UCLouvain

UCLouvain

Institute of mechanics, materials and civil engineering

Prof. Philippe Chatelain

PRACE workshop: lessons learned

October 4, 2018

Outline

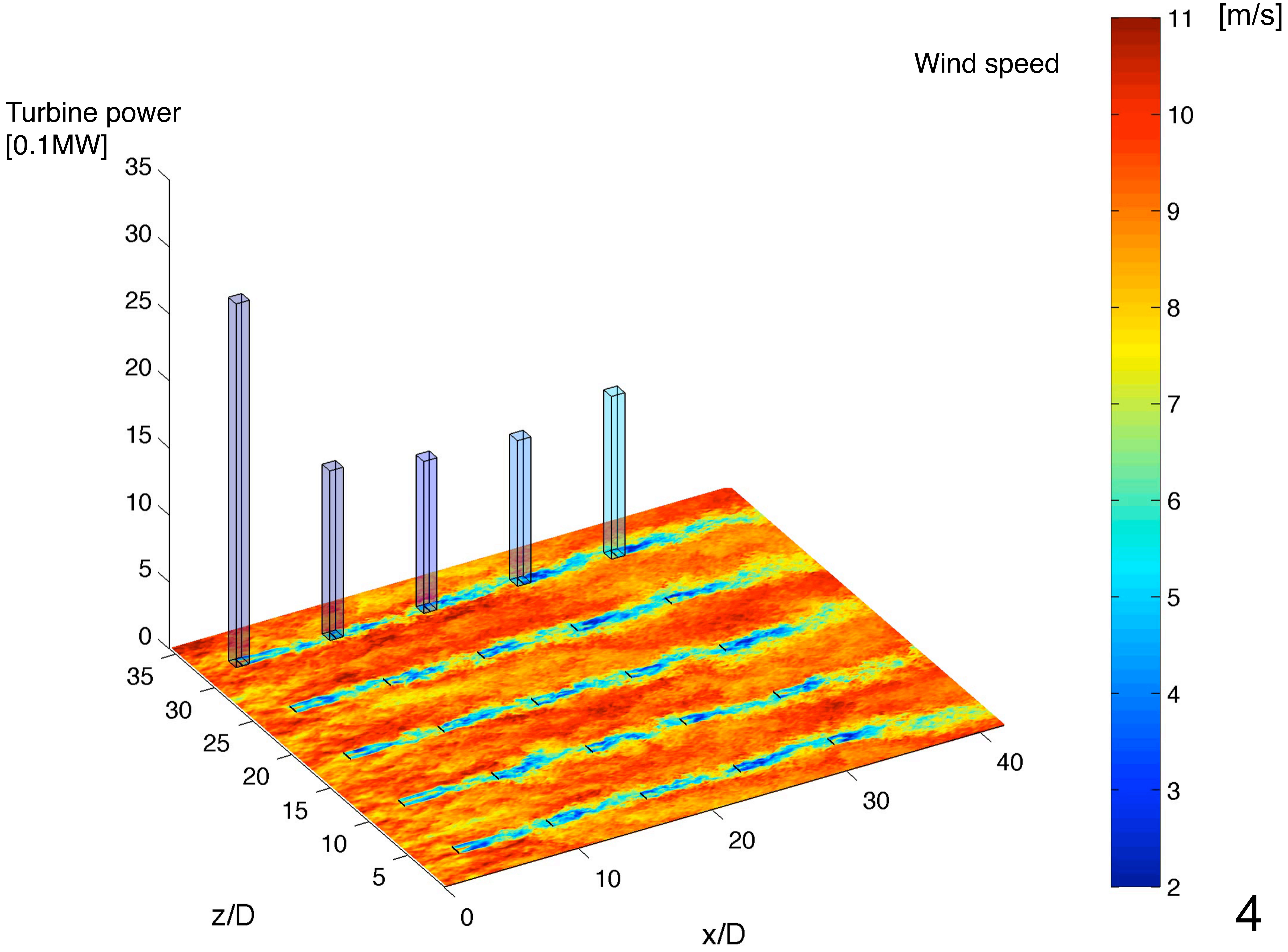
- Project description
  - Context
  - Technical
- Proposal writing
- Reviews
- Conclusions / Lessons learned

Wind farms

- Optimization of wind resource exploitation over concessions
- Wake phenomena
  - Power losses
  - Fatigue loads
- Wake dissipation crucial

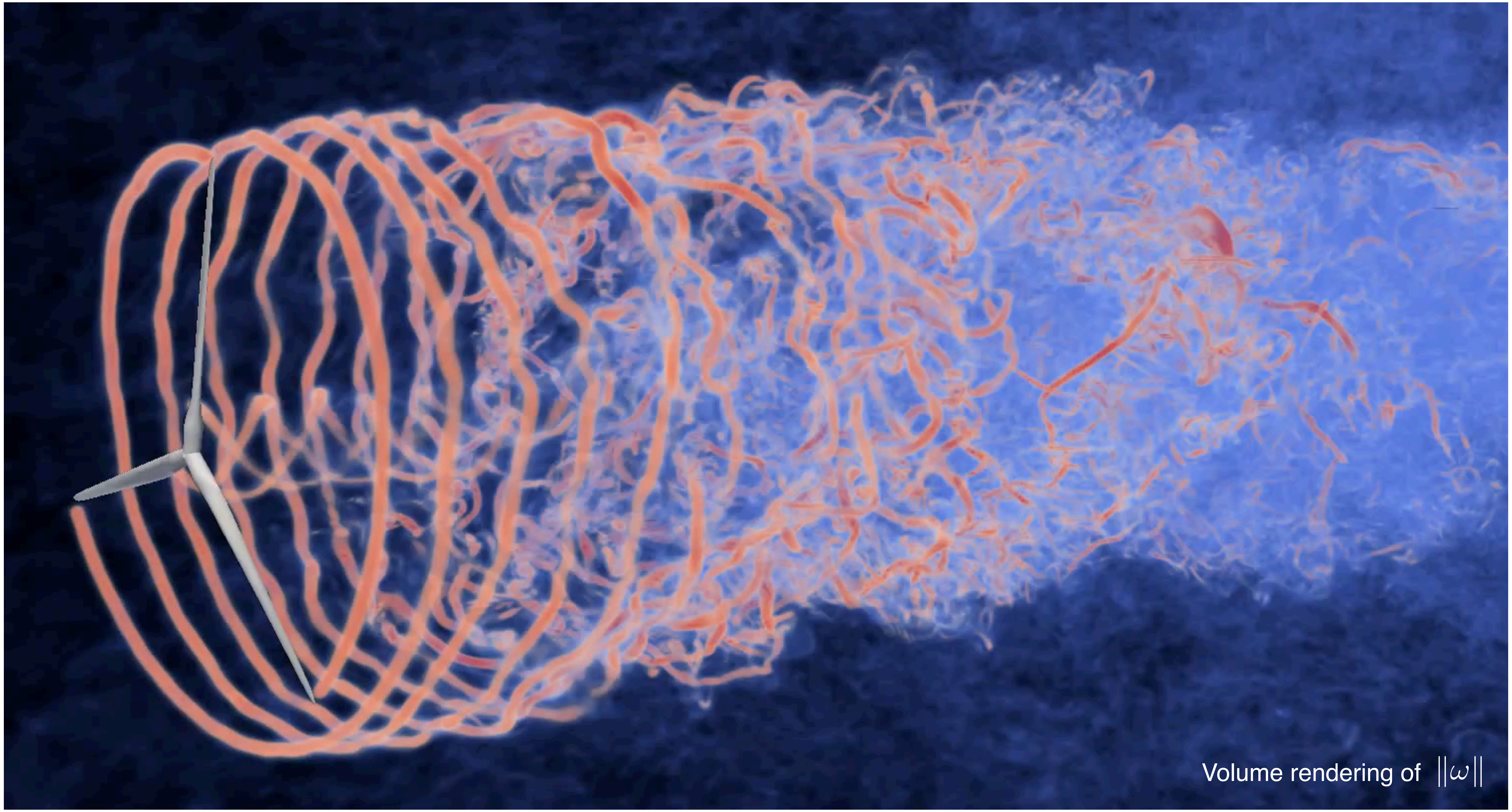
Wind farms

- Optimization of wind resource exploitation over concessions
- Wake phenomena
  - Power losses
  - Fatigue loads
- Wake dissipation crucial

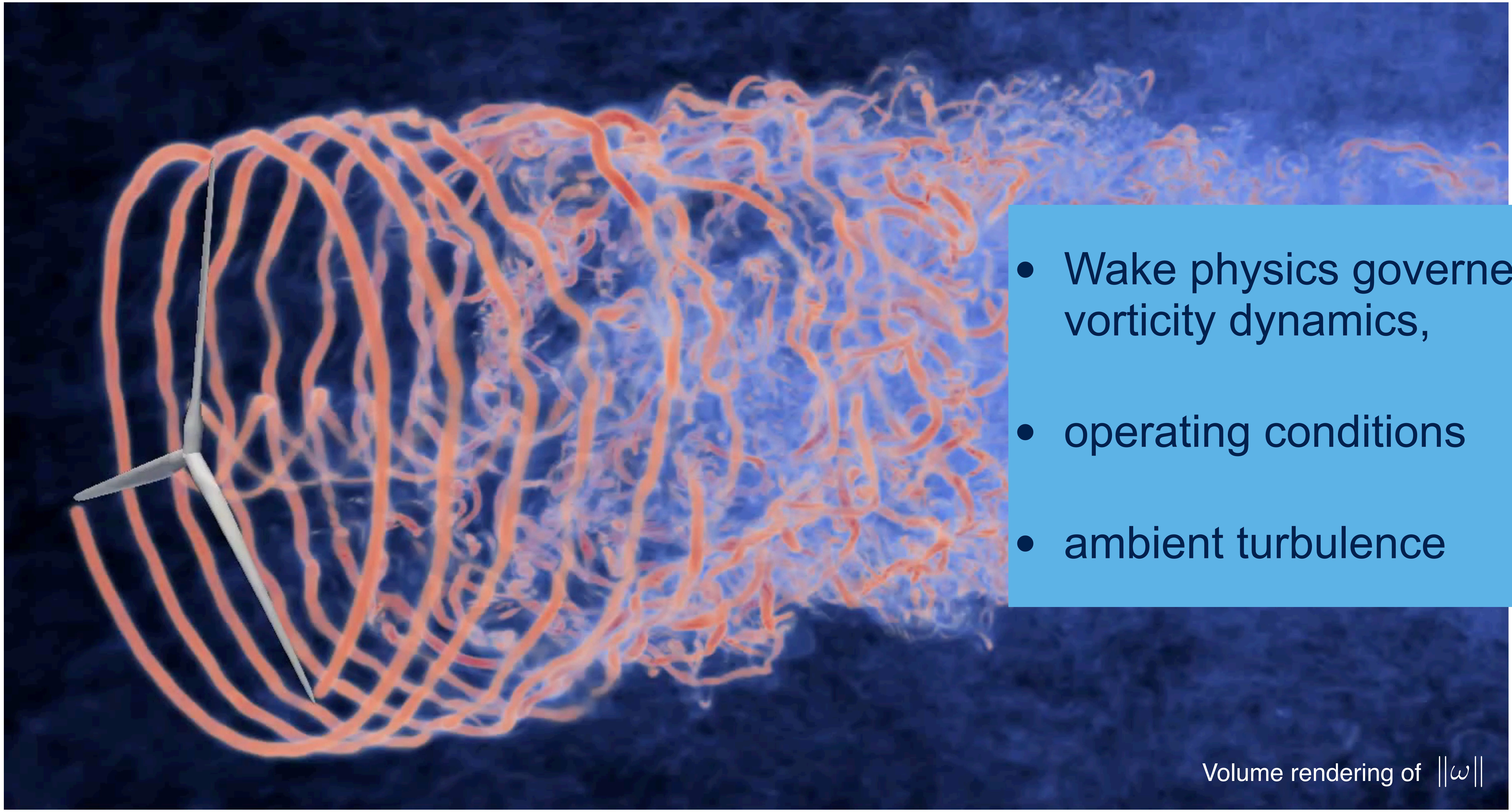


Wakes and vortices

Wakes and vortices



Wakes and vortices

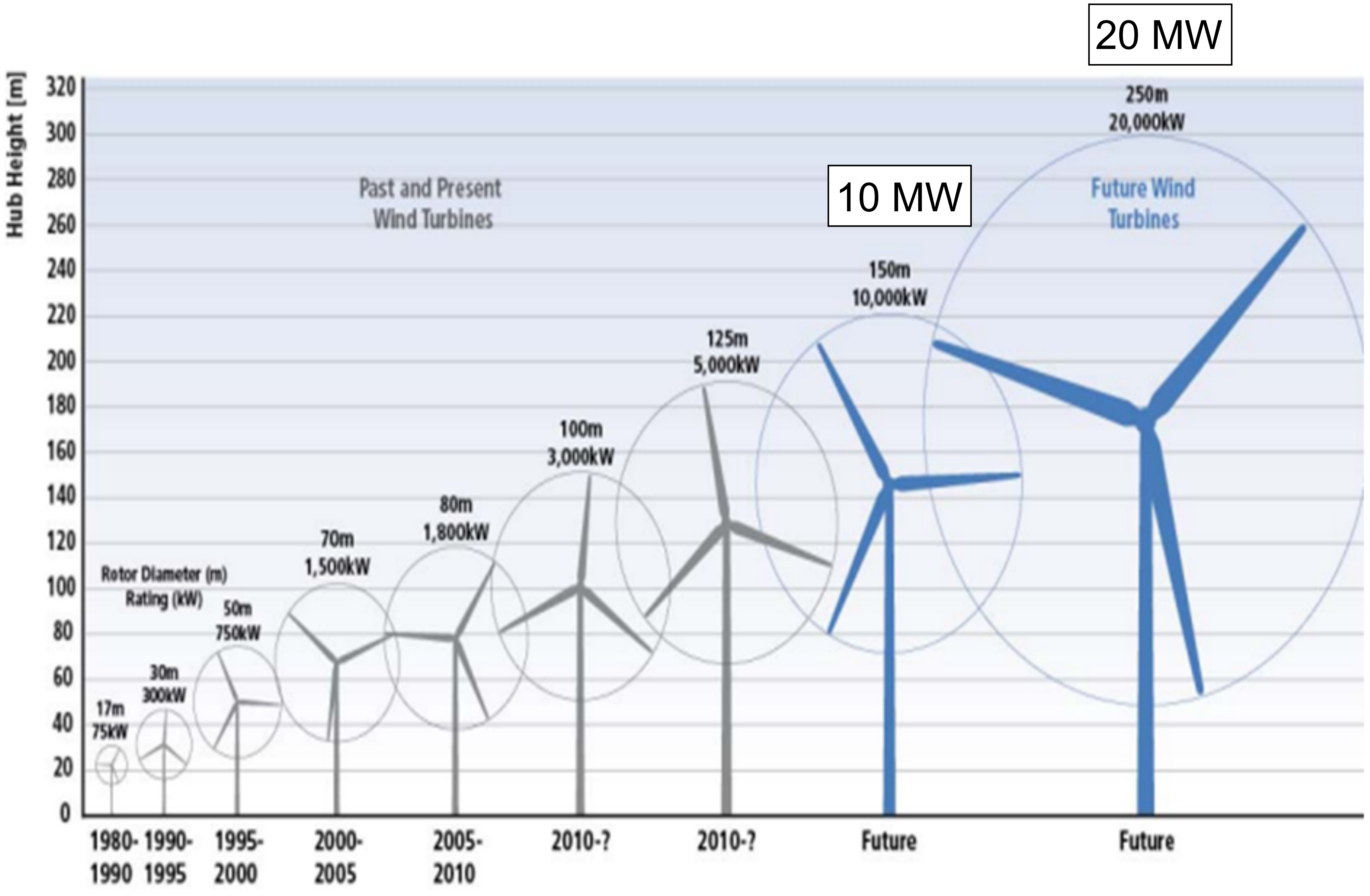


Volume rendering of $\|\omega\|$

- Wake physics governed by vorticity dynamics,
- operating conditions
- ambient turbulence

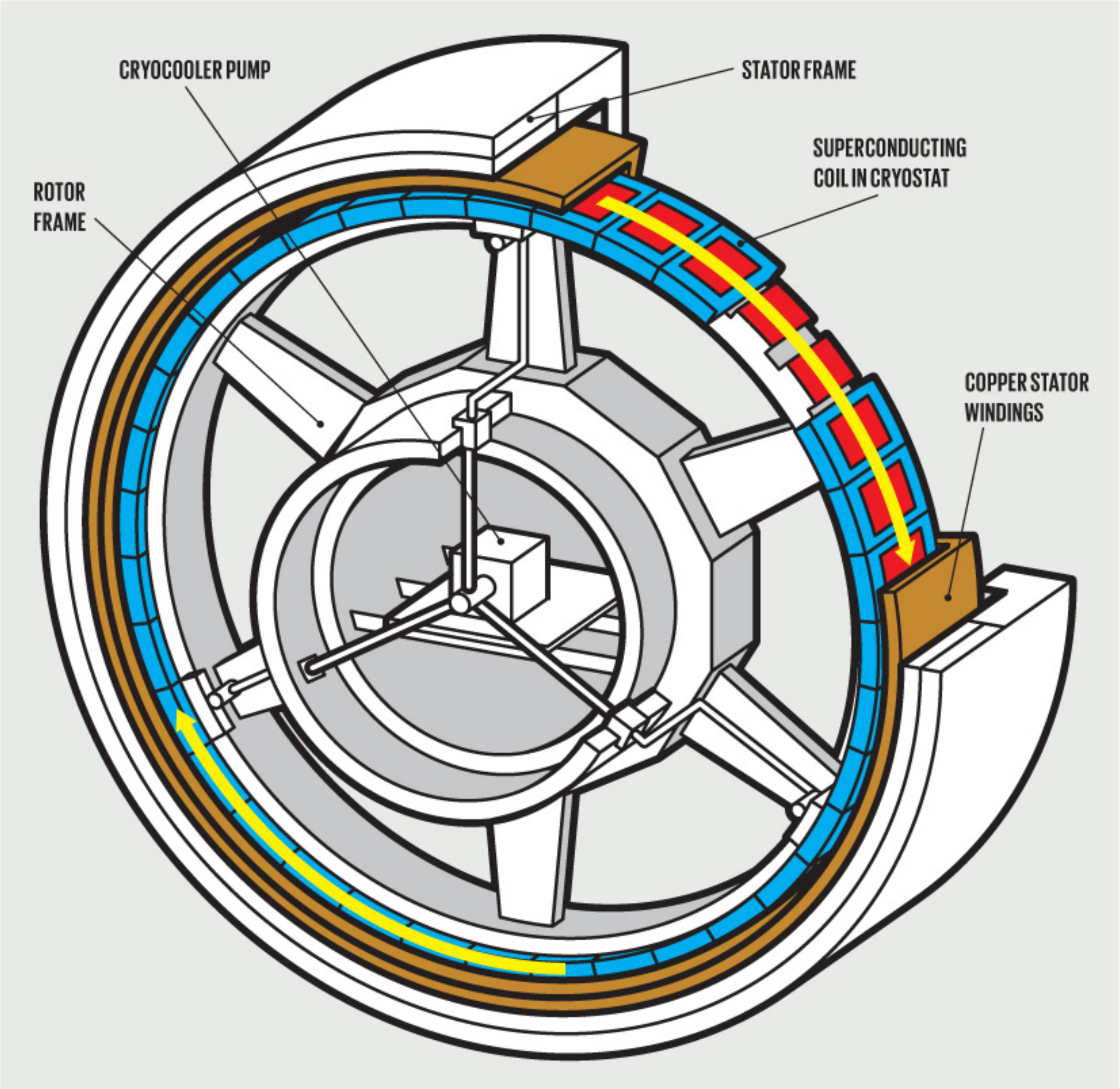
Trends and challenges

- Cost-effectiveness (LCOE) drives turbines to larger sizes
- Upscaling of classical Horizontal Axis Wind Turbine sustainable beyond 20MW?
- Nacelle/generator weight most penalizing factor
- 10MW = 400 metric tons
  20MW = 1100 metric tons

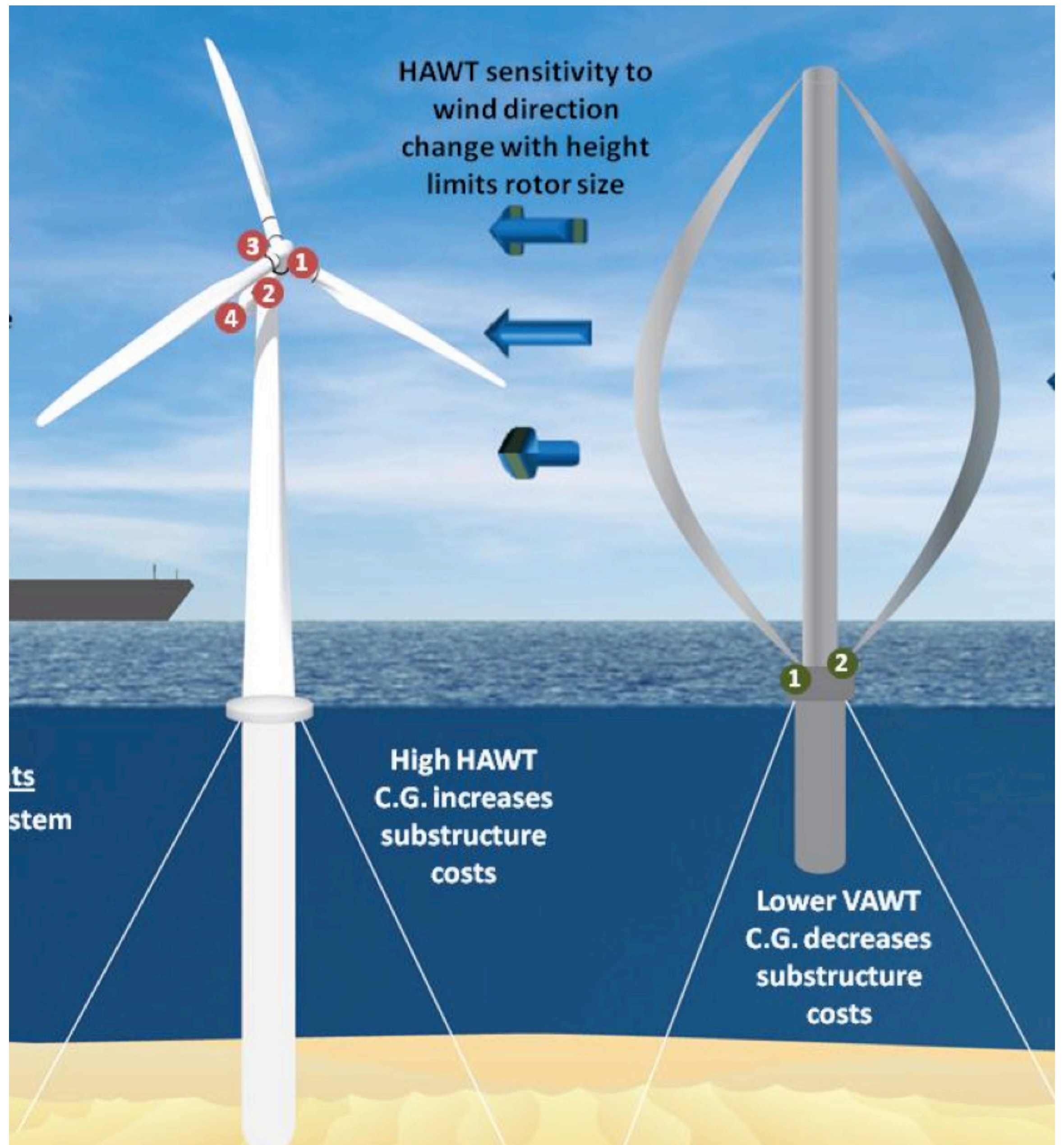


Solutions

- Converters based on
  - Superconducting windings
  - New permanent magnets
- Vertical Axis Wind Turbines (VAWTs) bring the nacelle down
  - Cheaper structures/foundations
  - Lower maintenance costs



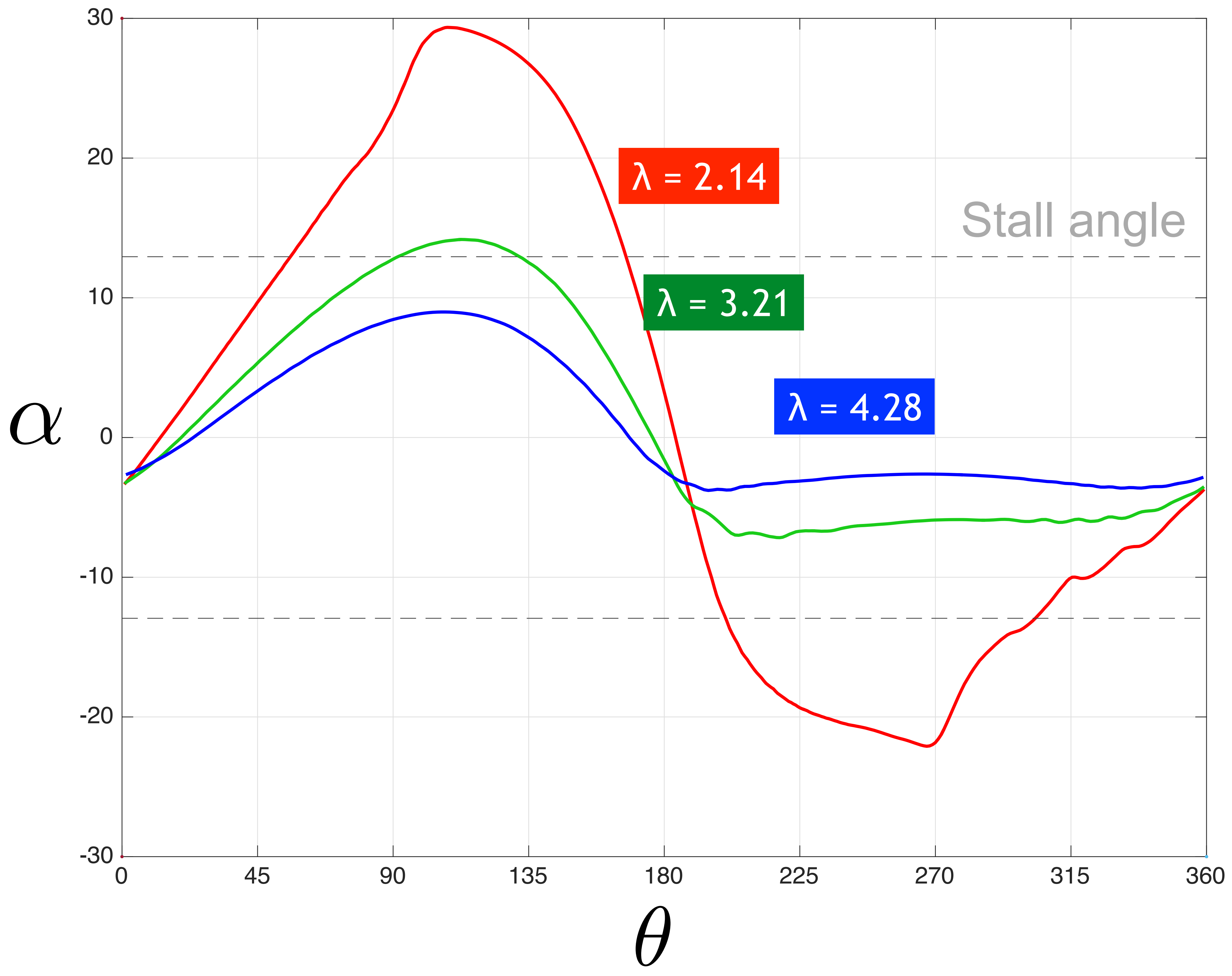
10MW generator (currents = 58 A/mm^2), Suprapower project



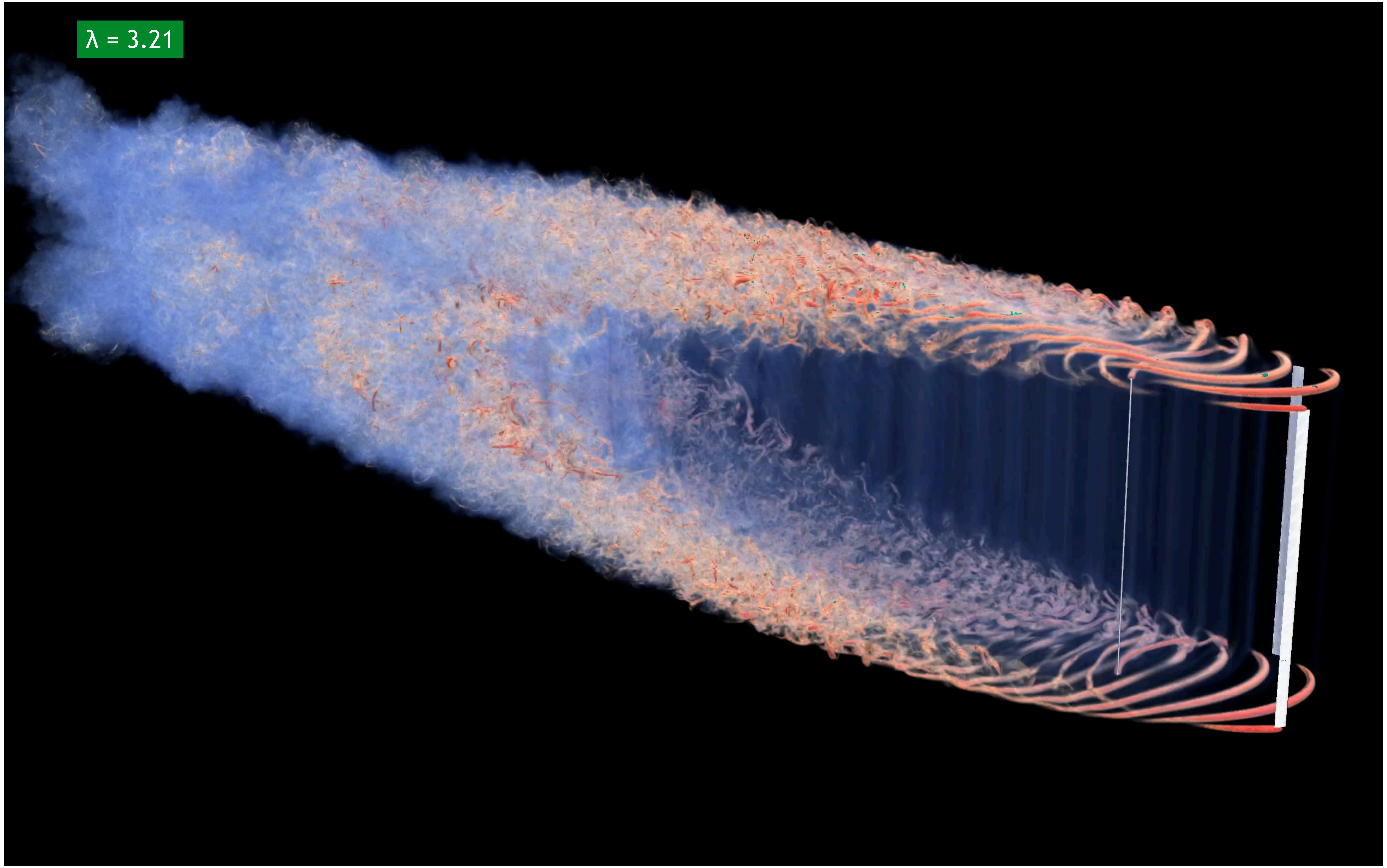
10MW Upwind turbine

Vertical Axis Wind Turbines

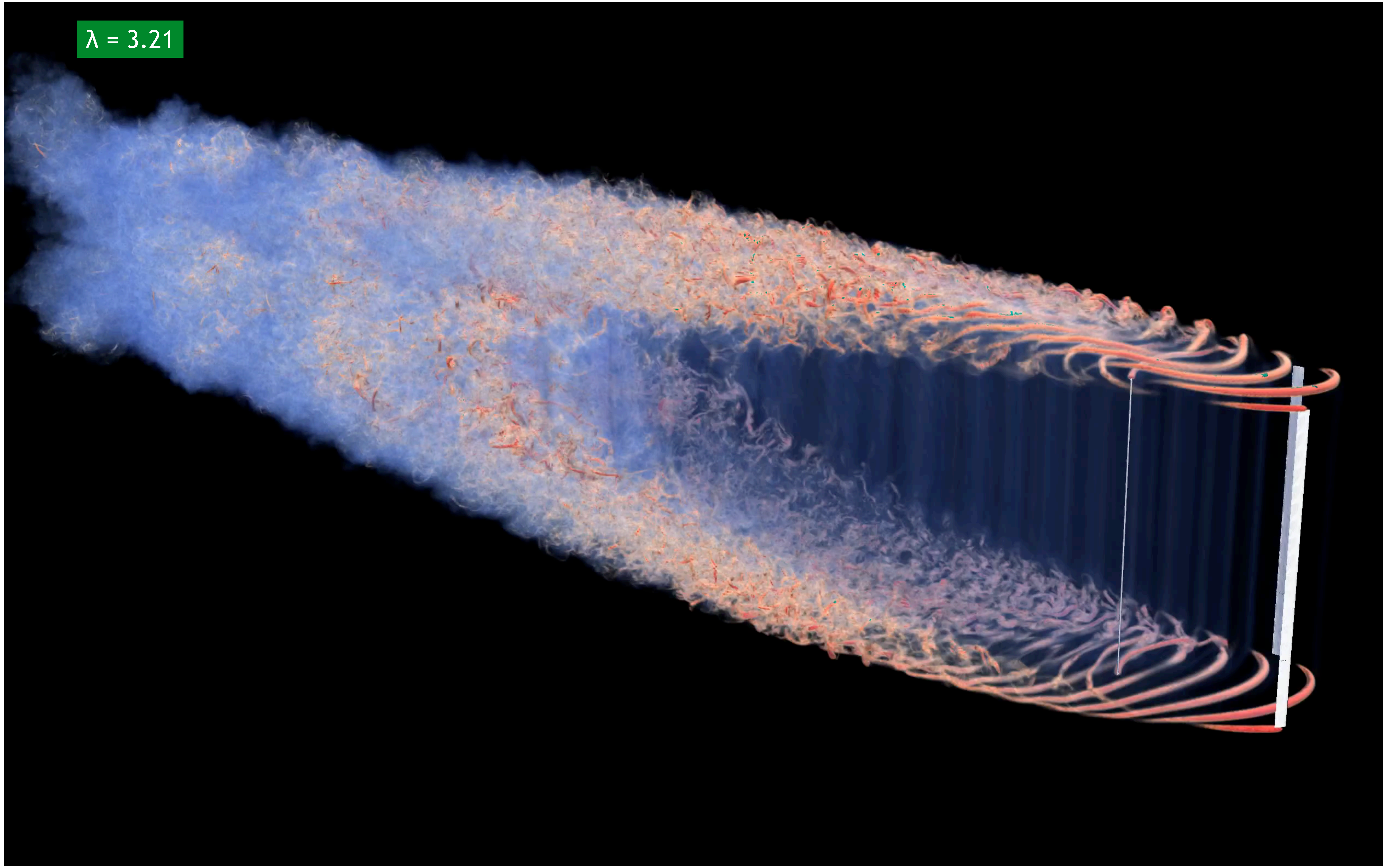
- Inherently unsteady aerodynamics
- Wake physics poorly known
  - Topology?
  - Decay mechanisms?
- Claims of faster decay enabling higher power densities for farms



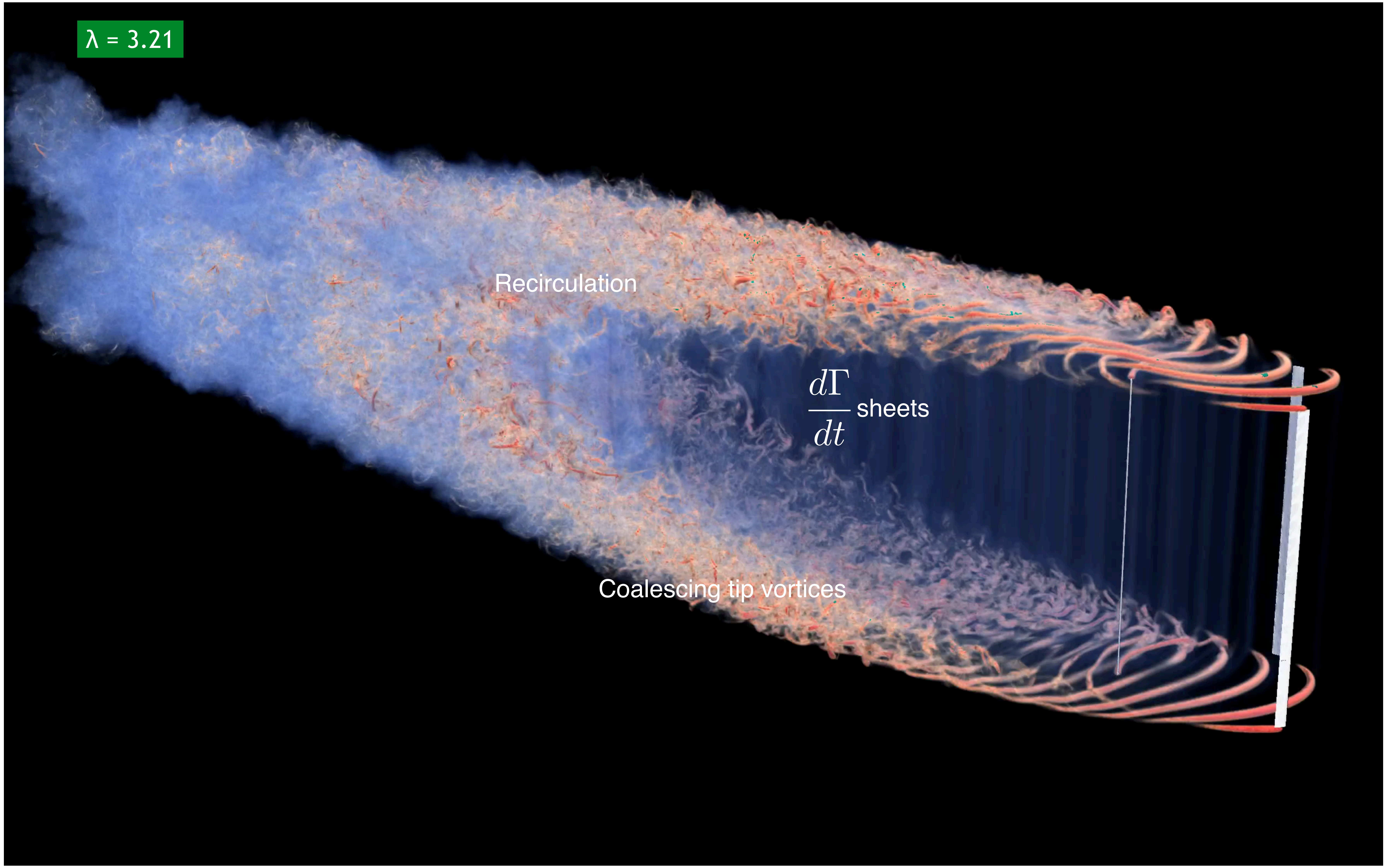
VAWT wake



VAWT wake

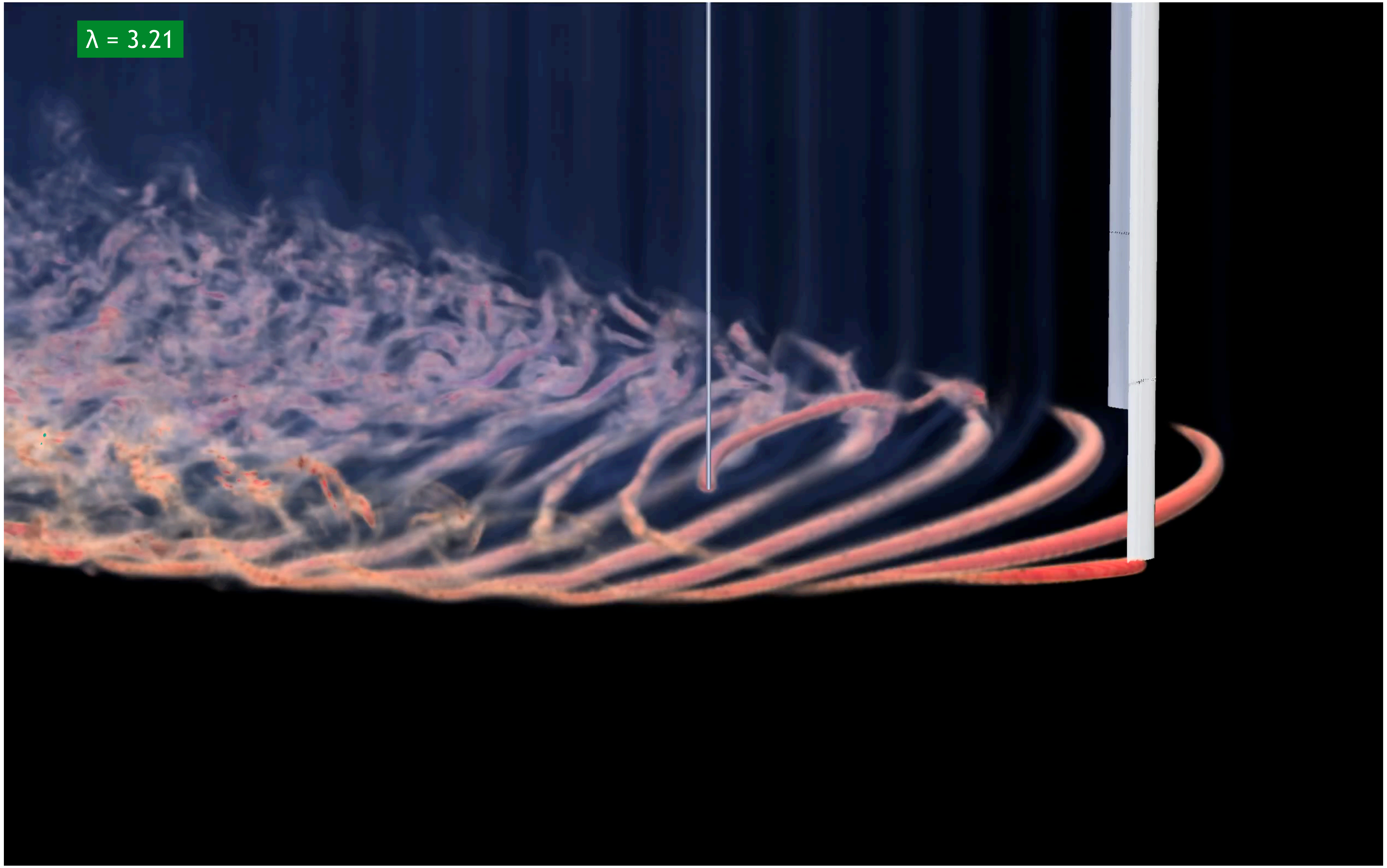


VAWT wake

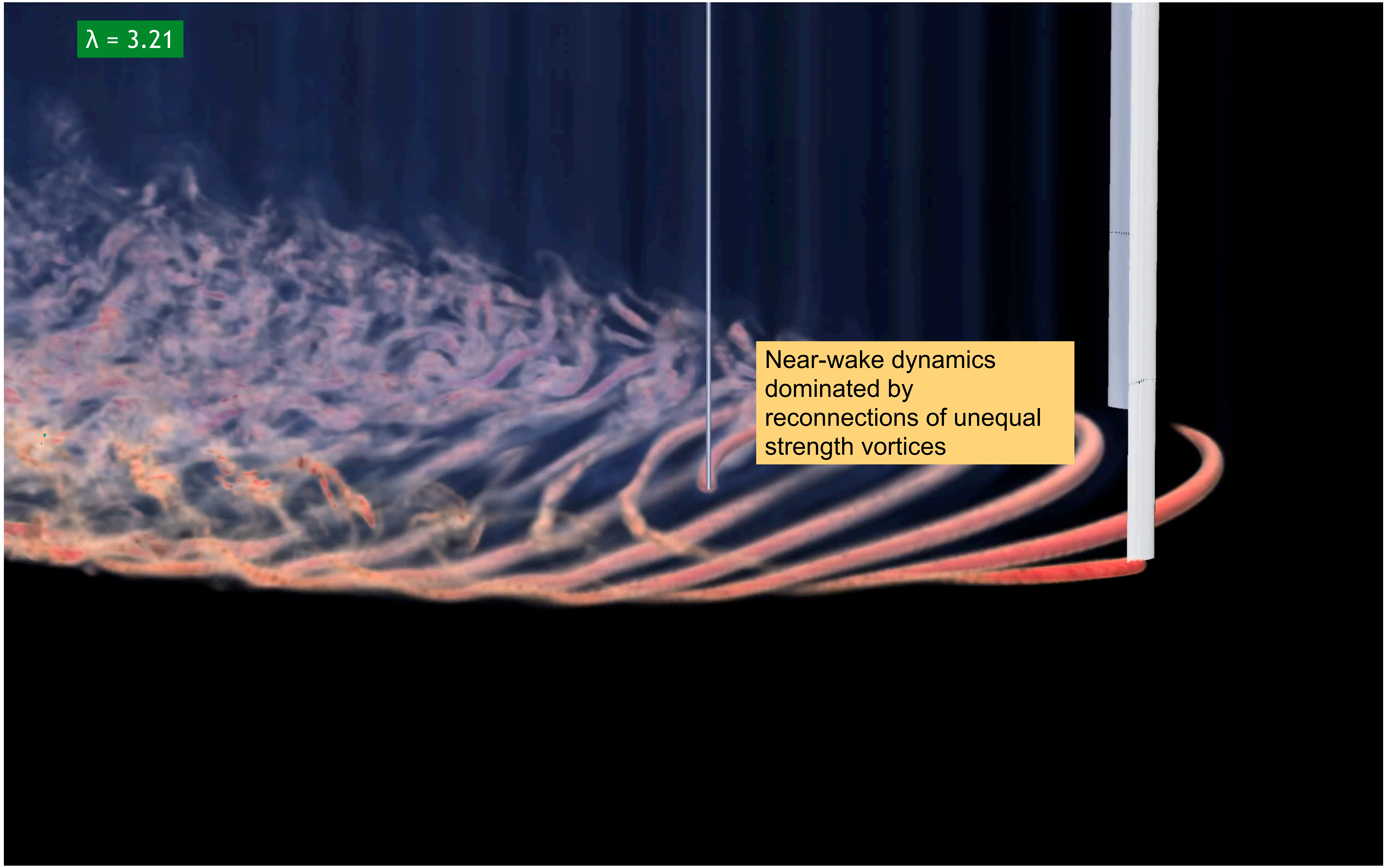


λ = 3.21
Recirculation
$\frac{d\Gamma}{dt}$ sheets
Coalescing tip vortices

VAWT wake

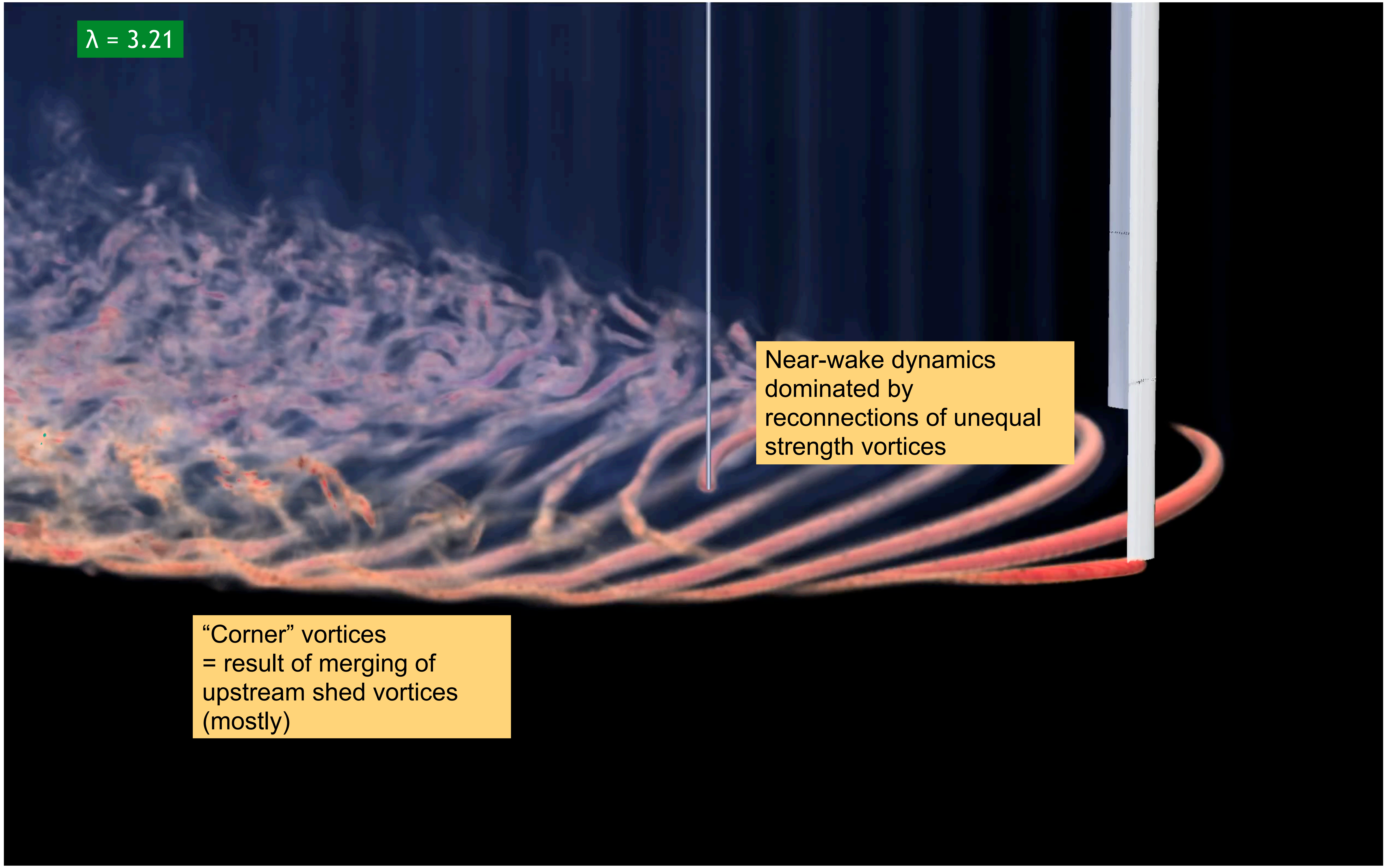


VAWT wake



λ = 3.21
Near-wake dynamics dominated by reconnections of unequal strength vortices

VAWT wake


λ = 3.21
Near-wake dynamics dominated by reconnections of unequal strength vortices
“Corner” vortices = result of merging of upstream shed vortices (mostly)

Vertical axis wind turbines for future large offshore farms

- Proposal for May 2012 call: 35 MCPUhours on Jugene (IBM BlueGene/P, Jülich SC) about to transition to Juqueen (IBM BlueGene/Q)
- Turbulent decay of wake of a single VAWT
- Scenarios with multiple machines interacting through their wakes

Consortium

- UCLouvain (Ph. Chatelain):
  - Numerical method: Vortex Particle-Mesh method and immersed lifting lines
  - its massively parallel implementation
- ETH Zurich (P. Koumoutsakos)
  - Open-source Parallel Particle-Mesh (PPM) library
- IBM Research Zurich (A. Curioni)
- GE Global Research Munich (D. von Terzi)
  - Industrial back-up

Consortium

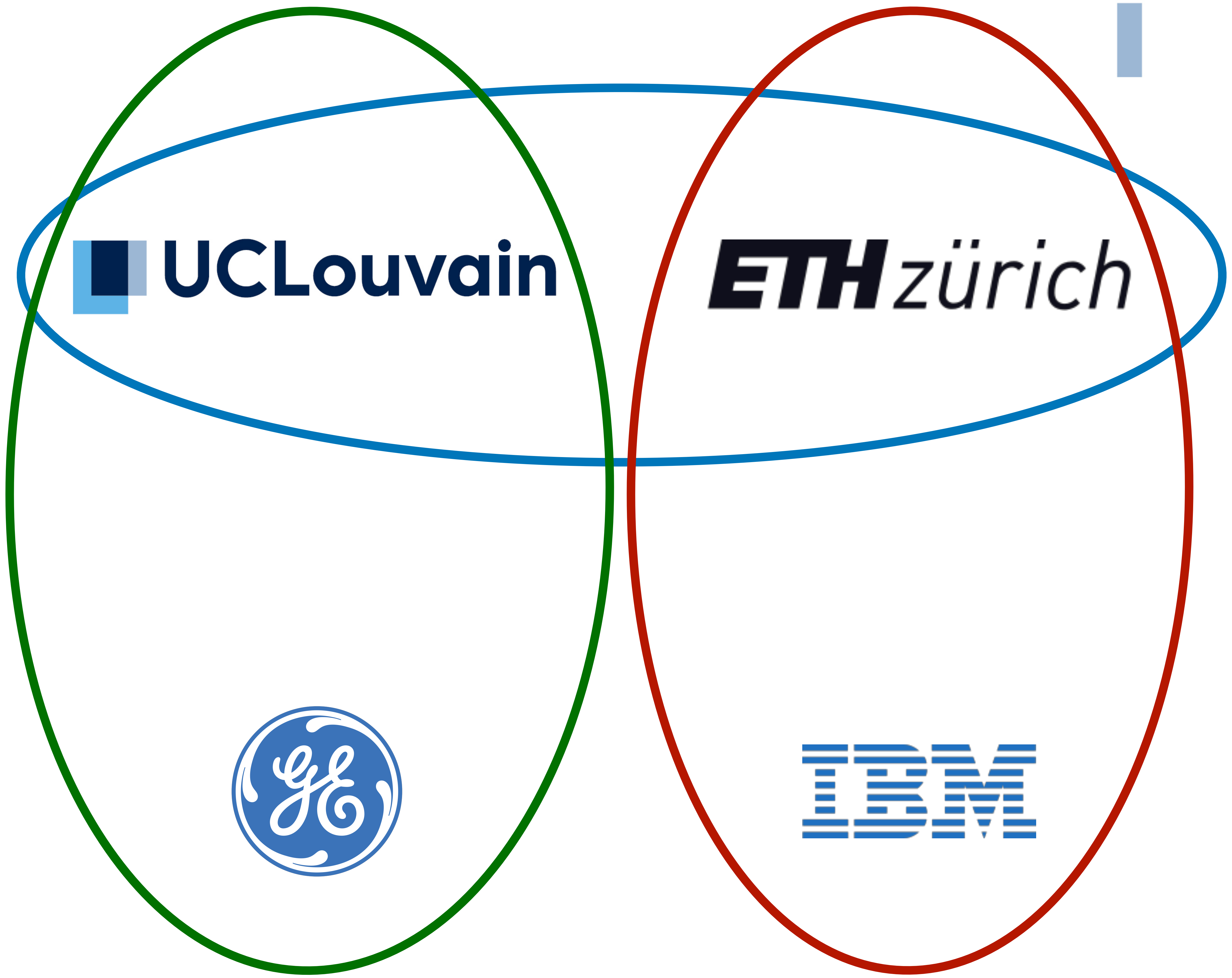
- UCLouvain (Ph. Chatelain):
  - Numerical method: Vortex Particle-Mesh method and immersed lifting lines
  - its massively parallel implementation
- ETH Zurich (P. Koumoutsakos)
  - Open-source Parallel Particle-Mesh (PPM) library
- IBM Research Zurich (A. Curioni)
- GE Global Research Munich (D. von Terzi)
  - Industrial back-up

Consortium

- UCLouvain (Ph. Chatelain):
  - Numerical method: Vortex Particle-Mesh method and immersed lifting lines
  - its massively parallel implementation
- ETH Zurich (P. Koumoutsakos)
  - Open-source Parallel Particle-Mesh (PPM) library
- IBM Research Zurich (A. Curioni)
- GE Global Research Munich (D. von Terzi)
  - Industrial back-up

Consortium

- UCLouvain (Ph. Chatelain):
  - Numerical method: Vortex Particle-Mesh method and immersed lifting lines
  - its massively parallel implementation
- ETH Zurich (P. Koumoutsakos)
  - Open-source Parallel Particle-Mesh (PPM) library
- IBM Research Zurich (A. Curioni)
- GE Global Research Munich (D. von Terzi)
  - Industrial back-up



Consortium: existing collaborations

- UCLouvain - ETH Zurich

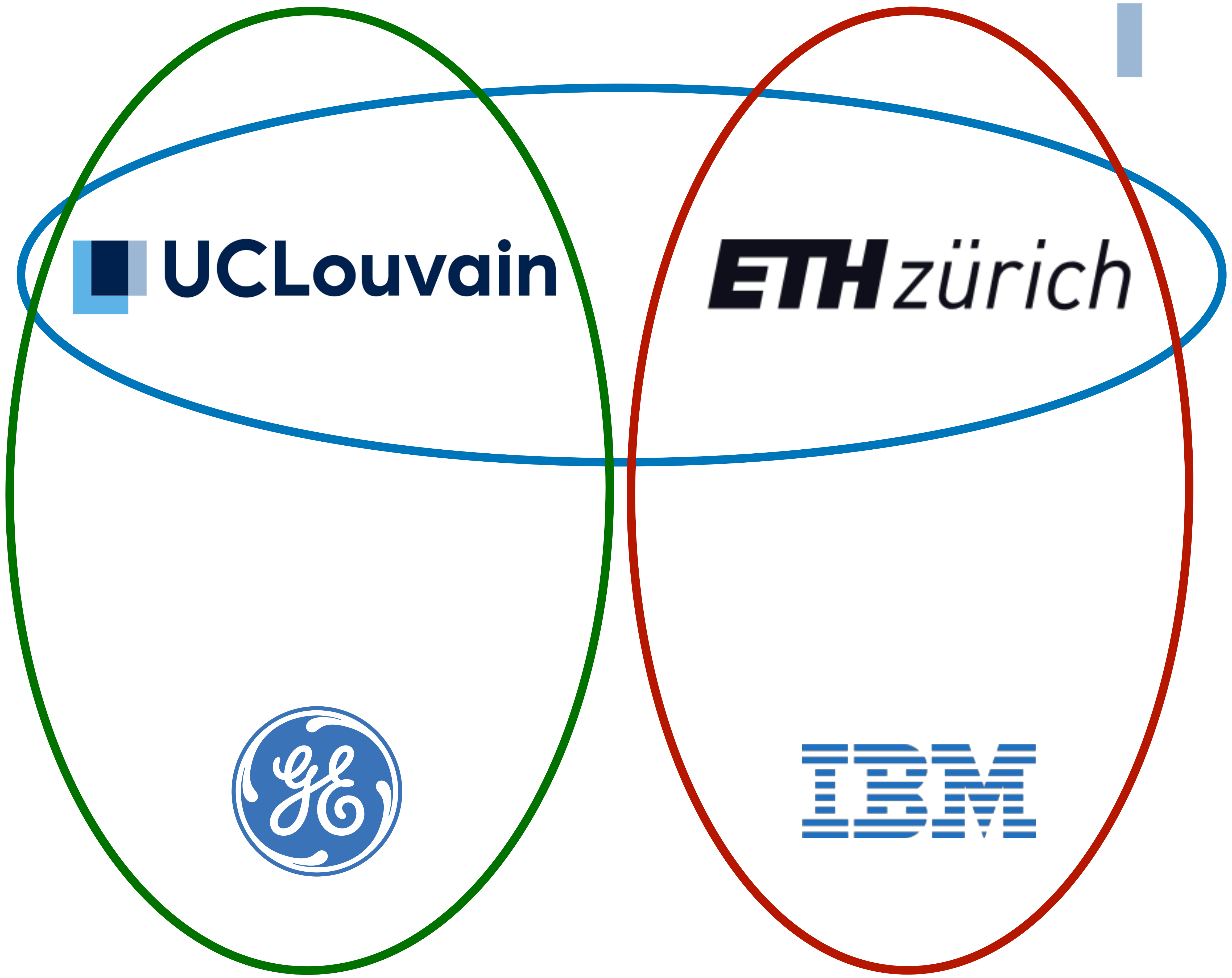
  Numerical method - implementation

- UCLouvain - GE GR

  Application of VPM to wind turbine wakes

- ETH Zurich - IBM Zurich

  Software deployment on IBM BlueGene architectures

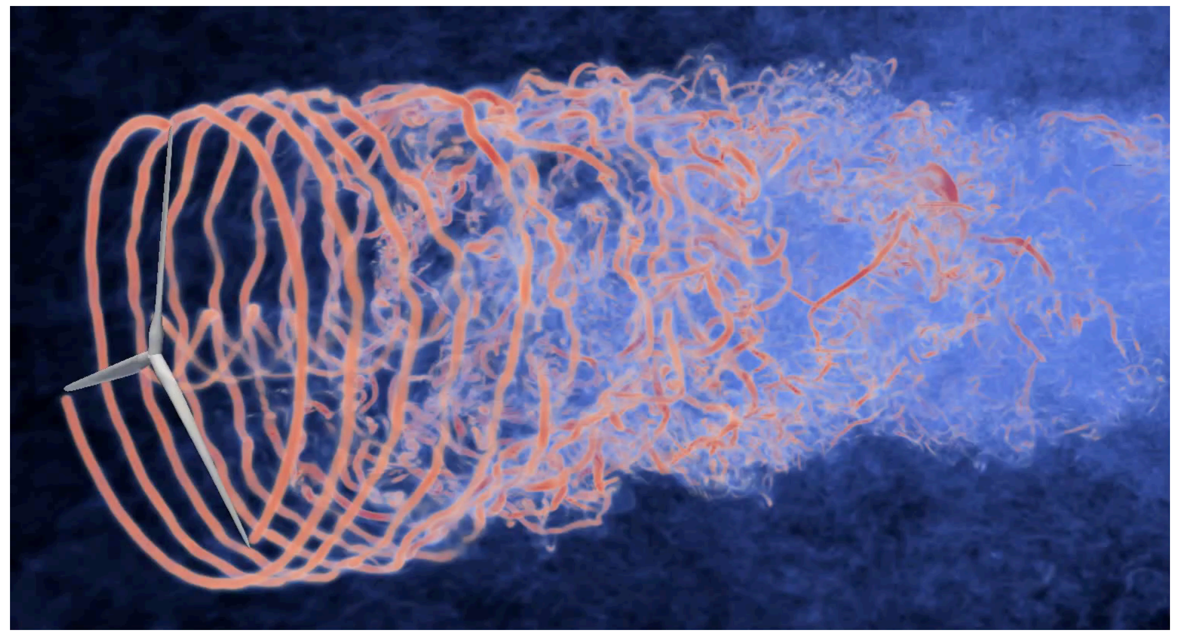


Proposal writing: technical justifications

- Scientific challenges
  - insights into decay of VAWT turbulent wakes
  - power production of arrays of interacting VAWTs
- Societal impact and timeliness
  - Potential game-changer for wind energy
  - Low carbon economy

Proposal writing: justifications

- Methodological adequacy
  case for VPM method in large-scale simulation of vortex dynamics, wind turbine and aircraft wakes
- Software readiness
  - Proof-of-concept runs
  - Scalability tests already performed on BGP architecture
  - Production campaigns on BGP (up to 32k cores)
- In-situ processing not ready but proposed as collaboration work with Jülich SC



# cores	256	512	1024	2048	4096	8192	16384
absolute timing (s)	254.39	253.54	261.22	261.39	263.21	269.17	273.86
η_{weak}	1	1.003	0.974	0.973	0.967	0.945	0.929

Table 1: Time per timestep for the weak scaling runs on the BG/P

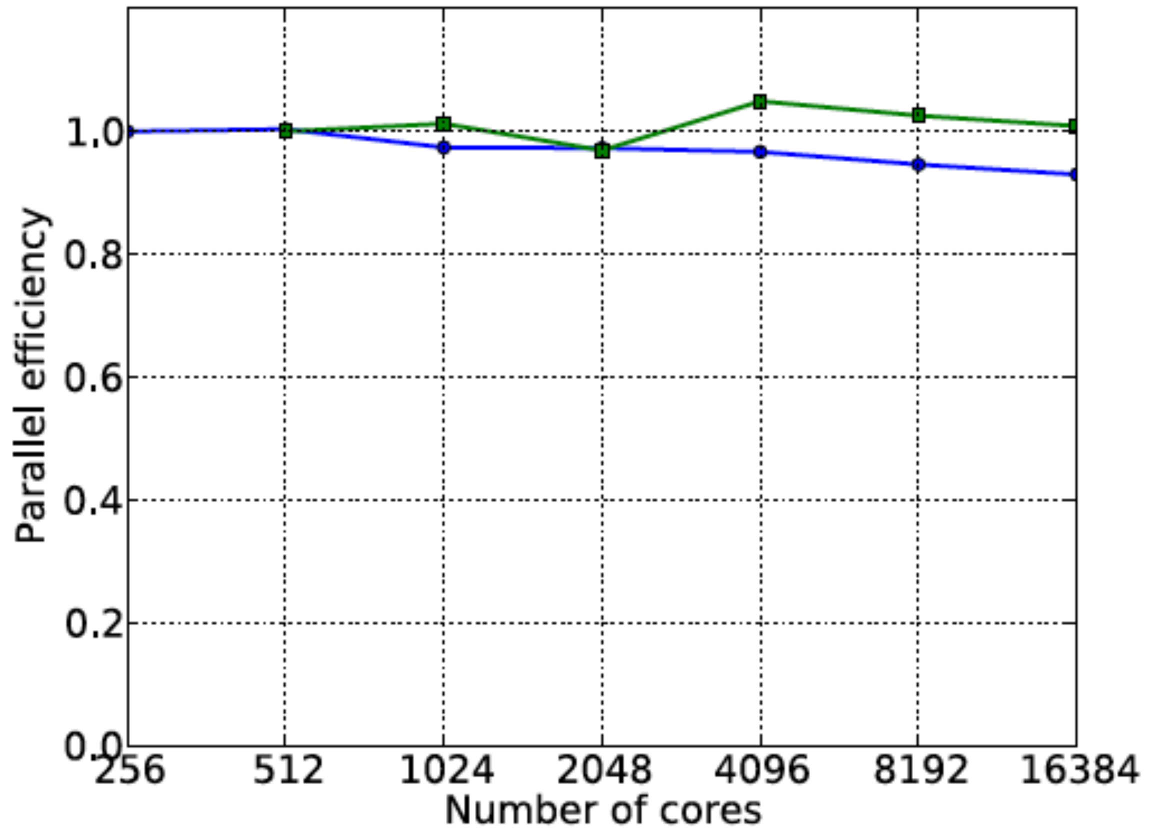


Figure 2: Weak (blue) and strong (green) scalability of the vortex client on BG/P

Proposal writing: justifications

- Methodological adequacy
  case for VPM method in large-scale simulation of vortex dynamics, wind turbine and aircraft wakes

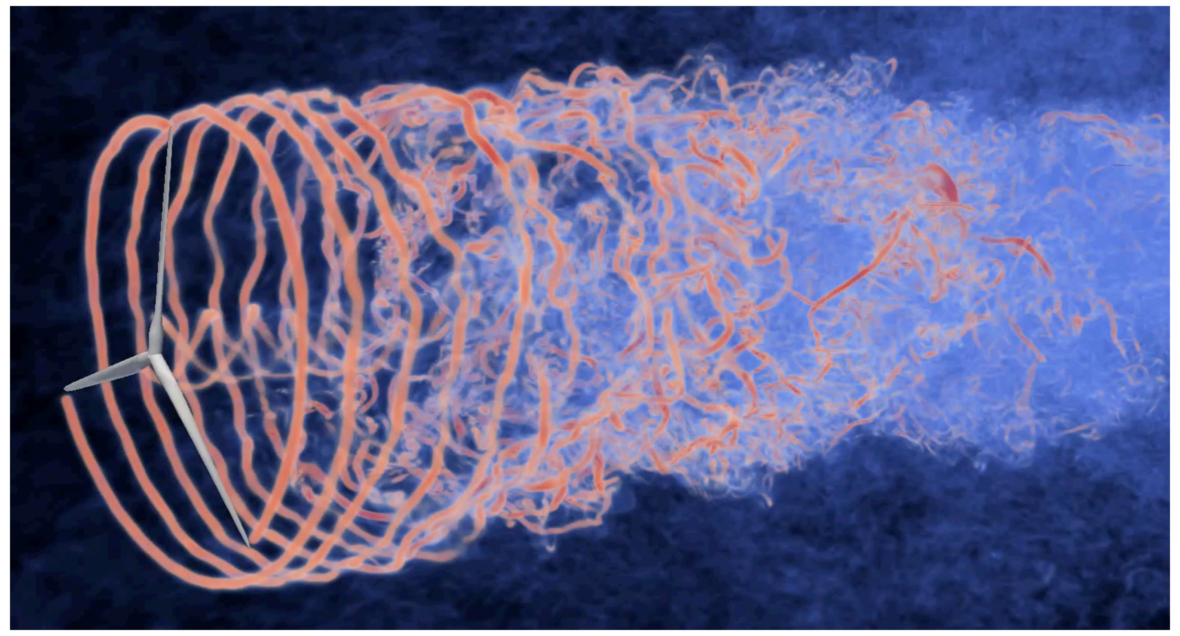
- Software readiness

  - Proof-of-concept runs

  - Scalability tests already performed on BGP architecture

  - Production campaigns on BGP (up to 32k cores)

- In-situ processing not ready but proposed as collaboration work with Jülich SC



# cores	256	512	1024	2048	4096	8192	16384
absolute timing (s)	254.39	253.54	261.22	261.39	263.21	269.17	273.86
η_{weak}	1	1.003	0.974	0.973	0.967	0.945	0.929

Table 1: Time per timestep for the weak scaling runs on the BG/P

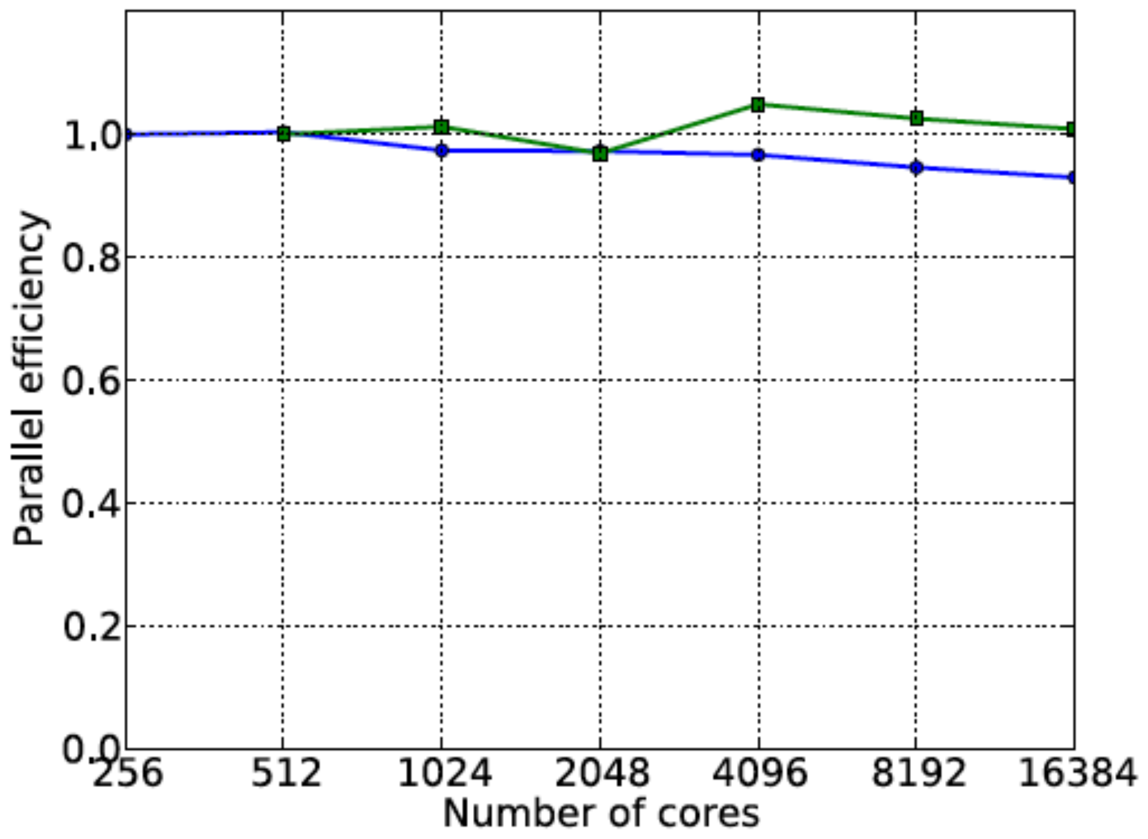


Figure 2: Weak (blue) and strong (green) scalability of the vortex client on BG/P

Proposal writing: resource justification

- Detailed plan of production campaign
  Run type, number
- Leveraging scalability studies to provide CPU costs
- Also memory and storage footprints
- Include deployment/test/scalability checks
- No preparatory calls yet back in 2012

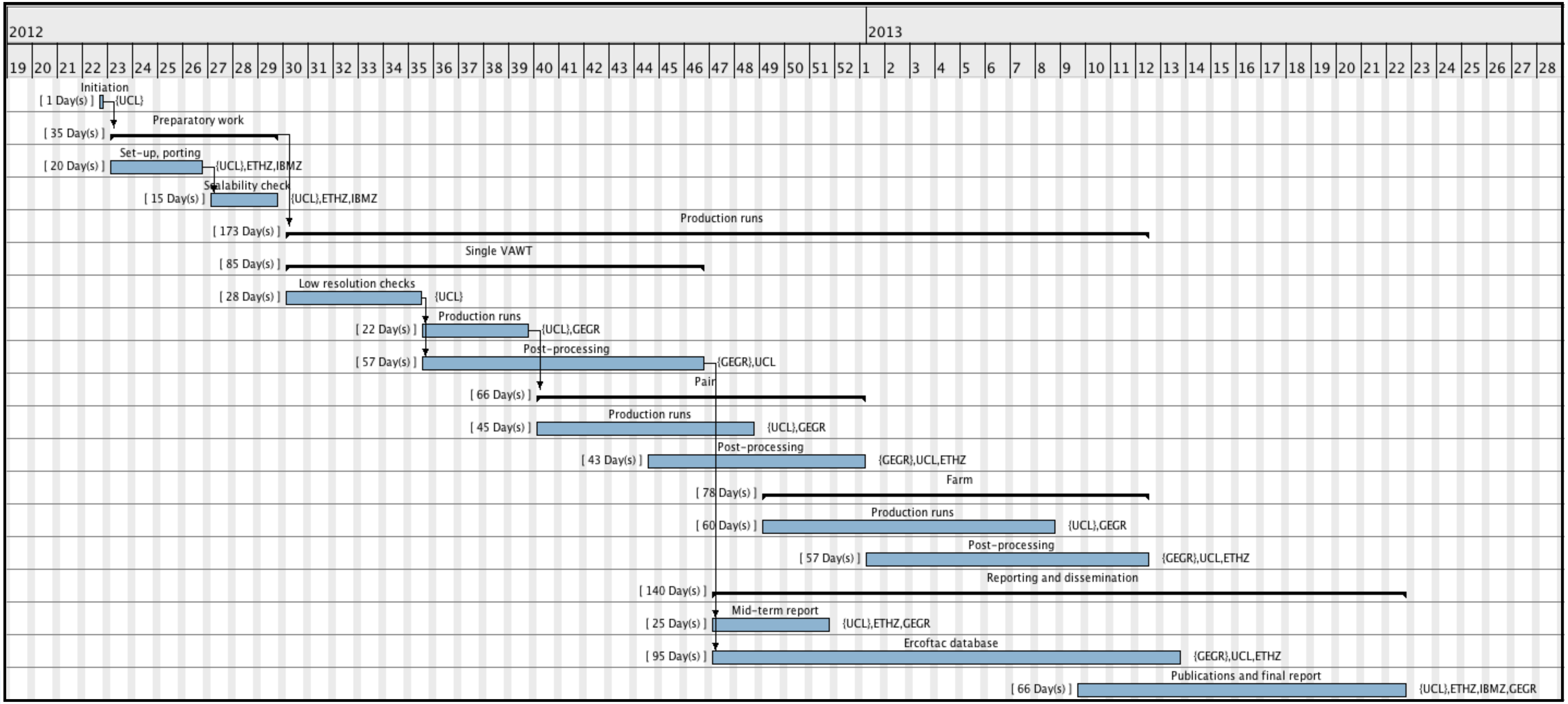
Run type	# points per D	Domain length (D)	Grid
Single_0	160	8	512x512x1280
Pair_0	160	16	512x512x2560
Single_1	256	8	768x768x2048
Single_2, Pair_1	256	16	768x768x4096
Single_3	384	8	1024x1024x3072
Farm_1	256	16	768x512x4096
Farm_2	256	16	768x1024x4096
Farm_3	256	16	1024x2048x4096

Table 2: Run configurations

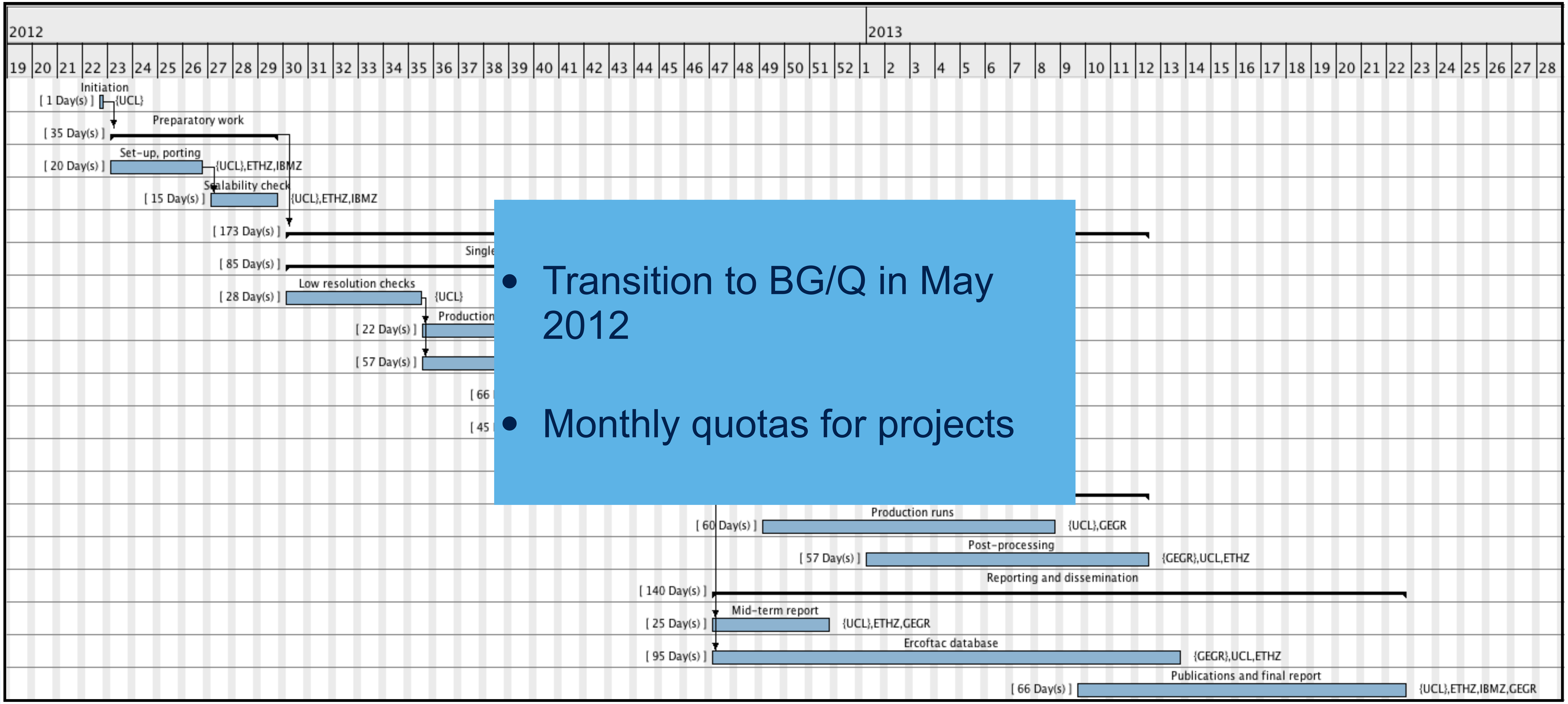
Run type	# Runs	# Steps/Run	Walltime/Step (s)	# CPU cores (/1024)	Total core hours/Type Run
Single_0	1	3.0E+04	5.0	4	1.7E+05
Single_1	1	3.0E+04	15.0	4	5.1E+05
Single_2	2	3.0E+04	17.0	8	2.3E+06
Single_3	1	4.5E+04	18.0	16	3.7E+06
Pair_0	1	3.0E+04	6.0	8	4.1E+05
Pair_1	4	3.0E+04	25.0	8	6.8E+06
Farm_1	2	3.0E+04	20.0	8	2.7E+06
Farm_2	2	3.0E+04	22.0	16	6.0E+06
Farm_3	2	3.0E+04	22.0	32	1.2E+07
TOTAL					*3.5E+07*

Table 3: Computational requirements

Proposal writing: Gantt chart



Proposal writing: Gantt chart



- Transition to BG/Q in May 2012
- Monthly quotas for projects

Reviews

- Technical (Gauss/Jülich SC): allocation strongly recommended
  - *IO loads of full 3D flow field dumps*: alleviation by coarsened/zoomed dumps, in-situ processing mentioned (although could not get it to work at JSC)
- Scientific (4 reviewers), salient points:
  - *No milestones in project planning*: clarification that each sub-campaign in fact entails production and basic post-processing as milestone
  - *Mention of preliminary scalability studies*: account for IO and application-specific effects on performance for more accurate evaluation of CPU costs
  - *Box size effects*: clarification that method entails no blockage effect (exact unbounded directions)
  - *For wakes, only large scales matter*: wake generated by fine blade-shed vortical structures, instabilities and merging lead to localized inverse cascade, crucial for decay

Reviews

- Technical (Gauss/Jülich SC): allocation strongly recommended
  - *IO loads of full 3D flow field dumps*: alleviation by coarsened/zoomed dumps, in-situ processing mentioned (although could not get it to work at JSC)
- Scientific (4 reviewers), salient points:
  - *No milestones* … s production and basic post-pro…
  - *Mention of pre* … ects on performance f…
  - *Box size effec* … ed directions)
  - *For wakes, or* … uctures, instabilities ar…

- 2 reviewers out of 4 familiar with our track record, very appreciative of proposed work
- 1 reviewer’s questions revealed lesser proficiency in vorticity-based methods, wakes, turbulence,…
- 1 reviewer’s questions focused on project planning, secondary aspects (dissemination),…

Conclusions

- This PRACE allocation was my 3rd attempt at call-based CPU allocation
  - First two attempts (PRACE and INCITE) focused on Clay Millenium problem: Navier-Stokes/Euler equations singularity
  - …met with quite antagonistic scientific reviews
  - (Four years later, PRACE grants Millenium problem-related allocation to Italian teams with questionable track-record and methodology)
- Success probably due to…
  - a good story
  - unquestionable scientific and societal impact
  - care in proposal writing with well laid out plan

UCLouvain