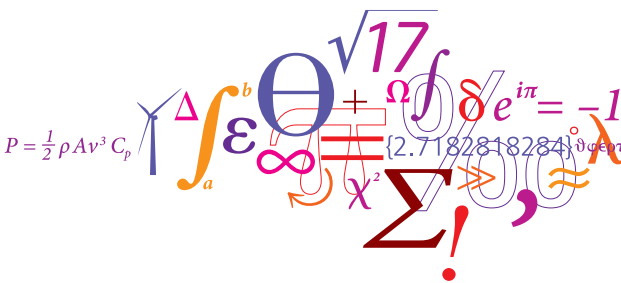
Relevance of sea waves and farm-farm wakes for offshore wind resource assessment

Jana Fischereit and Xiaoli Guo Larsén

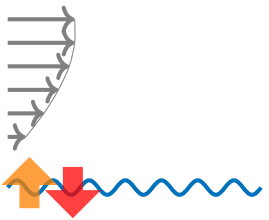
janf@dtu.dk



DTU Wind Energy
Department of Wind Energy

Introduction

Introduction



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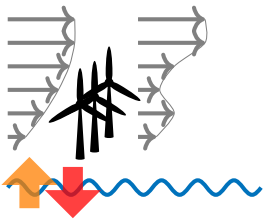

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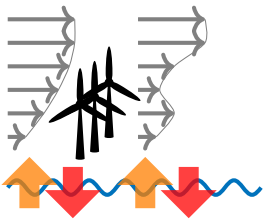

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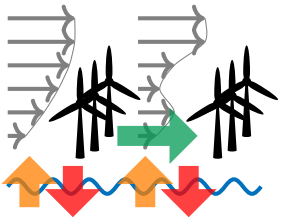
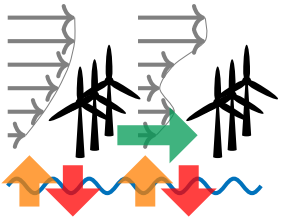


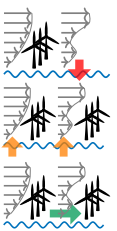
Introduction: Research Questions



Aim: How much do...

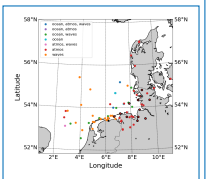
- wind farms wakes affect the wave field?
- waves affect the wind resources?
- other wind farms wakes affect the wind resources?

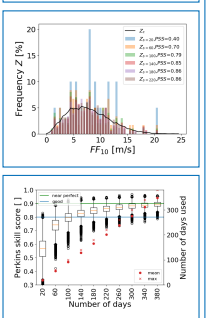
→ Under certain **conditions** / on a **climatic** average
→ Is atmosphere-wave coupling necessary?



Method[1]: 30 years wind and wave effects

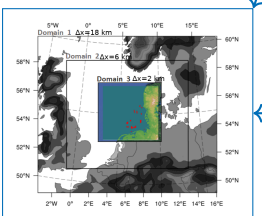
Statistical (1)





+

dynamical downscaling (2)



ATM + WAVE

ATM + WAVE + WAKE

ATM + WAKE

=

Effects: -climatic -situational

Wakes → Waves

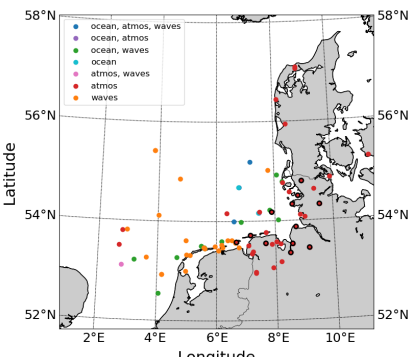
Wakes → Resource

Waves → Resource

[1]Method based on Boettcher et al. (2015)

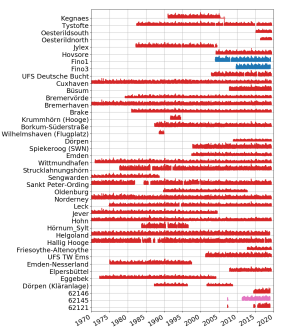
Method (1): Statistical selection of days

1. Collection of measurement station in and around the North Sea



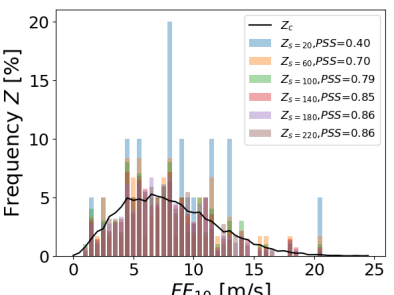
Method (1): Statistical selection of days

1. Collection of measurement station in and around the North Sea
2. Selection of measurement stations with long time series (WS_{10} 1989 – 2018)



Method (1): Statistical selection of days

1. Collection of measurement station in and around the North Sea
2. Selection of measurement stations with long time series (WS_{10} 1989 – 2018)
3. Fitting of random days to climatic distribution (Perkins Skill Score)



$$PSS = \sum_{i=1}^{n} \min(Z_{c,i}, Z_{s,i})$$

Method (1): Statistical selection of days

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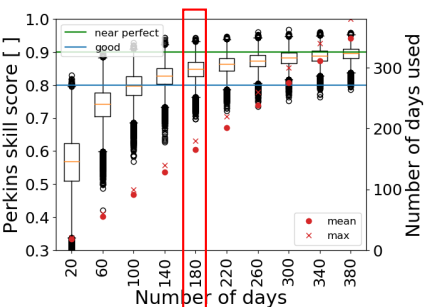
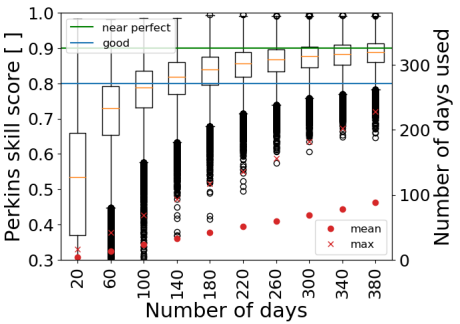
4. Select number of required days based on WS_{10} fit for all stations



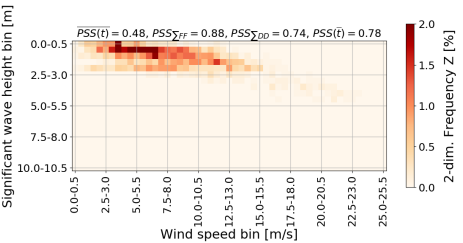
Method (1): Statistical selection of days

1. Collection of measurement station in and around the North Sea
2. Selection of measurement stations with long time series (WS_{10} 1989 – 2018)
3. Fitting of random days to climatic distribution (Perkins Skill Score)
4. Select number of required days based on WS_{10} fit for all stations
5. Check that also distribution of other variables ($h_{m,0}$, DD, θ) and 2d distributions (e.g. $h_{m,0}$ vs. WS_{10}) are met

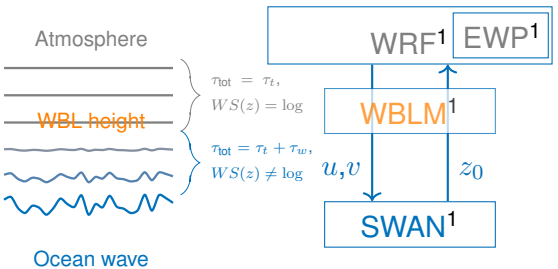
$h_{m,0}$



WS_{10} **vs.** $h_{m,0}$



Method (2): Dynamical downscaling using coupled simulations



[1]COAWSTv3.2 (Warner et al., 2010): WRFv3.7 (Skamarock et al., 2008), EWP (Volker et al., 2015), SWAN v41.01AB (Booij et al., 1999), WBLM (Du et al., 2019)

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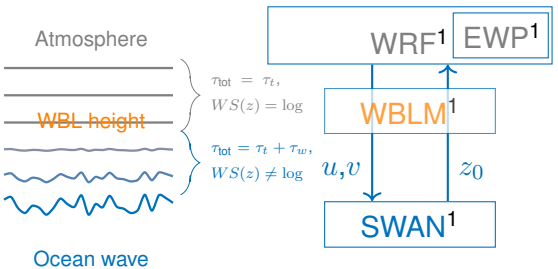
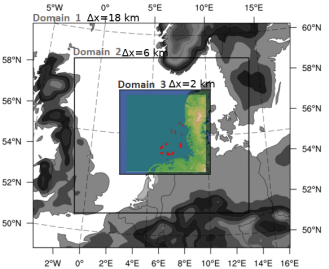
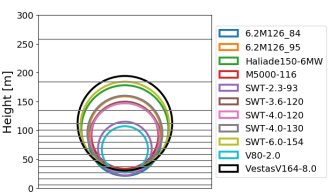




- Forcing data: CFSR + OISST



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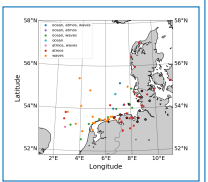
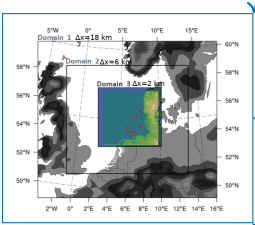
Method (3): Overview

Statistical (1)



+

dynamical downscaling (2)



ATM + WAVE

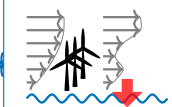
ATM + WAVE + WAKE

ATM + WAKE

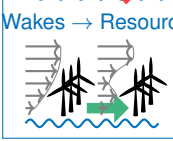
=

Effects: -climatic -situational

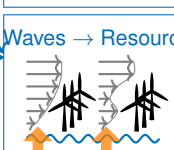
Wakes → Waves



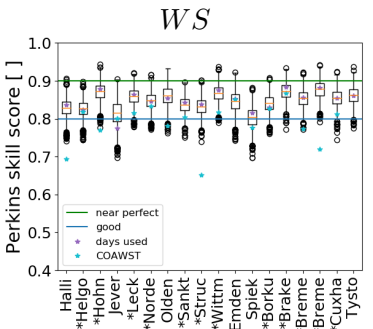
Wakes → Resource

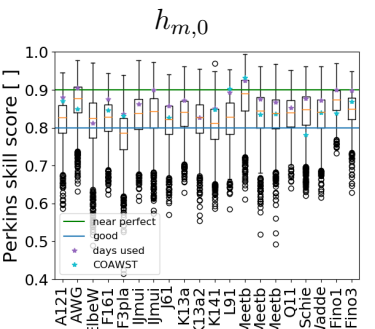


Waves → Resource



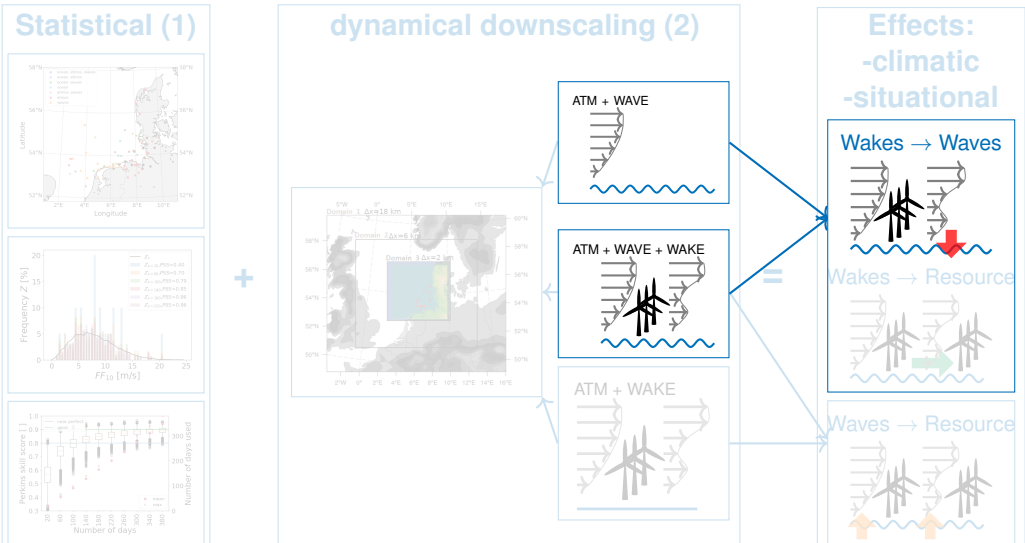
Results: Validation





$$PSS(t,l) = \sum_{i=1}^{n} \min\left(Z_{c,i}(t,l), Z_{s,i}(t,l)\right)$$

Results: wakes → waves: 30 years climate



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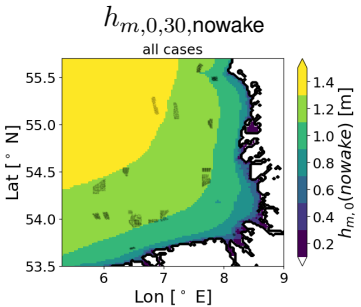

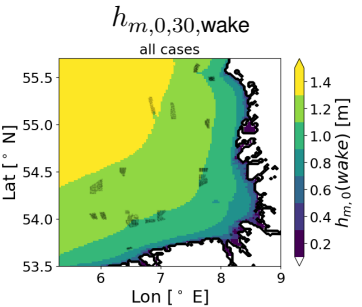

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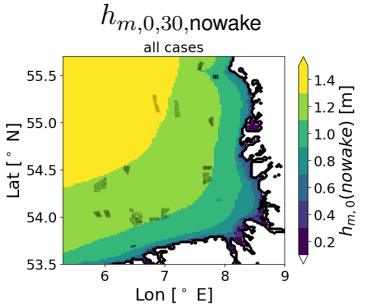
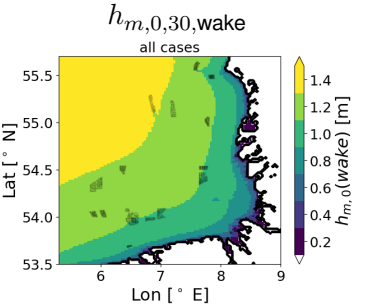
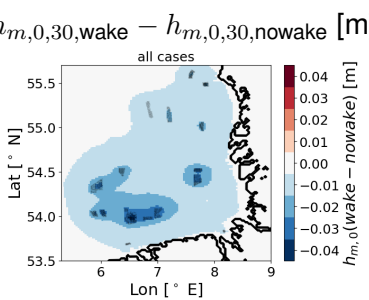
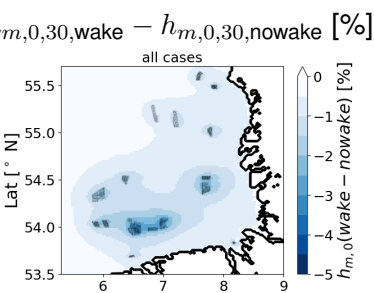
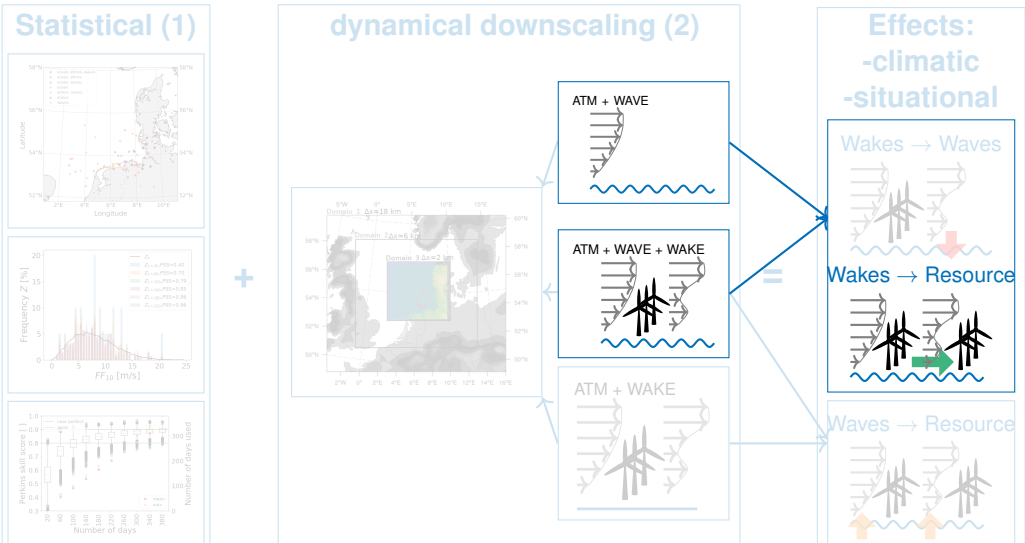




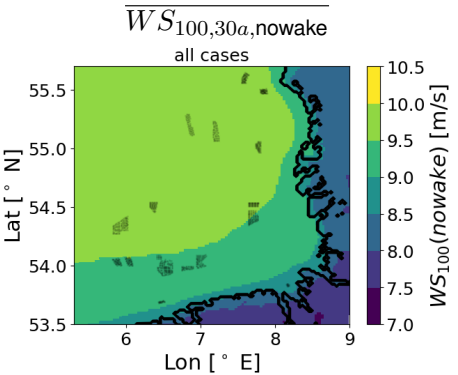


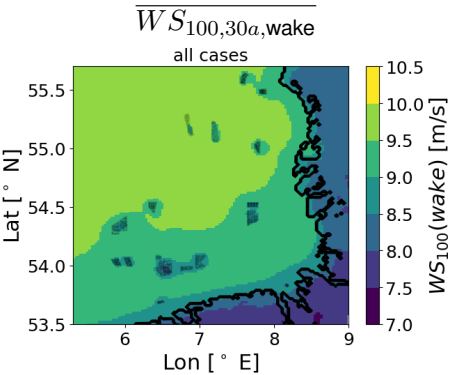


Results: wakes → resources: 30 years climate

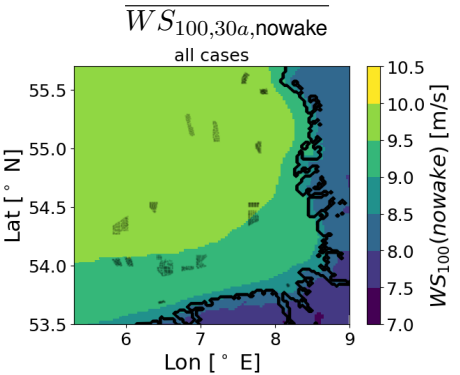


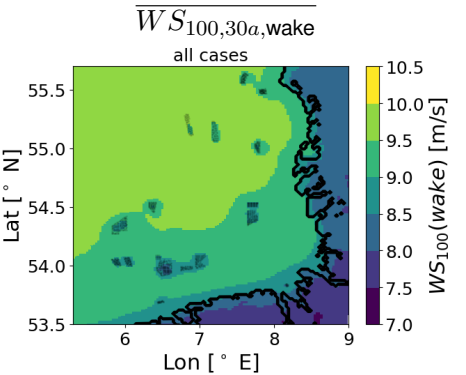
Results: wakes → resources: 30 years climate





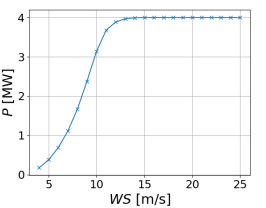
Results: wakes → resources: 30 years climate





Implication for power:

1. Use a SWT-4.0-120 turbine power curve
2. Derive $\overline{P_{100,30a,\text{wake}}}$ and $\overline{P_{100,30a,\text{nowake}}}$ from $\overline{WS}_{100,30a,\text{wake}}$ and $\overline{WS}_{100,30a,\text{nowake}}$



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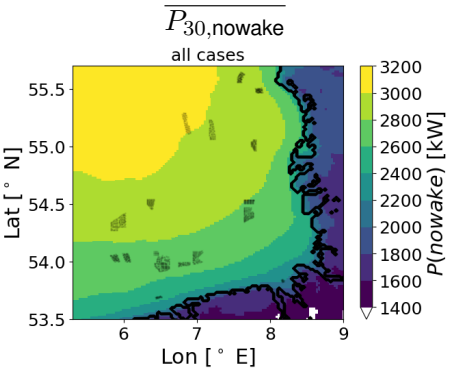
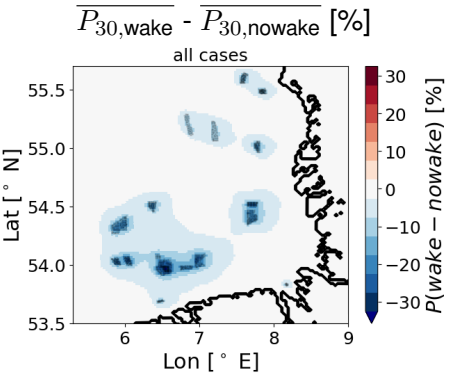
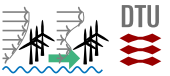


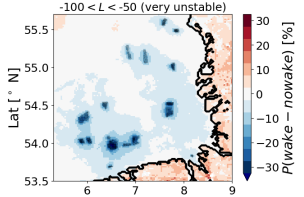


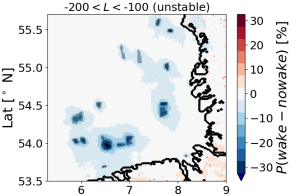
Results: wakes $\rightarrow$ resources: Stability dependence



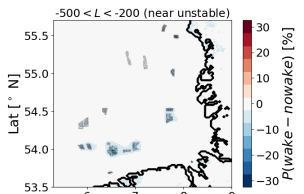
$$\overline{P_{\text{wake}}(x,y,t)|_{L_{\text{nowake}}}} - \overline{P_{\text{nowake}}(x,y,t)|_{L_{\text{nowake}}}}$$

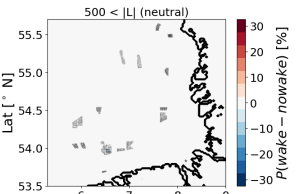
Results: wakes → resources: Stability dependence

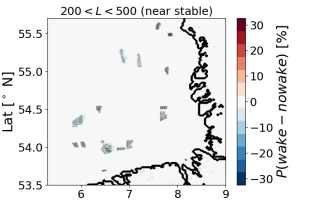


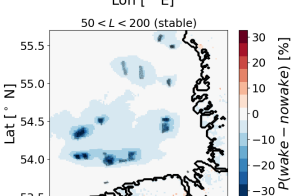


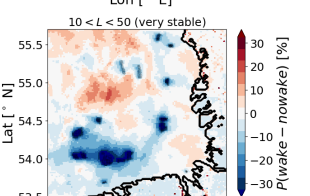
$$\overline{P_{\text{wake}}(x,y,t)|_{L_{\text{nowake}}}} - \overline{P_{\text{nowake}}(x,y,t)|_{L_{\text{nowake}}}}$$



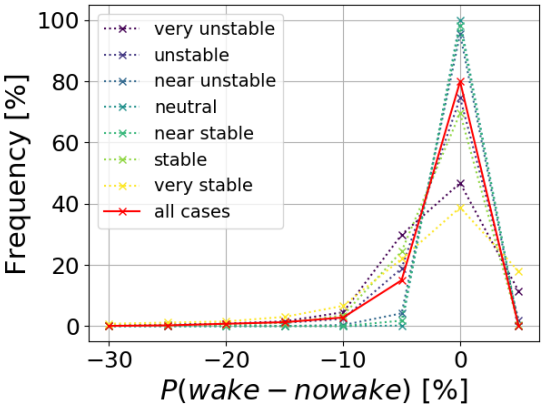






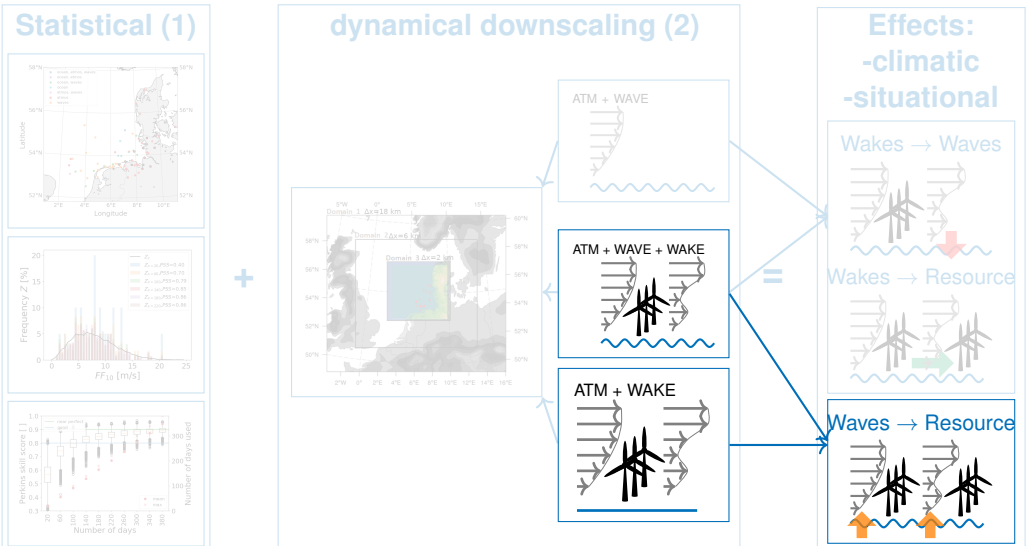


Results: wakes → resources: Stability dependence

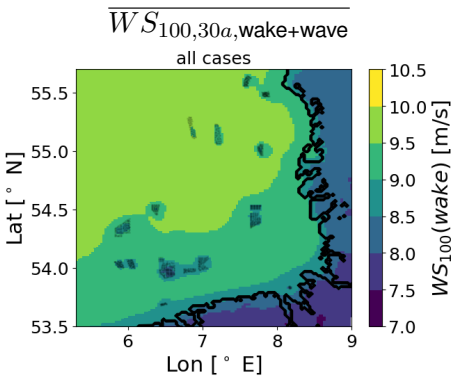


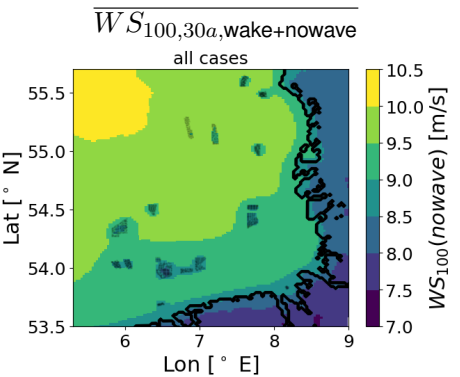
Note: both on- and offshore areas included

Results: waves → resources: 30 years climate

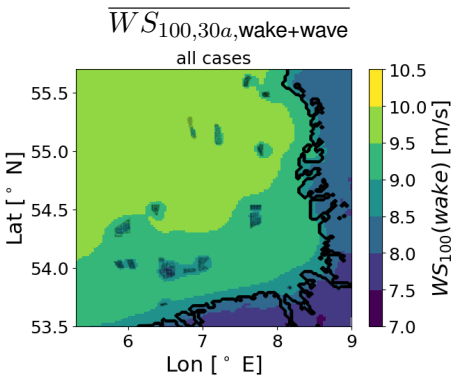


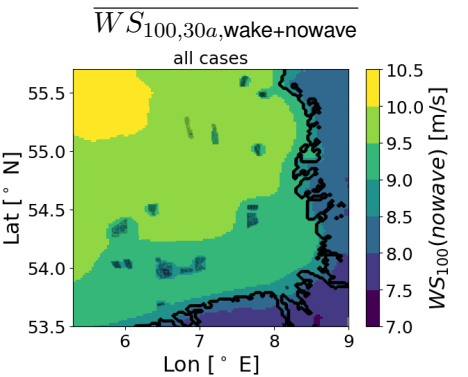
Results: waves → resources: 30 years climate





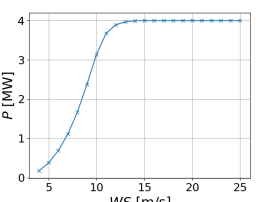
Results: waves → resources: 30 years climate





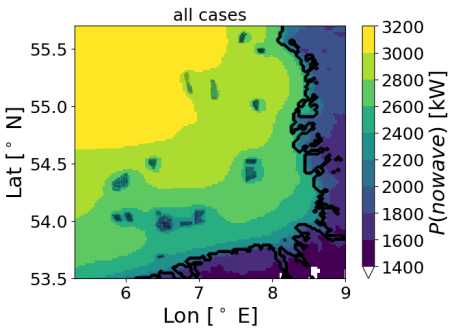
Implication for power:

1. Use a SWT-4.0-120 turbine power curve
2. Derive $\overline{P_{30,\text{wake+wave}}}$ and $\overline{P_{30,\text{wake+nowave}}}$ from $\overline{WS_{30,\text{wake+wave}}}$ and $\overline{WS_{30,\text{wake+nowave}}}$

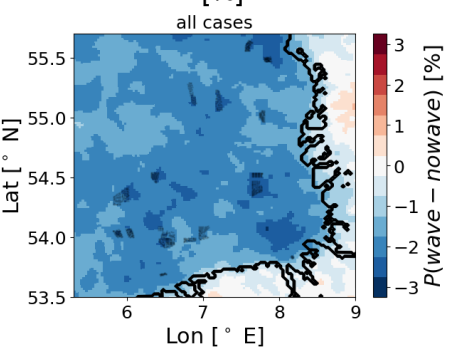


Results: waves → resources: 30 years climate

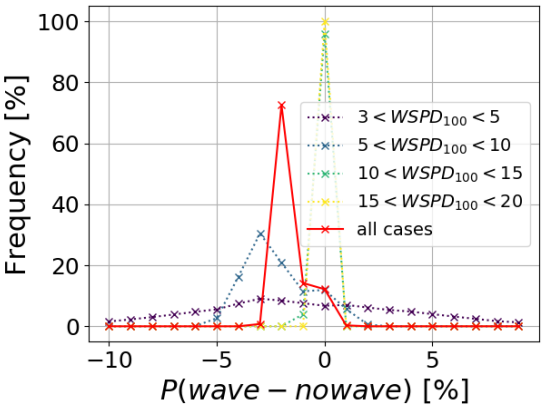
$\overline{P_{100,30a,\text{wake+nowave}}}$



$\overline{P_{100,30a,\text{wake+wave}}}$ - $\overline{P_{30,\text{wake+nowave}}}$ [%]



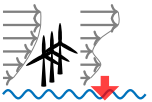
Results: waves → resources: 30 years climate



Note: both on- and offshore areas included

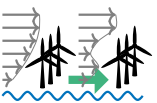
Conclusion

Wakes→Waves



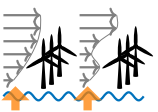
- wave height reduces by 3-5 % on average

Wakes→Resources

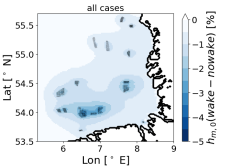


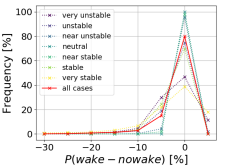
- Zone of reduced wind resources extends to other wind farms
- Depends on stability

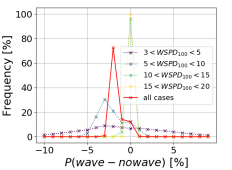
Waves→Resources



- Wave effect one $\mathcal{O}$ smaller
- non-linear effect within the wake region







→ Coupled atmosphere-wave simulation for offshore resource predictions?

Conclusion

Wakes→Waves

- wave height reduces by 3-5 % on average

Wakes→Resources

Thank you!
Contact: Jana Fischereit janf@dtu.dk

Waves→Resources

- Wave effect one $\mathcal{O}$ smaller
- non-linear effect within the wake region

→ Coupled atmosphere-wave simulation for offshore resource predictions?

References and Acknowledgments

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Data sources:

- **Deutscher Wetterdienst (German Weather Service), Climate Data Center (CDC)**
- **FINO Datenbank (Bundesamt für Seeschifffahrt und Hydrographie)**
- **EMODnet Physics system** http://www.emodnet-physics.eu/Map/
- **CFSR data from http://rda.ucar.edu/datasets (National Center for Atmospheric Research Staff (Eds), 2017)**
- **DTU Wind Energy mast measurements** http://rodeo.dtu.dk/rodeo/ProjectListMap.aspx?&Rnd=441824

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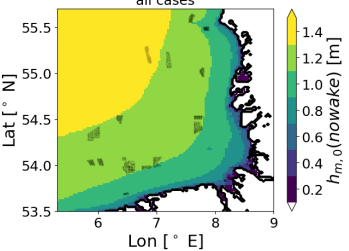
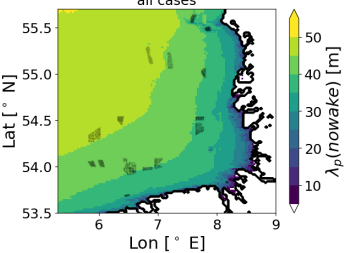
Results: wakes → waves: 30 years climate

$\overline{x_{30,\text{nowake}}}$

$h_{m,0}$



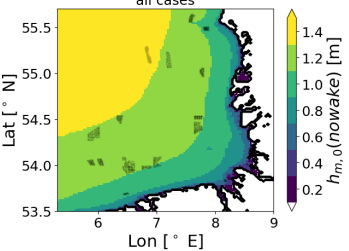
λ_p



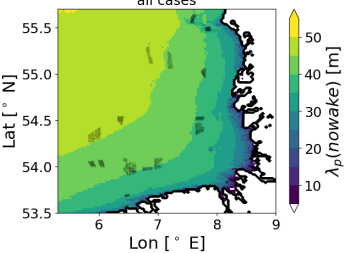
Results: wakes → waves: 30 years climate

$\overline{x_{30,\text{nowake}}}$

$h_{m,0}$



λ_p

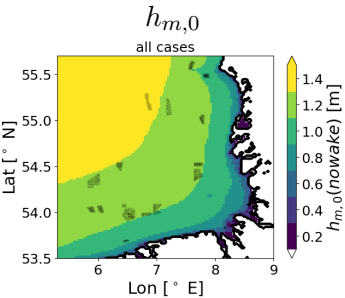


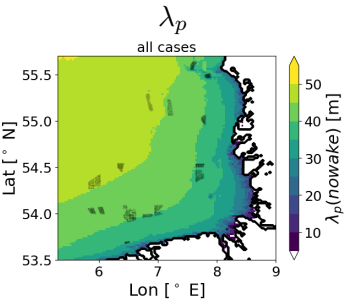
Results: wakes → waves: 30 years climate

$\overline{x_{30,\text{nowake}}}$

$\overline{x_{30,\text{wake}}} - \overline{x_{30,\text{nowake}}}$

[m]

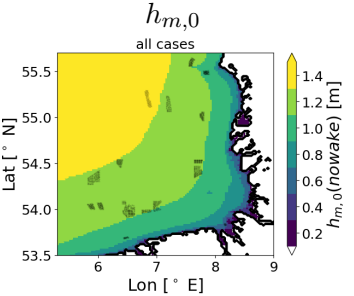


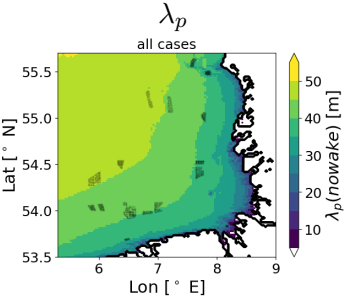


Results: wakes → waves: 30 years climate

$h_{m,0}$ | λ_p

$\overline{x_{30,\text{nowake}}}$





$\overline{x_{30,\text{wake}}} - \overline{x_{30,\text{nowake}}}$

[%]