

Response to reviewer 1

The authors would like to thank the reviewer for the insightful comments which have been thoroughly addressed below and have contributed to improving the clarity of the manuscript. In the following sections, the reviewer’s original comments are in [blue](#) and our response are in [black](#).

This paper compares newly implemented CO₂ output from variable resolution runs of the MPAS model to observations and two other modeling systems. The high-resolution region of the MPAS runs was centered over North America so most of the comparisons are made in this region but global comparisons with the relatively low resolution region of the model are also made. The MPAS CO₂ output generally compares well with both the observations and other model output in the variety of known sharp gradient features, such as across cold fronts. The results suggest a successful implementation of CO₂ into the MPAS model and the possibility to do focused high-resolution model runs in regions of interest.

The techniques and methodology are clearly described and the results are well supported by the figures and discussion. There are many grammatical errors and I have tried to list some of them here but there are certainly more. My main comments are regarding figure clarification and are minor. I recommend publication with consideration of the specific comments below.

We really appreciate the referee’s comprehensive and constructive comments. Through addressing these comments, we have substantially improved the quality of the manuscript.

Specific comments

1. Figure 6: You should add a label to the y-axis on at least the left column of plots. It’s apparent that you are plotting CO₂ mole fraction in ppm but the labels should still be included. Also, I would recommend adding the labels ‘ACT’, ‘MPAS’, ‘WRF-Chem’ and ‘CT2019’ in the appropriate regions on at least one of the plots in the top row, or all of the top row plots to make it clear without reading the caption what is being plotted. Red ‘warm sector’ and blue ‘cold sector’ labels somewhere in the figure would also help. In line 3 of the caption ‘measurement’ should be ‘measurements’. In line 5 I think you mean ‘quartiles’ instead of ‘percentiles’.

Thanks for pointing this out.

Please note this figure is Fig. 12 in the revised the manuscript.

The figure has been updated: (1) In figure, a Y-axis has been added and labeled with CO₂ dry air mole fraction (ppm). On the X-axis, labels are added for “ACT”, “MPAS-A”, “WRF-Chem”, “CT2019”.

(2) “measurement” is corrected to “measurements”.

(3) “percentiles” is corrected to “quartiles”.

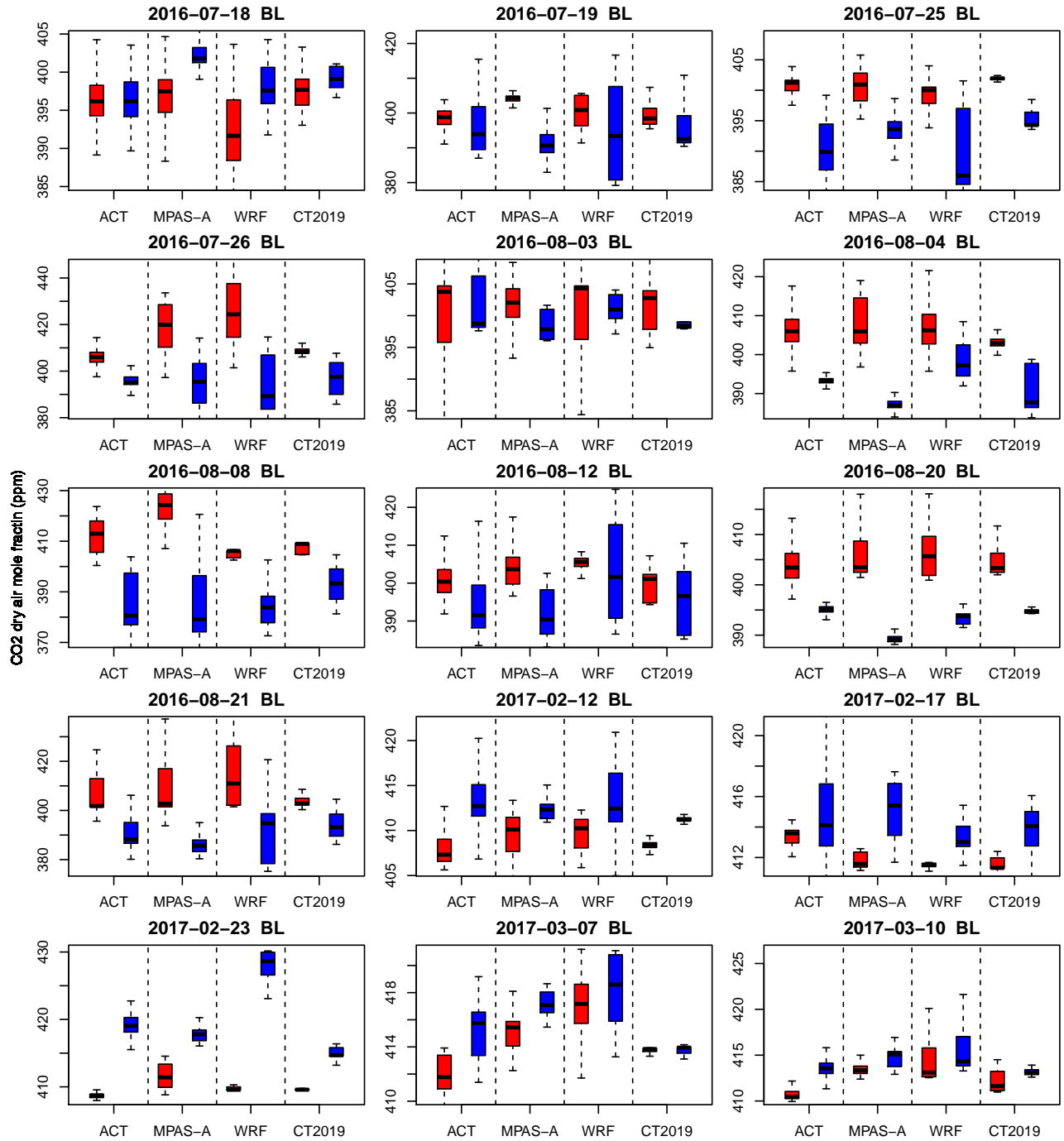


Figure Caption: Comparison of CO₂ mole fraction in frontal-crossing level-leg flights in boundary layer between ACT aircraft measurements and model simulations. Flight date and aircraft type are labeled in title for each flight leg. X-axis is UTC time, and Y-axis is CO₂ mole fraction (ppm). Aircraft measurements are in black, MPAS-A in red, WRF-Chem in blue, and CT2019 in green. In each figure, the pair of vertical dashed lines mark CO₂ enhancement observed by the aircraft along a frontal boundary, and the warm and cold sectors associated with the frontal boundary are labeled as warm and cold, respectively.

2. Section 3.3.3: It would be helpful to include a summary of the warm-cold sector differences for each season and each model or measurement system. This could either be included in Table 4 or just in the text.

Following the referee's suggestion, the following statements have been added to the revised manuscript (P16 Lines 10-16):

Table 11 lists the mean CO₂ of the warm sector, cold sectors, and their difference as calculated from the ACT measurements, MPAS-A, WRF-Chem, and CT2019. The table shows that the MPAS-A simulations are similar to WRF-Chem, and both tend to have larger CO₂ differences between the warm and cold sectors than CT2019. For instance, the 2016-08-08 case where the observed mean CO₂ difference between warm and cold sector is 26.9 ppm, MPAS-A and WRF simulations resulted in 36.9 ppm and 21.2 ppm respectively, while CT2019 resulted in a 15.3 ppm difference. The above evaluation indicates that MPAS-A CO₂ model is capable of well representing the observed CO₂ difference between the warm and cold sectors, and its accuracy in this respect is comparable to WRF-Chem and CT2019.

3. Figure 9: It's not clear if you intended to have a Figure 10 on Pg. 36 or continue Figure 9 onto two pages. In the caption of Figure 10 and 11 you refer to 'Figs. 9 and 9', which should either be 'Fig. 9' or 'Figs. 9 and 10' if you've split the figure into two. I would actually recommend moving Figure 9 into the supplement. 48 individual plots are too many for a single figure, or even two figures.

One option to summarize the information in Figure 9 is to make normalized composites for each season. These could just emphasize the mole fraction differences across the fronts so that the measurements and models are each subtracted from their respective values at the front location. As the figure is now, the absolute value offsets are most visible rather than the differences across the front. The RMSEs calculated for Fig. 10 could also be based on the normalized mole fractions.

Following the reviewer's suggestion, the figure has been remade to include only eight cases while the the full list of cases are provided in the supplement Figure S3.

In the updated figure, the CO₂ enhancement along the frontal boundaries in the aircraft measurement are marked with the two dashed vertical lines.

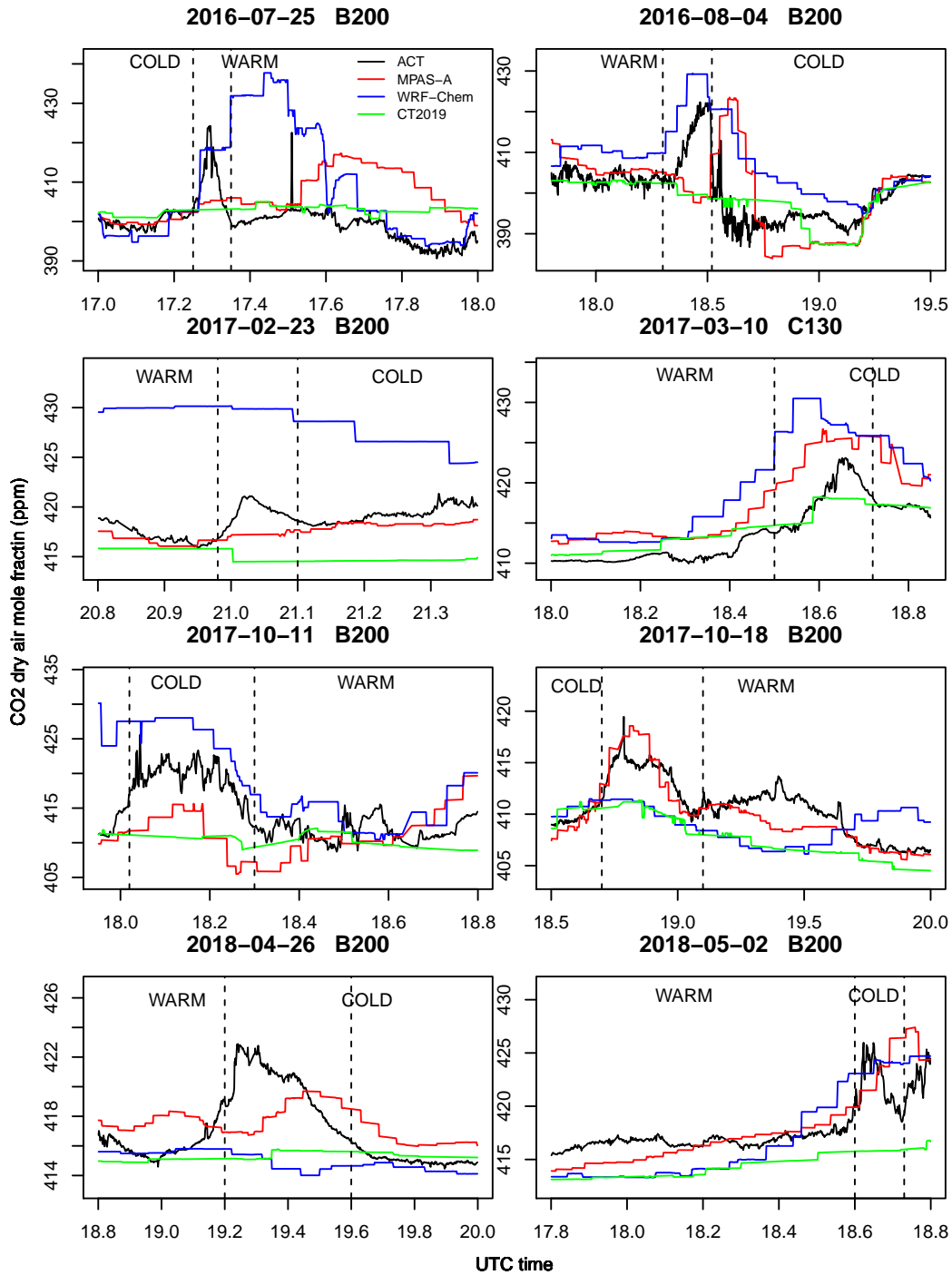


Figure caption: Comparison of CO₂ mole fraction in frontal-crossing level-leg flights in boundary layer between ACT aircraft measurements and model simulations. Flight date and aircraft type are labeled in title for each flight leg. X-axis is UTC time, and Y-axis is CO₂ mole fraction (ppm). Aircraft measurements are in black, MPAS-A in red, WRF-Chem in blue, and CT2019 in green. In each figure, the pair of vertical dashed lines mark CO₂ enhancement observed by the aircraft along a frontal boundary, and the warm and cold sectors associated with the frontal boundary are labeled as warm and cold, respectively.

Technical comments

Pg. 6, line 24: ‘first set of simulations. . .’

Fixed. It has been changed from “first set simulations” to “first set of simulations”.

Pg. 7, line 14: A question mark appears to be inadvertently left in parentheses.

Fixed.

Pg. 7, line 19: Did you mean ‘reanalysis’ instead of ‘analysis’? Here and in the next line.

Fixed. ‘analysis’ has been changed to ‘reanalysis’ in both cases.

Pg. 8, line 16: Should be ‘subscript k’ instead of ‘subscript j’ for the vertical level.

Fixed. Subscript j has been changed to subscript k .

Pg. 8, line 18: Should be ‘ $h_{i,k}$ ’ not ‘ $h_{i,j}$ ’

Fixed.

Pg. 8, line 20: Should be ‘rho i,k’ not ‘rho I,j’ and ‘q I,k’ not ‘q I,j’

Fixed. $\rho_{i,j}$ has been changed to $\rho_{i,k}$, $q_{i,j}$ has been changed to $q_{i,k}$.

Pg. 9, line 3: Add comma after ‘MPAS’

Fixed.

Pg. 10, line 26: Why is this information in Table 6 instead of Table 3 since at this point in the text Tables 3-5 haven’t been referred to yet? It seems to make sense to switch Tables 3 and 6 so they coincide with where they are discussed in the text.

Fixed. The order of the tables has been corrected in the revised manuscript.

Pg. 11, line 32: change ‘he’ to ‘the’

Fixed.

Pg. 12, line 9: change ‘resulted in’ to ‘had’

Fixed.

Pg. 12, line 10: ‘accuracy than MPAS, likely because it applied. . .’

Fixed.

Pg. 12, line 12: change ‘large’ to ‘larger’

Fixed.

Pg. 21, line 12: ‘compared’

Fixed.

Pg. 12, line 31: ‘in the next two sections. . .’

Fixed.

Pg. 13, line 5: add ‘the’ before ‘warm’

Fixed.

Pg. 13, line 10: remove the second 'well' in this sentence.

Fixed.

Pg. 13, line 27: 'represents'

Fixed.

Pg. 13, line 32: One of the 'BL' subscripts should be changed to 'FT'

Fixed.

Pg. 14, line 2: 'observations'

Fixed.

Pg. 14, line 4: 'are a substantial. . .'

Fixed.

Pg. 14, line 5: 'majority of cases. . .', 'the rest of the three. . .'

Fixed.

Pg. 14, line 15: 'shows'

Fixed.

Pg. 14, line 22: 'seasons'

Fixed.

Pg. 14, line 34: should be 'Fig. S2'

Fixed.

Pg. 15, line 7: 'flights'

Fixed.

Pg. 15, line 30: 'MPAS performs. . .'

Fixed.

Pg. 16, line 24: 'this results in. . .'

Fixed.

Pg. 16, line 33: 'mean sea level. . .'

Fixed.