An introduction of image processing methods to the wake detection

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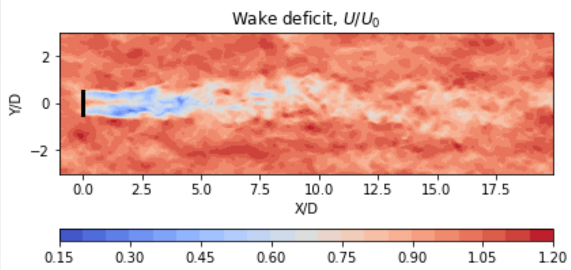
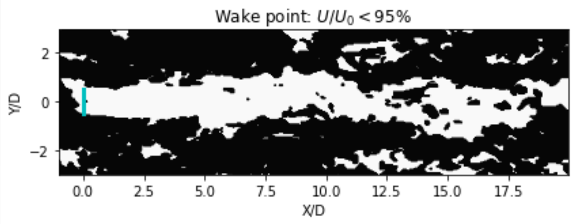
Introduction

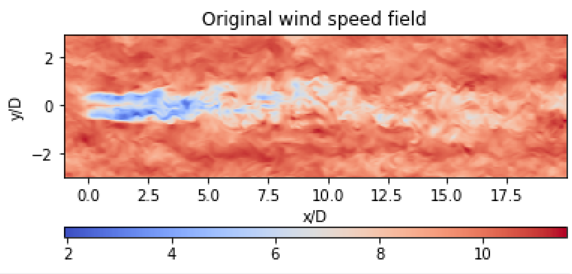
- Wake detection: define the wake shape and centerline.
- Wake detection is particularly important for:
  - wake meandering (instantaneous wake shape evolution),
  - yaw deflection (wake centerline).
- **Quick detection**: wake deficit $U/U_0 < 95\%$ – wake [1].
  - Needs additional cleaning.
  - Not automatic, may require threshold adjustment.





Gaussian wake detection methods

- **1D Gaussian distribution fit** to the wake profile
  - $f(y) = U_0 \, exp\left(-\frac{(y-\mu_y)^2}{2\sigma_y^2}\right)$
  - Wake center — mean value μ_y.
  - Wake width — $\mu_y \pm 2\,ln2 \cdot \sigma_y$ (95% confidence interval)



- Alternatives:
  - **2D Gaussian distribution fit** to the cross-section,
  - or **center of the rotor-sized area** with the minimum power potential [2].
- **Cons**:
  - Strong discrepancy in the instantaneous far wake.
  - Needs enough data points for the fit.

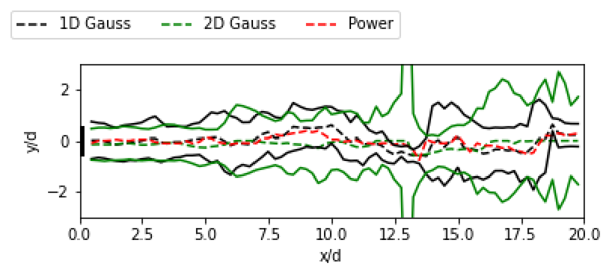
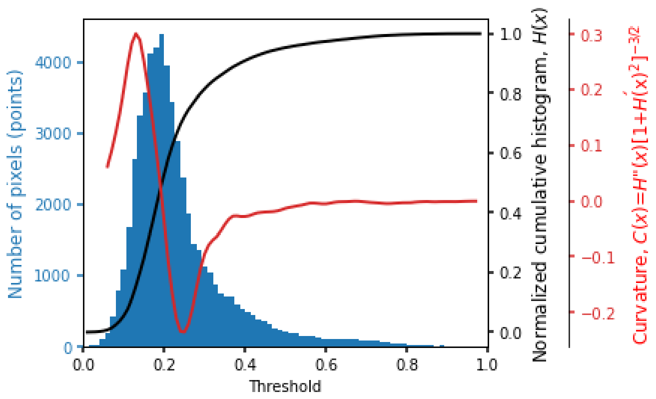
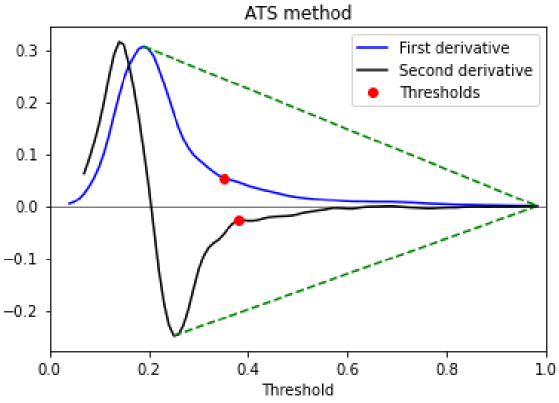
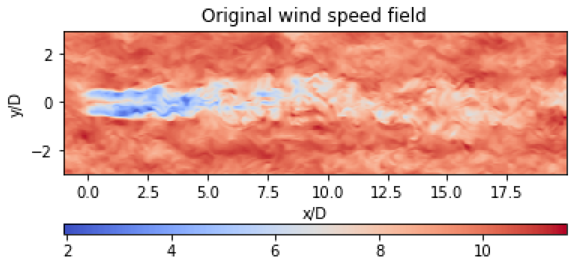


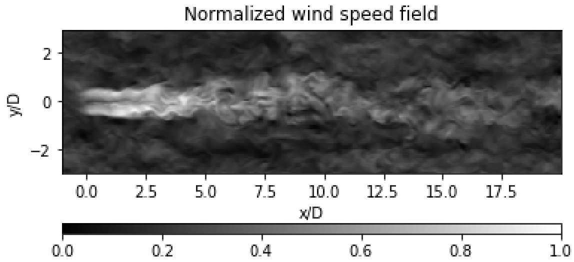
Image processing method

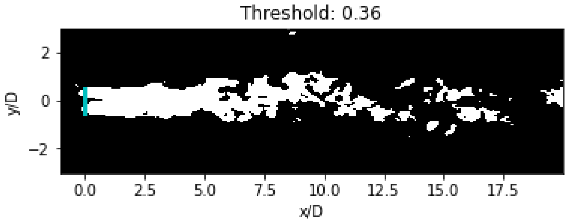
- **Automatic method** – Adaptive Thresholding Segmentation (ATS) [3].
- **Source data**: large-eddy simulation of a single wake.
  - gray scale image (no wind speed data),
  - or original wind speed data normalized to range [0,1]
- The threshold separates group of wake pixels in the histogram tail from the free-flow pixels.
- **Threshold** – maximum curvature of the normalized cumulative histogram.







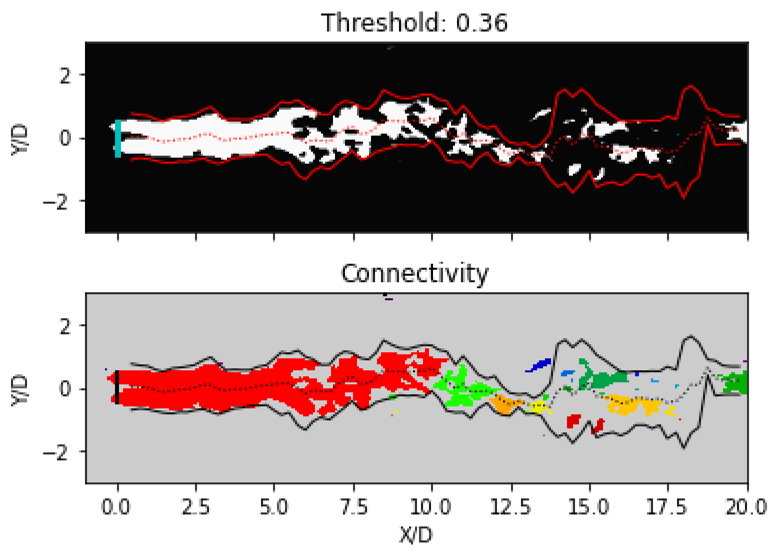




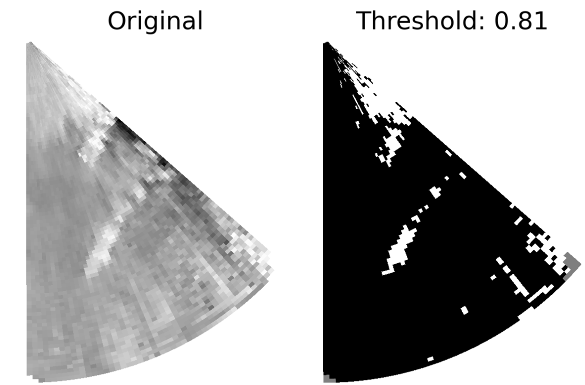
Comparison vs. 1D Gaussian fit

- The methods agree well on the near wake.
- The wake detected using ATS image processing method lies mostly within Gaussian wake borders.
- ATS method detects separate structures in the far wake.
  Further development:
  - Study the continuity of the far wake.
  - Apply individual thresholds to the near and far wake sections to improve the detection.

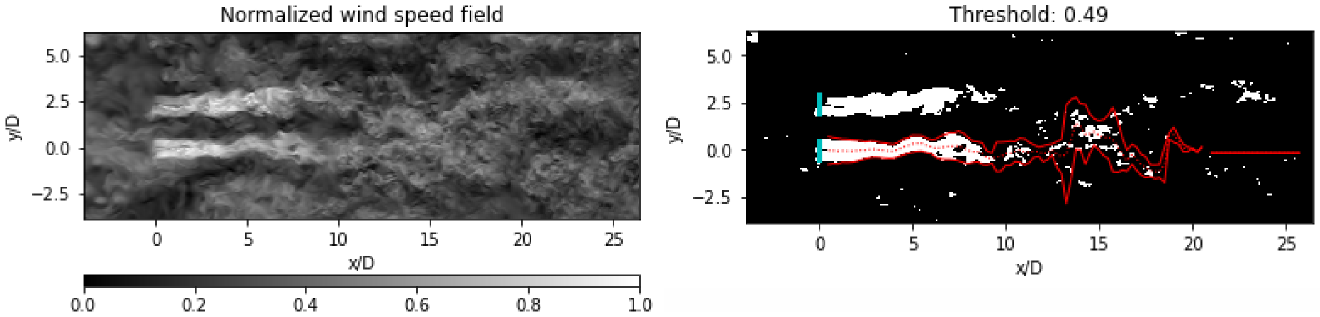
- **Threshold detection on the image**: similar result, but limited information on the wind speed values.



Conclusions & Outlook



- ATS and Gaussian fit methods work well on their own.
  - Especially good detection in **the near wake**.
  - Combined, the methods can improve the result in **the far wake**.
- ATS has a potential where Gaussian distribution gets insufficient data for the fit:
  - interacting wakes,
  - lidar or satellite data.



References

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