Vertical Momentum Exchange and Implications for Runout Distances in Turbidity Currents*

Mike Tilston[1], Bill Arnott[2], and Colin Rennie[3]

Search and Discovery Article #51183 (2015)**
Posted October 19, 2015

*Adapted from oral presentation given at AAPG Annual Convention & Exhibition, Denver, Colorado, May 31-June 3, 2015

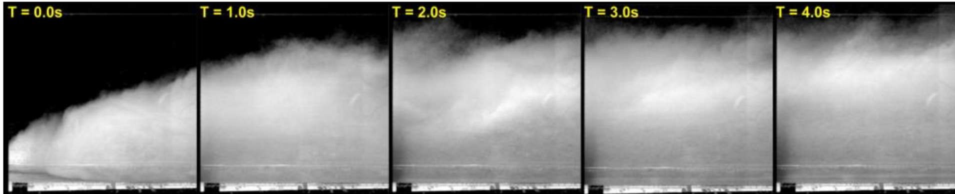
[1]Earth Sciences, University of Ottawa, Ottawa, Ontario, Canada (miketilston@hotmail.com)
[2]Earth Sciences, University of Ottawa, Ottawa, Ontario, Canada
[3]Civil Engineering, University of Ottawa, Ottawa, Ontario, Canada

Abstract

It is well known that many turbidity currents originate on the upper continental slope, accelerate downslope, and then deposit much of their sediment load on the deep basin floor. What's less clear is how these currents are able to achieve run-out distances of hundreds to thousands of kilometers along the basin floor under virtually zero grade conditions. Although numerous researchers have suggested that this is related to the internal momentum of the flow, obtaining simultaneous high-resolution velocity and density datasets of sediment gravity currents is notoriously difficult. Consequently, many experimental studies employ saline density currents as surrogates for particle gravity flows, even though it is unclear how suitable they are as proxies for explaining run-out distances since they omit the effects of varying particle settling velocities and fluid-particle and particle-particle interactions, all which must have played some, if not major role in governing the internal characteristics of the turbidity currents. Here we report on a series of experiments that paired a three-dimensional ultrasonic Doppler velocity profiler (UDVP-3D) and a medical grade computed tomography (CT) scanner to simultaneously examine the velocity and density structure of sediment gravity currents across a range of particle sizes (d50: 70, 150, 230, 330 µm) and sediment concentrations (~5–18% by mass; 2–8 sediment volume %). Results show that compared to coarser-grained flows, finer-grained flows are less density stratified, have a more bulbous velocity profile and the high velocity core is positioned higher above the bed. Reduced density stratification, in addition to reduced grain settling velocity and increased particle-particle interactions, controls the shape of the velocity profile, which in fine-grained flow leads to a more symmetric ("plug-like") profile between the bed and the top of the boundary layer. It is this more vertically uniform density structure in fine-grained flows, rather than the velocity profile, that controls the local momentum gradient, and as a consequence reduces mixing between the current and the ambient fluid. Reduced mixing allows these flows to retain more of their initial momentum, and accordingly, promotes longer run-out distance across a virtually horizontal deep basin floor.

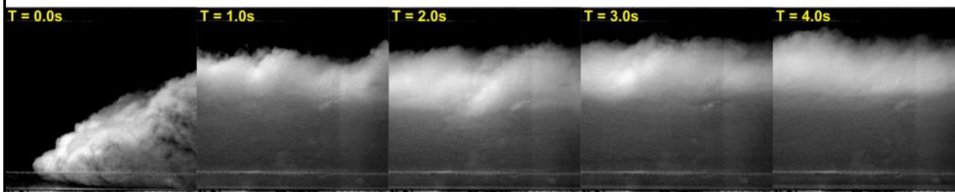
Reference Cited

Stow, D.A.V., and M. Mayall, 2000, Deep-water Sedimentary Systems: New Models for the 21st Century: Marine Petroleum Geology, v. 17, p. 125-135.



Vertical Momentum Exchange & Implications for Runout Distances in Turbidity Currents

M. Tilston[1], R.W.C. Arnott[1] and C. Rennie[2]
[1]Department of Earth Sciences, University of Ottawa, Ottawa ON
[2]Department of Civil Engineering, University of Ottawa, Ottawa ON



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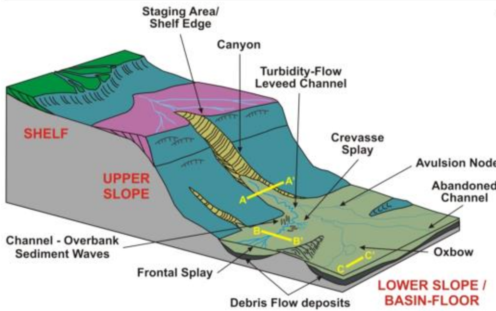
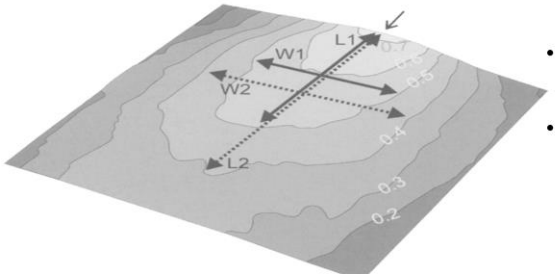
1.1. Introduction





Turbidity Currents: special type of gravity current where the density difference is attributed to suspended sediments.

- Flow for 1000's km under ~0% grades on basin floor
- Change from gravity to momentum driven flows at slope basin transition
- Question: What the sources of momentum loss (i.e. runout distances & deposit morphology)
- Hypothesis: largely controlled by grain size of particles that make up the flow
- Problem: necessitates both velocity AND density data (ρU) → numerous technical challenges associated with obtaining both

Presenter's notes: Turbidity currents are little more than turbulent particle suspensions, and the density contrast generated by the presence of these suspended sediments is what allows them to flow down slope, forming a vast distributary networks along the basin-floor.
Direct study is impractical due to their highly destructive and episodic nature, so most commonly studied via outcrop.

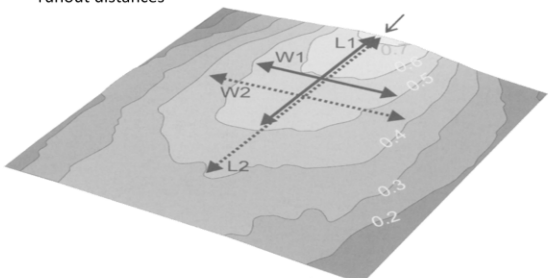
1.1. Introduction

Grain size controls on momentum loss:

1. <u>Δ's in settling velocity (w_s)</u>: coarse grained flows → higher settling velocities → lower conservation of mass → shorter runouts
2. <u>Δ's in roughness</u>: coarse grained flows → higher near-bed density gradient → production of angular bedforms → grain AND form roughness → shorter runouts
3. <u>Δ's in entrainment</u>: (hypothesis) coarse grained flows → strong, continuous density stratification → vertically extensive region of ambient entrainment (mixing) → shorter runouts → what about density & mixing?

- Effect of these 3 controls: creates a negative feedback loop of momentum/energy loss

Objective: To investigate the influence of grain size and concentration on momentum loss in sediment gravity currents & the implications for runout distances



Presenter's notes: Entrainment is much like mixing (i.e. turbulence), and therefore represents a source of energy dissipation.

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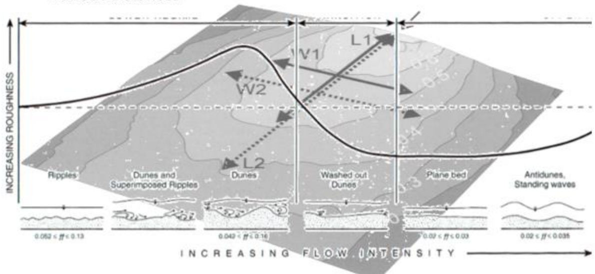

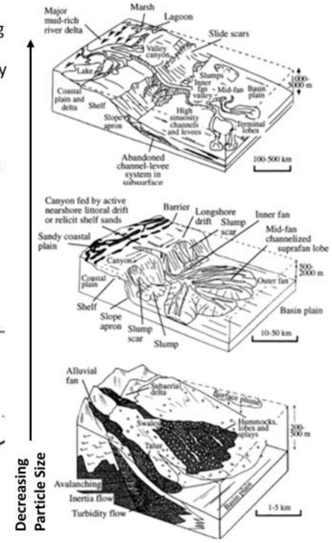

Effect of grain size on deposition style (Stow & Mayall, 2000)

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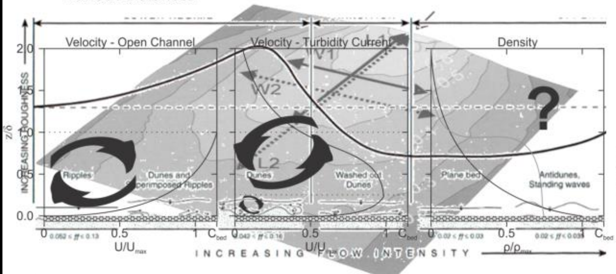

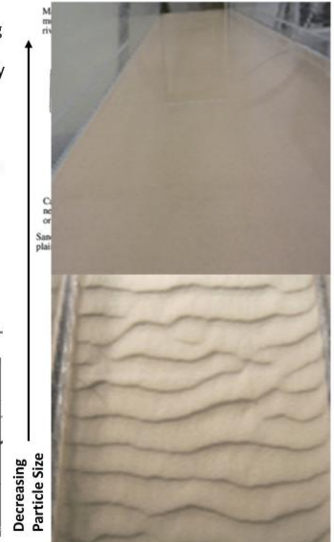

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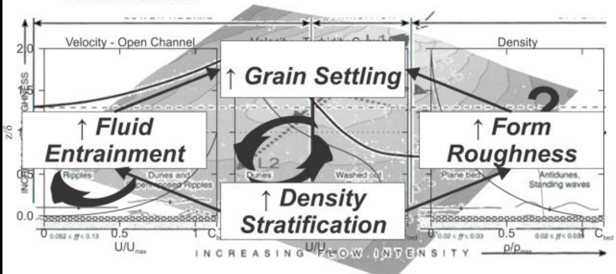

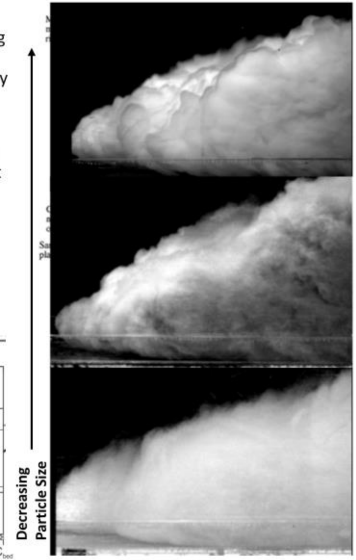

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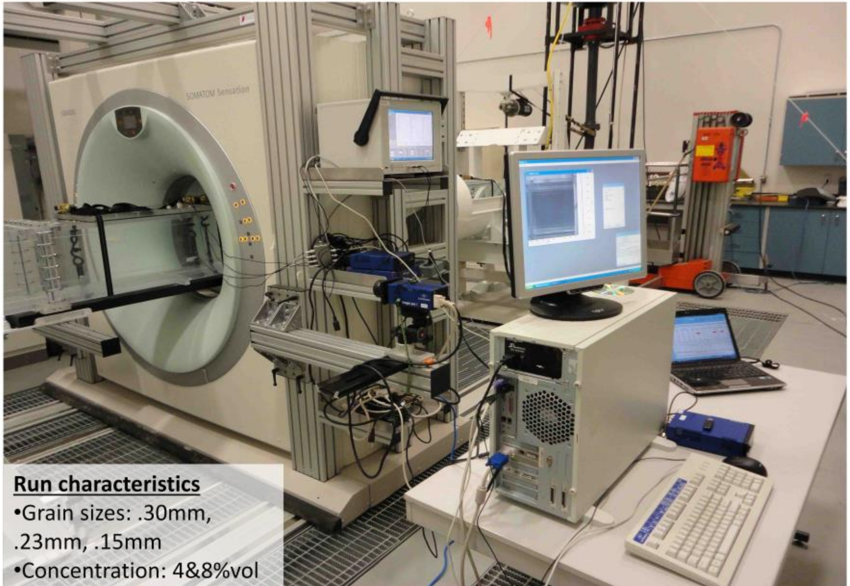

Run characteristics

- Grain sizes: .30mm, .23mm, .15mm
- Concentration: 4&8%vol

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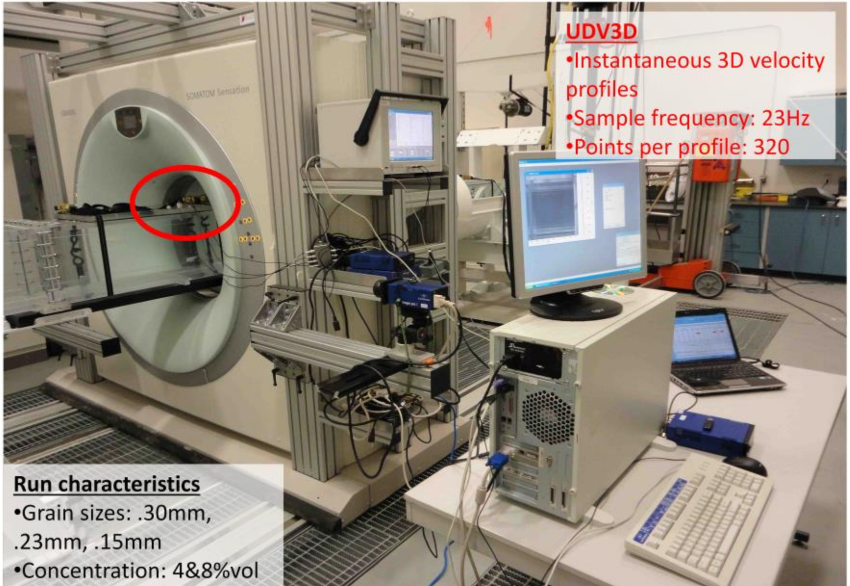

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- Instantaneous 3D velocity profiles
- Sample frequency: 23Hz
- Points per profile: 320

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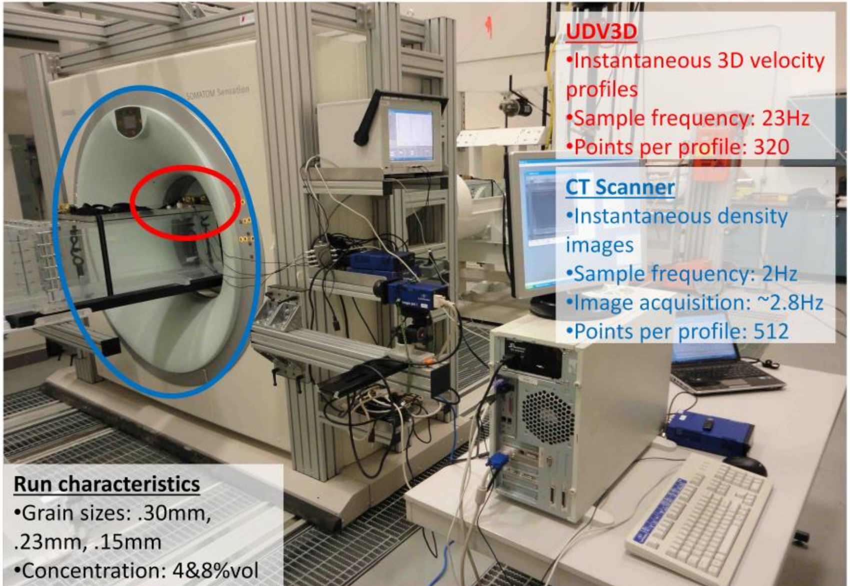

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CT Scanner
- Instantaneous density images
- Sample frequency: 2Hz
- Image acquisition: ~2.8Hz
- Points per profile: 512

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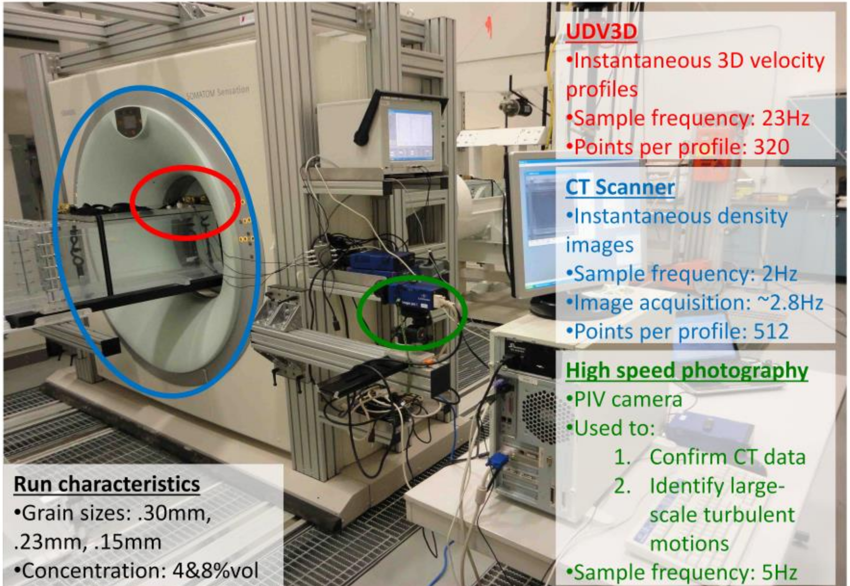

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CT Scanner
- Instantaneous density images
- Sample frequency: 2Hz
- Image acquisition: ~2.8Hz
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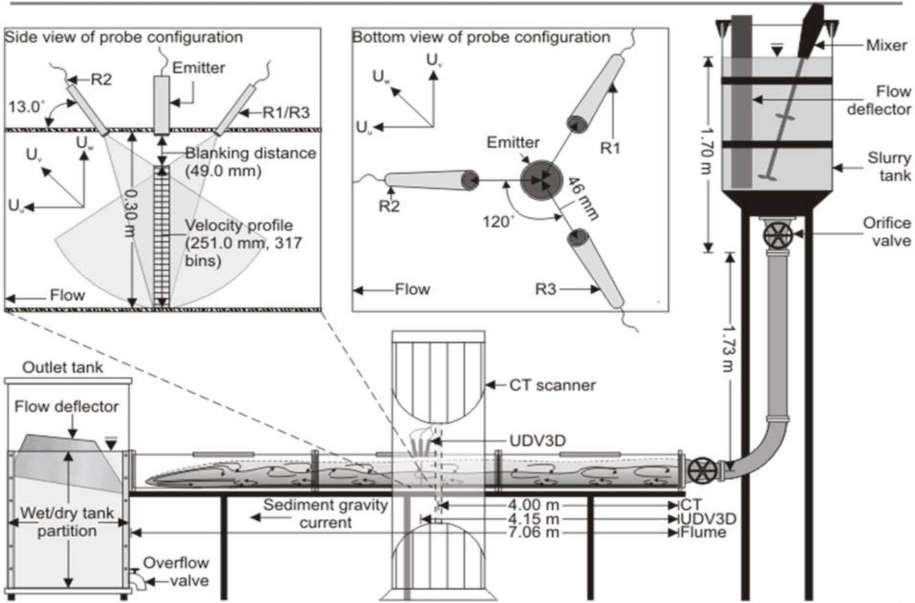
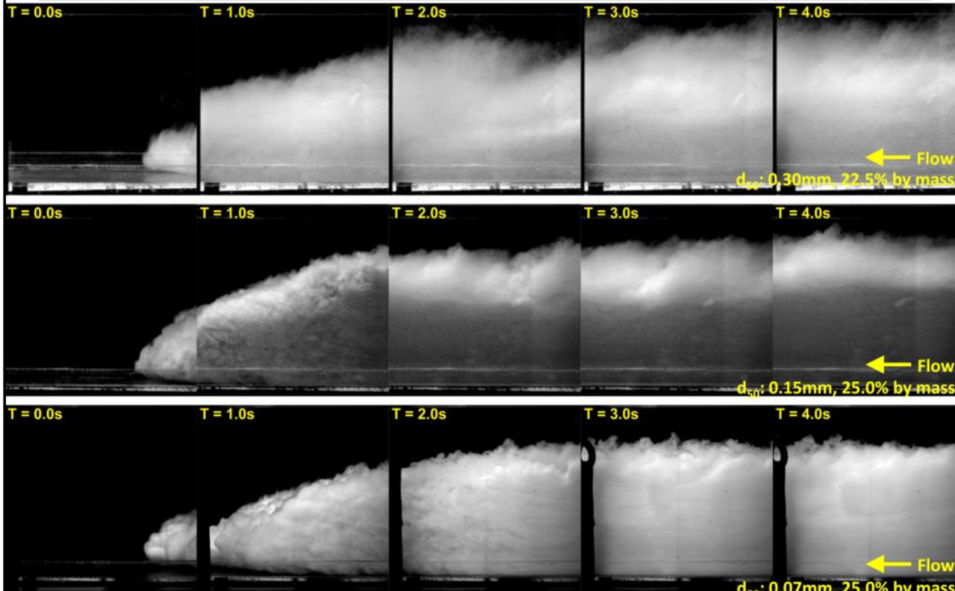
High speed photography
- PIV camera
- Used to:
    1. Confirm CT data
    2. Identify large-scale turbulent motions
- Sample frequency: 5Hz

Run characteristics
- Grain sizes: .30mm, .23mm, .15mm
- Concentration: 4&8%vol

2.1. Experimental Setup - schematic



2.2. Experimental Setup: qualitative grain size controls



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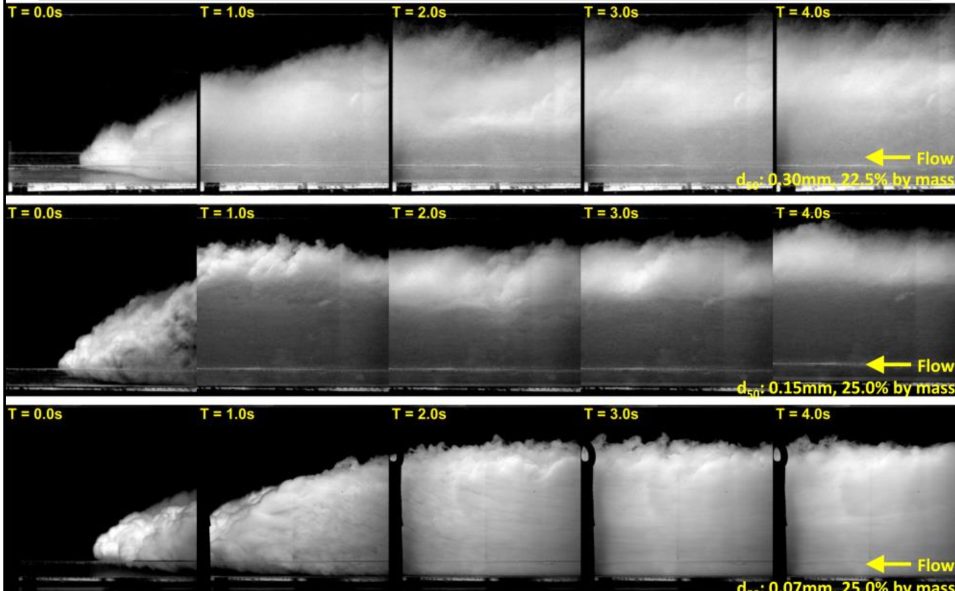

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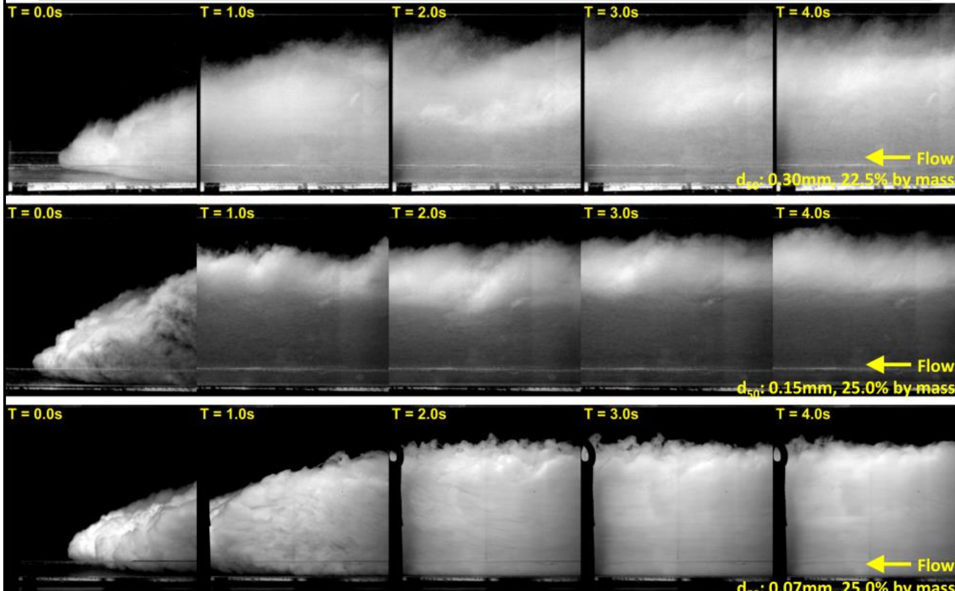

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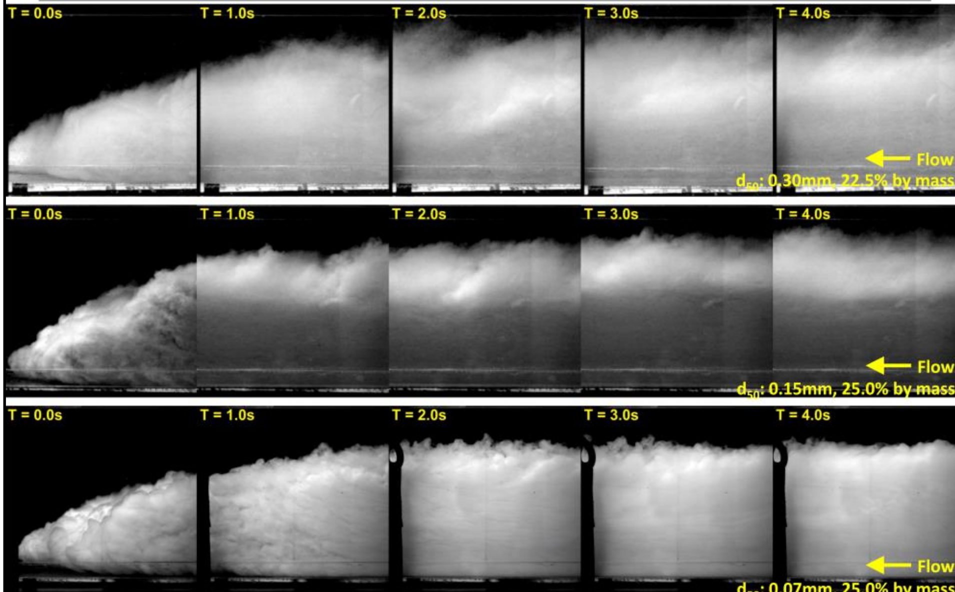

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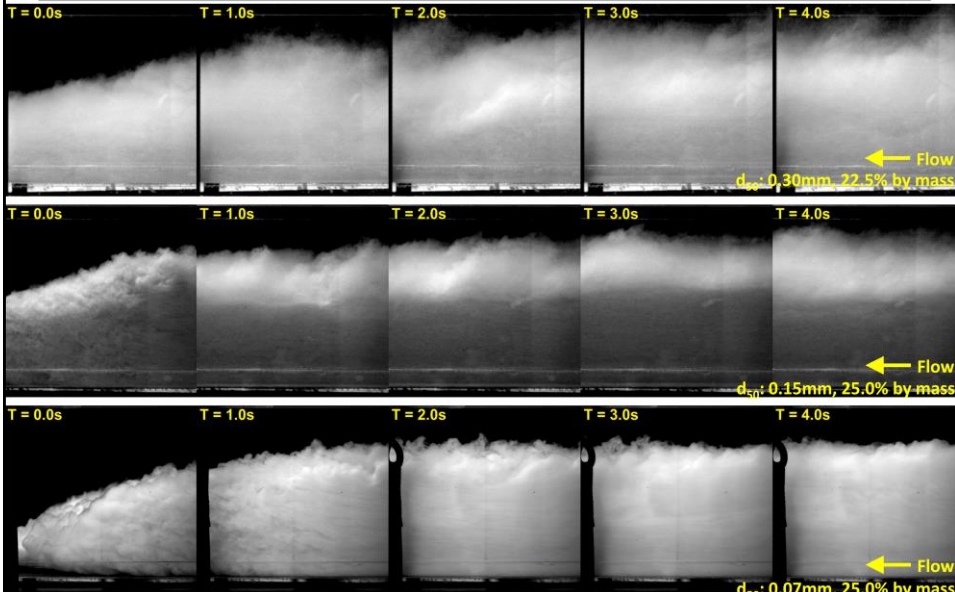

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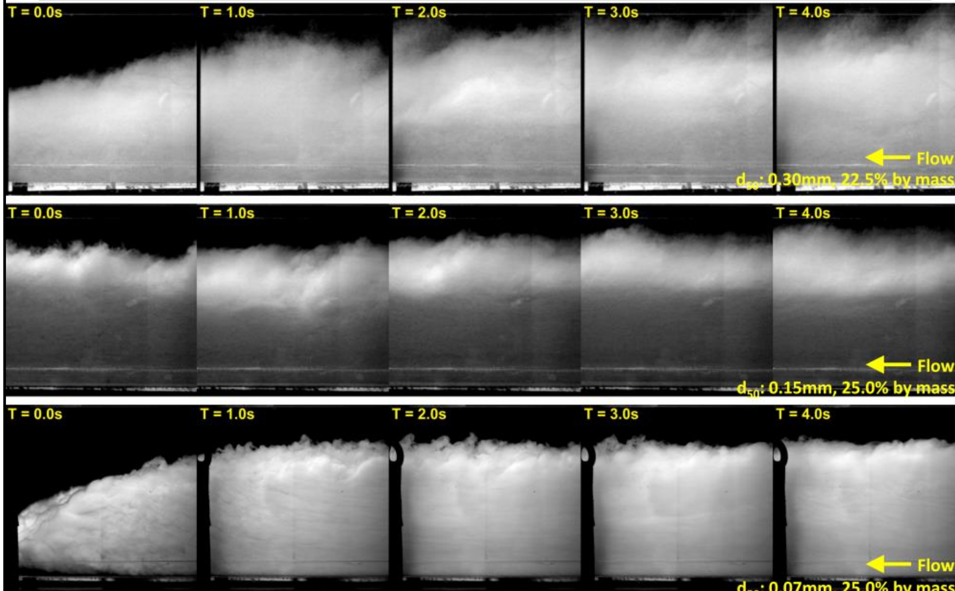

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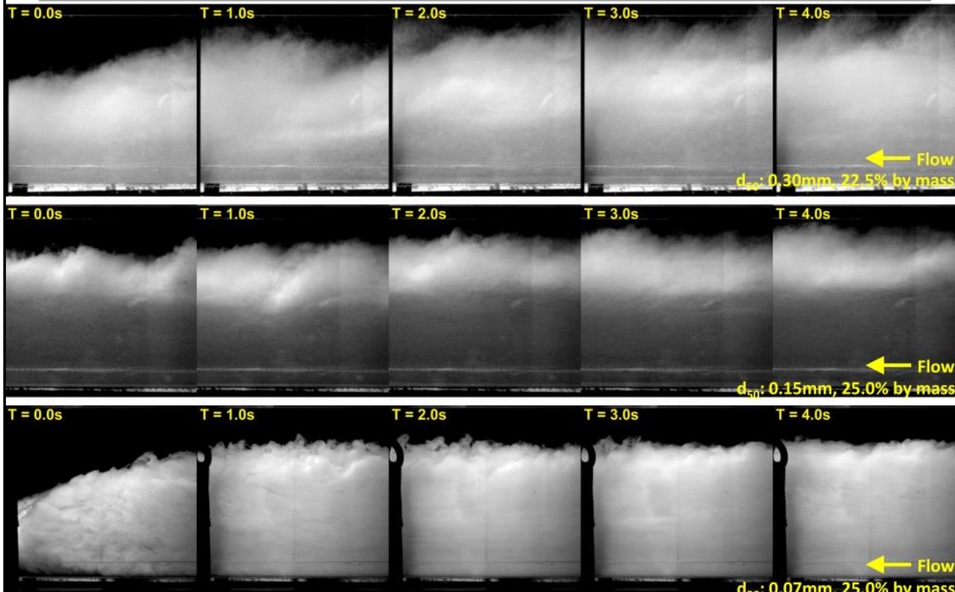

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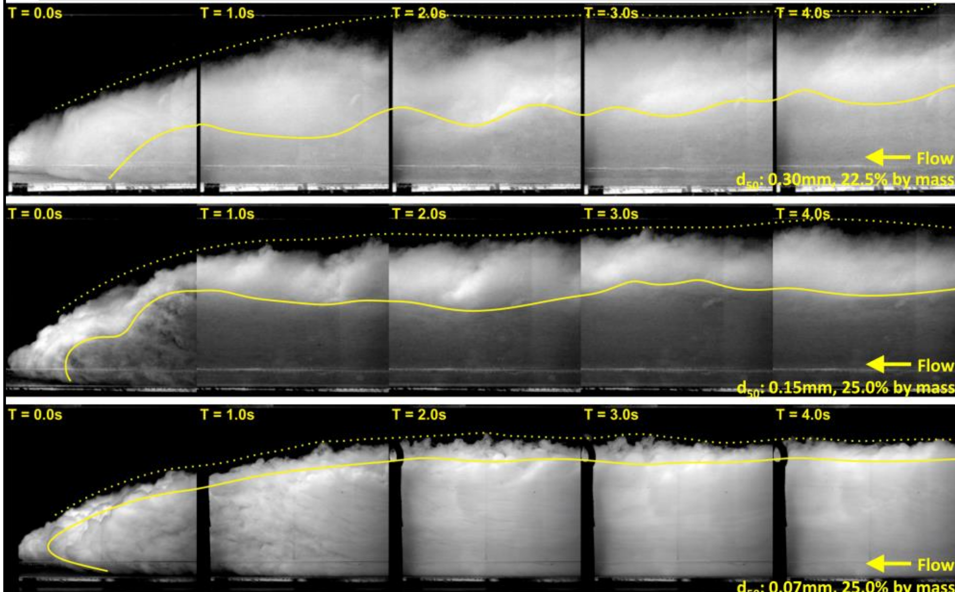
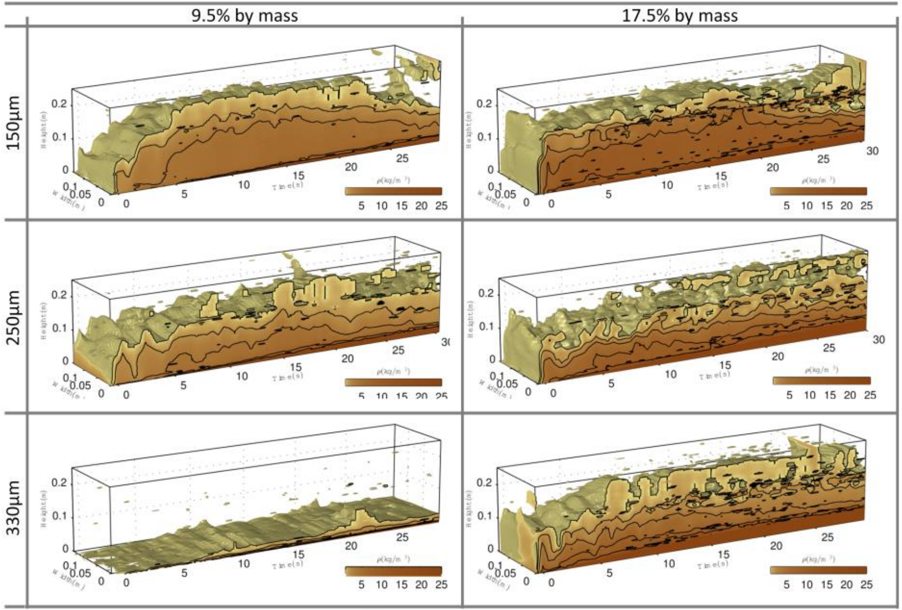


3.1. Results: density structure



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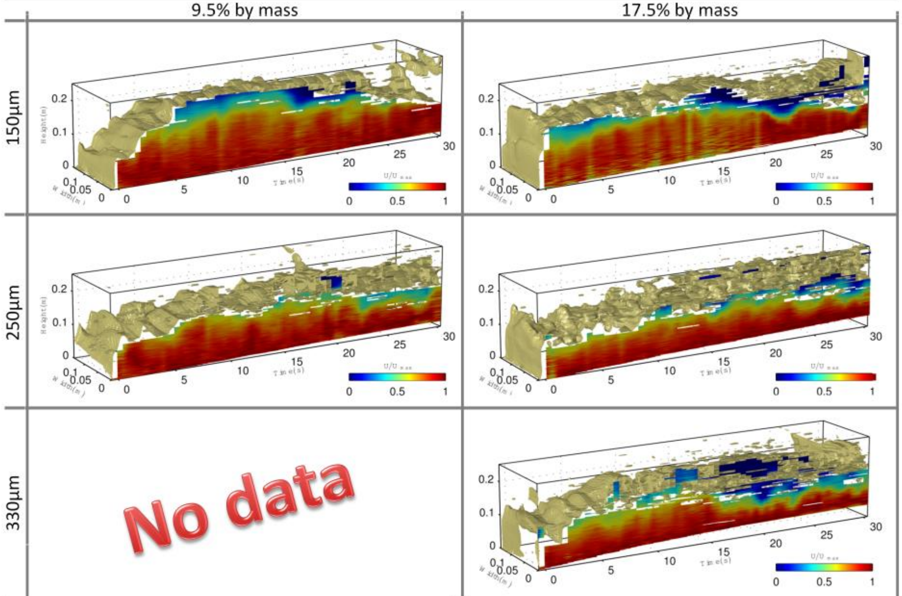
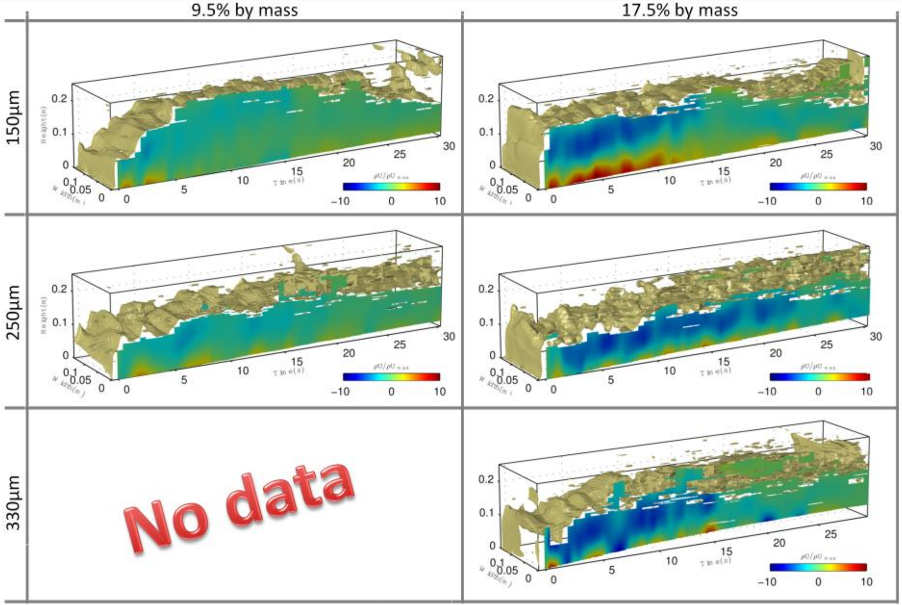
Presenter's notes: Increase in near-bed density stratification associated with increasing grain-size and decreasing concentration → hydrodynamic instability for the development of 2-D bedforms. Decrease in grainsize or increase in flow energy → more plug-like flow → lower propensity for development of 2D bedforms and reduce mixing with ambient fluid.

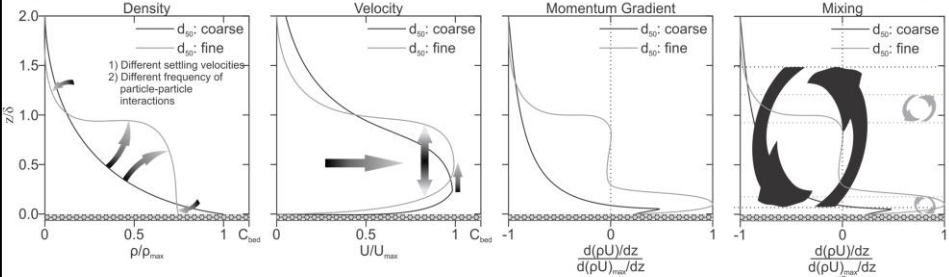
3.1. Results: velocity structure



3.1. Results: momentum gradient structure

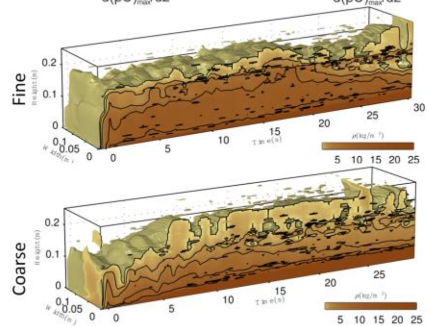


4.1. Discussion: implications for mixing and runout distances



General trends:

1. Density structure: thickness of the denser, basal region of flow ↓ with:
   i. ↓ slurry density
   ii. ↑ D_{50}
2. Velocity structure: Generally insensitive to slurry density, but with ↓D_{50}, U_{max}:
   i. More bulbous/vertically smeared
   ii. Positioned higher above the bed
3. Momentum gradient structure (dρ/dz):
   i. ↓ slurry density: ↓ gradient strength
   ii. ↓ D_{50}: weak & thin +ve basal region, strong & thick –ve top → strong & thick +ve basal region, low gradient core, Strong & thin –ve top



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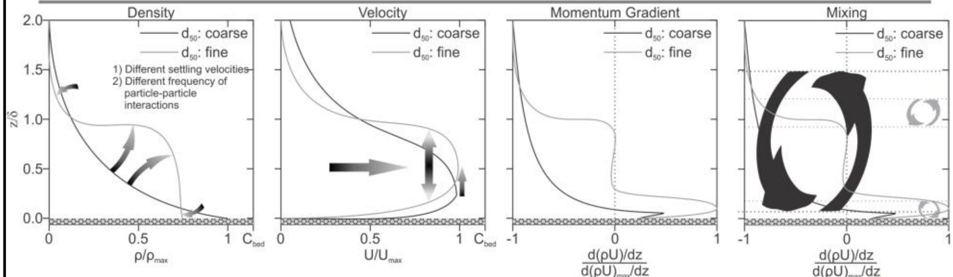

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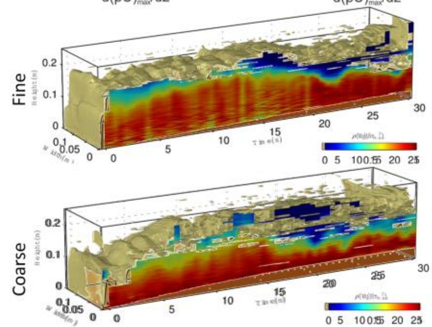

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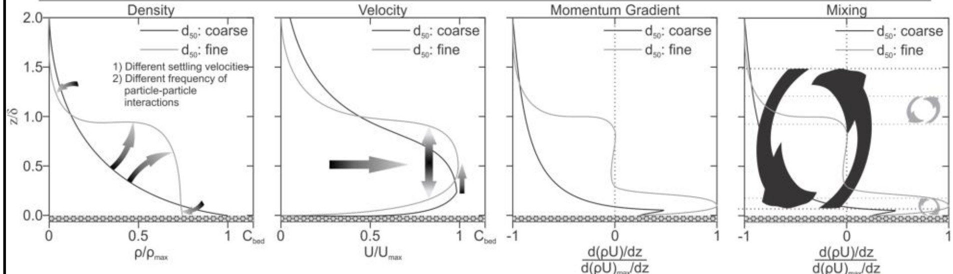

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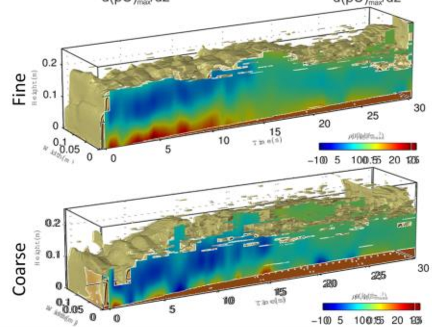

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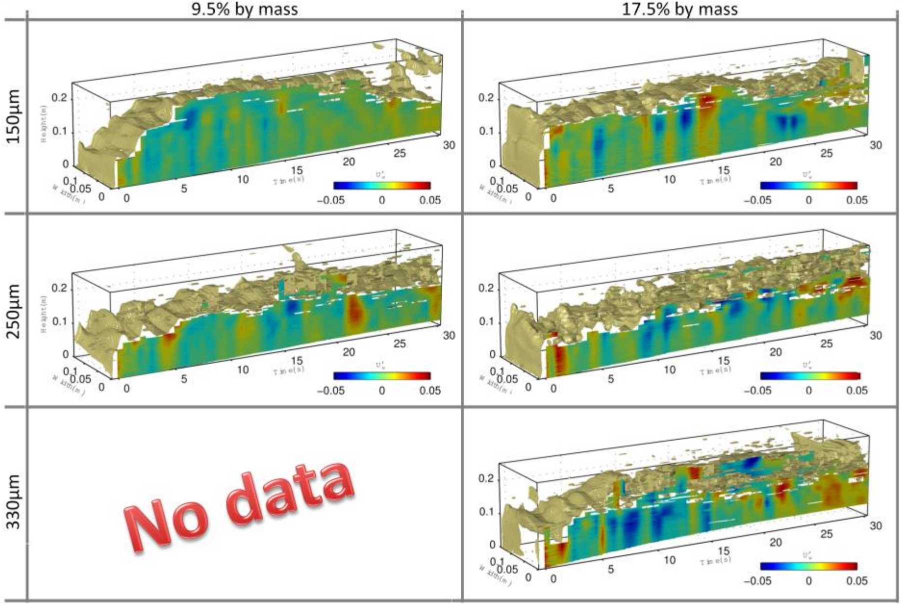
4.1.1. Discussion: mixing and ambient fluid entrainment



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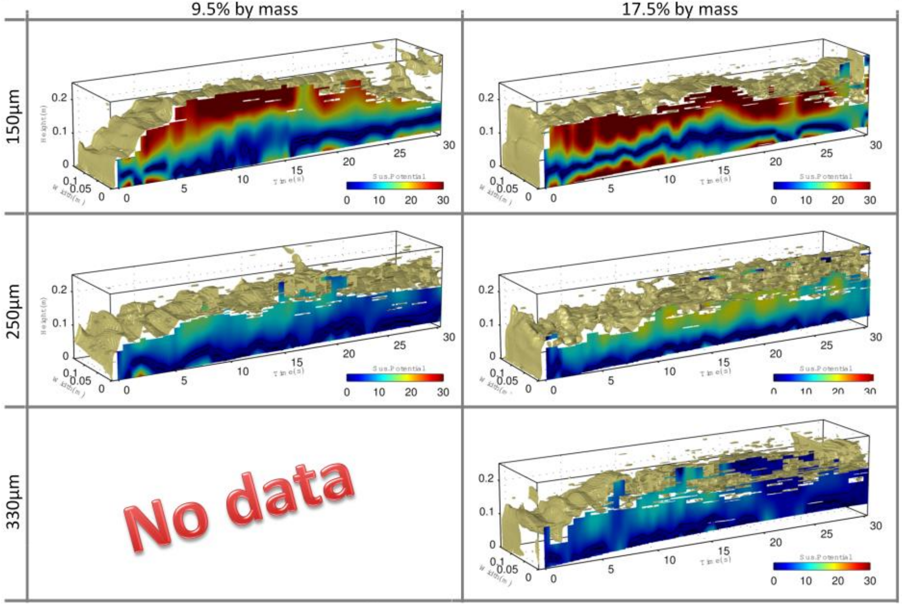

5. Conclusion

Remaining questions:

1. Implications for vertical extent of ambient fluid entrainment (size of K-H instabilities):
   - i. ↓ slurry density → ↓ intensity of vertical motions
   - ii. ↑ D_{50} → ↑ intensity & extent of vertical motions
2. Implications current runout distances
   - i. ↓ slurry density → ↓ sediment suspension potential
   - ii. ↑ D_{50} → ↓ sediment suspension potential

Final remarks:

1. The parameters: both velocity and density need to be considered for investigating the dynamics of density currents
2. Grain size: given the same initial conditions, exerts a first order control on density structure
3. Density structure: exerts a first order control on velocity structure (and momentum)
4. Momentum gradient structure: determines the vertical extent and intensity of mixing of mixing (i.e. momentum loss)
5. Suspension Potential: reduction in mixing offset by reduction in w_s

Last points to ponder:

- Density structure is likely controlled by $\rho U:w_s$, not $\rho U:D_{50}$
- Δ'ing D_{50} may be a viable analogue for flow deceleration in laboratory settings to explain downflow/off-axis Δ's in depositional morphology

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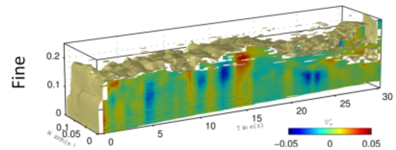

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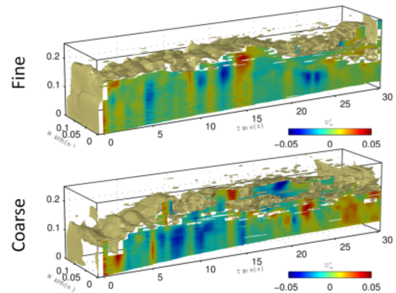

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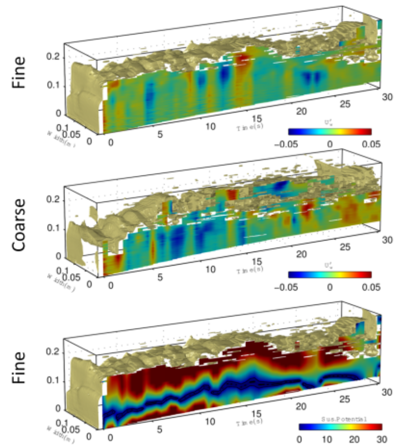


AAPG 2015
Denver, Colorado

5. Conclusion

Remaining questions:

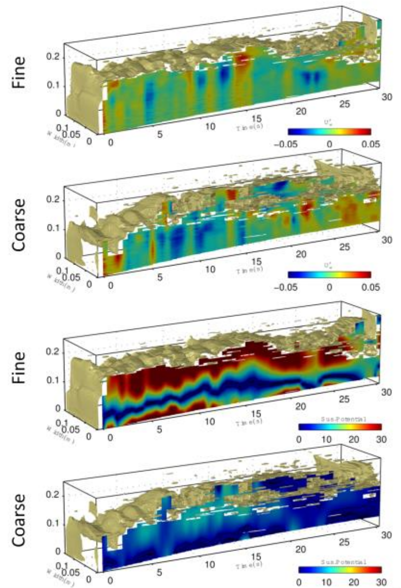
1. Implications for vertical extent of ambient fluid entrainment (size of K-H instabilities):
   - i. ↓ slurry density → ↓ intensity of vertical motions
   - ii. ↑ D_{50} → ↑ intensity & extent of vertical motions
2. Implications current runout distances
   - i. ↓ slurry density → ↓ sediment suspension potential
   - ii. ↑ D_{50} → ↓ sediment suspension potential

Final remarks:

1. The parameters: both velocity and density need to be considered for investigating the dynamics of density currents
2. Grain size: given the same initial conditions, exerts a first order control on density structure
3. Density structure: exerts a first order control on velocity structure (and momentum)
4. Momentum gradient structure: determines the vertical extent and intensity of mixing of mixing (i.e. momentum loss)
5. Suspension Potential: reduction in mixing offset by reduction in w_s

Last points to ponder:

- Density structure is likely controlled by $\rho U:w_s$, not $\rho U:D_{50}$
- Δ'ing D_{50} may be a viable analogue for flow deceleration in laboratory settings to explain downflow/off-axis Δ's in depositional morphology




Thanks!