Models and perspectives of wake dynamics and turbulence

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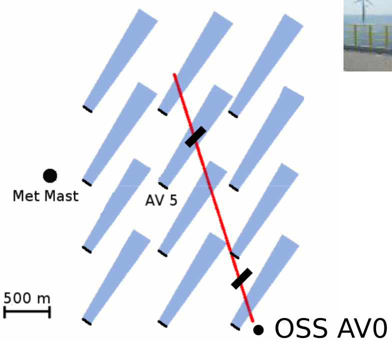
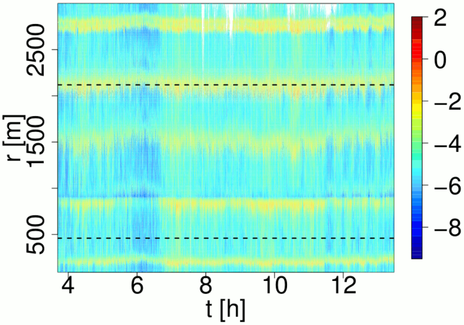
Lidar measurements of wake turbulence: Setup

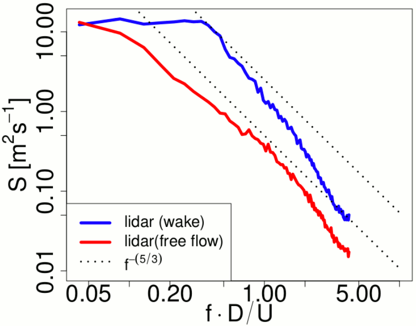
Measurement Scenario





- Quasi-stationary for ca. 10 h
- Velocity u_{los} with ca. 1 Hz

Lidar measurements of wake turbulence: Spectra



- Idea: Wake starts new turbulent cascade at $\approx D$

[Bastine e.a. 2015, J. Phys. Conf. Ser. 625]

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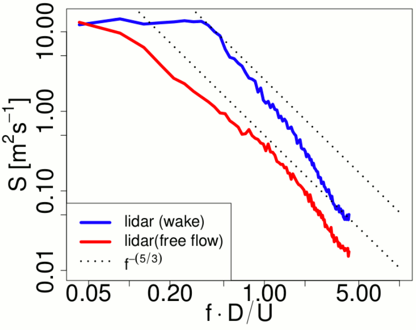

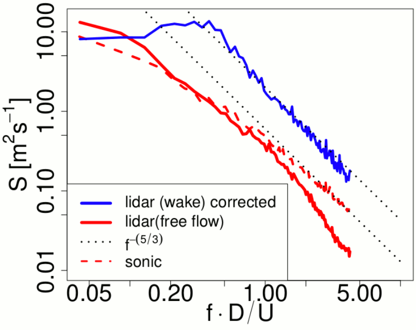

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- Simplistic lidar correction using FINO I sonic

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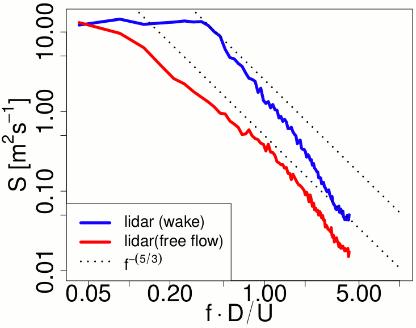
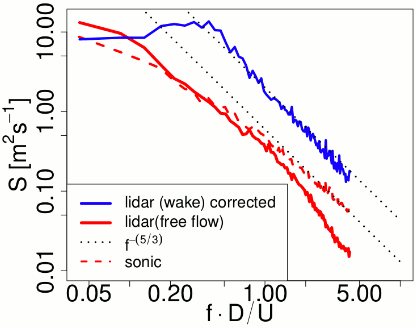
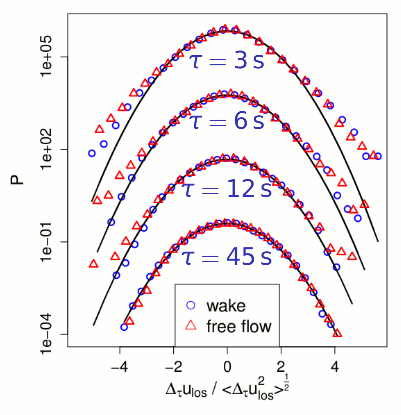




[Bastine e.a. 2015, J. Phys. Conf. Ser. 625]

- Idea: Wake starts new turbulent cascade at $\approx D$
- Simplistic lidar correction using FINO I sonic
- $\Rightarrow f^{-5/3}$ decay as in idealized turbulence

Lidar measurements of wake turbulence: Intermittency



- PDF of $\Delta_\tau u = u(t+\tau) - u(t)$ show "heavy tails"

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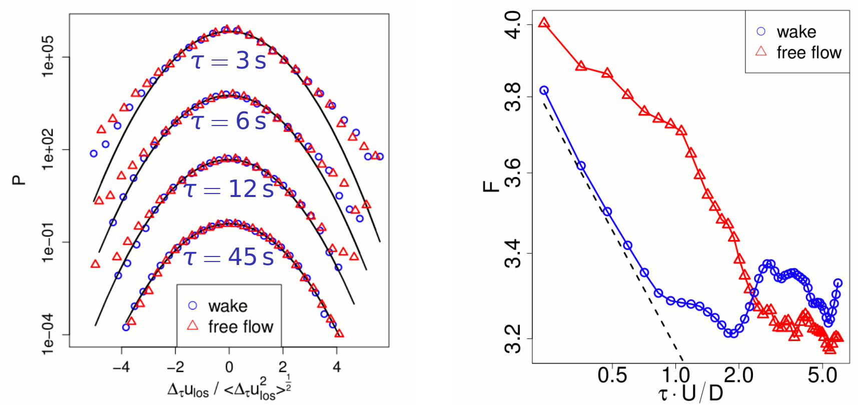

- PDF of $\Delta_\tau u = u(t+\tau) - u(t)$ show “heavy tails”
- Lower flatness in wake than in free flow

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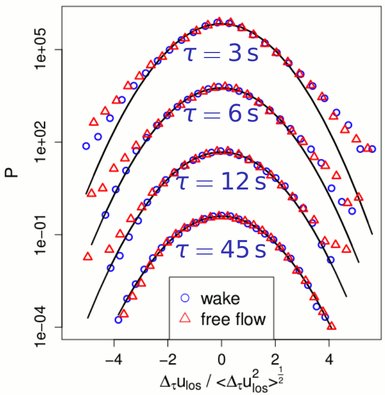
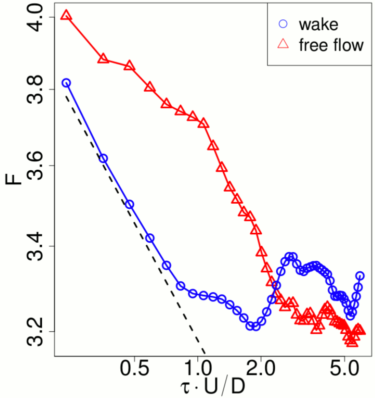




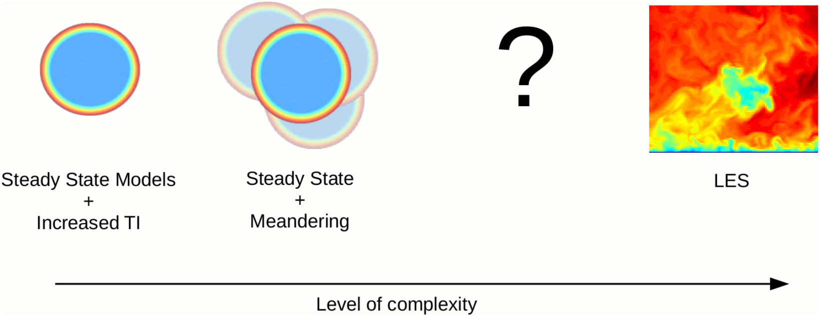
- PDF of $\Delta_\tau u = u(t+\tau) - u(t)$ show "heavy tails"
- Lower flatness in wake than in free flow
- Flatness decay $F \propto \tau^{-\mu \cdot 4/9}$, $\mu \approx 0.27$

  $\Rightarrow$ Wake core follows K62 idealized turbulence

[Bastine e.a. 2015, J. Phys. Conf. Ser. 625]

Reduced-order wake model using POD

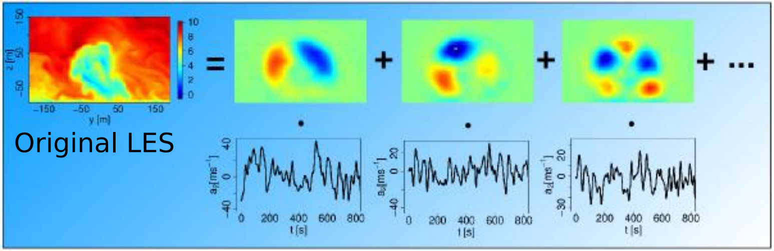
Do we need another wake model?



Aim: Include wake structures and dynamics by "Proper Orthogonal Decompsition" (POD)

Reduced-order wake model using POD

Principle of POD: Decomposition into orthogonal modes



ϕ_j
POD modes

$a_j(t)$
weighting coefficients

Reduced-order wake model using POD

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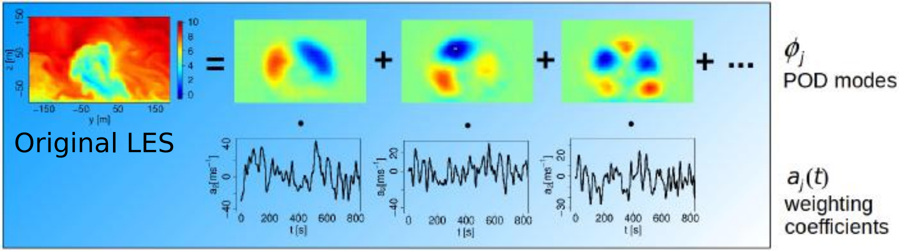

- Reduce complexity of hi-fi LES flow field

Reduced-order wake model using POD

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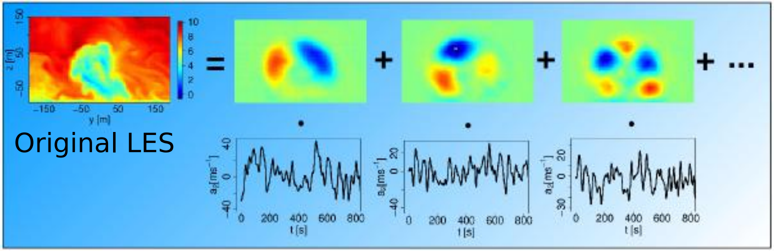


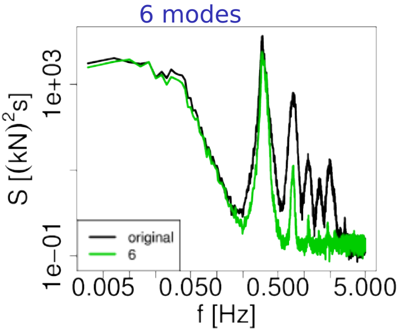
ϕ_j
POD modes

$a_j(t)$
weighting coefficients

- Reduce complexity of hi-fi LES flow field
- Keep only few most energetic modes

Reduced-order wake model using POD

Results for thrust at downstream turbine (FAST sim.)



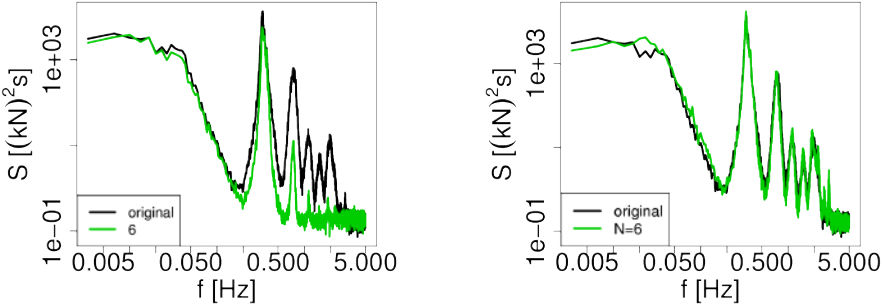
- First modes cover slow dynamics (only)

[Bastine e.a. 2018, Energies 11]

Reduced-order wake model using POD

Results for thrust at downstream turbine (FAST sim.)

6 modes + "added turb."



- First modes cover slow dynamics (only)
- Gaussian random field models effects of small scales

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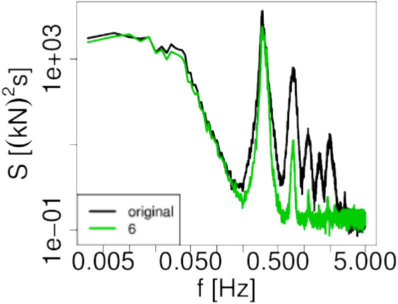

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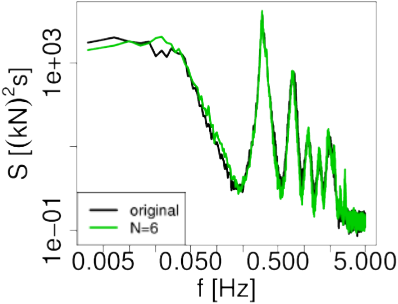

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- Models can be designed to match necessary complexity

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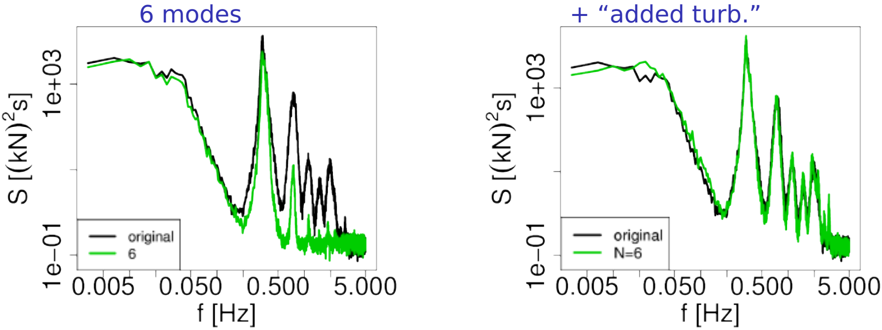
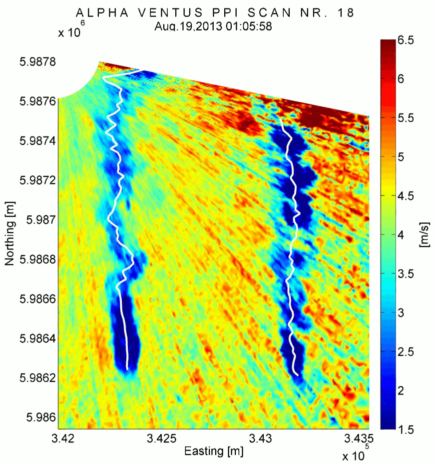


- First modes cover slow dynamics (only)
- Gaussian random field models effects of small scales
- Models can be designed to match necessary complexity
- Option for efficient long-time studies

[Bastine e.a. 2018, Energies 11]

Wake tracking in lidar measurements

Question: Lateral movement of wake center?



[Trujillo e.a. 2017, EERA DeepWind]

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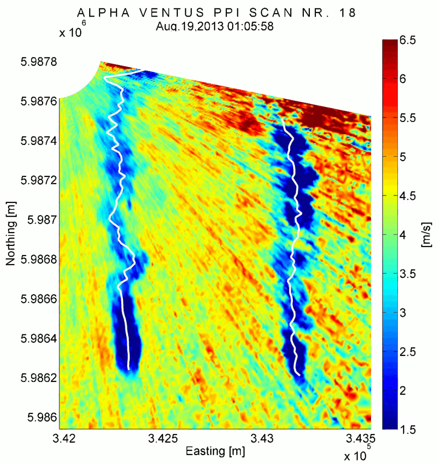

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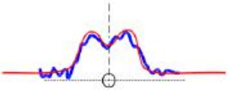

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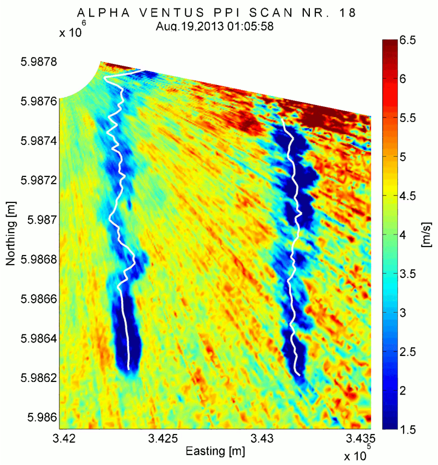

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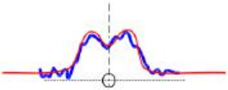

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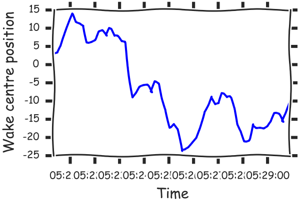

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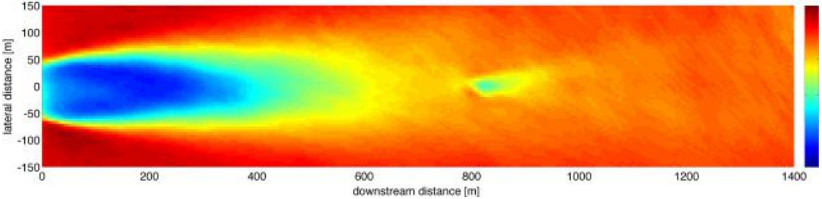
Wake tracking in lidar measurements

Disentangling of wake deficit and meandering

Fixed frame of reference



[Beck e.a., DEWEK 2015]

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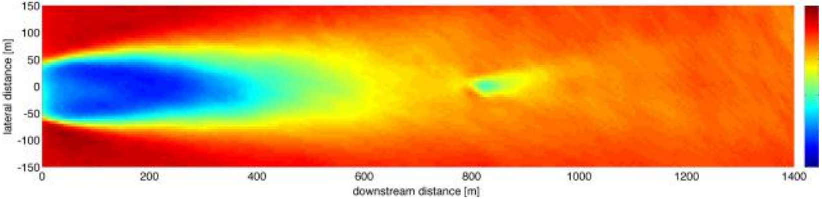
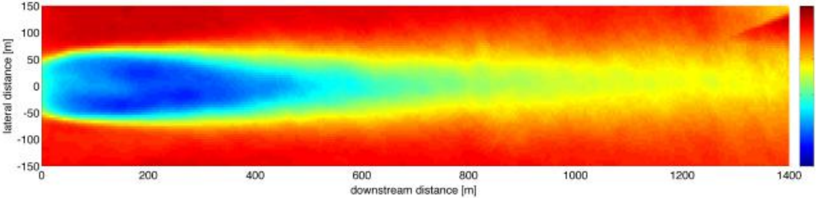


Moving “wake center” frame of reference



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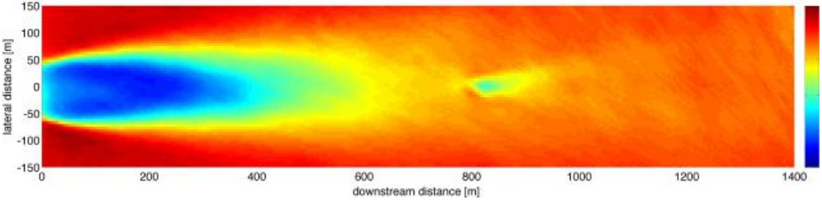

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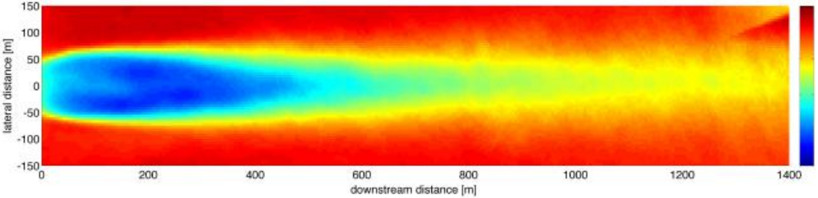
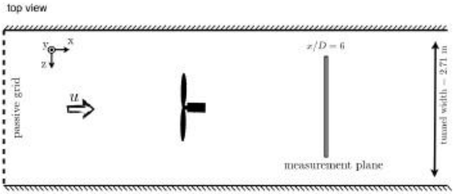


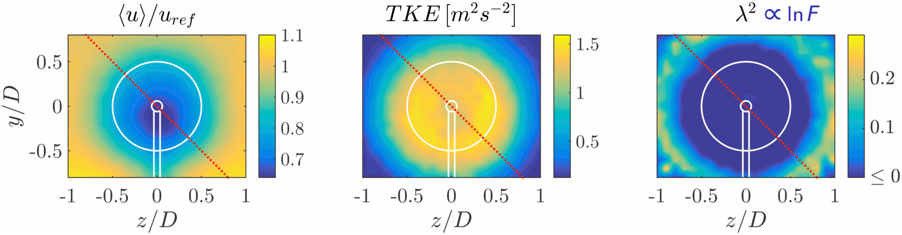
Wake structure fully recovered from meandering flow

[Beck e.a., DEWEK 2015]

Wind tunnel wakes: Turbulence interaction

$D \approx 0.6\,\mathrm{m}$





[Schottler e.a. 2018, WES 3]

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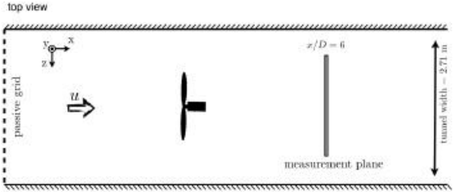

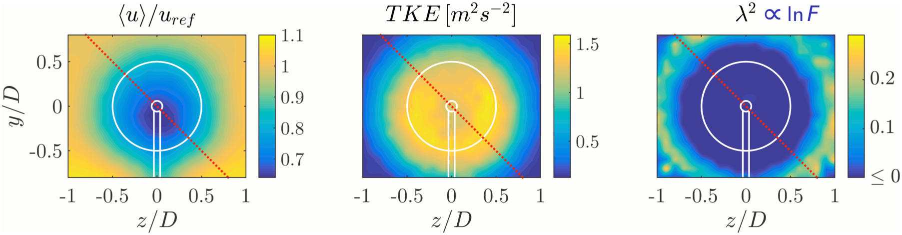

- High & homogeneous turbulence in wake
- Turbulence interaction ⇒ high intermittency
- Also in field campaign (not shown)

[Schottler e.a. 2018, WES 3]

Summary & Conclusions

- RAVE measurements lead to new insights in wakes
  - Structure of wake turbulence
  - Wake meandering: origin and measurement
  - Towards improved and efficient wake models

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"Gigawatt Wakes" & other projects: on the basis of a decision by the German Bundestag

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Thank you for your attention!

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