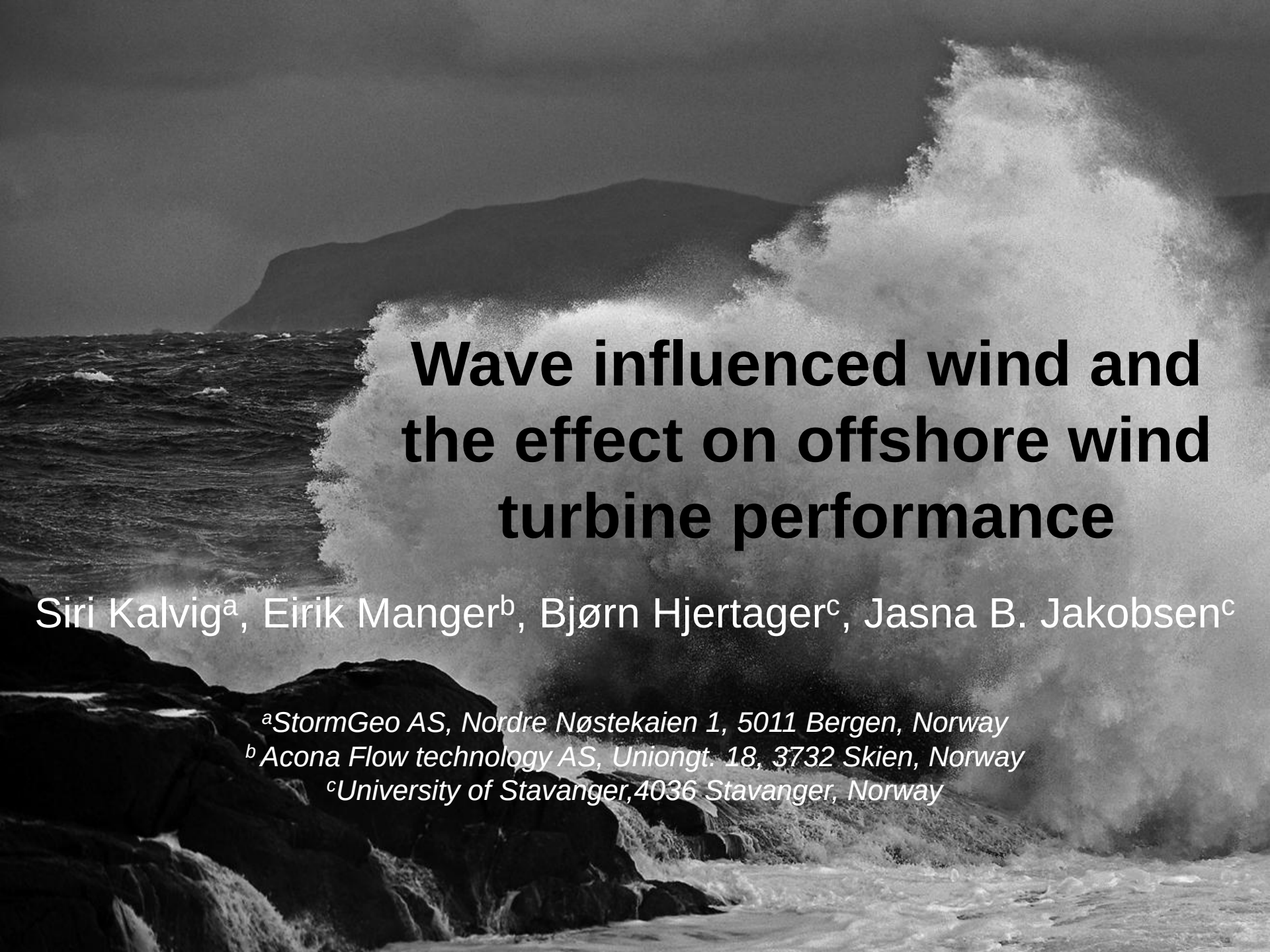

Wave influenced wind and the effect on offshore wind turbine performance

Siri Kalvig[a], Eirik Manger[b], Bjørn Hjertager[c], Jasna B. Jakobsen[c]

[a]*StormGeo AS, Nordre Nøstekaien 1, 5011 Bergen, Norway*
[b] *Acona Flow technology AS, Uniongt. 18, 3732 Skien, Norway*
[c]*University of Stavanger,4036 Stavanger, Norway*

Introduction

StormGeo
Control in a changing environment

- Motivation
- Wave influenced wind
- Wind turbine performance
- Method, WIWTS
- Results
- Conclusions & comments

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Motivation

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Statoil's Hywind Norway, Photo; Lene Eliassen

http://www.sorenlarsen.co.nz

- Will wave influenced wind at an offshore wind site result in different wind shear and more turbulence than expected ?
- And if so, how will this affect the turbines?

Wave influensed wind

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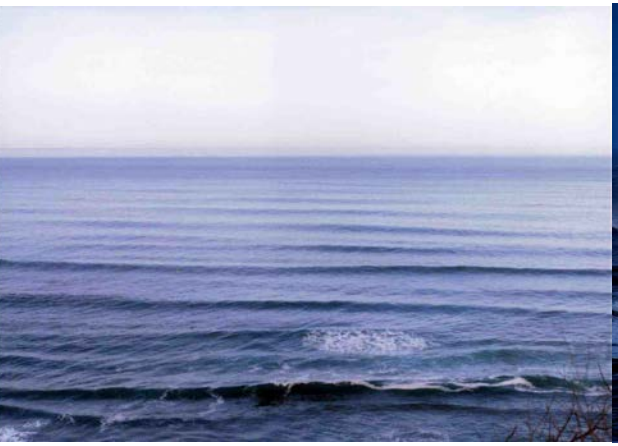
Wind sea and swell influences the atmosphere different!

Wind sea - waves generated by local wind
Swell - long period waves generated by distant storms

Most common is a mixture of wind sea and swell, and this makes the picture even more complicated.



Method – wave generation

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Need to simulate wave movements!

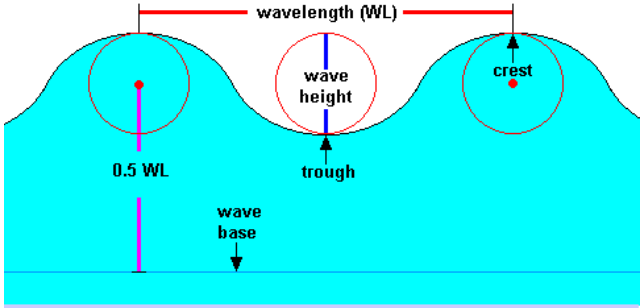
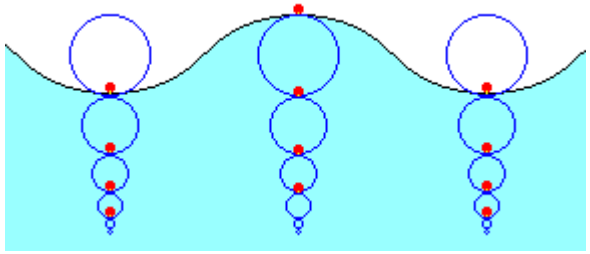
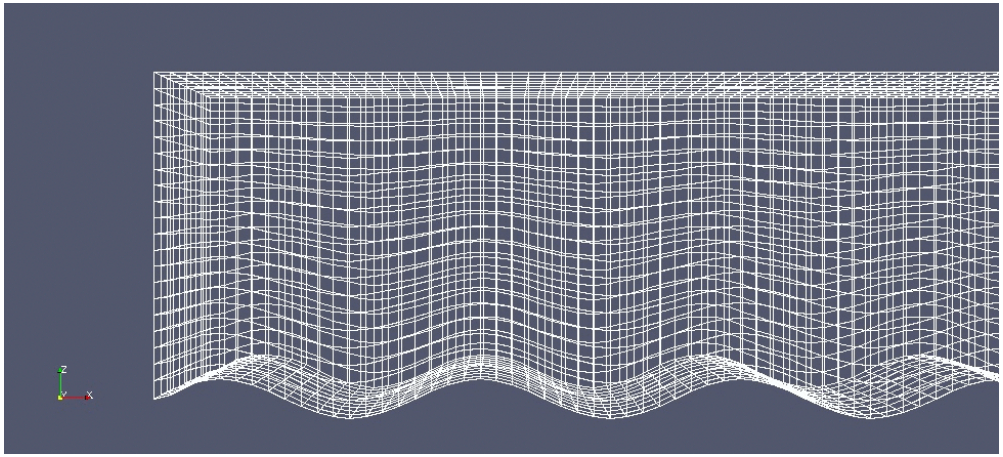


Figure 1. Depiction of deep water waves (water deeper than 0.5 WL).



From: Grand Valley State University, http://faculty.gvsu.edu/videticp/waves.htm

Need a new boundary condition that take into account the sinusoidal movement of the “ground”.



Method – wave generation

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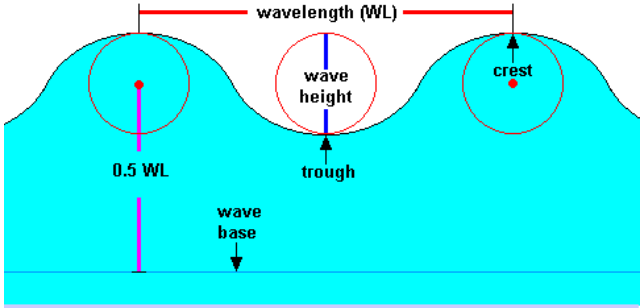

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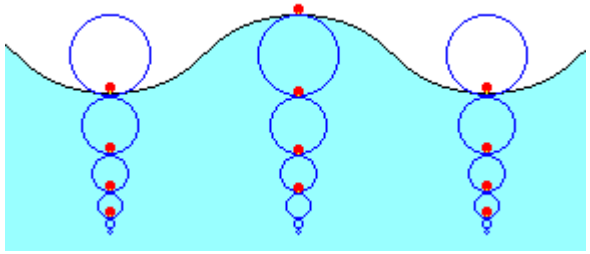
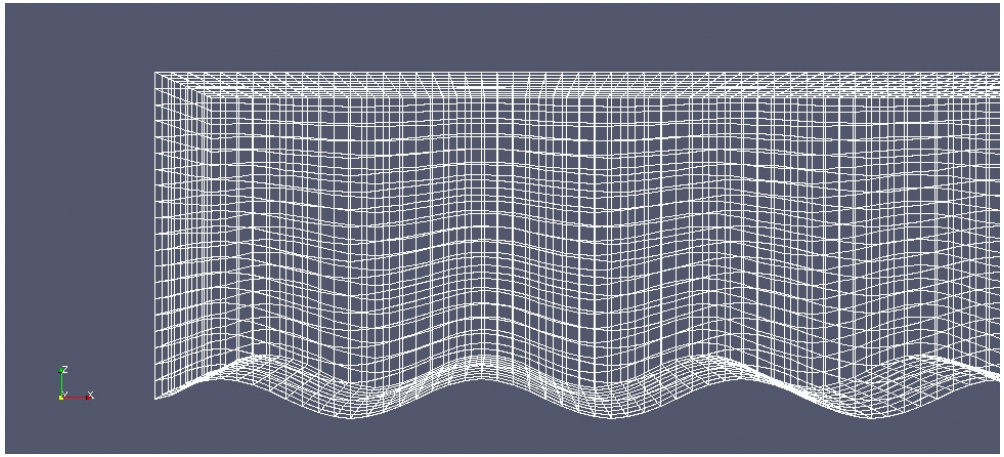


From: Grand Valley State University, http://faculty.gvsu.edu/videticp/waves.htm

Need a new boundary condition that take into account the sinusoidal movement of the “ground”.

Solution:
Transient OpenFOAM simulation with pimpleDyMFoam. New boundary condition implemented with mesh transformations.



Wave influenced wind

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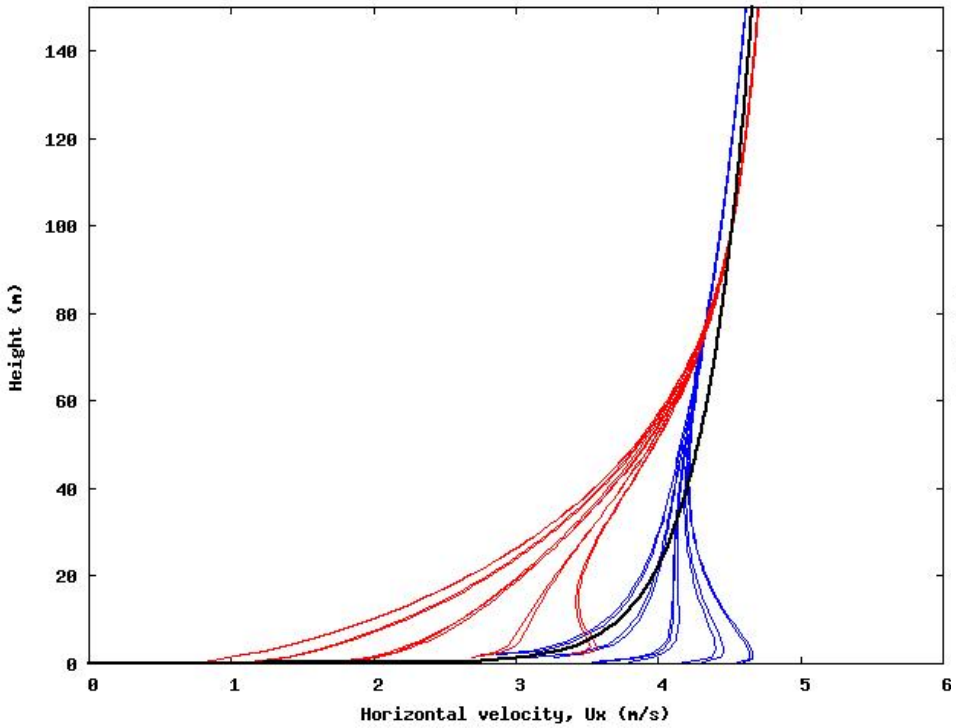
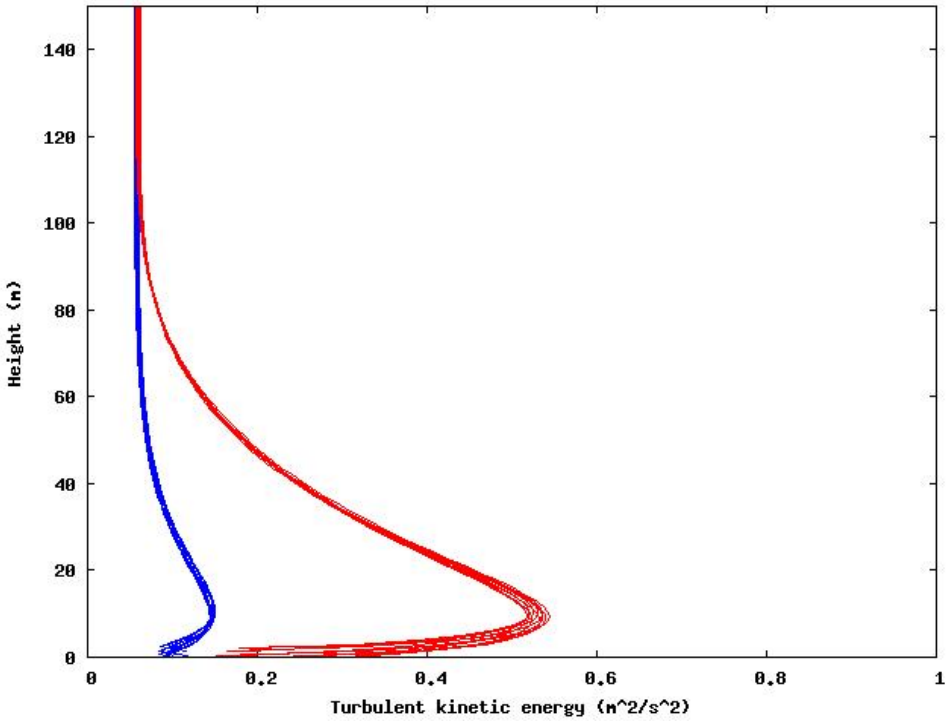
Control in a changing environment





Domain: 1200m x 25 m x 400 m
Logarithmic wind at inlet with U_{100m} =5 m/s, z_0=0.0002 m, U*=0.15 m/s. Wave with C=12,5 m/s, L=100 m, a=1,6 m

In general:

The wind speed profile and the turbulent kinetic energy pattern far above the waves will be different depending on the wave state and wave direction.

Method - Actuator line method in SOWFA

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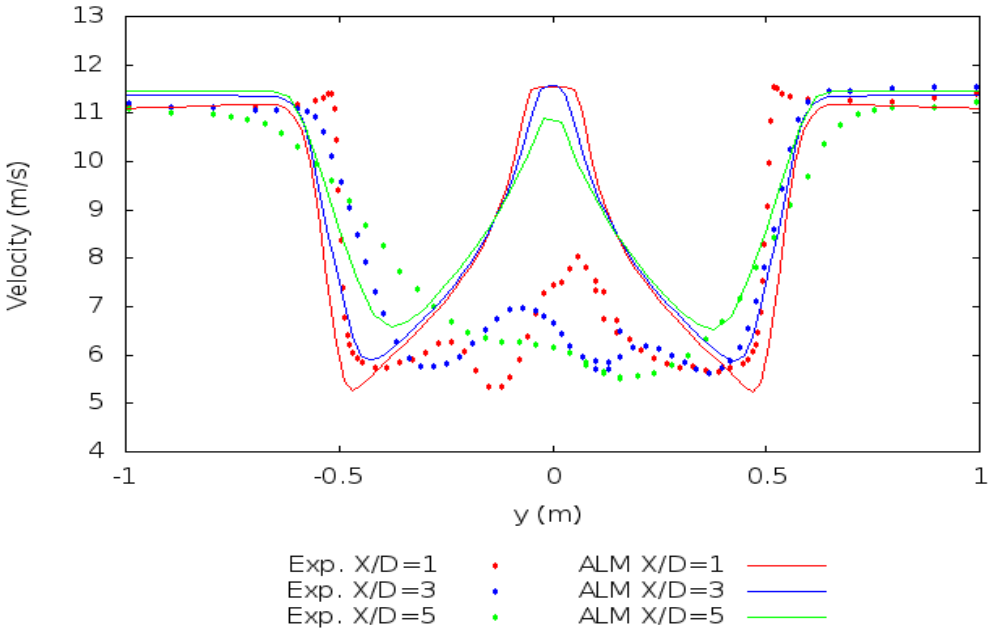
Actuator line method of Sørensen and Shen used in the
Simulator for Offshore Wind Farm Applications
SOWFA

Method - Actuator line method in SOWFA

StormGeo
Control in a changing environment



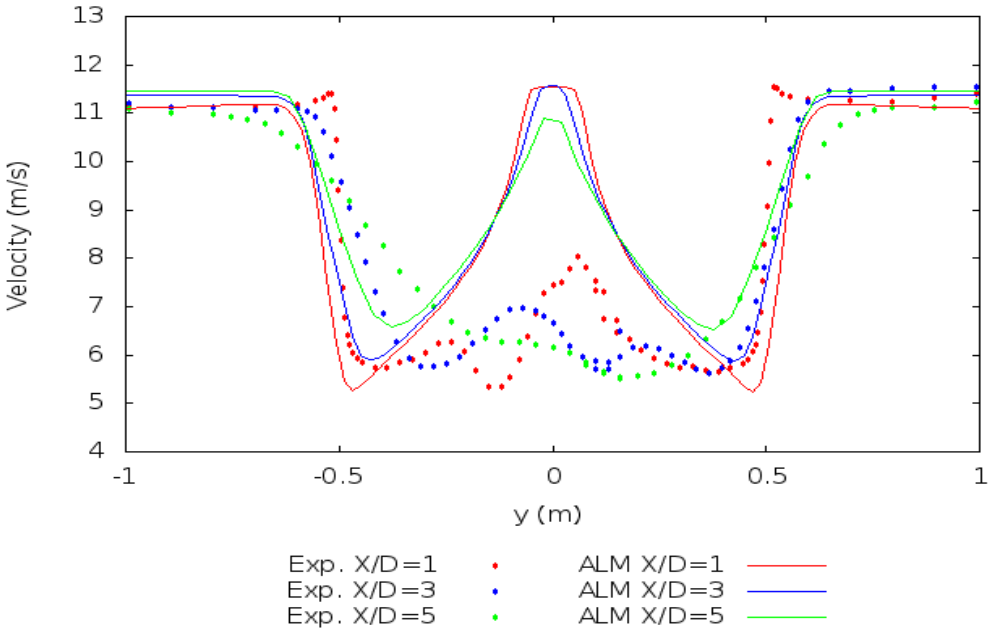
Testing the model:
Blind test1: NORCOWE & NOWITECH organized a wind turbine blind test in 2011-2012

Tip speed ratios		Experiment	FRM	Deviation	ALM	Deviation
3	C_P	0.12	0.23	91.6 %	0.17	43.3 %
	C_T	0.40	0.46	15.0 %	0.34	- 15.3 %
6	C_P	0.45	0.46	2.2 %	0.45	0.8 %
	C_T	0.92	0.85	- 7.6 %	0.86	- 6.7 %
10	C_P	0.20	0.16	- 20.0 %	0.04	- 80.1 %
	C_T	1.17	1.03	- 12.0 %	0.88	- 24.4 %

Table 1: Power coefficient (C_P) and thrust coefficient (C_T) from FRM and ALM simulations for different tip speed ratios (λ) are compared with experimental values.

Method - Actuator line method in SOWFA

StormGeo
Control in a changing environment



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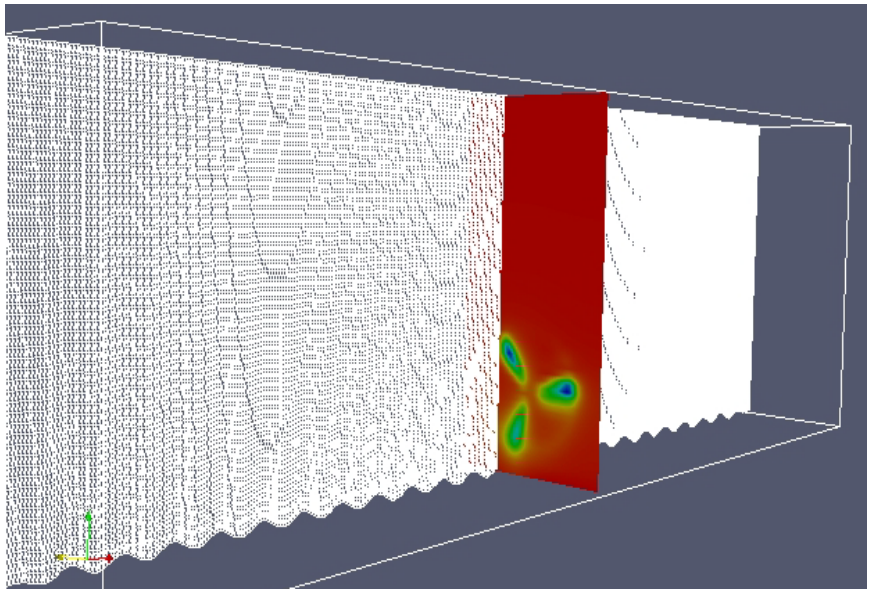
Method – combined set up - WIWTS

StormGeo
Control in a changing environment

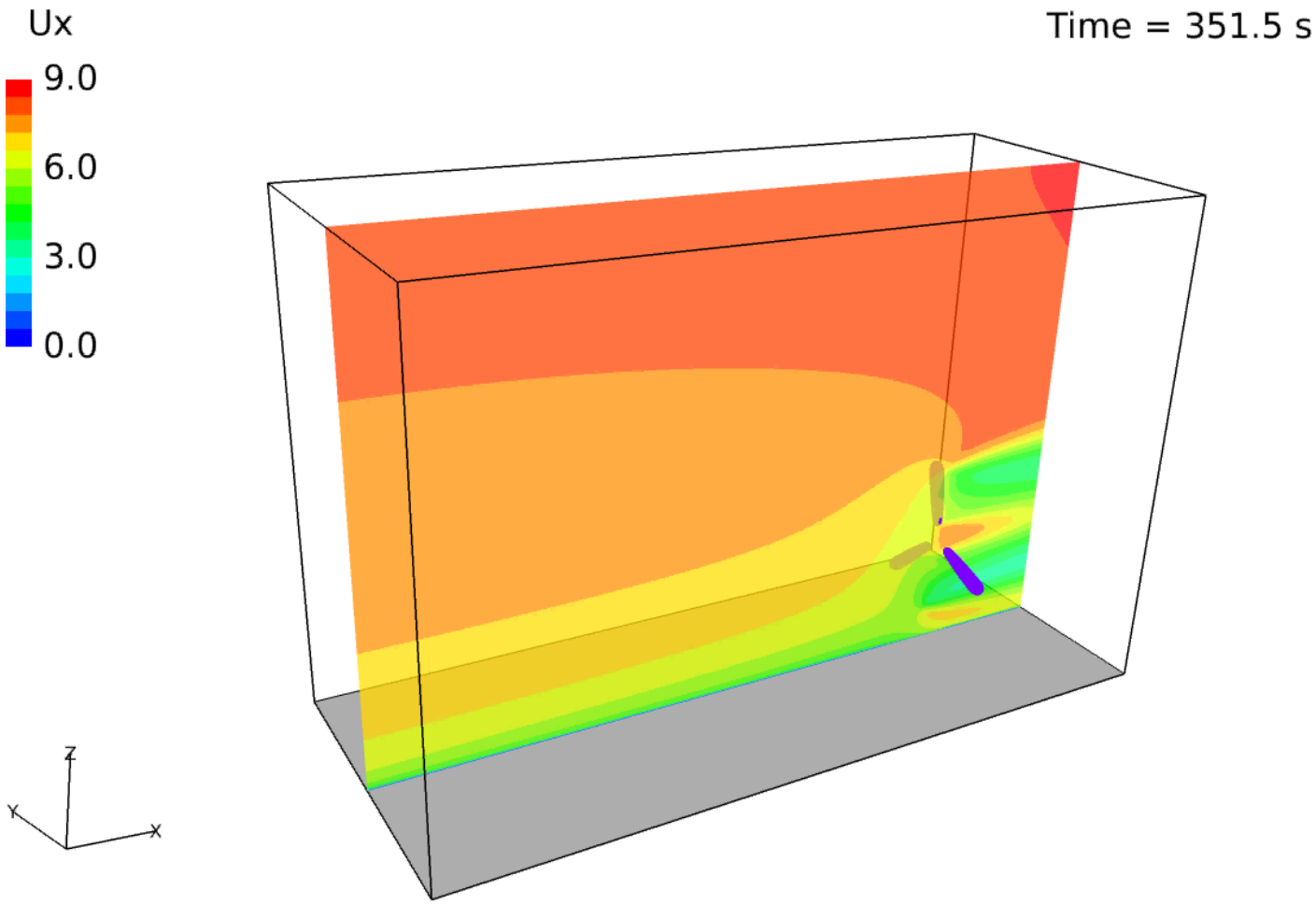
Wave simulations are combined with the actuator line simulations of SOWFA

Wave Influenced Wind Turbine Simulation
WIWTS



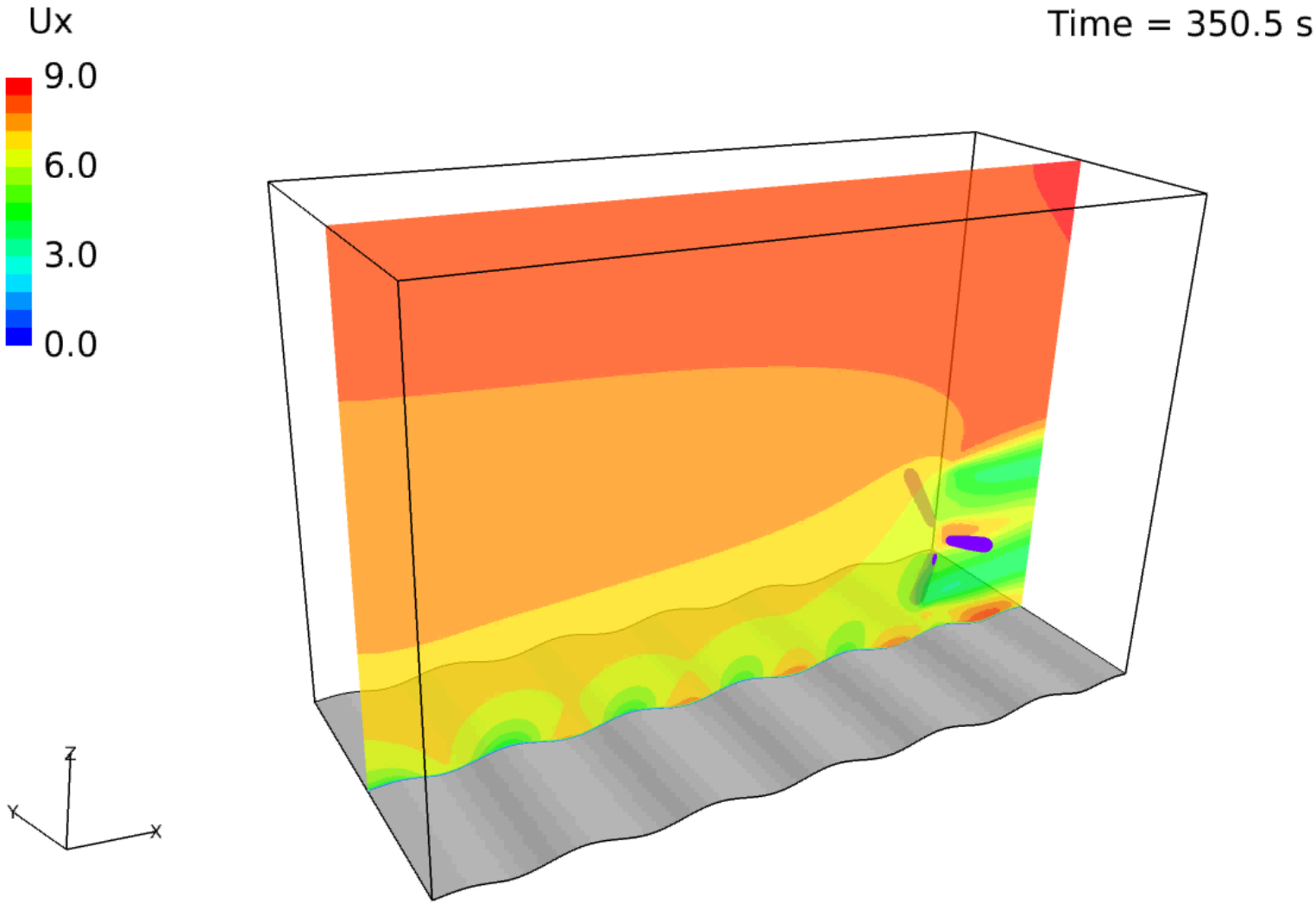
WIWTS

StormGeo
Control in a changing environment



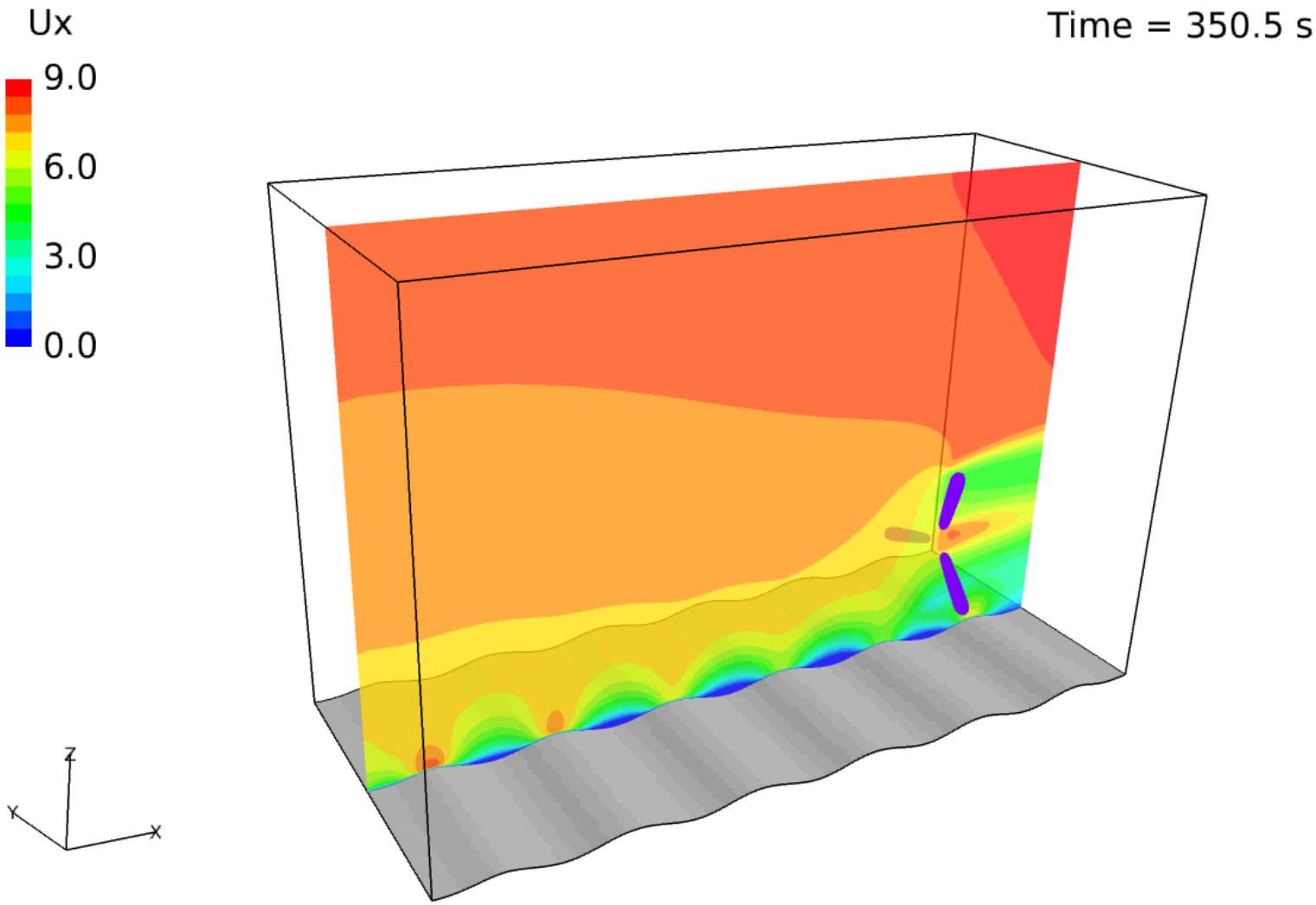
WIWTS

StormGeo
Control in a changing environment



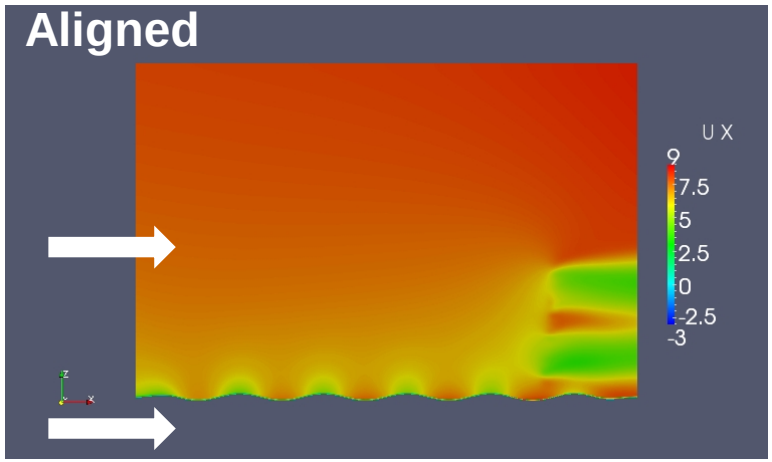
WIWTS

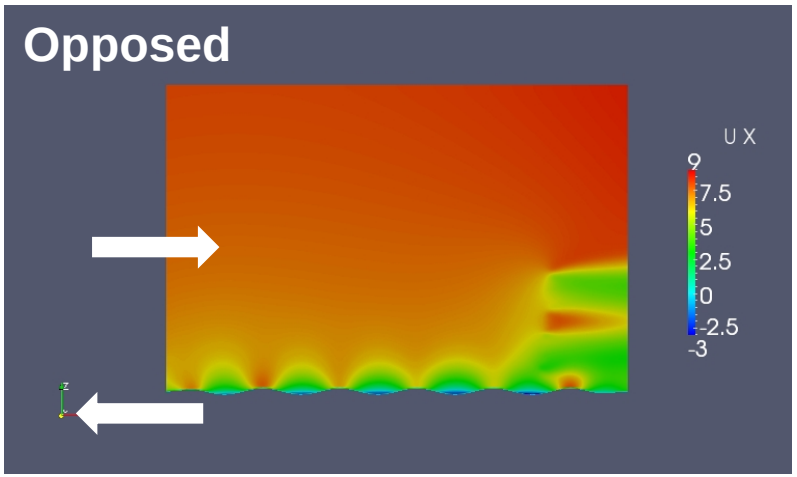
StormGeo
Control in a changing environment



WIWTS Results

StormGeo
Control in a changing environment

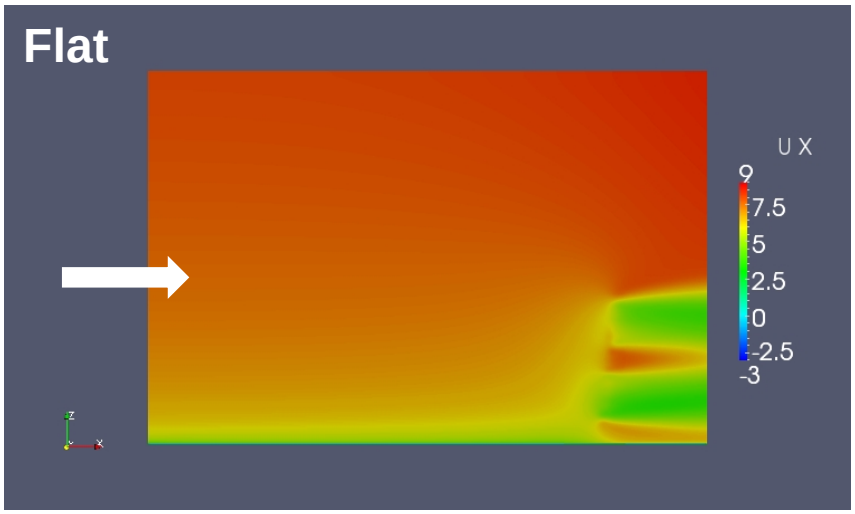




Domain: 600 x 260 x 400 m
Turbine in x=500

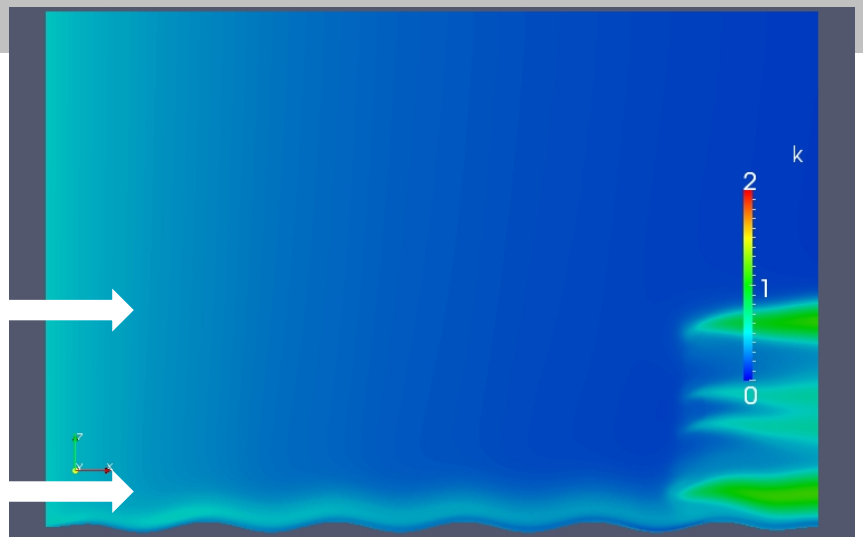
Wave:
Amplitude = 4 m
Length =100 m
c=12,5 m/s

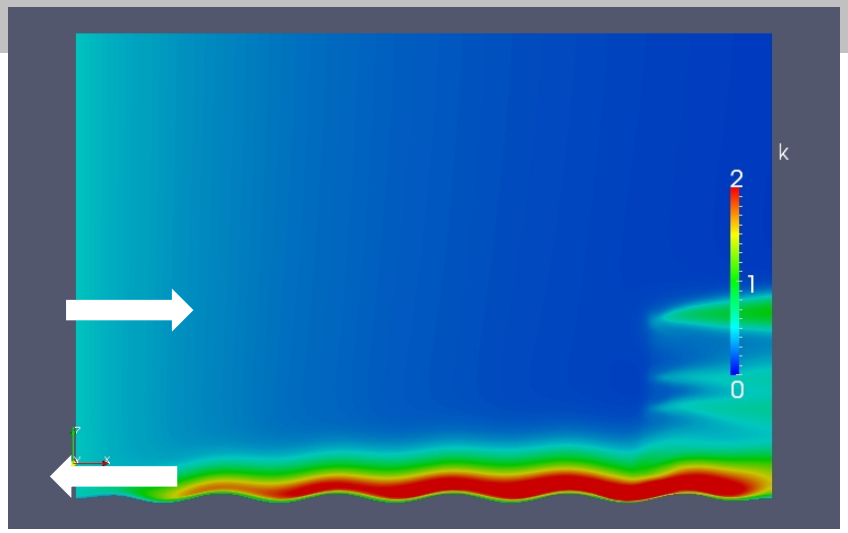
Wind = 8 m/s

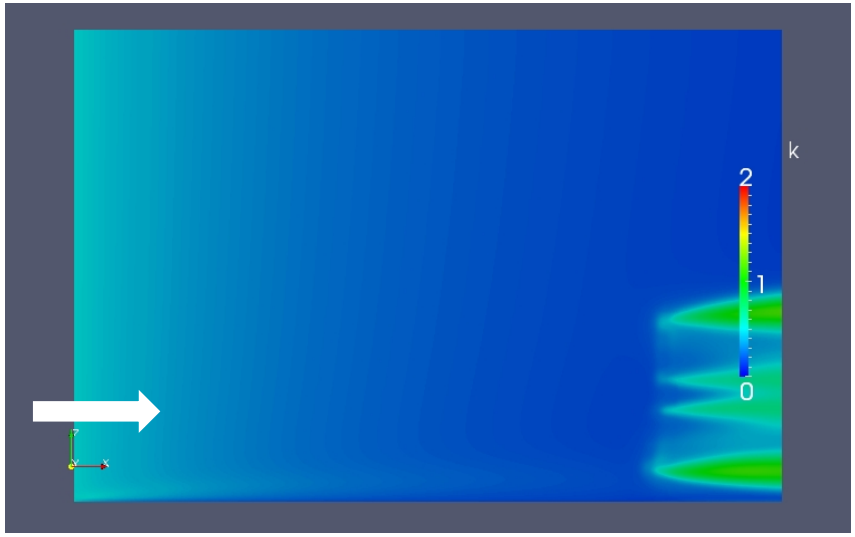


WIWTS Results

StormGeo
Control in a changing environment







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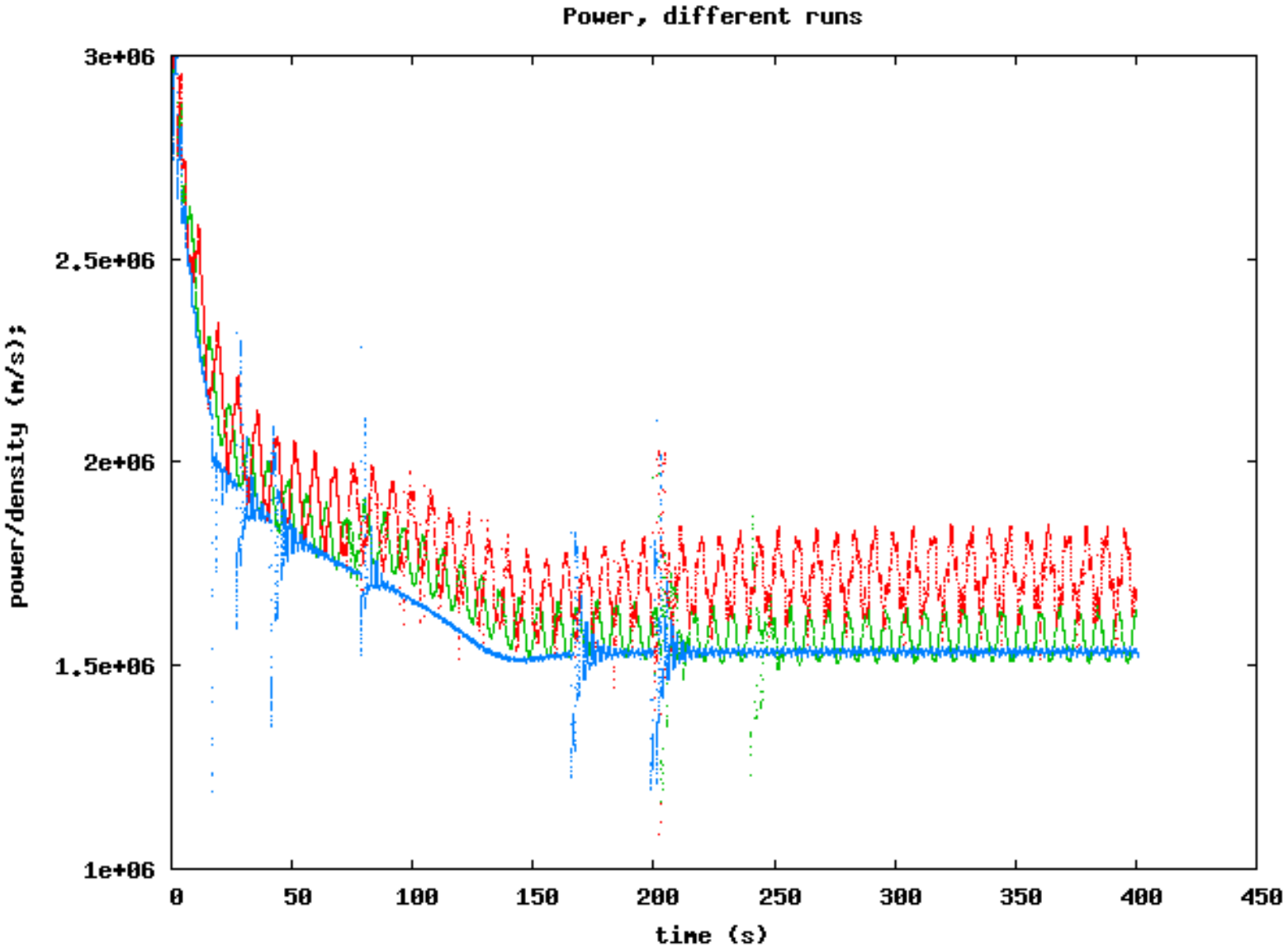
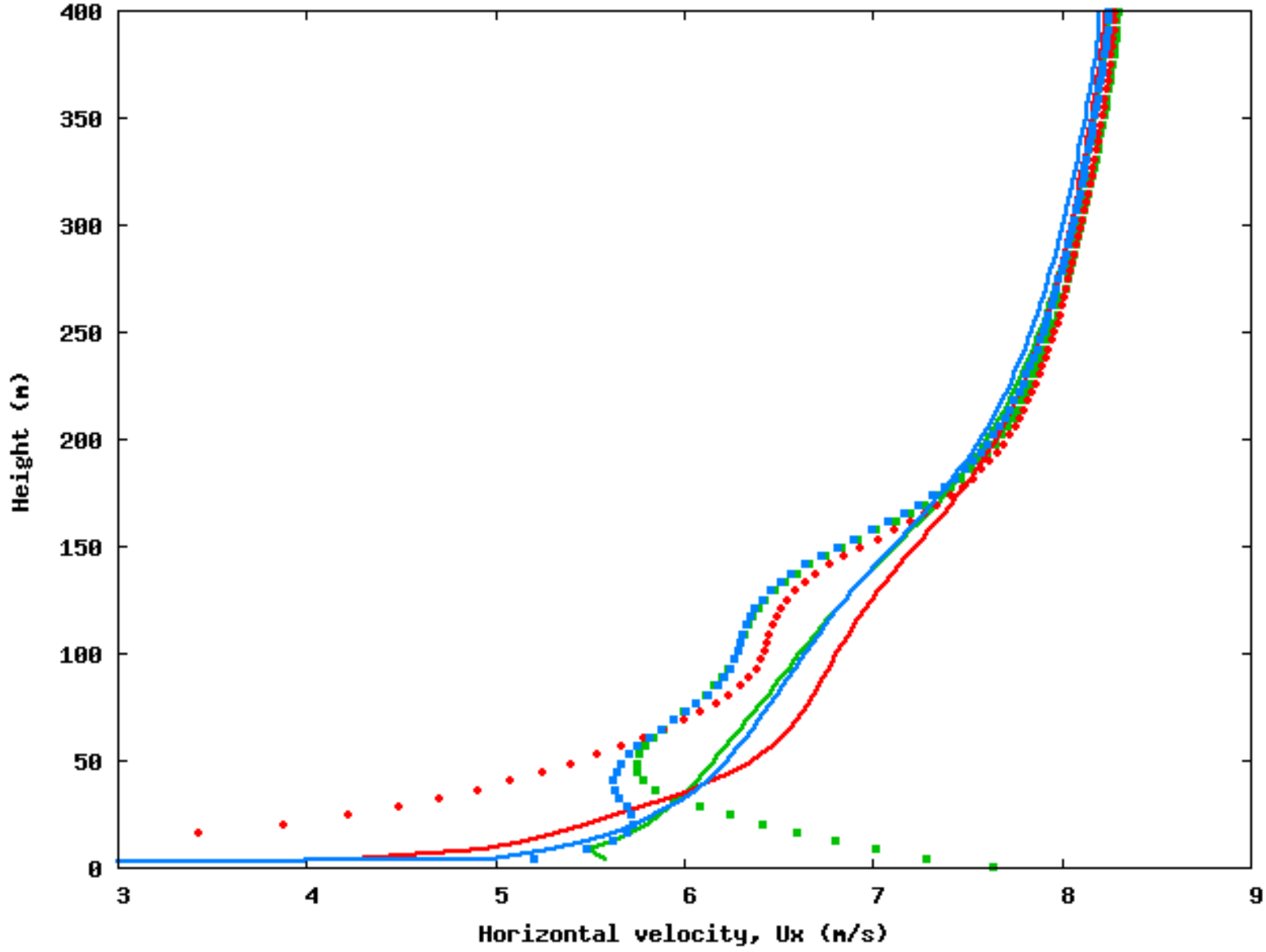
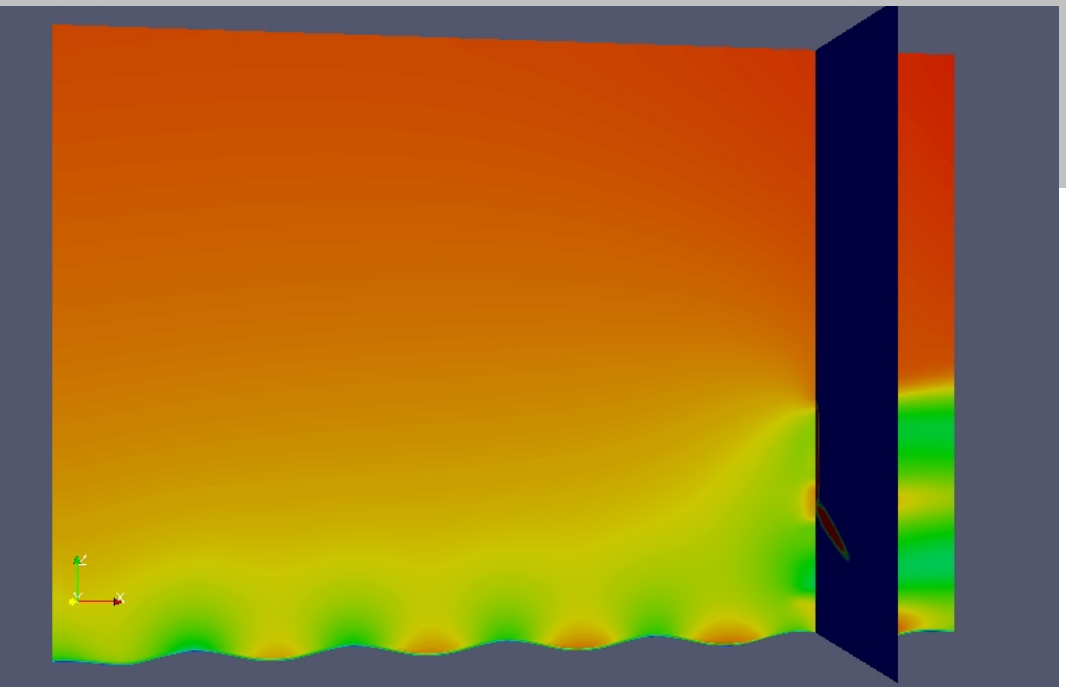

Power, different runs
power/density (m/s);
time (s)
3e+06
2.5e+06
2e+06
1.5e+06
1e+06
0
50
100
150
200
250
300
350
400
450

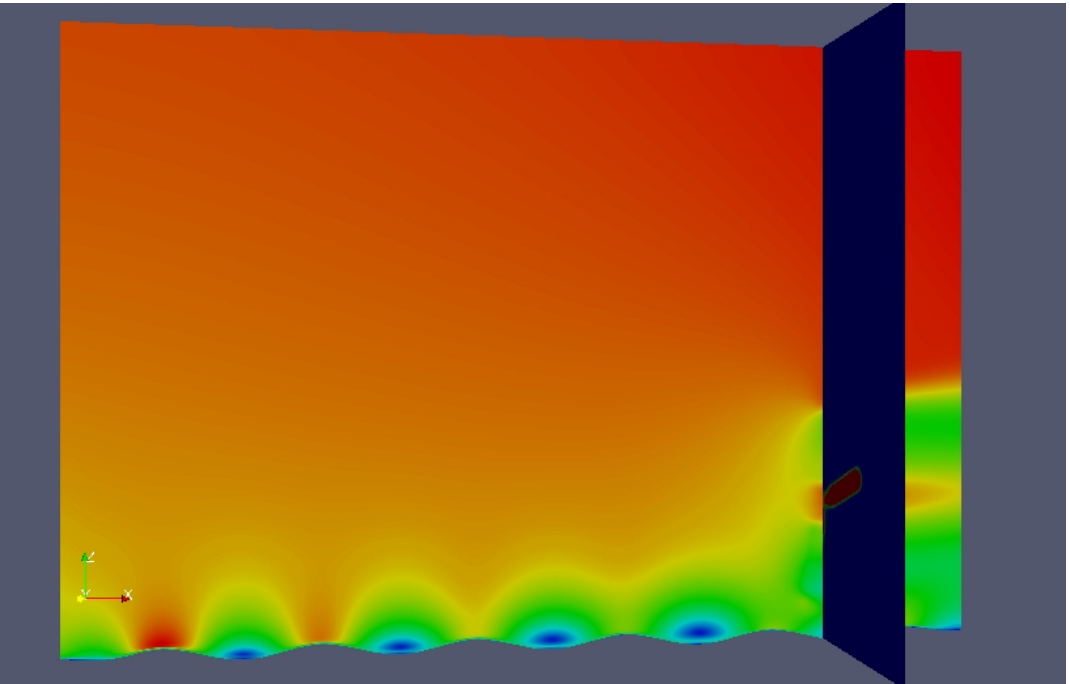


Line, x=437 m
Point, x=469 m

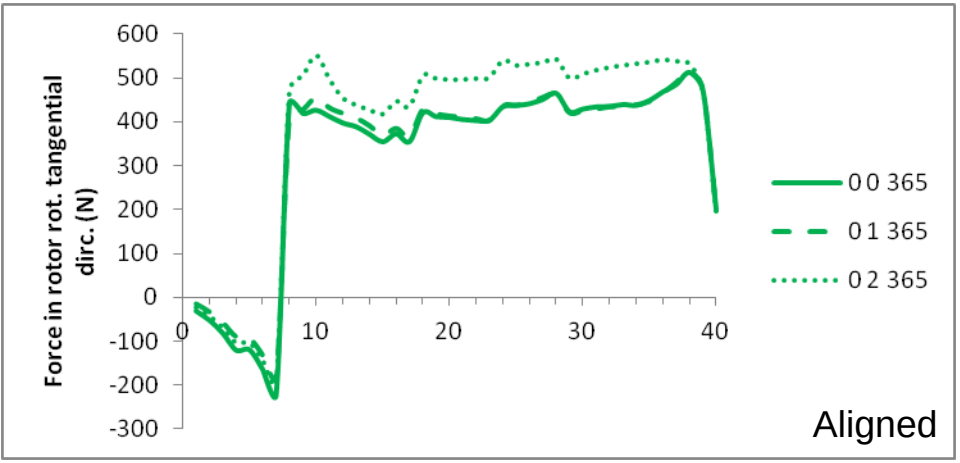
T = 200 sec

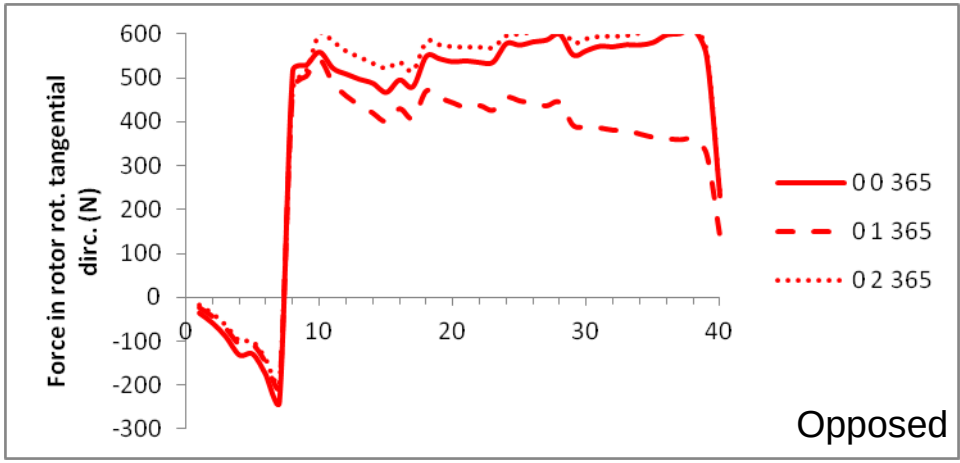


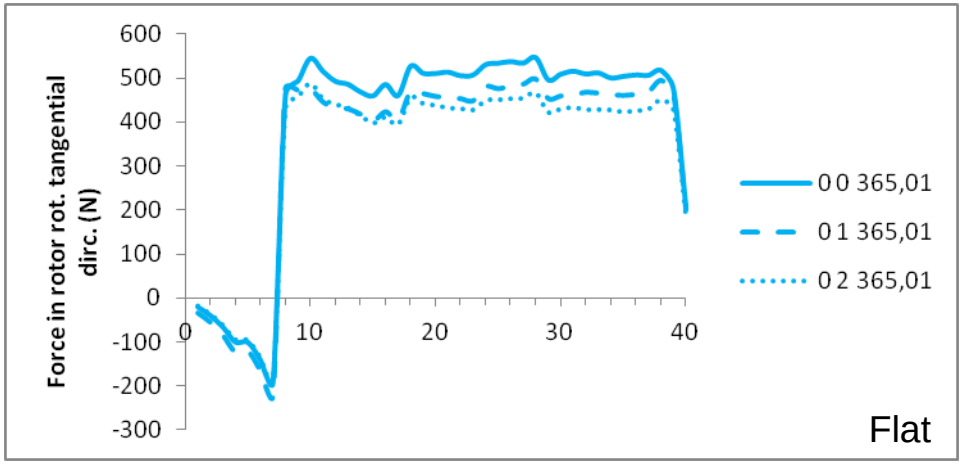
365 sec – position over wave aligned situation



365 sec – position over wave opposed situation

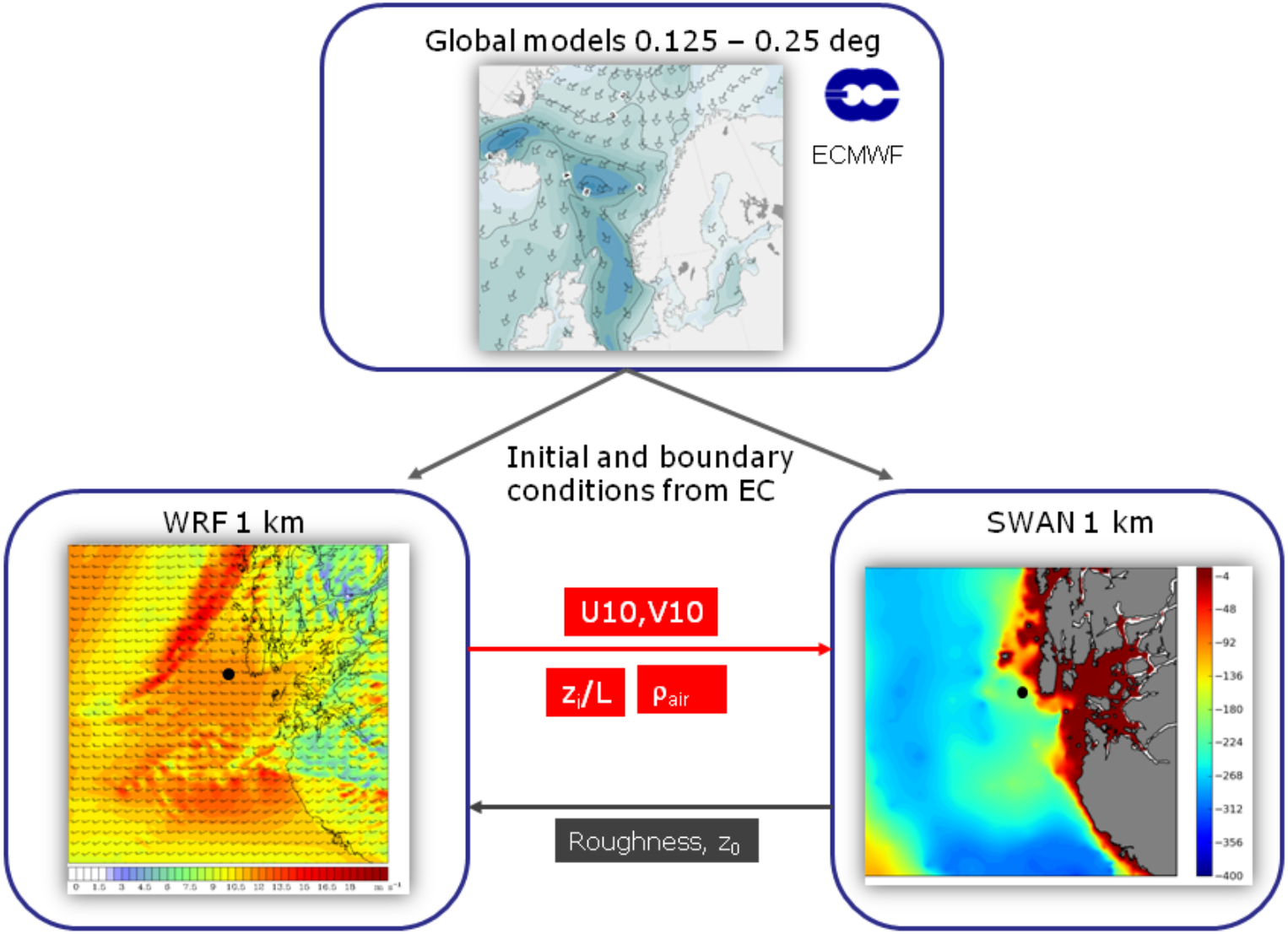

Force in rotor rot. tangential dirc. (N)
600
500
400
300
200
100
0
-100
-200
-300
0
10
20
30
40
0 0 365
0 1 365
0 2 365
Aligned


Force in rotor rot. tangential dirc. (N)
600
500
400
300
200
100
0
-100
-200
-300
0
10
20
30
40
0 0 365
0 1 365
0 2 365
Opposed

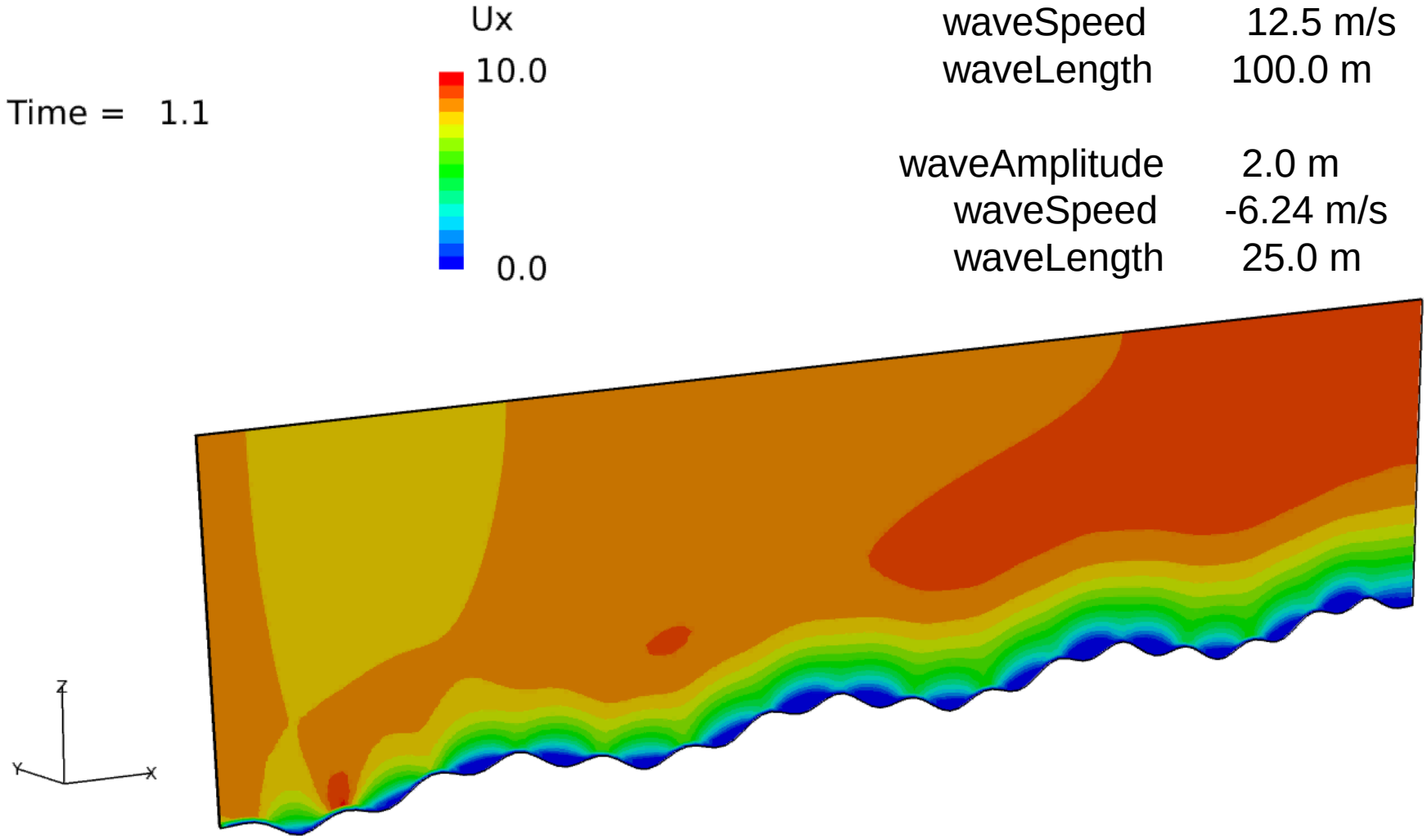

Force in rotor rot. tangential dirc. (N)
600
500
400
300
200
100
0
-100
-200
-300
0
10
20
30
40
0 0 365,01
0 1 365,01
0 2 365,01
Flat

StormGeo/UiS/NORCOWE project: Coupled meso scale atmosphere model with wave model

StormGeo
Control in a changing environment



waveAmplitude	4.0 m
waveSpeed	12.5 m/s
waveLength	100.0 m
waveAmplitude	2.0 m
waveSpeed	-6.24 m/s
waveLength	25.0 m



Summary

✓ Wave-wind simulations with openFOAM is ongoing PhD work at University of Stavanger, StormGeo and Norcowe.

✓ A new set up: Wave influenced wind turbine simulations – **WIWTS**. The actuator line part of SOWFA are slightly changed and coupled with the wave simulations.

✓ The flow response over the waves are very different for cases where the wind is aligned with the wave propagation and wind opposing the wave.

✓A low level speed up in the lowest meters for wind aligned with a fast moving wave. The profiles over the waves are not logarithmic. Turbulent kinetic energy is slightly higher for wind opposing the wave than wind aligned with the wave.

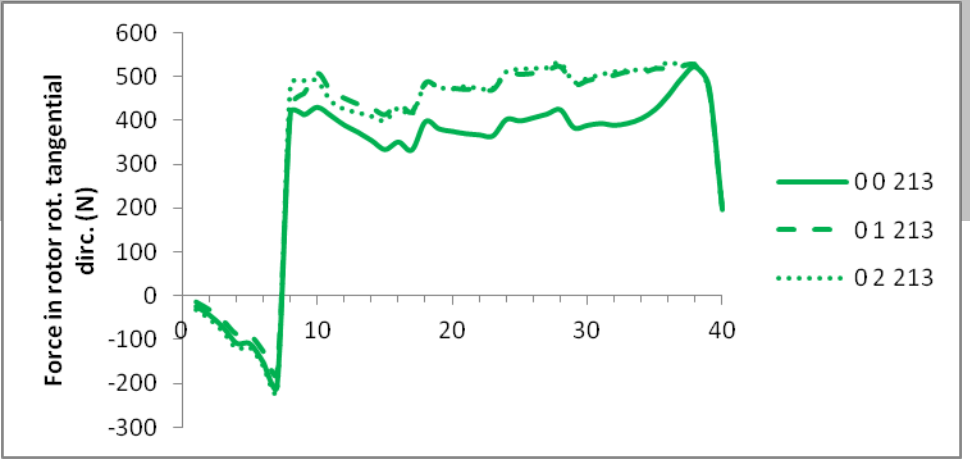
✓ A case study of a large fast moving swell, with amplitude 4 m, shows implications for both power production and loads. Problem with the grid size. The domain should be higher and longer. Grid independency was not completely reached.

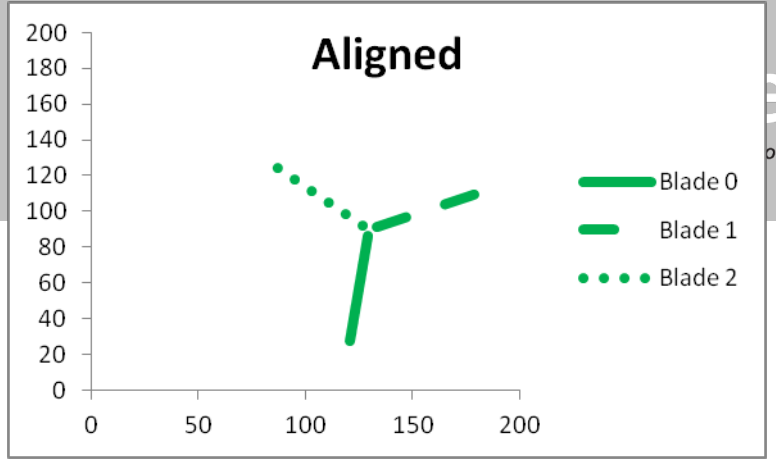
✓ Future work: Simulate more realistic waves. Link result to metocean statistics in order to reveal if interesting situations will occur often enough in order to be of any significance to power harvest and load considerations.

Thanks!

* Corresponding author. Tel.: +47 91604181
E-mail address: siri.kalvig@uis.no /
siri.kalvig@stormgeo.com

Control in a changing environment


Force in rotor rot. tangential dirc. (N)
600
500
400
300
200
100
0
-100
-200
-300
0
10
20
30
40
0 0 213
0 1 213
0 2 213


Aligned
200
180
160
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120
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20
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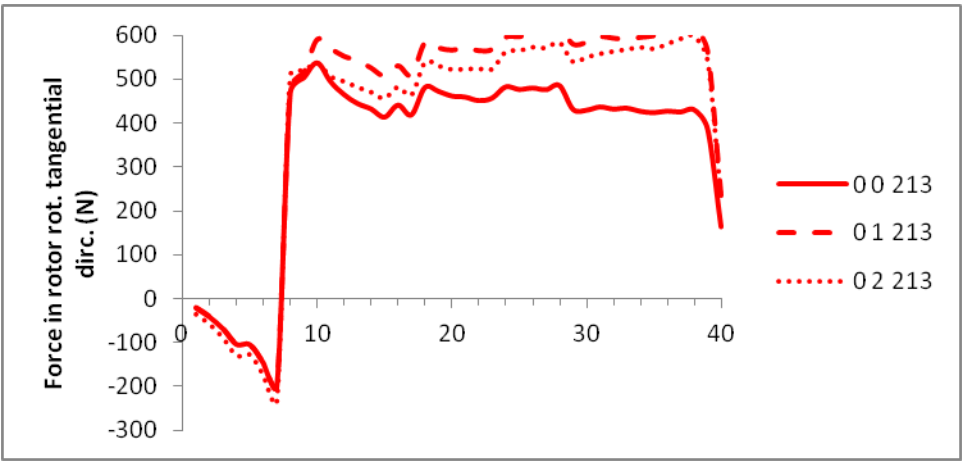
50
100
150
200
Blade 0
Blade 1
Blade 2


Force in rotor rot. tangential dirc. (N)
600
500
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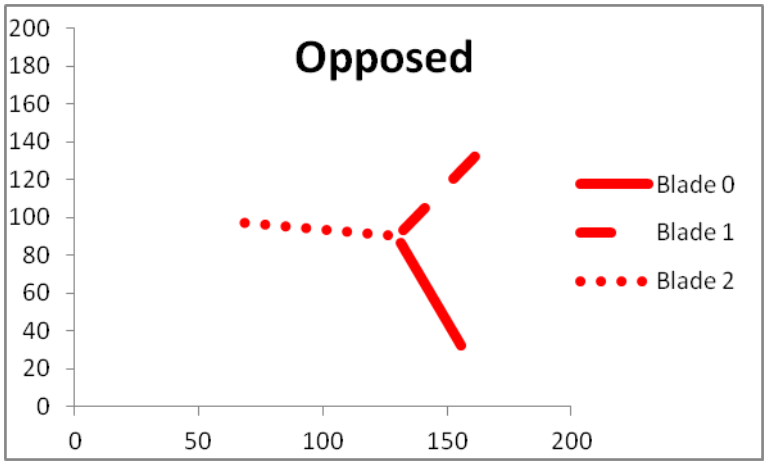
Opposed
200
180
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120
100
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100
150
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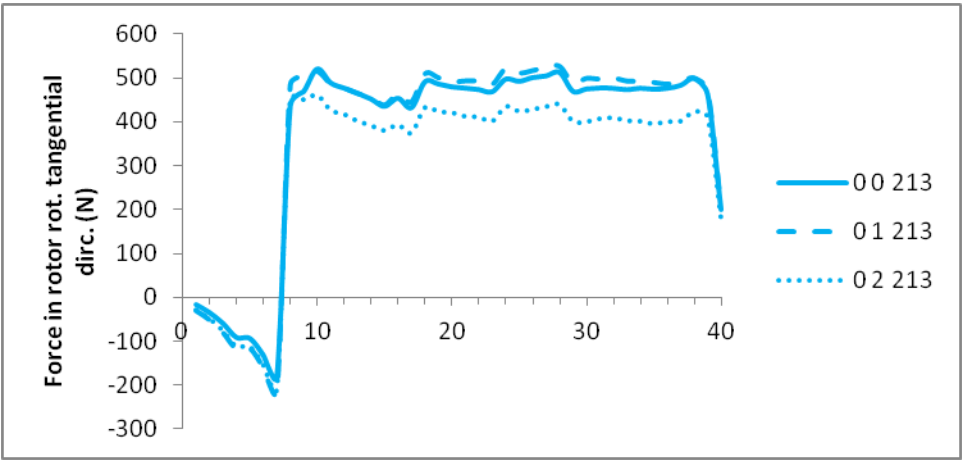
Blade 0
Blade 1
Blade 2


Force in rotor rot. tangential dirc. (N)
600
500
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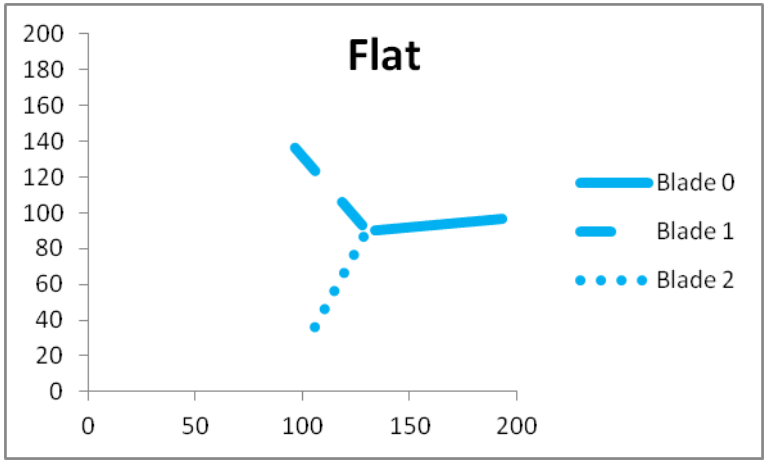
0 1 213
0 2 213


Flat
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180
160
140
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100
80
60
40
20
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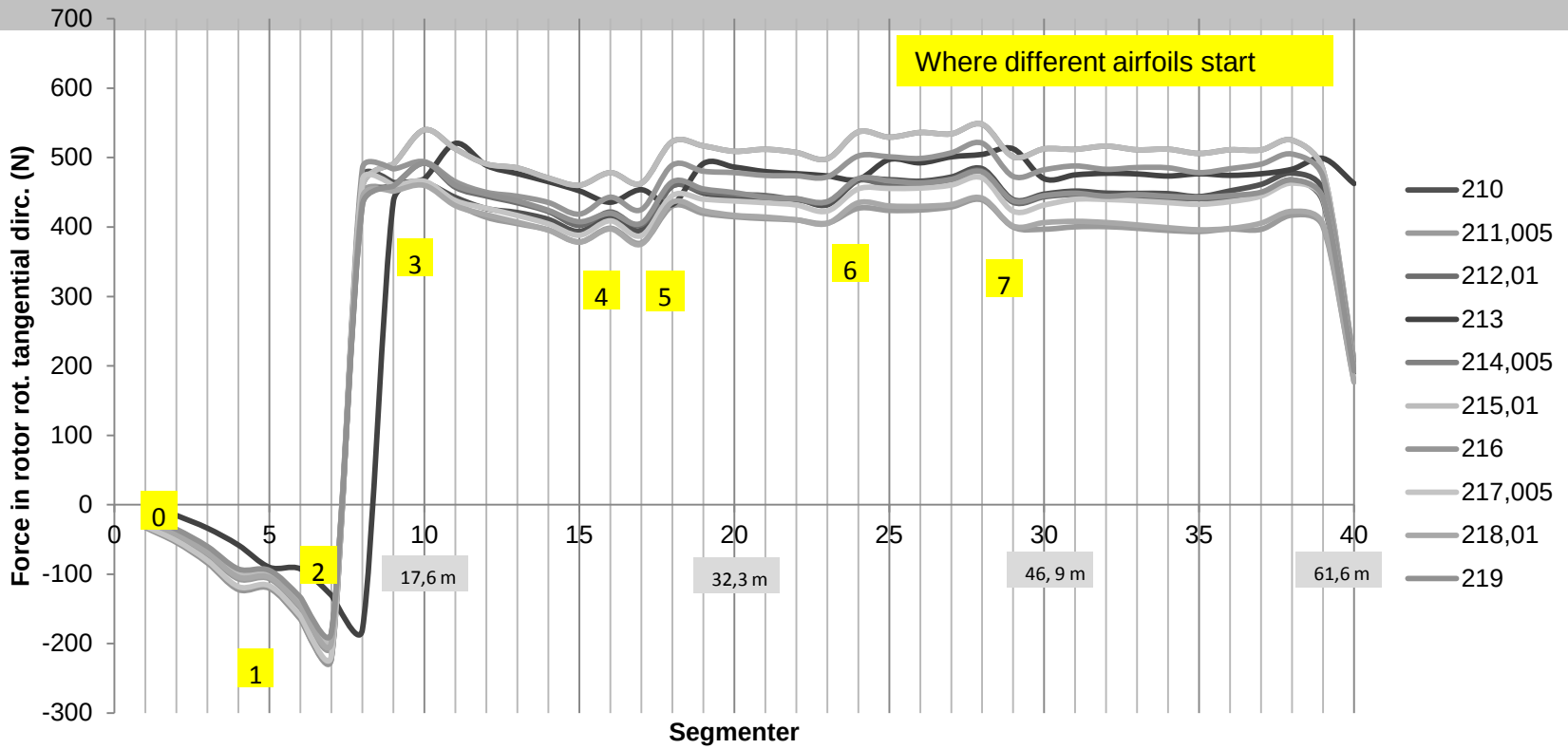
0
50
100
150
200
Blade 0
Blade 1
Blade 2

Tangential force, flat



Viser bare hvor på en av force kurvene de forskjellige airfoilene “slår” inn. Tror vi kan si at mesteparten av “hoppene” I kurven relateres til endring av airfoilegenskaper…?

NEK IEC 61400-1;
Wind turbines - part 1; Design requirements

NEK IEC 61400-3;
Wind turbines - part3: Design requirements for offshore wind turbines

NS-EN 1991-1-4;
Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions

- Only log profile or power law is used
- Only neutral stratification
- Charnock relation to some extend used when calculating turbulent intensity
- Turbine classes on shore is used offshore
- 33 design load cases versus 22 for onshore
- No hydrodynamic influence or wave influence on rotor-narcelle assembly or wind flow

There is a gap between “best knowledge” (science) and “best practice” (codes, standards) and there is a need for improved guidance on the impact atmospheric stability and wave-wind interaction in the MABL can have on the offshore wind industry

Kalvig, Gudmestad & Winther: Exploring the gap between ‘best knowledge’ and ‘best practice’ in boundary layer meteorology for offshore wind energy, Wind Energy, published online: 30 JAN 2013, doi: 10.1002/we.1572

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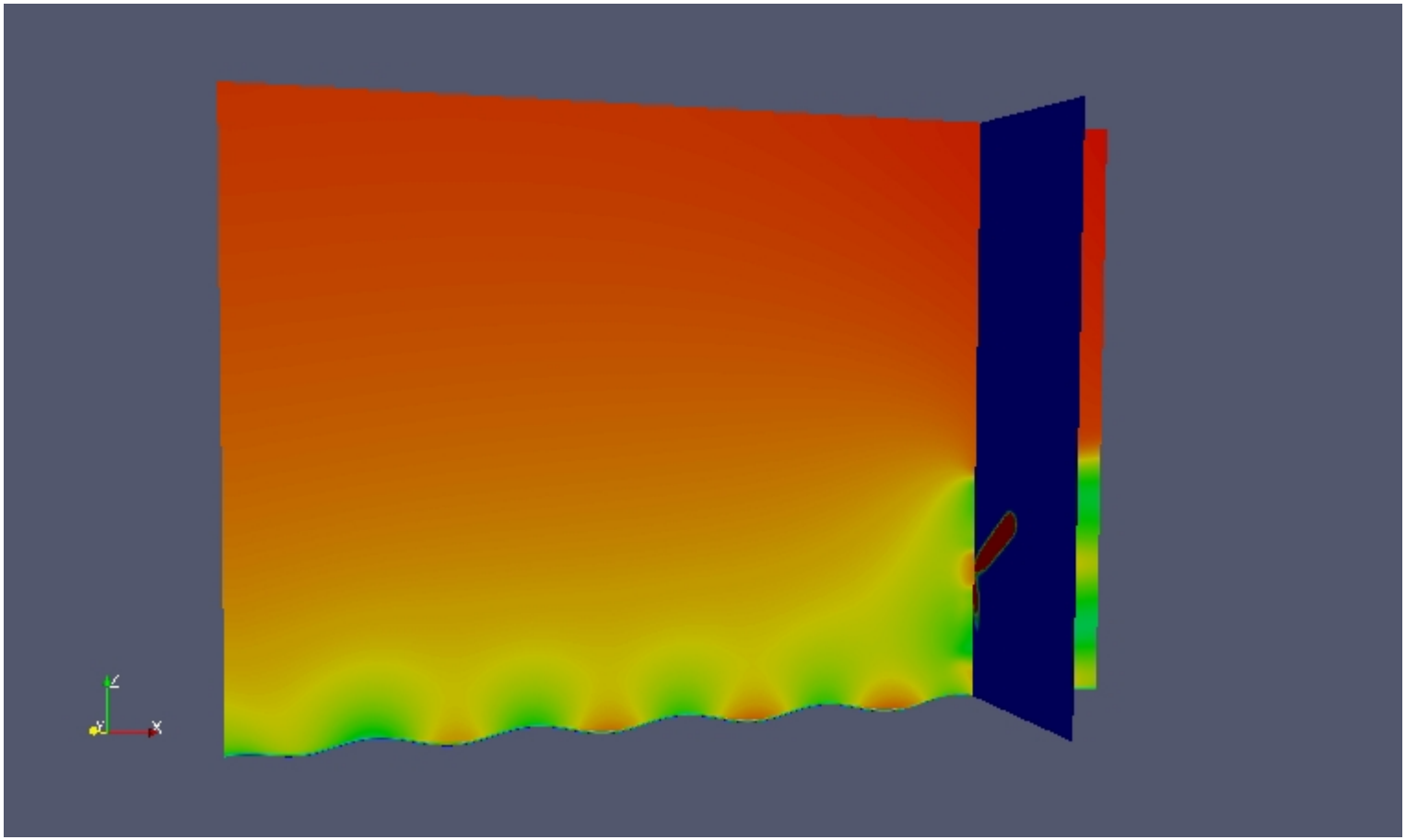
StormGeo
Control in a changing environment



213 sec – position over wave aligned situation