Are Numerical Models Useful? Lessons Learned from Twenty Years of Modeling Coastal Morphology Change in the State of Florida

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FLORIDA SHORE & BEACH
PRESERVATION ASSOCIATION
A League of Cities and Counties on Beach and Coastal Issues

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All models are wrong, some models are useful

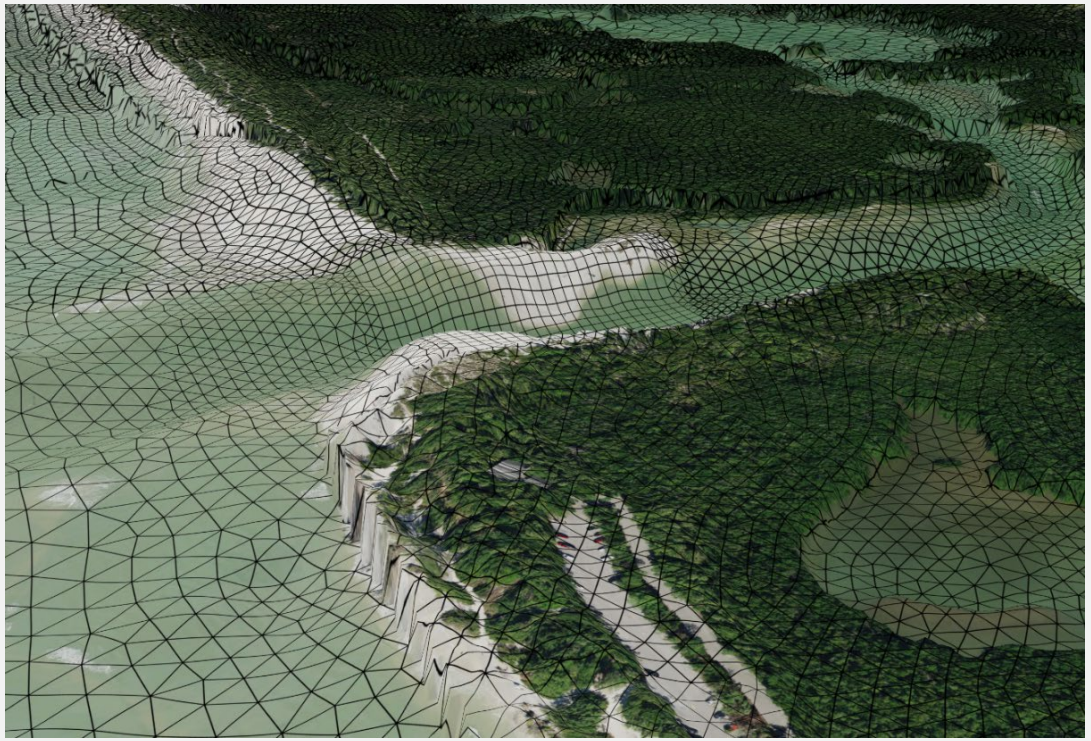
George Box, British Statistician

A scientific theory [model] should be as simple as possible, but not simpler

Albert Einstein

WHY MODEL A COASTAL PROJECT?

- To understand coastal processes/performance drivers.
- To balance sand retention and downdrift impacts on coastal structures projects.
- To fine tune beach fill total volume placement and fill alongshore density distribution.
- To refine channel cut design and refine cut volumes.
- To evaluate the impacts from coastal projects.
- **To evaluate performance of design alternatives relative to one another.**



WHY DID WE START USING DELFT3D

Longboat Key, Islander, Permeable Adjustable Groins

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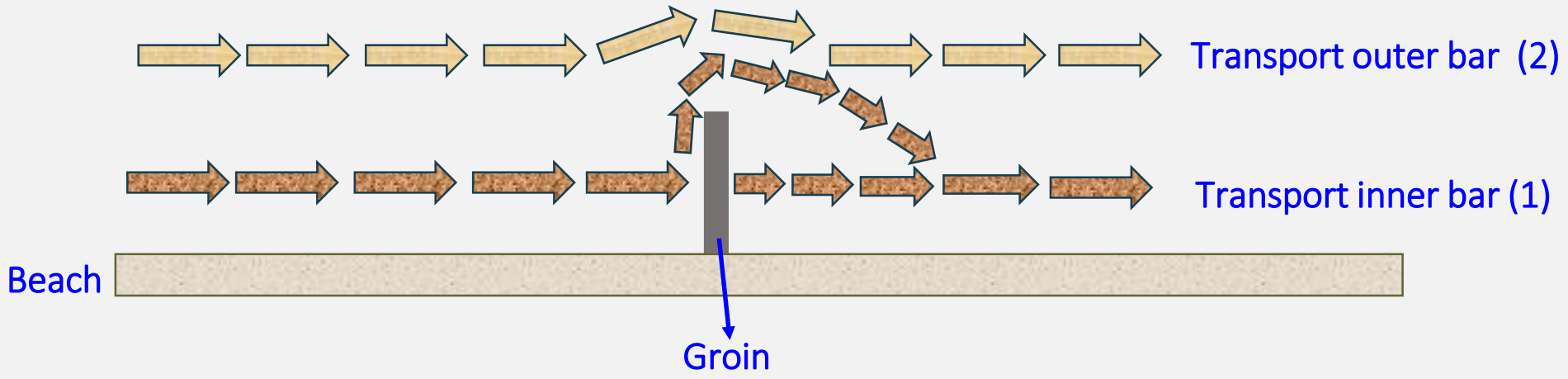
WHY DID WE START USING DELFT3D



No numerical model at the time could simulate these processes.
Difficult to optimize the design of a permeable structure.

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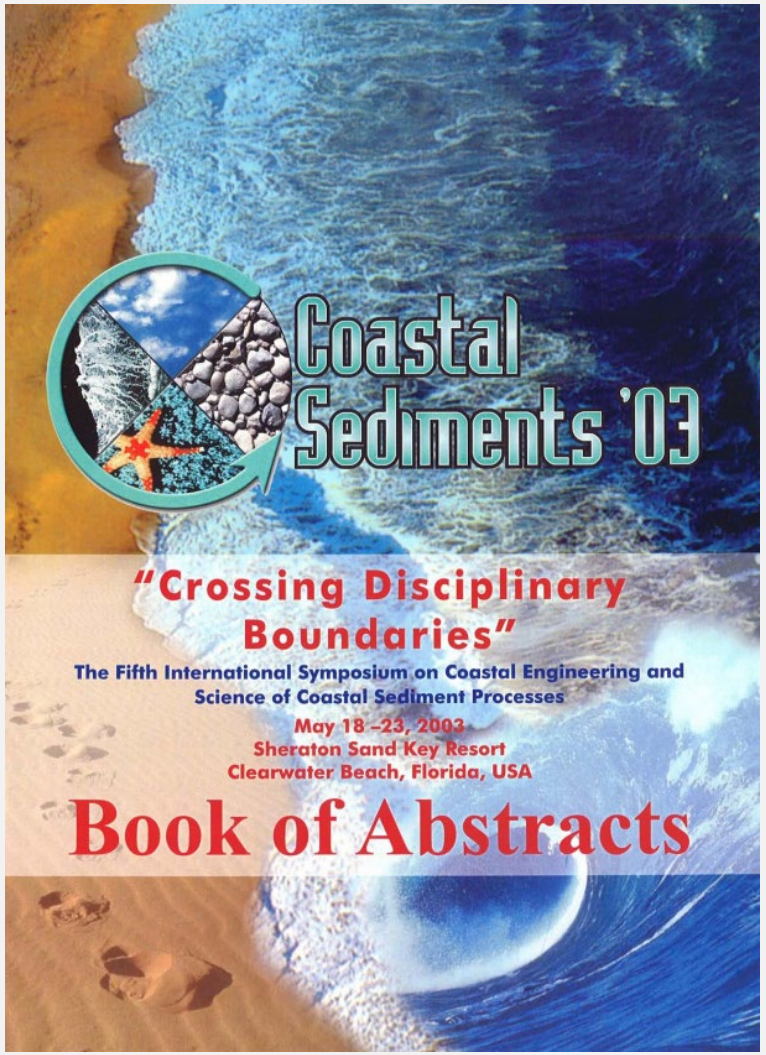
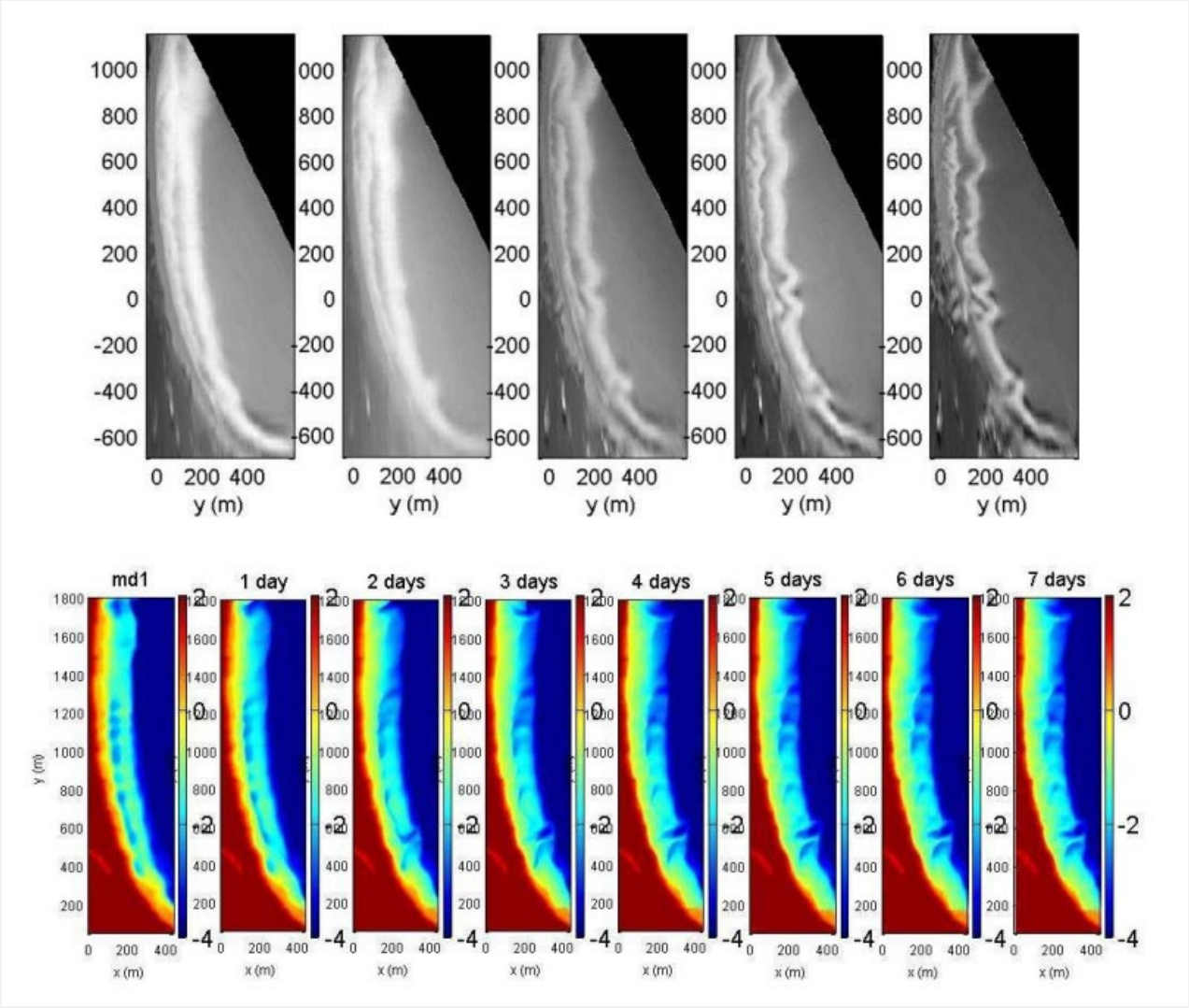
WHY DID WE START USING DELFT3D





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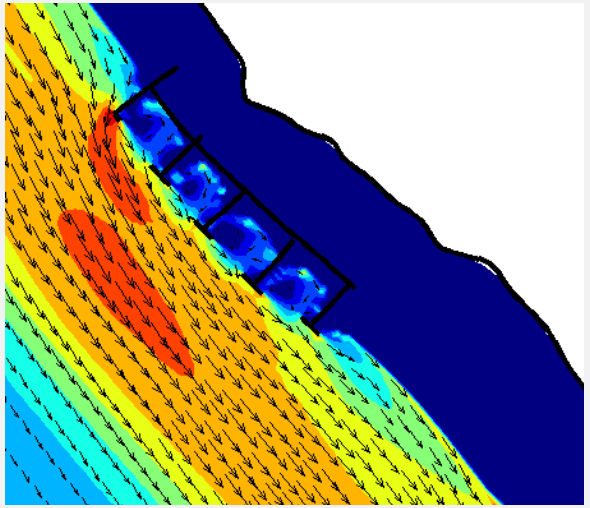
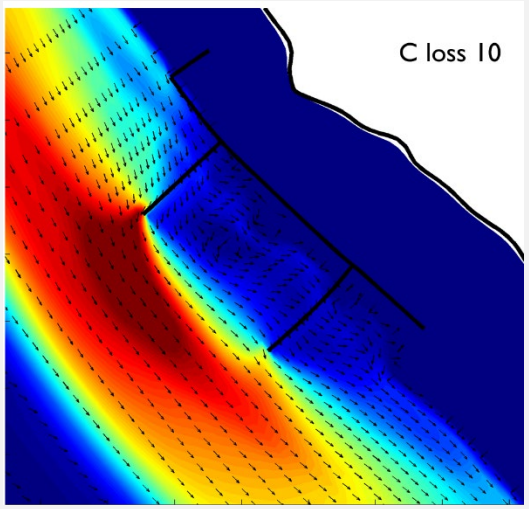
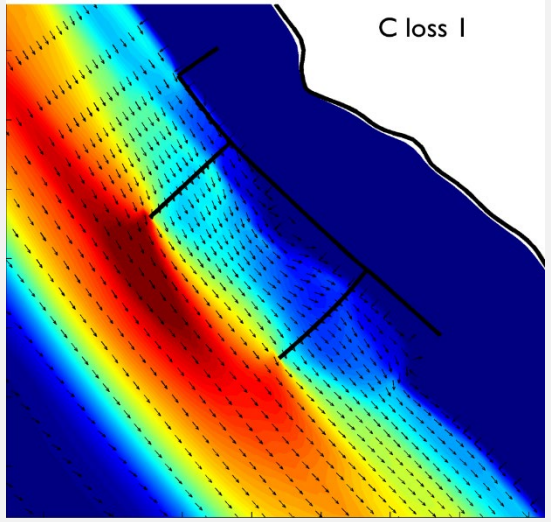
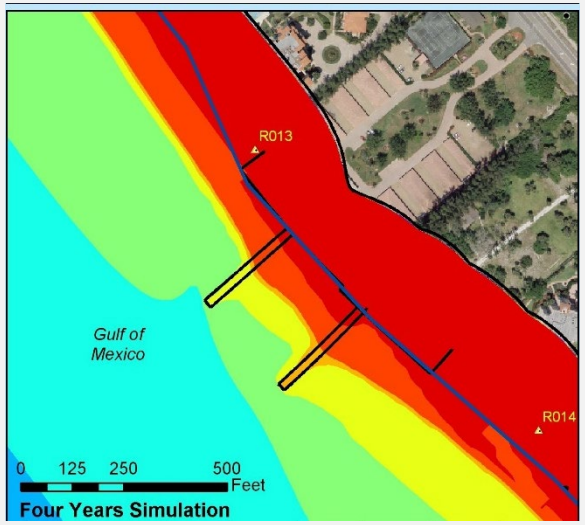
THE FIRST STUDY – LONGBOAT KEY ISLANDER, 2004









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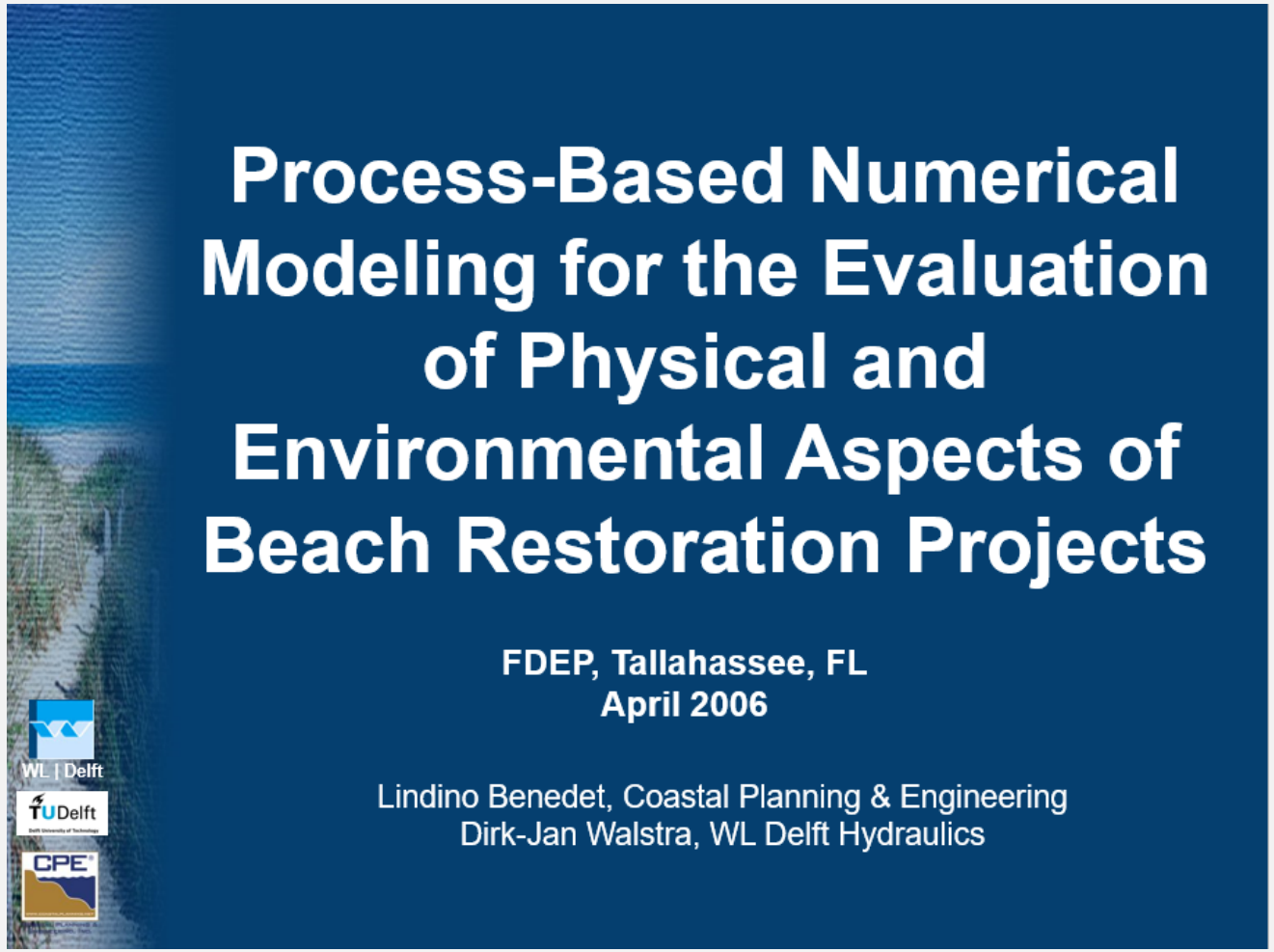
FDEP COORDINATION AND DELFT3D GUIDELINES



Guidelines for Documenting DELFT3D Model Applications in Submittals to the FDEP Bureau of Beaches and Coastal Systems

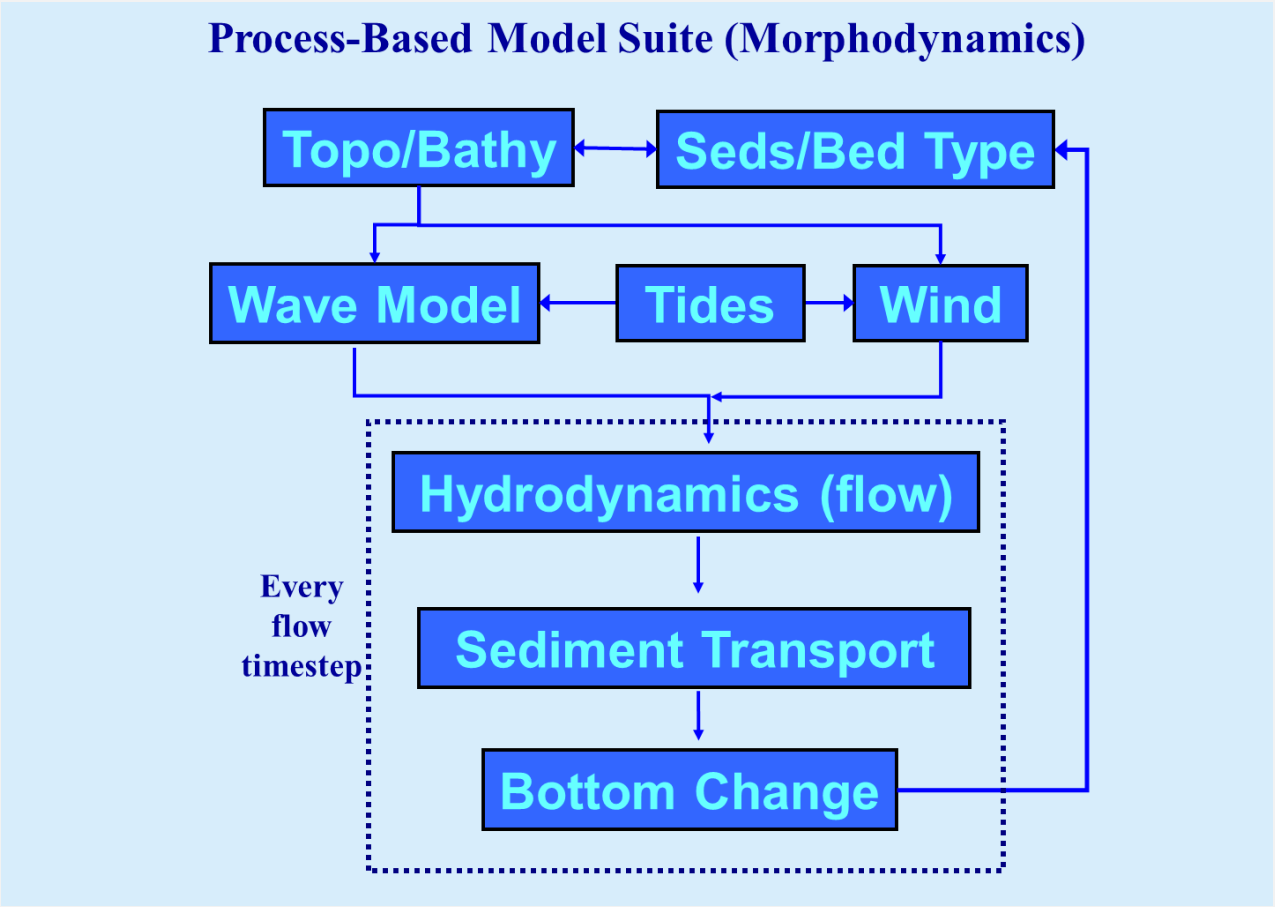
This is a listing of information recommended to be provided for studies using the **DELFT3D model**, including the **sediment transport module**. If the DELFT3D implementation includes wave modeling, either independently of the flow model or for providing inputs to the flow and sediment transport simulations, those wave modeling efforts should be documented according to the wave model guidance. The design professional may chose to omit or deviate from recommendations in these guidelines based upon site or project specific circumstances that affect the scope of the model study effort. The model study report shall identify which of these recommendations are not applicable to the study and the circumstances specific to the study.

1. Modeling Objectives

State the purpose of the modeling analysis and the intended use of the modeling outputs. Identify the versions of DELFT3D model and the modules used in the study. This statement should include a discussion of the coastal system at the project site, the potential effects of the design alternatives on the coastal system and the ability of the DELFT3D model to accurately predict these potential effects that justifies the use of DELFT3D model rather than another numerical model. The discussion of the coastal system should include a brief description of the site, including critical structures and any other features. Discuss the choice of using the depth-averaged (2D) model option or the 3D model option for the analysis. The discussion should include role of vertical velocity profiles, vertical density stratification, wind shear, water depth and other features of the system that could create significant 3D flow response.

floridadep.gov/sites/default/files/GuidNumModSubBBCS_0.pdf

DELFT3D MORPHOLOGY IN A NUTSHELL



- Delft3D is **process-based model**. Genesis, SBeach *etc.* are **data-driven empirical models**.
- **Process Based Model:** Built on an understanding of the underlying physical principles and mechanisms governing the system.
- **Data-Driven Model:** Developed based on observed patterns and relationships in data. Doesn't rely on explicit knowledge of underlying physical processes.

CHALLENGES TO MODEL COASTAL MORPHOLOGY

- Computation requirements
- Model complexity: No. of parameters, how to make sense of results
- Hydrodynamics timescale and morphological change timescale differences

1

- Site specificity: there is no one size fits all model approach
- Heterogeneity of sediments and resistant layers in the coastal systems – *i.e.,* inlet and beach systems

2

- Uncertainties in future wave climate
- State of the art – unknown processes, science is still evolving (and it always will)

3

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CHALLENGES TO MODEL COASTAL MORPHOLOGY

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1

- **Wave climate schematization:** Reduces timeseries to a set of representative conditions.
- **Tide schematization:** Done so every wave case can be run over the same tidal amplitude. Very important for inlets.
- **Wind schematization:** Done in conjunction with wave (wind associated with wave records)
- **Morfac**: Morphology acceleration factor, morphology upscaling technique.
  Simple example: One wave case run over a 12hr cycle with a Morfac of 10 will represent 12 days of morphological change.
- **Improvements in computing power** over the years, cloud super-computers

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WAVE CLIMATE SCHEMATIZATION

Wave Case	Hs (feet)	Tp (sec.)	Wave Dir. (°)	Dir. Spread-ing (°)	Wind Speed (feet/s)	Wind Dir. (°)	Percent Occur. In One Year	Days in Model in One Year	Morfac (Calibration)
#1	2.92	9.35	37.93	25.00	8.11	256.36	5.52%	20.15	38.95
#2	3.72	5.64	119.07	4.00	20.98	313.08	4.11%	15.02	29.03
#3	9.78	10.09	18.06	25.00	30.40	179.55	0.93%	3.39	6.55
#4	6.03	10.10	29.55	25.00	18.60	223.40	1.53%	5.58	10.78
#5	6.77	6.98	74.42	15.00	30.54	270.82	1.11%	4.04	7.8
#6	5.23	7.80	51.83	15.00	24.29	256.04	1.84%	6.71	12.97
#7	3.40	7.60	16.90	15.00	13.28	185.16	8.26%	30.16	58.29
#8	8.34	9.87	37.90	25.00	30.69	238.99	0.67%	2.45	4.74
#9	2.23	5.30	119.89	4.00	15.10	310.43	11.75%	42.88	82.89
#10	6.11	8.72	17.13	25.00	22.68	181.73	2.44%	8.91	17.23
#11	6.30	6.51	121.16	15.00	28.66	311.29	1.17%	4.27	8.25
#12	2.65	7.01	77.08	15.00	15.82	276.22	7.45%	27.18	52.53
#13	8.77	10.84	29.20	25.00	27.66	222.11	0.70%	2.56	4.94
#14	5.52	9.58	38.03	25.00	20.76	245.32	1.57%	5.73	11.08
#15	3.32	8.78	29.61	25.00	7.86	226.61	5.31%	19.39	37.48
#16	7.81	8.56	51.10	25.00	32.37	252.89	0.75%	2.73	5.29
#17	4.49	6.51	76.13	15.00	23.65	272.56	2.91%	10.64	20.56
#18	2.91	8.36	52.20	25.00	12.98	265.86	5.43%	19.81	38.29
#CALM	0.98	6.00	20.00	15.00	6.56	20.00	36.55%	133.40	257.85

DRAFT

WAVE CLIMATE SCHEMATIZATION

1. Started quite simple – ‘fixed Hs and Dir. bins’

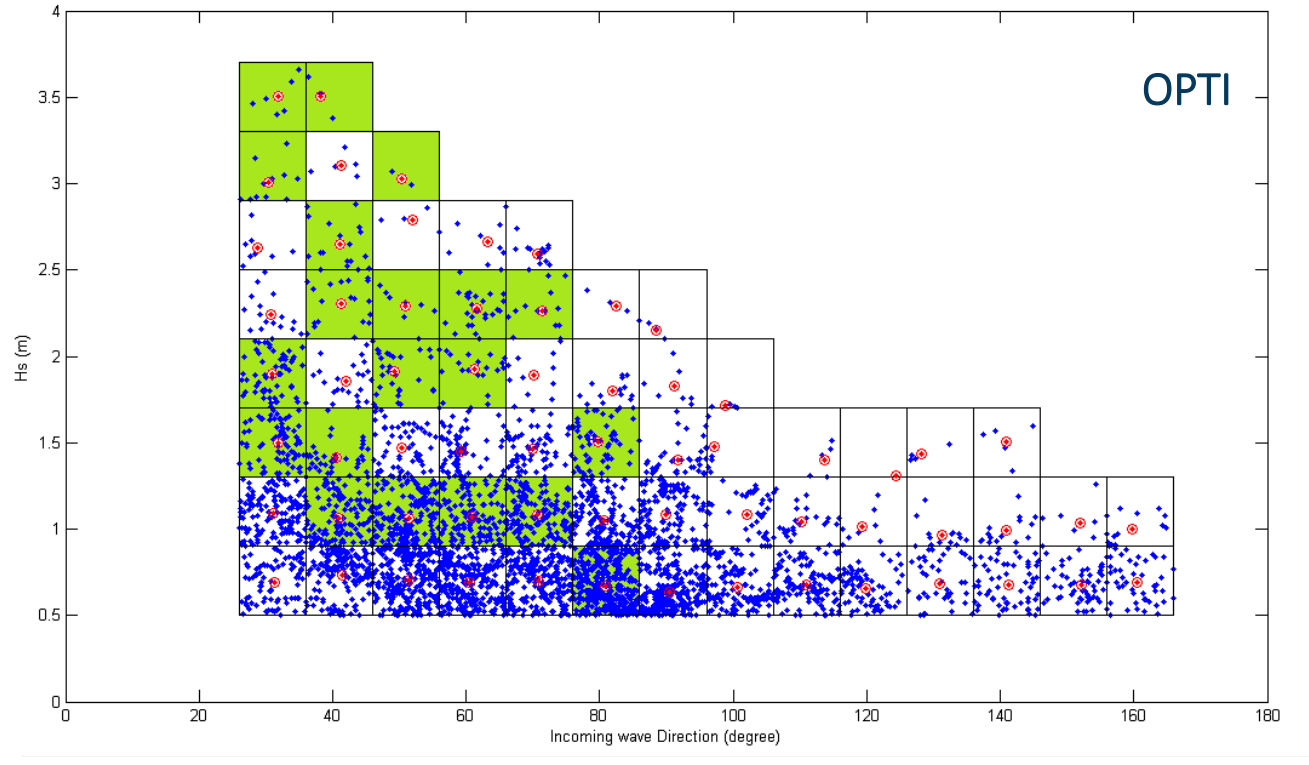
2. Got more complicated adding wave energy and transport considerations.

3. Got even more complicated – intercalated with storms in timeseries mode when needed.

4. Got way more complicated – OPTI (but not necessarily better).

5. Still coming up with new methods (*i.e.* SJP).

- Most of the time we use #2, sometimes #3
- Chronology considerations and Mormerge



X Axis: Wave Height

Y Axis: Wave Direction

Each Box: Wave records in the **wave case**

Each red dot: Wave case *per se*

Benedet et al., 2010

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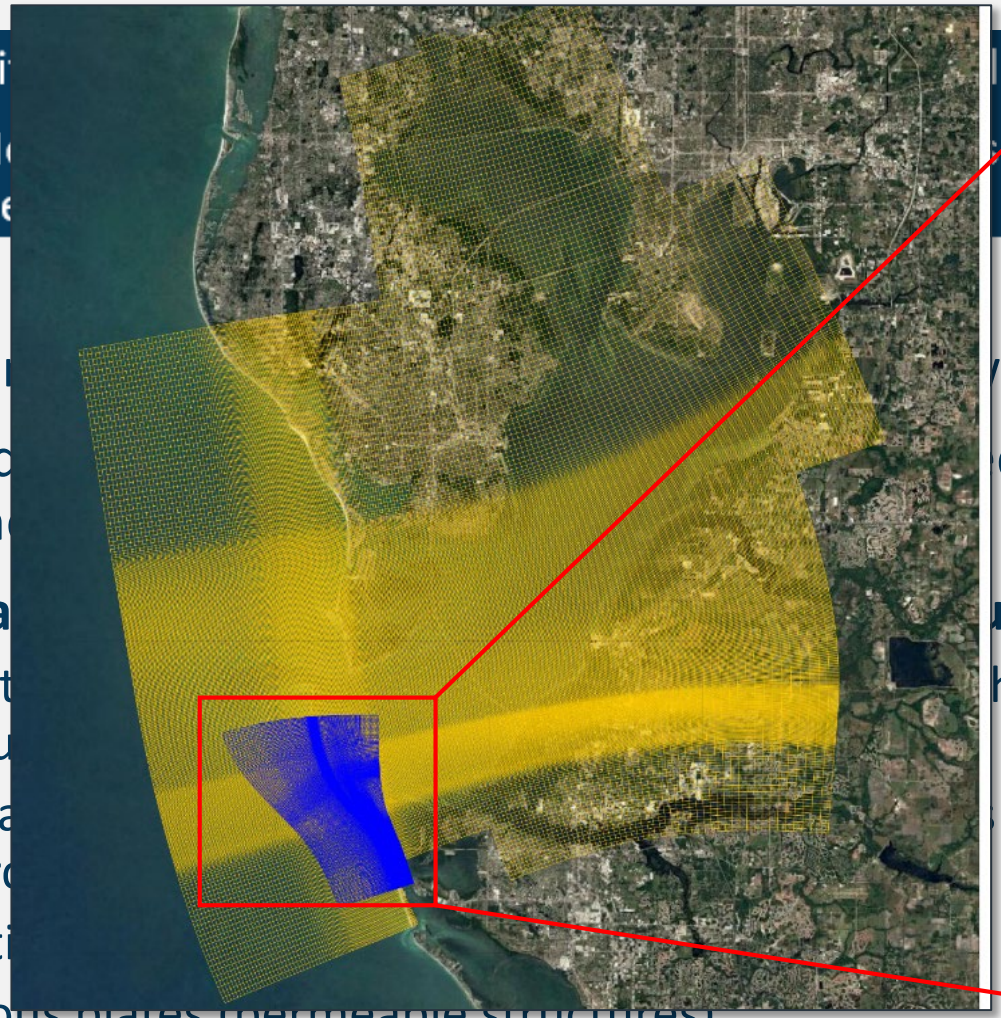
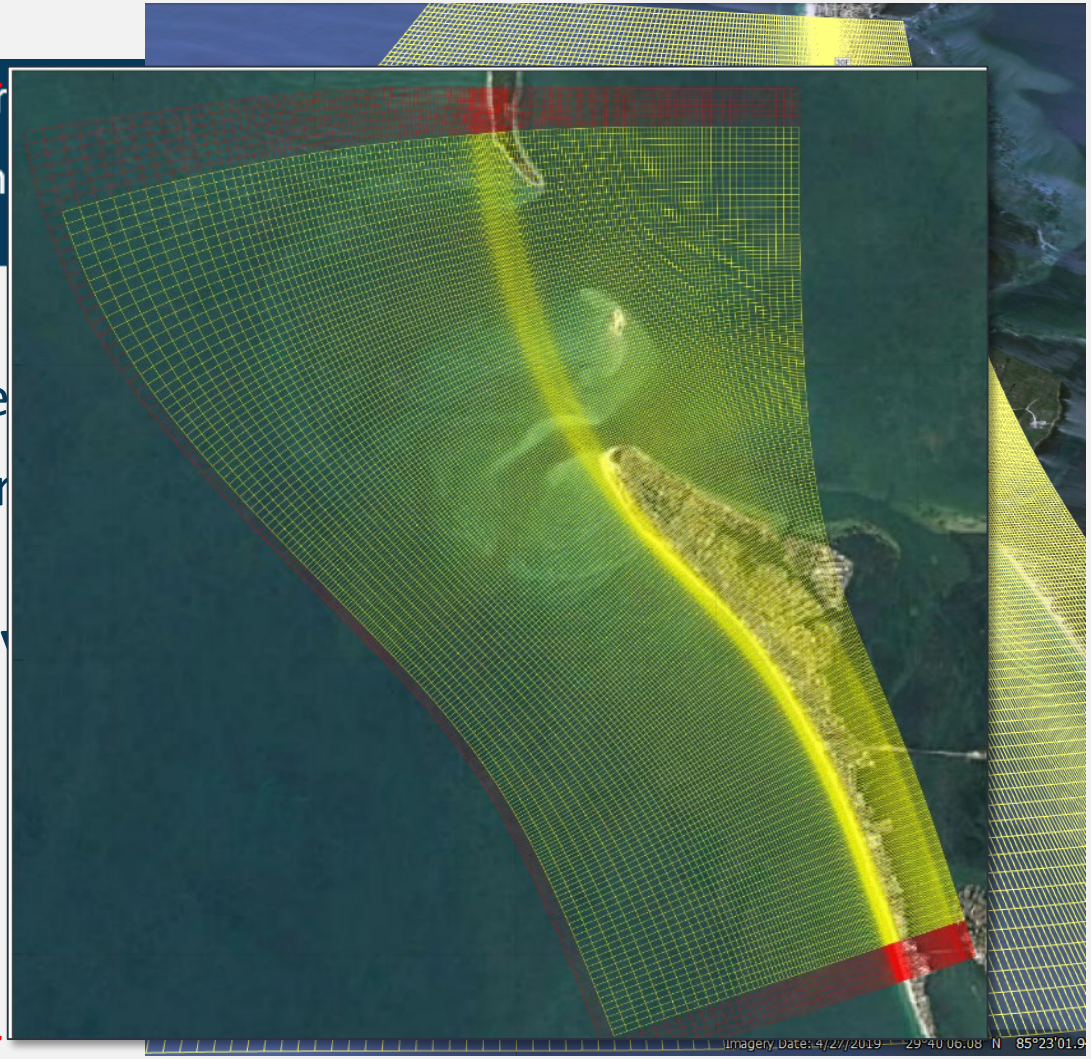
SITE SPECIFICITY AND COMPLEXITY

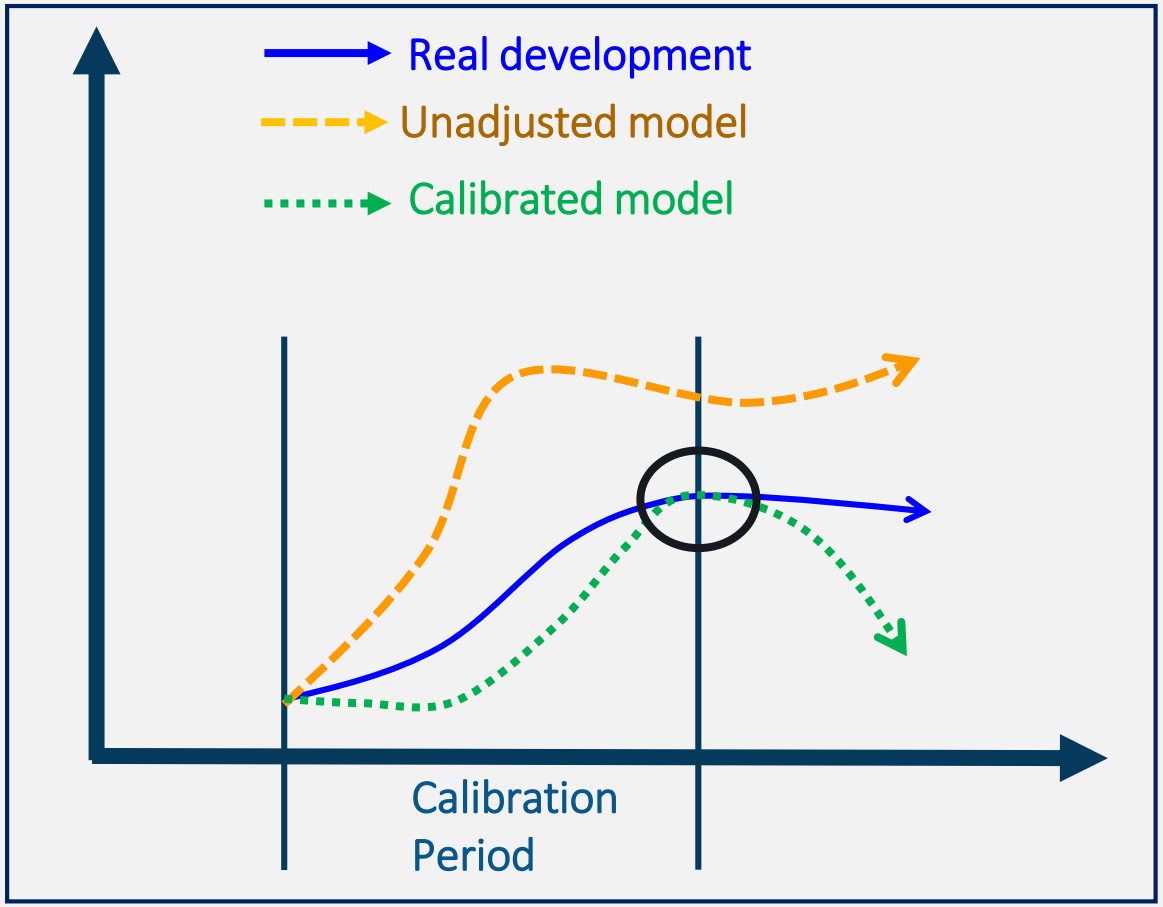
- There's
- The Grid
  surf zon
- **Importa**
  - Mult
    inclu
  - Varia
    (hard
  - Verti
  - Porous plates (permeable structures)





MORPHOLOGY MODEL CALIBRATION

- Define calibration objective.
- Waves, WL, and currents - first step.
- When simulating morphology need to calibrate to morphology – volumes, transport, morphology change patterns.
- The modeler needs to understand the coastal processes - what is going on, why it is not 'converging'.
- Creativity is necessary to avoid never ending loops. Also know when to stop.
- **Morphology calibration is a journey, it is time intensive (60%-70% of the effort), it can be stressful, and it requires a collaborative team effort.**



Adapted from Roelvink, D. and Reniers, A., 2012.

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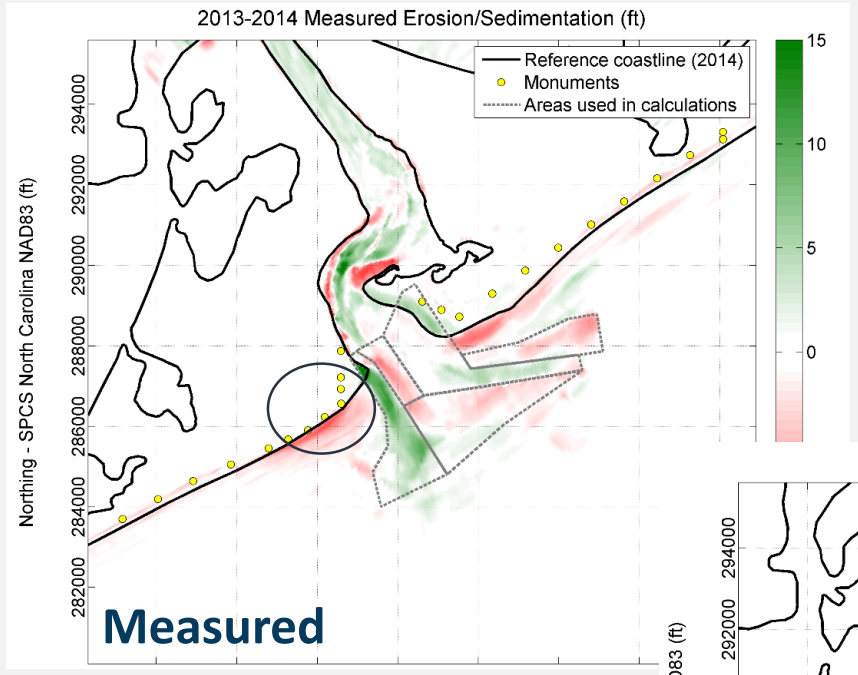
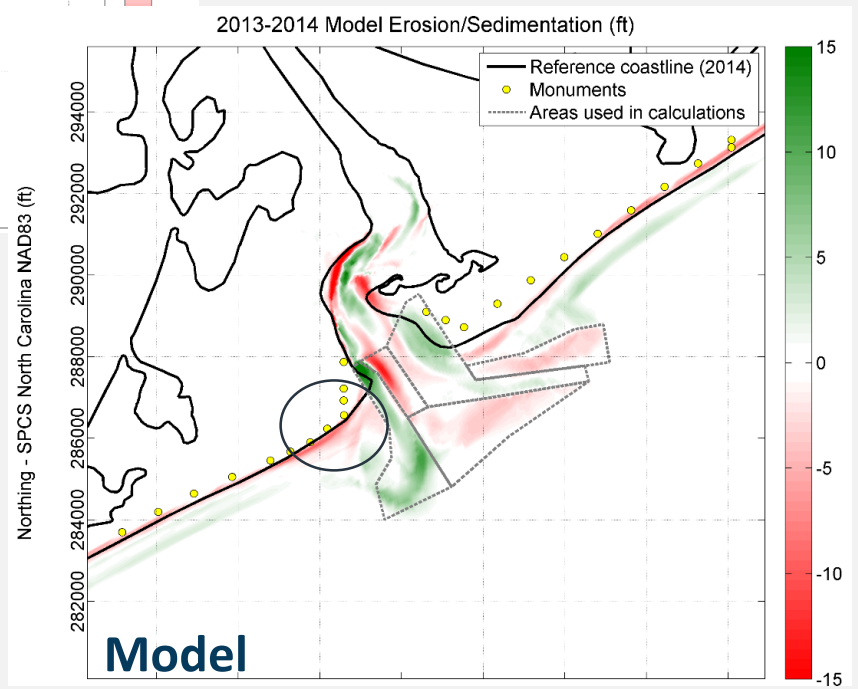
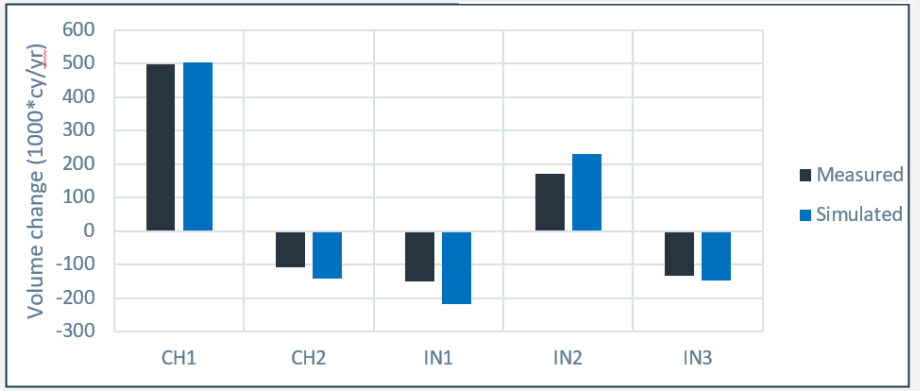
MORPHOLOGY MODEL CALIBRATION



Beach and inlet example: Model to be used evaluate a channel relocation project and erosion of beach to the SW.





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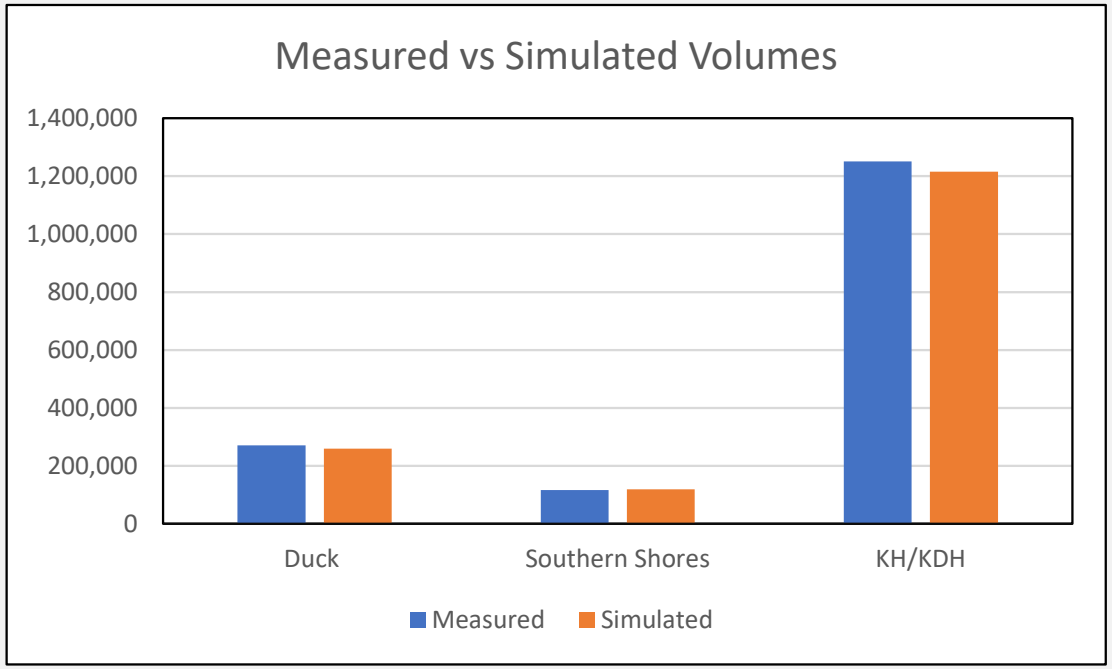
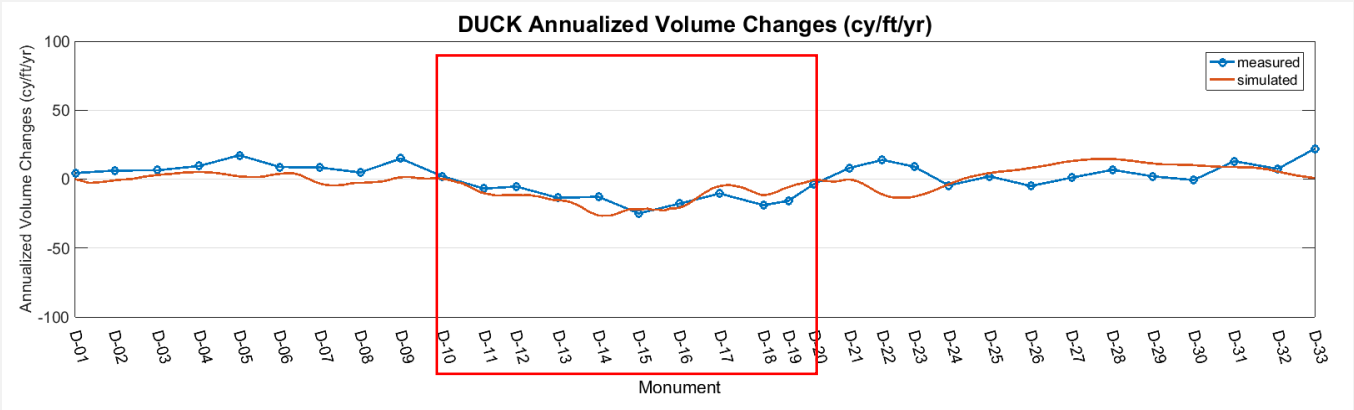
MORPHOLOGY MODEL CALIBRATION

Open Beach Example: Model to be used to support beach nourishment design - refine volumes and alongshore placement.



Total fill volume loss



Volume change alongshgore

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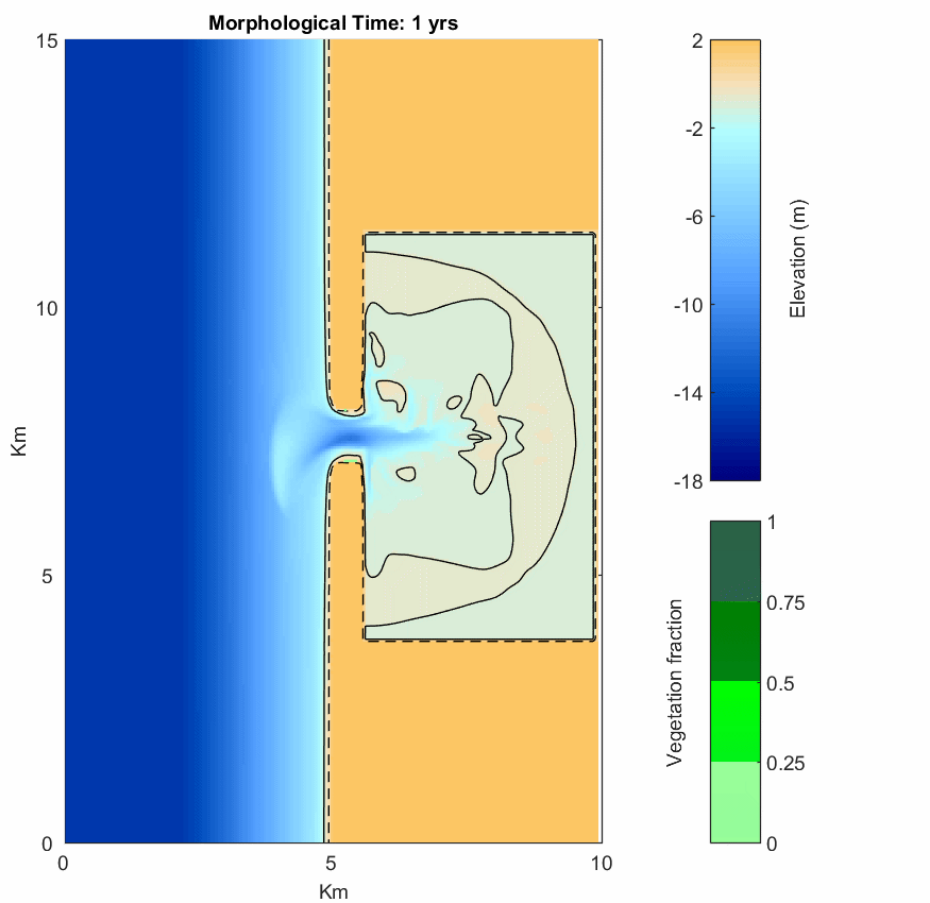
STATE OF THE ART AND UNCERTAINTIES

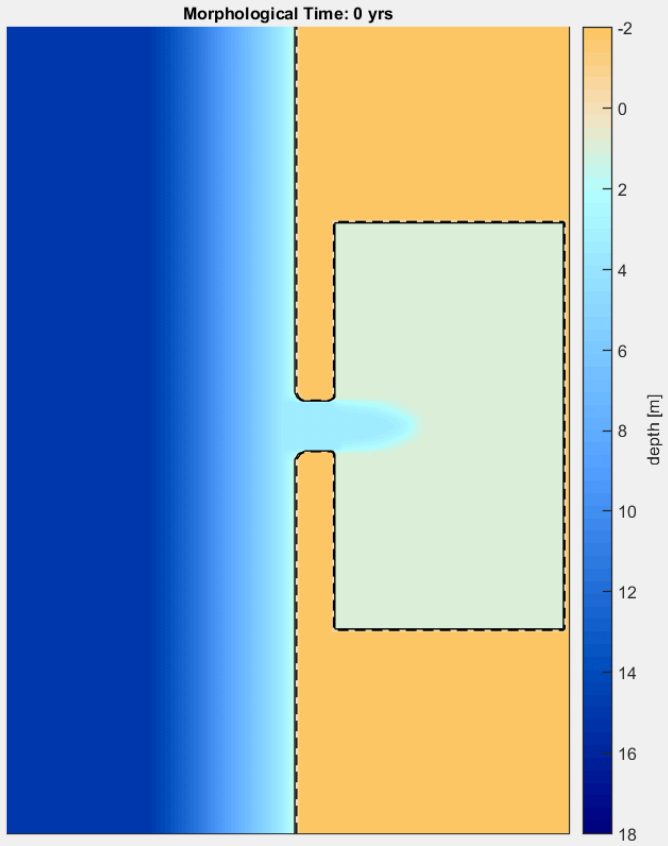
- Uncertainties in future wave climate
- State of the art – unknown processes, science is still evolving (and it always will)

3

- Keep up with the latest science and model releases, colleagues in the field
- Uncertainties will all always exist (relative changes *vs* absolute positions)
- Interesting recent developments that are still to transition from academia to our industry
  - Aeolian transport module/coupling
  - Coupling Morphology with Eco and vegetation growth and decay – Marsh and mangrove restoration
  - Morphology using flexible mesh – Combined coastal morphology change and flooding
  - Continuous improvement in underlying physical equations *i.e.* to describe bar movements, better resolve wet/dry interface, sediment transport formulations *etc.*

STATE OF THE ART – RECENT DEVELOPMENTS





Morphology change with marsh vegetation growth and decay in decadal scales (Albernaz, M. *et al.*, 2023)

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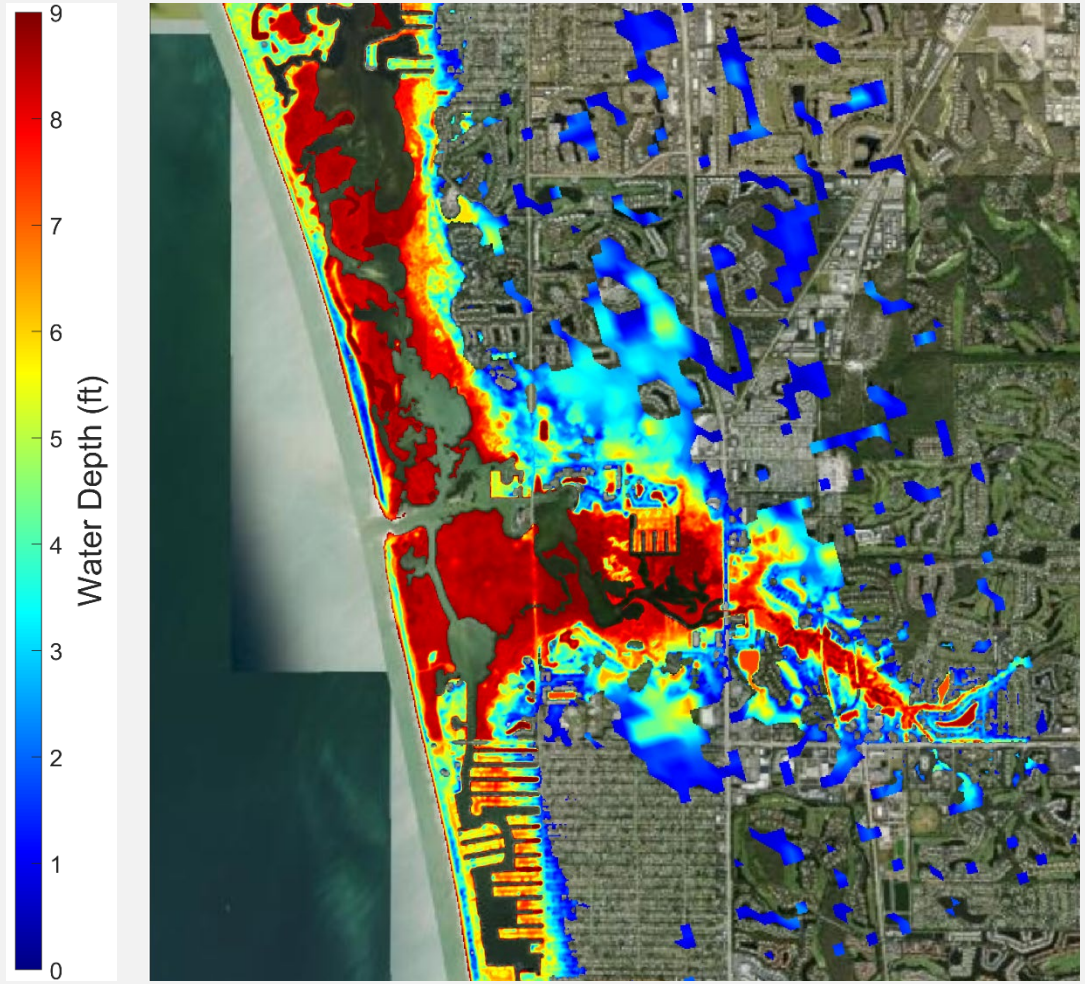
STATE OF THE ART AND UNCERTAINTIES



Collier County (Wiggins Pass), Flooding during H. Ian (Benedet, L. 2023-FSBPA)

- **Currently 100% of all coastal flooding simulations assume the beach and dune are static, do not change, during major storms.**
- Delft3d Flexible Mesh (FM) combines hydrodynamic and hydrological Processes. Tests using the Delf3D-FM to simulate morphology are currently ongoing.
- More realistic coastal flooding simulations during extreme storms (beach and dunes will no longer be a wall!).

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Are coastal morphology models useful?

Yes! Very useful, but need to…

- Follow best practices
- Understand coastal processes
- Have good data and ‘treat it well’
- Be creative - can’t be a ‘button pusher’
- Be able to work in multidisciplinary teams
- Be able to make sense of and communicate results
- Keep up with latest science/model developments
- It is a very powerful tool, but part of the toolbox
- Data and judgement are also important

20 years later, Delft3d continues to be the state-of-the-art

THANK YOU!

Special thanks to:

Our amazing team at Coastal Protection Engineering!

All my Dutch colleagues who got me into this journey, especially Prof. Marcel Stive and DJ Walstra!

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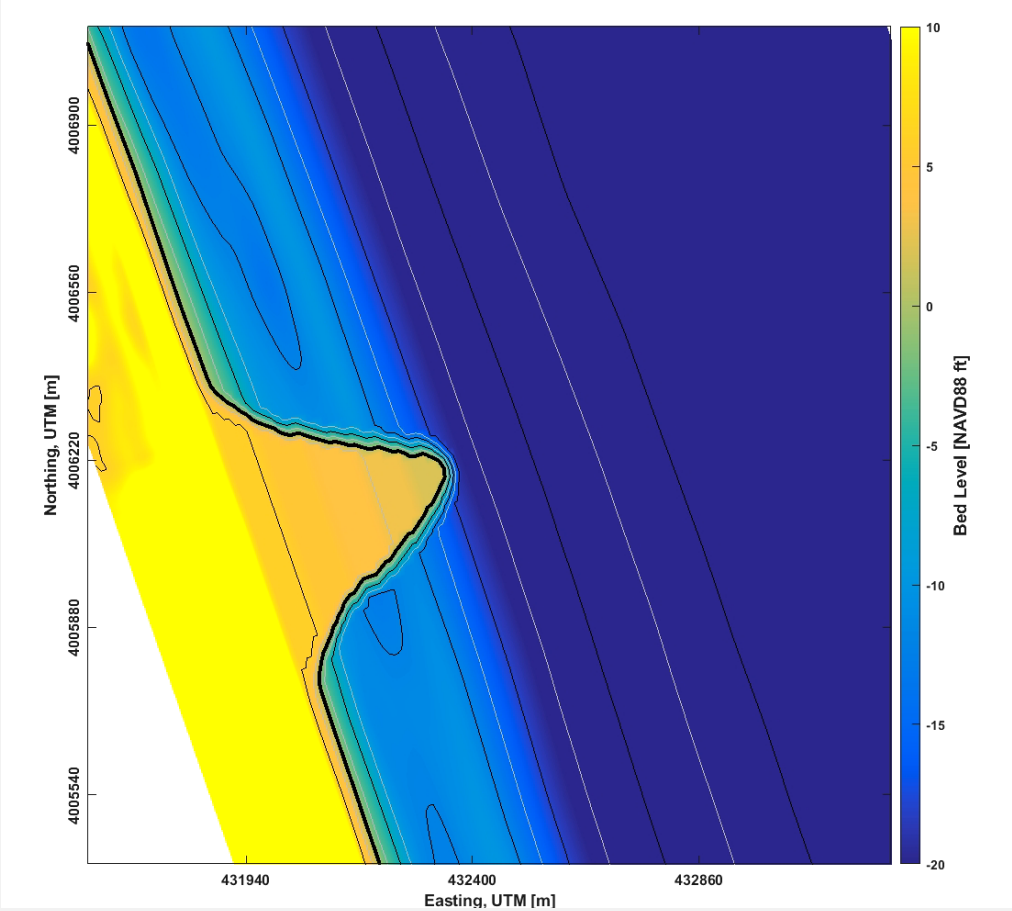
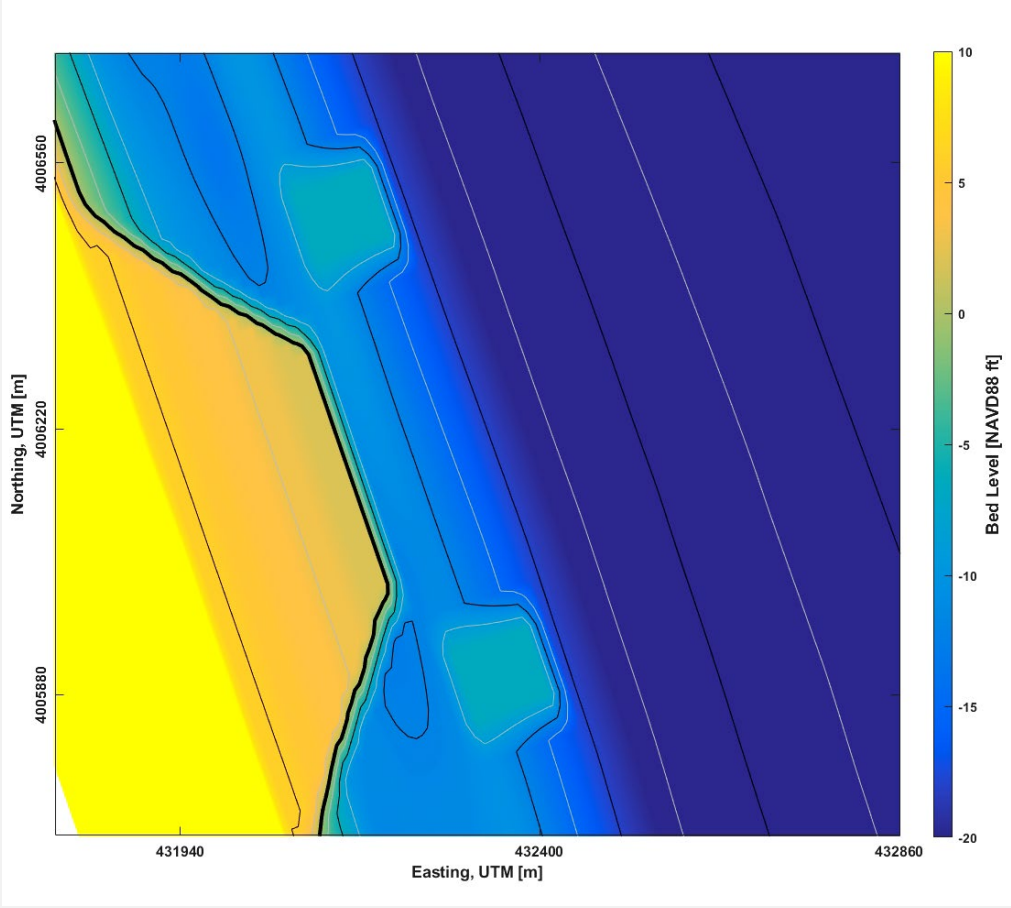
POST PROJECT: WHAT IF…

- Wonder what happens if we try some alternative placements that may reduce construction costs and provide temporary recreational amenity?



680k over ~1000 ft of beach (avg 680 cy/ft)



750k over ~3000 ft of beach

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