Sub-decadal Submarine Landslides on the Mississippi River Delta Front: Magnitude, Frequency, and Forcings

KEHUI (KEVIN) XU

DEPARTMENT OF OCEANOGRAPHY AND COASTAL SCIENCES

LOUISIANA STATE UNIVERSITY

24 AUGUST 2017

THE GEOLOGICAL SOCIETY OF AMERICA®

Sub-decadal submarine landslides are important drivers of deltaic sediment flux: Insights from the Mississippi River Delta Front

Jeffrey Obelcz[1,2]*, Kehui Xu[1,2], Ioannis Y. Georgiou[3], Jillian Maloney[4], Samuel J. Bentley[2,5], and Michael D. Miner[6]

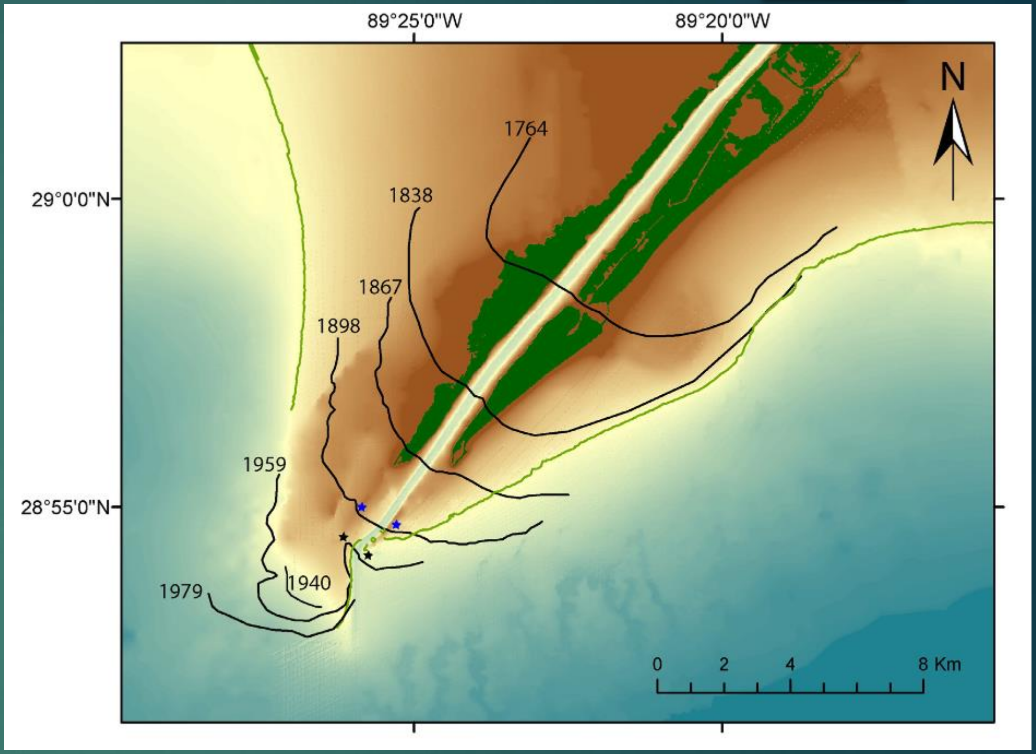
[1]Department of Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge, Louisiana 70803, USA
[2]Coastal Studies Institute, Louisiana State University, Baton Rouge, Louisiana 70803, USA
[3]Department of Earth and Environmental Sciences and Pontchartrain Institute for Environmental Sciences, University of New Orleans, New Orleans, Louisiana 70148, USA
[4]Department of Geological Sciences, San Diego State University, San Diego, California 92182, USA
[5]Department of Geology and Geophysics, Louisiana State University, Baton Rouge, Louisiana 70803, USA
[6]Bureau of Ocean Energy Management, U.S. Department of the Interior, New Orleans, Louisiana 70123, USA

- **Geology (2017) 45 (8): 703-706.**
- **DOI: https://doi.org/10.1130/G38688.1**

- **Part 1: Morphological change**
- **Part 2: triggering mechanism**

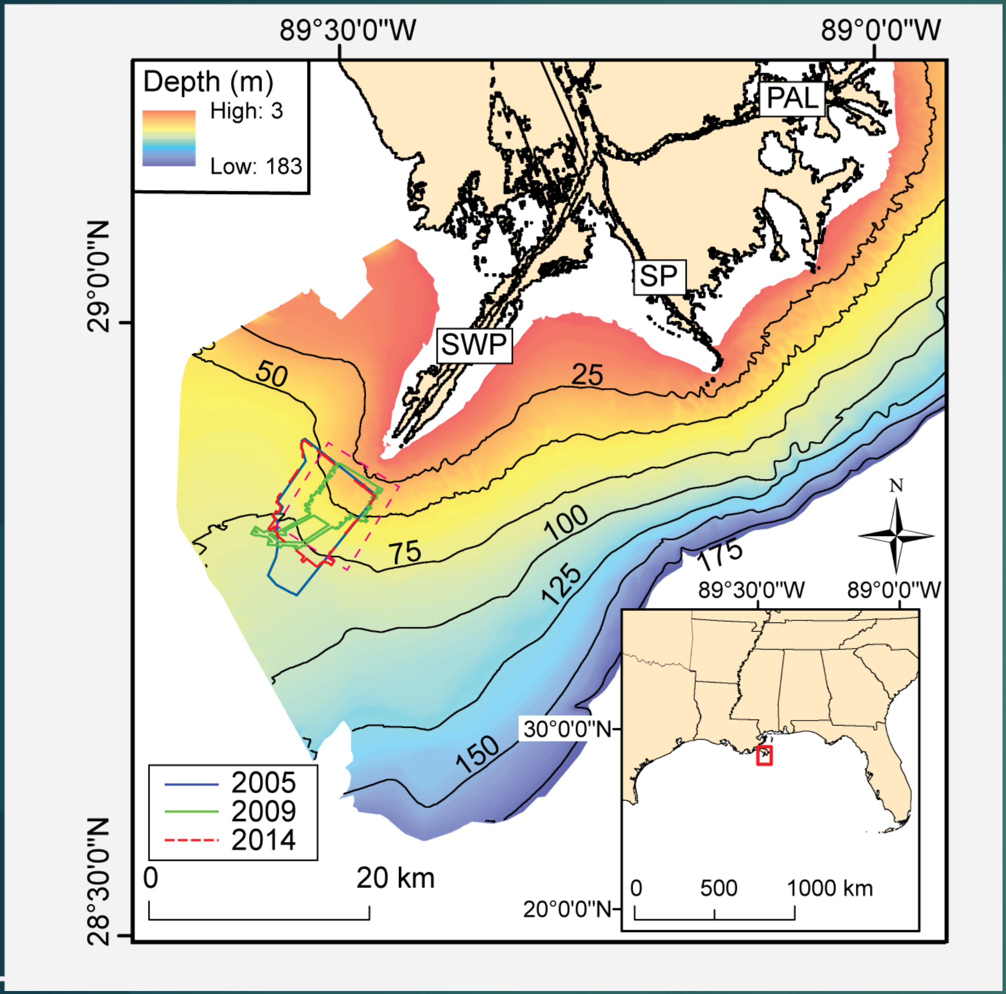
Background and Goals

- Subaqueous Mississippi River Delta Front (MRDF)-rapid deposition of fine-grained, organic-rich, underconsolidated sediment
- Infrastructure damage associated with major hurricane passage, seafloor failure well documented (Bea and Aurora, 1981; Hitchcock et al., 2008)
- Seafloor behavior in between major hurricanes (≥ category 3) largely unexplored
- MRDF is in declining stage of deltaic cycle



Black lines = 10 m isobath
From Bentley et al., 2015

Background and Goals



SWP = Southwest Pass, SP = South Pass
PAL = Pass a Loutre

- Qualify and quantify seafloor movement during a relatively quiescent northern Gulf of Mexico (NGOM) hurricane decade (post-Rita 2005-2014)
- Assess stability of mudflow zones: do they migrate during non-major hurricane intervals?
- Compare magnitude of sediment flux during major hurricane and non-major hurricane intervals
- Identify potential forcings for quiescent landslides

Submarine Landslides on Mississippi River Delta Front

Figure 21: Extent of MRDF mudslides, circa 1980 (from Coleman and Prior, 1980b)

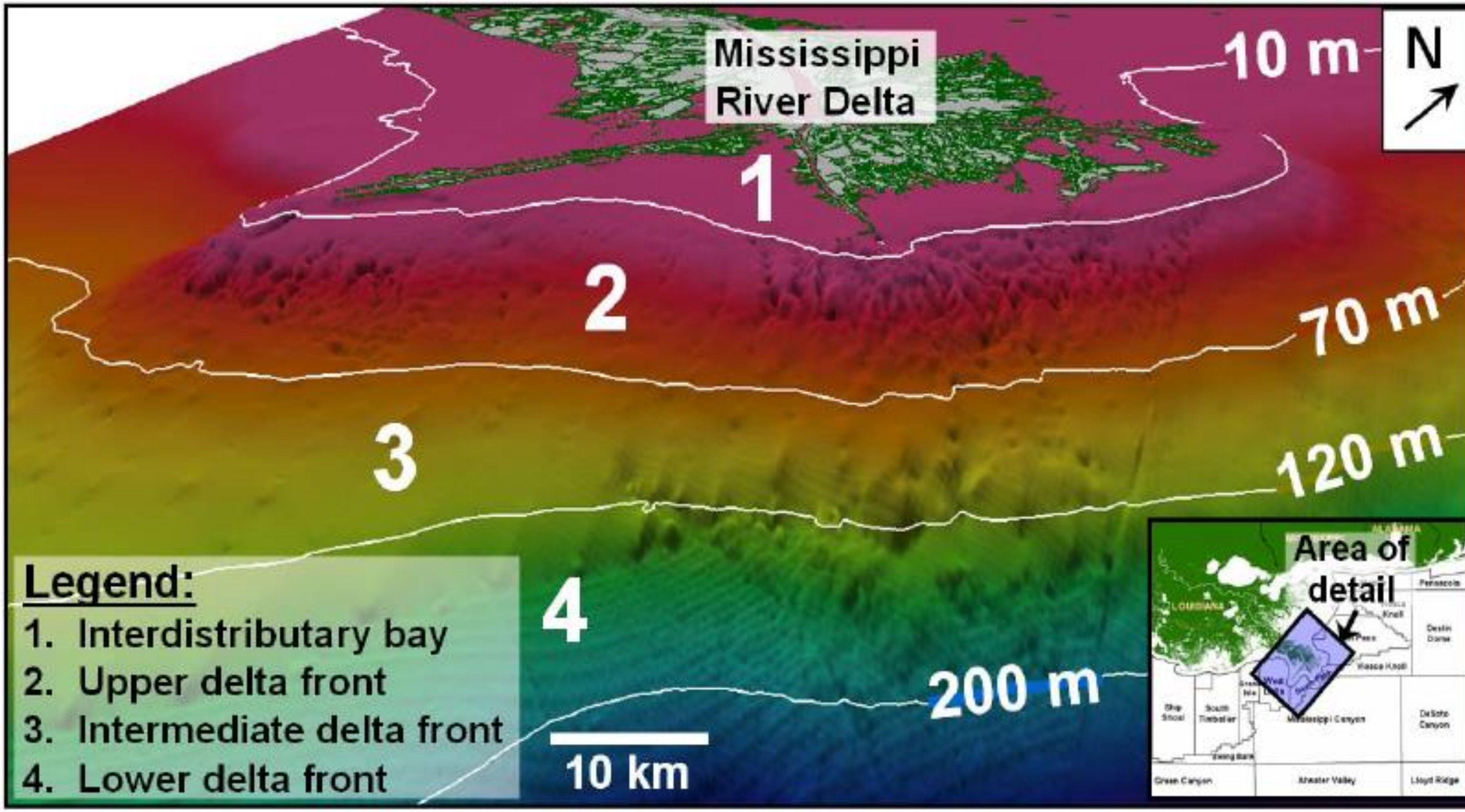
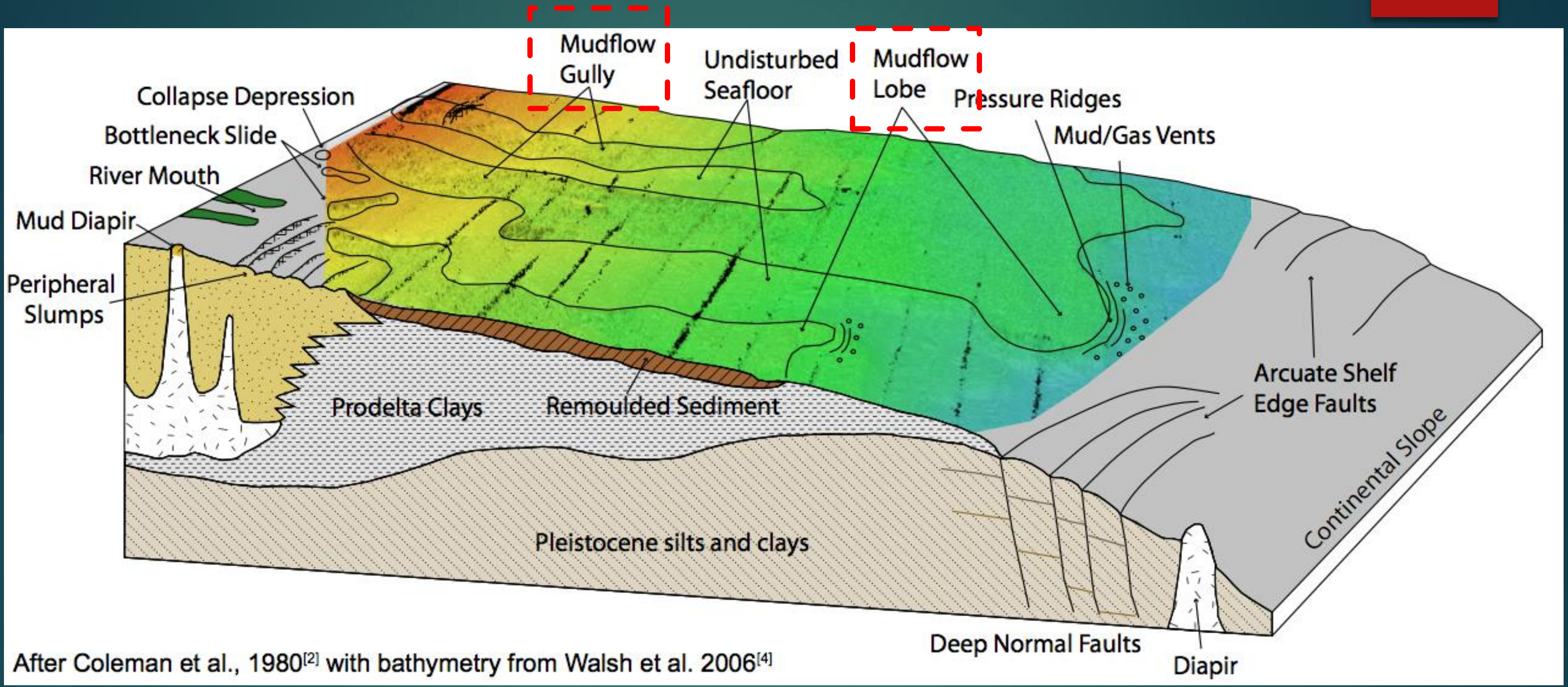


Figure 8: Mississippi River Delta Front (delta front classification from Coleman et al. (1998) superimposed on top of raw data extracted from NOAA, 2009; vertical exaggeration 40:1)

Guidroz (2009)

Geomorphic Setting

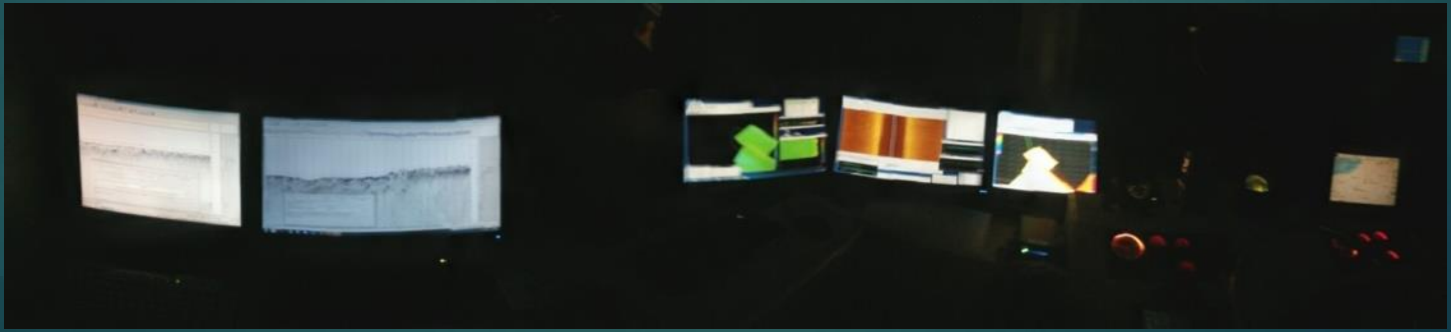


From Bentley et al., 2015

- Mudflow gullies: seafloor depressions, km-scale length, 1-10m scale relief
- Mudflow lobes: seafloor mounds, km-scale length, 10 m scale relief
- Other facies: “interfluve”-between gullies but undisturbed,
- “prodelta”-downslope of gullies/lobes, undisturbed

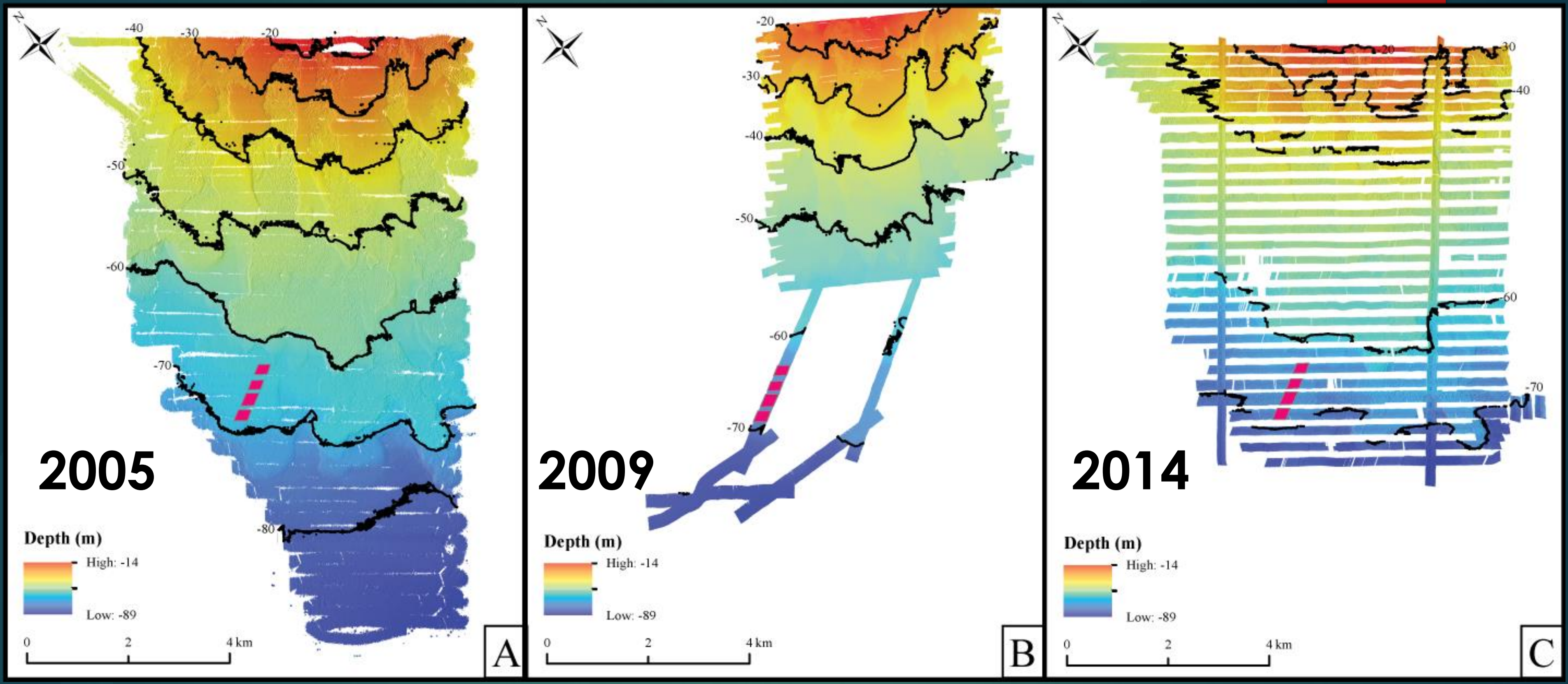
Bathymetry Methodology

- Datasets:
  - 2014 Data is from Edgetech 4600 (coregistered bathy and sidescan)
  - Various multibeam datasets (Walsh, 2006; Fugro, 2009)
- All newly acquired data processed in Caris HIPS and SIPS, turned from pings into Digital Elevation Model (DEM) with resolution of 25 m^2
- All data analyzed in ArcGIS; Difference of Depth (DoD)



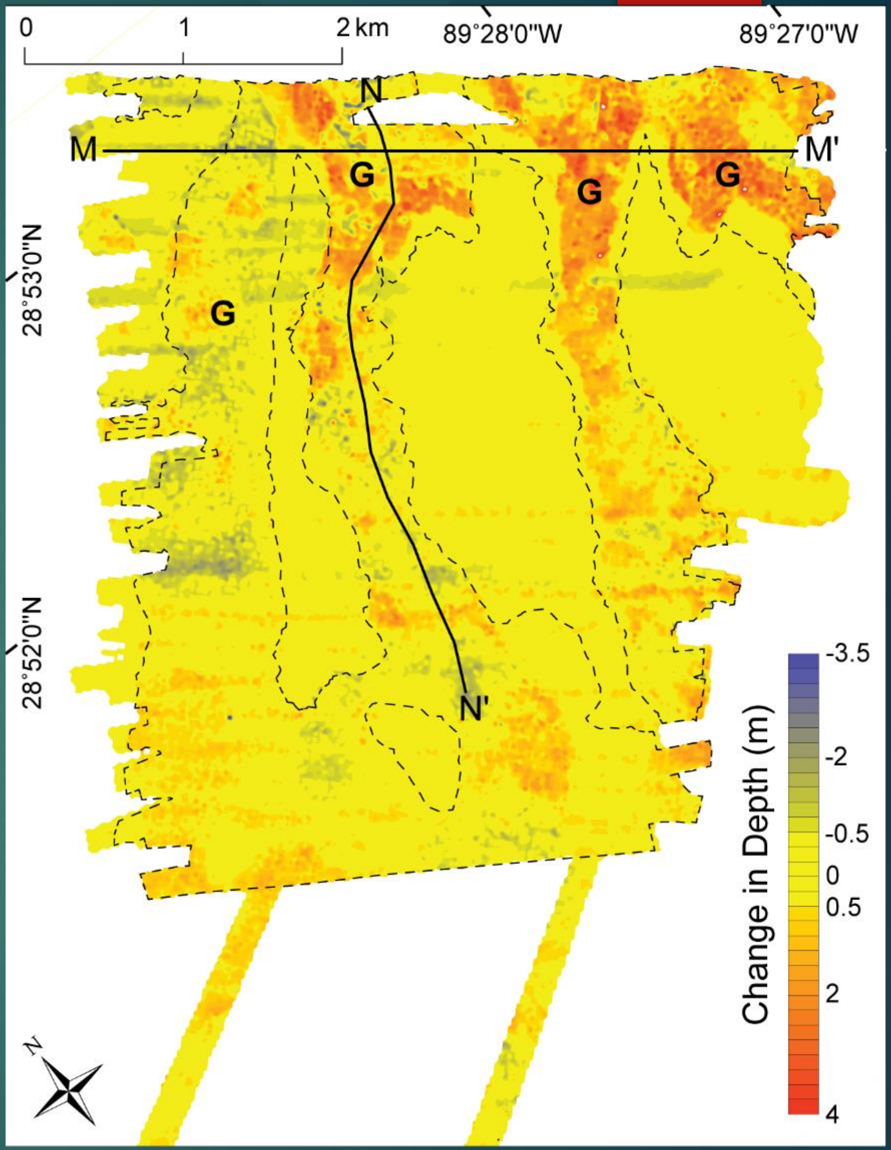
Seabed sonar data collected with LSU-CSI Edgetech 4600 swath/sidescan, in Mississippi River Delta Front

Depth Change



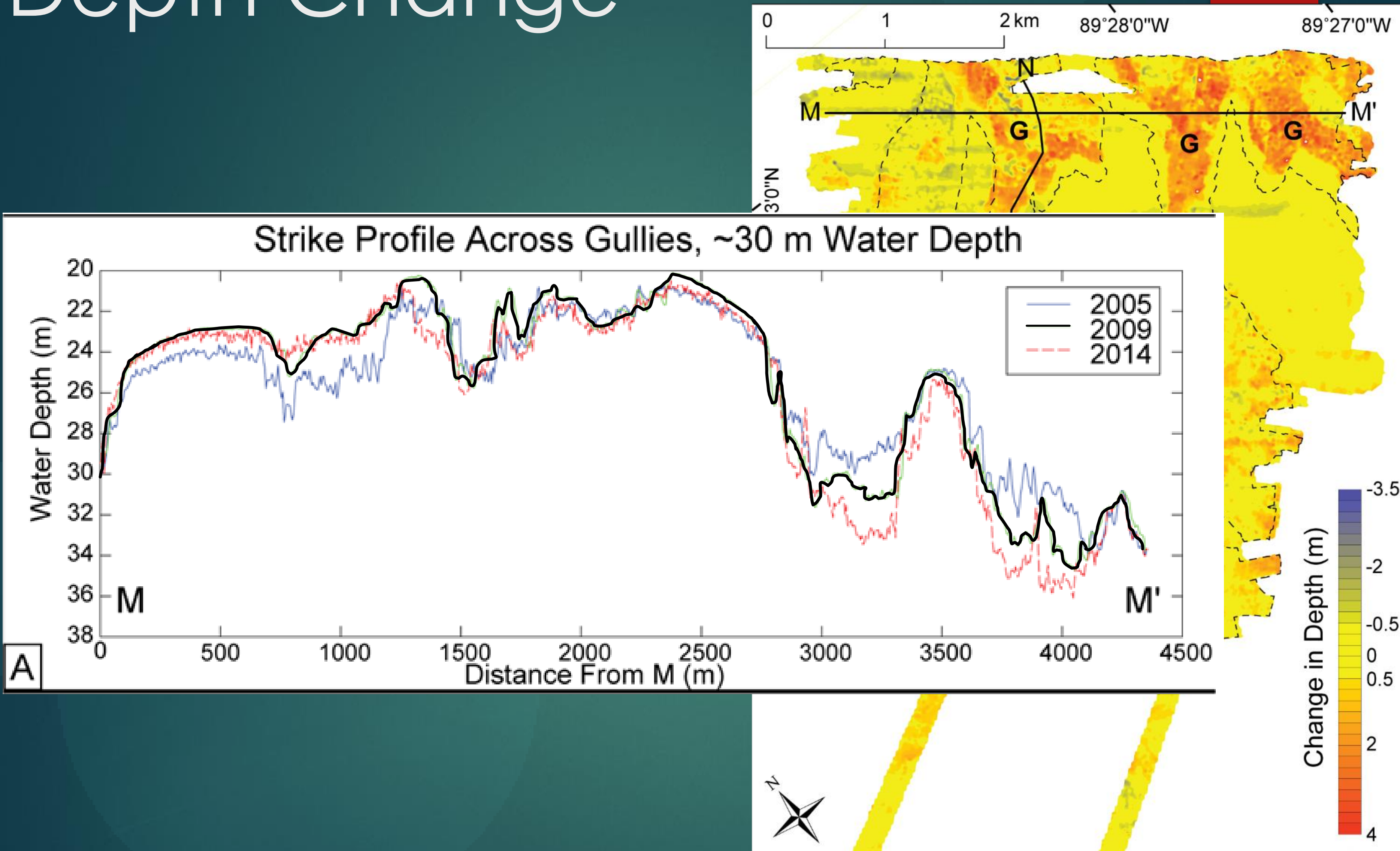
- Three surveys with repeat coverage in October 2005, February 2009, and June 2014
- 2014 survey had incomplete coverage, only used for 2-D transects
- Pink squares used to calculate uncertainty, 2σ (95% CI) = 0.5 m vertical

Depth Change



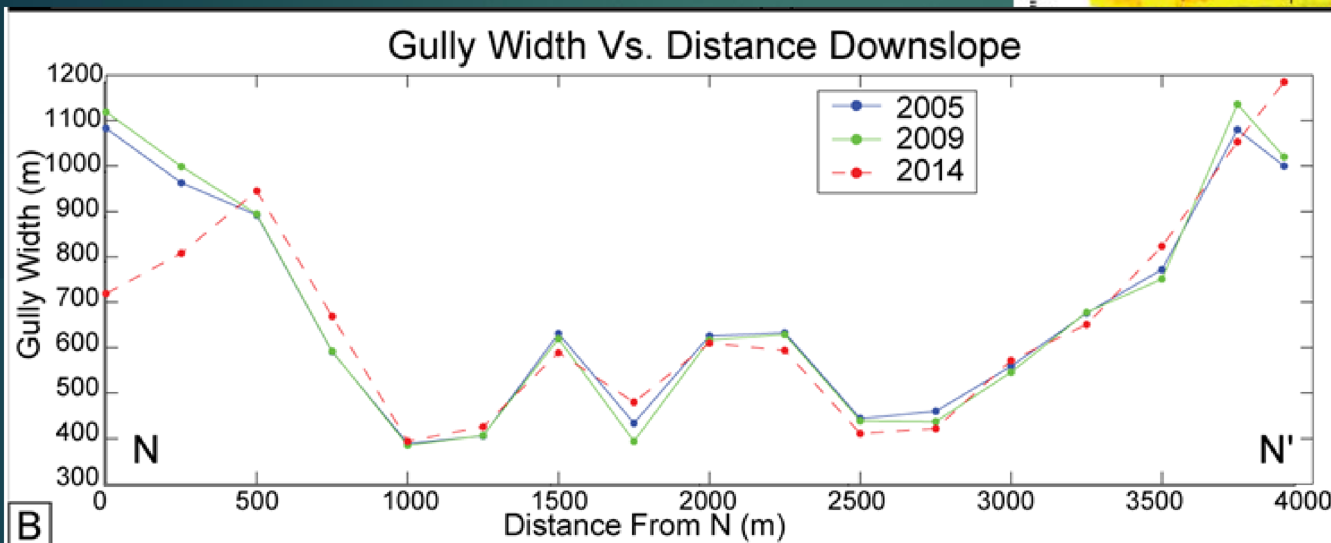
G = mudflow gully zone

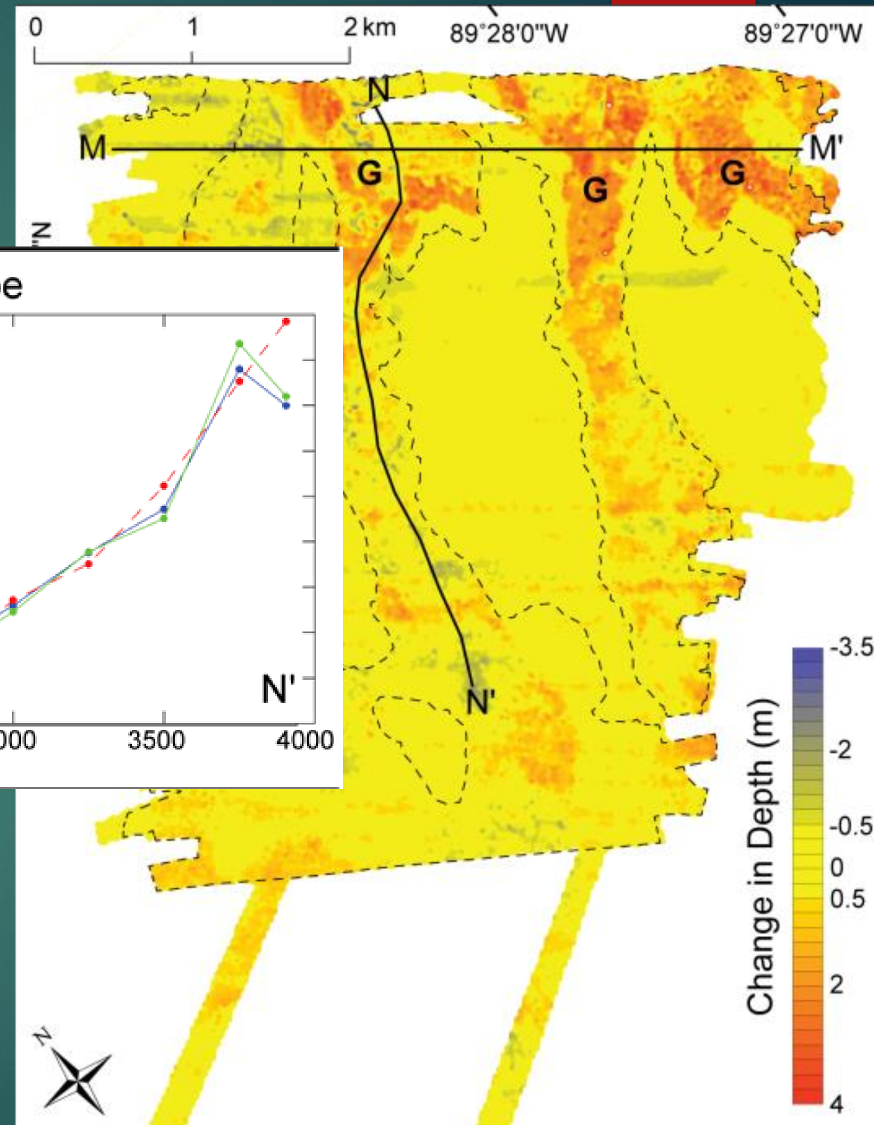
Depth Change



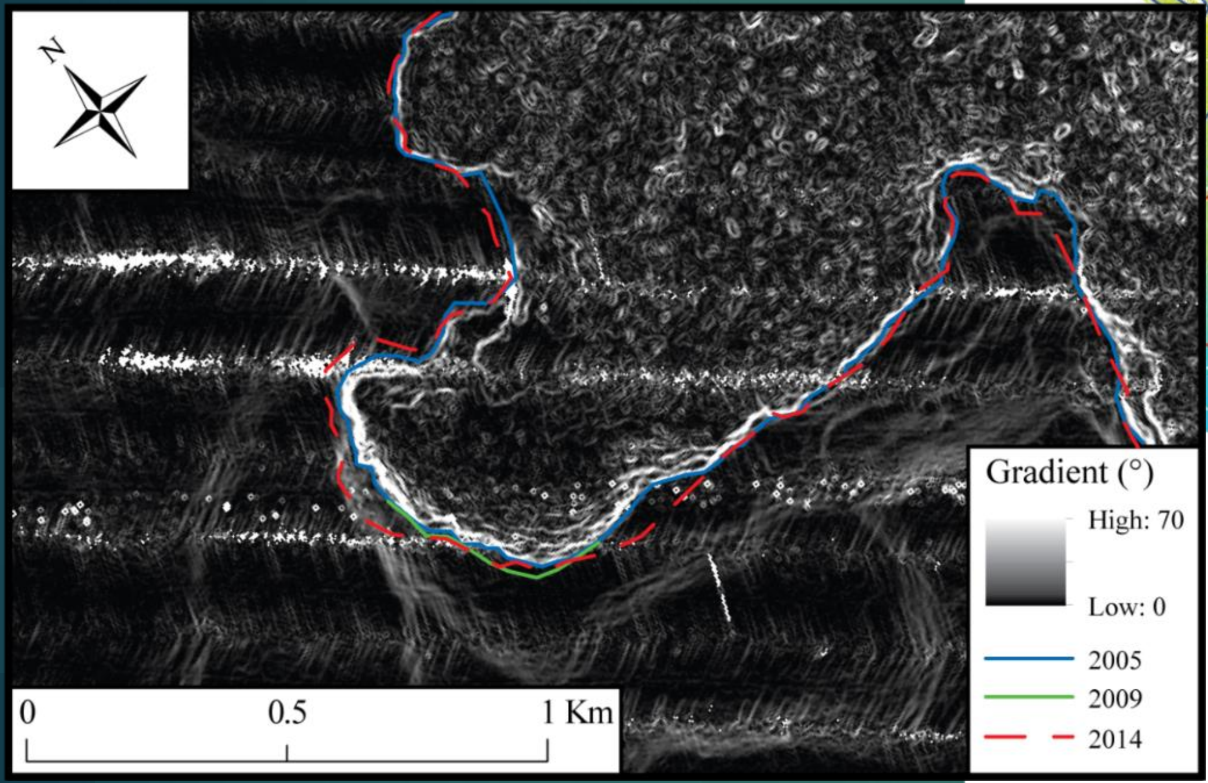
G = mudflow gully zone

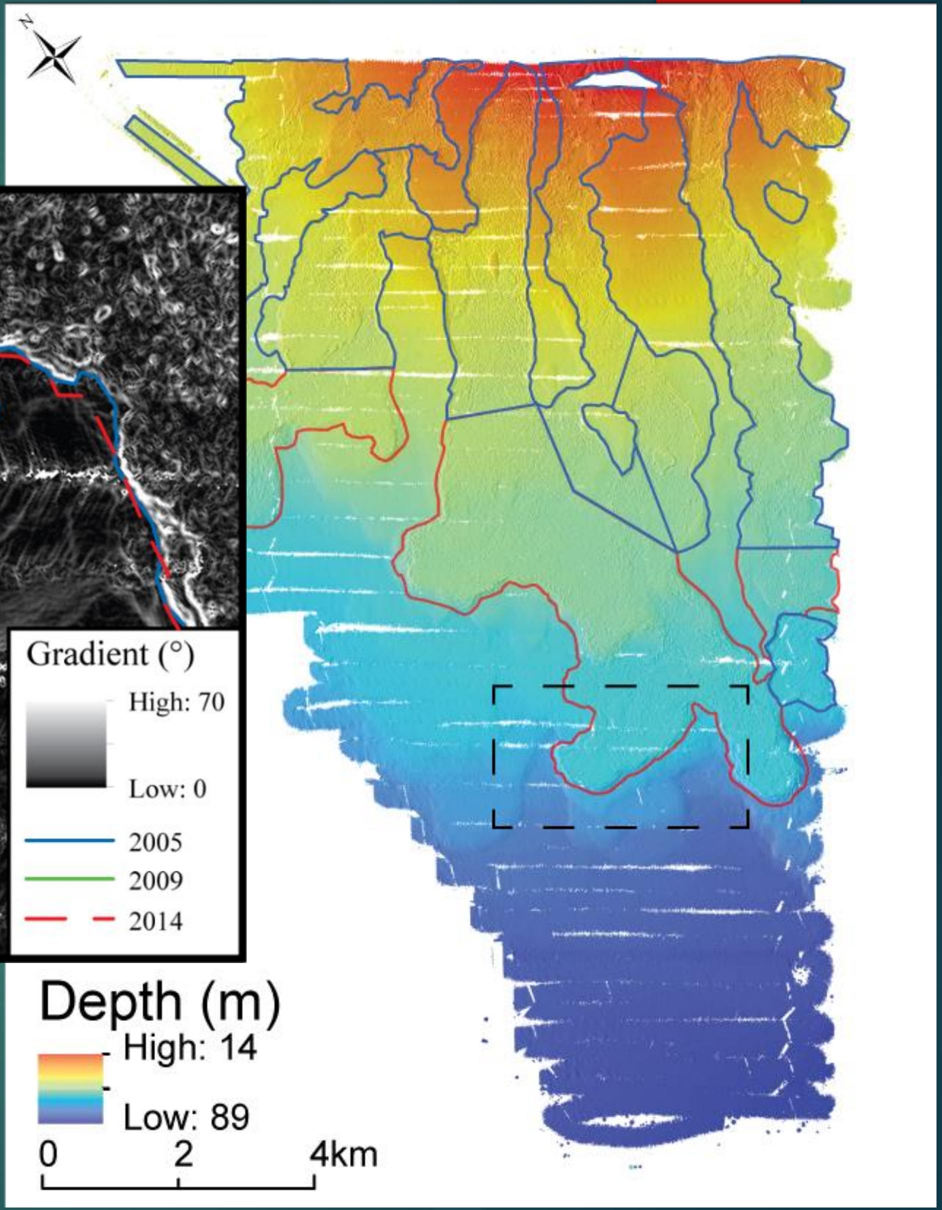
Mudflow Lateral Movement (or lack thereof)





Mudflow Lateral Movement (or lack thereof)





Volumetric Change: Major Hurricane and Low Energy Intervals

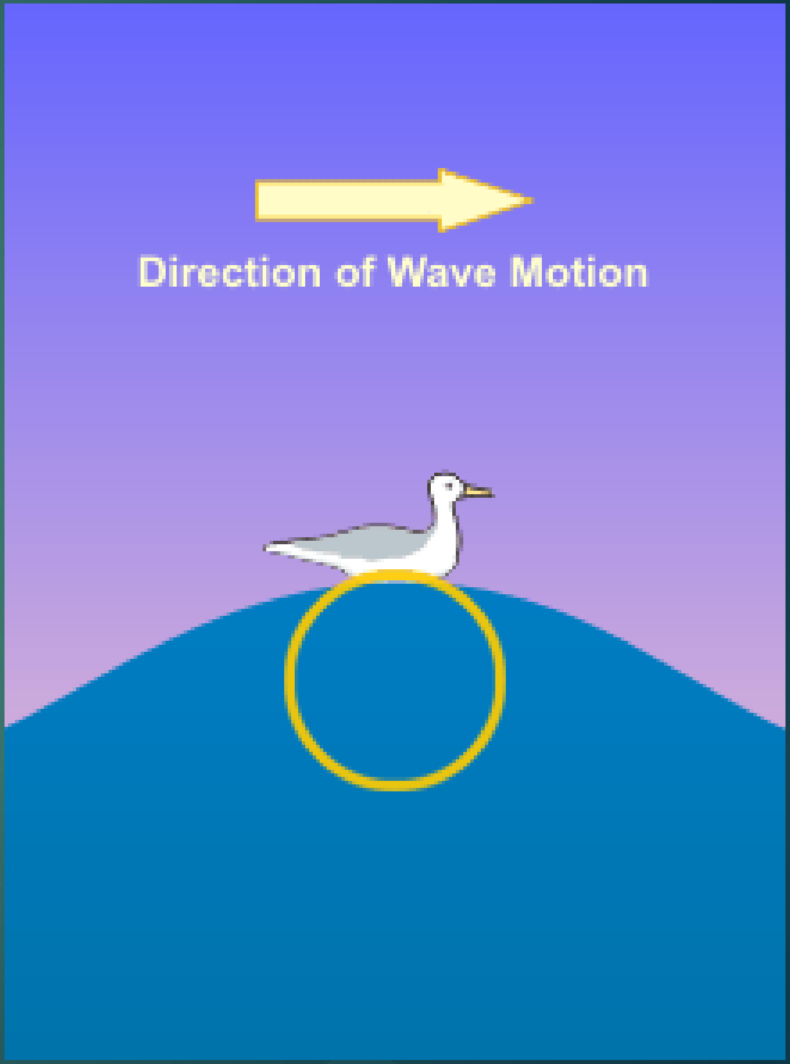
MISSISSIPPI RIVER DELTA FRONT VOLUMETRIC CHANGES

Time Interval	Subset of Study Area	Area (m^2)	Bulk Volumetric Change (m^3)	Net Volumetric Change (m^3)	Uncertainty (+/- m^3)	Annual Volume Transported (m^3/y)
March 1979-October 2005	Mudflow Lobes	6.8×10^6	1.2×10^7	2.8×10^7	3.8×10^6	$1.1 \times 10^6 \pm 1.5 \times 10^5$
October 2005-February 2009	Mudflow Gullies	6.3×10^6	5.5×10^6	2.2×10^6	3.2×10^6	$5.5 \times 10^5 \pm 8 \times 10^5$

Gravity Wave Motion

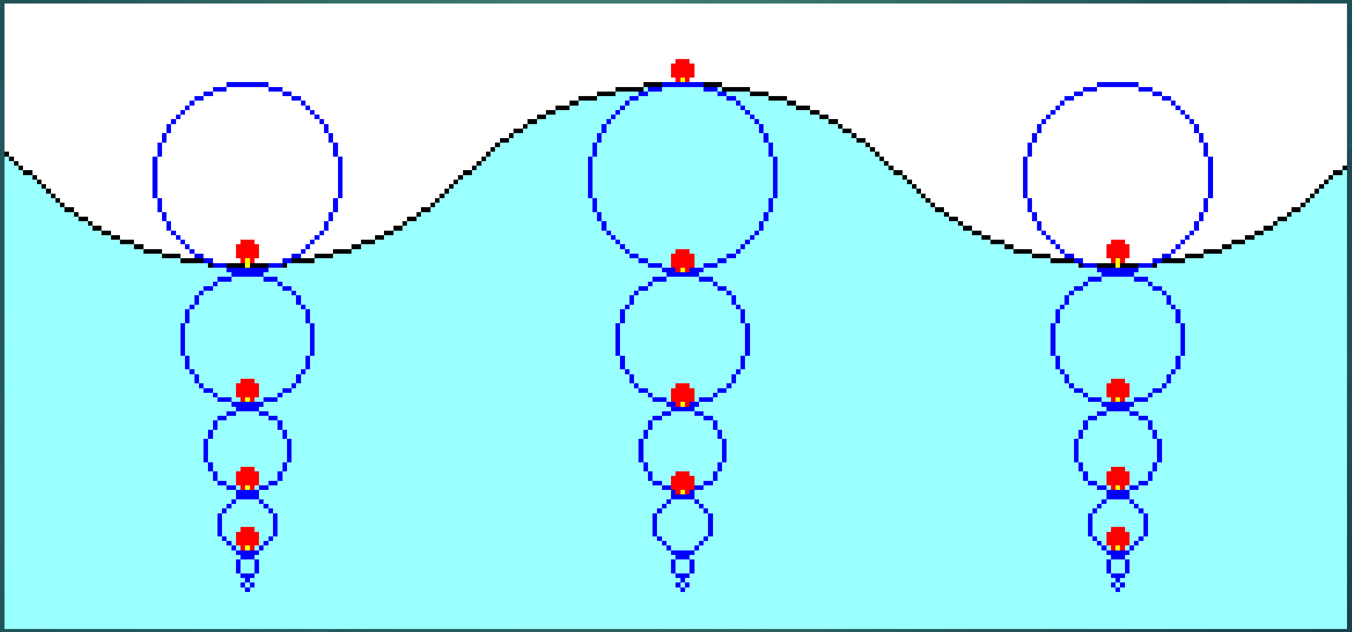
Gravity waves set particles of water in motion

Gravity waves are NOT flows of water, they are flows of motion (energy)



Gravity Wave Motion

- Water particles follow circular paths
  - Orbits
  - Energy is transferred downward but quickly lost



Wave Terms

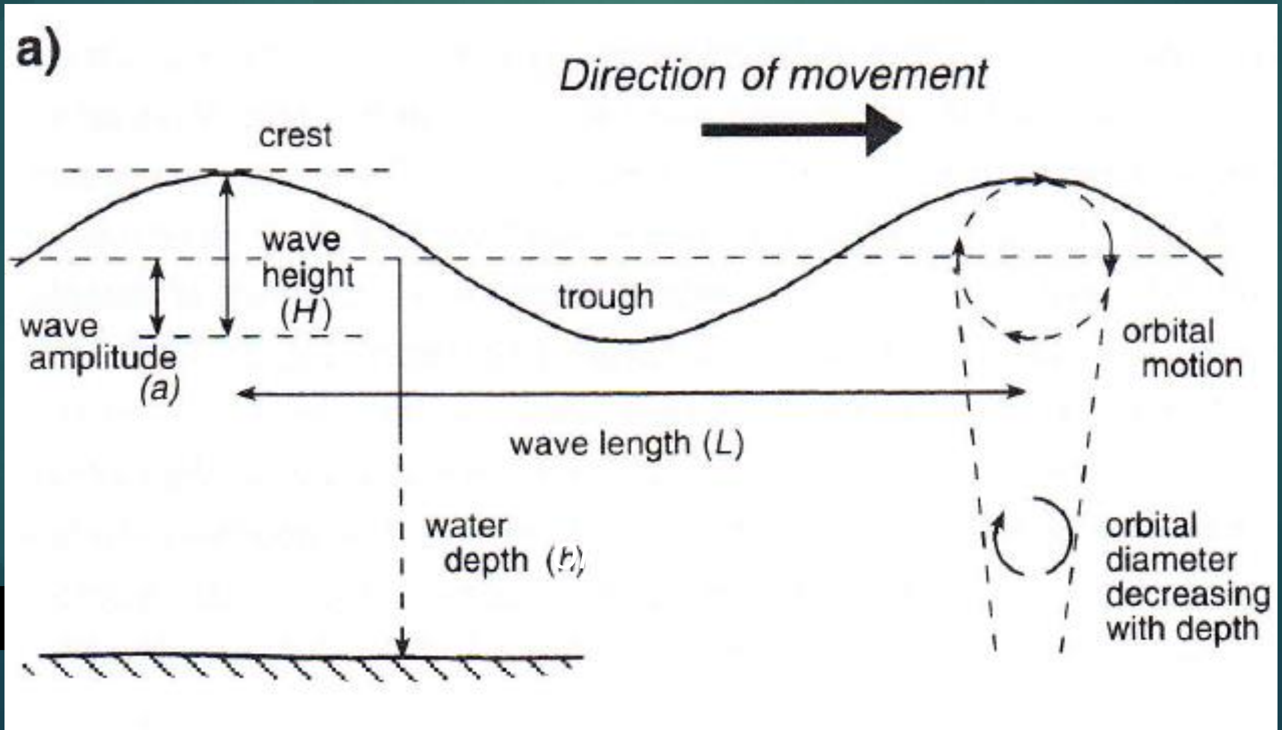
Water Depth, h (or sometime d)

Crest, high water level

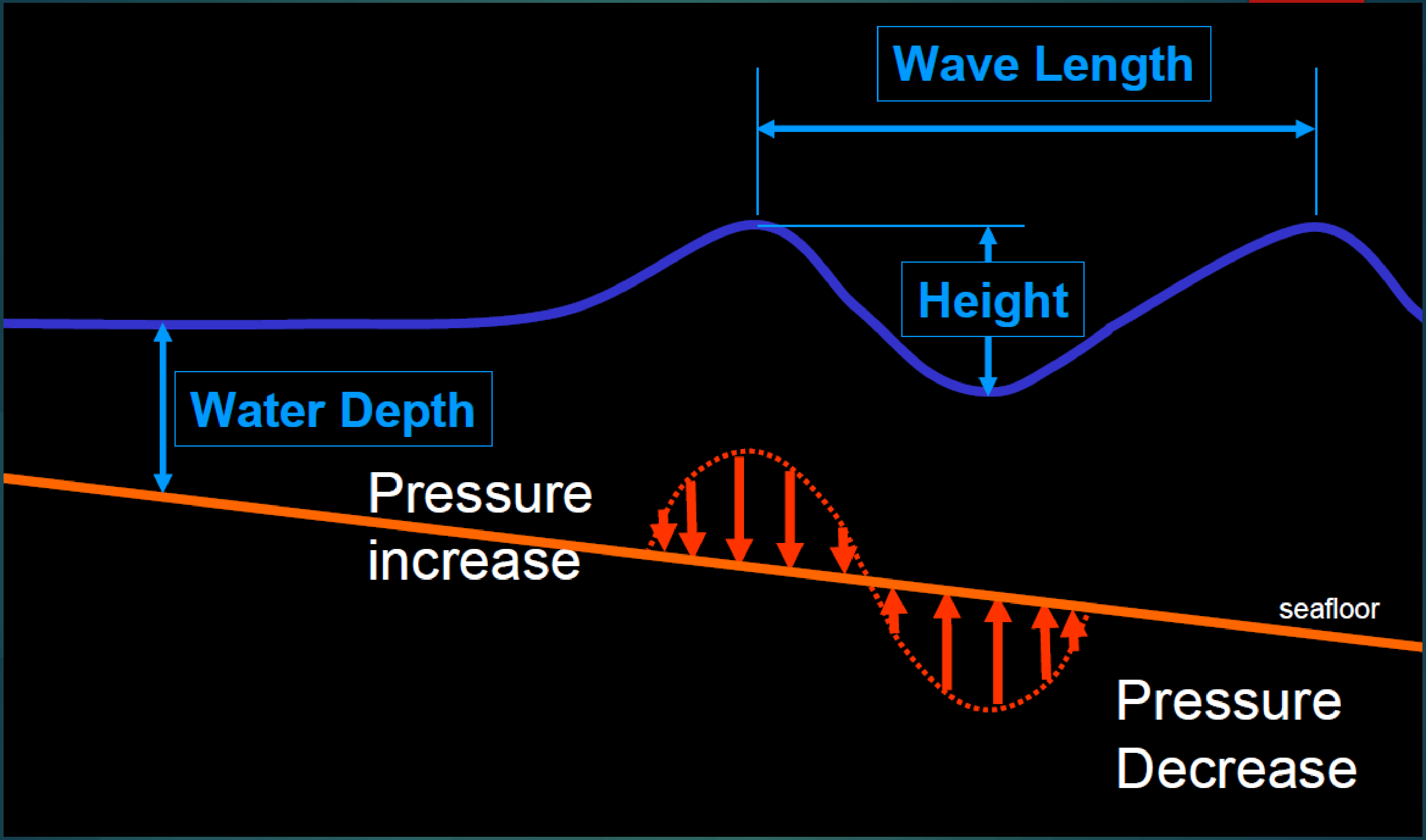
Trough, low water level

Wave height (*H*) = vertical distance from crest to trough

Wave length (L) = distance between crests

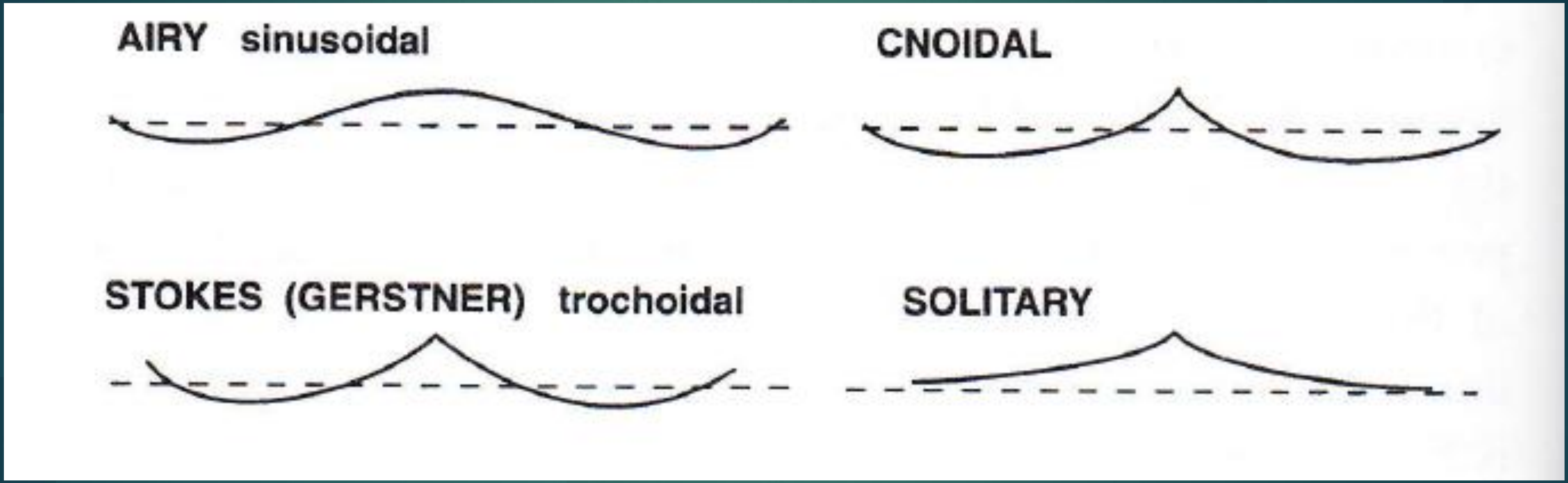


[redacted]



From Hooper 2005

Linear Airy Wave, first order
Stokes Wave, second, third and higher order
Cnoidal and solitary, complex

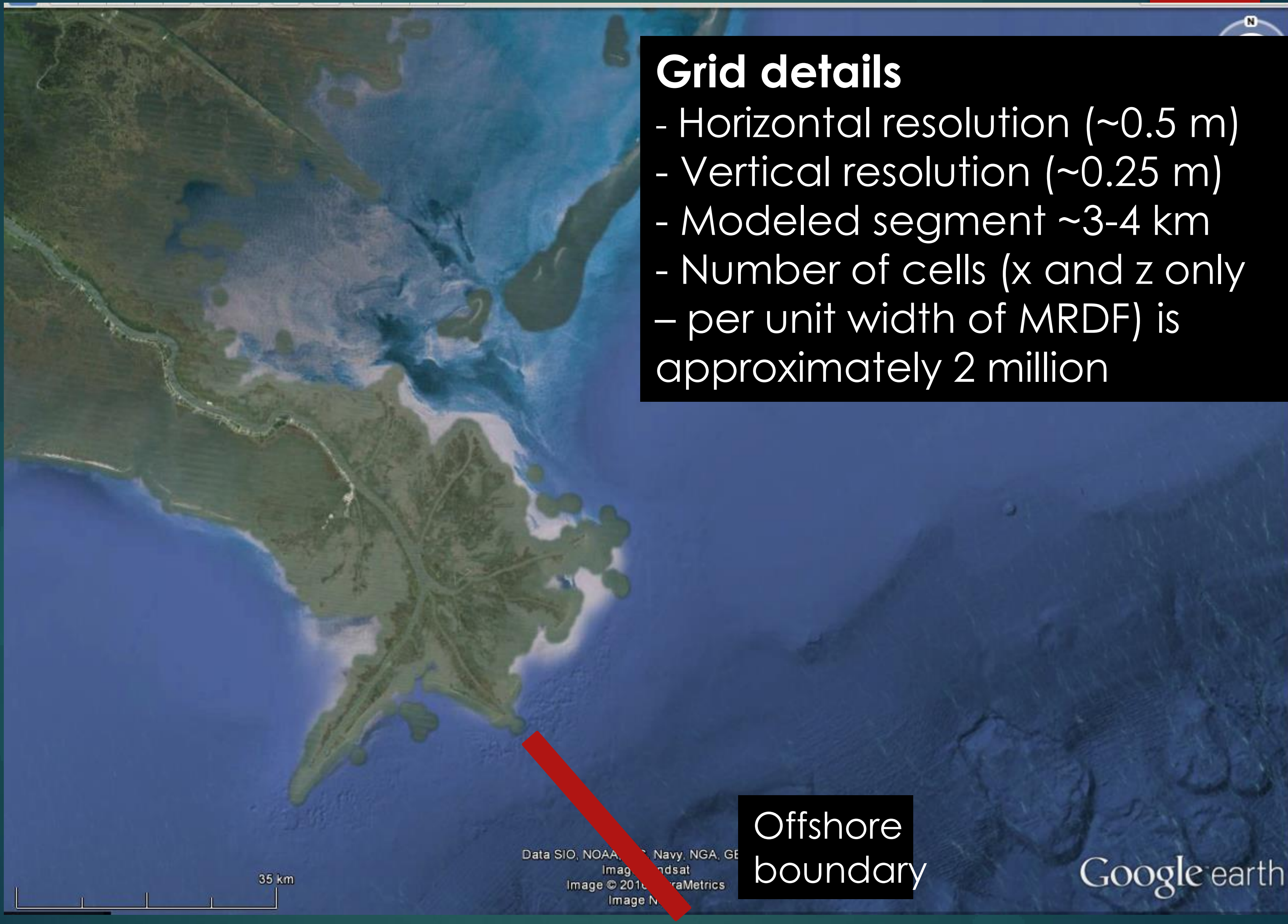


The characteristic wave shapes on which major wave theories were based

Methodology - Model domain

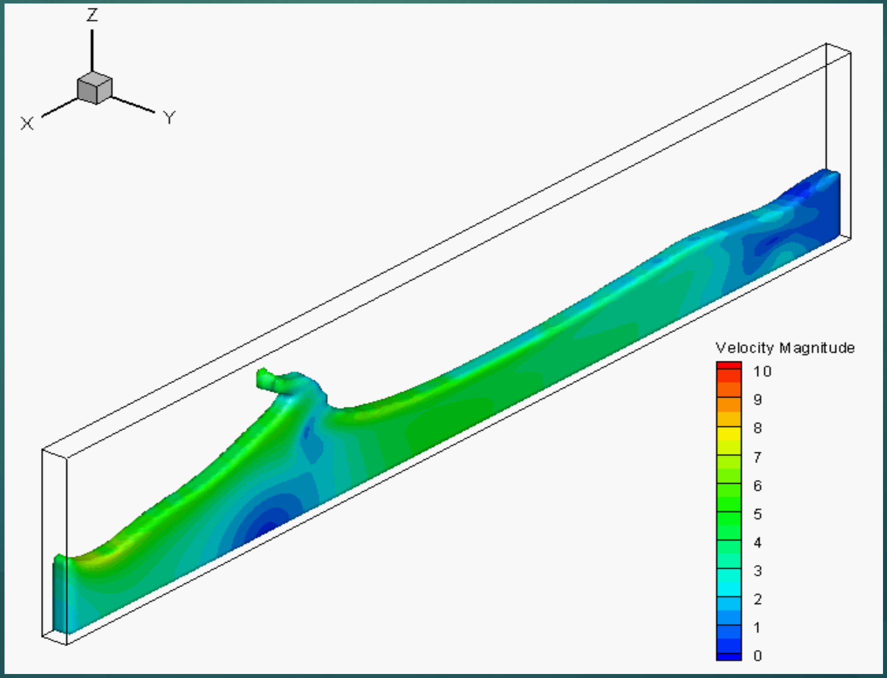
Grid details

- Horizontal resolution (~0.5 m)
- Vertical resolution (~0.25 m)
- Modeled segment ~3-4 km
- Number of cells (x and z only – per unit width of MRDF) is approximately 2 million



Methodology

- Selected FLOW3D (flow Science) – for initial experiments
  - ***Sharp interface*** (water surface elevation) through Volume of Fluid Approach (***VOF***)
  - Many options for higher order advection and turbulence
  - ***non-linear (wave) boundary conditions***

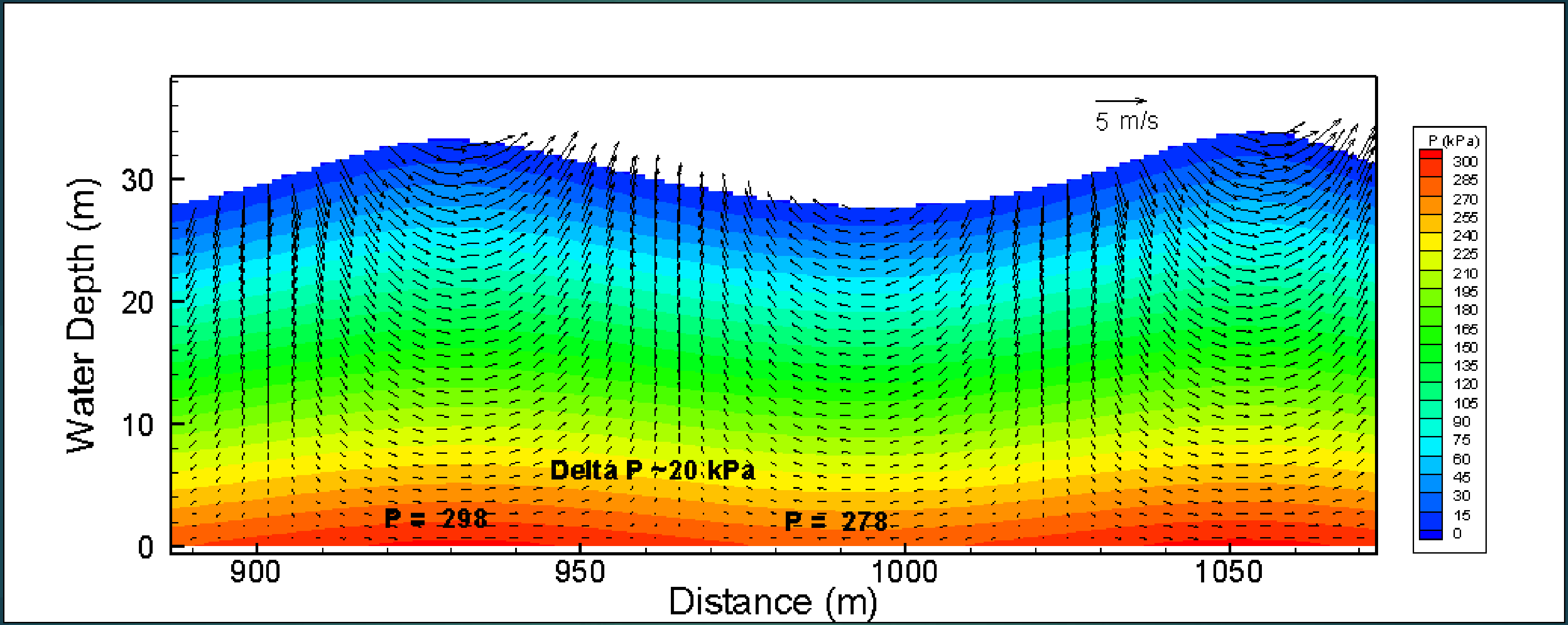


Wave Forcing Modeling

- Three nonlinear wave theories are used for nonlinear wave generation:
  - the fifth-order Stokes wave theory (Fenton, 1985),
  - the Fourier series method for Stokes and cnoidal waves (Fenton, 1999),
  - McCowan's theory for solitary wave (McCowan, 1891; Munk, 1949).

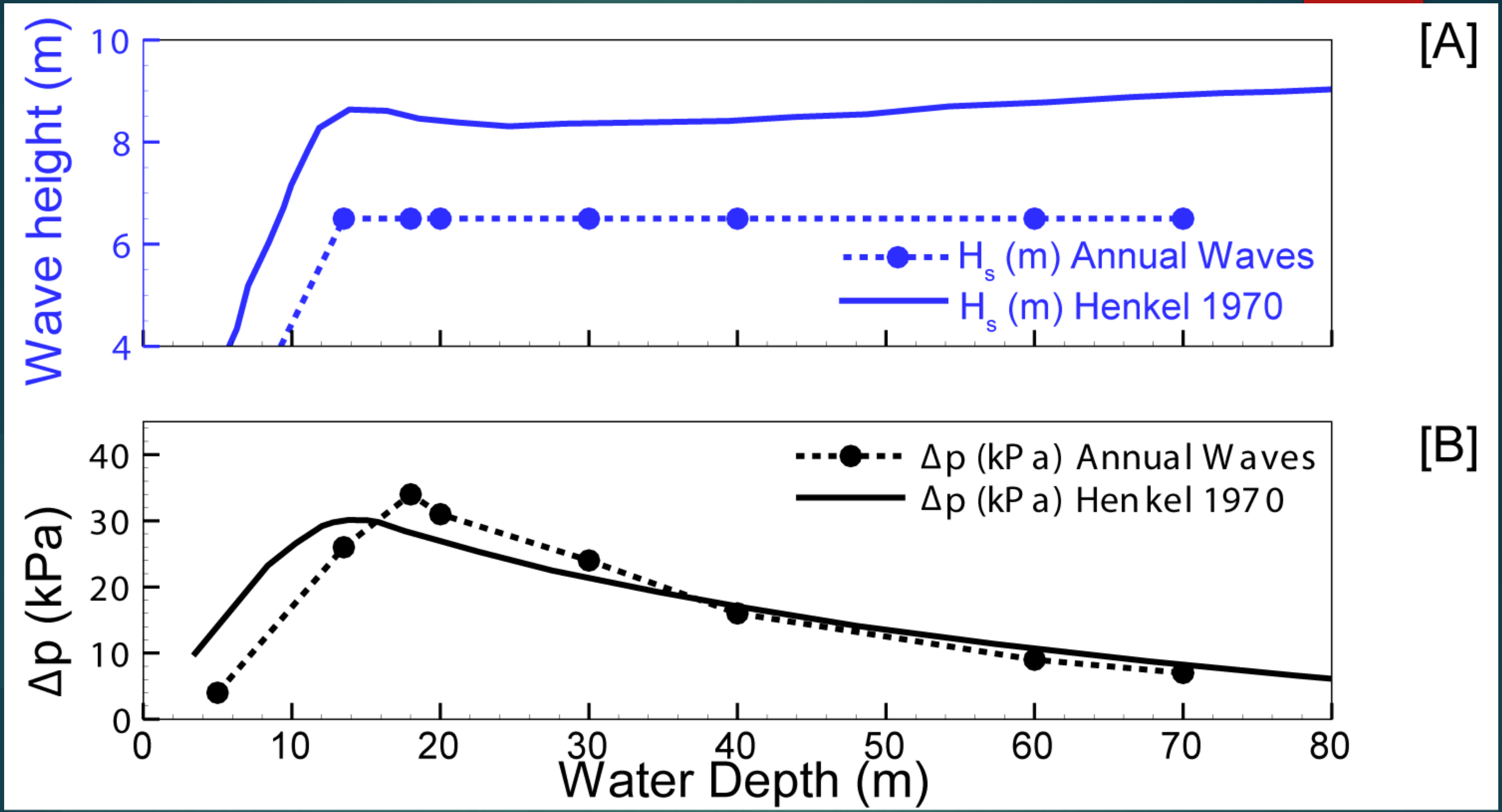
- Fourier series method was used in Obelcz et al.(2017)

Wave Forcing Modeling



Pressure differential resulting from the 1 yr wave on the MRDF – flat slope

MRDF Wave Modeling



- Comparable peak-trough pressure differential between linear hurricane waves and nonlinear 1-year waves
- Both above threshold estimated by Seed and Rahman (1978) to destablize seafloor, initiate landslides

Interpretation and Implications – Bathymetry

- Appreciable vertical seafloor movement (~1 m/year) occurs in lieu of major hurricane passage on the MRDF

Interpretation and Implications – Bathymetry

- Appreciable vertical seafloor movement (~1 m/year) occurs in lieu of major hurricane passage on the MRDF
- Low energy seafloor movement is largely confined to existing mudflow zones-this is NOT the case for submarine landslides associated with major hurricane passage

Interpretation and Implications – Bathymetry

- Appreciable vertical seafloor movement (~1 m/year) occurs in lieu of major hurricane passage on the MRDF
- Low energy seafloor movement is largely confined to existing mudflow zones - this is NOT the case for submarine landslides associated with major hurricane passage
- Normalized for time, “fair weather” submarine landslides transport about half the volume downslope major hurricane-forced landslides do - more than previously conceptualized

Interpretation and Implications – Bathymetry

- Appreciable vertical seafloor movement (~1 m/year) occurs in lieu of major hurricane passage on the MRDF
- Low energy seafloor movement is largely confined to existing mudflow zones-this is NOT the case for submarine landslides associated with major hurricane passage
- Normalized for time, “fair weather” submarine landslides transport about half the volume downslope major hurricane-forced landslides do-more than previously conceptualized
- Similar observations have been made (more frequent, smaller magnitude landslides comparable to less frequent, larger ones) on other margins (Kelner et al., 2016)

Interpretation and Implications – Bathymetry

- Appreciable vertical seafloor movement (~1 m/year) occurs in lieu of major hurricane passage on the MRDF
- Low energy seafloor movement is largely confined to existing mudflow zones-this is NOT the case for submarine landslides associated with major hurricane passage
- Normalized for time, "fair weather" submarine landslides transport about half the volume downslope major hurricane-forced landslides do-more than previously conceptualized
- Similar observations have been made (more frequent, smaller magnitude landslides comparable to less frequent, larger ones) on other margins (Kelner et al., 2016)
- If this trend applies to margins worldwide, budgets for flux of sediment, organic carbon, and particulates (heavy metals) from shelf to deep sea may be temporally long-skewed and in need of revision

Interpretation and Implications – Wave Modeling

- Smaller nonlinear waves with similar differential **crest-trough pressure** as larger nonlinear waves: importance of realistically simulating "sharper" nonlinear waveforms

Interpretation and Implications – Wave Modeling

- Smaller nonlinear waves with similar differential peak-trough pressure as larger nonlinear waves: importance of realistically simulating "sharper" nonlinear waveforms
- One year return period waves: cold fronts, tropical storms

Interpretation and Implications – Wave Modeling

- Smaller nonlinear waves with similar differential peak-trough pressure as larger nonlinear waves: importance of realistically simulating “sharper” nonlinear waveforms
- One year return period waves: cold fronts, tropical storms
- One year waves are only one possible forcing mechanism, others include river floods, growth fault movement

Interpretation and Implications – Wave Modeling

- Smaller nonlinear waves with similar differential peak-trough pressure as larger nonlinear waves: importance of realistically simulating "sharper" nonlinear waveforms
- One year return period waves: cold fronts, tropical storms
- One year waves are only one possible forcing mechanism, others include river floods, growth fault movement
- *In situ* observation necessary to elucidate forcing mechanism(s) of sub-decadal MRDF landslides

Questions?

- References Cited

- Bea, R.G., and Aurora, R.P., 1981. A simplified evaluation of seafloor stability: Offshore Technology Conference, Houston, Texas, 4-7 May.
- Bentley Sr., S.J., Blum, M.D., Maloney, J., Pond, L., Paulsell, R., 2015. The Mississippi River source-to-sink system: Perspectives on tectonic, climatic, and anthropogenic influences, Miocene to Anthropocene. Earth-Science Reviews 153: 139-174.
- Henkel, D.J., 1970, The role of waves in causing submarine landslides. Geotechnique 20: 75-80.
- Hitchcock, C., Angell, M., Givler, R., and Hooper, J., 2008. Transport and depositional features associated with submarine mudflows, Mississippi Delta, Gulf of Mexico. Gulf Coast Association of Geological Societies Transactions 58: 801–809.
- Kelner, M., Migeon, S., Tric, E., Couboulex, F., Dano, A., Lebourg, T., Taboada, A, 2016. Frequency and triggering of small-scale submarine landslides on decadal timescales: analysis of 4D bathymetric data from the continental slope offshore Nice (France). Marine Geology 379: 281-297.
- Obelcz, J., Xu, K., Georgiou, I.Y., Maloney, J., Bentley, S.J., Miner, M.D., 2017, Sub-decadal submarine landslides are important drivers of deltaic sediment flux: insights from the Mississippi River Delta Front. Geology (in press).
- Walsh, J.P., Corbett, D.R., Mallison, D., Goni, M., Dail, M., Loewy, C., Marciniak, K., Ryan, K., Smith, C., Stevens, A., Sumners, B., Tesi, T., 2006. Mississippi Delta mudflow activity and 2005 Gulf hurricanes. Eos 87: 477-478.