Terrain Following and Cut-Cells using a model with Curl-free Pressure Gradients

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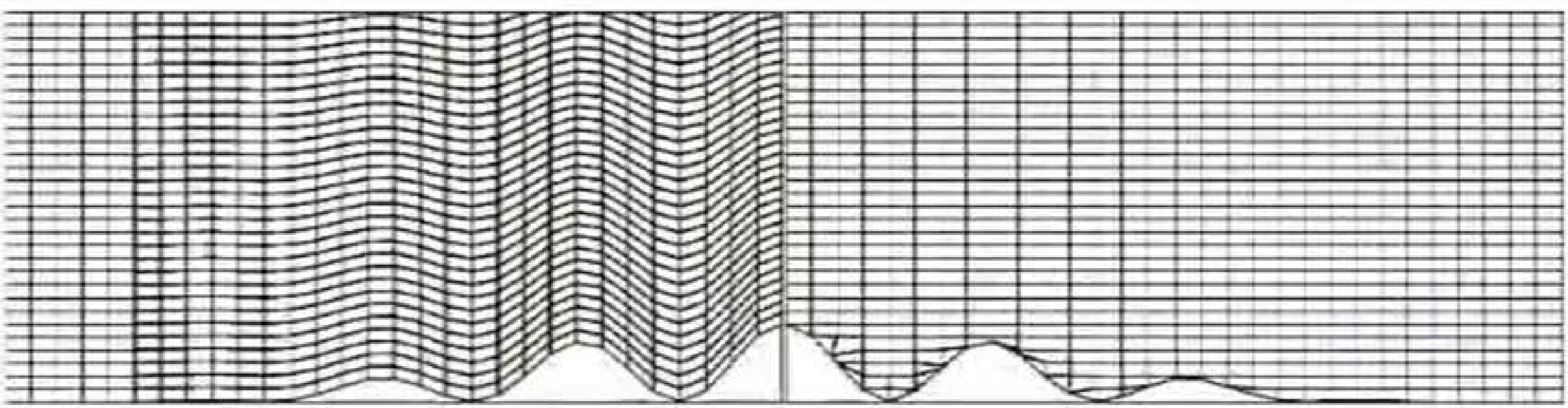


Motivation:

Solving Problems of Terrain Following and Cut Cells

Terrain Following

Problem: Horizontal pressure gradients (non-orthogonality)

Solution: Curl-free pressure gradients

Problem: Lack of alignment of mesh with flow

Solution: r-adaptivity

Cut Cells

Problem: Small cells

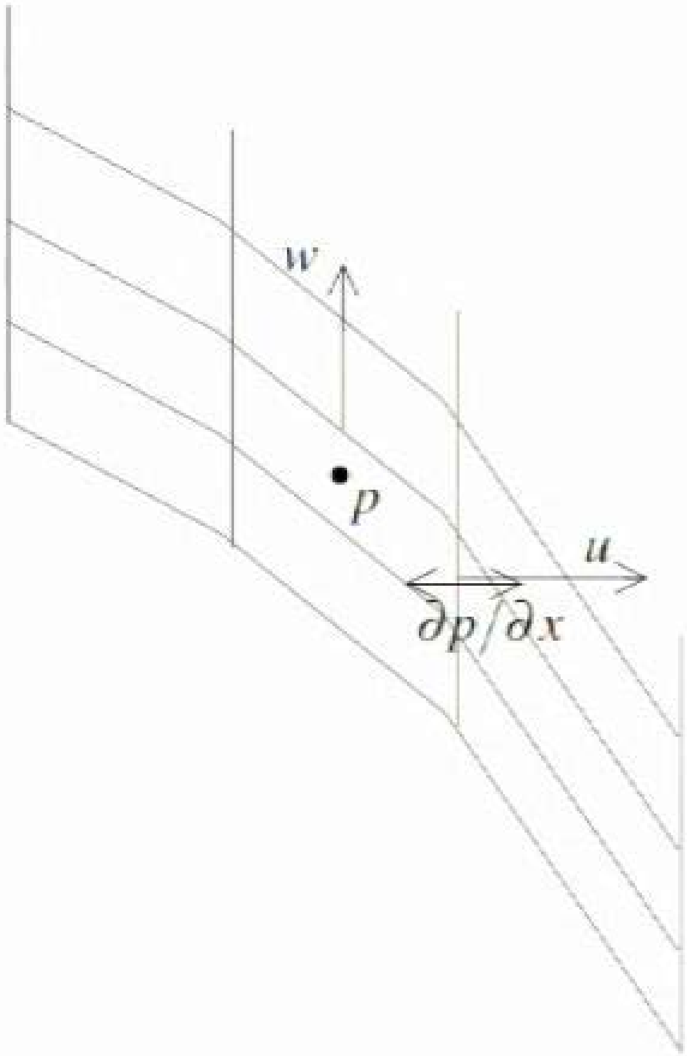
Solution: Combine cells or implicit methods

Problem: Vertical resolution at the top of mountains

Solution: Local mesh refinemnt

Ultimate Solution: a combination of both

Horizontal Pressure Gradients

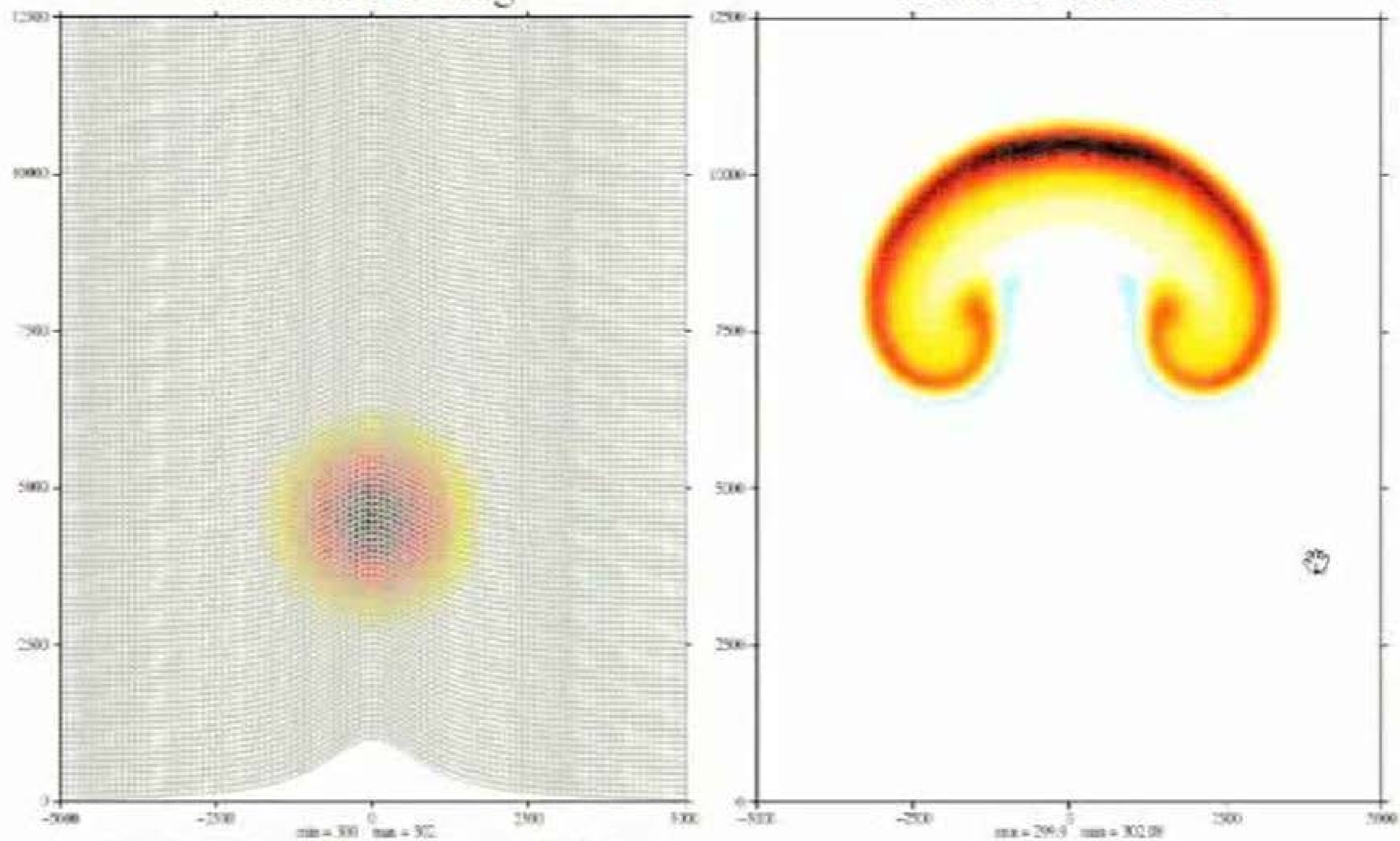


- Finite-volume C-grid
- Mesh in columns $\therefore$ non-orthogonal
- orthogonal prognostic velocity variables u, v, w in horizontal and vertical
- $\therefore$ find $\frac{\partial p}{\partial x}$ co-located with u
- $\rightarrow$ pressure gradients not curl free
- $\rightarrow$ spurious source of vorticity

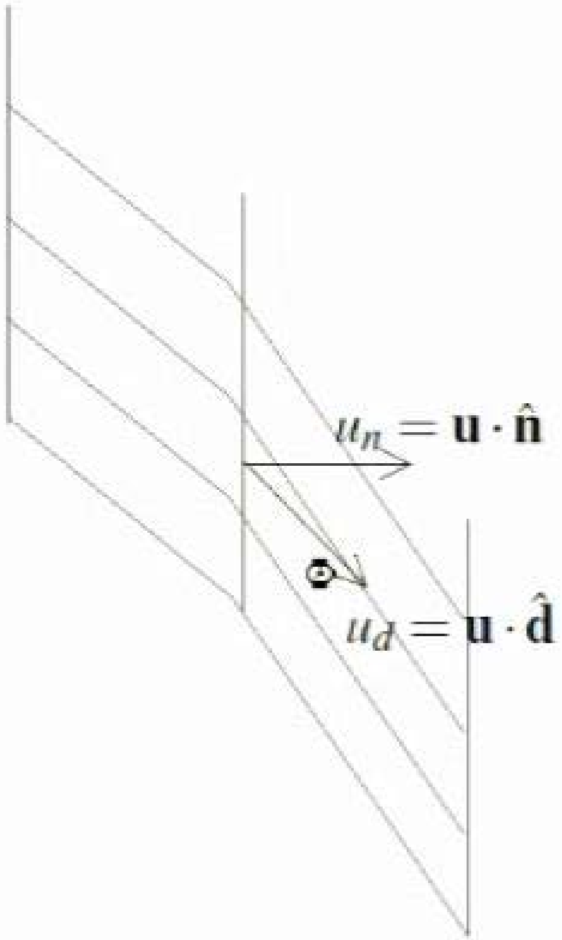
Warm Bubble Rising Over Orography

Final maximum Courant number, 0.9 ($\Delta t = 5s$)

Terrain following | Realistic solution



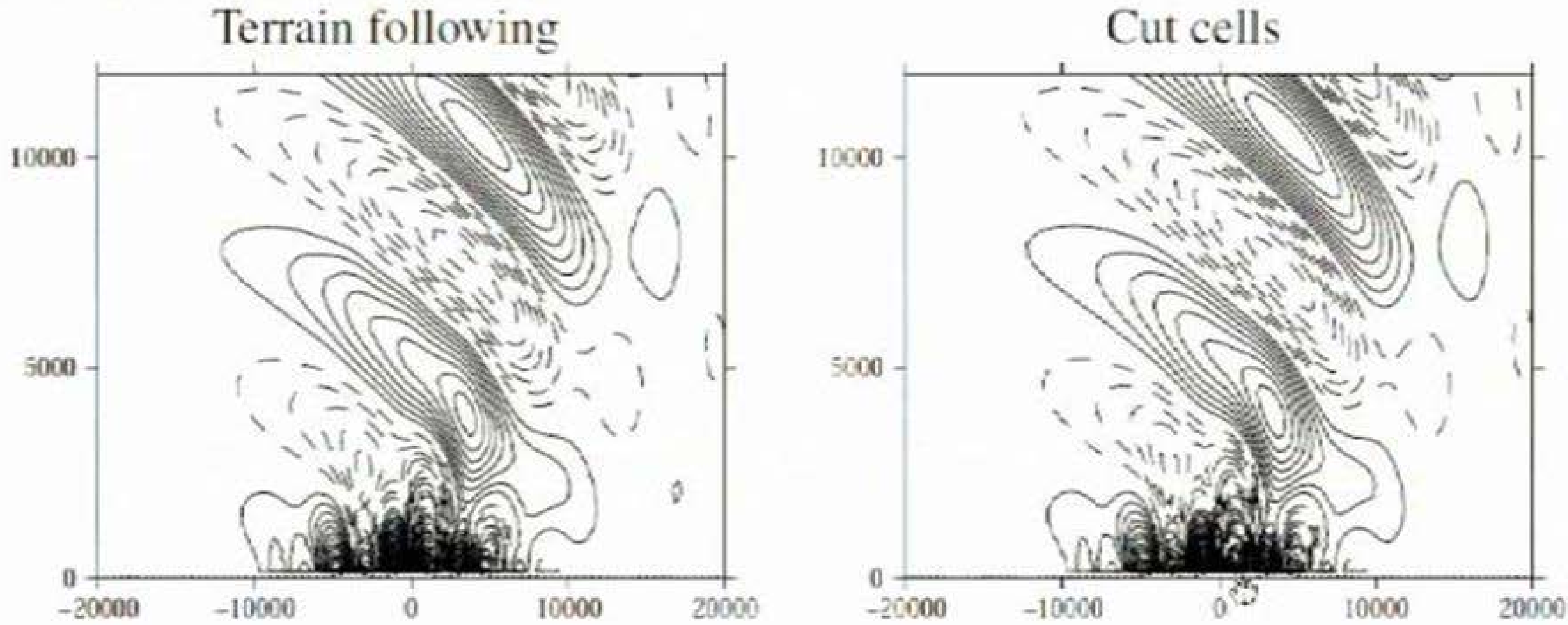
Solution: non-orthogonal prognostic variables (covariant) [Weller and Shahrokhi, 2014]



- Still need mass flux $u_n = \mathbf{u} \cdot \hat{\mathbf{n}}$ in continuity equation
- Use a least squares fit which reconstructs a uniform velocity field exactly to find u_d from u_d

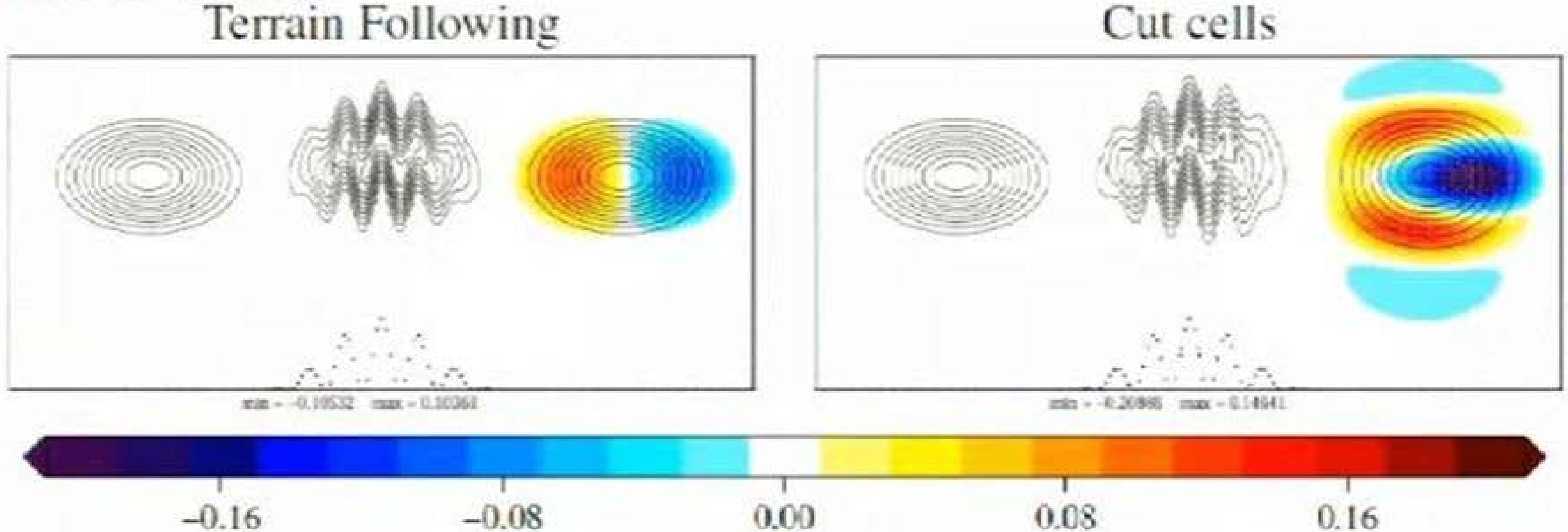
Gravity Waves over Orography [Schär et al., 2002]

Stratified flow with $N = 0.01\ s^{-1}$, $U = 10\ ms^{-1}$, mountains $\leq 250\ m$.
$\Delta x = 500\ m$, $\Delta z = 300\ m$, $\Delta t = 20\ s$
Vertical velocity after 5 hours:



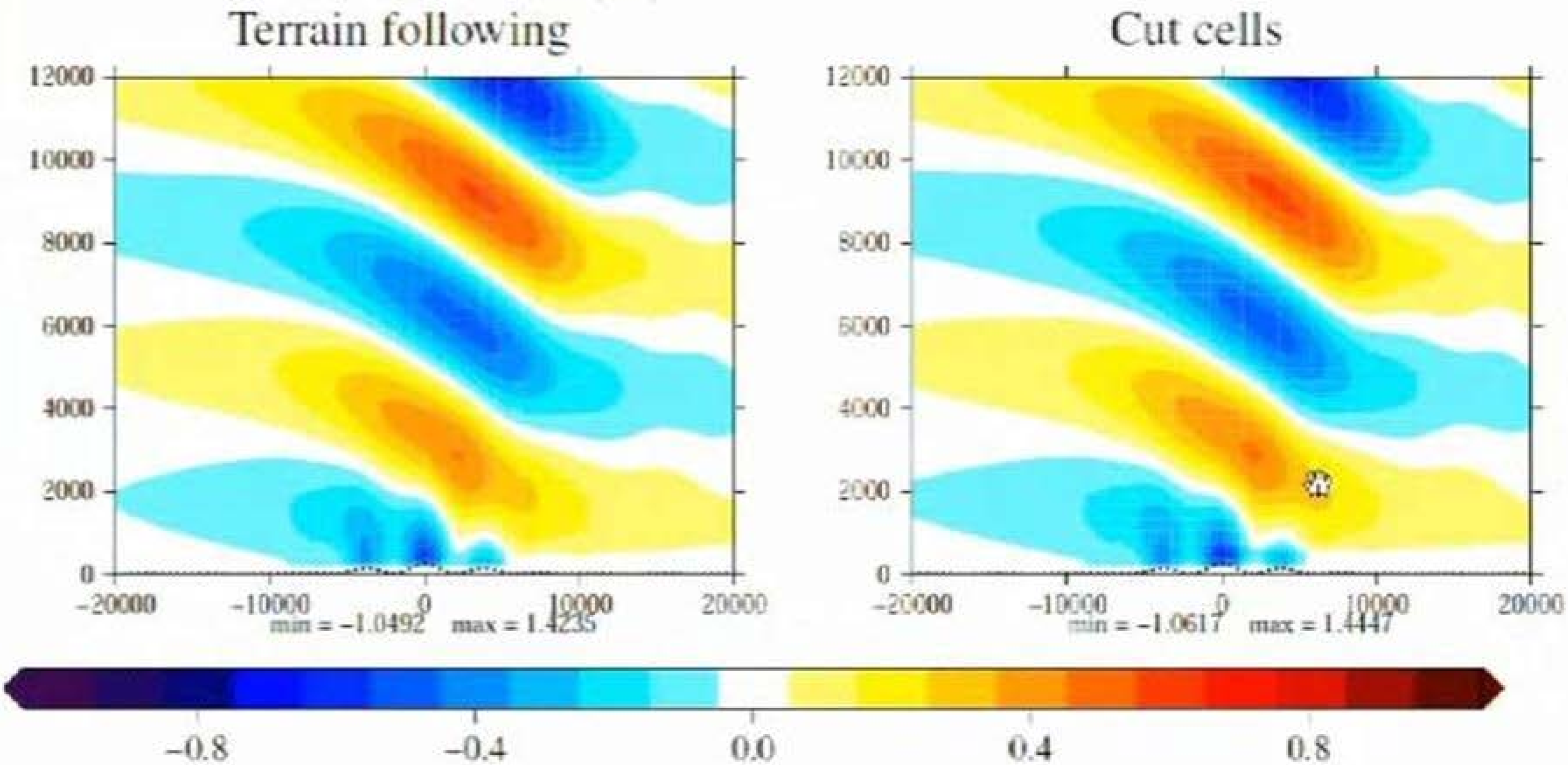
Terrain Following Advection

Should come out the same shape downstream but have travelled 51.5km rather than 50km.



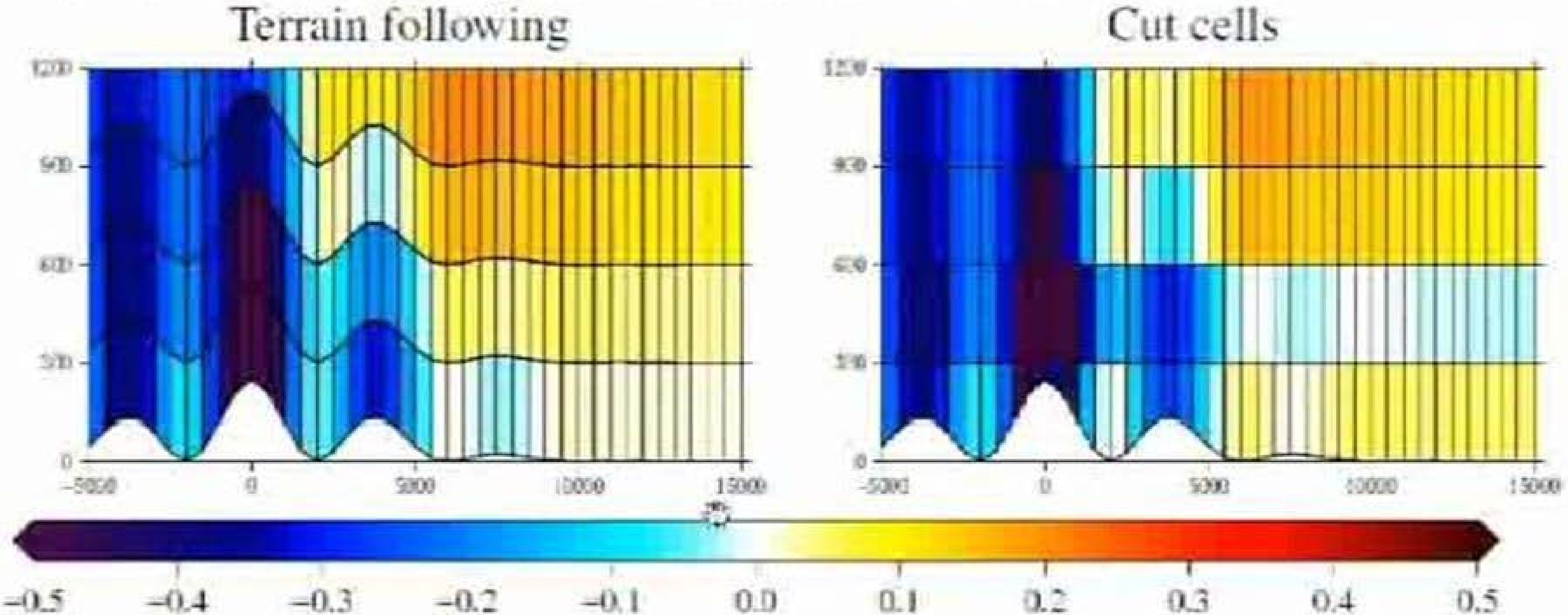
Gravity Waves over Orography [Schär et al., 2002]

Potential temperature, $\theta = T\left(\frac{p_0}{p}\right)^{\frac{R}{c_p}}$ difference from initial conditions



Gravity Waves over Orography [Schär et al., 2002]

A closer look at the change in θ downstream of the mountains



Challenges Overcome

Terrain Following: Curl-free pressure gradients removes the horizontal pressure gradient problem

Both: Accurate advection scheme ameliorates problems with non-aligned flow

- New test case with terrain following wind to challenge cut-cell model. (Contact h.weller@reading.ac.uk or j.shaw@pgr.reading.ac.uk for details)

Remaining Challenges

Cut cells: Lorenz grid computational mode

Cut cells: Vertical resolution at the top of mountains. Requires:

- local refinement :-(
- Hybrid between terrain following and cut cells :-)