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Atmospheric Measurement Techniques Discussions

Interactive comment on "Using computational fluid dynamics and field experiments to improve vehicle-based wind measurements for environmental monitoring" *by* Tara Hanlon and David Risk

Tara Hanlon and David Risk

thanlon@stfx.ca

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We would like to thank Anonymous Reviewer #2 for their time in suggesting changes that will improve our manuscript. Our responses to the review comments are provided below in blue.

General Comments:

The reasons for focusing on installation of an instrument atop of a pickup cap are not provided and not clear. Much of the initial discussion focuses on the work of Straka et

al. (1996) and others that chose to put the anemometer out front of the vehicle to avoid the vehicle's flow field. And the authors show in their results (e.g. Fig. 3) that such a location would indeed be preferable. The authors need to be much more clear about the reasons to choosing to focus only on one location on top of a cap.

Problems with wind direction and speed data from a mobile instrument occur when the vehicle is experiencing acceleration (either changes in speed or direction). Data under such conditions should be removed from the analysis. However this issue is not mentioned by the authors, even though it has a significant influence on both methods and results. I can only assume the authors have left these data in, and it helps to explain some of the large scatter in Fig. 7. This issue needs to be fully addressed.

The authors provide corrected wind data in Figs. 7 and 8 but readers (including myself) will want to see uncorrected data in these plots as well. This will have the side benefit of making the plots larger and more legible.

Lastly, there is quite a bit of material relating to ships in the paper, and the reason is not entirely clear. Unless the authors can justify the inclusion of all of this material, it would be good to pare this down to essentials.

We appreciate these general comments. We have used these general remarks to direct each detailed change suggested in comments below.

Detailed Comments

1. Page 2 Line 3 – There have been a number of other field studies that have made use of mobile measurements, including studies in Canada related to severe weather-related mesoscale meteorology (Taylor et al. 2011, Curry et al. 2017), air quality (Brook et al. 2013) and urban meteorology (Joe et al. 2018). The authors should consider including these in the literature review and possibly make use of some of the results.

We have considered the recommended literature, and updated the manuscript with the following:

A reference to Curry et al., 2017 and Taylor et al., 2011 has been added to Page 2 Line 3 of the manuscript.

We have used the literature to add to the discussion in the manuscript. We comment on the updates in detailed comments 25 and 26.

2. P4 L10 – re 22.222 m/s – do the authors believe the inlet velocity could be controlled to this accuracy? Please use a reasonable number of significant digits.

The text has been modified, 22.222 m/s has been replaced with 22.2 m/s.

3. P4 L26 - To eliminate confusion here, it should read "The flow around a pickup truck with an open box is more complex than...because of wake interactions".

P4 L26 has been modified to "The flow field around a pickup truck is more complex than the flow around an SUV of sedan because of wake flow interactions."

4. P4 L31 – Why is this the 'area of interest', and what evidence is there to support that flow atop the cap of the vehicle is located away from large pressure gradients?

The text "Our area of interest, the flow atop the cap of the vehicle is located away from large pressure gradients. Because the cap eliminates large pressure gradients at the area of interest, k-ε performance in the drag comparison, and its results in other studies, we have selected the k- ε turbulence model as appropriate for our analysis in the velocity field above a capped pickup truck."

Has been replaced with,

"Our motivation for placing an anemometer atop a pick-up truck came to assist vehicle-based gas monitoring systems (Atherton et al., 2017; Baillie et al., 2019; O'Connell et al., 2019) measuring gas emissions to achieve practical placement and further calibration practices. In these studies, the anemometer was mounted above a truck cap. Because of the differing vehicle shape from an open bed pickup truck, k-ε performance in the drag comparison, and performance in other studies, we have selected the k- ε

turbulence model as appropriate for our analysis in the velocity field above a capped pickup truck."

We removed the statement , "Because the cap eliminates large pressure gradients at the area of interest" in the methods portion of the manuscript, as we have not yet presented our CFD results.

5. P5 L5 - Were the speeds ranging from 40 to 100 also applied to these eight domains? Need to be more clear about this.

Yes, the same speed ranges were applied to all eight domains. The following text has been added to P5 L10:

"We used the additional computational domains to test all combinations of yaw under inlet speeds ranging from 40 km h-1 to 100 km h-1 in 5 km h-1 increments.

6. P5 L16 – Given known problems with measuring during acceleration, why make fixed measurements in the corners rather than the straight-aways? Why were the corners chosen in the first place?

The following text has been added to P5 L17:

"The stationary anemometers were placed on the corners to provide opportunity for comparison with both legs of the straightaway. This ensured that we would have data for comparison with each leg should an anemometer malfunction.

We consistently found locations with flat, treeless terrain and no surrounding infrastructure at locations approximately 300 m from each corner. The accessibility of these stationary anemometer sites also influenced our selection of placing the stationary anemometers near the corners.

7. P5 L19 – The meaning of this sentence is not clear – what is the 'frontal wind' from the vehicle? Please revise.

This sentence was unclear and not necessary, it has been removed.

8. P6 L1 – Data should only be used when the vehicle speeds were kept constant – the authors do not mention this, and should fully explain their decisions here.

This is an excellent point. The objective of our field study was to collect measurements at fixed vehicle speeds that could be compared with stationary anemometers. The measurements from the corners when the vehicle was turning, and accelerating up to cruise control speed should be excluded. The following text has been inserted to P6 L6:

“The 1Hz geolocation measurements were used to compute the vehicle speed and bearing, field measurements that deviated more than 2.5 km h-1 from the implemented cruise control speed, vehicle bearing measurements that differed more than 5° from designated vehicle course were removed from the data set.”

Figure 7 and 8 have been modified to exclude non-steady-state measurements.

9. P6 L12 – I would like to see the detailed calculations included in an appendix.

We removed the text, “and a true wind vector was computed by removing the vehicle vector from the vehicle wind vector. All computations were completed using R 3.4.1 statistical software (R Core Team. 2016)”

And replaced it with, “We calculated the vehicle’s course over the ground using the GPS coordinates to obtain a vector of equal magnitude and opposite direction to be the frontal wind induced by the vehicle’s motion (F). We compute the meteorological wind vector (W) by subtracting the frontal wind induced by the vehicle’s motion (F) from the raw anemometer measured wind vector (A). The calculation is presented in Equation (1) . The computation comes from the method calculating the meteorological true wind from a moving vessel presented by Smith et al., 2009.

$W = A – F$

We have included a figure and details describing the vector translation required in the computation to S1 in the supplementary information.

10. P7 L25 – The meaning of this sentence is not clear to me. Please reword.

P7 L25 has been reworded to say “The second set of simulations in this study are of particular interest because they evaluate the flow field under cross wind conditions. Many previous CFD and wind tunnel studies (Yang and Khalighi 2009; Holloway et al., 2009) examine the flow field resulting from inlets, which direct the airflow along the longitudinal axis of the vehicle. Aside from Houston et al. 2016, we have not found studies using CFD to conduct crosswind experiments to study the flow field around a vehicle.

11. P8 L14 – It is not clear what these sentences are referring to – I see nothing in Table 2 that “shows” this.

The two sentences beginning on P8 L14 have been reworded to say:

“Table 2 shows that the height required for an anemometer to experience bias below 2% increases with increasing yaw angle. Anemometer heights selected through frontal wind tunnel tests would still experience bias under cross wind conditions.”

12. Figure 7 – A few problems here – the grey bars need to be explained, another panel that shows the uncorrected mobile measurements needs to be included, and the separation of data at 0/360 degrees needs to be addressed so that there are only four ‘bars’ of C3 data, as in the control.

The following changes have been made to figure 7 to address both the above detailed comment and the general comments made by the reviewer.

The measurements have been regrouped so that the figure shows measurements corresponding to vehicle bearing measurements of 0°, 90°, 180°, 270° corresponding to the vehicle travelling in the North, East, South and West directions. This change removes the separation of the data at 0° and 360°.

The grey bars represent measurements that were collected in tail wind conditions. A second sentence has been added to the figure caption that reads, “The shaded grey bars represent measurements acquired when the vehicle was driving in tail wind conditions."

The change addressed in detailed comment 8 reduces the scatter in this figure. Figure 7 now includes measurements where the vehicle speed deviates no more than 2.5 km h-1 from the implemented cruise control speed, and the vehicle bearing measurements differ no more than 5° from designated vehicle course.

13. Page 11 L5 – 'data was' should be 'data were'

This change has been made

14. Figure 8 – A few issues here – the wind rose plot details are illegible particularly the frequency values (which appear to be missing entirely), a diagram the uncorrected mobile winds needs to be included, and the reason needs to be given to explain the WNW winds measured only along the top, headwind leg. The authors also need to specify what samples are being plotted here – certainly not 1 Hz data.

The following changes have been made to figure 8:

The measurements presented in the figure have been modified to reflect the change made in response to detailed comment 8, removing measurements outside of the speed test. The data was previously the 70 km h-1 speed test, but was replaced with the 60 km h-1 speed test because fewer measurements were excluded as a result of being 2.5 km h-1 outside the speed test range.

The wind rose frequency values are now legible. The stationary anemometers report one minute averages. The instrument collects a wind speed and direction measurement every 10 seconds and reports the average of those six. The instrument also reports a wind gust measurement which is the highest instantaneous wind speed measured during the selected averaging interval. The wind roses are the average wind direction measurement and wind gust reported for each minute. The wind roses contain 14 minutes of data, and are the measurements acquired during the 60 km h-1

speed test.

Adding another plot with raw measurements to Figure 8 is not ideal for space, this plot is added to appendix A.

15. P12 L7 – The use of 'levels' as a verb here is confusing. Please reword.

P12 L7 has been reworded to say, "Applying the empirical correction reduces the difference in the mean of the wind direction measurements across the four vehicle bearings."

16. P13 L4 – Over what periods are the data for the wind roses taken? This needs to be specified.

The data displayed in the wind roses was taken over a 14 minute period, which was the duration of the 60 km h-1 field test. This information has been added to the manuscript to further describe 8.

The following text has been added to P13 L4, " The measurements in the wind roses are the wind gust and average wind direction measurements reported each minute of the 14 minute time speed test."

17. P13 L5 – Why not also average the winds over the leg and compare to the wind rose over that leg?

Figure 8 has been modified to include a table comparing the mobile measurements averaged over the leg with the average from the wind rose.

The wind rose at each corner is a representation of the wind patterns we would expect to see across the survey leg. We did not obtain raw one second measurements from the stationary anemometers making it difficult to average the measurements in an identical way. Our study instead uses the stationary measurements as a guide to evaluate the accuracy and precision of the 1 Hz vehicle-based anemometer measurements.

18. P13 L10 – The authors drove the route at speeds of 40, 50, 60, 70, and 80 km/h but only present results from 70 km/h in Fig 8. They need to also show results from the

other speeds (perhaps best using averages).

Figure 8 was constructed to show – in detail - the variability in the mobile wind measurements after the CFD calibration was applied. It was more the purpose of Figure 7 to show the general impact of the CFD calibration across all speed tests.

19. P13 L10 – Re "improved", it is difficult to see this and is not quantative. The authors need to better support/interpret the results.

The text "Figures 7 and 8 demonstrate that measurement reliability and likely accuracy is improved by applying an empirical correction to vehicle anemometer measurements prior to correcting for the vehicle vector. The empirical correction from CFD improved the field measurements, but still could improve in tail wind."

Has been changed to "Figure 8 shows that applying the CFD calibration improves the agreement of the average mobile wind speed and direction measurements with the average stationary measurements in three of the four legs of the route."

The text "In the top plot, black arrows representing wind speeds over 50 km h-1 are present. In the bottom plot, these arrows are replaced with wind speeds 6-8 km h-1 lower. The empirically-corrected data appears to match the stationary measurements better in tail wind, but still experiences difficulty with direction." has been removed.

20. P13 L15 – I understand that CFD cannot simulate this but it could use a clearer explanation.

The text has been replaced with: "Field measurements were the only method of obtaining data under tail wind conditions in our study. Our CFD model was limited to a single inlet, and did not have the capability to simultaneously model oncoming air from the vehicle's motion, and wind blowing from behind the truck."

21. P13 L26 – Why is there more variability in tailwind conditions? Please explain for readers.

This comment is addressed in the next detailed comment response.

22. P13 L30 – Perhaps this could be better explain – the tail wind will be 'embedded' in the flow around the vehicle in real-world conditions, so why wouldn't it be 'detected'?

We have added the bolded text in at P13 L30 to address detailed comments 21 and 22 together, into the paragraph beginning at P13 L24. The text has been changed to:

"The plotted wind vectors in Fig. 8 show that the 1 Hz mobile wind measurements experience the most variability in speed and direction when the vehicle is travelling in tail wind conditions. The empirically corrected tail wind direction measurements were in reasonable (within $\sim 30^{\circ}$) agreement with stationary direction measurements on field days with winds greater than 25 km h-1, but deviated on days with lower wind speeds. When the vehicle speed is much larger than the wind speed, the vehicle creates a continuous flow field that can obstruct natural winds. The anemometer detects continuous frontal wind from the vehicle, and becomes less sensitive to components of the wind coming from behind the vehicle. It is likely that a windspeed threshold for the magnitude of tail wind detected by the mobile anemometer, and that this threshold varies with vehicle speed. Additional field testing on field days with low winds is recommended to evaluate the quality of tail wind measurements, identify windspeed thresholds, and develop quality control criteria for tail wind measurements. As CFD is limited in developing an empirical correction for tail wind, additional filed data is recommended to develop a correction for tail wind measurements.

23. P14 L1 – Should be 'mobile anemometers'

This change has been made.

24. P14 L1 – Not sure where the 'mean' was compared. Please expand on this.

We have moved the text, "The results are displayed in Table 3." From P14 L4 to P14 L2 to draw attention to Table 3 which compares the percent difference between mean short and tall anemometer measurements across vehicle speed.

25. P14 L7 – What about other uses of mobile wind data? How would this improve a meteorological field study, for example?

In the discussion we have added the statement, “Vehicles outfitted to study severe weather (Curry et al., 2017; Taylor et al., 2011), and urban meteorology (Joe et al., 2018) show resilience to bias by also outfitting vehicles with wind sensors above and ahead of the vehicle.”

This comment is also addressed in the response to the detailed comment below.

26. P15 L20 – On a daily basis? Only during field studies?

The following text has been added to P15 L24

“Vehicle-based wind measurements from field studies can be used to contribute to detailed observing networks of specific sites. Furthermore, vehicle-based wind measurements can be collected conveniently by vessels of opportunity that travel routine routes, and contribute to weather data assimilation to evaluate accuracy for air quality and weather forecasting models (Brook et al., 2013).

27. P15 L30 – But what is the representative height being aimed for? You could try to install at 20 m mast and it would certainly be out of the vehicle envelope, but do you want to know the winds at that height? The authors have not made it clear at what height stakeholders require wind data.

P15 L32 has been modified to:

“For applications requiring near surface wind measurements to be paired with other vehicle-based measurements, and similar anemometer placements to those in this study, we recommend anemometers on truck caps be mounted at least 1 m above the vehicle, and that an empirical correction be applied. While mounting the anemometer at larger heights above the vehicle reduces the impact of flow distortion resultant from the vehicle’s motion, placement must be practical and safe for road travel. For larger vehicle’s, we expect mounting anemometers on vehicle’s at heights much greater than

1 m to be potentially impractical. It is important that placement keeps the sensor below common road clearance limits for bridges and underpasses.”

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