
DTU

Wind and rain climate in offshore wind farms including energy production and leading edge erosion perspectives

Charlotte Hasager, Anna-Maria Tilg, Jakob Ilsted Bech (DTU Wind Energy)
Flemming Vejen (Danish Meteorological Institute)

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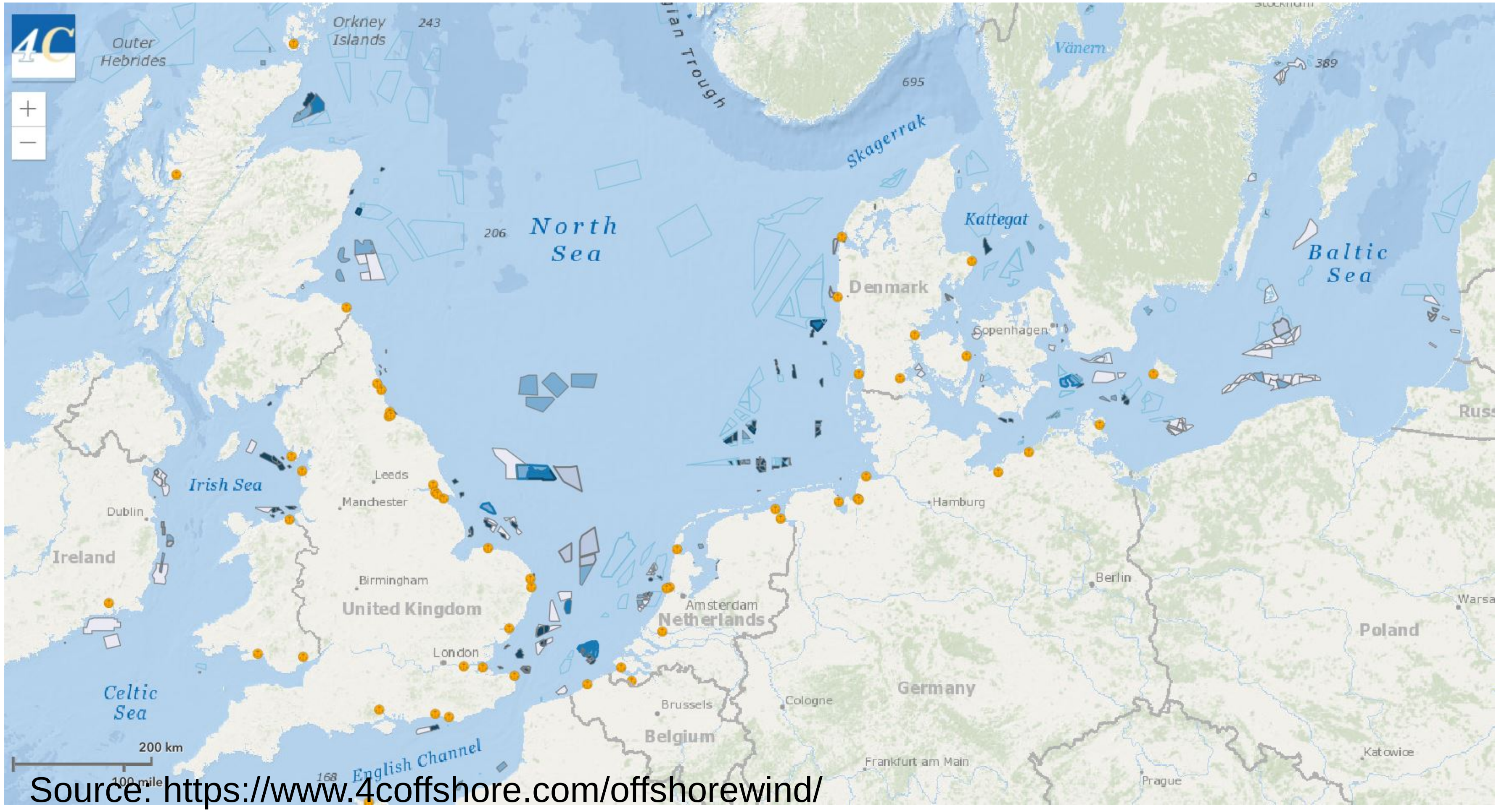
Content

- Offshore wind farms and motivation on rain erosion research
- Observation of rain drop sizes
- Rain and wind statistics
- Erosion safe mode control from simulation
- Summary

Offshore wind farms in Northern Europe



Source: https://www.4coffshore.com/offshorewind/

Motivation

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.

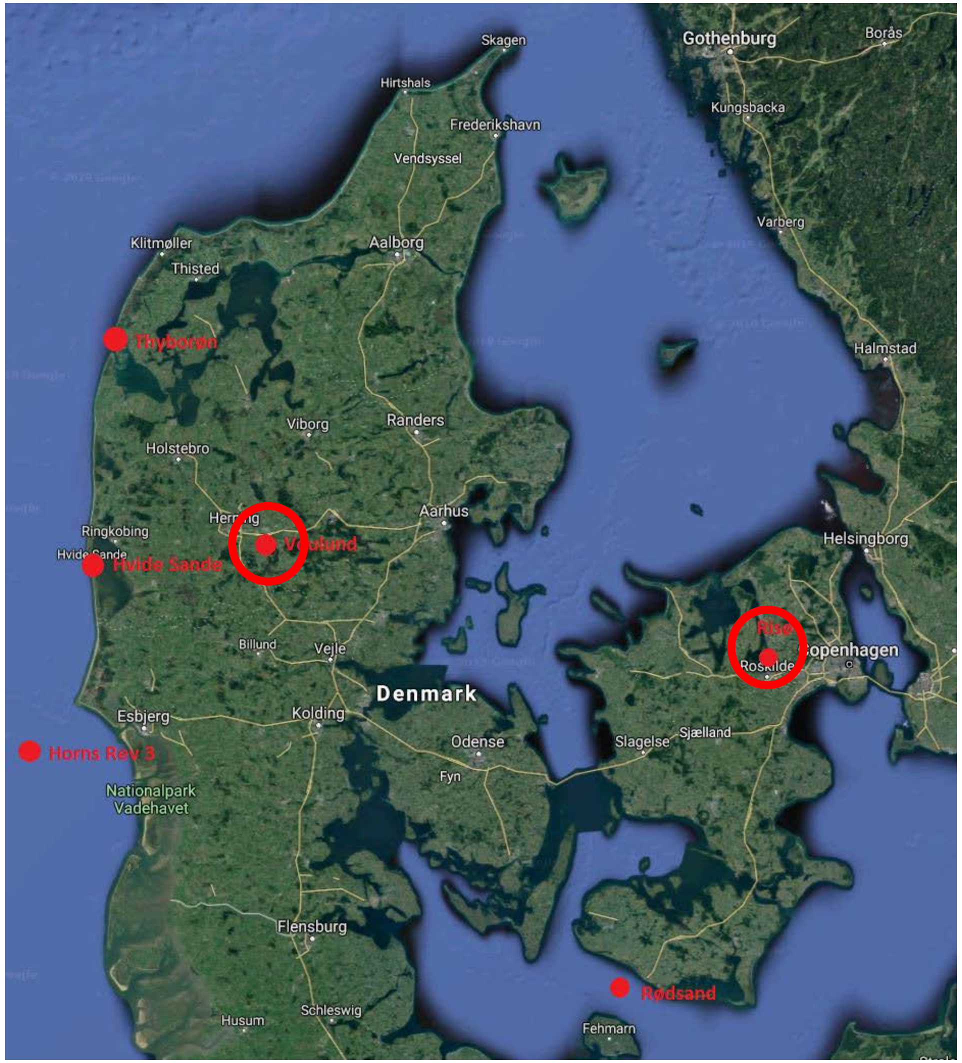
3. **Measurement Device:** Low-cost prototype for precipitation measurement on site and real time warning device enabling modern control of wind turbines.

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.

I will focus on rain

Denmark with disdrometer observations stations

- Map of stations



Disdrometer type in EROSION project

- Disdrometers are based on an optical principle (laser) to measure drop size distribution and velocity of precipitation particles

- PARSIVEL^2 (PARticle SIze and VELocity) from OTT

www.ott.com

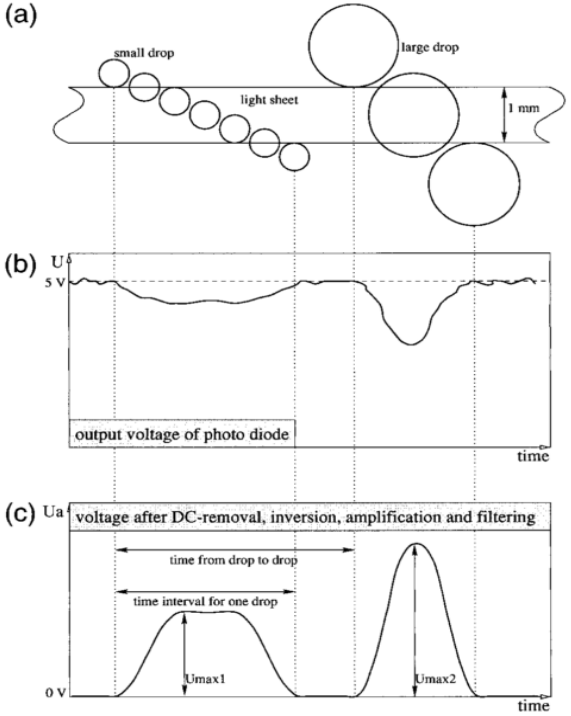
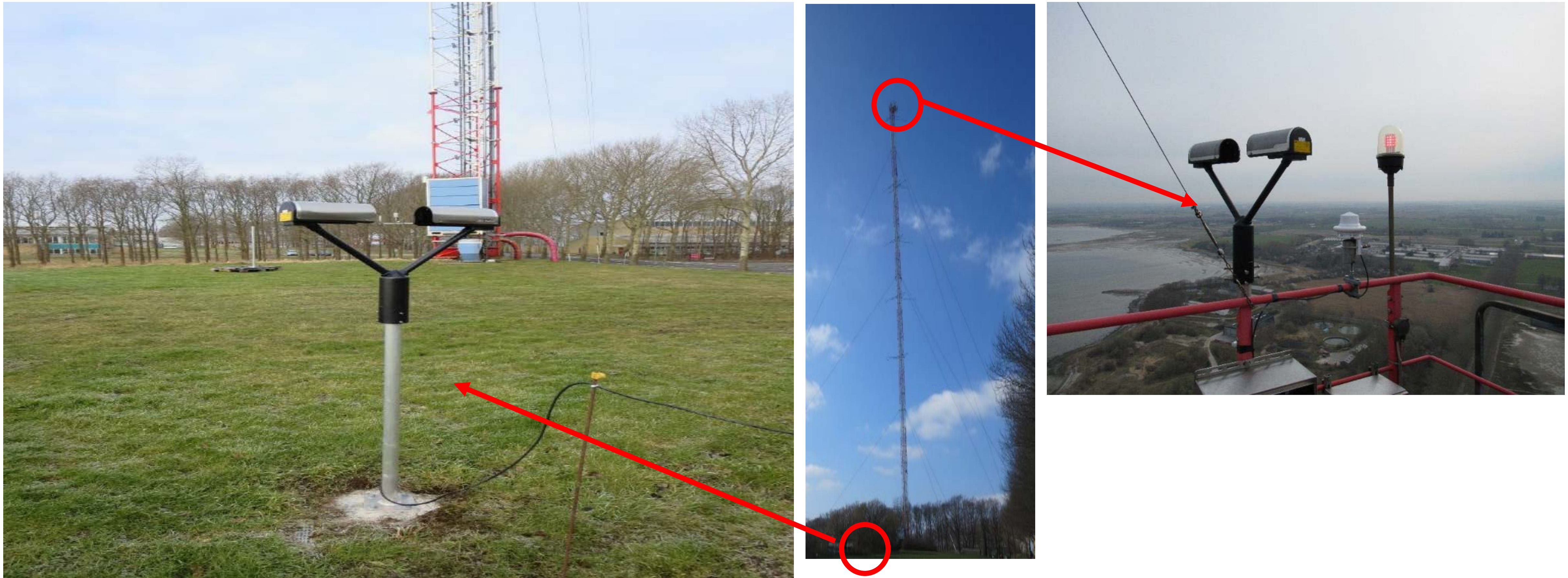


FIG. 1. Signals of particles falling through the light sheet. (a) Small and large particles, (b) raw signal from the sensor, and (c) inverted and amplified signal after thresholding for measuring purposes.

Löffler-Mang and Joss (2000)

Disdrometers at Risø Campus



123 m tall meteorological mast

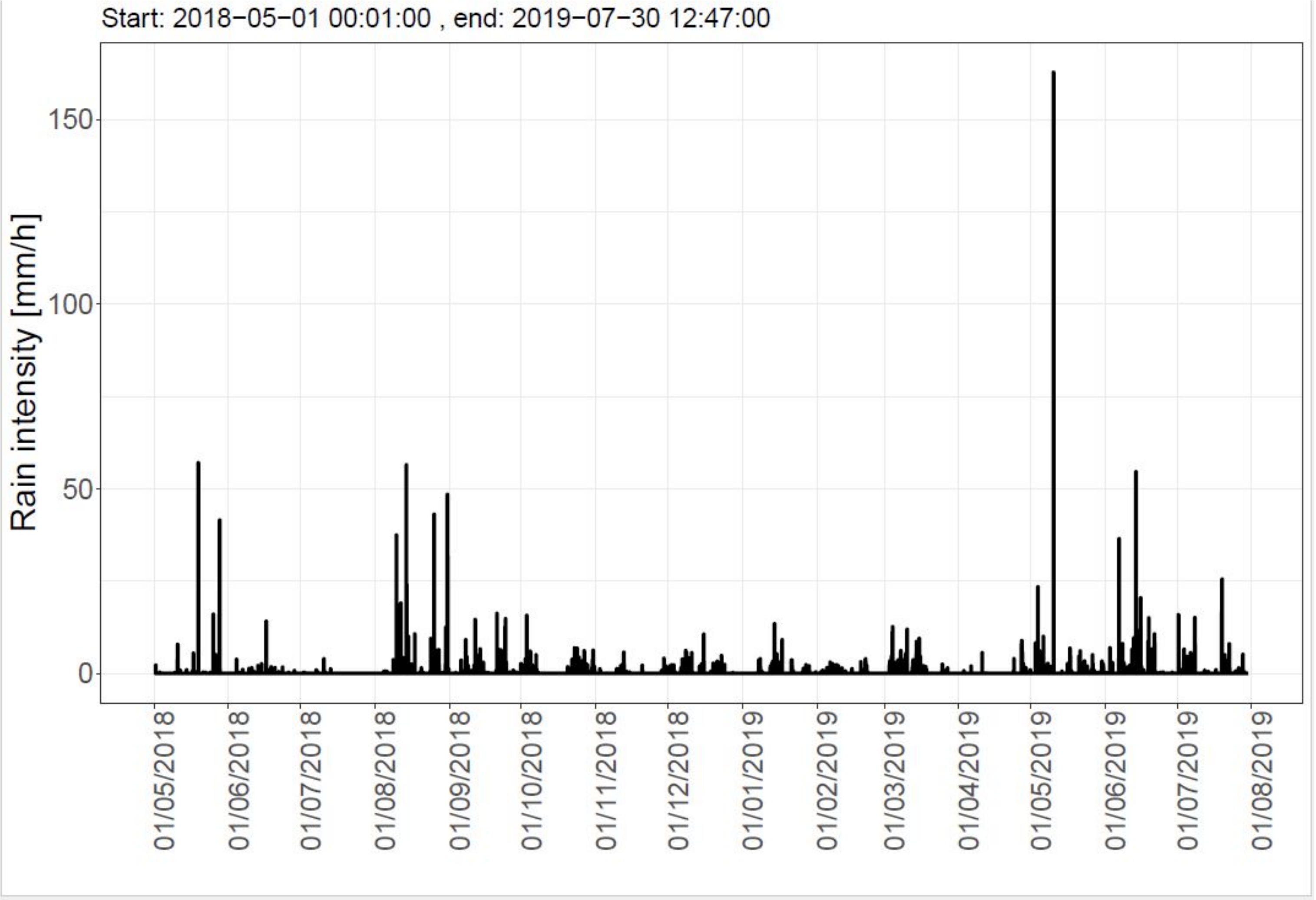
Risø Campus disdrometer data one month

Example of data from three month:

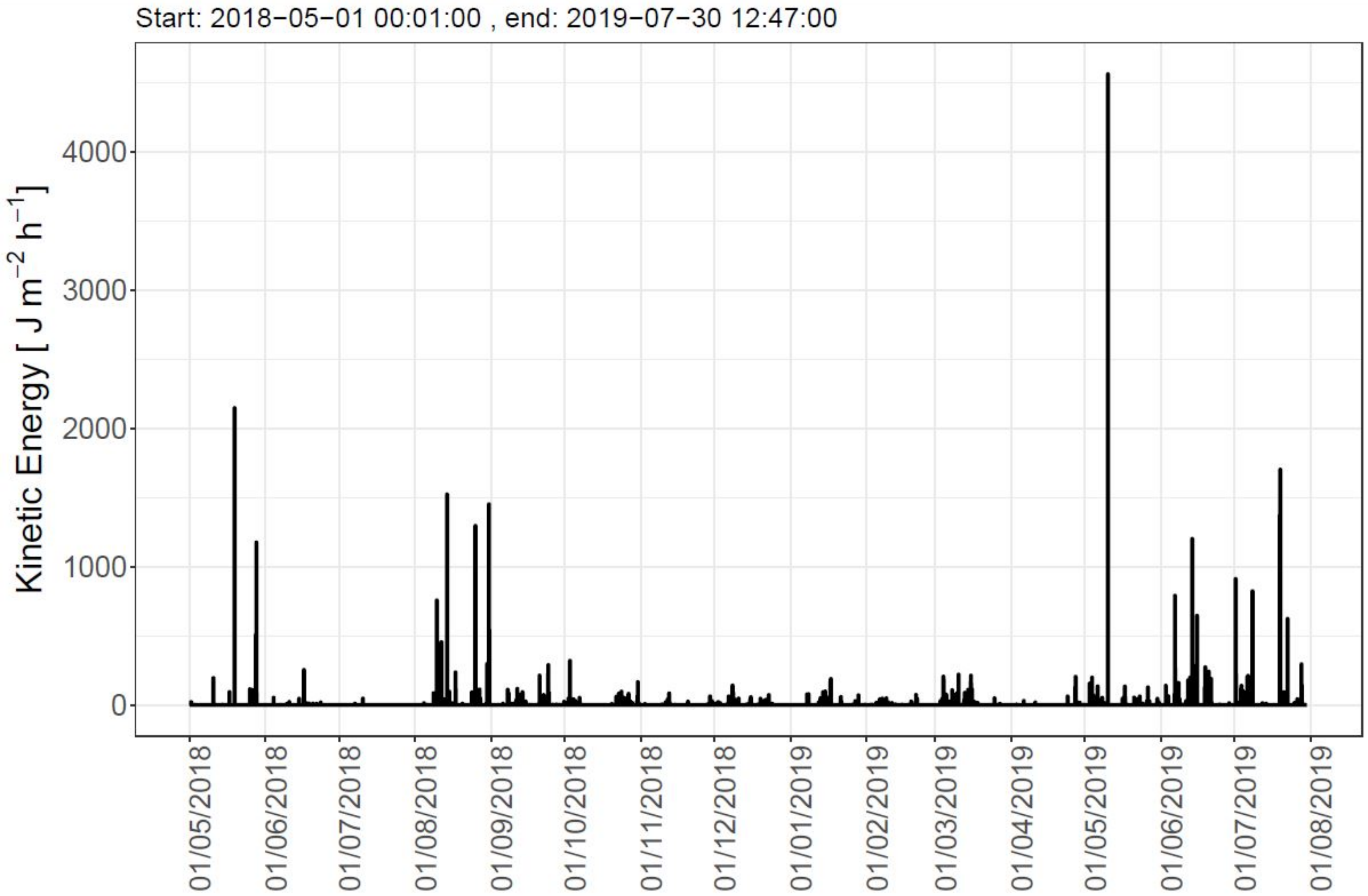
1 to 30 July 2019 measured with a time resolution of 1 minute:

- Rain intensity [mm/h]
- Rainfall kinetic energy [$Jm^{-2}h^{-2}$]
- Size-velocity histogram / drop-size distribution (DSD)

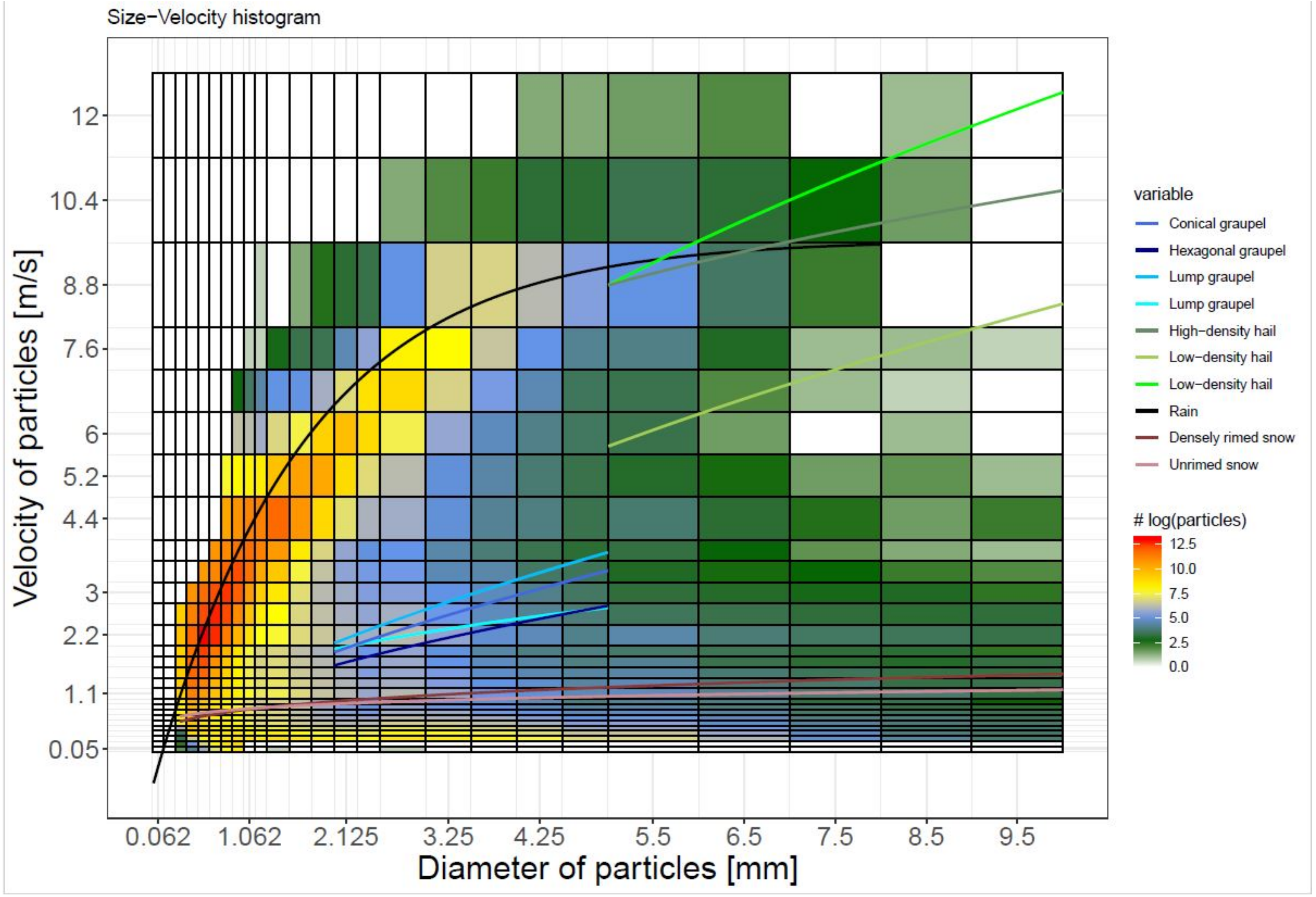
Rain intensity observed at Risø Campus (1 year 3 months)



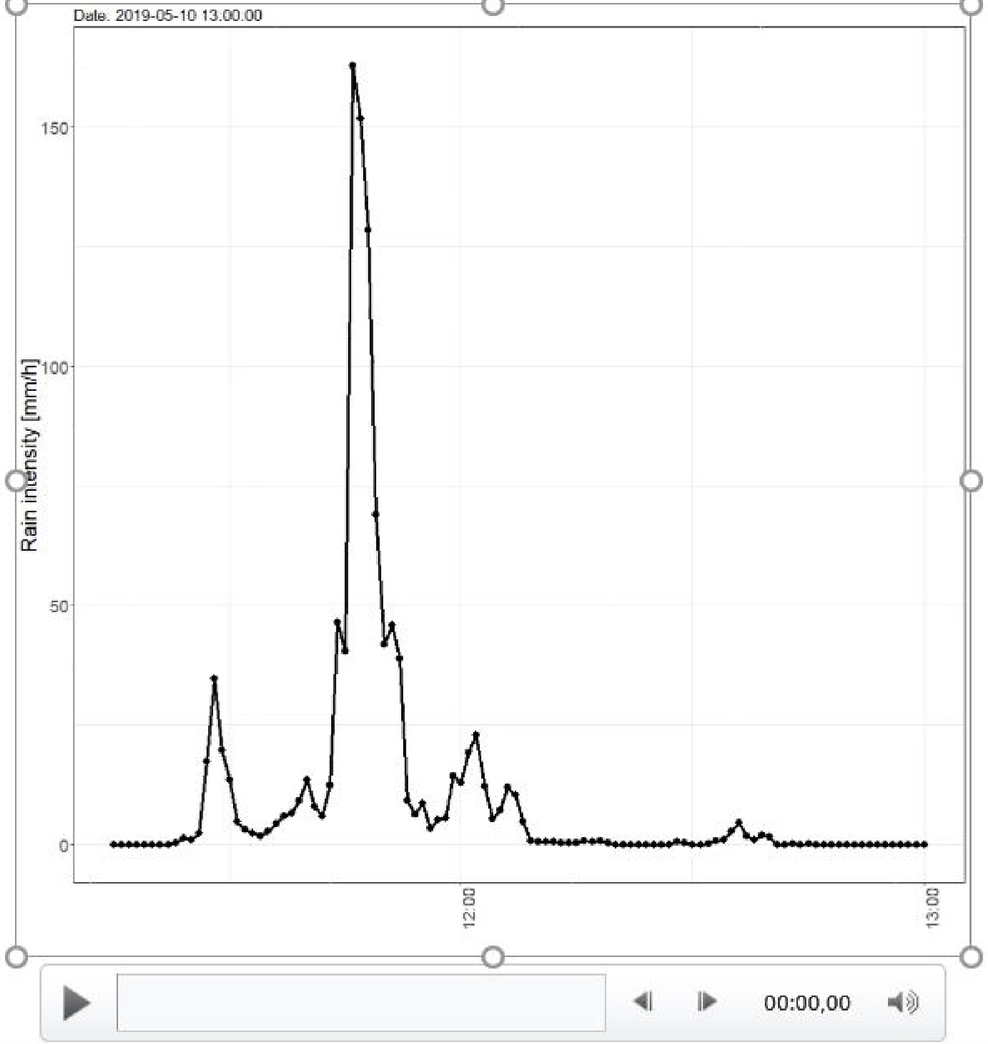
Kinetic energy from rain observed at Risø Campus



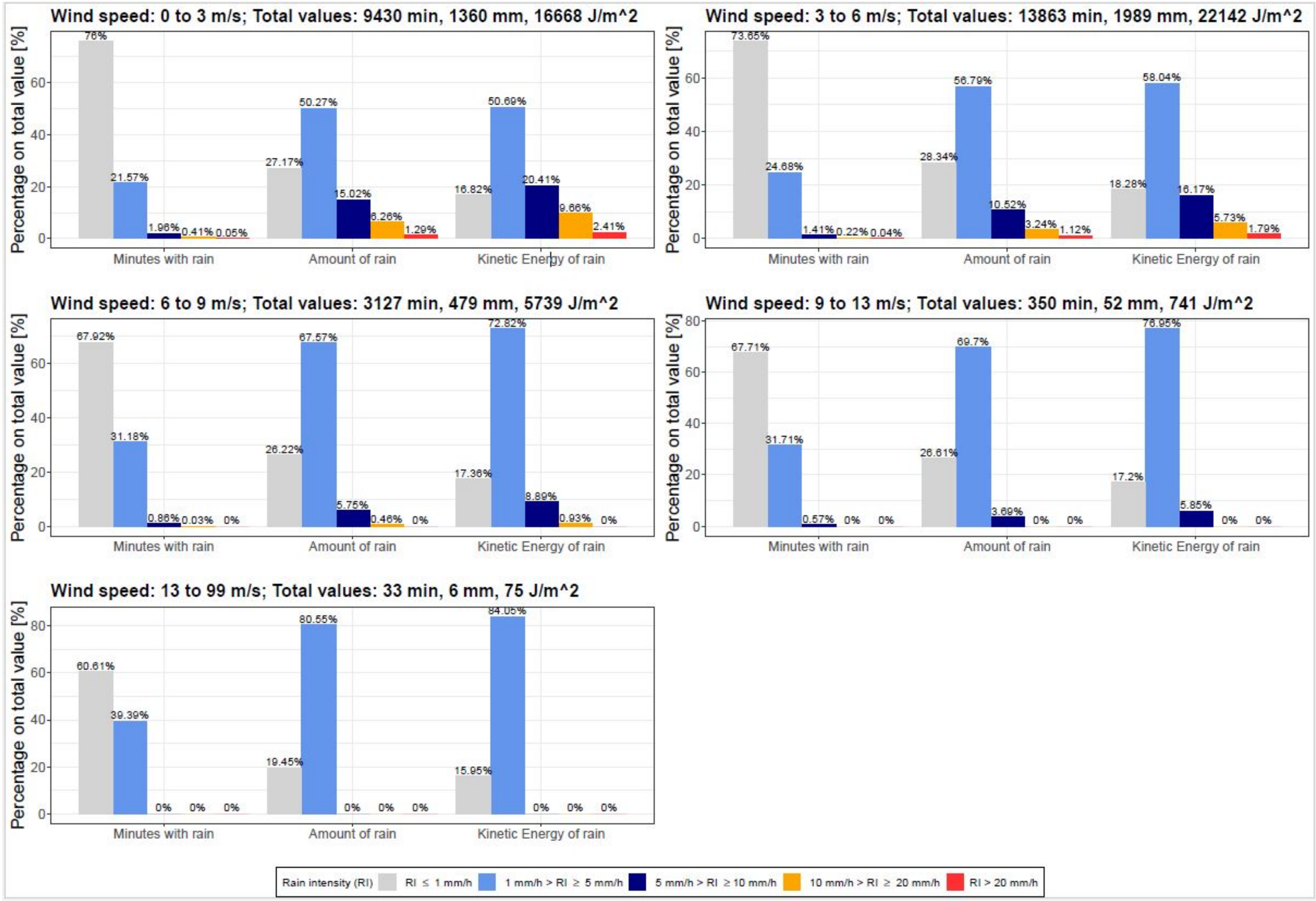
Size-velocity diagram of rain observed at Risø Campus



Event with high rain intensity at Risø campus



Voulund: Minutes with rain, rain amount, rain kinetic energy as function of wind speed (6 years)



Wind speed: 0 to 3 m/s; Total values: 9430 min, 1360 mm, 16668 J/m^2

Wind speed: 3 to 6 m/s; Total values: 13863 min, 1989 mm, 22142 J/m^2

Wind speed: 6 to 9 m/s; Total values: 3127 min, 479 mm, 5739 J/m^2

Wind speed: 9 to 13 m/s; Total values: 350 min, 52 mm, 741 J/m^2

Wind speed: 13 to 99 m/s; Total values: 33 min, 6 mm, 75 J/m^2

Station: Voulund; Data source wind speed: DMI – Danish Meteorological Institute

What does it mean for wind production?

Example of Erosion Safe Mode Control

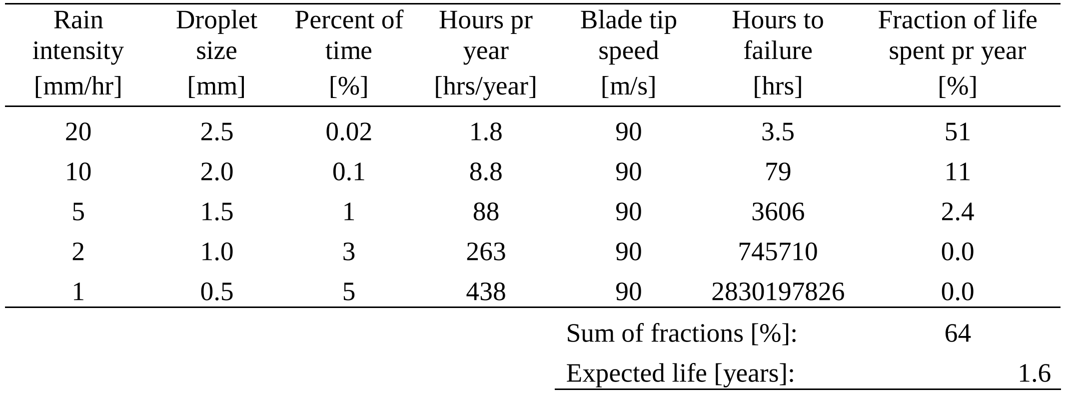
Control strategies

Control strategy 1: No reduction	90 m/s
Control strategy 2: Little reduction	80 m/s and 70 m/s
Control strategy 3: Much reduction	55m/s, 65m/s and 70m/s

Vestas V52 850 kW pitch regulated variable speed and modified rotation speed to make it consistent with larger turbines.

Control strategy 1: No reduction (NORMAL)

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



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

Control strategy 2: Little reduction

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

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

Control strategy 3: Much reduction

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

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

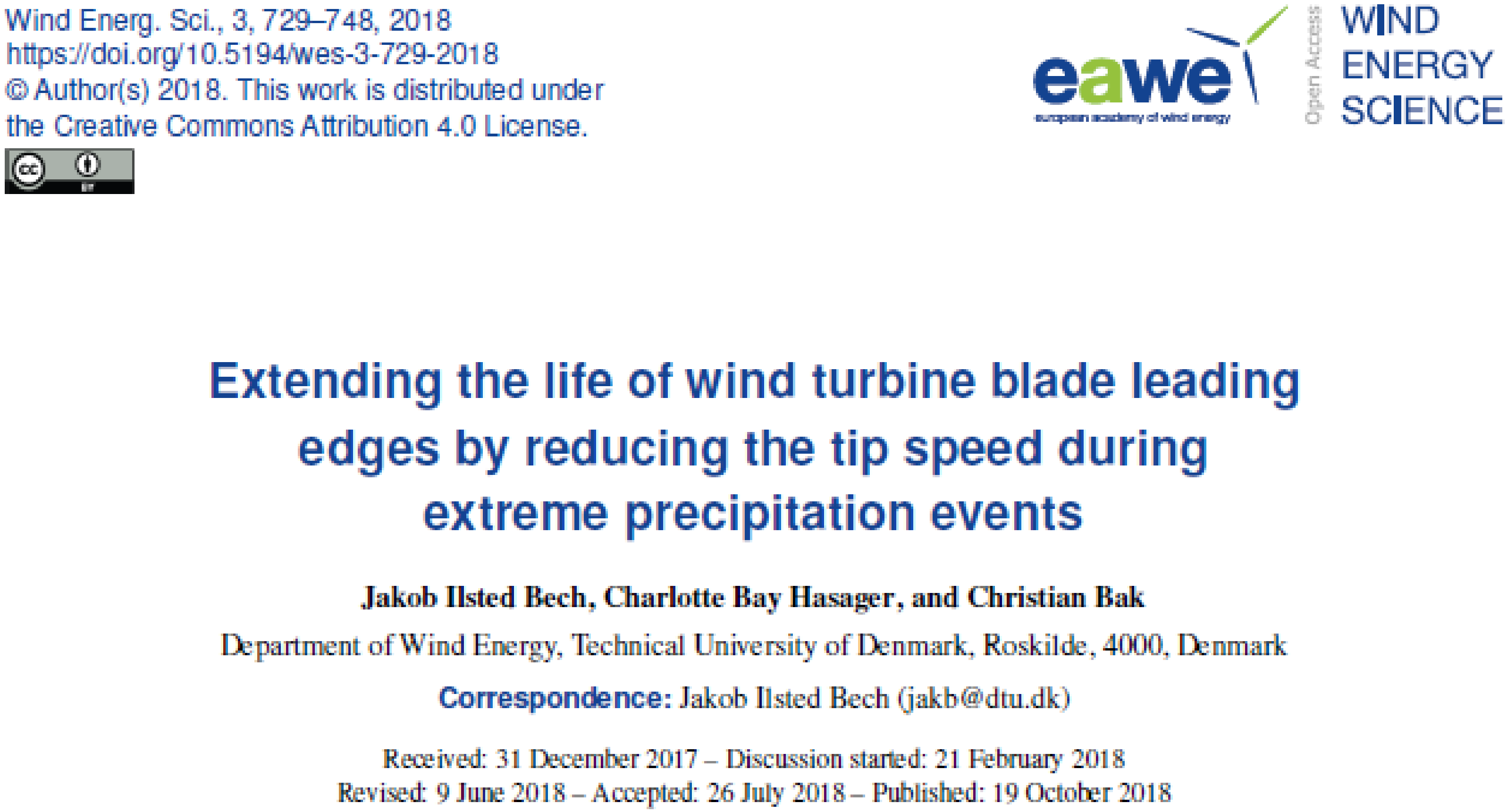
Summary on control

Control strategy	Loss in AEP relative to idealized case (%)	Saved cost on repair relative to idealized case (%)
Control 1	3.2	12.0
Control 2	2.3	3.8
Control 3	0.7	0.5

Assumed costs:

- Electricity price 50 EUR per MWh^{-1}
- Repair cost 20000 EUR/rotor
- Inspection cost 1500 EUR/rotor

Reading:



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Extending the life of wind turbine blade leading edges by reducing the tip speed during extreme precipitation events

Jakob Ilsted Bech, Charlotte Bay Hasager, and Christian Bak

Department of Wind Energy, Technical University of Denmark, Roskilde, 4000, Denmark

Correspondence: Jakob Ilsted Bech (jakb@dtu.dk)

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Summary

- Rain cause leading edge erosion
- It cost much in maintenance to repair blades offshore
- Need to observe and quantify rain at wind farm locations
- Suggestion to use erosion safe mode control

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www.rain-erosion.dk

Innovation Fund Denmark