DNS of Suspensions of Rigid Particles with Feedback

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Flows of Interest

- Channel flows containing suspensions of solid particles in air: density ratio=1000
- Particle diameters < Kolmogorov scale
- Particle feedback on gas modeled by point forces
- Efficient collision algorithm for small particles
- Only binary particle collisions are considered
- In some cases, the disturbance flows created by particles are considered (“6-way coupling”)
- Particle mass loadings: 0, 20%, 40%

- Particle equation of motion includes drag and lift
- Particle collisions handled with Chen et al. (1998) algorithm
- Particle feedback on the gas phase is modeled by imposing a reaction force
- 1-way coupling: ignore effect of particles on fluid
- 2-way coupling": particle feedback on fluid
- 4-way coupling: two-way coupling + particle-particle collisions
- 6-way coupling: particle disturbance flows included

DNS Methods

- Turbulent channel flow for moderate concentrations of small particles is simulated with a pseudospectral method. (Nasr et al., JFM 2009)
- The fluid velocity field is computed with a pseudospectral code that uses a splitting method (McLaughlin, Phys. Fluids 1989).

Turbulent Channel Flow

- 3-d turbulent shear flow
- channel width = 250 wall ("+") units = 2.5 cm
- periodic b.c.'s in streamwise and spanwise
- streamwise period = 1260 wall units
- spanwise period = 630 wall units
- 64x65x64 grid (Chebyshev collocation pts in y)
- Some simulations were performed for a downstream period = 630 wall units
- Re~8000 based on hydraulic diameter

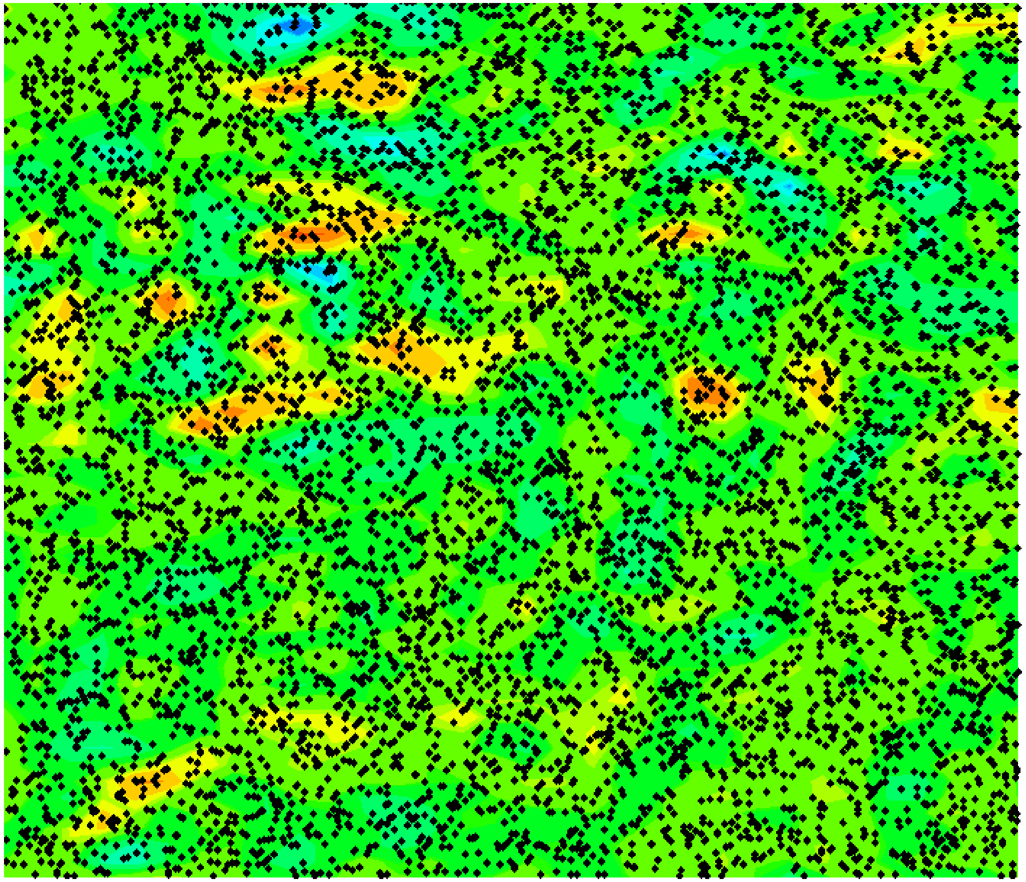
Particle Trajectory Calculations

- Gravity is neglected (vertical flow, small particles)
- Nonlinear drag and lift forces are included
- The time steps used in particle calculations are smaller than the time step used for fluid velocity field calculation.
- Only binary particle collisions are considered.
- Particles are assumed to deposit when they reach a wall and a “new” particle is randomly introduced into the flow.
- In some cases, an aerodynamic interaction force was included but found to be unimportant.

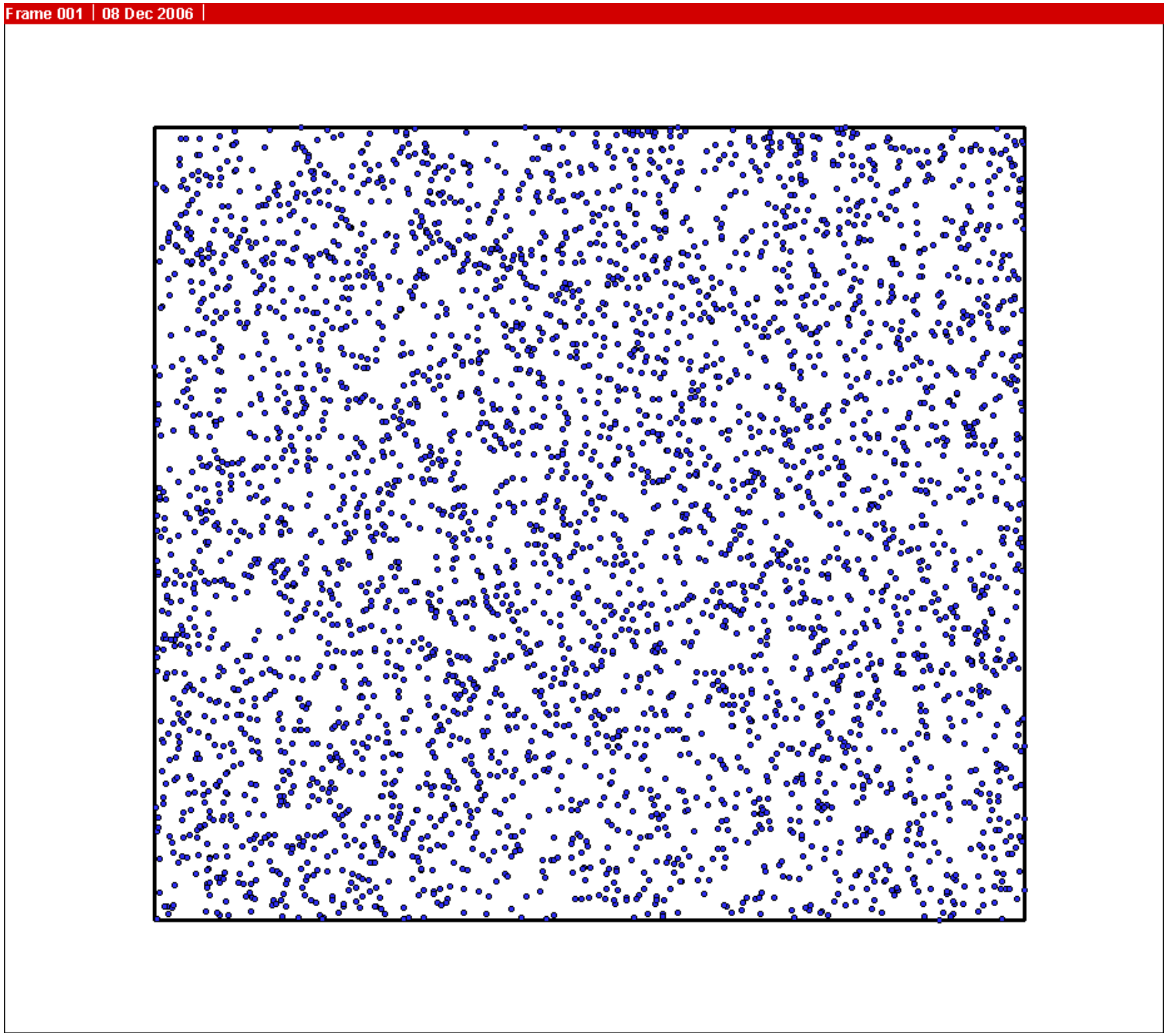
Particle Parameters

- Particle mass loadings = 0, 0.2, 0.4
- Particle-air density ratio = 1000
- Particle diameter = 25 or 30 microns
- Fluid: air at 288 K, density = 1.2 kg/m^3
- Coefficient of restitution for particle-particle collisions = 0.95
- As many as 1.2 million particles were used in one simulation

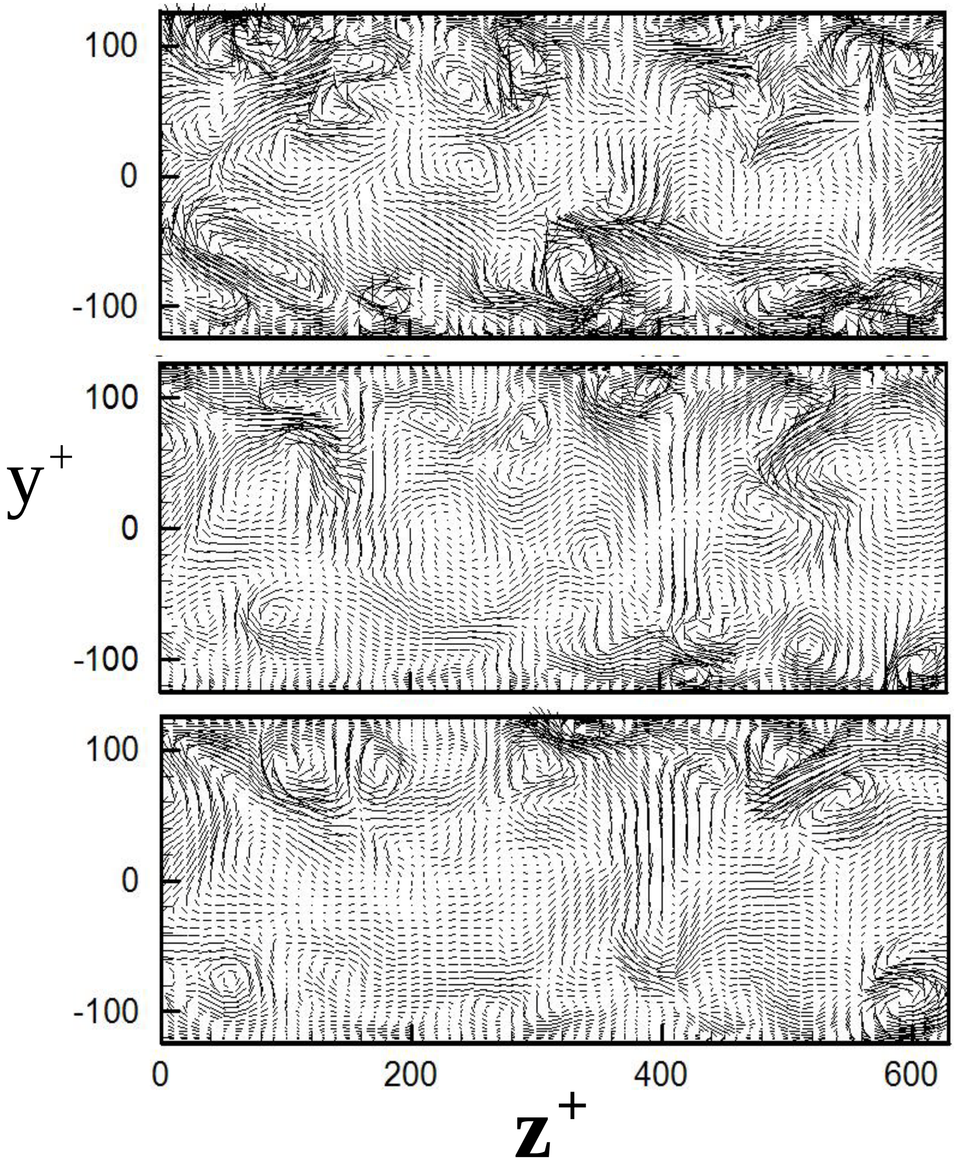
Channel Center Plane



Particles Near Wall



Effect of Particle Feedback on Flow



One-way coupling

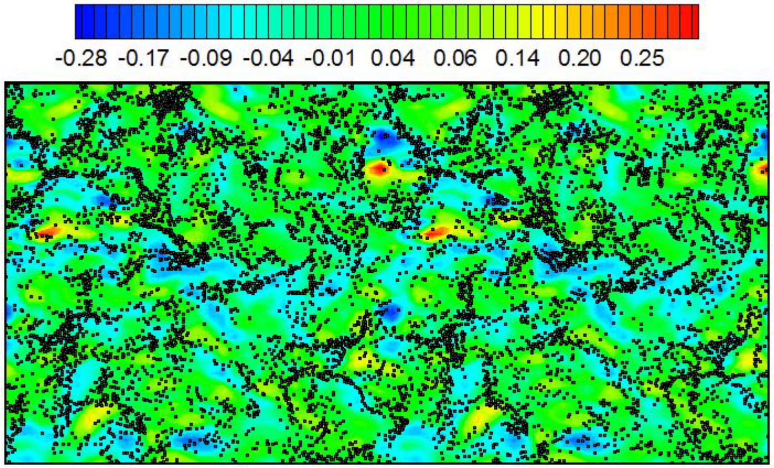
Four-way coupling, M.L.=20%

Four-way coupling, M.L.=40%

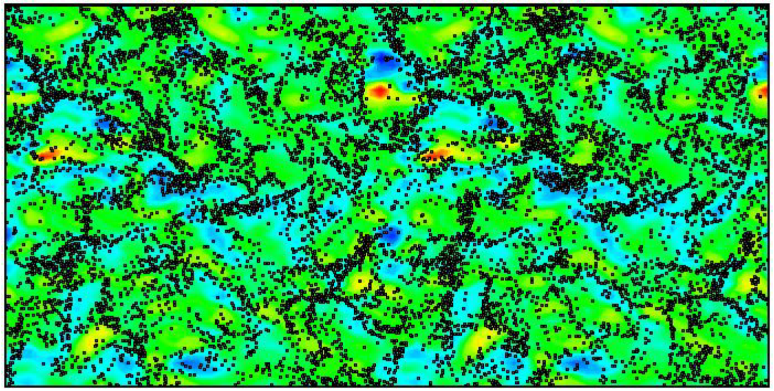
Particle Distribution at The Channel Center-Plane

$\tau^{+} = 20.0$ $\qquad$ M.L. = 40%

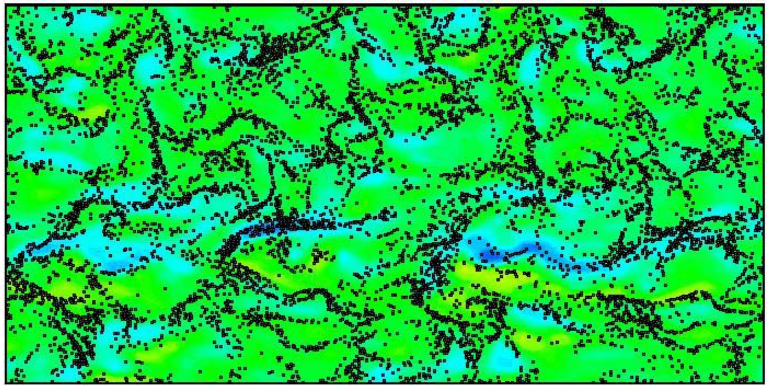
One-way



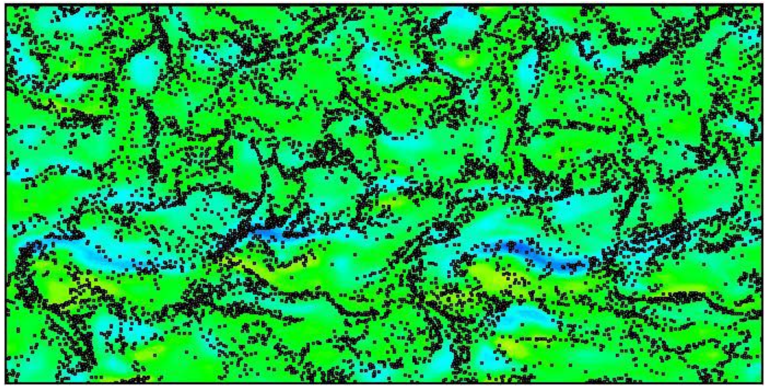
Collisions only



Two-way



Four-way



Particle Distribution in the Wall Region

$\tau^{+} = 20.0$ M.L. $= 40\%$ $y^{+} = 10$

One-way

Collisions Only

Two-way

Four-way

Summary

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- Particle feedback weakens the fluid turbulent fluctuations.
- Particle-particle collisions increase the particle Re, but two-way coupling reduces it.
- 4-way coupling reduces the particle Re.
- 4-way coupling reduces the RMS particle normal vel. for y+>10, but increases it for y+<10.
- 2-way coupling decreases particle deposition, but particle collisions increase it.
- 4-way coupling increases particle deposition.
- 2-way coupling and collisions both reduce particle concentration near the walls.

Reference

Nasr et al., Journal of Fluid Mechanics, volume 640, pp. 507-536 (2009)