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Geoscientific Model Development Discussions
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Interactive comment on "Development and evaluation of CO_2 transport in MPAS-A v6.3" *by* Tao Zheng et al.

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General comments:

This paper implements CO2 transport in a numerical weather prediction model, MPAS-A. The unique feature of this model is that utilizing variable-resolution capability in the model simulation. It enables simulating CO2 and weather forecasts on a higher horizontal resolution (centred on North America in this paper) without lateral boundary conditions. The performance of the developed model is compared with two global modelling systems, CT2019 and IFS, and one regional modelling system, WRF-Chem. Also, the results are verified against radiosonde stations around the globe for weather forecasts and surface in-situ CO2 measurements and aircraft measurements from the ACT-America campaign for CO2 simulations. It seems that the implementation of CO2 transport is possibly successful, while it is not shown clearly. Although the paper fits

well within the scope of GMD, there is a large room for improvement toward being more rigorous in writing and better experimental design. Therefore, several major concerns listed below for the authors should be addressed to meet the quality of paper required by GMD.

Major comments:

1. Although MPAS-A CO2 is a global transport model, the experiment design is organized as though it tries to verify a regional model. Despite 50 surface CO2 stations around the globe are used in the verification, this only looks at the near surface, not at higher altitudes and larger scales. Using an additional global network (e.g., TCCON) and three-dimensional CO2 fields from a global model (e.g., CT2019 or IFS) would provide complementary verification on the performance of the model for the whole domain. You could refer to Agusti-Panareda et al. (2014) and Polavarapu et al. (2016), which are already cited in the paper, to get an idea of how to verify the model on the global scale. Also, for presenting results, it is better to investigate the global simulation results first. Then, you can narrow down the scale from the globe to eastern United States where ACT data are measured.

2. The simulation period is too short for investigating the model performance, including mass conservation (details in specific comments) and CO2 simulation. At least, one or more year simulation is necessary to see how the model works. Because the initial condition of CO2 is taken from CT2019, without a proper spin-up period, the CO2 field from 60 km grids still has a signature of CT2019 transport, not MPAS transport. Authors argue that one benefit of the approach that MAPS CO2 uses is the consistent LBC from the coarse domain. To take advantage of such consistent LBC that MPAS produces, the simulation period should be extended.

3. Mass conservation is one of the major concerns in this paper. Since the model is run without surface CO2 flux, the results shown here are not enough to prove the mass conservation is acquired in the model. The model should run with ingesting surface

CO2 fluxes that have complex and strong spatial gradients. Also, it should run for an extended period as well. Please see the detail for this issue in specific comments.

4. Is it possible to run MPAS CO2 without the local grid refinement? If so, it is possible to investigate the benefit and impact of using local grid refinement on the performance of CO2 simulation by running the model with and without a higher-resolution grid. Also, it is associated with the question about the parametrisation scheme in the specific comments. Maybe authors can highlight the benefit of the unique feature of MPAS by adding coarse resolution results in Table 3 or Table S3, for example.

5. Although two global models (IFS and CT2019) are presented in the paper to compare MPAS results, CT2019 is only used to be compared with ACT data. Why isn't CT2019 used in the verification on the global scale (in section 3.4)?

6. Two different sampling methods (taking nearest land cell to a given location interpolation in space and time) are used in two different sections. But a discussion on this is missing in the paper.

Specific comments:

1. Despite the developed model is named MPAS-A in the title, MPAS-A and MPAS are flurried through the manuscript, making confusion to readers.

2. P1L6: "only major research and operation centers can afford it" would be not necessary because the definition is somewhat vague. This is the same in the introduction.

3. P1L15: Why all hourly data is used? The statistics for sure is exacerbated by including nighttime data.

4. P1L21: The conclusion of comparisons with WRF-Chem and CT2019 is missing

5. P1L24: I don't think "often" is necessary for this sentence.

6. P1L24: It needs to use surface CO2 flux rather than CO2 flux because there are other usages for CO2 fluxes used throughout the manuscript (e.g., horizontal CO2

fluxes and vertical CO2 fluxes).

7. P2L7-8: It needs to add a reference for the sentence.

8. P2L11: What does "simulation resolution" mean by?

9. P2L18-19: This sentence is a little bit confusing. A regional model could require more computational cost than a global model does. Because the cost of a model depends on the configuration (e.g. the number of grids and the period of interest, etc.). Thus, it needs to clarify it.

10. P3L23: It seems that MPAS CO2 is an online transport model. But it is not mentioned explicitly in the paper.

11. P5L20: Does "CO2 eddy diffusivity" mean vertical eddy diffusivity for CO2? And is there any cap (minimum or maximum) applied to Kh to prevent too strong or weak vertical mixing?

12. P7L16: What does third-order advection mean?

13. P7L17: Table 1, are parameterisation schemes here an optimal choice for the best CO2 simulation by MPAS? An explanation of why these parameterisations are used in the simulation is lacking.

14. P7L17: How do parameterisation schemes work for the weather forecast and CO2 transport on a variable-resolution grid? Is it anticipated that parameterisation schemes work identically with the different area of a grid?

15. P7L19: Because of the difference in grid between ERA-I and MPAS, how is the conservation of tracer mass guaranteed after interpolation of wind fields to the MPAS grid? Is there any kind of "pressure fixer" as used in GEOS-Chem or a flux adjustment as done by CarbonTracker (Segers et al., 2002)?

16. P8L25, Fig. 2: Are fluxes used in these simulations? If not, the simulation should be repeated with CO2 surface flux inputs. This is important because the surface fluxes

create strong gradients which challenge a model's numerical schemes. Without surface fluxes, the CO2 field is very smooth and easy to model. Also, can you increase the length of the simulation?

17. P8L28: What does maximal variation mean? The change from one data point to the next? If so, it seems much smaller than 1.95E-12 kg/mˆ3 for dry air in Fig. 2. If it is the maximum value in the plot, it seems to low since the maximum is around 4E-12.

18. P9L11: It sounds like Dee et al. mentioned about dry air mass change. Since the reference is already cited in the paper. This one could be taken off.

19. P9L26, Fig. 3: This test should be repeated with realistic CO2 surface fluxes. You know what the flux is over 3 hours so the change in global CO2 mass is known. Then the expected total CO2 from fluxes, assuming an initial value, can be compared with the model global CO2 mass. Fluxes create strong gradients that are usually challenging for the numerics, and you will see more realistic magnitudes of temporal variations. Those changes in Fig. 3 may be unrealistically low. Also 48 days is too short. Tests for a year would be good.

20. P10L8-17: the paragraph does not include information about section 3.3.1. Please revise the text.

21. P10L16: The current configuration heavily relies on the IC from CarbonTracker, due to the short period of simulation. It does not show the quality of CO2 transport by MAPS CO2 on a global scale. This is another reason why the simulation period should be extended.

22. P10L19: The conclusion for section 3.3.1 is missing.

23. P10L20-21: It is not clear why this sentence is here. Has Michaelis et al. verified MPAS simulation already? If so, please rephrase it.

24. P10L23: For the verification at 00 UTC, are 24 h forecasts at 0 UTC used? Since the meteorological re-initialisation at the 24-hour interval, it needs to clarify it.

25. P10L24: Fig. S3 is referred to earlier than Fig. S2.

26. P10L26: Table 6 is referred to earlier than Table 3, 4 and 5.

27. P11L3: Because section 3.3.2 utilizes data focused on North America, not on the globe, the title should be revised accordingly.

28. P11L9: "regional NWP WRF" sounds strange. Please clarify it.

29. P11L14: Which "the analysis" do you mean? ERA5 reanalysis or ERA-interim analysis?

30. P12L4: The PBL height between models are probably different, how did you consider that in Fig. 4 in order to obtain a fair comparison?

31. P12L4-5: Flux error would be not the main culprit. It can be also attributed to the larger error in the weather forecast in BL than in FT, associated with the accuracy of PBL height in the model simulation.

32. P12L8: Although Fig. 4 shows dots with different colours to represent results from different seasons, the differences between seasons are not explained explicitly in the text. This is the case in Fig. 5.

33. P12L9-10: This sentence is a contradiction with what is mentioned in the introduction (3rd paragraph). This sentence sounds like that a regional model using the nudging scheme is better than a global model that does not require any lateral boundary conditions.

34. P12L12-13: Why does a coarse resolution model simulate better atmospheric CO2 than a higher resolution model?

35. P12L23: Fig. 4 and Fig. 5 can be combined into a single figure using Taylor diagram. Then, the interpretation of results may be easier and more concise.

36. P13L10: In Fig. 6, please add names on the x-axis to make easy to understand

the figure and add the unit on y-axis or in the caption.

37. P13L13, Table 4: I don't see this date (2016-08-24) in Table 4. There are cases where CT2019 does better than the other 2. The date mentioned in the text may be cherry-picked. To get a better sense of how often CT2019 does better/worse than the higher resolution models, please list the differences between warm and cold in a separate column for easy comparison between the models and observations.

38. P13L19: The explanation about the sampling strategy is missing in this section, in particular vertical sampling method. Results might be sensitive to the method.

39. P14L20, Table 5: The sample sizes are quite small so some significance test would be useful to evaluate if the differences in scores between cases are important. In fact, when comparing scores between models, in other Tables as well, significance test would be useful.

40. P14L21-23: The sentence is difficult to understand, please rephrase it

41. P14L32, Fig. 8: Presumably, this figure is shown as an example to demonstrate how MPAS CO2 simulates the CO2 enhancement well at the specific date. Since overall CO2 enhancement is mentioned in Fig. 9. It may be better to swap Fig. 8 and Fig. 9 to make structure organized better.

42. P14L34: It is the wrong figure number. Please change Fig. S2 and Fig. S3.

43. P15L3: Numbers in Fig. 8 are very difficult to read. Please change the font size or colour or both.

44. P15L13: It is difficult to find when the CO2 enhancement is shown. Maybe it would be helpful to add a mark in Fig. 9 to indicate when the CO2 enhancement happened. Otherwise, as there are too many panels in the single figure, you may consider to keep the small number of panels in Fig. 9 and to move the rest of them to supplementary.

45. P15L17: It is difficult to recognize colour lines without information. Please add a

legend for lines in Fig. 9.

46. P15L18: I cannot see the date 2017-10-28 in Fig. 9.

47. P15L19: Looking at the date 2017-11-03, the CO2 enhancements happen not only at the front boundary but also around other locations such as at 19 and 19.8 UTC in the panel. Can you explain why CO2 enhancements are shown at other times either? Isn't the CO2 enhancement a unique feature happening at the front?

48. P15L25: What is the "level-leg flights"?

49. P16L3: Because the developed model is a global model, it would be better to evaluate result over the globe first then narrow down the scales of interest (North America). In that sense, section 3.4 should be placed before section 3.3. Also, including more observations (e.g., TCCON) in section 3.4 is beneficial to evaluate the behaviour of the global scale CO2 transport by MPAS CO2, with an extended simulation period.

50. P16L14: What is the difference between Mean RMSE vector wind and RNSE wind speed in Table 3? Since RMSE wind speed is not mentioned in the text, it is difficult to understand why two different metrics are shown separately.

51. P16L14-15: I am just curious that numbers for the mean difference wind direction in Table 3 are always positive by any chance.

52. P16L15: Table 3 is mentioned later than Table 4 and 5. Please change the order.

53. P16L25-26: Vertical sampling method is missing. It is better to add a discussion about vertical sampling strategy. In addition, why is the horizontal sampling method used in this section different from that in the previous section?

54. P17L8: Because MPAS utilizes variable horizontal resolution (60-15 km), it may be possible to find a benefit of higher horizontal resolutions by splitting results into two groups, one on 60 km grid and the other on 15 km. Results at sites on 15 km grid may be comparable with results in IFS 9 km.

55. P17L8: Why are 46 stations used in the calculation rather than 50 stations? This is a different number from what is mentioned above (50 stations).

56. P17L10: Table S2 is mentioned later than Table S3.

57. P17L17: The sentence sounds strange. Please rephrase it.

58. P37: Figure 10. In the caption, what does “Figs. 9 and 9” mean?

Technical corrections:

1. Overall, it was able to find lots of typos and technical corrections, grammar and format issues. So, presented here might be not the completed set.

2. The subscript for 2 is missing in CO2 in many places, including the main text, captions and figures, throughout the paper.

3. Many acronyms are defined in wrong places or multiple times. Please correct them.

4. P2L13: This is the first place to define PBL.

5. P2L28: This is the first place to define FT.

6. P3L13: This is not the first place to define PBL.

7. P3L18: Remove space between “)” and “,”

8. P4L23: “planetary boundary layer (PBL)” -> PBL

9. P4L24: This is the first place to define BL.

10. P6L12: Carbon dioxide -> CO2

11. P7L14: What is “(?)”?

12. P7L21: Carbon dioxide -> CO2

13. P7L24: CO2 fluxes -> surface CO2 fluxes

14. P9L4: Fig.2 -> Fig. 2 (add space)

15. P10L7: It may be a typo of evaluation.

16. P10L14: boundary layer -> BL

17. P10L24: 850 is duplicated

18. P11L9: chemistry transport model -> CTM

19. P11L11: Missing year for Hersbach et al.

20. P11L12: boundary conditions -> lateral boundary conditions

21. P11L12: Jacoboson et al. (2007) is not the proper reference for CarbonTracker.

22. P11L13: CO2 fluxes -> surface CO2 fluxes

23. P11L14: Jacobson al. (2007) is the not proper reference for CarbonTracker.

24. P11L15: atmosphere -> atmospheric

25. P11L16: chemical transport model -> CTM

26. P11L17: planetary boundary layer -> PBL

27. P11L21: Remove space between “)” and “,”

28. P11L25: change double parenthesis to single

29. P11L32: It is not the first place to define BL and FT.

30. P11L32: he -> the

31. P12L6: exception -> exceptions

32. P12L9: free troposphere -> FT

33. P13L24: “boundary layer (BL) and free toposphere (FT)” -> BL and FT

34. P14L15: 2015? It might be a typo.

35. P14L15: Fall -> fall

36. P14L15: show -> shows

37. P14L17: tend -> tends

38. P14L29: boundary layer -> BL

39. P15L11: wrong order; 2017-02-23 after 2017-03-10

40. P16L32: “The Schauinsland station” should be moved to P16L29.

41. P17L2: Add space between “23.99” and “ppm”.

42. P30: Figure 4: Unit is missing in the caption or figure.

43. P32: Figure 6: Unit is missing in the caption or figure. Add names on x-axis.

44. P43: Table 3. Add space between number and the unit (m/s) and parenthesis for degree. Numbers should be integer.

45. P44: Table 4. Add “date (yyyy-mm-dd)” at the top left.

46. P45: Table 5. Num -> Number

47. P47: Table 7. Make Station IDs capital letters (including main text).

References

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