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Next Generation Limited Area Models

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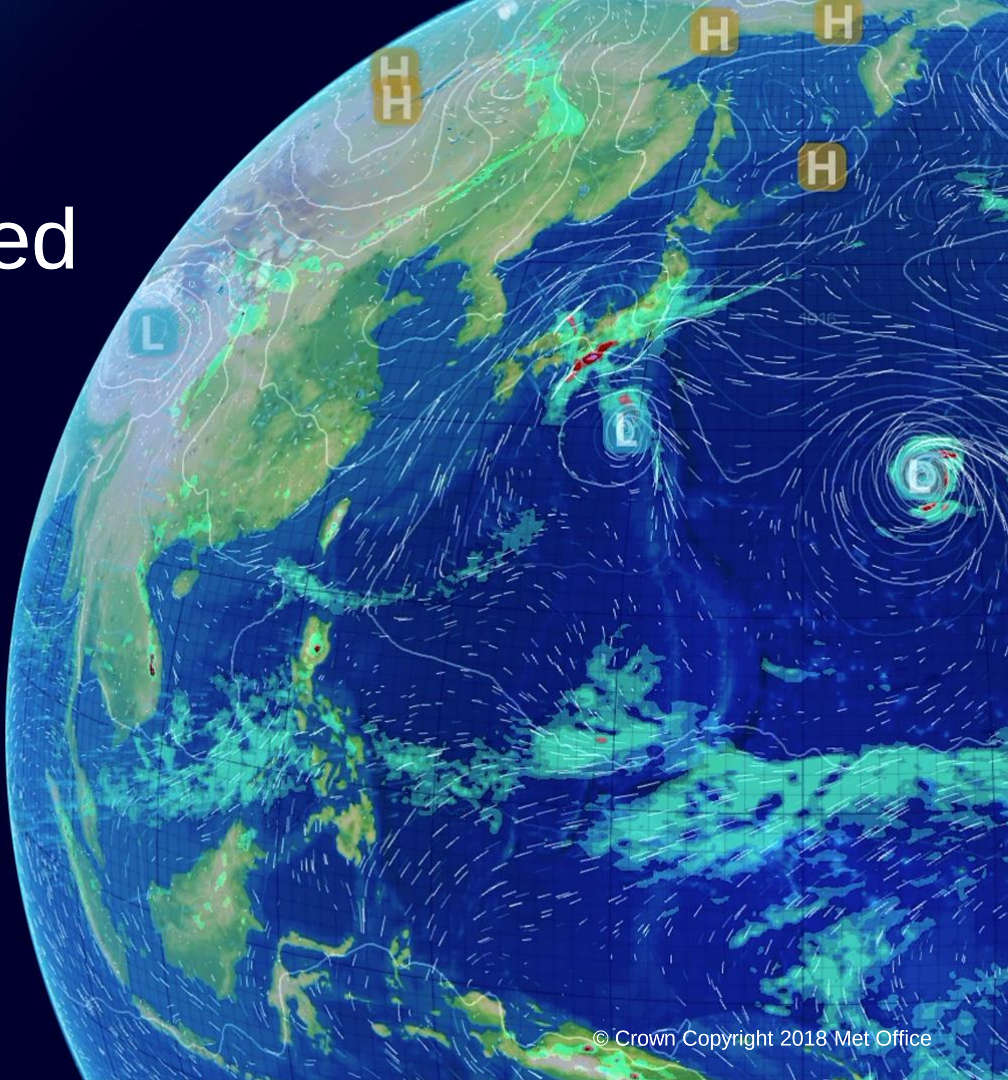

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Next generation model development

Aim: Maintain the benefits of the current UM, whilst improving the scalability.

LFRic:
Infrastructure that allows **separation of concerns** – separating science code from computer optimization code.

GungHo:
A new dynamical core. **Finite-elements** give flexibility for the choice of mesh, **finite-volume** transport gives improved conservation.

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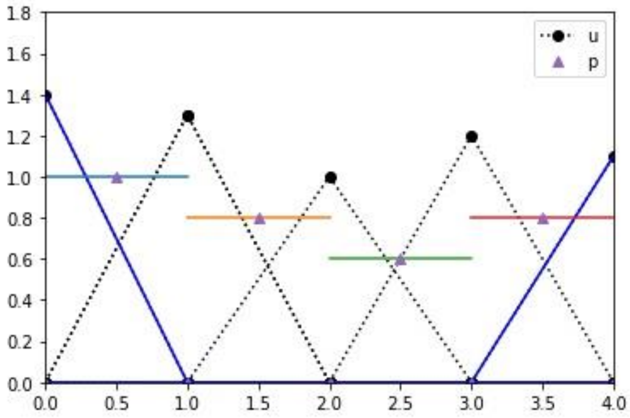
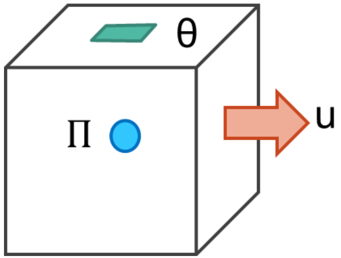
Mixed finite elements



Wind is continuous between cells. Pressure is discontinuous.



	Variable	Node location
u	Wind	Cell faces
Π	Exner pressure	Cell centres
θ	Temperature	Upper and lower faces

This gives:

- **Compatibility:** e.g. Divergence of wind, $\nabla . u$ is in the same space as pressure, Π.
- **Staggering:** equivalence to the C-grid, Charney-Phillips in the UM.

Semi-implicit time discretization

The governing equations can be written as

$$R(x^{n+1}) = 0 \quad \text{where } x = (u, \rho, \theta, \Pi).$$

This includes dynamics forcings, fast and slow physics and transport.

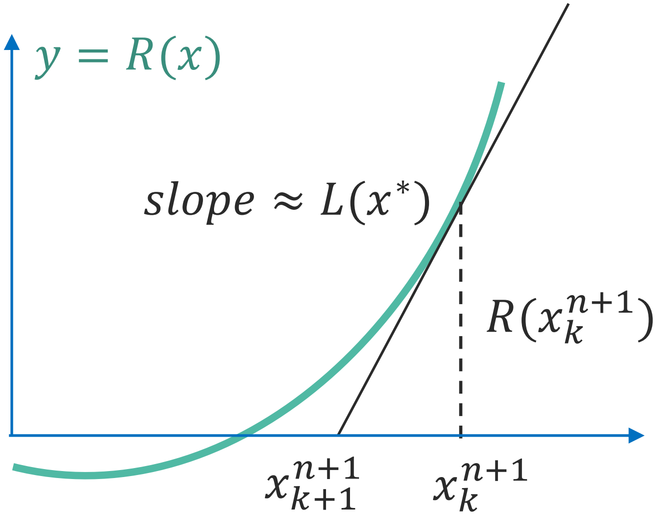
Let the state at time t^{n+1} and iteration $k+1$ be

$$x_{k+1}^{n+1} = x_k^{n+1} + x'_k, \qquad x_0^{n+1} = x^n.$$

and solve using a **quasi-Newton method**:

$$L(x^*)(x'_k) = -R\left(x_k^{n+1}\right)$$

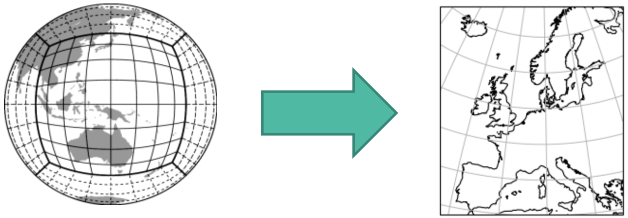
where L is an approximation to the Jacobian, using the basic state $x^* = x^n$.



Limited-area model development

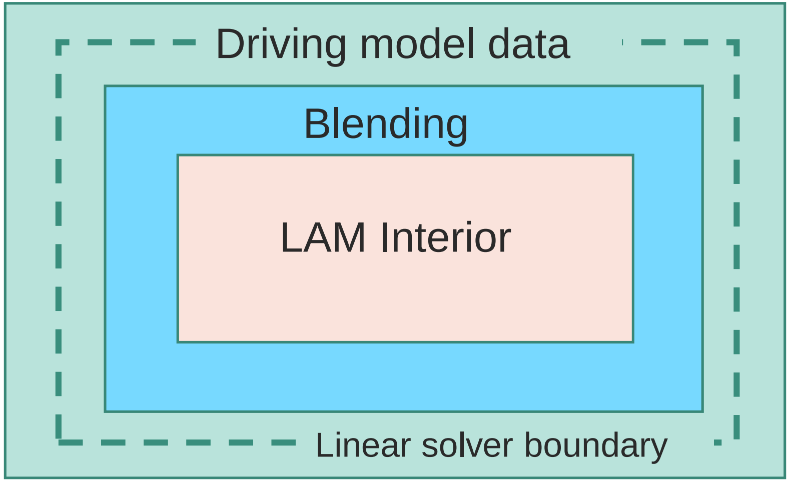
Aim: Develop a limited-area version of GungHo, using lateral boundary conditions (LBCs) such that the model can be nested in a driving model.

- Similar approach to the UM
- One-way nesting



LFRic Global

LFRic LAM



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Apply LBCs to the linear solver

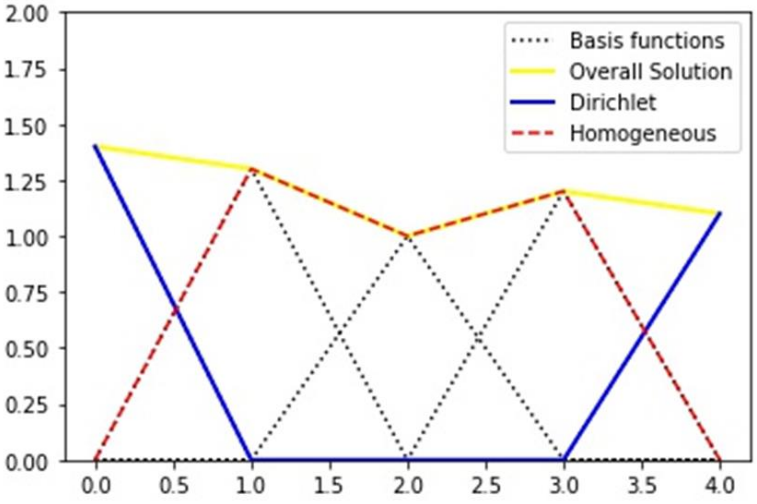
Split the increment into the homogeneous interior and boundary components

$$x_k{}' = x'_H + x'_B$$

This gives the modified linear solver

$$L(x^*)(x'_H) = -R(x^n) - L(x^*)(x'_B)$$

which we solve with the same Krylov solver as the full model.



x'_B is the difference in the **wind** between the driving model and LAM.

Identify the lateral boundary cells

Create a mask of 1s and 0s – that identifies the boundary cells/nodes.

Apply the boundary conditions using the masks and built-in operations.

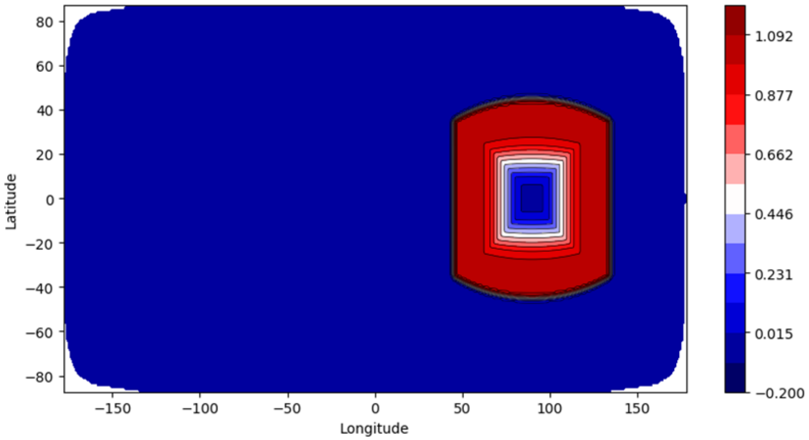
```
call invoke( X_times_Y( boundary_data,
                        driving_model,
                        mask ))
```

Blending

We need blending to prevent imbalances resulting from mismatches between the interior and the driving model.

$$x_{LAM}^{blended} = w \, x_{driving} + (1 - w) \; x_{LAM}$$

Apply at the end of every iteration.



Blending weights: w is 1 near the edge of the domain, and then ramps down to zero towards the centre of the domain.

Big brother experiments

Nest the LAM in the driving model using

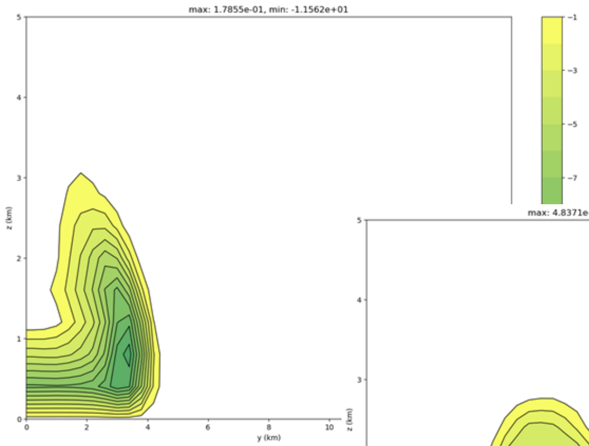
- Same mesh
- Same model configuration
- LBCs updated on every timestep

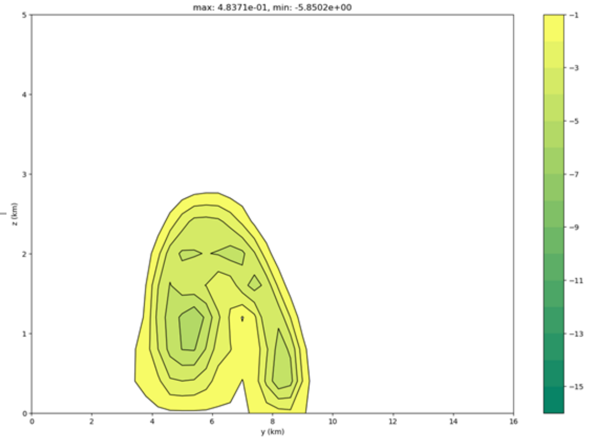
The LAM solution should be almost identical to the driving model solution.

Operational Mesh: the target operational LAM mesh is a rotated pole, lat-lon mesh and the global model will use a cubed-sphere mesh.

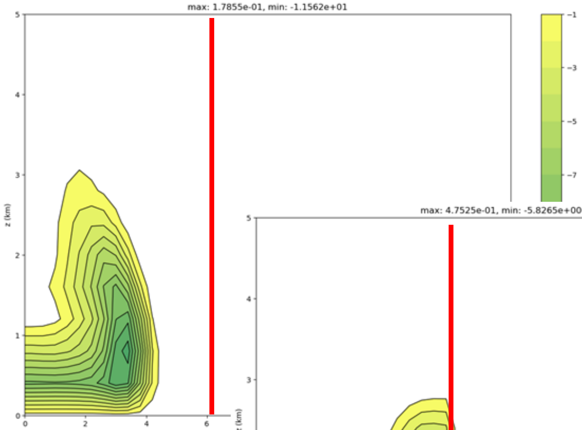
Pseudo-LAM: in these experiments, we run the LAM on exactly the same mesh and domain as the driving model – but the LAM is only allowed to evolve in a small region.

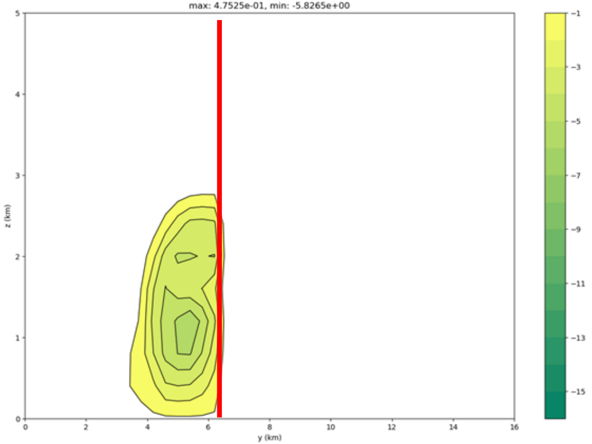
Straka Bubble Test





Driving model, θ

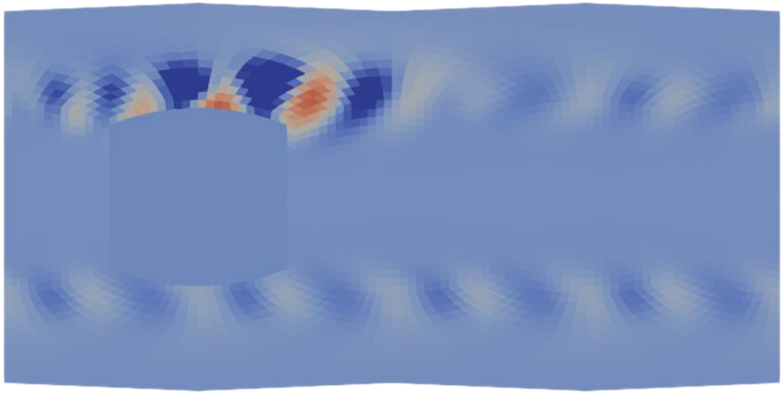




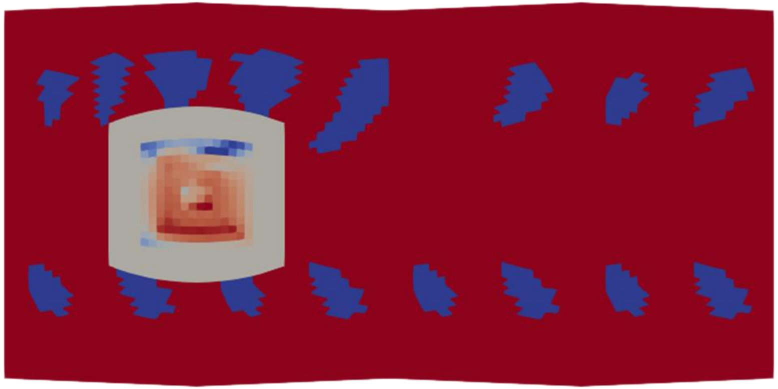
LAM, θ

Baroclinic wave test

Differences between driving model and LAM, for Exner pressure at the surface.



a) Contour interval [-0.002, 0.006]



b) Contour interval [-5e-8, 5e-8].

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Timescales (tentative - to be confirmed)

Mar 2021	Mar 2022	Mar 2023	Mar 2024	Mar 2025	Mar 2026	Mar 2027	Mar 2028
Basic RA-RL	Proto RA-RL			Proto NWP	Oper LFRic global	Oper LFRic regional	LFRic RCM

LFRic LAM nested in UM driving model.

Smagorinsky, prognostic aerosol, stochastic physics.

Suites with cycling data assimilation.

UM LAM nested in global LFRic.

LFRic LAM nested in global LFRic.

Regional climate model.