Advances in sediment-transport modeling offshore of a fluvial source

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1. Motivation and Approach

Radioisotopic tracers have long been used to infer the depositional history of marine sediment, based on conceptual models that rely on assumed rates of mixing and burial (e.g. Nittrouer *et al.*, 1984). Additionally, radioisotope tracers can be used to infer the relative influence of terrestrial and marine processes on sediment deposits (e.g. Corbett *et al.*, 2004). These geochronological data, however, have not been suitable for direct comparison to numerical models that deal solely with sediment grain size. This disconnect has perpetuated a difficulty in evaluating the relative importance of bioturbation, resuspension, erosion, and deposition in marine sedimentation.

A one-dimensional (vertical) ROMS CSTMS model was modified to include ^{7}Be, a proxy for terrestrial sources, and ^{234}Th, a proxy for suspension in marine environments, as reactive tracers associated with sediment particles. The model was tested with idealized forcings to evaluate the effects of bioturbation, wave-resuspension, and flood layer thickness. Additionally, sediment was added to a 3D hydrodynamic model to investigate along- and across-shelf sediment transport.

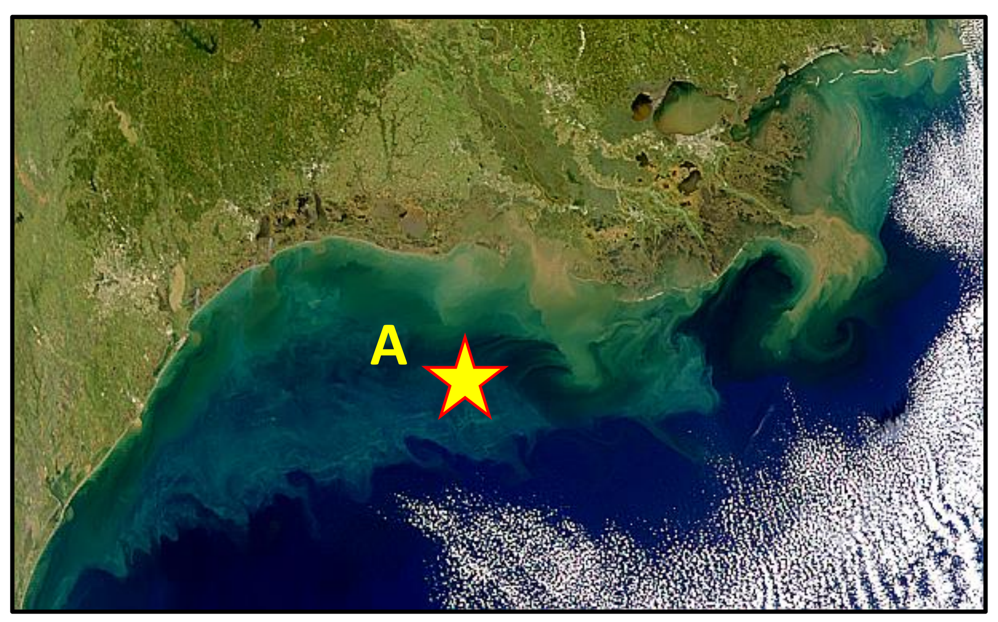


Fig 1. Gulf of Mexico. Experiments of the 1D radioisotope model were based on parameters observed at the marked location.

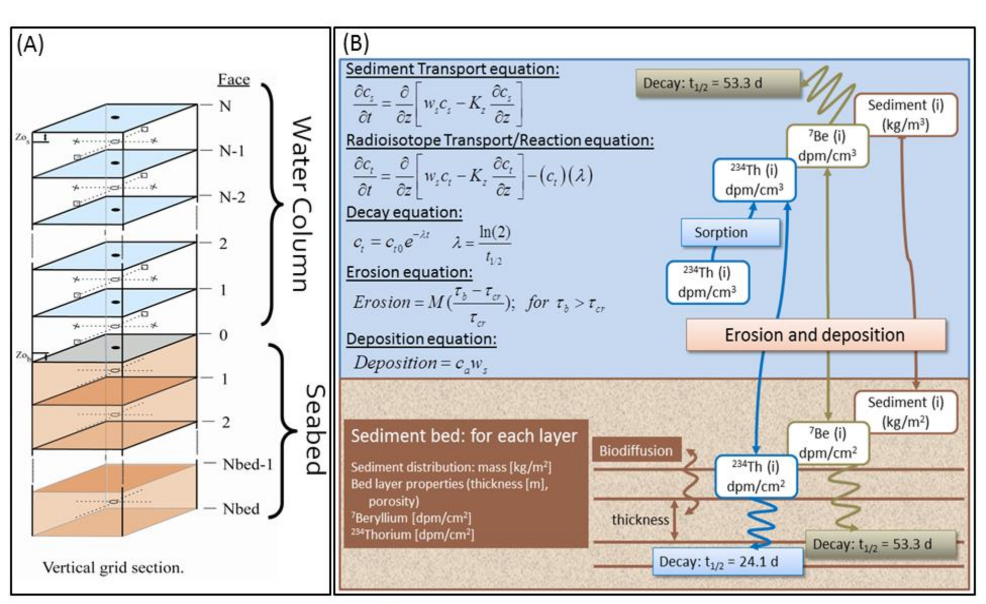


Fig 2. (A) One-dimensional sediment bed model illustration (Warner *et al.*, 2008). Water column layers (blue and white) overlie seabed layers (brown) of variable thickness. (B) Schematic of the combined CSTMS sediment transport and geochronology model.

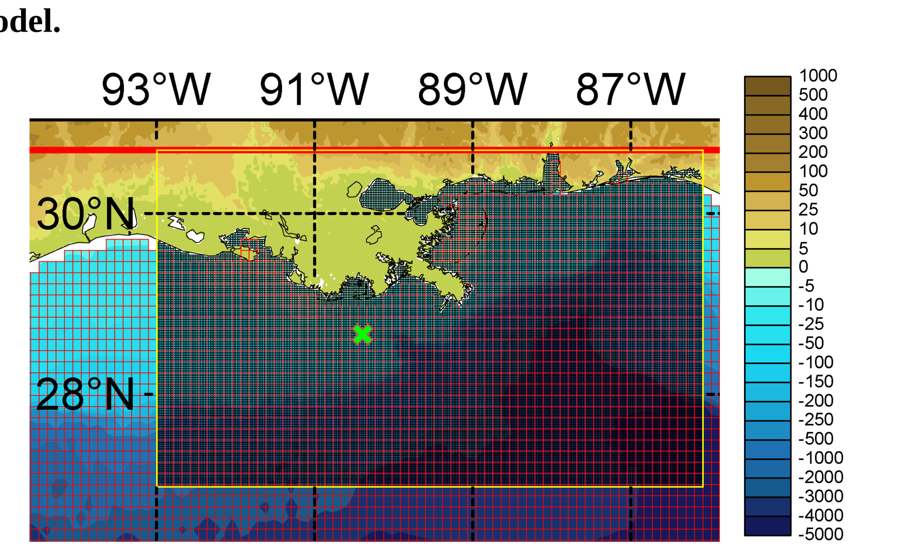


Fig 3. The 3D model grid for Mississippi River delta and continental shelf. The green x denotes the location for the timeseries in Figure 13.

2A. Results of 1D coupled geochronology-sediment transport model: idealized experiments

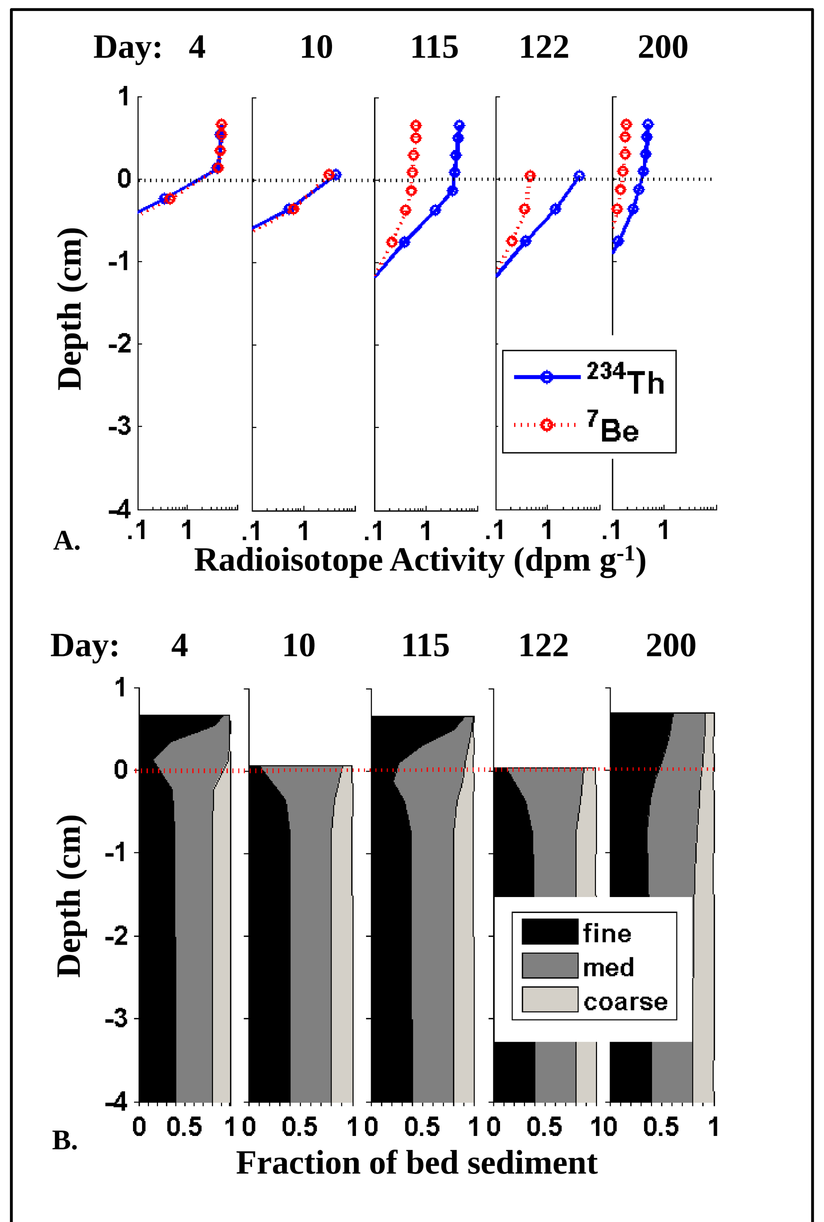


Fig 4. Base Case with vertically decreasing bioturbation rate of ~0.1 cm^2 yr^{-1}, flood layer thickness of 0.75 cm. Panels show (A) radioisotope activity profiles and (B) grain-size seabed fraction. Dashed lines at 0 cm indicates initial (time zero) seabed surface elevation. Grain-size profiles changed markedly with each resuspension and deposition event.

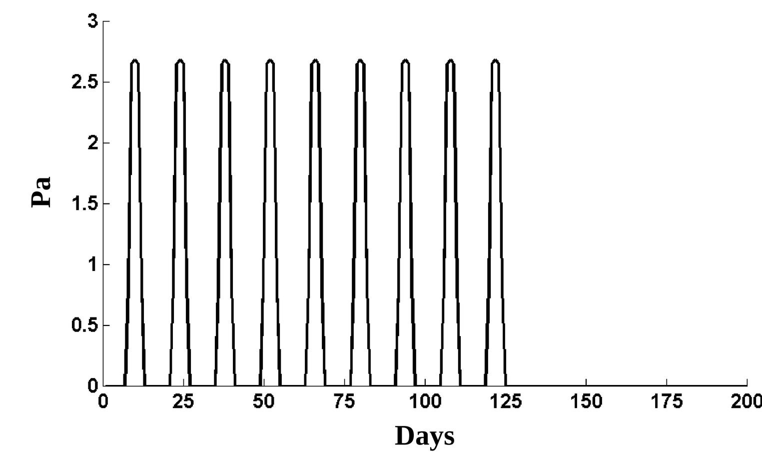


Fig 5. Bed stress for the Base Case, with nine resuspension events.

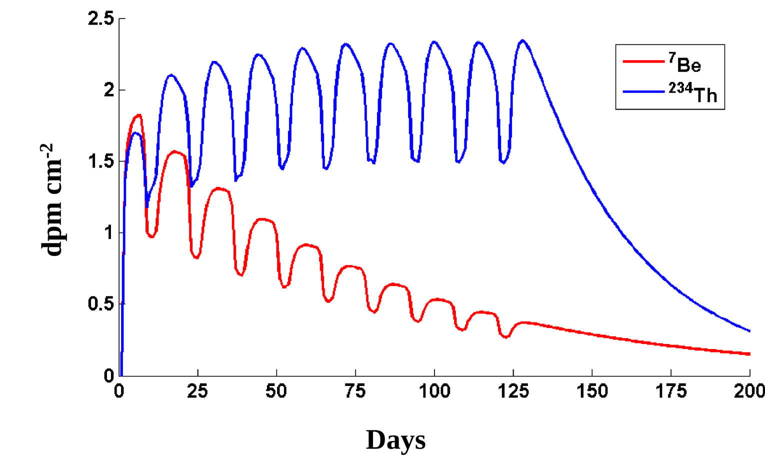


Fig 6. Radioisotope bed inventories for the Base Case.

Model Case	Max ^{7}Be depth (cm)	^{7}Be detection (months)	Max ^{234}Th depth (cm)	234Th detection (months)
Base	1.95	4.5	1.94	5.2
No Bioturbation	1.09	5.4	1.08	5.7
High Bioturbation	5.25	2.9	5.56	4.0
No Resuspension	1.87	4.6	1.21	5.1
High Resuspension	1.98	4.5	1.99	5.3
Low Flood Thickness	1.58	3.7	1.90	5.1
High Flood Thickness	2.61	5.3	2.23	5.4

Table 2. Penetration depth and period of detectability of ^{7}Be and ^{234}Th. Limits determined by the detection limits of gamma detectors (~0.1 dpm g^{-1}). Bioturbation mixed sediments downward into the sediment bed, reducing radioisotope activities, which eventually decayed below detection limits. Flood delivery also strongly influenced detection limits and penetration depths.

2B. Comparison of 1D model with accumulation predicted by radioisotope profiles

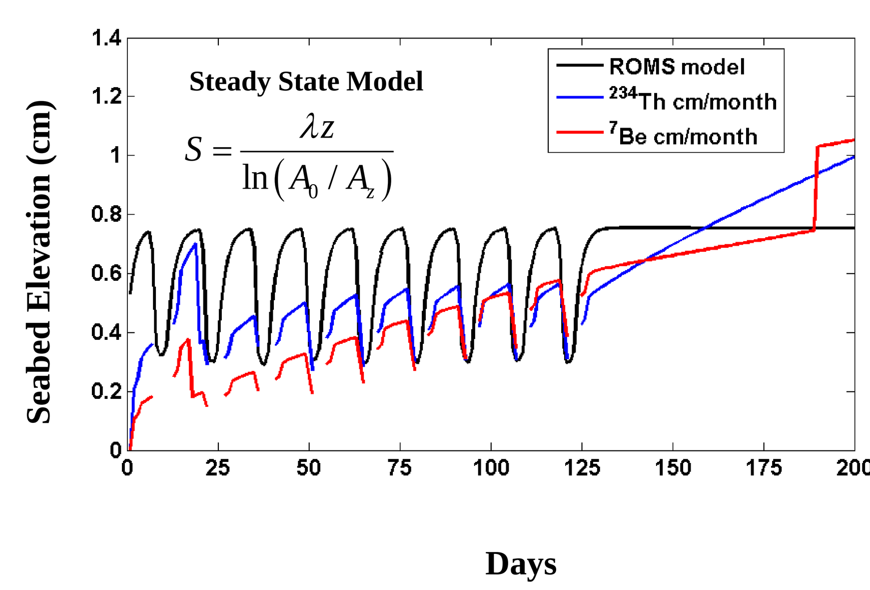


Fig 7. Steady state models cannot reproduce accumulation simulated by the model. Accumulation rates were calculated for each day using ^{234}Th and ^{7}Be radioisotopes. S is the accumulation rate; λ is the decay constant; z is depth; and A_o and A_z are radioisotope activities at the surface and at depth, respectively.

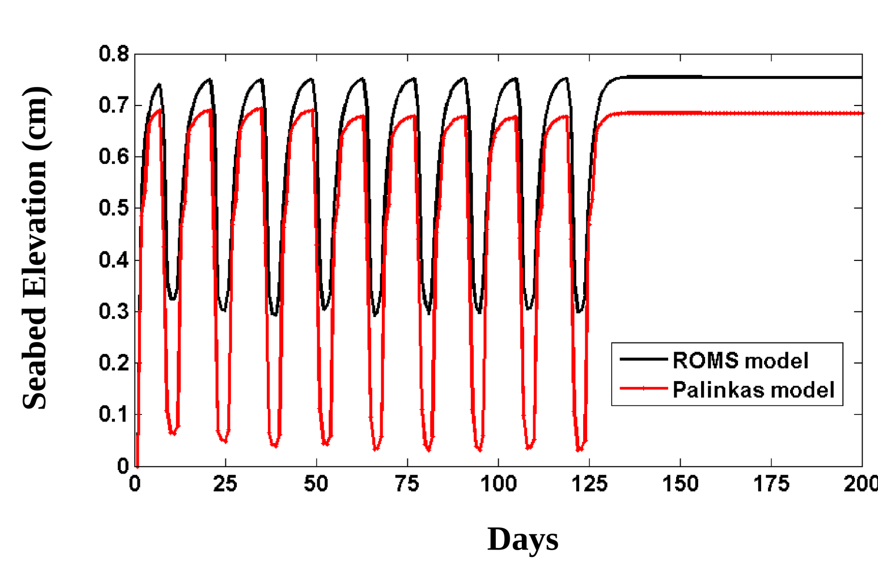
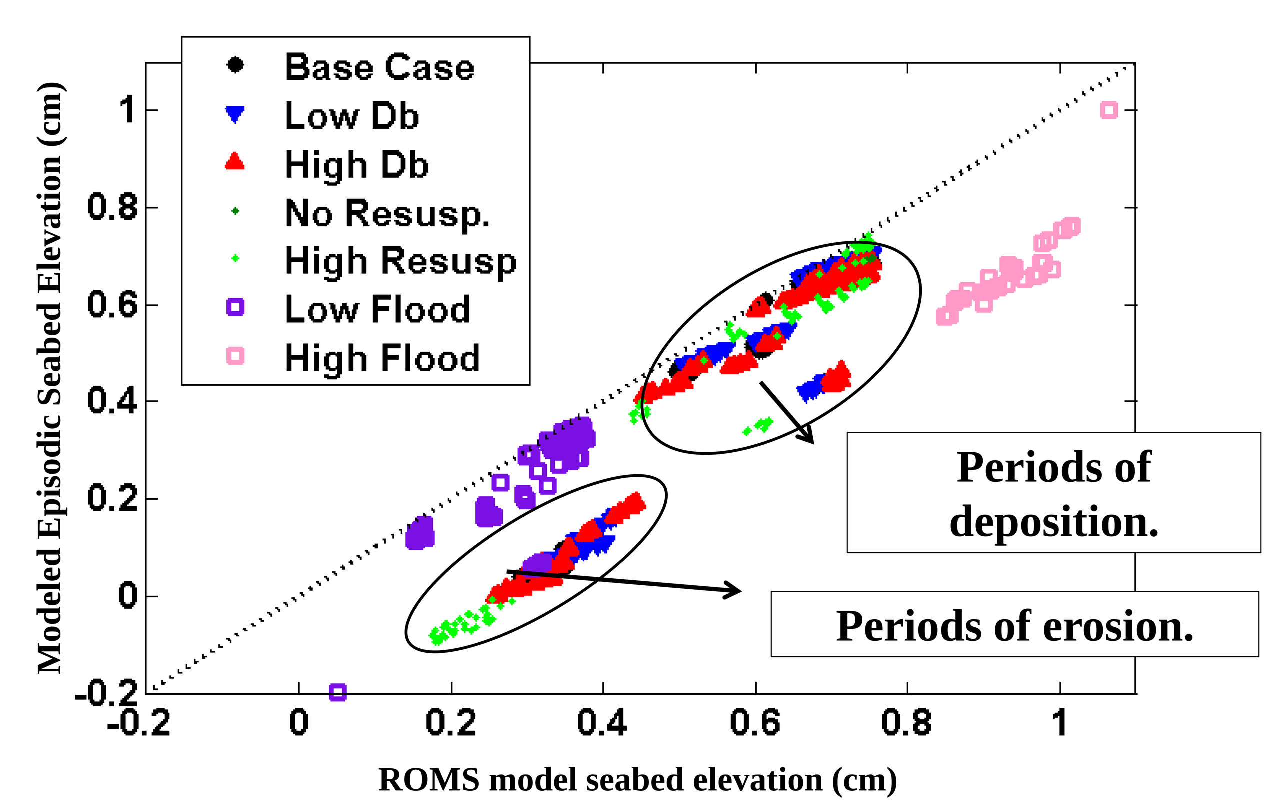


Fig 8. Seabed surface elevation over time as observed in the ROMS model and estimated using an episodic depositional model for the Base Case. Following the methods of Palinkas et al. (2005).



$A_z = A_o \exp(-z(D_b/\lambda)^{-0.5})$ Episodic Model

Fig 9. Seabed surface elevation simulated by the model versus estimated seabed elevation following the approach by Palinkas *et al.* (2005) for each model run. A_z is radioactivity at depth, z; A_o is radioactivity at the surface; D_b is bioturbation rate; and λ is the decay constant of the radioisotope. The episodic approach does best for periods of deposition, and less well during periods of erosion. These results indicate that in-depth knowledge of the hydrodynamic conditions is essential to interpreting radioisotope activity profiles in areas subject to frequent deposition and erosion.

3. Gulf of Mexico 3D ROMS model During Hurricane Ike 2008

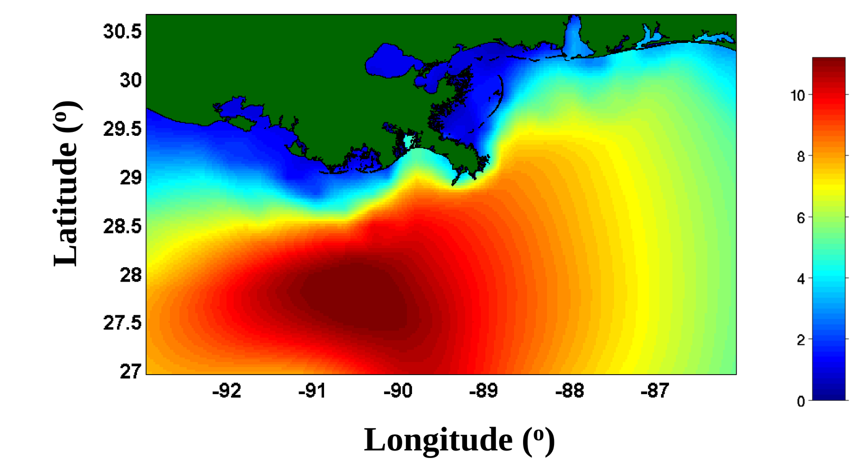


Fig 11. Modeled wave height (m), September 12, 2008, during Hurricane Ike. Wave Heights based on WWII data. Coastline in black.

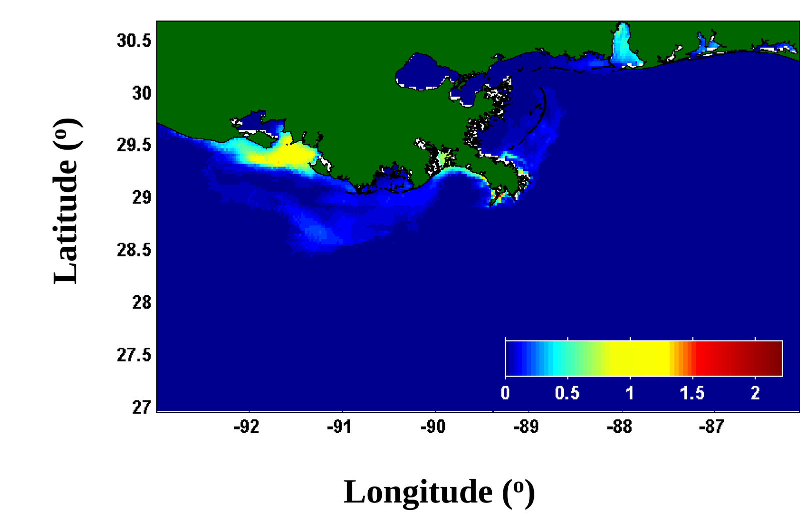


Fig 12. Nearbed suspended sediment (kg m^{-3}).

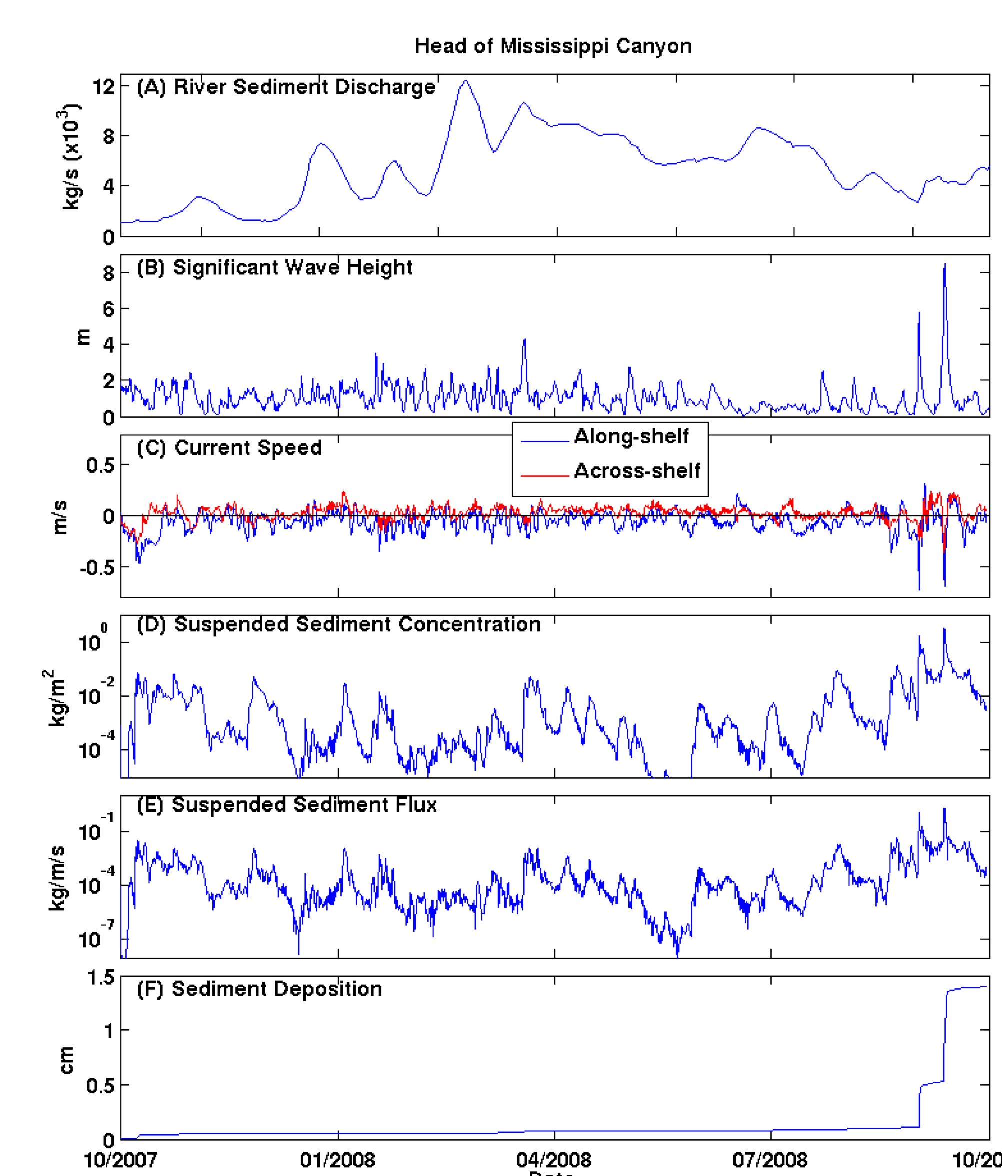


Fig 13. Time-series of the model run for 90 m deep site located at the head of Mississippi Canyon (see Fig. 3). (A) Mississippi river sediment discharge, (B) significant wave height, (C) depth-averaged along-shelf and across-shelf current speed, (D) suspended sediment concentrations, (E) suspended sediment flux and (F) sediment deposition.

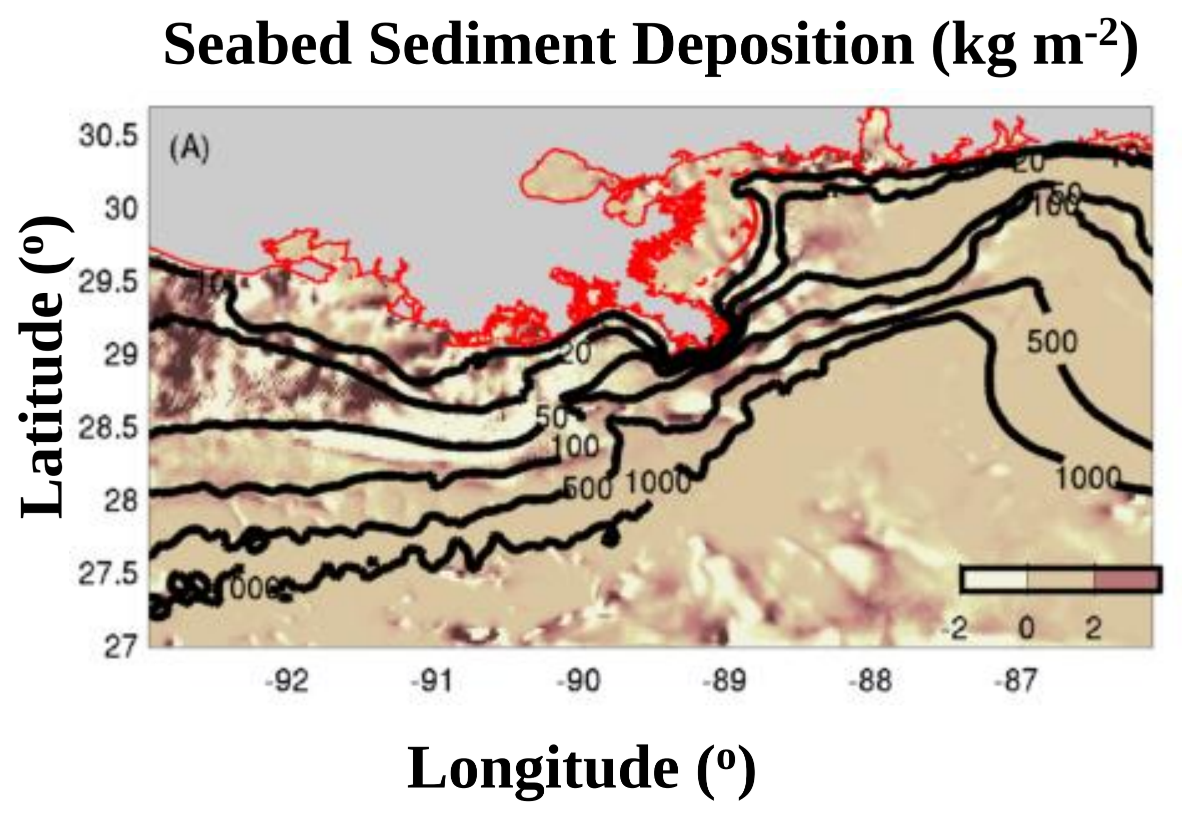
The 3D ROMS model was implemented as follows:

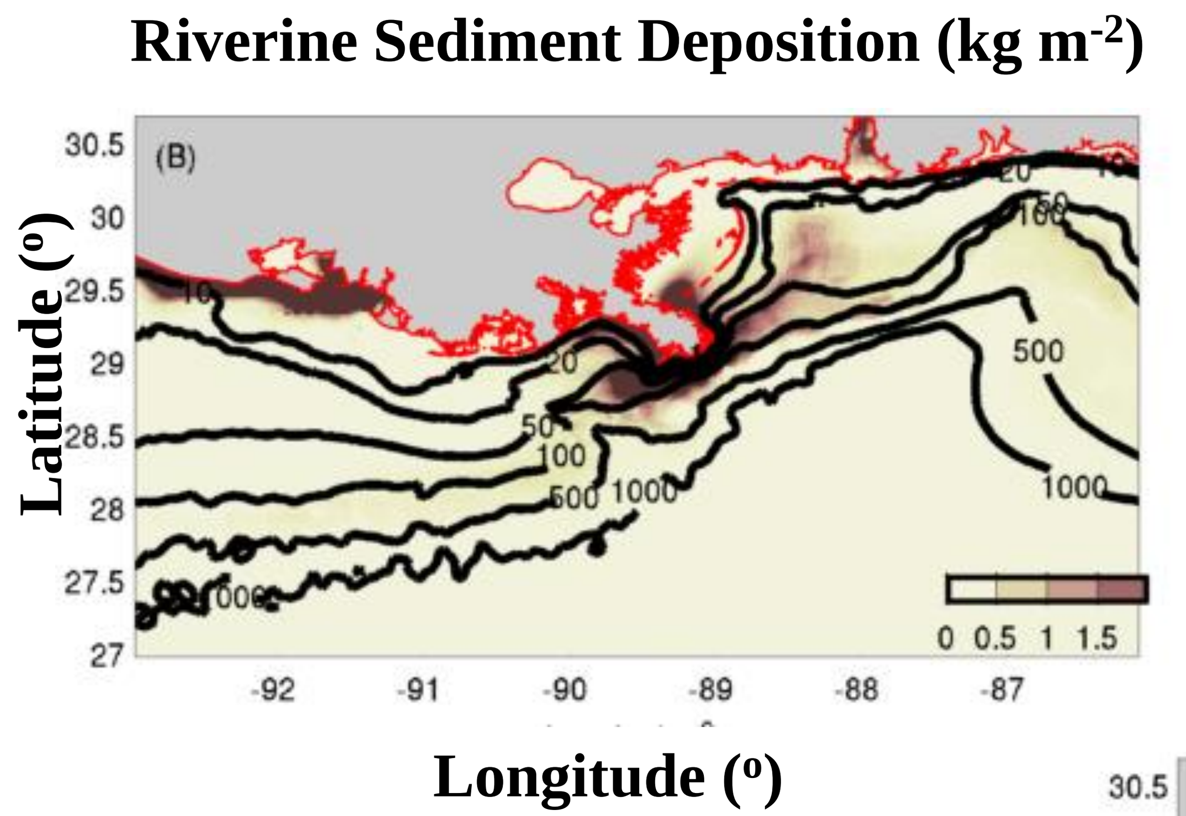
- Represented October, 2007 to September, 2008.
- Sediment bed initialized using dbSEABED (Jenkins, 2011), using sediment properties in Table 1.
- Freshwater and sediment discharge obtained from USGS for three rivers: Mississippi, Atchafalaya, and Mobile.
- Wave data obtained from NOAA WaveWatchIII.
- Atmospheric forcing from the European Centre For Medium-Range Weather Forecasts (ECMWF).

Class	Source	Sediment Type	D (mm)	t_{cr} (Pa)	w_s (mm/s)
1	Seabed	Mud	0.063	0.11	1.0
2	Seabed	Sand	0.125	0.13	10.0
3	Seabed	Gravel	10.0	10.0	70.0
4	Miss. River	Micro-floc	0.015	0.11	0.1
5	Miss. River	Macro-floc	0.063	0.11	1.0
6	Atch./Mobile Rivers	Micro-floc	0.015	0.03	0.1
7	Atch./Mobile Rivers	Macro-floc	0.063	0.03	1.0

Table 1: Sediment parameters for the three-dimensional sediment-transport model. Three sediment classes represented the initial seabed, two sediment classes were discharged by the Mississippi River and two sediment classes were discharged by the Atchafalaya and Mobile rivers.

3. Gulf of Mexico 3D ROMS model results – most sediments deposit proximal to their source.





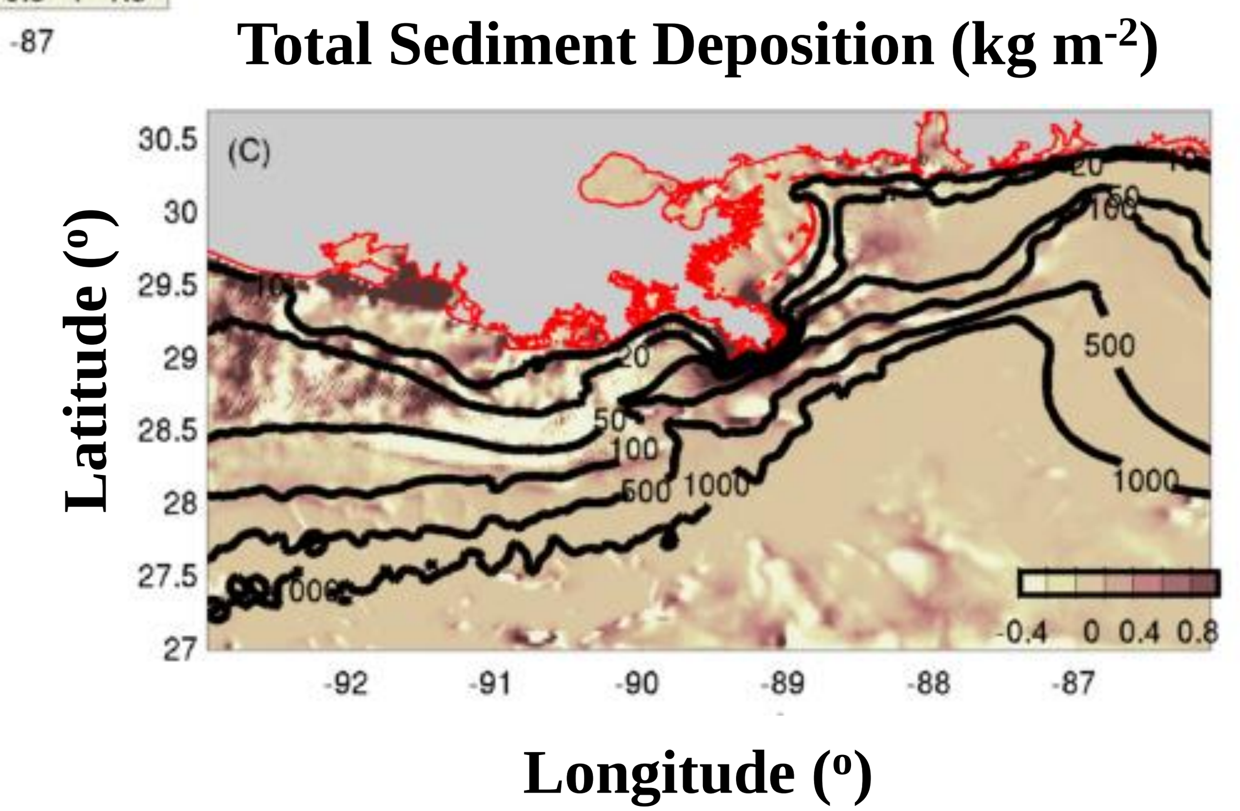


Fig 10. Three-dimensional sediment model estimates for October, 2007 to September, 2008. (A) Estimated deposition of sediment initially on the seabed, (B) deposition of riverine sediment, and (C) combined deposition. Note changes in scales between figures. Coastline shown in red, while bathymetric contours in black.

4. Conclusions

One Dimensional Coupled Geochronology – Sediment Transport Model:

- Represented deposition of flood sediments and reworking by bioturbation and resuspension for both an idealized case and one configured to represent conditions in the Gulf of Mexico.
- Bioturbation rates and flood load markedly influenced radioisotope detectability over time.
- Steady state models applied to the simulated radioisotope profiles did not reliably reproduce accumulation, especially during periods of frequent resuspension.
- An approach designed to estimate episodic deposition overlying older sediments was needed to accurately estimate deposit thickness from radioisotope profiles (c.f. Palinkas et al., 2005).

Three-Dimensional Model of the Gulf of Mexico

- A large fraction fluvial sediments are deposited proximal to their source, with cross-shelf transport enhanced during storms.
- Future work will include incorporating the reactive radioisotope tracers into the 3D model., and linking this model to models for other transport mechanisms (slope failure, turbidity current).

References

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