Dear editor and reviewer,

First of all, we would like to express our sincere appreciation to your valuable feedbacks. Your comments are highly insightful and enable us to substantially improve the quality of our manuscript. Below are our point-by-point responses to all the comments. The red fonts describe how the manuscript has been modified.

Responses to the comments of referee #2

1. According to several parts of this paper, three mesh index reordering strategies are investigated to improve cache efficiency. However, there is no discussion about the cache efficiency differences in the three index reordering strategies. Therefore, it is unclear if the outcome of the investigation is due to cache efficiency or something else.

[Response]:

We have improved the presentation related to this part in the third paragraph of Section 2.3 and the last paragraph of Section 3.4. The only difference between the reordered and the original codes are the loop ordering, which mainly affects the data locality during model iterations. As is known, the data locality is an important factor to the cache reuse, which has a strong effect on the efficiency of memory access. This is the reason why the index reordering strategies work. Similar speedup results from index reordering methods are obtained in Sarje et al. (2015), where two space filling curve (SFC) index reordering strategies (Hilbert and Morton curves) are used and obtained 40% improvement. Therefore,

we think it is sufficient to conclude that the speedup is due to the cache efficiency. Note that the three index reordering strategies behaves much similar, all of which are able to accelerate the calculations with a similar amount of time. Therefore, we did not make further discussions about the differences in the three strategies.

2. In section 2.2, it is claimed that scientific model developers can implement communication without knowing the communication details by using "exchange_data_add" and "exchange_data" based on "linked list". It is unclear how much details of communication this tool hides when compared to conventional methods.

[Response]:

In "exchange_data", we packed the conventional communication interfaces (MPI nonblocking communication interfaces) and made some data assignment before and after the communication, which is explained in the three steps (i), (ii), and (iii) of Section 2.2. The “linked list” is used to enable communicating multiple variables (variables that added to this list) at the same time. The interface "exchange_data_add" is used to add variables whose Halo area need to be updated to this “linked list”, as stated in Section 2.2. The aim of packing is to simplify the communication procedure and ease the model development.

We have provided an example in the end of Section 2.2 to more clearly demonstrate the use of these tools given specific solution methods and workflow.

3. It is unclear if the timing of group I/O in Fig. 8 includes any overhead for implementing group I/O such as selecting one designated process for communication.

[Response]:

The timing in Fig. 8 does not include the overhead for implementing the group I/O method. The additional work for using the group I/O method is done only once in the model initialization part, which consumes much less time than performing the I/O during model integration. Therefore, the overhead for implementing the group I/O method is negligible and not shown in this figure. We have clarified this point in the first paragraph of Section 4.3 in the revised manuscript.

4. In section 2.3, there are statements: "It should be noted that all the actual run times of the G10 grid are shorter than the corresponding ideal run times, that is, the superlinear speedup is achieved for the G10 grid. This abnormal phenomenon indicates that there is still room for improving the computational efficiency of running with smaller numbers of processes." It is unclear why the super-linear speedup happens. Also, it is also unclear why the super-linear speedup indicates that the room for improving the computational efficiency exists.

[Response]:

In the third paragraph of Section 2.3, we have added the following sentences to explain the super-linear speedup phenomenon:

"This abnormal phenomenon arises mainly because of the inefficiency of running with low processor counts. Based on our analysis and numerical experiments, this inefficiency results from the less cache hits rate due to the discontinuous memory access of an unstructured-grid model, which has a much stronger impact on running with low-processor counts than running with high-processor counts. The reason is that as the number of processors increases, the number of mesh points distributed to each processor decreases, implying that the

percentage of data that can be put into the cache is increased and therefore the cache hits rate is increased. This leads to the super-linear speedup phenomenon."

Based on previous studies on the unstructured-grid models (e.g. Sarje et al. 2015), improving the data locality during model integration is an effective way to improve the cache efficiency, especially for running with low processor counts. This is the reason why we implemented the mesh index reordering strategies. We have improved the presentation related to this part in the fourth paragraph of Section 2.3.

5. In the paper, there are terms of "toolkit" and "framework". It is unclear what is the relationship between them.

[Response]:

In our terms, "modelling framework" denotes the entire modelling system, including the parallel infrastructure and the scientific models. "Toolkit" denotes several key tools (which is the major focus of this study) offered by the parallel infrastructure to the scientific models. The parallel infrastructure also has other necessary functions. They are not mentioned in this paper because they are either more scientifically oriented (e.g., computation of mesh weight), or too common to be specifically described (e.g., time management, error handling). We have added necessary information in the introduction (see footnote 2) to more clearly explain these terms.

We really appreciate your highly constructive comments. If there are any other questions, please do not hesitate to contact us.

Best wishes,

Xiaomeng Huang