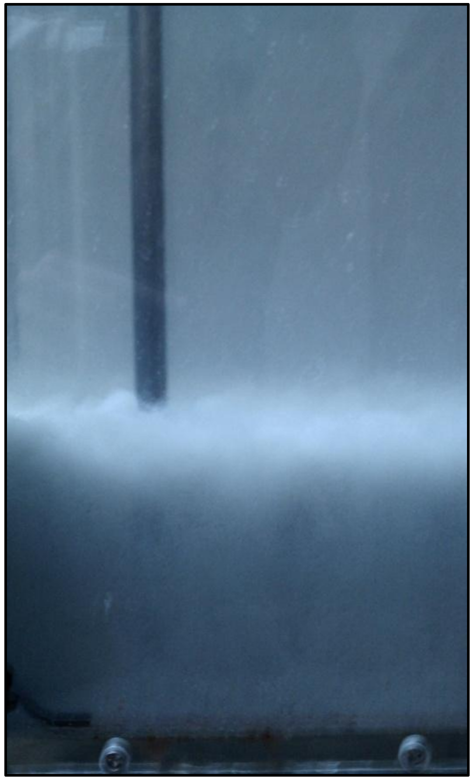
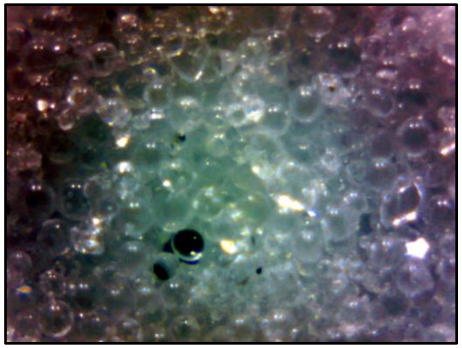


Schmidt Number of Sand Suspensions In Oscillating-Grid Turbulence.

Daniel Buscombe & Daniel C. Conley

Plymouth University, UK

daniel.buscombe@plymouth.ac.uk



COASTAL PROCESSES WITH PLYMOUTH UNIVERSITY

Schmidt Number

$$\beta = \frac{\nu_t}{\varepsilon_s}$$

Ratio of momentum and mass diffusivities

Many models assume β=1. Only for fine particles in very dilute concentrations C=O(0.001)

β>1: particles lose correlation with fluid motion as settle through eddies?

β<1: centrifugal forces have larger effect on particles than on surrounding fluid?

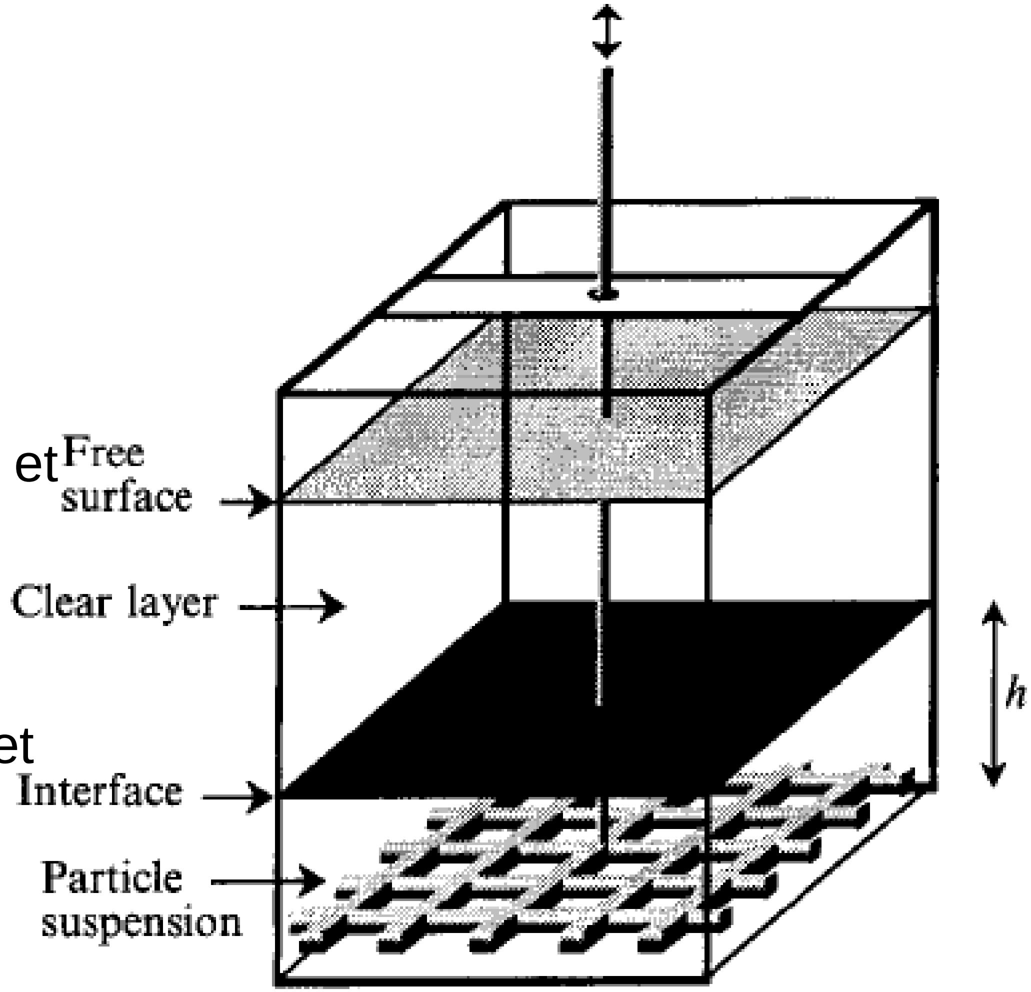
Literature reports values 0.1 to 10

May depend on model equations and boundary conditions

Often used as a tunable parameter

Oscillating Grid Turbulence

- Statistical characteristics of turbulence well-known (e.g. Hopfinger & Toly, 1976; Matsunaga et al., 1999)
- Non-cohesives: sediment initiation of motion (e.g. Medina et al., 2001)
- Cohesives: stratification (e.g. Michallet & Mory 2004; Gratiot et al., 2005)
- Sediment diffusivity: stationary sediment suspension, gradient diffusion



Huppert et al., JFM 1995

Oscillating Grid Turbulence Tank

50x50x80cm

Bar thickness m = 1 cm, mesh size M = 5 cm (M/m = 5)

Grid porosity 65% = most efficient for reducing secondary flows (Hopfinger and Toly, 1976)

Fresh tap water at 20°C

seeded with 11um

hollow spheres

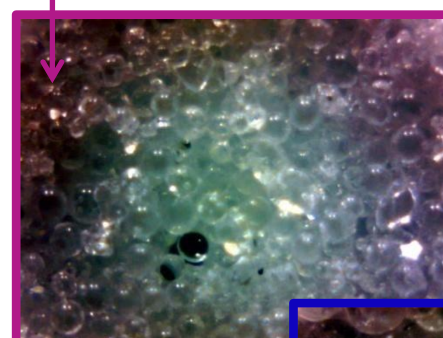
f=2Hz, S=10cm

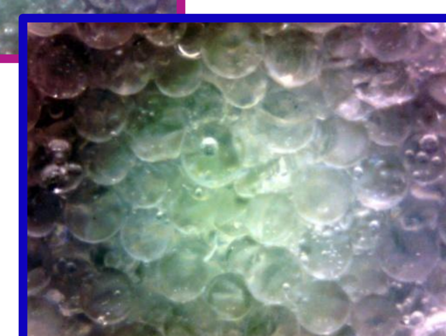
f=3Hz, S=7cm

$$Re = \frac{fS^2}{\upsilon}$$

Solid glass spheres:

70-110µm and 145-205µm



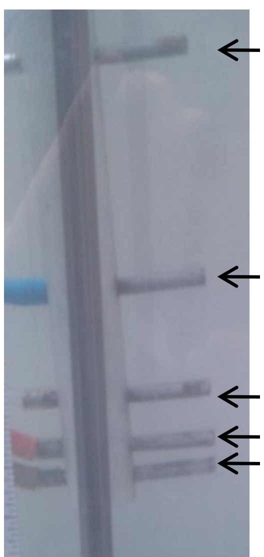


Nortek Vectrino II
Acoustic Doppler Profiler
(30mm profiles at 100Hz)

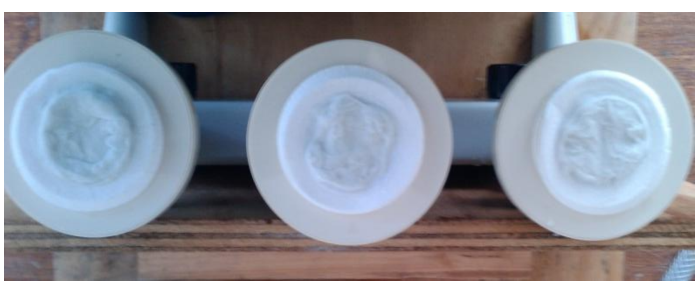
Only R>90%,
Amplitudes>-50dB
Phase-space de-spiking
(Goring and Nikora, 2002)

1,2,4MHz Acoustic Backscatter
System (ABS)
Suspension of spheres:
analytical form
function

Physical
samples: pump
sampler with 5
intake hoses
(5mm ID)



Sediment Size and Fall Velocity



Stokes' law used for **fine sediment**

$$\mathrm{Re} = \frac{w_s D}{\nu} = 0.45 \qquad w_s = \frac{RgD^2}{C_1 \nu}$$

Re=2.5 for **coarser sediment**

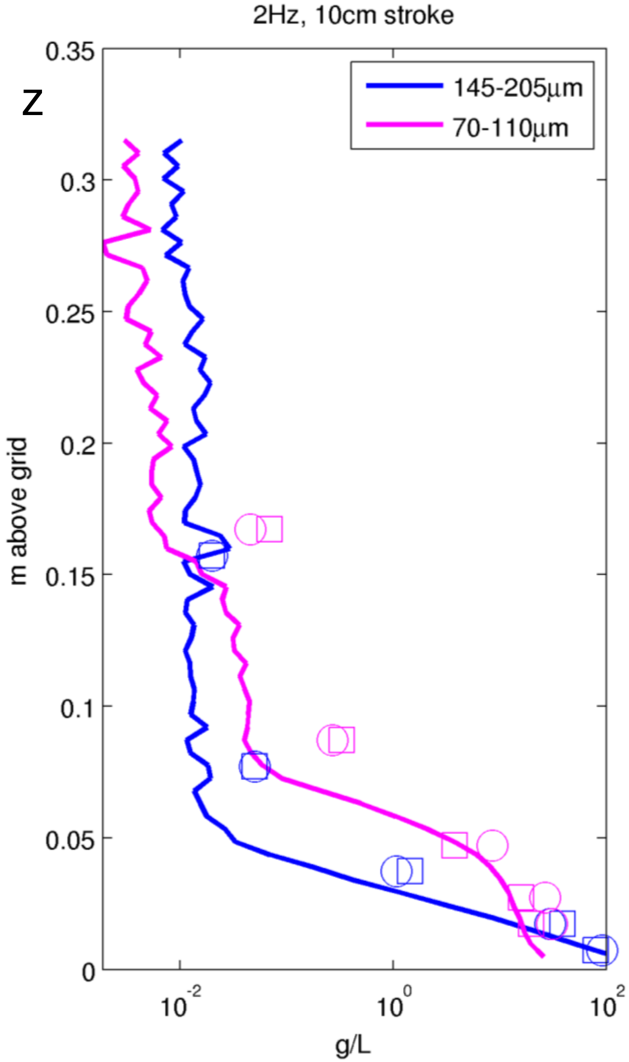
Ferguson and Church (2004):

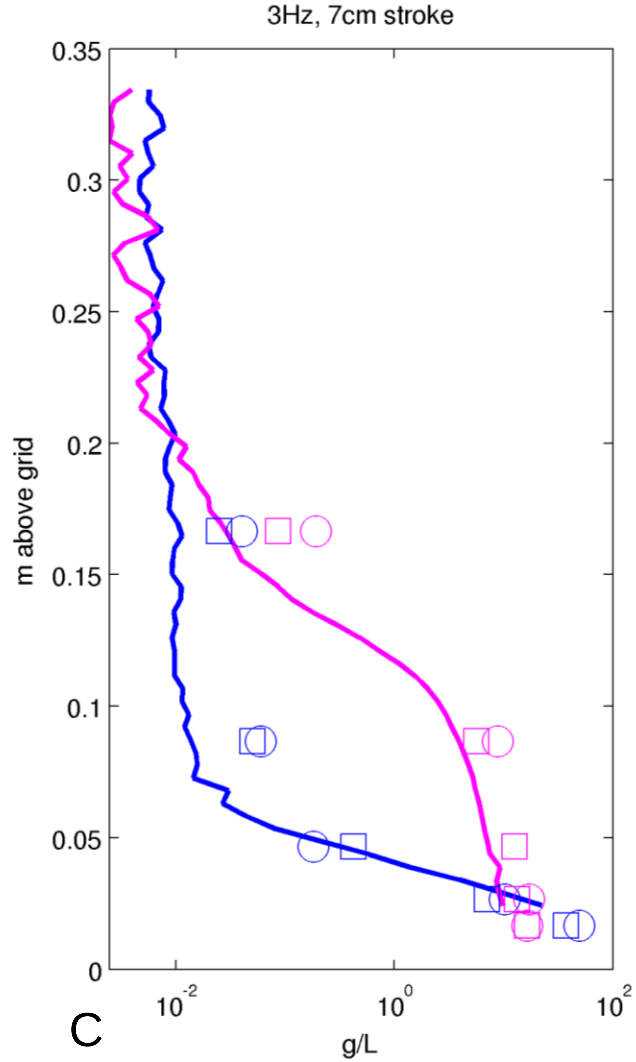
$$w_s = \frac{RgD^2}{C_1 \nu + \sqrt{0.75\, C_2 RgD^3}}$$

C_1 = 18
C_2 = 0.4 for smooth spheres
R = 1.65 for quartz in water

Sediment Concentration

Time-averages of C from ABS:

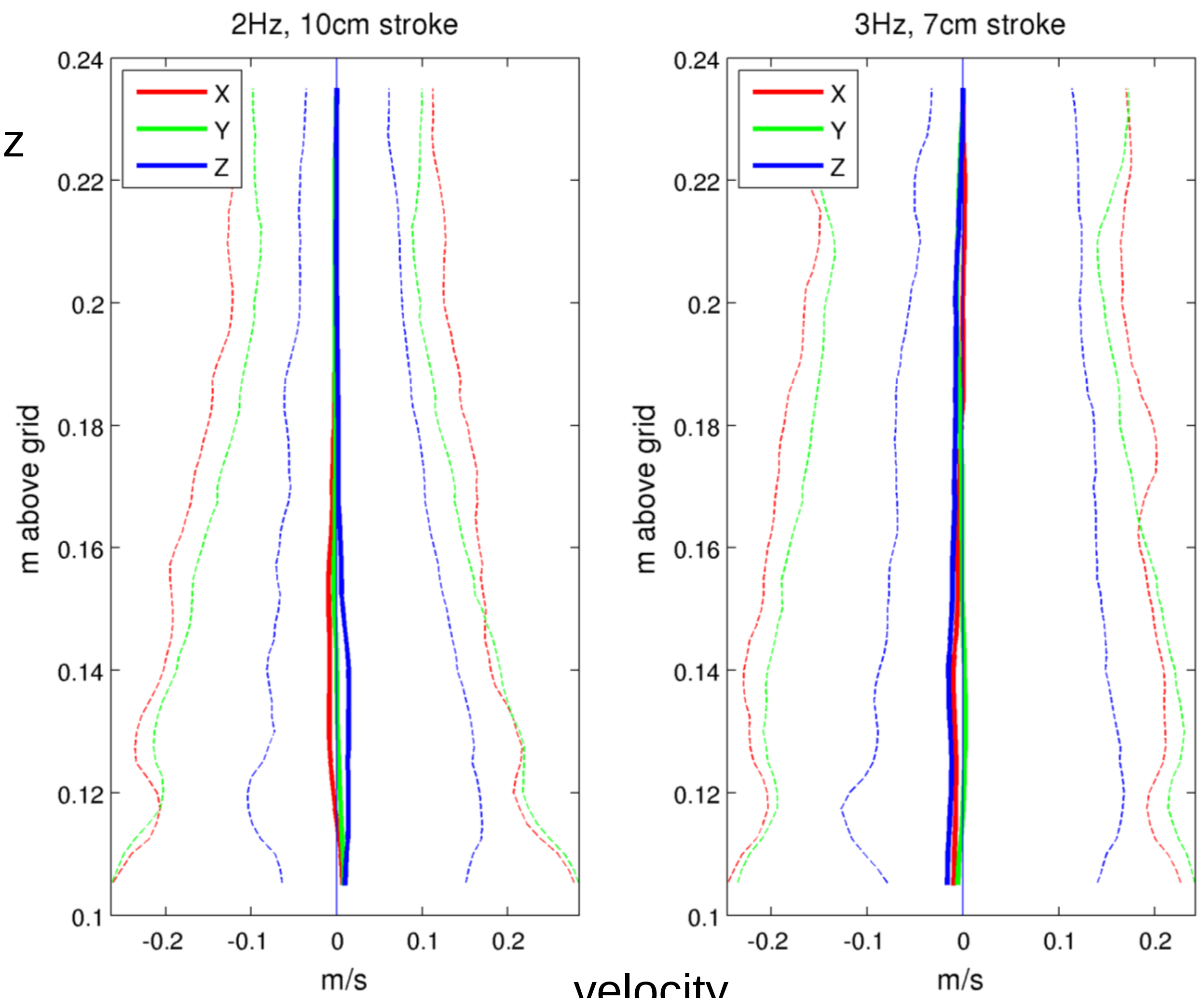




COARSE

FINE

Mean Velocity Profiles



z

velocity

$$0.8 \le \frac{\overline{\rho u' w'}}{\rho \sigma_u \sigma_w} \le 1$$

(=1 for homogeneous and isotropic turbulence)

Gradient Diffusion

$$\varepsilon_s \frac{d\overline{C}}{dz} - \overline{C}(z) w_s = 0$$

Upward mixing flux:
proportional to concentration gradient

Downward settling flux

$$\varepsilon_s = \frac{-w_s \overline{c}}{\frac{d\overline{c}}{dz}}$$

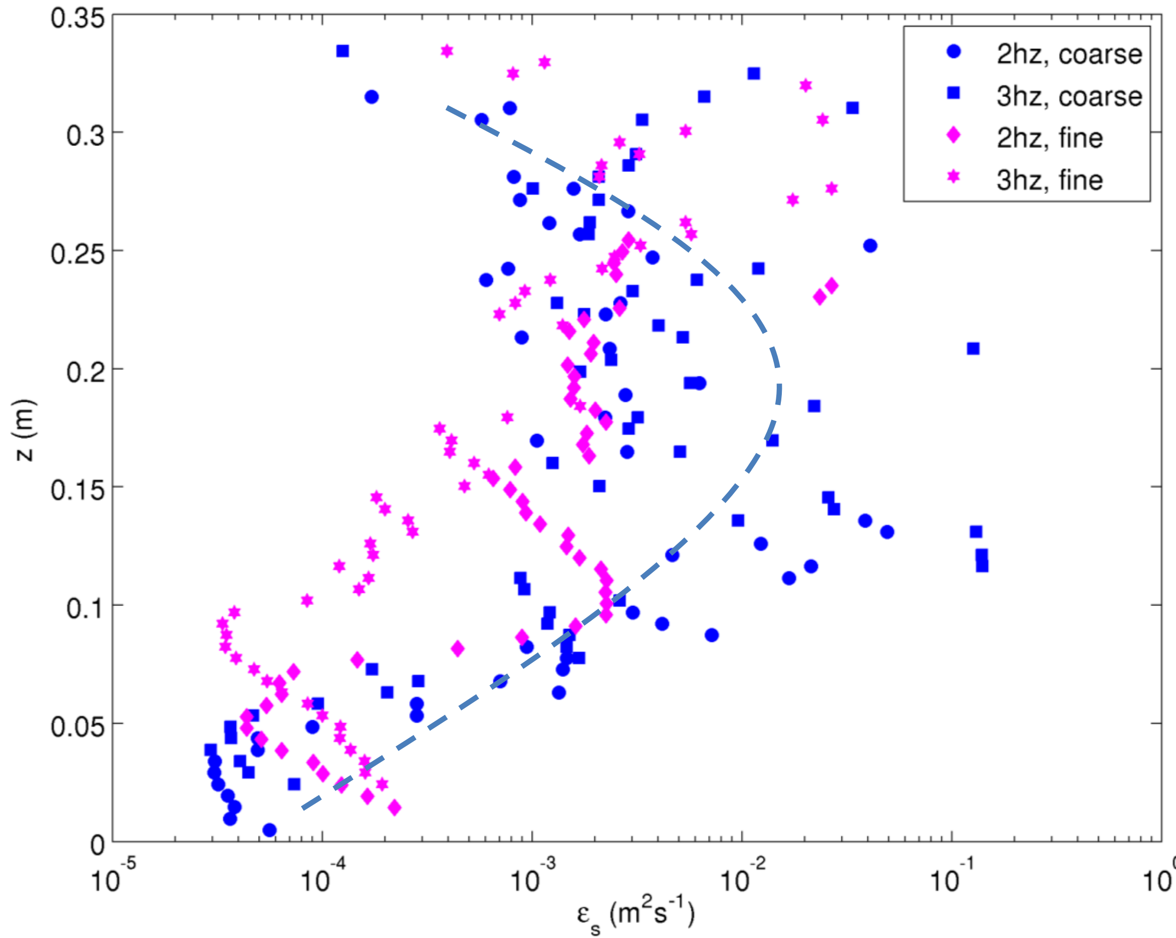
Diffusivity of Sediment

$$\varepsilon_s = \frac{-\dfrac{w_{sj} + w_{sk}}{2}\,\dfrac{\bar{c}_j + \bar{c}_k}{2}\, z}{\dfrac{\bar{c}_k - \bar{c}_j}{\Delta jk}}$$

$\Delta jk = 5\text{mm}$

COARSE

FINE



Model for Concentration Profile

$$\bar{c} = \bar{c}_{z=za}\left(\frac{h-z}{z}\frac{z_a}{h-z_a}\right)^{-w_s/\kappa u_*}$$

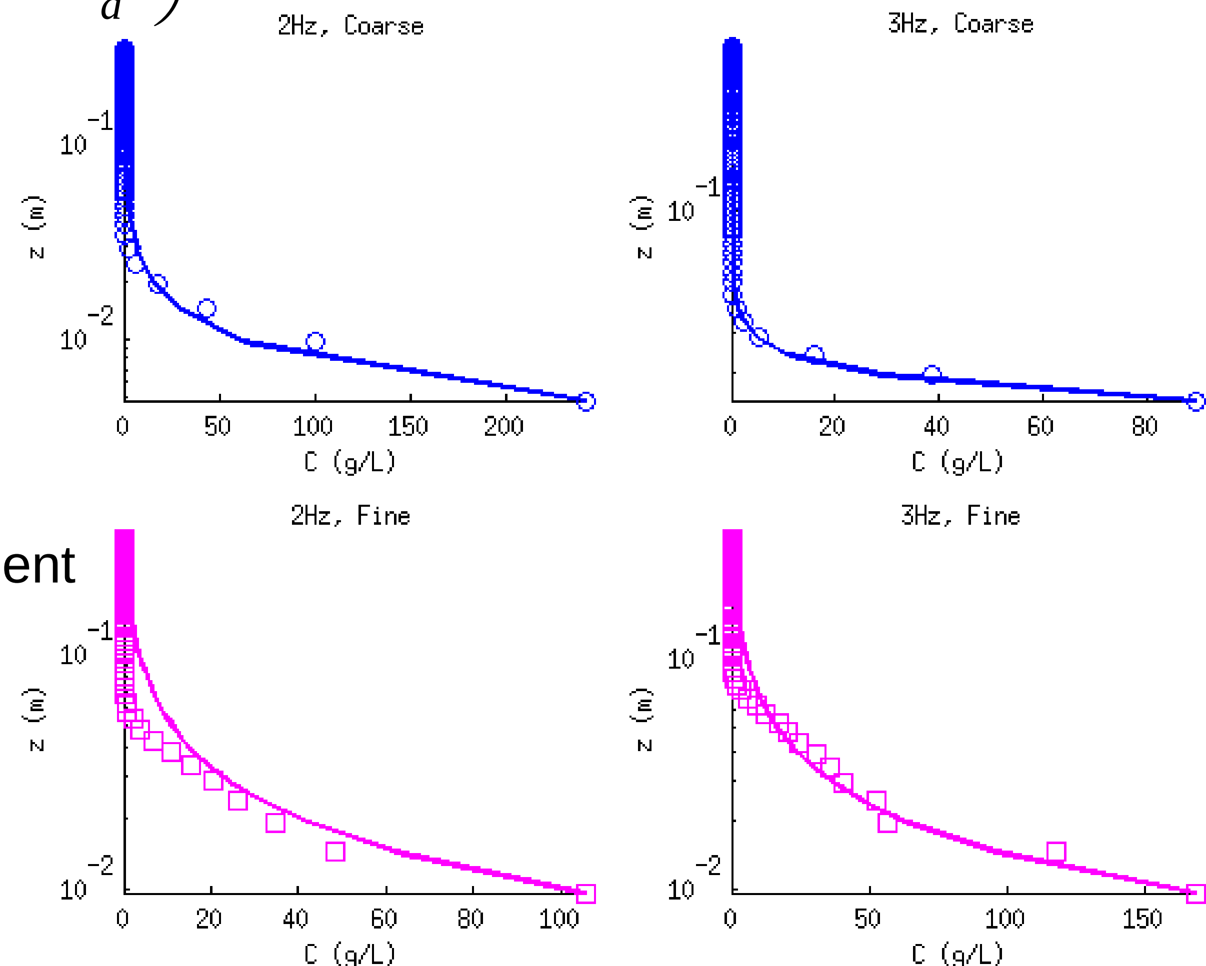
Rouse

Replace with the form:

$$\bar{c} = \alpha\left(\frac{h-z}{z}\right)^{\gamma}$$

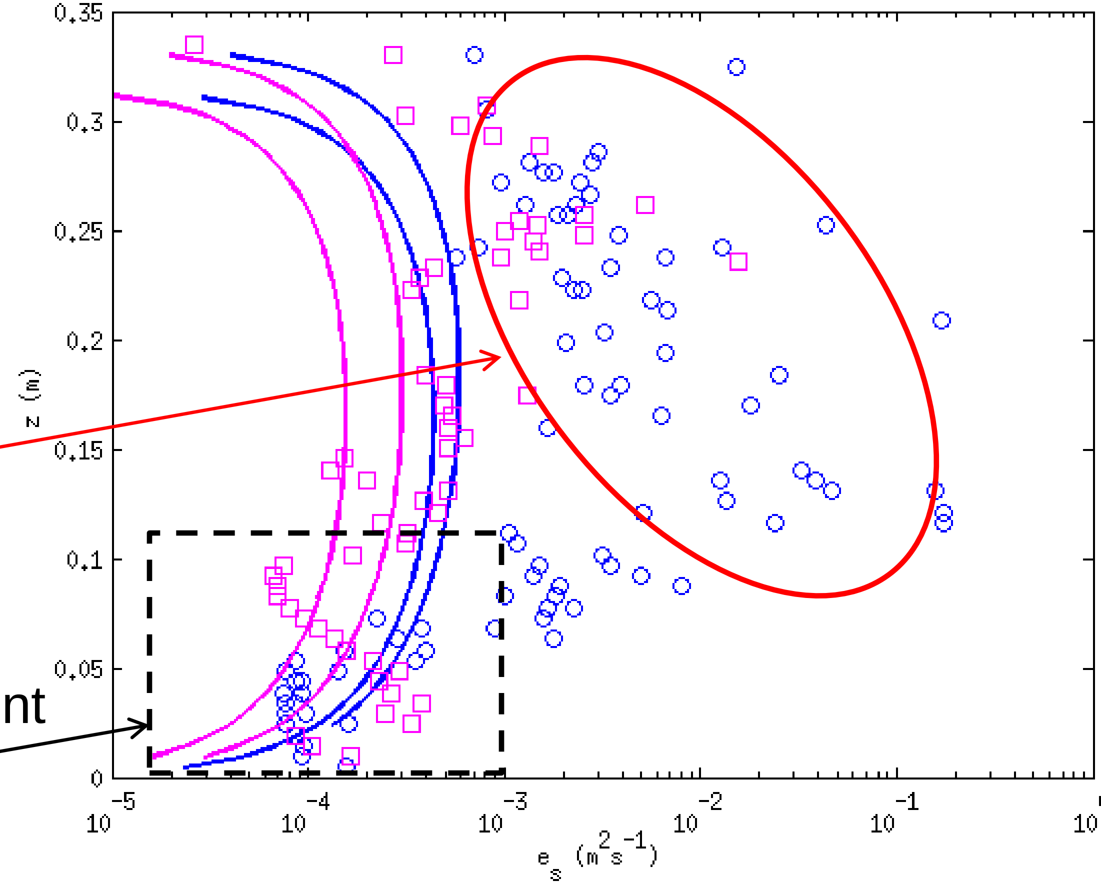
diffusion coefficient

'reference concentration'



Expression for Sediment Diffusivity

$$\varepsilon_s = \frac{-w_s \bar{c}}{\dfrac{-\alpha\gamma h}{z^2}\left(\dfrac{h-z}{z}\right)^{\gamma-1}}$$



Worse agreement when C measurements don't rapidly go to zero

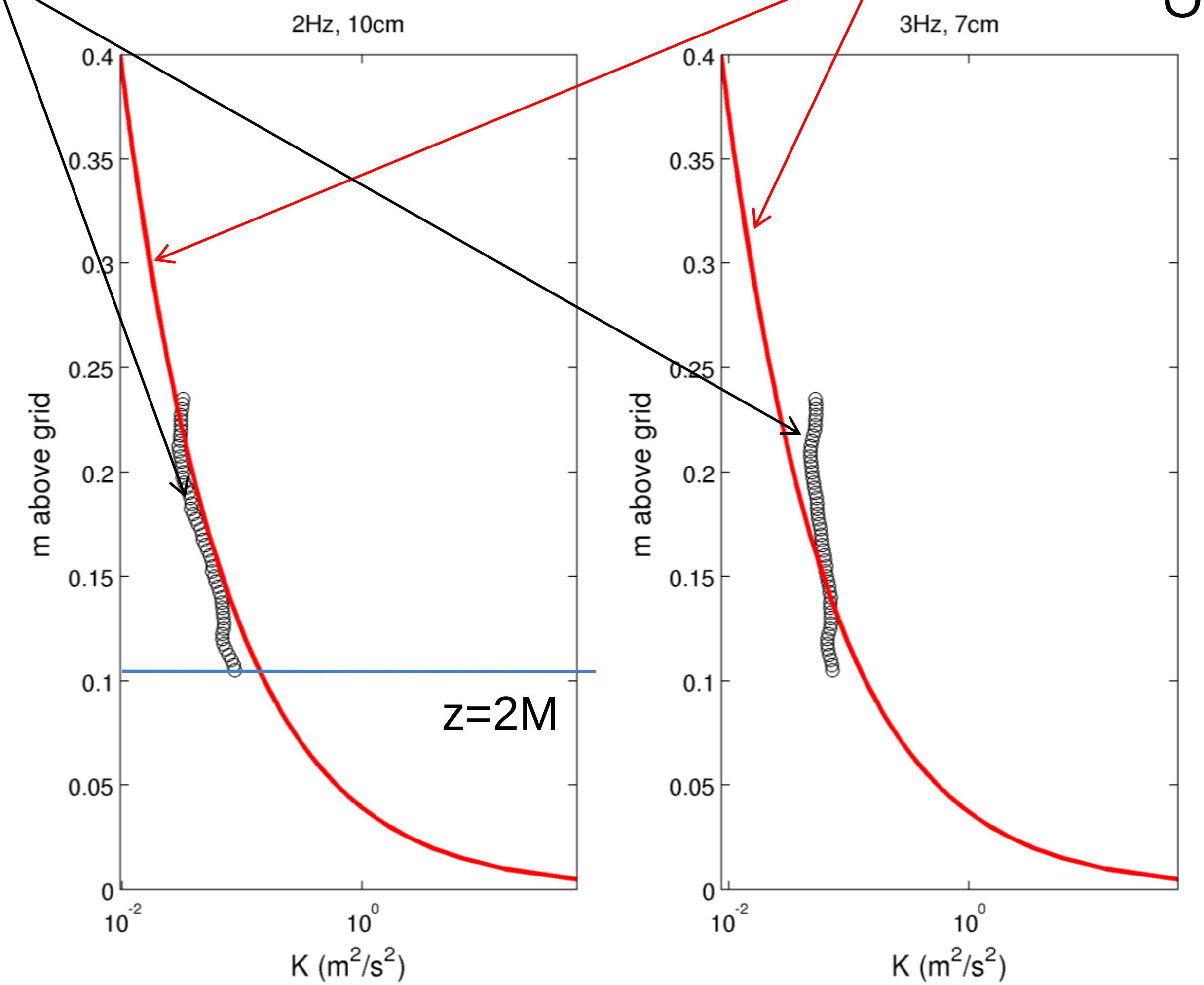
Good agreement at high C

Turbulent Kinetic Energy

$$k = \frac{1}{2}\left(u'^2 + v'^2 + w'^2\right)$$

$$k = \frac{1}{2}\left(2C_1^2 + C_2^2\right)\left(M^{0.5} S^{1.5} fz^{-1}\right)^2$$

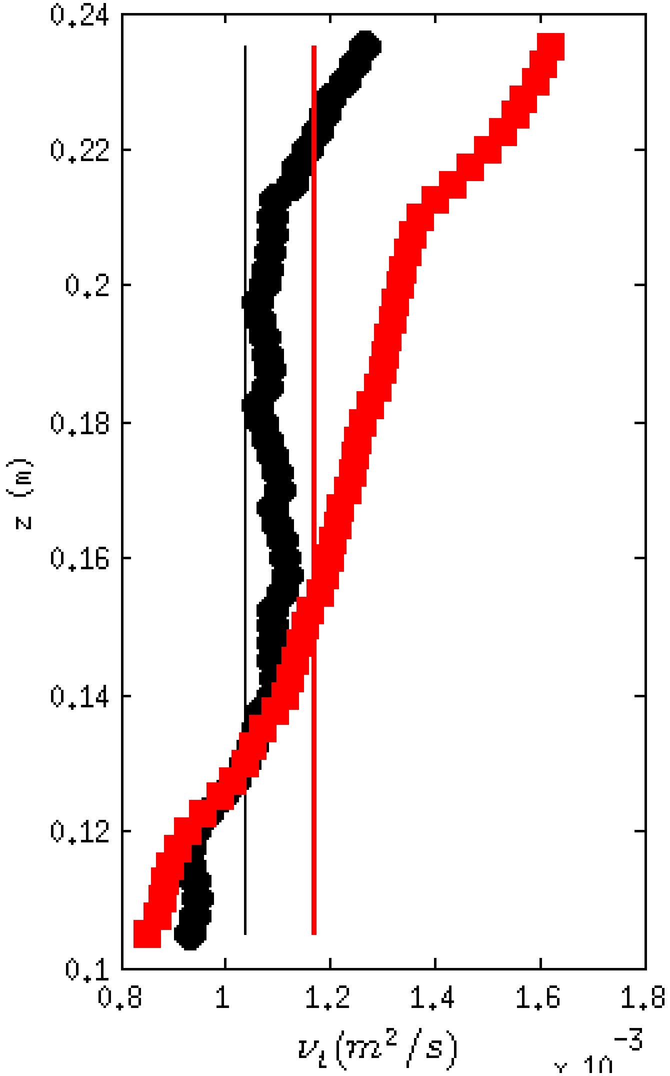
Orlins & Gulliver (2003)



C1 = 0.22
C2 = 0.26
DeSilva & Fernando (1992)

M=5
S=10 or 7 cm
f= 2 or 3Hz

Expression for Momentum Diffusivity



$$\nu_t = C_\mu k^2 / \varepsilon$$

$$\varepsilon = C_\mu^{3/4} \frac{k^{3/2}}{l}$$

$$l = 0.1z$$

$$k = \frac{1}{2}\left(2C_1^2 + C_2^2\right)\left(M^{0.5} S^{1.5} fz^{-1}\right)^2$$

$$\nu_t = \sqrt{C_\mu} \sqrt{\frac{1}{2}\omega\left(S^{1.5} fz^{-1}\sqrt{M}\right)0.1z}$$

$$\omega = 2C_1^2 + C_2^2$$

$$\beta = \frac{\nu_t}{\varepsilon_s}$$

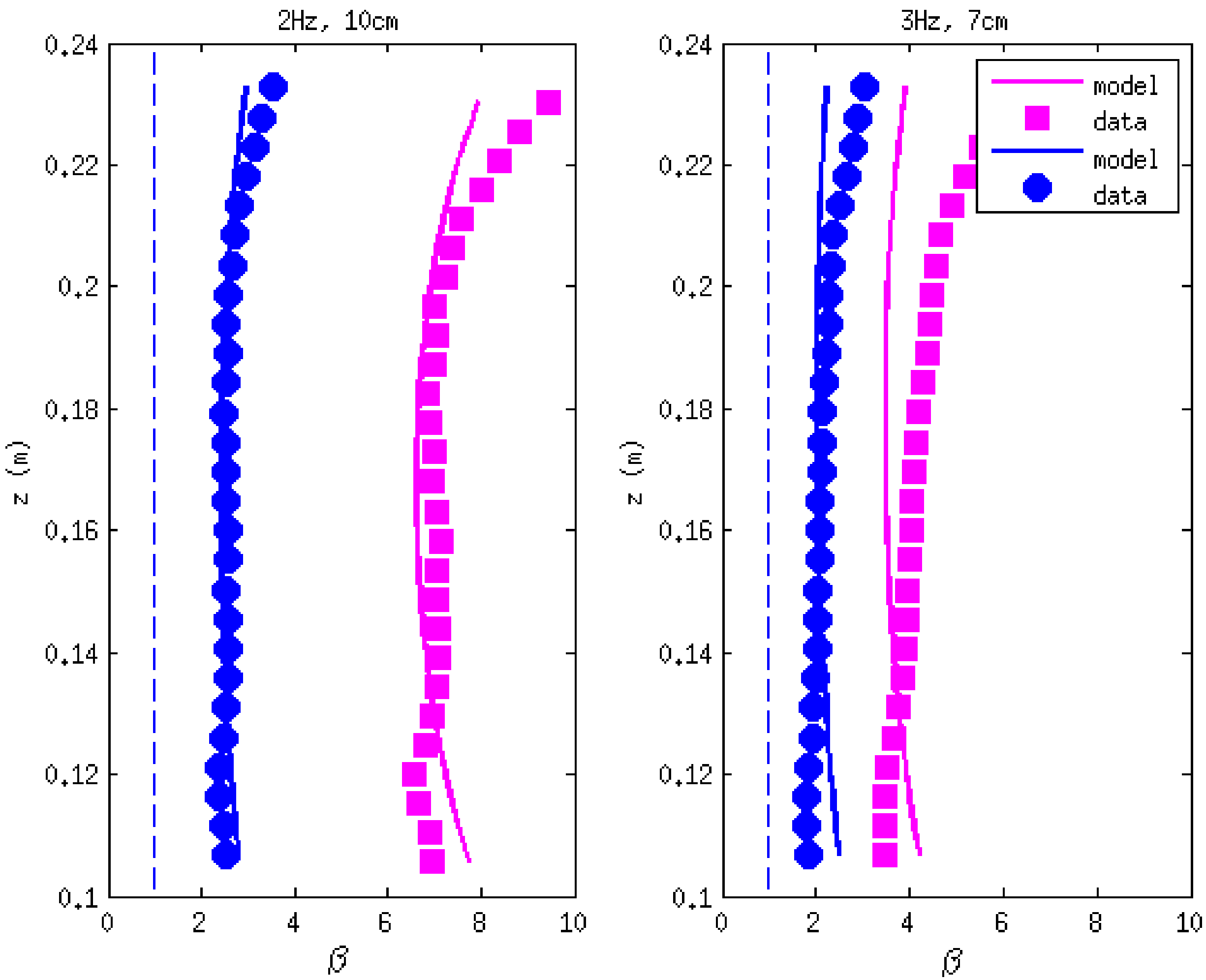
Schmidt Number

COARSE

FINE

coarse sand momentum more diffusive than sediment

fine sand momentum **much** more diffusive than sediment



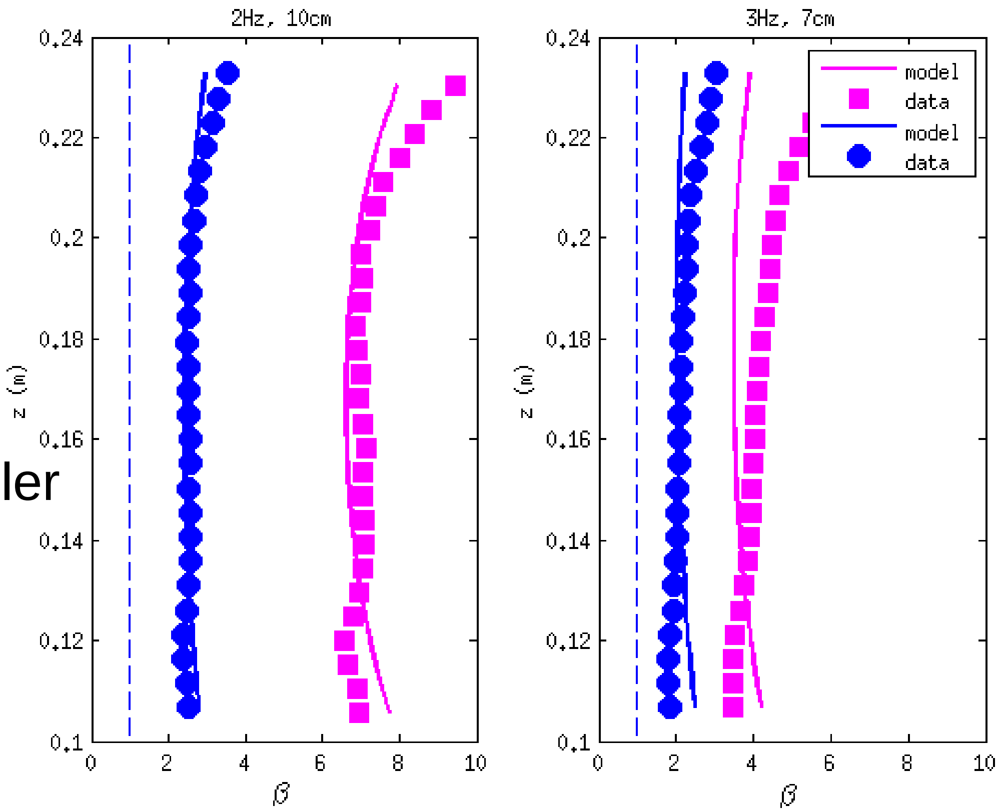
relatively invariant with depth

analytical model gives good approximation

$$\mathrm{Re} = \frac{fS^2}{\upsilon} = 14705 \qquad = 10808$$

Grain Size Dependence?

- Nielsen & Teakle (2004) also observed >β for smaller particles
- Settling of finer grains faster in turbulence than in still water?
- Mixing length for finer grains smaller than for the fluid?
- β increases with C because of negative feedback? (Lees, 1981; Amoudry et al., 2005)
- Stratification effects (which would reduce eddy viscosity and β)



Conclusions

- Calculated Schmidt number for sand suspensions in near-isotropic grid turbulence in zero-mean-shear flows
- 2 flow conditions and 2 different sized glass spheres

- **Momentum diffusivity greater than sediment diffusivity** (β>1)
- Grain-size dependence?
- Reynolds number dependence

Ongoing work:

- Spectral estimation of ε
- Greater range of flow conditions and sediment types
- Stratification effects
- Further investigation of Vectrino II

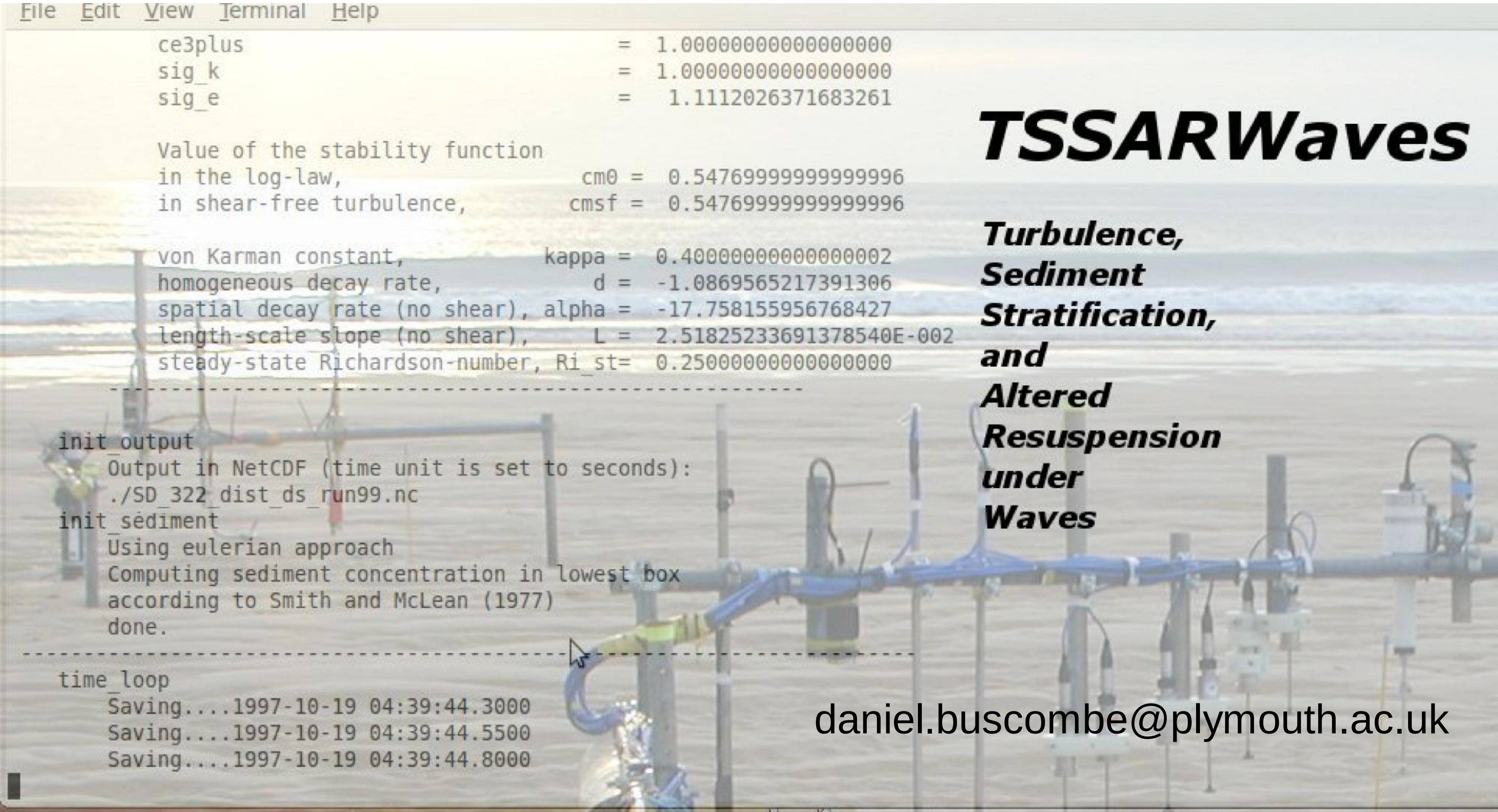
How do these results apply when gradient diffusion not dominant process (e.g. large mixing lengths)?

Thanks for your attention.

www.research.plymouth.ac.uk/tssar_waves/

www.coastalprocesses.org

COASTAL PROCESSES WITH PLYMOUTH UNIVERSITY

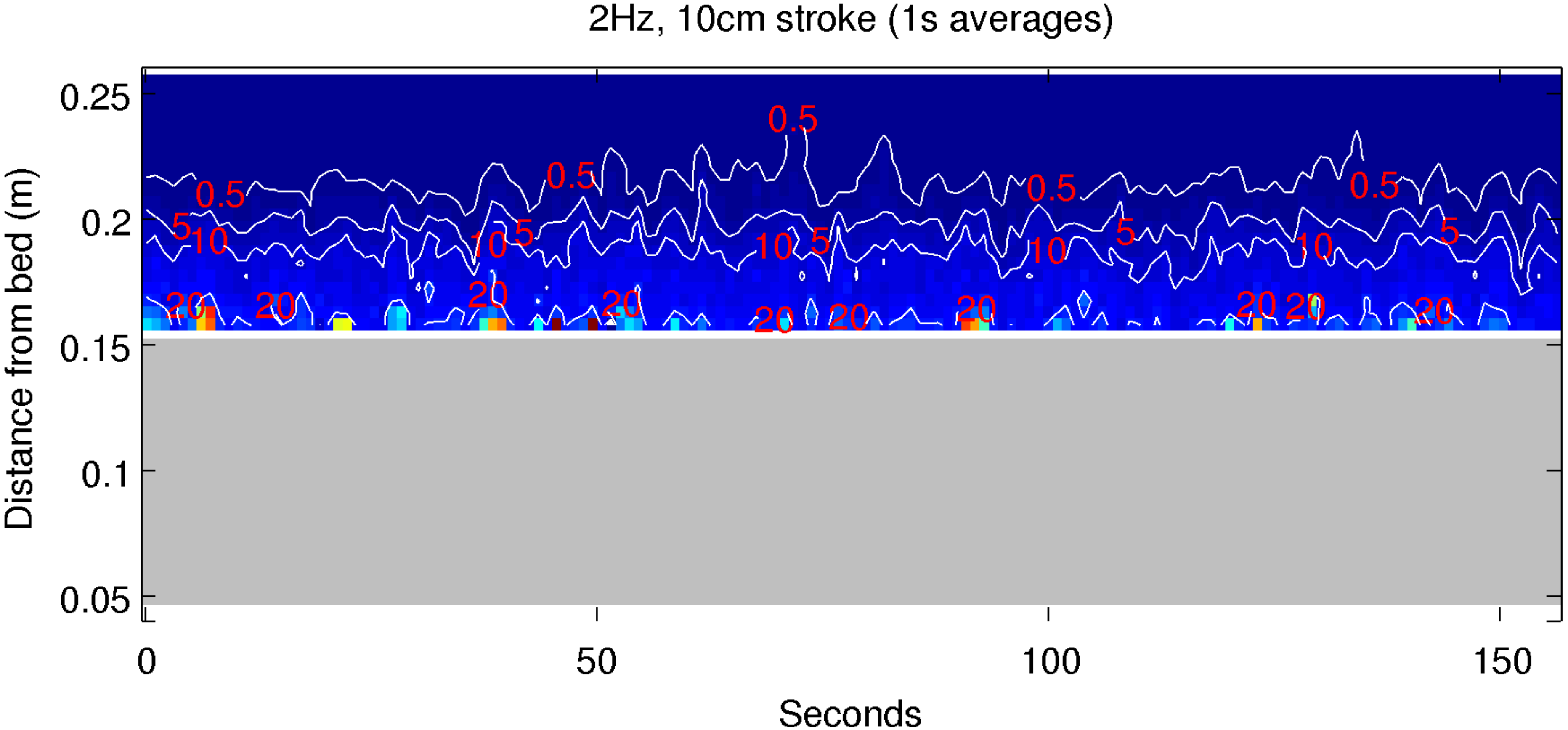


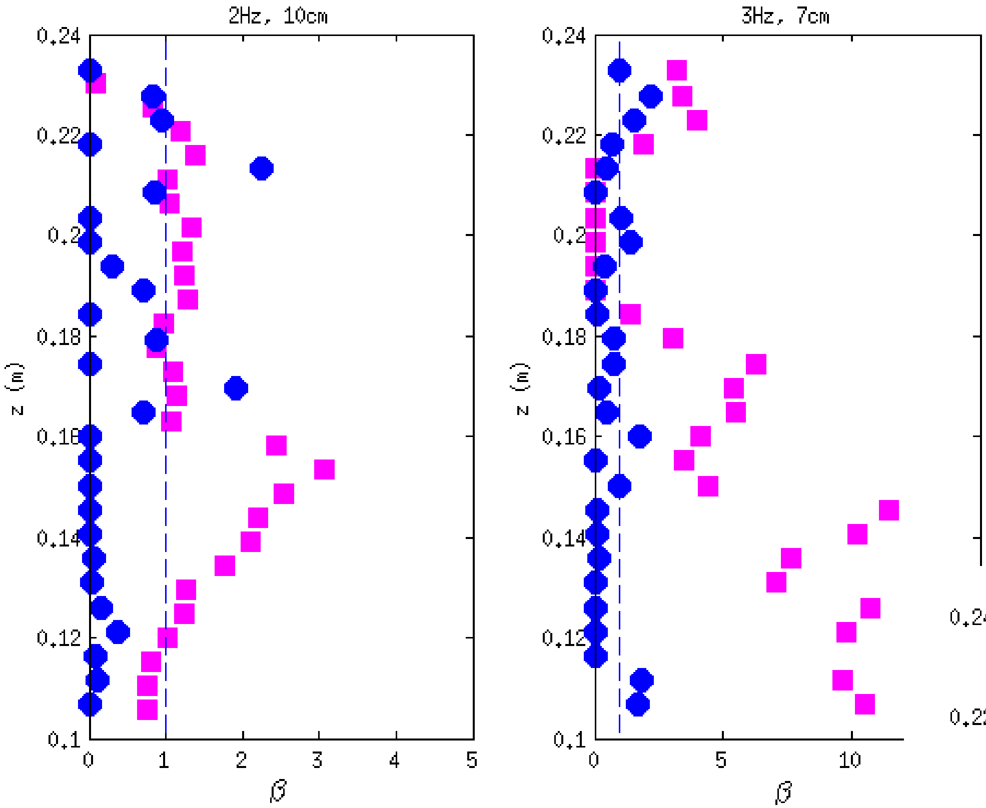
TSSARWaves

Turbulence, Sediment Stratification, and Altered Resuspension under Waves

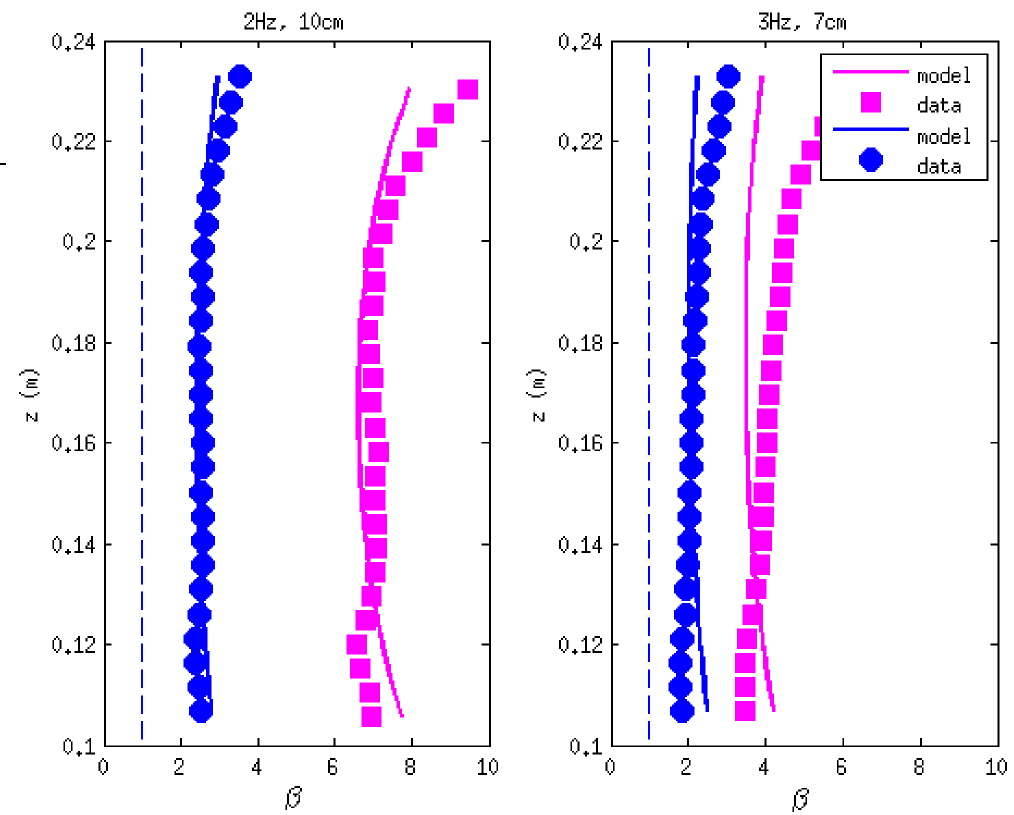
daniel.buscombe@plymouth.ac.uk

Stationary Suspension





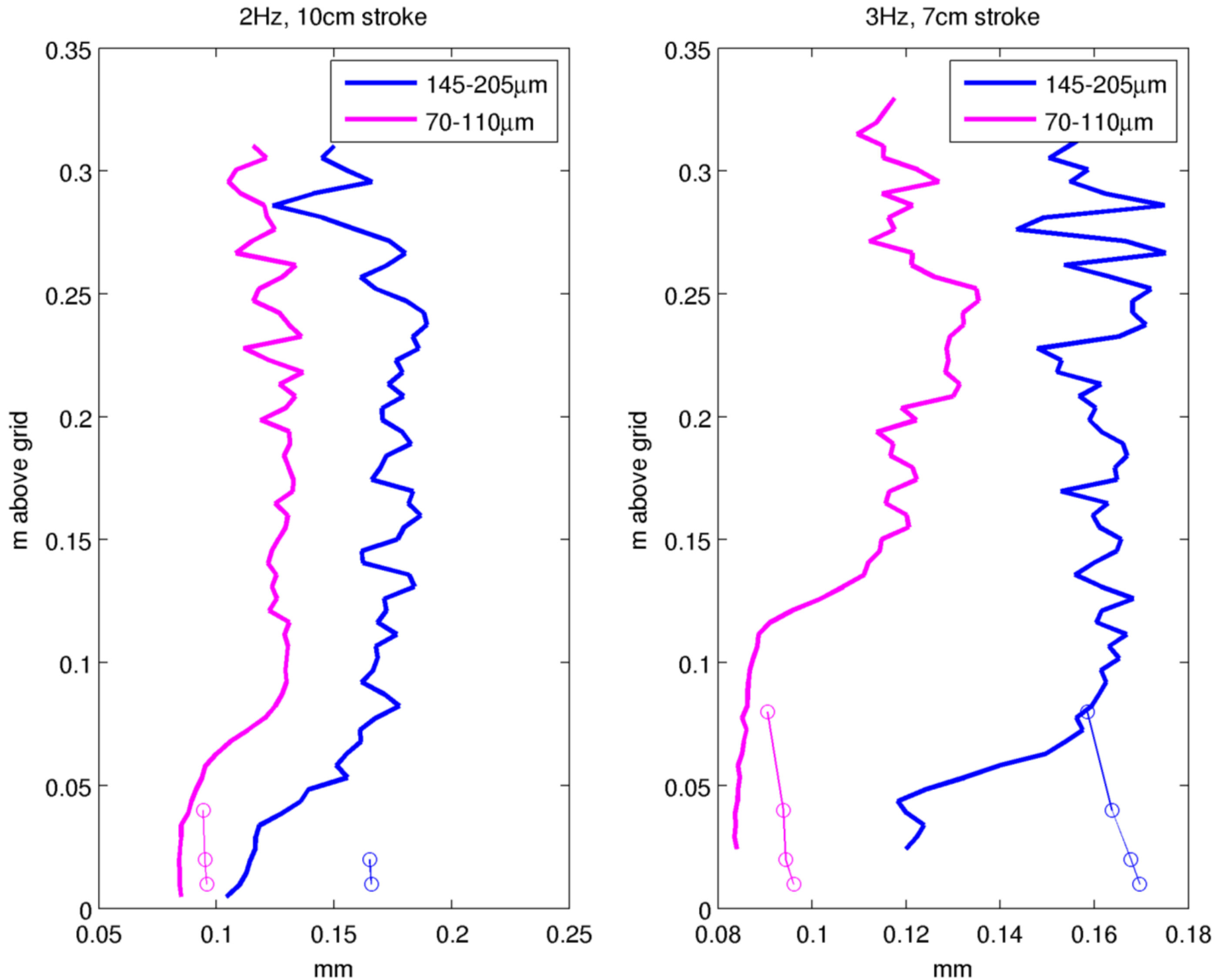
Measured ε_s and v_t based on measured k



Dots: modelled ε_s and v_t based on measured k

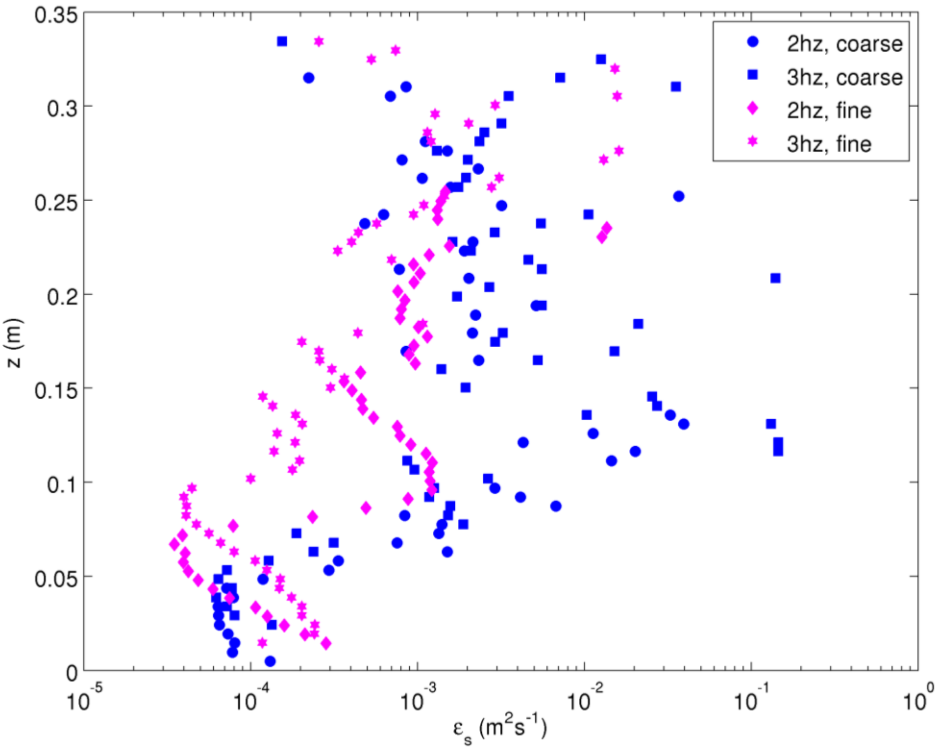
Lines: modelled ε_s and v_t based on modelled k

Variation of D

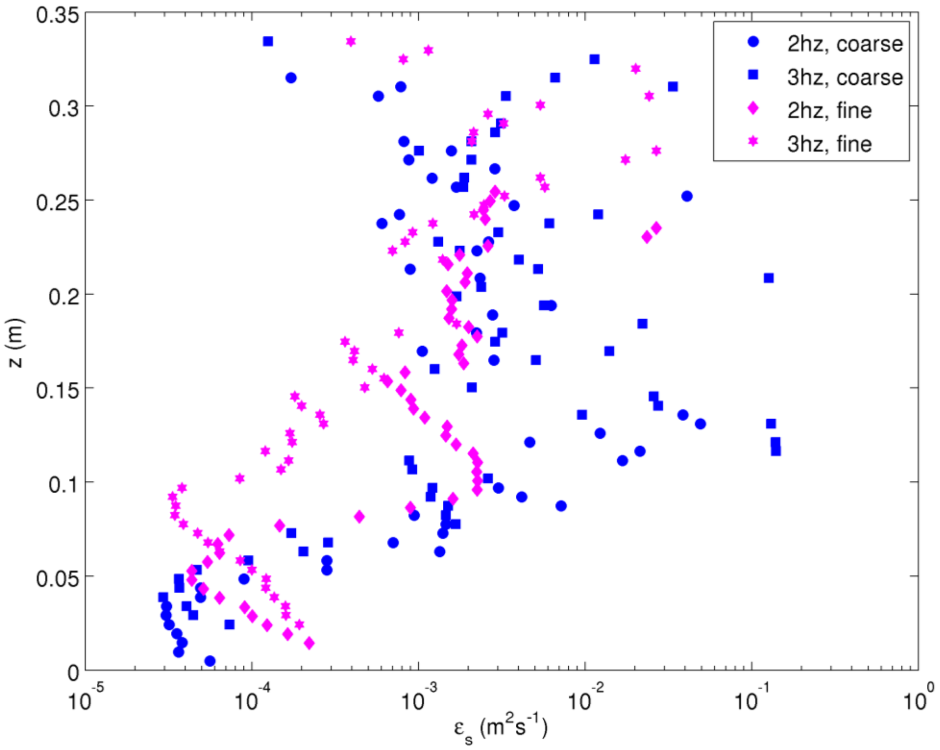


Grain Size Effect on ε_s

Constant D



D(z)



Talk Outline

- Oscillating grid turbulence
- Experiments and measurements
- Profiles of velocity and concentration
- Analytical expressions for sediment diffusivity and turbulent mixing
- Vertical profiles of Schmidt number
- Discussion of these initial results and ongoing/future work