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Rethinking Lightning Risk at Tall Structures

Why meteorology and the season matter more than height

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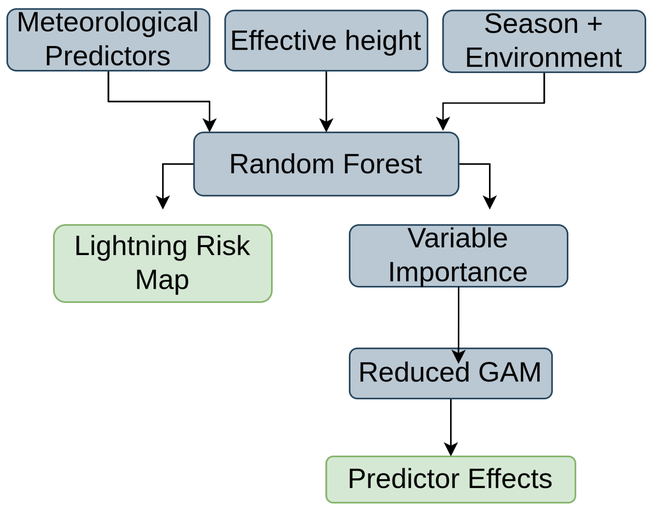
Why should we care?

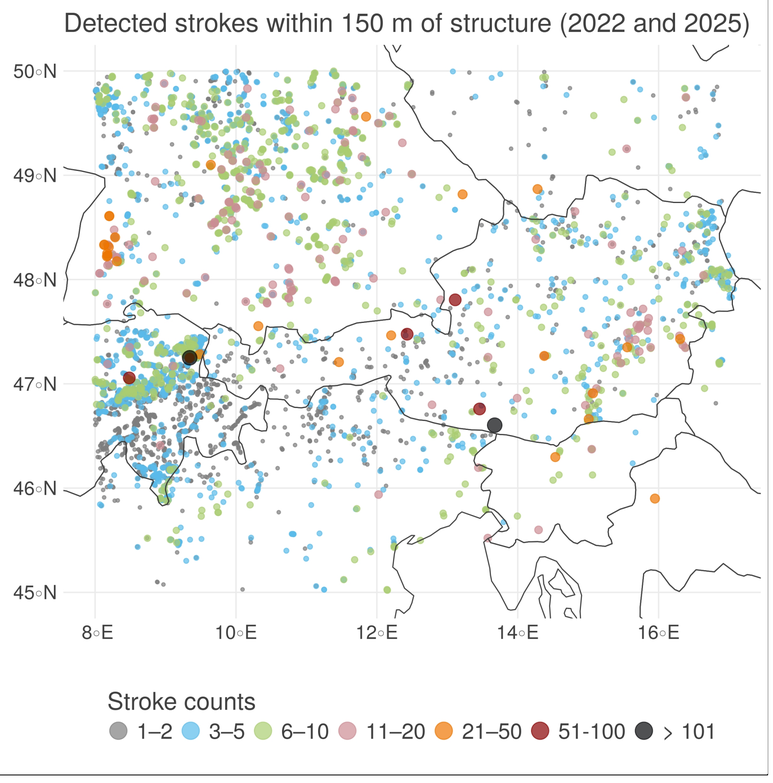
- Tall structures face rising **lightning risk**, especially from **upward lightning**.
- Upward lightning can be more **destructive** and occurs **year-round**.
- The influence of the **environment and meteorology** is **not adequately represented** in lightning protection standards.

From strokes to statistics

- **Tall structures:** >8,300 structures ≥100 m effective height (masts, towers, wind turbines etc.) from aviation authority records. At effective heights of ~100 m, upward lightning becomes physically plausible.
- **Lightning:** >20,000 strokes detected by the ALDIS lightning location system (2022 – 2025) within 150 m of each tall structure.
- **Meteorology:** ERA5 (hourly, 1 km² interpolation).
- **Model:** Random Forest, binary classification.
  → **Response:** lightning stroke at structure (0 or 1).
  → **Predictors:** ERA5 + spatio-temporal covariates.
  → **Output:** cross-validated conditional probability.
- **Interpretation:** Generalized Additive Models (GAMs) to isolate individual predictor effects.



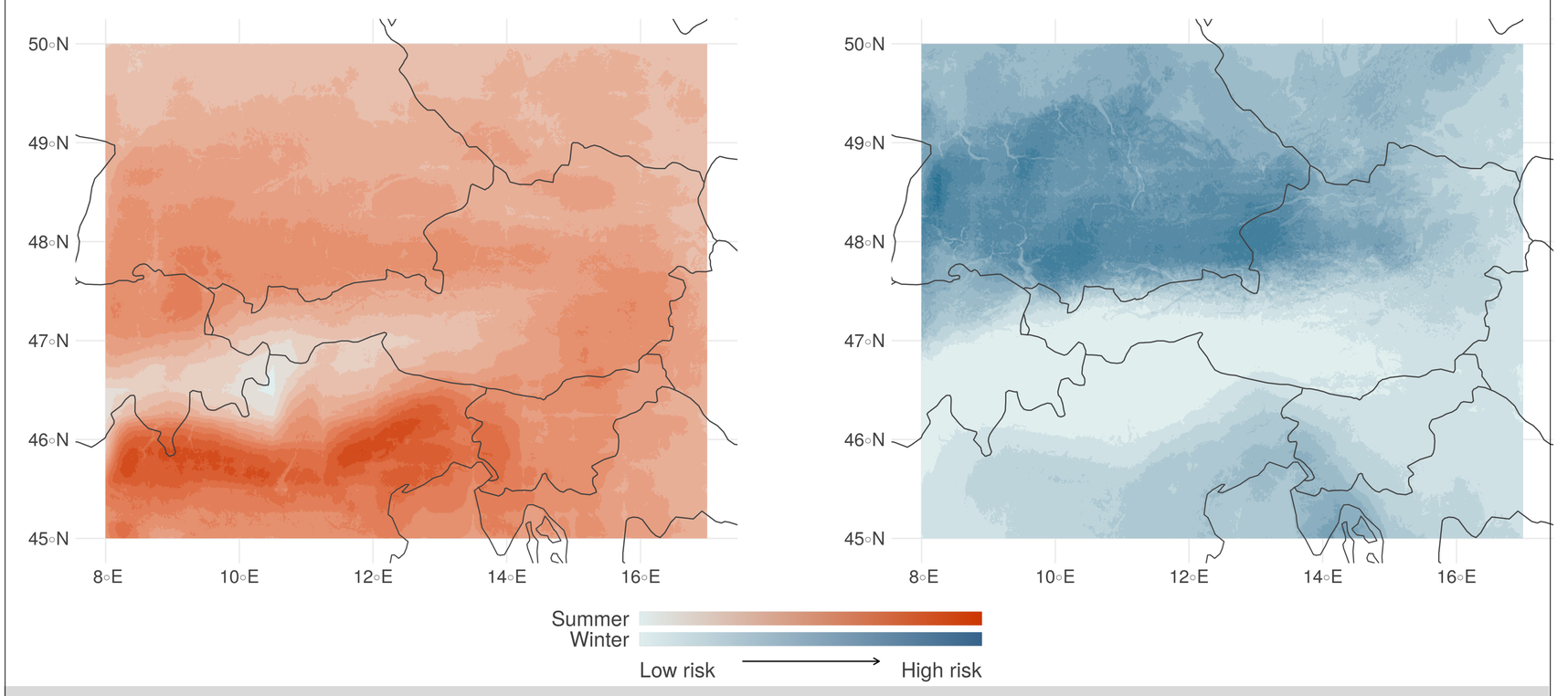
The study area of interest



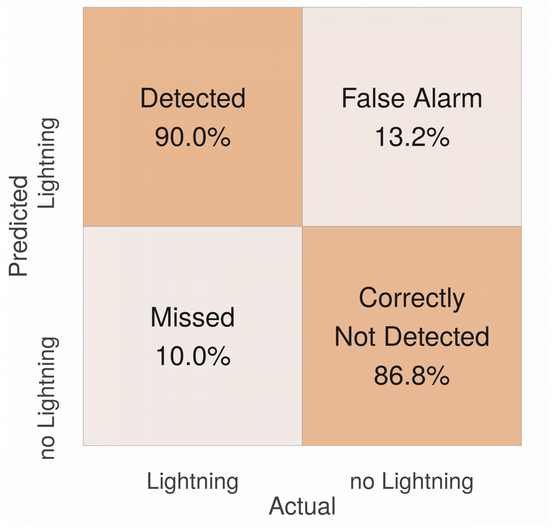
Objectives

- Map lightning risk at tall structures across the Eastern Alps to strengthen wind energy resilience.
- Understand the influence of meteorological and environmental variables, including effective height.

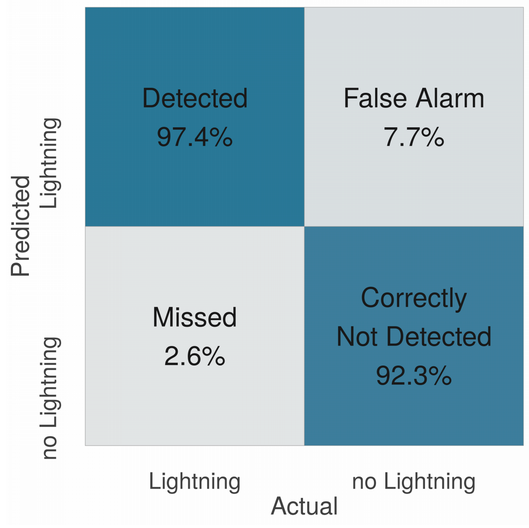
Summer versus winter lightning risk



Can we predict lightning before it strikes a structure?



Performance improvement in winter likely reflects winter storms' stronger link to large-scale meteorology.



What influences the risk, and how?

Wind & cloud physics

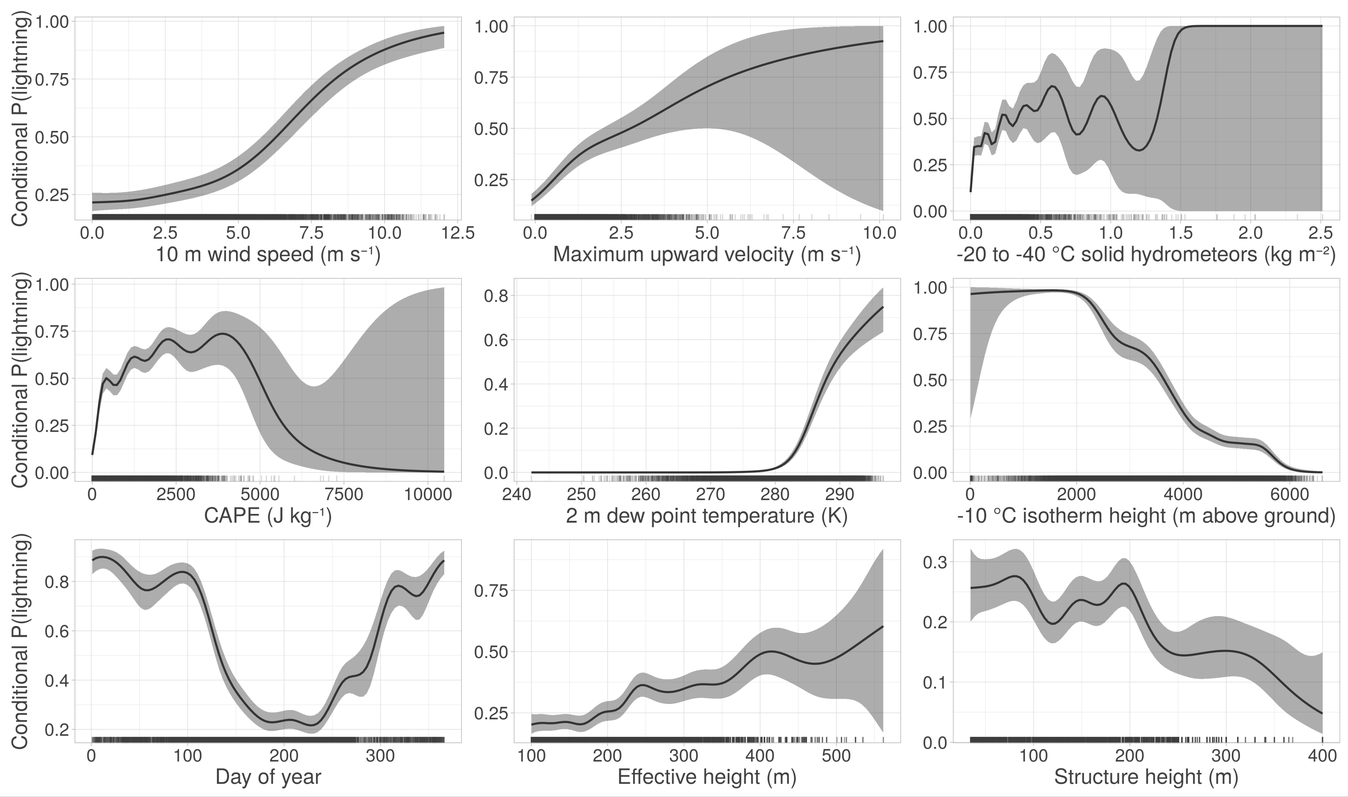
Probability **increases** with:
↑ wind
↑ solid hydrometeors

Thermodynamics

Probability **increases** with:
↑ CAPE
↑ dewpoint temperature
↓ −10 °C isotherm height

Season & height

Probability **increases** with:
Winter conditions
↑ effective height
↓ structure height



Takeaways

- **Winter lightning risk at tall structures** is notably **enhanced north of the Alps**, contrasting the region's overall lightning maximum, which lies to the south.
- **Large-scale meteorology dominates**: risk rises with ↑ wind, solid hydrometeors, CAPE and dewpoint temperature, but ↓ −10 °C isotherm height.
- **Effective height matters less** than meteorology and its **effect opposes** that of **physical structure height**.
- Random Forests capture nearly all lightning events at tall structures, with **higher predictive skill in winter** than summer.

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