Investigating the Sensitivity of a 1-D Cohesive Sediment Total Entrainment Function that Incorporates Bioturbation and Consolidation

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Outline

1) Introduction: Power law entrainment function

2) Non-uniqueness of power law entrainment function

3) Bioturbation & consolidation functions

4) Relative effects of Bioturbation and Consolidation on entrainment

5) Comparison of power law and exponential entrainment functions

6) Conclusion

Introduction

Cohesive sediment transport impacts bays, estuaries, rivers:

1) Sediment redistribution: Erosion and Deposition
2) Pollutants: transport by sediments
3) Water clarity: Impact on biology, water chemistry

External Forces:

1) Wave (Bottom boundary layer, wave-driven circulation)
2) Wind (mean current, waves)
3) Tides (tidal asymmetry, residual tidal motion)

Biogeochemical forces:

1) Bioturbation within sediments (local ecosystem)
2) Consolidation (physical-chemical changes with in sediment)
3) External biogeochemical forcing in the water column and water-sediment interface (i.e. benthic boundary layer)
4) Flocculation

Power Law Entrainment Function

(1)
$$E_B = A_0\left(\frac{\tau}{\tau_c} - 1\right)^m = A_0\left(\tau^*\right)^m$$

E_B = Total entrainment kg m^{-2}
A_0 = Fundamental Entrainment parameter (kg m^{-2})
τ^* = excess shear stress (non-dimensional)
τ = bottom shear stress (Pa)
τ_c = critical shear stress (Pa)
m = non-dimensional parameter

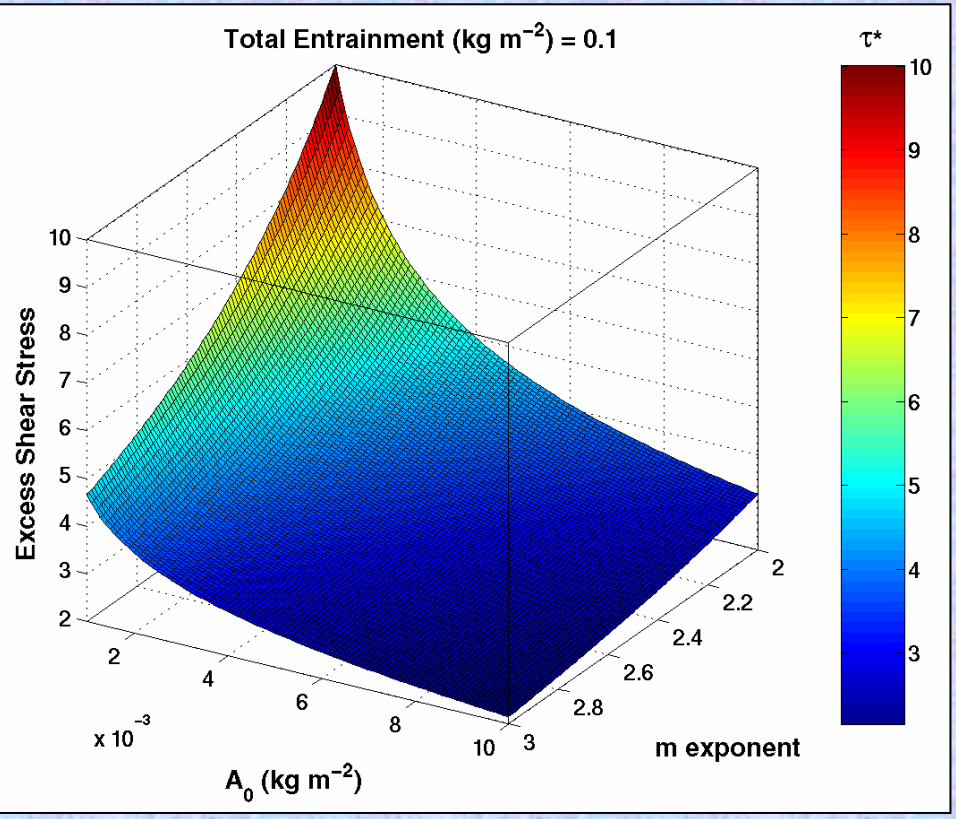
Inversion of entrainment function: Excess Shear Stress

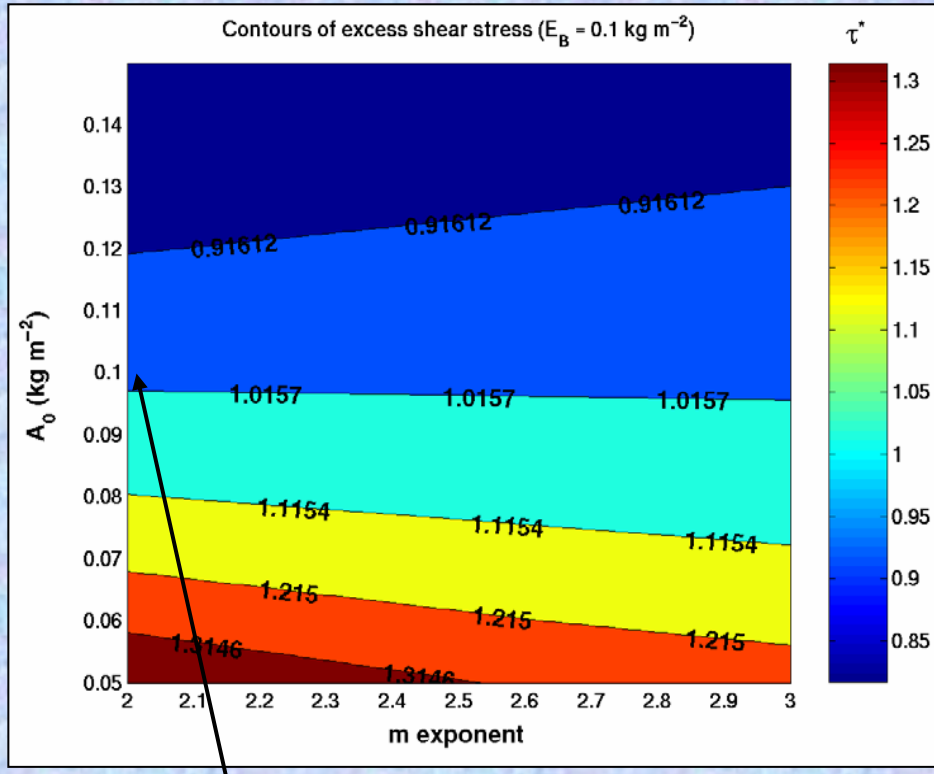
(2)
$$\tau^* = e^{\frac{-\ln\left(\frac{A_0}{E_B}\right)}{m}} = \left(\frac{A}{E_B}\right)^{-\frac{1}{m}}$$

Non-Uniqueness of Total Entrainment Function

Isosurface of total entrainment

Contours of excess shear stress



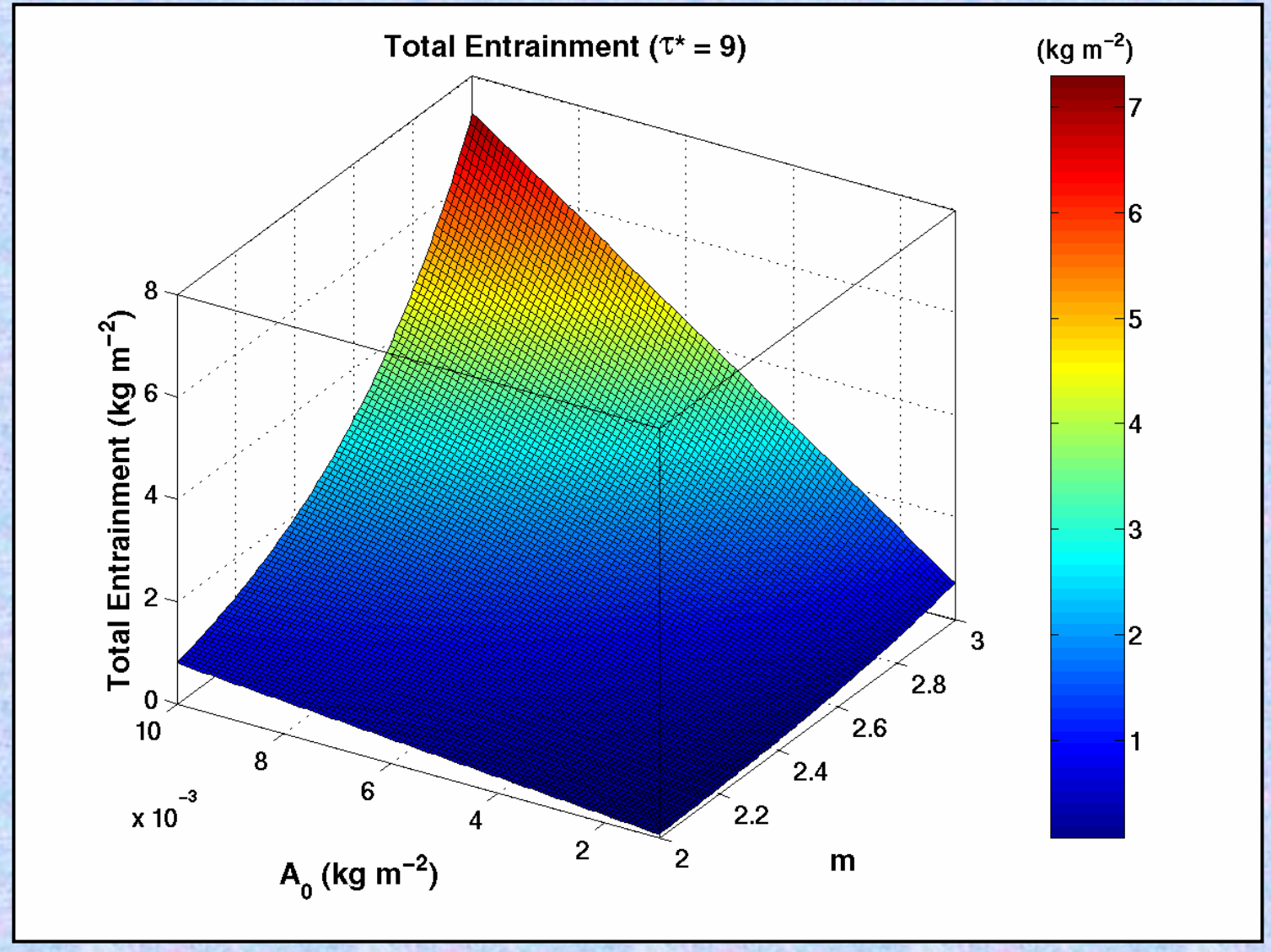


Infinite parameter space of (t^*,A_0,m) values for E_B=0.1 (kg m^{-2})

Transition point for excess shear stress contours: $E_B/A_0 = 1$

Isosurface of Excess Shear Stress

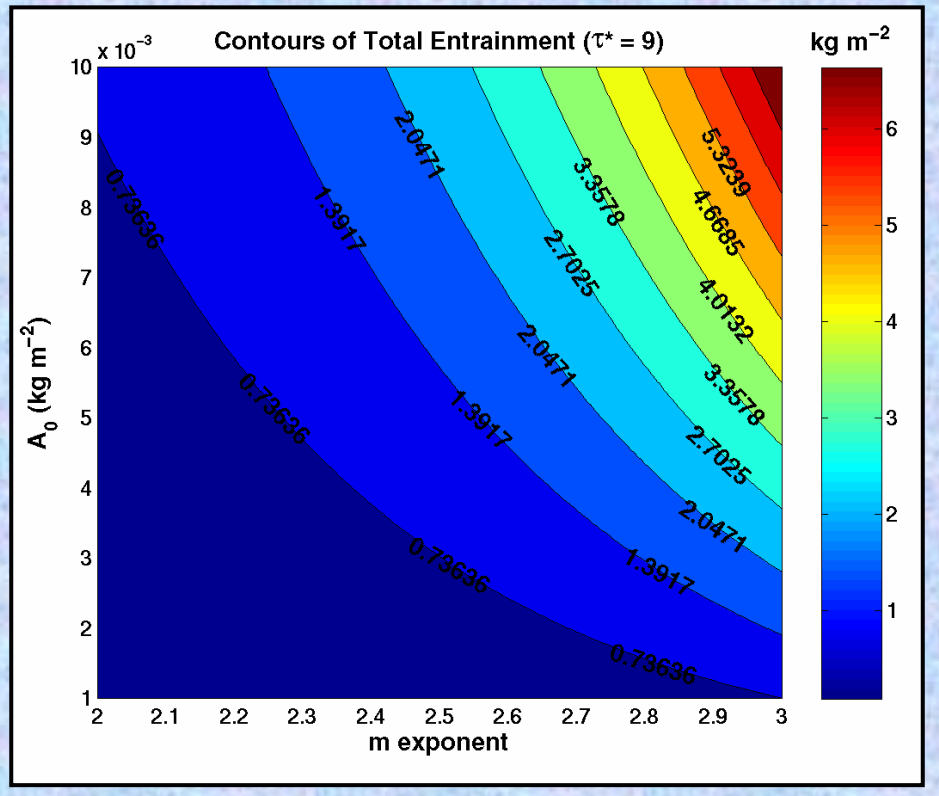
Infinite parameter space of (E_B,A_0,m) values for $t^* = 9$



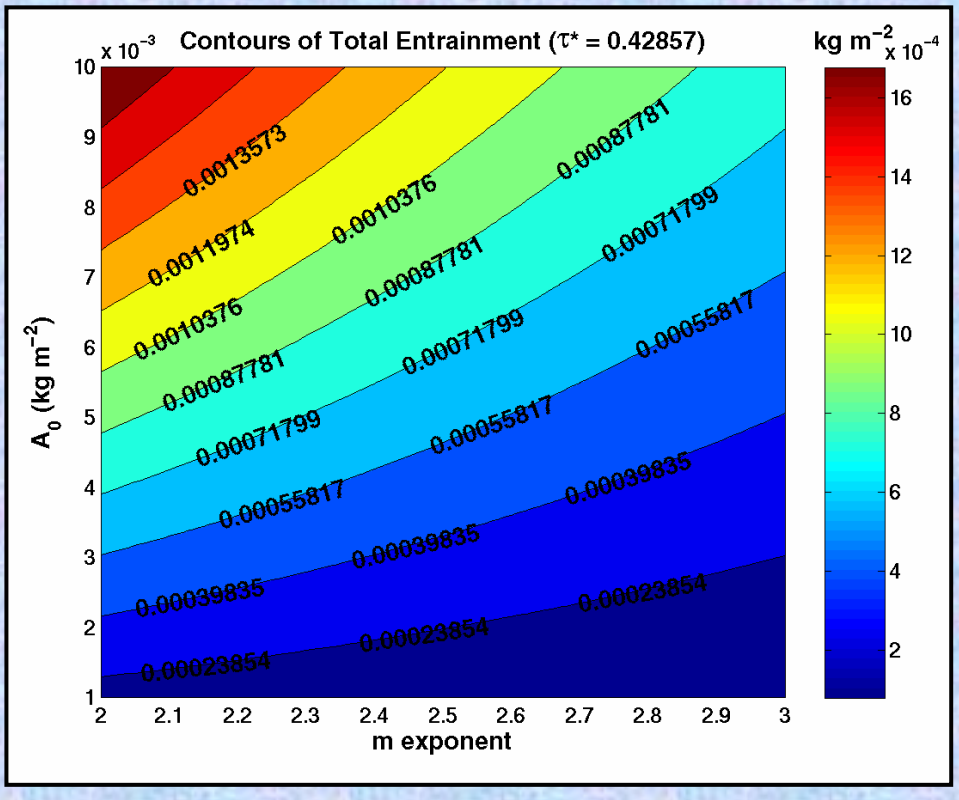
Contours of Total Entrainment

Change in parameter space contours for different values of excess shear stress

Excess shear stress = 9

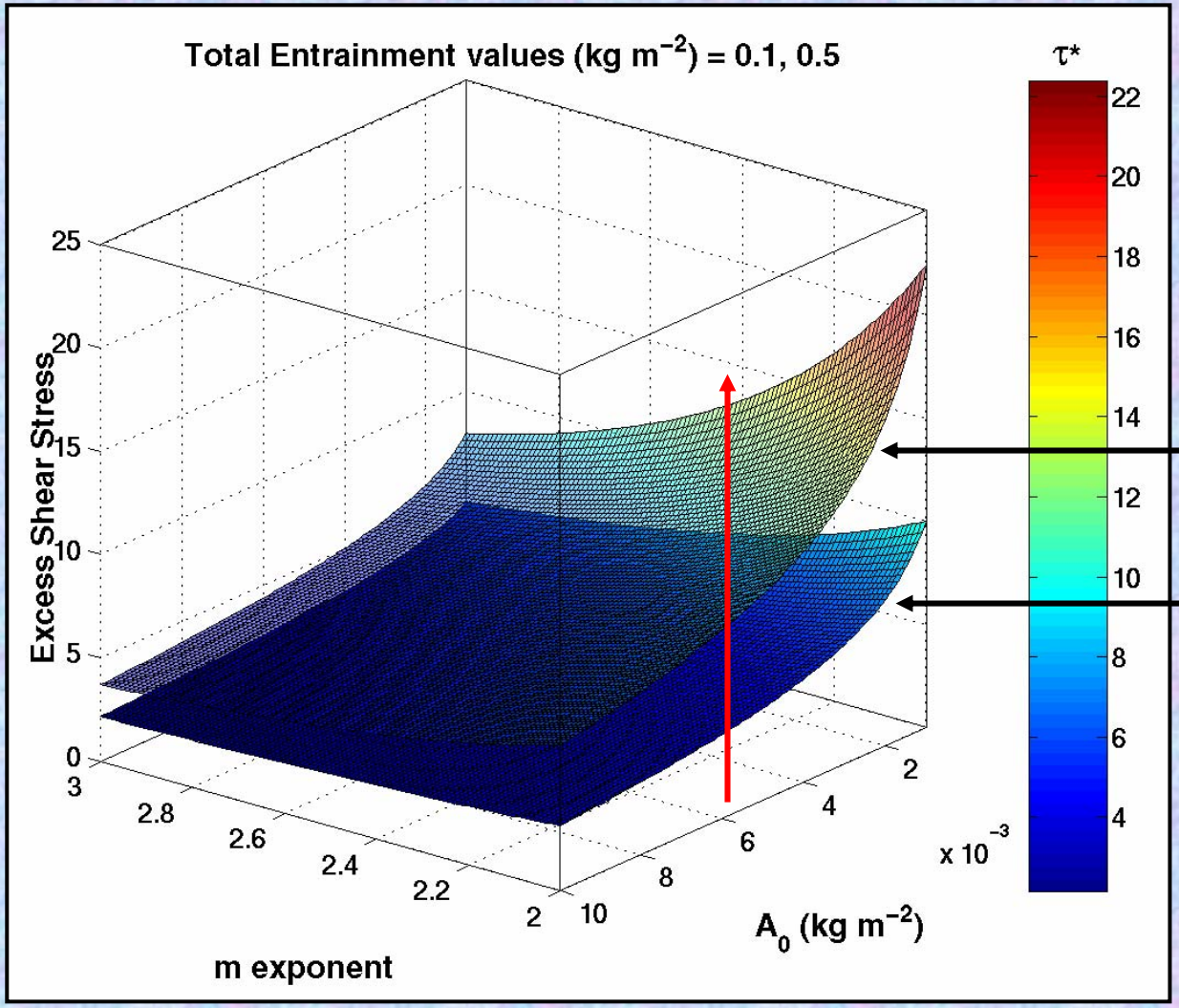


Excess shear stress = 0.42857



Multiple Surfaces of Constant Entrainment

Fitting a data set of entrainment vs. excess shear stress to the entrainment function: Draw a line parallel to z-axis at a specified A_0 and m value



Sensitivity to data error depends on region of parameter space and value of excess shear stress.

Total Entrainment Function: Bioturbation and Consolidation

Total Entrainment kg m^{-2}:

$$E_B = A_0 A_B A_C \left(\frac{\tau}{\tau_c} - 1 \right)^m$$

Bioturbation Coefficient:
t = deposition time
A_2= 9.53721
B= 0.33687 day^{-1}

$$A_B = A_2 + Bt$$

Parameters fitted using laboratory slurries dominated by bioturbation

Consolidation Coefficient:
X= water content (%)
t_1= 4.08878
A_1= 9.4837 x 10^{-9}

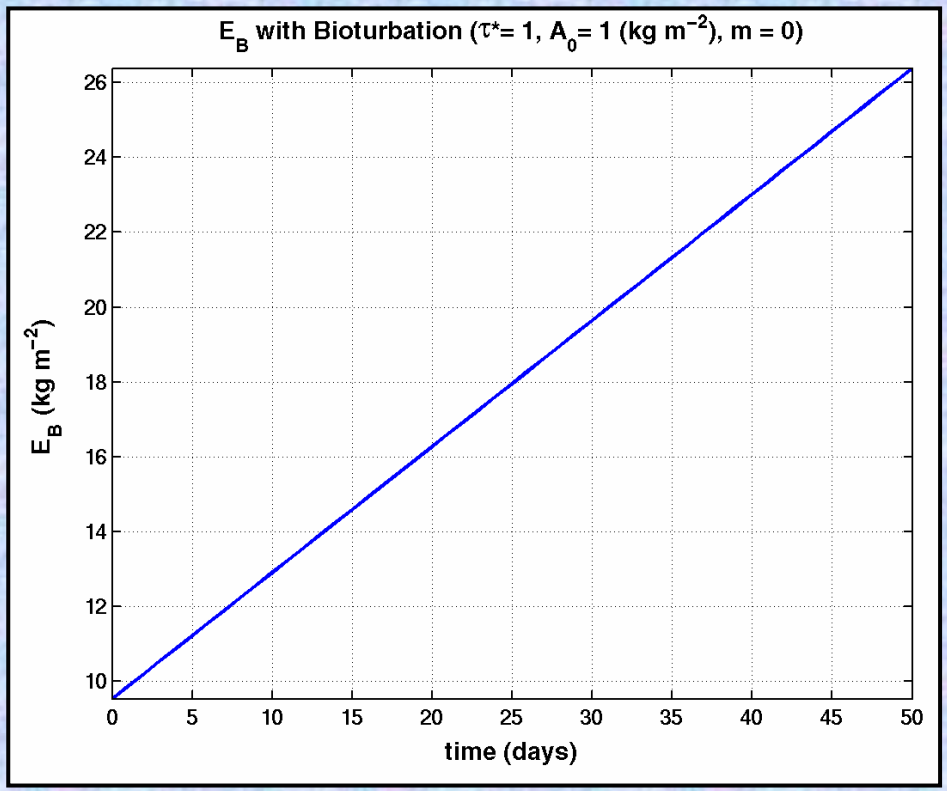
$$A_C = A_1 e^{X/t_1}$$

Parameters fitted using sterile laboratory slurries.

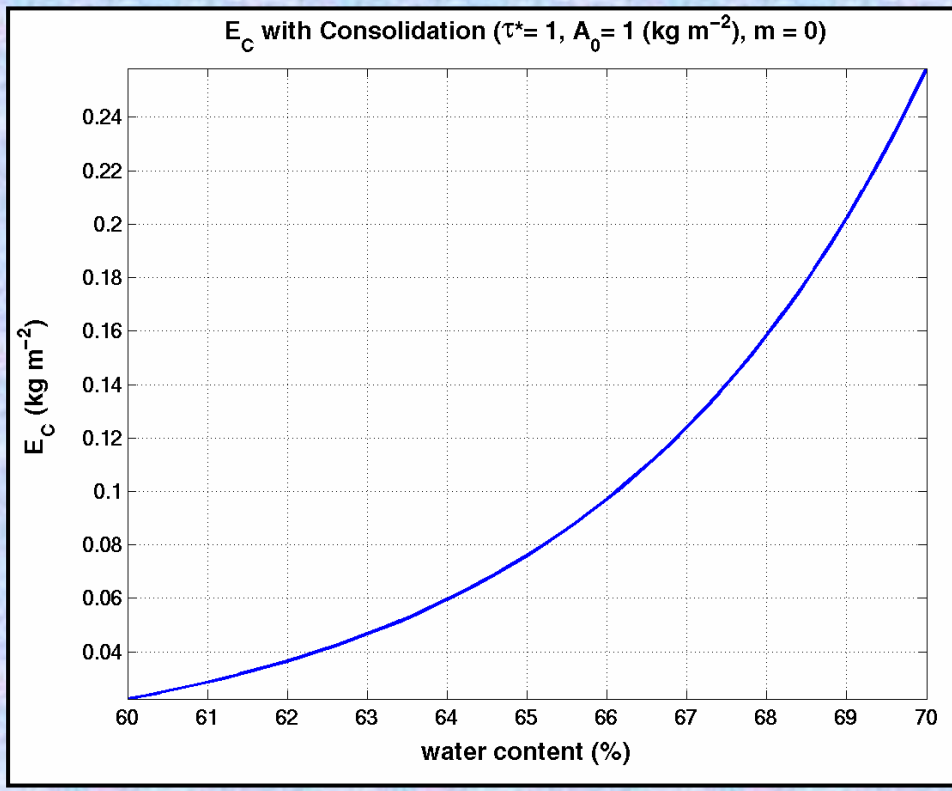
Critical issues: dynamic response of bioturbation and consolidation to:

1) **Initial state**
2) **Depositional history**
3) **Biogeochemical forces**
4) **Data sets used in parameterizations**

Entrainment vs. time



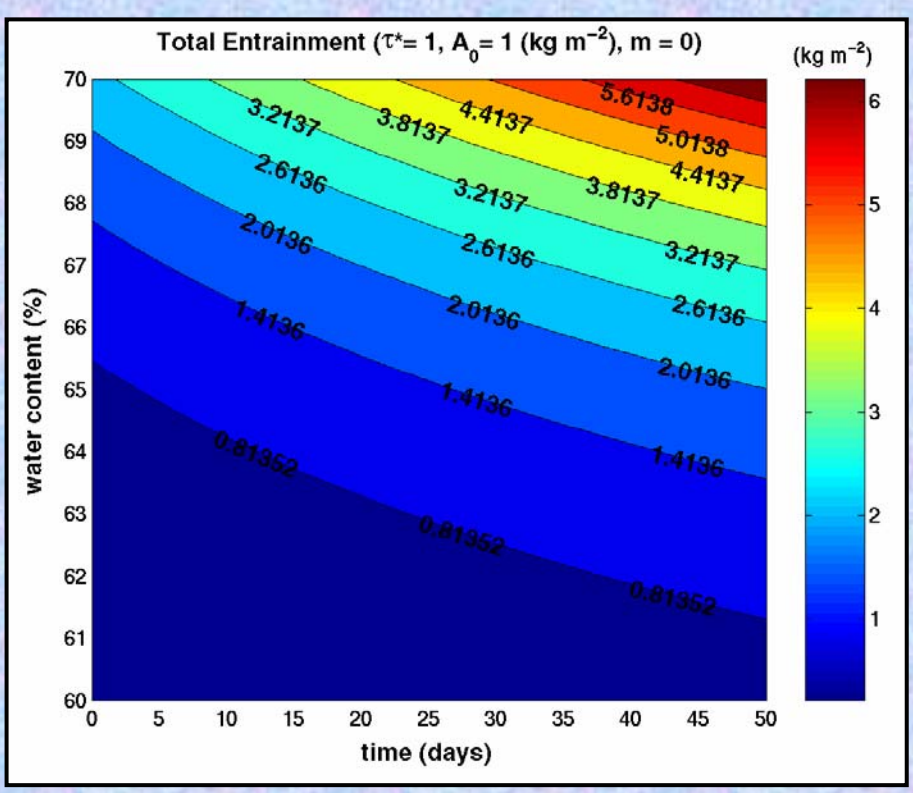
Entrainment vs. Water Content



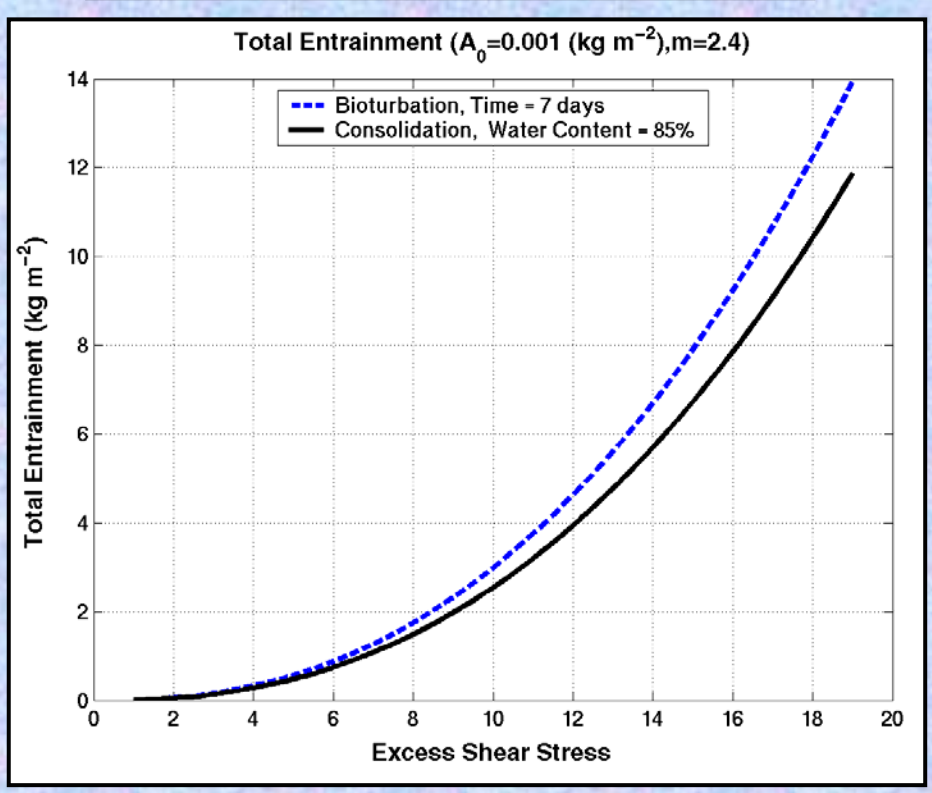
Relative Effects of Bioturbation vs. Consolidation

1) Competing processes in cohesive sediments determine total entrainment.
2) Physics based models are required to describe the time dependence of each process.

Contours of total entrainment



A_B and A_C entrainment curves



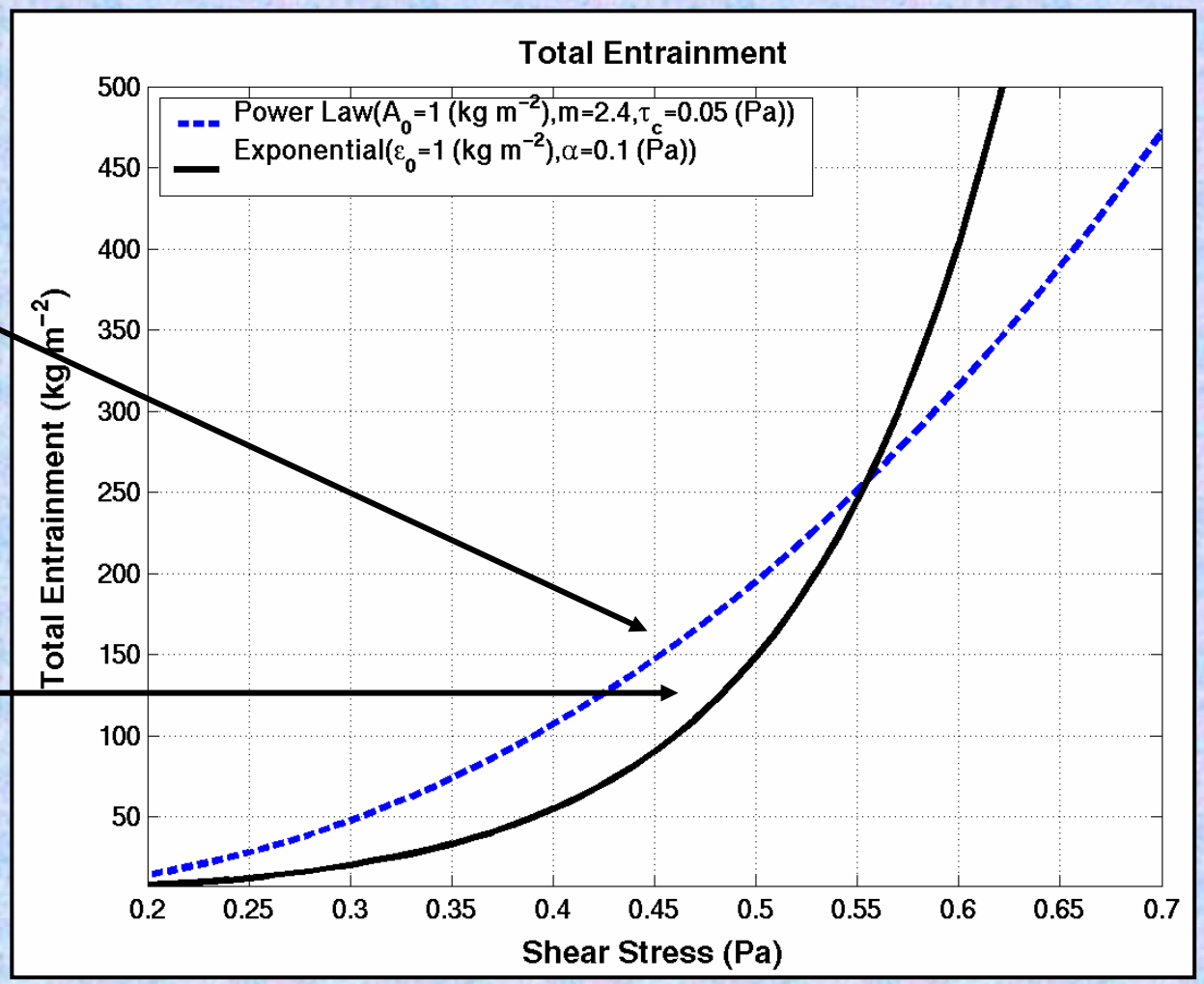
Comparison of Power Law and Exponential Entrainment Functions

$$E_B = \varepsilon_0 e^{\tau/\alpha}$$

ε_0= fundamental entrainment parameter (kg m^{-2})
α = shear stress parameter (Pa)
τ = shear stress (Pa)

Power Law:
A_0= 1 kg m^{-2}
m= 2.4
τ_c= 0.5 Pa

Exponential:
ε_0= 1 kg m^{-2}
α = 0.1 Pa



Conclusion

1) Demonstrated non-uniqueness and complexity of power law's parameter space

2) Biogeochemical effects and data error must be considered when fitting data to a parameterized entrainment function

3) Development of physics based models are required to predict parameter values. Dynamical models are essential.

4) A total entrainment function based on an exponential parameterization appears to be more robust

5) Future directions: Development of a coupled water column-benthic boundary layer model: LSOM (Keen) and BIOX (Furukawa) NRL models are initial starting points