

Like-for-like Comparison of Terrain Following and Cut Cell Grids

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Introduction

Orography creates downslope winds and affects local precipitation. Mountains also exert non-local influences by the atmospheric response to form drag and gravity wave drag.

The most common representation of terrain in atmospheric models is that of terrain following (TF) layers. An alternative is the cut cell method, which has been found to give more accurate results in a limited number of test cases from the literature.

This project assesses the accuracy of TF and cut cell style grids, using the same model to enable a like-for-like comparison between grids.

Grids

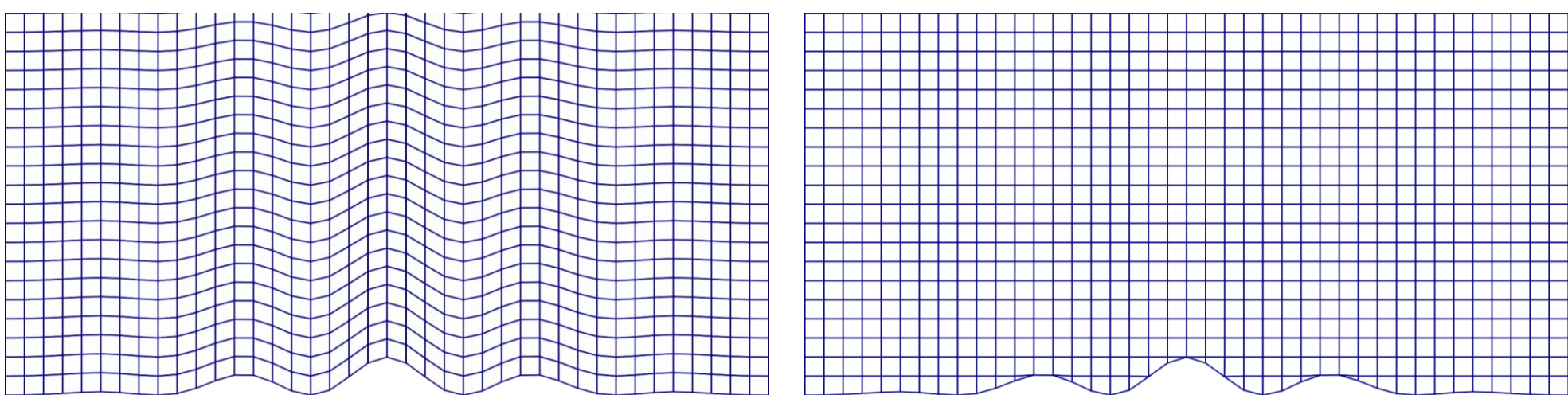


Figure 1 – Vertical cross sections of (left) Basic Terrain Following, and (right) cut cell style grids

Tests are performed on two different grids: Basic Terrain Following (BTF) and cut cell style. TF grids have the problem that, as model resolution increases, gradients tend to become steeper, which can lead to greater numerical errors (Steppeler et al. 2002). Cut cell grids are better able to represent steep slopes, but can result in very small cells that limit the model timestep unless the grid or the discretisation is modified to account for them (Jebens et al. 2011).

Tracer advection

A tracer is transported above orography by solving the advection equation for two non-divergent wind fields:

1. Purely horizontal flow, following Schär et al. (2002)
2. Terrain following flow

The tests challenge the accuracy of the advection scheme in the presence of grid distortions and flow that is misaligned with the grid. A cubic upwind-biased scheme is used that is non-monotonic and is not flux corrected.

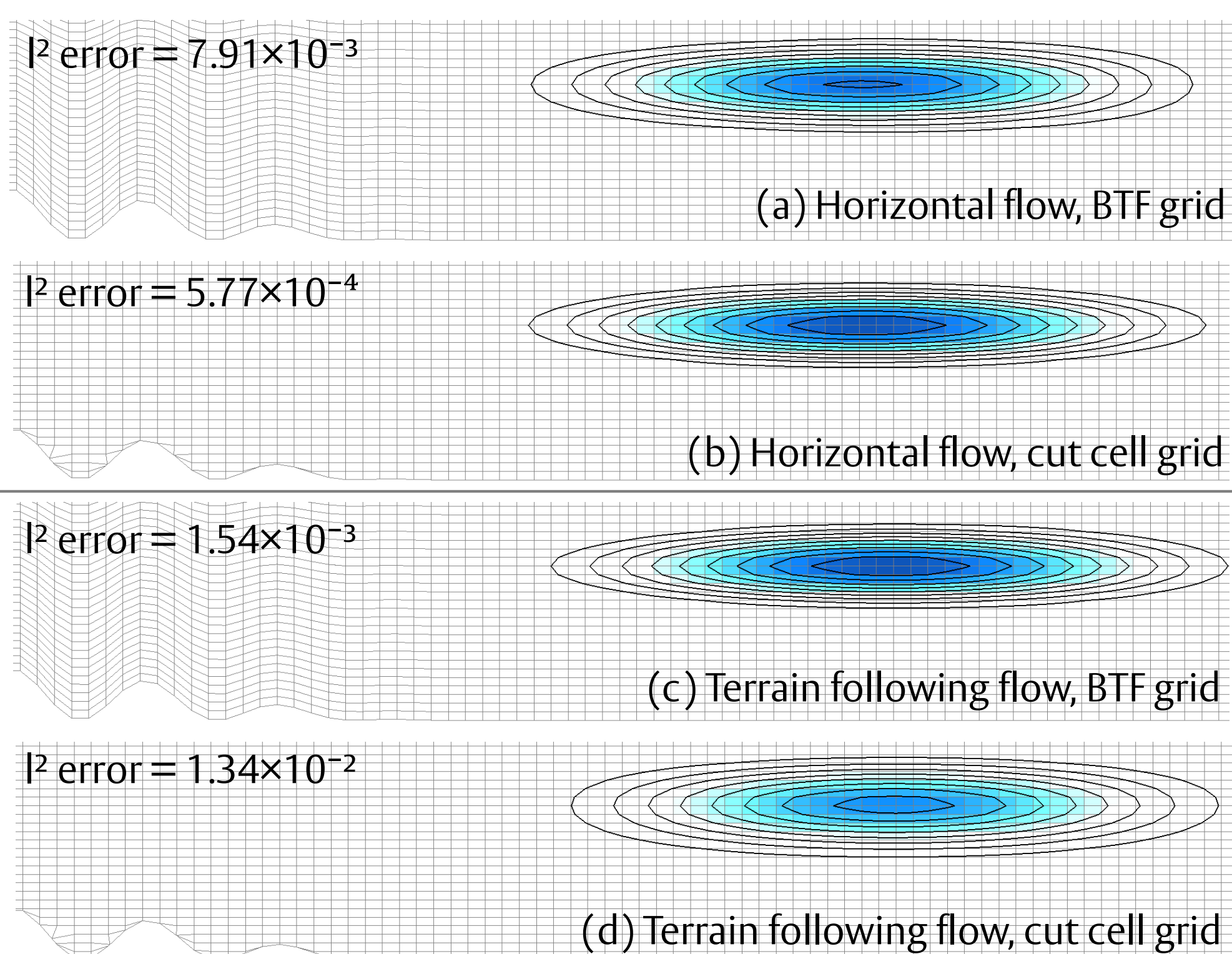


Figure 2 – Tracer advection contours at end of integration

Orographically induced gravity waves

Following Schär et al. (2002), uniform flow over an idealised two-dimensional mountain ridge induces gravity waves in a stable atmosphere. A Lorenz grid is used in which values of potential temperature, density, and the Exner function of pressure are collocated at cell centres.

Potential temperature anomalies are similar on both grids (figures 3a and 3b). Examining the cut cell style grid more closely in the lee of the mountain, figure 3c shows that the bottommost layer is anomalously warm and the layer above it is anomalously cold. This is a typical manifestation of the Lorenz computational mode in which discrete hydrostatic balance is preserved despite anomalies in the vertical thermal profile.

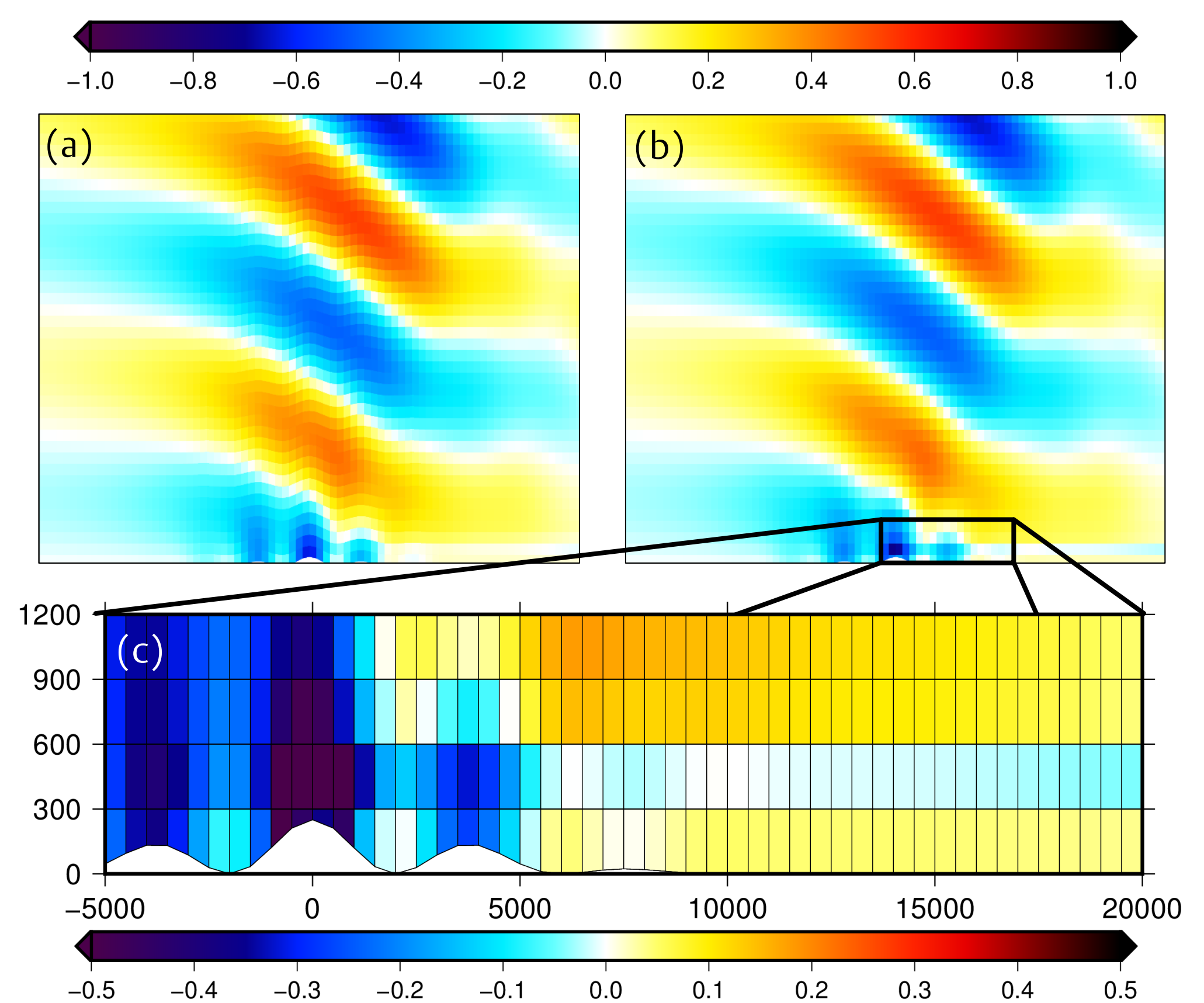


Figure 3 – Potential temperature anomalies in the gravity waves simulation after 18000 s on (a) BTF grid and (b) cut cell style grid; potential temperature scale ranges between ± 1 K. (c) Enlargement of the lowest 1200 m on the cut cell style grid; note that the scale ranges between ± 0.5 K.

Summary

- Tracer advection is most accurate when the flow is aligned with grid layers, and is less affected by grid distortions.
- Terrain following grids give better accuracy when simulating orographically induced gravity waves.
- The Lorenz computational mode was found in the gravity waves test only on the cut cell style grid. This motivates the formulation of a Charney–Phillips staggering for cut cell grids in which potential temperature values are stored at cell faces instead of cell centres.

References

1. Jebens, S., O. Knöth and R. Weiner, 2011: Partially implicit peer methods for the compressible Euler equations. *J. Comp. Phys.*, **230**, 4955–4974.
2. Schär, C., D. Leuenberger, O. Fuhrer, D. Lüthi and C. Girard, 2002: A new terrain-following vertical coordinate formulation for atmospheric prediction models. *Mon. Wea. Rev.*, **130**, 2459–2480.
3. Steppeler, J., H.-W. Bitzer, M. Minotte and L. Bonaventura, 2002: Nonhydrostatic Atmospheric Modeling using a z-Coordinate Representation. *Mon. Wea. Rev.*, **130**, 2143–2149.

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