be carried out using the Boussinesq model FUNWAVE. New simulations of landslide sources resulting from a more extensive analysis of the Cape Fear complex will be carried out using the NHWAVE model.

The URI team will concentrate on the additional analysis of landslide tsunami sources needed for this work, and on tailoring intermediate scale propagation modeling results needed for input to the nested high resolution regional and local simulations. High resolution inundation modeling and the development of inundation lines and tabulation of velocity and momentum flux results will be carried out by the UD team. Inundation lines will be developed in GIS format for utilization by individual state mapping agencies, who will be informed of results during the course of the study.

What NTHMP Strategic Plan outcomes(s) does this support?
MMS: Tsunami Hazard Assessment that Supports Informed Decision Making in Tsunami-Threatened Communities

Where applicable:	FY13: Complete first generation hazard assessment for Virginia Beach, VA, (Task 1.1, April 2014), Savannah, GA (Task 1.2, June 2014) and Jacksonville, FL (Task 1.3, August 2014)
	FY13 Cost: \$20,000 (Task 1.1), \$20,000 (Task 1.2), \$30,000 (Task 1.3), \$70,000 (total)

Task 2: *Perform inundation studies for Miami Beach and Palm Beach, FL:*

Task 2.1: Selection and model simulation of sources in Grand Bahama Bank
Task 2.2: Inundation study for Miami, FL
Task 2.3: Inundation study for Palm Beach, FL

Miami Beach, FL, and Palm Beach, FL are heavily populated coastal areas which are largely sheltered by the Grand Bahama Bank from the open ocean sources we have been considering to date, but which are potentially impacted by SMF sources along the western flank of that bank itself. The possibility of SMF events along the eastern side of the Florida Strait has drawn increasing interest recently (see Mulder et al., 2012, for a recent synthesis of ongoing drilling programs and analysis of bathymetry data). In particular, it is thought that, in contrast to the silicate composition of the continental shelf to the north of Florida, that the carbonate formation of banks such as the Grand Bahama Bank may potentially be most subject to instability and failure during rising sea level scenarios, thus making present environmental conditions more favorable to the occurrence of SMF events.

We divide Task 2 into three subtasks.

Task 2.1: *Literature review and selection and simulation of SMF sources on Grand Bahama Bank*. In this task, we will examine the available geologic record (see Figure 2 for example, for indications of scarping and mass wasting events) and construct plausible scenarios for SMF events on the western boundary of Grand Bahama Bank. We will simulate slides based on these scenarios using NHWAVE. Slides will be simulated both as solid sliding objects (Ma et al., 2012), corresponding to existing NTHMP benchmark standards, and as deformable masses using models based either on dilute Newtonian suspensions (Ma et al., 2013) or on granular flow models with significant intergranular stresses (under development with non-NTHMP funding) in order to assess the sensitivity to these underlying assumptions about the generation mechanism. URI will lead this task and perform the bulk of the source geology and geometry and the main NHWAVE-based simulations, with UD conducting the main work examining sensitivity of results to the choice of solid or deformable slide configurations.

Task 2.2: *Inundation study for Miami, FL*. Results for new Bahama sources as well as existing distant sources (Task 1) will be used to conduct high resolution inundation studies for Miami, FL. This work will require the construction of a high resolution DEM from available storm surge DEM's (FEMA and other sources) as in Task 1.3 above. This work will be carried out primarily by UD with URI input.

Task 2.3: *Inundation study for Palm Beach, FL.* Results for new Bahama sources as well as existing distant sources (Task 1) will be used to conduct high resolution inundation studies for Palm Beach, FL. This work will be carried out using an existing high resolution DEM (Friday et al., 2012). This work will be carried out primarily by UD with URI input. Inundation modeling in Tasks 2.2 and 2.3 will be done using the model FUNWAVE. Results for inundation and runup as well as maps of maximum velocities and momentum fluxes will be saved for subsequent map development.	
What NTHMP Strategic Plan metric(s) does this support? MMS: Tsunami Hazard Assessment that Supports Informed Decision Making in Tsunami-Threatened Communities	
Where applicable:	FY13: Analysis of potential SMF sources in Grand Bahama Banks (Task 2.1, May 2014), Complete first generation hazard assessment for Miami FL (Task 2.2, August 2014) and Palm Beach FL (Task 2.3, August 2014)
	FY13 Cost: $29,001 (Task 2.1), $25,000 (Task 2.2), $20,000, (Task 2.3), $74,001 (total)

Summary of Task Plan

FY13 Milestone Schedule (September 1, 2013 – August 31, 2014)

Task	Key Milestone	Expected Month/Year of Completion	Requested Funding
Capability 1: Threat/hazard Assessment			
Task 1: Tsunami hazard analysis for Virginia Beach VA, Savannah GA and Jacksonville FL	Completion of inundation results for map development		
Task 1.1 Inundation study for Virginia Beach, VA		**4/2014**	**$20,000**
Task 1.2 Inundation study for Savannah, GA		**6/2014**	**$20,000**
Task 1.3 Inundation study for Jacksonville/St. Augustine FL		**8/2014**	**$30,000**
Task 2: Tsunami hazard analysis for Miami and Palm Beach, FL	Completion of inundation results for map development		
Task 2.1: Selection and model simulation of sources in Grand Bahama Bank		**5/2014**	**$29,001**
Task 2.2: Inundation study for			

Miami, FL Task 2.3: Inundation study for Palm Beach, FL		**8/2014** **8/2014**	**$25,000** **$20,000**
		Subtotal Capability 1:	**$144,001**
Capability 2: Preparedness for response to tsunami emergencies			
		Subtotal Capability 2:	
Capability 3: Sustaining tsunami warning dissemination and TsunamiReady program maintenance			
		Sub-Total Capability 3:	
Capability 4: NTHMP directed tasks to state programs			
		Sub-Total Capability 4:	
		Total FY2013:	144,001

Grand Total of Award: $144,001

BIOGRAPHICAL SKETCH

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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.
Visiting Professor, Grupo de Dinamica de Flujos Ambientales, Universidad de Granada, 2010, 2012.
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.
Associate Professor, Department of Civil and Environmental Engineering, University of Delaware, 1989 to 1994.
Associate Professor, Department of Coastal and Oceanographic Engineering, University of Florida, 1988 to 1989.
Assistant Professor, Department of Coastal and Oceanographic Engineering, University of Florida, 1984 to 1988.
Assistant Professor, Marine Sciences Research Center, SUNY Stony Brook, 1983 to 1984.

C. Publications

1. 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.
2. 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.
3. 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.
4. 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.
5. 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 Syst. Sci.*, **10**, 2109-2125.
6. 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 Reviews*, **28**, 1006-1019.
7. 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", *J. Geophys. Res.*, **112**, C07024, doi:10.1029/2006JC003850.
8. 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, Coast. and Ocean Engrng.*, **133**, 414-428.
9. 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.

10. Kirby, J. T., 2003, "Boussinesq models and applications to nearshore wave propagation, surfzone processes and wave-induced currents", in *Advances in Coastal Modeling*, V. C. Lakhan (ed), Elsevier, 1-41.

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-present).
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

Collaborators and Co-Editors (last 5 years)
Hernan G. Arango (Rutgers), Chris Baxter (URI), Sachin K. Bhate, Alan F. Blumberg (Stevens), Brad Butman (WHOI), Tim J. Campbell (NRL), Yeon Chang, Bruce Cornuelle (SIO), T. Duman (U AR), Kasey Edwards (NRL), Steve Elgar (WHOI), Katja Fennel (Dalhousie), Diane Foster (UNH), W. Fox, David Froehlich (NOAA), W. Rockwell Geyer (WHOI), Stephan Grilli URI), Kevin Haas (GaTech), Merrick Haller (OSU), Daniel Hanes (St. Louis U), Jeffrey L. Hanson (USGS), Ruoying He, Bill Hodgkiss (SIO), H. R. Albert Jagers, James M. Kaihatu (Texas A&M), Timothy R. Keen (NRL), Michael Kemp (UMd), Bill Kuperman (SIO), Ming Li (UMD), Jamie MacMahan (NPS), Tim Masterlark (U Alabama), James C. McWilliams (UCLA), H. Tuba Özkan-Haller (OSU), Natalie Perlin (OSU), John Proakis (UCSD), Ad Reniers (U Miami), Donald T. Resio (UNF), Jan A. Roelvink (TU Delft), D. Rouseff (U Wash), Lawrence P. Sanford (UMD), Alexander Shchepetkin (UCLA), Chris Sherwood (USGS), Richard P. Signell (USGS), Eric D. Skyllingstad (OSU), Jerry Smith (SIO), Richard L. Soulsby (Wallingford), Tim Stanton (NPS), Keith D. Stolzenbach (UCLA), Emanuele Terrile (U. Genoa), Ed Thornton (NPS), Peter A. Traykovski (WHOI), John H. Trowbridge (WHOI), Jay Veeramony (NRL), John C. Warner (USGS), Phil Watts (Appl Sci), Richard J. S. Whitehouse, (Wallingford) Johan C. Winterwerp (TU Delft).

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, US Naval Academy), Gangfeng Ma (2012, Old Dominion U), Zhifei Dong (expected 2013), Babak Tehranirad (expected 2014), Morteza Derakhti (expected 2015), Ryan Mieras (expected 2015), Saiedeh Banihashemi (expected 2017).

Biographical Sketch for Stephan Grilli

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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 Li`ege (Belgium).

C. Visiting positions :

2007, *Research Director*, C.N.R.S., University of Toulon, LSEET, France (Spring 07).
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. Some Recent Relevant Publications: (see http://www.oce.uri.edu/ grilli/resume.html)

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 Haz. 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. (2012). Numerical simulation of the 2011 Tohoku tsunami based on a new transient FEMco-seismic source: Comparison to far- and near-field observations. *Pure and Appl. Geophys.*, DOI 10.1007/s00024-012-0528-y (published online).

8. Harris, J.C., S.T. Grilli, S. Abadie and T. Tajalibakhsh (2012). Near- and far-field tsunami hazard from the potential flank collapse of the Cumbre Vieja Volcano. In *Proc. 22nd Offshore and Polar Engng. Conf.* (ISOPE12, Rodos, Greece, June 17-22, 2012), Intl. Society of Offshore and Polar Engng., 242-249.
9. 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 .
10. Grilli, S.T., J.C. Harris, J.T. Kirby, F. Shi, and G. Ma, T. Masterlark, D.R. Tappin and T.S. Tajali-Bakhsh (2013). Modeling of the Tohoku-Oki 2011 tsunami generation, far-field and coastal impact: a mixed coseismic and SMF source. In *Proc. 7th Intl. Conf. on Coastal Dynamics* (Arcachon, France, June 2013) (ed. P. Bonneton), 10 pps., paper 084 (in press).
11. Grilli, S.T., Harris, J., F. Shi, J.T. Kirby, T.S. Tajalli Bakhsh, E. Estibals and B. Tehranirad (2013). Numerical modeling of coastal tsunami dissipation and impact. In *Proc. 33rd Intl. Coastal Engng. Conf.* (J. Mc Kee Smith, ed.) (ICCE12, Santander, Spain, July, 2012), 12 pps. World Sci. Pub. Co. Pte. Ltd.

E. Synergistic Activities:
1. NOAA-NTHMP : Current projects on the numerical simulation of tsunami inundation maps for the US East Coast (near-field landslide sources, and far-field coseismic or volcanic sources).
2. NSF : Current project on improving tsunami generation/propagation/coastal impact models.
3. Appointed member of the US *National Research CouncilMarine Board* (2010-); East Coast co-representative on the US *National Tsunami Hazard Mitigation Program* mapping and modeling committee (2010-).
4. Co-convener at AGU 2012 of 2 sessions on "The March 2011 Tohoku-oki tsunami, Japan"; editorial Board, *Engng. Analysis with Boundary Elements* (1989-)

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.

SUPPLEMENTAL MATERIAL

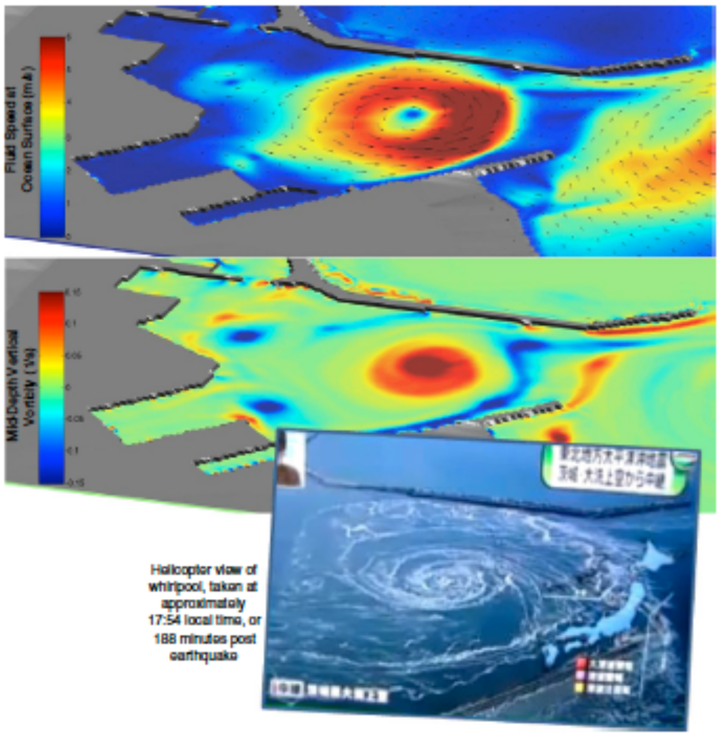

Figure 1: Numerical model results of the Tohoku tsunami in the Port of Oarai. Snapshots are from 188 min after the earthquake. (top) Fluid speed, (middle) vertical vorticity at mid-depth, and (bottom) aerial image of the rotational feature at approximately the same time. (From Lynett et al., 2012).

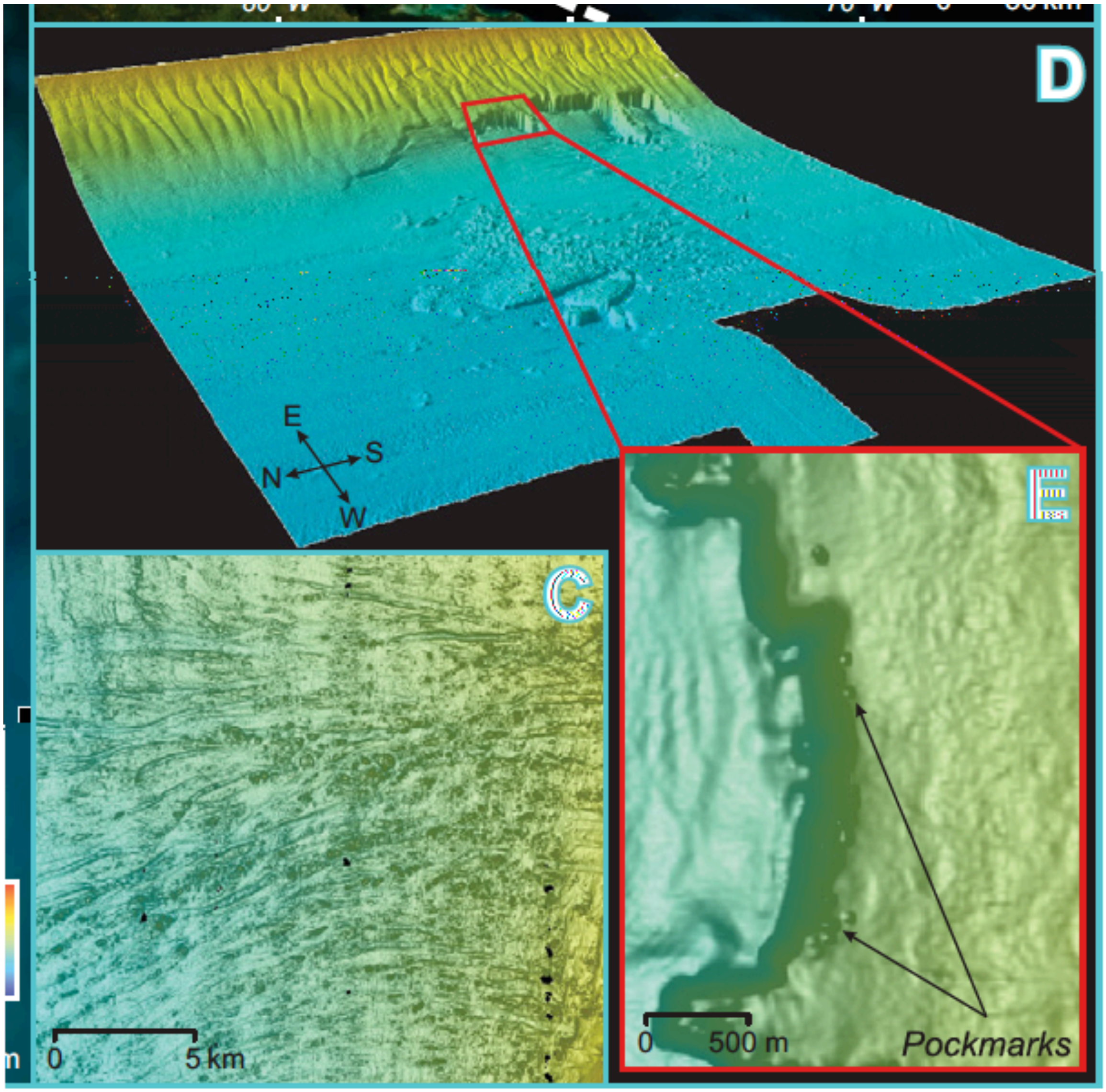

Figure 2: SMF failure in carbonate deposits on the western Grand Bahama Banks. C: Detail of erosive furrows, D: Three dimensional vierw of mass transport complex, E: Detail of small pockmarks at top of northern scar. (from Figure 1 in Mulder et al. 2012)

REFERENCES

Abadie, S., Morichon, D., Grilli, S.T. and Glockner, S. 2010. Numerical simulation of waves generated by landslides using a multiple-fluid Navier-Stokes model. *Coastal Engineering*, **57**, 779-794, doi:10.1016/j.coastaleng.2010.03.003.

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, doi:10.1029/2011JC007646.

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", *Journal of Waterway, Port, Coastal and Ocean Engineering*, **126**, 48-56.

Friday, D.Z., L.A. Taylor, B.W. Eakins, R.R. Warnken, K.S. Carignan, R.J. Caldwell, E. Lim and P.R. Grothe, 2012. Digital Elevation Models of Palm Beach, Florida: Procedures, Data Sources and Analysis, NOAA Technical Memorandum NESDIS NGDC-54, U.S. Dept. of Commerce, Boulder, CO, 34 pp.

Grilli, S.T. and P. Watts. 2005. Tsunami generation by submarine mass failure Part I : Modeling, experimental validation, and sensitivity analysis. *J. Waterway Port Coastal and Ocean Engng.*, **131**, 283-297.

Grilli, S.T., Ioualalen, M, Asavanant, J., Shi, F., Kirby, J. and Watts, P. 2007. Source Constraints and Model Simulation of the December 26, 2004 Indian Ocean Tsunami. *J. Waterway, Port Coastal and Ocean Engng.*, **133**, 414-428.

Grilli, S. T., Harris, J. C., Tajalli Bakhsh, T., Masterlark, T. L., Kyriakopoulus, C., Kirby, J. T. and Shi, F., 2012. Numerical simulation of the 2011 Tohoku tsunami based on a new transient FEM co-seismic source: Comparison to far- and near-field observation. *Pure and Applied Geophysics*, doi:10.1007/s00024-012-0528-y.

Ioualalen, M., Asavanant, J., Kaewbanjak, N., Grilli, S. T., Kirby, J. T. and Watts, P., 2007, ``Modeling the 26 December 2004 Indian Ocean tsunami: Case study of impact in Thailand", *J. Geophys. Res*., **112**, C07024, doi:10.1029/2006JC003850.

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 Engng.*, **126**, 39-47.

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.

Locat, J., H. Lee, U. S. ten Brink, D. Twichell, E. Geist, and M. Sansoucy. 2009. Geomorphology, stability and mobility of the Currituck slide. *Marine Geology*. **264**, 28-40.

Lynett, P. J., Borrero, J. C., Weiss, R., Son, S., Greer, D. and Renteria, W., 2012, Observations and modeling of tsunami-induced currents in ports and harbors, *Earth and Planetary Science Letters,* **327-328**, 68-74.

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.

Ma, G., Kirby, J. T. and Shi, F., 2013, Numerical simulation of tsunami waves generated by deformable submarine landslides, *Ocean Modelling*, revised and resubmitted, May.

Mulder T., E. Ducassou , G.P. Eberli, V. Hanquiez , E. Gonthier , P. Kindler, M. Principaud , F. Fournier, P. Léonide, I. Billeaud, B. Marsset, J.J.G. Reijmer, C. Bondu , R. Joussiaume, and M. Pakiades. 2012, New insights into the morphology and sedimentary processes along the western slope of Great Bahama Bank, *Geology,* **40**(7), 603–606.

Shi, F., Kirby, J. T. and Hanes, D. M., 2007. An efficient mode-splitting method for a curvilinear nearshore circulation model, *Coastal Engineering*, **54**, 811-824.

Shi, F., Kirby, J. T., Tehranirad, B., Harris, J. C. and Grilli, S. T., 2011a. FUNWAVE-TVD, Fully nonlinear Boussinesq wave model with TVD solver, documentation and user's manual (Version 2.0). Research Report No, CACR-11-04, Center for Applied Coastal Research, Univ. of Delaware, Newark.

Shi, F., Hanes, D. M., Kirby, J. T., Erikson, L., Barnard, P. and Eshleman, J., 2011b. Pressure gradient-dominated nearshore circulation on a beach influenced by an adjacent large inlet. *J. Geophys. Res.*, **116**, C04020, doi:10.1029/2010JC006788.

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

Synolakis, C. E., Bernard, E. N., Titov, V. V., Kanoglu, U. and Gonzalez, F. I., 2007. "Standards, criteria and procedures for NOAA evaluation of tsunami numerical models. NOAA Technical Memorandum OAR PMEL-135.

Taylor, L.A., B.W. Eakins, K.S. Carignan, R.R. Warnken, T. Sazonova, D.C. Schoolcraft, and G.F. Sharman, 2008a. Digital Elevation Model of Virginia Beach, Virginia: Procedures, Data Sources and Analysis, NOAA Technical Memorandum NESDIS NGDC-7, National Geophysical Data Center, Boulder, CO, 34 pp.

Taylor, L.A., B.W. Eakins, K.S. Carignan, R.R. Warnken, T. Sazonova, D.C. Schoolcraft, and G.F. Sharman, 2008b. Digital Elevation Model of Savannah, Georgia: Procedures, Data Sources and Analysis, NOAA Technical Memorandum NESDIS NGDC-6, National Geophysical Data Center, Boulder, CO, 28 pp.

Tehranirad, B., Shi, F., Kirby, J. T., Harris, J. C. and Grilli, S., 2011. Tsunami benchmark results for fully nonlinear Boussinesq wave model FUNWAVE-TVD, Version 1.0. Research Report No. CACR-11-02, Center for Applied Coastal Research, Univ. of Delaware, Newark.

Tehranirad, B., Kirby, J. T., Ma, G. and Shi, F., 2012. Tsunami benchmark results for non-hydrostatic wave model NHWAVE (Version 1.1). Research Report No. CACR-12-03, Center for Applied Coastal Research, Univ. of Delaware, Newark.

Wei, G., Kirby, J. T., Grilli, S. T. and Subramanya, R., 1995. A fully nonlinear Boussinesq model for surface waves. I. Highly nonlinear, unsteady waves, *J. Fluid Mech.*, **294**, 71-92.