Wind and Precipitation Conditions in Offshore Wind Farm Zones: Insights from Satellites and Weather Simulations

Tsvetelina Ivanova[1,2], Alexandros Palatos-Plexidas[1,3],
Sara Porchetta[4], Sophia Buckingham[5],
Jeroen van Beeck[1], Lesley De Cruz[3,6],
Jan Helsen[2], and Wim Munters[1]

[1]Environmental and Applied Fluid Dynamics, von Karman Institute, Belgium
[2]Department of Engineering Technology, Vrije Universiteit Brussel, Belgium
[3]Electronics and Informatics Department, Vrije Universiteit Brussel, Belgium
[4]Delft University of Technology, The Netherlands
[5]Research & Innovation, ENGIE Laborelec, Belgium
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VUB VRIJE UNIVERSITEIT BRUSSEL

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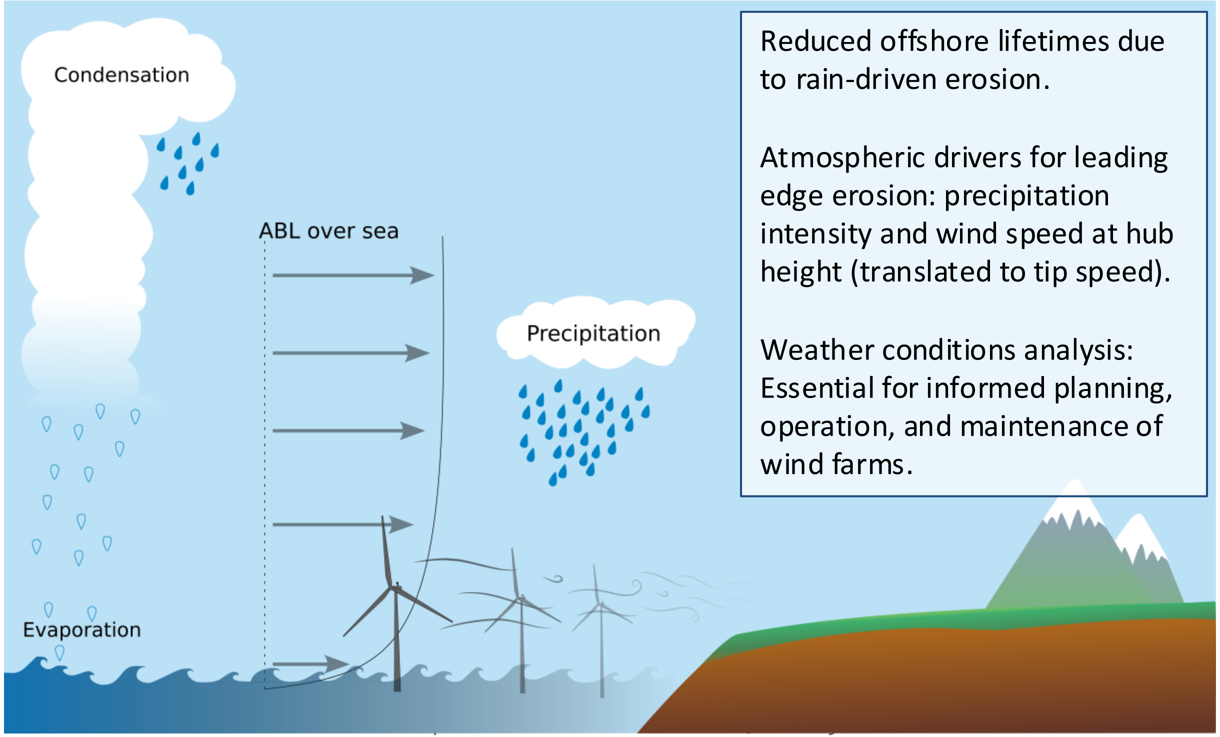

Reduced offshore lifetimes due to rain-driven erosion.

Atmospheric drivers for leading edge erosion: precipitation intensity and wind speed at hub height (translated to tip speed).

Weather conditions analysis: Essential for informed planning, operation, and maintenance of wind farms.

Framework & Focus

- Large-scale analysis: Long-term trends in wind and precipitation across Europe using 10 years of IMERG and ERA5 data.
- Regional insights: Assessments for the Belgian North Sea using ERA5 reanalysis data and WRF model output.

Retrieved decades of daily precipitation estimations

IMERG: Integrated Multi-Satellite Retrievals algorithm combines information from satellites

https://doi.org/10.5067/GPM/IMERGDF/DAY/07

Retrieved decades of hourly precipitation and wind speed data

ERA5 climate reanalysis: a numerical product that combines models with observations

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Three years of model simulation using the WRF solver

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What are the atmospheric conditions at various wind farm zones?
Which zones could have elevated rain-driven erosion risk?

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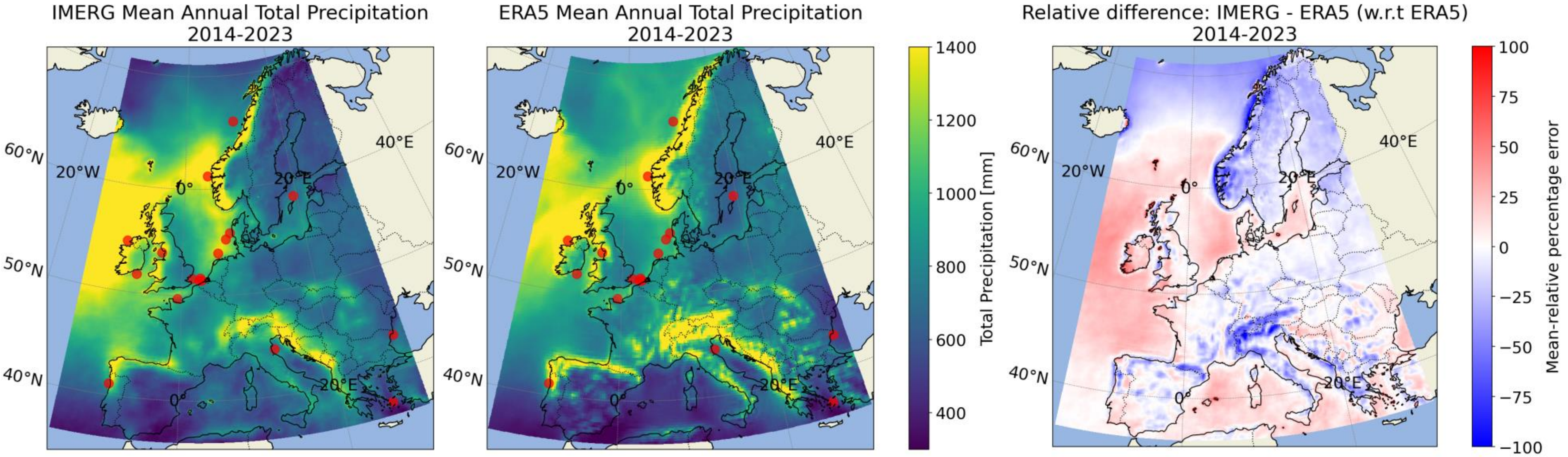
Large-scale analysis using ERA5 and IMERG

Investigating offshore wind farm zones (commissioned, under development, early-concept zones) throughout a broad area of Europe.

Differences between the IMERG and ERA5 product across 10 years



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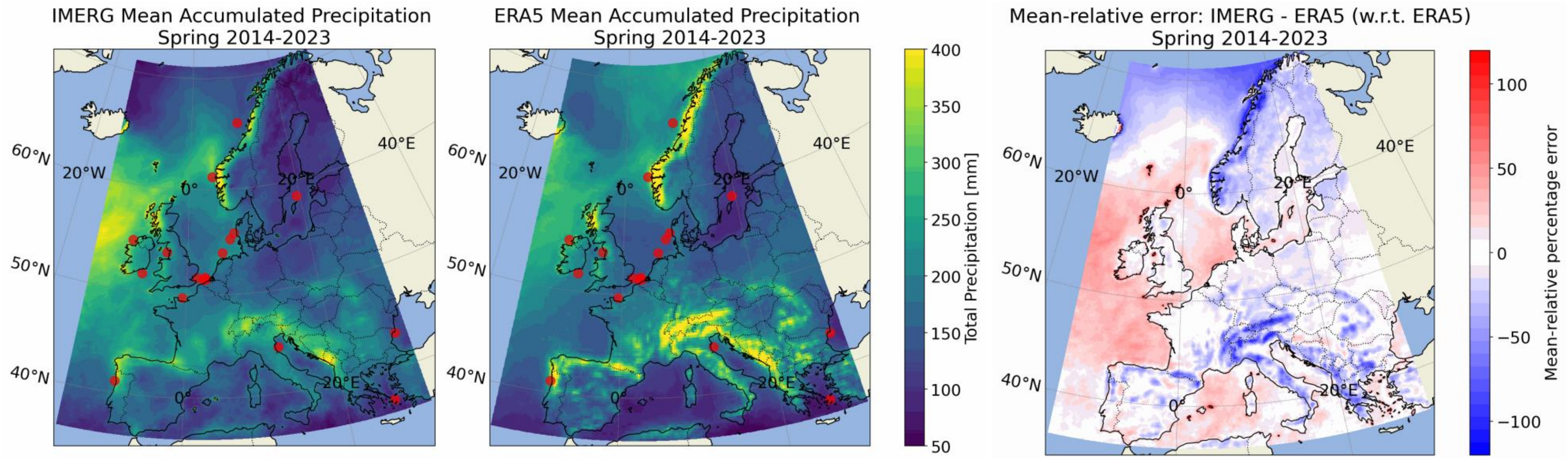
IMERG always overestimates in the North Sea. Discrepancies at mountainous regions



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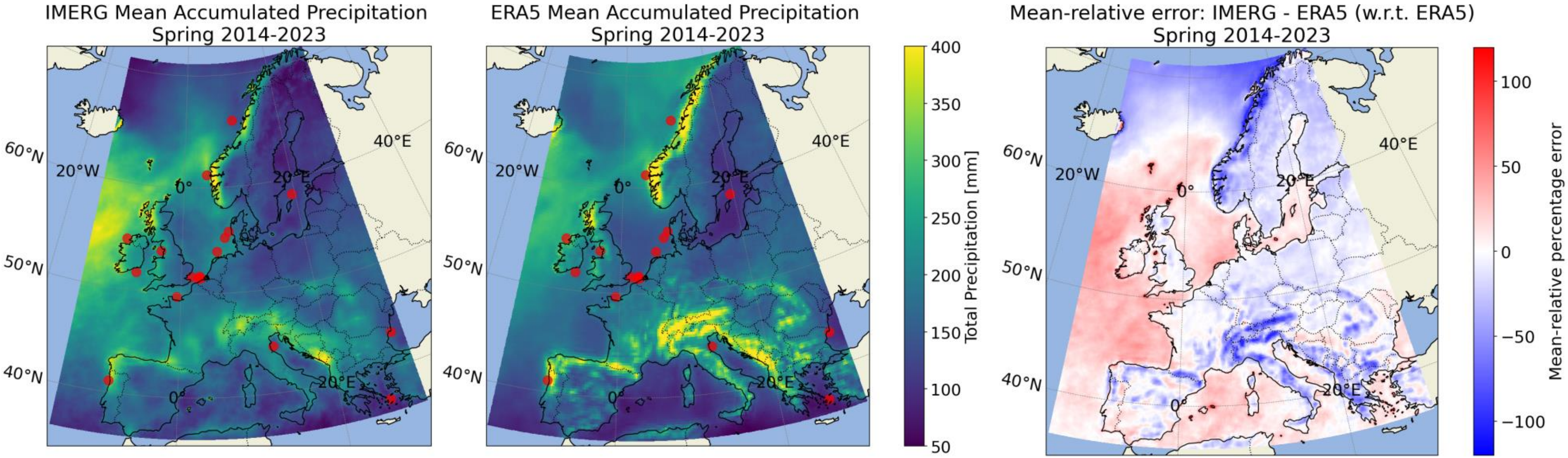

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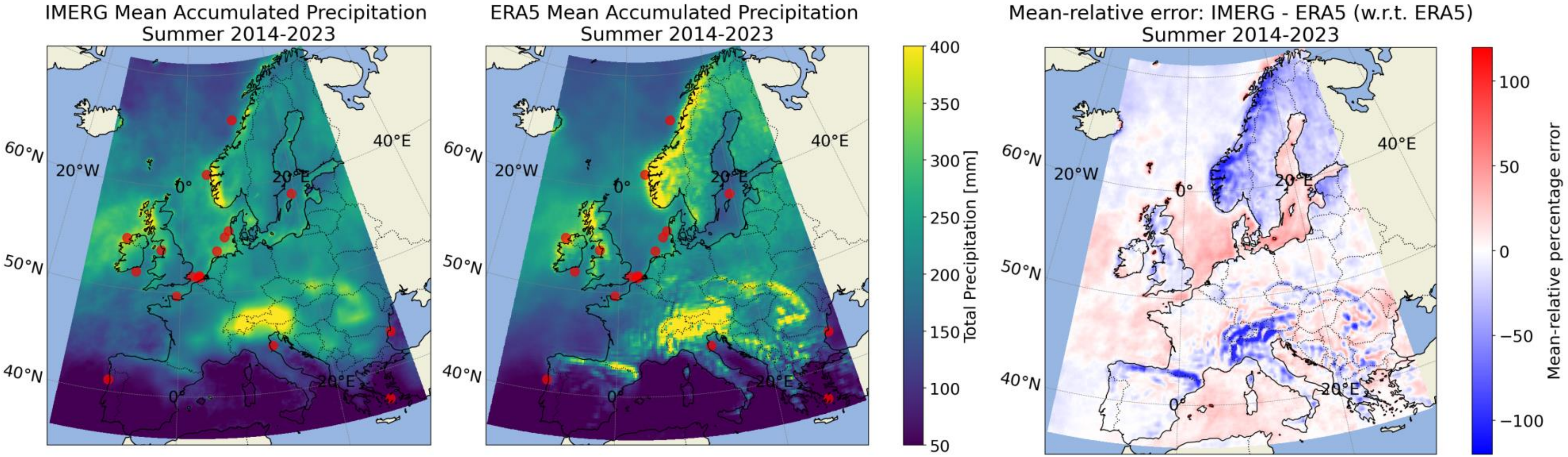

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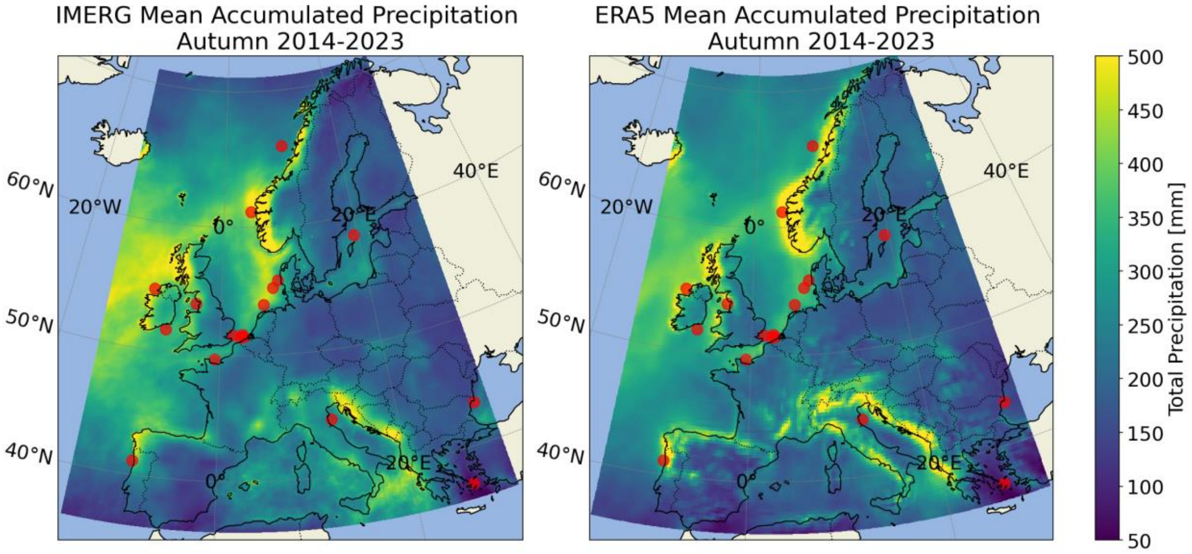

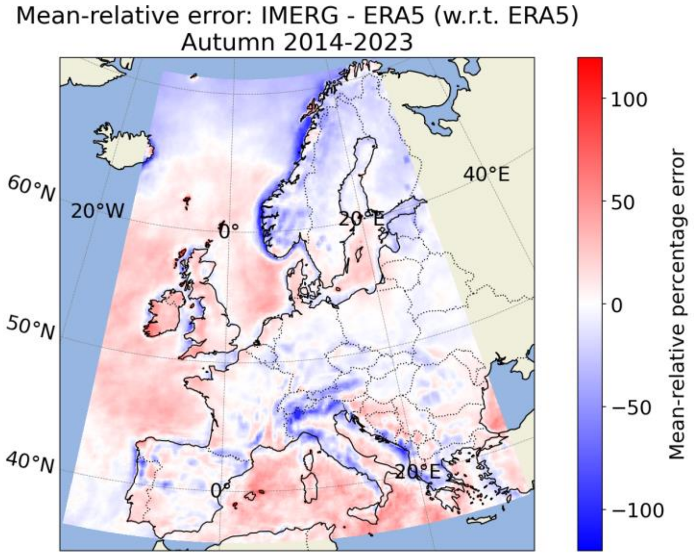

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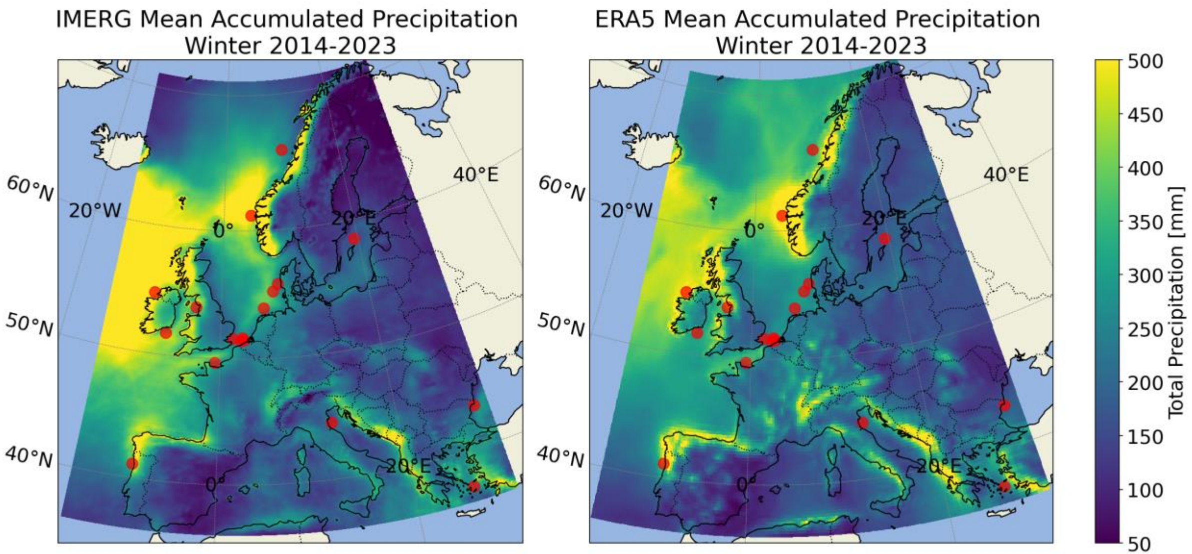

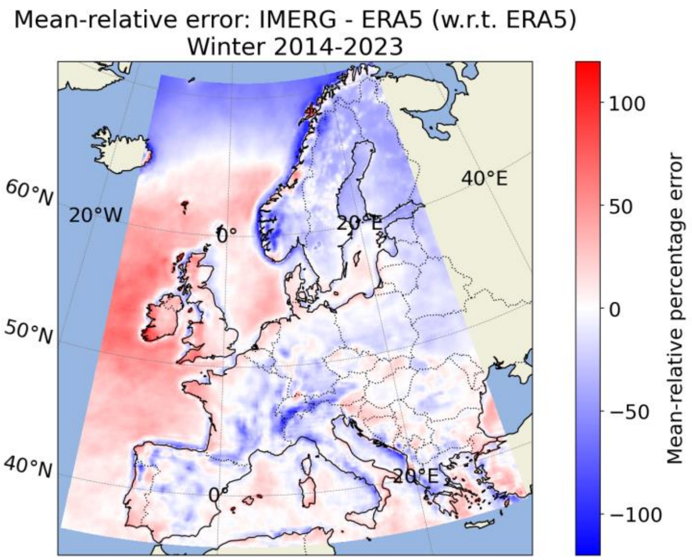

Large-scale analysis: Erosion risk map

Atmospheric drivers for leading edge erosion:

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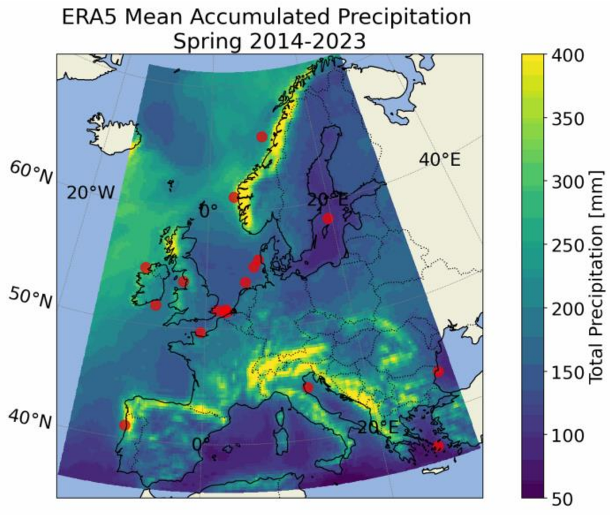

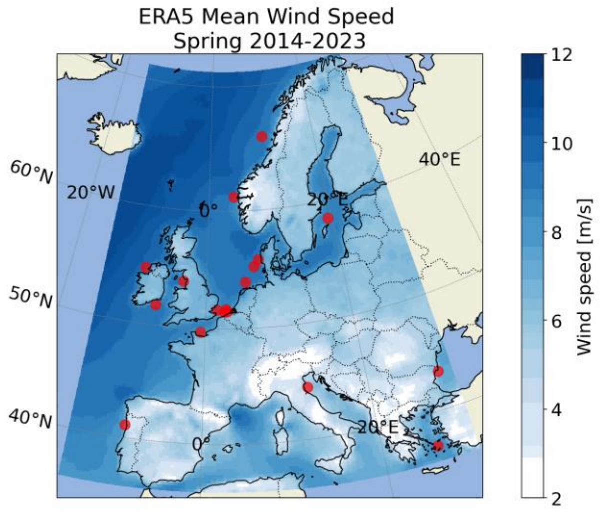

Large-scale analysis: Erosion risk map

Power curve of [IEA 10MW WT]

cut-in wspd = 4 m/s
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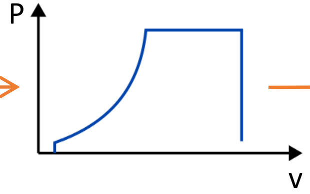
TSR = 7

Wind speed
(time series)



Tip speed
(time series)

Erosion risk:
normalized product
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Precipitation
(time series)

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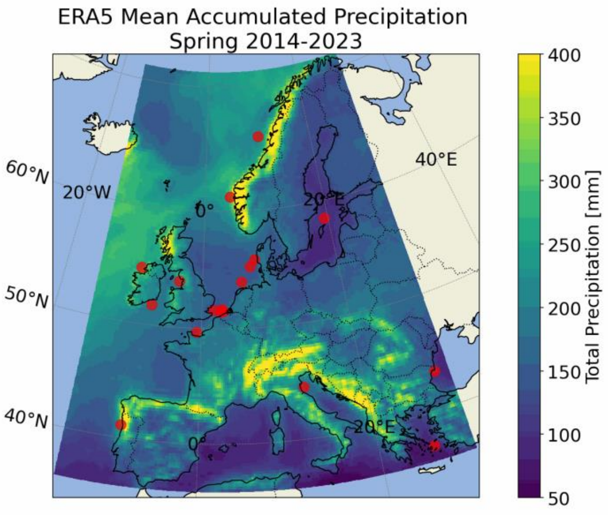

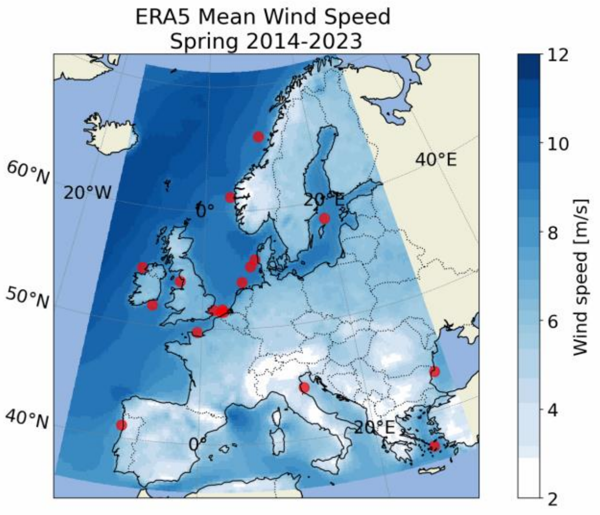

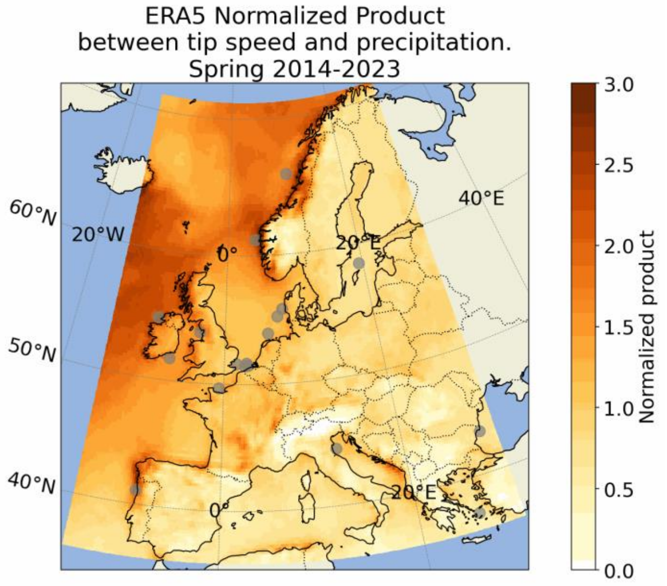

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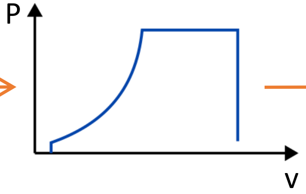

Tip speed (time series)

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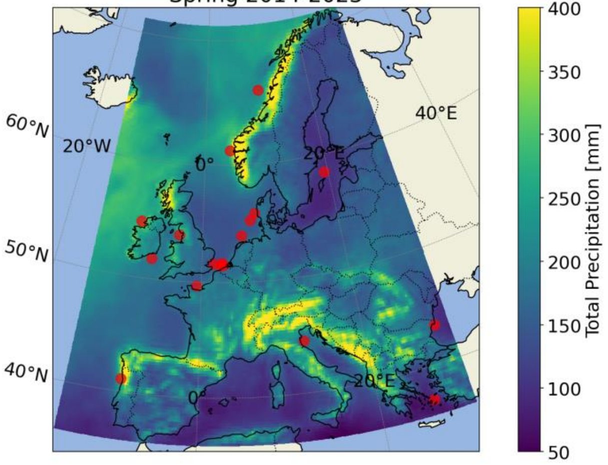
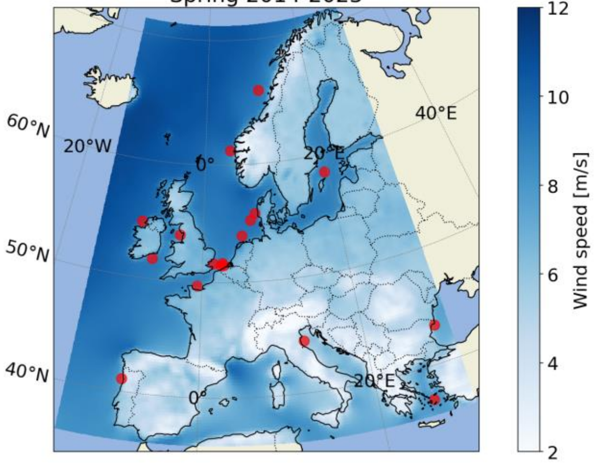
ERA5 Mean Accumulated Precipitation
Spring 2014-2023



ERA5 Mean Wind Speed
Spring 2014-2023



ERA5 Normalized Product
between tip speed and precipitation.
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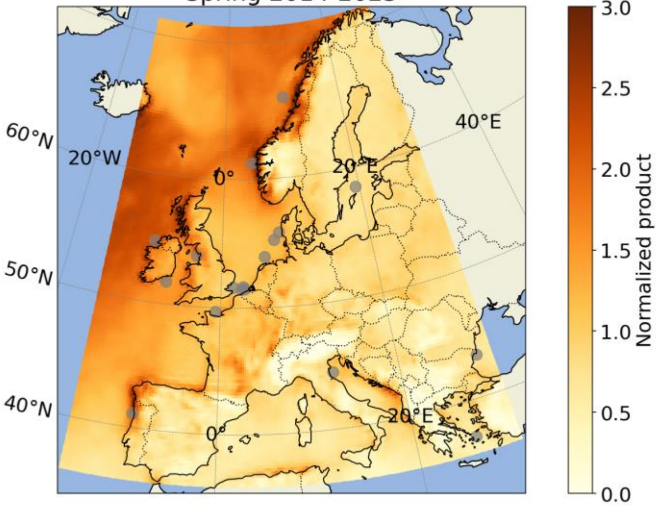

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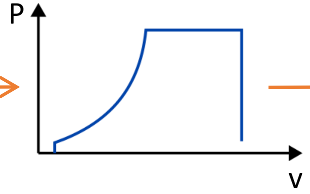

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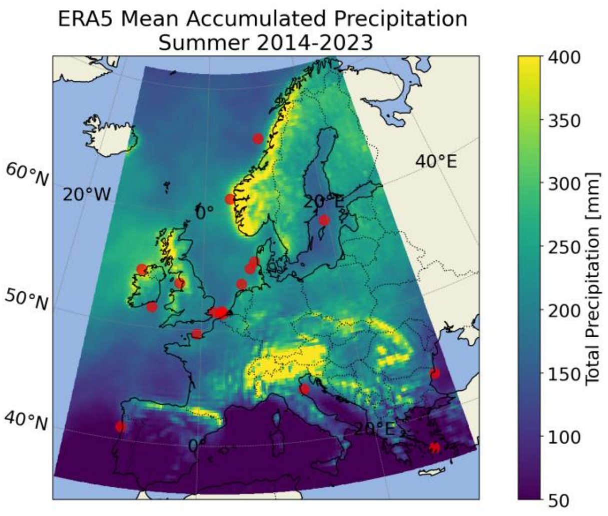

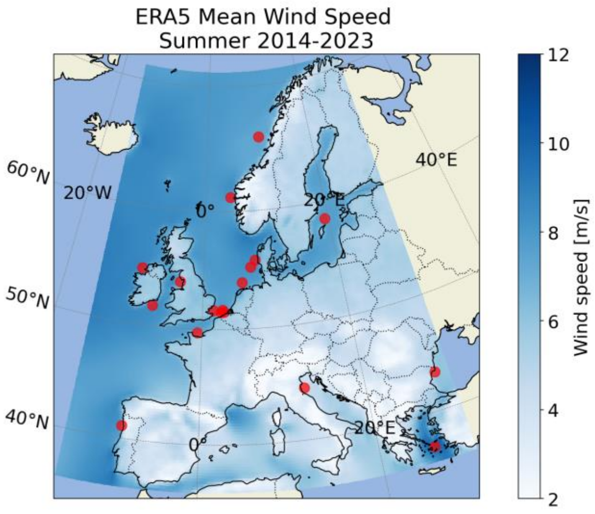

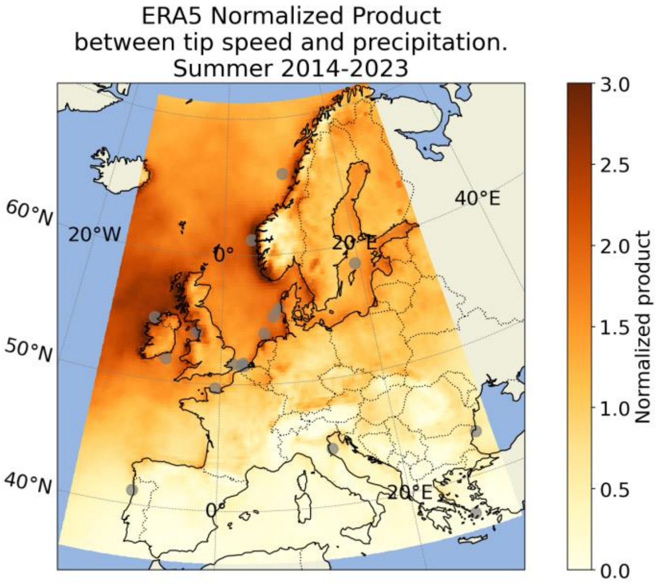

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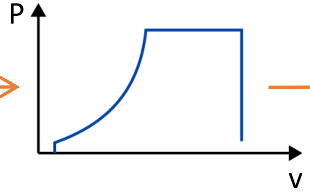

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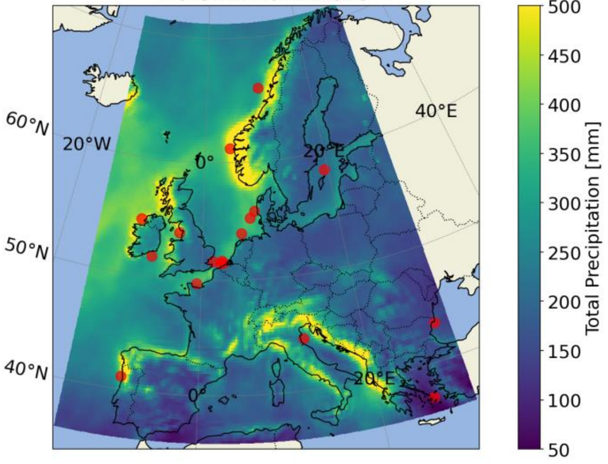

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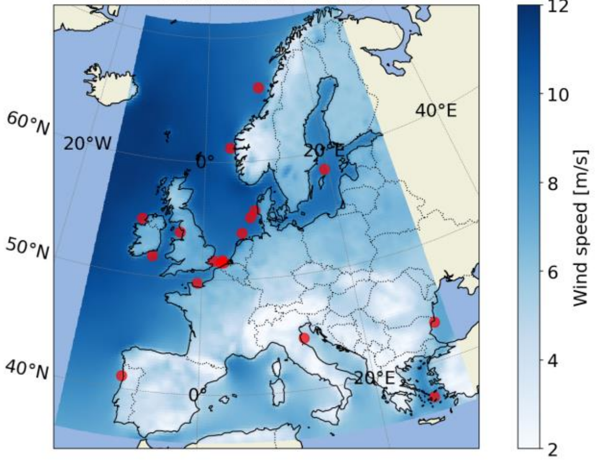

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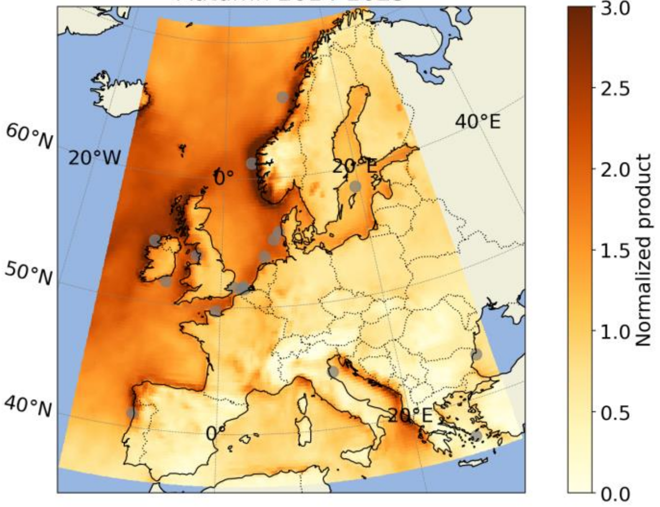

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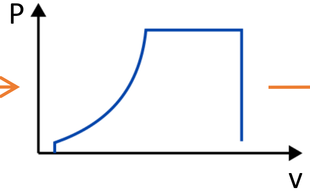

→ Tip speed (time series) → Erosion risk: normalized product (time series)

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ERA5 Mean Accumulated Precipitation
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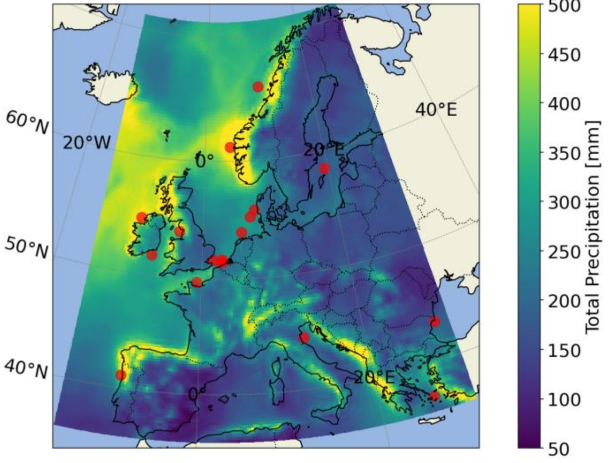

ERA5 Mean Wind Speed
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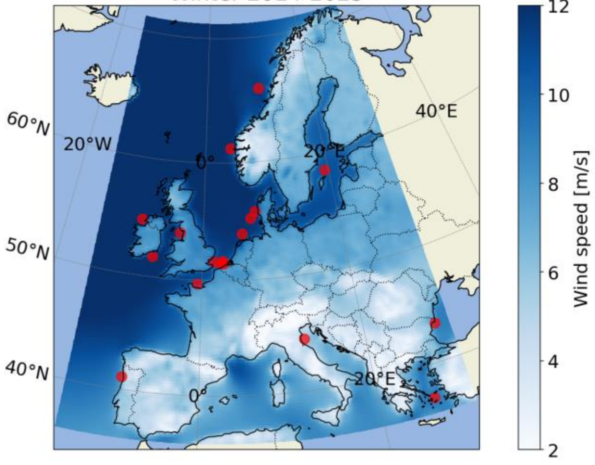

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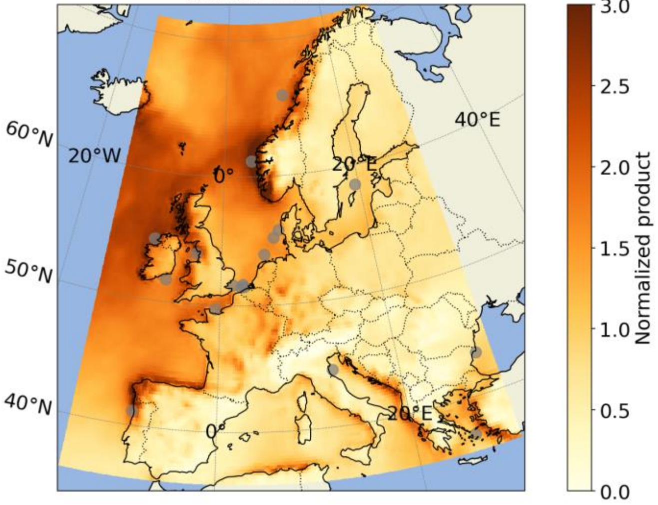

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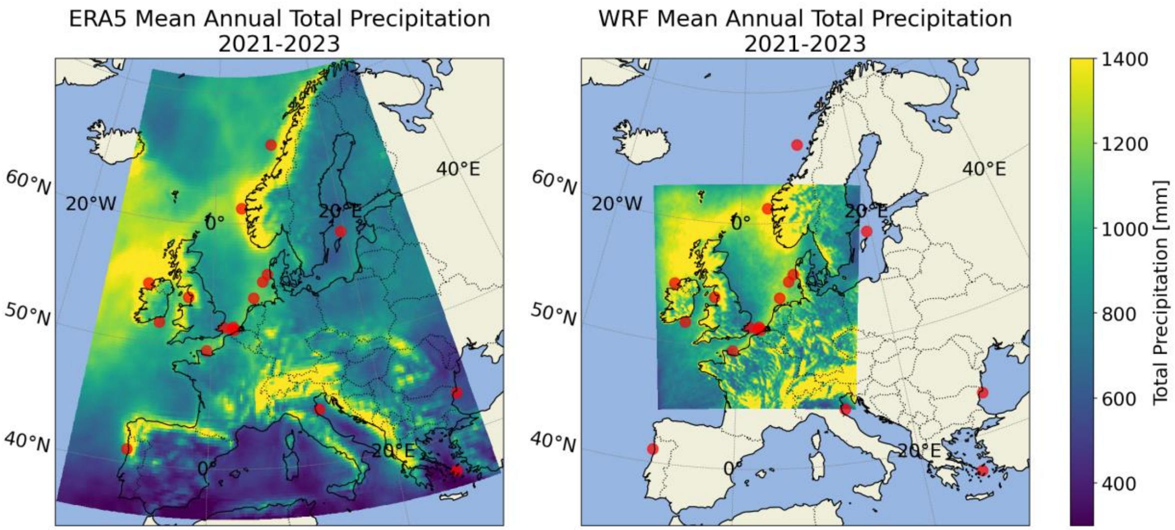
Framework: WRF model configuration



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- Physics based on New European Wind Atlas (NEWA) analysis: PBL scheme MYNN level 2.5 (5). Cumulus Kain-Fritsch scheme (1) is on for the 9-km domain only. Microphysics scheme WSM5 (4).

Three full years of WRF results from January 2021 to December 2023 in our team repo at VKI.
WRF simulations have been performed by Alexandros Palatos-Plexidas.
Data validation is ongoing.

In this work, we use 3 years of WRF data on the 9 km domain

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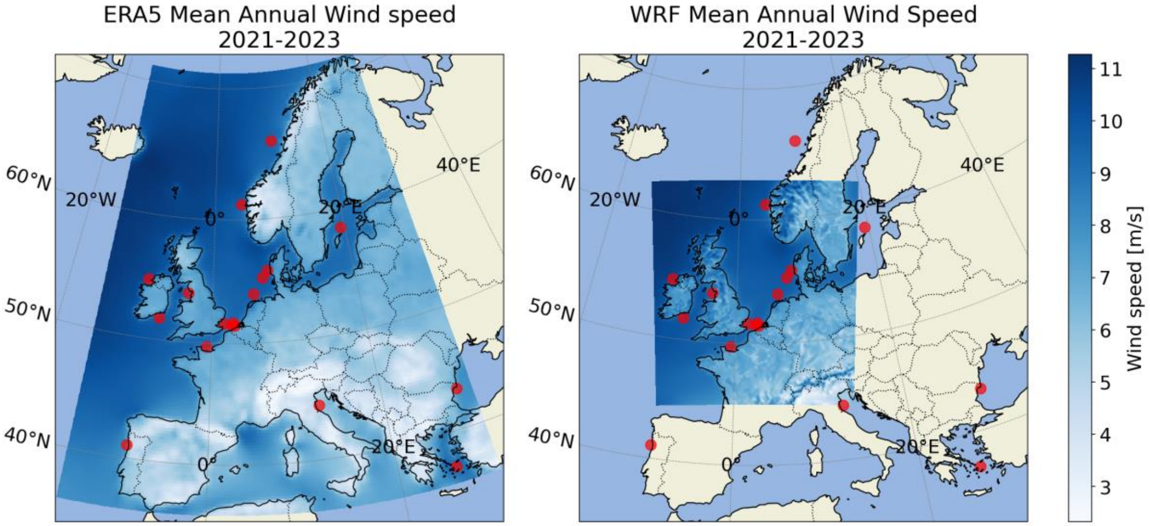

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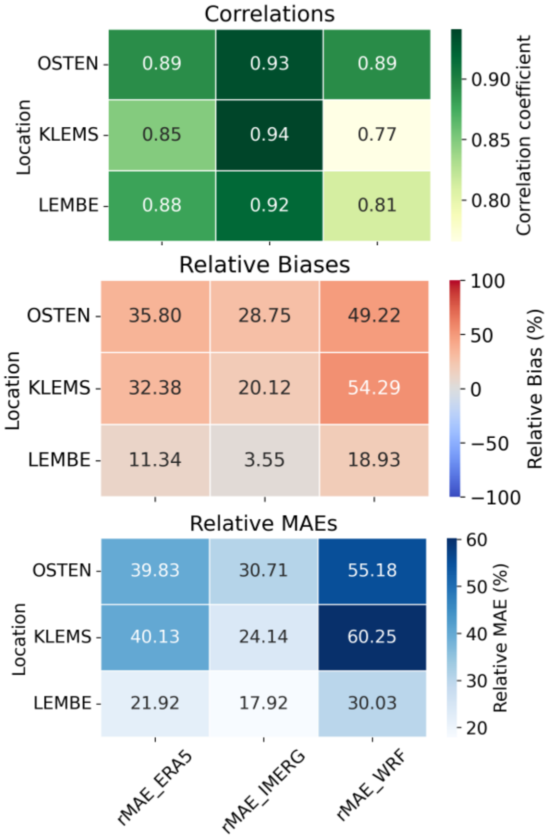
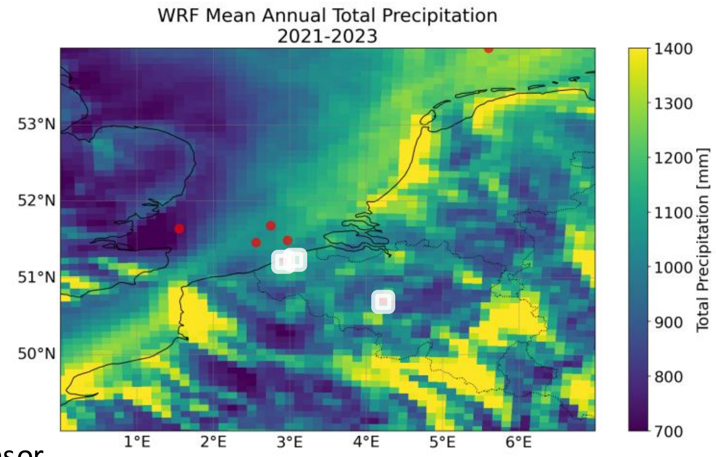
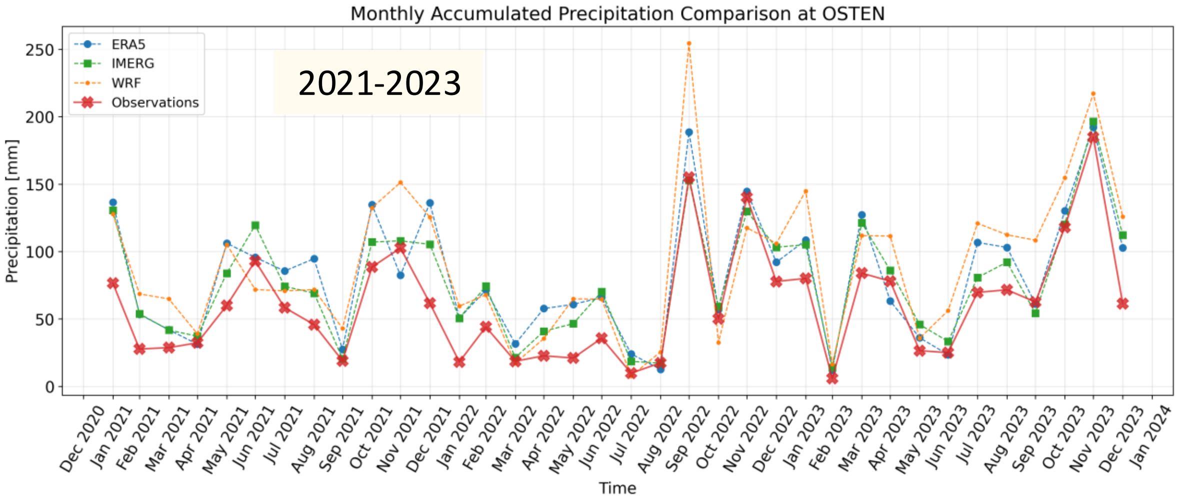
Comparing to three weather stations



ERA5, IMERG, WRF compared to weather stations: all datasets tend to overestimate precipitation. IMERG performs best.



Weather station at Ostend, Belgium
Precipitation data from Thies Clima sensor



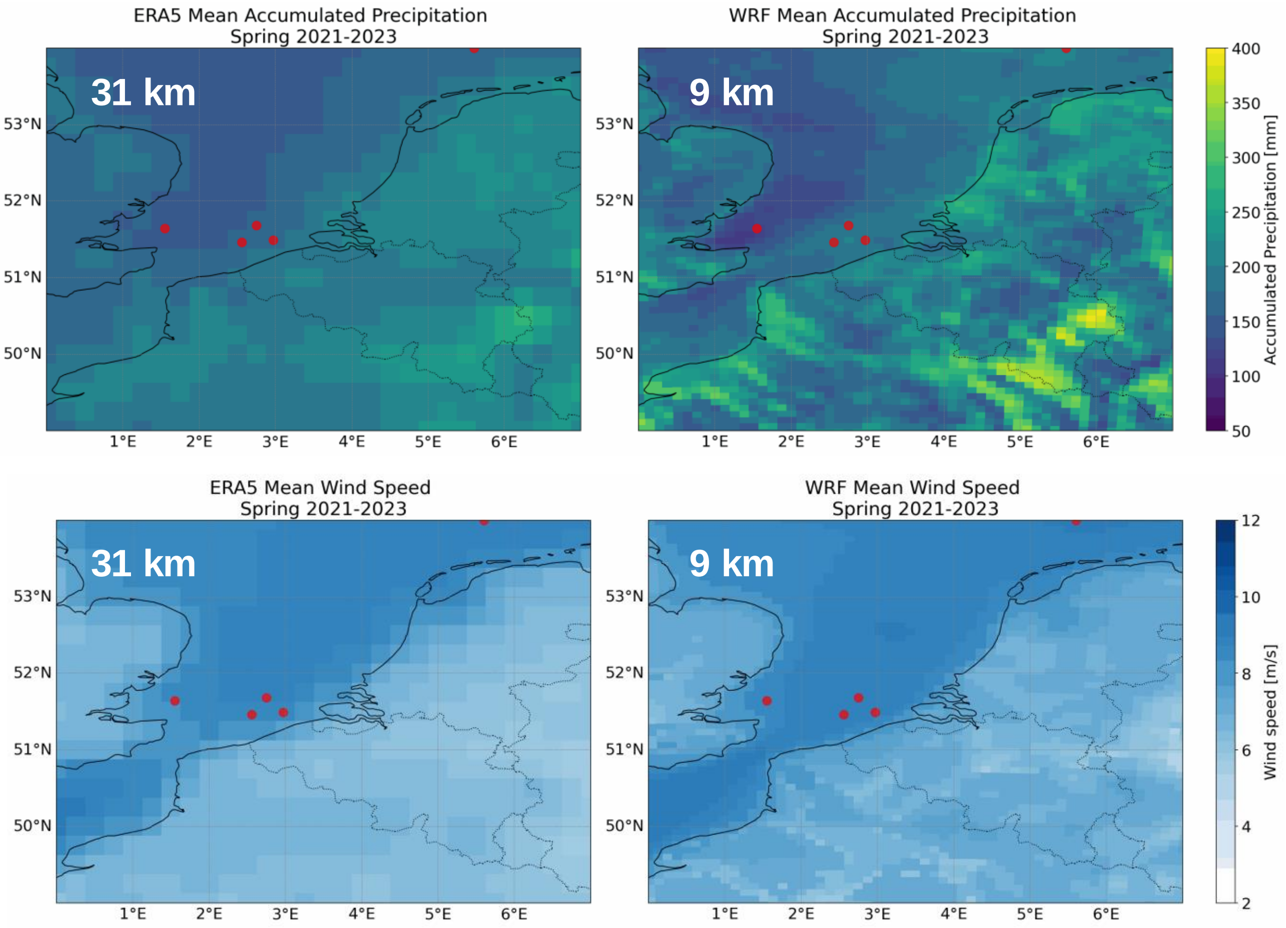
Regional insights

Close to Belgium:
ERA5 vs WRF across seasons, 2021-2023

Long-term averaged quantities

- on land: spatial heterogeneity of precipitation in WRF.
- offshore: fields are more homogeneous in both ERA5 and WRF.

WRF provides more insight in spatial and temporal patterns!



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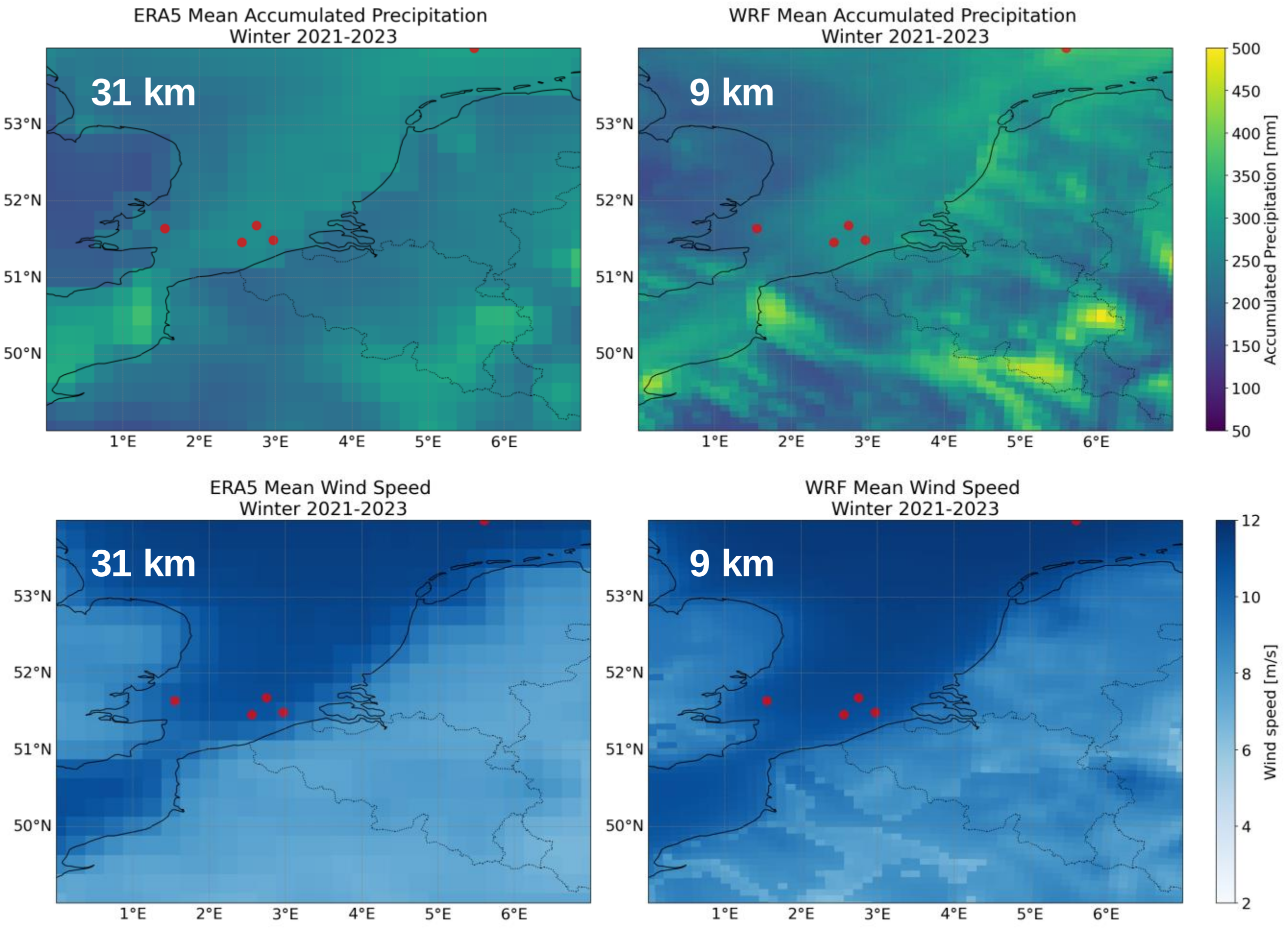

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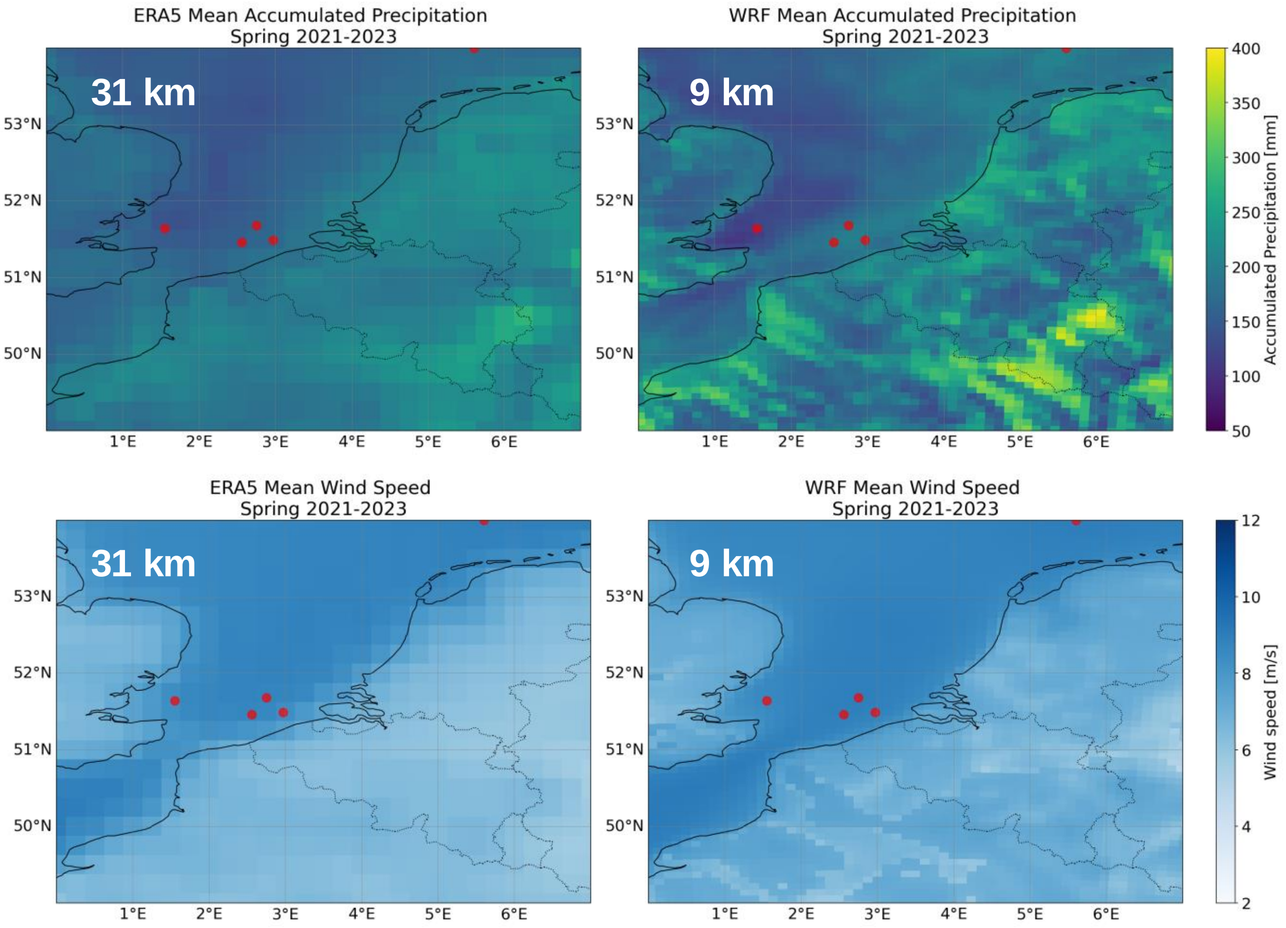

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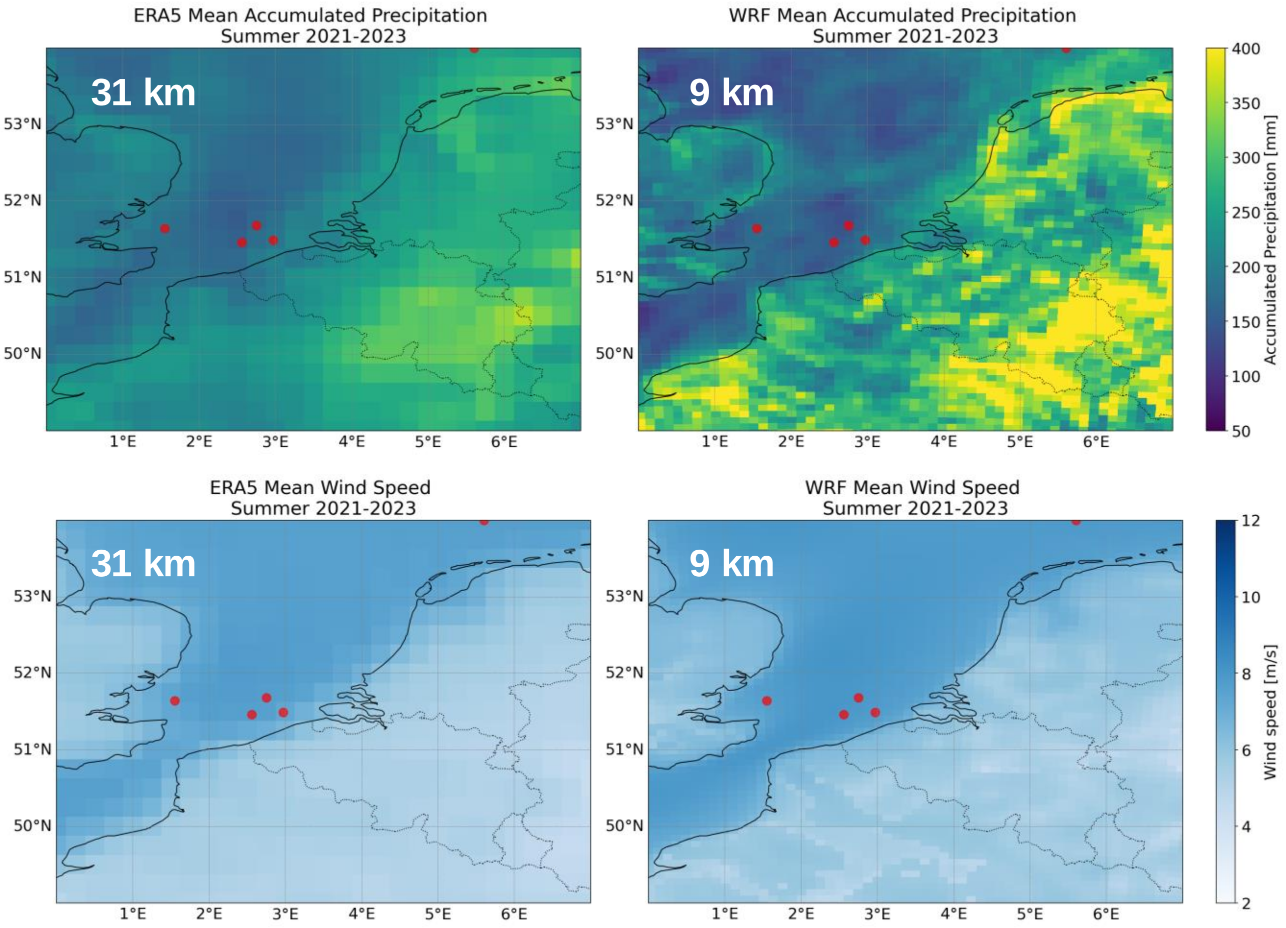

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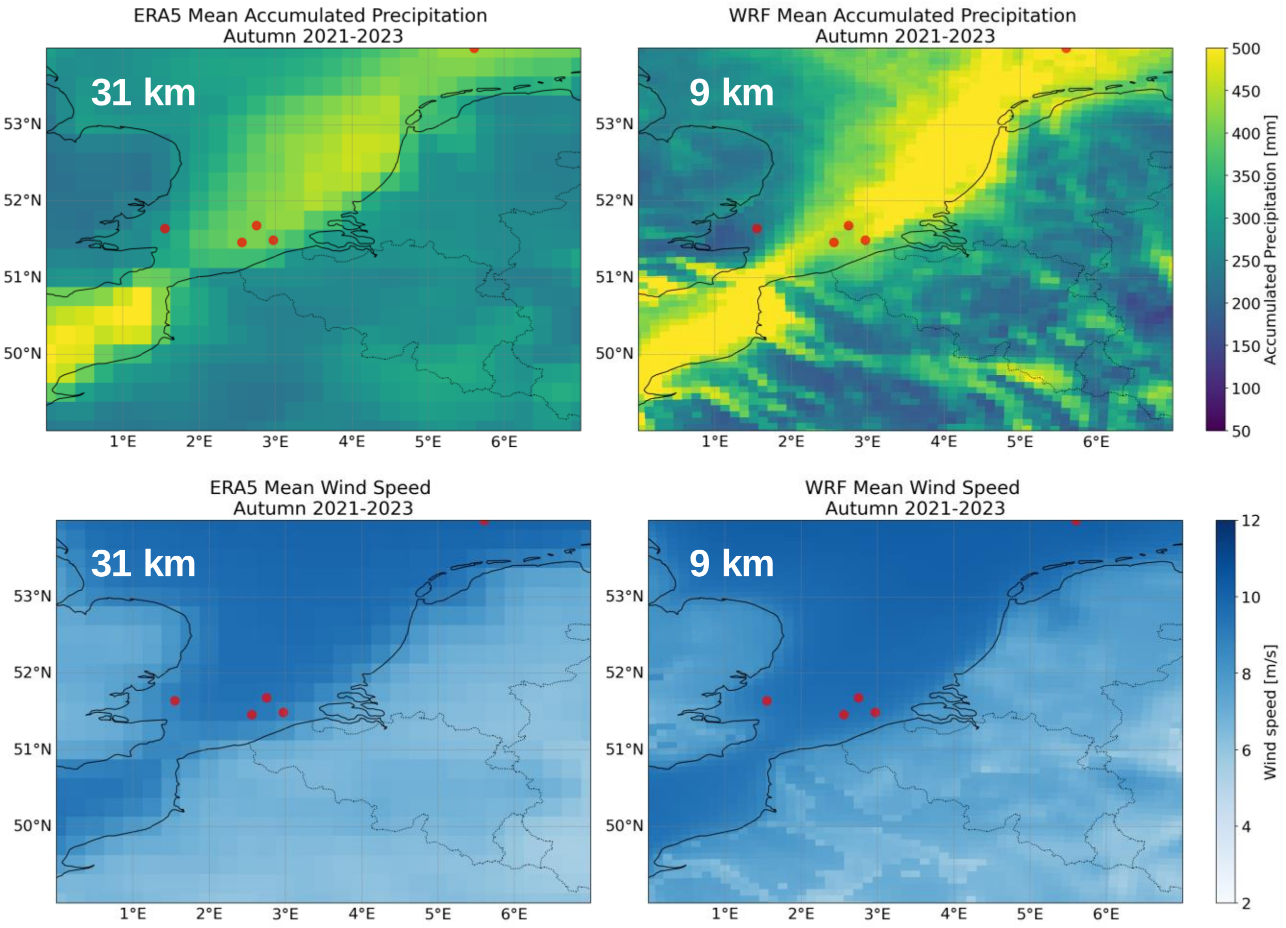

Regional insights: North Sea

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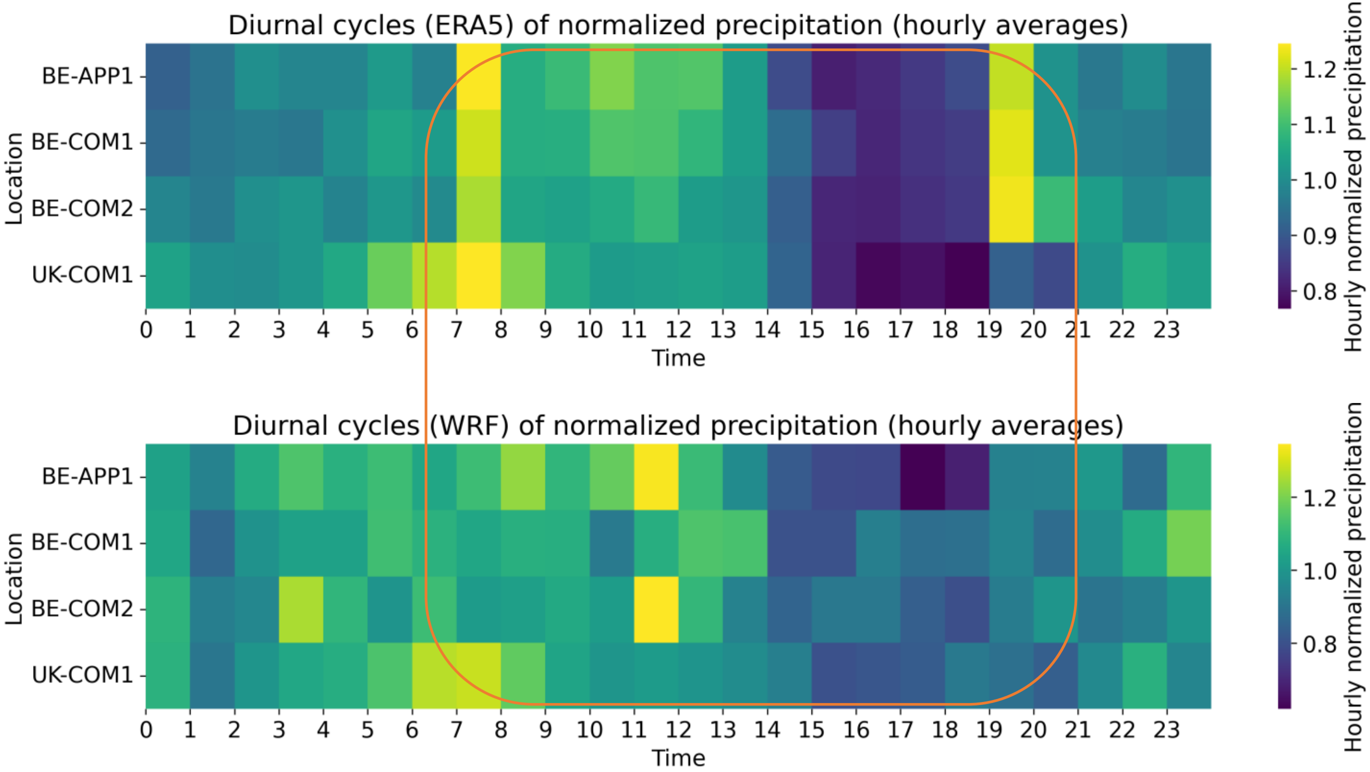

Regional insights: North Sea

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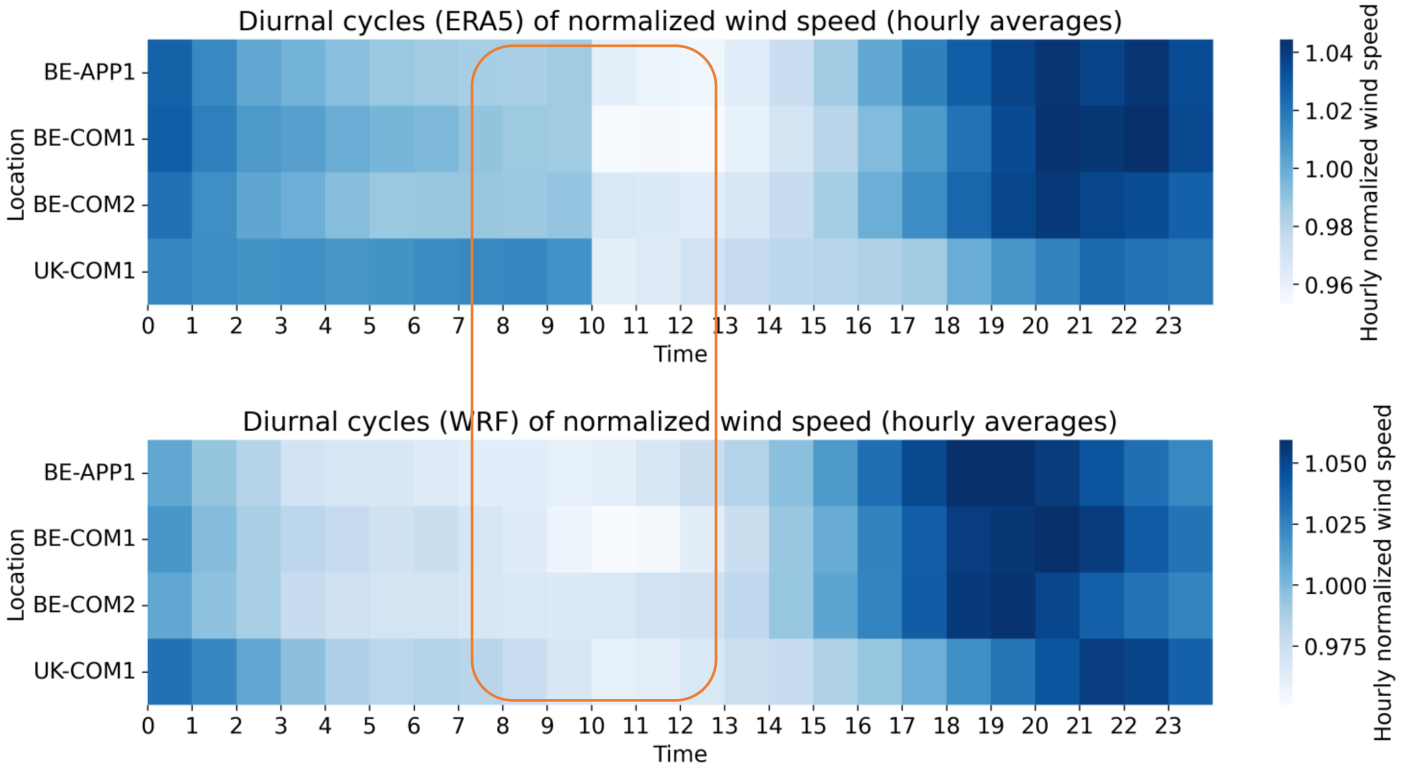
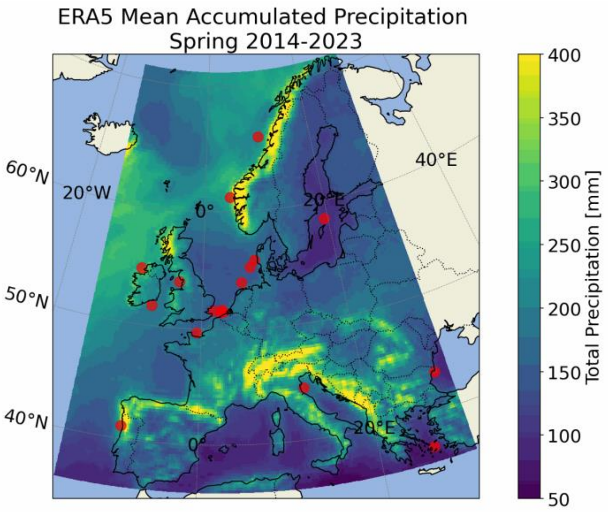
WRF depicts a more realistic cycle than ERA5, which has a data assimilation window scheduled at 09:00 → discrepancy when transitioning from one cycle to another (known issue in ERA5).

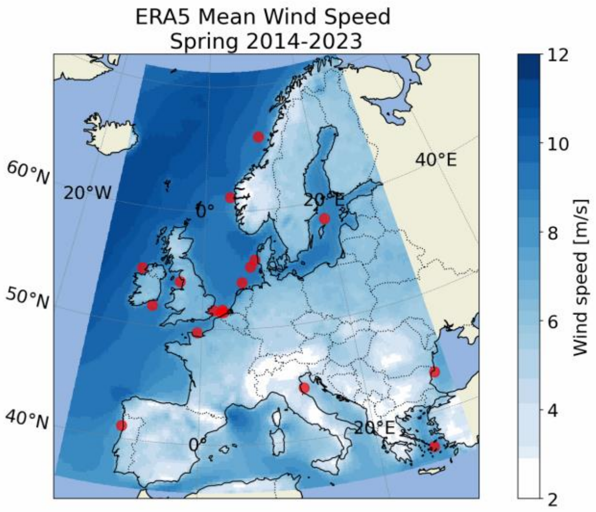
This can lead to overestimated wind speed (and consequently power) before 09:00 with ERA5.

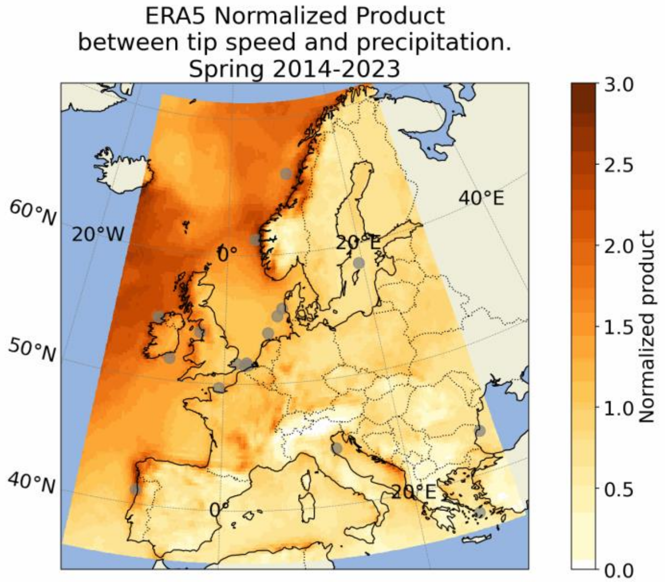


Conclusions

- Observed discrepancies between ERA5 and IMERG on-land and offshore.
- Erosion risk map estimated as a product between 10-year time series of precipitation and tip speed; seasonal variability.
- Intercomparison of IMERG, ERA5 and WRF precipitation with Belgian weather station data across 3 years: consistent estimates by all datasets.
- WRF showcases spatial heterogeneity of precipitation fields on-land, but not offshore.







This work is funded by the Flemish agency for Innovation and Enterpreneurship (VLAIO), as well as by the BeFORECAST project, which is supported by the Energy Transition Fund of the Belgian Federal Government.

Thank you !

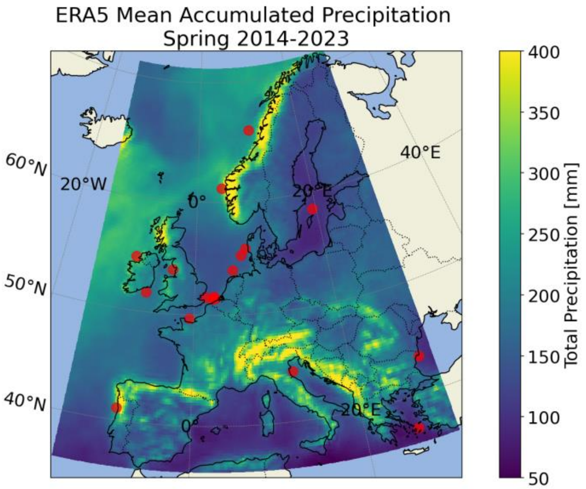
Discussion ?

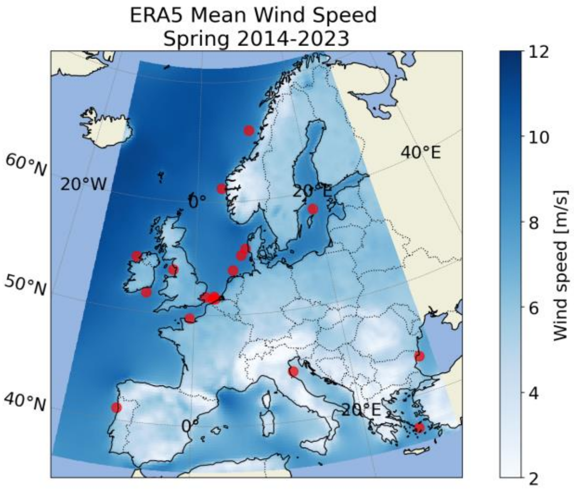
Wind and Precipitation Conditions in Offshore Wind Farm Zones: Insights from Satellites and Weather Simulations

Tsvetelina Ivanova
PhD candidate
tsvetelina.ivanova@vki.ac.be

DeepWind 2025

backup


ERA5 Mean Accumulated Precipitation
Spring 2014-2023
60°N
50°N
40°N
20°W
0°
20°E
40°E
Total Precipitation [mm]
400
350
300
250
200
150
100
50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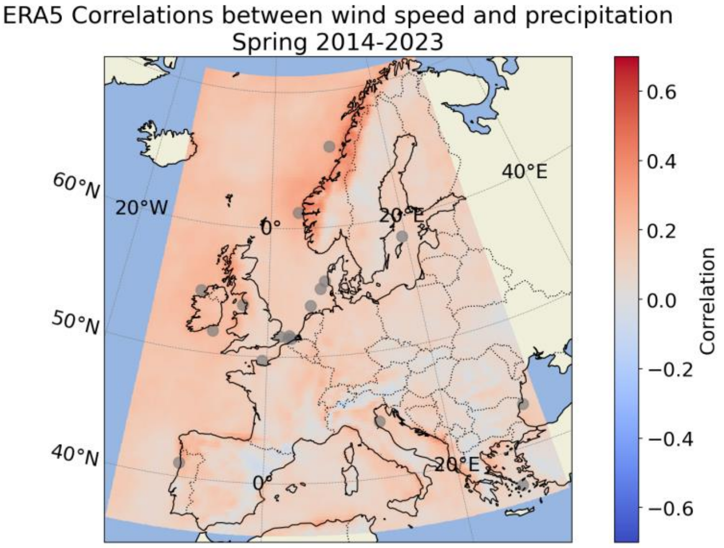
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0°
20°E
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0.4
0.2
0.0
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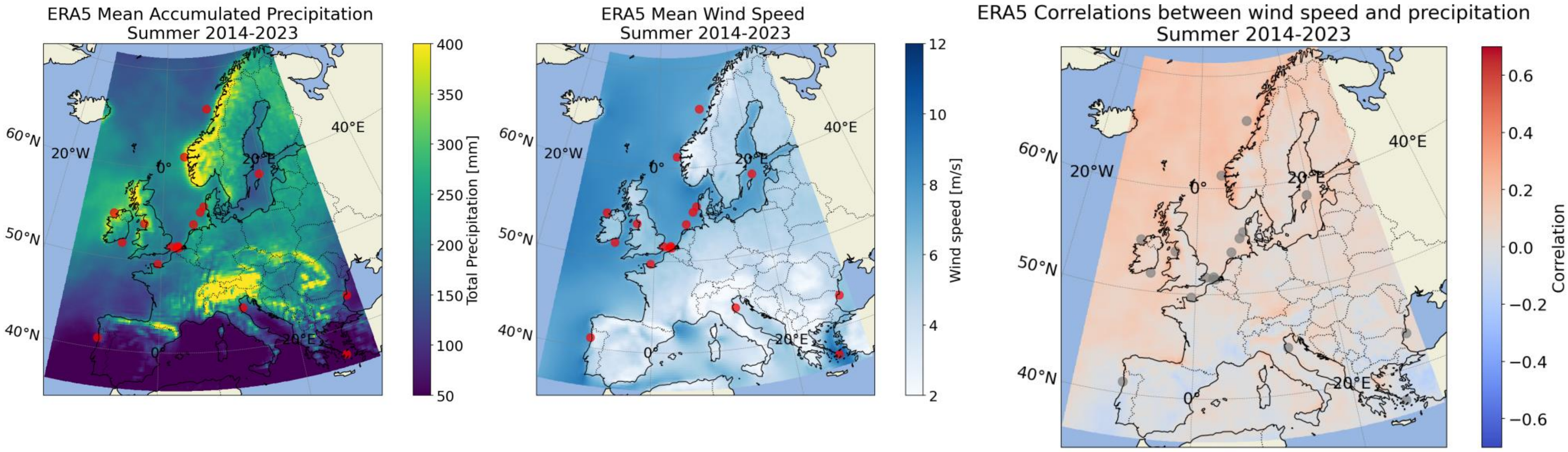
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Total Precipitation [mm]
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100
150
200
250
300
350
400
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40°N
20°W
0°
20°E
40°E
ERA5 Mean Wind Speed
Summer 2014-2023
Wind speed [m/s]
2
4
6
8
10
12
ERA5 Correlations between wind speed and precipitation
Summer 2014-2023
Correlation
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−0.4
−0.2
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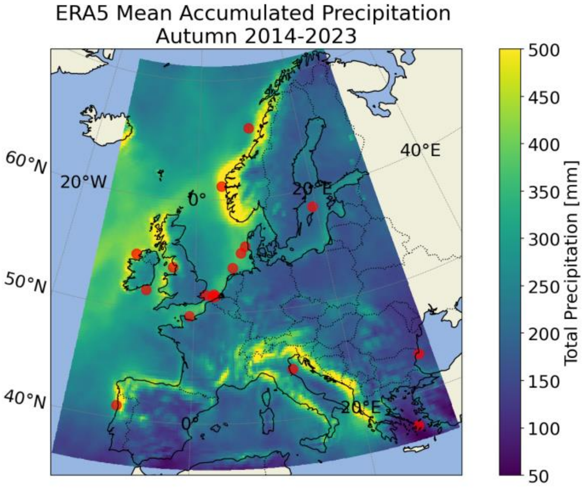
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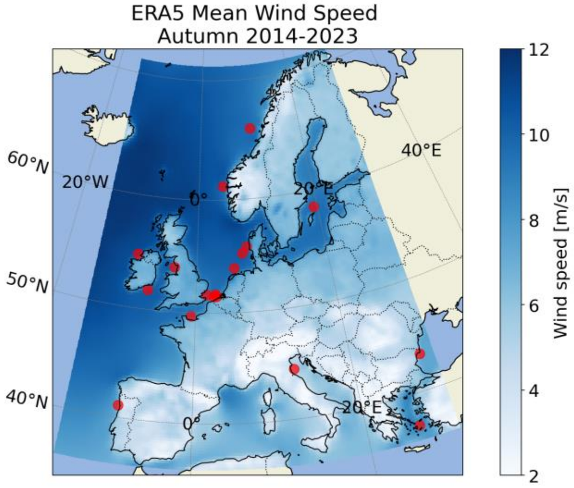
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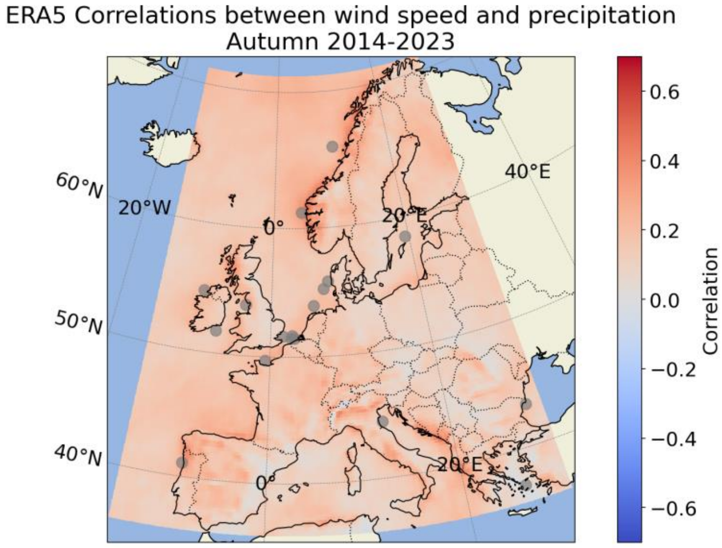
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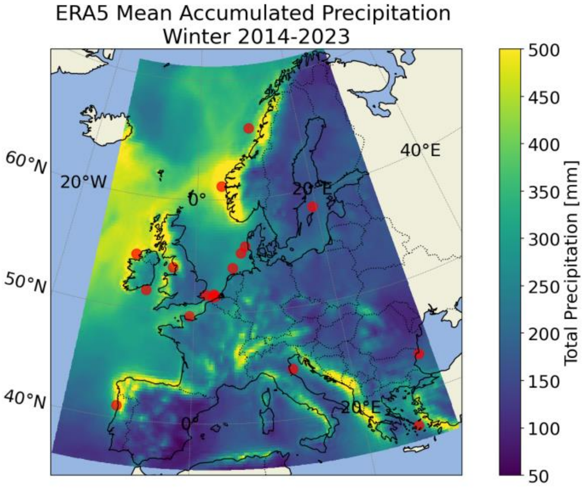

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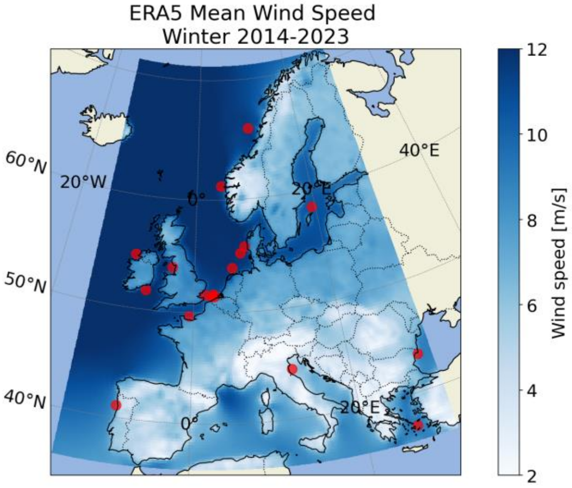

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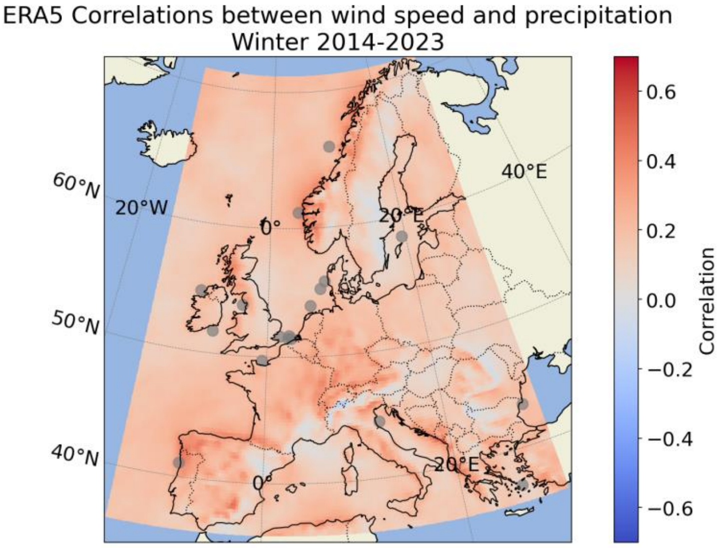

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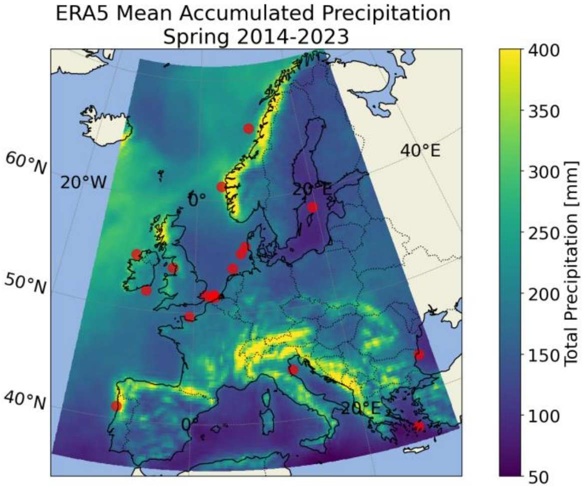
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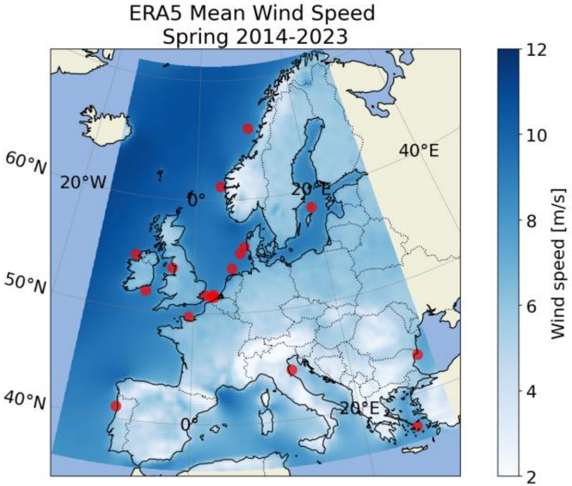
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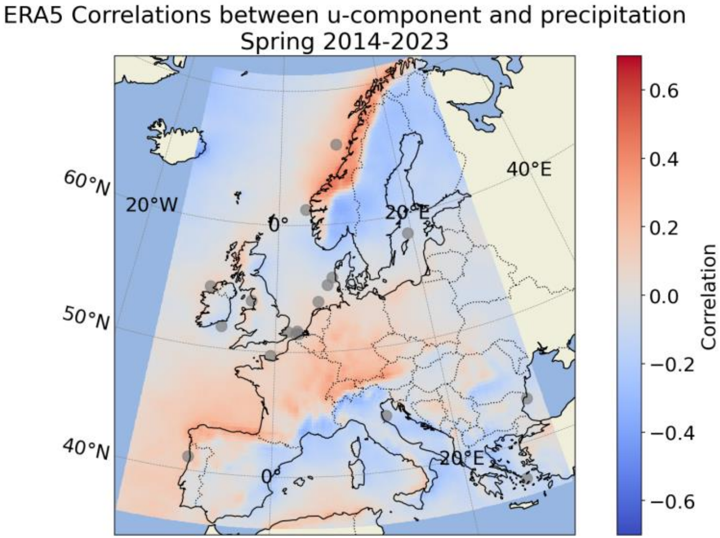
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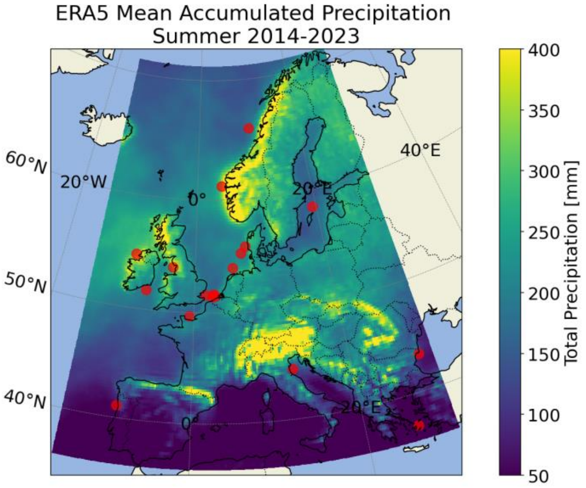
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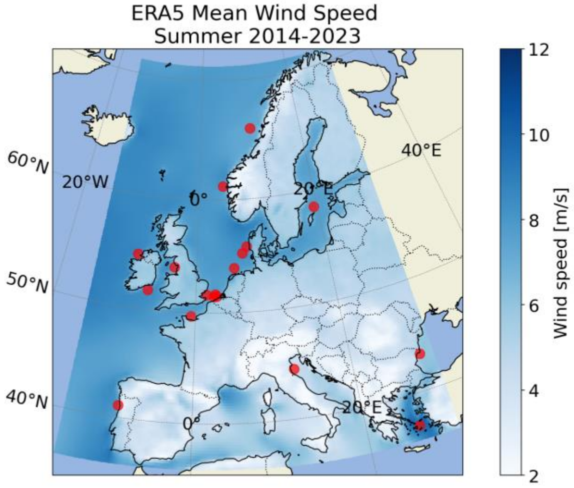
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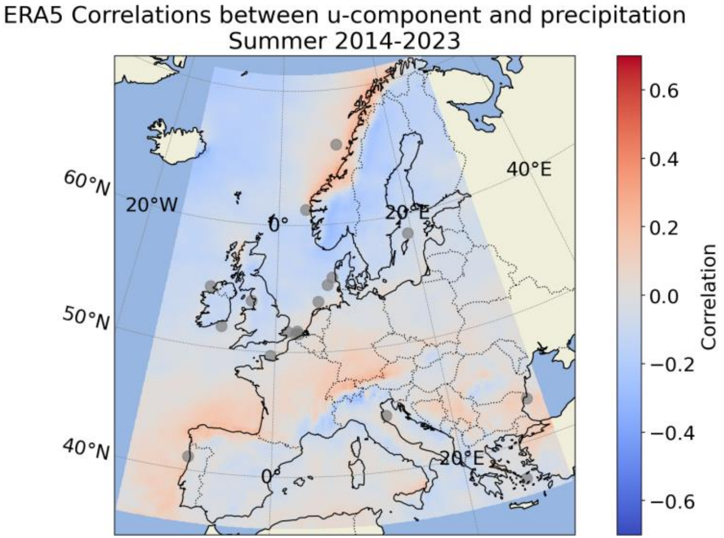
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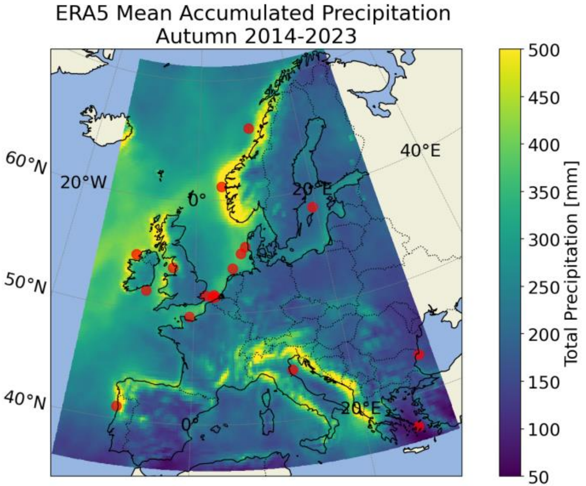
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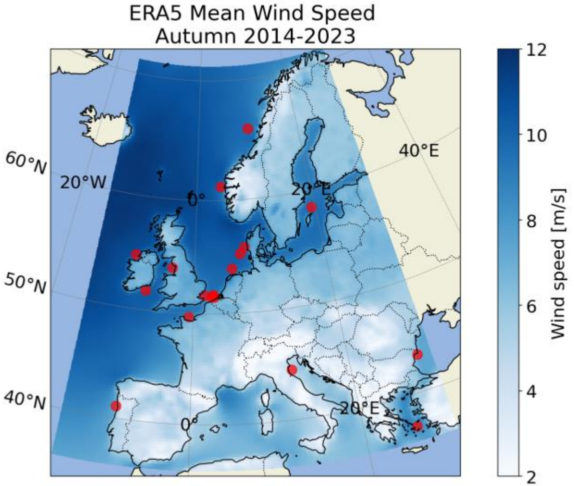
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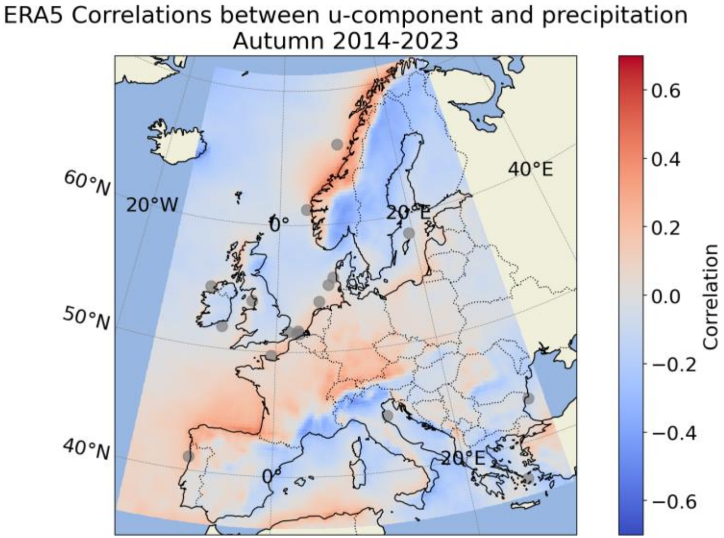
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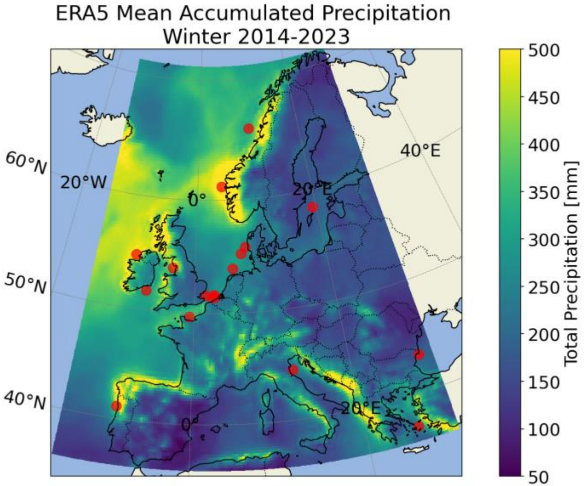
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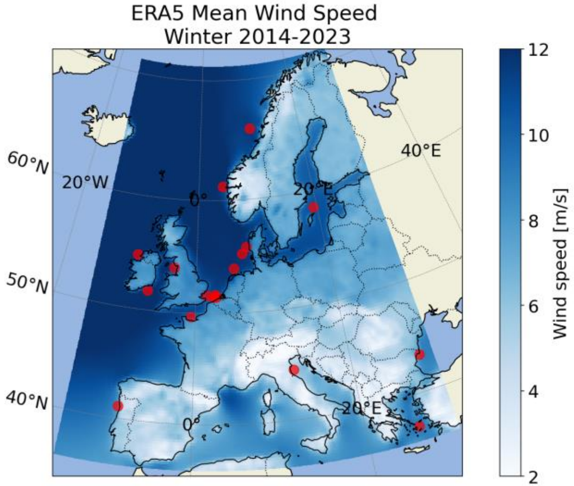
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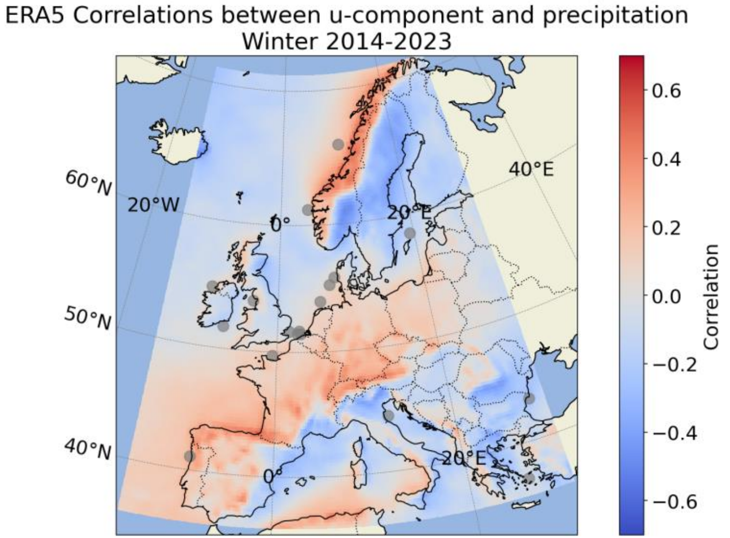
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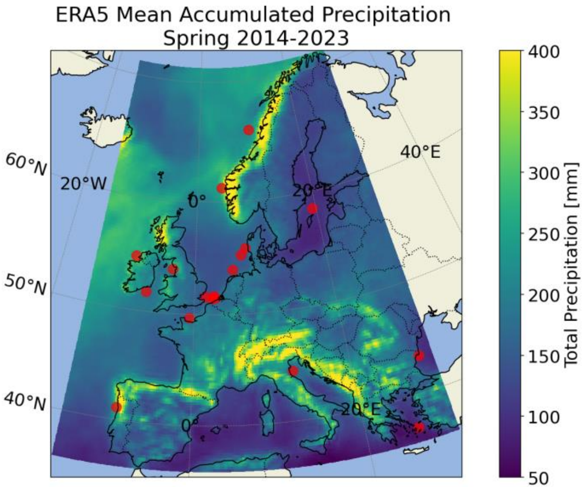
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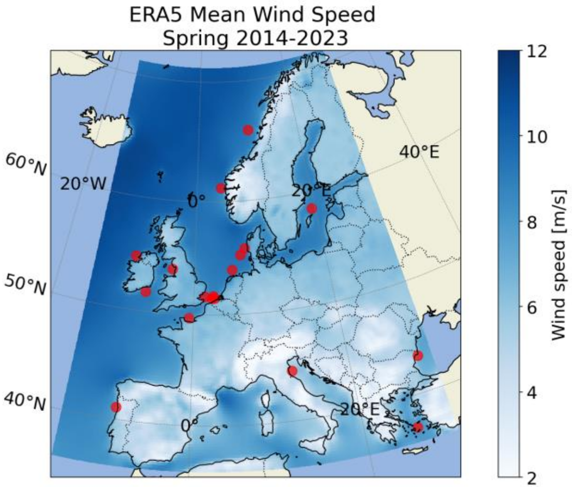
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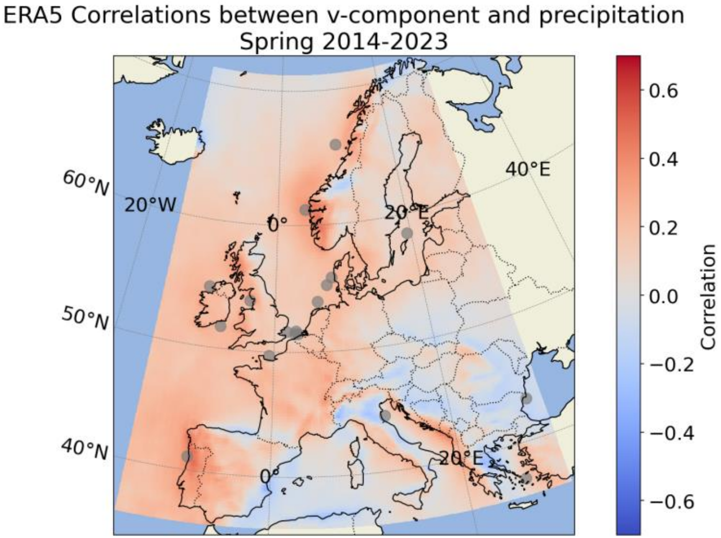
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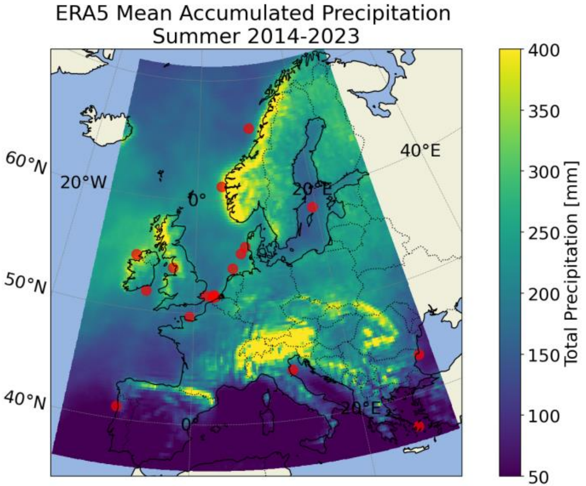

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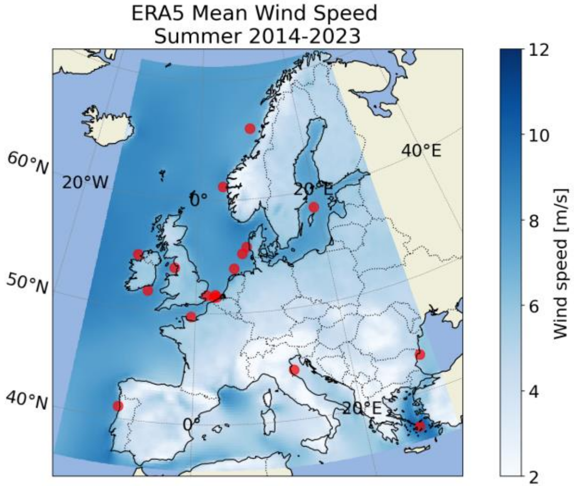

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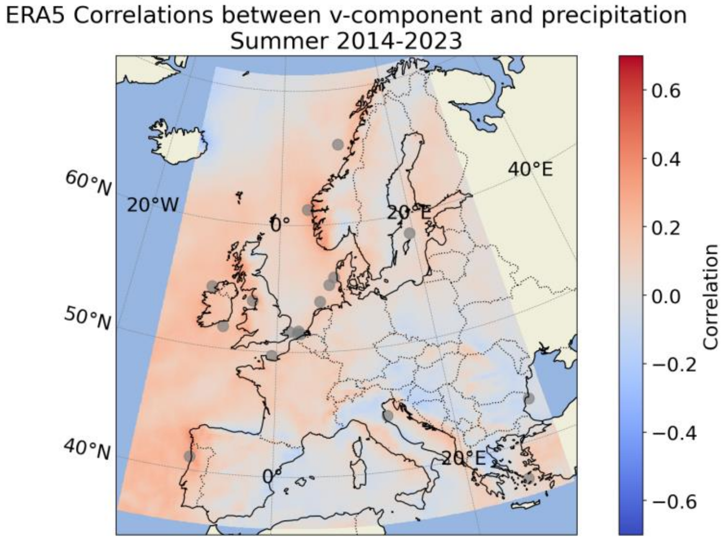

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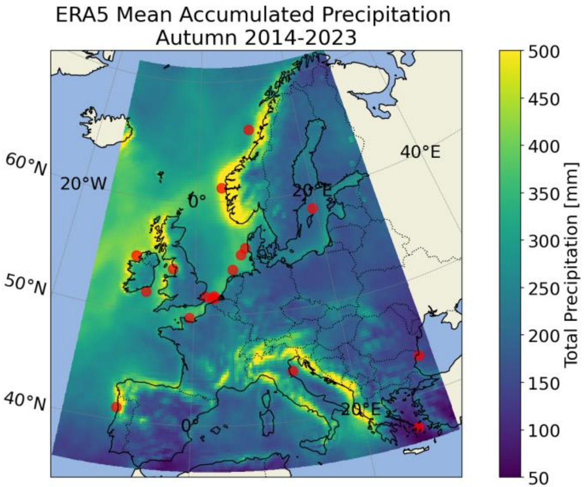
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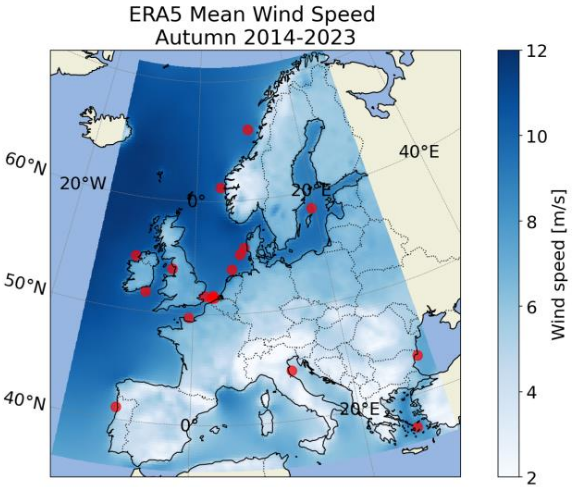
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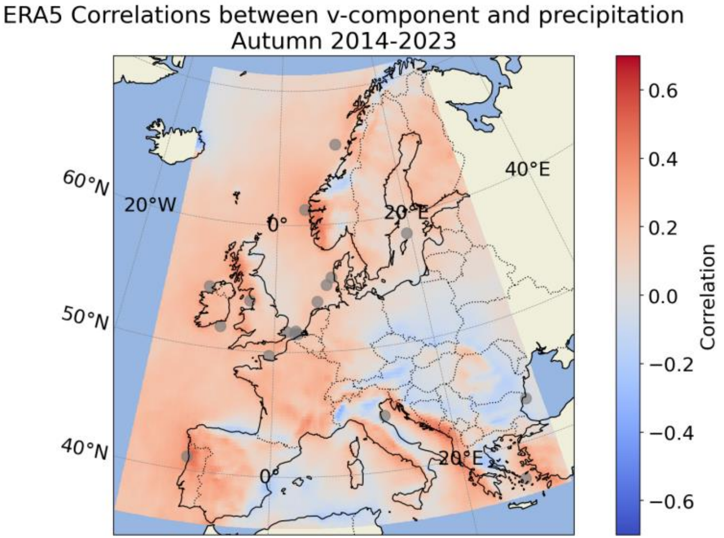
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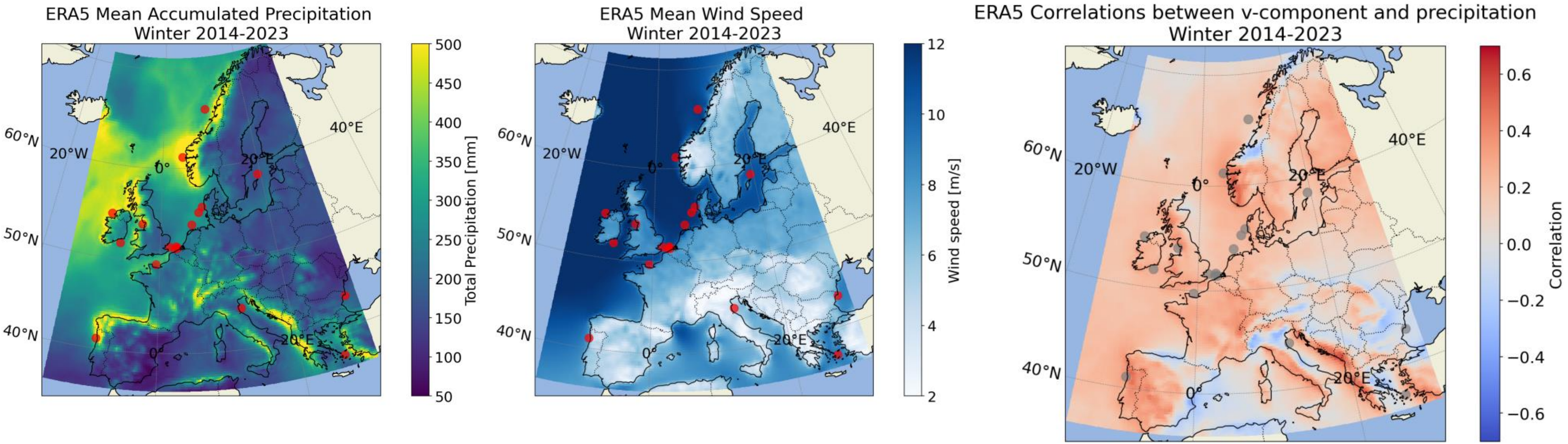
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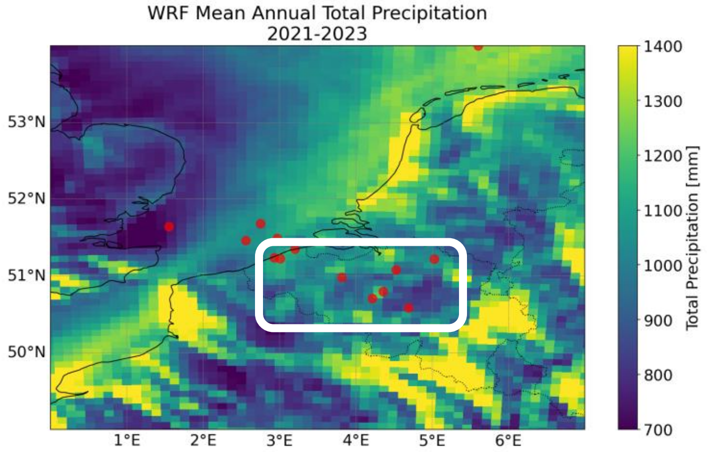
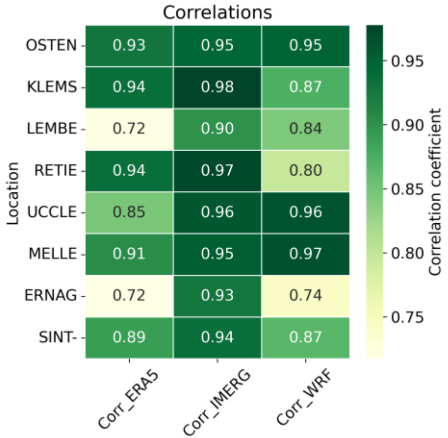
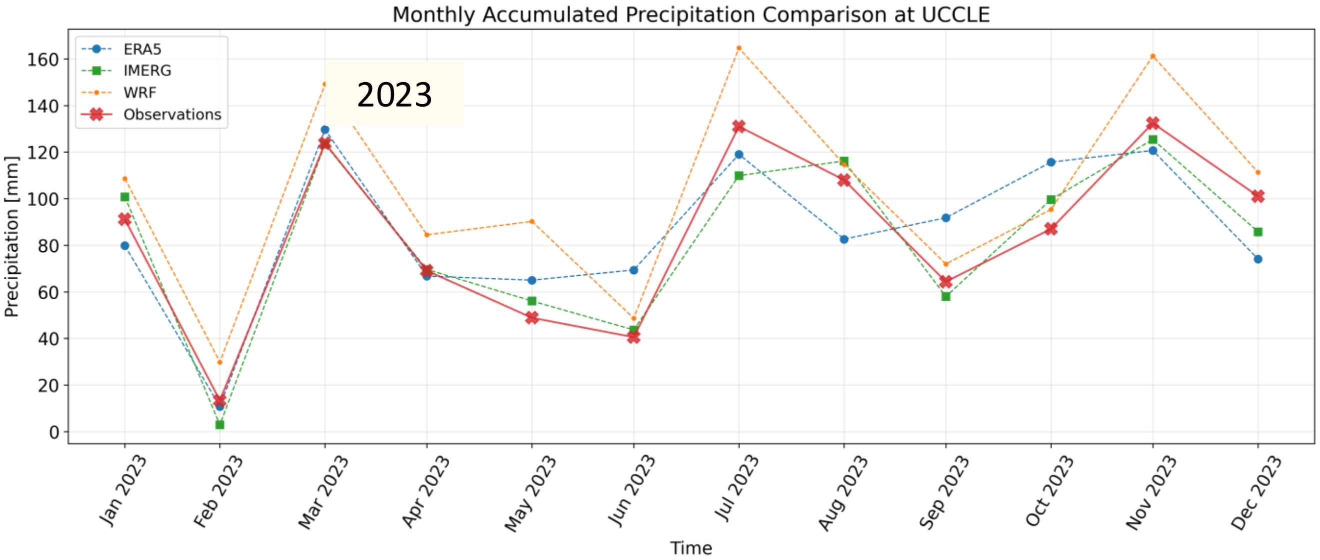
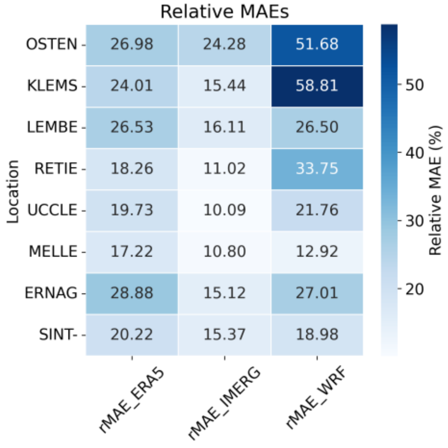
Comparing to local data

Additional eight automatic weather stations in Belgium

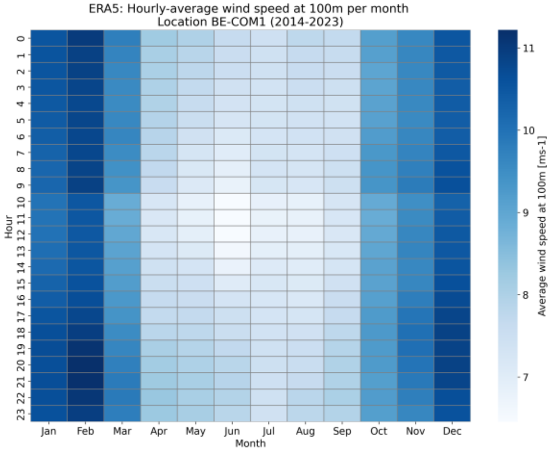


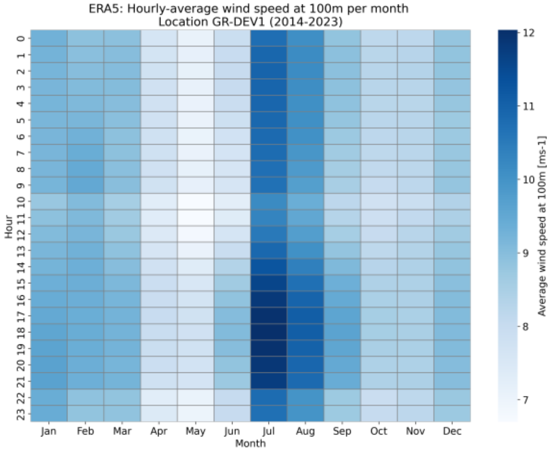


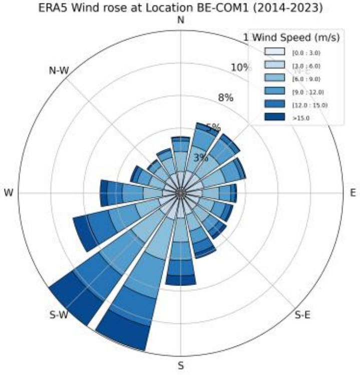


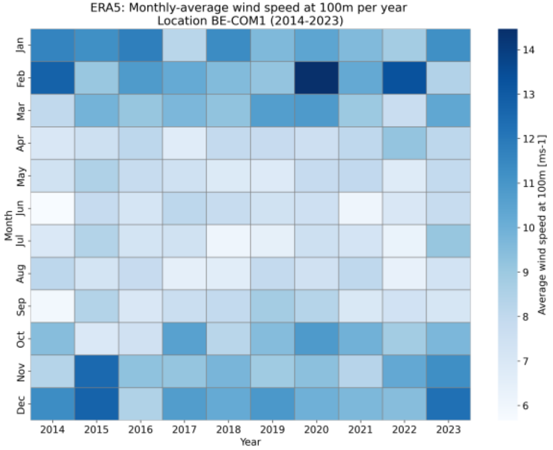


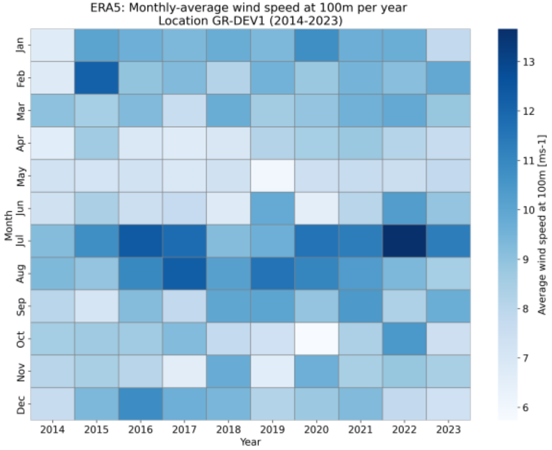
Results at two locations: North Sea and Aegean Sea

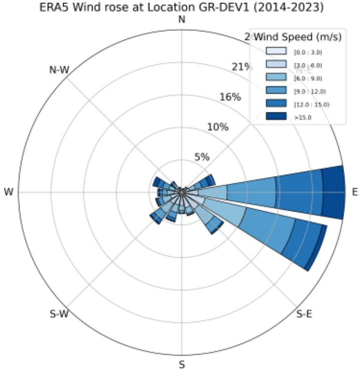




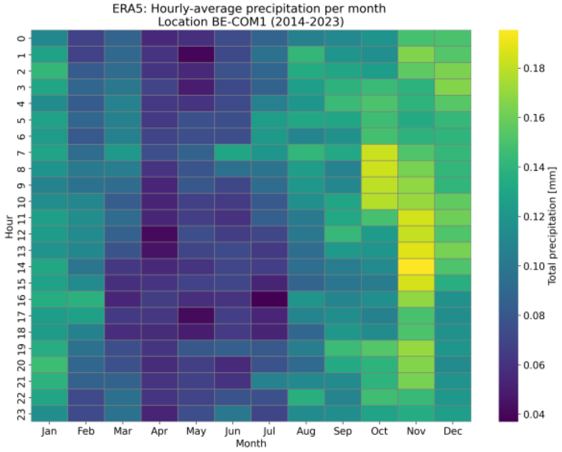


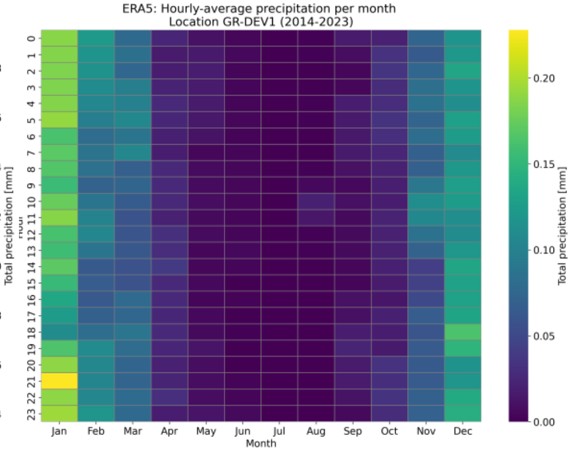


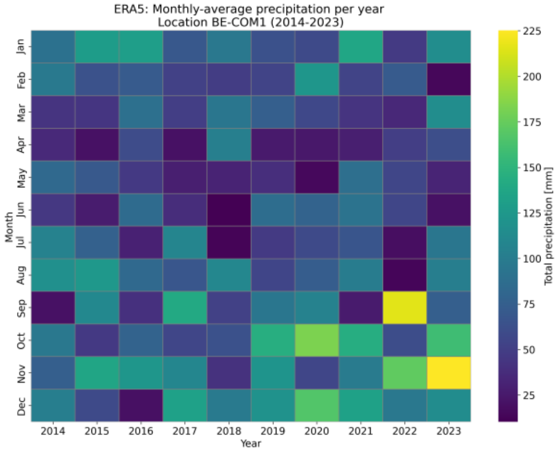


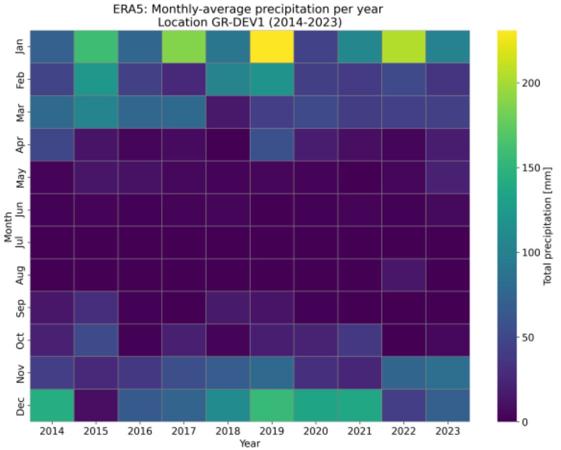


Results at two locations: North Sea and Aegean Sea









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