Icing alleviation for wind turbines with no ice-protected blades

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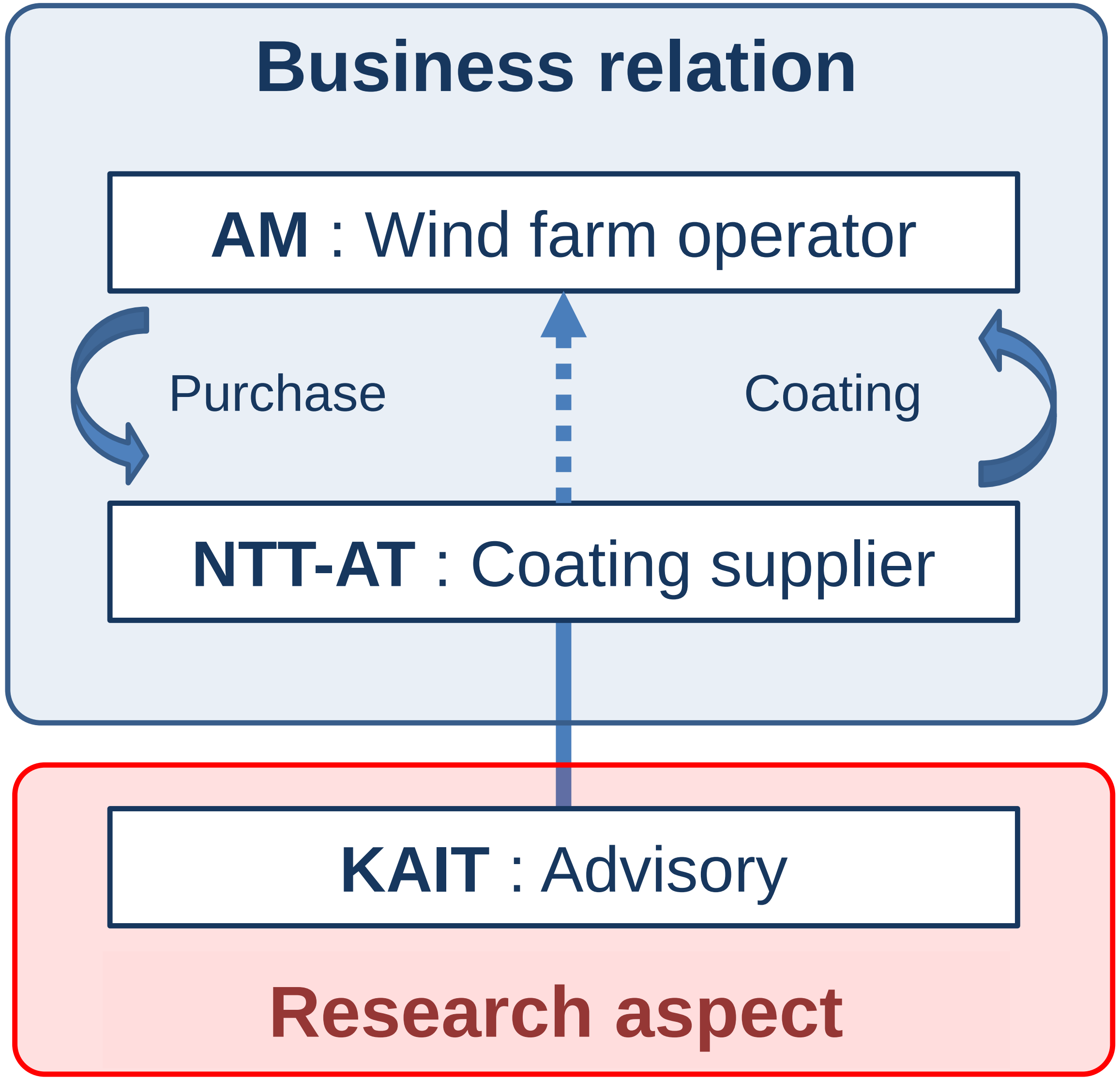
Overview



Background

- Wind farm itself is run by Anemos Makedonias
- Icing greatly affected the energy production
- Needed the anti- or de-icing for existing wind turbines
- Planed field trial study of anti-icing system by applying icephobic coating HIREC onto wind turbine blades
- Effectiveness of the coating on the operating turbine blades weren’t known well
- KAIT started contributing from the research aspect

Fundamentals

Objectives

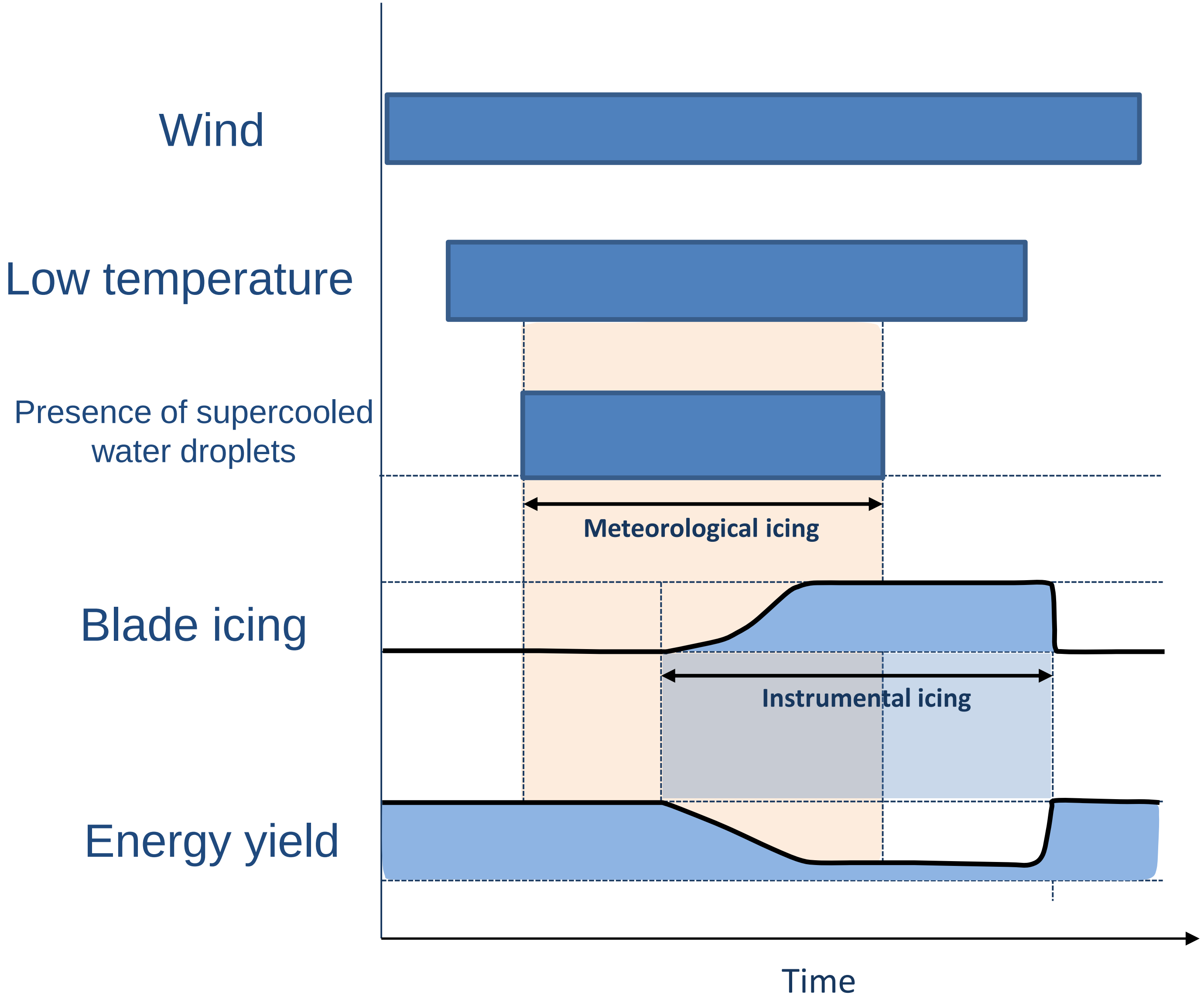
To evaluate the effectiveness of the icephobic coating on blades with given data

Difference from pure research

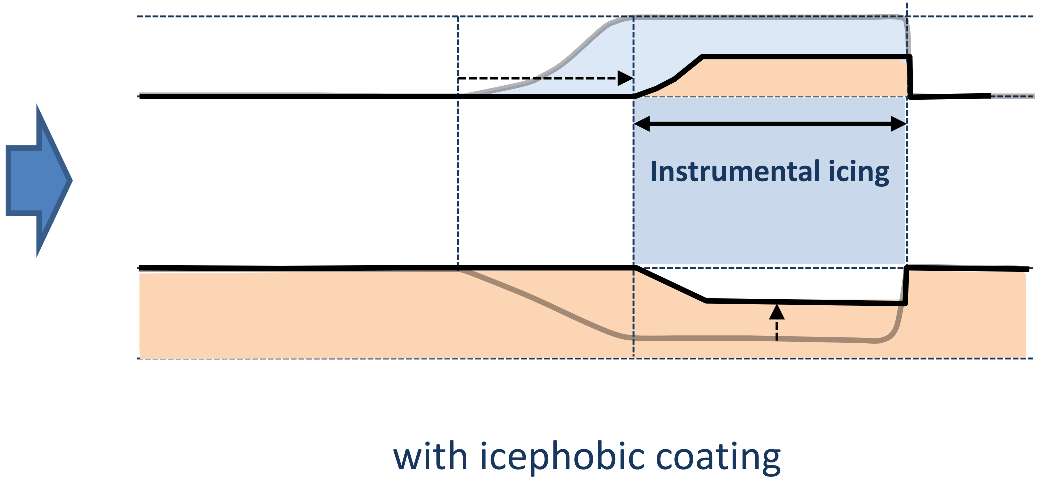
- Limited data resource because the wind farm wasn’t established for the research purpose in the first place
- No perfect references for the comparison in terms of identical wind turbine sites, meteorological conditions, measurement periods, etc
- Effect on economic benefits isn’t available

Contents

Icing on blades

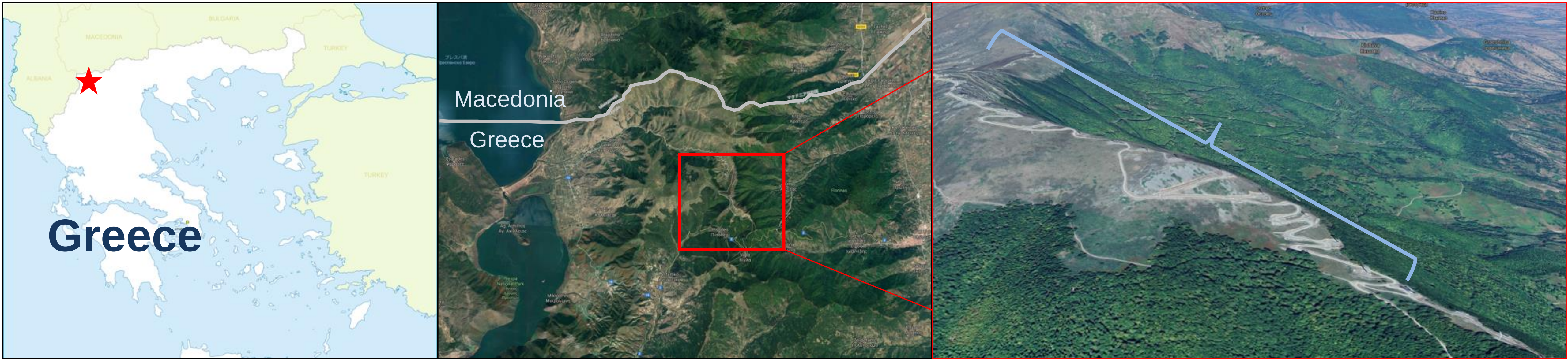


- Icing occurs in the cold climate with the presence of supercooled water droplets
- Energy yield decreases during instrumental icing
- Energy yield returns either when ice on blades is melted or thrown off by the centrifugal force



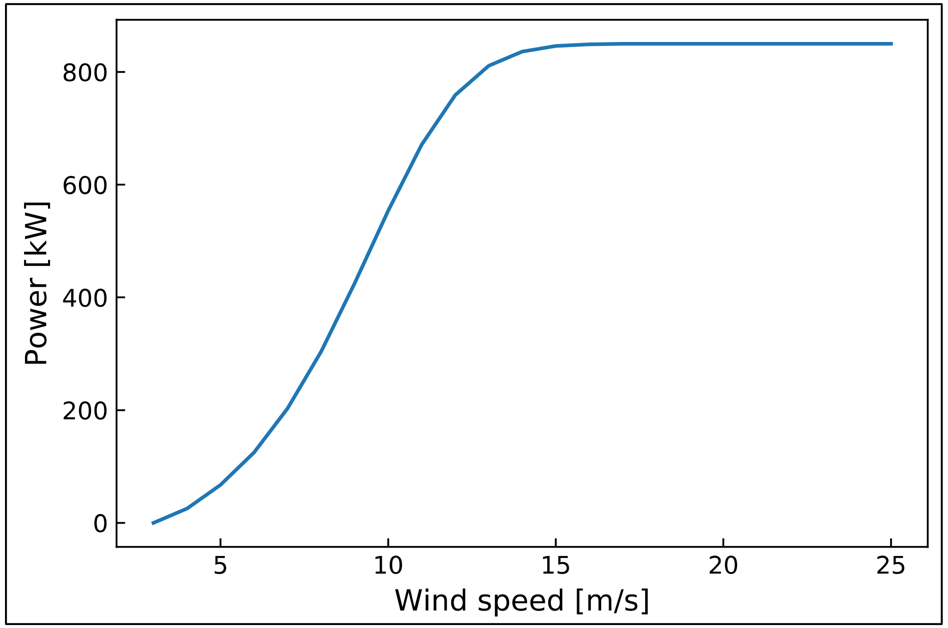
Wind farm – Anemos Makedonias

- Anemos Makedonias is a wind farm operating company based in Athens
- The farm is established in West-Makedonia (see figures below)
- Total nominal power is 28,900 kW produced from 34 wind turbines
- Commissioning in 2009 & full connection in 2013
- Roughly 20% of the annual income is getting lost according to their estimation



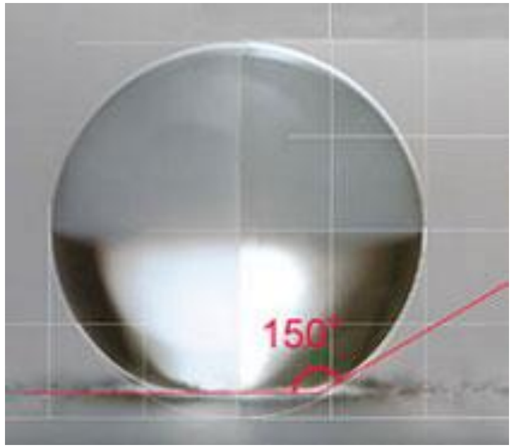
Wind turbine specifications

- Company : VESTAS
- Type/Version : V52
- Rated Power : 850.0 [kW]
- Rotor diameter : 52.0 [m]
- Cut-in wind speed : 4.0 [m/s]
- Cut-out wind speed : 25.0 [m/s]



Icephobic coating - HIREC100

HIREC100

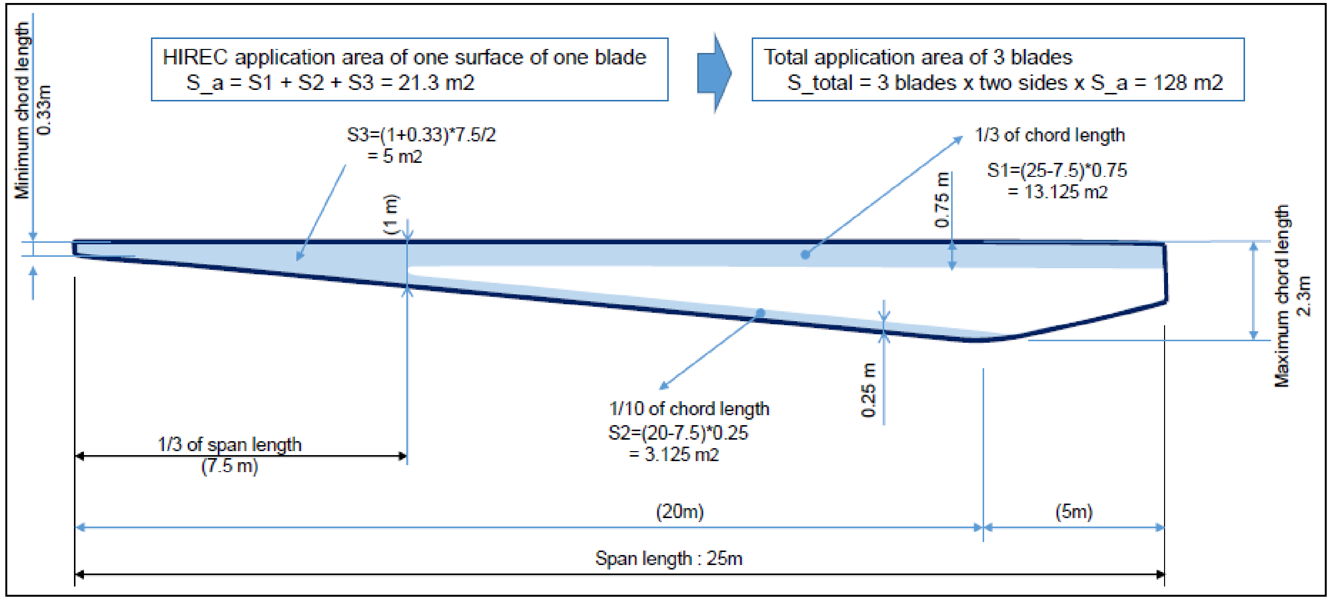


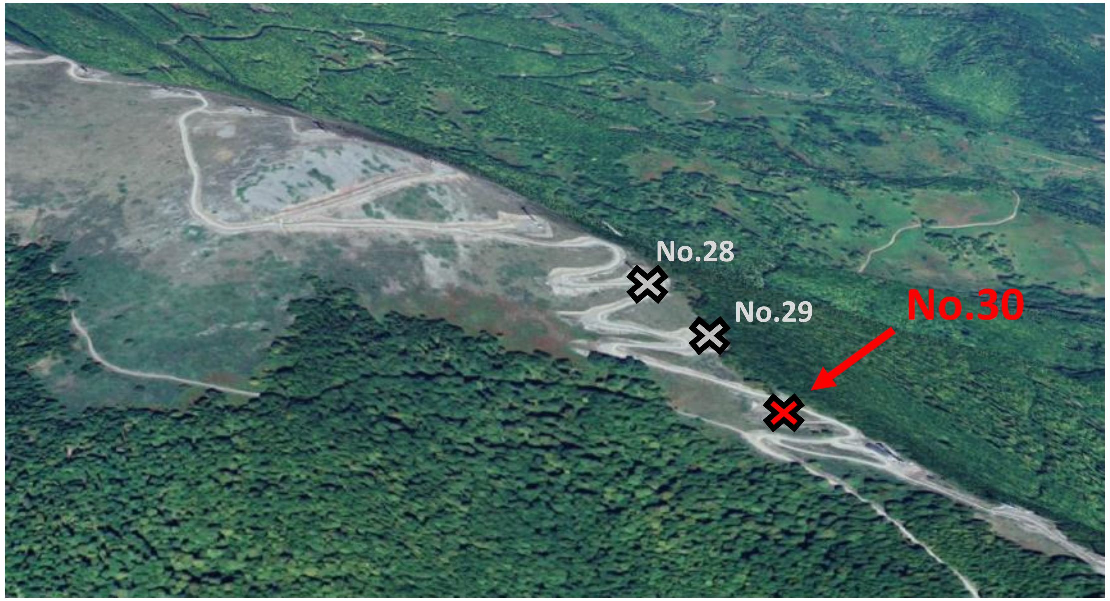
- Undercoating: Requires primer coating
- Life Span: 3 seasons (years) outdoors
- Best for Repelling: Water &snow
- Film thickness: about 30 microns

Coating work (primer & HIREC100)

- Date: Oct. 2017
- Method: By brush
- Applied to Wind turbine No.30
- Coated areas: shown at the bottom

(not strictly followed due to on-site coating)





Comparison method

Acquired data (every 10 min)

- Average wind speed : v [m/s]
- Actual energy yield : ε [kWh]
- Average temperature [℃]
- Average wind direction [deg]
- Average rotor RPM

Energy loss calculation

$$\boldsymbol{Energy\ loss} = \frac{\boldsymbol{E_{est} - E_{act}}}{\boldsymbol{E_{est}}} \times \mathbf{100}\ [\%]$$

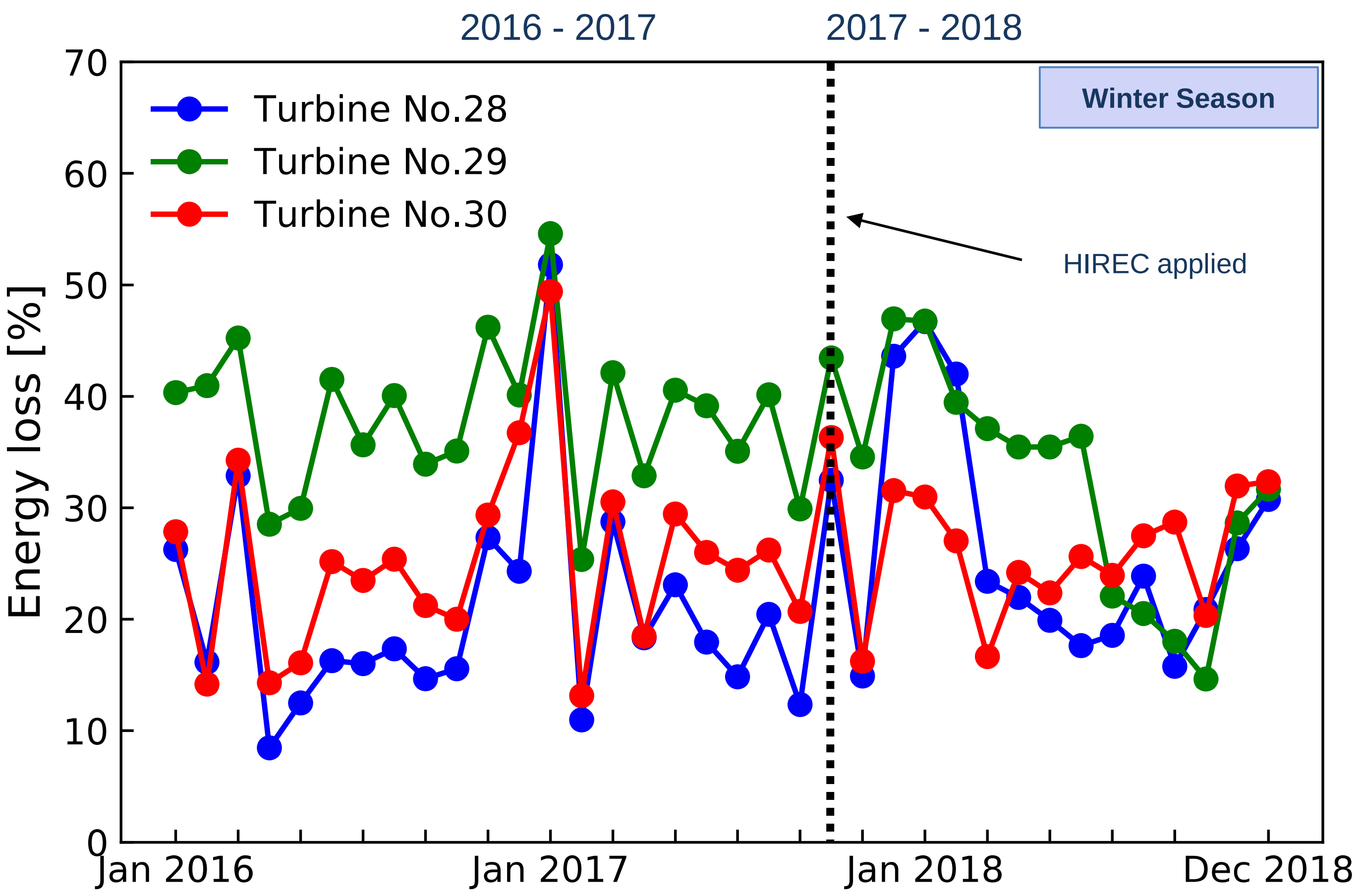
Actual energy yield : $E_{act} = \sum \varepsilon$ [kWh]

Estimated energy yield : $E_{est} = \frac{1}{6} \sum f_{(v)}$ [kWh]

where $f_{(v)}$ is a function of the power curve

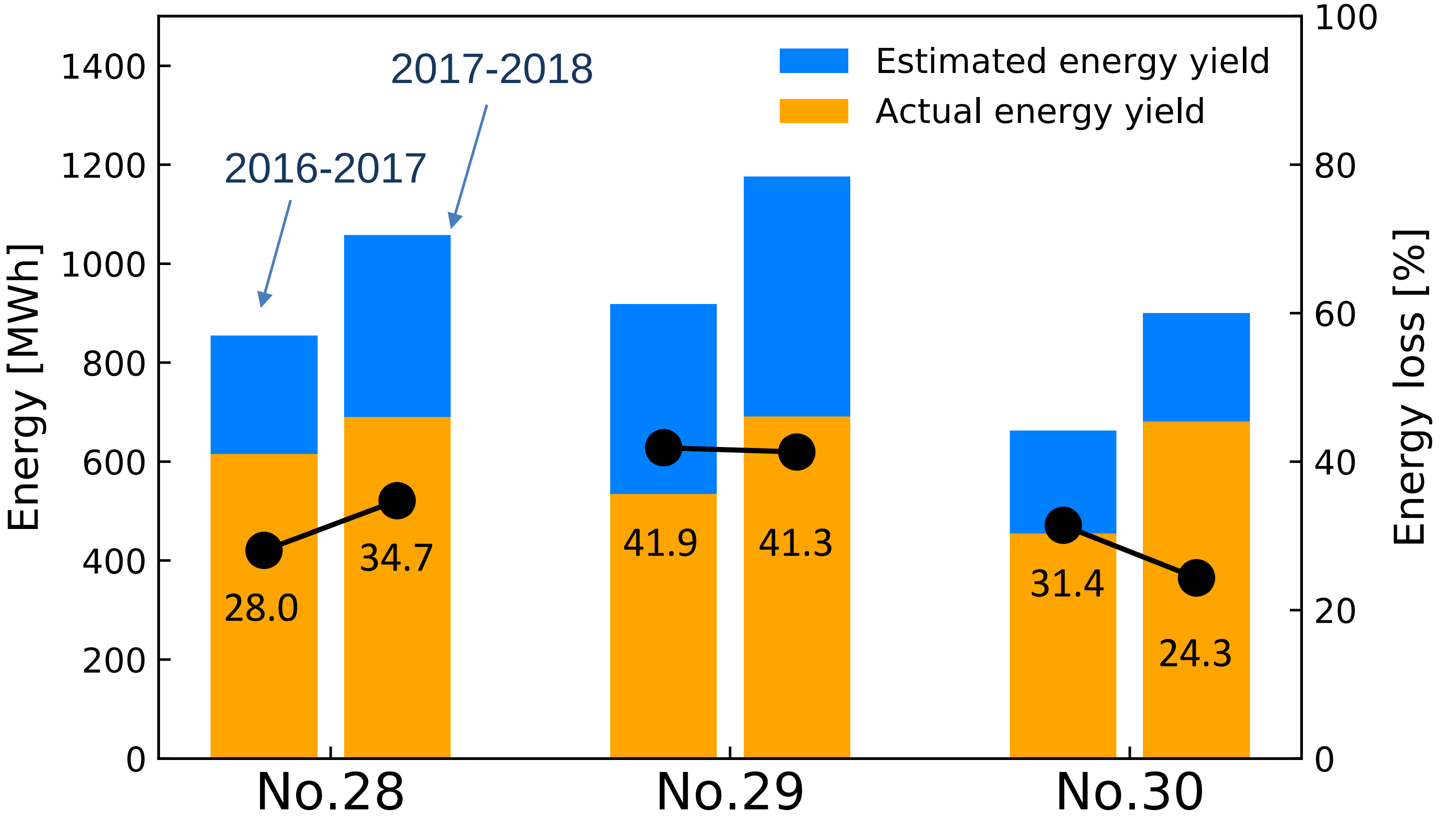
- Estimated energy was calculated only when $4 < v < 25$ [m/s]
- Calculation doesn't include missing data due to the unexpected failure of loggers

Energy loss per a month



- Monthly energy loss from Jan 2016 to Dec 2018 are shown
- Black doted-line is when HIREC was applied on blades of No.30
- Winter season (from Nov to Mar) is colored blue
- Energy loss increased in 2016-2017 winter season
- In 2017-2018 winter, No.28 & No.29 showed relatively increased energy loss, while that of No.30 had little rise

Estimated & Actual energy yield in winter



- Actual energy yield is shown over the estimated energy as bars
- Left bars are the data obtained during winter ”before” HIREC was applied, and right bars are after that.
- Wind speed in the second winter was more favorable
- Although estimated energy yield was increased, actual energy production didn’t follow in No.28 and 29
- HIREC led the lower energy loss in No.30

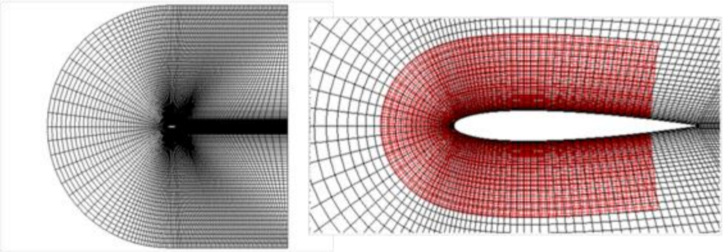
Erosion

Impingement of minute droplets

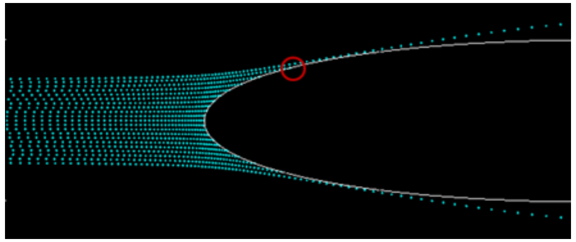
- Erosion of surface coating in the LE area is caused by impingement of minute water droplets in clouds when wind turbine is operating
- It is important to know how the droplets collide with the blade surface and how wide erosion occurs afterwards
- Hence, CFD analysis (NS-eqs + Continuity eq) is implemented.

Calculation conditions

Wing section	NACA0012
Grid	C-type
Grid points	26000
MVD(μ)	10, 20, 30, 40
LWC(gm^{-3})	0.8
Airspeed(ms^{-1})	10 - 110



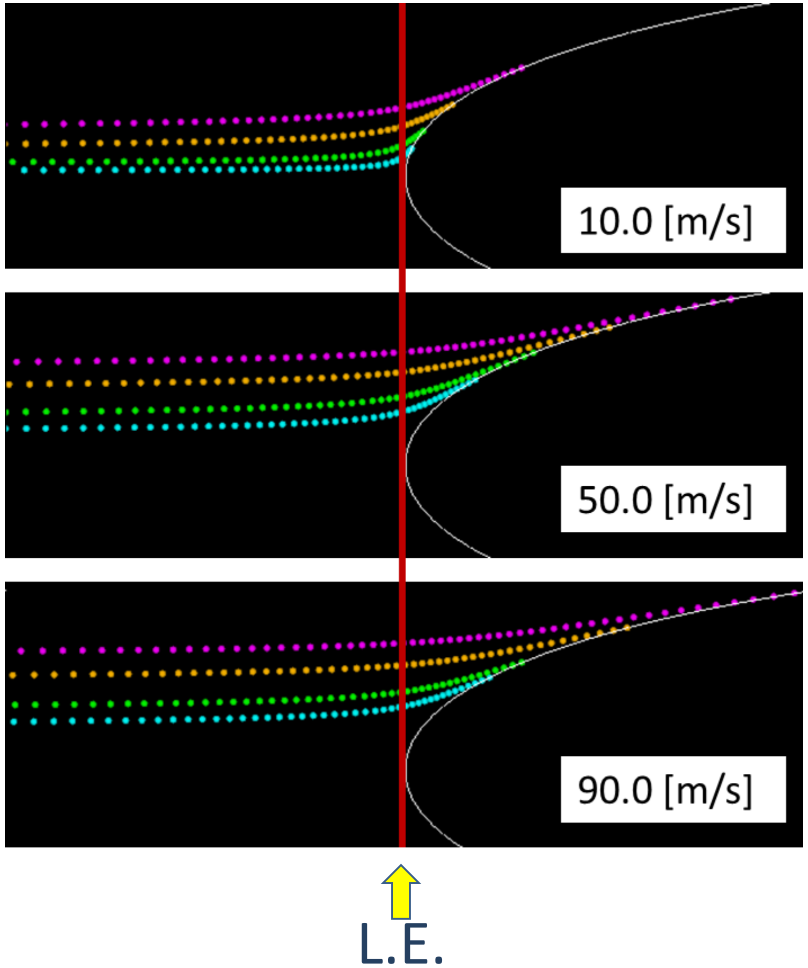
Cal. domain & Grids

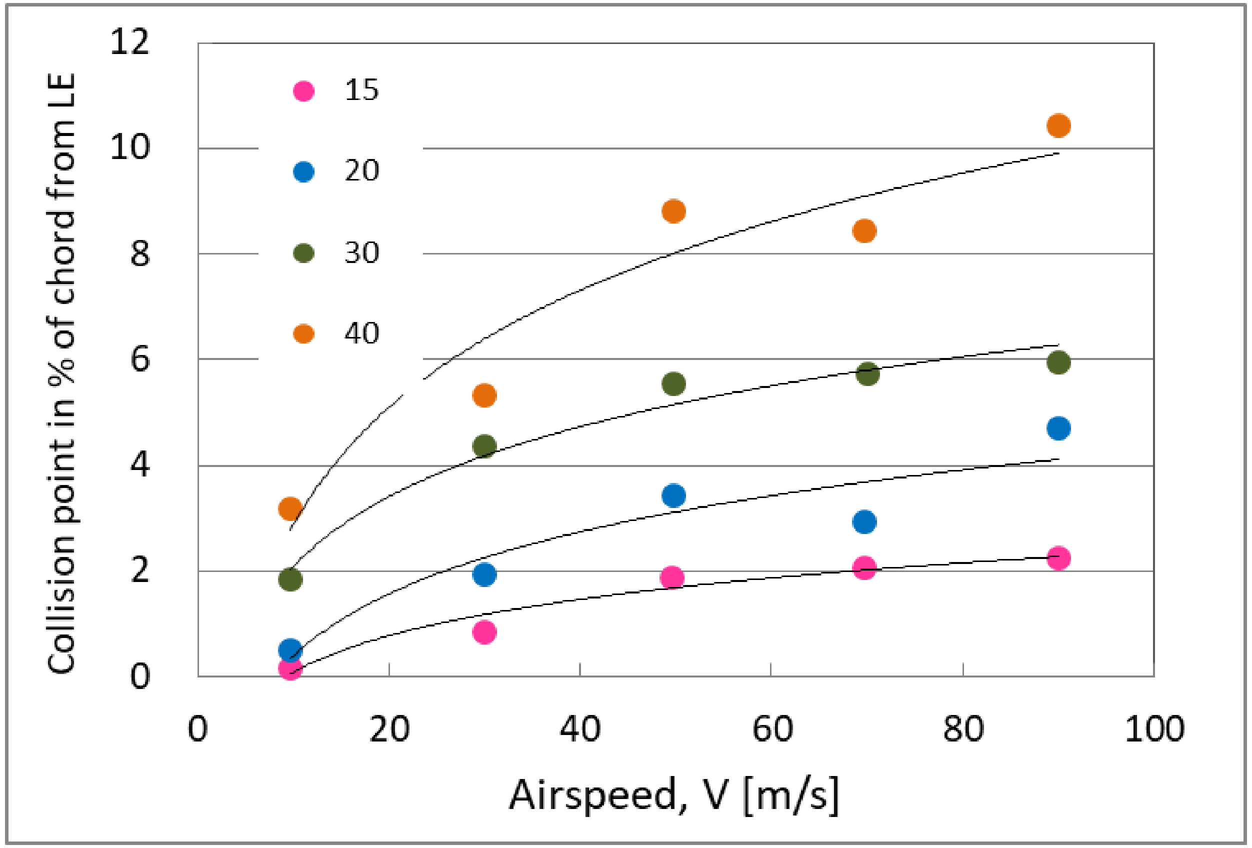


Droplets' trajectories & impingement

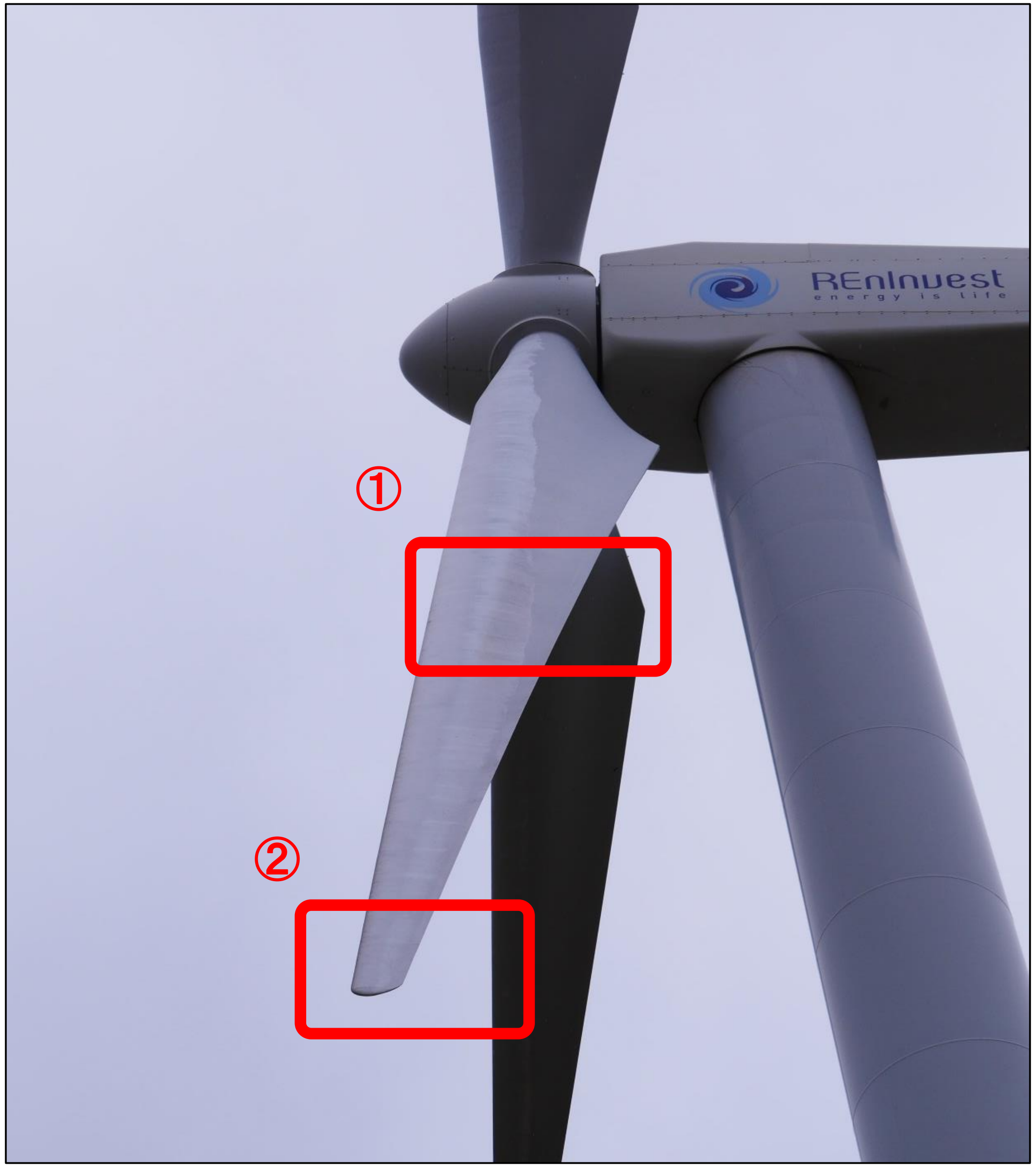
Erosion

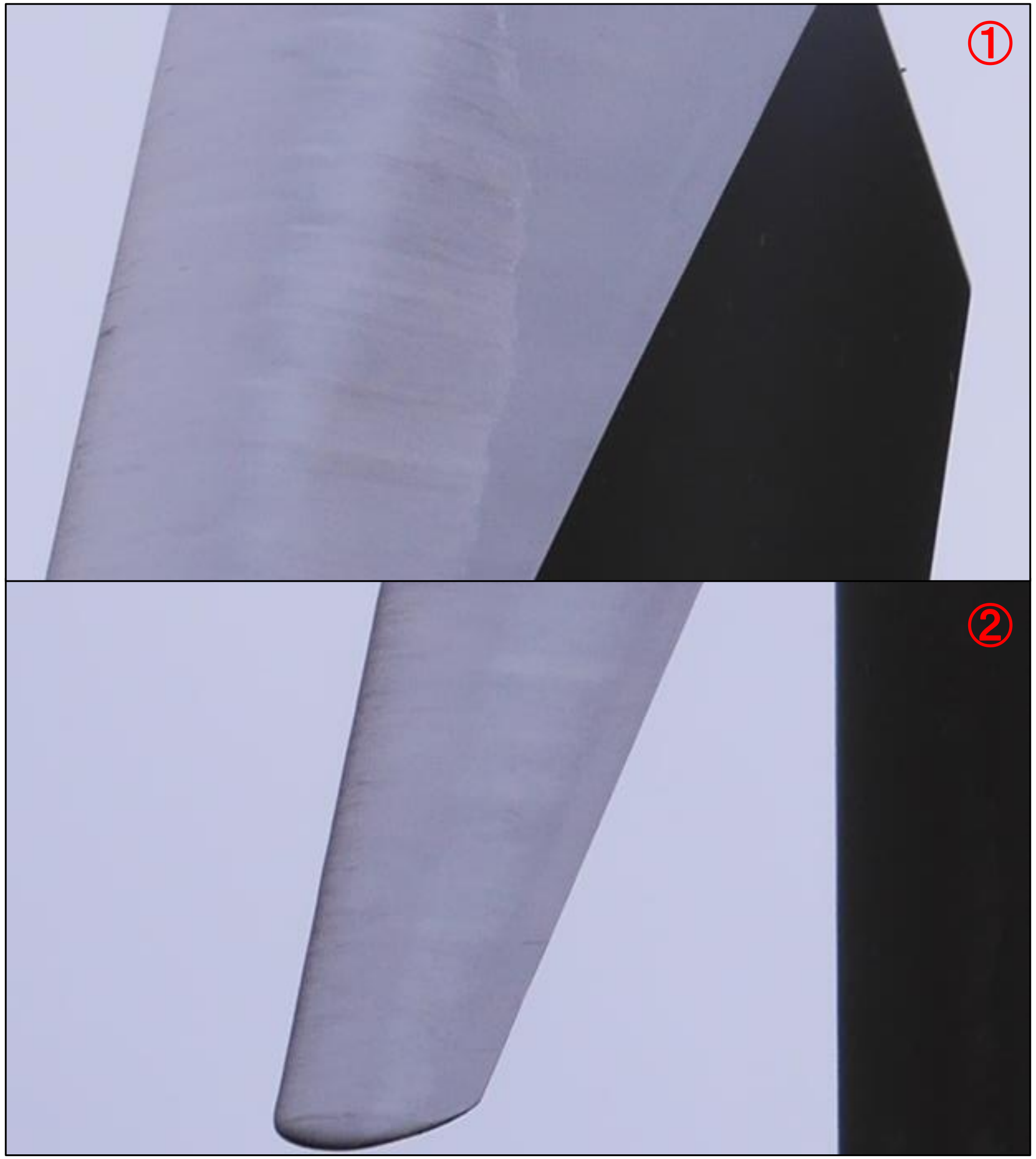
Collision limit point



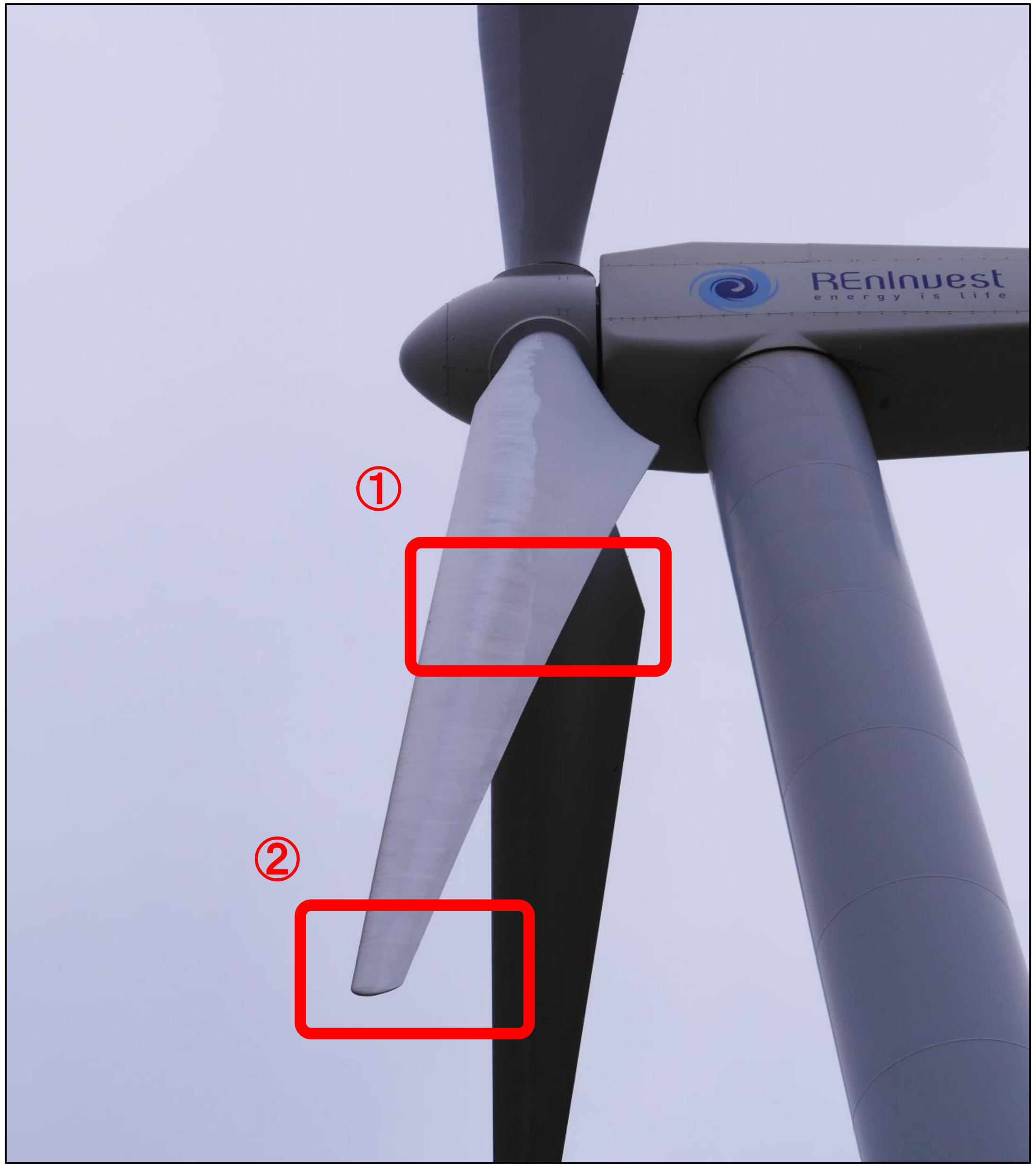


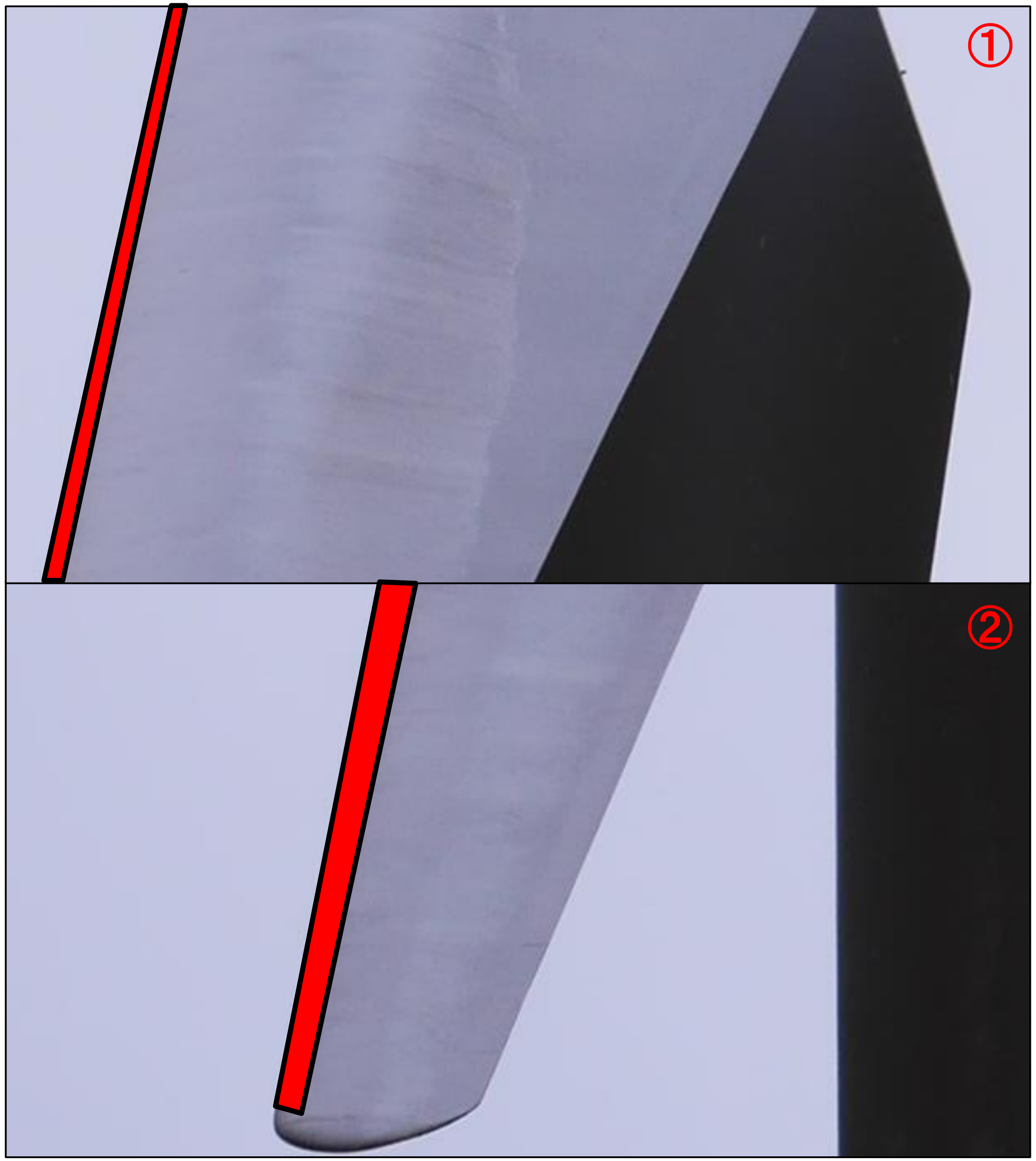
Erosion





Erosion





Ice fragments flown from coated blades

Taking pictures and collection of flown ice fragments:
Mar.2018

The area the samples were collected

Ice fragments flown from coated blades

A transparent ice fragment flown from the LE

Ices were colored reddish yellow with sands from Sahara desert

Very tiny thin ice piece

Summery

- Energy loss of 3 wind turbines(No.28, 29, and 30) was studied
- The loss was relatively increased in winter
- After icephobic coating was applied onto blades of No.30, the loss seemed ameliorated & its energy yield was increased
- Erosion of the coating was observed at the leading edge and more severe at the tip
- The coating might cause thinner & smaller ice fragments found near the wind turbine

Thank you