Challenges and Progress in Cross-Shore Transport

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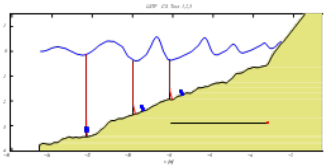
- Why is this so difficult?
- New method for computation of sand transport

Scales of Nearshore Modeling

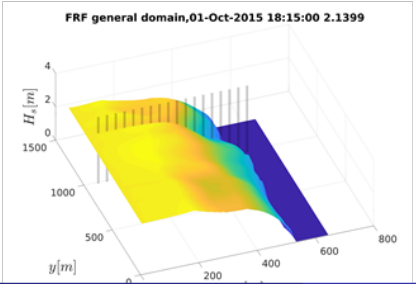
Phase-resolving, Wave Model

- Resolves η, u, v, p
- Accurate predictions of time-dependent variations
- Time scale hours, length scale 1 km
- To date, poor skill in predictions of coastal morphology



Phase-Averaged, Current Model

- Resolves $\eta, u, v, \sigma_\eta, \sigma_u, etc$
- Accurate predictions of nearshore statistics Undertow, Longshore cur., Rip
- Time scale days, length scale 10 km
- Poor skill in predictions of coastal morphology

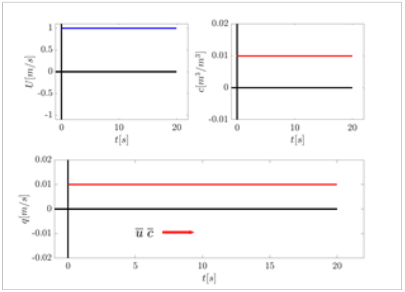


Wave/Current Transport

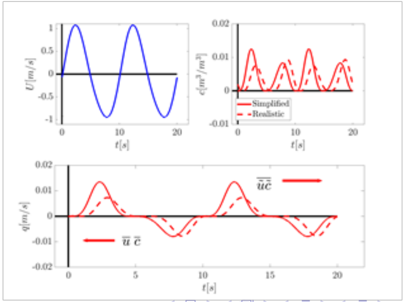
$$q_s = \overline{uc} \quad \overline{u}\,\overline{c} + \overline{\tilde{u}\,\tilde{c}}$$

- Bedload USUALLY transports sand in wave direction, on average.
- Relatively accurate predictions of steady offshore-directed currents
- Wave-related phase-coupled nonzero $\overline{\tilde{u}\tilde{c}}$ reduces steady contribution
- Time-dependent contribution is unknown in magnitude and phasing.

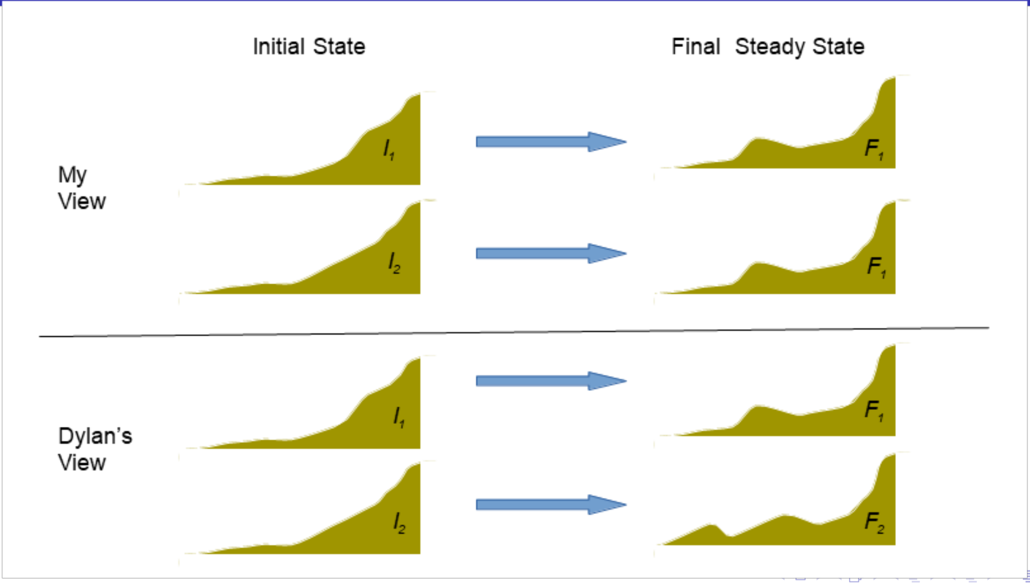
River:



Nearshore:



Hydro/wave/morphology interaction



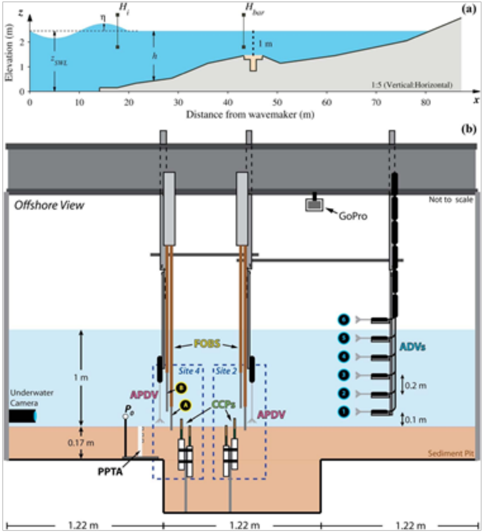
New Modeling Strategy

Is it hopeless?
Maybe, but let's attempt a 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 $U_r(ka, kh) \rightarrow r, \varphi$
- Invent time series of free-stream velocity
- Estimate velocity in the boundary layer
  - Solve BL approximations for synthetic free-stream time-series where first 1 or 2 wave periods have nonphysical transients.
  - Cheat and use interpolated-matching BL velocity
- Numerically evolve sed conc field based on coupled two-layer model
- With estimates of c, u, v, predict transport

BARSED experiments

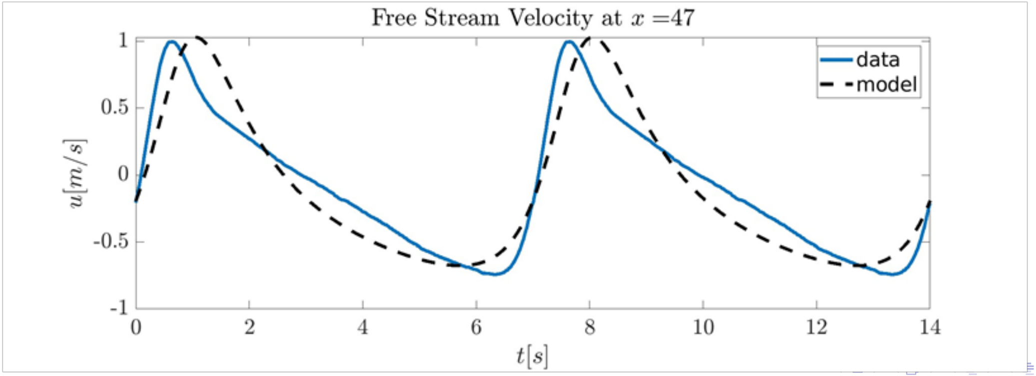
- OSU tank, 2015
- Wave packets, little bed change
- Direct measurement of free-surface and water-column velocity
- Sed concentration measured over the water column, including bedload layer
- First comprehensive set of direct estimates for transport including bedload



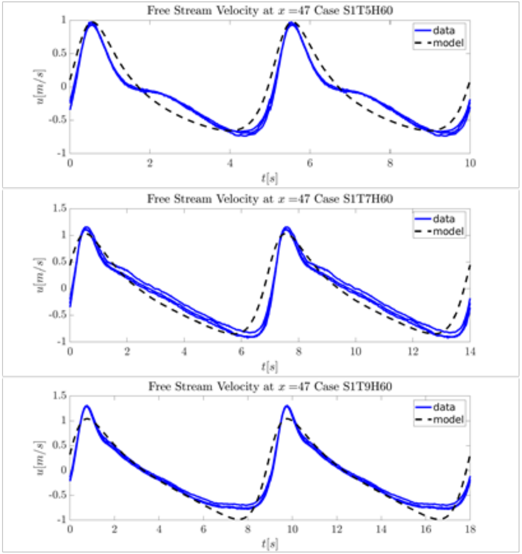
Free-Stream Velocity Model (Skip the wave height)

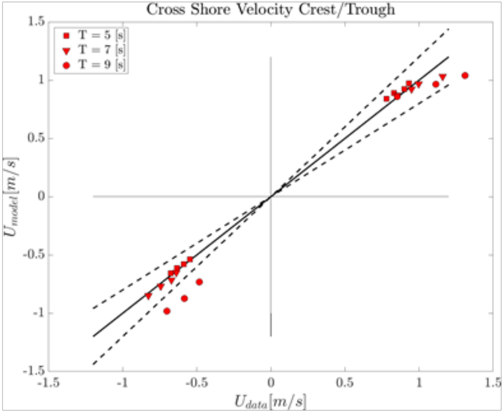
Initial execution of phase-averaged model provides free-surface and velocity statistics.
Estimate skew and asymmetry from Abreu *et al.* (2010) $U_r \rightarrow r, \varphi$

$$u_\infty = U_w f \frac{\sin\left(-\int_0^x k\,dx + \omega t\right) + \frac{r \sin\varphi}{1+\sqrt{1-r^2}}}{1 - r\cos\left(-\int_0^x k\,dx + \omega t + \varphi\right)}$$



Model/data Free stream velocity





Alternative: Boundary Layer Model

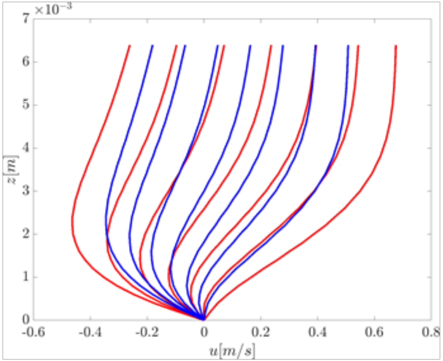
$$\frac{\partial u}{\partial t} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \frac{1}{\rho}\frac{\partial \tau}{\partial z}$$

is easily recast

$$\frac{\partial\, u - u_\infty}{\partial t} = \frac{\partial}{\partial z}\quad \nu\frac{\partial u}{\partial z}$$

or

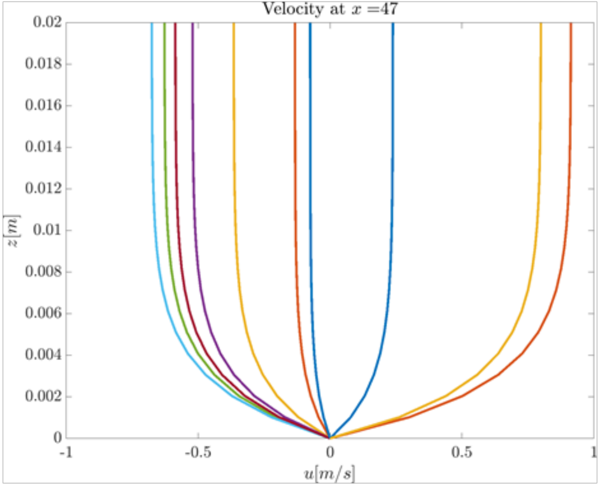
$$\frac{\partial u_\delta}{\partial t} = \frac{\partial}{\partial z}\quad \nu\frac{\partial u_\delta}{\partial z}$$



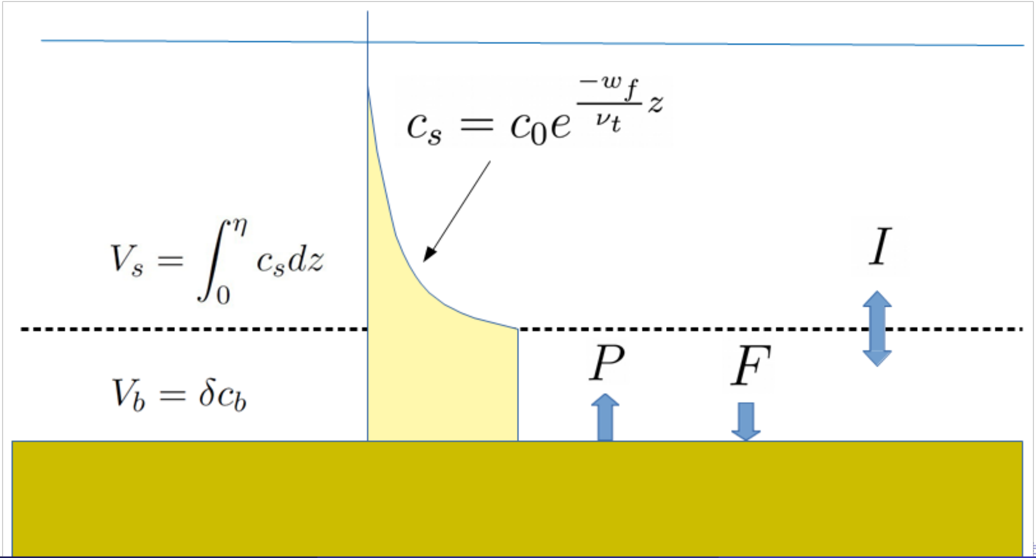
Alternative:Idealized Boundary Layer Model

Simplified computation based on match at estimated boundary layer thickness

$$u(z) = u_\infty(1 - e^{-kz})$$



Conceptual Sediment Model



Sediment Model Boundary Specification

- Sediment entrainment from bed begins with defining an equilibrium concentration:

$$V_{be} = \frac{b_1}{\rho g(s - 1)} \tau'$$

and pickup function is cast to have correct time-steady asmyptote

$$P = \frac{w_f}{\delta} V_{be}$$

- Fallout is proportional to concentration

$$F = c_b w_f = \frac{w_f}{\delta} V_b$$

- Interchange has positive vertical gradient diffusion and negative fallout

$$I = -\nu_s \frac{\partial c}{\partial z} - c_s w_f$$

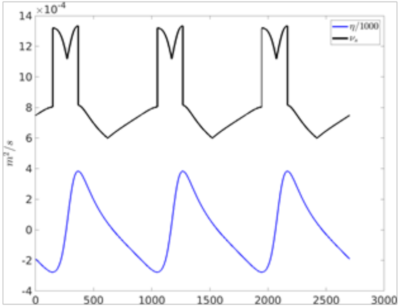
Sediment Diffusivity

Empirical Length scale and Velocity scale:

$$\nu_s = \nu_t = c_0 + c_1\delta\left(\frac{D_f}{\rho}\right)^{1/3} + c_2 h\left(\frac{D_b(\eta > 0)}{\rho}\right)^{1/3}$$

Diffusive mixing derives from

- waves,
- bottom shear dissipation,
- breaking dissipation



Simplified description of sediment, based on two coupled layers:

Suspended Layer: Exponential decay in height

$$V_s = \int_0^{\eta} c_s dz \quad ; \quad \boxed{\frac{\partial V_S}{\partial t} + u\frac{\partial V_S}{\partial x} = I}$$

where

$$\boxed{I = -\nu_s \frac{\partial c}{\partial z} - w_f c_b}$$

Bedload Layer: Constant or well-mixed

$$V_b = \delta c_b \quad ; \quad \boxed{\frac{\partial V_B}{\partial t} + u\frac{\partial V_B}{\partial x} = P - F - I}$$

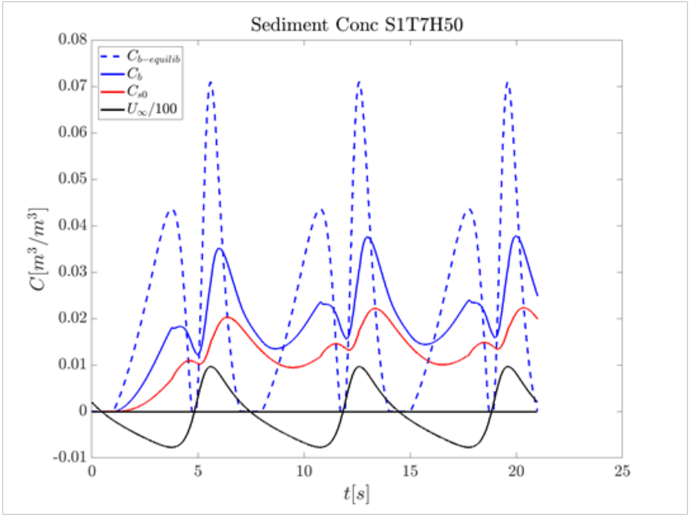
where

$$\boxed{P = f(\tau_b)} \quad \boxed{F = c_b w_f}$$

Time-evolution of sediment concentration

Note

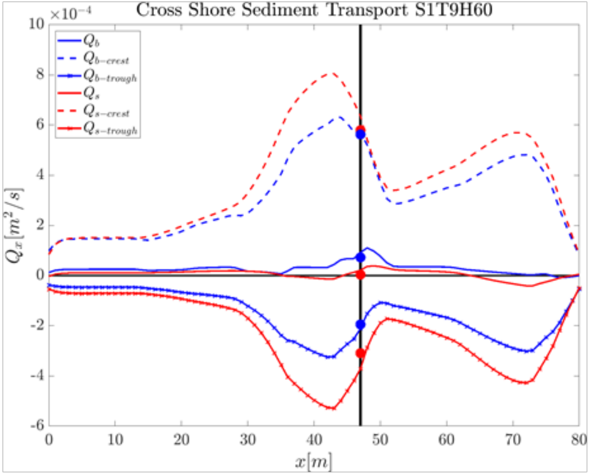
- Cold start
- All pde's integrated in time to 1st order with upwinding
- Crest/trough equilibrium conc differences derive mostly from skewness
- Lags in U_∞^3 and c_b evolve naturally–no guessing phase shift
- Additional lags in c_{s0}



Sediment transport

Note

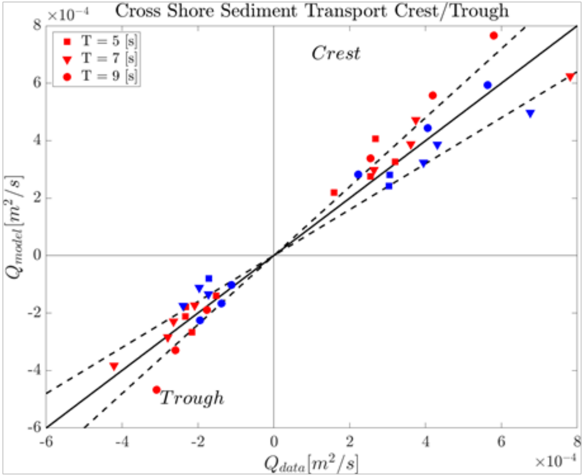
- Cross-shore distribution of crest/trough transport
- Data are provided for one test case
- Bedload is everywhere onshore
- Suspended load is on/off



Sediment transport under Trough/Crest

Note

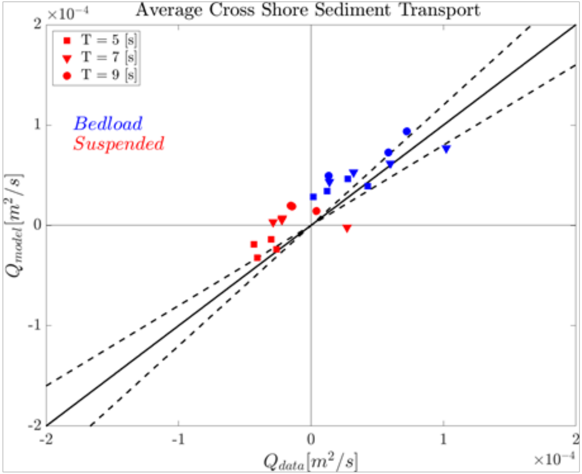
- Crest/Trough based on Pos/Neg U_∞
- Provides some estimate of gross transport accuracy
- ν_s are tailored to these data
- Skewness included, but not asymmetry: $P(S(d^2), A(d^3))$



Phase-Averaged Sediment Transport

Note

- Averaged transport is O(10) smaller than gross transport
- Bedload estimates are suitably accurate
- Suspended transport data are surprising
- Error in suspended transport may be due inaccurate mean velocity



New Modeling Strategy

The hybrid approach affords opportunities:

- Process-based estimates for the wave-related transport
- Incorporate myriad other processes, e.g. impact of bed slope where $G_s\bar{\tilde{q}} \neq \overline{G_s\tilde{q}}$
- Possibility to incorporate the conservation of tke
- New closure for rad stress –a different subject

Next Steps–carefully: Greater complexity does not necessarily lead to greater accuracy and generality is a challenge

- Complete comparisons to other BARSED, HYDRALAB data.
- Compare modeled transport to LSTF
- Compare predicted wave shape to field data