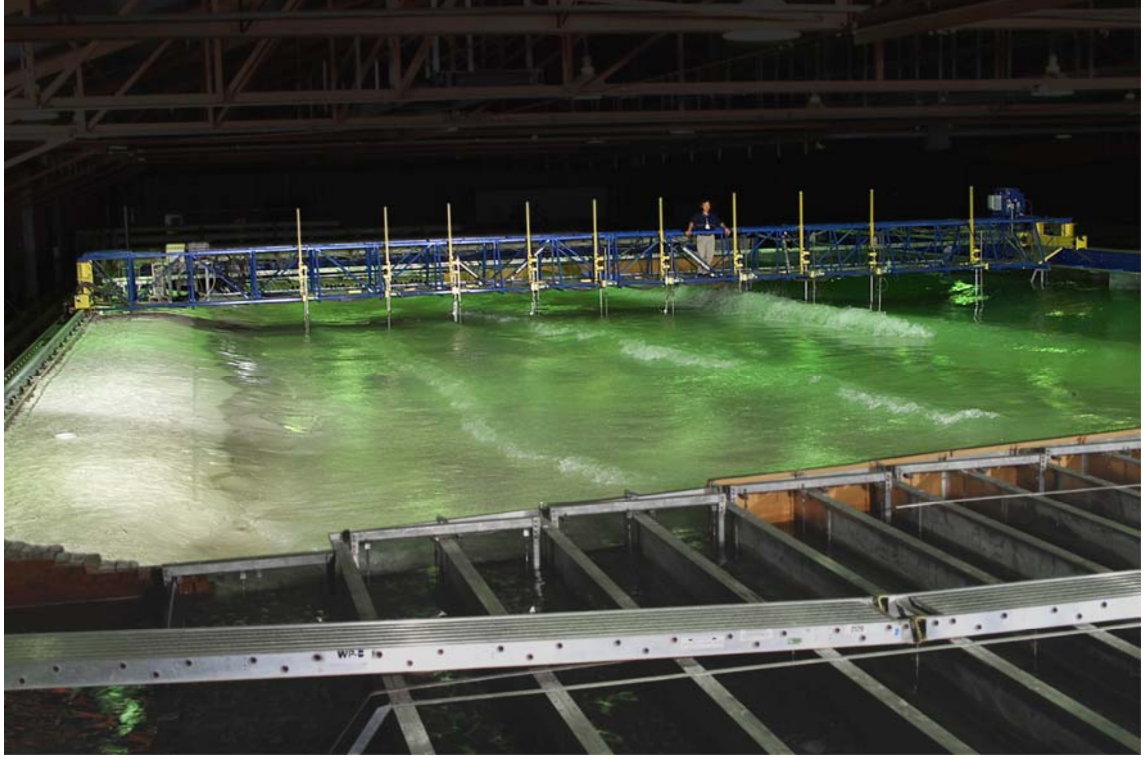


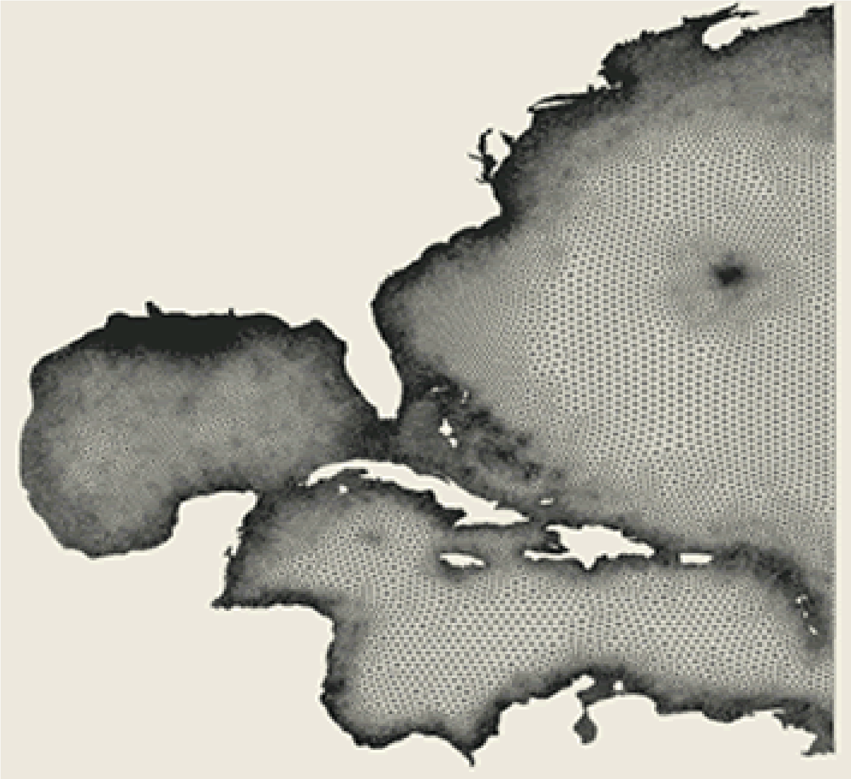
Nearshore sediment entrainment under breaking waves

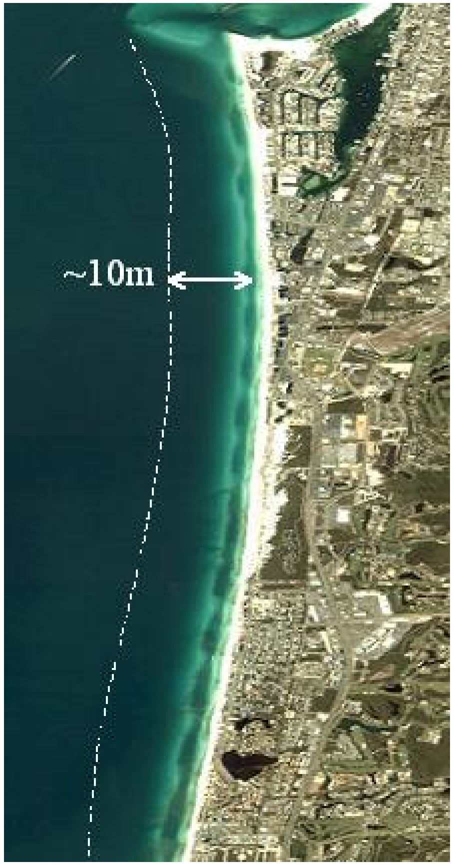
Bradley Johnson

- –Scales of Modeling
- –Laboratory experiments and data
- –A new modeling strategy
- –Defensible expression for entrainment of sand
- –Phase-resolving/Phase averaging models combine to predict transport

Scales of Modeling Circulation

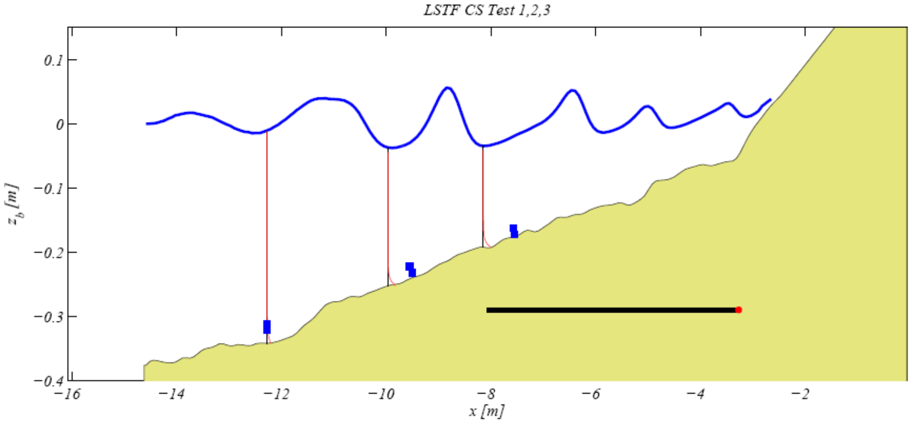
Basin ⟶ Nearshore



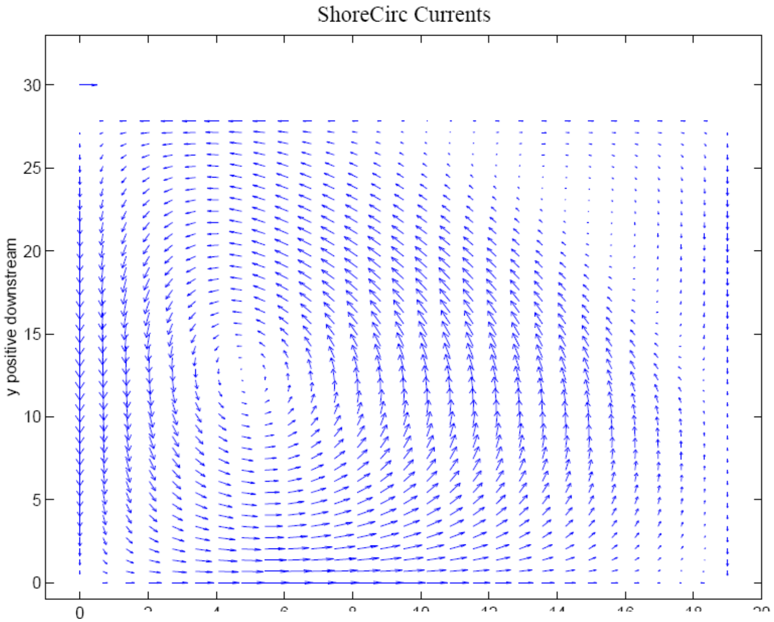


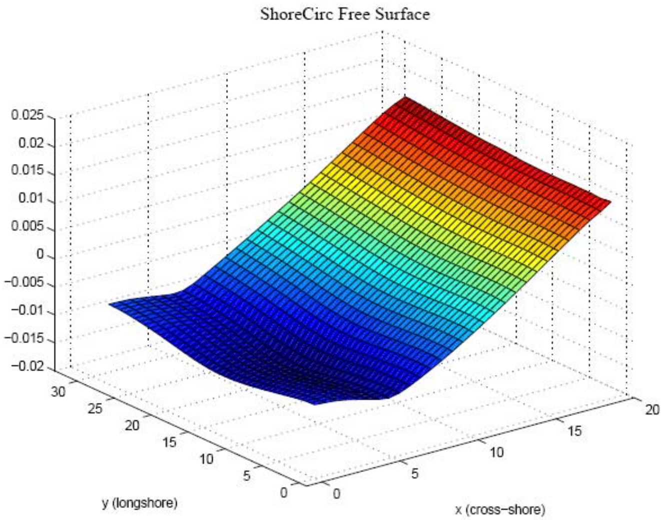
Scales of Modeling Morphology

Phase-resolving, ‘Wave Model’



Phase-Averaged, ‘Current Model’





Scales of Modeling Morphology

Current model: e.g. Shorecirc, AdCirc, AdH

- Accurate predictions of nearshore currents
  - Undertow
  - Longshore current
  - Rip
- Time scale ~days, length scale ~10 km

- Predicts sediment transport poorly
- No treatment of swash, dune erosion, overtopping

Scales of Modeling Morphology

Wave model:, e.g. Boussinesq models

- Accurate predictions of nearshore hydrodynamics
  - Waves, wave breaking, spectral transformations
  - Velocities
  - Moving shorelines, swash, overtopping

- Time scales ~hr; length scale ~100m
- Predictions of currents are, in general, less accurate

The scourge of Nearshore Morphology modeling

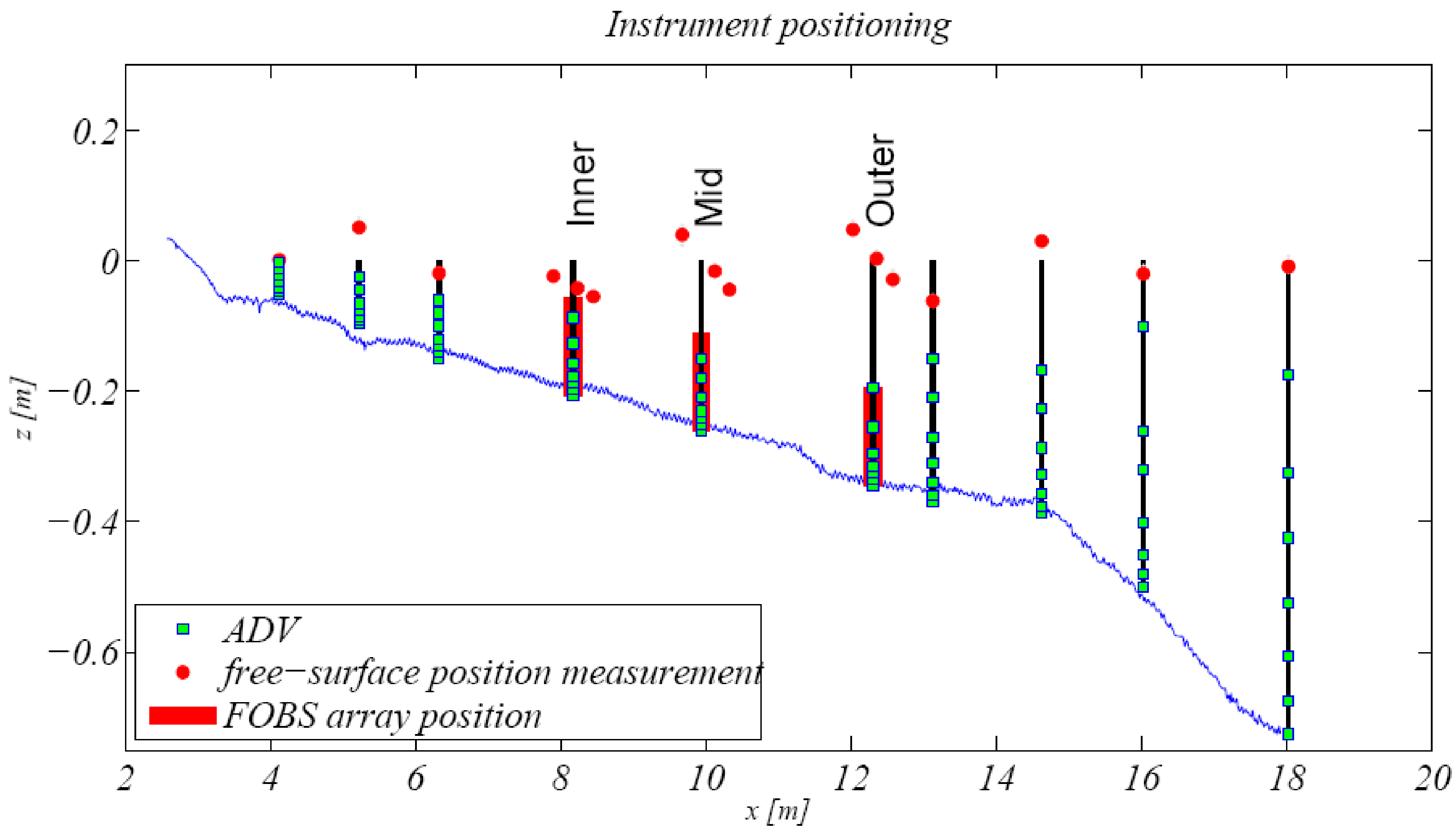
- All of the action occurs at the wave time scale
    - Sediment entrainment
    - Wave-related onshore flux
    - Swash and overtopping

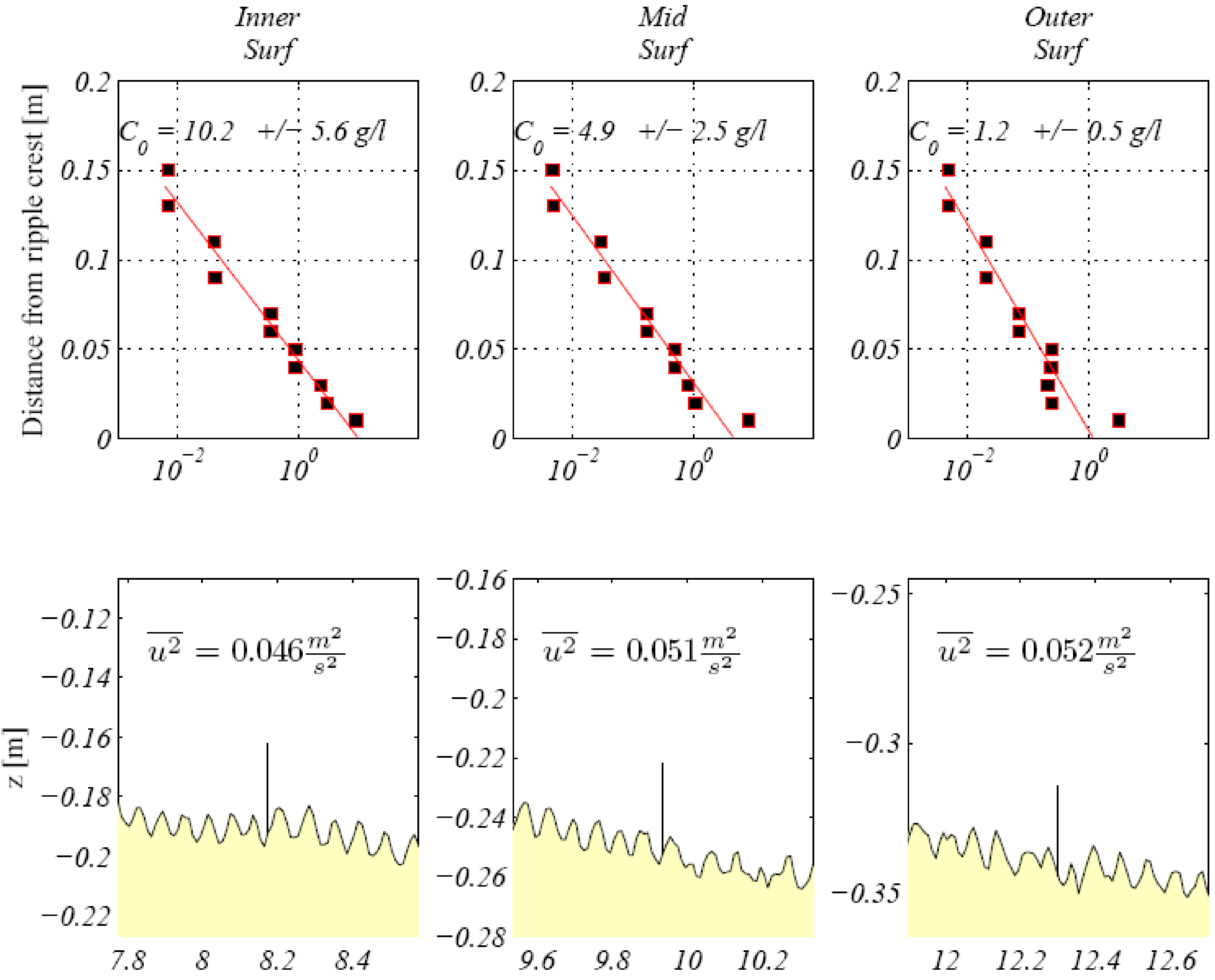
- All of the work happens at another!
    - Currents advect suspended sediment
    - Morphology changes over days

Can we incorporate both?

• Experimental Results

•Previous data collection and modeling have focused on hydrodynamics or phase-averaged flow. A new set recently collected to study phase depended transport in the surf.




Inner Surf
Mid Surf
Outer Surf
Distance from ripple crest [m]
0.2
0.15
0.1
0.05
0
C_0 = 10.2 +/− 5.6 g/l
C_0 = 4.9 +/− 2.5 g/l
C_0 = 1.2 +/− 0.5 g/l
10^{-2}
10^{0}
z [m]
−0.12
−0.14
−0.16
−0.18
−0.2
−0.22
$\overline{u^2} = 0.046 \frac{m^2}{s^2}$
7.8
8
8.2
8.4
−0.16
−0.18
−0.2
−0.22
−0.24
−0.26
−0.28
$\overline{u^2} = 0.051 \frac{m^2}{s^2}$
9.6
9.8
10
10.2
−0.25
−0.3
−0.35
$\overline{u^2} = 0.052 \frac{m^2}{s^2}$
12
12.2
12.4
12.6

$$\frac{\partial\,\mathbf{U}}{\partial t} + \frac{\partial\,\mathbf{F}}{\partial x} = \mathbf{S}$$

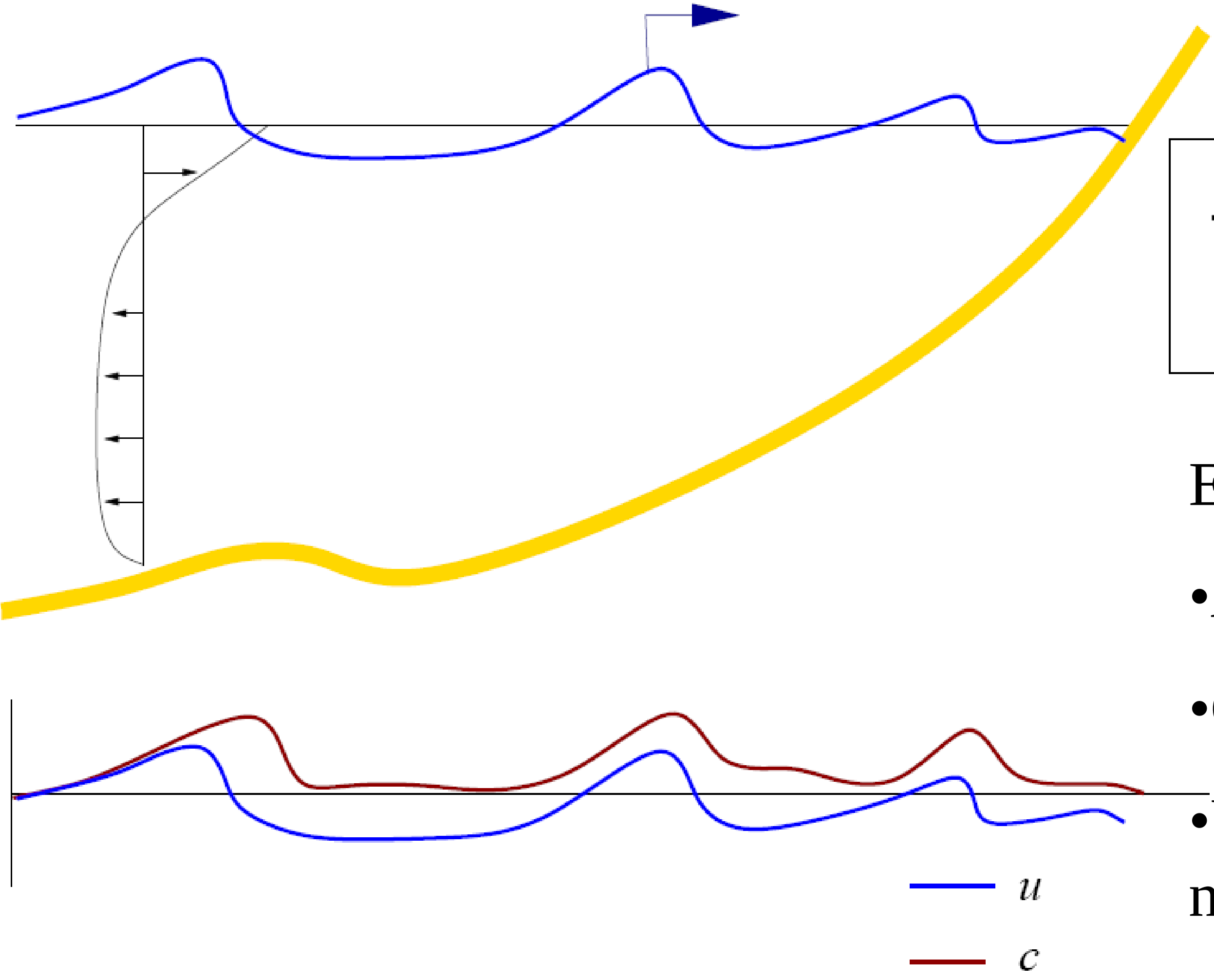
Phase-Resolving Set

$$\mathbf{U} = \begin{bmatrix} h \\ q + \mathrm{b} \\ hC \end{bmatrix} \quad ; \quad \mathbf{F} = \begin{bmatrix} q \\ \frac{q^2}{h} + \frac{g}{2} h^2 \\ qC \end{bmatrix} \quad ; \quad \mathbf{S} = \begin{bmatrix} 0 \\ -gh\frac{\partial\, z_b}{\partial x} - \tau_b/\rho + \mathrm{B} \\ S - C_0 w_f \end{bmatrix}$$

Phase-Averaged Set

$$\mathbf{U} = \begin{bmatrix} \overline{h} \\ \overline{q} \\ 0 \end{bmatrix} \quad ; \quad \mathbf{F} = \begin{bmatrix} \overline{q} \\ \frac{\overline{q}^2}{\overline{h}} + \frac{g}{2} \overline{h}^2 + S_{xx} \\ \overline{q}\,\overline{C} + \overline{\tilde{q}\ \tilde{c}} \end{bmatrix} \quad ; \quad \mathbf{S} = \begin{bmatrix} 0 \\ -g\overline{h}\frac{\partial\, z_b}{\partial x} - \overline{\tau_b}/\rho \\ n\frac{\partial\, z_b}{\partial t} \end{bmatrix}$$

The analogous problem in cross-shore transport



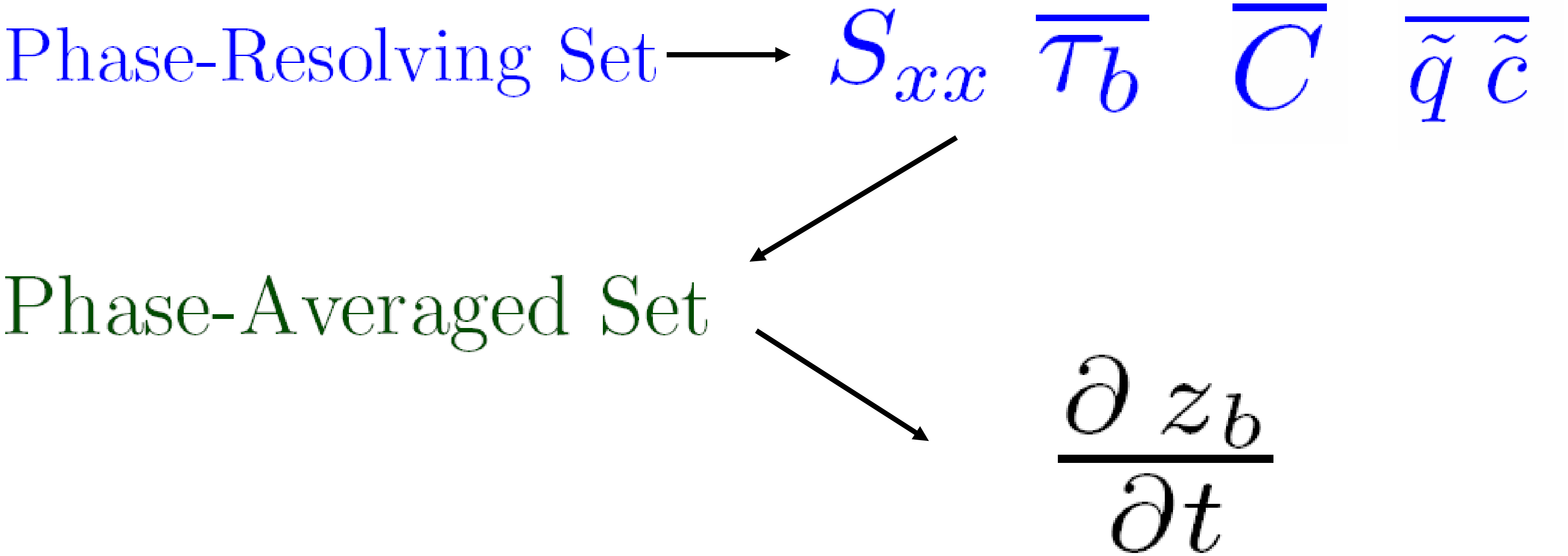
$$\overline{q_x} = \overline{uc} + \overline{\tilde{u}\tilde{c}}$$

Existing strategy:

- Avoid
- Completely Empirical
- Use narrow range of numerical closure

New modeling strategy:

- Let’s use the phase-resolving model to ‘close’ the unknowns in the phase-averaged model
  - Uses the same equations
  - Same grid but decimated
  - Same hydro, flux solver used for both models



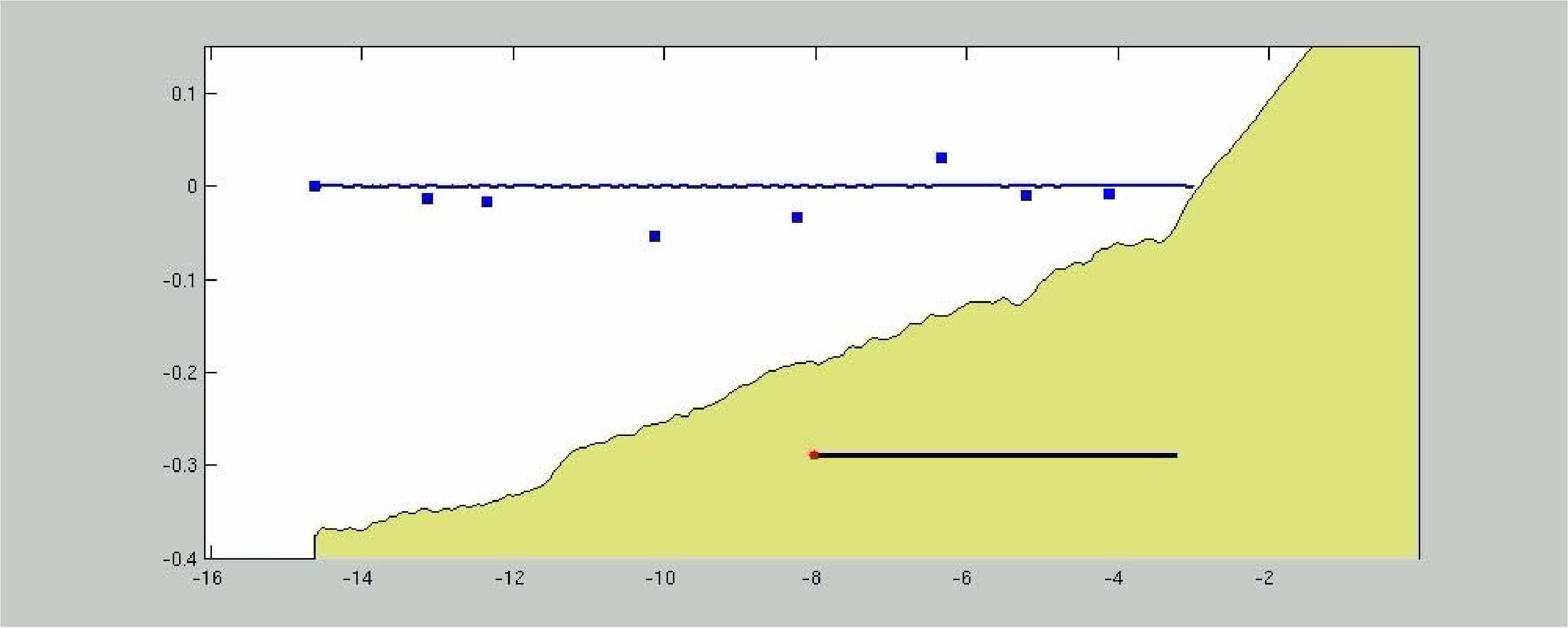
Phase-Resolving Set $\longrightarrow$ S_{xx} $\overline{\tau_b}$ $\overline{C}$ $\overline{\tilde{q}\,\tilde{c}}$

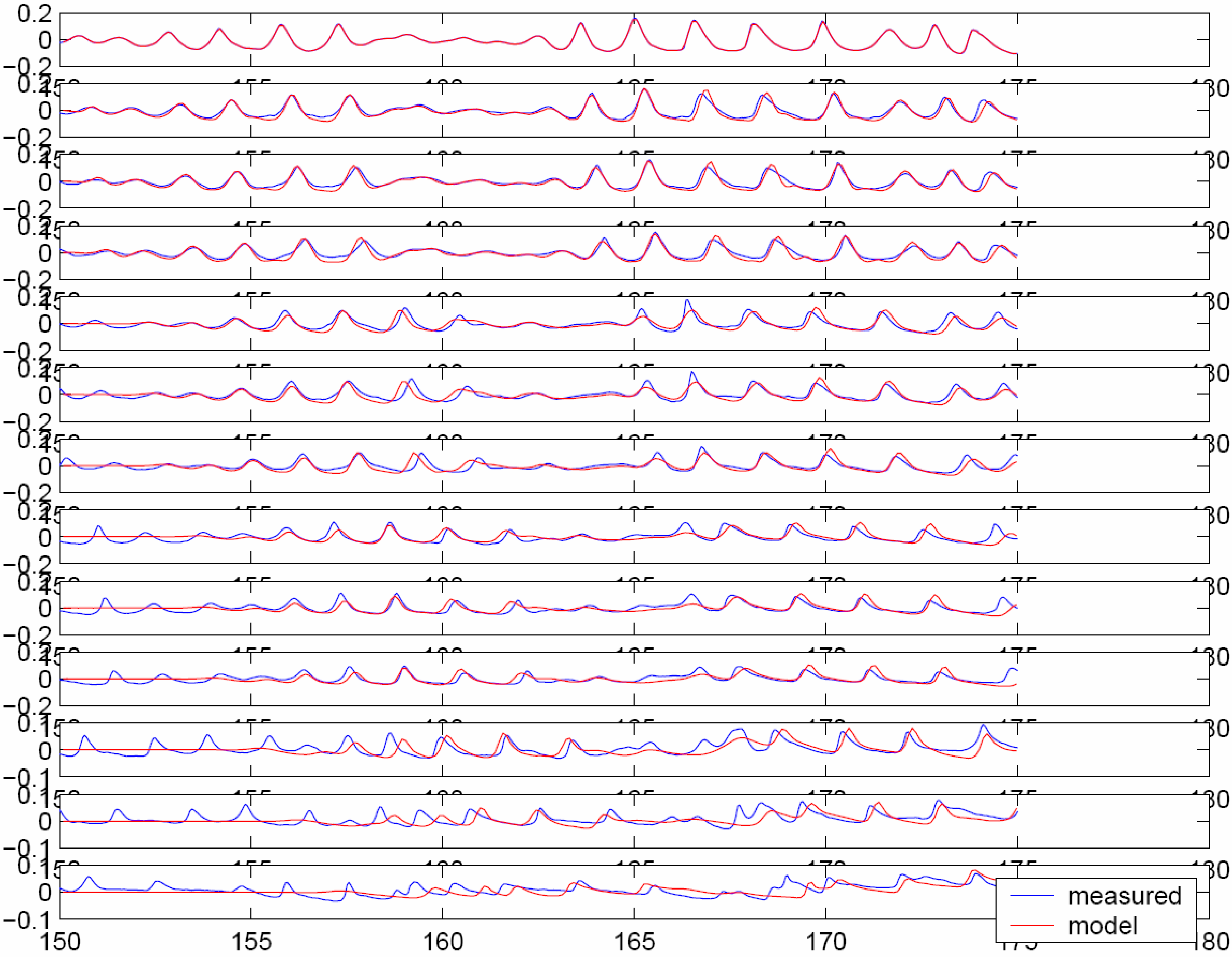
Phase-Averaged Set

$$\frac{\partial z_b}{\partial t}$$

Phase Resolving: Boussinesq

- Flux formulation
- Originally by Madsen and Sorenson (1991), (1992)
- Extended in Dingemans (1997)
- WAF or predict-corrector, limiters switch to upwinding




0.2
0
−0.2
0.15
0
−0.1
150
155
160
165
170
175
180
measured
model

Sediment Entrainment

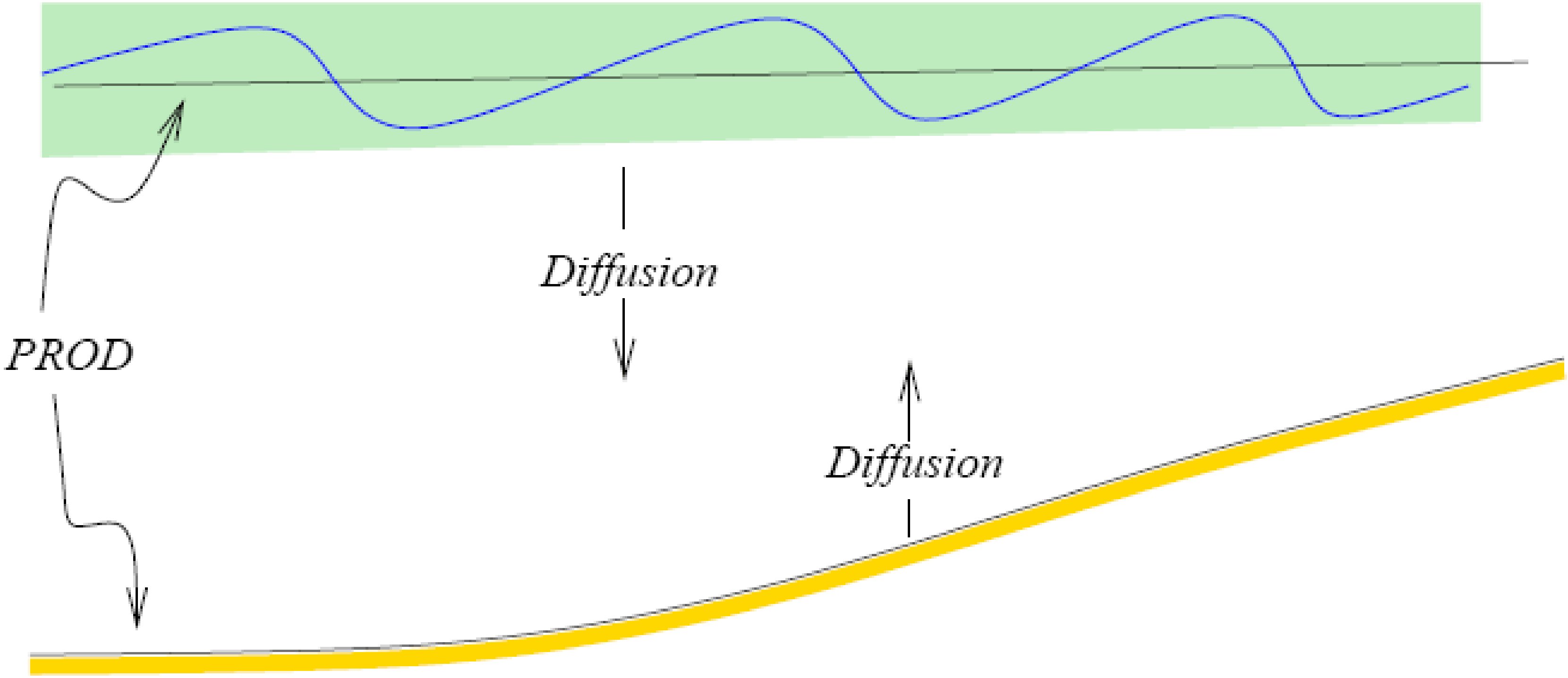
- Recall: sediment transport models relate either directly or indirectly on the near bed shear stress (or the near-bed turbulence which is assumed to be bed shear generated)
- My new data set is unusual—energetic, near the breaking process, reveals different physics.

Starting at the source: It seems reasonable to assume that the entrainment is a function of near-bed dissipation

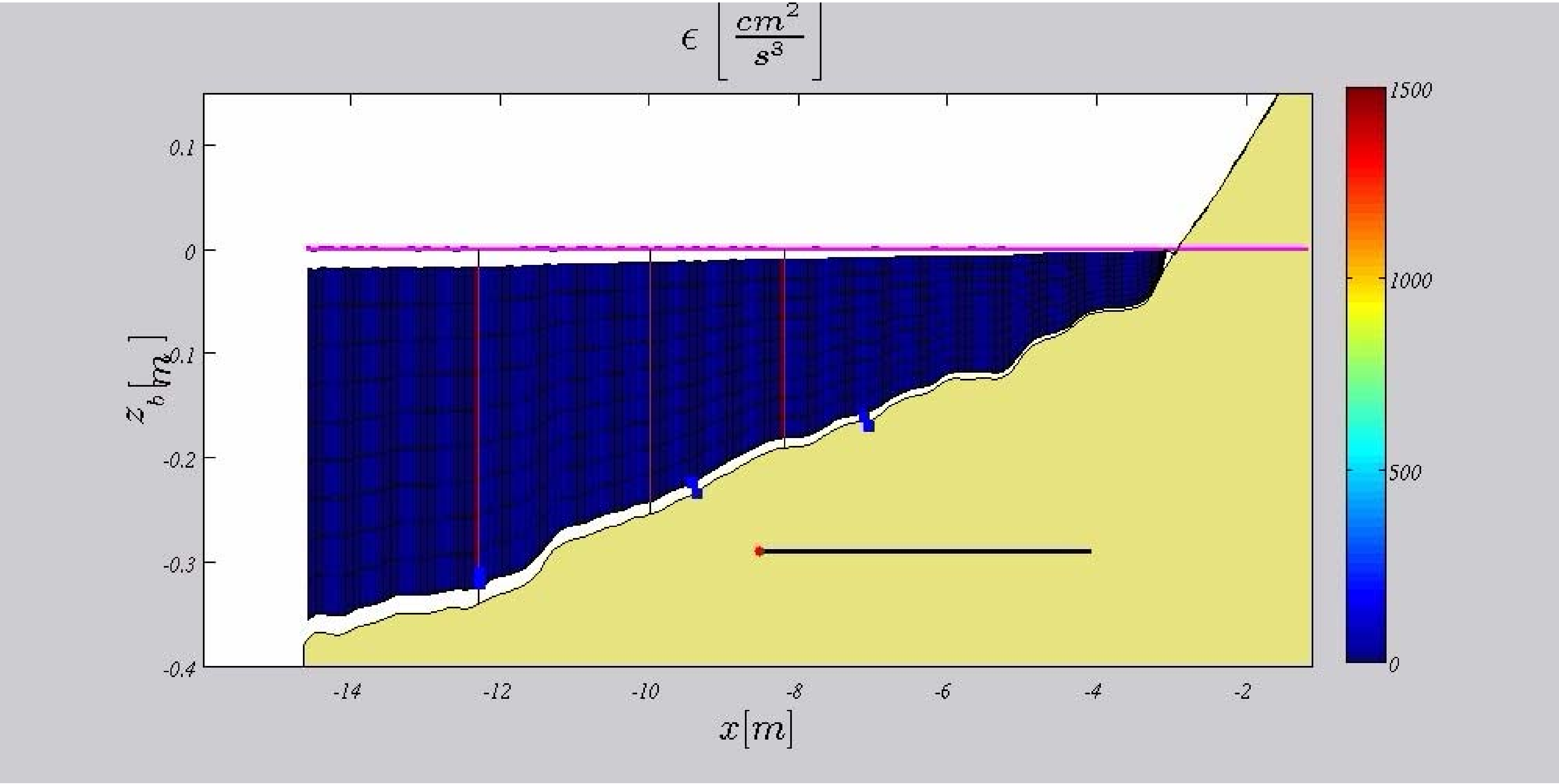
$$p = \frac{1}{g(s-1)}\underset{\text{Efficiency}}{e}\overset{\text{Dissipation}}{\epsilon}$$

An idealized surf zone turbulence balance:

$$\frac{\partial\, k}{\partial t} = -\frac{\partial\, kU}{\partial x} + \frac{\partial}{\partial z}\left\{\nu_t \frac{\partial\, k}{\partial z}\right\} + P - \epsilon$$



$$\frac{\partial E}{\partial t} + \frac{\partial E_f}{\partial x} = -D \;\; ; \quad P = D/\rho/\Delta z$$



Recall entrainment function:

$$p = \frac{1}{g(s-1)} e\epsilon$$

If $\epsilon = \epsilon_b$

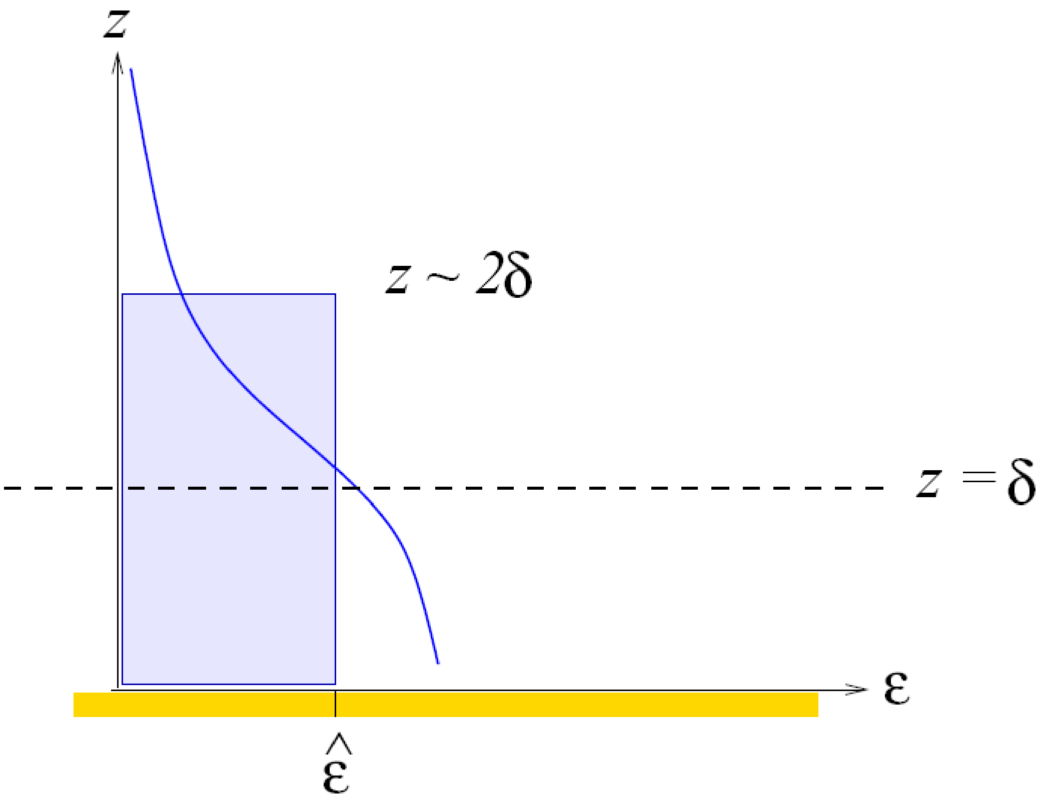
Only, then can be consistant with BBB, Van Rijn (1984)

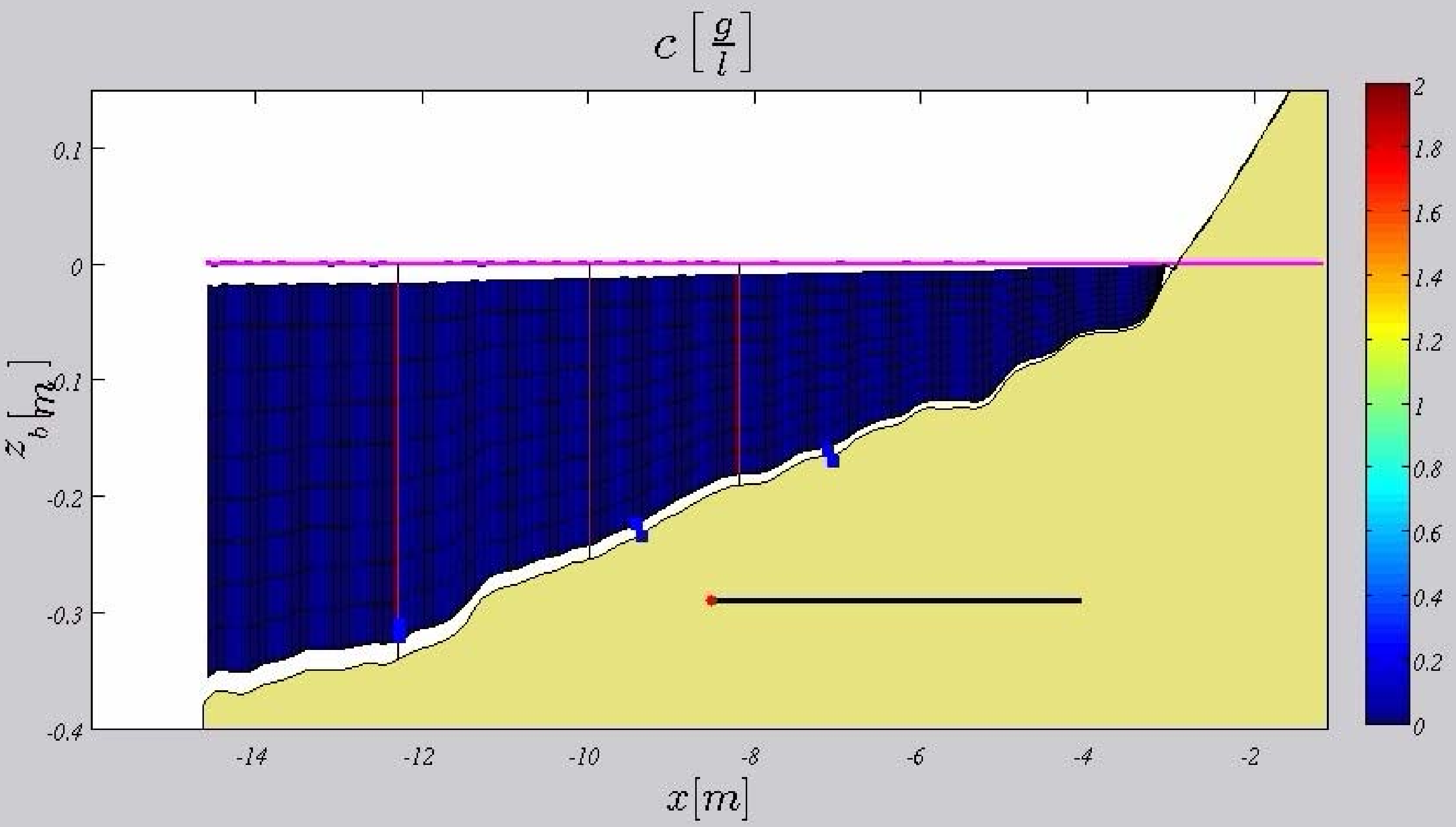
But, breaking appears to be important, so propose

$$\epsilon = \epsilon_s + \epsilon_b$$

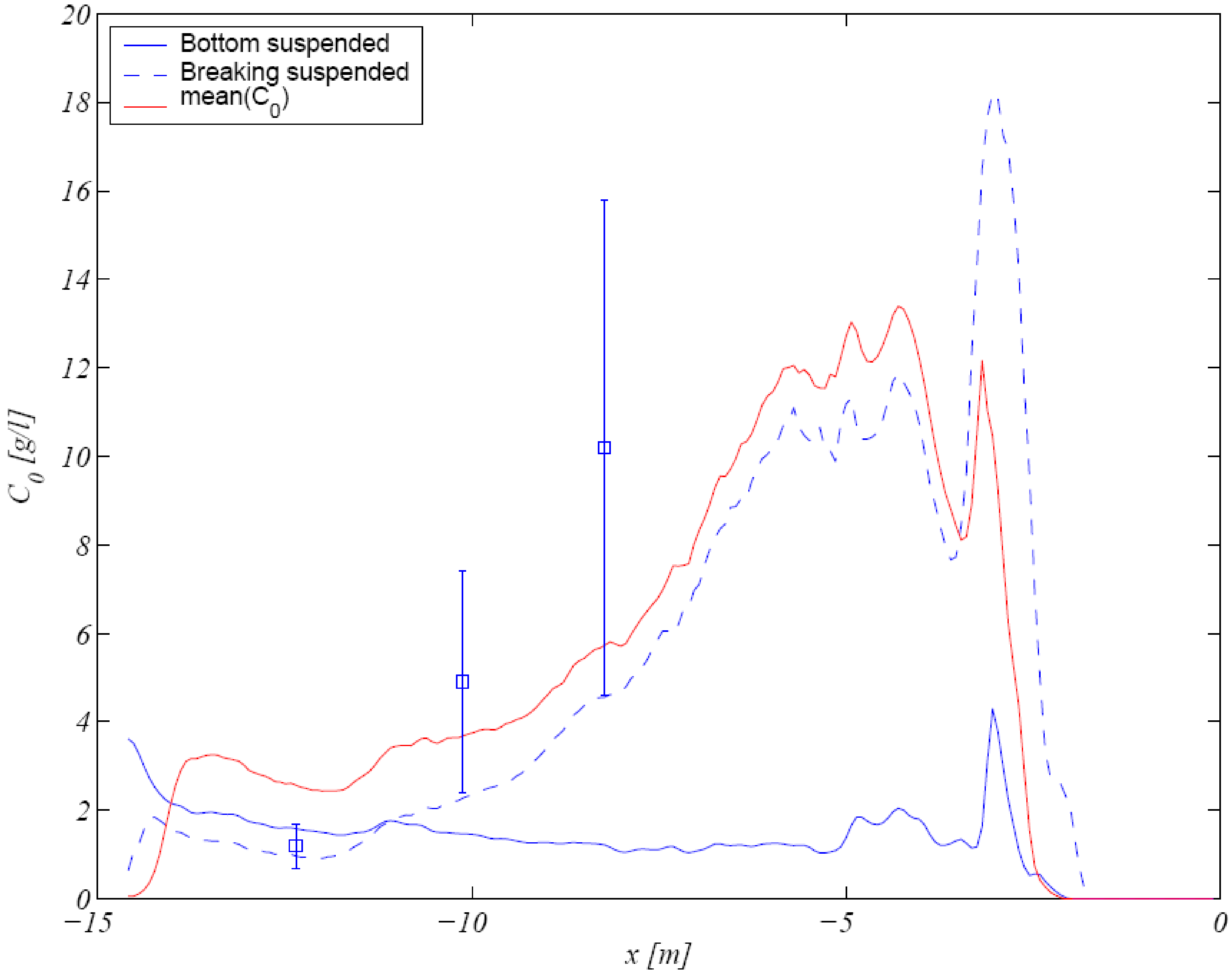
To determine near-bed dissipation, a representative dissipation is developed:

$$\hat{\epsilon}_b = \frac{c_f}{2\delta}|u|^3$$

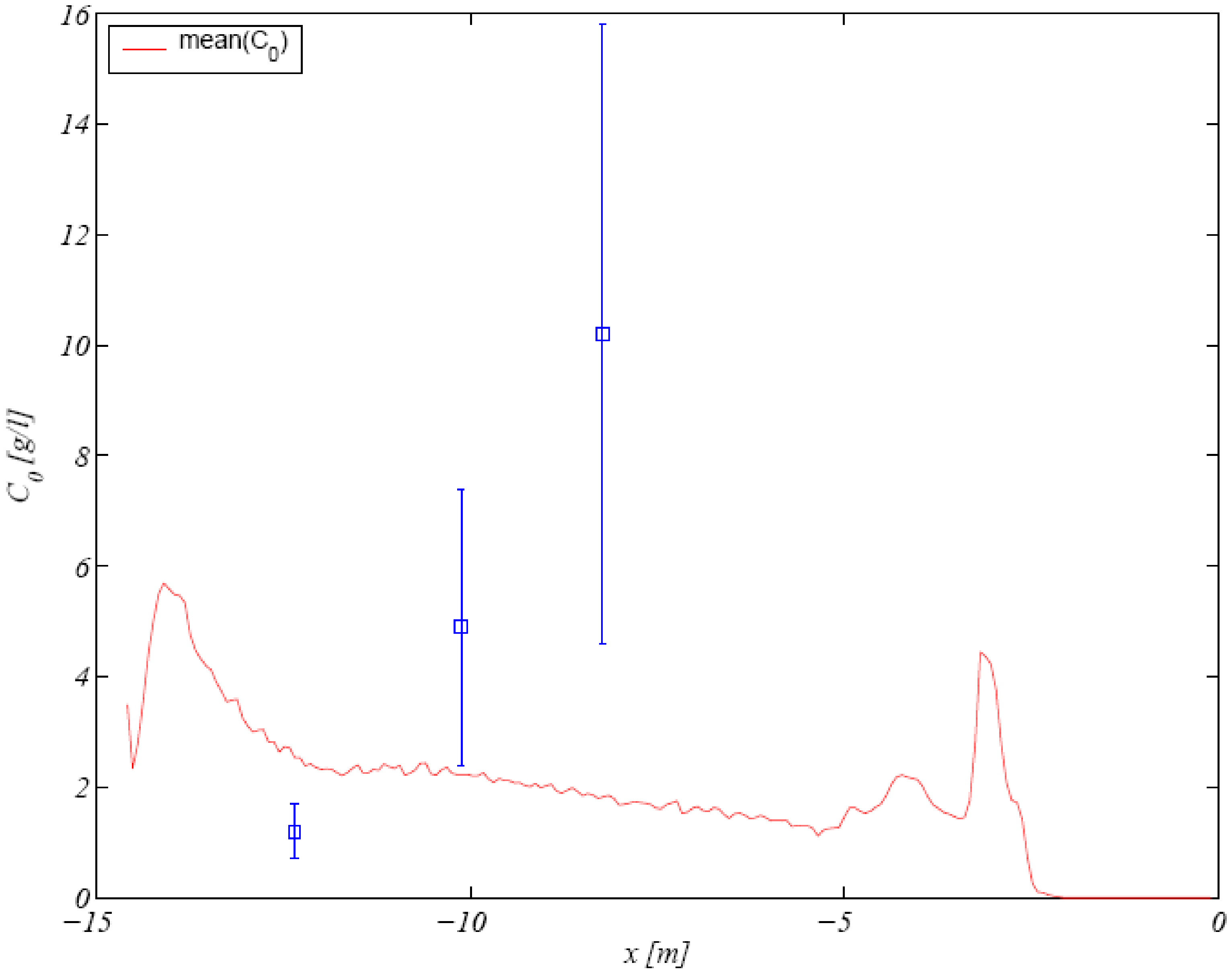



$c\left[\frac{g}{l}\right]$
$z_b[m]$
$x[m]$
0.1
0
-0.1
-0.2
-0.3
-0.4
-14
-12
-10
-8
-6
-4
-2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0

Suspended sediment predictions

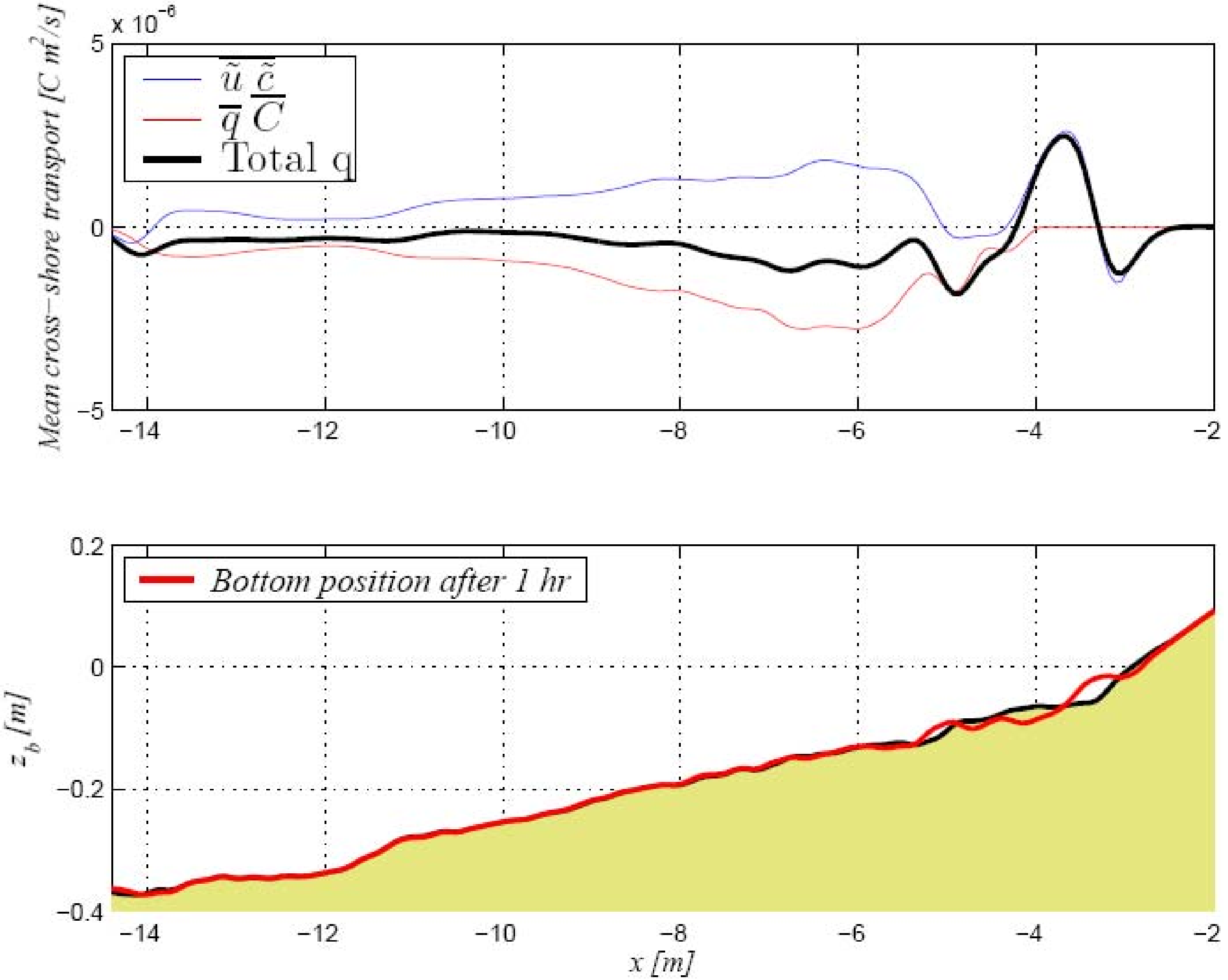


Using VanRijn (1984) entrainment



Conservation of sand in phase-averaged model

$$n\frac{\partial z_b}{\partial t} = -\frac{\partial}{\partial x}\left(\overline{\tilde{q}\,\tilde{c}} + \overline{q}\,\overline{C}\right)$$



Summary and Conclusions

- No surprise: morphology models fail. The important physical processes are not incorporated!
- A presentation of detailed surf zone hydrodynamic and sediment data.
- Proximity to breaking dissipation is likely explanation for disparity in concentration over surf.
- A simple physical basis is presented for an entrainment that incorporates breaking and turbulence decay
- A coupled model strategy can incorporate high-fidelity results into a predictive tool
- A reasonable prediction of the cross-shore balance of sediment is demonstrated with standard friction and *k*-*l* parameters.