Responses to Topic editor’s Comments for Manuscript egusphere-2024-2986

Enhancing Single-Precision with Quasi Double-Precision: Achieving Double-Precision Accuracy in the Model for Prediction Across Scales-Atmosphere (MPAS-A) version 8.2.1

Addressed Comments for Publication to

Geoscientific Model Development

by

The Authors

Dear Editor,

Enclosed herewith is the updated edition of our earlier submission titled "Enhancing Single-Precision with Quasi Double-Precision: Achieving Double-Precision Accuracy in the Model for Prediction Across Scales-Atmosphere (MPAS-A) version 8.2.1" assigned the manuscript number egusphere-2024-2986. We extend our sincere appreciation to you for offering invaluable feedback, which has significantly improved the overall quality of our manuscript. In this updated version, we have carefully addressed the suggestions provided by you. Herein, you will discover a summary of the modifications implemented, along with a thorough response to the your comments.

Sincerely,
The Authors

Note: To enhance the legibility of this response letter, editor's comments are typeset in boxes. Rephrased or added sentences are typeset in color. The respective parts in the manuscript are highlighted to indicate changes.

Response to the editor

Comment 1.1

Computational Efficiency Analysis: In the discussion section, further elaborate on the practical significance and potential impacts of the improved computational efficiency. For example, explain how it benefits large - scale climate simulations in terms of faster result acquisition and resource utilization. Also, discuss its stability and scalability across different hardware environments.

Response 1.1:

Thank you for your valuable feedback. I have made the necessary revisions to the discussion section (line 334 - 343 in manuscript) in response to your suggestion, further elaborating on the practical significance and potential impacts of the improved computational efficiency. And beneficials on large-scale simulations have been well discussed. Thank you for your guidance and support.

> This substantial memory reduction and relatively modest increase in computational cost can be attributed to the inherent trade-off between precision and performance. In large-scale numerical simulations, the impact of rounding errors cannot be ignored, which is why double precision is commonly employed to maintain the accuracy of results. However, double-precision computations significantly increase computation time and resource consumption, which is often impractical for large-scale simulations. By using QDP, we not only reduced memory and communication overhead but also enhanced scalability, particularly in ultra-large parallel simulations where internode communication can become a major performance bottleneck. Moreover, while our experiments did not include vectorization techniques, there is considerable potential for further performance improvements. In similar computational environments, vectorization optimization combined with QDP has been shown to offer significant computational efficiency advantages over double precision (Dmitruk et al., 2023). Although this study is limited by hardware and scale, vectorization will be a key area for future research, especially in fully exploiting the potential of HPC architectures.

Comment 1.2

Model and Algorithm Application: Explore the potential for applying the algorithm in the spatial discretization process in future work and provide examples of its application in different scenarios to aid understanding.

Response 1.2:

Thank you for your helpful suggestions. Unfortunately, the quasi double-precision algorithm is currently mainly applied in the process of time-integration, where its core function is to compensate for the larger round-off errors caused by the reduction in significant digits. The primary application addresses the issue of increased round-off errors in numerical computations due to the addition of numbers with vastly different magnitudes. However, it is uncertain whether this method would be beneficial for spatial discretization. In spatial discretization algorithms, a common source of increased rounding errors occurs when subtracting two nearly equal numbers. We hope to make progress in addressing these types of errors in the future.

Comment 1.3

Experimental Setup and Case Selection: Add a subsection summarizing and comparing the characteristics and applicability of different cases. Mention future plans for expanding the case study range, if any.

Response 1.3:

Thank you for your insightful feedback, it's been very helpful. We selected these two ideal cases and the real-data case because they are the only complete datasets available for download on the MPAS website. In Section 2.4, we provide a description of the selected cases (line 192 - 200 in manuscript). We also plan to explore other cases in the future to validate the applicability of the algorithm across different scenarios.

> To assess the application effect of the quasi double-precision algorithm, We selected these two ideal cases and the real-data case because they are the only complete datasets available for download on the MPAS website:
> (1) **Jablonowski and Williamson baroclinic wave**: A deterministic initial-value test case (Jablonowski and Williamson 2006) for dry dynamical cores of atmospheric general-circulation models, is presented that assesses the evolution of an idealized baroclinic wave in the northern hemisphere. The primary objective is to assess the model's efficacy in replicating the typical dynamics of moist atmospheric conditions across various precision settings.
> (2) **Super-cell**: A reduced-radius sphere (Klemp et al. 2015) can be used to assess the behavior of nonhydrostatic processes in global atmospheric dynamical cores, as long as the simulated cases demonstrate good agreement with the corresponding flows in Cartesian geometry, for which analytical solutions are available.
> (3) **Real data**: with initial conditions generated using GFS data at 2014-09-10_00) using two different resolutions (total domain size of 120 km × 120 km and 240 km × 240 km).

Comment 1.4

Metrics Comparison: Analyze the correlation and complementarity between different metrics, such as when spatial RMSE or MAE is more suitable, and how to use them comprehensively for algorithm performance evaluation.

Response 1.4:

Thank you for your constructive feedback, it is greatly appreciated. We have added a section (line 227 - 233 in the manuscript) to explain the correlation and complementarity between these two different evaluation metrics. The added content is as follows:

RMSE is primarily used to measure the difference between predicted and actual values and is more sensitive to large errors. MAE calculates the average absolute prediction error, and is less sensitive to outliers than RMSE, making it more suitable for conventional error measurements. Therefore, the combination of RMSE and MAE provides a more comprehensive evaluation. When comparing the performance of different experiments, RMSE may be used to quantify differences in extreme values (such as temperature fluctuations, ocean current speeds, etc.), while MAE is used to assess the accuracy of the model's overall trend. Combining both provides a better reflection of the algorithm's performance advantages.

Comment 1.5

Figure Improvement: Optimize the overall layout of figures for better aesthetics and readability. Use a unified style for related figures. Enrich figure captions to guide readers in interpreting the information and its connection to the paper's key points.

Response 1.5:

I'm grateful for your thoughtful suggestions and the improvements they've brought. I have enriched and revised the figure captions accordingly.

Figure 1. The ~~quasi double-precision~~ QDPalgorithm in case of a step-by-step integration. The line 3 to 7 represent the iterative process of applying the QDP method.

Figure 2. The ~~quasi double-precision~~ QDP algorithm adding a precondition of magnitude. This step is designed to ensure that large and small numbers can always be identified during the addition process.

Figure 3. The time evolution of difference between DBL and SGL, as well as difference between DBL and QDP of (a)Total Energy, (b)Total Mass in case of Jablonowski and Williamson baroclinic wave. Both figures (a) and (b) demonstrate the advantages of QDP in compensating for errors, with this advantage becoming more apparent after integrating for a period of time.

Figure 4. Spatial distributions of averaged (1-15days) difference of surface pressure (units: Pa) between DBL and (a) SGL simulations, (b) QDP simulations in case of Jablonowski and Williamson baroclinic wave. The figure shows that the QDP method improves the overall error, with more pronounced effects in the mid- to high-latitude regions.

Figure 5. The time evolution of difference between DBL and SGL, as well as difference between DBL and QDP of (a) Total energy, (b) Total mass in case of super-cell. Both figures (a) and (b) demonstrate the advantages of QDP in compensating for errors, with this advantage becoming more apparent after integrating for a period of time.

Figure 6. Perturbation theta in super-cell development at 5400s in the (a) DBL simulation, (b) SGL simulation and (c) QDP simulation (bias has reduced), unit: K, the circle represents the pattern bias (the same color means the consistent value). In figure (a), after reducing the double-precision experiment to single precision (b), error regions (in blue) appear. The application of the QDP method is able to improve

the errors in these regions (c).

Figure 7. The temporal evolution of spatially averaged difference of total energy between DBL and SGL, as well as difference between DBL and QDP in case of real data, with resolution of (a) 240 km × 240 km, (b) 120 km × 120 km. Different resolutions exhibit varying degrees of error improvement. However, overall, the application of QDP (red line) is able to reduce the errors generated by the loss of numerical precision (blue line).

Figure 8. Spatial distributions of averaged (1-15days) difference of surface pressure (units: Pa) between DBL and (a) SGL simulation, (b) QDP simulation (the total domain size: 240 km × 240 km). The spatial RMSE of surface pressure between DBL and (a) SGL simulation is 6.68×10^{-2} Pa, (b) QDP simulation is 2.25×10^{-3} Pa. The reduction in error is quite significant, with each region showing a decrease of several orders of magnitude spatially, demonstrating a substantial improvement in error correction.

Figure 9. Spatial distributions of averaged (1-15days) difference of 500 hPa height (units: m) between DBL and (a) SGL simulation, (b) QDP simulation (the total domain size: 240 km × 240 km). The spatial RMSE of 500 hPa height between DBL and (a) SGL simulation is 2.80×10^{-1} m , (b) QDP simulation is 1.40×10^{-1} m (round-off error has reduced). From a spatial perspective, the errors in each region have shown notable improvement.

Figure 10. Distributions of averaged (1-15days) difference of surface pressure (units: Pa) between DBL and (a) SGL simulation, (b) QDP simulation (the total domain size: 120 km × 120 km). The spatial RMSE of surface pressure between DBL and (a) SGL simulation is 6.33×10^{2} Pa, (b) QDP simulation is 2.25×10^{3} Pa(The color bars in (a) and (b) are different). With the addition of QDP, the errors have shown noticeable improvement across all regions from a spatial perspective.

Figure 11. Spatial distributions of averaged (1-15days) difference of 500 hPa height (units: m) between DBL and (a) SGL simulation, (b) QDP simulation (the total domain size: 120 km × 120 km). The spatial RMSE of 500 hPa height between DBL and (a) SGL simulation is 4.35×10^{3} m , (b) QDP simulation is 1.90×10^{3} m. This is consistent with the overall improvement shown in Fig. 10.

Comment 1.6

Terminology and Expression: Conduct a consistency check for terminology and expressions throughout the paper. Provide detailed explanations for technical terms upon first use to assist non - specialist readers.

Response 1.6:

Thank you very much for your constructive suggestion. I have carefully conducted a consistency check for terminology and expressions throughout the paper. Detailed explanations for technical terms have been provided upon first use to assist non-specialist readers. These changes aim to improve the clarity and accessibility of the paper.

Comment 1.7

Code and Data Availability: Include a FAQ section in the README file, addressing common issues like operating system - specific problems and key parameter settings.

Response 1.7:

Thank you very much for your valuable suggestion. We have added a FAQ section to the README file, and the specific content to be added is as follows:

> FAQ:
> Q1: How do I select different cases for the simulation, and how do I set the time step?
> A1: The case selection is controlled by modifying the config_init_case parameter in the namelist.init_atmosphere file. The time step is set by modifying the config_dt parameter in the namelist.atmosphere file.
> Q2: How can I modify the variables in the output file?
> A2: To modify the output variables, you need to edit the stream_list.atmosphere.output file. Currently, variables related to physical processes have been removed from the output.
> Q3: How can I optimize parameter settings when facing memory limitations or computational resource constraints?
> A3: You can optimize by setting the precision parameter to single in the streams.atmosphere and streams.init_atmosphere files. This will force real-valued fields to be written as 4-byte floating-point values, rather than the default 8-byte floating-point values.

Comment 1.8

Uncertainty Analysis: If possible, present a preliminary framework for future uncertainty analysis, including methods and expected results.

Response 1.8:

I sincerely appreciate your suggestion on uncertainty analysis. I will provide a preliminary framework for future uncertainty analysis in the paper as follows (line 301 - 305 in manuscript).

> Due to the current limitations on the MPAS-A website, which only provides a single set of terrain and initial condition fields for different experiments, our future plan is to request assistance from the MPAS-A website to construct different terrain and initial condition fields for a specific experiment. We aim to conduct sensitivity analysis, particularly for real data experiments. Provided that computational resources allow, we plan to carry out simulations with different resolutions and initial conditions. This will help lay the data foundation for future uncertainty analysis.

Comment 1.9

Logical Coherence: Check the transitions between sections for smoothness and ensure the paper structure adheres to academic norms with a reasonable distribution of content.

Response 1.9:

Thank you for your insightful comments, which have been very helpful. I have carefully reviewed the transitions between sections and made necessary revisions to ensure smooth flow. Additionally, I have adjusted the paper structure to better align with academic norms and ensured a more balanced distribution of content across the sections.