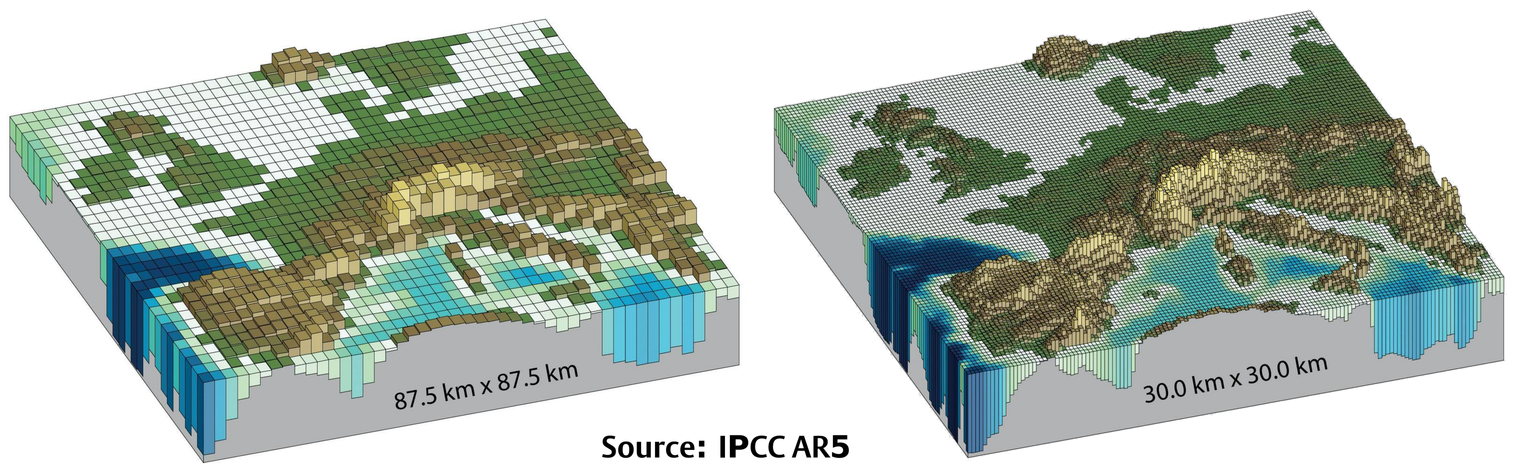
Improving numerical accuracy over steep slopes

James Shaw | Hilary Weller | John Methven | Terry Davies

js102@zepler.net | @hertzsprrrung | datumedge.co.uk

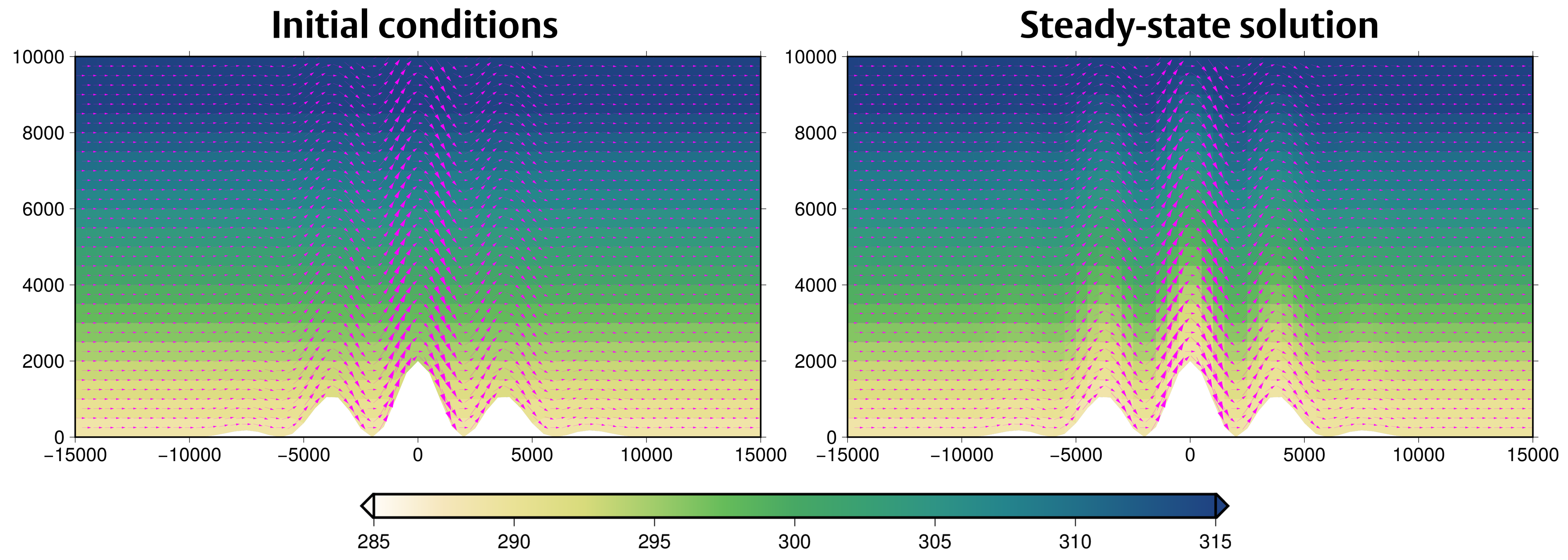
Motivation

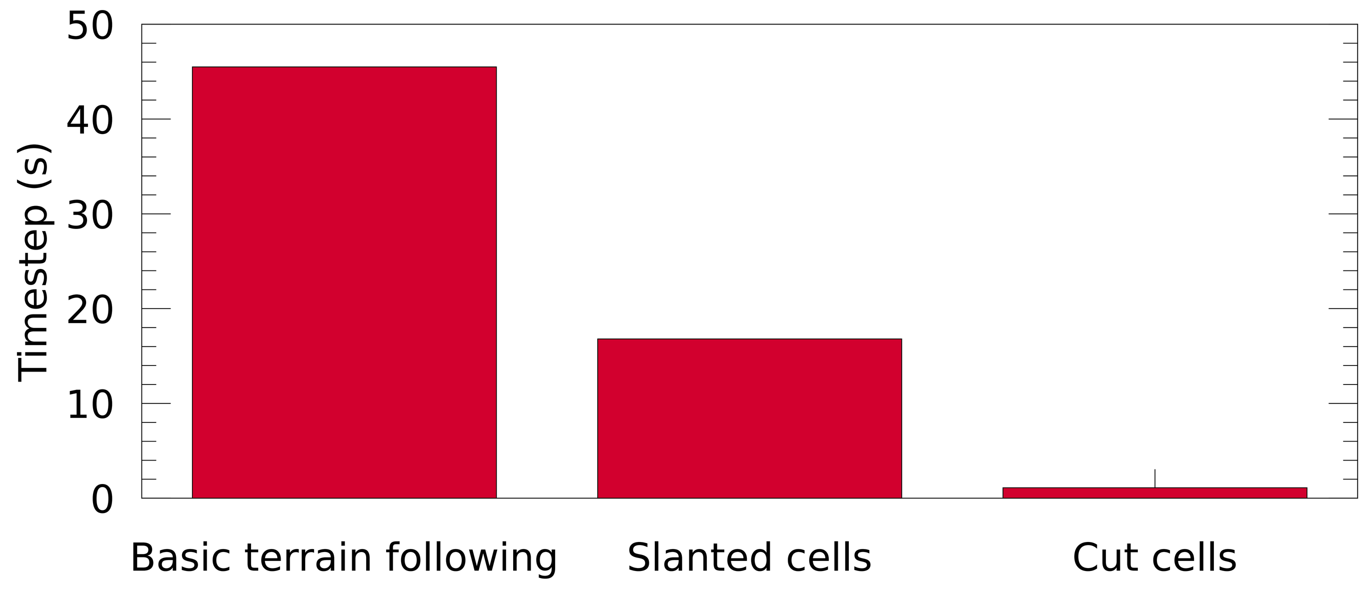


- Increasingly fine meshes allow atmospheric models to resolve small-scale, steep slopes
- Steep slopes reduce accuracy when traditional numerical schemes are used
- I am exploring new meshes and numerical schemes to improve accuracy over steep slopes

Slanted cells avoid severe timestep constraints

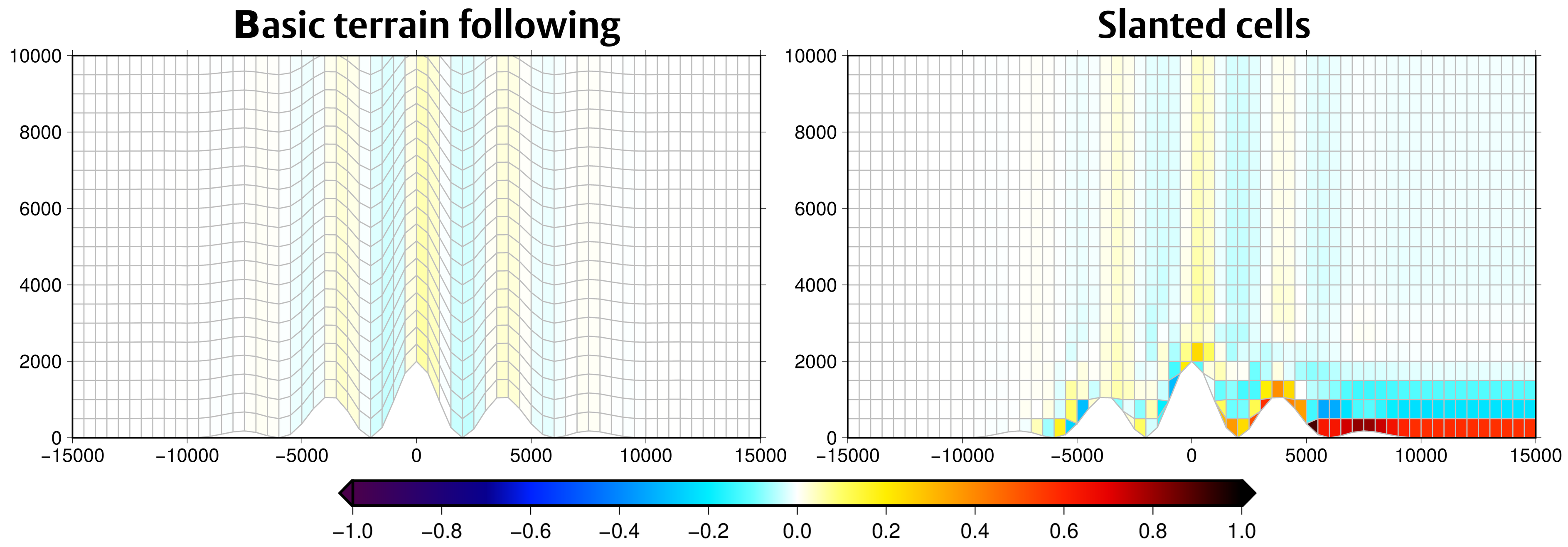
- A new advection test is used to examine timestep constraints on the slanted cell mesh
- The test has a stratified thermal profile advected in a prescribed wind field
- Mimics real atmospheric flow over orography
- Steady-state thermal field has an analytic solution
- A multidimensional method-of-lines advection scheme is used that is cheap to compute





Comparison of largest stable timesteps (Courant number ≈ 1)

- Slanted cells alleviate the timestep constraint associated with cut cells



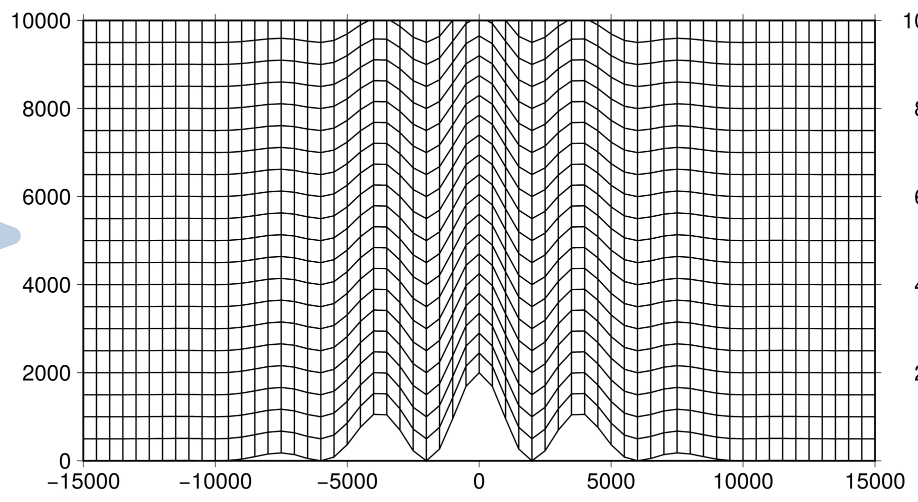
Numerical errors in the steady-state thermal field

- Downslope errors are advected along the lee side on the slanted cell mesh
- Work is ongoing to improve stability and accuracy for arbitrary meshes

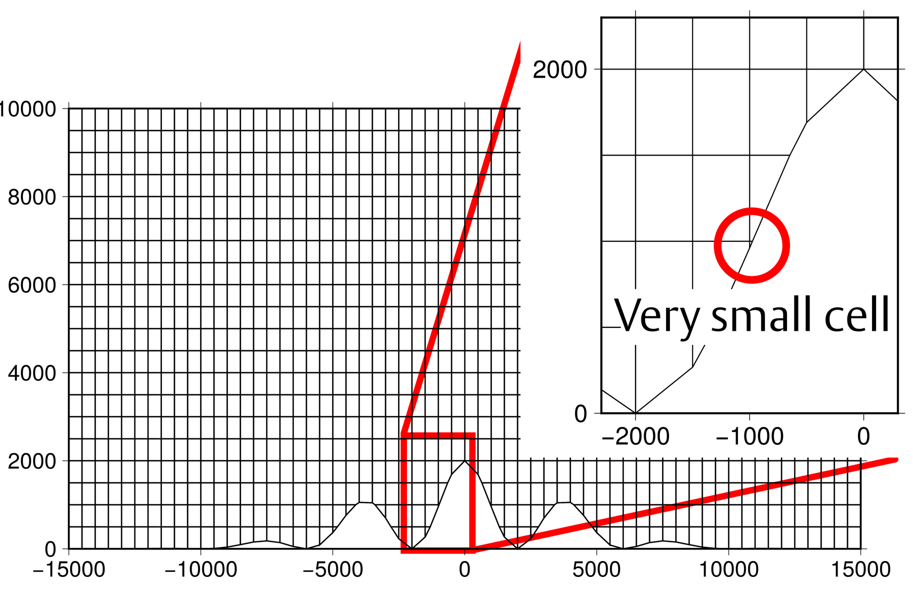
Further reading

Shaw, J., and H. Weller, 2016: Comparison of terrain following and cut cell grids using a non-hydrostatic model. Mon. Wea. Rev., **144**, 2085–2099, doi:10.1175/MWR-D-15-0226.1

Existing types of mesh



Terrain following



Cut cells

Terrain following

- \+ Widespread operational use
- \+ Modelled with simple data structures
- – Mesh can be highly distorted

Cut cells

- \+ More orthogonal
- \+ Can improve numerical accuracy
- – Small cells constrain the timestep

A new type of mesh: the slanted cell mesh

- The slanted cell mesh is designed to improve accuracy without severely constraining the timestep
- Slanted cell meshes are easy to construct

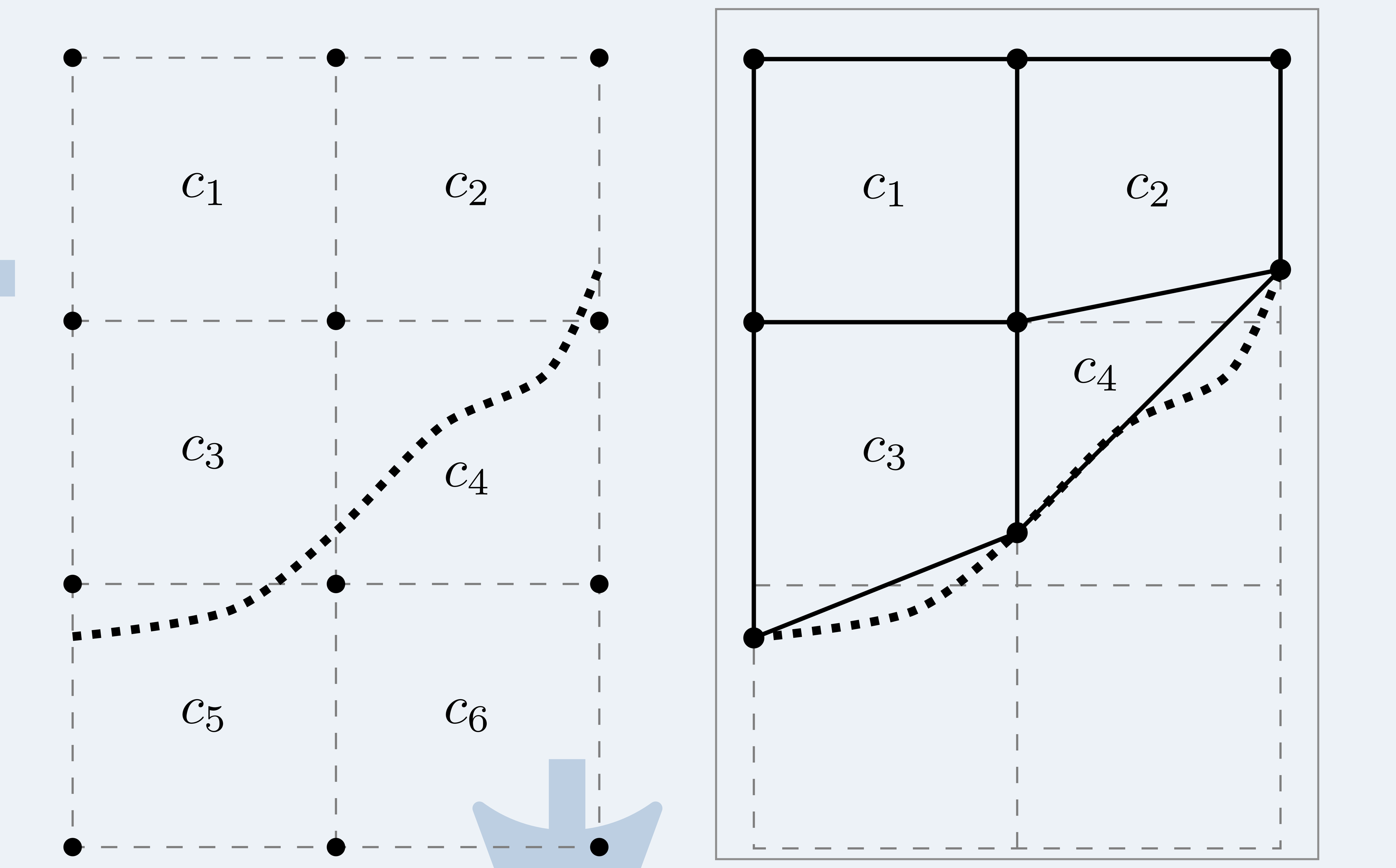
Make your own slanted cell mesh

The push pins are the cell vertices and the elastic bands form the cell edges

To create a slanted cell mesh, start from a uniform mesh of quadrilaterals:

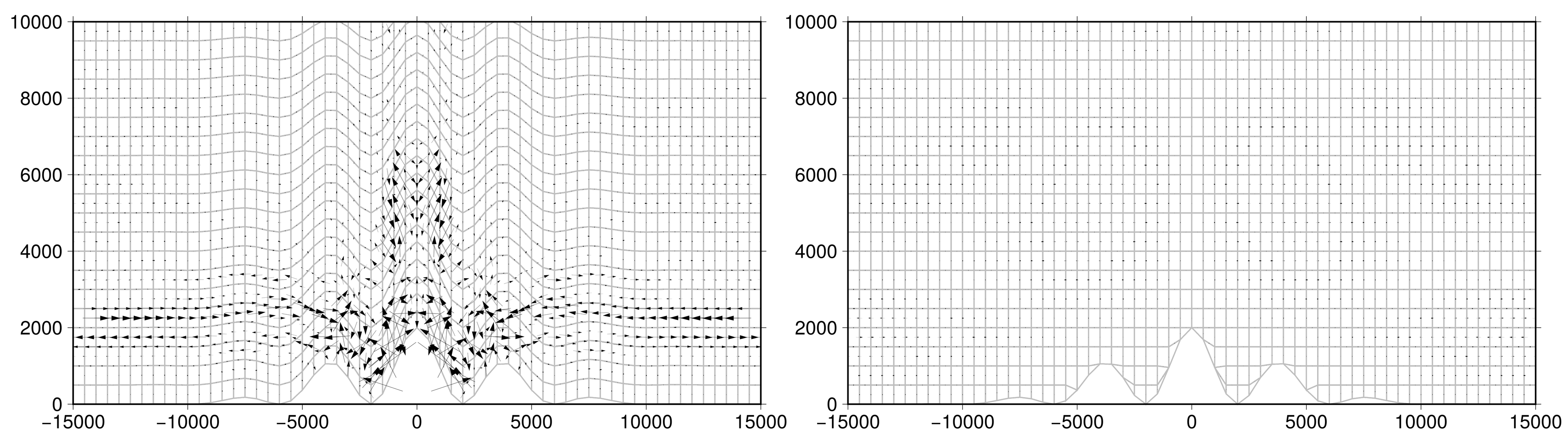
1. Move any push pins that are just above the ground to the surface
2. Move any push pins that are underground upwards so that they are at the surface
3. Wrap elastic bands around the push pins to create triangles and quadrilaterals

Lift the flap to check that your mesh matches ours



Slanted cells reduce pressure gradient errors

- Numerical errors in calculating pressure gradients generate spurious circulations
- Calculations are tested using a stratified atmosphere initially at rest
- An inversion layer that intersects the orography challenges the numerical scheme



Basic terrain following | **Slanted cells**

- Spurious circulations are much smaller on the slanted cell mesh