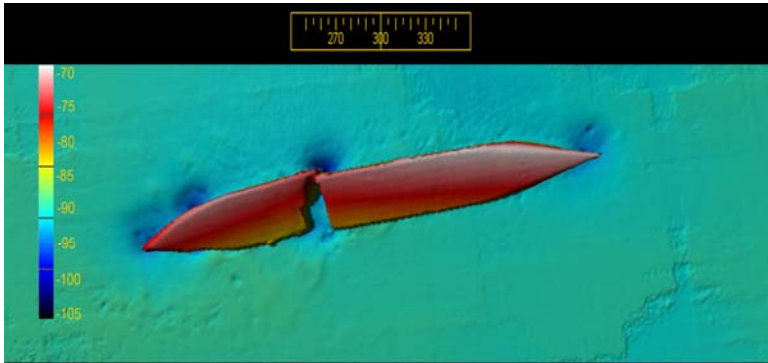
Hurricane-induced bottom stirring on the Louisiana-Texas continental shelf

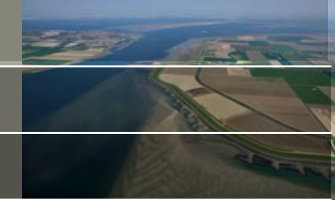
João Rego[1], Katherine Cronin[1], Patrick Hesp[2], Deepak Vatvani[1], Amanda Evans[3], Matthew Keith[3]

[1] Unit Marine and Coastal Systems, Deltares (The Netherlands)
[2] Dept. Geography and Anthropology, Louisiana State University (USA)
[3] Tesla Offshore LLC. (USA)

JONSMOD 2012
Ifremer
Brest, France; 21-23 May



Overview



1. Motivation
2. Data
3. Model(s)
4. Results
5. Conclusions & Recommendations

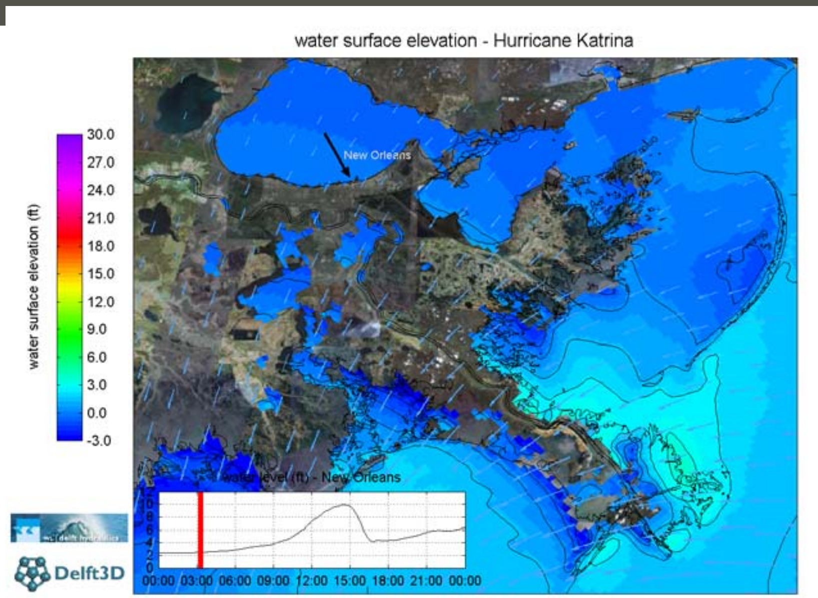
This presentation is entitled:

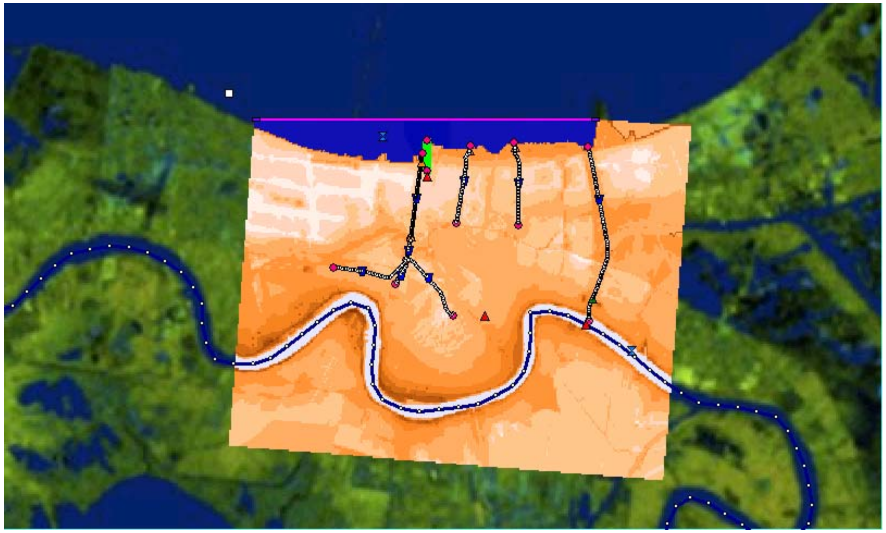
“Hurricane-induced bottom stirring on the Louisiana-Texas continental shelf”

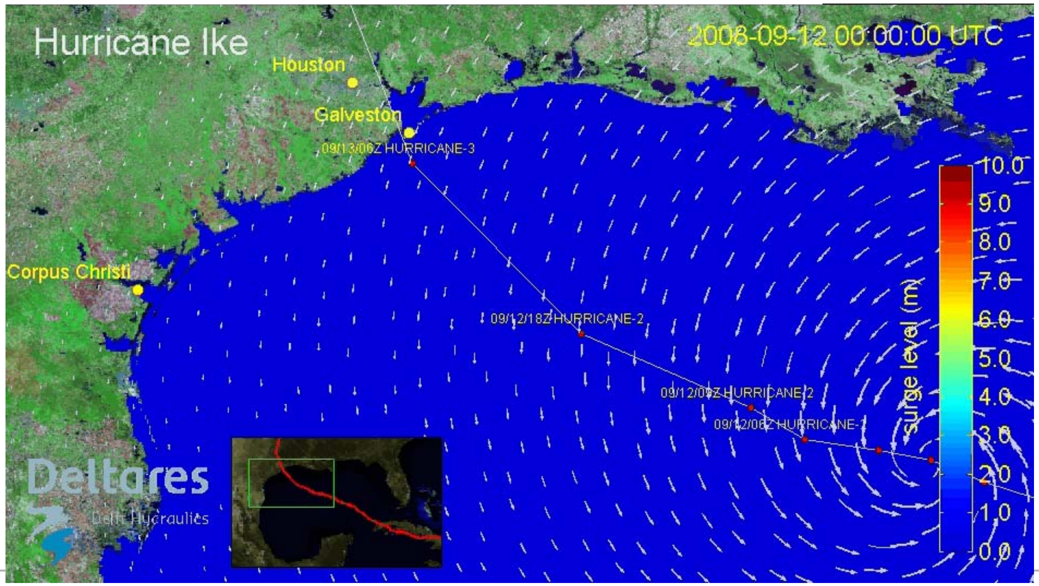
Perhaps a good sub-title would be…

**“Using models to answer an open question,
with little data and a small budget”**

"Typical" Hurricane Surge Modelling







Hurricane Katrina (Sept. 2005)

Typically:
? What is overland surge ?

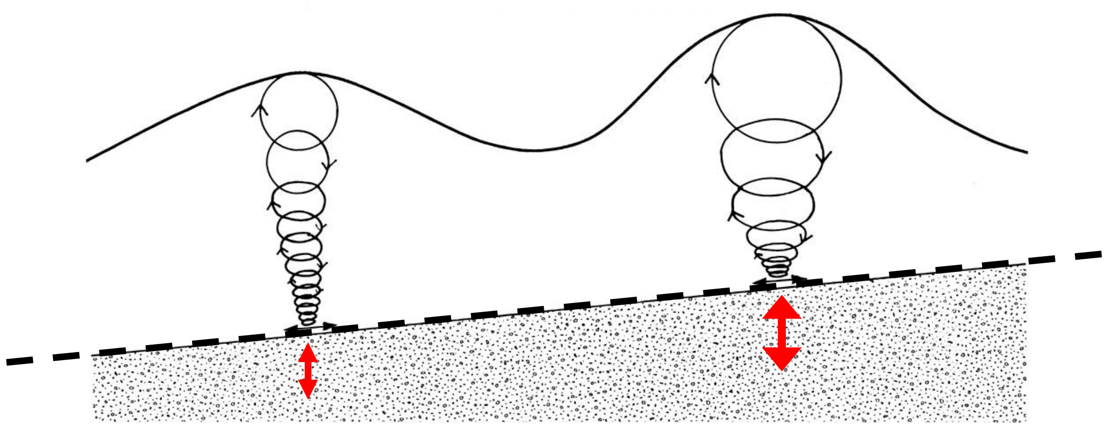
Hurricane Ike (Sept. 2008)

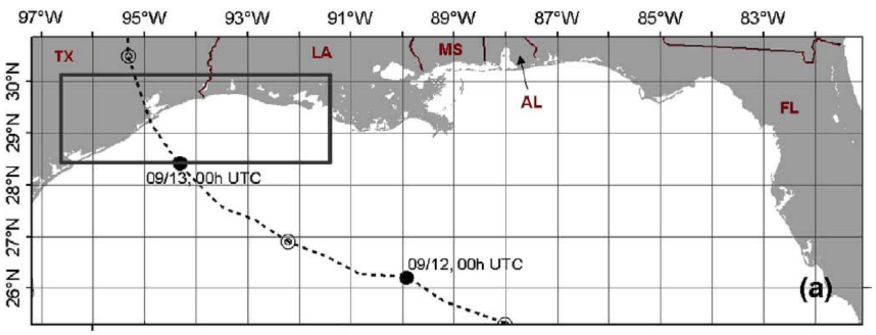
Deltares

Hurricane modelling: Effect on bottom?

Determine **<u>hurricane stirring depth</u>**, for archeologists studying buried shipwrecks

=> How deep into the bottom does hurricane passage have impact?



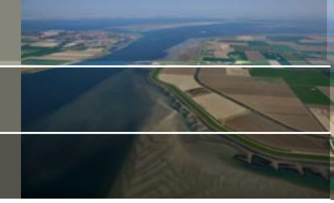


TESLA EXPLORATION LTD.

LSU

Deltares

Summary



GOAL: to estimate morphological impacts to historic shipwrecks in the northern Gulf of Mexico.

WHY?

Shipwreck components buried underneath seafloor sediments are well protected from deterioration,
The long-term stability of a given site depends on sediment accretion and seafloor scour patterns.

WHAT?

We estimate the range of bottom sediment thicknesses that can be disturbed during the passage of strong tropical storms, in three specific sites on the upper Texas-Louisiana shelf.

HOW?

- Three local models, nested in a larger regional model, simulating hydrodynamics, waves and scour of cohesive bottom sediment, including transport and sedimentation under 2 hurricanes.
- Delft3D-FLOW running in 2DH, coupled with Delft3D-WAVE.
- Two “ends of spectrum” were simulated: very loose and extremely consolidated fine sediments.

Study in support of a project funded by the U.S. Department of the Interior, Bureau of Ocean Energy Management (formerly MMS)

In the literature …

Many many adhoc observations;
Poststorm surveys performed anywhere from 12 hours to 2 weeks after hurricane landfall.
Each survey looks at 2-3 sites, typically at greater depths, with specific sediment composition, for specific hurricane path, using varying methods…

Allison et al. (2005) measured three stacked event layers down a box core collected from approximately 20 m below MSL, offshore Louisiana. The bottommost event layer, ~7 cm thick, was attributable to Hurricane Ivan. The overlying two layers were produced by Hurricane Katrina and are ~19 cm thick, with the uppermost 9 cm representing sediment reworking as a result of Hurricane Rita.

Teague et al. (2006) estimate that for every 3 m of wave height, about 1 cm of sediment displacement can be expected (at the level they studied, about 60 m depth). Hurricane Ivan produced H_s of ~18 m (H_{max} of 28 m), thus they estimated 6 cm of sediment displacement in such areas.

Goff et al. (2010) found that Hurricane Ike was capable of adding up to 2.5 m of sediment to a site north of Big Reef, offshore Texas. They also observed that shell-gravel ridges of ~3 m height and 150 m width (pre-storm) were drastically degraded by the hurricane, becoming ~2 m shorter and migrating seaward by ~50 m. Even during lower energy events, with H_s of 1m in shallow water depths of 4 m, significant resuspension and bed reworking takes place (Sahin et al., 2011).

Sediment properties: Field data

Unlike the erosion equations used for sandy beds the erosion equations for mud beds do not include an equilibrium condition, but depend on the flow conditions and the bed properties (van Ledden et al., 2004).

BUT little information was available on the bed properties for this study; only grain sizes were known and not parameters such as bulk density and plasticity. Information on the bulk density is required to determine the degree of consolidation.

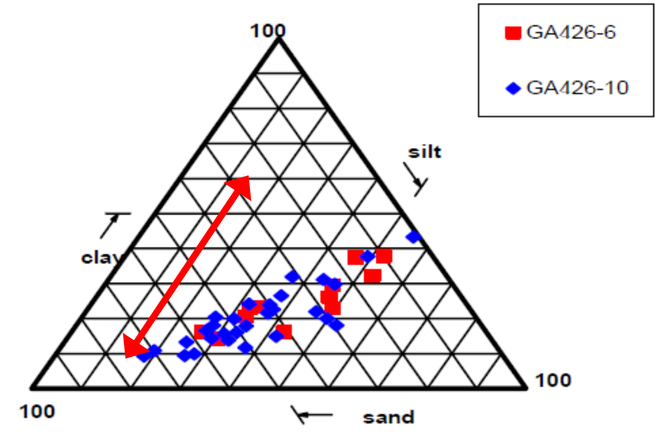


Figure 2.2 Sand- silt-clay triangle for study site GA 426 (two samples)

Sediment cores taken at each of the study sites were analyzed for fractions of
- sand (63-200 µm),
- silt (4-63 µm),
- clay (<63 µm)

Samples at all three sites fell into the cohesive-clay dominated category (van Ledden et al., 2004) with greater than 10% clay content.

=> Cohesive sediment transport equations should be used

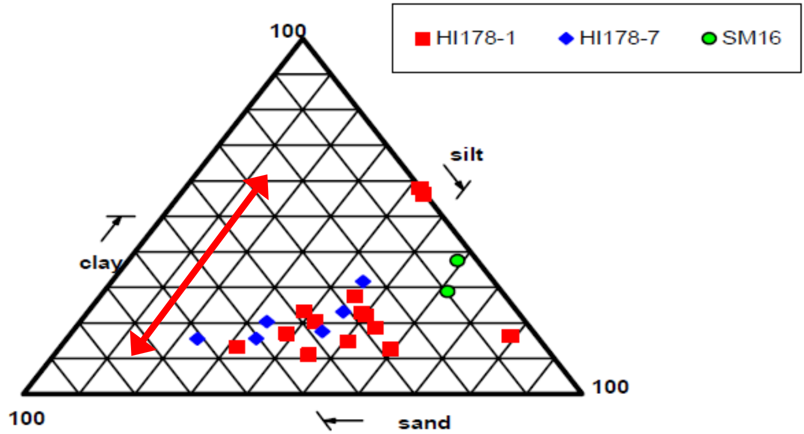
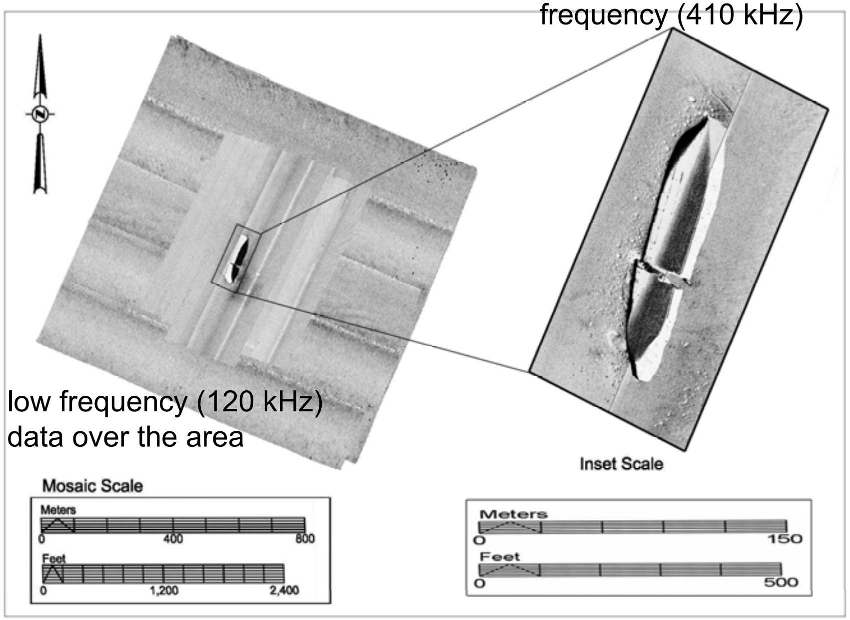


Figure 2.3 Sand-silt-clay triangle for study sites HI 178 (two samples) and SM 16

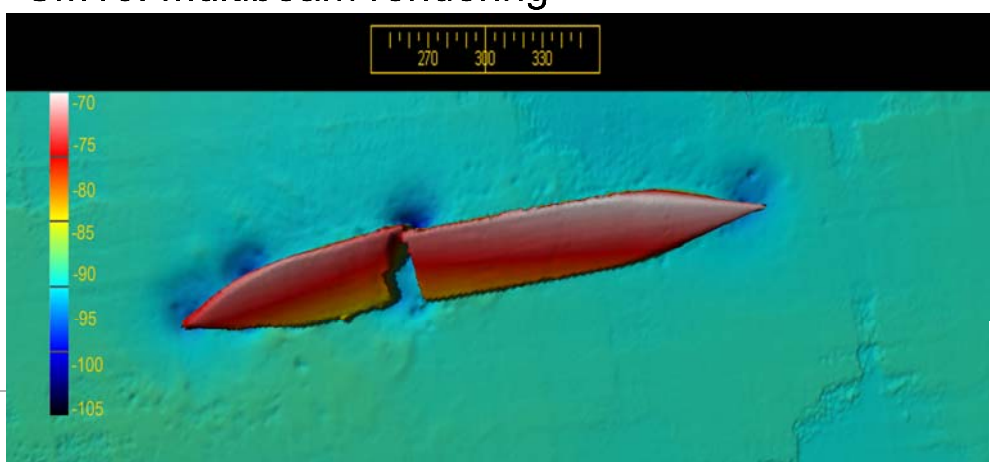
The shipwrecks: geophysical data

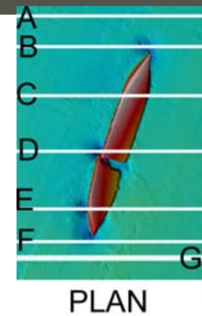
SM16: Sonar mosaics

just the wreck at high frequency (410 kHz)



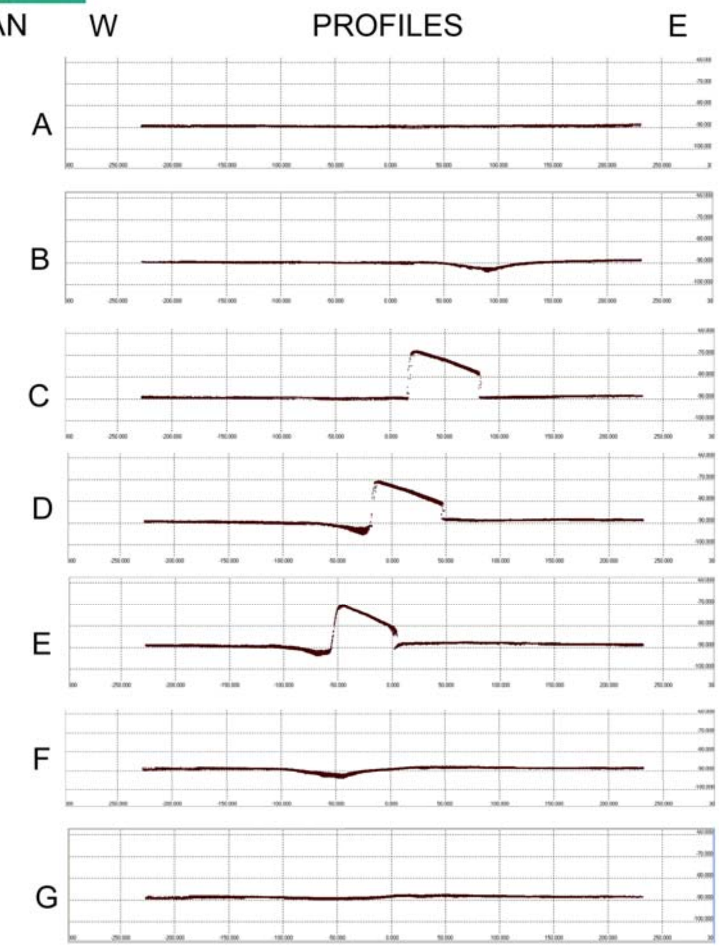
SM16: Multibeam rendering





SM16: Multibeam with profiles

multibeam rendering and individual slices over the profile of the wreck



Field data: Sediment properties

Diver in water with corer

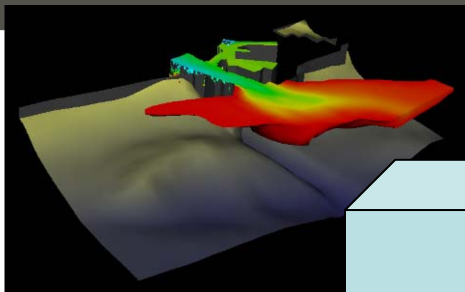
Diver on deck with corer

The modified Wildo sediment sampler used for coring in the field. Corer is a 10cm diameter barrel, 1 meter in length.

This and previous slide:

Evans, A.M., **M.E. Keith**, E.E. Voisin, **P. Hesp**, G. Cook, M. Allison, G. da Silva, and E. Swanson. 2012. Archaeological Analysis of Submerged Sites on the Gulf of Mexico Outer Continental Shelf. U.S. Department of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEMRE 2012-xx. 371pp.

The model: Delft3D

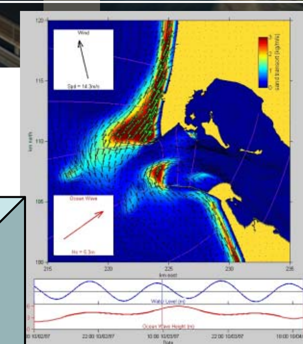


Fresh water bell - River Rhine mouth, Rotterdam, The Netherlands

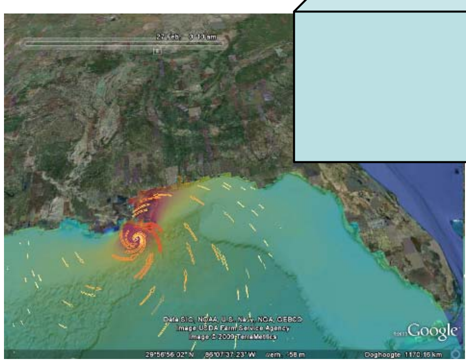
Overall menu

FLOW | MOR | WAVE | WAQ | SED | ECO | PART

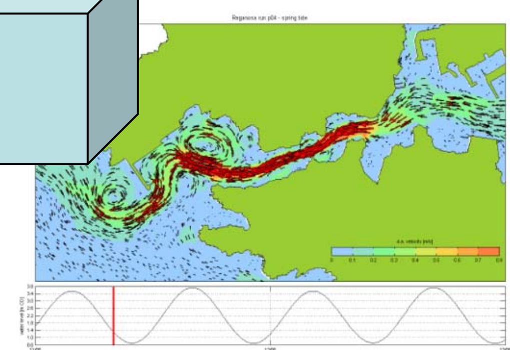
Tools and add-ons



Sand transport during storm event, Columbia River Estuary and Coast, USA

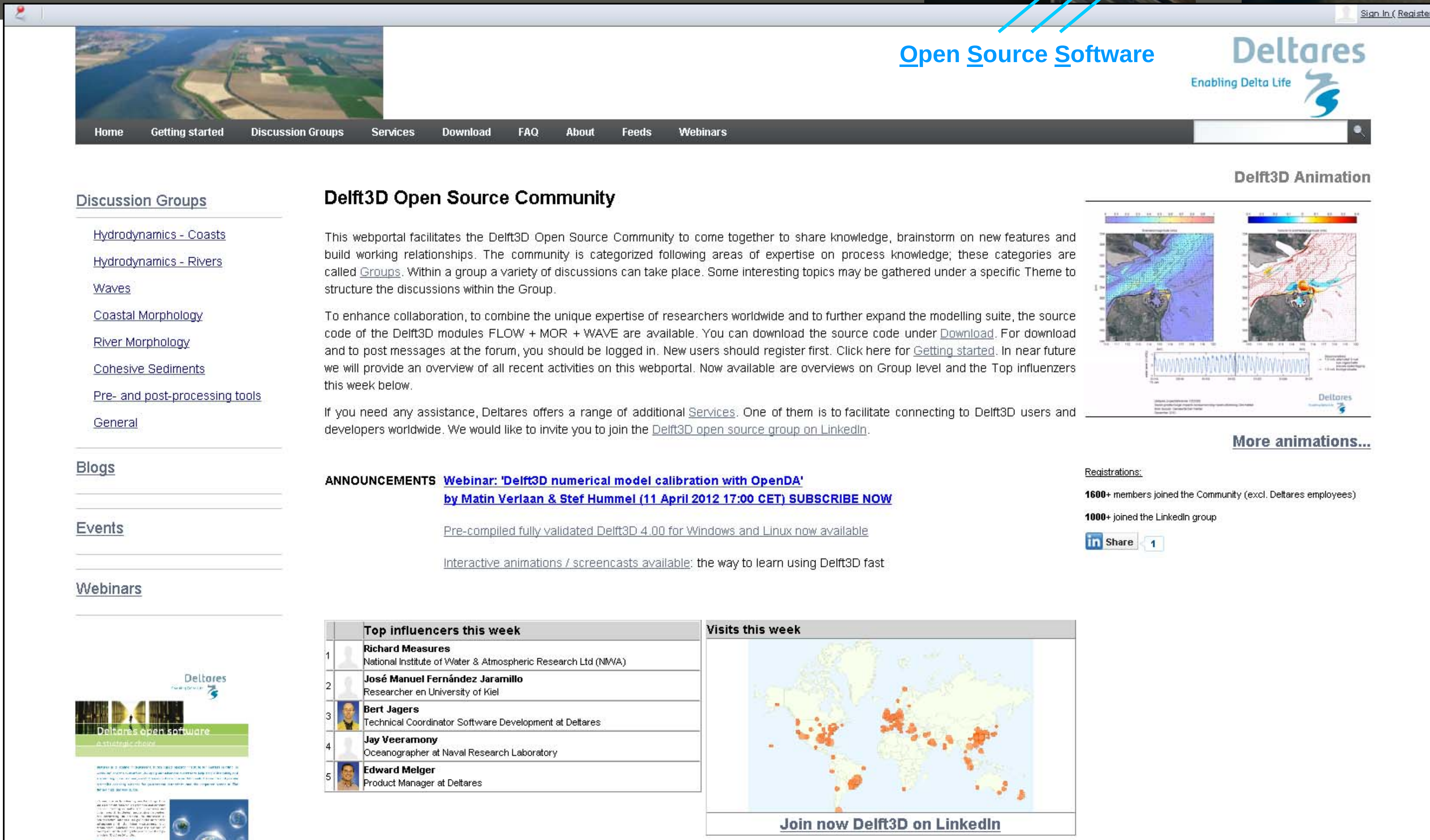


Hurricane Katrina, 2005, USA



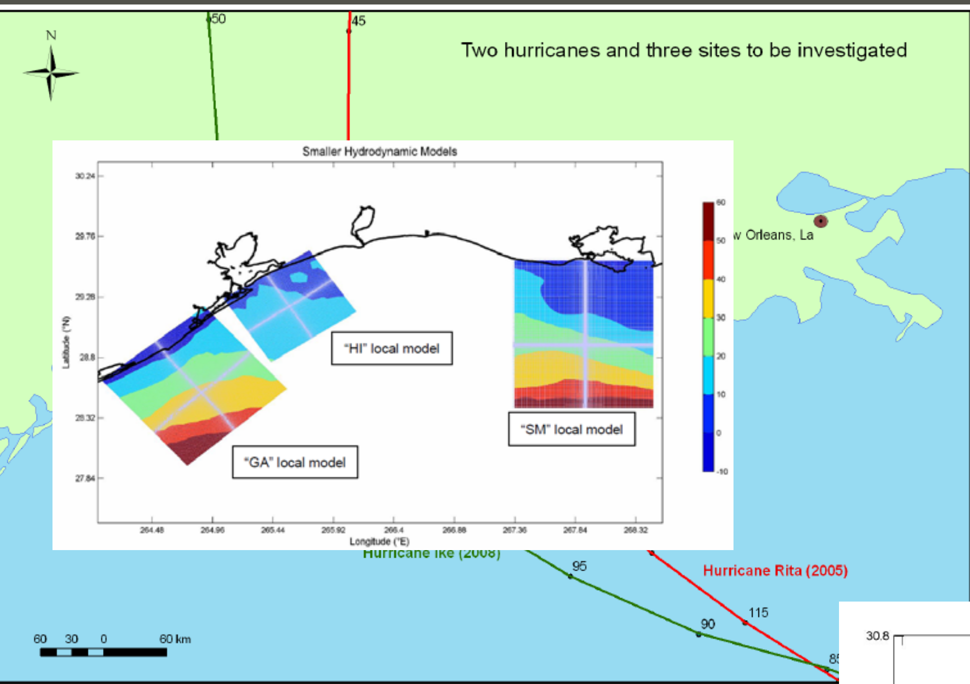
Detailed modelling of flow circulation to support nautical and safety studies, Reganossa, Spain

Delft3D open source website (http://oss.delft3d.nl)



=> An invitation to all leading experts to <u>collaborate in development and research</u> using Delft3D

Hurricane modelling in GoM: Regional and local models

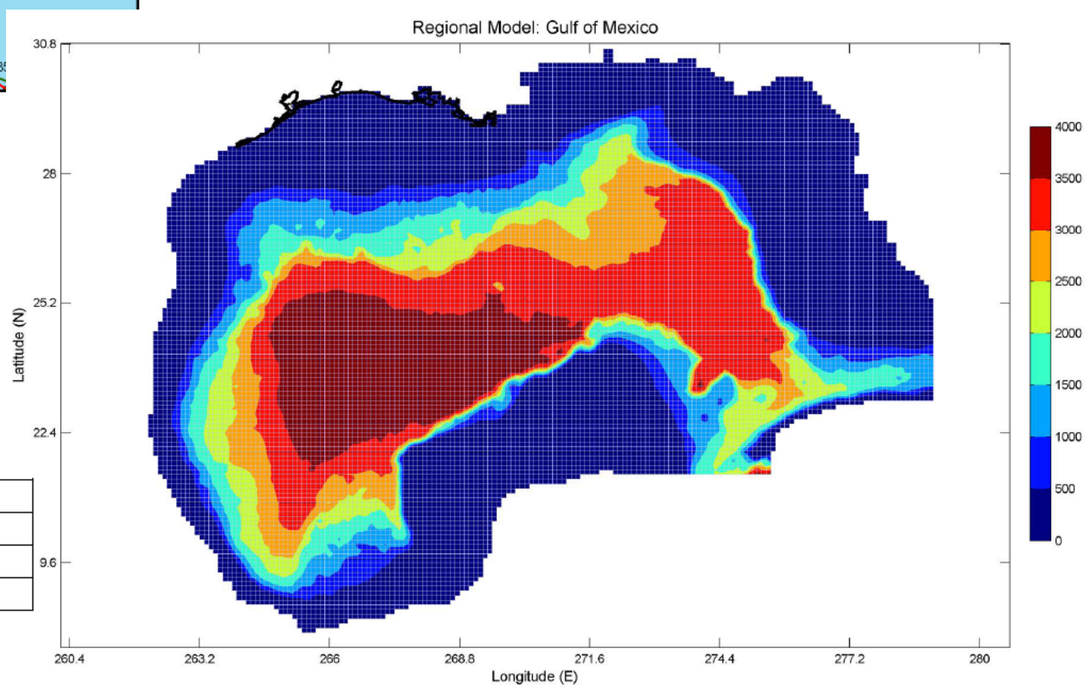


“Model cascade” based on 10-km regional Gulf of Mexico Delft3D-FLOW & WAVE model

Studied impact of
2 major storms on…
3 focus sites

Table 1.1: Sites of interest; horizontal position and depth information.

ID	water depth (m)	Longitude	Latitude
HI 178	15.5	094° 25' 49.81" W	29° 12' 20.50" N
SM 16	26.0	092° 04' 56.78" W	28° 53' 53.18" N
GA 426	31.0	095° 07' 42.30" W	28° 31' 10.16" N



Model forcing data; sources

“Static”

Coastline: from NOAA's National Geophysical Data Center (NGDC) Coastline Extractor (online at http://www.ngdc.noaa.gov/mgg/coast/)

Bathymetry: detailed depth information ADCIRC composite LIDAR + bathymetry mesh (version ‘SL15v06r09’), validated for applications in coastal Louisiana (Dietrich et al, 2010; Dietrich et al, 2011).

Tide: Harmonic constituents, along Florida and Yucatan straits, from ADCIRC / USACE EastCoast2001.

Event-specific

Winds: NOAA’s H*WIND dataset representing hurricane surface winds (Powell et al, 1998; Powel and Houston, 1998). Online at http://storm.aoml.noaa.gov/ss/analysisoutput/. These wind speeds (averaged over only 1 minute) had to be converted to 10-minute averages, i.e. multiplied by 0.87.

Air pressure: The *UNISYS* Atlantic Tropical Storm Best Track Reanalysis Center (online at http://weather.unisys.com/hurricane/atlantic/) provided timeseries of the hurricanes central position and pressure-drop. Fields of surface air pressure generated using using Holland’s (1980) air pressure profile.

Hydrodynamic models

MODEL GRIDS

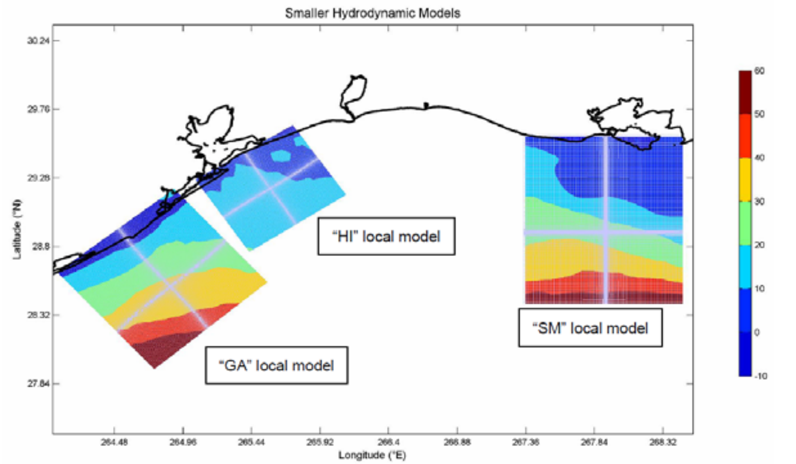
Regional Gulf of Mexico model with grid dimensions: $M^{max} \times N^{max} = 171 \times 128$.
It has a uniform, <u>rectangular</u>, resolution of 10 km.

Local models have <u>curvilinear</u> grids with resolutions varying from about 3 km to about 50 m near each site.

The 2D model around HI-178 has dimensions $M^{max} \times N^{max} = 122 \times 112$

The 2D model around SM-16 has dimensions $M^{max} \times N^{max} = 131 \times 126$

The 2D model around GA-426 has dimensions $M^{max} \times N^{max} = 133 \times 133$



We ensured that the in-situ measured depths were observed at the centre of each local model.

RELEVANT PARAMETERS

Regional model with time-step of 5 minutes.
Bottom roughness of 0.035 (Manning formulation) along the coastline and 0.024 everywhere else.
Background horizontal eddy viscosity was spatially uniform, at 10 m^2/s.

Local models with time-step of 1 minute.
Uniform bottom roughness of 0.022 (Manning formulation).
Background horizontal eddy viscosity was spatially uniform, at 1 m^2/s.

Slightly lower than Delft3D-FLOW's default value, in order to represent smoother, fine-sediment bottoms.

Modelling Sediment scour, transport, settling

The transport of cohesive sediments between the bed and water column in Delft3D is calculated by Partheniades (1965). The calculated erosion or deposition flux is applied to the near-bottom computational cell.

Ariathurai, (1974) parameterised Partheniades' results which can be combined with Krone's deposition formula to compute the water-bed exchange rate for cohesive sediment.

The erosion flux can be integrated (Winterwerp and van Kesteren, 2004) to yield the erosion depth,

$$E^{depth} = M \cdot \left(\frac{\tau_b - \tau_{cr}}{\tau_{cr}} \right) \cdot \frac{T}{\rho} \qquad \text{(m)}$$

where T is the relevant time period (s), and ρ is the sediment density (kg/m^3).

Two sediment scenarios were established: a well consolidated bed scenario and a loose bed scenario, in order to determine a range of possible scour depths, depending on the bed properties and the bed shear stress exerted during the storm event.

A uniform cohesive bed fraction was modelled, with an initial bed thickness of 2 m throughout the domain (three local models). The regional model was used only to force the local models, and was run without sediment.

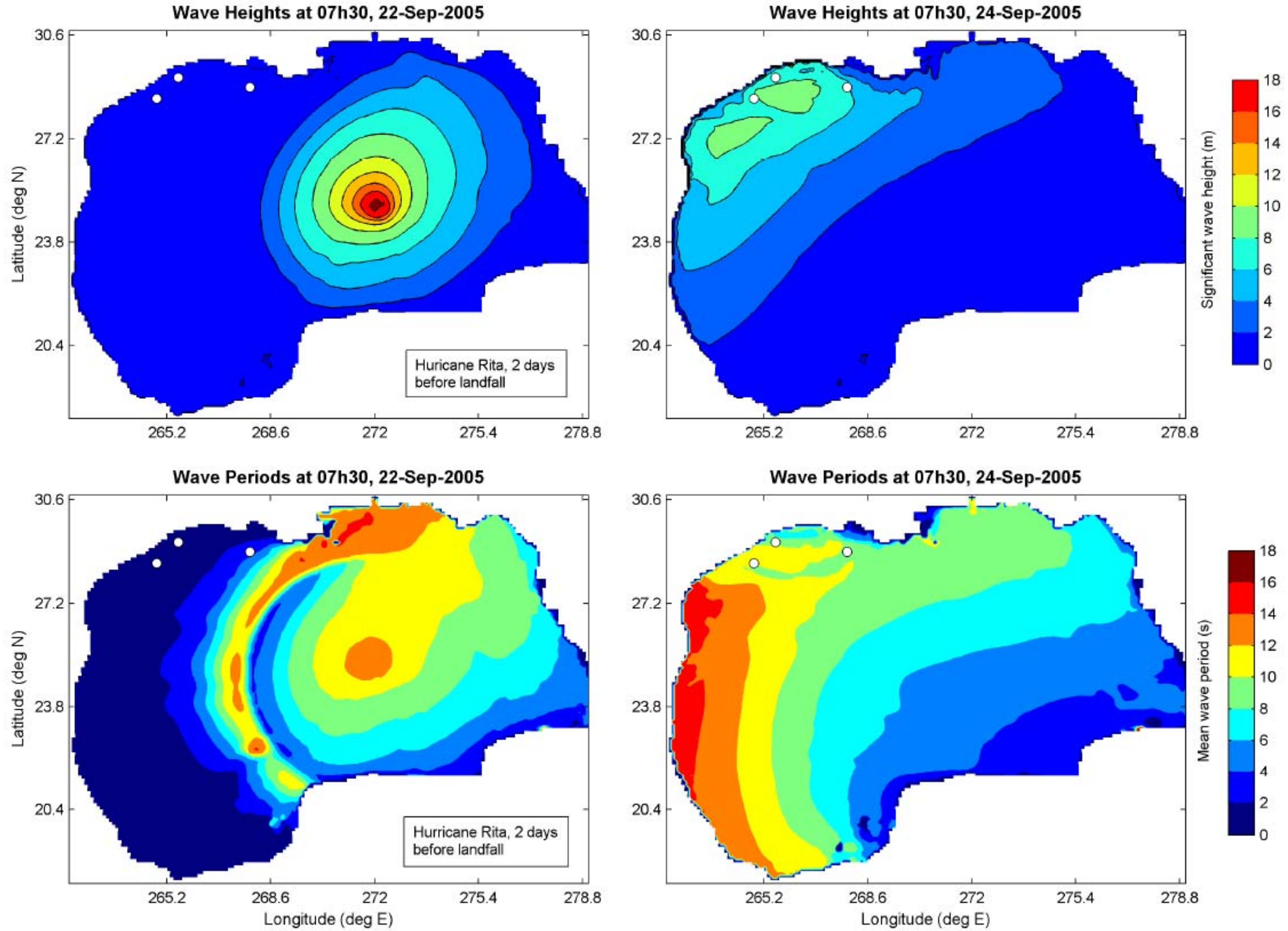
=> There is zero suspended sediment entering the local models, and this may have an impact if open boundaries are near to area of interest.

M, erosion parameter [kg/m2/s]
- loose: 1.0e-04
- consolidated: 1.0e-06

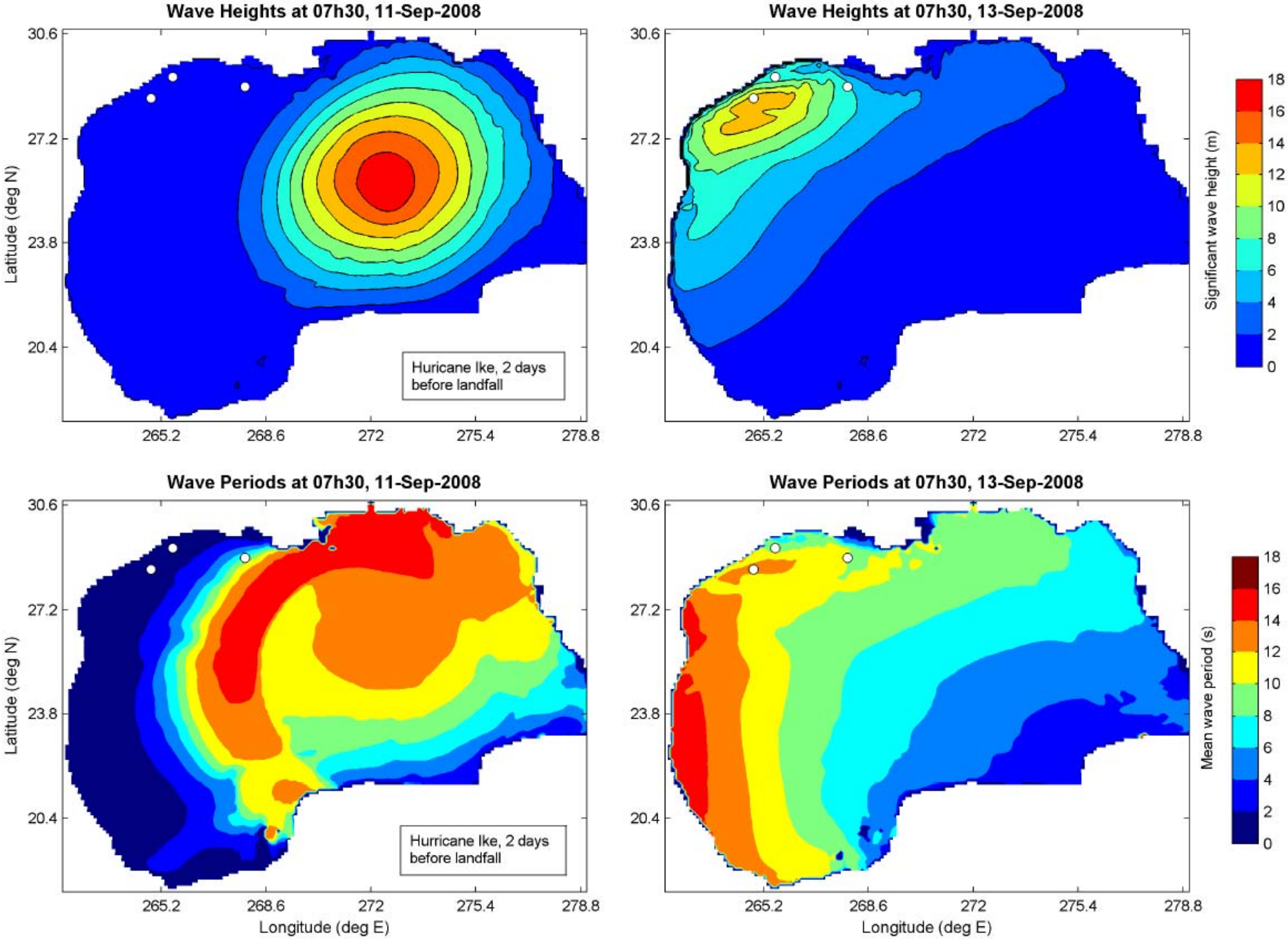
τ_{cr}, Critical bed shear stress for erosion [N/m^2]
- loose: 0.2
- consolidated: 1.0

Deltares

Regional model; Hurricane Rita

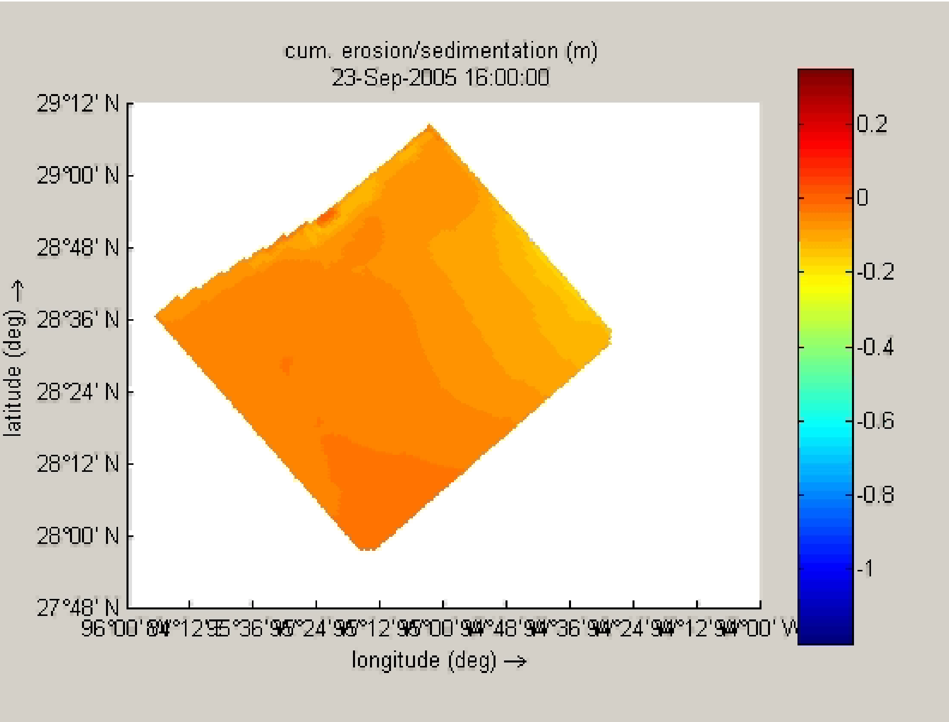


Regional model; Hurricane Ike



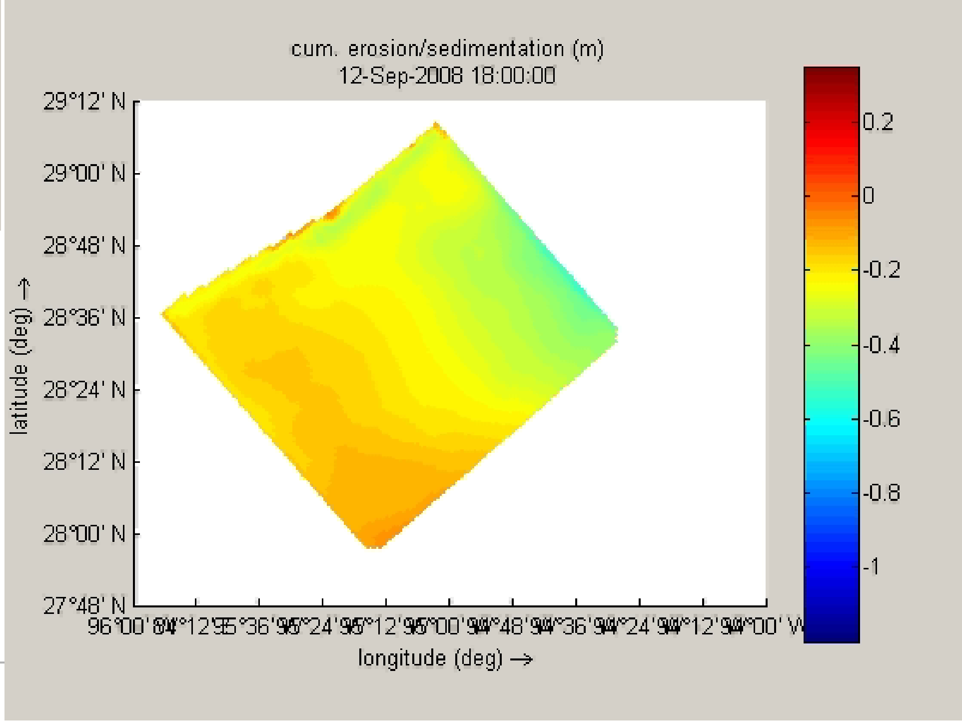
Deltares

Animations: example at site GA

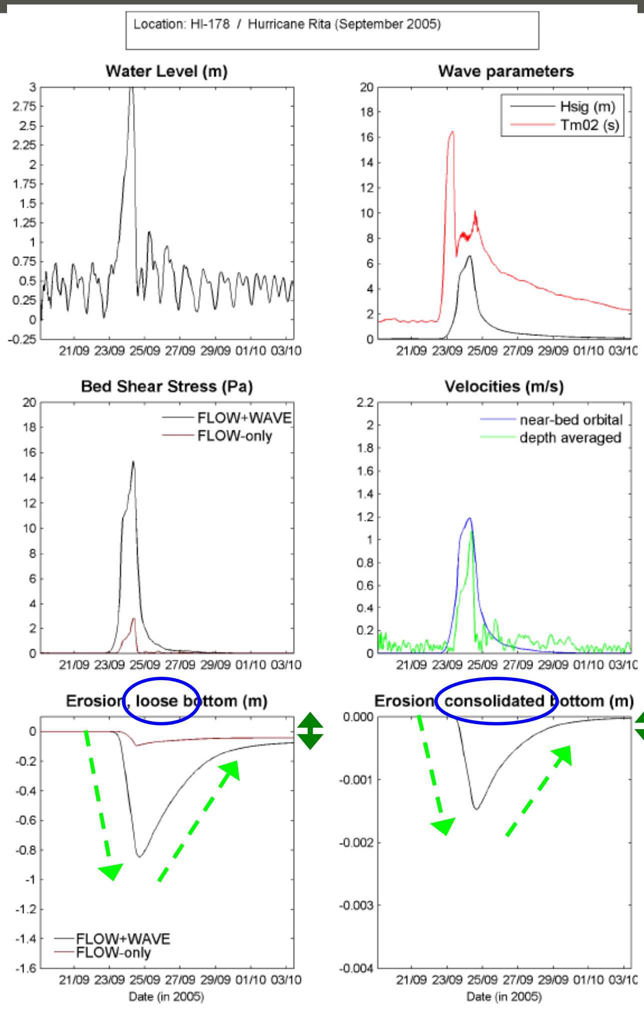


during Hurricane Rita

during Hurricane Ike

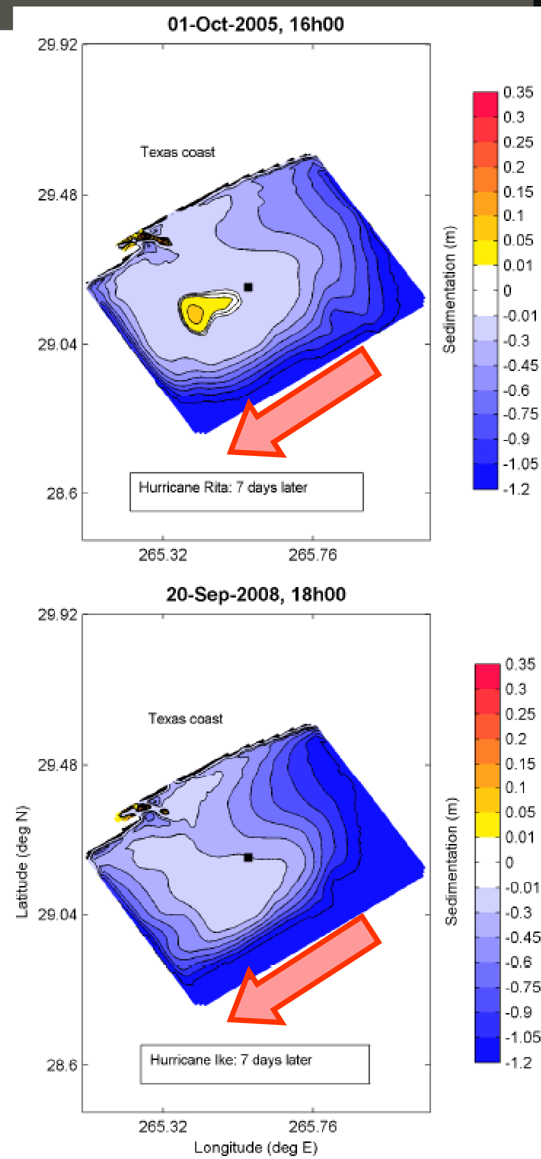


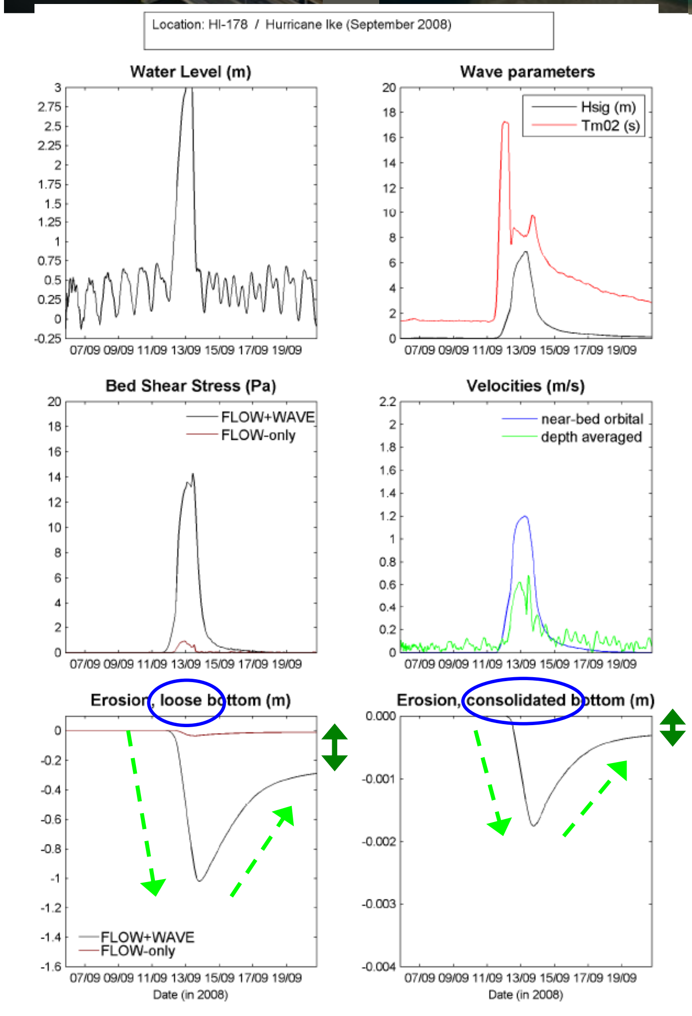
Results from local model: site GA-426



7 days

7 days



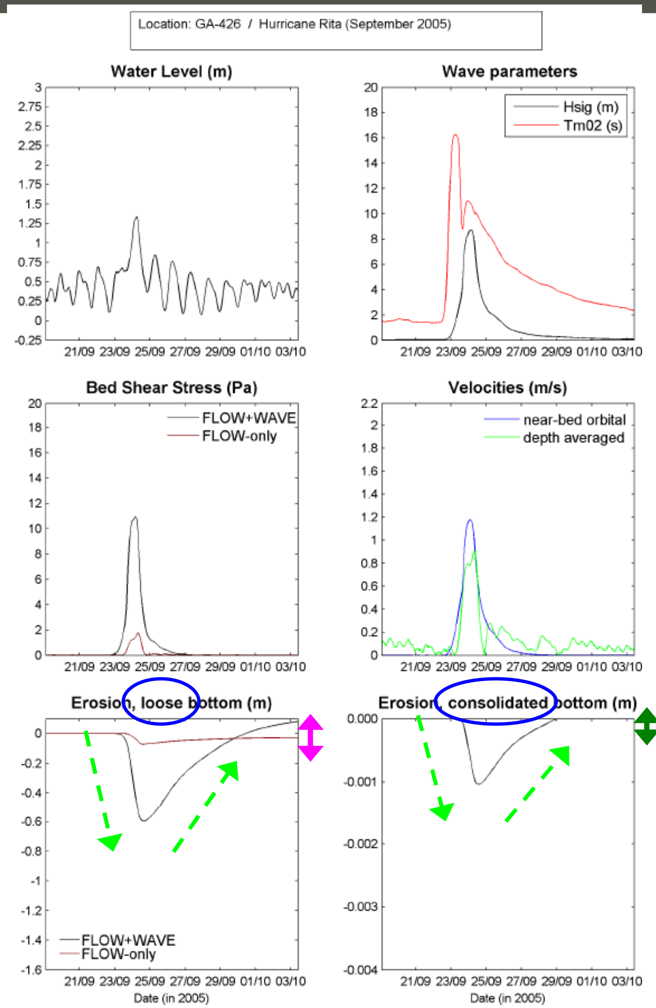


7 days

7 days

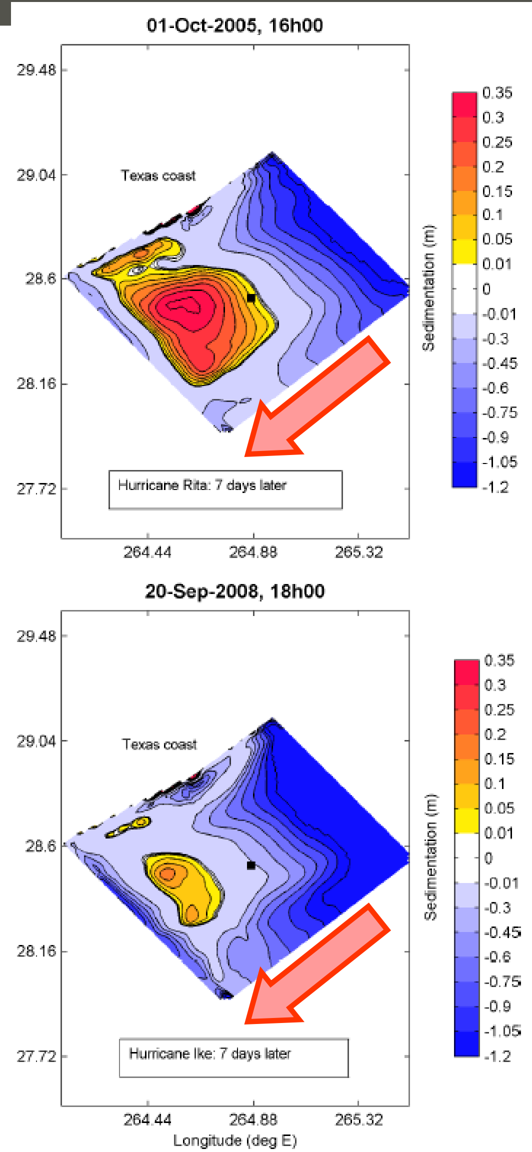
Deltares

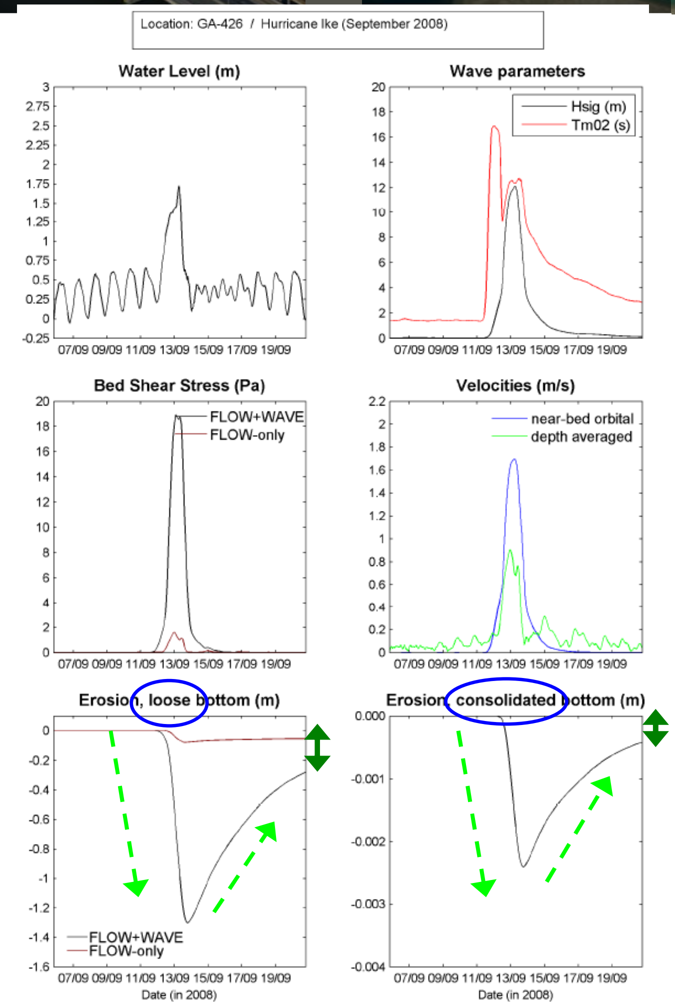
Results from local model: site GA-426



7 days

7 days



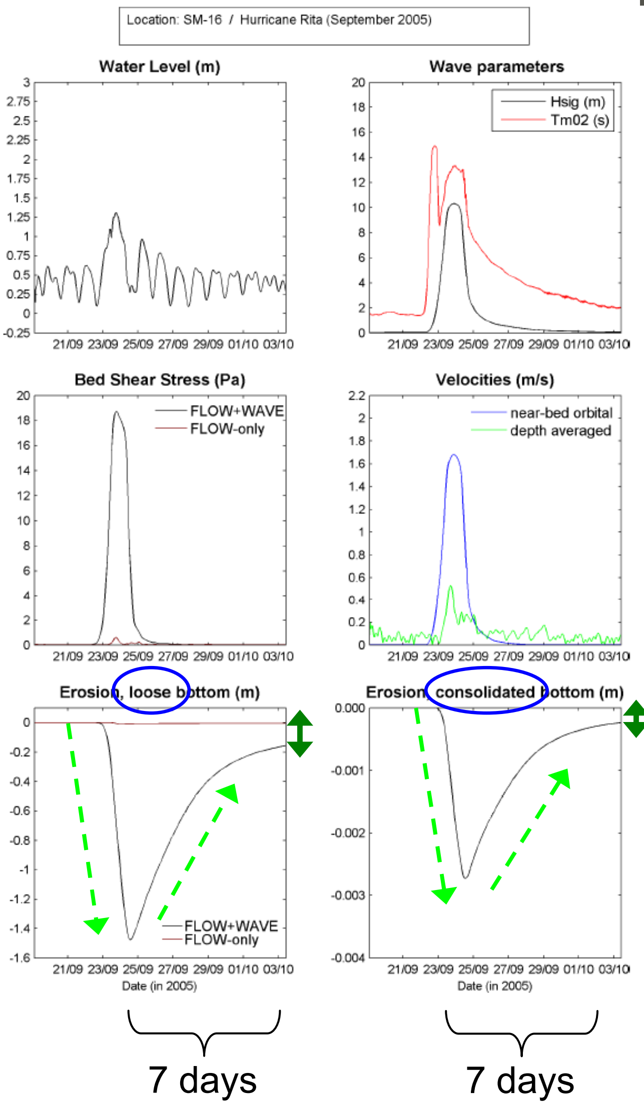


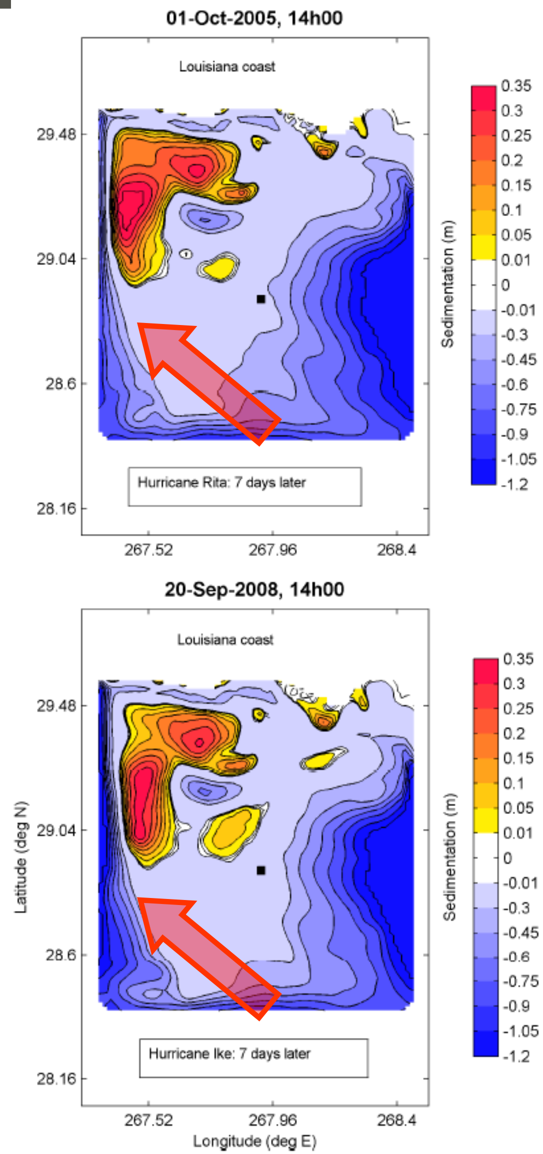
7 days

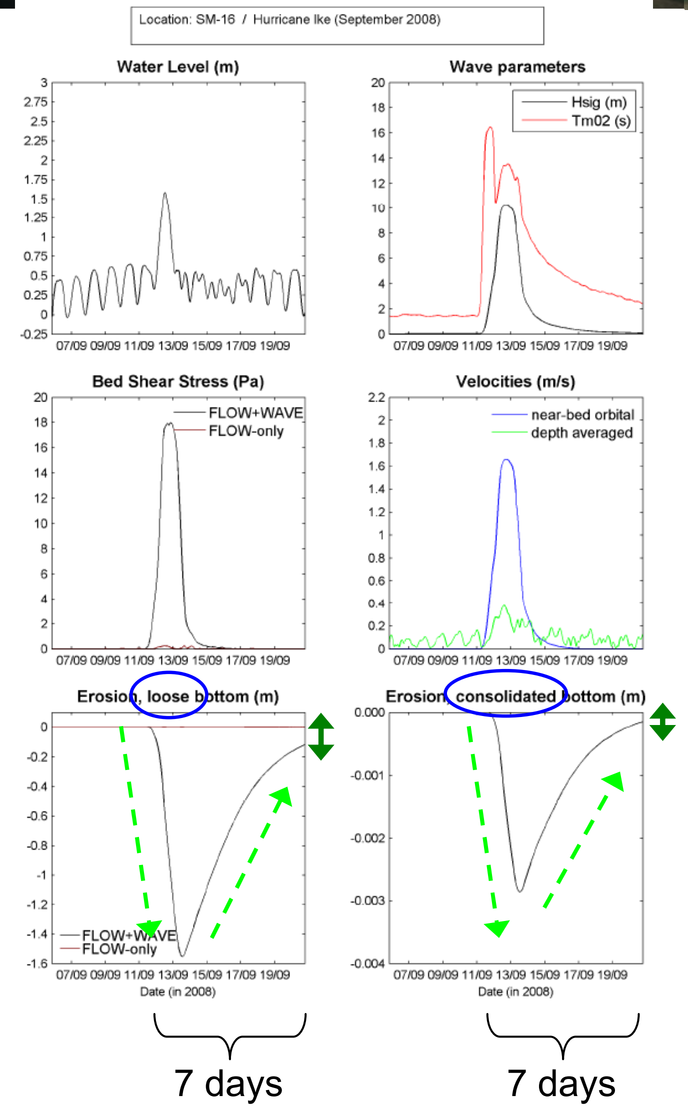
7 days

Deltares

Results from local model: site SM-16







Major Conclusions

Estimated range of thicknesses of bottom sediment that can be disturbed during the passage of strong tropical storms in three specific sites on the upper Texas-Louisiana continental shelf. One regional and three local models, representing the hydrodynamics, surface waves and sediment scour, transport and re-sedimentation simulated the effect of Hurricanes Rita and Ike.

SM-16 is the most dynamic of the three sites, with more scour occurring during the hurricanes but also more re-sedimentation occurring after the hurricanes have passed.

Hurricane Ike caused the most scour at the three sites as it was the largest of the two hurricanes (e.g., Powell and Reinhold, 2007).

Table 5.1 Summary of model results at the 3 sites, for the two storms studied. "Final" refers to 7 days after peak erosion. See Table 8.1 with a summary of results for secondary sites within each domain.

Site, storm (depth)	Peak water level (m)	Peak Hs (m)	Peak bed shear stress (Pa)	Peak erosion, loose (m)	Final erosion, loose (m)	Peak erosion, consol. (mm)	Final erosion, consol. (mm)
SM-16, Rita (26 m)	1.31	10.3	18.5	1.47	0.21	2.8	0.3
SM-16, Ike (26 m)	1.58	10.2	17.8	1.55	0.13	2.9	0.2
HI-178, Rita (15.5 m)	3.15	6.6	14.5	0.84	0.10	1.5	0.1
HI-178, Ike (15.5 m)	3.33	6.9	13.5	1.02	0.29	1.8	0.3
GA-426, Rita (31 m)	1.34	8.7	11.0	0.59	-0.05	1.0	-0.2
GA-426, Ike (31 m)	1.73	12.1	18.8	1.30	0.28	2.4	0.4

OUTCOME:

- Results show range of thicknesses that vary greatly (0.003 - 1.5 m), depending on degree of consolidation.
- The sites are very dynamic; strong scour occurs during storm passage but strong resedimentation occurs after storms passes.
- For loose fine sediment of unlimited thickness, scour depth peaks at 0.6-1.5m but is reduced to only 0.1-0.3 m one week later.
- Observed values for net scour (measured days after event) thus tend to underestimate thickness of disturbed bottom sediment.
- Using an "intermediate" set of values in (integrated) Erosion Depth Equation, i.e. *M* = 5.0e-05 $kg.m^{-2}.s^{-1}$ and *tau_cr* = 0.6 Pa, one obtains peak erosion depths of 0.12 - 0.22 m.

Recommendations for further analyses

Erosion rates depend on many factors, including bulk density, particle size, mineralogy, organic content, salinity of the pore water and consolidation time (e.g., Gailani et al., 2001; Lick and McNeil, 2001). For example bulk properties and erosion rates were measured in Mobile Bay, Alabama. These sediments had high concentrations of manganese and smectite. These components caused significant increases in the critical shear stress for erosion (circa 1.5 Pa) and decreases in the erosion rates (Gailani et al., 2001). In order to more accurately determine the degree of consolidation at the bed, and thus better estimate the critical shear stress for erosion and erosion parameters, information on the bulk density of the sediment samples taken are required. The bulk density of the bed can vary in both the horizontal and vertical direction and variations can cause changes in the erosion rates (Lick and McNeil, 2001).

Required: Bulk density of sediment samples. (may vary both in horizontal and vertical)

A standard soil mechanical analyses should be performed, providing information on the erodibility and stability of the bed. Surface samples can be taken using a 1-litre van Veen grab. Visual inspection of the samples by an expert should be undertaken to determine which samples to further analyse. In addition to bulk density, the parameters to be measured include grain size, salinity, organic content, the Atterberg limits (liquid limit and plastic limit), strength and CST (Capillary Suction Time) testing. Deflocculation of the sediment samples prior to grain size analysis would provide a better estimate of particle size distribution.

Desired: Info on erodibility and stability of bed.
Desired: More standard sediment parameters.
Desired: Deflocculation of samples prior to grain size analysis.

Vertical profiles of the bed properties from cores would provide the information necessary to model a stratified bed instead of a uniform bed. This would produce more realistic results of the amount of scouring experienced at each location as the vertical density structure of the bed would be known.

Desired: Vertical profiles of bed properties, to allow modelling of (non-uniform) stratified bed

The "boundary effects" that have been identified (e.g., Figure 4.14) and that might result in a small underestimation of *net scour* values may be minimized if, instead of such a fine resolution of 50m, a larger domain is chosen. Proximity to open boundaries does not affect peak scour.

Desired: Probably best to "trade" local model's central fine resolution for larger domain

Because bottom shear stress is important in determining scour patterns, the formulation (and the value) used for bottom roughness will also affect sediment results. Here a Manning coefficient of 0.022 is used. Sensitivity tests using Chezy or another formulation is recommended, once there is available data for validation.

Desired: Wise to perform sensitivity tests, using different bottom roughness formulations

Thanks for your attention!

Hurricane-induced bottom stirring on the Louisiana-Texas continental shelf

João Rego, Katherine Cronin, Patrick Hesp, Deepak Vatvani, Amanda Evans, Matthew Keith

joao.rego@deltares.nl katherine.cronin@deltares.nl pahesp@lsu.edu
deepak.vatvani@deltares.nl evansa@teslaoffshore.com keithm@teslaoffshore.com

TESLA EXPLORATION LTD.

LSU

Deltares