Modeling Tsunami Inundation and Assessing Tsunami Hazards for the U. S. East Coast (Phase 2)

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Project Progress Report
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BACKGROUND

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 have concentrated on developing tsunami inundation maps for a nearly continuous coastal region located north of Ocean City, MD to Cape Cod, MA, plus Myrtle Beach, SC, including Long Island Sound but excluding major bays or estuaries such as Chesapeake Bay, Delaware Bay, the Hudson River and Narragansett Bay). FY13 work centers on continuing to develop inundation maps for the southern coastal areas along the US east coast, following the same methodology. 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.

Our proposed new tasks in FY13 were:

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.

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, and NHWAVE, a RANS three-dimensional, sigma-coordinate model for simulating fully non-hydrostatic short wave response to large scale ground motion.

FUNWAVE and NHWAVE are open source, publically available programs, which have been benchmarked according to NTHMP standards 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. In addition to results needed to construct inundation maps, we are collecting information on flow fields and velocities in affected navigable inlets and harbor facilities that will be useful in future navigation hazard analysis.

ACCOMPLISHMENTS

The following section summarizes the status of accomplishments for each Objective and related Tasks funded under this grant award. Summary descriptions are organized according to the overall objectives of the NTHMP that reflects the Sub-Committee structure. The work is divided between the two participating institutions, with the University of Rhode Island working on source identification and tsunami generation and large scale/regional propagation modeling, and the University of Delaware working on tsunami nearshore propagation and inundation modeling and on developing the final inundation maps.

Objective. Modeling Tsunami Inundation and Assessing Tsunami Hazards for the U. S. East Coast

Mapping and Modeling Sub-Committee:

Task #	Project	Strategic Plan Metric	Subcom.	Accomplishment
1	*Perform inundation studies for Virginia Beach, VA, Savannah, GA and Jacksonville, FL*	*Successful execution of NTHMP tsunami mapping, modeling, mitigation, planning and education efforts*	*MMS*	*Source and propagation modeling have been conducted in order to provide boundary data for regional grids indicated by the red boxes in Figure 1, using sources developed for FY10-12 work.* *Nesting for the regional grids down to local resolution (10 or 30m) is being developed. Local inundation mapping to be conducted during winter 2014-2015 during no cost extension.*
2	*Perform inundation studies for Miami Beach and Palm Beach, FL:*	*Prioritize inundation map development*	*MMS*	*SMF source has been developed in conjunction with the University of Miami, and UM has conducted initial regional modeling.* *Results from other sources have been collected for the boundary of the southernmost red box in Figure 1, for use in Florida coastal inundation studies.* *After obtaining a DEM from NGDC for Miami, FL, we will conduct inundation studies for the region from Miami Beach to West Palm Beach.*

PROBLEMS ENCOUNTERED

The DEM for the Miami Beach, FL area is still under development by NGDC. We will be able to begin detailed local work on that area when the DEM becomes available. It has also been difficult to obtain detailed DEM's from FEMA work for the same areas, and for this reason we have shifted our focus from the Jacksonville FL region to the Outer Banks region of North Carolina, for which an NGDC DEM exists.

Work for the entire East Coast region has been slowed by the decision to reduce the size of the CVV source, which acts as the "design" event for most of the region. This step was taken after discussions at the summer NTHMP MMS meeting in August 2014, which also involved Eric Geist of USGS.

ANTICIPATED OUTCOMES

Results for the additional mapping efforts described here will be presented in the form of technical reports for each NGDC DEM or similarly sized coastal region, and in the form of draft inundation maps for coastal communities within the DEM regions. The technical reports describe the model nesting procedure for each region, the hierarchy of model input files and stored output, the and the structure of GIS data sets available for map development and analysis. Figure 3 shows a sample draft map for Ocean City, MD (FY10-12) work, which is our present prototype for our map products. Project results are displayed at the project website http://chinacat.coastal.udel.edu/nthmp.html and will be displayed at the NTHMP website ws.weather.gov/nthmp/index.html as they are finalized.

PUBLICATIONS AND PRESENTATIONS REFERENCING FY13 WORK

Grilli, A. and Grilli, S. T., 2013. Far-field tsunami impact on the US East Coast from an extreme flank collapse of the Cumbre Vieja volcano (Canary Islands). Research Report No. CACR-13-03, Center for Applied Coastal Research, University of Delaware.

Grilli, A and Grilli, S. T., 2013. Modeling of tsunami generation, propagation and regional impact along the upper US East Coast from the Puerto Rico Trench. Research Report No. CACR-13-02, Center for Applied Coastal Research, University of Delaware.

Grilli, A. and Grilli, S. T. 2013c. Modeling of tsunami generation, propagation and regional impact along the upper US East Coast from the Azores convergence zone. Research Report No. CACR-13-04, Center for Applied Coastal Research, University of Delaware.

Grilli, S. T., O'Reilly, C. and Tajalli Baksh, T., 2013. Modeling of SMF tsunami generation and regional impact along the upper US East Coast. Research Report No. CACR-13-05, Center for Applied Coastal Research, University of Delaware.

Grilli, S. T., O'Reilly, C., Harris, J. C., Tajalli Bakhsh, T., Tehranirad, B., Banihashemi, S., Kirby, J. T., Baxter, C. D. P., Eggeling, T., Ma, G. and Shi, F., 2014 "Modeling of SMF tsunami hazard along the upper U. S. East Coast: Detailed impact around Ocean City, MD", submitted to *Nat. Hazards*, February.

Harris, J. C., Tehranirad, B., Grilli, A. R., Grilli, S. T., Abadie, S., Kirby, J. T. and Shi, F., 2014, "Far-field tsunami hazard on the western European and US east coast from a large scale flank collapse of the Cumbre Vieja volcano, La Palma", submitted to *Pure and Applied Geophysics*, April.

Schnyder, J. S. D., Kirby, J. T., Shi, F., Tehranirad, B., Eberli, G. P., Mulder, T., Ducassou, E. and Principaud, M., 2013, ``Potential for tsunami generation by submarine slope failures along the western Great Bahama Bank", *6th Int. Symp. on Submarine Mass Movements and their Consequences*, GEOMAR, Kiel, September 23-25.

Schnyder, J. S. D., Kirby, J. T., Shi, F., Tehranirad, B., Eberli, G. P., Mulder, T. and Ducassou, E., 2013, "Potential for tsunami generation along the western Great Bahama Bank by submarine slope failures", Abstract NH41A-1689, *AGU Fall Meeting*, San Francisco, December.

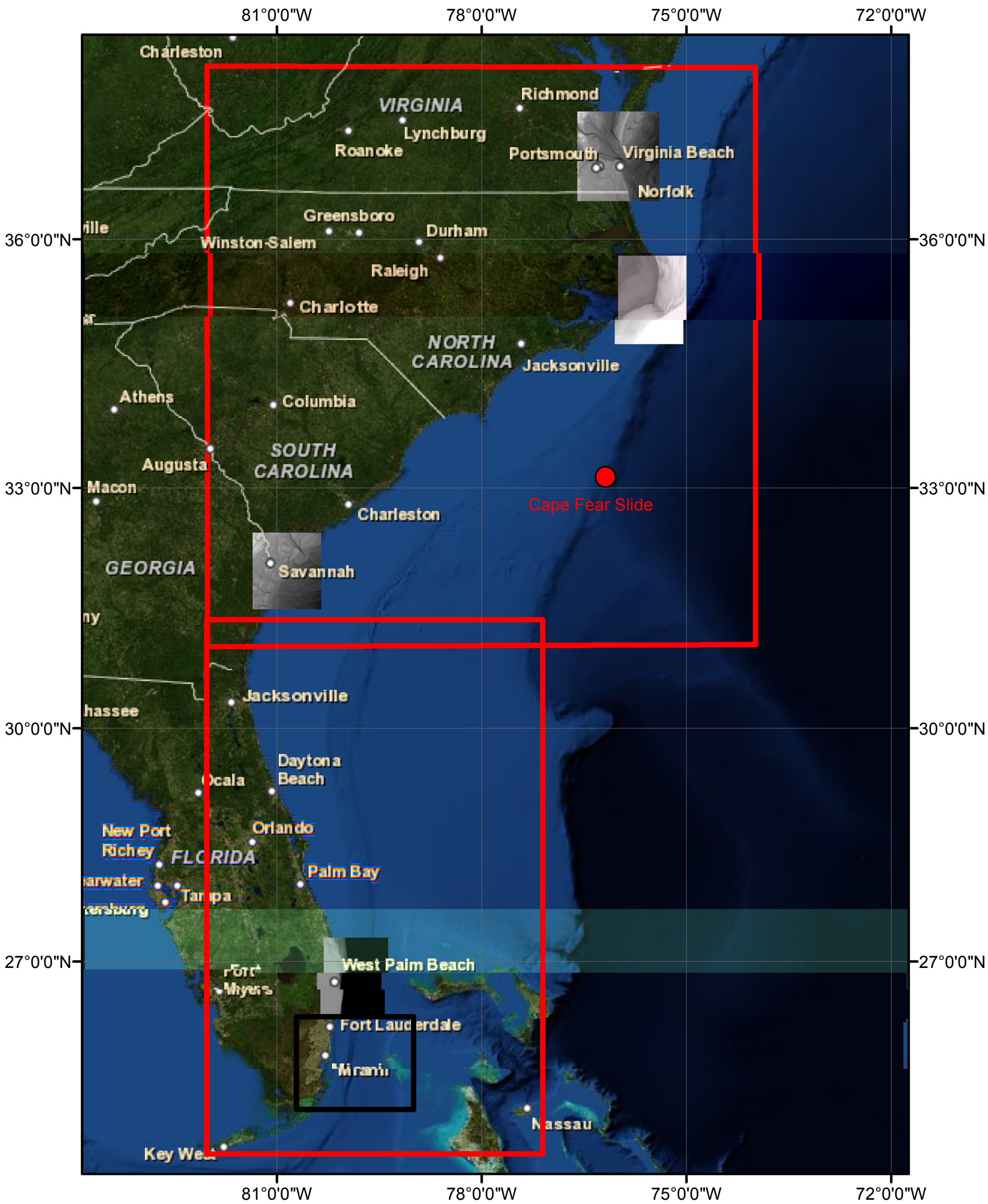

Figure 1: Sequence of DEM's being used for high resolution modeling in S.E. US., including an approximate outline for the anticipated DEM for Miami Beach, FL. Red boxes indicate regions gridded at 500m resolution which represent the transfer of data from URI ocean scale or landslide modeling to UD regional scale propagation and inundation modeling.

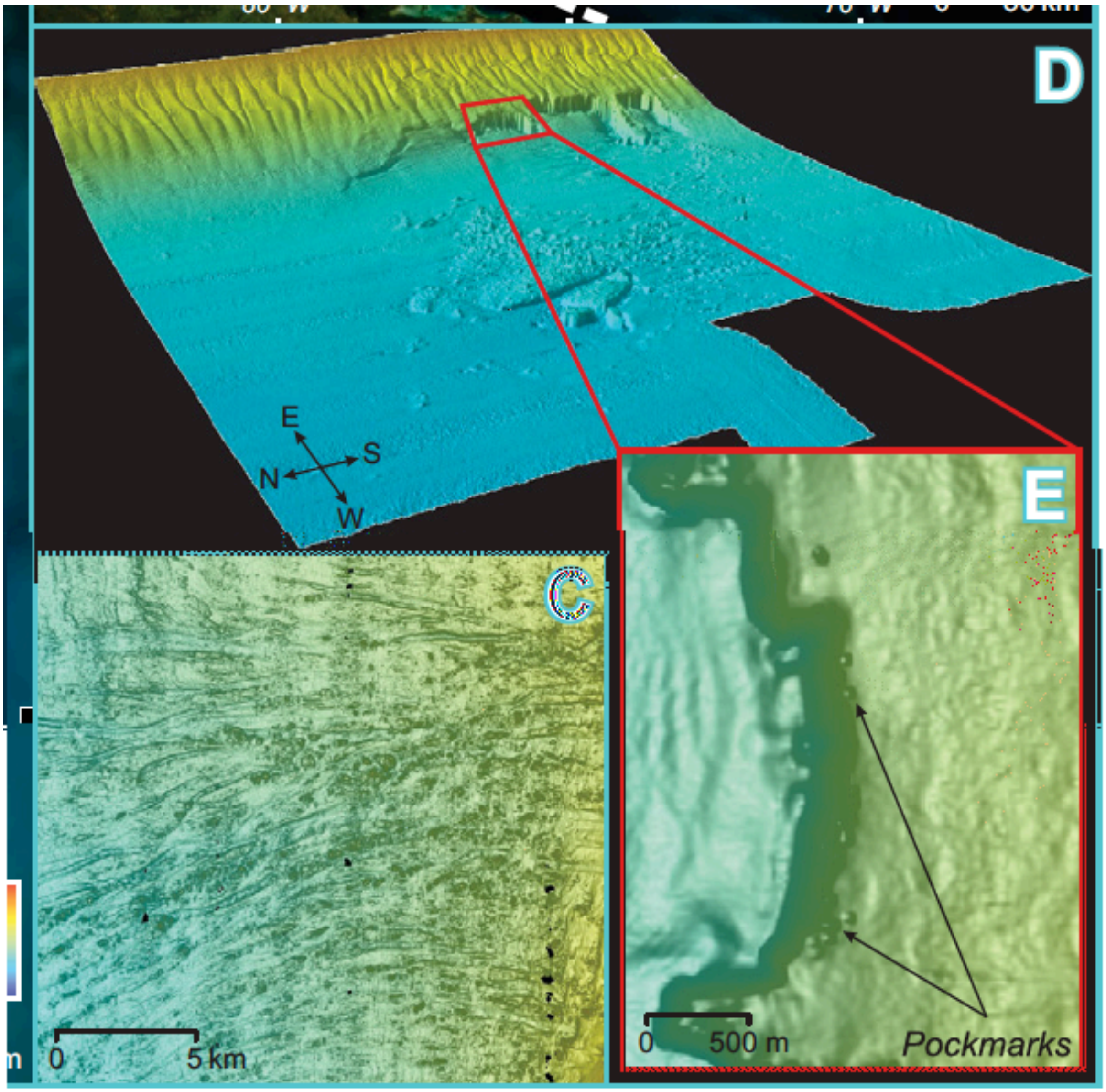

Figure 2: SMF landslide source being developed for inundation modeling for eastern Florida. The SMF is based on failure in carbonate deposits on the western Grand Bahama Banks. C: Detail of erosive furrows, D: Three dimensional vierw of mass transport complex, E: Detail of small pockmarks at top of northern scar. (from Figure 1 in Mulder et al. 2012)

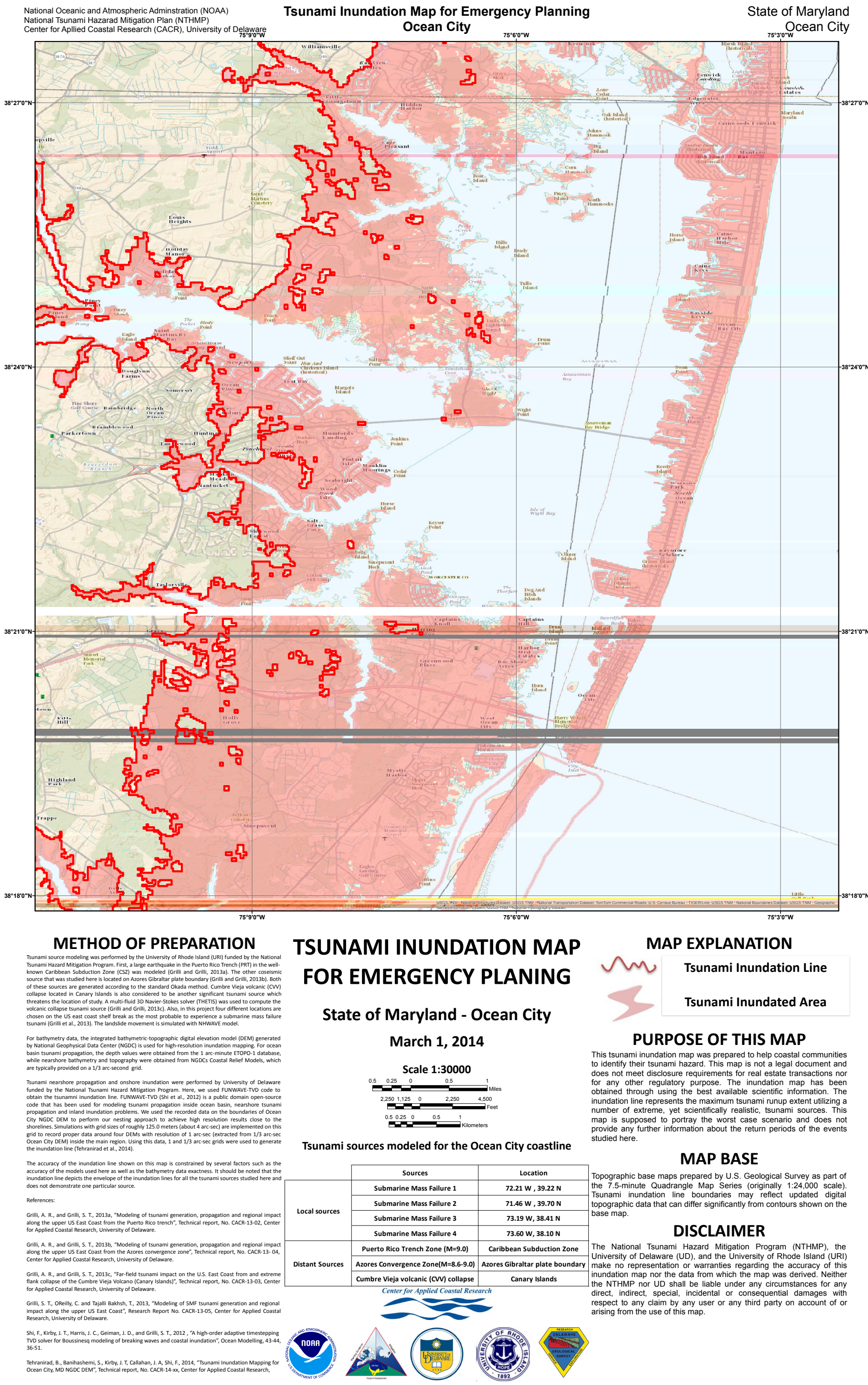

Figure 3. Draft inundation map for Ocean City, MD. Maximum inundation extent here results entirely from the large (450 km^3) CVV event, and indicates a complete overtopping of the heavily developed barrier island and extensive flooding of low lying marshy areas behind it.