The Trapping and Delivering of Fine Sediment in the Coastal Environment

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1. Objective – Study S2S processes as buoyancy-driven flow

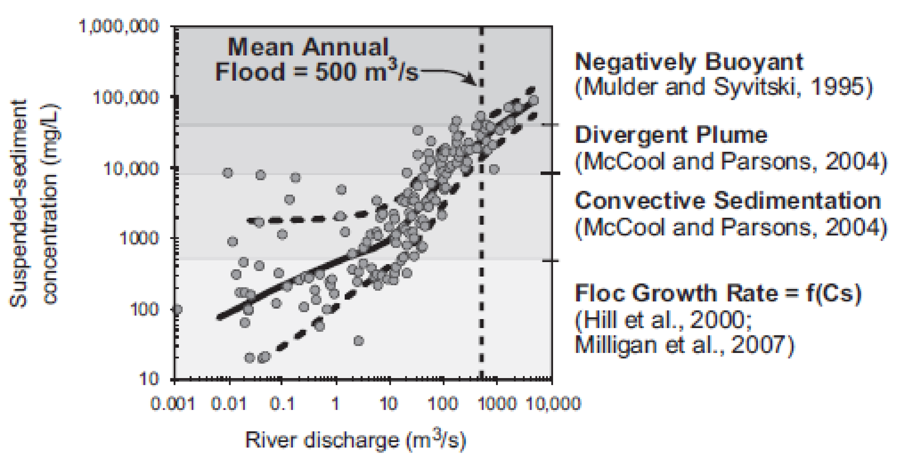
1) **Initial deposition**
   a) Hypopycnal plume – convective sedimentation
   What are the criteria for the occurrence of rapid settling due to convective instability?
   b) Hyperpycnal plume (see also Chen et al., this conference).

2) **Resuspension by waves and currents:**
   a) Wave-supported gravity-driven fluid mudflows *(Hsu et al. 2009, JGR).*
   b) Wave dissipation over muddy seabed *(Torres-Freyermuth & Hsu 2010, JGR)*
   c) 3D turbulence-resolving simulation of fine sediment transport in wave boundary layer. *(Ozdemir et al. 2010, JFM).*

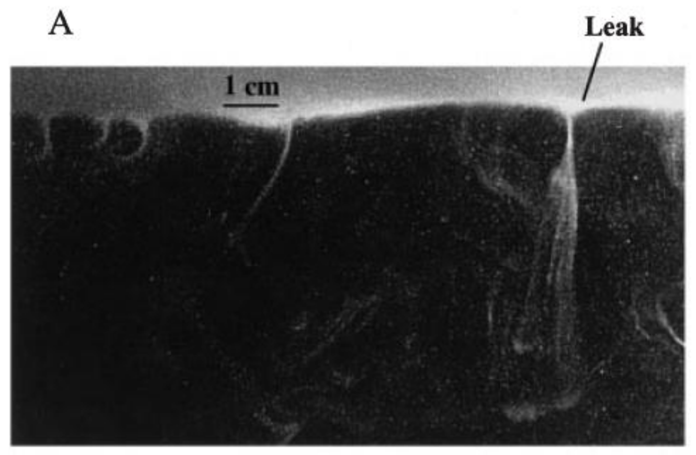
2. Initial Deposition at River mouth

Positively Buoyant Plume (<~36g/l):
1) Primary particle (↓ 0.01~0.1 mm/s)
2) Flocculation process (↓ 0.1~1 mm/s)
3) Convective sedimentation (↓ 1 cm/s)
(e.g., Parsons et al. 2001)

Negatively Buoyant Plume (>~36g/l)
Hyperpycnal flow (e.g., Mulder & Syvitski 1995).



Mechanisms of rapid settling; adopted from Warrick, Xu, Noble & Lee (2008) Cont. Shelf Res.



Sediment fingers due to convective instability; adopted from Parsons, Bush, Syvitski,, 2001, *Sedimentology,* 48, 465-478.

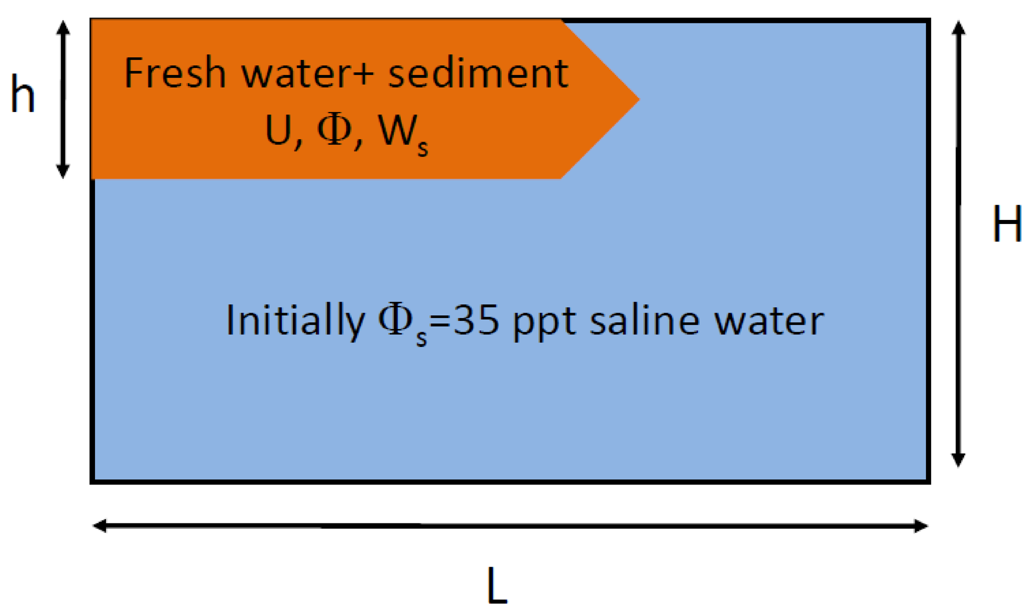
Hypothesis:

Observed rapid settling is caused by some sort of convective instability.
What parameters control the occurrence of convective instability?

2.1 Numerical model

- Two-Dimensional-Vertical (2DV) nonhydrostatic Reynolds-averaged Navier-Stokes model for salt-stratified fine sediment laden-flow.
- The effects of salinity and sediment on flow momentum are modeled as buoyancy driven flow.
- k-ε turbulence closure incorporates salinity & sediment-induced density stratification.

2.2 Idealization



2DV numerical model is utilized to carry out idealized study of convective settling from a hypopycnal plume.

U: inlet flow velcity
h: inlet hight
Φ: inlet sediment concentration
W_s: Stokes settling velocity
Φ_s: initial salinity of receiving water

Three main nondimensional parameters:

Inlet Reynolds number: $Re = \frac{Uh}{\nu}$

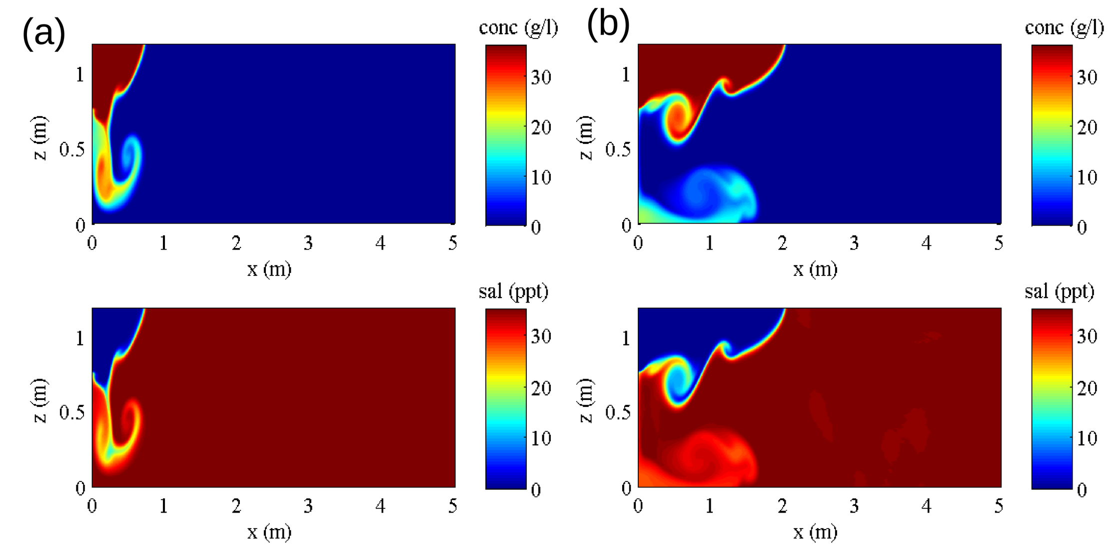
Particle Reynolds number: $Re_p = \frac{W_s d}{\nu}$

Density ratio: $\gamma = \frac{\rho_m - \rho}{\rho_a - \rho} = \frac{\Phi(\rho_s - \rho)}{\Delta\rho}$

2.3 Four flow regimes

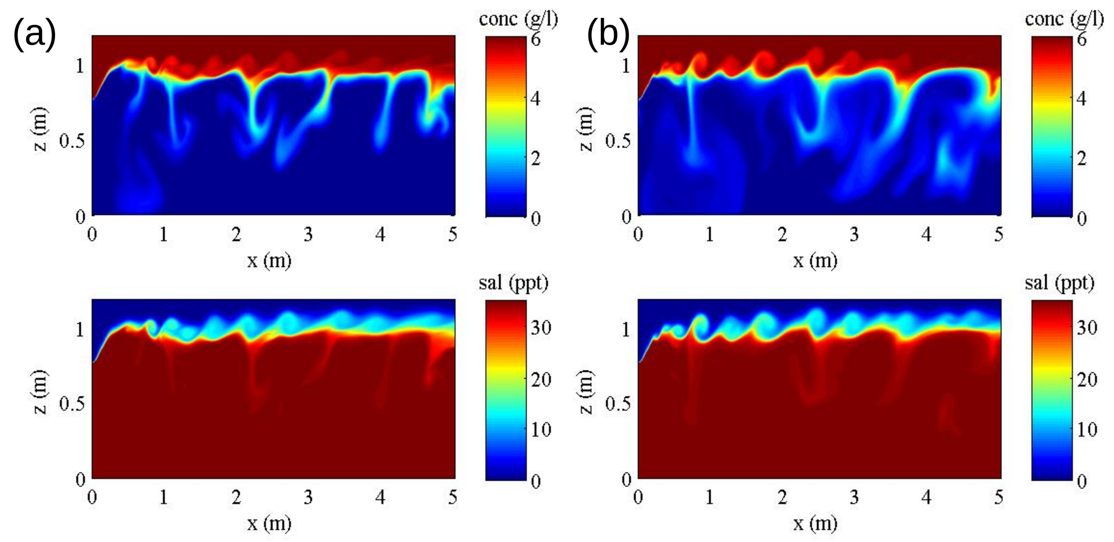
1) Divergent Plumes (DP regime)

Numerical model results with C=36 g/l at (a) t=9 sec and (b) t=20 sec.
W_s=1.4 mm/s
Re=4.2×10⁴
Re_p=0.058
γ=0.8



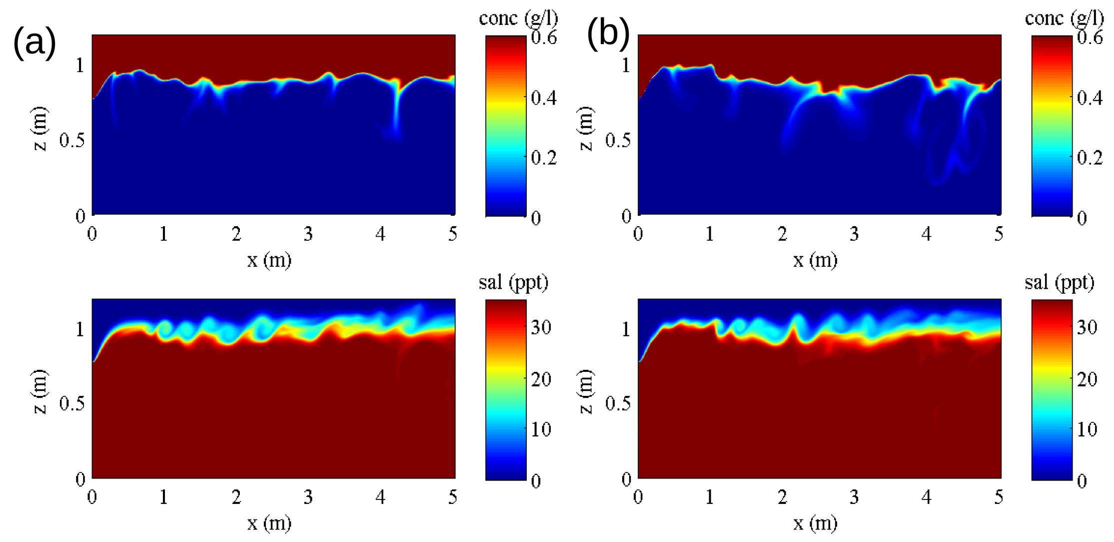
2) Intense Convective Finger (ICF regime)

Numerical model results with C=6.6 g/l at (a) t=55 sec and (b) t=75 sec.
W_s=3 mm/s
Re=4.2×10⁴
Re_p=0.194
γ=0.146

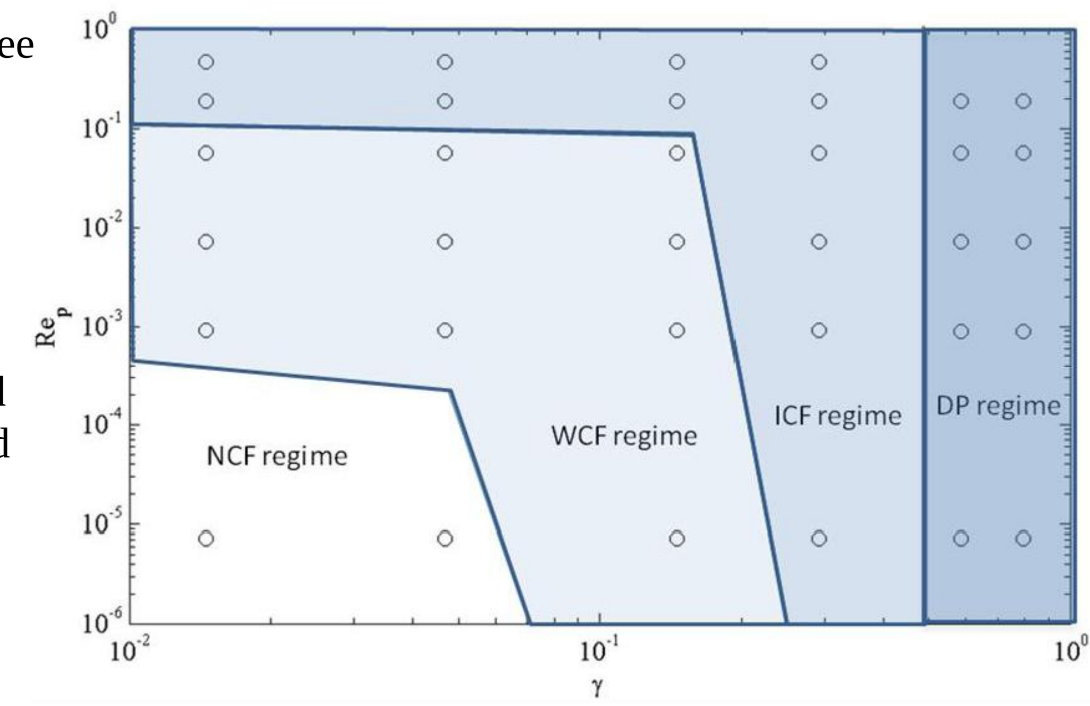


3) Weak Convective Finger (WCF regime)

Numerical model results with C=6.6 g/l but smaller W_s=0.36 mm/s at (a) t=55 sec and (b) t=75 sec.
Re=4.2×10⁴
Re_p=0.0072
γ=0.146



- Model results suggest three regimes of convective sedimentation (44 runs).
- DP and ICF regimes are already insensitive to inlet Reynolds number (Re).
- Significant deposits (rapid sedimentation) are obtained for DP (γ>0.5) and ICF (0.2<γ<0.5 and Re_p>0.1) regimes.



3. Resuspension of fluid mud in the WBL

Science Issues:
What controls the formation of dense mud layer?
What controls the carrying capacity of a wave-current boundary layer?

3.1Nondimensional parameters:

Nondimensionalization: Stokes boundary layer thickness: $\tilde{\Delta} = \sqrt{2\nu_f/\tilde{\omega}}$
Oscillatory velocity amplitude: $\tilde{U}_0$

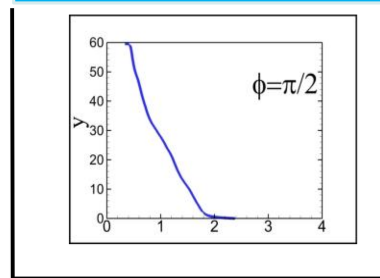
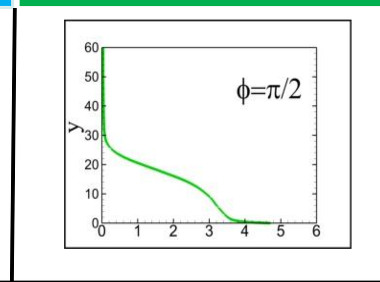
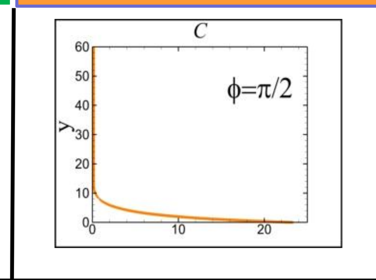
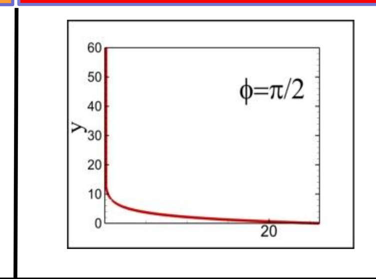
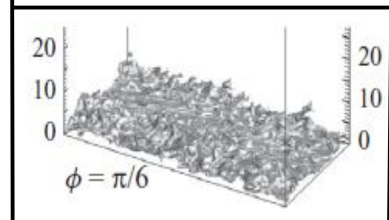
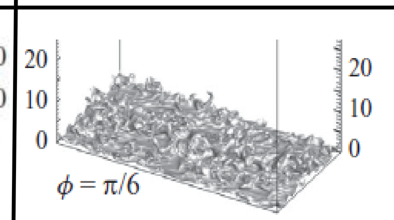
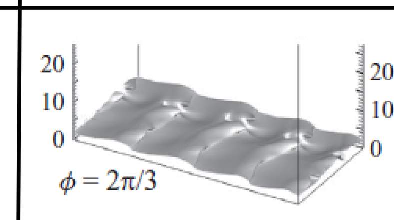
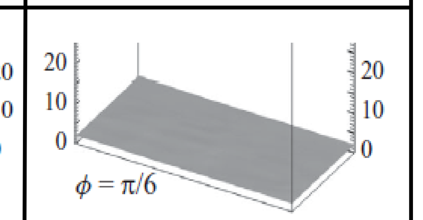
This problem is controlled by: $Re_\Delta = \frac{\tilde{U}_0\tilde{\Delta}}{\nu_f}$ $\quad Ri = \frac{(\rho_p-\rho_f)g\tilde{\Delta}}{\rho_f \tilde{U}_0^2}\bar{\tilde{C}}$ $\quad V_s = \frac{\tilde{V}_s}{\tilde{U}_0}$

Wave period of 10 second $\tilde{\Delta} = 1.8$ mm
Wave velocity amplitude $\tilde{U}_0 = 0.56$ m/s $\Rightarrow Re_\Delta = 1000$ i.e., $Re_w = 5\times10^6$
Settling velocity of W_s=0.5 mm/s ⇒ $V_s = 9\times10^{-4}$

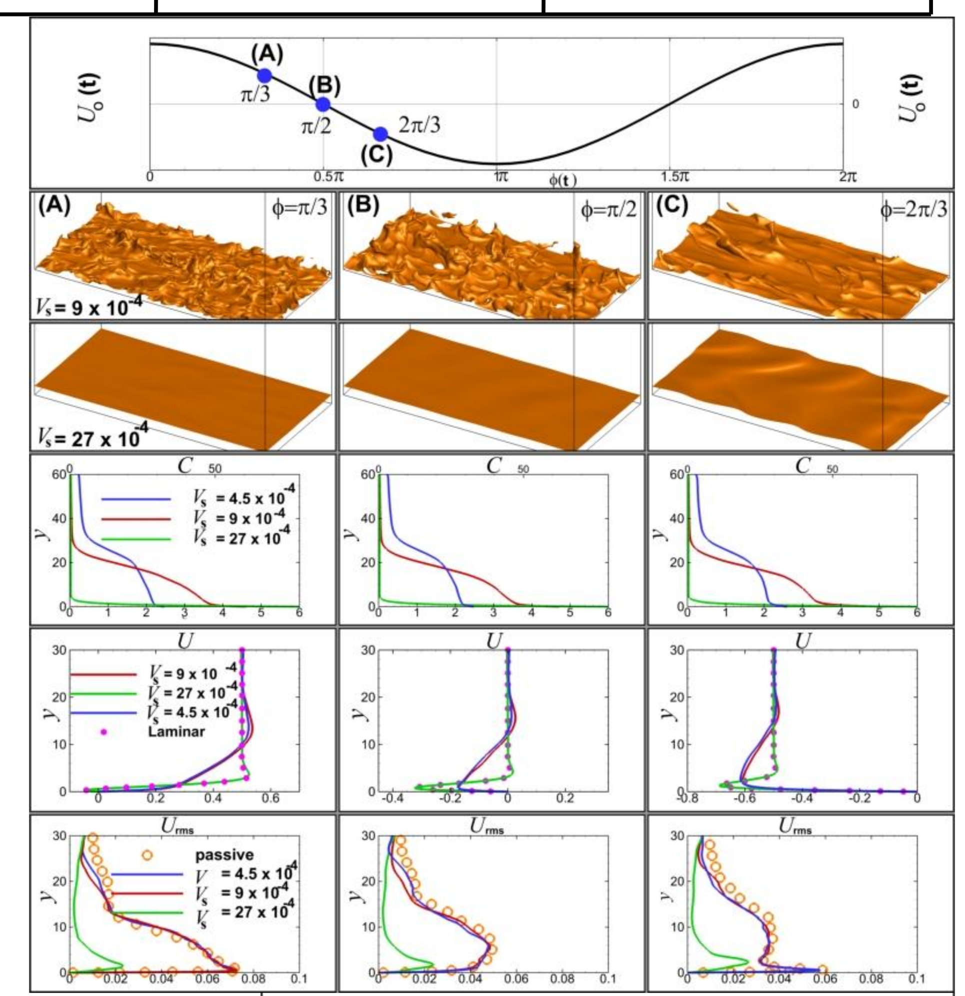
At this Reynolds number, we can afford to resolve all the scales of turbulence!

3.2 Finding – simulation results

- Four flow regimes due to different sediment availability (Ozdemir et al. 2010):

$\bar{\tilde{C}} = O(0.1$ g/l$)$	$\bar{\tilde{C}} = O(10$ g/l$)$	$\bar{\tilde{C}} = O(50$ g/l$)$	$\bar{\tilde{C}} = O(100$ g/l$)$
Regime I	Regime II	Regime III	Regime IV
			
			
Sediment is well-mixed and passive to flow turbulence	Formation of lutocline where turbulence is damped; flow remains turbulent below the lutocline	Collapse of turbulence except flow reversal; mean flow approaching laminar solution	Complete collapse of turbulence; laminar solution

- Similar flow regimes are also observed for different settling velocities but fixed sediment availability.



Lutocline location is lower for sediment of larger settling velocity; large settling velocity eventually leads to laminarization.

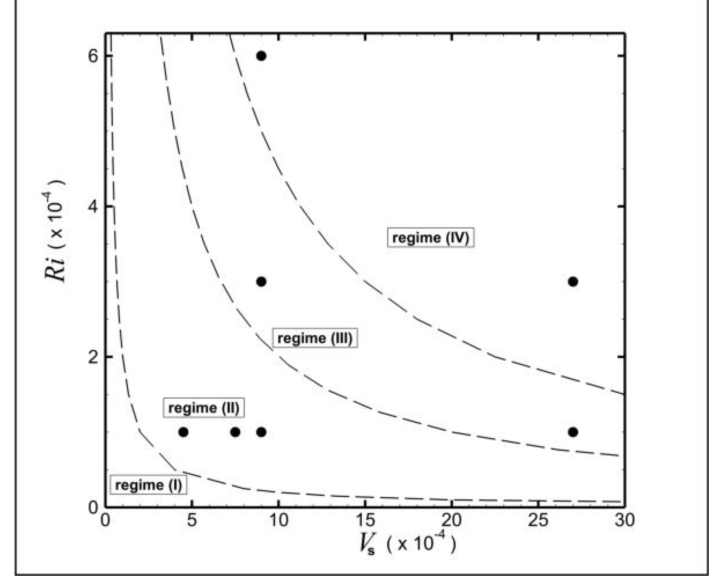
Ensemble-averaged velocity profiles match with laminar solution very well for regimes 3 and 4

Flow remains very turbulent below the lutocline in regime 2.

- A predictor of the state of muddy seabed under waves: $f(Re_\Delta, Ri, V_s)$

$V_s \cdot Ri = f(Re_\Delta)$=constant (in this study)

Similar formulation has been used to predict saturation condition for fluid mud in the tidal boundary layer Winterwerp (2001), JGR.



4. Acknowledgements/References

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