NTHMP Project Narrative

Project Name/Title:	**Modeling Tsunami Inundation and Assessing Tsunami Hazards for the U. S. East Coast**
Project Dates:	FY 2010, 2011, 2012
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 (PR) trench 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 this project, we propose to assess tsunami hazard from the above and other relevant tsunami sources recently studied in the literature (ten Brink et al., 2008; MG special issue, 2009), and model the corresponding tsunami inundation in affected US East coast communities. Based on our experience with a variety of tsunami sources and case studies, we will model tsunami propagation, inundation, and runup using the robust and well-validated Fully Nonlinear Boussinesq Model (FNBM) FUNWAVE (Wei et al., 1995; Kennedy et al., 2000; Chen et al., 2000; Shi et al., 2001). Both Cartesian and curvilinear grids will be used for a variety of nested computational domains, at various grid scales. Whether frequency dispersion matters (e.g., for the SMF and other slide sources) or not (e.g., for the large co-seismic sources), this FNBM framework contains all the relevant physics without need to modify the model or its equations, whether one type of tsunami source or another is used. The same goes for linear versus nonlinear effects in generated tsunami wave trains, as well as for dissipation by bottom friction or bathymetrically induced breaking (which are modeled through adequate semi-empirical terms). Finally, a recent spherical coordinate implementation of FUNWAVE including Coriolis effects (Kirby et al., 2009), together with a very efficient parallel MPI and nested-domain

implementation, make FNBM transoceanic simulations possible on a typical multi-core desktop computer or on the cluster computing environment available at the University of Delaware (UD), Center for Applied Coastal Research.

Large co-seismic sources (e.g., PR trench or Lisbon 1755 sources) will be modeled as initial instantaneous ocean surface deformations, based on estimates of event size, magnitude and geological parameters, using Okada's (1985) method. For reference, we recently successfully conducted a case study of the 2004 Indian Ocean tsunami using FUNWAVE, following this methodology (Grilli et al., 2007; Ioualalen et al., 2007; Karlsson et al., 2009). Co-seismic source parameters will be obtained from both our past work (Grilli et al., 2008, 2010) and other recent work reported in the literature (e.g., MG special issue, 2009).

Both historical (e.g., 1929 Grand Bank) and other local SMF sources will be modeled according to the methodology reported in Watts et al. (2003, 2005) and Grilli et al. (2005), and validated for a number of historical case studies (e.g., Day et al., 2005; Tappin et al., 2008). In this method, relevant SMF sources are semi-empirically generated from geomechanical, geological, and geometrical parameters, and specified as initial conditions (wave elevation and velocities) in the FNBM propagation model. Such (experimentally validated) sources were derived, based on a large number of 3D simulations of slide kinematics using a model solving fully nonlinear (inviscid) 3D Euler eqs. with a free surface. Since our earlier modeling and scaling analyses showed that the key parameter in SMF tsunami generation is initial acceleration, and typical SMF deformation rates do no significantly affect key tsunami features (Grilli and Watts, 2005), the methodology assumes rigid (translational or rotational) slides. But this is not a limitation and if known from sediment rheological properties, slide deformation effects can be included in the tsunami source.

Location and parameters for local SMF sources (other than historical) will first be identified by performing a first-order probabilistic analysis of SMF hazard along the east coast. Such work was already conducted by Grilli et al. (2009), for coastal areas from New Jersey to Maine. Results of this analysis were presented in terms of 100 and 500 year runup from seismically induced tsunamigenic SMFs. An extensive Monte Carlo (MC) model was developed and employed, in which distributions of relevant parameters (seismicity, sediment properties, type and location of slide, volume and dimensions of slide, water depth, etc.) were used to perform large numbers of stochastic stability analyses of submerged slopes (along actual transects across the shelf), based on conventional pseudo-static limit equilibrium methods for both translational and rotational failures. The distribution of predicted slope failures along the upper US East Coast was found to match published data quite well (Booth et al., 1985, 1993; Chaytor et al., 2007, 2009). Estimates of tsunami runup associated with SMF hazard were found to be low at most locations except, for the 500-yr tsunami, for two regions off Long Island, NY (up to 3-m) and off the New Jersey coast (up to 4-m). However, detailed deterministic tsunami generation, propagation and inundation modeling is required, in order to accurately estimate the inundation (and runup) hazard at these sites. This will be done in this project. Further, to estimate relevant SMF sources from the Florida border to New Jersey, we will perform a similar MC analysis for this East coast region, and observed slope failure distributions will again be used to ground truth the MC model predictions.

Recent field measurements, slope stability analyses, and 3D-Navier-Stokes multi-fluid (material) modeling work (Abadie, et al., 2009) will be reviewed and used to define and simulate realistic scenarios for a CVV flank collapse source. These will be used to develop a defensible approach for estimating tsunami hazard from this hypothetical event. We will simulate tsunami hazard from the few selected CVV flank collapse scenarios.

We will combine ocean scale simulations of transoceanic tsunami sources, such as Lisbon 1755 like or Puerto Rico Trench co-seismic events, and CVV collapse, with regional scale simulations of these events, along with the regional scale SMF events, in order to establish the relative degree of hazards for East Coast communities. Detailed inundation studies will be conducted for highest-risk East Coast communities, and results of these studies will be used to construct a first-generation of tsunami inundation maps for the chosen communities.

Background

Provide Background information including history of NTHMP partnership, experience with tsunamis, and past achievements with NTHMP funding (5,000 characters or less):

No previous projects under NTHMP funding. Kirby is member of NTHMP Mapping and Modeling Subcommittee. PIs have extensive experience in tsunami model development and application to ocean scale propagation, submarine mass failure generation mechanisms, and inundation modeling.

Provide a synopsis tasks within this application which are either a continuation or sustainment from earlier grant awards. Include the percentage overall completion for each task included in this section and whether or not the proposed work effort is different than in prior grant awards (3,000 characters or less):

This work represents the initiation of NTHMP East Coast modeling and mapping work, and does not build on earlier NTHMP projects.

Component 1: NTHMP

Section 1: Mapping and Modeling

Task 1.1: Review of existing literature on tsunami hazard assessment and tsunamigenic sources affecting the U. S. East Coast.

Existing literature, in particular the report by ten Brink et al (2008) and the related MG special issue (2009) both encompassing all relevant available examples, will be reviewed to establish the basis for performing a comprehensive analysis of East Coast tsunami hazards.

What NTHMP Strategic Plan metric(s) does this support?

1. Successful execution of NTHMP tsunami mapping, modeling, mitigation, planning and education efforts

Where applicable:	FY10: Literature Review, December 2010.
	FY10 Cost: $16,000

Task 1.2: Probabilistic analysis of coastal hazards associated with submarine mass failures (SMF).

First-order SMF tsunami hazard will be obtained by performing a probability analysis with Grilli et al's (2009) Monte Carlo (MC) model, which was developed and applied to the region from New Jersey to Maine. We will extend the latter work to coastal regions down to the Florida border. A number of subtasks will be required to develop the new geographic implementation of the MC model, as detailed in Grilli et al (2009). In particular, this includes developing a series of data bases (typically in a GIS environment) for:

1. Seafloor bathymetry; and from this derive a simplified shoreline geometry and shallow

water transects, for the purpose of tsunami propagation, as well as a series of representative cross-shelf transects all the way down to the abyssal plain, for the purpose of conducting slope stability and SMF tsunami generation analyses;
2. Surficial sediment types and properties, in relation to slope stability analysis (e.g., bulk density, cohesion, shear strength);
3. Seismicity; in terms of probability distributions of Peak Horizontal Acceleration (PHA) over a fine offshore grid covering all regions of expected SMF tsunami generation (this is typically obtained by reprocessing data generated by USGS for the considered region, into log-normal probability curve fits, for each grid cell);
4. Predictions of the MC model will be calibrated/validated based on published slide observations (e.g., distributions of failure slope angle, volume/area, type; Booth et al., 1985, 1993; Chaytor et al., 2007, 2009). Similar to Grilli et al. (2009), calibration will involve adjusting the (largely unknown) level of excess pore pressure in the sediment (i.e., pre-existing or seismically induced), for the MC model to predict the observed failure known characteristics.

Based on results of the MC analysis from Florida to Maine, parameters for a large number of realistic SMF sources, representing specific SMF tsunami hazard in the region (e.g., 500, 1000 years) will be selected, and the tsunami sources designed as detailed in Grilli and Watts (2005) and Watts et al. (2005). Other relevant SMF sources will also be designed from historical cases known in the region (e.g., 1929 Grand Bank, Piper et al., 1999; Currituck slide, Geist et al., 2009, Locat et al., 2009).

Deterministic simulations of tsunami propagation and coastal impact (inundation and runup) will be performed for each of the selected SMF sources (with associated estimated return period, although final inundation maps will be devoid of probabilistic information), and inundation maps will be developed based on these and implemented into the GIS environment. To do so, a series of regional computational grids will be designed, that will have typically a resolution of 0.25'x 0.25' or better, depending on coastal features, and will encompass regions from deep water, at the toe of the continental slope, to the shoreline. Much finer nested grids (e.g., 2"x 2") will be used to perform coastal inundation and runup simulations, in selected areas, as detailed elsewhere.

Inundation data from each type of the simulated SMF sources will be combined into "envelope" inundation maps for the selected areas.

What NTHMP Strategic Plan metric(s) does this support?

1. Successful execution of NTHMP tsunami mapping, modeling, mitigation, planning and education efforts
2. Prioritize inundation map development

Where applicable:	FY10: Extend MC simulation of SMF risks to southern portion of U. S. East Coast region.
	FY10 Cost: $60,000
	FY11: Design SMF tsunami sources based on both MC simulation results and historical cases in the region.
	FY11 Cost: $32,774

Task 1.3: Simulation of transoceanic tsunamis from co-seismic and other relevant sources (e.g., Cumbre Vieja Volcano (CVV) flank collapse)

A number of subtasks are identified as follows to perform simulations of co-seismic sources:

1. Based on available literature, relevant co-seismic sources will be designed and their parameters selected, for the Caribbean subduction zone (PR trench north of PR; Leeward Islands, East of PR) and the Azores-Gibraltar convergence zone, (USGS, 2001; ten Brink and Lian, 2004; ten Brink, 2005; Dawicki, 2005; Jansma, 2008; Grilli et al., 2008, 2010; Barkan et al., 2009). A few co-seismic sources for the maximum expected seism off of the East Coast (7.5 magnitude) will also be considered.
2. Transoceanic propagation of each selected source will be run, using our latest spherical FNBM (Kirby et al., 2009). Propagation will first be run over a coarse (e.g., 2'x2') deep ocean grid (based on ETOPO2 topography), initialized using Okada's (1985) method.
3. Much finer nested coastal grids will then be used to predict detailed coastal tsunami impact in areas of the East Coast where significant tsunami waves are predicted to arrive in the coarser grid. Initial conditions for those fine grids will be obtained from waves simulated in the coarser grid. The coastal grids will have a resolution of 0.25'x0.25' or better, depending on coastal features to be resolved and will typically encompass regions from deep water, at the toe of the continental slope, to the shoreline.
4. Finer nested grids will be used to perform coastal inundation simulations (see below).

Subtasks are identified as follows to perform flank collapse simulations for a CVV-like source:

1. Earlier work on the CVV flank collapse will be reviewed in order to develop realistic mass failure scenarios (e.g., Moss et al., 1999; Day et al., 1999; Ward and Day, 2001; Hildenbrand et al., 2003; Pérignon, 2006; Grilli et al., 2006; Lovholt et al., 2008; Abadie et al, 2009a,c).
2. The selected scenarios will be used as a basis for running a series of 3D simulations of subaerial landslide tsunami sources, using a multi-fluid Navier-Stokes (NS) VOF model (Abadie et al., 2008, 2009a,b,d). Recent surveys of both CVV topography and seafloor bathymetry will be used in those simulations (Abadie et al., 2009c).
3. Transoceanic propagation of each selected source will be run, using our latest spherical FNBM (Kirby et al., 2009). Propagation will first be run over a coarse 2'x2' deep ocean grid (based on ETOPO2 topography), initialized with results of the 3D-NS-VOF model.
4. This will be followed by Tasks 3,4 detailed above for the co-seismic sources.

What NTHMP Strategic Plan metric(s) does this support?

1. Successful execution of NTHMP tsunami mapping, modeling, mitigation, planning and education efforts

Where applicable:	FY10: Review of literature on relevant co-seismic sources, and earlier co-seismic source simulation work. Source parameter definition, estimation of return periods, and initial 3D computations of source scenarios.
	FY10 Cost: $50,000
	FY11: Review and definition of CVV-like source. Initial computations of transoceanic propagation up to the coast of CVV-like sources using nested grids (coarse ocean basin scale and a series of finer coastal grids)
	FY11 Cost: $50,000

	FY12: Additional transoceanic simulations for co-seismic and CVV-like sources.
	FY12 Cost: $60,000

Task 1.4: Inundation modeling for high risk East Coast communities

Tsunami inundation modeling will be carried out at high resolution, corresponding to available DEMs (e.g., 2” to 3” grids) or new DEMs being developed in other work, using the long wave Boussinesq model FUNWAVE (described in the supporting documentation), as well as other validated community models (e.g., MOST). Inundation modeling will begin in the second year of the project, after shelf conditions resulting from transoceanic and local SMF sources have been established by lower resolution modeling. The first communities studied will likely be Atlantic City, NJ, which has been shown to be a relative hot spot in Monte Carlo simulations of SMF sources at the 500 year return period level, and Ocean City, MD, which represents a unique evacuation situation due to its large summertime population, restricted access by road and isolation as a barrier island. Both locations have availables high resolution DEMs. Subsequent studies will be prioritized based on the findings in Tasks 1.2 and 1.3.

What NTHMP Strategic Plan metric(s) does this support?

1. Successful execution of NTHMP tsunami mapping, modeling, mitigation, planning and education efforts

Where applicable:	FY10: Develop methodology for applying results of probabilistic analysis to determination of model parameters for deterministic inundation simulations
	FY10 Cost: $50,000
	FY11: Run tsunami propagation and inundation simulations for the SMF, co-seismic and volcanic sources in a series of coastal grids with some level of nesting. Modeling for Atlantic City, NJ and Ocean City, MD
	FY11 Cost: $60,000
	FY12: Continue running tsunami propagation and inundation simulations for SMF and other sources.
	FY12 Cost: $79,854

Task 1.5: Construct inundation maps for modeled East Coast communities

This task covers the development of inundation maps based on the detailed modeling of coastal communities to be carried out in Task 1.4. The first year will be devoted to development of the GIS database to support the mapping process, and examination and augmentation of existing DEMs, based on improved subaerial Lidar data and other available sources. The second and third years will be devoted to construction of maps based on inundation modeling efforts in Task 1.4. Other NTHMP partners will be consulted to obtain guidance on present standards for map development and presentation. In particular, based on earlier released maps (e.g., for CA), it is expected that these first-generation maps will feature the envelope of maximum expected tsunami inundation elevations, for a composite of all identified and simulated sources.

What NTHMP Strategic Plan metric(s) does this support? 1. Tsunami inundation maps that support informed decision making	
Where applicable:	FY10: Assist in assembling DEM's for simulations, establish GIS data base for analysis and presentation of inundation results – July 2011
	FY10 Cost: $20,081
	FY11: Develop inundation maps for first round of modeled communities – July 2012
	FY11 Cost: $55,000
	FY12: Continue map development for additional communities – July 2013
	FY12 Cost: $60,000

Summary of Task Plan

FY10 Milestone Schedule (August 1, 2010 – July 31, 2011)

Task	Key Milestone	Expected Month/Year of Completion	Requested Funding
Component 1: Mapping and Modeling			
Task 1.1	Literature Review	12/10	**16,000**
Task 1.2	MC modeling of East Coast SMF	7/11	**60,000**
Task 1.3	Reanalysis of previous Cumbre Vieja simulations. Simulation of event using 3D- multi-fluid VOF model	12/10 7/11	 **50,000**
Task 1.4	Establish method for determining sources for inundation models based on MC simulation	7/11	**50,000**
Task 1.5	DEM, GIS database	7/11	**20,081**
		Sub-Total Component 1:	196,081
		Total FY2010:	196,081

FY11 Milestone Schedule (August 1, 2011 – July 31, 2012)

Task	Key Milestone	Expected Month/Year of	Requested Funding

		Completion	
Component 1: Mapping and Modeling			
Task 1.2	Determination of tsunami source scenarios for detailed study	2/12	**32,774**
Task 1.3	Ocean scale simulations for Cumbre Vieja and other co-seismic sources	7/12	**50,000**
Task 1.4	Inundation modeling for coastal communities	7/12	**60,000**
Task 1.5	Map development for coastal communities	7/12	**55,000**
		Sub-Total Component 1:	197,774
		Total FY2011:	197,774

FY12 Milestone Schedule (August 1, 2012 – July 31, 2013)

Task	**Key Milestone**	**Expected Month/Year of Completion**	**Requested Funding**
Component 1: Mapping and Modeling			
Task 1.3	Simulation of additional ocean scale tsunami scenarios as needed	7/13	**60,000**
Task 1.4	Inundation modeling for additional coastal communities	7/13	**79,854**
Task 1.5	Map development for modeled coastal communities	7/13	**60,000**
		Sub-Total Component 1:	199,854
		Total FY2012:	199,854

Grand Total of Award: $593,709

SUPPORTING DOCUMENTATION

By contrast with the long history of tsunami hazard assessment on the US West coast and Hawaii, along the eastern US coastline, tsunami hazard assessment 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 (e.g., Barkan et al., 2009), a large earthquake in the Caribbean subduction zone in the Puerto Rico (PR) trench or near Leeward Islands (e.g., Grilli et al., 2008, 2010), or a flank collapse of the Cumbre Vieja Volcano (CVV) in the Canary Islands (e.g., Ward and Day, 2001; Grilli et al., 2006; Pérignon, 2006; Lovholt et al., 2008; Abadie et al., 2009a) (see Fig. 1a).

Moreover, considerable geologic and some historical evidence (e.g., the 1929 Grand Bank landslide tsunami, Currituck slide site off NJ) 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 (see Fig. 1a).

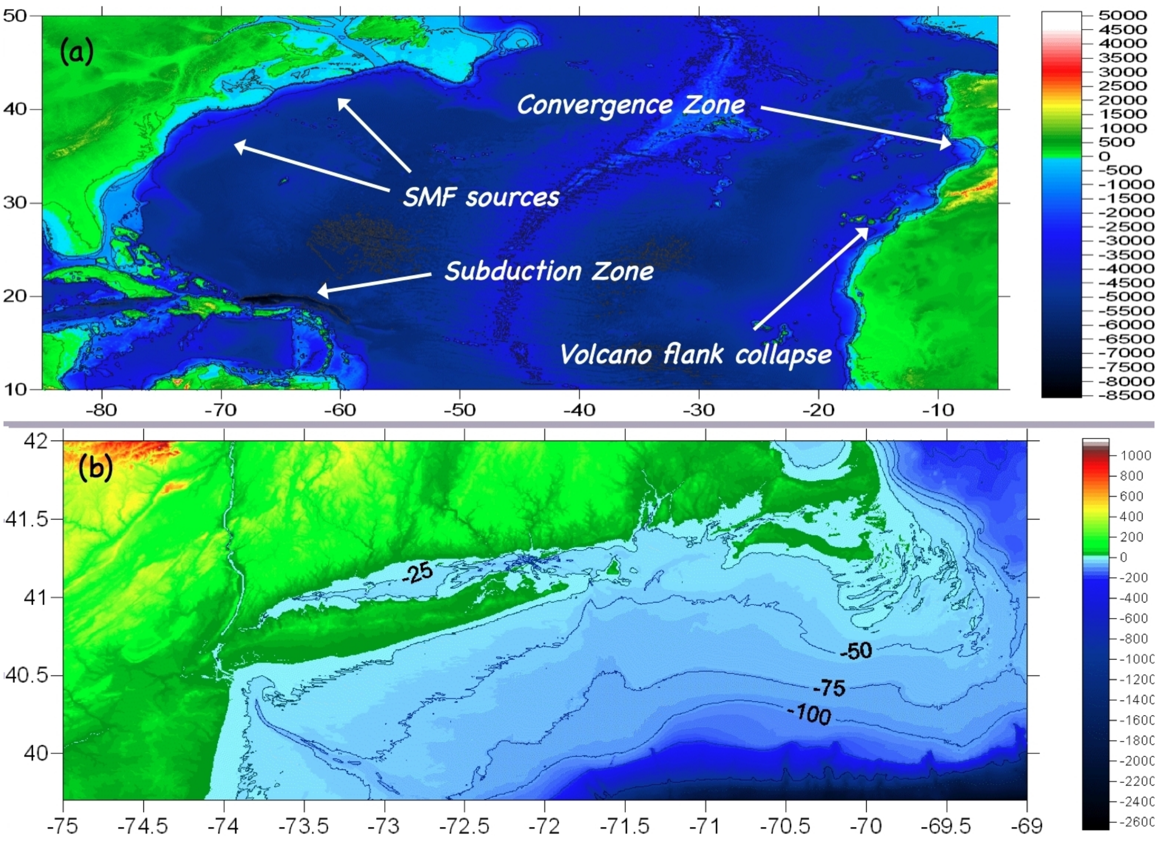

Figure 1: (a) ETOPO2 bathymetry (m) in North Atlantic basin, with indication of potential local and transoceanic tsunami sources for the US East Coast; (b) Detailed bathymetry in part of the upper East Coast (USGS).

In this project, we propose to assess tsunami hazard from the above and other relevant tsunami sources recently studied in the literature (e.g., MG issue, 2009; ten Brink et al., 2008), and model the corresponding tsunami inundation in affected US East coast communities.

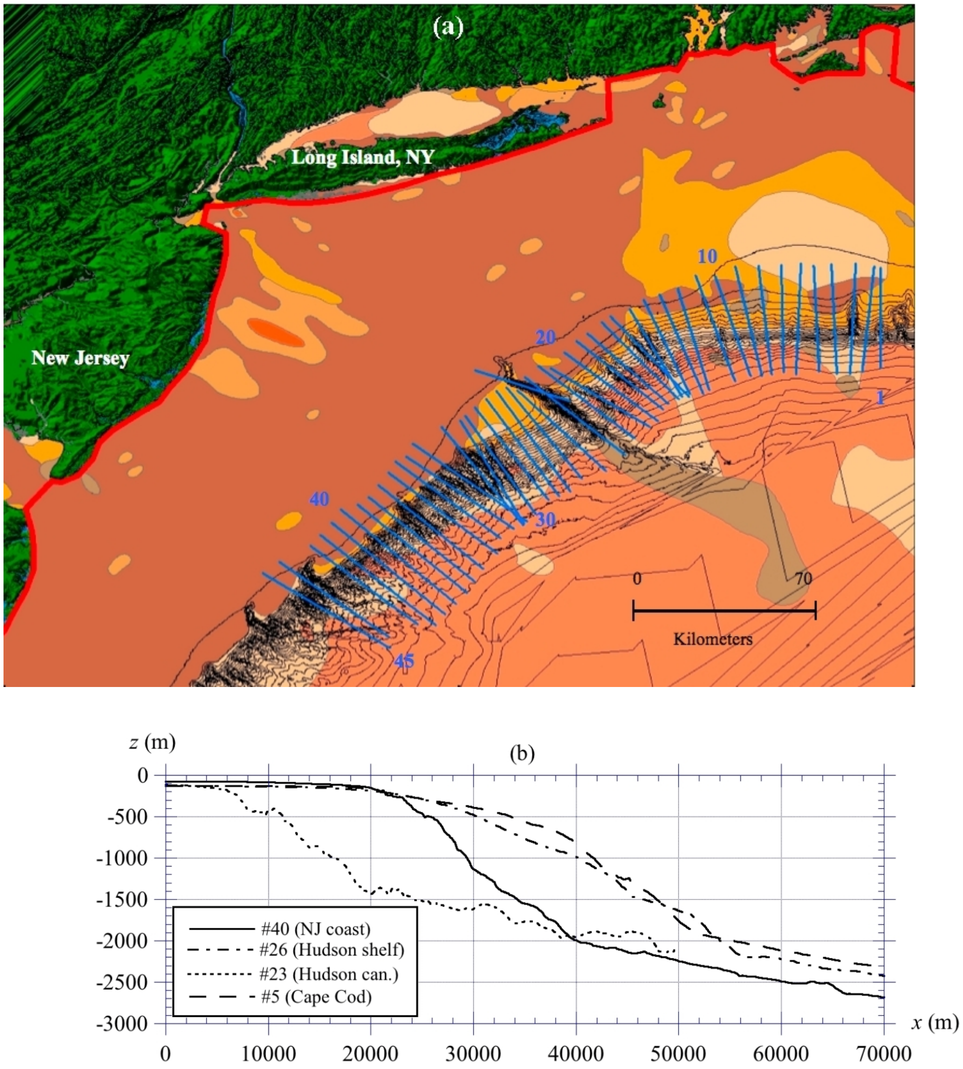

Figure 2: (a) Bathymetry, simplified coastline, sediment types (see Fig. 3 for definitions) and selected transects to study slope stability in the upper US East Coast; (b) Examples of transects (from Grilli et al., 2009).

Based on our experience with a variety of tsunami sources and case studies, we will model tsunami propagation, inundation, and runup using the same robust and well-validated Fully Nonlinear Boussinesq Model (FNBM): FUNWAVE (Wei et al., 1995; Kennedy et al., 2000; Chen et al., 2000; Shi et al., 2001). Relevant tsunami sources for earthquakes (co-seismic), SMF, and volcano collapse will be specified as initial (i.e., “hot start”) conditions into FUNWAVE. A following section details the proposed methodology regarding the definition and modeling of such sources. Both large scale oceanic as well as finer regional nested grids will be used in the tsunami propagation and coastal impact modeling. Even finer coastal grids will be used for inundation simulations. Details regarding tsunami propagation and inundation modeling with FUNWAVE are given in a following section.

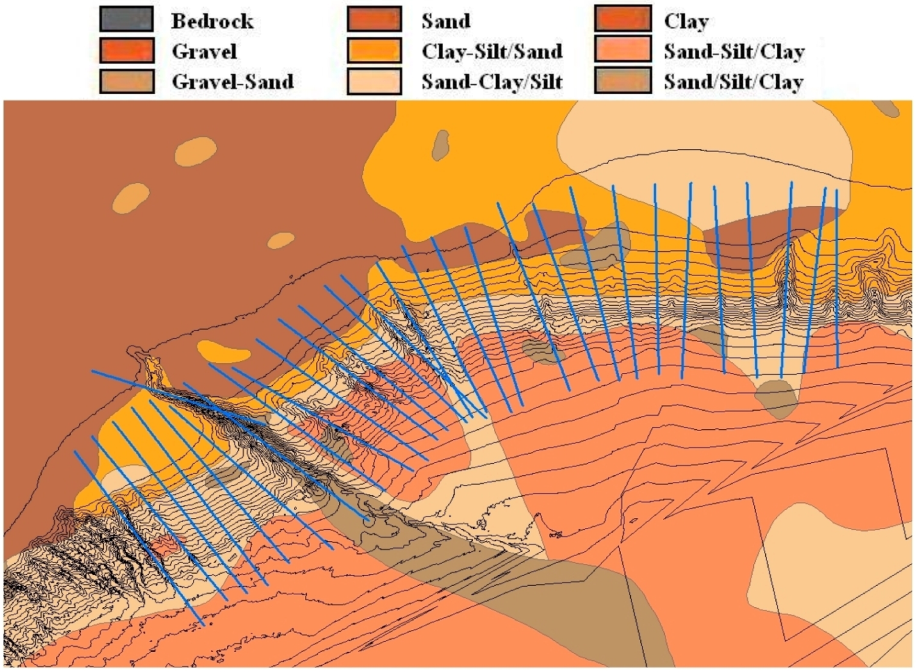

Figure 3: Sediment types and slope stability transects in the upper US East Coast (from Grilli et al., 2009).

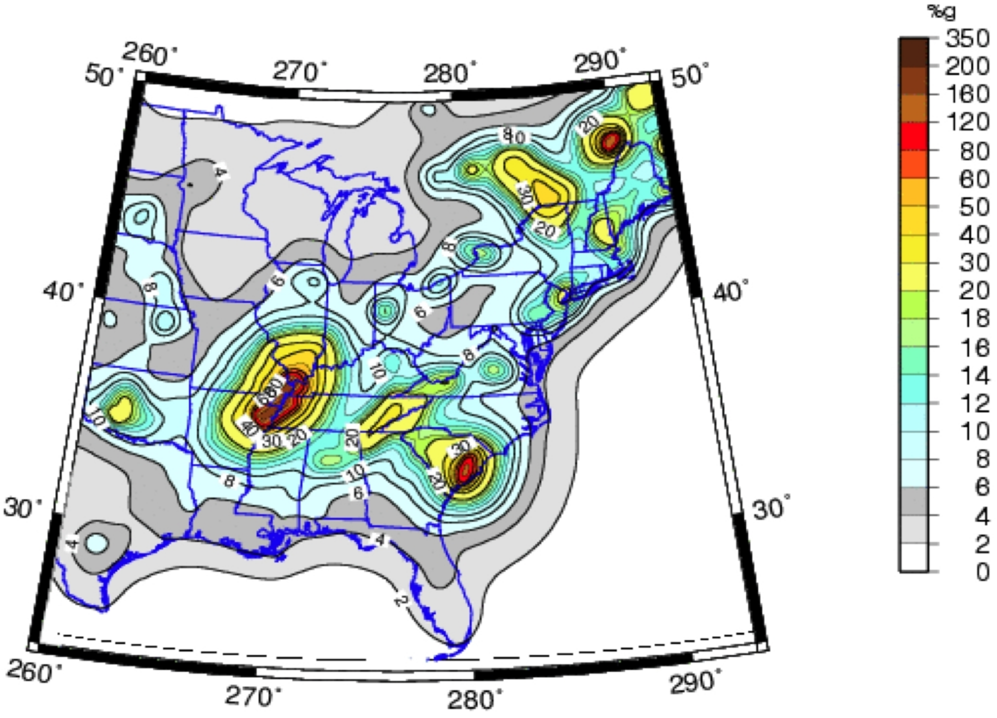

Figure 4: Typical expected Peak Horizontal Acceleration (PHA) from historical earthquakes in North America (USGS).

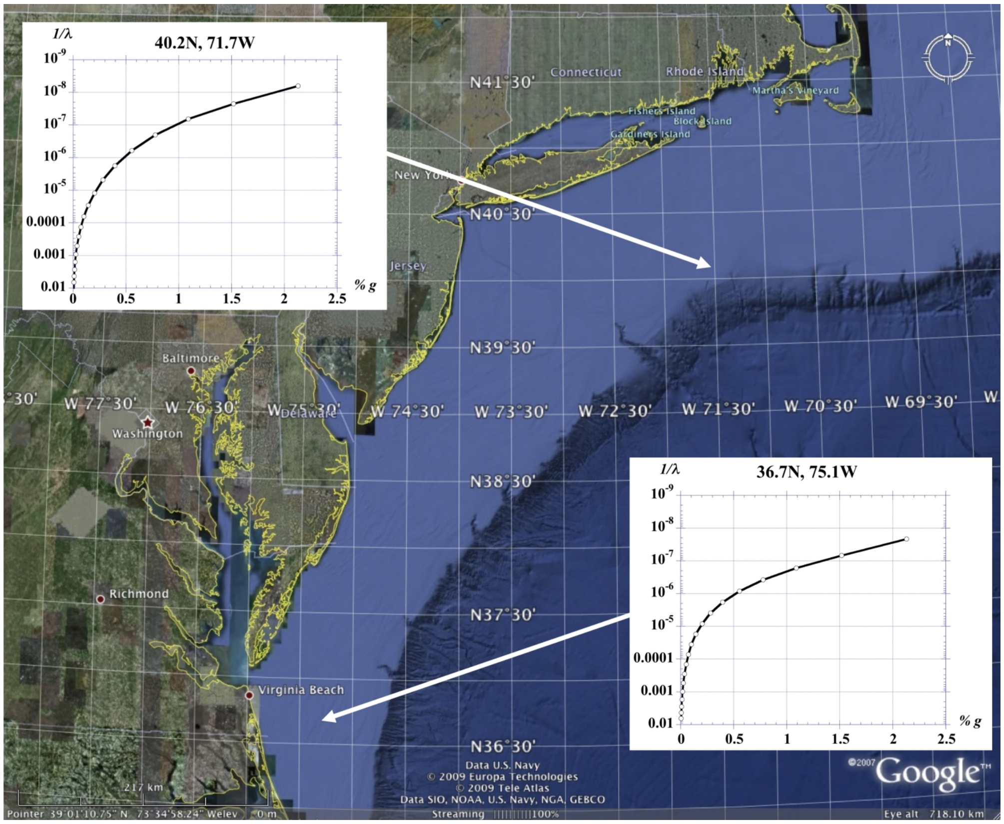

Figure 5: Two local probability distributions of Peak Horizontal Acceleration reprocessed from USGS data for historical earthquakes in North America (Grilli et al., 2009).

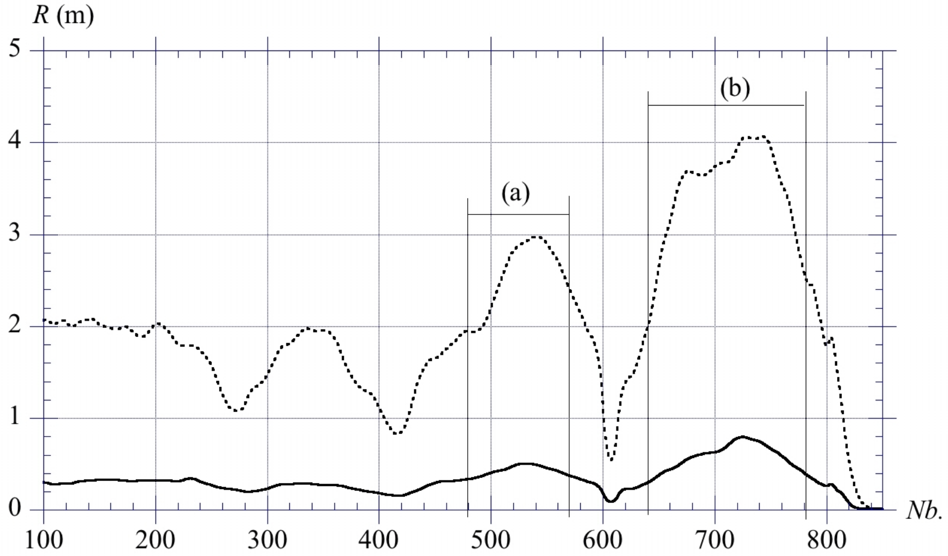

Figure 6: Tsunami runup from MC simulations, for design tsunamis of 1 (——) and 0.2 (- - - -) % annual probability, as a function of coastal point number (Nb.), increasing from N to S. Coastal regions with relatively increased tsunami hazard are marked for points: (a) 480–570 (Long Island, NY) and (b) 640–780 (New Jersey coast) (Grilli et al., 2009)

MODELING METHODOLOGIES: PROBABILISTIC ANALYSIS OF SMF

A probabilistic estimate of first-order hazard associated with tsunamis generated by Submarine Mass Failure (SMF) (i.e., rotational slumps and translational slides), occurring on the continental shelf margin, will first be carried out to identify: (i) areas at risk; (ii) the magnitude of such risk; and (iii) the associated SMF parameters.

To do so, we will follow the methodology established by Grilli et al (2009), who developed and applied a Monte Carlo (MC) model to the region from New Jersey to Maine. We will extend the latter work to coastal regions down to the Florida border. A number of subtasks will first be required to develop the new geographic implementation of the MC model. In particular, this will include developing a series of databases (in a typical GIS environment) for:

- *Seafloor bathymetry*: and from this derive a simplified shoreline geometry and shallow water transects, for the purpose of tsunami propagation, as well as a series of representative cross-shelf transects all the way down to the abyssal plain, for the purpose of slope stability and SMF tsunami generation analyses. Figure 2 shows an example of bathymetric and selected transect data for the upper US East Coast.
- *Surficial sediment types and properties*: in relation to slope stability analysis (e.g., bulk density, cohesion, shear strength,…). Figure 3 shows a map of surficial sediment types for the upper US East Coast coastal area.
- *Seismicity*: in terms of probability distributions of Peak Horizontal Acceleration (PHA) over a fine offshore grid covering all regions of expected SMF tsunami generation. This is typically obtained by reprocessing data generated by USGS (e.g., Fig. 4) for the considered region, into log-normal probability curve fits, for each grid cell. Figure 5 shows an example of such data for the upper US East Coast.

Based on these databases, the MC model uses geographically located probability distributions of relevant parameters (seismicity, sediment properties, type and location of slide, volume and dimensions of slide, water depth, etc.) to perform a large number (10,000s) of stochastic stability analyses of submerged slopes (along actual transects across the shelf), based on conventional pseudo-static limit equilibrium methods, for both translational and rotational failures (see details in Grilli et al., 2009). [The distribution of predicted slope failures derived this way by Grilli et al. (2009) was shown to match published field data quite well (Booth et al., 1985, 1993; Chaytor et al., 2007, 2009) along the considered upper US East Coast section.]

For each random trial indicating a SMF slope failure, the MC model estimates tsunami generation following Watts et al.'s method (2005), in which semi-empirical landslide tsunami sources (for slides and slumps) were developed based on results of many landslide tsunami generation simulations. The semi-empirical relationships describing source elevation are function of SMF geometrical, geological and geomechanical parameters. Each generated tsunami is then propagated along a ray of initial direction parallel to the considered transect (with some randomness added to it). Following an ad hoc *correspondence principle* established in the latter work, maximum coastal runup due to each tsunami is estimated from the initial maximum depression of the water surface at the failure location. Finally, a Gaussian distribution of runup, (with some randomness in its spreading parameter), is used to express the coastal distribution of runup due to each identified SMF tsunami. Statistics of coastal runup are finally calculated and runup values at selected coastal points are found for selected return periods. In Grilli et al.'s (2009) work, estimates of SMF tsunami runup derived this way were found to be quite low at most locations except, for the 500-yr tsunami, for two regions off Long Island, NY (up to 3-m) and off the New Jersey coast (up to 4-m) (see Fig. 6).

SMF tsunami hazard predictions will be made, using the proposed new implementation of the MC model, for the region south of New Jersey to the Florida border. These will be calibrated/validated based on published slide observations (e.g., distributions of failure slope angle, volume/area, type; Booth et al., 1985, 1993; Chaytor et al., 2007, 2009). Similar to Grilli et al. (2009), this calibration will involve adjusting the (largely unknown) level of excess pore pressure in the sediment (i.e., pre-existing or seismically induced), for the MC model to predict known characteristics of the observed failure.

Based on MC results from Florida to Maine, parameters will be selected for a large number of realistic SMF sources, representing specific SMF tsunami hazard in the region (e.g., 500, 1000 years) and realistic tsunami sources will be designed. These will finally be used to perform a series of deterministic tsunami propagation simulations (including inundation and runup). See a following section for more details.

MODELING METHODOLOGIES: DETERMINISTIC INUNDATION MODELS

Modeling of ocean scale wave propagation and shelf and local scale propagation and inundation will be carried out using the Boussinesq model system FUNWAVE, which has been developed at the University of Delaware over the past 15 years. FUNWAVE was originally developed as a model for wind waves, swell and infragravity and mean motions in the nearshore environment. The code is based on the fully nonlinear formulation of Wei et al (1995) and incorporates algorithms to handle depth-limited wave breaking, shoreline runup and bottom friction (Kennedy et al, 2000; Chen et al, 2000). The initial development and distribution of FUNWAVE utilized several of the benchmark tests described in Synolakis et al (2007) as documented model examples. Model benchmarking will be extended to cover all NTHMP-mandated benchmark tests prior to the start of the proposed project.

The standard distribution of FUNWAVE will be upgraded with a number of revisions for use in the proposed project. These revisions will incorporate the more stable staggered-grid scheme of Shi et al (2001) in the standard model. The model will also be parallelized for more rapid use on MPI clusters, using a framework developed by Pophet (2008), which uses a parallel pipelining algorithm to speed up the solution of tridiagonal matrices, which are heavily utilized in the solution scheme. An initial version of the parallelized code based on the present public distribution of FUNWAVE is described in Pophet (2008) and Pophet et al (2009). FUNWAVE is an open source code and is freely distributed from the website http://chinacat.coastal.udel.edu/~kirby/programs/funwave/funwave.html, managed by PI Kirby at the University of Delaware, Center for Applied Coastal Research.

For ocean scale propagation, an MPI version of the code has been developed in spherical (latitude-longitude) coordinates (Kirby et al, 2009). The resulting code is basically similar to the model employed in Lovholt et al (2008) to model ocean scale propagation of waves from a hypothetical volcanic cone event in the Canary Islands.

FUNWAVE has been established as an accurate model for shoreline inundation for tsunami events along low-lying coastal plains. Recent applications of the model to the coast of Thailand during the 2004 Indian Ocean tsunami have established that the model reproduces the spatial distribution of observed runup resulting from wave propagation over wide continental shelf regions (Ioualalen et al, 2007) as well as reproducing local detail in observed inundation elevations and flow velocity (Karlsson et al, 2009).

MODELING METHODOLOGIES: CO-SEISMIC, LANDSLIDES AND VOLCANO COLLAPSE SOURCES

Tsunami propagation and coastal impact (inundation and runup) simulations will be performed for each of a series of transoceanic tsunami sources identified as having the potential to affect the US East Coast. Based on these simulations, inundation maps will be developed and implemented into the GIS environment, as detailed above.

A coarse (e.g., 2’ x 2’) ocean basin scale grid will first be used to propagate tsunamis from their distant generation area to the most affected shorelines (using the latest spherical implementation of FUNWAVE). A series of finer nested regional grids will then be designed around those shorelines, and used to perform more detailed and accurate tsunami propagation simulations in shallow water (using the Cartesian or boundary fitted implementation of FUNWAVE). These will typically have a resolution of 0.25’x0.25’ or better, depending on coastal features to be resolved, and will encompass regions from deep water, at the toe of the continental slope, to the shoreline. Even finer grids (e.g., 2” x 2”) will be used to perform coastal inundation and runup simulations, for areas identified to have significant tsunami impact, as detailed above.

Figure 7: The Cumbre Vieja Volcano (CVV) on the Canary Island of La Palma

CV volcano collapse tsunami source

Although still somewhat controversial, this potential tsunami source for the US East Coast has gained wider acceptance in the community, since the initial study of Ward and Day (2001), which featured a catastrophic and likely unrealistically large scenario, coupled to a simplified model, that predicted extremely high inundation hazard along the East Coast, particularly for Florida and New England. In the interim, deposits at the toe of the volcano were dated that showed that such large scale flank collapses have periodically occurred in the past on geologic scales on the order of 250-350Ky, the latest collapse being about that old. Additionally, sediment deposits were identified and dated back to this latest event in Bermuda, which could be associated with a tsunami runup of 20+ m (McMurtry et al., 2007). Finally, recent studies (discussed below), both field and modeling, were conducted that may help defining a more realistic and defendable collapse scenario, which is proposed as a basis for work in this project.

A series of scenarios for tsunami sources resulting from the flank collapse of the Cumbre Vieja volcano (CVV) in the Canary Island (Fig. 7) will thus be simulated based on recent slope stability and 3D-Navier-Stokes modeling work (Abadie, et al., 2009a,c; Fig. 8).

To perform CVV flank collapse simulations, a number of subtasks are identified as follows:

- Earlier work on the CVV flank collapse will be reviewed in order to develop realistic scenarios, with estimated return probability (e.g., Moss et al., 1999; Day et al., 1999; Ward and Day, 2001; Hildenbrand et al., 2003; Pérignon, 2006; Lovholt et al., 2008; Abadie et al, 2009a,c).
- Such scenarios will be used as a basis for running a series of 3D simulations of subaerial landslide tsunami sources, using a multi-fluid Navier-Stokes (NS) VOF model (Abadie et al., 2008, 2009a-d). Recent surveys of both topography and seafloor bathymetry near and around the CVV will be used in those simulations (Abadie et al., 2009c). Figs. 9 and 10 show results of typical simulations with a multi-fluid (material) 3D-NS-VOF model for a CVV flank collapse extreme scenario, with a slide volume of 100 km^3.
- Transoceanic propagation of each selected CVV source will be carried out using the spherical coordinate FUNWAVE model (Kirby et al., 2009). Propagation will first be run over a coarse 2'x2' deep ocean grid (based on ETOP2 topography), initialized with results of the 3D-NS-VOF model. Fig. 11 shows an example of tsunami propagation calculated for an earlier more extreme scenario (with empirical source definition), with a slide volume of 300 km^3 (Grilli et al., 2006; Pérignon, 2006), using the Cartesian version of FUNWAVE (over a distance corrected 2'x2' oceanic grid).
- Nested coastal grids of finer resolution will then be used to predict detailed tsunami impact in coastal areas of the East Coast where significant tsunami waves are predicted to arrive in the coarser grid. Initial conditions for those fine grids will be obtained from waves simulated in the coarser grid. The coastal grids will have a resolution of 0.25'x0.25' or better, depending on coastal features and will typically encompass regions from deep water, at the toe of the continental slope to the shoreline. Fig. 12 illustrates propagating the incoming tsunami into a finer 0.25'x0.25' regional nested grid in the area off of Long Island and Rhode Island; and Fig. 13 shows 3 successive snapshots of tsunami propagation computed in this regional grid.
- Even finer grids will be finally used to perform coastal inundation and runup simulations, as detailed in a section above.

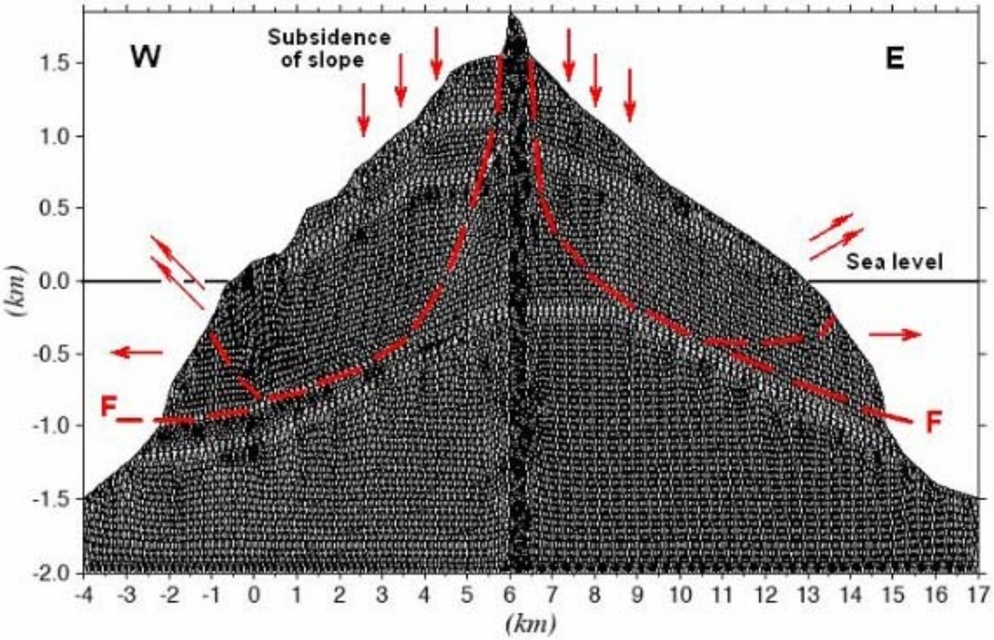

Figure 8: Recent slope stability analysis of the CVV, performed using FLAC-2D and 2D-FEM (this figure) models (Abadie et al., 2009a,c)

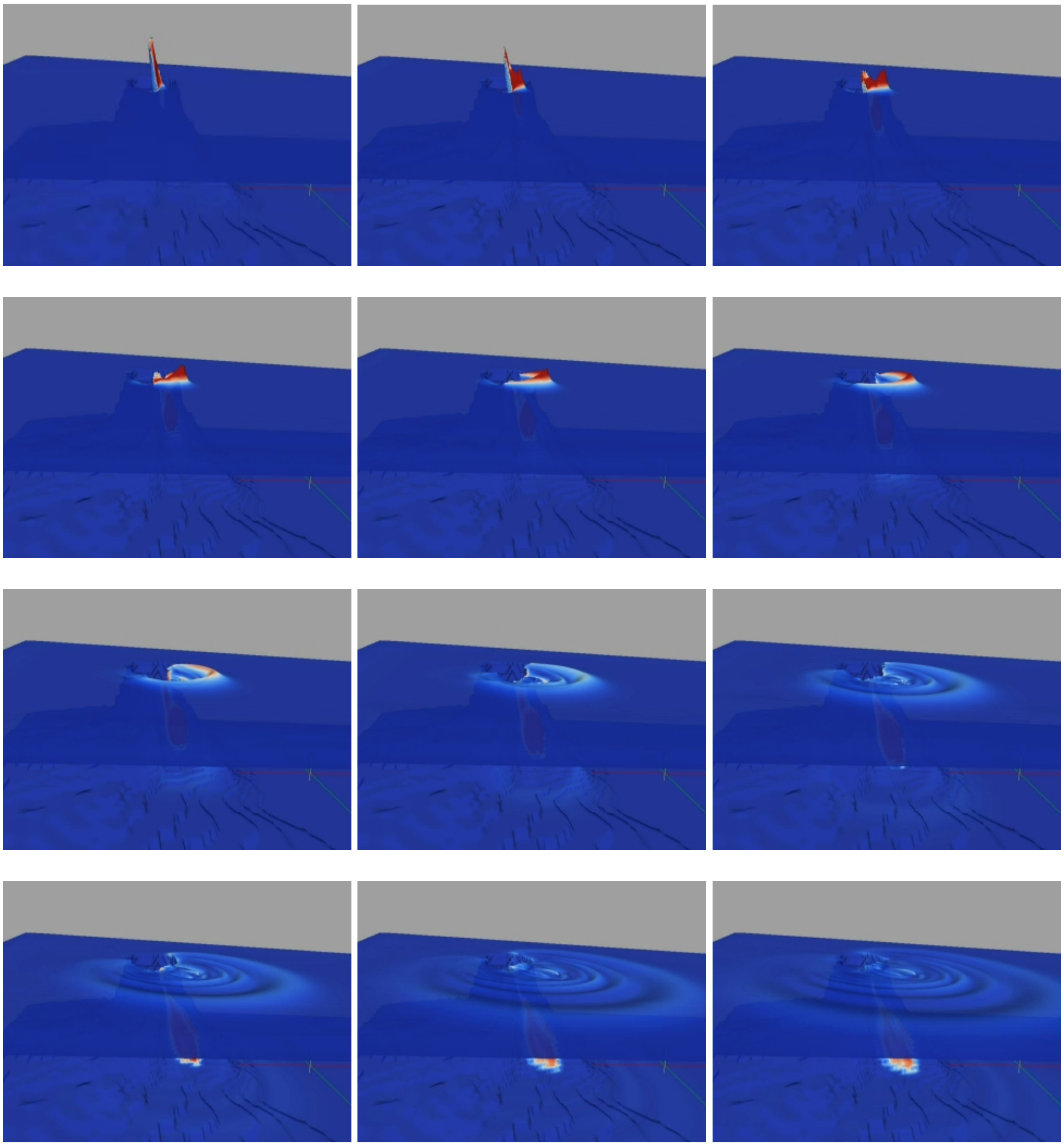

Figure 9: 3D-NS-VOF multi-fluid (material) modeling of landslide and tsunami generation, for CVV flank collapse, 100 km^3 scenario (Abadie et al., 2009a,c). Time sequence of simulated snapshots for the first 12 min. or so of slide motion and tsunami generation. The first picture (after about 1min.) shows maximum surface elevation (about 800 m). The fourth picture (after about 4 min.) shows the minimum surface depression (about -400 m).

Co-seismic tsunami sources

Transoceanic co-seismic sources will be modeled, following the standard procedure, as an initial (instantaneous; i.e., “hot start”) ocean surface deformation based on estimates of event moment magnitude, geographic extent and depth, and geological parameters (material property, fault slip, strike, rake), using Okada's (1985) method. A recent case study of the 2004 Indian Ocean tsunami was successfully conducted with FUNWAVE following this methodology (Grilli et al., 2007; Ioualalen et al., 2007; Karlsson et al., 2009).

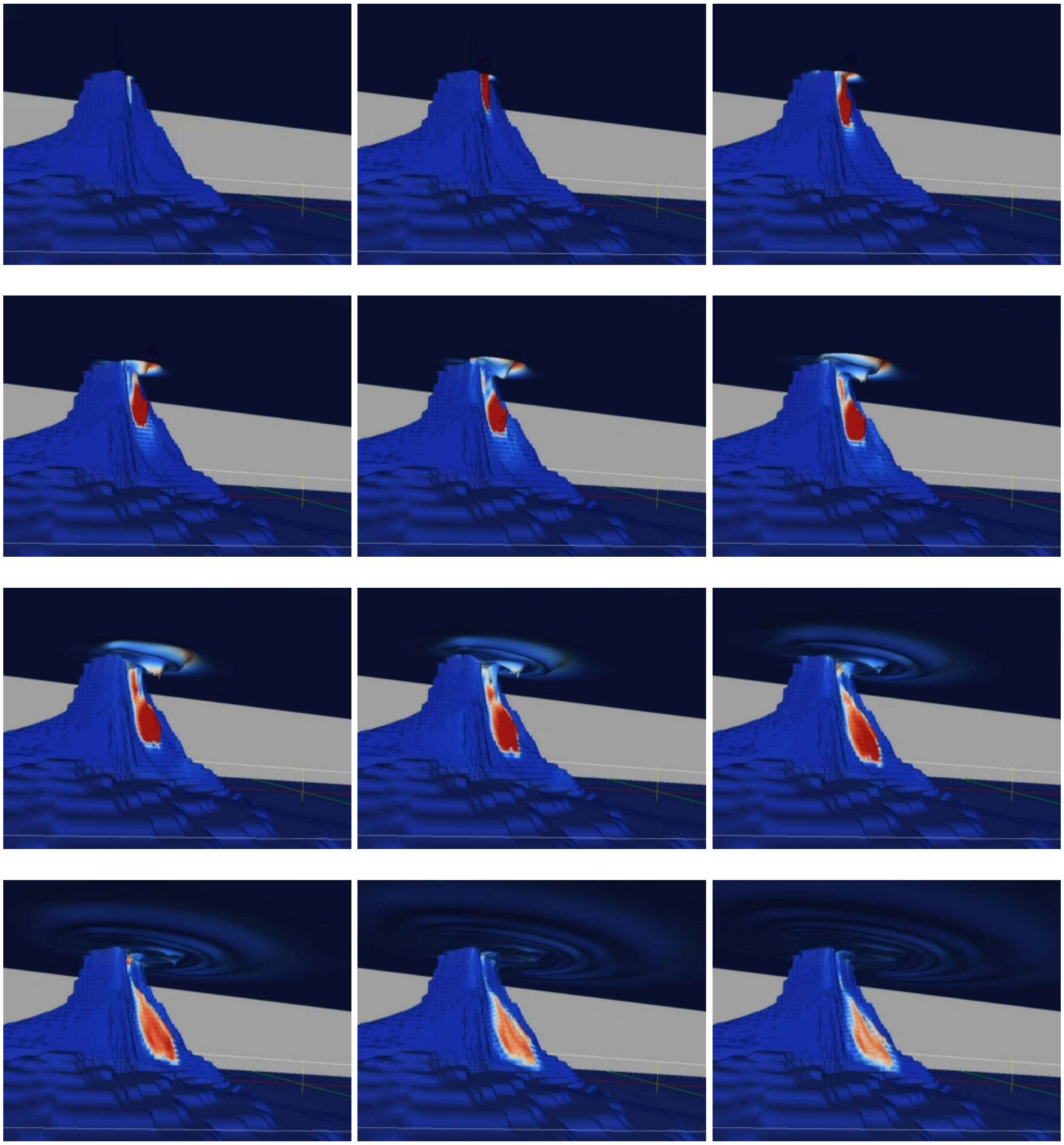

Figure 10: Same as Fig. 9, for underwater view.

Parameters for co-seismic sources, in the Caribbean subduction zone North of PR and near the Leeward Islands, will be obtained from both our past work (Grilli et al., 2008, 2010) and other work reported in the literature (USGS, 2001; Dawicki, 2005; ten Brink and Lian, 2004; ten Brink, 2005; Jansma, 2008). Parameters for Lisbon 1755 type sources near the Azores-Gibraltar convergence zone will similarly be obtained from recently published work (Barkan et al., 2009).

Finally, for completeness, a co-seismic source corresponding to the expected maximum earthquake magnitude off of the East coast (7.5 or so), will be specified at a number of possible locations aimed at maximizing coastal impact in selected areas.

As an example, Figs. 14-16 show simulations with FUNWAVE of a tsunami caused by a 9.1 magnitude PR co-seismic source (Knight and Banks; personal communication, 2006). As before, a coarse 2’x2’ grid is used for the transoceanic simulations and a finer nested regional grid (0.25’x0.25’ resolution) is used to simulate the tsunami coastal propagation.

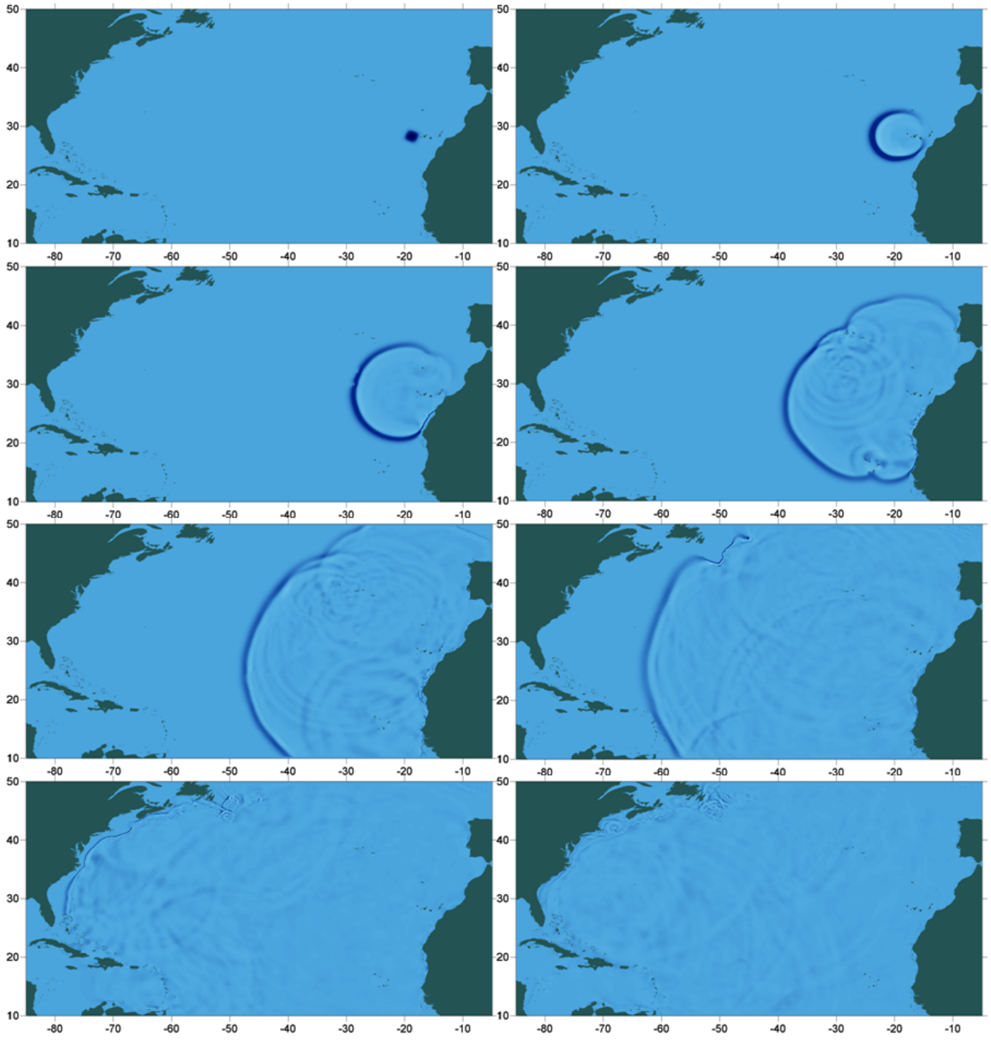

Figure 11: Tsunami simulations for a CVV collapse, with subaerial slide volume of 300 km^3 (Grilli et al., 2006; Pérignon, 2006), using the Cartesian FUNWAVE (distance corrected 2’x2’ oceanic grid). The picture sequence covers approximately 8 hrs. of tsunami propagation.

SMF tsunami sources

Location and parameters for relevant local SMF sources will be identified, as detailed in a preceding section, by performing a first-order probability analysis of SMF hazard along the US East coast, using a Monte Carlo simulation model. Additional, historically known, landslide tsunami sources, or sources in areas thought to be at risk of future slope instability based on the known geology, will also be specifically and deterministically modeled as SMF sources (e.g., 1929 Grand Bank, Piper et al., 1999; Curritck slide, Geist et al., 2009, Locat et al., 2009; MG issue, 2009).

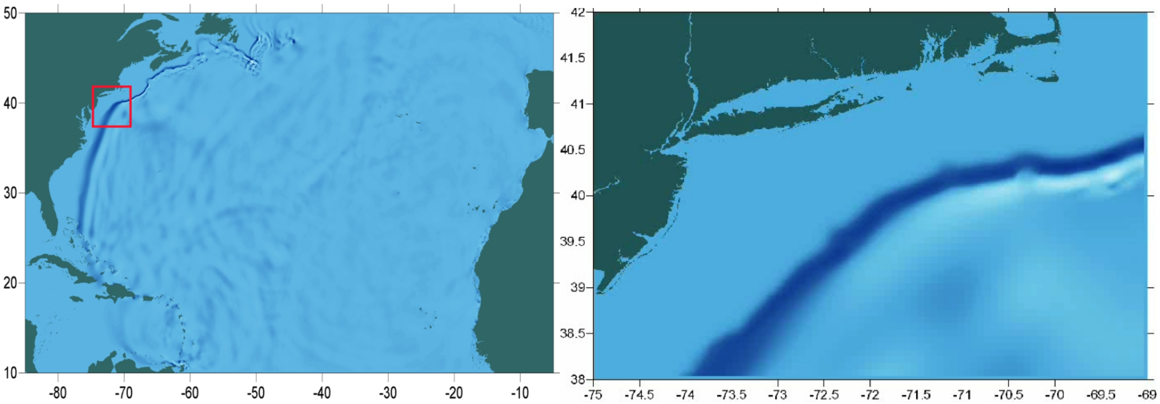

Figure 12: Same case as Fig. 11. Propagation of the incoming tsunami into a finer 0.25'x0.25' regional nested grid in the area off Long Island and Rhode Island.

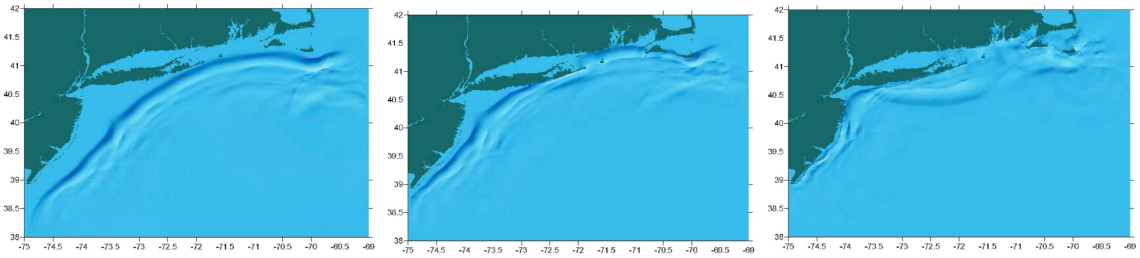

Figure 13: Same case as Figs. 11 and 12. Three snapshots of tsunami coastal impact simulated in the finer regional grid.

Once their parameters selected, local SMF sources will be modeled as initial condition (i.e., "hot start") in the FNBM model FUNWAVE, according to the methodology reported in Watts et al. (2003, 2005) and Grilli et al. (2005), and validated for a number of historical case studies (e.g., Day et al., 2005; Tappin et al., 2008). In short, in this method, SMF sources are semi-empirically generated from geomechanical, geological, and geometrical parameters, and specified as initial wave elevation and velocities in the propagation model. These semi-empirical equations were derived, based on a large number of 3D simulations of slide kinematics, using a model solving fully nonlinear (inviscid) 3D Euler eqs. with a free surface, and subsequently experimentally validated (Enet and Grilli, 2007). This 3D modeling and other scaling analyses finally showed that the key parameter in SMF tsunami generation is initial acceleration and, to the first-order, typical SMF deformation does no significantly affect key tsunami features (Grilli and Watts, 2005). Once deformation is large, the slide is usually deeply submerged and no longer tsunamigenic. The methodology proposed in this study for generating SMF tsunami sources thus assumes rigid (translational or rotational) underwater slides, which is expected to capture the key features of the generated tsunamis (e.g., leading depression and elevation waves) expected to cause maximum coastal inundation hazard. However, this is not a limitation and, if known from sediment rheological properties, slide deformation effects could be included in this methodology (see Grilli and Watts, 2005). Alternately, for specific historical cases (e.g., 1929 Grand Bank or Currituck), tsunami source could be simulated using a model similar to that proposed for the CVV collapse (i.e., based on a 3D-NS-VOF multi-fluid simulations).

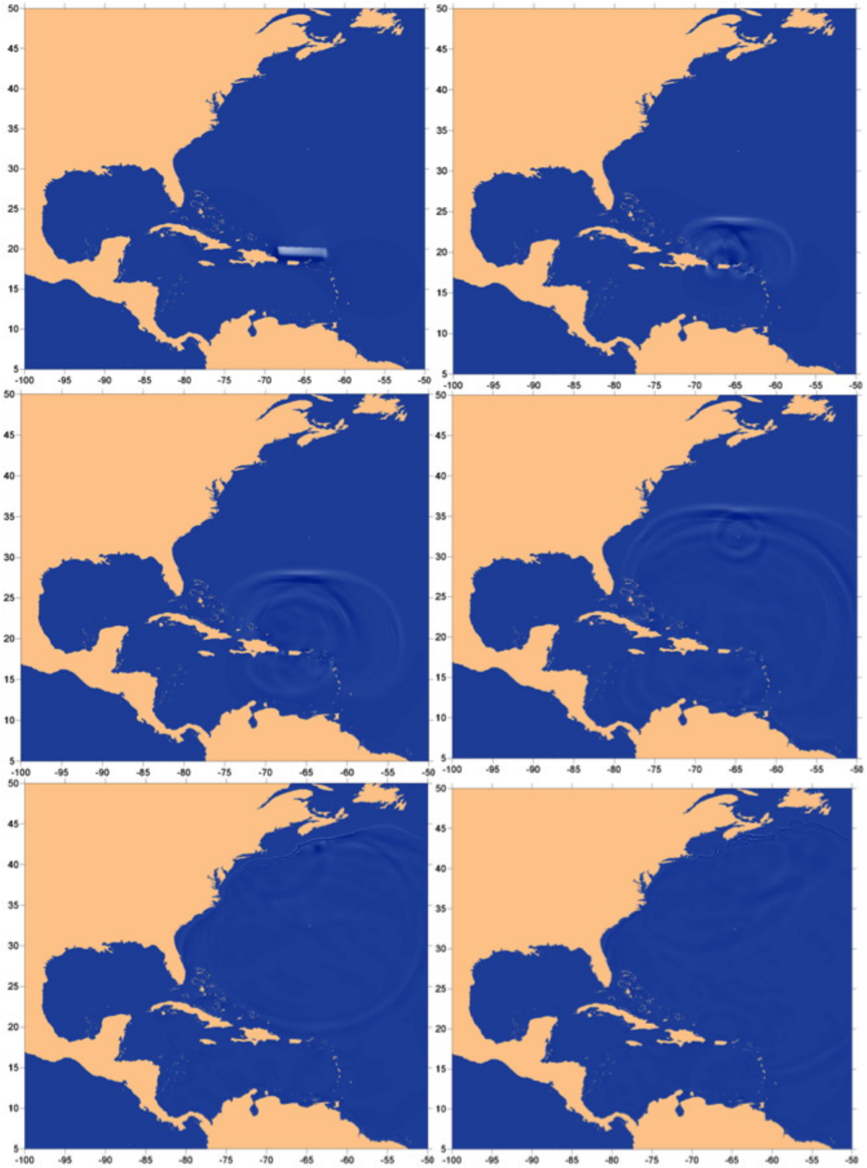

Figure 14: Snapshots of tsunami propagation caused by a 9.1 magnitude co-seismic source in the the Caribbean subduction zone, North of PR (Grilli et al., 2006, 2010).

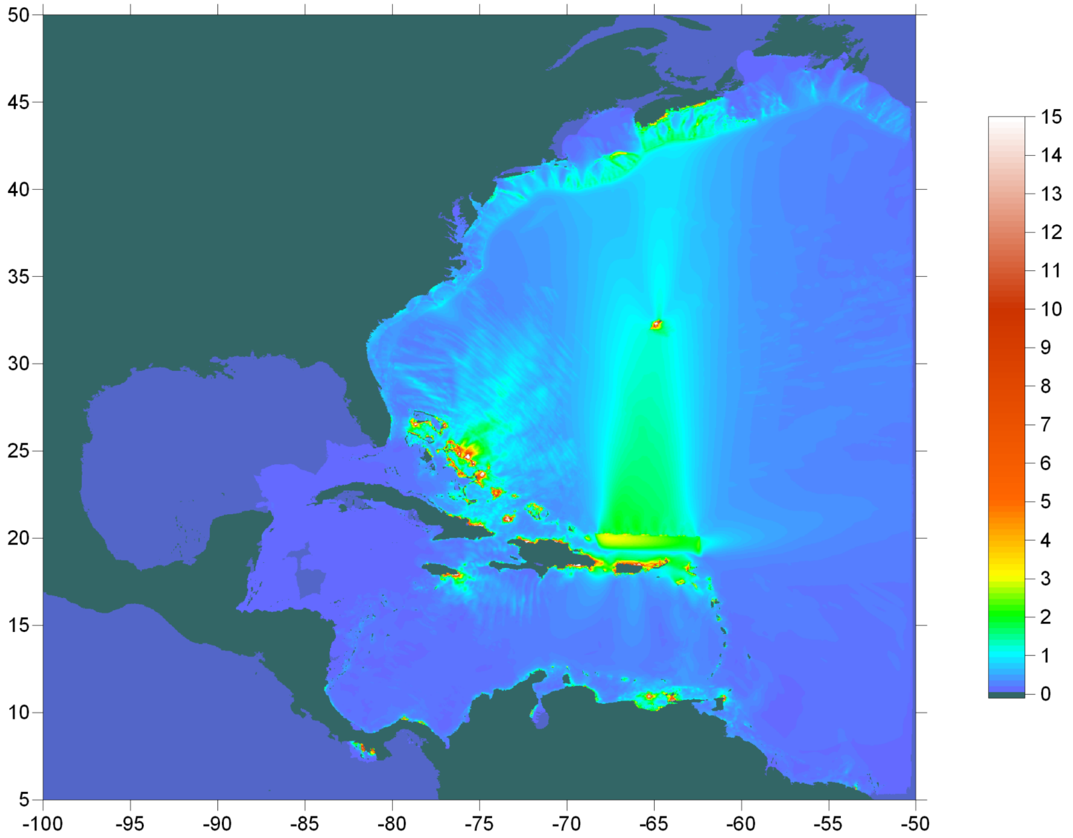

Figure 15: Same case as Fig. 14. Envelope of maximum predicted surface elevation in the 2’x2’ deep ocean ocean grid.

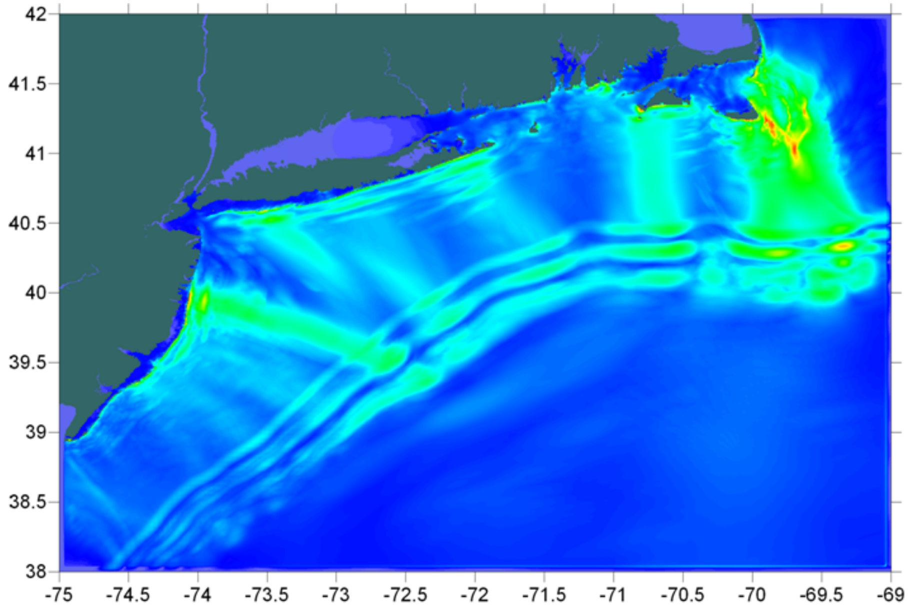

Figure 16: Same case as Figs. 14, 15. Envelope of maximum predicted surface elevation in the 0.25’x0.25’ nested regional coastal ocean grid.

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Publications related to proposal

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.

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Five additional publications

Zhang, W.-Z., Shi, F., Hong, H.-S., Shang, S.-P., Kirby, J. T., 2010, “Tide-surge interaction intensified by the Taiwan Strait”, *J. Geophys. Res.*, in press.

Debsarma, S., Das, K. P. and Kirby, J. T., 2010, “Fully nonlinear higher order model equations for long internal waves in a two fluid system'”, *J. Fluid Mech.*, in press.

Terrile, E., Brocchini, M., Christensen, K. H. and Kirby, J. T., 2008, "Dispersive effects on wave-current interaction and vorticity transport in nearshore flows", *Physics of Fluids*, **20**, 036602 .

Misra, S. K., Kirby, J. T., Brocchini, M., Veron, F., Thomas, M. and Kambhamettu, C., 2008, "The mean and turbulent flow structure of a weak hydraulic jump *Physics of Fluids*, **20**, 035106 .

Long, W., Kirby, J. T. and Shao, Z., 2008, "A numerical scheme for morphological bed level calculations", *Coastal Engineering*, **55,** 167-180.

Synergistic Activities

Associate Editor of Journal of Engineering Mechanics, 1994-1995. Editor of the J. of Waterway, Port, Coastal and Ocean Engineering, 1996-2000. Editor of J. Geophysical Research - Oceans, 2003-2006. Editor-in-Chief of J. Geophysical Research – Oceans, 2006-2009. Member, Coordinating Committee, National Tsunami Hazard Mitigation Program. Organizer of a successful NOPP nearshore community modeling project (1999-2004). Development of graduate courses in ocean surface wave dynamics, fluid mechanics, time series analysis and numerical methods. Developer of the widely used surface wave transformation programs REF/DIF and FUNWAVE and nearshore community model NearCoM.

Recent Collaborators (outside University of Delaware): Hernan G. Arango, Sachin K. Bhate, Alan F. Blumberg, Brad Butman, Tim J. Campbell, Yeon Chang, Kasey Edwards, Steve Elgar, Diane Foster, David Froehlich, W. Rockwell Geyer, Stephan Grilli, Kevin Haas, Merrick Haller, Daniel Hanes, Jeffrey L. Hanson, Ruoying He, H. R. Albert Jagers, James M. Kaihatu, Timothy R. Keen, Jamie MacMahan, James C. McWilliams, H. Tuba Özkan-Haller, Natalie Perlin, Donald T. Resio, Jan A. Roelvink, Lawrence P. Sanford, Alexander Shchepetkin, Chris Sherwood, Richard P. Signell, Eric D. Skyllingstad, Jerry Smith, Richard L. Soulsby, Keith D. Stolzenbach, Peter A. Traykovski, John H. Trowbridge, Jay Veeramony, John C. Warner, Phil Watts, Richard J. S. Whitehouse, Johan C. Winterwerp, Maurizio Brocchini, Riccardo Briganti, Qin Chen, Mauricio Gobbi, Mansour Ioualalen, Emanuele Terrile. Jamie MacMahan, Ed Thornton, Tim Stanton, Ad Reniers, Michael Kemp, Ming Li, Katja Fennell, Bill Hodgkiss, Bruce Cornuelle, Bill Kuperman, J. Proakis, T. Duman, W. Fox, D. Rouseff.

Graduate and Postgraduate Advisees: Ph.D. Students: James Kaihatu (1994), Changhoon Lee (1994), Ge Wei (1997), H. Tuba Özkan-Haller (1997), Mauricio Gobbi (1998), Arun Chawla (1999), Shubhra Misra (2005), Wen Long (2006).

Postdoctoral Research Associates: Francis C. K. Ting (1989-1992), Qin Chen (1997-2000), Andrew Kennedy (1997-2001), Fengyan Shi (1998-2000), Valeria Rego (2000-2001), Tom Hsu (2003), Riccardo Briganti (2004), Dongming Liu (2008-2009)

Ph.D. Thesis Advisor: Robert A. Dalrymple, Dept. of Civil Engineering, Johns Hopkins University.

STEPHAN T. GRILLI

Biographical Sketch

Dept. of Ocean Engineering
University of Rhode Island
Narragansett, RI 02882
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Research Interests:	Ocean wave processes and modeling, co-seismic tsunami and landslide tsunami modeling, extreme waves, sediment transport, nonlinear floating body dynamics
Education:	University of Liège, Ph.D., Ocean Engineering, 1985. Sc.M., Physical Oceanography, 1983. Sc.M., Civil and Hydraulic Engineering, 1980.
Professional Experience:	1985-1987, *Research Associate* F.N.R.S., University of Liège (Belgium). 1987-1991, *Research Assistant Professor*, Univ. of Delaware, Dept. of Civil Engng. 1991-1993, *Assistant Professor*, University of Rhode Island, Dept. of Ocean Engng. 1993-1998, *Associate Professor*, University of Rhode Island, Dept. of Ocean Engng. 1998-present, *Distinguished Professor*, Univ. of Rhode Island, Dept. of Ocean Engng. 2002-2008, *Chairman*, University of Rhode Island, Dept. of Ocean Engng. 1999, *Visiting Senior Scientist*, Univ. of Nice, Institut Nonlineaire, France (Spring 99). 2007, *Associate Research Director*, C.N.R.S., Univ. of Toulon, France (Spring 07).
Technical Societies:	American Geophysical Union, Intl. Society for Offshore and Polar Engineers. American Society of Civil Engineers, Marine Technology Society
Awards:	Hydrodynamic Research Prize, Intl. Society for Offshore and Polar Engineers (2008)

Five Publications related to proposal

1. Grilli, S.T., Vogelmann, S. and Watts, P. (2002). Development of a 3D Numerical Wave Tank for modeling tsunami generation by underwater landslides. *Engng. Analysis Boundary Elemt.*, **26(**4), 301-313.
2. Ioualalen, M. , Asavanant, J., Kaewbanjak, N., Grilli, S.T., Kirby, J.T. and P. Watts (2007). Modeling the 26th December 2004 Indian Ocean tsunami: Case study of impact in Thailand. *J. Geophys. Res.*, **112**, C07024.
3. Abadie, S., Morichon, D., Grilli, S.T. and Glockner, S. (2008). VOF/Navier-Stokes numerical modeling of surface waves generated by subaerial landslides. *La Houille Blanche*, **1** (Feb. 2008), 21-26.
4. 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.
5. 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.

Five additional publications

1. Guyenne, P. and Grilli, S.T. (2006) Numerical study of three-dimensional overturning waves in shallow water. *J. Fluid Mechanics*, **547**, 361-388.
2. 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. Waterw. Port Coastal and Ocean Engng.*, **133**(6), 414-428.
3. Fochesato C., Grilli, S.T. and Dias F. (2007). Numerical modeling of extreme rogue waves generated by directional energy focusing. *Wave Motion*, **44**, 395-416.
4. Enet, F. and Grilli, S.T. (2007). Experimental Study of Tsunami Generation by Three-dimensional Rigid Underwater Landslides. *J. Waterway Port Coastal and Ocean Engng.*, **133**(6), 442-454.
5. Grilli, S.T., Dias, F., Guyenne, P., Fochesato, C. and F. Enet (2010). Progress in Fully Nonlinear Potential Flow Modeling of 3D Extreme Ocean Waves. Chapter in *Advances in Numerical Simulation of Nonlinear Water Waves* (Series in Advances in Coastal and Ocean Engineering). World Scientific Publishing Co.Pte.Ltd., 55 pps. (in press; June 2010).

Synergistic Activities

1. ONR (Coastal Division) : Development of experimentally validated Numerical Wave Tanks for studying mine burial in Sandy bottom. Development and modeling (both laboratory and numerical) of systems for ocean wave energy production Development of numerical wavetanks for wave and wave-induced sediment transport modeling.
2. US Navy/ONR : Development and application of a numerical wave tank to compute the (nonlinear) wave resistance of high speed Surface Effect Ships. Validation with towing tank experiments.
3. Chairman of the *Hydrodynamic Committee* and *Numerical Wave Tank Group* (NWT) of the *Intl. Soc. Of Offshore and Polar Engineers* (ISOPE). Organizer of NWT Workshop at ISOPE 2001 and LongWave/Tsunami Session at ISOPE Conferences 2003, 2004, 2006.
4. Associate Editor of *Intl. J. Offshore and Polar Engng.* (2003-2009). On the Editorial Board of *Engng. Analysis with Boundary Elements* (1989-)

Recent Collaborators

Prof. F. Dias (Ecole Normale Superieure, Cachan, France); Profs. M. Saillard and Ph. Fraunie (Univ. of Toulon, France); Prof. S. Abadie (University of Pau, France); Profs. M.L. Spaulding and C. Baxter (colleagues in the Ocean Engineering Department at URI); Dr. P. Watts (AFE, Inc.); Prof. R. Street (Stanford Univ.); Prof. R.A. Dalrymple (Johns Hopkins Univ.); Profs. J. Fernando and S. Voropayev (Arizona State Univ.); Prof. J.T. Kirby (Univ. of Delaware).

Graduate and Postgraduate Advisees: Ph.D. Students (past 5 years):

Taylor Asher, Marty Ingraham, Kevyn Bollinger (current MS student, URI), Benjamin Biausser (PhD, Technip, France), Myriam El Bettah (current PhD student, URI) Kevyn Bollinger (current MS student, URI), Sara Dubosq (current PhD student, Univ. of Toulon, France), Yann Drouin (MS, Ecole Centrale de Nantes, France), Francois Enet (PhD, Alkyon Inc., Holland), Christophe Fochesato (PhD, Ecole Normale Superieure, France), Nate Greene (MS, Raytheon, RI), Richard Gilbert (MS, McLaren Inc, New Yor, NY), Philippe Guyenne (PhD postdoc, University of Delaware, DE), Jeff Harris (current PhD student, URI), Stefan Maretzki (MS, back to Germany), Kristy Moore (MS, NUWC, RI), Yves Perignon (MS, PhD student, ECN, Nantes, France) Mat Schultz (MS, Woods Hall Engineering Inc.), Hong Gun Sung (PhD, postdoc, KORDI, Seoul, Korea),

Ph.D. Thesis Advisor: Profs. A. Lejeune and N.M. Dehousse at the University of Liege, Belgium.

Biographical Sketch for Stéphane Abadie

Name : Stéphane M. Abadie	Title : Professor
Http : http://lasagec2.univ-pau.fr/live/Genie-cotier/cv+abadie	Adress : LASAGEC2, Université de Pau, Allée du Parc Montaury, 64600 Anglet, France
Tel/Fax : 00 33 5 59 57 -44 21/-44 39	Email : stephane.abadie@univ-pau.fr

A. Education :

- 1986-1989 : Mathématiques Supérieures et Spéciales, Lycée Montaigne – Bordeaux. France.
- 1992 : Ecole Supérieure d'Ingénieurs de Marseille. France.
- 1993 : Master in Fluid Mechanics, University of Aix Marseille II. France.
- 1994-1998 : PhD, University of Bordeaux I, Title: « Numerical modeling of plunging wave breaking using the VOF method ». Highest distinction. France.
- 2007: Post doctoral degree required to lead research (HDR). University of Pau, Title: « On breaking waves and their effects at the coast ». France.

B. Permanent Positions :

- 1996-1998 : Research assistant (ATER) in University of Bordeaux I.
- 1998-2008 : Assistant Professor (Maître de Conférence) in University of Pau.
- 2008-present : Professor in University of Pau.
- 1999-present : Head of the « wave structure interactions » research team in LASAGEC Laboratory (JE 2519) - University of Pau.
- Director of the second year of studies at ISABTP – School of Civil Engineering - University of Pau

C. Visiting Positions :

- 2005 : visiting scholar at Department of Ocean Engineering, University of Rhode Island, USA, January 5 to June 30.

D. Publications :

Five recent relevant publications

- Abadie, S, Grilli, S., Glockner, S., 2006, "A coupled numerical model for tsunami generated by subaerial and submarine mass failures", in *Proc. 30th Intl. Conf. on Coastal Engineering* (2006, San Diego, California, USA). 1420-1431.
- Abadie, S, Morichon, D., Grilli, S., Glockner, S., 2008, "VOF/Navier-Stokes numerical modeling of surface waves generated by subaerial landslides", *La Houille Blanche,* **1**, 21-26.
- Abadie, S, Gandon, C., Grilli, S., Fabre R., Riss, J., Tric, E., Morichon D., Glockner, S., 2009, "3D Numerical simulations of waves generated by subaerial mass failures. Application to La Palma case", *31th Intl. Conf. on Coastal Engineering* (2008, Hamburg).
- Abadie, S, Morichon, D., Grilli, S., Glockner, S., "A three fluid model to simulate waves generated by subaerial landslides", Submitted to *Coastal Engineering* (in revisions).
- Morichon, D., Abadie, S., Glockner, S., Grilli, S., 2009, "Validation of a Navier-Stokes VOF solver used to simulate impulse waves generated by mass failure", *Proc. 3rd Intl. conf. on Approximation Methods and Numerical Modelling in Environment and Natural*

Resources (2009, Pau, France), pp. 683-688.

Five other relevant recent publications

- Lubin, P., Vincent, S., Abadie, S. & Caltagirone, J.P., 2006. “Three-dimensional Large Eddy Simulation of air entrainment under plunging breaking waves”, *Coastal Engng.*, **53**(8), .631-655.
- Brière, C., Abadie, S, Bretel, P., Lang, P., 2007, “Assessment of hydrodynamic modelling systems, a case study of Anglet, France”, *Coastal engng.*, **54**(4), 345-356.
- Mory, M., Michallet, H., Bonjean, D., Piedra-Cueva, I., Barnoud, J.M., Foray, P., Abadie S., Breul, P., 2007, “Momentary liquefaction and scour caused by waves around a coastal structure”*, J. Waterways, Port, Coastal and Ocean Engineering,* **133**, 1, 28-38.
- Mory, M., Mauriet, S., Abadie, S., Lubin, P., 2009, “Numerical simulations of turbulent bore run-up and run-down”, *31th Intl. Conf. on Coastal Engineering* (2008, Hamburg).
- Arnaud G., Mory M., Abadie S. and Cassen M., 2009, “Use of a resistive rods network to monitor bathymetric evolution in the surf/swash zone”, *10th Intl. Coastal Symposium*, Lisbonne (Portugal, 13-18 avril 2009), *J. of Coastal Research*, **SI 56**.

E. Student supervising :

- S. Mauriet (M.S., 2004), University of Brest, numerical modeling of longshore current
- G. Arnaud (M.S., 2004), University of Caen, A new instrument to monitor real time sea bed changes in the surf zone
- P. Lubin (PhD, 2004), University of Bordeaux I, Large Eddy Simulation of plunging wave breaking
- C. Brière (PhD, 2005), University of Pau, numerical modeling of the Adour estuary
- C. Gandon (M.S., 2008), University of Paris 6, numerical modeling of waves generated by landslides.
- D. Dailloux (PhD, 2008), University of Pau, Video monitoring of the Adour River Plume.
- S. Mauriet (PhD, 2009), University of Pau, VOF numerical simulation of swash flow.
- G. Arnaud (PhD, 2009), University of Pau, resistive measurements of sea bed changes in the surf zone.
- C. Mokrani (PhD in progress), University of Pau, VOF simulation of overtopping events

F. Research grants :

- “IMARTEC project” (2004), PI, to support the development and test of a new electrical instrument to monitor sand level changes in the surf zone.
- “PATOM/IDAO Project” (2000-2008). PI, CNRS-INSU to study wave breaking in the surf zone by VOF numerical modeling
- “Nearshore observation Project” (2004-2006). Co PI, Aquitaine Euskadi funding program to develop a video monitoring system for the Adour river mouth.
- “Tsunami Risk And Strategies For the European Region” FP6 project (2006-2009). PI. European community to study wave generated by landslide by numerical modeling.
- “RRLA Project” (2006-2009). PI. Aquitaine Region to complete the development of the electrical rod (see IMARTEC project).
- “ECORS project” (2007-2010). PI, DGA (French army) to perform real time survey of local sea bed changes in the surf zone during the field campaign ECORS in 4/2008.

CURRICULUM VITAE

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Center for Applied Coastal Research & Department of Civil and Environmental Engineering
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Professional Employment

Research Assistant Professor, Department of Civil and Environmental Engineering & Center for Applied Coastal Research, University of Delaware, 2007 - present
Associate Scientist, Center for Applied Coastal Research, University of Delaware, 2003 - 2007
Associate Professor, State Key Laboratory of Estuarine and Coastal Research, East China Normal University, China, 1996 – 1998

Education

Post-Doc, Coastal Engineering, Center for Applied Coastal Research, University of Delaware, 1998-2003
Ph.D. Environmental & Physical Oceanography, Ocean University of Qingdao, 1995
M.Sc. Physical Oceanography, Ocean University of Qingdao, 1991
B.Sc. Physics, Wuhan University of Technology, 1984

Professional Activities

Reviewer –

Journal of Geophysical Research, Journal of Waterway, Port, Coastal and Ocean Engineering, International Journal for Numerical Methods in Fluids, Journal of Coastal Research, IAHR Journal of Hydraulic Research, Coastal Engineering, Physics of Fluids, ACTA Oceanologica Sinica

Member –

American Geophysical Union (AGU), convener and chair of session of nearshore processes at AGU 2008 Fall Meeting

Recent Journal Publications

1. Waythomas C.F., Watts P., Shi F., and Kirby J. T., 2008, Pacific basin tsunami hazards associated with mass flows in the Aleutian Arc of Alaska, *Quaternary Science Review*, 28, 1006-1019.
2. Smith K. A., North E. W., Shi F. Chen S-N, Sanford L., Hood R. R., Koch E. W. and Newell R. I. E., 2008, Modeling the effects of oyster reefs and breakwaters on seagrass beds, *Estuaries and Coasts*, 32 (4), 748-757.
3. Shi, F. and Kirby, J. T. and Hanes, D., 2007, An efficient mode-splitting method for a curvilinear nearshore circulation model, *Coastal Engineering*, 54 (11), 811-824.
4. Chen S-N, Sanford, L. P., Koch, E. W., Shi, F., North, E. W., 2007, A nearshore model to investigate the effects of seagrass bed geometry on wave attenuation and suspended sediment transport, *Estuaries and Coasts,* Vol. 30, No.2, 296-310.
5. Watts, P., Ioualalen, M., Grilli, S., Shi, F., Kirby, J. T., 2007, Numerical simulation of the December 26, 2004 Indian Ocean tsunami using a higher-order Boussinesq model, *Journal of Waterway, Port, Coastal and Ocean Engineering,Special Issue on Tsunami Engineering,* Vol. 133, No.6, 414-428.
6. Shi, F. and Kirby, J. T., 2005, Curvilinear parabolic approximation for surface wave transformation using covariant-contravariant tensor method, *Journal of Computational Physics*, 204, 562-586

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Delaware Geological Survey, University of Delaware

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Education:
Student Sustaining Status in M. Sc. in Geography, University of Delaware, GPA - 3.79.
Thesis: *Estimation of Precipitable Water Over the Amazon River Basin Using GOES Imagery*.

B. Sc. in Physics, Temple University, Philadelphia, PA, Feb 1994.
B. Sc. in Mathematics, Temple University, Philadelphia, PA, Feb 1994.

Professional Experience:
Delaware Geological Survey, University of Delaware, Newark, Delaware (Feb 2008 - Present). Research Associate III / Geospatial Application Developer. My current role within the DGS is divided into three primary categories:

> To conduct research individually and with DGS colleagues to better understand the geology and hydrology of the State of Delaware. My areas of expertise include GIS analysis, spatial statistics, image interpretation, and general data analysis.
> To manage DGS' data and applications. This includes all DGS public and internal websites (including online mapping, CMS-based sites, etc...), information catalogs, numerous databases, GIS data holdings, digital photo inventory, and more.
> To continuously develop and maintain the Delaware DataMIL. This includes ArcIMS and OGC mapping services, metadata, and the future direction of the Delaware Spatial Data Framework.

Research & Data Management Services, University of Delaware, Newark, Delaware (Feb 2001 – Jan 2008). Information Resource Consultant III. Acted as GIS coordinator and primary technical support person for the entire University of Delaware. Primary responsibility was to support GIS in all aspects of teaching and research activities by UD faculty, staff, and students. Includes developing and teaching workshops, technical training, project design, statistical and geospatial analysis consulting, design and implementation of web and database applications, and representation of UD in numerous state and national GIS activities. This position also allowed room for new application development: two significant applications were the Delaware State Geospatial Information Clearinghouse and the Delaware DataMIL.

Environmental Systems Research Institute (ESRI) Inc., King of Prussia, Pennsylvania (Apr 2000 – Jan 2001). GIS Consultant / Application Developer. Developed custom applications for a variety of ESRI software products, including ArcView 3.x, ArcInfo 7.x/8, ArcObjects and ArcIMS. Duties also included on-site consulting, developing workshops and training, project management, client relationships, and small proposal writing.

Earth Satellite Corporation, Rockville, Maryland (Oct 1999 – Mar 2000).

Applications Scientist. Performed land use classifications on Landsat scenes and developed several automated techniques through ERDAS Imagine EML/SML and ARC/INFO AML.

Synergistic Activities:
Co-Investigator, "A Prototype Coastal Flood Monitoring System for Delaware", Funding from Delaware NSF EPSCoR and Delaware Dept. of Environmental Control, July 2009 – July 2010

Co-Principal Investigator, "DGS Digital Image Metadata", USGS National Geological and Geophysical Data Preservation Program, July 2009 – June 2010

Co-Principal Investigator, "NSDI Cooperative Agreements Program, Category 3: Clearinghouse Integration with Web Mapping Services", October 2002 – September 2003.

Co-Principal Investigator, "The USGS National Map/Delaware Framework DataMIL Project", USGS Title VII Funding Initiatives, August 2001 – December 2002.

Co-Collaborator, "A University Teaching Laboratory for Geographic Information Science", University of Delaware, College of Arts and Sciences, September 2001.

Teaching Experience:
GIS in Natural Resource Management (FREC480), Climate and Life (GEOG152)
Meteorology (GEOG220), Computer Methods in Geography (GEOG250)
"Introduction to GIS", Two-day workshop to UD College of Marine and Earth Science
"Internet Mapping using ArcIMS", Two-day seminar, USGS MCMC, Rolla, MO

Recognition and Awards:
Delaware State Geographic Service Award, 2007
USGS John Wesley Powell Award, 2003
ESRI Special Achievement in GIS (SAG) Award, 2002

Selected Papers:
"Probability and Mitigation of Vessel Encounters with North Atlantic Right Whales", James Corbett, Jeremy Firestone (CMES, University of Delaware), AngeliaVanderlaan and Chris Taggart (Dept of Oceanography, Dalhousie University), *Endangered Species Research* (Accepted, Ms. No. 200801014), November 2008.

"Geospatial Modeling of Ship Traffic and Air Emissions, Chengfeng Wang (California EPA) and James Corbett (CMES, University of Delaware), June 2007.

Callahan, John A., Christina L. Callahan, Richard S. Sacher, Michael B. Mahaffie, William, S. Schenck, Shannon S. Bain, and Robert E. Rinehart, 2002, "The Delaware DataMIL: A Web-Based Mapping Collaboration" ArcNews, ESRI, Vol. 24, No. 2, Summer 2002. p. 18-19.