GungHo!

Nigel Wood, Dynamics Research, UK Met Office

Outline

- GungHo!
- Challenges
- Where we are now
- Summary

GungHo!

Met Office

Globally

Uniform

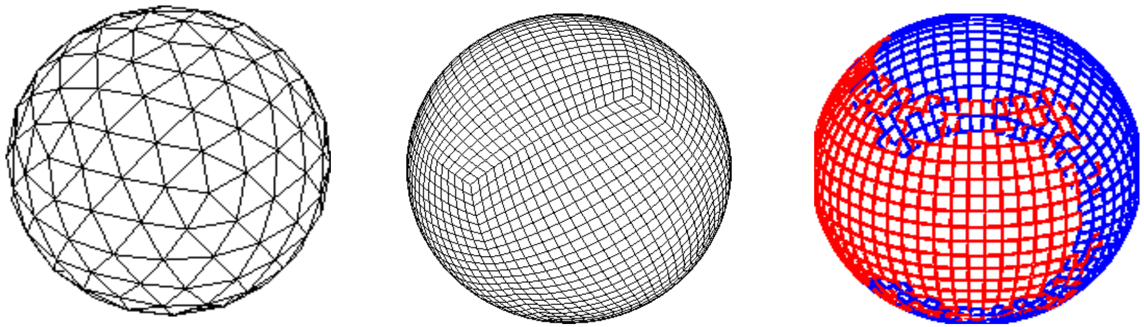
Next

Generation

Highly

Optimized

工合



NATURAL ENVIRONMENT RESEARCH COUNCIL

Science & Technology Facilities Council

"Working together harmoniously"

5 Year Project

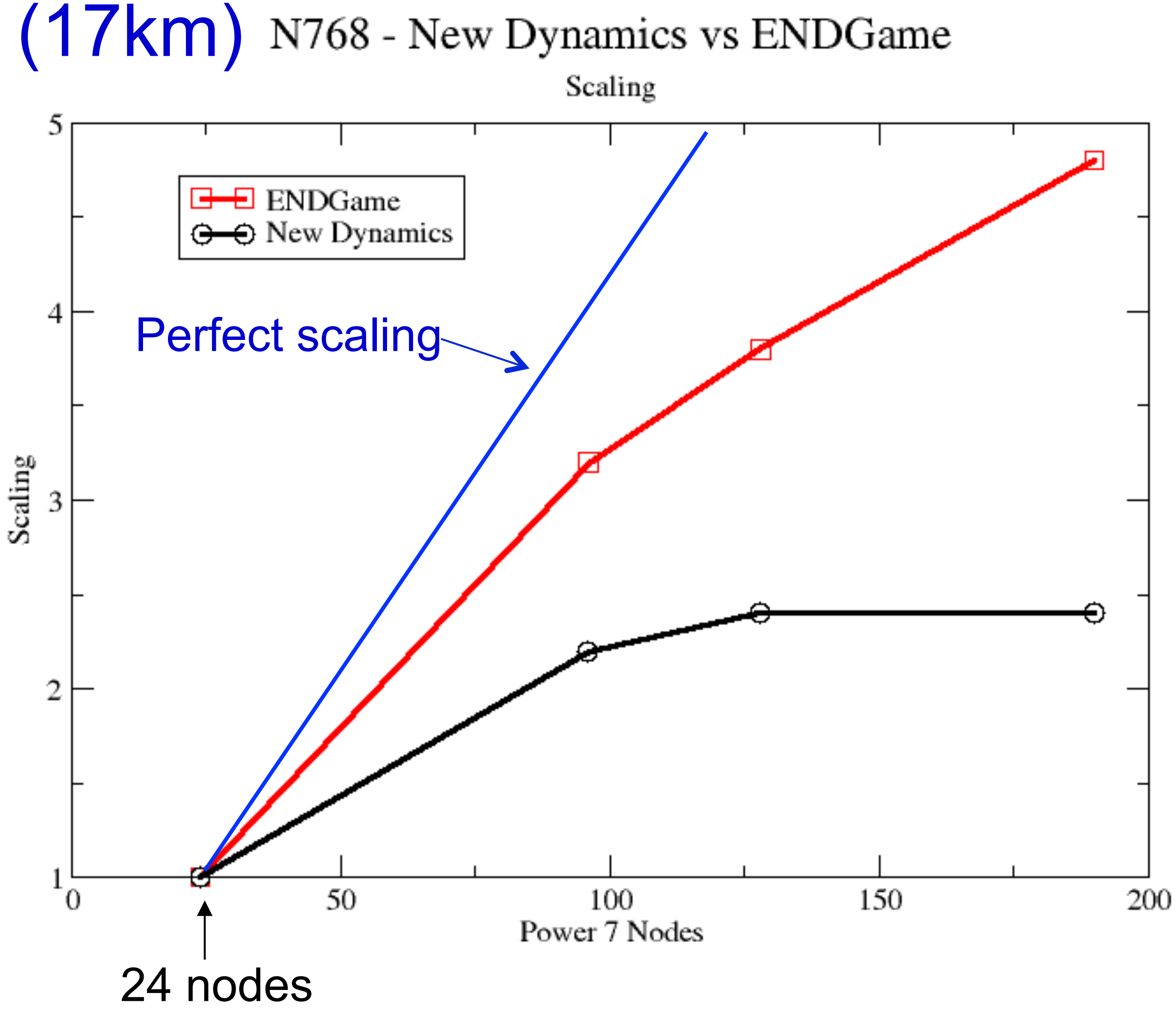
Met Office

- "To research, design and develop a new dynamical core suitable for operational, global and regional, weather and climate simulation on massively parallel computers of the size envisaged over the coming 20 years."
- Split into two phases:
  - 2 years "research" (2011-13)
  - 3 years "development" (2013-2016)
- Met Office, STFC, Universities of: Bath, Exeter, Imperial, Leeds, Manchester, Reading, Warwick

Scalability

T_{24}/T_N

(17km)

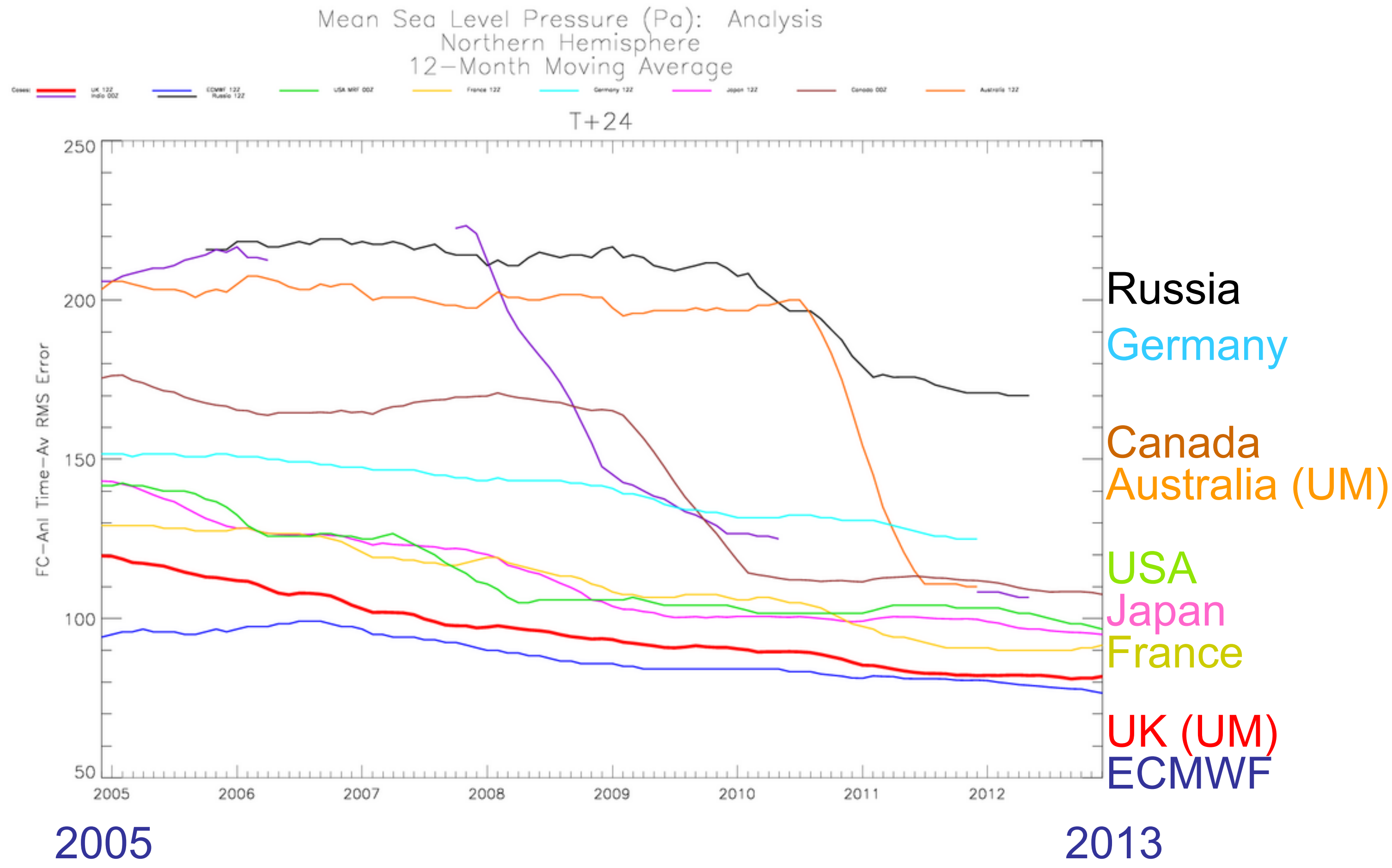


(1 node=32 processors)

Relative performance

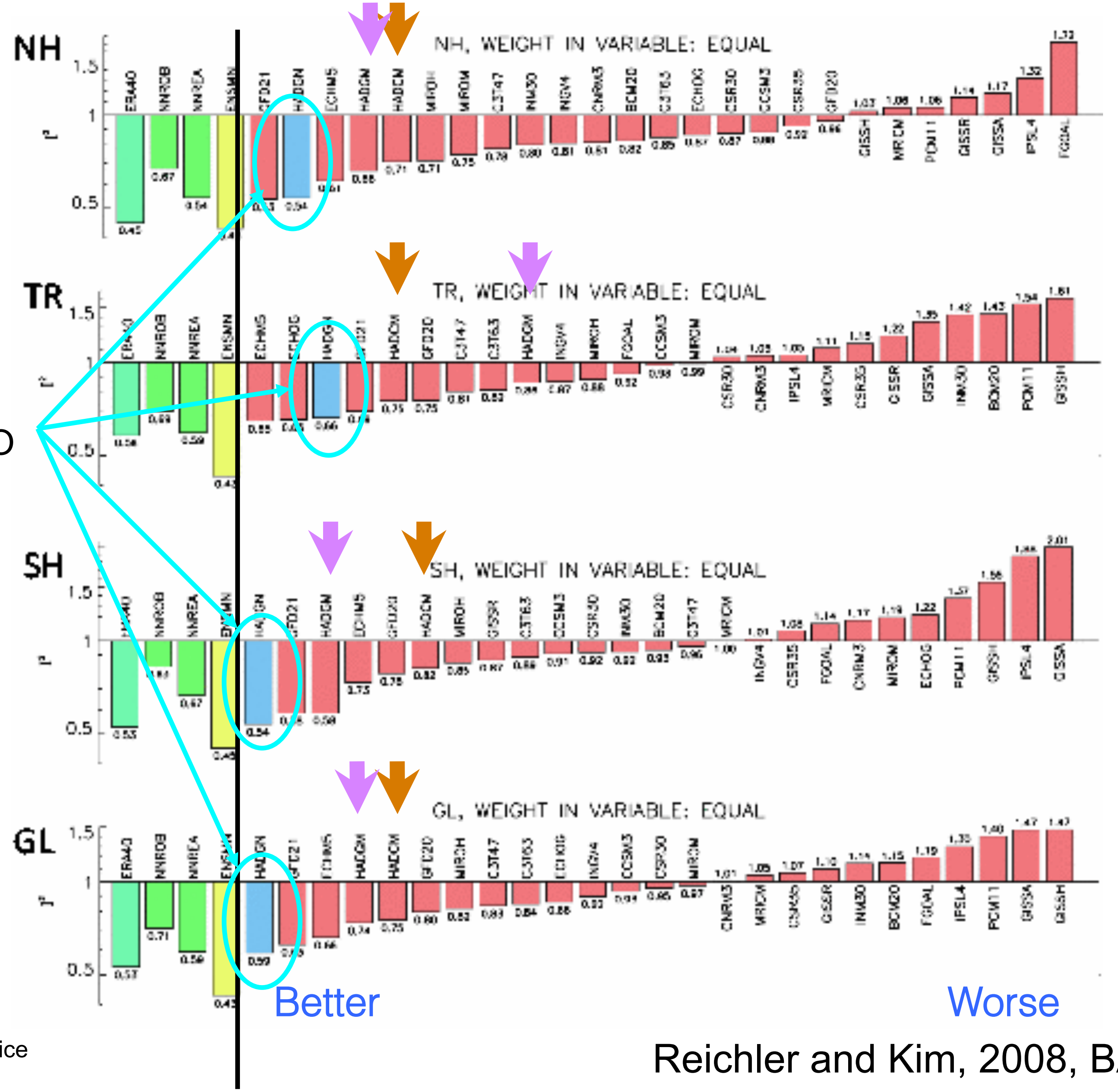
Met Office

24 hour Northern Hemisphere surface pressure errors



Performance metric for CMIP3 climate models

Met Office



- HadGEM2-AO
- HadGEM1
- HadCM3
- Reanalyses
- Mean model

Reichler and Kim, 2008, BAMS

From GungHo to not so GungHo

Staniforth & Thuburn 2012 identified ten

"*Essential and desirable properties of a dynamical core*":

1. Mass conservation

2. Accurate representation of balanced flow and adjustment

3. Computational modes should be absent or well controlled

From GungHo to not so GungHo

Met Office

4. Geopotential gradient and pressure gradient should produce no unphysical source of vorticity $\nabla \times (\nabla p) = 0$

5. Terms involving the pressure should be energy conserving. $\mathbf{u} \cdot \nabla p + p \nabla \cdot \mathbf{u} = \nabla \cdot (\mathbf{u} p)$

6. Coriolis terms should be energy conserving

$$\mathbf{u} \cdot (\boldsymbol{\Omega} \times \mathbf{u}) = 0$$

7. There should be no spurious fast propagation of Rossby modes; geostrophic balance should not spontaneously break down

8. Axial angular momentum should be conserved

These 5 properties relate to the *mimetic* properties of the numerics

From GungHo to not so GungHo

9. Accuracy approaching second order
10. Minimal grid imprinting

These are particularly challenging for grids with special points/regions

$\Rightarrow$ likely to require higher order schemes…

…whilst maintaining (1)-(8)

Hexagonal C-Grid Problem: Non-Stationary Geostrophic Mode

Slide courtesy of Bill Skamarock and Joe Klemp (NCAR)

New Coriolis velocity evaluation (Thuburn, 2008 JCP)

$$\partial_t u_1 + g\delta_{x_1} h + \frac{f}{\sqrt{3}}(u_{31} - u_{21}) = 0$$

$$\partial_t u_2 + g\delta_{x_2} h + \frac{f}{\sqrt{3}}(u_{12} - u_{32}) = 0$$

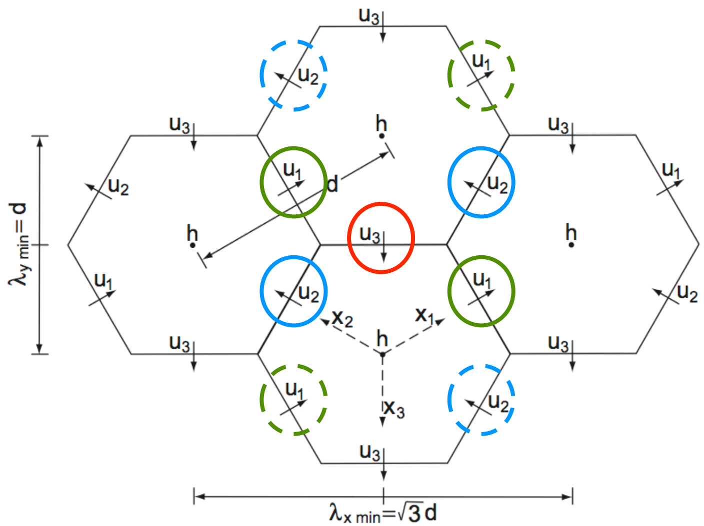
$$\partial_t u_3 + g\delta_{x_3} h + \frac{f}{\sqrt{3}}(u_{23} - u_{13}) = 0$$

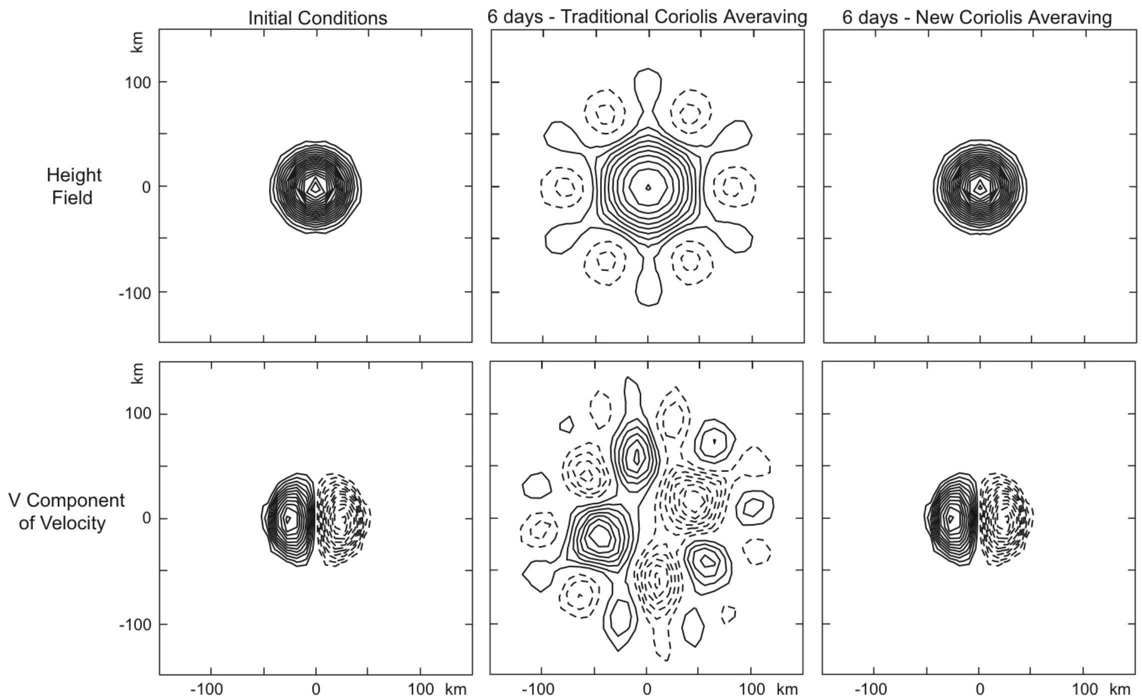
$$\partial_t h + \tfrac{2}{3}H(\delta_{x_1} u_1 + \delta_{x_2} u_2 + \delta_{x_3} u_3) = 0$$

$$u_{21} = \tfrac{1}{3}\overline{u_2}^{x_3} + \tfrac{2}{3}\overline{\overline{u_2}^{x_1}}^{x_2}, \quad u_{31} = \tfrac{1}{3}\overline{u_3}^{x_2} + \tfrac{2}{3}\overline{\overline{u_3}^{x_1}}^{x_3},$$

$$u_{12} = \tfrac{1}{3}\overline{u_1}^{x_3} + \tfrac{2}{3}\overline{\overline{u_1}^{x_1}}^{x_2}, \quad u_{32} = \tfrac{1}{3}\overline{u_3}^{x_1} + \tfrac{2}{3}\overline{\overline{u_3}^{x_2}}^{x_3},$$

$$u_{13} = \tfrac{1}{3}\overline{u_1}^{x_2} + \tfrac{2}{3}\overline{\overline{u_1}^{x_1}}^{x_3}, \quad u_{23} = \tfrac{1}{3}\overline{u_2}^{x_1} + \tfrac{2}{3}\overline{\overline{u_2}^{x_2}}^{x_3}$$

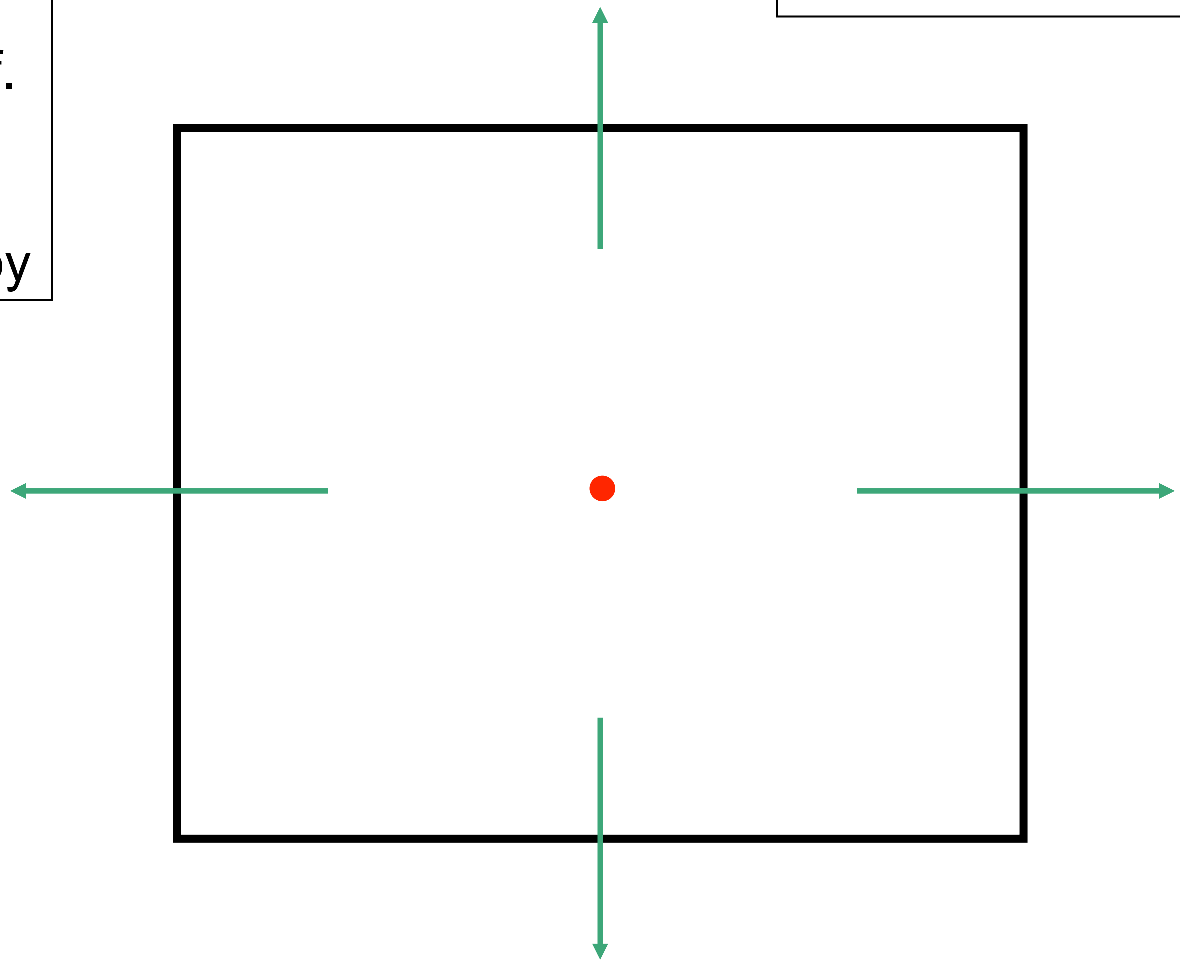




C-grid on Quads

- 2 wind d.o.f's
- 1 pressure d.o.f.
- Cf. analytical
- 2 GWs 1 Rossby

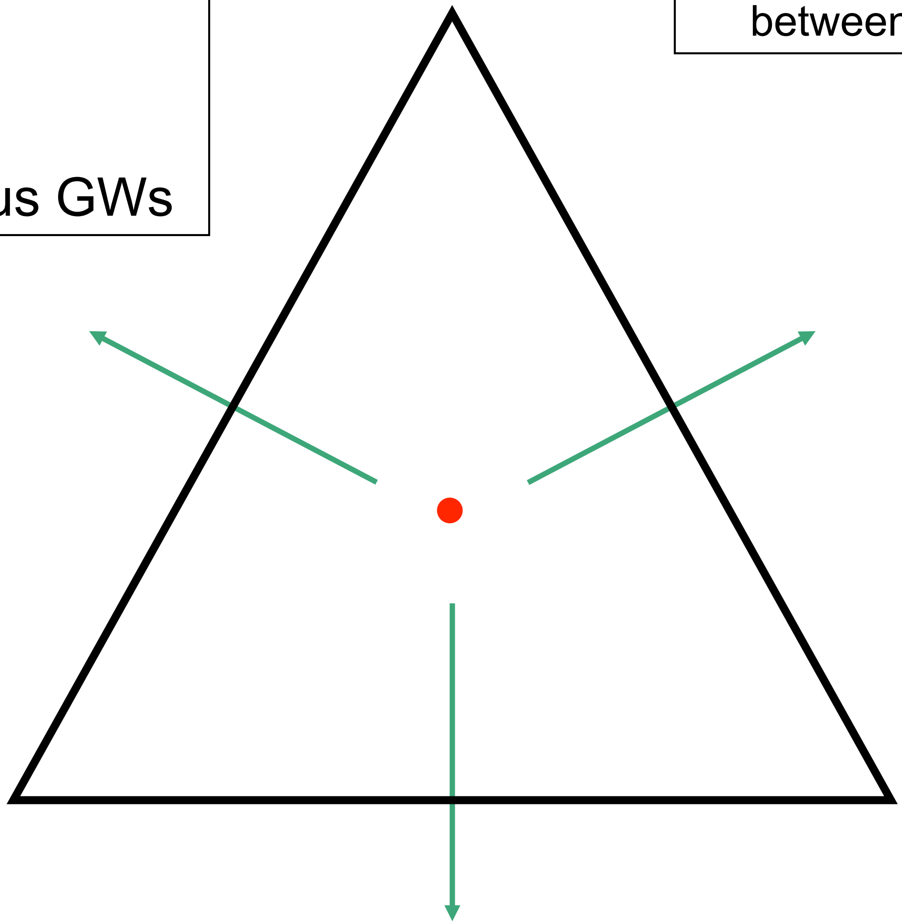
- Green ⇒ Continuous between cells
- Red ⇒ Discontinuous between cells



C-grid on Triangles

- 3 wind d.o.f's
- 2 pressure d.o.f.'s
- ⇒ Branch of spurious GWs

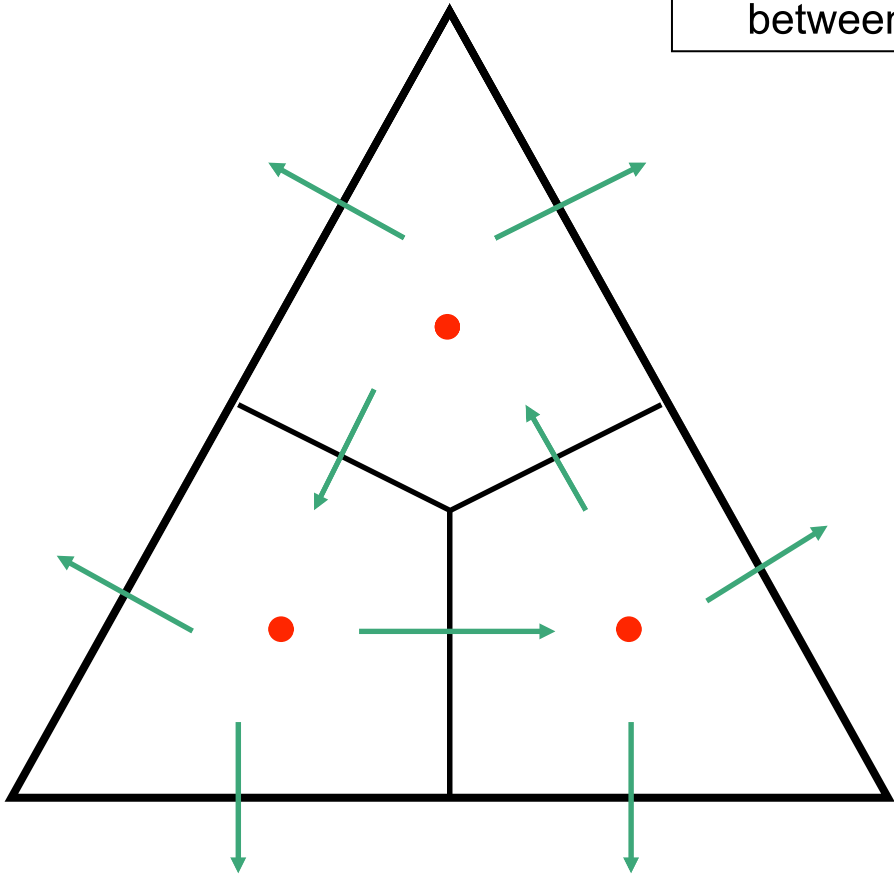
- Green ⇒ Continuous between cells
- Red ⇒ Discontinuous between cells



Triangle as 3 Kites

- 6 wind d.o.f's
- 3 pressure d.o.f.'s
- ⇒ Balanced d.o.f.'

- Green ⇒ Continuous between cells
- Red ⇒ Discontinuous between cells

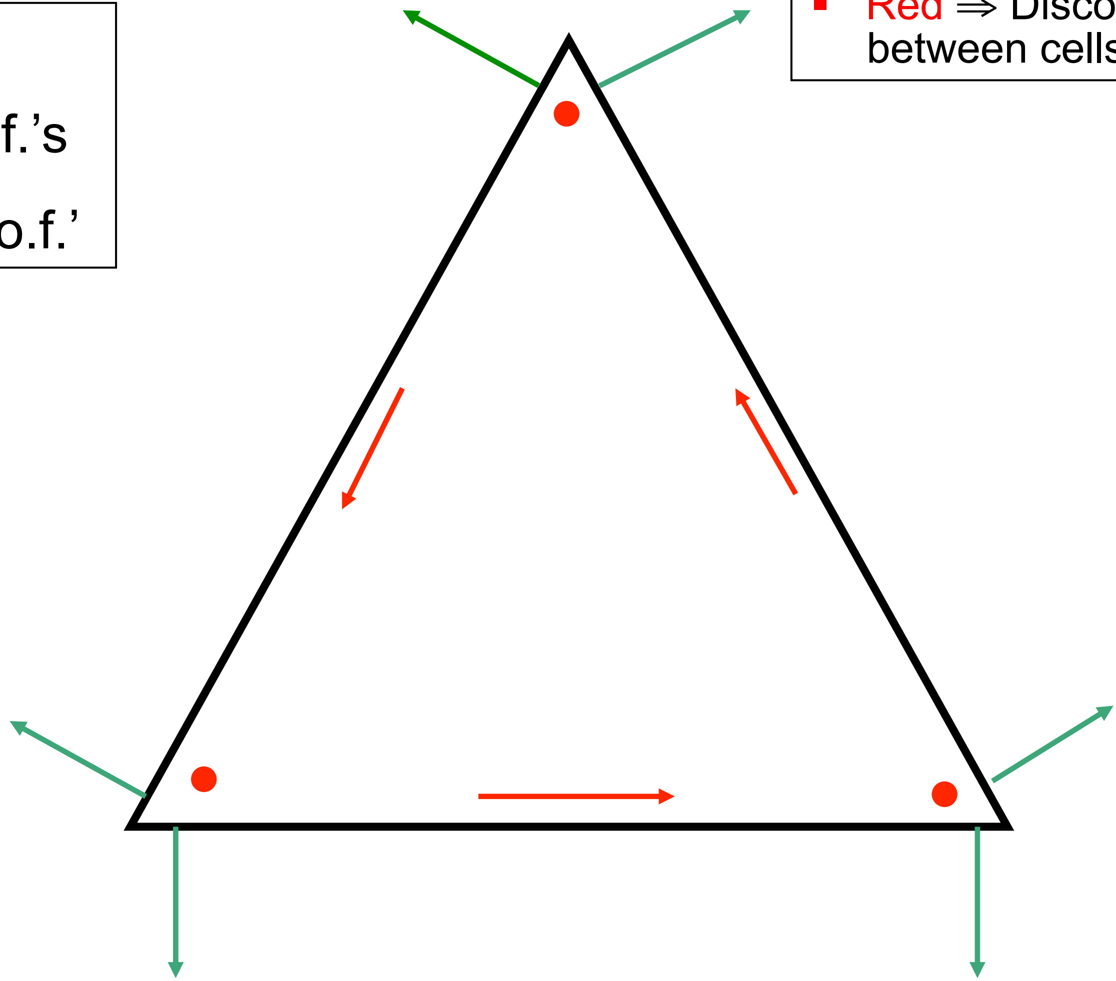


Staniforth (Met O)
Cotter (Imperial)

⇒ BDFM1 element!

- 6 wind d.o.f's
- 3 pressure d.o.f.'s
- ⇒ Balanced d.o.f.'

- Green ⇒ Continuous between cells
- Red ⇒ Discontinuous between cells



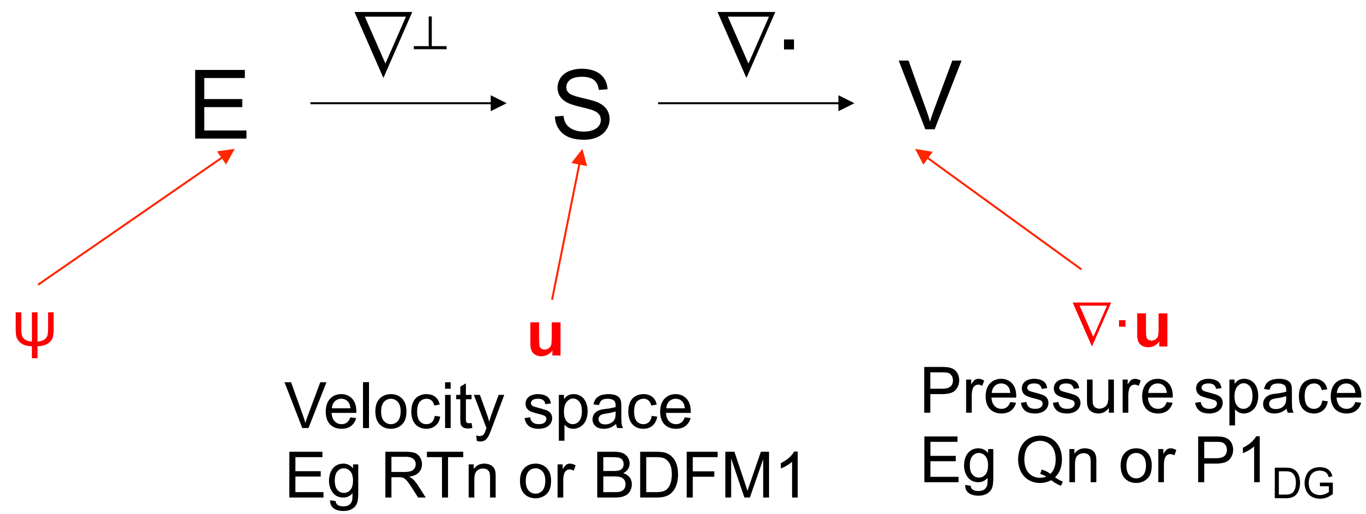
Two ways forward

Cotter (Imperial)

- Vector invariant form of equations:

$$\mathbf{u}\cdot\nabla\mathbf{u} \rightarrow (\nabla\times\mathbf{u})\times\mathbf{u} + \nabla(\mathbf{u}\cdot\mathbf{u}/2)$$

- *Mixed* finite-elements, Primal-only:



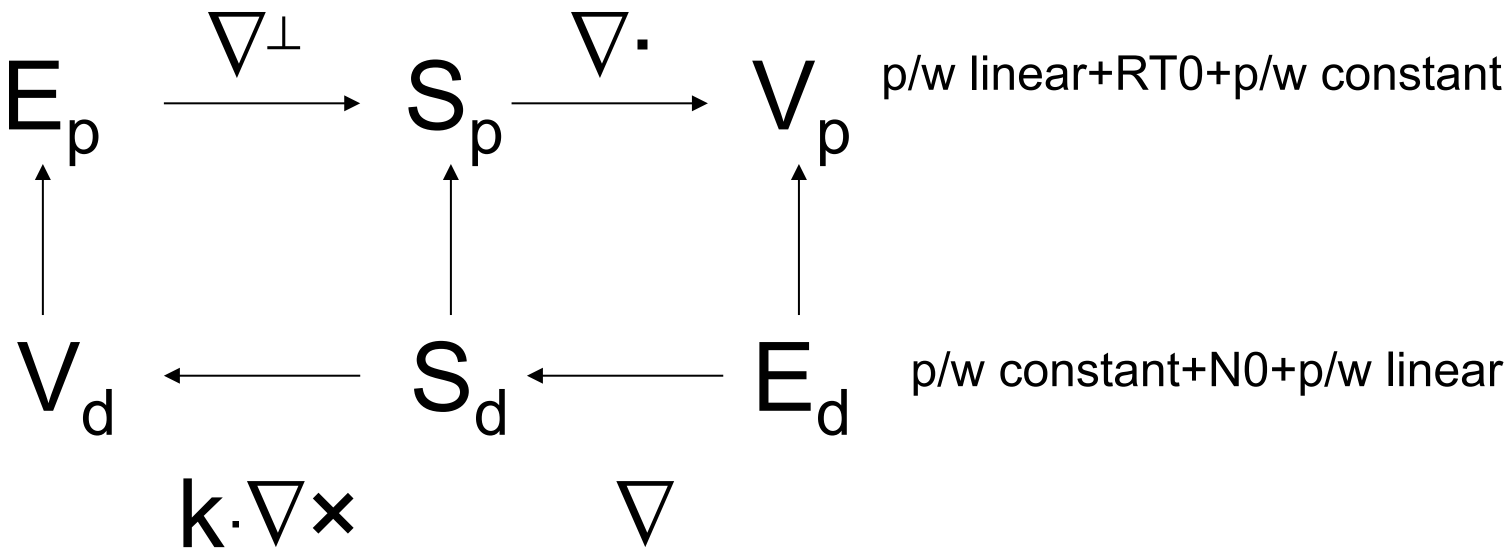
Two ways forward

Cotter (Imperial)
& Thuburn (Exeter)

- Vector invariant form of equations:

$$\mathbf{u}\cdot\nabla\mathbf{u} \rightarrow (\nabla\times\mathbf{u})\times\mathbf{u} + \nabla(\mathbf{u}\cdot\mathbf{u}/2)$$

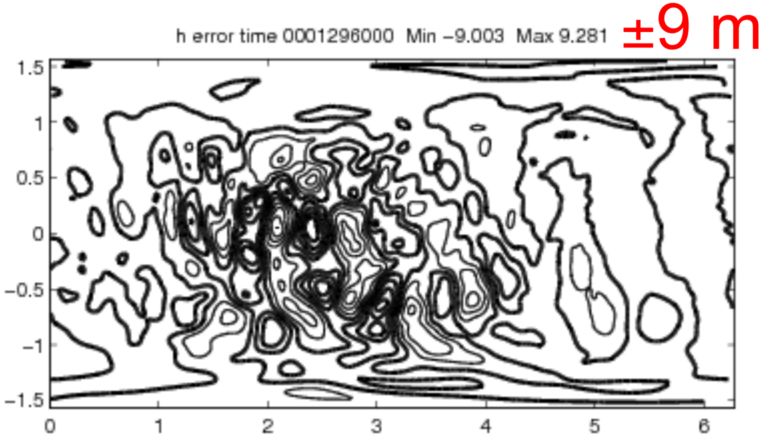
- *Mixed* finite-elements, Primal-Dual:



Some primal-dual results

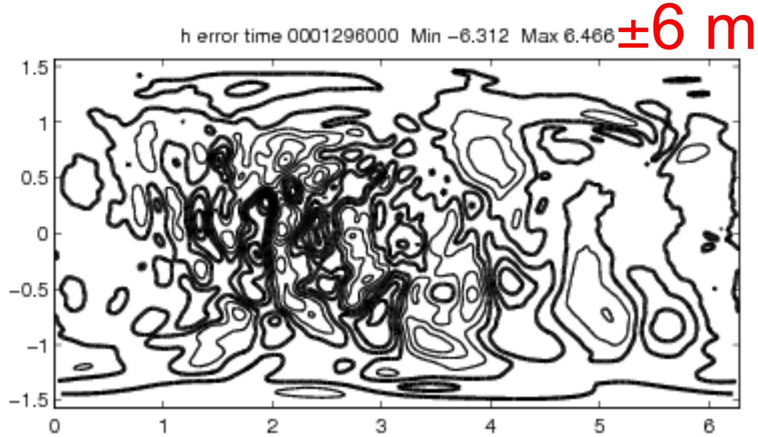
Williamson Test Case 5 with 160K d.o.f.s (320x160)

±9 m



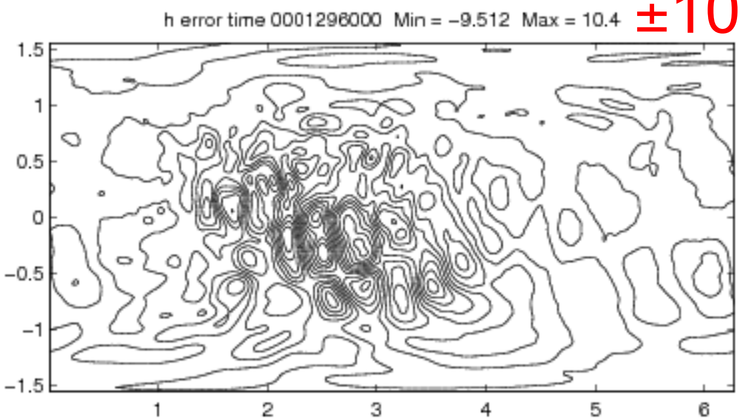
FEM Hexagonal

±6 m



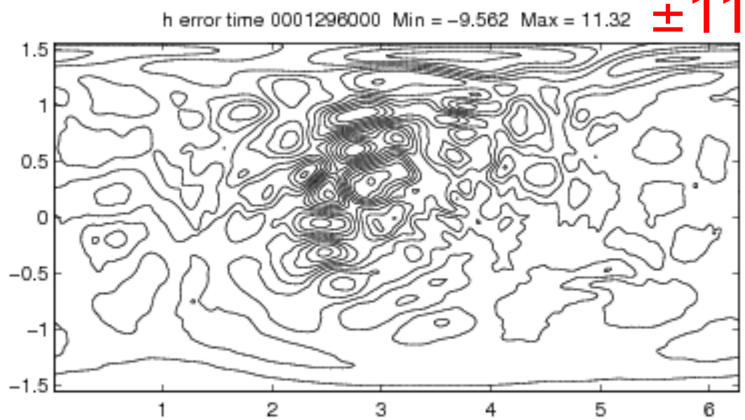
FEM Cubed-sphere

±10 m



ENDGame lat-lon

±11 m

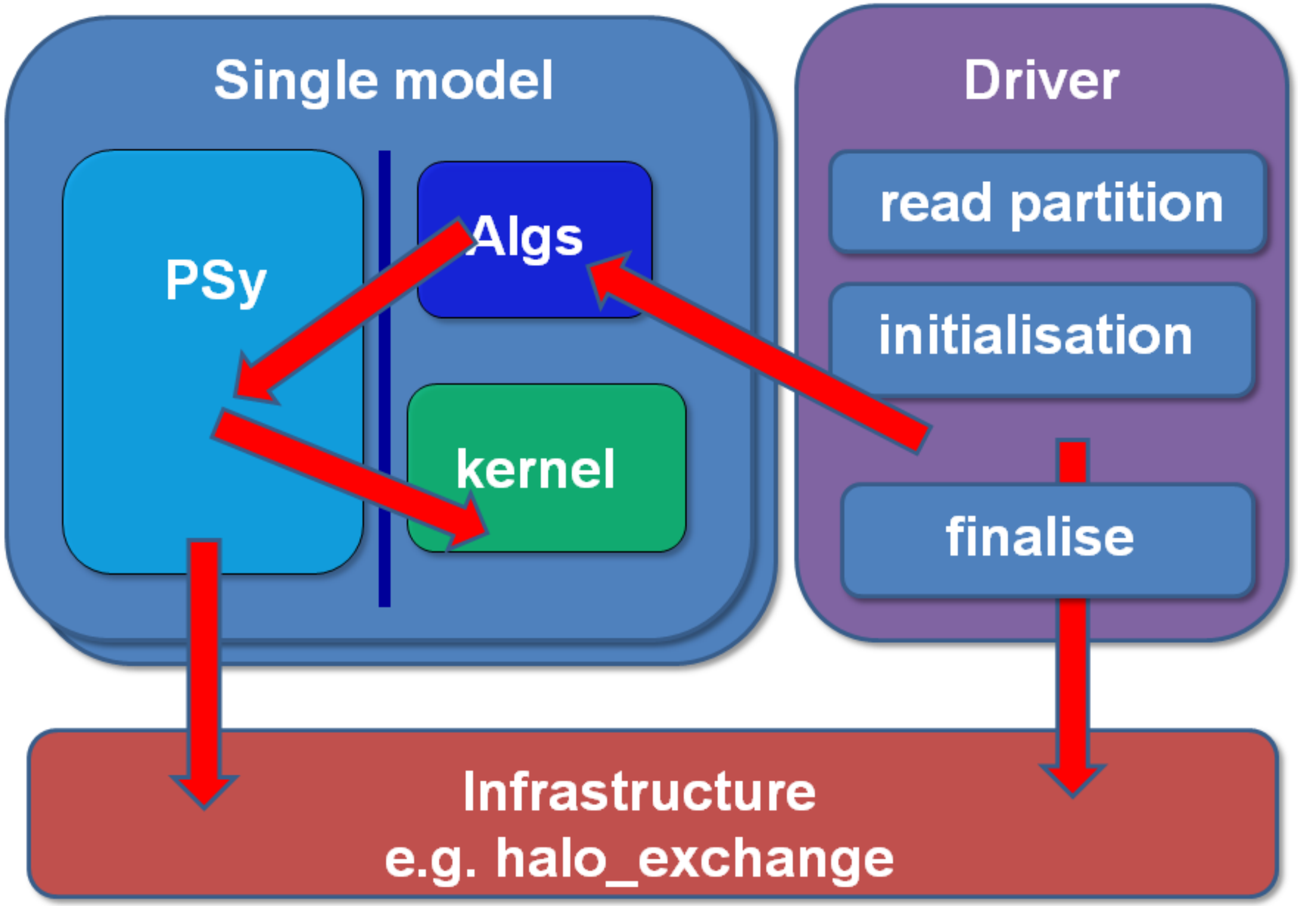


ENDGame rotated lat-lon

Thuburn (Exeter)

Computational Science & LFRIC

Ham (Imperial), Ford & Pickles (STFC), Riley (Manchester), Maynard & Glover (MetO, HPC)



- Vertical loop inner most
- Indirect addressing for horizontal
- F2003

Timetable…

- Further development and testing of horizontal [2013]
- Testing of proposals for code architecture [2013]
- Vertical discretization [2013]
- 3D prototype development [2014-2015]
- Operational around 2020…?

Met Office

Thank you!

Questions?