Predicting Mesh Density for Adaptive Modelling of the Atmosphere

NERC Centres for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

NCAS Climate Hilary Weller h.weller@rdg.ac.uk March 2009 The University of Reading

Motivation

- Adaptive meshing for improved resolution of important features without the expense of high resolution globally. Features such as:
  - Tropical cyclones
  - Extratropical fronts
  - Deep convection
- But mesh adaptation is expensive and can introduce errors
- So can it be done less frequently?
- How to predict in advance where resolution will be needed?

OpenFOAM

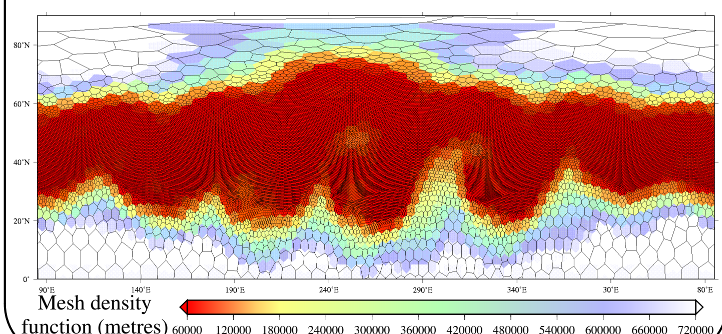
- Open source, free software library released by OpenCFD `www.opencfd.co.uk`
- Finite-volume on 3D polyhedral meshes in parallel

AtmosFOAM

- Currently global shallow water model written using OpenFOAM
- Quadratic and cubic differencing schemes explicit correction on implicit linear differencing
- Quadratic interpolation onto new meshes

Voronoi Meshes based on a Given Density Function

- Points are added and removed so that the point density conforms approximately to a given density function
- Points are Delaunay triangulated (using CGAL)
- Triangle edges are treated as springs with un-stretched edge length equal to given density function
- Springs are relaxed
- Voronoi dual used as mesh for AtmosFOAM



Outcomes

- At day 6 the adaptive model uses 21% of the cells of the mesh with uniform resolution as fine as the finest adaptive resolution.
- Remeshing every 12 hours (72 time steps) rather than every 1 or 20 minutes (St-Cyr et al, 2008) or every time step (Läuter et al, 2007).
- Power et al (2006) used one adjoint step to estimate where to refine for the following 40 time steps. But non-linear interactions cannot be predicted.
- Refined region of mesh does not lag behind regions of intense activity.
- Refinements based on $|\nabla\sqrt{\zeta^2+\delta^2}|$ more efficient than based on $\sqrt{\zeta^2+\delta^2}$.
- Technique could be used with convection parameterisation on coarse mesh to predict where high resolution will be needed to resolve deep convection before it breaks out.

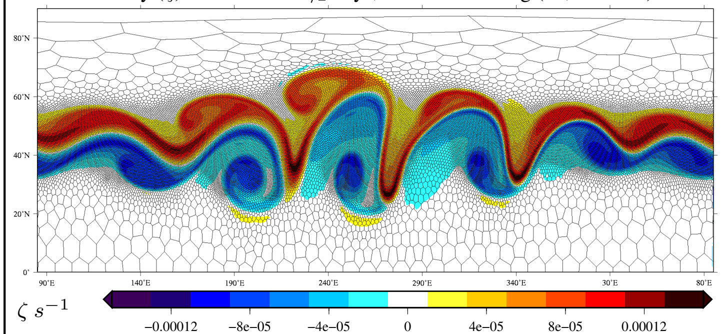
References

- CGAL: Computational Geometry Algorithms Library `http://www.cgal.org`
- J. Galewsky, R.K. Scott and L.M. Polvani. 2004. *Tellus 56A:429-440*
- Läuter, M. et al, 2007 *J. Comp. Phys* 223:609-628
- Power, P.W. et al, 2006 *Ocean Modelling* 15:3-38
- St-Cyr, A. et al, 2008 *Mon. Wea. Rev.* 136:1898-1922
- Hilary Weller, and H.G. Weller. 2007. *Int. J. Num. Meth. Fluids* 56:1589-1596
- Hilary Weller, H.G. Weller and A. Fournier. 2009. *Submitted to Mon. Wea. Rev.*
- Hilary Weller. 2009 *Submitted to Special issue of Phil. Trans. R. Soc.*

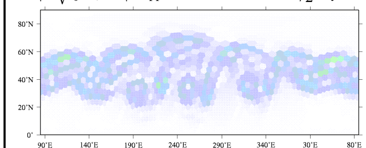
Adaptation Procedure

- Barotropically unstable jet test case of Galesky et al (2004).
- Mesh adaptation every 12 hours

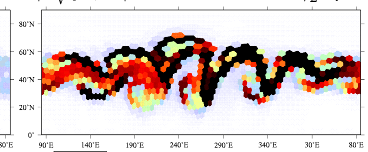
Vorticity (ζ) and mesh at $5\frac{1}{2}$ days, before remeshing (31,467 cells)



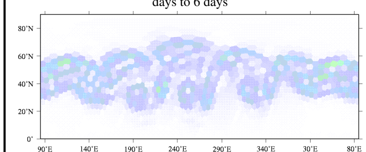
$|\nabla\sqrt{\zeta^2+\delta^2}|$ mapped onto coarse mesh at $5\frac{1}{2}$ days



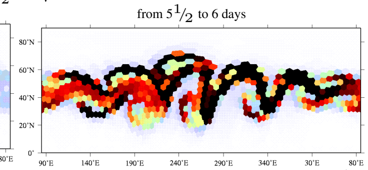
$|\nabla\sqrt{\zeta^2+\delta^2}|$ unresolved on coarse mesh at $5\frac{1}{2}$ days

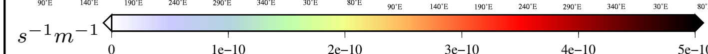


$|\nabla\sqrt{\zeta^2+\delta^2}|$ simulated on uniform coarse mesh from $5\frac{1}{2}$ days to 6 days



$|\nabla\sqrt{\zeta^2+\delta^2}|$ unresolved on coarse mesh passively advected from $5\frac{1}{2}$ to 6 days





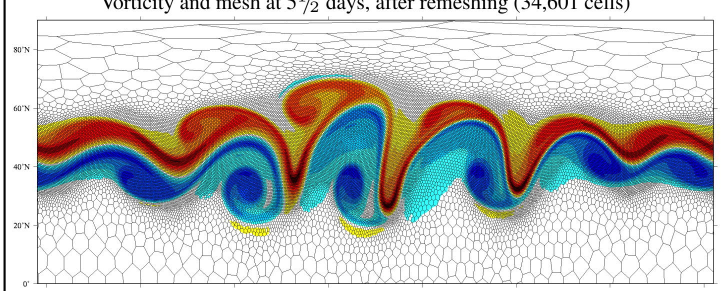
Based on coarse mesh results (2,562 cells) over 12 hours, calculate required mesh density function and remesh

If δx = mesh density function

$$1/\delta x = 1/\delta x_{\max} + \left(1/\delta x_{\min} - 1/\delta x_{\max}\right) \max\left(\max\left(R_{rc}, \max_{12\text{ hours}} R_r\right)/R_{rc}, \max\left(R_{uc}, \max_{12\text{ hours}} R_u\right)/R_{uc}\right)$$

where
R_r = $|\nabla\sqrt{\zeta^2+\delta^2}|$ resolved on the coarse mesh
R_u = $|\nabla\sqrt{\zeta^2+\delta^2}|$ unresolved and advected on the coarse mesh
R_{rc} = critical value for $R_c = 1 \times 10^{-10} s^{-1} m^{-1}$
R_{uc} = critical value for $R_u = 4 \times 10^{-10} s^{-1} m^{-1}$
$\delta x_{\max}$ = 960km
$\delta x_{\min}$ = 60km

Vorticity and mesh at $5\frac{1}{2}$ days, after remeshing (34,601 cells)



Vorticity and mesh simulated on new mesh (34,601 cells) until 6 days