Cumulative physical effects of offshore wind energy development on oceanographic processes

Jeff Carpenter
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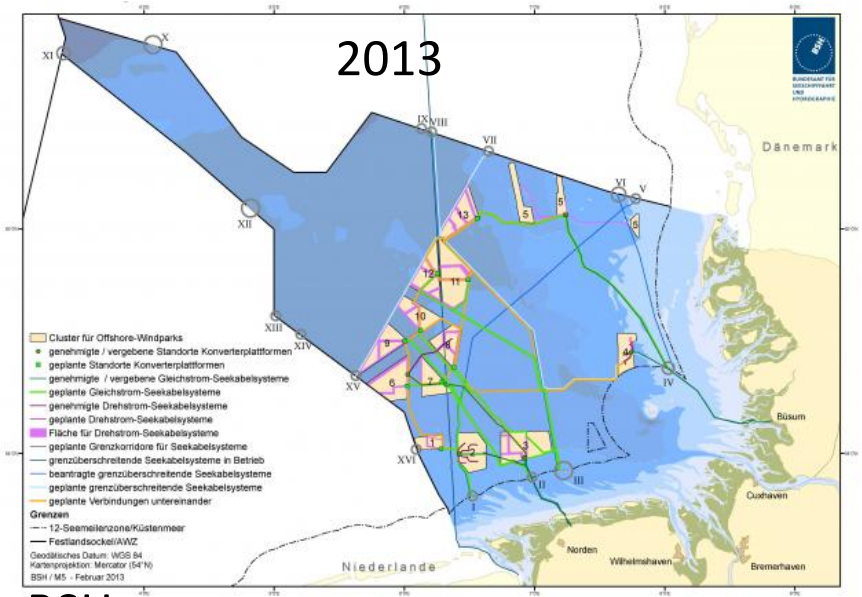
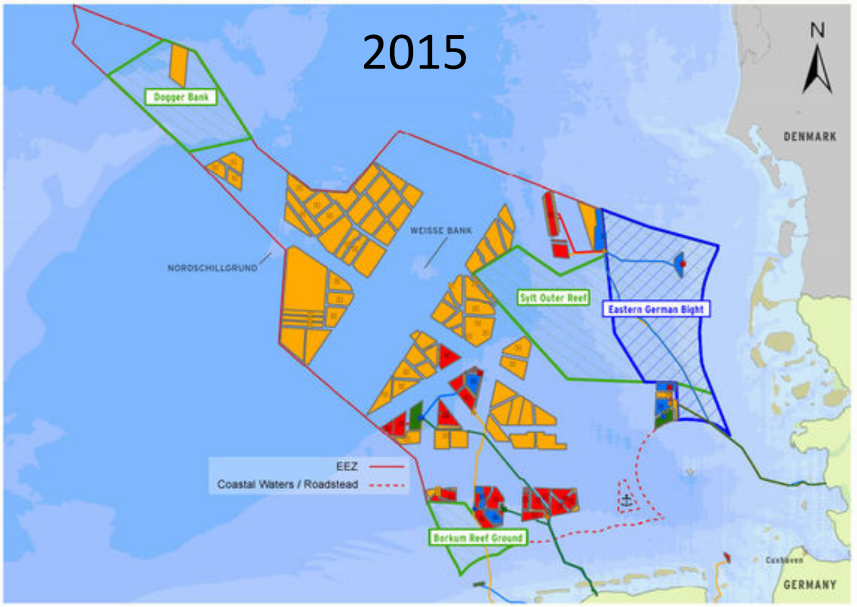
Centre for Materials and Coastal Research

OWF planning on the European Shelf



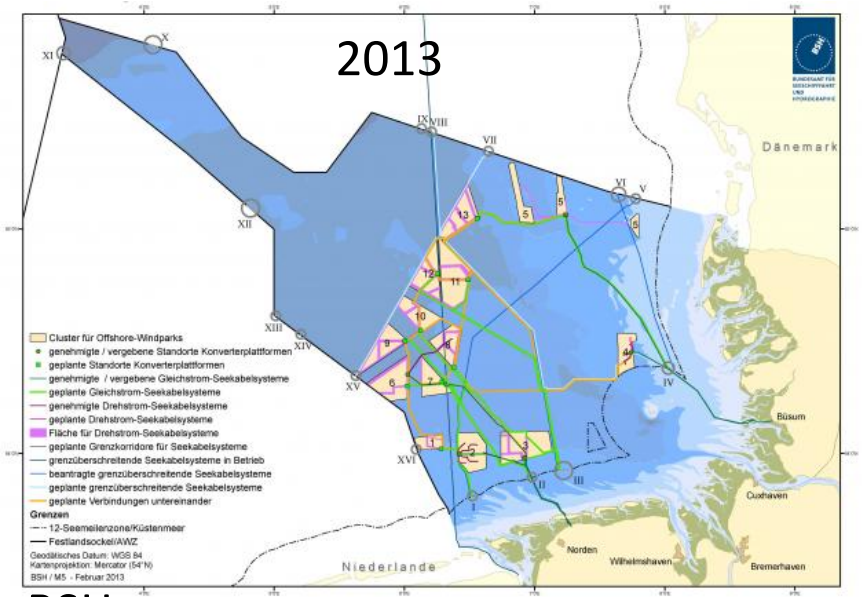
BSH



Bundesamt für Naturschutz

- ***OWF planning changes rapidly and drastically***

OWF planning on the European Shelf



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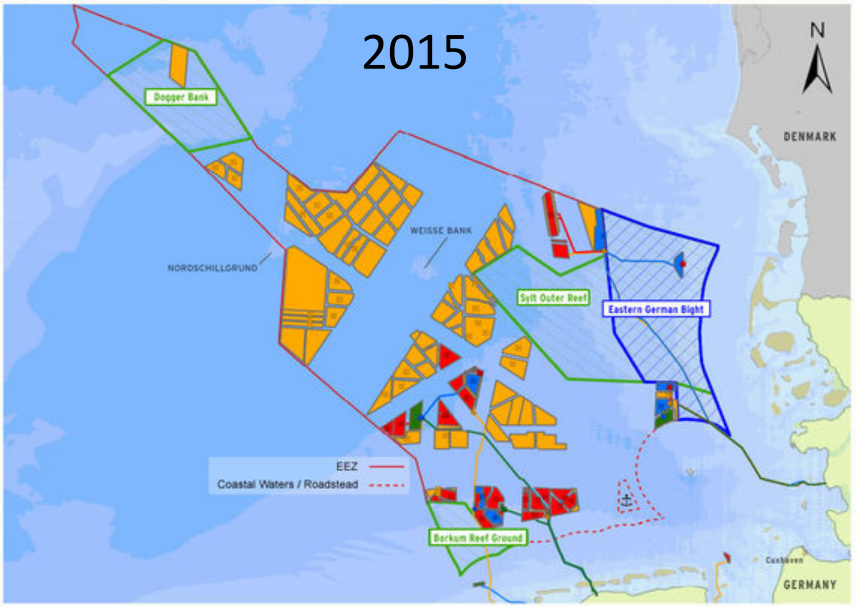

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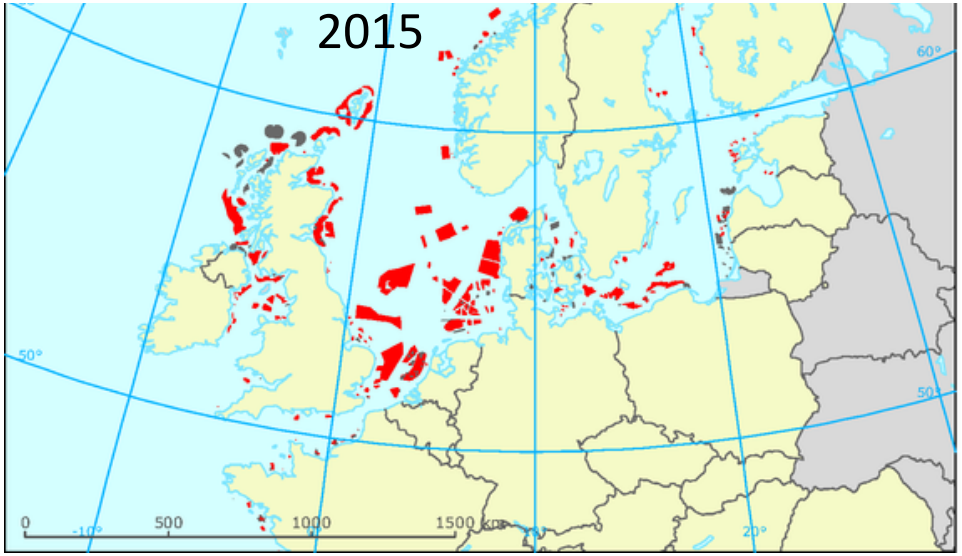


European Environment Agency

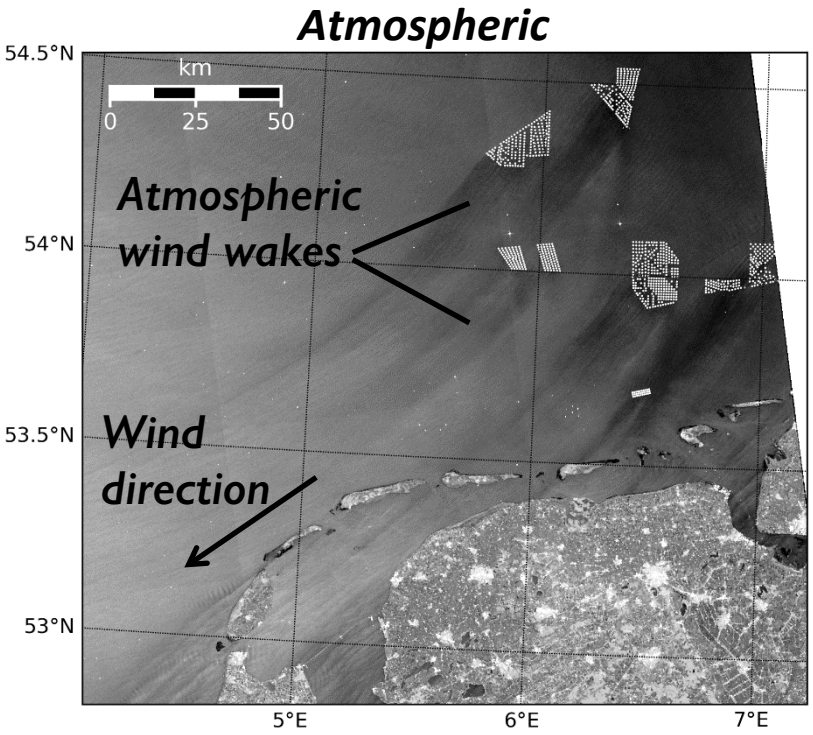
- *OWF planning changes rapidly and drastically*
- *OWFs are planned to occupy LARGE regions of the German EEZ and the Northern European shelf seas*

OWF planning on the European Shelf

- ***What are the impacts to coastal seas?***
  → Physical, biological, chemical, social, etc.

OWF planning on the European Shelf

- ***What are the impacts to coastal seas?***
  → ***Physical***, biological, chemical, social, etc.

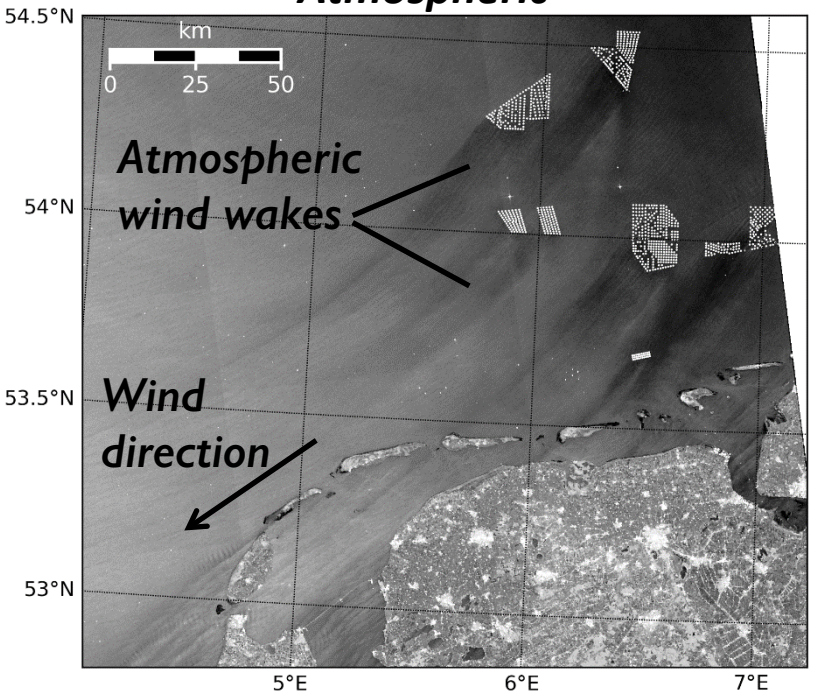


Djath et al. (2018)
Djath & Schultz-Stellenfleth (2019)

OWF planning on the European Shelf

- ***What are the impacts to coastal seas?***
  → ***Physical***, biological, chemical, social, etc.

Atmospheric



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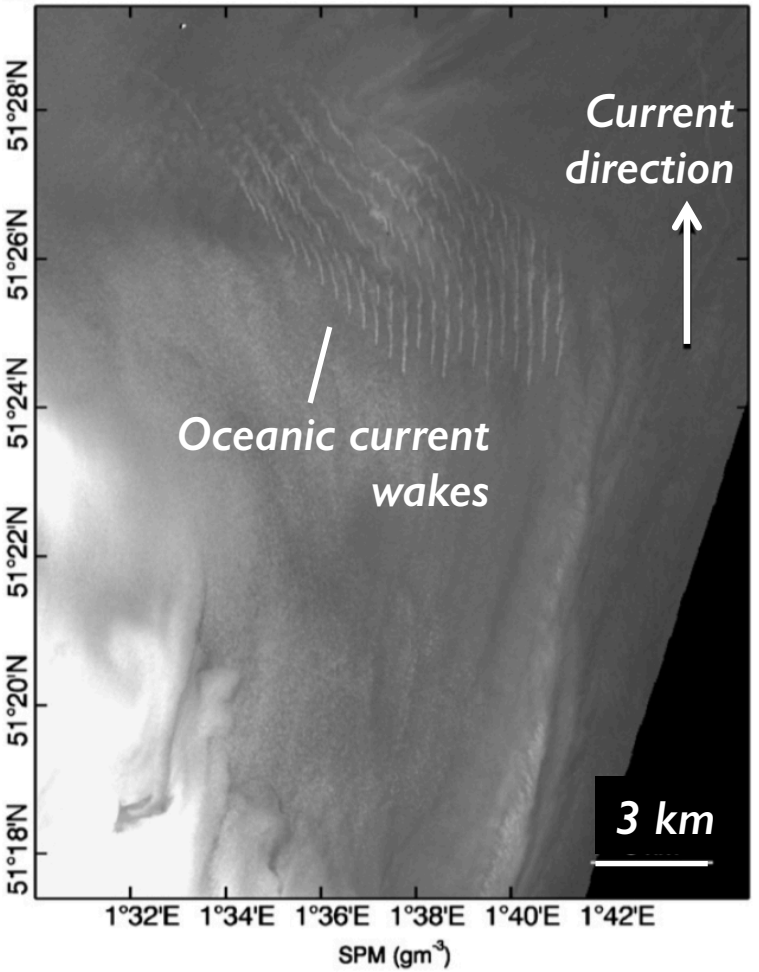
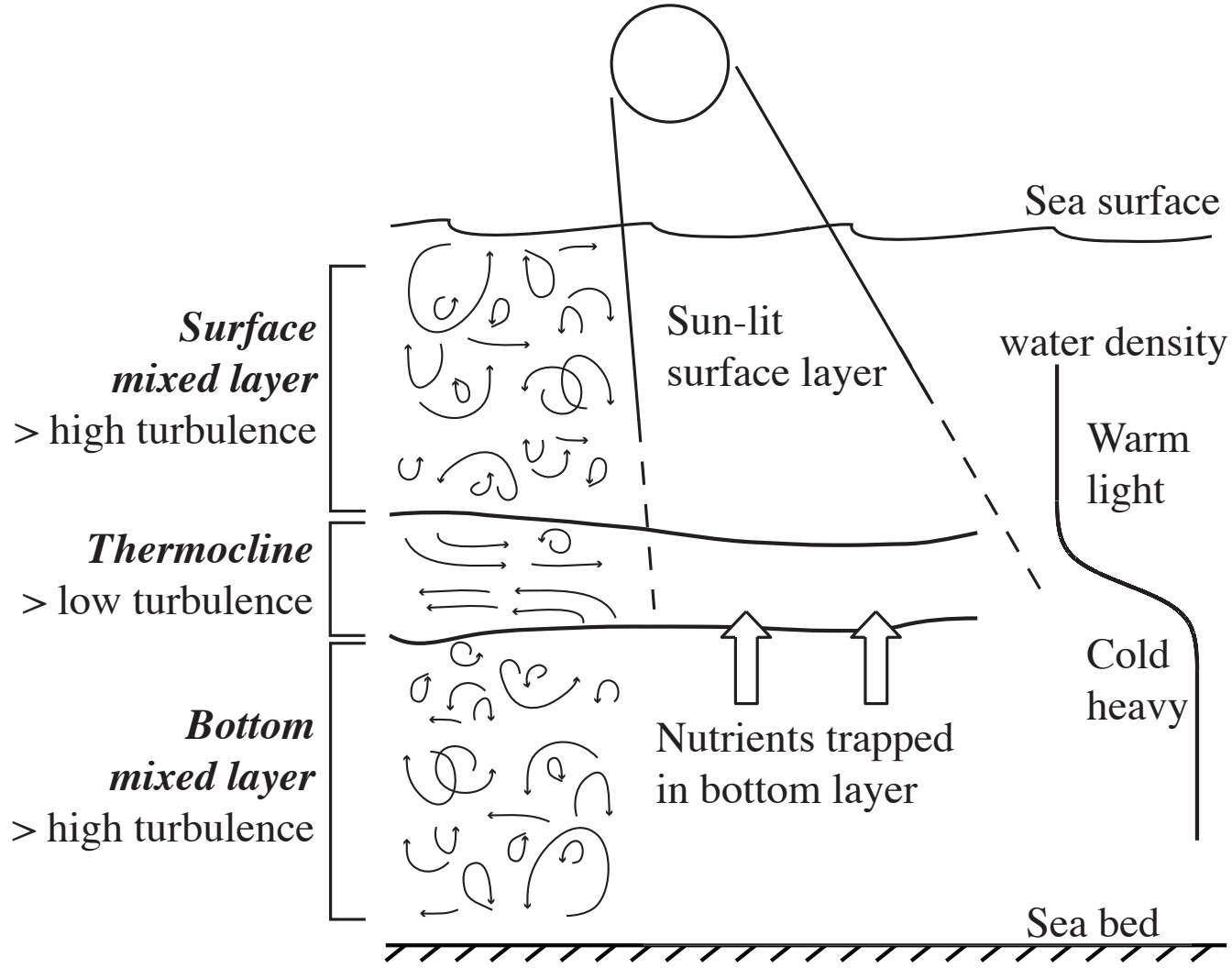
Oceanic

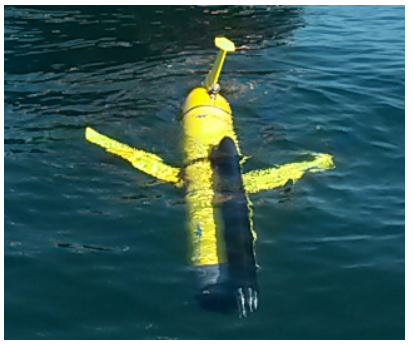


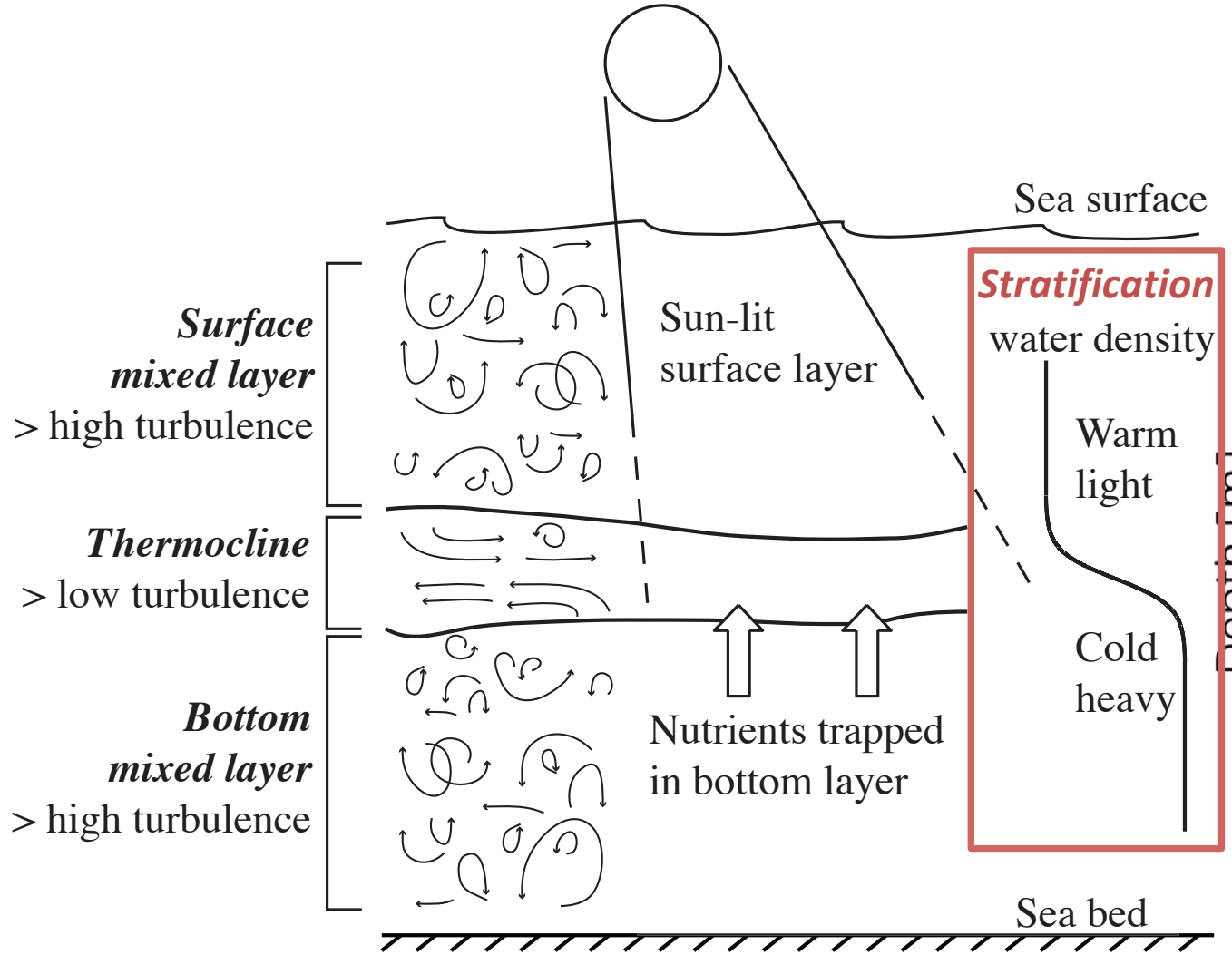
Vonhellemont & Ruddick (2014)

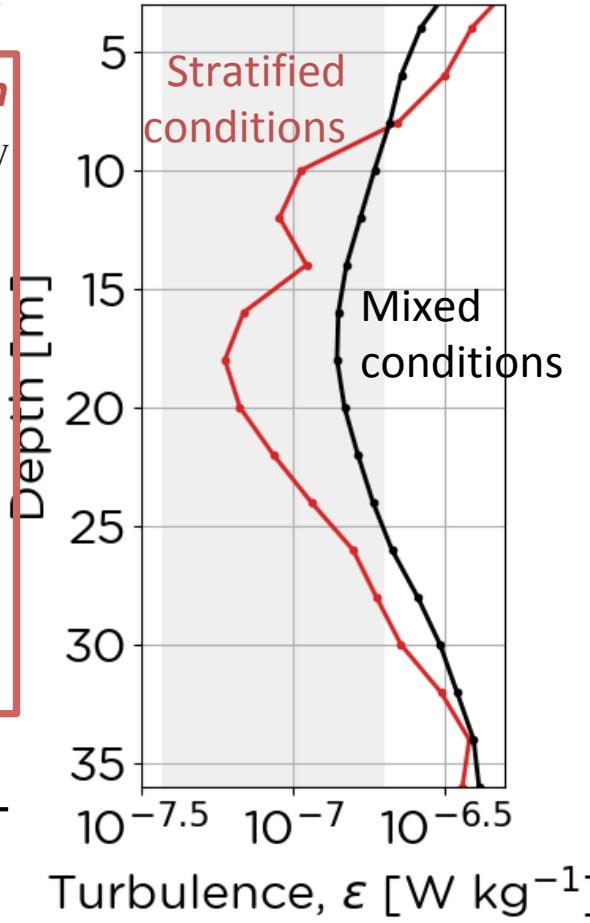
Structure of shelf seas



Structure of shelf seas

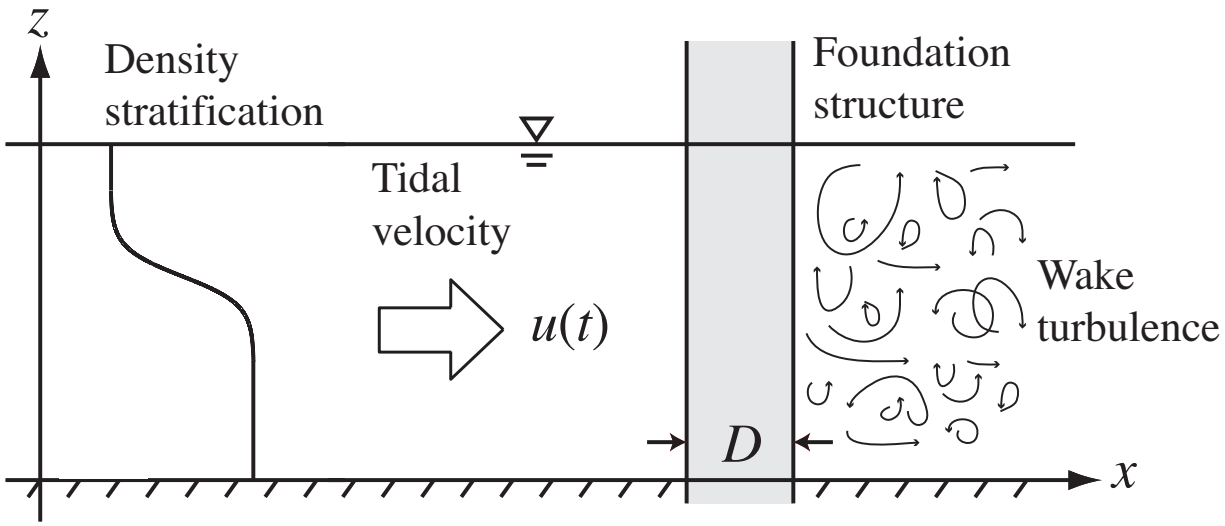


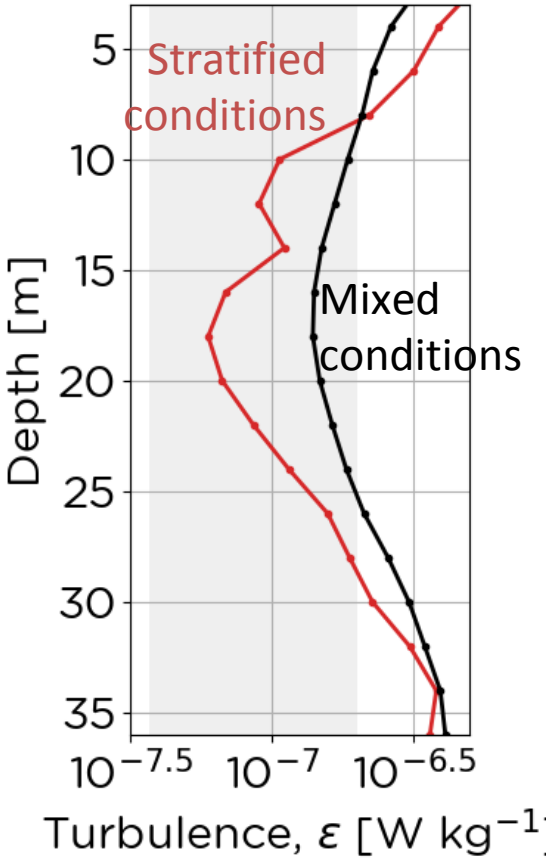




Schultze et al. (2017)

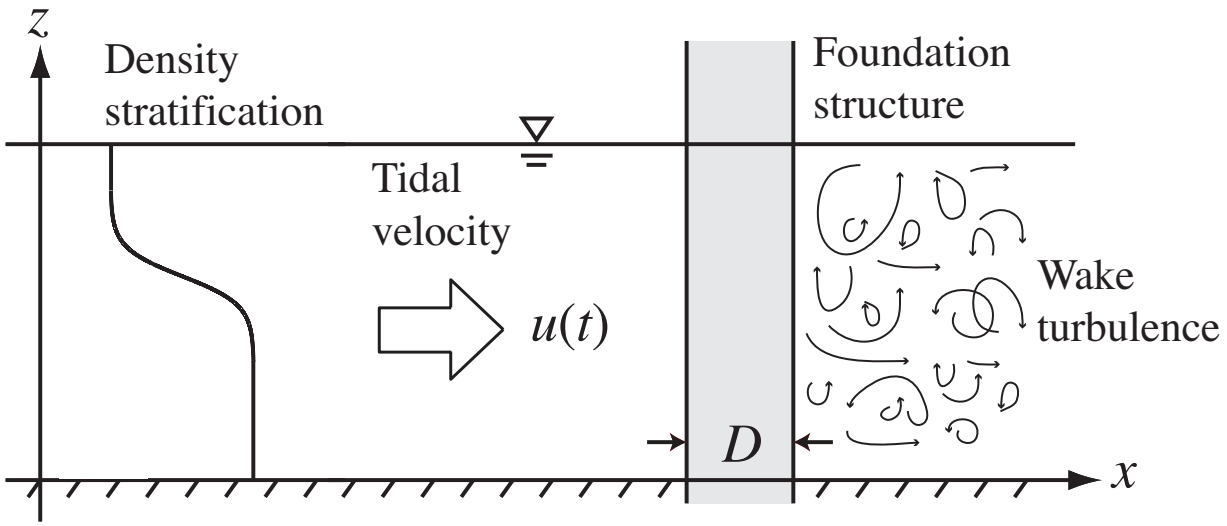
Impacts of OWFs on shelf sea stratification

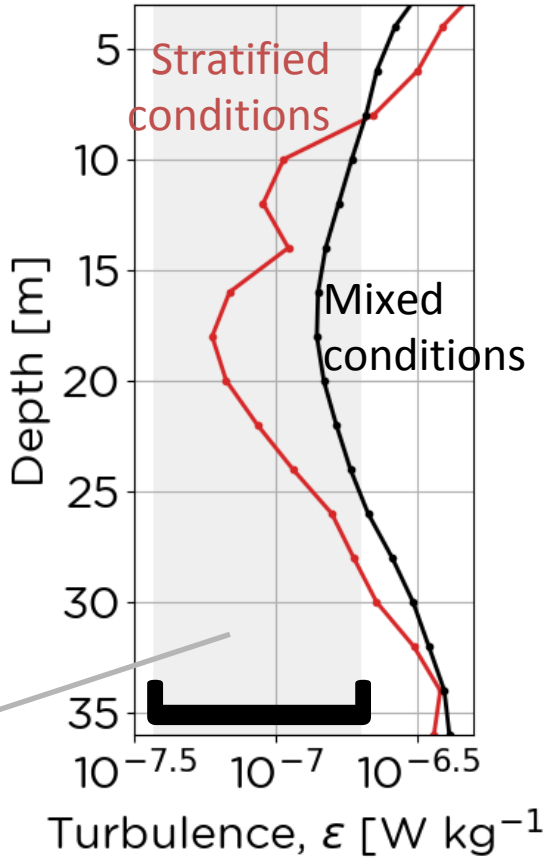




Carpenter et al. (2016), Schultze et al. (2017)

Impacts of OWFs on shelf sea stratification

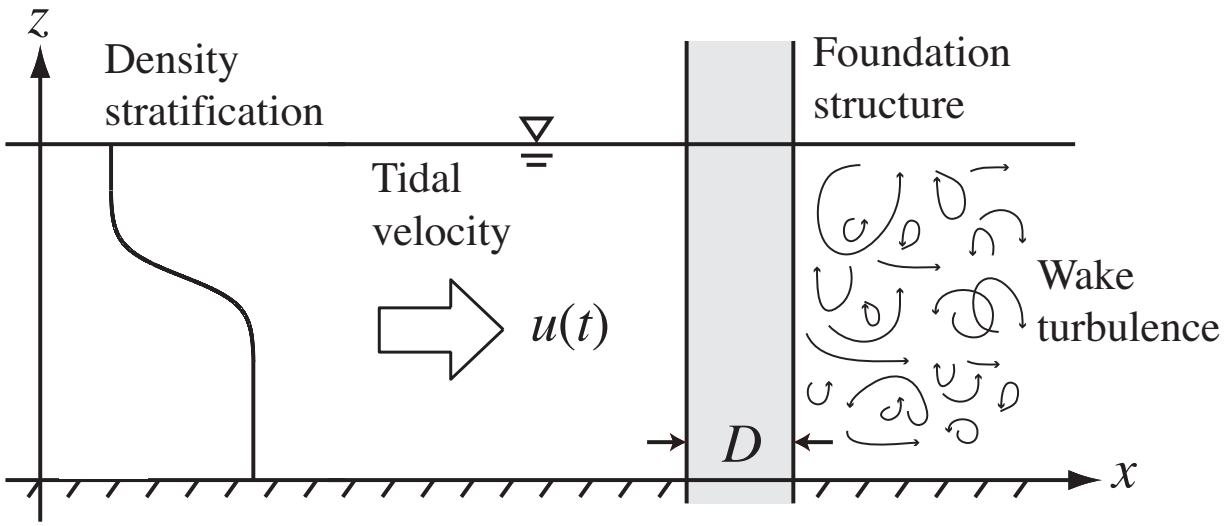


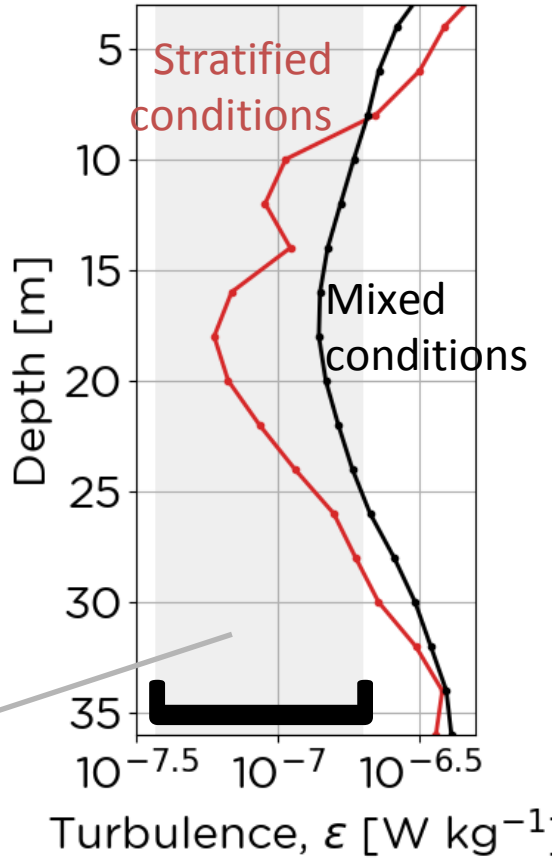


Mean turbulence expected within OWF

Carpenter et al. (2016), Schultze et al. (2017)

Impacts of OWFs on shelf sea stratification





Mean turbulence expected within OWF

- ***Enhanced OWF turbulence is comparable to and can exceed the natural state (particularly when concentrated in a narrow wake region)***

Carpenter et al. (2016), Schultze et al. (2017)

Impacts of OWFs on shelf sea stratification

- ***Question:*** ***Can OWF-driven mixing significantly alter shelf sea stratification?***

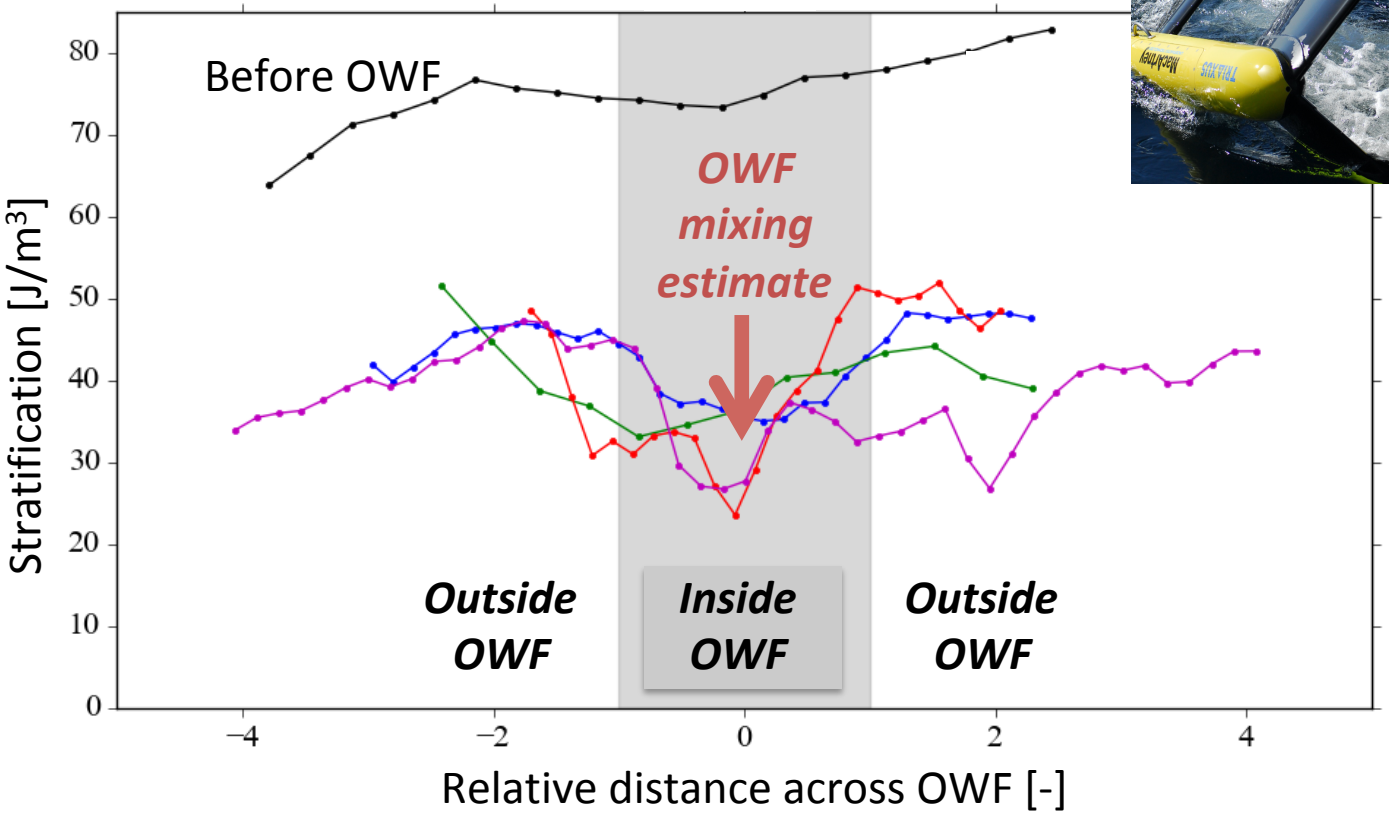
Impacts of OWFs on shelf sea stratification

- ***Question:*** ***Can OWF-driven mixing significantly alter shelf sea stratification?***
- Need a diverse set of methods:
  - Idealised/theoretical modelling
  - Field observations and measurements
  - Numerical modelling

    → Multiple models over a broad range of scales

Idealised modelling -- Observations

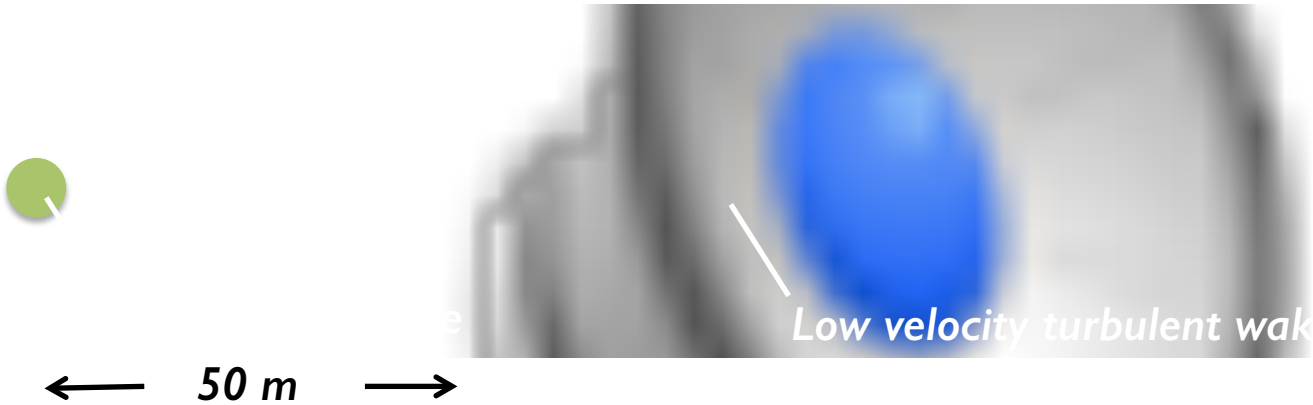
Jens Flöter (UHH)



Flöter et al. (2017), Carpenter et al. (2016)

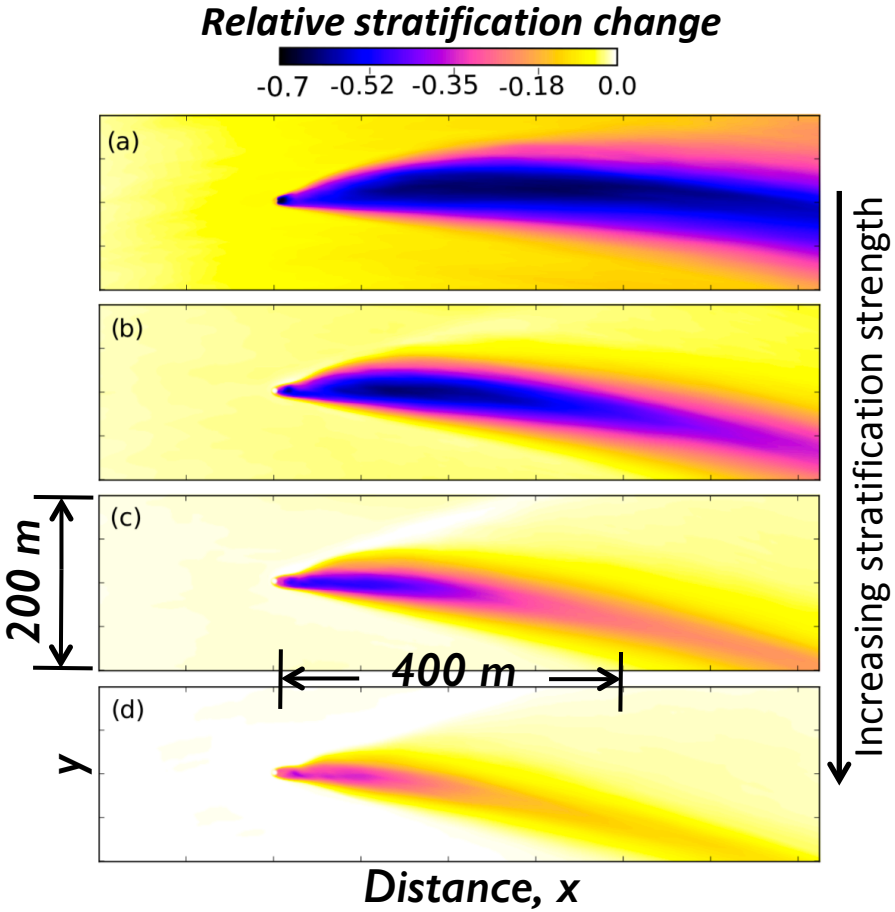
Turbulence modelling

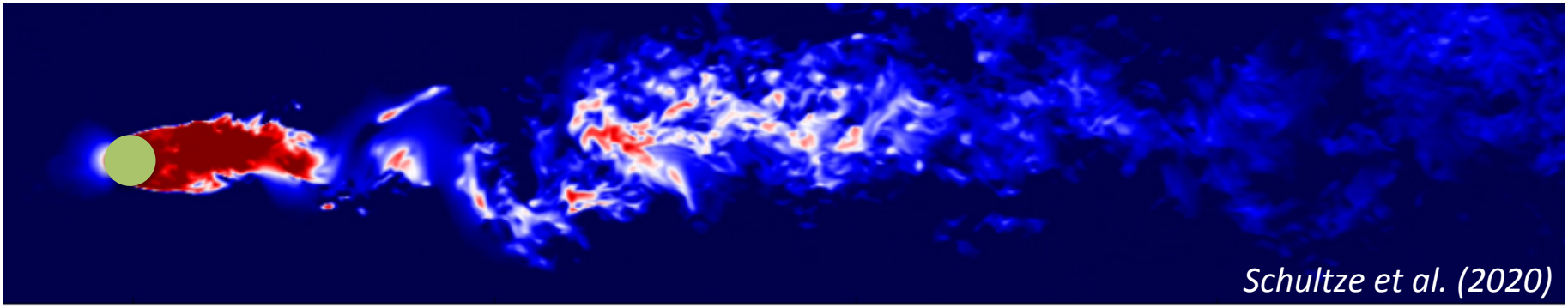
Turbulence-resolving simulation of OWF turbulence:



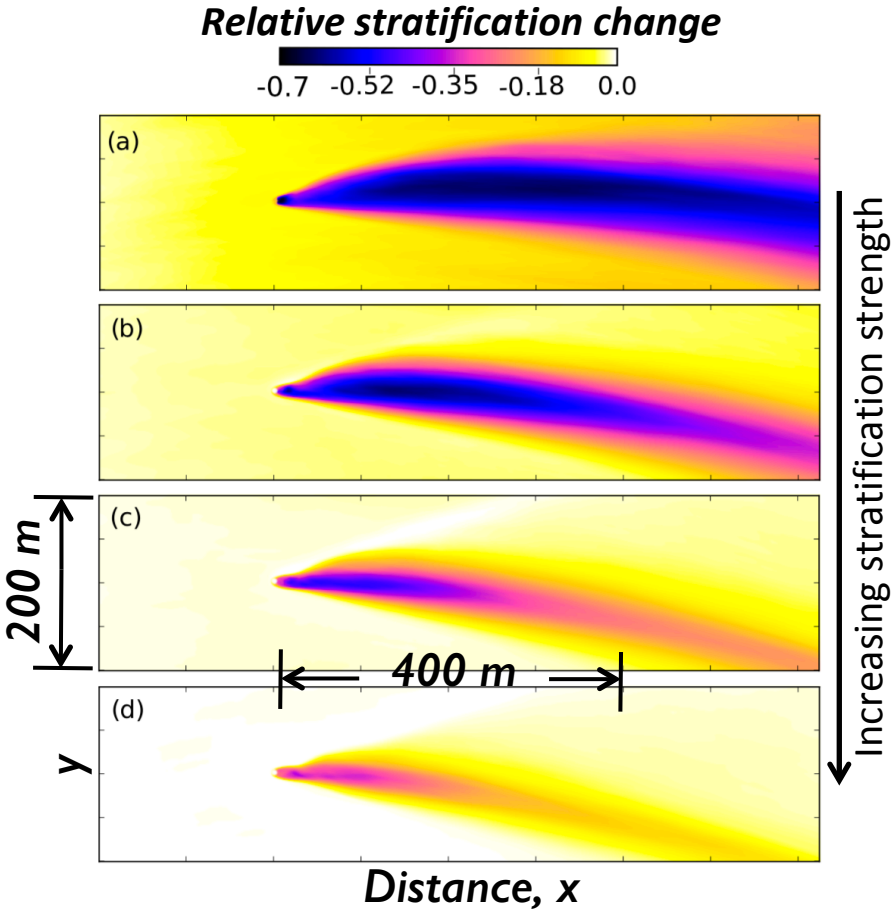
Schultze et al. (2020)

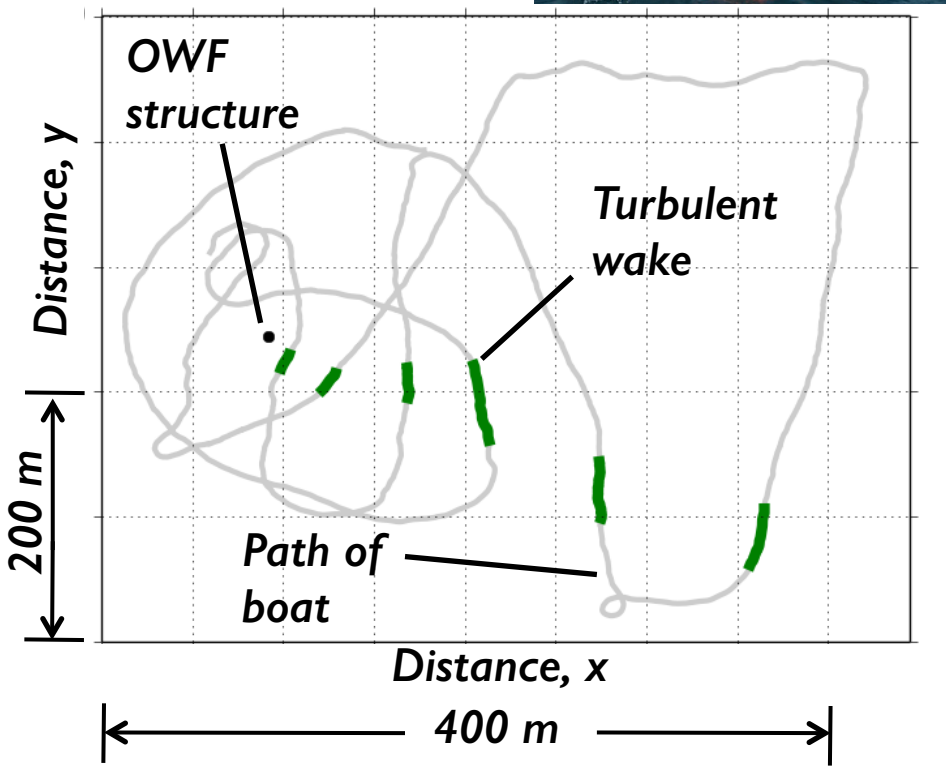
Turbulence modelling

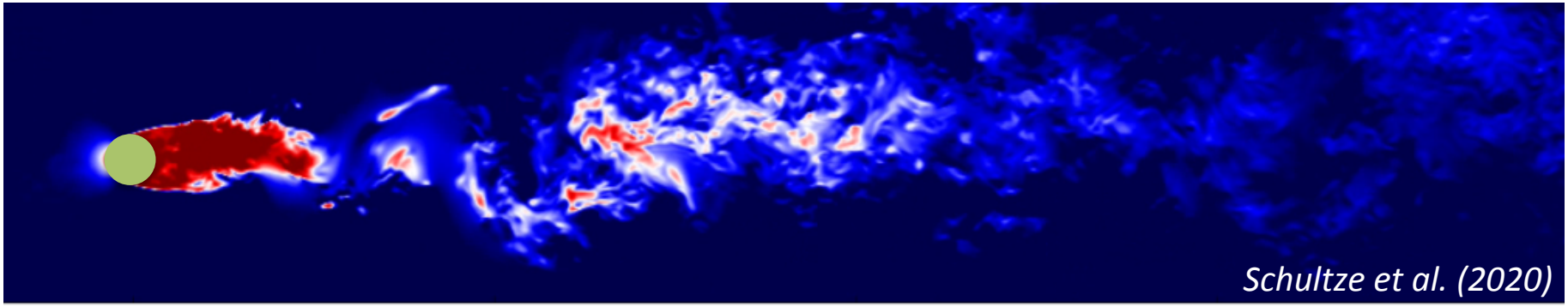




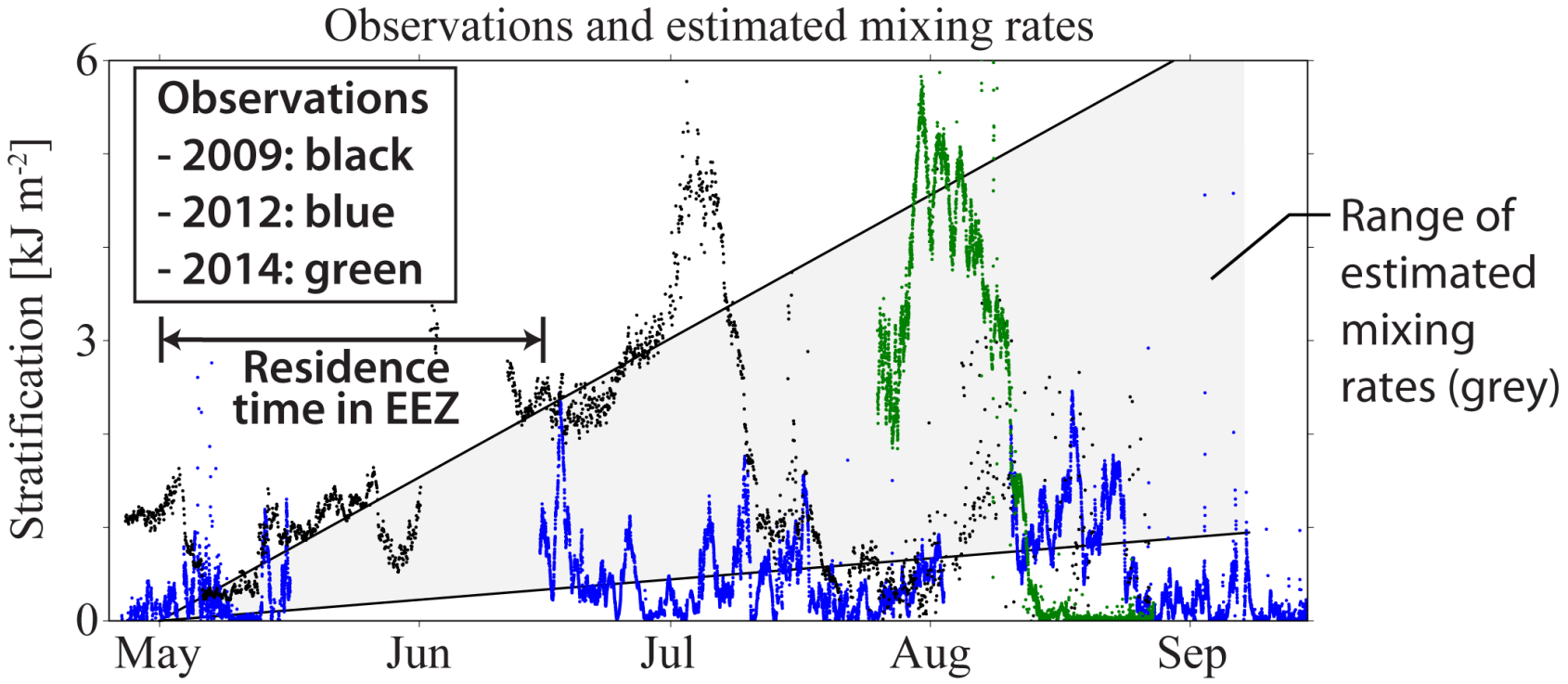
Turbulence modelling and observations





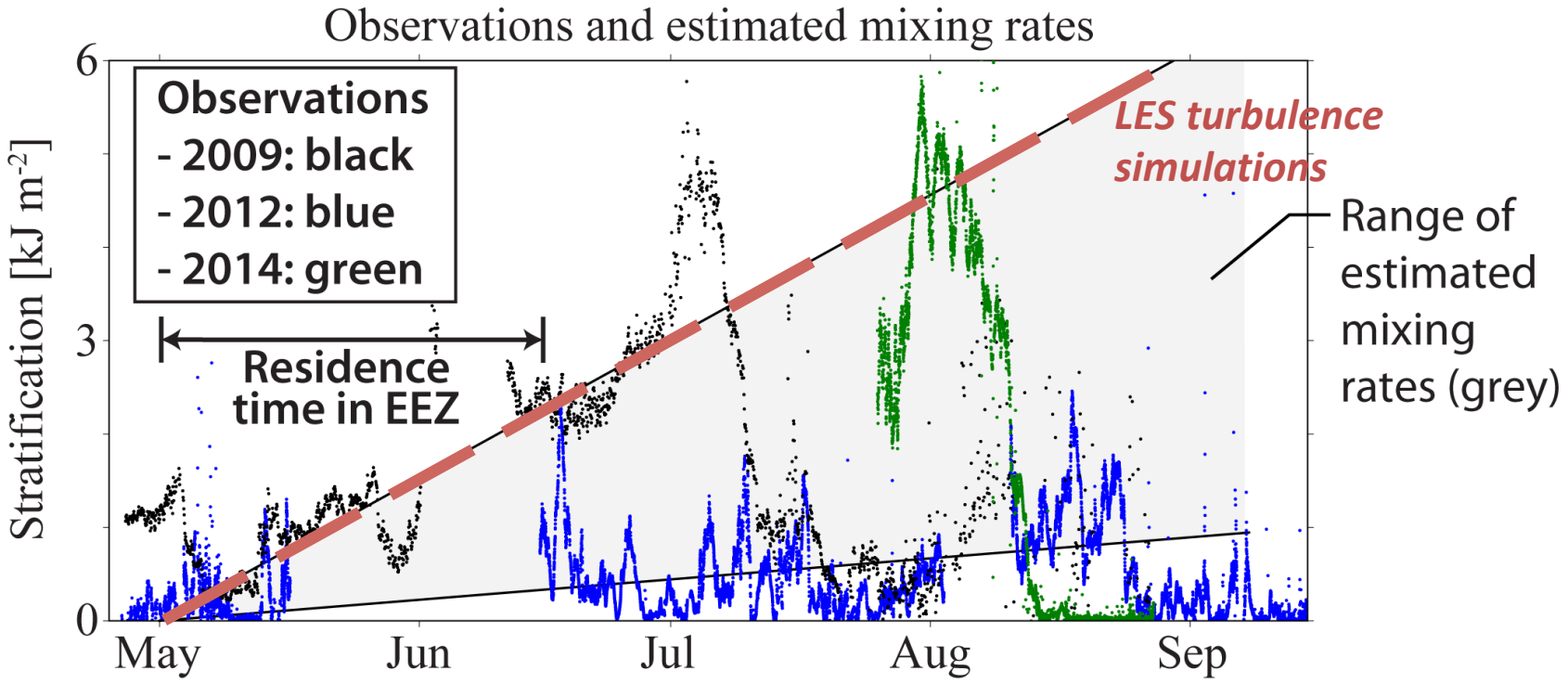


Idealised modelling and observations



Carpenter et al. (2016)

Turbulence modelling and observations



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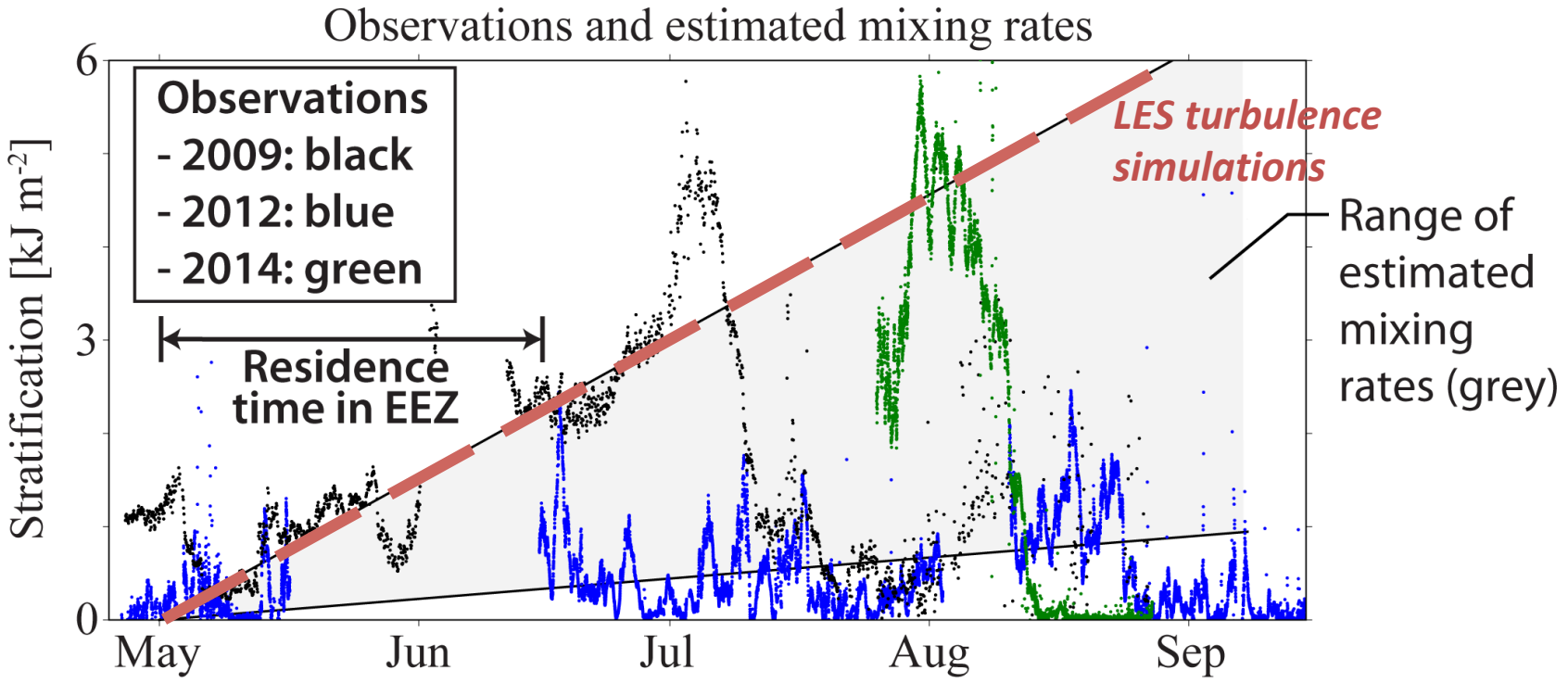

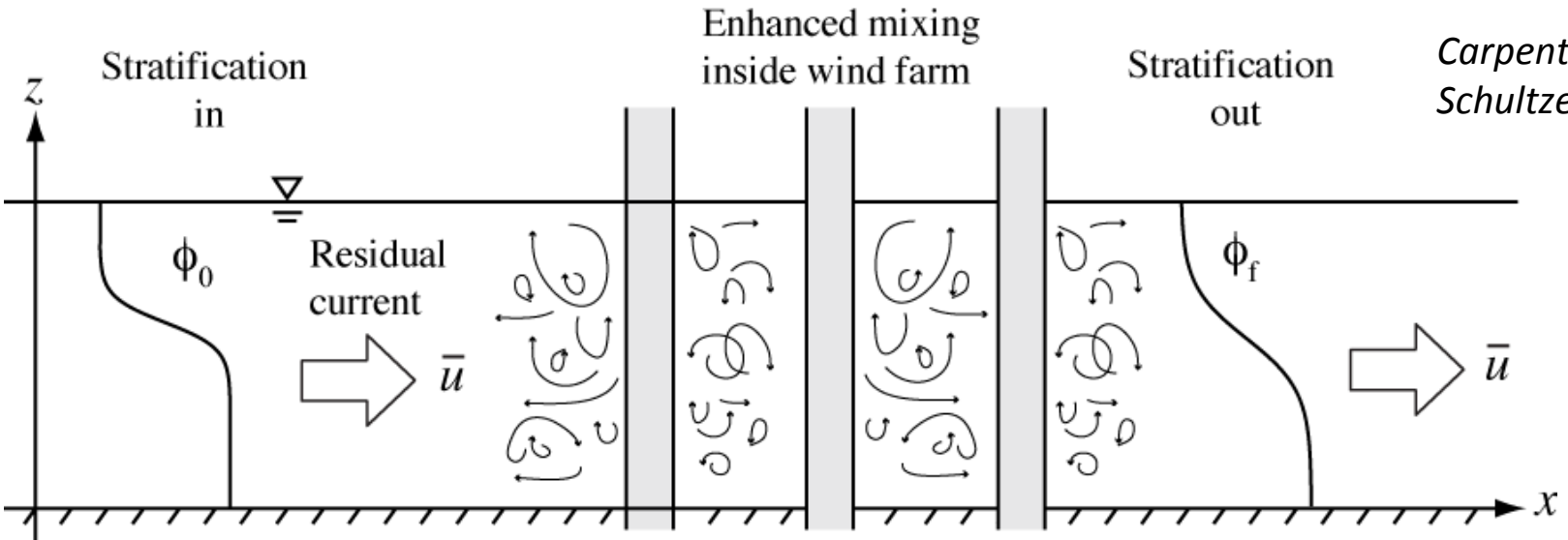

Carpenter et al. (2016)
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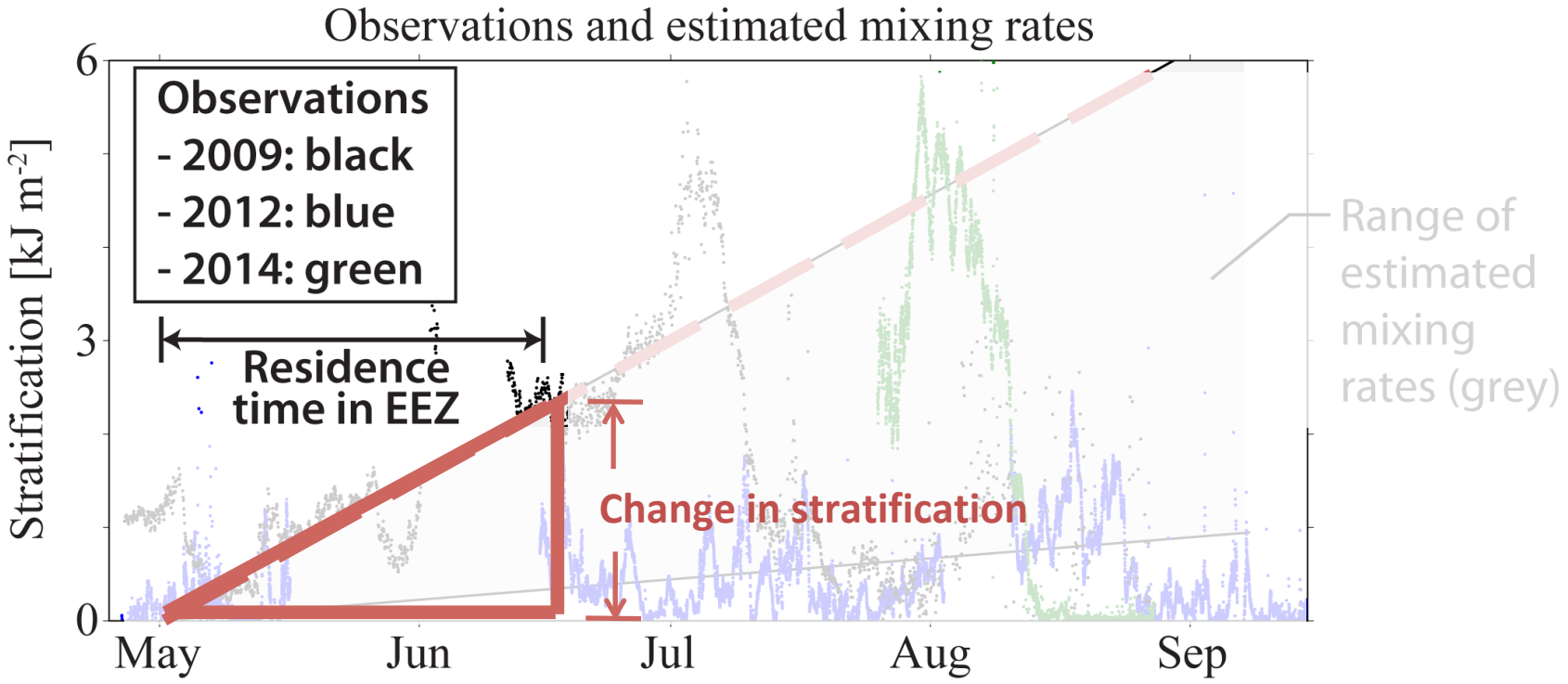
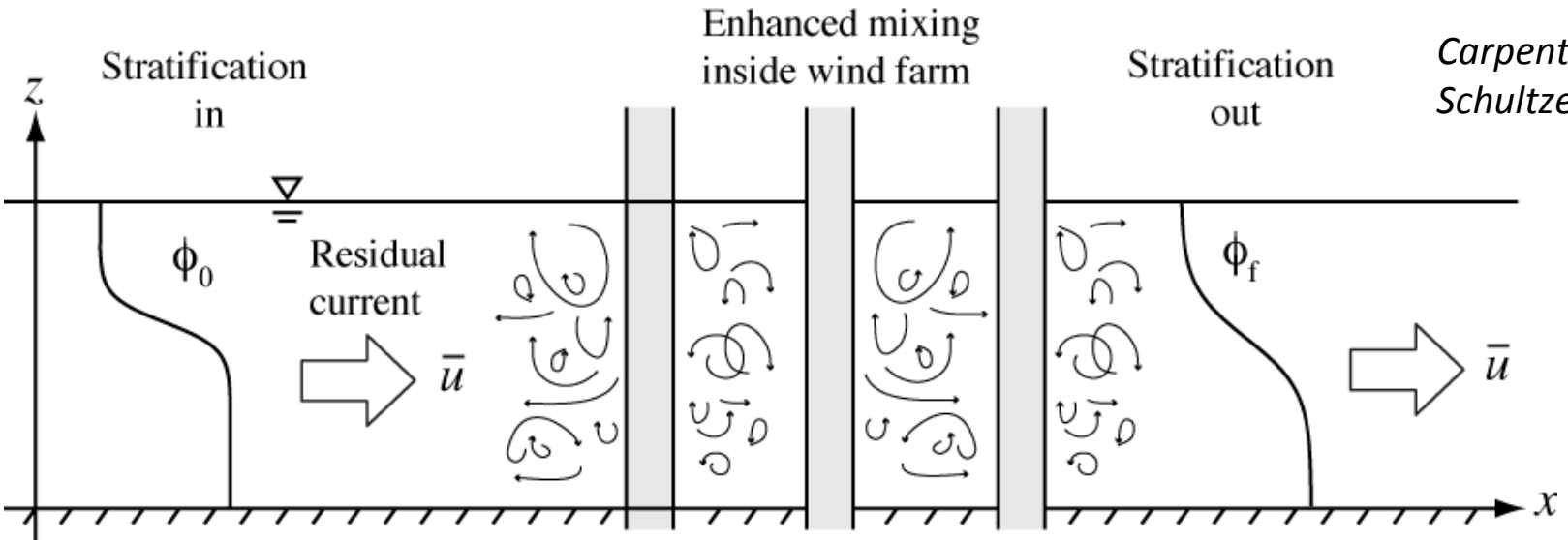
Idealised modelling -- Observations





Carpenter et al. (2016)
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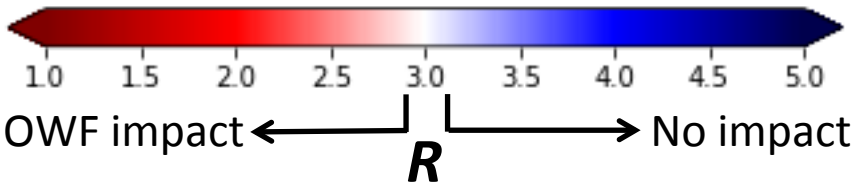
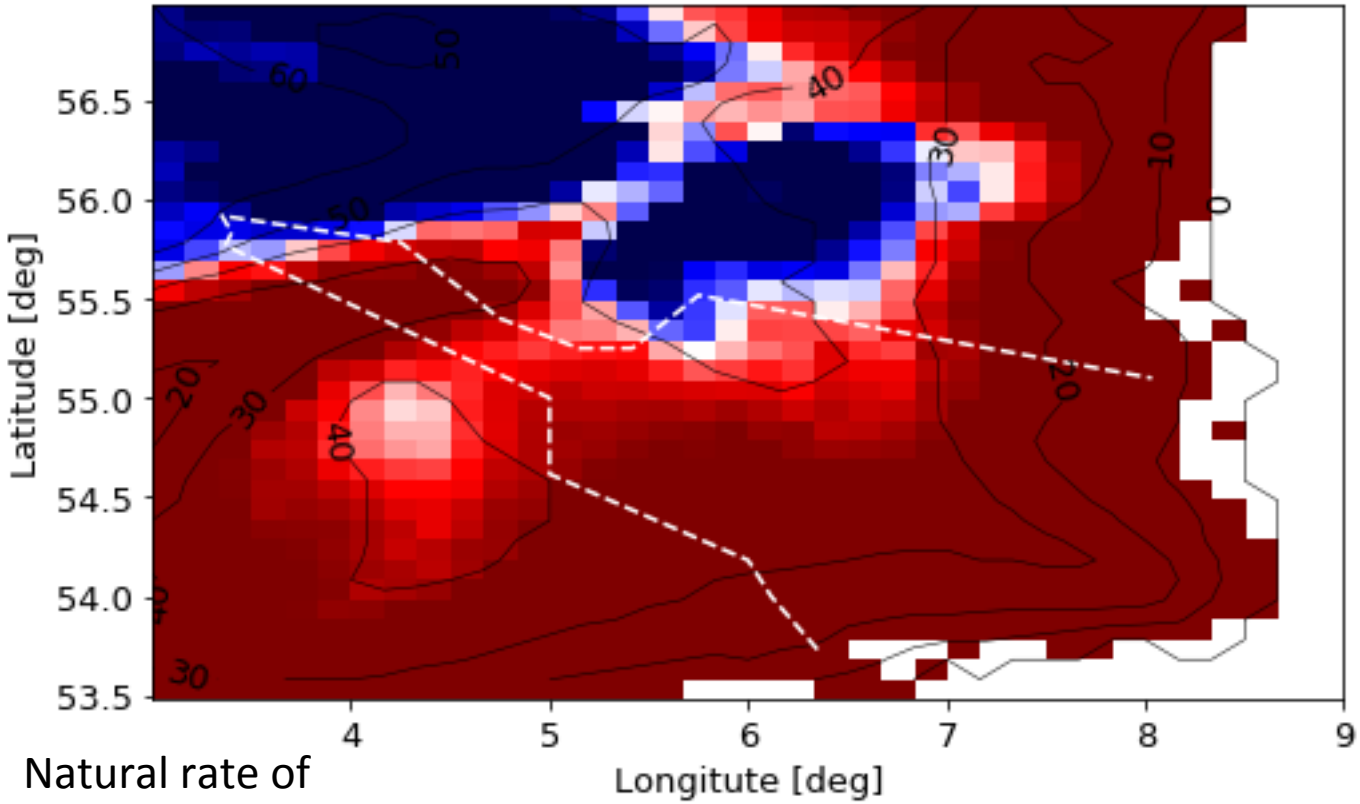
Relevance in the German EEZ

$$R = \frac{\text{Natural rate of stratification increase}}{\text{Rate of OWF mixing (stratification decrease)}}$$



- ***Can OWF-driven mixing significantly alter shelf sea stratification?***

Relevance in the German EEZ



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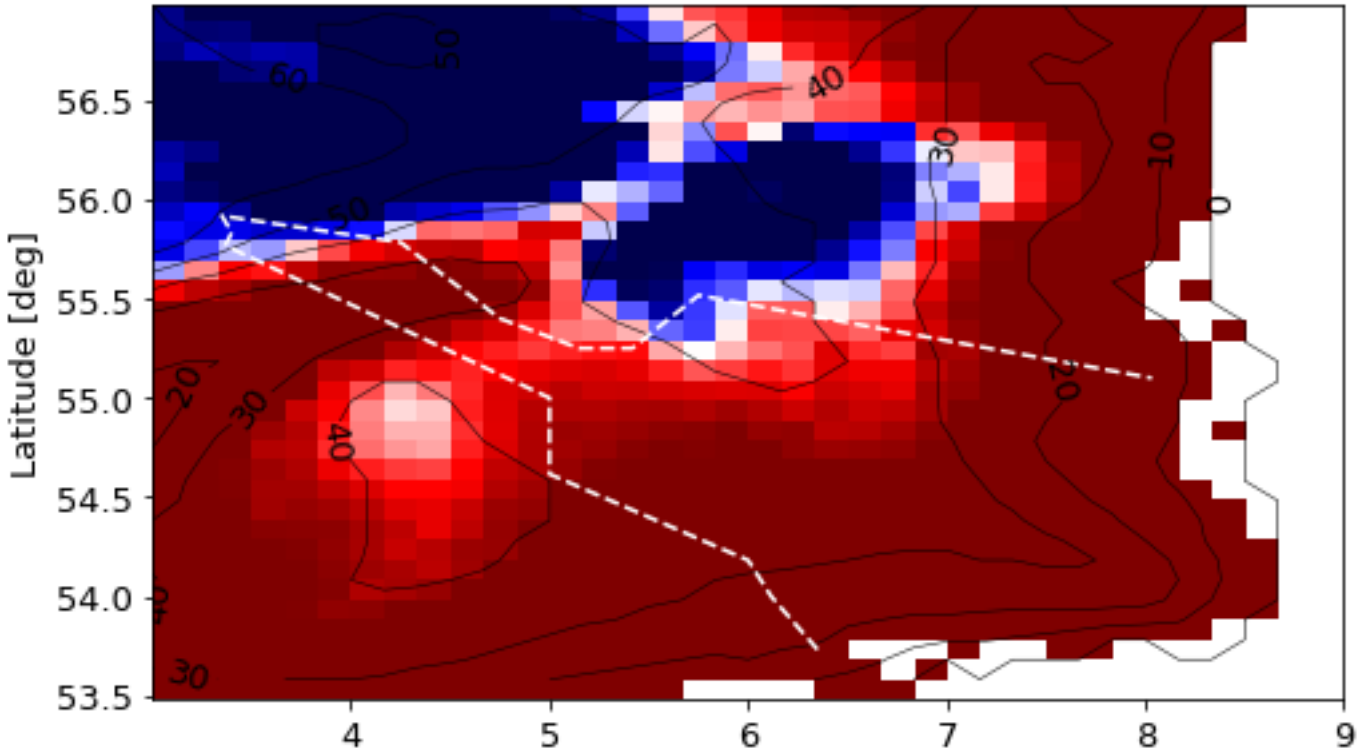
- ***Can OWF-driven mixing significantly alter shelf sea stratification?***

Relevance in the German EEZ



$$R = \frac{\text{Natural rate of stratification increase}}{\text{Rate of OWF mixing (stratification decrease)}}$$

- ***Can OWF-driven mixing significantly alter shelf sea stratification? → YES, when built over large regions***

Summary

- *OWF development is planned to be widespread* over the NW European shelf but can change rapidly in scope.
- Enhanced ocean *turbulence from OWF foundations exceeds natural sources* and can affect mixing of stratification
- First *rough parameterisation of OWF foundation mixing* developed and tested. → Much more needs to be done!
- The seasonal *changes in stratification expected to be significant when OWFs built over large scales*, i.e., on the order of ~100 km.
- These *stratification changes* can likely be expected *throughout the German EEZ*.

Future Work

- Develop a robust parameterisation for small-scale mixing in OWFs and integrate into regional scale models
  → Integrating the physical impacts into the wider picture
  → Study changes in primary production, ecosystem structure and fisheries over the European shelves
  → Run impact scenarios for various development strategies
  → Include coupled atmosphere-ocean impacts

A tool to manage this "green" offshore resource sustainably and optimally

References this presentation is based on

1) Carpenter, J.R., L. Merckelbach, U. Callies, S. Clark, L. Gaslikova & B. Baschek (2016): Potential impacts of offshore wind farms on North Sea stratification. *PLoS ONE*, 11(8), e0160830.

2) Flöter, J., J. van Beusekom, D. Auch, U. Callies, J.R. Carpenter, et al. (2017): Pelagic effects of offshore wind farm foundations in the stratified North Sea. *Progress in Oceanography*, 156, pp. 154-173.

3) Schultze, L.K.P., L. Merckelbach & J.R. Carpenter (2017): Turbulence and mixing in a shallow stratified shelf sea from underwater gliders. *Journal of Geophysical Research: Oceans*, 122, doi: 10.1002/2017JC012872.

4) Schultze, L.K.P., L. Merckelbach, J. Horstmann, S. Raasch & J.R. Carpenter (2020): Increased mixing and turbulence in the wake of offshore wind farm foundations. *Journal of Geophysical Research: Oceans*, 125, doi: 10.1002/2019JC015858

Thank you

Important points to consider

- Variability of stratification and residual currents in the North Sea is enormous! → *OWF mixing variability enormous*

- Many *different types of OWF foundation structures* – each has different turbulence production and mixing.

- Many processes not accounted for yet
  → Interaction with the turbulent surface mixed layer
  → Wake-wake interactions
  → Parameter space not properly explored (various stratification strengths and structures, foundation diameters, current speed, etc…)

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