



## Wind farm effects of European on- and offshore turbines on weather forecast

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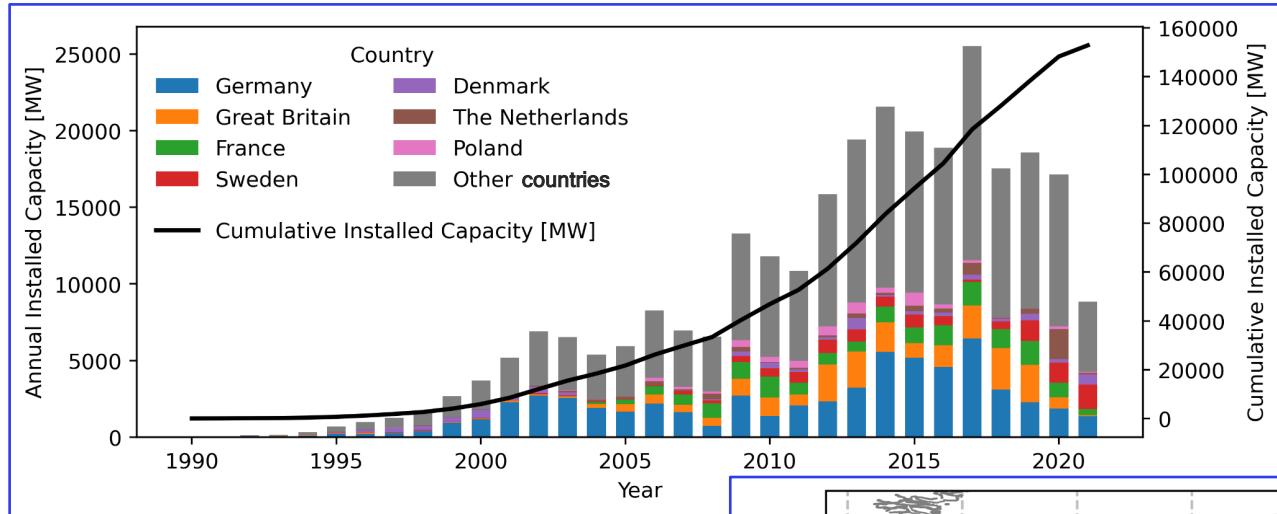
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Bjarke T. Olsen<sup>1</sup>, Marc Imberger<sup>1</sup>, Henrik Vedel<sup>2</sup>, Xiaoli Guo Larsén<sup>1</sup>,  
Andrea Hahmann<sup>1</sup>, Gregor Giebel<sup>1</sup>, Eigil Kaas<sup>2</sup>

<sup>1</sup>DTU Wind and Energy Systems

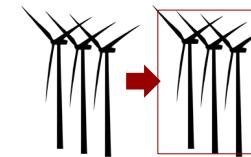
<sup>2</sup>Danish Meteorological Institute

# Wind farm effects of European on- and offshore turbines on weather forecast

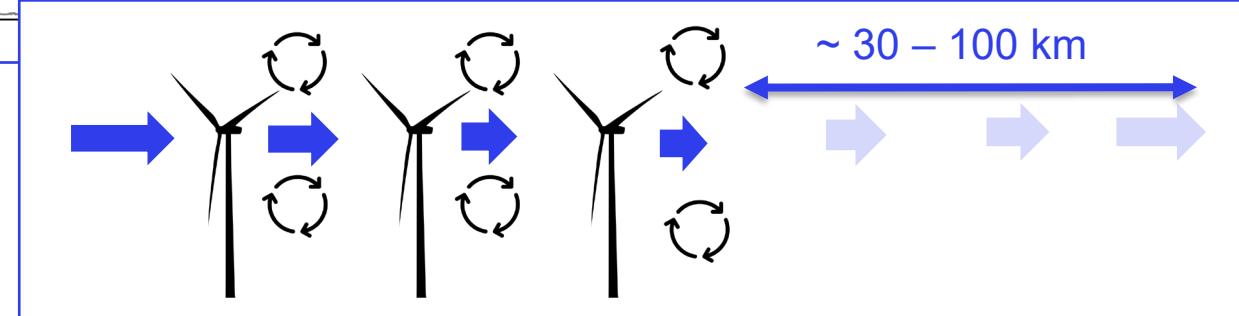
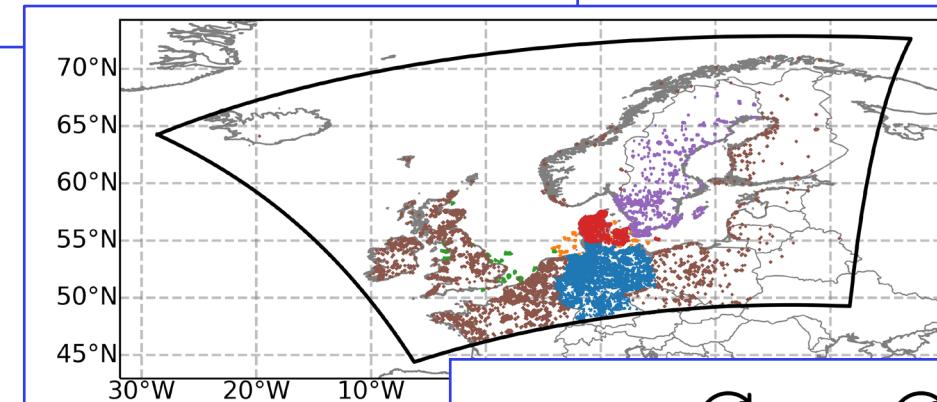
# Motivation: Wind farm wakes



RQ1: How much do existing wind turbines in Europe affect wind resources?

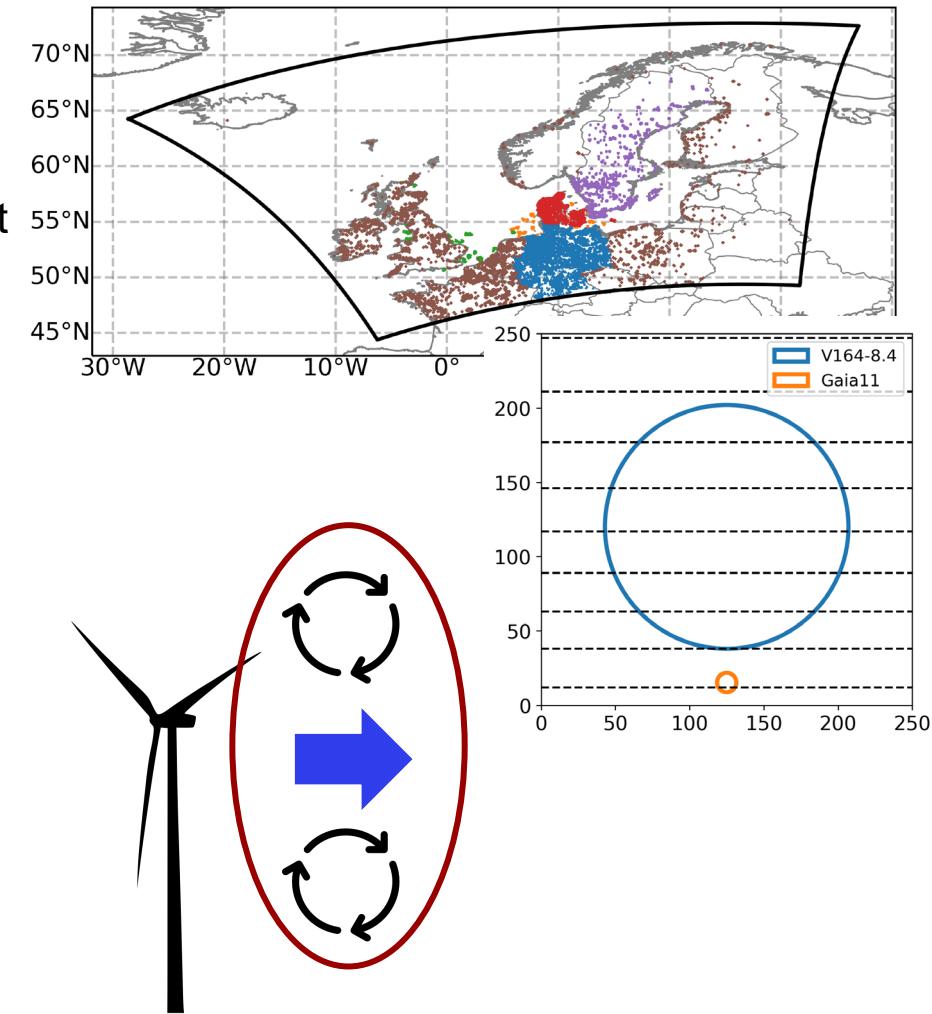


RQ2: How much do existing wind turbines in Europe affect weather (forecast)?



# Method (1): HARMONIE-Arome

- NWP model used by ~ 11 national weather services in Europe
  - Non-hydrostatic, convection-permitting, limited-area (Bengtsson et al., 2017).
- Operational NWP set-up at DMI (data assimilation e.g. satellite, scatterometer, aircraft; IFS boundary conditions)
- August 2022: 48 hour forecasts every 12 hours with hourly output (1 week of spin-up period prior)
- 3 Scenarios
  - Two wind farm parameterizations
    1. Fitch et al. (2012) implemented by van Stratum et al. (2022)
    2. Explicit Wake Parameterisation (EWP; Volker et al., 2015) implemented and evaluated by Fischereit et al. (2023)
  - One reference simulation without wind farms



→ European wind turbine data base (position and turbine properties)

Fischereit, J., Olsen, B. T., Imberger, M., Vedel, H., Larsén, X. G., Hahmann, A. N., Giebel, G., & Kaas, E. (2023). Modelling wind farm effects in HARMONIE-AROME (cycle 43.2.2) -- part 1: Implementation and evaluation *Geoscientific Model Development*, Submitted

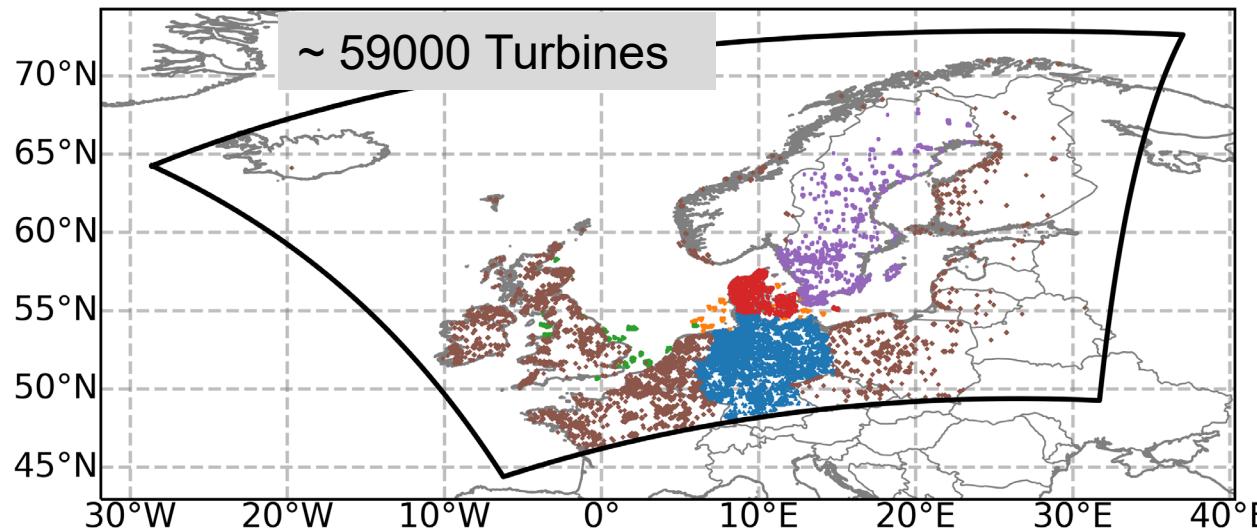
Fitch, A. C., Olson, J. B., Lundquist, J. K., Dudhia, J., Gupta, A. K., Michalakes, J., & Barstad, I. (2012). Local and Mesoscale Impacts of Wind Farms as Parameterized in a Mesoscale NWP Model. *Monthly Weather Review*, 140(9), 3017–3038.

<https://doi.org/10.1175/MWR-D-11-00352.1>

van Stratum, B., Theeuwes, N., Barkmeijer, J., van Ulft, B., & Wijnant, I. (2022). A One-Year-Long Evaluation of a Wind-Farm Parameterization in HARMONIE-AROME. *Journal of Advances in Modeling Earth Systems*, 14(7). <https://doi.org/10.1029/2021MS002947>

Volker, P. J. H., Badger, J., Hahmann, A. N., & Ott, S. (2015). The Explicit Wake Parametrisation V1.0: a wind farm parametrization in the mesoscale model WRF. *Geoscientific Model Development*, 8(11), 3715–3731. <https://doi.org/10.5194/gmd-8-3715-2015>

# Method (2): European wind turbine data base - positions



- **Onshore (Germany DE, Denmark DK)**  
**Onshore/Offshore (Sweden SE):** Individual turbine position data from German Federal Network Agency [1], Danish Energy Agency [2] and Swedish Energy Agency [3]
- **Onshore outside DE, SE, DK:**  
WFSA (wind farm splitting algorithm) combining commercial wind farm data product (farm level) [4] with turbine location information from OpenStreetMap (turbine level) [5]
- **Offshore wind farms around Denmark:**  
adapted from Fischereit et al. 2022a [6]
- **Offshore (not included in [6] or [3]):** Offshore wind farm assembly algorithm (OWFAA) combining shapefiles from EMODnet database [7] and data from [4] & [5]

[1] <https://www.marktstammdatenregister.de/MaStR/Einheit/Einheiten/OeffentlicheEinheitenuebersicht>, last accessed: 19 Oct 2021,

[2] <https://ens.dk/service/statistik-data-noegletal-og-kort/data-oversigt-over-energisektoren>, last accessed: 20 Oct 2021,

[3] <https://vbk.lansstyrelsen.se/en>, last accessed: 16 March 2022,

[4] [https://www.thewindpower.net/store\\_continet\\_en.php?id\\_zone=1001](https://www.thewindpower.net/store_continet_en.php?id_zone=1001), European subset of global data product purchased in Oct 2021,

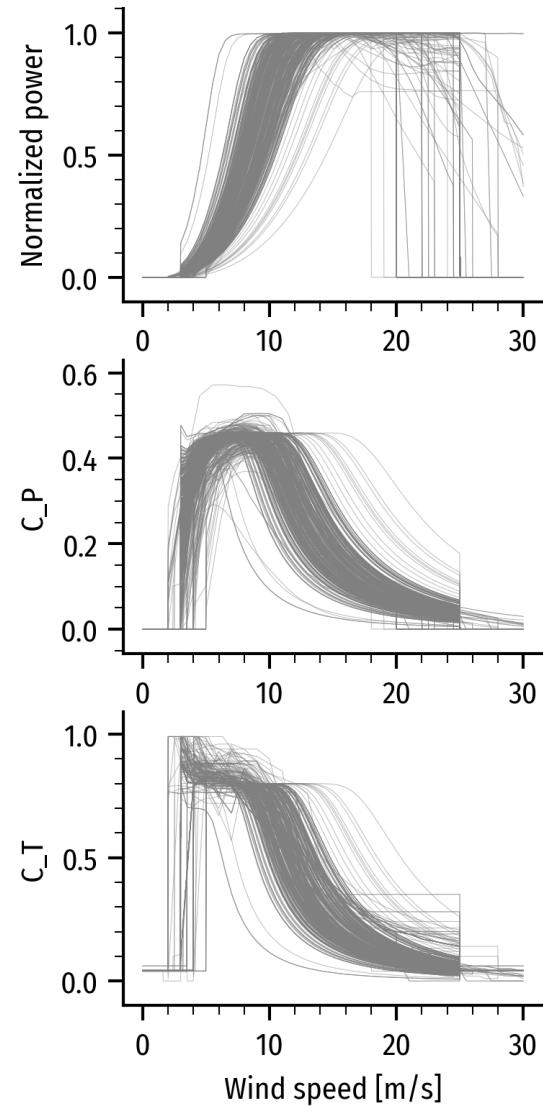
[5] <https://www.openstreetmap.org>, 1 December 2021 snapshot, last queried on 1 Oct 2022

[6] Fischereit et al. (2022a): Climatic Impacts of Wind-Wave-Wake Interactions in Offshore Wind Farms. Frontiers in Energy Research. <https://doi.org/10.3389/fenrg.2022.881459>

[7] European Marine Observation and Data Network (EMODnet) Human Activities, Wind Farms (Polygons), [https://ows.emodnet-humanactivities.eu/geonetwork/srv/api/records/8201070b-4b0b-4d54-8910-abcea5dce57f/attachments/EMODnet\\_HA\\_WindFarms\\_20211210.zip](https://ows.emodnet-humanactivities.eu/geonetwork/srv/api/records/8201070b-4b0b-4d54-8910-abcea5dce57f/attachments/EMODnet_HA_WindFarms_20211210.zip), last accessed April 2022

# Method (3): European wind turbine data base - properties

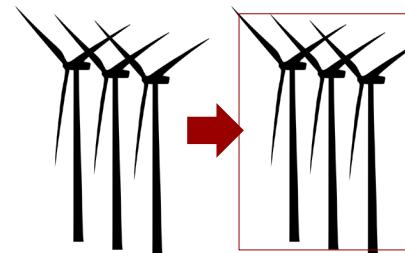
- The European turbine dataset:
  - Position,
  - Hub height
  - Rotor diameter
  - Rated power
  - Turbine model
- Gaps were filled one variable at a time using random forest regression
  - Rated power <1% missing
  - Rotor diameter ~5% missing
  - Hub height ~15% missing
  - Turbine models were not gap-filled
- Real power and ct curves were used for the 212 most frequent models
- Other turbines use generic power and ct curves from PyWake
  - Depends on the rated power and rotor diameter
  - Uses the default settings for all other parameters (e.g. air density, max\_cp, constant\_ct, and losses) [1]



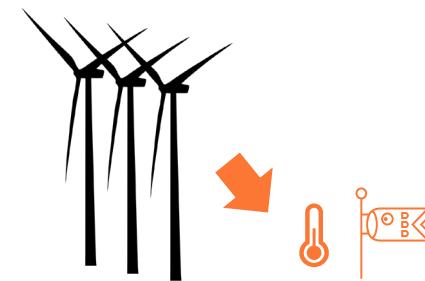
[1] [https://gitlab.windenergy.dtu.dk/TOPFARM/PyWake/-/blob/master/py\\_wake/utils/generic\\_power\\_ct\\_curves.py](https://gitlab.windenergy.dtu.dk/TOPFARM/PyWake/-/blob/master/py_wake/utils/generic_power_ct_curves.py)

# Results

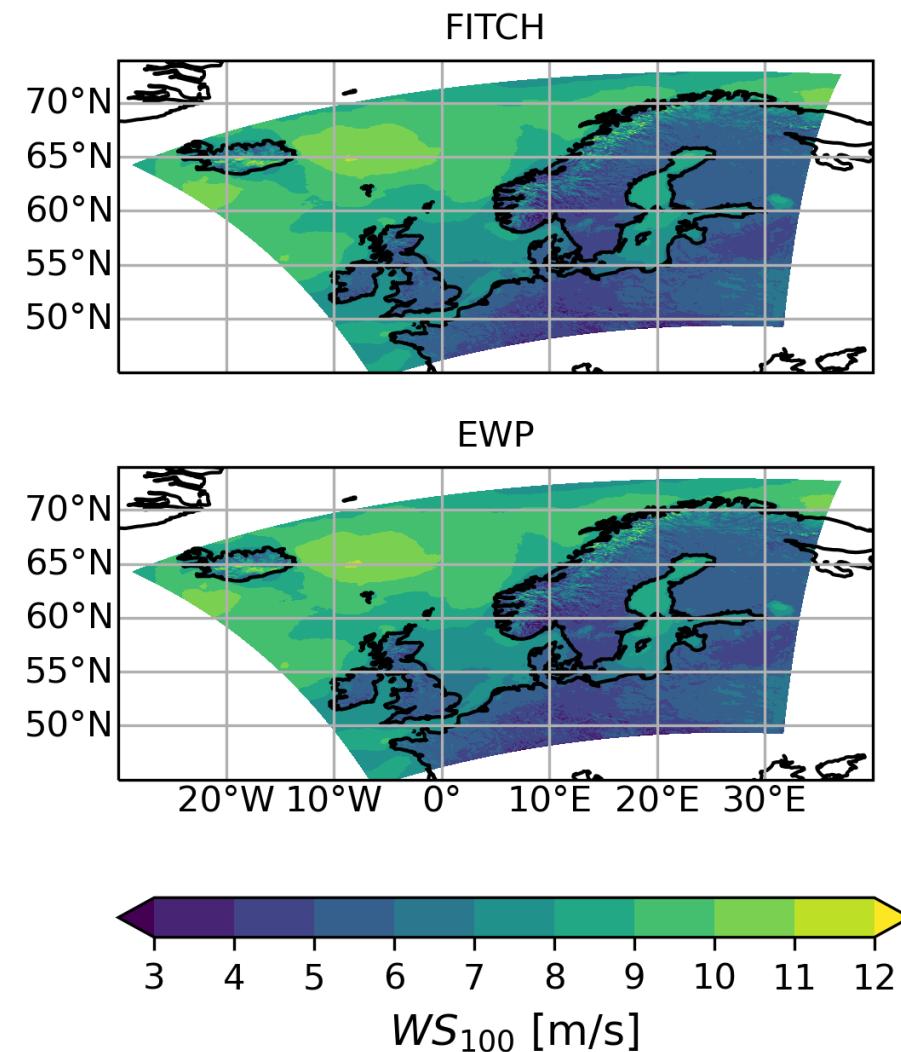
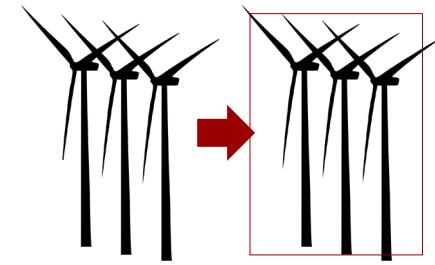
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RQ2: How much do existing wind turbines in Europe affect weather (forecast)?

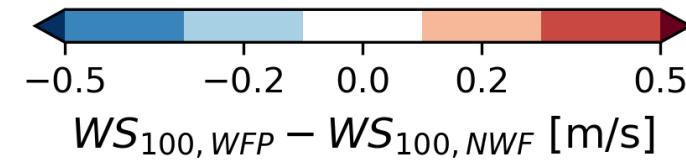
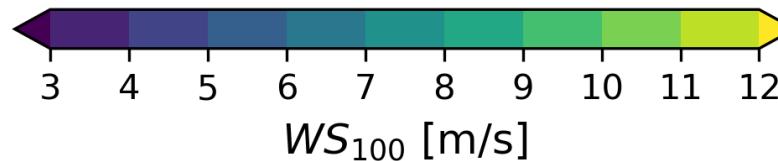
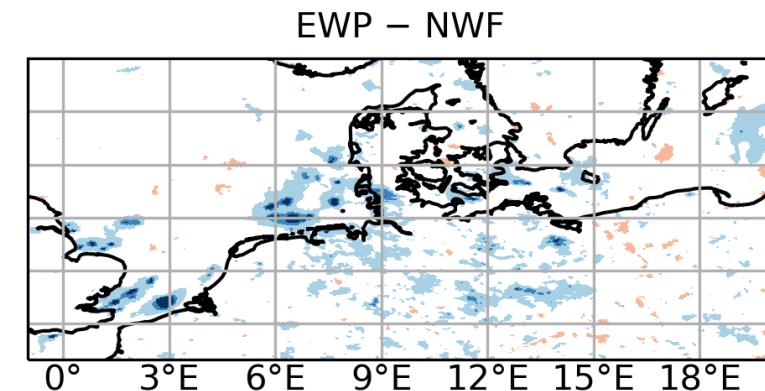
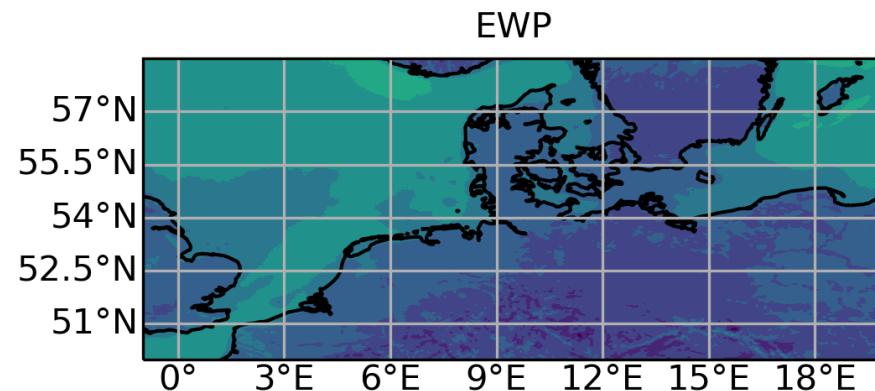
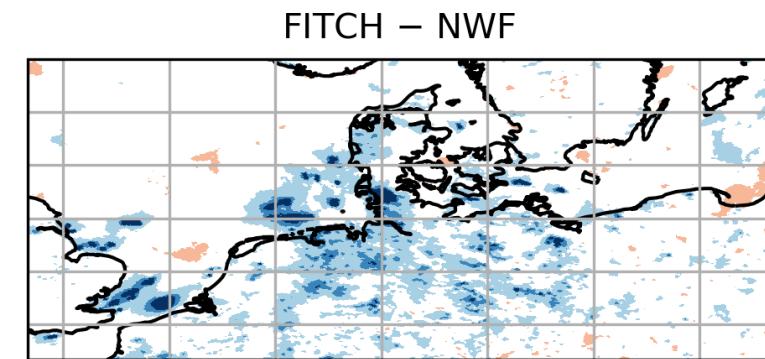
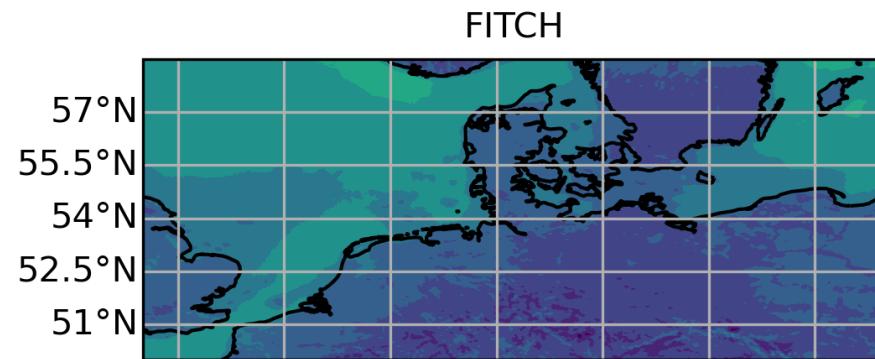
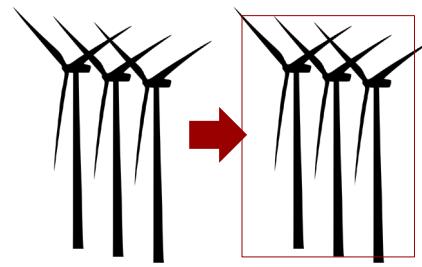


# Results RQ1: WF on Wind resources – WS<sub>100</sub>



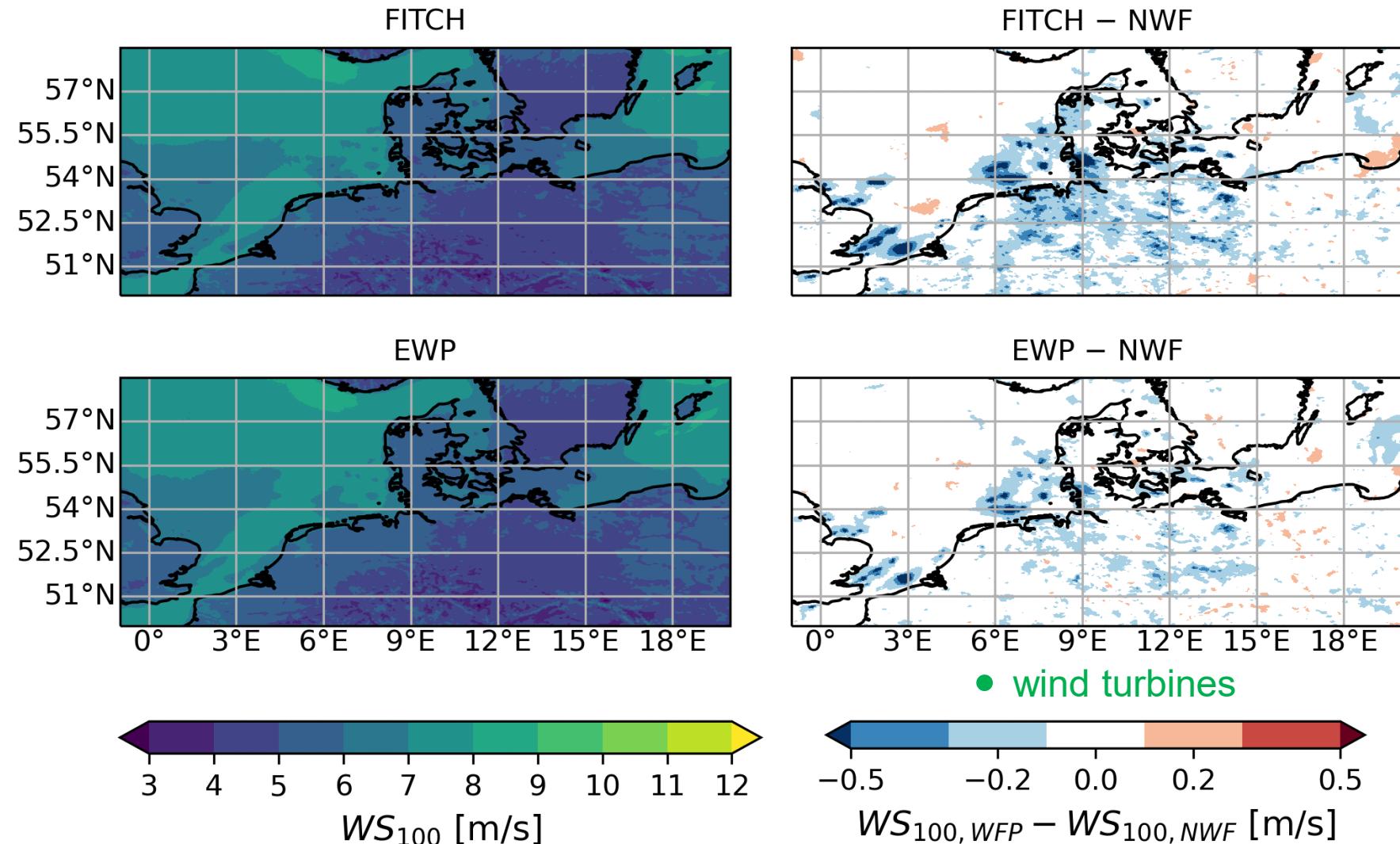
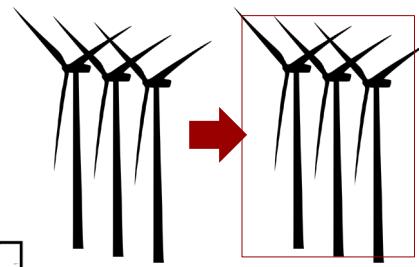
Mean over August 2022 (24 hour forecasts starting at 00:00)

# Results RQ1: WF on Wind resources – WS<sub>100</sub>



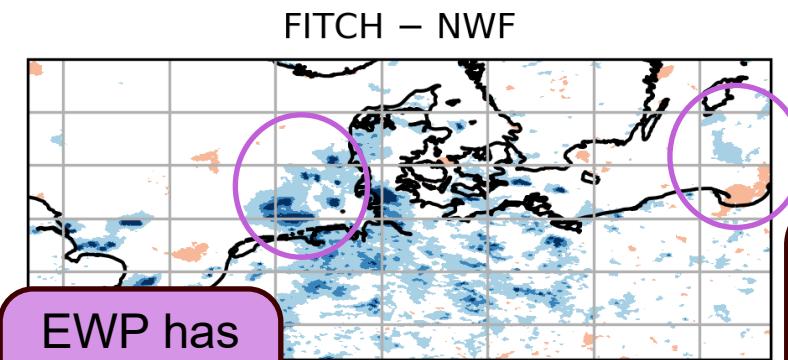
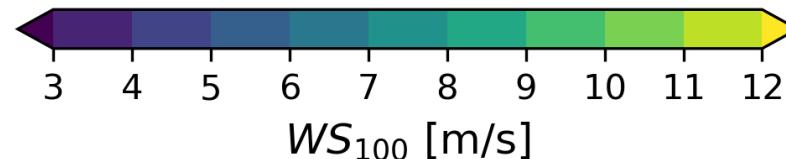
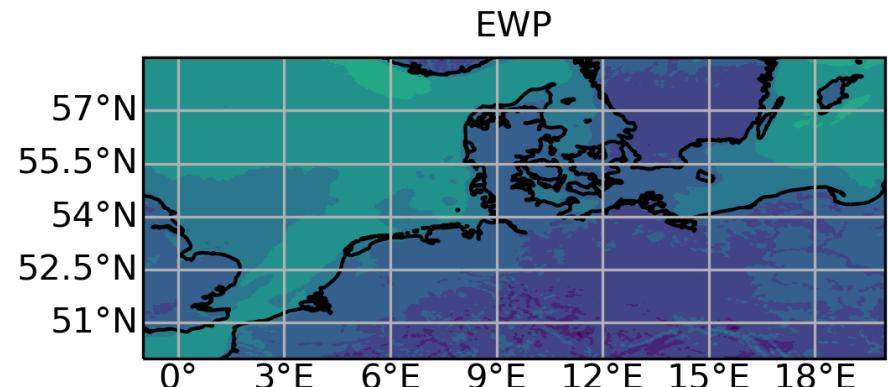
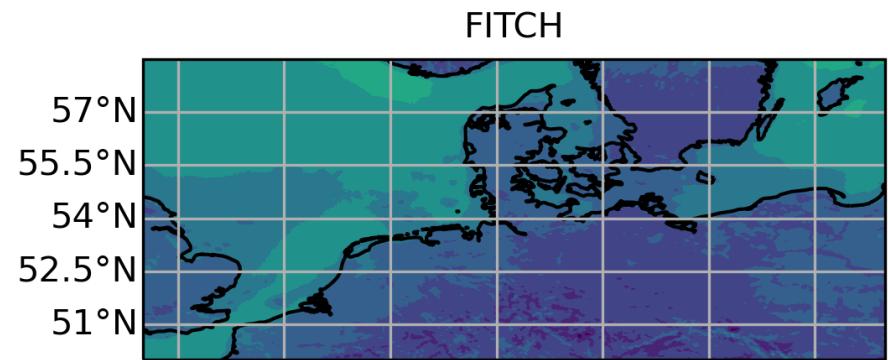
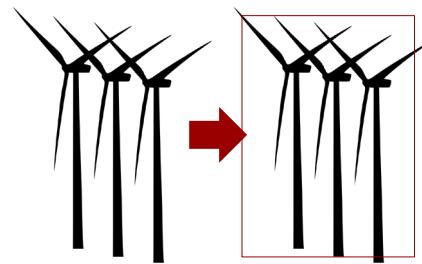
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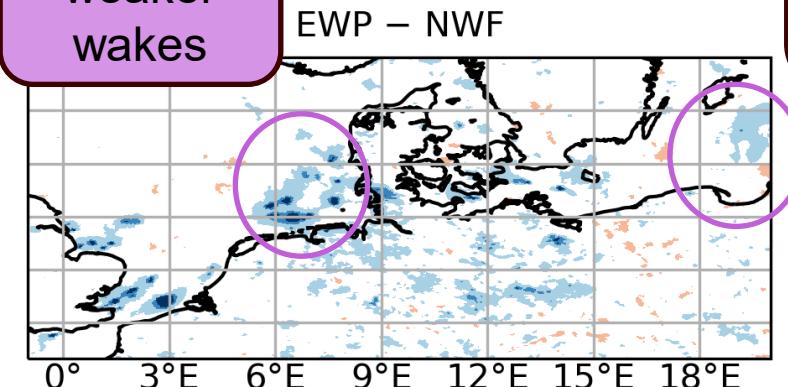


Mean over August 2022 (24 hour forecasts starting at 00:00)

# Results RQ1: WF on Wind resources – WS<sub>100</sub>



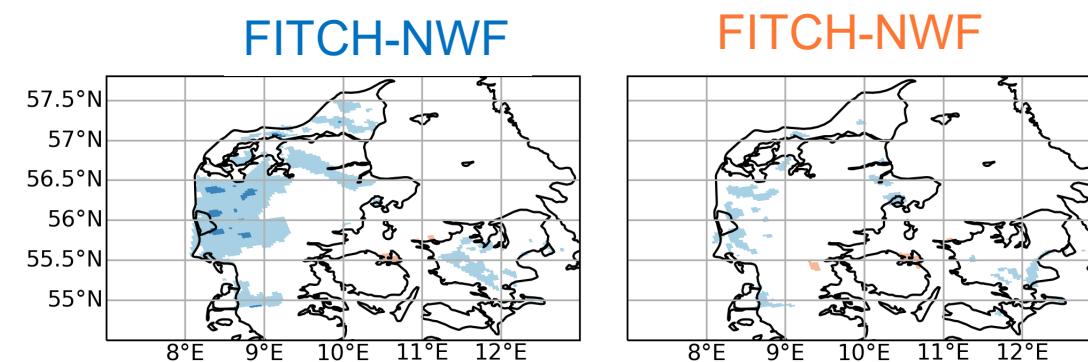
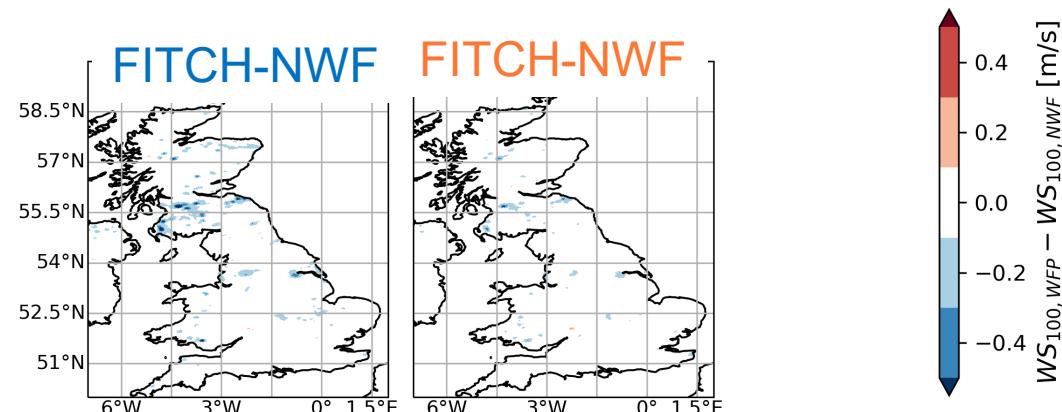
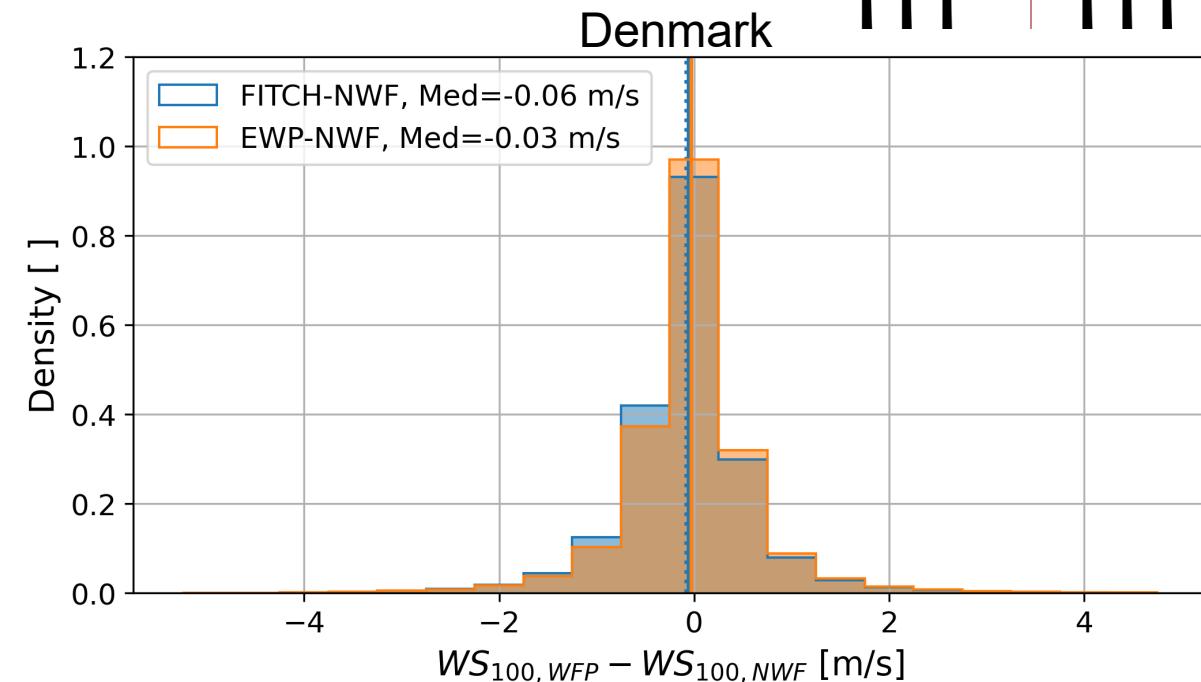
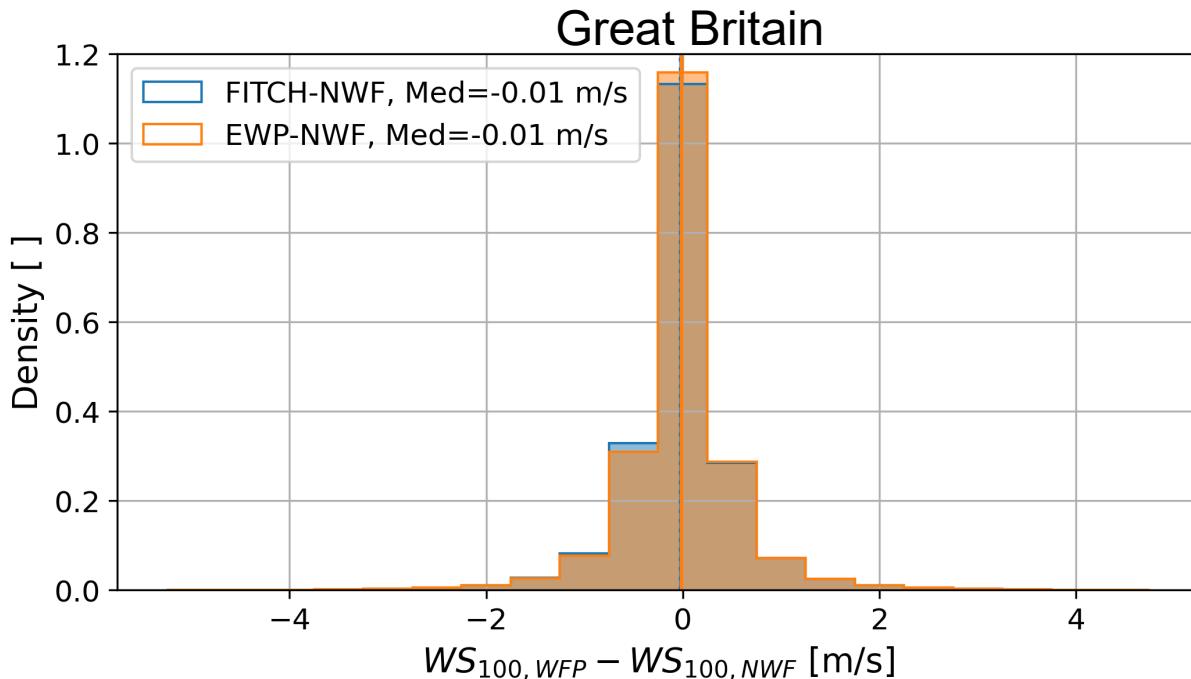
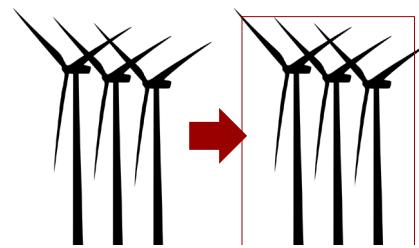
EWP has weaker wakes



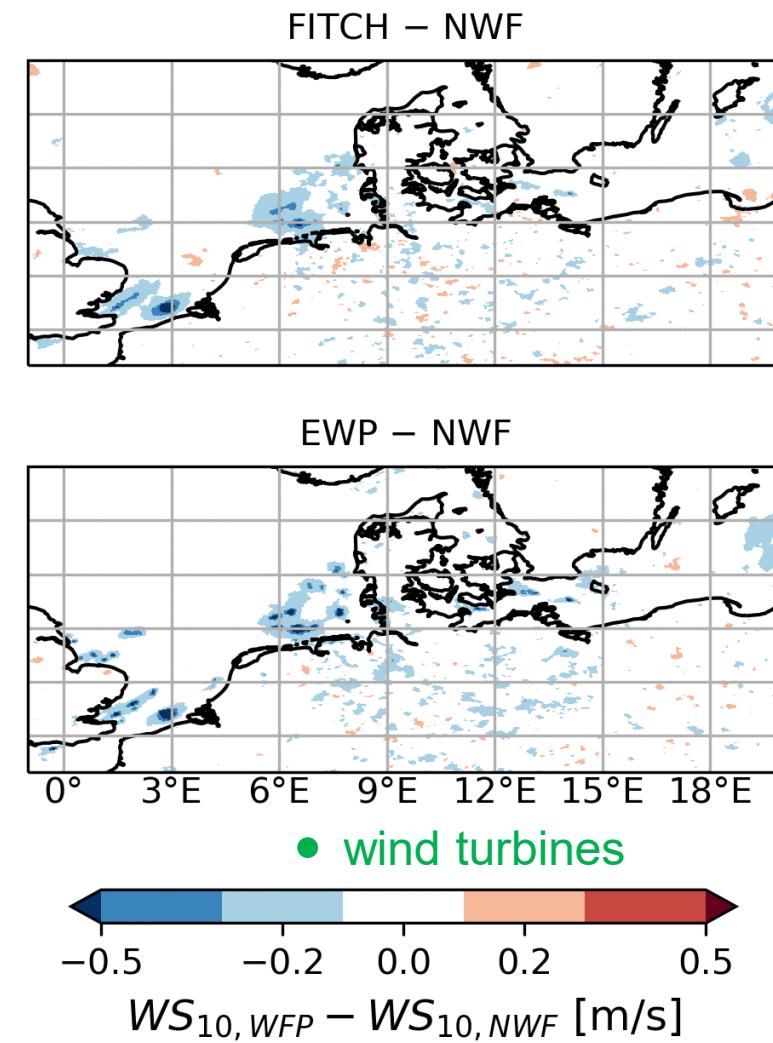
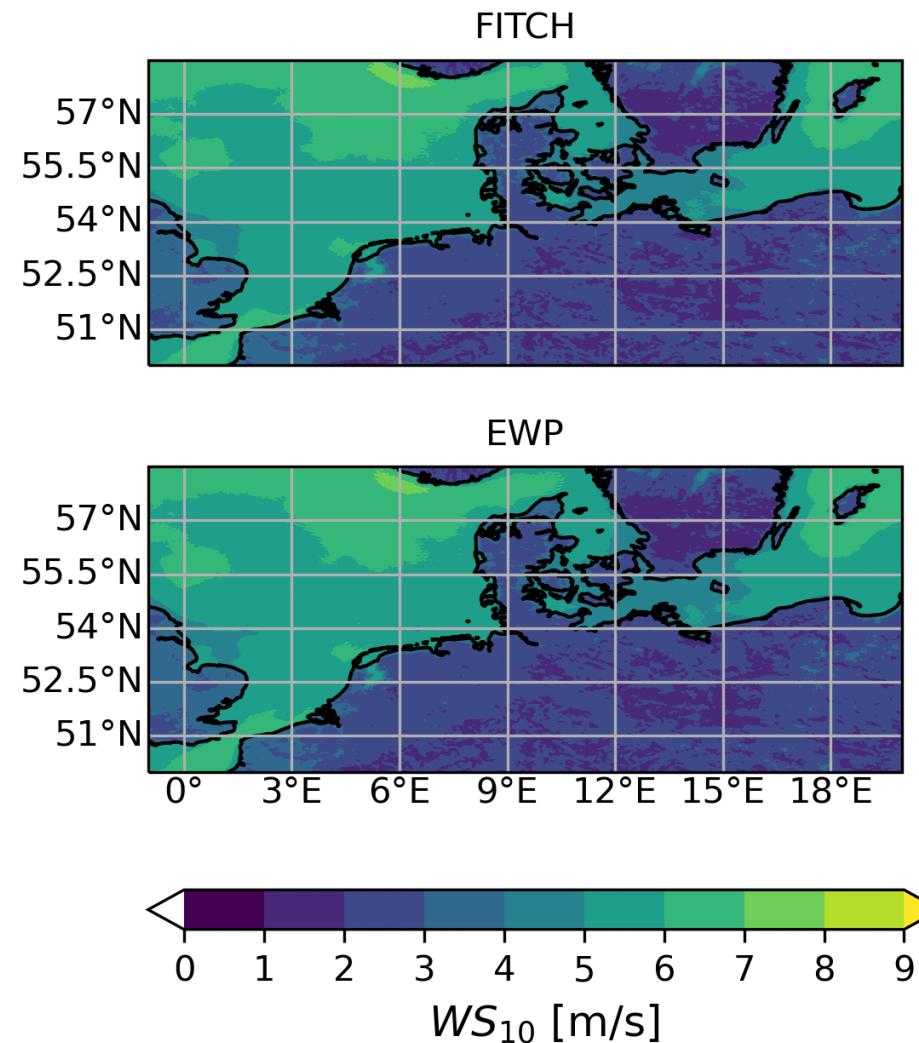
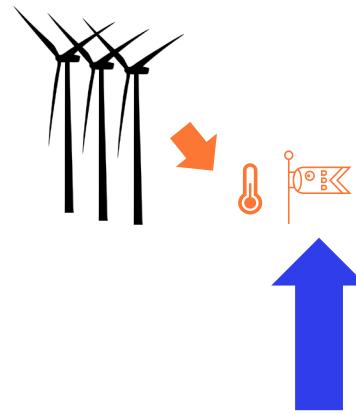
Remote effects agree to certain extent

Mean over August 2022 (24 hour forecasts starting at 00:00)

# Results: RQ1: WF on Wind resources

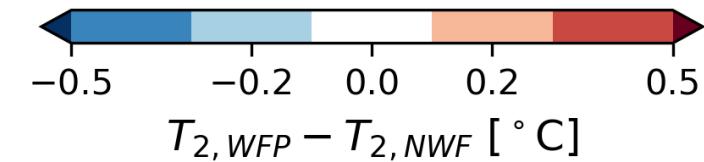
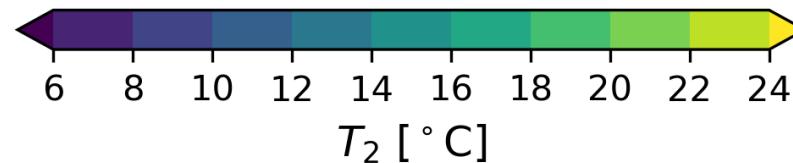
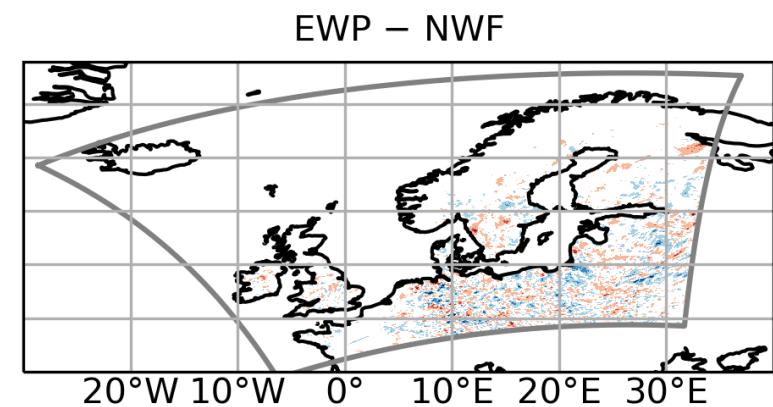
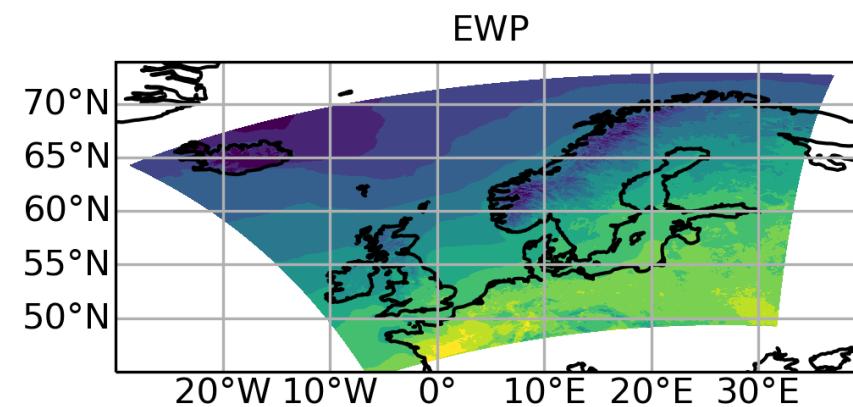
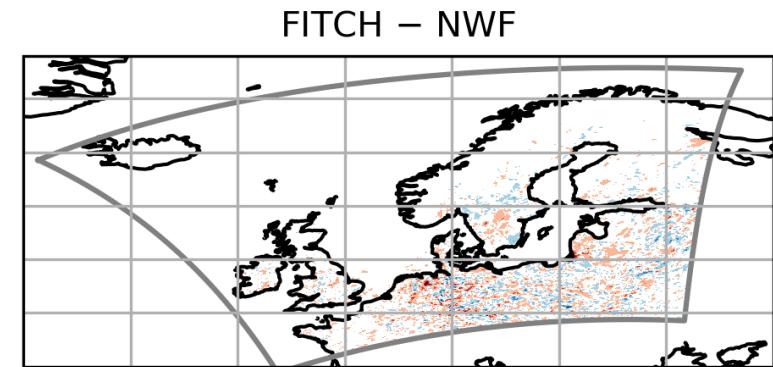
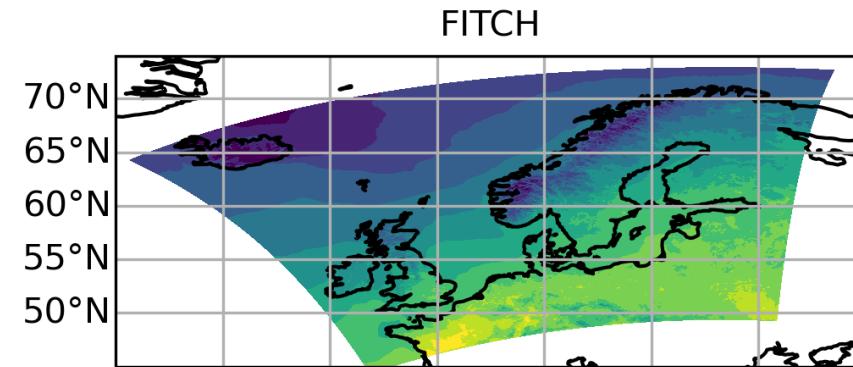
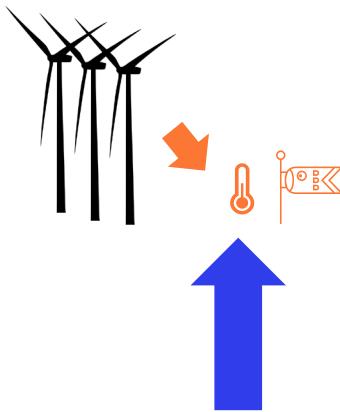


# Results: RQ2: WF on weather - WS<sub>10</sub>



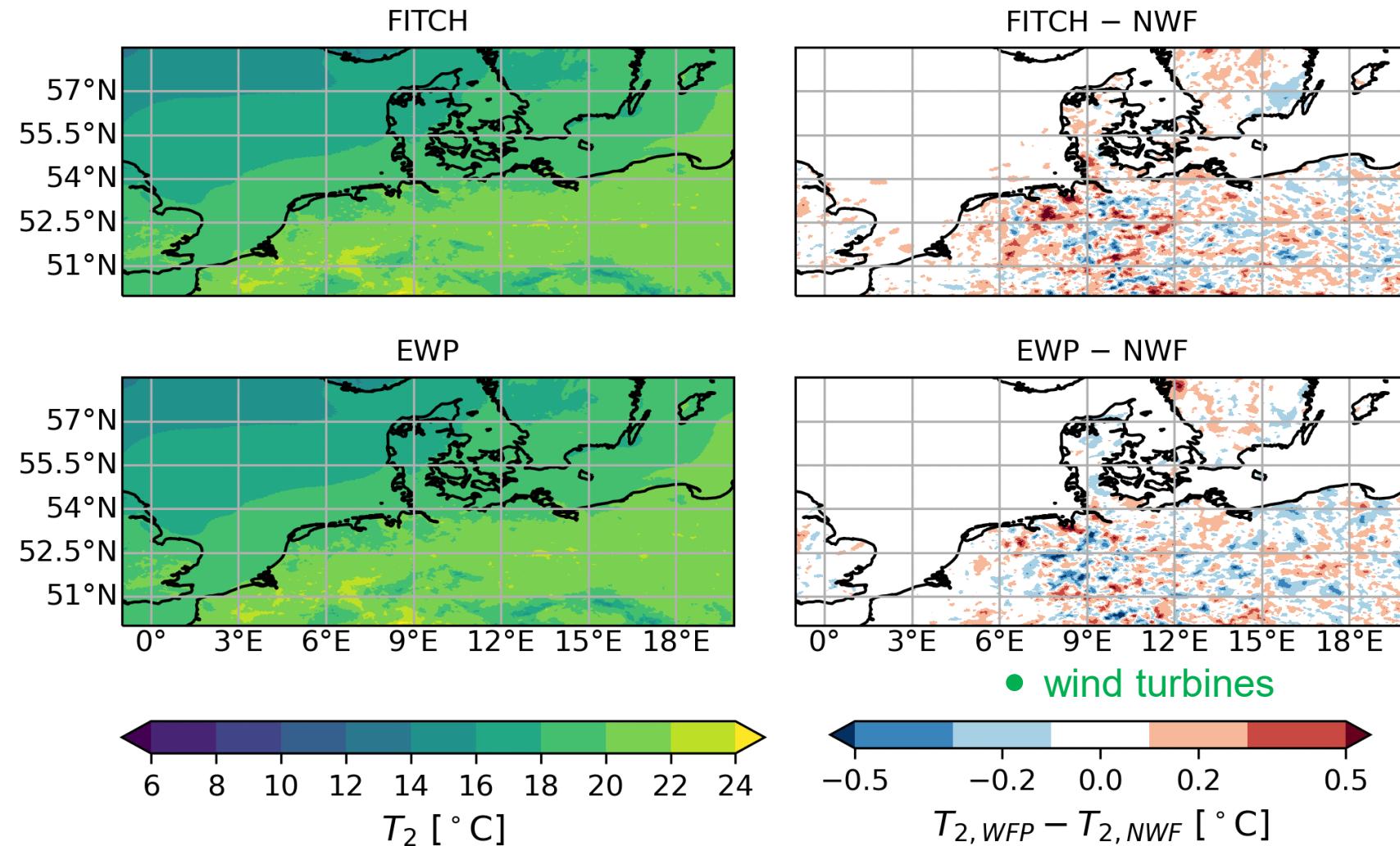
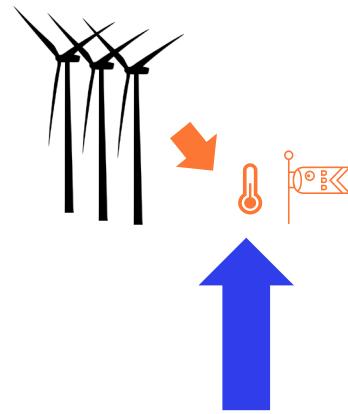
Mean over August 2022 (24 hour forecasts starting at 00:00)

# Results: RQ2: WF on weather - $T_2$



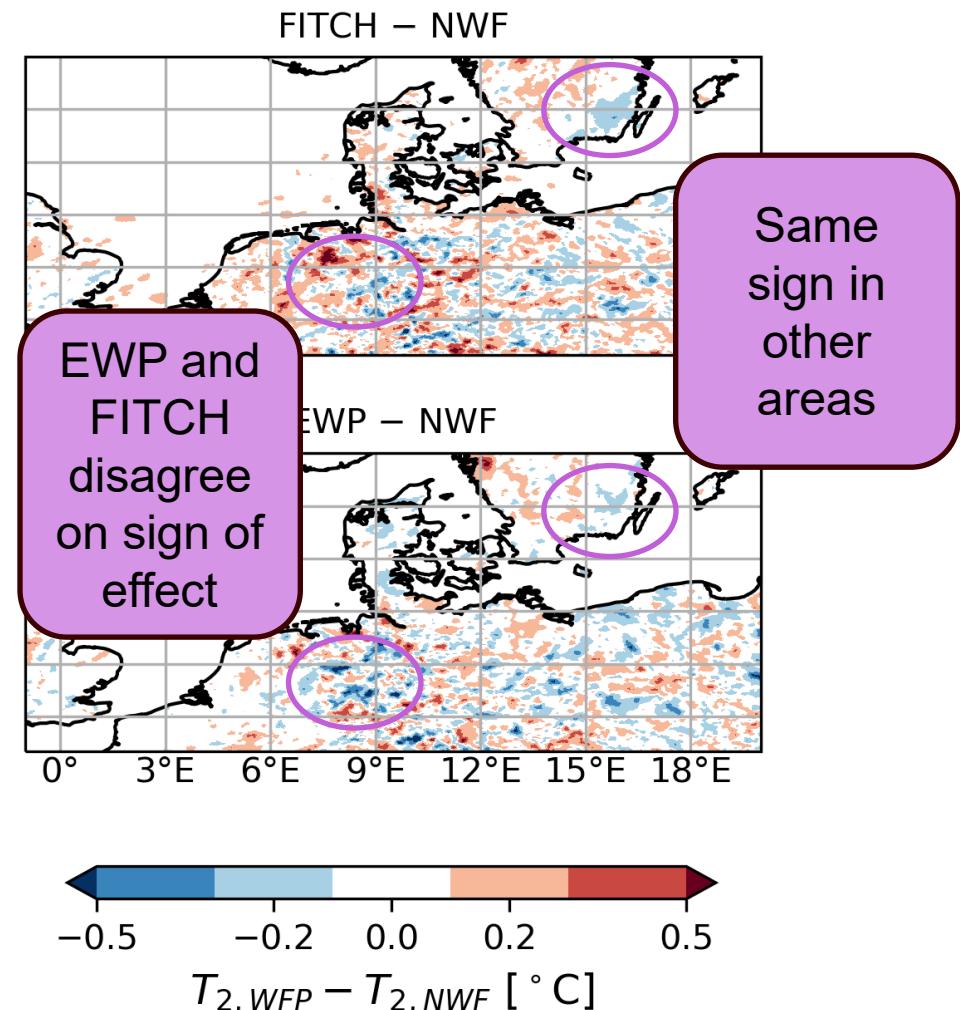
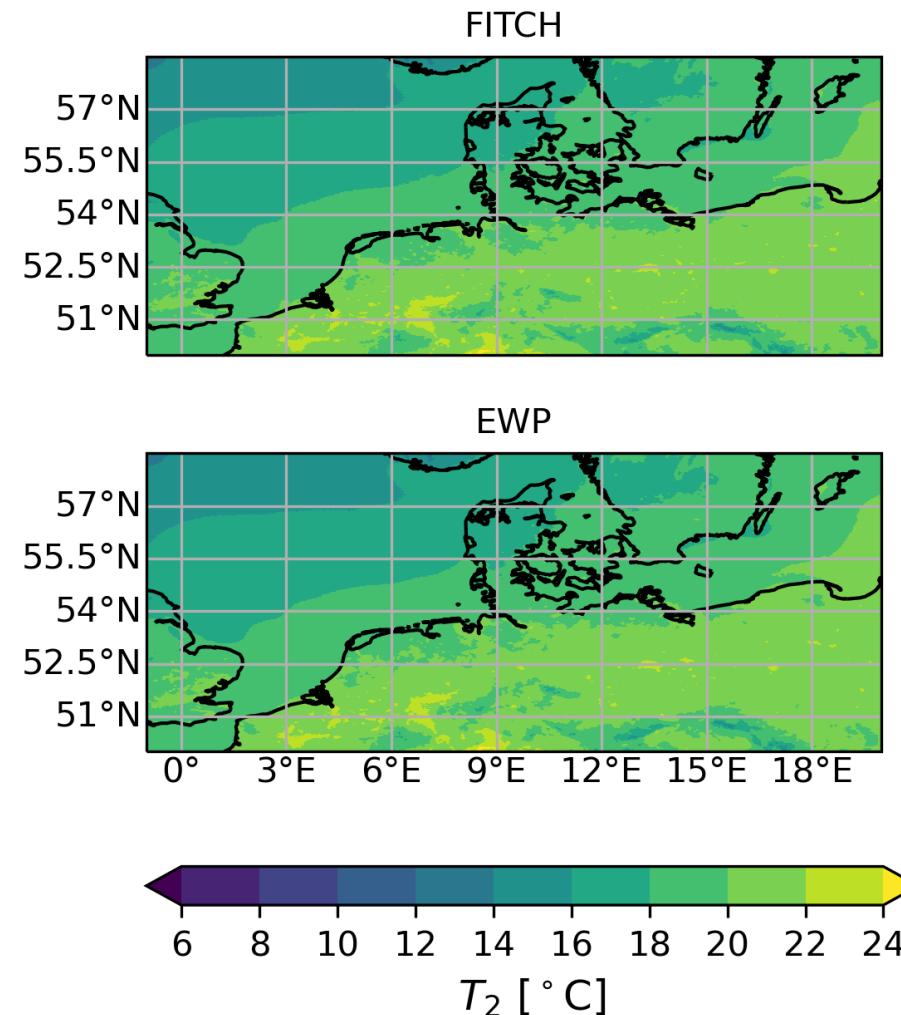
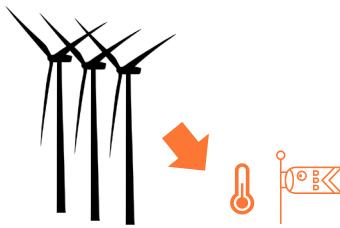
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# Results: RQ2: WF on weather - $T_2$



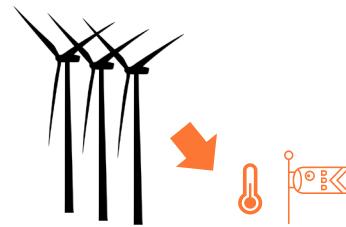
Mean over August 2022 (24 hour forecasts starting at 00:00)

# Results: RQ2: WF on weather - $T_2$

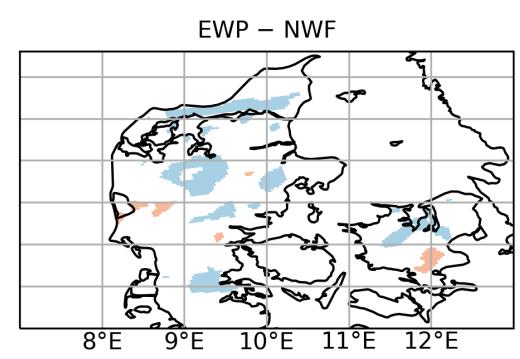
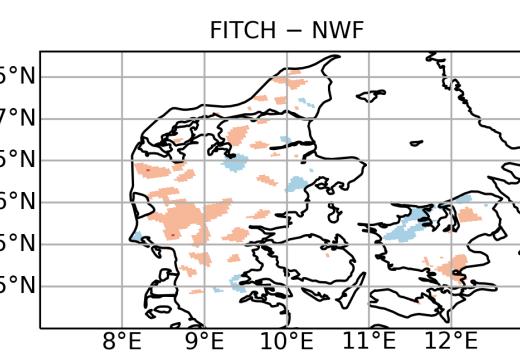
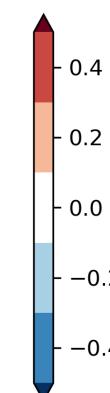
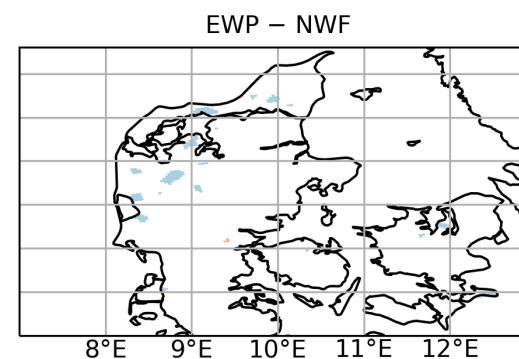
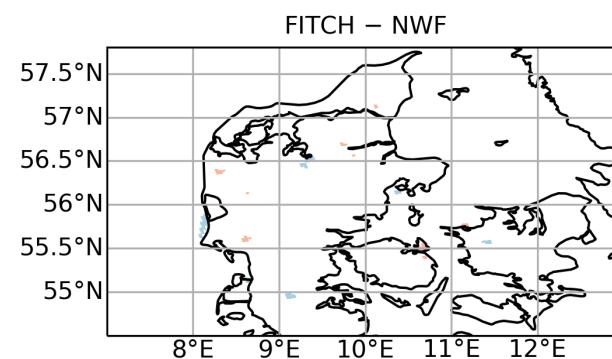
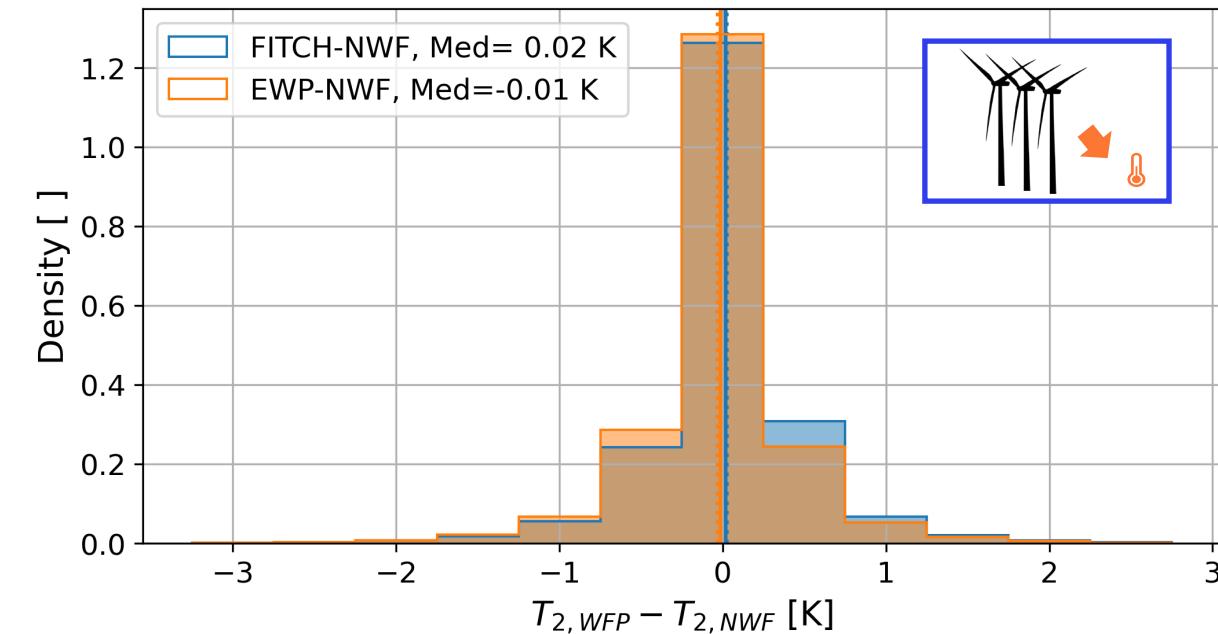
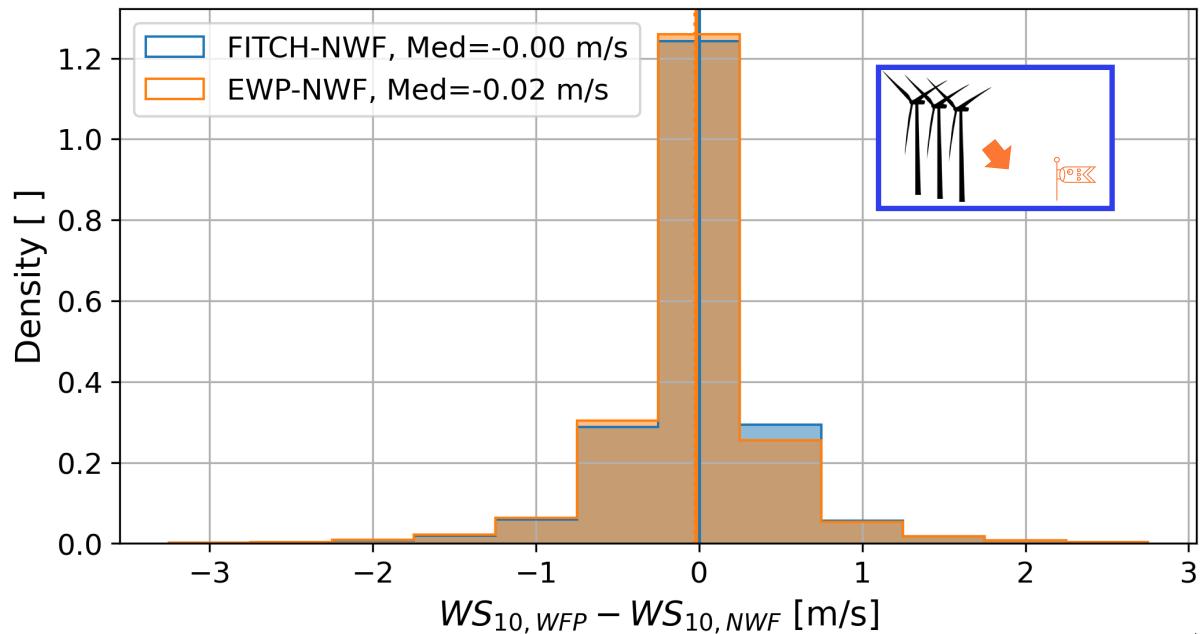


Mean over August 2022 (24 hour forecasts starting at 00:00)

# Results: RQ2: WF on weather



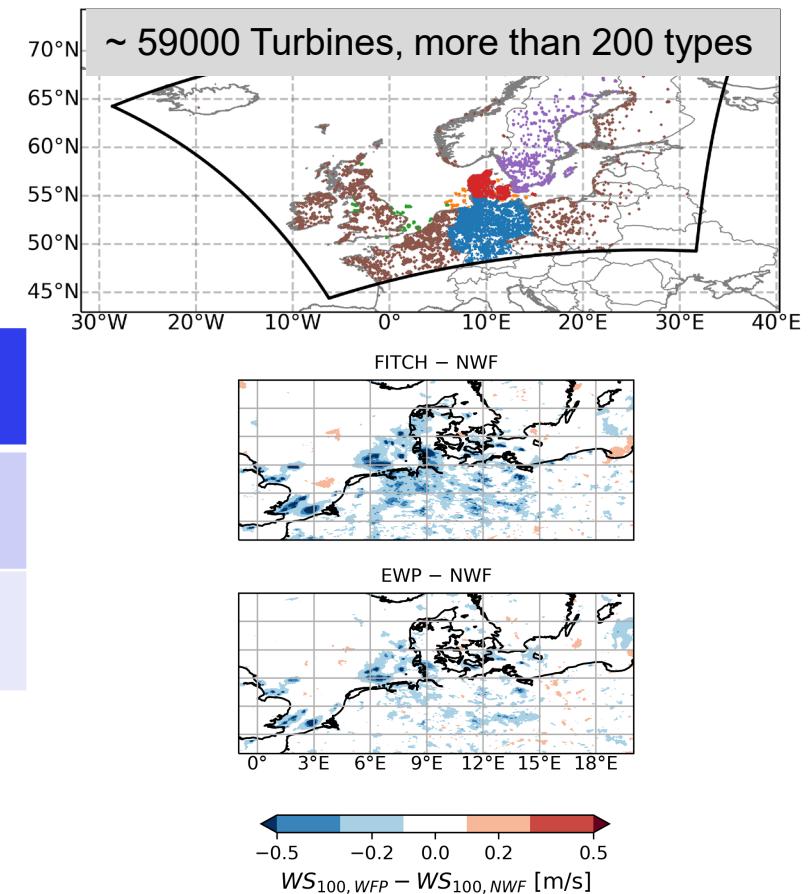
## Denmark



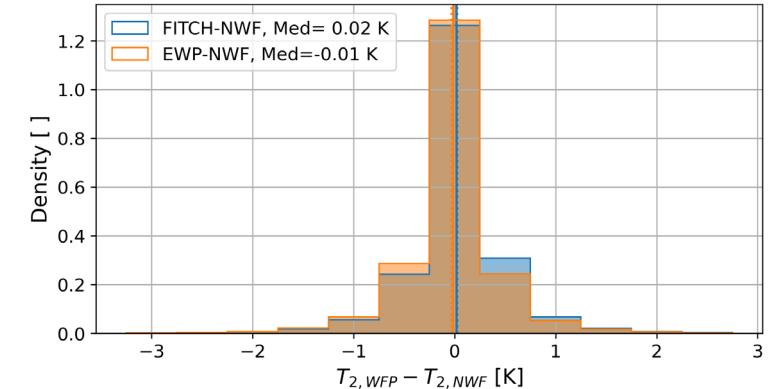
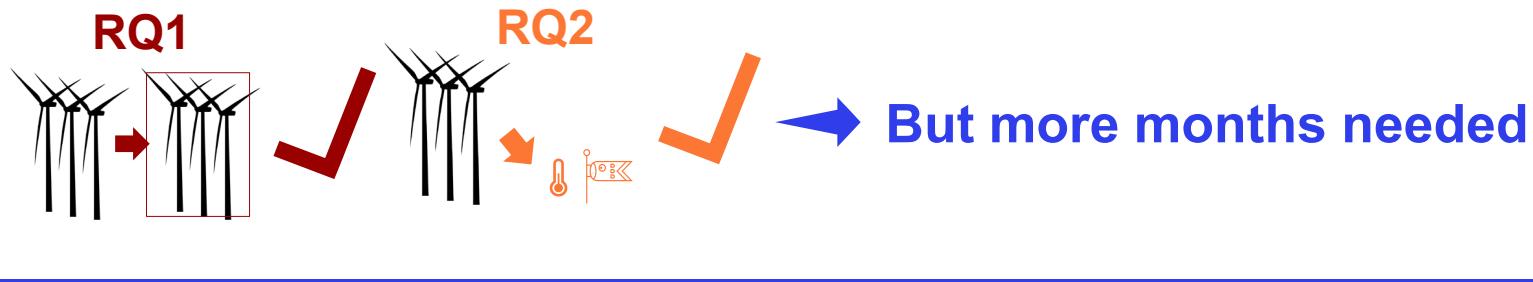
# Conclusions

- 2 WFP implemented in HARMONIE-Arome and August 2022 was forecasted with 3 scenarios with all turbines present November 2021

	Monthly average	Short-term (over Denmark)
$WS_{10}$ $WS_{100}$ [m/s]	$\pm 0.5$ : mostly offshore (around farms), $WS_{10}$ minor changes over land	$\pm 3$
$T_2$ [K]	$\pm 0.5$ : mostly onshore, almost no effect offshore	$\pm 2$



- FITCH and EWP
  - Agree mostly for WS
  - Have sometimes different signs for T



# Acknowledgements

Part of the funding is by the Danish state through the National Centre for Climate Research (NCKF).