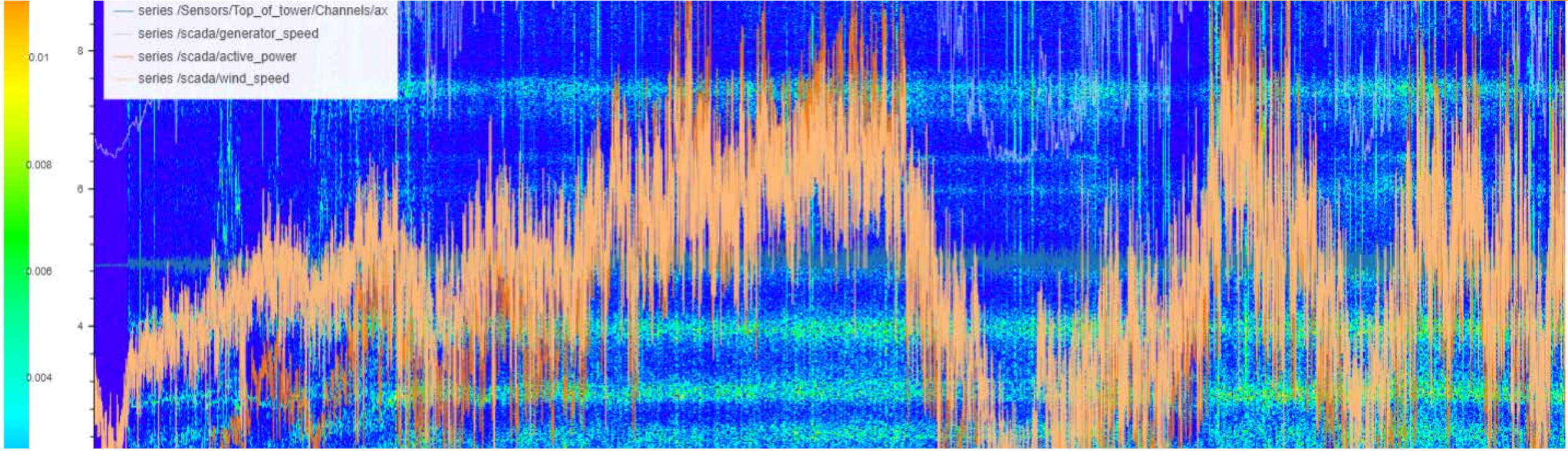


Real time structural analyses of wind turbines enabled by sensor measurements and digital twin models

Mateusz Graczyk, Senior Project Manager
SAP Norway, Engineering Center of Excellence

EERA DeepWind '2019 Trondheim, January 16-18, 2019

THE BEST RUN SAP

413,000+
Customers in more than 180 countries

95,000
Employees from 140+ countries

€23.46bn
Total Revenue (Non-IFRS) in FY2017

170 mil.
Subscribers in our cloud user base

46 yrs.
Of history and innovation

100+
Innovation and development centers

18,000+
SAP partner companies globally

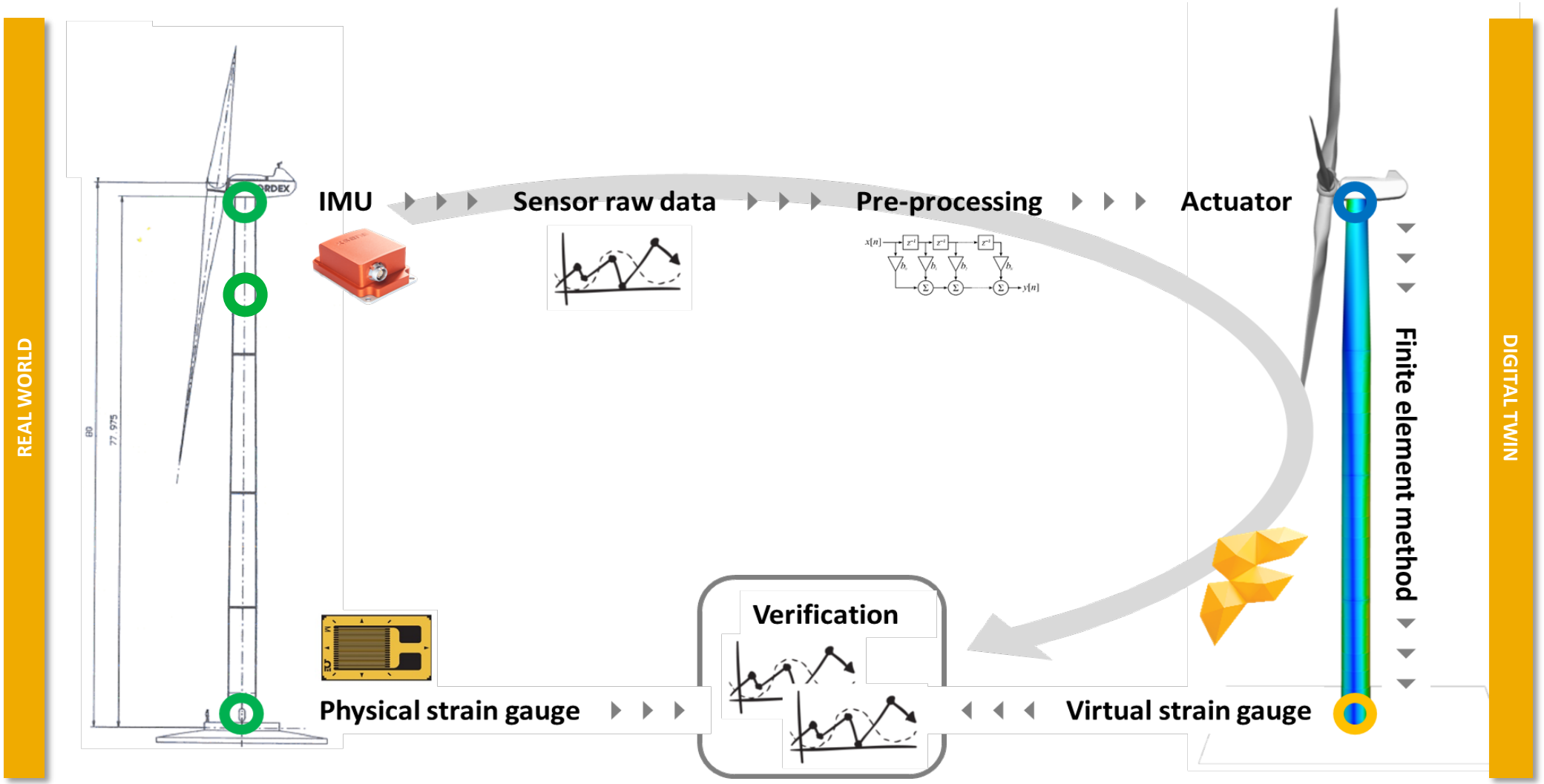
92%
Of Forbes Global 2000 are SAP customers

Engineering Center of Excellence

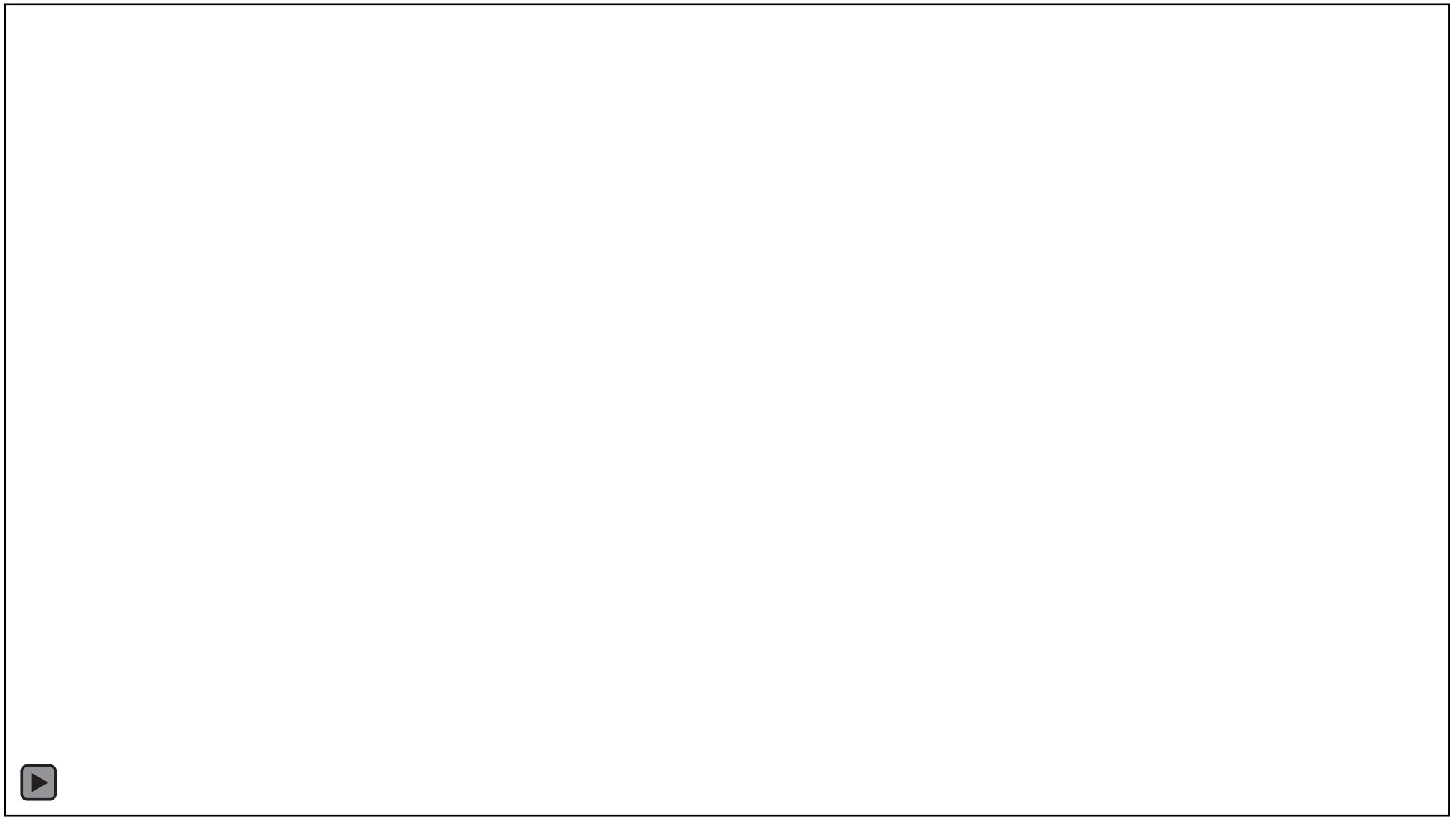
Do we need predictive maintenance?

www.adressa.no/nyheter/trondelag/2019/01/17/Vindmølle-står-i-brann-18265222.ece

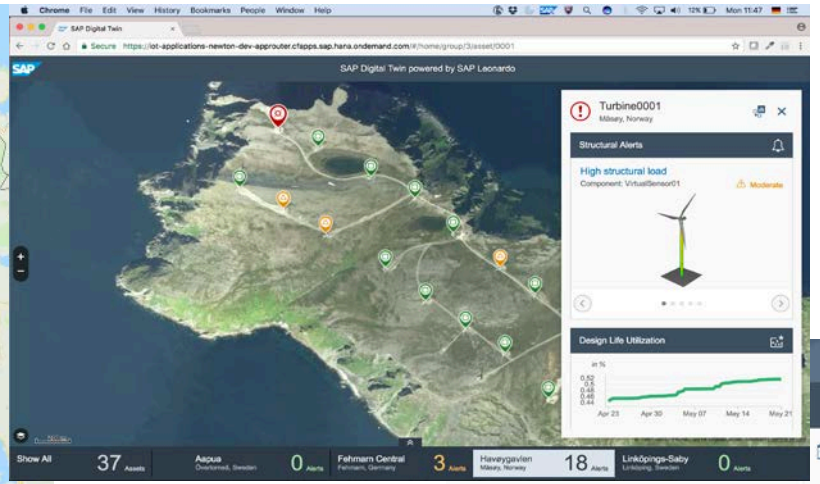
Digital twin method overview



Tower structure monitoring



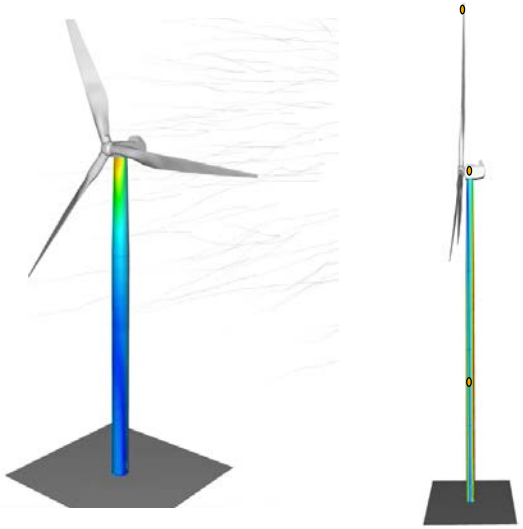
Prototype at Havøygavlen



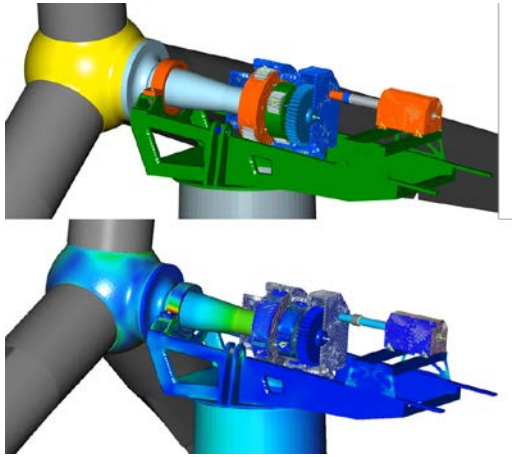
SAP Predictive Engineering Insights (PEI)

SAP Predictive Engineering Insights application areas

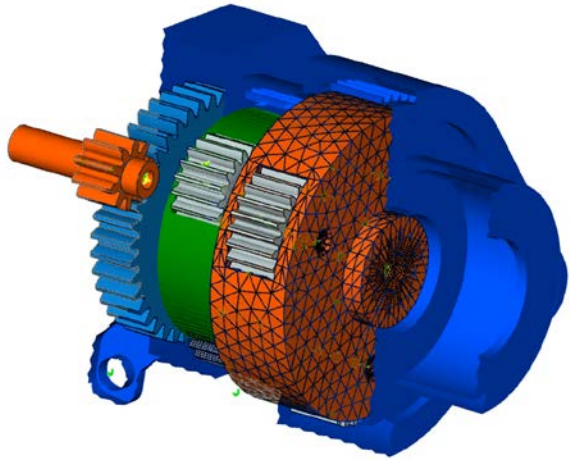
1 Structural diagnostics



2 Fatigue and durability



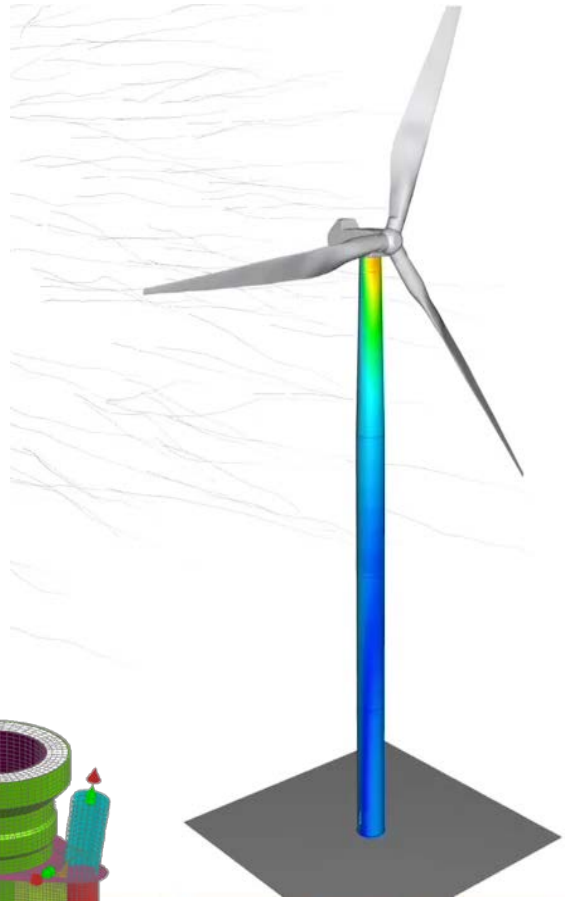
3 Vibrations diagnostics



Why response of the tower structure

- Structural issues
  - Fatigue of the flanges
  - Top section of the tower

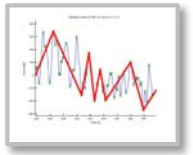
  + for offshore WT:
  - Fundament and grouting
  - Taller towers



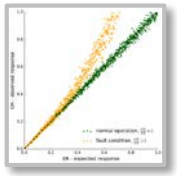
Insight of system state…

history | today | future

Structural and wind loads for control decisions



Fatigue analysis for remaining life



Condition- and trend-based maintenance

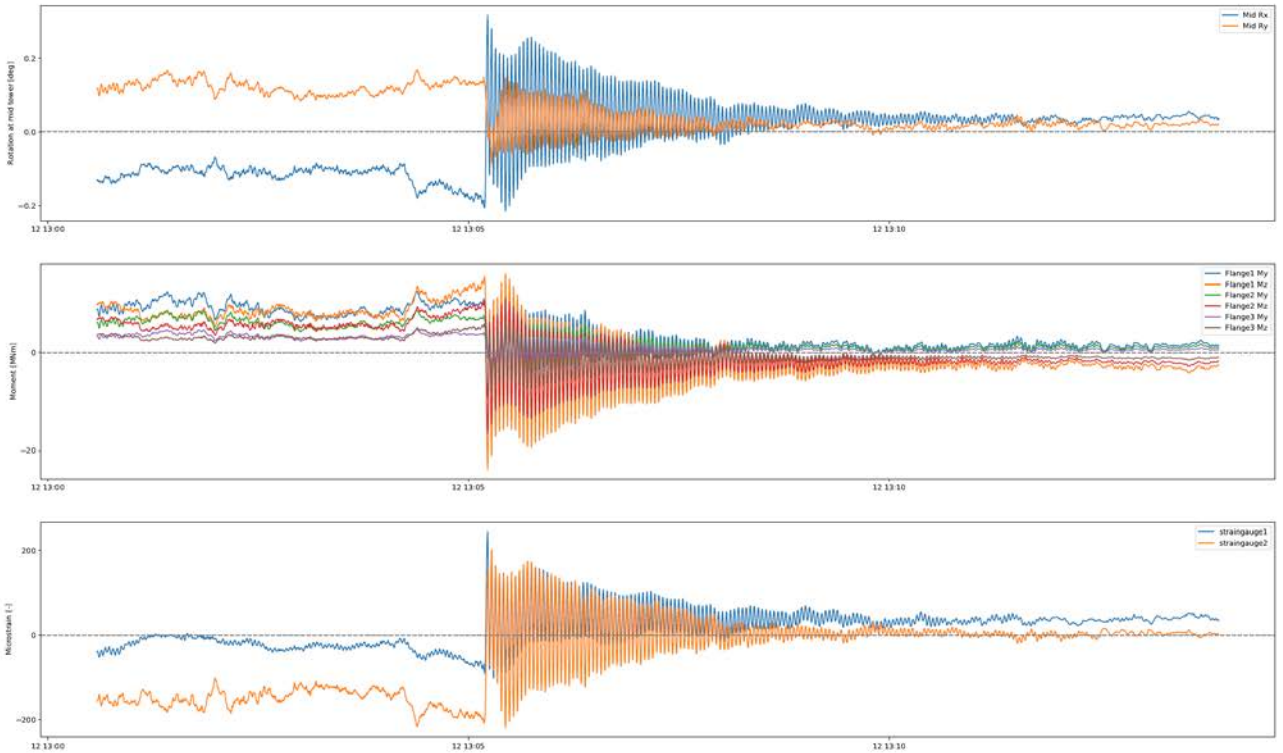
…used for both **hindsight** and **foresight**

Why response of the tower structure

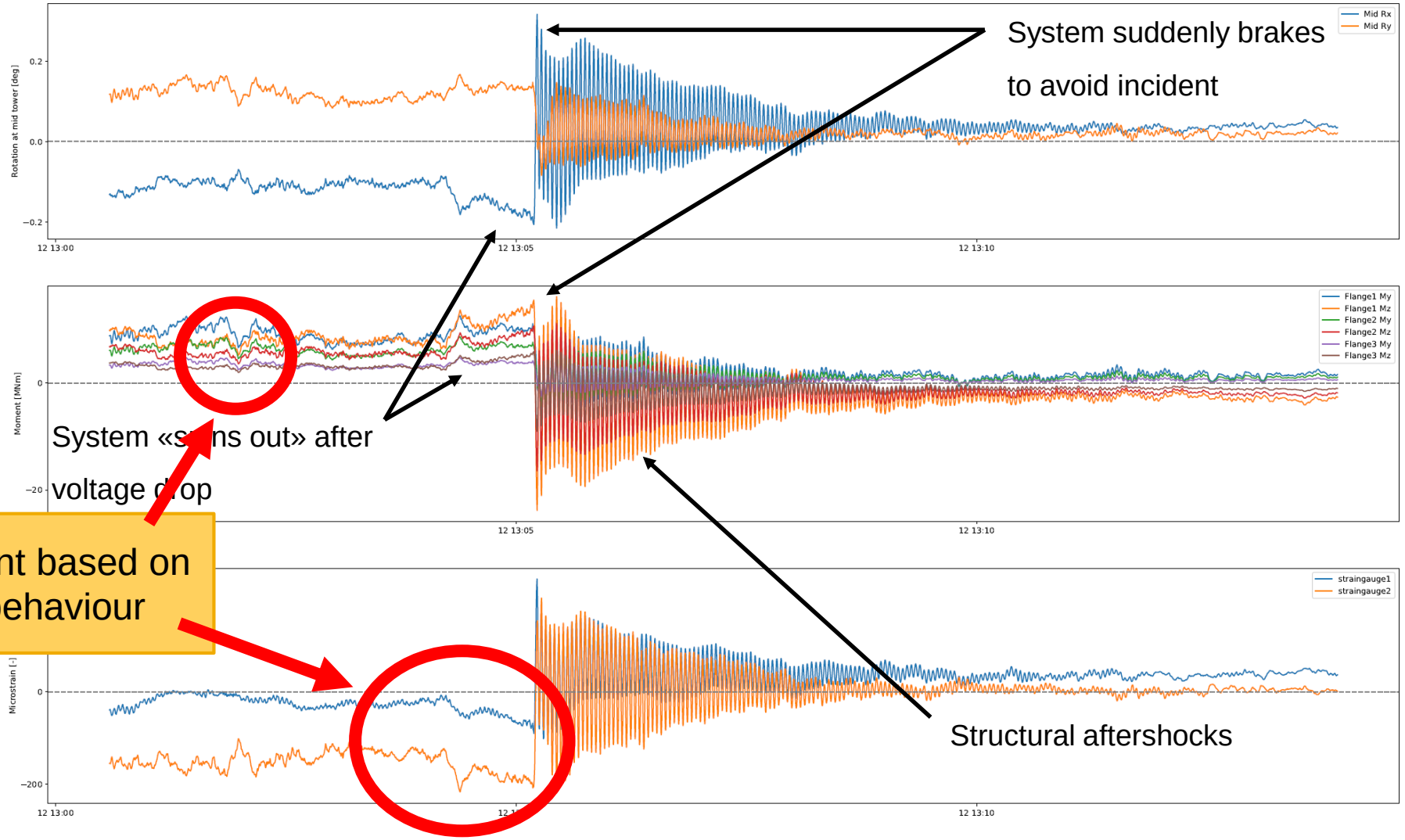
- Structural issues
  - Fatigue of the flanges
  - Top section of the tower

  + for offshore WT:
  - Fundament and grouting
  - Taller towers

- Wind response “gauge” for the system:
  - Emergency brake
  - Start/stop and yaw algorithms
  - Yaw misalignment
  - Mechanical issues

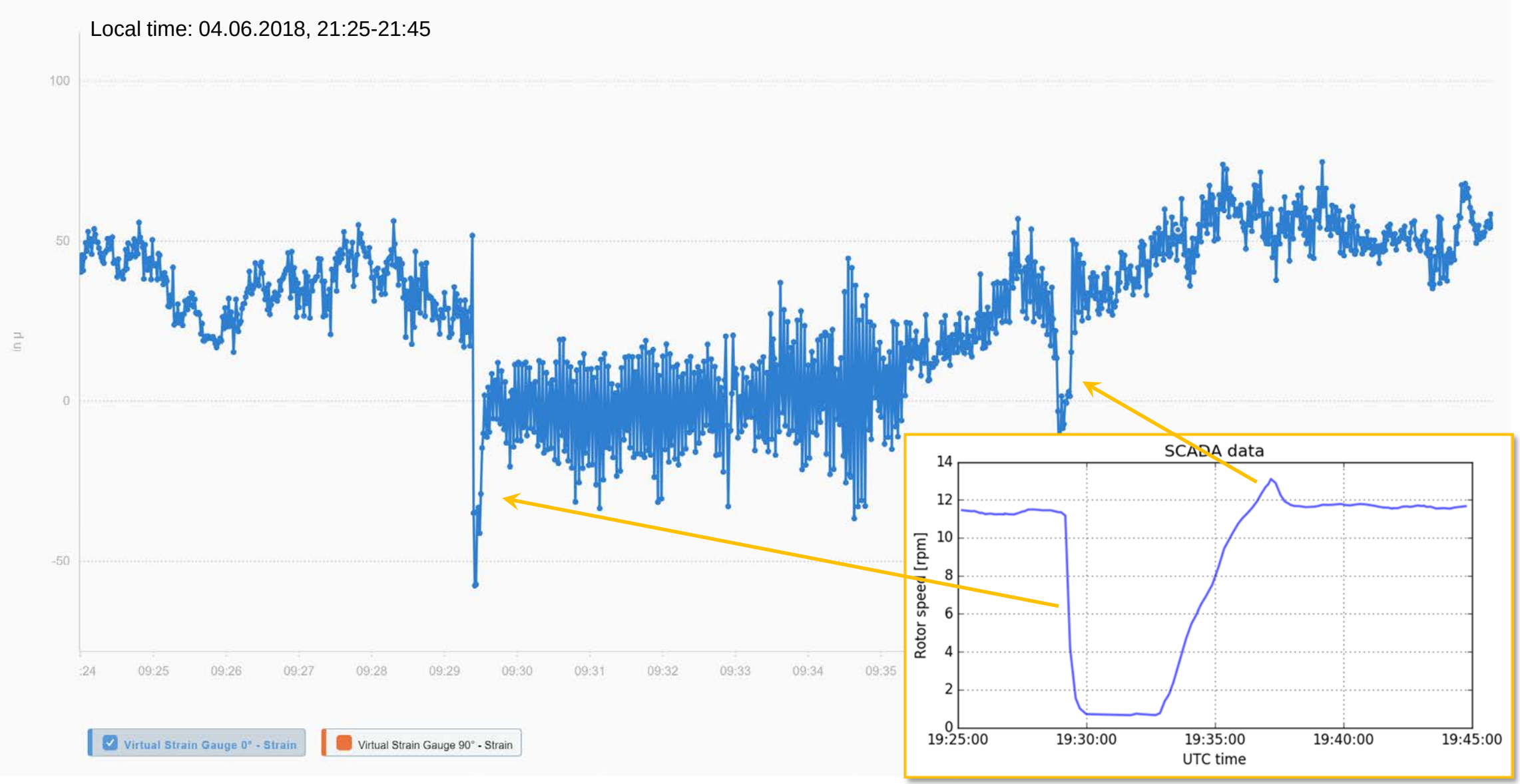


Emergency stop due to sudden voltage drop from converter fault

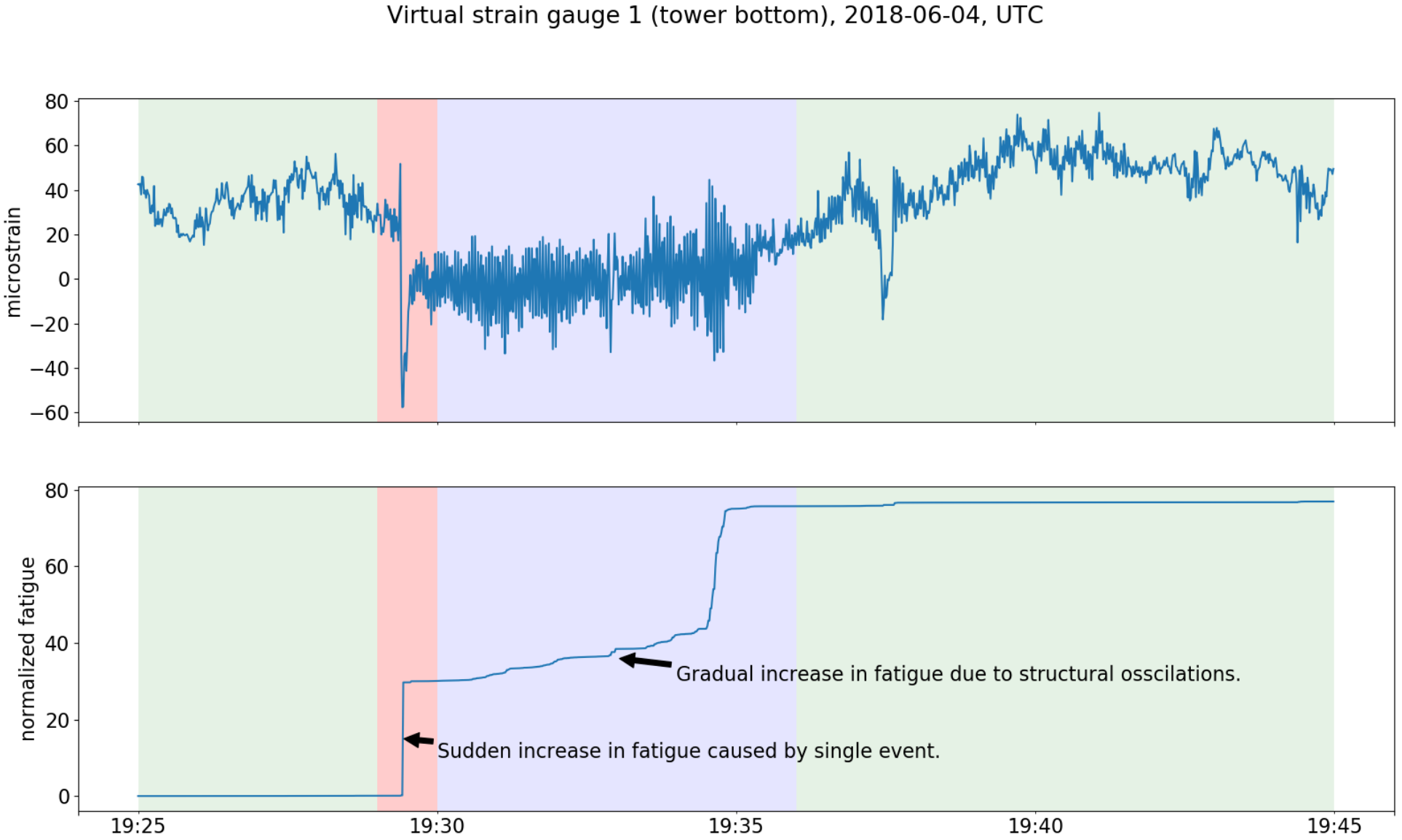


Predict event based on system behaviour

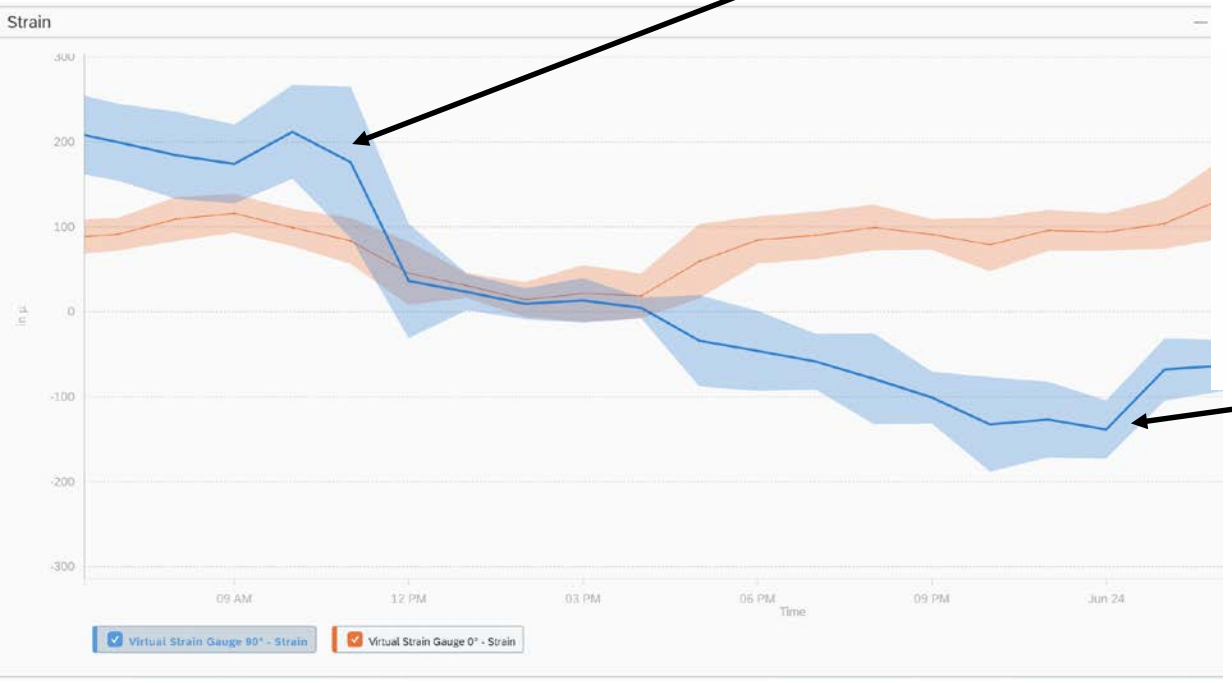
Extreme loads from rapid changes in state, production > stop > production



One radical happening (orange and blue) ≈ 4 days normal life (green)



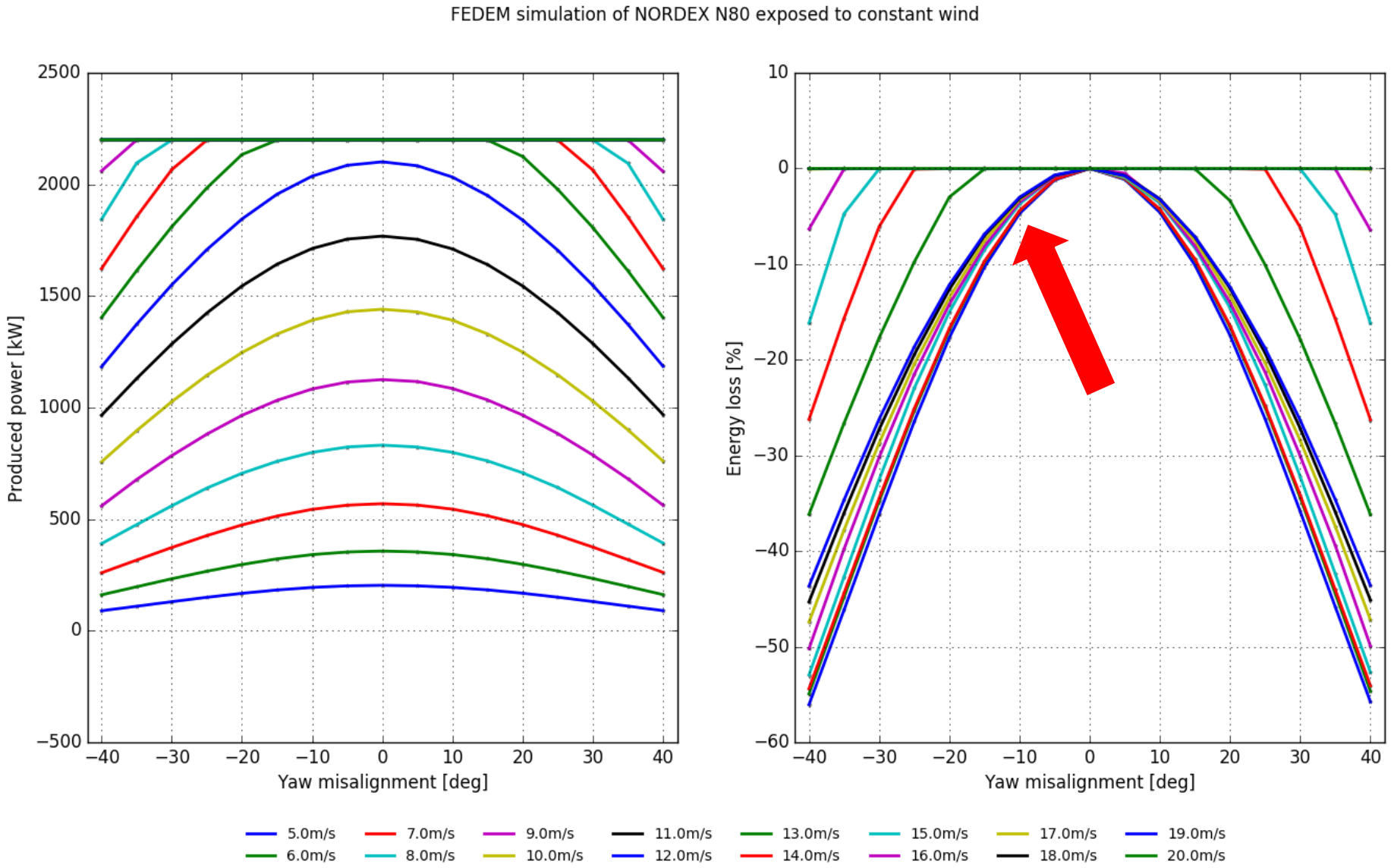
Wind changes direction rapidly, June 23rd 2018, 12-24



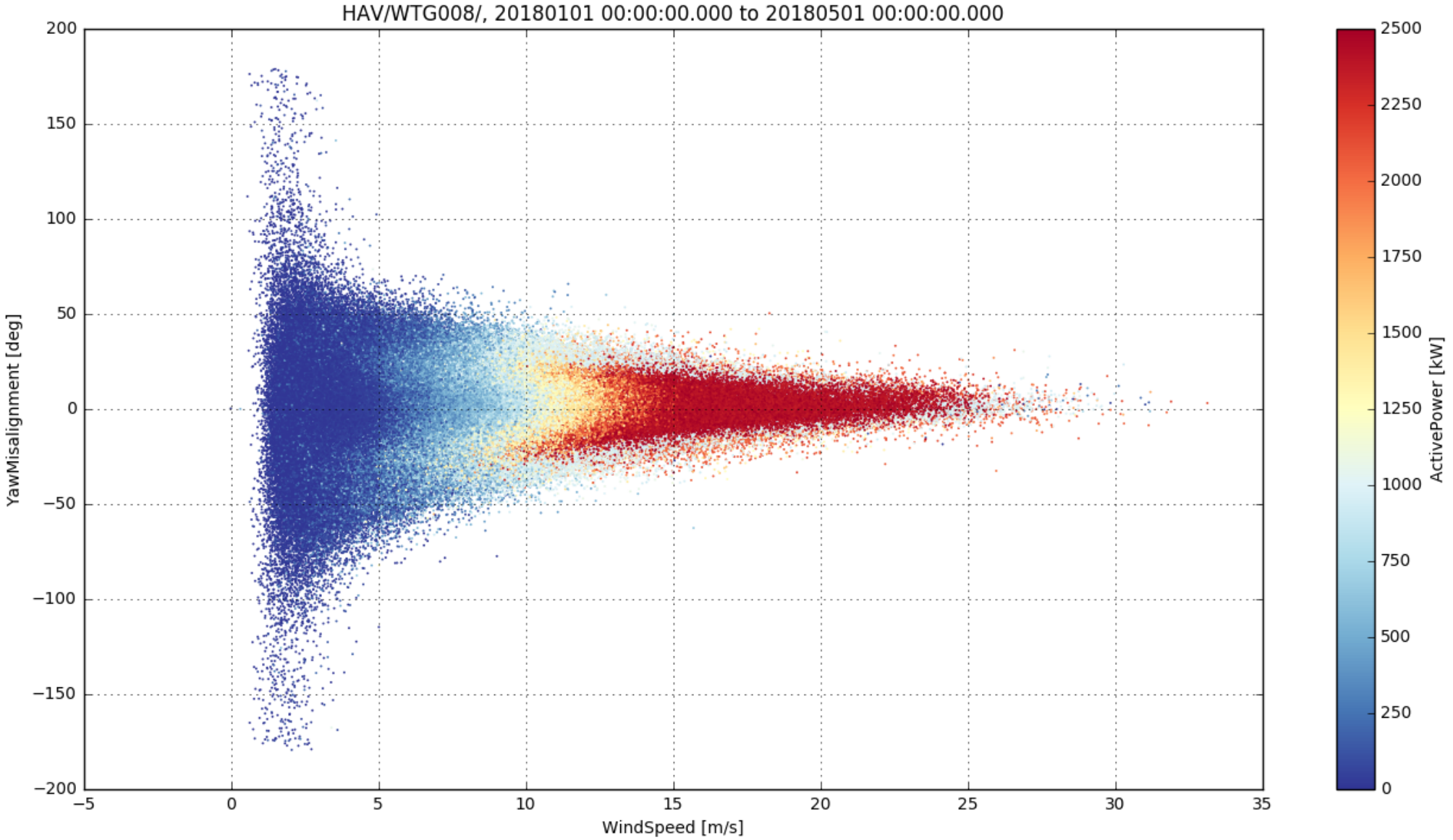
Saturday 10:00	-	6.3°C	6.3°C	6.1°C	-	Strong breeze, 10.5 m/s from north	12,7 m/s	96 %
Saturday 11:00	-	6.5°C	6.5°C	6.3°C	-	Strong breeze, 11.1 m/s from north	14,0 m/s	97 %
Saturday 12:00	-	6.9°C	6.9°C	6.5°C	-	Fresh breeze, 9.7 m/s from north-northeast	13,7 m/s	97 %
Saturday 13:00	-	6.9°C	6.9°C	6.8°C	-	Moderate breeze, 7.1 m/s from north-northeast	11,2 m/s	98 %
Saturday 14:00	-	7.0°C	7.0°C	6.9°C	-	Light breeze, 3.0 m/s from north	6,8 m/s	97 %
Saturday 15:00	-	7.1°C	7.1°C	6.9°C	-	Light air, 0.8 m/s from east-northeast	3,1 m/s	97 %
Saturday 16:00	-	7.7°C	8.2°C	7.1°C	-	Light breeze, 1.6 m/s from south-southwest	2,5 m/s	96 %
Saturday 17:00	-	7.4°C	7.7°C	7.4°C	-	Gentle breeze, 4.2 m/s from south-southwest	5,6 m/s	96 %
Saturday 18:00	-	6.9°C	7.4°C	6.9°C	-	Moderate breeze, 6.2 m/s from south-southwest	7,8 m/s	97 %
Saturday 19:00	-	7.0°C	7.1°C	6.9°C	-	Moderate breeze, 6.8 m/s from southwest	8,3 m/s	97 %
Saturday 20:00	-	6.9°C	7.2°C	6.9°C	-	Moderate breeze, 7.3 m/s from southwest	10,6 m/s	96 %
Saturday 21:00	-	6.7°C	6.9°C	6.7°C	-	Fresh breeze, 10.0 m/s from southwest	12,3 m/s	98 %
Saturday 22:00	-	6.6°C	6.7°C	6.6°C	-	Fresh breeze, 10.4 m/s from south-southwest	12,7 m/s	98 %
Saturday 23:00	-	6.8°C	6.8°C	6.6°C	-	Fresh breeze, 10.2 m/s from south-southwest	12,8 m/s	99 %

https://www.yr.no/place/Norway/Finnmark/M%C3%A5s%C3%B8y/Hav%C3%B8ygavlen/almanakk.html?dato=2018-06-23

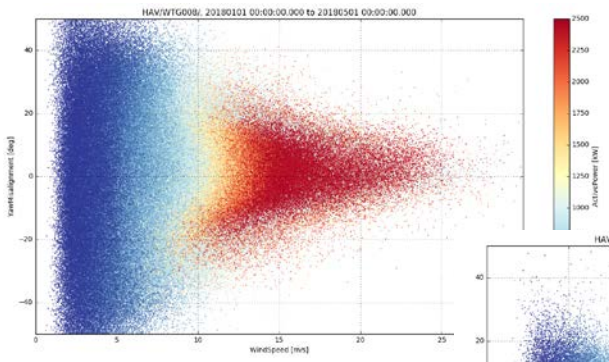
Impact of yaw misalignment on produced power (simulation study)



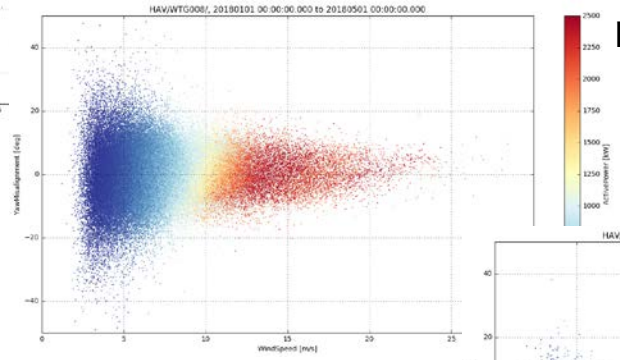
Yaw misalignment based on SCADA raw data – WTG008



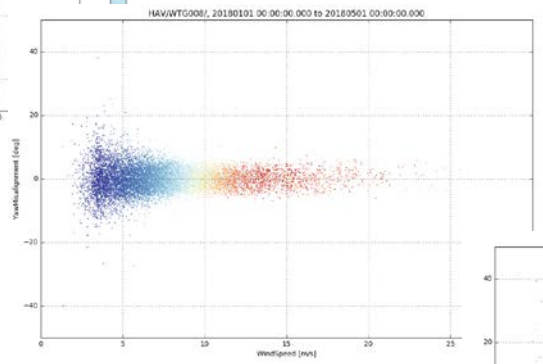
Yaw misalignment based on SCADA data time intervals – WTG008



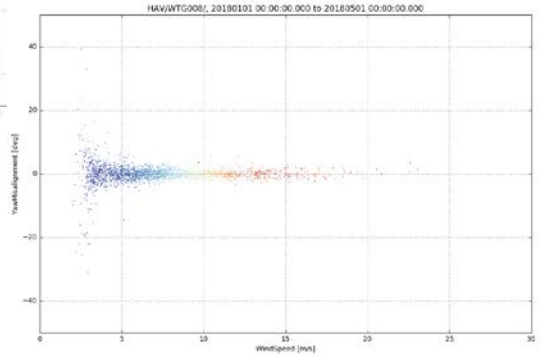
raw data



mean over 60s



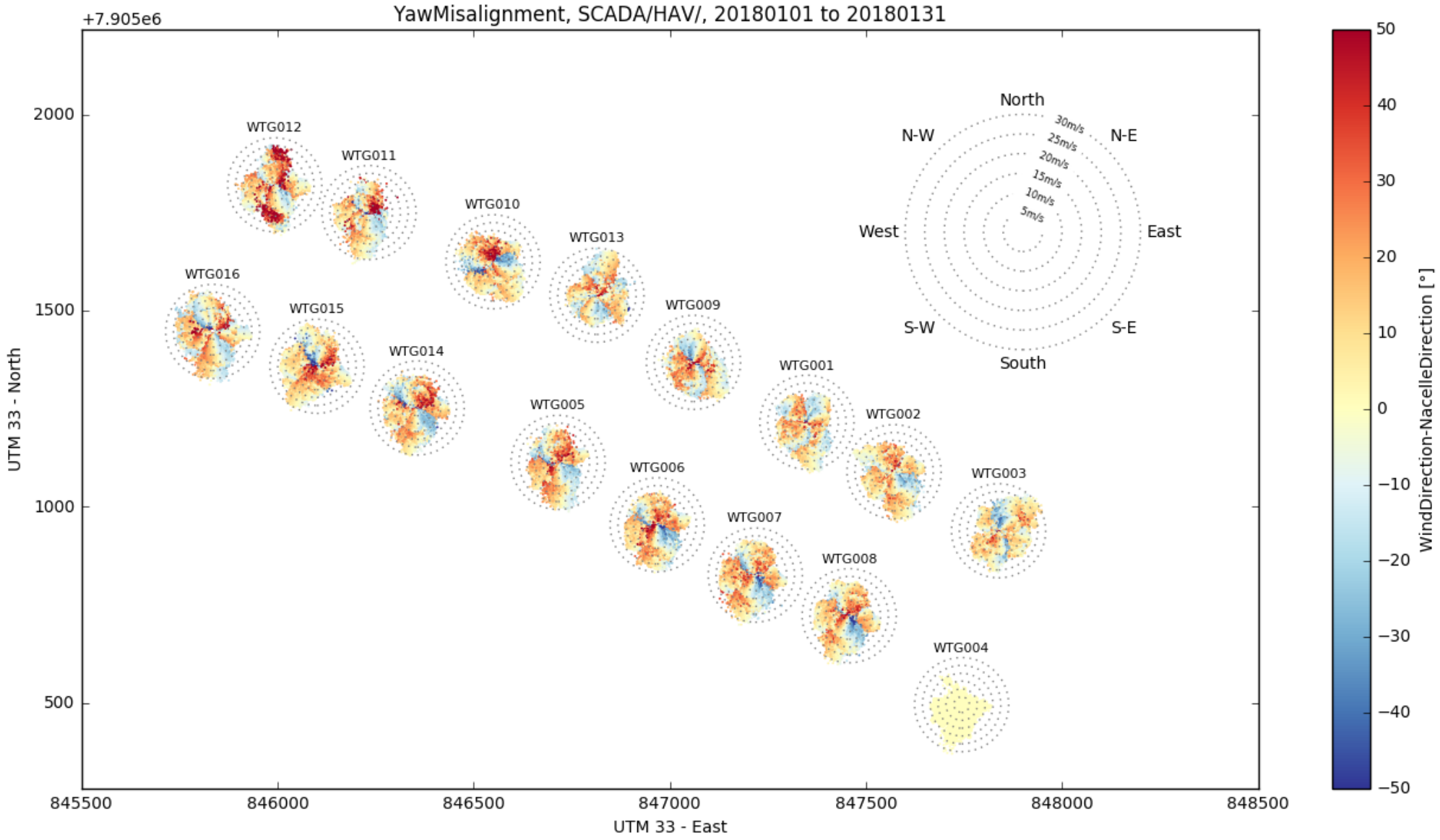
mean over 600s



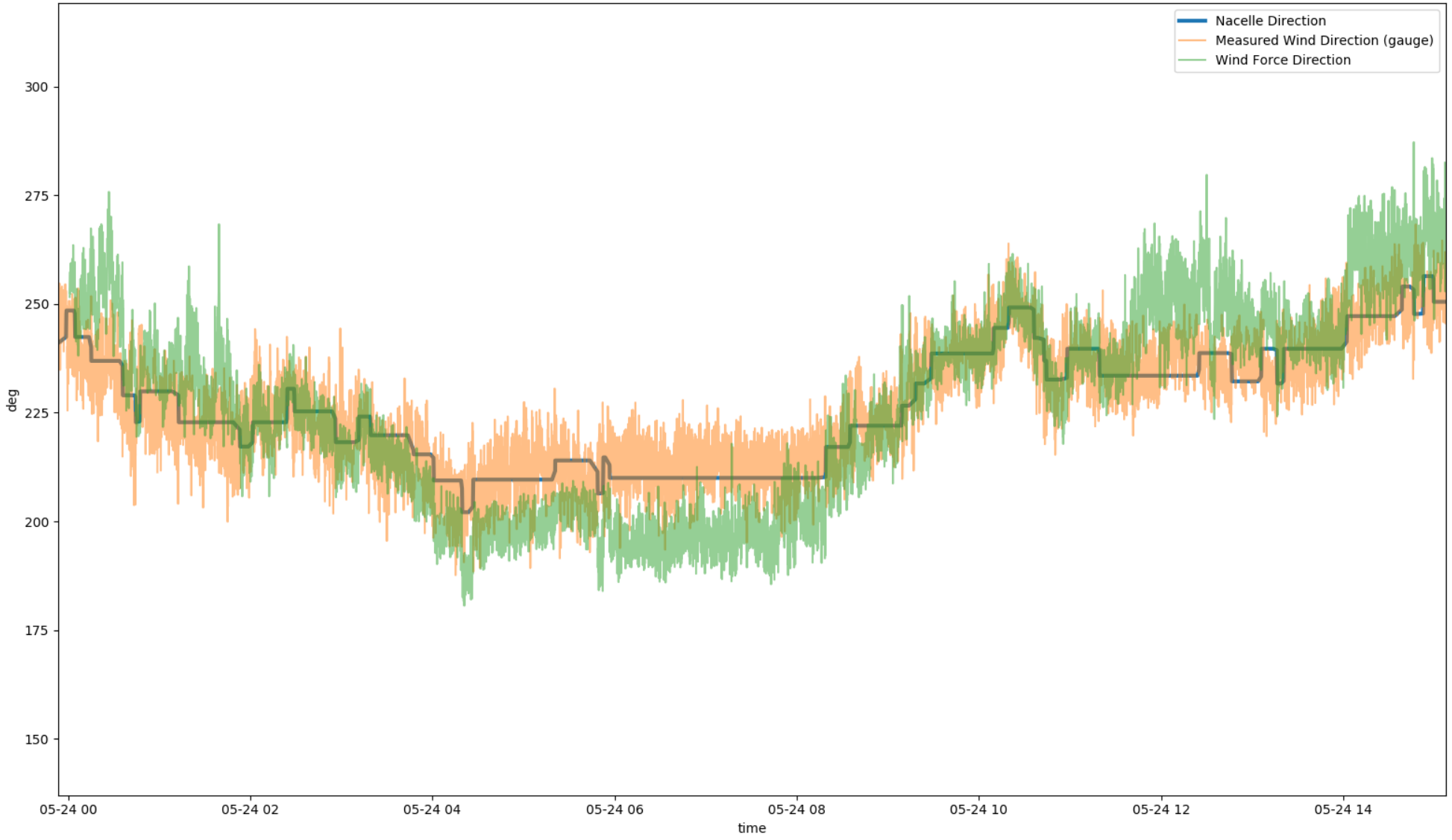
mean over 3600s

significant decrease in variance of yaw misalignment

Yaw misalignment based on SCADA raw data – wind farm level

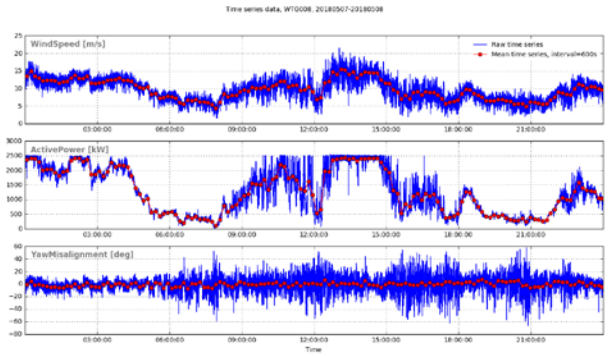


Yaw misalignment, wind direction, yaw angle, wind force direction



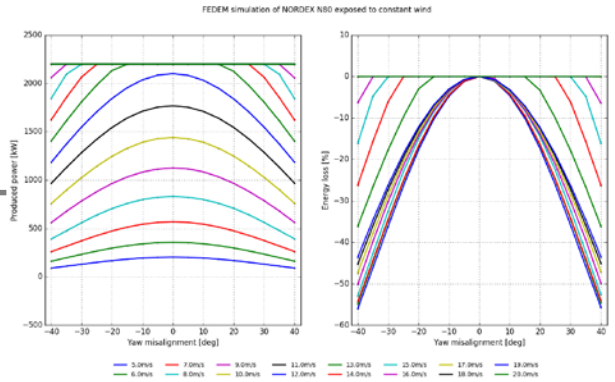
Analysis approach for each data point of mean time series (step 1)

SCADA



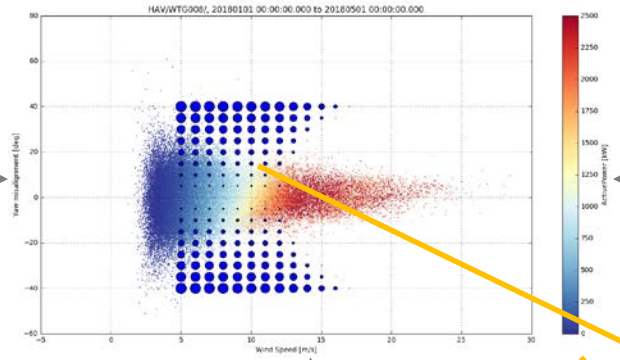
Theoretical *EnergyLoss* [%]

@ *WindSpeed*, *YawMisal*.



FEDEM

YawMisalignment [deg]



WindSpeed [m/s]

ActivePower [kW]

$$ProducedEnergy\,[\mathrm{kWh}] = ActivePower\,[\mathrm{kW}] \cdot \mathrm{time}\,[\mathrm{h}]$$

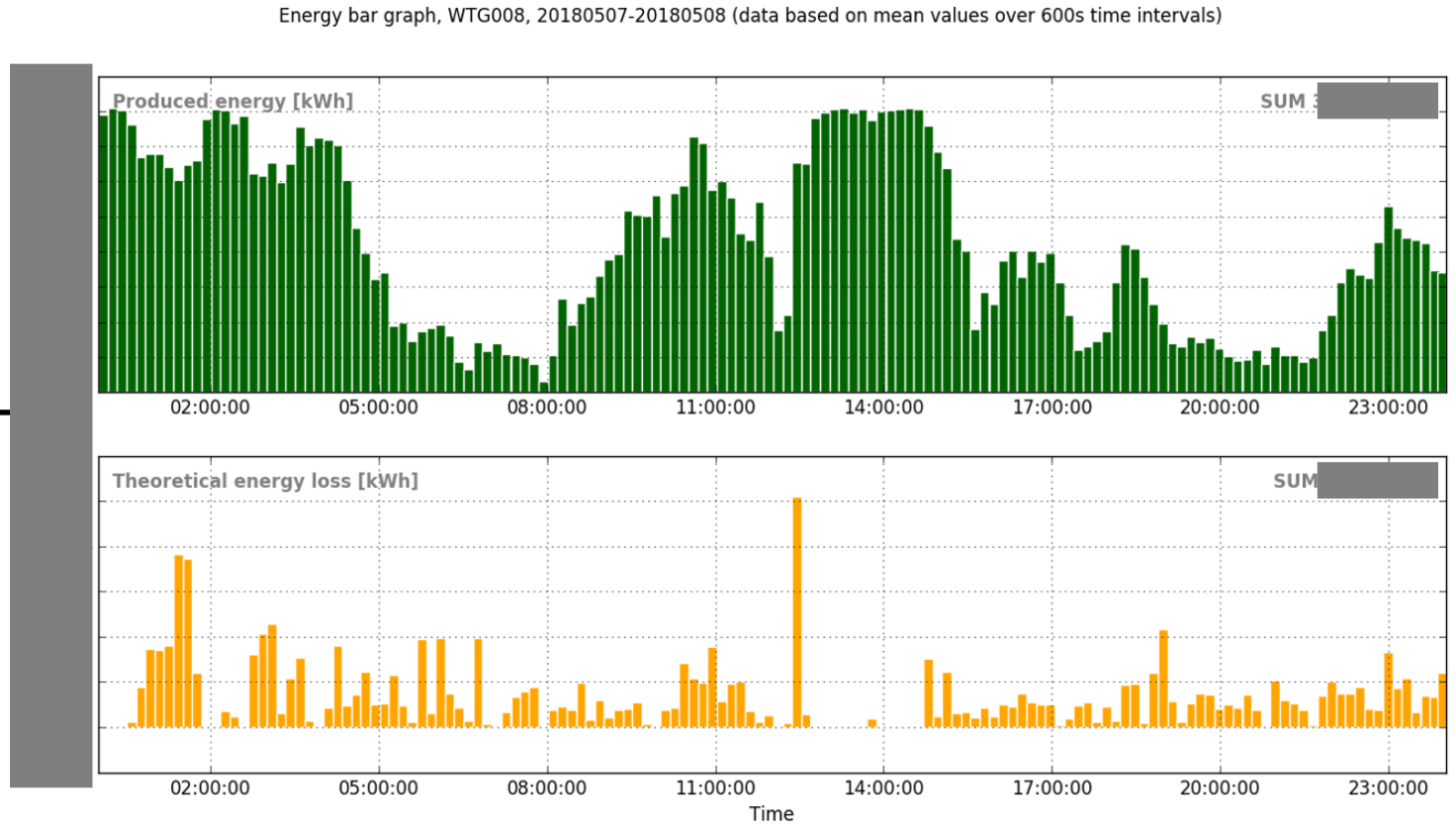
$$\text{Theoretical } EnergyLoss\,[\mathrm{kWh}] = ProducedEnergy\,[\mathrm{kWh}] \cdot EnergyLoss\,[\%]$$

Analysis for mean time series

$$ProducedEnergy\,[\text{kWh}] = ActivePower\ [\text{kW}] \cdot \text{time}\ [\text{h}]$$

$$\text{Theoretical}\ EnergyLoss\,[\text{kWh}] = ProducedEnergy\ [\text{kWh}] \cdot EnergyLoss\,[\%]$$

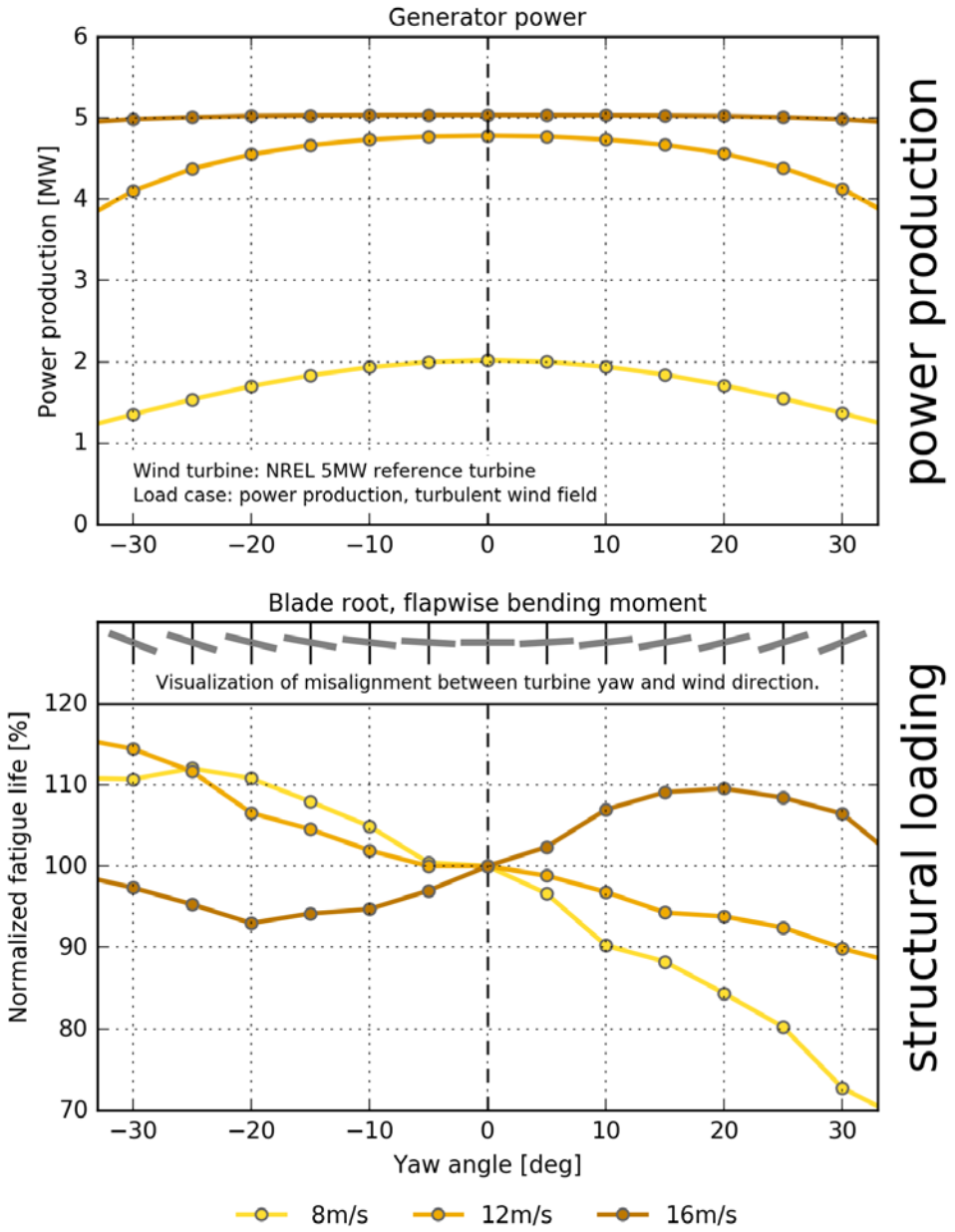
Calculated values for each time step of mean time series.



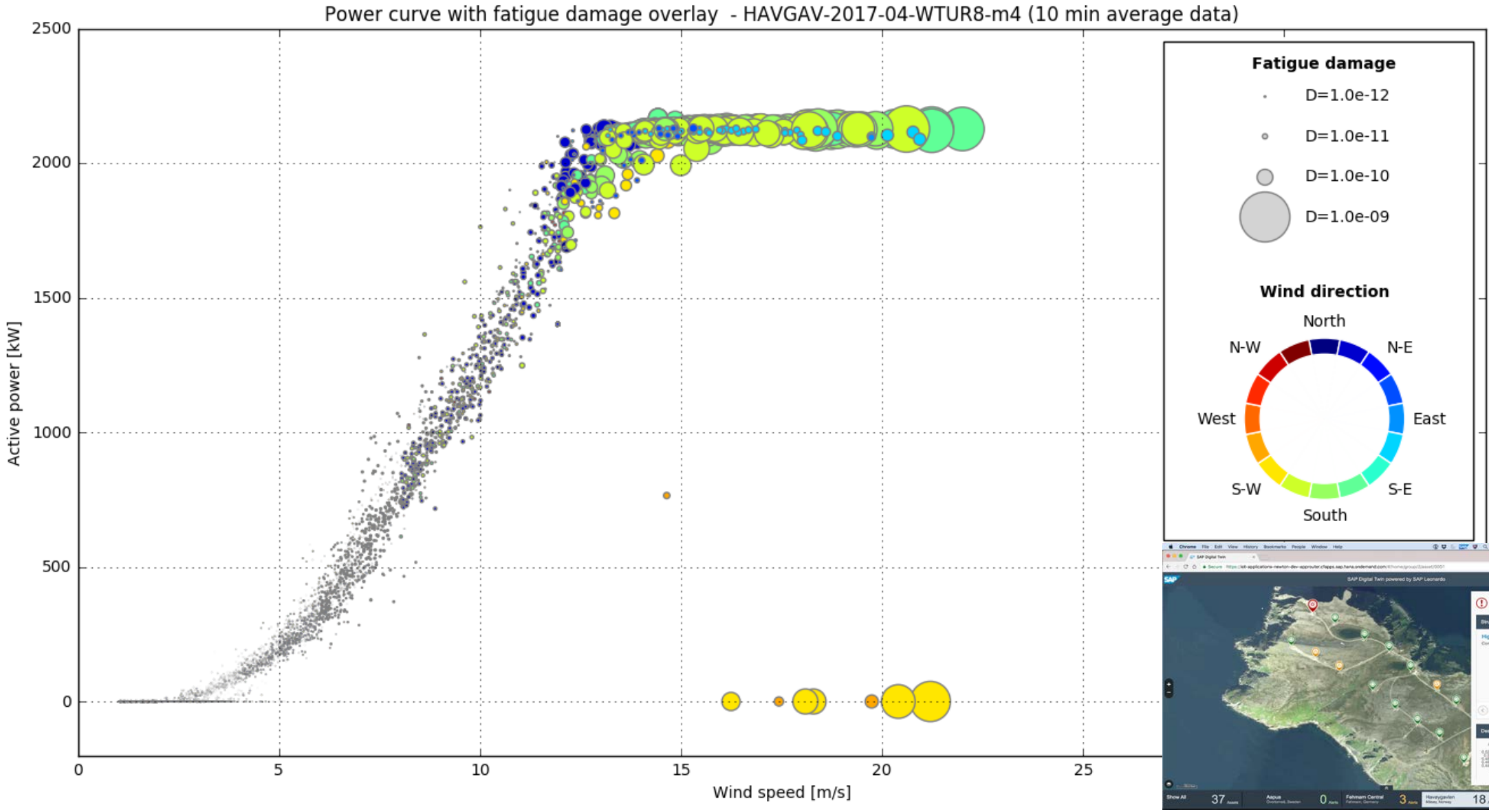
Σ

Total numbers calculated for both individual turbines as well as complete wind farm.

Not just the power production that will take a hit…

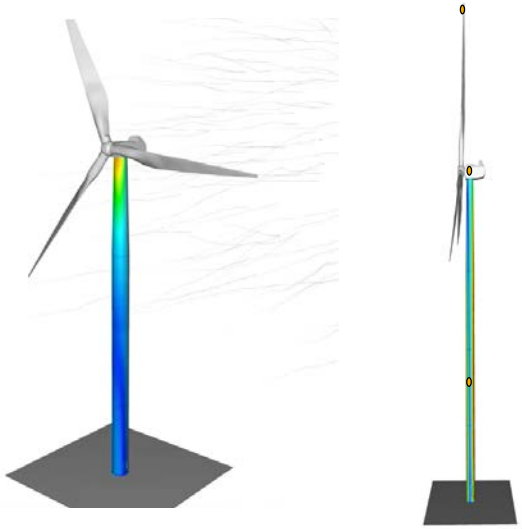


Produced power vs fatigue

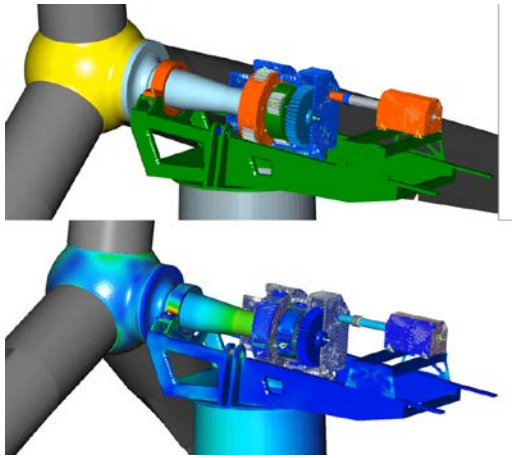


SAP Predictive Engineering Insights application areas

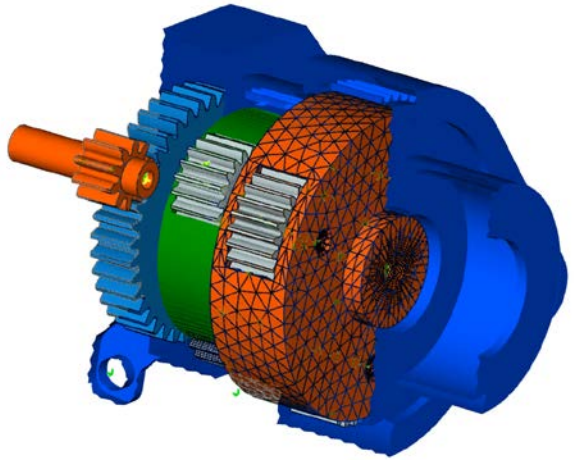
1 Structural diagnostics



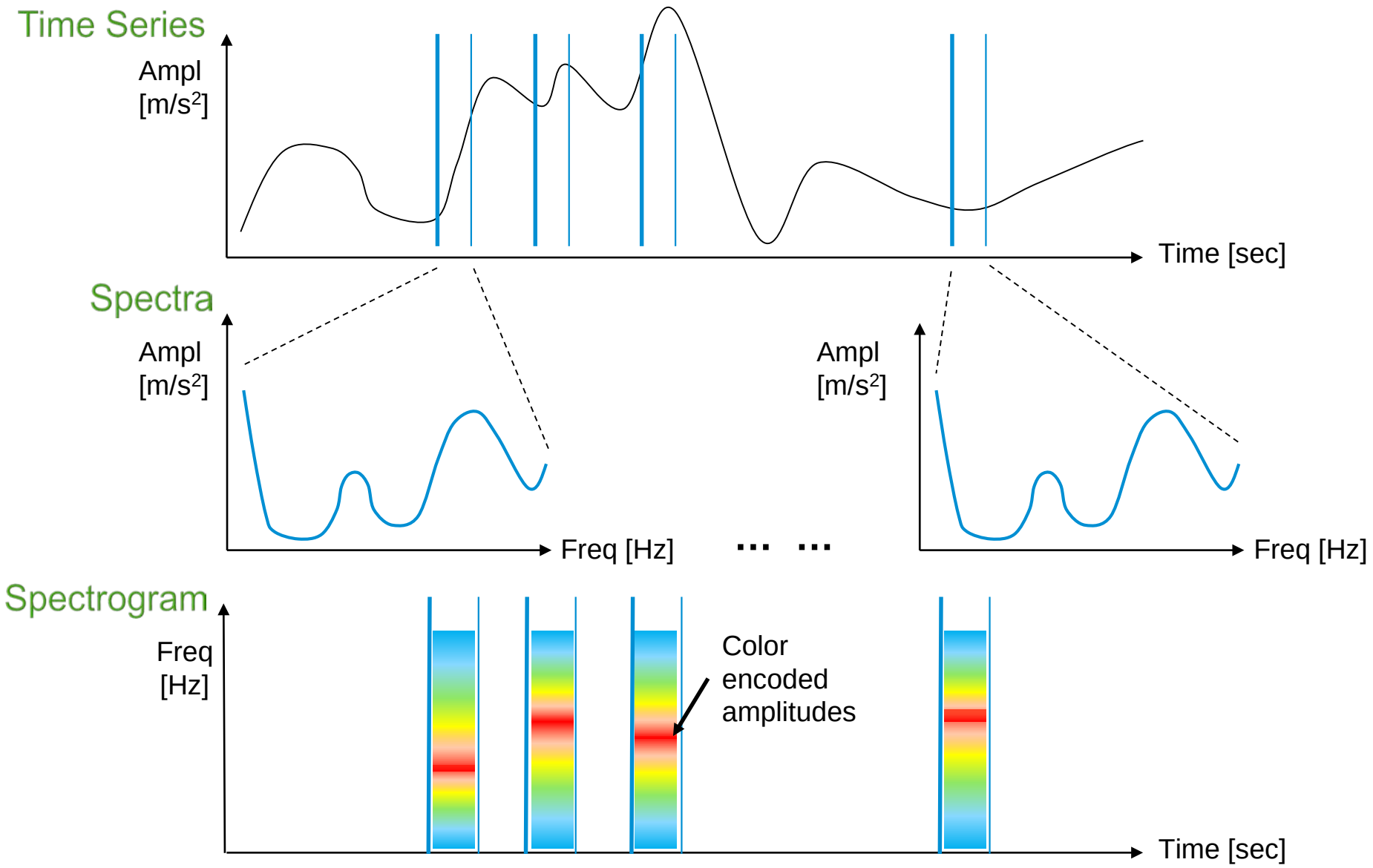
2 Fatigue and durability



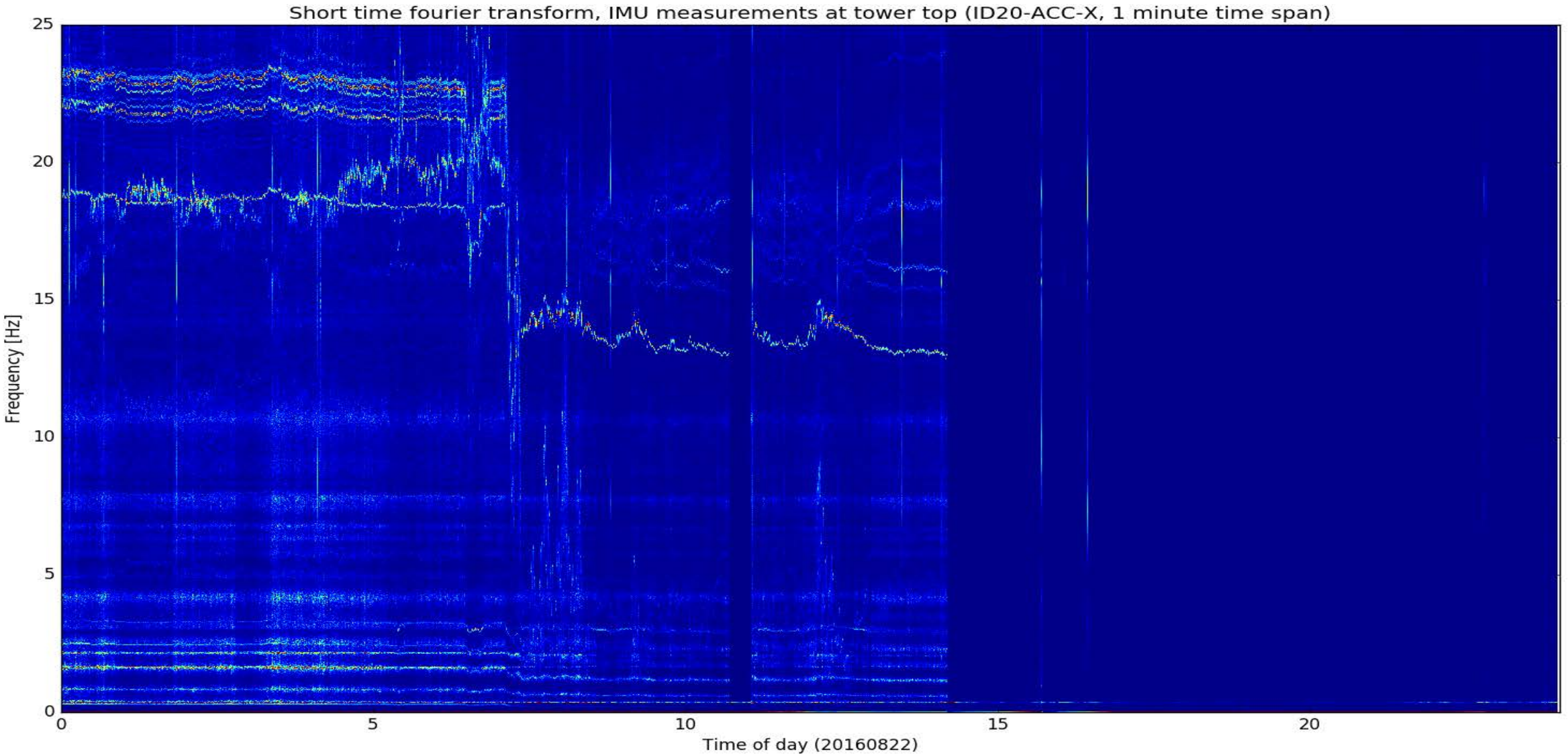
3 Vibrations diagnostics



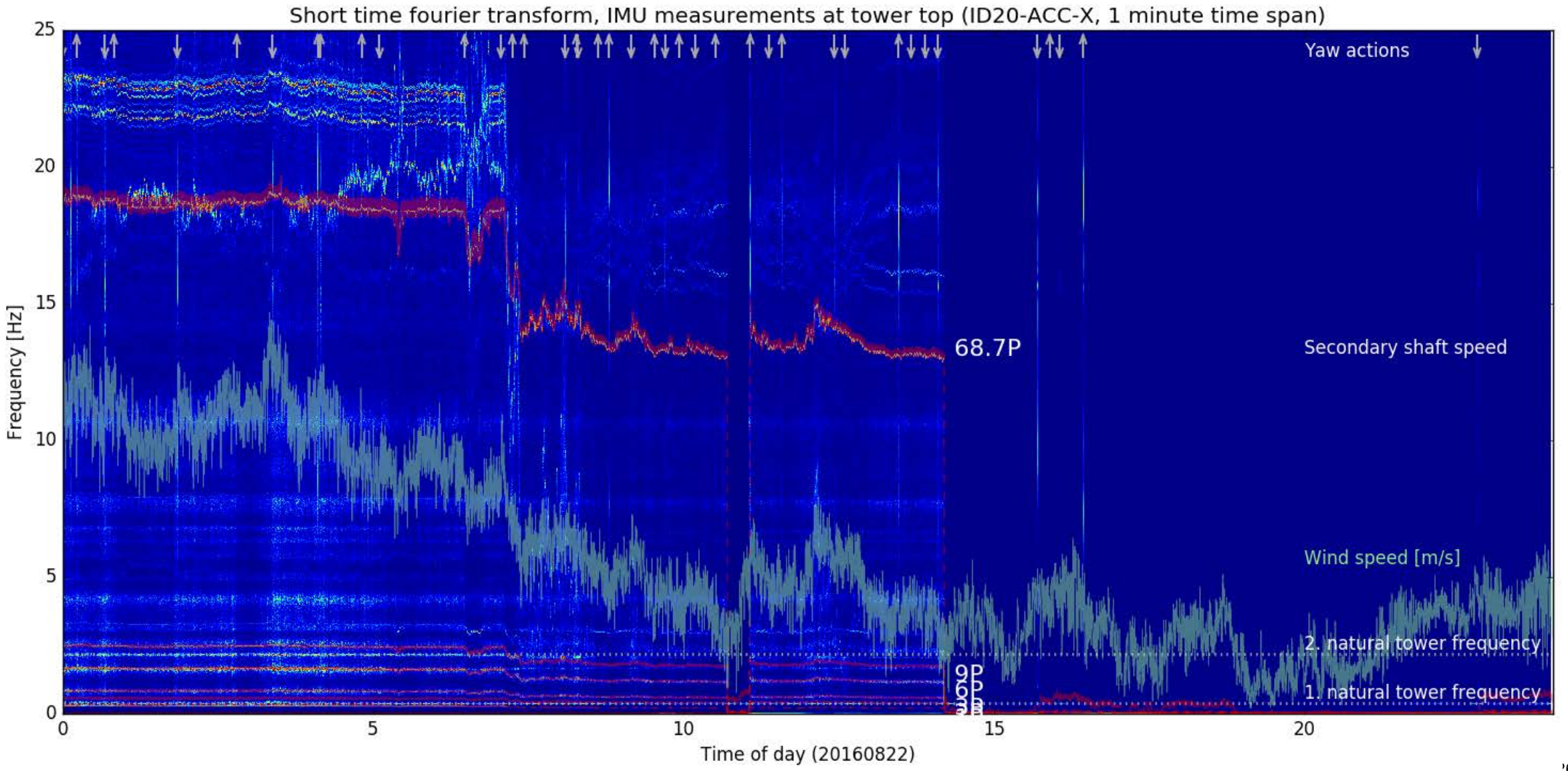
From time series to spectrogram



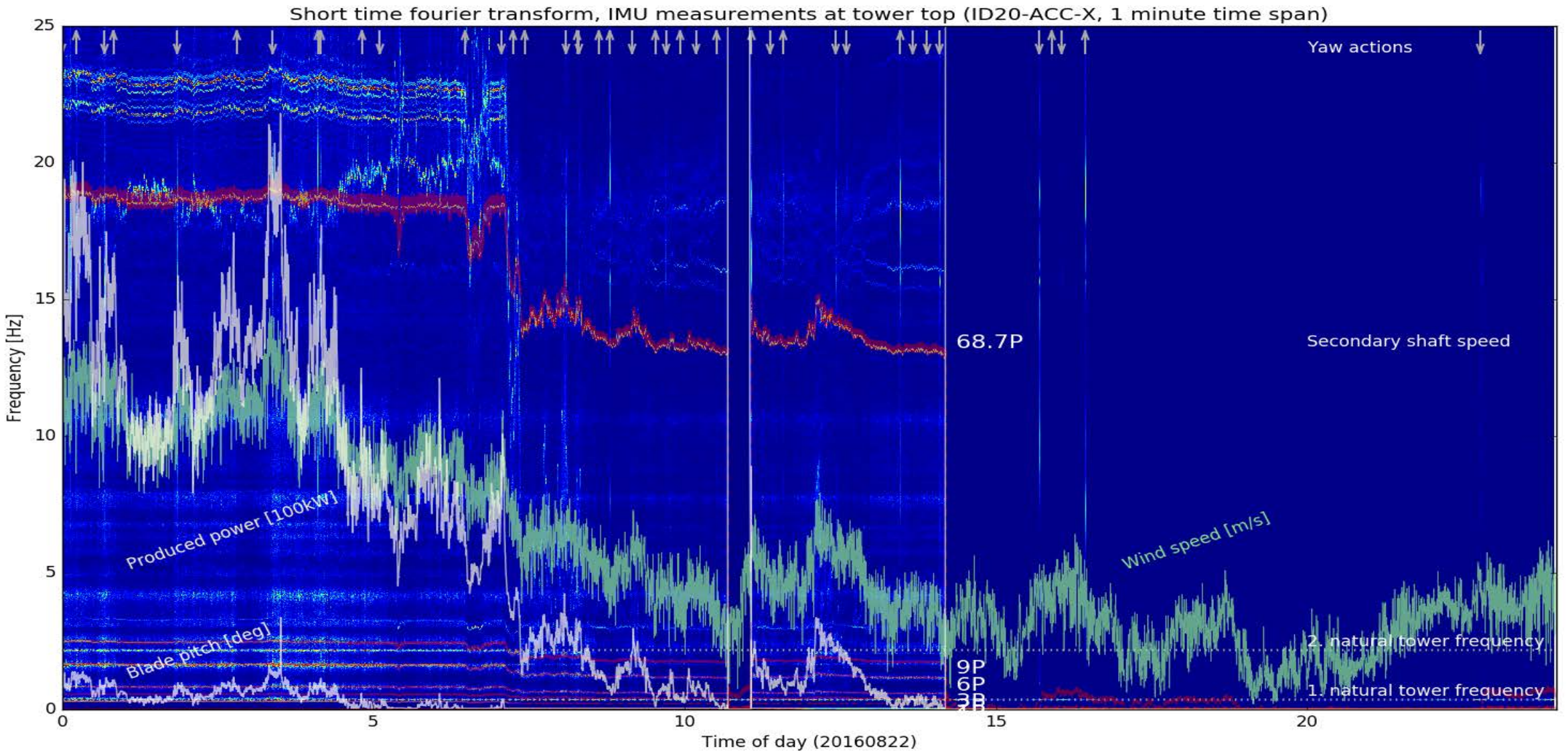
Case study: One day in the North, 50 Hz IMU readings, looking for issues



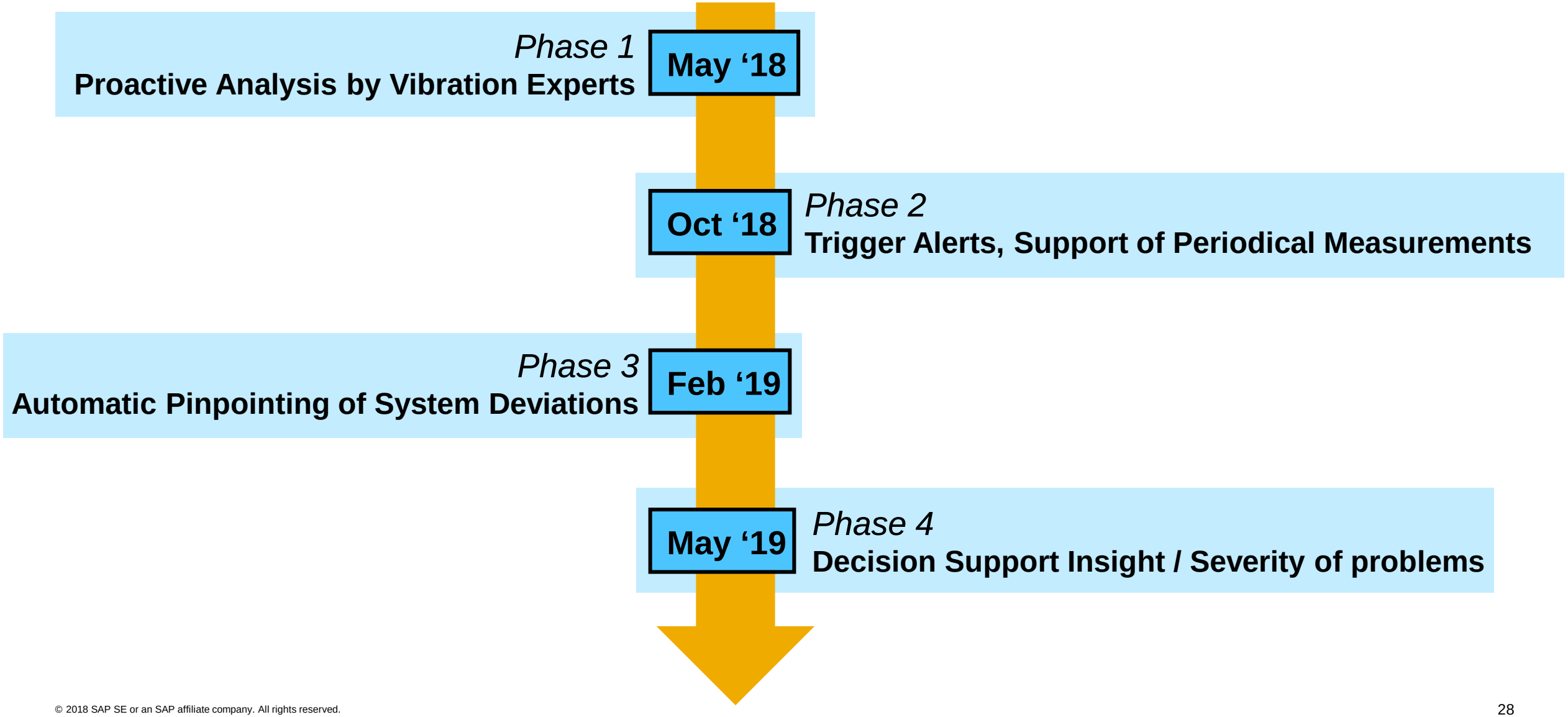
Case study: One day, diagnostics using Digital Twin and some SCADA-data



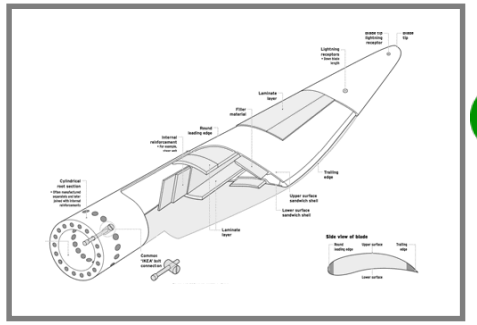
Including more SCADA-data, diagnostics getting quite complex



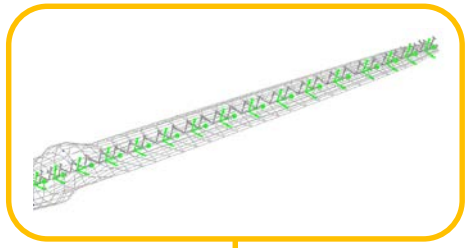
Vibration Monitoring - roadmap

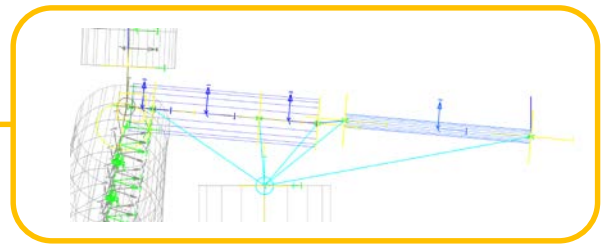


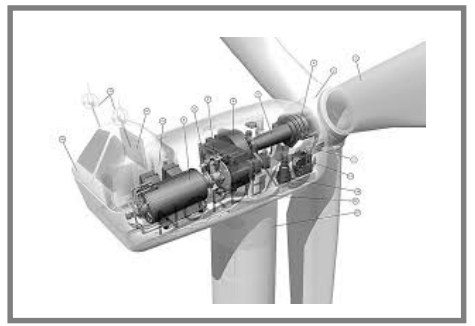
Digital twin integrated model based on simplified models by suppliers



Blade design

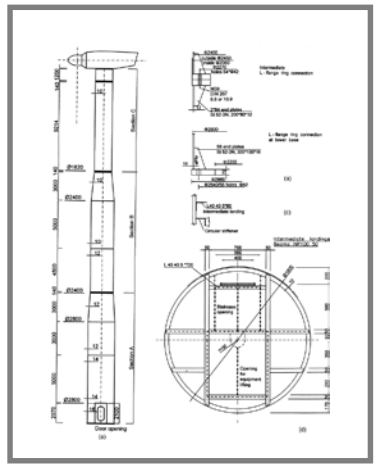


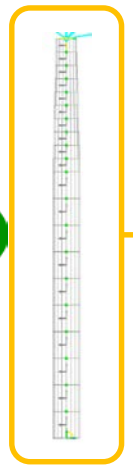


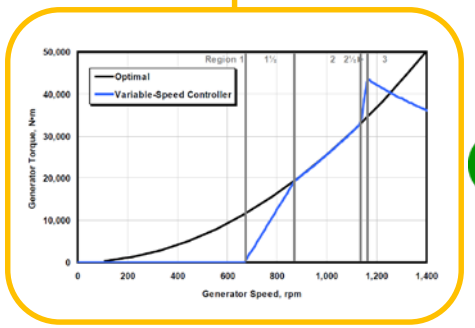


Drive train

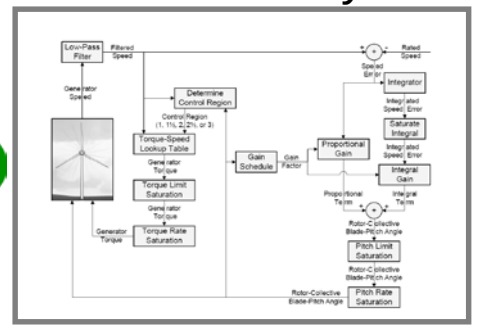
Tower design





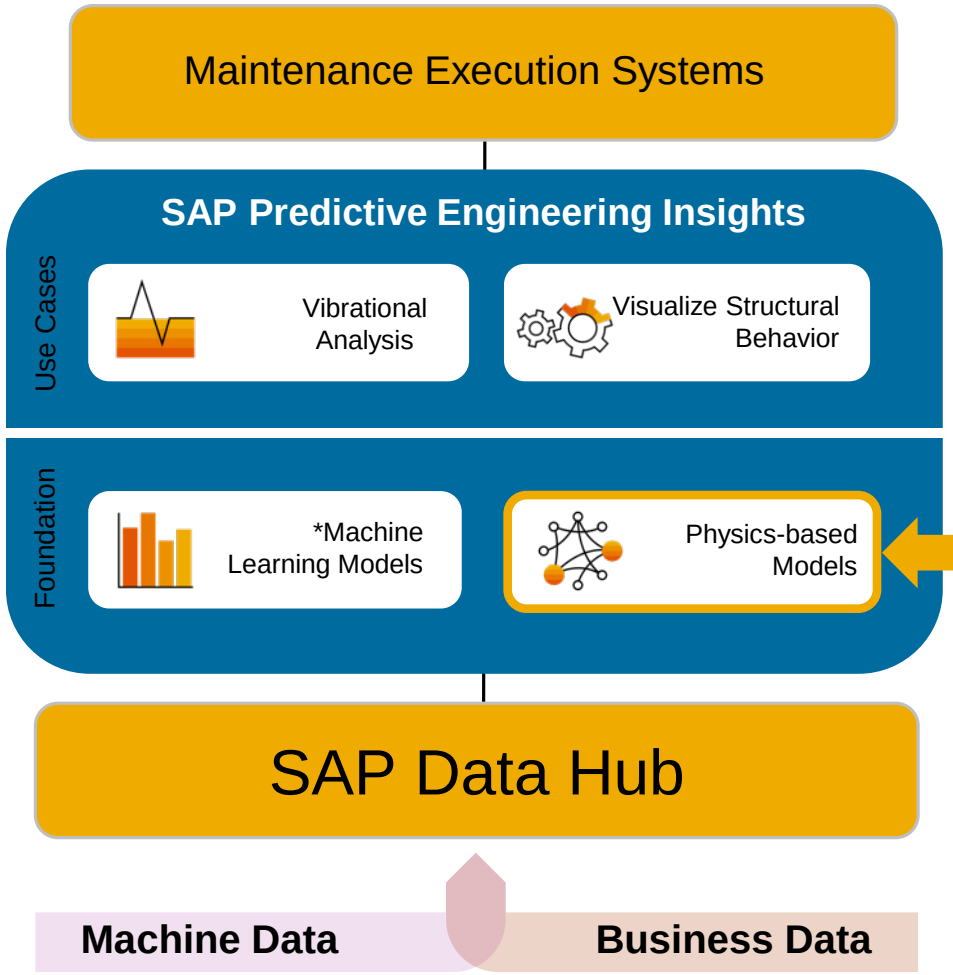


Control system

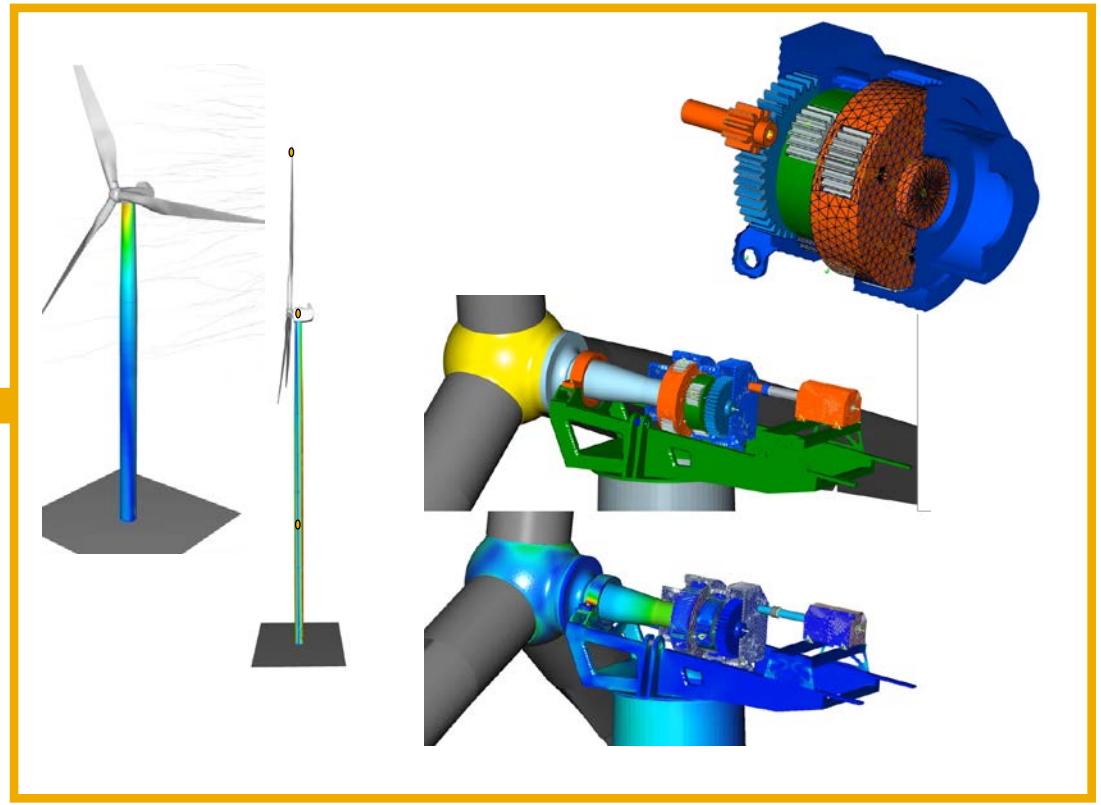


Detailed model by supplier
Simplification and hand-over
Digital twin integrated model

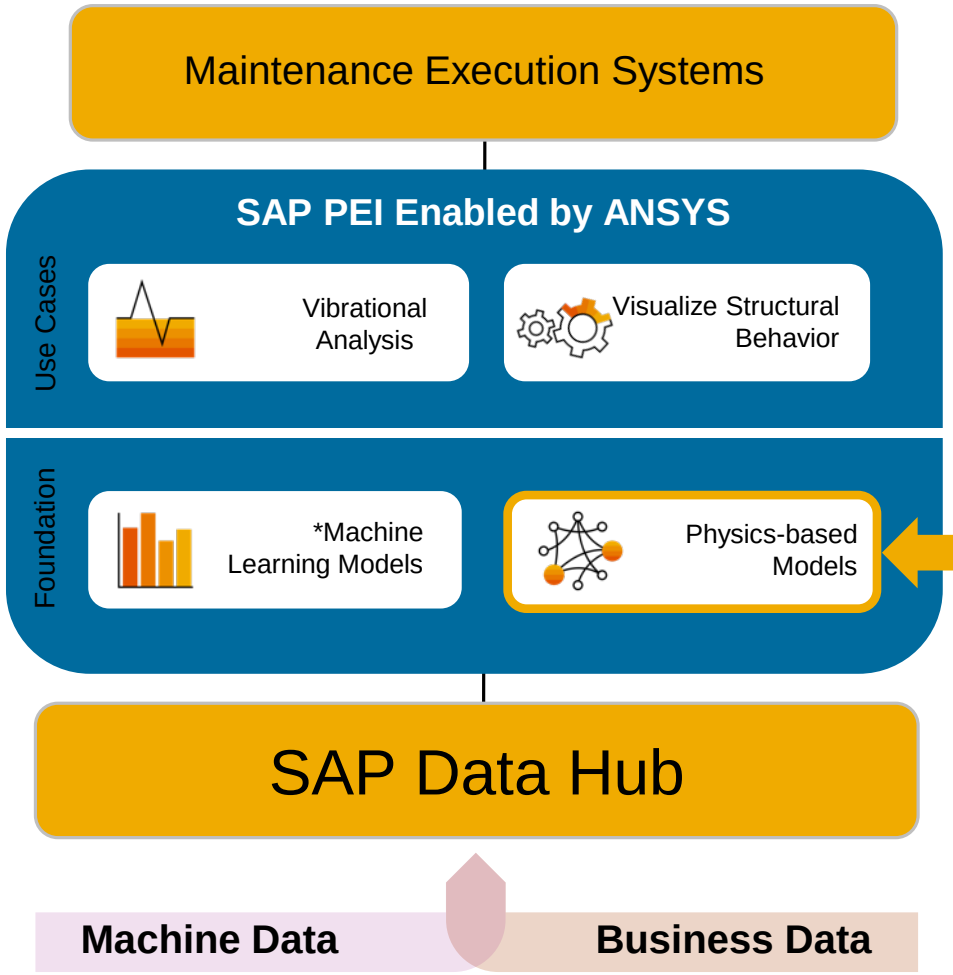
SAP Predictive Engineering Insights



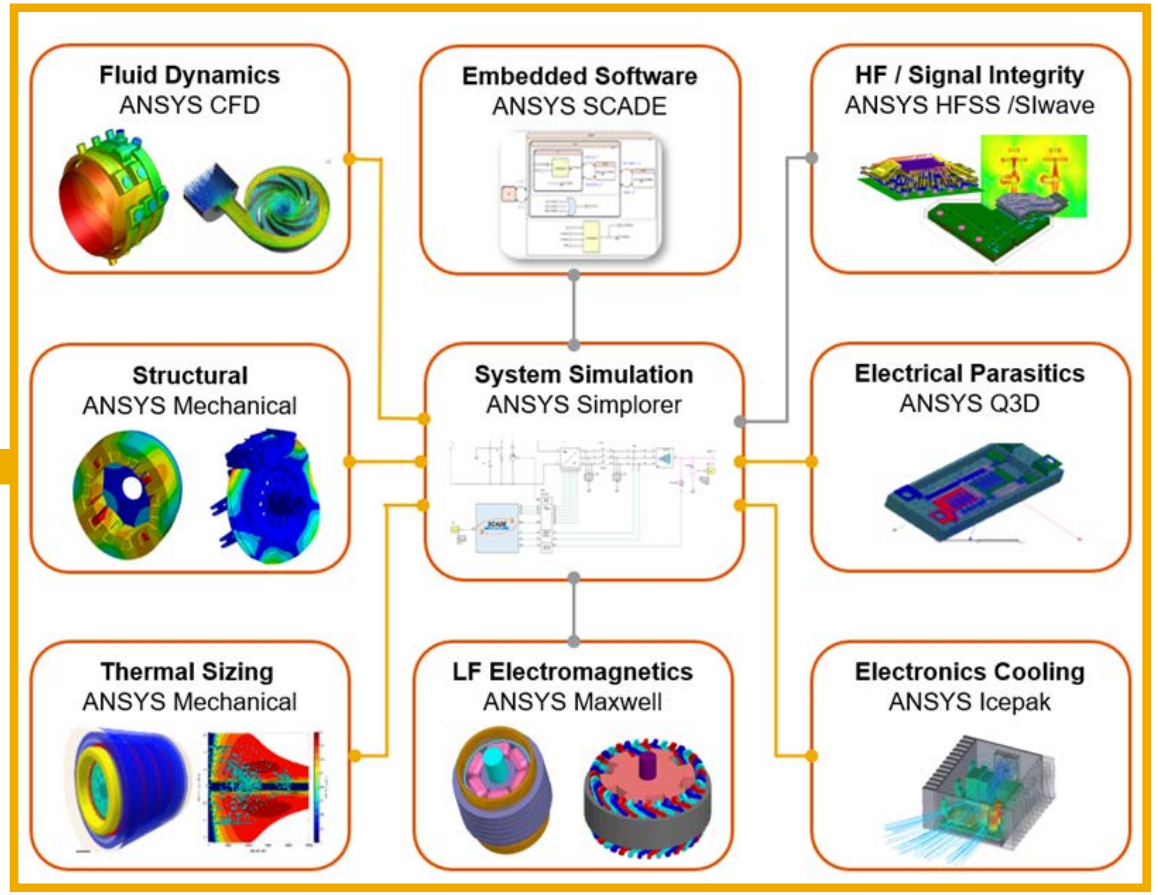
FEDEM Structural Dynamics Simulation Models



SAP Predictive Engineering Insights Enabled by ANSYS



ANSYS Multi-physics Simulation Models



Thank you!

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