
TORQUE
2024
SESSION: Erosion and blade performance characterization
TRACK: Measurement and testing
Funded by the European Union
AIRE

TORQUE 2024

Experimental campaign for the characterization of precipitation in a complex terrain site using high resolution observations

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CENER, University of Barcelona & Universitat Politecnica de Catalunya

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Wind turbine blade erosion

Precipitation

Blade damage

Impact on wind turbine performance

Wind farm operation and control effect

Detailed precipitation studies are required

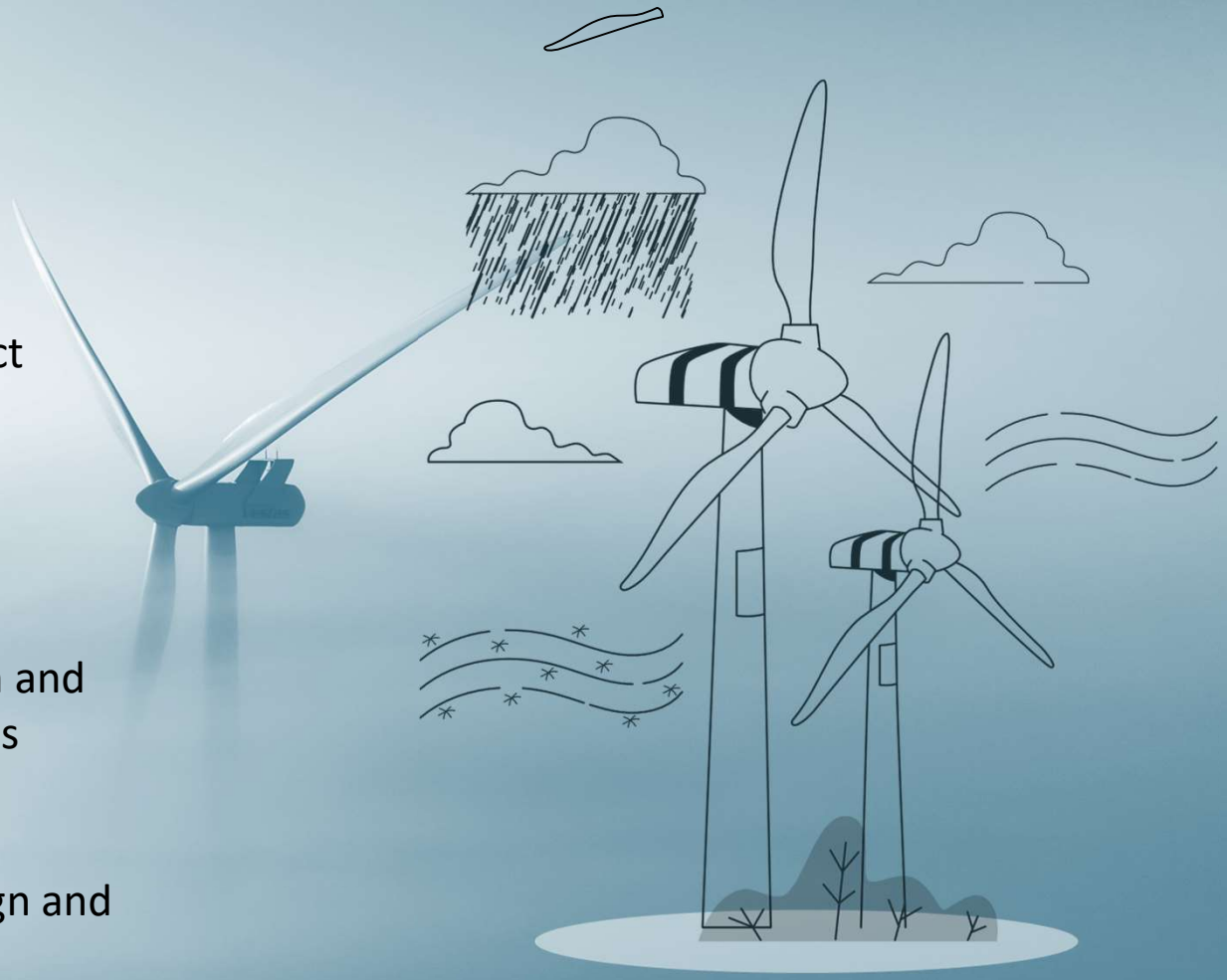
AIRE

Horizon Europe Project

How **site location** and **climate conditions** affect wind turbine and wind farm operation and design?

AIRE makes a **holistic approach** to:

- Study the effect that variables such as rain and dust have on wind turbines and wind farms operation.
- Improve wind turbine and wind farm design and control.
- **Increase** wind energy efficiency.



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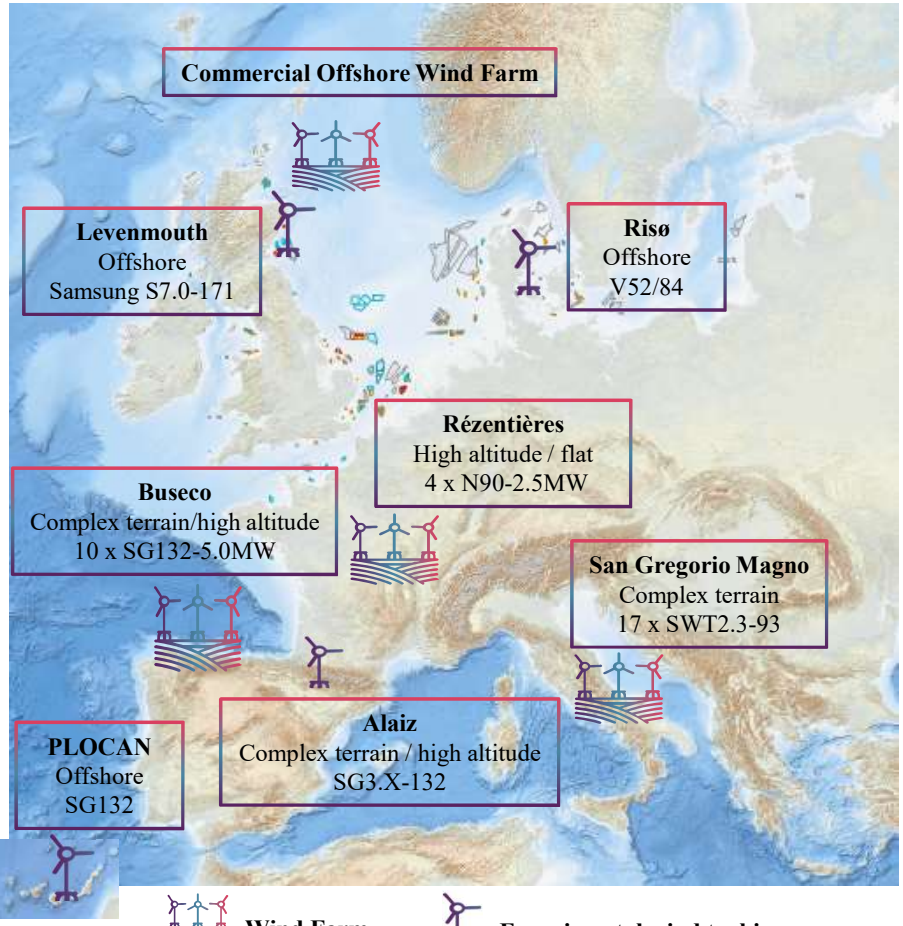
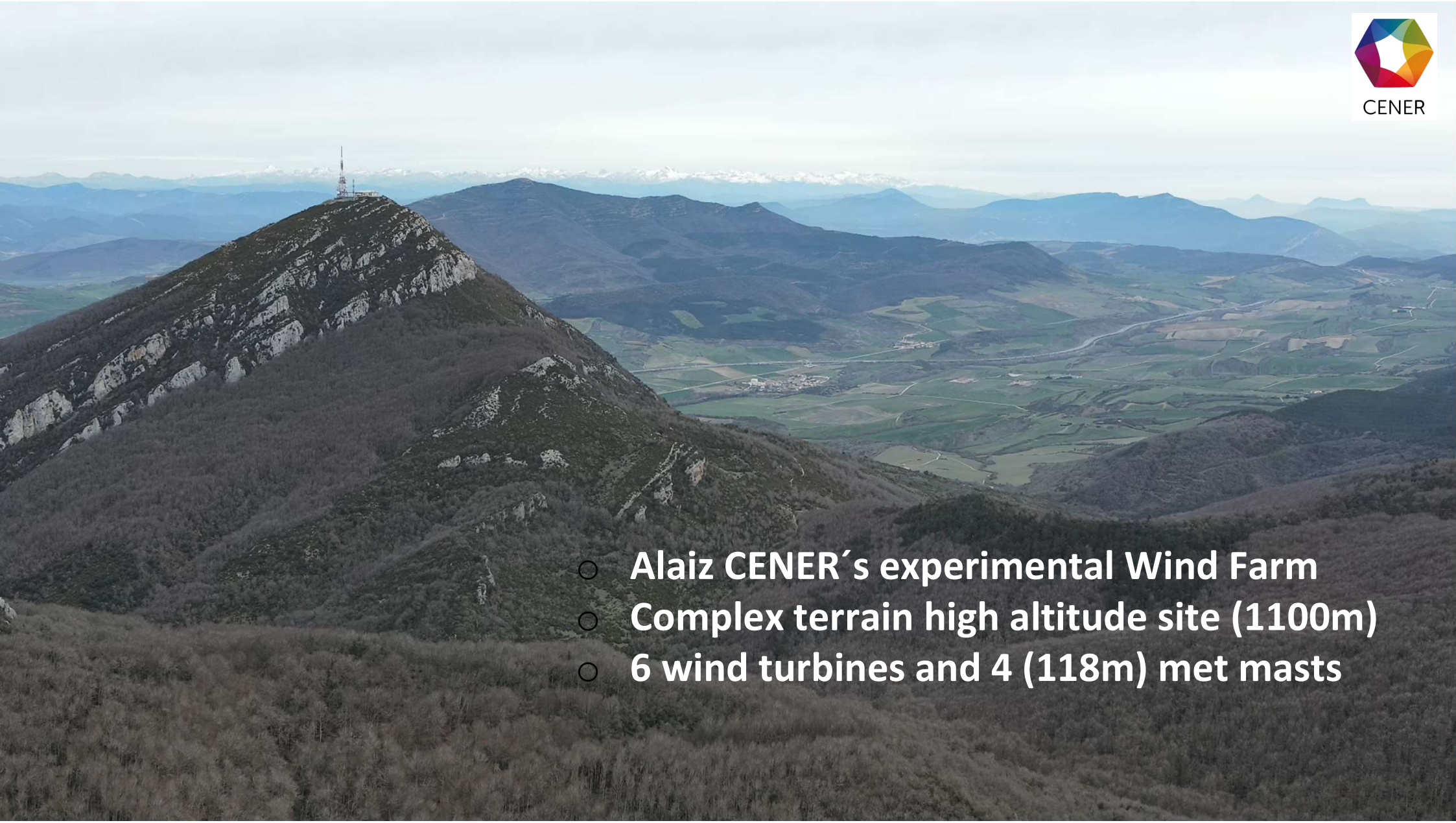


Sites and Equipment

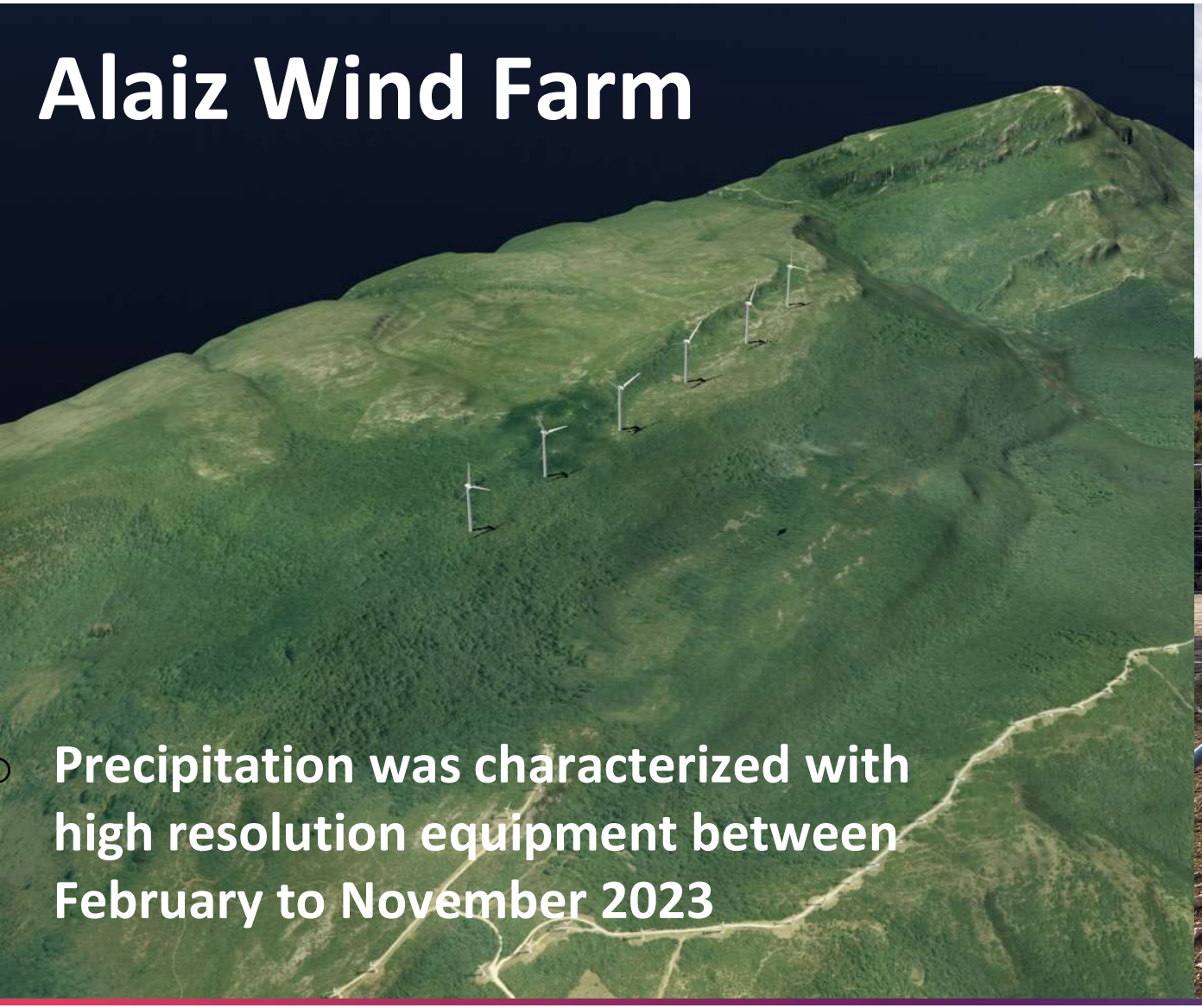
Owner	Name of site	Location	Onshore/ Offshore	Height of location (m)	Average Wind (m/s) / Max wind (m/s)	Average precipitation / Max precipitation	Terrain characteristics and Other	Wind turbine model / hub height	ATMOSPHERIC MEASUREMENTS	EQUIPMENT	WIND POWER PRODUCTION RELATED DATA	USED IN
CENER	Alaiz Experimental Wind farm	Navarra (SP)	Onshore	1130	8.5/35.0	700mm/year 80mm max at 24h	Complex terrain	SG3.X-132 hub height 117.5m	Rain (up to 2km) Droplet size, distribution & frequency Wind speed (up to 2km) & direction Temperature, Humidity Pressure sensor on blade	Micro Rain Radar and WLS70 lidar 4 met mast 118m Wind vanes, cup anemometers, sonic anemometers	Energy production (SCADA) Blade Erosion status Surrounding characteristics Wind and Precipitation	Knowledge hub (WP2) Wind Farm tools develp (WP4)
DTU	Risø Campus experimental turbine	Roskilde (DK)	Onshore	Sea level	7.2/30.1	833/29.2	Coastal fjord, flat landscape	V52/44	Wind speed up to 2km Precipitation,Temperature, Droplet size, distribution & frequency	Meteorological mast up to 123m Disdrometer Micro Rain Radar (MRR PRO) and WLS70 lidar	Wind turbine energy production (SCADA) Site meteorological characteristics (wind and precipitation)	Knowledge hub (WP2) Mesoscale and wake models (WP3) Wind Farm tools develp (WP4)
OREC	Levenmouth Demonstrator Turbine (LDT)	Levenmouth (UK)	Offshore	Sea level	9.41 (average from nearby weather station)	625 mm/year 40 mm/hr (current maximum recorded)	Offshore	Samsung S7.0-171 Precipitation data from 12/2020	Precipitation, Wind speed Ultraviolet radiation Temperature, Humidity Precipitation intensity distribution Rain dropplet distribution Wind speed	PWS100 Campbell Scientific dendrometers Radiometer (to be selected & installed) Lidar (to be selected & installed) KIPP & ZONEN UVS Radiometer NOAH Offshore Anemometry Hub (Blyth)	Blade status Representative reduction in annual energy production (TBC)	Knowledge hub (WP2) Airfoil performance models (WP3) AEP prediction tool (WP4)
PLOCAN	Oceanic offshore platform and test site Canary Islands	Canary Island (SP)	Offshore	Sea level	5.40/19.42	300mm/year	Haze (Wind + sand from Sahara desert)	SG132	Rain Wind speed and wind profile Sand ("Calima") data from University of Las Palmas (ES)	Vaisala meteorological station (WXT530) Solar radiation sensor (Apogee Instruments model SQ-215) UV sensor (SGLUX model UV-Cosine) LIDAR ZX300M	Energy production (SCADA) Blade Erosion status Blade status after a haze period	Knowledge hub (WP2) Airfoil performance model & blade damage model (WP3) Wind Farm tools develp (WP4) AEP prediction tool (WP4)
CAPITAL ENERGY	Buseco wind farm	Asturias (SP)	Onshore	856m-977m	6.4m/s to 7.4m/s. /	Not measured	Complex terrain, 13km away from the sea.	SG132-5.0MW hub height 84 (wind farm under construction)	Wind speed and direction (up to 500m) Rain (up to 2km height)	Micro Rain Radar and WLS70 lidar (rain and precipitation up to 2 km)	Energy production (SCADA) Wind turbine operation Blade Erosion status Wind & Precipitation	Case study 2 : high altitude + complex terrain (WP5)
ENGIE	Rézentières wind farm	Cantal Department in South-Central France (FR).	Onshore	1120	7.0/	~900 mm/year	Flat-high altitude	4 x N90-2.5MW	Standard meterological data	Meteorological mast	Energy production (SCADA) Wind turbine operation Blade erosion status Wind and Precipitation	Knowledge hub (WP2) Airfoil performance model & blade damage model (WP3) Wind Farm tool develp (WP4) Case study 3: high altitude (WP5)
ENGIE	San Gregorio Magno wind farm	Salerno (IT)	Onshore	960-1290	7.2/	~700 mm/year	Complex terrain	17 x SWT2.3-93	Standard meterological data	Meteorological mast	Energy production (SCADA) Wind turbine operation Blade Erosion status Surrounding characteristics Wind and Precipitation	Knowledge hub (WP2) Airfoil performance model & blade damage model (WP3) Wind Farm tools develp (WP4) Case study: blind test (WP5)
ENGIE	Offshore Wind farm	Scotland (UK)	Offshore	Sea level	10/32	1600 mm/year (estimation)	Offshore	100 x V164-9.5MW	Precipitation Wind speed and direction Droplet size distribution and range cloud base height	Nacelle weather sensor Disdrometer (nacelle mounted) Precipitation holographic imaging sensor (SAKU III) Ceilometer (ground/substation mounted)	Energy production (SCADA) Blade Erosion status Surrounding characteristics Wind and Precipitation	Knowledge hub (WP2) Wind turbine protection models (WP3) & tools (WP4) Case study 1 and 5: offshore (WP5) Durable wind blades (WP6)


CENER
Alaiz CENER´s experimental Wind Farm
Complex terrain high altitude site (1100m)
6 wind turbines and 4 (118m) met masts

Alaiz (CENER´s experimental wind farm)

September 2023

Alaiz Wind Farm



Precipitation was characterized with high resolution equipment between February to November 2023

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Equipment

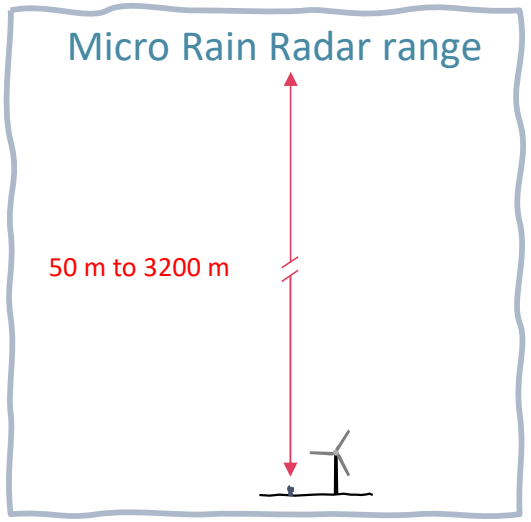
Micro Rain Radar

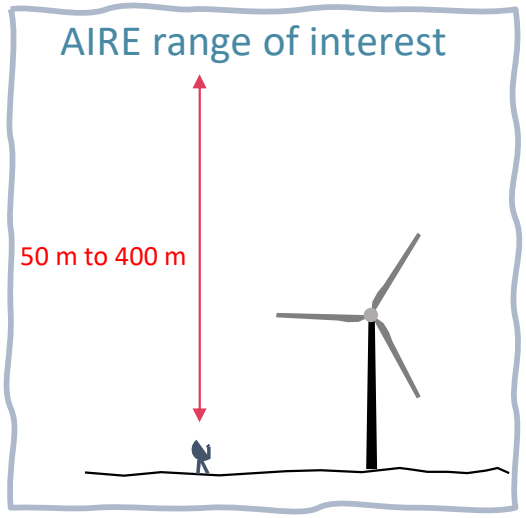
Metek MRR-PRO

- Raindrop size distribution
- Precipitation fall speed
- Rain intensity
- Type of precipitation

Data at 0.2 Hz

Measures at different heights





Disdrometer OTT Parsivel²

- Raindrop size distribution
- Precipitation fall speed
- Rain intensity
- Type of precipitation

Measures at ground level

Data at 0.02 Hz (1 per minute)

Pluviometer

R M YOUNG 52203

- Average rainfall intensity

Measures at ground level

Data averaged 1min and 10min

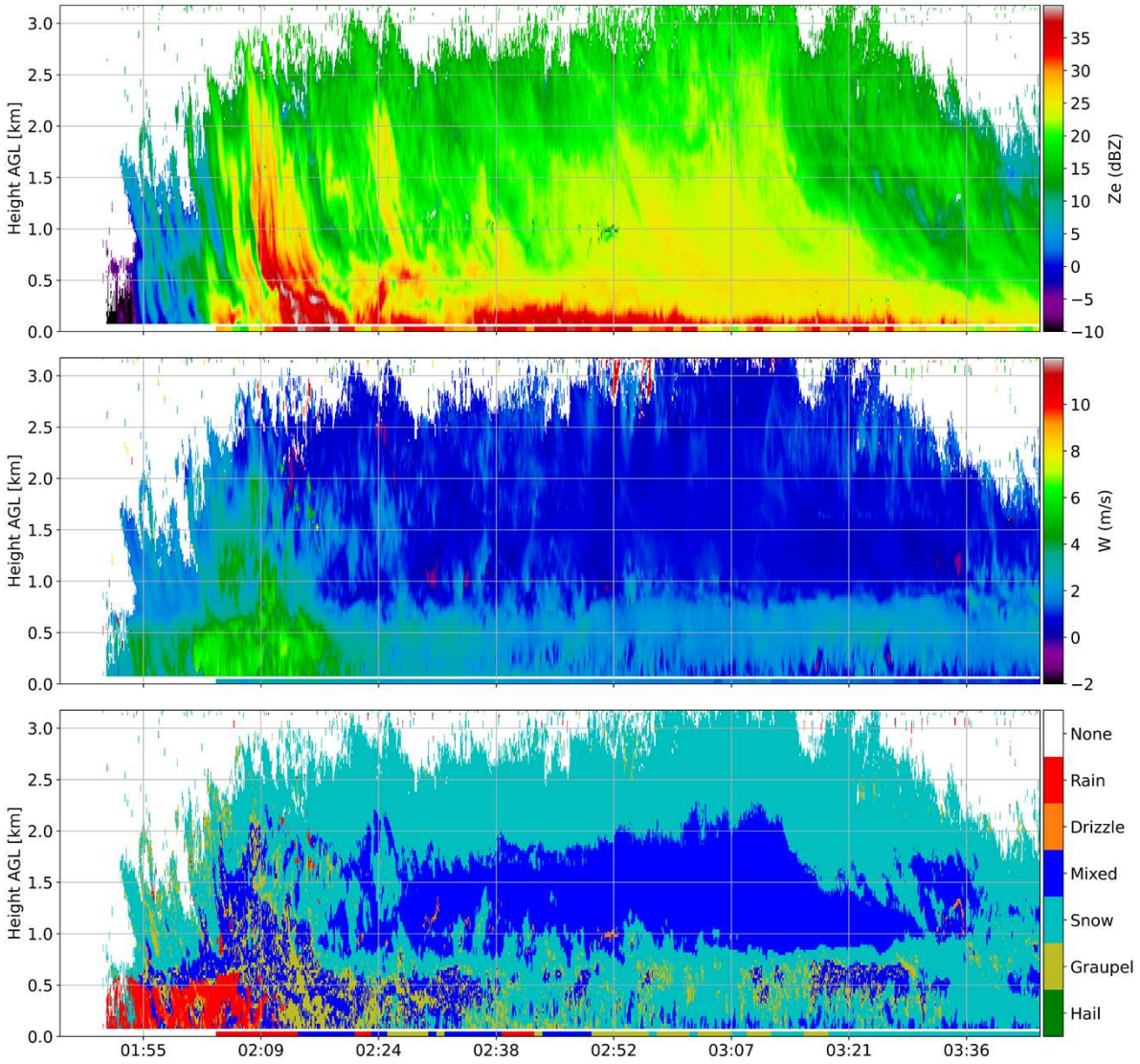
Case Study 1

23rd February 2023 from 1:45 to 3:45 UTC

Equivalent radar reflectivity Z_e

Vertical fall velocity W

Estimated precipitation type



***Parsivel observations are shown at the lowest level of each panel using the same color scale as MRR data.*

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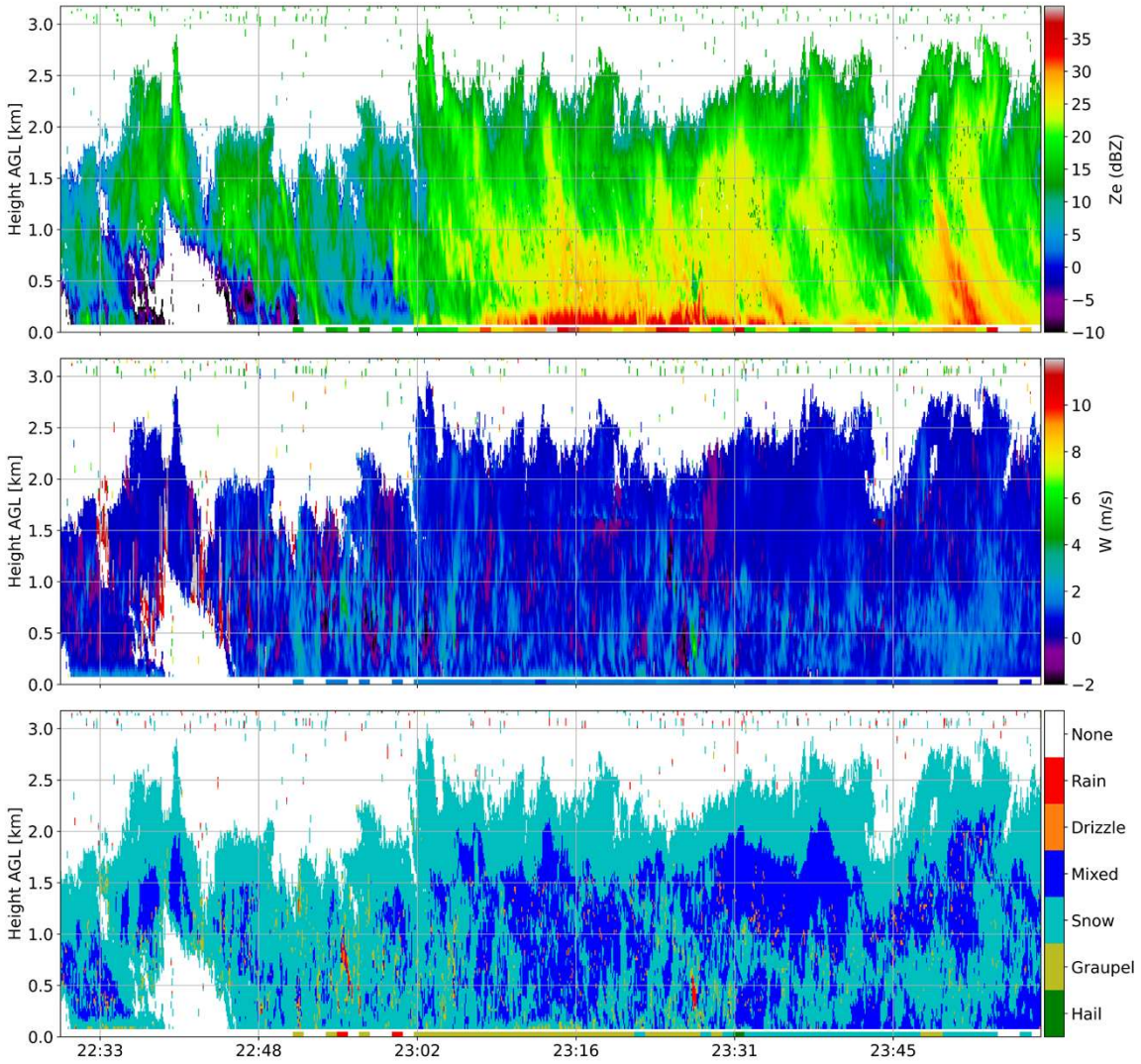
Case Study 2

1st April 2023 from 22:30 to 23:59 UTC

Equivalent radar reflectivity Z_e

Vertical fall velocity W

Estimated precipitation type



***Parsivel observations are shown at the lowest level of each panel using the same color scale as MRR data.*

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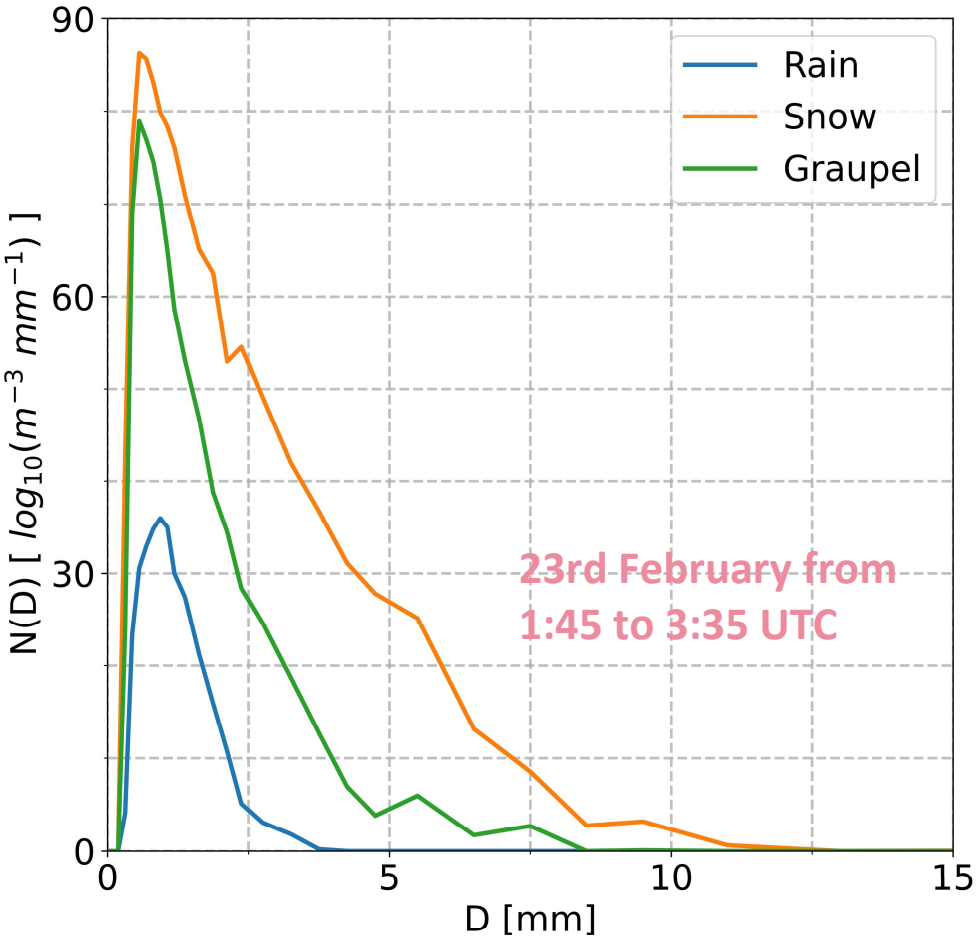
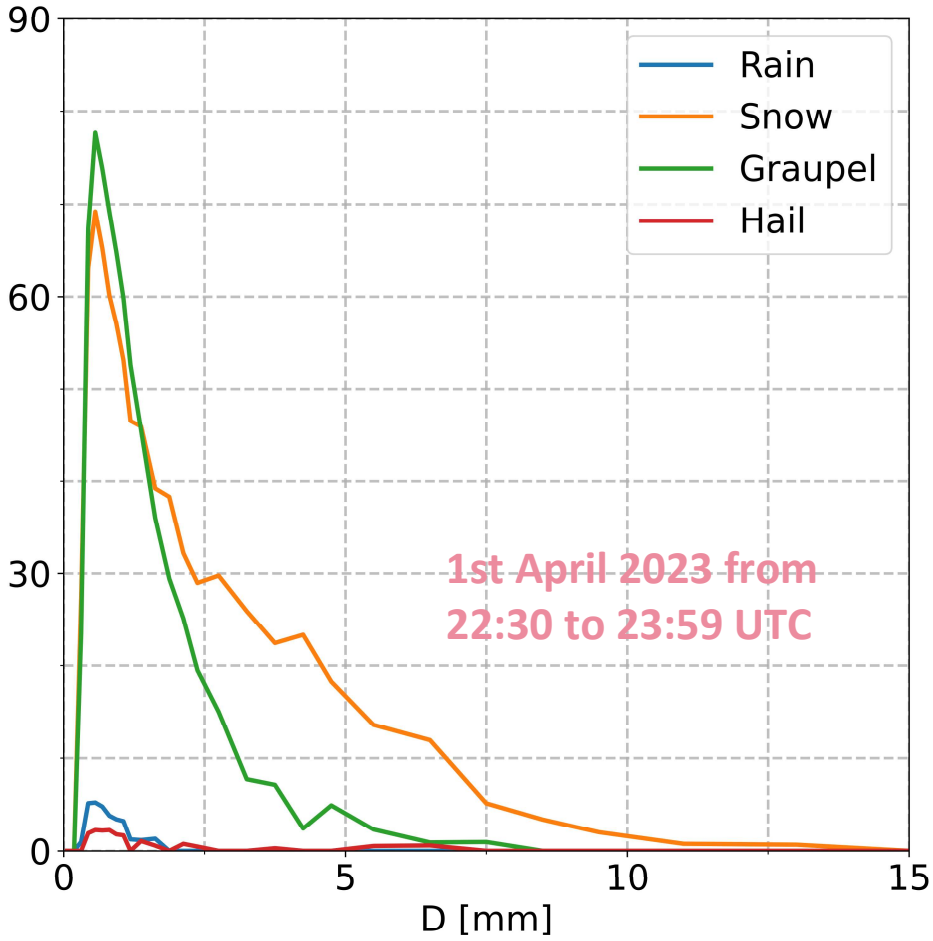
Case Studies

Particle size distribution from the Disdrometer for the different precipitation types





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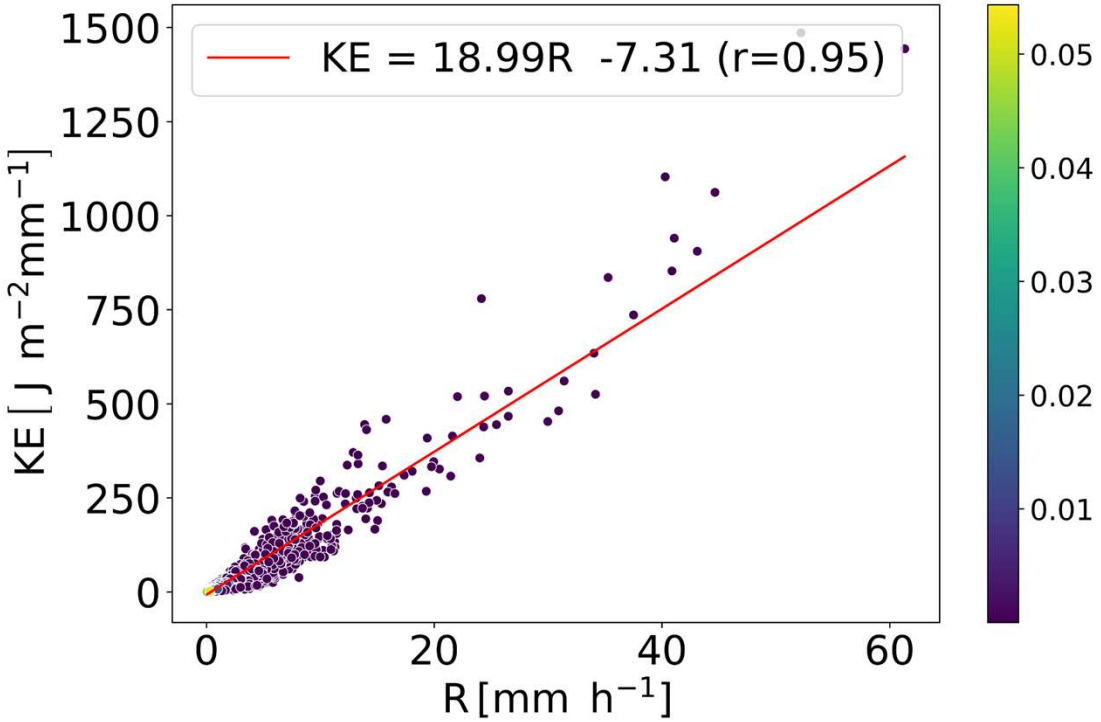
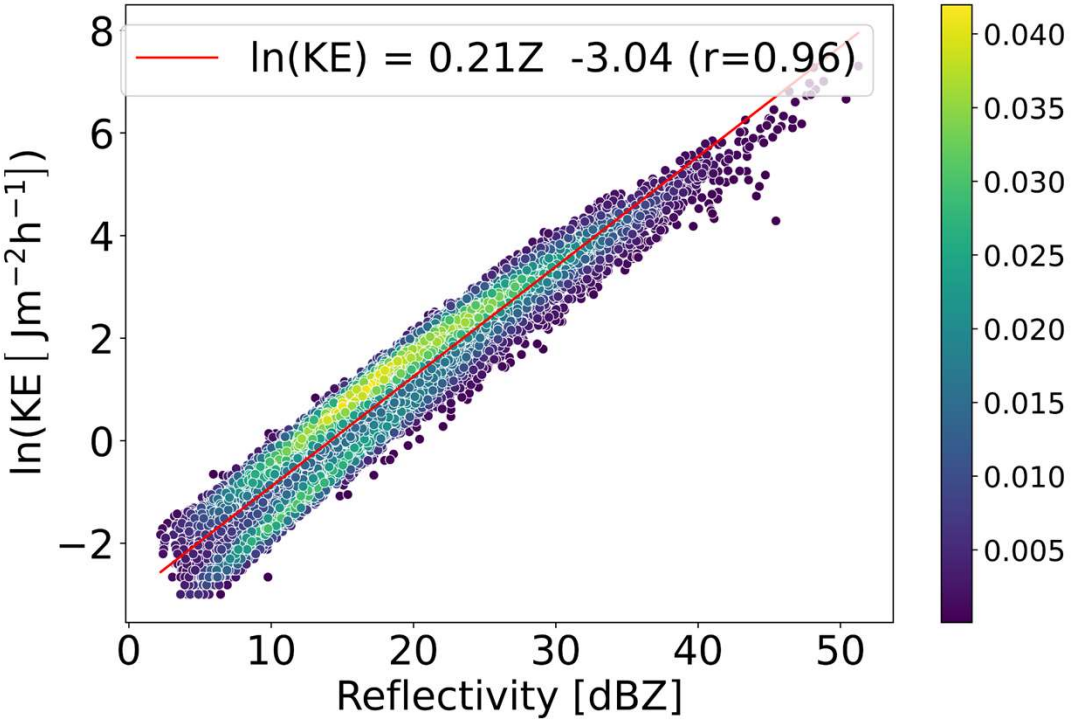
Kinetic Energy

Kinetic Energy (KE) vs Rainfall Rate (R) and Kinetic Energy (KE) vs Radar Reflectivity (Z)
Scatter density plots and fitted functions with their Pearson correlation coefficient (r) for 11,135 1-minute records





MRR describes precipitation metrics in the vertical range in which wind turbines operate. Agreement of **hydrometeor types** classified at the lowest MRR height available compared to Parsivel is found.

Fitting functions to the data sets are defined to estimate the **KE** that could be used to improve measurements with traditional meteorological equipment.

Future work will be devoted to combine drop size distribution data and subsequent rainfall erosivity estimates from MRR data, wind data, and wind turbine rotation speed to accurately **predict and prevent blade erosion**.

In 2024 a **second precipitation campaign** will be done at Alaiz wind farm including precipitation equipment and **lidar** measurement.

Key outputs and Future

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Thank you.

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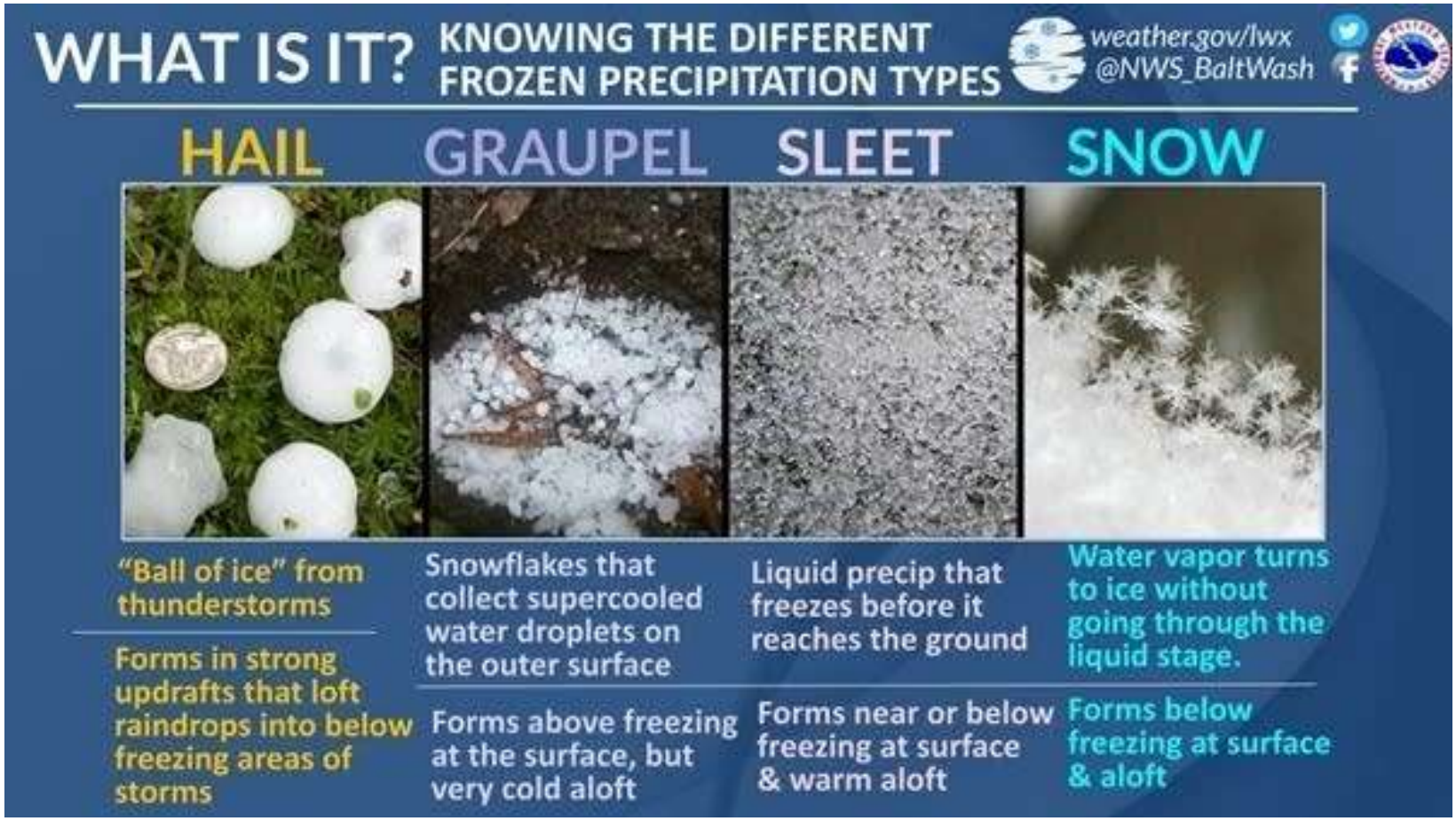
WHAT IS IT?
KNOWING THE DIFFERENT FROZEN PRECIPITATION TYPES
weather.gov/lwx
@NWS_BaltWash
HAIL
GRAUPEL
SLEET
SNOW
"Ball of ice" from thunderstorms
Forms in strong updrafts that loft raindrops into below freezing areas of storms
Snowflakes that collect supercooled water droplets on the outer surface
Forms above freezing at the surface, but very cold aloft
Liquid precip that freezes before it reaches the ground
Forms near or below freezing at surface & warm aloft
Water vapor turns to ice without going through the liquid stage.
Forms below freezing at surface & aloft