Icing impact on trailing edge Noise in Wind Turbines

19/04/2021 VTT – beyond the obvious

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Motivation

- Noise caused by aerodynamic effects
- Icing impacts aerodynamics
- Effects of icing on wind turbine noise not as well researched as icing impact on production
- Noise effects relevant for public acceptance
- Ice detection ?

Approach

- Look at existing research on the topic
- Simulation study to look at the impact of changes in surface roughness on aerodynamic noise
- Corresponds to early stages of icing event

Cold climate wind and noise

- Overall ~25 relevant articles
- Two main themes were visible:
  - Aerodynamic noise at the blade
  - Changes in environmental sound propagation
    - Snow
- More of this kind of research has been done related to aviation, airfoils, helicopters etc.

Sound propagation

- Field measurements and modeling
- Snow can have a dampening effect
  - Depends on snow conditions (snow surface)
  - Snow on trees
- Atmospheric conditions
  - Turbulence
  - Vertical temperature and wind speed gradients
  - Wind maximum below hub height reduced sound levels at ground level

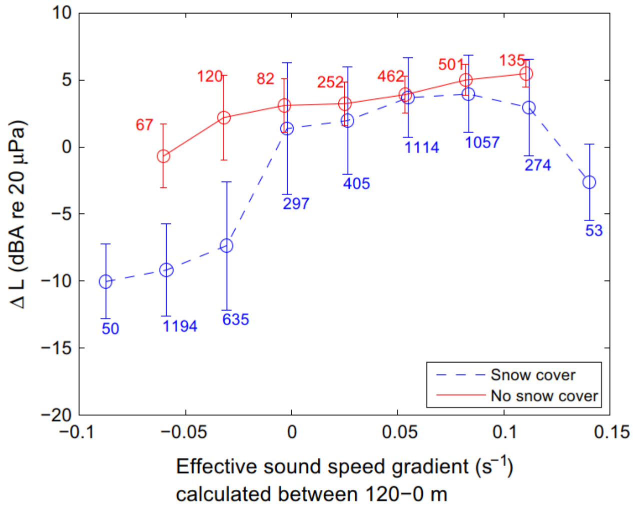
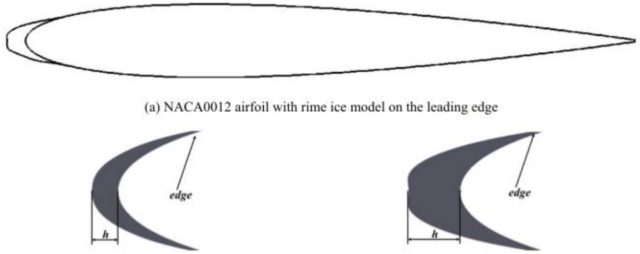


Fig. 12. Relative SPL for different effective sound speed gradients and ground properties for the Dragaliden site. The effective sound speed gradient is calculated from 120 to 0 m. The numbers indicate the total number of measurements, the rings gives the median values and the bars indicate one standard deviation of the data within each bin.

(Larsson and Öhlund, 2015)

Blade noise

- Mainly CFD models, some amount of wind tunnel measurements and field measurement campaigns
- Ice on the leading edge
- Rime ice, thickness some mm
- Ice causes boundary layer flow separation
- Result is increased noise at the trailing edge
- Field measurements point to increase in sound pressure levels during icing events



(a) NACA0012 airfoil with rime ice model on the leading edge

(b) Ice model with maximum thickness of 2.29mm (c) Ice model with maximum thickness of 4.54mm

Fig. 3. Schematic map of rime ice model and NACA0012 airfoil with rime ice model on the leading edge.

(Xiao and Tong, 2021)

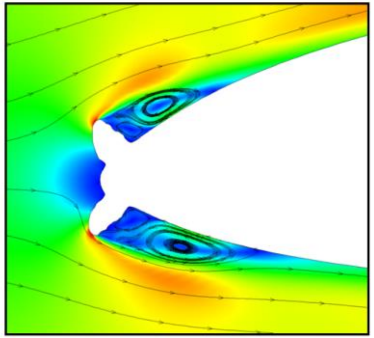


Figure 3: Flow separation on the leading-edge due to icing.

(Hann et al., 2013)

Blade noise

- Noise levels increase with ice thickness
  - Wind speed
  - Angle of attack
- Icing at the outer part of the blade has higher impact
  - Higher speed
- Up to 10 dB increase in noise levels in the iced case

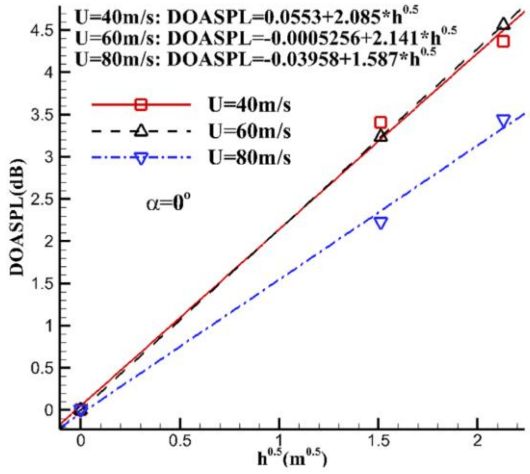


Fig. 8. Averaged *OASPL* difference between airfoil with ice model and baseline airfoil for different ice thickness (U = 40 ~ 80 m/s, α = 0°).

(Xiao and Tong, 2021)

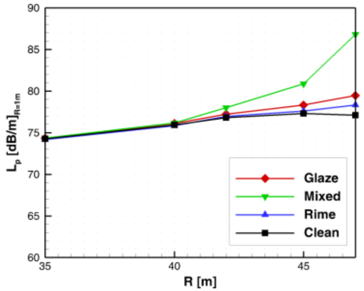


Figure 10: TE noise (RNOISE) for the blade tip.

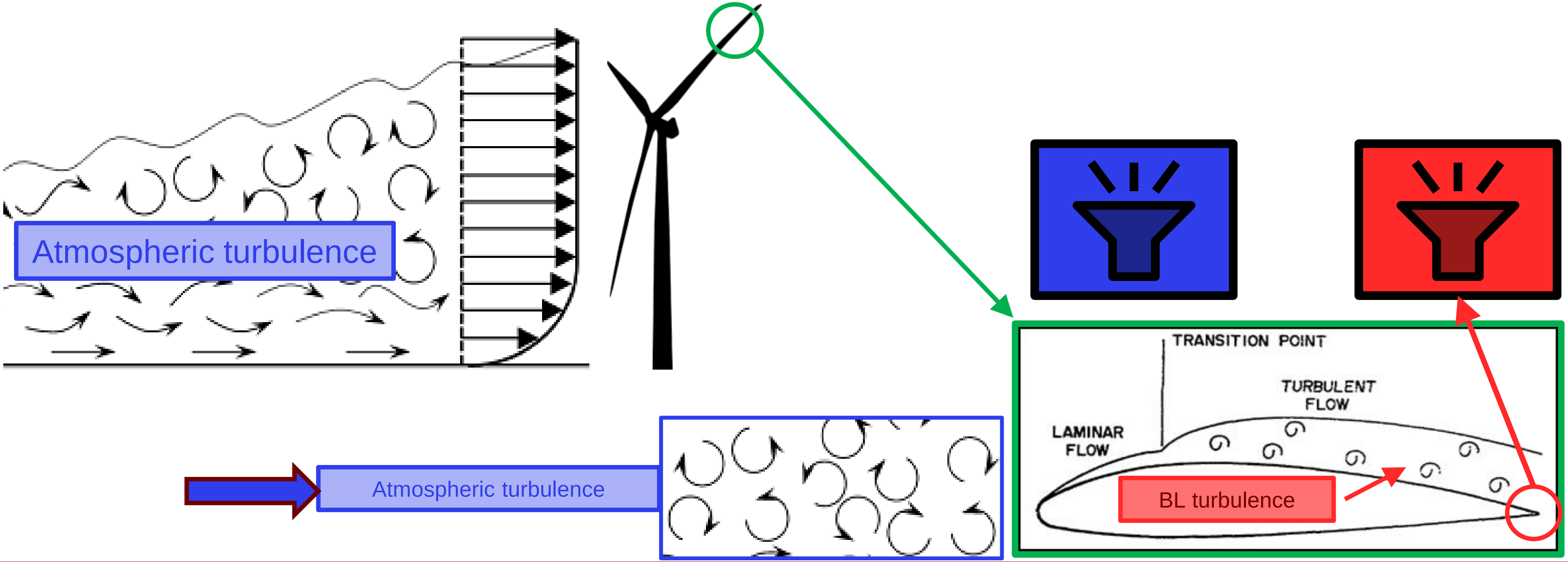
(Hann et al., 2013)

A simplified model for influence of blade icing on rotor trailing edge noise

Wind turbine aerodynamic noise mechanisms

<u>2 main mechanisms</u>:

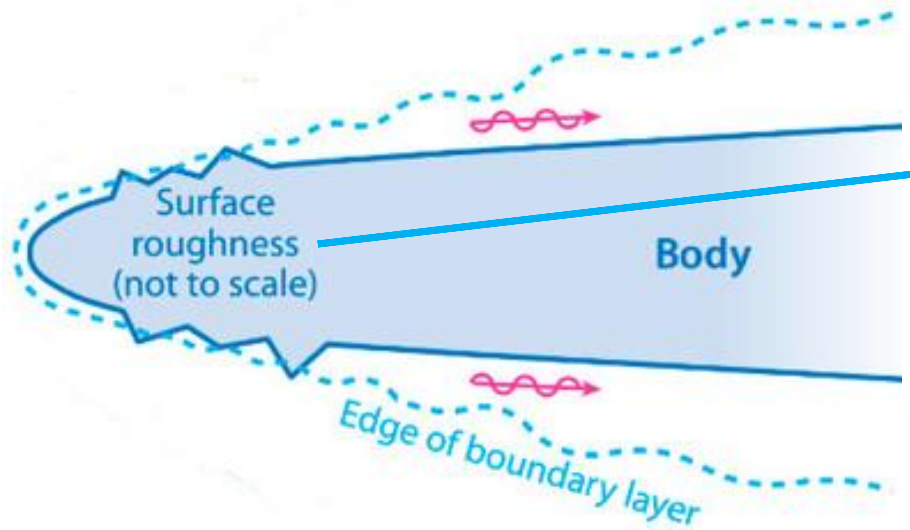
- **Turbulent Inflow (TI) noise** ➡ Interaction of blades with atmospheric turbulence
- **Trailing Edge (TE) noise** ➡ Scattering of boundary layer turbulence at TE

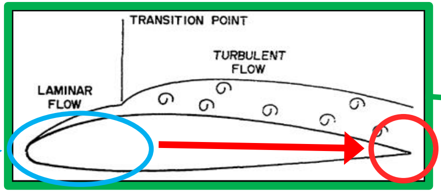


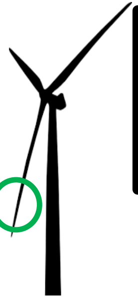
Icing modeled as roughness – Increase BL turbulence

TE noise mechanism is considered:

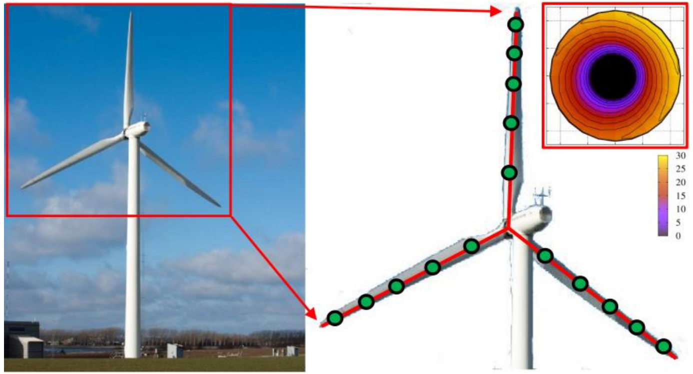
- **Trailing Edge (TE) noise** ➡ Scattering of boundary layer turbulence at TE







Numerical model for rotor noise



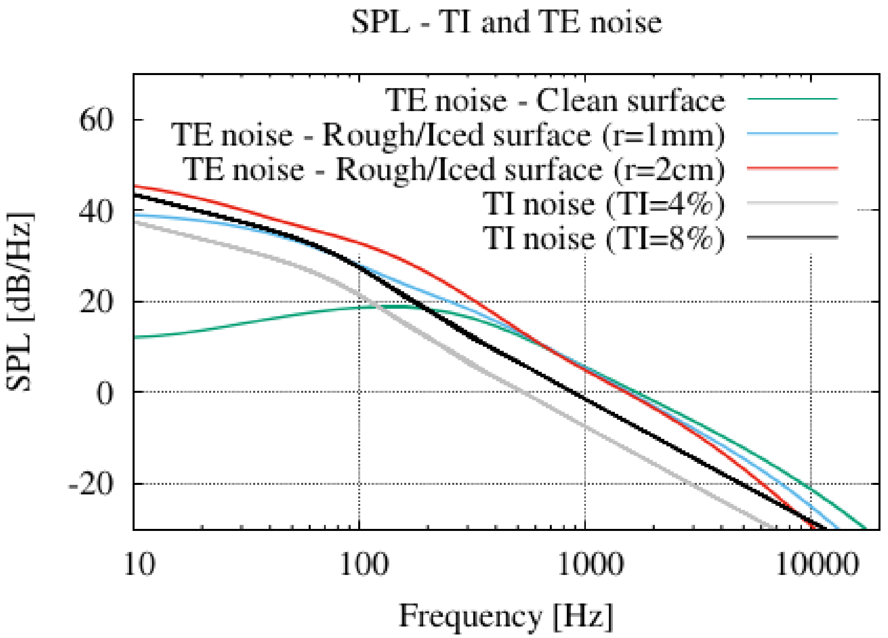
Here: Ice model by roughness r=1mm and r=20mm

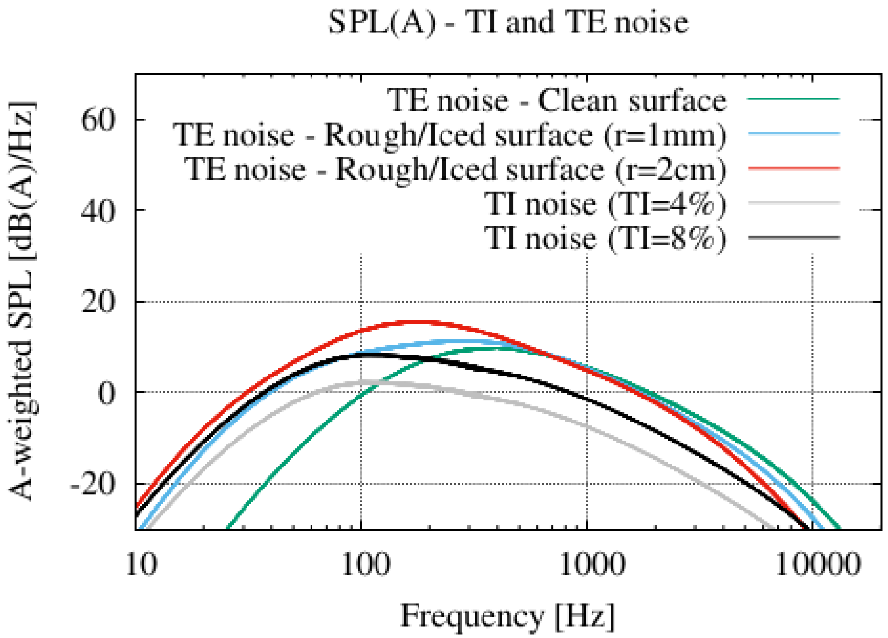
r=1mm ~ Very coarse sandpaper (P20)

Over 50% of airfoil chord

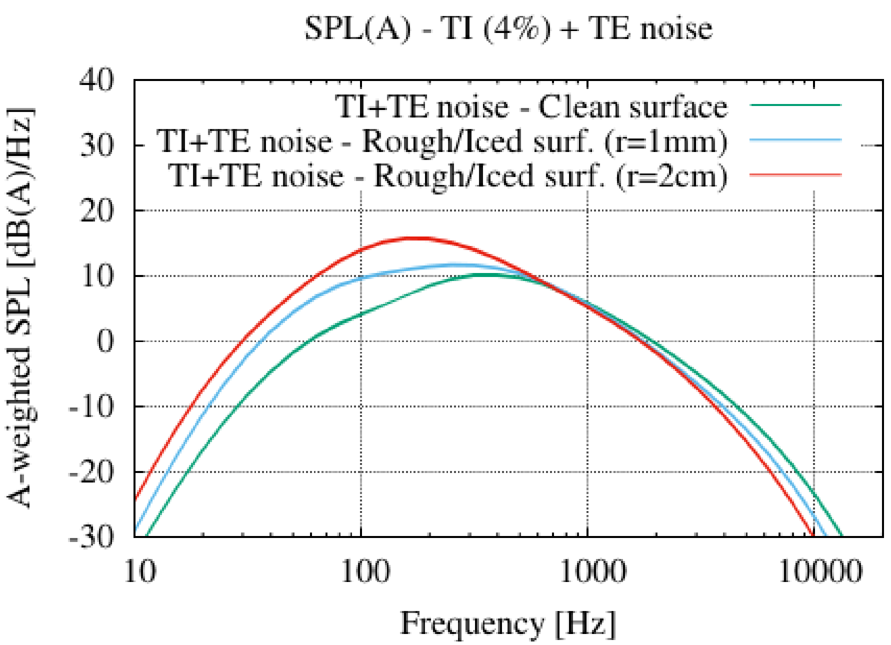
A modern 2.5MW-sized wind turbine

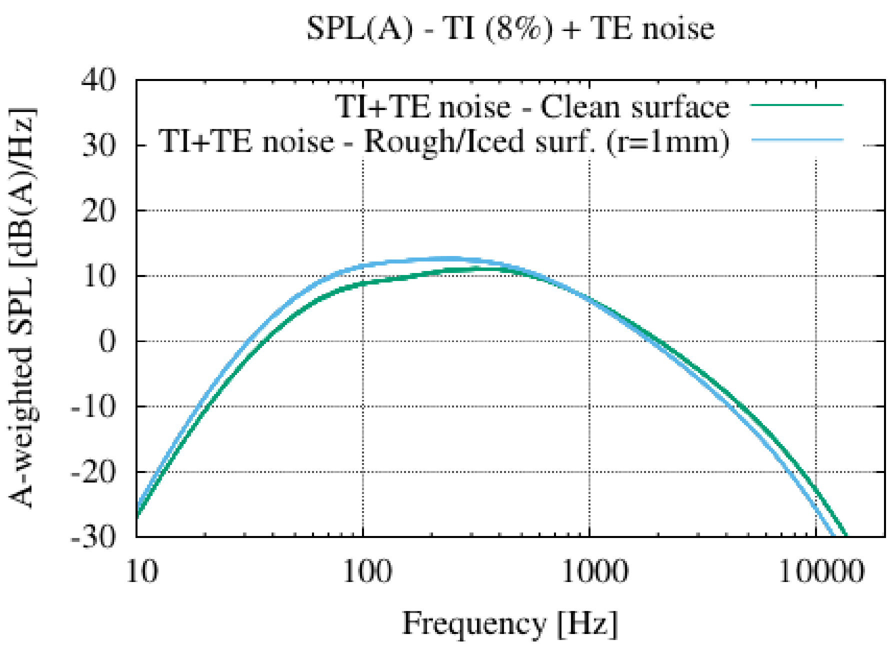
TI and TE noise spectra – Clean / Iced – TI 4% / 8%



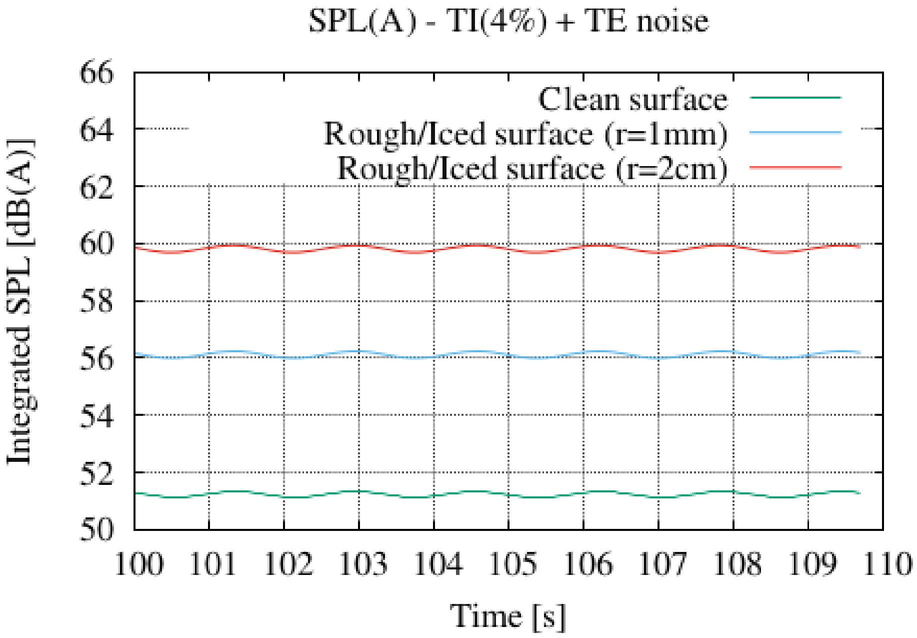


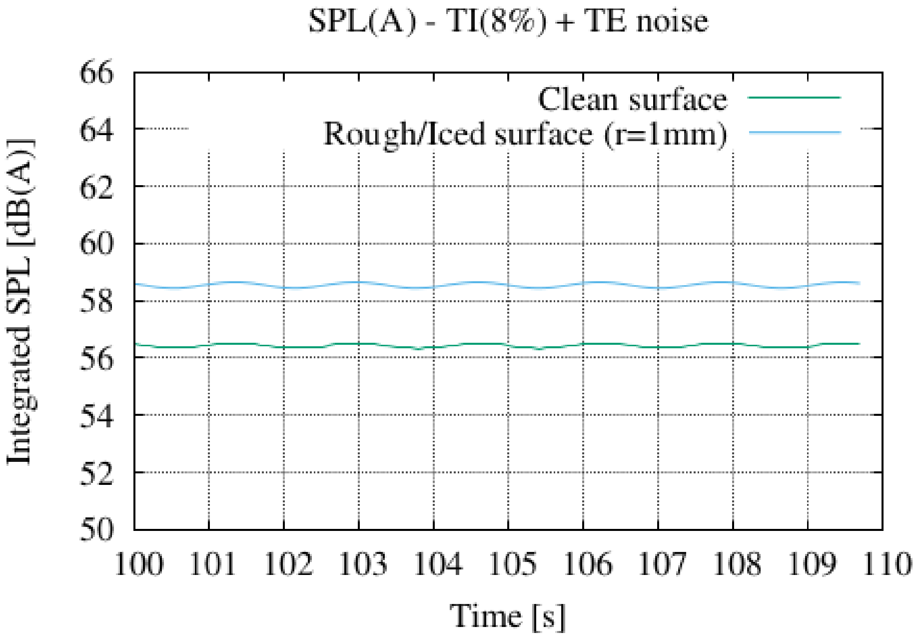
TI + TE SPL(A) noise spectra – Clean / Iced – TI 4% / 8%





TI + TE SPL(A) time-series – Clean / Iced – TI 4% / 8%





Conclusions on present modeling approach

- Crude approximation of icing effects through surface roughness (relatively *light icing: r=1mm and 2cm*)

- Only trailing edge induced noise is considered as noise source mechanism

- These VERY preliminary results show that for low atmospheric turbulence conditions (e.g. at night), noise emission differences should be noticeable

- More severe conditions need to be investigated – As well as other possible noise generation mechanisms...

Conclusions

- Ice on blades has noticeable effect
  - Noise created on the trailing edge
  - Noise levels correlate with
    - Ice thickness
    - Tip speed
- Sound propagation different in winter
  - Snow
  - Atmospheric conditions
- Evidence points to increase in noise levels in icing conditions
- Questions remain
  - Magnitude?
  - Sensitivity to icing?
- Impacts
  - Siting
  - Acceptance
- Applications
  - Ice detection
  - Active curtailment

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