LES OF JETS WITH EMBEDDED VORTICES IMPINGING ON A FLAT SURFACE

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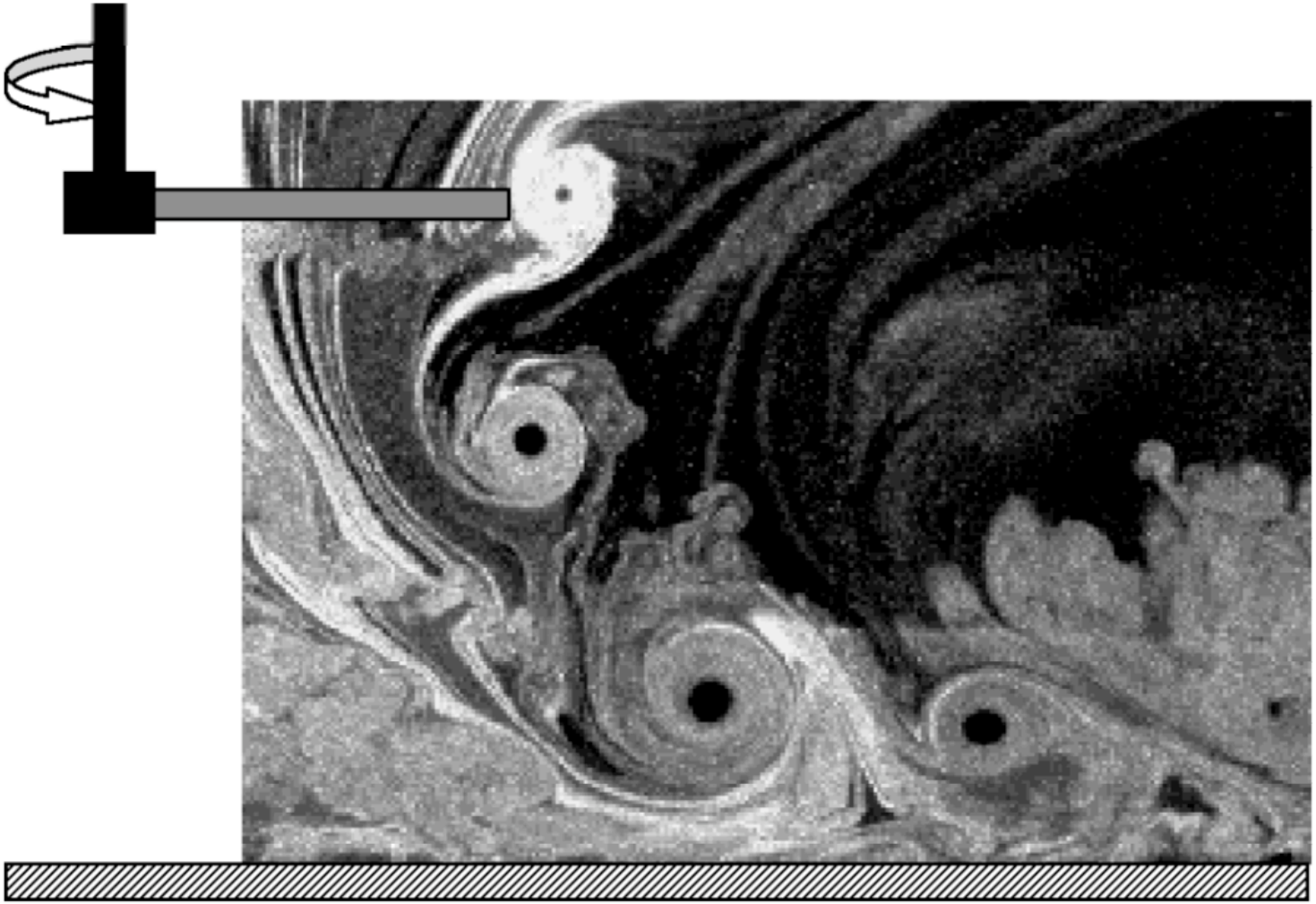
Motivation

- Impinging jets occur in
  - *Heat transfer applications*
  - *Meteorology (downdrafts)*
  - *Helicopter aerodynamics*

Motivation



From T. Lee, J. G. Leishman, and M. Ramasamy, (2008)

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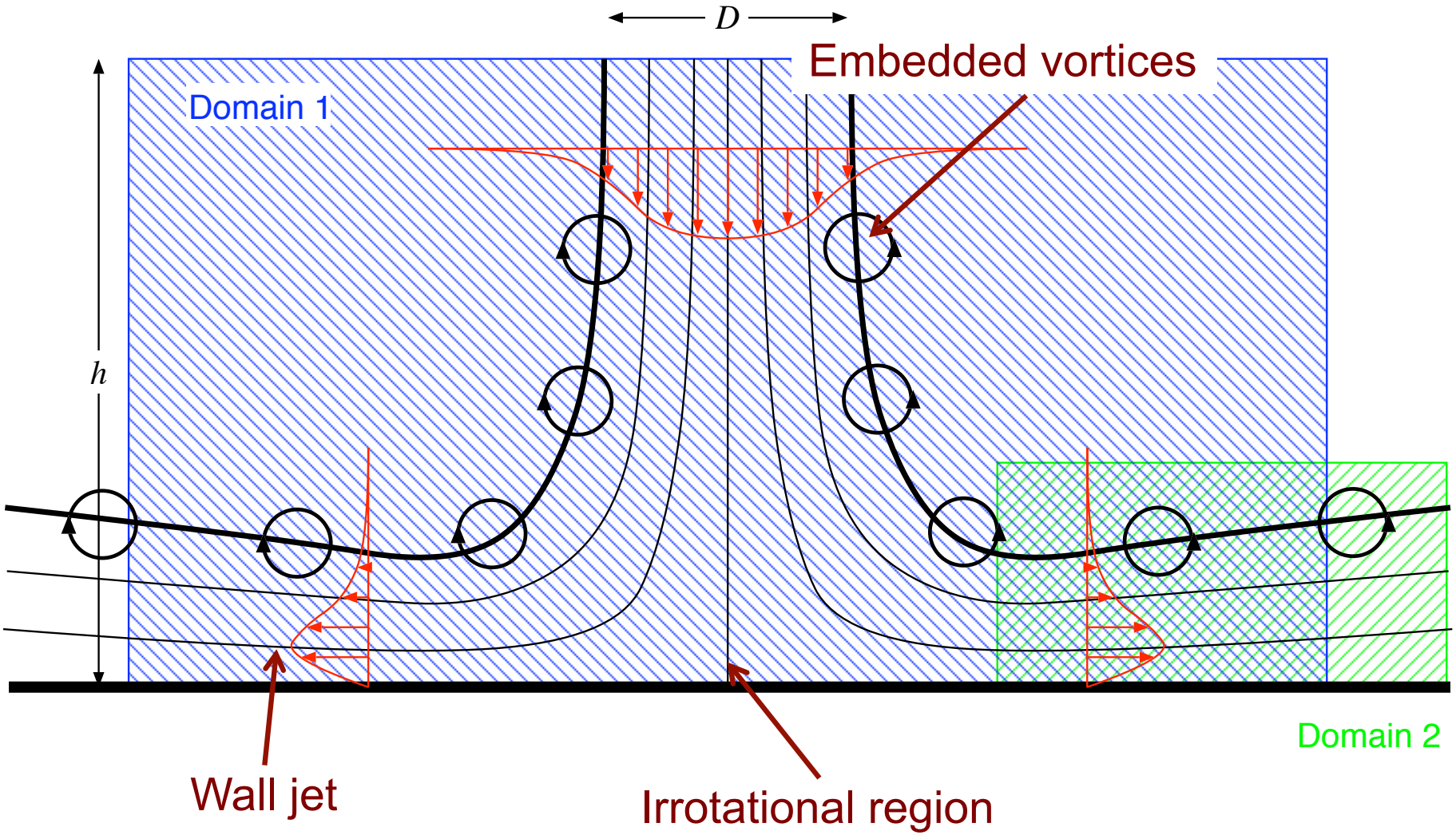
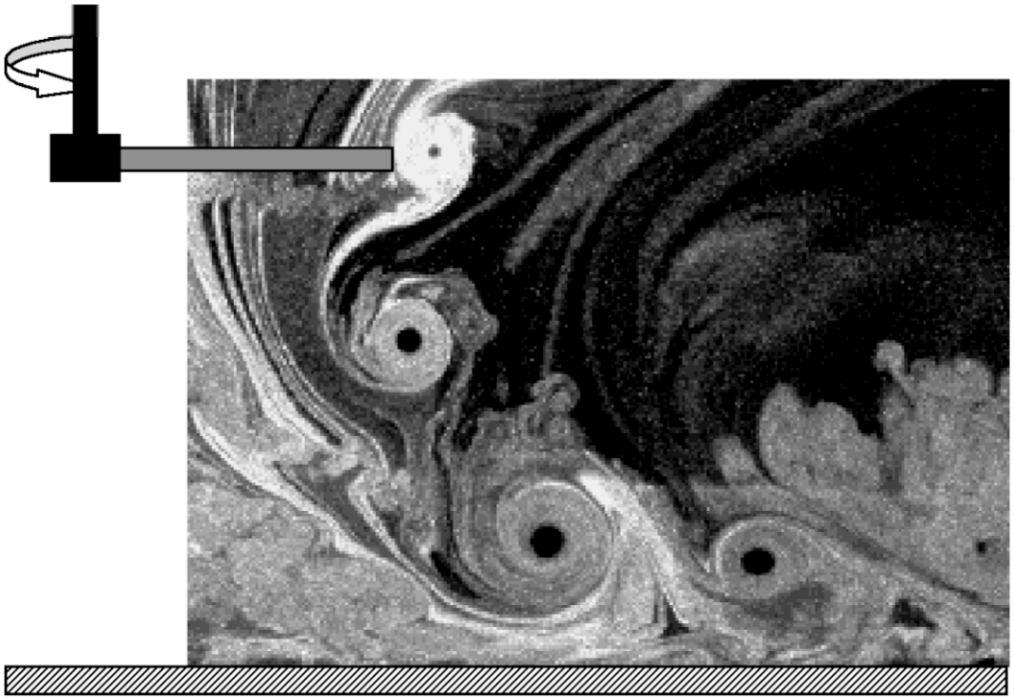

D
Embedded vortices
Domain 1
h
Domain 2
Wall jet
Irrotational region

Motivation

- The interaction of the vortices with the ground
  - *Changes the turbulent flow field near the wall.*
  - *Results in the development of secondary vortices, which interact with the primary ones*
  - *Changes the vortex development and decay.*
  - *May result in particle lifting and suspension.*



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- It is important to develop models that relate the impinging jet (i.e., rotor wake) and vortex characteristics to the particle dynamics.
  - *Existing models are usually inviscid (vortex line)*

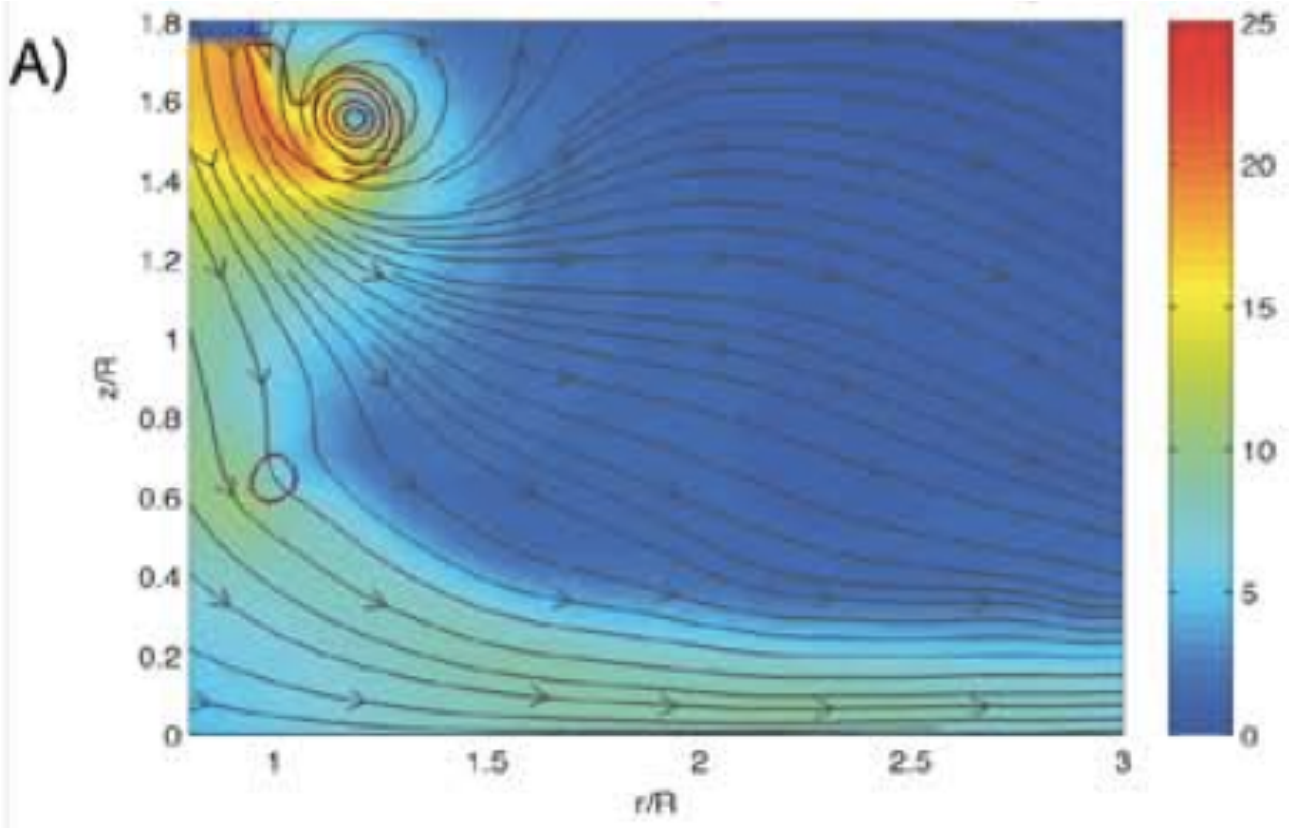
Objectives

- Study the interaction between the vortices and the near-wall turbulence.
- Quantify the vortex decay in a turbulent wall-bounded flow
- Improve the understanding of the particle liftup and transport in impinging and wall jets.

- Develop correlations that can be included in inviscid models to account for both viscous and turbulent effects.

Benchmark test case

- Experiment from UMd:
  - *Round jet near a flat surface*
  - *Periodic excitation generates arrays of toroidal vortices that are advected towards the wall and outwards.*



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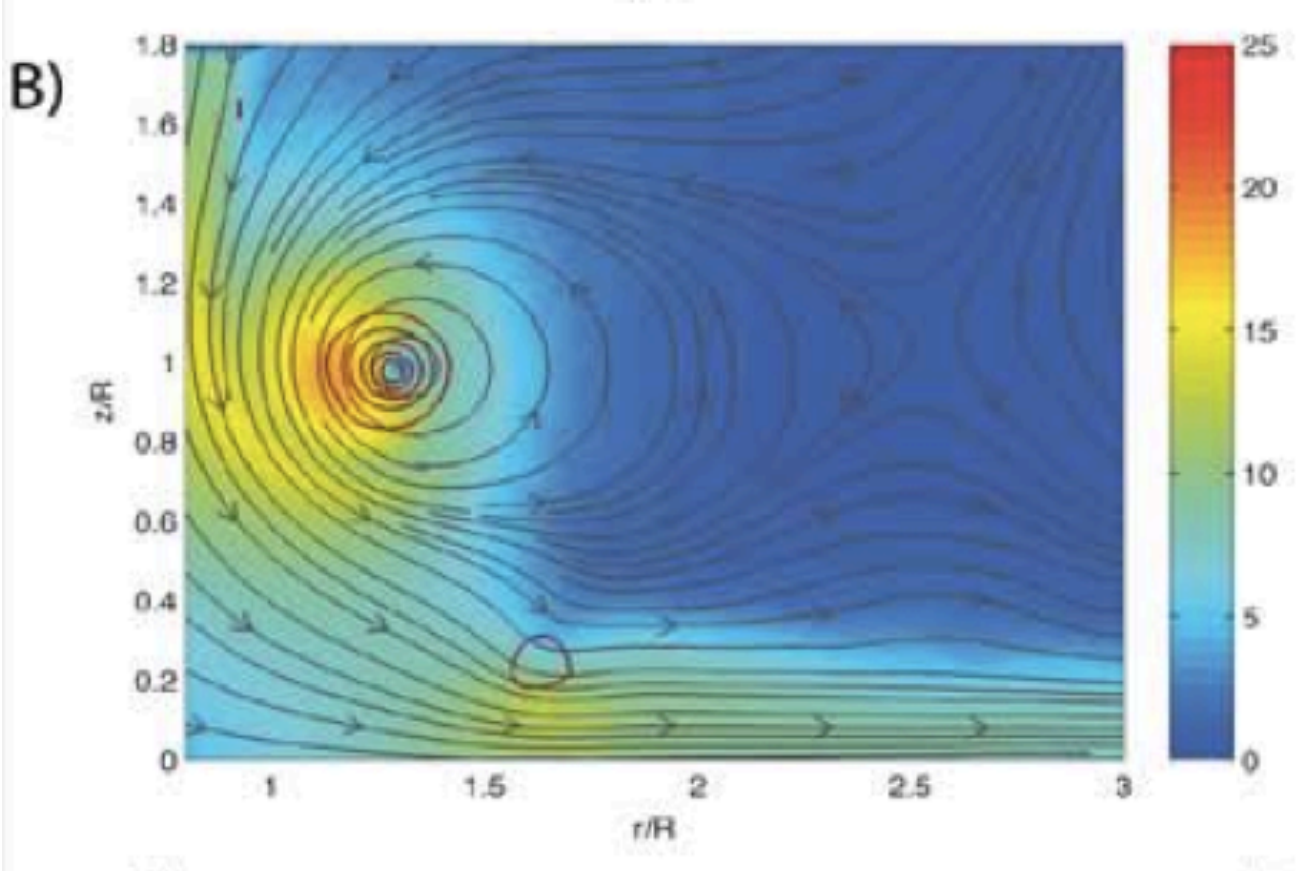

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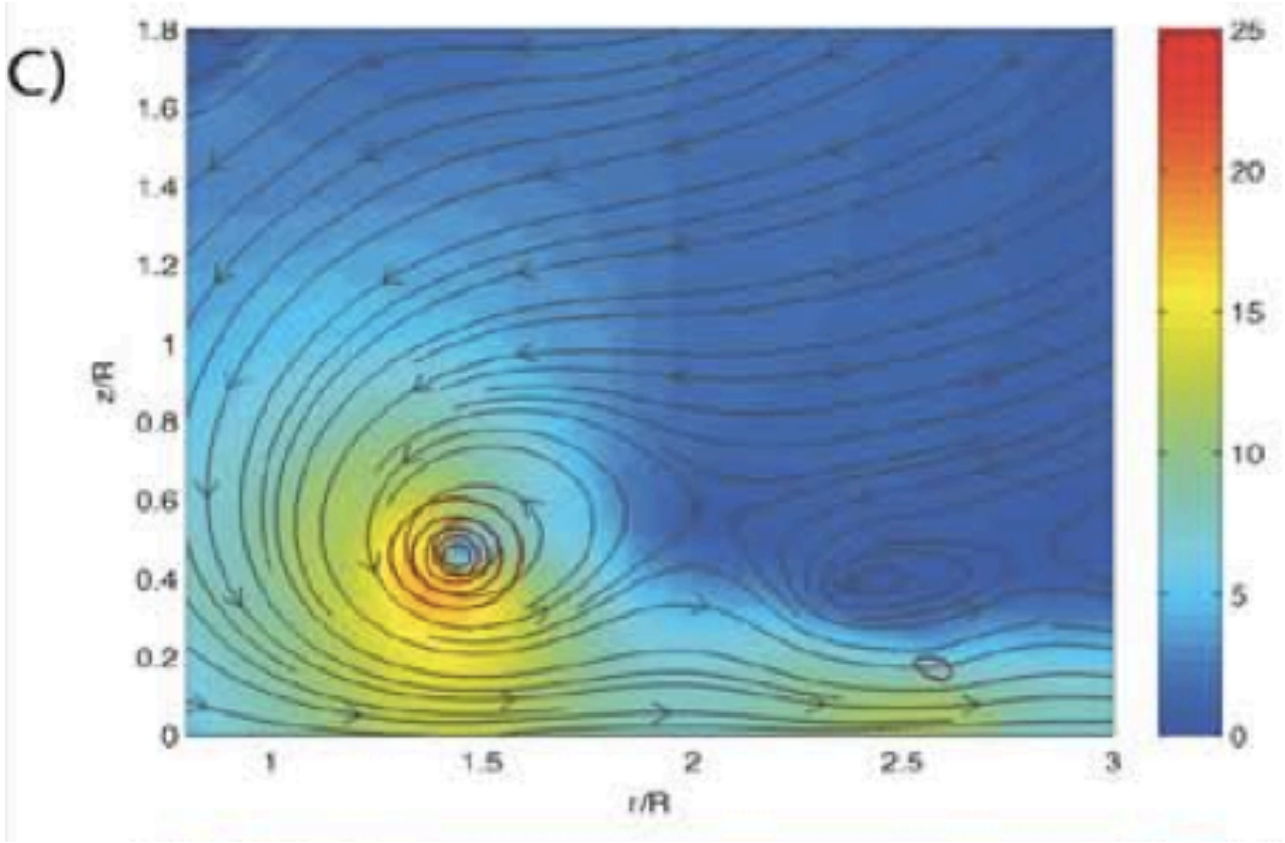

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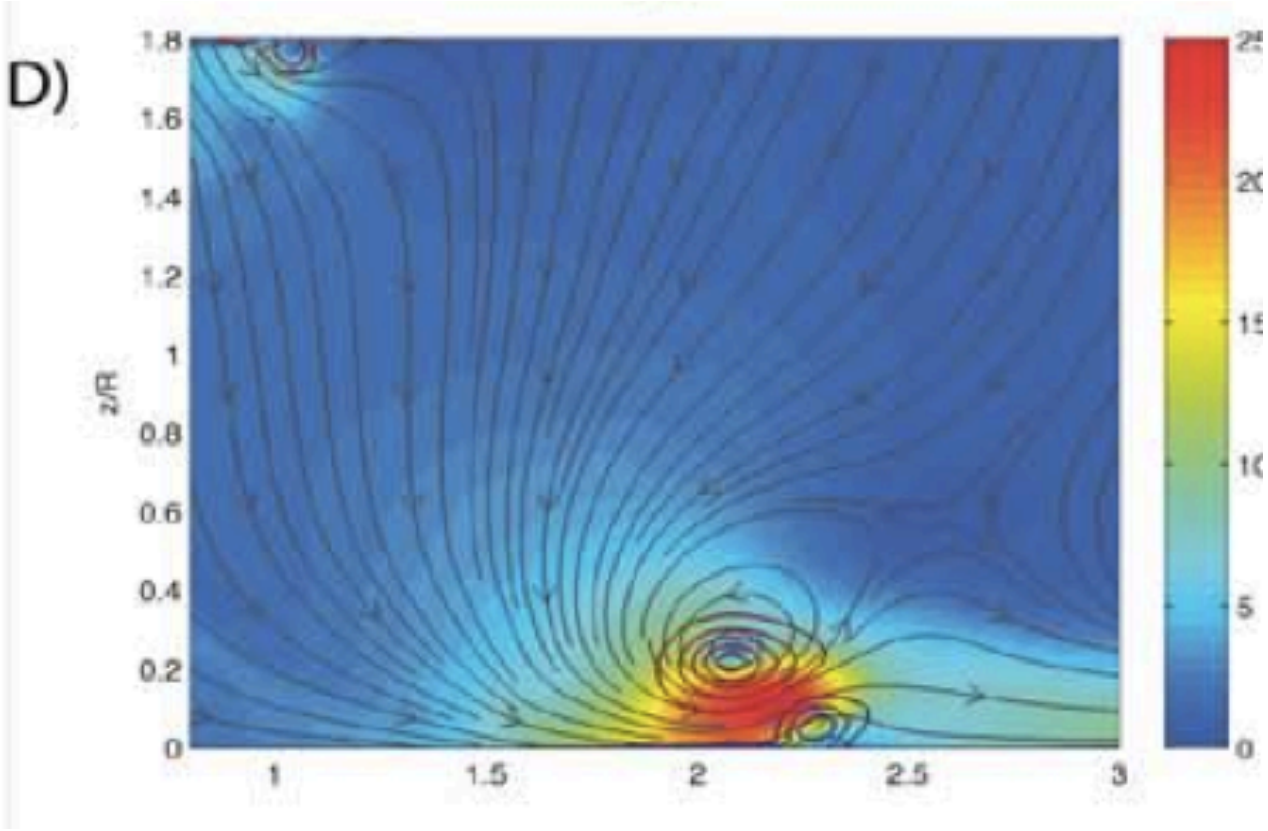

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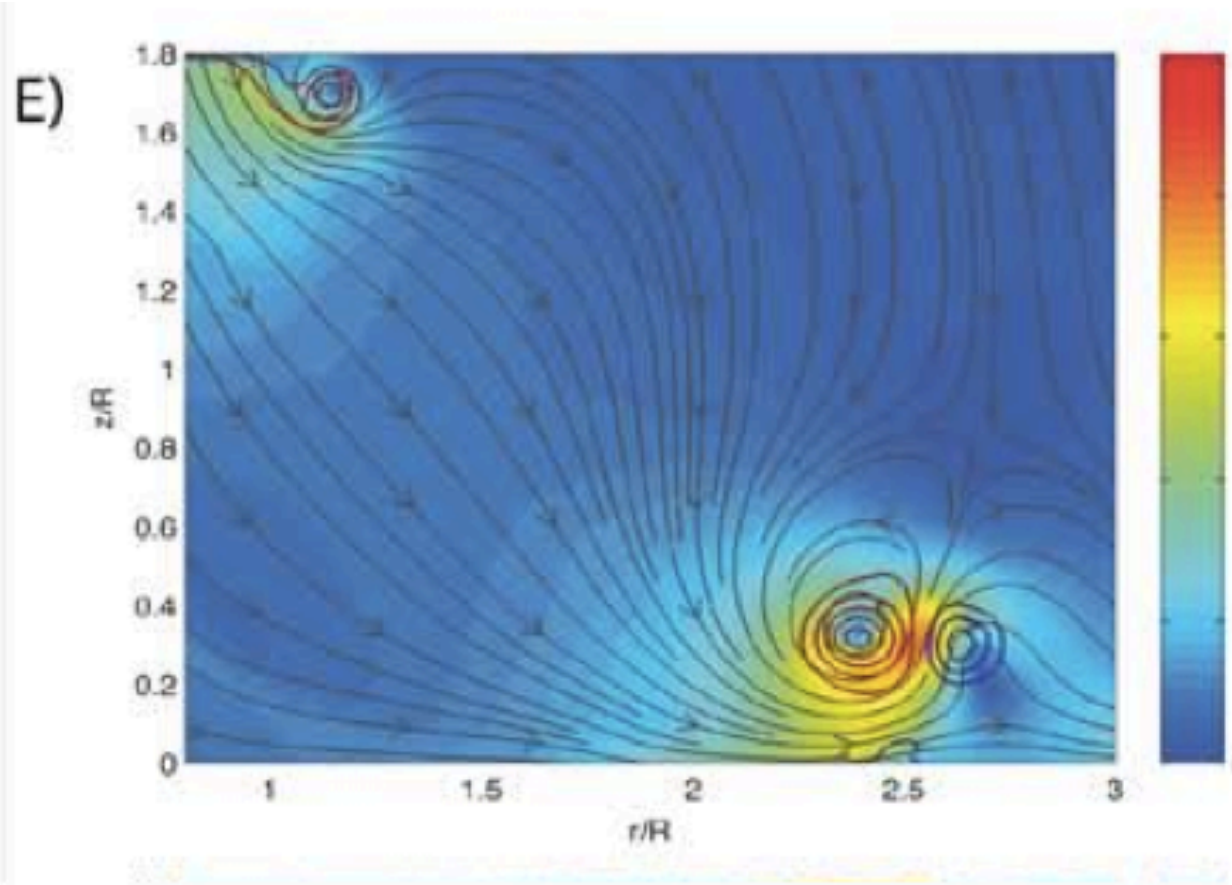
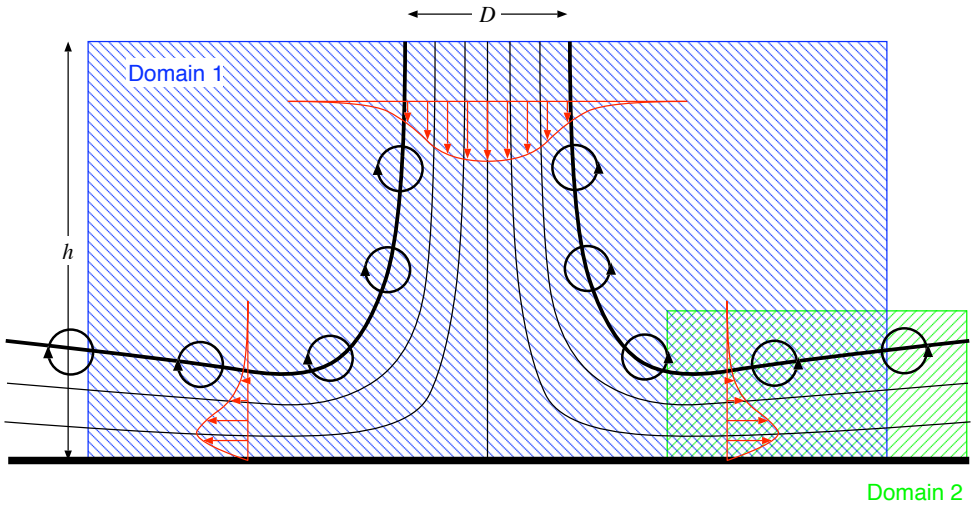


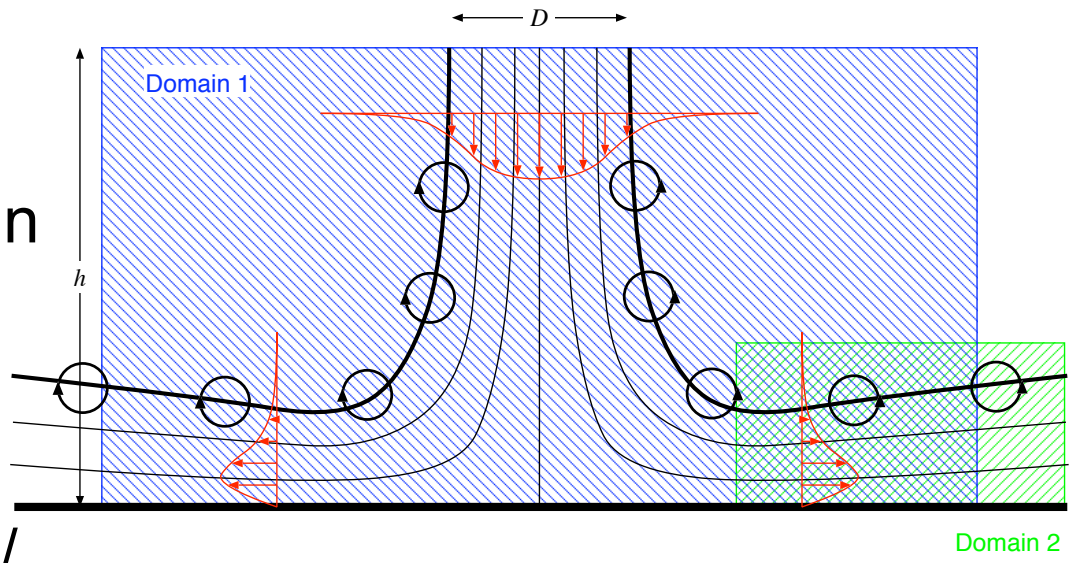
Methodology



- Ingredients:
  - *Impinging jet*
  - *Vortex generation*
  - *Wall jet*
  - *High Reynolds-numbers*

Methodology

- Perform numerical simulations of vortex/ boundary layer interactions in increasingly realistic configurations.
- Estimate the effect of the viscous and turbulent vortex/ ground interactions
  - *Include sediment transport model to account for dust uplift and motion.*
- Develop improvements for vortex filament models.



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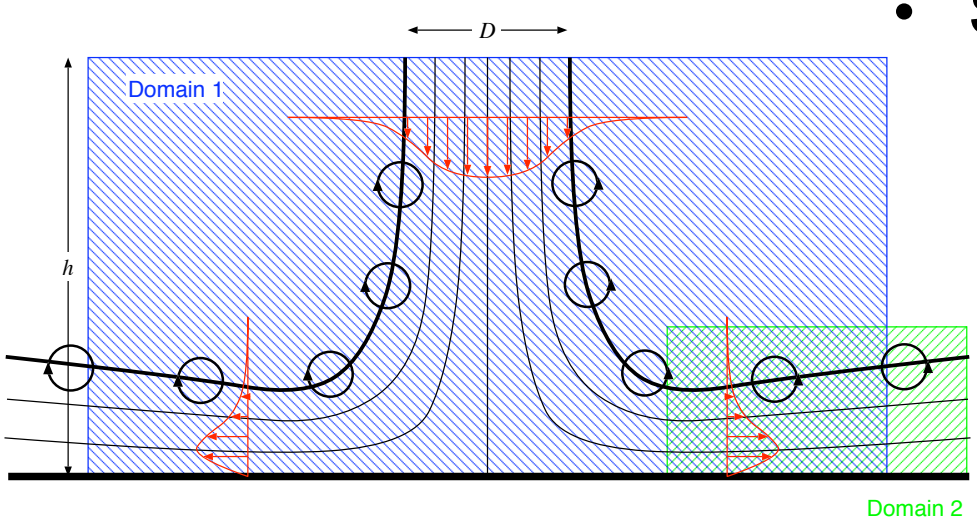

- Ingredients:
  - *Vortex generation*
  - *Impinging jet*
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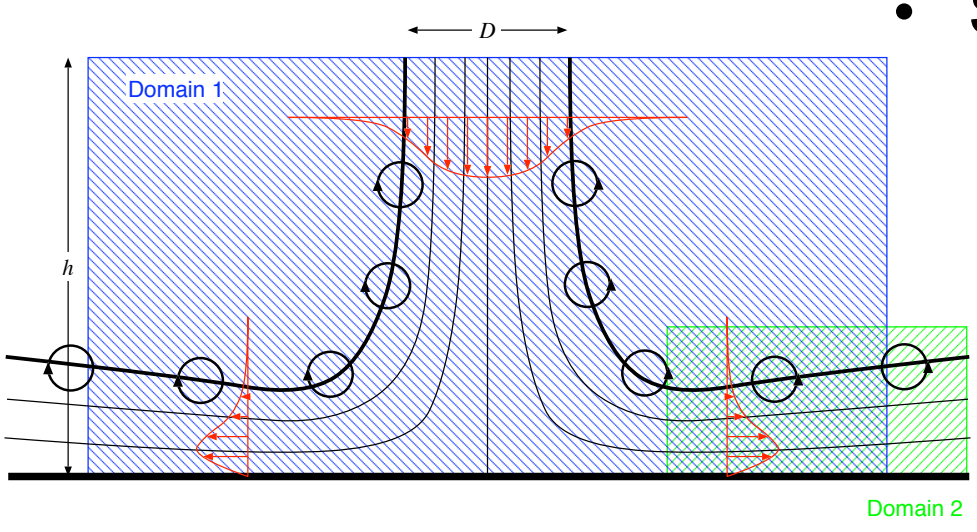
- Strategy:
  - *Develop a vortex-generation method that is*
    - Non-intrusive, Controllable
  - *Use LES or exp. data for the impinging jet to provide b.c. for the interaction region*
  - *Simulate increasingly realistic configurations*
    - 2D impingement
    - Axisymmetric impingement
    - Axisymmetric wall jet
  - *Perform hierarchical model validation:*
    - DNS to validate LES
    - LES to validate Hybrid RANS
    - LES models for high Re.
  - *Extend to high Re*

Methodology



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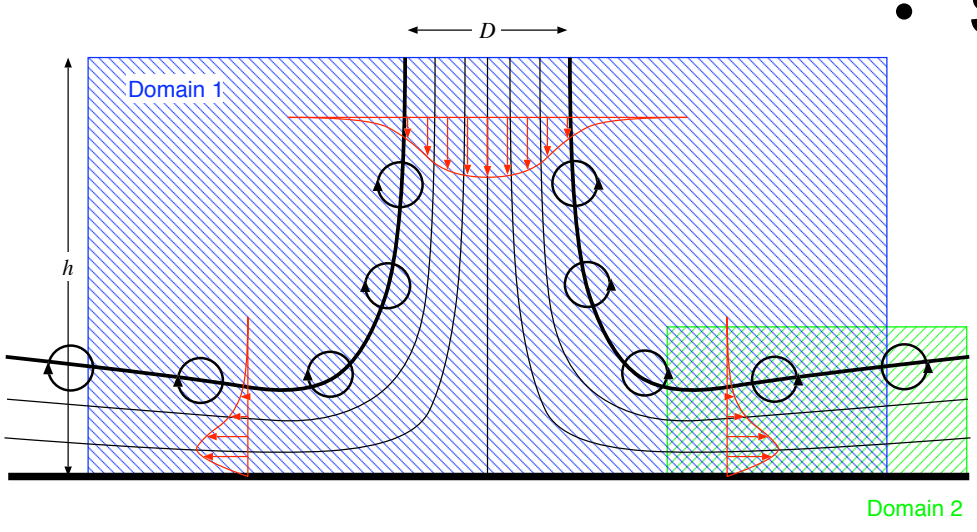

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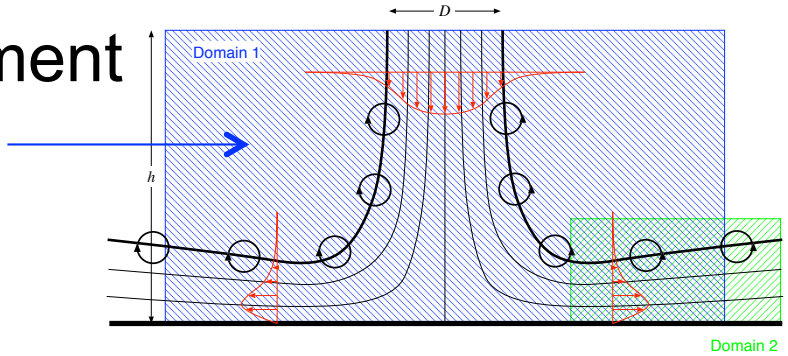
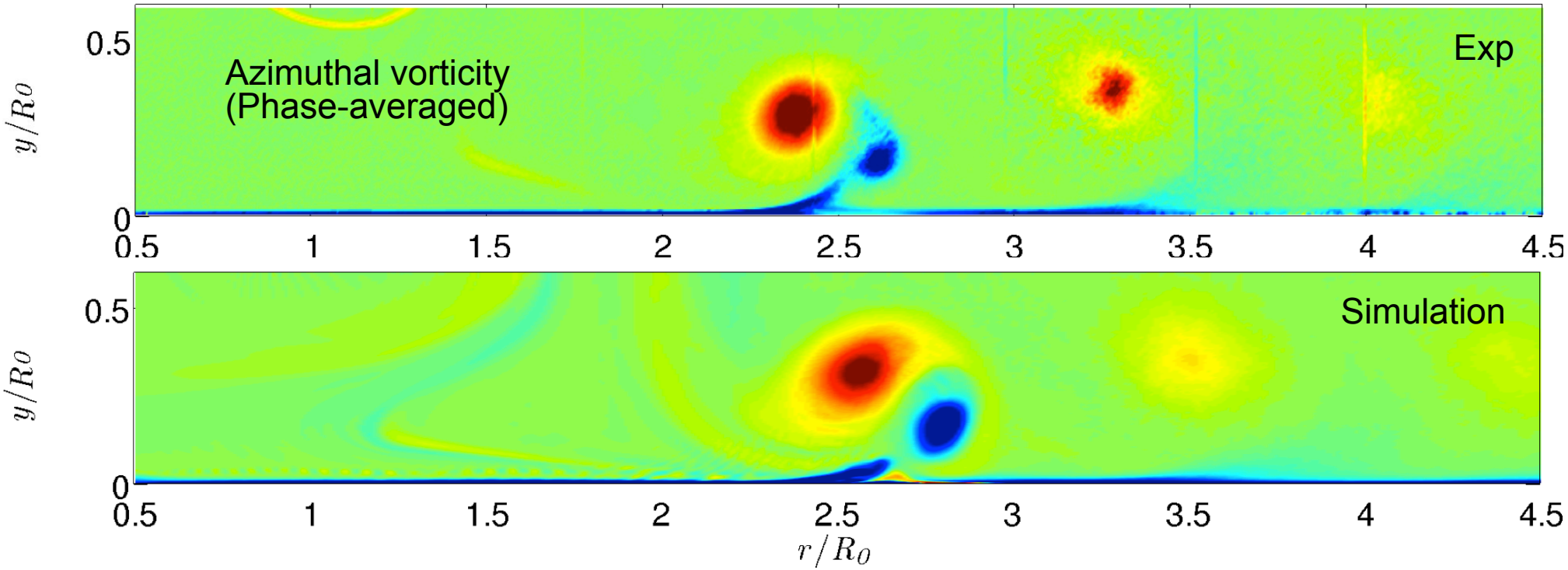
Achievements to date

- Development of vortex generation method
  - *Initial tests in boundary layers*
- Calculation of vortex/bl interaction in the impingement region
  - *2D*
  - *Axisymmetric*
- Matching benchmark validation case:
  - *Experiment from UMd. (ongoing)*
- Initial calculations of the wall-jet region
  - *Effect of roughness*

Impinging jet

- Configuration similar to UMD experiment
  - $Re = U_{jet} D_{jet} / \nu = 66{,}000$
  - $768 \times 500 \times 256$ *grid points*
  - *DNS-like resolution*
- Periodic forcing at jet exit
  - *Stronger than experiment*
- Good qualitative, fair quantitative agreement.





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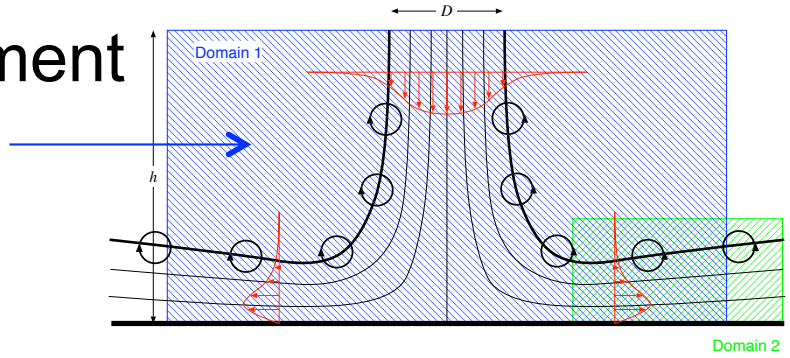
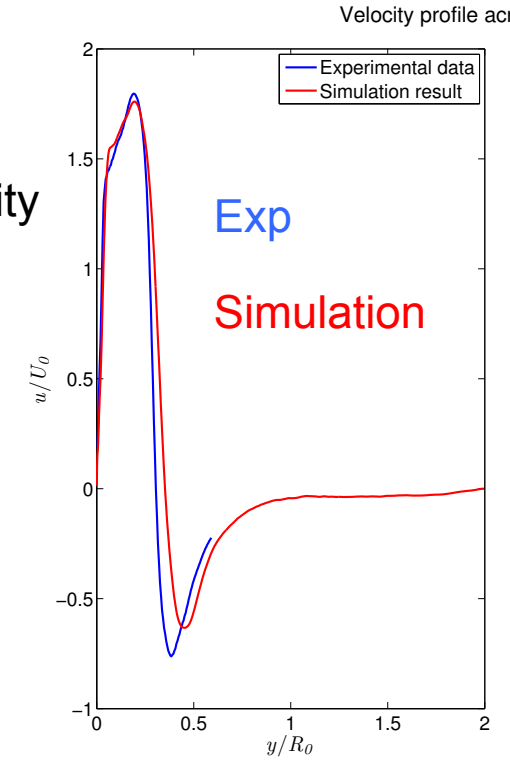
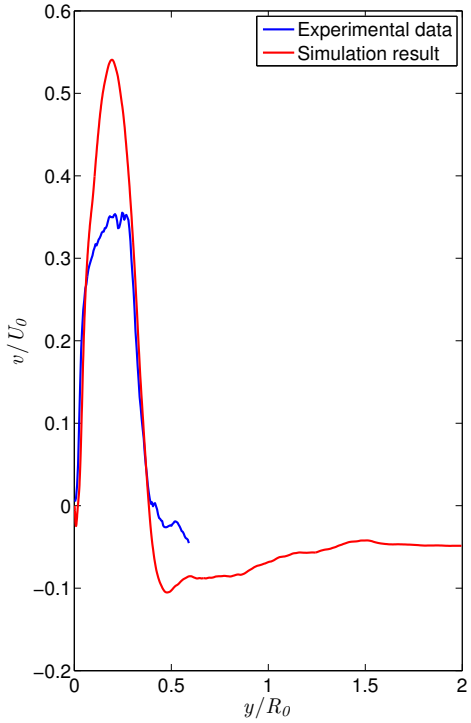


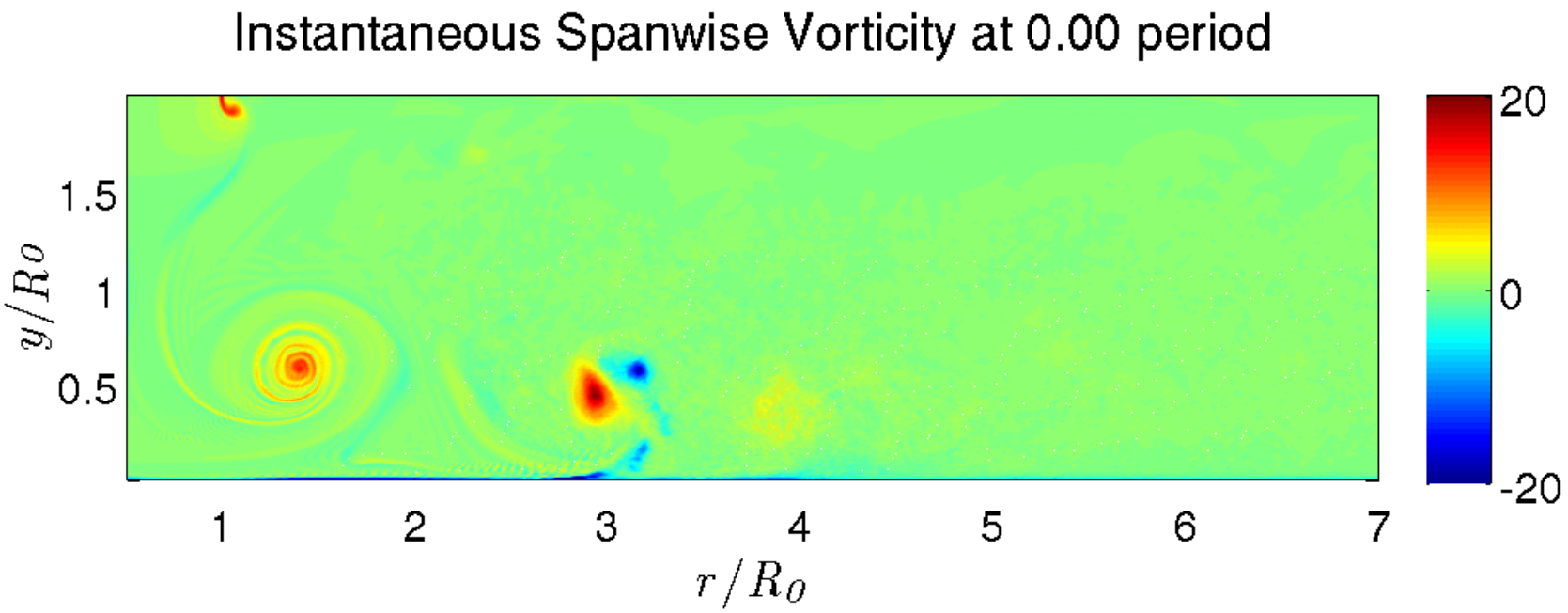
Radial velocity





Wall-normal velocity

Impinging jet: Azimuthal Vorticity



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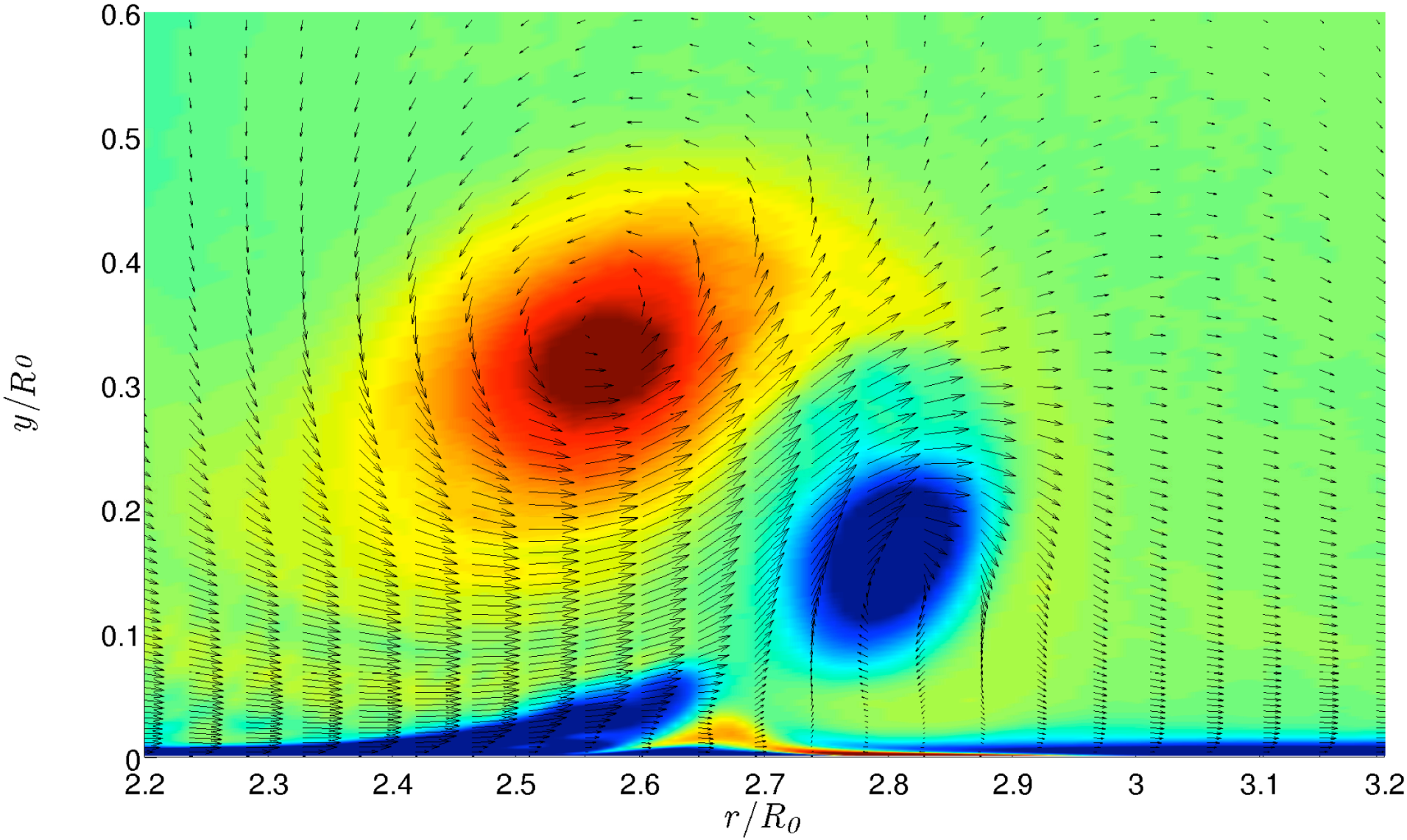
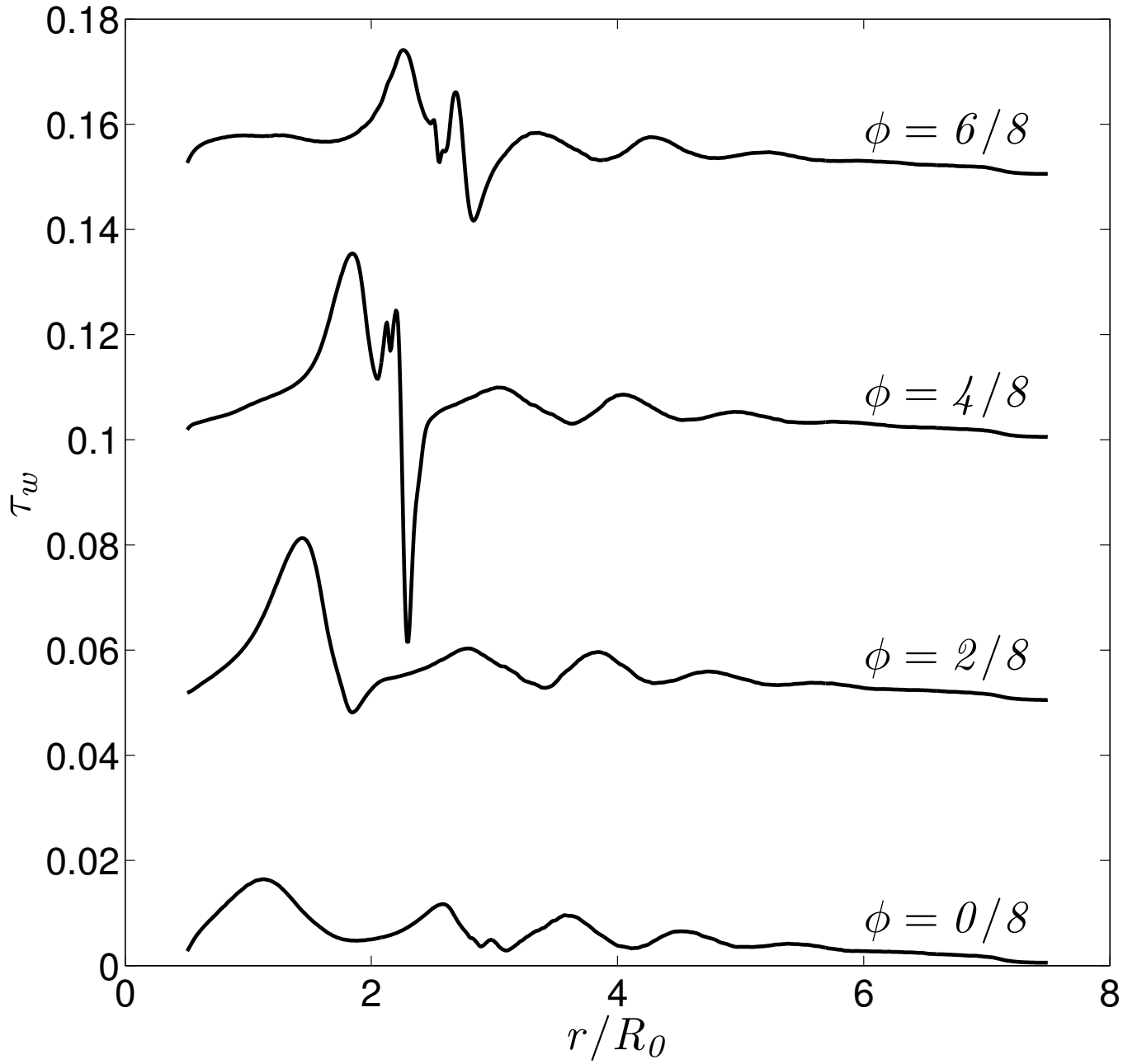
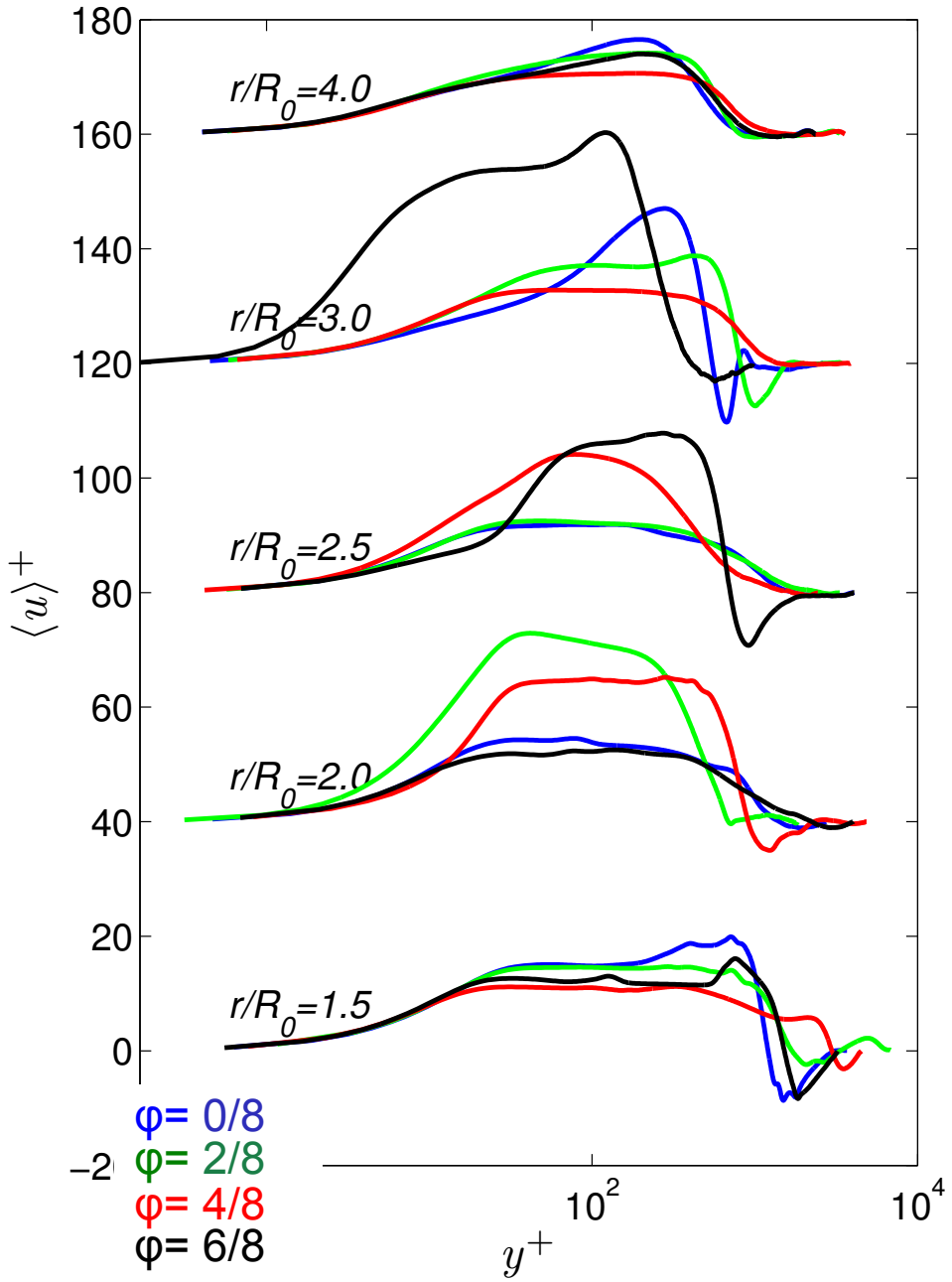


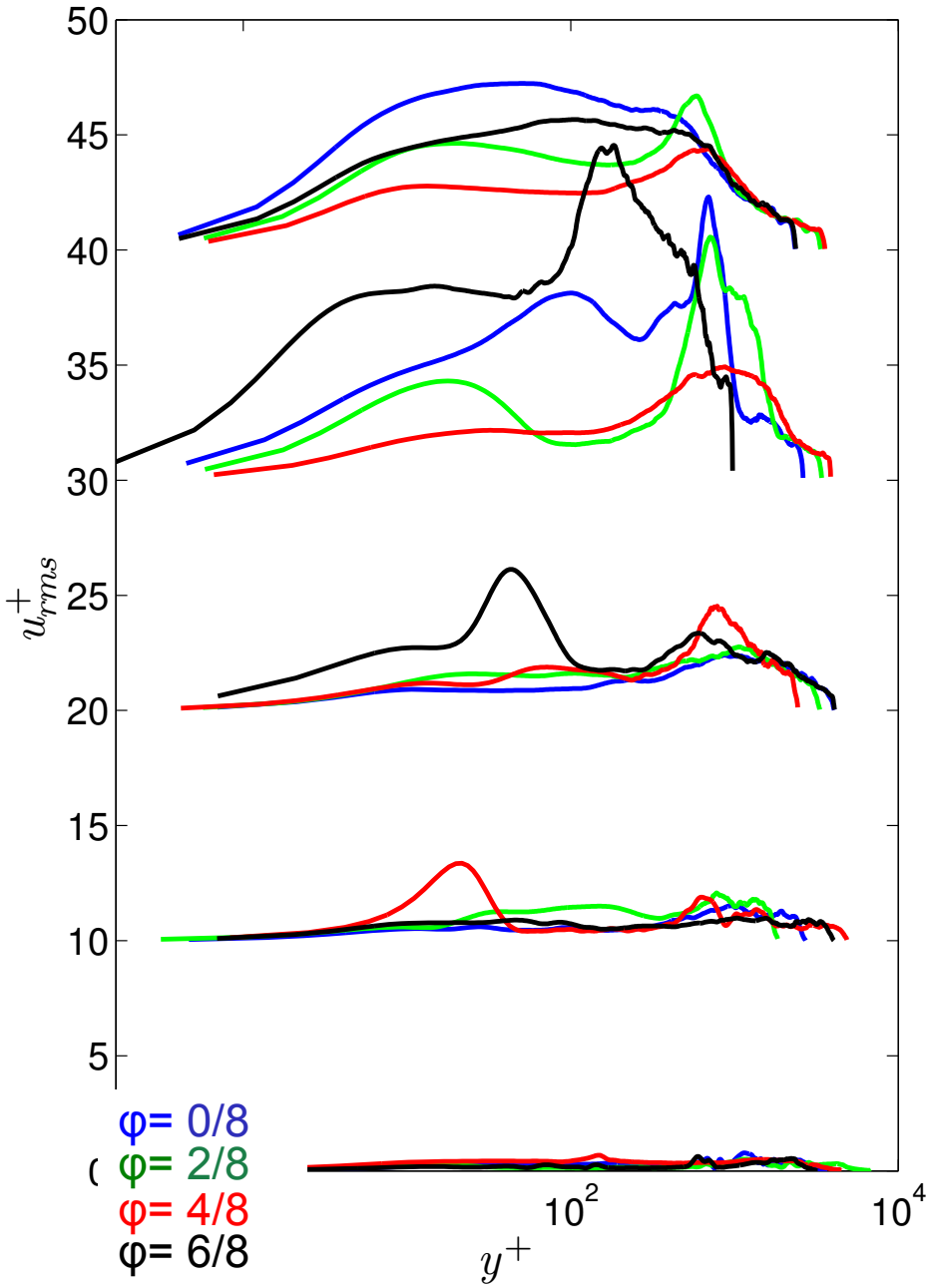
Impinging jet: Wall Stress



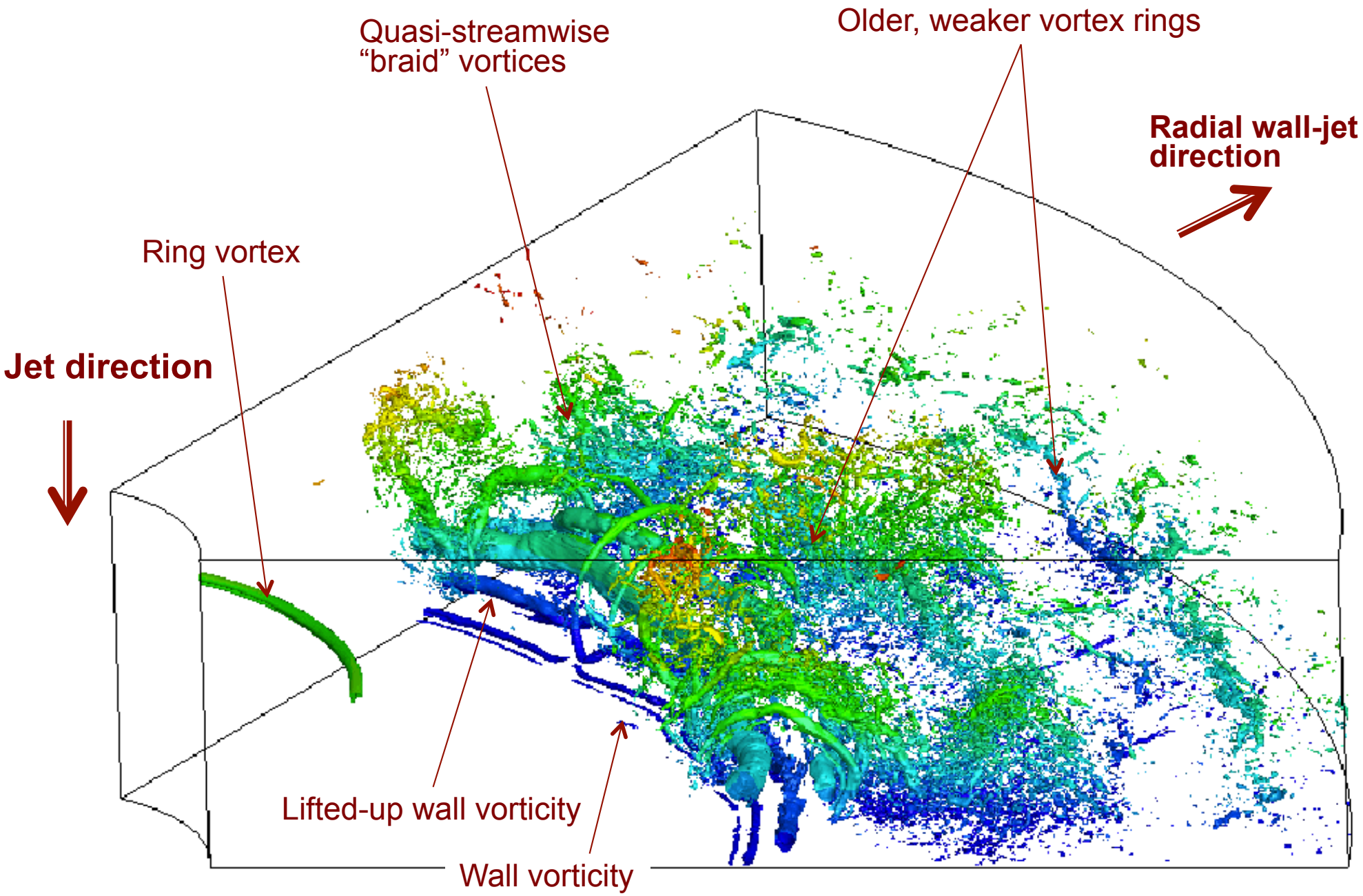
Impinging jet: Radial Velocity



Impinging jet: rms fluctuations



Impinging jet: Vortex Development



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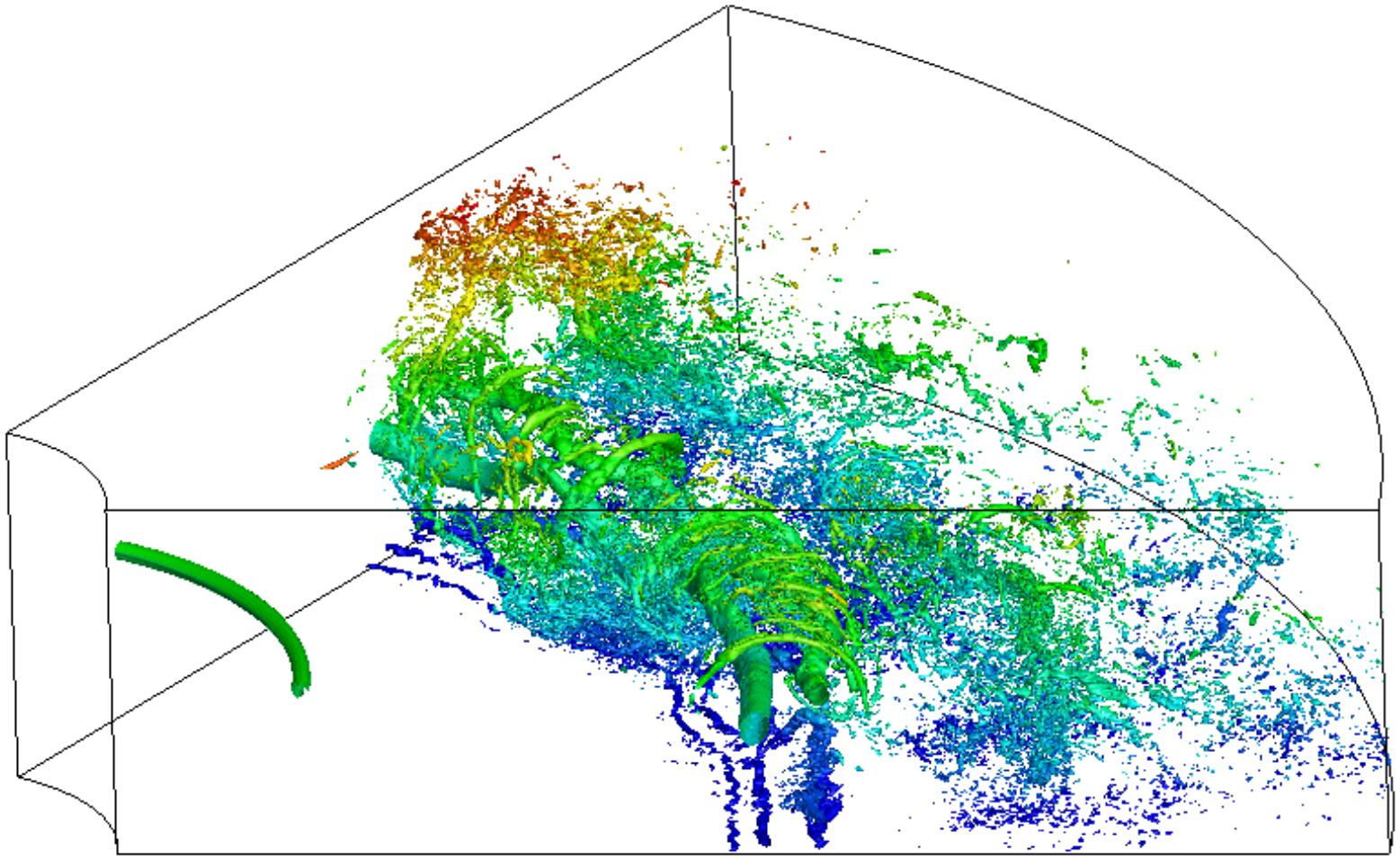

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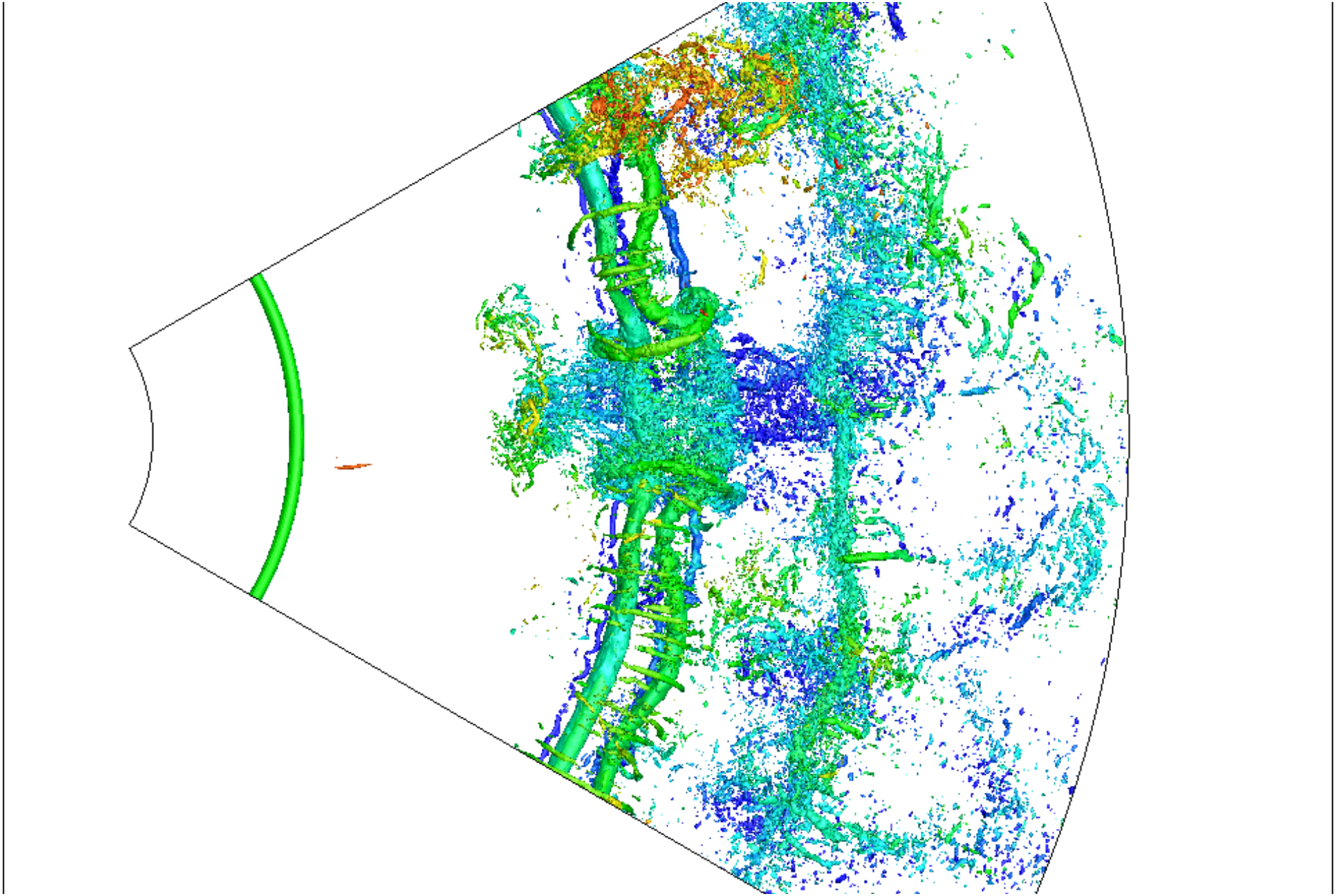
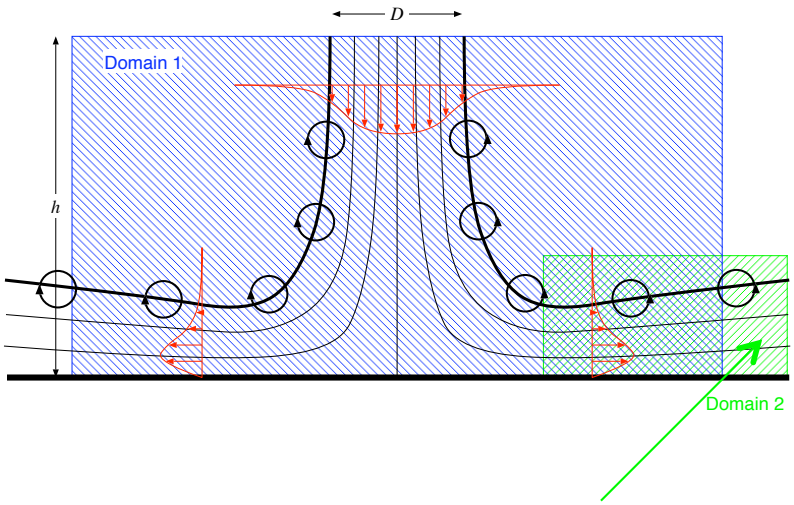
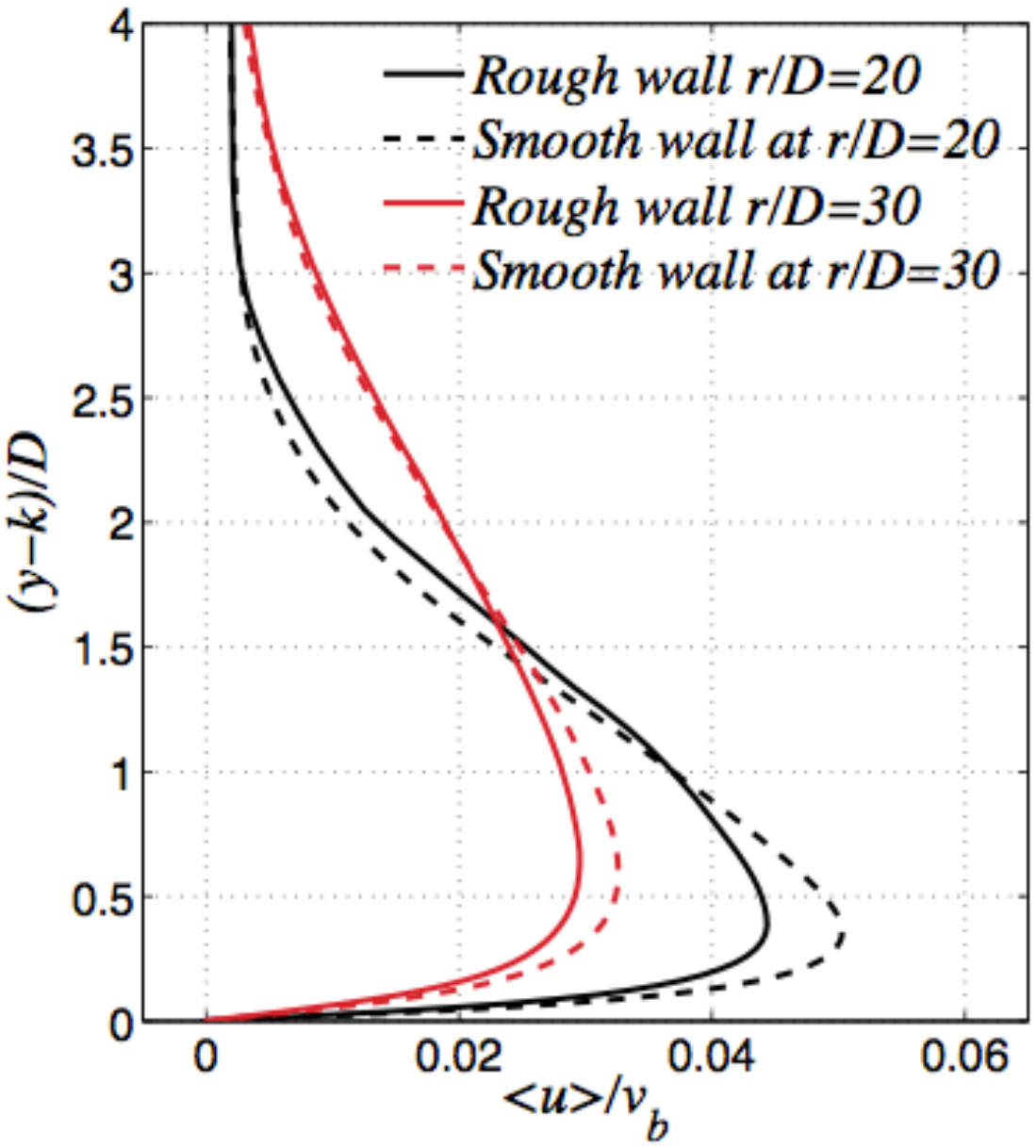


ROUGHNESS


D
Domain 1
h
Domain 2


Rough wall r/D=20
Smooth wall at r/D=20
Rough wall r/D=30
Smooth wall at r/D=30
(y−k)/D
<u>/v_b
0
0.02
0.04
0.06
0.5
1
1.5
2
2.5
3
3.5
4

Future work

- Moderate Reynolds number:
  - *Complete the comparison with experiments*
- High Reynolds number
  - *Compare wall-resolved and wall-modeled LES in the wall jet*
  - *Quantify the vortex decay in high-Re wall-jet-like flow fields.*
- Particle dynamics
  - *Implement particle motion model.*

Future challenges

- Practical issues:
  - *Vortex generation on marginal grids*
    - Avoid numerical instabilities due to high Re_{cell}
  - *Extension to high Re*
    - Wall modelling
- Theoretical issues:
  - *Particle lift-up model*
  - *Eulerian or Lagrangian tracking*
  - *Compressibility effects*
  - *Connection with inviscid vortex-line models of the rotor wake*