Ice accretion prediction on wind turbines based on a combined LES-LPT method

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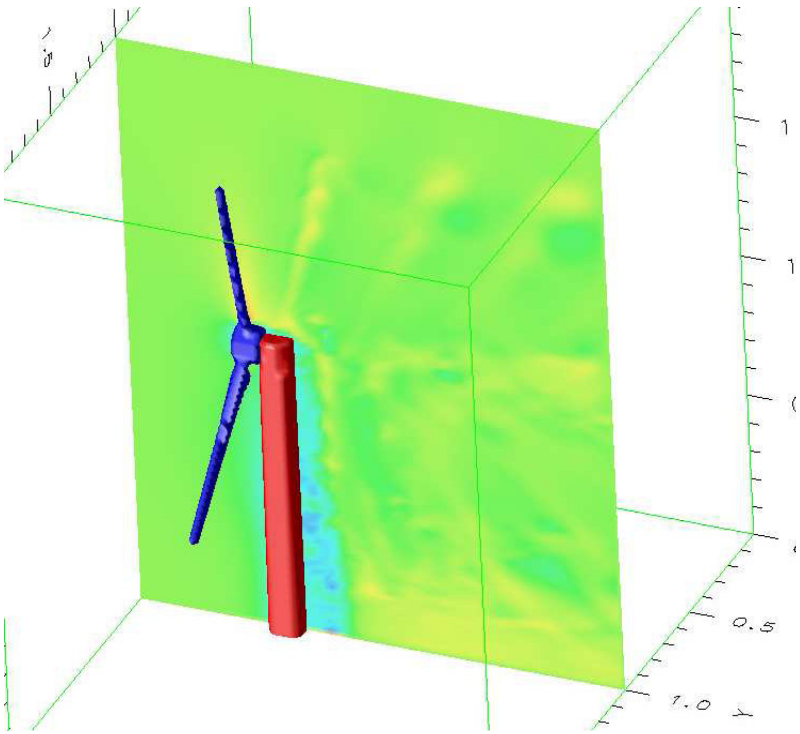
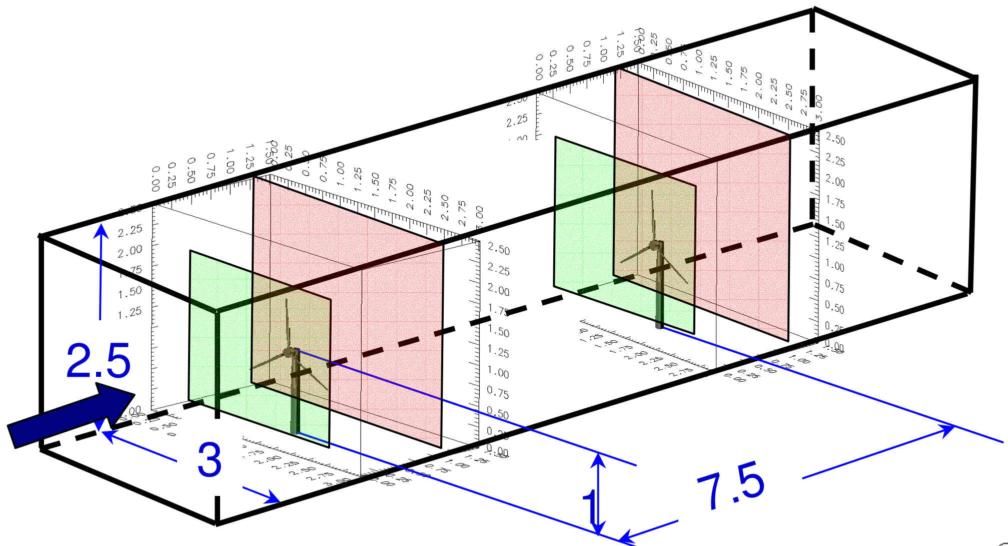
Goals

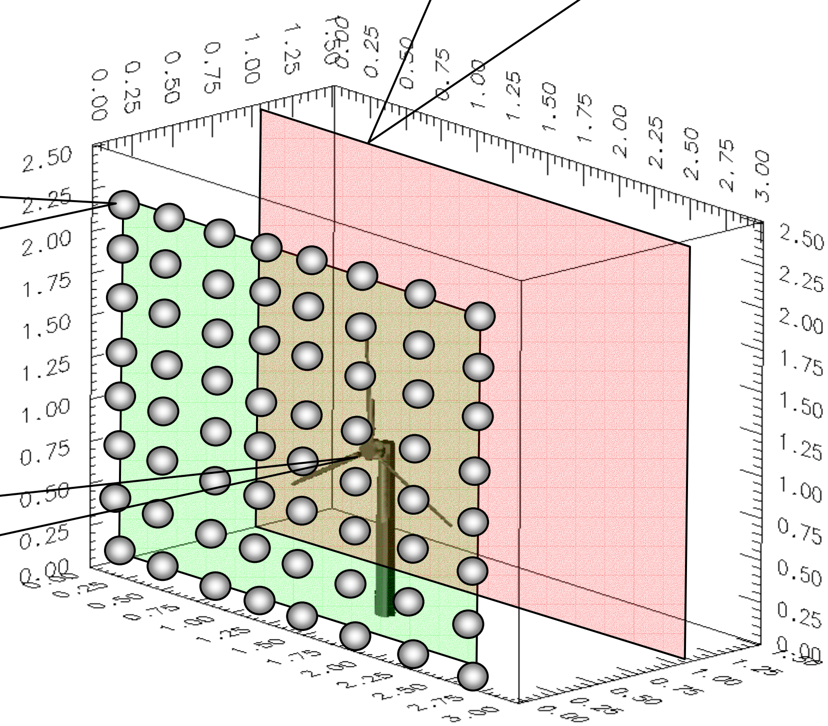


- Develop numerical tool to predict ice accretion
- Account for both the rotor and the tower
- Possibility to account for
  - upstream wake
  - droplet size
  - landscape

Problem set-up



3 Droplets not deposited are removed from the domain @ 0.2 downstream



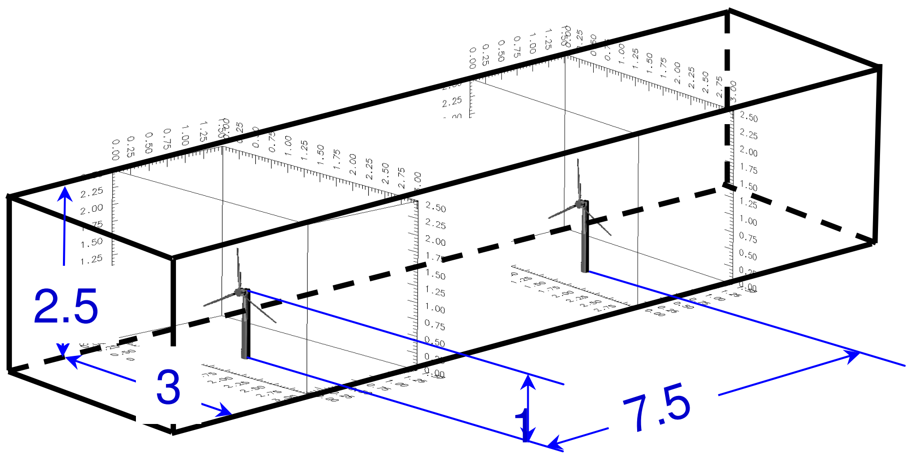
1 201 x 201 droplets realeased every timestep, 0.2 units upstream the W.T.

2 Droplets hitting the tower / rotor are considered to freezeinstantaneously

Numerical methods

- **Flow**
  - 3^{rd} & 4^{th} o. Finite differences
  - Cartesian grid => efficient methods
  - Solids: virtual boundary
  - Turbulence => LES
  - Parallell computations (MPI)
- **Droplets**
  - Lagrangian Particle Tracking (LPT)
  - Transported by the instantaneous flow
  - Equi-sized and spaced droplets
  - Drag force
  - Droplets hitting a solid surface freeze instantaneously

Case set-up



- 2 tandem WTs
- Tower height = 1 LU
- Blade length = 0.7 LU
- NACA 4415, twisted, ca. 7 degree a.o.a.

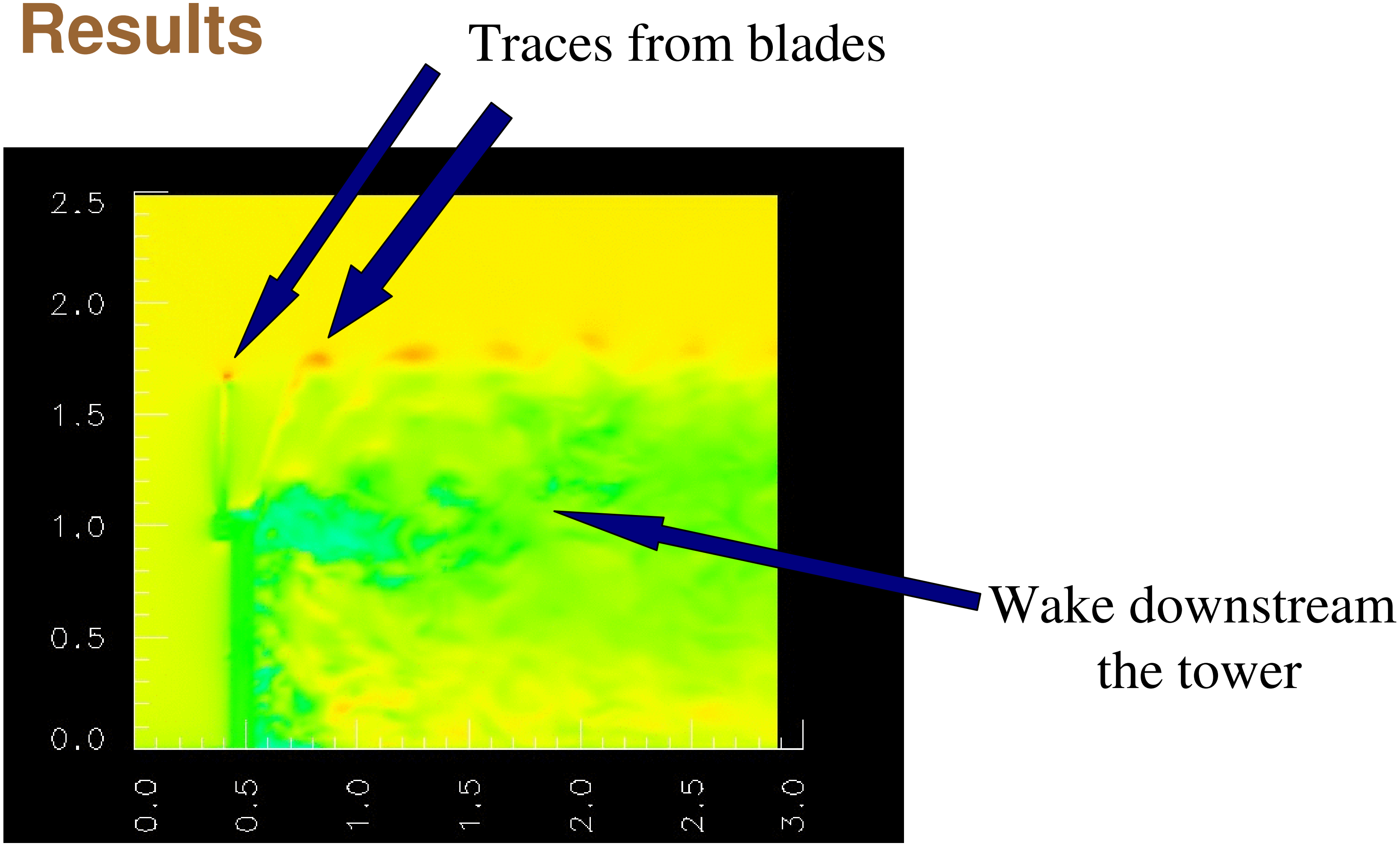
- ABL inlet velocity:

$$w(x) = Cx^{0.1}$$

ω = 0.39 rot/s
  - Tip Speed Ratio = 3.5
- 10 x 6.2 mill.cells
- Started from already converged flow case
- 10+ rotations

- 3 droplet diameters
  - 0.1 mm
  - 1 mm
  - 10 mm

Results

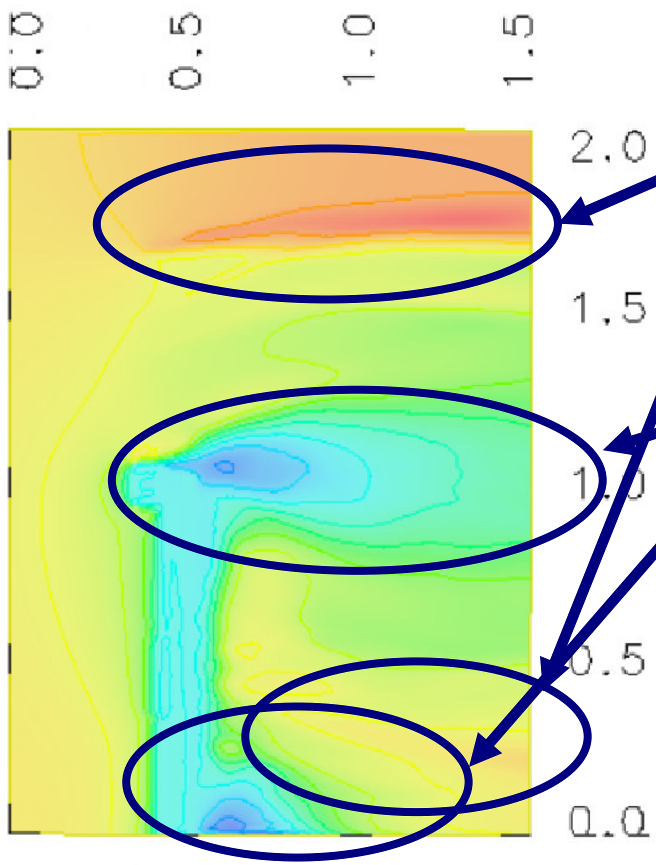

Traces from blades
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Wake downstream
the tower

Average velocity components

•Maxima due to tip vortices

•Close to ground lower maxima due to mast

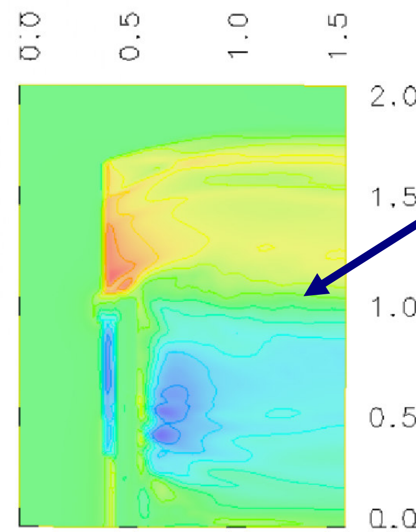
•Recirculation zones



Average
axial velocity

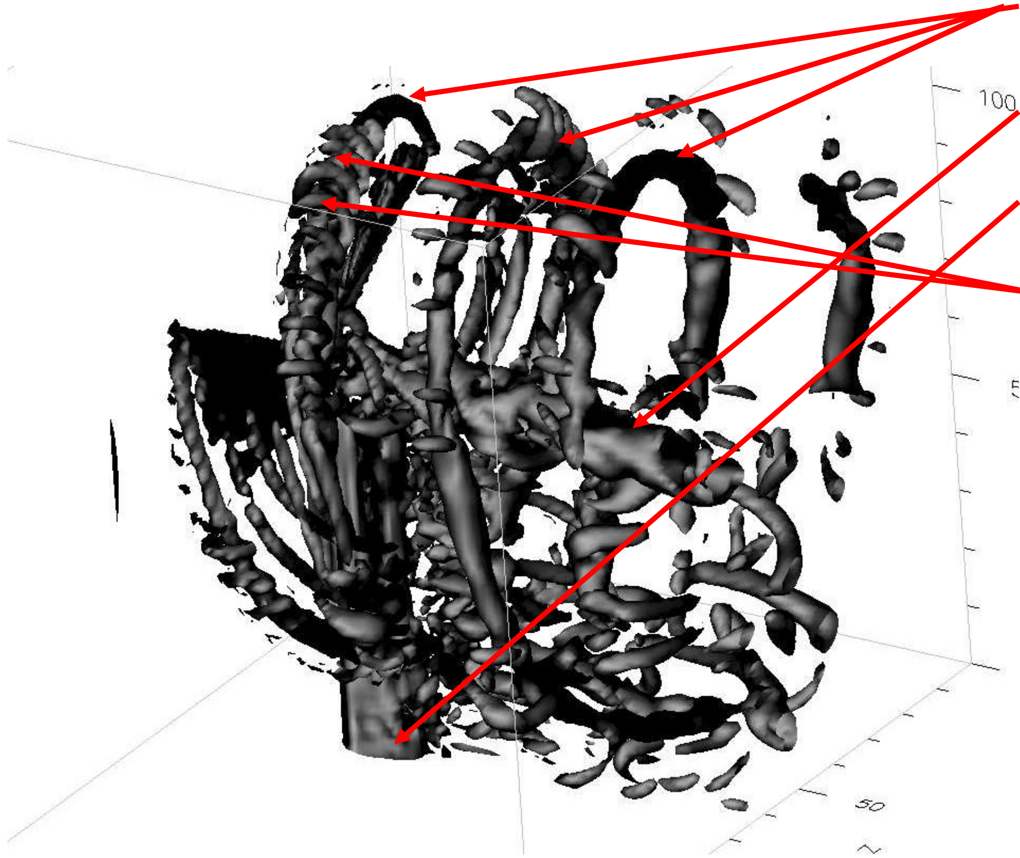
•Swirl

Enhances recirculation zone



Average azimuthal velocity

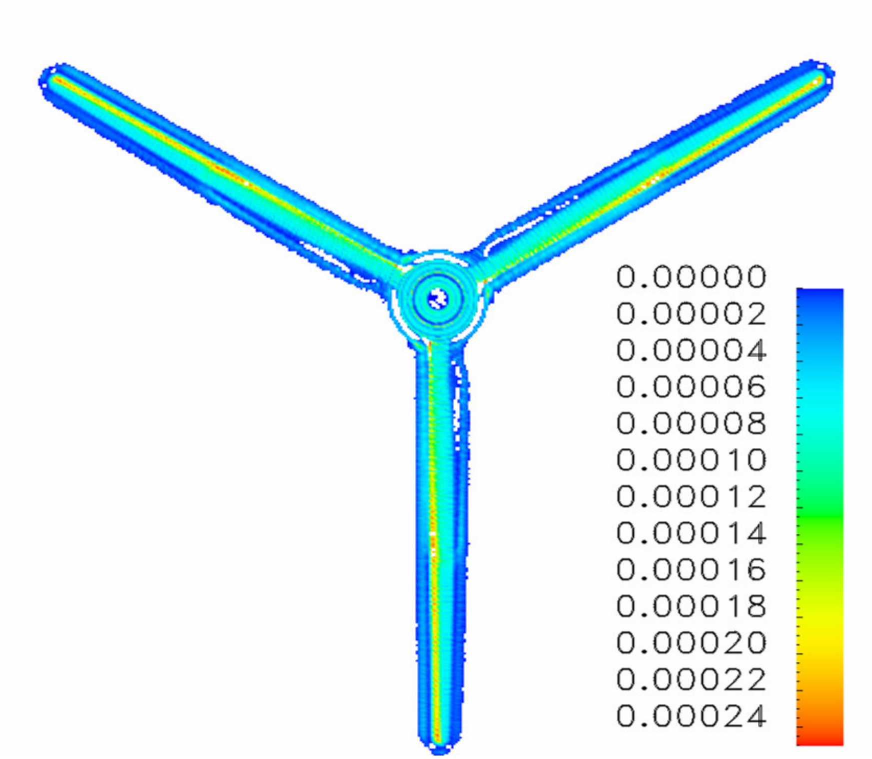
Vortices (λ2)



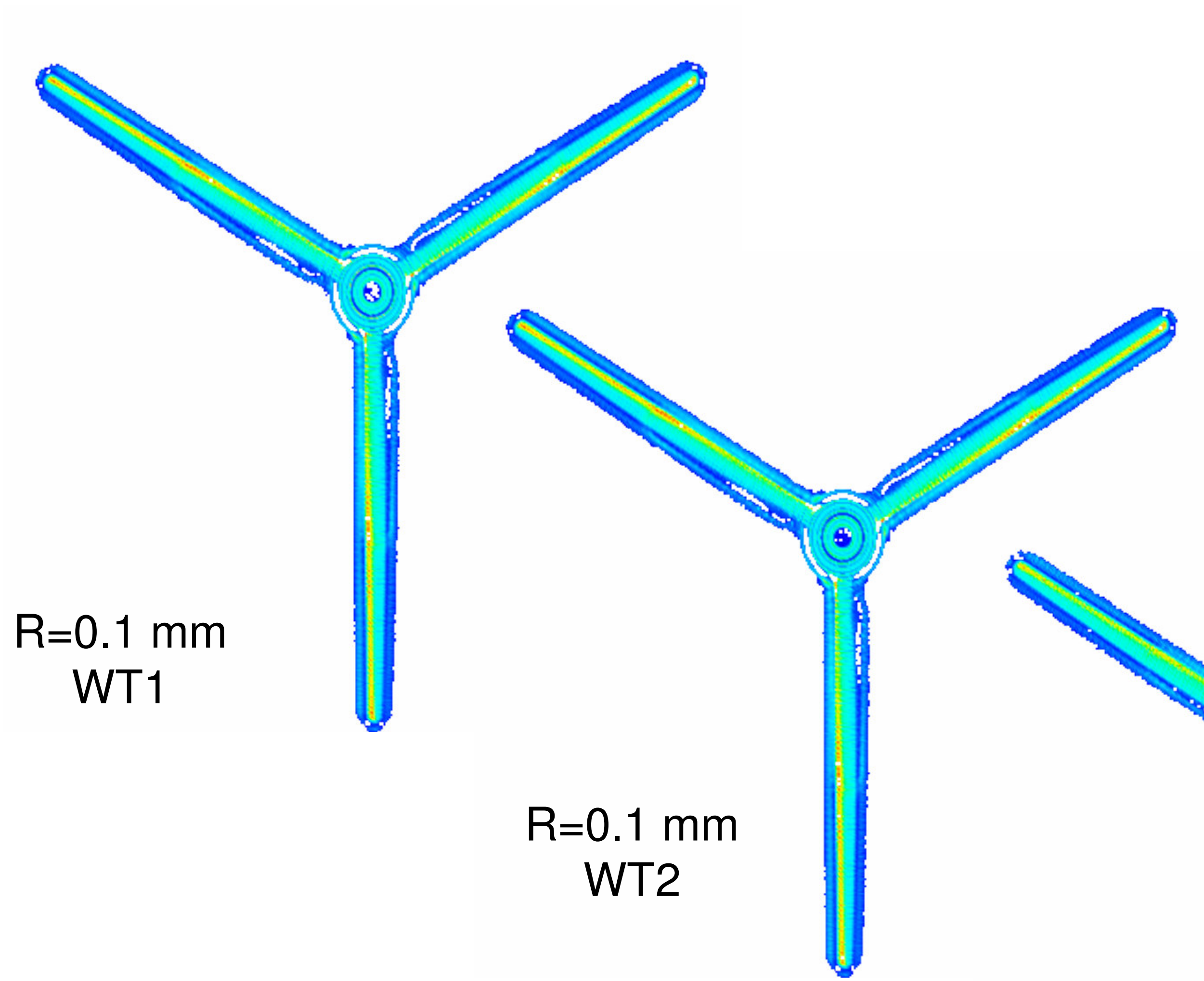
- Tip vortices
- Swirl
- Wake
- Secondary vortices

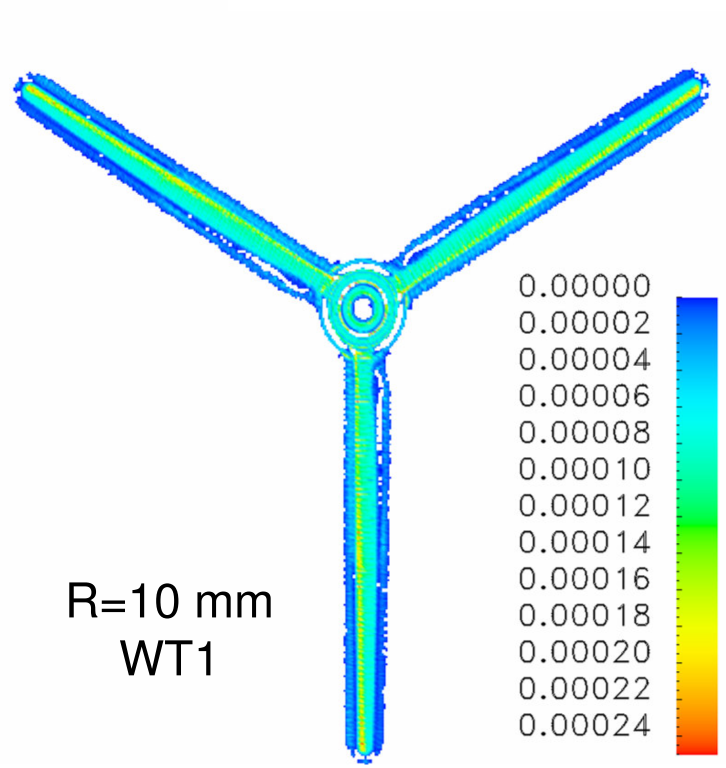
- Long lifetime of vortices
- Interaction with downstream power plants

Deposited particle 'density'



- Number of droplets deposited on the rotor blade
  - 400x400 bins
  - normalized with the total number of deposited droplets
  - d=0.1 mm
  - upstream W.T.
- Larger concentration of deposited droplets
  - leading edge
  - second third of the span

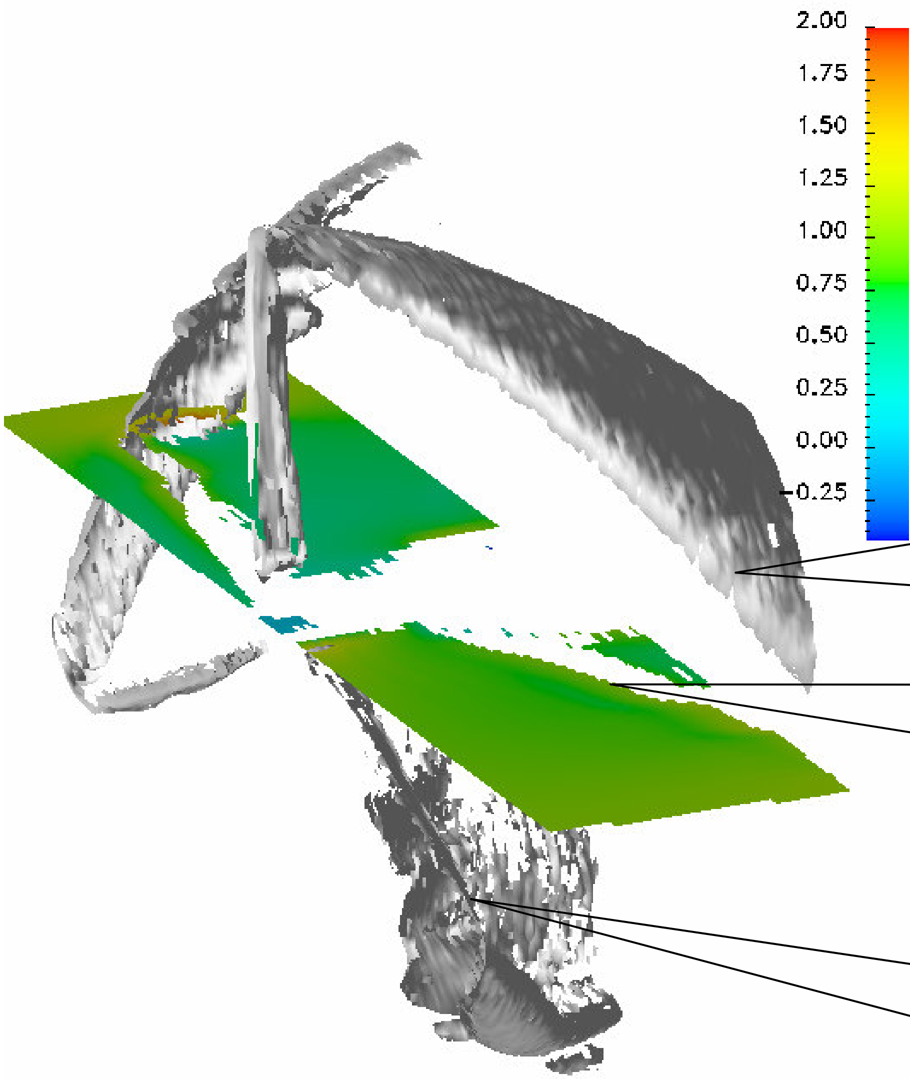




Qualitatively the same behaviour for different droplet radii and for upstream and downstream wind turbines

Particle axial velocity

- 200x200x200 bins
- Normalized with wind velocity at hub height
- R=0.1 mm, WT1

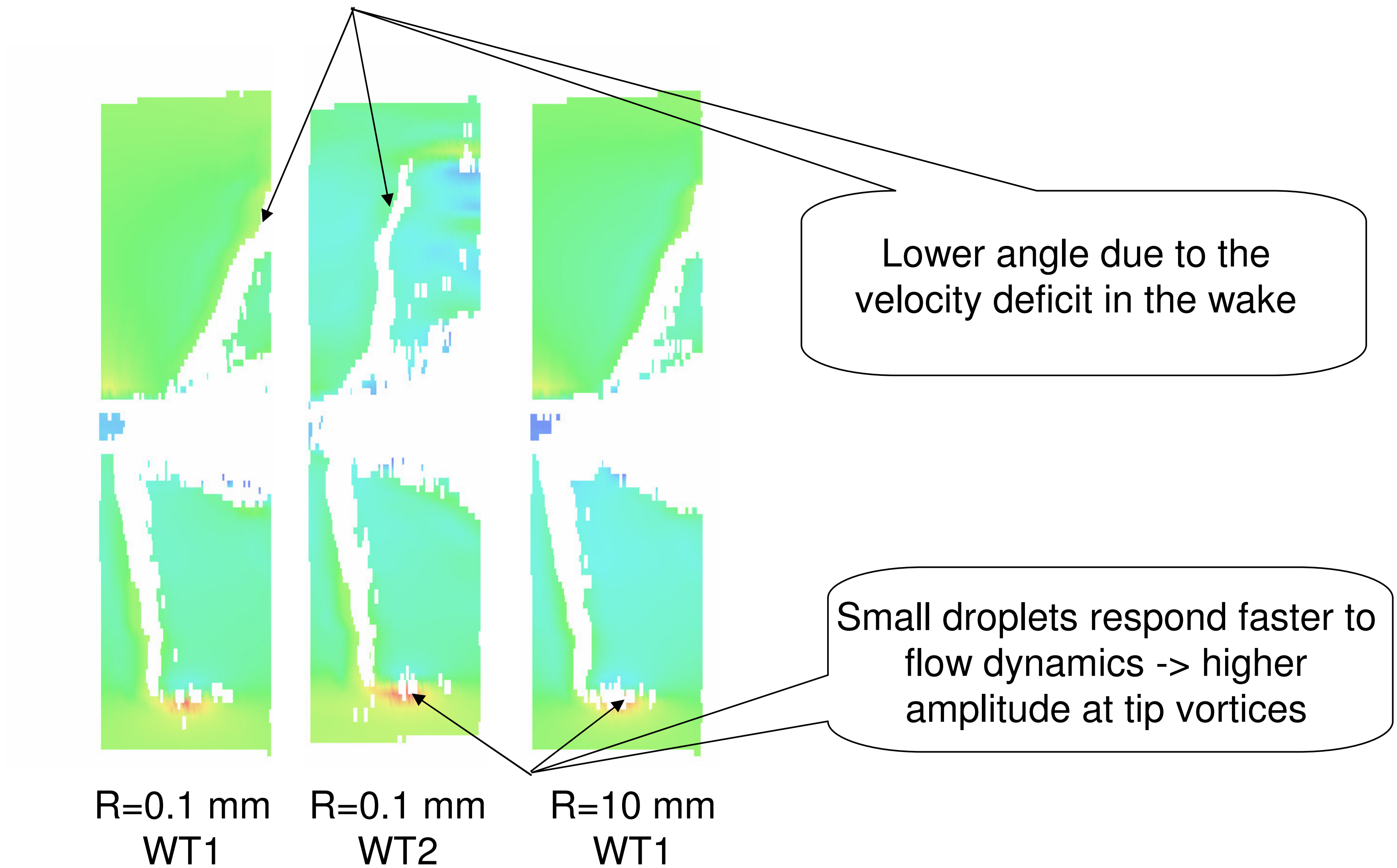


Isosurface of $w_{part}=1.5$
Particles accelerated by the tip vortices

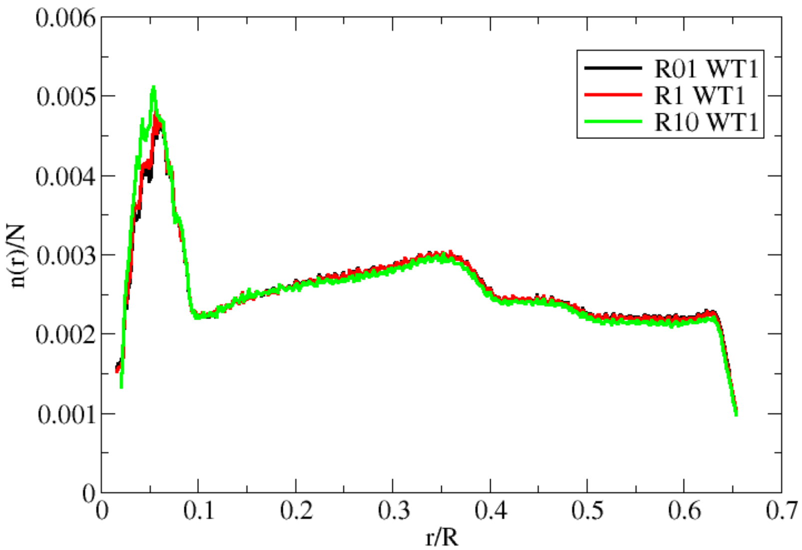
'white regions' = lack of droplets because of accretion

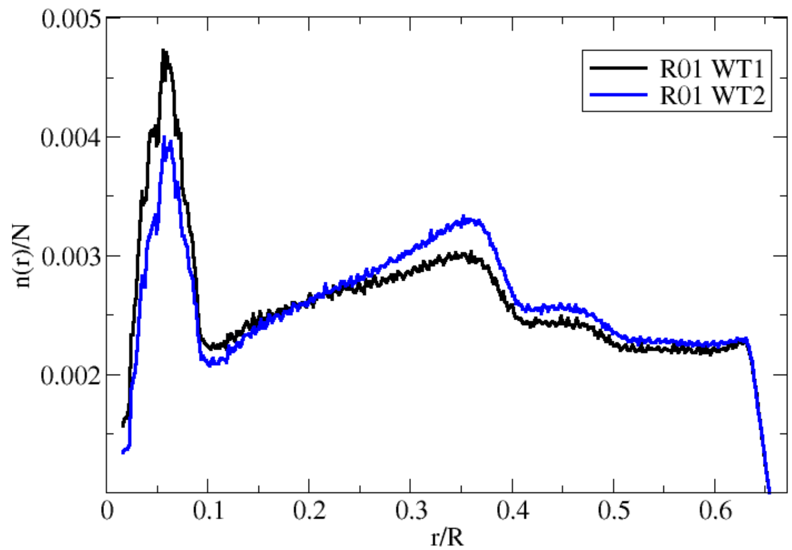
Much stronger wrinkling due to interaction with the tower wake

Particle axial velocity
plane parallel to ground, hub height



Radial distribution of the deposited droplets

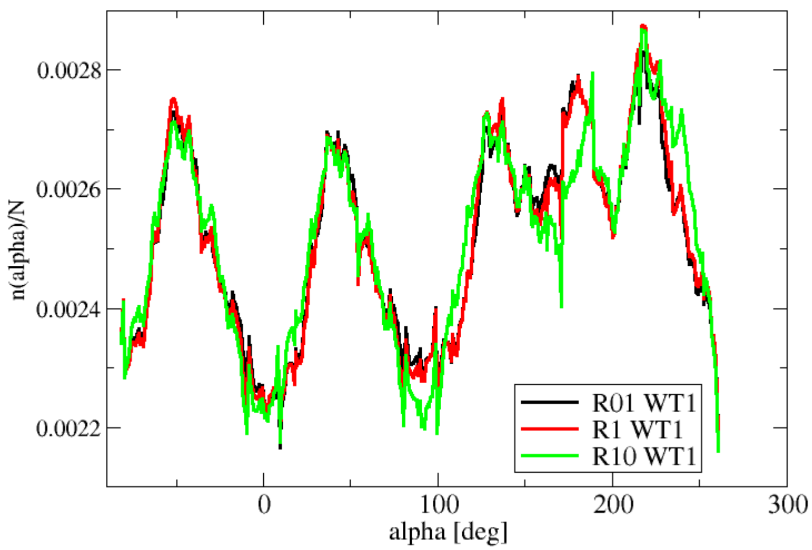


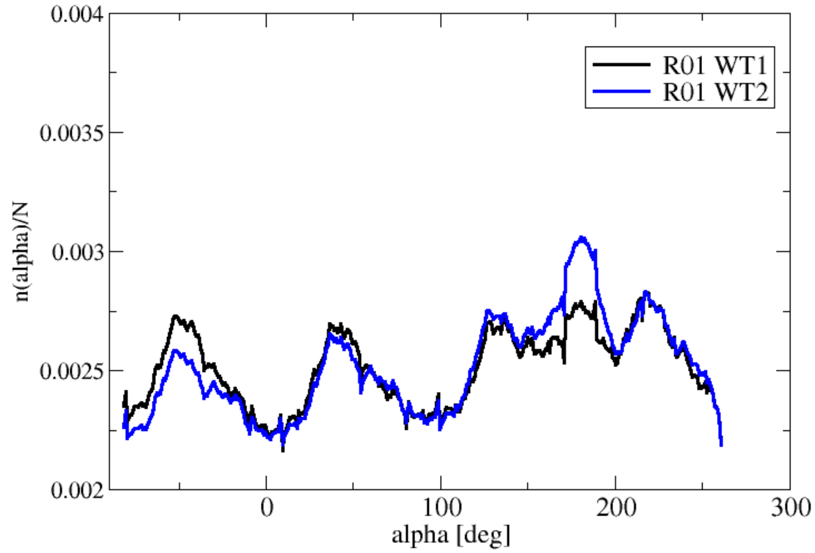


- No visible influence of droplet radius on average distribution
- peak @ 0.05 large impact area at the hub
- second peak around r=0.35

- For downstream wind turbine (WT2)
  - less particles deposited in the hub region
  - more particles deposited at r=0.35

Azimuthal distribution of droplet impact frequency

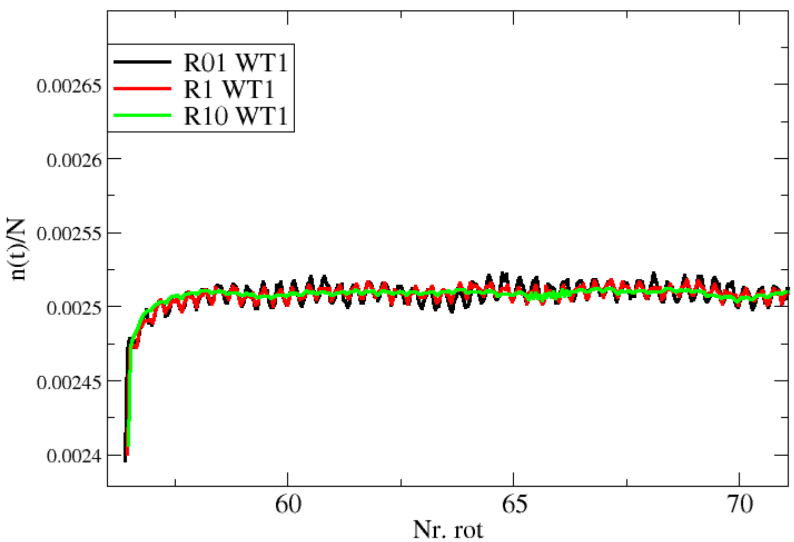


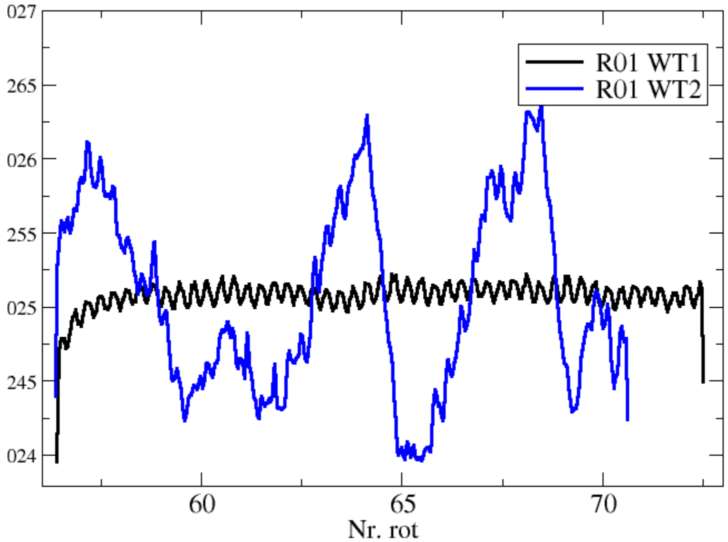


- Traces of the blades and the tower visible
- relatively symmetric (Y-axis is zoomed in)

- Downstream WT shows more asymmetry

Time evolution of droplet deposition

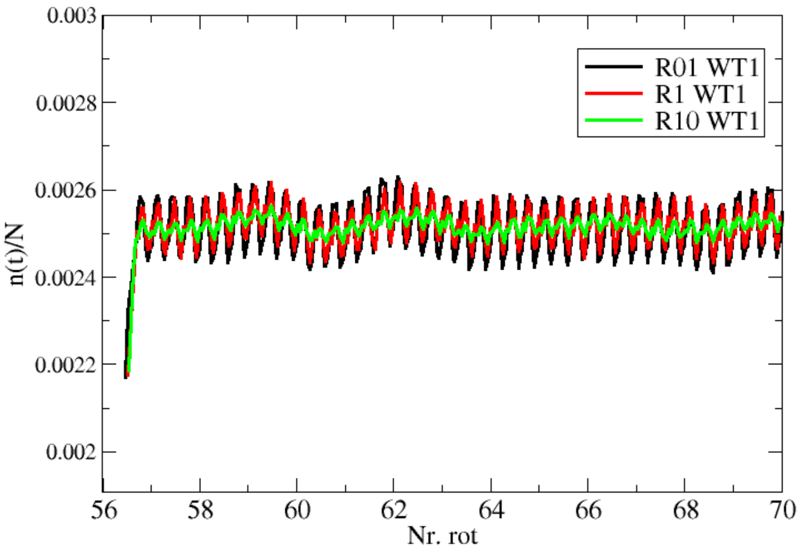


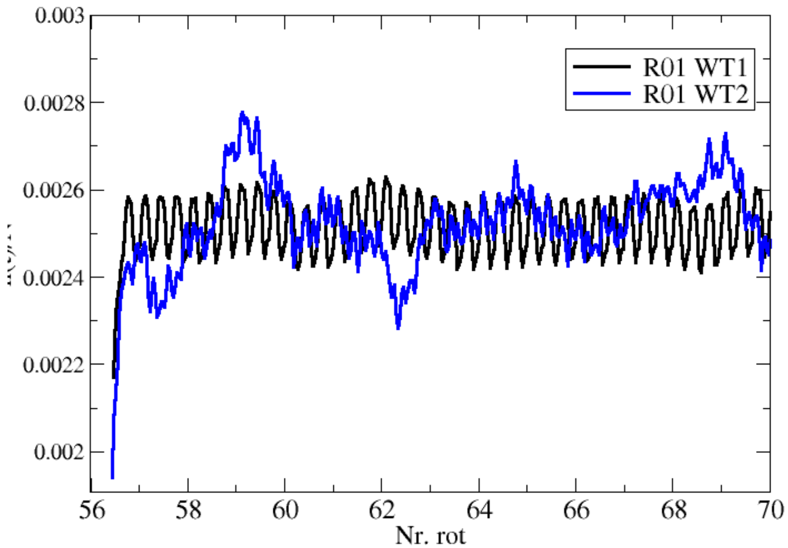


- Blade passages visible
- Large droplets have smoother history due to inertia

- Low frequency large amplitude variations due to the upstream wake

Droplet deposition on the tower





- Blade passages visible
- Large droplets have smoother history due to inertia
- Larger variations than for the droplets deposited on the blades

- Low frequency large amplitude variations due to the upstream wake

Conclusions

- Influence of droplet size
  - In average, no visible influence on the droplet distribution
  - Instantaneously, smaller droplets more sensitive to flow dynamics
- Influence of upstream wake
  - Radial distribution affected: more droplets at blade half radius
  - Large fluctuations in time due to low frequency wake oscillations

Future plans

- Include other forces (e.g. gravity)
- 2/4 way interactions
- Models for different icing conditions (instead of instantaneous droplet freezing)
- Account for the change in blade shape according to the amount of deposited ice
- Landscape effects