Potential for tsunami generation by submarine slope failures along the western Great Bahama Bank

CSL Center for Carbonate Research

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Introduction

Multibeam and seismic data reveal repeated slope failures at various scales along the western slope of Great Bahama Bank. In addition, creeping and incipient slump scars indicate slope instabilities that will lead to large-scale slope failures in the near future. To assess the potential of tsunami generation by these mass movements several tsunami scenarios have been constructed and simulated numerically for the Straits of Florida; i.e. Single Slope Failure (SSF), Combined Slope Failure (CSF) and Major Slope Failure (MSF). They are based on the estimated volume and nature of a potential landslide, and failure scenarios of the known scars and mass transport complexes (MTC).

Key Findings

- High-quality multibeam datasets along western Great Bahama Bank reveal large-scale slope failures on the middle and lower slope. These datasets allow to estimate volume and nature of the mass movement and therefore to assess their tsunamigenic potential.
- Numerical models show that in a worst-case scenario these mass movements can generate an incipient wave up to 2 and 26 m height within 1 and 4 min, respectively.
- The tsunami wave height is strongly dependent on the outrun velocity of the landslide.
- The tsunami propagates through the Straits of Florida and impacts on the eastern coast within 8-15 min after the landslide event.

Study Area

The western slope of Great Bahama Bank is located in 150 km distance from the southern Florida shoreline. During different research cruises in 2010 and 2012 an abundance of morphological features indicative for slope instabilities were identified by swath bathymetric data.

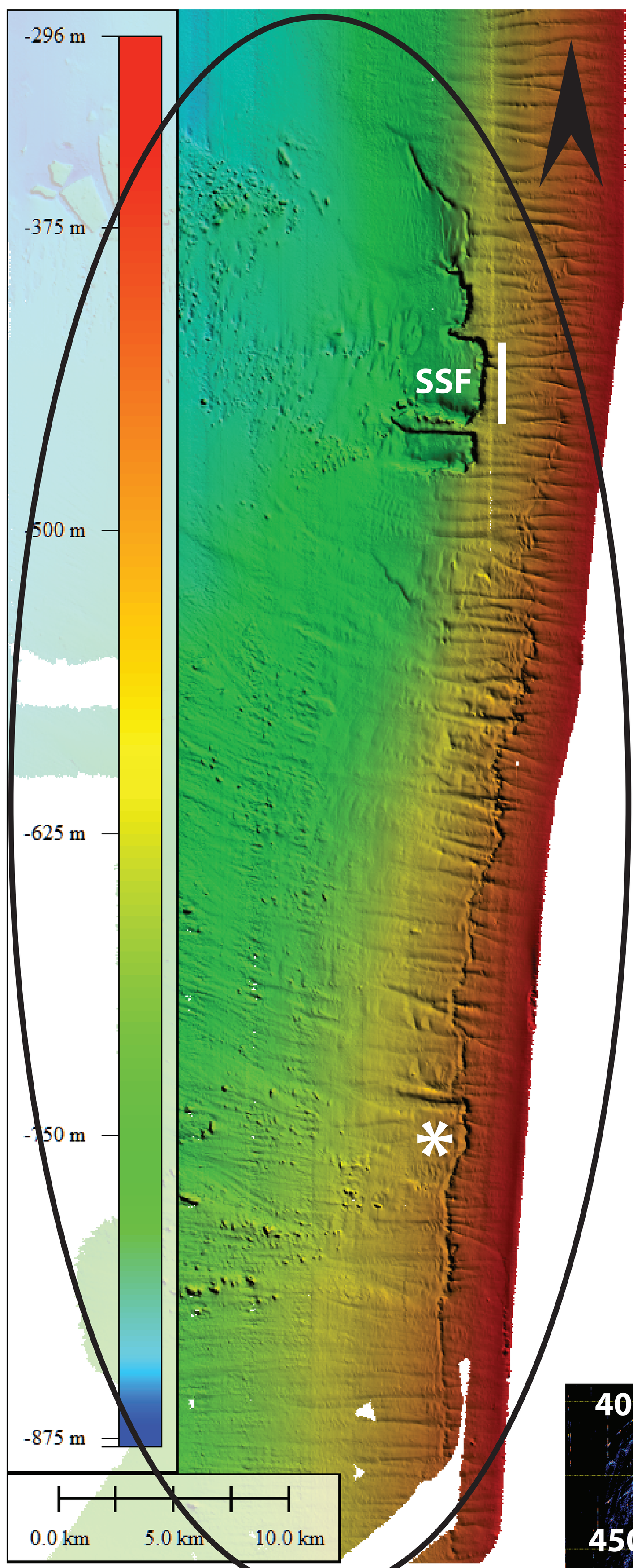


Fig. 1: Large failure scars of several kilometers extent between 25° N and 24° N indicate past slope failures and were proposed to be tsunamigenic by Mulder et al. (2012). These features are located in water depths of 550-700 m. Failure scenario SSF outlined in white. White star in Fig. 3 & 4.

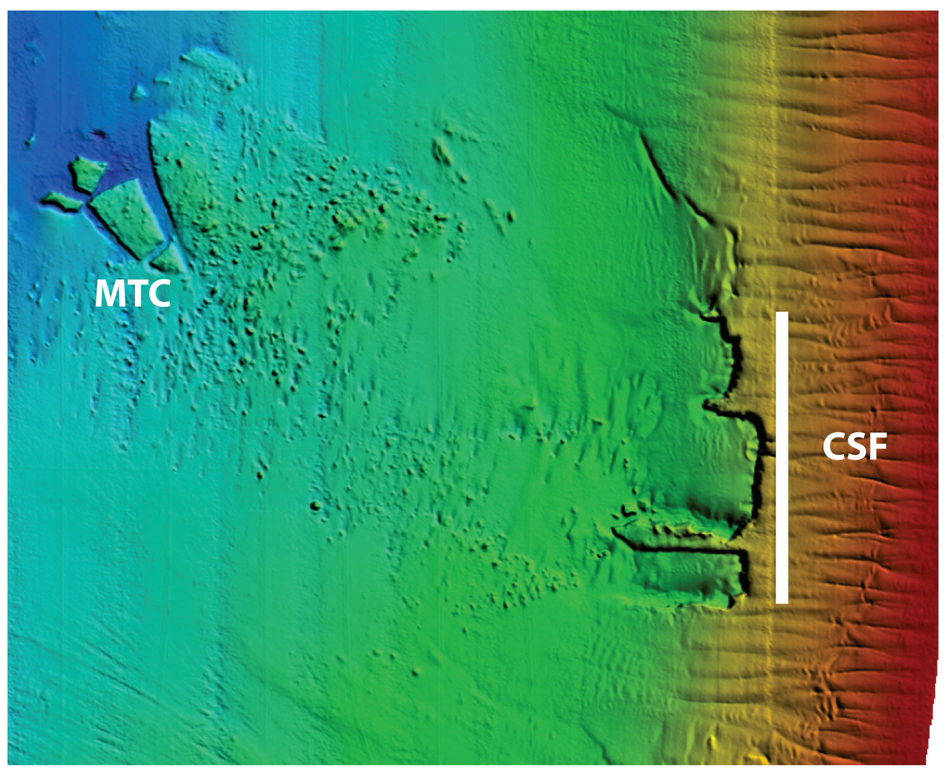


Fig. 2: A major MTC in 15 km distance of the failure scars indicates that the landslide at least partially did not disintegrate but travelled as blocks into the basin. Failure scenario CSF.

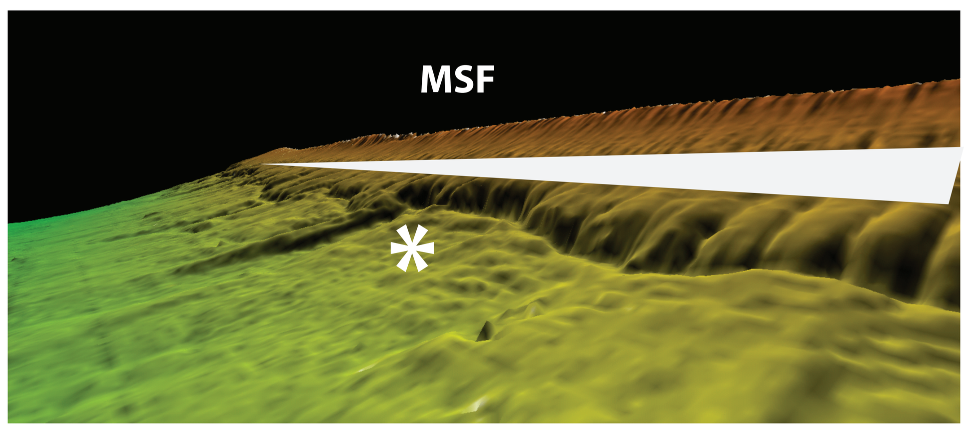


Fig. 3: A large incipient scar of 80 km extent is documented at 450 m water depth. Height is 150 m, whereas just the top 50 m are visible. Failure scenario MSF.

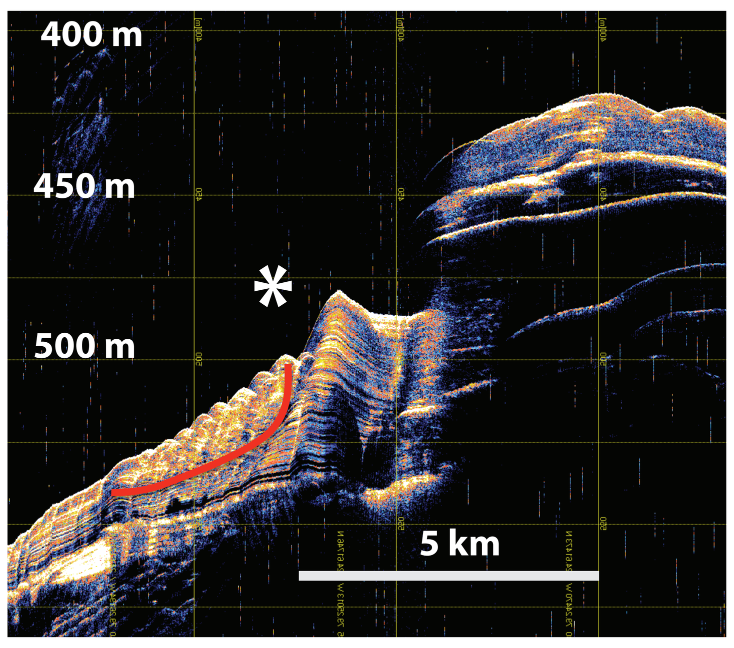
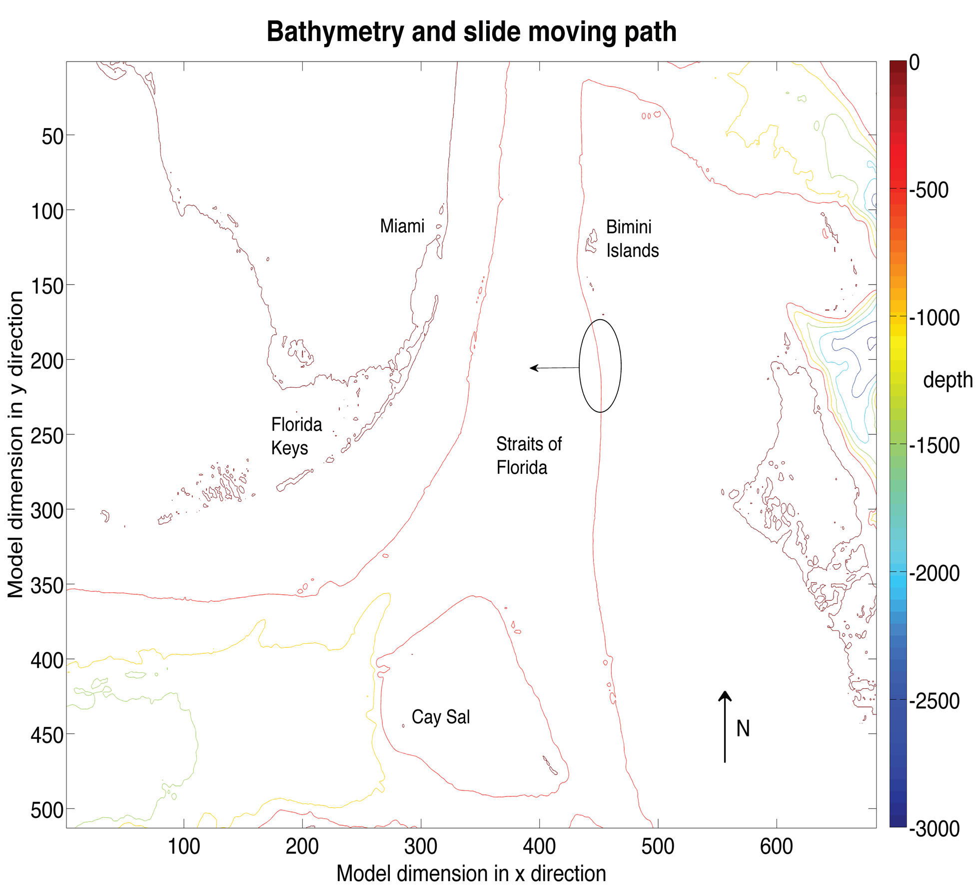


Fig. 4: Parasound profile. The genesis of a detachment surface is favored by a cemented layer in the slope. The slump mass can move on this weak layer and slide basinwards. An initiationof a landslide on such a surface is likely.

Failure Scenarios

Three tsunami scenarios have been chosen and simulated numerically for the Straits of Florida. The first scenario (Fig. 1), Single Slope Failure (SSF), takes a failure mass volume of 1.18 km^3, which corresponds to the largest of the three failure scars identified. The effective local slope angle was estimated as 3.2° based on bathymetry contours. Further, we assumed that the landslide moved orthogonal to the slope. For the second scenario, Combined Slope Failure (CSF), we added the extent of the three failure scars together, 3.42 km^3, and assumed that the landslides were sliding in a single event (Fig. 2).



For the third Major Slope Failure scenario (MSF), a scar length of 80 km, observed south of the mass transport complexes, and failure volume of 24 km^3 is used (Fig. 3). The codes for the numerical model used in this work were developed at the Center for Applied Coastal Research (University of Delaware) and are approved standards of the National Tsunami Hazard Mitigation Program.

Fig. 5: Area where the three scenarios were implemented and the direction of slide movement with respect to north. The model dimension is 513 x 684 x 3 (points in x, y and z). Resolution is dx = dy = 700 m, based on the bathymetry grid resolution.

Modeling of Submarine Slope Failure

We simulate tsunami generation based on the proposed SMF scenarios for the first 240 seconds, in the non-hydrostatic wave model NHWAVE (Ma et al., 2012). With increasing failure mass, incipient wave heights increase as well (eta_max). The farther the landslide propagates the longer it takes it to achieve the terminal velocity v_t and therefore peak levels of the incipient wave trains change. Terminal velocities of 20, 50 and 100 m/s were chosen. For higher outrun velocities, incipient wave heights increase substantially.

Tab. 1: Parameters and results for different simulation scenarios. Width = w, length = L, height = h, slope angle = angle. eta_min and eta_max denotes minimum and maximum wave height, respectively. T = 60, 120, 180, 240 seconds after initiation of sliding.

Scenario		w [km]	L [k]	h [m]	angle [deg]	v_t [m/s]	eta_min 60s [m]	eta_min 120s [m]	eta_min 180s [m]	eta_min 240s [m]	eta_max 60s [m]	eta_max 120s [m]	eta_max 180s [m]	eta_max 240s [m]
SSF	A	3.7	3.2	100	3.2	20	-0.50	-0.81	-0.70	-0.48	0.57	0.50	0.50	0.52
	B	3.7	3.2	100	3.2	50	-1.06	-2.34	-2.22	-2.59	1.00	1.01	1.04	0.72
	C	3.7	3.2	100	3.2	100	-1.06	-3.10	-6.54	-8.95	1.00	1.86	4.06	5.74
CSF	D	9	3.8	100	3.2	20	-1.08	-0.78	-0.78	-0.92	1.11	0.58	0.50	0.50
	E	9	3.8	100	3.2	50	-2.03	-4.28	-3.77	-3.50	2.27	2.52	1.20	1.24
	F	9	3.8	100	3.2	100	-2.03	-5.22	-13.10	-24.15	2.27	4.24	8.90	11.59
MSF	G	80	2	150	3	20	-2.77	-3.05	-2.04	-2.72	2.15	2.95	1.98	1.57
	H	80	2	150	3	50	-3.81	-8.04	-6.90	-8.40	2.48	5.48	5.38	4.88
	J	80	2	150	3	100	-3.81	-8.61	-22.56	-36.36	2.48	7.29	16.78	26.27

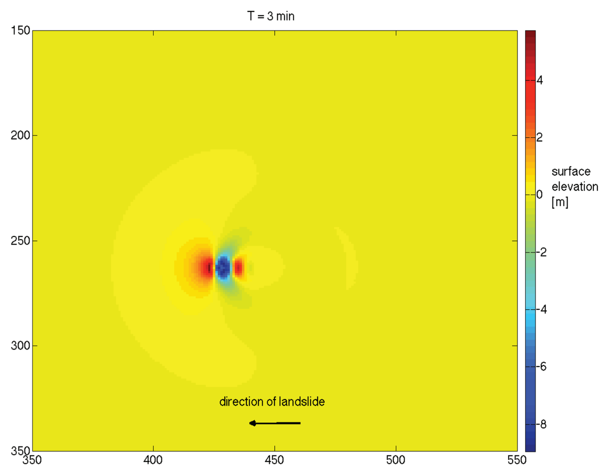


Fig. 6: Initial wave generated 3 min after beginning of the landslide. This result is based on SSF_C. The wave form strongly depends on the landslide orientation and geometry.

Then surface elevation and horizontal velocities are interpolated as initial conditions into the long wave Boussinesq model FUNWAVE-TVD (Shi et al., 2012). For the MSF_H scenario, we simulated propagation through the Straits of Florida starting with an initial wave of 4.88 m height. Within 5 min after landslide initiation the waves come up to 2.5 m. They then continue propagation towards the eastern Florida coastline and the Bahamas (Fig. 8&9).

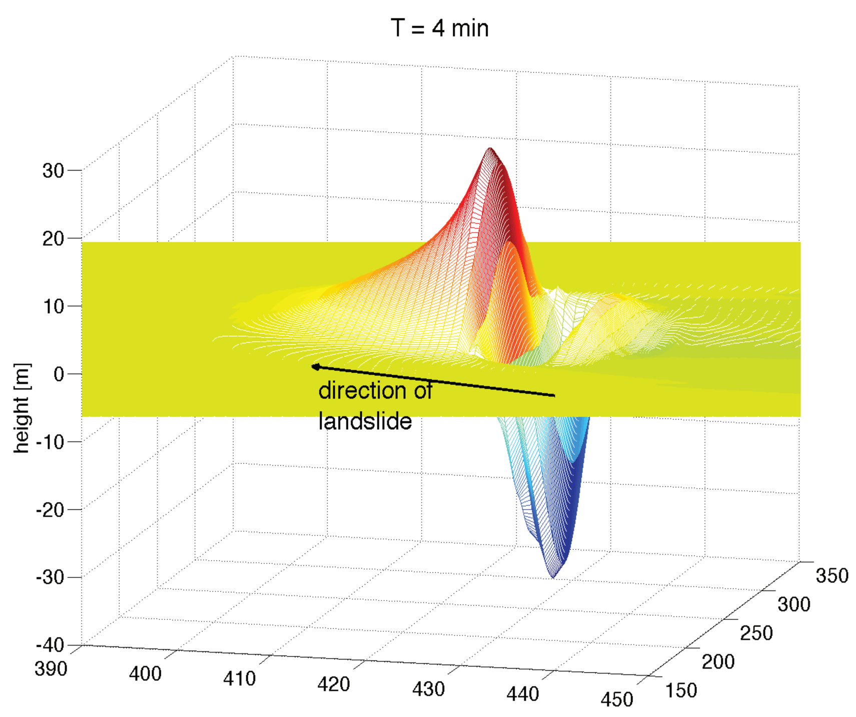


Fig. 7: Enlarged view on the initial wave after 4 min for the catastrophic scenario MSF_J.

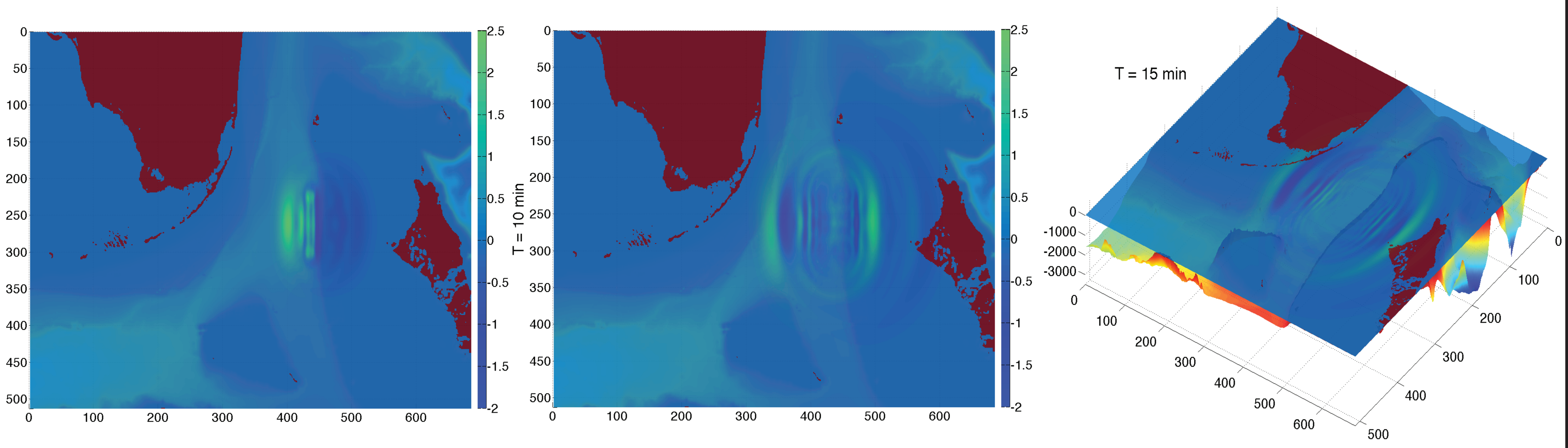


Fig. 8: Surface elevation with underlying gebco grid. The first wave front with following wave train behind propagates with approximately 160 m/s and takes around 10 min from landslide initiation to arrive at the shelf break before southern Florida and the Keys. Maximum amplitude is 2.5 meters. It takes 2 – 3 min more to impact on the mainland and the Bahamas.

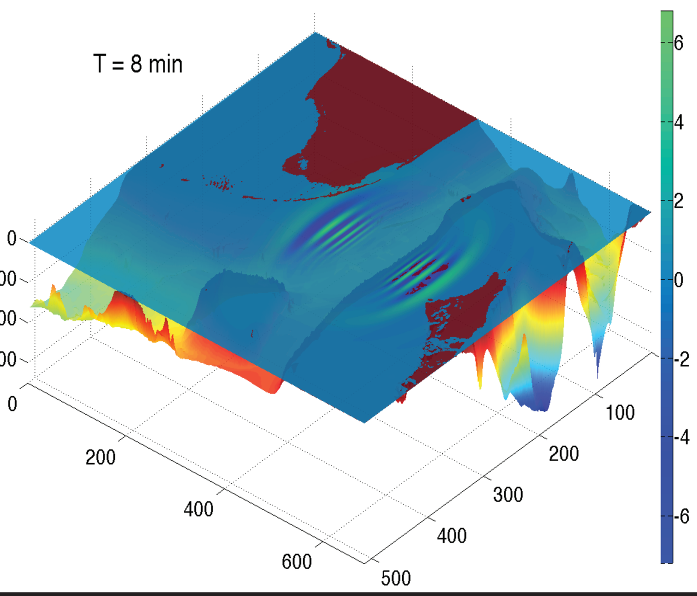
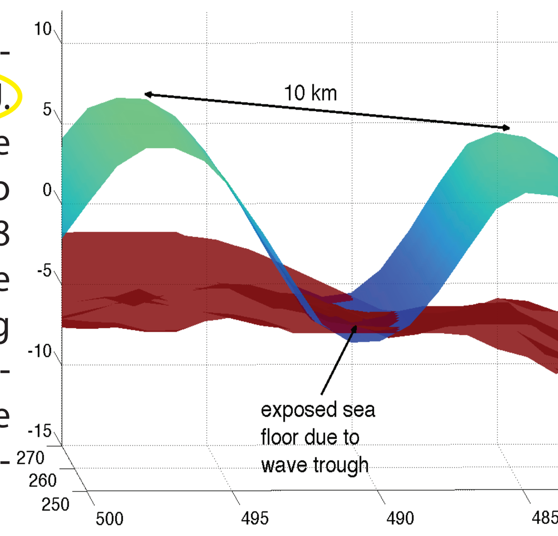


Fig. 10: Surface elevation and underlying gebco grid for MSF_J. The propagation of the wave train is substantially faster, due to longer wave lengths. Within 8 min the first waves impact on the eastern Florida coastline. During propagation the waves get attenuated but due to incipient wave height the final run-up is estimated still up to 6 meters.



Outlook

Landslide generated tsunami wave, propagation and run-up need different model setups. Especially the models for the impact with the coastline need to be improved. Outrun velocity is the main governing factor. Due to low slope gradient we cannot expect high terminal velocities. The simulations here were conducted with rigid landslide geometry. In reality we expect deformable landslides and therefore other hydrodynamic response. Next step will be the wave initialization using a new code, which allows the landslide to deform internally and disintegrate. Seen, that the terminal velocity is such a governing factor, we will have to find evidence to make realistic estimates of landslide outrun velocities.

In southern Great Bahama Bank not just slope failures on the lower slope were observed, but huge outbreak areas of the platform margin itself. Seismic shaking may have triggered them considering proximity to the Cuban margin. High terminal velocities can be expected for such failures and therefore large incipient wave heights and comparable effects of magnitude like MSF_H or higher. Such a wave may not be attenuated sufficiently during propagation through the Straits and poses a large risk to the eastern Florida coastline.

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