Upward Lightning Exposure Assessment for Wind Power Plants in Low Altitude Thunderstorms using Comsol Mulitphysics

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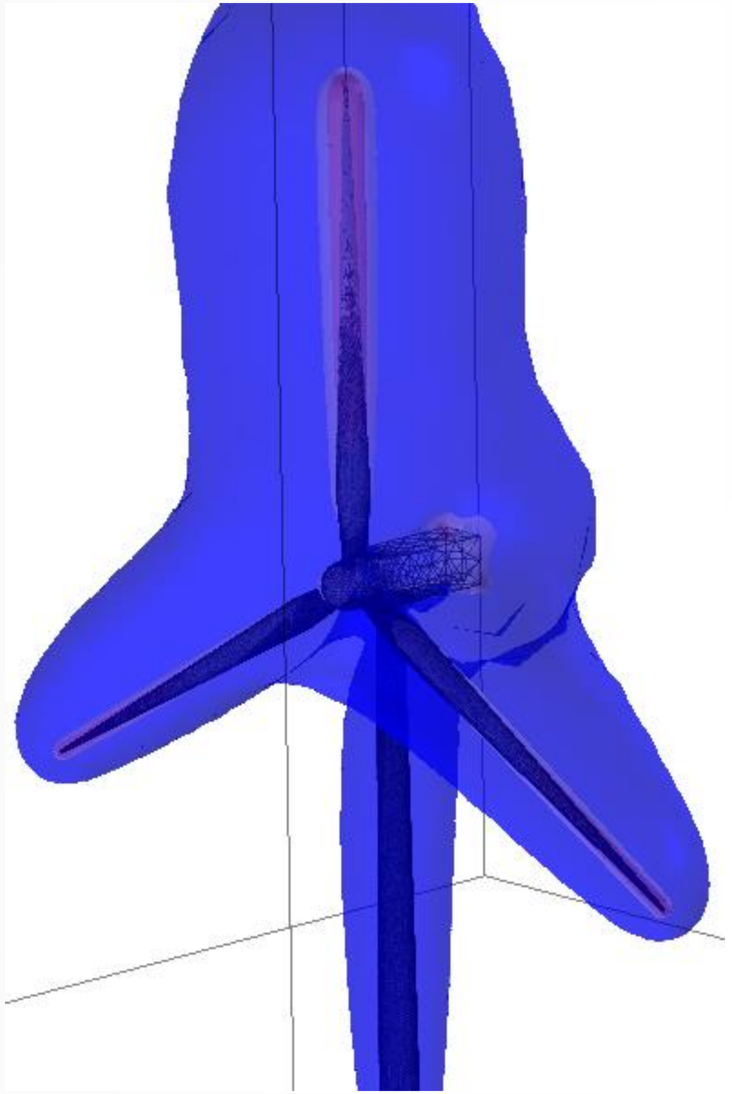
Introduction

→ Low altitude thunderstorms and upward lightning

- Upward lightning special type of lightning:
  - Low peak current I_p
  - Long flash duration T
  - High charge Q
- Upward lightning leader initiated at ground and propagating towards the cloud
  - Point of highest electric field defines the attachment point
- Low altitude thunderclouds can trigger frequent upward lightning discharges on wind turbines at certain locations in the world

Isosurfaces electric field

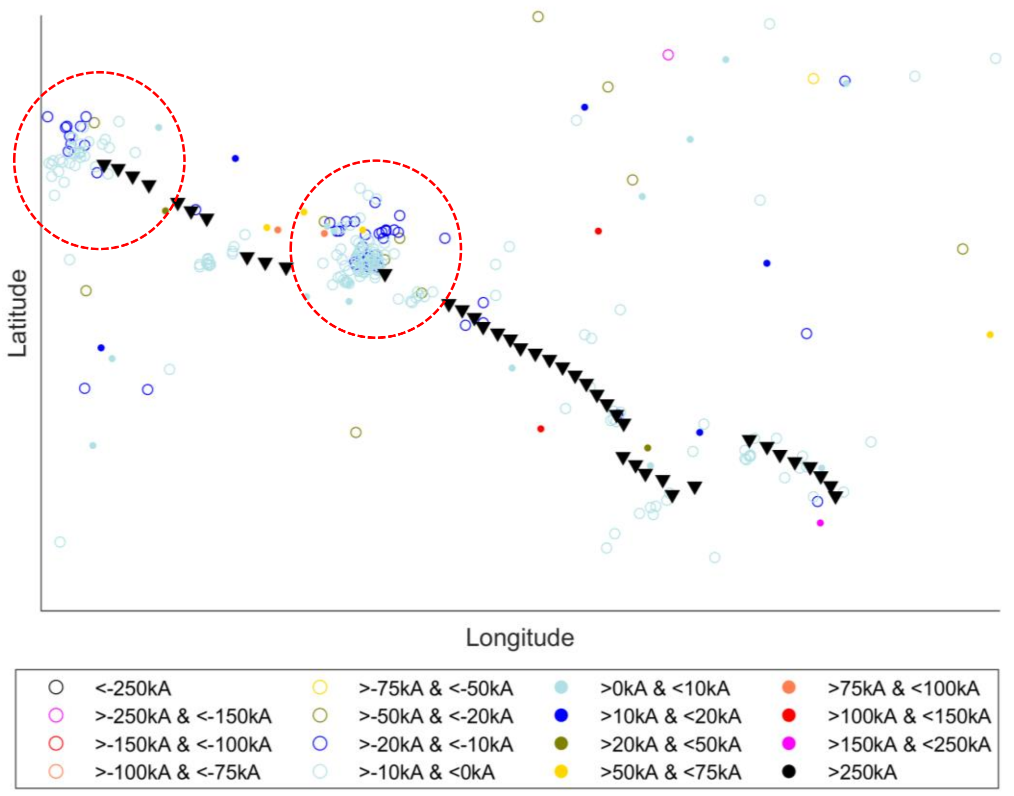


Challenge

→ Lightning distribution within wind farm is unevenly distributed

- Certain wind turbines are more affected by lightning exposure than others
- Influencing factors
  1. Elevation profile of a wind power plant
  2. Wind direction (700hPa)
  3. Height of charge in cloud
  4. Magnitude (concentration) of charge in cloud

Lightning detection plot



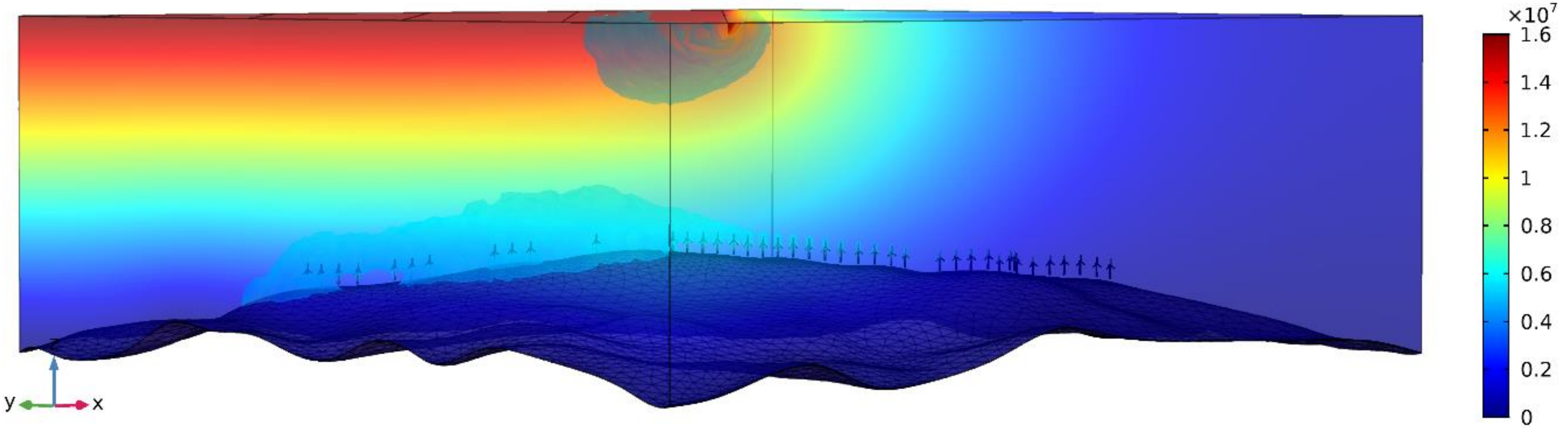
Can we predict which wind turbines are predominantly struck by lightning flashes?

Model properties

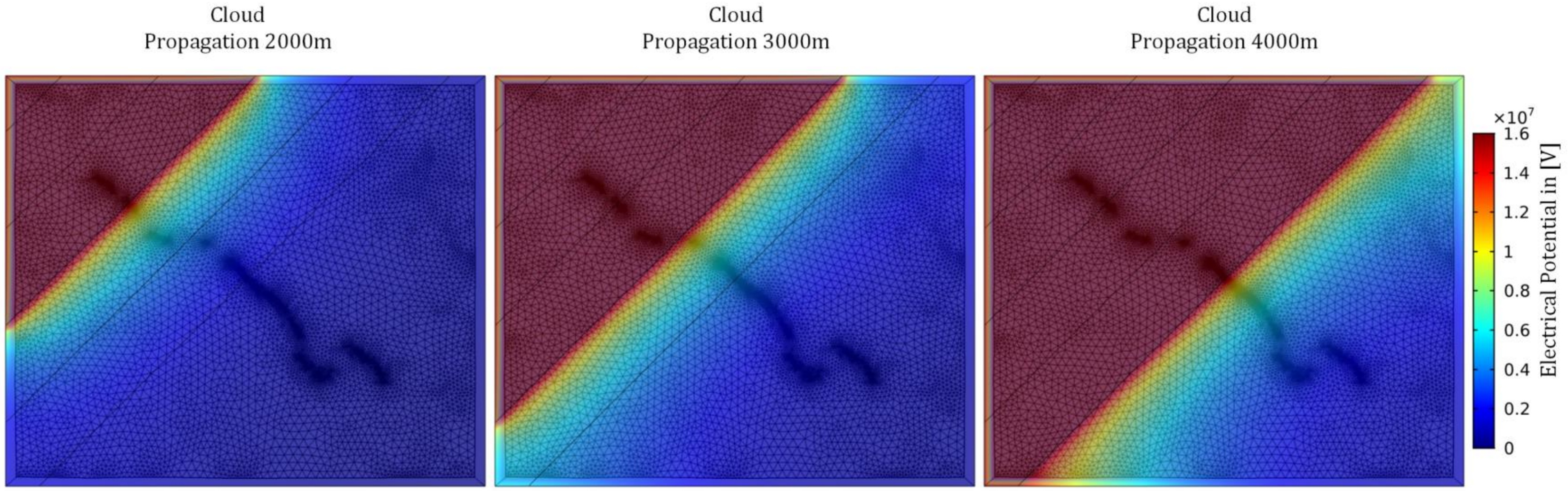
- 3D electrostatic Comsol model with Matlab Livelink to control the simulation
- Input parameters:
  - Elevation profile of the site
  - Wind turbine model with representative height and location of turbines
  - Meteorological data during previous thunderstorm episodes (10 low altitude thunderstorms)
    1. Height of -10° isotherm (To quantify the height of the charge in the cloud)
    2. Wind direction (To quantify where the thundercloud is approach from)
- Potential plane is approaching the wind farm from the wind direction and with the corresponding height of the main charge layer

Voltage and electric field plot

Voltage plot with electric field isosurface (blue cloud).



Potential plane ”propagates ”over wind power plant and exposes the turbines to a changing electric field



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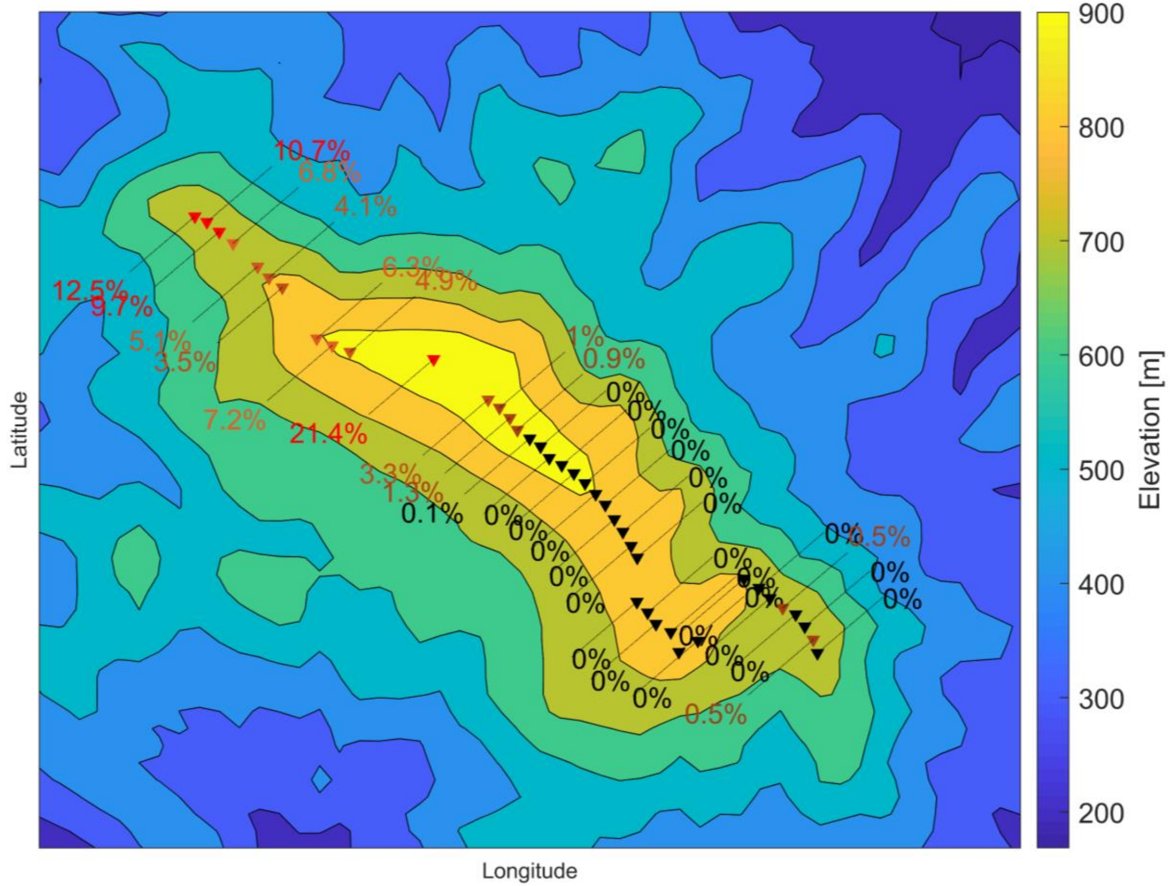
Methodology

- Upward lightning leader propagation model by Becerra et al. is used to determine whether there is sufficient potential at the tip of the wind turbine to generate upward lightning (based on potential distribution between turbine and cloud).
- Propagation of the thundercloud (potential plane) over the wind power plant with
  - U_min = Potential where one upward lightning leader is developed when the cloud is fully above the wind power plant
  - U_2 = U_min*133%
  - U_3 = U_min*166%
- Simulation terminates when:
  - Potential plane has fully propagated above the wind power plant
  - 20% of wind turbines have developed upward lightning leaders
- Charge of each leader is stored and probability of attachment is calculated according to magnitude of charge level

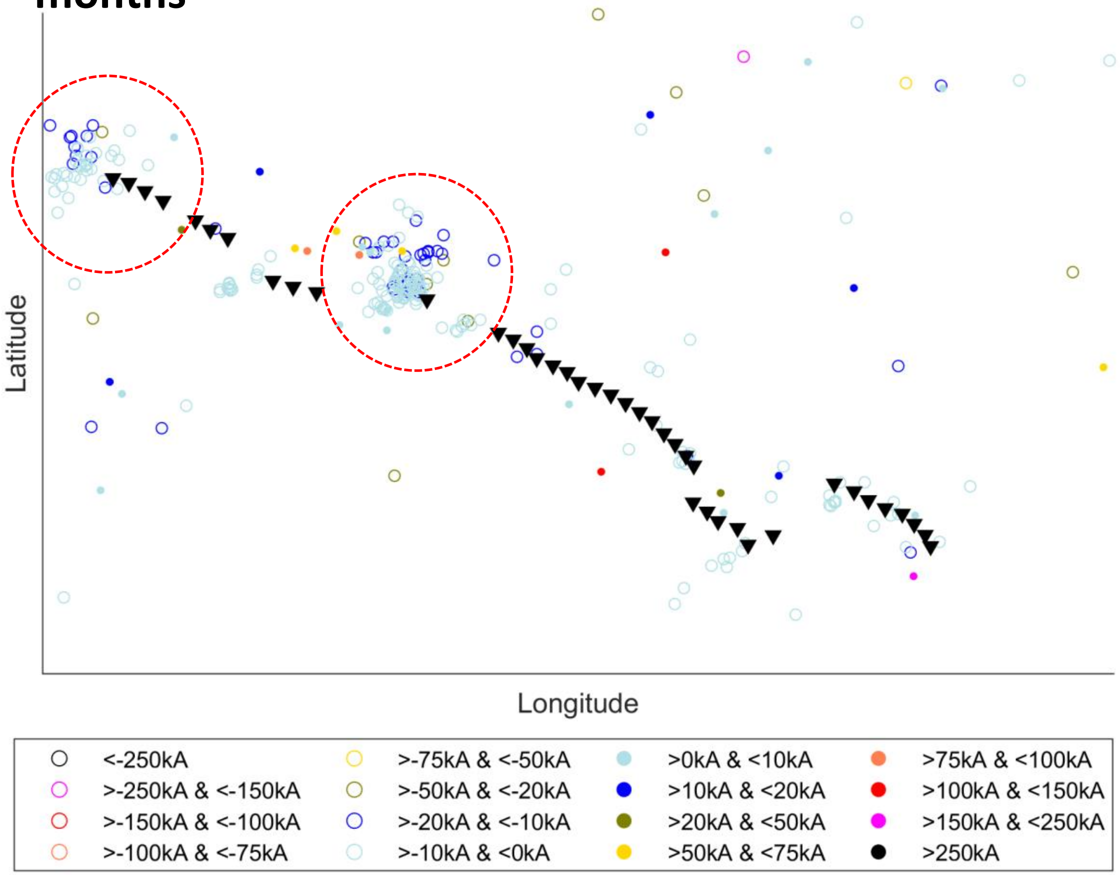
Result

→ Comparison simulation vs. measured lightning activity

Simulation



Lightning detection in winter months



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Conclusion

- Simulation can identify wind turbines that are most affected by upward lightning flashes during low altitude thunderstorms
- Wind turbine operator can use this information to:
  - Improve lightning protection for affected turbines
  - Pre-order necessary spare parts
  - Install lightning measurement devices in affected turbines
  - Schedule extraordinary maintenance for these wind turbines