Rain and wind conditions at offshore wind farms

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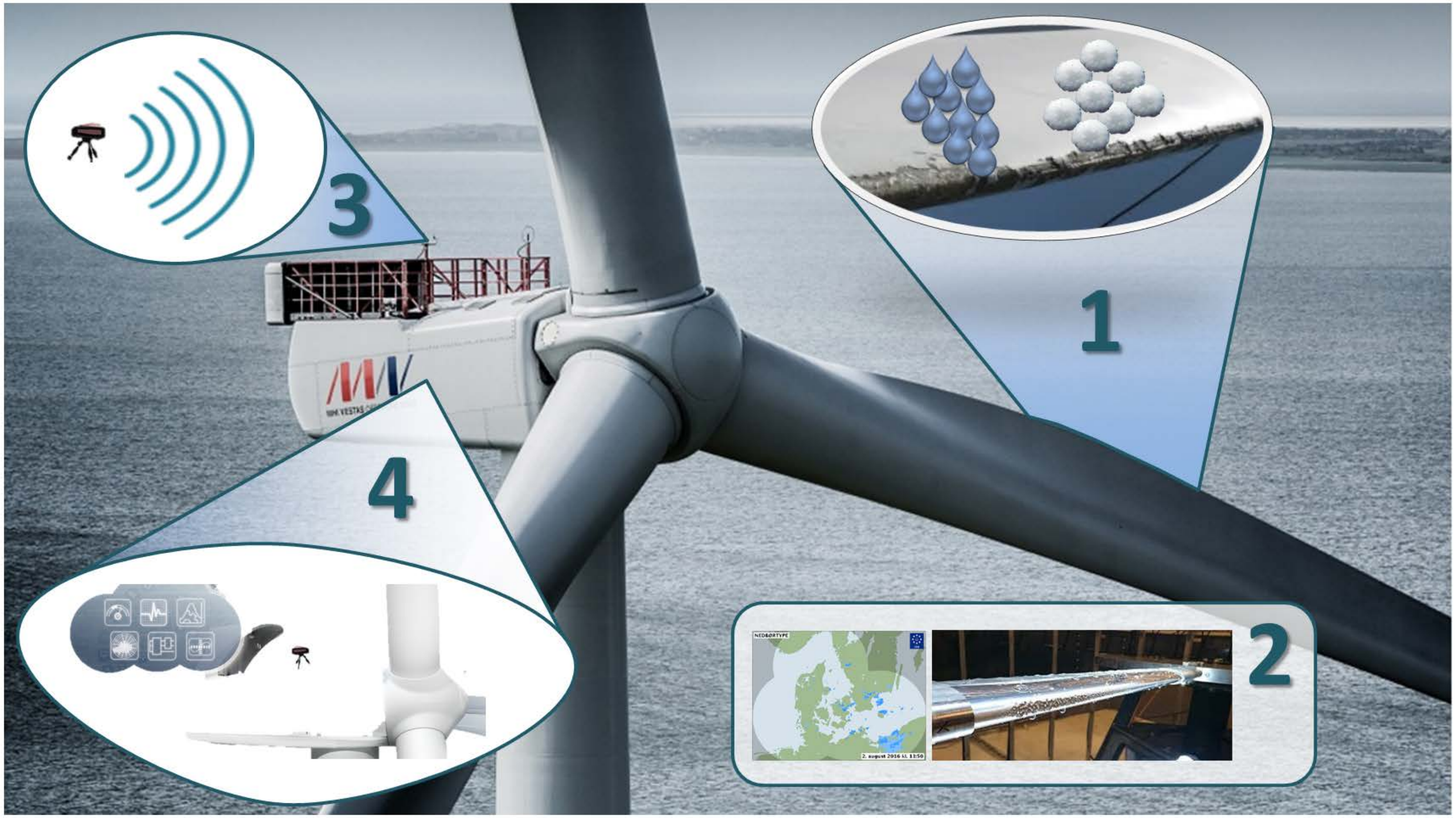
Motivation

Repair of blades at several wind farms mentioned in popular media

Working hypothesis



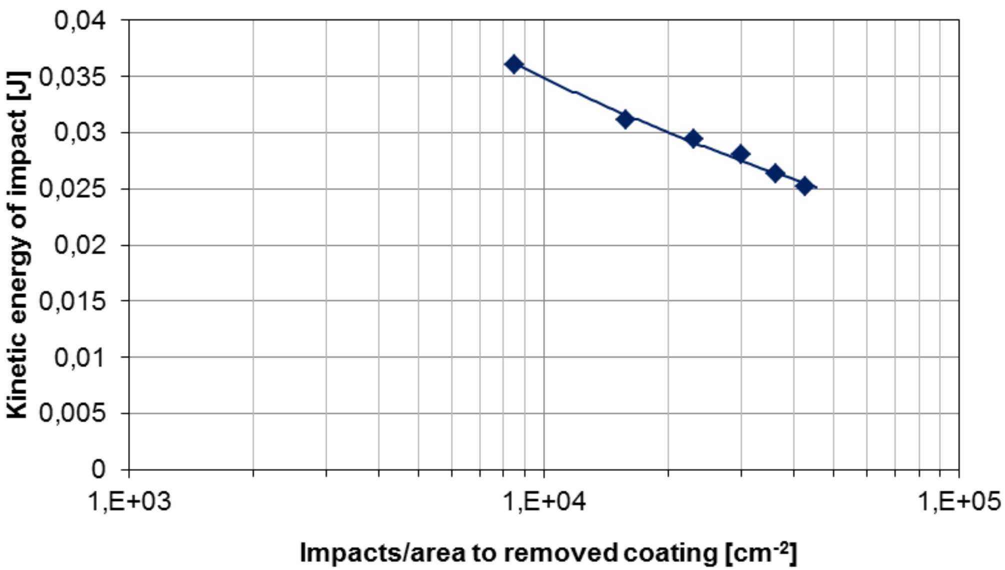
1. **Research hypothesis:** Erosion damage is mainly generated during heavy precipitation (big drops of rain or hail), which occurs in a very little fraction of the turbines operation time. By reducing the tip speed of the blades in these few hours a significant extension of the leading edge lifetime can be obtained with negligible loss of production.

2. **Methodology:** Define rain and hail erosion classes to quantify leading edge blade in-field and in lab testing. Correlations between rain intensity, droplet size, impact speed, materials properties, etc. will be established.

3. **Measurement Device:** Low-cost prototype for precipitation measurement on site and real time warning device enabling modern control of wind turbines.

4. **Erosion safe mode:** A safe mode control based on the erosion classes to control the wind turbine, reducing the tip speed under severe conditions – preventing aerodynamic degradation and reducing maintenance costs.

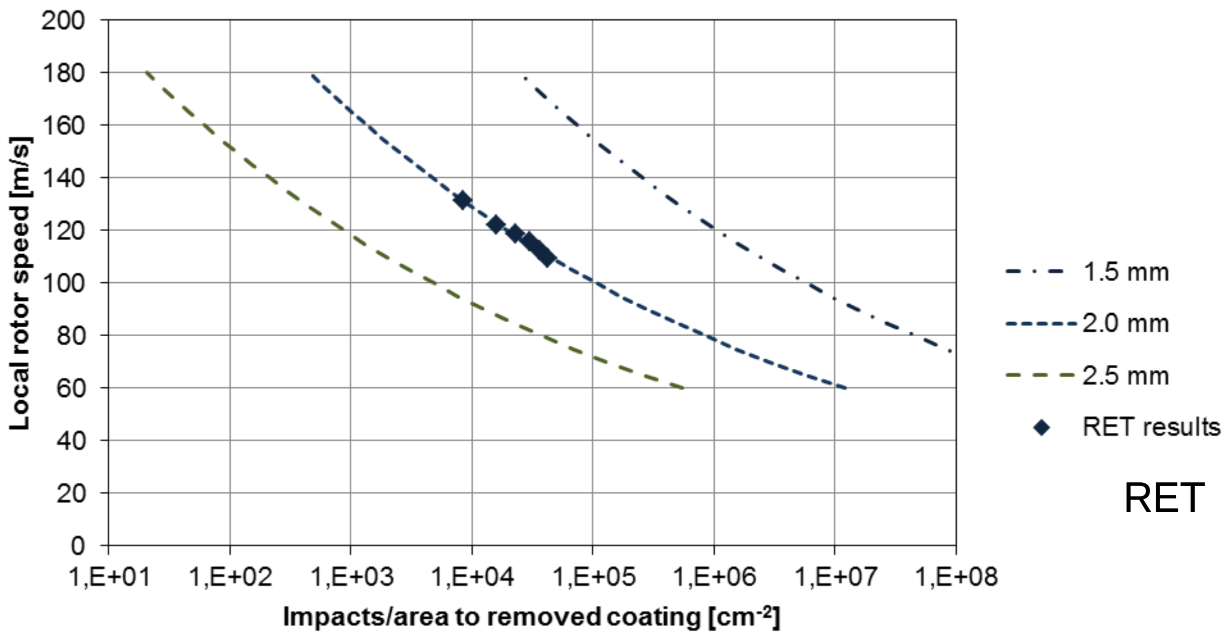
Rain erosion test data plotted as a Wöhler curve: Impacts per unit area to failure as function of the kinetic energy for each impact



$$E_k = \frac{1}{12}\rho \pi D^3 v_t^2 \ \text{[J]}$$

Bech *et al.* 2018, WES

Wöhler curves for droplet diameters of 1.5, 2.0 and 2.5 mm



RET is Rain Erosion Test

Bech *et al.* 2018, WES

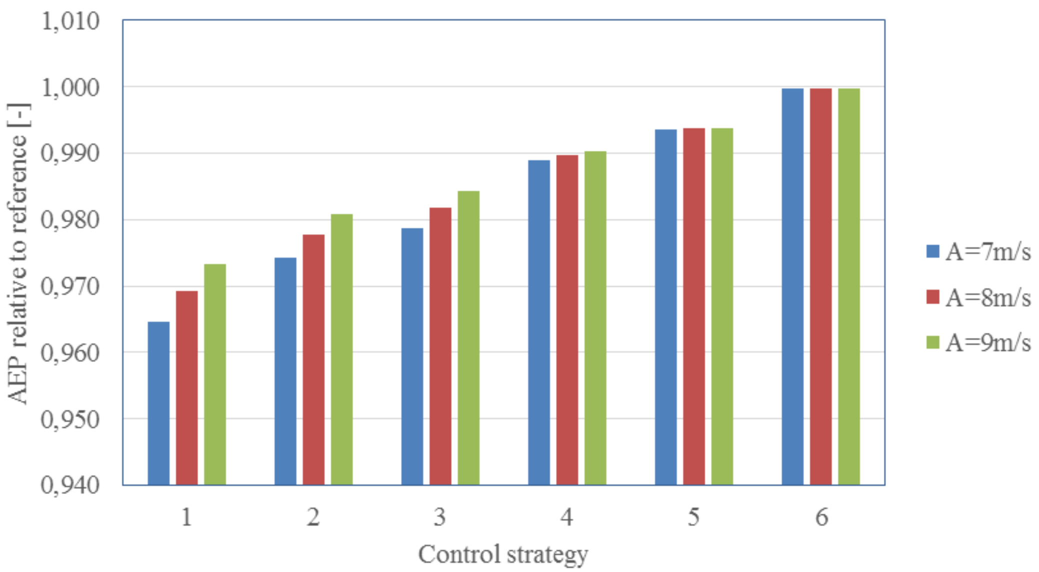
Extending lifetime

Control strategies

- Control strategy 1 No reduction (90 m/s)
- Control strategy 2 Reduction ”light” 80 m/s and 70 m/s
- Control strategy 3
- Control strategy 4
- Control strategy 5 Reduction ”severe” 55m/s, 65m/s and 70m/s
- Control strategy 6 Idealized

Bech *et al.* 2018, WES

AEP relative to AEP with no erosion



Bech *et al.* 2018, WES

Life time of the blade leading edge with no reduction of the tip speed. Control strategy 1

Rain intensity [mm/hr]	Droplet size [mm]	Percent of time [%]	Hours pr year [hrs/year]	Blade tip speed [m/s]	Hours to failure [hrs]	Fraction of life spent pr year [%]
20	2.5	0.02	1.8	90	3.5	51
10	2.0	0.1	8.8	90	79	11
5	1.5	1	88	90	3606	2.4
2	1.0	3	263	90	745710	0.0
1	0.5	5	438	90	2830197826	0.0
				Sum of fractions [%]:		64
				Expected life [years]:		1.6

Bech *et al.* 2018, WES

Life time of the blade leading edge with reduction of the tip speed to 70m/s and 80m/s.
Control strategy 2

Rain intensity [mm/hr]	Droplet size [mm]	Percent of time [%]	Hours pr year [hrs/year]	Blade tip speed [m/s]	Hours to failure [hrs]	Fraction of life spent pr year [%]
20	2.5	0.02	1.8	70	46	3.8
10	2.0	0.1	8.8	80	263	3.3
5	1.5	1	88	90	3606	2.4
2	1.0	3	263	90	745710	0.0
1	0.5	5	438	90	2830197826	0.0
				Sum of fractions [%]:		9.6
				Expected life [years]:		10.4

Bech *et al.* 2018, WES

Life time of the blade leading edge with reduction of the tip speed to 55m/s, 65m/s and 70m/s. Control strategy 5

Rain intensity [mm/hr]	Droplet size [mm]	Percent of time [%]	Hours pr year [hrs/year]	Blade tip speed [m/s]	Hours to failure [hrs]	Fraction of life spent pr year [%]
20	2.5	0.02	1.8	55	541	0.3
10	2.0	0.1	8.8	65	2215	0.4
5	1.5	1	88	70	47514	0.2
2	1.0	3	263	90	745710	0.0
1	0.5	5	438	90	2830197826	0.0
				Sum of fractions [%]:		0.9
				Expected life [years]:		107

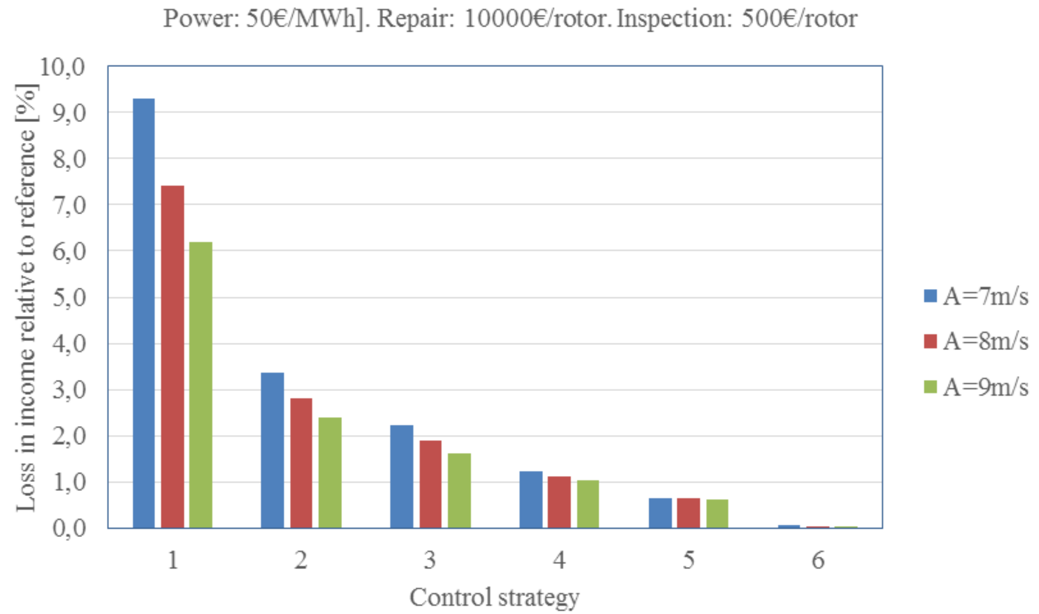
Bech *et al.* 2018, WES

Cost of operation and maintenance

- Energy price:
  - 50 €/MWh
  - 250 €/MWh
- Inspection cost:
  - 500 €/rotor
  - 1500 €/rotor
- Repair cost
  - 10000 €/rotor
  - 20000 €/rotor

Stand still of 1 day inspected

Stand still of 2 days repaired

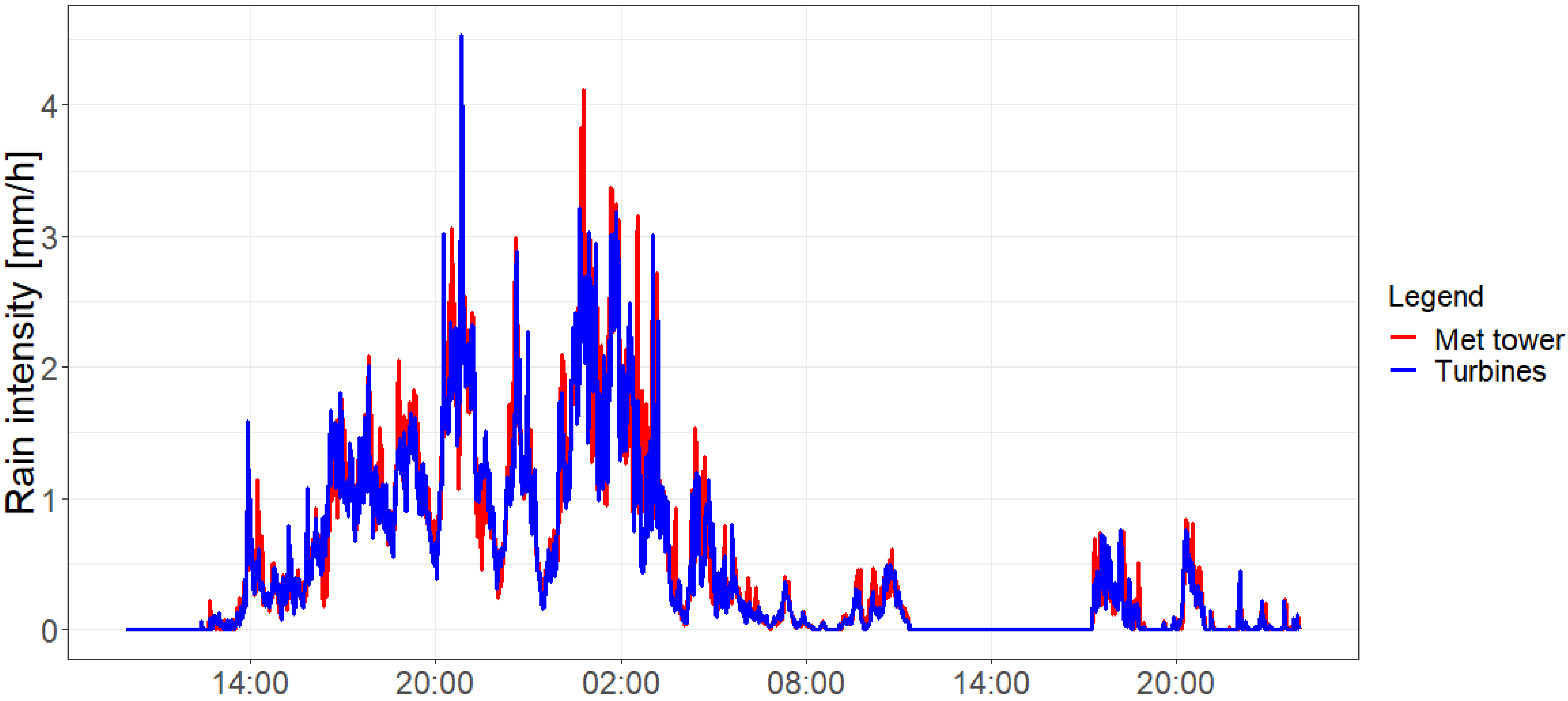


Bech *et al.* 2018, WES

Disdrometer at DTU Risø Campus

Disdrometer at DTU Risø Campus

August 12 & 13, 2018



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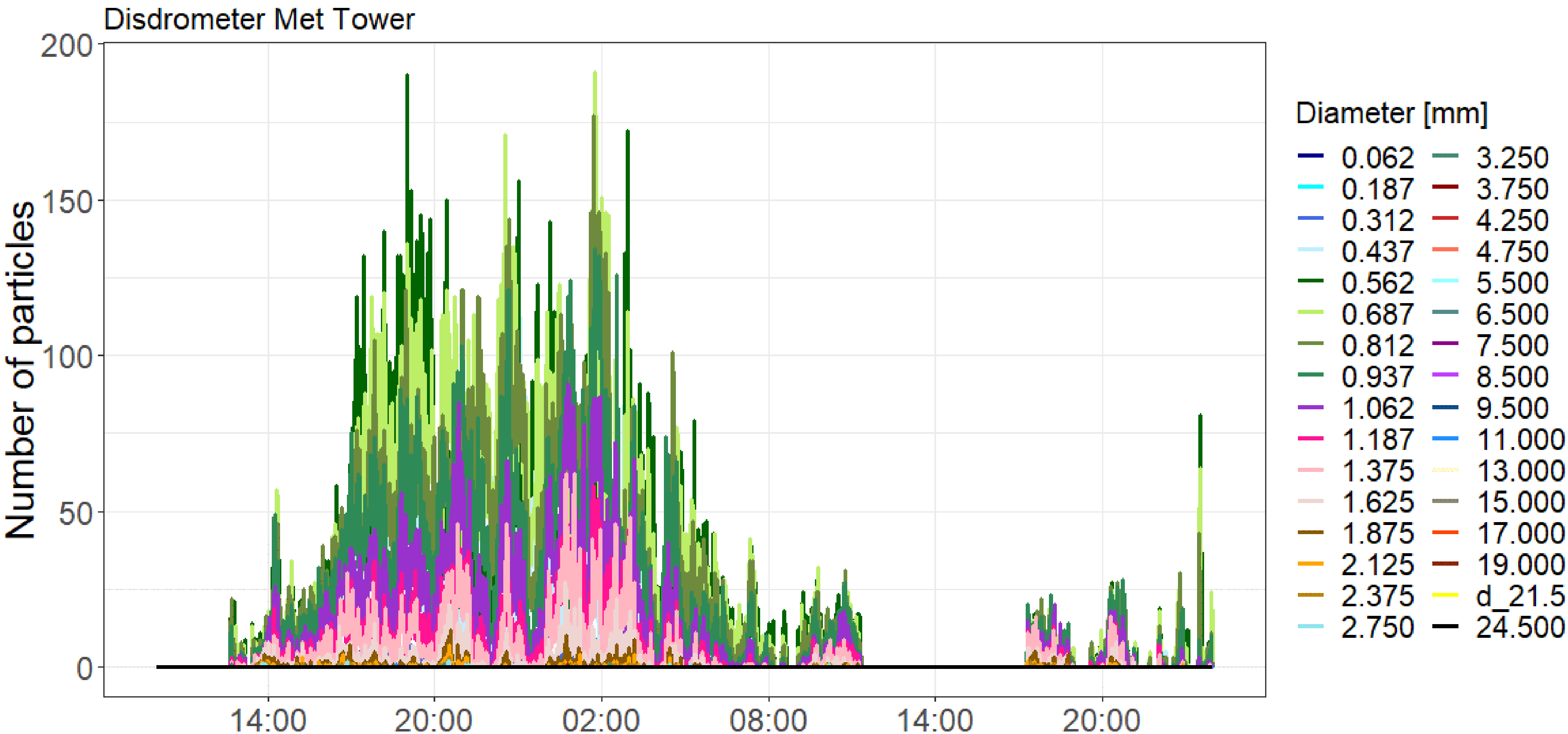

Conclusions

- Rain erosion is novel research area for topics
  - Materials
  - Rain erosion testing
  - Weather
  - Control strategy erosion safe mode
- Potential cost savings are significant
- Understanding rain-wind climate is limited

Acknowledgements

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www.rain-erosion.dk