



# 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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# 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:**



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



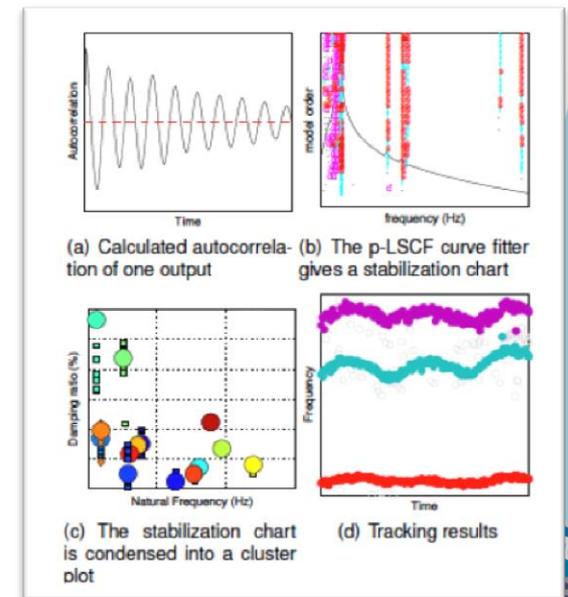
**Large Climatic Test Chamber  
(focus extreme temp)**



# 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

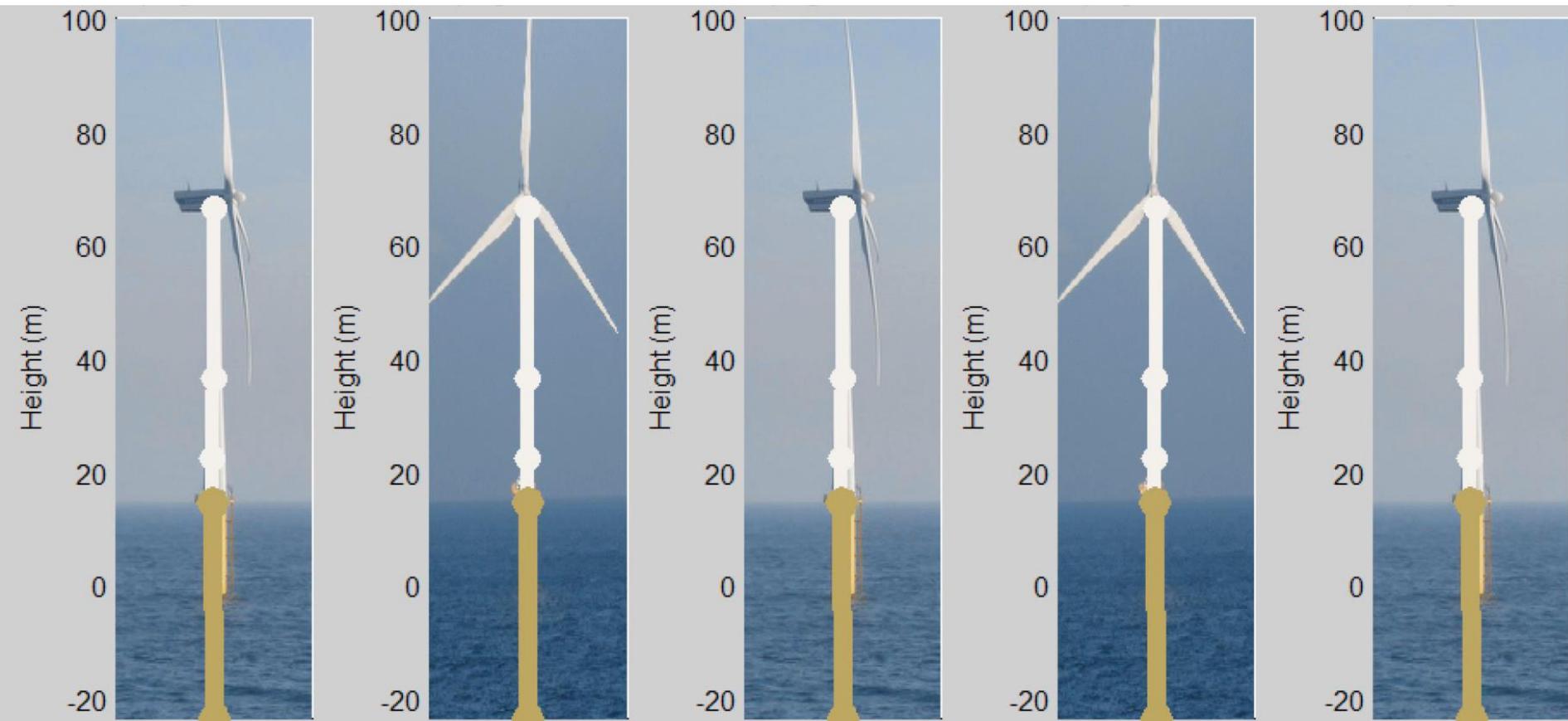
FA1

SS1

BLADE!

SS2

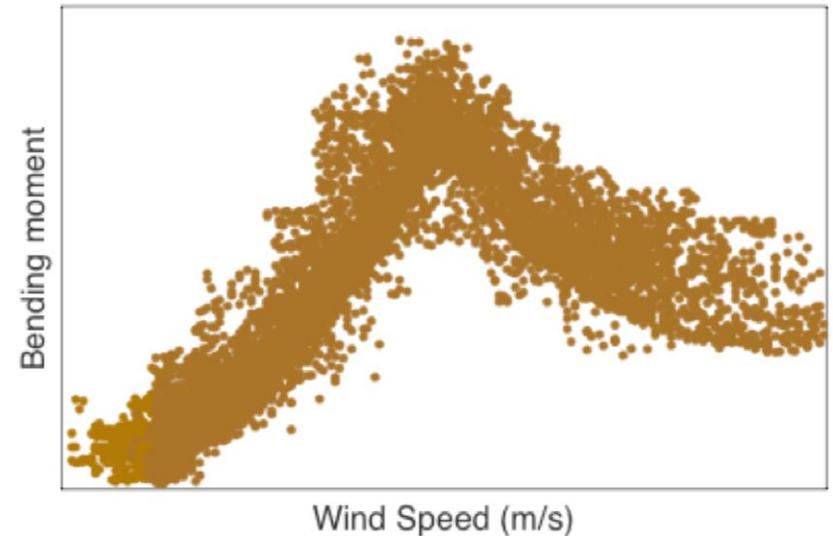
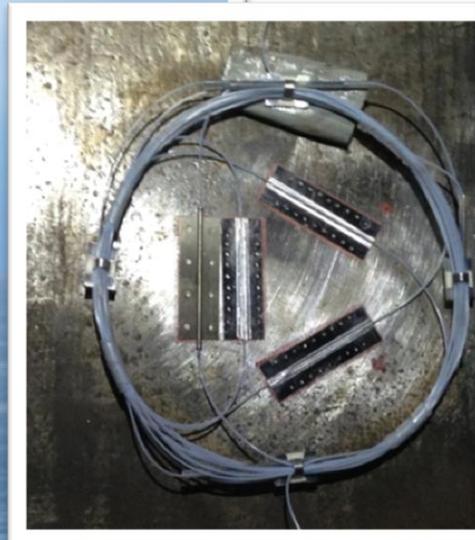
FA2



# 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

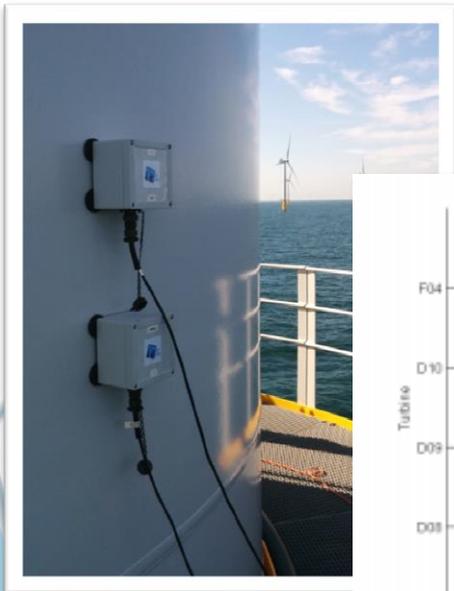
Monitoring Resonances Frequencies and Damping

Monitoring Fatigue

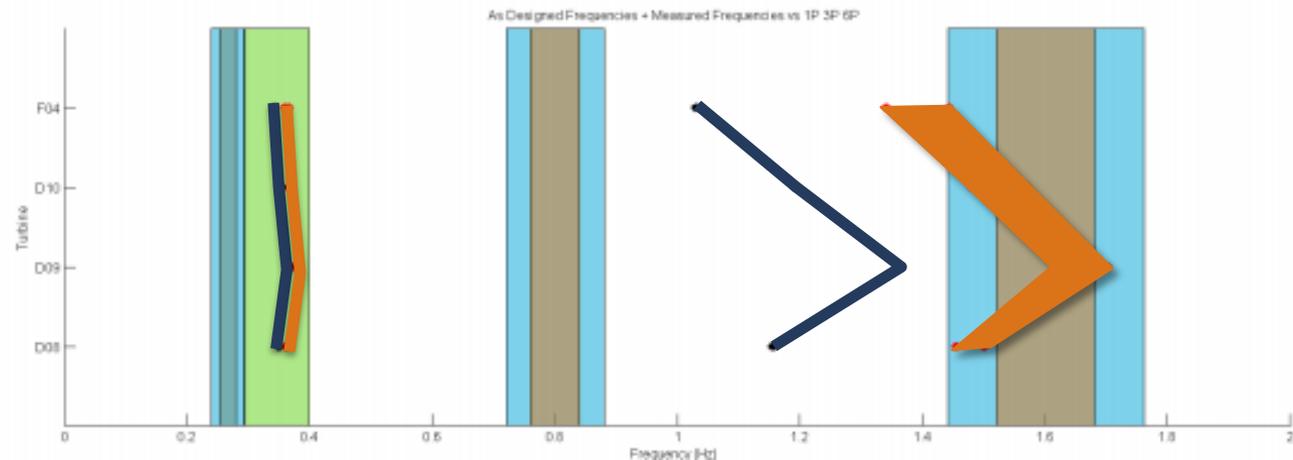
Design

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?**

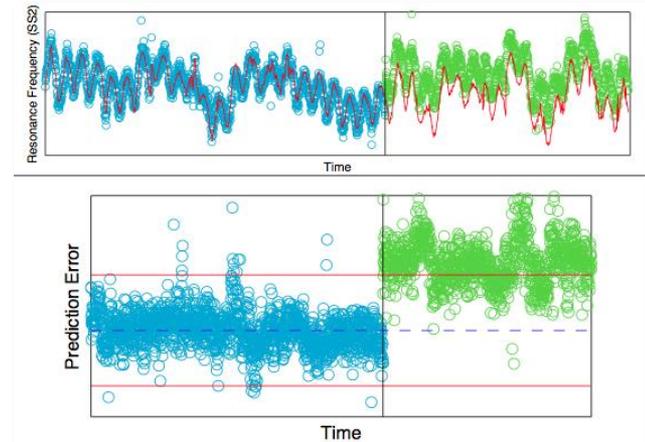
**Is there any significant *scouring* ?**

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

Design

O&M

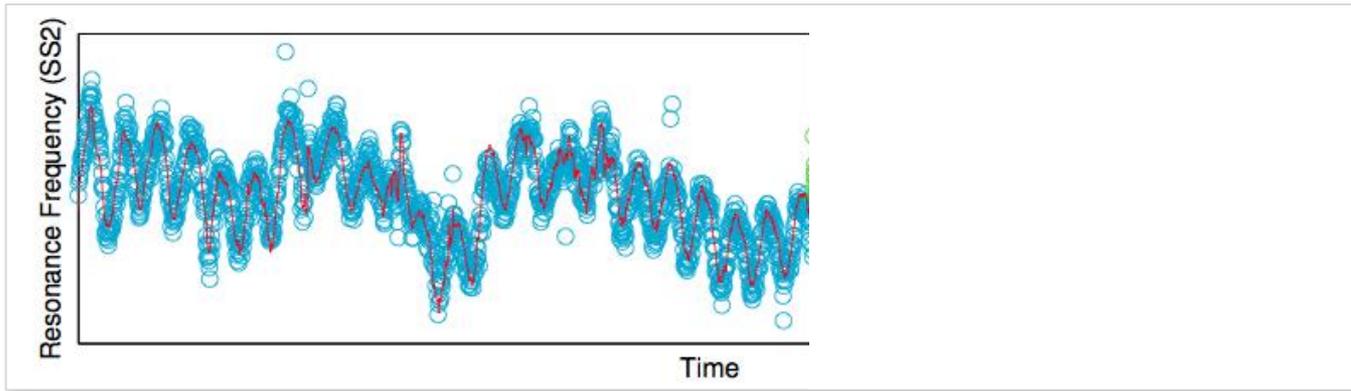
End of life



# Evolution of the Resonance Freq.

@ Belwind offshore wind farm

Predicting the resonance frequencies >1 year further in time.

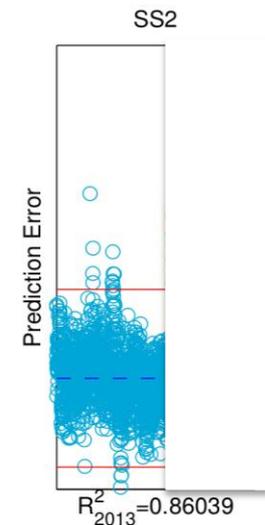


Training

Prediction

Use relative error as a damage feature

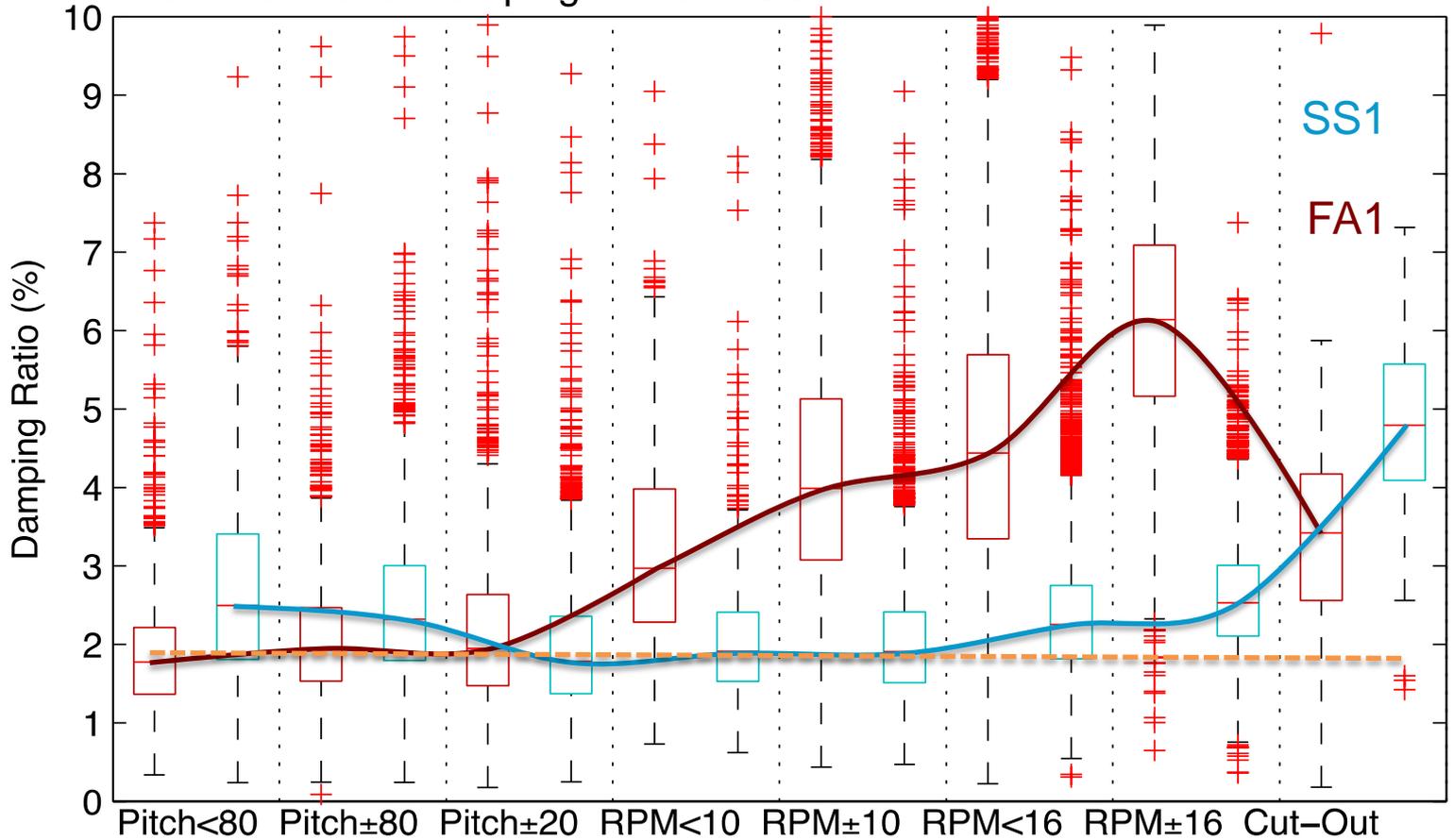
Residual error leaves  $3\sigma$  boundary



# Monitoring Damping Values



Mean values for damping FA1 and SS1 mode



- 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

**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?**

Design

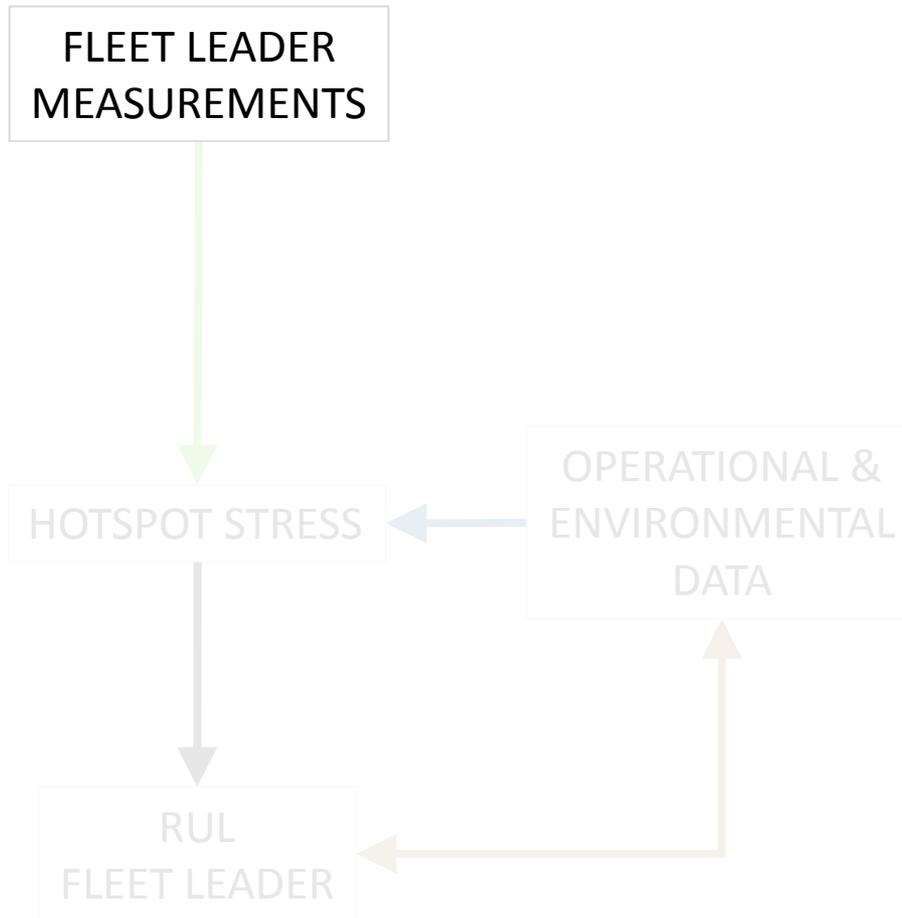
O&M

End of life

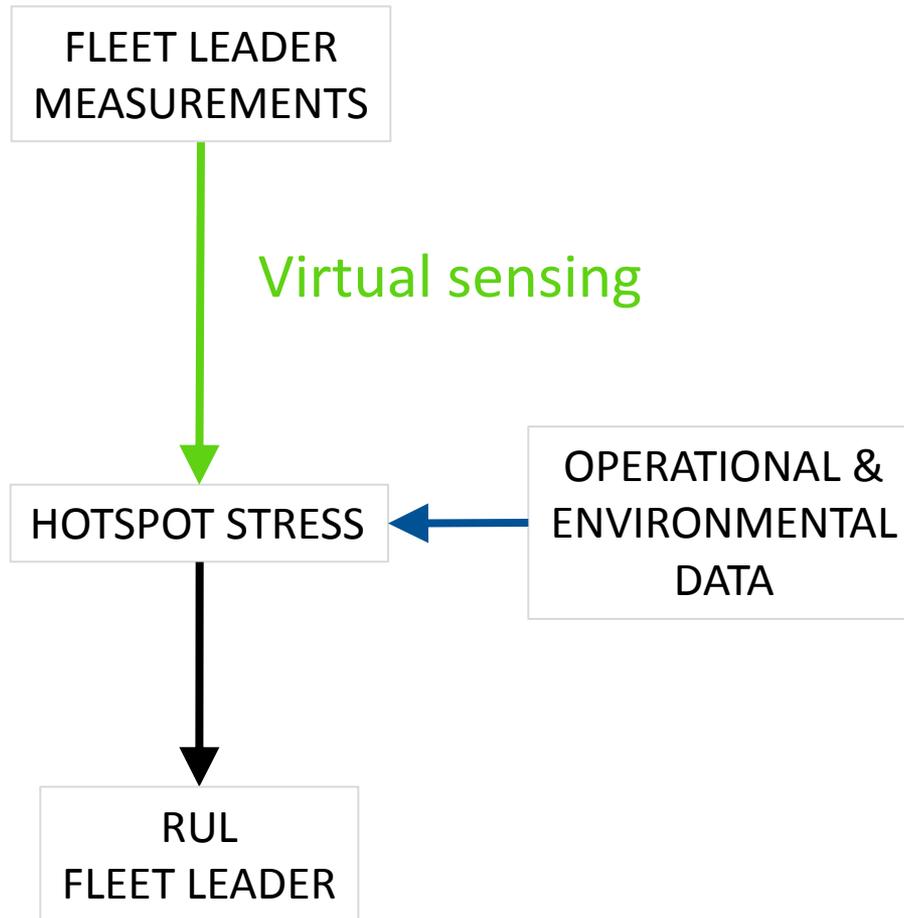
**Monitoring the main design driver and an important concern of operators**

# Our Philosophy towards Fatigue

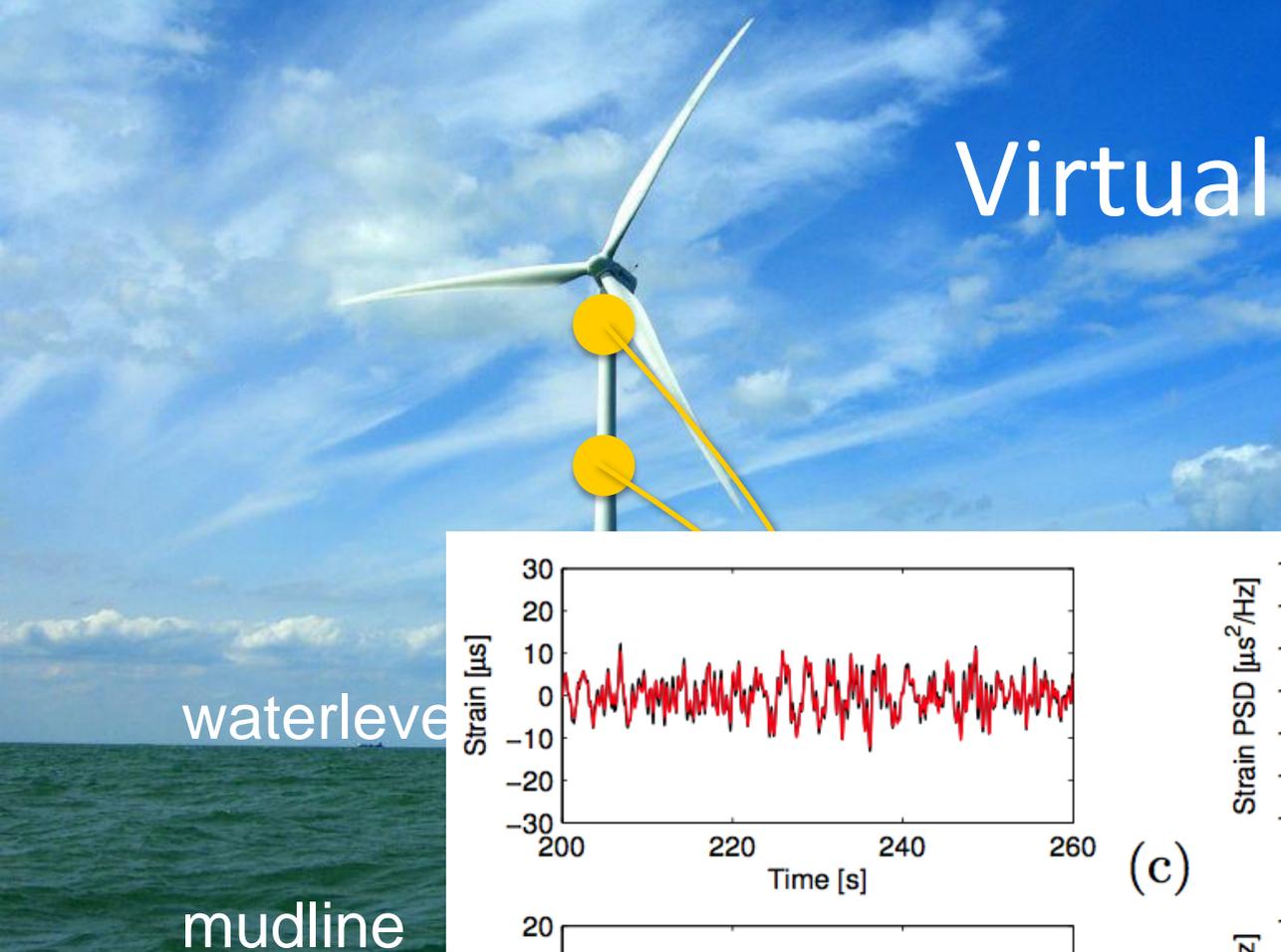
It is too expensive to monitor every turbine,



# Our Philosophy towards Fatigue



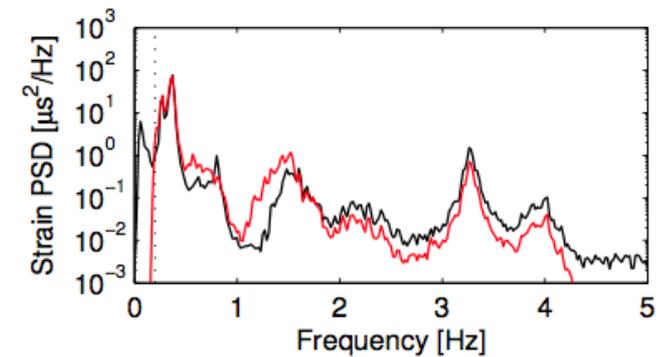
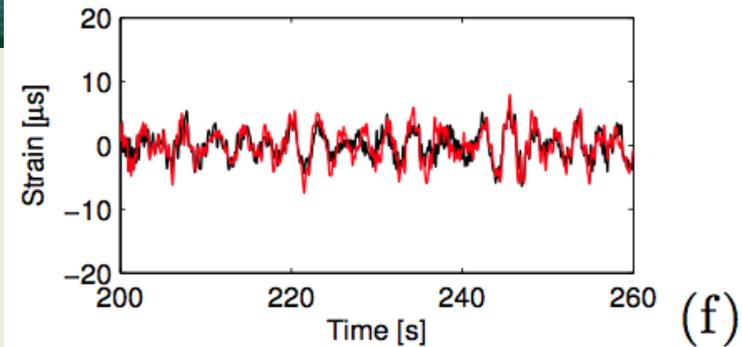
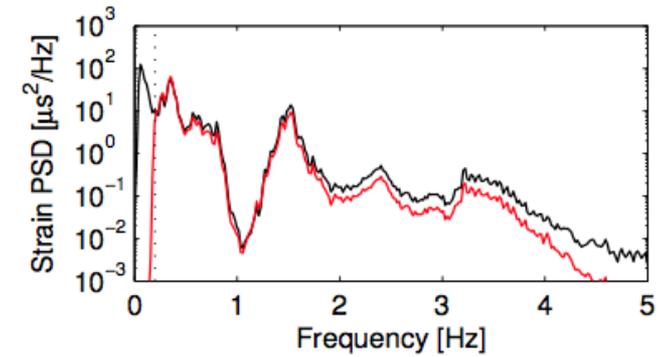
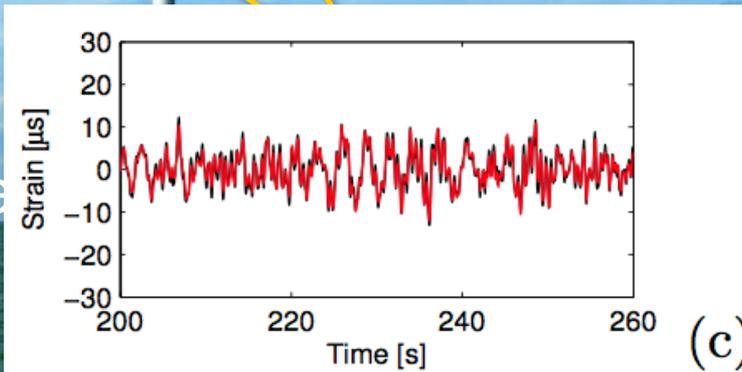
# Virtual sensing



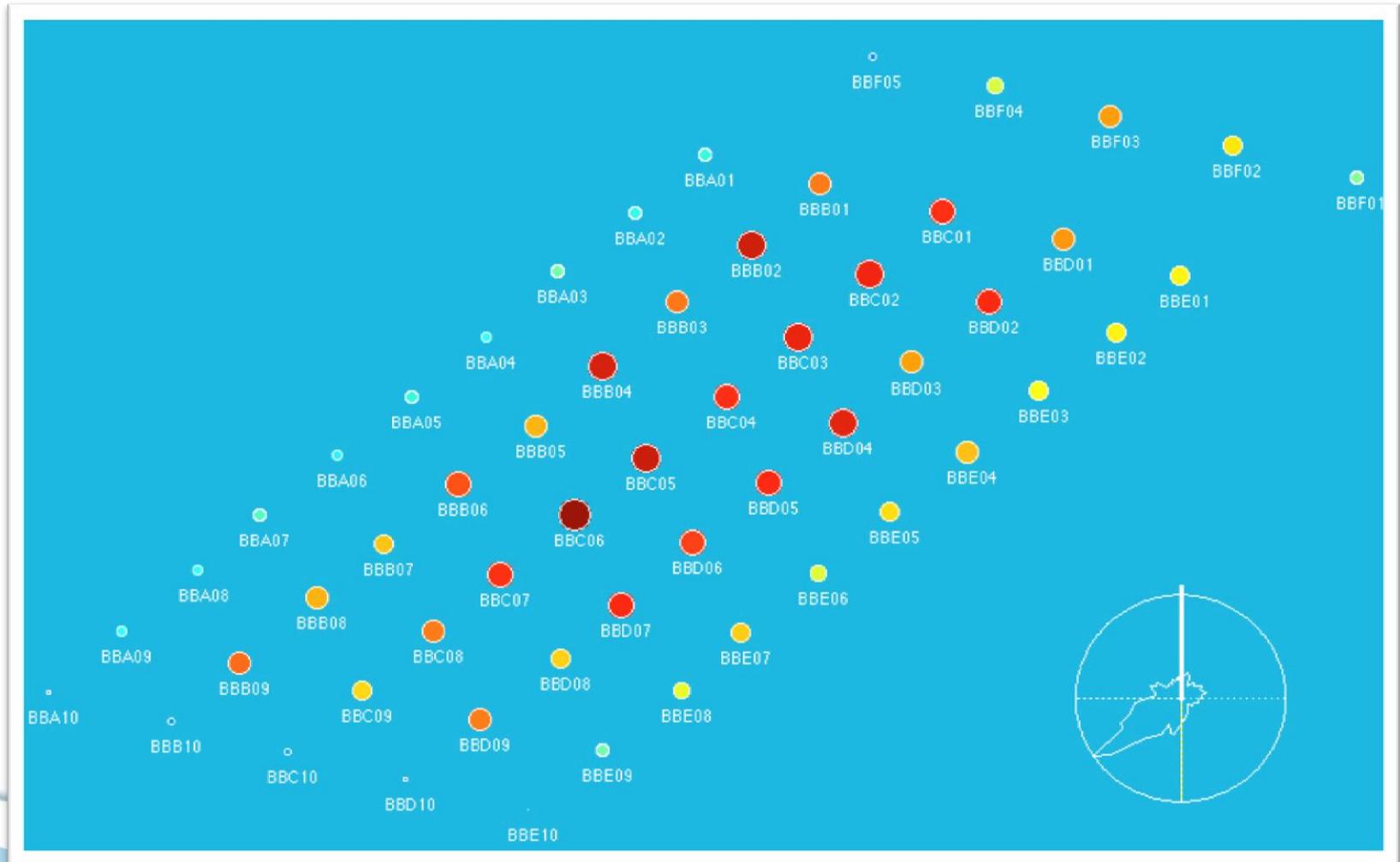
waterlevel

mudline

hotspot



# Our Philosophy towards Fatigue



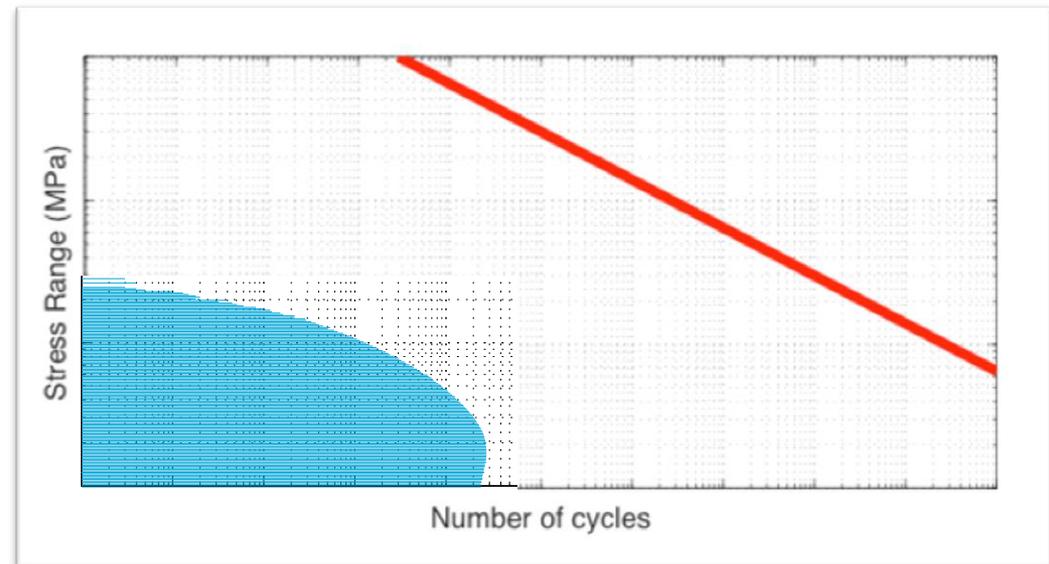
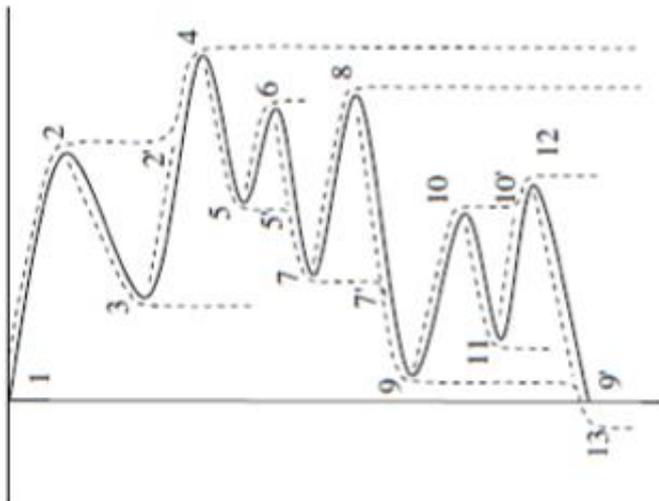
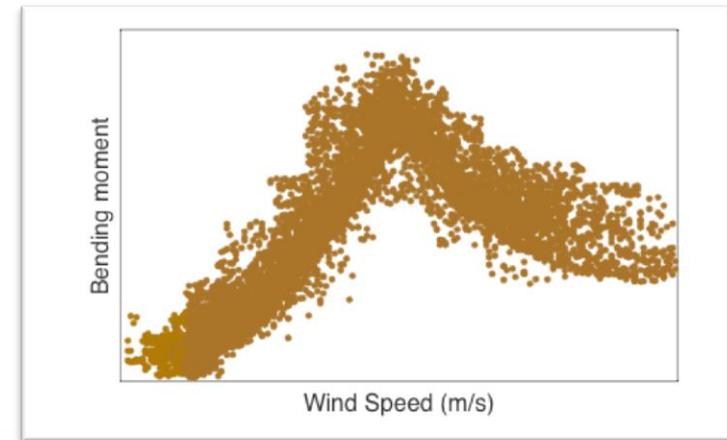
# Monitoring Fatigue

Stresses induced by bending moments

Rainflow counting on measured data

*Assess damage with*

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



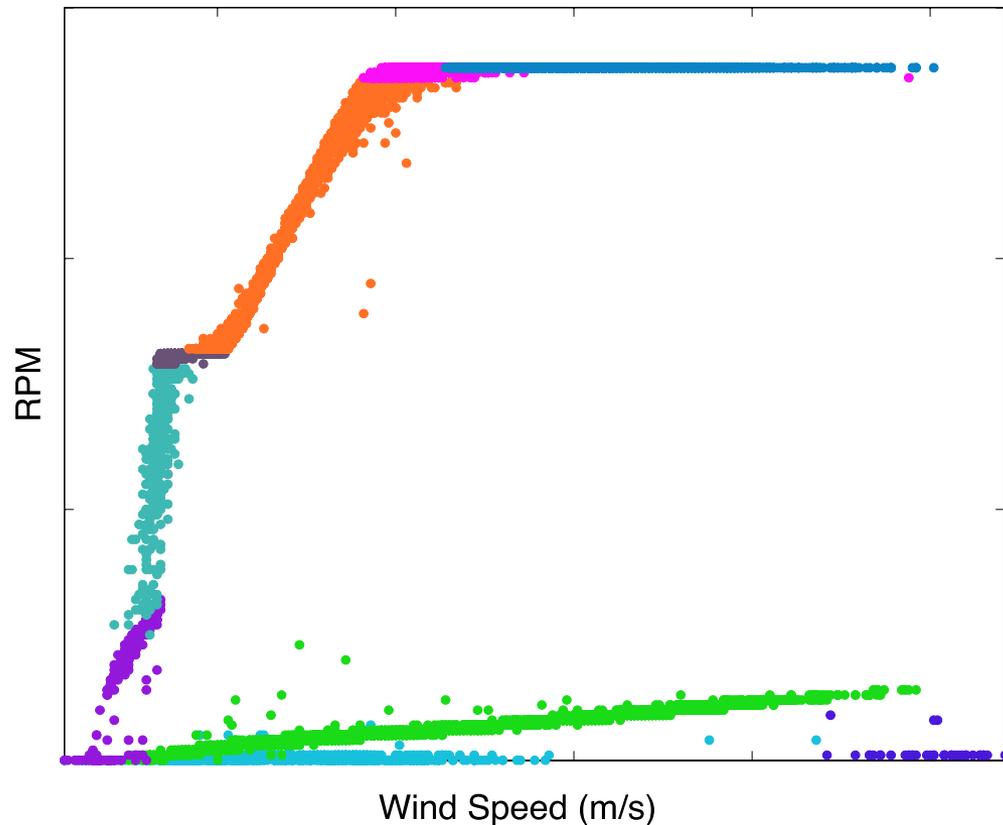
# What is costing fatigue life?

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

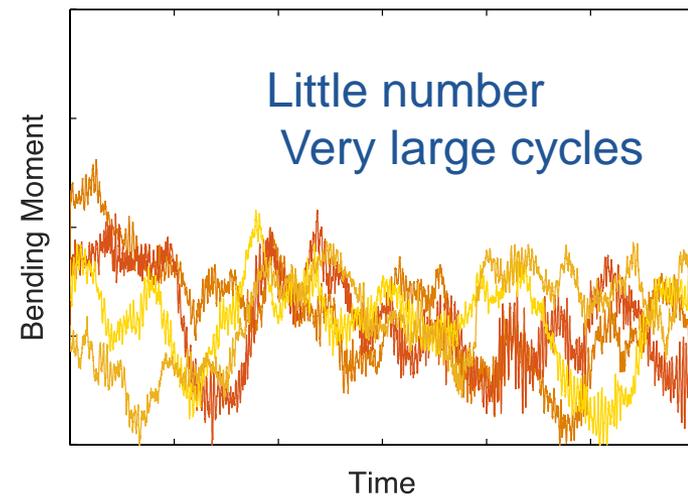
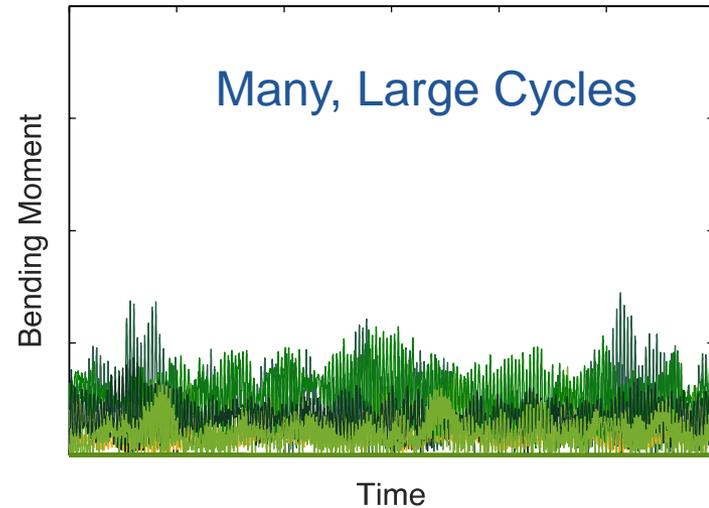
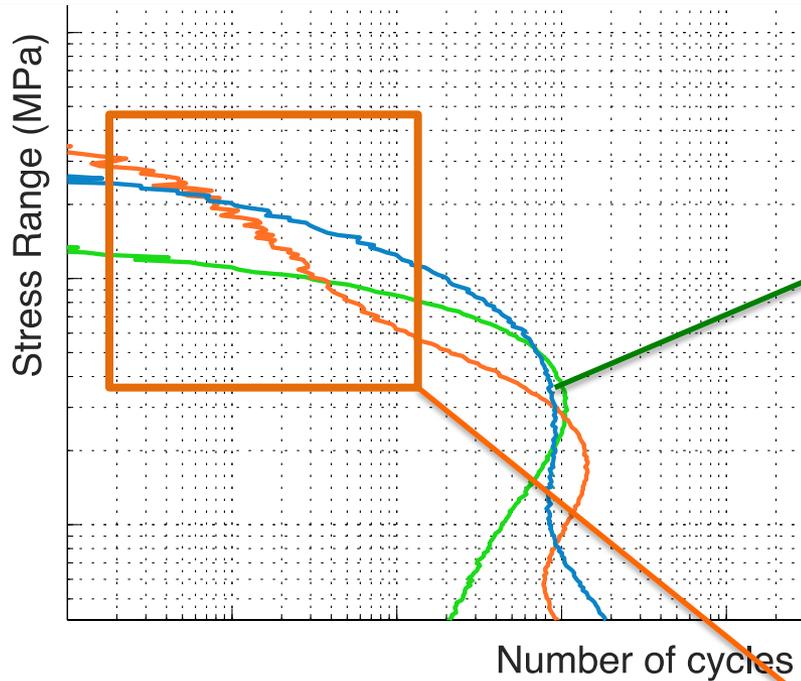
Dividing all data into different **Operational cases**

Focus on:

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



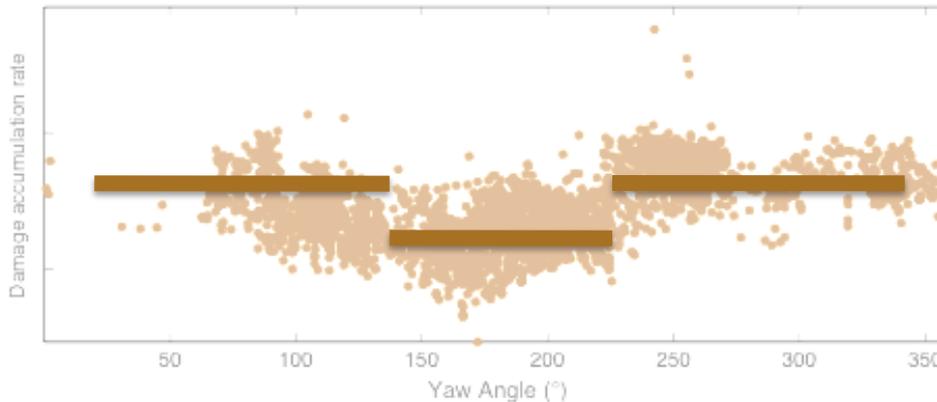
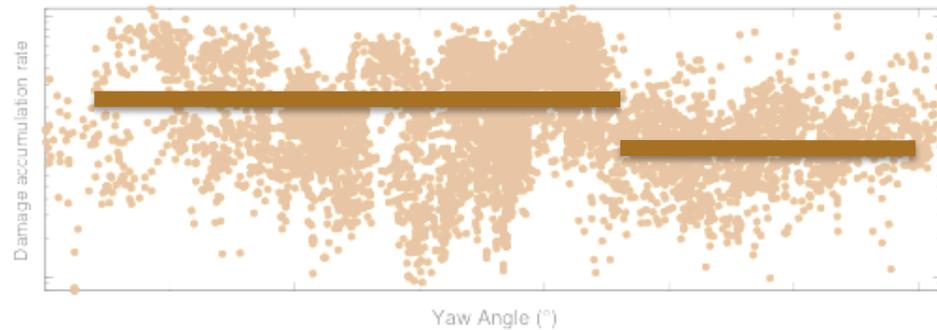
# What is costing fatigue life?



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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