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 of 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 ($d_{50}: 70, 150, 230, 330 \mu m$) 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

Vertical Momentum Exchange & Implications for Runout Distances in Turbidity Currents

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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. A’s in settling velocity (w): coarse grained flows → higher settling velocities → lower conservation of mass → shorter runouts
2. A’s in roughness: coarse grained flows → higher near-bed density gradient → production of angular bedforms → grain AND form roughness → shorter runouts
3. A’s in entrainment: (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.
1.1. Introduction

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**Grain size controls on momentum loss:**
1. $d_s$ in settling velocity ($w_s$): coarse grained flows $\rightarrow$ higher settling velocities $\rightarrow$ lower conservation of mass $\rightarrow$ shorter runouts
2. $d_s$ in roughness: coarse grained flows $\rightarrow$ higher near-bed density gradient $\rightarrow$ production of angular bedforms $\rightarrow$ grain AND form roughness $\rightarrow$ shorter runouts
3. $d_s$ in entrainment: (hypothesis) coarse grained flows $\rightarrow$ strong, continuous density stratification $\rightarrow$ vertically extensive region of ambient entrainment (mixing) $\rightarrow$ shorter runouts $\rightarrow$ what about density & mixing?

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1.1. Introduction

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1. $\delta$'s in settling velocity ($w$): coarse grained flows $\rightarrow$ higher settling velocities $\rightarrow$ lower conservation of mass $\rightarrow$ shorter runouts
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Effect of grain size on entrainment (Glow & Mayall, 2000)

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

Run characteristics
• Grain sizes: .30mm, .23mm, .15mm
• Concentration: 4&8%vol
2.1 Experimental Setup - equipment

**UDV3D**
- Instantaneous 3D velocity profiles
- Sample frequency: 23 Hz
- Points per profile: 320

**Run characteristics**
- Grain sizes: .30 mm, .23 mm, .15 mm
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2.1 Experimental Setup - equipment

**UDV3D**
- Instantaneous 3D velocity profiles
- Sample frequency: 23Hz
- Points per profile: 320

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

**Run characteristics**
- Grain sizes: .30mm, .23mm, .15mm
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**CT Scanner**
- Instantaneous density images
- Sample frequency: 2Hz
- Image acquisition: ~2.8Hz
- Points per profile: 512

**High speed photography**
- PIV camera
- Used to:
  1. Confirm CT data
  2. Identify large-scale turbulent motions
- Sample frequency: 5Hz
2.2. Experimental Setup: qualitative grain size controls
2.2. Experimental Setup: qualitative grain size controls

- $d_{50} = 0.30\text{mm}$, 22.6% by mass
- $d_{50} = 0.15\text{mm}$, 25.0% by mass
- $d_{50} = 0.07\text{mm}$, 25.0% by mass

Flow
2.2. Experimental Setup: qualitative grain size controls

\[ d_{15} = 0.30 \text{mm}, \, 22.5\% \text{ by mass} \]

\[ d_{15} = 0.15 \text{mm}, \, 25.0\% \text{ by mass} \]

\[ d_{15} = 0.07 \text{mm}, \, 25.0\% \text{ by mass} \]
2.2. Experimental Setup: qualitative grain size controls

- $d_s = 0.30 \text{mm}$, 25.0% by mass
- $d_s = 0.15 \text{mm}$, 25.0% by mass
- $d_s = 0.07 \text{mm}$, 25.0% by mass
2.2. Experimental Setup: qualitative grain size controls

- T = 0.0s
- T = 1.0s
- T = 2.0s
- T = 3.0s
- T = 4.0s

Flow

- d = 0.30mm, 25.0% by mass
- d = 0.15mm, 25.0% by mass
- d = 0.07mm, 25.0% by mass
2.2. Experimental Setup: qualitative grain size controls

- $d_s = 0.30\,\text{mm}$, 22.5\% by mass
- $d_s = 0.15\,\text{mm}$, 25.0\% by mass
- $d_s = 0.07\,\text{mm}$, 25.0\% by mass
2.2. Experimental Setup: qualitative grain size controls

- $d_{90} = 0.30\text{ mm, 22.5\% by mass}$
- $d_{90} = 0.15\text{ mm, 25.0\% by mass}$
- $d_{90} = 0.07\text{ mm, 25.0\% by mass}$
2.2. Experimental Setup: qualitative grain size controls

$T = 0.0s$  $T = 1.0s$  $T = 2.0s$  $T = 3.0s$  $T = 4.0s$

$\text{Flow}$

$d_{50} = 0.30\, \text{mm}, 25.0\% \text{ by mass}$

$d_{50} = 0.15\, \text{mm}, 25.0\% \text{ by mass}$

$d_{50} = 0.07\, \text{mm}, 25.0\% \text{ by mass}$
3.1. Results: density structure

9.5% by mass

17.5% by mass

150μm

250μm

350μm

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

<table>
<thead>
<tr>
<th>Size</th>
<th>9.5% by mass</th>
<th>17.5% by mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>150µm</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
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<tr>
<td>250µm</td>
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<td>350µm</td>
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No data
### 3.1. Results: momentum gradient structure

<table>
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<tr>
<th>9.5% by mass</th>
<th>17.5% by mass</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>150μm</strong></td>
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</tr>
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<tr>
<td><strong>350μm</strong></td>
<td><em>No data</em></td>
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</tbody>
</table>

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4.1. Discussion: implications for mixing and runout distances

General trends:
1. Density structure: thickness of the denser, basal region of flow \( \downarrow \) with:
   i. \( \downarrow \) slurry density
   ii. \( \uparrow \) \( D_{50} \)
2. Velocity structure: Generally insensitive to slurry density, but with \( \downarrow \) \( D_{50} \), \( U_{max} \):
   i. More bulbo/vertically smeared
   ii. Positioned higher above the bed
3. Momentum gradient structure \( (dp/\delta z) \):
   i. \( \downarrow \) slurry density; \( \downarrow \) gradient strength
   ii. \( \downarrow \) \( D_{50} \): weak \& thin +ve basal region, strong \& thick – ve top \( \rightarrow \) strong \& thick +ve basal region, low gradient core, Strong \& thin –ve top
4.1. Discussion: implications for mixing and runout distances

**General trends:**

1. **Density structure:** thickness of the denser, basal region of flow $\downarrow$ with:
   - $\downarrow$ slurry density
   - $\uparrow D_{50}$

2. **Velocity structure:** Generally insensitive to slurry density, but with $\downarrow D_{50}, U_{max}$:
   - More bulbous/vertically smeared
   - Positioned higher above the bed

3. **Momentum gradient structure ($d\rho/\rho dz$):**
   - $\downarrow$ slurry density: $\downarrow$ gradient strength
   - $\downarrow D_{50}$ weak & thin +ve basal region, strong & thick $\rightarrow$ strong & thin $\rightarrow$ weak basal region, low gradient core, Strong & thin $\rightarrow$ top

(dpU/dz)
(dpU$_{max}$/dz)
(dpU$_{max}$/dz)
(dpU$_{max}$/dz)
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 (dp/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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4.1.1. Discussion: mixing and ambient fluid entrainment

<table>
<thead>
<tr>
<th>150µm</th>
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<tbody>
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<td>350µm</td>
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*No data*
4.1.2. Discussion: suspension potential and runout distances

9.5% by mass

17.5% by mass

150μm

250μm

350μm

No data
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. ↑ D90 → ↑ intensity & extent of vertical motions
2. Implications: current runout distances
   i. ↓ slurry density → ↓ sediment suspension potential
   ii. ↑ D90 → ↓ 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 \(w_c\)

Last points to ponder:
- Density structure is likely controlled by \(pU/w_c\), not \(pU/D_{90}\)
- \(\Delta'\)ing \(D_{90}\) may be a viable analogue for flow deceleration in laboratory settings to explain downflow/off-axis \(\Delta'\)'s in depositional morphology
5. Conclusion

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

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5. Suspension Potential: reduction in mixing offset by reduction in \( w_r \)

Last points to ponder:
- Density structure is likely controlled by \( pU/w_r \), not \( pU/D_{50} \)
- \( \Delta ' \)ing \( D_{50} \) may be a viable analogue for flow deceleration in laboratory settings to explain downflow/off-axis \( \Delta ' \)'s in depositional morphology
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:
3. The parameters: both velocity and density need to be considered for investigating the dynamics of density currents
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6. Momentum gradient structure: determines the vertical extent and intensity of mixing of mixing (i.e. momentum loss)
7. Suspension Potential: reduction in mixing offset by reduction in w_s

Last points to ponder:
• Density structure is likely controlled by \( pUw_s \), not \( pU/D_{50} \)
• \( \Delta' \) ing \( D_{50} \) may be a viable analogue for flow deceleration in laboratory settings to explain downflow/off-axis \( \Delta's \) in depositional morphology
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_e  

Last points to ponder:
• Density structure is likely controlled by pU:w_e, not pU: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
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. ↑ Dₜ₀ → ↑ intensity & extent of vertical motions
2. Implications: current runout distances
   i. ↓ slurry density → ↓ sediment suspension potential
   ii. ↑ Dₜ₀ → ↓ 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
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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 wᵣ

Last points to ponder:
- Density structure is likely controlled by pU.wᵣ, not pU/Dₜ₀
- Δ‘ing Dₜ₀ may be a viable analogue for flow deceleration in laboratory settings to explain downflow/off-axis Δ’s in depositional morphology