

# Authors' Response

We would like to once again express our gratitude to both referees and the editor. Referee comments are included in **Black**. Our detailed responses are highlighted in **Blue**. The changes implemented in the revised manuscript are indicated in **Red**.

## Response to Referee #2

Thank you to the authors for carefully addressing all the review comments. The remaining suggestions are mostly just wording clarifications, mostly around the theme of 'improving accuracy' and providing enough context so that the reader understands the tradeoffs of modifying the terrain. This smoothing approach is like a bandaid - sometimes it's necessary - but if the terrain is too steep, and you make it less steep, then errors are introduced - and the paper should make this clear. The items below are mostly just examples where the wording might be modified slightly.

Note: the line numbers below refer to the tracked changes version of the manuscript.

We thank the reviewer for reading the revised manuscript and for their additional suggestions. We are pleased that the previous revisions were positively received. Following the comments presented here, we have introduced further clarifications in the manuscript, regarding the implications of terrain smoothing. We hope that the manuscript is now suitable for publication.

1. "the SimGrid namelist (topo\_average\_opt) and is included in the upcoming model release (version 5.0, April-May 2026; see the release notes for further details)."

Thanks for implementing this!

We thank the reviewer for highlighting this during the first review round, which motivated the implementation of this preprocessing option in FastEddy.

2. Line 64 - "The lowest model level is located at approximately 15 m above ground level (domain mean). Subsequent levels are located at approximately 46 m, 78 m, 110 m, 144 m, and 180 m, with a vertical spacing that gradually increases with height."

Can you state the stretching ratio, similar to how it is stated for FastEddy? Also, what is the aspect ratio  $dz/dx$  at the surface, compared to the terrain slope? This matters for steep terrain. See Mahrer 1984. Also, clarify that the grid levels given are at the center of the cells.

We thank the reviewer for this comment. We have clarified in the manuscript that the reported vertical levels correspond to the centers of the model layers.

As indicated in our earlier response regarding this aspect, the vertical levels in WRF were manually defined through an eta-coordinate list, and therefore there is no single constant stretching ratio throughout the vertical grid. The effective near-surface stretching ratio, estimated from the spacing between consecutive model-layer centers, increases gradually from about 1.01 near the surface to

about 1.10 by the eighth model level. For the sake of reproducibility, the eta-coordinate distribution used in the simulations has also been included in the appendix describing the WRF configuration (Appendix A).

Near the surface, the vertical spacing is approximately 30 m, compared to a horizontal grid spacing of 200 m (i.e.,  $dz/dx \approx 0.15$ ). As noted by the reviewer and discussed by Mahrer (1984), the relationship between terrain slope and grid aspect ratio is relevant in steep-terrain simulations and contributes to the numerical limitations encountered in this case.

“The **cell center of the lowest model layer** is located at approximately 15 m above ground level (domain **average**). Subsequent **model-layer centers** are located at approximately 46 m, 78 m, 110 m, 144 m, and 180 m, with a vertical spacing that gradually increases with height.”

“The vertical grid includes 45 eta levels explicitly defined in the model configuration (**see Appendix A**), with enhanced resolution near the surface, and the model top set at 50 hPa.”

Text added to Appendix A: “**The eta-coordinate distribution used in the simulations was explicitly prescribed in the model configuration for enhanced near-surface resolution and was defined with *eta\_levels* = 1.00000, 0.99629, 0.99257, 0.98879, 0.98486, 0.98071, 0.97622, 0.97130, 0.96585, 0.95977, 0.95299, 0.94540, 0.93692, 0.92744, 0.91686, 0.90507, 0.89195, 0.87737, 0.86120, 0.84331, 0.82356, 0.80181, 0.77793, 0.75181, 0.72335, 0.69246, 0.65911, 0.62329, 0.58506, 0.54455, 0.50195, 0.45755, 0.41175, 0.36503, 0.31802, 0.27144, 0.22617, 0.18317, 0.14344, 0.10788, 0.07710, 0.05132, 0.03028, 0.01343, 0.00000.**”

3. Line 82- "This configuration is appropriate for a microscale LES setup focused on resolving boundary-layer processes for the stability conditions considered herein."

With 500 m mountains, a very high domain top is recommended. LES with a lid at 2700 m would not be appropriate, due to reflecting internal waves and BL perturbations from the topography that could reach to 2 km. For assessing stability, this small domain may work, but the text should be rewritten so it doesn't imply that 2700 m is enough for LES over mountains.

We thank the reviewer for this comment. We agree that the suitability of the domain-top height depends on the specific application and flow configuration. The text has been revised to clarify that, in the present study, the selected setup is considered appropriate for assessing the numerical stability of the simulations under the conditions analyzed here.

“This configuration is appropriate for **assessing the numerical stability of the** microscale LES setup **under** the stability conditions considered herein.”

4. Response file: "so further coarsening of the vertical grid would reduce the intended resolution of the lower atmosphere." Coarsening the vertical grid will reduce resolution but will allow your model to run without blowing up. It also doesn't seem accurate to change the mountain shape - this will also give you errors! (e.g. the specific mountain elevation affects near-surface predictions, for example) So it's important to acknowledge the trade offs.

We thank the reviewer for this comment. Please, see the response to comment 6, where points 4-6 are discussed in detail.

5. Line 265 - "High-resolution simulations aim to maximize accuracy, making such adjustments undesirable." This statement would also apply to changing the terrain slopes - i.e. changing the terrain is also undesirable to maximize accuracy.

We thank the reviewer for this comment. Please, refer to the response of comment 6.

6. Line 285 - "Without appropriate terrain treatment, simulations may fail due to CFL-related instabilities, while excessive global smoothing can significantly distort the terrain, effectively undermining the benefits of high-resolution modeling."

But getting it to run by smoothing can also be risky! Please add some caveats, that clearly the terrain following coordinates are not able to handle this setup, so that even if the model runs, there will be errors due to the topography representation.

We thank the reviewer for these comments. We agree that any terrain modification may introduce deviations from the original topography, just as vertical-grid coarsening may limit the representation of near-surface processes, and therefore potentially affect the physical realism of the simulation. All numerical modeling approaches involve compromises between physical realism, numerical stability, and computational cost. Terrain smoothing (global or local) therefore represents one among many approximations commonly introduced in atmospheric simulations, similarly to the use of finite spatial resolution, parameterized physical processes, or "imperfect" geophysical datasets. However, the objective of the present work is not to eliminate these compromises completely, but to reduce them.

The focus of this study is not on whether terrain should ever be modified or whether smoothing is physically perfect, but rather on **how we can minimize the impacts of the standard global smoothing** approaches commonly applied in practice to ensure numerically stable simulations. In fact, the reviewer's concern regarding the modification of the terrain shape directly motivates the proposed local smoothing approach. If terrain modifications are considered undesirable because they may introduce errors, then minimizing the spatial extent and magnitude of those modifications (which are necessary in some cases) becomes especially important.

In this context, the proposed local smoothing approach seeks to achieve the required numerical stability while introducing **smaller and more localized terrain alterations than global methods**. In the present study, only a very small fraction of the terrain points require modification, while **the vast majority of the domain**, including the main area of interest, **remains unchanged**. In this sense, the local approach seeks to **preserve the intended terrain representation, vertical resolution, and model configuration** to the greatest extent possible, while avoiding the use of stronger artificial damping or more aggressive global terrain smoothing (that would modify the entirety of the domain, introducing bigger potential errors). Although local smoothing still modifies the terrain, it allows previously unstable simulations to run while introducing substantially smaller and more localized terrain modifications than global methods, therefore minimizing the associated terrain-representation errors.

Furthermore, we agree that terrain-following coordinates over steep topography remain inherently challenging, and that simulations may still contain errors associated with the terrain representation even when numerical stability is achieved. Our manuscript already includes some discussions

stating that the local smoothing preserves the original shape to a larger extent than global smoothing, although it still introduces modifications to the terrain. However, following comments 4-6, additional clarifications have been incorporated into the revised manuscript to better reflect these trade-offs and limitations.

In the line referred to in comment 5, we have removed the sentence: “High-resolution simulations aim to maximize accuracy, making such adjustments undesirable.”

In the paragraph referred to in comment 6, we have included a brief discussion: “Although the global smoothing method also ensures numerical stability in both models, it substantially compromises fine-scale terrain features. These high-resolution details are essential for accurately representing local processes, particularly in simulations aimed at capturing small-scale atmospheric dynamics. ~~Without appropriate terrain treatment, simulations may fail due to terrain-driven instabilities, while excessive global smoothing can significantly distort the topography, effectively undermining the benefits of high-resolution modeling.~~ **High-resolution simulations using terrain-following coordinates over steep topography remain challenging. Any terrain modification, including the proposed local smoothing approach, may introduce deviations from the original topographic representation. However, the original setups could not be integrated successfully without appropriate terrain treatment due to terrain-driven instabilities. Excessive global smoothing can significantly distort the topography, effectively undermining the benefits of high-resolution modeling. In contrast, the local smoothing approach restricts terrain modifications to a limited number of localized steep-slope points, leaving most of the domain unchanged. Compared to global smoothing methods, this preserves the original terrain and intended model configuration to a much greater extent, avoiding the use of artificial damping or reduced near-surface vertical resolution.**”

7. Table B1 and B2 - perhaps put in supplemental info instead of appendix?

We thank the reviewer for this suggestion. We understand the reasoning behind moving the tables to the supplementary material. We agree that these details are not central to the main objectives of the study, which is why they were placed in Appendix B rather than in the main text. However, we would prefer to keep them in the appendix, as they contain information about the FastEddy model configuration described in the manuscript. In our view, this improves the self-contained nature of the paper, allowing readers to access the full modeling setup without referring to external supplementary files.