Advancement in a Multi-Scale Approach to Modeling Coastal Processes

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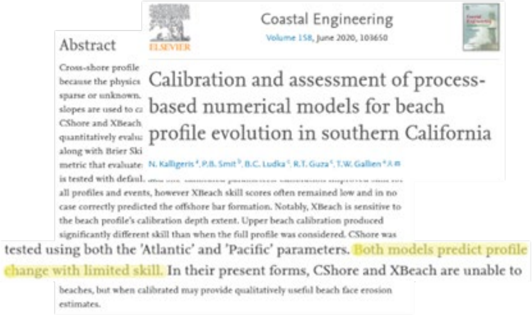
Process-based Modeling

- USACE is wed to the phase-averaged modeling platform: AdCirc, CMS, Xbeach, CSHORE
- Some degree of reliability in the wave/hydro predictions, yet the accuracy of the sand transport problem lags.
- Enormous resources into making these estimates, yet two mature process-based nearshore morphology models:



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Calibration and assessment of process-based numerical models for beach profile evolution in southern California

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Abstract

Cross-shore profile because the physics sparse or unknown. slopes are used to ca CShore and XBeach quantitatively evalu along with Brier Ski metric that evaluate is tested with defaul...

all profiles and events, however XBeach skill scores often remained low and in no case correctly predicted the offshore bar formation. Notably, XBeach is sensitive to the beach profile's calibration depth extent. Upper beach calibration produced significantly different skill than when the full profile was considered. CShore was tested using both the 'Atlantic' and 'Pacific' parameters. Both models predict profile change with limited skill. In their present forms, CShore and XBeach are unable to ... beaches, but when calibrated may provide qualitatively useful beach face erosion estimates.

Gap in Process-Based Promise and Delivery

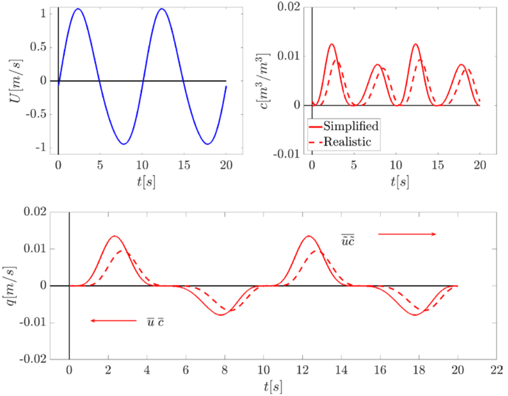
Why do these models fail to deliver on the promise? Inaccuracies in phase-averaged predictions for wave-dominated environments are attributable (at least in part) to a failure in 'closures'.

Closure: Cross-shore Sediment Transport

$$\overline{q} = \overline{uc} \simeq \overline{u}\,\overline{c} + \overline{\tilde{u}\tilde{c}}$$

Even in the rarefied form where $c = f(u)$, the process-based solution is complicated, e.g.:

- Waveform for u may depart from sinusoidal, leading to nonzero contribution to $\overline{q}$
- q is not a linear function of u or u^2 or u^3 – owing to nonzero sed. movement initiation, phase-lags, etc.
- Typically wave-terms are onshore, steady terms are offshore, and we predict the small residual

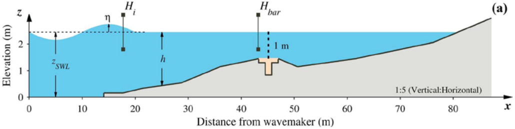


Is it hopeless? Perhaps the idea of collapsing closures (e.g. sed transport) to a general simple algebraic expression is actually hopeless.

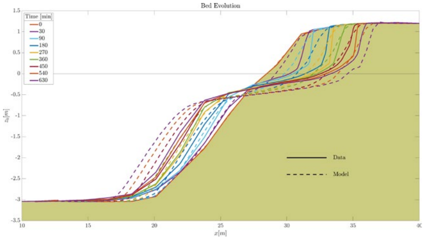
Consider some multi-scale alternatives (to guessing) that utilize finer-scale models to resolve the phase-dependent quantities

- Simple: Use phase-averaged quantities along with empirical procedure to determine details of wave-shape, apply representative hydrodynamics to equations governing relevant process (Two examples today)
- Complex: Build a well-populated 'library' of suitably accurate responses for use by ML (not covered)

- BARSED Sediment Transport Example



- OSU GEE Morpho Change Example

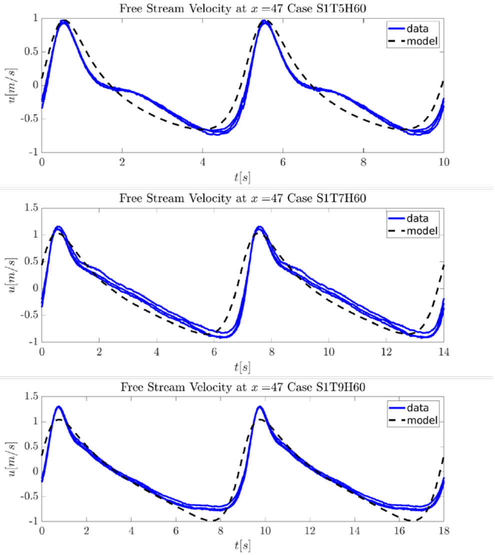


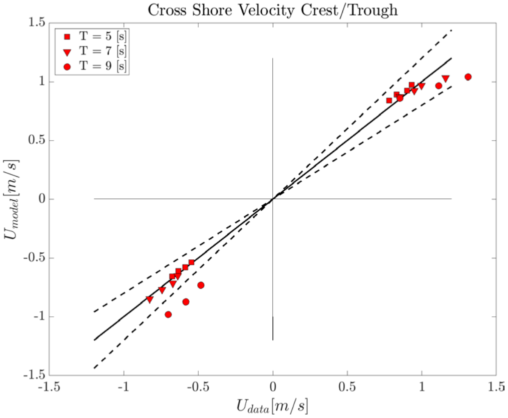
New Modeling Strategy

Consider the simple hybrid approach where numerically-derived closures are utilized in the phase-averaged system:

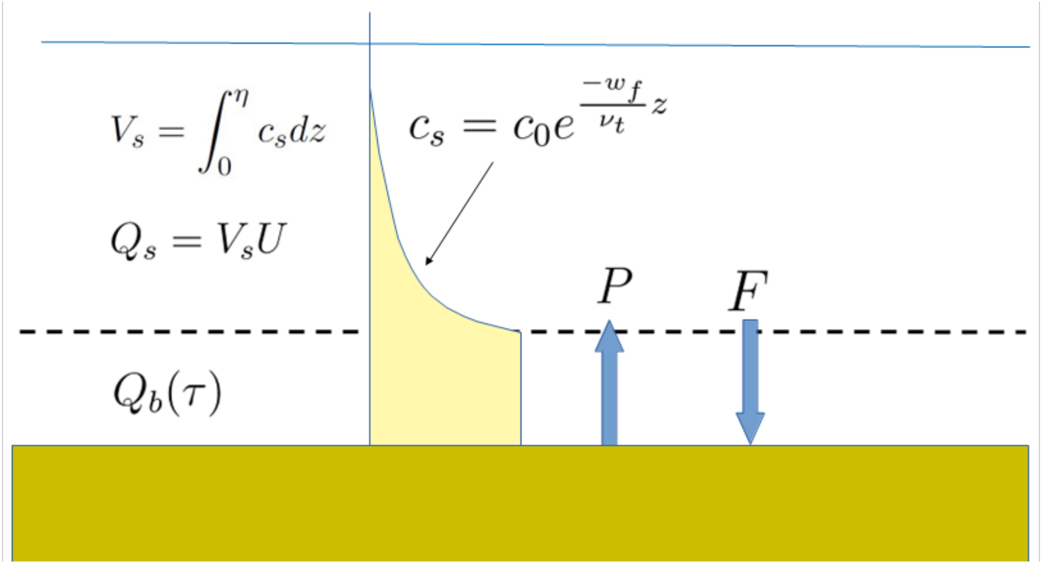
- Deploy phase-averaged model: $h, H_s, (U, V)$
- Estimate skew, asym from $U_r\,(ka, kh) \rightarrow r, \phi$
- Invent time series of free-stream velocity
- Numerically evolve relevant physics, e.g., Vegetation forces or sediment concentration
- With detailed estimates of F, c, u, v, compute time-averages
- Incorporate 'closed' values in phase-averaged model

Example: BARSED Model/data near-bed velocity





Conceptual Sediment Model



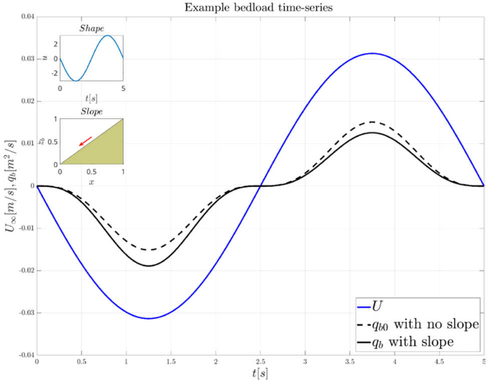
Sediment Model: Bedload Layer

Bedload Layer: A simple traction (energetics) model that assumes transport is in equilib with forcing

$$q_B = 8B\sqrt{g(s-1)d_{50}^3}(\theta(t)-\theta_{cr})^{3/2}G_s$$

With a phase-dependent model, we have the opportunity to correctly include slope dependence

$$G_S = \mathrm{sign}\left(u\frac{\partial z_b}{\partial x}\right)\frac{\tan\phi}{\mathrm{sign}\left(u\frac{\partial z_b}{\partial x}\right)\tan\phi + \left|\frac{\partial z_b}{\partial_x}\right|}$$



Sediment Model: Suspended Layer

Evolution Eqn: $$\frac{\partial V_S}{\partial t} + u\frac{\partial V_S}{\partial x} = P - F$$ where $\mathbf{P}$ = Pickup ; $\mathbf{F}$ = Fallout

$\mathbf{F}$ is straightforward, expressed as $\mathbf{F} = w_f c_0$ but requires estimate of near-bed concentration. Recall the prescribed vertical profile:

$$c_s = c_0 e^{\frac{-\omega_f}{v_t} z}$$ and definition: $$V_s = \int_0^h c_s dz \rightarrow c_0 = \frac{V_s \omega_f}{v_t\left(1 - e^{\frac{-\omega_f}{v_t} h}\right)}$$

The Pickup is cast to have the correct units and time-steady asymptote

$$\mathrm{P} = \omega_f c_{0eq} = \frac{V_{seq}\omega_f}{v_t\left(1 - e^{\frac{-\omega_f}{v_t} h}\right)} \quad \text{where} \quad V_{seq} = \frac{e_B \tilde{D}_B + e_f \tilde{D}_f}{\rho g (s-1)\omega_f}$$

Sediment Entrainment

Model is cast with phase-dependent sediment pickup, but no first-principles statement in

$$P = \omega_f c_{0eq} = \frac{V_{seq}\omega_f}{v_t\left(1-e^{\frac{-\omega_f}{v_t}h}\right)} \quad \text{where} \quad V_{seq} = \frac{e_B\tilde{D}_B + e_f\tilde{D}_f}{\rho g(s-1)\omega_f}$$

Frictional dissipation is expressed: $\tilde{D}_f = \rho c_f |u|^3$ but no analogous accepted model exists for the breaking. We have adopted an intuition-based

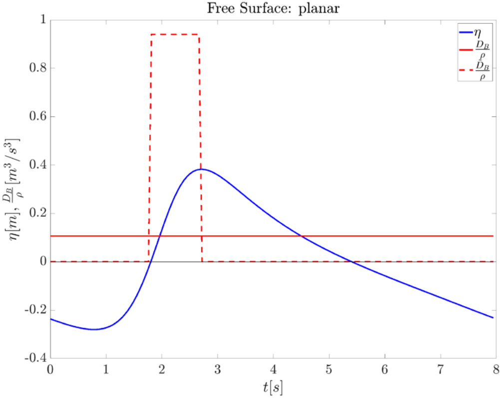
$$\tilde{D}_B = \alpha H(\eta) H\left(\frac{\partial \eta}{\partial t}\right) D_B$$

where D_B is known from the average model and α such that

$$\int_0^T \tilde{D}_B \, dt = \int_0^T D_B \, dt$$

$$H(\eta) = 1 \text{ for } \eta > \bar{\eta}$$

$$H\left(\frac{\partial \eta}{\partial t}\right) = 1 \text{ for } \frac{\partial \eta}{\partial t} > 0$$



Sediment Diffusivity

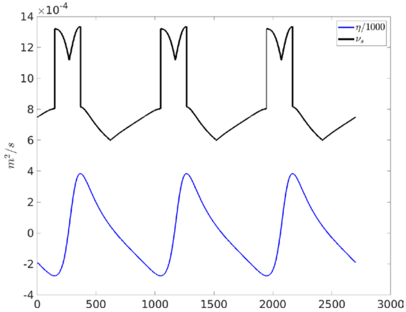
Empirical Length scale and Velocity scale:

$$\nu_s = \nu_t = c_0 + c1\delta\left(\frac{\tilde{D}_f}{\rho}\right)^{1/3} + c2h\left(\frac{\tilde{D}_b}{\rho}\right)^{1/3}$$

Diffusive mixing derives from

- waves,
- bottom shear dissipation,
- breaking dissipation

This is in lieu of a proper turbulence model. Ramification of instantaneous transport of turbulence and sediment is unclear

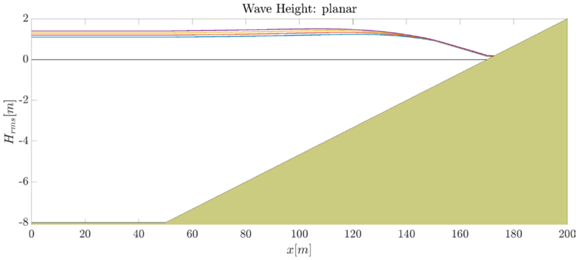


Simple Application Examples

Let's examine the impact of Wave Shape, Bed Slope, and Undertow using simple numerical experiment:

- Idealized bathy
- $T = 8s$
- Increasing wave height
- $d_{50} = 3.5mm$

Phase-averaged results are consistent with a Battjes and Janssen(1978) model – so not presented here

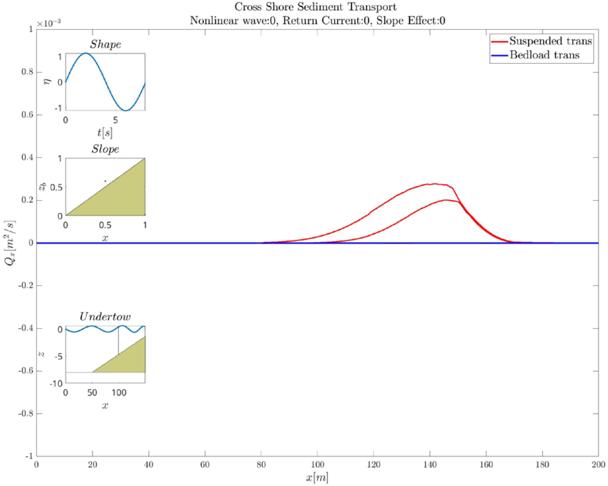


Simple Application Examples: continued

Will show low/high wave heights to show impact.

Wave Shape: Linear
Slope Effect: Off
Undertow: Off

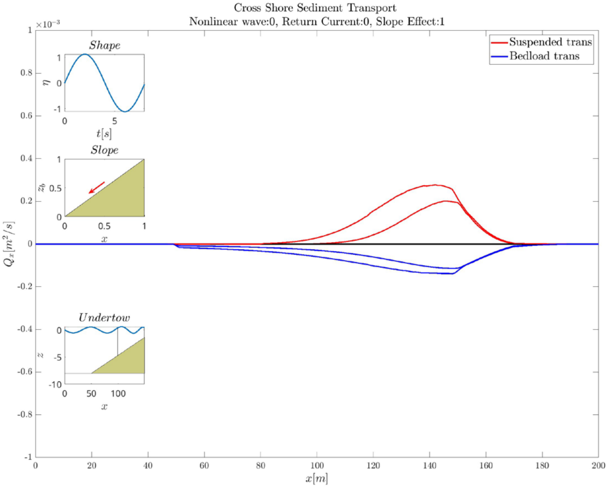
- Bedload ~ 0
- Onshore-directed Suspended transport owing to the phasing of $\tilde{D}_B$



Simple Application Examples: Slope effect

Wave Shape: Linear
Slope Effect: On
Undertow: Off

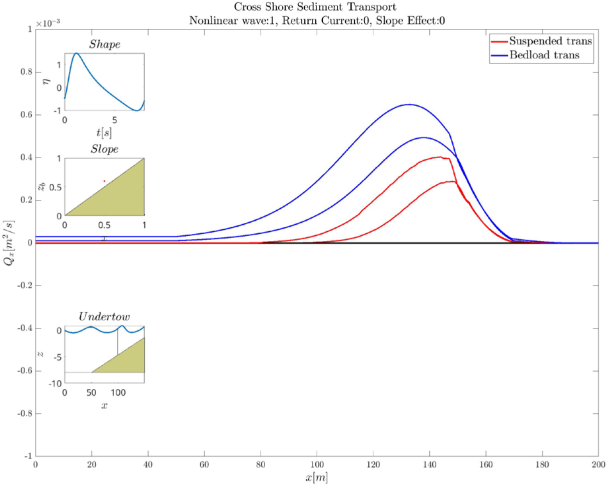
- Offshore-directed Bedload due to preferential down-slope transport
- Onshore-directed Suspended



Simple Application Examples: Shape effect

Wave Shape: Non-linear
Slope Effect: Off
Undertow: Off

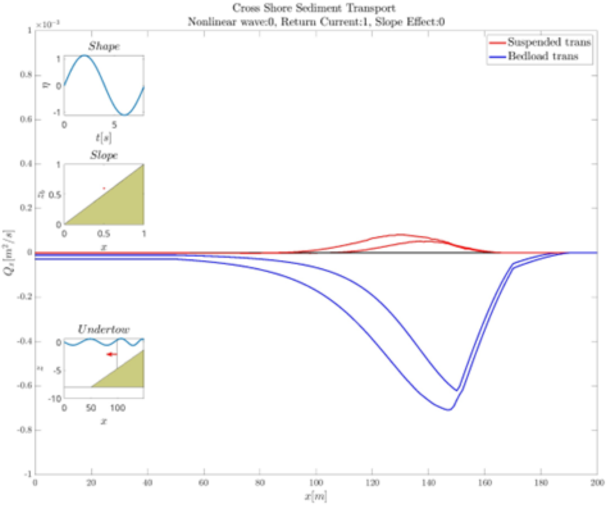
- Onshore-directed Bedload due to non-linearity in the form of q_B
- Onshore-directed Suspended



Simple Application Examples: Undertow effect

Wave Shape: Linear
Slope Effect: Off
Undertow: On

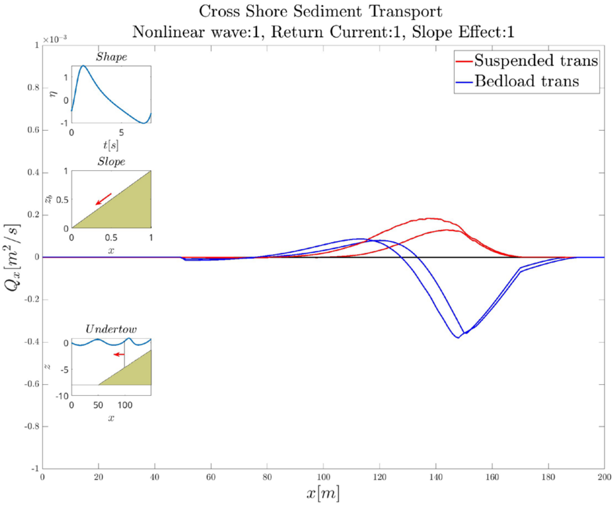
- Offshore-directed Bedload due to current
- Reduced Onshore-directed Suspended



Simple Application Examples: All effects

Wave Shape: Non-linear
Slope Effect: On
Undertow: On

- On/off-directed Bedload
- Onshore-directed Suspended

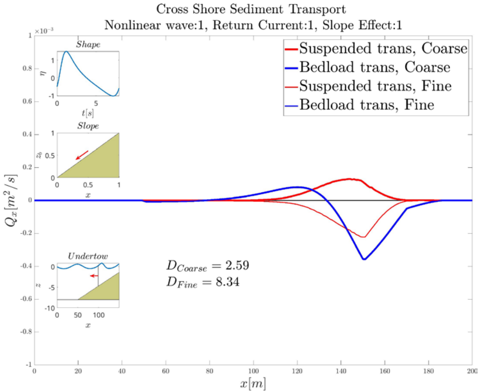


Simple Application Examples: All effects, Sediment variation

- Bedload essentially no impact
- Suspended:
  - fine sand: erosional
  - coarse sand:accretional
- $D = \frac{H}{w_f T}$, where $D > 2$ associated with erosive

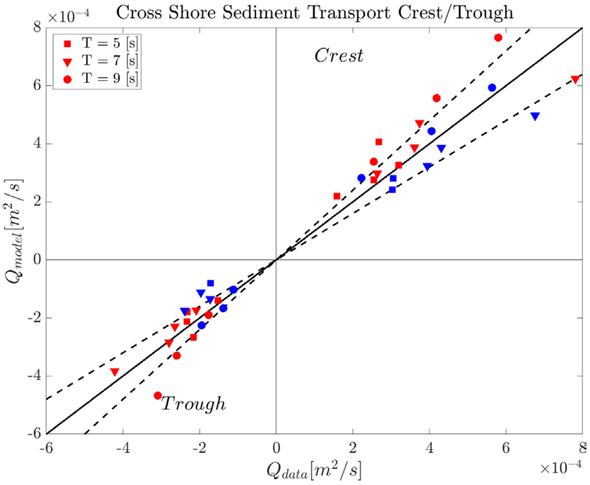
New Model

Moving towards a 'simple' system that computes–rather than guesses–the 1st order processes.



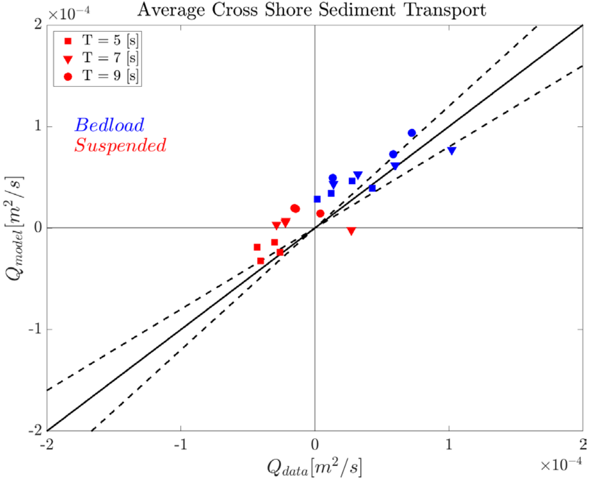
Example: Sediment transport under Trough/Crest

- Crest/Trough based on Pos/Neg U_∞
- Provides some estimate of phase-resolved gross transport accuracy
- v_s are tailored to these data
- Skewness included, but not asymmetry: $T_A(d^3)$



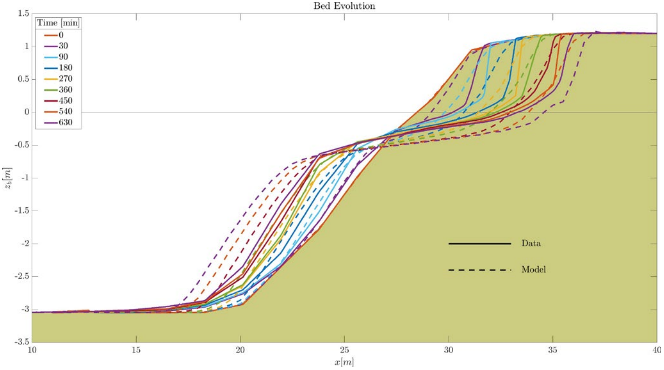
Phase-Averaged Sediment Transport

- Averaged transport is O(10) smaller than gross transport
- Bedload estimates are suitably accurate
- Error in suspended transport may derive from inaccuracies in mean velocity

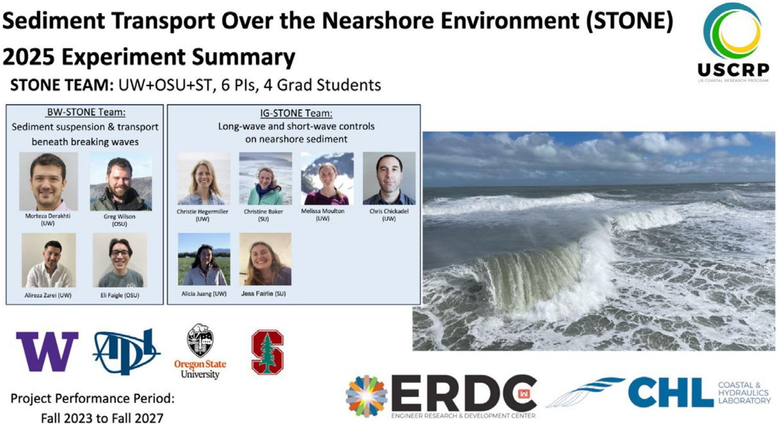


OSU GEE experiment

- Long run of erosive waves
- Dominated by slope effect
- Time-evolution: under-erode and then over-erode



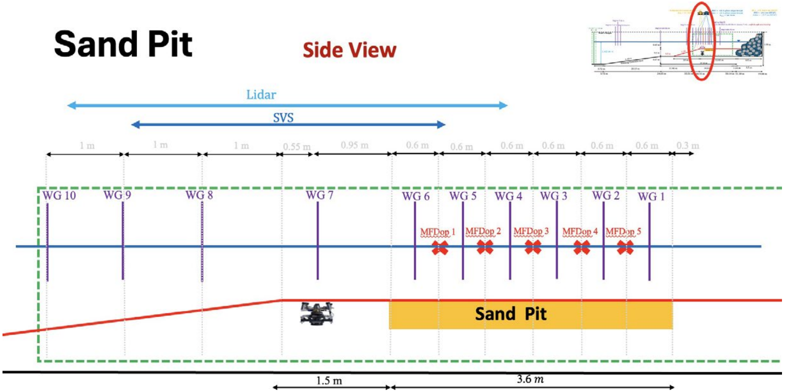
- Series of lab experiments in CHL flume
- UW and OSU Sediment Transport Collaborative LABoratory Experiment
- Repeatable focused wave packets
- SPH model as wave/hydro digital twin of experiment



USCRP SEDCOLAB: Conventional data

A conventional data collection

- hard bottom except for sand-pit
- Free Surface - LIDAR and WG
- u, v, w from ADV

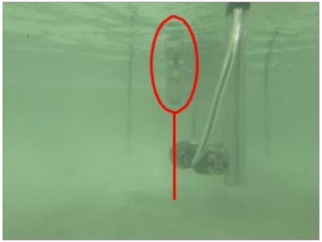


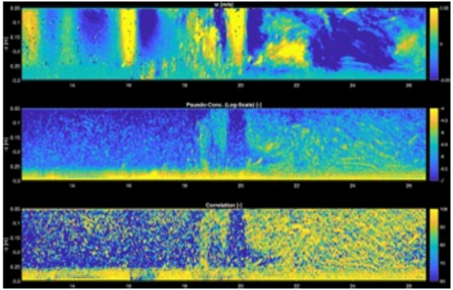
USCRP SEDCOLAB: Unconventional data

Unconventional data collection

- Acoustic instrument for sediment quantification
- vertical and horizontal beams
- Provides estimates for concentration and velocity (so, transport)

Vertical Beam





Conclusions and Possibilities

- The multi-scale approach affords opportunity to incorporate 1st order phase-dependent processes: e.g.
  - Impact of bed slope
  - Impact of wave non-linearity
  - Fully resolved wave/current bottom shear stress
  - Transport from phase-coupled variation in velocity and concentration
- Simple two-scale approach presented where phase-averaged → idealized phase-resolved
  - Process-based estimates for the wave-related physics (shape, slope, currents)
  - Gross Transport predictions compare well to data
  - Net Transport predictions are reasonable, with respect to data
  - Morphology change is under-predicted initially, then over-predicted. Indicates a shortcoming in the simple description
- New effort
  - Phase-resolved UW/OSU data are ideal data for comparison with model
  - First results expected by March