



Three years of monitoring at the Belgian offshore wind turbines, lessons learned

Offshore Wind Infrastructure Application Lab

For efficient and reliable offshore wind energy

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Vrije
Universiteit
Brussel



Offshore Wind Infrastructure Application Lab

- R,D&I platform for (offshore) wind energy in Flanders
- Embedded in **Sirris**, the **collective centre** of the Belgian technological industry
- Initiated by industry (2010)



Industry Coordinator



Research Coordinator



OWI-lab Investment Program



**Floating LIDAR
System**

Spin-out:

FLiDAR
POWERED BY WINDCUBE™



**Test & Monitoring hardware,
data platform and
dedicated
analysis tools**



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sirris

driving industry by technology



**Large Climatic
Test Chamber
(focus extreme temp)**



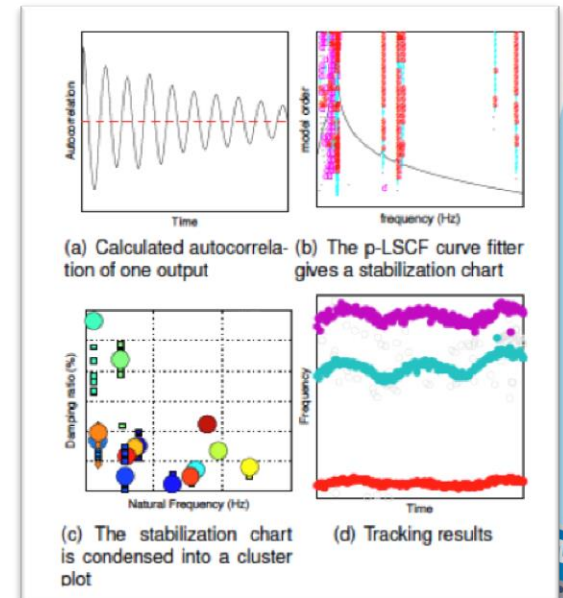
sirris

driving industry by technology

Monitoring setup

Continuous measurements of the tower accelerations

- FA-SS Accelerations at 3 tower levels
- Resonance frequencies and Damping



What modes are we looking at?

- Tower & Foundation structural modes

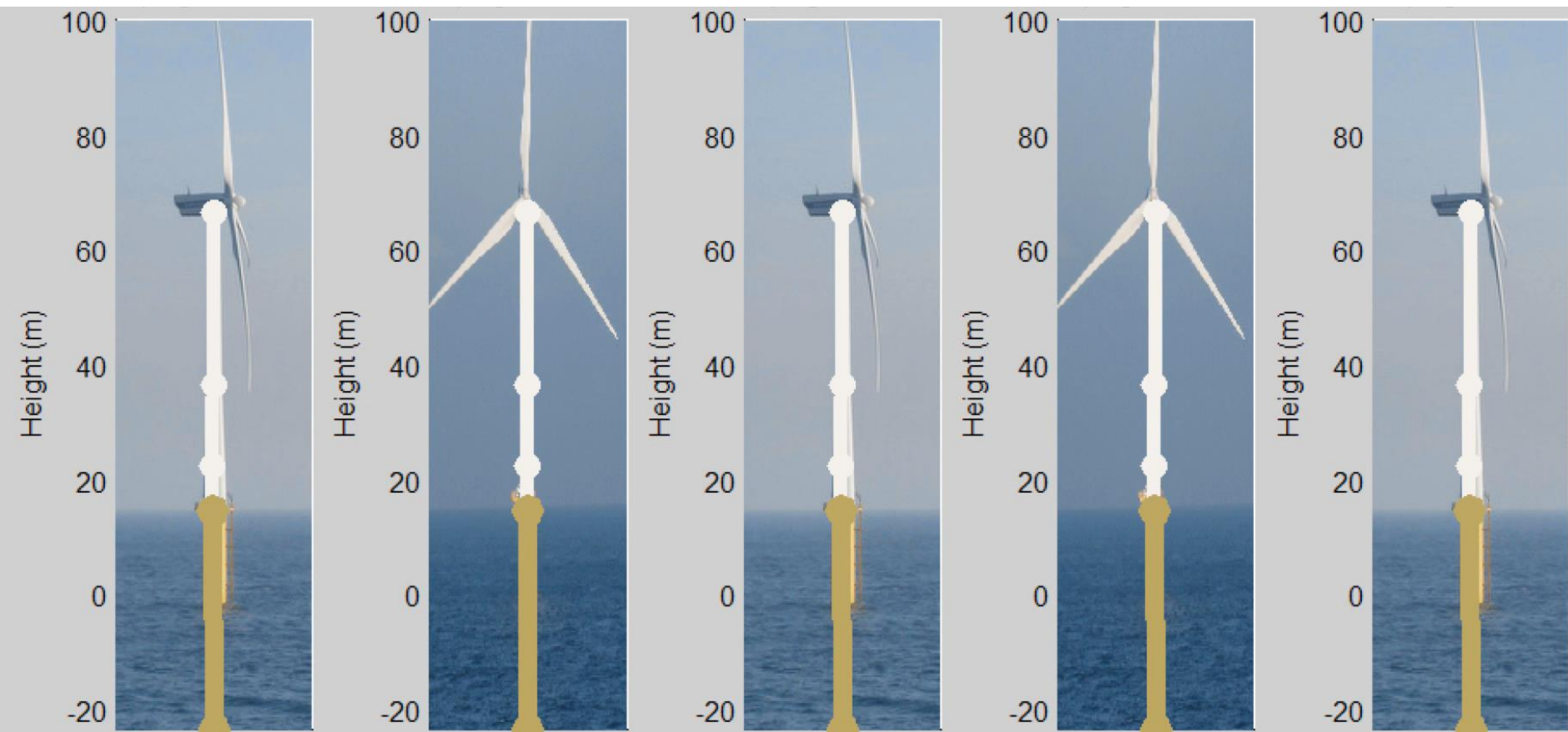
FA1

SS1

BLADE!

SS2

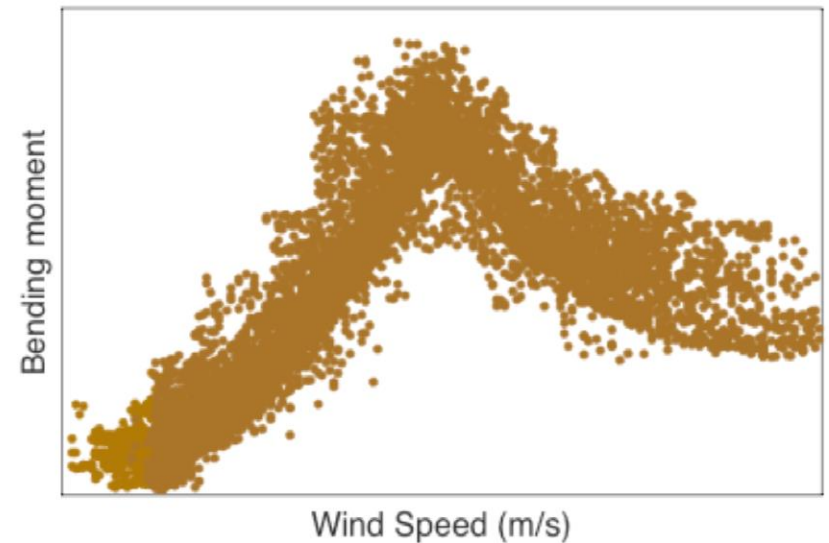
FA2



Monitoring setup

Continuous measurements of the strains

- Optical strain gauges at two levels
- **Bending moments at interfaces**
 - Tower – TP
 - TP - Monopile



Co-operation with Parkwind & C-Power

Five instrumented turbines spread over three farms



2011 Belwind (1)

- 55 Vestas 3MW V90 turbines
- Monopile foundations

2014 Northwind

- 72 Vestas 3MW V112 turbines
- Monopile foundations

2015 C-Power

- 54 Senvion 5 - 6MW turbines
- **Jacket foundations**



What does OWI-lab offer?

Operator / Developer driven

Design validation

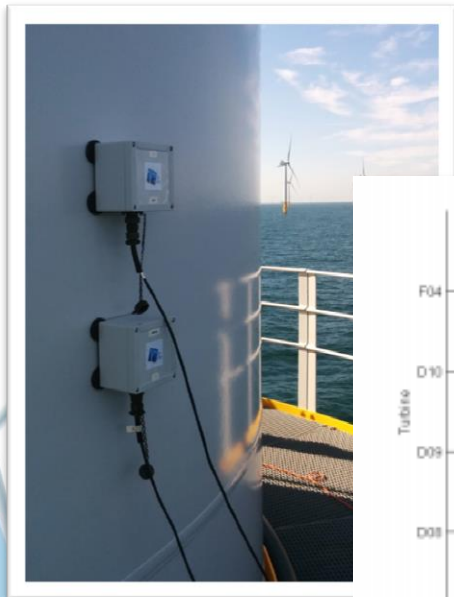
Monitoring Resonances Frequencies and Damping

Monitoring Fatigue

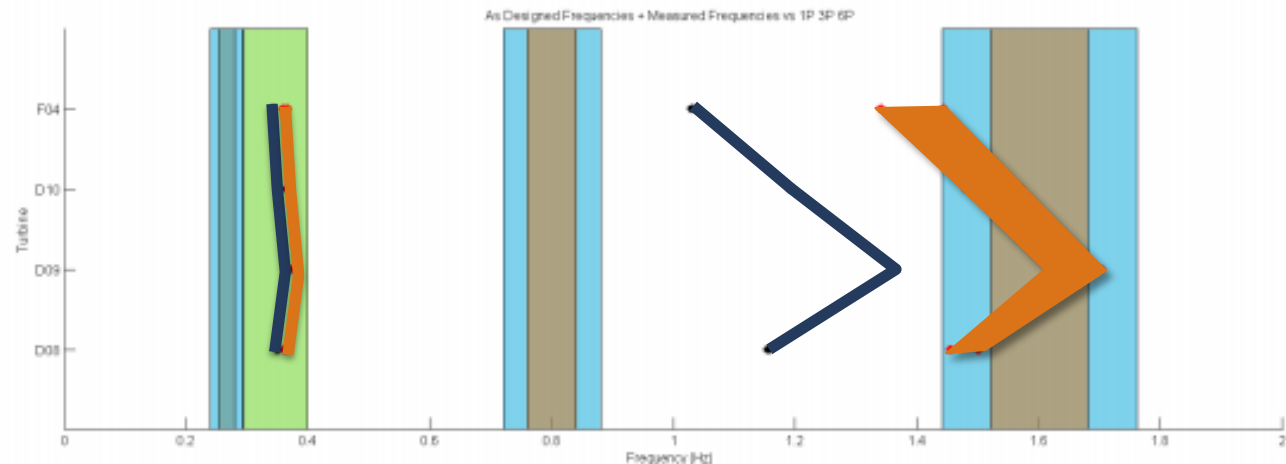
Design

O&M

End of life



Are resonance frequencies in the park matching the as designed values?



What does OWI-lab offer?

Operator / Developer driven

Design validation

Monitoring Resonances Frequencies and Damping

Monitoring Fatigue

Were the as designed damping values correct?

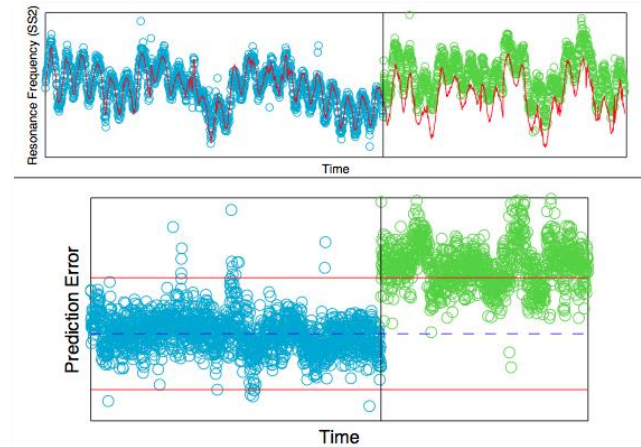
Is there any significant *scouring* ?

Are resonance frequencies in the park still matching the as designed values?

Design

O&M

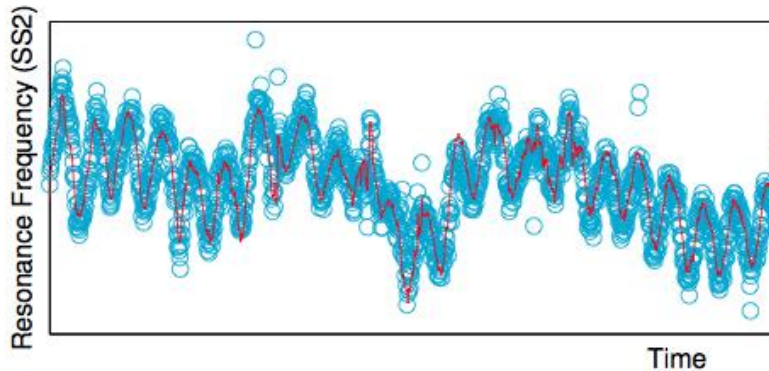
End of life



Evolution of the Resonance Freq.

@ Belwind offshore wind farm

Predicting the resonance frequencies >1 year further in time.

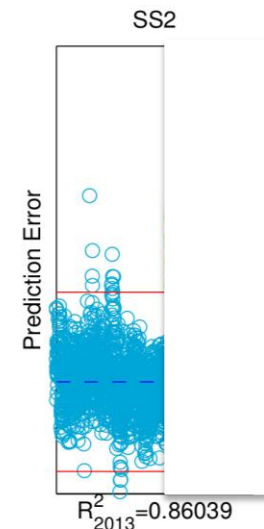


Training

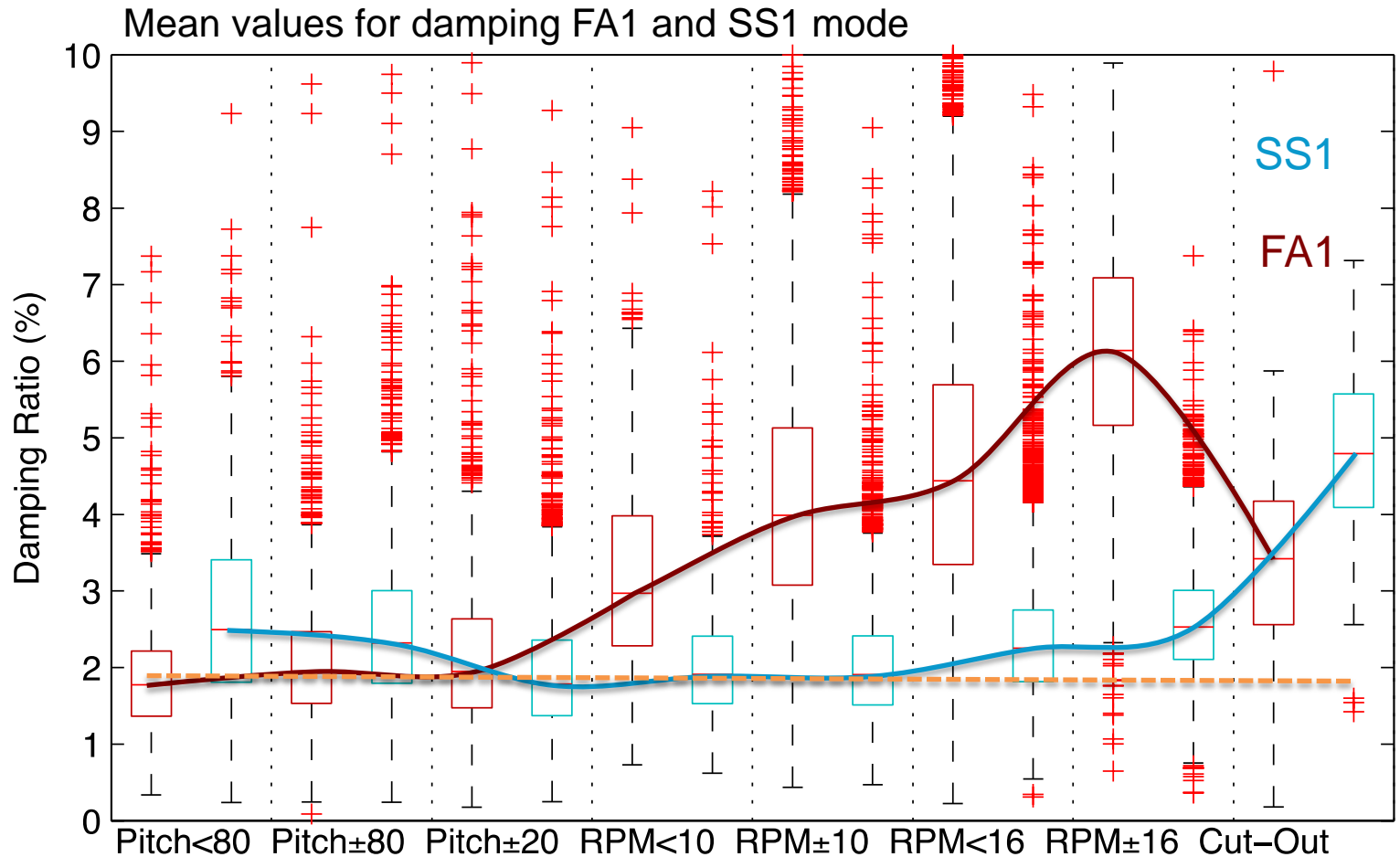
Prediction

Use relative error as a damage feature

Residual error leaves 3σ boundary



Monitoring Damping Values



- 1: Pitch : >80
- 2: Pitch : ±80
- 3: Pitch : ±20
- 4: RPM : <10
- 5: RPM : ±10
- 6: RPM : <16
- 7: RPM : ±16
- 8: Cut-Out

What does OWI-lab offer?

Operator / Developer driven

Design validation

Monitoring Resonances Frequencies and Damping

Monitoring Fatigue

Design

O&M

End of life

Is fatigue assumptions correct for every turbine in every farm?

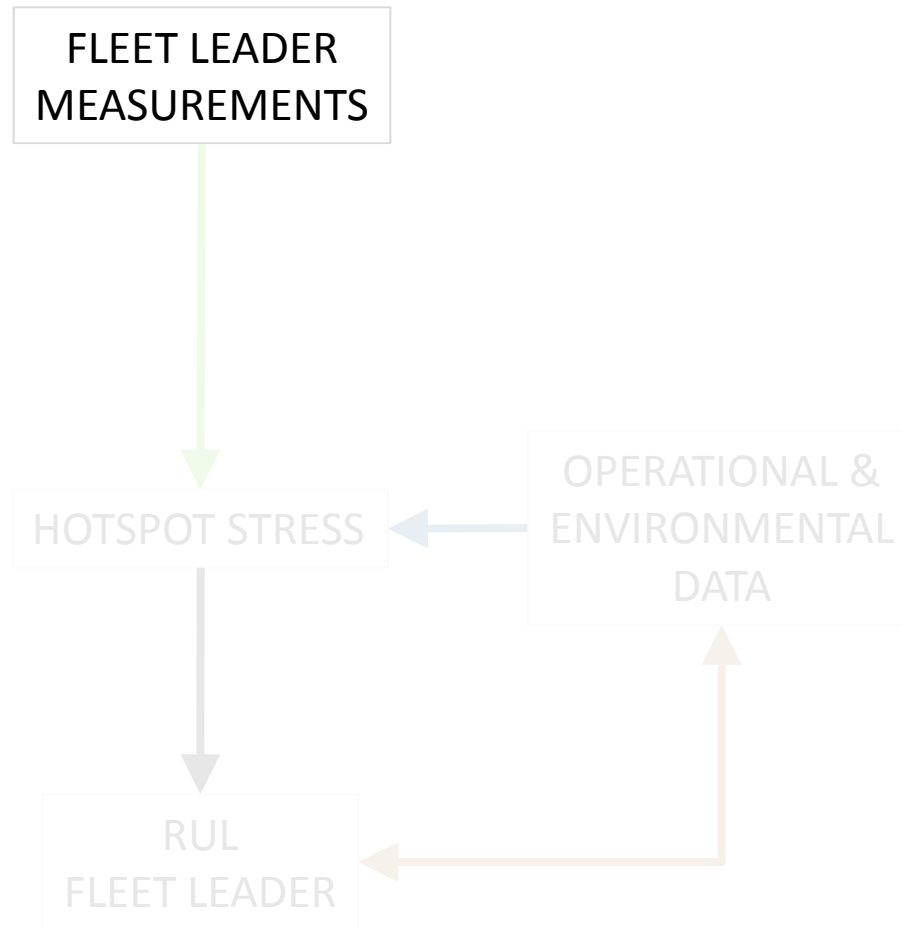
Is there an issue causing increased fatigue rates?

How much of our fatigue life has been consumed?

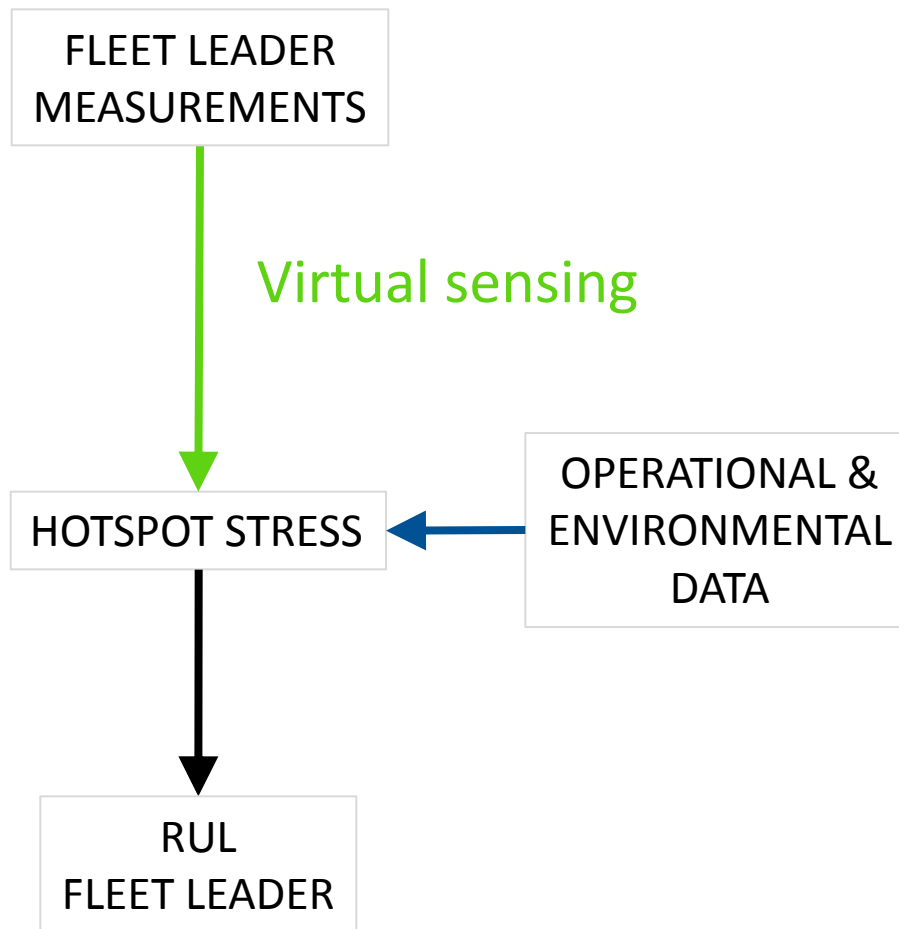
Monitoring the main design driver and an important concern of operators

Our Philosophy towards Fatigue

It is too expensive to monitor every turbine,



Our Philosophy towards Fatigue

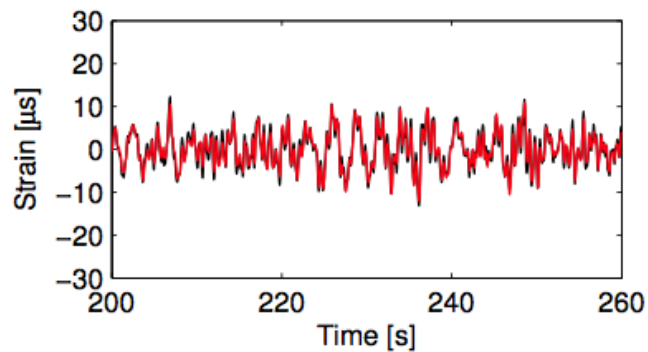


Virtual sensing

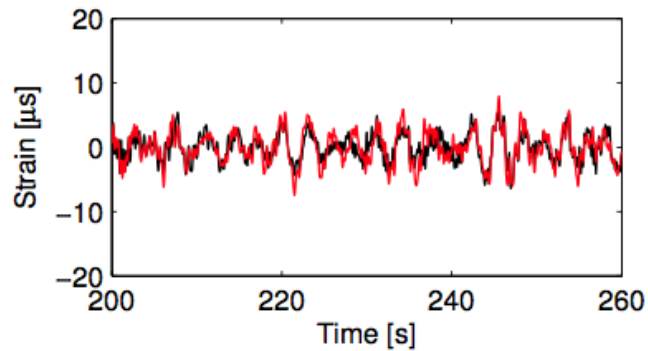
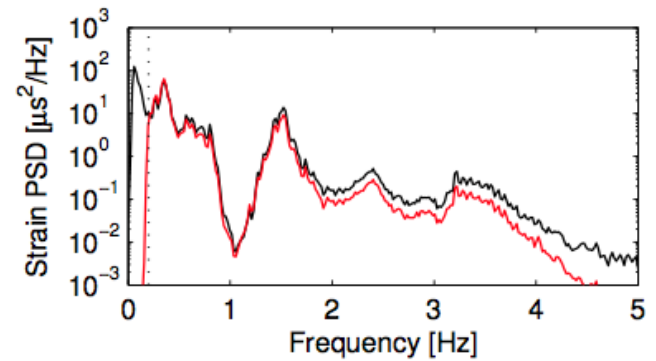
waterlevel

mudline

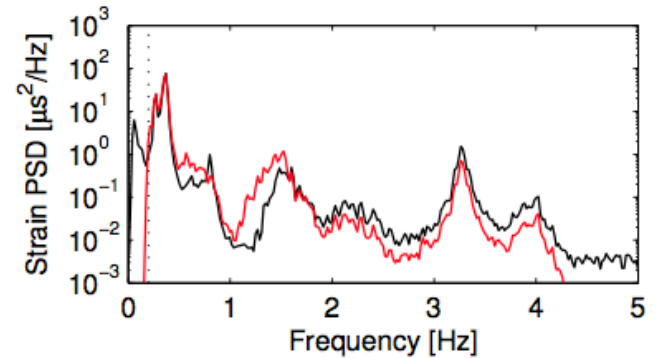
hotspot



(c)



(f)



Our Philosophy towards Fatigue



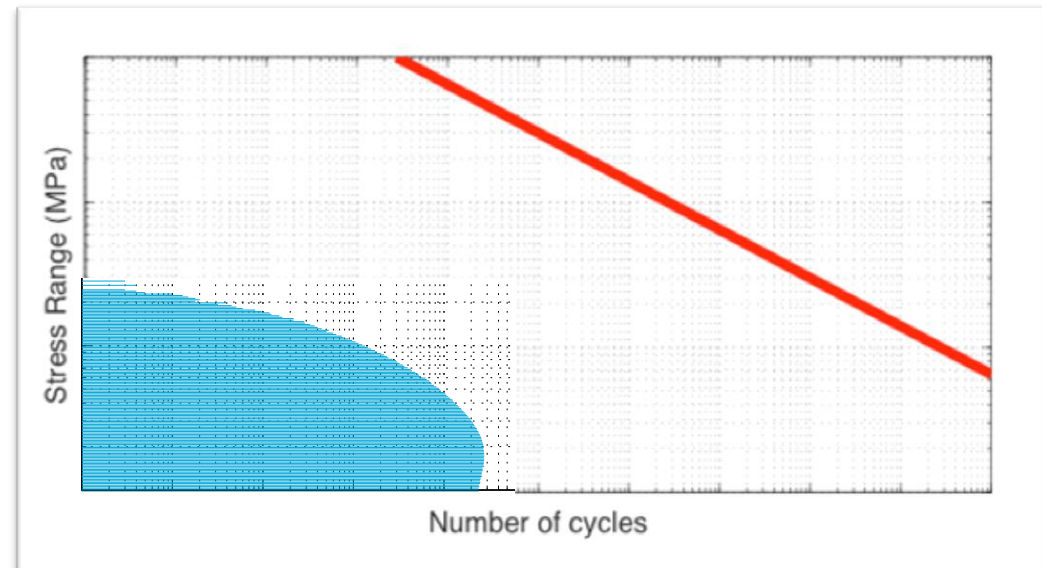
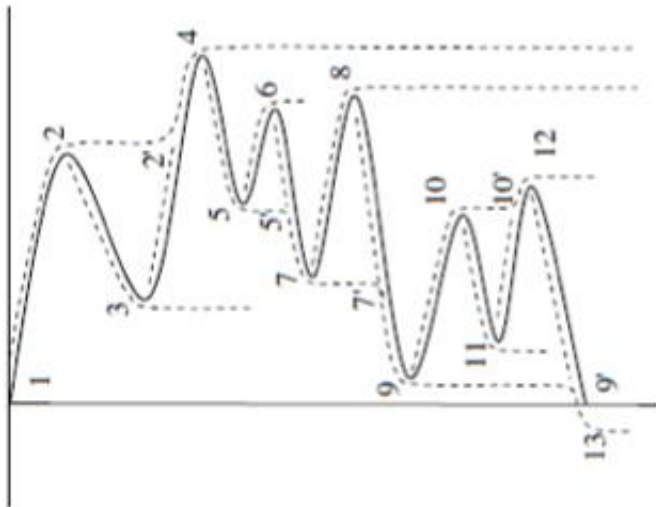
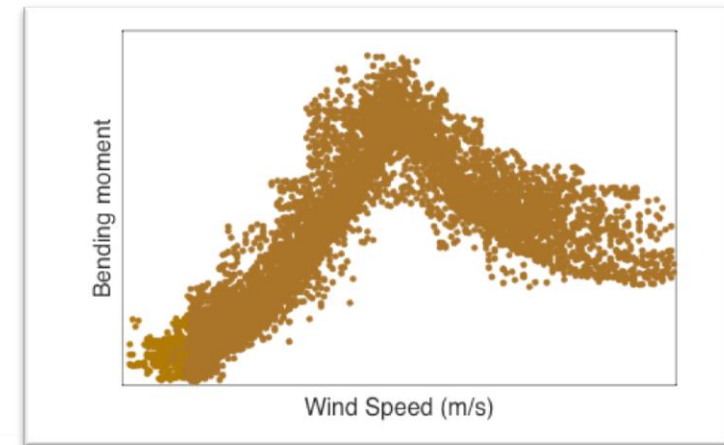
Monitoring Fatigue

Stresses induced by bending moments

Rainflow counting on measured data

Assess damage with

- *Appropriate S/N-Curves*
- *Stress concentration factors*



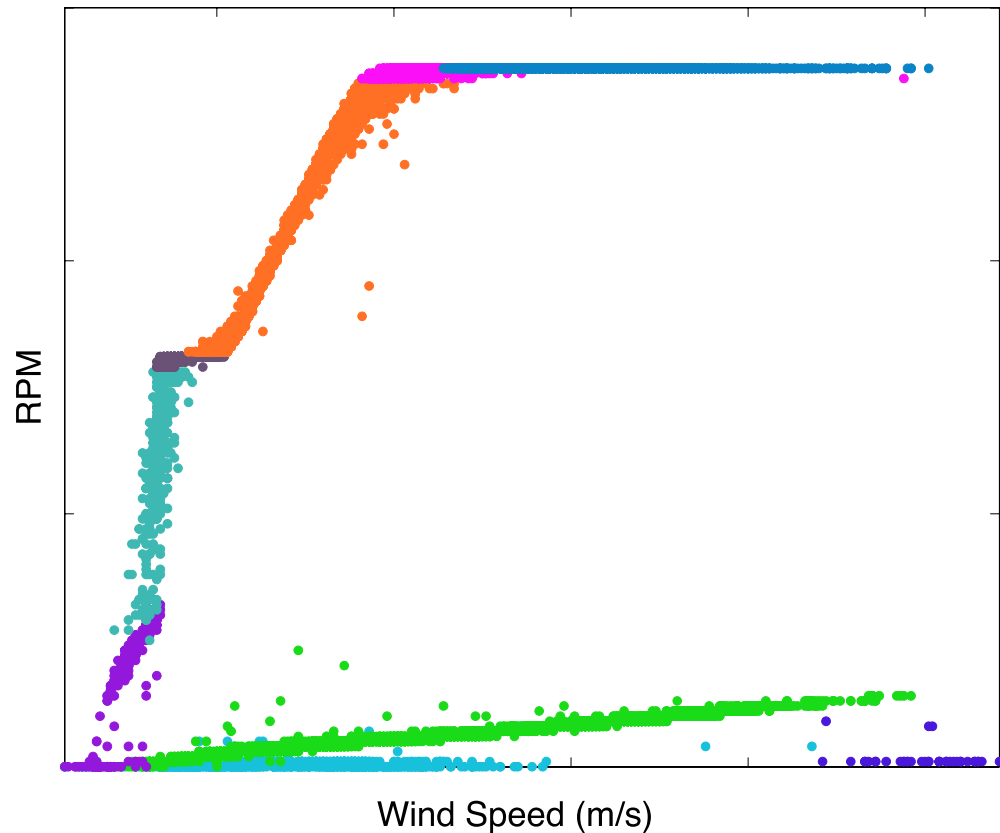
What is costing fatigue life?

Is there a **difference in fatigue life consumption between operational conditions?**

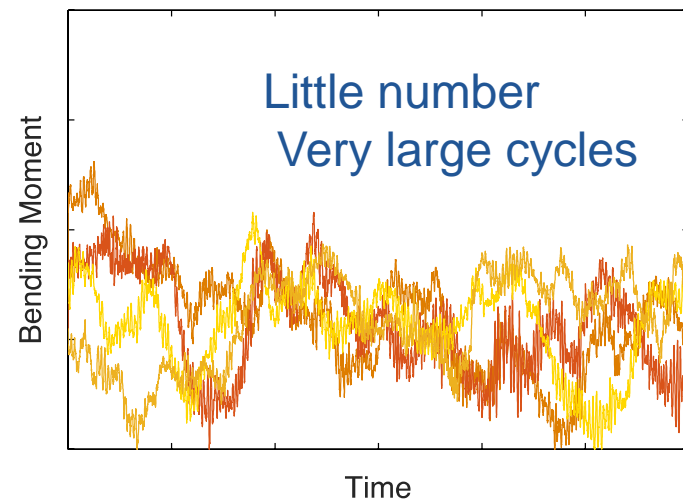
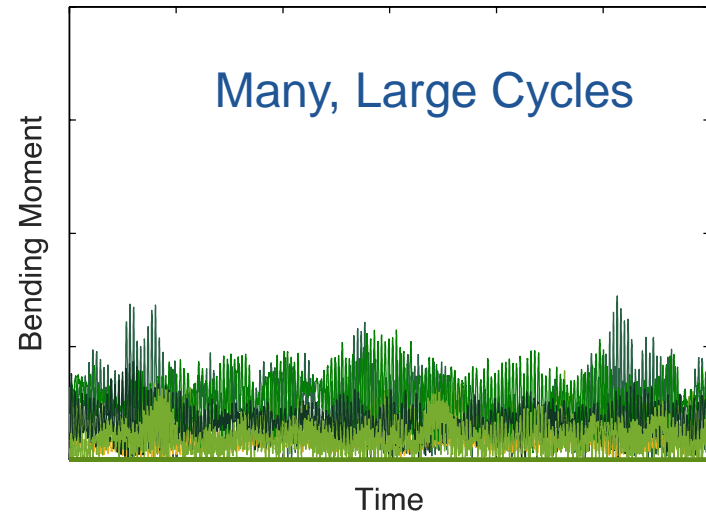
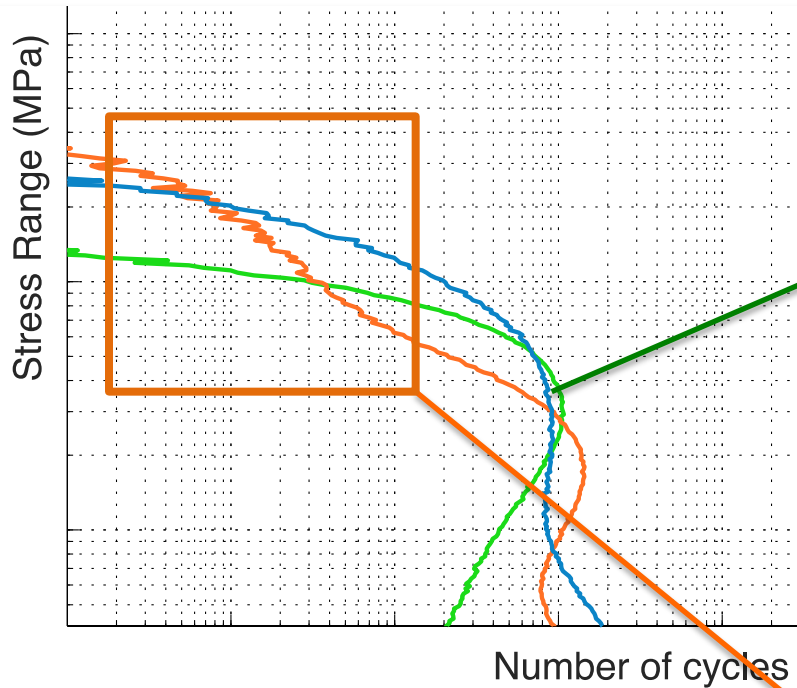
Dividing all data into different
Operational cases

Focus on:

- **Parked**
- **Run-up**
- **Max Power**



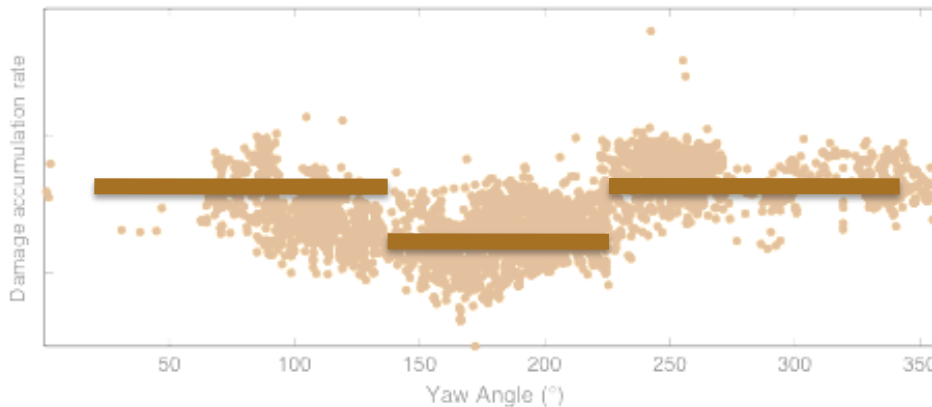
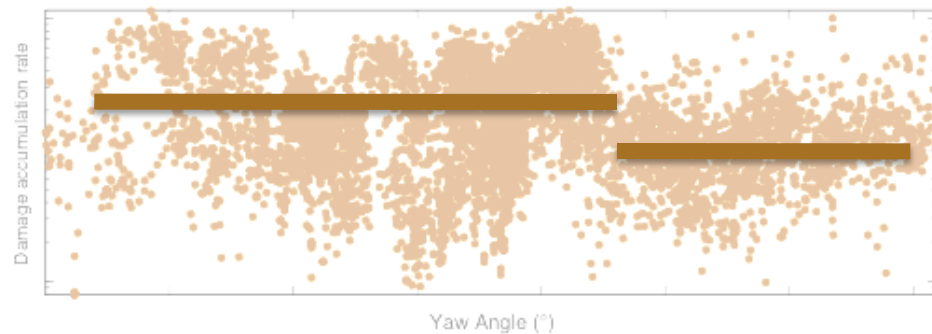
What is costing fatigue life?



In run up a limited number of large cycles occur

What is costing fatigue life?

At Northwind the two instrumented turbines do not only differ structurally, **also their position in the farm affects fatigue life**



Thank you for your attention



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