Efficient Stochastic Wake Modeling for Wind Farm Control

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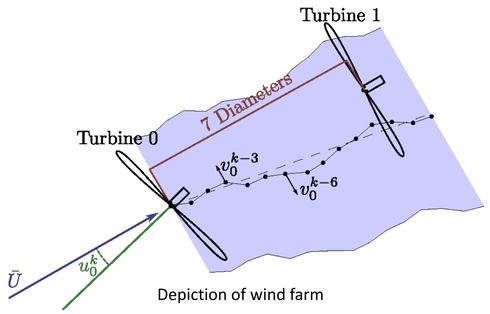
Introduction

- Uncertainty in Wind
  - Speed
  - Direction
- Wind Farm Control
  - Steady-state models
  - Stochastic models and robust design

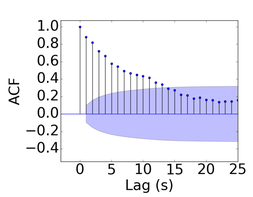


Depiction of wind farm

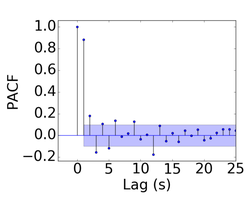
ARMAX Model

- Autoregressive Terms (φ)
  - Auto-Correlation (ACF)
- Moving Average Terms (θ)
  - Partial Auto-Correlation (PACF)
- Exogenous Term (ξ)
  - Expected Value

$$z^k - \sum_{n=0}^{L} \xi_n g(u^{k-n}) = \sum_{m=1}^{Q} \phi_m \left(z^{k-m} - \sum_{n=0}^{L} \xi_n g(u^{k-n-m}) \right) + w^k + \sum_{\ell=1}^{K} \theta_\ell w^{k-\ell}$$



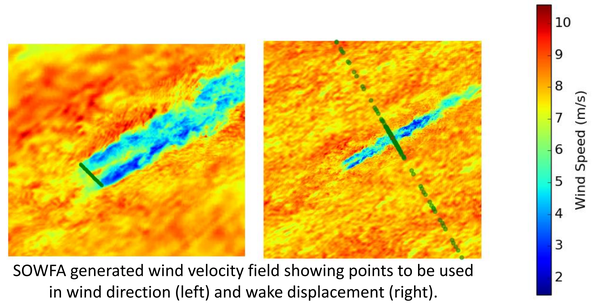
ACF of wind direction from SOWFA



PACF of wind direction from SOWFA

SOWFA

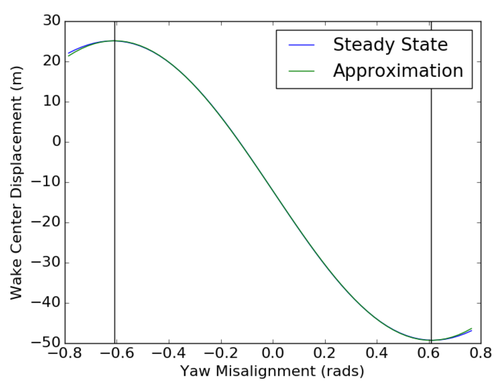
A large eddy simulation in SOWFA [1] is used for validation of wind direction and wake displacement.



SOWFA generated wind velocity field showing points to be used in wind direction (left) and wake displacement (right).

DStoDyn

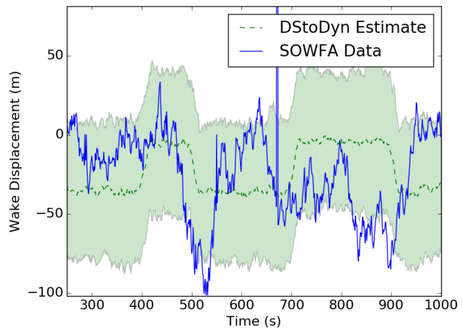
- Wind Direction
  - ARMA model fitted to SOWFA
- Yaw Misalignment
  - Exogenous input fitted to [2]
- Crosswind Velocity
  - Combined ARMAX model
  - $Q = 1, K = 9, L = 1$
- Wake Displacement
  - Linear transform of cross-wind velocity

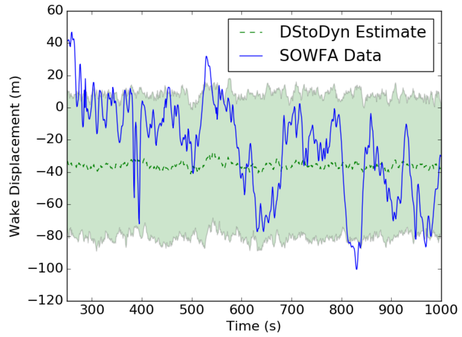


Fit of the exogenous input $\xi_1 g(u^k)$ to steady state mean wake displacement empirically found in [2].

Results

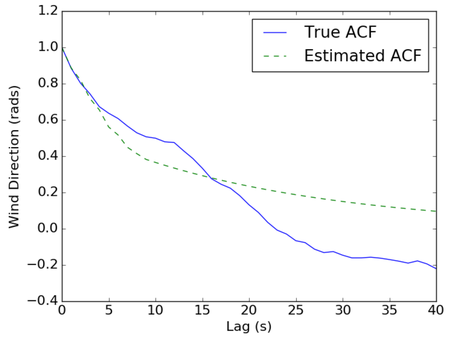
Wake displacement at 6 diameters downwind is used to compare 150 simulations in DStoDyn. The SOWFA data remains within 2 standard deviations but still has un-modeled dynamics.

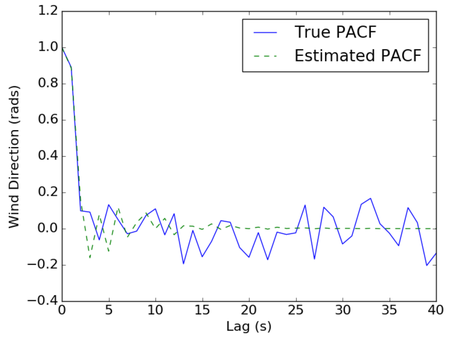




Time series plots of wake displacement with turbine 0 on top and turbine 1 on bottom showing two standard deviations.

ACF and PACF are compared for the wake displacement from 250-400s. Both ACF and PACF demonstrate good agreement up to 5s, but does not agree beyond that.

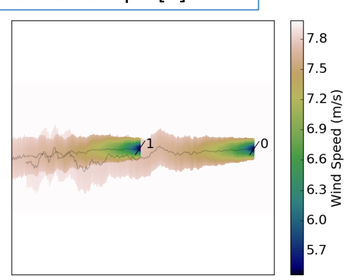




Statistical characteristics plotted of wake displacement with ACF on top and PACF on bottom.

Future Work

- Turbine correlation
- Power Prediction
- Wake Modeling
  - Top-hat shape [2],[3]
  - Gaussian shape [4]



DStoDyn generated Gaussian wind velocity field .

References

[1] P. Fleming, P. Gebraad, J.-W. van Wingerden, S. Lee, M. Churchfield, A. Scholbrock, J. Michalakes, K. Johnson, and P. Moriarty, "The SOWFA super–controller: A high–fidelity tool for evaluating wind plant control approaches," in *EWEA 2013*. European Wind Energy Association, 2013.

[2] P. Gebraad, "Data-driven wind plant control," Ph.D. dissertation, Delft University of Technology, 2014.

[3]N. O. Jensen, "A note on wind generator interaction," *Risø-M*, vol. 2411, 1983

[4] J. Park and K. Law, "Cooperative wind turbine control for maximizing wind farm power using sequential convex programming," *Energy Conversion and Management*, vol. 101, pp. 295-316, 2015.

Acknowledgments

This material is based upon work supported by Envision Energy. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of Envision Energy.