CMS & C2SHORE
MODEL DEVELOPMENT AND VALIDATION

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COASTAL INLETS RESEARCH PROGRAM
FY22 IN PROGRESS REVIEW

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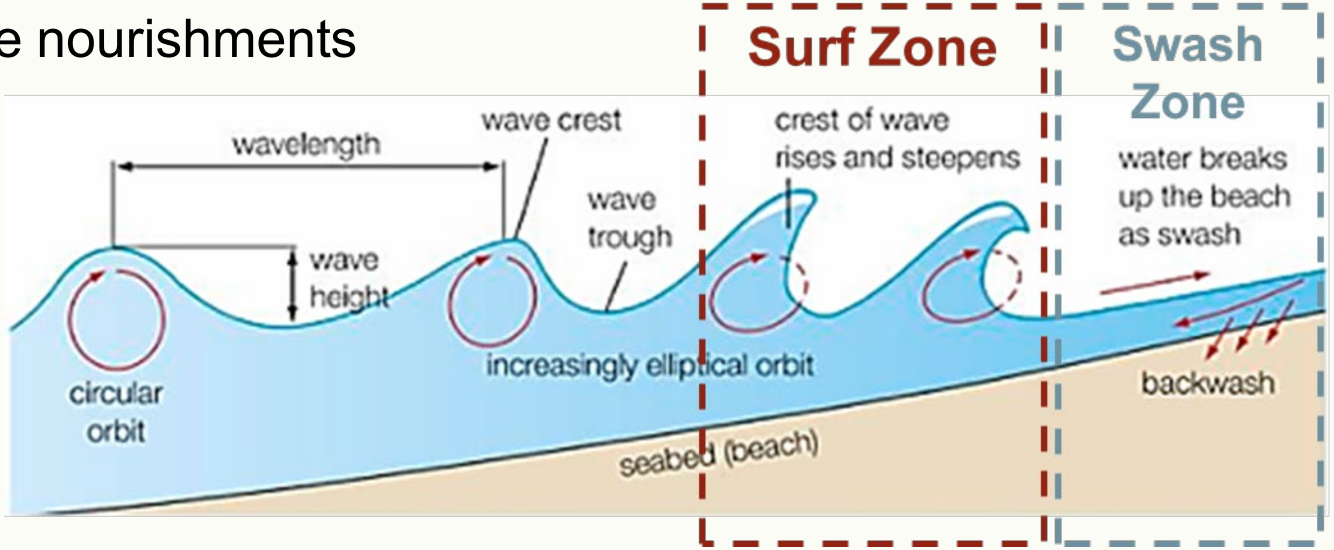
Problem Statement – Surf & Swash Complexities

- Accuracy of the widely used Coastal Modeling System (CMS) with C2SHORE model is essential for accurate planning and design
  - Navigation – sediment transport from open coasts to coastal inlets and channels
  - BUDM – fate and evolution of nearshore nourishments
  - FRM – design of flood protection dunes
- Limited testing of swash-zone formulations of hydrodynamic and sediment transport hinders applicability

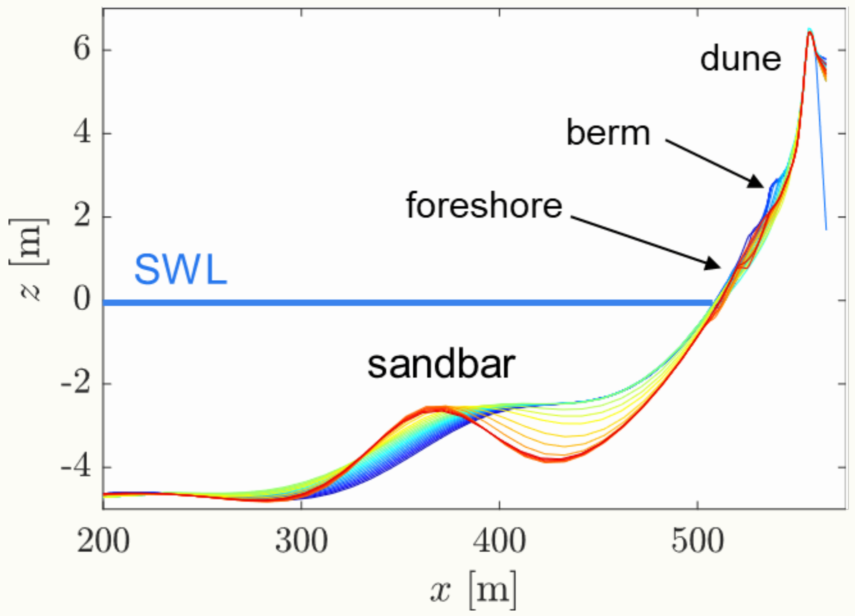


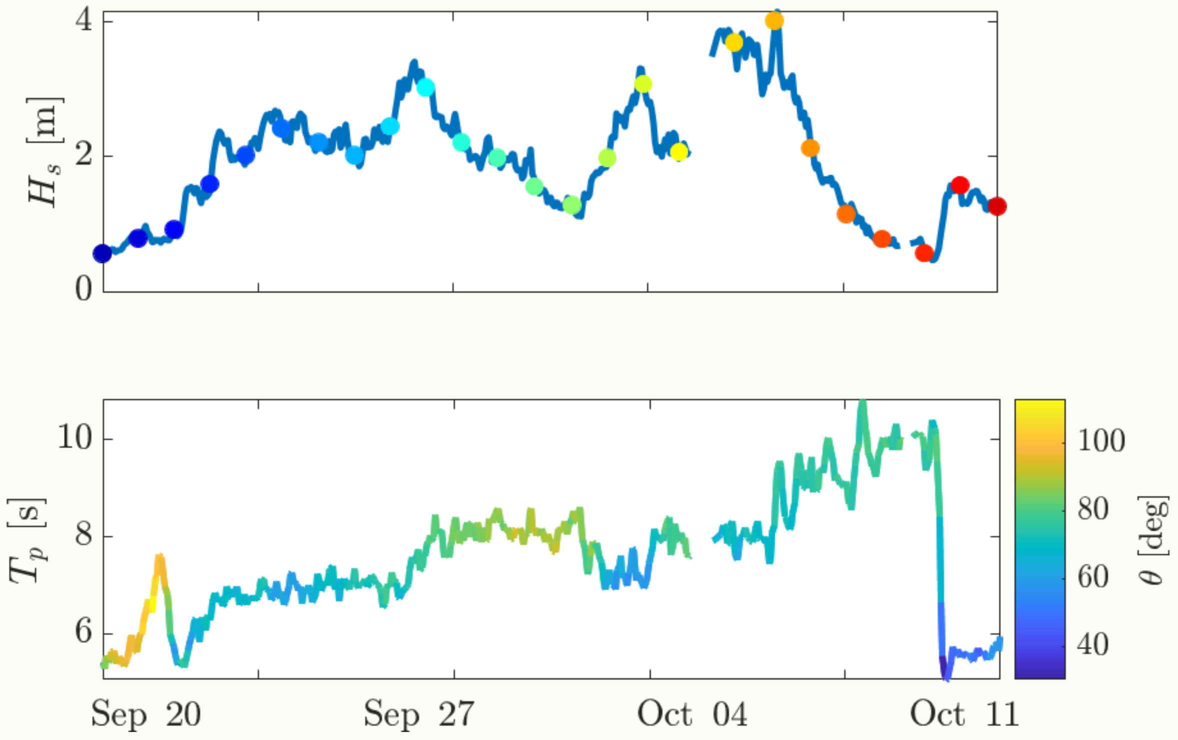
Navigation Statements of Need

- 2024-N-1906: Quantification of Shoreline Response to Nearshore Berms
- 2024-N-1906: Multi-scale analyses of BUDM impacts on long-term navigation channel maintenance
- 2021-N-1538: Nearshore Processes Research and Development

FY22 Tasks

- Adding vertical velocity variation to improve sediment transport (largely completed in FY21)
- Validate swash-zone processes on wave-dominated coast (FRF, Duck, NC)
  - 2D case, comparison of surf zone velocity field collected via aerial optical imagery (*TD on Tues 4/25*)
  - ***1D case, comparison of wave runup statistics collected via continuous laser scanning (LiDAR)***
    - CMS/CSHORE and comparison models with range of complexity (algebraic to nonhydrostatic)
    - 533 “snapshots” of runup stats over 1.5 months





Comparison models

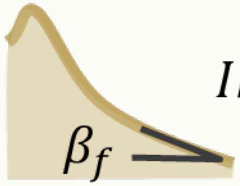
- **Stockdon, et al. (2006) – least complex, <u>mostly widely used</u> Runup model**
  - Algebraic equation developed from observations at Duck FRF, West Coast, and abroad
  - Separate terms for different key physical processes, all dependent on Iribarren number (*Ib*)

$$R_{2\%} = 1.1\left\{0.35\beta_f(H_{mo}L_o)^{1/2} + \frac{1}{2}(H_{mo}L_o\left[0.563\beta_f^2 + .004\right]^{1/2}\right\}$$

wave setup $\overline{\eta}$

incident swash elevation

infragravity (IG) swash elevation



$$Ib = \frac{\tan(\beta_f)}{\sqrt{H_{mo}/L_o}}$$

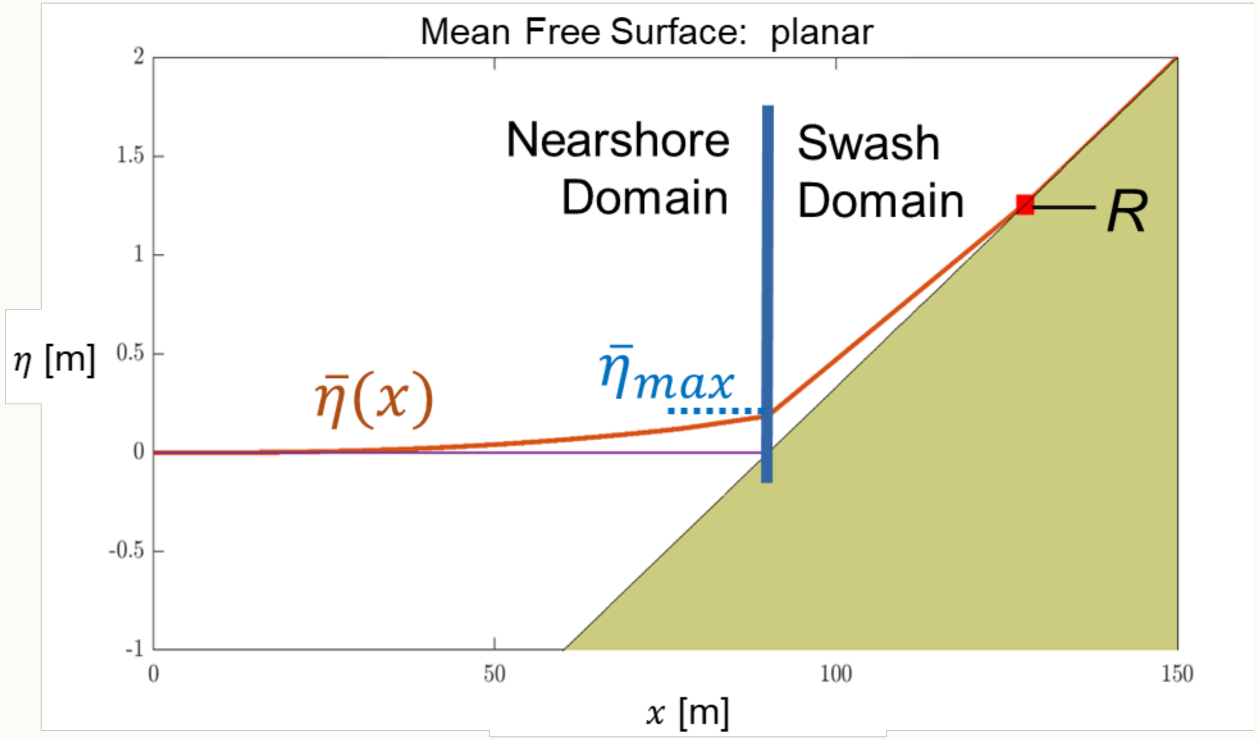
H_{mo} = deep water wave height

L_o = deep water wavelength

- **XBeach – more complex, two modes with distinctly different physics**
  - Surfbeat – phase averaged; swash routine forced with IG energy band and wave group envelope
  - Nonhydrostatic (most complex) – phase (wave-by-wave) resolving, similar to Boussinesq models, nonlinear frequency interactions, breaking, fully dispersive

C2SHORE & CMS Advancement: Domain partition

- Slope break of water line indicates differing physics
- Separate model domain, solve separately
  - Non-IG wave models assume *locally-identical* saturated wave height condition near the shoreline
  - Demarcation at a *constant depth* results in predictions of runup that are not proportional to incident wave heights (unmatched variation)

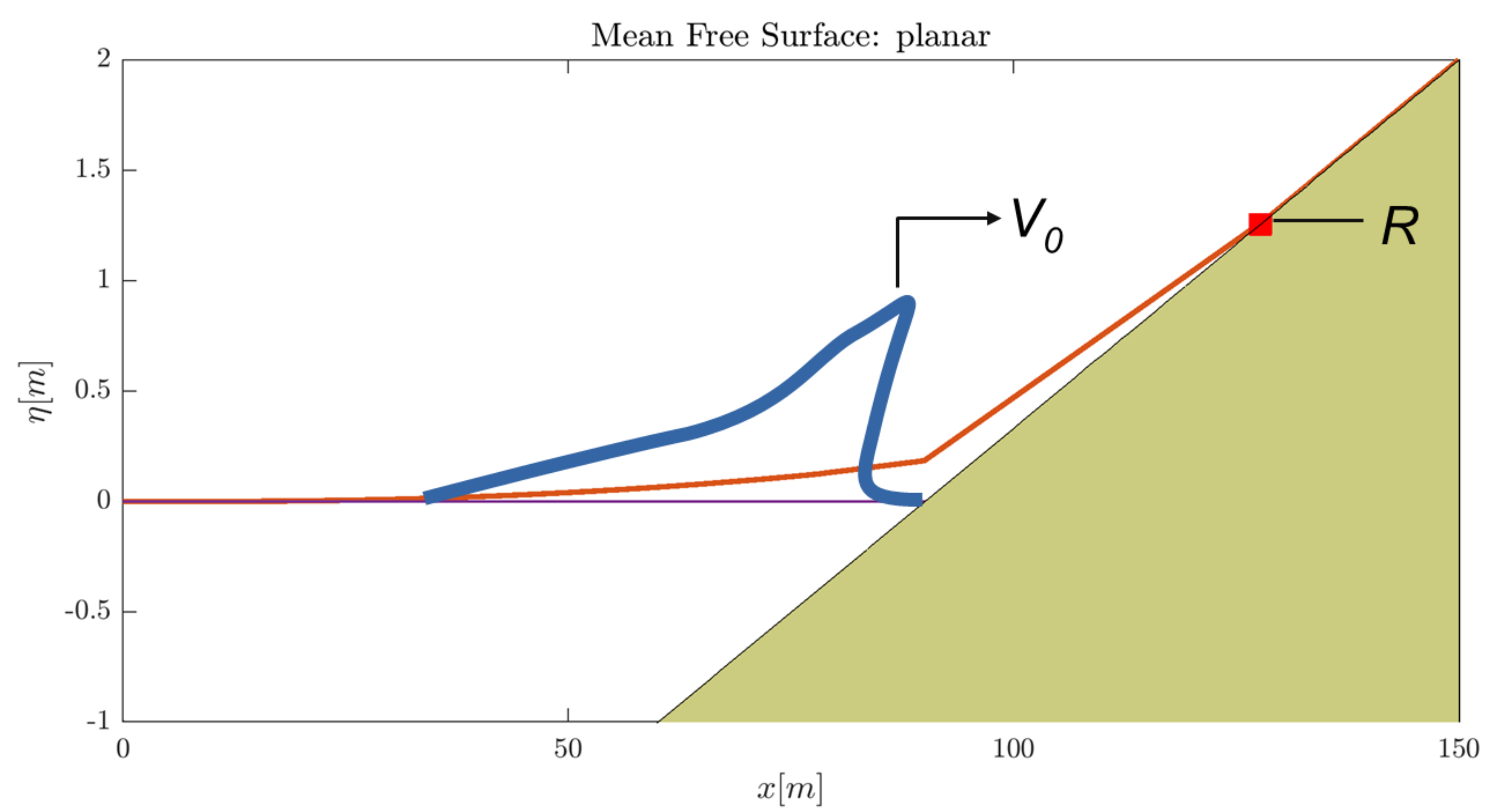


- Data (and intuition) indicate as $H_{mo}\uparrow$, $R_{2\%}\uparrow$ from both dynamic (oscillatory swash) and static (wave setup) components
  - NEW demarcation set to depth of max wave setup
  - Requires NEW simplified wave ray-tracing in CMS (trivial for steady 1D models)
  - Results in IG and setup components that are set proportional to *H* offshore

C2SHORE & CMS Advancement: NEW Formulation and Justification

Consider: Frictionless planar beach and monochromatic waves

Classic view of swash has a position at shoreline where bores collapse, generating fluid velocity V_0 and resulting in runup R



C2SHORE & CMS: NEW Formulation and Justification

Up-rush friction-less momentum balance

$$\frac{\partial M}{\partial x} = \frac{\partial}{\partial x}\{A_0 g h^2\} = -gh\frac{\partial z_b}{\partial x}$$

Momentum balanced by bottom pressure

For planar friction-less slope (rewrite, integrate over x)

$$\int \left[\frac{\partial h}{\partial x} = \frac{\frac{\partial z_b}{\partial x}}{2A_0}\right] dx$$

Integrate at h = 0 (i.e., end of uprush film)

limit of uprush $(h = 0)$

$$R_{CMS} = 2A_0 h_0$$

CMS Runup R_{CMS} requires single-parameter closure A_0

Alternatively, Shen and Meyer, or Bernoulli, or ballistics

$$R_{CMS} = \frac{V_0^2}{2g}$$

Intuitively, Newtonian ballistics, or velocity "head"

where Baldock and others cast V_0 in terms of initial wave height or depth

$$V_0 = 2\sqrt{gH_0} = \sqrt{8}\sqrt{gh_0}$$

Shallow water flow

Comparing estimates of runup indicates $A_0 \simeq 2$ for monochromatic waves. Using $H_{2\%}$ results in

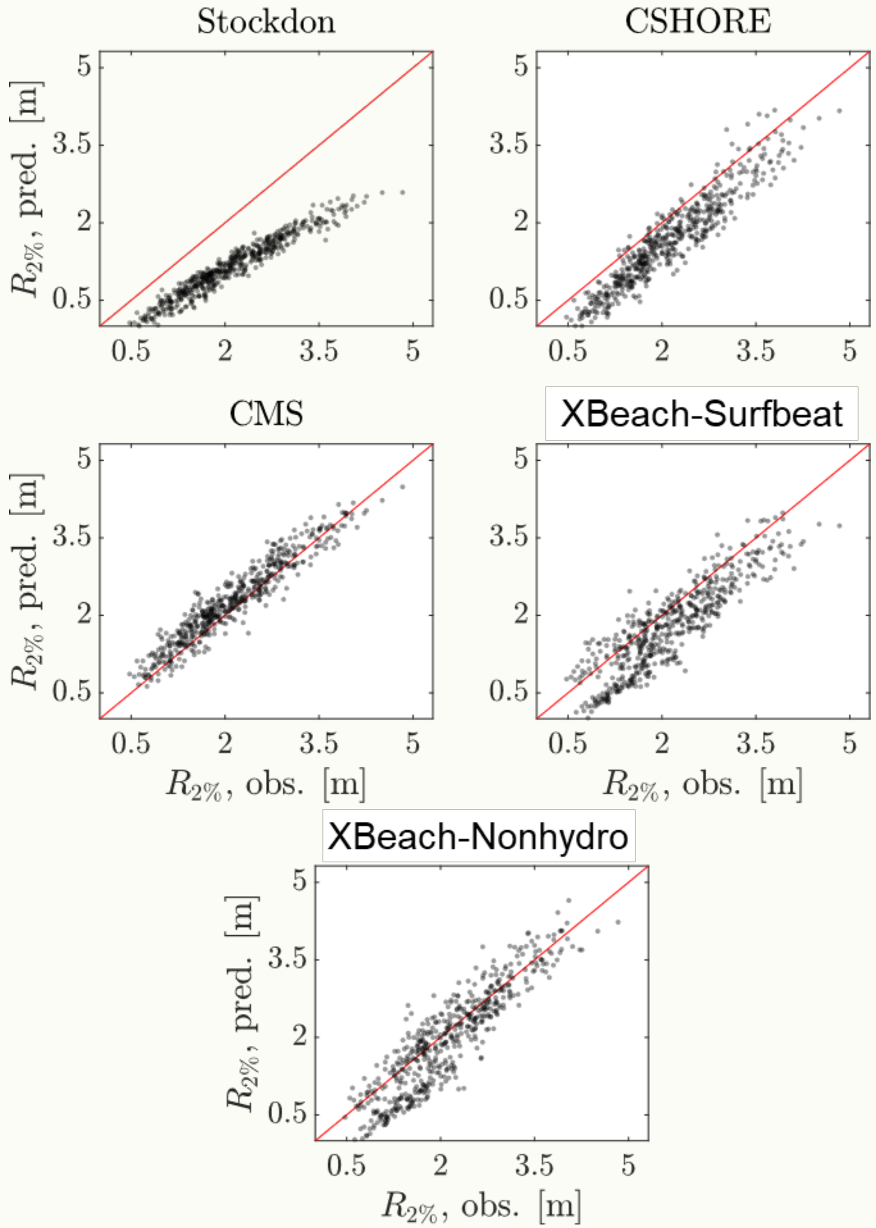
$$A_0 \simeq 4$$

Closure A_0 varies for monochromatic H vs $H_{2\%}$

Intermodel comparison

	Runtime	RMSE (m)	NRMSE (-)
Stockdon, et al. (2006)	0.18 s	1.01	0.89
CSHORE	25.0 s	0.55	0.34
CMS – new formulation	**4.1 min**	**0.29**	**0.13**
XBeach-Surfbeat	35.5 hr	0.53	0.30
XBeach-Nonhydrostatic	124.4 hr	0.45	0.23

- After model improvements, CMS had the lowest (N)RMSE
- FRF observations indicated closure parameter A_0 does have some dependence on ***Ib***
  - Revise formulation, $A_0 = 2.6 + 4.5Ib$



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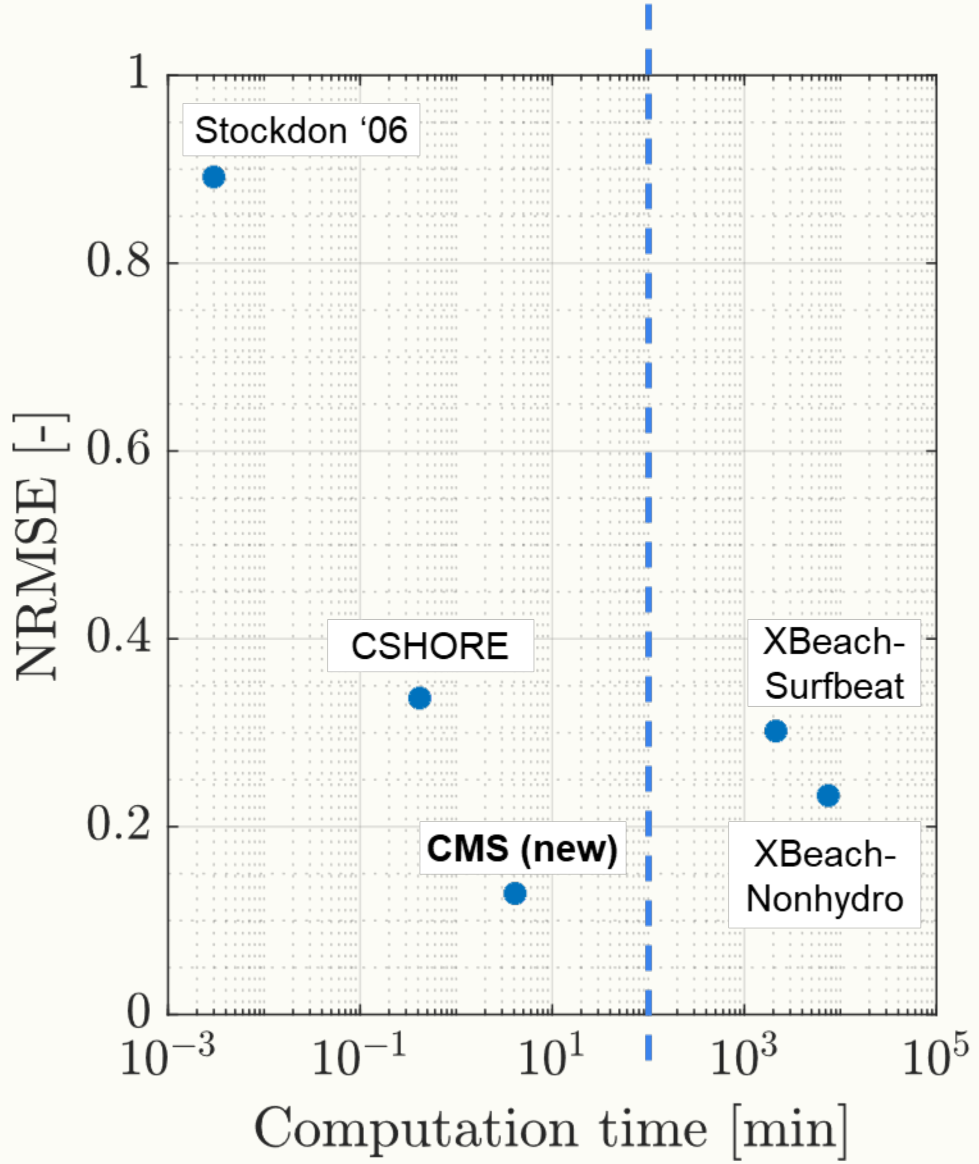
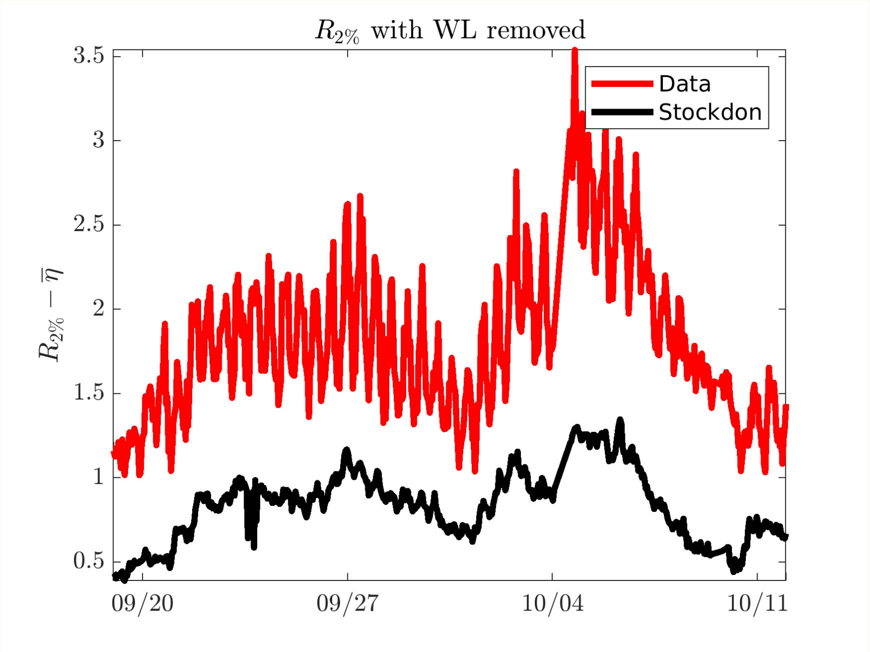
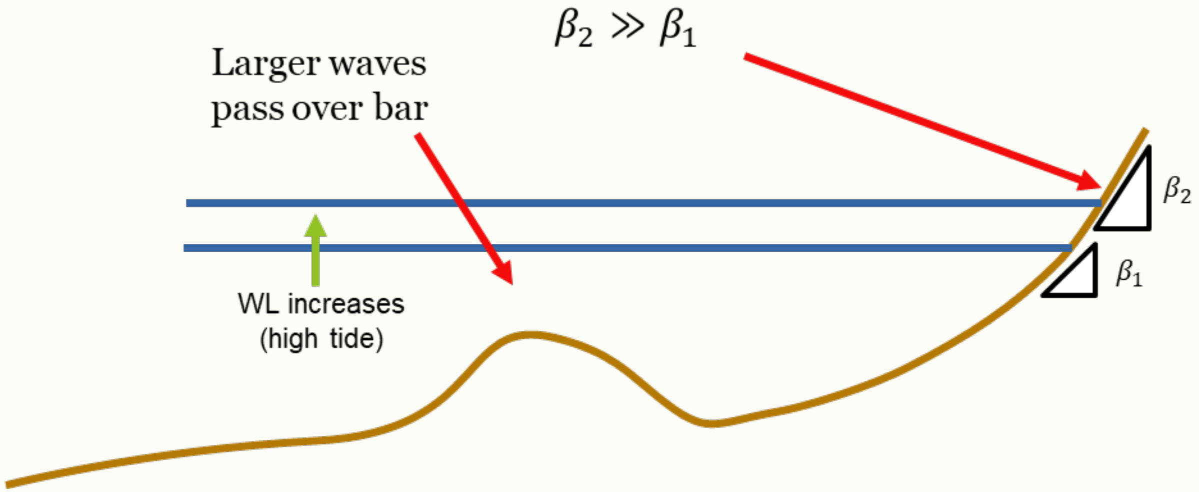


Intermodel comparison

- De-tided $R_{2\%}$ time series shown to vary with tidal stage, although Stockdon prediction does not
  - Since Stockdon formulation depends only on beach foreshore slope, increased water level cannot be simply explained by concave-up beach profile
  - Instead, sandbar acts to modulate the wind-wave component as water level increases (breaking wave height increases)
- Thus, not only is new CMS formulation fast and more accurate, but includes important bar morphology (unlike Stockdon et al., 2006)





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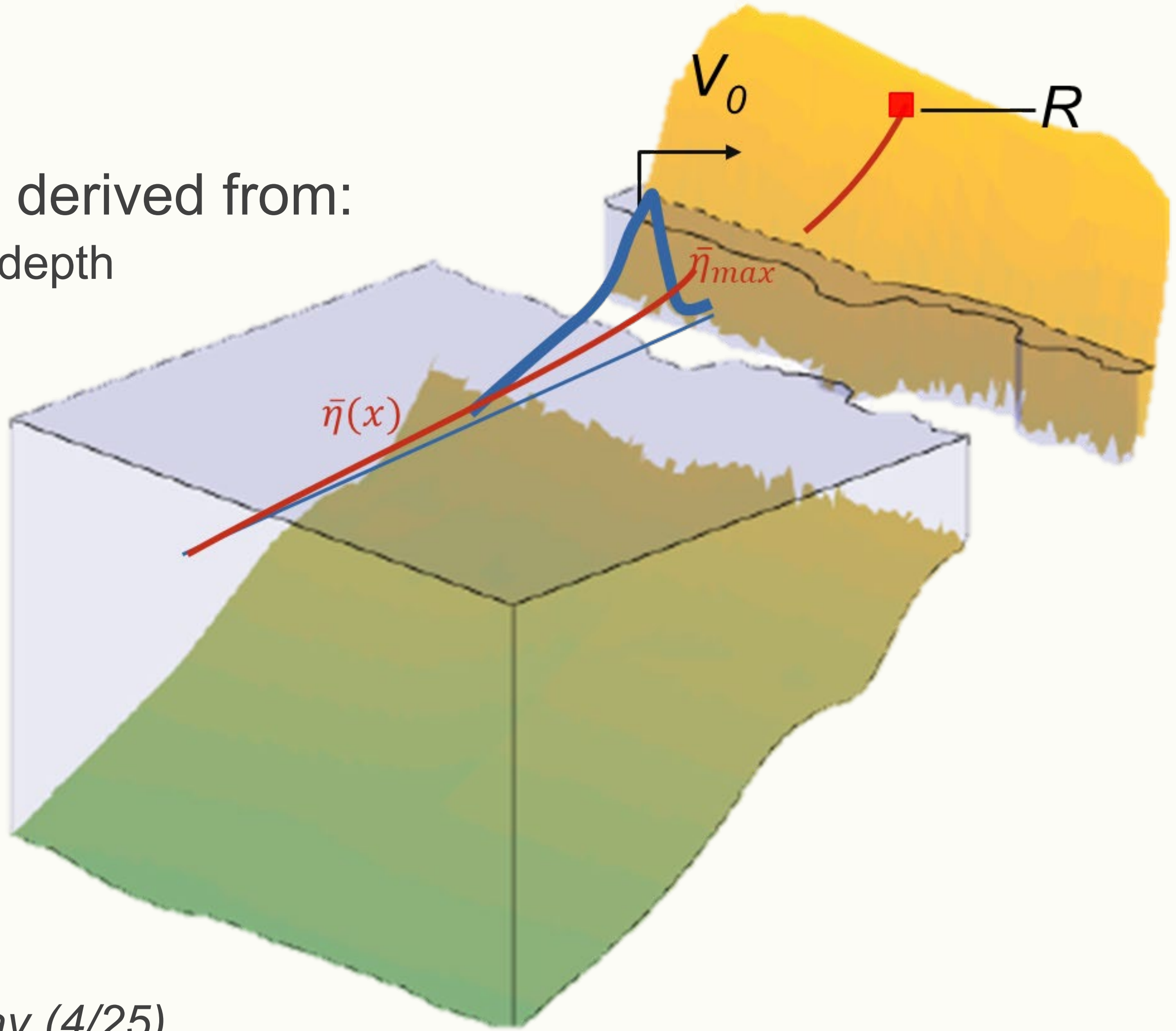
Summary



- FY22 Major Advances in Capability
  - Surf- and swash-zone ***domain partition*** derived from:
    - Separated impact of waves, not a fixed water depth
    - Resolved with backwards ray-tracing
  - Wave ***runup formulation*** improvement
    - Swash closure parameter dependent on wave height, Iribarren number
    - More accurate and faster than models with more physical processes resolved
    - Includes sandbar hydrodynamics (key!)

- FY22 Major Products & Collaborations
  - Technical Report (in progress)
  - CIRP Tech Discussion (Jan 2023)
  - *TD Next Tuesday! 2D Surf Modeling next Tuesday (4/25)*
  - CW Weekly (Feb 2023)