# IEA Task 46 Erosion of Wind Turbine Blades

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Operating Agent

Technology Collaboration Programme
by iea

Sandia Blade Workshop

17-18 September 2024, Albuquerque, New Mexico, USA

# The Purpose of This IEA Wind Task is to:

IEA Wind TCP

- improve understanding of the erosion driving factors,
- develop datasets and model tools to enhance prediction of leading-edge erosion likelihood,
- identify damage at the earliest possible stage and,
- advance potential solutions.

# Coordination

IEA Wind TCP

**Climatic conditions driving erosion (WP2)**

Sara C. Pryor and Rebecca Barthelmie (Cornell University)

**Wind turbine operations with erosion (WP3)**

David C. Maniaci (Sandia National Laboratory)

**Laboratory testing of erosion (WP4)**

Nicolai Frost-Jensen Johansen (DTU)

**Erosion mechanics & material properties (WP5)**

Fernando Sánchez (Univ. Cardenal Herrera CEU)

**Management (WP1)** - Charlotte Hasager (DTU) Operating Agent

# Questions For All of You

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1) What challenges do you foresee on blade erosion 10 years from now?

# Mentimeter – Results From the Survey (September 18, 2024)

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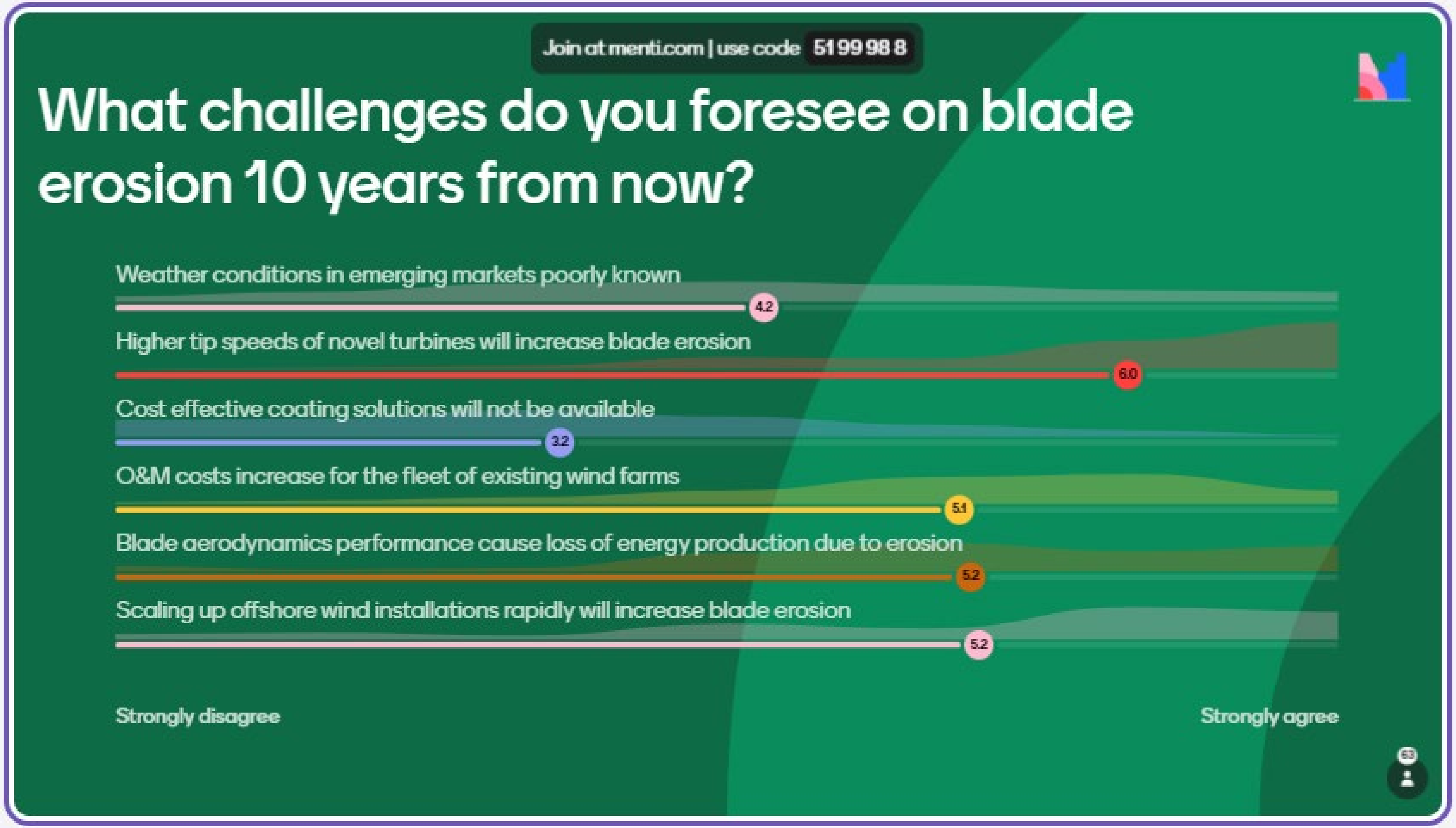

# IEA task 46 webinar 31 May 2022

3:57 | 2 questions | 33 of 39 (84%) participated

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1. What challenges do you foresee on blade erosion 10 years from now? (Multiple Choice) *

33/33 (100%) answered

- Weather conditions in emerging markets poorly known (13/33) 39%
- Higher tip speeds of novel turbines will increase blade erosion (20/33) 61%
- Cost effective coating solutions will not be available (7/33) 21%
- O&M costs increase for the fleet of existing wind farms (16/33) 48%
- Blade aerodynamic performance cause loss of energy production due to erosion (16/33) 48%
- Scaling up offshore wind installations rapidly will increase blade erosion (20/33) 61%

2. Which concepts have the highest potential to tackle blade erosion? (Multiple Choice) *

33/33 (100%) answered

| | |
| --- | --- |
| Wind farm planning, e.g. site specific erosion assessment maps | (10/33) 30% |
| Blade design, e. g. new coating materials | (32/33) 97% |
| Blade design, e. g. blade design for lower tip speed | (5/33) 15% |
| O&M, e. g. cost effective inspection | (6/33) 18% |
| O&M, e. g. cost effective service and repair | (16/33) 48% |
| Wind turbine control, e. g. erosion safe operation | (11/33) 33% |
| Disruptive innovation tackling blade erosion 100% | (14/33) 42% |

# Participants

Wind TCP

- The work plan is delivered by 41 organizations from 12 countries:
  - 1 certification body
  - 8 wind farm owners
  - 2 consultancy
  - 4 wind turbine manufacturers
  - 7 coating manufacturers
  - 19 academic/R&D organizations

| Country | Contracting Party | Participant Organization |
|---|---|---|
| Belgium | Belgian Ministry of Economy | Engie |
| Canada | Natural Resources Canada | WEICan |
| Denmark | Danish Energy Agency | DTU , Hempel, Ørsted, PowerCurve |
| Finland | Business Finland | VTT |
| Germany | Federal Ministry for Economic Affairs and Energy | Fraunhofer IWES , Covestro, Emil Frei (Freilacke), Nordex Energy SE, DNV, Mankiewicz, RWE, Henkel |
| Ireland | Sustainable Energy Authority of Ireland | South East Technological University, University of Galway, University of Limerick |
| Japan | New Energy and Industrial Technology Development Organization | AIST, Osaka University, Tokyo Gas Co. Asahi Rubber Inc. |
| Netherlands | Netherlands Enterprise Agency | TU Delft, TNO |
| Norway | Norwegian Water Resources and Energy Directorate | Equinor, University of Bergen, Statkraft |
| Spain | Centre for Energy, Environmental and Technological Research | Aerox, CENER, Nordex Energy Spain, Siemens Gamesa Renewable Energy, Universidad Cardenal Herrera - CEU |
| UK | Offshore Renewable Energy Catapult | ORE Catapult, University of Bristol, Lancaster University, Imperial College, Vestas UK, Ilosta |
| US | US Department of Energy | Cornell University, Sandia National Laboratories, 3M |

# Who Can Participate in Task 46?

# IEA Task 46 Phase 1 and Phase 2

IEA Wind TCP

- Phase 1 started 15 March 2021 and end 14 March 2025
- Phase 2 starts 15 March 2025 and end 14 March 2029

# R&D Rain Erosion Tester

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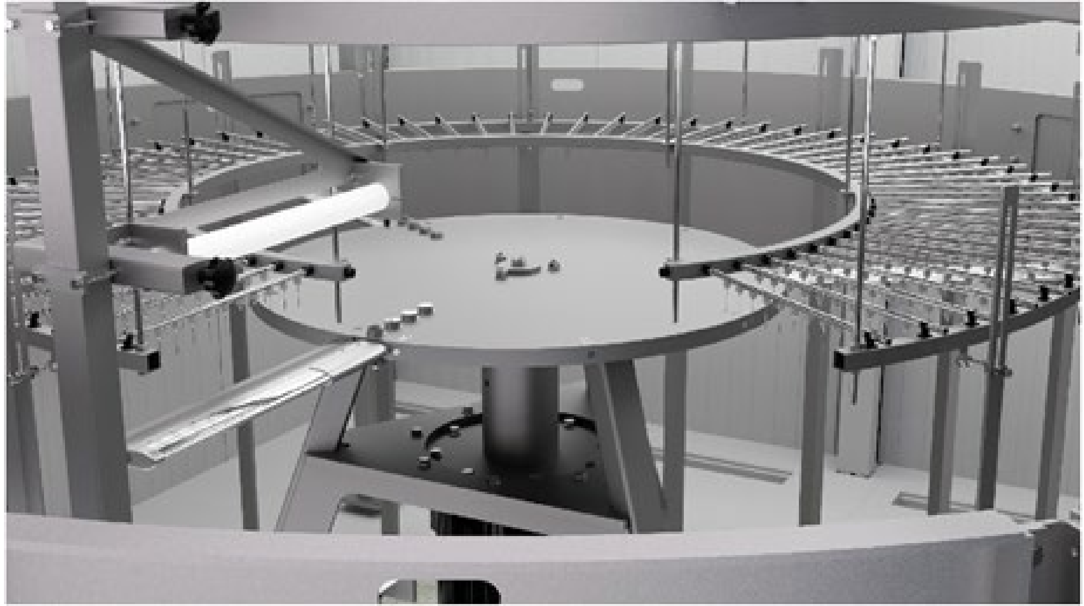

# Technical Results – Technologies For Lab Erosion Testing

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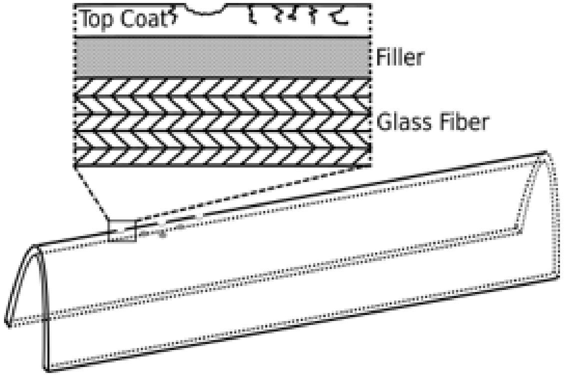
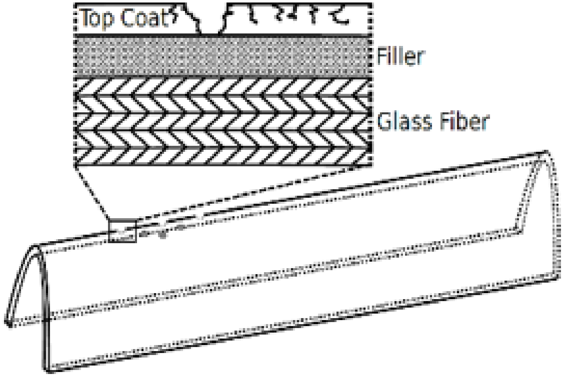


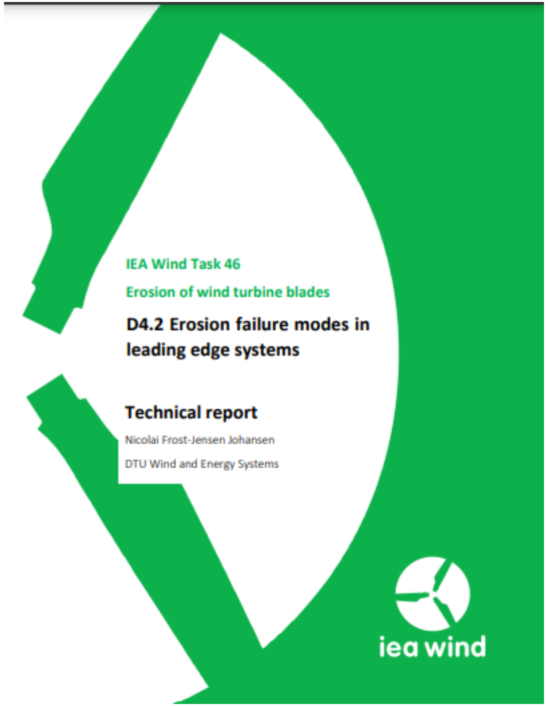




**Pre-incubation**
- Homogeneous roughening

**Incubation**
- Initial material loss
- Local erosion/point erosion

**Sudden failure (no incubation)**
- Failure at n to n-1 layer interface

**Post-incubation Erosion to substrate**
- Adheasive failure
- Coheasive failure
- Break through substrate



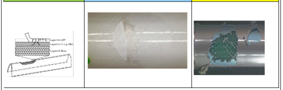
# Laboratory Testing of Erosion

IEA Wind TCP

- Johansen, N. F.-J., Erosion failure modes in leading edge systems (06/2023)

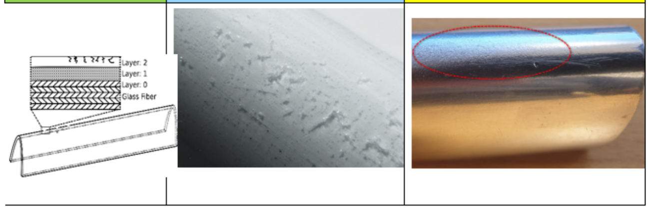
### 3.4 failure before incubation - failure at n to n-1 layer interface

| Description | | | | | | Defect Appearance |
|---|---|---|---|---|---|---|
| This failure mode covers adhesive failure between layers in the coating system this can be between LEP and topcoat, or LEP to porefiller. Also seen on tape/shell solution as failure of the adhesive to n layer interface. This can also result from a local defect, on cohesively strong coatings. When the coatings tensile strength exceeds the adhesive strength at the interface pealing can occur | | | | | | Typically presents as peeling of the coating<br>Underlying layer relatively undamaged |
| **Affecting layers** | | | | | | **Interchangeable defects** |
| **Example of coating specific layer name** | LEP | Coating | Filler | Surface laminate | Laminate | Point erosion can be due to this type of failure |
| **Layer number** | n | n-1 | n-2 | 0 | -1 | Approximate IEA erosion severity Level: |
| **Affecting layers** | x | x | (x) | | | 0: / 1 / 2:42% / 3:14 / 4:29% / 5: 14% |
| **Example images** | | | | | | |
| **Illustration** | | | 1 | | | 2 |



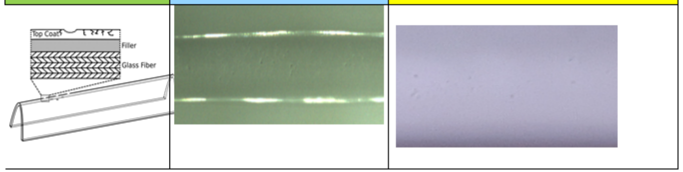
### 3.1 Pre incubation - Homogeneous roughening

| Description | | | | | | Defect Appearance |
|---|---|---|---|---|---|---|
| The defect type is characterized by morphology change with little to none material removal. Typically seen on homogeneous materials. It is usually the first defect appearing during a RET. As can be seen on the illustration, the rough/matt appearance occur because of crack formation in the n layer (LEP). These cracks results in reflected light being diffused giving rise to the matt appearance | | | | | | The appearance is very dependent on the material, on metallic surfaces it is seen as a loss of gloss. On Clear coatings it can be seen as cracks normal to the surface as illustrated |
| **Affecting layers** | | | | | | **Interchangeable defects** |
| **Coating specific layer name** | LEP | Coating | Filler | Surface laminate | Laminate | This type of defect is similar to initial material removal. Can also look like point erosion. |
| **Layer number** | n | n-1 | n-2 | 0 | -1 | Approximate IEA erosion severity Level: |
| **Affecting layers** | x | | | | | 0: 28% / 1:29% / 2 / 3 / 4:29% / 5: 15% |
| **Example images** | | | | | | |
| **Illustration** | | 1 | | | | 2 |

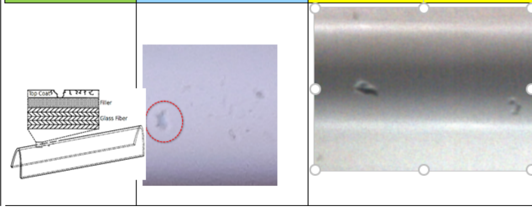



### 3.2 End of Incubation - Initial material removal

| Description | | | | | | Defect Appearance |
|---|---|---|---|---|---|---|
| The defect is characterized by local material loss and is usually the starting point of erosion development. The damage is within a confined area without connecting to preexisting erosion, limited to the top coating within a single layer. | | | | | | Defect size is equal to coating thickness squared or smaller. The damage is entirely confined to the outer n layer with no penetration |
| **Affecting layers** | | | | | | **Interchangeable defects** |
| **Example of coating specific layer name** | LEP | Coating | Filler | Surface laminate | Laminate | • Homogeneous roughening – distinct spots with clear difference from the neighboring area<br>• Local erosion – Limited to single layer |
| **Layer number** | n | n-1 | n-2 | 0 | -1 | Approximate IEA erosion severity Level: |
| **Affecting layers** | x | | | | | 0: 29% / 1: 14% / 2: 14% / 3 / 4:28 % / 5:14% |
| **Example images** | | | | | | |
| **Illustration** | | 1 | | | | 2 |




| Description | | | | | | Defect Appearance |
|---|---|---|---|---|---|---|
| The defect is characterized by local material loss exposing an underlying layer. This is usually the starting point of erosion development. The damage is within a confined area without connecting to preexisting erosion. Within this area, the defect can propagate to the underlying area. | | | | | | Defect size is equal to coating thickness squared or larger. The damage has removed part of the n layer exposing the n-1 layer. Typically, underlying layers have different colors to the top coating. This makes this type of damage, relatively easy to identify. And |
| **Affecting layers** | | | | | | **Interchangeable defects** |
| **Example of coating specific layer name** | LEP | Coating | Filler | Surface laminate | Laminate | • Initial material removal<br>• Homogeneous roughening |
| **Layer number** | n | n-1 | n-2 | 0 | -1 | Approximate IEA erosion severity Level: |
| **Affecting layers** | x | x | (x) | | | 0: / 1:29% / 2:14% / 3:14% / 4:29% / 5: 14% |
| **Example images** | | | | | | |
| **Illustration** | | 1 | | | | 2 |




Classification system to better indentify incubation damages and seperate rain erosion test failure modes

# VN-curve Based RET Testing

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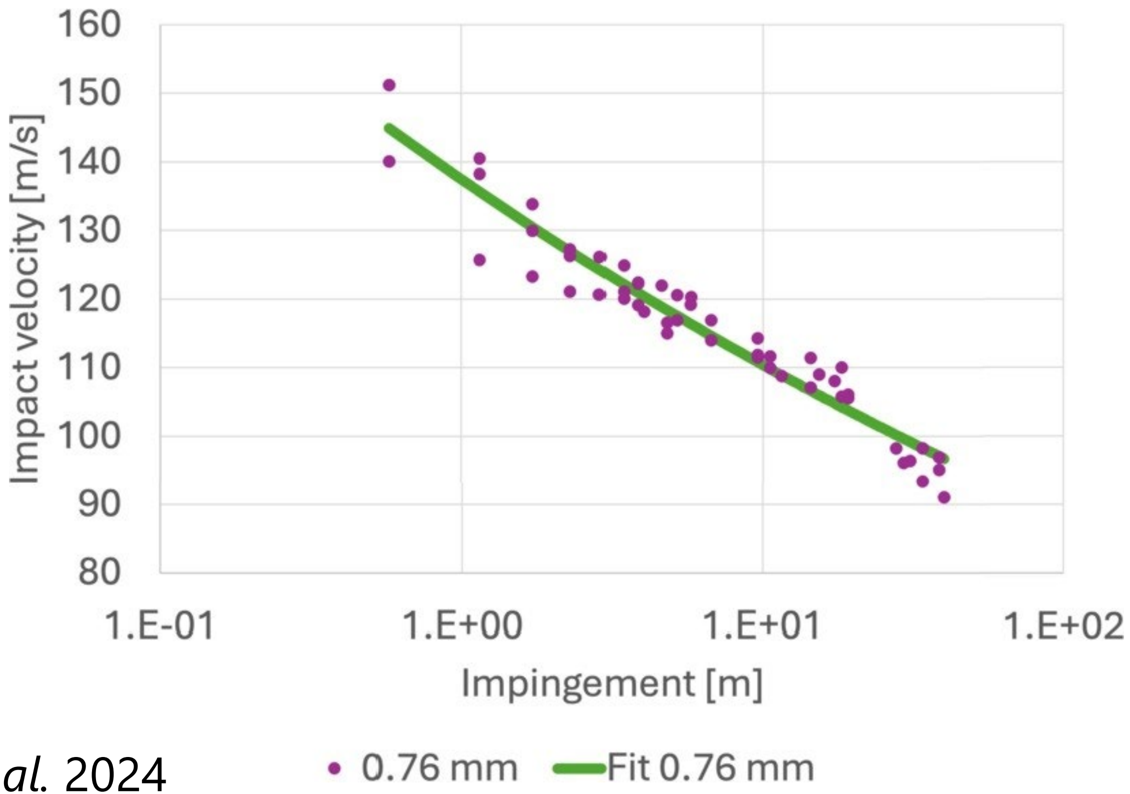
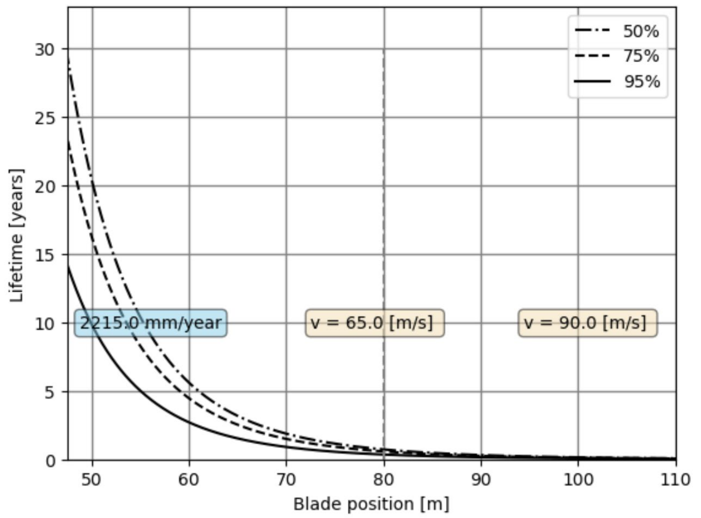



Bech *et al.* 2022
Hannesdóttir *et al.* 2024

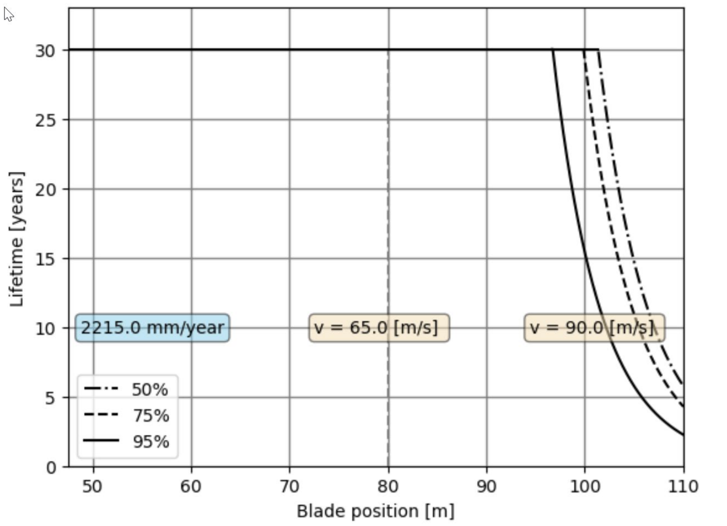
# Open Software

IEA Wind TCP

- Python-Jupyter notebook implementation of DNV-GL 0573
  - Improved regression analysis
    - High impact on predicted lifetimes
- N-dependent




V-dependent



# From Lab to Field Data

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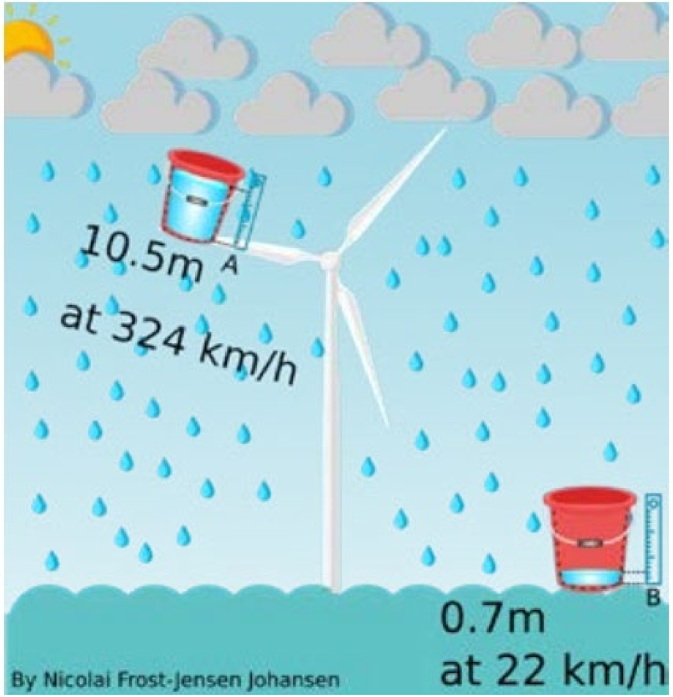


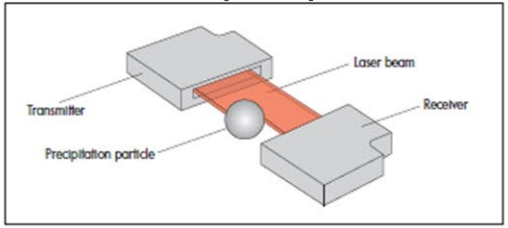
# Laser optical disdrometers/present weather sensors:

OTT Parsivel[2]

**Outputs ~ 1000 values/minute:**

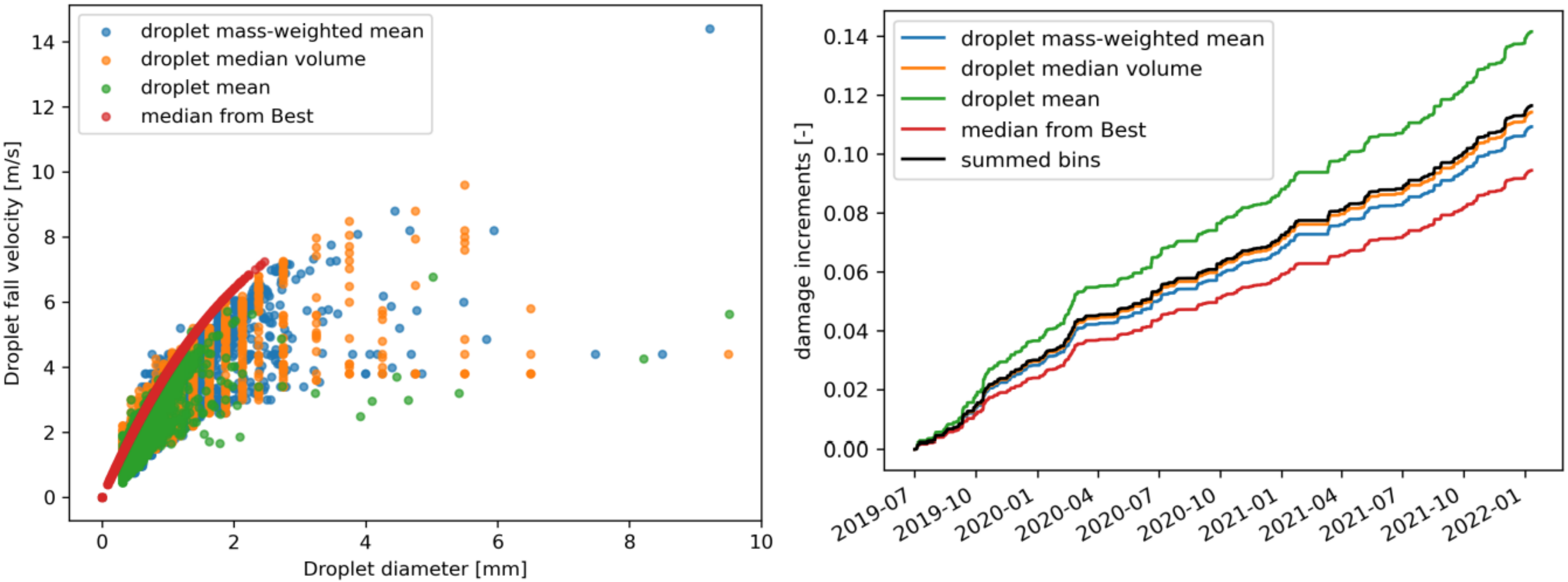
1. Rain intensity
2. Weather code (precipitation type)
3. Droplet diameter
4. Droplet velocity

**Measurement principle**



# Disdrometer Data From 2.5 Years at DTU Risø



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ENGIE
Offshore
Levenmouth
Offshore
Risø
OffShore
Rézentières
High altitude /flat
Tadeas
Medium complex
terrain
San Gregorio
Magno
Complex terrain
Alaiz
Complex
terrain/high altitude
PLOCAN
Offshore

IEA Wind TCP

# Technical Results – Atmospheric Drivers of Erosion

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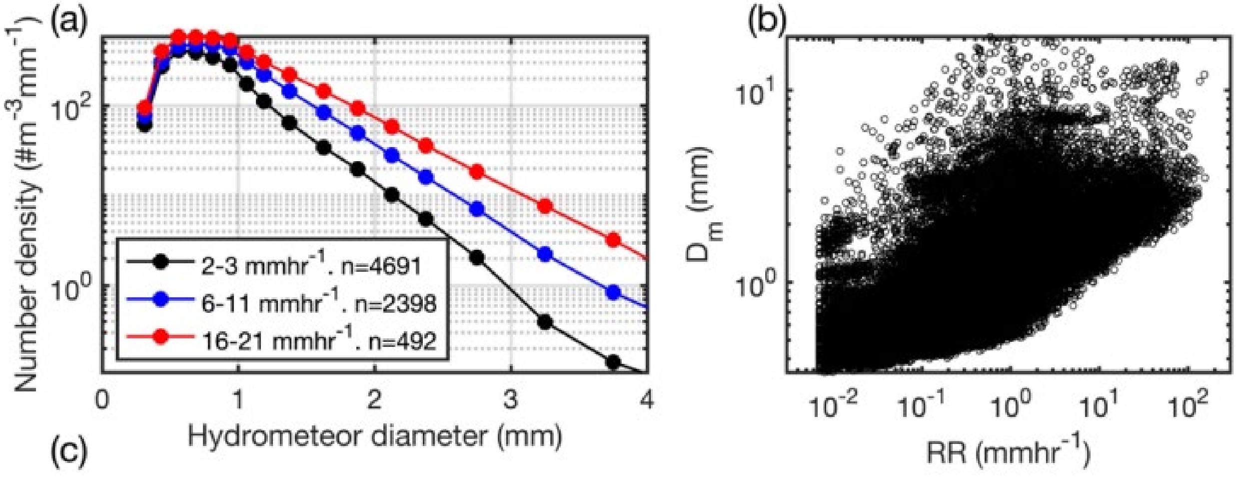


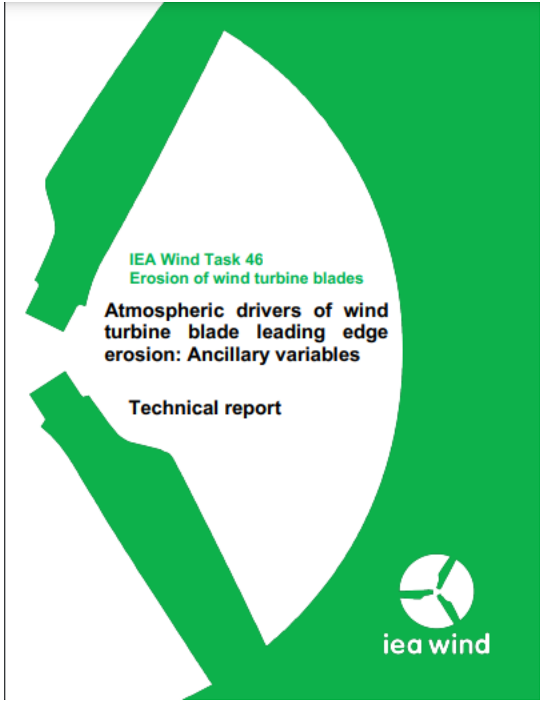

# Erosion Risk Atlas

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# Scandinavia, Model Domains and Stations

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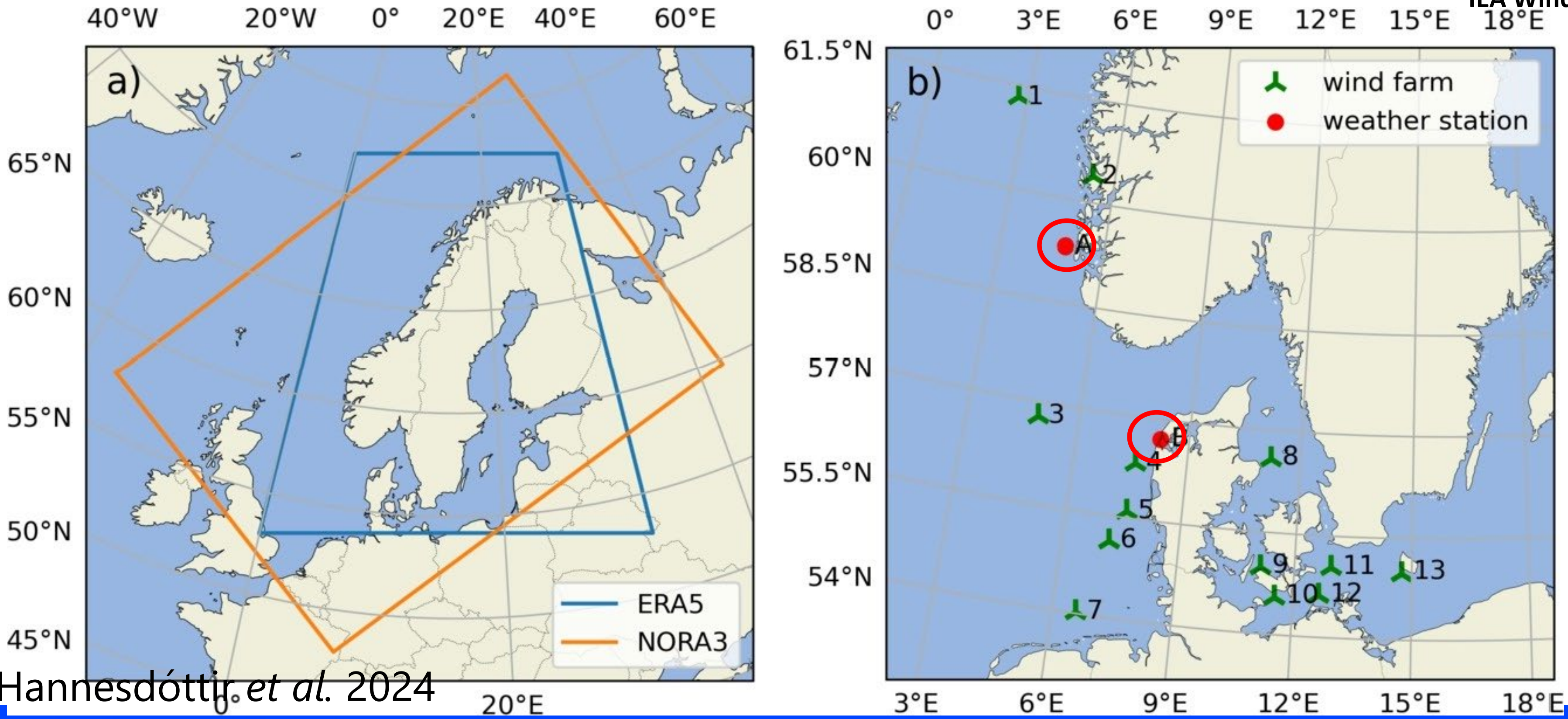


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# Comparison of Cumulative Rainfall

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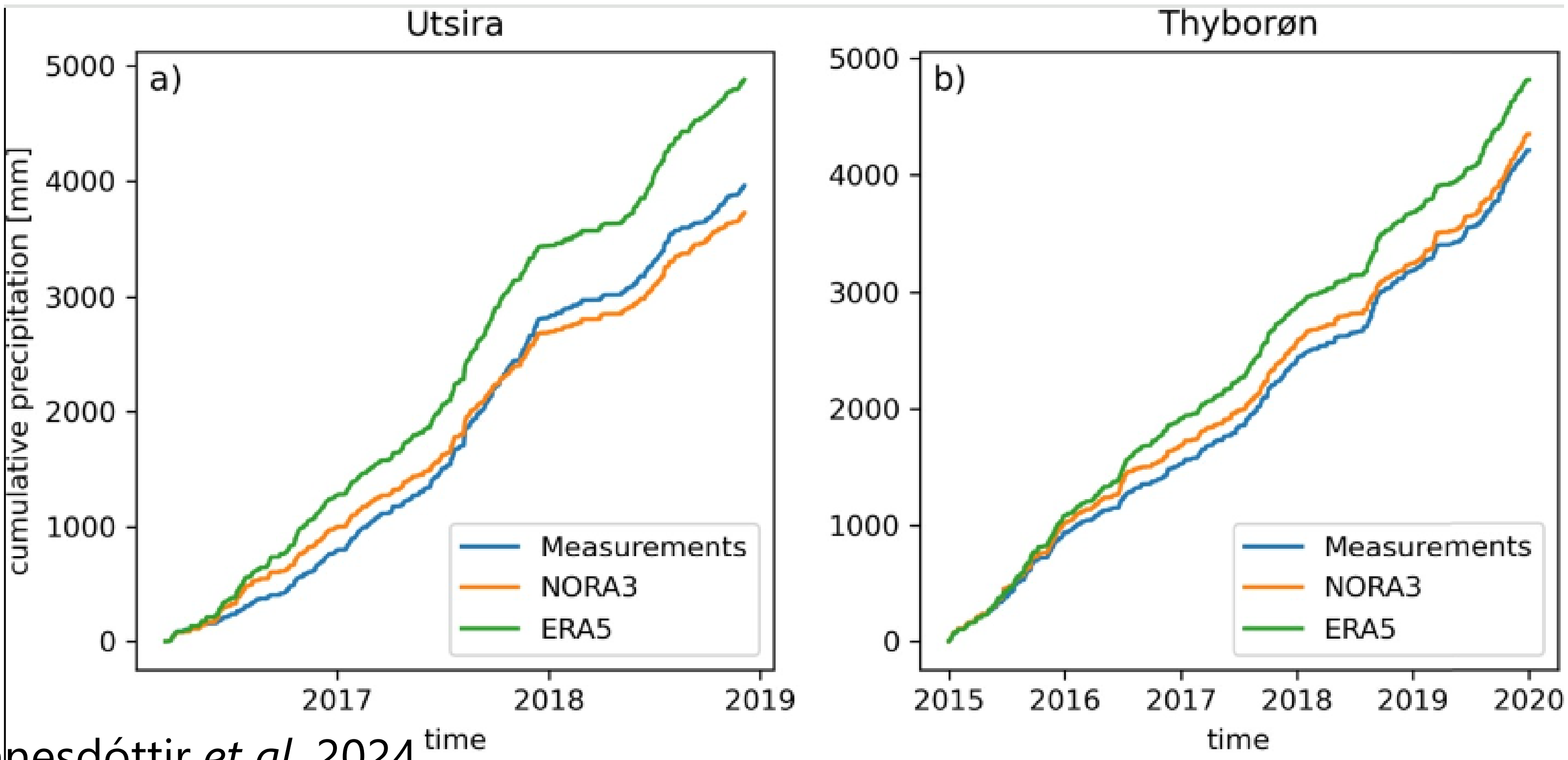


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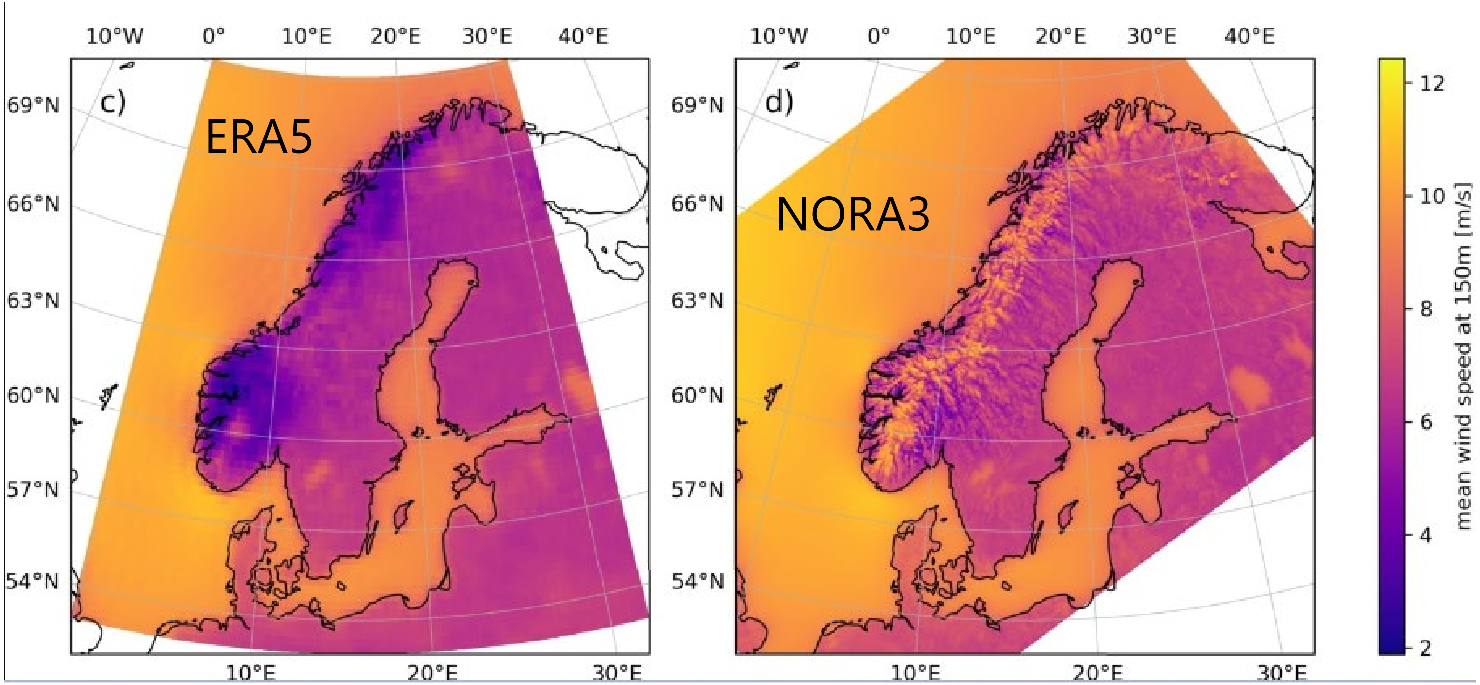
# The Annual Average Wind Speed at 150 m



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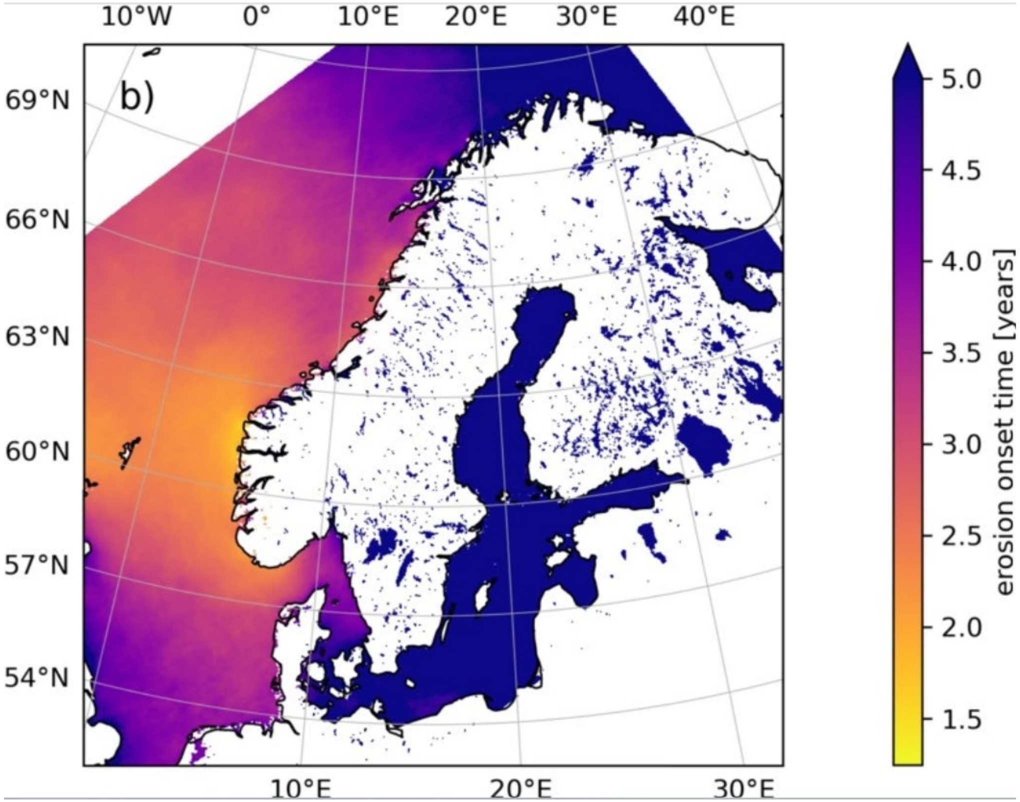
# Erosion Onset Time Offshore

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NORA3 meteorological data, the IEA 15 MW wind turbine and a commercial blade material.

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# On Erosion Classification System

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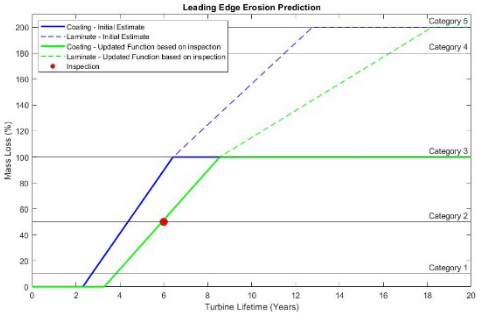
## Visual Condition

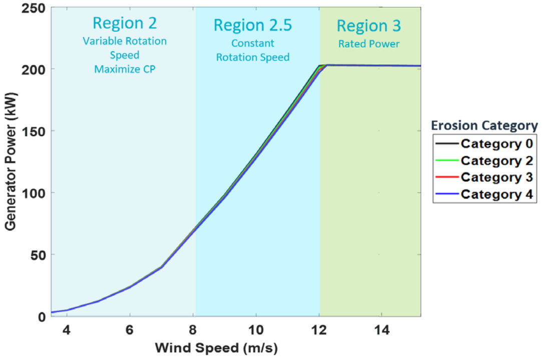
Report contains many visual examples of categories of blade and LEP damage.

## Mass Loss



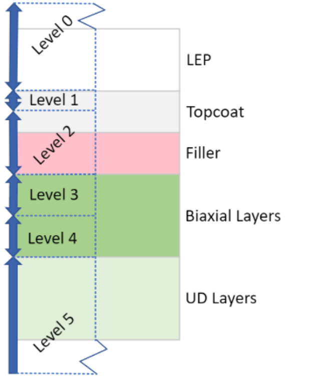

Prediction of future erosion level progression.

## Aerodynamic Performance




Power loss is defined in Region 2 of the power curve.

## Structural Integrity

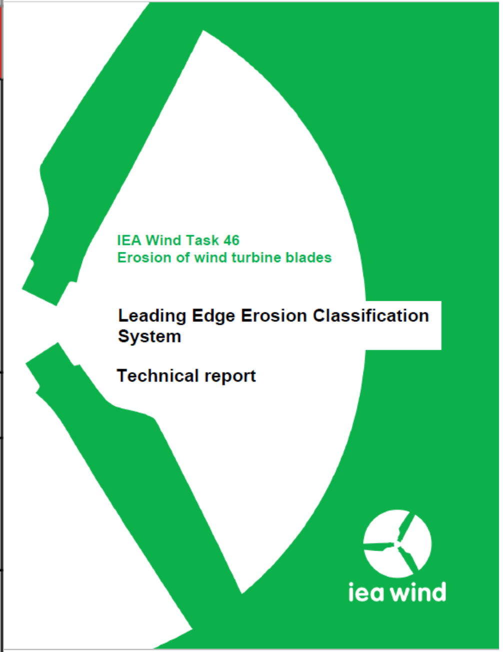



Detailed description of severity level definitions and thresholds.

# Technical Results – Erosion Classification System

IEA Wind TCP

| Evaluation Criteria | Severity Level 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Visual Condition (LEP) | Initial factory condition | Lightly worn external coating/LEP<br><br>Instances of reduced LEP adhesion | Notable areas of localized damage on external coating/LEP<br><br>Individual Instances of LEP adhesive failure. | LEP is largely compromised over a large area and no longer providing protection to underlying layers | Delamination of topcoat with immediate layer underneath clearly visible and exposed | Notable damage to substrate |
| Visual Condition (No LEP) | | Erosion barely visible or pinholes | Localized pitting | Widespread or coherent pits, some gouges | | |
| Mass-loss | | Coating <10%<br>Laminate 0% | Coating 10-50%,<br>Laminate 0% | Coating 50-100%,<br>Laminate <10% | Coating 100%<br>Laminate 10-100% | Coating 100%,<br>Laminate 100% |
| Aerodynamic Performance | | Normal surface roughness<br><br>Region 2 Power loss 0 -1% | Region 2 Power loss 1%-2% | Region 2 Power loss 2%-3% | Region 2 Power loss 3-4% | Region 2 Power loss >4% |
| Blade Integrity | | Initial erosion of topcoat | Erosion through topcoat | Initial exposure of immediate laminate layers | Erosion through immediate laminate layers | Exposure of structural laminate layers |



# Damage Models Based on Fundamental Material Properties

- ✓ Test data for UV degradation combined weathering and RET; different chemistry comparison
- ✓ Damage progression analysis based on 1) images V-N curves, 2) intermediate mass loss measurements and 3) micro-CT and 3D scanner for damage progression based on intermediate geometry evolution

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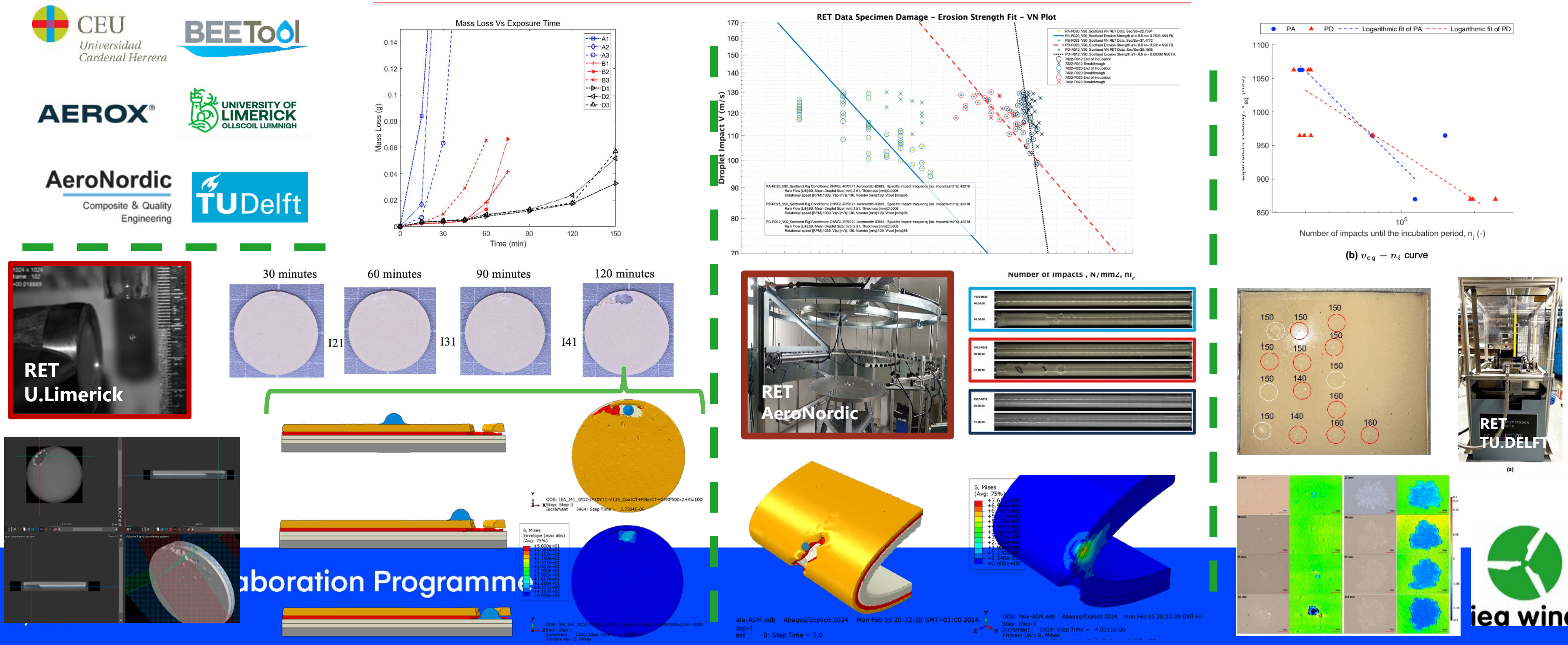
BEETooL

AEROX

UNIVERSITY OF LIMERICK OLLSCOIL LUIMNIGH

AeroNordic Composite & Quality Engineering

TU Delft




aboration Programme

iea wind

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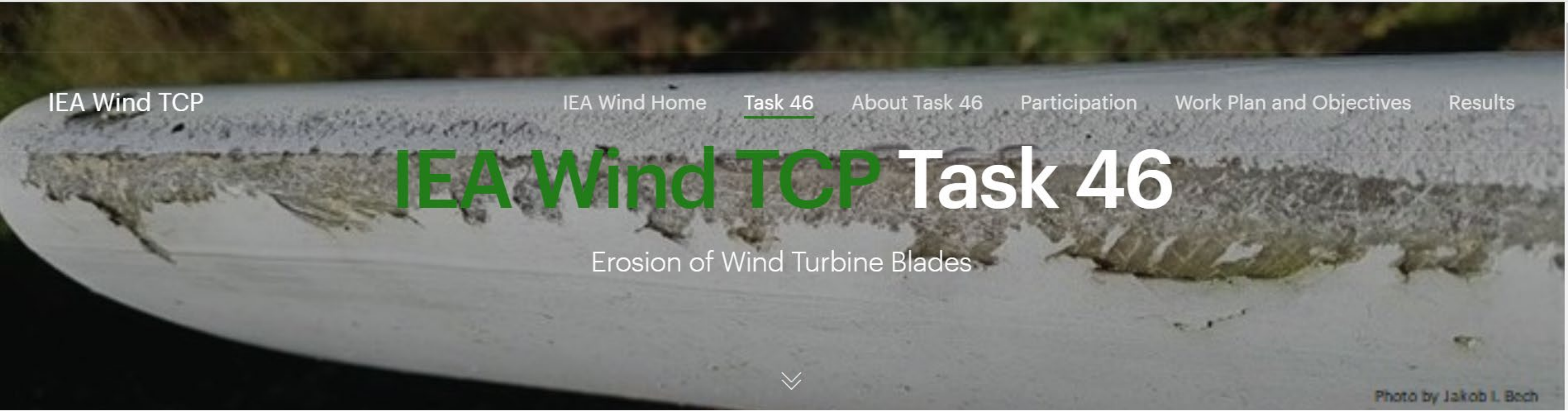
# https://iea-wind.org/task46/



# Acknowledgements

IEA Wind TCP


- EUDP for funding of the IEA task 46, Erosion of wind turbine blades grant J.nr. 64021-0003.
- European Commission's Horizon Europe funding with Grant agreement ID: 101083716 for the financial support of the AIRE project.
- "Estimation and Prevention of Erosion on Off-Shore Wind Turbine Blades" (102235103) funded by the Academia Agreement between the University of Bergen and Equinor.
- U.S. Department of Energy via a sub-contract to Sandia National Laboratory and grant (DE-SC0016605), plus NASA grant #80NSSC21K1489.
- ACTRIS-DK: The Aerosol, Clouds and Trace gases Research Infrastructure – Denmark
- Innovation Fund Denmark - Grand Solutions projects, Grant 6154-00018B "EROSION" and Grant 9067-00008B "Blade Defect Forecast".

# Thank you!

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