Review of the manuscript

Observations of wind farm wake recovery at an operating wind farm

authored by Raghavendra Krishnamurthy , Rob K. Newsom , Colleen M. Kaul , Stefano Letizia , Mikhail Pekour , Nicholas Hamilton, Duli Chand , Donna Flynn , Nicola Bodini , Patrick Moriarty

General comments

The manuscript is about the analysis of an interesting observation data set for vertical momentum fluxes upstream and downstream of wind farms. The study gives insight into the dynamics of wakes depending on the background atmospheric conditions. The study is of high relevance for the validation and improvement of numerical models required to optimize the design and operation of wind farms. The manuscript is well written and understandable. We recommend publication with minor revisions. The identified deficits are mainly related to the theoretical background, which should be explained a little bit more carefully, as well as the spectrum of citations, which could be a little bit broader in some places.

Specific Comments

Page 2, Line 49:   Maybe one should better say "Todays wind turbines operate …"

Page 2, Line 49: Maybe one could add that in some cases the boundary layer is not even that thick.

Page 2, Line 60: "As wakes grow …" Please be more specific. Do you mean growth in the lateral vertical extend?

Page 2: Please add some brief info about satellite radar wake measurements for offshore wind farms, e.g.

> B. Djath, J. Schulz-Stellenfleth, and B. Canadillas, "Impact of atmospheric stability on X-band and C-band Synthetic Aperture Radar imagery of offshore windpark wakes," *Journal of sustainable and renewable Energy*, vol. 10, no. 4, 2018, doi: 10.1063/1.5020437.

in the intro paragraph mentioning different observation systems. The above publication also points out the importance of a better understanding of vertical momentum fluxes for the interpretation of SAR observations.

Please also mention airborne campaigns, e.g.

> A. Lampert *et al.*, "In situ airborne measurements of atmospheric and sea surface parameters related to offshore wind parks in the German Bight," *Earth System Science Data*, vol. 12, no. 2, pp. 935–946, 2020, doi: 10.5194/essd-12-935-2020.

which also provided info about vertical momentum fluxes.

Page 3, Line 88: "… change in surface roughness .."

I think this statement is based on a simplified view of the real processes, which is perfectly fine, but this should be stated somehow. Please cite

> P. Taylor, "On wind and shear stress profiles above a change in surface roughness," *Quarterly Journal of the Royal Meteorological Society*, vol. 95, no. 403, pp. 77–91, 1969.

in this context too.

Page 3, Line 91: " …growth with downstream distance …"

But it will not grow forever (?)

Page 4, Line 96: "During stable …"

Did you mean "unstable" ?

Page 4, Line 103: Please explain the meaning of the function F_1 more carefully (Buckingham Pi theorem, I guess)

Page 4: I was a little bit confused, because the roughness length $z0$ of the surface without wind farms and the stability seems to be irrelevant in this discussion (?), see e.g.

> S. Emeis, "A simple analytical wind park model considering atmospheric stability," *Wind Energy*, vol. 13, no. 5, pp. 459–469, 2010, doi: 10.1002/we.367].

Please explain this part a little bit more carefully.

Page 5, Line 140: Please use a different notation for "v", e.g. $v\_\perp$, here. Is it so obvious that $<w>=0$, e.g. in cases with convective cells?

Page 5: I think a figure explaining the geometry would be helpful.

Figure 1a: The R^2 value is hard to believe. I think the reason is that there are so many points on top of each other. Please use a density plot, i.e. 2D histogram. Please indicate in the caption that different axis scaling is used in a) and b).

Page 7, eq. 7: Maybe I missed it somehow, but how did you measure the vertical heat flux?

Page 12, Line 274: "… median streamwise momentum …"
I did not fully understand which upstream/downstream distances the curves in Figure 4 correspond to.

Page 14, Line 303: "… in Figure 4b …"   Did you mean Figure 3 ?

Page 14, Line 324. "Larger …"   please correct sentence.

I think it would be good to learn more about the wind speed profiles upstream to see where we see the largest vertical gradients and where mixing can increase vertical momentum fluxes most effectively.

Page 22: In the context of the discussion about good definitions of wake length one should also mention that it is sometimes not trivial to distinguish wakes from variations in the background wind field, e.g.

B. Djath and J. Schulz-Stellenfleth, "Wind speed deficits downstream offshore wind parks - A new automised estimation technique based on satellite synthetic aperture radar data," *Meteorologische Zeitschrift*, vol. 28, no. 6, pp. 499–515, 2019, doi: 10.1127/metz/2019/0992.

Page 30, line 550: " … upwind surface roughness ($z_{(0,hi)}$) …"
I'm confused, because I thought $z_{(0,hi)}$ is the "…roughness due to the presence of a windfarm …" (page 4, line 119)