

Quality assessment of the GPM IMERG product for lifetime prediction of turbine blades in complex terrain

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Leading Edge Erosion (LEE) poses a significant challenge for wind turbine blades

- LEE can occur in the presence of heavy rain and strong winds.
- The shape and smoothness of the blade's leading edge are crucial for maintaining optimal aerodynamic performance. Erosion can disrupt the smooth airflow over the blade.
- The roughening of eroded blades generates less lift and more drag, which can reduce power output.
- The costs for repairing or replacing eroded blades can be substantial. If erosion-related issues are not managed effectively, they can impact the overall financial performance of the wind farm [1].

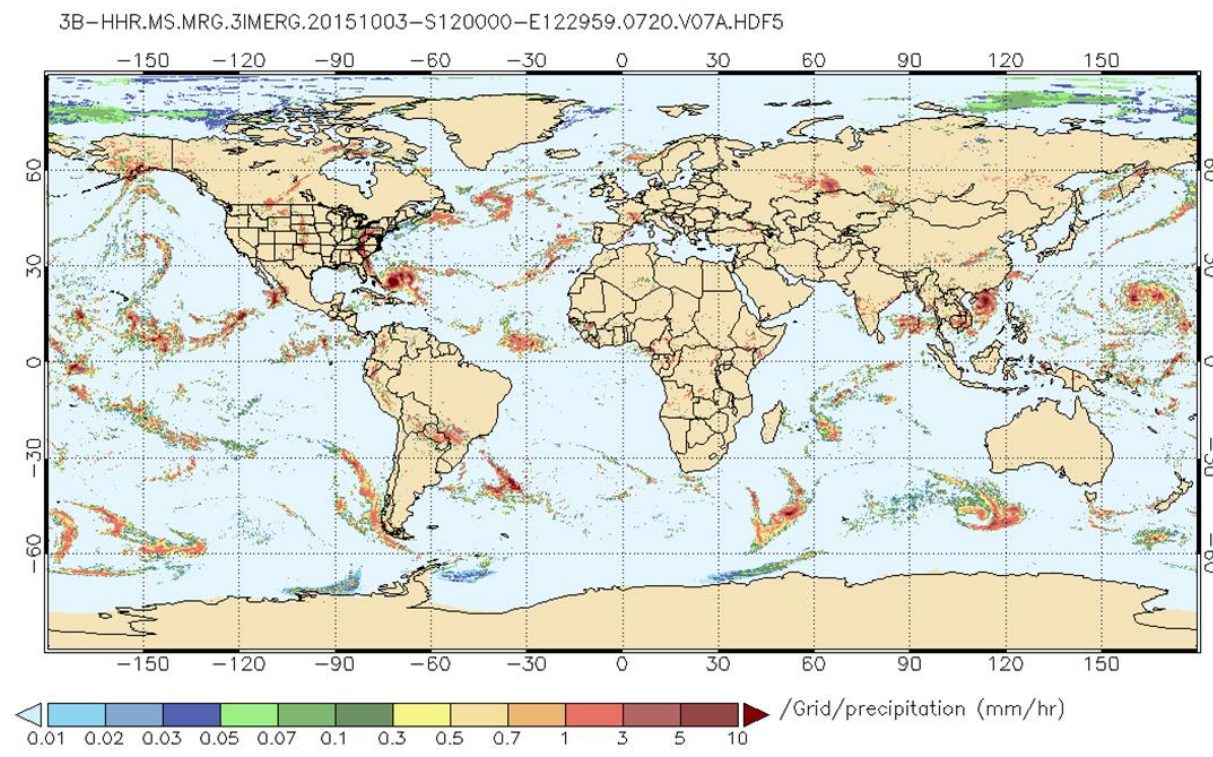


Wind turbine blade with damage on the leading edge
Courtesy of Jakob Ilsted Beck

- The Global Precipitation Measurement (GPM) mission, launched in 2014, is an international satellite-based initiative designed to enhance our understanding of global precipitation patterns.
- GPM involves a constellation of satellites equipped with advanced instruments that provide a comprehensive and unified global precipitation dataset covering hail, heavy and light rainfall, and snow.
- The GPM-IMERG precipitation product is the output.

Can IMERG rainfall intensities be utilised for the prediction of erosion damage on wind turbine blades in complex terrain?

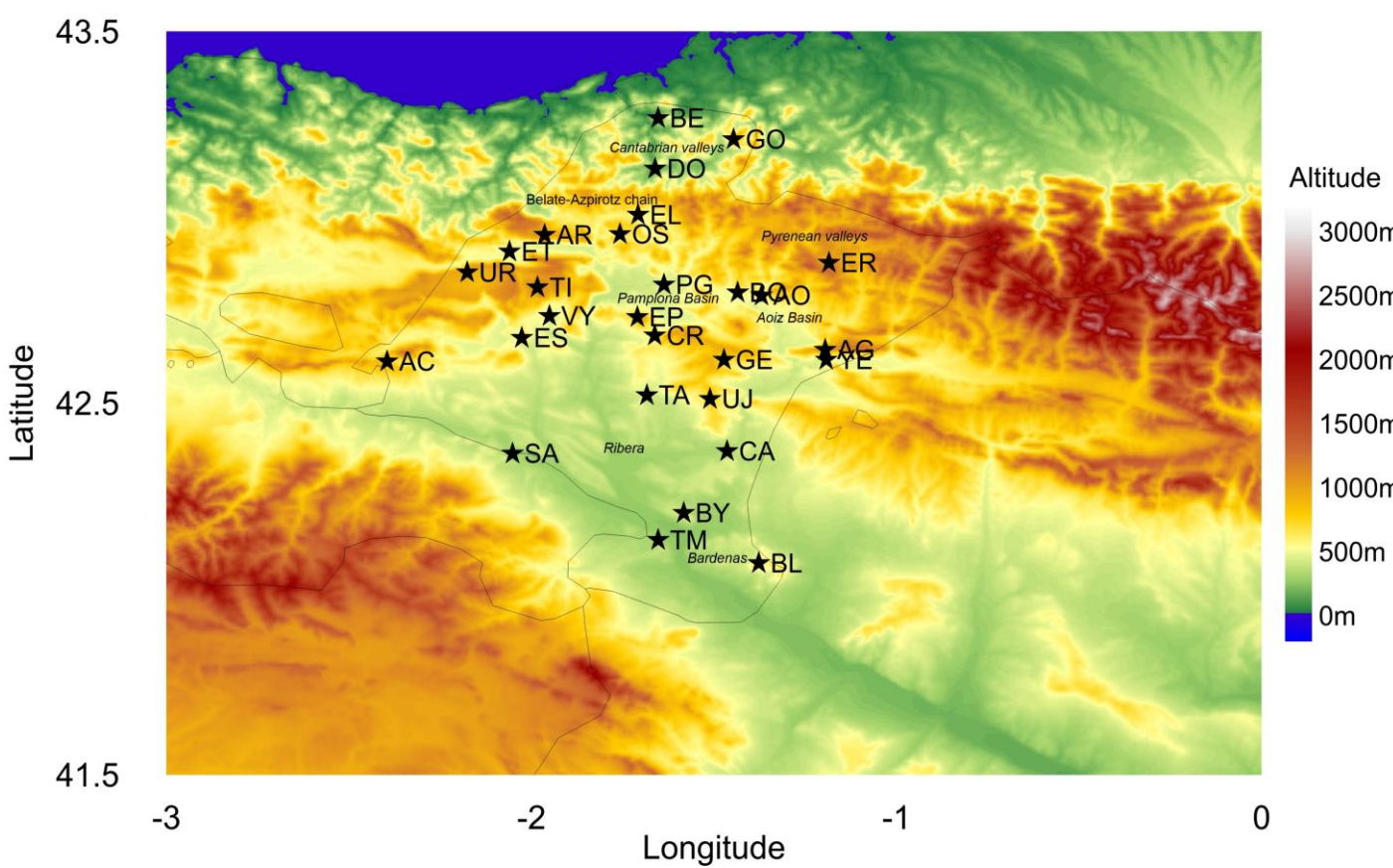
The Integrated Multi-satellite Retrievals for GPM (IMERG) product



GPM IMERG precipitation L3 Half Hourly 0.1° x 0.1° Source: NASA

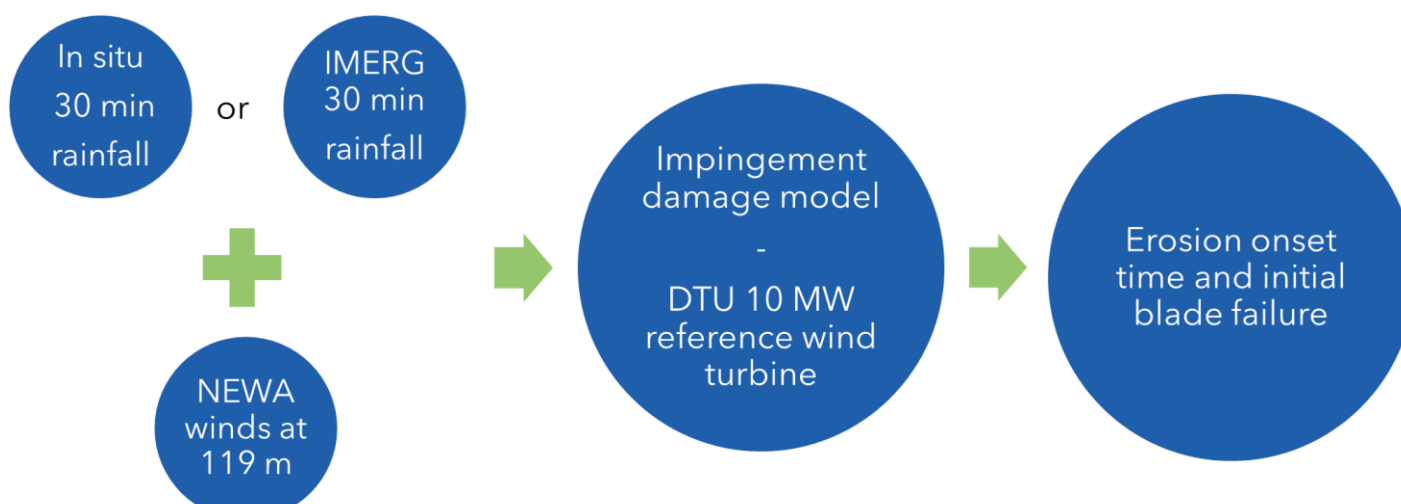
- IMERG provides an estimation of global surface precipitation rates from passive microwave and infrared satellite sensors [2].
- IMERG covers an area from 60° N to 60° S latitude, with a uniform grid spacing of 0.1° (~11 km), and a temporal resolution of 30 min.
- The GPM IMERG Final Precipitation L3 Half Hourly product V06B is used. This product is recommended for research purposes since it has undergone a monthly gauge adjustment with inputs from the Global Precipitation Climatology Center (GPCC).
- The study period covers 2015-2020.

In-situ measurements



- Rain gauge data from 28 meteorological stations in Navarra, Spain, located in orographically complex terrain with elevation heights from 125 to 1353 m.
- Navarra's climate is highly diverse, encompassing climatic types from the temperate and humid Cantabrian valleys to the arid and dry Mediterranean climate of southern Ribera.
- In-situ 10-minute data are aggregated in 30-minute intervals to match IMERG.
- IMERG satellite rainfall is validated against the in situ rainfall in the 28 stations.

The impingement damage model

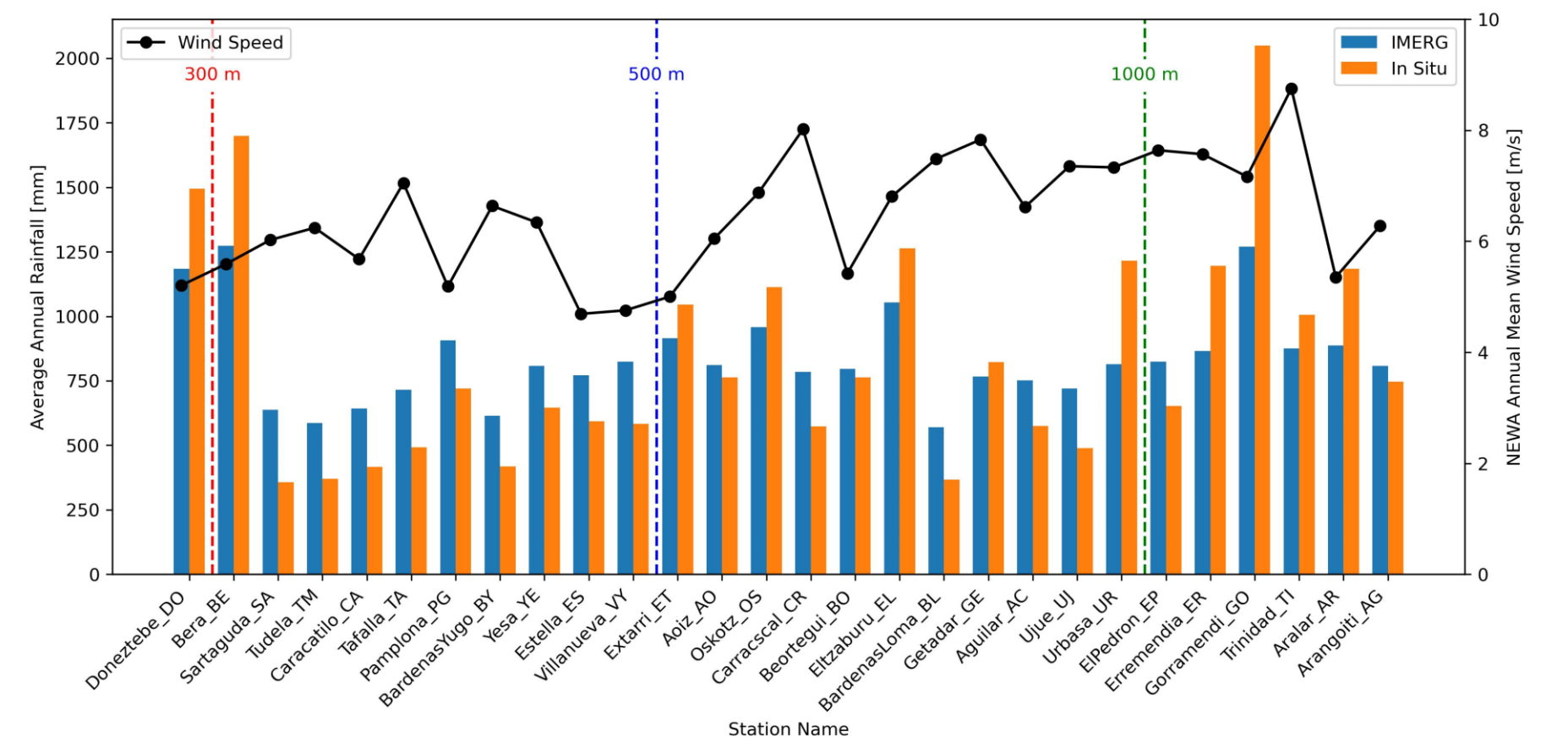


- We model the gradual leading-edge erosion damage caused by the impingement of precipitation during turbine operation [3].
- Rainfall data are converted to impinged water (H) at the tip of the blade, considering rainfall intensity and fall velocity of rain droplets.
- The DTU 10 MW reference wind turbine is used for the two calculations.
- The impingement model also requires wind speeds at hub height. We utilize New European Wind Atlas (NEWA) wind speeds at 100 and 150 m at the location of each station. The NEWA wind speed is interpolated to 119 m, the hub height of the DTU 10 MW wind turbine.

References

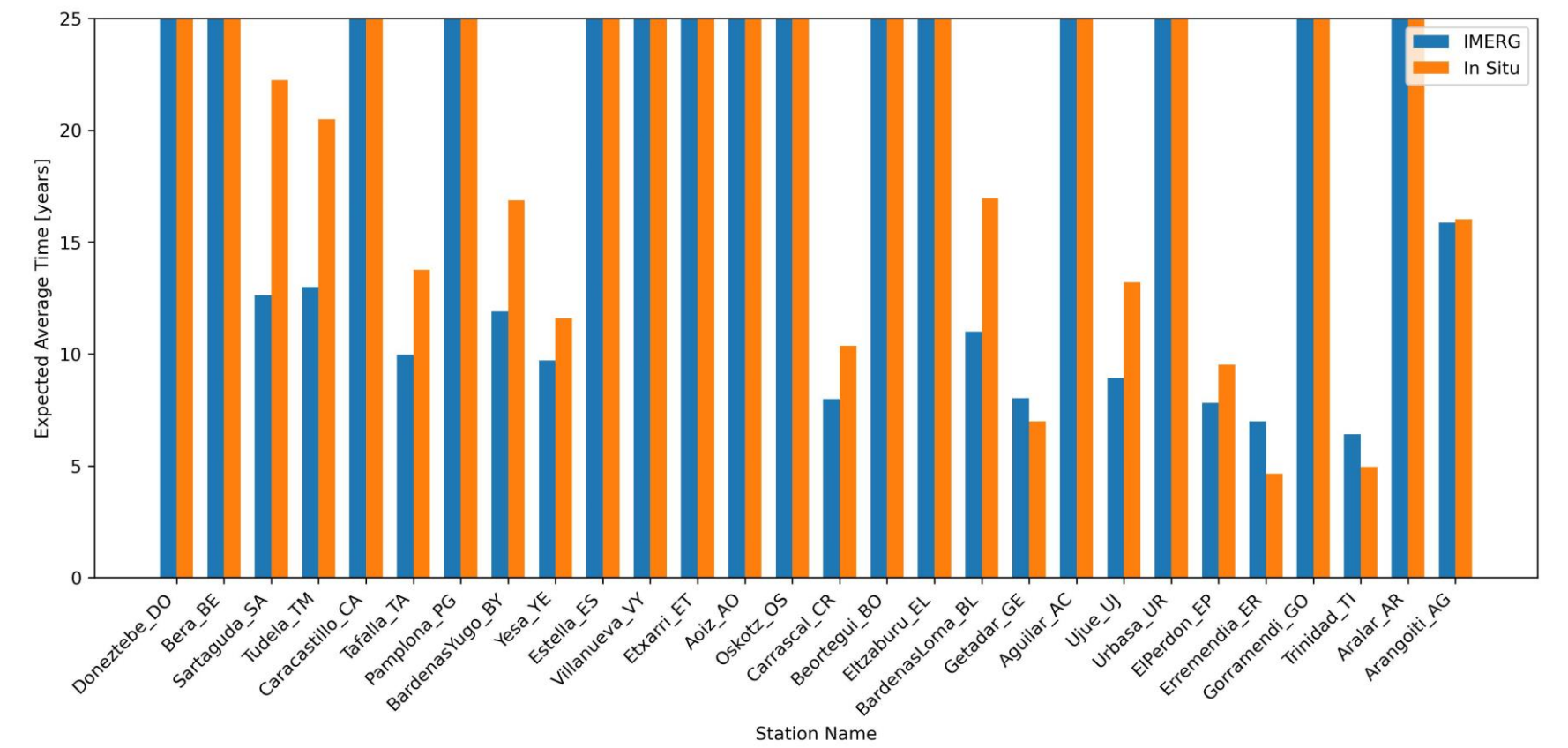
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- [3] Beck, J. I. et al. (2022). Experimental study on the effect of drop size in rain erosion test and on lifetime prediction of wind turbine blades. *Renewable Energy*, 197, 776-789. <https://doi.org/10.1016/j.renene.2022.06.127>

IMERG data validation



- Agreement between the two datasets increases when aggregating them in longer time periods. The highest correlation of 0.74-0.93 appears in monthly aggregations (not shown).
- The highest annual average rainfall of more than 1500 mm and the most significant discrepancies between IMERG and in situ data are observed in stations GO, BE, and DO. These stations are within proximity to the coast and likely affected first by the advection of wet maritime air masses from the Atlantic Ocean.
- IMERG overestimates rainfall in 15 stations and underestimates in 8 stations.
- The NEWA mean wind speeds at 119 m height span from 4.7 m/s to 8.8 m/s.

Estimation of erosion onset time



- In 15 stations, the lifetimes extend beyond the typical lifetime of a blade (25 years).
- IMERG shows an erosion onset time between 8 - 17 years in the same stations.
- In-situ data show an erosion onset time between 6 - 22 years in 13 stations, underlying the erosion criticality in the area.
- The observed discrepancies may be attributed to the area's climate in combination with the limitations of the two datasets and their different detection principle. Satellites measure air volumes from infrared and microwave sensors, while rain gauges measure the weight of rain droplets at point locations.

Conclusions

- The IMERG rainfall observations from the GPM satellite mission can be utilized as input for a blade lifetime prediction model in the orographically complex area of Navarra in Spain.
- The comparison of the average annual rainfall between IMERG and in situ data during the studied period revealed an over and underestimation of the rainfall in 15 and 8 stations, respectively, in line with previous studies.
- The 30-minute resolution of IMERG and in situ measurements in combination with NEWA winds at a reference hub height of 119 m predict blade lifetimes of 8 - 17 (IMERG) and 6-22 (in-situ) years in 13 stations, thus underlying the erosion criticality in the area.
- The IMERG final product requires additional calibration and adjustments to better represent rainfall variability in complex terrain since its accuracy is linked to the rain climate of the region.