Evaluation of meteorological models against in-situ measurements for estimating leading-edge erosion in wind turbine blades

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AIRE

01

MOTIVATION

MOTIVATION

- Heavy **precipitation** and strong **winds** can cause leading edge erosion (LEE)
- Leading edge erosion (LEE) → Impact on wind turbines operation and maintenance cost
- AIRE* project aims to develop and improve models and tools to reduce the impact of erosion on wind turbines
- Numerical weather prediction (NWP) models commonly used for resource assessment (wind)...and precipitation?
- **Objective: analyse the benefit of using outputs from NWP models as inputs in an erosion onset prediction model that allows us to have an estimate of blade lifetimes in wind farm sites**

* **A**dvanced study of the atmospheric flow **I**ntegrating **RE**al climate conditions

02

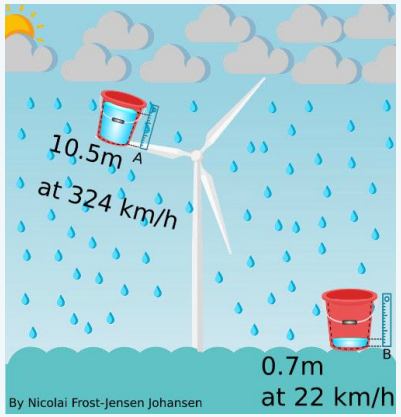
MODELS

MODELS

BLADE DAMAGE MODEL

Wind turbine model

Wsp data → Tip speed/impact speed

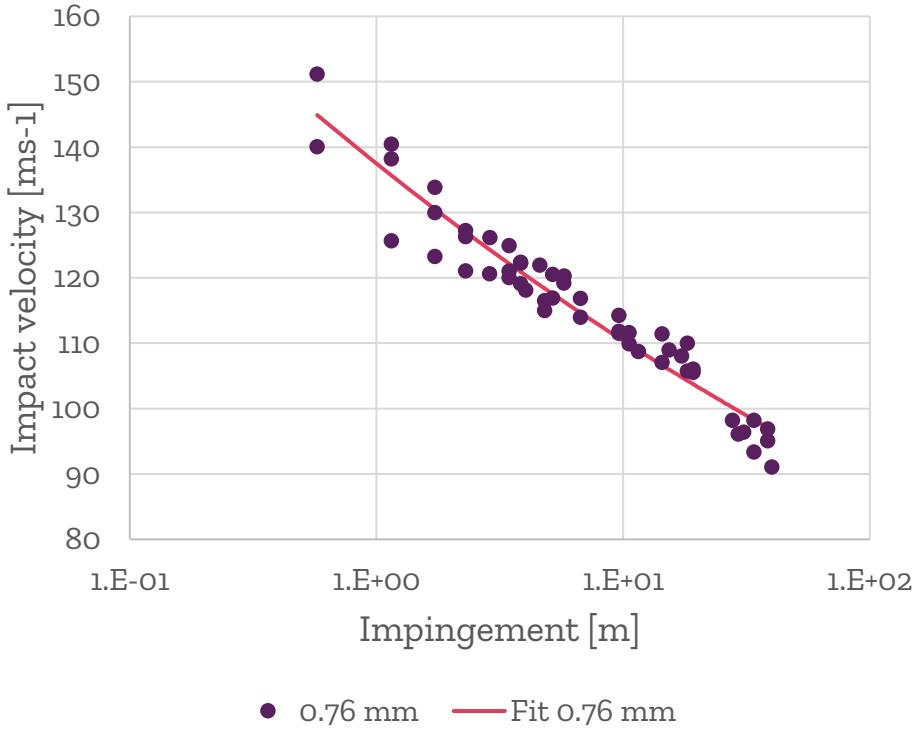


$$F = 1 - e^{\left(-\frac{d}{1.3 \cdot I^{0.232}}\right)^{2.25}}$$

Best droplet distribution

Rainfall data → Impinged rainfall

Surface fatigue: VH curve (Wöhler curve)
Rain erosion test data (Bech et al. 2022)

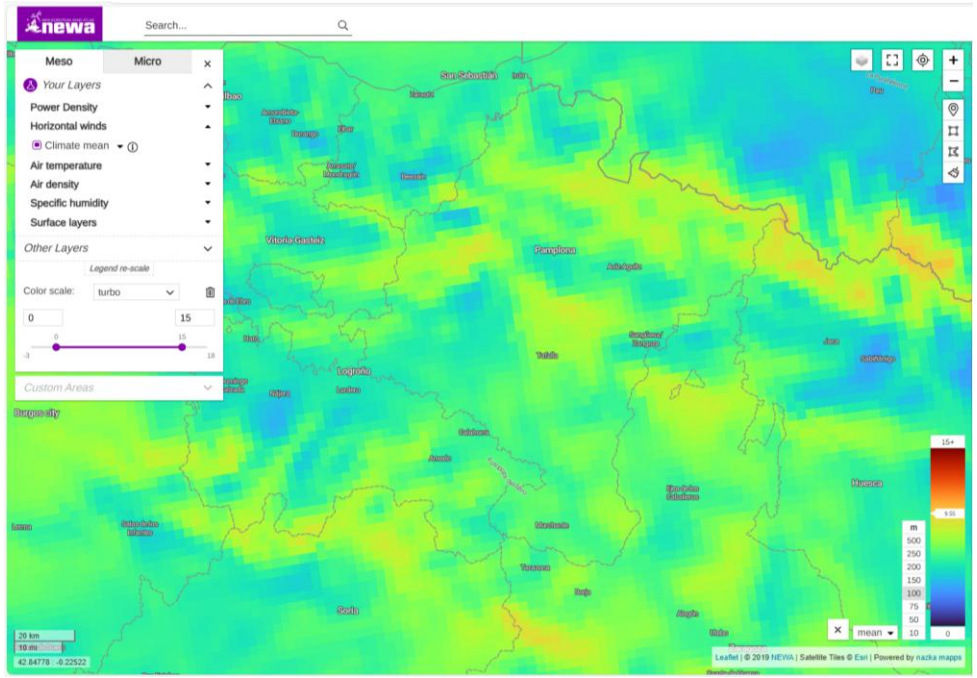


→ Damage increments

MODELS

METEOROLOGICAL MODELS EVALUATED

Model	Spatial resolution	Temporal resolution	Comments
MERRA2	0.5° x 0.625°	Hourly	Values from M2T1NXFLX/M2T 1NXSLV
ERA5	0.25° x 0.25°	Hourly	data on single level
WRF_NEWA	3 km	30 min	
WRF_AIRE	2 km	10 min	Optimized for Cabauw (NL)



Source: [New European Wind Atlas](https://map.neweuropeanwindatlas.eu)
https://map.neweuropeanwindatlas.eu

03

CASE STUDY

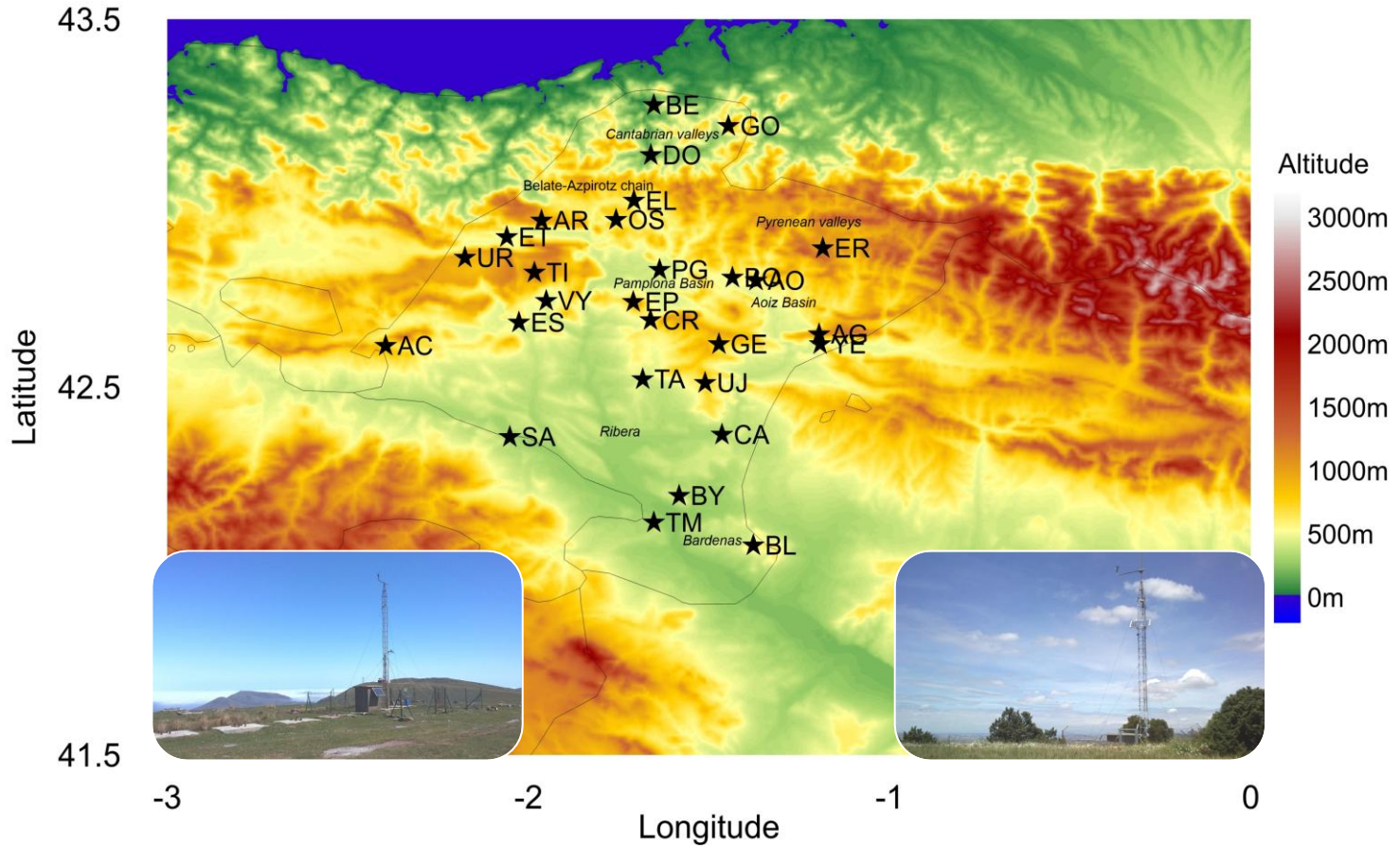
CASE STUDY: NAVARRE (SPAIN)

- Navarre's climate is highly diverse
- Simple to complex terrain (elevation heights range from 125 m to 1353 m)
- Wind and rain (gauge) data from:

  - 28 meteorological stations at 10 m height (Meteo Navarra - Gobierno de Navarra)

  - 1 wind farm mast at 118 m height (CENER experimental wind farm in Alaiz)

- 11 months of 10-minute data



04

RESULTS

RESULTS

MERRA 2 :

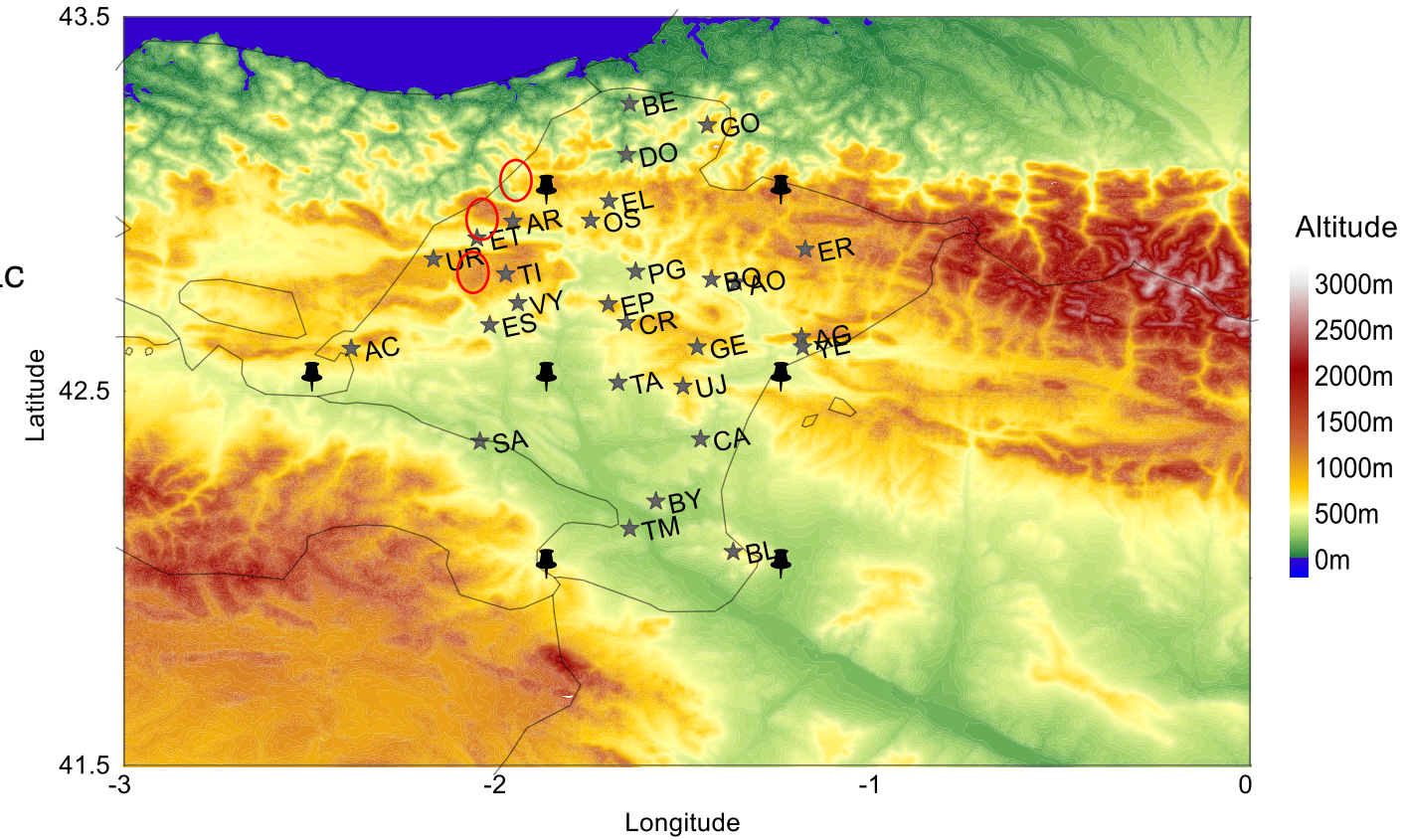
- 7 mesh points available for the entire region
- Different terrain complexities and climatic conditions in the vicinity of the sites

Station	Altitude [m]	V10 [m/s]	P [mm/year]
TI	1224	7.00	920.91

Station	Altitude [m]	V10 [m/s]	P [mm/year]
ET	505	1.51	1101.49

Station	Altitude [m]	V10 [m/s]	P [mm/year]
MERRA2	640	4.71	1345.66

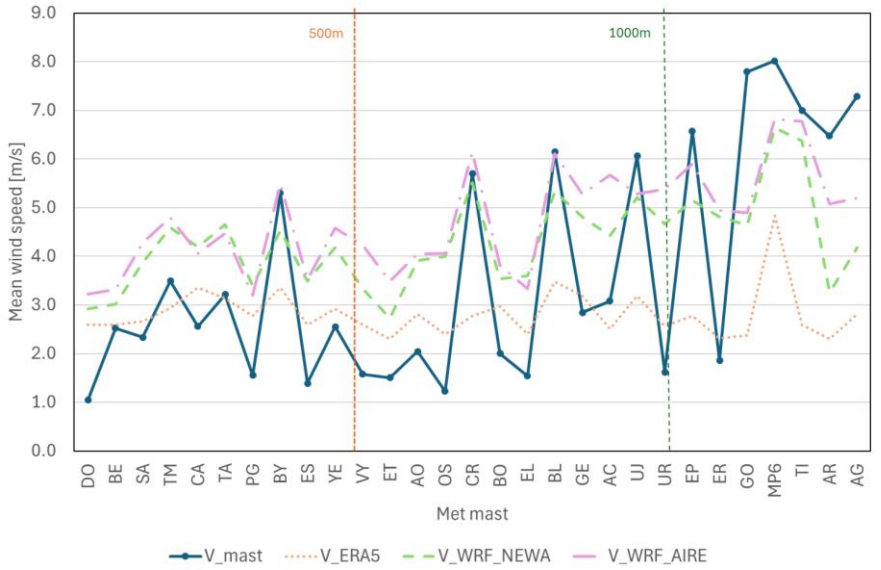
- Spatial resolution is not adequate

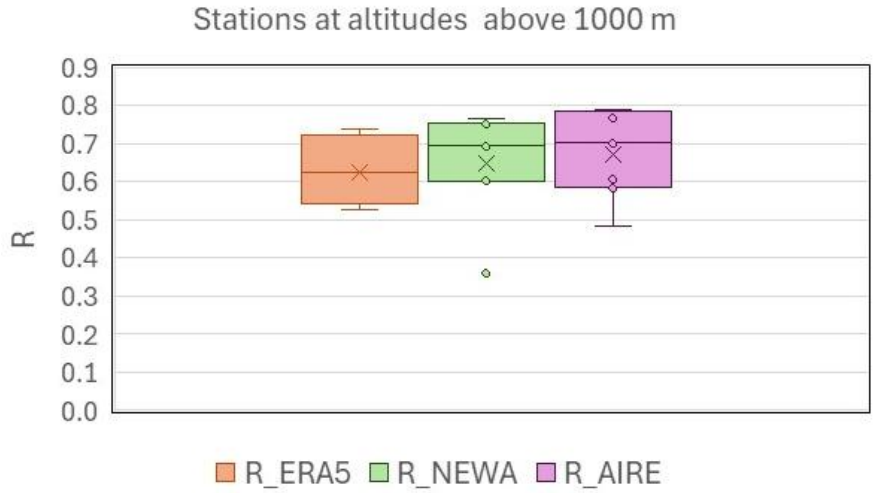


RESULTS

Comparison: **Wind**

- ERA5 average wind speed are lower than those simulated with WRF_NEWA or WRF_AIRE
- Sites with average wind speed above 5 m/s are better simulated with WRF than with ERA5
- R coefficients are similar with the three simulations (between 0.8 and 0.3)
- Stations at altitudes above 1000 m presents higher R with WRF_AIRE simulations, the rest with ERA5





RESULTS

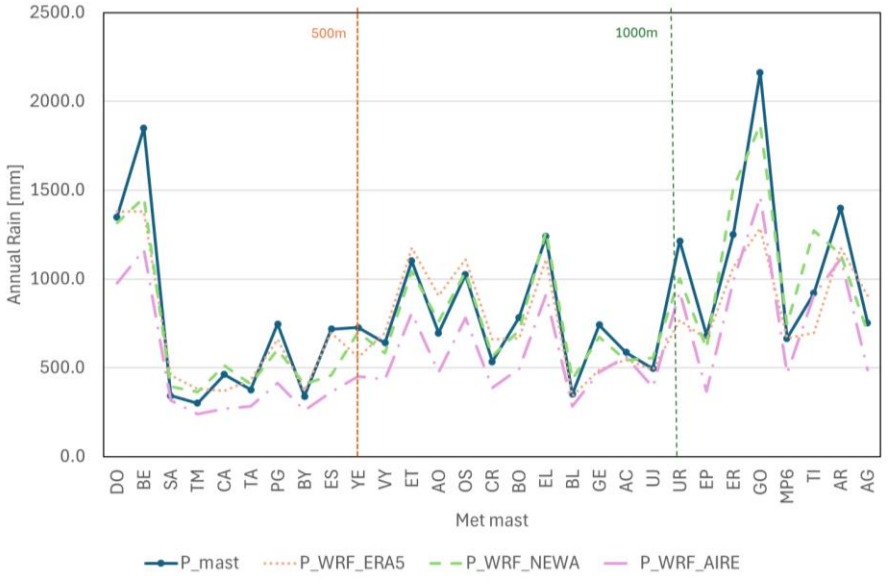
Comparison: **Rain**

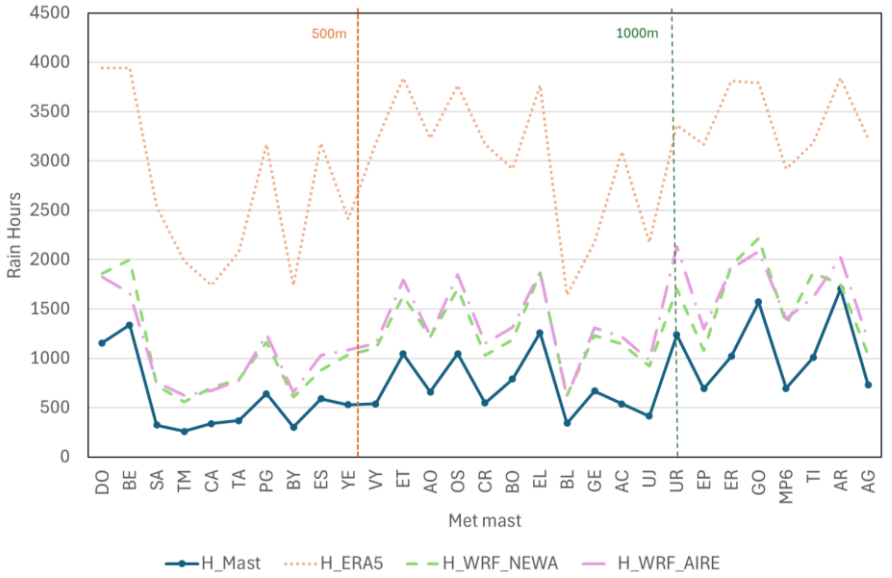
- The R and bias results are slightly better for ERA5 than for the other simulations

	max	min	mean	std
R_ERA5	0.423	0.175	0.305	0.056
R_NEWA	0.377	0.048	0.212	0.077
R_AIRE	0.365	0.107	0.221	0.067

- WRF_AIRE simulations underestimate annual precipitation in all the masts

- All three simulations overestimate the number of time steps with rain accurate. Especially the ERA5 simulation!

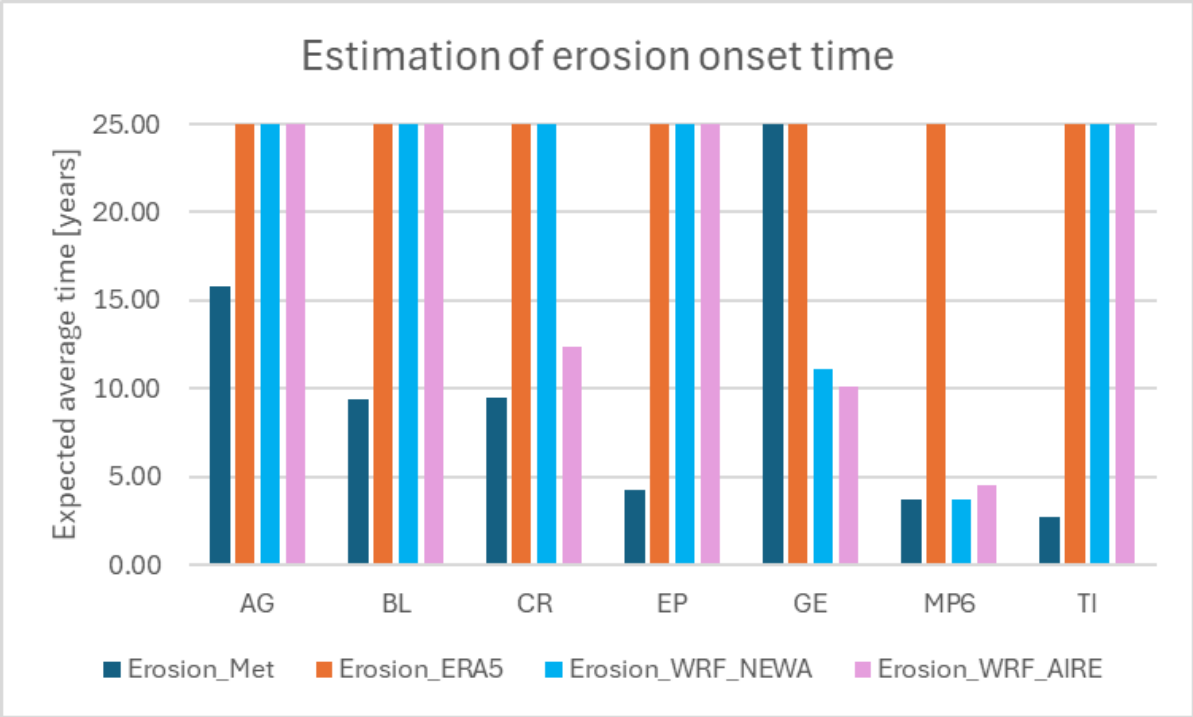




RESULTS

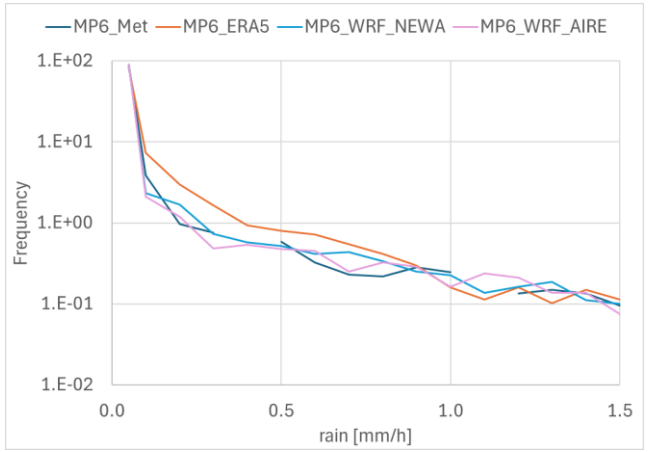
Comparison: **Damage model**

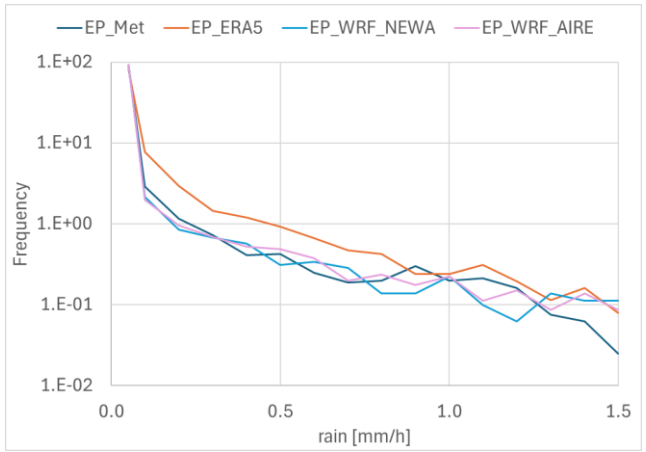
- 6 sites with erosion onset time less than 25 years
- ERA5 overestimate the values in all the sites
- WRF_AIRE gives good estimation for CR and MP6 (Alaiz), WRF_NEWA only for MP6



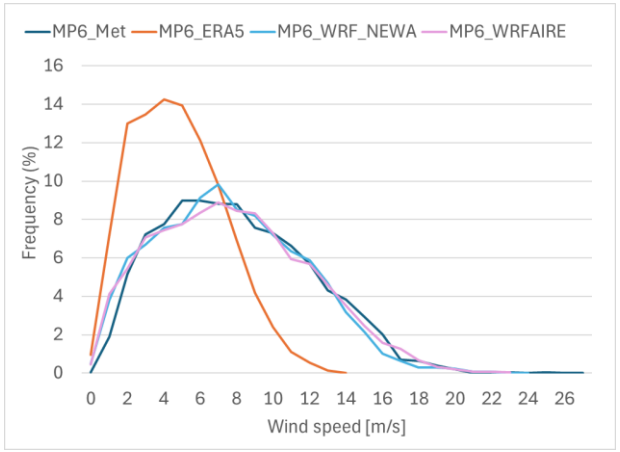
RESULTS

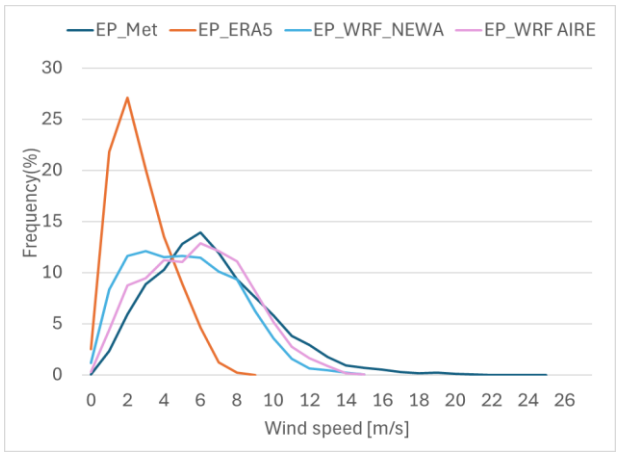
Comparison: **Damage model**

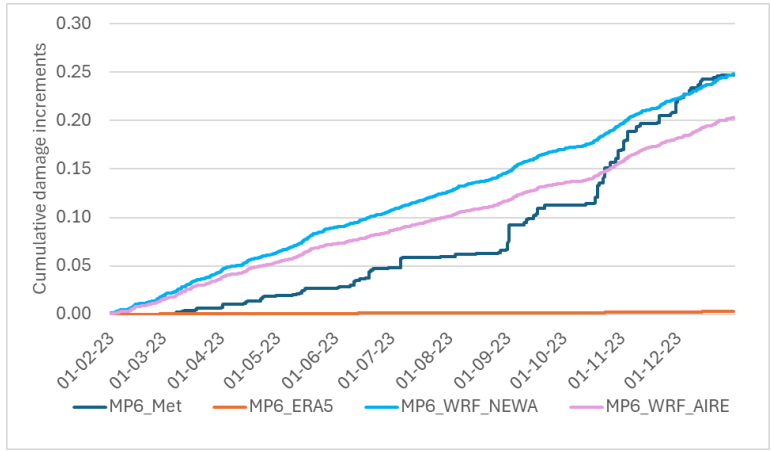


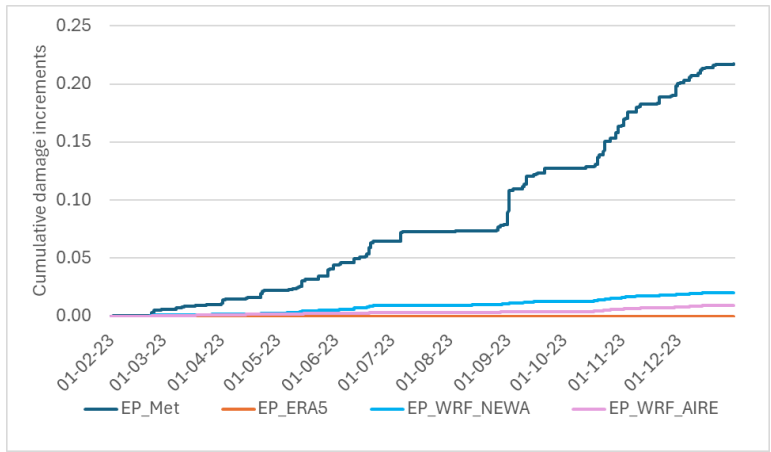


Which variable impacts the damage model most?









RESULTS

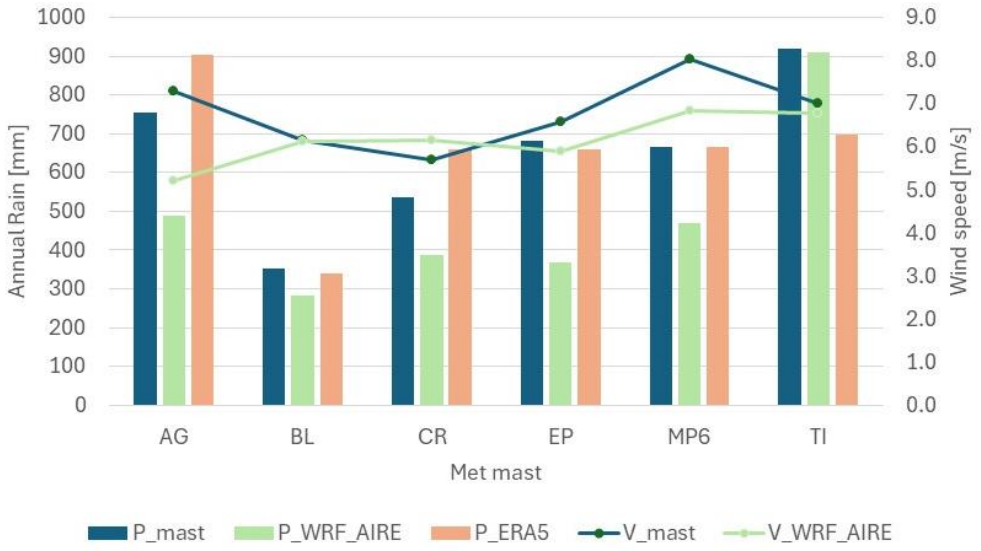
Comparison: **Damage model**

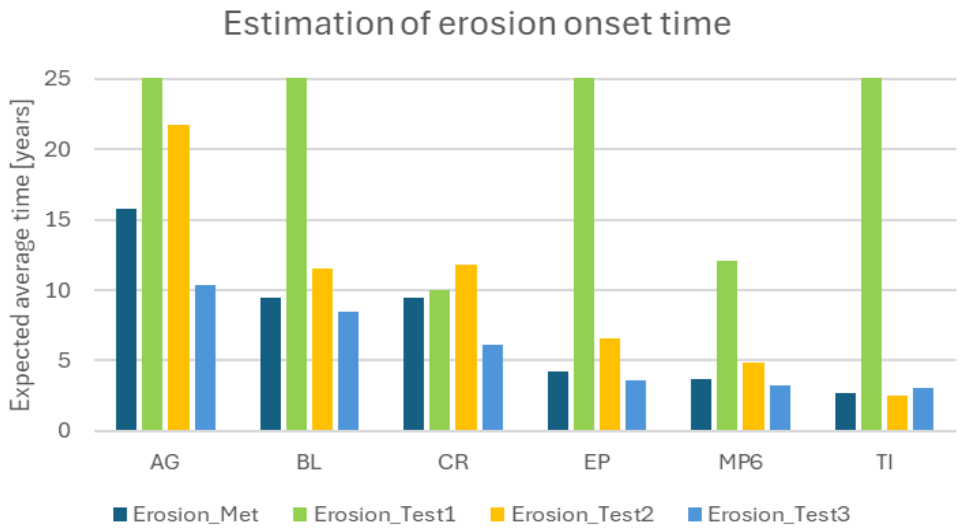
- Which variable impacts the damage model most?

  * Test1 > $V_{WRF\_AIRE} + P_{mast}$

  * Test2 > $V_{mast} + P_{WRF\_AIRE}$

  * Test3 > $V_{mast} + P_{ERA5}$





RESULTS

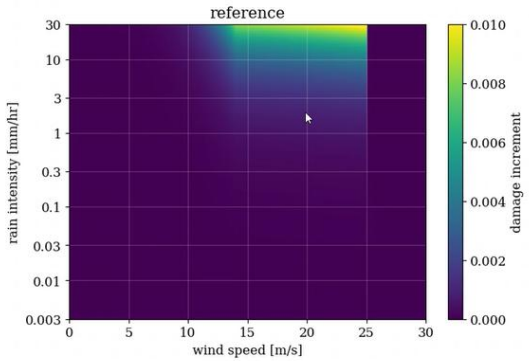
Comparison: **Damage model**

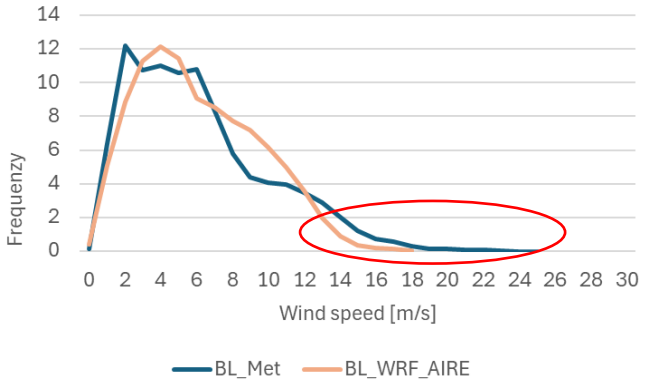
- Which variable impacts the damage model most?

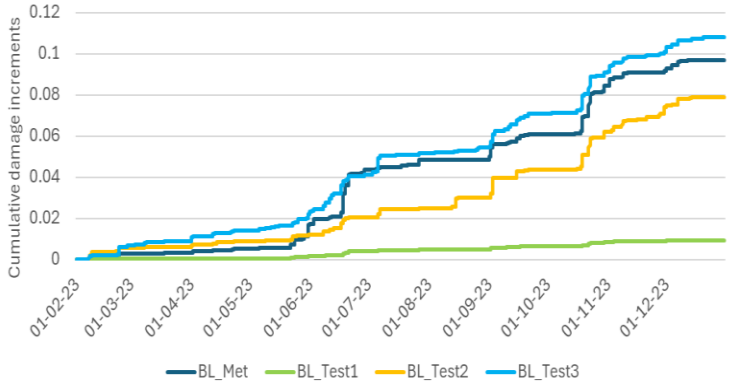
  * Test1 > V_{WRF_AIRE} + P_{mast}

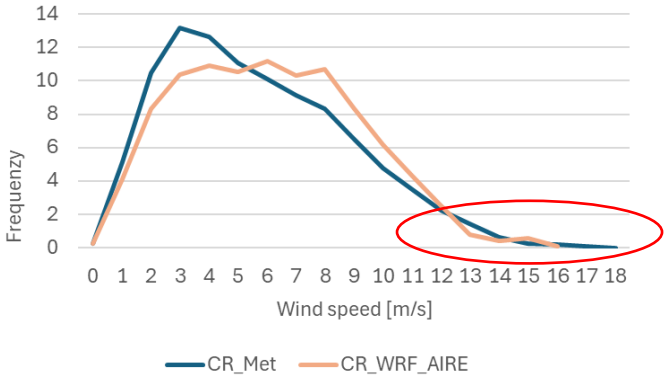
  * Test2 > V_{mast} + P_{WRF_AIRE}

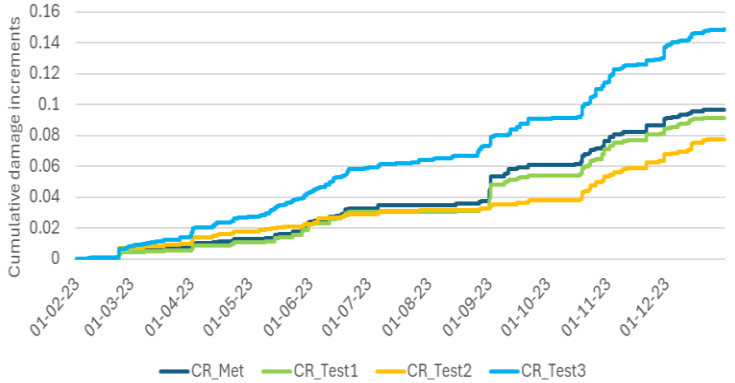
  * Test3 > V_{mast} + P_{ERA5}











05

CONCLUSIONS

CONCLUSIONS

Meteorological Model:

- MERRA2 simulations do not have sufficient spatial resolution to characterize precipitation and wind speed at a site
- ERA5, has good correlation coefficients but tends to underestimate mean wind speed. For precipitation the R and bias results are better for ERA5 than for the other simulations
- WRF, improves wind estimation especially at high altitude locations. The AIRE configuration tend to underestimate annual precipitation

CONCLUSIONS

Damage Model:

- The results of the damage model using wind speed and precipitation from NWPM show significant deviations from the results obtained with the measurements
- Deviations in the wind speed estimation, especially for speeds above 15 m/s, result in greater impact than deviations in the rainfall estimation
- Using ERA5 or WRF rain simulations combined with local wind data as input for the damage model provides damage estimates useful to have an estimate of blade lifetimes in wind farm sites
- Overestimation in annual accumulated rain implies that the estimate erosion time is lower

Thank you

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