KJELLER
VINDTEKNIKK

Sensitivity of icing losses

Terrain versus elevation – a case study

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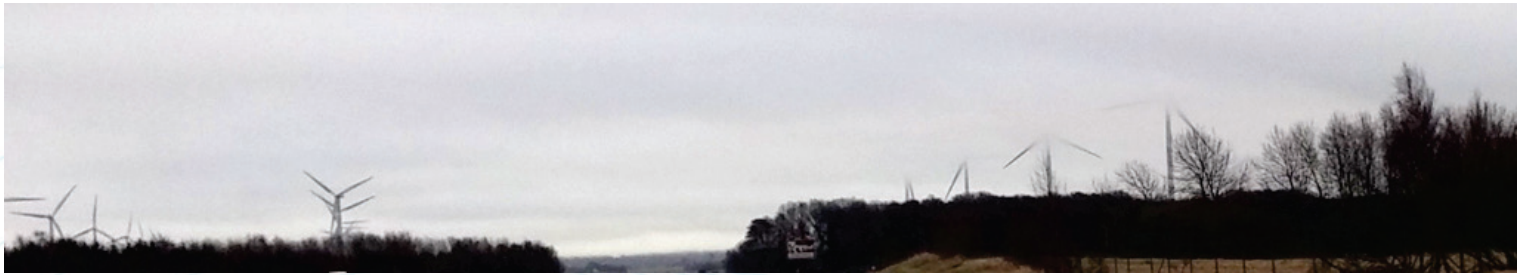
Atmospheric Icing

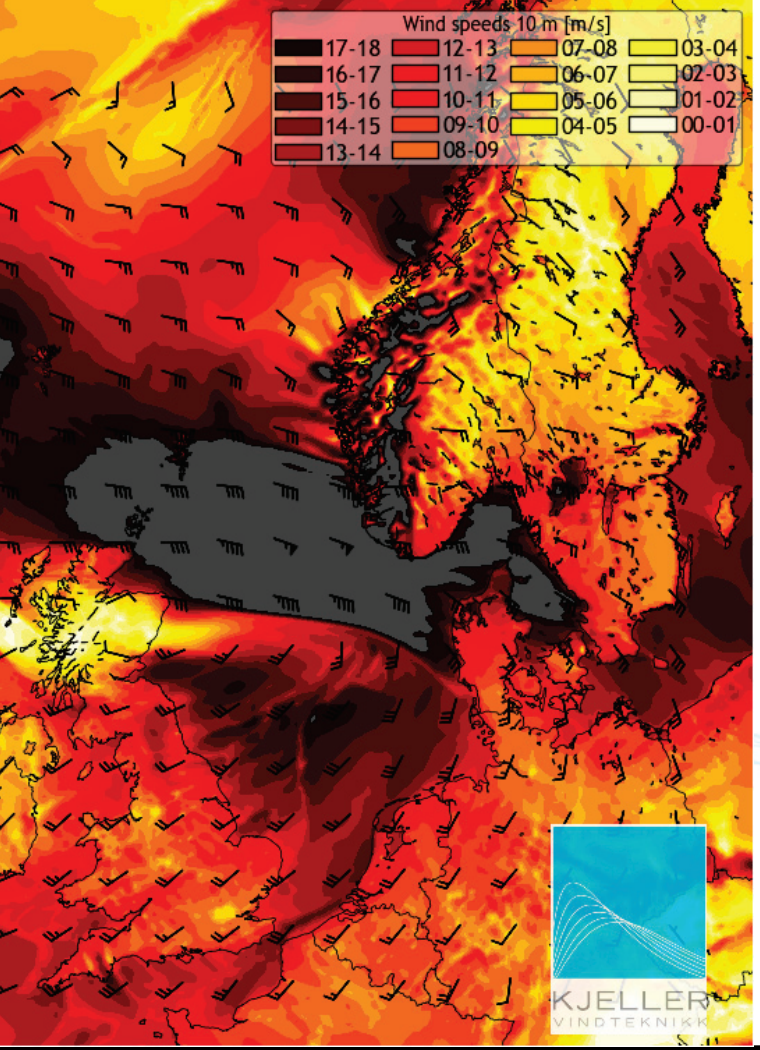
- Temperature
- Water droplets
- Object to freeze on



Atmospheric Icing

- Temperature
- Water droplets
- Object to freeze on

- In-cloud icing
  - ~100 million cloud droplets per m^3
  - Droplet size ~20 µm



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Approach by Kjeller Vindteknikk

- Explain meteorological processes of icing
- Mesoscale model simulations
- Dynamic modeling
  - Wind, Temperature, Solar radiation, Moisture, Clouds, Precipitation etc.
- Icing exposure and sheltering
- Calculations in the time domain

Case study – Background

- Two wind farms, WF1 & WF2
- 60 km apart
- 26 m elevation difference
- HH WF1: 95 m, WF2: 125 m
- HH (a.s.l) WF1 ≈ HH (a.s.l) WF2
- Modelled long-term icing losses
  - WF1: 6.3 %
  - WF2: 3.5 %

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  - WF2: 3.5 %

What is causing this large difference in the modelled losses?

Case study – Comparison of modelled results

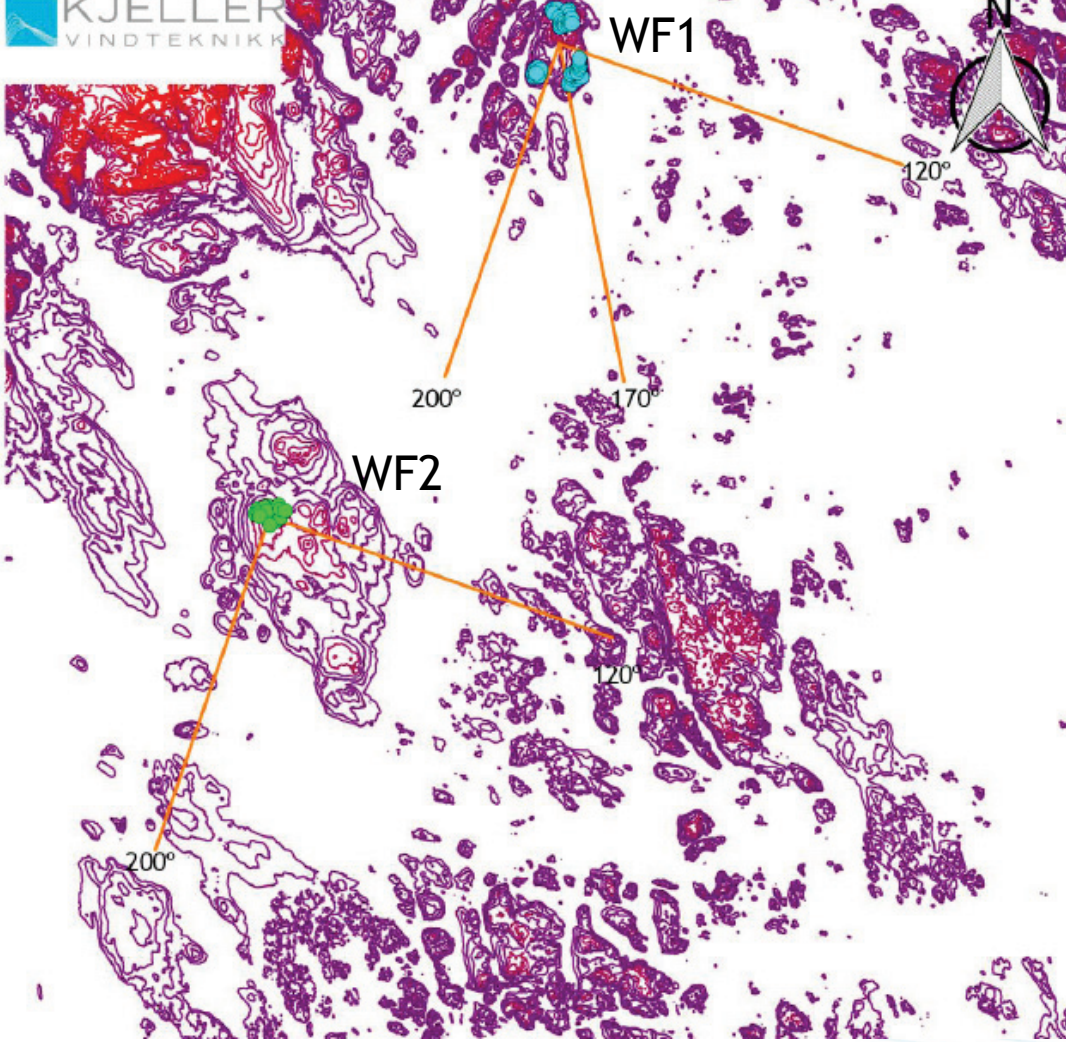
- Icing occurs simultaneously at WF1 & WF2
- Icing mainly occurs between 120 and 200 degrees

Could there be something in the surroundings that explains the difference?

Case study - Comparison

- Elevation
  > 350 m a.s.l.

- Main ”ice sectors”
  indicated by yellow lines



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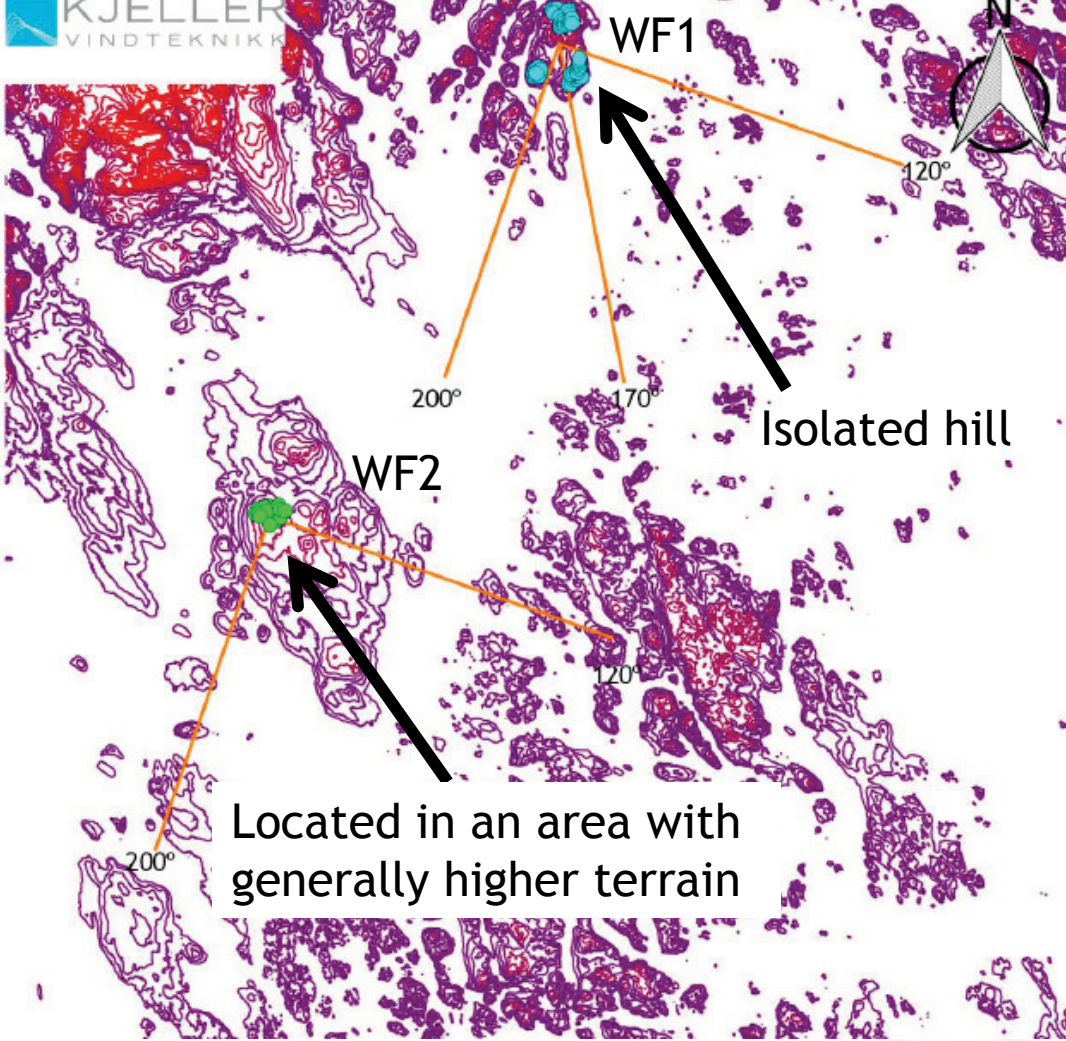

Case study - Comparison

- Elevation
  > 350 m a.s.l.

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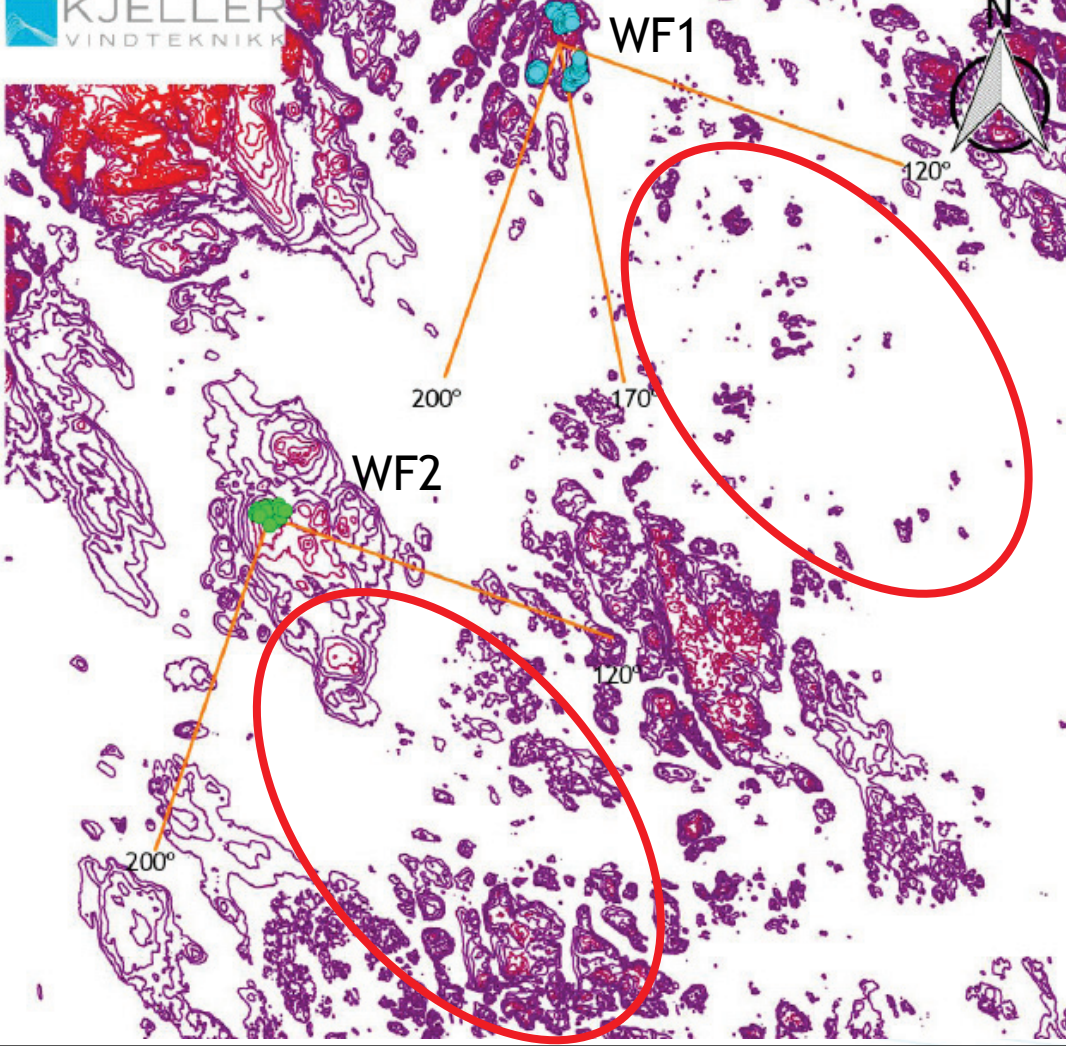
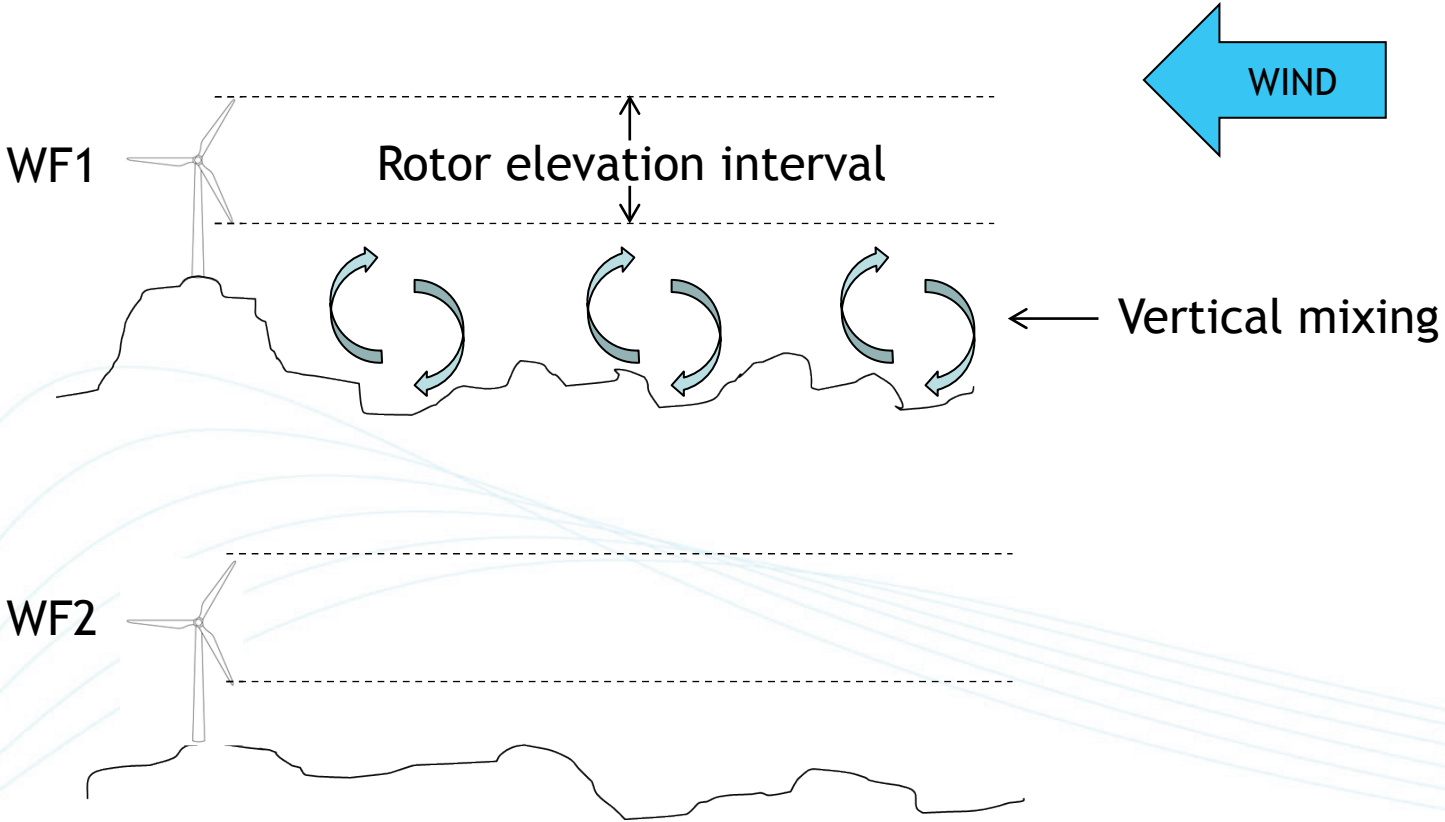
More higher elevated terrain
upstream of WF2



Case study - Comparison

A terrain related explanation for the differences



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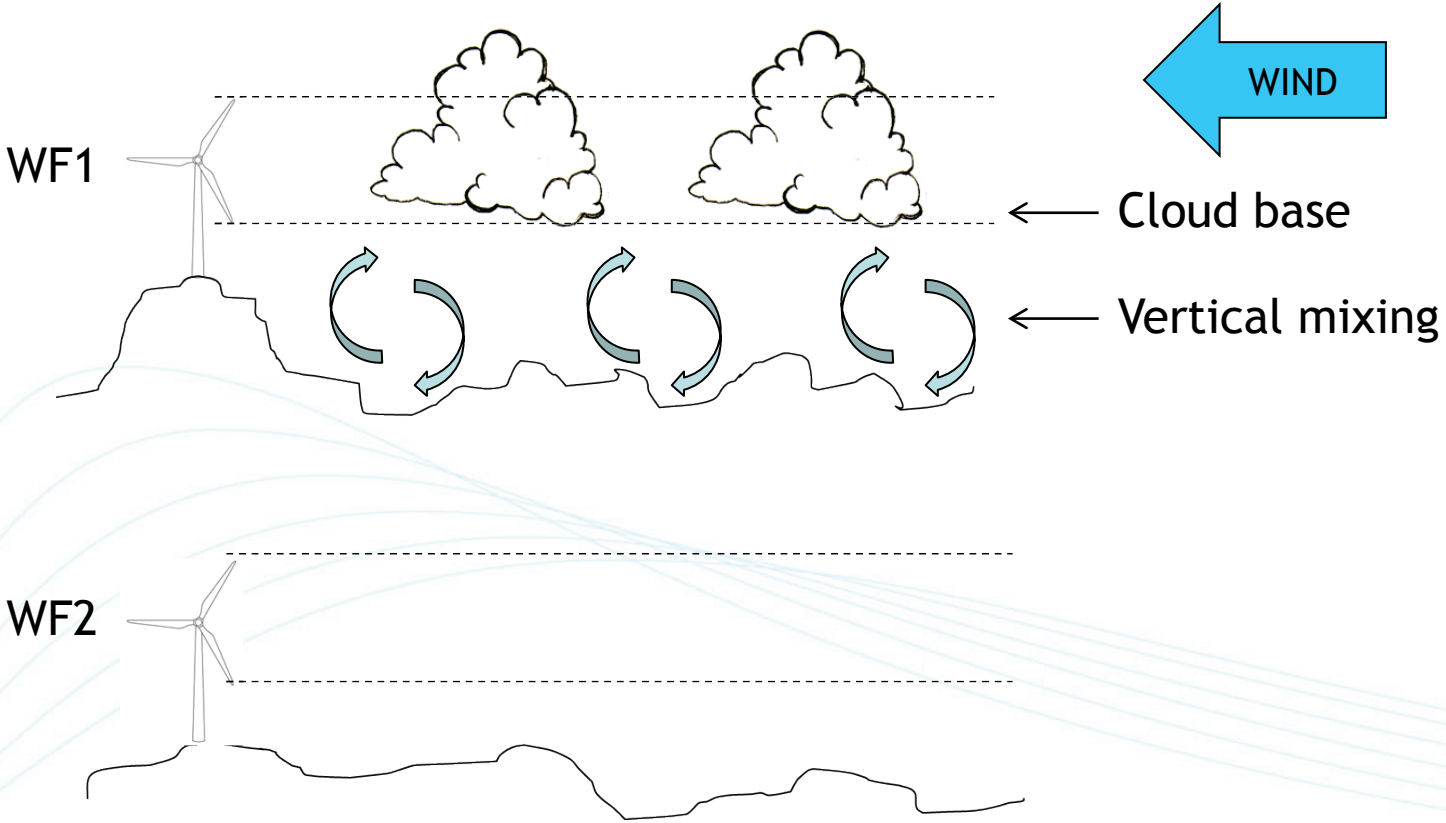

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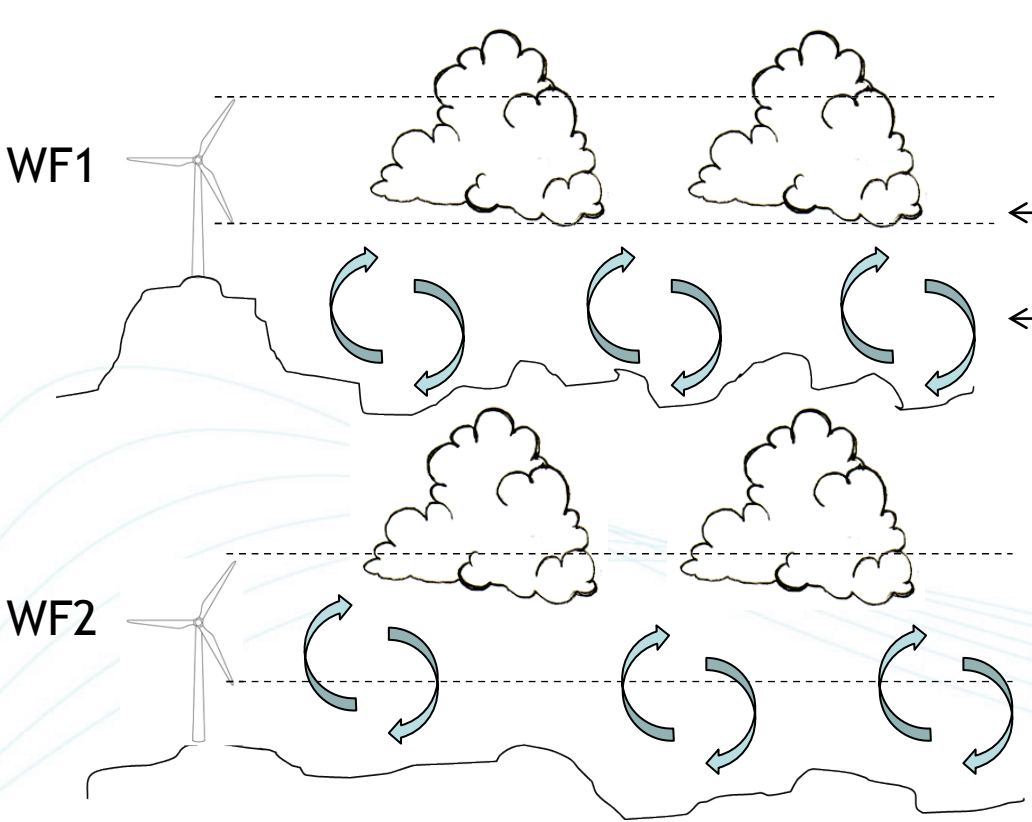

- Upstream terrain similar
- Mixing affects rotor elevation interval more
- Less cloud formations in rotor interval

Case study - Comparison

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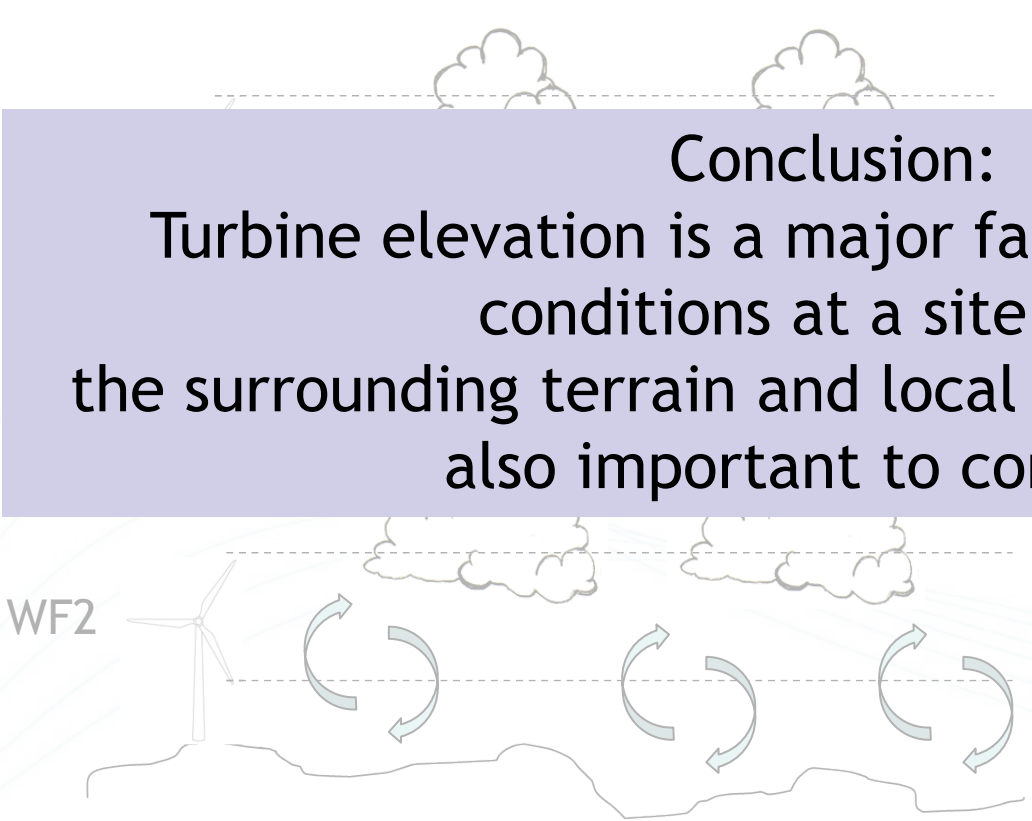
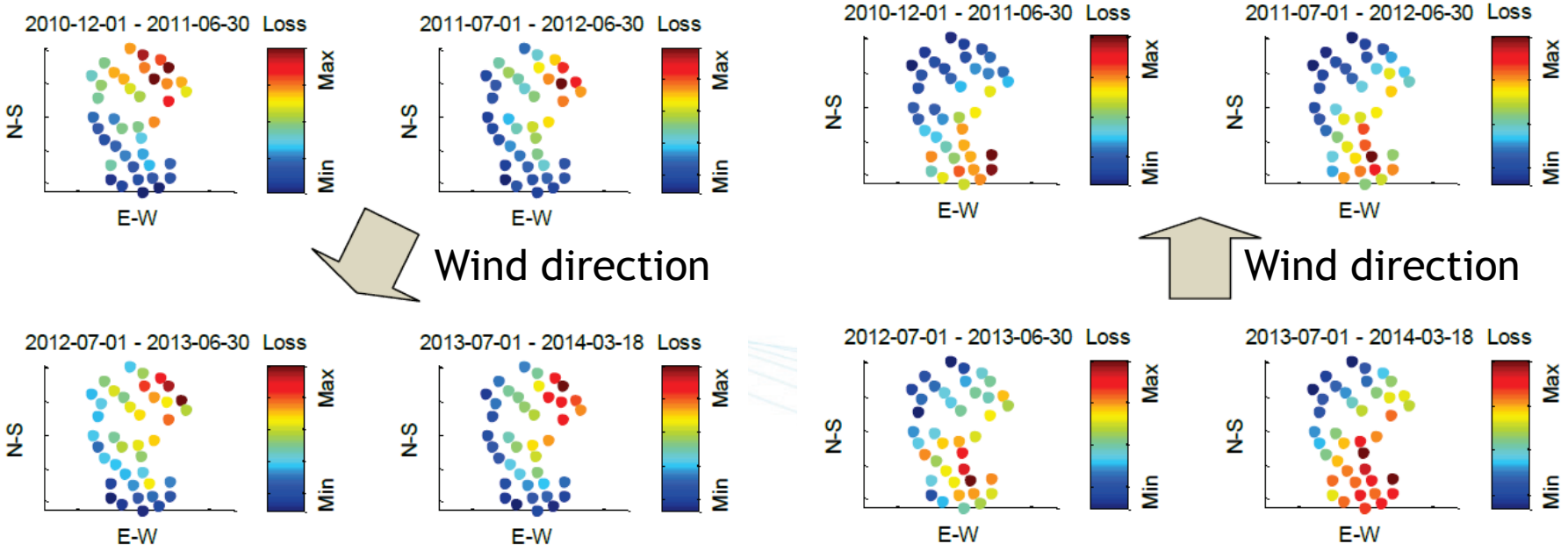


Conclusion:
Turbine elevation is a major factor for the icing conditions at a site, but,
the surrounding terrain and local weather patterns is also important to consider!

- Upstream terrain similar
- Mixing affects rotor elevation interval more
- Less cloud formations in rotor interval

Distribution of icing losses in a wind farm

- Observed losses in an operational wind farm



Icing conditions within a wind farm

- Vertical mixing induced by the rotor
  - “Drier” clouds downstream of a turbine
- Ice accretion on the rotor
  - Fewer droplets downstream of a turbine
- Passage of air across the rotor
  - Pressure drop->ice particles
    ->fewer supercooled droplets
  - Bergeron-Findeisen effect
- Wind wake related effects
  - Reduced wind speed -> icing less effective
  - Collisions of ice particles and supercooled

Thank you for your attention!

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