Project Progress Report
Period March /2014 to Aug/2014

TAMUG Contract Number: 10-480811
Sponsor Award No.NA13NWS4670018
Contract Sponsor: National Tsunami Hazard Mitigation Program (NTHMP-NOAA)
Title: **A probabilistic methodology for hazard assessment of tsunami generated by submarine landslide and for construction of tsunami inundation maps in the Gulf of Mexico.**

Project Dates:	September 1, 2013 – August 31, 2015
Recipient:	Texas A&M University at Galveston (TAMUG)
Contact:	Dr. Juan J. Horrillo Texas A&M University at Galveston Maritime Systems Engineering (MASE) 200 Seawolf Park or P.O. Box 1675 Galveston, TX 77553-1675 Phone: (409) 740-4465 horrillj@tamug.edu
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PI
Name: Juan J. Horrillo
Contribution to Project: Dr. Horrillo's responsibilities are: the coordination and assembling of multidisciplinary tasks, the creation of a simplified model which transforms the sediment-slide characteristic to an initial wave configuration or source and the optimization of an existing tsunami non-hydrostatic model for fast and efficient calculation of waves propagation and runup; and the development of a 2D simplified slope stability analyses for the generation of extreme values of the initial tsunami wave configuration

CO-PI
Name: John Sweetman
Contribution to Project:
Dr. Sweetman's responsibilities are: to develop the probabilistic tsunami hazard assessment tools in general; to perform the parametric statistical study to determine which specific physical parameters are most important for extreme values of tsunami initiation source; the determination of the distribution of the physical parameters and the analytical combination of the random variables using random variable algebra.

Research Associate (PostDoc student in the original proposal)
Name: Dr. Alyssa Pampell
Contribution to Project:
Dr. Pampell's responsibilities are: to assemble a comprehensive geo-dataset for underwater landslide in the GOM and the assembling of all the basic methodology for the probabilistic approach; to gather the available geotechnical parameters necessary for the characterization of soil sediments by region in the

GOM; to build the geotechnical database needed for slope stability analysis; to set computer inputs, batch jobs for all possible combinations of the distributed physical parameters and doing the post-processing required for the preparation of report, journal papers, meetings and conferences.
Dr. Pampell already established the formal probabilistic methodology and conducted a probabilistic tsunami hazard assessment to identify potential submarine landslides with the higher probability of generating a tsunami in several region of the GOM. The work includes the analysis of the statistical study to determine which specific physical parameters are most important for probabilistic hazard assessment and combine them with the deterministic stability slope analyses for underwater sediments and with the hydrodynamic model for wave propagation and runup.

OBJECTIVES

The project objective is to assess the tsunami hazards generated by submarine landslides that may impact coastal communities and infrastructure in the Gulf of Mexico (GOM) by implementing a probabilistic approach. The approach combines probabilistic submarine landslide analyses (multiple scenarios) with deterministic estimate of: a) sediment slope stability; b) wave propagation and runup. Nowadays, despite the extensive research and significant advances in this field, our previous and current project results, Construction of Tsunami Inundation Maps for Port Aransas, Texas (NA09NWS4670006), and Construction of Five Additional Tsunami Inundation Maps for the GOM (NA12NWS4670014) lack of a fully nondeterministic methodology. Therefore, our current/future mapping products is getting updated in the probabilistic field to fill the gap on tsunami hazard development as compared to others US states efforts.

The proposed nondeterministic assessment is based on a large number of Monte Carlo simulations in which distributions of certain parameters (seismicity acceleration, sediment mechanic properties, landslide type, landslide volume or area, failure location and water depth, etc.) are used to carry out simplified slope stability analyses for the generation of extreme values of the initial tsunami wave configuration. Site-specific analysis with a lesser number of tsunami calculations will be performed using a fast-optimized 2D shallow water numerical model to establish probabilistic extreme values for runup height in the Northwest of GOM. The methodology is supported using a parametric statistical study that is applied initially to determine which specific physical parameters are important in the generation of extreme values of the initial tsunami wave configuration and thus diminishing the number of possible combinations. A site-specific, map-based hazard assessments with the greatest flood for specified annual exceedance values and locations associated to potential underwater landslide events with probability of recurrences will be obtained along the Northwestern part of the GOM. The deliverable products will be useful to urban planners and emergency managers. Results of this project will play a role in advancing our understanding of landslide tsunamis in the GOM, and thus contribute to build a safer coastal community.

BACKGROUND

The Gulf of Mexico states have been included to the U.S. Tsunami Warning System since January 2005. The main purpose of the warning system is to enable local emergency management to act in response to warnings. To plan for the warning response, emergency managers must understand what specific areas within their jurisdictions are threatened by tsunamis. Potential tsunami sources for the GOM are local submarine landslides and earthquakes (induced co-seismic tsunami source) along the Caribbean plate boundary faults. However, preliminary modeling of potential tsunami sources outside the GOM by Knight, (2006) indicated a very low threat and may not pose a tsunami hazard to the GOM coastal communities or infrastructure. Nevertheless, recent assessments of tsunami hazards along the Gulf of Mexico (GOM) carried out by the U.S. Geological Survey (USGS) and the National Tsunami Hazard Mitigation Program (NTHMP) have identified underwater landslides as the primary potential source of tsunami generation, ten Brink et al., (2009). Although a massive underwater landslide in the GOM is considered a potential hazard, the probability of such an event is quite low, Dunbar, (2008). The probability of occurrence is related to large ancient landslides which were probably active prior to 7,000 years ago when large quantities of sediments were emptied into the GOM, tenBrink et al., (2009). However, nowadays sediments continue to empty into the GOM mainly from the Mississippi river. The sediment supply contributes to slope steepening and also to the increasing of the excess pore water pressure in the underlying soils, which may lead to further landslide activities. Recent evidence from seismic records of small-scale energetic seismic-waves in the GOM have confirmed that there is a probability of recurrence, Dellinger and Blum, (2009).

Hazard areas can be determined by historical events, by modeling potential tsunami events (worst case scenario), or by using a probabilistic approach. As the GOM has no significant recent historic tsunamis records, addition of a probabilistic component to the existing numerical modeling capability will enable a realistic assessment of coastal hazard zones. The proposed method is to determine the likelihood of tsunami events by combining critical physical parameters to develop probability distributions of the magnitude of the initial tsunami and predicting the probabilistic tsunami hazard at specific locations along the shoreline. Several efforts in recent years on the topic are palpable and are contributing to this effort; for instance: Maretzki, Grilli and Baxter, (2007), presented results of a probabilistic analysis that estimates the hazard expressed in terms of runup at a given probability of occurrence of the slide mass failure tsunamis triggered by earthquakes, on the upper northeast coast of the United States. They employed a large number of Monte Carlo Simulation (MCS), in which distributions of relevant parameters (seismicity, sediment properties, slide type, location of slide, volume of slide, water depth, etc.) were used to perform large numbers of stochastic stability analyses of underwater slopes, based on standard geotechnical methods. Later, Gonzalez, et al., (2009) generated the first probabilistic tsunami flooding maps by using integrated tsunami propagation modeling with methods of probabilistic seismic hazard assessments with application to Seaside, Oregon, which yielded estimates of the spatial distribution of 100 and 500 years maximum tsunami amplitudes. The method quantified estimates of the likelihood and severity of the tsunami hazard, which could then be combined with vulnerability and exposure to yield estimates of tsunami risk. Our methodology shares several aspects of the cited works. Yet, it is envisaged to assess the tsunami hazards by means of a more complete and efficient methodology where the large number of MCS for the distribution of relevant parameters to obtain the tsunami initial source from the sediment-slope stability analysis is combined with a lesser number of tsunami propagation model predictions inferred from a parametric statistical in which most important physical parameters are identified for extreme values of tsunami initiation. The probabilistic methodology alternates with deterministic estimate of: a) sediment-slope stability using Limit Equilibrium Methods; b) wave propagation and runup by means of optimized 2D and efficient hydrodynamic numerical model. A site-specific, map-based hazard assessments with the greatest flood for 2500, 5000 and 10000 year annual exceedance values and locations associated to potential underwater landslide events with probability of recurrences will be obtained along the Northwestern part of the GOM.

PROJECT FINDINGS SUMMARY

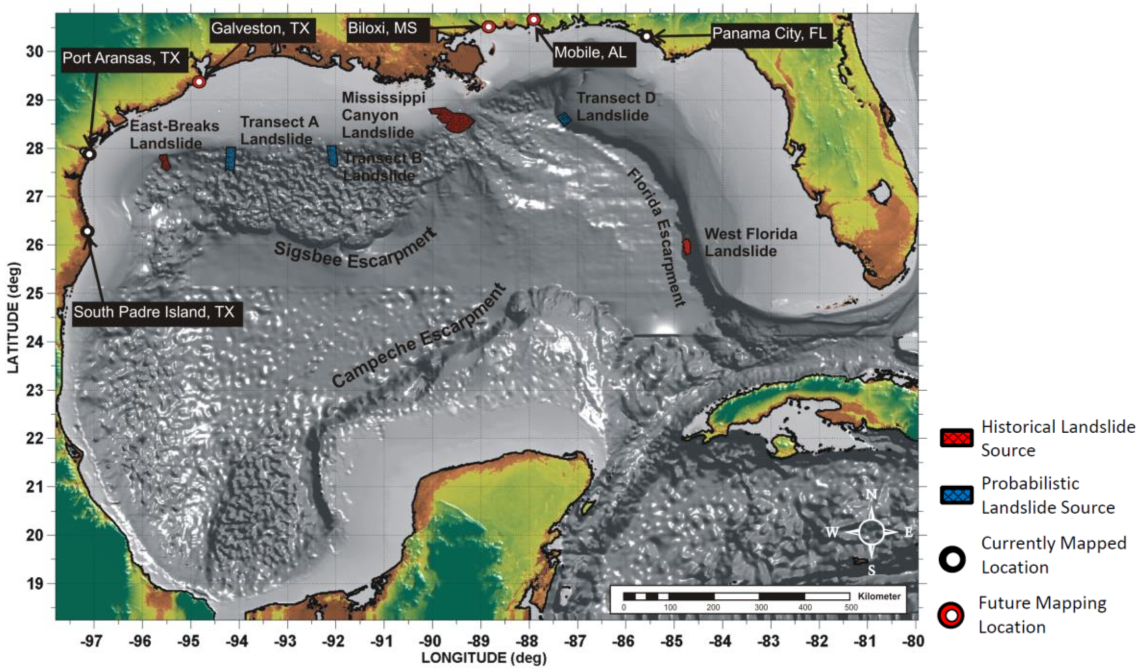

Figure 1. Submarine landslide locations for ancient landslide, in red (tenBrink, et al., 2009), and generated by means of a probabilistic approach, in blue)

In addition of the ancient landslide scenarios identified by tenBrink, (2009), three new landslide scenarios (Transect A, B and D) has been determined using the probabilistic approach described above, see Figure 1. These landslides sources obtained by using the probabilistic approach have in average a rate of return of the order of 10,000 years.

To develop inundation maps of landslide-generated tsunamis in the GOM, a common approach is to combine a 3D model for the landslide-induced waves with a 2D depth integrated non-hydrostatic model for the wave propagation and runup (coupled model). The 3D model provides the wave kinematic and the free surface configuration for the initial tsunami wave source, which are then input as the initial condition (hot start) to the more numerically efficient 2D non-hydrostatic model (which has nesting capability) for the calculation of the wave propagation and detailed runup. One critical step in the coupling process of the two models is to determine the right moment of transferring the 3D model's wave kinematic and free surface field to the 2D model. The right time of transferring the wave kinematic and free surface amplitude is constrained by two main factors: the 3D domain size, and the total energy (in time) of the water waves induced by the submarine landslide. The 3D domain must be large enough to fully develop the generated waves without leaving the domain boundaries, together with the wave energy to verify if the generated waves are fully or mostly developed. If both considerations have been fulfilled, then the 3D field information or variables are converted to two dimension by a simple column wise depth averaging and inputted as initial condition to the 2D numerical model. This step is achieved by performing a certain number of simulations that ultimately yield the most appropriate time, hence the choice of the right moment of transferring is done through trial and error.

Figure 2 shows maximum wave amplitude using the coupled 3D-2D model for some of the indicated tsunami sources depicted in Figure 1.

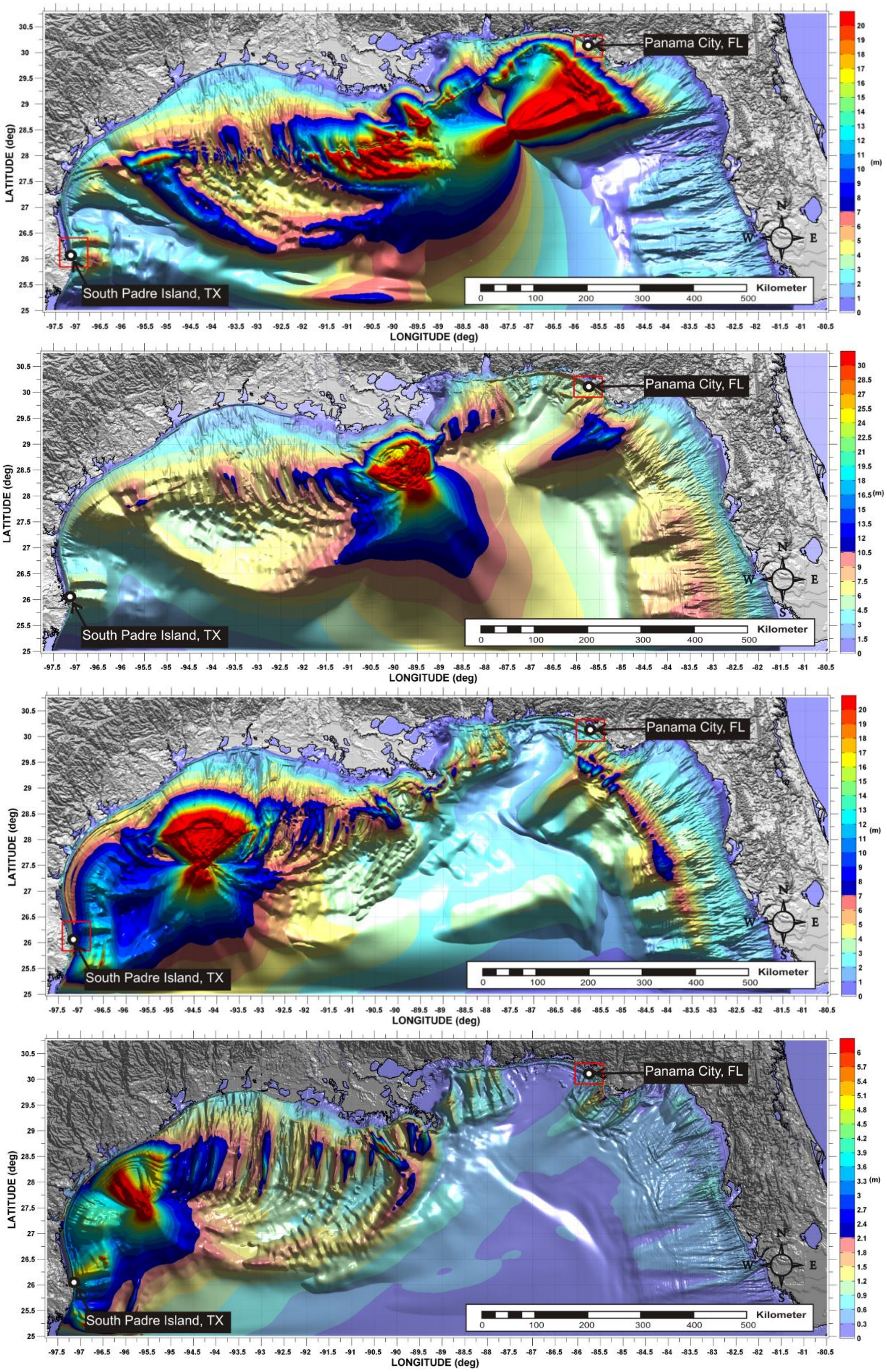

Figure 2. Maximum wave amplitude: Top panel, Transect D (probabilistic landslide); second panel, Mississippi canyon landslide; third panel, Transect A (probabilistic landslide); last panel, East-Breaks landslide.

In general for these sources depicted in Figure 2, tsunami wave amplitude ranges between 2.0 to 8.0 m offshore of South Padre Island, TX and between 0.3-6.0 m in Panama City, FL. Tsunami energy amplifications on shallow coastal regions are persistently observed in: South Padre Island, TX, the strip from Pensacola to Cape San Blas, FL, Grand Isle, LA and Port Aransas, TX. Wave-guides (tsunami energy focusing) are observed along the Sigsbee Escarpment, Mississippi Canyon and other small canyon morphologies along the US-GOM. The Sigsbee escarpment seems to play an important role for tsunami wave enhancement in the coastal region around South Padre Island, TX, the strip from Pensacola to Cape San Blas, FL, Grand Isle LA, and Port Aransas, TX. On the western side of the GOM, as the tsunami (e.g., East-Breaks scenario) propagates parallel or along the Western shelf break slope, wave energy is refracted against the coasts and redirected into South Padre Island, and the northern region of the state of Tamaulipas, Mexico.

DELIVERABLES SUMMARY

1- Report documenting the submarine landslide tsunami hazard analysis tools.

2-Application of the hazard analysis tools to the GOM's northwestern region (South Padre Island, TX.).

3- GOM's sediment/soil parameters (geo-dataset) assimilated from publically available information and determined from laboratory testing in form of a database for slope stability and debris flow analyses and ultimately, tsunami modeling.

4- Probabilistic tsunami runup model output data and products

5- Simplified 2D sediment/soil slope stability analysis and debris flow model

6- Fast-optimized 2D shallow water numerical code for wave propagation and runup.

7- Site-specific, map-based hazard assessments with the greatest flood hazard

8- Site-specific 2500, 5000 and 10000 years annual exceedance values (runup height)

9- Locations and characterization of most likely tsunami scenarios (tsunami sources) associated to potential landslide events with probability of recurrences

10- At least two publications in recognized journal papers in joint probabilities

PROJECT SCHEDULE to August 31/2014

Project Dates: **September/01//2013- August/31/2015**
PI: **Dr. Juan J. Horrillo**
CO-PI: **Dr. John Sweetman**
Research Associate (RA): **Dr. Alyssa Pampell**
Emergency Management Representative (EMR): Mrs. **Amy Godsey**

Strategy	Schedule	Tasks	Resources Execution %
Compilation of all publicly-available information, example: bathymetry/topography, soil & sediment logs information, documents & research papers, etc.	Sep. 1/13 to Apr. 30/14	Research literature	PI, CO-PI and RA 97%
	Sep. 1/13 to Apr. 30/14	Obtain GOM bathymetric and topographic data at specific location on the GOM Northwest	70%
	Sep. 1/13 to Apr. 30/14	Obtain soil & sediment logs sample information	80%
Probabilistic model development	Sep. 1/13 to Apr. 30/14	Simplified 2D sediment/soil slope stability analysis model	PI, CO-PI and RA 96%
		Determine simple tsunami wave configuration based on subsea landslide volume and morphology.	96%
		Do parametric statistic to identify most important physical parameters for extreme values of tsunami initiation	60%
Submit Monte Carlos Simulation (MCS) model jobs to Texas A&M University at Galveston (TAMUG)	May. 1 To June. 30/14	landslide configuration with probability of recurrences at different locations or transects;	50%

Cray Super computer to obtain:		and generate computational grid based on landslide configuration (scarp, plane of failure, etc.) for the simplified 3D Navier-Stokes (NS) numerical model	30%
Submit simplified 3D NS model jobs to TAMUG's Cray super computer to obtain:	May. 1/14 To Aug. 30/15	Initial wave configuration (on six transects) for the 2500, 5000, 10000 years period of return based on the landslide sources	PI and RA 40%
Submit simplified 2D depth integrated model jobs to TAMUG's Cray super computer to obtain:	May. 1/14 To Aug. 31/15	Probabilistic Inundation limits (runups) on a specific site in the GOM Northwest coastline for 2500, 5000, 10000 years period of return	PI and RA 20%
Plotting results in the Northwest of GOM	Jun.1/14 To Aug. 31/15	Post-processing-results to construct probabilistic hazard maps for the GOM Northwest site	PI and RA 10%
Report to NTHMP documenting the submarine landslide tsunami hazard analysis	Jul.1/15 To Aug. 31/15	Result Assemble and document	PI , CO-PI, RA and EMR 0%

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