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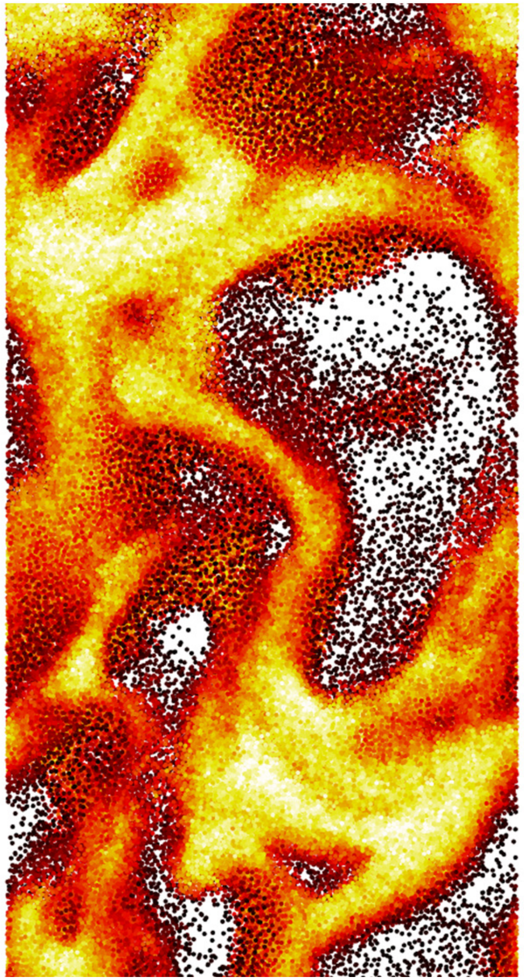
Coarse-Grid Simulations Using Parcels

An Advanced Drag Model based on Filtered CFD-DEM Data



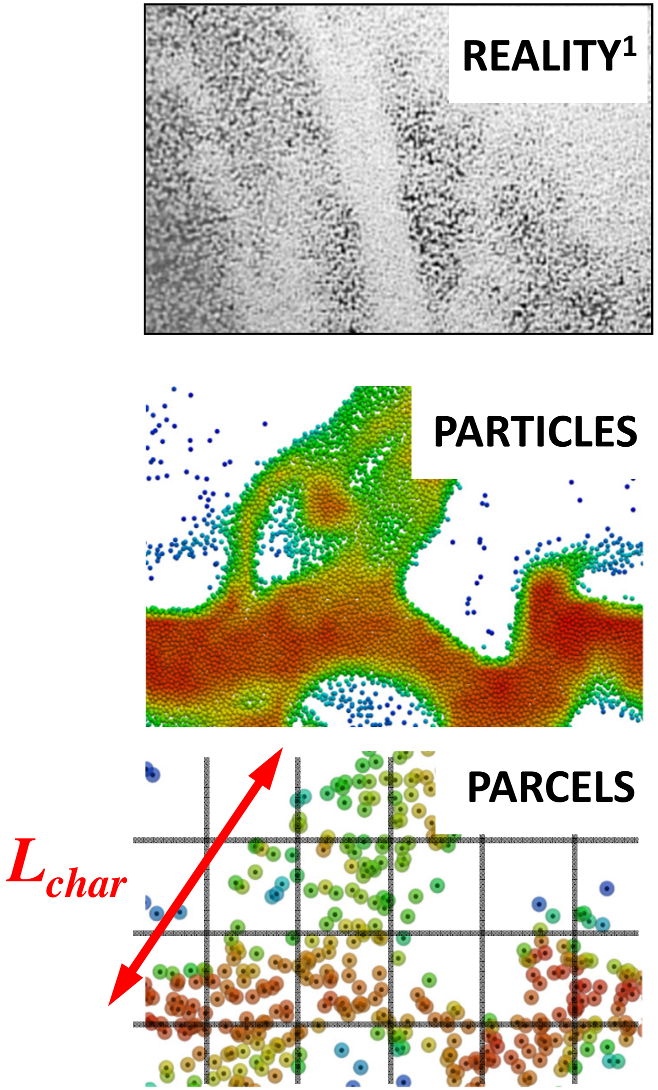
Stefan Radl and
Sankaran Sundaresan

Talk 5-4

Fluidization XIV
Noordwijkerhout, The Netherlands

Outline

- **Motivation**
- **Simulation Setup**
- **Drag Model Results**
- **A Short Review of Important Length Scales**



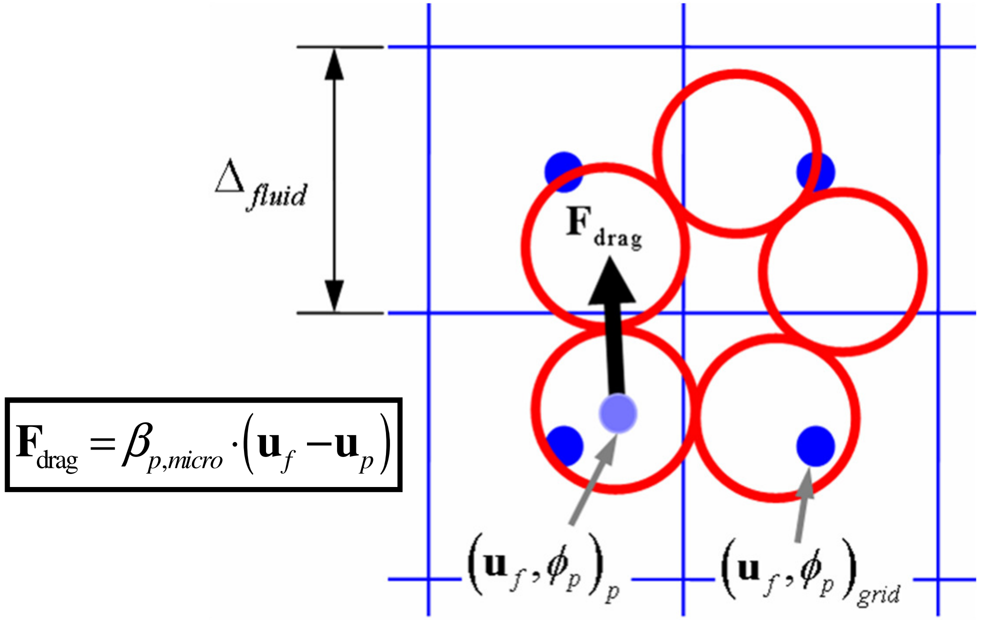
[1]Courtesy: Franklin Shaffer, NETL, Morgantown, WV (2009).

Simulation Setup

- In the CFD-DEM[2,3] the fluid flow is calculated on a **computational grid that is larger than the particles** - **„microscopic“ drag law**.
- In the CFD-DPM one computes **virtual „contact“ forces** via a DEM-like tracking of **parcel collisions.**[4] **Microscopic draw law often not suitable.**

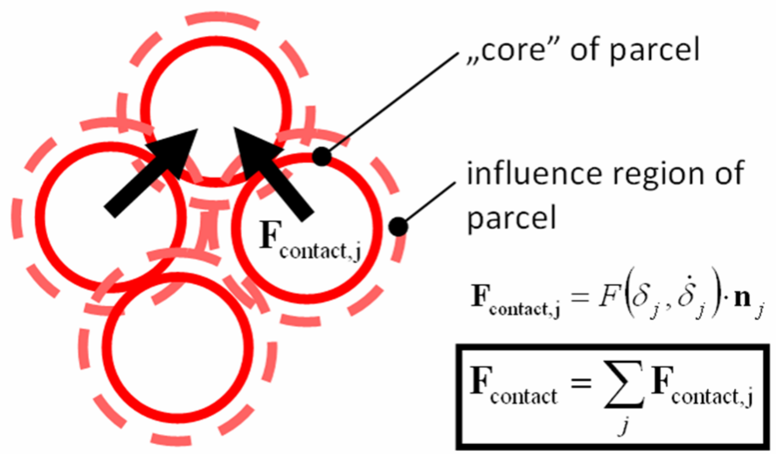
CFD-DEM

(Zhou et al.,[2] Link et al.[3])



(CFD-)DPM

(Patankar and Joseph[4])



[2]Zhou et al., ***JFM*** 661 (2010) , [3]Link et al., ***Powder Tech*** 189 (2009), [4]Patankar and Joseph, ***IJMF*** 27 (2001).

Simulation Setup

$$\nabla p = \nabla p_{dyn} + \rho_{mix}\mathbf{g}$$

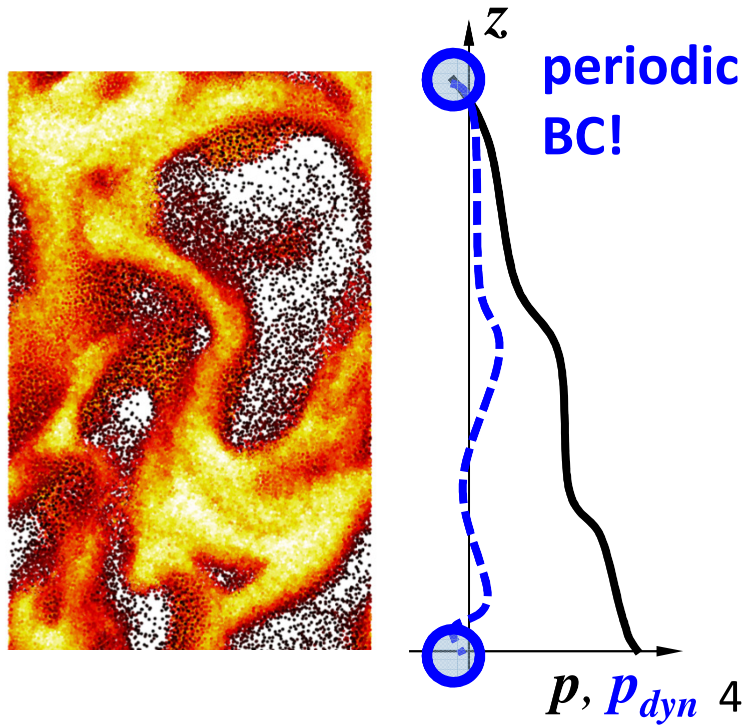
Momentum Balance Equation in a Periodic Box

$$\partial_t\left(\phi_f \rho_f \mathbf{u}_f\right) + \nabla\cdot\left(\phi_f \rho_f \mathbf{u}_f \mathbf{u}_f\right) = -\phi_f \cdot \nabla p - \nabla\cdot\left(\phi_f \cdot \boldsymbol{\tau}_f\right) + \phi_f \rho_f \mathbf{g} + \boldsymbol{\Phi}$$

$$\partial_t\left(\phi_f \rho_f \mathbf{u}_f\right) + \nabla\cdot\left(\phi_f \rho_f \mathbf{u}_f \mathbf{u}_f\right) = -\phi_f \cdot \nabla p_{dyn} - \nabla\cdot\left(\phi_f \cdot \boldsymbol{\tau}_f\right) + \phi_f\left(\rho_f - \rho_{mix}\right)\mathbf{g} + \boldsymbol{\Phi}$$

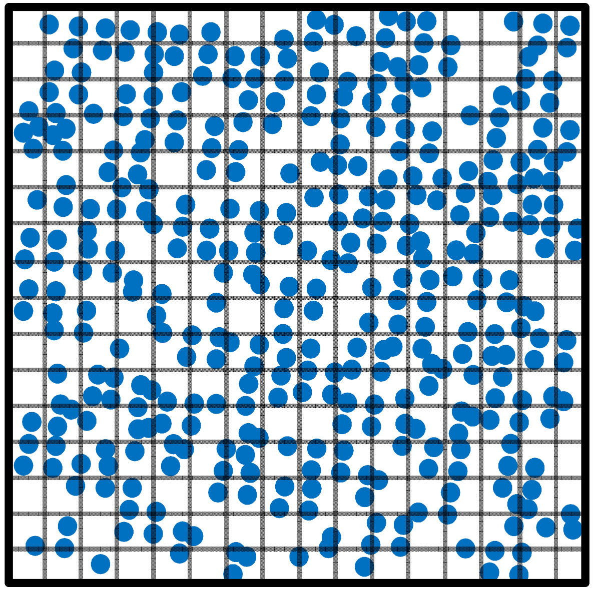
…pressure "as usual", but with different meaning!

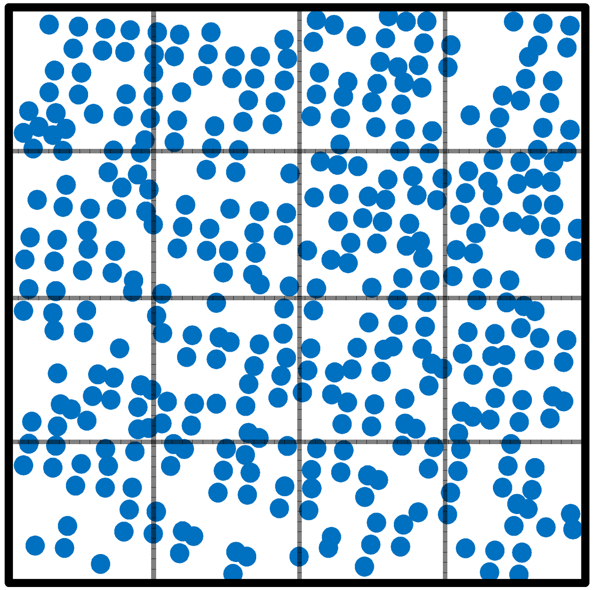
…treat as explicit term in the fluid's momentum balance equation



Drag Model Results (75µm)

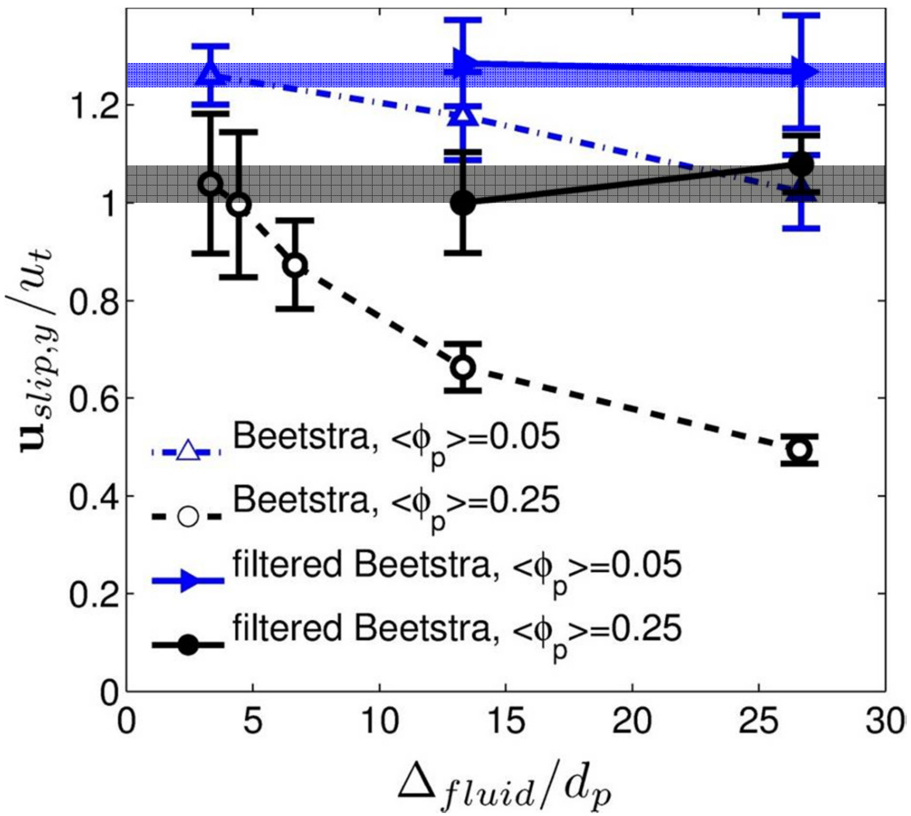
1. **CFD-DEM**
   - **Fine fluid grid**
   - Track **all the particles**
   - **Micro-scale** drag law
   - **Obtain filtered drag law**
2. **Coarse Grid CFD-DEM**
   - **Coarse fluid grid**
   - Track **all the particles**
   - **Use filtered drag law**





Drag Model Results (75µm)

Q: *Do **CFD-DEM** and **Coarse Grid CFD-DEM** yield the same results?*



- Large decrease of slip velocity if using **“microscopic”** drag law **(Beetstra; -53% for <ϕ_p>=0.25)**.
- Coarse Grid CFD-DEM with **filtered drag law** is within **+2% (<ϕ_p>=0.05)** and **±3.8% (<ϕ_p>=0.25)** of well-resolved CFD-DEM!

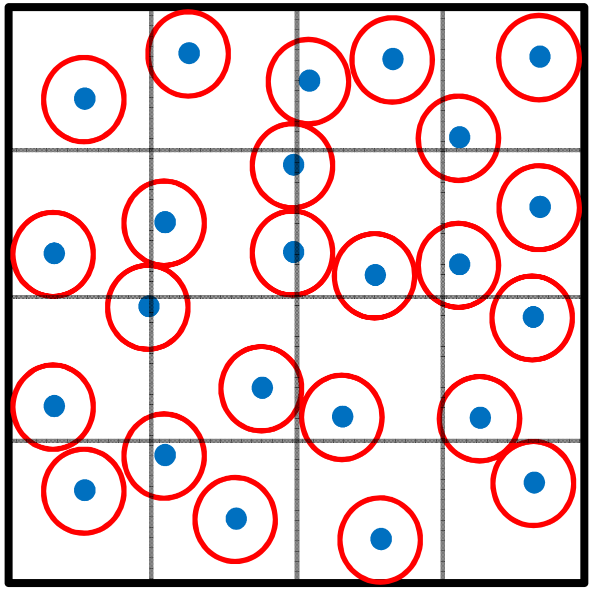
75 µm particles, 8 x 32 x 8 mm domain, 0.46M - 2.32M particles.

Drag Model Results (75μm)

3. CFD-DPM

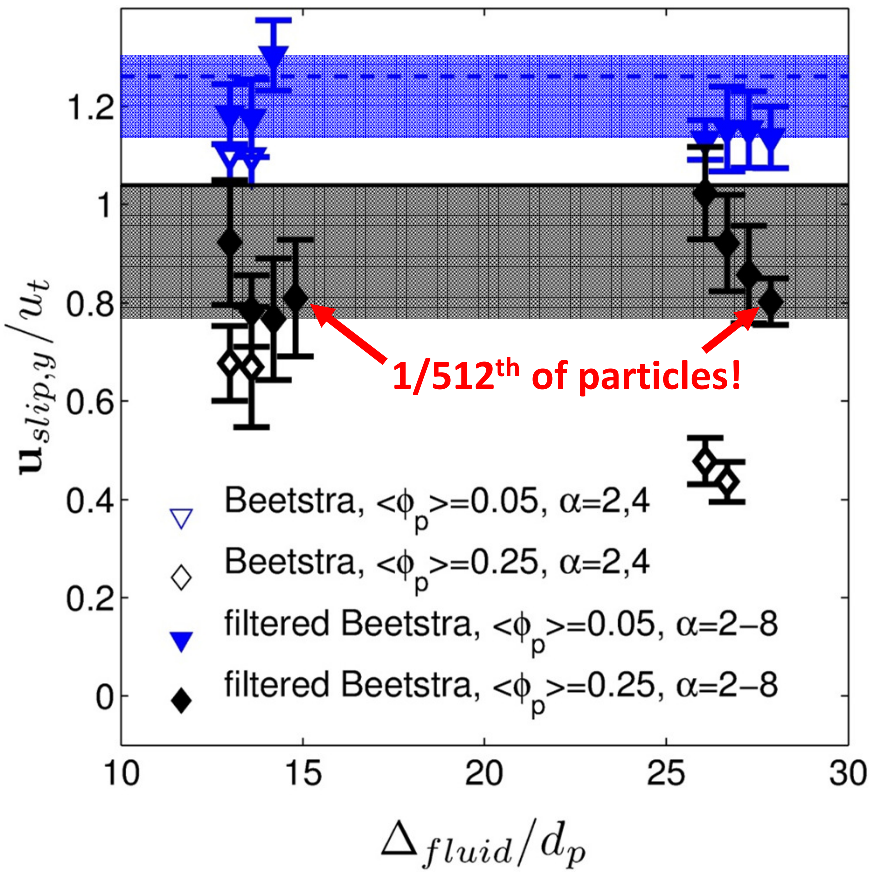
- **Use filtered drag law**
- **Coarse fluid grids**
- Track **parcels of size**

  $\boldsymbol{d_p = \alpha\, d_{prim}}$



Drag Model Results (75µm)

Q: Do **CFD-DEM** and **CFD-DPM** yield the same results?



- CFD-DPM with **"microscopic" drag law** significantly under-predicts slip **(-58% for <ϕ_p>=0.25)**.
- **Filtered drag law** improves results, but still significant under prediction: **-22% (<ϕ_p>=0.25)**
- Now, we introduce **a correction to account for parcel size effects**:

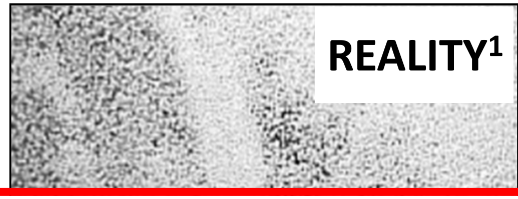
$$c_{corr} = \exp\left[-k\left(\alpha - 1\right)\right]$$

k = 0.05 (based on calibration)

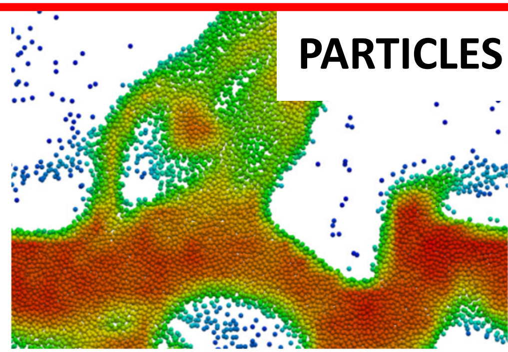
75 µm particles, 8 x 32 x 8 mm domain, 0.46M - 2.32M particles, pairs of symbols represent CFD-DPM result, horizontal lines are results of well-resolved CFD-DEM simulations.

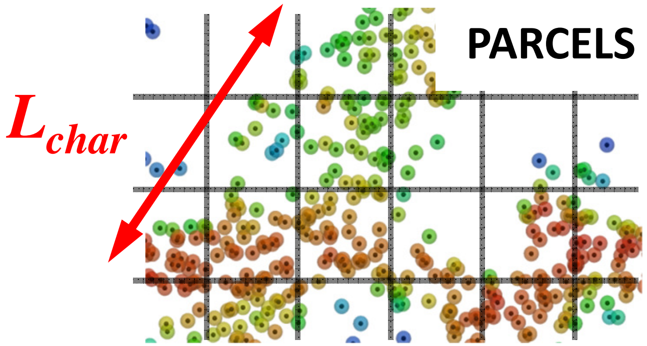
Outline

- **Motivation**
- **Simulation Setup**
- **Drag Model Results**
- **A Short Review of Important Length Scales**
  - ➢ **What is the effective force on an ensemble of particles?**
  - ➢ **What is the characteristic size of a particle cluster… …to make Δ_{fluid} dimensionless?**



$$\frac{\bar{\beta}_p}{\beta_{p,micro}} = c_{corr}(\alpha)\left[1 - f\left(\Delta_{fluid}, \bar{\phi}_p\right) h\left(\bar{\phi}_p\right)\right]$$

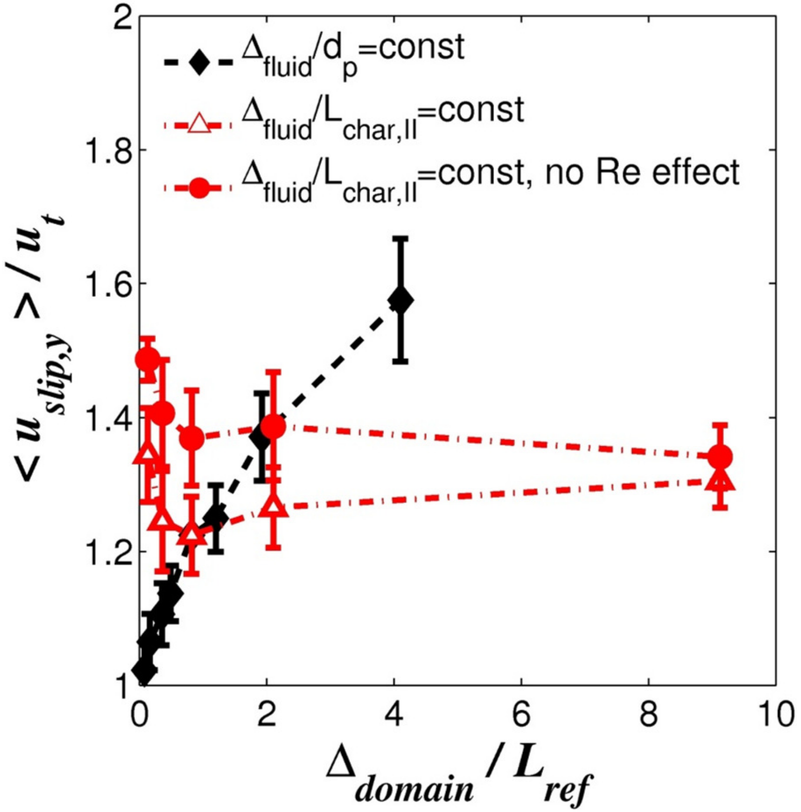




[1]Courtesy: Franklin Shaffer, NETL, Morgantown, WV (2009).

Drag Model Tests (CFD-DEM)

- Test 1: Use $\boldsymbol{d_p}$ **or** $L_{char,II} = u_t^2 / g \, Fr_p^{-2/3} = const$ and test sensitivity to $L_{ref} = u_t^2 / g$

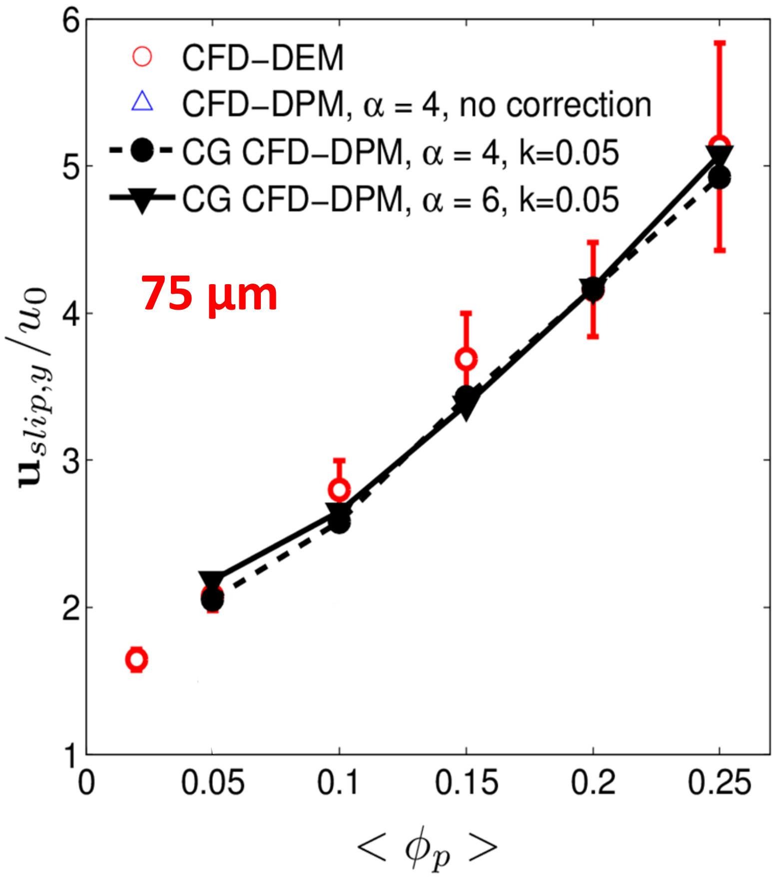


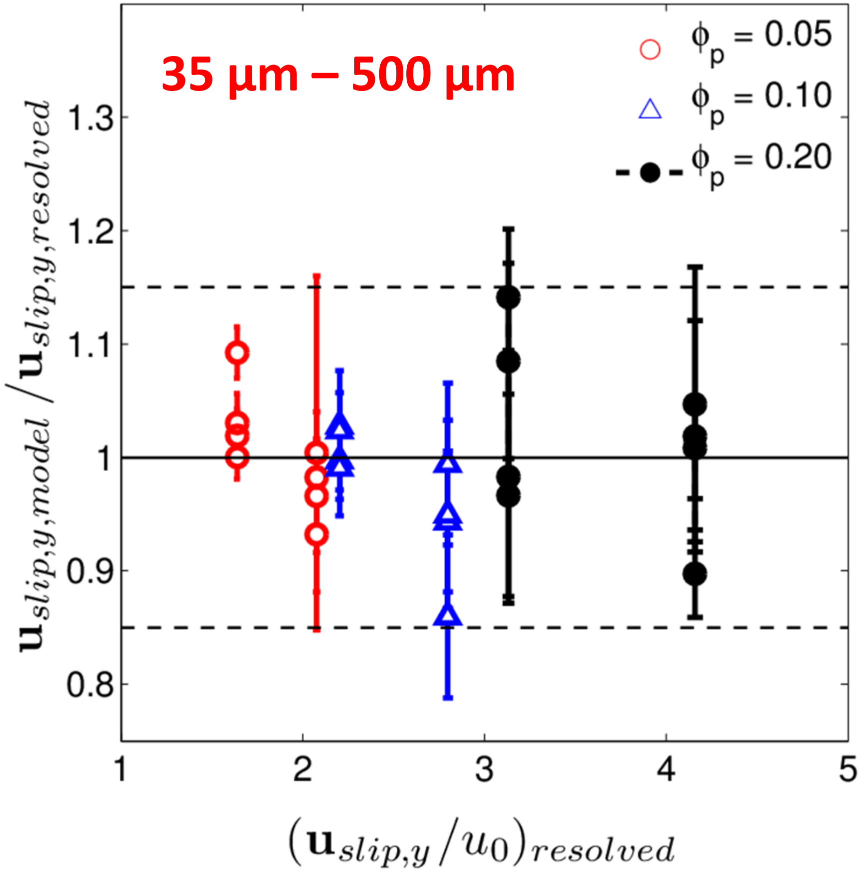
- $\boldsymbol{\Delta_{fluid}/d_p}$ **= const** **does NOT** yield results independent of L_{ref}. Same is true for $\boldsymbol{\Delta_{fluid}/d_p}$ **= const.**
- $\boldsymbol{\Delta_{fluid}/L_{char,II}}$ **= const** works much better! This is true with/without Reynolds number dependent drag.
- ***$L_{char,II}$ seems to be a useful reference length – WHY?***

Domain-averaged slip velocity for constant $L_{char,II}$, and variation of particle diameter & density ($<\phi_p>$ = 0.05).

Drag Model Tests

- Test 2: Use $L_{char,II} = u_t^2 / g\, Fr_p^{-2/3} = const$ and test sensitivity to d_{prim} and d_p for **various <ϕ_p>**





Review of Length Scales

Inspiration from Continuum-Based Theory

- Particle-Phase Momentum Balance*

$$\rho_p u_t^{\,2}\left[\frac{1}{u_t}\partial_t(\phi_p \mathbf{u}_p^*) + \nabla\cdot\left(\phi_p \mathbf{u}_p^* \mathbf{u}_p^*\right)\right] = -\nabla\cdot\boldsymbol{\sigma}_p - \phi_p \nabla\cdot\boldsymbol{\sigma}_g + \beta u_t \mathbf{u}_{slip}^* + \rho_p \phi_p g \mathbf{g}^*$$

- ***Estimate*** for the ***granular temperature*** (shear production vs. dissipation)

$$\sqrt{T} \approx \frac{d_p}{L_{visc,II}} u_t$$

- A length scale based on the balance of ***viscous particle stress & gravity*** is:

$$L_{visc,II}^{\;3}\mathbf{g}^* = \left(\frac{u_t^{\,2}}{g}\right)^3 \left(\frac{d_p g}{u_t^{\,2}}\right)^2 \frac{1}{\phi_p} \cdot \nabla^* \cdot \left[2C_{KT} F_{diss}^{\;*}\left(\nabla^* \mathbf{u}_p^* + \nabla \mathbf{u}_p^{*\,T}\right)\right]$$

n = -2/3

*with some obvious scalings, however, still **no specification of a length scale**.

Summary

- The advanced drag model takes the effect of **grid resolution, parcels size, local particle concentration and particle properties into account.** It is valid for flow situations **far away from walls**.
- For the smallest **length relevant for particle clustering,** our simulations suggest (tested for Re_p = O(1)…O(100)):

$$L_{char,II} = \frac{u_t^{\ 2}}{g} Fr_p^{\ -2/3}$$

- $L_{char,II}$ appears to be the key **reference length scale for the fluid grid size in coarse-grid simulations,** in case **particle inertia is not that important (compared to ρ_pT)**.

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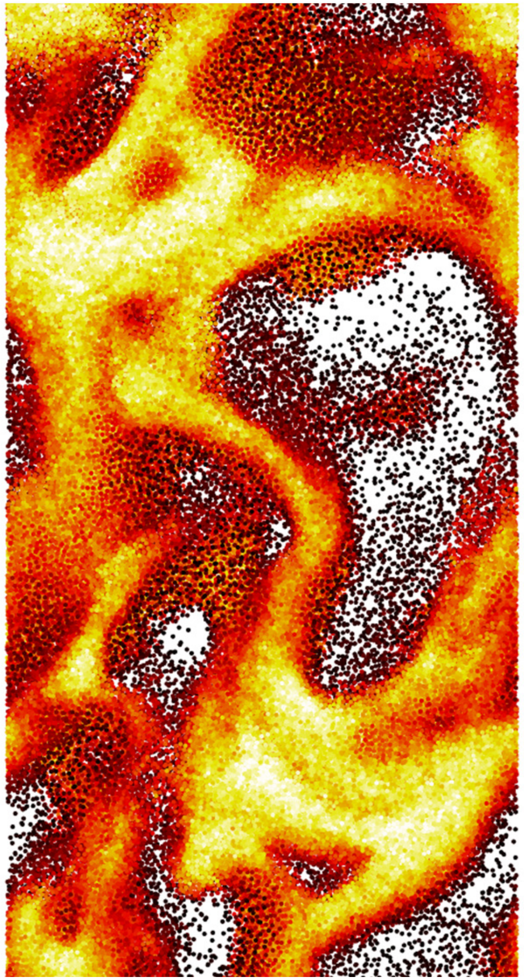

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